SPACE SECURITY INDEX 2018

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Featuring a global assessment of space security
by Dr. Rajeswari Pillai Rajagopalan

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ACRONYMS AND ABBREVIATIONS

ADR	Active Debris Removal
AEHF	Advanced Extremely High Frequency system (U.S.)
AFSC	Air Force Space Command (U.S.)
AIDA	Asteroid Impact Deflection Assessment
AIS	Automatic Identification System
ALTB	Airborne Laser Test Bed
ANGELS	Automated Navigation and Guidance Experiment for Local Space (U.S.)
APRSAF	Asia-Pacific Regional Space Agency Forum
APSCO	Asia-Pacific Space Cooperation Organization
ARM	Asteroid Redirect Mission (NASA)
ASAT	Anti-Satellite Weapon
ASI	Agenzia Spaziale Italiana
BDS	BeiDou Navigation Satellite System
BMD	Ballistic Missile Defense
CALT	China Academy of Launch Vehicle Technology
CAST	China Academy of Space Technology
CD	Conference on Disarmament
CEOS	Committee on Earth Observation Satellites
CNES	Centre national d'études spatiales (France)
CNSA	China National Space Administration
COPUOS	Committee on the Peaceful Uses of Outer Space (UN)
COTS	Commercial Orbital Transportation Services (U.S.)
CSA	Canadian Space Agency
CSpoC	Combined Space Operations Center (U.S.)
CSSMA	Commercial Smallsat Spectrum Management Association
CSSS	Canadian Space Surveillance System
CWC	Chemical Weapons Convention
CYGNSS	Cyclone Global Navigation Satellite System (NASA)
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	Search-and-Rescue
SBIRS	Space-based Infrared System
SBSS	Space Based Space Surveillance (U.S.)
SDA	Space Data Association
SDG	Social Development Goal
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 2018 is the fifteenth annual report on developments related to safety, sustainability, and security in outer space, covering the period January-December 2017. 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 well-being 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 structure of the 2018 report is as follows:

Theme 1: Condition and knowledge of the space environment

- Indicator 1.1: Orbital debris
- Indicator 1.2: Radio frequency (RF) spectrum and orbital positions
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Indicator 4.2: Multilateral forums for space governance
Indicator 4.3: Other initiatives.

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 manmade space debris in orbit is growing each year, concentrated in the orbits where human activities take place.

Today the U.S. Department of Defense 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. This is particularly concerning as a growing number of states view outer space as a domain of warfare.

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 antisatellite attacks have been carried out against an adversary; however, recent incidents testify to the availability and effectiveness of antiballistic 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 linked to transparency and confidence-building measures.

Because our coverage of space security is captured across many different indicators, *Space Security Index 2018* 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. Rajeswari Pillai Rajagopalan**, a Distinguished Fellow and Head of the Nuclear and Space Policy Initiative at Observer Research Foundation in New Delhi, India and Technical Advisor to the Group of Governmental Experts on the Prevention of an Arms Race in Outer Space (PAROS).

The information in *Space Security Index 2018* 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.

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. Note that, unless specified, all monetary amounts are in U.S. dollars.

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EXECUTIVE SUMMARY

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 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 Cosmos 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 UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) 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, or on who should do it and how. Lack of consensus is linked in part to concerns that these capabilities could be used as weapons. Funding debris removal is another difficulty.

2017 Developments

Space object population

- Older spacecraft generate debris
- The number of objects in orbit increases swiftly

Debris-related risks and incidents

- Safety measures ongoing to identify and reduce threats posed by debris

International awareness of debris problem and solutions

- Inadequate compliance with debris mitigation rules in LEO
- Efforts to update debris mitigation recommendations in step with changing uses of space
- Projects to develop capabilities to more quickly de-orbit small satellites advance
- Ideas for Active Debris Removal proliferate, but technology and political will lag
- Commercial approaches to managing debris considered

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 satellite orbits. 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 satellite systems require overlapping frequencies within the same coverage zone on Earth. More satellites are locating in both Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO), using frequency bands in common and increasing the likelihood of interference. The increased competition for orbital positions, particularly in GEO, where most communications satellites traditionally operate, has caused occasional disputes between satellite operators. The International Telecommunication Union (ITU) has been pursuing reforms to address backlogs in orbital assignments and other related challenges. Requests for resources to support large constellations of satellites are another source of pressure.

2017 Developments

- Smallsat companies establish new spectrum advocacy organization
- Competition grows for radio frequencies in transition to 5G connectivity, Internet of Things
- Continued efforts to regulate and harmonize rules for large constellations of satellites
- DARPA pursues new initiatives to better manage spectrum use

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-2018 NASA's Center for Near Earth Object Studies had identified 18,136 known Near-Earth Asteroids, 1,900 of which were categorized 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 140 meters in diameter). Increasing international awareness of the threat posed by NEOs has prompted international discussions on the technical and policy challenges related to mitigation and the creation of an International Asteroid Warning Network (IWAN) and a Space Mission Planning Advisory Group (SMPAG). Ongoing technical research is exploring how to mitigate a NEO collision with Earth.

Space weather refers to a collection of physical processes, beginning at the Sun and ultimately affecting infrastructures on Earth and in space that support human activities. 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 slow down satellites, making them move to 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.

2017 Developments

Near-Earth Objects

- Asteroid detection capabilities rise, but gaps remain in efforts to identify threats
- International Asteroid Warning Network tested
- Some asteroid deflection and sample return missions progress, but others cancelled

Space weather

- UN COPUOS continues to lead efforts toward improved space weather warning, coordination, and mitigation
- New missions, projects dedicated to understanding space weather

INDICATOR 1.4: Space situational awareness — 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. Commercial actors are also developing tracking capabilities and services.

SSA is also critical to the safety of collective operations in space and necessary for the development of any Space Traffic Management (STM) regulatory system, which could minimize the impact of growing congestion in space. Although widely recognized as important, STM is still at the discussion stage.

2017 Developments

- The United States continues to prioritize SSA capabilities and mission
- New Russian surveillance and tracking capabilities go online
- Coordination of European Space Surveillance and Tracking capabilities improves
- USSTRATCOM pursues additional data-sharing beyond traditional allies
- FAA requests funds to initiate Space Traffic Management pilot program
- Commercial actors continue to expand SSA capabilities and role in providing space safety and traffic management support

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

INDICATOR 2.1: Space-based global utilities — 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 Global Navigation Satellite Systems (GNSS) 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. Space-based data is increasingly being provided as a means of monitoring global climate change and supporting socioeconomic development.

2017 Developments

- Global Navigation Satellite Systems improve interoperability and reduce reliance on GPS
- Greater access to high-resolution and frequent-revisit Earth-Observation data
- Weather monitoring and prediction capabilities continue to improve
- Increased data collaboration to monitor climate change
- Satellites continue important role in disaster response
- Leveraging space capabilities for sustainable development

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 has 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.

2017 Developments

- Investment in advanced space programs accelerates
- Emerging space programs in Africa and Latin America focus on socioeconomic development and environmental monitoring
- New space agencies established
- Access to space remains a priority of civil space programs
- Growing focus on robotic lunar and planetary space exploration
- Continued efforts to develop new human spaceflight capabilities

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. The International Space Station remains the most prominent example of international cooperation. 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. Emerging spacefaring states that currently lack the technological means for independent space access have entered cooperation agreements on space activities. Cooperation agreements also enable established spacefaring countries to tackle high-cost, complex missions as collaborative endeavors with international partners. Several modes of cooperation and capacity building are coordinated through UN bodies. Finally, cooperation enhances the transparency of space programs and can foster both technical and cultural understandings. As a source of technology transfer and influence, it can also be used to advance strategic and political interests.

2017 Developments

- The International Space Station continues to foster international cooperation; NASA shifts involvement toward private sector
- Focus of next-generation space cooperation shifts to the Moon and Mars
- Developing countries engage in international cooperation for space activities
- Developments in international cooperation on space resource extraction
- Nascent modes of cooperation bridge geopolitical tensions

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.

2017 Developments

- Telecommunications continue to dominate commercial space industry
- Plans for satellite constellations support new space-based services and big data
- Small satellites and launchers drive increased access to space
- Reusability reduces cost of commercial launch service
- Private actors continue projects for human spaceflight, lunar exploration
- Novel space-based activities and services develop

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.

2017 Developments

- National security interests continue to influence commercial space industry
- Government efforts support national space industries
- Leveraging the private sector for next-generation space exploration and technology
- Public investment in future commercial activities in space
- Commercial capabilities continue to support national security and militaries

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.

2017 Developments

- U.S. military reorganization linked to possible extension of war into space
- Funding and hardware to modernize U.S. military space capabilities
- Growing focus on space for U.S. missile defense
- China investing in military space capabilities to advance regional interests
- Russia prioritizes military space capabilities, but few satellites launched
- Continued development of joint and independent military capabilities in Europe
- Space-based military capabilities and strategic cooperation develop in Asia
- Emerging space programs in the Middle East, Africa, and Latin America acquire military capabilities

- Australia and Canada attempt to expedite development of space-based military capabilities
- Alliance structures extend into space

Theme 3: Security of space systems

INDICATOR 3.1: Vulnerability of satellite communications, broadcast links, and ground stations — Satellite ground stations and communications links are common targets for space negation efforts, since they are vulnerable to a range of widely available conventional and electronic weapons. Electronic warfare in particular is a renewed focus of counter-space activities. 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.

2017 Developments

- Growing investment in electronic warfare capabilities
- New measures protect satellite communications and mitigate interference
- United States establishes Cyber Resilience Office for Weapons Systems as vulnerabilities continue
- Investment grows in quantum experiments to enable secure space communication

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 restore 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. Sensitive components and critical capabilities could be distributed among more small satellites, thus improving continuity of system operation and enhancing 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.

2017 Developments

- Growing U.S. focus on rapid acquisition of space capabilities
- On-orbit satellite servicing closer to operational
- Continued invest in rapid launch capabilities

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 direct ascent, kinetic antisatellite capability. Ground-based antisatellite 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 antisatellite 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. Incidents involving state use of antiballistic 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. Lasers and directed energy can temporarily interfere with satellite operations, but thus far the combination of capabilities required to destroy a satellite with such means has not been developed.

2017 Developments

- Exoatmospheric tests of ballistic missile defense systems continue as capabilities spread
- Renewed focus on dedicated ASAT capabilities
- DPRK advances technical military capabilities
- Laser development and research more sophisticated, but of limited use use against space objects

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. 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.

2017 Developments

- Demonstration of advanced space-based capabilities raises questions
- U.S. Congress and political leaders continue to press for a space-based missile defense testbed

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. All 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 and more states are able to use 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, while a number of states now view outer space as an extension of terrestrial domains of warfare.

2017 Developments

- U.S. National Security Strategy prioritizes strategic value of space
- States pursue enhnaced national regulatory regimes for commercial space activities
- Statements indicate support for norms and rules in 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 bodies related to space include the General Assembly First and Fourth Committees, UN Space, the UN Committee on the Peaceful Uses of Outer Space (COPUOS), and the Conference on Disarmament (CD). Additionally, the International Telecommunication Union is a specialized body of the UN and the International Committee on Global Navigation Satellite Systems functions under the umbrella of the UN. New governance mechanisms have progressed in recent years at COPUOS in the form of voluntary guidelines for the long-term sustainability of outer space. But consensus on additional measures to restrict the use of force in outer space has not been reached, with one camp in favor of a legally binding arms control framework and another in favor of voluntary rules.

2017 Developments

- UN General Assembly adopts new resolutions on the security of outer space
- Space launches by DPRK and Iran create concern at UN Security Council
- CD remains stalled, while EU renews call for common guidelines
- COPUOS expands membership, continues to work on peaceful uses of outer space
- 50th anniversary of the Outer Space Treaty commemorated
- UNISPACE+50 preparations
- UNOOSA promotes the role of women in outer space
- UNOOSA and the International Civil Aviation Organization combine efforts

INDICATOR 4.3: Other initiatives — A growing number of diplomatic initiatives relate to bilateral or regional collaborations in space activities. Examples 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. Academic and civil society organizations are also actively engaged in issues related to space governance. The Space Generation Advisory Council aims to bring the views of youth and young professionals to bear on outer space governance. Academics are involved in efforts to clarify existing laws and norms applicable to military operations in space, both in times of peace and in the event of war; examples include the McGill Manual on International Law Applicable to Military Uses of Outer Space (MILAMOS) and the Woomera Manual on the International Law of Military Space Operations, both under development. Finally, forums such as the International Astronautical Congress provide a means of engagement for the global space community as a whole.

2017 Developments

- Regional activity to coordinate and integrate Africa's space activities
- High-Level Forums provide networking opportunities for global space stakeholders
- Civil society organizations explore limits on the use of force in outer space
- The Hague International Space Resources Governance Working Group convenes
- Expanding societal engagement in outer space activities and governance

THEME ONE

Condition and knowledge of the space environment

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.

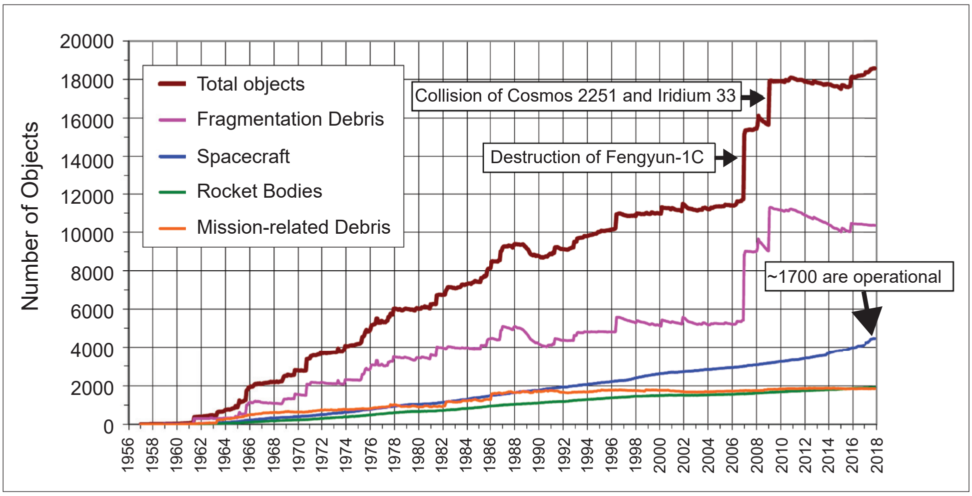
While all space missions create some debris—mainly as rocket booster stages are expended and released to drift in space along with bits of hardware—more serious fragmentations are usually caused by energetic events such as explosions or collisions. These can be either unintentional, as in the case of 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 1 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) (scheduled to transition to the Combined Space Operations Center [CSpOC] before the end of 2018[3]) of the U.S. Strategic Command (USSTRATCOM) in the Department of Defense (DoD) uses the SSN to track more than 18,000 *cataloged* objects with known origins,[4] of which approximately 5% are functioning payloads or satellites, 8% rocket bodies, and 87% debris and/or inactive satellites.[5] 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).[6] 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.[7] The ISS has had to be repositioned on several occasions to avoid collision with a large piece of debris. Other precautionary measures such as sheltering in place have also been necessary.

Collision warnings based on conjunction analyses are provided to satellite operators, notably by JSpOC, using space surveillance data (see Indicator 1.4). An email warning is provided for all "emergency" conjunctions, defined by USSTRATCOM as a time of closest approach of less than three days, and an estimated miss of less than 5 km for objects in GEO and 1 km in LEO.[8] However, these datapoints 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.[9] Such debris avoidance warnings are becoming more frequent, averaging more than 10 per day, as are avoidance maneuvers.[10] The challenge is currently less with overcrowding and more with insufficiently precise data on the location of both satellites and tracked debris.

Figure 1.1 Growth in on-orbit population by category [11]



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.[12] Objects need to be one meter in diameter or larger to be accurately tracked in GEO.[13]

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 manmade 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.[14] The second most debris-causing satellite breakup took place in February 2009, when the inactive Russian satellite Cosmos 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%.[15]

Figure 1.2 Top 10 breakups of on-orbit objects based on amount of debris produced[16]

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
Cosmos 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
Cosmos 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 production of debris is still increasing. 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[17]

Year	Event
1991	Inactive Cosmos-1934 satellite hit by cataloged debris from Cosmos 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 Cosmos-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 Cosmos 2251 collides with U.S. satellite Iridium 33
2013	Ecuadorean satellite Pegasus collides with debris from S14 Soviet rocket launched in 1985

Debris that reenters Earth's atmosphere can also be harmful. While most objects burn up upon reentry, this is not always the case. Damage from objects impacting Earth is rare, but concerns have been raised about environmental contamination caused by residual fuel—in particular, unsymmetrical dimethylhydrazine—that escapes from incoming rocket stages launched from Russia over sensitive areas such as the Arctic.[18]

Growing awareness of space debris threats has led to efforts to decrease the amount of new debris. Between 1961 and 1996, an average of approximately 240 new objects 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.[19] 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.[20]

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.[21] In 2007, COPUOS adopted a version of these guidelines, which were endorsed by the UN General Assembly (UNGA), as voluntary measures with which all states should comply.[22] 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.[23] 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[24]

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.

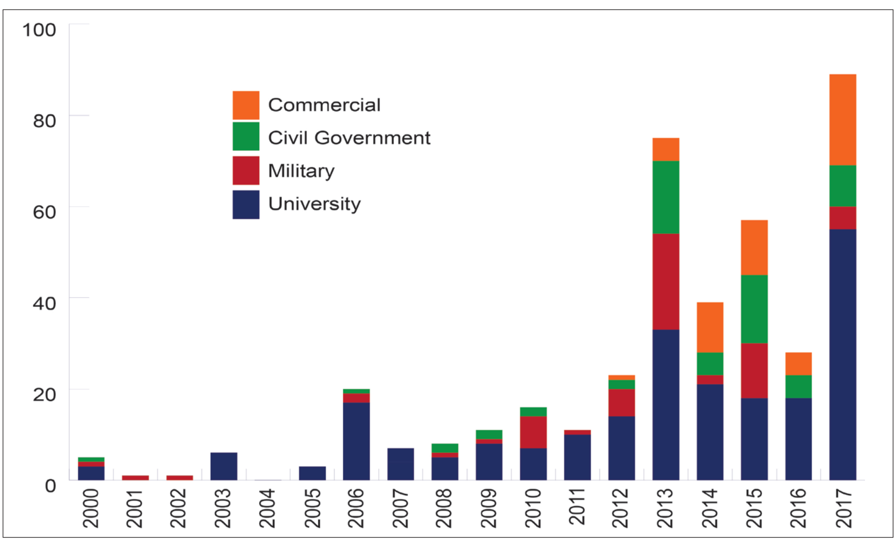
However, compliance with mitigation guidelines is inconsistent. Analysis from ESA and the U.S. National Aeronautics and Space Administration (NASA) suggests that in GEO, many satellites continue to reach end-of-life without being moved higher to a safe "graveyard" orbit.[25] In LEO, a Centre national d'études spatiales (CNES) study of debris mitigation practices from 2000 to 2012 found that 40% of satellites and rocket bodies are left at altitudes high enough to make atmospheric reentry through natural orbital decay within the 25-year window specified in the guidelines impossible.[26]

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).[27] More than 500 microsatellites (less than 100 kg) were launched between 2002 and 2015. Many more are planned, including thousands of even larger spacecraft for large commercial constellations.[28]

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 often end up in the orbital regime of the primary payload, which means that many of them are in orbits too high to rapidly decay.[29] The lower cost of a cubesat also allows for more experimentation and less stringent quality control, which can result in more on-orbit failures.

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 them are in orbits that do not comply with guidelines calling for satellites to stay in orbit no more than 25 years after mission completion.[30] 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.[31] Planet Labs, a pioneer of cubesats for commercial purposes, has publicly announced its adoption of NASA's best practices for limiting orbital debris.[32] But a recent study suggests that approximately 18% of all cubesats are dead-on-arrival or within their first week in space.[33] Those 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.[34]

Figure 1.5 Number of cubesats by mission type[35]



Recently, numerous commercial plans have emerged for constellations of thousands of satellites in LEO, which will pose new challenges to long-term sustainability (see below).[36] The number of satellites being proposed is unprecedented and challenging. The IADC added the subject of large constellations of satellites to its agenda in 2015. Studies indicate that proposed constellations in LEO could increase collision warnings for the ISS sixfold,[37] and that a constellation of more than 4,000 satellites would result in 64-million collision warnings per year, just among spacecraft in that constellation.[38]

In the long term, mitigation may not be enough 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.[39] 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.[40] Authors of an IADC study representing six member space agencies recommended that remediation measures, such as active debris removal (ADR), be considered to stabilize the future LEO environment. To date, no ADR mechanisms have been implemented, although research and technology development continue. For example, in 2016, China launched a space-debris-removal experiment, Aolong-1 (Roaming Dragon), developed by the China Academy of Launch Vehicle Technology (CALT) and the Harbin Institute of Technology. It was equipped with an onboard robotic arm, which was intended to demonstrate the removal of a simulated space debris object by moving it into a reentry trajectory.[41] However, there is currently no international consensus that debris removal should be done, or 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).

2017 Developments

Older spacecraft generate debris

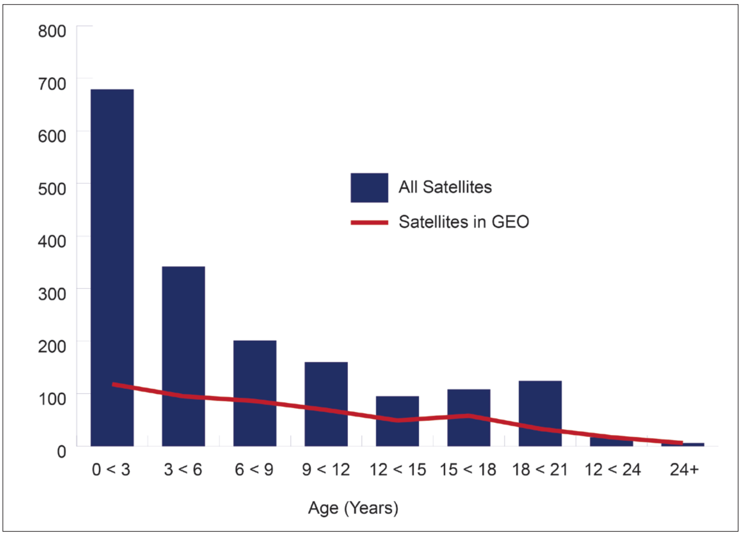
Several events in 2017 point to the safety challenges posed by older spacecraft on orbit. In late June, satellite operator SES of Luxembourg lost contact with satellite AMC-9, launched in 2003. At least four pieces of debris were noted around the spacecraft, but NASA is unsure of their origin.[42] The satellite was retired a year early and safely moved to a graveyard orbit after the operator regained control.[43]

On 25 August, contact with 18-year-old Indonesian satellite Telkom 1 was lost and the satellite shed massive debris fragments in GEO, which were captured and reported by ExoAnalytic Solutions.[44] Over time, the cloud of debris is expected to drift, forcing debris-avoidance maneuvers by spacecraft in GEO.[45] Also in August, EchoStar lost contact with the 20-year-old EchoStar 3 satellite, which began to drift in GEO; the satellite was moved to a graveyard orbit after contact was regained.[46]

It is difficult to generalize from these events. Older satellites do not necessarily become inoperable or shed debris; many are deorbited or moved to safer orbits (see below). And younger satellites can also fail. However, the number of anomalies in older spacecraft in 2017 raises concerns. It is possible that with the coming online of new capabilities for satellite servicing (see Indicator 3.2), spacecraft will have extended lifespans.

According to data acquired from the Union of Concerned Scientists database, the average age of all operational satellites is approximately 6.5 years. The median is 4.5 years. In GEO, the average age is 2.5 years older at almost nine years.

Figure 1.6 Age of operational satellites [47]



Additional debris was created on 3 September when a SOZ ullage auxiliary motor from a Proton Block DM fourth stage, used to launch a GLONASS satellite in 2010, disintegrated. These motors have a long history of fragmentations; this event was the forty-eighth known disintegration of a SOZ motor.[48] *Orbital Debris Quarterly News* reports that of the 380 such motors launched, 64 remain on orbit and 37 are believed to be intact.[49]

The number of objects in orbit increases swiftly

Both the number and mass of objects on orbit are growing rapidly as space activities expand. In 2017, the amount of space debris surpassed 7,600 metric tons,[50] produced partly by the launch that year of a record 466 satellites, 403 of which were launched to LEO.[51] The number broke the record set in 2014, when 302 spacecraft were launched.[52] Plans for large constellations of satellites (see Indicators 1.2 and 2.4) will shatter this new record; more than 6,200 satellites could be launched between 2017 and 2026.[53] This will mark a significant change to the space environment in LEO and will seriously challenge sustainability and safe operations.

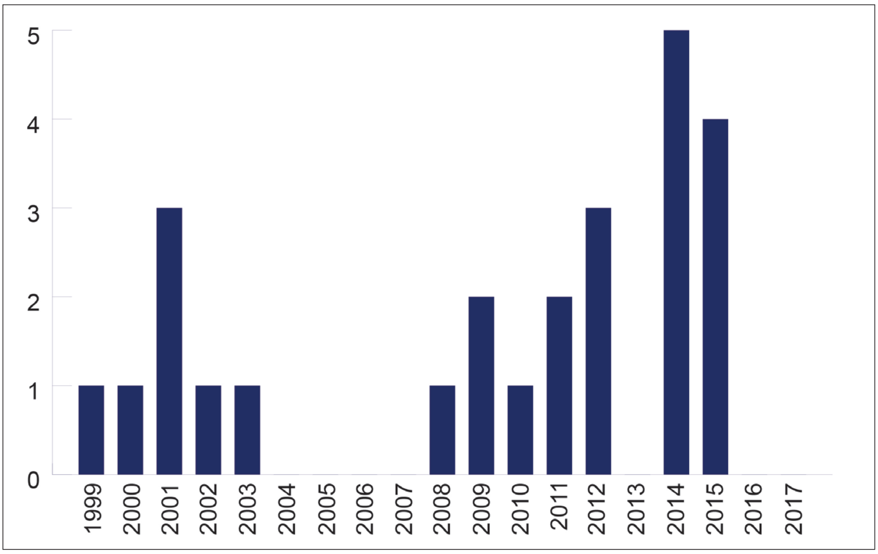
The year 2017 also saw a record number—290—of cubesats launched (see Figure 1.5 and Indicator 2.4).[54]

Both because there is more debris and because the ability to identify and track debris has improved, the number of objects 10 cm and larger in Earth orbit recorded by the U.S. Satellite Catalog continued to increase.[55] The number of tracked debris is expected to jump dramatically in 2019, when the space fence, which will be capable of tracking much smaller objects in LEO, becomes operational (see Indicator 1.4).

Safety measures ongoing to identify and reduce threats posed by debris

In 2017, the International Space Station did not have to conduct any collision-avoidance maneuvers. One spacecraft on its way to the ISS did conduct such a maneuver, as did another to avoid a conjunction with the ISS.[56] NASA conducted or assisted with both, and with 19 other collision-avoidance operations. Four of the 19 were to avoid debris from China's 2007 antisatellite test, and two to avoid debris from the collision of Cosmos 2251 and Iridium 33 in 2009.[57]

Figure 1.7 International Space Station debris avoidance maneuvers by year[58]



The U.S. Space Surveillance Network provided data on 308,984 close calls with space junk and issued 655 emergency alerts to satellite operators.[59] The risks, however, are even greater than these figures suggest. NASA reported, "Current conjunction assessments and collision avoidance maneuvers against the tracked objects (which are typically 10 cm and larger) only address a small fraction (~1%) of the mission-ending risk from orbital debris."[60] Spacecraft operators find the number of warnings overwhelming for practical use. Even more than orbital crowding, the main challenge is to provide accurate orbital data (see Indicator 1.4).

NASA's Space Debris Sensor (SDS) was installed on the ISS on 1 January 2018. It will monitor the small debris environment around the space station for several years, recording debris between 0.05 and 0.5 mm in diameter—smaller than what can currently be monitored from the ground. According to NASA, "Data gathered during the SDS investigation will help researchers map the entire orbital debris population and plan future sensors beyond the space station and low-Earth orbit, where the risk of damage to spacecraft from orbital debris is even higher."[61]

An estimated 176 objects reentered Earth's atmosphere in 2017.[62] While reentries rarely pose a risk, in November, an Antares rocket body flew over a populated area of Canada; ultimately, it caused no harm. The rocket had been expected to fall closer to Australia.[63] The international liability of states for damage caused by launched objects is prescribed by Article

VII of the 1967 Outer Space Treaty, reaffirmed by the 1972 Convention on International Liability Caused by Space Objects (see Indicator 4.2), and further clarified by end-of-mission disposal parameters in the 2007 IADC Space Debris Mitigation Guidelines.[64]

On 4 May, China formally notified the UN Office for Outer Space Affairs (UNOOSA) of the anticipated uncontrolled reentry of the Tiangong-1 space laboratory in 2018, and committed to working with the IADC to track its degrading orbit.[65] The station's altitude was 349 km at the time of the announcement, but had dropped to 280 km by the end of the year.[66] Chinese officials stated that "most parts of the space lab will burn up during falling."[67] The space station is 10.4 m long and weighs 10.5 metric tons. 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 is the risk of an explosive breakup when it reenters the atmosphere.

The reentry will be the biggest uncontrolled event since the 2015 failure of the Russian Progress M-27M unmanned ISS resupply freighter, which had a reentry mass of 7 tons and burned up over the Pacific Ocean.[68] The event is being used by IADC members, including China, to conduct the annual reentry test campaign to assess collective predictive capabilities and pool tracking datasets.[69] The IADC has conducted such campaigns since 1998.

The 13 October launch of a Russian Rokot launch vehicle transporting an ESA Sentinel 5 Precursor satellite heightened concerns over environmental contamination.[70] The Rokot is a repurposed Soviet-era S-19 intercontinental ballistic missile consisting of two stages topped by a Briz-KM propulsion module. Due to the trajectory of the launch, one of the intermediate stages landed in waters in the Canadian "Exclusive Economic Zone," as defined by the 1982 United Nations Convention on the Laws of the Sea[71]—the eleventh such "splashdown" in 15 years.[72] Canadian Inuit groups protest the launches because of the potential dispersal of toxic hydrazine rocket fuel in a sensitive ecological environment.[73]

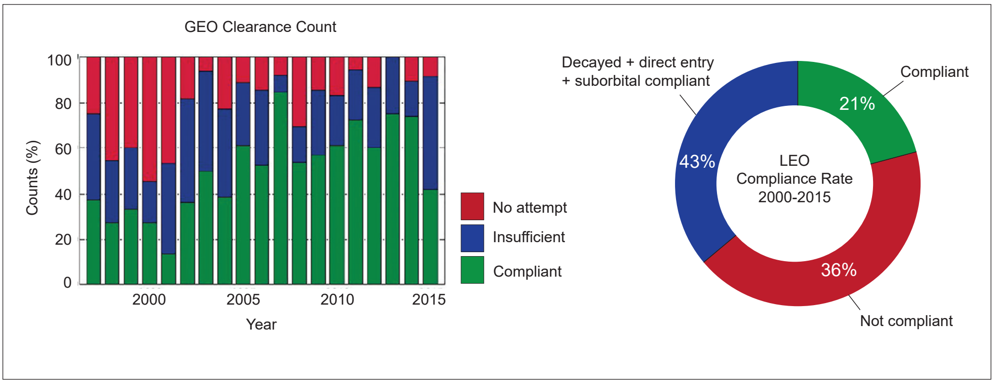
Inadequate adherence to debris mitigation rules in LEO

Adherence to guidelines on debris mitigation remains inconsistent. IADC guidelines specify that spacecraft in LEO should deorbit or be placed in an orbit that avoids long-term presence in LEO within 25 years, but the February 2018 IADC report submitted to COPUOS indicates inadequate implementation, with no trend to improvement.[74] As thousands of satellites could be launched into LEO as parts of constellations in the next few years (see above), this lack of compliance is concerning.

In GEO, IADC guidelines direct spacecraft at end of mission to be moved into higher graveyard orbits. Seventeen satellites were reportedly retired in 2017,[75] marking a trend toward better levels of compliance.[76] However, the orbit of the spacecraft Kodama is lower than the IADC recommendation and, at the end of the year, Asiasat 4, Astra 1H, and Afristar, while located above GEO, were still below graveyard altitudes.[77]

In 2017, Iridium Communications launched 40 Iridium-NEXT satellites to replace aging Iridium legacy satellites. Thirteen of the older spacecraft were removed from active orbits and six have reentered Earth's atmosphere.[78]

Figure 1.8 Compliance with debris mitigation guidelines in LEO, GEO[79]



Efforts to update debris mitigation rules and practices in step with changing uses of space

That humans are using space more intensively can be seen in proposals for large satellite constellations and growth of national space programs (see Indicator 2.2). Exploration missions into deep space reveal more extensive use. Both trends have debris implications, which were addressed in 2017 in several ways.

NASA updated its Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environment (NPR 8715.6B). Changes largely clarify institutional roles and responsibilities, but add the intent to limit the generation of debris not only in Earth orbits, but wherever debris might pose a hazard to future spacecraft, including around the Moon and Mars, and the Sun-Earth and Earth-Moon Lagrange Points.[80]

The IADC compiled a study by experts on space-debris-environment modeling to assess the implications of constellation traffic.[81] In a closed session in Darmstadt, Germany, the IADC conducted discussions on the need to revise mitigation guidelines to align with mega-constellations.[82] Scientists at the meeting estimate that the risk of collision could increase by 50%.[83] A NASA study that models the future effects of cubesats on the amount of space debris demonstrates the importance of post-mission disposal of even the smallest spacecraft.[84] Currently, almost all cubesats lack propulsion systems, so they cannot maneuver independently in space to deorbit (see below).

In early 2018, the IADC updated its 2015 statement on large constellations in LEO with new recommendations to mitigate risk to other spacecraft and the environment.[85] The concern is both with the growing number of objects that could be launched, and the potential for collisions within a constellation. Current recommendations to minimize the risk of collision address constellation design, such as altitude separations; spacecraft design, including minimizing the likelihood of explosions; on-ground risk, with an emphasis on performing controlled reentry; structural integrity, with an emphasis on spacecraft reliability; the importance of trackability and collision avoidance; and disposal measures that lower the 25-year lifetime limit and minimize post-operational time on orbit.[86]

Projects to develop capabilities to more quickly deorbit small satellites advance

Two propulsion boosters for cubesats, using electrospray thrusters, were successfully demonstrated in space: on the 2015 IMPACT mission by Aerospace Corporation and on the U.S. Naval Academy's BRICSaT-P satellite.[87] Progress was made on the thrusters, which use static electricity and tiny drops of water, in advance of a 2018 demonstration.[88]

On 23 June, new technology demonstrator D-Sat by D-Orbit LLC was launched. Described as "the first nanosatellite with the ability to remove itself from orbit in a direct and controlled way through a dedicated device at the end of its mission," it uses an independent propulsion system that functions even if the satellite is unresponsive.[89] D-Orbit claims that this form of propulsion can be scaled to function on a spacecraft of up to 5 tons. However, the deorbit motor misfired on 2 October and rather than deorbiting, the spacecraft went into a higher orbit.[90]

Another approach uses passive means to deorbit a satellite. At a demonstration in May at the Space Flight Laboratory at the University of Toronto, Canadian experimental nanosatellite CanX-7's drag-sail technology showed early success in accelerating the altitude decay rate.[91] The increase in the number of cubesats using drag sails to accelerate reentry is a positive development.

OneWeb, which has plans for a constellation of thousands of large satellites (see Indicator 2.4), indicated in 2017 that within five years it will deorbit satellites by equipping them with an ion electric propulsion system.[92] Such a system has never been used for this function. OneWeb spacecraft will be substantial, carry tracking systems, and be visible to ground observation systems. OneWeb is willing to use active-debris-removal services for those spacecraft that fail to deorbit, when such services become commercially available (see below).

Ideas for Active Debris Removal proliferate, but technology unproven

Founded in 2013 in Singapore, Astroscale is the first private company committed to making ADR work in space.[93] It partnered with Surrey Satellite Technology Ltd. (SSTL) in 2017 to develop a component for its upcoming End-of-Life Service demonstration (ELSA-d), expected in 2019. SSTL will build a target spacecraft that will launch attached to Astrocale's "chaser" spacecraft; the two will separate and the chaser will attempt to rendezvous and capture the target in both a stable and tumbling mode before deorbiting.[94] By July, Astroscale had raised $53-million to mitigate space debris.[95] The service is intended for commercial use, particularly for large constellations. However, it is not clear that a market will develop,[96] particularly without changes to debris mitigation requirements.

In September, Astroscale signed a joint research agreement with the Japan Aerospace Exploration Agency (JAXA).[97] Earlier in the year, JAXA's electrodynamic tethers, used to remove spent rocket bodies (18% of all tracked objects) from LEO orbit by generating magnetic drag, failed to deploy properly.[98] The Astroscale launch of IDEA OSG 1, a space-debris-monitoring microsatellite, into LEO to aid in the creation of a debris distribution map was scheduled for November.[99] However, the Soyuz-2 launch vehicle experienced a launch anomaly before payload deployment and the satellite was lost.[100]

SSTL's RemoveDEBRIS experiment, designed by the University of Surrey, will test three concepts for deorbiting debris: a "harpoon," a "net," and a drag sail. Originally scheduled for delivery to the ISS in 2017, the experiment was delayed for additional safety review and rescheduled for 2018.[101]

ESA is supporting research on using a magnetic space tug to deorbit derelict space objects.[102] Its own e.Deorbit ADR mission, intended for use on large objects in space, is scheduled to launch in 2023. It will test non-cooperative rendezvous and formation flight, capture, and control of large non-cooperative objects; and adaptive guidance and navigation control.[103]

In September, Airbus Defense and Space announced that it would develop an ADR vehicle called Space Tug, whose "main missions [would be] maintenance, logistics and the cleaning up of Space debris."[104] No launch date was announced.

Stanford researchers began testing a robotic gripper to grab and dispose of space debris.[105] A few proposals are also being pursued to remove debris from GEO. British firm Hempsell Astronautics proposes to use its Necropolis spacecraft to collect and deliver dead satellites in GEO to graveyard orbit. Researchers at the University of Colorado Boulder are thinking about pushing defunct satellites away from crowded orbits in GEO with a "pulsed electron gun."[106]

However, many of the ADR technologies remain speculative and risk creating more debris. All these capabilities have potential dual-use applications (see Indicator 3.4).

Commercial approaches to managing debris considered

A key constraint on the active removal of debris is an ongoing lack of political will, combined with uncertain economic incentives. In December, Japan and the United Kingdom signed a memorandum of understanding on space debris mitigation, hoping to promote public-private partnership by introducing a system for rating space-related companies on their debris reduction protocols.[107] The Japanese Ministry of Economy, Trade and Industry was to send a research team to the UK early in 2018.

Small-satellite developers have some incentive to address the problem of space debris to preempt a legislative approach in the United States. At the 31st Annual Conference on Small Satellites in August, industry experts presented a proposal to create a "Smallsat Space-traffic Safety Consortium," a self-regulatory organization to develop best practices in collision avoidance and minimizing total time on orbit.[108]

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 satellite orbits. The current International Telecommunication Union (ITU) Constitution,[109] originally adopted in 1992, governs international sharing of the radio spectrum and the specific orbital slots used by satellites in GEO, both recognized as 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.[110] 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) can transmit 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.[111]

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, relieving some pressure on available bandwidth. Ultra- High Frequency, X-, and K-bands (240-340 megahertz [MHz], 8-12 GHz, and 18-27 GHz, respectively) have traditionally been reserved in the United States for the military.[112]

Figure 1.9 Radio frequency bands [113]

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 (500-1,000 MHz)	UHF (300-1000 MHz) L Band (1-2 GHz) S Band (2-3 GHz)	300-3,000 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) G 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

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 the lower section (3.4-3.6 GHz) of C-band has been opened for terrestrial use, reserving Ka-band for satellite use.[114]

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."[115] Military communications are exempt from the ITU Constitution under Article 48, adding 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.[116] By May 2016, the application of Article 48 for the purposes of "national defense, military, or government use"[117] had been requested on behalf of 120 satellite networks across 62 unique orbital positions. WRC-15 sought to limit such wide application of this provision 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 respective state.

