Space Debris

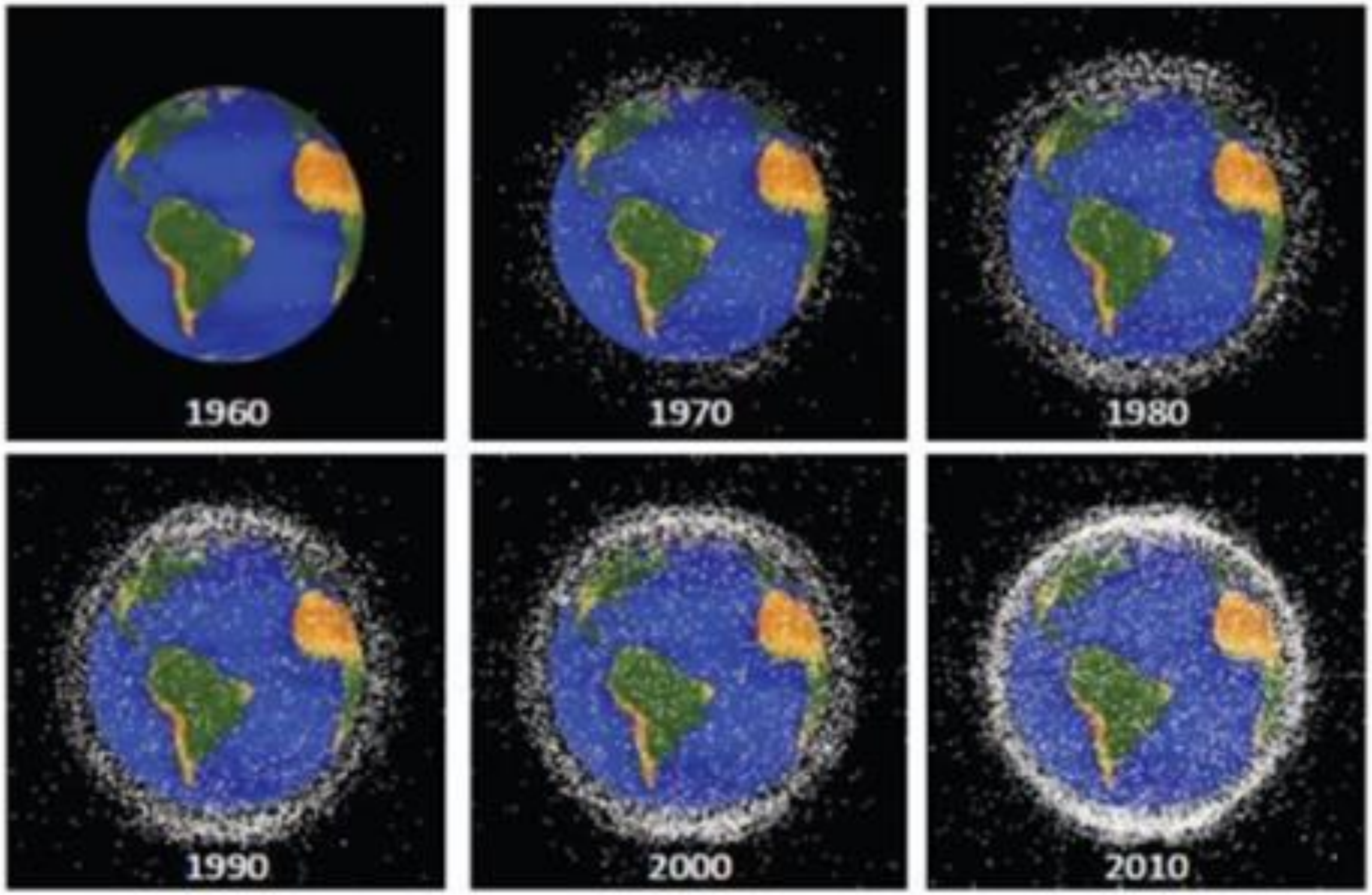
Technology and Finance of Space and Defense
26/10/2021
Alessandra Di Cecco, PhD

Outline

1. **State-of-the-Art**
    - Definition of Space Debris (SD)
    - Sources of SD
    - SD population characteristics (mass, orbits, etc)
    - Famous SD generation events
2. **Investigation methods**
    - Instruments (radio and optical telescopes)
3. **Problems related to SD**
    - Problems in orbit
    - Problems in Earth's atmosphere
4. **International programmes** *(next lecture)*
    - EU, ESA, COPUOS activities
    - Mitigation guidelines and Space Traffic Management

Space Debris

"SD all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional…"
(Inter-Agency Space Debris Coordination Committee)



Satellites and debris in low Earth orbit, 1960-2010. Courtesy NASA.

Sources of Space Debris

- ❑Non-functional spacecrafts

  (abandoned/old satellites) (large debris)

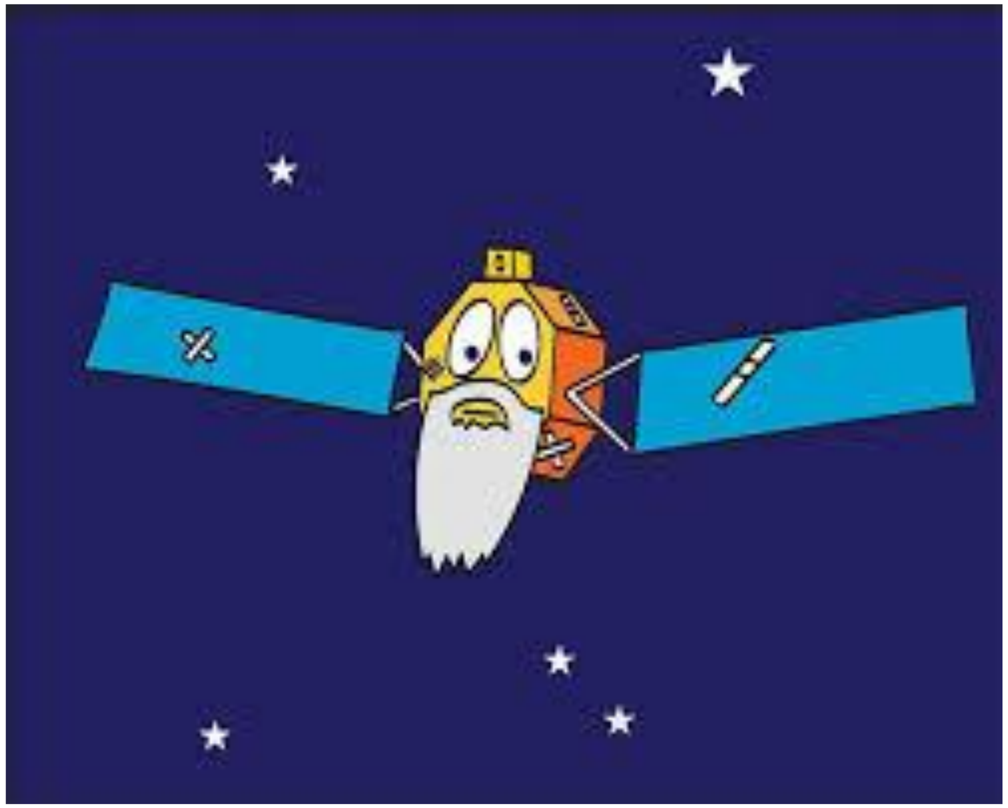
- ❑Rocket Bodies (large debris)

- ❑Mission-related objects (small debris)

- ❑Fragments (large or small debris)

Non-functional spacecrafts

- 6,100 launches since 1957
- 12,000 satellites released in space
- 7,500 already in space
- 4,700 still functioning



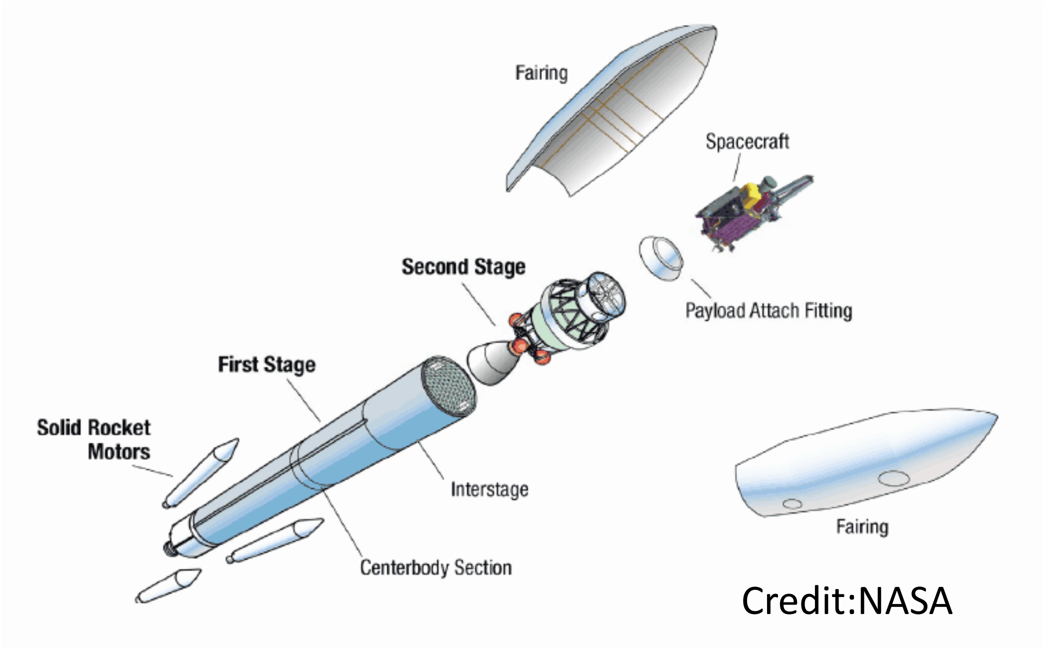
A class of SD is composed by abandoned satellites!

Rocket stages

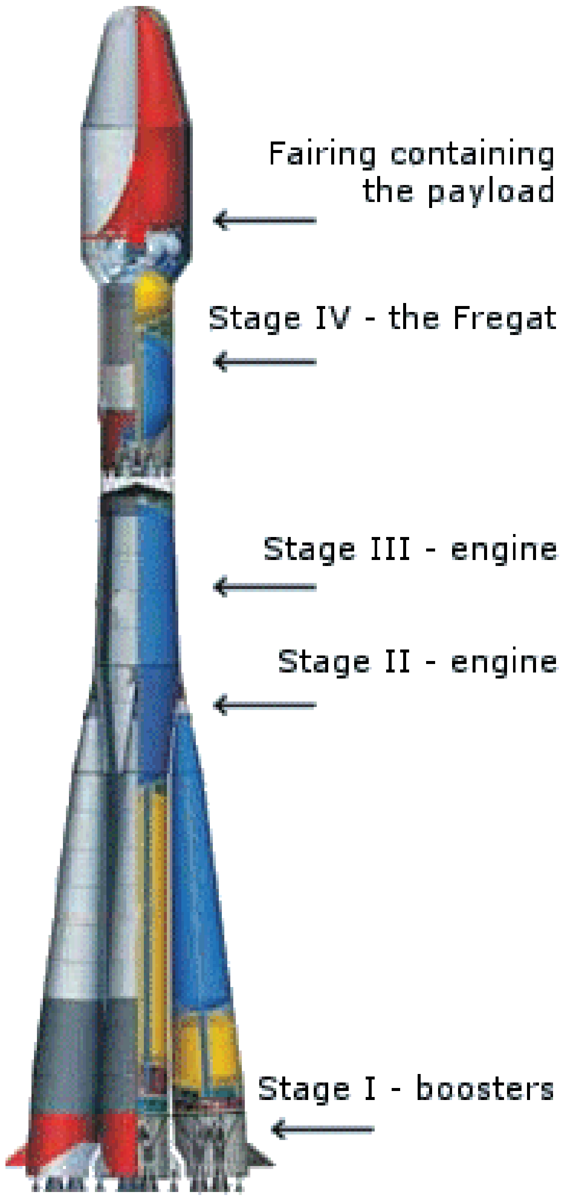
Rockets is composed by stages, each with its engine and propellant

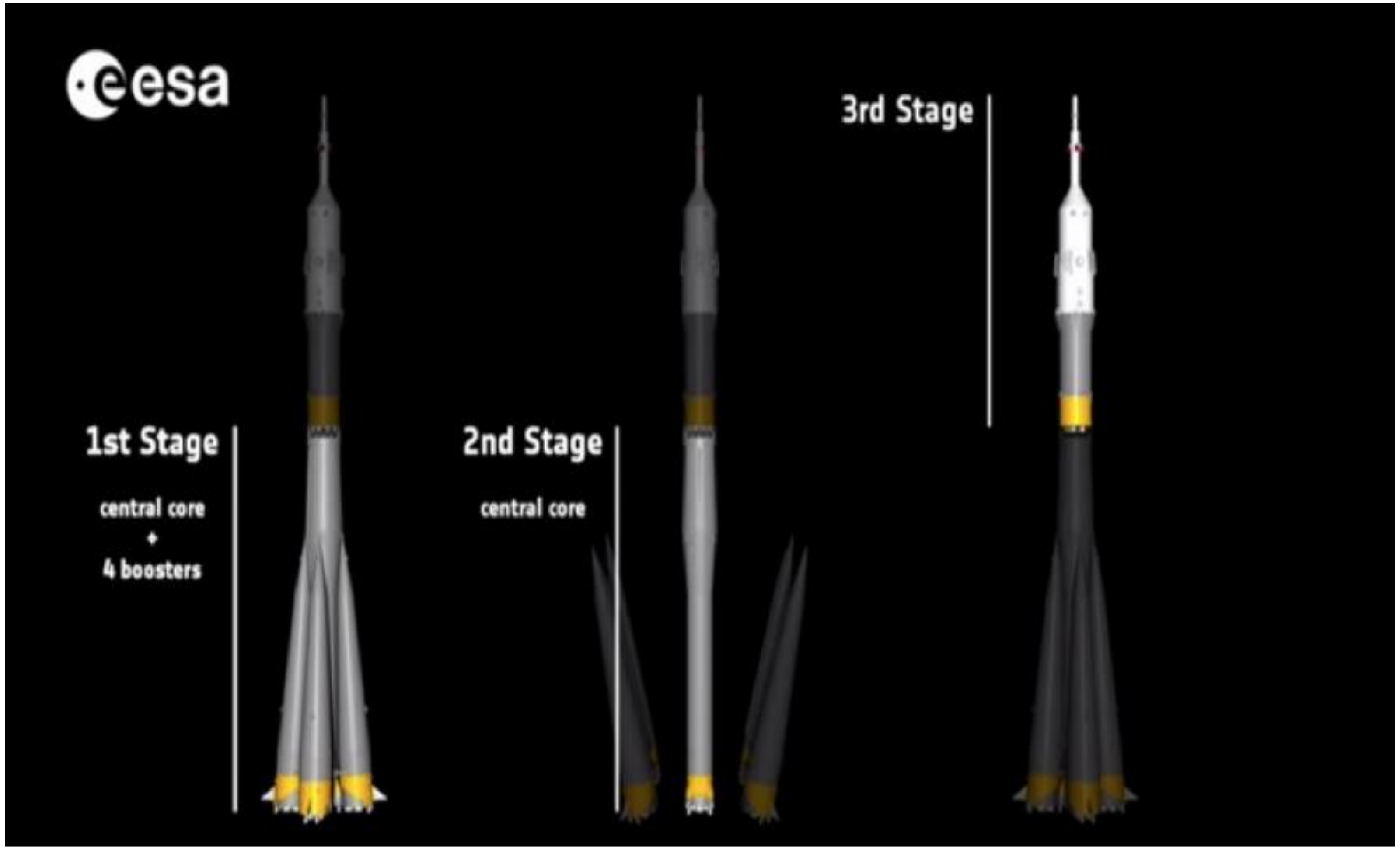
Rocket upper stages are released in orbits.

