Emerging Space Technologies

… (Legal issues)

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M.A. (Space & Telecommunications Laws] Course
NALSAR PRO
NALSAR University of Law
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Outline

- Introduction
  - Emerging Scenario
- Space Debris
  - Active Debris Removal
  - On Orbit Servicing
- Innovative Technologies Being Developed
- Small/ Nano Satellite Constellations
- Space Resources Utilization
- Space Tourism
- Counter Space Technologies
- Conclusion

Emerging Scenario

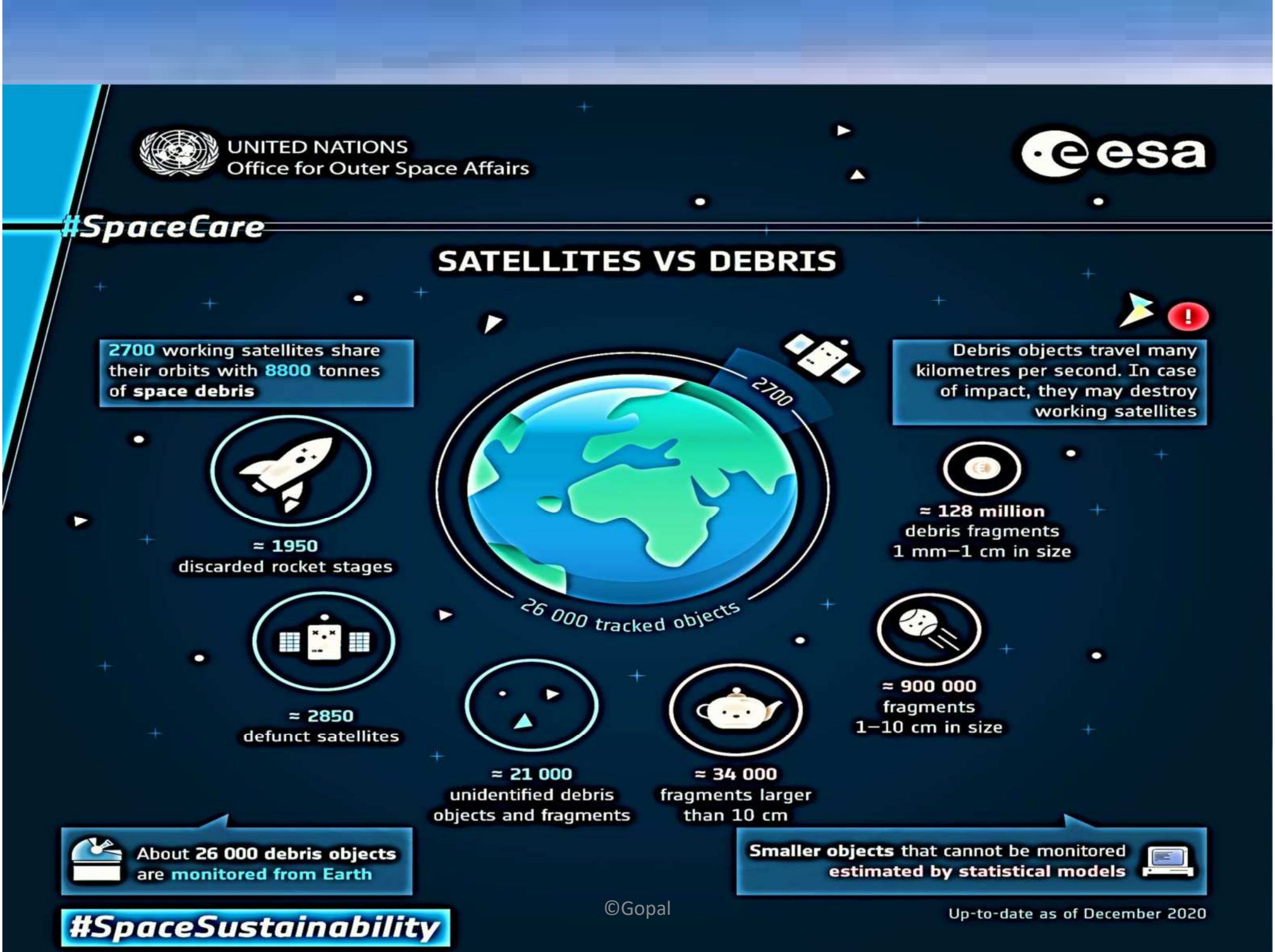
- **Growth of Space Debris in outer space**
  - ***Active Debris Removal Techniques***
  - ***On Orbit Servicing***
- **Nano Satellite/ Small Satellite Constellations**
- **Utilization of Space Resources Space Tourism**
- **Counter Space Technologies**
- **New Technologies being developed / demonstrated**