Issues of interference arise primarily when two satellite systems require overlapping frequencies within the same coverage zone on Earth. More satellites are locating in both GEO and LEO, using frequency bands in common and increasing the likelihood of interference.

Emerging plans for large constellations of satellites are 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 worldwide; more have followed.[118] Interference with traditional communications satellites operating in GEO is a significant concern; because communications satellites in both LEO and GEO use the same frequency, the process of coordinating radio frequencies is more complex.[119] Competition for frequencies with terrestrial mobile broadband providers is also a concern.[120] To further exploit the available radio frequency spectrum, operators are proposing options that use V and Q bands.[121]

Concerns 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.[122] 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.[123]

Unable to verify claims, the ITU has a limited ability to respond to complaints of interference. 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. The resolution 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.[124]

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 positions

Today's satellites operate mainly in LEO, MEO, and GEO. As of 30 April 2018, 1,886 active satellites were in orbit: 1,186 in LEO, 112 in MEO, 548 in GEO, and 40 in Highly Elliptical Orbit (HEO).[125] 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 (EO), and MEO is home to Global Navigation Satellite Systems (GNSS) such as the U.S. Global Positioning System (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;[126] 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.[127] To avoid radio frequency interference, GEO satellites are required to maintain a minimum degree of orbital separation, depending on the band they are using to transmit and receive signals, the service they provide, and the technical capabilities of ground stations.[128] 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 a concern, 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, Japan, 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 positions, 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.[129] 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,"[130] 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. 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.[131] Extensions may be granted in some circumstances. 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."[132]

2017 Developments

Smallsat companies establish new spectrum advocacy organization

Governance of the distribution and use of RF spectrum, a shared resource, is becoming more challenging with the growing use of constellations of small satellites (see Indicator 2.4). In September 2017, 11 smallsat companies established the Commercial Smallsat Spectrum Management Association (CSSMA) to address policies and regulations specific to their industry.[133] Founding members include Astro Digital, HawkEye 360, Kepler Communications, Planet, and Spire; ground station operators KSAT and RBC Signals; manufacturer Blue Canyon Technologies; law firm Hogan Lovells; NanoRacks; and the Aerospace Corporation.[134] By May 2018, there were 41 members.[135] The association offers no specific definition of a small satellite, because it aims to be "a broad and inclusive organization," according to Spire's Jonathan Rosenblatt.[136] Topics of concern include spectrum management, frequency interference, geostationary satellites, smallsats/cubesats, best industry practices, and regulatory challenges. CSSMA grants U.S. federal agencies, including the Federal Communications Commission (FCC), NASA, and the National Oceanic and Atmospheric Administration (NOAA), observer status. With smallsat regulatory cooperation strengthening in the Americas,[137] CSSMA hopes also to grow its membership internationally.[138]

Under current rules, new companies seeking to use spectrum or asking to rearrange the use of broadband by others must engage directly with other companies already using the spectrum to settle interference disputes.[139] The approach adopted by the company Ligado in 2017, using a combination of dialogue and technology, is informative.

Ligado aims to build the world's first wireless network using a combination of ground-based airwaves (long considered unsuitable for cellular use), and satellite communications compatible with 4G/LTE and emerging 5G standards.[140] The company's first plan to build a nationwide 4G network in the United States was thwarted in 2012 when the FCC rescinded the company's airwaves license, citing concerns that its satellite would interfere with GPS navigation devices.[141] Following restructuring of the company (and a name change from LightSquared to Ligado), management sought to defuse tension with the GPS industry. After making some serious concessions, such as reducing their transmission power levels to ensure that data travelling over their airwaves would not jam GPS signals, and committing to never use one of its satellite channels for ground-based purposes, Ligado reached compromises with GPS industry officials and is hoping to receive the green light from the FCC to begin building its cell towers.[142]

Transition to 5G connectivity, Internet of Things creates competition for radio frequencies

The global transition to 5G connectivity for mobile broadband—"the Internet of Things" or "IoT"—is creating new challenges for spectrum management. This connecting of traditionally non-wireless devices with the Internet and/or to each other stems from the growing availability of broadband Internet worldwide and the creation of devices with built-in wi-fi capabilities.[143] Ahead of the ITU's next World Radiocommunication Conference in 2019 (WRC-19), mobile networks are preparing to ask for use of higher frequencies, such as the C- and Ku-bands that satellite operators currently use, since the 5G network will need more than 30 GHz of spectrum bandwidth (roughly 15 times what is currently being used by 2G, 3G, and 4G combined).[144] Tension is rising between satellite and mobile network operators.[145]

In October, Intelsat, working with Intel, submitted a request to the FCC to allow terrestrial communication companies to make use of satellite-controlled C-band spectrum for the future 5G networks on satellite-industry terms. It proposed collaboration between satellite operators and terrestrial networks to find ways to clear swaths of C-band from 3,700 to 4,200 MHz, based on 5G needs.[146] The satellite operators would retain ownership of the spectrum and auction the right for joint use of frequencies with terrestrial companies. However, satellite operators generally argue that sharing spectrum would cause unacceptable interference.[147] Concerns have also been raised about interference with L-band, which "is currently used by weather satellites, GPS satellites, mobile operators, aircraft surveillance systems, and multiple other applications."[148]

The transition to 5G was featured at the ITU 2017 Radiocommunication Seminar for Asia and the Pacific, attended by more than 140 industry experts and stakeholders, representatives, operators, associations, and ITU Member States from 22 countries of the Asia-Pacific region.[149] In September, the United Arab Emirates (UAE) hosted the ITU's first mobile task group meeting in the Middle East;[150] 200 delegates from 35 countries met with the goal of making 5G connectivity a reality by 2020.[151] Artificial intelligence, 5G connectivity, and the Internet of Things were also the lead topics at the ITU Telecom World 2017 Conference in September.[152]

Continued efforts to regulate and harmonize rules for large constellations of satellites

Plans to deploy large constellations of satellites (see Indicator 2.4) are testing existing regulations and regulators. While the current "first come, first served"' and "use it or lose it" approaches to frequency assignment worked fairly well for single satellites or small constellations, large constellations introduce new complications. For example, regulators are having to define more clearly what it means for a constellation to be "brought into use," which must happen before frequencies are entered in the Master International Frequency Register, which then offers legal protection against harmful interference.[153] Are all frequencies associated with a constellation considered in use "with the first satellite launched, or when the constellation is completed? If the launch of one is deemed adequate, what happens if the operator subsequently goes bankrupt and fails to complete the scheme?"[154] The ITU is the global regulator. Satellite missions might also require licensing or regulation by a national authority, depending on the home country.[155] Efforts are being made to both clarify and harmonize existing rules, particularly in the United States, where most constellation filings are being made.[156]

The new U.S. FCC regulations, adopted in September 2017, defer to the ITU approach on spectrum sharing among non-geostationary-orbit systems for non-U.S. systems operating outside of the United States.[157] The previous six-year constellation completion deadline imposed by the FCC was relaxed; only half of a constellation needs to be completed within that timeframe,[158] with the full constellation launched within nine years.

In 2016, Boeing applied to the FCC to use the high-frequency V-band, a higher frequency signal not historically used by commercial satellite operators, for a proposed constellation. The FCC gave other companies until 1 March 2017 to disclose whether they also had such intentions.[159] Boeing subsequently submitted a new application in 2017, asking for swaths in the V-band for a constellation of between 1,396 and 2,396 broadband communications satellites in LEO. SpaceX, OneWeb, Telesat, O3b Networks, and Theia Holdings indicated that they had plans "to field constellations of V-band satellites in non-geosynchronous orbits to provide communications services in the United States and elsewhere"[160] (see Figure 2.14). The FCC is reportedly looking for ways to share spectrum efficiently.[161]

On 22 June, the FCC approved OneWeb's request to provide broadband Internet service to the United States with a constellation of 720 LEO satellites using Ku- and Ka-band spectrum (OneWeb has since requested approval for an additional 1,200 satellites). OneWeb plans to have Arianespace launch the first satellites in 2018, so that operations can begin in 2019.[162] In November, the FCC granted Telesat LEO U.S. market access, approving its LEO constellation.[163] Competitor ViaSat had strongly urged the FCC to deny permission, pending approval of its MEO system.[164] Telesat now has worldwide rights to the use by its LEO system of approximately 4 GHz of Ka-band spectrum, ideal for high-performing broadband satellite networks.[165] Telesat LEO service is planned to begin in 2021. SpaceX's Starlink constellation of 4,425 satellites was approved in 2018.

There are indications that China plans to launch at least one communications constellation in LEO.[166]

Large constellations also challenge space traffic management and debris mitigation (see Indicator 1.1).

DARPA pursues new initiatives to better manage spectrum use

To find new ways to manage the increasingly crowded electromagnetic spectrum, the U.S. Defense Advanced Research Projects Agency (DARPA) created the Spectrum Collaboration Challenge, a three-phase contest that began in 2016 and will culminate in 2019. The 30 chosen contenders include 22 teams from academia and business, plus eight individuals. All aim to develop a new wireless paradigm in which radio networks will autonomously collaborate and determine how to share the radiofrequency spectrum, avoid interference, and jointly exploit the available spectrum as efficiently as possible.[167] On 13 December 2017, 10 teams were each awarded $750,000 in prize money.[168] The second preliminary event will be held in December 2018.

DARPA envisions moving away from the practice of exclusive allocation of specific frequencies governed by license agreements.[169] On 8 November 2017, DARPA announced its new Radio Frequency Machine Learning Systems program for situational awareness, the goal of which is "to see and understand the composition of the radio frequency spectrum—the kinds of signals occupying it, differentiating those that are 'important' from the background, and identifying those that don't follow the rules."[170] Such situational awareness will support shared spectrum use, which would expand the wireless communications capacity of the electromagnetic spectrum.

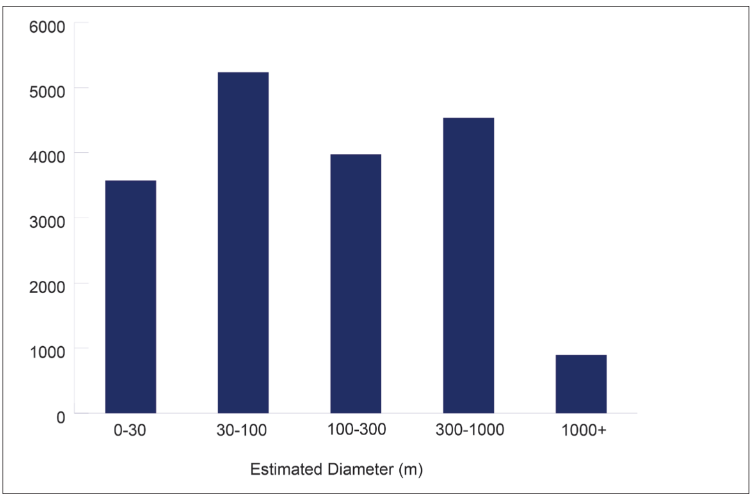
Indicator 1.3: Natural hazards originating from space

Near-Earth Objects

Near-Earth Objects (NEOs) are asteroids and, more rarely, comets whose orbits bring them into close proximity to Earth. Potentially Hazardous Asteroids (PHA) are those whose orbits intersect that of Earth and have a relatively high potential of impacting Earth itself. 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).[171] As of May 2018, there were 18,136 identified NEOs, of which 1,900 were considered potentially hazardous, according to NASA.[172]

Initial efforts to find threatening NEOs focused on objects more than one kilometer in diameter—the so-called "civilization-killer class." However, asteroids as small as 20 or 30 meters are considered large enough to be "city killers."[173] The NEO that entered Earth's atmosphere near Chelyabinsk, Russia on 15 February 2013[174] was a previously undetected orbiting asteroid, 17 m in diameter, classified as a bolide because it disintegrated as it entered the atmosphere. The energy given off when it exploded was equivalent to 470 kilotons of TNT (30 times more powerful than the atomic bomb dropped on Hiroshima);[175] more than 1,200 people were injured and more than 4,000 structures damaged by the blast.

Figure 1.10 Near-Earth asteroids discovered (by class) [176]



Mitigation of the effects of small NEOs would require enough 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.

In 2015, NASA formalized its Planetary Defense Coordination Office, which supervises all NASA-funded projects to find and characterize asteroids.[177] This office also issues warnings and works with the Federal Emergency Management Agency (FEMA) to develop both warning and response processes. In 2016, the U.S. White House issued the National Near-Earth Orbit Preparedness Strategy,[178] 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. Similar programs to detect and track NEOs are run by ESA and Russia.[179]

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), part of the High Earth Orbit Surveillance System project by Defence Research and Development Canada,[180] is dedicated to detecting and tracking asteroids, as well as orbital debris and satellites.[181] The Minor Planet Center operated by the International Astronomical Union in Cambridge, Massachusetts acts as a central clearinghouse for asteroid and comet observations.

There is some technical research into how to mitigate a NEO collision with Earth. Challenges arise because of the 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.[182] However other programs such as NASA's Asteroid Redirect Mission (ARM), have been cancelled.[183] It should be noted that such capabilities would also have dual-use security-related implications, particularly in the absence of international consensus and transparency.

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.[184] 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).[185] IAWN is a group of governmental and intergovernmental organizations, institutes, and individuals involved in detecting, tracking, and characterizing NEOs;[186] it currently has eight signatories from observatories in Europe, Colombia, Mexico, the Republic of Korea, Russia, the United States, and the United Kingdom.[187] SMPAG is a forum for space-capable nations to build consensus on recommendations for planetary defense measures. Recommended criteria and thresholds for impact response actions that were released in 2016 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.[188]

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.[189] 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 infrastructures on Earth and in space that support human activities.[190] 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.[191] Rapid increases in the number and energy of charged particles can induce power surges in transmission lines and pipelines, azimuthal errors in directional drilling, and disruptions to high-frequency radio communication and GPS navigation, as well as cause failure or operational errors of satellites.[192]

The effect of space weather on spacecraft was demonstrated by the 1994 outage of two Canadian telecommunication satellites for seven hours following damage to their control electronics.[193] 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-Québec power grid collapsed. The blackout left more than six million people in Québec and the northeastern United States without power for nine hours.[194] 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.[195]

The effects of space weather are complicated by documented changes to the magnetic field around Earth, which provides protection from cosmic radiation and electrically charged particles thrown by solar winds.[196] As the magnetic poles shift, the magnetic field is weakening,[197] making Earth more vulnerable to solar storms. 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 humanmade impacts on the space environment include chemical release experiments, high-frequency wave heating of the ionosphere, and the interaction of very-low-frequency waves with the radiation belts.[198]

Various programs have been developed to study and predict harmful space weather. NOAA and the United States Air Force (USAF) jointly operate the Space Weather Prediction Center (SWPC), the national and global warning center for disturbances that can affect people and equipment operating in the space environment.[199] Data for SWPC predictions comes from a variety of sources, ranging from satellites to ground stations.[200] 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.[201] Fourteen European countries contribute to this network, which is coordinated by the ESA's Space Weather Coordination Centre in Brussels, Belgium.[202] An expert group on space weather was established by the COPUOS STSC in February 2014.[203] 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. China established its National Space Weather Forecast Station of the China Meteorological Administration in 2015.

Plans are being developed to prepare for, and mitigate the effects of, space weather. 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.[204] 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."[205] 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.[206] The U.S. space weather program currently has the capability to predict and warn about severe solar events 30 minutes before their occurrence.[207]

2017 Developments

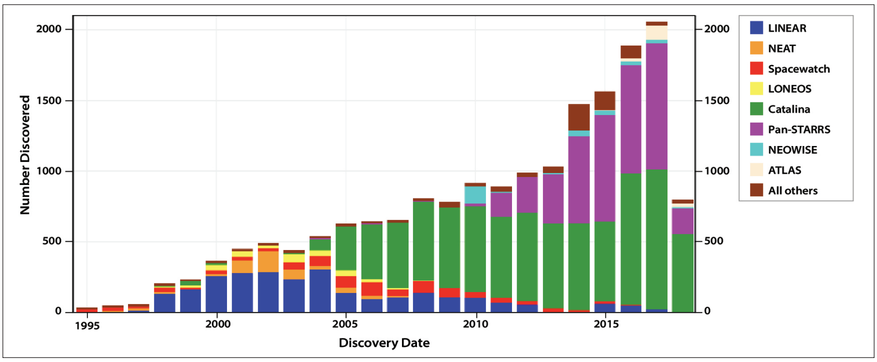
Asteroid detection capabilities rise, but gaps remain in efforts to identify threats

The number of known potentially harmful NEOs continues to increase as detection capabilities improve. As of 28 March 2018, there were 17,936 known Near Earth Asteroids (NEAs), 1,895 of which were identified as Potentially Hazardous Asteroids by NASA.[208] A 2017 updated report of the Near-Earth Object Science Definition Team on NEAs confirmed that NASA is making progress in detecting objects that pose the greatest risk if they were to collide with Earth. The report validates a 2003 report that concluded that asteroids 140 m and larger are of greatest concern and should continue to be the focus of global detection efforts, which will require space-based search systems to be successful.[209] By 2017, 93% of the "civilization-killer class" of NEOs had been identified.[210] While the NASA Authorization Act of 2005 directed NASA to identify and characterize 90% of NEOs with a diameter of 140 m or more by 2020,[211] by November 2017 it was estimated that just over 30% had been identified.[212]

In 2017, NASA's Near-Earth Object Wide-field Infrared Survey Explorer mission discovered 10 objects that have been classified as potentially hazardous.[213] In Russia, the Central Research Institute for Mechanical Engineering is conducting research to support a proposed project to detect and identify asteroids 10 m and larger.[214] They have recommended a dedicated network of robotic telescopes to detect such NEOs. However, the project is not part of the current Federal Space Plan for 2025.[215] The Canadian Space Agency (CSA) NEOSSat microsatellite, which searches for near-Earth asteroids that are difficult to spot using ground-based telescopes,[216] resumed operations in 2017 following an earlier failure of its magnetometer and all torque rods.[217]

In July, Asteroid 2017 001, measuring between 25 and 78 m, was only discovered as it made a close pass by Earth.[218] In total, 17 NEOs made close approaches to Earth in 2017.[219] The most prominent was the three-mile-wide asteroid Phaetheon, which came within 6.4-million miles of Earth. Other smaller asteroids, such as the 15-30 m 2012 TC4, passed within 42,000 km, approximately one-tenth the distance to the Moon and just above the orbital positions of satellites in GEO.[220]

Figure 1.11 Annual NEA discoveries by survey[221]



International Asteroid Warning Network tested

In 2017, the IAWN received roughly 22-million observations (201,000 on NEOs) from 47 different countries.[222] The close approach of the 2012 TC4 in October served as an opportunity to test the capabilities and coordination of the network in real time.[223] More than a dozen observatories, universities, and labs around the globe collectively observed and tracked the asteroid. Many professionally operated telescopes made ground-based observations in wavelengths from visible to near-infrared to radar. The event tested communications both within the NEO community and among the public and governments and other agencies.[224]

The SMPAG accepted Austria as its seventeenth member in October.[225] It continued to develop recommendations to increase planetary defense efforts and awareness, including defining an approach for authorizing and coordinating a multination cooperative effort on NEO threat mitigation.[226] The group also made progress on setting thresholds and standards for warning criteria, terrestrial preparedness planning (when an impact can be predicted to be within 20 years with probability of impact greater than 10% and an object characterized as greater than 20 m in size), and mission planning (when an impact can be predicted within 50 years with a probably of impact greater than 1% and an object characterized to be greater than 50 m in size).[227]

Figure 1.12 Top 10 close approaches to Earth by asteroids [228]

Distance (AU*)	Date	Provisional designation	Absolute magnitude (H+)
0.000039	June 2018	2018 LA	30.6
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

*An astronomical unit (AU) is approximately the mean distance of the Earth from the sun (149,597,870 km).
The mean distance of the Moon is 0.0026 AU.
+Absolute magnitude is a measure of brightness, used to estimate the diameter of an asteroid. H 30 corresponds to a diameter of 2-6 m.

Some asteroid deflection and sample return missions progress, others cancelled

In June 2017, NASA announced that the first mission to demonstrate the kinetic impact technique to deflect asteroids for planetary defense, the Double Asteroid Redirection Test (DART), was moving from concept development to the preliminary design phase.[229] Kinetic impact involves striking the asteroid to shift its orbit, so that the asteroid avoids contact with Earth. DART's target is the asteroid Didymos, with orbiting bodies Didymos A and Didymos B. DART is intended to impact the smaller of the two bodies, using an autonomous targeting system to strike it at roughly 6 km/second.[230]

DART is part of the AIDA mission, partnered by NASA, the ESA, the Côte d'Azur Observatory, and the Johns Hopkins University Applied Physics Laboratory. The ESA's Asteroid Impact Mission was intended to orbit around the target asteroid.[231] The project was cancelled in 2016 when it failed to secure full funding from EU ministers, but scientists and some states, including Luxembourg, would like it reinstated.[232]

The U.S. Asteroid Redirect Mission was cancelled by White House Space Policy Directive 1, issued 11 December 2017, which redirects resources toward a human return to the Moon and then Mars (see Indicator 2.2).[233] ARM was intended to develop a robotic spacecraft that would visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect the boulder into orbit around the Moon, to be explored by astronauts who would return to Earth with samples.

Collaborating with the Canadian Space Agency, NASA's OSIRIS-REx, launched in 2016, is on its way to the asteroid Bennu to acquire and return a sample of the asteroid back to Earth. The approach to Bennu will begin in August 2018. Analysis of the sample should help to answer questions about the history of the solar system, develop knowledge on one of the most potentially hazardous types of asteroids, and better understand the types of natural resources that asteroids contain, including water and precious metals.[234]

Japan's Hayabusa-2 spacecraft is expected to reach the small asteroid, Ryugu, in 2018. Japan's first Hayabusa spacecraft conducted the first successful asteroid sample-return mission from Itokawa in 2005.[235]

Space weather

UN COPUOS leads efforts on improved space weather warning, coordination, and mitigation

Space weather became a regular agenda item of the COPUOS Scientific and Technical Subcommittee in 2013, with an Expert Group in 2015 part of the initiative to develop voluntary guidelines for the sustainable use of outer space (see Indicator 4.2).[236] Building on success from the 2016 space weather workshop, the group made progress on a roadmap for greater international cooperation and information exchange on space weather events for the purpose of developing modelling and forecasting capabilities.[237]

The fourth thematic priority for the 2018 UNISPACE+50 symposium is "International Framework for Space Weather Services" (see also Indicator 4.2). The Expert Group announced plans to create the groundwork for a new International Coordination Group on Space Weather.[238] In preparation for UNISPACE+50 a UN/U.S. collaborative workshop was held in July and August 2017 at Boston College in Massachusetts.[239] There were presentations from 46 countries on space weather-related activities.[240] For its part, UNOOSA, in its capacity as the secretariat of UN-Space, prepared a special report on space weather that emphasized the need for additional international coordination.[241]

At an August 2017 workshop of the International Space Weather Initiative of COPUOS, Member States acknowledged that space weather is a global challenge that requires improved and sustained international coordination. Recommendations included creating a coordinating body to mitigate the impact of space weather and recognizing and building on prior and continuing work by space weather stakeholders. Countries were urged to work together to improve predictions and preparedness for space weather events.[242]

A new report from the European Commission's Joint Research Centre identified knowledge gaps and called for better coordination to reduce the potential impact of space weather events on critical infrastructure.[243]

New missions, projects dedicated to understanding space weather

In 2017, NASA revealed several projects, including Focusing Optics X-ray Solar Imager (FOXSI), a mission to reveal unprecedented details on solar flares; and Goddard mission Mechanisms of Energetic Mass Ejection – eXplorer (MEME-X), which aims to understand the physical mechanisms that unleash these bursts of energy and light.[244]

In April, Ex-Alta 1, a small satellite built by students at the University of Alberta in Canada, was delivered to the International Space Station, from which it was later ejected into orbit. The spacecraft is designed to monitor and capture data on solar flares. Ex-Alta 1 was able to monitor the massive solar flare that erupted in September.[245]

India's national space agency announced plans for the Aditya-1 mission to study the Sun's corona. The major scientific objectives are to achieve a fundamental understanding of the physical processes that heat the solar corona, accelerate the solar wind, and produce coronal mass ejections.[246]

The year 2017 saw the public release of more than 16 years of space-weather data collected by monitoring instruments on GPS satellites. The new data will allow a better understanding of space weather and permit better protection of critical infrastructure.[247]

A report by ESA indicates that investment to better understand and predict space weather has numerous social and environmental benefits on Earth.[248]

Indicator 1.4: Space situational awareness

"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; observe space weather and NEOs (see Indicator 1.3); and monitor spacecraft and payloads for maneuvers and other events.[249] 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.

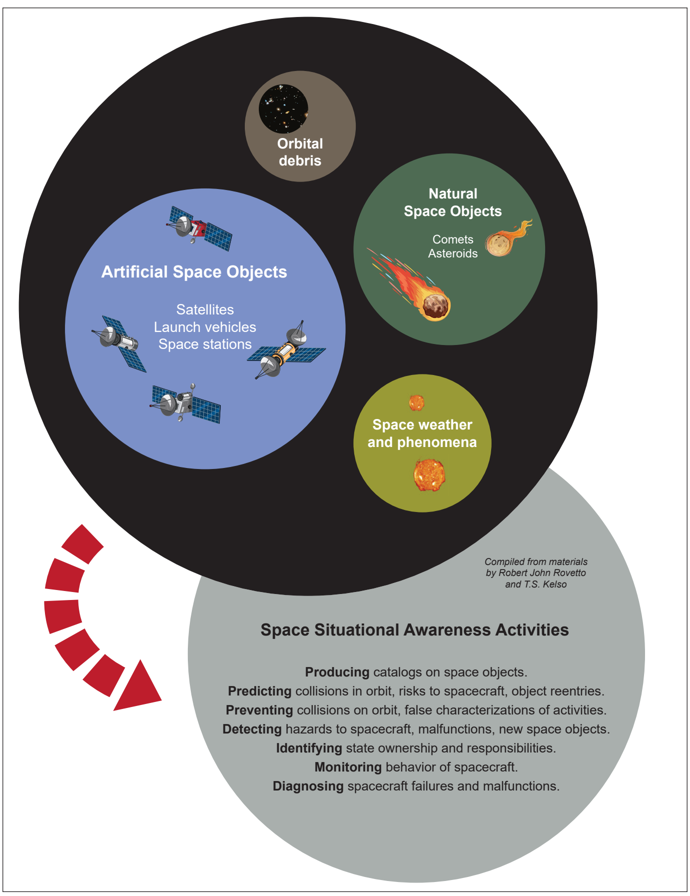
As well as helping to prevent accidental collisions and otherwise harmful interference with space objects, SSA enhances the ability to distinguish space negation attacks from technical failures or environmental disruptions, and can thus contribute to stability in space by preventing grave misunderstandings 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.[250] 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[251] (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. The creation of such a picture requires a network of globally distributed sensors, as well as data sharing between satellite owners/operators and sensor networks.[252] The United States maintains the most significant SSA capability through its worldwide Space Surveillance Network, composed of satellite, radar, and optical sensors.[253] Currently the system relies on "a core group of 8 dedicated and 18 multiple-mission sensors, most of which are operated by DOD."[254]

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.[255]

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.[256] On 2 June 2014, the DoD announced a contract with Lockheed Martin to build the USAF's next-generation space surveillance system.[257] 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.[258]

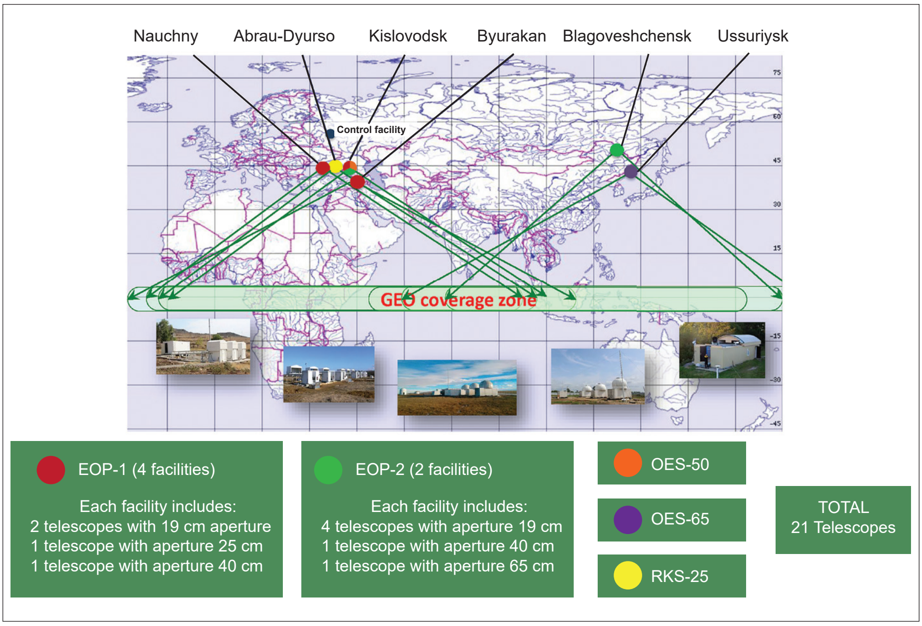
This system will replace the Air Force's Space Surveillance System, which began operations in 1961 and ceased operations in September 2013.[259] When the Space Fence becomes operational in early 2019, it is expected to increase the detection and tracking capacity from approximately 20,000 to 100,000+ objects.[260] 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 picture of space.[261] 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.[262]

The Canadian Department of National Defence is developing the Canadian Space Surveillance System (CSSS), which contributes to the U.S. SSN primarily through the Sapphire microsatellite system in LEO.[263] 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) maneuverable satellites into near-geosynchronous orbit to improve the tracking and characterization of humanmade orbiting objects.[264] Their orbital positions are not publicly known.

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.[265] Efforts are under way to upgrade its space surveillance capabilities. New ground-based telescopes were added in 2015.[266] 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)."[267] 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."[268] It reached full capacity in 2015[269] and has a reported range of 50,000 km.[270] Additional complexes for the Space Surveillance System are being planned in the Crimea and Far East, as part of "a network of next-generation special radio-electronic surveillance complexes."[271] 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.[272] "The main goal…is to monitor dangerous approaches of the devices operating on orbit with orbital debris and to follow falling satellites."[273]

Figure 1.14 Operational optical facilities of the Automated Warning System on Hazardous Situations in Outer Space[274]



European states are pooling national capabilities for SSA under a Space Surveillance and Tracking (SST) and Support Framework. 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 data from their national assets, as well as from the EU Satellite Centre. This plan has an end date of 2020 and is estimated to cost €70-million ($80-million).[275] National capabilities include France's GRAVES space radar system, used to detect foreign intelligence satellites and their orbits, as well as space debris that could threaten French satellites, operated in tandem with Germany's Tracking and Imaging Radar.[276] 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,[277] and so reduce Europe's reliance on the U.S. Space Surveillance Network.[278]

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 Defense 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."[279]

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."[280] 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.[281]

Japan's Self-Defense Forces are developing their first space monitoring capabilities—new facilities for optical telescopes and radar. Information will be shared with the United States. JAXA, a civilian space agency, currently collects information using telescope and radar facilities in Okayama. Each new facility will cost about 10-billion yen ($88.8-million).[282]

Data sharing and space traffic management (STM)

There is currently no operational global system for space surveillance, in part because of the sensitive nature of surveillance data, and no global system for space traffic management. Options for multilateral sharing of orbital data were presented at UN COPUOS in 2016; however, there is no consensus on an appropriate approach.[283] Nonetheless, among the seven themes agreed to for the UNISPACE+50 process (see Indicator 4.2) is Theme 3, "Enhanced information exchange on space objects and events."[284] 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 to include their consideration as a new agenda item for the Scientific and Technical Subcommittee of COPUOS.[285]

Considerable SSA data is shared bilaterally. The U.S. SSA Sharing Program is run by U.S. Strategic Command (USSTRATCOM) through the Joint Space Operations Center, which also supports space safety operations.[286] Data from the U.S. SSN flows into the SSA Sharing Program, which has three levels of SSA support services.[287] The first 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 second is emergency notifications, which alert satellite operators to potential collisions (see Figure 1.16 below). In 2014, the JSpOC Mission System (JMS) provided 671,727 possible collision warning notifications to satellite owners/operators.[288] Data is currently provided to support more than 285 satellite operators, of which only 14% are part of the U.S. government.[289]

Figure 1.15 Space-Track criteria for various conjunction warnings[290]

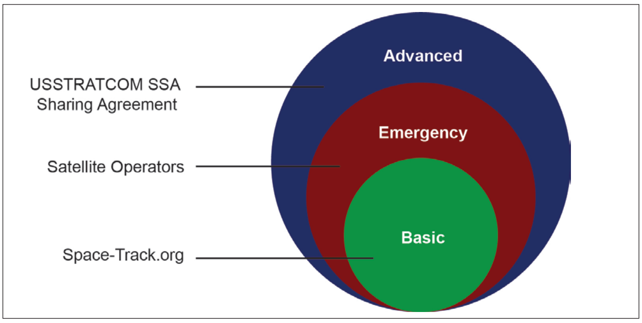
Notification method	Conjunction data message	Emergency criteria (message and email)	Emergency phone call criteria
GEO	TCA ≤ 10 days & overall miss ≤ 10 km	TCA ≤ 3 days & overall miss ≤ 5 km	TCA ≤ 3 days & overall miss ≤ 500 m
HEO	Reporting based on regime of secondary object in the conjunction using miss distance criteria only		
MEO	TCA ≤ 3 days & overall miss ≤5 km	TCA ≤ 3 days and overall miss ≤ 5 km	TCA ≤ 3 days and & overall miss ≤ 500 m
Near Earth (LEO 1-4)	TCA ≤ 3 days & overall miss ≤ 1 km and Pc≤e^-4	TCA ≤ 3 days & overall miss ≤1 km & Pc≤e^-4	TCA ≤ 3 days & overall miss ≤ 75 m & Pc≤e^-2

TCA = time of closest approach   Pc = probability of collision

The third level of sharing includes specific advanced services supporting safe spaceflight operations during launch, on-orbit, and decay or reentry operations. This level is available to commercial and governmental satellite and launch operators with which the U.S.

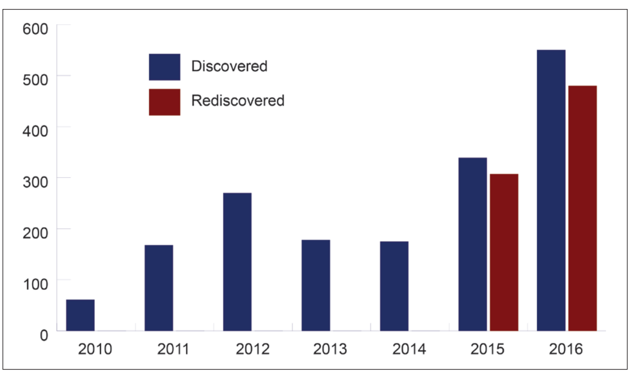
DoD has established written agreements. The number of such agreements has expanded significantly in recent years. Not all data-sharing agreements include classified data. U.S. DoD officials have indicated that the United States has signed more than 50 unclassified data-sharing agreements with both government and private sector organizations.[291] The 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.[292]

Figure 1.16 U.S. STRATCOM SSA sharing program [293]



The International Scientific Optical Network is focused on detecting humanmade debris in high-altitude orbits, primarily GEO, from 38 facilities with 90 telescopes in 16 countries. [294] 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; 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, free, and complete than the data provided via the SSA Sharing Program." [295]

Figure 1.17 Number of objects discovered by ISON [296]



Commercial operators are also contributing to global SSA capabilities. U.S. company Analytical Graphics Inc., which provides data for space collision avoidance, maneuver detection, and debris modeling,[297] announced the opening of its Commercial Space Operations Center (ComSpOC) in March 2014.[298] The center is the first and most 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.[299] ComSpOC has tracked more than 9,000 objects in the public catalog, as well as non-public objects—more than 75% of all active GEO satellites and 100% of all active GEO satellites over the continental United States.[300] Other commercial service providers include the Schafer Corporation, which established an SSA business unit in 2016, using electrooptical systems, radio frequencies, and laser sensors to monitor LEO and GEO.[301] LeoLabs, which spun out of the nonprofit research center SRI International, was founded in 2016 to provide SSA services for commercial operators. It tracks debris in LEO with phased array radars located in Texas and Alaska.[302]

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

2017 Developments

The United States continues to prioritize SSA capabilities and mission

The U.S. government continued to support the development of more advanced capabilities to monitor debris and activities in space. In the proposed FY2018 budget, the USAF requested $600-million for SSA technologies and operations.[303]

Space Fence

At the heart of updated SSA capabilities is the S-Band Space Fence, being built on Kwajalein Atoll. This system, designed to replace the USAF Space Surveillance System, is capable of tracking more than 100,000 objects in orbit. Although the Space Fence was originally slated to be operational in December 2018, there have been delays and hardware installation did not begin until June 2017.[304] While Gen. John Raymond, head of Air Force Space Command, remarked in an October interview that Space Fence "is moving along pretty well,"[305] the new deadline for initial operational capability is April 2019. Radar checkout was rescheduled for early 2018 and operational tests are to take place between December 2018 and February 2019.[306]

Space Based Space Surveillance (SBSS)

U.S. efforts to improve the ability to identify, track, and monitor objects in GEO include investment in the Space Based Space Surveillance 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. In December, Boeing was awarded a modified contract to sustain the satellite through June 2022.[307] While there were plans for a follow-on SBSS satellite to be launched in late 2021, with a contract awarded in 2017, the USAF noted at a February industry day that the recently released Space Enterprise Vision reflected a changing program that required a system that is more "focused" and capable of surviving in an "operationally challenging" environment[308] (see Indicator 3.2.).