Rocket stages are large debris (> 1m)

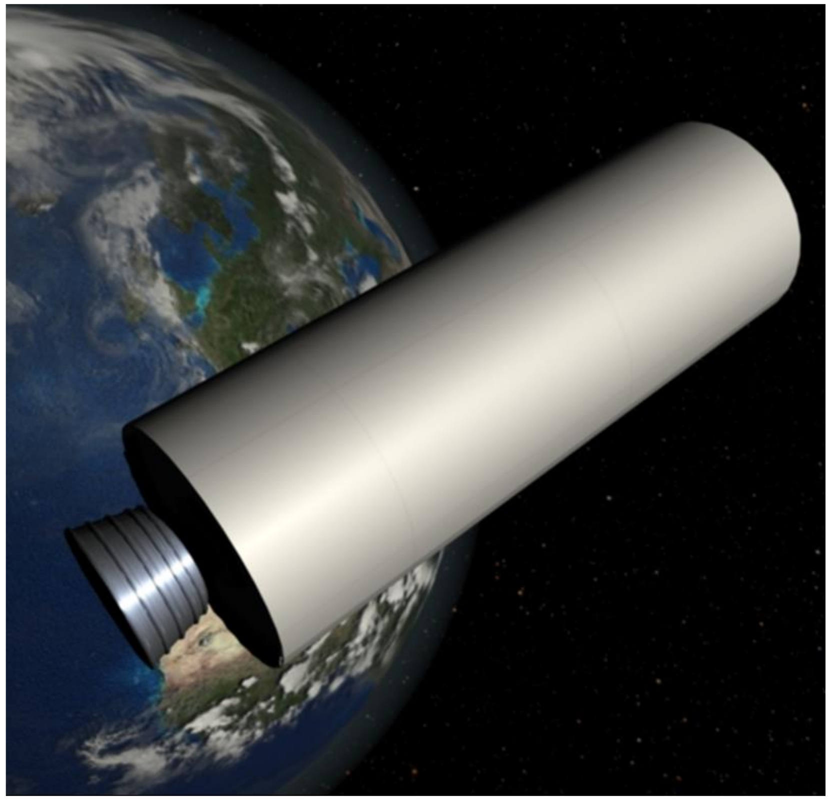


Credit:NASA

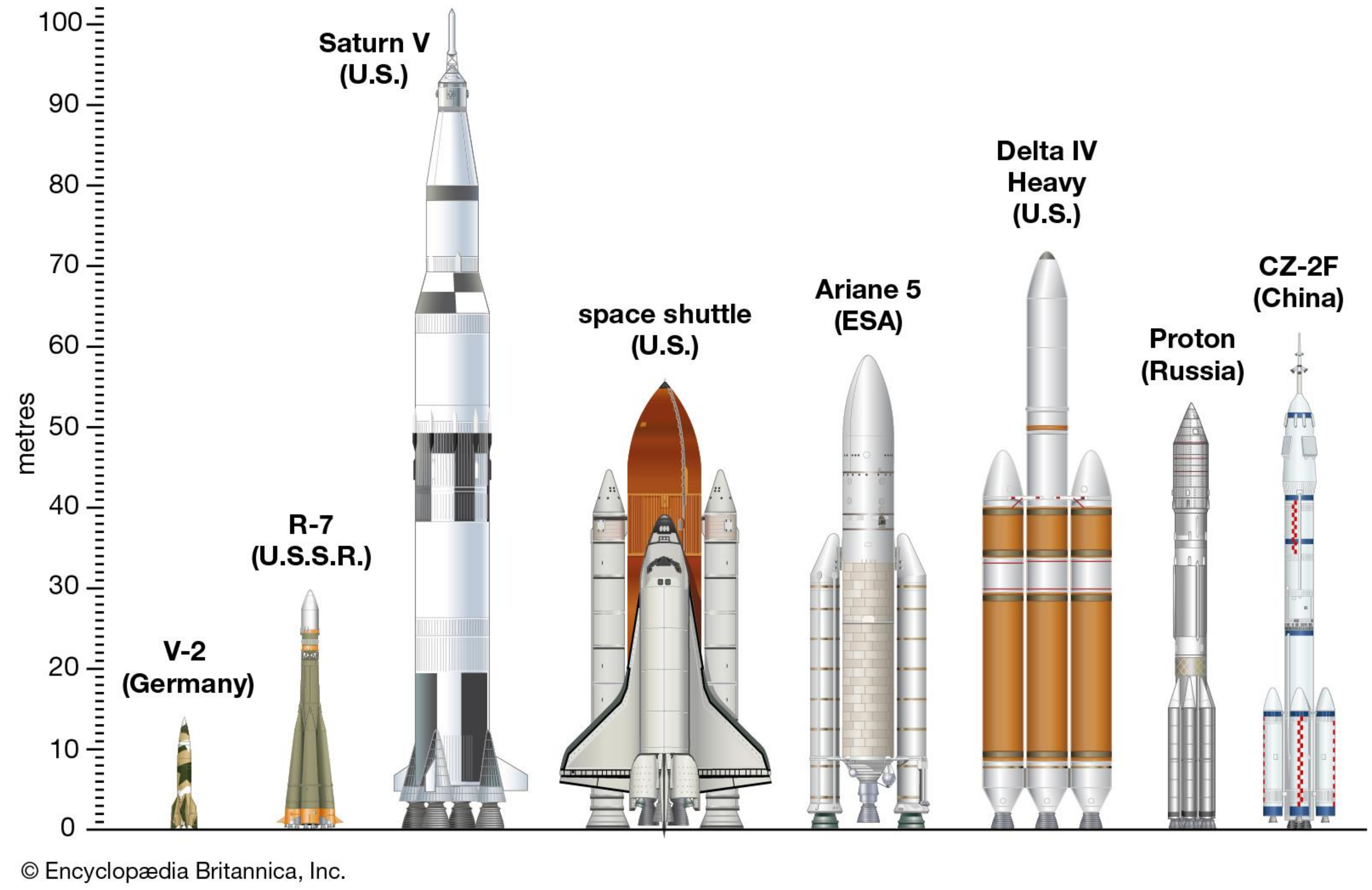




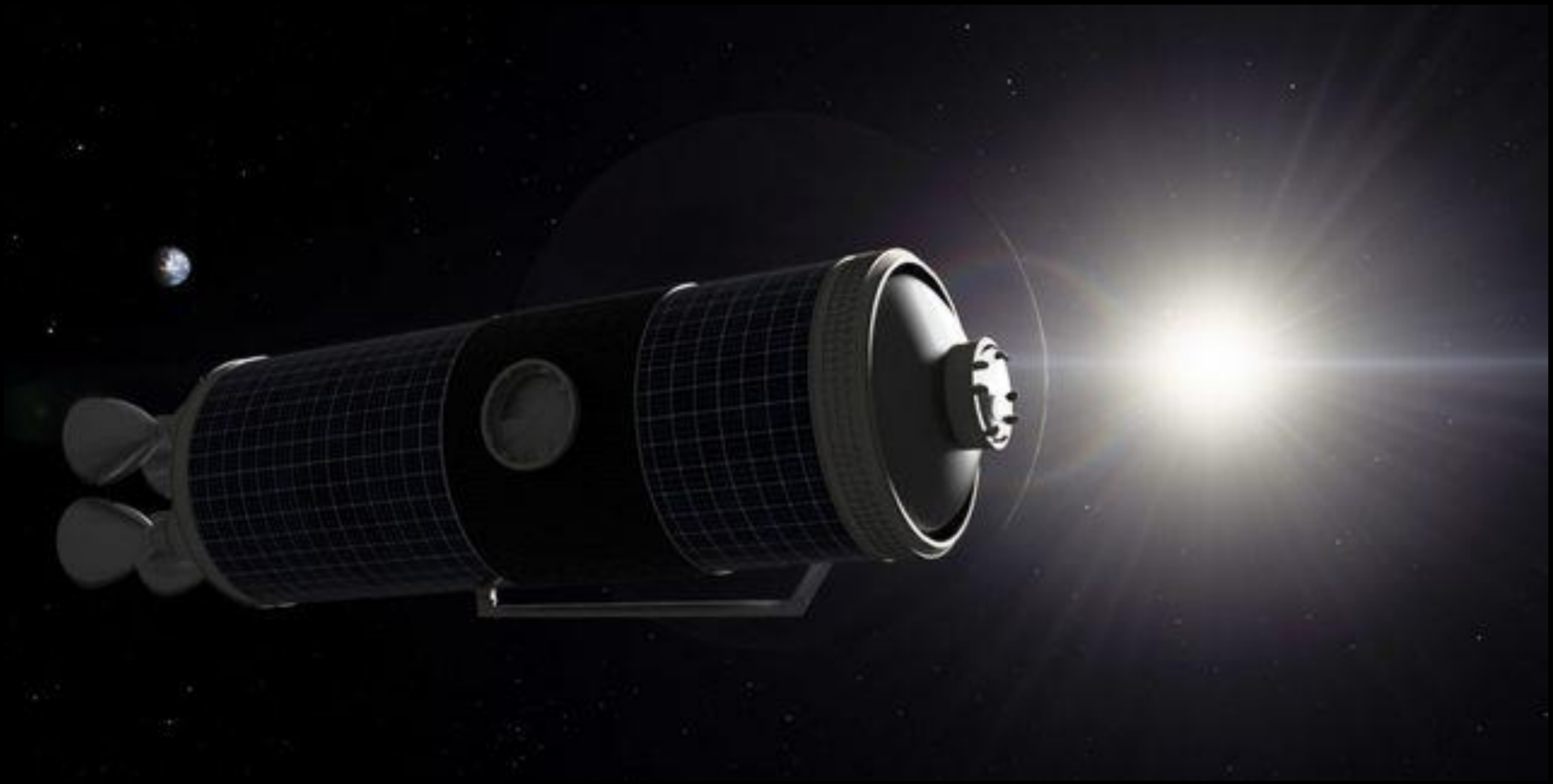
Rocket stages



Launch vehicle size



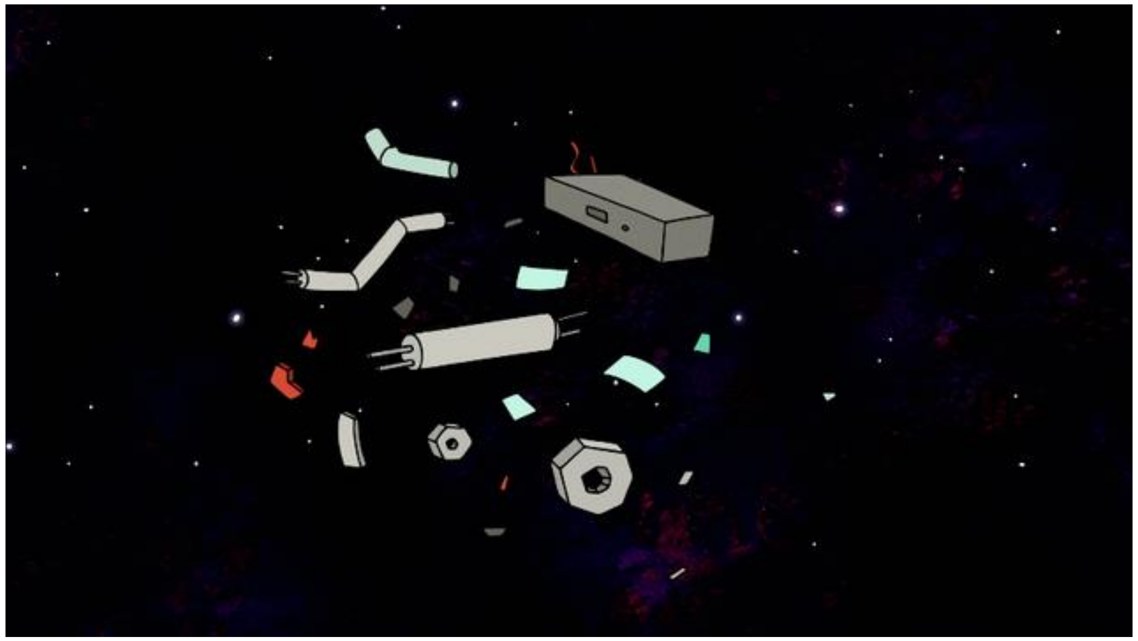
Rocket stage debris



Credit: sploid

Mission-related objects

Mission-related objects have been released in space by satellites/rocket (bolts, covers, caps, adapters, thermal blankets, etc.)



Astronauts’ equipment has been also lost in space (cameras, toothbrush, etc.)

1965 Edward White (Gemini 4) lost a glove during spacewalk

Fragments

Space debris fragments are produced by following mechanisms:

- **Spontaneous break-up event**, such as explosion due to battery, pressurized modules, electrical power subsystem failure, etc.
- **Accidental collision** between two operational satellites, or one satellite and one debris, either two debris
- **Intentional collision,** such as ballistic tests or Anti SATelllite (ASAT) tests
- Number of fragments increases as the involved mass (size) increases

Spontaneous break-up

Accidental collisions

On February 2009 the US Iridium 33 and the Russian COSMOS 2251 collided at an altitude of 800 km, on the sky of Siberia

Iridium 33 was operational at the moment of collision and had a mass of approx. **600 kg,** while **Cosmos** was inactive with a mass of approx. **900 kg**

Approx. 2,000 fragments were generated by the collision

Accidental collisions between two objects

Intentional collisions

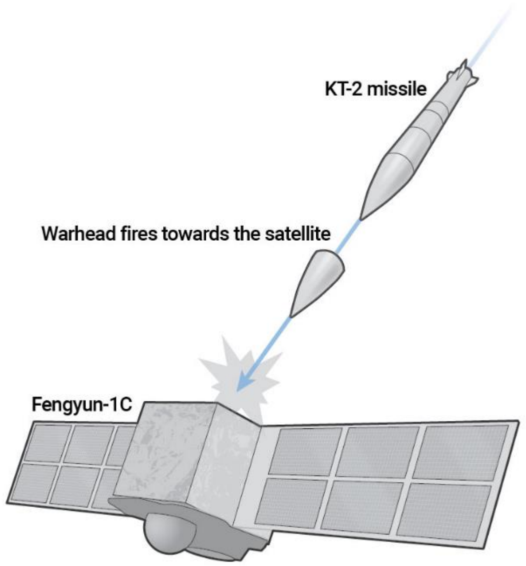
In 2007 China decided to destroyed its weather satellite Fengyun-1C (no more operational)

Collision occurred at 860 km, the mass of FY1C was 750 kg

Previous ASAT was in 1985 by US

A fragment of the Chinese Fengyun 1C weather satellite is supposed to damaged the Russian nanosatellite BLITS.

Many nations reacted negatively (Russia, US, UK, Japan, etc).



