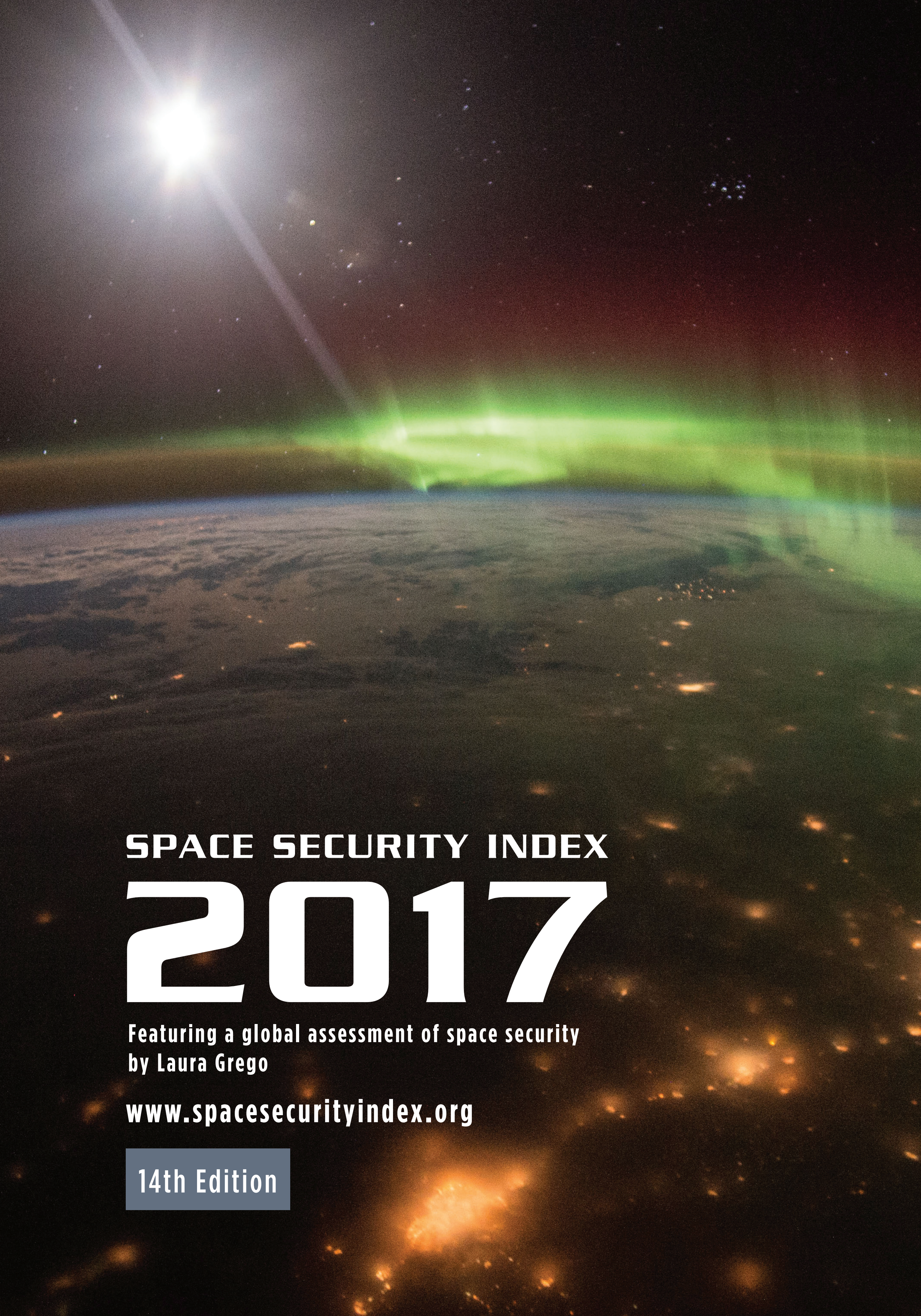

SPACE SECURITY INDEX 2017

Featuring a global assessment of space security
by Laura Grego

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ACRONYMS AND ABBREVIATIONS

ADR	Active Debris Removal
AEHF	Advanced Extremely High Frequency system (U.S.)
AIDA	Asteroid Impact Deflection Assessment
AIM	Asteroid Impact Mission (ESA)
AIS	Automatic Identification System
ALTB	Airborne Laser Test Bed
ANGELS	Automated Navigation and Guidance Experiment for Local Space (U.S.)
ARGOS	Army Global on the Move Satcom (U.S.)
ARM	Asteroid Redirect Mission (NASA)
ARRM	Asteroid Redirect Robotic Mission (NASA)
ASAT	Anti-Satellite Weapon
ASI	Agenzia Spaziale Italiana
BiU	Bringing into Use
BMD	Ballistic Missile Defense
CALT	China Academy of Launch Vehicle Technology
CD	Conference on Disarmament
CNES	Centre national d'études spatiales (France)
CNSA	China National Space Administration
ComSpOC	Commercial Space Operations Center (U.S.)
COPUOS	Committee on the Peaceful Uses of Outer Space (UN)
COTS	Commercial Orbital Transportation Services (U.S.)
CSA	Canadian Space Agency
CSSS	Canadian Space Surveillance System
DARPA	Defense Advanced Research Projects Agency (U.S.)
DART	Double Asteroid Redirection Test (NASA)
DE-STAR	Directed Energy System for Targeting of Asteroids and exploRation
DLR	German Aerospace Center
DMSP	Defense Meteorological Satellite Program (U.S.)
DoD	Department of Defense (U.S.)
DSCOVR	Deep Space Climate Observatory (U.S.)
EDA	European Defence Agency
EDRS	European Data Relay System
EELV	Evolved Expendable Launch Vehicle (U.S.)
EGNOS	European Geostationary Navigation Overlay System
EGS	Enterprise Ground Service
EKV	Exoatmospheric Kill Vehicle
EO	Earth Observation
ESA	European Space Agency
ESOA	EMEA Satellite Operators Association
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FALCON	Force Application and Launch from the Continental U.S.
FCC	Federal Communications Commission (U.S.)
FEMA	Federal Emergency Management Agency (U.S.)

FMCT	Fissile Material Cut-off Treaty
FREND	Front-end Robotics Enabling Near-term Demonstration
GAO	Government Accountability Office (U.S.)
GEO	Geostationary Earth Orbit
GEOSS	Global Earth Observation System of Systems
GGE	Group of Governmental Experts
GLONASS	Global Navigation Satellite System (Russia)
GMES	Global Monitoring for Environment and Security (Europe)
GNSS	Global Navigation Satellite Systems
GOES-R	Geostationary Operational Environmental Satellite-R Series
GOLD	Global Observations of the Limb and Disk (NASA)
GPS	Global Positioning System (U.S.)
GSSAP	Geosynchronous Space Situational Awareness Program (U.S.)
GTO	Geostationary Transfer Orbit
HELLADS	High Energy Liquid Laser Area Defense System (U.S.)
HEO	Highly Elliptical Orbit
IADC	Inter-Agency Space Debris Coordination Committee
IAWN	International Asteroid Warning Network
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS (UN)
ICoC	International Code of Conduct for Outer Space Activities
ICON	Ionosphere Connection Explorer (NASA)
IGS	International GNSS Service
IRNSS	Indian Regional Navigation Satellite System
IRS	Indian Remote Sensing
ISON	International Scientific Optical Network
ISRO	Indian Space Research Organisation
ISS	International Space Station
ITAR	International Traffic in Arms Regulations (U.S.)
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
JICSpOC	Joint Interagency Combined Space Operations Center (U.S.)
JMS	JSpOC Mission System (U.S.)
JPSS	Joint Polar Satellite System (U.S.)
JSDTF	Joint Space Doctrine and Tactics Forum
JSpOC	Joint Space Operations Center (U.S.)
KARI	Korea Aerospace Research Institute
KITE	Kounotori Integrated Tether Experiments (Japan)
LEO	Low Earth Orbit
M3MSat	Maritime Monitoring and Messaging Microsatellite (Canada)
MDA	Missile Defense Agency (U.S.)
MEO	Medium Earth Orbit
MEV	Mission Extension Vehicle

MIFR	Master International Frequency Register
MiTEx	Micro-satellite Technology Experiment (U.S.)
MPC	Minor Planet Center
MUOS	Mobile User Objective System
NASA	National Aeronautics and Space Administration (U.S.)
NDAA	National Defense Authorization Act (U.S.)
NEO	Near Earth Object
NEOSSat	Near-Earth Object Surveillance Satellite (Cda)
NGA	National Geospatial-Intelligence Agency (U.S.)
NGSO	Non-Geostationary Orbit
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NRO	National Reconnaissance Office (U.S.)
OCX	Operational Control System
ODPO	Orbital Debris Program Office (NASA)
OECD	Organisation for Economic Co-operation and Development
OPALS	Optical Payload for Lasercomm Science
OPIR	Overhead Persistent Infrared
ORS	Operationally Responsive Space (U.S.)
OST	Outer Space Treaty
PAROS	Prevention of an Arms Race in Outer Space
PDCO	Planetary Defense Coordination Office
PDSA	Principal DoD Space Advisor
PHA	Potentially Hazardous Asteroid
PNT	Position, Navigation, and Timing
PPWT	Treaty on the Prevention of the Placement of Weapons in Outer Space, and of the Threat or Use of Force against Outer Space Objects
QUESS	Quantum Experiments at Space Scale
QZSS	Quazi-Zenith Satellite System (Japan)
RF	Radio Frequency
Roscosmos	Russian Federal Space Agency
RRB	Radio Regulations Board
SAR	Synthetic Aperture Radar
SBIRS	Space-based Infrared System
SBMD	Space-based Missile Defenses
SBSS	Space Based Space Surveillance (U.S.)
SDA	Space Data Association
SEV	Space Enterprise Vision (U.S.)
SIA	Satellite Industry Association
SIGINT	Signals Intelligence
SLS	Space Launcher System (U.S.)
SMF	Space Mission Force (U.S.)
SMPAG	Space Missions Planning Advisory Group
SPARTACUS	Satellite Based Asset Tracking for Supporting Emergency Management

	in Crisis Operations (Europe)
SPR	Strategic Portfolio Review
SSA	Space Situational Awareness
SSI	Space Security Index
SSN	Space Surveillance Network (U.S.)
SSO	Sun-synchronous Orbit
SST	Space Surveillance Telescope (U.S.-Australia)
STSC	Scientific and Technical Subcommittee (COPUOS)
TCBM	Transparency and Confidence-building Measure
TeSeR	Technology for Self-Removal of Spacecraft (ESA)
TROPICS	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats (NASA)
UAV	Unmanned Aerial Vehicle
UNGA	United Nations General Assembly
UNIDIR	United Nations Institute for Disarmament Research
UNOOSA	United Nations Office for Outer Space Affairs
UN-Space	United Nations Inter-Agency Committee on Outer Space
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
USAF	United States Air Force
USCYBERCOM	United States Cyber Command
USSTRATCOM	United States Strategic Command
VLF	Very Low Frequency
WGS	Wideband Global SATCOM
WMO	World Meteorological Organization
WRC	World Radiocommunication Conference
XSS	Experimental Spacecraft System (U.S.)

INTRODUCTION

Space Security Index 2017 is the fourteenth annual report on developments related to safety, sustainability, and security in outer space, covering the period January-December 2016. It is part of the broader Space Security Index (SSI) project, which aims to improve transparency on space activities and provide a common, comprehensive, objective knowledge base to support the development of dialogue and policies that contribute to the security and sustainability of outer space.

The definition of space security guiding this report reflects the intent of the 1967 Outer Space Treaty that outer space should remain open for all to use for peaceful purposes now and in the future:

The secure and sustainable access to, and use of, space
and freedom from space-based threats.

The key consideration in this SSI definition of space security is not the interests of particular national or commercial entities, but the security and sustainability of outer space as an environment that can be used safely and responsibly by all. This broad definition encompasses the sustainability of the unique outer space environment, the physical and operational integrity of manmade objects in space and their ground stations, as well as security on Earth from threats and natural hazards originating in space.

Outer space resources play a key role in the activities and wellbeing of all nations, supporting applications from global communications to financial operations, farming to weather forecasting, and environmental monitoring to navigation, surveillance, and treaty monitoring. In this context, issues such as the threat posed by space debris, the priorities of national civil space programs, the growing importance of the commercial space industry, efforts to develop a robust normative regime for outer space activities, and concerns about the militarization and potential weaponization of space are critical elements influencing overall space security.

The information in the report is organized under four broad Themes, with each divided into various indicators of space security. This arrangement is intended to reflect the increasing interdependence, mutual vulnerabilities, and synergies of outer space activities.

The most critical challenge to the safety, security, and sustainability of outer space continues to be the threat posed by space debris to the spacecraft of all nations. The total amount of human-made space debris in orbit is growing each year, concentrated in the orbits where human activities take place.

Today the U.S. Department of Defense (DoD) is using the Space Surveillance Network to track some 23,000 pieces of debris 10 centimeters in diameter or larger. Experts estimate that there are more than 500,000 objects with a diameter larger than one centimeter and several million that are smaller. As debris increases and outer space becomes more congested, the likelihood that space assets may collide with a piece of orbital debris or even with one another increases, making all spacecraft vulnerable, regardless of the nation or entity to which they belong.

Awareness of the space debris problem has grown considerably in recent years, and significant efforts have been made to mitigate the production of new debris through compliance with national and international guidelines. The development and testing of technology to actively remove debris may one day contribute to the sustainability of outer space; however, there is currently no political consensus that this should be done or by whom, and financial challenges exist. The growing use of small satellites and recent proposals to deploy large constellations of commercial satellites are raising additional questions about long-term sustainability.

Similarly, the development of space situational awareness (SSA) capabilities to track space debris provides significant space security advantages—for example, when used to avoid collisions. The sensitive nature of some information and the small number of space actors with advanced tools for surveillance have traditionally kept significant data on space activities shrouded in secrecy. But recent developments followed by the Space Security Index suggest that there is a greater willingness to share SSA data through international partnerships—a most welcome trend. In addition, commercial providers of SSA information have recently emerged.

More nations are participating in outer space activities as technological barriers to entry go down. However, the limitations of some space resources such as radio frequencies and orbital positions challenge the ability of newcomers to gain equitable access.

Access to the benefits of outer space has also accelerated through the growth of space-based global utilities over the last decade. Millions of individuals rely on space applications on a daily basis for functions as diverse as weather forecasting, navigation, and search-and-rescue operations.

International cooperation remains key to both civil space programs and global utilities. Collaboration in civil space programs can assist in the transfer of expertise and technology for the access to, and use of, space by emerging space actors. Projects that involve complex technical challenges and mammoth expense, such as the International Space Station, require nations to work together. The degree of cooperation in space, however, may be affected by geopolitical tensions on Earth.

The role that the commercial space sector plays in the provision of launch, communications, imagery, and manufacturing services and its relationship with civil and military programs make this sector an important determinant of space security. A healthy space industry can lead to decreasing costs for space access and use, and may increase the accessibility of space technology for a wider range of space actors. Recently, commercial actors are driving the development of new technologies, services, and economic activities in outer space.

The military space sector wields considerable influence in the advancement of capabilities to access and use space. Many of today's common space applications, such as satellite-based navigation, were first developed for military use. Space systems have augmented the military capabilities of a number of states by enhancing battlefield awareness, offering precise navigation and targeting support, providing early warning of missile launch, and supporting real-time communications. Furthermore, remote sensing satellites have served as a technical means for nations to verify compliance with international nonproliferation, arms control, and disarmament regimes.

However, the use of space systems to support terrestrial military operations could be detrimental to space security if adversaries, viewing space as a new source of military threat or as critical military infrastructure, develop negation capabilities to neutralize the space systems of other nations.

The security dynamics of space systems protection and negation are closely related and space security cannot be divorced from terrestrial security. In this context, it is important to point out that offensive and defensive space capabilities are not only related to systems that are physically in orbit, but include orbiting satellites, ground stations, and data and communications links.

No hostile anti-satellite attacks have been carried out against an adversary; however, recent incidents testify to the availability and effectiveness of anti-ballistic missile systems to destroy satellites in outer space. The ability to rapidly rebuild or repair space systems after an attack could reduce vulnerabilities in space by making these systems more resilient to harmful acts. Similarly, the use of smaller spacecraft that may be deployed as distributed systems can improve continuity of capability and enhance security through redundancy and rapid replacement of assets. However, the development of advanced on-orbit capabilities in outer space could also enable space-based negation activities.

International instruments that regulate space activities have a direct effect on space security because they establish key parameters for acceptable behavior in space. These include the right of all countries to access space, prohibitions against the national appropriation of space, and the obligation to ensure that space is used with due regard to the interests of others and for peaceful purposes. International space law, as well as valuable unilateral, bilateral, and multilateral transparency and confidence-building measures, can make space more secure by regulating activities that may infringe upon the ability of actors to access and use space safely and sustainably, and by limiting space-based threats to national assets in space or on Earth.

While there is widespread international recognition that the existing regulatory framework is insufficient to meet current and future challenges facing the outer space domain, the development of an overarching normative regime has been slow. Space actors have been unable to reach consensus on the exact nature of a space security regime, although specific alternatives have been presented.

Proposals include both legally binding treaties, such as the proposed Treaty on the Prevention of the Placement of Weapons in Outer Space, and of the Threat or Use of Force against Outer Space Objects (known as the PPWT), and politically binding norms, such as the proposed International Code of Conduct for Outer Space Activities.

Because our coverage of space security is captured across many different indicators, *Space Security Index 2017* includes a Global Assessment, which is intended to analyze and evaluate the effects of changing trends, critical themes, key highlights, breaking points, and new dynamics that are shaping the security of outer space and require international attention.

The Global Assessment is prepared by a different expert on space security every year to encourage a range of perspectives over time. The author of the current assessment is Dr. Laura Grego, a Senior Scientist at the Union of Concerned Scientists and longtime contributor to the Space Security Index project.

The information in *Space Security Index 2017* is from open sources. Great effort is made to ensure a complete and factually accurate description of events. Project partners and sponsors trust that this publication will continue to serve as both a reference source for capacity building, and as a tool for supporting trust, transparency, and dialogue in the pursuit of policymaking to enhance the safe, sustainable, and secure use of outer space for all users.

Expert participation in the Space Security Index is a key component of the project. The primary research is peer-reviewed prior to publication through various processes. For example, the Space Security Working Group in-person consultation is held each spring for two days to review the draft text for factual errors, misinterpretations, gaps, and misstatements. This meeting also provides an important forum for related policy dialogue on recent developments in outer space.

Note that, unless otherwise indicated, all monetary amounts in this volume are in U.S. dollars.

For further information about the Space Security Index, its methodology, project partners, and sponsors, please visit the website **www.spacesecurityindex.org**. Comments and suggestions are welcome.

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Definition of space security: secure and sustainable access to and use of space, and freedom from space-based threats

Theme 1: Condition and knowledge of the space environment

INDICATOR 1.1: Orbital debris — Space debris poses a significant, constant, and indiscriminate threat to all spacecraft. Most space missions create some space debris, mainly rocket booster stages that are expended and released to drift in space along with bits of hardware. Serious fragmentations are usually caused by energetic events such as explosions. These can be both unintentional, as in the case of unused fuel exploding, or intentional, as in the testing of weapons in space that utilize kinetic energy interceptors. Traveling at speeds of up to 7.8 kilometers (km) per second, even small pieces of space debris can destroy or severely disable a satellite upon impact.

The number of objects in Earth orbit has increased steadily. This was accelerated by recent events such as the Chinese intentional destruction of one of its satellites in 2007 and the accidental 2009 collision of a U.S. Iridium active satellite and a Russian Kosmos defunct satellite. There have already been a number of collisions between civil, commercial, and military spacecraft and pieces of space debris. Although a rare occurrence, the reentry of very large debris could also potentially pose a threat on Earth.

There is international consensus that debris is a problem that needs to be mitigated. Voluntary guidelines have been developed by the Inter-Agency Space Debris Coordination Committee (IADC) and endorsed by the UN General Assembly, but implementation remains a challenge that is further complicated by new technologies and practices. Capabilities for active removal of existing debris are being developed, but there is no consensus that it should be done.

2016 Developments

- Legacy hardware failures cause several minor on-orbit breakups
- Minor damage to spacecraft, orbital maneuvers caused by space debris
- Concerns raised by uncontrolled spacecraft reentries
- Compliance with debris mitigation guidelines varies
- Focus expands on deorbiting LEO satellites to mitigate debris
- First substantive efforts made to develop active-debris-removal capabilities
- Filings for large constellations of satellites raise questions about debris mitigation
- Political efforts made to minimize space debris

INDICATOR 1.2: Radio frequency (RF) spectrum and orbital positions — The growing number of spacefaring nations and satellite applications is driving the demand for access to limited radio frequencies and orbital slots. While interference is not epidemic, it is a growing concern for satellite operators, particularly in crowded space segments. Issues of interference arise primarily when two spacecraft require the same frequencies at the same time and their fields of view overlap or they are transmitting in close proximity to each other. More satellites are locating in Geostationary Earth Orbit (GEO), using frequency bands in common and increasing the likelihood of frequency interference. The increased competition for orbital slot assignments, particularly in GEO, where most communications satellites operate, has caused occasional disputes between satellite operators. The International Telecommunication Union (ITU) has been pursuing reforms to address slot allocation backlogs and other related challenges. Prospects for large constellations of satellites are adding pressure to the regulation of these space resources.

2016 Developments

- Bringing-into-Use deadlines extended for expanded range of cases
- Filings for large satellite constellations spur concerns about regulation, congestion, and interference
- Technological efforts made to use radio frequency more efficiently
- Radio frequency interference remains a concern

INDICATOR 1.3: Natural hazards originating from space — Such hazards fall into two categories: Near-Earth Objects (NEOs) and space weather. NEOs are asteroids and comets in orbits that bring them into close proximity to Earth. By mid-2016, there were 14,653 known Near-Earth Asteroids, 1,723 of which were identified as Potentially Hazardous Asteroids, whose orbits come within 0.05 astronomical units of Earth's orbit and have a brightness magnitude greater than 22 (approximately 150 meters in diameter). Increasing international awareness of the potential threat posed by NEOs has prompted discussions at various multilateral forums on the technical and policy challenges related to mitigation. Ongoing technical research is exploring how to mitigate a NEO collision with Earth.

"Space weather" is a term that over the past few years has come to refer to a collection of physical processes, beginning at the Sun and ultimately affecting human activities on Earth and in space. The Sun emits energy as flares of electromagnetic radiation and as electrically charged particles through coronal mass ejections and plasma streams. Powerful solar flares can cause radio blackouts and an expansion of Earth's atmosphere, which has the effect of slowing down satellites in LEO, causing them to move into lower orbits. Increases in the number and energy of charged particles can induce power surges in transmission lines and pipelines, disruptions to high-frequency radio communication and Global Positioning System (GPS) navigation, and failure or incorrect operation of satellites.

2016 Developments

Near-Earth Objects

- United States emphasizes NEO early warning and preparedness, but knowledge gaps remain
- Coordination through International Asteroid Warning Network and Space Missions Planning Advisory Group progresses
- Efforts to mitigate threats from hazardous asteroids face several setbacks

Space weather

- United States begins implementation of National Space Weather Action Plan and National Space Weather Strategy
- Efforts continue to improve space weather forecasting, response
- UNISPACE+50 process includes focus on international space weather framework
- Concerns grow about vulnerabilities to solar storms and changes in Earth's magnetosphere

INDICATOR 1.4: Space situational awareness — SSA refers to the ability to detect, track, identify, and catalog objects in outer space, such as space debris and active or defunct satellites, as well as observe space weather and monitor spacecraft and payloads for maneuvers and other events. SSA enhances the ability to distinguish space negation attacks from technical failures or environmental disruptions and can thus contribute to stability in space by preventing misunderstandings and false accusations of hostile actions. Increasing the amount of SSA data available to all states can help to increase the transparency and confidence of space activities, which can reinforce the overall stability of the outer space regime. The Space Surveillance Network puts the United States far in advance of the rest of the world in SSA capability. Other states are developing independent SSA capabilities, but there is currently no global system for space surveillance or data sharing, in part because of the sensitive nature of surveillance data.

2016 Developments

- United States continues to prioritize improved SSA capabilities
- Russia, France, Japan, China advancing independent SSA capabilities
- United States expands SSA cooperation
- Proposals presented on multilateral sharing of orbital data
- United States considers a civilian role in space traffic management
- U.S. commercial actors continue to expand SSA role, upgrade capabilities to meet need

Theme 2: Access to and use of space by various actors

INDICATOR 2.1: Space-based global utilities — These global utilities are space assets that can be used by any actor equipped to receive the data they provide. The use of space-based global utilities has grown substantially over the last decade. Millions of individuals rely on space applications on a daily basis for functions as diverse as weather forecasting; navigation; surveillance of borders and coastal waters; monitoring of crops, fisheries, and forests; health and education; disaster mitigation; and search-and-rescue operations. Global utilities are important for space security because they broaden the community of actors that have a direct interest in maintaining space for peaceful uses. Many, such as the Global Positioning System (GPS) and weather satellites, were initially developed by military actors, but have since become applications that are almost indispensable to the civil and commercial sectors. Advanced and developing economies alike depend on these space-based systems.

2016 Developments

- Positioning, Navigation, and Timing (PNT) systems upgraded; interoperability and cooperation improvements attempted
- Efforts made to prevent gaps in global weather monitoring and forecasting
- Satellite-based Automatic Identification System (AIS) contributes to global marine governance
- Access to high-resolution remote sensing data expands
- Importance of space resources to monitor climate change recognized
- New initiatives make data from national space systems public
- Space resources remain important for disaster response

INDICATOR 2.2: Priorities and funding levels in civil space programs — Civil space programs can have a positive impact on the security of outer space. They constitute key drivers in the development of technical capabilities to access and use space, such as those related to the development of space launch vehicles. As the number of space actors able to access space increases, more parties have a direct stake in space sustainability and preservation for peaceful purposes. As well, civil space programs and their technological spinoffs on Earth underscore the vast scientific, commercial, and social benefits of space exploration, thereby increasing global awareness of its importance.

As the social and economic benefits derived from space activities have become more apparent, civil expenditures on space activities have continued to increase, as have the number of states participating in space activities. Virtually all new spacefaring states explicitly place a priority on space-based applications to support social and economic development as well as dual-use security-related functions.

2016 Developments

- Major space programs prioritize access to space and deep space exploration
- Investment in emerging space programs focuses on joint military/industrial benefits
- China's space program achieves significant milestones
- Democratic People's Republic of Korea completes second successful satellite launch
- Global participation expands, with focus on industrial and socioeconomic benefits

INDICATOR 2.3: International cooperation in space activities — Due to the huge costs and technical challenges associated with access to and use of space, international cooperation has been a defining feature of civil space programs throughout the space age. Scientific satellites, in particular, have been cooperative ventures. International cooperation remains a key feature of both civil and global utilities space programs. By allowing states to pool resources and expertise, international civil space cooperation has played a key role in the proliferation of the technical capabilities needed by states to access space. Cooperation agreements on space activities have proven to be especially helpful for emerging spacefaring states that currently lack the technological means for independent space access. Cooperation agreements also enable established spacefaring countries to tackle high-cost, complex missions as collaborative endeavors with international partners.

Finally, cooperation enhances the transparency of space programs and can foster both technical and cultural understandings. The International Space Station (ISS) remains the most prominent example of international cooperation. As a source of technology transfer and influence, it can also be used to advance strategic and political interests.

2016 Developments

- Cooperation holds as partners consider the future of the ISS
- Lunar exploration emerges as focus for expanded international cooperation
- Geopolitical ties shape space cooperation
- Cooperation accelerates capabilities for emerging space programs
- Cooperative initiatives broaden space access for developing countries
- Nascent United States-China space cooperation proceeds cautiously

INDICATOR 2.4: Growth in the commercial space industry — The role that the commercial space sector plays in the provision of launch, communications, imagery, and manufacturing services, as well as its relationship with civil and military programs make this sector an important component of space security. A healthy space industry can lead to decreasing costs for space access and use, and may increase the accessibility of space technology for a wider range of space actors. Increased commercial competition in the research and development of new applications can also lead to the further diversification of capabilities to access and use space. Recent growth in the commercial space sector has been driven by the pursuit of new satellite and launch technologies; new services related to communications and Earth observation; and the pursuit of new activities, including human space launch, exploration, and resource extraction.

2016 Developments

- Proposals for large satellite constellations see internet as space-based telecommunications service
- Increased revenues made available for commercial space launch providers
- Launch failures demonstrate vulnerability of commercial sector to disruption
- Innovations in manufacturing, services, and launch capabilities linked to small satellites
- Nascent space-based industry focused on exploration and resource extraction
- Private sector experiments with new funding models

INDICATOR 2.5: Public-private collaboration on space activities — The commercial space sector is significantly shaped by the particular security concerns and economic interests of national governments. There is an increasingly close relationship between governments and the commercial space sector. Various national space policies place great emphasis on maintaining a robust and competitive industrial base and encourage partnerships with the private sector. The space launch and manufacturing sectors rely heavily on government contracts. The retirement of the space shuttle in the United States, for instance, opened up new opportunities for the commercial sector to develop launch services for human spaceflight. Governments play a central role in commercial space activities by supporting research and development, subsidizing certain space industries, and adopting enabling policies and regulations. Conversely, because space technology is often dual-use, governments have sometimes taken actions, such as the imposition of export controls, which hinder the growth of the commercial market.

2016 Developments

- Regulatory and financial incentives encourage growth of national space industries
- Commercial space launch, Earth-imaging companies still face national security restrictions
- Some setbacks to increasing U.S. defense use of private sector capabilities
- United States remains focused on public-private partnerships for next-generation space exploration
- India and China encourage more private participation in domestic space programs

INDICATOR 2.6: Space-based military systems — Space assets are being used for terrestrial military purposes by a growing number of states. The United States has dominated the military space arena since the end of the Cold War and continues to give priority to its military and intelligence programs, which are now integrated into virtually all aspects of military operations. Russia maintains a large fleet of military satellites, but many of its systems were developed during the Cold War. China does not maintain a strong separation between civil and military applications, but its program is growing rapidly and supports an increasing number of military functions, as does India's. In the absence of dedicated military satellites, many actors use their civilian satellites for military purposes or purchase data and services from civilian satellite operators. However, the number of states with dedicated military satellites is increasing.

2016 Developments

- United States prioritizes Space Mission Assurance
- Changes in U.S. force integration and space control proceed
- Russia modernizes surveillance and reconnaissance capabilities
- China enhances access to reconnaissance and PNT capabilities
- Europe seeks to enhance cooperative, dual-use of space capabilities
- Germany, United Kingdom, France look to next-generation military systems
- India takes steps to formalize its military uses of outer space
- Rising security tensions in Asia drive increased focus on military space
- Focus on military space capabilities emerges in the Middle East

- Canada, Australia continue to develop space-based military capabilities
- U.S. military pursues international cooperation, adds space component to existing alliances

Theme 3: Security of space systems

INDICATOR 3.1: Vulnerability of satellite communications, broadcast links, and ground stations — Satellite ground stations and communications links constitute likely targets for space negation efforts, since they are vulnerable to a range of widely available conventional and electronic weapons. While military satellite ground stations and communications links are generally well protected, civil and commercial assets tend to have fewer protective features. Many actors employ passive electronic protection capabilities, such as shielding and directional antennas, while more advanced measures, such as burst transmissions, are generally confined to military systems and the capabilities of more technically advanced states. Because the vast majority of space assets depend on cyber networks, the link between cyberspace and outer space constitutes a critical vulnerability.

2016 Developments

- Electromagnetic interference with satellite communications remains widespread
- United States enhances protected SATCOM
- Ground stations demonstrate vulnerabilities to cyberattacks; industry pursues voluntary cybersecurity measures
- Laser-based communications between satellites advance
- China launches quantum entanglement experiment

INDICATOR 3.2: Reconstitution and resilience of space systems — The ability to rapidly rebuild or repair space systems after an attack could reduce vulnerabilities in space. The capabilities to refit space systems by launching new satellites into orbit in a timely manner to replace satellites damaged or destroyed by an attack are critical resilience measures. Multiple programs show the prioritization of, and progress in, new technologies that can be integrated quickly into space operations. Smaller, less expensive spacecraft that may be fractionated or distributed on hosts can improve continuity of capability and enhance security through redundancy and rapid replacement of assets. While these characteristics may make attacks against space assets less attractive, they can also make assets more difficult to track, and so inhibit transparency. The ability to use redundant terrestrial capabilities or to operate through the systems of other space actors is also an important source of resilience.

2016 Developments

- U.S. focus on Space Mission Assurance continues emphasis on resilience
- Several countries continue work on reusable and rapid-response launch systems
- Civil and commercial on-orbit satellite servicing capabilities advance
- Efforts continue to build resilience through alternatives to space-based GPS
- United States enhances capabilities to detect threats to space-based systems
- U.S. DoD and National Reconnaissance Office (NRO) experiment with CubeSats
- United States looks for deeper space system integration with international partners

INDICATOR 3.3: Earth-based capabilities to attack satellites — Launching a payload to coincide with the passage of a satellite in orbit is the fundamental requirement for anti-satellite capability. Ground-based anti-satellite weapons (ASATs) employing conventional, nuclear, and directed energy capabilities date back to the Cold War, but no hostile use of them has been recorded. Conventional anti-satellite weapons include precision-guided kinetic-intercept vehicles, conventional explosives, and specialized systems designed to spread lethal clouds of metal pellets in the orbital path of a targeted satellite. A space launch vehicle with a nuclear weapon would be capable of producing a High Altitude Nuclear Detonation that would cause widespread and immediate electronic damage to satellites and produce the long-term effects of false radiation belts, which would have an adverse impact on many satellites. Security concerns about the development of negation capabilities are compounded by the fact that many key space capabilities are dual-use. Recent incidents involving state use of anti-ballistic missile systems against their own satellites (China in 2007 and the United States in 2008) underscore the detrimental effect that such systems can have for space security. Such use not only produces space debris, but contributes to a climate of mistrust among spacefaring nations.

2016 Developments

- Development and testing of exoatmospheric anti-missile technology continues
- Interest renewed in directed energy applications, but capabilities against space objects nascent

INDICATOR 3.4: Space-based negation-enabling capabilities — Deploying space-based ASATs—using kinetic-kill, directed energy, or conventional explosive techniques—would require enabling technologies much more advanced than those required for orbital launch. Space-based negation efforts require sophisticated capabilities, such as precision on-orbit maneuverability and space tracking. Microsatellites, maneuverability, and other autonomous proximity operations are essential building blocks for a space-based negation system, but they have dual-use for a variety of civil, commercial, and non-negation military programs. While some nations have developed these technologies, there is no evidence that they have integrated them into dedicated capabilities for space system negation.

2016 Developments

- U.S. Congress opens door for possible space-based missile defense, options to defeat space-based threats
- Military, civilian, and commercial actors demonstrate advancing capabilities for on-orbit maneuvering and proximity operations

Theme 4:
Outer space governance

INDICATOR 4.1: National space policies — The development of national space policies that delineate the principles and objectives of space actors with respect to access to and use of space has been conducive to greater transparency and predictability of space activities. National civil, commercial, and military space actors all operate according to these policies. Most spacefaring states explicitly support the principles of peaceful and equitable use of space, and emphasize space activities that promote national socioeconomic, scientific, and technological goals. Virtually all space actors underscore the importance of international cooperation in their space policies; several developing nations have been able to access space because of such cooperation. Major space powers and emerging spacefaring nations increasingly view space assets such as multiuse space systems as integral elements of their national security infrastructure. The military doctrines of a growing number of states emphasize the use of space systems to support national security and as an extension of terrestrial domains of warfare.

2016 Developments

- Developments in U.S. military strategy recognize 'normalized' warfighting in space
- Security-related aspects of European space policy included in the European Defence Action Plan
- China's White Paper on Space Activities emphasizes peaceful use, cooperation, and comprehensive space power
- National policies seek to advance private space exploration and use of space resources
- African Space Policy and Strategy links to Agenda 2063 for socioeconomic transformation
- New national space policies signal growing importance of outer space

INDICATOR 4.2: Multilateral forums for space governance — A number of international institutions make available multilateral forums where space security issues can be addressed. The United Nations provides the General Assembly (UNGA) First and Fourth Committees, UN Space, the UN Committee on the Peaceful Uses of Outer Space (COPUOS), the International Telecommunication Union, the Conference on Disarmament (CD), and the International Committee on Global Navigation Satellite Systems. Europe has led in an initiative to develop an International Code of Conduct for Outer Space.

2016 Developments

- UN COPUOS agrees on an initial set of draft guidelines for long-term sustainability of space activities, develops a compendium on non-legally binding UN instruments on outer space, and expands agenda
- Work at the CD remains stalled
- UNGA resolutions reflect points of consensus, divide
- UNISPACE+50 preparations proceed with adoption of themes
- India joins the Missile Technology Control Regime and The Hague Code of Conduct Against Ballistic Missile Proliferation
- EU remains committed to International Code of Conduct process within a UN framework
- International Civil Aviation Organization calls for UN space travel regulations

INDICATOR 4.3: Other initiatives — A growing number of diplomatic initiatives relate to bilateral or regional collaborations in space activities. Examples of this include the work of the Asia-Pacific Regional Space Agency Forum and discussions in the African Union to develop an African space agency. The UN Institute for Disarmament Research (UNIDIR)—an autonomous unit in the UN system—has also played a key role in facilitating dialogue among key space stakeholders. Every year, UNIDIR partners with civil society actors and some governments to bring together space security experts and government representatives at a conference on emerging security threats to outer space.

2016 Developments

- First UN High-Level Forum adopts the Dubai Declaration
- The Hague Space Resources Governance Working Group initiates work
- International Committee of the Red Cross warns of grave humanitarian consequences to weaponization of outer space
- BRICS Declaration calls for international agreement to prevent weaponization of outer space
- G7 Summit in Hiroshima, Japan considers outer space governance
- Host Germany asked to focus on space at G20 Summit in 2017
- Process initiated to develop Manual on International Law Applicable to Military Uses of Outer Space
- China and the United States hold first Dialogue on Outer Space Security
- Asgardia declares itself the first space nation

Condition and knowledge of the space environment

THEME ONE

Indicator 1.1: Orbital debris

Space debris—predominantly objects generated by human activity in space—represents a growing and indiscriminate threat to all spacecraft. The impact of space debris on space security is related to a number of key issues examined in this volume, including the amount of space debris in various orbits, space surveillance capabilities that track space debris to enable collision avoidance, as well as policy and technical efforts to reduce the amount of new debris and remediate existing space debris in the future.

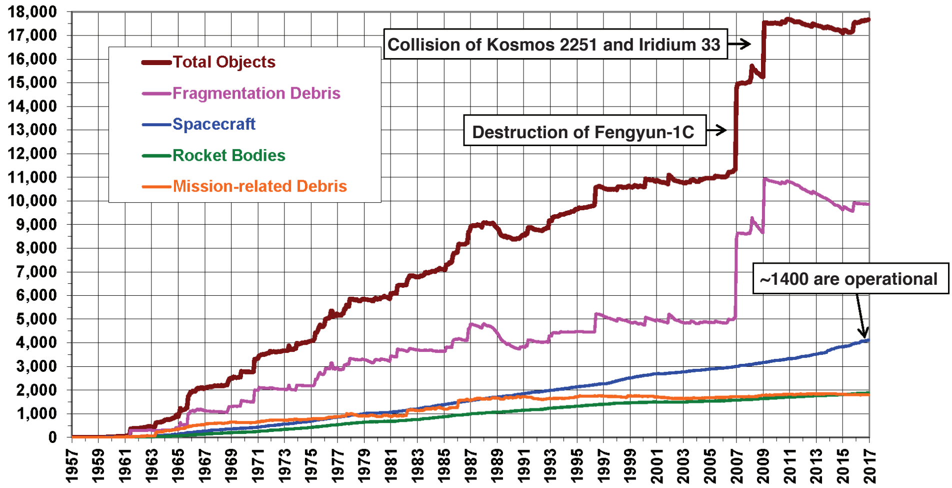
While all space missions create some debris—mainly as rocket booster stages are expended and released to drift in space along with bits of hardware—more serious fragmentations are usually caused by energetic events such as explosions or collisions. These can be either unintentional, as in the case of unused fuel exploding, or intentional, when testing weapons in space that utilize kinetic energy interceptors. Together, these events have created thousands of long-lasting pieces of space debris.

The U.S. Space Surveillance Network (SSN) currently tracks approximately 23,000 pieces of debris, most 10 cm in diameter or larger.[1] This total does not include roughly 500,000 smaller pieces between one and 10 cm in diameter, which are more difficult to track, but still have the potential to cause serious damage to spacecraft, or millions of even smaller pieces that could damage subsystems and cause degradation over time.[2] The Joint Space Operations Center (JSpOC) of the U.S. Strategic Command (USSTRATCOM) uses the SSN to track more than 17,000 *cataloged* objects with known origins,[3] of which approximately 5% are functioning payloads or satellites, 8% rocket bodies, and 87% debris and/or inactive satellites.[4] However, the number of *active* satellites in orbit continues to increase and is expected to accelerate as more states access space via independent satellites (see Indicator 2.2) and plans for large constellations of satellites in Low Earth Orbit (LEO, less than 2,000 km above Earth) materialize (see below and Indicator 2.4).

The average velocity of both satellites and debris in LEO is 7 kilometers per second (km/s) and 3.1 km/s in Geostationary Earth Orbit (GEO, more than 36,000 km above Earth).[5] Thus, collisions with large pieces of debris would be catastrophic and even very small pieces can cripple or destroy working spacecraft or endanger astronauts. Collisions between such space assets as the International Space Station (ISS) and very small pieces of untracked debris are frequent but manageable.[6] The ISS has had to be repositioned on several occasions to avoid collision with a large piece of debris. Other precautionary measures have also been necessary.

Although collision warnings based on conjunction analyses are provided to operators, notably by JSpOC using space surveillance data (see Indicator 1.4), these data points are imprecise due to uncertainty of both the object's track and a satellite's orbital position, leaving operators to set thresholds for risk and to decide when to maneuver a satellite out of harm's way.[7] Such debris avoidance maneuvers are becoming more frequent.[8]

Figure 1.1 Growth in on-orbit population by category[9]



Low Earth Orbit, especially the Sun-synchronous region, is the most highly congested area and the location of roughly half of all debris. Some debris in LEO will reenter Earth's atmosphere and disintegrate quite quickly from atmospheric drag, but debris in orbits above 600 km will remain a threat for decades and even centuries. It is particularly difficult to track objects in higher orbits; only about 1,000 objects are tracked in each of Medium Earth Orbit (MEO, 2,000-30,000 km above Earth) and Geostationary Earth Orbit.[10] Objects need to be one meter in diameter or larger to be accurately tracked in GEO.[11]

Ten space missions—the most significant of which occurred within the last 10 years—account for roughly one-third of all cataloged objects in Earth orbit. By far the greatest source of human-made debris in orbit was caused by the Fengyun (FY)-1C, which China intentionally destroyed in January 2007; this incident produced approximately 20% of the objects currently cataloged.[12] The second most debris-causing satellite breakup took place in February 2009, when the inactive Russian satellite Kosmos 2251 and U.S. satellite Iridium 33 accidentally collided.

To date, problems with propulsion systems have caused about 45% of all known satellite breakups, deliberate actions approximately 29%, unknown causes 20%, battery problems 4%, and accidental collision roughly 2%.[13]

Figure 1.2 Top 10 breakups of on-orbit objects based on amount of debris produced[14]

Common name	Launching state	Owner	Year of breakup	Altitude of breakup (km)	Total cataloged pieces of debris	Debris still in orbit	Cause of breakup
Fengyun-1C	China	China	2007	850	3,4288	2,880	Intentional Collision
Kosmos 2251	Russia	Russia	2009	790	1,668	1,141	Accidental Collision
STEP 2 Rocket Body	United States	United States	1996	625	745	84	Accidental Explosion
Iridium 33	United States	Iridium	2009	790	628	364	Accidental Collision
Kosmos 2421	Russia	Russia	2008	410	509	0	Unknown
SPOT 1 Rocket Body	France	France	1986	805	498	32	Accidental Explosion
OV 2-1 / LCS-2 Rocket Body	United States	United States	1965	740	473	33	Accidental Explosion
CBERS 1 Rocket Body	China	China	2000	740	431	210	Accidental Explosion
Nimbus 4 Rocket Body	United States	Unites States	1970	1,075	376	235	Accidental Explosion
TES Rocket Body	India	India	2001	670	372	80	Accidental Explosion

Although over the last five years the total number of objects in orbit has been decreasing, as the debris from a few large collisions and explosions degrades into the atmosphere (see Figure 1.6), the long-term trend is still going up. Moreover, debris is concentrated in the orbits where human activities take place. There have already been a number of collisions between civil, commercial, and military spacecraft and pieces of space debris.

Figure 1.3 Unintentional collisions between space objects[15]

Year	Event
1991	Inactive Kosmos-1934 satellite hit by cataloged debris from Kosmos 296 satellite
1996	Active French Cerise satellite hit by cataloged debris from Ariane rocket stage
1997	Inactive NOAA-7 satellite hit by uncataloged debris large enough to change its orbit and create additional debris
2002	Inactive Kosmos-539 satellite hit by uncataloged debris large enough to change its orbit and create additional debris
2005	U.S. rocket body hit by cataloged debris from Chinese rocket stage
2007	Active Meteosat-8 satellite hit by uncataloged debris large enough to change its orbit
2007	Inactive NASA Upper Atmosphere Research Satellite believed hit by uncataloged debris large enough to create additional debris
2009	Retired Russian communications satellite Kosmos 2251 collides with U.S. satellite Iridium 33
2013	Ecuadorean satellite Pegasus collides with debris from S14 Soviet rocket launched in 1985

Growing awareness of space debris threats has led to efforts to decrease the amount of new debris.

Between 1961 and 1996, approximately 240 new objects on average were cataloged each year. They were largely the result of fragmentation and the launching of new satellites. Between October 1997 and June 2004, the rate of annual increase in debris dropped by more than half—a noteworthy decrease, particularly given improvements in surveillance and the cataloging system. Combined with a lower number of launches per year, this decline can be directly related to international debris mitigation efforts, led primarily by the Inter-Agency Space Debris Coordination Committee (IADC) and the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS).

The IADC is an international forum of national and multinational space agencies for the coordination of activities related to space debris, formed in 1993 by the European Space Agency (ESA) and the national space agencies of the United States, Russia, and Japan.[16] The IADC allows the exchange of information on space debris research activities among member space agencies, facilitates opportunities for cooperation in space debris research, reviews the progress of ongoing cooperative activities, and identifies debris mitigation options.[17]

UN COPUOS initiated discussions on space debris in 1994 and published its *Technical Report on Space Debris* in 1999. In 2001, COPUOS asked the IADC to develop a set of international debris mitigation guidelines, on which it based its own draft guidelines in 2005.[18] In 2007, these guidelines were adopted by UN COPUOS and endorsed by the UN General Assembly (UNGA) as voluntary measures with which all states should comply.[19] Canada, the Czech Republic, and Germany have developed a compendium of space debris mitigation standards adopted by states and international organizations to inform states of the current instruments and measures.[20] Efforts to mitigate space debris are also incorporated into the 2016 guidelines for the long-term sustainability of outer space activities adopted by COPUOS (see Indicator 4.2).

Figure 1.4 UN Space Debris Mitigation Guidelines[21]

Space Debris Mitigation Guidelines
1. Limit debris released during normal operations.
2. Minimize the potential for breakups during operational phases.
3. Limit the probability of accidental collision in orbit.
4. Avoid intentional destruction and other harmful activities.
5. Minimize potential for post-mission breakups resulting from stored energy.
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the LEO region after the end of their mission.
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the GEO region after the end of their mission.

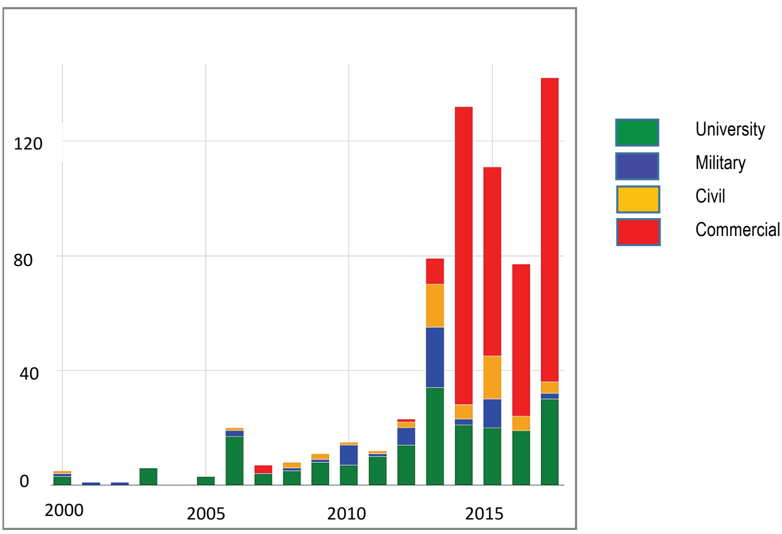
However, compliance with mitigation guidelines is inconsistent. Analysis from ESA suggests that in GEO, many satellites continue to reach end of life without being moved higher to a safe, “graveyard” orbit.[22] A Centre national d’études spatiales (CNES) study of debris mitigation practices from 2000 to 2012 found that 40% of satellites and rocket bodies are left in LEO at altitudes high enough to make impossible reentry due to natural orbital decay within the 25-year window specified in the guidelines.[23]

Debris mitigation is further complicated by the growing use of small satellites such as nanosats (with a mass of between one and 10 kg) and CubeSats (a nanosat built according to a construction standard first developed in 1999, which includes a modular 10-cm cube design weighing less than 1.33 kg).[24] More than 500 microsatellites (less than 100 kg) were launched between 2002 and 2015. Many more are planned, including thousands for large commercial constellations.[25]

With limited capabilities, CubeSats generally have shorter lifespans, and since they lack onboard propulsion systems they are not able to maneuver on orbit to avoid collisions or execute controlled atmospheric reentries upon mission completion. Moreover, because CubeSats are typically launched as secondary payloads, they generally end up in the orbital regime of the primary payload, which means that many of them are in orbits too high to rapidly decay.[26] The lower cost of a CubeSat also allows for more experimentation and less stringent quality control, which can result in more failed satellites in orbit.

The Orbital Debris Program Office (ODPO) at NASA's Johnson Space Center released new analytical data on CubeSats in 2015, claiming that approximately 20% of CubeSats are in orbits that do not comply with guidelines calling for satellites to stay in orbit no more than 25 years after mission completion.[27] Nonetheless, others have argued that CubeSats may pose less of a debris hazard as their small size makes them less destructive and their lack of propellant makes them less likely to explode.[28] Planet Labs, a pioneer of CubeSats for commercial purposes, has publicly announced its adoption of NASA's best practices for limiting orbital debris.[29] But a recent study suggests that approximately 18% of CubeSats are dead-on-arrival or within their first week in space.[30] Still, CubeSats that are launched in lower LEO orbits (thus respecting the 25-year rule) do not significantly raise the rate of collision or the amount of debris.[31]

Figure 1.5 Number of CubeSats by mission type[32]



Recently, commercial plans have emerged for large constellations of hundreds and even thousands of satellites in LEO, which will pose new challenges to long-term sustainability (see below).[33] The IADC added the subject of large constellations of satellites to its work in 2015.

In the long term, mitigation may not be sufficient to maintain a stable operating environment in outer space, particularly in LEO. The "Kessler Syndrome" describes a scenario in which collisions in LEO could generate space debris that increases the likelihood of future collisions—creating a cascading effect.[34] There are concerns that we have already reached the point at which the amount of debris will continue to grow in spite of mitigation measures.[35] Authors of an IADC study representing six member space agencies recommended that remediation measures, such as active debris removal (ADR), should be considered to stabilize the future LEO environment. To date, no active debris removal mechanisms have been implemented, although research continues. Currently there is no political consensus that debris removal should be done, and by whom; as well, financial challenges remain. Transparency will be important for any such effort, since this capability could also be used against active satellites (see Indicator 3.4).

2016 Developments

Legacy hardware failures cause several minor on-orbit breakups

The U.S. SSN detected 12 minor satellite fragmentations in 2016, none of which contributed long-term damage to the space environment.[36] However, several of the breakups were from legacy systems, raising questions about the future stability of these spacecraft. Following the breakup of U.S. Air Force (USAF) weather satellite DMSP F-13 in 2015 and DMSP F-11 in 2004, DMSP F-12 broke up in orbit in October. The F-12 had been safely shut down in 2008, with remaining fuel burned off, compressed gasses released, and the battery discharged. With no ongoing communication with the satellite, the cause of the breakup is difficult to determine, but could be linked to the same battery assembly that caused the fragmentation of the F-13 in 2015.[37] The USAF also lost control of DMSP F-19 in February, due to a power system failure.[38] There is increasing concern about the stability of the remaining six DMSP F-class satellites in orbit and of the threat posed by other legacy designs. Of the six DMSP satellites still in orbit, one is operational.