The ORS-5 mission, developed by the USAF Operationally Responsive Space Office and known as SensorSat, is intended as a "gap filler" between the SBSS-1 pathfinder and a follow-on SBSS satellite.[309] Costing $85.7-million, and thus substantially cheaper than the SBSS satellite, ORS-5 will operate from a low-inclination, low-altitude orbit and monitor spacecraft in the geosynchronous belt. The spacecraft was successfully launched on 26 August.[310]

Geosynchronous space surveillance

Objects in geosynchronous orbit cannot be imaged in detail by current ground-based telescopes. In early 2017, the Intelligence Advanced Research Projects Activity (IARPA) announced its plan to develop ground-based imaging technology that is precise enough to gather high-resolution images of objects orbiting in GEO.[311] Named Amon-Hen, the program's goal is a passive, ground-based optical interferometer, which combines multiple sources of light waves to obtain high-resolution measurements, costs less than $25-million, and uses a smaller platform than current instruments. Data is to be gathered within a one-hour timeframe and processed within 24 hours.[312] Proposals for the 33-month program were solicited in August. Phase 1, lasting 15 months, was to begin in March 2018 and focus on technology development, system modeling capabilities, and image reconstruction algorithms. Phase 2, lasting 18 months, will focus on maturation of technologies and initial operations.[313]

The Geosynchronous Space Situational Awareness Program provides detailed inspection of objects in GEO, using dedicated satellites that operate in the near-geosynchronous orbit. The first two satellites, GSSAP 1 and 2, were launched in 2014. GSSAP 3 and 4 were launched on 19 August 2016; on 12 September 2017, the USAF 1st Space Operations Squadron activated them and began operations.[314] In March 2017, Orbital ATK disclosed that it had begun working on GSSAP 5 and 6 in late 2016, but did not indicate a launch date.[315]

Canada's NEOSSat microsatellite, which contributes data to the U.S. SSN, recovered operations in 2017 following an earlier failure of its magnetometer and all torque rods.[316]

The C-Band Space Surveillance Radar System becomes operational

The C-Band Space Surveillance Radar System near Exmouth, Australia—a joint initiative of the Australian Defence Force and the USAF—reached full operational capability in March. The radar will provide coverage of the southern and eastern hemispheres and is ideally located to track polar-orbiting reconnaissance satellites. Originally located on the Caribbean island of Antigua, the radar system was gradually moved, beginning in 2014.[317]

DARPA Hallmark

DARPA's Hallmark Software Testbed, intended to "quickly evaluate and integrate technologies for space command and control," showed signs of progress in late 2017. In November, DARPA awarded BAE Systems a contract worth up to $12.8-million to develop a space evaluation and analysis testbed. The testbed will allow military personnel to practice multidomain operations so that data collected in space, on land, at sea, in the air, or in cyberspace can be combined and analyzed to support simultaneous space and terrestrial missions.[318] BAE will "host exercises to collect metrics for Hallmark's cognitive evaluation team, and to identify technologies for future use by the Defense Department's Joint Space Operations Center and the National Space Defense Center."[319]

New Russian surveillance and tracking capabilities go online

Early in 2017, Russia's Space Forces began deploying "ground-based means of space monitoring" capable of tracking in-orbit satellites. Russia's Ministry of Defense indicated that the new-generation system in Altai Territory, bordering Kazakhstan, had been completed and was operational. The system will reportedly make it "possible to carry out global non-stop monitoring at all altitudes and angles by 2020."[320] By the end of March, it is reported that the new system had already identified 15,000 space objects, verified the deorbiting of approximately 5,000 space objects, and issued 300 warnings about space objects approaching operational Russian spacecraft and satellites.[321] According to Russian state news agency TASS, Russia intends to set up more than 10 new SSA complexes before 2020.[322]

Russia's first ground station of the Automated Warning System on Hazardous Situations in Outer Space, a program aimed at monitoring orbital debris, opened at the Pico dos Dias Observatory in western Brazil. The facility is one of four specialized centers to be created by Roscosmos.[323]

Coordination of European Space Surveillance and Tracking capabilities improves

Efforts continued in 2017 to coordinate the provision of SSA data by pooling national capabilities (provided by France, Germany, Italy, the United Kingdom, Spain, and the European Union Satellite Centre) through the EU Space Surveillance and Tracking Framework. However, in October, the head of the ESA's European Space Operations Centre, which coordinates ESA's SSA work (primarily tracking NEOs and space weather (see Indicator 1.3)) claimed that the EU initiative remained too fragmented to provide the level of detail needed to monitor and manage the increasingly cluttered orbital environment.[324] The EU SST Framework is currently in the networking phase of the agreement, which is aimed at connecting national assets of consortium members; investment to upgrade national capabilities is expected to begin in 2018.

USSTRATCOM pursues data-sharing beyond traditional allies

SSA data-sharing agreements enhance multinational space cooperation and streamline the process by which international partners request specific data and information gathered by U.S. Strategic Command. USSTRATCOM signed such an agreement with Belgium's Federal Science Policy Office in February[325] and another with the Norwegian Ministry of Defense and Norwegian Ministry of Trade, Industry, and Fisheries in April.[326] By early 2018, USSTRATCOM had agreements with 14 states (the United Kingdom, the Republic of Korea, France, Canada, Italy, Japan, Israel, Spain, Germany, Australia, Belgium, the United Arab Emirates, Norway, and Denmark), two intergovernmental organizations (ESA and the European Organisation for the Exploitation of Meteorological Satellites [EUMETSAT]), and more than 65 commercial satellite owner/operator/launchers.[327]

The bilateral sharing of data for combined space operations with military allies continued to expand. Going beyond the traditional Five Eyes intelligence-sharing alliance (of Australia, Canada, New Zealand, the United Kingdom, and the United States), in June, USSTRATCOM and the German Air Force signed a memorandum of agreement to assign a German liaison officer to the Joint Functional Component Command for Space.[328] The offer is based on a 2015 arrangement for each country to enhance the other's awareness of the space domain.[329]

In September, USSTRATCOM led an SSA exercise “Global Sentinel 2017,” with participants from Australia, Canada, France, Germany, Italy, Japan, the United Kingdom, and the commercial sector. Italy participated for the first time, and representatives from Spain and the Republic of Korea were first-time observers. During the exercise, the participating states maintained space operations centers for their respective SSA assets and experimented with a fully integrated command center. While the first three Global Sentinel events were labelled “SSA tabletop exercises,” the new name reflects the growing importance of international engagement and combined SSA.[330]

Members of the Japanese SSA policy office visited U.S. Eglin Air Force Base in October, as part of an effort to encourage Japan’s development of its SSA capabilities and dedicated space surveillance force. Demonstrations showcased equipment for space situational awareness, phased array radars, integration of intelligence, mission planning and debriefing, space surveillance operations, the processing of radar data, and training for space operations.[331]

FAA requests funds to initiate space traffic management pilot program

In the United States, there is a movement to shift responsibility for global STM support from the military to the civil sector. Accordingly, a portion of the FY2018 budget of the FAA Office of Commercial Space Transportation will be used to initiate an STM pilot program. Funds will be used to acquire a high-performance computing system of analytic software developed by commercial and government entities, capable of tracking an object database of roughly 500,000 individual space objects.[332]

Report on Space Traffic Management Assessments, Frameworks, and Recommendations, mandated by the 2015 Commercial Space Launch Competitiveness Act and prepared and submitted by U.S. company SAIC in November 2016, recommended that a civil government agency take over responsibility for orbital traffic management from the Department of Defense. However, it did not specify an agency to assume that responsibility.[333] The FAA Office of Commercial Space Transportation’s budget request for the pilot program stemmed from its determination that it could take over the job of providing collision warnings for satellites, if authorized to do so. FAA Associate Administrator for Commercial Space Transportation George Nield has called for the office to be given the responsibility in a phased transition, beginning with this pilot program.[334]

Commercial actors expand SSA capabilities and role in providing space safety and traffic management support

Following a robust year in 2016, the nascent U.S. commercial SSA industry grew in 2017 to meet demands from commercial operators and national governments for services and support. In February, three companies—ExoAnalytic Solutions, OmniSpace, and Spire Global—joined the Space Data Association.[335]

In March, SDA and Analytical Graphics, Inc. agreed to launch an updated Space Data Center Space Traffic service, SDC 2.0, which will provide satellite tracking, radio frequency spectrum management, and conjunction warning services to member companies of SDA.[336] SDC 2.0 is built on the first iteration of the center, another cooperative effort by SDA and AGI that began in 2012. SDC 2.0's independently generated catalog of tracked space objects will include objects larger than 20 cm in the GEO arc; the service also features functions to mitigate radio frequency interference, including the construction of geolocation scenarios and a Carrier ID database.[337]

Astroscale, a Singapore-based startup focused on space debris mitigation, raised $25-million from investors in July; its first satellite, a 22-kg small satellite named "Idea OSG-1," is scheduled to launch in 2018. Idea OSG-1 is designed to identify and monitor sub-millimeter-sized debris in orbit for eventual targeting by Astroscale's debris-removal spacecraft (see Indicator 1.1).[338]

LeoLabs, which was spun out of the nonprofit research center SRI International to provide SSA services for commercial operators, raised $4-million from investors that included Airbus Ventures. In February, LeoLabs began operating its phased-array radar in Midland, Texas. With this radar and one in Alaska, the company can track 94% of all objects 10 cm or larger in low Earth orbit. LeoLabs continued to work with the small-satellite company Planet to demonstrate how satellite operators can use commercial tracking data to prevent collisions. LeoLabs used data from U.S. Strategic Command to provide Planet with additional information on debris threatening its satellites.[339] In September, the company was presented with a "FinSpace Award" as one of the most promising space sector startups.[340]

ArianeGroup announced on 14 December that France's Joint Space Command would be the first customer for GEOTracker, a network of ground-based telescopes that monitor the geostationary arc.[341] GEOTracker consists of six ground-based telescopes—two in Australia, two in France, one in Spain, and one in Chile—and can detect objects down to one meter in diameter in GEO. ArianeGroup self-financed GEOTracker for four years; now, with a revenue-generating customer, it is seeking to expand the system. According to ArianeGroup, GEOTracker will initially focus on smaller objects in GEO and could then expand to monitor other orbits.

At the Space Symposium in April 2017, several companies proposed ideas and provided updates of SSA products in development. Ball Aerospace's PROXOR simulation tool helps customers to determine and evaluate how well new sensors will perform SSA functions.[342]Astra LLC is developing a computational model, Dragster, to improve the military's ability to determine how much drag a satellite is experiencing. Cosmic Advanced Engineering Solutions developed a new way to estimate the range of satellites from the glint observed by ground-based sensors.[343] Launchspace Technologies is working on a space debris removal spacecraft that contains SSA sensors.[344]

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. Every day, millions of individual and corporate actors rely on space applications 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 become indispensable to the civil and commercial sectors.

Global navigation satellite systems

There are currently two operational global navigation satellite systems: U.S. GPS, and Russian GLONASS.

GPS, declared operational in 1993, works with a minimum of 24 satellites that orbit in six different planes in MEO. GPS operates a Standard Positioning Service for civilian use and a Precise Positioning Service for use by the U.S. DoD and its military allies. However, by 2001, military use accounted for only about 2% of its total market. As of May 2018, GPS consists of 31 operational satellites.[1] The next-generation GPS III system has been significantly delayed,[2] which may impact the long-term health of an ageing system.

GLONASS uses principles like those used in GPS. It is designed to operate with a minimum of 24 satellites in three orbital planes.[3] The system initially attained full operational capability in 1995,[4] but this capability was subsequently degraded by the loss of a number of satellites and only regained in 2011.[5] GLONASS operates a Standard Precision service available on a continuous, worldwide basis and a High Precision service available to all commercial users since 2007.[6] Russia is cooperating with China and India,[7] among others, to improve the system's accuracy and precision by building a network of ground stations around the world.[8] In 2015, China and Russia signed a Compatibility and Interoperability Cooperation Joint Statement aimed at increasing cooperation and providing cross-system compatibility between China's BeiDou system and Russian GLONASS system.[9]

Under development are two other global systems: the EU/ESA Galileo Navigation System and China's BeiDou Navigation System.

Galileo is designed to operate 30 satellites in MEO in a constellation like that of the GPS, providing Europe with independent GNSS capabilities. The first pair of In-Orbit Validation satellites were launched in 2011. Currently 14 spacecraft are operational.[10] Initial services began in 2016, with completion of the system planned for 2020.[11] Galileo will offer a range of services, including an encrypted, jam-resistant, publicly regulated service reserved for civil protection, national security, and law enforcement.[12]

The BeiDou system consists of BeiDou-1, a limited test system that has been operating since 2000; and COMPASS or BeiDou-2, a global system currently under construction. In

2015, China established stable regional operation and formal deployment of next-generation satellites for BeiDou-2,[13] which will include eight satellites in GEO and 35 in MEO. Global service is expected by 2020. The system currently has 15 operational spacecraft.[14]

Other actors are developing regional systems. Japan's Quazi-Zenith Satellite System (QZSS) now has four satellites in HEO interoperable with GPS to enhance regional navigation over Japan; plans are for a total of seven satellites.[15] India is developing the seven-satellite Indian Regional Navigation Satellite System (IRNSS).[16] The Iran Space Agency (ISA) has a long-term plan to fund an Iranian Local Positioning System. Until then, Iran will use a national radio navigation system (Naba), which is under development.[17]

Despite the desire to develop independent systems, almost all states remain dependent on GPS, with cooperation and interoperability becoming the norm. The United States has agreements with all systems under development.[18] Cooperation is facilitated by the International Committee on Global Navigation Satellite Systems (ICG), established in 2005 under the umbrella of the United Nations.[19]

Remote sensing

Remote-sensing satellites are used extensively for a variety of EO functions, including weather forecasting; surveillance of borders and coastal waters; monitoring of crops, fisheries, and forests; and monitoring of natural disasters. Agencies around the world seek to enhance the efficiency of data sharing.[20]

Global weather monitoring and forecasting are enabled by the international sharing of space-based meteorological data. EUMETSAT and NOAA provide meteorological data for Europe and the United States respectively.[21] 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.[22] Data collected is made freely available to the WMO, which distributes it to more than 3,000 weather forecast outlets in its 185 member states and six territories.[23] U.S. weather satellites, a critical component, are reaching the end of their lifespans. The U.S. GAO warned of a potential gap in weather satellite data provided by NOAA in 2013,[24] prompting discussion on purchasing data from commercial sources and cooperating with Europe or India.[25] New satellite capabilities have since been deployed by Russia, India, Japan, and China.[26]

The use of space-based capabilities to monitor Earth's environment and changing climate is increasing. Prominent examples include Copernicus, a joint program of the European Commission and ESA.[27] The satellite will record mean sea-level measures over the next 30 years and provide other support for oceanography in Europe. Italy's dual-use COSMO-SkyMed will offer thematic mapping for environmental applications such as forestry and agriculture,[28] and provide commercial data. The Global Climate Observing System (GCOM), a WMO program, is expected to provide users with information needed to "address pressing climate-related concerns."[29] NASA and the U.S. Agency for International Development have initiated an environmental monitoring program in West Africa called SERVIR,[30] to use data from NASA's EO satellites "to help improve environmental decision-making among developing nations."[31] At a 2016 meeting of heads of space agencies, participants committed to coordinating efforts to monitor Earth's climate, particularly the water cycle.[32]

Several initiatives aim to expand access to EO data. The 2014 U.S. National Plan for Civil Earth Observation seeks to maximize interagency coordination across more than 100 government programs.[33] The 2015 Copernicus Cooperation Agreement between the United States and the EU promotes "a shared U.S.-EU vision to pursue full, free, and open data policies for government Earth observation satellites,…foster greater scientific discovery and encourage innovation in applications and value added services for the benefit of society at large."[34] 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.[35] The Committee on Earth Observation Satellites is composed of 60 agencies from around the world that work to coordinate and harmonize civil EO programs and data exchange for societal benefit.[36] The Group on Earth Observations is an international partnership of more than 100 governments and more than 100 Participating Organizations from academia, the private sector, and civil society that aims to leverage EO data to inform global governance decisions. This includes the creation of a Global Earth Observation System of Systems (GEOSS) to better integrate and share data, which currently includes resources from more than 150 providers.[37]

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 (see Indicator 2.4). Some data is made available for global benefit. DigitalGlobe (now part of Maxar Technologies) has an agreement with UNOOSA to collaborate on satellite imagery and geospatial solutions for development.[38] BlackSky has partnered with the UN Institute for Training and Research (UNITAR) to "explore how imaging can be applied to humanitarian relief, human security, climate change adaptation, sustainable water management, territorial management, high priority peace-keeping missions, maritime monitoring of illegal activity, and more."[39] In 2016, GeoOptics committed to making all data from its planned commercial constellation of climate- and environment-monitoring satellites free for research purposes.[40]

Figure 2.1 Detection capabilities of EO satellites at various ground sample distance (GSD)[41]

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)

GSD (m)	Examples of detection capabilities
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

Communications

Most satellite communications services are provided by commercial actors and covered under Indicator 2.4. However, from a global utility perspective, it is worth pointing to the emergence of many of these services within broad intergovernmental organizations, often with mandates to enhance global coverage and accessibility of these services. For example, the International Telecommunications Satellite Organization (ITSO) is based on the principle "that communication by means of satellite should be available to the nations of the world as soon as practicable on a global and non-discriminatory basis."[42] The Intersputnik International Organization of Space Communications, established in 1971 and headquartered in Moscow, is primarily involved in satellite capacity leasing.[43] ArabSat, an intergovernmental organization founded by the Arab League in 1976, connects Arab society and the world through telecommunications services that are aligned with Arab values and culture.[44] Today, private companies such as OneWeb aim to provide Internet service to the more than 50% of the globe that does not currently have access to "reliable high-speed connectivity"[45] (see Indicator 2.4).

Automatic Identification System (AIS)

The Automatic Identification System (AIS) is used by ships to monitor marine traffic, providing information on identity, position, course, and speed. At first, as a radio-based communications system, marine monitoring experienced transmission limitations.[46]

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 that include the United States, Canada, Norway, Germany, and China.

Disaster relief and search-and-rescue

Under the International Charter on Space and Major Disasters, participating space agencies provide space-based data and information in support of relief efforts during emergencies caused by major disasters.[47] Members include the Argentine Space Agency, CNES, China National Space Administration (CNSA), CSA, ESA, EUMETSAT, the German Aerospace Center (DLR), ISRO, JAXA, Korea Aerospace Research Institute (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. Upon activation of the Charter, a Project Manager is appointed to maintain communication with the affected country and to coordinate access to useful satellite data.[48]

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.[49] 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.[50] Cospas-Sarsat provides alert and location data to national search-and-rescue authorities worldwide, without discrimination, independent of country participation in the program.[51] Between September 1982 and December 2015, Cospas-Sarsat assisted in the rescues of 41,750 people in 11,788 search-and-rescue events.[52] 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.[53]

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.[54] 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.[55]

Through UN-SPIDER, UNOOSA launched the Global Earth Observation Partnership with 17 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.[56] 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."[57]

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.[58] The goal is to harness the capabilities of satellite operators to provide access to communications capabilities during a disaster. This charter's operation is like that of the International Charter on Space and Disaster Management.

2017 Developments

Global Navigation Satellite Systems improve interoperability and reduce reliance on GPS

The ICG held its twelfth meeting in Japan on 2-7 December. Members provided updates on the status and plans of various systems, discussed research and development for the next generation GNSS, and joined working groups. Work in 2017 focused on systems, signals, and services; enhancement of GNSS performance, new services and capabilities; information dissemination and capacity building; and reference frames, timing, and applications.[59]

U.S. GPS

The United States slowly advanced the next-generation Global Positioning System. Upgraded Lockheed Martin GPS III satellites received final approval from the USAF. The first satellite, SV01, is expected to launch in 2018. The new satellites, with a lifespan of 15 years (three more than current satellites) will provide "a new civil signal that will improve future connectivity worldwide for commercial and civilian users."[60] The constellation currently consists of 12 GPS IIR, seven GPS IIR-M, and 12 GPS IIF satellites, which have an average age of 10 years.[61] Released performance reports for 2014 and 2015 confirm that the system satisfied nearly all measurable performance commitments to the civil sector.[62] However, launch of SV01 is four years behind schedule. Moreover, the lack of launches in 2017 raises concerns about the long-term health of the aging system. Delays in the production and delivery of the first 10 satellites resulted in a $600-million cost increase. The USAF is now planning to release a request for proposals to produce future satellites.[63]

In December 2017, the United States and China released a *Joint Statement on Civil Signal Compatibility and Interoperability Between the Global Positioning System (GPS) and the BeiDou Navigation Satellite System (BDS)*, the product of an ongoing United States-China GNSS Cooperation Dialogue that began in May 2014.[64] Negotiated compatible signal characteristics will result in an improved service for users of both GPS and BDS.[65]

Russian GLONASS

GLONASS currently has 24 operational satellites and one satellite in flight tests.[66] After the oldest satellite was removed in June 2017,[67] the Uragan-M satellite (Cosmos 2516) was launched. Russia is advancing international use of the system. The new satellite station in Nicaragua that opened in 2017 is the first GLONASS station in Central America.[68] It will be part of a global network that will monitor the performance of all GNSS, including GLONASS, GPS, Galileo, and BeiDou, with the aim of improving the interoperability of GLONASS with other systems, while also improving accuracy and reliability.[69] Russia's spending on space has been severely cut in recent years (see Indicator 2.2) and it is not clear how future performance will be affected.

ESA Galileo

Initial operations began in 2016, but work continues to complete the system. Galileo satellites 15 and 16 were launched in June 2017 and Galileo 19, 20, 21, and 22 in December.[70] Also in 2017, Galileo 17 and 18 underwent testing[71] and another 12 spacecraft were commissioned.[72] At the end of the year, there were 14 operational satellites in the constellation.[73] After one more launch, the constellation will be able to deliver global coverage, pinpointing a location on Earth to within one meter.[74] Ten atomic clocks onboard Galileo satellites failed in 2017,[75] but did not compromise the system, because of designed-in redundancy.[76] Completion of the 30-satellite system has been delayed until 2021.[77] The European Global Navigation Satellite Systems Agency (GSA) has taken responsibility for Galileo operations and service provision.[78]

Chinese BeiDou

After a four-month delay,[79] China launched the first two BeiDou-3M satellites into MEO in November 2017, marking the official expansion of the system into a global network.[80] The launch of the second pair of satellites was delayed until January 2018, and 18 additional BeiDou-3 satellites are expected to launch this year,[81] marking a step toward global service.[82] This new generation of satellites has an accuracy of 2.5-5 m, which is comparable with GPS, and can provide both navigation and communication services. The system is also compatible with other satellite navigation systems.[83] The service is a core component of the Belt and Road Initiative's "Spatial Information Corridor," which includes satellite communication and remote-sensing applications[84] (see Indicator 2.3).

Indian IRNSS (Regional)

ISRO plans to offer a GPS-type service for mobile users of its Indian Regional Navigation Satellite System (IRNSS). The Navigation with Indian Constellation (NavIC) service is expected to provide a standard positioning service with an accuracy of 5 m.[85] The system, which requires seven satellites for reliable operation, is almost complete. An eighth satellite was intended to replace the malfunctioning IRNSS-1A, on which three atomic clocks were showing unexplained errors.[86] The August 2017 launch of that new satellite failed,[87] but the system remained functional.[88]

Japanese Quasi-Zenith Satellite System (Michibiki) (Regional)

Japan currently relies on U.S. GPS for satellite navigation and positioning, but is developing a regional GNSS system to enhance service in the Asia-Pacific region. In 2017, JAXA, in cooperation with Mitsubishi Heavy Industries, launched two satellites[89] to join the original satellite launched in 2010. The system is called "Michibiki," which means guidance.[90] In conjunction with GPS, the Japanese system will be able to reduce positioning errors to only a few centimeters.[91] A fourth satellite is expected for launch in 2018 to initiate the service, and there are plans to increase the number of satellites in orbit to seven by 2023.[92]

Other

Geoscience Australia and Lockheed Martin initiated a research program to demonstrate how signals from GPS and Galileo satellites can be augmented to enhance positioning and navigation for a range of applications. Over two years the project will explore the ability of a second-generation Satellite-Based Augmentation System (SBAS) testbed to use signals from both constellations to achieve higher GNSS integrity and accuracy. Agriculture, aviation, construction, maritime, mining, rail, road, spatial, and utilities applications will be validated. A master station in Spain will collect reference station data from locations operated by Geoscience Australia; the data will be available to end users within six seconds via an uplink antenna and a GEO satellite.[93]

A new EU-funded TREASURE project will integrate signals from GPS, GLONASS, BeiDou, and Galileo to provide instant, high-accuracy positioning anywhere in the world. The project will run over four years and will focus on mitigating the effects of the atmosphere on satellite communication and positioning.[94]

Greater access to high-resolution and frequent-revisit EO data

Commercial and national projects are expanding the coverage of, and access to, free and lower-cost high-resolution Earth imagery.[95] DigitalGlobe is building a new constellation of satellites, WorldView Legion (to be completed by 2021), which will expand the revisit capabilities of its high-resolution system, capable of capturing the image of a book on a coffee table, to every 20 minutes for parts of the planet.[96] Currently, small-satellite company Planet provides high-revisit data, but at much lower resolution. Planet launched 88 of its small Dove satellites in February 2017 as part of its Flock 3P launch (see Indicator 2.4).[97] The constellation is now able to image all of Earth every day.[98] Planet also purchased Terra Bella from Google, which will add another seven satellites to their constellation and facilitate the sale of data.[99]

Commercial companies are making EO data more readily available to the public. Canadian-based Skywatch "collects images and other data from hundreds of satellites" for use on its EarthCache platform, which allows any software developer or business to easily integrate it into applications; so far 3,000 companies have used it to create 1,000 unique applications for satellite data.[100]

National programs such as South Africa's proposed EOSat-1 are also focused on improving access to high-resolution data, with a maximum resolution of about 2.5 m. The stated mission priorities are food security, tracking land use, and disaster management. The government intends to share data with other African countries.[101]

A joint AU-EU initiative is attempting to address the growing need for EO data in Africa. In May 2017, eligible African institutions were invited to apply for a share of the €30-million in grants for Global Monitoring for Environment and Security (GMES) in Africa.[102] In November, 13 were awarded contracts[103] to extend and develop applications linked to water and natural resources as well as regional and national capacities to generate EO data for such purposes.[104]

An international conference of scientists was convened in Nairobi by the Regional Centre for Mapping of Resources for Development to explore the applications of space science.[105]

The South African National Space Agency (SANSA) has developed a new crop-monitoring program that transforms EO data into understandable and usable information. The system will be made available to other African countries.[106] Researchers at Stanford are using high-resolution satellite images to estimate crop yields, so that resources can be more efficiently managed in poor parts of the world.[107] Researchers at the University of Illinois are harnessing electromagnetic imaging from satellites to estimate crop yield in the U.S. corn belt. This is the first time that spectral bands, including visible, infrared, thermal, and passive and active microwave, have been used together to look at crops; this method “greatly increases the capacity to monitor crops and crop yield.”[108]

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) is using satellite imagery to monitor damage to heritage sites caused by conflict as part of a six-year plan that runs until 2021.[109] In 2017, the EU provided prolonged satellite imagery support to assist the Organization for Security and Co-operation in Europe (OSCE) in monitoring the conflict in eastern Ukraine;[110] this mission was still functioning in March 2018.[111]

The International Partnership Programme of the UK Space Agency awarded approximately £70-million to UK space businesses for projects that help emerging and developing economies use satellite data to tackle problems such as flooding, drought, and deforestation.[112] A UK crowdfunded project aims to use satellite images to identify possible sites that employ slaves.[113]

To facilitate greater access to EO data, the Committee on Earth Observation Satellites (CEOS) released a 2018-2020 Work Plan focused on “improved EO systems coordination and enhanced data access for key global programs and initiatives.”[114] CEOS aims to ensure “international coordination of civil space-based Earth observation programs and promotes exchange of data to optimize societal benefit and inform decision making for securing a prosperous and sustainable future for human kind.”[115] Five working groups address capacity building and data democracy, climate, calibration and validation, disasters, and information systems and services.[116]

Broad access to high-resolution Earth imaging also poses security concerns (see Indicator 2.5).

Weather monitoring and prediction capabilities continue to improve

In October 2017, the United States launched the first Joint Polar Satellite System (JPSS-1) satellite, which can monitor and predict weather, in addition to monitoring atmospheric temperatures and moisture, and sea-surface temperatures and ocean color.[117] The satellite, a joint venture between NASA and NOAA, is the first in a series of four “next-generation operational environmental satellites representing major advancements in observations used for severe weather prediction and environmental monitoring.”[118]

The JPSS-2 satellite was set to be launched by United Launch Alliance in mid-2021.[119] However, in early 2018, the U.S. administration requested 20% cuts to NOAA’s budget, including weather satellite programs,[120] following on 2017 budget cuts for future polar-orbiting weather satellites.[121]

NOAA continued to develop the GOES-S and GOES-T series of satellites, to be launched in 2018 and 2020, respectively, to join the GOES-R series launched in 2016. The GOES-16 of the R series is described as the “most advanced weather satellite NOAA has ever developed”[122] and is NOAA’s first geostationary weather satellite to carry a lightning detector. It covers the eastern United States and the Atlantic Ocean, and began regular weather observations in December 2017.[123] Next-generation geostationary weather satellites can scan the Earth five times more quickly than the current GOES fleet, at four times the image resolution and with triple the number of channels.[124] The data from the new satellites distinguishes among snow, fog, clouds, volcanic ash, and other particles.

Japanese scientists have made a breakthrough in modelling weather patterns in areas under heavy cloud. The project at the Riken Science Institute is pairing data from the Himawari-8 satellite with a program run on a supercomputer to gauge the height of the top of clouds, information that is vital in estimating factors such as wind and temperature. The program could help improve forecasting during heavy weather when ground-based and airborne monitors can be unreliable and has the potential to improve weather warnings, allowing more time for evacuations.[125]

In May, NASA's Cyclone Global Navigation Satellite System (CYGNSS) began to release regular public data, including measurements of ocean surface wind speeds and roughness, primarily to allow the monitoring of location, intensity, size, and development of tropical cyclones.[126] CYGNSS is a constellation of eight microsatellite spacecraft that were launched in 2016 and which interact with GPS to take frequent measurements of ocean surface winds in the tropics.[127]

Russia's November 28 launch of a $45-milliion weather satellite, Meteor-M No.2.1, failed and the satellite was lost.[128]

Increased data collaboration to monitor climate change

France's space agency, CNES, hosted the One Planet Summit in December. Leaders of space agencies made plans to set up a Space Climate Observatory to improve collaboration in achieving long-term sustainability and accessibility of climate data captured by satellites.[129]

The space agencies of France and the United Kingdom agreed to launch satellite mission MicroCarb in 2020 to measure sources and sinks of carbon, the principal gas driving global warming.[130] ESA launched the fourth Copernicus satellite (Sentinel 2-B) from French Guiana in March to support a focus on changes in the Earth's mass and coastal zones. With its twin Sentinal-2A (launched in June 2015) it will cover the Earth's entire surface in five days.[131] The Copernicus Sentinel-5P pollution monitoring satellite was launched in October, with its mission expected to begin in 2018.[132] The British-built satellite will provide pollution data within three hours of detecting it and will remain in orbit for seven years.[133]

The pair of U.S./German GRACE satellites were retired in October after 15 years of in-space service. NASA launched replacement satellites (GRACE-FO) on 22 May 2018.[134]

Toronto's Space Flight Laboratory has agreed to provide Dubai-based Mohammed Bin Rashid Space Centre with a microsatellite for aerosol and greenhouse gas monitoring.[135]

To better leverage space data, the November 2017 Florianopolis Declaration created the Atlantic International Research Centre, an international scientific network headquartered in the Azores islands of Portugal. The center is intended to integrate space, climate-energy, oceans, and data sciences for diverse applications, including security, agriculture, biodiversity, and urban planning.[136]

Satellites continue important role in disaster response

China joined the International Cospas-Sarsat Programme as its 44th member in October.[137] China's BeiDou system will collaborate with GPS, GLONASS, and Galileo systems in search-and-rescue missions.[138] Cospas-Sarsat aided in the rescue of at least 2,057 persons in 876 events in 2016, the latest year for which data is available.[139] It has helped to rescue at least 43,807 persons since 1982.

Figure 2.2 Cospas-Sarsat rescues, 2016[140]

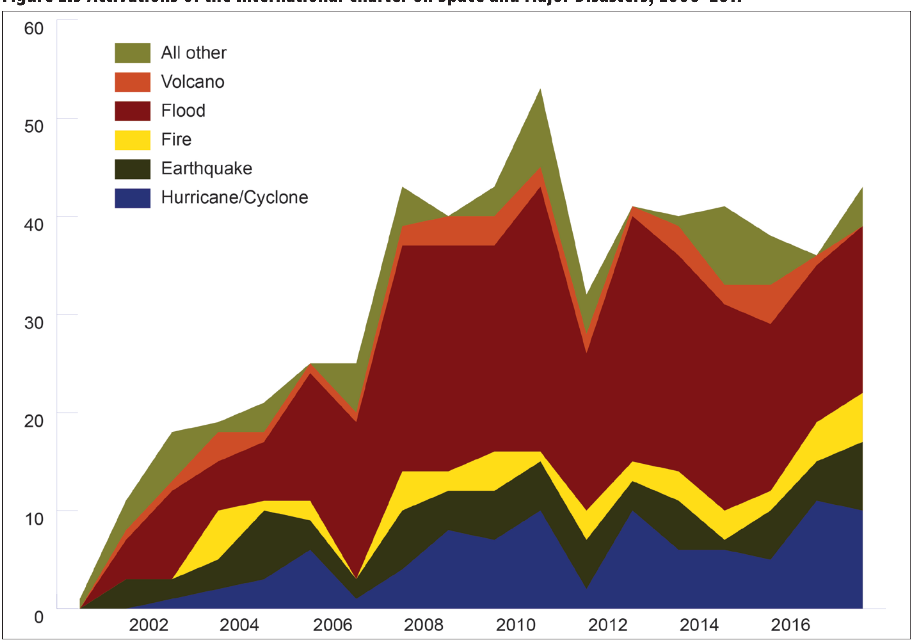
Type of distress	Search-and-rescue events	Persons rescued
Aviation	177	355
Maritime	349	1,201
Land	350	501
Total	876	2,057

International Charter Space and Major Disasters was activated 44 times in 2017. The Charter provides a unified system of space-data acquisition and delivery during humanmade or natural disasters to mitigate the effects on human life and property.[141] The UAE became a member in 2017.[142] The Charter was awarded the William Thomas Pecora Award in November for its "outstanding support to the global community during times of crisis."[143]

The UAE's Mohammed Bin Rashid Space Centre joined Sentinel Asia,[144] a voluntary international initiative established in 2005 to support disaster management in the Asia-Pacific region by sharing imagery from EO satellites.[145] It will provide high-resolution data from its DubaiSat-2 satellite that was launched in 2013, and through its long-term EO program.[146]

Mainland China and Taiwan agreed to share electromagnetic satellite data to better track earthquakes. China will give Taiwan partial access to data collected by an electromagnetic surveillance satellite to be launched next year.[147]

Figure 2.3 Activations of the International Charter on Space and Major Disasters, 2000-2017



* All Other includes landslides, oil spills, ice events, typhoons, and other uncategorized events.

Leveraging space capabilities for sustainable development

Space capabilities such as GNSS, weather data, and satellite communications are considered critical for the achievement of the global Sustainable Development Goals (SDGs). Seventeen SDGs are outlined in the 2030 Agenda for Sustainable Development,[148] which was adopted by 194 countries at the UN General Assembly in September 2015.[149] Using space to achieve these goals is a focus of UNISPACE+50 in 2018 and the Space 2030 Agenda led by UNOOSA and UN COPUOS. In November, UNOOSA and the UAE conducted a high-level forum on space as a driver for socioeconomic sustainable development, which resulted in recommendations for the use of space as a tool for sustainable development.[150] UNOOSA and the UAE also signed an agreement to increase cooperation in the peaceful uses of outer space, including applications for sustainable development.[151]

At the end of 2017, UNOOSA and the UN Development Programme (UNDP) agreed to increase sharing of space technology. In particular, UNOOSA will "work to provide UNDP with access to satellite imagery and analysis, and leverage UNDP's global user network to deliver space-based solutions for the SDGs.[152] UNOOSA is also working with the ESA to develop a "space solution catalogue" to help countries attain SDG targets; the catalog will work as a portal through which countries can find possible space solutions.[153] UNOOSA held discussions with China on how its Spatial Information Corridor—part of the Belt and Road Initiative—can be used to meet SDGs (see Indicator 2.3).[154]

The Economic Community of West African States (ECOWAS) met in October to unite national space agencies and related technical bodies in Africa behind a strategy for space science and geomatics, which is linked to mutual peacekeeping and economic development.[155]

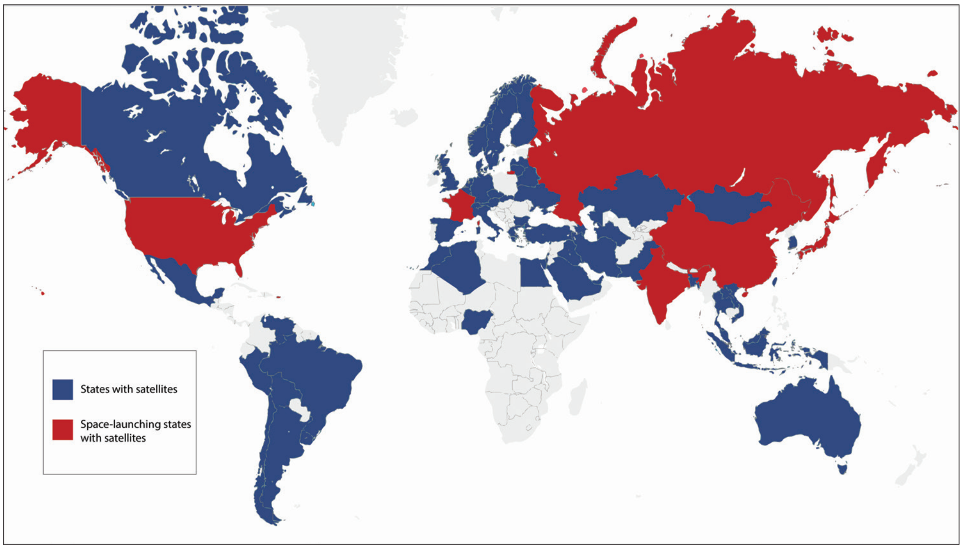
Indicator 2.2: Priorities and funding levels in civil space programs

Civil space programs now account for approximately 65% of global space expenditures.[156] 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. Activities include national (nonmilitary) satellites, science missions, the development of launch vehicles, and space exploration.

Civil space programs 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 can 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.

Access to and use of space is expanding rapidly. In 2017, ESA, the United States, Russia, China, Japan, India, Israel, Iran, the Democratic People's Republic of Korea (DPRK), and the Republic of Korea had independent launch capabilities.[157] As of 30 April 2018, the Union of Concerned Scientists Satellite Database listed ESA, Taiwan, and the following 62 states as owners/operators of active satellites: Algeria, Argentina, Australia, Austria, Azerbaijan, Bangladesh, Belarus, Belgium, Bolivia, Brazil, Canada, Czech Republic, Chile, China, Denmark, Egypt, Finland, France, Germany, Greece, India, Indonesia, Iran, Iraq, Israel, Italy, Japan, Kazakhstan, Laos, Latvia, Lithuania, Luxembourg, Malaysia, Mexico, Monaco, Mongolia, Morocco, Netherlands, Nigeria, Norway, Pakistan, Peru, Russia, Saudi Arabia, Singapore, Slovakia, South Korea, Sri Lanka, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, Turkmenistan, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela, and Vietnam.[158]

Figure 2.4 Global access to space, 2018[159]



Space agencies

There are more than 70 national space agencies. ESA reports that 58 countries invested more than $10-million each in space programs in 2017.[160]

NASA oversees mission design, integration, launch, and space operations, while also conducting aeronautics and aerospace research. Reaching over $20-billion annually, NASA's budget is by far the world's largest civilian space budget.[161] Recent priorities include the development of new capabilities for space launch, human spaceflight, and deep space exploration.[162] While much of the operational work is carried out by NASA, major commercial contractors such as Boeing and Lockheed Martin develop technologies for new space exploration projects.

Roscosmos is the Russian coordinating hub for space activities. Its numerous civilian activities include Earth monitoring and the astronaut program; it also coordinates military launches with the Defense Ministry.[163] Much 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 recovering from a string of approximately 15 failed launches of its Proton rockets between 2012 and 2016.[164] Roscosmos was formally dissolved in 2015 and in early 2016 joined the recently nationalized United Rocket and Space Corporation to form the Roscosmos State Corporation.[165] Roscosmos faced a reduction of more than 60% to the 10-year budget announced in 2015, which primarily affected the development of a super heavy launch rocket for space exploration.[166] The 2016-2025 budget is approximately $20.5-billion,[167] or roughly $2.05-billion annually.

The China National Space Administration, established in 1993, became the second largest space program in 2016, with spending estimated at $4.9-billion.[168] 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. China's rapidly expanding investment in its space program 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 recent years, China has launched new rockets (Long March 6 and Long March 11), opened Wenchang Space Launch Center on Hainan Island, and advanced development of the Tiangong space station program.