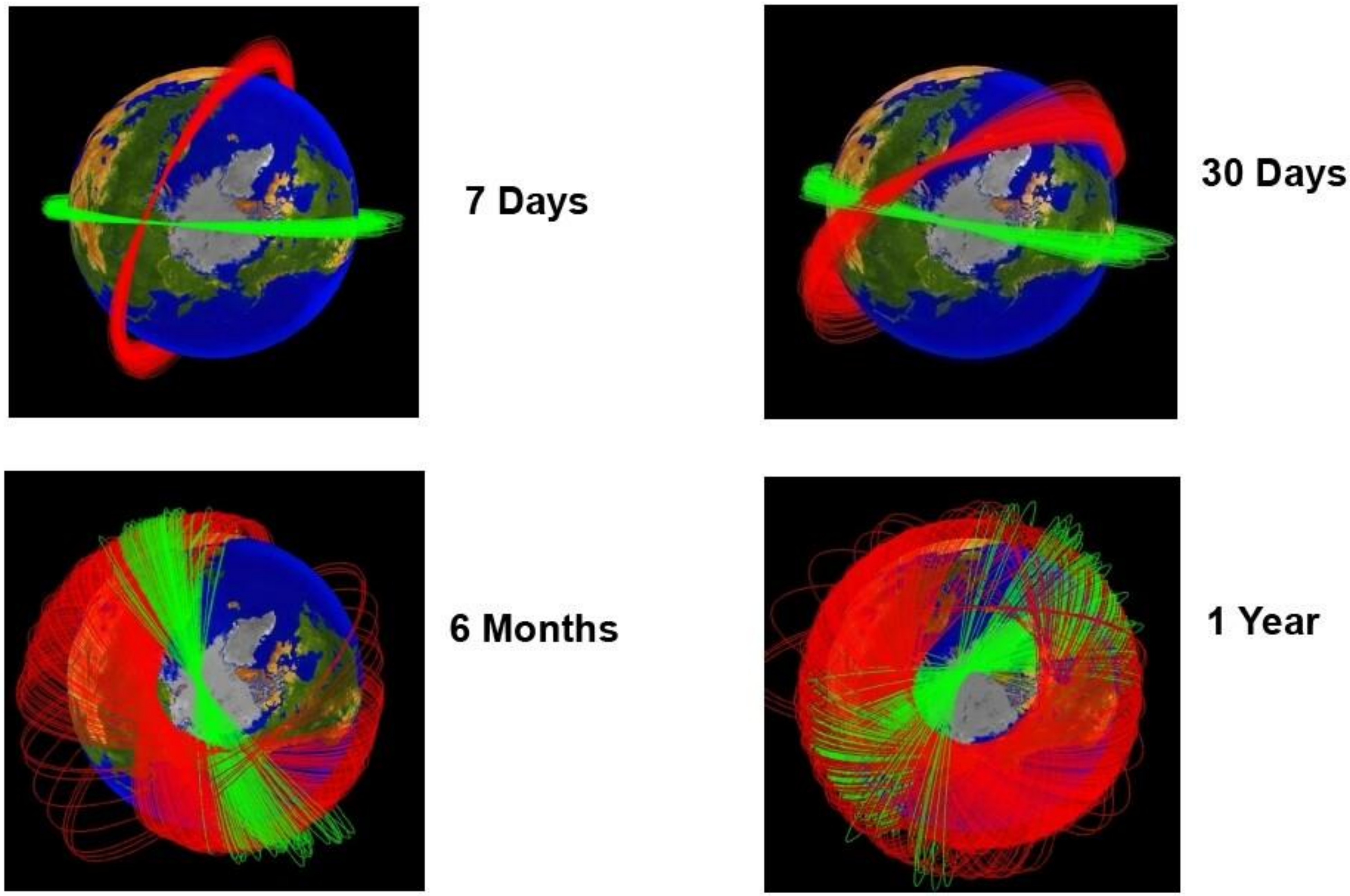
Anti-satellite Chinese test (Fengyun-1C, 2007)

Orbital collisions

Common name	Owner	International designator	Cataloged debris*	Debris in orbit*	Year of breakup	Altitude of breakup	Cause of breakup
Fengyun-1C	China	199-025A	3218	2989	2007	850km	Intentional collision
Cosmos 2251	Russia	1993-036A	1559	1371	2009	790	Accidental collision
STEP 2 Rocket Body	USA	1994-029B	710	58	1996	625	Accidental collision
Iridium 33	USA	1997-051C	567	487	2009	790	Accidental collision
Cosmos 2421	Russia	2006-025A	509	0	2008	410	Unknown
SPOT 1 Rocket Body	France	1986-091C	492	32	1986	805	Accidental collision
OV 2-1/LCS 2 Rocket Body	USA	1965-082DM	473	35	1965	740	Accidental collision
Nimbus 4 Rocket Body	USA	1970-025C	375	245	1970	1075	Accidental collision
TES Rocket Body	India	2001-049D	370	111	2001	670	Accidental collision
CBERS 1Rocket Body	China	1999-057C	343	178	2000	740	Accidental collision
Total			8616	5506			

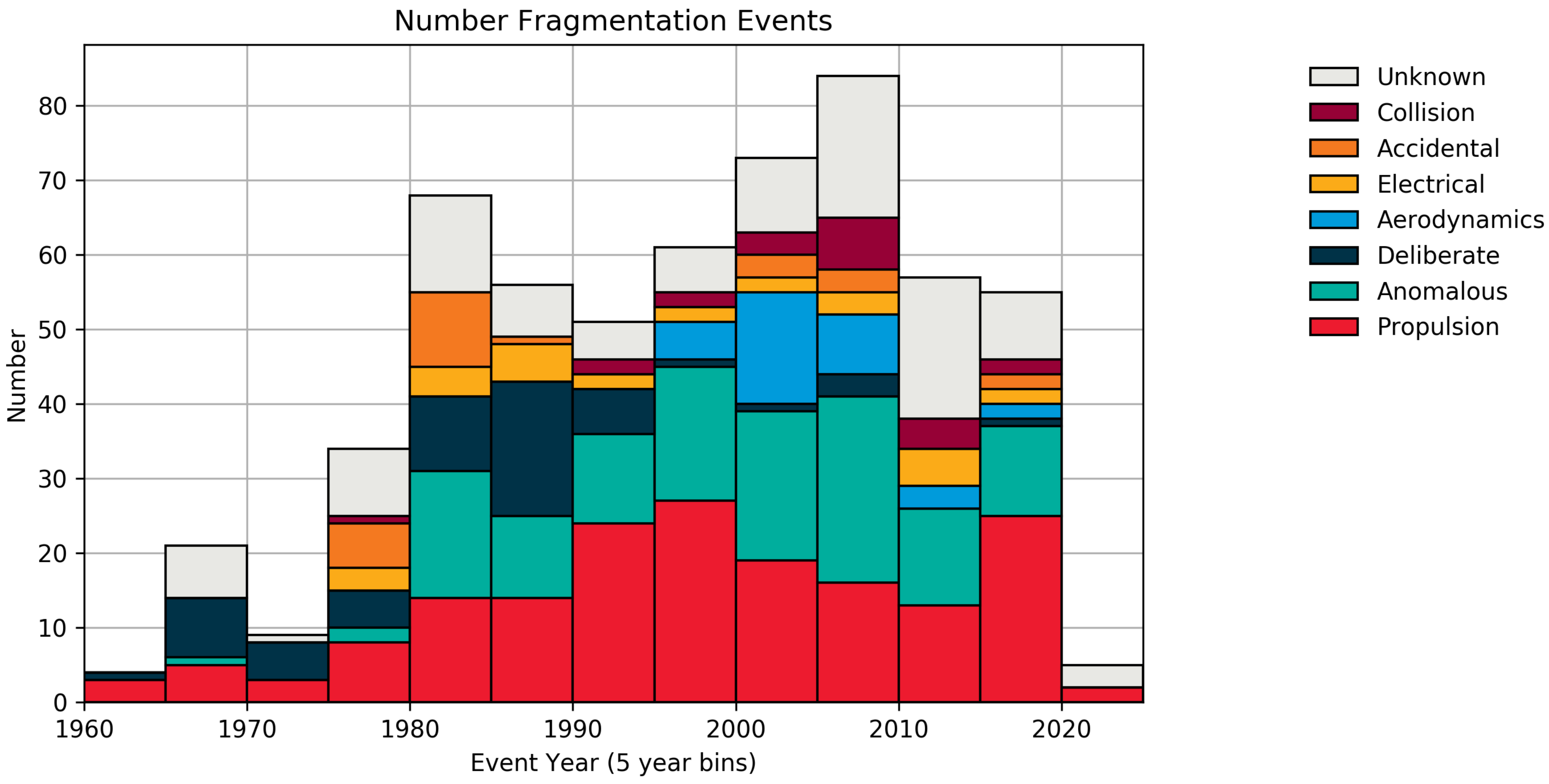
*As of March 2012 [*Source:* National Aeronautics and Space Administration (NASA), *Orbital Debris Q News*, (2010)][4]

Fragments dispersion



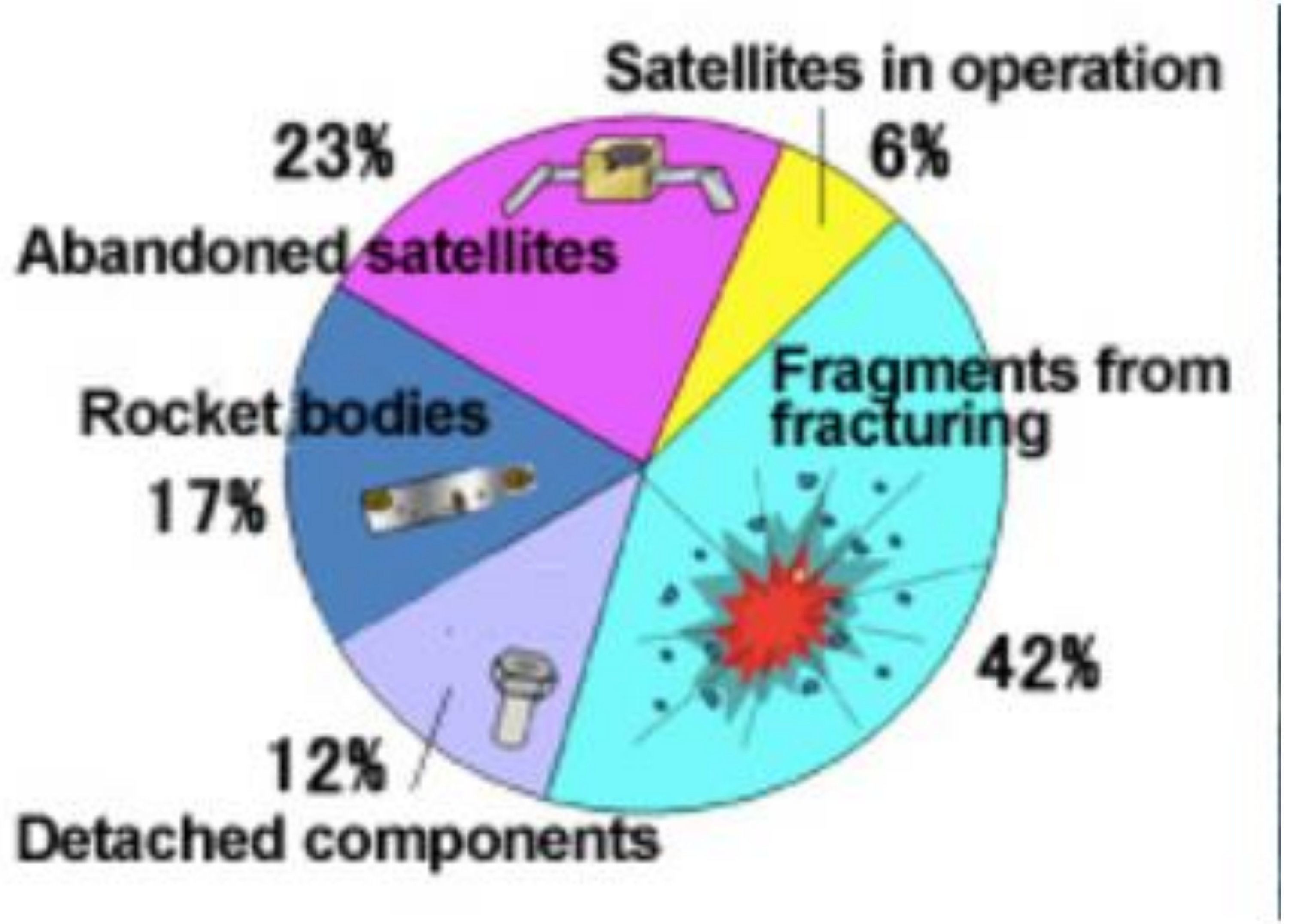
Credit: NASA

ESA Report 2021



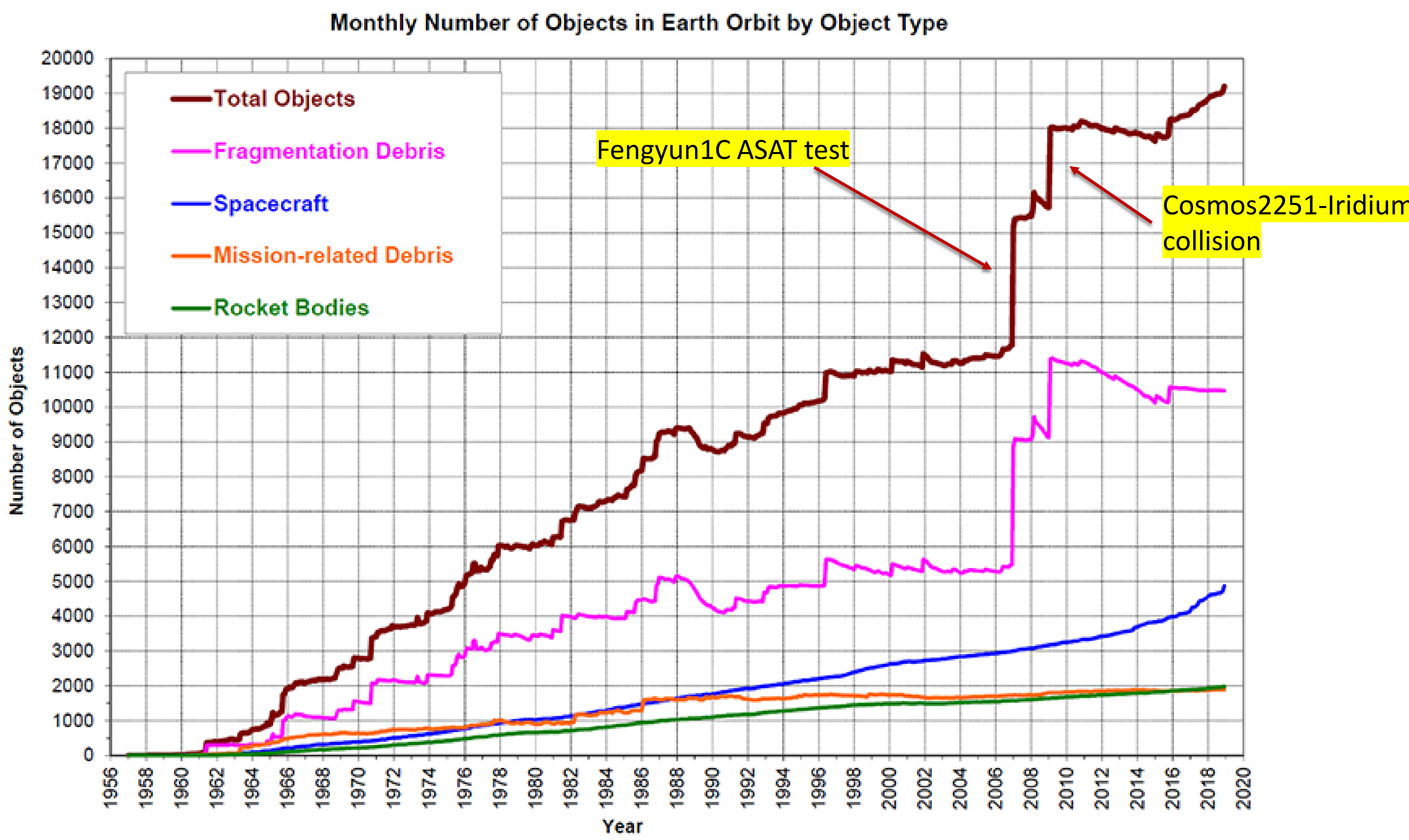
SD population

- Fragments class is the most populated
- Less than 6% of satellites are operational