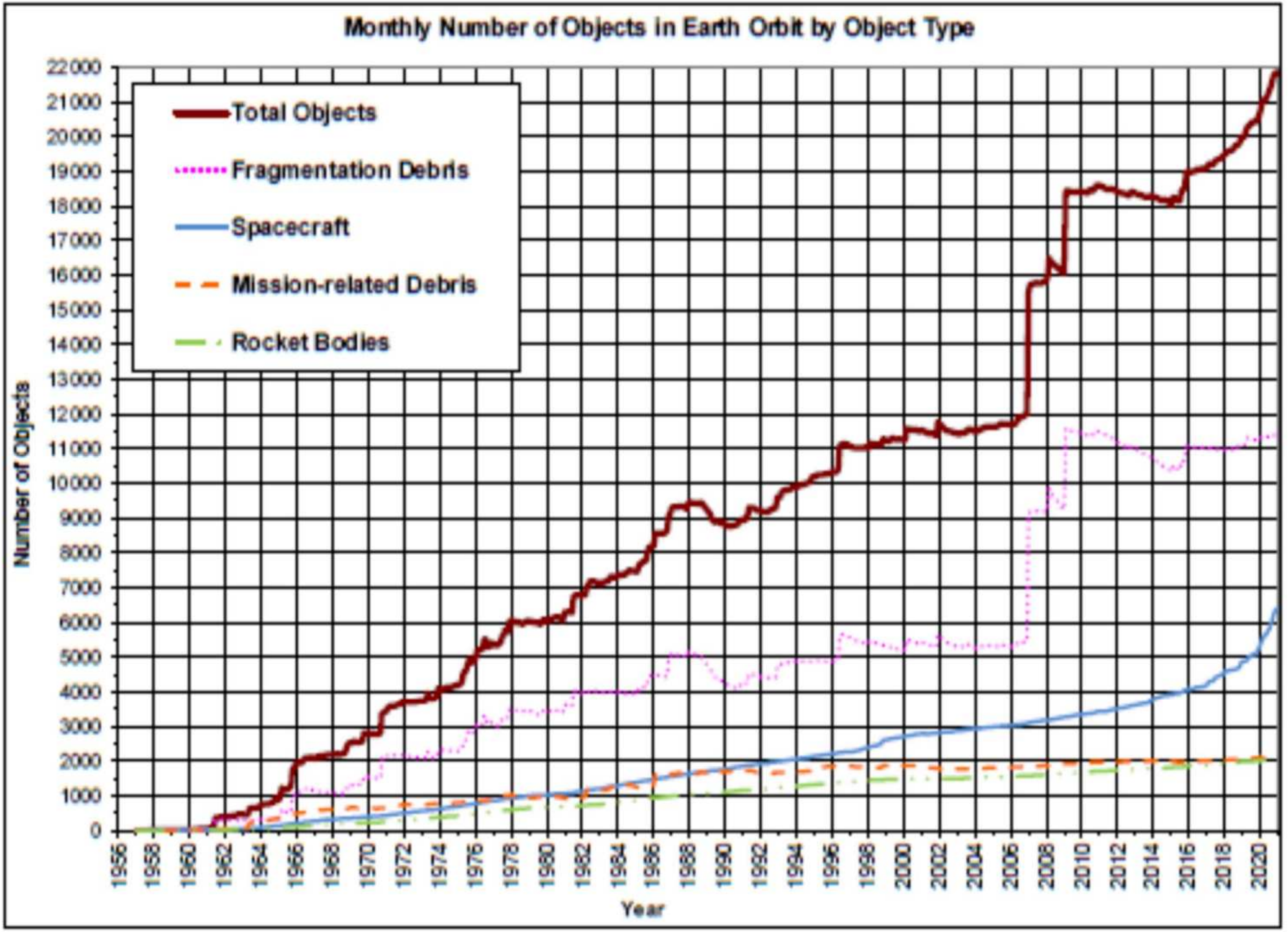
Space Debris

Space Debris in motion

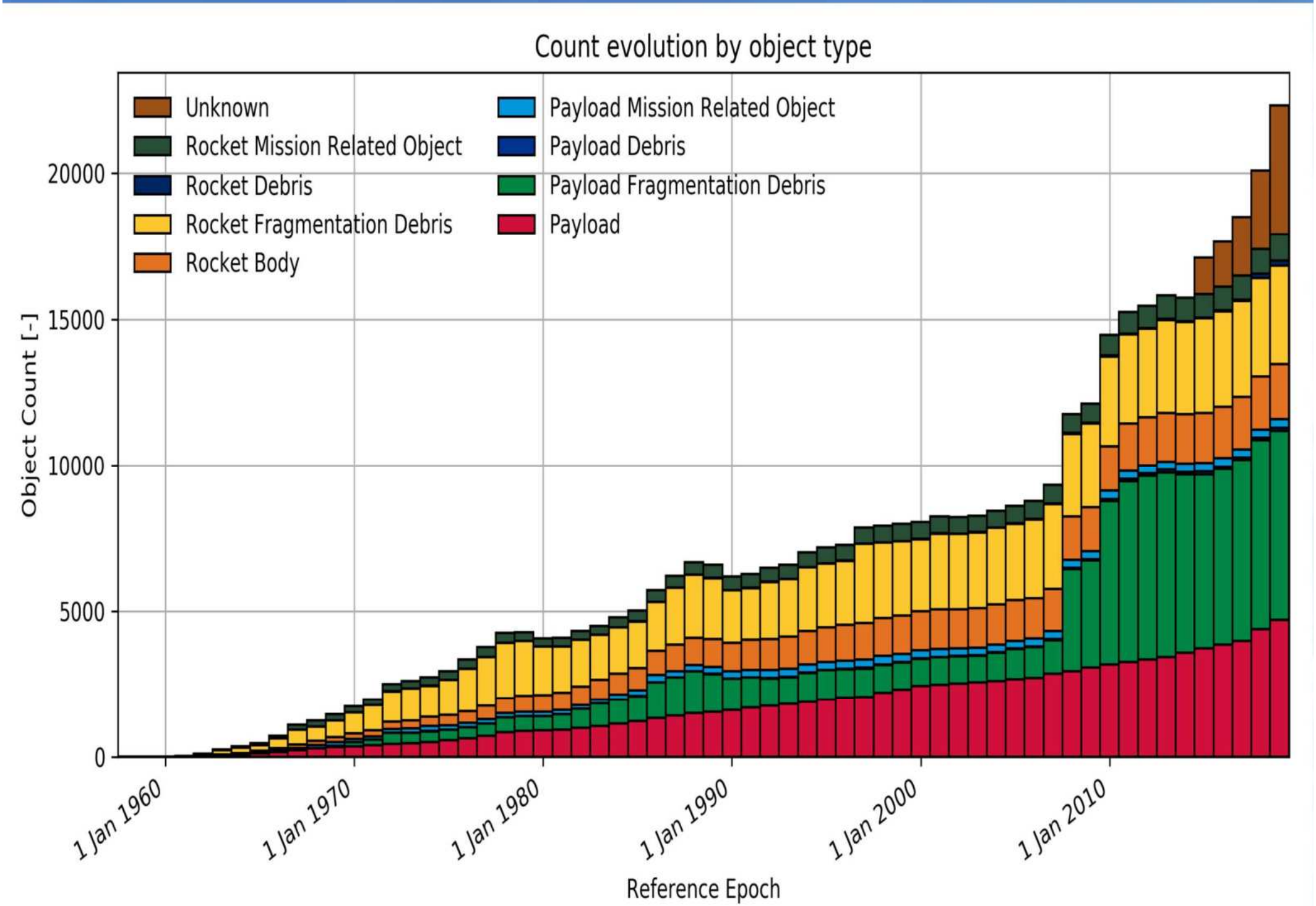
Sources of Space Debris

- **Mission related - Satellites, Rocket bodies**
- **Accidental – Satellite break-ups, On-Orbit Collisions, Drop-outs from astronaut's extra-vehicular activities**
- **Intentional or Avoidable – ASAT tests, Intentional Destructions, Abandonment of space objects in LEO, launching of Space Objects non-compliant to UN debris mitigation measures, micro and small satellites … …**


UNITED NATIONS
Office for Outer Space Affairs
esa
#SpaceCare
SATELLITES VS DEBRIS
2700 working satellites share their orbits with 8800 tonnes of space debris
Debris objects travel many kilometres per second. In case of impact, they may destroy working satellites
2700
26 000 tracked objects
≈ 1950
discarded rocket stages
≈ 128 million
debris fragments
1 mm–1 cm in size
≈ 2850
defunct satellites
≈ 900 000
fragments
1–10 cm in size
≈ 21 000
unidentified debris objects and fragments
≈ 34 000
fragments larger than 10 cm
About 26 000 debris objects are monitored from Earth
Smaller objects that cannot be monitored estimated by statistical models
#SpaceSustainability
©Gopal
Up-to-date as of December 2020



Orbital Debris- Quarterly news- Feb 2021- NASA



Source: ESA- Space Debris Office

Recent Space Debris Break up

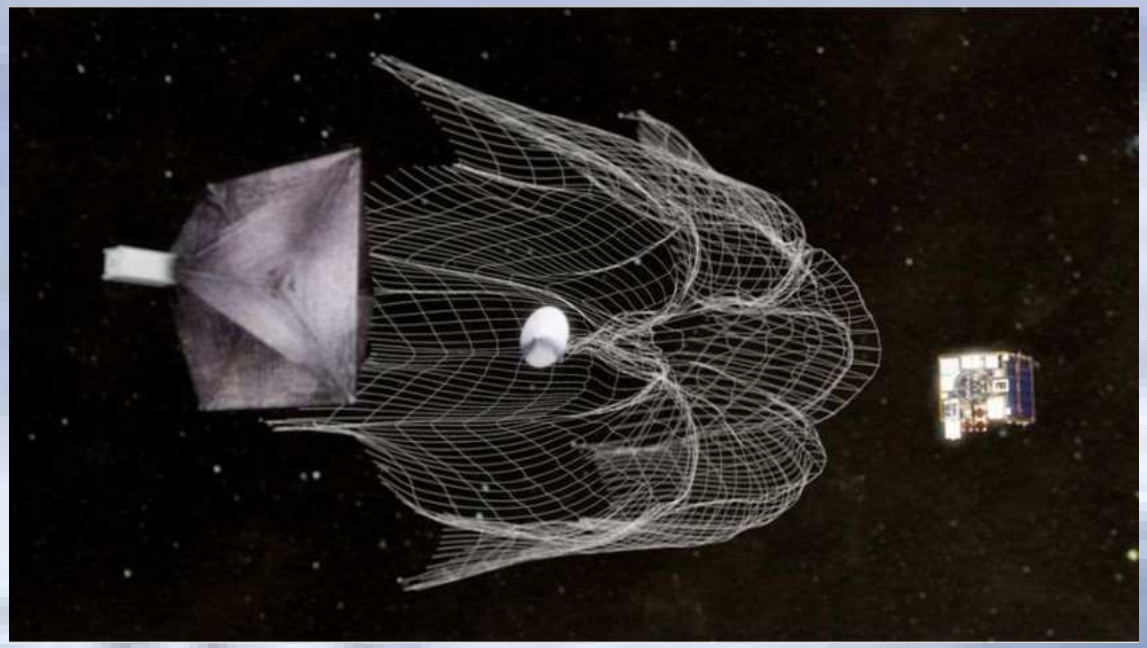
SPACENEWS

Decommissioned NOAA weather satellite breaks up

by Jeff Foust — March 20, 2021

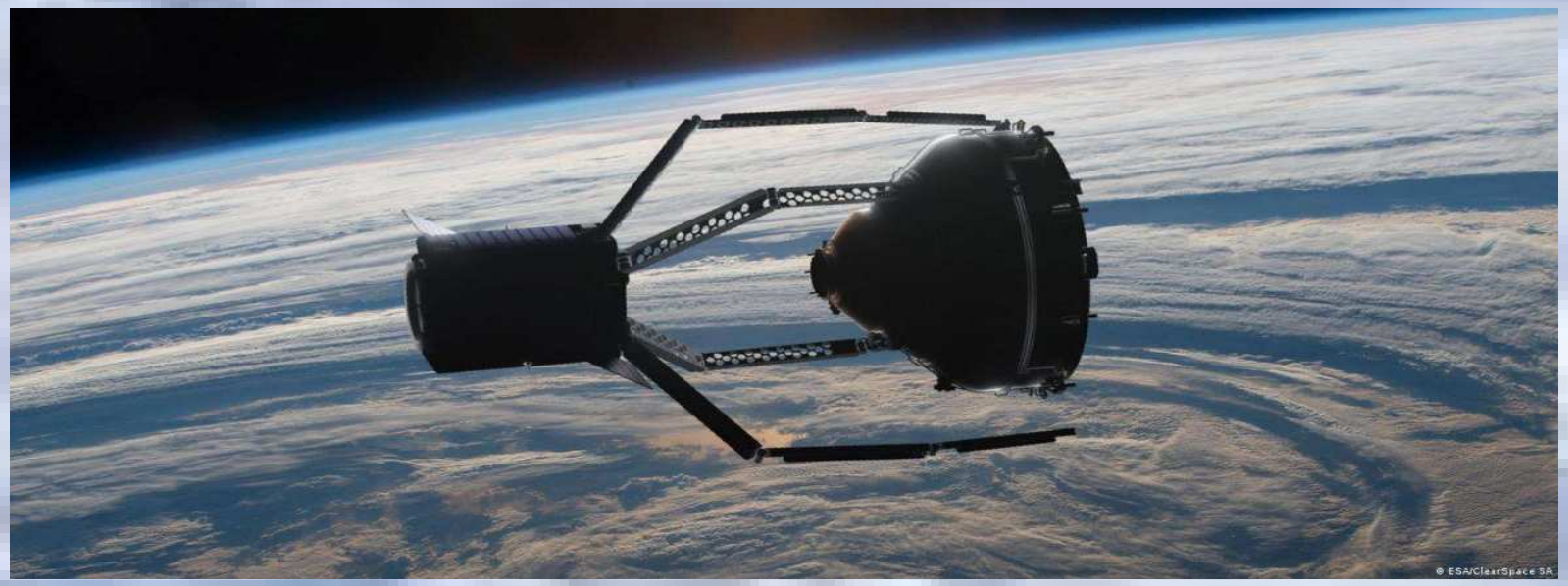
NOAA- M Spacecraft launched June 2002 - Decommissioned in April, 2013 – Break-up on March 20, 2021