Euroconsult reports that Japan, France, Germany, India, and the EU all invested more than $1-billion in their space programs in 2016.[169]

In 1961, France established the Centre national d'études spatiales, which remains the largest EU national-level agency. Italy established a national space agency, Agenzia Spaziale Italiana (ASI), in 1989, and Germany consolidated various space research institutes into the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt or DLR) in 1997. The European Space Research Organisation and the European Launch Development Organisation merged in 1975 into the European Space Agency. ESA currently has 22 Member States: Austria, Belgium, the 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.[170]

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.[171] India's 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.[172] Iran has since launched four satellites into orbit. In 2014, Iran formulated a 10-year strategic plan with a focus on telecommunications and remote-sensing satellites, as well as human spaceflight.[173] Many of the international sanctions that had previously limited Iran's space program were lifted under the conditions of the 2015 Joint Comprehensive Plan of Action to limit its nuclear program. In 2018, however, the United States withdrew from the agreement and reimposed sanctions.

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.[174]

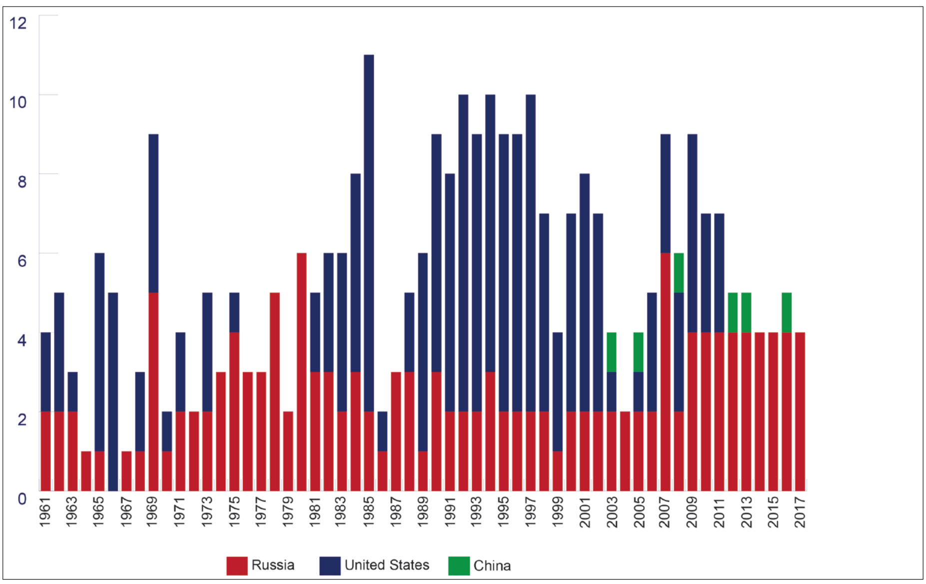
Human spaceflight

Human spaceflight represents the largest civil space expenditure, estimated annually at $11.4-billion.[175] 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.[176] 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.[177]

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 is working with private companies SpaceX and Boeing on the Commercial Crew Program to provide human spaceflight to the ISS in the future, but the program is significantly behind schedule;[178] operational launches of the Dragon V and Starliner CST-100 spacecraft are unlikely before 2019 or 2020.[179] NASA's new heavy-launch Space Launch System remains a priority; it is intended to support deep space exploration, one day taking astronauts to Mars. Human exploration beyond LEO has been an elusive goal since the 2004 announcement that NASA would return humans to the Moon by 2020. The Journey to Mars was announced in 2014, which plans to send humans first to an asteroid, then to Mars after 2030.[180] Cost remains a challenge.

China began developing the Shenzhou human spaceflight system in the late 1990s and completed a successful human mission in 2003.[181] 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 Chinese Space Station, to be finished by 2022, following the launch of two Tiangong space laboratories in 2011 and 2016.[182]

Figure 2.5 Human spaceflight missions by launching state, 1961–2017



Socioeconomic development

Most civil space agencies are created to contribute to national socioeconomic development. Earth observation is a key driver of such benefits and the second highest spending area, totaling $10.9-billion in 2016, with investments by 58 countries.[183]

Although it has recently adopted new priorities, including national security and space exploration, India's space program exemplifies the benefits for developing countries of investing in outer space.[184] China has also 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 socioeconomic development issues through Space technologies”[185] and is linked to the Agenda 2063 framework for socioeconomic transformation (see Indicator 4.3). Africa overall currently lacks significant access to space (see Figure 2.4).

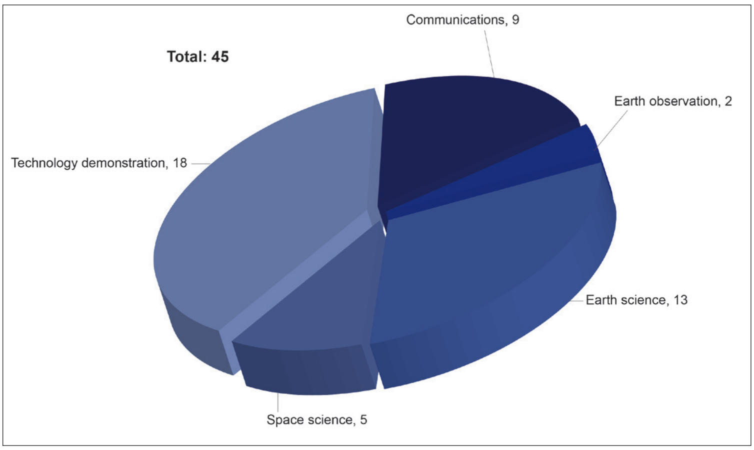
The high-level forums in advance of UNISPACE+50 in 2018 focused on space as a driver of socioeconomic development,[186] recognizing that access to outer space is linked to achievement of the Sustainable Development Goals.

2017 Developments

A total of 45 satellites classified as civilian by the Union of Concerned Scientists were launched by Australia, Bangladesh, Belgium, Canada, Chile, China, Finland, France, Germany, India, Israel, Italy, Japan, Kazakhstan, Latvia, Lithuania, Mongolia, Nigeria, Russia, Slovakia, Taiwan, Turkey, Ukraine, United Arab Emirates, the United Kingdom, and the United States.

Figure 2.6 Civil satellites launched in 2017, by purpose* [187]

* Spacecraft with two purposes are counted twice



Investment in advanced space programs accelerates

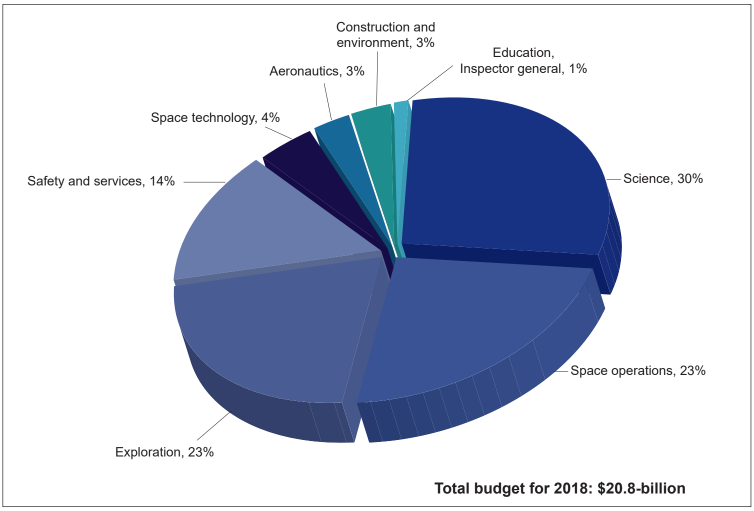
Global spending on civil space programs increased in 2017, after five years of erosion;[188] total government spending on space was $62.2-billion in 2016, down 2% from the previous year. It is predicted that annual global spending will reach $79-billion by 2026. Major space programs focused on developing new capabilities to enhance access to outer space and enable space exploration.

United States

The U.S. Congress passed the NASA Transition Authorization Act of 2017, the first NASA authorization in nearly 6.5 years. The $19.65-billion funding allocation for FY2017 was an increase of $368-million over the previous year. The Act includes numerous policy provisions, including the development of a detailed plan for NASA’s human exploration programs, particularly to Mars, which received $408-million.[189] Planetary science funding includes $275-million for the Europa Clipper and a proposed lander.[190] NASA’s Earth science program received $1.92-billion, the same as in 2016. The space technology program received $686.5-million. Space operations, which include the International Space Station and related projects, received $4.95-billion, $125-million less than requested. The new U.S.

focus on lunar exploration will constrain NASA's budget in the next few years (see below). An omnibus spending bill signed by the President in March 2018 boosted the FY2018 budget $1.1-billion above the FY2017 budget and $1.6-billion above the President's request of $20.7-billion.[191]

Figure 2.7 NASA budget priorities, 2017-18 [192]



China

While it is known that China is investing heavily in its civil space program, few details are available. China did expand overall research and technology spending by 11.6% in 2017, to roughly 1.75 trillion yuan ($257-billion), approximately 2% of GDP.[193] Estimates set spending on space at between four and six billion dollars.[194] High-profile activities in 2017 include the Tiangong-2 space laboratory, which received its first resupply and refueling missions, while several new heavy launch rockets (Kuaizhou-1A & Kaituozhe-2) were debuted. CNSA also has short- and medium-term plans to land the first rover on the far side of the Moon, to develop a Mars rover, and for human space missions.[195]

Russia

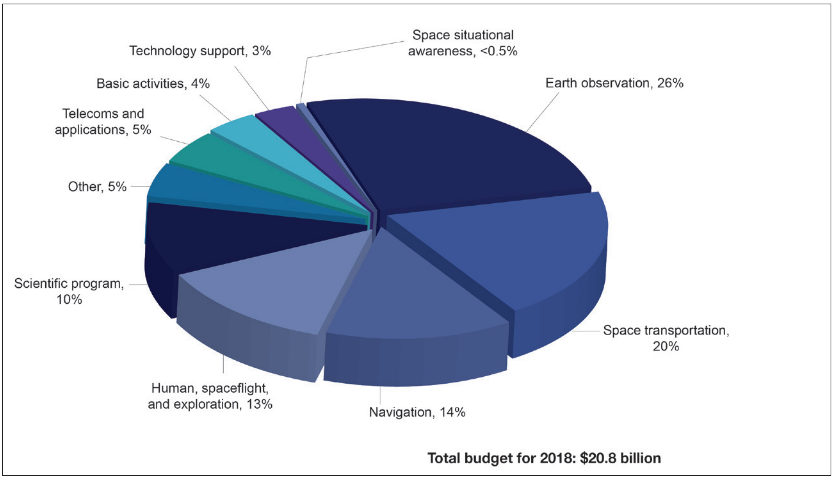
Roscosmos has been struggling to formulate a coherent long-term space strategy. In the last five years, it has produced a plan for space activities for 2013–2020, a 2013 national space strategy that goes to 2030, the Federal Space Program 2016–2025, and a Roscosmos strategy that goes to 2030, which was awaiting final approval in late 2017.[196] These plans focus on human spaceflight and heavy launchers for deep space exploration. Following significant budget cuts in the previous three years, 2017 saw an additional cut of 58.8-billion rubles ($871-million).[197] Spending for the Federal Space Program was supposed to have been 92.5-billion rubles in 2017 ($1.4-billion), in addition to 38.3-billion rubles ($570-million) for the GLONASS program (see Indicator 2.1).[198]

Russia's space program faced several setbacks in 2017, not only the failure of a Soyuz rocket carrying supplies to the ISS, but the loss of a weather satellite and 20 micro-satellites from other nations following a failed launch on 28 November.[199] For the first time, Russia had fewer space launches than either the United States or China. Its Soyuz U launch vehicle was officially retired after 40 years of service and 786 launches.[200]

Europe

Funding for ESA increased by 9.5% in 2017 to €5.75-billion ($6.7-billion).[201] 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. ESA plans to invest in a Vega small satellite launcher and a miniature reusable robotic space plane, awarding €89.7-million to private companies Avio and Thales.

Figure 2.8 ESA spending by domain, 2017 [202]



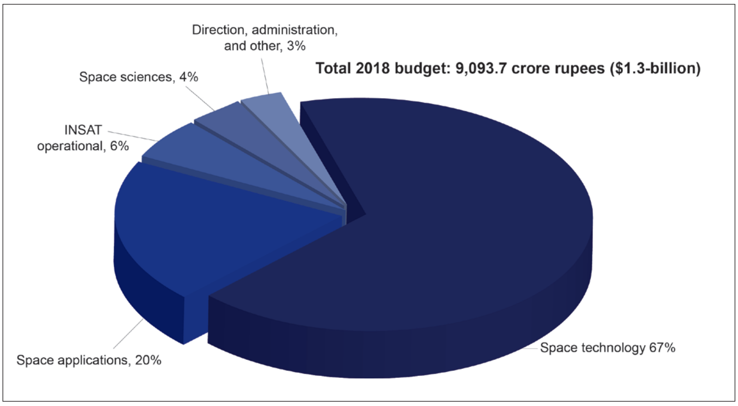
* Indicates less than 0.5%

The budget of CNES increased by 10% in 2017 to €2,3-billion ($2.7-billion),[203] with 80% allocated to prime contractors and service companies and €833-million to the ESA.[204] Germany allocated approximately €1.4-billion ($1.7-billion) to space research, including institutional funding for the German Aerospace Center. Just under €276-million ($322-million) was allocated to the National Space Program. The German contribution to ESA fell to approximately €755-million ($881-million).[205] The UK Space Agency's budget for 2017-2018 is £386.8-million ($498-million),[206] while the United Kingdom allocated more than €1.4-billion ($1.6-billion) for the ESA for the 2017-2019 period, including €670.5-million for satellite technology, €71-million for the ESA's ISS program and deep space exploration, and €82.4-million for the final phase of the ExoMars program, which aims to launch a British-built rover in 2020 to collect and analyze Martian samples.[207]

India

ISRO had a budget of approximately $1.3-billion in 2017 (Rs. 9,093.71 Crores), an increase of roughly 20% over the previous year.[208] New exploration projects include one to Mars and one to Venus. In 2017, ISRO successfully tested its largest cryogenic engine, which powered the GSLV Mark III rocket and GSAT 19 into space on 5 June.[209] The rocket was designed and made in India, and is capable of propelling 4-tonne satellites into geosynchronous orbit.[210] This rocket could also be capable of lifting a crew into space, allowing India to become the fourth country to achieve human spaceflight.

Figure 2.9 ISRO spending by category, 2017 [211]



Japan

The 2017 budget for JAXA stayed steady at ¥153.7-billion ($1.4-billion), of which ¥19.1-billion was to develop the H3 launch vehicle, set to launch in 2020. Another ¥2.3-billion was allocated to the X-ray Astronomy Satellite and ¥800-million to the development of the next-generation engineering test satellite.[212]

Canada

In 2017, the Canadian government announced C$80.9-million ($62.4-million) in new funding over the next five years to develop emerging space technologies, such as radar instruments for future orbiter missions to Mars to look for water on the surface and subsurface (see Indicator 3.1).[213] CSA's budget for 2017-2018, not including the additional funding, was C$353.8-million ($272-million). If the projected spending for 2018-19 remains at C$348-million, it will be the lowest budget since 2003-2004.[214]

UAE

The UAE Federal Cabinet allocated Dh204-million ($55.5-million) to the UAE Space Agency in 2017.[215] Key priorities include enhancing the lives of citizens, national security, crisis management, natural resource discoveries, climate monitoring, diversification of the UAE economy, and collaboration with other states.[216] The UAE is the first Arab country to manufacture its own satellite.

Emerging space programs in Africa and Latin America focus on socioeconomic development and environmental monitoring

In 2017, there were 72 civil space programs, up from 47 a decade earlier. More recently established programs, particularly in Africa, concentrate on improving space industry and EO capabilities with direct social and economic applications.

Algeria

Algeria's fifth satellite, communication satellite Alcomsat-1, was successfully launched in December on a Long March 3B space launch vehicle from the Chinese launch site at Xichang. Built by China Great Wall Industry Corp., it will allow national telecommunications—digital radio, TV broadcast, distance learning, telemedicine, and videoconferencing—to function during major natural disasters. The satellite will provide high-speed Internet for all of Algeria and mid-speed Internet to Morocco, Mauritania, Western Sahara, Mali, Niger, Burkina Faso, Libya, Tunisia, northern Chad, and northern Sudan.[217] Plans for more satellites are outlined in Algeria's 2020-2040 Space Program.

Argentina

Argentina's space commission CONAE (Comision Nacional de Actividades Espaciales) plans to have its satellite SAOCOM 1A launched by SpaceX in August 2018, in cooperation with Italy. The satellite will form part of the Italian-Argentine System of Satellites for Emergency Management. Data collected by SAOCOM 1A will be used to create risk maps of plant diseases, detect humidity levels, and help scientists develop more effective and complex flood recovery plans.[218] Twin satellite SAOCOM 1B is expected to launch in 2019.[219] Argentina is planning to increase its annual space budget to $103-million[220] through 2027 to advance this project.[221]

Costa Rica

In October, Costa Rica announced the successful construction of Central America's first indigenously manufactured satellite, Proyecto Irazú. The cubesat, a Birds-2 project of the Central American Aeronautics and Space Association, the Costa Rican Technological Institute, and Japan, will monitor carbon emissions and capture in Costa Rican forests[222] (see Indicator 2.3).

Ghana

In August, Ghana's GhanaSat-1 cubesat was launched to conduct research; monitor illegal mining, water use, and deforestation; and improve mobile and TV reception. The satellite was developed by graduates from Ghana's All Nations University and launched by JAXA as part of the Joint Global Multi-Nation Birds Satellite project (Birds project) between the Kyushu Institute of Technology in Japan and Asian and African states (see Indicator 2.3).[223] Satellites from Mongolia, Nigeria, and Bangladesh were also launched through the Birds program.

It is hoped that GhanaSat-1 will inspire STEM (science, technology, engineering, mathematics) education in national high schools.[224] The government promotes investment in space to leapfrog over development stages in a variety of economic sectors.

Ethiopia

Ethiopia's Ministry of Science and Technology announced plans to build its own space launch vehicle and have a domestically built EO satellite within three to five years. The government sees enormous economic and military benefits to the satellite (see also Indicator 2.6) and intends to use satellite data to improve agriculture, guard tropical forests from deforestation, forestall climate change, and improve disaster planning, while providing Internet to rural communities.[225]

South Africa

The South African National Space Agency (SANSA) announced that its next satellite, EOSat-1, which will be built by South African company Spaceteq, is expected to launch in 2019-2020 and will support food security, track land use, and help in disaster management.[226] SANSA will offer these services to other African countries through the NEPAD (New Partnership for Africa's Development) Agency, which coordinates continentwide economic development (see Indicator 2.3).[227]

Venezuela

In October, China launched Venezuela's remote-sensing satellite, VRSS-2, from the Jiuquan Satellite Launch Center. Manufactured by China Great Wall Industry Corporation, VRSS-2 was the third Venezuelan satellite (the second remote-sensing) launched by China. The satellite will aid in land resources inspection, environmental protection, disaster monitoring and management, crop yield estimation, and city planning.[228]

New space agencies

Many of the countries that established new civil space agencies in 2017 focused on the four major steps on the "space technology ladder," the first of which is establishing a national space agency. The others are owning and operating a satellite in LEO, owning and operating a satellite in GEO, and launching satellites.[229]

Australia

At the 68th International Astronautical Congress in Adelaide in September, the Australian government announced that it would establish a national space agency,[230] leaving Iceland the only OECD country without one.[231] The Australian agency officially launched on 1 July 2018.[232] The agency will be "small" but effective in coordinating Australia's involvement in the global space industry.[233]

Egypt

In December, Egypt established its space agency. The first goal is to launch a research satellite, and then a fully operational pan-African space station. The new agency will work closely with Japanese and Chinese agencies.[234] Egypt plans to create a satellite-manufacturing center in 2019 and launch its first indigenously made satellite in 2020. According to a September 2017 Memorandum of Understanding between Egypt and China, China will give $45-million toward the design and manufacture of satellite EgyptSat 2/MisrSat 2 (see Indicator 2.3).[235] Egypt is also participating in satellite programs with France and Russia.[236]

Kenya

In March, the Kenya Space Agency was established to coordinate Kenya's growing community of space technology practitioners.[237] Organized under the Ministry of Defence, the agency is tasked with promoting, coordinating, and regulating national space activities (see Indicator 2.6).[238] Kenya is also the first recipient of the UNOOSA-JAXA KiboCUBE initiative, a program that helps developing countries launch cubesats into space at no cost (see Indicator 2.3). Kenya's first microsatellite, 1KUNS-PF, is scheduled for launch by Japanese astronauts from the ISS in 2018.[239]

New Zealand

With a new regulatory regime to enable space launches (see Indicator 4.1), New Zealand plans to open a Centre of Space Science and Technology to advance the development and application of space-based data in agri-technology, hazard management, oceanography, and meteorology. New Zealand also plans to develop satellite design and manufacturing capabilities.[240] Its first orbital launch site opened in 2017, operated by private company Rocket Lab.

Turkey

In 2017, a parliamentary subcommittee approved a draft bill to establish a national space agency;[241] Under this bill, the mission of the Turkish Space Agency will be to reduce dependence on foreign technology; coordinate work for space platforms; launch facilities and systems; and help to develop, integrate, launch, monitor, and operate aerospace systems. Turkey is also planning to build a satellite launching station. In December, Turkey's Göktürk-1, a new military and civilian satellite to support counterterrorism efforts, was launched by Arianespace (see Indicator 2.6). Turkey aims to build the first fully indigenous Turkish satellite by 2019 and own a fleet of 10 satellites by 2023.

Access to space remains a priority of civil space programs

New launch vehicles for satellites and heavy launch vehicles for deeper space missions are being developed. China debuted two launch vehicles in 2017: the Kuaizhou-1A, a small, solid fueled vehicle designed for rapid launch (see Indicator 3.2), and the Kaituozhe-2 (KT-2), which launched secretly in March and carried an experimental satellite. The KT-2 is a responsive launcher that uses a mobile launch capability.[242] China has introduced five new rockets, including three in the Long March series, the backbone of China's space program, in the last two years.[243] China is also working on reusable launch vehicles with parachutes and propulsion landing. A Heavy-Lift Long March-9 is expected by 2030.

In November, the China Aerospace Science and Technology Corporation released a roadmap for planned developments in space technology, space science, and space applications through 2045.[244] Priorities include a reusable spaceplane, super heavy launch vehicles, and a nuclear-powered spacecraft, intended to facilitate large-scale space exploration, asteroid mining, and space travel.[245]

In June, ISRO successfully tested its largest cryogenic engine, which powered the GSLV Mark III rocket carrying GSAT 19 into space.[246] The rocket was designed and made in India and can lift 4-ton satellites into GEO.[247] This rocket could be capable of lifting a crew into space, allowing India to become the fourth country to achieve human spaceflight. India is eager to end dependence on foreign launch facilities;[248] ISRO's new launch pad can launch 12 rockets a year.[249]

Following the January grounding of the Russian Proton rocket fleet because of systemic engine problems,[250] a Proton rocket launched U.S. telecom satellite Echostar-21 in June.[251] The Soyuz booster, which failed in December 2016, successfully launched an unpiloted cargo ship to the ISS on 13 February 2018 from Baikonur Cosmodrome.[252] Russia continued development of its Vostochny Spaceport, which has been under construction since 2012 and has faced delays.[253] In July 2017, Phase I was completed and work begun on Phase II. Vostochny Spaceport is expected to reduce Russia's dependency on the Baikonur space center in Kazakhstan, currently leased to Russia until 2050.[254] It will be used to develop heavy rockets for deep space exploration and for military and civilian launches. A maiden launch was carried out in April 2017, with a Soyuz-2.1 carrying three research satellites.

Brazil's Air and Space Institute is developing proprietary rocket technology to send microsatellites into low orbit by 2019.[255]

In July 2017, Iran attempted its first satellite launch using the new Simorgh space launch vehicle at the Khomeini National Space Center.[256] While Iran declared the launch a success, no space objects have been detected.[257] Iran is also cooperating with Russia to achieve a human mission into suborbital space.[258]

There were indications in 2017 that the DPRK was continuing to develop a space launch vehicle. Three new long-range ballistic missile rocket engines were tested in March and the government stated its intention to soon launch two satellites for Earth exploration and communications.[259] In December, significant activity was noted at the Sanum-dong Research Center, where launch development takes place.[260] There are concerns that the new rocket engines could be repurposed to launch missiles.[261] Since 1998, two of six North Korean satellite launches have placed satellites in orbit, although neither was apparently able to transmit.

Growing focus on robotic lunar and planetary space exploration

China's Chang'e 4 lunar lander is set to be the first probe to land on the far side of the Moon. The original launch date of 2015 has been postponed to 2018. CNSA also plans to launch a robotic probe to a gravitationally stable location beyond the lunar far side, known as the Earth-Moon Lagrange Point 2, to relay communications from Chang'e 4 back to Earth and to explore both lunar poles.[262] A Moon-sampling mission is planned for Chang'e 5, which will be the first to retrieve lunar material since the Soviet Union's Luna 24 spacecraft in 1976. Chang'e 5 was planned to launch on the Long March 5 in November 2017,[263] but had to be rescheduled to 2019 after a rocket failure in July 2017.[264] The long-term goal is to land Chinese astronauts on the Moon, but not before 2030 (see below).[265]

ISRO is planning a second mission to the Moon in 2018; Chandrayaan-2 includes an orbiter, lander, and small rover. It will be launched aboard a GSLV Mark 2 rocket on ISRO's first deep-space launch of this newer, heavier launch vehicle. Roscosmos was an early partner on Chandrayaan-2, but had to drop out.[266] ISRO is also planning a mission to the Sun, Aditya-L1, in 2019.[267] The satellite will image the Sun's magnetic field from space.[268] The Korea Aerospace Research Institute's first lunar mission is planned for December 2020 on the Korea Pathfinder Lunar Orbiter.[269]

In 2017, China unveiled illustrations of a probe and rover that it aims to send to Mars in 2020 to collect samples. The probe will carry 13 types of payload, including six rovers, which will collect data on the environment, morphology, surface structure, and atmosphere of Mars. China's plans for the next decade include deep-space exploration of Jupiter, Venus, and asteroids.[270]

ISRO is planning Mars Orbiter Mission II, with a lander to launch in 2021-2022.[271] In September 2014, India became the fourth actor, after the United States, the Soviet Union, and the ESA, to successfully orbit a spacecraft around Mars.[272] ISRO is also developing plans to send a spacecraft on a three-month journey to Venus and another to Jupiter. The UAE aims to launch its first mission to Mars in 2020 on the unmanned orbiter, Hope, from Japan's space center. The UAE also aims to launch KhalifaSat from Japan in 2018.[273]

NASA's current robotic program Mars 2020 seeks signs of habitable conditions on Mars and of microbial life.[274]

In July, the CNSA successfully launched the Long March-4B, its first X-ray space telescope, to study black holes, pulsars, and gamma-ray bursts. Another astronomical satellite, jointly developed by China and France, will be launched in 2021 to study gamma rays and provide data for research in dark energy and the evolution of the universe.

The European-led BepiColombo mission will launch for Mercury in 2018 on the Mercury Magnetospheric Orbiter (MMO) and an ESA orbiter. After a six-year journey, the MMO will study Mercury's magnetic field and examine its polar regions for water.[275] In October 2018, Roscosmos is expected to launch the Spektr-RG (Spectrum Roentgen Gamma) space observatory with the German eROSITA X-ray telescope, which will survey the sky for four years and monitor the most interesting targets for another three years.[276]

Continued efforts to develop new human spaceflight capabilities

At the U.S. National Space Council's inaugural meeting on 5 October, Vice President Mike Pence announced that the United States would focus on returning humans to the Moon.[277] On 11 December, President Trump signed Space Policy Directive #1, formally initiating NASA's return to the Moon and a new journey to Mars.[278] Other developments this year that support this policy include the NASA Transition Authorization Act,[279] which requires NASA to establish a roadmap for human missions to Mars in the 2030s and maintains programmatic consistency for NASA's SLS rocket and Orion spacecraft currently in development.[280] NASA's exploration program received $4.32-billion, including $2.15-billion for the SLS and $1.35-billion for Orion.[281]

The SLS rocket, the world's most powerful, will be used to propel the new human capsule Orion into deep space, potentially carrying human passengers around the Moon, to an asteroid, or even to Mars by the 2030s. The goal is to enable future human settlement on the Moon.[282] Powered by four RS-25 engines firing simultaneously, the SLS will provide 2-million pounds of thrust and work in conjunction with a pair of solid rocket boosters.[283] In May 2017, NASA engineers successfully conducted the second of a series of RS-25 flight controller tests. NASA's Exploration Mission 1, which will be the first joint flight of the Orion capsule and SLS rocket, taking Orion on a three-week trip around the Moon, has been postponed until 2019.[284]

China's first cargo-carrying spacecraft, Tianzhou-1, is integral to its goals in human spaceflight and to the development of China's space station. Tianzhou-1 was launched successfully in April 2017 on a Long March-7 booster from Wenchang spaceport and docked with the orbiting Tiangong-2 space lab to refuel the facility.[285] Tianzhou-1 successfully separated from the space lab in September. In November, China's Shenzhou-11 spacecraft returned two astronauts to Earth from China's longest crewed orbital mission. The core module of the Space Station is expected to launch in 2020,[286] after delays caused by the Long March 5 failure.[287] In addition to the planned heavy launch Long March 9, China is developing two next-generation crewed spacecraft for deep space missions.[288]

Roscosmos is reportedly recruiting astronauts for a lunar mission in 2031 in a new, crewed launch vehicle, the Federatsiya, with a first test launch tentatively scheduled for 2024.[289] Work has begun on the first components of the spacecraft, with the rocket switched from the Angara 5 to the Soyuz 5 super-heavy rocket.[290]

In December, the UAE announced plans to send astronauts to the ISS within five years.[291] In June, JAXA announced plans to put an astronaut on the Moon by or about 2030, in its first human mission beyond the ISS.[292]

The UAE announced its Mars 2117 project, which aims to see settlement on Mars within 100 years and to help solve problems such as food and water scarcity on Earth.[293] The project has received steadfast financial support from the government and military.[294] The UAE also announced the creation of a Mars Science City that will provide a long-term simulated Martian environment. UAE is interested in space mining on asteroids for metals and water to help fuel missions to Mars.[295]

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). Cooperation also enhances the transparency of certain civil programs that could potentially have military functions.[296]

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.[297] Many barriers to global partnership have lifted since the end of the Cold War.

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.[298] The ISS has hosted astronauts from 15 countries.[299] On 8 January 2014, the Obama Administration announced an extension of support for the ISS until at least 2024;[300] since then, there have been efforts to identify a path to commercial use and operation. Current international cooperation on the ISS is being extended to developing countries, as in the 2015 KiboCUBE initiative by UNOOSA and JAXA.[301] New concepts for cooperation in human space exploration beyond Low Earth Orbit, including the Moon, are beginning to take shape.

Political developments in Ukraine in 2014 created tension between Russia and the United States, European states, and NATO allies. NASA announced that, except for activities involving the ISS, NASA employees are barred from traveling to Russia, hosting Russian visitors, and emailing or holding teleconferences with Russian counterparts.[302] The U.S. Congress continues to make efforts to prohibit the purchase of Russian RD-180 engines, used on launch vehicles for U.S. defense satellites (see Indicator 2.5), although such use continues. Russia has since strengthened cooperative efforts with India and China.[303]

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 (see Indicator 3.3).[304] 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.[305] 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.[306]

China maintains extensive bilateral cooperation in space with others, including Russia and the ESA, and has welcomed international participation in its space station program.[307] China has more than 100 cooperation agreements with 30 state-level space institutions and international organizations.[308] CNSA signed a Framework Agreement and a Funding Agreement with UNOOSA in 2016 to open China's future space station to science experiments and astronauts from UN member states.[309] China will also train astronauts for other countries.[310] CNSA claims that such cooperation will promote better accessibility to space for developing countries.

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.[311] Space activities in Asia have been described as "highly nationalistic, sometimes secretive, and mostly competitive."[312] However, two Asian-based organizations foster 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.[313] The intergovernmental Asia-Pacific Space Cooperation Organization (APSCO) was established by China in 2005;[314] members include Bangladesh, China, Iran, Mongolia, Pakistan, Peru, Thailand, and Turkey. APSCO currently has 10 aerospace projects on its agenda. In 2016, it agreed to include Iran's satellite in its Small Multi-Mission Satellite Constellation program.[315]

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 that included a new Joint Institute for Space Research.[316] The BRICS (Brazil, Russia, India, China, South Africa) economic association is also emerging as a vehicle for space cooperation, primarily to decrease dependency on the West,[317] but must deal with vastly different space capabilities and internal competition.[318]

Latin America has no regional mechanism for cooperation in space,[319] but Latin American states engage in 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. Emerging spacefaring states that currently lack the technological means for independent space access have entered cooperation agreements on space activities. In the Middle East, such cooperation has been critical to the development of advanced capabilities in Iran and the UAE.

There is also significant cooperation around global utilities (see Indicator 2.1), 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).

2017 Developments

The International Space Station continues to foster international cooperation; NASA shifts involvement to private sector

While the ISS remains a keystone of international cooperation in space, participation is evolving. Russia, the United States, ESA, Canada, and Japan have committed to operations until 2024.[320] So far, the space station has remained a focus of cooperation that transcends geopolitical tension.[321] However, Russia wants to end its reliance on the United States for satellite communication with the ISS, while the United States, now using Russian rockets to get to the ISS,[322] is developing the Commercial Crew public-private program to achieve independent access (see Indicator 2.5).[323]

The U.S. budget in 2017 for the ISS was $1.4-billion,[324] half of NASA's human exploration budget. After 2024, NASA intends to transition its portion of the station to private sector activity.[325] The National Aeronautics and Space Administration Transition Authorization Act of 2017 directs NASA to plan for such a transition.[326] Some private activities are already in place, including cargo resupply missions and the Expandable Activity Module by Bigelow Aerospace (see Indicator 2.5). However, it is unlikely that commercial space companies will be able to take over fully by 2024. Not only is the ISS expensive to operate, but existing hardware is aging. Moreover, having already spent $67-billion, NASA has ongoing interests, including the ISS lab and ISS availability as a destination base for astronauts and cargo.[327] As the only site available to test the long-term effects of space on humans, the ISS is an essential element in future ventures to the Moon and Mars.

In April 2017, Roscosmos Director General Igor Komarov expressed an interest in extending Russia's ISS commitment to 2028, emphasizing its use for testing life-support systems needed to enable human exploration of the Moon, and in maintaining Russia's stake in low Earth orbit.[328] Russian engineers have proposed the addition of a tourist module to their section (NEM-2).[329]

Focus of next-generation space cooperation shifts to the Moon and Mars

Next-generation projects to the Moon and Mars have the potential to broaden cooperation with China and India, as well as emerging space programs. While financial, political, and technical challenges remain, existing ISS partners are planning to launch a cis-lunar space station (in orbit around the Moon) to advance deep space activities, including future trips to Mars.

In September, NASA and Roscosmos agreed to collaborate on the Deep Space Gateway, which they described as a "strategic component of human space exploration architecture." NASA had already engaged industry partners while Roscosmos and other partner agencies were preparing to do the same.[330] The first NASA components could be launched in 2023, followed by a Russian module.[331] NASA awarded contracts to Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada Space Systems, and Space Systems Loral to explore the development of the initial element of the station.[332]

JAXA will contribute technology in water and air purification and protection of astronauts from radiation, hoping to use the station to put its astronauts on the Moon in the 2020s.[333] The CSA could contribute various robotics capabilities, building on its success with the Canadarm on the ISS and planetary rovers, and a crew health program.[334]

ESA contributions could include its own module, supplied by a European space transportation system.[335] There is room for additional modules, and potentially new partners, which might someday include China.[336] China is currently developing its own Chinese Space Station.

The launch of NASA's Exploration Mission-1 to the near-Moon region is tentatively scheduled for 2019. This uncrewed flight test will be the first for the Orion spacecraft using NASA's heavy launch Space Launch System (see Indicator 2.2). Orion's propulsion and life support systems are provided by the ESA's European Service Module. Flight hardware for SLS and Orion is currently in production; life support and related technologies are being tested on the ISS, and habitation and propulsion development activities are progressing.[337]

Another potential international project is the "Moon Village"—a human settlement concept developed by ESA's Director General Jan Woerner involving international cooperation and commercialization.[338] By 2017, ESA and CNSA were in discussion. In November, the International Space University hosted an International Moon Village Workshop. It addressed "topics ranging from the technical framework of the Moon Village concept, prospective government missions and commercial markets for the Moon (including cis-lunar space), future coordination and cooperation vis-à-vis the Moon Village, and the ways in which human culture will influence choices and later be impacted by the expansion of humanity to the Moon." The consensus of workshop participants was that "the Moon Village concept has immense potential to focus and communicate broadly an emerging focus on the lunar exploration and development and activities throughout cis-lunar space."[339]

In November, Russia and China agreed to cooperate on space exploration and technology, including "the study of the moon and deep space, space science and related technology; satellites and their applications; element base and materials; cooperation on Earth remote-sensing data; monitoring of space debris and practical study of relevant issues; and other topics."[340] The goal is to combine Russian experience and technology with Chinese resources to advance missions such as lunar exploration.[341]

India and Japan agreed to cooperate on a robotic mission to explore the polar regions of the Moon for water and return a lunar sample to Earth, although both ISRO and JAXA have independent lunar missions (see Indicator 2.2).[342] The Italian Space Agency and the China Manned Space Agency signed an agreement to cooperate on long-term human spaceflight.[343]

Efforts to explore Mars—currently through robotic missions—are also bringing states together. NASA is expected to launch two Mars Cube One microsatellites in the summer of 2018 as part of the Insight Mission to explore the solar system, which will include a Seismic Experiment for Interior Structure provided by CNES and a Heat Flow and Physical Properties Package provided by DLR.[344] In June, acting NASA administrator Robert Lightfoot and CNES President Jean-Yves Le Gall reiterated their common desire to collaborate to advance science and enable robotic and human exploration of the solar system. [345]

Russia is collaborating with ESA on the ExoMars 2020 mission, which aims to prove the existence of methane in the Martian atmosphere.[346]

Developing countries engage in international cooperation for space activities

China is providing financial and technical support to Venezuela's and Egypt's space programs (see Indicator 2.6). Egypt's first indigenous satellite is scheduled to launch in 2020, with $45-million from China, in addition to $23-million contributed in March 2017 as part of a $65-million aid package to the Egyptian space program.[347] Part of China's Belt and Road development and infrastructure initiative, which is intended to integrate China into a network of global trade, this support of development in Egypt will give China access to the Mediterranean Sea via the Suez Canal. The Belt and Road includes the creation of a "Spatial Information Corridor" that integrates participants into China's space-based infrastructure services, including the BeiDou Satellite Navigation System, satellite communications, and remote sensing (see Indicator 2.1).[348] China now has substantial partnerships with Indonesia, Laos, Iran, Saudi Arabia, UAE, Egypt, India, Pakistan, Kazakhstan, Russia, Ukraine, Belarus, Poland, and Romania.[349] UNOOSA has held discussions with China on how Belt and Road can be used to fulfill the Sustainable Development Goals (see Indicator 2.1).[350]

In November, CNSA's Earth Observation and Data Center signed a contract with APSCO for the implementation of the system design and definition phase (phase B) of the Small Multi-Mission Satellite (SMMS) constellation program.[351] Phase B includes the construction of both the space and ground segments of the remote-sensing satellite system and the integration of remote-sensing satellite data, which will allow member states multi-channel access to satellite data.[352] The first spacecraft, HJ 1A/SMMS-1, was launched by China in 2008.