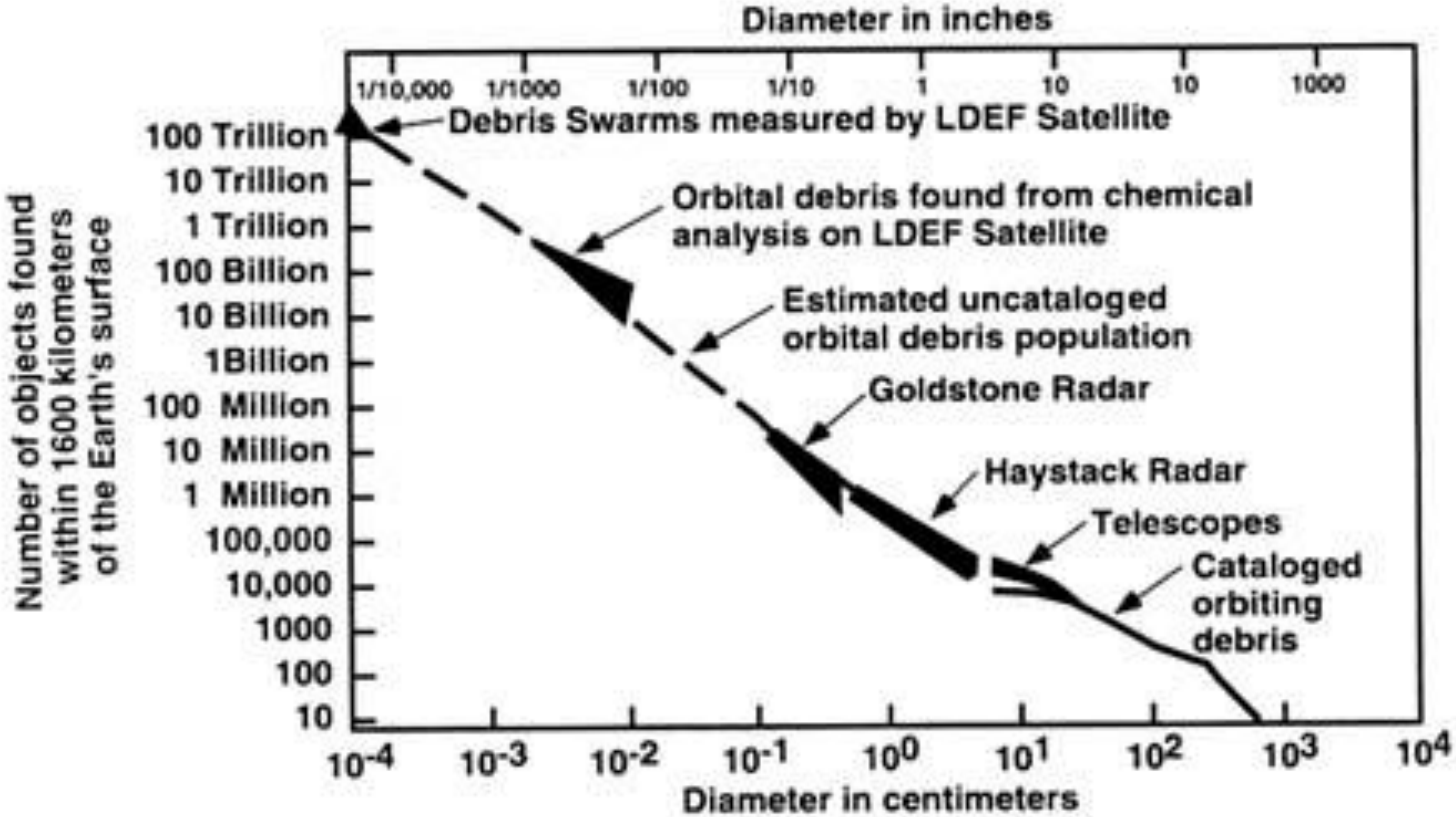


SD tracking

More than 20,000 objects detected and tracked by US Space Command

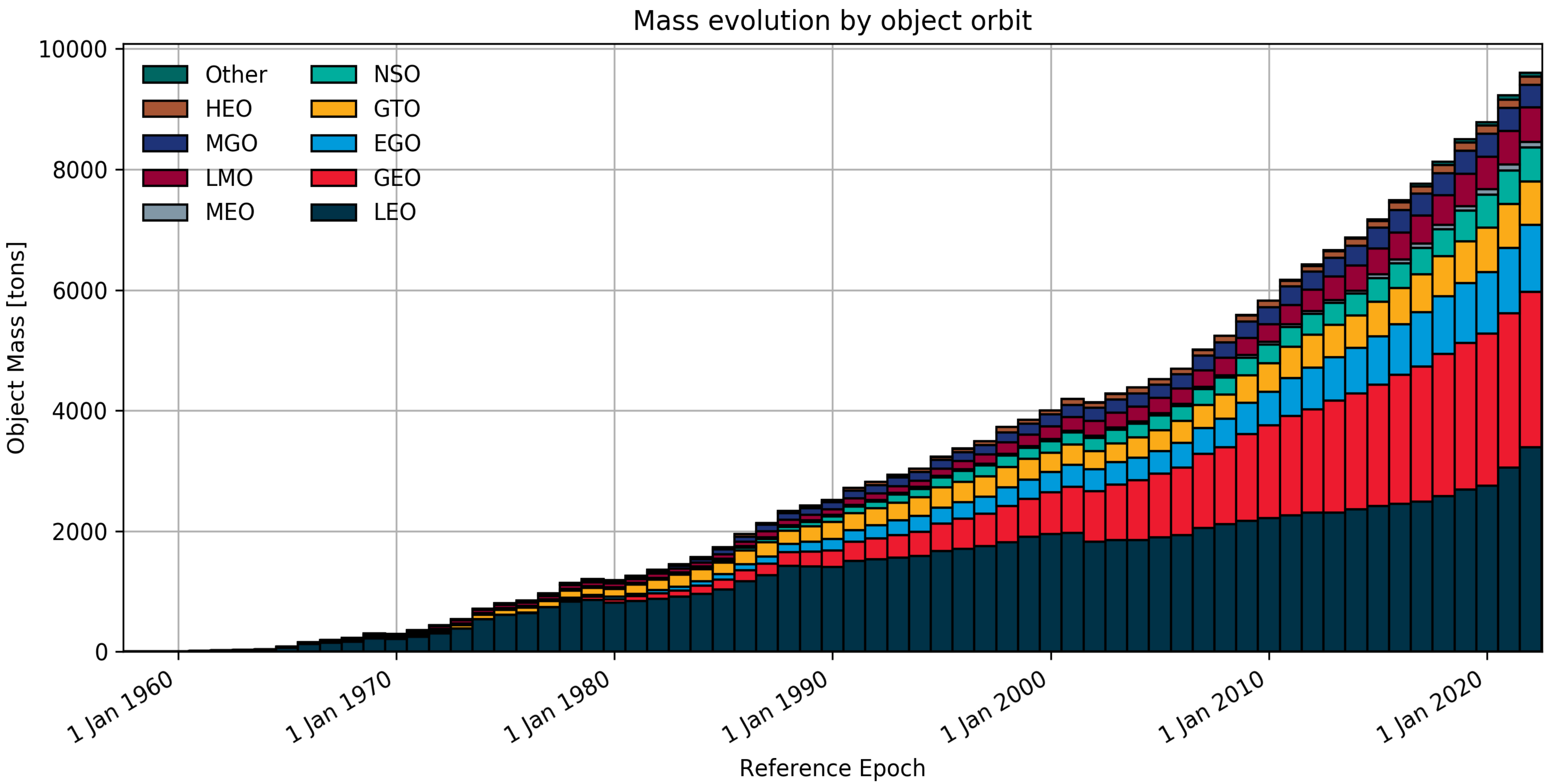


SD dimensions



The Long Duration Exposure Facility (LDEF) is a test conducted in LEO orbit to estimate impact damaging through collisions/craterizations by SD

SD masses



Credit: ESA’S ANNUAL SPACE ENVIRONMENT REPORT 2021

ESA Report Sept. 2021

Environment Report

The latest Space Debris Environment Report issued by ESA's Space Debris Office is available here. The fifth edition has been released on 27/05/2021.

The AMOS 2019 keynote on the topic of the report by Dr. Francesca Letizia is available from these links: slides, transcript.

Environment Statistics

Last update: 20 September 2021

Space debris by the numbers

Number of rocket launches since the start of the space age in 1957
About 6110 (excluding failures)

Number of satellites these rocket launches have placed into Earth orbit
About 12070

Number of these still in space
About 7550

Number of these still functioning
About 4700

Number of debris objects regularly tracked by Space Surveillance Networks and maintained in their catalogue
About 29490

Estimated number of break-ups, explosions, collisions, or anomalous events resulting in fragmentation
More than 570

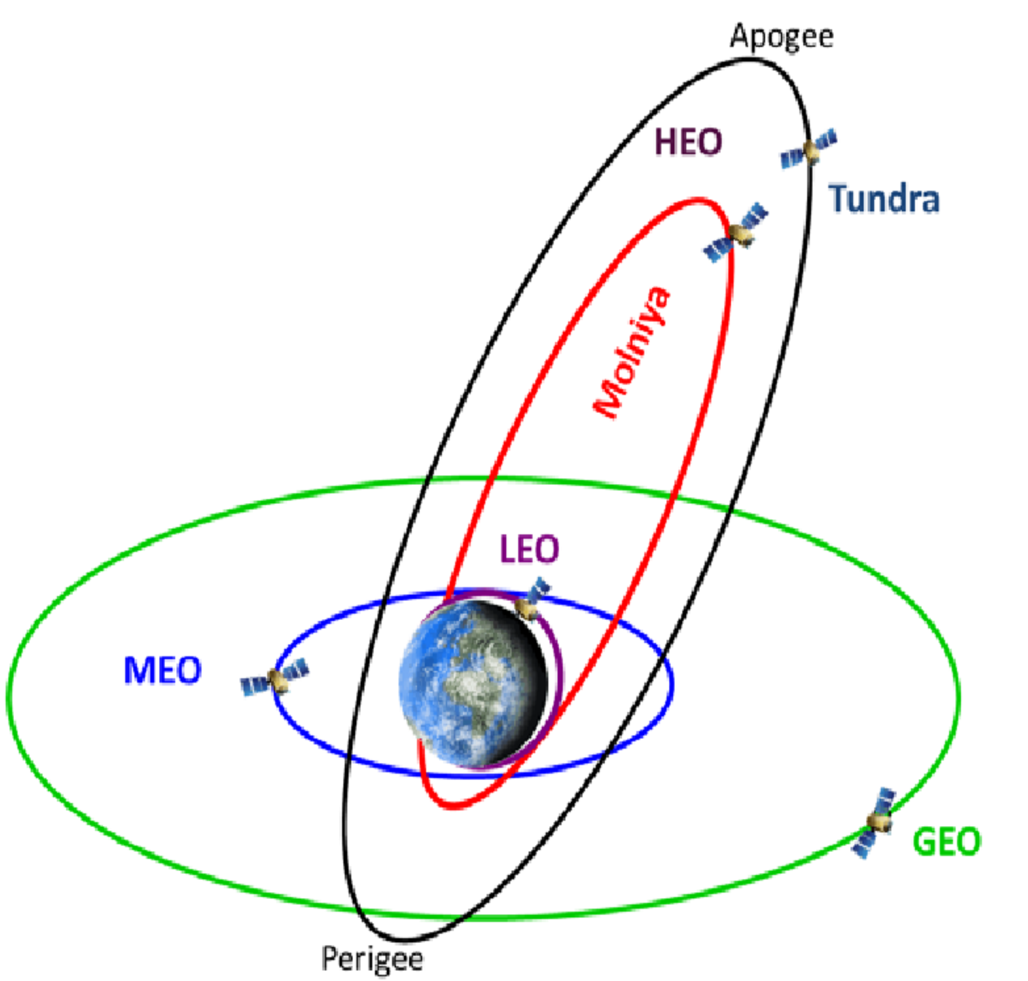
Total mass of all space objects in Earth orbit
More than 9600 tonnes

Number of debris objects estimated by statistical models to be in orbit
36500 objects greater than 10 cm
1000000 objects from greater than 1 cm to 10 cm
330 million objects from greater than 1 mm to 1 cm

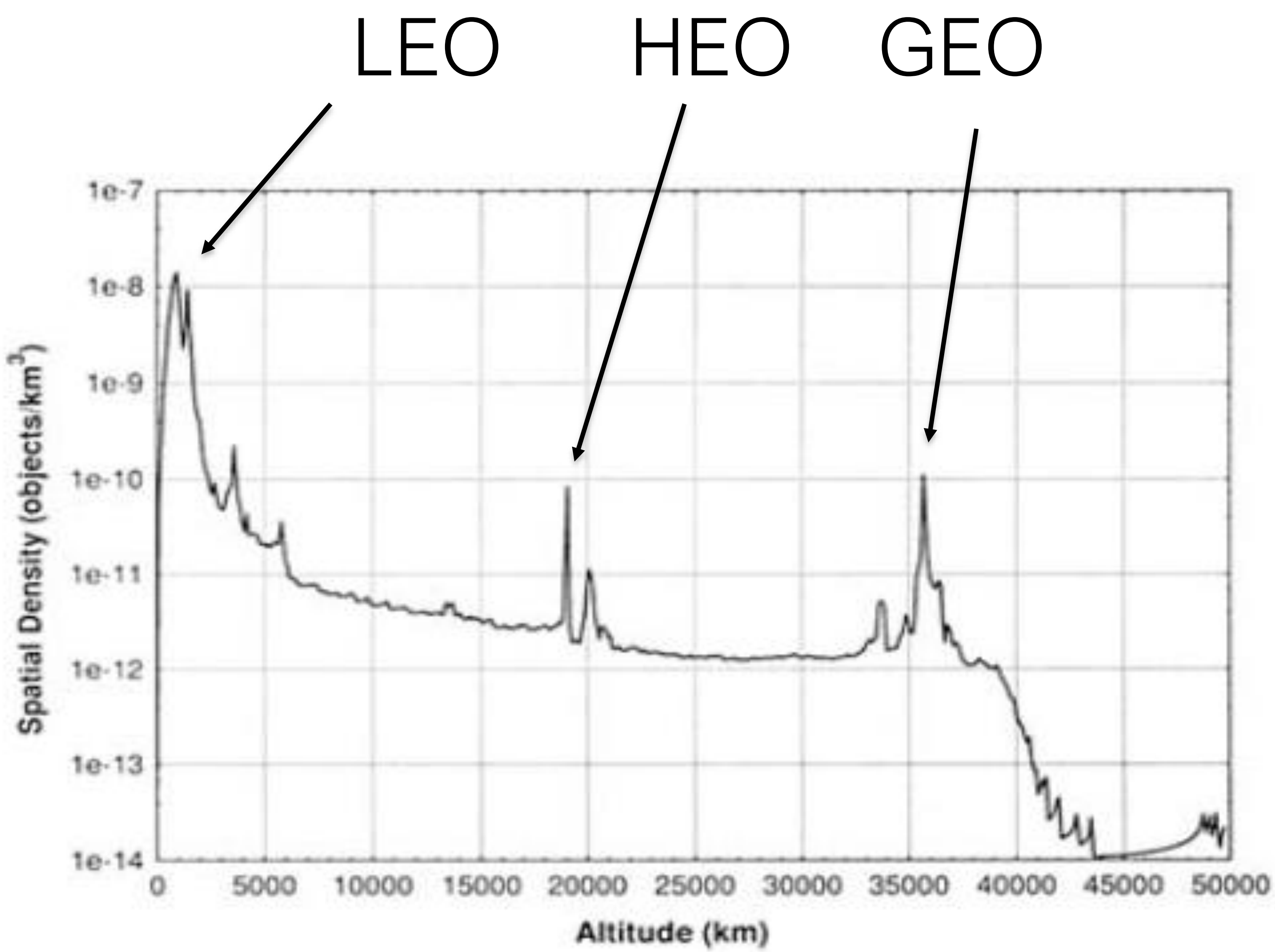
Where are SD?