Active Debris Removal Technologies



- **The RemoveDEBRIS platform developed by a technical team led by Surrey Space Centre at the University of Surrey, UK was launched to the International Space Station by Space X rocket in 2018.**
- **RemoveDEBRIS carried out a test of its onboard vision-based navigation (VBN) system on Sunday 28 October, 2018.**
- Video Link: https://www.bbc.com/news/science-environment-45565815

Space Tug Experiment by China

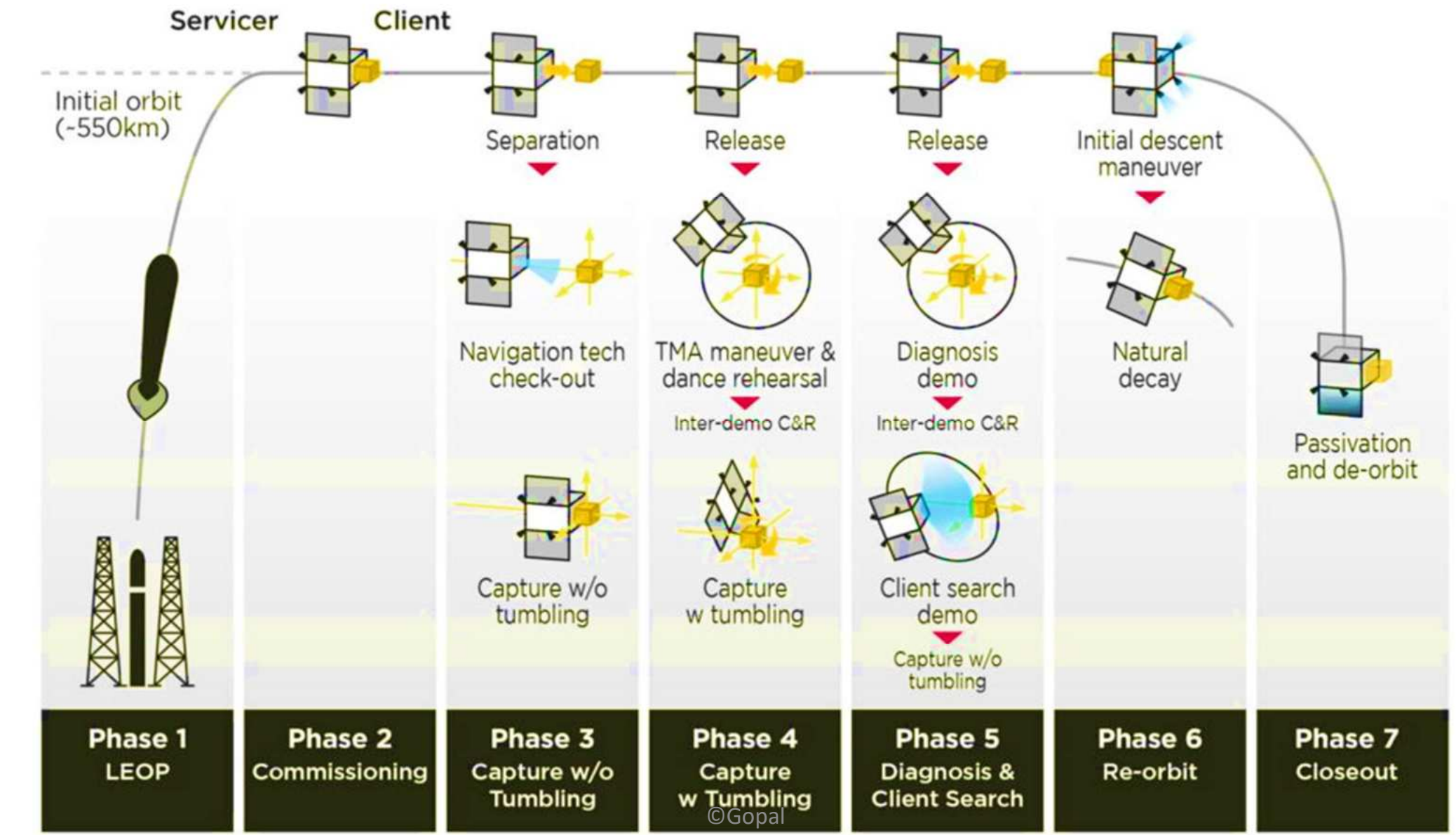


- A Chinese satellite SJ-21 (2021) changed its Geo orbital position and grabbed another long-dead satellite, (Compass –G2) (2009) and days later threw it into a "graveyard" orbit 300 km away.
- A dual use technology demonstrated by China

Active Debris Removal Technologies- ELSA-D

- M/s. ASTROSCALE, Japan/ USA, Launched a satellite, for providing retrieval services for satellite operators.
- End-of –Life Services by Astroscale – Demonstration (ELSA-D) on Mar 22, 2021
- ELSA-D consists of two spacecraft: a servicer satellite (~175kg) and a client satellite (~17kg), launched stacked together.
- The servicer satellite has been developed to safely remove debris objects from orbit, equipped with proximity rendezvous technologies and a magnetic docking mechanism. The client satellite is a piece of replica debris fitted with a ferromagnetic plate that enables the docking.
- The servicer repeatedly released and docked with the client in a series of technical demonstrations, proving the capability to find and dock with defunct satellites and other debris. Demonstrations include client search, client inspection, client rendezvous, and both non-tumbling and tumbling docking