On 5 May, India launched the GSAT-9 South Asian Satellite as a "gift" to South Asia; it will make available to the region various communication applications in Ku-band. Participating countries must develop their own ground infrastructure, although India has offered technical assistance. Currently use of the satellite is shared with Nepal, Bhutan, the Maldives, Bangladesh, Sri Lanka, and possibly Afghanistan; Pakistan declined to participate.[353] In this initiative, India is seen to leverage its outer space activities for distinct foreign policy goals.[354] In 2017, Afghanistan asked India to launch a separate satellite for its exclusive use.[355]

In 2017, members of BRICS agreed to build a Remote Sensing Satellite Constellation. The first phase would create a "virtual" constellation through a data-sharing system, with the potential to expand cooperation on a new EO satellite constellation.[356] The first substantive BRICS project in space cooperation is linked to the SDGs, environmental protection, and economic objectives.[357] Interest in cooperation extends to space science missions, telecommunications, and navigation systems.[358]

In 2017, Ethiopia announced its intention to build its own space launch vehicle and develop capabilities to build its own satellites, with minimum reliance on foreign partners, although cooperation with India is possible.[359] India and Portugal agreed to create a Space Alliance for advancing collaborative research.[360] India is also seeking greater cooperation with Israel on electric propulsion and optical communications.[361]

On 5 October, Saudi Arabia and Russia committed to cooperation on space exploration.[362] The UAE and Russia are reportedly discussing Russian training and transportation of Emirati astronauts to the ISS.[363] Russia also offered to integrate the UAE into its GLONASS satellite navigation service.[364] Turkey's new space agency is also expected to benefit from cooperation with Russia (see Indicator 2.2).[365]

The UN/Japan Cooperation Programme on CubeSat Deployment from the International Space Station Japanese Experiment Module (KiboCUBE), which helps educational and research institutions from developing countries launch cubesats, is ongoing. It aims to "lower the threshold of space activities" and "build national capacity in spacecraft engineering, design and construction."[366] The first satellite to be deployed under the program, First Kenyan

University Nano Satellite-Precursor Flight (1KUNS-PF) from the University of Nairobi, was launched from the Kibo module at the ISS in May 2018.[367] In 2017, UNOOSA and JAXA selected for the second deployment a team from the Universidad del Valle de Guatemala, which plans to use their cubesat to test equipment for monitoring the concentration of harmful cyanobacteria (algae blooms) over inland bodies of water.[368]

Ghana's first satellite, developed by students at All Nations University in Koforidua, was sent into orbit from the ISS. JAXA provided training and funds through the Birds project,[369] which also supported spacecraft developed by engineers from Bangladesh, Mongolia, Nigeria, and Japan.[370] A second round of launches is planned for satellites from Bhutan, Philippines, Malaysia, Kenya, Turkey, and Costa Rica.[371]

Developments in international cooperation on space resource extraction

In 2017, Luxembourg reached an agreement with the UAE Space Agency on collaboration and the exchange of information and expertise in the fields of space science, research, and technology. The UAE's national space policy alludes to the extraction of space resources as part of its future economic strategy.[372] Luxembourg also signed agreements with Japan and Portugal on resource management and commercial use of those resources,[373] and signed a joint statement with ESA on future asteroid missions and the exploration and utilization of space resources.[374]

Nascent modes of cooperation bridge geopolitical tensions

The 3rd China-U.S. Civil Space Dialogue on 30 November in Beijing included discussion on human and robotic space exploration and space-related multilateral mechanisms, such as the Charter on Space and Natural Disasters and UN COPUOS.[375] In December, the United States and China negotiated compatible signal characteristics that will protect and enhance GPS and equivalent Chinese system user services (see Indicator 2.1).[376]

U.S. law prohibits cooperation between NASA and Chinese government entities[377] but does not ban private sector agreements. In July 2017, SpaceX carried the first experiment independently designed and fabricated in China to the ISS. Chinese-American Leroy Chiao, former NASA astronaut and ISS commander, said, "I think this is a good step forward. I have always believed that cooperation is the best way forward for both the US and China, particularly using civil space exploration as an avenue."[378]

Indicator 2.4: Growth in commercial space industry

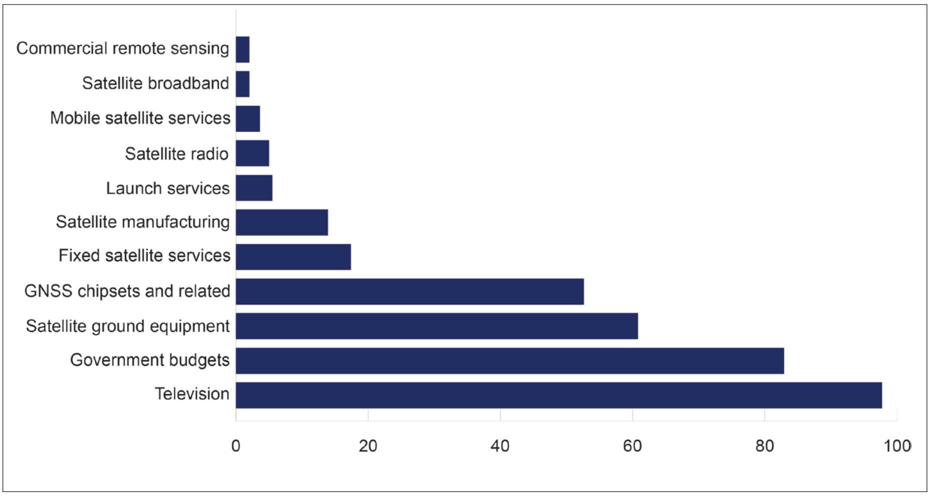
This section covers primarily activities that can be described as fully commercial—activities in which only private entities are involved in financing, decision-making, and management. Indicator 2.5 includes joint government-private ventures.

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 2016.[379] Revenues from the global satellite industry nearly tripled between 2004 and 2013 and reached $268-billion in 2017, most from satellite services.[380] The FAA reports that the global space industry took in approximately $345-billion in 2017, which includes government spending.

Figure 2.10 Global space economy revenues, 2017 ($-billions)[381]



The commercial space industry is becoming more global. Although Europe, Russia, and the United States are still dominant players, India and China have become more involved, with developing countries their prime focus.[382] 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.[383] India is also moving into commercial satellite manufacturing as part of its "Made in India" campaign.[384] 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.[385]

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.[386] Private investment in startup space ventures is growing substantially.[387] In 2017, 164 investors directed $2.5-billion into 73 startup space ventures in 77 deals, attracting nearly $1.6-billion in venture capital.[388] Most of this activity is based in the United States. Recipients include SpaceX, Spire, Planet, OneWeb, and Rocket Lab.

Figure 2.11 Investments in startup space, by type ($-millions)[389]

Investment type	2015	Change	2016	Change	2017
Seed/Prize/Grant	$268.4	56%	$419.7	30%	$546.5
Venture capital	$1,891.7	-15%	$1,602.8	0%	$1,596.6
Private equity	$143.0	-100%	$0	-	$0
Acquisition	$109.2	781%	$962.5	-63%	$360.0
Public offering	$14.0	-100%	$0	-	$0
Total investment	$2,426.3	23%	$2,985.0	-16%	$2,503.1
Debt financing	$371.2	-99%	$1.9	163%	$5.0
Total with debt	$2,797.5	7%	$2,986.9	-16%	$2,508.10

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.[390] Approximately 10 private companies engage in space transport, including SpaceX, created by Elon Musk, and Blue Origin, founded by 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 focus for private space investment. SpaceX has plans for a 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.[391]

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%.[392] 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 the SpaceX Falcon 9.[393] 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, to reduce launch costs.[394]

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.[395] 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.[396]

Small satellites, constellations, and new services

Innovative uses of small satellites and renewed proposals for constellations of satellites mark a new direction for satellite services, manufacturing, and launch.[397] Over 1,000 smallsats (mainly cubesats) were launched between 2012 and 2017.[398] Companies including OneWeb and SpaceX are planning massive constellations of small (and larger) satellites to provide new broadband Internet services and are attracting significant investment. In 2015, Google invested $1-billion in SpaceX.[399] New uses, including the potential to use smallsats in space to support decentralized blockchain services, are envisioned.[400]

The growth in data generated by new, affordable commercial space services is fueling the Big Data economy on Earth, which means that space is becoming more deeply integrated with the global economy through a greater variety of users and uses.[401]

Economic activity in space

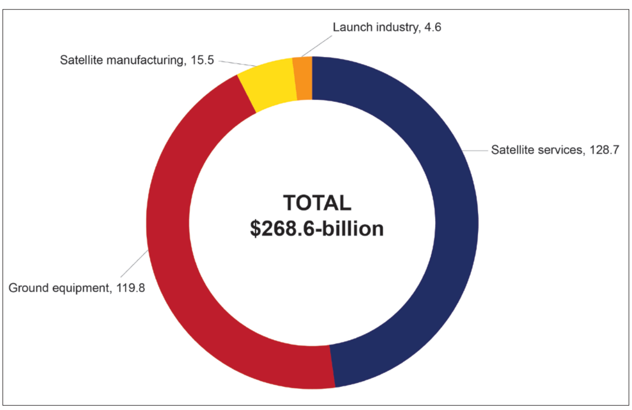
Private companies are developing business plans for new on-orbit commercial activities such as tourism. Bigelow Aerospace is developing an Expandable Activity Module, which will be attached to the ISS to support zero-gravity research, including scientific missions and manufacturing processes, and has potential as a destination for space tourism.[402] Capabilities for space-based manufacturing and spacecraft servicing are also slowly emerging (see also Indicator 3.2).[403] 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.[404] Financial and technical hurdles mean that mining asteroids remains "a long term endeavor."[405] A 2018 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 is to exploit lunar resources such as water. National governments support and incentivize much of this new activity (see Indicator 2.5).

2017 Developments

Telecommunications continue to dominate commercial space industry

Satellite services continue to dominate revenue in the satellite industry.

Figure 2.12 Satellite industry revenues, 2017 ($-billions)[408]



Satellite service industry	Revenue ($B)
Television	97
Radio	5.4
Broadband	2.1
Fixed	17.9
Mobile	4
Earth observation	2.2

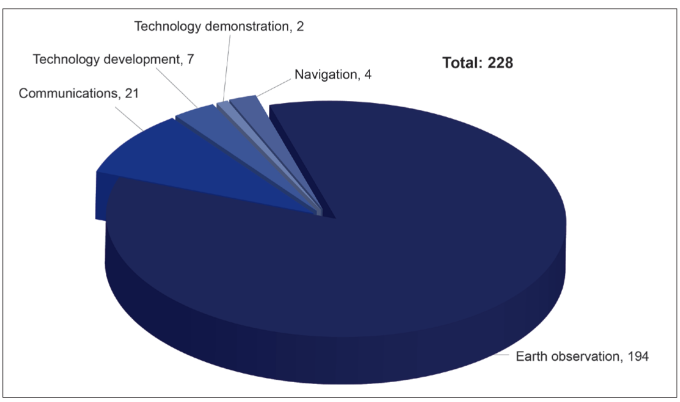
According to the Satellite Industry Association, in 2017,[409] revenue from satellite services grew by 1% and satellite manufacturing revenue by 10%. In contrast, launch industry revenue declined by 16%, with launch operators increasingly relying on less expensive launch services such as ridesharing (see below). Commercial satellites are overwhelmingly used for telecommunications, including television, radio, and broadband, as well as Earth observation.

In 2017, plans to deploy satellites shifted to using the highest LEO frequency or V-band spectrum, particularly to deliver broadband Internet services, because of the increased bandwidth available compared to more traditional LEO Ku- and Ka-band spectrums.[410] In January, Boeing applied to the U.S. FCC to deploy a constellation of V-band satellites. SpaceX, OneWeb, Telesat, O3b Networks, and Theia Holdings soon followed. Their intent is to complement services that use Ku- or Ka-bands; Canadian company Telesat will deploy a V-band constellation as a second-generation supplement to their Ka-band constellation.

The provision of Internet services enabled by a renewed commercial focus on satellite constellations in LEO marks a second significant shift within space-enabled telecommunications, serving a growing demand for data, particularly in underserved regions. Data-reliant technological advances such as artificial intelligence, virtual reality, autonomous cars, and the Internet of Things will also increase demand for bandwidth (see Indicator 1.2).[411]

Iridium Communications plans to replace its existing 20-year-old fleet of communications satellites with a constellation of 66 satellites in LEO, operating in L-band, to enable services such as global aircraft tracking and surveillance and a new global broadband service, Iridium Certus. Certus should provide service for aviation, maritime, and land-mobile industries, as well as a data link to other satellites in space. Service is planned to begin in early 2020. Forty second-generation NEXT satellites were launched in 2017.[412]

Figure 2.13 Commercial satellites launched by type, 2017 [413]



Plans for satellite constellations support new space-based services and big data

Large constellations of telecommunications and commercial smallsats have many possible uses, including data analytics, communication services, and Earth observation.

Figure 2.14 Non-geostationary orbit constellation applications to the FCC, March 2017 [414]

Company	Location	No. of satellites	Spectrum band	Services
SpaceX	Hawthorne, CA	7,518	V	Global broadband
SpaceX	Hawthorne, CA	4,425	Ka, Ku	Global broadband
Boeing	Seattle, WA	2,956	V	Advanced communications, Internet-based services
OneWeb	Arlington, VA	1,280	Ka, Ku, V	MEO Global broadband
OneWeb	Arlington, VA	720	Ka, Ku	First Generation LEO Global broadband
OneWeb	Arlington, VA	720	Ka, Ku, V	Second Generation LEO Global broadband
Kepler Communications	Toronto, ON	140	Ku	Machine-to-machine communications (Internet of Things)
Telesat Canada	Ottawa, ON	117	Ka	Wide-band and narrow-band communications services
Telesat Canada	Ottawa, ON	117	V	Wide-band and narrow-band communications services
Theia Holdings A, Inc.	Philadelphia, PA	112	Ka, V	Integrated Earth observation and communications network
Spire Global	San Francisco, CA	100	AIS, ASM, GNSS	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
O3b	Washington, DC	24	V	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

OneWeb LLC intends to provide global commercial broadband service. In 2017, OneWeb proposed adding almost 2,000 satellites to its initially planned constellation of 720, for which most capacity is already sold. Its satellite factory officially opened in Florida in March,[415] with the first launches scheduled for 2018.[416] SpaceX is expected to launch its first prototype in 2018.[417] The U.S. FCC intended to encourage competition by approving as many operators as possible.[418]

Planet is the current leader in Earth observation satellites. In 2017, approximately 20 companies raised roughly $600-million to build constellations to facilitate high-revisit EO data using smallsat or cubesat technology (see also Indicator 2.1)[419] A planned real-time Earth-imaging data package by UrtheCast and Beijing Space View will give customers multiple daily revisit capabilities. The partners signed a strategic cooperation agreement in 2017 to combine data from their space assets Deimos-1, Deimos-2, and the SuperView constellation.

China's Chang Guang Satellite Technology Co. also launched three remote-sensing video satellites, joining four EO satellites as part of the Jilin-1 constellation, which will be used to capture data for commercial customers to forecast and mitigate geological disasters and exploit natural resources. The new satellites are designed to take video with a resolution of approximately 1 m across a swath 11 km x 4.5 km. The company intends to build a constellation of 60 spacecraft by 2020 and 138 by 2030, which will allow it to observe any point on Earth within 10 minutes.[420]

The comprehensive coverage of Earth provided by constellations is expected to provide significant big data, which has innumerable commercial applications for value-added services, with a combined market potential of $15-billion, according to Euroconsult.[421] The EO data and services market enabled by smallsats technology has been evaluated as reaching $8.5-billion by 2026.[422] While defense customers dominate the high-quality data market, commercial infrastructure and natural resources customers dominate the services segment (see Indicator 2.5).

Artificial intelligence and machine-to-machine learning could further expand value-added services derived from space data.[423] In 2017, Orbital Insights and AllSource Analysis used their EO data to build algorithms to generate predictive analytics.[424] Applications could even emerge in the highly data-storage-reliant blockchain industry, particularly as demand for cryptocurrencies increases. Startups such as Spacechain plan to launch a cubesat to service the software, data storage, and backup requirements of cryptocurrency developers.[425]

Many other practical applications are enabled by space data.[426] In 2017, human rights monitors were able to map the Rohingya population in Myanmar;[427] researchers helped farmers estimate crop yields and improve agricultural productivity in sub-Saharan Africa (see also Indicator 2.1).[428]

On the other hand, problems such as orbital debris and interference will grow with the rising number of orbiting satellites, as will the need for regulation (see Indicators 1.1 and 1.2).[429] Uncertainty about the licensing price of bandwidth in some countries also makes it unclear which business models will thrive in the satellite telecommunications industry.[430] Mega-constellations remain untested.[431]

Small satellites and launchers drive increased access to space

Smallsats, weighing less than 600 kg, remained in high demand, driving further growth in the satellite launch market and facilitating more regular access to space. A record 335 smallsats were launched in 2017 (130 in 2016[432]); 87% were cubesats and 67% were for commercial use.[433] More cubesats were launched than in any previous year (see also Indicator 1.1).[434] Nearly half of the smallsats were Dove satellites built by Planet for its commercial EO system.[435] Smallsat technology is expanding access to space for academic and nonprofit uses: the number of such organizations to build smallsats quadrupled between 2012 and 2017.[436]

There is reportedly a backlog of small satellites waiting to be launched.[437] With only a few dedicated small launchers currently operational, the price to launch smallsats remains high. Price per kilogram of payload has historically been inversely proportional to the launch capacity of the vehicle, with larger launchers costing less.[438] While an Electron launch with

RocketLab costs $5-million, compared to $62-million for a SpaceX rocket launch, the starting cost to launch a single cubesat on Electron is still $77,000.[439]

Costs could go down with emerging competition between China and India. Following an announcement from China that it intends to cut launch prices to $5,000/kg, ISRO announced an intent to reduce its launch price to 10% of current prices.[440]

The more cost-effective option remains ridesharing on larger vehicles.[441] It has been argued that the record number of smallsat launches in 2017 is evidence that the secondary-payload market is able to accommodate near-term demand without additional dedicated smallsat launchers.[442] In February, 104 smallsats were launched onboard a single ISRO PSLV-C73 rocket in a record-breaking ridesharing launch.[443] However, secondary payload launches are not ideal for commercial service providers. The orbital schedule prioritizes the primary payload,[444] which could jeopardize the commercial viability of the small payload. Dedicated small launchers offer satellite operators more control over scheduling and orbital position, which will become increasingly valuable in creating and sustaining satellite constellations.

A more robust dedicated smallsat launch market is developing.[445] The U.S. FAA reports that more than 50 small launcher vehicles are at the concept stage.[446] Commercial small launch vehicles flight tested in 2017 include RocketLab's Electron vehicle and Vector's Vector-H. RocketLab considers smaller launch vehicles an emerging market.[447] The market is projected to reach $30-billion over the coming decade.[448]

Micro launchers operate in a perceived gap in the smallsat launcher market for payload capacities of less than 500 kg to LEO.[449] The first micro-launcher to LEO, the Orbital ATK Pegasus, was one of the most expensive vehicles in the launch market at the time.[450] Avio's Vega Light, announced in June, will be a mini-launcher for payloads weighing 250-350 kg.[451] It will share components with the Vega C and compete directly with launchers by Virgin Orbit and Rocket Lab, among others.[452] In March, Spanish startup Zero 2 Infinity conducted a test launch of the Bloostar prototype rocket; a stratospheric balloon lifted the launcher 25 km into the atmosphere before the primary engine was ignited.[453] Bloostar, sea-launched, will carry a payload of 100 kg into LEO on demand.[454]

Micro-launcher operators will need to make frequent launches to obtain economies of scale.[455]

Figure 2.15 Commercially available launch vehicles, 2017 [456]

Vehicle*	Company	Country	Est. $M per launch	Launch sites
Angara A5	VKS/Roscosmos/ILS	Russia	100	Plesetsk, Vostochny
Antares	Orbital ATK	US	80-85	MARS
Ariane 5	ArianeSpace	France	178	Guiana Space Center
Atlas V	ULA and LMCLS	US	110-230	CCAFS, VAFB
Electron	Rocket Lab	US	164-400	PSCA, Mahia,NZ
Falcon 9	SpaceX	US	61.2	CCAFS, VAFB, KSC
GSLV	ISRO/Antrix	India	47	Satish Dhawan
H-IIA/B	MHI Launch Services	Japan	90-112	Tanegashima
Kuaizhou 1/1A	EXPACE/PLA	China	3	Jiuquan

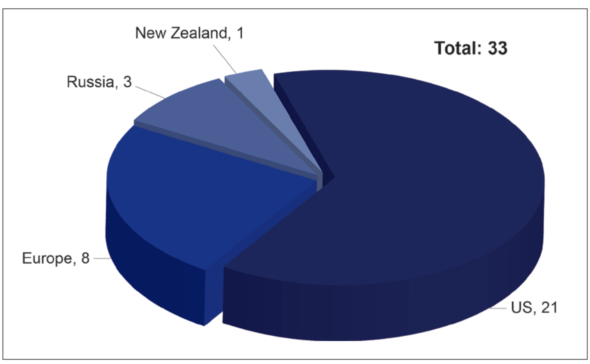
Vehicle*	Company	Country	Est. $M per launch	Launch sites
Long March 2D	PLA/CGWIC	China	30	Jiuquan
Long March 3A	PLA/CGWIC	China	70	Xichang
Long March 3B	PLA/CGWIC	China	70	Xichang
Long March 5	PLA/CNSA/CGWIC	China	Undisclosed	Wenchang
Long March 6	PLA/CGWIC	China	Undisclosed	Taiyuan
Long March 11	PLA/LandSpace	China	5.3	Jiuquan
LVM3	ISRO/Antrix	India	60	Satish Dhawan
Minotaur-C	Orbital ATK	US	40-50	CCAFS, MARS, VAFB, WFF
Pegasus XL	Orbital ATK	US	40	CCAFS, Kwajalein, VAFB, WFF
Proton M	VKS/Roscosmos/ILS	Russia	65	Baikonur
PSLV	ISRO/Antrix	India	21-31	Satish Dhawan
Rockot	VKS/Eurorockot	Russia	41.8	Plesetsk
Soyuz 2	VKS/Arianespace/GK Launch Services	Russia/France	80-85	Plesetsk, Guiana Space Center
Vega	ArianeSpace	France	37	Guiana Space Center

*Commercial status of the Dnepr and Zenit launch vehicles currently uncertain and not included here.

Reusability reduces cost of commercial launch service

In 2017, 90 orbital launches (33 commercial) were completed, an increase over 2016.[457] Twenty-one commercial launches were for U.S. companies, eight for European, and three for Russian; the New Zealand launch failed in orbit.[458]

Figure 2.16 Launches by commercial providers, 2017 [459]



More reusable components in launch vehicles reduce the cost of launches. SpaceX has led the way. In March, SpaceX completed the first reuse of its Falcon 9 rocket, using a previously landed first stage.[460] The first stage was recovered again after the second launch. In June, another booster was reflown.[461] Also in June, Blue Origin completed a fifth flight test of the New Shepard launch vehicle using the same engine and the same rocket; unlike the Falcon 9, this vehicle is designed for suborbital flights only.[462] In March, Blue Origin signed its first commercial customer for orbital launch vehicle New Glenn, which has a reusable first stage.[463]

Estimates suggest that a reusable Falcon 9 costs the customer between 21-40% less than a traditional launch, with some savings not passed on to the customer.[464] Comparisons of costs associated with national security launches in the United States using heavy launch vehicles by ULA (Delta Heavy) and SpaceX (Falcon Heavy) suggest that the latter costs at least 40% less.[465]

SpaceX dominated commercial launches in 2017 with a total of 18.[466]

Figure 2.17 Proposed commercial orbital launch vehicles[467]

Vehicle	Company	Country	Est. launch year	Projected orbit	Est. $M per launch
Alpha	Firefly Aerospace	US	TBD	LEO / SSO	10
Ariane 6	Arianespace	France	2020	LEO / SSO / GTO	94-117
Arion 2	PLD Space	Spain	2020	LEO	4.8-5.5
Bloostar	Zero2Infinity	Spain	2019	LEO / SSO	4
Cab-3A	CubeCab	US	2017	LEO / SSO	25
Falcon Heavy	SpaceX	US	2017	LEO / SSO / GTO	270
Haas 2C	ARCA Space Corporation	US	2018	LEO / SSO	Undisclosed
Intrepid 1	Rocket Crafters, Inc.	US	2018	LEO / SSO	5.4
Kuaizhou 11	EXPACE/PLA	China	2018	LEO / SSO	15 (est)
LS-1**	LandSpace	China	2018	LEO / SSO	Undisclosed
LauncherOne	Virgin Orbit	US	2017	LEO / SSO	10
New Glenn	Blue Origin	US	2020	LEO / SSO / GTO	Undisclosed
New Line 1	Link Space	China	2021	LEO / SSO	2.3-4.5
NGL	Orbital ATK	US	2021	LEO / SSO / GTO	Undisclosed
OS-M1	OneSpace	China	2019	LEO / SSO	Undisclosed
Proton Medium	VKS/Roscosmos/ILS	Russia	2018	GTO	<65
Soyuz 5	VKS/GK Launch Services	Russia	2022	LEO / SSO / GTO	50
Stratolaunch	Stratolaunch Systems	US	2018	LEO / SSO	Undisclosed
Vector R/H	Vector Space Systems	US	2018/2019	LEO / SSO	1.5-3.5
Vulcan	ULA	US	2019	LEO / SSO / GTO	85-260

Private actors continue projects for human spaceflight, lunar exploration

More private U.S. companies are engaging in the next generation of space exploration.[468] Commercial competition is seen to be beneficial because it attracts substantial private investment and lowers the cost of space access for civil actors. Along with efforts in the public-private NASA Crew program to deliver crew and cargo to the ISS and beyond (see Indicator 2.5), SpaceX, Blue Origin, and Virgin Orbital are pursuing projects to make space accessible to private individuals.[469]

In September, Elon Musk updated plans for the new SpaceX Big Falcon Rocket launch vehicle and spacecraft, which will replace both the Falcon Heavy and Falcon 9 and provide cargo and human delivery to the Moon and Mars.[470] SpaceX plans to send four cargo ships to Mars by 2024, two with crews, using the Big Falcon Rocket.[471] Blue Origin and Virgin Orbital are developing space vehicles for commercial suborbital flight. Blue Origin's New Shepard is expected to test its first human launch to an altitude of 100 km in 2018. Virgin Orbital plans to send tourists to the edge of space on a regular Gateway to Space flight, using a spaceplane rather than a vertical launcher.[472] Having already taken seven tourists to the ISS since 2001,[473] Russian company RSC Energia announced further plans to orbit tourists around the Moon and deliver them to the ISS. So far, private space tourism has not attracted much demand;[474] private spaceflight company XCOR Aerospace filed for bankruptcy in 2017.[475] SpaceX, however, announced that, by the end of 2018, it would send two private citizens around the Moon on the furthest human journey into space in more than 40 years.[476]

Moon Express is developing commercial landers to facilitate lunar exploration. It was expected to launch its first lander, the MX-1E, in 2017 to win the $20-million Google Lunar X Prize, but was unsuccessful and the prize went unclaimed.[477] The launch was rescheduled to 2018;[478] Moon Express is the first private company approved by the U.S. government to land on the Moon.

Novel space-based activities and services develop

NASA's 3D Printing In Zero-G Technology Demonstration project illustrated that a 3D printer works normally in space.[479] U.S. company Made In Space has demonstrated similar capabilities in a zero gravity environment on Earth.[480] Such a capability has a variety of applications, from building space habitation with Additive Manufacturing to space mining.[481] Printing in 3D in space could eliminate the need to launch tools from Earth.

The 3D printing of components for space vehicles and satellites on Earth is already beginning to dramatically reduce manufacturing costs and time and could drive down launch costs. SSL is using 3D printing combined with additive manufacturing to build satellites.[482] In July, new launch startup Relativity announced plans for orbital launches at costs significantly lower because of its 3D printing and automation capabilities.[483]

Space mining could substantially reduce launch costs for deep space exploration by reducing reliance on Earth-based resources, such as propellant. Mining water in space has applications for rocket fuel, oxygen, and drinking water, making water "the new oil in space."[484] Analysis suggests that the cost of space exploration could be cut by up to 75% through asteroid mining.[485] Consulting company Navitas Resources expects private companies to begin launching satellites to prospect for resources within the next five years and to begin mining within eight.[486]

In November, Planetary Resources announced plans to launch the Arkyd-6 infrared imaging satellite in a rideshare launch with ISRO.[487] Infrared imagery can determine potential resource targets. Shackleton Energy is proposing to mine ice water on the Moon, using in-space manufacturing applications.[488]

In-orbit servicing of satellites for repair or refuelling is emerging as a commercially available service. With technology advances, the market is "poised for growth," with a forecasted value of $3-billion over the next decade. Much of the value is expected to come from life-extension, but applications that repair, alter, deorbit, and even salvage could also be significant,[489] especially in sustaining satellite constellations.[490]

In June, DARPA announced an investment of $228-million in a partnership with Maxar Technologies' Space Systems Loral to produce an autonomous satellite-servicing vehicle.[491] Maxar simultaneously launched Space Infrastructure Services (SIS). Satellite operator SES then announced an agreement with SIS and global communications and information company MDA Canada, both members of the Maxar Technologies Group, for an initial satellite life-extension mission in 2021.[492] SES would be the first commercial customer of in-orbit servicing.

In December, the FCC approved the first part of Orbital ATK's satellite-servicing mission for Intelsat-901, a 16-year-old satellite in a graveyard orbit.[493]

Because the technology to service satellites is still largely untested and safety regulatory requirements are not clear (see Indicator 4.3),[494] satellite servicing is unlikely to increase significantly in the short term.

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 support research and development, subsidize certain space industries, and adopt 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."[495] Under Title IV—Space Resource Exploration and Utilization, 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. Luxembourg's Spaceresources.lu initiative of legislative and financial measures positions the country as a hub for businesses involved in the exploration and use of space resources[496] (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 has partnered with the private sector 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.[497] This program produced two families of launch vehicles: Boeing's Delta IV and Lockheed Martin's Atlas V. In 2006, Boeing and Lockheed Martin formed a joint venture: United Launch Alliance (ULA). 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.[498]

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.[499] NASA is currently working with SpaceX and Boeing on the Commercial Crew Program to provide human spaceflight to the ISS;[500] however, both the Dragon V and Starliner CST-100 spacecraft are behind schedule and not expected to fly to the ISS before 2019 or 2020.[501] 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.[502] NASA is also pursuing privatization of U.S. activities on the ISS by the mid-2020s, as it refocuses on deep space missions, which will also have private sector partners.[503]

Europe has a long partnership with its commercial space industry. Arianespace was founded in 1980 as the world's first commercial satellite launch company.[504] Its launcher, Ariane 5, commands half the global commercial launch market.[505] 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.[506]

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."[507] The USAF Space and Missile Systems Center's Hosted Payload Solutions Program will involve "hitchhiking" sensors into space on commercial satellites.[508] 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[509] and is exploring options for outsourcing maintenance of satellite-operating facilities to the private sector.[510] The U.S. DoD continues to purchase commercially available bandwidth.[511] In 2015, the National Geospatial-Intelligence Agency (NGA) released its Commercial GEOINT [Geospatial Intelligence] Strategy.[512] 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.[513]

In the October 2016 Space Strategy for Europe, the ESA and EU agreed to protect and develop their mutual interests in space.[514] A key goal is to keep the EU's private and public space industries competitive. China's "Made in China" initiative aims to increase "the profitability and efficiency of China's defense enterprises" and private sector participation in the state-dominated industry.[515]

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.[516]

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. ULA is working with Blue Origin to develop a domestically sourced BE-4 rocket engine,[517] and with Aerojet Rocketdyne Holdings to develop the AR1 engine,[518] but the ban on the Russian engine remains an ongoing concern.

The 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.[519] 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;[520] most U.S. commercial communications satellites were no longer considered defense articles subject to ITAR.

2017 Developments

National security interests continue to influence commercial space industry

Lobbying by the commercial space industry led to the adoption in 2017 of several changes related to Category XV (spacecraft and related articles) of the U.S. Munitions List, removing some space technologies from the most stringent export controls, including most remote-sensing and crewed spaceflight capabilities.[521]

The U.S. DoD finalized a list of geographic exclusion zones—areas that cannot be imaged—to prevent commercial shortwave infrared and nighttime imaging of military operations.[522] The list is part of a broader move to simplify and expedite the licensing process for commercial remote sensing; other efforts streamline interagency review and make the process more transparent.[523]

Following its accession to the Missile Control Technology Regime in 2016 and its designation as a Major Defense Partner of the United States, India now has much greater access to controlled technologies, including items for both military and dual-use purposes (see also Indicator 2.6).[524] In January 2017, the United States approved a more favorable licensing policy for the export of most controlled items to India and expanded the list of exemptions for eligible Indian entities.[525] For example, ISRO can now access previously controlled cryogenic technology for space launch purposes.[526] In 2017, an agreement was struck to launch a joint NASA/ISRO Synthetic Aperture Radar satellite on India's domestically developed GSLV rocket.[527] DARPA is also planning to launch small satellites for its EXCITE cellular satellite mission on Indian PSLV rockets.[528] The launching of these larger satellites, especially those with military functions, is seen by India as critical in the development and growth of its space industry.[529]

Reform of U.S. export controls facilitated the establishment of U.S. Rocket Lab's launch facilities in New Zealand in 2017. The Technology Safeguards Agreement signed by the United States and New Zealand categorizes regulated items of U.S. technology more broadly than does ITAR's Category XV.[530] The Agreement does not allow New Zealand to accept significant contributions of technology or data on controlled rockets from states that are not signatories to the MTCR without U.S. government approval.[531] There are also restrictions on the launching of foreign payloads on U.S.-controlled rockets without U.S. consent. Only 35 countries are MTCR members; non-members include China, Saudi Arabia, the UAE, Mexico, and Pakistan, as well as almost all African and Southeast Asian states. However, New Zealand's Outer Space and High-Altitude Activities Act gives it the power to license and regulate launch providers and the right to refuse payloads it believes are counter to national interest.[532]

National defense interests continue to restrict some commercial activities. U.S. access to Russian engine technology—namely, the RD-180 used in the EELV program for national security launches—remains contentious. Following events in Crimea in 2014 and subsequent U.S. sanctions on Russia, the U.S. Congress has waffled on whether to prevent or limit the ability of United Launch Alliance to purchase these engines.[533] Despite calls for a domestic replacement, it remains unlikely that any replacement will be operational before 2024-2025.[534] One possible alternative is the BE-4 engine being developed by Blue Origin for its heavy-lift New Glenn rocket, which started testing in October 2017.[535] Blue Origin claims that the rocket will "end [U.S.] dependence on Russian-built engines by 2019,"[536] but it is not clear that ULA will purchase it.[537]

Eight commercial satellites were removed from a 26 August rideshare launch on the Minotaur-4, leaving only government-owned satellites onboard. The commercial satellites, part of Spire's Lemur-2 cubesat constellation, were eventually launched on a different rocket.[538] It is possible that the satellites were removed because of the presence onboard of Orbital ATK's ORS-5 satellite, which is described as sensitive technology used to detect space junk and "aid military space situational awareness,"[539] or because the Minotaur rocket uses parts from ICBMs and U.S. policy forbids nongovernmental launches on such a rocket.[540] U.S. government agencies agreed to investigate the procedures around such mixed rideshare agreements and to clarify the rules for commercial operators.

China is developing policies to regulate its growing and ambitious commercial industry. The State Administration for Science, Technology, and Industry for National Defense is formulating Guidelines for the Development of Commercial Space Activities in China; it serves the needs of national defense, military forces, national economy, and military-related organizations.[541] CNSA is creating Regulations on the Administration of Export of Space Products.[542]

Government efforts support national space industries

China

The Chinese government is investing in its nascent domestic commercial space industry.[543] It has also made technology available to private space launch companies OneSpace, Exspace, and LandSpace. OneSpace is developing new launch capabilities, beginning with the suborbital OS-X, a ballistic missile with a sounding rocket payload, which is a response to a national civil-military integration strategy to provide flight test services for research purposes.[544] ExSpace, a quasi-private commercial space company started by China Aerospace Science Industry Corporation, plans to begin launching rockets in 2018;[545] they aim to achieve a launch cost of $10,000/kg for commercial satellite launches (see also Indicator

2.4). LandSpace, started by veterans from China's space program, uses already extant Chinese technology for their launches, with the first launch planned for 2018. In 2017, LandSpace became the first Chinese commercial space company to secure a contract with a foreign company; Gomspace, a Danish surveillance and communications nanosatellite manufacturer, has contracted to put satellites in orbit onboard the LandSpace-1 rocket in 2018.[546] China is also developing national guidelines to regulate its emerging space industry (see Indicator 4.1).

Russia

The formation of the state-owned Russian Venture Company represents an effort by the Russian government to invest in private companies to "widen the bottleneck in Russian Aerospace," according to Director Andrei Vvedensky. The company partners with private industry to fund startups and foster a commercial space industry in Russia.[547] Russia's Skolkovo Innovation Center, established in 2010, encourages startups in five fields, including space technologies.[548] In 2017, it signed an agreement with established company Russian Space Systems to support resident startups and help commercialize their products. Areas of cooperation include the GLONASS satellite navigation system, space search-and-rescue systems, and remote-sensing ground stations.[549] Also coming from the Skolkovo program, Sputnix, a manufacturer of microsatellite parts, signed an agreement in 2017 to cooperate with the Far Eastern Federal University to develop joint research, educational programs, and seminars, and to use the Vostochny Cosmodrome.[550] On 14 July, Russia launched two satellites constructed by Dauria Aerospace, a partner in the Skolkovo program,[551] for Roscosmos—a first in public-private partnerships in the country.[552]

India

ISRO supports technology transfers to a selection of companies for such critical hardware as rocket engines and satellite components and is subcontracting more of its work.[553] In November, the Indian government introduced the Space Activities Bill 2017 to allow private-sector companies to build satellites, rockets, and satellite subsystems;[554] it includes measures to regulate commercial space activities (see Indicator 4.1).[555] This bill supports IRSO's plans to double indigenous satellite launches by 2020, partly by privatizing their PSLV launch vehicle.[556] ISRO also aims to have 30 of its own satellites built by private firms over the next five years, approximately half of the total planned launches.[557]

UK

By August 2017, 26 proposals had been submitted in response to a government call for proposals to support small satellite launch and suborbital flight.[558] In June, the United Kingdom introduced the Space Industry Bill, which will allow the issuing of licenses and regulate activities involving spaceplanes, satellites, and spaceports, creating a "framework for liability, indemnities and insurance for UK space activities."[559] The Bill became law in March 2018.[560] The U.K. intends to establish an operational commercial spaceport by 2020. [561]

Europe

Public-private partnerships created in 2017 include an $81-million deal with ViaSat, funded by ESA, Switzerland, Romania, and the Netherlands, to develop broadband connections in homes, aboard planes, and in cars.[562] ESA supports 140 startups each year, with 88% of them still in business as of November 2017.[563] It also supports initiatives to give greater access to the ISS, through projects like ICE Cubes, which will allow commercial operators on

Earth to interact with experiments aboard the ESA's Columbus module.[564] The ESA Grand Challenge, issued in February 2017, encouraged innovators in both science and industry to submit ideas relating to space mining, cybersecurity, space for people with physical disabilities, and autonomous vehicles.[565] It is part of a growing development to open up participation in space to non-space industry, as well as the wider public (see Indicator 4.3).

Leveraging the private sector for next-generation space exploration and technology

The private-public Commercial Crew Program is critical to NASA's future ability to send astronauts to the ISS. In May 2017, Sierra Nevada Corporation's Dream Chaser spacecraft passed Milestone 3, with NASA approving safety and hazard reports.[566] In November, the Dream Chaser completed an atmospheric flight test, navigating a preplanned flight path and successfully completing an autonomous landing in California.[567] The Dream Chaser is scheduled to begin flying in 2019.[568] NASA purchased four additional Crew Rotation Missions from Boeing and SpaceX in 2017, with each company booked for six missions to fly NASA astronauts to and from the ISS through 2024.[569] However, both SpaceX and Boeing experienced delayed crew tests in 2017,[570] raising questions about the feasibility of flight tests anticipated for 2018. NASA is already using private-sector space vehicles for robotic resupply missions to the ISS. This activity is transforming NASA's Kennedy Space Center into a "multiuser spaceport" that includes commercial investment.[571]

A joint NanoRacks/Boeing project will install a commercial airlock on the ISS.[572] The Bigelow Expandable Activity Module, already installed on the ISS, is providing valuable data on expandable habitats, radiation dosage, and the space environment.