Three Russian SOZ ullage motors from the Proton-DM rocket launcher broke up in 2016. The third event of the year marked the 46th breakup of this class of object since the program's inception.[39] The Proton-DM was subsequently grounded in January 2017 for a minimum of six months to address ongoing problems with quality control.[40] It was previously grounded in 2010, following a launch failure that destroyed three GLONASS navigation satellites.[41]

A Russian Breeze-M upper stage from a Proton rocket exploded on 16 January, following the launch of Kosmos 2513.[42] (In 2007, a Breeze-M exploded in LEO.) By April, 10 pieces of debris had been observed, but none officially cataloged; however, as the explosion occurred in GEO, where smaller pieces of debris are difficult to identify and track, it is likely that hundreds of additional untracked pieces of debris were created.[43] From 2001 to 2016, Proton flew 129 missions, 12 of which failed.[44]

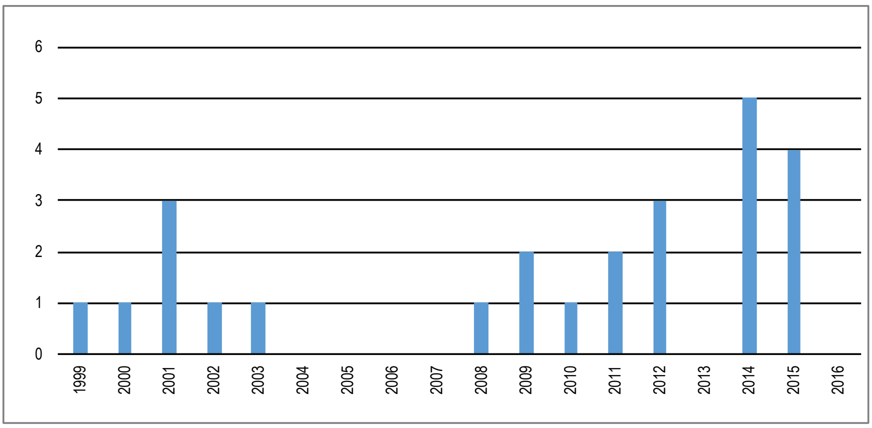
Figure 1.6 Debris-generating events in 2016[45]

Month	Mission/Object	State	Altitude of breakup (km)	Pieces of debris
January	Briz-M rocket body (Kosmos 2513)	Russia	34,866	10 observed, more likely
March	Hitomi	Japan	562	10 cataloged
March	SOZ/SL-12 motor (Kosmos 2447-2449)	Russia	18,840	21 observed, more likely
June	SOZ/SL-12 motor (Kosmos 2447-2449)	Russia	18,786	20 observed, more likely
June	Beidou G2	China	36,257	5 observed
July	Worldview2	United States	768	9 cataloged
July	SOZ/SL-12 motor (Kosmos 2424-2426)	Russia	19,088	Uncertain
September	RISAT-1	India	550	12 observed (1 cataloged)
October	DMSP F-12	United States	839	Uncertain

Minor damage to spacecraft, orbital maneuvers caused by space debris

The impact of space debris on space operations is still largely limited to isolated instances, which nevertheless illustrate the increasing threat posed by the ongoing accumulation of orbital debris. In August 2016, the solar panel of the ESA's Copernicus Sentinel 1A satellite was hit by a debris particle less than 3 mm in diameter. Although the impact did not impede regular operation of the satellite, it did cause a slight power reduction and changes to the satellite's orientation and orbit, demonstrating the threat posed by even small particles of debris.[46] In 2016, the International Space Station also incurred minor debris damage, including a 7-mm chip on the ESA's Cupola observation module; extensive shielding minimized damage.[47] The effects of hits to the PMA-2 docking cover were studied in 2016; conclusions will inform future construction on the space station.[48] Further, the ISS Space Debris Sensor was completed and prepared for a 2017 launch; it is intended to detect and characterize impacts on the station from small pieces of debris.[49]

Figure 1.7 International Space Station debris avoidance maneuvers by year[50]



In 2016, one debris avoidance maneuver of the ISS was suggested, but later aborted.[51] However, on 16 July, a piece of debris from METEOR 2-5 was not detected approaching the ISS until it was too late to execute a maneuver, so the ISS crew "sheltered in place" in the Soyuz spacecraft attached to the ISS, which served as a "life boat." This was the fourth shelter-in-place incident for an ISS crew in 15 years of operation.[52] NASA also executed or assisted spacecraft with 20 collision avoidance maneuvers in 2016, including four to avoid debris from the Fengyun-1C and four to avoid debris from the collision of the Kosmos 2251 and Iridium 33, both of which continue to have a strong influence on the amount of debris in LEO.[53]

A concern was raised in 2016 that the increasing number of CubeSats in orbit could force the ISS to make more avoidance maneuvers. By September 2016, the ISS had made three maneuvers to avoid CubeSats, having made two in 2015 and three in 2014. A recent study by Aerospace Corporation suggests that proposed constellations in LEO could increase collision warnings for the ISS sixfold (see below and Indicator 2.4).[54]

Concerns raised by uncontrolled spacecraft reentries

Safety and environmental concerns were raised regarding three uncontrolled spacecraft reentries in 2016. On 1 January, what appeared to be a spent second stage from a Russian

Zenit rocket landed in Vietnam with no advanced warning.[55] News spread following the recovery of three metal spheres, with diameters ranging from 27 to 80 cm and weighing as much as 45 kg. Analysis of their configuration and the Cyrillic writing found on them resulted in their identification as fuel tanks from a Zenit upper stage. The probable debris track extended into China's Guangxi province, but there have been no reports of debris in that region.

The anticipated reentry over Canadian Arctic waters of an intermediate stage of a Russian Rokot launch vehicle, which uses modified SS-19 intercontinental ballistic missiles, raised concerns about potential environmental contamination. The vehicle uses toxic hydrazine fuel, some of which remains unspent after launch.[56] Although its initial response to Russian warnings of the reentry was muted, the Canadian government later stated, "We have stressed to the Government of Russia the need for greater advance warning of planned launches to ensure that all precautions, relating both to the safety and security of our airspace and any potential environmental concerns, can be appropriately addressed."[57] However, the Russian government fulfilled its obligations to the Canadian government as directed by the IADC and The Hague Code of Conduct (see Indicator 4.2). The last two launches of the Rokot are scheduled for 2018, after which it will be replaced by newer Angara and Soyuz vehicles.[58]

In March 2016, China announced that its experimental space station Tiangong-1, launched in 2011, had ceased operations and would reenter the atmosphere in 2017.[59] China had originally stated its intention to deorbit Tiangong-1 in 2013, following the end of manned operations,[60] but later decided to keep it in orbit. The Chinese lost communications with the station in December 2015, possibly prior to further reorbit maneuvers,[61] which moved the station to progressively higher altitudes.[62] At the time of the announcement, the station was tracked at an altitude of 380 km and a velocity of 27,500 km/h.

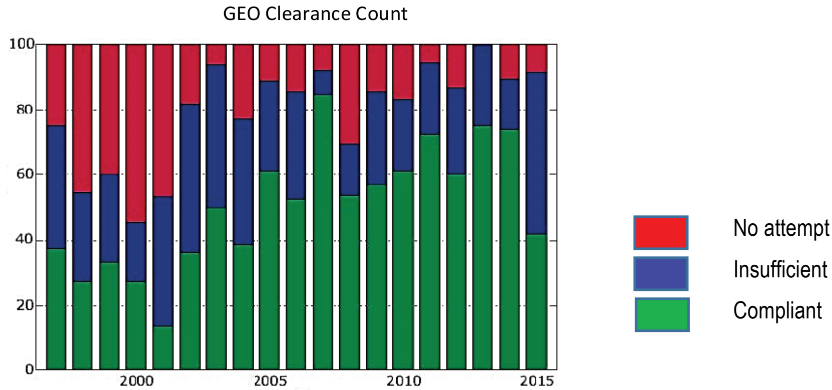
Chinese officials stated that "most parts of the space lab will burn up during falling."[63] However, approximately 40% of the station's dry mass (mostly engines) is expected to survive until impact. The space station is 10.4 m long and weighs 10.5 tonnes. It is possible that a significant portion will hit Earth, with no more than a few hours' notice. If Tiangong-1 has not undergone passivation—the elimination of stored energy—there could be an explosive breakup when it reenters the atmosphere.

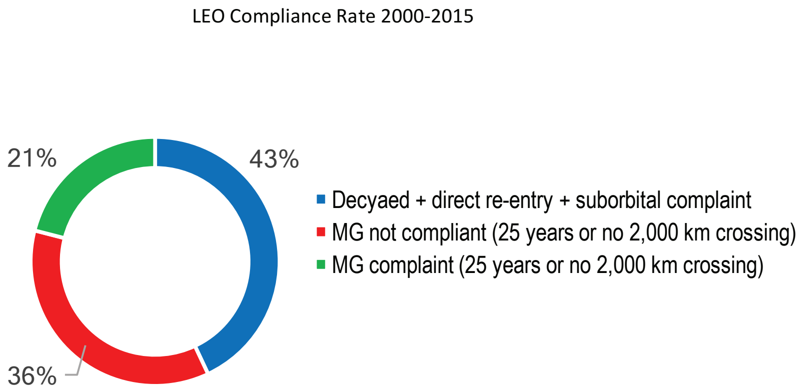
According to IADC guidelines, the Chinese government should take three major actions.[64] First, it should produce a debris management plan to share with IADC members as a basis for further communication. Next, the reentering vehicle should undergo passivation, which involves burning remaining fuel, discharging batteries, venting and draining pressurized systems, and bringing any remaining motive components to a stop. Finally, the Chinese should try to ensure a controlled deorbit that minimizes the station's time in LEO and minimizes the chances of terrestrial damage. It is not clear how these obligations ought to be fulfilled in the case of unforeseen loss of control of a space vehicle.

Compliance with debris mitigation guidelines varies

An assessment of compliance with IADC debris mitigation guidelines in 2016 highlights the need for improvement. The IADC noted that only 40% of GEO satellites were properly reorbited in 2015, compared to 75% in 2014, and that compliance with the 25-years-to-deorbit rule in LEO is static at 65%.[65] This has led to consideration of revisions to mitigation guidelines as well as confirmation that the use of the 2,000-km orbit as a graveyard will not be sufficient for the number of large satellite constellations that are being proposed. The 25-year deorbit rule for LEO is also under renewed consideration (see below).

Figure 1.8 Compliance with debris mitigation guideline (MG) in LEO, GEO[66]





Focus expands on deorbiting LEO satellites to mitigate debris

A stronger focus on mitigating debris by deorbiting satellites at the end of their useful life emerged in 2016, as many efforts moved toward testing and early utilization. For example, in December 2016, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) announced that its Metop-A meteorological satellite would conduct maneuvers to move the satellite from a Sun-synchronous orbit to a slightly drifting orbit.[67] The maneuver will not compromise its ability for Earth observation, but will allow the satellite to conduct a deorbit burn with its remaining fuel in either 2021 or 2022. This maneuver was not part of the spacecraft's original mission, but the mission design allotted a greater fuel budget for debris avoidance than was actually used. This surplus provided EUMETSAT with the opportunity to prevent Metop-A from deteriorating into space debris and to practice a potential debris mitigation option for other satellites. However, the maneuver will compromise Metop-A's ability to collect solar power and radiate heat from its components.

As the steady rise in CubeSats continues, investigation into the use of passive deorbit mechanisms such as drag sails has been accelerating. Small spacecraft that are launched at an altitude near the ISS (400 km) will naturally decay in orbit within 25 years; however, such a reentry is uncertain beyond 600 km, raising the risk of long-term debris, since such systems typically lack either propulsion systems or sufficient propellant to deorbit.[68] In September 2016, the Royal Military College of Canada's CanX-7 nanosatellite was launched. Although the primary mission of the spacecraft is to detect and track aircraft from LEO, it includes a testbed for the use of drag sails to deorbit a satellite at the end of its operations without the use of propulsion systems.[69] The deployment and the subsequent deorbit will be tracked via an onboard camera. Even with the drag sail, deorbit is still expected to take several years. Although not the quickest method of deorbiting, the passive drag sail, with its small mass and volume requirements as well as operational simplicity, may help to mitigate the risk of an accumulation of dead CubeSats in LEO.

Electromagnetic tethers have also been demonstrated to effectively deorbit satellites.[70] In December 2016, Japan's Kounotori Integrated Tether Experiments (KITE) arrived at the International Space Station on 12 December via the Japan Aerospace Exploration Agency's (JAXA) HTV-6 Transfer Vehicle; it was launched from the ISS on 27 January 2017. First announced in 2014, KITE involved the use of a 700-m electrodynamic tether designed to encourage the conduct of electricity to help to deorbit the spacecraft.[71] The tether was meant to unfurl from the resupply vehicle as it returned to Earth and pull it into a reentry trajectory.[72] However, the tether failed to deploy and the experiment was declared a failure in February 2017. Experiments with electromagnetic tethers in the 1990s never reached their intended length.[73]

Not limited to CubeSats, the ESA's TeSeR (Technology for Self-Removal of Spacecraft) project will research and develop three strategies for the 'self-removal' of satellites:[74]

1. A modular solid propulsion unit (distinct from the propulsion a satellite uses for standard orbital maneuvers) that would be dedicated to a single deorbit burn at the end of a satellite's operational life;
2. Drag augmentation; and
3. An electromagnetic tether.

All three capabilities are intended to be mounted in automatic modules that operate independently of normal satellite operations to facilitate operations at the end of life. These initiatives are particularly important since current implementation of IADC debris mitigation guidelines varies (see above).

First substantive efforts made to develop active-debris-removal capabilities

China launched Aolong-1 (Roaming Dragon) in June. A collaborative effort of the China Academy of Launch Vehicle Technology (CALT) and the Harbin Institute of Technology, Aolong-1 was a small satellite equipped with an onboard robotic arm.[75] The mission was to demonstrate the removal of a simulated space debris object, capturing it and bringing it into a reentry trajectory to burn up in Earth's atmosphere.[76] On 26 August, the mission ended when Aolong-1's orbit decayed.[77]

The ESA is currently pursuing several ADR efforts. The RemoveDebris research program is intended to demonstrate several key elements of an ADR capability using a microsatellite RemoveSat, which will release, capture, and deorbit two space debris targets, called DebrisSats.[78] The 1,300-kg debris-removal satellite will attempt to secure two CubeSats—one with a net, and one with a harpoon—before deorbiting both CubeSats and itself. RemoveSat's own deorbit will be accomplished with a drag sail (see above).[79] The mission was scheduled to be deployed from the ISS in June 2017.[80] Currently in its conceptual design stage, E.deorbit has been promoted as the first ADR mission, with a planned 2023 launch.[81] Once in orbit, it is intended to rendezvous with Envisat, a derelict and tumbling ESA Earth observation (EO) satellite, capture it in a net, and pull it to a controlled reentry in Earth's atmosphere.[82] Once the derelict satellite is secured, the capturing vehicle will maneuver it into a flight path for reentry. Polish company SKA Polska was awarded the contract to design the net deployment system.[83]

An ADR project based in Singapore, Astroscale has raised $43-million—mainly from Japan—for its orbital debris-removal mission to develop a "satellite tug."[84] The ADRAS (or ELSA 1) satellite, when launched in 2018,[85] will carry sensors and maneuvering thrusters to enable it to autonomously track and intercept a piece of debris.[86] The ADRAS docking system is "adhesive-based," rather than using mechanical or electromagnetic systems to capture its targets. The satellite will consist of a base element, dubbed "Mother," and a part dubbed "Boy," which will separate from the base in space. Boy will carry a pad coated in special glue that will allow it to latch onto the target vehicle. It will then deorbit, burning up along with the debris it has captured. By the end of 2016, Astroscale had developed the adhesion.

The U.S. Aerospace Corporation is developing the Brane Craft.[87] This spacecraft would be a pseudo-two-dimensional square with a surface area on each greater face of one square meter and a thickness of only 30 microns. The membrane will be primarily composed of thin film solar cells and have a mass of approximately 50 g. While this vehicle will not be able to produce the thrust to effectively deorbit larger satellites, a flock of Brane Craft could be included at minimal cost on another launch and dispersed to clean up derelict CubeSats. The Brane Craft is still in early development, with no planned launch date.

Despite technological progress on ADR, political and financial constraints remain. Given the development of advanced on-orbit capabilities against uncooperative spacecraft (see Indicator 3.4), there are concerns that an ADR capability could be used as an anti-satellite weapon.[88] However, it should be noted that these programs are being publicly developed and transparently tested; there are no indications that they are part of any weapons programs. Perhaps more challenging are the economic considerations: economic incentives for ADR are nascent and it is not clear who should pay for a cleanup of the outer space commons.

Filings for large constellations of satellites raise questions about debris mitigation

Concerns that the increased use of CubeSats will exacerbate debris have been expressed for several years, with a growing focus on constellations of thousands of satellites. In 2015, the IADC committed to investigating debris-related implications. In 2016, companies including SpaceX, OneWeb, and Boeing (see Indicator 2.4) filed proposals for such constellations. An initial IADC statement released in 2016 indicates that such activity represents "a step change in the number of satellites operating in the low Earth orbit regime, and may question the validity of the assumptions used to derive the existing space debris mitigation guidelines," and cautions that the guidelines may not be sufficiently robust to mitigate the impact on the environment.[89] The statement also highlighted the need for the maturation of end-of-life disposal methods (see above). The IADC concludes that the most immediate impact of these constellations on the space environment will stem from their operational use. The possibility of close approaches will increase the burden of conjunction assessments and greater fuel margins to allow for avoidance maneuvers. A conservative estimate is that a constellation of more than 4,000 satellites would result in 64-million collision warnings per year, just among spacecraft in that constellation.[90] A study by researchers from several European space agencies concurs with the thinking of the IADC, and argues that post-mission disposal will be the necessary driver of space sustainability.[91]

Political efforts advance to minimize space debris

Significant actions were taken in 2016 to raise awareness of the debris problem and to advance mitigation policies, including ongoing work to draft guidelines for the long-term sustainability of space at UN COPUOS (see Indicator 4.2 and Annex 6).[92] Guidelines 12 and 13 promote greater accuracy in tracking space objects and the sharing of orbital data and space-debris-monitoring information. Guideline 28 promotes the consideration of new measures to manage space debris. Other relevant guidelines are still being drafted.

To spread awareness of "high risk re-entry events," the IADC continued to organize reentry-prediction campaigns; two were conducted in 2016.[93] The IADC also continued regular LEO surveys and undertook studies to model the beneficial impact of currently pursued ADR technologies. The United Kingdom launched a public awareness campaign in 2016 called Project Adrift, using museum-style art exhibits and Twitter to make the issue of space debris accessible to a general audience.[94]

The United States and China continued bilateral discussions related to space debris, although no specific content was made available (see Indicator 4.3). Further talks in 2017 have been confirmed.[95]

Indicator 1.2: Radio frequency (RF) spectrum and orbital positions

The growing number of spacefaring nations and satellite applications is driving greater demand for access to radio frequencies and orbital slots. Originally adopted in 1994, the ITU Constitution[96] governs international sharing of the radio spectrum and orbital slots used by satellites in GEO, both of which it acknowledges to be limited natural resources.

Radio frequencies

The RF spectrum is part of the electromagnetic spectrum that can pass through Earth's atmosphere and is used for communication between satellites and ground stations.[97] It is divided into portions known as frequency bands. Frequency is generally measured in hertz, defined as cycles per second. Radio signals can also be characterized by their wavelength, which is the inverse of frequency. Higher frequencies (shorter wavelengths) are capable of transmitting more information than lower frequencies (longer wavelengths), but are more susceptible to degradation through the atmosphere. However, congestion in the lower frequency bands is leading to efforts to make better use of high frequencies.[98]

Certain widely used frequency ranges have been given alphabetical band names in the United States. Communications satellites tend to use the L-band (1-2 gigahertz [GHz]) and S-band (2-4 GHz) for mobile phones, ship communications, and messaging. The C-band (4-8 GHz) is widely used by commercial satellite operators to provide services such as roving telephone services, and the Ku-band (12-18 GHz) is used to provide connections between satellite users. The Ka-band (27-40 GHz) is now being used for broadband communications, which relieved some pressure on available bandwidth. Ultra-High Frequency, X-, and K-bands (240-340 megahertz, 8-12 GHz, and 18-27 GHz, respectively) have traditionally been reserved in the United States for the military.[99]

Radio spectrum must also be shared between space-based and terrestrial users; new rules issued at the World Radiocommunication Conference 2015 (WRC-15) made changes to the allocation of spectrum and frequencies for current and future satellite uses; notably it opened up the lower section (3.4-3.6 GHz) of C-band for terrestrial use, while reserving Ka-band for satellite use.[100]

Figure 1.9 Radio frequency bands[101]

Band name			Frequency (ITU)	Common uses	
ITU	NATO	IEEE		Space	Ground
Very High Frequency (FHV)	A Band (0-250 MHz)	VHF	30-300 MHz	Satellite uplinks	Analog TV
Ultra High Frequency (UHF)	B Band (250-500 MHz) C Band (500-1000 MHz)	UHF (300-1000 MHz) L Band (1-2 GHz) S Band (2-3 GHz)	300-3000 MHz	Mobile Satellite Services Satellite navigation signals	Analog TV, 2-way radio, cordless phones, Wi-Fi, Bluetooth, mobile phones
Super High Frequency (SHF)	F Band (3-4 GHz) Band (4-6 GHz) H Band (6-8 GHz) I (8-10 GHz) J (10-20 GHz) K Band (20-30 GHz)	S Band (3-4GHz) C Band (4-8 GHz) X Band (8-12 GHz) Ku Band (12-18 GHz) K Band (18-27 GHz) Ka Band (26.5-40 GHz) V Band (40-75 GHz) W Band (75-110 GHz)	3-30 GHz	Fixed Satellite Services Broadcast Satellite Services Satellite uplinks and downlinks	Weather radar, amateur radio, imaging radar, air traffic control
Extremely High Frequency (EHF)	K Band (30-40 GHz) L Band (40-60 GHz) M Band (60-100GHz)		30-300 GHz	Inter-satellite links Military survivable satcom	Microwave data links, active denial system

Article 45 of the ITU Constitution stipulates that "all stations…must be established and operated in such a manner as not to cause harmful interference to the radio services or communications of other members."[102] Military communications are exempt from the ITU Constitution under Article 48; this adds to the challenge of managing radio frequency coordination and interference. National defense services include a variety of apparently commercial and civilian applications and constitute one of the largest groups of space users.[103] By May 2016, requested application of Article 48 for the purposes of "national defense, military, or government use"[104] had been made on behalf of 120 satellite networks across 62 unique orbital positions. WRC-15 sought to limit such wide application of this Article by emphasizing that it refers specifically to "military use," and that exemption from the Master International Frequency Register would only be granted if Article 48 were specifically invoked by the requesting state.

Issues of interference arise primarily when two spacecraft require the same frequencies at the same time and their fields of view with the Earth overlap, or when they are transmitting in close proximity to each other. While interference is not epidemic, it is a growing concern for satellite operators, particularly in crowded space segments. For example, more satellites are locating in GEO, using frequency bands in common and increasing the likelihood of frequency interference.

Emerging plans for large constellations of satellites is raising additional concerns for coordination of radio frequencies in the future. Between November 2014 and February 2015, the ITU registered at least a half-dozen filings for satellite networks using low, medium, and highly elliptical Earth orbits to provide broadband communications links worldwide; more have followed.[105] Interference with traditional communications satellites operating in GEO is a significant concern; because they use the same frequency, the process of coordinating radio frequencies is more complex.[106] Competition for frequencies with terrestrial mobile broadband providers is also a concern.[107] To further exploit the available radio frequency spectrum, operators are considering options for using V and Q bands.[108]

Worries about the ability of small-satellite operators to meet the regulatory requirements of the ITU and the Registration Convention have prompted discussion about altering the regulatory regime to accommodate small satellites.[109] However, the ITU believes that there are limits to the ability to set separate rules; all satellite operators have the same responsibilities for non-interference.[110]

The ITU has a limited ability to respond to complaints of interference because it lacks the means to verify claims. However, at the ITU Plenipotentiary Conference in 2014, a resolution was passed to support ITU efforts to track reported cases of interference with satellite broadcasts; it invites the ITU to enter into agreements with satellite-monitoring facilities to detect the sources of interference (a process known as "geo-location") and calls on the ITU to create a database on interference.[111]

New technologies allow more satellites to operate in closer proximity without interference. Frequency hopping, lower power output, digital signal processing, frequency-agile transceivers, and software-managed spectrum have the potential to improve bandwidth use and alleviate conflicts over bandwidth allocation. Research has also been conducted on the use of lasers for communications, particularly by the military. Lasers transmit information at very high bit rates and have very tight beams, which could allow for tighter placement of satellites, thus alleviating some of the current congestion and concern about interference (see Indicator 3.1).

Orbital slots

Today's satellites operate mainly in LEO, MEO, and GEO. As of 31 December 2016, 803 active satellites were in LEO, 96 in MEO, 522 in GEO, and 38 in Highly Elliptical Orbit (HEO),[112] for a total of 1,459. HEO is increasingly used for specific applications, such as early warning satellites and polar communications coverage. LEO is often used for remote sensing and Earth observation, and MEO is home to space-based navigation systems such as GPS.

Most communications and some weather satellites are in GEO. Because orbital movement at this altitude is synchronized with Earth's 24-hour rotation, a satellite in GEO appears to "hang" over one spot on Earth. GEO slots are located above or very close to Earth's equator, creating a low inclination that maximizes the reliability of the satellite footprint. For signals to the United States, the orbital arc of interest lies between 60° and 135° W longitude, because satellites in this area can serve the entire continental United States;[113] these slots are also optimal for the rest of the Americas. Spots as desirable exist over Africa for Europe and over Indonesia for Asia.

GEO satellites must generate high-power transmissions to deliver a strong signal to Earth, due to distance and the use of high-bandwidth signals for television or broadband applications.[114] To avoid radio frequency interference, GEO satellites are required to maintain a minimum of two and up to nine degrees of orbital separation, depending on the band they are using to transmit and receive signals, the service they provide, and the field of view of their ground antennas.[115] Thus, only a limited number of satellites can occupy the prime equator (0 degree inclination) orbital path. In the equatorial arc around the continental United States there is room for only an extremely limited number of satellites.

Originally, crowding in the MEO region was not an issue, as the only major users were the United States with GPS and Russia with its Global Navigation Satellite System (GLONASS). However, concern is increasing as systems are expanded and additional, independent systems are developed by the European Union, China, and India (see Indicator 2.1). All these systems use or will use multiple orbits in different inclinations and each system has a different operational altitude. While not necessarily a problem for daily operations, the failure to properly dispose of MEO satellites at the end of their operational life could cause future problems if the disposal is done within the operational altitude of another system.

To deal with restricted availability of orbital slots, the ITU Constitution states that radio frequencies and associated orbits, including those in GEO, "must be used rationally, efficiently and economically…so that countries or groups of countries may have equitable access" to both.[116] In practice, orbital slots in GEO have been secured on a first-come, first-served basis. However, Article 44 of the ITU Constitution recognizes "the special needs of developing countries and the geographical situation of particular countries,"[117] which can affect allocation decisions on a case-by-case basis.

The increased competition for orbital slots, particularly in GEO, where most communications satellites operate, has caused occasional disputes between satellite operators. The ITU has been pursuing reforms to address intentional signal jamming, slot allocation backlogs, and other related challenges. WRC-15 clarified several deadline requirements for orbital slots in GEO, which must be brought into operation/use no later than seven years after submission to the ITU of the Advanced Publication of Information, a general description of the network or system that is required before the coordination process for frequency allocation can begin.[118] For example, in the event of a satellite launch failure, an extension may be granted, based on a *force majeure* argument. Rules were also clarified on "satellite hopping" or "the use of one space station to bring frequency assignments at different orbital locations into use within a short period of time."[119]

2016 Developments

Bringing-into-Use deadlines extended for expanded range of cases

In 2015, the ITU agreed to consider the "special circumstances" of a developing country (Laos) in extending the deadline to bring into use (BiU) an orbital slot allocation. In February 2016, the ITU allowed Egypt to plead *force majeure* to extend the May occupancy deadline by three years for six orbital slots, based on "internal political disruptions and unfavorable economic conditions." Egypt contended that political instability degraded its financial condition and that these circumstances qualify as *force majeure*—unforeseen circumstances that prevented it from fulfilling the contract.

Wary of setting a precedent, the Radio Regulations Board (RRB) discussed the case at length. The majority of the board agreed to extend the BiU deadline by three years for the orbital position 35.5° East. Other such situations will be considered on a case-by-case basis.[120] It is important to note that accepting "internal political disruption and unfavorable economic conditions" as *force majeure* is unprecedented under international jurisprudence and international law.

The RRB also considered Israel's request to extend the regulatory BiU time limit for its satellite network, AMS-CK-17E. Israel based its request on *force majeure* after the explosion of the SpaceX Falcon 9 rocket that carried Israeli satellite AMOS-6. The RRB concluded that the Falcon 9 accident fulfilled the conditions and granted a three-year extension. Similar requests by France and Indonesia were also accepted by the RRB.[121] These fall under the traditional interpretation.

However, Papua New Guinea's request for flexibility in meeting its BiU deadline, requested because its satellite will be all-electric and thus takes six to eight months longer than a traditional satellite to move into the appropriate orbit, was denied. The RRB, while encouraging more energy-efficient technology, noted that the Radio Regulations are "technology-neutral" and that it had no grounds to extend the BiU deadline in this case.[122]

Filings for large satellite constellations spur concerns about regulation, congestion, and interference

The filings made in 2016 for large constellations of broadband-communications satellites pose challenges for the regulation and governance of outer space resources. In 2016, SpaceX filed a proposal with the U.S. Federal Communications Commission (FCC) to orbit 4,425 satellites to create, in phases, a global internet network utilizing Ku- and Ka-band frequencies.[123] Boeing filed for a license to orbit 2,956 satellites that would operate in the V-band spectrum, which remains untouched as a commercial broadcast frequency. Boeing plans to use advanced technology, allowing "effective sharing of spectrum for the delivery of global communications services, including satellite-delivered broadband and terrestrial 5G applications."[124] OneWeb Satellites, Thales' Group, LeoSat, Sky and Space Global, ViaSat, and O3b planned to launch constellations of tens or hundreds of satellites (see Indicator 2.4). The use of satellite constellations is not new: navigation systems such as GPS and GLONASS operate through a constellation architecture. Commercial operator Iridium experimented with this approach in the 1990s. But the number of satellites being proposed is unprecedented and challenging. If actually launched, the SpaceX constellation alone would quadruple the number of currently active satellites in orbit.

The ITU has previously noted that small satellites and satellite constellations challenge coordination procedures.[125] In 2016, the ITU hosted a symposium and workshop in Chile on small satellite regulation and communication systems, focusing on sustainable development of small satellite systems, the space law regime, Radio Regulations, and the outcomes of WRC-15 relating to small satellites, authorizations under national space law, and future small satellite systems.[126]

Regulatory challenges posed by large constellations of communications satellites in LEO include the application of BiU requirements and the potential for RF interference with communications satellites in GEO, as well as with terrestrial communications services, which share the same spectrum. Increasing use by these new applications of the V-band raises questions about potential conflicts with emerging 5G carriers, which have recently been provided access to this band in the United States by the FCC.[127] The potential for interference is not limited to communications satellites; operators of radar EO satellites have also expressed concerns (see below). ITU executive Yvon Henri warned that developers of large constellations may try to work around BiU deadlines by orbiting one or two CubeSats as place-savers for the entire constellation.[128] He urged close monitoring to avoid interference and coordination issues with other satellites in LEO and GEO, and also the encroachment on frequencies used by terrestrial operators.[129] SpaceX intends to launch the first two prototype satellites in 2018, with first launches for the operational system in 2019. OneWeb also plans to launch several test satellites in 2017 or 2018.

Technological efforts made to use radio frequency more efficiently

Technological solutions are being developed to resolve the regulatory difficulties relating to harmful interference and effective use of the RF spectrum. The U.S. Defense Advanced Research Projects Agency (DARPA) announced a $2-million Grand Challenge for developing techniques that intelligently distribute RF spectrum and significantly improve cooperation among users.[130] DARPA is also invested in developing an advanced RF map through the RadioMap program, which "seeks to provide real-time awareness of radio spectrum use across frequency, geography and time,"[131] and signal detection and reasoning technology through the CommEx program, which allows "radios to recognize interference and jamming, and adapt to maintain communications—even in the presence of severe and/or adaptive jamming and interference sources."[132]

The projected increase in RF demand linked to the development of broadband communications constellations in LEO (see above) is also driving satellite operators to consider ways of using frequencies that were previously unused for commercial space applications, including Q- and V-bands in the Extremely High Frequency range of the radio spectrum. These frequencies are more prone to degradation as they travel through the atmosphere and are sensitive to weather conditions, but are able to transmit large volumes of data.[133] These bands are becoming useful with the development of new technological capabilities for spectrum sharing, beam control, and receiving stations and antennas.[134]

By early 2017, Boeing, SpaceX, OneWeb, Telesa, O3b Networks, and Theia Holding had filed plans to use V-band satellites as part of their communications constellations in LEO.

Radio frequency interference remains a concern

Increased RF demand threatens increased user interference. The ESA has modified the frequencies used by some of its radar EO satellites to reduce interference from terrestrial communications systems, some of which operate illegally.[135] The Space Data Association (SDA), established by major commercial satellite operators Intelsat, SES, and Inmarsat in 2009, began offering its members a free geolocalization service to better identify sources of interference.[136]

In June 2016, the ITU International Satellite Communication Symposium was held in Geneva, Switzerland to address "interference-free satellite services." Experts from the satellite industry, operators, regulators, and broadcasters from around the world examined the current situation and technology "to detect, identify, locate and mitigate harmful interference, which may severely impact satellite services, including safety operations."[137] The Secretary-General of the ITU reiterated its commitment to find technical and regulatory solutions and to "enhance and strengthen international cooperation amongst ITU member states."[138]

Indicator 1.3: Natural hazards originating from space

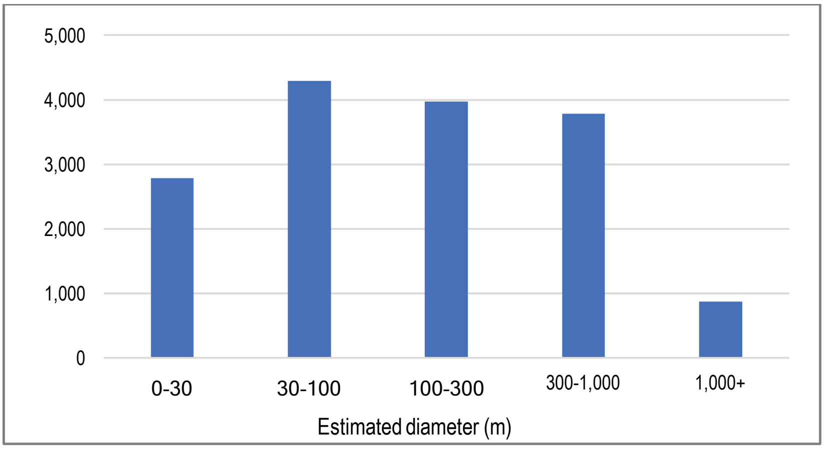
Near-Earth Objects

Near-Earth Objects (NEOs) are asteroids and, more rarely, comets whose orbits bring them into close proximity to Earth. Potentially Hazardous Objects are those whose orbits intersect that of Earth and have a relatively high potential of impacting Earth itself. As comets represent a very small portion of the overall collision threat, most NEO researchers commonly focus on Potentially Hazardous Asteroids (PHAs). A PHA is defined as an asteroid whose orbit comes within 0.05 astronomical units of Earth's orbit and has a brightness magnitude greater than 22 (approximately 150 m in diameter).[139] As of 2 March 2017, there were 15,719 known Near-Earth Asteroids, 1,776 of which were identified as Potentially Hazardous Asteroids, according to NASA.[140]

Initial efforts to find threatening NEOs focused on objects more than one kilometer in diameter—the so-called "civilization-killer class." It is estimated that 90% of these NEOs have now been identified.[141] The NASA Authorization Act of 2005 directed NASA to identify and characterize 90% of NEOs with diameters of 140 m or more by 2020;[142] by 2016, an estimated 25% had been identified.[143]

Many more smaller NEOs also constitute a hazard to Earth; asteroids as small as 20 or 30 meters are considered large enough to be "city killers."[144] The NEO that entered Earth's atmosphere near Chelyabinsk, Russia on 15 February 2013[145] was a previously undetected orbiting asteroid, 17 m in diameter, classified as a bolide because it disintegrated as it entered the atmosphere. The energy of the explosion was equivalent to 470 kilotons of TNT (30 times more powerful than the atomic bomb dropped on Hiroshima);[146] more than 1,200 people were injured and more than 4,000 structures damaged by the blast. Mitigation of the effects of small NEOs would require sufficient warning and involve civil defense/disaster plans, including evacuation. Increasing international awareness of the potential threat posed by NEOs has prompted discussions at various multilateral forums on the technical and policy challenges related to mitigation.

Figure 1.10 Near-Earth asteroids discovered by class[147]



In 2015, NASA formalized its Planetary Defense Coordination Office, which supervises all NASA-funded projects to find and characterize asteroids.[148] This office also issues warnings and works with the Federal Emergency Management Agency (FEMA) to develop both warning and response processes. Funding for the NEO Observation Program grew from $4-million in 2010 to an allocated $50-million for 2016; in 2015, it supported 54 ongoing projects aimed at detection and tracking and nine studies on impact mitigation. Similar programs were being developed by the ESA and Russia.[149] The International Scientific Optical Network (ISON) is a growing international network of small telescopes linked together to discover and track space debris and asteroids from around the world. Canada's Near-Earth Object Surveillance Satellite (NEOSSat) is dedicated to detecting and tracking asteroids as well as orbital debris and satellites.[150] The Minor Planet Center (MPC), operated by the International Astronomical Union in Cambridge, Massachusetts, acts as a central clearing house for asteroid and comet observations.

There is ongoing technical research into how to mitigate a NEO collision with Earth. Challenges arise because of the potentially extreme mass, velocity, and distance from Earth of the impacting NEO. If warning times are in the order of years or decades, constant thrust applications could potentially be used to gradually change the NEO's orbit. Otherwise, kinetic deflection methods, such as ramming the NEO with a series of projectiles, could be applied. Nascent projects include the Asteroid Impact Deflection Assessment (AIDA) mission to test and demonstrate the ability to deflect an asteroid using kinetic force, announced in 2015,[152] and NASA's Asteroid Redirect Mission (ARM), tentatively scheduled for launch in 2021.[153] These capabilities would also have dual-use security-related implications, particularly in the absence of international consensus and transparency.

Figure 1.11 Top 10 close approaches to Earth by asteroids[151]

Distance (AU)	Date	Provisional designation	Absolute magnitude
0.000043	October 2008	2008 TC3	30.4
0.000043	January 2014	2014 AA	30.9
0.000079	February 2007	2011 CQ1	32.1
0.000086	March 2004	2004 FU162	28.7
0.000090	October 2008	2008 TS26	33.2
0.000125	June 2011	2011 MD	28.0
0.000136	November 2009	2009 VA	28.6
0.000140	March 2017	2017 EA	30.8
0.000201	January 2016	2016 AH164	29.7
0.0008206	October 2008	2008 US	31.6

1 AU is approximately the mean distance of the Earth from the sun (149,597,870 km).
The mean distance of the Earth from the Moon is 0.0026 AU.

NASA is also considering the use of nuclear weapons to eliminate asteroids that are close to Earth and constitute threats; both NASA and the U.S. National Nuclear Security Administration have considered this in the past and in 2015, they signed an agreement to jointly characterize threats and research options for deflection with relatively little early warning.[154] However, this method would create additional threats to the environment and to the stability of outer space, present complex technical challenges, and have serious policy implications.

In 2013, UN COPUOS sanctioned the creation of two new international networks: the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG).[155] IAWN is a group of governmental and intergovernmental organizations, institutes, and individuals involved in detecting, tracking, and characterizing NEOs.[156] SMPAG is a forum for space-capable nations to build consensus on recommendations for planetary defense measures.

In 2016, the United Nations formally recognized 30 June as International Asteroid Day to raise public awareness and highlight global mitigation efforts. The first official observance took place in 2017.[157] The date commemorates the anniversary of the Tunguska, Siberia asteroid impact, which flattened 2,000 sq km of forest in 1908.

Space weather

"Space weather" refers to a collection of physical processes, beginning at the Sun and ultimately affecting human activities on Earth and in space.[158] The Sun emits energy as flares of electromagnetic radiation and as electrically charged particles through coronal mass ejections and plasma streams. Powerful solar flares can cause radio blackouts and an expansion of Earth's atmosphere, which has the effect of slowing down satellites in LEO, causing them to move into lower orbits.[159] Rapid increases in the number and energy of charged particles can induce power surges in transmission lines and pipelines, azimuthal errors in directional drilling, disruptions to high-frequency radio communication and GPS navigation, and cause failure or operational errors of satellites.[160]

The effect of space weather on spacecraft was demonstrated by the 1994 outage of two Canadian telecommunications satellites for seven hours following damage to their control electronics.[161] On Earth in March 1989, a geomagnetic storm generated electrical currents in power lines in Quebec, Canada, causing protective devices to take sections of the grid offline. This action tripped other protective devices and, in 90 seconds, the entire Hydro-Quebec power grid collapsed. The blackout left more than six million people in Quebec and the northeastern United States without power for nine hours.[162] In 2013, Lloyd's of London predicted that a solar storm similar to the Carrington Event of 1859, which induced sparks along telegraph wires, would cause outages to the North American power grid that would last from 16 days to two years and cost up to $2.6-trillion.[163]

The effects of space weather are complicated by documented changes to the magnetic field around the Earth, which protects it from cosmic radiation and electrically charged particles thrown at the Earth by solar winds,[164] and is weakening as the magnetic poles shift.[165] Human activity also has effects. The high-altitude nuclear explosions by the United States and the Soviet Union in the 1960s created artificial radiation belts near Earth and an electromagnetic pulse (see Indicator 3.3). A recent study notes that other human-made impacts on the environment include chemical release experiments, high-frequency wave heating of the ionosphere, and the interaction of very low frequency (VLF) waves with the radiation belts.[166]

Various programs have been developed to study and predict harmful space weather. The U.S. National Oceanic and Atmospheric Administration (NOAA) and the USAF jointly operate the Space Weather Prediction Center (SWPC), the national and world warning center for disturbances that can affect people and equipment working in the space environment.[167] Data for SWPC predictions comes from a variety of sources, ranging from satellites to ground stations.[168] The United Kingdom officially opened the Met Office Space Weather Operations Centre in Exeter on 8 October 2014.[169] An expert group on space weather was established by the COPUOS STSC in February 2014.[170] Its objective is to take stock of relevant technology, information, and observation systems around the world and make recommendations on, for example, areas of future study. In 2009, the ESA launched a warning network to monitor the Sun's activity and protect Earth from solar storms; it is also now mandated to study space weather events.[171] Fourteen European countries contribute to this network, which is coordinated by the ESA's Space Weather Coordination Centre in Brussels, Belgium.[172] China established its National Space Weather Forecast Station of the China Meteorological Administration in 2015.

Plans to prepare for and mitigate the effects of space weather are being developed. In 2015, the World Meteorological Organization (WMO) released the first draft of a "Four-Year Plan for WMO Coordination of Space Weather Activities," that includes identifying best practices for international coordination and cooperation, as well as practical risk mitigation strategies.[173] The WMO plans to integrate space weather efforts into its core work and "facilitate the effective coordination with initiatives external to WMO and to enable the long-term improvement of space weather service capabilities."[174] In October 2015, the United States released a National Space Weather Strategy and National Space Weather Action Plan, which recognize and assess the dangers posed to Earth by various space weather phenomena, include strategies to respond to and seek protection from them, and highlight the role of international cooperation.[175] The U.S. space weather program currently has the capability to predict and warn about severe solar events 30 minutes before their occurrence.[176]

2016 Developments

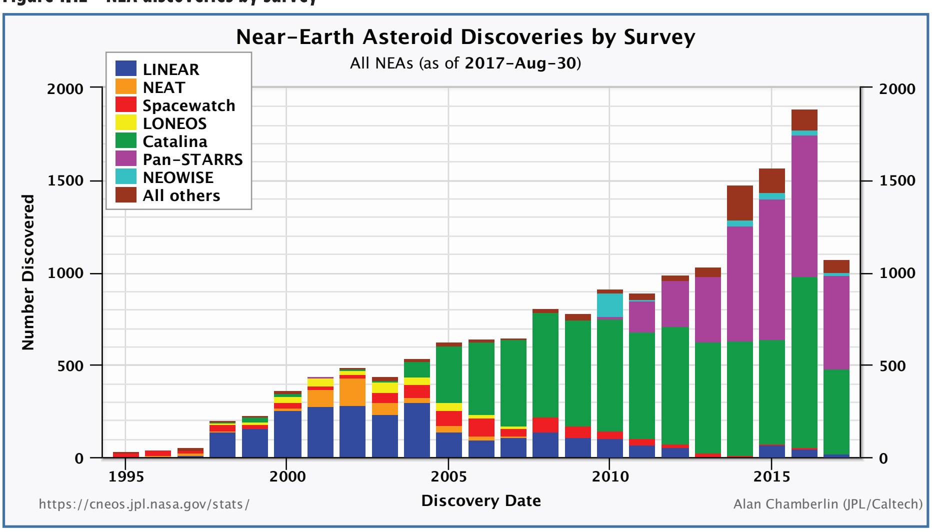
United States emphasizes NEO early warning and preparedness, but knowledge gaps remain

With improved technological capabilities and renewed efforts, government and private actors were able to identify and track more NEOs in 2016; the known number surpassed 16,000 in March 2017.[177] The United States also worked to improve preparedness for a possible asteroid collision with Earth. To ensure sufficient warning, the NASA Jet Propulsion Laboratory began testing a new computer program called "Scout," which is intended to serve as an early warning system using data from multiple telescopes.[178] The Scout system, which is focused on locating smaller NEOs and providing calculated warnings well in advance, participates in joint NASA-FEMA contingency plans.[179] Funding for the identification of NEOs and planetary defense has been increasing, reaching $50-million in FY2016, in comparison to $4-million in 2010.[180]

NASA established the Planetary Defense Coordination Office (PDCO)[181] in 2016, managed by the Planetary Sciences Division of the Science Mission Directorate at NASA Headquarters in Washington, DC.[182] The PDCO is tasked with early detection of PHOs, issuing warnings of potential impacts, and providing timely and accurate information on PHOs. The primary function of the PDCO is to help the U.S. government prepare for an actual asteroid impact, as directed in the 2010 National Space Policy.[183] As part of this effort, on 25 October, NASA and FEMA held their third joint tabletop exercise, simulating responses to the impact of a fictitious asteroid in 2020 that allowed for a long lead time to prepare, but insufficient time for deflection. The focus was to inform and maintain control of public responses. The event included participation by officials from NASA, FEMA, NASA's Jet Propulsion Laboratory, the Department of Energy's National Laboratories, the USAF, and the California Governor's Office of Emergency Services.[184]

In December 2016, the White House issued the National Near-Earth Orbit Preparedness Strategy,[185] developed by the Interagency Working Group for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects of the National Science and Technology Council. The seven high-level goals set out in the strategy paper address enhanced detection of NEOs, methods of response, integration of information, developing procedures, and national and international collaboration.

Figure 1.12 NEA discoveries by survey[186]



Coordination through International Asteroid Warning Network and Space Missions Planning Advisory Group progresses

The IAWN and SMPAG made progress in coordinating international efforts to detect, identify, warn, and prepare for asteroid threats. Following a record year for asteroid discoveries in 2015,[187] the IAWN increased its efforts to provide the international community with information related to NEOs and to stimulate widespread interest through an open forum, held in February 2016 with the SMPAG as part of the 53rd session of the UN COPUOS STSC meeting in Vienna.

The IAWN also upgraded capabilities to discover NEOs at the Catalina Sky Survey observatory site and at the ATLAS Project funded by NASA at the University of Hawaii.[188] With enhanced capabilities the IAWN was able to identify and track several close approaches of asteroids during the year.[189]

The SMPAG met twice in 2016. The Korea Aerospace Research Institute (KARI) was admitted as a member during the February meeting and an Ad Hoc Working Group on Legal Issues was established to "formulate and prioritize relevant legal issues and questions requiring clarification in regard to the work of SMPAG; consider the legal questions in the context of existing treaties; and devise a plan of action to tackle outstanding issues."[190] The SMPAG also released a Statement on Asteroid Orbit Deflection Demonstrations, encouraging demonstration of the kinetic deflector technique and investigation of the tractor gravity technique to establish confidence in the viability of proposed efforts to deflect asteroids. Recommended criteria and thresholds for impact response actions were released at the October meeting, which stipulated that the IAWN should "warn of predicted impacts exceeding a probability of 1% for all objects characterized to be greater than 10 meters in size"; that preparedness planning should begin for threats predicted for the next 20 years; and that SMPAG should begin mission planning for threats for the next 50 years.[191]

Efforts to mitigate threats from hazardous asteroids face several setbacks

Although policy is focused on not only preparing for asteroid impacts, but also attempting to deflect asteroids before they reach Earth, technological efforts on the second front experienced several setbacks in 2016. The planned Asteroid Impact and Deflection Assessment Mission involving ESA's Asteroid Impact Mission (AIM) and NASA's Double Asteroid Redirection Test (DART), scheduled for launch in 2020,[192] was to conduct the first demonstration of kinetic impact changing the trajectory of an asteroid. However, ESA's AIM component was cancelled when member states failed to pledge the required funding[193] at the December 2016 ESA Council meeting, despite the "I Support AIM" campaign led by scientists and asteroid experts.[194] The plan had been for AIM to study the moonlet of an asteroid known as Didymos and observe the collision with the asteroid by NASA's DART. NASA indicated that DART would continue without AIM; there may be future efforts to revive a scaled-down version of AIM.[195]

NASA's Asteroid Redirect Mission was defunded in the NASA Authorization Act signed by the President in March 2017 and has since been formally cancelled by NASA.[196] ARM had been intended to be the "first-ever robotic mission to visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect it into a stable orbit around the moon"; plans included sending humans into lunar orbit.[197]

United States begins implementation of National Space Weather Action Plan and National Space Weather Strategy

In 2015, the U.S. Department of Defense identified space weather as a national security concern and the U.S. government adopted the National Space Weather Action Plan and the National Space Weather Strategy[198] that describe how the government will coordinate its efforts on space weather, engage other stakeholders, and enhance national preparedness. In October 2016, the Obama administration issued an Executive Order defining agency roles and responsibilities and directed agencies to take specific actions to prepare for the hazardous effects of space weather.[199] A key objective was to coordinate scientific institutions and the DoD to ensure preparedness for space weather events and so minimize human and economic hardship.

Efforts continue to improve space weather forecasting, response

In 2016, the ESA expanded services related to space weather as part of its space situational awareness program. Access to its Space Weather Service Network expanded and new services were introduced to assist power-grid operators in addressing challenges such as magnetically induced currents.[200] The 2023 launch of a satellite to monitor space weather was approved at the ESA Council meeting in November. Funding for the first design phase of between €20-million and €30-million was approved. The total cost of the project is estimated at €450-million ($478-million).[201]

In September, NOAA's Deep Space Climate Observatory (DSCOVR) satellite officially replaced NASA's ACE research satellite as the "primary [U.S.] warning system for solar magnetic storms and solar wind data."[202] DSCOVR's advanced instrumentation provides better information and new opportunities for NOAA's Space Weather Prediction Center to gain a deeper understanding of coronal mass ejections and high speed solar wind,[203] allowing more accurate space weather forecasts. It should be noted that the budget blueprint released by the White House in early 2017 proposes funding cuts for four missions, including DSCOVR.[204]

In November, the NOAA GOES-R weather satellite was launched;[205] it is one of a series of four R-series Geostationary Operational Environmental Satellites collaboratively developed by NOAA and NASA.[206] In addition to monitoring weather events on Earth, the new satellite will provide space weather motoring to improve storm forecasting. Scheduled for launch in 2017 are the NASA-funded satellite mission Ionospheric Connection Explorer (ICON), led by the University of California, Berkeley; and Global Observations of the Limb and Disk (GOLD), led by the University of Florida. According to space scientist Scott England, "We will be using these two missions together to understand how dynamic weather systems are reflected in the upper atmosphere, and how these changes impact the atmosphere."[207]

UNISPACE+50 process includes focus on international space weather framework

Space weather emerged as a significant focus for COPUOS in 2016. The initial set of draft guidelines on long-term sustainability for outer space activities, agreed to in 2016 by the COPOUS Scientific and Technical Subcommittee's Working Group on the Long-term Sustainability of Outer Space Activities and adopted by COPUOS at its 59th Session, include two items on space weather. Guideline 16 emphasizes sharing operational space weather data and forecasts and Guideline 17 is on developing space weather models and tools and collecting established practices on the mitigation of space weather effects.[208]

The adoption of the Thematic Priorities for the UN Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE+50), scheduled for 2018, includes development of an International Framework for Space Weather Services. It is proposed that the existing STSC Expert Group on Space Weather be supported by UNOOSA in, inter alia, capacity-building activities related to space weather.[209] It is expected that international coordination of mechanisms for operational space weather services could be achieved for the ultimate goal of protecting life on Earth.

Concerns grow about vulnerabilities to solar storms and changes in Earth's magnetosphere

Attention is being paid to risks to Earth's magnetosphere, which shields the planet from solar winds and cosmic radiation. Analysing data gathered by the GRAPES-3 muon telescope at the Tata Institute in India, scientists determined that a two-hour burst of galactic cosmic rays in June 2015 resulted in a temporary crack in Earth's magnetic field, causing additional radiation to flow through into Earth's atmosphere, which triggered a severe geomagnetic storm that caused radio signal blackouts in some countries.[210]

Additional research suggests that Earth is becoming more vulnerable to solar storms due to changes in the magnetosphere. In 2016, at the Living Planet Symposium in Prague,[211] the ESA released a study based on information from its trio of Swarm satellites, launched in 2013 to study the Earth's magnetic field. According to the study, Earth's magnetic field "has weakened by about 3.5% at high latitudes over North America."[212] It is believed that this weakening is happening 10 times more rapidly than initially thought, making some regions more susceptible to solar storms; these changes are also shifting the Earth's magnetic north pole eastward.[213] The Swarm constellation is expected to operate until at least 2017.[214]

Indicator 1.4: Space situational awareness

"Space situational awareness" refers to the ability to detect, track, identify, and catalog objects in outer space, such as space debris and active or defunct satellites; observe space weather and NEOs; and monitor spacecraft and payloads for maneuvers and other events.[215] In an increasingly congested domain, with new civil and commercial actors gaining access every year, SSA constitutes a vital tool for the protection of space assets.