ELSA-D Demonstration Techniques



On-Orbit Servicing by M/s. Northrop Grumman, USA in Feb-April, 2020

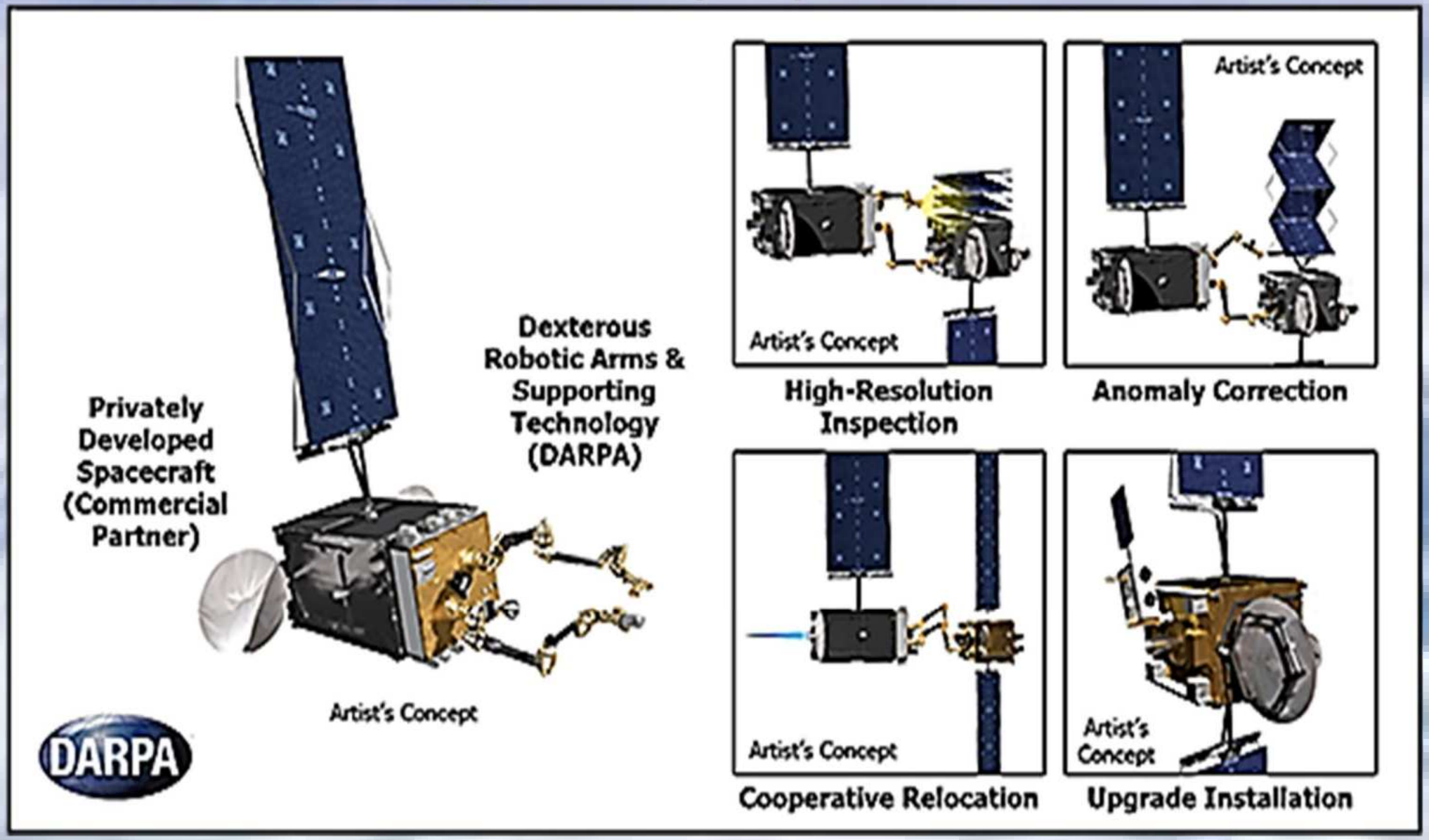
- **Intelsat 901 commercial communication satellite launched in June 2001, placed at 342 Deg East on Geo-Stationary Orbit –Became non-functional in 2019 due to depletion of fuel.**
- **Mission Extension Vehicle (MEV) was launched by Northrop Grumman on October 09, 2019 docked with client satellite Intelsat 901 (IS-901) on February 25, 2020-**
- **Intelsat 901 successfully returned to service on April, 02, 2020**

Youtube link- ***https://www.youtube.com/watch?v=XBOQSRZSFgs***

Robotic Servicing of Geosynchronous Satellites (RSGS)

- DARPA's Robotic Servicing of Geosynchronous Satellites (RSGS) program is intended to develop technologies that would enable cooperative inspection and servicing in GEO and demonstrating those technologies on orbit.
- Under the RSGS vision, a DARPA-developed modular toolkit, including hardware and software, would be joined to a privately developed spacecraft to create a commercially owned and operated robotic servicing vehicle (RSV) that could make house calls in space.

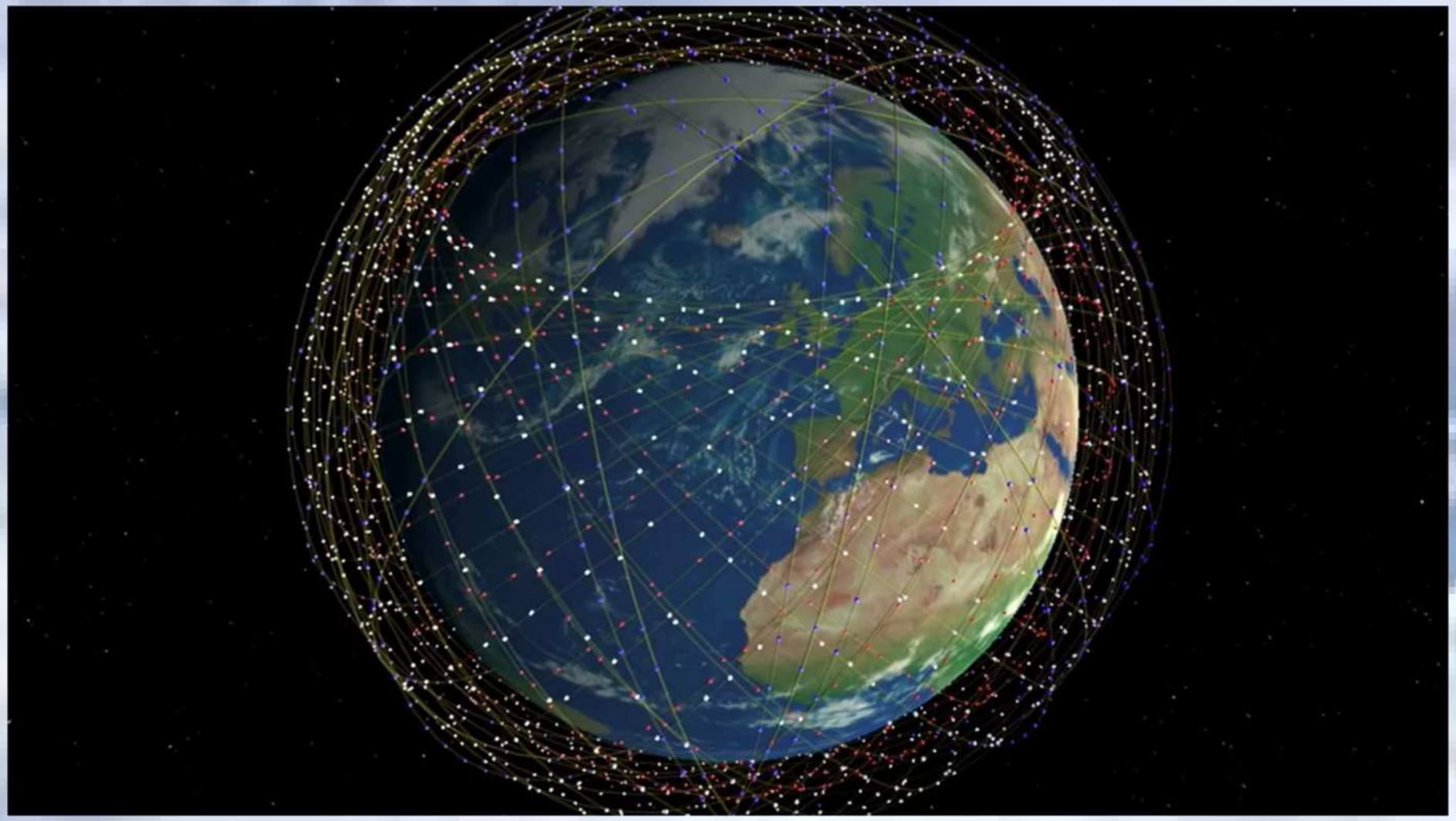
Robotic Servicing Vehicle (RSV) & Envisioned Missions



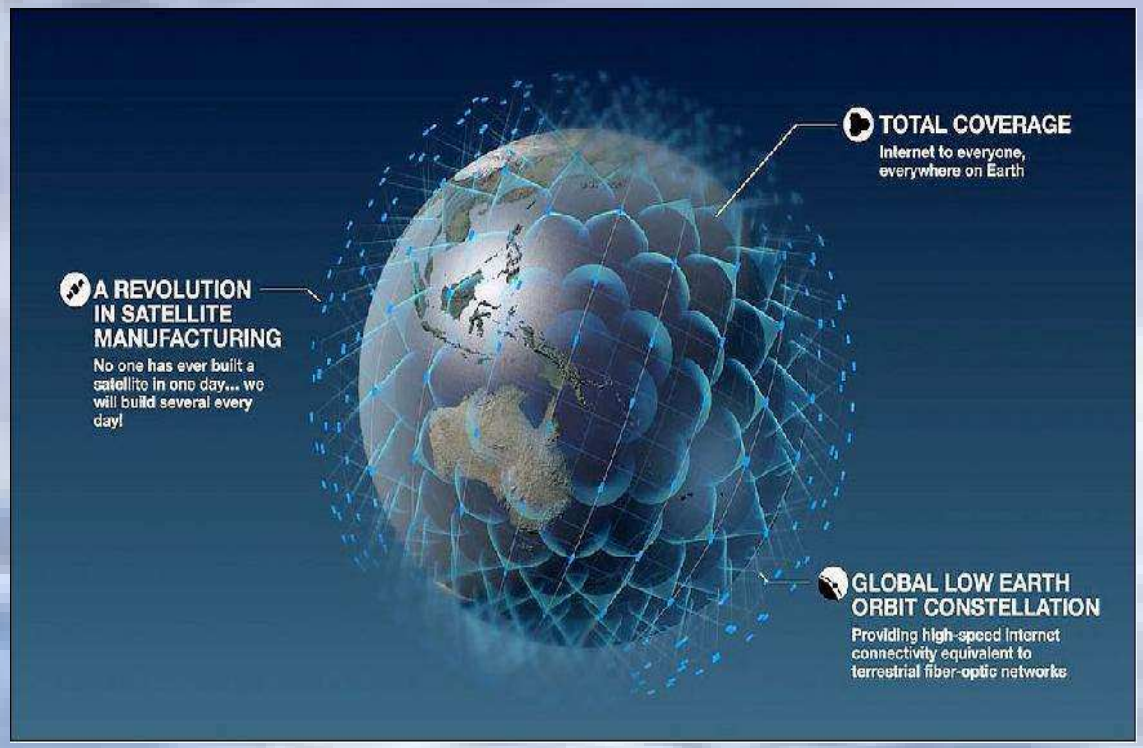
Source: https://www.darpa.mil/program/robotic-servicing-of-geosynchronous-satellites