In February, NASA announced a new funding vehicle that will support eight U.S. companies in advancing small spacecraft and launch vehicle technologies that are nearing maturation and could benefit NASA and the commercial space market. ExoTerra is looking at solid iodine as a fuel source for secondary payloads; HRL Laboratories is developing high-temperature materials for launch vehicles and their engines; Masten Space Systems is developing a low-cost engine.[573]

The NASA Transition Act, passed in March, includes measures to encourage NASA to consider servicing and maintenance operations for spacecraft and satellites to increase their longevity, while also supporting the burgeoning commercial spacecraft servicing industry.[574] Public support for private satellite servicing capabilities can be seen in the SSL/NASA Restore-L project to service LEO satellites, including those not originally designed for refueling and servicing, by 2020[575] and SSL's project with DARPA to service satellites in GEO (see also Indicator 3.2).

China is seeking to apply the skills of their burgeoning private sector in space exploration. CNSA Secretary General Tian Yulong has acknowledged the value of the participation of small and medium enterprises in deeper space exploration.[576]

Public investment in future commercial activities in space

Luxembourg is replicating its earlier model to attract private space industry through investments by its Luxembourg Future Fund to lead in asteroid mining. It will invest $238-million in space resources initiatives, including U.S.-based Deep Space Industries and Planetary Resources, both of which intend to mine asteroids and have established headquarters in Luxembourg. Agreements with Germany's Blue Horizon (a "life sciences company") and Japan's Lunar X prize team show an early commitment to diversified space technologies.[577] Luxembourg has also invested in more conventional space companies like Spire, which has agreed to establish its European headquarters in Luxembourg in return for a $70-million investment.[578] Luxembourg has committed to establishing a space agency that will be set up as a public-private company to support commercial use of space resources[579] and is adopting a national regulatory framework to support it (see Indicator 4.1).

Middle East states, particularly Saudi Arabia and the UAE, are investing in the next-generation resource economy[580] and have expressed interest in building a commercially viable space mining economy.[581] The UAE's state investment vehicle bought a 32% stake in Virgin Galactic for $280-million in 2017 and offered an extra $100-million to construct a spaceport in Abu Dhabi and finance the launch of a series of small satellites.[582] In October, Saudi Arabia invested approximately $1-billion, split among Virgin Galactic for space tourism; the smaller Virgin Orbit, which intends to launch satellites from planes; and Spaceship Co., which is building propulsion systems and the space plane and carrier aircraft for Virgin Galactic.[583]

Commercial capabilities continue to support national security and militaries

The U.S. DoD is under increasing pressure to use available and affordable commercial services instead of developing its own, more costly satellites. It currently uses approximately 5% of the world's commercial bandwidth; the United States is the single largest purchaser of commercial satellite bandwidth in the world.[584] In March, the DoD announced that it was investigating the leasing of communications satellites through the Wideband Communications Services Analysis of Alternatives,[585] which will determine whether the United States could be better served by a commercial satellite communications network. Factors under consideration include the speed at which damaged or destroyed satellites can be replaced, the resilience of the network, and the suitability of the range of options available to operators.[586] A 2017 Task Force on Military Satellite Communication and Tactical Networking included a recommendation to "leverage and utilize existing/evolving commercial communication satellites systems."[587]

Speedcast currently provides Australia, New Zealand, and the Philippines with military communications, while PlanetComm covers Thailand's secure communications. In May, Airbus acquired PlanetComm and added it to their Skynet-5 communication services, which are offered partially through a partnership with Speedcast.[588] Airbus provides communications and satellite access to the UK Ministry of Defence, which in turn allows access to all NATO and Five Eyes countries.

The use of commercial remote-sensing data is growing, with the market estimated to reach between $8.5-billion and $15-billion by 2026. The main buyers are expected to be governments, particularly for defense functions.[589] The Chinese government and military are the main customer for the commercial remote-sensing Jilin constellation operated by China's Chang Guang Satellite Technology Co.[590] The UK military is investing in a commercial program by Surrey Satellite Technology to test the use of constellations in LEO for tactical intelligence gathering (see Indicator 2.6).

The United States operates 175 DoD satellites and computer systems that link 150 communications satellites, including those used for NATO. Growing cyber-vulnerabilities of space systems led the United States to request information on industry capability to enhance defensive cyber operations.[591] A request for information to "conduct market research to assess industry capability for the Cybersecurity and Defensive Cyberspace Operations (DCO) for 50 SW Space Mission Systems to enable protection, detection, response, and sustainment of 50th Space Wing cyber defense missions" was issued in May.[592]

Indicator 2.6: Space-based military systems

The space age broke new ground in intelligence, surveillance, and reconnaissance systems by using 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 global navigation satellite systems such as GPS, which provided increasingly accurate geographical positioning information. Building on these capabilities, the United States began to expand the tactical role of military space systems; it now 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 2018, the United States operated 128 dedicated military satellites, in addition to 31 GPS satellites.[593]

Figure 2.18 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. By 2015, the Space-Based Infrared System (SBIRS) missile warning program begun in 1996 was more than 300% over budget and a decade behind schedule;[594] it will be augmented by and eventually replaced with a next-generation system.[595] The next-generation GPS III system is now more than five years behind schedule;[596] delays risk capability limitations as the previous system ages. 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 United States is reorienting its military organization and capabilities to maintain core military functions in the event of warfare in outer space. A 2015 initiative created a Space Mission Force to train military satellite operators to operate in contested environments,[597] while the Space Vision Enterprise established a blueprint for fighting wars in space with a focus on resilience (see also Indicators 3.2 and 4.1).[598] An increased focus on the space domain includes planned spending of up to $8-billion over the next five years.[599]

The 2015 National Defense Authorization Act mandated development of a concept for a space-based ballistic missile intercept component, with emphasis on fielding improved sensors, but also a study of options to eventually deploy space-based interceptors. The goal is to contribute to boost-phase missile defense or "defensive options against direct ascent anti-satellite weapons, hypersonic glide vehicles, and maneuvering reentry vehicles."[600] Support has continued in subsequent years. However, numerous assessments since the concept was first promoted 30 years ago have pointed to both high costs and technical challenges.[601] The presence of space-based interceptors, if developed, would also counter a long-standing norm against orbiting weapons in outer space (see Theme 4).

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.[602] 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.[603] Since 2004, Russia has worked on "maintaining and protecting" its fleet of satellites and developing satellites with post-Soviet technology.[604] 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.[605] The Russian space budget rose again by up to 144% between 2008 and 2013.[606] But, both investment and satellite launches have decreased in recent years. With 59 dedicated military satellites as of January 2018, in addition to 29 GLONASS navigation satellites,[607] 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, including civilian satellites, were assigned to conduct imagery and radar reconnaissance in Syria.[608]

China's space program is dedicated to science and exploration, but, like programs of many other actors, it also provides 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.[609] The major military restructuring that China announced in December 2015 includes combining its space, cyber, and electronic warfare forces into a new Strategic Support Force—an approach that China believes will better enable it to synergize these capabilities and improve its ability for information dominance in warfare.[610] The BeiDou regional navigation system was originally designed to enable China to maintain navigational capability if the United States were to deny GPS services in times of conflict;[611] it has since evolved into a global, full-service system. BeiDou may also improve the accuracy of China's intercontinental ballistic missiles and cruise missiles.[612] The Union of Concerned Scientists database lists 48 of China's satellites as primarily military, operated by the People's Liberation Army, in addition to 23 BeiDou navigation satellites.[613]

Recently, India has been more open about its military space capabilities. India's National Satellite System is one of the most extensive domestic satellite communications networks in Asia. India is also nearing completion of its own Indian Regional Navigation Satellite System, an ISRO initiative to develop independent satellite-based navigation capabilities.[614] Civilian-developed and -controlled, these technologies are used in Indian military applications. The Cartosat-series of remote-sensing satellites are generally considered dual-use. 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.[615] Plans continue for the creation of a cross-service Defence Space Agency as an element of an integrated Cyber, Aerospace, and Special Operations Command.[616]

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.[617] The plan prioritizes space-based navigation, communications, and reconnaissance capabilities[618] and emphasizes cooperation with other countries, specifically the United States.[619] In early 2015, Japan launched two new reconnaissance satellites: a synthetic aperture radar satellite[620] and an optical imaging satellite.[621]

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

In Europe, several ESA projects, including Galileo and Sentinel, have dual-use applications. European defense agencies have expressed growing interest in using ESA satellite data.[622] In 2016, the European Commission published the Space Strategy for Europe, which promotes synergies between civilian and security activities.[623] European states also 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.[624] France and Italy cooperate on the provision of military broadband service.[625]

Within the next decade approximately 50 countries are expected to have Earth imaging capacity; a study of civil space capabilities for military purposes by non-Western states found that most use satellites for dual commercial/civil and military purposes.[626] However, more states in Asia, the Middle East, and Latin America are acquiring dedicated space-based military capabilities.

Cooperation is extending to military and space-based capabilities through existing alliances and strategic relationships. 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.[627]

In September 2014, the Combined Space Operations Memorandum of Understanding was signed by the United Kingdom, the United States, Canada, and Australia;[628] 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."[629] The United States is also extending cooperation with India and Japan. The first meeting of the United States-India Space Security Dialogue[630] and the first United States-India Strategic and Commercial Dialogue occurred in 2015.[631] The revised Guidelines for Japan-U.S. Defense Cooperation, released in 2015, included cooperation in space programs, such as "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."[632]

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) and investment in counterspace capabilities (see Theme 3). The deployment of space-based interceptors would also mark a breach of this traditional interpretation and use.

2017 Developments

U.S. military reorganization linked to possible extension of war into space

In 2017, U.S. military space organizations, especially the USAF, were motivated to make reforms[633] by the growing possibility of warfare in outer space, advancing military capabilities by Russia and China (see below), and a shift among major space powers toward multidomain warfare—integrating space, air, and cyber capabilities.[634] According to high-level defense officials, modern space organizations require more funding, streamlined acquisition of new technologies, improved resiliency, and preparations for conflict in space.[635]

The Joint Interagency Combined Space Operations Center was renamed the National Space Defense Center (NSDC)[636] to better reflect its purpose, "to defend and secure the space domain."[637] The NSDC is the core of what is called a Space Warfighting Construct, revealed in April by Air Force Space Command (AFSC) head General Raymond. This command-and-control structure is built on the growing closeness between the AFSC and the National Reconnaissance Office (NRO), believed essential to winning a war that extends into space.[638]

The Space Warfighting Construct is a framework for operationalizing the Space Enterprise Vision created in 2015.[639] The Construct is based on a series of new, integrated Concepts of Operations for warfighting in space that are being developed by the USAF and the NRO[640] to document how the United States expects to "achieve synchronized planning and integrated operations in order to protect and defend the national security space enterprise."[641] This vision of space as a warfighting domain has led to the development of a Battle Management Command and Control system to enable "operational commanders to simultaneously maneuver space assets and direct defensive operations against multiple threats while maintaining space effects for the warfighter."[642]

The uncertainty about future responsibility for military space operations can be seen in congressional struggles in 2017 over a proposal in the 2018 defense budget by the House

Strategic Forces Subcommittee to create a Space Corps, a separate branch of the armed services within the Air Force dedicated to space as a domain of warfare.[643] This plan was opposed by the Air Force, DoD, the White House, and the Senate.[644] Although it was not included in the final version of the FY2018 National Defense Authorization Act, the issue could be raised again.[645] The NDAA mandates the elimination of the position of Principal Defense Space Adviser, created in 2015, and consolidates authority for personnel, operations, and acquisitions for all Air Force space forces under the Air Force Space Command.[646]

Funding and hardware to modernize U.S. military space capabilities

The USAF controls roughly 90% of U.S. military space programs, not including those by the National Reconnaissance Office; in 2017, it requested $7.7-billion (a 20% increase) for space systems,[647] primarily for space superiority, space support to operations, and assured access to space. Research and development of new technologies account for $3.4-billion.[648]

New programs in the funding request included the joint space operations center mission system, electro-optical infrared weather surveillance, protection for tactical satellite communications (see Indicator 3.1), a space surveillance telescope (see Indicator 1.4), modernizing the missile warning constellation, and more secure GPS signals. The request emphasized commercial providers, particularly for communications, but also for hardware such as cubesats (see Indicator 2.5).[649]

Several spacecraft were launched in 2017 to upgrade existing capabilities, particularly reconnaissance. The NRO launched a series of classified satellites, including NROL 42,[650] NROL 52,[651] NROL 76,[652] and NROL 79.[653] NROL 42 is believed to be the second Trumpet-Follow-On-2 signals intelligence satellite operating in a highly elliptical orbit to complement other SIGINT spacecraft in GEO.[654] NROL 52 is thought to be a fourth-generation Space Data System satellite, used to relay data from intelligence-gathering satellites in real time.[655] NROL 76 appears to be carrying out a technology demonstration mission (see Indicator 3.4),[656] while NROL 79 may be part of the third generation of the Naval Ocean Surveillance System.[657]

The ninth Wideband Global SATCOM satellite (WGS-9) was launched aboard a ULA Delta IV rocket to provide allied military communications capabilities for attack prevention, protection, and response.[658] WGS-9, which supports the existing WGS network in carrying broadcasts of video, image, and other high-bandwidth data, is funded by a consortium of nations, including the United States, Canada, Denmark, Luxembourg, the Netherlands, and New Zealand.[659]

The fifth Mobile User Objective System (MUOS-5) was brought online to provide secure UHF communications for legacy equipment to support Navy mobile forces.[660] Other launches include the SBIRS GEO-3 satellite launched in January to supplement the early warning constellation; it was joined by the HEO-4 elliptical orbit payload in September.[661] The ORS-5 (SensorSat) satellite was launched to an equatorial low Earth orbit, with a mission to monitor debris and orbital activity in GEO (see Indicator 1.4), as was the X-37B spaceplane (see Indicator 3.4).

The U.S. Army launched the Kestrel Eye electro-optical technical demonstration microsatellite from the ISS airlock to pursue near-real-time situational awareness and battlefield imagery.[662] Orbital ATK was awarded $78-million under the Air Force Space

Test Program STPSat-6. The primary payload, to be launched in 2019, will be a Space and Atmospheric Burst Reporting System (SABRS), designed to detect nuclear explosions and collect data on space weather.[663]

In August, it was announced that the Defense Meteorological Satellite Program (DMPS) Flight 19 would end operational service after 3.5 years because of a power failure. The satellite provided tactical weather and atmospheric data to the DMSP mission.[664] In November, Joint Polar Satellite System-1 was launched to provide global weather observations.[665]

A May 2017 GAO report showed that many projects to modernize existing systems and develop new capabilities for warfighting have experienced significant cost increases and scheduling delays.[666] The cost of the AEHF satellite communications program increased by 118%, with the first spacecraft launched three years late. The SBIRS for missile early warning incurred a 300% cost overrun and arrived nine years late, while the upgraded GPS III ground control system (OCX) is currently "5 years behind schedule."[667]

Figure 2.19 U.S. dedicated military satellites launched in 2016[668]

Satellite name	Operator	Primary function	Orbit	Launch date
DHFR	DARPA	Technology Development	LEO	2017-08-26
Improved Trumpet 7	National Reconnaissance Office	Earth Observation	Elliptical	2017-09-24
KestrelEye IIM	SMDC / Army Forces Strategic Command	Earth Observation / Technology Development	LEO	2017-10-24
NROL-76 (USA 276)	National Reconnaissance Office	Technology Development	LEO	2017-05-01
ORS-5	USAF / Operationally Responsive Space Office	Technology Demonstration	LEO	2017-08-26
Prometheus 2.3	Los Alamos National Laboratory	Technology Development	LEO	2017-08-26
Prometheus 2.4	Los Alamos National Laboratory	Technology Development	LEO	2017-08-26
SBIRS GEO 3	U.S. Air Force	Earth Observation	GEO	2017-01-20
SB-WASS 3-8	National Reconnaissance Office / U.S. Navy	Earth Observation	LEO	2017-03-01
SB-WASS 3-8	National Reconnaissance Office / U.S. Navy	Earth Observation	LEO	2017-03-01
SDS IV-2	National Reconnaissance Office / USAF	Communications	GEO	2017-10-15
SHARC	Air Force Research Laboratory	Technology Demonstration	LEO	2017-05-18
Wideband Global Satcom 9	USAF	Communications	GEO	2017-03-17
X37-B OTV-5	USAF Rapid Capabilities Office	Technology Development	LEO	2017-09-07

Growing focus on space for U.S. missile defense

Ballistic missile defense, especially space-based sensors for missile early warning and tracking,[669] gained importance as the DPRK's nuclear and missile program escalated in 2017 (see Indicator 3.3).[670] The FY2018 NDAA directed the Missile Defense Agency to develop both a persistent space sensor architecture for detection, tracking, and kill assessments of threats, as well as an intercept layer to respond (see Indicator 3.4).[671] In May, Lockheed Martin was awarded nearly $46-million to build two SBIRS missile warning satellites.[672]

China investing in military space capabilities to advance regional interests

In 2017, China's defense budget increased by as much as 8% to 1.04 trillion yuan ($153-billion).[673] Much effort is being put into improving technology and advancing logistics capabilities, including space launch, satellite communication and navigation, robotics, and improved ground infrastructure.

China continued to develop its Strategic Support Force, which integrates space, cyber, and electronic warfare capabilities,[674] including command and control, communications, computers, intelligence, surveillance, reconnaissance, and counterspace (see Indicators 3.1 and 3.4).[675] This force has been characterized as a Chinese center for research and development, tasked with 'leapfrog' technological developments.[676]

Much of China's space activity has a regional focus, particularly the geopolitically sensitive South China Sea. New satellite launches in 2017 augmented the BeiDou Navigation System (see Indicator 2.1), which supports surveillance, reconnaissance, and joint operations across the globe for both military and civilian users.[677]

Communications

On 5 February, CNSA launched Tongxin Jishu Shiyan Weixing (Communications Technology Experiment Satellite) 2, a "communications technology test satellite" developed by the China Aerospace Science and Technology Corporation.[678] It appears to have a military function.[679] A similar satellite, launched in 2015, is thought to test Ka-band communications technology.[680]

Remote sensing and AIS

On 15 June, Zhuhai Orbita Control Engineering Ltd.'s OVS-1A and OVS-1B, the first two satellites of the Zhuhai-I remote-sensing micro-nano satellite constellation, were launched. According to the Beijing Institute of Space Science and Technology Information, they are expected to improve the monitoring of geographical, environmental, and geological changes in China and have the ability to view more than 85% of the world's population.[681] Both satellites feature a high-resolution video system capable of capturing 20 frames per second and reaching a 1.98-m ground resolution.[682] They could support military applications.

In December, China covertly launched two high-resolution LKW Land Survey Satellites, which are thought to have military reconnaissance functions. Built by the China Academy of Space Technology, these satellites seem to be linked to the Yaogan reconnaissance satellite constellation,[683] marking a technology shift. Launches for the commercially operated Jilin satellite system also provide dual-use military support (see Indicators 2.4 and 2.5).

Plans include launching three optical remote-sensing satellites in 2019. By 2021, three optical satellites, two hyperspectral satellites and two synthetic aperture radar satellites will be launched to complete the constellation,[684] which is intended to provide scientific support for the 21st Century Maritime Silk Road and emergency response efforts at sea, but could also support military reconnaissance.

Signals intelligence

Nine Yaogan-30 satellites built by the Chinese Academy of Sciences' Small Satellite Center were placed in orbit by three launches on 29 September, 23 November, and 25 December. These satellites are believed to provide intelligence-gathering support, with signals-interception capabilities that can detect ships by their radio emissions.[685] Officially, they are conducing "electromagnetic probes and other experiments."[686]

Experimental

On 5 March, the small experimental satellite Tiankun-1 (TK-1) was launched on a KT-2 rocket from the Jiuquan space center.[687] Its launch from a military-controlled center may indicate a military function.[688] It is the first satellite developed by China Aerospace Science and Industry Corporation and will be used for remote sensing, telecommunications, and experiments in mini-satellite-based technologies, using the new minisatellite bus developed in 2014.[689]

Figure 2.20 Chinese dedicated military satellites launched in 2017[690]

Satellite name	Operator	Primary function	Orbit	Launch date
LKW-1	People's Liberation Army	Earth Observation	LEO	2017-12-04
LKW-2	People's Liberation Army	Earth Observation	LEO	2017-12-22
NUDTSat	National University of Defence	Earth Science	LEO	2017-06-23
Yaogan 30-1-1	People's Liberation Army	Earth Observation	LEO	2017-09-29
Yaogan 30-1-2	People's Liberation Army	Earth Observation	LEO	2017-09-29
Yaogan 30-1-3	People's Liberation Army	Earth Observation	LEO	2017-09-29
Yaogan 30-2-1	People's Liberation Army	Earth Observation	LEO	2017-11-26
Yaogan 30-2-2	People's Liberation Army	Earth Observation	LEO	2017-11-26
Yaogan 30-2-3	People's Liberation Army	Earth Observation	LEO	2017-11-26
Yaogan 30-3-1	People's Liberation Army	Earth Observation	LEO	2017-12-25
Yaogan 30-3-2	People's Liberation Army	Earth Observation	LEO	2017-12-25
Yaogan 30-3-3	People's Liberation Army	Earth Observation	LEO	2017-12-25

Russia prioritizes military space capabilities, but few satellites launched

While Russia's defense budget decreased in 2017 by approximately 5% to 2.8-trillion rubles ($41-billion) the effect on military space programs, particularly new acquisitions, is unclear.[691] Russia is reportedly prioritizing the modernization of space assets, particularly communications, navigation, EO systems, electronic intelligence, and early warning. The low number of spacecraft launches in 2017 can be attributed to decreased spending and the unreliability of launch vehicles.[692]

Launch vehicles

In April, the Russian Defense Ministry announced that it would further develop the infrastructure of the Russian spaceport Plesetsk to increase the number of annual military, civilian, and dual-use space launches.[693] A secret military satellite was launched from the spaceport in June, using a modified version of Russia's Soyuz rocket.[694] In August, it was announced that Roscosmos and the Russian Ministry of Defense would likely cooperate to complete construction of the launch pad at Vostochny Cosmodrome for the new Angara heavy-lift carrier rockets, which will have military and civilian functions. That month, it was announced that the first technological equipment for the launch of the Angara heavy-lift carrier rocket had been delivered to the Vostochny Space Center.[695]

Communications

On 16 August, Russia's Aerospace Forces launched military satellite Cosmos-2520.[696] The Ministry of Defense identified it as the first Blagovest No. 11L military communications satellite.[697] It may be the first Russian satellite operating in Q-band as well as Ka-band.

Electronic and signals intelligence

In January, Defense Minister Sergei Shoigu stated that Russia continues to develop the Liana Electronic Intelligence Program, using Lotos-S and Pion-NKS satellites. These new radio surveillance satellites are intended to replace Soviet-era spy satellites.[698] The second Lotos-S signals intelligence satellite was launched on 1 December.[699] The first Pion satellite has not yet been launched. Russia's Defense Ministry expects the program to be completed in 2018.[700]

Missile warning

On 25 May, the Russian Aerospace Forces launched Cosmos-2518,[701] the second of six EKS missile early warning satellites.[702] Part of the Tundra family of launch detection spacecraft, it is intended to replace aging early-warning infrastructure. It will detect the launch of any intercontinental ballistic missiles during the boost phase of flight.[703]

Reconnaissance

In May, Russian President Vladimir Putin announced that Russia intends to operate 15 more remote-sensing satellites by 2020, specifically noting their usefulness for defense and security.[704] The Cosmos 2519 spacecraft launched on 23 June might be a classified remote-sensing satellite, but reports of its mission are conflicting. Prior to launch it was thought to be a geodetic satellite designed to take accurate measurement of Earth's shape and gravitational field, which could be used to provide ballistic missile guidance.[705] Subsequent orbital data conflicts with this description, but may support later claims by the Russian Defense Ministry that it would be used for remote sensing of Earth.[706]

Experimental

In August, an orbital "Inspector Satellite" separated from satellite Cosmos 2519 (see Indicator 3.4).[707]

Figure 2.21 Russian dedicated military satellites launched in 2017[708]

Satellite name	Operator	Primary function	Orbit	Launch date
Cosmos 2519	Ministry of Defense	Space Observation	LEO	2017-06-23
Cosmos 2519 Subsatellite	Ministry of Defense	Space Observation	LEO	2017-06-23
EKS-2	Ministry of Defense	Earth Observation	Elliptical	2017-05-25
Lotos-S1	Ministry of Defense	Earth Observation	LEO	2017-12-03

Continued development of joint and independent military capabilities in Europe

Following the 2016 adoption of the EU Global Strategy for Foreign and Security Policy, 23 of the 28 EU Member States signed a common notification on the Permanent Structured Cooperation on security and defense (PESCO) on 13 November. PESCO is a joint military program that invests in equipment, research, and development. While no specific statements have been made about space, this program could have implications for space-based military cooperation.[709]

The European Commission is allocating €13-billion ($15-billion) over seven years (2021-2027) to the European Defence Fund, which might indicate further investment in military space capabilities.[710]

The European Defence Agency, in partnership with the European Commission and ESA, continued to develop the GOVSATCOM (Governmental Satellite Communications) program to provide member states with access to secure, dual-use satellite communications capability by 2018 by pooling existing government SATCOM resources.[711] On 11 September, it was reported that Airbus had been given a contract to demonstrate government information-sharing with the Newtec Dialog system.[712]

National military space programs also underwent development (see below).

United Kingdom

The British Skynet 6 communications satellite program is intended to fill a potential gap in service between the current Skynet 5 constellation and a next-generation system. In July, the Ministry of Defence contracted with Airbus to produce the first Skynet 6A satellite, which could be operational by 2025.[713]

The British military is testing constellations of LEO satellites for tactical space-based intelligence gathering. In November, it claimed a share in a commercial satellite launched by Surrey Satellite Technology. Carbonite-2 is a dual-use satellite with color video intelligence capabilities.[714]

Germany

The German parliament's Budget Committee approved construction of up to three new Earth-imaging reconnaissance satellites for the Federal Intelligence Service. The initiative, projected to cost $465-million, will give Germany independent space-based intelligence-gathering capabilities.[715] Nicknamed Georg, the system could be launched in the early 2020s and would be the first German spacecraft launched by a German intelligence agency.[716]

Italy

On 1 August, Arianespace launched the OPTSAT-3000 for the Italian Ministry of Defense. This optical EO satellite is able to capture high-resolution images from across the globe and will be interoperable with existing COSMO-SkyMed radar satellites. The satellite and ground control systems were built by Israel Aerospace Industries.[717] Italy signed a launch contract for two COSMO-SkyMed Second-Generation satellites that will provide the Italian Ministry of Defense and the Italian Space Agency with radar imagery for commercial, scientific, and defense purposes.[718]

France

In January, France contracted with Airbus Defence and Space to supply the French public procurement agency with satellite communication systems to support civilian and military uses. The satellites will operate in the Ku and Ka frequencies.[719]

Spain

The launch of the first Spanish radar-imaging satellite, PAZ, from Vandenberg Air Force Base was postponed to 2018.[720] With up to 25-cm resolution, the dual-use satellite will contribute to the Copernicus program.[721] Possible applications include surveillance and support for European External Action.[722]

Figure 2.22 Other dedicated military spacecraft launched in 2017 [723]

Satellite name	Operator	Primary function	Orbit	Launch date
Kirameki 2 (DSN-2)	Japan, Ministry of Defense	Communications	GEO	2017-01-24
Optsat-3000	Italy, Ministry of Defense	Earth Observation	LEO	2017-08-01

Space-based military capabilities and strategic cooperation develop in Asia

Geostrategic tensions in Asia continue to spur development of space-based capabilities for military and other security applications, while also encouraging strategic cooperation, including with China (see above) and the United States (see below).

India

In 2017, Indian Defence Secretary Sanjay Mitra announced the creation of a dedicated space defense unit, tasked with developing space as an operational theatre for the military.[724] This followed a public call by Army Lt.-Gen. PM Bali in February for a well-resourced and dedicated military space program to ensure security in a changing space environment.[725]

Three dual-use remote-sensing Cartosat-2 satellites were launched on 12 January, 15 February, and 23 June.[726] Managed by ISRO, they are intended to provide the Indian Army with images of India's contested borders and data on the activities of rival states.[727] A fourth launch was rescheduled for 2018.[728] In February, Russia agreed to install GLONASS satellite-positioning system ground stations in India for the use of the Indian military.[729]

Japan

On 24 January, JAXA launched Japan's first military X-band communications satellite, the Kirameki-2, for the Self-Defense Forces. Launch of the Kirameki-1 was delayed after it was damaged before launch in 2016.[730] Both belong to a planned series of three spacecraft that will replace civilian satellites currently used by the military.[731]

On 17 March, Japan launched the Information Gathering Satellite Radar 5, increasing Japan's ability to gather information on North Korean activities.[732] It is the thirteenth information-gathering satellite to achieve orbit since 2003.[733]

Pakistan

Pakistan space agency SUPARCO announced that Pakistan Remote Sensing Satellite 1 (PRSS-1), a dual-use, high-resolution electro-optical EO satellite, would be launched in 2018. PRSS-1 will gather intelligence, monitor borders, and enhance Pakistan's security. It was built by the China Academy of Space Technology and will be launched by China Great Wall Industries Corporation. This satellite is like a CAST satellite built for Venezuela, launched on 8 October (see also Indicator 2.3).[734]

Australia and Canada attempt to expedite development of space-based military capabilities

Australia

The Australian Defence Force has been constrained by the delayed rollout of several programs involving military satellite telecommunications, including a WGS ground station;[735] Northrop Grumman was awarded a contract to facilitate the establishment of integrated communications.[736]

The Australian military announced its JP 9102 program for 2019 to fund future satellite communications projects.[737] In July, Northrop Grumman won a contract to build a ground station for Australian military satellite communications near Wagga Wagga, New South Wales. The estimated completion date is 2021.[738]

Canada
Canada intends to prioritize satellite technologies relating to communication and remote sensing—especially for the Arctic—and promote international norms for responsible space behavior (see Indicator 4.1).[739] Its 2017 defense strategy points to investment in long-term national security space capabilities. Brigadier-General Kevin Whale, Director General & Component Commander – Space, stated that he would be tripling his staff, adding 120 new positions over five years.[740]

Canada's RADARSAT Constellation Mission is to be launched on a refurbished SpaceX Falcon 9 in 2019.[741] The Constellation of three synthetic aperture radar satellites will provide daily monitoring of Canadian territory as well as 90% of the world's surface.[742] Data from the new constellation will be restricted to military use and will not be available commercially.[743]

Emerging space programs in Middle East, Africa, and Latin America acquire military capabilities
While emerging space programs typically emphasize socioeconomic uses of space (see Indicator 2.2), dedicated and dual-use military applications are becoming more prevalent.

Saudi Arabia
In May, the Saudi Arabia Military Industries Company signed a partnership agreement with Raytheon for technology development and defense-related projects, which are believed to include space-based military capabilities.[744] Saudi Arabia and the United States have a memorandum of agreement to increase cooperation on defense and cyber capabilities.

Morocco
On 7 November, Arianespace launched Morocco's Mohammed VI-A Earth Observation Satellite.[745] The satellite will be used for border and coastal surveillance as well as mapping and land surveying, socioeconomic development, agricultural and environmental monitoring, and management of natural disasters.[746]

Ethiopia
The Ethiopian Ministry of Science and Technology announced a plan to launch a remote-sensing satellite within three to five years. The satellite could be used for intelligence gathering.[747]

Kenya
Kenya established a new space agency in 2017 (see Indicator 2.3) under the mandate of the Ministry of Defence, which organized a multiagency forum on space technology and data use in September. The space program is linked to national defense, security, and collaboration.[748]

Venezuela
In cooperation with China, Venezuela launched its second remote-sensing satellite, VRSS 2, on 9 October. A dual-use satellite, it will be used "primarily for land resources inspection, environmental protection, disaster monitoring and management, crop yield estimation and city planning,"[749] according to China. The Venezuelan government noted that it will also be used by its security forces. The satellite includes a high-resolution camera with a maximum resolution of 1 meter, as well as an infrared camera capable of imaging Earth at night.[750]

Brazil

Brazil's military and civilian Geostationary Communications Satellite was launched on 4 May to provide secure X-band communications services for the military and Ka-band for strategic government communications, as well as Internet broadband service.[751]

Alliance structures extend into space

Military cooperation in space has been evolving. It includes sharing of space surveillance data (see Indicator 1.4) as well as shared programs such as the Wideband Global Satcom program (see above), in which Canada, Denmark, Luxembourg, the Netherlands, New Zealand, the United States, and Australia partnered to fund the WGS-9 military communications satellite that was launched on 18 March. Each state has access to the satellite, increasing military interoperability and expanding high-data-rate communications.[752]

Cooperation can include joint operations. In October, the 11th Schriever Wargame exercise explored critical space and cyberspace issues. Participation included the traditional Five Eyes alliance partners (Australia, Canada, New Zealand, the United Kingdom, and the United States), as well as France and Germany.[753] For the first time, Japan's Self-Defense Forces attended.[754]

In August, following increasing threats from the DPRK, Japan indicated interest in additional cooperation with the United States on missile defense and space capabilities, and an expansion of the U.S.-Japan 2015 defense cooperation agreement.[755] In May, a joint statement by Japan and the United States on their space strategy partnership emphasized the importance of space cooperation, including the sharing of information and expertise, and the importance of maintaining a rules-based order in space (see Indicators 4.1).[756]

India's strategic relationship with the United States as a "Major Defence Partner," established in 2015, was reaffirmed in 2017.[757] This means that India is entitled to purchase and receive both military and dual-use items under U.S. export control regulations, including those related to space (see Indicator 2.5).[758] India stated that cooperation with the United States would help to reinforce the global rules-based order.[759]

THEME THREE

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.

Most electromagnetic interference with satellites remains inadvertent, but capabilities for purposeful interference exist 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 antisatellite weapons (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.[1]

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 ASATs (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.[2]

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.[3] The USAF's Counter Communications System, designed to block a potential enemy's satellite communication using radio frequency interference, became operational in 2004.[4] 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,[5] but no new system is anticipated before 2023.[6]

Allegations of electronic warfare, including jamming, have been widespread in relation to conflicts in both Ukraine and Syria. This includes reported deployments of the Russian Krasukha-4 system.[7] The Krasukha-4 is described as 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 150 km to 300 km…by creating powerful jamming at the fundamental radar frequencies and other radio-emitting sources."[8] Turkey reportedly deployed its own Radar Electronic Attack System, which is similar to the Krasukha, on its border with Syria.[9] China is also thought to be developing counterspace capabilities, including "terrestrially-based communications jammers."[10] Jamming is commonly reported near the DPRK.[11]

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 humanmade 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.[12] Advanced capabilities for encryption using quantum computing are being pursued in Canada, China, Japan, and the EU; China is leading efforts for space-based demonstration.[13]

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.'"[14] 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).[15]

Civil and commercial communications links tend to have fewer protective features; 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.[16]

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."[17] 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.[18]

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. 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.[19]

Ground stations are more difficult to protect; new efforts focus on resiliency and redundancy. The USAF is 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.[20] Based on the experimental Multi-Mission Satellite Operations Center,[21] the EGS will replace individual, custom-built ground systems.[22] 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.

Because most 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. Most cyber intrusions involve denial-of-service attacks; there are no documented cases of infiltration of a satellite's command-and-control capabilities.

The U.S. Cyber Command, which is responsible for the military's Internet and other computer networks, became fully operational in 2010.[23] Within this Command, 24th Air Force (AFCYBER) is designated the cybersecurity service provider for the Air Force.[24] But there is no coherent, global approach to cybersecurity in space and the threat is constantly evolving.[25] A U.S. GAO report indicates that NOAA officials 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.[26] The ground control software of the next-generation U.S. GPS III system remains vulnerable to attack, particularly in the wake of continued delays in the development of Raytheon's Operational Control System, which is intended to defend the GPS system against cyberattacks.[27]

2017 Developments

Growing investment in electronic warfare capabilities

Proliferation of and ease of access to technology such as GPS jammers—which can be purchased online—are significant concerns. Between 22 and 24 June 2017, more than 20 vessels in the Black Sea reported incorrect GPS locations that indicated that they were 32 km inland—an instance of GPS spoofing.[28] In a 29 March 2017 U.S. congressional hearing on space threats and homeland security, experts recommended strict regulation of the manufacture and sale of jamming equipment and penalties for misuse.[29]

More significant is the growing investment and formalization of infrastructure and military organization of electronics as part of a growing focus to deny adversaries use of critical information and communications systems.[30] A 2017 report by the U.S. DoD suggests that the Chinese army's Strategic Support Force, which integrates space, cyber, and electronic warfare missions, is putting more emphasis on electronic warfare (EW) capabilities that will produce "a fully networked war-fighting force."[31] Capabilities that have been tested and deployed include jamming equipment to interfere with communications and radar systems, as well as GPS satellite systems.[32]

Russia is thought to be developing and deploying EW capabilities against satellite communications, notably in relation to conflicts in Syria and Ukraine. In 2017, reports suggest that Russia conducted a drill against its own forces.[33] It is also believed that Russia employed widespread jamming of cellular and GPS signals in Latvia and Norway during military exercises in August.[34] A 2017 report indicates that EW capabilities are being integrated into Russia's military organization, doctrine, and command structure.[35] Its 2018-2027 armaments program indicates that Russia is also developing a "ground-based mobile complex of radio-electronic destruction of communications satellites, 'Tirade-2C,'"[36] or Tirade-2S.[37]

According to the USAF, which is also focusing on EW capabilities, "he that dominates the spectrum wins."[38] In 2017, an Enterprise Capability Collaboration Team was created to lead a "concept of operations study that will explore how to best dominate the electronic warfare spectrum.[39] A classified electronic warfare strategy was adopted by the Secretary of Defense in 2017,[40] which calls for increased investment in capabilities. Harris Corporation is contracted by the Air Force Space and Missile Systems Center to complete an upgraded Counter Communications System Block 10.2, which involves updating 13 existing antennas.[41] This mobile, ground-based system can target and jam signals from individual satellites in GEO.[42]

New measures protect satellite communications and mitigate interference

The U.S. military's AEHF satellite system for protected communications no longer meets demand[43] and significant new investment is needed.[44] Optical lasers, which are more difficult to intercept, are being developed to replace radio waves for communication. NASA's advanced laser communications system LEMNOS (Laser-Enhanced Mission and Navigation Operational Services) will enable future communications with Orion spacecraft in deep space.[45] In 2017, NASA's Optical Communications and Sensor Demonstration project sent two cubesats built by Aerospace Corporation to the ISS to test a laser-based, space-to-ground communication system, which can also be used for satellites to communicate with each other in orbit.[46] Airbus announced that it will add a third node to the European Data Relay System (EDRS) of satellites, which uses laser links to download imagery from EO satellites.[47] The expansion will provide near-global coverage.