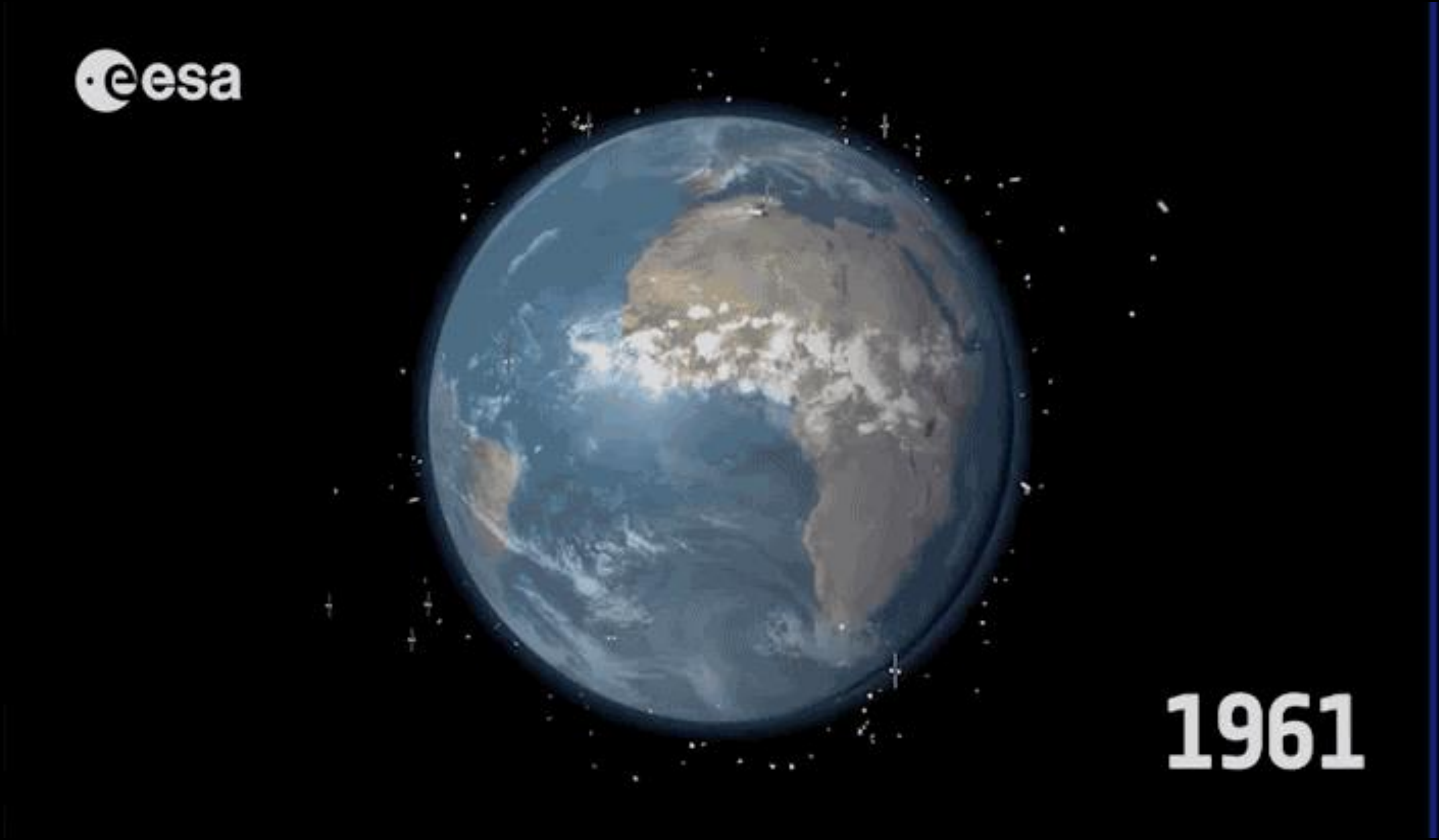
Orbital regions

As expected, the space debris occupy the most used orbital regions: Geostationary Orbits (GEO), Low Earth Orbits (LEO), High Elliptical Orbit (HEO)

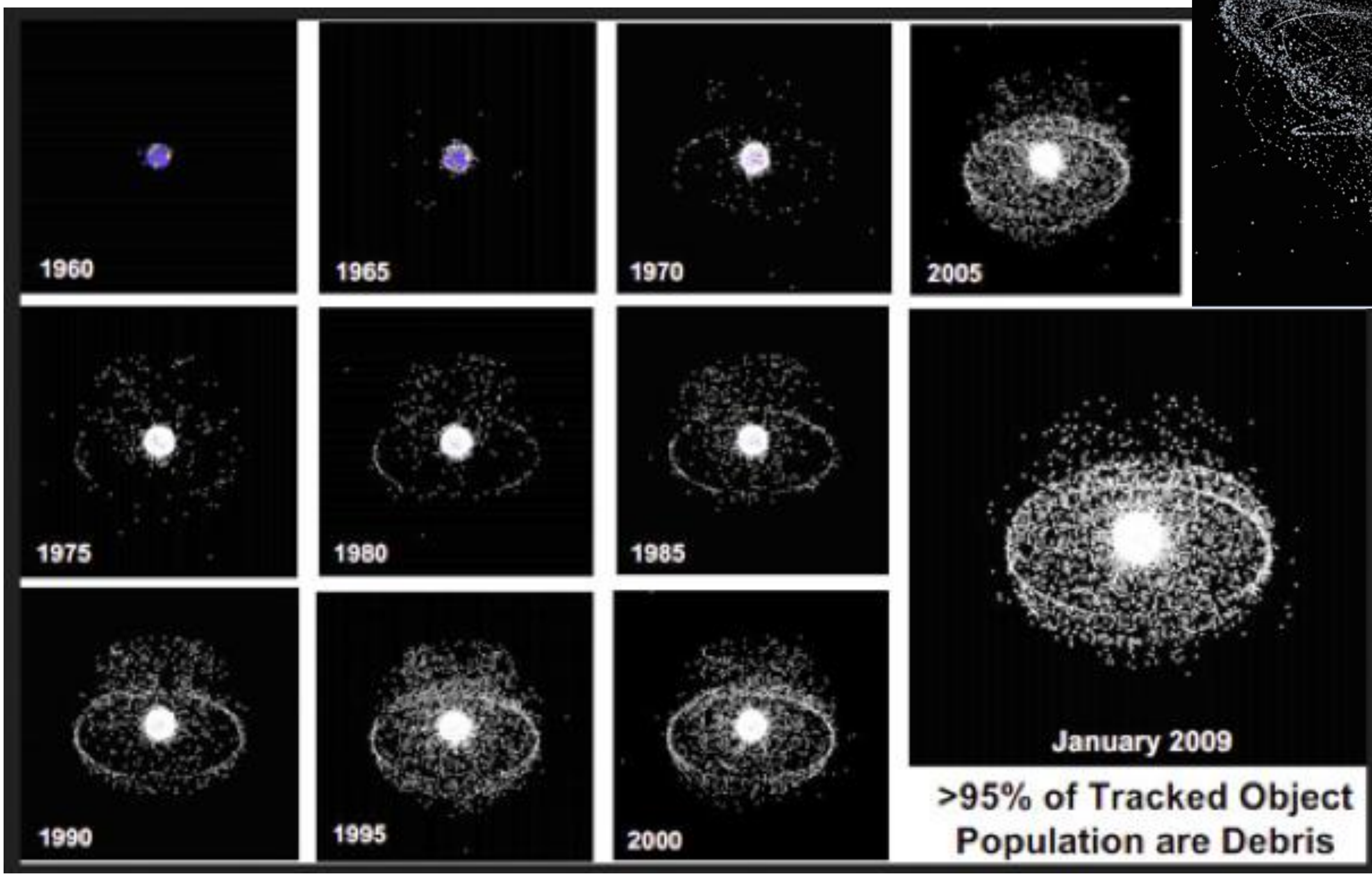


Orbit		Altitude [km]	
		Perigee	Apogee
LEO: low earth orbit		200–2 000; normally: 600–1 000	
MEO: medium earth orbit		2 000–GEO; normally: 10 000–20 000	
GEO: geostationary orbit		35 786	
HEO: high elliptical orbit	Molniya (12 h)	~500	~40 000
	Tundra (24 h)	~24 000	~48 000




esa
1961

Orbital discks



How do we observe SD?

Instruments

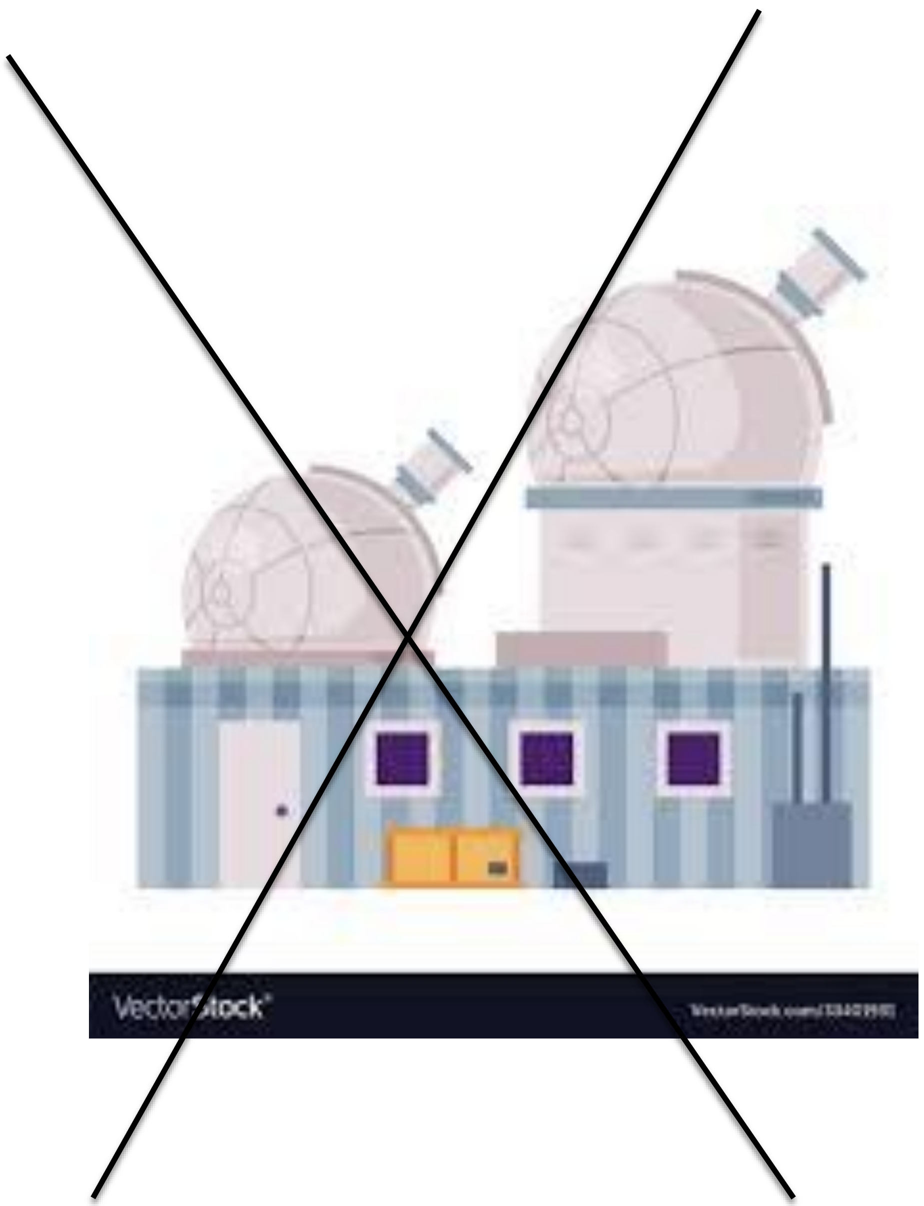
The observations of space debris occurs by using three main instruments:

- optical telescopes
- radars/radiotelescopes
- lasers

Optical telescopes

Credit: astroshop.eu

Telescope's dome



Credit: Middlebury College Observatory

Observations with optical telescope

Space debris passage through a stars field

Observations with optical telescope

Standard astronomical observations are taken in tracking-mode telescope, i.e. correcting the pointing for the Earth rotation speed.

GEO satellite constellation passes through a star field, in tracking-mode (pixel rows)

GEO objects in de-tracking mode (central points)

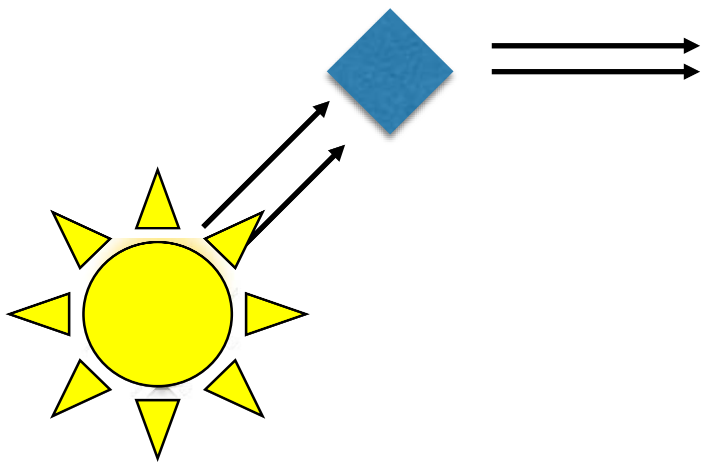
Optical investigations

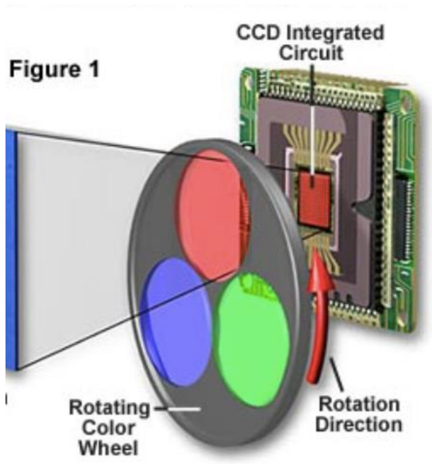
By using optical telescopes it is possible to investigate:

- ➢SD orbit (astrometry)
- ➢SD surface materials (photometry)
- ➢SD rotational period/tumbling (light-curves)

✓Astrometry technique allows to measure the position of SD respect to the background stars

✓Photometry technique uses colored filters in front of a telescope to study the light reflection by the SD surface materials