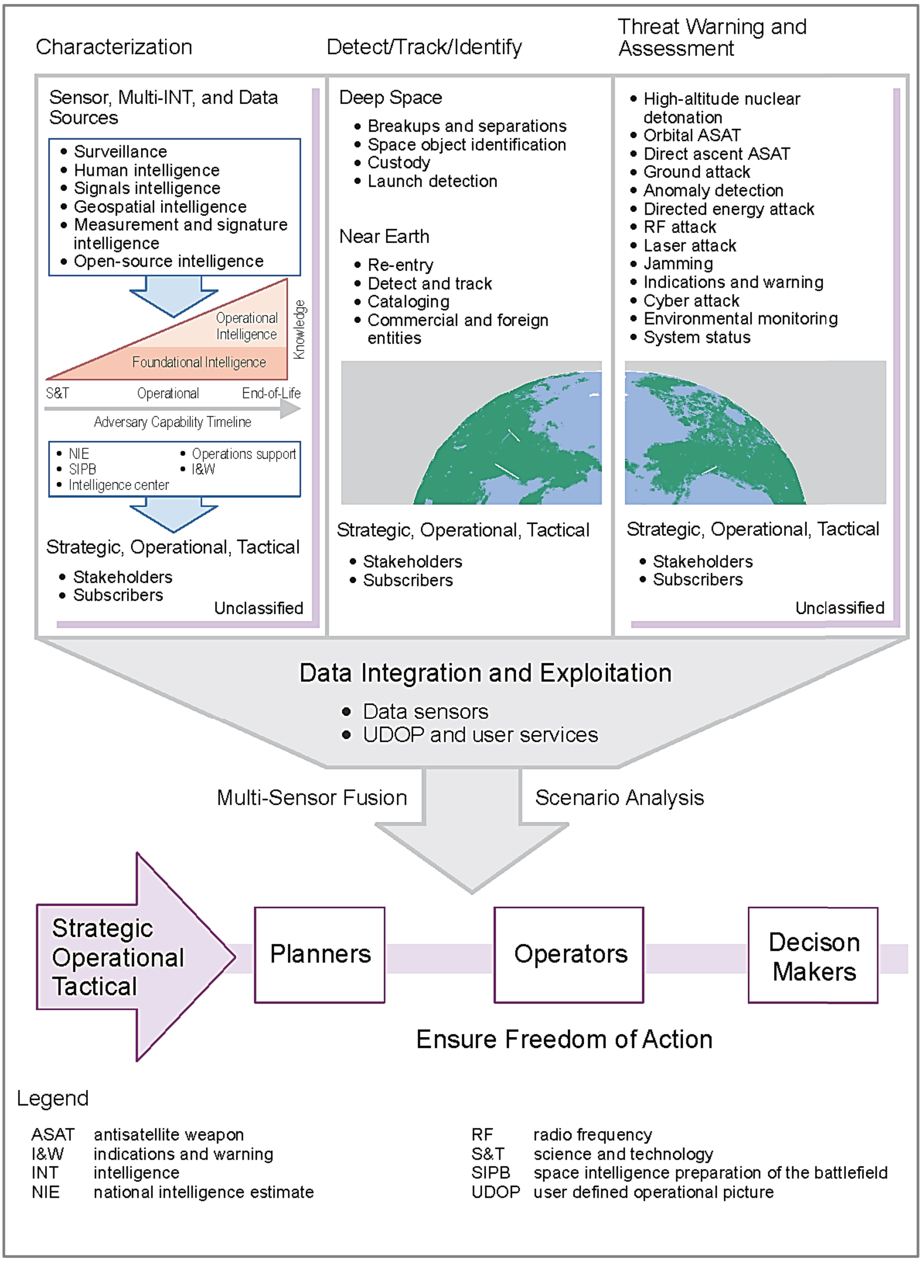
As well as helping to prevent accidental collisions and otherwise harmful interference with space objects, SSA enhances the ability to distinguish space negation attacks from technical failures or environmental disruptions, and can thus contribute to stability in space by preventing grave misunderstandings and false accusations of hostile actions. SSA also increases awareness of potential negative impacts of certain activities in space, such as explosions and collisions, and their role in degrading the space environment.[216] Heightened awareness encourages the development of best practices to avoid accidents or other activities that can harm the space environment (see Indicator 1.1).

SSA also plays a role in ongoing political initiatives aimed at tackling space sustainability and security. For example, information exchange on space activities was cited in the 2013 report of the UN Group of Governmental Experts as an important transparency and confidence-building measure for space activities[217] (see Indicator 4.2).

While all spacefaring nations and even amateur astronomers have knowledge of some orbiting objects, a complete picture of the space environment and of activities in space is beyond the capability of any single actor at present. It requires a network of globally distributed sensors as well as data sharing between satellite owners/operators and sensor networks.[218] The United States maintains the most significant SSA capability through its worldwide Space Surveillance Network, composed of satellite, radar, and optical sensors.[219] Currently the system relies on "a core group of 8 dedicated and 18 multiple-mission sensors, most of which are operated by DOD."[220]

SSA was first identified as a separate mission area for the U.S. military in the 2013 version of *Joint Publication 3-15*, where it is divided into four functional capabilities as shown in Figure 1.13 below.[221]

Figure 1.13 Space situational awareness functional capabilities



Improvements to SSA are a priority for the United States. In 2015, the U.S. Government Accountability Office (GAO) indicated that the government would spend up to $6-billion on these improvements over the next five years, primarily via the DoD.[222] On 2 June 2014, the DoD announced a contract with Lockheed Martin to build the USAF's next-generation space surveillance system.[223] Known as Space Fence, the new system will use S-band (2-4 GHz) ground-based radars to provide the USAF with un-cued detection, tracking, and accurate measurement of space objects, primarily in LEO.[224]

This system will replace the Air Force's Space Surveillance System, which began operations in 1961 and ceased operations in September 2013.[225] When the Space Fence becomes operational (currently scheduled for December 2018), it is expected to increase the detection and tracking capacity from approximately 20,000 to 100,000+ objects.[226] Space Fence data will be directed to the Joint Space Operations Center at Vandenberg Air Force Base in California and combined with other SSN information to establish a more comprehensive vision of space.[227] With an estimated cost of $6.1-billion over its lifetime, the Space Fence was poised to be the USAF's largest single investment in SSA sensors. However, budget constraints in recent years forced the USAF to reduce financial commitments to $800.9-million over the six years beginning with FY2015.[228]

The Canadian Department of National Defence is developing the Canadian Space Surveillance System (CSSS), which will contribute to the U.S. SSN primarily through the Sapphire microsatellite system in LEO.[229] The U.S. Space-based Surveillance Satellite, launched in 2010, is the only other satellite in the SSN solely dedicated to SSA.

Limited SSA capabilities in GEO impact both the safety and transparency of space operations. In 2014, the USAF launched two Geosynchronous Space Situational Awareness Program (GSSAP) satellites in near-geosynchronous orbit to improve the tracking and characterization of human-made orbiting objects.[230]

Russia has relatively extensive SSA capabilities; its military maintains a space surveillance system of early-warning radars and monitors objects (mostly in LEO). It does not widely disseminate data.[231] Efforts are under way to upgrade its space surveillance capabilities. The deployment of more than 10 new-generation stations is intended to increase the precision of observations. New ground-based telescopes were added in 2015.[232] The system is reportedly able to "compil[e] and updat[e]…the Space Objects Catalogue containing over 5,000 objects larger than 10 cm in size (at low orbits) and larger than 1 m (at geostationary orbits)."[233] Design of the new Okno-M ("Window") optoelectronic space surveillance system located in Nurak, Tajikistan passed tests in 2014 and, according to an official, "four optoelectronic space surveillance and data gathering stations have been put into service."[234] It reached full capacity in 2015[235] and has a range of 50,000 km.[236]

European states are developing an independent Space Surveillance Network. In June 2015, France, Germany, Italy, Spain, and the United Kingdom agreed to coordinate "their existing optical and radar tracking telescopes in a five-year effort funded by the 28-nation European Union," including both civilian and military components. The agreement signed by these countries will give the EU Space Surveillance and Tracking Network access to their assets. This plan had an end date of 2020 and was estimated to cost €70-million ($80-million).[237] This EU network is separate from a similar, strictly civilian, program sponsored by the ESA, started in 2014 to establish a database on all existing European space surveillance systems,[238] and so reduce Europe's reliance on the U.S. Space Surveillance Network.[239]

China and India have significant satellite tracking, telemetry, and control assets essential to their civil space programs. In 2015, China opened a new government center to monitor both NEOs and space debris. The center, managed by the State Administration of Science, Technology and Industry for National Defence and the Chinese Academy of Sciences, will share data with international partners. According to reports, "the center will utilize existing observatory facilities in China while taking advantage of surveillance data from both home and abroad to set up its own monitoring network for space debris."[240]

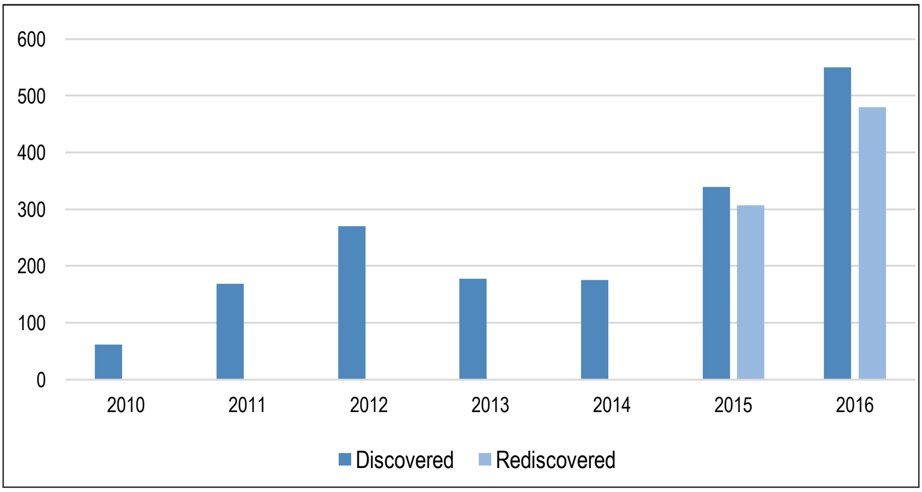
The Indian Space Research Organisation (ISRO) is developing its own radar space tracking system and in 2015 tested its "multi-object tracking radar" for LEO, which can reportedly "track 10 objects simultaneously up to 30cm by 30cm at distance of 800km."[241] The radar is expected to be used to support India's human spaceflight program, since reentering the atmosphere requires tracking during descent. It will also be useful for identifying debris in LEO.[242]

Commercial operators are also contributing to global SSA capabilities. U.S. company Analytical Graphics Inc. announced the opening of its Commercial Space Operations Center (ComSpOC™) in March 2014.[243] AGI provides data for space collision avoidance, maneuver detection, and debris modeling.[244] The center is the first and most highly robust global system, consisting of an SSA facility that relies on commercial optical and radio tracking assets and the company's own space surveillance software. It draws on data from 70 telescopes aimed primarily at GEO, along with two radar sensors for LEO.[245] ComSpOC™ is now tracking 4,426 space objects—75% of all active GEO satellites and 100% of all active GEO satellites over the continental United States.[246]

There is currently no operational global system for space surveillance, in part because of the sensitive nature of surveillance data. The U.S. SSA Sharing Program is run by USSTRATCOM through the Joint Space Operations Center.[247] Data from the U.S. SSN flows into the SSA Sharing Program, which has three levels of SSA support services.[248] The first is emergency notifications, which alert satellite operators to potential collisions. In 2014, the Joint Space Operations Center Mission System (JMS) provided 671,727 possible collision warning notifications to satellite owners/operators and supported 93 space launches (52 foreign and 41 domestic).[249] The second level is the USSTRATCOM-sponsored website, Space-Track.org, which serves as an available repository of basic satellite catalog information, including positional data and background information (country of origin, launch date, etc.). The third level includes specific advanced services supporting safe spaceflight operations during launch, on-orbit, and decay or reentry operations. This third level of services is available to commercial and governmental satellite and launch operators with which the U.S. DoD has established written agreements. By early 2017, USSTRATCOM had agreements with 11 states (the United Kingdom, the Republic of Korea, France, Canada, Italy, Japan, Israel, Spain, Germany, Australia, and the United Arab Emirates), two intergovernmental organizations (ESA and EUMETSAT), and more than 50 commercial satellite owner/operator/launchers.[250] Not all data-sharing agreements include classified data. U.S. Defense officials have indicated that the United States has signed more than 50 unclassified data-sharing agreements with both government and private sector organizations.[251]

ISON has concentrated on detecting human-made debris in high-altitude orbits, primarily GEO, from 38 facilities with 90 telescopes in 16 countries, using more than 60 telescopes.[252] Russia's Keldysh Institute of Applied Mathematics coordinates the project and provides conjunction analysis for the Russian Federal Space Agency (Roscosmos). It produces orbital predictions, solutions, and analysis, but it asserts that the different models it uses can produce higher quality data than what is provided through the SSA Sharing Program. Because ISON has no military ties, it also claims that its data is more open, freer, and more complete than data provided through the SSA Sharing Program.[253]

Figure 1.14 Number of objects discovered by ISON[254]



Nongovernmental actors have recognized the increased importance of data sharing. The nonprofit Space Data Association serves as a central hub for sharing data among participants. The SDA's main functions are to share data on the positions of members' satellites and information to prevent electromagnetic interference.

2016 Developments

United States continues to prioritize improved SSA capabilities

In 2016, the U.S. government continued to support the development of more advanced SSA capabilities. A 2015 GAO report estimated that the U.S. government would spend up to $6-billion on SSA in the next five years, primarily through the DoD,[255] which plans to "relocate sensor systems, develop and field several additional sensors and systems, conduct technology development, and upgrade some of its current sensors."[256] The ability to monitor objects in more distant GEO belts is a key focus of these efforts.

S-Band Space fence

At the heart of updated SSA capabilities is the S-Band Space Fence, being built on Kwajalein Atoll. This system is designed to replace the Air Force Space Surveillance System and to be capable of tracking more than 100,000 objects in orbit. Funding for the system increased from $200-million in FY2015 to roughly $244-million in FY2016.[257] In March, Lockheed Martin opened a Space Fence Test Facility in New Jersey, which will be used to test key elements.[258] In April, General Dynamics completed construction of the foundation for the Space Fence radar array, which will eventually be moved to Hawaii.[259] But software for the system was expected to be delayed by 19 months following rollout problems with phase two of the Joint Space Operations Center Mission System that will replace the Space Defense Operations Center, upgrading the Air Force's abilities to detect, track, and analyze objects picked up by the Space Fence.[260] With this delay, it is not clear that the Space Fence will become operational in December 2018, as planned.

SBSS

U.S. efforts to improve the ability to identify, track, and monitor objects in GEO include investment in the Space Based Space Surveillance (SBSS) program. The first Block 10 pathfinder satellite launched in 2010 uses an optical telescope to look closely at objects in GEO from its position in a Sun-synchronous, low Earth orbit. The spacecraft is expected to operate until 2020. A competition for a $400-million follow-on satellite was opened in 2016, with an award expected in 2017 and launch in 2021.[261] The Lincoln Laboratory at the Massachusetts Institute of Technology is building the Operationally Responsive Space (ORS)-5 space surveillance satellite, scheduled to launch in late 2017 to bridge capability between the two satellites.[262]

GSSAP

The Geosynchronous Space Situational Awareness Program is used for detailed inspection of objects in GEO, using dedicated satellites that operate in the near-geosynchronous orbit.[263] The first two satellites were launched in 2014. The system has reportedly been deployed on several missions, including a 2016 investigation of the U.S. Navy's MUOS-5 satellite after it experienced a problem reaching its target altitude of 35,400 km[264] (see Indicator 3.4). Two additional GSSAP satellites were launched on 19 August.[265]

Space Surveillance Telescope

DARPA transitioned operation of the Space Surveillance Telescope (SST) to the USAF in October 2016.[266] Located in Australia, the SST will be jointly operated by the United States and Australia and is the first U.S. surveillance asset to operate from the Southern Hemisphere. The SST will be able to survey large areas of space, focusing on objects in GEO. It is also capable of detecting asteroids and discovering and tracking other small space objects that were previously difficult to find.[267] The program cost approximately $150-million.

DARPA Hallmark

Efforts to integrate SSA data into space command and control capabilities advanced in 2016. DARPA called for research-and-development proposals for the Hallmark Software Testbed to "design, develop, and maintain a state-of-the-art enterprise software architecture for the integration of multiple tools and capabilities for supporting space enterprise command and control."[268] Contracts for up to $16-million were to be awarded for the first phase, with multiple awards possible. According to the Director of DARPA's Tactical Technology Office, the goal is to develop a system that "would fuse information from diverse sources and vastly reduce the overall time required to make and execute decisions and observe results."[269] It is a first step toward a long-term Hallmark Space Evaluation and Analysis Capability, intended to provide "effective development, integration, modeling and simulation, and realistic testing of software and decision-support processes relevant to space command and control."

18th Space Control Squadron

In July 2016, the USAF announced reactivation of the 18th Space Control Squadron, tasked specifically with SSA.[270] The squadron, located at Vandenberg Air Force Base in California and commanded by Lieutenant Colonel Scott Putnam, assumed responsibility for the entire satellite catalog of the 614th Air Operations Center. The move reverses the 2008 decision to stand down the squadron and transfer its function to the Center. The 18th will monitor SSN data, update and augment the Space Catalog, and back up other SSA-focused units.

Commercial capabilities

The United States is bolstering its SSA capabilities with additional commercial capabilities. Applied Defense Solutions was awarded a contract with the Air Force Research Laboratory to provide SSA data that will feed directly to the Joint Interagency Combined Space Operations Center (JICSpOC).[271] ADS will work with industry partners to provide aggregated SSA data to the Air Force. The contract, with two one-year options, was valued at approximately $38.5-million. On 19 October, ADS was awarded a second one-year contract to develop a fully commercial SSA catalog on objects in GEO, drawing on data derived only from commercial sources.[272] The intention is to supplement government data in areas that are not well covered, and to provide a redundant source of information; it is also thought that commercially derived SSA data could be more easily shared with international partners.

Artificial Intelligence

On 18 July, BAE Systems was awarded a $9.4-million contract to develop machine-learning software and reports on the feasibility of machine learning to help improve SSA capabilities.[273] Completion is anticipated by July 2019.

Russia, France, Japan, China advancing independent SSA capabilities

Russia

Russia's Automated Warning System on Hazardous Situations in Outer Space began operations in January 2016. The system currently draws on data from six facilities with a total of 21 telescopes.[274] "The main goal…is to monitor dangerous approaches of the devices operating on orbit with orbital debris and to follow falling satellites."[275]

In February, Russia announced that new radars were being developed for its Main Space Intelligence Center, headquarters for Russia's space surveillance network and part of the Aerospace Forces.[277] The main objective is to track foreign spacecraft and systems, while monitoring Russian spacecraft and global space traffic. The Center reportedly conducted approximately 2,000 special operations, detecting and monitoring 930 space objects in 2015. Additional complexes for the Space Surveillance System will be deployed in the next few years in the Crimea and Far East, as part of "a network of next-generation special radio-electronic surveillance complexes" intended to enable permanent, 24/7 monitoring of the near-space environment.[278]

Russia also reported work on new radars and intelligence centers to bolster the capabilities of the international ISON system.

France

In 2016, France signed a €40-million ($42-million) contract with the ONERA aerospace research office to upgrade the GRAVES space radar system, located in the Bourgogne-Franche-Comté region of France.[279] GRAVES is used to detect foreign intelligence satellites and their orbits, as well as space debris that could threaten French satellites. This deal potentially extends GRAVES operations until 2030. Graves is operated in tandem with Germany's Tracking and Imaging Radar; together they form the core of SSA capabilities in Europe.[280]

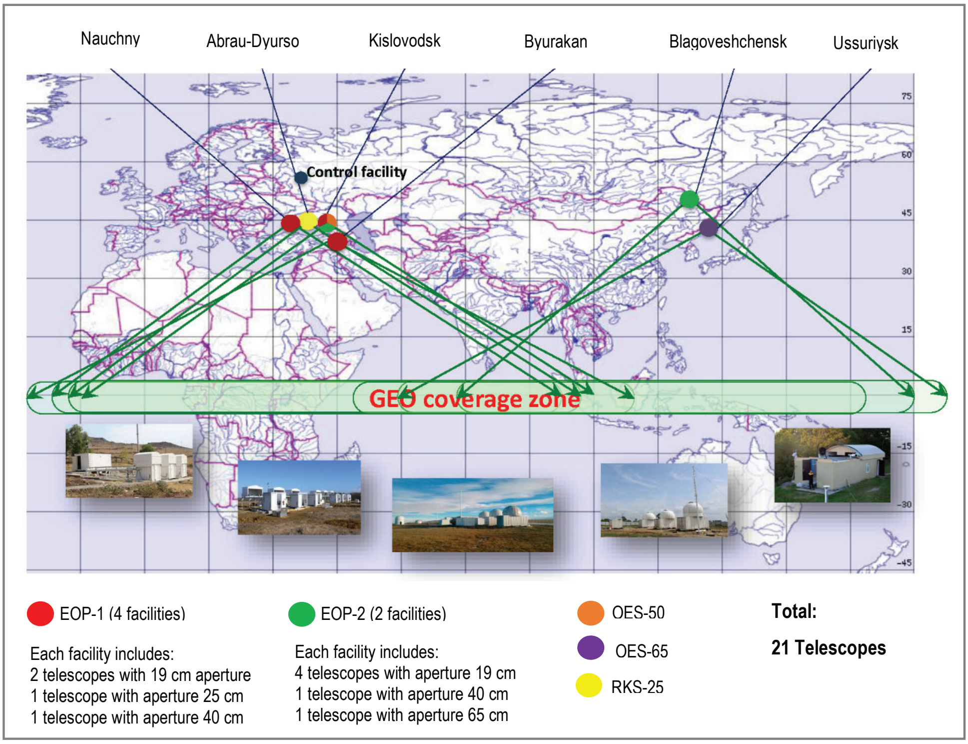
Japan

Japan's Self-Defense Forces committed to developing by 2022 its first space monitoring capabilities—new facilities for optical telescopes and radar. Information will be shared with the United States. JAXA, a civilian agency, currently collects information using telescope and radar facilities in Okayama. Each new facility will cost about 10-billion yen ($88.8-million).[281]

China

The China National Space Administration (CNSA) released a White Paper on China's Space Activities in 2016[282] that included a five-year plan to expedite the development of its space capabilities, including SSA. Section III notes the need to develop "space debris monitoring facilities, early warning, and emergency responses."[283] The paper described China's monitoring systems for Earth orbit as "preventative capability." Section V mentions the China-ESA Space Cooperation agreement, which includes a provision on sharing data about space debris. This agreement is effective from 2015 to 2020.

Figure 1.15 Operational optical facilities of the Automated Warning System on Hazardous Situations in Outer Space[276]



United States expands SSA cooperation

The United State agreed to share data from its High Accuracy Catalog with new partners in 2016. USSTRATCOM signed agreements with the UAE Space Agency[284] and the Spanish Instituto Nacional de Técnica Aeroespacial.[285] Efforts are being made to expand beyond the bilateral sharing of data to greater cooperation and combined space operations with military allies. For example, within the Five Eyes alliance (Australia, Canada, New Zealand, the United Kingdom, and the United States), a 2014 agreement between Australia, Canada, the United Kingdom, and the United States created the Combined Space Operations Initiative, which includes SSA, force support, launch and reentry assessment, and contingency operations.[286] British, Australian, and Canadian officers are stationed at JSpOC and consideration is being given to expanding this partnership to include Germany and Japan.[287] Five Eyes partners participated in the 2016 Shriver Wargame, which focused on resilience and the potential for space conflict.[288] A 2016 tabletop exercise led by the United States focused on tactical issues associated with SSA data-sharing. Participating were officials from the United Kingdom, the

Republic of Korea, France, Canada, Italy, Japan, Israel, Spain, Germany, Australia, and the United Arab Emirates; intergovernmental organizations ESA and EUMETSAT; and more than 50 commercial satellite owners and operators.[289]

Proposals presented on multilateral sharing of orbital data

Options for multilateral sharing of orbital data were presented at UN COPUOS in 2016. Russia submitted a working paper that called for a UN database of space objects and indicated that Russia would "establish a national information service, whose function shall be to provide open access to the results of monitoring objects and events in outer space," which could then be incorporated into such a system.[290] Presumably this disclosure would include the military satellites of the United States and its allies, which are not currently in the public catalog.[291] There is no consensus for such an approach. However, among the seven themes agreed to in 2016 for the UNISPACE+50 process (see Indicator 4.2) is Theme 3, "Enhanced information exchange on space objects and events."[292] The objective is to identify "requirements for enhanced information exchange and notification procedures under the United Nations Register of Objects Launched into Outer Space" and include consideration of this as a new agenda item for the Scientific and Technical Subcommittee of COPUOS.[293]

United States considers a civilian role in space traffic management

The U.S. DoD has been investigating the possibility of turning over the task of providing collision warnings to commercial and international satellite operators to a civilian service. In August 2016, the Institute for Defense Analyses released its report *Evaluating Options for Civilian Space Situational Awareness*.[294] The report found that maintaining a "high-accuracy catalog and performing conjunction assessment screenings" requires a "relatively small number of personnel." It argues that these SSA activities can be provided by an increasingly diverse U.S. commercial space sector that is able to provide the data, software, and services to meet, and potentially exceed, government needs for SSA. The report notes that a lack of publicly available data is preventing commercial actors from taking over the outmoded government oversight system.

A September 2016 report to the U.S. Congress detailed how to transition civil, commercial, and foreign SSA-sharing duties from the DoD to the Federal Aviation Administration.[295] Congress would need to pass legislation to shift this role,[296] which could cost approximately $100-million.[297]

The idea that SSA oversight needs to change was corroborated by a November 2016 "Orbital Traffic Management Study" by Science Applications International Corporation (SAIC), which detailed five proposed frameworks to address future U.S. SSA needs. The report ultimately preferred "Option 3: Civil-Based Space Traffic Safety Monitoring and Facilitation," which would give SSA responsibilities to a civilian agency[298] "to replicate the current DoD function of providing Space Traffic Safety products and services to private and foreign entities, facilitating information sharing among those owner-operators."[299]

U.S. commercial actors continue to expand SSA role, upgrade capabilities to meet needs

The nascent commercial SSA industry became more robust in 2016 to meet the growing demands from commercial operators for services and support. Analytical Graphics Inc. expected its Commercial Space Operations Center to have data on the same number of tracked objects in orbit as the U.S military's JSpOC by the end of 2016.[300] A key boost in capabilities was expected from the agreement with Thoth Technology to upgrade and repurpose the Algonquin Radio Observatory in Ontario, Canada.[301] The upgrade to the 46-m radio astronomy antenna will allow the observatory to view previously unseen objects in the GEO Belt. AGI now tracks more than 9,000 objects in LEO, HEO, MEO, and GEO that are logged in the public catalog, as well as non-public objects.[302]

New businesses are emerging. The Schafer Corporation formed a Commercial Space Situational Awareness business unit in May 2016 to "meet the growing need for technically accurate, timely and relevant information on the location of natural and manmade objects in orbit."[303] The unit, led by retired Air Force Colonels Donald Greiman and Mark Brown, consists of eight aerospace and defense companies and is intended to provide comprehensive coverage of space across the electromagnetic spectrum.

LeoLabs, which spun out of the nonprofit research center SRI International, was founded in 2016 to provide SSA services for commercial operators. On 21 September, the company announced the construction of a space object-tracking radar at the Midland International Air and Space Port in Texas.[304] To meet growing commercial needs for SSA in LEO created by networks of small satellites and human spaceflight/tourism, LeoLabs plans to deploy Tracking as a Service. Testing will essentially be free, because the city of Midland is providing LeoLabs with reciprocal support in advertising and marketing campaigns. The radar facility is valued at approximately $1.5-million.

THEME TWO

Access to and use of space by various actors

Indicator 2.1: Space-based global utilities

Space-based global utilities are space assets that can be used by any actor equipped to receive the data that they provide. The use of space-based utilities has grown substantially over the last decade. Millions of individuals rely on space applications on a daily basis for functions as diverse as communications, Earth observation, weather forecasting, navigation, and search-and-rescue: operations.

Global utilities are important for space security because they broaden the community of actors that have a direct interest in maintaining space for peaceful uses. While key global capabilities such as GPS and weather satellites were initially developed by military actors, today these systems have grown into space applications that have become indispensable to the civil and commercial sectors.

Satellite navigation systems

There are currently two operational global satellite navigation systems: U.S. GPS and Russian GLONASS. Work on GPS began in 1978 and it was declared operational in 1993, with a minimum of 24 satellites that orbit in six different planes at an altitude of approximately 20,000 km in MEO. GPS operates a Standard Positioning Service for civilian use and a Precise Positioning Service that is intended for use by the U.S. DoD and its military allies. GPS military applications include navigation, target tracking, missile and projectile guidance, search-and-rescue, and reconnaissance. However, by 2001, military uses of the GPS accounted for only about 2% of its total market. The nonmilitary market for GPS includes automotive, marine, and aviation users, as well as GPS-enabled mobile phones and GPS cameras. At the end of 2016, global precision of the system was 0.715 m, 95% of the time,[1] and is improving as the system is modernized. The next-generation GPS III system has been significantly delayed. [2]

GLONASS uses principles similar to those used in GPS. It is designed to operate with a minimum of 24 satellites in three orbital planes, with eight satellites equally spaced in each plane, in a circular orbit with an altitude of 19,100 km.[3] The first GLONASS satellite was orbited in 1982[4] and the system initially attained full operational capability in 1995. This capability was subsequently degraded by the loss of a number of satellites, but regained in 2011.[5] GLONASS operates a Standard Precision service available to all civilian users on a continuous, worldwide basis and a High Precision service available to all commercial users since 2007.[6] Russia continues to allocate significant funding for system upgrades independent of the main Roscosmos budget. It has extended cooperation on GLONASS to China and India.[7] Russia is intent on improving the system's accuracy and precision by building a network of ground stations around the world, with the cooperation of other countries.[8] In 2015, China and Russia signed "China's BeiDou system and Russian GLONASS system Compatibility and Interoperability Cooperation Joint Statement," aimed at increasing cooperation in developing their independent systems, as well as providing cross-system compatibility.[9] At the end of 2016, GLONASS consisted of 25 functional satellites, one spare, one under service, and one satellite in a testing phase.[10] It had a positioning accuracy of 3.5 m.[11]

Two additional independent, global satellite navigation systems are being developed: the EU/ESA Galileo Navigation System and China's BeiDou Navigation System. Galileo is designed to operate 30 satellites in MEO in a constellation similar to that of the GPS, providing

Europe with independent navigation capabilities. The first pair of In-Orbit Validation satellites were launched in 2011 and a second pair in 2012; four pairs of fully operational satellites were launched in 2014 and 2015; initial services began in 2016, with completion of the system planned for 2020.[12] Galileo will offer open service; commercial service; safety-of-life service; search-and-rescue service; and an encrypted, jam-resistant, publicly regulated service reserved for public authorities that are responsible for civil protection, national security, and law enforcement.[13]

The Chinese BeiDou system consists of two separate satellite constellations: BeiDou-1, a limited test system that has been operating since 2000; and COMPASS or BeiDou-2, a full-scale global navigation system that is currently under construction. In 2015, China established stable regional operation and formal deployment of next-generation satellites for COMPASS,[14] which will include five satellites in GEO and 30 in MEO. Global service is expected by 2020.

Japan is developing the Quazi-Zenith Satellite System (QZSS), which is to consist of four satellites interoperable with GPS in HEO; it will enhance regional navigation over Japan by 2018, with plans for a total of seven satellites in the future.[15] The first satellite in the QZSS, Michibiki, was launched in 2010.[16] India is developing an independent, regional system—the Indian Regional Navigation Satellite System (IRNSS)—intended to consist of a seven-satellite constellation.[17] The first satellite of the constellation, IRNSS-1A, was launched in 2013.[18] The system is expected to be operational in 2018.

The underlying drive for independent systems is based on a concern that reliance on foreign global satellite navigation systems such as GPS may be risky, since access to signals is not assured, particularly during times of conflict. Nonetheless, almost all states remain dependent on GPS service, and cooperation and interoperability are becoming the norm; the United States has agreements to this end with all systems under development.[19] Cooperation is facilitated by the International Committee on Global Navigation Satellite Systems (ICG), established in 2005 under the umbrella of the United Nations, which "promotes voluntary cooperation on matters of mutual interest related to civil satellite-based positioning, navigation, timing, and value-added services," including interoperability.[20]

Remote sensing

Remote-sensing satellites are used extensively for a variety of Earth observation functions, including weather forecasting; surveillance of borders and coastal waters; monitoring of crops, fisheries, and forests; and monitoring of natural disasters such as hurricanes, droughts, floods, volcanic eruptions, earthquakes, tsunamis, and avalanches. To ensure broad access to data, agencies across the globe have sought to enhance the efficiency of data sharing with international partners.[21] According to a 2014 Euroconsult report, more than 50 countries are now investing in EO programs, and 353 EO satellites are expected to be launched in the next decade—more than double the number launched in the previous one.[22]

Global weather monitoring and forecasting is a critical utility enabled by the international sharing of space-based meteorological data. EUMETSAT provides meteorological data for Europeans, while NOAA provides the United States with meteorological services.[23] Satellite operators from China, Europe, India, Japan, the Republic of Korea, Russia, and the United States, together with the World Meteorological Organization, make up the Co-ordination Group for Meteorological Satellites, a forum for the exchange of technical information on geostationary and polar-orbiting meteorological satellite systems.[24] Data collected is made freely available to the World Meteorological Organisation, which distributes it to more than 3,000 weather forecast outlets in its 185 member states and six territories.[25] U.S. weather satellites are a critical component, but are reaching the end of their lifespans. A potential gap in weather satellite data provided by NOAA was labelled high-risk by the U.S. GAO in 2013,[26] prompting discussion on the advisability of purchasing data for weather forecasting from commercial sources, and options for cooperation from Europe or India.[27] In 2015, Roscosmos launched the Elektro-L2 satellite into GEO to monitor changing weather and climate on Earth as well as space weather; it will provide data globally.[28]

The use of space-based capabilities to monitor Earth's environment and changing climate is increasing. Prominent examples include Copernicus, formerly called "Global Monitoring for Environment and Security," a joint program of the European Commission and ESA to establish a consistent and reliable EO capability for purposes including environmental management, disaster mitigation, agriculture, forestry, and commercial and civil use.[29] In 2015, its Jason-CS Ocean Topography Satellite received formal approval ahead of the COP (Conference of the Parties) 21 climate conference.[30] The satellite will extend the record of mean sea-level measures that have been accumulated by Topex-Poseidon, Jason, Jason-2, and Jason-3 altimeter missions over the next 30 years, as well as support oceanography in Europe. Italy's dual-use COSMO-SkyMed will also offer thematic mapping for environmental applications such as forestry and agriculture,[31] and provide commercial data.

Several initiatives are under way to expand global access to EO data. The U.S. Government is the largest provider of environmental and Earth-system data in the world. To maintain this capability and service, in 2014, the National Science and Technology Council of the Executive Office of the President of the United States announced the National Plan for Civil Earth Observation.[32] The plan establishes priorities and supporting actions to advance civil EO capabilities. That year, the European Parliament adopted the Copernicus Regulation, which defines the objectives, governance, and funding of Copernicus.[33] The European Commission and ESA signed an agreement worth more than €3-billion ($3.8-billion) to manage and implement Copernicus through 2021.[34]

Sharing EO data between Europe and the United States is set to increase following signing of the "Copernicus Cooperation Agreement" on 16 October 2015. This agreement promotes "a shared U.S.-EU vision to pursue full, free, and open data policies for government Earth observation satellites…[to] foster greater scientific discovery and encourage innovation in applications and value added services for the benefit of society at large."[35]

The Global Earth Observation System of Systems (GEOSS), coordinated by the Group on Earth Observation, has the goal of "establishing an international, comprehensive, coordinated and sustained Earth Observation System."[36] GEOSS members include 97 state governments and the European Commission;[37] 67 intergovernmental, international, and regional organizations are recognized as Participating Organizations.[38] The European Global Monitoring for Environment and Security (GMES) initiative and the Japanese Sentinel Asia program are examples of centralized databases of EO data made available to users around the world.[39]

The importance of commercial providers of global EO data is growing, along with the trend of using constellations of small satellites to allow imagery to be updated more frequently. Leading companies include Planet and Spire. Private-sector actors such as OneWeb, ViaSat Inc., and SpaceX (backed by Google) are also increasing global access to communications services such as the internet (see Indicator 2.4).[40] A number of private companies are working with governments to provide expanded services for capabilities such as communications and meteorology (see Indicator 2.5).

Several private sectors actors are providing data for global public uses. In 2015, DigitalGlobe signed an agreement with UNOOSA to collaborate on satellite imagery and geospatial solutions for development.[41] Members of the EMEA (Europe, Middle East, and Africa) Satellite Operators Association (ESOA), and the Global VSAT (very small aperture terminal) Forum, which represents organizations such as EUTELSAT, HISPASAT, Inmarsat, Intelsat, SES, Thuraya, and Yahsat, in coordination with the UN Office for the Coordination of Humanitarian Affairs and the Emergency Telecommunications Cluster and led by the World Food Programme, signed the Crisis Connectivity Charter in October 2015.[42] The goal is to harness the capabilities of satellite operators to provide access to communications capabilities during a disaster. This charter's operation is similar to that of the International Charter on Space and Disaster Management, which is comprised mainly of civil space agencies and government satellite operators; both focus on the mobilization of orbital infrastructure to assist in disaster management (see below).

Automatic Identification System

AIS is used by ships to monitor marine traffic, much as air traffic control monitors air traffic. It provides information on identity, position, course, and speed. At first, as a radio-based communications system, marine monitoring experienced transmission limitations.[43] Detection of AIS signals using satellite-based receivers was initiated in 2005 and has been used successfully since the 2008 demonstration by ORBCOMM in conjunction with the U.S. Coast Guard. Currently, commercial services are provided by ORBCOMM, exactEarth, Spacequest, Spire, and LuxSpace; government capabilities are supported in countries including the United States, Canada, Norway, Germany, and China.

Disaster relief & search-and-rescue

Space has become essential for disaster relief. The International Charter on Space and Major Disasters is an international arrangement among participating space agencies to provide space-based data and information in support of relief efforts during emergencies caused by major disasters.[44] Member organizations include the Argentine Space Agency, CNES, CNSA, Canadian Space Agency (CSA), ESA, EUMETSAT, the German Aerospace Center (DLR), ISRO, JAXA, KARI, National Institute for Space Research, NOAA, Roscosmos, the UK Space Agency, the U.S. Geological Survey, and DMC International Imaging. To activate the Charter, an Authorized User (typically a Charter member) submits a request related to a disaster occurring in their country, or on behalf of a non-member country for a disaster in its territory. Upon activation of the Charter, a Project Manager is appointed to maintain communication with the affected country and to coordinate access to satellite data that will be most useful in managing that particular type of disaster.[45]

The International Cospas-Sarsat Programme is a satellite-based search-and-rescue distress alert detection and information distribution system, best known for detecting and locating emergency beacons activated by aircraft, ships, and backcountry hikers in distress.[46] Participants include the four original parties to the Cospas-Sarsat International Programme Agreement (Canada, France, Russia, and the United States), 26 Ground Segment Providers, 10 User States, and two Organizations.[47] Cospas-Sarsat provides alert and location data to national search-and-rescue authorities worldwide, without discrimination, independent of country participation in the program.[48] Between September 1982 and December 2015, Cospas-Sarsat assisted in the rescues of 41,750 people in 11,788 search-and-rescue events.[49] The space segment of the program currently includes five fully operational satellites in LEO and nine fully operational satellites in GEO, with four extra satellites undergoing tests.[50]

The UN Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) is an open network of providers of space-based solutions to support disaster management activities.[51] Its official mission is to "ensure that all countries and international and regional organizations have access to, and develop the capacity to use, all types of space-based information to support the full disaster management cycle." China agreed to provide EO data to UN-SPIDER in a September 2015 agreement.[52]

Through UN-SPIDER, UNOOSA launched the Global Earth Observation Partnership with 17 other partners in March 2015 to facilitate the use of EO and space-based technologies to support implementation of the Sendai Frameworks for Disaster Risk Reduction.[53] A successor to the Hyogo Framework for Action, Sendai's goal is to provide "substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."[54]

2016 Developments

Positioning, Navigation, and Timing (PNT) systems upgraded; interoperability and cooperation improvements attempted

GPS

The U.S. GPS constellation expanded to 31 satellites following a successful launch of GPS IIF-12 into MEO from Cape Canaveral Air Force Station, Florida.[55] This final GPS IIF satellite enabled a 36.5-cm accuracy in average user range error, improving civilian and military capabilities.[56] The USAF completed negotiations with Lockheed Martin for the $395-million purchase of satellites SV-09 and SV-10 as part of the GPS III constellation. The Air Force had contracted with some private entities to provide feasibility assessments of GPS III satellite designs and to enhance the accuracy and security of signal generation and ensure compliance with next-generation air traffic control requirements.[57] The allocated budget for the procurement and development of GPS III satellites was approximately $380-million for FY2016[58] and approximately $206-million for FY2017.[59]

The lack of interoperability between GPS and other navigation systems remained "a serious obstacle in the growth of the GPS market,"[60] while international collaboration between system providers of GNSS signals moved ahead. Russia and China improved the harmonization and synchronization of the GLONASS and BeiDou navigation systems. [61] China also offered to cooperate with countries in the Asia-Pacific region, members of ASEAN, and members of the League of Arab States.[62] These sustained efforts signal a desire to shift from reliance on U.S. GPS.

GLONASS

After final testing of the ground control system in April, control of the ground infrastructure was transferred to the Russian Defense Ministry.[63] The updated system is precise up to 30.48 cm. It is designed for civilian use and can be used in scientific applications requiring highly accurate navigation data.[64] Two GLONASS-M replenishment satellites were launched in 2016 to replace two decommissioned spacecraft and one newer GLONASS-K satellite went online.[65] At the end of 2016, GLONASS consisted of 25 operational satellites; there were plans to launch another eight replenishment satellites by late 2017.[66]

BeiDou

In 2016, China successfully launched three next-generation BeiDou satellites for its BeiDou 2 global constellation, creating a system of 23 satellites.[67] The goal is to provide basic services to neighboring regions by 2018, and to complete the constellation of 35 satellites for global service by 2020.[68] In addition to its Belt and Road initiative (see Indicator 2.3), China is promoting BeiDou to Arab states.[69] Memoranda of understanding on satellite navigation cooperation were signed with Saudi Arabia and the Arab League in 2016.[70] Tests in Doha, capital of Qatar, showed that local ground facilities could receive signals from up to eight BeiDou satellites. This shows that the system is able to independently provide PNT services to local users, with accuracy as good as other space-based navigational systems in the region.[71]

Galileo

In January 2016, ESA's Galileo satellites 9 and 10 broadcast the system's first navigation signals.[72] Six additional satellites were launched between May and November.[73] On 15 December 2016, the European Commission issued the Galileo Initial Services Declaration and the European GNSS agency awarded a 10-year contract to the Galileo service operator at the "Galileo Goes Live" ceremony. Although the system signals are highly accurate, they are not consistently available, because the constellation is not complete.[74] The first Galileo signals will be used in combination with other satellite navigation signals until the constellation expands to improve coverage, which is expected to occur by 2020. The constellation is to consist of 24 satellites, with six orbital spares.

IRNSS

In 2016, India launched IRNSS satellites 1E, 1F, and 1G, completing the constellation of seven satellites and enabling India's independence from GPS and GLONASS.[75] The primary function of IRNSS is to provide a Standard Positioning Service for all users and an encrypted Restricted Service to authorized users in its primary service area of India and 1,500 km around the Indian mainland, with accuracy better than 20 m.[76]

Efforts made to prevent gaps in global weather monitoring and forecasting

Key U.S. weather satellites are reaching the end of their lifespans. In 2016, the U.S. Congress appropriated $370-million to build two final spacecraft for the Joint Polar Satellite System (JPSS), which will replace NOAA's DSCOVR system by 2022. NOAA plans to launch JPSS-1 in 2017 and JPSS-2 in 2021.[77] NOAA is obtaining data from NASA's 12-CubeSat Time-Resolved Observations of Precipitation structure and storm intensity Constellation of Smallsats (TROPICS) and eight-satellite Cyclone Global Navigation Satellite system to mitigate any data gap until JPSS-1 becomes fully operational.[78]

NOAA requested $752.8-million for 2017 for maintenance and development of four next-generation GOES-R series geostationary weather satellites. The first, launched in November and expected to become operational in 2017, will provide faster and more frequent, accurate, and detailed weather forecasts and warnings; and three times more data at four times the resolution. It will scan the landscape five times more quickly than its predecessors. GOES-S, T, and U are scheduled to launch in 2018, 2019, and 2024, respectively, and will provide weather data until at least 2036. The budget for the program between 2005 and 2036 is $10.8-billion, with $6.1-billion spent by the end of FY2015.[79]

In June, EUMETSAT agreed to use its Meteosat-8 satellite to replace Eumetsat-7 when it retires in 2017, thus continuing to fill a weather coverage gap over the Indian Ocean.[80] In

October, EUMETSAT and the ESA contracted to build Europe's next-generation Metop polar-orbiting satellites, expected to be in operation between 2021 and 2042, when the third and final first-generation Metop satellite, Metop-C, is expected to cease operation. Metop-C was to be launched in 2017 and remain operational beyond 2021.[81]

In September, India successfully launched meteorological weather observation satellite INSAT-3DR to replace INSAT-3D.[82] In November, Japan launched Himawari-9, a next-generation geostationary meteorological satellite. Himawari-8, launched in 2014, and Himawari-9 are replacements for Japan's meteorological satellites MTSAT 1R and MTSAT 2, launched in 2005 and 2006. The pair of Himawari satellites can take a full picture of East Asia and the Western Pacific every 10 minutes, improving upon the MTSAT update time of 30 minutes.

China launched its first next-generation geostationary meteorological satellite, Fengyun-4, in December.[83] The satellite's imaging sensor for the observation of lightning and continuous atmospheric monitoring will improve weather forecasts and alerts of natural disasters.[84]

Satellite-based AIS contributes to global marine governance

Private companies ExactEarth and Digital Globe announced a strategic alliance to offer services to the commercial fishing industry. ExactEarth offered a new and enhanced vessel information service, exactShipDB, which uses the Genscape Vesseltracker Ship Database.[85]

Following a successful 2015-2016 trial, the U.K. Space Agency awarded $1.4-million to exactEarth under its International Partnerships Programme to support the operational deployment of AIS-based small-vessels-tracking technology, exactTrax, on South Africa's small boats.[86] The International Partnership Programme is a multiyear program that uses space knowledge, expertise, and capability to provide sustainable, economic, or societal benefits to undeveloped nations and developing economies.

In March 2016, geospatial imaging services provider UrtheCast announced its intention to equip eight commercial synthetic aperture radar (SAR) satellites with AIS sensors for maritime ship tracking. These satellites will operate with eight optical satellites from UrtheCast's 16-satellite OptiSAR constellation (see below). The cross-cueing capability of the constellation will enable the SAR satellites to transition from surveying wide areas of ocean to providing high-resolution imagery of targets of interest within minutes of detection.[87]

On 21 June 2016, the CSA successfully launched the Maritime Monitoring and Messaging Microsatellite (M3MSat), improving wide-area surveillance coverage of Canadian territorial waters.[88] Operators can use AIS aboard the satellite independently or in conjunction with Canada's RADARSAT-2.[89] By May 2017, the satellite had completed all necessary tests and was fully operational.[90]

Access to high-resolution remote sensing data expands

New small-satellite technology is improving access to high quality Earth-imaging data, primarily through commercial ventures. By 2016, Planet's constellation of 63 small satellites had photographed 50-million km^2 of Earth in two years in operation. Planet plans to increase the constellation to 120 satellites. The data, which will be available to the public, will provide more current imagery than what is available from Google Maps and Bing. Such information is expected to impact many human sectors.[91]

In December, DigitalGlobe released its first public high-resolution image from the WorldView-4 satellite launched on 11 November.[92] The satellite, which is capable of producing the world's highest-resolution 30-cm commercial imagery, has applications in disaster management and situational monitoring for intelligence surveillance and reconnaissance.[93]

In April, ESA's Sentinel-1B was launched into LEO, increasing imaging frequency over Europe to every two days from every four days. Applications include a new satellite-based wildlife monitoring tool for airports, using data from Copernicus.[94]

In May, Planetary Resources announced a $21.1-million investment in its EO program, Ceres, aimed at delivering affordable imaging of any location on Earth. The company expects to reduce the cost of Earth imagery to a tenth of the present cost. Within the next three years, PR plans to have a constellation of 10 Akryd 100 microsatellites in LEO, with inbuilt thermal infrared and hyperspectral sensors that can be used to track and monitor natural disasters such as bushfires and floods.[95] The same technology will be used to test the viability of asteroids for commercial mining of water (see Indicator 2.4).

In June, U.S. company Spaceflight Industries invested $18-million in new venture capital in OpenWhere, an online portal for satellite imagery. CEO Jason Andrews noted its value for "the democratization of data about the planet" and its usefulness for satellite subsidiary BlackSky.[96] On 26 September, Spaceflight Industries successfully launched its first demonstration satellite, Pathfinder-1, from the Satish Dhawan Space Centre in India.[97] Geospatial imaging from the satellite is delivered at a rate of 90 minutes for $90, a price currently unmatched in the market. Through its global network of partners, ground stations, and launch vehicle providers, Spaceflight Industries offers satellite infrastructure, rideshare services, and global communications networks to commercial and government entities.[98]

In June 2015, UrtheCast announced the world's first commercial SAR and optical satellite constellation for Earth observation. The constellation consists of eight SAR satellites paired with eight optical satellites, travelling over two orbital planes. In May 2016, UrtheCast announced its successful completion of prototype hardware testing of "the principal core enabling elements" of its SAR technology.[99] The constellation is expected to provide "unmatched space-imaging capabilities,"[100] with its SAR technology allowing for "unprecedented performance and imaging flexibility…, all at much lower cost than the currently operating state-of-the-art SAR systems."[101] The data collected is expected to serve traditional EO as well as emerging geoanalytics markets.

Figure 2.1 Detection capabilities of EO satellites at various GSD (ground sample distance)[102]

GSD (m)	Examples of detection capabilities
+9.00	• Distinguish urban and agricultural areas, wetlands/floodplains, forests • Detect medium-sized port facilities, major highway and rail bridges over water • Observe weather patterns and natural resource distribution
9.00—4.50	• Detect large buildings (e.g., factories, hospitals, sports stadiums, etc.) • Identify road layouts on major highway systems • Detect large ships and aircraft (not by type) • Identify water current direction by color variations
4.50-2.50	• Detect individual houses in residential areas • Observe road layouts in urban areas • Detect large ships by type • Distinguish between large and small aircraft • Identify trains (not individual railway cars)
2.50-1.20	• Distinguish between farm buildings (e.g., barns, silos, etc.) and residential housing • Identify sports courts (e.g., tennis, basketball, etc.) • Detect small boats (4.5-6 m in length) in open water • Identify individual railway tracks • Detect large fighter jets by type
1.20-0.75	• Detect individual railway cars and trains by type • Identify larger than two-person tents at an established camping ground • Observe large animals in grassland (e.g., elephants, giraffes, rhinoceros, etc.) • Identify cars in parking lots
0.75-0.40	• Roughly detect individual persons • Distinguish between station wagons and sedans • Detect electric/telephone poles in residential areas • Observe foot tracks in grassland and barren areas • Detect spare tire on a mid-size truck
0.40-0.20	• Detect limbs (arms, legs) on a person • Identify individual steps on stairways • Identify rocks, stumps, and mounds in fields and forest clearings • Identify underwater pier footings • Detect small aircraft by type
0.20-0.10	• Detect facial features (partial discrimination of some features) • Identify individual small animals (e.g., cats, dogs, piglets, etc.) • Detect windscreen wipers, grill detailing, and license plates on vehicles
-0.10	• Identify construction or gardening tools (e.g., saw, level, shovel, pick, etc.) • Identify license plate numbers/vehicle registration numbers on trucks • Detect individual barbs on barbed wire fence • Identify individual grain heads on wheat

Importance of space resources to monitor climate change recognized

Space-based systems are critical to monitor climate change.[103] At the November 2016 meeting of heads of space agencies (part of the COP22 climate change summit in Marrakesh, Morocco), participants committed to coordinating efforts to monitor Earth's climate, particularly the water cycle.[104] The ESA and European Commission noted progress on defining a global carbon dioxide monitoring system, with the support of NASA and JAXA. UN COPUOS named seven "thematic priorities" to be addressed during the UNISPACE+50 conference (see Indicator 4.2);[105] No. 6, *International cooperation towards low-emission and resilient societies*, identifies a need to "develop a road map for enhanced resiliency of space-based systems and the affiliation of existing and future Earth observation, global navigation satellite system and telecommunication constellations."[106]

In July, NASA and USAID began an environmental monitoring program in West Africa called SERVIR,[107] which will use climate, weather, and other data from NASA's constellation of EO satellites "to help improve environmental decision-making among developing nations."[108] This constellation is expected to grow with the completed construction of two high-precision Earth-monitoring satellites for its Gravity Recovery and Climate Experiment Follow-On mission. The satellites are scheduled for launch in late 2017 or early 2018 and will monitor changes to the Earth's mass, underground water storage, ice sheets, glaciers, and sea level.[109]

The NOAA/EUMETSAT Jason-3 weather satellite, launched in January, measures ocean levels, currents, and temperature with high precision—monitoring climate change and improving weather forecasts.[110] ESA's Sentinel-3A, launched in February as part of the Copernicus environmental monitoring program, provides greater coverage of Earth, and will help to monitor climate, pollution, and biological productivity.[111] Sentinel-3B is scheduled for launch in 2017. In December, China launched its first mini-satellite, TANSAT, which has improved cloud-screening technology to monitor the Earth's atmosphere and study atmospheric carbon dioxide.[112]

But political support for this global service may be waning in the United States. In November, a senior advisor to President Trump's election campaign indicated that NASA's Earth science satellites would be re-tasked to conduct deep space research.[113] In March 2017, the Trump administration announced plans to eliminate four EO missions, including DSCOVR.[114]

New initiatives make data from national space systems public

At the 22nd User Interaction Meet of the National Remote Sensing Centre in Hyderabad in February, ISRO Chairman A.S. Kiran Kumar announced that some geospatial data as recent as six-months-old from the Indian Remote Sensing (IRS) satellites would be made available for free.[115] ISRO also reduced the prices of other IRS data products by 30-50%.[116] Lockheed Martin announced that data from the Space Based Infrared System (SBIRS) would be made available at the new Air Force data utilization lab in Boulder, Colorado, to encourage researchers to identify innovative uses for the data to improve situational awareness for applications, including monitoring weather events and military battlefield surveillance.[117] GeoOptics committed to making all data from its planned commercial constellation of climate and environment monitoring satellites free for research purposes.[118]

At the thirteenth plenary meeting in November in St. Petersburg, Russia, 103 member governments and 106 organizations of the Group on Earth Observations promoted "free, full, open and timely access to Earth observation datasets, products and services."[119] Under its 2017-2019 plan to advance data-sharing principles, the Group is tasked to deliver revised implementation guidelines, a national data-sharing progress report, a living document on international open data trends and benefits of data sharing, and a regional workshop on data sharing.