In 2017, the USAF awarded Lockheed Martin a contract to provide Military Code Early Use for GPS. This upgrade, which provides a signal that is more secure and difficult to jam or spoof for military GPS, will be rolled out on some existing GPS II satellites and on future GPS III satellites.[48] Galileo signals will also become more difficult to spoof, with the recently announced addition of more secure electronic signatures, which are scheduled to undergo testing and evaluation before a limited public release in 2018.[49]

Increasing GPS jamming capabilities are spurring the development of technologies that ignore malicious interference. The U.S. Army is seeking missile antenna configurations that can determine an incoming signal's direction of arrival.[50] Other efforts mitigate interference. In 2017, Intelsat validated a way to digitally reconfigure its satellites upon detection of malicious activity. This Interference Resolution is part of Intelsat's new generation of Epic^{NG} satellites.[51]

United States establishes Cyber Resilience Office for Weapons Systems as vulnerabilities continue

Commercial off-the-shelf cyber capabilities are increasingly available, while new network architecture such as space constellations systems are increasingly vulnerable.[52] In 2016, NASA experienced nearly 1,500 cyber incidents,[53] which seemed to focus on websites or web-app attacks. The Chief Information Security Office indicated that NASA, which is "challenged with security sensitive data that makes its way to and from Earth" is "working to harden old industrial-control systems, such as those used to launch spacecraft."[54]

Military satellite systems are also vulnerable, given the high value of the data transmitted, and the constant evolution of threats; however, discovery of vulnerabilities is classified.[55] States are investing more in cyberwarfare capabilities. For example, documents leaked in 2017 point to ongoing activity in Russia to hijack satellite signals.[56] In the United States, discussion in 2017 continued on expanding the warfighting mandate of the U.S. unified Cyber Command.[57] The DoD's 2017 report to Congress on China's military power suggests that the Chinese army's Strategic Support Force may be creating a unified cyber force similar to that of the United States (see Indicator 2.6).[58]

The USAF established the Cyber Resiliency Office for Weapons Systems, which operates from Hanscom Air Force Base in Massachusetts, to protect against cyber threats. The goal is to "maintain mission-effective capabilities of weapons during a cyber attack."[59] Functions of the office include integrating cyber intelligence, enabling cyber operation flights, and creating cyber protection teams.[60] The office was officially operational as of 21 December 2016; in 2017, it developed an accurate understanding of cyber threats to Air Force missions and advocated the design of modular weapons systems that can be quickly redesigned or have components replaced.[61] This approach to resilient system architecture is also a focus of U.S. military space systems generally (see Indicator 3.2). Additionally, the Air Force is exploring options to contract out cyber defense to the private sector (see Indicator 2.5).[62]

Investment grows in quantum experiments to enable secure space communications

Quantum computing and cryptography are the focus of next-generation efforts to secure satellite communications.[63] In 2016, China was the first to launch a quantum key entanglement experiment. In June 2017, Chinese spacecraft demonstrated the first space-based quantum entanglement between a satellite and three ground stations,[64] and even hosted a secure, intercontinental videoconference.[65] Military applications ranging from cryptography to decryption and stealth operations are believed to be linked to this capability.[66]

With CSA funding, the Institute for Quantum Computing at the University of Waterloo in Canada, conducted research for the Quantum Encryption and Science Satellite mission.[67] Japan's National Institute of Information and Communications Technology developed the world's smallest quantum-communication transmitter onboard the microsatellite SOCRATES and demonstrated a quantum-communication experiment from space.[68] Germany's Max Planck Institute for the Science of Light demonstrated ground-based measurements of quantum states sent by a laser onboard a satellite. [69]

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,[70] but there is no evidence that this capability has been developed.

The United States has longstanding efforts to develop responsive space capabilities, including rapid launch, although this remains elusive. The concept for a U.S. Space Maneuver Vehicle or military spaceplane first emerged in the 1990s. The first technology demonstrators were the X-40 (USAF) and the X-37A (NASA/DARPA).[71] Efforts continue under the USAF's two X-37B unmanned, reusable spaceplanes, which have flown four missions testing experimental payloads, with the last launch in 2017 (see Indicator 3.4).

In 2003, the Force Application and Launch from the Continental U.S. (FALCON) program of the USAF and DARPA began to develop and validate in-flight technologies for prompt global reach missions, while demonstrating affordable and responsive space lift.[72] The program supported the emergence of commercial launch innovations, including funding for SpaceX's Falcon-1 launch system in 2004 under the Small Launch Vehicle component (see also Indicator 2.4). After stalling, support for a hypersonic spaceplane was revamped in 2015.[73]

DARPA supports the Experimental Spaceplane (XS-1) first announced in 2013,[74] 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.[75]

The U.S. DoD Operationally Responsive Space Office opened in 2007 to coordinate the development of hardware and doctrine in support of ORS across the various agencies.[76] The Office faced a setback in 2015 when its experimental, rail-launched Super Strypi launch vehicle failed minutes after takeoff,[77] but the vehicle remains the focus of efforts to develop responsive space systems, including modular design approaches (see below).[78]

China's Kuaizhou ("quick vessel") is being developed by the China Aerospace Science and Industry Corporation in collaboration with the Harbin Institute of Technology. Kuaizhou is an integrated launch vehicle system that can 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.[79] Experts believe that the Kuaizhou rocket can launch from a wheeled mobile transporter within days of call-up. It first launched in 2013 and again in 2014.[80] China's "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."[81] First launched in September 2015, China's Long March 11 is a small, solid-fueled quick-reaction launch vehicle developed by China Academy of Launch Vehicle Technology (CALT).[82] It can be stored for extended periods to provide reliable launch on short notice.

India has been working on a Reusable Launch Vehicle[83] and capabilities to launch record-setting numbers of microsatellites on a single launch.[84] Europe is also investing in several rapid launch programs, as are private sector actors (see Indicator 2.4).

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.[85] 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.[86] This approach was expanded in the 2015 White Paper *Space Domain Mission Assurance: A Resilience Taxonomy*, which illustrated the three components of mission assurance: defensive operations, resilience, and reconstitution. Resilience approaches, which include protection, proliferation, disaggregation, diversification, distribution, and deception,[87] are also the focus of the Space Enterprise Vision (see Indicators 2.6 and 4.1).[88] However, the U.S. GAO has highlighted limitations of this approach.[89] Further, the characteristics that might make attacks against space assets less attractive can also make assets more difficult to track, and so inhibit transparency of activities in outer space.

On-orbit servicing, repairs, and/or refueling of spacecraft could extend the operational lives of satellites, reduce the costs of accessing space, and mitigate orbital debris. On-orbit servicing is technically challenging, requiring advanced space-based capabilities to rendezvous with and manipulate a non-responsive satellite. According to NASA, the five key enabling technologies are: autonomous, real-time relative navigation; servicing avionics; dexterous robotic arms; advanced tool drive and tools; and propellant transfer.[90] Such capabilities under development include Orbital ATK's Mission Extension Vehicle, 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.[91] NASA's Satellite Servicing Capabilities Office is developing the Restore-L robotic spacecraft to service satellites on-orbit in LEO.[92] DARPA is currently exploring the feasibility of such capabilities in GEO, including a plan for commercialization.[93] China prioritized plans to "build in-orbit servicing and maintenance systems for spacecraft" in its 2016 White Paper on Space Activities.[94] Such capabilities could have dual-use applications (see Indicator 3.4).

Other approaches to resilience emphasize capabilities rather than systems. This includes maintaining non-space systems for critical capabilities. For example, eLoran is a ground-based Position, Navigation, and Timing (PNT) system that can back up GPS, Galileo, and other space-based PNT systems.[95] Although mostly replaced by satellite capabilities, such ground systems are regaining popularity because of ongoing GNSS vulnerability (see Indicator 3.1).[96] Efforts to enhance cooperation and even interoperability with partners and allies also contribute to the resilience of capabilities (see Indicator 2.6). The U.S. DoD has indicated interest in allowing the transfer of certain space capabilities to international partners to support space system resiliency and considered using international navigation satellites to guide U.S. weapons if GPS satellites were jammed or unavailable.[97]

2017 Developments

Growing U.S. focus on rapid acquisition of space capabilities

The 2018 National Defense Authorization Act mandates that the Operationally Responsive Space Office be renamed the Space Rapid Capabilities Office in the next fiscal year.[98] Established in 2007, the mission of the ORS Office is "to plan and prepare for the rapid development of highly responsive space capabilities that enable delivery of timely warfighting effects and, when directed, develop and support deployment and operations of these capabilities to enhance and assure support [of] the needs of Joint Force commanders and other users for on-demand space support, augmentation, and reconstitution."[99] While the mandate of the office remains intact, the new name represents "a change in capabilities and capacity to get after what we need to do, and that's to go fast."[100]

Designed to be a small, nimble organization, the ORS Office manufactures its satellites relatively cheaply and quickly at a unique factory located at Kirtland Air Force Base.[101] Its latest project, SensorSat (ORS 5), was launched on 26 August 2017 to conduct space surveillance as a gap filler for the SBSS Block 10 satellite (see Indicator 1.4).[102] The first known project completed by the unit was the X-37B space plane.[103] The Space Rapid Capabilities Office took over leadership of the X-37B Orbital Test Vehicle from DARPA; operations are overseen by Air Force Space Command's 3rd Space Experimentation Squadron.[104] The objectives are developing "reusable spacecraft technologies for America's future in space and operating experiments which can be returned to, and examined, on Earth."[105] It is linked to both rapid access to space (see below), but lack of transparency also raises questions about possible dual-use negation capabilities (see Indicator 3.4).

On-orbit satellite servicing closer to operational

In 2017, the first missions for on-orbit servicing of spacecraft moved closer to becoming operational. Orbital ATK subsidiary Space Logistics Services is developing a fully commercial satellite servicing capability. In September, Orbital ATK began construction on the first Mission Extension Vehicle (MEV-1).[106] MEV-1's scope and goals are like those of Robotic Servicing of Geosynchronous Satellites (RSGS) and Restore-L (see below). Intelsat has purchased two MEVs, the first of which is scheduled to launch in 2018; it will dock with the Intelsat 901 satellite and move it to another orbit.[107]

NASA's Restore-L is a robotic spacecraft with capabilities to extend the lives of satellites, even those not designed to be serviced on orbit.[108] Expected to launch in mid-2020,[109] the project passed its preliminary design review on 26 December 2017. Its first mission is to rendezvous with a U.S. government-owned satellite in LEO, grasp it with telerobotic arms, and perform repair and refueling operations. Restore-L can also relocate target satellites to new orbits.[110]

RSGS is DARPA's on-orbit servicing project for spacecraft in GEO.[111] In February, DARPA selected SSL (formerly Space Systems/Loral) as its commercial partner.[112] DARPA will develop the robotic module, including hardware and software, and provide a government-funded launch. SSL will provide the spacecraft and be responsible for integrating the robotic module onto it to create a robotic servicing vehicle.[113] Goals include inspection, refueling, orbit relocation, and servicing operations.

U.K.-based Effective Space Solutions is developing Space Drones. Its first multiyear commercial contract, valued at $100-million, is to provide station-keeping and attitude control in early January 2018, with launch expected in 2020[114] (see also Indicator 2.4).

China is building "in-orbit servicing and maintenance systems for spacecraft and [will] make in-orbit experiments on new theories, technologies and products by tapping various resources."[115] China is one of only a few states to successfully refuel a satellite on orbit, which it did in 2016.[116]

In 2017, DARPA and NASA jointly launched the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) program, which provides a platform for government and the space industry to participate in research, exchange ideas, and establish safety standards for outer space robotic servicing.[117]

Continued investment in rapid launch capabilities

The development of rapid and responsive launch capabilities is a priority for states and commercial companies. Combined with available backup spacecraft and/or rapid manufacturing capabilities (see above), access to rapid launch could enable the quick reconstitution of space capabilities that fail or are otherwise disabled.

In the United States, DARPA made progress on its hypersonic spaceplane, the XS-1,[118] which is intended to provide short-notice, low-cost access to space.[119] The goal is to reuse spacecraft weighing up to 2,226 kg as often as 10 times in 10 days at a cost of less than $5-milion per flight.[120] In 2017, DARPA selected Boeing, which completed advanced design work for the spaceplane, to proceed with fabrication and flight testing. The spacecraft, officially named Phantom Express, will take off and land horizontally like a normal aircraft.[121] A demonstration vehicle is tentatively scheduled for 2019.

In early 2016, the China Aerospace Science Industry Corporation (CASIC) established a subsidiary called ExPace, which markets the Kuaizhou rocket family. The *China Space Report* calls Kuaizhou "the world's first integrated launcher-satellite system, similar in concept to the U.S. Operationally Responsive Space (ORS) initiative."[122] It is based on a solid-fuel missile interceptor developed by CASIC in 2002.[123] The goal is to enable "rapid deployment of tactical space-based capabilities in response to an emergency such as a natural disaster" or to replace satellites damaged through warfare.[124]

In November 2016, ExPace expected to "launch 10 of its Kuaizhou solid-fueled rockets per year between 2017 and 2020."[125] It appears to be behind schedule. The light Kuaizhou-1A had its first flight in January 2017, from the Jiuquan Satellite Launch Center.[126] The heavier Kuaizhou-11 launcher is expected in 2018.[127] ExPace secured nearly $182-million in 2017 to develop its launch vehicles.[128]

India's ISRO continues to develop its Reusable Launch Vehicle – Technology Development Programme.[129] A test of the engine and other technologies took place in 2016, but no tests appear to have been conducted in 2017. The goal is to drastically reduce the cost of space launch.[130]

European developers continued to develop reactive satellite launch capability to capitalize on the smallsat and cubesat launches expected in the next decade (see Indicator 2.4). Private companies sought to disrupt the satellite launch market by developing cost-effective launch methods for small satellites through initiatives like the Horizon 2020 EU Research and Innovation Programme and the ESA's Future Launchers Preparatory Programme.

The Small Innovative Launcher for Europe project was initiated in 2016 to foster the development of rocket prototypes by Nammo Raufoss and PLD Space/DLR.[131] In 2014, Nammo, an international aerospace and defense company headquartered in Norway, began developing a modular nano-launcher capable of burning an environmentally friendly hybrid of solid and liquid fuel. The hybrid motor was successfully tested at flight-weight in 2016.[132]

Nammo is collaborating with the Andøra Space Center and Norwegian Space Centre as part of the NorthStar initiative.[133] PLD Space and DLR are collaborating on the development of a reusable, liquid-fueled nano-launcher;[134] in December, the LOX/Kerosene engine was test-fired using a 3D-printed injector.[135]

Development of other commercial small launch vehicles is covered under Indicator 2.4.

Indicator 3.3: Earth-based capabilities to attack satellites

Ground-based antisatellite 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 direct ascent, kinetic ASAT 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.[136] Kinetic hit-to-kill technology, which involves interception and destruction of a target, 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.[137]

The United States tested the Air-Launched Miniature Vehicle, a two-staged missile launched from an F-15 fighter jet, several times, and intercepted an aging satellite in 1985, after which tests were banned by Congress.[138] The U.S. Army later 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 was later granted funding from FY1996 through FY2005.[139]

Between 1984 and 1989, the Soviet Union worked on an air-launched direct ascent ASAT system known as Kontakt.[140] In 2013, the Russian Duma reportedly called for the military to restart the Kontakt program.[141]

Today, capabilities that could intercept space-based targets are tested 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.[142] EKVs use infrared sensors to detect ballistic missiles in midcourse and maneuver into the trajectory of the missile.[143] With limited modification, the EKV may be used against satellites in LEO.[144] In 2008, the United States reconfigured a Standard Missile (SM)-3 antimissile to destroy failing satellite USA-193 as it deorbited. The United States has stressed that this was a "one-time event,"[145] not part of an ASAT development and testing program.

The SM-3 Block 2A missile, which the United States is developing and testing with partner Japan, has greater range and velocity, a more sensitive seeker, and a better divert capability than legacy SM-3s and will be capable of reaching higher altitudes in outer space.[146]

Russia developed a long-range (350-km) exoatmospheric missile, the Gorgon, for its A-135 anti-ballistic missile system to defend Moscow.[147] Up to three tests of the next-generation A-235 missile defense system took place in 2016.[148] Russia's Nudol ground-launched, direct-ascent intercept system is being developed by the Almaz-Antey Air Defense Concern. It shares characteristics with midcourse ballistic missile intercepts, but U.S. military intelligence assessments suggest that it is primarily focused on ASAT missions, with capabilities to target satellites in LEO.[149] 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)."[150] Russia has reportedly also resumed development of an air-based anti-satellite system.[151] A flight test of the system is believed to have been conducted in 2015.[152]

China has developed an advanced hit-to-kill capability, demonstrated by its intentional destruction of a Chinese weather satellite in 2007.[153] China called the event an experiment, not an antisatellite test.[154] 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."[155] In 2013, China launched the Dong-Neng (DN-2) rocket, which is able to reach altitudes as high as GEO.[156] In 2015, China reportedly conducted a "final-phase missile interception test…in the upper atmosphere"[157] of a third possible system, identified by U.S. military sources as the Dong Neng-3 (DN-3).[158] Like the SC-19 used in 2007, the DN-3 appears to use a road-mobile launcher, which would be more useful against satellites.[159]

The United Kingdom, Israel, and India have explored techniques for exoatmospheric interceptors.[160] 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.[161] 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 operate,[162] but it is not clear if it still uses nuclear interceptors.

Lasers have been used against objects in space and have been elements of dedicated weapons programs. Low-powered lasers have been used to "dazzle" or degrade unhardened sensors on satellites in LEO.[163] 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.[164] This suggests that even a commercially available low-watt laser on the ground could be used to "dazzle" or temporarily disrupt satellites designed to collect optical energy. Academic research suggests that a laser system in China with a range of 50-100 kw may have been used in a nondestructive test against a satellite in LEO in 2005.[165]

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.[166] High-energy laser capabilities have matured and diversified rapidly,[167] but steep hurdles must still be overcome before terrestrial deployment is a reality. Current laser technologies are overpowered for dazzling satellites, but underpowered for more destructive tasks.

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.[168] Adaptive optics research and development have been conducted by Canada, China, India, Japan, Russia, and the United States.[169]

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[170] and may have had ASAT capabilities.[171] The program was initiated in 1996 and developed over 12 years at a cost of $5-billion.[172] On 3 and 11 February 2010, the ALTB system successfully destroyed threat-representative ballistic missiles in flight.[173] The program was cancelled in 2011.[174] In 2015, the Missile Defense Agency 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.[175] Work is ongoing.[176] Technologies from the ALTB have been reused in high-altitude unmanned aerial vehicles for boost-phase missile defense.[177] DARPA's High Energy Liquid Laser Area Defense System 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.[178]

In a September 2015 defense and security exposition, 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.[179] India, Russia, and China are believed to be pursuing similar capabilities.[180] Russia's Almaz-Antey and the China Poly Group Corp. are world leaders in laser technology.[181]

There were indications in 2016 that Russia intends to resume flight testing of a flying laser system capable of dazzling or damaging satellite sensor components in LEO. Sokol Eshelon is the revival of a legacy program that began in the 1980s and was terminated in 2011.[182] Significant challenges remain in using high-energy lasers against objects in space. Previous efforts "have faced extreme challenges with aeromechanical jitter and shooting lasers through the atmosphere."[183]

Researchers at the University of California, Santa Barbara continued work on DE-STAR, "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).[184]

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		■					

■ = enabling capability

2017 Developments

Exoatmospheric tests of ballistic missile defense systems continue as capabilities spread

In 2017, testing continued of exoatmospheric interceptors developed for missile defense, but which are also capable of targeting satellites. The midcourse kinetic interceptor targets an incoming ballistic target after its active flight phase has concluded and it is beyond Earth's atmosphere, about to descend at hypersonic speeds. Such an interceptor can be used as an ASAT platform[185] and threatens all spacecraft in LEO and even as high as GEO.

China

On 23 July, China reportedly flight tested the DN-3 direct ascent missile (an interceptor), at the Jiuquan Satellite Launch Center in Inner Mongolia. The missile apparently malfunctioned in the upper atmosphere. Chinese authorities previously warned airlines to avoid flying near the flight path of the missile. The DN-3 is believed to have been previously tested in 2015 and again in 2016.[186] According to Chinese authorities, these tests are "land-based missile interception tests,"[187] for missile defense capabilities, but there are concerns about possible linkages to antisatellite missile capabilities.[188]

United States

The United States and Japan conducted the first intercept test (and third flight test) of the Standard Missile 3 Block IIA (SM-3 IIA) interceptor against a medium-range ballistic missile in February 2017.[189] The interceptor forms part of the Aegis Ballistic Missile Defense system and features a larger, more maneuverable exoatmospheric kill vehicle than the Block

II version[190] used to intercept a deorbiting, toxic satellite in 2008. The system is also mobile, launching from both Aegis ships and ground locations.[191] A second test failed in June.[192]

The Ground-based Midcourse Defense (GMD) system[193] currently consists of 44 Ground-Based Interceptors at Fort Greely, Alaska and Vandenberg Air Force Base, California. Congress increased the defense budget for 2018 by $383-million to add 20 GMD System interceptors,[194] asking the Secretary of Defense to deploy them to Fort Greely as soon as possible;[195] the plan is to have 104 interceptors by 2023.[196]

In May 2017, the first live test of the GMD system was conducted against an intercontinental ballistic missile.[197] The system successfully intercepted the missile with an upgraded CE-II Block-1 EKV, which had last been tested in 2014, when it destroyed a target that resembled an intermediate-range ballistic missile.[198] Because the system's success rate is low, $259-million was requested for 2018 to develop a multi-object kill vehicle that fires multiple warheads on a single rocket.[199]

The MDA has revived an interest in lasers (see below) and was directed by the 2018 NDAA to begin developing a testbed for a space-based interceptor layer (see Indicators 2.6 and 3.4).

India

India is making progress in developing an indigenous ballistic missile defense (BMD) program that uses the Prithvi Defence Vehicle (PDV).[200] This vehicle, tested in February 2017, is intended to provide exoatmospheric intercept capability. Although tests have only reached an altitude of 97 km, capabilities are advancing, and viewed as a significant achievement.[201] There are no indications that India intends to leverage BMD as an ASAT capability.[202]

Renewed focus on dedicated ASAT capabilities

In November, Oleg Ochasov of the Russian Ministry of Defense stated that the new Russian Federal Defense Procurement Program would be allocated funding to develop the Rudolph mobile antisatellite complex.[203] However, while a new state armaments program was to have been submitted to the President by 15 December,[204] its status is uncertain.

A Russian Aerospace Forces squadron commander seemed to confirm that an ASAT missile has been designed for use on Russia's new supersonic MiG-31 BM interceptor aircraft.[205] When asked if targets included satellites, the commander responded that satellites were included. The initiative is seen by some as a potential revival of the Soviet-era Kontakt Program to launch ASAT missiles from a MiG-31D.[206]

In *Worldwide Threat Assessment of the US Intelligence Community,* a report released in May, National Intelligence Director Daniel Coats stated, "Russian lawmakers have promoted military pursuit of ASAT missiles to strike low-Earth orbiting satellites, and Russia is testing such a weapon for eventual deployment."[207]

DPRK advances technical military capabilities

The DPRK demonstrated advanced military capabilities that could eventually have implications in outer space. In September, the government announced that it had carried out a thermonuclear test.[208] In addition, the DPRK tested the Hwasong-14 (KN-20), believed to be an intercontinental ballistic missile, on 4 and 28 July, using a lofted trajectory. Estimates place the range of the missile at approximately 10,000 km. There was also evidence of preparations for an additional space launch (see Indicator 2.2). There is speculation that North Korea might be able to combine a ballistic missile and a nuclear warhead into an electromagnetic pulse weapon to target satellites,[209] although there is no evidence of any intent to do so.

Laser development and research more sophisticated, but of limited use against space objects

While there are no known intentions to develop lasers for dedicated ASAT purposes, renewed development of high-powered lasers for a variety of military purposes, including missile defense, has potential applications against objects in space and has been a focus of ASAT capabilities in the past.

United States

In 2017, the USAF Research Lab awarded Lockheed Martin $26.3-million for the design, development, and production of a high-power fiber laser to be mounted on an aircraft, as part of its Self-protect High Energy Laser Demonstrator program. Components include a beam control system, which will direct the laser to the target, and the high energy laser itself.[210] Fiber lasers are able to deliver stable, straight, and focused optical beams that can maintain high levels of power.[211] Lockheed also delivered a 60kW-class laser to be installed on a U.S. Army ground vehicle.[212] In July, the U.S. Navy conducted a test of a drone-killing Laser Weapons System.[213] Navy engineers believe future versions could intercept missiles in the air.[214]

The National Defense Authorization Act for FY2017 included a 51% increase in funding ($328-million) to develop and procure laser weapons,[215] with the acknowledgement that, while progress had been made in raising power levels, "[the DoD] has also demonstrated the need for emphasis on development in other technology areas necessary to realize the full potential of laser weapons."[216] The enabling technologies, including beam directors and adaptive optics, could also be relevant for use against objects in outer space.

China

While China continues to invest in military applications of laser technology,[217] Chinese researchers are also studying the potential to use space-based lasers to remove debris from orbit (see Indicator 1.1).[218]

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 a weapon armed with conventional explosives into the same orbit as the target satellite, which could be detonated when the target moves near enough to be destroyed.[219] The Soviet Union/Russia has observed a voluntary moratorium on antisatellite tests since 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.[220]

Technologies developed for peaceful purposes could also be used to enable space-based negation activities. For example, "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 noncooperative rendezvous and docking (see Indicator 3.2). 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.[221] 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 Microsatellite 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.[222] In January 2009, the Pentagon confirmed that the two MiTEx microsatellites had maneuvered into close proximity with a failing satellite in GEO.[223] This incident elicited concerns that the ability to achieve such proximity could be used for hostile actions.[224]

Four GSSAP satellites launched by the USAF in 2014 and 2016 have the capability to perform rendezvous and proximity operations with noncooperative satellites and to maneuver widely through geostationary orbit (see Indicator 1.4).[225] The satellites' primary purpose, space situational awareness, is achieved through an ability to approach and observe noncooperative satellites by maneuvering widely through geostationary orbit, propelling and operating in close proximity to other satellites.[226] Although the program is public, orbital positions of the satellites are not. The Automated Navigation and Guidance Experiment for Local Space program, which also tested maneuverability capabilities, was cancelled in 2017.[227]

Russia's Cosmos 2491 and 2499 were launched in 2014 and Cosmos 2504 in 2015.[228] These satellites have been observed conducting proximity operations with the Briz-M upper stage of the launch vehicle.[229] Roscosmos asserted that the maneuvers were peaceful;[230] there are no reports that these satellites approached any active satellites.[231] 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).[232] Maneuvering in space could support a number of functions, including spying, antisatellite missions, recovery and repair of a broken satellite, and clearing satellite junk out of orbit.[233]

China demonstrated advanced maneuverability and rendezvous capabilities in 2008 and 2010.[234] In 2014, Shijian 15 and Shiyan 7, satellites launched in 2013,[235] performed multiple maneuvers; Shiyan 7 then maneuvered to rendezvous with Shijian 7, a Chinese satellite launched in 2005.[236]

Space control emerged as a 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 included "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."[237] Significant funding is provided for this mission.[238]

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.[239] This continued interest by U.S. lawmakers in pursuing weapons and other space negations systems in space is reportedly inspired by the strategic defense initiative of the 1980s.[240] A 2012 study published by the National Academies estimated that deployment of even a minimal system would cost about $200-billion, and billions more to operate.[241] The 2016 Act provided $20.7-million for space BMD programs, separate from existing missile-sensing and -tracking programs (see Indicator 2.6).[242]

2017 Developments

Demonstration of advanced space-based capabilities raises questions

The ability to maneuver close to an uncooperative object, such as a rocket, is critical for such operations as repair and refueling (see above),[243] as well as some forms of space-based surveillance (see Indicator 1.4), but also enables possible covert or negation activities in space. This duality is of greater concern when activities are conducted with little or no transparency.

China

Chinese experimental satellite SJ-17, funded by the China Academy of Space Technology, made a series of maneuvers in GEO in 2017, following its launch in October 2016.[244] The SJ-17 is described as testing advanced technologies such as environmentally friendly chemical propellant, ion propulsion, quadruple junction gallium arsenide solar panels, and an onboard optical surveillance sensor.[245] Since November 2016, SJ-17's movements have included a rendezvous and proximity operation with the retired Chinasat 5A, relocating close to Chinasat 6A, and a rendezvous and proximity operation with Chinasat 20 in early 2018.[246] These activities could support space-based surveillance or satellite servicing capabilities, or space-based negation.

Russia

Russian satellites performed on-orbit maneuvers in 2017, after remaining idle for approximately a year.[247] Cosmos-2504, launched in 2015, appeared to maneuver, lowering its perigee in April,[248] in what could be a retirement operation. Representatives from Russia's space agency provided no answer when asked by reporters about the unusual behavior.[249] Cosmos 2499, launched in 2013, also appeared to maneuver slightly in March 2017,[250] in what could be a proximity operation. In 2014, Cosmos-2499's movements were tracked as it maneuvered under its own power, eventually approaching the rocket stage that launched it; Roscosmos director Oleg Ostapenko stated that the Cosmos satellites were for peaceful purposes.[251]

The military-operated Cosmos-2519 satellite was launched in June 2017.[252] The Ministry of Defense announced that on 23 August it had released an inspector satellite, Cosmos 2521 (Sputnik Inspektor)[253] that will be used to inspect the host satellite. The announcement, which seems to emphasize that the satellite will not be used to approach foreign satellites, might mean that the Cosmos-2499 and Cosmos-2504 were also small inspector satellites.[254] On 30 October, Cosmos 2523 was released from Cosmos 2521; it was also stated that this small satellite would have an inspection function.[255] The spacecraft carry amateur radio payloads.

United States

The GSSAP-3 and GSSAP-4 space-based surveillance satellites were brought into operation in September 2017. The satellites are part of the USAF Geosynchronous Space Situational Awareness Program (see Indicator 1.4), which characterizes and tracks objects in space to support what is described as a neighborhood watch in orbit.[256] The satellites can maneuver and inspect other satellites without their cooperation, an ability that could also be used for harmful purposes. Orbital data for these satellites is not public.[257] Little is known about their actual capabilities.

The fifth X-37B Orbital Test Vehicle was launched from a SpaceX Falcon 9 on 7 September for an extended stay in space after the fourth mission landed in May. While the program is publicly known, officials have not commented fully on payloads for the missions, each of which is classified.[258] The X-37B will operate in a higher-inclination orbit than those of previous missions.[259] Onboard the spacecraft is the USAF Research Laboratory's Advanced Structurally Embedded Thermal Spreader, or ASETS-11, which, according to Secretary of the Air Force Heather Wilson, will test experimental electronics and oscillating heat pipes in the long-duration space environment.[260] The nature of other payloads is not known.

On 1 May, classified U.S. National Reconnaissance Office satellite NROL-76 was launched by SpaceX into an unusual 50° inclined orbit, like that of the ISS.[261] On 3 June, the satellite passed the ISS within roughly 6.4-km, not quite encroaching on the "danger zone" that would trigger an avoidance maneuver by the ISS.[262] It is not clear if this move was intentional. NROL-76 was produced by Ball Aerospace, which has previously worked on both optical remote sensing satellites and autonomous satellite rendezvous and servicing missions. The satellite "could be a technology demonstrator of a spacecraft intended to monitor close approaches and berthing in space in detail." Because the ISS receives frequent and predictable cargo and crew spacecraft, it could be used as a test object.[263]

U.S. Congress and political leaders continue to press for a space-based missile defense testbed

The December 2017 U.S. National Security Strategy (see Indicator 1.4) prioritized the deployment of a layered missile defense system to defend against missile attacks, including boost-phase interception before or shortly after the missile is launched. [264] While it does not specify that this additional capability will be space-based, few other options are available.[265] Moreover, the U.S. NDAA for FY2018 specifies that, if consistent with the recommendations of the ongoing Ballistic Missile Defense Review due in 2018, the Missile Defense Agency is to establish a testbed to conduct research and rapid development of a space-based layer that includes kinetic interceptors and directed energy platforms, contingent on the 2018 Missile Defense Review.[266] This is consistent with congressional mandates to the MDA in the previous two years.

Such a system, if deployed, would be capable of striking objects on Earth and in space.[267] It would represent the first dedicated destructive weapons systems in space.

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. All 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 called 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] Cooperation remains an element of the most recent 2018 National Space Strategy; however, the emphasis has shifted to “America first.”[2]

Russia has been deeply engaged in cooperative space activities, is a major partner of the ESA,[3] and cooperates with other key spacefaring nations, including China and India.[4] 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 face significant budget constraints in the 2016-2025 program (see Indicator 2.2).[5]

China’s 2016 White Paper on outer space activities confirms its commitment to international cooperation and the principles of the Outer Space Treaty.[6] However, like the United States and Russia, China’s pursuit of space capabilities is also part of the buildup of its “overall strength,” as China seeks to be a “space power in all respects.”[7]

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.[8]

ESA facilitates European space cooperation by providing a platform for discussion and policymaking for the European scientific and industrial community.[9] 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.

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. Japan’s third Basic Plan on Space Policy, adopted in 2015, is notable for its new focus on national security.[10] The European Commission published its first Space Strategy for Europe, which aims to enhance the use of European space capabilities for military and security purposes, specifically by "reinforcing synergies between civil and security space activities."[11] This marks a shift in an approach to space that had been predominantly civilian. Space is also an element of the Commission's 2016 European Defence Action Plan[12] and the Global Strategy for the EU's Foreign and Security Policy.[13]

Space is being depicted by some states as a domain of warfare. China's first Defense White Paper on Military Strategy emphasizes the strategic concept of "active defense"—adherence to the unity of strategic defense and operational and tactical offense; to the principles of defense, self-defense, and post-emptive strike; and to the stand that "we will not attack unless we are attacked, but we will surely counterattack if attacked."[14] 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.[15] A similar sentiment is echoed in the 2017 U.S. National Security Strategy.[16]

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 several years and is consistent with the 2011 National Space Security Strategy, it stands out in a 2016 USAF White Paper, *Space Mission Force: Developing Space Warfighters for Tomorrow,*[17] which declares that "space is no longer a sanctuary" and emphasizes the maintaining of critical space operations during a potential conflict.[18]

More states have come to view national space industries as fundamental drivers and components of their space policies. The United Kingdom, Germany, Australia, and the United States, among others, have prioritized innovation and development of industrial space sectors in national space strategies. In 2016, the United Arab Emirates adopted the Middle East's first dedicated national space policy, which emphasizes increased cooperation between government and private sectors and encourages synergies between the space sector and other key industries.[19]

Both the United States and Luxembourg have adopted national legislation that includes commercial rights to the extraction and use of space resources such as minerals.[20] Other states are considering similar legislation, raising legal and regulatory questions related to international space law.

2017 Developments

U.S. National Security Strategy prioritizes strategic value of space

In December, the current U.S. Administration released its first National Security Strategy, which emphasizes space as a priority domain for national security.[21] It clarifies that unimpeded access to and use of space is a vital national interest while removing sustainability and security of outer space as priorities. Labelling Russia and China political, economic, and military competitors and potential adversaries, it advocates "peace through strength" and views freedom of action in space as a core element of U.S. national security.[22]

Further, the strategy emphasizes deterrence in space, declaring the intent to respond to actions below the threshold of war that represent "continuous competition" and "irregular warfare" by adopting new operational concepts and capacities to win, even in the absence of dominance.[23]

Another priority is the integration of all space sectors, including the commercial. Regulations should be simplified and updated to strengthen commercial space competitiveness and capabilities, expand public-private space partnerships, and promote international cooperation for missions beyond LEO.[24] The National Space Council, chaired by the Vice President, was reestablished to coordinate cross-government space policy. The Council includes the Secretaries of State, Defense, Commerce, Transportation, and Homeland Security; the NASA Administrator; and the Chairman of the Joint Chiefs of Staff.[25]

The National Security Strategy commits the United States to developing "a layered missile defense system" that "will include the ability to defeat missile threats prior to launch"[26] (see Indicators 2.6 and 3.4). It is part of a wider policy shift that includes a new National Defense Strategy and National Space Strategy in 2018.

States pursue enhanced national regulatory regimes for commercial space activities

Luxembourg

A law on space resources was passed in July and entered into force in August.[27] It may entitle private operators to resources extracted in space and establishes a regulatory framework for the approval and supervision of missions to explore and use space resources. The law is another pillar in Luxembourg's SpaceResources.lu initiative, which seeks to make the country a key hub in the emerging space resources industry (see Indicator 2.5). With the law's passage, Luxembourg became the first European country to establish a legal framework for the use of space resources.[28]

India

In November, ISRO began a process of public consultation on a draft Space Activities Bill to encourage private sector participation in space activities and services and regulate space sector growth and performance.[29] The bill covers exploration and use of outer space for peaceful purposes and for national security.[30] It seeks to establish a regime for commercial space activity, lays out licensing requirements for space activities and operators and penalties for violations, establishes a registry of licensed space objects, and provides government indemnity for harm that commercial space activities may cause.[31]

New Zealand

In July, the government signed into law the Outer Space and High-Altitude Activities Bill; it came into force on 21 December.[32] The law seeks to enable the development of a safe and secure space industry in New Zealand. It establishes a regulatory regime for launch and payload licenses for launches from New Zealand and by New Zealand nationals operating overseas.

United Kingdom

In June, the House of Lords introduced the Space Industry Bill, which seeks to establish an enabling regulatory regime for commercial spaceflight from UK spaceports.[33] Many provisions are based on the Civil Aviation Act of 1982. This new bill creates licenses for a wide range of spaceflight activities by vertically launched rockets, spaceplanes, satellites, and spaceports; institutes measures to regulate unauthorized access and interference with spacecraft and spaceports; and provides a regulatory framework to cover operational insurance, indemnity, and liability.[34] Under this new regime, the UK Space Agency would oversee space activities, while the Civil Aviation Authority will oversee suborbital activities.[35] The bill became law in March 2018.

United States

The National Security Strategy call for simplified and updated regulations should strengthen commercial space competitiveness and capabilities, increase public-private space partnerships, and promote international cooperation for missions beyond LEO.[36] In June, the House of Representatives Science, Space and Technology Committee introduced the American Space Commerce Free Enterprise Act,[37] which will streamline the U.S. commercial space licensing and regulatory regime. The Office of Space Commerce in the Department of Commerce will become the single authority for nongovernmental space activities, with responsibility for remote sensing licenses, authorizing and supervising "non-traditional" space activities,[38] and overseeing "in-space activities" not previously covered.[39] The act was passed by the House of Representatives in April 2018.[40]

Statements indicate support for norms and rules in outer space

Canada's new defense policy, *Strong, Secure, Engaged,* prioritizes satellite technologies for communication and remote sensing; it states, "Canada can demonstrate leadership by promoting the military and civilian norms of responsible behaviour in space required to ensure the peaceful use of outer space."[41]

A joint statement from the fourth U.S.-Japan Comprehensive Dialogue on Space in May emphasizes a whole-of-government approach to civil, commercial, and national security space cooperation, and reaffirms the commitment of both states to the rule of law in outer space and to transparency and confidence-building measures to ensure stability in space activities.[42]

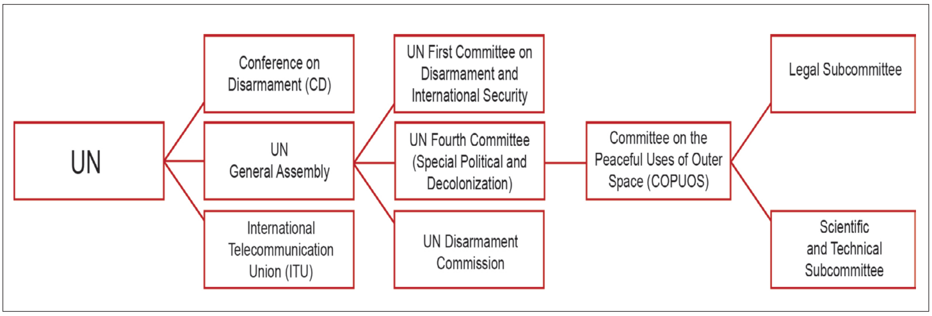
The United States indicates in its National Security Strategy that it will provide both leadership and technology to keep common domains such as space within the framework of international law. While the strategy supports the peaceful resolution of disputes, it indicates that the United States will defend its interests "to ensure common domains remain free."[43]

Indicator 4.2: Multilateral forums for space governance

Several international institutions provide multilateral forums to address space security issues. UN bodies include the UNGA First Committee on Disarmament and International Security and UN COPUOS, which reports to the UNGA Fourth Committee (Special Political and Decolonization), and the UN Inter-Agency Committee on Outer Space. As the single multilateral disarmament negotiation forum for the international community, the Conference on Disarmament in Geneva, Switzerland, adopts its own agenda and procedural rules, but has a special relationship with the UNGA First Committee (Disarmament &

International Security). 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).