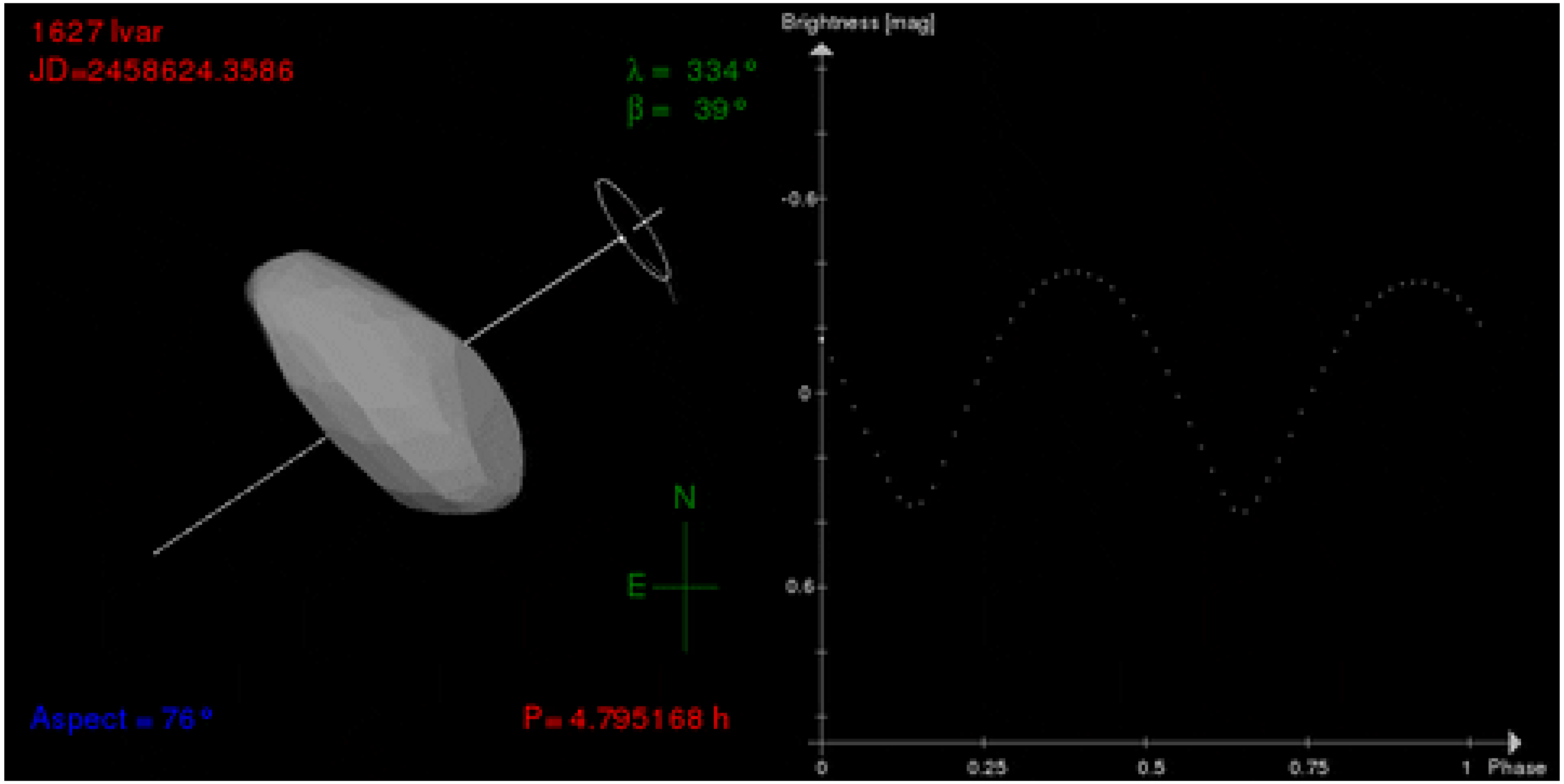




Light-curves technique

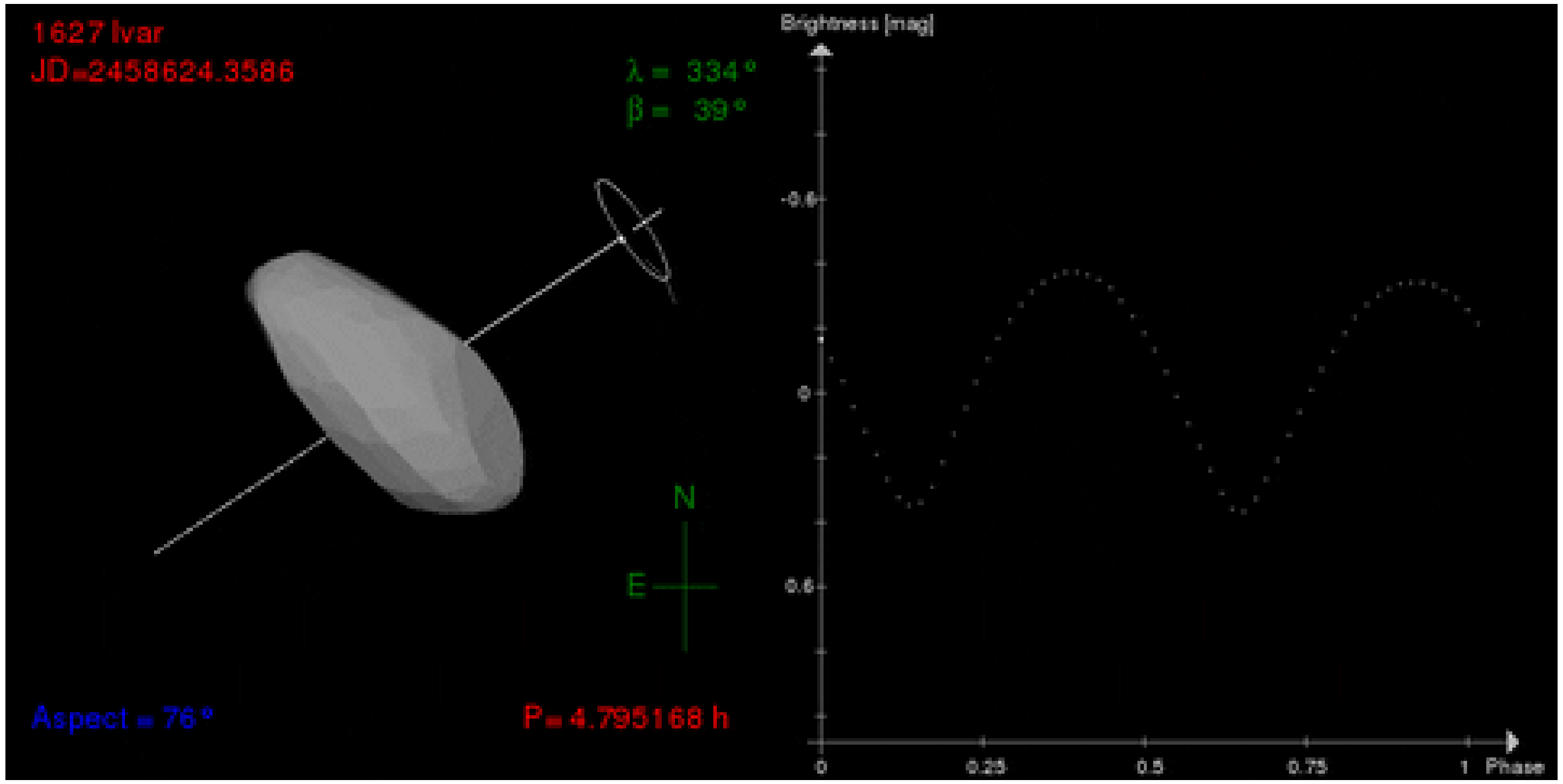
Light-curves analysis provides the rotational period and the geometry of a SD, including the occurrence of solar-panels, antennas, etc.

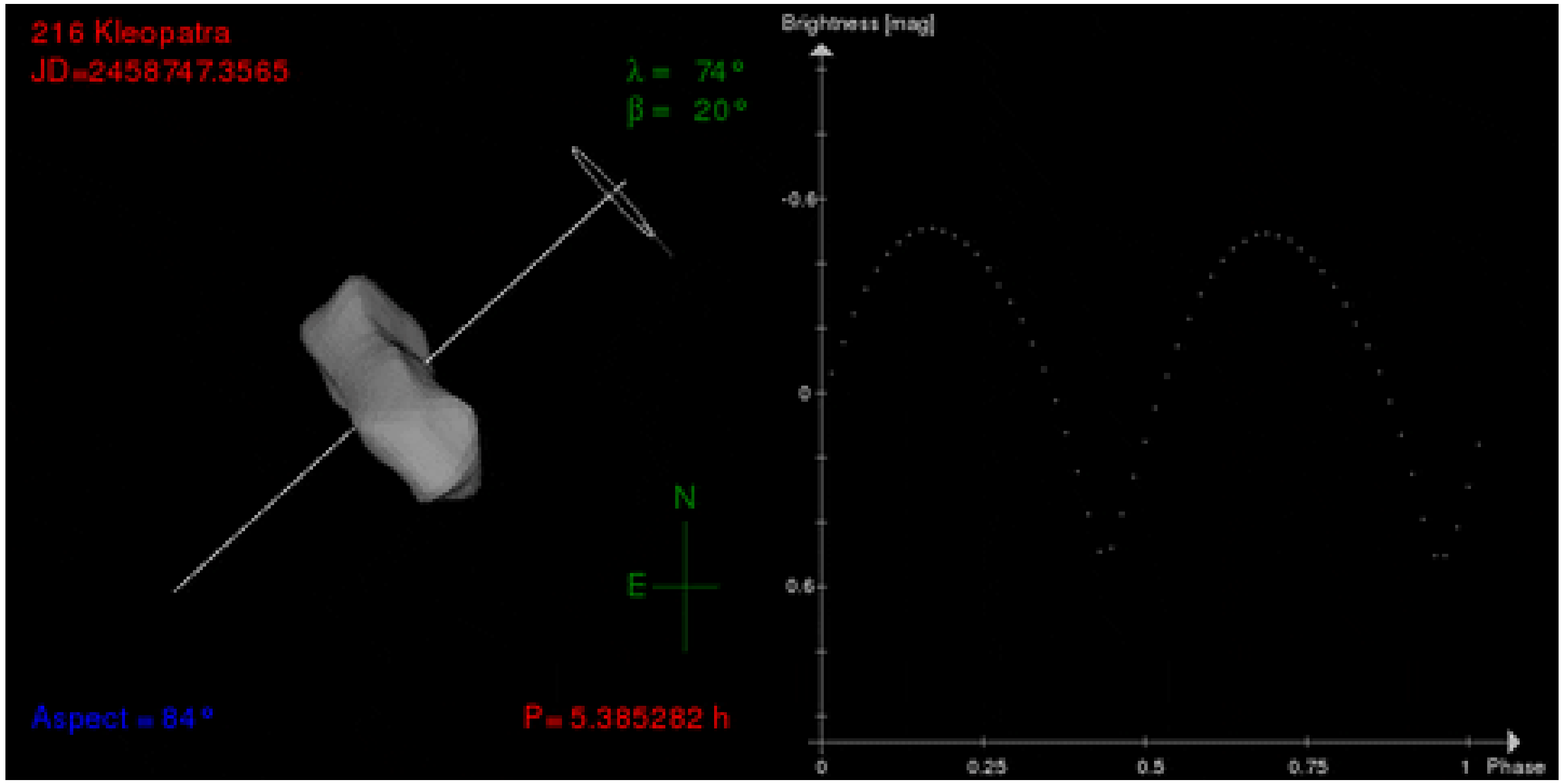
This technique is widely used for asteroids investigations



Credit: Interactive service for asteroid models
http://isam.astro.amu.edu.pl

Geometry affects light-curves



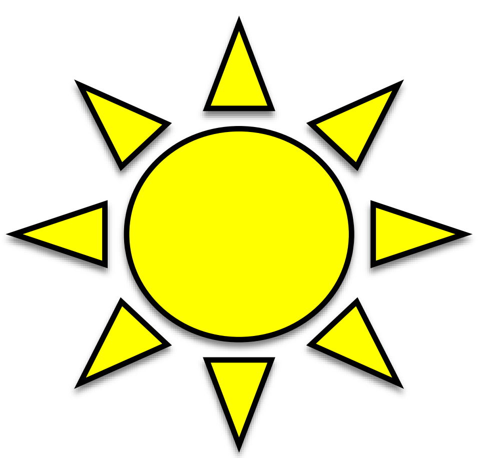


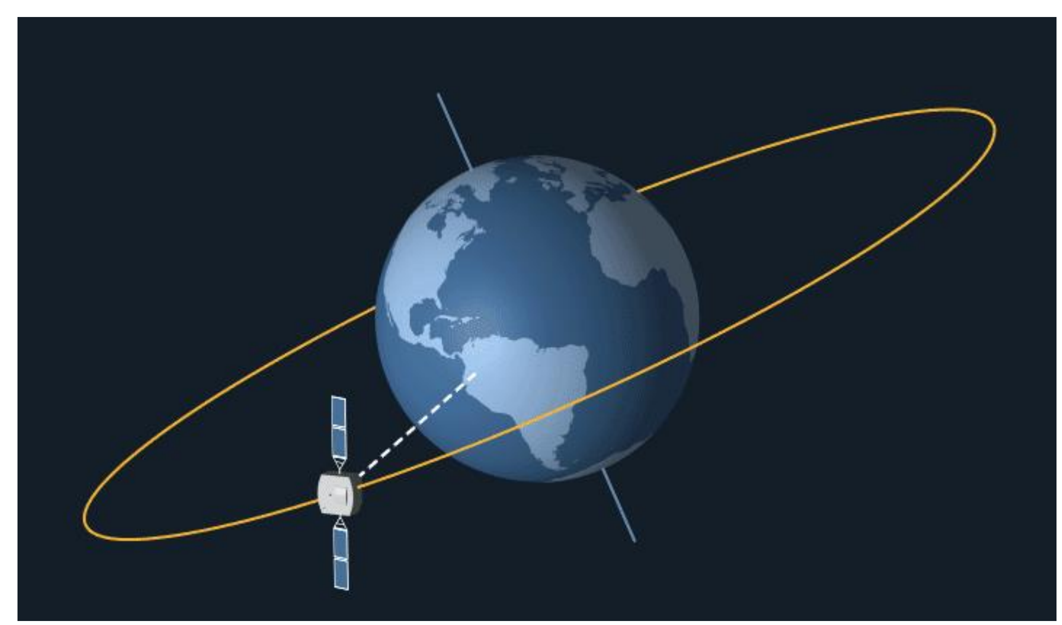
Credit: Interactive service for asteroid models
http://isam.astro.amu.edu.pl

Optical telescopes

They require:

- ❖good weather (no rain, no clouds)
- ❖nighttime
- ❖low background luminosity (away from inhabited centers)
- ❖good “astronomical seeing” (no air turbulence)
- ❖SD need to be illuminated by the Sun (good Sun-Earth-SD illumination angle)





Radiotelescope

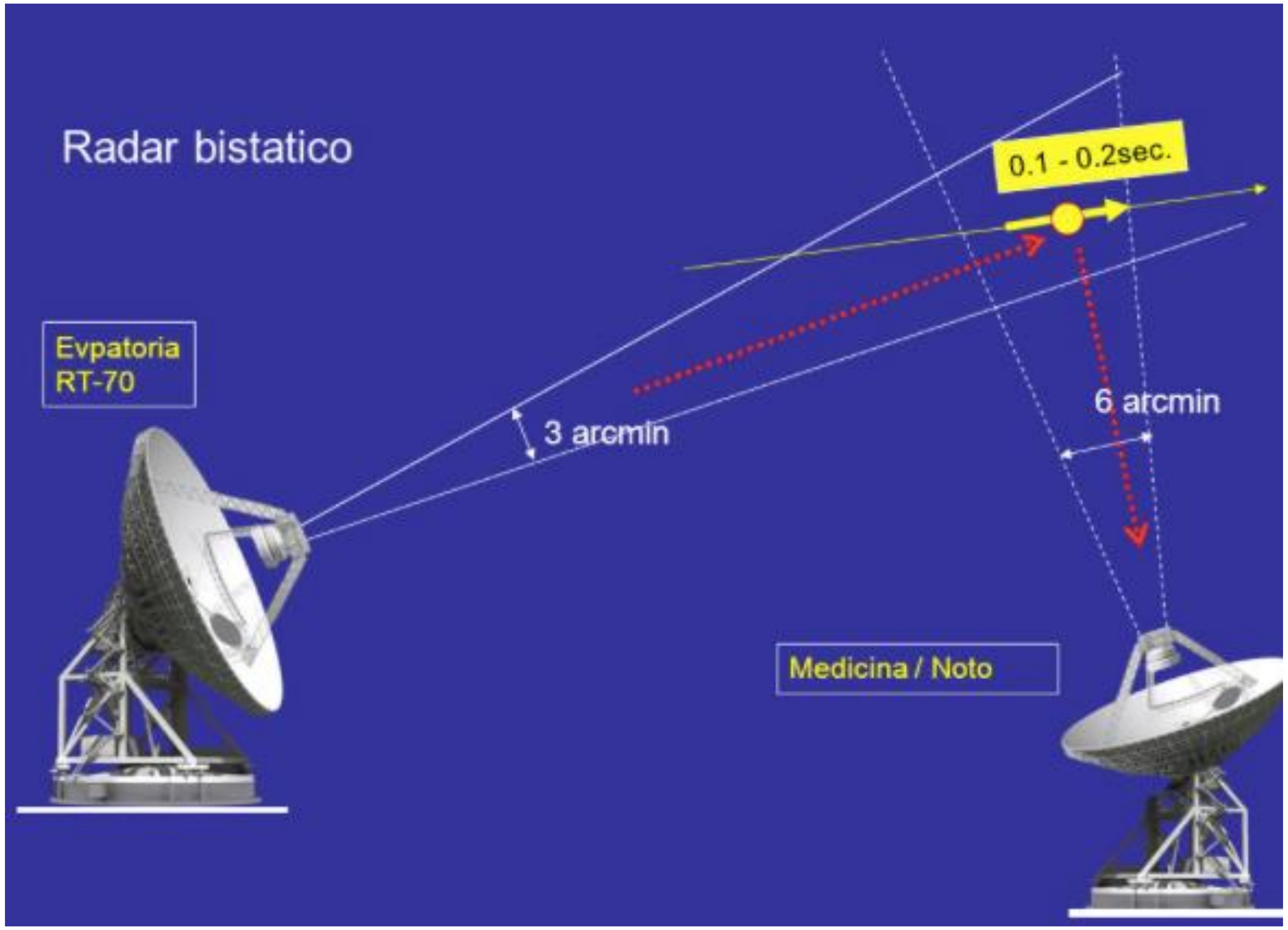
- The observations do not depend on daytime/nighttime or weather
- Very useful for LEO, but not for GEO
- The INAF “Croce del Nord” radiotelescope is located in Medicina, Northern Italy
- Monostatic or bi-static configuration with MoD emitter in Sardinia Island

Radio observations

In monostatic or bistatic configuration

- Monostatic: transmitter and receiver in the same place/same antennae
- Bistatic: transmitter and receiver in different place/different instruments

Radio-telescopes allow to measure SD direction (orbit), size and velocity



Why is it important to study SD?