Small / Nano Satellite Constellations

Proposed Starlink Satellite Constellation

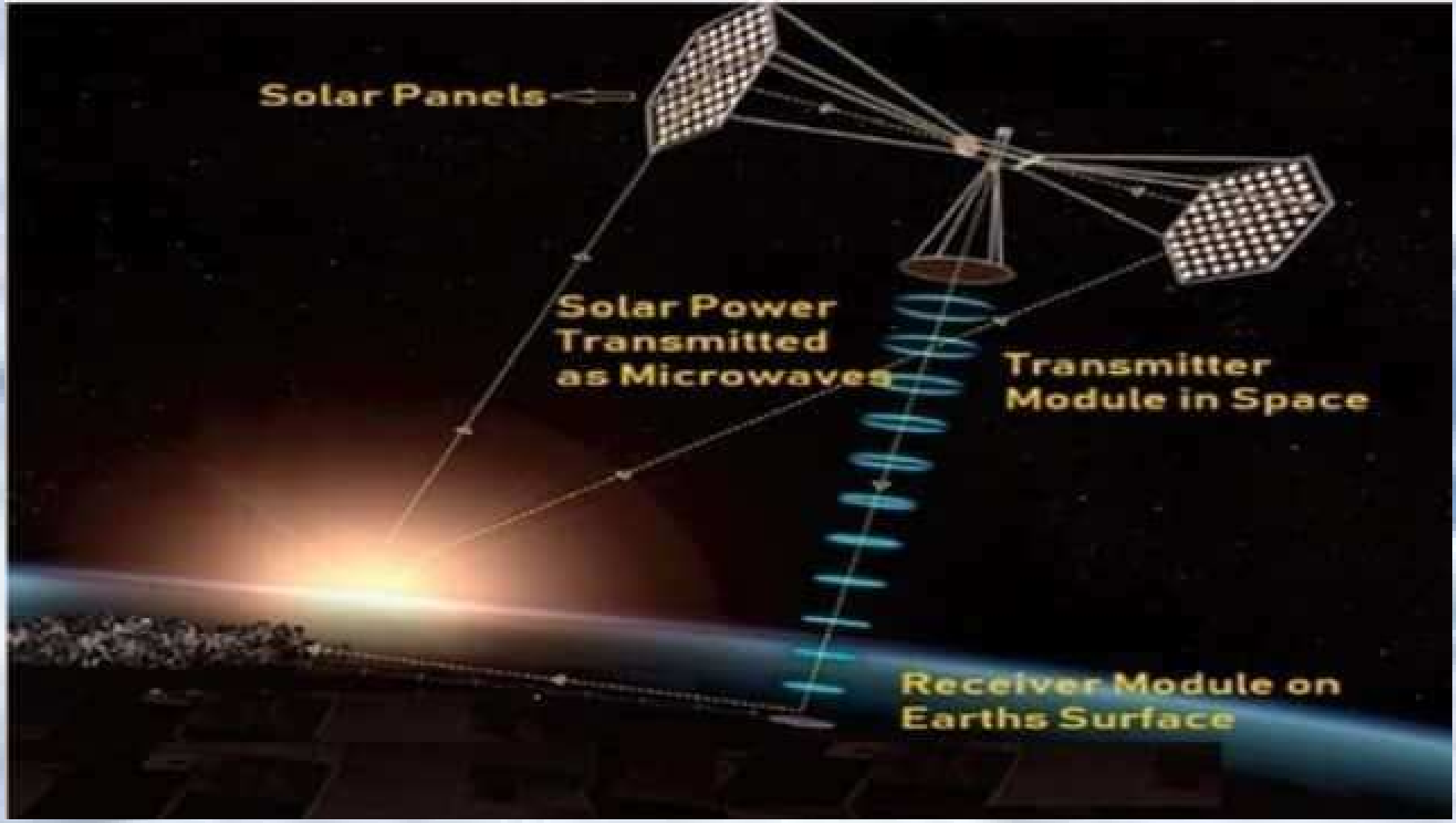


One Web Constellation



- **OneWeb intends to cover the Earth with a nominal constellation of 648 LEO mini satellites built by Airbus Defence and Space (image credit: Airbus DS)**
- Of the constellation, 648 of them will be placed in18 orbital planes with an altitude of about 1200 km. ..(Source : eoPortal Directory- https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/oneweb
- On October 23, 2022 – ISRO's LVM 3 launched 36 satellites of Oneweb
- This is OneWeb's 14th launch, bringing the constellation to 462 satellites.