In September, China announced its plan to establish a nonprofit geographic information system by 2020. The system will provide global geoinformation resources; and surveying, mapping, and condition monitoring services for aerial and space remote sensing and for emergency response within China.[120]

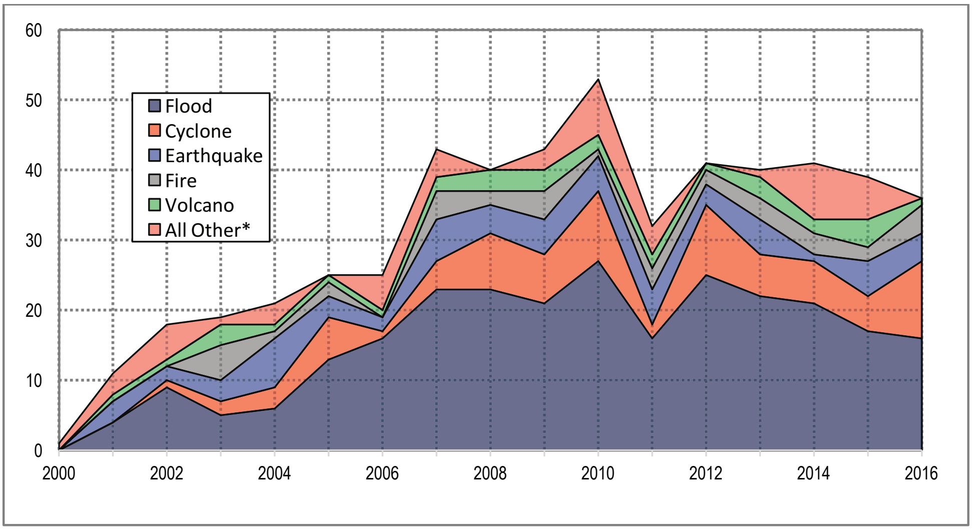
In November, new sea-state data was publicly released from the Space GNSS Receiver Remote Sensing Instrument on board the UK's TechDemoSat-1.[121] Wind and wave measurements could be found on the Measurements of Earth Reflected Radio-navigation

Signals By Satellite (MERRByS) website.[122] The satellite's GNSS data collections are valuable for weather forecasting and long-term climate change monitoring.[123]

Space resources remain important for disaster response

The Charter on Space and Major Disasters was activated 36 times in 2016 (39 times in 2015), more for floods than any other disaster.[124]

Figure 2.2 Activations of the Charter on Space and Major Disasters, 2000–2016[125]



The total number of search-and-rescue events aided by Cospas-Sarsat in 2016 is not yet publicly available; however, indications from countries including Australia, New Zealand, France, and the United States suggest an increase in 2016 of roughly 10% over 2015, which saw 718 events.[126] Europe's Galileo satellites 13 and 14, India's INSAT-3DR, and U.S. GOES-16 and GPS satellite IIF-12, all launched in 2016, will participate in the Cospas-Sarsat program.[127]

During a space summit in New Delhi in April, India and China discussed a proposed BRICS satellite constellation for disaster risk reduction.[128] The proposal was advanced in discussions between BRICS member states (Brazil, Russia, India, China, and South Africa) in November, when an agreement was made to set up a group of EO satellites.[129]

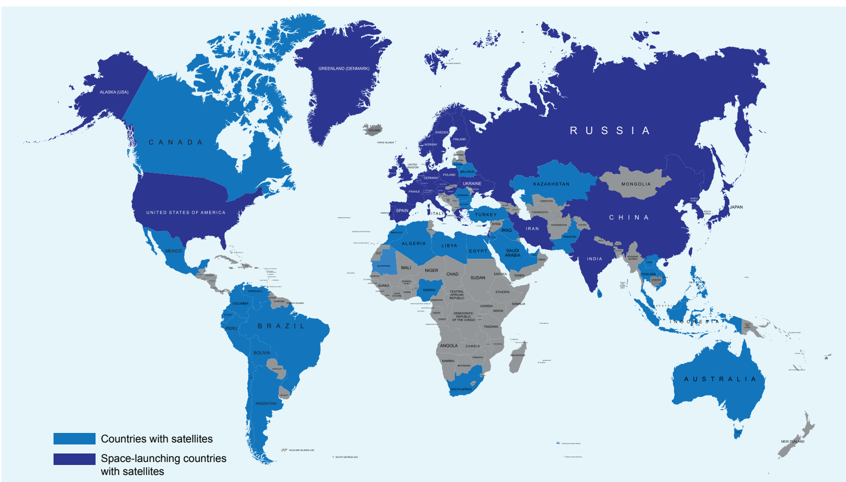
In September, Europe's Satellite Based Asset Tracking for Supporting Emergency Management in Crisis Operations (SPARTACUS) system completed a feasibility test. Using the European Geostationary Navigation Overlay Service (EGNOS) and the Galileo GNSS, SPARTACUS can monitor and manage assets, aid delivery, and help first responders at the scene of a crisis, improving the effectiveness of emergency operations.[130]

Indicator 2.2: Priorities and funding levels in civil space programs

The civil space sector is made up of organizations engaged in the exploration of space, or in scientific research in or related to space, for noncommercial and nonmilitary purposes. Civil space activity includes national (nonmilitary) satellites, science missions, the development of launch vehicles, and space exploration. Civil space programs can contribute to economic growth, social well-being, and sustainable development. The prestige associated with civil space accomplishments can be a significant driver of national policy. But distinguishing civil space activity from other types of activity may be difficult. Capabilities developed by civil space programs often find later applications in the military or commercial sectors; thus, investment in civil space activities can be a predictor of a state's plans in other sectors.

In 2016, the ESA, the United States, Russia, China, Japan, India, Israel, Iran, Democratic People's Republic of Korea (DPRK), and the Republic of Korea had independent launch capabilities.[131] The Union of Concerned Scientists Satellite Database listed the ESA and 55 countries as owners/operators of active satellites as of January 2017; the countries are Algeria, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Bolivia, Brazil, Canada, Chile, China, Denmark, Egypt, France, Germany, Greece, India, Indonesia, Iran, Iraq, Israel, Italy, Japan, Kazakhstan, Laos, Luxembourg, Malaysia, Mexico, Monaco, Morocco, Netherlands, Nigeria, Norway, Pakistan, Peru, Republic of Korea, Russia, Saudi Arabia, Singapore, South Africa, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, Turkmenistan, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela, and Vietnam.[132]

Figure 2.3 Global access to space[133]



Space agencies

The main U.S. civil space agency, NASA, is in charge of mission design, integration, launch, and space operations, while also conducting aeronautics and aerospace research. At almost $20-billion annually, NASA's budget is consistently the world's largest civilian space budget.[134] Recent priorities include the development of new capabilities for space launch, human spaceflight, and deep space exploration.[135] While much of the operational work is carried out by NASA, major commercial contractors such as Boeing and Lockheed Martin often develop technologies for new space exploration projects.

Roscosmos is the coordinating hub for space activities in Russia. Its numerous civilian activities include Earth monitoring and the astronaut program; it also coordinates military launches with the Defense Ministry.[136] A lot of work is done by design bureaus—state-owned companies established during the Cold War that have been integrated into "Science and Production Associations" (NPOs), such as NPO Energia, NPO Energomash, NPO Lavochkin, and the Khrunichev Space Center. A major provider of launch services to other countries, Roscosmos is currently battling a string of approximately 15 failed launches of its

Proton rockets between 2012 and 2016.[137] Roscosmos was formally dissolved in 2015 and in early 2016 combined with the recently nationalized United Rocket and Space Corporation to form the Roscosmos State Corporation.[138] Roscosmos faced a reduction of more than 60% to the 10-year budget announced in 2015; the chief victim was a super heavy launch rocket for space exploration.[139]

The China National Space Administration was established in 1993. As the central civil space agency in China, it reports to the State Administration for Science, Technology and Industry for National Defense, a civilian authority under the Ministry of Industry and Information Technology. Although a relative latecomer to space, in 2003, China became the third country to achieve human spaceflight. Since 2013, China has had the second-largest funded space program after the United States.[140] China is rapidly expanding investment in its space program, which includes space launch, human spaceflight, and space exploration capabilities, in addition to Earth observation and a Global Navigation Satellite System (see Indicator 2.1). In 2015, China launched rockets Long March 6 and Long March 11, finalized a new launch site on Hainan Island, and advanced development of the Tiangong space station.

In 1961, France established its national space agency, the Centre national d'études spatiales, which remains the largest EU national-level agency. Italy established a national space agency (ASI) in 1989, and Germany consolidated various space research institutes into the German Aerospace Center in 1997. The European Space Research Organisation and the European Launch Development Organisation merged in 1975 into the European Space Agency (ESA). ESA currently has 22 member states: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, and the United Kingdom. Slovenia is an Associate Member while Bulgaria, Canada, Cyprus, Malta, Latvia, Lithuania, and Slovakia are Cooperating States; discussions for cooperation are under way with Croatia.[141]

JAXA was formed in 2001 by the merger of the Institute of Space and Aeronautical Science of the University of Tokyo, the National Aerospace Laboratory, and the National Space Development Agency.[142] ISRO was founded as a dedicated civil space agency in 1969. The Israel Space Agency was formed in 1982, the CSA in 1989, and Brazil's Agência Espacial Brasileira in 1994.

The Iranian Space Agency began operating on 27 September 2010.[143] Iran has successfully launched four satellites into orbit. Many of the international sanctions that limited Iran's space program were lifted when the Iran nuclear deal was concluded in 2015. In 2014, Iran formulated a 10-year strategic plan with a focus on telecommunications and remote-sensing satellites, as well as human spaceflight.[144]

The UAE Space Agency was established in 2014. National investment in space is estimated to be $5.44-billion annually, with a significant portion allocated to the agency. The primary focus is on launching an unmanned Mars probe in 2020.[145]

There are more than 70 national space agencies.

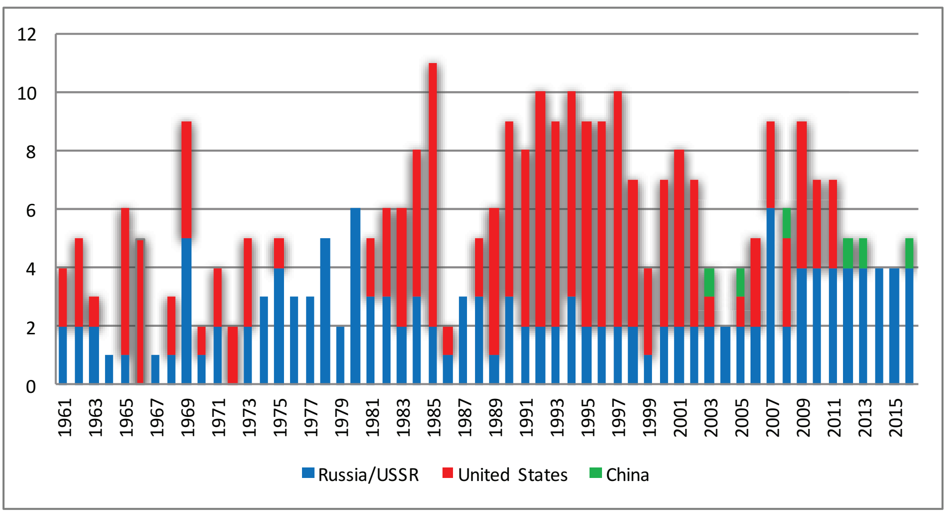
Human spaceflight

The USSR dominated the early years of human spaceflight. Russia maintains domestic human spaceflight capability with the Soyuz program. The 2006-2015 Federal Space Program included human spaceflight, specifically development of a reusable spacecraft to replace the Soyuz vehicle, and completion of the Russian segment of the ISS, which remains incomplete.[146] The new 2016-2025 Federal Space Program again commits to completion of the ISS and includes plans for a human-rated version of the Angara rocket to be launched from a new launch pad at the Vostochny spaceport, but without a clear allocation of funding.[147]

The first U.S. human space mission was completed in 1961. The Space Shuttle program provided human spaceflight capability from 1981 until 2011. Since then, an independent human launch capability has been an ongoing challenge for NASA, which currently purchases flights to the ISS on Russia's Soyuz rocket. NASA works with private companies SpaceX and Boeing on the Commercial Crew Program to provide human spaceflight to the ISS in the future;[148] the Dragon V and Starliner CST-100 spacecraft are currently scheduled to transport U.S. astronauts to the ISS in 2018.[149] NASA's new heavy-launch Space Launch System remains a priority; the system is intended to support deep space exploration, one day taking astronauts to Mars. Human exploration beyond LEO has been a goal since the 2004 announcement that NASA would return humans to the Moon by 2020. In 2006, a new strategy was announced for exploration of the Moon and then Mars.[150] In 2009, the U.S. Human Spaceflight Plans Committee found that the human spaceflight program was on an unsustainable trajectory.[151] The Journey to Mars was announced in 2014, which plans to send humans first to an asteroid, then to Mars after 2030.[152] But cost remains a challenge.

China began developing the Shenzhou human spaceflight system in the late 1990s and completed a successful human mission in 2003.[153] A second mission was completed in 2005, followed by missions in 2008, 2012, 2013, and 2016. China is progressing toward launch of a permanent, crewed space station in 2022.

Figure 2.4 Human spaceflight missions by country 1961–2016



Socioeconomic development

Most civil space agencies are created to contribute to national socioeconomic development. Although it has recently adopted new priorities, including national security and space exploration, India's space program embodies this intent[154] and exemplifies the benefits of investing in outer space for developing countries.[155] China, too, has invested in space technologies to drive national development.

The African Space Policy and Strategy adopted by the African Union in 2016 aims to mobilize the "unique opportunities for the continent to collectively address socio-economic development issues through Space technologies"[156] and is linked to the Agenda 2063 framework for socioeconomic transformation (see Indicator 4.1). Africa currently lacks significant access to space (see Figure 2.3).

The high-level forums in advance of the 2018 UNISPACE+50 event at UN COPUOS focus on space as a driver of socioeconomic development,[157] recognizing that access to the benefits of outer space is linked to achievement of the Sustainable Development Goals.

2016 Developments

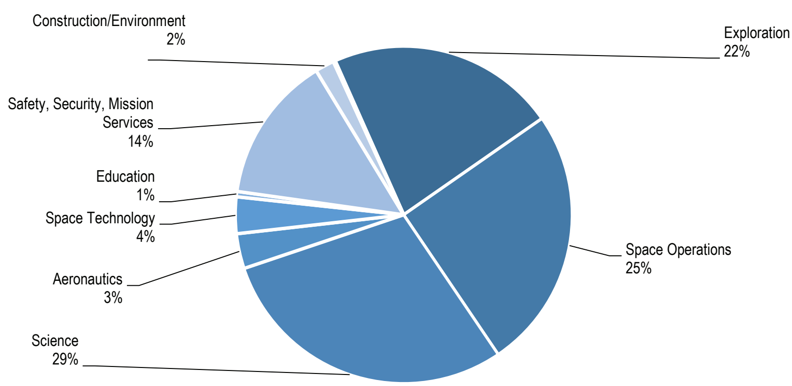
Major space programs prioritize access to space and deep space exploration

With the notable exception of Roscosmos, major civil space agencies increased their budget allocation in 2016. Priorities across space programs were generally consistent, with a common focus on human spaceflight, deep space exploration, and scientific development.

United States

With an approved budget of $19.65-billion for FY2017,[158] NASA was allocated significantly more than any other civil space agency in the world. The amount constituted an increase of approximately 1.8% over FY2016.[159] The Space Launch System for deep space exploration, Orion Multi-purpose Crew Vehicle, and Ground Exploration System received independent funding increases.[160] While a guideline authorization act by President Trump omitted funding for Earth sciences,[161] the U.S. Congress opted to keep funding stable at $1.9-billion.[162] NASA continued to prioritize the development of human spaceflight through the Space Launch System and Orion Spacecraft, the James Webb Telescope, and the Europa Clipper robotic mission to Venus.

Figure 2.5 NASA FY2017 budget distribution[163]



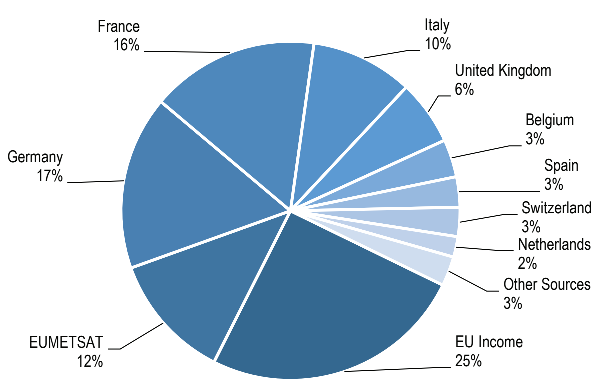
Continued prioritization of the SLS heavy lift rocket and Orion spacecraft reflects a continued commitment to deep space exploration. The SLS RS-25 engine, a modified version of the one used in the Space Shuttle program, had numerous successful test-firings between June and August 2016.[164] The 2017 NASA Authorization Bill contained a directive to investigate the use of SLS and Orion for ISS resupply missions if commercial alternatives fail (see Indicator 2.5).[165]

China
China invested heavily in its civil space program in 2016, reaching several significant milestones. The Tiangong-2 space laboratory was launched and several new heavy launch rockets made their debuts. China does not publicly release financial details of its space programs. Approximately $39.9-billion was allocated to general science and technology[166] and estimates place the total civil space allocation somewhere between $4-billion and $6-billion.[167] The 2016 White Paper on Chinese Space Activities set out priorities, including the expansion of human spaceflight, the BeiDou navigation system (see Indicator 2.1), lunar exploration plans, and the enhancement of space infrastructure.[168]

Russian Federation
For the first time, in 2016, there were fewer Russian rocket launches than launches by China and the United States.[169] Russia is the only major space actor currently reducing funding for its civil space program. The updated Federal Space Program 2016-2025 provides a 10-year budget of approximately $20.5-billion[170] or roughly $2.05-billion annually. Priorities include development of satellite networks to maintain current capabilities and space exploration. Funding for a new heavy launcher is notably absent. In an effort to combat poor productivity and allegations of corruption, the Russian Federal Space Agency was reformed as the Roscosmos State Corporation in 2016.[171] Director Igor Komarov reported that the transition was successful and effective in achieving its goals.[172] After several delays, the Roscosmos State Corporation began operations at the new Vostochny Cosmodrome with the 28 April launch of a Soyuz-2.1a carrying three satellites to orbit.[173] The Federal Space Program outlined a plan to upgrade Vostochny for heavy launchers and prioritized the streamlining of current launch systems to reduce costs.[174] Russia faced a further setback in 2016, when launches of its most powerful Proton M heavy lift rocket were postponed following a June launch in which the rocket's second stage was shedding debris (see Indicator 1.1). The rocket was grounded in January 2017.[175]

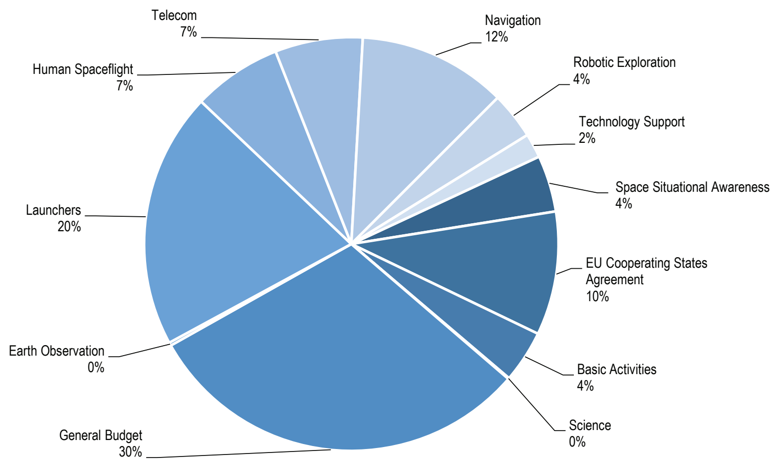
European Space Agency
ESA funding increased to €5.25-billion ($5.65-billion) for FY2016[176]—almost €1-billion ($1.1-billion) more than in FY2015.[177] The largest contributing states were Germany ($920-million), France ($890-million), Italy ($540-million), and the United Kingdom ($342-million).

Figure 2.6 Sources of income for the European Space Agency FY2016[178]



Italy increased its contribution by 55%, likely to support the development of the Italian-led Vega rocket, while Germany and France increased their contributions by 9.4% and 17.5% respectively. The EU contribution increased by 28% as several key EU projects, including the Galileo navigational network, the Copernicus Earth Observation system, the Sentinel Program, and the EU Geostationary Navigation Overlay System, entered deployment phases.[179] Earth observation remains a strong priority, with related projects receiving approximately 30% of the total budget. Another beneficiary of the larger budget was launcher development, with a 72% increase for such projects as Ariane-6 and Vega. Ariane-6 is intended to replace the existing Ariane-5, at half the cost.[180] The upper-stage Vinci restartable engine completed its initial round of testing,[181] and the final $3.2-billion in contracts for development of the launcher and its complex were approved.[182]

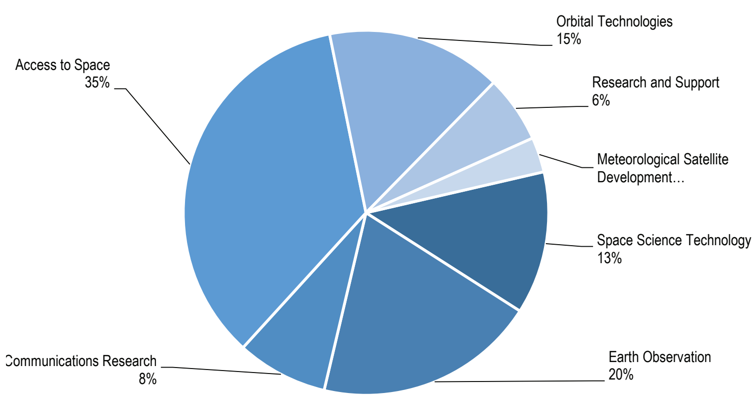
Figure 2.7 ESA budget priorities for FY2016[183]



France

CNES had a budget of $1.49-billion in FY2016.[184]

Figure 2.8 CNES budget priorities for FY2016[185]



Germany

The German space budget is administered through the nonprofit DLR, which was allocated roughly $700-million.[186]

Italy

The FY2016 budget for ASI was approximately $615-million, with Vega launcher research a continuing priority.[187]

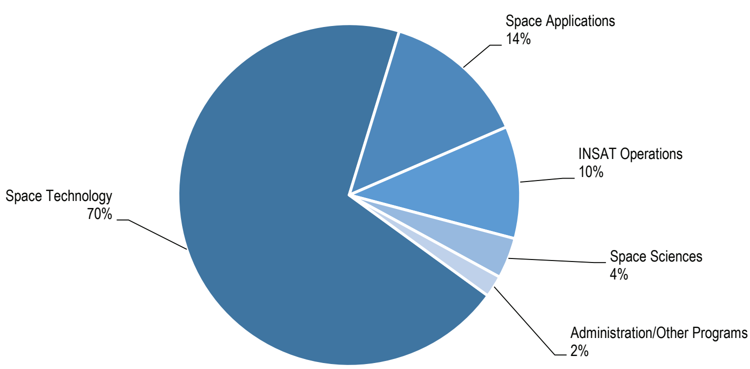
Spain

INTA, an autonomous body under the Spanish Ministry of Defense, received approximately $77.8-million in FY2016 for civilian space programs.[188]

India

ISRO's budget for FY2016-2017 was $1.12-billion.[189] This was a 1% increase over the FY2015-2016 approved allocation and a 7.9% increase over actual spending.[190] Priorities for 2016 included space technology, specifically the enhancement of indigenous launch capabilities through launchers such as the PSLV and GSLV.[191] ISRO continued to develop satellite telecommunications and navigation programs.

Figure 2.9 ISRO budget priorities for FY2016-2017[192]



ISRO successfully tested the reusable RLV-TD winged aerospace vehicle, which on 23 May flew to a peak altitude of 65 km and commenced a high-stress atmospheric reentry at Mach-5. The agency also tested experimental scramjet technology with an ATV booster at Mach-6. These two projects are designed to increase sustainability and reduce long-term launch costs.[193]

Japan

JAXA's budget for FY2016 was approximately $1.36-billion, a marginal increase from the allocation for FY2015.[194] In 2016, as in previous years, JAXA was also granted access to supplementary funds.[195] The agency's primary focus was the continuing development of the H3 rocket project to secure launch autonomy; an ISS cargo transport system and communications systems also received significant support.[196]

Republic of Korea

The budget for KARI in FY2016 was $608-million, a 0.1% increase over FY2015.[197] Priorities included autonomous launch capabilities, deep space exploration, increased international and private cooperation, and space facility construction.[198]

Canada

For FY2016-2017, the CSA was allocated $320-million[199]—a decrease of 11% from the previous year. Spending is expected to be reduced by a further 22% in FY2017-2018, after the completion of numerous key projects. The agency's priorities included EO (through the RADARSAT Constellation mission), space exploration, and space science and technology.

The United Kingdom

The United Kingdom Space Agency received $472-million for FY2016-2017, an increase of $8.8-million.[200] During the previous financial year the agency underspent by an estimated $15-million when several contracts were postponed.[201] The focus remained on ESA programs, expanding the space economy, and space exploration through projects such as the NovaSAR spacecraft. The UK announced a $4.4-million investment with ESA on a National Propulsion Test Facility that will research interplanetary travel methods.[202]

Investment in emerging space programs focuses on joint military/industrial benefits

Emerging civil space programs experienced strong growth. Support grew for domestic space industries and collaboration with the private sector. Investment was strong for EO programs, cross-industry technologies, and dual-use capabilities.

United Arab Emirates

The UAE Space Agency, established in 2014, does not release an official budget, but the government reported an annual investment of $5.44-billion in the space industry.[203] Its National Space Sector Policy 2016 (see Indicator 4.1) focused on increased public and private sector cooperation, a Mars lander planned for 2020, and EO through the KhalifaSat system.[204]

Ukraine

The budget for the State Space Agency of Ukraine in FY2016 was $125-million.[205] The State Space Strategic Plan 2022 contains a stronger focus on defense and national security, and prioritizes development of the Cyclone-4M launcher[206] and cooperation with the ESA. A 2016 IMF report predicted that political friction with Russia and associated contract cancellations would reduce revenue for national companies managed by the Space Agency by up to 80%.[207]

Brazil

The Brazilian Space Agency was allocated a 10-year budget of $2.97-billion under the National Program for Space Activities 2012-2021.[208] However, slower than expected economic growth led to wide-ranging budget cuts.[209] The Agency focused on engaging with the private sector to reduce costs. Brazil's new dual-use Geostationary Defense and Strategic Communications Satellite was built by private corporation Thales Alenia Space and launched on 4 May 2017.[210]

Argentina

The FY2017 budget for Argentina's space agency was $113-million,[211] an $8-million decrease from the previous year. Priorities included EO to enhance environmental awareness and productivity, development of satellite technology, and launch capabilities.

Mexico

The Agencia Espacial Mexicana was allocated $4.47-million for FY2016, but, as in previous years, did not receive the full amount.[212] The agency continued to prioritize the development of satellite infrastructure, coordination with the international community, and building national space capacities through education and research.[213]

See Annex 5 for additional information on national civil space budgets.

China's space program achieves significant milestones

On 15 September, the Tiangong-2 manned space laboratory was launched on a Long March 2F rocket.[214] The 8.6-tonne station orbits at 393 km and has an operational lifespan of two years.[215] The station is being used to conduct research on space habitability and to act as a precursor for China's future space station program. In 2016, it successfully housed two astronauts for the maximum duration of 30 days; its first docking and resupply mission took place in April 2017.[216] The Yuanwang-7 aquatic tracking ship was also commissioned, and played a role in tracking the station;[217] its maiden voyage took place in the Indian and Pacific oceans on 26 July 2016.

China debuted the Long March 5 (CZ-5) heavy lift rocket and the Long March 7 (CZ-7) carrier rocket in 2016. The Long March 5 was successfully launched on 3 November from Wenchang Space Launch Centre, Hainan.[218] The rocket has a payload of 25 tonnes to LEO, 14 tonnes to geostationary transfer orbit (GTO) and eight tonnes to lunar transfer orbit. The launcher consists of two core stages and four boosters, and uses combinations of liquid oxygen, kerosene, and liquid hydrogen as environmentally sustainable fuel. The Long March 7 achieved successful liftoff from Wenchang Space Launch Center on 25 June, carrying a next-generation crew capsule.[219] The medium-sized two-stage rocket is capable of lifting 13.5-tonnes to LEO, and uses environmentally sustainable fuel.[220] The CZ-7 launch also marked the inauguration of the Wenchange Space Launch Center, which will support ambitious new space programs such as its space station and deep space missions to the Moon and Mars; planning has taken decades and construction seven years.[221]

China launched the world's first x-ray pulsar navigation satellite, the XPNAV-1, aboard a Long March 11 rocket on 10 November from the Jiuquan Satellite Launch Center.[222] The satellite uses x-ray emissions from pulsars to determine a precise location in deep space. Although the technology is still in its infancy, in the future it could function as an extremely accurate deep space navigation system.[223]

The Chinese Academy of Sciences completed construction of the Tianyan telescope, a 500-m aperture spherical radio telescope. The project, initiated in 2011, cost an estimated $180-million, and with 4,450 reflective panels is the largest radio-telescope in the world.[224] After an initial debugging phase, the telescope will be tasked with pulsar observation and interstellar molecule analysis, with limited foreign access. The telescope successfully received electromagnetic waves of high quality from a distance of 1,351 light-years.

Democratic People's Republic of Korea completes second successful satellite launch

On 7 February, the DPRK's National Aerospace Development Administration launched the Kwangmyongsong-4 satellite to a polar orbit of 500-km, using its Unha space launch vehicle.[225] The government has stated that the satellite is for Earth observation. Prior to the launch, the DPRK reportedly provided forewarning, in compliance with international standards, to the International Maritime Organisation and ITU, but there are claims that it did not meet all international obligations associated with a launch.[226] The satellite appears to be non-functional.[227]

The DPRK space program illustrates the close relationship between civilian and military technologies. The launch followed the DPRK's fourth nuclear test in January 2016 and ongoing missile tests. The international community has previously expressed fear that such launches are used as cover for the testing of ballistic missile technology.[228] Indeed, the launch violated international sanctions imposed against the DPRK's use of ballistic missile technology that go back to 2006. In Resolution 2270, the UN Security Council unanimously condemned the launch and introduced additional prohibitions and sanctions,[229] intended to prevent future space launches and interrupt the transfer of financial and technical resources to and from the DPRK, stating that any launch of ballistic missile technology, "even if characterized as a satellite launch or space launch vehicle," contributes to the DPRK's development of systems to deliver nuclear weapons.[230] Former U.S. Ambassador to the UN Samantha Power noted that the resolution went further than any others in the last 20 years in freezing assets and sanctions.[231]

Many longstanding sanctions against Iran were lifted in 2016, after implementation of the 2015 Joint Comprehensive Plan of Action.[232] The expectation that Iran would then emerge as a significant regional player in space has not yet been realized.[233] While there were indications of preparations in early 2017 to launch Iran's fifth satellite, using its new Simorgh liquid fuel space launch vehicle to inaugurate the Imam Khomeini Launch Pad,[234] no satellite has yet been placed in orbit.[235] The launcher, said to be capable of delivering larger satellites into higher orbits (still under 100 kg in LEO), is part of an ongoing effort to develop independent satellite construction, control, communications, and launch capabilities.[236] Some concern has been expressed that the development of a space launch vehicle represents a proliferation risk, given the close association between space launch and ballistic missile delivery; Iran is banned from nuclear-capable missile activities under the Plan of Action.[237]

Global participation expands, with focus on industrial and socioeconomic benefits

The new space agencies that began in 2016 were eager to encourage and facilitate local space industries. In several cases, laws were introduced or amended to reduce barriers to the private access and use of space. The strategic use of satellite and space technology to address such domestic concerns as agriculture and disaster management was another priority.

The Philippine Space Act 2016, which established a national space agency,[238] was passed after the Philippine's first microsatellite, Diwata-1, was successfully launched by JAXA on 23 March and deployed from the ISS on 27 April.[239] The new agency will focus on EO to alleviate poverty through better farming practices, as well as weather imaging and telecommunications.

New Zealand announced that it would establish a national space agency in 2017 to expand its space industry.[240] A proposed regulatory framework for access to and use of space is intended to reduce barriers for private actors.[241] New commercial launch company RocketLab is expected to open a small, low-cost launch service at New Zealand's first private spaceport.[242]

Egypt's government approved draft legislation to establish a space agency with a focus on Earth observation.[243] Belgium announced plans to introduce an interfederal space agency by mid-2017.[244] Australia's review of the Space Activities Act 1998 led to several proposed reforms and new legislation to facilitate private access to space.[245]

Indicator 2.3: International cooperation in space activities

Due to the huge costs and technical challenges associated with access to and use of space, international cooperation has been a defining feature of civil space programs (see Indicator 2.2). Scientific satellites in particular have been cooperative ventures. Cooperation enhances the transparency of certain civil programs that could potentially have military functions.[246]

The earliest large international cooperation program was the Apollo-Soyuz Test Project, which saw two Cold War rivals work collaboratively to achieve a joint docking in space of U.S./USSR human modules in July 1975. The 1980s saw a plethora of international collaborative projects, involving the USSR and partners that included the United States, Afghanistan, Austria, Bulgaria, Canada, France, Germany, Japan, Slovenia, Syria, and the United Kingdom, which enabled astronauts to conduct experiments onboard the Mir space station.[247] Many barriers to global partnership have lifted since the end of the Cold War.

However, political developments in Ukraine in 2014 created tension between Russia and the United States, European states, and NATO allies. NASA announced that, with the exception of activities involving the ISS, NASA employees were barred from traveling to Russia, hosting Russian visitors, and emailing or holding teleconferences with Russian counterparts.[248] The U.S. Congress made efforts to prohibit the purchase of Russian RD-180 engines, used for U.S. defense launches, and Russia announced that it would prohibit such sales.[249] However, U.S. use of the engines has continued. In the wake of increased tensions with the United States, Russia strengthened cooperative efforts with India and China.[250]

The ISS is the most prominent example of international civil space cooperation: a multinational effort with a focus on scientific research at an estimated cost of more than $150-billion to date. The project partners are NASA, Roscosmos, ESA, JAXA, and the CSA. Brazil participated through a separate agreement with NASA from 1998 to 2007.[251] The ISS has hosted astronauts from 15 countries.[252] On 8 January 2014, the Obama Administration announced an extension of support for the ISS until at least 2024.[253] International cooperation on the ISS is being extended to developing countries, as in the 2015 KiboCUBE initiative by UNOOSA and JAXA.[254]

There is no significant cooperation between the United States and China. The Chinese ASAT test that destroyed a weather satellite in 2007 ended all discussion.[255] In April 2011, the U.S. Congress passed legislation prohibiting any scientific activity between the United States and China that involves NASA or is coordinated by the White House Office of Science and Technology Policy.[256] However, in 2015, the United States and China initiated efforts to improve cooperation and transparency in outer space at an inaugural Civil Space Dialogue held in Beijing as part of the seventh annual United States-China Strategic and Economic Dialogue.[257]

China maintains extensive bilateral cooperation in space with others, including Russia and the ESA, and has welcomed international participation in its space station program.[258] China has more than 100 cooperation agreements with 30 state-level space institutions and international organizations.[259]

Regional cooperation is most developed in Europe, where cooperation among states in research and technology and relevant space applications is promoted and provided for by ESA.[260] Space activities in Asia have been described as "highly nationalistic, sometimes secretive, and mostly competitive."[261] However, two Asian-based organizations foster space cooperation. The Asia Pacific Regional Space Agency Forum (APRSAF) was established by

Japan in 1993 as an open cooperative framework that takes in space agencies, governmental bodies, international organizations, private companies, universities, and research institutes from more than 40 countries and regions.[262] The intergovernmental Asia Pacific Space Cooperation Organization (APSCO) was established by China in 2005;[263] members include Bangladesh, China, Iran, Mongolia, Pakistan, Peru, Thailand, and Turkey. APSCO currently has 10 aerospace projects on its agenda. In 2016, APSCO agreed to include Iran's satellite in its Small Multi-Mission Satellite Constellation program.[264]

In 2015, some members of the Commonwealth of Independent States (Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Russia, and Ukraine) signed a new protocol on cooperation in space, including a new Joint Institute for Space Research.[265] The BRICS bloc is also emerging as a vehicle for space cooperation, primarily to decrease dependency on the West,[266] but faces practical obstacles such as vastly different space capabilities and competition between China and Russia.[267]

Latin America has no regional mechanism for cooperation in space,[268] but some Latin American states have significant bilateral cooperation, particularly with the United States, China, and Russia.

By allowing states to pool resources and expertise, international civil space cooperation has played a key role in disseminating technical capabilities to access space. Cooperation agreements on space activities have proven to be especially helpful for emerging spacefaring states that currently lack the technological means to access space independently. In the Middle East, such cooperation has been critical to the emergence of space programs in Iran and the UAE.

There is also significant cooperation around global utilities (see Indicator 2.1). The International Committee on Global Navigation Satellite Systems promotes voluntary cooperation on matters of mutual interest related to civil satellite-based PNT and value-added services.[269] The ICG encourages coordination among providers of GNSS, regional systems, and augmentations to ensure greater compatibility, interoperability, and transparency; and promotes the introduction and utilization of these services and their future enhancements, including in developing countries. The U.S. 2010 National Space Strategy encourages international cooperation around GPS and GNSS.[270]

There is also growing cooperation in responding to the threat of NEOs (Indicator 1.3), space weather (Indicator 1.3), and space situational awareness (Indicator 1.4), as well as between military space programs (Indicator 2.6).

2016 Developments

Cooperation holds as partners consider the future of the ISS

Key ESA partners France and Germany considered ending Europe's role in the ISS in 2020, due to high costs and disagreements over member contributions.[271] However, an August 2016 report by ESA emphasized that "the on-going international cooperation between agencies on the ISS has formed foundations to solid interagency relationships and ESA's participation to the programme has proven Europe's value as a viable partner." [272] A commitment until 2024 was reached in Lucerne, Switzerland in December. [273]

U.S.-Russian cooperation on the ISS continued in 2016,[274] as the United States continued to rely on Russian Soyuz vehicles for access. Future crew exchanges have been proposed (see Indicator 2.5).[275]

NASA's role in the ISS after 2024 is not yet clear; however, efforts are ongoing to identify a path toward commercial use and operation for research, tourism, and other applications, as part of its goal to economically develop LEO (see Indicators 2.4 and 2.5).[276] Russia appears to be moving forward on a 2014 proposal for a national Russian orbital station, using the newest Russian modules, which would be removed from the ISS.[277] RKK Energia received the formal technical assignment from Roscosmos for a scaled-down version of the station in August 2016, but ongoing budget cuts (see Indicator 2.2) could have a major impact.

Lunar exploration emerges as focus for extended international cooperation

NASA continued to develop its vision for a manned space station orbiting near the Moon that could support longer-term efforts for deep-space exploration.[278] Orbital ATK revealed preliminary plans to establish a manned, cislunar habitat with NASA under the Next Space Technologies for Exploration Partnerships program,[279] using the Space Launch System and Orion deep-space transportation system (see Indicator 2.2). Other partners include Roscosmos, ESA, JAXA, and CSA.[280]

ESA is working with international partners to return humans to the Moon by the end of the next decade and establish a Moon Village with a sustainable human presence.[281] The space community sees the Moon as a springboard to human exploration of the solar system, with Mars the next goal. While this program includes specific missions, such as ESA cooperation on the Roscosmos-led Luna-27 robotic lander to the Moon,[282] it also incorporates "a larger vision of broad international, academic, and private sector lunar cooperation under the title Space 4.0."[283] ESA approved funding for the ESA-Roscosmos ExoMars mission (see Indicator 2.2), despite the crash of demonstrator lander Schiaparelli in October.[284] ExoMars could serve as a model for further lunar cooperative ventures.

China has been invited to participate in the Moon Village.[285] In 2016, ESA Director General Johann-Dietrich Woerner met with top space officials in China. "Let's open space. Space is beyond all borders so let's also have the cooperation beyond borders," Woerner said during his visit. "When you ask astronauts, and I'm sure also the Chinese astronauts will tell you the same: they cannot see any border from space. So this is a very nice vision. We should use this and cooperate worldwide on different schemes, and I think Moon Village has its value for that," he added.[286] Woerner's Moon Village plan involves selecting a location on the lunar surface where different countries could place habitats and other elements for human exploration. ESA and China are currently working together on a space-weather observatory. ESA personnel have visited Chinese human spaceflight training facilities. Several European astronauts have been learning Chinese in a joint cooperation program.

Geopolitical ties shape space cooperation

China's 2016 *White Paper on Space Activities* notes that extending cooperation is a central pillar of China's leadership strategy in outer space. Included are efforts to work with organizations such as the UN to extend global participation in outer space (see below), and more geo-strategic initiatives such as the Belt and Road Initiative and BRICS cooperation.[287] The Silk Road Economic Belt and the 21st-Century Maritime Silk Road (Belt and Road Initiative) was introduced in 2013 by Chinese President Xi Jinping during a trip to Central and Southeast Asia to rebuild the close economic integration of the ancient Silk Road.[288] It is described as an "ambitious development campaign" aimed at "building massive amounts of infrastructure connecting [China] to countries around the globe"[289] and includes a Space Information Corridor. Although focused on Asia, the initiative extends participation to Africa and parts of Europe. It involves roughly $150-billion of spending per year in the 68 countries that have thus far signed up.[290] Members of the Belt and Road Initiative will have first access to the BeiDou-2 satellite navigation system projected to be operational by 2020 (see Indicator 2.1).[291] Access will be extended to Earth observation, communications, and other satellite services. The creation of the China-Pakistan Economic Corridor is central to the Belt and Road Initiative and includes plans to launch a land-surveying satellite.[292]

China also emphasized cooperation in space activities with the Shanghai Cooperation Organization (China, Kazakhstan, Kyrgyzstan, Russia, Tajikistan, and Uzbekistan), which aims to foster broad cooperation, including on economic and security issues,[293] and with the BRICS economic association. During his visit to India, Wu Yanhua, CNSA Deputy Administrator, announced that Chinese and Indian space scientists would begin cooperating on a joint system of satellites in the context of BRICS.[294] The members of BRICS aim to become more independent of U.S. technology and to implement more complex engineering projects of their own. In 2016, a proposal by India to provide a meteorological satellite for the South Asian Association for Regional Cooperation was rejected by Pakistan (see Indicator 2.6), and replaced with a new proposal by India and China for a BRICS remote sensing satellite constellation for disaster risk reduction.[295] At a November meeting in Zhuhai, China, BRICS space agencies discussed a draft document on joint use of data constellations from Earth remote sensing satellites, and signed a cooperation protocol on the use and exploration of outer space for peaceful purposes.[296] The countries also agreed to deepen cooperation in navigation and space research.

On the sidelines of the BRICS 2016 summit, Russia and India reaffirmed their commitment to cooperation in outer space to advance socially useful applications and scientific knowledge, signing an MoU in October[297] that allows each to set up and use ground stations in the other's territory to enhance the usefulness of their respective navigation satellite constellations. The space agencies of India and Russia intend to engage more actively in space technology applications, launch vehicles, satellite navigation, space science, and planetary exploration.[298]

China and Russia are cooperating on "several dozens of projects," according to China's Deputy Industry and Information Technology Minister, including satellite and launch technology.[299] Roscosmos CEO Igor Komarov took part in China's National Space Day on 24 April 2016 to commemorate the forty-sixth anniversary of the launch of the first Chinese satellite.

In January 2016, India announced a new satellite tracking and imaging center in southern Vietnam, which will also serve as a data reception point for India's EO satellites, providing Vietnam with direct access to imagery of the region, including China and the South China Sea.[300] ISRO will run the $24-million facility.[301] This move deepens ties between India and Vietnam, both of which have territorial disputes with China; Earth-imaging technology is routinely used in security and defense (see Indicator 2.6). In September, the two countries signed the Inter-Governmental Framework Agreement for Exploration of Outer Space for Peaceful Purposes.[302] In November 2016, ISRO signed a Memorandum of Understanding with JAXA to identify and carry out mutually beneficial and strategic cooperative projects on space applications, space exploration, space science, research and development, and the promotion of the space industry.[303]

Cooperation accelerates capabilities for emerging space programs

Since international sanctions were lifted in January 2016, Iran has been attempting to revitalize its nascent space program, including satellite manufacturing and launch capabilities. Announcing ambitious plans for suborbital and then orbital human spaceflight,[304] Iran turned to Russia and Kazakhstan for critical support in enhancing its launch capabilities.[305] Russian experts reportedly helped to lay the foundation of the Iranian space program.[306] Iran and Roscosmos agreed on the general design, development, and launching of an Iranian remote-sensing satellite and were negotiating the finances of the deal. An Iranian astronaut might participate in a Russian space mission.[307] In April 2016, a protocol on cooperation was signed following the fifth Russian-Iranian working group on space cooperation.[308] The agreement provides Iranian access to Russian satellite imagery from its Resurs-DK and Rsurs-P satellites and develops plans for a ground station in Iran to directly receive imagery.

Iran signed a Memorandum of Understanding with Kazakhstan on 12 April that allows each country access to the other's space launch and satellite facilities. Kazakhstan is home to Baikonur Cosmodrome, which is leased to Russia, but also used by the Kazakh space agency. The Iranian space agency maintains launch facilities at Emamsharh and near the city of Qom in the interior; another site was under development near the city of Semnan. Both countries are keen to accelerate their respective space programs to meet prestige, national security, and strategic autonomy objectives.[309]

In 2016, the UAE signed new cooperation agreements with states with dominant space programs, including the United States, India, Japan, and the UK.[310]

Cooperative initiatives broaden space access for developing countries

Japan extended partnerships with developing and emerging states, providing training, technical support, and assistance packages, as part of an effort to expand opportunities for its space industry. About a dozen working groups targeting specific countries, including newly added Myanmar, were active in 2016.[311] JAXA has a number of cooperative agreements that allow access to its module and equipment (Kibo) on the ISS for conducting scientific experiments with CubeSats. In 2016, projects were launched by Turkey and the Philippines.[312]

The UN/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (KiboCUBE) helps educational and research institutions from developing countries launch CubeSats from Kibo. In August 2016, UNOOSA selected a CubeSat proposed by the University of Nairobi in Kenya as the first KiboCUBE satellite, and opened a second call for missions in September.[313] The UN announced that it had secured a dedicated mission on a Sierra Nevada Corporation Dream Chaser spacecraft to fly in 2021. The mission is currently planned as a two-week free-flyer mission in LEO. The goal is to give developing states an opportunity to fly experiments in space. Proposals for payloads will be solicited in 2017, with the final selection made by UNOOSA in 2018.

On 31 March 2016, the China National Space Administration signed a Framework Agreement and a Funding Agreement with UNOOSA to open China's future space station to science experiments and astronauts from UN member states.[314] China will also train astronauts for other countries.[315] CNSA claims that such cooperation will promote better accessibility to space for developing countries.

Nascent United States-China space cooperation proceeds cautiously

The United States and China held their first dialogue on Outer Space Security in May 2016 (see Indicator 4.3). The two countries reconfirmed the 2015 goal of advancing civil space cooperation at the June U.S.-China Economic and Strategic Dialogue. Head of NASA's Earth science division Michael Freilich met with counterparts at the Chinese Academy of Sciences on 12 July to discuss a scientific data exchange and China's plans for the launch of its new carbon monitoring mission TanSat. A representative confirmed that the meeting "was conducted in full accordance with all applicable USA laws."[316] The second Civil Space Dialogue, held on 20 October in Washington, DC,[317] was led by the U.S. Department of State and included participants from CNSA, NASA, NOAA, the U.S. Geological Survey, the FAA, and the U.S. DoD. The meeting included the exchange of information on space policies and programs, and discussions on possible collaboration related to science, space and terrestrial weather, space debris, safety, and sustainability.

Indicator 2.4: Growth in the commercial space industry

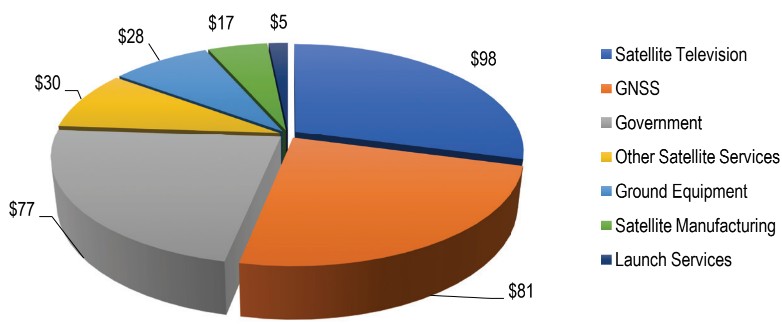
This section covers primarily activities that can be described as fully commercial—activities in which only private entities are involved in financing, decision-making, and management. Indicator 2.5 focuses on joint government-private ventures.

The commercial space sector is an important determinant of space security because of its role in the provision of launch, telecommunications, Earth imagery, and manufacturing services, as well as its relationship with civil and military programs. A healthy space industry can lead to decreasing costs for space access and use, and may increase the accessibility of space technology for a wider range of space actors. Increased commercial competition in the research and development of new applications can also lead to the further diversification of capabilities to access and use space.

Today's commercial space sector is dominated by telecommunications, which emerged from government-operated bodies that were deregulated and privatized in the 1990s. Inmarsat and Intelsat were privatized in 1999 and 2001, respectively.

According to the Space Foundation, commercial space products and services, infrastructure and support industries comprised 76% of the global space economy in 2015.[318] Revenues from the global satellite industry nearly tripled between 2004 and 2013 and reached $261-billion in 2016, dominated by satellite services.[319] While the annual average growth rate over that period was 11%, growth of the global satellite industry has slowed since 2010. However, services provided directly to consumers—in particular satellite TV and new services for Internet—are driving renew growth in the industry. The FAA reports that the global space industry as a whole took in approximately $335-billion in 2016.

Figure 2.10 Global space economy revenues, 2016, $-billion[320]



The commercial space industry is becoming more global. Although Europe, Russia, and the United States are still dominant players, India and China have become increasingly involved, with developing countries their prime focus.[321] Since the commercial arm of ISRO—Antrix Corporation Limited—was established in 1992, India has been positioning itself to compete for a portion of the commercial launch service market by offering lower-cost launches.[322] India is also moving into commercial satellite manufacturing as part of its "Made in India" campaign. In 2015, Dhruva Space signed an agreement to work with German startup Berlin Space to build a satellite manufacturing company in India.[323] The China Great Wall Industry Corporation is the only commercial organization authorized by the Chinese government to provide satellites and commercial launch services and to carry out international space cooperation. For the first time in 2007, China both manufactured and launched a satellite for another country: Nigeria's Nigcomsat-1.[324]

Private investment in commercial space ventures

Growing private investment is changing the commercial space industry, particularly in the United States. According to 2015 reports, the number of companies in the global space industry had increased sixfold since 2010, to more than 800.[325] Private investment in startup space ventures, which reached $13.3-billion between 2000 and 2015, is supporting substantial growth.[326] Significant investment comes from companies such as Alphabet, Microsoft, Amazon, PayPal, and Virgin Records.

Silicon Valley is the epicenter of private investment in space technologies, with big and small enterprises aiming to disrupt space technology and revolutionize telecommunications, Earth observation, satellite manufacturing, and space travel.[327] Spire (formerly Nanosatisfi, Inc.) launched its first satellite in 2013, after raising funds through crowdfunding. In 2014, Spire raised $25-million for the 2015 launch of 20 CubeSats that track shipping and weather.[328]

Commercial space travel is benefitting from investment by 70 individuals with at least $30-million in net assets. "Investment in commercial space flight has become one of the big trends among the super-rich," said Liam Bailey, head of global research at Knight Frank.[329] Approximately 10 private companies engage in space transport, including SpaceX, created by billionaire PayPal co-founder Elon Musk, and Blue Origin, founded by Amazon's chief executive Jeff Bezos. Space tourism, driven by companies such as Sir Richard Branson's Virgin Galactic and Jeff Greason's XCOR Aerospace, will offer suborbital spaceflights.