SD related problems

SD cause potential hazardous in space and potentially on Earth

❖**Problems in space:**

- **Risks of collision events,** with impact velocity greater than 7-11 Km/s
- **Collision Avoidance** Manouvre for operational satellite
- **Risks for new launches →** accurate mission analysis for new spacecrafts
- **Risks for astronauts,** on ISS or during extravehicular activity (EVA)

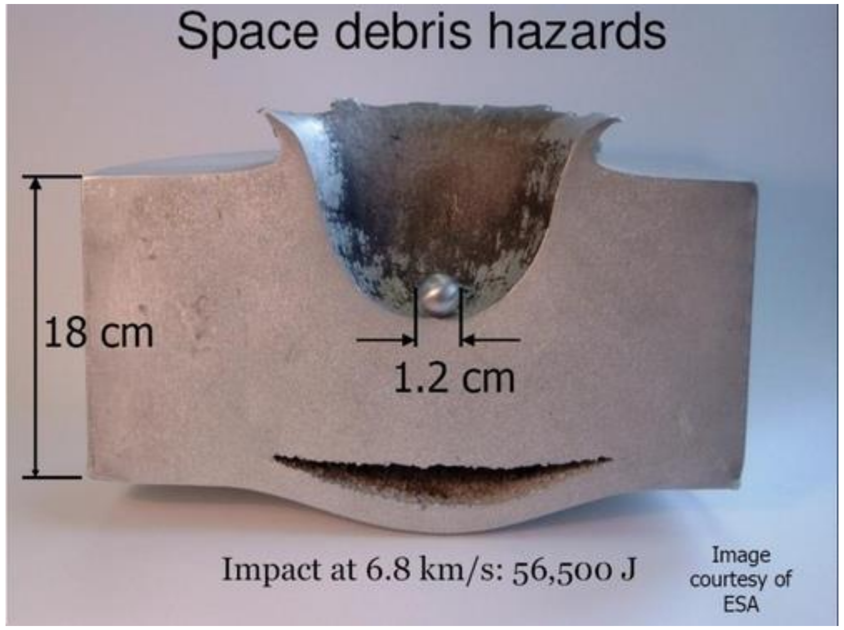
❖**Problems in re-entry Earth's atmosphere:**

- Uncontrolled re-entry (air traffic, population)

Damages by SD impacts

Impacts with space debris can cause:

- degradation of surfaces
- subsystem damage
- craters generation
- destruction of a satellite



Hole created by a spherical debris of 1.2 cm of diameter (laboratory experiment)

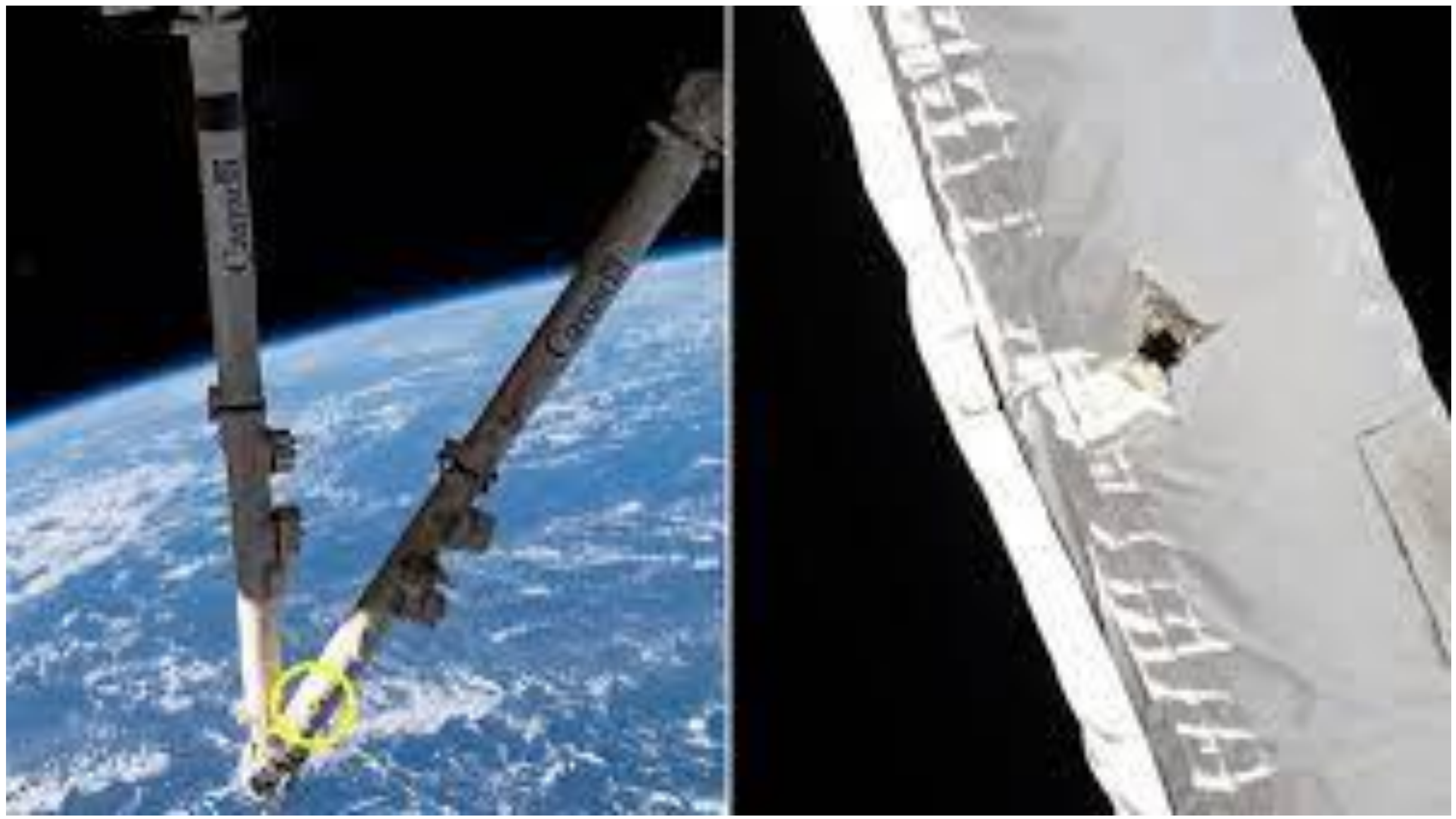
The damages depend on the velocity and mass of the impactor debris

- Due to **high velocity of debris**, a 10 cm object can create a catastrophic impact (Hypervelocity impacts)

Space impacts

MIR Space Station impacted by SD (cedit: NASA)

Space impacts

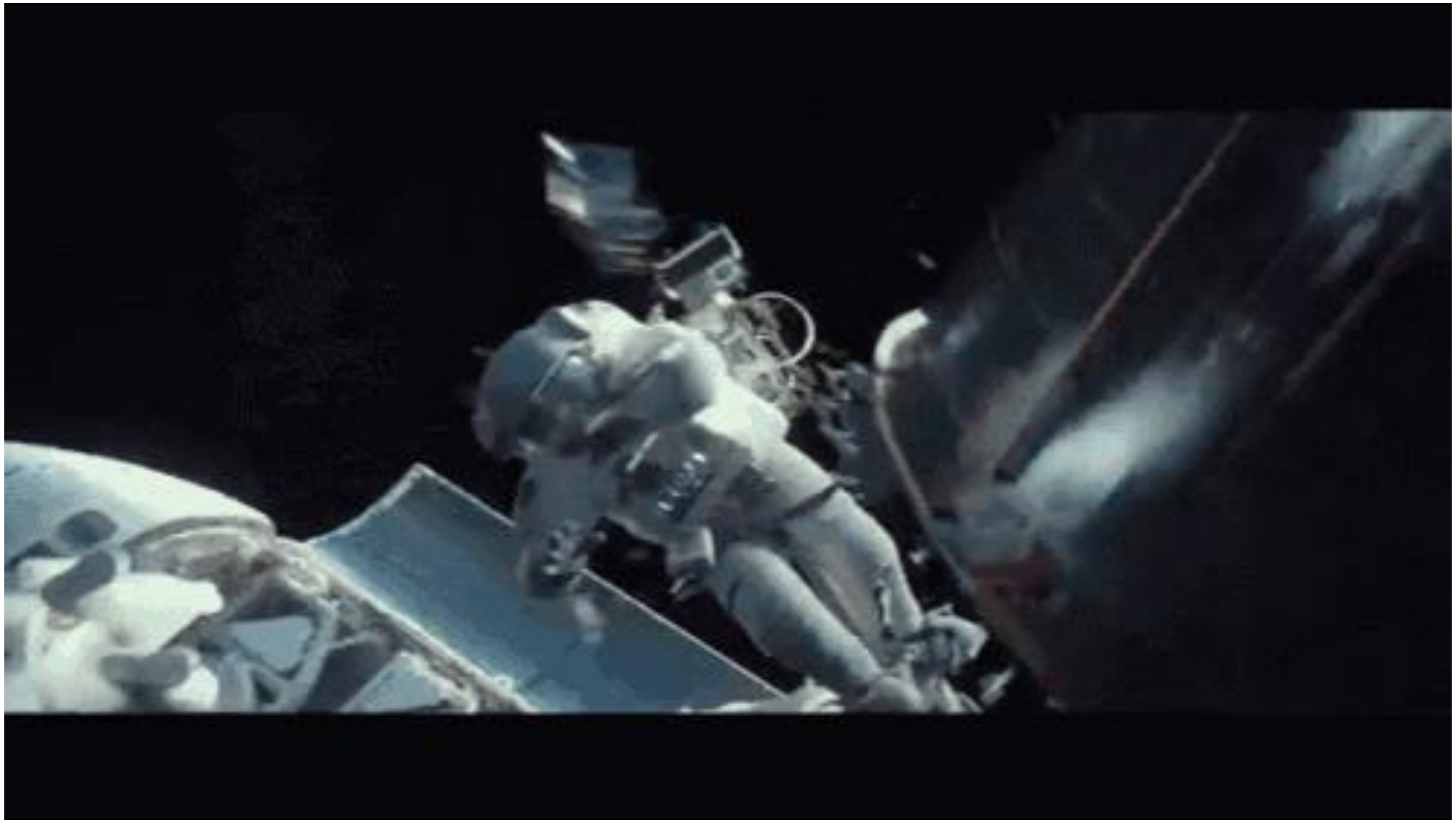


A space debris impacted the robotic harm of the ISS in June 2021

Risks for astronauts

ISS has the Debris Avoidance Manoeuvre (DAM) and evaciuating module for astronauts

Extra-vehicular activity (EVA) are most exposed to SD problems

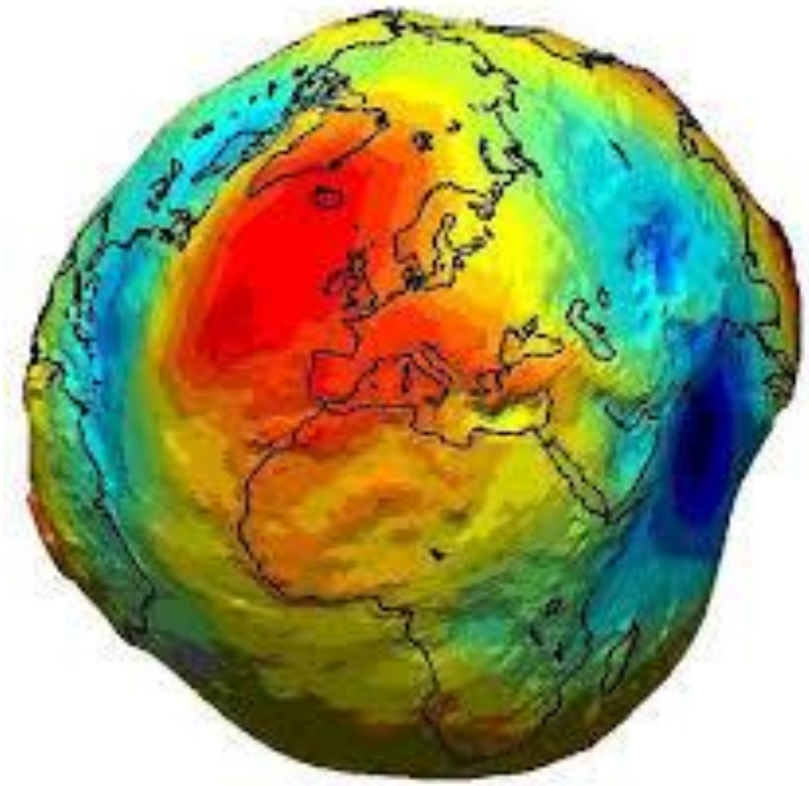


Credit: Gravity Movie

Problems in Earth's atmosphere

Satellite's orbit is subjected to perturbations:

1. Non-spherical Earth gravitational potential
2. Luni-solar perturbation (gravitational)
3. Radiation pressure by Sun
4. Atmospheric drag for LEO



Earth without oceans. Its not-spherical shape causes perturbations on satellites' orbit (credit: ESA)