Figure 4.1 UN-related institutions relevant to international space security



UN General Assembly

The UNGA has long believed 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.[44]

Figure 4.2 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.

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 a 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.

In 2011, the UN Secretary-General established a Group of Governmental Experts on Transparency and Confidence-building Measures in Outer Space Activities as a pragmatic way to advance international dialogue on space security issues. The Group was composed of 15 international experts nominated by UN Member States, including five by the permanent members of the UN Security Council (China, France, Russia, the United Kingdom, and the United States) with the remaining based on geographic representation (Brazil, Chile, Italy, Kazakhstan, Nigeria, Romania, South Africa, South Korea, Sri Lanka, and Ukraine).[45]

Chaired by the Russian expert, the group provided its final consensus report to the 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,[46] which was included in a 2014 UNGA resolutions on TCBMs in Outer Space Activities. This meeting took place in October 2015; a second meeting was held in 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. It works by consensus. Membership has expanded significantly in recent years; as of 2017 there are 87 Member States. Some intergovernmental and nongovernmental organizations have permanent observer status at 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 (OST), 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.

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.[47] 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. 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 deploying weapons in space or attacking the space assets of another nation from Earth, antisatellite capabilities have been tested by some states against their own satellites—for example, by China in 2007[48] and the United States in 2008.[49]

There have been repeated calls from different quarters for an updated normative regime.

Rescue and Return 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 humanmade space debris and spacecraft. Article II 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." When a launching state causes damage to a space asset belonging to another state anywhere other than on the surface of the Earth, it is liable only if it is at fault. 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.[50] 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 UN Secretary-General.[51]

Moon Agreement (1979)—The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies further extends the language and spirit of the OST. Specifically, the Moon Agreement prohibits any "threat or use of force or any other hostile act or threat of hostile act" on and around the Moon, and prohibits the installation of weapons and establishment of military bases. It also prohibits the use of the Moon to threaten the Earth, "spacecraft, personnel of spacecraft or man-made space objects." 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 4.3 Status of major UN space treaties, January 2018[52]

Treaty	Date	Total parties	Total signatories	Total Declaration of Acceptance of Rights and Obligations
Outer Space Treaty	1967	107	23	0
Rescue Agreement	1968	96	23	2
Liability Convention	1972	95	19	3
Registration Convention	1975	67	3	3
Moon Agreement	1979	18	4	0

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 the 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. An initial set of 12 voluntary guidelines was adopted in 2016; a preambular text and a further set of nine guidelines were agreed to by the Scientific and Technical Subcommittee in February 2018.

In recent years, the Legal Subcommittee has addressed single-issue agenda items, reflecting an interest to respond to emerging space activities in a timely manner. In 2016, these included a "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."[53]

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."[54] 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's 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. 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. The UNGA resolution "No First Placement of Weapons in Outer Space," first introduced in 2014,[55] urges 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 (PPWT) (see below) when a committee on PAROS is established; however, support is divided.

Efforts to establish a voluntary International Code of Conduct for Outer Space Activities have likewise faltered since 2015. While the need for additional governance measures is seen, the way forward is not clear; global support has not emerged for either the legally binding PPWT or voluntary commitments. Lack of verification remains an obstacle to supporting a weapons ban for some, including the United States.[56]

2017 Developments

UN General Assembly adopts new resolutions on the security of outer space

Seven UN resolutions relating to space were adopted in 2017 (see Figure 4.4 below). Four were adopted by consensus, including Resolution 72/56 on transparency and confidence-building measures, with the United States, Canada, Japan, and Australia indicating that implementation measures will be added to the agenda of the United Nations Disarmament Commission in 2018.[57] In April 2017, the commission held informal meetings on "Practical implementation of transparency and confidence-building measures in outer space activities with the goal of preventing an arms race in outer space."[58]

There is longstanding disagreement on how to proceed with additional security measures, whether through a legally binding arms control framework such as Russia and China's draft Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Objects Treaty, or through the political measures favored by many Western states (see Resolution 72/26). In 2017, three additional states supported a perennial political statement on no first placement of weapons in outer space (Resolution 72/27). Resolution 72/250, sponsored by Russia and China, authorizes the establishment of a new Group of Governmental Experts to make recommendations on a new legal instrument for PAROS.[59] The UN Secretary-General was to establish the Group in early 2018 with an expanded membership of up to 25 Member States based on fair and equitable geographical representation. Working by consensus, it is expected to report to the 2019 session of the UNGA.[60]

Figure 4.4 UN Resolutions adopted, 2017

Resolution	Title	Voting record of UN Member States			
		For	Against	Abstained	Nonvoting
A/RES/72/250	Further practical measures for the prevention of an arms race in outer space. Statement of financial implications	108	5	47	33
A/RES/72/79	Consideration of the fiftieth anniversary of the United Nations Conference on the Exploration and Peaceful Uses of Outer Space	Adopted without a vote			
A/RES/72/78	Declaration on the fiftieth anniversary 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	Adopted without a vote			
A/RES/72/77	International cooperation in the peaceful uses of outer space	Adopted without a vote			
A/RES/72/56	Transparency and confidence-building measures in outer space activities	Adopted without a vote			
A/RES/72/27	No first placement of weapons in outer space	131	4	48	10
A/RES/72/26	Prevention of an arms race in outer space	182	0	3	8

Space launches by DPRK and Iran create concern at UN Security Council

The UN Security Council adopted Resolution 2397 on 22 December in response to ongoing nuclear weapon and ballistic missile tests by the Democratic People's Republic of Korea, reaffirming its decision that "the DPRK shall not conduct any further launches that use ballistic missile technology, nuclear tests, or any other provocation" and "shall immediately suspend all activities related to its ballistic missile program."[61] Although the launch of satellites is closely linked to ballistic missile technology, North Korea signaled an intent to proceed with plans to launch a satellite in 2018, asserting that its space program complies with international law on the use of outer space (see Indicator 2.2).[62] A February report by the United Nations Sanction Committee Panel of Experts indicated that ballistic missile launches, some related to outer space activities, were in breach of UN-imposed sanctions.[63] Some launches appeared to be inconsistent with peaceful purposes.

The United States, Germany, France, and the United Kingdom claimed that Iran's launching of a satellite on a Smorgh rocket in July (see Indicator 2.2) was in violation of UN Security Council Resolution 2231, which is related to the Joint Comprehensive Plan of Action that limits Iran's nuclear program.[64] Iran maintained that the launch was in accordance with international law. The Security Council discussed the space launch on 8 September, but did not reach consensus on how it related to Resolution 2231.[65]

CD remains stalled, while EU renews call for common guidelines

The prevention of an arms race in outer space remained an agenda item under consideration by the Conference on Disarmament, which held 32 formal plenary meetings and six informal plenary meetings, but failed again to reach consensus on a program of work.[66] On 16 June, during a meeting of the Working Group established to chart a "Way Ahead" for the CD, the EU suggested a multilateral but nonbinding framework for space security based on transparency and confidence-building measures.[67] In a statement, the EU encourages "all States to work together to elaborate common guidelines such as principles of responsible behaviour in outer space…agreeable by a vast majority of spacefaring nations."[68]

COPUOS expands membership, continues work on peaceful uses of outer space

UNGA Resolution 72/77 added Bahrain, Denmark, and Norway to COPUOS, which had 87 members in 2017.[69] The European Science Foundation, represented by the European Space Sciences Committee, and University Space Engineering Consortium-Global were granted observer status.[70]

The DPRK requested observer status for the first time at the 72nd meeting of COPUOS in June. Some delegations believed that granting such a request would be inconsistent with repeated violations by the DPRK of Security Council resolutions 1718 (2006), 1874 (2009), 2087 (2013), 2094 (2013), 2270 (2016), 2321 (2016), and 2356 (2017) related to the development and testing of ballistic missile-related weapons.[71] Resolution 2270 suspends scientific and technical cooperation with the DPRK related to aerospace engineering. Others noted that the resolutions impose no ban on observing the work of the committee. North Korea's request was granted for the 2017 session.

The COPUOS Legal Subcommittee's Working Group on the Review of International Mechanisms for Cooperation in the Peaceful Exploration and Use of Outer Space was given a five-year mandate to understand how international organizations and states cooperate in space and promote cooperation in space activities. Its work ended in 2017; a comprehensive final report was submitted to inform and guide cooperation as it intensifies and evolves.[72] It recommended that the International Institute of Space Law and the European Centre for Space Law organize an international conference "to reflect a broader range of opinions."[73]

At its 56th session in spring 2017, the Legal Subcommittee hosted the first "General exchange of views on potential legal models for activities in exploration, exploitation and utilization of space resources."[74] As part of this agenda item, COPUOS, in partnership with the International Institute of Space Law and the European Centre for Space Law, held a Space Law Symposium on "Legal Models for Exploration, Exploitation and Utilization of Space Resources 50 Years After the Adoption of the Outer Space Treaty."[75] Other work related to the application of international law to smallsat activities and space traffic management.[76] A questionnaire on small satellites, which includes questions on the legal and policy implications of their use, was adopted.[77]

The Scientific and Technical Subcommittee continued to seek consensus on a second round of voluntary guidelines for long-term sustainability of space activities, nine of which were adopted in February 2018 (see Annex 4). These voluntary guidelines cover research and development, space operations, and capacity-building.[78]

50th anniversary of the Outer Space Treaty commemorated

The OST opened for signatures on 27 January 1967. Although there were calls to mark the 50th anniversary with a meeting of States Parties to the Treaty, none took place. Multilateral organizations did host several celebrations, however. In June, the COPUOS draft report for the 60th session included in the annex a resolution commemorating the anniversary.[79]

This resolution was considered at the UNGA, which adopted by consensus two resolutions: "Declaration on the Fiftieth Anniversary 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" (RES/72/78)[80] and "Consideration of the Fiftieth Anniversary of the United Nations Conference on the Exploration and Peaceful Uses of Outer Space" (RES/72/79).[81]

On 12 October, a joint-panel meeting of the UNGA Disarmament and International Security Committee (First Committee) and the Special Political and Decolonization Committee (Fourth Committee) was held to commemorate the OST anniversary. Discussion focused on challenges to the security and sustainability of space, and transparency and confidence-building mechanisms.[82] This was the second such meeting held to facilitate trust and transparency-building measures related to the security of outer space.

In 2017, UNIDIR's annual space security conference was on "The Outer Space Treaty's 50th Anniversary: Reviewing the Regime."[83]

UNISPACE+50 preparations

Preparations continued for the June 2018 UNISPACE+50 Conference in Vienna to mark the 50th anniversary of the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space.[84] Included were events on space accessibility, diplomacy, economy, and society; special programs on young people and women in space; and a special high-level segment of the 61st session of COPUOS.[85] The goal is to articulate a long-term vision for outer space that includes stronger space governance and international cooperation for the benefit of humankind. It is hoped that the conference will produce a blueprint for a Space 2030 agenda on space as a driver for sustainable development.[86]

On 22-23 May, UNOOSA and the Committee on Space Research held a joint discussion on research required to meet the UNISPACE+50 objectives.[87]

UNOOSA promotes the role of women in space

In New York in October, the UN Office for Outer Space Affairs and UN Women held an Expert Meeting on Space for Women to encourage more girls and women to study and take up careers in STEM (Science, Technology, Engineering, and Mathematics) disciplines. The event launched the Space for Women project,[88] a forum to facilitate the empowerment of women in space science and technology, increase their role in decision-making processes, and facilitate the creation and enhancement of partnerships for such purposes.

In commemoration of International Woman's Day, a special podcast entitled "Ladies Do Launch" was broadcast. In it, women talked about their careers in Science, Technology, Engineering, Entrepreneurship, Arts and Mathematics (STEEAM) fields, including some space-related.[89]

UNOOSA and the International Civil Aviation Organization combine efforts

Between 29-31 August, ICAO and UNOOSA held a symposium in Vienna on "Emerging Space Activities and Civil Aviation Challenges and Opportunities."[90] Topics included cooperation and coordination, space traffic management, and regulatory approaches to space activities. This symposium was the third of a tripartite series, with the first held in Montreal in March 2015 and the second in Abu Dhabi in March 2016.

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 initiatives relate to bilateral or regional collaborations. Examples include the work of the Asia-Pacific Regional Space Agency Forum. The African Union adopted an African Space Policy and Strategy in 2016, intended as the beginning in creating an African Space Program under the AU Agenda 2063 strategic framework for socioeconomic transformation.[91] Groups of leading industrialized states such as the G7 and BRICS are becoming more engaged with questions of space governance, including nonweaponization.[92]

Bilateral initiatives also contribute to space governance. In 2016, China and the United States met for the first time to discuss topics related to outer space security, including space debris, preventing collisions on orbit, and China's antisatellite systems.[93]

Nongovernmental organizations have contributed to the dialogue on gaps in the international legal framework. The Union of Concerned Scientists drafted a model treaty banning ASATs in 1983.[94] In 2002, the Stimson Center first proposed a Code of Conduct for responsible spacefaring nations and has continued to promote this effort.[95] 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.[96] A founder of the SSI project and manager of the annual SSI reports, Project Ploughshares also explores the enhancement of the security of outer space, including the nonweaponization of space.[97] Other organizations active in space governance include The Simons Foundation in Canada[98] and the Observer Research Foundation in India.[99]

UNIDIR has played a key role in facilitating dialogue among key space stakeholders. Every year since 2002, it 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. The Space Generation Advisory Council aims to bring the views of youth and young professionals to bear on outer space governance.

In the absence of a framework to govern new space activities associated with the exploration and extraction of space resources, the Hague International Space Resources Governance Working Group, led by the Institute of Air and Space Law at Leiden University in the Netherlands, is formulating governance recommendations and guidelines for space resource utilization.[100]

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 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.[101] This study, carried out by an international and interdisciplinary team of more than 100 international experts, was published in 2017.[102]

Academics are also involved in efforts to clarify existing laws and norms applicable to military operations in space, both in times of peace and in the event of war. The McGill Manual on International Law Applicable to Military Uses of Outer Space (MILAMOS) is an academic initiative intended to clarify existing international law applicable to the military uses of space during times of peace and in times of rising tensions.[103] The Woomera Manual on the International Law of Military Space Operations is led by the University of Adelaide, the University of Exeter, the University of New South Wales, Canberra, and the University of Nebraska, Lincoln. It is a multi-stakeholder project intended to articulate and clarify how existing international law—specifically, the law on the resort to the use of force and the law of armed conflict—applies to outer space.[104]

Segments of civil society are becoming engaged directly in issues related to outer space. In October 2016, plans to create the first space nation, named Asgardia, were announced in Paris.[105] Asgardia is envisioned as a "global, unifying and humanitarian project" to prevent "Earth's conflicts from being transferred into space."[106]

2017 Developments

Regional activity to coordinate and integrate Africa's space activities

In Cairo in October, the African Union discussed the African Space Policy at the second ordinary session for the specialized technical committee meeting on education, science, and technology.[107] The policy seeks to provide a regional regulatory framework for the peaceful use of outer space. Also in October, the AU published its fifth draft Statute of the African Space Agency.[108] If adopted, the statute would establish an African Space Agency as an organ of the African Union, linked to the AU Agenda 2063 strategic framework for socioeconomic transformation.

High-Level Forums provide networking opportunities for global space stakeholders

The following three forums were preludes to UNISPACE+50 (see Indicator 4.2). The UN/UAE high-level forum, "Space as a Driver for Socioeconomic Sustainable Development," was held on 6-9 November to include nonstate actors, particularly the commercial sector, in discussions pertaining to the sustainable and peaceful use of outer space.[109] A UN/South Africa symposium in Stellenbosch, South Africa in December[110] focused on small satellites, capacity-building for the African space industry, and legal and regulatory issues. The final report's recommendations, if implemented, would help African nations take advantage of the small satellite industry.[111] The Manfred Lachs Conference on Global Space Governance was organized by McGill University's Institute of Air and Space Law, the International Association for the Advancement of Space Safety, UNOOSA, the CSA, Secure World Foundation, and *ROOM: The Space Journal*. Held in Montreal in May, the conference focused on global governance of space activities.[112]

The 68th International Astronautical Congress, hosted by the Space Industry Association of Australia in Adelaide, brought stakeholders in the global space community together to focus on secure and assured access to satellites that provide global utilities (communications, GNSS, remote sensing).[113] ESA held its 6th High-Level Forum in October in Paris.[114] Representatives from various organizations in the European space industry discussed challenges and objectives for the European space sector. The state of implementation of recommendations from previous forums was reviewed and discussions were held on Space 4.0 and digital technology.

Civil society organizations explore limits on the use of force in outer space

On 22 March, Secure World Foundation discussed findings from a 2016 Table-Top Exercise on conflict dynamics in space at a presentation in Washington, DC hosted by the Center for Strategic and International Studies and the Prague Security Studies Institute.[115] Secure World hopes to raise awareness of the impact of various policies on potential space-related crises, identify policy gaps, and outline mechanisms that could prevent space conflicts.

On 20-21 April, UNIDIR held a Space Security Conference that reviewed the primary multilateral initiatives in place to safeguard access to, and use of, outer space in a time of rapid change.[116]

In 2016, the Centre for Research in Air and Space Law at McGill University, and the University of Adelaide launched the McGill Manual on International Law Applicable to Military Uses of Outer Space (MILAMOS) project to compile a comprehensive manual that clarifies and outlines international law applicable to military uses of outer space. In 2017, the University of Exeter became a Partner Institution.

The first MILAMOS workshop took place on 20-22 February in Adelaide, focusing on rules that demonstrated connections between international space law, humanitarian law, and the law on the use of force. The second workshop was held in New Delhi, India on 20-23 June, and the third in Colorado Springs on 9-13 October.[117] These workshops, which brought together lawyers, academics, scientists, representatives of private space companies, members of the military, and government officials, built consensus and drafted rules. Publication of the final rules is expected by 2020.[118] The project on the Woomera Manual launched in early 2018.

On 27 June, the International Committee of the Red Cross held a roundtable discussion on "Applying International Humanitarian Law in Cyberspace and Outer Space: Intersecting Critical Challenges."[119]

The Hague International Space Resources Governance Working Group convenes

The Hague International Space Resources Governance Working Group was established in January 2016. Its first phase concluded in December 2017, with a final report published on 18 December.[120] (The second phase began in January 2018.) In September 2017, it published *Draft Building Blocks for the Development of an International Framework on Space Resource Activities,*[121] which set out guidelines that are intended to work in harmony with national, regional, and international space policy to regulate space activities.[122] Comments on the draft could be submitted until October 2018; afterwards, the Draft Building Blocks will be reconsidered, amended, and finalized.

Expanding societal engagement in outer space activities and governance

Asgardia, the self-proclaimed first space nation, added "The Space Kingdom" to its name. Led by Dr. Igor Ashurbeyli, Asgardia plans to apply for UN membership. On 12 November 2017, it opened nominations for elections for parliamentary seats and government positions and launched its first satellite, the Asgardia-1.[123] The experimental cubesat tests the long-term fate and reliability of data in the high radiation environment of space.[124] In June, UNESCO and Ashurbeyli, on behalf of the Asgardia International Non-Governmental Research Society on Space, signed an agreement to facilitate "high-quality research and education by rewarding individuals and institutions for their outstanding contributions to the development of space science and the expansion and dissemination of knowledge about space."[125]

In April, the Autonomous Space Agency Network, a group of U.S. citizens interested in the use of outer space, held the "first space protest"[126] against the current U.S. administration's oppression of science. The network advocates for a "decentralized network of community-based, autonomous space agencies."[127]

Achieving global cooperation in space security: Settling for less than the ideal

Dr. Rajeswari Pillai Rajagopalan

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Security of outer space is beginning to assume greater attention in the international discourse on global security. Framing new rules of the road for outer space activities has been gaining particular attention in this regard. This has been driven primarily by the fact that the number and types of players in this domain are changing dramatically and that outer space has become crowded, congested, and contested. Meanwhile, there is also increasing concern about the possibility of weaponization of outer space. While there are certain treaties and legal instruments in this domain, we still lack an effective space regime. In this essay, I first outline the evolution of outer space governance and subsequently look at the new challenges that suggest the need for additional efforts in this area.

Evolution of space governance

Outer space has been governed by a few foundational treaties and legal measures that came about in the 1960s and 1970s. The space domain has undergone big changes since the launch of Sputnik six decades ago in 1957. For the first several decades, outer space was dominated by the two major Cold War powers, the United States and the Soviet Union (USSR). With outer space increasingly interlinked with their nuclear competition and other political issues of the Cold War, maintaining space as a peaceful domain was challenging. However, recognizing the pitfalls of the spiraling competition between the two, the United States and the USSR submitted their respective versions of treaties on the uses of space to the UN in 1966. In the subsequent months, negotiations within the Legal Subcommittee of the UN Committee on the Peaceful Uses of Outer Space led to resolving the differences in the two texts. This document was then approved by the UN General Assembly and the Outer Space Treaty was opened for signature on 27 January 1967 and came into force on 10 October 1967.

The Outer Space Treaty is the most comprehensive and foundational instrument governing outer space activities. The treaty was meant to deal with the then prevailing dominant challenges such as preventing states from placing weapons of mass destruction (WMD) in outer space, banning military activities on celestial bodies, specifying legally binding rules for ensuring peaceful exploration of outer space, and prohibiting any nation state from claiming sovereignty on outer space, including the Moon and other celestial bodies.

In addition, there are four other agreements; with the Outer Space Treaty, they make up the "five United Nations treaties on outer space." These include the Rescue Agreement (1968), Liability Convention (1978), Registration Convention (1976), and the Moon Agreement

(1984). Each of the four agreements outlines the responsibilities and obligations of states in ensuring safe, secure, and continued access to outer space.

Other international measures that have relevance to space include the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water (1963), Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (1978), and the International Telecommunication Constitution and Convention (1994). Nevertheless, there is considerable ambiguity around outer space activities in the current context. Also, the UN Charter takes precedence over all other treaty obligations. Article 2.4 and Article 51 of the UN Charter have been often referred to in outer space debates. These deal, respectively, with the threat or use of force including in outer space and the right to self-defense, which could be interpreted to suggest the right of states to deploy weapons in outer space, too.

Even as these five treaties and agreements are in place, there are ambiguities and weaknesses in the current outer space regime. The principles governing the five agreements were perfectly in line with the challenges of the day, but the outer space environment of today is very different and complex. New challenges are driving the need to develop new rules and regulations that would address the loopholes in the existing mechanisms. For instance, the Outer Space Treaty prohibits only the placement of weapons of mass destruction and not conventional weapons. The existing instruments have also been found wanting when it comes to interpretation and definition of key concepts and terms. Unclear definitions, especially in the current space security context, hurt the process of developing new rules of the road. Questions include: What is a space weapon? and What is meant by peaceful use or defensive use of outer space? As the possibility of space tourism increases, even the definition of an astronaut has been questioned. Should a space tourist travelling on a Virgin Galactic spaceship be considered an astronaut?

Other measures, such as Prevention of an Arms Race in Outer Space, a Chinese and Russian proposal, has not found much traction, even though there has been an annual resolution passed in its favor in the UN General Assembly since 1981. PAROS goes beyond the goals of the Outer Space Treaty to extend the ban on the placement of any weapons, including conventional ones, in outer space. While there is a near consensus on the idea behind PAROS, progress has been stalled because some important states have not been in favor and it has been embroiled in larger international political debates.

Thus, there is little question that the international community recognizes the need for new efforts in space governance, though this recognition has not yet compelled them to reach an agreement. In the next section, I outline new challenges to space governance that point to the need for greater multilateral effort in new space governance instruments. I conclude with some thoughts about how the international community could move forward on this critical issue.

New challenges for outer space governance

Over the past two decades, outer space has seen significant changes. To use the most clichéd phrase, space has become even more crowded, congested, and contested. But like many clichés, it is also true.

New players

A domain that was once dominated by the two Cold War superpowers has today more than 80 actors, including commercial ones, making outer space a lot more crowded and congested. Space exploration and growing dependence on outer space for development will increase the number of players many-fold in the coming years. A growing number of countries, especially from the developing world in Africa and Latin America, are starting their space programs to meet their social, economic, and developmental needs. Countries in Asia are looking to outer space for applications to deal with climate change and disaster management, among other tasks. As more states pursue space to satisfy a wide variety of requirements, regional and international cooperation is going to gain further ground.

Space cooperation is also a function of demand and supply. On the supply side, growing prosperity means that states have greater resources for space programs. Also, as countries progress, industrialization and technology spread almost organically. On the demand side, there are competitive pressures working to further proliferation of space technology and collaboration.

However, unregulated cooperation could spur both regional and international insecurities. New regulations should not curb international collaboration or promote technology denial. Rather, regulations should spell out clear rules for both international cooperation and space activities. There is little question that some countries seeking space technology for civil space cooperation could divert that technology for the development of ballistic missiles or a military space program. With overcrowding of outer space from both satellites and space debris, safe and secure access also becomes a big challenge, one that affects all space-using states equally.

In some cases, greater cooperation in outer space utilization has come through regional space agencies. In both Africa and South America, regional institutions have played a role in creating more cooperative ventures. This has not been the case with Asia. In Asia, there are two regional space cooperation mechanisms: the Asia-Pacific Regional Space Agency Forum under Japanese aegis and the Asia-Pacific Space Cooperation Organization under China's lead, with no institutional arrangements for the two to coordinate or collaborate. This is partly a reflection of the regional geopolitical competition, with space one more arena in which this competition is playing out.

A second important phenomenon has been the growth of private sector participation in outer space ventures. While primarily a Western phenomenon, such activity could travel to Asia and other regions. There is a growing recognition of a capacity gap on the part of state agencies in meeting large-scale demand across different spectrums, which raises many questions about the complex roles of space actors. Other questions relate to the new satellite mega-constellations, which are mainly put up by commercial players. How might these affect the space environment? How will they impact on the long-term sustainability of outer space? These are real concerns. Thus, commercial actors are adding to the woes of global governance.

Space debris

The challenge of space debris has grown enormously in the last decade. The number of pieces of space debris floating in outer space is enormous. There are more than 21,000 items larger than 10 cm, an estimated 500,000 items between 1 and 10 cm, and more than 100 million smaller than 1 cm.

Given the growth in space exploration and the crowded nature of space, collision avoidance measures, promotion of space situational awareness, and planetary defense measures are important. While the U.S. space surveillance network of radars and sensors is the largest, it is still not comprehensive. U.S. coverage of the southern hemisphere is not considered strong. Russia and the European Union also have capabilities for tracking space objects, debris, and space weather, as well as the ability to predict reentry of space objects into the atmosphere, although at a lower level of capacity. Because space debris is a problem for all actors who use outer space, there is greater common interest in managing the problem. However, the enormity of the problem and the division of responsibilities and costs are still significant barriers to solutions.

Strategic competition

Space is once again becoming the sphere of international political rivalry and potential conflicts, another domain in which the geopolitical competitions of Earth are beginning to play out. Dependence on outer space obviously creates vulnerabilities. The growth in the last decade in counterspace capabilities—kinetic means such as direct ascent antisatellite missiles, co-orbital systems (satellites that sidle up to their targets and detonate to kill both) that create permanent and irreversible destruction, and even electronic or cyber means to create temporary disruptions and/or destruction—is a major emerging problem. While none of these capabilities is new, there is a renewed determination and push to develop them. The temptation to use them could be irresistible. Jamming and use of cyber means to damage and destroy outer space assets could become more popular measures for states to target their adversaries.

Of course, militarization of outer space has already happened. Militaries around the world have been using space assets for such passive military applications as communications, surveillance, reconnaissance, and intelligence gathering. But the task must be to prevent the expansion to weaponization. Early steps toward weaponization have been taken, but the major powers have not made any feasible and realistic efforts to curb them. Common ground is hard to find. States differ on the definition of a space weapon, for instance. Dual-use assets make distinguishing between a peaceful object and a hostile weapon increasingly difficult. Equally pertinent has been the threat from ground-based ASAT-like systems, which contemporary initiatives have not effectively addressed.

New push for global governance

New, growing challenges call for new rules of the road. There have been some efforts in the last decade, although none has led to any successful conclusion as yet. Building consensus among the major powers to develop an effective outer space regime has been fraught with challenges.

New rules of the road, in the form of norms of responsible behavior, must be based on Transparency and Confidence-Building Measures, such as a code of conduct. At present, space security has no effective multilateral management regime. Such a regime should guarantee the security of space; ensure a certain amount of order, predictability, and stability; and uphold the long-term sustainability of outer space. While most states declare these as their own national goals and objectives, there is a yawning gap between the rhetoric and reality.

Heightened international political tensions make developing legally binding measures much more challenging. Western countries, by and large, have preferred TCBMs because of the absence of an agreement among spacefaring powers on many of these issues. TCBMs offer good temporary measures until consensus is reached among all the space players on a more binding legal instrument. As the name suggests, TCBMs are primarily voluntary measures designed to build confidence among space powers while making efforts at strengthening transparency and openness. TCBMs can include a codification of best practices and over a period of time they can be helpful in developing certain norms of responsible behavior in space. Thus, they can be seen as important intermediate measures between recognizing a functional need and developing an enduring solution. TCBMs can institute multiple levels of international dialogue and encourage different stakeholders to talk to each other, which is essential for building the political confidence in each other necessary for the more onerous task of making actual binding treaties. TCBMs are generally easier to agree upon because they are voluntary, but are valued less by states.

UN Groups of Governmental Experts on outer space remain another measure that has had reasonable successes, at least in debating issues relating to space security. GGEs, established by the UN General Assembly, are important means to debate and resolve contemporary challenges and consider possible solutions. Three GGEs have completed their work so far and a fourth has been constituted to debate PAROS. GGEs have enjoyed quite a bit of political support and credibility; since they are formed under UN auspices, they might overcome some of the hurdles to consensus.

However, most GGEs have 15 seats for member countries, with five seats reserved for the P5 of the Security Council. Thus, GGEs are rarely considered adequately representative. Even though GGE reports are based on consensus, they may not be seen to represent all interests, especially those of weaker powers and developing countries. That GGE reports can offer only suggestions and recommendations is again seen as a weakness. However, recommendations can be taken up by the UN General Assembly as resolutions, thus subjecting them to larger scrutiny and possibly building more support from a broader set of countries.

The EU-proposed International Code of Conduct was a recently debated initiative that had the potential to gain greater traction, with most countries quite satisfied with the code's text. Problems with process and then politics have now stalled this effort. The EU developed the ICoC by itself, neglecting an important opportunity to reach out to a larger number of states and so develop a globally viable instrument. Many countries, especially in the developing world, perceived the EU's attempt to develop the code as the EU's determining what is good for the rest of the world. Although the EU eventually recognized some of its mistakes and attempted to rectify them, it was too late. A wedge between the EU and certain other space powers had already developed and is now so deep that the effort does not seem worth pursuing at this stage.

Many spacefaring powers see significant political advantages in participating in shaping and formulating a code such as the ICoC. Their sense of ownership is hugely beneficial in getting a broad-based support for the code, thus ensuring its longevity or even its evolution into a broader treaty.

What is the way forward?

Given the growing number of threats and challenges, the need for regulation of outer space is real. Efforts must be made to determine the ideal approach and end-state, but also what might be feasible in the near term. Space is truly a global commons and also a limited commodity; hence, it is incumbent upon every state to join in preserving it for future generations. One state's action can affect others. Debris, to mention only one example, does not distinguish among the assets of different states. All will be affected.

Moving forward also means learning some lessons from recent failed efforts so that new efforts do not suffer the same fate. For one, new efforts should not make the mistake that the Hague Code of Conduct against Ballistic Missile Proliferation did. Though generally considered a successful TCBM with a large number of members, the Hague Code does not include critical missile powers China, Pakistan, Iran, and Israel. It must be remembered that the value of TCBMs is a function not just of the number of members, but also the membership of critical actors.

Another lesson is about the need for inclusivity. Including many countries, even if the measure being developed is not ideal, gives those states a sense of ownership that can have a far-reaching impact. A measure developed by Western countries without the involvement of others from the developing world may not go down very well (see the ICoC above).

There is an additional lesson in the ICoC's failure. It unintentionally created the perception that it would lead to limiting or even denying technologies to some. Many developing countries that were just starting their space programs were wary of signing a code that they believed would restrict their programs' development. Such a misperception could have been laid to rest by earlier and wider consultation. This is particularly pertinent because, historically, the West has not enjoyed much credibility in developing measures that ensured a level playing field in high technology.

Space technology, unlike nuclear technology, has dual use and cannot be controlled. Thus, the Chemical Weapons Convention (CWC) model may be more applicable than the nuclear Non-Proliferation Treaty (NPT) model. The CWC attempts to monitor and prevent the misuse of chemicals manufacturing technology rather than control the spread of this technology ("technology-denial"). The spread of chemicals manufacturing technology to many countries, including the developing world, made any effort to control its spread unworkable. Alternatively, the NPT attempts to prevent the spread of many elements of nuclear technology, including for civilian purposes.

Another lesson concerns the feasibility of a legally binding instrument. Treaty-making and consensual decision-making worked well in the past, when there were a limited number of players with an inherent interest in controlling the flow of technology. Today, great power politics has become so contentious that developing consensus on any global security issue has become problematic. This crisis in decision-making could deepen in the future. Thus, there is a need to develop more innovative approaches to common problems, beyond insisting on legally binding treaties. Multilateral confidence-building measures might be a useful starting point.

We should also recognize the importance of multilateral negotiations to prevent the emergence of its alternative, the deterrence model, in managing outer space. If there is no success in multilateral negotiations, states will be forced to rely on deterring others from undertaking undesirable activities in outer space by threatening to retaliate with similar activities. Such threats could spiral out of control. Multilateral negotiations present a possible way to prevent such an occurrence.

Space traffic management is vital. Could a structure like the International Civil Aviation Organisation fulfill this function for space? The ITU has managed spectrum allocation quite well, but space traffic management goes beyond the ITU. More importantly, can we make progress toward a global SSA authority? The creation of such a body would be an important step in understanding the space environment that we are operating in, and essential for safe, secure, and uninterrupted access to outer space. And it could have an impact on further cooperation between states. Global cooperation in outer space is an absolute must, but the way forward may be to agree on a common minimum program, rather than to hold out for the most ideal solution.

ANNEX 1: Working Group Meeting

Space Security Working Group Meeting

Best Western Ville-Marie Hotel
Montreal, Canada
19-20 May 2018

Invited Experts:

Timiebi Aganaba-Jeanty
Centre for International Governance Innovation (CIGI)

Alexander Batalov
Russian Delegation to ICAO

Upasana Dasgupta
Institute of Air and Space Law, McGill

Philip De Man
Leuven Centre for Global Governance Studies

Karl Doetsch
International Astronautical Federation

Gilles Doucet
Spectrum Space Security

Laura Grego
Union of Concerned Scientists

Markus Gronbach
INTRA GmbH

David Kendall
Canadian Space Agency (retired), International Space University
Chair UN COPUOS (2016-17)

Virendra Jha
VRSPACe Consultants Inc. (CSA, retired)

Christopher Johnson
Secure World Foundation

Kuan-Wei Chen
Institute of Air and Space Law, McGill University

Jonathan McDowell
Harvard-Smithsonian Center for Astrophysics

Michelle Mendes
Canadian Space Commerce Association

Elina Morozova
Intersputnik International Organization of Space Communications

Martin Sarret
European Space Policy Institute

Lucy Stojak
HEC Montreal

Kuan Yang
School of Law, Beijing Institute of Technology

Researchers:

Valérie Bastien-Dupuis
Institute of Air and Space Law, McGill University

Chris Beauregard
Space Policy Institute, The George Washington University

Lachlan Blake
Research Unit on Military Law and Ethics, The University of Adelaide

Jamil Castillo
Institute of Air and Space Law, McGill University

India Hopkins
Research Unit on Military Law and Ethics, The University of Adelaide

Cody Knipfer
Space Policy Institute, The George Washington University

Craig Martin
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Kirin Nair
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Clare Nolan
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Lukas Price
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Frankie Rodney
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Peter Hays
Space Policy Institute, The George Washington University

Ram Jakhu
Institute of Air and Space Law, McGill University

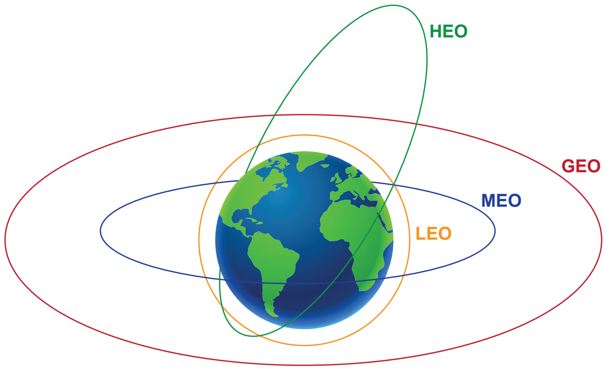
Cesar Jaramillo
Project Ploughshares

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.

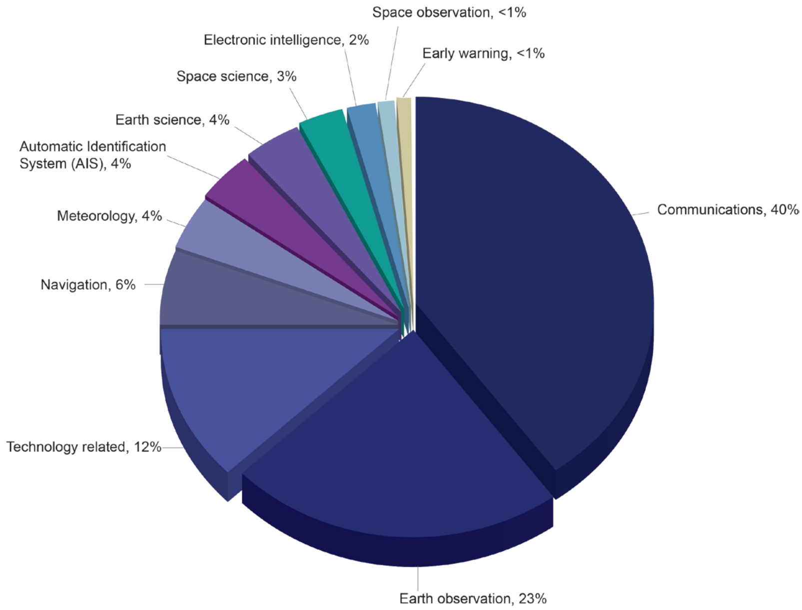
GEO transfer orbit (GTO) is an elliptical orbit of the Earth, with the perigee in LEO and the apogee in GEO. This orbit is generally a transfer path after launch to LEO by launch vehicles carrying a payload to GEO.

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.

ANNEX 3: Operational Satellites

Operational satellites by function 2018



Total operational satellites: 1,886

As of 30 April 2018

Source: Based on data provided by the Union of Concerned Scientists. For more information see *UCS Satellite Database*.

ANNEX 4: COPUOS Guidelines

Guidelines for the long-term sustainability of outer space activities*

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
Guidelines 6	Enhance the practice of registering space objects
Guidelines 11	Provide updated contact information and share information on space objects and orbital events
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
Guidelines 14	Perform conjunction assessment during all orbital phases of controlled flight
Guidelines 15	Develop practical approaches for pre-launch conjunction assessment
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 23	Promote and facilitate international cooperation in support of the long-term sustainability of outer space activities
Guidelines 24	Share experience related to the long-term sustainability of outer space activities and develop new procedures, as appropriate, for information exchange
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
Guideline 30	Design and operation of space objects regardless of their physical and operational characteristics
Guideline 31	Take measures to address risks associated with the uncontrolled re-entry of space objects
Guideline 32	Observe measures of precaution when using sources of laser beams passing through outer space

*Note: A first set of voluntary guidelines was agreed to by consensus at the COPUOS plenary held from 8-17 June 2016 in Vienna, as contained in report A/AC.105/2016/CRP.17. The Scientific and Technical Subcommittee adopted a second set during its 29 January–9 February 2017 meeting, as contained in report A/AC.105/C.1/2018/CRP.18. The guidelines have yet to be adopted by the UN General Assembly.

Endnotes

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