The development of reusable launch vehicles is a particular focus for private space investment. SpaceX is leading this development, with a planned reusable first-stage motor on its Falcon 9 rocket, which it successfully landed for the first time in 2015. Blue Origin is working on reusable launch vehicles for both orbital and suborbital flights; Virgin Galactic and XCOR Aerospace are developing reusable space planes SpaceShipTwo and Lynx, respectively, which will take paying passengers to suborbital space and back.[330]

The ability to reuse the first, booster stage of the launch vehicle could reduce the cost of space launches. At this early stage, a fully reusable Falcon 9 Rocket has been projected to decrease launch costs by approximately 30%.[331] A relative lack of commercial competition and capacity keeps costs high and makes the industry vulnerable to disruption from such failures as the June 2015 launch of SpaceX's Falcon 9.[332] Established launch companies continue to dominate the market. However, ULA has announced that it will phase out its Delta 4 and Atlas 5 launchers after it transitions to a new, reusable, commercially competitive launch vehicle, Vulcan, in an effort to reduce launch costs.[333]

Other nations are eager to replicate U.S. success. The Russian Skolkovo innovation hub near Moscow is trying to foster a viable startup industry, with 141 space-focused "early-stage companies" based there.[334] ISRO is building a new satellite manufacturing facility in Ahmedabad that will also host a "vendor complex" that will give as many as 20 "entry-level entrepreneurs who want to work with ISRO" space for their machinery and staff.[335]

Small satellites and satellite constellations

Innovative uses of small satellites and renewed proposals for large constellations of satellites drive the development of new space-based services. In 2014, 101 commercial CubeSats were launched for EO services and communications; 93 were built and operated by Planet.[336] Other companies that use small satellites (less than 200 kg) include Dauria/Elcnor, DigitalGlobe, and Spire. Companies including OneWeb and SpaceX are planning large constellations of small satellites to provide new broadband internet services, and are attracting significant investment. In 2015, Google invested $1-billion in SpaceX.[337]

Industry in space

Private companies are developing business plans for new on-orbit commercial activities such as tourism. Bigelow Aerospace is developing an Expandable Activity Module, which will be attached to the ISS to support zero-gravity research, including scientific missions and manufacturing processes, and has potential as a destination for space tourism.[338] Capabilities for space-based manufacturing and spacecraft servicing are also slowly emerging (see also Indicator 3.2). Interest is growing in space exploration and resource extraction. Mars exploration is a long-term goal for SpaceX founder Elon Musk. Companies such as Deep Space Industries and Planetary Resources are developing long-term business models aimed at the eventual extraction of resources from asteroids; potential returns could be in excess of $100-trillion.[339] Planetary Resources successfully launched its Arkyd 3 Reflight from the ISS in 2015 to "test the avionics, control systems and software needed to make asteroid mining possible,"[340] but transmission from the spacecraft failed. Financial and technical hurdles mean that mining asteroids remains "a long term endeavor."[341] National governments support and incentivize much of this new activity (see Indicator 2.5).

2016 Developments

Proposals for large satellite constellations see internet as space-based telecommunications service

Plans to create large constellations of communications satellites in non-geostationary orbits that provide global broadband internet and other services reached a tipping point in 2016. After OneWeb filed with the FCC to launch and operate a satellite constellation of 700+ satellites in LEO, 11 additional proposals were filed.[342] These large constellations have significant implications for space debris and traffic management (see Indicator 1.1) and rules for accessing and regulating radio frequency and orbital positions (see Indicator 1.2). They also mark a new direction for satellite services, manufacturing, and launch.[343] A recent report by Northern Sky Research estimates that manufacturing and launch revenues alone are expected to be $175-billion[344] in a vastly expanding sector.

Figure 2.11 Satellite constellation filings with the FCC in 2016[345]

Company	Location	No. of satellites	Bands	Services
SpaceX	Hawthorne, CA	4,425	Ka, Ku	Global broadband
Boeing	Seattle, WA	2,956	C, V	Advanced communications, Internet-based services
WorldVu (OneWeb)	Arlington, VA	720	Ku	Global broadband
Kepler Communications	Toronto, ON	140	Ku	Machine-to-machine communication (internet of things)
Telesat Canada	Ottawa, ON	117	Ka	Wide band and narrow band communication services
Theia Holdings A, Inc.	Philadelphia, PA	112	Ka	Integrated Earth observation and communications network
Spire Global	San Francisco, CA	100	Ka	Maritime monitoring, meteorological monitoring, and Earth imaging services
LeoSat MA	Pompano Beach, FL	80	Ka	Broadband services
Boeing	Seattle, WA	60	Ka	Very-high-speed connectivity for end-user Earth stations
O3b	Washington, DC	60	Ka	Broadband services
ViaSat	Carlsbad, CA	24	Ka, V	Broadband services
Karousel LLC	Alexandria, VA	12	Ka	Communications
Audacy Communications	Walnut, CA	3	K, V	Data relay constellation providing satellite operators with seamless access to NGSO satellites
Space Norway AS	Oslo, Norway	2	Ka, Ku	Arctic broadband

China, through the government-owned China Aerospace Science & Industry Corp. (CASIC), announced plans to expand into the commercial satellite market via its Hongyun Project, with the support of local internet providers Baidu Inc., Alibaba Group Holding Inc., and government-owned China Telecom. The project aims to provide global internet coverage to remote areas and onboard aircraft and maritime vessels through the creation of a constellation of 156 communications satellites in LEO. Four satellites are to be launched before 2019, with the remainder following over the next 12 months.[346] Facebook had planned on launching its first Internet.org satellite, intended to deliver free internet service to parts of sub-Saharan Africa, but lost it in the September 2016 SpaceX explosion (see below).

Filing is just the first of many hurdles, including regulatory approval, coordination with other operators, securing financial support, building and launching the system, and having a ground station capable of operating such a complex system. In 2015, Elon Musk of SpaceX estimated that his initial system could cost $10-billion and take five years to build.[347] He described the venture as “rebuilding the Internet in space.”[348]

As the first to file, OneWeb has a regulatory deadline of 2019 to begin service. In 2016, OneWeb contracted with Airbus Defense and Space to manufacture the satellites and procured launches with Arianespace and Virgin Galactic.[349] Together with Airbus, its dedicated manufacturing plant in Florida is expected to build up to three, 150-kg spacecraft per day using mass production robotic technology within the next two years. By March 2017, OneWeb had raised $1.7-billion, with $1.2-billion coming from Japan's SoftBank.[350] Qualcomm and Virgin Galactic are other significant investors.

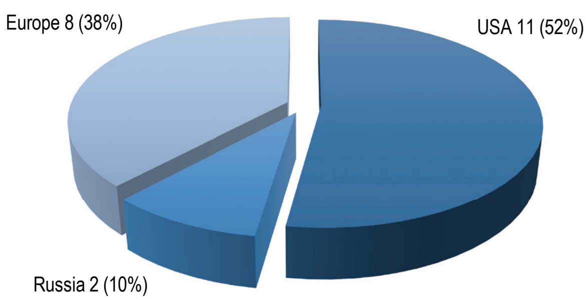
SpaceX's plan for a 4,425-satellite constellation in LEO—with an additional 7,000 satellites to follow—is being financially supported by companies such as Fidelity and Alphabet (Google).[351] Launch will be provided by its own Falcon-9. Boeing is currently in talks with Apple.[352]

Expanding space-based broadband is also projected to expand global internet access. OneWeb aims to provide internet service to the more than 50% of the globe that does not currently have access to "reliable high-speed connectivity."[353] Boeing has promoted its constellation in a similar way.[354] There is also an intention to use this capability to provide new services, such as in-flight internet access and space-based access. SpaceX aspires to provide internet services that reach as far as Mars.[355]

Increased revenues made available for commercial space launch providers

The commercial space launch industry is critical to the success of other space sectors because it enables physical access to the space environment. In 2016, launch services accounted for $5.4-billion of the global space economy,[356] with the commercial sector conducting 21 of 85 attempted orbital launches.[357] Since 2014, U.S. launch companies have increased their share of commercial launches, primarily by offering lower-cost options. Of the estimated $2.5-billion generated for commercial launches, roughly $1.2-billion went to U.S. companies, up from $617-million in 2015.[358]

Figure 2.12 Commercial orbital launches in 2016[359]



SpaceX's Falcon 9 and Falcon Heavy vehicles had the largest market share; Europe's Arianespace was a close second with their Ariane 5, ECA, Soyuz 2, and Vega rockets.[360] Japan's Mitsubishi Heavy Industries Ltd. captured a small market share with H-IIA/B, as did India's Antrix with its PSLV heavy lift vehicles. ULA announced plans to service the commercial space sector in 2017.[361] The Russian-made Angara rocket won its first commercial contract to launch the Republic of Korea's Kompsat 6 EO satellite into orbit.[362]

Figure 2.13 Commercially available launch vehicles, 2016[363]

Vehicle	Company	Country	Estimated $M per launch
Angara	VKS / Roscosmos / ILS	Russia	100
Antares	Orbital ATK	United States	80-85
Ariane V	Arianespace	France	175
Atlas V	ULA, LMCLS	United States	110-230
Delta IV	ULA	United States	164-400
Dneper	ISC Kosmotras	Russia	29
Falcon 9	SpaceX	United States	61.20
GSLV	ISRO/Antrix	India	47
H-IIA/B	MHI Launch Services	Japan	90-112.5
Kuaizhou 1	Expace / PLA	China	3
Long March 2D	PLA/CSWIC	China	30
Long March 3A	PLA/CSWIC	China	70
Long March 3B	PLA/CSWIC	China	70
Minotaur-C	Orbital ATK	United States	40-50
Pegasus XL	Orbital ATK	United States	40
Proton M	VKS / Roscosmos / ILS	Russia	65
PSLV	ISRO / Antrix	India	21-31
Rockot	VKS / Eurockot	Russia	41.80
Soyuz 2	Starsem / Arianespace	Russia / France	80
Vega	Arianespace	France	37

The orbital launch vehicles currently under development will add capacity to the industry and reduce cost. However, challenges remain, including technical problems with payloads and launch vehicles, weather, regulatory roadblocks, and geopolitical tensions.[364]

Figure 2.14 Proposed commercial orbital launch vehicles[365]

Vehicle	Company/provider	Country	Estimated launch year	Projected orbit	Estimated $M per launch
Orbital Launch Vehicle	Blue Origin	United States	2020	LEO / SSO	Unavailable
Cab-3A	CubeCab	United States	2017	LEO	0.25
Electron	Rocket Lab	United States/ New Zealand	2017	LEO / SSO	4.90
Falcon Heavy	SpaceX	United States	2017	LEO / SSO / GTO	270
LauncherOne	Virgin Galactic	United States	2017	LEO / SSO	10
StratoLaunch	Stratolaunch Systems	United States	2018	LEO / SSO	Unavailable
Vector RH	Vector Space Systems	United States	2017	LEO / SSO	3
Vulcan	ULA	United States	2019	LEO / SSO / GEO	85-260

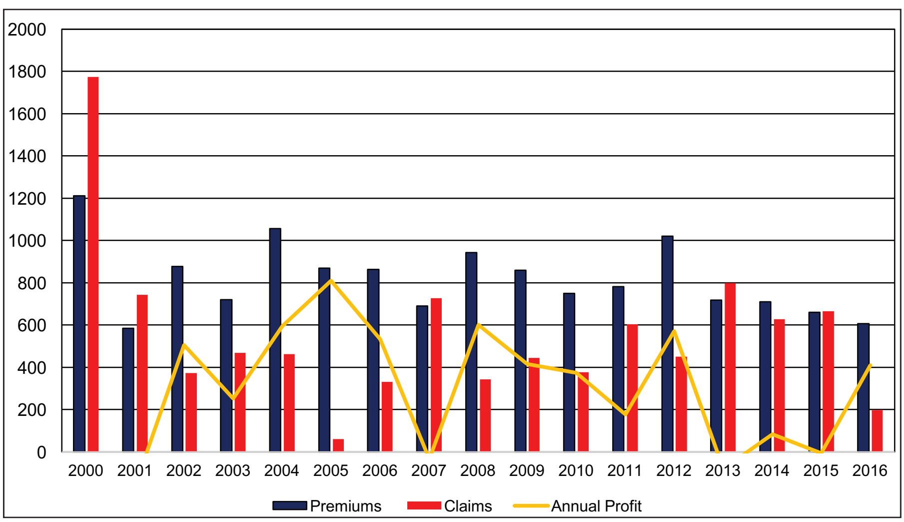
Launch failures demonstrate vulnerability of commercial sector to disruption

On 1 September, SpaceX's Falcon 9 rocket exploded on the launch pad. Its $195-million payload, Spacecom's AMOS-6 communications satellite,[366] was destroyed. SpaceX remained grounded until March 2017. The likely cause of the explosion was an "accumulation of oxygen between the composite overwrapped pressure vessel (COPV) liner and overwrap in a void or buckle in the liner, leading to ignition and the subsequent failure of the COPV."[367] SpaceX has since reviewed its technologies and made improvements in hardware and tanking procedures.[368]

The loss of the AMOS-6 and the subsequent grounding of SpaceX launchers had far-reaching effects. Spacecom lost share price and a sale to BXTG.[369] The scheduled launch of 20 Iridium-NEXT satellites was affected, as were additional launches scheduled for 2017; nine other payloads from around the world had been scheduled for launch on the Falcon in 2016.[370] NASA had scheduled a November resupply mission to the ISS using SpaceX's Dragon. NASA payloads were also stalled by launch setbacks by Orbital ATK's Cygnus and JAXA's H-II Transfer Vehicle.[371]

The SpaceX explosion cast a spotlight on risk management in the commercial space industry. Various forms and levels of specific space insurance are commercially available to protect against financial losses that may be incurred before, during, and after launch.[372] On average, one in 20 launches will fail; thus, commercial launch insurance has become a particular consideration to guard against disastrous financial losses. However, only between 20 and 50 launches a year are insured, because premium charges are in the range of $750-million, and could be higher for those that have previously processed a claim.[373]

Figure 2.15 Space insurance premiums v claims[374]



A separate prelaunch policy will usually cover loss or damage to the satellite from the time it leaves the manufacturer until the point at which the launch vehicle is ignited.[375] The AMOS-6 satellite was covered by a Lloyd's of London All Risks Pre-Launch Policy;[376] such coverage is a form of marine cargo insurance.

The SpaceX explosion also destroyed the launch pad, but generally only satellites are insured due to their net worth and contractual obligations to data providers. Historically, rockets are used once, and even though reusable technology is improving the lifecycle of launch vehicles, they are rarely insured. Insurance policies are offered by companies including AIG, Munich Re, Swiss Re, and Allianz.[377] After the explosion, CEO Musk stated that SpaceX did not insure launches, only the potential ground damage.[378] In 2017, the FAA required SpaceX to be insured against potential damage to nearby government property prior to ignition before it approved a license to launch an EchoStar Corp broadcast satellite from the Kennedy Space Centre. At $63-million, the policy was five times more expensive than a launch policy.[379]

Insurance companies are broadening their policies to include new technology, such as imaging and EO satellites.[380] More than 40 companies now underwrite space-specific policies. With more competition, premiums are going down.

Innovations in manufacturing, services, and launch capabilities linked to small satellites

In 2016, the value of the small satellite market was estimated at $2.22-billion, with a projected worth of $5.32- billion by 2021.[381] To better service this market, the launch industry has been developing dedicated launch vehicles for payloads of less than 500 kg. Still, some small satellite operators, such as Spire, were forced to operate at reduced capacity because of launch delays. While the cost per kilogram to use dedicated small-satellite launchers remains relatively high compared to traditional 'piggyback' launches, there are cost savings to be had from timely launches and better orbital placement.[382]

Dedicated small launch vehicles under development include the Electron Program by Rocket Lab, a U.S. company that will launch from New Zealand (see Indicator 2.5). The Electron is a dedicated lightweight launch vehicle that will transport payloads of up to 150 kg to Sun-synchronous orbit (SSO) for $4.9-million per launch.[383] In December, Rocket Lab announced that it should be ready for test flights in 2017.[384] In March 2017, Virgin Galactic Ventures announced that new company Virgin Orbit will "lead the world in responsive, affordable, dedicated launch for small satellites."[385] The LauncherOne small satellite vehicle was in testing in 2016 and was expected to launch 300 kg into SSO for less than $10-million.[386] On 6 October, Orbital ATK and Stratolaunch Systems (Vulcan Aerospace) announced a partnership to offer accessible and affordable launches to LEO for the commercial small satellite sector, using their Pegasus XL air-launch vehicles and Stratolaunch aircraft.[387]

CASIC announced in April that its commercial launch subsidiary, ExPace Technology Corp., would also service the smallsat industry with its Kuaizhou solid fueled rockets.[388] ExPace will charge approximately $10,000 per kg per launch and is aiming for 10 launches between 2017 and 2020. A contract worth an estimated $14.5-million with China's Changguang Satellite Technology Co. to launch three EO satellites to LEO was negotiated with a launch date of 31 December 2016; the satellites were successfully launched on 9 January 2017.[389]

Small satellites have been mainly used commercially to provide remote sensing services, and in constellations can deliver new capabilities, including greater global coverage and faster revisit times (see also Indicator 2.1). The launch of 1,445 commercial remote sensing satellites is anticipated by 2026.[390]

Planet has planned a constellation of 100 3U CubeSats (Doves) to monitor environmental changes and provide other EO data with a resolution capability of 3-5m.[391] In June 2016, Planet successfully launched 12 Flock 2p Dove satellites into SSO,[392] followed by a further eight from the ISS on 13 September.[393] In October, Planet provided detailed flood mapping to Australia within 18 hours of a request under the terms of the International Charter for Space and Major Disasters (see Indicator 2.1).[394]

Spire Global is using CubeSats with GPS Radio Occultation sensors to provide timelier weather forecasting and AIS sensors for maritime tracking.[395] Spire launched 13 CubeSats (Lemurs) in 2016.[396]

GeoOptics will deploy a constellation (CICERO) of 6U CubeSats to collect data about the state of the Earth's atmosphere, surface, and subsurface for greater weather predictability.[397] It aims to have 24 satellites launched into LEO by the end of 2018, utilizing Virgin's LauncherOne.[398] An initial CICERO Pathfinder is scheduled for launch in mid-2017.[399]

New entrants could include Planetary Resources, which announced a spinoff of its technology to identify water and other resources on asteroids to provide the first commercial infrared and hyperspectral sensor to provide intelligence on natural resources on Earth, using a constellation of 10 satellites in LEO.[400]

In 2016, OneWeb partnered with Airbus to set up a new high-volume satellite manufacturing plant in Florida, with the goal of producing three satellites per day.[401] SpaceX is also investing in its satellite lab in Seattle, ahead of plans to launch thousands of satellites for broadband internet service (see above).[402] Similar strategies are being used by Boeing and Blue Origin to offset the costs of manufacturing new launch vehicles.[403]

Nascent space-based industry focused on exploration and resource extraction

The space industry's focus is broadening to include new capabilities that will support a space-based economy based on exploration, resource mining, manufacturing, refueling and repair, and habitation.[404]

In 2016, NASA issued a request for information on how to use the ISS as a means to advance economic development in LEO.[405]

The planned 2017 Moon Express robotic mission will be the first beyond LEO by a private company.[406] CEO Bob Richards called it "a threshold for the entire commercial space industry."[407] The long-term goal of the company is to exploit lunar resources such as water.

The ability to mine water and carbon dioxide could support the more efficient propellant technology needed for deep space exploration.[408] Electrolysis technology is being tried to separate hydrogen and oxygen from water, with the hydrogen then combined with carbon dioxide to create methane, a gas used in rocket launching. SpaceX and Blue Origin are creating methane-propelled rocket engines, intending to use space-manufactured fuels for the return to Earth. SpaceX's Interplanetary Transport System, being developed to support human settlements on Mars, tested its Raptor engine for the first time on 25 September.[409] Blue Origin started work on its BE-4 engine in 2012 and reached an agreement with ULA in March 2017 to use the engine in the Vulcan rockets.[410]

In November, asteroid-mining company Planetary Resources announced that, in partnership with Luxembourg (see Indicator 2.5),[411] it will test thermographic mapping technology that can detect the presence of water and water-bearing minerals on asteroids.[412] Deep Space Industries (DSI), also in partnership with Luxembourg, announced that its first commercial interplanetary mining mission would take place in 2017; it hoped that its prototype exploration spacecraft, Prospector-X, would lead to a capability to "harvest and supply in-space resources to support the growing space economy" and underpin low-cost space exploration.[413] DSI also planned to test its Comet water propulsion system, which uses superheated water vapor to generate thrust. As water will likely be the first material mined, the ability to refuel its Prospector vehicles in space has the potential to substantially reduce operational costs for the company.[414]

Commercial satellite companies continued to develop capabilities for robotic, on-orbit servicing.[415] In April, Orbital ATK signed a contract with Intelsat for a "revived satellite life extension program" for on-orbit service satellites (see Indicator 3.2).[416] Its Mission Extension Vehicle (MEV-1) is intended to dock with a commercial satellite that will maneuver using fuel from the MEV, thus extending its life by approximately five years. The MEV will initially be tested on a retired satellite in a graveyard orbit.

There was a new effort in 2016 to develop 3D-printing capabilities to produce materials for space missions on-orbit. The Organization for Economic Co-operation and Development (OECD) reported that preliminary work in this area indicated significant future reductions in cost and labor; completed and ongoing experiments on the ISS produced positive results.[417] Registration for NASA's 3D Printed Habitat Challenge ended in late 2016; contestants will vie for $2.5-million in prize money.[418]

In partnership with NASA, Bigelow Aerospace tested its Bigelow Expandable Activity Module on the ISS. Delivered by SpaceX's Dragon cargo spacecraft on 10 April, the inflatable habitat was to be used to test protection against radiation, space debris, and contamination.[419] The experimental program will also test and validate expandable habitat technology for future missions, including to Mars[420] (see Indicator 2.5).

Private sector experiments with new funding models

Governments remain the primary source of R&D funding to the commercial space sector. However, venture capital, seed funding, and private equity, along with crowdfunding and private donations through challenges and competitions are becoming more frequent sources. The Google-sponsored XPRIZE Foundation Competition, launched in 2007, promised to award a $20-million Grand Prize to the first team that, before the end of 2017, successfully placed on the Moon's surface a spacecraft that then travelled 500 m and transmitted high-definition video and images back to Earth.[421] At the end of 2016, the five remaining teams had secured launch contracts with a mix of commercial and civil providers (SpaceX, Rocket Lab, Interorbital Systems, and ISRO).

In November, Project Blue, a consortium of technical telescope experts, began a crowdfunding campaign for a small space telescope that will image planets and the double suns of Alpha Centauri. The consortium hoped to raise at least $1-million of the final cost of between $10-milliion and $50-million.[422] The telescope will be more affordable than telescopes such as Hubble, because the target of study is only 4.3 light years from Earth.

Indicator 2.5: Public-private collaboration on space activities

There is an increasingly close relationship between governments and the commercial space sector. Some national space policies place great emphasis on maintaining a robust and competitive industrial base and encourage partnerships with the private sector. Many spacefaring states consider their space systems an extension of critical national infrastructure; a growing number view their space systems as inextricably linked to national security.

Governments play a central role in commercial space activities by supporting research and development, subsidizing certain space industries, and adopting enabling policies and regulations. In 2015, the United States adopted the Commercial Space Launch Competitiveness Act, intended to facilitate a "pro-growth environment for the developing commercial space sector."[423] The Act covers, inter alia, the extension of indemnification for third-party launch losses until 2025 and an extension of the "learning period" to 2025 before FAA safety regulations for human spaceflight are imposed.

More significantly Title IV—Space Resource Exploration and Utilization—is intended to support private investment in a new arena of activity for the space industry: commercial resource extraction. Federal agencies shall "facilitate commercial exploration for and commercial recovery of space resources by United States citizens" and "promote the right of United States citizens to engage in commercial exploration for and commercial recovery of space resources free from harmful interference, in accordance with the international obligations of the United States and subject to authorization and continuing supervision by the Federal Government" (§51302). Similar legislation is being developed by other states (see Indicator 4.1).

Full state ownership of space systems has now given way, in cases such as space launch, to a mixed system in which commercial space actors receive significant government and military contracts and a variety of subsidies. The United States, in particular, has partnered with the private sector to subsidize the commercial development of systems intended to meet national needs. The Evolved Expendable Launch Vehicle (EELV) program was initiated in 1994 to provide the U.S. government with competitively priced, assured access to space.[424] This program produced two families of launch vehicles—Boeing's Delta IV and Lockheed Martin's Atlas V—to provide critical space launch capability that supported DoD and other national security missions. Boeing and Lockheed Martin merged the Delta IV and Atlas V programs to form the United Launch Alliance (ULA) in 2006. November 2011 saw the approval of a new EELV Acquisition Strategy, which continued procurement of launch services and launch capability from ULA for the next several years, but provided for a full and open competitive environment for alternative sources as soon as they were certified. In 2015, SpaceX became the second commercial provider approved to launch military payloads for the USAF.[425]

NASA has been working with the private sector to develop new, commercially operated resupply services and human space transportation services to the ISS. Under the Commercial Orbital Transportation Services (COTS) program, SpaceX and Orbital ATK resupply the ISS.[426] NASA is currently working with SpaceX and Boeing on the Commercial Crew Program to provide human spaceflight to the ISS;[427] the Dragon V and Starliner CST-100 spacecraft are currently scheduled to transport U.S. astronauts to the ISS in 2018.[428] The NextStep space habitat program is "a public-private partnership model that seeks commercial development of deep space exploration capabilities to support more extensive human space flight missions" and includes partners such as Bigelow Aerospace.[429] NASA's decision to extend participation in the ISS until 2024 (see Indicator 2.3) is viewed as an important opportunity for the private sector to develop its technical capacities and revenues in LEO.[430]

Europe has a long partnership with its commercial space industry. Arianespace was founded in 1980 as the world's first commercial satellite launch company.[431] Its launcher, Ariane 5, commands half the global commercial launch market.[432] Over the years, Ariane-5 has benefited from continuous support from the ESA-funded Ariane Research and Technology

Accompaniment program; other support has come from the European Guaranteed Access to Space Program.[433]

Increasingly, governments are turning to the commercial sector for lower-cost services and innovation. The U.S. National Security Space Strategy of 2011 states, "Strategic partnerships with commercial firms will be pursued in areas that both stabilize costs and improve the resilience of space architectures on which we rely."[434] The USAF Space and Missile Systems Center's Hosted Payload Solutions Program will involve "hitchhiking" sensors into space on commercial satellites.[435] The USAF is also working with Intelsat to explore opportunities to leverage commercially available satellite tracking, telemetry, and command technologies for use on government satellites[436] and is exploring options for outsourcing maintenance of satellite-operating facilities to the private sector.[437] The U.S. DoD continues to purchase commercially available bandwidth.[438] In 2015, the National Geospatial-Intelligence Agency (NGA) released its Commercial GEOINT Strategy.[439] In 2016, NOAA released its Commercial Space Policy, which provides a framework for using commercial space-based approaches, including the purchase of satellite data as well as the use of hosted payloads.[440]

The growing interdependence of the military and commercial space industry complicates space security by making commercial space assets potential targets of military attacks. Although the U.S. military has long depended on commercial space-based services, practices such as the use of hosted payloads clearly blur the distinction between commercial and military satellites. Reports indicate that the USAF has begun inviting commercial satellite communications companies such as Intelsat to war-gaming sessions.[441]

National security concerns play an important role in the commercial space industry. Export controls aim to strike a balance between commercial development and the proliferation of sensitive technologies that could pose security threats. Achieving this balance is not easy, particularly in an industry characterized by dual-use technology. Space launchers and intercontinental ballistic missiles use almost identical technology, and many civil and commercial satellites contain advanced capabilities with potential military applications.

Political and military tensions can impede commercial space activities. Political developments in Ukraine in 2014 led to the U.S. restriction of imports of the Russian RD-180 engines that are used by ULA's Atlas V launch vehicle. Later in 2014, ULA announced a partnership with Blue Origin to develop a domestically sourced rocket engine,[442] but the ban on the Russian engine remains an ongoing concern.

International Traffic in Arms Regulations (ITAR) control the export and import of defense-related articles and services on the U.S. Munitions List. In 1999, satellites and satellite components became subject to ITAR. The commercial satellite industry argued that the regulation of space-related commodities by ITAR eroded U.S. competitiveness in the international space market.[443] On 13 May 2014, the U.S. Departments of State and Commerce released a set of interim final rules that moved many commercial satellites and related items from the U.S. Munitions List to the Commerce Control List;[444] most U.S. commercial communications satellites were no longer considered defense articles subject to ITAR.

2016 Developments

Regulatory and financial incentives encourage growth of national space industries

In 2016, Luxembourg launched Spaceresources.lu, an initiative of legislative and financial measures that positions the country as a hub for businesses involved in the exploration and use of space resources.[445] The framework will give private companies that establish their business in Luxembourg clear ownership to resources retrieved from outer space (see Indicator 4.1). Legislation, currently in draft form, will provide funding and R&D support to those companies. Under this initiative, agreements were concluded between the Luxembourg Government and Société Nationale de Crédit et d'Investissement (a public-law banking institution) and U.S. asteroid mining companies Deep Space Industries and Planetary Resources.[446] Funding from the Luxembourg space program will be used to develop and launch DSI's Prospector-X, a robotic spacecraft for prospecting and mining near-Earth asteroids. Planetary Resources will work exclusively in Luxembourg to develop space hardware and services and to conduct research.[447]

In September, New Zealand authorized Rocket Lab to conduct space launches on its territory and released its Outer Space and High Altitudes Activities Bill, which comes into force in mid-2017.[448] The bill aims to facilitate the development of the domestic space industry, including the domestic launch industry,[449] while ensuring that safety requirements and international obligations are met.[450]

In the October 2016 Space Strategy for Europe, the ESA and EU agreed to protect and develop their mutual interests in space.[451] A key goal is to keep the EU's private and public space industries competitive. By fostering stronger links with commercial sector companies, the European Commission hopes to advance the EU space industry to include new users and connections.

UK Export Finance (UKEF) has funded five satellite projects in the past 10 years, but is hoping to expand this role.[452] In 2016, the rules governing funding changed, making UKEF a more attractive source of funding for commercial satellite projects.[453] Unlike counterparts in other countries, such as the U.S. EXIM Bank and France's Coface, which guarantee loans only when a majority of the project has been completed domestically,[454] UKEF can provide financial support to projects that contain as little as 20% UK content. The UK tabled the Modern Transport Bill, which includes support for a new commercial spaceport that will provide low-cost access to space and service the UK's small satellite and space tourism industries. The port has a targeted date of operation of 2020.[455] Possible locations include Newquay (Cornwall), Llandbedr (Snowdonia), Glasgow Prestwick, Stornoway, and Campbeltown (Scotland).

In October, the U.S. Office of Science and Technology Policy announced a new initiative, "Harnessing the Small Satellite Revolution," to promote the use of small-satellite technology in the commercial sector and increase government use of commercial sector data.[456] Various federal agencies are funding opportunities for government and commercial companies to better use data from small-satellite programs, including:

- $25-million from NASA to promote the purchase of data from nongovernmental small-satellite constellations;[457]
- NOAA awards to GeoOptics ($695,000) and Spire Global ($370,00) for the use of weather data;[458] and
- A $20-million NGA agreement with Planet to acquire imagery from Planet's constellation of nanosatellites.[459]

Initiatives in the wake of a GAO report[460] were intended to provide significantly more funding to the FAA to speed up commercial space launch licensing and safety inspections.[461] The FAA approved the first private space mission to travel beyond Earth's orbit, by Moon Express (see Indicator 2.4).

Commercial space launch, Earth-imaging companies still face national security restrictions

The ongoing saga of U.S. national security launches on Russian-manufactured RD-180 rockets continued. In May, Senator John McCain filed amendments to the FY2017 Defense Authorization Bill that required the Treasury Department to authorize all USAF contracts, to ensure that they did not violate U.S. sanctions on RD-180 rockets.[462] Amendments included a condition that the Pentagon no longer purchase the engines after 2022, allowing the Pentagon time to find an alternative. In June, a draft of the Act passed in the Senate, allowing the U.S. military to purchase nine of the 18 Russian engines they had originally planned to acquire.[463]

Two potential replacement engines are being developed domestically. ULA partnered with Blue Origin in 2014 to develop the BE-4 rocket.[464] Both hope to incorporate the engine into their launch systems by 2019. In February 2016, the USAF selected ULA and Aerojet Rocketdyne Holdings, a rocket-propulsion manufacturer, to develop the AR1 engine. The contract, valued at $804-million, requires a fully developed engine by 2019.[465]

The launch of U.S. commercial satellites by India remained controversial and uncertain. In September 2015, the day after India conducted the first launch of U.S. satellites. the FAA endorsed the recommendation that U.S. commercial companies remain barred from using Indian PSLV rockets to launch their satellites.[466] While U.S. launch companies are lobbying to maintain the restriction, waivers are still being granted for Indian launches; "more than a dozen satellites built by U.S. companies [were launched] on an Indian Polar Satellite Launch Vehicle (PSLV) June 22."[467]

In September, Taiwan's Defence Ministry spokesperson Chen Chung-chi confirmed Taiwan's request to Google to blur images of new structures on the island of Itu Aba in the South China Sea.[468] Chen stated that, because the island contains a military airport, it is "classified as a strategic military facility restricted area in accordance with the National Security Act."[469]

Some setbacks to increasing U.S. defense use of private sector capabilities

In 2016, the U.S. DoD awarded a $400-million, five-year contract for unlimited access to the Iridium communications system,[470] and $8.57-million to upgrade the dedicated government gateway for the system.[471] In November, Intelsat General Corporation was awarded a contract to provide satellite connectivity services for the Army's RiteNet Corp.[472] Inmarsat, Intelsat, SES, and Eutelsat all indicated increased demand for their communications services from the U.S. DoD.[473] In August, the NGA and the NRO agreed to the Commercial GEOINT Activity initiative, which will allow them to efficiently explore commercial businesses for alternative methods of data collection, while giving commercial companies more opportunities for public-private relationships.[474] However, despite an agreement to procure data from such private companies as GeoOptics and Spire Global, NOAA expressed doubts about their ability to meet government standards.[475]

Closer integration of public and private capabilities has been slowed for a variety of reasons relating to private clashes with government programs, inflexible government rules and lack of enabling regulations, and government suspicion of the motivations of commercial companies.[476] In August, the USAF aborted plans to utilize hosted payloads to close a weather forecasting gap, preferring cooperation with allied states.[477]

United States remains focused on public-private partnerships for next-generation space exploration

NASA signaled again that it intends to privatize U.S. activities on the ISS in the mid-2020s as it focuses on deep space missions, which will also have private sector partners.[478] Moon Express expanded its partnership with NASA through the Lunar Scout Program; the company will provide $500,000 "for each instrument selected by NASA to fly aboard the company's first three commercial lunar missions," with its first mission approved for 2017.[479] Moon Express first partnered with NASA in 2014 under the Lunar Cargo Transportation and Landing by Soft Touchdown program, intended to generate commercial cargo transportation capabilities to the Moon.

Progress continued on NASA's Commercial Crew Program, which involves partnerships with Boeing and SpaceX worth almost $8-billion,[480] to develop commercial human spaceflight systems for LEO, including to the ISS.[481] The program is intended to provide direct U.S. access to the ISS, improve research capabilities, and advance deep space travel capabilities. However, initial crew flight tests, originally scheduled for 2015, are now set for 2018.[482] In March, Blue Origin was also approved to carry payloads to the ISS.[483] Blue Origin will receive up to $3.7-million to develop and test their New Shepard reusable rocket system, designed to carry a six-member human crew.[484]

Bigelow Aerospace's BEAM expandable habitat was successfully launched by the SpaceX Dragon capsule and attached to the ISS in April.[485] Developed under a public-private partnership with NASA,[486] the BEAM habitat is an early demonstration of deep-space habitat capabilities. NASA is considering Bigelow Aerospace's B330 and a module by Axiom Space for the ISS.[487] Axiom intends that their module will eventually detach from the ISS and become a separate space station to succeed the ISS.[488]

In August, NASA selected six private companies to develop space habitat prototypes for deep space.[489] Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada Corporation's Space Systems, and NanoRacks were awarded a total of approximately $65-million to develop ground prototypes within 24 months.

In September, SpaceX founder Elon Musk outlined a vision to take humans to Mars by 2028 through a public-private partnership that he hopes will eventually involve government contracts, crowdfunding, and public support.[490]

India and China encourage more private participation in domestic space programs

In January, ISRO announced two new space parks for Sriharikota and Bengaluru, to encourage new partnerships with private domestic companies.[491] ISRO held the Conference on Enabling Spacecraft Systems Realisation through Industries in July to help private industry deliver space-based services. ISRO Chairman Shri A.S. Kiran Kumar stressed the need to work in conjunction with private industry "in order to meet the increased demand for space based services."[492] Introduced at the conference was the "Expression of Interest" page on the ISRO website, on which private companies can register their interest in partnering on future projects.[493]

China introduced a "Made in China" initiative that aims to increase "the profitability and efficiency of China's defense enterprises" and increase private sector participation in the state-dominated industry.[494] President Xi Jinping announced a plan to partially privatize the R&D centers of some state-owned businesses. Chinese authorities are developing legislation and other tools to support and regulate the commercial space industry.[495]

Indicator 2.6: Space-based military systems

The space age broke new ground in the development of intelligence, surveillance, and reconnaissance through the use of satellite imagery and space-based electronic intelligence collection. Satellite communications also provided extraordinary new capabilities for real-time command and control of military forces deployed anywhere in the world. Military satellites perform navigation, communications, weather, and technology development missions, in addition to intelligence gathering. Extensive military space systems were developed by the United States and the USSR during the Cold War.

By the end of the Cold War, the United States and Russia had begun to develop satellite navigation systems that provided increasingly accurate geographical positioning information. Building on the capabilities of its GPS, the United States began to expand the role of military space systems. The United States dominates the military space arena and leads in deployment of dedicated space systems to support military operations. According to the Union of Concerned Scientists database, as of January 2017 the United States operated 150 dedicated military satellites, in addition to 31 GPS satellites.[496]

Figure 2.16 U.S. Space-based military force enhancement missions and satellites

Environmental monitoring	Satellite communications	PNT	Missile warning	Intelligence, surveillance, and reconnaissance
Polar LEO	GEO and LEO	Semi-synchronous orbit	Various orbits	Various orbits
Defense meteorological support program ******************** National polar-orbiting operational environmental satellite system. Defense weather satellite system (DWSS)	Defense satellite communications system DSCS II, DSCS III, ultra-high frequency follow-on, Milstar, global broadcast system, iridium, commercial systems, advanced extremely high frequency, wideband global system, mobile user objective system, enhanced polar system ******************** Transformational communication system, enhanced polar system	Global positioning system GPS II GPS IIR GPS IIR-M GPS IIF GPS III ********************	Defense support program, GPS, space-based infrared system, space tracking and surveillance system ******************** Precision tracking space system	Geospatial intelligence satellites, signals intelligence satellites, overhead persistent infrared, commercial systems, integrated overhead SIGINT architecture-next ******************** Future imagery architecture, space radar

Items below **** are programs of record that have been cancelled.

The priority in recent years has been to modernize capabilities through the launch of next-generation systems; however, several of these efforts have faced technological delays and budget overruns. The SBIRS program begun in 1996 was, by the end of 2015, 300% over budget and more than nine years behind schedule.[497] The next-generation GPS III system is now more than three years behind schedule.[498] In addition, the United States faces a potential environmental monitoring gap as the Defense Meteorological Satellite Program (DMSP) system reaches end of life without a ready replacement.

The 2015 National Defense Authorization Act (NDAA) mandated development of a concept for a space-based ballistic missile intercept component. This would contribute to boost-phase missile defense or "defensive options against direct ascent anti-satellite weapons, hypersonic glide vehicles, and maneuvering reentry vehicles." Under study are operational concepts and an assessment of how much this component could contribute to missile defense, the required architecture and components, how it could be used against anti-satellite weapons, and the effort required to make it operational.[499] However, numerous assessments since the concept was first promoted 30 years ago have pointed to both high costs and technical challenges.[500]

Russia's early warning, imaging intelligence, communications, and navigation systems were developed during the Cold War; by 2003, 70-80% of these spacecraft had exceeded their designated lifespans.[501] Russia focused first on upgrading its early warning systems and is attempting to complete the GLONASS navigation system, which was declared fully operational in 2011.[502] Since 2004, Russia has worked on "maintaining and protecting" its fleet of satellites and developing satellites with post-Soviet technology.[503] In 2006, the first year of a 10-year federal space program, Russia increased its military space budget by as much as a third, following a decade of severe budget cuts.[504] The Russian space budget rose 144% between 2008 and 2013.[505] With 54 dedicated military satellites as of January 2017, in addition to 27 GLONASS navigation satellites,[506] Russia's military space program may still be considered the second largest, but is closely matched by China's. Russia also makes use of civilian satellites for military purposes. In 2015, 10 Russian spacecraft were assigned to conduct imagery and radar reconnaissance in Syria.[507]

Officially, China's space program is dedicated to science and exploration, but, like programs of many other actors, it is widely believed to provide support to the military. The 2015 White Paper, *China's Military Strategy*, cites outer space as a "commanding height" of strategic competition and links it to "informationized" warfare.[508] The major military restructuring China announced in December 2015 includes combining its space, cyber, and electronic warfare forces into a new Strategic Support Force, an approach China believes will better enable it to synergize these capabilities and improve its ability to conduct informationized warfare.[509] The BeiDou regional navigation system is designed to enable China to maintain navigational capability if the United States were to deny GPS services in times of conflict.[510] BeiDou may also improve the accuracy of China's intercontinental ballistic missiles and cruise missiles.[511] The Union of Concerned Scientists database lists 58 of China's satellites as primarily military, including 30 EO, 22 navigation, four communications, and two technology development.[512]

India's National Satellite System is one of the most extensive domestic satellite communications networks in Asia. India has been developing GAGAN, a satellite-based augmentation system, to enhance its use of GPS and IRNSS and so provide independent satellite navigation capability. These civilian-developed and -controlled technologies are used in Indian military applications. The Cartosat-series remote sensing satellites are generally considered dual-use. Recently, India has been more open about its military space capabilities. ISRO indicated that the launch of the GSAT-6 communications satellite in 2015 would provide service for "strategic users"; military analysts have identified the users as the armed forces and suggest that the GSAT-6 is India's second dedicated military communications satellite.[513]

Japan's 2015 Basic Plan on Space Policy noted the increasing importance of space for national security, indicating a significant shift toward greater military and security uses of space.[514] The plan prioritizes space-based navigation, communications, and reconnaissance capabilities[515] and emphasizes cooperation with other countries, specifically the United States.[516] In early 2015, Japan launched two new reconnaissance satellites: a synthetic aperture radar satellite[517] and an optical imaging satellite.[518]

Australia, Canada, France, Germany, Israel, Italy, Japan, and Spain are developing dedicated military satellites and multiuse satellites with a wide range of functions.

Several ESA projects, including Galileo and Sentinel, have dual-use applications. European defense agencies have expressed growing interest in using ESA satellite data.[519] European states engage in bilateral and multilateral cooperative efforts for defense and security purposes. The European Defence Agency acts as the central purchasing body of commercial satellite communications for 10 EU Satcom Market members.[520] France and Italy cooperate on the provision of military broadband service.[521]

Increasingly, the United States is working with key allies on space situational awareness (see Indicator 1.4). Since 2016, Canada, the Netherlands, and the United Kingdom have been partners in the U.S. Advanced Extremely High Frequency (AEHF) program.[522] In September 2014, the Combined Space Operations Memorandum of Understanding was signed by the United Kingdom, the United States, Canada, and Australia;[523] participating nations gain "an understanding of the current and future space environment, an awareness of space capability to support global operations and military-to-military relationships to address challenges and ensure the peaceful use of space."[524]

The first meeting of the United States-India Space Security Dialogue[525] and the first United States-India Strategic and Commercial Dialogue occurred in 2015.[526]

The revised Guidelines for Japan-U.S. Defense Cooperation released in 2015 included cooperation in space programs, including "space-based positioning, navigation, and timing; enhanced space situational awareness; use of space for maritime domain awareness; research and development in space technologies; and use of hosted payloads."[527]

Concern has been expressed that extensive use of space in support of terrestrial military operations blurs the notion of "peaceful purposes" enshrined in the Outer Space Treaty, but state practice over the past 40 years has generally accepted these applications as peaceful insofar as they are not aggressive in space. However, nonaggressive use could be abandoned with the growing focus on space as a domain of warfare (see Indicator 4.1). A 2014 U.S. Strategic Portfolio Review for Space concluded war on Earth could extend to space and that the United States needed to work diligently on both Offensive and Defensive Space Control capabilities. The Review led to significant additional funding for DoD and Intelligence Community space and counterspace capabilities (see Theme 3) and the creation of the Joint Space Doctrine and Tactics Forum (JSDTF),[528] the Joint Interagency Combined Space Operations Center,[529] and the position of Principal DoD Space Advisor.

In China, a 2015 restructuring of the People's Liberation Army created two new entities related to military space technology. The Rocket Force is intended to be the leading unit of the Army, responsible for strategic deterrence via missile and nuclear counterattack. The Strategic Support Force is "a new-type combat force to maintain national security and an important growth point of the PLA's combat capabilities."[530]

In 2015, Russia merged the Air Force and Aerospace Defense Force into the Aerospace Forces.[531] Core responsibilities include defending against airborne attacks and ballistic missiles; providing aviation support for other armed services; providing early warning of attacks; monitoring, identifying, and responding to space threats; launching military and dual-use satellites; maintaining military satellites; and using both conventional and nuclear weapons to defeat opposed forces.[532]

2016 Developments

United States prioritizes Space Mission Assurance

U.S. military investments in space totaled more than $7-billion for FY2017, with the emphasis on maintaining assured access to space and developing next-generation capabilities, including PNT, secure communications, and early warning; and a new operational focus on system resilience and deterrence (see Indicator 3.2).[533]

Launch

The Evolved Expendable Launch Vehicles program procured five launches (budgeted at $1.8-billion) and planned for 23 more in the next five years (at a cost of $9.4-billion).[534] However, only $160-million of $296-million requested for launch system development under the EELV program was approved; $220-million was approved to develop an alternative propulsion system to the Russian RD-180 engines currently in use (see Indicator 2.5).[535] The DoD was directed to "develop a plan to use allied launch vehicles to meet the requirements for achieving the policy relating to assured access to space."[536]

ISR

The National Reconnaissance Office launched three satellites in 2016. NROL-45, launched on 10 February into a retrograde LEO orbit, is reportedly Topaz 4, the fourth in a series of radar-imaging satellites built by Boeing.[537] NROL-37, launched on 11 June into GEO, is reportedly a Mentor 7 satellite used to gather signals intelligence from communications satellites.[538] NROL-61, launched on 28 July, is believed to be a new generation of a communication relay system for LEO imagery intelligence satellites.[539] A fourth launch scheduled for December was delayed; five launches are scheduled for 2017.[540]

Missile warning and missile defense

Dedicated missile warning satellite SBIRS GEO Flight 3 was scheduled to launch in 2016, but was delayed in May, July, and October.[541] SBIRS provides a transition between the Defense Support Program and the next-generation Overhead Persistent Infrared (OPIR) sensors to support missile early warning, missile defense, and battlespace awareness; and to enable technical intelligence gathering.[542] In 2016, the SBIRS constellation consisted of two HEO and two GEO satellites; the full constellation is to include four satellites in GEO to provide global coverage. In 2016, $181.6-million was authorized for SBIRS.[543]

Initial operational capability for the Space Based Infrared System OPIR Battlespace Awareness Center was announced in September.[544]

In 2016, Missile Defense Agency (MDA) head James Syring confirmed that a space-based sensor layer is part of MDA's long-term plans.[545] For FY2017, MDA requested $20-million for the Space-based Kill Assessment experiment, aimed at creating a network of sensors hosted on commercial payloads that will determine if an incoming missile has been destroyed by the ballistic missile defense system; it is expected to launch in 2017. Current space-based capabilities for missile defense include two demonstration satellites that form part of the Space Tracking and Surveillance System launched in 2009. The MDA requested $32-million for this program in 2016.[546] Currently DoD is studying options for on-orbit capabilities.[547]

This extended space mission for missile defense was bolstered in the November 2016 NDAA, which removed the limited national mandate of ballistic missile defense and directed the DoD to examine the feasibility of new space-based missile defense capabilities (see Indicator 3.4).[548] The 2015 NDAA included a mandate to develop a concept for a space-based ballistic missile intercept component that would contribute to boost-phase missile defense, which was extended in 2016 (see Indicator 3.4).[549]

Environmental monitoring

Efforts continued to maintain complete environmental monitoring (see Indicator 2.1), following the loss of control of DMSP-19 in February 2016.[550] The first of three gap-filler satellites, Compact Ocean Wind Vector Radiometer, will replace the NRO's aging Windsor satellite in providing ocean wind data, possibly in 2017; the budget request for this project for FY2017 was $119-million.[551] The DoD indicated that it would also make use of the capabilities of allied nations.[552]

SATCOM

Two dedicated SATCOM satellites were launched. The fifth Mobile User Objective System (MUOS)-5 satellite was launched into GEO on 24 June to provide dedicated tactical communications for the U.S. Navy.[553] MUOS-5 experienced technical problems after launch as it transferred to its final orbit and had to be temporarily "parked" in a safe intermediate orbit to allow the MUOS team, with the help of a USAF GSSAP satellite, to evaluate the situation before proceeding[554] (see Indicator 3.4). The eighth Wideband Global SATCOM (WGS-8) satellite was launched into GEO on 7 December; it is the second Block II follow-on satellite, supporting communications links in the X-band and Ka-band spectra, and plays an important role in high-capacity and protected tactical satellite communications.[555] The WGS-8 has nearly double the bandwidth of previous WGS satellites available for military users;[556] $51.6-million was allocated to the Wideband Global SATCOM program for FY2017.[557]

In FY2017, $229.1-million was allocated to the AEHF program. AEHF SV-4 was slated for launch in late 2017, while AEHF SV-5 and SV-6, which will complete the constellation, are in the procurement stages.[558]

PNT

The GPS Block 2F-12, the last of the series, was successfully launched on 5 February; the first next-generation GPS III satellite is scheduled for launch in 2017. The program was allocated $908.262-million for FY2017.[559] The ground station component—Raytheon's Operational Control System—faced more delays and cost overruns. The program, estimated at $3.6-billion, had its budget cut by $600-million for FY2017.[560] A mandatory review of the program was triggered in 2016 after the cost estimates were exceeded by more than 25%, but, with no alternatives, the program was allowed to proceed.[561]

Other missions

Two GSSAP satellites were launched on 19 August (see Indicators 1.4 and 3.4). DARPA worked toward a launch of the Hallmark-ST software testbed program, which is intended to provide breakthrough capabilities in U.S. space command and control; the testbed will create an advanced enterprise software architecture to test tools that will integrate a full spectrum of real-time space-domain systems and capabilities.[562] GSSAP, Hallmark, and other SSA developments are considered in Indicator 1.4. Defense funding in 2016 also included $34.4-million for counter-space programs, $7.5-million for space control technology, $61.2-million for advanced spacecraft technology, $108.7-million for the Space Security and Defense Program, and $13.9-million for space superiority intelligence.[563]

The total USAF space procurement request for FY2017 was $3.033-billion, up from $2.811-billion in enacted funding in FY2016.[564]

Figure 2.17 U.S. dedicated military satellites launched in 2016[565]

Satellite Name	Operator	Primary function	Orbit	Launch date
Navstar GPS IIF-12	DoD/USAF	Navigation / Global Positioning	MEO	05-Feb-16
FIA Radar 4	National Reconnaissance Office	Earth Observation	LEO	10-Feb-16
Advanced Orion 7	National Reconnaissance Office	Earth Observation	GEO	11-Jun-16
MUOS-5	DoD/U.S/ Navy	Communications	GEO	24-June-16
SDS IV-1	National Reconnaissance Office	Communications	GEO	28-Jul-16
GSSAP 3	Air Force Satellite Network	Space Observation	GEO	19-Aug-16
GSSAP 4	Air Force Satellite Network	Space Observation	GEO	19-Aug-16
CELTEE-1	Air Force Research Laboratory	Technology Development	LEO	11-Nov-16
Prometheus 2.1	Los Alamos National Laboratory	Technology Development	LEO	11-Nov-16
Prometheus 2.2	Los Alamos National Laboratory	Technology Development	LEO	11-Nov-16
Wideband Global Satcom 8	USAF	Communications	GEO	07-Dec-16

Changes in U.S. force integration and space control proceed

In March, USSTRATCOM commander Admiral Cecil D. Haney testified that the JSDTF had made progress in integrating exercises and wargames of the defense and intelligence communities, and had revised joint doctrine, tactics, and procedures to coordinate operations. Haney also reported progress on the Joint Interagency Combined Space Operations Center, which "combines the efforts of USSTRATCOM, Air Force Space Command, and the intelligence community with a goal to create unity of effort and facilitate information sharing across the national security space enterprise."[566] He reported that the JICSpOC had completed two of nine joint Air Force and NRO scenarios to craft concepts of joint operations and improve military and intelligence community integration on monitoring and operating in the space domain. In 2016, the Air Force requested $30-million to support test and experimentation at the Center, which include efforts to see how the DoD and intelligence community would react during a war in space.[567] At his confirmation hearing to become Commander of USSTRATCOM, General John Hyten testified that U.S. space control efforts, including the JICSpOC, will "change the warfighting culture of our space cadre as well as ensuring we have the ability to fully plan and employ our space control capabilities."[568]

The process of integrating space under the Principal DoD Space Advisor experienced both progress and setbacks. The PDSA was designed to enhance governance of the DoD space enterprise by more clearly defining the space portfolio, including authorities and responsibilities. It is to oversee all departmental space matters, including policies, strategies, plans, programming, and architecture assessment across the entire space enterprise and conduct an annual space portfolio review. Significantly, FY2017 was the first year in which space operations existed as an independent funding line in the DoD budget. However, initial 2016 assessments of the PDSA were not positive. A 27 July GAO report stated that officials and experts remained skeptical that the PDSA position would have sufficient decision-making authority to effectively consolidate fragmented leadership responsibilities.[569]

The USAF under General Hyten's leadership moved forward with an initiative to create a Space Mission Force to train military satellite operators to operate in contested environments. In a 29 June White Paper, Hyten indicated that the SMF aims to establish "the Ready Spacecrew Program, which enhances training to create a force capable of performing combatant commander-directed missions in the face of dynamic and varied threats," and to adjust "force presentation and command and control constructs to mirror other Air Force combat units…similar to Combat Air Forces, Mobility Air Forces and AF Special Operations Forces, which have operated with incredible effectiveness in the contested air domain for several decades."[570] The SMF concept was adopted at the July 2016 Operation Red Flag integrated air operations exercise.[571] An increased focus on the space domain includes planned spending of up to $8-billion over the next five years[572] (see Indicator 4.1).