Solar Power Satellites

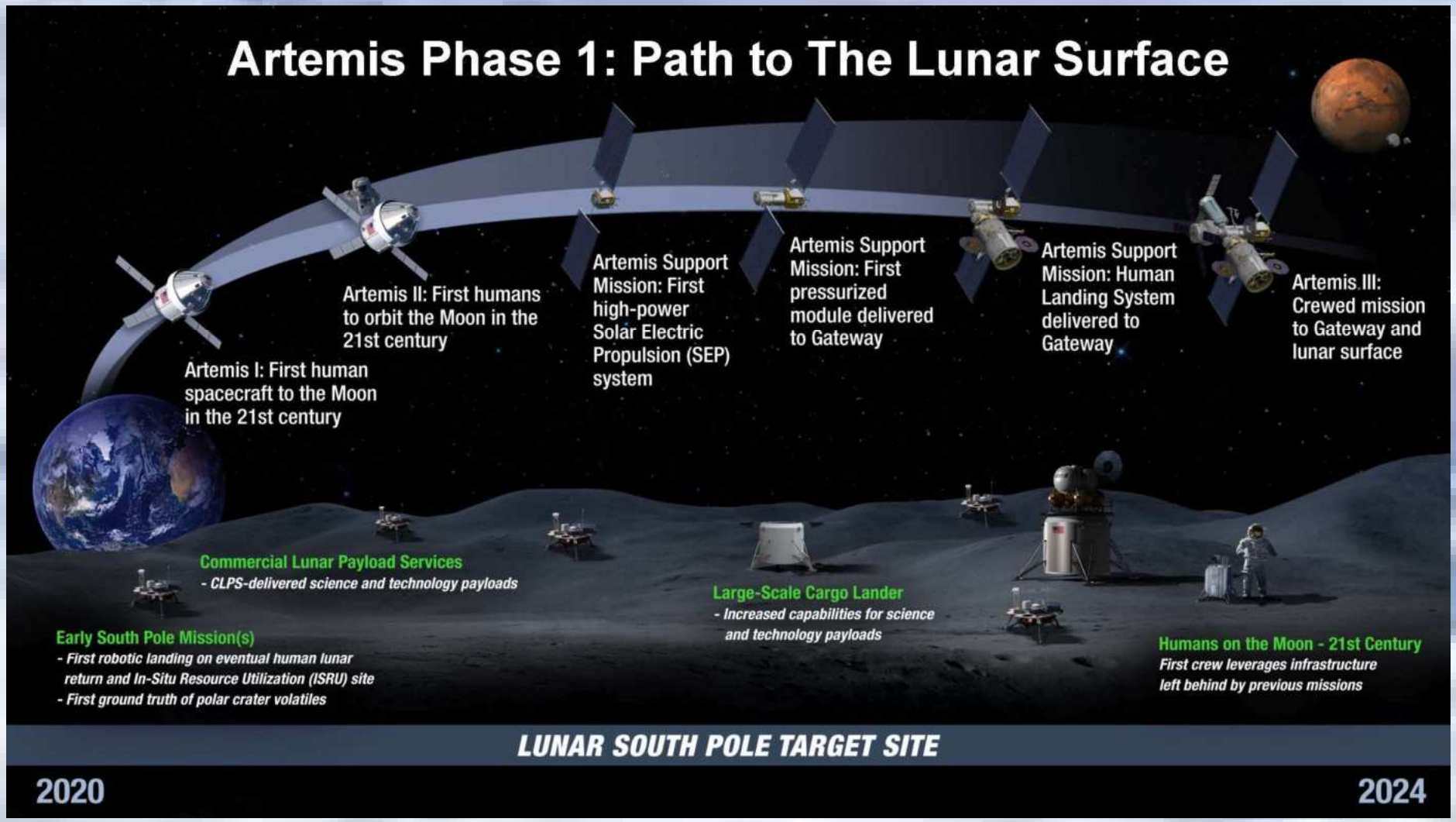


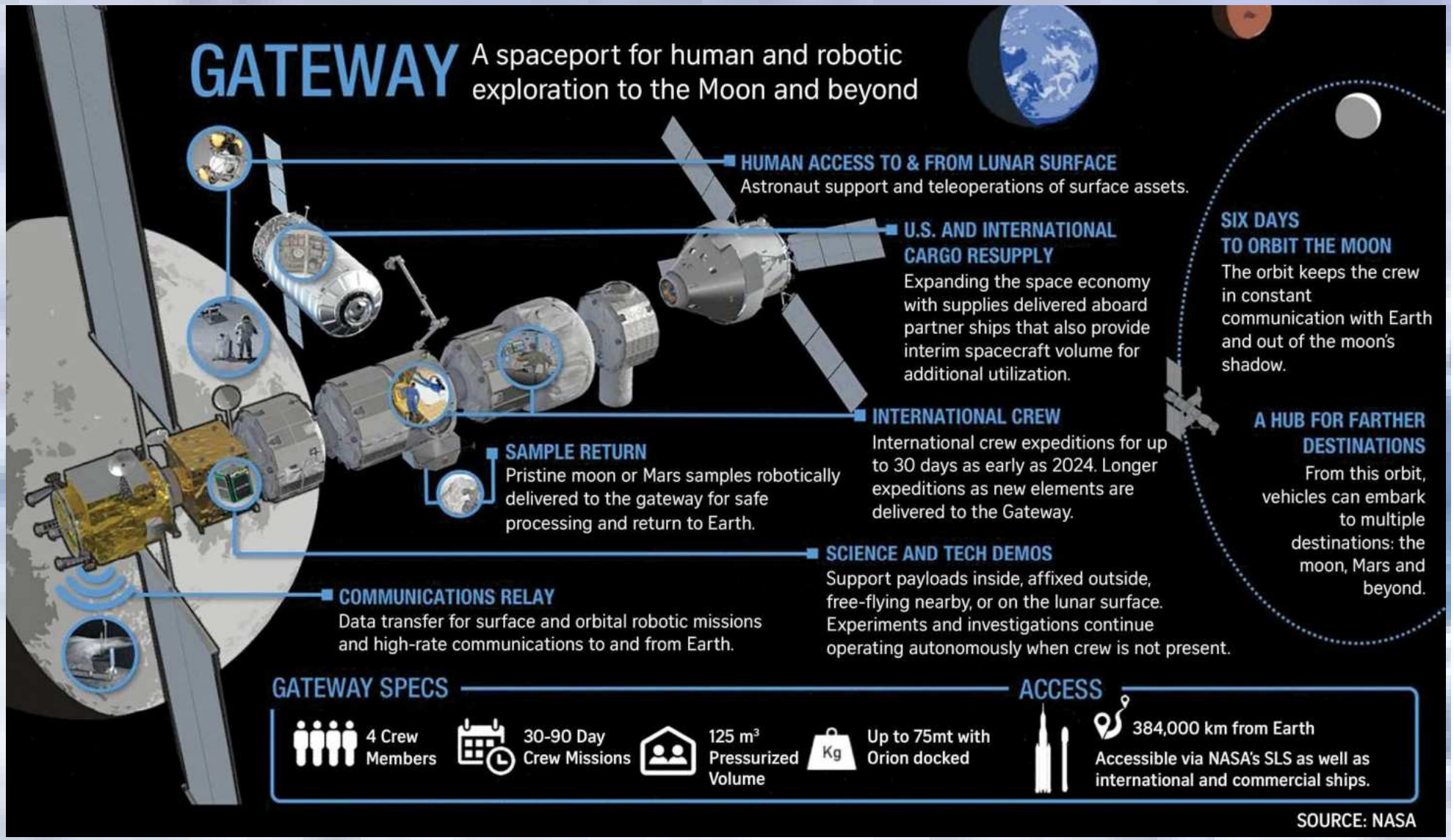
Issues & Challenges of SPS

- Radio frequency interference and electromagnetic interference
- Need for better standards coordination between ITU, energy industries, and national administrations responsible for the regulation of electrical power grids
- New frequency allocations
- Health standards for SBSP system related emissions
- Coordination of orbital assignments for SBSP systems vis à vis telecommunications and other application satellites
- Orbital Debris Build up

Space Resources Utilization

ARTEMIS Program



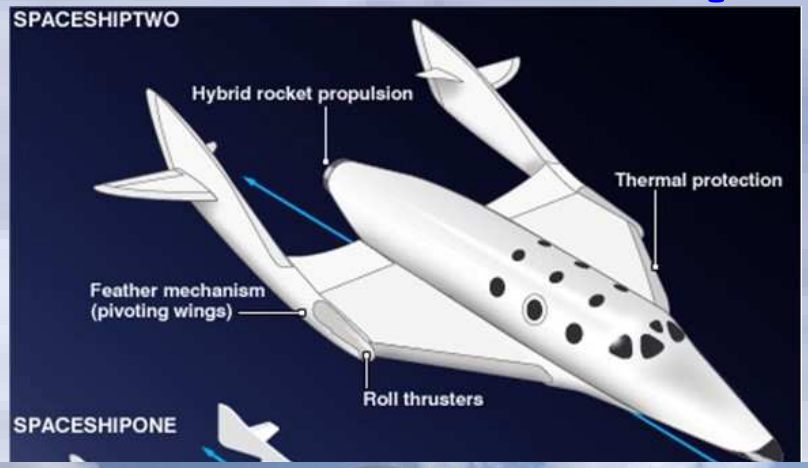

GATEWAY
A spaceport for human and robotic exploration to the Moon and beyond
HUMAN ACCESS TO & FROM LUNAR SURFACE
Astronaut support and teleoperations of surface assets.
U.S. AND INTERNATIONAL CARGO RESUPPLY
Expanding the space economy with supplies delivered aboard partner ships that also provide interim spacecraft volume for additional utilization.
SIX DAYS TO ORBIT THE MOON
The orbit keeps the crew in constant communication with Earth and out of the moon's shadow.
INTERNATIONAL CREW
International crew expeditions for up to 30 days as early as 2024. Longer expeditions as new elements are delivered to the Gateway.
A HUB FOR FARTHER DESTINATIONS
From this orbit, vehicles can embark to multiple destinations: the moon, Mars and beyond.
SAMPLE RETURN
Pristine moon or Mars samples robotically delivered to the gateway for safe processing and return to Earth.
SCIENCE AND TECH DEMOS
Support payloads inside, affixed outside, free-flying nearby, or on the lunar surface. Experiments and investigations continue operating autonomously when crew is not present.
COMMUNICATIONS RELAY
Data transfer for surface and orbital robotic missions and high-rate communications to and from Earth.
GATEWAY SPECS
4 Crew Members
30-90 Day Crew Missions
125 m³ Pressurized Volume
Kg
Up to 75mt with Orion docked
ACCESS
384,000 km from Earth
Accessible via NASA's SLS as well as international and commercial ships.
SOURCE: NASA

Lunar Gateway Program

- **Lunar Gateway program, an advanced planned mini-space station to orbit the moon and intended to serve as a home base for missions to the moon's surface, including the Artemis 3 mission to land the first woman and next man on the moon by 2024?!.**
- **From facilitating short-term missions, the station will evolve and pioneer what will become the first sustainable human presence on the moon.**
- **Artemis Programme to facilitate NASA to land the first woman and next man on the Moon by 2024, using innovative technologies to explore more of the lunar surface than ever before. The learning through Artemis programme, to take the next giant leap of sending astronauts to Mars.**

Space Tourism

Space Tourism



Space Tourism Flights in 2021

- Blue Origin – Jeff Bezos
  - NS-16 on July 20, 2021, NS -18 on October 13, 2021; NS -19 on December 11, 2021 NS-19 on Jeff Bezos – Blue Origin flights -
- Virgin Galactic - Richard Branson-
  - Unity 21 May 22, 2021: Unity 22 on July 11, 2021
- SpaceX- Elon Musk
  - SpaceX Inspiration4 Mission on September 15, 2021; 4 Non-Professional Astronauts flew
- ISS
  - October 05, 2021: First Feature Film Shot In Space onboard ISS by Russian film crew
- Soyuz
  - MS-20 Mission on December 08, 2021: Japanese billionaire and online fashion tycoon Yusaku Maezawa, his production assistant flew

Source: https://news.abplive.com/science/how-space-tourism-took-flight-in-2021-check-out-the-list-of-all-commercial-spaceflight-missions-1499432

Counter -Space Technologies

Space weapons

- Kinetic and non-kinetic Earth-to-space weapons like DA-ASATS, jammers, dazzlers, and cyberattacks
- Kinetic and non-kinetic space-to-space weapons like on-orbit projectiles or microwaves
- Kinetic and non-kinetic space-to-Earth weapons like jammers, lasers, or projectiles that come down from orbit.