Russia modernizes surveillance and reconnaissance capabilities

In March, Russia launched its second Bars-M optical military reconnaissance satellite, Kosmos 2515. Analysts believe that the satellite has digital imaging capabilities that will replace older satellites with film cameras.[573] The new Bars program was started in the 1990s, halted in the early 2000s, and restarted in 2007.

A five-satellite radar reconnaissance satellite system is under development by the Lavochkin Research and Production Association. According to the Ministry of Defense, the system will capture live imagery in all weather conditions and generate an accurate three-dimensional model of Earth's surface for cruise missile missions. The first two satellites are expected to launch in 2019.[574]

A new Razdan surveillance system being developed by the Progress Rocket Space Center[575] will feature a new high-speed secure radio channel and advanced optical systems. Three Razdan-class satellites are set to launch in 2019, 2022, and 2024.[576] The third satellite will be the first to carry a 2-m mirror optics.[577] The Razdan system is expected to replace the 14F137 Persona optical-electronic satellites, in use since 2008.[578]

In September, Moscow-based OKB MEI, a division of the RKS Corporation, announced that it had been working on a space-based antenna with an aperture of up to 24-m. An earlier description by the company indicates that it will be used for "all-weather, round-o'clock monitoring of the Earth surface and its air space, as well as for weapons guidance in order to 'provide informational superiority, particularly, during military conflicts.'"[579]

Figure 2.18 Russian dedicated military satellites launched in 2016[580]

Satellite Name	Operator	Primary function	Orbit	Launch date
Glonass 751	Ministry of Defense	Navigation/Global Positioning	MEO	07-Feb-16
BARS-M	Ministry of Defense	Earth Observation	LEO	24-Mar-16
Glonass 753	Ministry of Defense	Navigation/Global Positioning	MEO	29-May-16
GEO IK2	Ministry of Defense	Earth Science	LEO	05-Jun-16

China enhances access to reconnaissance and PNT capabilities

On 15 May, China launched the Yaogan-30 remote sensing satellite in LEO. According to the government, the satellite is used for experiments, land surveys, crop yield estimates, and disaster relief.[581] It is thought that this class of electro-optical observation satellites, based on the military Jianbing-6 series, could have military functions.[582]

China launched its second Ziyuan 3 spacecraft on 30 May. This remote sensing satellite is China's first stereoscopic mapping satellite, carrying three high-resolution panchromatic cameras and an infrared multispectral scanner.[583] The civilian satellite is operated by the Satellite Surveying and Mapping Application Center,[584] but could have military functions.

China launched three additional BeiDou-2 navigation satellites, bringing the total to 23 (see Indicator 2.1). The system is expected to provide regional service in 2018.

Figure 2.19 Chinese dedicated military satellites launched in 2016[585]

Satellite name	Operator	Primary function	Orbit	Launch date
BeiDou 3M-3S	Chinese Defense Ministry	Navigation/Global Positioning	MEO	01-Feb-16
BeiDou IGSO-6	Chinese Defense Ministry	Navigation/Global Positioning	GEO	30-Mar-16
Yaogan 30	People's Liberation Army	Earth Observation	LEO	15-May-16
BeiDou 2-23	Chinese Defense Ministry	Navigation/Global Positioning	GEO	12-Jun-16

Europe seeks to enhance cooperative, dual-use of space capabilities

In 2016, the European Commission published the Space Strategy for Europe, which promotes synergies between civilian and security activities[586] (see Indicator 4.1). Included were preparations for the next phase of the Governmental Satellite Communications initiative, begun in 2013 by partners EDA (European Defence Agency) and ESA to prepare the next generation of satellite communications.[587] According to EDA, "the aim of the GovSatCom initiative is to provide member states and European actors with appropriate capabilities through an innovative and sustainable cooperation model.... It further signals a new partnership not only between military and civil institutional actors, but also with industry."[588] Growing information exchange demands, increasingly networked capabilities, and significantly improved sensor technology are expected to lead to more demand for satellite communication capacity over the next decade.

In July, the EDA and the EU Satellite Centre identified specific areas of cooperation: imagery exploitation, geospatial analysis and applications, future space-based EO systems, cyber defense, Big Data exploitation in the space and security domain, space situational awareness, and maritime surveillance.[589] A joint roadmap will detail activities of common interest and will be updated annually.

Germany, United Kingdom, France look to next-generation military systems

Germany awarded Airbus Defence and Space, which has been operating the SATCOMBw system since 2006, a $153-million contract for the long-term operation of this secure satellite communications system. Included under this contract is the operation until 2022 of the military COMSATBw 1 and COMSATBw 2 satellites and their teleport and associated networks in Weilheim, Germany.[590]

The United Kingdom was exploring various options and had not decided if it would renew its $5.4-billion, 19-year Skynet 5 contract with Airbus Defence and Space, due to expire in 2022.[591] Skynet is a commercial system operated on behalf of the UK Ministry of Defence. The United Kingdom enhanced its military communications capability in southeast Asia by moving one of the Skynet 5A satellites into that region; a new ground station will be hosted by Australia.[592]

France planned future military space capabilities, including optical imaging, signals intelligence, and satellite communications capabilities.[593] The CERES (Space Signal Intelligence Capacity) ELINT satellite system, expected to include three closely positioned satellites to detect and locate ground signals, was scheduled for launch in 2020.[594] Two Comsat NG military communications satellites, contracted for in December 2015 to replace the Syracuse 3A and 3B satellites, are expected between 2020 and 2022.[595] Three new military observations satellites for the Composante Spatiale Optique (CSO, Optical Space Component) are to replace the Helios 2; the first is scheduled for a 2018 launch.[596]

India takes steps to formalize its military uses of outer space

Plans continued for the creation of a cross-service Defence Space Agency as an element of an integrated Cyber, Aerospace, and Special Operations Command.[597] Coordination of military and defense uses of India's civilian space assets was managed by the Integrated Space Cell of the Integrated Defence Services of the Department of Defence. Such assets were used to gather intelligence on purported terrorist bases in Pakistan-occupied Kashmir and to support subsequent military strikes.[598]

In June, India launched an EO Cartosat-2 series satellite, which will provide remote sensing services using panchromatic and multispectral cameras. Identified uses for the imagery included cartographic applications, urban and rural applications, coastal land use and regulation, and various Land Information System and Geographical Information System applications.[599] The satellite also has significant military value.[600]

Rising security tensions in Asia drive increased focus on military space

The DPRK conducted its second successful satellite launch in February, using a liquid-fuel Unha-type rocket to launch the Kwangmyongsong-4, which is described as a civilian weather satellite (see Indicator 2.2).[601] But the satellite appears to be non-functioning, and the UN condemned the use of an independent space launch vehicle in defiance of sanctions on both its nuclear and ballistic missile programs.

In 2015, Japan released its Basic Plan on Space Policy, which outlined its strategic goals for the next 10 years. Japan had planned to launch its first military communications satellite, Kirameki-1, in July, but it was damaged during transport to the launch site;[602] Kirameki-2 was launched first, in early January 2017. These satellites and one to come will replace three civilian satellites currently used by the military. The new satellites are expected to facilitate communication within the Self-Defense Forces through a high-speed, high-capacity network. Kirameki-2 will operate over the Indian Ocean and be used by SDF personnel in UN peacekeeping operations in South Sudan and the anti-piracy mission off the coast of Somalia.

The Republic of Korea is considering leasing a reconnaissance satellite, possibly from Israel, lessening its reliance on U.S. reconnaissance. A government official claimed that "the military is expected to have its own surveillance satellites as early as 2023 that will allow Seoul to closely monitor military activities in DPRK…. It is years behind the Defense Ministry's original schedule to deploy five surveillance satellites between 2021 and 2022 as part of the country's 'kill chain' strike system to deal with missile threats from the North."[603]

India plans to build a $23-million Centre for Satellite Tracking and Data Reception facility in Vietnam[604] to allow Vietnam access to Earth imagery and help India to track and receive data from its satellites.[605] It is also expected to allow India to observe developments in the South China Sea, where Vietnam has an ongoing dispute with China (see Indicator 2.3).[606]

Focus on military space capabilities emerges in the Middle East

In 2016, Turkey launched optical EO satellite Göktürk-1.[607] It was reportedly allocated to the Turkish Air Force's Reconnaissance Satellite Battalion, which will use the satellite for intelligence, surveillance, and reconnaissance.[608] The satellite is also expected to support civilian functions such as disaster response and law enforcement.

On 21 February, DigitalGlobe signed an agreement with TAQNIA, "a firm dedicated to accelerating technology development for the Kingdom of Saudi Arabia," and King Abdulaziz City for Science and Technology to develop six or more Earth-imaging satellites.[609] The predicted launch dates are in late 2018 or early 2019.

In May, Israel launched its next-generation Ofek 11 EO satellite[610] to provide the Israeli military with surveillance imagery of the Middle East region.[611] In April, Egypt contracted with Airbus Space Systems and Thales Alenia Space to build a military telecommunications satellite worth $633.4-million.[612] There were indications that Iran was preparing to launch an EO satellite on its new two-stage Simorgh launcher in early March 2016.[613] While a launch apparently occurred, it did not place a satellite into orbit.[614] Iran's space program is civilian (see Indicator 2.2), but is linked to regional security dynamics.

Canada, Australia continue to develop space-based military capabilities

On 17 June, Canada's defense minister Harjit S. Sajjan announced a $48.5-million contract for delivery of the Polar Epsilon 2 system, which will use imagery from the three-satellite RADARSAT Constellation Mission, to be launched in 2018, to deliver advanced surveillance capabilities for domestic and global Canadian armed forces operations. It will also provide Automatic Identification Systems data (see Indicator 2.1). The satellites will provide daily revisits of Canadian territory and maritime approaches, as well as daily access to 90% of the world's surface.[615]

Australia committed to strengthening its space surveillance and SSA capabilities in its 2016 White Paper on Defence. Australia and the United States will jointly operate the space surveillance C-band radar, and a U.S. optical space surveillance telescope will be relocated to Australia.[616] Additional investment is planned in Australia's military space capability, including space-based and ground-based intelligence, reconnaissance, and surveillance systems.[617]

U.S. military pursues international cooperation, adds space component to existing alliances

The Schriever Wargame held in May focused on critical space issues and resilience (see Indicator 3.2), including U.S. operations with allies. At the event were representatives from the other member states of the Five Eyes alliance (Australia, Canada, New Zealand, and the United Kingdom).[618] Early in the year the desire was expressed to expand dialogue on space security to Gulf Cooperation Council states.[619] Cooperation on global MILSATCOM with key international partners and commercial entities grew to enhance the resilience of communications architectures and keep up with demand for protected SATCOM and MILSATCOM capabilities.[620] In December, U.S. Secretary of Defense Ash Carter and Japanese Defense Minister Tomomi Inada confirmed progress, including the implementation of new joint defense guidelines that facilitate cooperation across several domains, including space and cyberspace.[621] The United States and India discussed options for exchanging SSA data and mechanisms for sharing satellite data related to Maritime Domain Awareness,[622] following a 2015 effort to strengthen their strategic partnership on space security.

Security of space systems

Indicator 3.1: Vulnerability of satellite communications, broadcast links, and ground stations

Satellites typically transmit data to ground stations and receive information from ground stations using radio waves. Computer networks coordinate the process. Ground stations, communications links, and computer systems are likely targets for space negation efforts, since they are vulnerable to a range of negation techniques. Technology to interfere with satellite radio communication is mature and widely available, even at a consumer level. The USAF's Counter Communications System, designed to block a potential enemy's satellite communication using radio frequency interference, became operational in 2004.[1]

Most electromagnetic interference with satellites remains inadvertent, but capabilities for purposeful interference and the number of interference events are growing. Interference and disruption fall into two broad categories: physical attacks and computer-system attacks. Physical attacks include spoofing and jamming, as well as ASATs and blinding a satellite's optics. Computer-system attacks affect the computing systems on the satellite by gaining unauthorized access to the satellite's instruments, bus, and data.[2]

Figure 3.1 Types of electronic interference with space systems

Common name	Description
Orbital jamming	A beam of contradictory signals directed toward a satellite, which then mixes, overriding legitimate signals and blocking their transmission.
Terrestrial jamming	Rather than target a satellite itself, terrestrial jamming directs rogue frequencies to ground-based targets, such as consumer-level satellite dishes, and distorts their transmission accordingly.
Hijacking	The unauthorized use of a satellite for transmission, or seizing control of a signal, such as a broadcast, and replacing it with another.
Spoofing	"Spoofers" are devices that create false GPS signals to fool receivers into thinking that they are at a different location and/or time.
Scanning	A process for identifying, attacking, and stealing information from a targeted host.

While much of the public and policy interest in satellite vulnerabilities is on kinetic antisatellite weapons (see Indicator 3.3), electromagnetic attacks on communications, GPS, and remote sensing satellites and transmission points are far more widespread. Not only do they offer lower technological barriers of entry for attackers, but such interference is frequently not publicly acknowledged or countered; additionally, these types of attack can be perceived by the user as being less escalatory and thus more acceptable.[3]

In 2015, U.S. military forces identified the Russian Krasukha-4 system in Ukraine and later in Syria.[4] The Krasukha-4 is a "broad-band multifunctional jamming system designed to neutralize Low-Earth Orbit (LEO) spy satellites such as the US Lacrosse/Onyx series, airborne surveillance radars and radar-guided ordinance at ranges between 150km to 300 km…by creating powerful jamming at the fundamental radar frequencies and other radio-emitting sources."[5] Turkey reportedly deployed its own Radar Electronic Attack System, which is similar to the Krasukha, on its border with Syria.[6]

Although the United States curtailed its electronic warfare program in 1994, the United States and NATO reportedly have access to electronic counter-countermeasures to combat electronic interference.[7] In March 2015, Deputy Secretary of Defense Robert Work revealed a plan to create an Electronic Warfare Programs council to make strategic recommendations for future capabilities.[8]

In 2015, U.S. Gen. Hyten announced that the USAF was developing a common Enterprise Ground Service (EGS) for national security satellite systems, to contribute to resiliency and survivability in the event of military confrontations in space.[9] The EGS will replace individual, custom-built ground systems.[10] Many commercial space systems, with only one operations center and one ground station, are particularly vulnerable to negation efforts. However, standardized protocols and communications equipment could allow alternative commercial ground stations to be brought online in the event of an attack.

Safeguarding satellite communication links requires specific electronic measures, which are generally not made public. One can assume that most space actors take advantage of simple but reasonably robust electronic protections, including 1) data encryption; 2) error protection coding to increase the amount of interference that can be tolerated before communications are disrupted; 3) directional antennas that reduce interception or jamming vulnerabilities, or antennas that utilize natural or human-made barriers as protection from line-of-sight electronic attacks; 4) shielding and radio emission control measures that reduce the radio energy that can be intercepted for surveillance or jamming purposes; and 5) robust encryption onboard satellites.[11] Advanced capabilities for encryption using quantum computing are being pursued in Canada, China, Japan, and the EU, but have yet to be successfully demonstrated from space.[12]

Civil and commercial communications links tend to have fewer protective features and vulnerabilities can ripple beyond civil and commercial operators, many of which provide communications services to the military. In September 2015, researchers from Kaspersky Lab, a cybersecurity firm in Moscow, discovered how Russian hacking group Turla ATP had been able to compromise unencrypted commercial satellite connections for close to a decade, siphoning off sensitive diplomatic and military data from the United States and Europe.[13]

Efforts are being made to better protect commercial and government satellite communications. In 2015, the USAF asked Boeing to add additional antijamming capabilities to satellites and made a call for "proposals for terminal modems that support a newly developed protected tactical waveform transmitted through its Wideband Global Satcom satellites."[14] The USAF has also been working with commercial partners to test its protected tactical waveform modem, intended to provide low-cost, protected communications connections for commercial systems commonly used by the U.S. DoD.[15]

The USAF operates an initial constellation of three AEHF communications satellites, described as "the only system presently on orbit that can protect 'against the full spectrum of threats.'"[16] Not only is it nuclear-hardened, but it is designed to prevent jamming, eavesdropping, and cyberattacks and does not rely on ground relay stations to transmit data between satellites. Upgrades planned for the U.S. JSpOC Mission System for SSA include new capabilities for real-time alerts of jamming or other hostile acts against U.S. space-based sensors (see Indicator 1.4).[17]

Laser-based communication, which is being developed as an alternative to satellite radio communication, could provide greater immunity from conventional jamming techniques and more rapid communications. Prominent programs such as the European Data Relay System focus on space-to-space communications, rather than more vulnerable space-to-Earth links.

Because the vast majority of space assets depend on cyber networks, the link between cyberspace and outer space constitutes a critical vulnerability. Beyond jamming satellite signals, cyberattacks most often target ground infrastructure, with efforts to take control of a satellite much rarer but possible. The U.S. Cyber Command (USCYBERCOM), which is responsible for the military's internet and other computer networks, reached Full Operational Capability in 2010.[18] But there is no coherent, global approach to cybersecurity in space, and the threat is constantly evolving.[19]

2016 Developments

Electromagnetic interference with satellite communications remains widespread

The Organization for Security and Co-operation in Europe (OSCE) reported GPS and other electronic interference by Russia with the OSCE mission in Ukraine.[20] The OSCE identified Russian jamming communication stations in Donbas that were designed to detect, analyze, and jam satellite and cellular phone communication systems.[21] There were indications that Russia's Krasukha-4 electronic warfare system, which can jam satellite radar systems, remained deployed in Ukraine and Syria[22] and reports that Russia continued to test a new electronic warfare system, the Radio-Electronic Technologies Concern.[23] In March 2016, Gen. John Hyten of USAF Space Command reported that, in addition to kinetic capabilities (see Indicator 3.3), adversaries were developing "directed-energy and cyber tools to deny, degrade, and destroy" U.S. space capabilities. Lt. Gen. David Buck, commander of the U.S. Joint Functional Component for Space, stated that China is developing a host of counterspace capabilities, including "terrestrially-based communications jammers."[24]

There were frequent reports of satellite jamming, cyberattacks, and communications breaches of both commercial and military satellites, as well as suspected attempts to interfere with satellite operations and functions, including GPS. There were numerous reports of DPRK jamming of GPS signals near its territory and along the De-Militarized Zone,[25] which included interference with air and maritime navigation systems that led to warnings from the U.S. Department of State.[26] Additional reports warned that spoofing of the Global Navigation Satellite System is likely to become just as severe and frequent as computer viruses, as more machines, appliances, and other systems make use of GPS, while many space assets and capabilities remain unprotected.[27]

The U.S. DoD and the U.S. Army prioritized the development of offensive electronic warfare capabilities, but no new system is anticipated before 2023.[28] Funding for electronic warfare, including improved GPS, was reduced from a request of over $12-million to just over $9-million in the National Defense Authorization Act, with $34.4-million allocated to the broad category of counterspace systems.[29]

In October, mobile applications that used GPS were reportedly malfunctioning throughout Moscow.[30] It was speculated that the disruption was linked to jamming operations to prevent the use of drones over Moscow.[31] Mitigation technologies have become a growth industry.[32]

United States enhances protected SATCOM

On 7 December, military satellite Wideband Global SATCOM (WGS)-8 was launched, with nearly double the capacity of any previous spacecraft in the series. WGS system upgrades will better protect communications from interference and signal jamming[33] by uplinking new operating software to the orbiting satellites, modifying ground segments, and using phased array antennas that enable operators to shape the beams and control power to avoid intentional or accidental interference. Raytheon Co. Space and Airborne Systems, L-3 Communications Systems, and ViaSat received contracts for protected tactical service demonstrations for the WGS SATCOM program. These contracts, to be completed by 2020, are to "demonstrate the ability to provide wideband anti-jam communications to tactical users using the Wideband SATCOM constellation and commercial SATCOM."[34]

In June, the USAF awarded Lockheed Martin Space Systems a $48-million contract modification to continue transitioning the AEHF satellite communication system to full operational capability. AEHF satellites provide secure, high-data-rate, jam-resistant global communications for high-priority assets of the United States and some international partners.[35]

Raytheon was awarded a $37-million contract to demonstrate new technology for the USAF's Protected Tactical Services Field Demonstration, which aims to improve anti-jamming capability for satellites. The hardware developed under the contract can be deployed as upgrades to existing satellite communications terminals.[36]

Ground stations demonstrate vulnerabilities to cyberattacks; industry pursues voluntary cybersecurity measures

Ground stations remain a vulnerable component of space systems, particularly to cyberattacks on computer systems. In May, a GAO report indicated that NOAA officials had cited 10 "medium and high severity incidents" in 2014 and 2015, including "hostile probes" and unauthorized access to NOAA's Joint Polar Satellite System (JPSS) ground stations.[37] The ground control software of the next-generation U.S. GPS III system remained vulnerable to attack.

Efforts to employ Raytheon's Operational Control System (OCX) to defend the GPS system against cyberattacks continued, despite significant delays and several years of setbacks that put the project grossly over budget.[38] Following a mandatory review (see Indicator 2.6), the U.S. Congress and the DoD determined that the program was essential to U.S. national security, and that no alternatives existed to carry out program requirements.[39] OCX is designed to provide highly secure ground stations for the next generation of GPS satellites. The stations include substantial improvements to mission assurance and cybersecurity against both external and internal attacks, and will be able to communicate with all U.S. satellites.[40] Initial operations have been delayed until 2021.[41]

The USAF requested $20-million in 2016 to develop a prototype capability for its Enterprise Ground Services program, intended to provide a common ground service for future national security spacecraft that is cybersecure and resilient, based on the experimental Multi-Mission Satellite Operations Center.[42]

In November 2016, the Satellite Industry Association and the Global VSAT forum issued a joint statement of the industry's commitment to improved cybersecurity of commercial systems through voluntary measures aimed at implementing best practices and information sharing.[43]

Laser-based communications between satellites advance

The focus for laser-based communications is currently restricted to communications between satellites in orbit. Laser beams are stronger and more robust than radio waves, which degrade in the atmosphere and are more susceptible to disruption.[44] ESA launched the first dedicated European Data Relay System satellite (EDRS-C) into GEO in January. The satellite uses lasers to gather information from EO satellites in LEO and communicate with airborne platforms, but communicates with ground stations using high-speed radio frequency links. The first laser transfer of an image from EDRS-C took place in June 2016.[45] EDRS went into service in November. A second satellite is slated for launch in 2018.[46] The EDRS laser technology was created by Airbus at a cost of €500-million ($543-million). The platform and air- and ground-based terminals have both commercial and military applications, including rapid data collection and transfer in response to natural disasters and other contingencies.[47] EDRS is part of the ESA's "Space Data Highway," which provides commercial service to the European Commission's Copernicus Sentinel EO satellites—a public-private partnership between the ESA and Airbus Defence and Space.[48]

NASA, which is developing a similar capability to support deep space exploration, demonstrated its first space-based laser communication system in 2013 with the Lunar Laser Communications Demonstration mission. The Laser Communications Relay Demonstration, set to launch in 2019, will provide a longer-term demonstration. NASA is also developing the Deep-Space Optical Communications system with a ground-test anticipated for 2017.[49]

DARPA is also exploring laser-based communications between satellites. It ordered two LGS Innovations prototype optical communications terminals to facilitate light-based communications between microsatellites in LEO.[50] The terminals will be jam-resistant. The use of laser-based systems for communication between satellites and ground stations continues to face challenges, particularly degradation through atmospheric turbulence and cloud cover[51] (see also Indicator 3.3).

China launches quantum entanglement experiment

China launched the Quantum Experiments at Space Scale (QUESS) satellite on 17 August 2016 to test the capability for quantum optics over long distances, which would allow the development of quantum encryption technology for communications secure from third-party hacking. The purpose of the satellite is to demonstrate quantum key distribution between the satellite and two ground stations.[52] If successful, the experiment could represent a sea-change in cryptography.[53] Research is also under way at the University of Waterloo in Canada, and at the ESA, to use quantum payloads in space.[54]

Indicator 3.2: Reconstitution and resilience of space systems

The capability to rapidly rebuild space systems in the wake of a space negation attack could reduce vulnerabilities in space. It is also assumed that space actors have the capability to rebuild satellite ground stations. The capability to refit space systems by launching new satellites into orbit in a timely manner to replace satellites damaged or destroyed by a potential attack is a critical resilience measure.

During the Cold War the USSR and the United States led in the development of economical launch vehicles. The USSR/Russia launched less expensive, less sophisticated, and shorter-lived satellites than those of the United States, but launched them far more often. In 2004, Russia conducted a large military exercise that included plans for the rapid launch of military satellites,[55] but there is no evidence that this capability has been developed.

The United States has made significant efforts to develop responsive space capabilities. The DARPA- USAF Force Application and Launch from the Continental U.S. (FALCON) program began in 2003 to develop and validate in-flight technologies for prompt global reach missions, while demonstrating affordable and responsive space lift.[56] SpaceX received funding for its Falcon-1 launch system under the FALCON Small Launch Vehicle program in 2004. Falcon-1 delivered Malaysia's RazakSAT into LEO on 15 July 2009.[57] After stalling in recent years, the hypersonic effort was revamped in 2015.[58] DARPA supports the Experimental Spaceplane (XS-1) first announced in 2013,[59] which is intended to use a hypersonic propulsion system. The goal is to develop reliable access to space through a rapid, reusable spacecraft capable of launching as many as 10 missions in 10 days for less than $5-million a flight.[60] DARPA cancelled its Airborne Launch Assist Space Access program in 2015, following explosions during tests of new rocket fuel.[61]

In 2007, the U.S. DoD Operationally Responsive Space (ORS) Office opened to coordinate the development of hardware and doctrine in support of ORS across the various agencies.[62] ORS-1, a microsatellite designed to provide continuous battlefield intelligence, surveillance, and reconnaissance, was launched in 2011.[63] The ORS-3 mission centered on developing alternative launch technologies for CubeSats and delivered 28 CubeSats into orbit on 20 November 2013.[64] The Office faced a setback in 2015 when its experimental, rail-launched Super Strypi launch vehicle failed minutes after takeoff.[65]

The concept for a U.S. Space Maneuver Vehicle or military space plane first emerged in the 1990s. The first technology demonstrators were the X-40 (USAF) and the X-37A (NASA/DARPA).[66] The X-37B unmanned, reusable spacecraft was first launched in April 2010. The USAF's two X-37B planes have flown four missions, with the last launch in 2015. The primary purpose of the 2015 launch was to test experimental payloads, including a more advanced, powerful, electric ion propulsion system that would enhance the flexibility, survivability, and longevity of spacecraft.[67]

China's Kuaizhou ("quick vessel") is being developed by CASIC in collaboration with the Harbin Institute of Technology. Kuaizhou is an integrated launch vehicle system with the ability to rapidly replace satellites in orbit. The Kuaizhou launcher is composed of three solid-fueled rocket stages and a liquid-fueled fourth stage that is part of the spacecraft it is launching.[68] Experts believe that the Kuaizhou rocket can launch from a wheeled mobile transporter within days of call-up. The mobility of the system allows the rocket to launch from many locations. It first launched in 2013 and again in 2014.[69]

India has been working on a Reusable Launch Vehicle[70] and capabilities to launch record-setting numbers of microsatellites on a single launch.[71]

Under development by military and commercial actors are distributed constellations of smaller, less expensive spacecraft that would seem to enhance security through redundancy and rapid replacement of assets. However, in 2014, the U.S. GAO highlighted limitations of the approach.[72] Further, the characteristics that might make attack against space assets less attractive can also make assets more difficult to track, and so inhibit transparency of activities in outer space.

Thus far, key actors such as the USAF have continued to rely mainly on large, complex satellites. In recent years, though, the USAF has conducted several studies on the design of future space systems, including a comprehensive Strategic Portfolio Review for Space in 2014.[73] The focus has been on "disaggregation"—the dispersion of space-based missions, functions, or sensors across multiple systems spanning one or more orbital planes, platforms, hosts, or domains.[74] This approach was expanded in the 2015 White Paper *Space Domain Mission Assurance: A Resilience Taxonomy*, with mission assurance having three components: defensive operations, resilience, and reconstitution. Resilience approaches include protection, proliferation, disaggregation, diversification, distribution, and deception.[75]

Space-based protection efforts based on robotic inspection, refueling, and servicing are becoming more feasible. NASA's Satellite Servicing Capabilities Office is working with the CSA on remote-controlled robots that service satellites on-orbit via the Robotic Refueling Mission.[76] DARPA is currently exploring the feasibility of such capabilities in GEO.[77] In 2015, the Phoenix program—a modular satellite architecture based on satlets[78]—was expanded to include the launch of a robotic servicing vehicle and a plan for commercialization.[79] Orbital ATK and U.S. Space have developed the Mission Extension Vehicle (MEV), which attaches to a satellite and takes over the attitude control and its propulsion needs, extending its life or allowing it to be moved to a different orbit.[80] Skycorp envisions a servicing spacecraft that attaches to a satellite in GEO that has exhausted all of its onboard propellant, and moves that satellite into a "graveyard" orbit several hundred kilometers above GEO.[81]

2016 Developments

U.S. focus on Space Mission Assurance continues emphasis on resilience

On 20 June, U.S. Space Command issued the Space Enterprise Vision, a blueprint for a more resilient space architecture.[82] Its principles and action plan complement the 2011 National Security Space Strategy, providing a more detailed set of specific activities to achieve a resilient space infrastructure. The interoperability of space infrastructure with other segments of the U.S. armed forces is emphasized.

More resilient space capabilities could deter enemy attacks.[83] Resilience involves distributing assets, diversifying among commercial and military space systems,[84] and disaggregating national security space systems to spread redundant capabilities across numerous platforms;[85] scheduling launches at regular intervals; and creating ground system and small satellite architectures capable of rapidly and autonomously reacting to threats.[86] The FY2017 defense budget request indicates that the USAF is pursuing this approach to satellite architecture for new communications and missile warning systems.[87]

In mid-2016, the USAF rolled out new doctrinal, organizational, technological, and training approaches under the Space Mission Force, an overarching initiative intended to "prepare and present space forces as a ready force capable of operating in a contested, degraded, and operationally-limited environment"[88] (see Indicators 2.5 and 4.1).

In late 2015, the JICSpOC was tasked to develop, test, validate, and integrate new space system tactics, techniques, and procedures in support of DoD and intelligence community operations, to enhance operational command and control within DoD, and improve the U.S. ability to protect and defend space infrastructure.[89] JICSpOC is capable of monitoring the status of U.S. satellites to determine if they are being deliberately jammed or under physical attack.[90] In addition to simulation, JICSpOC has conducted live experiments with satellites that included maneuver operations.[91] The prototypes tested at JICSpOC include new C2 systems to improve unity of effort between the DoD and intelligence community.[92] Since October, JICSpOC has reportedly been running five rounds of experiments that would determine DoD responses to hostile actions in space.[93] JICSpOC initially received $16-million in FY2015; in July, the Pentagon asked for an additional $30-million.[94]

In February 2016, Secretary of Defense Ash Carter said that DoD would spend more in 2017 and 2018 on "securing" space operations.[95]

Several countries continue work on reusable and rapid-response launch systems

Rapid and reusable launch capabilities can make the replacement of components easier and more cost effective, and facilitate the launch of distributed constellations/systems. China's 2015 "Made in China 2025" initiative prioritizes a "reusable space-earth transportation system" and indicates that "priorities will be given to new-generation launch systems including…low-cost rapid-response launch vehicles."[96] A prototype model to test landing subsystems and complete experimental verifications has been built; however, Ma Zhibin of CALT noted that it could take “a considerably longer time before reusable launch vehicles could replace the current expendable rockets for good.”[97]

Commercial company CASIC Rocket Technology Co, Ltd. (renamed Expace)[98] was established on 16 February[99] to promote the use of China’s rapid-launch Kuaizhou rocket. The company expects to launch 10 Kuaizhou-1A rockets a year between 2017 and 2020 at a price of $10,000/kg of satellite payload, with the first commercial launch in 2017 valued at $14.5-million.[100] The KZ-1A inherited the basic design of the Kuaizhou launch system, with three solid-fueled stages and a liquid upper stage, but does not have the payload integrated with the launch vehicle’s fourth stage.[101] CASIC is also developing the KZ-11 for the commercial satellite market; it features a solid rocket that is 2.2-m in diameter and can place up to 10,000 kg in SSO. It is mobile launched and has a rapid launch capability. The first launch of KZ-11 was planned for 2017.[102]

On 10 November, China conducted the second launch of its Long March 11 rocket, carrying a group of five satellites.[103] First launched in September 2015, the Long March 11 is a small, solid-fueled quick-reaction launch vehicle developed by CALT.[104] It can be stored for extended periods to provide reliable launch on short notice.

India successfully launched a technology demonstration of its experimental reusable spaceplane on 23 May; a scaled prototype of the Reusable Launch Vehicle, the plane is 6.5-m long and able to achieve an altitude of 70 km. The flight was the first of a four-flight test sequence that will demonstrate the Hypersonic Flight Experiment, the Landing Experiment, the Return Flight Experiment, and the Scramjet Propulsion Experiment.[105] The vehicle will take at least 10 to 15 years to develop.[106]

In April, DARPA announced Phases 2 and 3 of its XS-1 project.[107] The project supports rapid deployment and reconstitution of small satellite constellations, enabling a more survivable disaggregated space architecture. It aims to be able to launch 100 small satellites in 10 days for $50-milliion. Phases 2 and 3 will move the program toward the test flights expected in 2019-2020. The vehicle must be capable of placing a 408-kg payload into LEO and be scalable up to 1,360-kg payloads using an expendable upper stage; it is intended to fly Mach 10+ at least once and stage at high Mach to minimize the size and cost of its upper stage.[108] In late 2016, DARPA awarded Phase 2 contracts to Boeing, Northrop Grumman, and Masten Space Systems; selected contractors will be required to match DARPA funding.[109]

The fourth USAF X-37B experimental spaceplane (OTV-4) marked a year in orbit on 20 May and continued to fly for the rest of the year.[110]

Civil and commercial on-orbit satellite servicing capabilities advance

In February, NASA’s Visual Inspection Poseable Invertebrate Robot inspected Canadarm 2 aboard the ISS.[111] Launched in 2015 as part of NASA’s Robotic Refueling Mission, this robot is designed to deliver near- and mid-range inspection capabilities in space; it can extend and navigate its miniaturized camera through openings as small as an inch in diameter to examine hardware.[112]

NASA’s Satellite Servicing Capabilities Office focused on the development of key technologies critical to in-space robotic servicing, identifying and developing new and innovative solutions for in-space servicing.[113] NASA issued a pre-solicitation notice for the Restore-L spacecraft bus—a spacecraft that will rendezvous with, grapple, refuel, and relocate a live satellite.[114]

On 5 December, NASA awarded a contract to Space Systems Loral to supply the chassis, hardware, and services for the mission. The three-year contract has a maximum value of $127-million and includes a two-year indefinite delivery/quantity portion.[115] NASA plans to refuel Landsat 7, a U.S. EO satellite in LEO, during the Restore-L mission.[116]

Orbital ATK signed up Intelsat as the first customer of its Mission Extension Vehicle (see above). In June, the spacecraft underwent its first system design review and in October, Orbital ATK secured a launch contract for its first mission in 2018 to GEO, where it will dock with multiple aging Intelsat communications satellites, keep their telecom stations pointed correctly, and potentially push them into new positions to cover different regions. Intelsat has agreed to use MEV-1 for five years, although MEV has enough fuel to operate for 10 to 15 years. Orbital ATK has plans to scale up the MEV program, adding up to five vehicles, and has a government contract to study the possibility of replacing payload packages or solar arrays.[117]

DARPA launched its Robotic Servicing of Geosynchronous Satellites program in March. DARPA and the Naval Research Lab[118] have developed the FREND (Front-end Robotics Enabling Near-term Demonstration) robotic arm, a critical element of a robotic servicing vehicle.[119] Constructed to enable automated, cooperative connections to satellites that are not designed for docking, the FREND arm can carry and switch among multiple generic and mission-specific tools. DARPA will add advanced algorithms for machine vision and supervised autonomous robotic operations to the arm.[120] DARPA held a proposer's day in December, intending to award a contract in early 2017.[121] Demonstrations are expected within five years.

China prioritized plans to "build in-orbit servicing and maintenance systems for spacecraft" in its 2016 White Paper on Space Activities.[122]

Efforts continue to build resilience through alternatives to space-based GPS

The FY2017 NDAA called for a report on requirements to "backup and complement the PNT capabilities of the Global Positioning System for national security and critical infrastructure."[123]

For FY2016, the U.S. Navy solicited proposals to "develop innovative systems that allow for affordable, robust, alternative forms of radiofrequency (RF) based Positioning, Navigation and Timing (PNT), providing an available substitute in environments where the Global Positioning System (GPS) functionality is degraded or completely denied." Contract winner Charles River Analytics, Inc. proposed to design a Stealthy RF-based Alternative PNT that will utilize an RF-based localization technology that is jam-resistant, GPS-independent, and as accurate as GPS.[124]

In May, Iridium Communications introduced its Satellite Time and Location (STL) service. The technology, fit in a chipset about the size of a postage stamp, can be embedded into many satellite systems and will be supported by the Iridium NEXT satellite constellation, which is scheduled for completion by late 2017.[125] STL delivers a unique code to each position on the ground that allows operation or access only if the user is in the expected location[126] and could make spoofing of GPS systems more difficult (see Indicator 3.1).

eLoran is a ground-based PNT system that can back up GPS, Galileo, and other space-based PNT systems. In 2016, France, Norway, Germany, and Denmark closed their eLoran transmitters; France and Germany claimed that with the navigation system Galileo, eLoran was not needed.[127] The General Lighthouse Authorities of the UK and Ireland expected to begin decommissioning stations. But in the United States, on 19 April, the Department of Homeland Security successfully demonstrated the eLoran system. Cooperating in eLoran R&D are the U.S. Coast Guard, UrsaNav Inc, and Harris Corporation.[128] On 27 September, the U.S. House of Representatives passed the Coast Guard and Maritime Transportation Amendments Act of 2016, which would require the Coast Guard to develop a reliable ground-based PNT system (eLoran) within three years.[129] The bill then went to the Senate's Committee on Commerce, Science, and Transportation.[130] Under the current U.S. Space-Based Positioning, Navigation, and Timing Policy, the Secretary of Transportation is tasked, in coordination with the Secretary of Homeland Security, to "develop, acquire, operate, and maintain backup position, navigation, and timing capabilities that can support critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the United States."[131]

In June, Norway indicated that it was in "constructive dialogue" with an English company to use infrastructure for Loran C and did not intend to dismantle its shutdown Loran stations.[132]

United States enhances capabilities to detect threats to space-based systems

The Space-Based Infrared System supports missile early warning, missile defense, battlespace awareness, and technical intelligence missions. Four current-generation satellites will launch between 2017 and 2021[133] and the next-generation SBIRS could begin launching in the mid-2020s. The USAF plans to launch the next Space Based Space Surveillance system in 2021 to track space objects, primarily satellites, in geosynchronous orbit (see Indicator 1.4).[134]

DARPA's Space Surveillance Telescope was turned over to the USAF on 18 October to begin its operational phase (see also Indicator 1.4). SST will provide key SSA information from the southern hemisphere, which has been under-observed.[135] It provides clear imagery across its wide field of view, has the fastest telescope camera shutter in the world, and is able to take thousands of pictures as it surveys the entire geosynchronous belt multiple times a night. It is able to track, identify, and predict the actions of satellites in orbit.[136]

U.S. DoD and NRO experiment with CubeSats

The U.S. Army's Space and Missile Defense Command continued research to determine if constellations of CubeSats could improve voice and data communications for troops or support ISR operations by providing images of targets on the ground in multiple wavelengths. In 2010, this Army flew five satellites as part of SMDC-ONE, showcasing over-the-horizon communications, including voice, text message, and data. Three technology demonstration CubeSats are still functioning.

In September, the Army announced that it was considering a constellation of 16 CubeSats in LEO for telecommunications services. Army Global on the Move Satcom (ARGOS) would determine if small-satellite constellations could practically support the telecommunications needs of ground forces.[137] ARGOS would service the U.S. Southern Command, Africa Command, and Pacific Command.

Army Earth-imaging nanosatellites Kestrel Eye 1 and 2 are scheduled for launch in 2017. Kestrel Eye 1, with 1.5-m resolution, is intended to demonstrate a tactical space-based imagery nanosat that could be proliferated in large numbers to provide a persistent capability to ground forces.[138] It was originally intended to fly in 2011. Kestrel Eye 2 is meant to demonstrate the application of low-cost, commercial technologies to enable a new tier of reconnaissance capability.

On 18 May, NRO director Betty Sapp said, "Cubesats, smaller sats, combined with affordable launch, are a huge enabler for us."[139] On 11 November, seven NRO CubeSats were launched on the DigitalGlobe WorldView-4 mission. All contribute to these demonstrations: AeroCube-8 demonstrates an electronic propulsion system; RAVAN measures Earth's radiation imbalance; CELTEE (Clean Energy Low Temperature Emissions-Free Engine) is a demonstration of a transponder developed using Low-SWaP (Size, Weight, and Power) tracking technology; OptiCube provides a target for Earth-based equipment to calibrate their sensors; and a DoD Nanosat Project experiment explores over-the-horizon communication capabilities.[140]

As part of its effort to build the Future Ground Architecture announced in 2015, the NRO began deploying prototypes of next-generation ground systems capable of autonomously directing space-based intelligence collection assets in response to targets of interest.[141] NRO is seeking the capability to adjust to new threats, enhance space-based capabilities as needed without launching new assets, and improve delivery of services. In 2015, Sapp described an experiment known as Sentient, which demonstrated automated tipping and cueing from one sensor to another.[142] Sentient was among the prototypes that were "driving operations" in 2016.[143]

United States looks for deeper space system integration with international partners

The 2016 Schriever Wargame aimed to discover how to increase space system resilience across the intelligence community, how to provide optimized support to the warfighter in coalition operations, and how to protect the security space architecture in a multi-domain conflict.[144] Approximately 200 military and civilian experts from more than 27 U.S. commands and agencies participated, as well as several allied nations, including France and, for the first time, Germany. Wargame director Jason Altchek said that partners voiced many legal and policy concerns and indicated that DoD leadership is aware of policy gaps.[145]

On 14 April, the DoD indicated that the Pentagon might allow the transfer of certain space capabilities to international partners to support space system resiliency, and was considering using international navigation satellites to guide U.S. weapons in the event that GPS satellites were jammed or unavailable.[146]

In 2015, the United States and Norway submitted requests to access the encrypted, government-only public regulated service offered by Europe's Galileo PNT system.[147] In June 2016, the EU Council authorized negotiations with both countries;[148] negotiations were ongoing at the end of the year. In November, a USAF spokesperson indicated that international partnership would be a key feature in space system resilience: "If we can move between our own milsatcom capabilities, commercial capabilities and allied capabilities, it makes it difficult for our adversaries to know where we are." The DoD asked 16 allied governments to take part in the Wideband Analysis of Alternatives "to assess how the U.S. military will address an expected shortfall in wideband capacity."[149]

Indicator 3.3: Earth-based capabilities to attack satellites

Ground-based anti-satellite weapons employing conventional, nuclear, and directed energy capabilities date back to the Cold War, but no hostile use of them has been recorded. Launching a payload to coincide with the passage of a satellite in orbit is the fundamental requirement for a conventional anti-satellite capability. Tracking capabilities would allow a payload of metal pellets or gravel to be launched into the path of a satellite by rockets or missiles (such as a SCUD missile).[150] Kinetic hit-to-kill technology, which involves destruction of a target as a result of collision with an interceptor, requires more advanced sensors to reach the target. Targeting satellites from the ground using any of these methods has been described as more cost-effective and reliable than space-based options.[151]Significant capabilities have been developed outside of dedicated ASAT programs.

The U.S. Army invested in ground-based kinetic energy ASAT technology in the late 1980s and early 1990s. The Kinetic Energy ASAT program was terminated in 1993, but later granted funding from FY1996 through FY2005.[152]

Today the development and testing of capabilities that could be used to intercept space-based targets occur primarily via midcourse ballistic missile defense systems, which intercept incoming missiles in space (exoatmospheric). The United States has deployed a limited number of ground-based exoatmospheric kill vehicle (EKV) interceptors, including the Aegis (Sea-Based Midcourse) and Ground-Based Midcourse Defense Systems.[153] EKVs use infrared sensors to detect ballistic missiles in midcourse and maneuver into the trajectory of the missile.[154] With limited modification, the EKV may be used against satellites in LEO.[155] In 2008, the United States reconfigured a Standard Missile (SM)-3 anti-missile to destroy failing satellite USA-193 as it deorbited. The United States has stressed that this was a "one-time event,"[156] not part of an ASAT development and testing program.

The SM-3 Block 2A missile, which is being developed and tested with Japan, has greater range and velocity, a more sensitive seeker, and improved divert capability than legacy SM-3s and will be capable of reaching higher altitudes in outer space.[157]

Between 1984 and 1989, the Soviet Union worked on an air-launched direct ascent ASAT system known as Kontakt.[158] Russia later developed a long-range (350-km) exoatmospheric missile, the Gorgon, for its A-135 anti-ballistic missile system.[159] In 2013, the Russian Duma reportedly called for the Russian military to restart the Kontakt program.[160] On 18 November 2015, Russia conducted a successful test of its Nudol ground-launched, direct-ascent ASAT system, designed to conduct kinetic energy attacks against LEO satellites.[161] Nudol, which is being developed by the Almaz-Antey Air Defense Concern, could have modified anti-satellite capabilities similar to those demonstrated by the U.S. SM-3.[162] Russian state media described the mobile transporter-launcher as "a new Russian long-range missile defense and space defense intercept complex," which is "being developed within the scope of the Nudol OKR [experimental development project]."[163] Russia has reportedly resumed development of an air-based anti-satellite system.[164]

China has developed an advanced hit-to-kill capability, demonstrated by its intentional destruction of a Chinese weather satellite in 2007.[165] China called the event an experiment, not an anti-satellite test.[166] Although China has not since intercepted a satellite, the system that brought down the satellite was launched again in 2010 and 2014 as "a test of land-based anti-missile technologies."[167] In 2013, China launched the Dong-Neng (DN-2) rocket, which is able to reach altitudes as high as GEO. [168] In 2015, China reportedly conducted a "final-phase missile interception test…in the upper atmosphere"[169] of a third possible system, identified by U.S. military sources as the Dong Neng-3 (DN-3).[170] Like the SC-19 used in 2007, the DN-3 appears to use a road-mobile launcher, which would be more useful against satellites.[171]

The UK, Israel, and India have explored techniques for exoatmospheric interceptors.[172] Japan is an important international partner of the United States on ballistic missile defense and has its own Aegis system.

A nuclear weapon detonated in space would generate an electromagnetic pulse that would be highly destructive to unprotected satellites, as demonstrated by the U.S. 1962 Starfish Prime test.[173] Given the current global dependence on satellites, such an attack could be devastating. Detonation of a nuclear weapon in space would violate the Comprehensive Test Ban Treaty. Both the United States and USSR explored nuclear-tipped missiles as missile defense interceptors and ASAT weapons. The Russian Galosh ballistic missile defense system surrounding Moscow employed nuclear-tipped interceptors from the early 1960s through the 1990s. The system continues to be operated,[174] but it is not clear if it still uses nuclear interceptors.

Russia's Almaz-Antey and China's Poly Group Corp. are world leaders in laser technology.[175] High-energy laser capabilities have matured and diversified rapidly,[176] but steep hurdles must still be overcome before terrestrial deployment is a reality. To damage the structure of a satellite with a directed energy system, a weapon must have not only high power (100 kW or more), but a mirror to track the satellite and adaptive optics to maintain cohesion of the laser beam as it travels through the atmosphere.[177]

Chemical lasers are the only systems that have produced megawatt-level power, but their fuel is toxic and they rely on access to an independent power source. Electrically powered solid-state lasers are easier to use, but produce less energy.[178] Adaptive optics research and development have been conducted by Canada, China, India, Japan, Russia, and the United States.[179]

Most directed energy systems are being developed for missile defense and anti-drone applications. The Boeing YAL-1 Airborne Laser Test Bed (ALTB) for the USAF was primarily designed as a missile defense system to destroy tactical ballistic missiles in boost phase[180] and may have ASAT capabilities.[181] The program was initiated in 1996 and developed over 12 years at a cost of $5-billion.[182] On 3 and 11 February 2010, the ALTB system successfully destroyed threat-representative ballistic missiles in flight.[183] The program was cancelled in 2011.[184] In 2015, the MDA resurrected ideas of using electric. solid state, high-energy lasers in boost-phase missile defense. However, at least a tenfold increase in power capabilities is required for deployment at an altitude high enough to ensure safety of the drone and to cope with atmospheric conditions.[185] DARPA's High Energy Liquid Laser Area Defense System (HELLADS) has demonstrated sufficient laser power and beam quality to advance to field tests that use the 150-kW laser against rockets, mortars, vehicles, and surrogate surface-to-air missiles.[186]

In a September 2015 defense and security expo, German defense contractor Rheinmetall Defense Electronics unveiled a sea-based anti-drone laser system with four 20-kW lasers that combine into a single 80-kW beam.[187] India, Russia, and China are believed to be pursuing similar capabilities.[188] There were reports in 2012 that Russia planned to modernize and refurbish their A-60 testbed aircraft to disable sensors and optical electronic systems by directed laser beam impulse.[189]

Low-powered lasers have been used to "dazzle" or degrade unhardened sensors on satellites in LEO.[190] In 1997, in preparation for a test of the megawatt U.S. Mid-Infrared Advanced Chemical Laser, a 30-watt laser was used for the alignment and tracking of a target satellite, unexpectedly damaging the satellite's sensors.[191] This suggests that even a commercially available low-watt laser functioning from the ground could be used to "dazzle" or temporarily disrupt a satellite.

Figure 3.2 Technologies required to develop ground-based capabilities to attack satellites

Capabilities	Conventional			Directed energy			Nuclear
	Pellet cloud ASAT	Kinetic-kill ASAT	Explosive ASAT	Laser dazzling	Laser blinding	Laser heat-to-kill	High altitude nuclear detonation
Suborbital launch	■	■	■				■
Orbital launch	■	■	■				■
Precision position/ maneuverability		■					
Precision pointing				■	■	■	
Precision space tracking (uncooperative)	■	■			■	■	
Approximate space tracking (uncooperative)			■	■			■
Nuclear weapons							■
Lasers > 1 W				■			
Lasers > 1 kW					■		
Lasers > 100 kW						■	
Autonomous tracking/ homing		■					

Key: ■ = enabling capability

2016 Developments

Development and testing of exoatmospheric anti-missile technology continues

It does not appear that any current technology has an operationally reliable system capable of targeting objects in space. On 25 May, Russia reportedly conducted a test of the A-235 ballistic missile defense system, which includes radar and ground systems that support the Nudol missile (see above).[192] Another test took place on 21 June,[193] with a third possibly conduted on 16 December.[194] It is not known if the missiles reached outer space. A-235 missiles are capable of operating at long-range, reaching a distance of 1,500 km or 800,000 m in height; medium-range, hitting targets as far away as 1,000 km and as high as 120,000 m; and a short range of 350 km, with a flight ceiling of 40,000-50,000 m.[195]

In December, Western media reported that China was preparing to carry out a test of the Dong Neng anti-missile system (see above). On 7 and 8 December, China announced the closure of air space near the Jiuquan and Korla launch facilities.[196] Satellite imagery suggested activity at the Jiuquan facility.[197]

The U.S. Ground-based Midcourse Defense (GMD) system, which uses exoatmospheric kill vehicles, carried out a non-intercept flight test on 28 January 2016.[198] The interceptor was to fly within a narrow "miss distance" of its target to test new thrusters, but one of the four thrusters failed, causing the interceptor to go off its intended course.[199] Five intercept and one non-intercept tests of the system are planned between 2016 and 2021.[200]

Work continued on the Common Kill Vehicle (CKV) program, a two-phase effort to develop strategies and technologies for the next generation of EKVs. While plans include a first test flight in 2019,[201] a GAO report has called this schedule "aggressive," since the system relies on "less mature technologies that have only been validated in a laboratory or simulated environment" and unproven commercial off-the-shelf components.[202]

In February, it was reported that the Navy will reduce the number of SM-3 Block IB missiles it procures from 52 in FY2017 to about 35 in FY2020, partly because of ongoing problems with the missile's third-stage booster. Plans to extend the service life of Block IA interceptors from eight to 12 years were announced in April.[203] The SM-3 Block IIA variant is being developed in collaboration with Japan (see above). Production of the interceptor could begin as early as 2017, with deployment on land and at sea in 2018. Two intercept flight tests of the SM-3 Block IIA were postponed from the second half of 2016 to 2017.[204]

Israel's Arrow-3, a U.S.-Israeli system designed to intercept medium-range ballistic missiles, underwent several tests in 2016. It is capable of exoatmospheric intercepts, with a reported range of up to 2,400 km, using a kill vehicle that can maneuver to intercept its target.[205] The United States contributed $89-million to its development in FY2016, with $55-million planned for FY2017.[206]

Interest renewed in directed energy applications, but capabilities against space objects nascent

Lasers have in the past been used against objects in space and have been elements of dedicated weapons programs. Recently, there has been renewed interest in Earth-based high-energy laser systems as weapons, including in missile defense. In 2016, the MDA continued to develop options for future use of high-energy laser systems for ballistic missile defense, and reported "two promising, high-energy laser candidates: the Diode Pumped Alkali Laser system and the Fiber Combining Laser system. In the 2025 timeframe, [the goal is] to integrate a compact, efficient, high power laser into a high-altitude, long endurance aircraft capable of carrying that laser and destroying threat missiles in the boost phase."[207] The first system "combines features of both gas and solid-state lasers, based on diode excitation of atomic alkali vapors," facilitating "extreme power scaling with good efficiency and beam quality."[208] Fiber-combining systems allow the power of fiber lasers to be scaled up. So far, these systems have not reached powers beyond 50 kW when tested.[209] Technologies from the ALTB, cancelled in 2011, have been resurrected for use in high-altitude unmanned aerial vehicles (UAVs) for boost-phase missile defense, using high-energy lasers.[210] Plans exist for a low-energy flight test by 2020, with beam stability testing in 2021. In 2016, MDA awarded five contracts for concepts of an airborne low-power demonstrator.[211] The 2016 NDAA "requires the DOD to establish a new position for a senior official with principal responsibility for directed energy weapons."[212]

The U.S. Army intended to allocate between $17-million and $30-million per year from 2017 to 2021 on High Energy Laser weapon technology.[213] In 2016, the Army was developing "ruggedization"—modifications of the laser system to withstand vibration, temperature, and contamination—of the 50-kW laser's components and its command, control, and computer subsystems.[214]

The U.S. Navy hoped to release a directed energy weapon roadmap early in 2016, but it had not been released by November.[215] The Pentagon is developing an across-the-services plan for directed energy and radio-frequency weapons.[216]

In February, the German military successfully tested Rheinmetall's high-energy laser effector aboard a German warship.[217] The Oerlikon Skyshield consists of a 10-kW fiber high-energy laser and a beam-forming unit. Beam-superimposing technology concentrates the power of single laser beams to produce "almost unlimited (e.g. 100-kW and more) power output."[218]

Russia prepared to renew flight testing of a flying laser system capable of dazzling or damaging satellite sensor components in LEO. Sokol Eshelon is a resurrection of a legacy program that began in the 1980s, but was terminated in 2011.[219]

It appears that China is continuing research on electromagnetic and microwave weapons, possibly for use against objects in space.[220] China is developing laser weapons for terrestrial uses, but Western countries currently have the technological edge.[221]

An October 2016 report by research firm Markets and Markets[222] projected that the market for fiber lasers, one category of directed-energy weapon, would rise from $6.9-billion in 2016 to $24.5-billion in 2021. However, significant challenges remain in using high-energy lasers against objects in space. Efforts by the USAF to develop their own airborne system "have faced extreme challenges with aeromechanical jitter and shooting lasers through the atmosphere."[223]

Researchers at the University of California, Santa Barbara continued work on DE-STAR (Directed Energy System for Targeting of Asteroids and exploRation), "a large phased-array laser in Earth orbit" capable of deflecting asteroids, comets, and other NEOs that pose a credible risk of impact (see Indicator 1.3).[224] The laser would heat the target's surface to a point of high surface vapor pressure, causing significant mass ejection that would form a plume of material that would act as a rocket to deflect the object. A smaller system, DE-STARLITE, could travel alongside the target, slowly deflecting it over a long period.[225]

Indicator 3.4: Space-based negation-enabling capabilities

A space-based ASAT program using kinetic-kill, directed energy, or conventional explosive techniques would require foundational technologies, including maneuverability, docking, and onboard optics. No hostile use of space-based ASATs has been recorded. Tests of space-based systems that could have residual ASAT capabilities must be distinguished from tests of weapons systems that are designed to provide specific, operationally useful military capabilities.

The Soviet Union developed a co-orbital ASAT system that used a space launch vehicle to place an interceptor into orbit; the interceptor could then maneuver to collide with or pass near the target.[226] The Soviet Union/Russia has observed a voluntary moratorium on anti-satellite tests since its last test in 1982.

The U.S. MDA's Near-Field Infrared Experiment was a satellite expected to employ a kill vehicle that would encounter a ballistic missile at close range. It was cancelled in 2005.[227]

Most enabling capabilities for space-based negation have other primary purposes. "Space mines"—space-based weapons targeting satellites with conventional explosives—could employ microsatellites to maneuver near a satellite and explode within close range.

Microsatellites are relatively inexpensive to develop and launch and have a long lifespan; their intended purpose is difficult to determine until detonation.

Many of the enabling technologies for space-based servicing, repair, and inspection could also be used in space-based negation efforts, particularly with advancements in non-cooperative rendezvous and docking (see Indicator 3.2).[228] More recent applications include satellite formation flying, on-orbit satellite servicing and refuelling, and some of the proposed methods for actively removing space debris from orbit.[229] These activities, if not conducted transparently, might be seen as threats to space security. Technology development for space debris removal has raised similar concerns (see Indicator 1.1).

The USAF Experimental Spacecraft System employed microsatellites to test proximity operations, including autonomous rendezvous, maneuvering, and close-up inspection of a target. XSS-11 was launched in 2005 and flew successful repeat rendezvous maneuvers. In 2006, the United States launched a pair of Micro-satellite Technology Experiment (MiTEx) satellites into an unknown geostationary transfer orbit. A major goal of the MiTEx demonstrations was to assess the potential of small satellites in GEO for defense applications.[230] In January 2009, the Pentagon confirmed that the two MiTEx microsatellites had maneuvered into close proximity with a failing satellite in GEO.[231] This incident elicited concerns that the ability to achieve such proximity could be used for hostile actions.[232]

Four GSSAP satellites launched by the USAF in 2014 and 2016 have the capability to perform rendezvous and proximity operations with non-cooperative satellites and to maneuver widely through geostationary orbit (see Indicator 1.4).[233] The satellites' primary purpose, space situational awareness (see also Indicator 1.4 and 3.2), is achieved through an ability to approach and observe non-cooperative satellites by maneuvering widely through geostationary orbit, and propelling and operating in close proximity to other satellites.[234] The Automated Navigation and Guidance Experiment for Local Space (ANGELS) program is also testing maneuverability capabilities (see Indicator 2.6).[235]

Russia's Kosmos 2491 and 2499 were launched in 2014 and Kosmos 2504 in 2015.[236] These satellites have been observed conducting proximity operations with the Briz-M upper stage of the launch vehicle.[237] Roscosmos asserted that the maneuvers were peaceful;[238] there are no reports that these satellites approached any active satellites.[239] But in 2015, Russian satellite Luch/Olymp drifted considerably throughout the year, coming within 5 km of another satellite on at least three occasions (anything less than 10 km is considered unsafe).[240] Maneuvering in space could support a number of functions, including spying, anti-satellite missions, recovery and repair of a broken satellite, and clearing satellite junk out of orbit.[241]

China demonstrated advanced maneuverability and rendezvous capabilities in 2008 and 2010.[242] In 2014, Shijian 15 and Shiyan 7 satellites launched in 2013,[243] performed multiple maneuvers; Shiyan 7 then maneuvered to rendezvous with Shijian 7, a Chinese satellite launched in 2005.[244]

Space control emerged as a central U.S. security focus in 2014. In 2015, the NDAA for FY2016 called for the establishment of an integrated policy to deter adversaries in space that includes "protecting and preserving the rights, access, capabilities, use, and freedom of action of the United States in space and the right of the United States to respond to an attack in space and, if necessary, deny adversaries the use of space capabilities hostile to the national interests of the United States."[245] The FY2016 budget included $2-billion for "space control" to address threats to U.S. space systems.[246]

2016 Developments

U.S. Congress opens door for possible space-based missile defense, options to defeat space-based threats

Following direction from Congress in the 2015 NDAA to the MDA and DARPA to develop a concept for a space-based ballistic missile intercept component for boost-phase missile defense, the 2016 NDAA authorized the DoD to begin "research, development, test and evaluation" of space-based systems for missile defense, and to explore the feasibility of defeating space-based threats to U.S. space systems.[247] This marks a continued interest on the part of U.S. lawmakers in pursuing weapons and other space negations systems in space, which is reportedly inspired by the strategic defense initiative of the 1980s.[248] However, a 2012 study published by the National Academy estimated that deployment of even a minimal system would cost about $200-billion, and billions more to operate.[249] The 2016 Act provided $20.7-million for space BMD programs, separate from existing missile sensing and tracking programs (see Indicator 2.6).[250]

Military, civilian, and commercial actors demonstrate advanced capabilities for on-orbit maneuvering and proximity operations

Various technologies that could enable space-based negation evolved, with varying levels of transparency.

On 19 August, two GSSAP satellites were launched and placed in a near-geosynchronous orbit 22,000 miles above Earth.[251] Their primary function is to provide close-up inspection of spacecraft in GEO (see Indicator 1.4), which requires not only the ability to maneuver widely through geostationary orbit, but advanced precision capabilities to propel and safely operate in close proximity to other satellites.[252] The GSSAP system provided inspection imagery of the U.S. Navy's MUOS-5 satellite, which suffered the failure of its primary orbit-raising system in June.[253] According to Secretary of the Air Force Deborah James, "GSSAP [used] its unique vantage point, capabilities and maneuverability in a rendezvous and proximity operation [that] allowed GSSAP to collect unique characterization data, ultimately allowing the Navy to fix the problem."[254]

Capabilities for advanced on-orbit maneuvering and proximity operations are being developed to support programs that service satellites in outer space (see Indicator 3.2), and for potential space debris removal efforts (see Indicator 1.1). Commercial actors are pursuing capabilities for more active space-based operations, such as future space-based mining. In January, the first demonstration of autonomous spacecraft maneuvering was conducted with the CanX (Canadian Advanced Nanospace eXperiments) 4 and 5 nanosatellites. These satellites were developed by the University of Toronto and Deep Space Industries to experiment with on-orbit formation flying and maintenance, using carrier-phase differential GPS techniques to obtain relative position measurements accurate to less than 10 cm.[255] CanX-4 autonomously programmed CanX-5 to perform an orbit change. The experiment was declared "a key demonstration of a critical capability for multi-spacecraft asteroid missions, as well as constellations of spacecraft in Earth orbit." The experiment also demonstrated in-space command relays, which could reduce the difficulty of communicating with small spacecraft at very long ranges.[256]

Outer space governance

Indicator 4.1: National space policies

The development of national space policies that delineate the principles and objectives of space actors with respect to access to and use of space has been conducive to greater transparency and predictability of space activities. National civil, commercial, and military space actors all operate according to these policies. Most spacefaring states explicitly support the principles of peaceful and equitable use of space and emphasize space activities that promote national socioeconomic, scientific, and technological goals. Virtually all underscore the importance of international cooperation in their space policies; several developing nations have been able to access space because of such cooperation (see Indicator 2.3).

The 2010 U.S. National Space Policy "calls on all nations to work together to adopt approaches for responsible activity in space" and affirms that the United States "renews its pledge of cooperation in the belief that with strengthened international collaboration and reinvigorated U.S. leadership, all nations and peoples—space-faring and space-benefiting—will find their horizons broadened, their knowledge enhanced, and their lives greatly improved."[1] Such cooperation is particularly linked to space exploration, space surveillance, and Earth observation.

Russia has been deeply engaged in cooperative space activities, is a major partner of the ESA,[2] and also cooperates with other key spacefaring nations, including China and India.[3] Russian space cooperation activities have tended to support broader access to and use of space. At the same time, Russian policy aims to maintain Russia's status as a leading space power, as indicated in the Federal Space Program for 2006-2015; however, efforts to maintain this role in the 2016-2025 program face significant budget constraints (see Indicator 2.2).[4]

China's 2011 White Paper on space[5] includes a commitment to the peaceful use of outer space in the interests of all humankind, linking this commitment to national development and security goals. While China actively promotes international exchanges and cooperation, it has also stated that such efforts must encourage independence and self-reliance in space capabilities.[6]

India is a growing space power that has pursued international cooperation from the inception of ISRO, although ISRO's mandate remains focused on national priorities. India has signed Memoranda of Understanding with almost 30 states and the ESA. India also provides international training on civil space applications at the Indian Institute of Remote Sensing and the Centre for Space Science and Technology Education in the Asia Pacific Region to support broader use of space data.[7]

ESA facilitates European space cooperation by providing a platform for discussion and policymaking for the European scientific and industrial community.[8] Many see this cooperation as one of the most visible achievements of Europe in science and technology. ESA has established strong links with larger space powers, such as the United States and Russia.

However, the military doctrines of a growing number of states emphasize the use of space systems to support national security. Major space powers and emerging spacefaring nations increasingly view space assets as integral elements of their national security infrastructure. For example, Japan's third Basic Plan on Space Policy, adopted in 2015, is notable for its focus on national security.[9] Space is also being viewed as a domain of warfare. For example, the 2015 U.S. National Defense Authorization Act described the need for a "multi-faceted space security and defense program," calling on the Secretary of Defense and the Director of National Intelligence to produce a study on the role of *offensive* space operations.[10] This is echoed in the 2015 National Security Strategy.[11] Similarly, China's first ever Defense White Paper on Military Strategy emphasizes the strategic concept of "active defense"—described as adherence to the unity of strategic defense and operational and tactical offense; adherence to the principles of defense, self-defense, and post-emptive strike; and adherence to the stand that "we will not attack unless we are attacked, but we will surely counterattack if attacked."[12] The White Paper includes a focus on "outer space and cyber space" as "commanding heights in strategic competition among all parties." Russia's 2015 National Security Strategy also articulates a desire to effectively use space for military and defensive purposes.[13]

More states have come to view national space industries as fundamental drivers and components of their space policies. Nations including the United Kingdom, Germany, Australia, and the United States have prioritized innovation and development of industrial space sectors in national space strategies. To further advance its domestic space industry, the United States has adopted national legislation that includes commercial rights to space resources.[14] Other states are considering similar legislation, which is raising legal and regulatory questions related to international space law.

2016 Developments

Developments in U.S. military strategy recognize 'normalized' warfighting in space

Increasingly, the U.S. defense community sees space as a hostile environment that faces a growing probability of armed conflict or harmful activities; thus, as in other domains, warfighting is seen as a normal function of U.S. military forces operating in space. While such thinking has been unfolding over a number of years and is consistent with the 2011 National Space Security Strategy, its assertion in public stood out in 2016, with an emphasis on maintaining critical space operations during a potential conflict.

A new initiative by the USAF Space Command was presented in the White Paper, *Space Mission Force: Developing Space Warfighters for Tomorrow,* in June.[15] The Space Command will provide new training that will enhance the readiness of space forces to operate in a contested, degraded, and operationally limited environment (see Indicator 2.6).[16] The Paper states, "Space is no longer a sanctuary where the United States or our allies and partners operate with impunity"; thus, "space forces must demonstrate their ability to react to a thinking adversary and operate as warfighters in this environment and not simply provide space services."[17] The SMF is guided by the Space Command's broader Space Enterprise Vision (SEV), which has been described as a "blueprint for fighting and winning wars in space" and follows from a study on how to make the national space security enterprise more resilient and better able to respond to threats (see Indicator 3.2).[18] The SEV complements the 2011 National Security Space Strategy, providing more detail on how to achieve defined goals of resiliency of space infrastructure vital to U.S. national interests. It emphasizes the interoperability of space infrastructure with U.S. armed forces and reaffirms national security implications of an engagement in space.

The U.S. Congress also expanded its direction to the military to move forward on options for space-based missile defense interceptors and means of defeating space-based threats (see Indicator 3.4).

Security-related aspects of European space policy included in the European Defence Action Plan

In November 2016, the European Commission published its first dedicated space strategy, *Space Strategy for Europe*, which focuses on[19]

- Maximizing the benefits of space for society and the EU economy;
- Fostering a globally competitive and innovative European space sector;
- Reinforcing Europe's autonomy in accessing and using space in a secure and safe environment;
- Strengthening Europe's role as a global actor and promoting international cooperation;
- Ensuring effective delivery.

As part of its focus on autonomy, the Strategy aims to enhance the use of European space capabilities for military and security purposes, specifically by "reinforcing synergies between civil and security space activities," with priority given to the creation of "resilient satellite communication services for governmental and institutional security users."[20] This marks a shift in an approach to space that had been predominantly civilian.

This new emphasis on military and security uses of space is also reflected in the July 2016 joint NATO/European Council/European Commission declaration at the NATO summit in Warsaw, calling for a deepening of the strategic partnership between the EU and NATO.[21] The September 2016 State of the Union speech by European Commission President Jean-Claude Juncker further highlighted the need for stronger joint defense capabilities by EU member states.[22]

In November, the Commission released the European Defence Action Plan, with specific proposals to foster a stronger defense industry in Europe and to support security-related research and development through a single European Defence Fund. The plan fosters synergies between the space sector and other defense- and security-related sectors in Europe and highlights the role of space in tackling contemporary and emerging security challenges in Europe. It aims to ensure resilience in critical European civil and military space infrastructure and to enhance the existing EU framework for space surveillance and tracking (see Indicator 2.5).[23]

The Global Strategy for the EU's Foreign and Security Policy and the EU Global Strategy Implementation Plan on Security and Defense were also published in 2016. They are intended to assist EU Member States to develop strategic defense capabilities in domains that include space, and to expand the capabilities of the EU's EO program Copernicus and governmental satellite communication services, among others.

China's White Paper on Space Activities emphasizes peaceful use, cooperation, and comprehensive space power

The People's Republic of China released its fourth White Paper on outer space activities in December. While much of the content of *China's Space Activities in 2016* focuses on achievements and future plans in outer space, it also provides insight into China's approach to international space governance. The White Paper confirms China's commitment to international cooperation and to the principles of the Outer Space Treaty and the 1996 Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interests of All States, Taking into Particular Account the Needs of Developing Countries. The White Paper reaffirms China's support of UN activities relating to the peaceful use of outer space. However, China's pursuit of space capabilities is seen as part of the buildup of its "overall strength" as China seeks to be a "space power in all respects."[24]

National policies seek to advance private space exploration and use of space resources

The 2015 U.S. Spurring Private Aerospace Competitiveness and Entrepreneurship Act[25] included measures to facilitate commercial exploration and recovery of space resources. In 2016, the White House Office of Science and Technology Policy endorsed FAA oversight of such "non-traditional" commercial space activities[26] (national supervision of space activities is required under international law). The U.S. government also granted regulatory approval for the first private space mission beyond Earth orbit; Moon Express was given permission to proceed with its robotic lunar landing mission after it submitted an application to the FAA on 8 April (see Indicator 2.4).[27]

The United States was the first to develop domestic legislation on the extraction and use of space resources. In February 2017, Luxembourg launched the SpaceResources.lu funding initiative to create a favorable domestic legal and regulatory environment for private companies to pursue activities associated with asteroid mining and the use of space resources (see Indicator 2.5).[28] Draft legislation introduced in November 2016 addressed commercial appropriation of resources in outer space, asserting that resources can be harvested and commercially utilized under international space law.[29] Luxembourg is the first European country to attempt to guarantee ownership of minerals, water, and other resources found on certain types of asteroids. Differing from the U.S. approach, this law, if adopted, would include not only its citizens, but any company with operations in Luxembourg.

The United Arab Emirates was also developing national legislation on the utilization of space resources as part of the New Space agenda of the UAE Space Agency.[30] This law will supplement the 2016 National Space Policy, which focuses on creating civil and commercial space programs (see below).[31]

There is some concern that proliferating legal and regulatory regimes could encourage companies to adopt "flags of convenience."[32]

African Space Policy and Strategy links to Agenda 2063 for socioeconomic transformation

The first comprehensive space policy for Africa was adopted in January 2016 at the Summit of Heads of State and Government; it is viewed as the beginning in creating an African Space Program under the AU Agenda 2063 strategic framework for socioeconomic transformation.[33] The intent is to leverage the potential for space activities to raise social and economic indicators; space-derived services are seen as crucial for Africa's economic development. Priority is being given to joint ventures by African countries that offer social and economic benefits, including disaster management, space-derived services for agriculture, satellite communication for distant and remote areas, telemedicine, social cohesion, and gender equality.

The strategy prioritizes capacity-building in Earth observation, satellite communication, navigation and positioning, and space science and astronomy.[34] Although Nigeria, South Africa, Kenya, Algeria, and Egypt have space programs, much of the continent has not yet engaged extensively in space activities and will need help to build capacity through technology transfers and investment in an African space industry.

New national space policies signal growing importance of outer space

National space policies and strategies were adopted in several European countries, as well as the UAE and New Zealand, signaling the growing importance of outer space, particularly for domestic economies. Denmark's inaugural space strategy[35] was published midyear, setting out the direction for business and research, and creating a formal framework for exploiting the potential of space activities. The strategy followed the adoption of Denmark's first law on space activities in May.[36]

In September, Poland unveiled its first national space strategy,[37] which was approved in early 2017. To invigorate the Polish space industry, the government plans to increase public investments from 0.01% of GDP to levels similar to those of Germany (0.05%) or France (0.1%).[38] Priorities include Earth Observation (with the application of EO systems in spatial planning) and satellite development and manufacturing.[39] The Italian Space Agency's 10-year *Strategic Vision Document 2016-2025* promotes, inter alia, the development of applications, services, and infrastructure for the space economy, on both national and European levels.[40]

Following the publication of its Research and Development and Innovation Strategy 2014-2020, the government of Estonia prepared the Estonian Space Action Plan 2016-2020. Priorities include the development of public sector services based on space applications, fostering an entrepreneurial and competitive Estonian space market and industry, and strengthening R&D capabilities.[41]

Two years after officially creating the UAE Space Agency, the United Arab Emirates adopted the first dedicated national space policy in the Middle East. Core objectives include a better quality of life for all UAE citizens, improved security, and better crisis and disaster responses.[42] The policy emphasizes increased cooperation between government and private sectors and encourages synergies between the space sector and other key industries.

Indicator 4.2: Multilateral forums for space governance

A number of international institutions provide multilateral forums to address space security issues. UN bodies include the UNGA First Committee on Disarmament and International Security and Fourth Committee (Special Political and Decolonization), UN Inter-Agency Committee on Outer Space (UN-Space), the UN Committee on the Peaceful Uses of Outer Space, and the Conference on Disarmament in Geneva, Switzerland. Outside the UN, there is also an important European-led initiative to develop an International Code of Conduct for Outer Space. Other specialized bodies that participate in space governance include the International Committee on Global Navigation Satellite Systems (see Indicator 2.3), and the International Telecommunication Union (see Indicator 1.2).

UN General Assembly

UNGA has long held the belief that preventing an arms race in outer space is a significant contribution to international peace and security. The UN Charter establishes the fundamental objective of peaceful relations among states. Article 2(4) prohibits the threat or use of force in international relations, while Article 51 codifies the right of self-defense in cases of aggression involving the illegal use of force.[43]

Every year UNGA examines outer space issues, primarily through the work of the First and Fourth Committees. Recurring resolutions are widely supported and include the Prevention of an Arms Race in Outer Space (PAROS), Transparency and Confidence-building Measures in Outer Space Activities (TCBM), and International Cooperation in the Peaceful Uses of Outer Space. In 2014, the resolution No First Placement of Weapons in Outer Space was introduced despite lack of consensus; it continues to face significant dissent.

In addition to treaties, six UN resolutions known as principles have been adopted by UNGA for the regulation of special categories of space activities. Although these principles are not legally binding, they provide internationally approved guidelines on appropriate state conduct.

Figure 4.1 Key UN space principles

Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space (1963)
Space exploration should be carried out for the benefit of all countries.
Outer space and celestial bodies are free for exploration and use by all states and are not subject to national appropriation by claim of sovereignty or by any other means.
States are liable for damage caused by spacecraft and bear international responsibility for national and nongovernmental activities in outer space.
Principles on Direct Broadcasting by Satellite (1982)
All states have the right to carry out direct television broadcasting and to access its technology, but states must take responsibility for the signals broadcasted by them or actors under their jurisdiction.
Principles on Remote Sensing (1986)
Remote sensing should be carried out for the benefit of all states, and remote sensing data should not be used against the legitimate rights and interests of the sensed state, which shall have access to the data and the analyzed information concerning its territory on a non-discriminatory basis and on reasonable cost terms.
Principles on Nuclear Power Sources (1992)
Nuclear power may be necessary for certain space missions, but safety and liability guidelines apply to its use.
Declaration on Outer Space Benefits (1996)
International cooperation in space should be carried out for the benefit and in the interest of all states, with particular attention to the needs of developing states.
Space Debris Mitigation Guidelines (2007)
These are voluntary guidelines for mission-planning, design, manufacture, and operational phases of spacecraft and launch vehicle orbital stages to minimize the amount of debris created.

In 2011, the UN Secretary-General established a Group of Governmental Experts (GGE) on Transparency and Confidence-building Measures in Outer Space Activities to advance international dialogue on space security issues. The Group consisted of 15 experts nominated by UN Member States based on geographical representation, and also including representatives from the five permanent Member States of the UN Security Council. Following a broad consideration of TCBMs in 2012, the Group provided its final consensus report to UNGA in July 2013, calling for collaborative efforts in the form of TCBMs to enhance the sustainability and security of outer-space activities. The report recommended information exchanges on national space policy and goals, military space expenditures, outer-space activities, and planned launches; prior notifications to reduce risks associated with orbital maneuvers, high-risk reentries, and intentional orbital breakups; and voluntary visits to launch sites and command and control centers. It also recommended a joint ad hoc meeting of the First and Fourth Committees of the General Assembly.[44]

In 2014, UNGA passed a resolution on TCBMs in Outer Space Activities without a vote, calling for the unprecedented joint meeting of the two Committees, bringing together the security and disarmament focus of the First Committee with the work on peaceful uses of outer space done at the fifty-seventh session of COPUOS (which reports to the Fourth Committee). The meeting took place in October 2015; a second meeting was scheduled for 2017.

COPUOS

Established in 1958, COPUOS reviews the scope of international cooperation in the peaceful uses of outer space, develops relevant UN programs, encourages research and information exchanges on outer space matters, and studies legal problems arising from the exploration of outer space. The Committee works by consensus. Membership has expanded significantly in recent years, with six new Member States added in 2015 (El Salvador, Israel, Oman, Qatar, Sri Lanka, and United Arab Emirates) and New Zealand in 2016; there are now 84 Member States. Some intergovernmental and nongovernmental organizations have permanent observer status in COPUOS and its subcommittees. A growing membership indicates that international governance of space activities is highly valued by the international space community. Debate on revisiting the mandate of COPUOS to include all issues affecting the peaceful uses of outer space—including those pertaining to militarization—has not reached consensus.

The five treaties that are considered to form the basis of international space law were negotiated at COPUOS. They are:

Outer Space Treaty (1967)—A cornerstone of the existing space security regime, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, commonly referred to as the Outer Space Treaty, represents the primary basis for legal order in the space environment, establishing outer space as a domain to be used by all humankind for peaceful purposes. However important this treaty may be for international space law, there have been repeated calls from different quarters for an updated normative regime for space activities.

The implications of the OST's definition of "peaceful purposes" have been the subject of debate among spacefaring states. The interpretation initially favored by Soviet officials viewed peaceful purposes as wholly nonmilitary.[45] However, space assets have been developed extensively to support terrestrial military operations; the position that "peaceful" in the context of the OST means "nonaggressive" has generally been supported by state practice. Moreover, Article IV of the OST bans the placement of weapons of mass destruction in outer space as well as military activities on celestial bodies, but is otherwise silent on the use of conventional weapons in orbit. While space actors have stopped short of actually deploying weapons in space or attacking the space assets of another nation from Earth, anti-satellite capabilities have been tested by some states against their own satellites—for example, by China in 2007[46] and the United States in 2008.[47]

Astronaut Rescue Agreement (1968)—The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space requires that assistance be rendered to astronauts in distress, whether on sovereign or foreign territory. The Agreement also requires that astronauts and their spacecraft be returned promptly to the responsible launching authority, should they land within the jurisdiction of another state party.

Liability Convention (1972)—The Convention on International Liability for Damage Caused by Space Objects establishes a liability system for activities in outer space, which is instrumental when addressing damage to space assets caused by human-made space debris and spacecraft. The Convention specifies that a launching state "is absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight" (Article II). When a launching state causes damage to a space asset belonging to another state, it is liable only if it is at fault for causing the damage. However, liability for damage caused by space debris is difficult to establish; smaller pieces of debris may not have a known source.

Registration Convention (1975)—The Convention on Registration of Objects Launched into Outer Space requires states to maintain national registries of objects launched into space and to provide information about their launches to the UN. The following information must be made available by launching states "as soon as practicable": name of launching state; an appropriate designator of the space object or its registration number, date, and territory or location of launch; basic orbital parameters; and general function of the space object.[48] Although the amount, accuracy, and timeliness of data provided by states in registering orbital objects varies considerably, roughly 92% of all objects launched into Earth orbit or beyond have been registered with the Secretary-General.[49]

Moon Agreement (1979)—The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies generally echoes the language and spirit of the OST in terms of the prohibitions on aggressive behavior on and around the Moon, including the installation of weapons and military bases, as well as other nonpeaceful activities. It also prohibits the use of the Moon to threaten the Earth. However, the Moon Agreement has not been widely ratified. States continue to object to provisions for an international regime to govern the exploitation of the Moon's natural resources and there are different interpretations of what it means for the Moon's natural resources to be the "common heritage of mankind." The right to inspect all space vehicles, equipment, facilities, stations, and installations belonging to any other party is also objectionable to some states.

Figure 4.2 Status of major UN space treaties as of January 2017[50]

Treaty	Date	Total parties	Total signatories
Outer Space Treaty	1967	105	25
Rescue Agreement	1968	95	24
Liability Convention	1972	94	20
Registration Convention	1975	63	4
Moon Agreement	1979	17	4

Supported by the UN Office for Outer Space Affairs, COPUOS and its two standing subcommittees—the Scientific and Technical Subcommittee and the Legal Subcommittee—meet annually to develop recommendations based on questions and issues put before them by UNGA and Member States. An ongoing priority initiative since 2010 falls to the COPUOS Working Group on the Long-Term Sustainability of Outer Space Activities. The objective of this group is to examine and propose practical measures to ensure the safe and sustainable use of outer space for peaceful purposes, for the benefit of all countries. A report of the working group and an initial set of draft voluntary guidelines to promote the long-term sustainability of outer space activities were provided in 2016.

Figure 4.3 UN-related institutions relevant to international space security

Conference on Disarmament

The CD is the designated forum established by the UN to negotiate multilateral arms control and disarmament agreements. With 65 current Member States, the CD works by consensus under a rotating presidency. It has repeatedly attempted to address the issue of the weaponization of space, driven by perceived gaps in the OST, such as its lack of verification or enforcement provisions and its failure to expressly prohibit conventional weapons in outer space or ground-based ASATs. In 1985, a committee to negotiate a treaty to address these shortcomings was created and given a mandate "to examine, as a first step…the prevention of an arms race in outer space."[51] From 1985 to 1994, the PAROS committee met and, despite a wide disparity of views by key states, made several recommendations for space-related confidence-building measures, including improved registration and notification of information, the elaboration of a code of conduct or rules of the road as a way to reduce the threat of possible incidents in space, the establishment of "keep-out zones" around spacecraft, the elaboration of an agreement dealing with the international transfer of missile technology and other sensitive technology, and widening the protection offered to certain satellite systems under United States-USSR/Russia arms control agreements.

Efforts to extend the PAROS committee mandate faltered in 1995 over an agenda dispute that linked PAROS with other items discussed at the CD—in particular, a Fissile Material Cut-off Treaty (FMCT). CD agenda negotiations were stalled between 1996 and 2009, leaving the CD without a formal program of work. The CD did adopt a program of work in 2009, but resumed its deadlock following objections from Pakistan over FMCT discussions. While the adoption of a Program of Work remains an elusive pursuit for the CD, overwhelming support for resolutions on PAROS and TCBMs in UNGA indicates a broad international desire to consolidate and reinforce the normative regime for space governance to enhance its effectiveness. The UNGA resolution "No First Placement of Weapons in Outer Space," first introduced in 2014,[52] urged the CD to begin substantive work based on the Chinese-Russian proposal for a treaty on the Prevention of Placement of Weapons in Outer Space (see below) when a committee on PAROS is established; however, support is divided.

Another relevant initiative is the voluntary International Code of Conduct for Outer Space Activities; however, efforts stalled in 2015. While there is recognition of the need for a new agreement, the way forward is not clear; global support has not emerged for either the legally binding PPWT or the politically binding ICoC. Lack of verification remains an obstacle to supporting a weapons ban for some, including the United States.[53]

2016 Developments

UN COPUOS agrees on an initial set of draft guidelines for long-term sustainability of space activities, develops a compendium on non-legally binding UN instruments on outer space, and expands agenda

The COPUOS STSC Working Group on the Long-term Sustainability of Outer Space Activities agreed to an initial set of 12 draft guidelines, which were adopted by the 59th session of COPUOS in June (see Annex 6).[54] These guidelines fall under the general categories of policy and regulatory frameworks, space operations, international cooperation and capacity-building, and scientific and technical research and development. Topics explored include national space regulations and supervision of space activities, use of radiofrequency spectrum and orbital positions, and the sharing of information related to space activities. The mandate of the Working Group was extended for two more years to enable work on a full set of guidelines, to be adopted by the Committee and submitted to UNGA for endorsement in 2018.[55]

Figure 4.4 Accepted guidelines for the long-term sustainability of outer space activities, 2016

Guideline	Summary
Guideline 1	Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities
Guideline 2	Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities
Guideline 3	Supervise national space activities
Guideline 4	Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites
Guideline 12	Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects
Guideline 13	Promote the collection, sharing and dissemination of space debris monitoring information
Guideline 16	Share operational space weather data and forecasts
Guideline 17	Develop space weather models and tools and collect established practices on the mitigation of space weather effects
Guideline 25	Promote and support capacity-building
Guideline 26	Raise awareness of space activities
Guideline 27	Promote and support research on and the development of ways to support sustainable exploration and use of outer space
Guideline 28	Investigate and consider new measures to manage the space debris population in the long term

The Committee's agenda is expanding. Two new single-issue agenda items appeared on the work plan of the 55th session of the Legal Subcommittee in 2016: "General exchange of views on the legal aspects of space traffic management" and "General exchange of views on the application of international law to small satellite activities."[56] The inclusion of new single-issue agenda items displays the Committee's interest in addressing emerging space activities in a timely manner.

COPUOS assembled a "Compendium on mechanisms adopted in relation to non-legally binding United Nations instruments on outer space" to "inform States of the current instruments and measures that have been implemented by States members of the Committee as well as international intergovernmental organizations having permanent observer status with the Committee."[57] The compendium is updated as members supply new information.

COPUOS also recommended that a second joint-panel discussion on space between UNGA's First and Fourth Committees be held in 2017.

Work at the CD remains stalled

The Conference of Disarmament was once again unable to agree to a formal program of work[58] and instead proceeded with informal deliberations. No significant developments were achieved on the updated draft PPWT.

UNGA resolutions reflect points of consensus, divide

The UN General Assembly adopted four resolutions related to outer space.[59] The resolution "International cooperation in the peaceful uses of outer space" was once again adopted unanimously without a vote, as was "Transparency and confidence-building measures in outer space activities." Near-consensus was reached on "Prevention of an arms race in outer space." There was less agreement on draft resolution "No first placement of weapons in outer space," introduced in 2014; "no" votes were cast by Georgia, Israel, Ukraine, and the United States.

Figure 4.5 Record of UNGA Resolutions related to outer space, 2016

Resolution number	Resolution name	Voting record		
		For	Against	Abstained
A/RES/71/90	International cooperation in the peaceful uses of outer space	Adopted without a vote		
A/RES/71/42	Transparency and confidence-building measures in outer space activities	Adopted without a vote		
A/RES/71/31	Prevention of an arms race in outer space	182	0	4
A/RES/71/32	No first placement of weapons in outer space	130	4	48

UNISPACE+50 preparations proceed with adoption of themes

UNOOSA and COPUOS devoted much time to UNISPACE+50, a special session of COPUOS on 20-21 June 2018 to mark the 50th anniversary of the first UN Conference on the Exploration and Peaceful Uses of Outer Space. In June, COPUOS adopted seven themes for the session:[60]

1. Global partnership in space exploration and innovation;
2. Legal regime of outer space and global space governance: current and future perspectives;
3. Enhanced information exchange on space objects and events;
4. International framework for space weather services;
5. Strengthened space cooperation for global health;
6. International cooperation towards low-emission and resilient societies;
7. Capacity-building for the 21st century.

The overarching goal of UNISPACE+50 is a comprehensive Space 2030 agenda that outlines the space activities that contribute to the 2030 Sustainable Development Goals. U.S. astronaut Scott Kelly was appointed the first United Nations Champion for Space to raise public awareness of UNOOSA and UNISPACE+50 and to promote the role of space in achieving the SDGs.[61] The first of three preparatory forums for UNISPACE+50 took place in November 2016 (see Indicator 4.3).

India joins the Missile Technology Control Regime and The Hague Code of Conduct Against Ballistic Missile Proliferation

In June 2016, India became the thirty-fifth member of the Missile Technology Control Regime, a voluntary multilateral export regime established in 1987 to limit the risk of proliferation of weapons of mass destruction by limiting exports of technologies linked to delivery systems such as missiles, space launch vehicles, and unmanned aerial vehicles. The Indian government stated that this decision will benefit the Indian space program by enabling exports and strengthening international cooperation in high technology areas with other spacefaring nations.[62] India also acceded to The Hague Code of Conduct against Ballistic Missile Proliferation, a voluntary TCBM to regulate ballistic missiles capable of carrying weapons of mass destruction. As a signatory, India will have to provide prelaunch notifications on ballistic missiles, space launch vehicles, and test flights, and must submit an annual declaration of policy on satellite launch vehicles and ballistic missiles.[63]

EU remains committed to International Code of Conduct process within a UN framework

Following its collapse in 2015, the EU-led ICoC process made no practical progress in 2016. However, public statements indicate that the EU remains committed to the development of an ICoC within a wider UN framework. The United Kingdom, Germany, and Italy planned to take leading roles in promoting the establishment of an international voluntary and regulatory mechanism to tackle civilian- and military-related space activities.[64]

International Civil Aviation Organization calls for UN space travel regulations

At the Second ICAO/UNOOSA Symposium in Abu Dhabi in March, the International Civil Aviation Organization (ICAO) called for deeper involvement of the UN in emerging suborbital flight and space tourism activities. This was the ICAO's first dedicated statement on this topic. During his speech, ICAO Council President Olumuyiwa Benard Aliu noted that the goal is to improve the regulatory regime for space within five years, in preparation for increased activity in suborbital and orbital human spaceflight.[65]

Indicator 4.3: Other initiatives

Historically, the key governance challenges related to outer space activities have been discussed at multilateral bodies related to, or under the auspices of, the United Nations, such as COPUOS, the General Assembly First Committee, or the CD. However, diplomatic efforts outside these forums are becoming more significant.

A growing number of diplomatic initiatives relate to bilateral or regional collaborations. Examples include the work of the Asia-Pacific Regional Space Agency Forum and discussions within the African Union to develop an African space agency. Nongovernmental organizations have also contributed to the dialogue on gaps in the international legal framework. For example, the Union of Concerned Scientists drafted a model treaty banning ASATs in 1983.[66] The UCS 2010 report *Securing the Skies* identifies 10 first steps by which the United States can protect its own assets while also enhancing security and sustainability in outer space.[67] In 2002, the Stimson Center first proposed a Code of Conduct for responsible spacefaring nations and has continued to promote this effort.[68]

More recently, Secure World Foundation has emerged as a significant "research body, convener, and facilitator" for a variety of space security initiatives, including significant work on space traffic management.[69] In addition to being a founder of the SSI project and manager of the annual SSI reports, Project Ploughshares continues to examine and identify means to enhance the security of outer space, including the continued nonweaponization of the space environment.[70] Other organizations active in this effort include The Simons Foundation[71] and the Observer Research Foundation in India.[72]

The UN Institute for Disarmament Research, an autonomous institute within the UN system, has also played a key role in facilitating dialogue among key space stakeholders. Every year since 2002, UNIDIR has partnered with civil society actors and some governments to bring together space security experts and government representatives at a conference on emerging security threats to outer space.

In 2014, the second Manfred Lachs International Conference on Global Space Governance, hosted by the McGill Institute of Air and Space Law in Montréal, Canada, adopted the so-called Montreal Declaration. It mandated the Institute to study the format and substance of a global space governance system to achieve, effectively and in practice, the goal of the sustainable use of space for peaceful purposes and for the benefit of all humankind.[73] This study is being carried out by an international and interdisciplinary team of more than 100 international experts.

2016 Developments

First UN High-level Forum adopts the Dubai Declaration

The preparatory process of UNISPACE+50 (see Indicator 4.2) includes three high-level forums. The first, the UN/UAE forum[74] on "Space as a driver for socio-economic sustainable development" took place in November 2016, with more than 100 delegates from 21 countries and various international governmental and nongovernmental organizations. Four days of talks produced the Dubai Declaration, a joint statement urging a strengthening of the role of UN COPUOS as the prime intergovernmental platform for international space cooperation. The Declaration identified space economy, space society, space accessibility, and space diplomacy as the four pillars to support "an inclusive global Space2030 agenda for exploration, innovation and inspiration that calls for strengthened cooperation and governance of outer space activities." Increased interconnectedness and sharing of information and knowledge among states and private and nongovernmental organizations were seen to be critical.[75]

The Hague Space Resources Governance Working Group initiates work

The Hague Space Resources Governance Working Group met in April and November to work on the legal, regulatory, and governance features of asteroid mining and utilization of resources in outer space. The group of international experts was led by principal partner, the Institute of Air and Space Law of Leiden University. The goal is to formulate building blocks that lead to recommendations on how to negotiate an international agreement or voluntary instrument for the governance of space resources. The list of building blocks was agreed to in April. In 2017, the group will work on formulating governance recommendations and guidelines for space resources utilization.[76]

International Committee of the Red Cross warns of grave humanitarian consequences to weaponization of outer space

Vice-President of the International Committee of the Red Cross Christine Beerli addressed the First Committee of the 71st session of UNGA in October 2016 to bring field-based experience and expertise in international humanitarian law to bear on security and disarmament issues, including the weaponization and hostile use of outer space. Her statement highlighted the far-reaching humanitarian consequences on Earth that would result from direct attacks against either dual-use or civilian satellites, as well as the legal limits on all forms of warfare, including in outer space.[77] It echoed a similar statement made in 2015, signaling heightened international—particularly civil society—attention to the need to apply humanitarian and other international law to potential conflicts in outer space.

BRICS Declaration calls for international agreement to prevent weaponization of outer space

The eighth BRICS summit meeting, "Building Responsive, Inclusive and Collective Solutions," took place on 15-16 October 2016 in Goa, India. The resulting Goa Declaration included several references to outer space governance, reiterating the principle that under international law all states have equal rights to the peaceful uses of outer space. It supported the decision of the COPUOS STSC Working Group on Long-term Sustainability of Outer Space Activities to conclude negotiations and achieve consensus on the full set of guidelines for the long-term sustainability of outer space activities by 2018. And it called upon the CD to update the draft treaty submitted by China and the Russian Federation to prevent the weaponization of space.[78]

G7 Summit in Hiroshima, Japan considers outer space governance

The G7 Summit in April focused on global peace, security, and prosperity, with great consideration given to outer space governance. For the first time, the Joint Communiqué of the Foreign Ministers Meeting emphasized the importance of outer space for social, economic, scientific, and technological development. It indicated that the G7 remained "concerned about the development of anti-satellite capabilities" and are "committed to enhancing the long-term safety, security, sustainability and stability of the space environment, to increasing transparency in space activities, and to strengthening norms of responsible behavior for all outer space activities."[79]

Host Germany asked to focus on space at G20 Summit in 2017

The International Lunar Decade Working Group sent an open letter to German Chancellor Angela Merkel in advance of the G20 Summit in Germany in 2017.[80] It includes a proposal that "Germany's G20 lay the foundations to build a positive, sustainable, long-term future for humanity through international collaboration toward creation of a self-sustaining space economy."[81]

Process initiated to develop Manual on International Law Applicable to Military Uses of Outer Space

At the 4th Manfred Lachs Conference on Conflicts in Space and the Rule of Law in May,[82] McGill University's Institute of Air and Space Law and The University of Adelaide Law School Research Unit on Military Law and Ethics launched a joint project to develop the McGill Manual on International Law Applicable to Military Uses of Outer Space. The goal is to draw on international experts and to engage with states to develop a comprehensive manual compiling and clarifying the existing international law and norms applicable to military uses of outer space.[83] Supporters include the Government of Canada, the Government of Australia, the U.S. Air Force, the Union of Concerned Scientists, and the International Committee of the Red Cross. The Manual will examine international law applicable to the conduct of military activities in outer space, with a focus on three issues: international space law. the use of force, and international humanitarian law. Completion of the Manual is projected to take three years.

China and the United States hold first Dialogue on Outer Space Security

In May, China and the United States met for the first time to discuss outer space security. Frank Rose, the U.S. Assistant Secretary of State for arms control, verification and compliance, and Wang Qun, Director General of the Department of Arms Control at China's Ministry of Foreign Affairs, reportedly discussed space debris, preventing collisions on orbit, and China's anti-satellite systems.[84]

Asgardia declares itself the first space nation

Plans to create the first space nation, named Asgardia, were announced at a press conference in Paris in October.[85] The project is led by a private company founded by Dr. Igor Ashurbeyli. Asgardia is envisioned as a "global, unifying and humanitarian project" to prevent "Earth's conflicts from being transferred into space."[86] It is proposed that some of Asgardia's citizens will eventually live on space stations.[87] Asgardia is taking applications for citizenship;[88] the goal is to collect a sufficient number of citizens (likely in the tens of thousands) before applying for UN membership.[89]

GLOBAL ASSESMENT

50 years after the Outer Space Treaty: How secure is space?

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> The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.

So stated the landmark Outer Space Treaty, which entered into force on 10 October 1967. With this treaty, scores of states, including all the spacefaring nations at the time, laid out the fundamental principles by which outer space is to be governed. Key among these principles: space is to be used for peaceful purposes; states parties must exercise due regard to the interests of others and avoid harmful contamination while using space; and no state can appropriate space or celestial bodies.

The OST's drafters could be forgiven for not anticipating the technological and geopolitical changes that have come about in the intervening decades. While the Treaty bans the placement of weapons of mass destruction in space, it provides less explicit guidance about other military uses of space. At the time, many national security activities in space, such as verification of arms control agreements and warning of ballistic missile launches, were essentially stabilizing. Today, military space capabilities are less clearly "peaceful" and are a yet greater source of contention. The Soviet Union wanted to ban nongovernmental activity in space, but the United States objected and, in the end, such activity was permitted, with states bearing responsibility for all nongovernmental activity. Today, commercial activity is poised to dwarf governmental activities.

Geopolitical trends

Space as just another warfighting regime

Space has for decades been "adjacent" to conflict, playing an important, but supporting role. Current trends put space at the center. For a small but increasing number of states, space services provide the capability to deploy military personnel globally and apply force more efficiently and effectively. Increasingly, these states view space as a sphere to be dominated and defended.

As Theresa Hitchens wrote in her 2015 SSI Global Assessment, "growing national security tensions among the major space actors threaten to negate the painstaking efforts toward multilateral governance," and thus space security is moving "one step forward, two steps back."[1]

In a significant shift in approach over the last couple of years, the Pentagon now assumes that operations in space will be challenged, and that plans should be laid to prevail in a contested environment. In 2017, this view was given clear expression when, within 24 hours of being sworn in, the Air Force Secretary declared that space is a warfighting regime, just like air, sea, and land. While it is prudent and may be stabilizing to devise plans to retain the use of space in the face of threats, militaries tend to seek solutions in their own bailiwick—hardware, operations, technology. A commensurate amount of energy has not been invested in shaping the space environment into a more secure and peaceful one using negotiated constraints.

Space is not insulated from conflict on Earth, and it can unpredictably escalate crises on the ground or be the spark that starts one. As Jana Robinson noted in the 2016 SSI Global Assessment, a number of difficult problems are brewing, particularly in the South and East China Seas and in Ukraine, which have the potential to pull into conflict space powers (which are also nuclear powers), including the United States, Russia, and China.

China's arrival

While the decades after the Second World War were marked by the space race between the United States and the Soviet Union/Russia, China has decisively arrived as a leader in the exploration and use of space. Having invested heavily in launchers and on-orbit space capability, it is hitting its stride. In 2016, the United States and China were tied for the greatest number of space launch attempts (22), and China recently eclipsed Russia in the number of operating satellites. This year saw the successful maiden flights of China's heavy-lift Long March 5 and Long March 7, which will be the "workhorse" launcher for China. China now fields a complement of communications satellites; intelligence, surveillance, and reconnaissance satellites; and position, navigation, and timing satellites. It has announced ambitious plans for space exploration and has sought regional and international cooperative relationships for space activities.

How might this new reality affect space security? The United States and China do not have a well-functioning relationship on space matters, in contrast to the decades of interaction and cooperation between the United States and the Soviet Union/Russia.

China has not been invited to become involved with the International Space Station and, for years, the United States Congress has restricted the use of funds to support bilateral discussions or projects with China on space. Until recently, no reliable line of contact between the U.S. Space Command and China existed by which the United States could share information about possible satellite collisions. Fortunately, in this last year of the Obama administration, the United States and China were able to initiate bilateral discussions on civil and security space matters.

The People's Republic of China was not a member of the United Nations when the Outer Space Treaty was negotiated, but it did eventually become a signatory. It has frequently stated in international forums and in domestic declaratory policy that limits should be placed on space weapons. China cooperated with Russia to draft and promote the Treaty on the Prevention of the Placement of Weapons in Outer Space. The United States has repeatedly stated that it has no interest in that effort, but has not offered its own vision of acceptable limits on space weapons. The UN Conference on Disarmament has not been functioning for years, so there has been little opportunity to come to a sound understanding of what common ground on space security issues might exist.

Technological trends

Anti-satellite weapons develop and proliferate

For the foreseeable future, military tensions among the United States, China, and Russia are likely to remain high, as are those between China and India. It is imperative to track investments and strategies that could escalate a crisis or lead actors to consider approaching or crossing the nuclear threshold. Attacks on satellites can create or escalate terrestrial crises in ways that are difficult to predict and which are particularly dangerous among nuclear powers.

While the OST prohibits nuclear weapons in space, it is less specific about other military activity, and states have different interpretations of "peaceful purposes." Thus, the drift is toward a space regime that includes increasingly sophisticated anti-satellite technology, with very little mutual understanding about how actions in space are perceived and what constraints, if any, global governance provides.

States—and, increasingly, sub-state actors—have been developing technologies that can be used to interfere with satellites. Not all such technologies are equally dangerous, and it may be possible to prioritize appropriate limits. Signals jamming, for example, is relatively low-tech, but is also limited temporally and spatially in its effects; identification of the perpetrator is relatively straightforward, even if remedies for the interference are less so. More concerning are technologies with a strategic-sized capability, or which are stealthy and hard to attribute, or which make intent difficult to discern; these technologies can provide new and unpredictable paths to crisis escalation. The inventories of such weapons are growing and relevant technology is proliferating.

Midcourse missile defense systems are of particular concern. Long-range ballistic missiles and satellites travel at similar speeds on similar trajectories, so the heart of these systems, the "kill" mechanism, can be used against either missiles or satellites. In fact, they're likely to be much more effective against satellites, which travel on repeated, predictable orbits.

The United States has an enormous advantage in missile defense capacity and sophistication. It has two missile defense systems that use hit-to-kill interceptors that could target satellites. The current fleet of Aegis missile defense interceptors can reach only satellites at the very lowest altitudes, at which satellites are very nearly de-orbiting. But the next generation of interceptors, the SM-3 IIA, should be able to reach any satellite in low Earth orbit.[2] The development of this interceptor, pursued jointly by Japan and the United States, saw some delays in 2016, but both countries are committed to it, and the accelerated pursuit of nuclear weapons and ballistic missiles by the Democratic People's Republic of Korea will reinforce support. These interceptors are likely to be deployed in much larger numbers, likely in the hundreds; in comparison, the currently deployed Ground-based Midcourse Defense system, which can in theory target all low-Earth-orbiting satellites, will soon comprise 44 interceptors. China and Russia each have in the order of 100 low-Earth-orbiting satellites. Thus, U.S. missile defenses potentially will have the capacity to hold a significant portion of an adversary's satellites at risk. This is essentially a strategic capability and has serious implications for stability and security in space.

While the Obama administration was not interested in space-based missile defenses (SBMD), certain members of the U.S. Congress have been pushing the idea for years. They had modest success in 2016, directing the Pentagon to come up with a space-based concept that could serve as a defense against ballistic missiles as they launched and/or against ground-launched anti-satellite weapons. The new president is likely to be more interested in SBMD, and has ordered a ballistic missile defense review.

While a full complement of hundreds or thousands of space-based interceptors would be prohibitively expensive to field (even with anticipated reductions in launch costs), it's quite possible that the Pentagon will be directed to build a testbed of a few interceptors. This is a concern for two reasons: 1) prototype interceptors in space would be viewed by adversaries and allies alike as putting the first dedicated space weapons in orbit, encouraging development of similar technologies by others; and 2) absent constraints, the development of weapons explicitly aimed at an adversary's anti-satellite weapons can lead to a dangerous "use it or lose it" dynamic.

The United States is not alone in pursuing midcourse missile defenses. China has reportedly tested hit-to-kill interceptors a number of times, both against a satellite in 2007 and subsequently against ballistic missiles. China has also demonstrated a high-altitude rocket that could potentially bring those interceptors in reach of satellites in geosynchronous orbits. Little is known publicly about the state of its development program and the numbers and types of interceptors China plans to field.

While Russia has long had a modest missile defense system for Moscow, it has begun work on another ground-based system, "Nudol," which reportedly has an anti-satellite mission. Russia upped the tempo on this system, reportedly flight testing it three times in 2016. (It is not clear whether it was tested against a target.) Other countries continue research and development of missile defense systems; as ballistic missiles proliferate, more states may seek them.

Because hit-to-kill weapons produce large amounts of dangerous, persistent space debris, some inherent self-restraint against on-orbit testing or hostile use of these systems is expected. But this is a weak deterrent to using missile defenses against satellites in an actual crisis. And because missile defenses are politically sensitive, both internationally as well as in the United States, starting a conversation on useful limits is difficult.

More complex, but just as concerning, are technologies that can be used both for peaceful and aggressive purposes. This ambiguity may lead to on-orbit behavior that is difficult to interpret. A prime example is satellites that are nimble on orbit and can closely approach another satellite without that satellite's cooperation. These "proximity operations" can be peaceful—inspecting or repairing a satellite, or salvaging or bringing a failed satellite safely out of orbit. But they can also facilitate interference with a satellite, since damaging a satellite is easier at close ranges and low relative speeds.