Types of Space Weapons

- Kinetic Physical
  - Direct-Ascent ASAT
  - Co-orbital ASAT
  - Ground Station Attack
- Non- Kinetic Physical
  - High Altitude Nuclear Detonation
  - High Powered laser
  - Laser Dazzling or Blinding
  - High Powered Microwave

Types of Space Weapons

- Electronic
  - Uplink Jamming
  - Downlink Jamming
  - Spoofing
- Cyber
  - Data Intercept or Monitoring
  - Monitoring Data
  - Seizure of Control

Global Assessment of Counter Space Capabilities

	China	Russia	U.S.	France	India	Iran	Japan	North Korea
LEO Co-Orbital	Y	G	Y	R	R	R	R	R
MEO/GEO Co-Orbital	Y	Y	Y	R	R	R	R	R
LEO Direct Ascent	G	Y	Y	R	Y	R	R	R
MEO/GEO Direct Ascent	Y	Y	Y	R	R	R	R	R
Directed Energy	Y	Y	Y	Y	R	R	R	R
Electronic Warfare	G	G	G	Y	Y	Y	R	Y
Space Situational Awareness	G	G	G	Y	Y	Y	Y	R

Legend: none R some Y significant G

Source: 'Global Counter Space Capabilities – An Open-Source Assessment', Secure World Foundation, April 2021

THE UNITED STATES

LEGEND: NONE SOME SIGNIFICANT UNCERTAIN "?" NO DATA "-"

	R&D	TESTING	OPERATIONAL	USE IN CONFLICT
LEO DIRECT ASCENT	SIGNIFICANT	SOME	-	NONE
MEO/GEO Direct Ascent	-	-	-	NONE
LEO Co-Orbital	SOME	?	-	NONE
MEO/GEO Co-Orbital	SOME	?	-	NONE
Directed Energy	SIGNIFICANT	SOME	?	NONE
Electronic Warfare	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT
Space Situational Awareness	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT

CHINA

LEGEND: NONE SOME SIGNIFICANT UNCERTAIN "?" NO DATA "-"

	R&D	TESTING	OPERATIONAL	USE IN CONFLICT
LEO DIRECT ASCENT	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	NONE
MEO/GEO Direct Ascent	SOME	SOME	-	NONE
LEO Co-Orbital	SOME	?	-	NONE
MEO/GEO Co-Orbital	SOME	-	-	NONE
Directed Energy	SIGNIFICANT	SOME	-	NONE
Electronic Warfare	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	?
Space Situational Awareness	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	?

INDIA

LEGEND: NONE SOME SIGNIFICANT UNCERTAIN "?" NO DATA "-"

	R&D	TESTING	OPERATIONAL	USE IN CONFLICT
LEO DIRECT ASCENT	SOME	SOME	-	NONE
MEO/GEO Direct Ascent	-	-	-	NONE
LEO Co-Orbital	-	-	-	NONE
MEO/GEO Co-Orbital	-	-	-	NONE
Directed Energy	SOME	?	-	NONE
Electronic Warfare	?	?	?	?
Space Situational Awareness	SOME	SOME	?	?

Legal Issues

Space Debris

Article IX of OST

- In the exploration and use of outer space, including the moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space, including the moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty.
- States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extra-terrestrial matter and, where necessary, shall adopt appropriate measures for this purpose. If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. ... ...

Space Debris Mitigation Guidelines

- United Nations Space Debris Mitigation Measures Guidelines – 7 Guidelines
  - Limit Debris released during normal operations
  - Minimize the potential for break-ups
  - Limit probability of accidental collisions in orbit
  - **Avoidance of intentional destructions**
  - Minimize potential for post-mission break-ups
  - Limit long term presence of space objects after EOL
  - Limit long-term interference of space objects with GEO region at EOL
- **Effectiveness of Mitigation Guidelines**
  - Soft Law - For voluntary implementation -Legally Non -Binding
  - Offers neither incentives for compliance nor penalty for non-compliance
  - Not effective to control the existing debris population – *Kessler Effect*

Space Debris – *Remedial Measures*

- Alternate Measures
  - Active Removal of Debris
  - On-Orbit Satellite Servicing
- Challenges
  - Technology – Development – Demonstration
  - High Cost – Sharing - International co-operation
  - Policy – Consensus – Willingness
  - Legal – Liability – Dispute Settlement

Space Debris – *Legal Issues*

- **Definitional issues**
  - **Space Object *Vs.* Space Debris : Functional *Vs.* Non-Functional**
- **Liability**
  - **Article VII of OST – Liability for damages**
  - **Article II & III of Liability Convention- Absolute and fault based liability**
- **State Responsibility**
  - **Article VI of OST – Internationally responsible for outer space activities- No Bar on Government or Non-Governmental activities**
  - **Article-VIII of OST- Jurisdiction and Control over space objects**
  - **Article-IX of OST – Due regards to interests of other states**

Active Debris Removal (ADR) – Legal Issues

- **Declaration of a Space Object as Space Debris**
  - Technical attempts for retrieval
  - Economic aspects – Cost of investment Vs. Returns through extended services
  - Past Experiences – Successful retrieval of spacecraft - Palapa B2, Galaxy -15, GOES-13
- **Abandonment of Space Objects**
  - State Responsibility – Art. VI of OST
  - Due Regards to Others interests – Art. IX of OST
  - Dereliction of ownership responsibility - Jurisdiction & Control - Art. VIII of OST
  - State Responsibility for Wrongful Act

Active Debris Removal (ADR) – Policy Issues

- **Technology Controls**
  - **Dual-Use Nature of Space Technology & applications**
- **Access to or Recovery of Abandoned space objects of one state by other technically competent state**
  - **Exposure of Systems, Technologies, Stored Data ...**
  - **Control Regimes- MTCR, Wassenaar Arrangement**
  - **Salvage value**
  - **Breach of Intellectual Property Rights**
  - **Motive for Removal – Operational Necessity or Self Defence or Intentional**
- **Liability for Accidents during removal or recovery operations**

Small / Nano Satellite Constellations

Starlink Satellites in orbit

A train of SpaceX Starlink satellites are visible in the night sky in this still from a video captured by satellite tracker Marco Langbroek in Leiden, the Netherlands on May 24, 2019, just one day after SpaceX launched 60 of the Starlink internet communications satellites into orbit. (Source: Space.com; Image: © Marco Langbroek via SatTrackBlog)

Space Traffic Management

- **European Satellite Dodges Potential Collision with SpaceX Starlink Craft**

- **The European Space Agency's (ESA) Aeolus Earth Observation satellite fired its thrusters as an evasive maneuver on Sept. 2, 2019 to make sure it didn't collide with one of SpaceX's recently launched internet craft.**
- **Prior warnings/ Negotiations Failed**
- **ESA Calls for Space Traffic rules**

ITU-Regulatory Procedures for Small Satellites

Regulatory Procedures
for Amateur-Satellite Service

- API must be submitted to ITU before coordinating frequency with IARU
- Note that frequency assignments in notification must be covered by frequency bands in API, therefore avoid submitting a very narrow frequency band at the API, in case there is a change needed during the comments/consultation process
- Administrations authorizing space stations in the amateur-satellite service shall ensure that sufficient earth command stations are established before launch to ensure that any harmful interference caused by emissions from a station in the amateur-satellite service can be terminated immediately (see No. **25.11**)
- Amateur-satellite service is exempted from cost recovery fee (please refer to **DEC 482**)

Source of Extract: ITU Regulatory Procedures- Space Services Dept, radio Communications Bureau, ITUu

Space Resources Utilization

Relevant Articles in OST

- **Article – II of OST: Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.**
- **Article III of OST: States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding.**

Space Tourism

Legal Challenges of Space Tourism

- Air law Vs Space Law
- Legal Status of Space Tourists
- Authorization and State Responsibility
- Liability issues
- Environmental Issues
- Registration & Jurisdictional issues
- New law for Space Tourism?!