A number of states and commercial actors are pursuing such cutting-edge technology. In 2016, the U.S. military bolstered its Geosynchronous Space Situational Awareness Program by adding two new satellites to the two already in orbit. The United States has been transparent about the existence of this and its Automated Navigation and Guidance Experiment for Local Space program.

While China and Russia are testing these technologies as well, they provide little public detail. In spring 2017, one of Russia's satellites reportedly demonstrated the ability to cease maneuvers for a period of time, then return to maneuvering, a capability which might increase the satellite's stealth. Stealth is likely to be perceived as a valuable technology, particularly since the United States has a large advantage in capability to surveil space.

There's been little appetite on a state level to discuss constraints on proximity-operations technology or norms for behavior. For example, how close may another satellite get without notification or prior permission? At present, individual states must deal with the possible collision or signals interference and with trying to interpret the intent of another state's actions. Such a situation increases the risks for miscalculation and misinterpretation.

Small satellites

The miniaturization of relevant technologies has led to the possibility of using smaller, lighter, and cheaper satellites to provide useful capability. The Obama administration began funding this "Small Satellite Revolution"[3] to harness its potential for innovation. This "revolution" has been somewhat limited by the capacity to get the small satellites to orbit; often they are launched using surplus mass capacity in the launch of large satellites, essentially hitching a ride. But, increasingly, small satellites are taking up significant parts of the payload of large launches; in February 2017, India launched 103 small satellites along with a larger payload. Launchers dedicated to launching multiple small satellites are being developed. Small satellites are likely to play an increasing role in any number of space endeavors.

With space becoming cheaper and more accessible, more states own their own satellites and non-state actors such as universities and space startups can also reach space. Every year, a few more countries see the launch of their first satellite; more than 60 have now done so.

This trend could increase stability in space by increasing the number of stakeholders, or it could challenge the sustainability of space. Smaller satellites are generally not equipped to maneuver, and so cannot move out of the way of a potential collision; the sheer number of satellites could make avoiding collisions more difficult. Additionally, smaller satellites may be stealthier, and their behavior less transparent and observable.

Commercial space innovations

Investors with sweeping visions and deep pockets are transforming space launch and space services. A number of constellations of huge numbers of satellites are being planned, primarily to provide broadband internet globally, some to collect Earth observation data. In 2016, commercial companies filed for U.S. Federal Communications Commission licenses for 8,731 non-geostationary communications satellites, including 4,425 for SpaceX, nearly 3,000 for Boeing, and 720 for OneWeb. (The total number of operating satellites today is about 1,500.) Done well, these constellations can transform life on Earth for the better—generating new capacities to help underdeveloped regions and transforming industries. Done poorly, they can pose a serious challenge to space traffic management and the health of the space environment and concentrate control of resources and what may amount to a global utility in the hands of those who are not accountable to the global populace.

Other transformative satellite-based capabilities that now are beginning to be provided by private companies include the publicly available, constant imaging of Earth, timely weather forecasting, and better maritime tracking. Planet Labs Inc. aims to provide high-resolution imagery of the entire Earth, every day. Planet has secured launches for its "Dove" satellites at a steady tempo; in early 2017, 88 Doves were onboard India's record-breaking launch. A number of new companies are developing commercial synthetic aperture radar capabilities, which can provide high-resolution Earth imagery at night or during cloud cover. Commercial SAR outfits currently operate from Germany, Italy, and Canada, among others; four new companies (one each from Canada and Finland, two from the United States) recently announced that they planned to pursue their own commercial SAR constellations.

Constant surveillance could be stabilizing and beneficial, especially if it provides accountability; Planet Labs' explicit aim is to foster solutions to ecological, social, and humanitarian problems and commercial data can provide unclassified, shareable, objective data to help resolve disputes. Constant Earth imaging can also, of course, be used for ill, for example, to target political enemies or those who are vulnerable.

Global governance under stress

Concurrent with these changes, and perhaps because of them, global space governance is under stress. Governance is becoming less global and is fracturing into smaller domains as actors respond to their perceived needs. Declaratory policy is being made on a state level, and states are establishing norms of behavior unilaterally. For example, some states, such as the United States, Luxembourg, and the United Arab Emirates, seek to create a favorable legal and regulatory environment for private companies to pursue resource extraction on celestial bodies, although it is not at all clear that other states see such regimes as consistent with OST principles. As this publication states, proliferating legal and regulatory regimes could encourage companies to adopt "flags of convenience" by which to do their business.

Militaries, which use space as an instrument of state power, have begun to declare that conflict in space is "inevitable." Civil society has been ineffective in calling for the robust exploration of diplomatic solutions and constraints to produce a less militarized space in the future. Commercial interests are moving to shape the regulatory regime to their preferences. These actions are likely to set the playing field for decades to come if global governance does not provide a strong cohesive counter-vision.

Should trends continue, the traditional balance of civilian-governmental-military uses of space will be shifted heavily toward commercial space, with militaries a significant part of the customer base. A number of the new commercial investors in space are from the internet-startup culture, which prefers few regulations. Current regulations provide little guidance on some commercial ventures, such as building big satellite constellations, extracting resources from celestial bodies, and transforming space launch and human spaceflight into affordable quotidian tasks. But companies are unlikely to wait for slow-moving bureaucratic processes to catch up and will exert pressure to shape the legal regime to their preferences. However, states must have a say in this, as the Outer Space Treaty clearly assigns responsibility for national space activities to states, even those performed by nongovernmental entities.

Few resources are being devoted to developing shared notions among states on issues such as how the principles of "peaceful purposes" and "due regard" interact with national security needs.

The venue where space security and arms control initiatives are to be discussed, the UN Conference on Disarmament, has been moribund for two decades, and little serious effort has been made to bridge the divides. The United States has rejected the Russia-China PPWT proposal, but offers no alternatives. Efforts to negotiate and sign an International Code of Conduct for Space have derailed, despite the successful assembling of relevant parties in New York in 2015 for the negotiation of the Code's language. While a UN Group of Governmental Experts completed their work in 2015 on a draft set of transparency and confidence-building measures for space, little has been done to implement them.

Without a renewed commitment by state actors, global governance will not be up to the task of shaping trends to ensure that space remains sustainable and secure, with its benefits equitably enjoyed. Judging from the slow progress of recent years, the going will be tough. However, some bright spots are evident, and there are reasons to think that robust engagement from the civil sector will play an important role.

Positive signs

The UN Committee on the Peaceful Uses of Outer Space (COPUOS) has been steadily making progress on a number of issues. In 2016, COPUOS had a banner year; it concluded negotiations on a set of 12 draft Long Term Sustainability Guidelines, and was poised to agree on more. COPUOS shepherded 84 states to agreement on seven themes for a formal marking of UNISPACE+50 in 2018. COPUOS identified clearly how important a secure and sustainable space environment is by connecting it to the UN 2030 Sustainable Development Goals, creating an important shared vision that resonates deeply with the original principle of the Outer Space Treaty, that space activities should be "to the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development."

The initiation of a number of high-level bilateral and multilateral dialogues on civil and security aspects of space should be noted, as should the accession of India to the Missile Technology Control Regime and The Hague ballistic missile code of conduct.

On some issues where states may find difficult terrain, civil society is stepping in. For example, 2016 saw the inception of an effort to clarify what existing international law, including the Law of Armed Conflict and International Humanitarian Law, says about military uses of outer space. The McGill Centre for Research in Air and Space Law and The University of Adelaide Research Unit on Military Law and Ethics have spearheaded a project to draft the Manual on the International Law Applicable to the Military Use of Outer Space,[4] in the vein of the Tallinn Manual on Cyber Operations.[5] The Secure World Foundation published a Handbook for New Actors in Space to assist new actors in conducting their space activities in a safe and sustainable manner.

Looking forward

Still, these efforts are no substitute for a comprehensive, forward-looking system of global space governance. Space is clearly at an inflection point. The global governance regime is being stressed by rapid technological innovation and geopolitical realities. The Outer Space Treaty presents an important framework, but the structure must be filled in, lest disparate interests carve out their own fragmented areas of influence. Should that happen, the risks of conflict escalation would grow; space actors would waste resources to build fortress-like protection around their space investments; and the pollution of the space environment would accumulate, perhaps spoiling its use for future generations. In this world, the most advanced and richest could reserve the benefits of space for themselves and leave the rest behind. But a different future is possible.

The golden anniversary of the Outer Space Treaty is a prime opportunity for the three depository states (United States, United Kingdom, Russia) to provide leadership and to convene a meeting, such as a review conference, to provide clarifying discussions about how different states view the balancing of freedom to use space for peaceful purposes, due regard to other actors, and the use of space to benefit all humankind. Or perhaps a new generation of space states or civil society will take the lead. The sense that space is fundamentally for peaceful purposes and that its use must be for the benefit of all humankind needs to be reaffirmed by practice and rhetoric, and the Treaty's basic principles must be elaborated to govern new challenges.

Space Security Working Group Meeting

Best Western Ville-Marie Hotel
Montreal, Canada
2-3, 2017

Invited Experts:

Kimberly Chan
Canadian Space Agency

Karl Doetsch
Athena Global

Gilles Doucet
Space Security Consultant

Marie-Soleil Facteau
Global Affairs Canada

Steven Freeland
Western Sydney University

Laura Grego
Union of Concerned Scientists

Shazmin Kanji
Canadian Space Agency

Sanat Kaul
International Foundation for Aviation, Aerospace, and Development

David Kendall
Canadian Space Agency (retired), International Space University
Chair UN COPUOS (2016-17)

Aram Kerkonian
Institute of Air and Space Law, McGill University

Ricky Lee
Globalex

Jonathan McDowell
Harvard-Smithsonian Center for Astrophysics

Joe Pelton
International Association for Advancement of Space Safety

Lucien Rapp
L'Université Toulouse Capitole
Space Institute for Research on Innovative Uses of Satellites (SIRIUS)

Maria Rhimbassen
Space Institute for Research on Innovative Uses of Satellites (SIRIUS)

Jana Robinson
Prague Security Studies Institute

John Rummel
SETI Institute, Mountain View
Visiting Scholar, Institute of Air and Space Law, McGill University

Isabelle Sourbès-Verger
National Centre for Scientific Research (CNRS)

Brian Weeden
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Research Unit on Military Law and Ethics, The University of Adelaide

Bayar Goswami
Institute of Air and Space Law, McGill University

Ryan Green
Space Policy Institute, The George Washington University

Tomas Hrozensky
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Jack Kiraly
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Shannon LaFontaine
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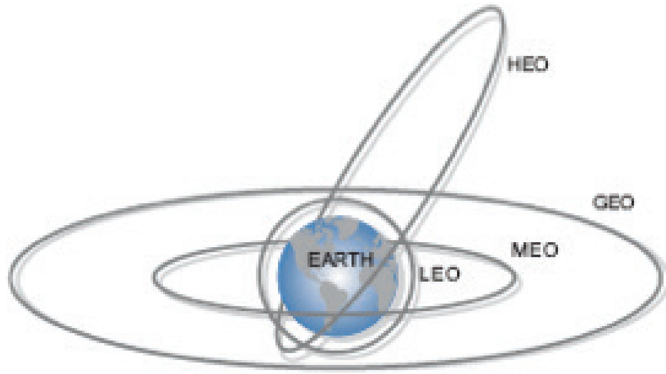
Project Ploughshares

Paul Meyer
The Simons Foundation

Dale Stephens
Research Unit for Military Law and Ethics, The University of Adelaide

Jessica West
Project Ploughshares

Types of Earth orbits*



Low Earth Orbit (LEO) is commonly accepted as below 2,000 km above the Earth's surface. Spacecraft in LEO make one complete revolution of the Earth in approximately 90 minutes.

Medium Earth Orbit (MEO) is the region of space around the Earth above LEO (2,000 km) and below GEO (36,000 km). The orbital period (time for one orbit) of MEO satellites ranges between two and 12 hours. The most common use for satellites in this region is navigation, as with the U.S. GPS.

Geostationary Orbit (GEO) is a region in which the satellite orbits at approximately 36,000 km above the Earth's equator. At this altitude GEO has a period equal to the period of rotation of the Earth. By orbiting at the same rate, in the same direction as Earth, the satellite appears stationary relative to the surface of the Earth. This is very useful for communications satellites. In addition, geostationary satellites provide a 'big picture' view of Earth, enabling coverage of weather events. This is especially useful for monitoring large, severe storms and tropical cyclones.

Sun Synchronous Orbit refers to an orbit at near-polar inclination and an altitude of between 200 and 1,200 km. The satellite passes over the equator and each latitude on the Earth's surface at the same local time each day, meaning that the satellite is overhead at essentially the same time throughout all seasons of the year. This feature enables collection of data at regular intervals and consistent times, which is especially useful for making long-term comparisons. Polar orbit is a more general term and includes all satellites with inclinations from approximately 70 degrees to 110 degrees at any altitude.

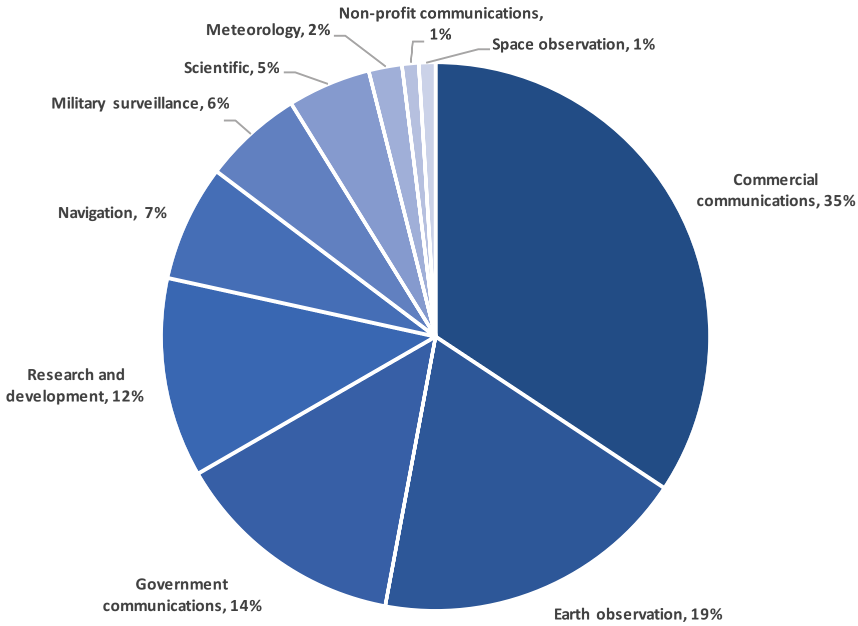
Highly Elliptical Orbits (HEO) are characterized by a relatively low-altitude perigee and an extremely high-altitude apogee. These extremely elongated orbits have the advantage of long dwell times at a point in the sky; visibility near apogee can exceed 12 hours. These elliptical orbits are useful for communications satellites. Molniya orbit is an example of HEO with excellent visibility of the Northern Hemisphere.

GEO transfer orbit (GTO) is an elliptical orbit of the Earth, with the perigee in LEO and the apogee in GEO. This orbit is generally a transfer path after launch to LEO by launch vehicles carrying a payload to GEO.

Apogee and **Perigee** refer to the distance from the Earth to the satellite. Apogee is the furthest distance from the Earth and perigee is the closest distance from the Earth.

* From the Space Foundation, *The Space Report 2008* (Colorado Springs: Space Foundation 2008), p. 52 with comments from Jonathan McDowell.

Operational satellites by function*



Total operational satellites: 1,459

* * As of 31 December 2016
Source: Bryce Space and Technology (Formerly Tauri Group), *State of the Satellite Industry Report 2017*

Summary of national civilian space budgets, 2016

Country	Agency name	Annual space budget ($M)	Budget as % of GDP[1]
United States	NASA	19,500	0.1081%
China*	CNSA	6,000	0.0542%
ESA	ESA	5,550	N/A
UAE+	UAESA	5,400	1.4583%
Russia	RSC	2,050	0.1501%
France**	CNES	1,490	0.0616%
Japan	JAXA	1,360	0.0310%
India	ISRO	1,120	0.0536%
Germany**	DLR	700	0.0208%
South Korea	KARI	608	0.0441%
United Kingdom	UKSA	472	0.0165%
Canada	CSA	320	0.0206%
Brazil	AEB	297	0.0165%
Kazakhstan	KazCosmos	184[2]	0.0998%
Ukraine	SSAU	125	0.1379%
Argentina	CONAE	113	0.0193%
Spain**	INTA	77.8	0.0065%
Peru	CONIDA	75.7[3]	0.0400%
Indonesia	LAPAN	58.3[4]	0.0068%
Norway (2015)**	NSC	52.8[5]	0.0137%
Sweden**	SNSB	45.3[6]	0.0091%
South Africa	SANSA	24.8[7]	0.0079%
Pakistan	SUPARCO	23.8[8]	0.0088%
Thailand	GISTDA	16.4[9]	0.0042%
Israel	ISA	15.8[10]	0.0053%
Nigeria	NASRDA	13.4[11]	0.0028%
Romania (2015)	ROSA	7.1[12]	0.0040%
Malaysia	ANGKASA	6.5[13]	0.0022%
Colombia	CCE	5.9[14]	0.0020%
Iran (2017)	ISA	4.6[15]	0.0011%
Mexico	AEM	4.0	0.0003%
Bangladesh	SPARRSO	2.6[16]	0.0013%
Morocco	CRTS	2.0[17]	0.0020%

* Estimate of final spending
** Excluding ESA contribution
\+ Total spending in space sector (Government estimate)

GDP figures sourced from World Bank using nominal 2015 values in USD.

Spacecraft launched in 2016*

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
Belintersat-1	Belarus	Government	Communications	GEO	5,223	Long March 3B	15-Jan-16
Jason 3	United States/ France	Government	Earth Observation	LEO	553	Falcon 9	17-Jan-16
IRNSS-1E	India	Government	Navigation/ Regional Positioning	GEO	1,425	PSLV-XL	20-Jan-16
Intelsat 29E	United States	Commercial	Communications	GEO	6,500	Ariane 5	27-Jan-16
Eutelsat Hot Bird 13E	Multinational	Commercial	Communications	GEO	5,200	Proton	29-Jan-16
BeiDou 3M-3S	China	Military/ Government	Navigation/Global Positioning	MEO	800	Long March 3C	1-Feb-16
GPS IIF-12	United States	Military/ Commercial	Navigation/Global Positioning	MEO	1,630	Atlas 5	5-Feb-16
Kosmos 2514	Russia	Military/ Commercial	Navigation/Global Positioning	MEO	1,415	Soyuz 2.1b	7-Feb-16
NROL-45 (Topaz 4)	United States	Military	Earth Observation	LEO	N/A	Delta 4	10-Feb-16
Sentinel 3A	ESA	Government	Earth Observation	LEO	2,300	Rokot	16-Feb-16
ChubuSat 2	Japan	Civil	Technology Development	LEO	50	H-2A	17-Feb-16
ChubuSat 3	Japan	Civil	Technology Development	LEO	50	H-2A	17-Feb-16
Horyu-4	Japan	Civil	Technology Development	LEO	10	H-2A	17-Feb-16
SES-9	United States	Commercial	Communications	GEO	5,271	Falcon 9	4-Mar-16
Eutelsat 65 West-A	Multinational	Commercial	Communications	GEO	6,654	Ariane 5	9-Mar-16
IRNSS-1F	India	Government	Navigation/ Regional Positioning	GEO	1,425	PSLV-XL	10-Mar-16
Resurs-P3	Russia	Government/ Commercial	Earth Observation	LEO	5,900	Soyuz 2-1b	13-Mar-16
Kosmos 2515	Russia	Military	Earth Observation	LEO	4,000	Soyuz 2.1a	24-Mar-16
BeiDou IGSO-6	China	Military/ Government	Navigation/Global Positioning	GEO	4,200	Long March 3A	30-Mar-16
AAUSAT-4	Denmark	Civil	Earth Observation	LEO	1	Soyuz 2.1a	25-Apr-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
e-st@r-2	Italy	Civil	Technology Development	LEO	1	Soyuz 2-1a	25-Apr-16
MICROSCOPE	ESA	Government	Space Science	LEO	300	Soyuz 2.1a	25-Apr-16
Sentinel 1B	ESA	Government	Earth Observation	LEO	2,300	Soyuz 2.1a	25-Apr-16
AIST-2D	Russia	Civil	Technology Development	LEO	531	Soyuz 2.1a	27-Apr-16
MVL-300	Russia	Civil/ Government	Space Science	LEO	645	Soyuz 2.1a	27-Apr-16
SAMSAT 218D	Russia	Civil	Technology Development	LEO	2	Soyuz 2.1a	27-Apr-16
IRNSS-1G	India	Government	Navigation/ Regional Positioning	GEO	1,425	PSLV	28-Apr-16
JCSat-14	Japan	Commercial	Communications	GEO	4,500	Falcon 9	6-May-16
Yaogan-30	China	Military	Earth Observation	LEO	2,700	Long March 2D	15-May-16
Dove 2e-1	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2e-2	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2e-3	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2e-4	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2ep-1	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2ep-2	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2ep-3	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Dove 2ep-4	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-May-16
Galileo FOC FM10	ESA	Commercial	Navigation/Global Positioning	MEO	723	Soyuz-ST	24-May-16
Galileo FOC FM11	ESA	Commercial	Navigation/Global Positioning	MEO	723	Soyuz-ST	24-May-16
Thaicom-8	Thailand	Commercial	Communications	GEO	3,025	Falcon 9	27-May-16
Kosmos 2516	Russia	Military/ Commercial	Navigation/Global Positioning	MEO	1,415	Soyuz 2.1b	29-May-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
ÑuSat-1	Argentina	Commercial	Earth Observation	LEO	35	Long March 4B	29-May-16
ÑuSat-2	Argentina	Commercial	Earth Observation	LEO	35	Long March 4B	29-May-16
Ziyuan 3-2	China	Government	Earth Observation	LEO	2,630	Long March 4B	29-May-16
Dove 2e-5	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	30-May-16
Dove 2e-6	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	30-May-16
Dove 2e-7	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	31-May-16
Dove 2e-10	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2e-11	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2e-12	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2e-9	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2ep-5	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2ep-6	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2ep-7	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2ep-8	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	1-Jun-16
Dove 2ep-10	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	3-Jun-16
Dove 2ep-11	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	3-Jun-16
Dove 2ep-12	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	3-Jun-16
Dove 2ep-9	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	3-Jun-16
Kosmos 2517	Russia	Military	Earth Science	LEO	900	Rokot	5-Jun-16
Intelsat 31/DLA 2	United States	Commercial	Communications	GEO	6,450	Proton	9-Jun-16
NROL-37 (Orion 9)	United States	Military	Earth Observation	GEO	5,000	Delta 4 Heavy	11-Jun-16
BeiDou 2-23	China	Military/ Government	Navigation/Global Positioning	GEO	3,800	Long March 3C	12-Jun-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
ABS-2A	Multinational	Commercial	Communications	GEO	1,800	Falcon 9	15-Jun-16
Eutelsat 117 West B	Multinational	Commercial	Communications	GEO	5,500	Falcon 9	15-Jun-16
BRISat	Indonesia	Commercial	Communications	GEO	3,540	Ariane 5 ECA	19-Jun-16
Echostar 18	United States	Commercial	Communications	GEO	6,300	Ariane 5 ECA	19-Jun-16
BIROS	Germany	Government	Earth Observation	LEO	130	PSLV XL	22-Jun-16
CartoSat 2C	India	Government	Earth Observation	LEO	727	PSLV XL	22-Jun-16
Dove 2p-1	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-10	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-11	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-12	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-2	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-3	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-4	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-5	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-6	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-7	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-8	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
Dove 2p-9	United States	Commercial	Earth Observation	LEO	4	PSLV XL	22-Jun-16
GHGSat-D	Canada	Commercial	Earth Science	LEO	15	PSLV XL	22-Jun-16
LAPAN A3	Indonesia	Government	Earth Observation	LEO	115	PSLV XL	22-Jun-16
M3MSat	Canada	Government	Earth Observation	LEO	85	PSLV XL	22-Jun-16
Sathyabamasat	India	Civil	Earth Science	LEO	2	PSLV XL	22-Jun-16
SkySat-3	United States	Commercial	Earth Observation	LEO	110	PSLV XL	22-Jun-16
Swayam	India	Civil	Technology Development	LEO	1	PSLV XL	22-Jun-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
MUOS-5	United States	Military	Communications	GEO	6,804	Atlas 5	24-Jun-16
Shijian 16 02	China	Government	Technology Development	LEO	N/A	Long March 4B	29-Jun-16
Dove 2e-8	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	31-Jun-16
NROL-61 (Quasar 20)	United States	Military	Communications	GEO	N/A	Atlas 5	28-Jul-16
Tiantong-1	China	Government	Communications	GEO	N/A	Long March 3B	5-Aug-16
Gaofen 3	China	Government	Earth Observation	LEO	1,000	Long March 4C	9-Aug-16
JCSat 16	Japan	Commercial	Communications	GEO	4,500	Falcon 9	14-Aug-16
QSS	China	Government	Space Science	LEO	700	Long March 2D	15-Aug-16
GSSAP 3	United States	Military	Space Observation	GEO	N/A	Delta 4M+	19-Aug-16
GSSAP 4	United States	Military	Space Observation	GEO	N/A	Delta 4M+	19-Aug-16
Intelsat 33	United States	Commercial	Communications	GEO	6,600	Ariane 5	24-Aug-16
Intelsat 36	United States	Commercial	Communications	GEO	3,250	Ariane 5	24-Aug-16
INSAT 3DR	India	Government	Earth Observation	GEO	2,200	GSLV Mk.2	8-Sep-16
Ofeq 11	Israel	Military	Earth Observation	LEO	300	Shavit	13-Sep-16
Dove 2ep-13	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	15-Sep-16
Dove 2ep-14	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	15-Sep-16
Dove 2ep-15	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	15-Sep-16
Dove 2ep-16	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	15-Sep-16
Dove 2ep-17	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	15-Sep-16
Dove 2ep-19	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	15-Sep-16
Dove 2ep-18	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	16-Sep-16
PeruSat-1	Peru	Government	Earth Observation	LEO	430	Vega	16-Sep-16
Skysat-4	United States	Commercial	Earth Observation	LEO	110	Vega	16-Sep-16
Skysat-5	United States	Commercial	Earth Observation	LEO	110	Vega	16-Sep-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
Skysat-6	United States	Commercial	Earth Observation	LEO	110	Vega	16-Sep-16
Skysat-7	United States	Commercial	Earth Observation	LEO	110	Vega	16-Sep-16
Dove 2ep-20	United States	Commercial	Earth Observation	LEO	4	Nanorack Deployer	17-Sep-16
Alsat-2B	Algeria	Government	Earth Observation	LEO	117	PSLV	26-Sep-16
Alsat-1B	Algeria	Government	Earth Observation	LEO	103	PSLV	26-Sep-16
AlSat-1N	Algeria	Government	Technology Development	LEO	10	PSLV	26-Sep-16
BlackSky Pathfinder 1	United States	Commercial	Earth Observation	LEO	44	PSLV	26-Sep-16
CanX-7	Canada	Civil	Technology Development	LEO	15	PSLV	26-Sep-16
PISAT	India	Government	Technology Development	LEO	6	PSLV	26-Sep-16
ScatSat-1	India	Government	Earth Observation	LEO	371	PLSV	26-Sep-16
GSAT-18	India	Government	Communications	GEO	3,404	Ariane 5	5-Oct-16
Sky Muster 2	Australia	Commercial	Communications	GEO	6,405	Ariane 5	5-Oct-16
Himawari 9	Japan	Government	Earth Observation	GEO	3,500	H-2A	2-Nov-16
Shijian 17	China	Government	Technology Development	GEO	3,800	Long March 5	3-Nov-16
XPNav-1	China	Government	Technology Development	LEO	240	Long March 11	9-Nov-16
Aerocube 8C	United States	Commercial	Technology Development	LEO	2	Atlas 5	11-Nov-16
Aerocube 8D	United States	Commercial	Technology Development	LEO	2	Atlas 5	11-Nov-16
CELTEE-1	United States	Military	Technology Development	LEO	3	Atlas 5	11-Nov-16
Prometheus 2.1	United States	Military	Technology Development	LEO	1	Atlas 5	11-Nov-16
Prometheus 2.2	United States	Military	Technology Development	LEO	1	Atlas 5	11-Nov-16
RAVAN	United States	Government	Technology Development	LEO	5	Atlas 5	11-Nov-16
Worldview 4	United States	Commercial	Earth Observation	LEO	2,485	Atlas 5	11-Nov-16
Yunhai-1	China	Government	Earth Observation	LEO	N/A	Long March 2D	11-Nov-16
Galileo FOC FM12	ESA	Commercial	Navigation/Global Positioning	MEO	723	Ariane 5	17-Nov-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
Galileo FOC FM13	ESA	Commercial	Navigation/Global Positioning	MEO	723	Ariane 5	17-Nov-16
Galileo FOC FM14	ESA	Commercial	Navigation/Global Positioning	MEO	723	Ariane 5	17-Nov-16
Galileo FOC FM7	ESA	Commercial	Navigation/Global Positioning	MEO	723	Ariane 5	17-Nov-16
GOES-R	United States	Government	Earth Observation	GEO	5,192	Atlas 5	19-Nov-16
TianLian 4	China	Government	Communications	GEO	2,200	Long March 3C	22-Nov-16
Göktürk 1	Turkey	Military	Earth Observation	LEO	1,060	Vega	5-Dec-16
Resourcesat-2A	India	Government	Earth Observation	LEO	1,235	PSLV	7-Dec-16
WGS 8	United States	Military	Communications	GEO	5,990	Delta 4	7-Dec-16
CYGNSS-A	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYGNSS-B	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYGNSS-C	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYNGSS-D	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYGNSS-E	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYGNSS-F	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYGNSS-G	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
CYGNSS-H	United States	Government	Earth Observation	LEO	29	Pegasus	15-Dec-16
Echostar 19	United States	Commercial	Communications	GEO	6,764	Atlas 5	18-Dec-16
STARS-C	Japan	Civil	Technology Development	LEO	N/A	J-SSOD 5	19-Dec-16
ERG	Japan	Government	Space Science	Elliptical	350	Epsilon	20-Dec-16
Chao Fenbianlu	China	Government	Earth Observation	LEO	50	Long March 2D	21-Dec-16

Satellite name	Owner	Actor type	Primary function	Orbit	Mass (kg)	Launch vehicle	Launch date
JCSat 15	Japan	Commercial	Communications	GEO	3,400	Ariane 5	21-Dec-16
Spark-1	China	Government	Earth Observation	LEO	50	Long March 2D	21-Dec-16
Spark-2	China	Government	Earth Observation	LEO	50	Long March 2D	21-Dec-16
Star 1 D1	Brazil	Commercial	Communications	GEO	6,433	Ariane 5	21-Dec-16
TanSat	China	Government	Earth Observation	LEO	620	Long March 2D	21-Dec-16
Superview 1-01	China	Commercial	Earth Observation	LEO	560	Long March 2D	28-Dec-16
Superview 1-02	China	Commercial	Earth Observation	LEO	560	Long March 2D	28-Dec-16

Guidelines for the long-term sustainability of outer space activities*

Committee on the Peaceful Uses of Outer Space – 15 June 2016

PART A: AGREED GUIDELINES

A. Policy and regulatory framework for space activities

Guidelines 1, 2, 3 and 4 provide guidance on the development of policies, regulatory frameworks and practices that support the long-term sustainability of outer space activities for Governments and relevant international intergovernmental organizations authorizing or conducting space activities.

Guideline 1: Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities

1.1 States should adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities, taking into account their obligations under the United Nations treaties on outer space as States responsible for national activities in outer space and as launching States. When adopting, revising, amending or implementing national regulatory frameworks, States should consider the need to ensure and enhance the long-term sustainability of outer space activities.

1.2 With the increase of outer space activities by governmental and non-governmental actors from around the world, and considering that States bear international responsibility for the space activities of non-governmental entities, States should adopt, revise or amend regulatory frameworks to ensure the effective application of relevant, generally accepted international norms, standards and practices for the safe conduct of outer space activities.

1.3 When developing, revising, amending or adopting national regulatory frameworks, States should consider the provisions of General Assembly resolution 68/74, on recommendations on national legislation relevant to the peaceful exploration and use of outer space. In particular, States should consider not only existing space projects and activities but also, to the extent practicable, the potential development of their national space sector, and envisage appropriate, timely regulation in order to avoid legal lacunae.

1.4 States, in enacting new regulations, or in revising or amending existing legislation, should bear in mind their obligations under article VI of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. Traditionally, national regulations have been concerned with issues such as safety, liability, reliability and cost. As new regulations are developed, States should consider regulations that enhance the long-term sustainability of outer space activities. At the same time, regulations should not be so prescriptive as to prevent initiatives addressing the long-term sustainability of outer space activities.

Guideline 2: Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities

2.1 When developing, revising or amending, as necessary, regulatory measures applicable to the long-term sustainability of outer space activities, States and international intergovernmental organizations should implement international obligations, including those arising under the United Nations space treaties to which they are party.

2.2 In developing, revising or amending, as necessary, national regulatory frameworks, States and international intergovernmental organizations should:

a) Consider the provisions of General Assembly resolution 68/74, on recommendations on national legislation relevant to the peaceful exploration and use of outer space;
b) Implement space debris mitigation measures, such as the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, through applicable mechanisms;
c) Address, to the extent practicable, risks to people, property, public health and the environment associated with the launch, in-orbit operation and re-entry of space objects;
d) Promote regulations and policies that support the idea of minimizing the impacts of human activities on Earth as well as on the outer space environment. They are encouraged to plan their activities based on the Sustainable Development Goals, their main national requirements, and international considerations for the sustainability of space and the Earth;
e) Implement the guidance contained in the Safety Framework for Nuclear Power Source Applications in Outer Space and satisfy the intent of the Principles Relevant to the Use of Nuclear Power Sources in Outer Space through applicable mechanisms that provide a regulatory, legal and technical framework that sets out responsibilities and assistance mechanisms, prior to using nuclear power sources in outer space;
f) Consider the potential benefits of using existing international technical standards, including those published by the International Organization for Standardization (ISO), the Consultative Committee for Space Data Systems and national standardization bodies. In addition, States should consider the utilization of recommended practices and voluntary guidelines proposed by the Inter-Agency Space Debris Coordination Committee and the Committee on Space Research;
g) Weigh the costs, benefits, disadvantages and risks of a range of alternatives and ensure that such measures have a clear purpose and are implementable and practicable in terms of the technical, legal and management capacities of the State imposing the regulation. Regulations should also be efficient in terms of limiting the cost for compliance (e.g., in terms of money, time or risk) compared with feasible alternatives;
h) Encourage advisory input from affected national entities during the process of developing regulatory frameworks governing space activities to avoid unintended consequences of regulation that might be more restrictive than necessary or that conflicts with other legal obligations;
i) Examine and adapt existing relevant legislation to ensure its compliance with these guidelines, considering the need for transition periods appropriate to their level of technical development.

Guideline 3: Supervise national space activities

3.1 In supervising space activities of non-governmental entities, States should ensure that entities under their jurisdiction and/or control that conduct outer space activities have the appropriate structures and procedures for planning and conducting space activities in a manner that supports the objective of enhancing the long-term sustainability of outer space activities, and that they have the means to comply with relevant national and international regulatory frameworks, requirements, policies and processes in this regard.

3.2 States bear international responsibility for national activities in outer space and for the authorization and continuing supervision of such activities, which are to be carried out in conformity with applicable international law. In fulfilling this responsibility, States should encourage each entity conducting space activities to:

a) Establish and maintain all the necessary technical competencies required to conduct the outer space activities in a safe and responsible manner and to enable the entity to comply with the relevant governmental and intergovernmental regulatory frameworks, requirements, policies and processes;
b) Develop specific requirements and procedures to address the safety and reliability of outer space activities under the entity's control, during all phases of a mission life cycle;
c) Assess all risks to the long-term sustainability of outer space activities associated with the space activities conducted by the entity, in all phases of the mission life cycle, and take steps to mitigate such risks to the extent feasible.

3.3 In addition, States are encouraged to designate a responsible entity or entities to plan, coordinate and assess space activities with the aim of promoting their effectiveness in supporting the Sustainable Development Goals and in supporting the objectives of the guidelines for the long-term sustainability of outer space activities in a broader perspective and vision.

3.4 States should ensure that the management of an entity that conducts outer space activities establishes structures and procedures for planning and conducting space activities in a manner that supports the objective of promoting the long-term sustainability of outer space activities. Appropriate measures to be taken by management in this regard should include:
a) A commitment at the highest levels of the entity to promoting the long-term sustainability of outer space activities;
b) Establishing and fostering an organizational commitment to promoting the long-term sustainability of outer space activities within the entity, as well as in relevant interactions with other entities;
c) Urging, to the extent practicable, that the entity's commitment to the long-term sustainability of outer space activities is reflected in its management structure and procedures for planning, developing and conducting outer space activities;
d) Encouraging, as appropriate, the sharing of the experiences of the entity in the conduct of safe and sustainable outer space activities as a contribution by the entity to enhancing the long-term sustainability of outer space activities;
e) Designating a contact point within the entity responsible for communication with relevant authorities to facilitate efficient and timely sharing of information and coordination of potentially urgent measures to promote the safety and sustainability of outer space activities.

3.5 States should ensure that appropriate communication and consultation mechanisms are in place within and among the competent bodies that oversee or conduct space activities. Communication within and among relevant regulatory bodies can promote regulations that are consistent, predictable and transparent so as to ensure that regulatory outcomes are as intended.

Guideline 4: Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites

4.1 In fulfilling their obligations under the Constitution and the Radio Regulations of the International Telecommunication Union (ITU), States should pay particular attention to the long-term sustainability of space activities and sustainable development on Earth and to facilitating the prompt resolution of identified harmful radio frequency interference.

4.2 As provided for in article 44 of the ITU Constitution, radio frequencies and any associated orbits, including the geostationary-satellite orbit, are limited natural resources that must be used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to those orbits and frequencies, taking into account the special needs of developing countries and the geographical situation of particular countries.

4.3 Consistent with the purpose of article 45 of the ITU Constitution, States and international intergovernmental organizations should ensure that their space activities are conducted in such a manner as not to cause harmful interference with the reception and transmission of radio signals related to the space activities of other States and international intergovernmental organizations, as one of the means of promoting the long-term sustainability of outer space activities.

4.4 In their use of the electromagnetic spectrum, States and international intergovernmental organizations should consider the requirements for space-based Earth observation systems and other space-based systems and services in support of sustainable development on Earth, in accordance with the ITU Radio Regulations and the ITU-R Recommendations.

4.5 States and international intergovernmental organizations should ensure the implementation of the radio regulation procedures established by ITU for space radio links. Moreover, States and international intergovernmental organizations should encourage and support regional and international cooperation aimed at improving efficiency in decision-making and implementation of practical measures to eliminate identified harmful radio frequency interference in space radio links.

4.6 Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the low-Earth orbit (LEO) region should be removed from orbit in a controlled fashion. If this is not possible, they should be disposed of in orbits that avoid their long-term presence in the LEO region. Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the geosynchronous Earth orbit (GEO) region should be left in orbits that avoid their long-term interference with the GEO region. For space objects in or near the GEO region, the potential for future collisions can be reduced by leaving objects at the end of their mission in an orbit above the GEO region such that they will not interfere with, or return to, the GEO region.

B. Safety of space operations

Guidelines 12, 13, 16 and 17 provide guidance to Governments and relevant international intergovernmental organizations on the conduct of space operations in a manner that supports the long-term sustainability of outer space activities.

Guideline 12: Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects

12.1 States and international intergovernmental organizations should promote the development and use of techniques and methods to improve the accuracy of orbital data for spaceflight safety and the use of common, internationally recognized standards when sharing orbital information on space objects.

12.2 Recognizing that spaceflight safety strongly depends upon the accuracy of orbital and other relevant data, States and international intergovernmental organizations should promote techniques and the investigation of new methods to improve such accuracy. Those methods could include national and international activities to improve the capabilities and geographical distribution of existing and new sensors, use of passive and active on-orbit tracking aids, and combining and validating data from different sources. Special attention should be paid to encouraging the participation and capacity-building of developing countries with emerging space capabilities in this domain.

12.3 When sharing orbital information on space objects, operators and other appropriate entities should be encouraged to use common, internationally recognized standards to enable collaboration and information exchange. Facilitating greater shared awareness of the current and predicted location of space objects would enable timely prediction and prevention of potential collisions.

Guideline 13: Promote the collection, sharing and dissemination of space debris monitoring information

13.1 States and international intergovernmental organizations should encourage the development and use of relevant technologies for the measurement, monitoring and characterization of the orbital and physical properties of space debris. States and international intergovernmental organizations should also promote the sharing and dissemination of derived data products and methodologies in support of research and international scientific cooperation on the evolution of the orbital debris population.

Guideline 16: Share operational space weather data and forecasts

16.1 States and international intergovernmental organizations should support and promote the collection, archiving, sharing, intercalibration, long-term continuity and dissemination of critical space weather data and space weather model outputs and forecasts, where appropriate in real time, as a means of enhancing the long-term sustainability of outer space activities.

16.2 States should be encouraged to monitor, to the extent feasible, space weather continuously and to share data and information with the aim of establishing an international space weather database network.

16.3 States and international intergovernmental organizations should support the identification of data sets critical for space weather services and research and should consider adopting policies for the free and unrestricted sharing of critical space weather data from their space- and ground-based assets. All governmental, civilian and commercial space weather data owners are urged to allow free and unrestricted access to, and archival of, such data for mutual benefit.

16.4 States and international intergovernmental organizations should also consider sharing real-time and near-real-time critical space weather data and data products in a common format, promote and adopt common access protocols for their critical space weather data and data products, and promote the interoperability of space weather data portals, thus promoting ease of data access for users and researchers. The real-time sharing of these data could provide a valuable experience for sharing in real time other kinds of data relevant to the long-term sustainability of outer space activities.

16.5 States and international intergovernmental organizations should further undertake a coordinated approach to maintaining the long-term continuity of space weather observations and identifying and filling key measurement gaps, so as to meet critical needs for space weather information and/or data.

16.6 States and international intergovernmental organizations should identify high-priority needs for space weather models, space weather model outputs and space weather forecasts and adopt policies for free and unrestricted sharing of space weather model outputs and forecasts. All governmental, civilian and commercial space weather model developers and forecast providers are urged to allow free and unrestricted access to and archival of space weather model outputs and forecasts for mutual benefit, which will promote research and development in this domain.

16.7 States and international intergovernmental organizations should also encourage their space weather service providers to:

a) Undertake comparisons of space weather model and forecast outputs with the goal of improved model performance and forecast accuracy;

b) Openly share and disseminate historical and future critical space weather model outputs and forecast products in a common format;

c) Adopt common access protocols for their space weather model outputs and forecast products to the extent possible, to promote their ease of use by users and researchers, including through interoperability of space weather portals;

d) Undertake coordinated dissemination of space weather forecasts among space weather service providers and to operational end users.

Guideline 17: Develop space weather models and tools and collect established practices on the mitigation of space weather effects

17.1 States and international intergovernmental organizations should undertake a coordinated approach to identifying and filling gaps in research and operational models and forecasting tools required to meet the needs of the scientific community and of the providers and users of space weather information services. Where possible, this should include coordinated efforts to support and promote research and development to further advance space weather models and forecasting tools, incorporating the effects of the changing solar environment and evolving terrestrial magnetic field as appropriate, including within the context of the Committee on the Peaceful Uses of Outer Space and its Subcommittees, as well as in collaboration with other entities such as the World Meteorological Organization and the International Space Environment Service.

17.2 States and international intergovernmental organizations should support and promote cooperation and coordination on ground- and space-based space weather observations, forecast modelling, satellite anomalies and reporting of space weather effects in order to safeguard space activities. Practical measures in this regard could include:

a) Incorporating current and forecast space weather thresholds into space launch criteria;

b) Encouraging satellite operators to cooperate with space weather service providers to identify the information that would be most useful to mitigate anomalies and to derive recommended specific guidelines for on-orbit operations. For example, if the radiation environment is hazardous, this might include actions to delay the uploading of software, implementation of manoeuvres, etc.;

c) Encouraging the collection, collation and sharing of information relating to ground- and space-based space weather-related impacts and system anomalies, including spacecraft anomalies;

d) Encouraging the use of a common format for reporting space weather information. In relation to the reporting of spacecraft anomalies, satellite operators are encouraged to take note of the template proposed by the Coordination Group for Meteorological Satellites;

e) Encouraging policies promoting the sharing of satellite anomaly data related to space weather-induced effects;

f) Encouraging training on and knowledge transfer relating to the use of space weather data, taking into account the participation of countries with emerging space capabilities.

17.3 It is acknowledged that some data may be subject to legal restrictions and/or measures for the protection of proprietary or confidential information, in accordance with national legislation, multilateral commitments, non-proliferation norms and international law.

17.4 States and international intergovernmental organizations should work towards the development of international standards and the collection of established practices applicable for the mitigation of space weather effects in satellite design. This could include sharing of information on design practices, guidelines and lessons learned relating to mitigation of the effects of space weather on operational space systems, as well as documentation and reports relating to space weather user needs, measurement requirements, gap analyses, cost-benefit analyses and related space weather assessments.

17.5 States should encourage entities under their jurisdiction and/or control to:

a) Incorporate in satellite designs the capability to recover from a debilitating space weather effect, such as by including a safe mode;

b) Incorporate space weather effects into satellite designs and mission planning for end-of-life disposal in order to ensure that the spacecraft either reach their intended graveyard orbit or de-orbit appropriately, in accordance with the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space. This should include appropriate margin analysis.

17.6 International intergovernmental organizations should also promote such measures among their member States.

17.7 States should undertake an assessment of the risk and socioeconomic impacts of adverse space weather effects on the technological systems in their respective countries. The results from such studies should be published and made available to all States and used to inform decision-making relating to the long-term sustainability of outer space activities, particularly with regard to mitigating the adverse impacts of space weather on operational space systems.

C. International cooperation, capacity-building and awareness

Guidelines 25 and 26 provide guidance on international cooperation measures aimed at promoting the long-term sustainability of outer space activities for Governments and relevant international intergovernmental organizations authorizing or conducting space activities.

Guideline 25: Promote and support capacity-building

25.1 States and international intergovernmental organizations with experience in space activities should encourage and support capacity-building in developing countries with emerging space programmes, on a mutually acceptable basis, through measures such as improving their expertise and knowledge on spacecraft design, flight dynamics and orbits, performing joint orbital calculations and conjunction assessments, and providing access to appropriate precise orbital data and appropriate tools for monitoring of space objects through relevant arrangements as appropriate.

25.2 States and international intergovernmental organizations should support current capacity-building initiatives and promote new forms of regional and international cooperation and capacity-building that are in accordance with national and international law to assist countries in gathering human and financial resources and achieving efficient technical capabilities, standards, regulatory frameworks and governance methods that support the long-term sustainability of outer space activities and sustainable development on Earth.

25.3 States and international intergovernmental organizations should coordinate their efforts in space-related capacity-building and data accessibility in order to ensure efficiency in the use of available resources and, to the extent that it is reasonable and relevant, avoid unnecessary duplication of functions and efforts, taking into account the needs and interests of developing countries. Capacity-building activities include education, training and sharing of appropriate experience, information, data, tools, and management methodologies and techniques, as well as the transfer of technology.

25.4 States and international intergovernmental organizations should also undertake efforts to make relevant space-based information and data accessible to countries affected by natural disasters or other catastrophes, guided by considerations of humanity, neutrality and impartiality, and to support capacity-building activities aimed at enabling the receiving countries to make optimal use of such data and information. These space-based data and information with appropriate spatial and temporal resolution should be freely, quickly and easily available for the countries in crisis.

Guideline 26: Raise awareness of space activities

26.1 States and international intergovernmental organizations should raise general public awareness of the important societal benefits of space activities and of the consequent importance of enhancing the long-term sustainability of outer space activities. To this end, States and international intergovernmental organizations should:

a) Promote institutional and public awareness of space activities and their applications for sustainable development, environmental monitoring and assessment, disaster management and emergency response;
b) Conduct outreach, capacity-building and education on regulations and established practices relevant to the long-term sustainability of space activities;
c) Promote activities of non-governmental entities that will enhance the long-term sustainability of outer space activities;
d) Raise awareness among relevant public institutions and non-governmental entities about national and international policies, legislation, regulations and best practices that are applicable to space activities.

26.2 States and international intergovernmental organizations should promote public awareness of space applications for sustainable development, environmental monitoring and assessment, disaster management and emergency response through information-sharing and joint efforts with public institutions and non-governmental entities, taking into account the needs of current and future generations. In designing space education programmes, States, international intergovernmental organizations and non-governmental entities should pay special attention to courses on enhancing knowledge and practice of the utilization of space applications to support sustainable development. States and international intergovernmental organizations should initiate the voluntary collection of information on public awareness and education tools and programmes with a view to facilitating the development and implementation of other initiatives with similar objectives.

26.3 States and international intergovernmental organizations should foster outreach activities by or with industry, academia and other relevant non-governmental entities. Outreach, capacity-building and educational initiatives could take the form of seminars (in person or broadcast over the Internet), published guidelines to complement national and international regulations or a website with basic information on a regulatory framework and/or a contact point within the Government for regulatory information. Appropriately targeted outreach and education can assist all entities engaged in space activities in gaining a better appreciation and understanding of the nature of their obligations, in particular relating to implementation, which can lead to improved compliance with the existing regulatory framework and the practices currently being employed to enhance the long-term sustainability of outer space activities. This is particularly valuable where the regulatory framework has been changed or updated, resulting in new obligations for participants in space activities.

26.4 Cooperation between Governments and non-governmental entities should be encouraged and fostered. Non-governmental entities, including professional and industry associations and academic institutions, can play important roles in increasing international awareness of issues associated with space sustainability, as well as promoting practical measures to enhance space sustainability. Such measures could include adoption of the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space; compliance with the ITU Radio Regulations related to space services; and the development of open, transparent standards for the exchange of data necessary to avoid collisions, harmful radio frequency interference or other harmful events in outer space. Non-governmental entities can also play important roles in bringing stakeholders together to develop common approaches to certain aspects of space activities that can collectively enhance the long-term sustainability of space activities.

D. Scientific and technical research and development

Guidelines 27 and 28 provide guidance of a scientific and technical nature for Governments, international intergovernmental organizations, and national and international non-governmental entities that conduct space activities. They encompass, among other things, the collection, archiving, sharing and dissemination of information on space objects and space weather, and the use of standards for information exchange. These guidelines also address research into, and the development of, ways to support the sustainable use and exploration of outer space.

Guideline 27: Promote and support research on and the development of ways to support sustainable exploration and use of outer space

27.1 States and international intergovernmental organizations should promote and support research into and development of sustainable space technologies, processes and services and other initiatives for the sustainable exploration and use of outer space, including celestial bodies.

27.2 In their conduct of space activities for the peaceful exploration and use of outer space, including celestial bodies, States and international intergovernmental organizations should take into account, with reference to the outcome document of the United Nations Conference on Sustainable Development (General Assembly resolution 66/288, annex), the social, economic and environmental dimensions of sustainable development on Earth.

27.3 States and international intergovernmental organizations should promote the development of technologies that minimize the environmental impact of manufacturing and launching space assets and that maximize the use of renewable resources and the reusability or repurposing of space assets to enhance the long-term sustainability of those activities.

27.4 States and international intergovernmental organizations should consider appropriate safety measures to protect the Earth and the space environment from harmful contamination, taking advantage of existing measures, practices and guidelines that may apply to those activities, and developing new measures as appropriate.

27.5 States and international intergovernmental organizations conducting research and development activities to support the sustainable exploration and use of outer space should also encourage the participation of developing countries in such activities.

Guideline 28: Investigate and consider new measures to manage the space debris population in the long term

28.1 States and international intergovernmental organizations should investigate the necessity and feasibility of possible new measures, including technological solutions, and consider implementation thereof, in order to address the evolution of and manage the space debris population in the long term. These new measures, together with existing ones, should be envisaged so as not to impose undue costs on the space programmes of emerging spacefaring nations.

28.2 States and international intergovernmental organizations should take measures at the national and international levels, including international cooperation and capacity-building, to increase compliance with the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space.

28.3 Investigation of new measures could include, inter alia, methods for the extension of operational lifetime, novel techniques to prevent collision with and among debris and objects with no means of changing their trajectory, advanced measures for spacecraft passivation and post-mission disposal and designs to enhance the disintegration of space systems during uncontrolled atmospheric re-entry.

28.4 Such new measures aimed at ensuring the sustainability of space activities and involving either controlled or uncontrolled re-entries should not pose an undue risk to people or property, including through environmental pollution caused by hazardous substances.

28.5 Policy and legal issues, such as ensuring that these new measures are compliant with the provisions of the Charter of the United Nations and applicable international law, may also need to be addressed.

**Note:* Part A, reproduced here, consists of the guidelines agreed upon at the fifty-ninth session of COPUOS held from 8-17 June 2016 in Vienna as contained in report A/AC.105/2016/CRP.17. Not included here is Part B, which contains draft guidelines still under discussion.

Endnotes

Theme One Endnotes

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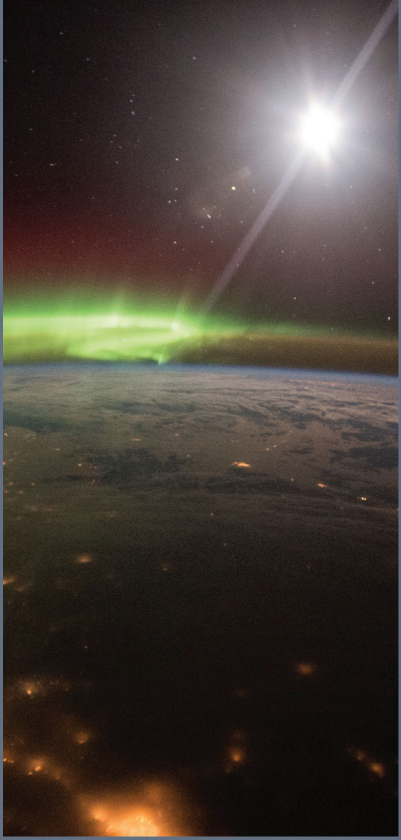

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