New Technologies

Non- Rocket Space Launch- Sling Shot

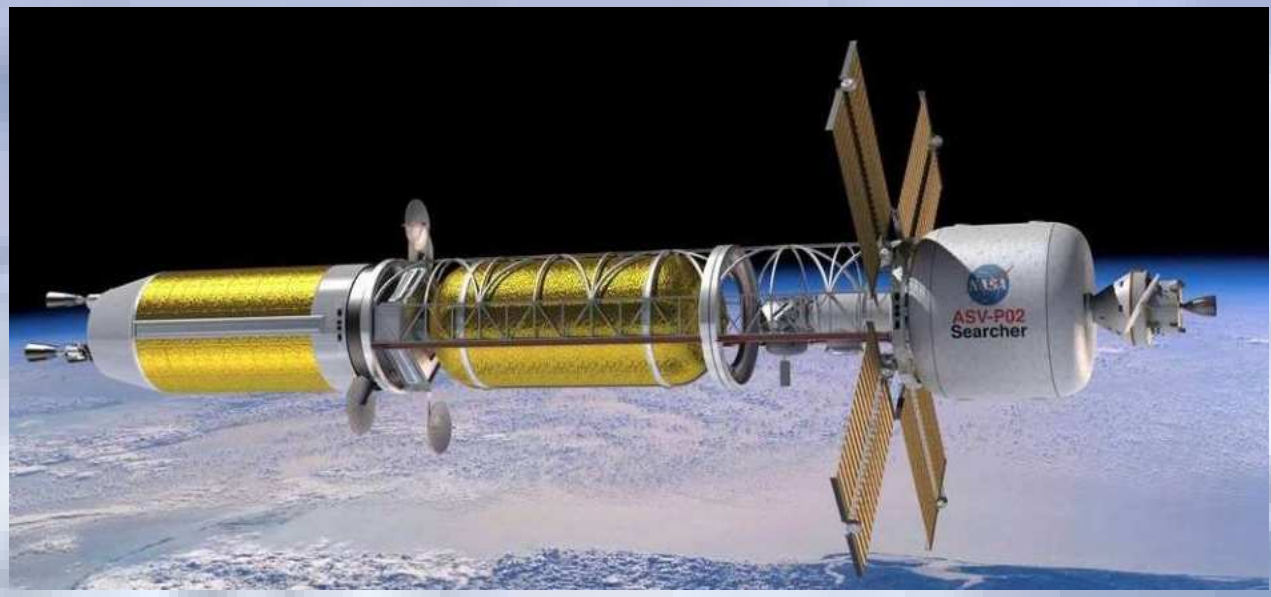
SpinLaunch, USA's Space Systems team has demonstrated satellites can be easily ruggedized for kinetic launch without compromising cost or increasing mass. ***(www.spinlaunch.com)***

On October 22nd, 2021, the Suborbital Accelerator was test launched

Kinetic energy is used as its primary method to get off the ground – with a vacuum-sealed centrifuge spinning the rocket at several times the speed of sound before releasing

Nuclear Propulsion Rockets

- Nuclear propulsion provides greater propellant efficiency as compared with chemical rockets.



- Nuclear thermal propulsion technology provides high thrust and twice the propellant efficiency of chemical rockets. The system works by transferring heat from the reactor to a liquid propellant. That heat converts the liquid into a gas, which expands through a nozzle to provide thrust and propel a spacecraft.
- Nuclear electric propulsion systems use a reactor to generate electricity that positively charges gas propellants like xenon or krypton, pushing the ions out through a thruster, which drives the spacecraft forward. Using low thrust efficiently, nuclear electric propulsion systems accelerate spacecraft for extended periods and can propel a Mars mission for a fraction of the propellant of high thrust systems.

3D Printed Rocket Engines

- 3D printing or Additive Manufacturing technology, uses heat-resistant metal alloys and prints layer by layer as the design of the rocket engine with intimate contours, fed to the system.
- It is revolutionising trial-and-error rocket development. Whole structures that would have previously required hundreds of distinct components can now be printed in a matter of days.
- Less manufacturing Cost with schedule advantage

Agniban engine manufactured by M/s Agnikul, Chennai

Iodine Electric Propulsion

A French Start-up company TrustMe has successfully powered a 20 kg cubesat satellite by iodine for the first time in Nov2020.

Iodine performed better than the traditional propellant of choice, xenon – highlighting iodine's potential utility for future space missions.

The iodine electric propulsion system firing in a vacuum chamber –M/s.*ThrustMe*

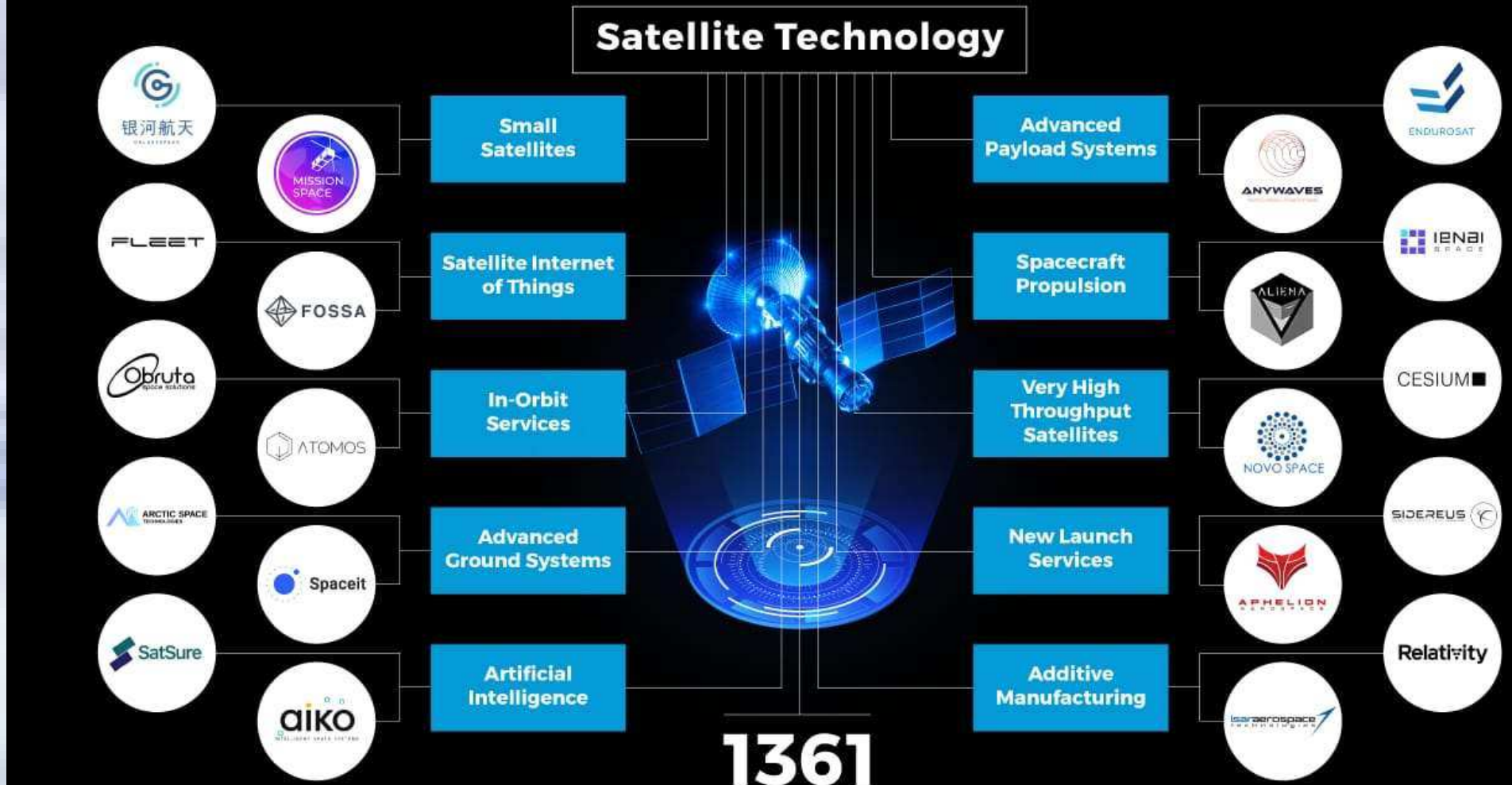
The propulsion system first heats up a solid block of iodine, turning it into a gas, which is bombarded with high-speed electrons, which turns it into a plasma of iodine ions and free electrons. Negatively charged hardware then accelerates the positively charged iodine ions from the plasma towards the system's exhaust and propels the spacecraft forwards

Currently, xenon is the main propellant used in electric propulsion systems, but the chemical is rare and expensive to produce

Green Propellants

- The propellants currently used for rocket propulsion are sold , liquid and Cryogenic . Of late, it has been realized that these propellants, especially hydrazine based liquid propellants are highly toxic and not environmental friendly during storage and rocket launch.
- Hence, to reduce air pollution during rocket launches much research has been done by various space agencies and space industry to develop space propellants that are environmental friendly (“green”) .
- Green propellants are generally easier and safer to handle than the conventional ones, and are expected to bring down the costs associated with propellant transport and storage.
- It will be more suitable for low cost micro-satellites and re- suable launches.
- ISRO will be using for Gaganyaan Mission.
- Indian start-up Bellatrix claim that they have successfully developed for satellites.

Top 10 Satellite Technology Trends & Innovations in 2022



Data provided by StartUs insights • November 2021

X-37 B Mission of USA

- An unmanned US space plane, known as Orbital Test Vehicle 6 has set its new endurance record after spending 908 days in orbit before landing on November 12, 2022.
- This is the sixth mission of the crewless reusable plane, built by Boeing and operated by the U.S. Space Force.
- It is used for U.S. military and NASA science experiments

Additional References

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- ***Thank you for your kind attention!***

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