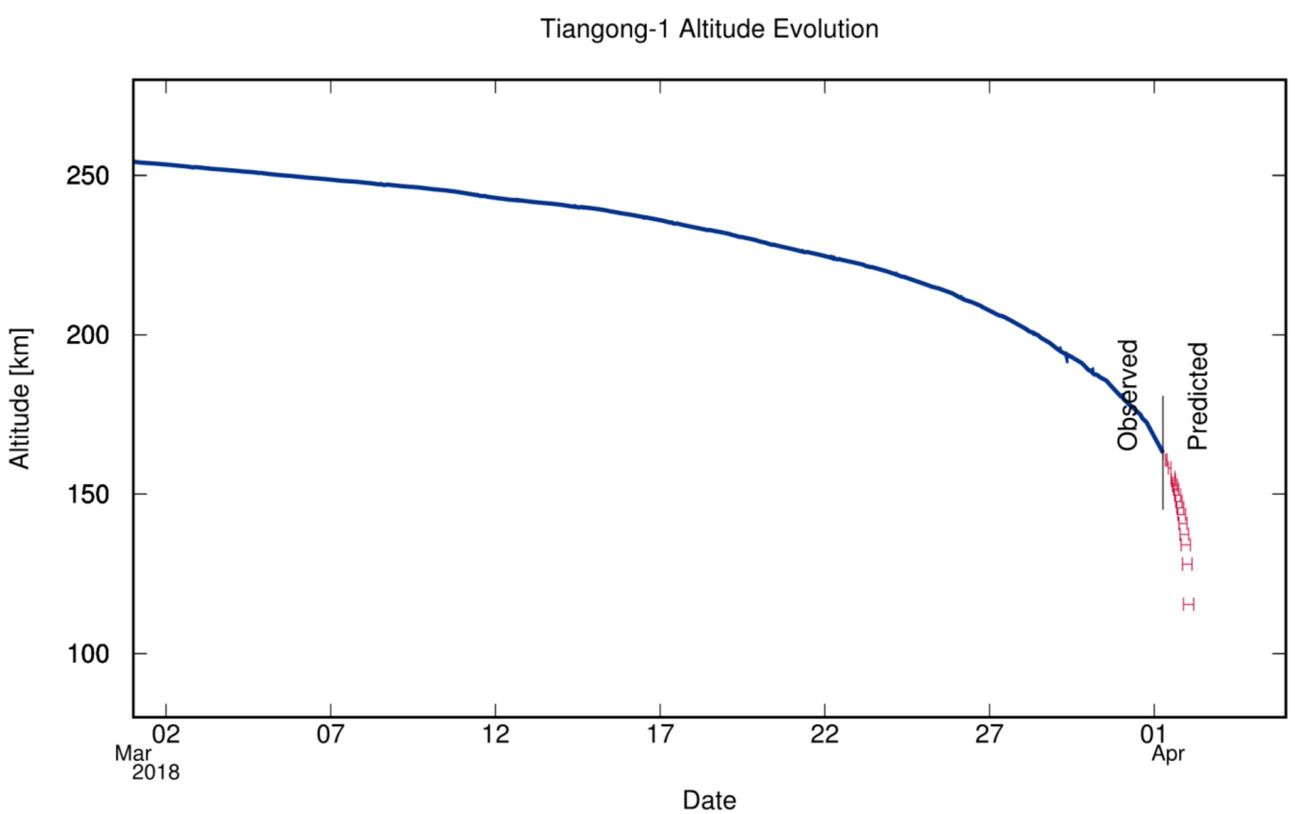
Owing to these effects, the LEO satellites can re-entry on Earth's atmosphere
Main satellites burn in upper atmosphere, but larger debris can impact on the ground.

Uncontrolled re-entry

Ground problems

Tiangong-1

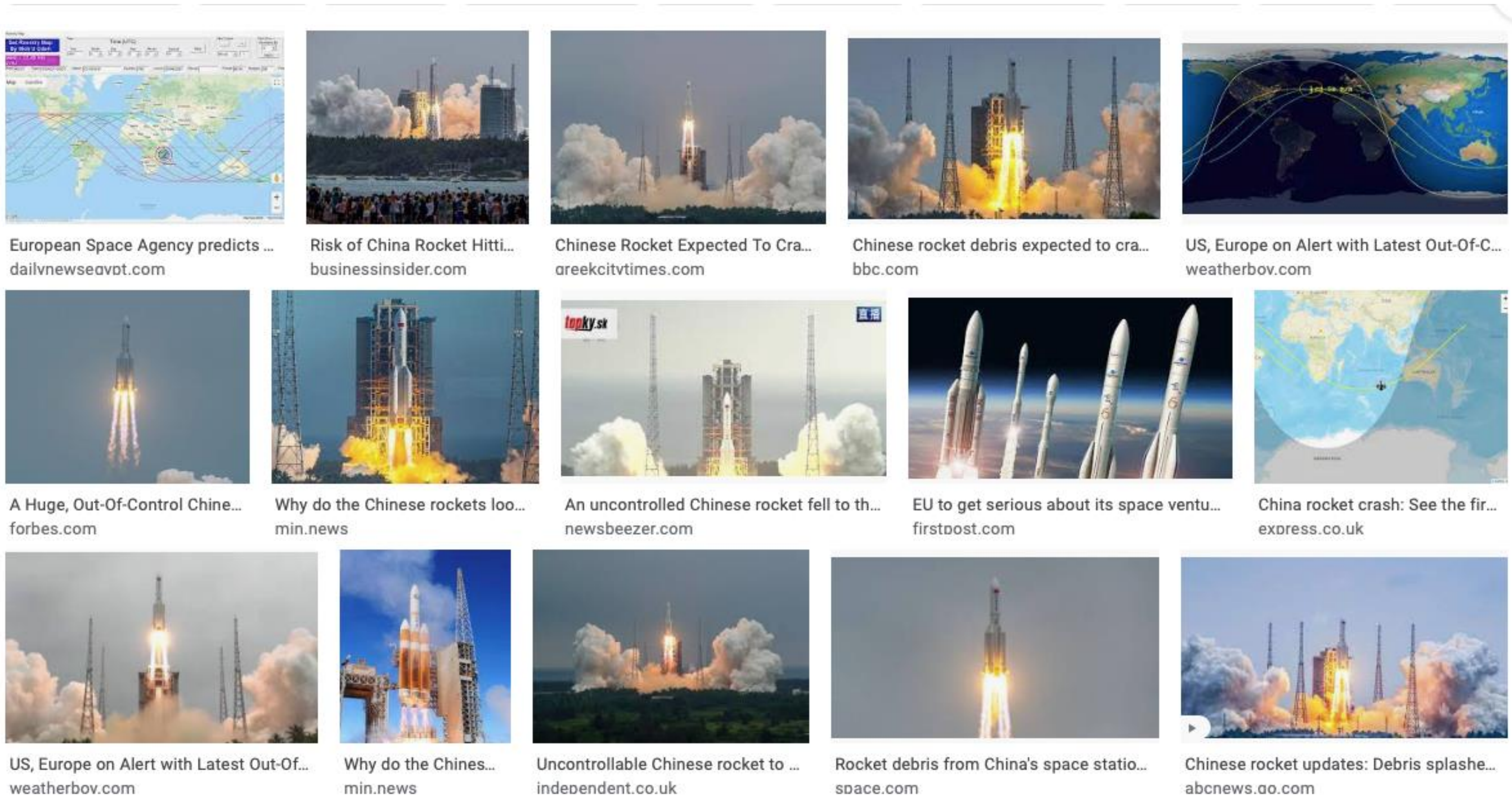
- China's first space station prototype for space laboratory experiments
- It demonstrated successfully docking of crewed and no-crewed modules
- It was in orbit during the period Sep. 2011-Apr. 2018
- China National Space Administration (CNSA) lost contact with Tiangong-1 on March 2016
- Intense observational campaigns worldwide to monitor the uncontrolled re-entry
- Owing to its mass of 8,500 kg (10x3.5 m), a part of it resisted to the burning due to Earth's atmosphere
- It re-entered on 2 Apr. 2018 in South Pacific Ocean



Tiangong-1 means "Celestial Palace"
Credit: ESA

Long-March 5B

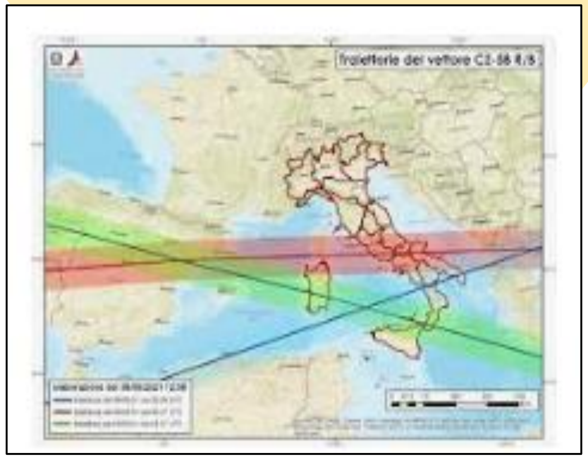
- LM-5 or CZ-5 is a Chinese launcher
- 21 ton
- A part of stage re-entered on May 2021
- The world press and social media had a big impact



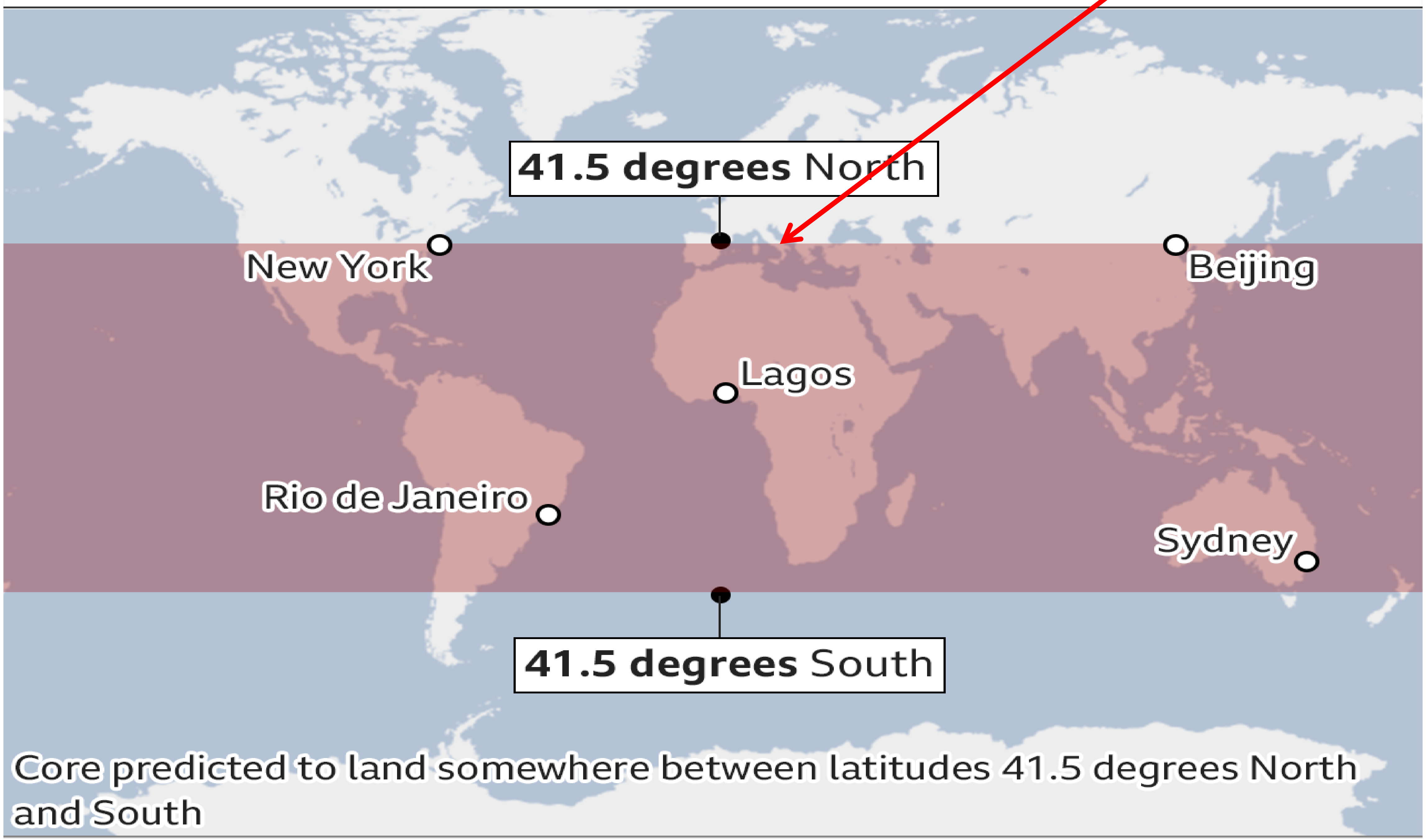
World press reports on LM 5B, May 2021 (Credit: Google)

Long-March 5B

Italian press reports on LM 5B, May 2021 (Credit: Google)



Where could the rocket core land?

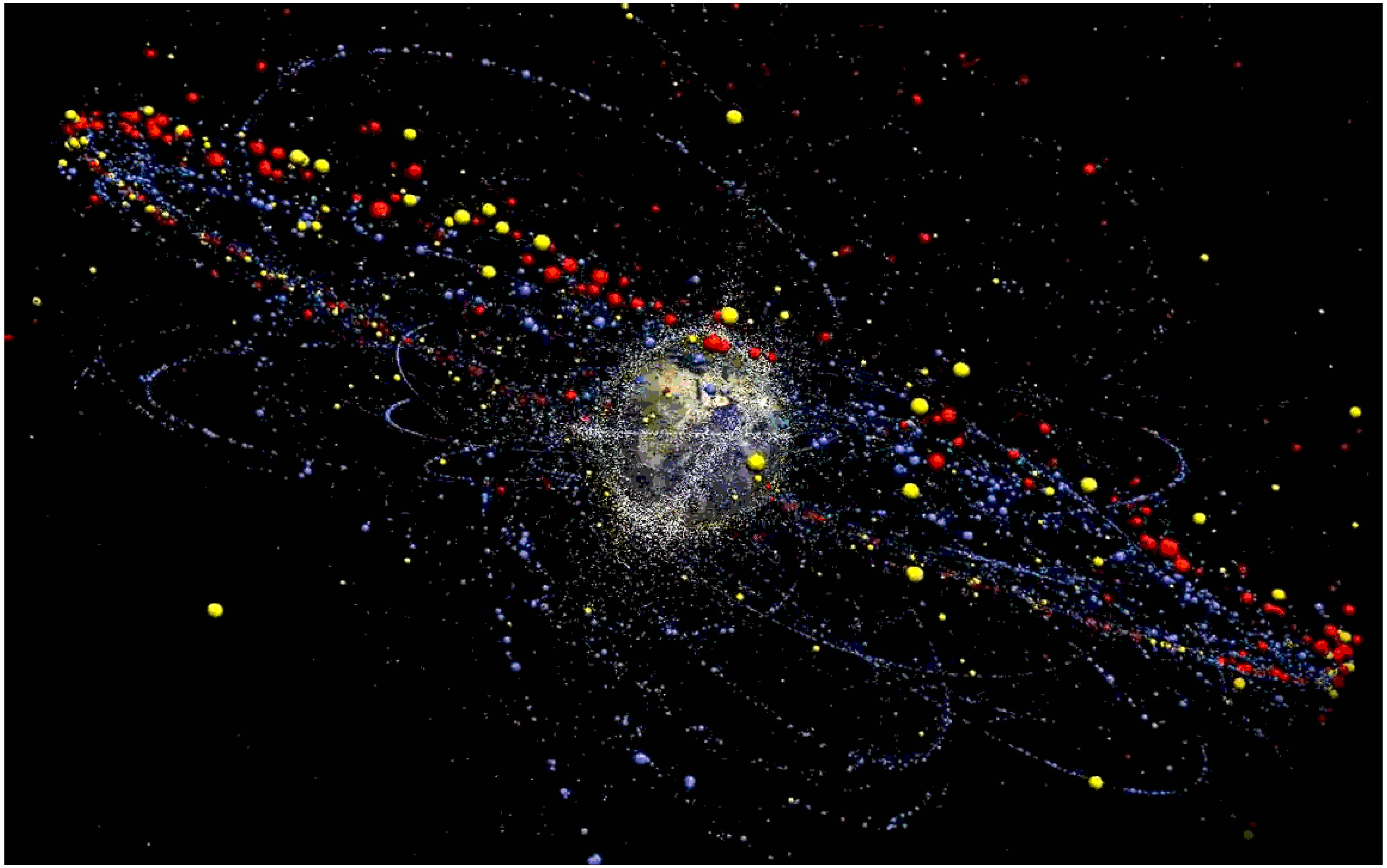


Source: Orbit.ing-now

BBC

Kessler’s Syndrome

- In future we expected thousands of LEO satellites in mega-constellation
- An important problem in space can be due to Kessler’s syndrome
- It suggests that a massive collision event in LEO can activate a chain of secondary impacts, due to the fragments dispersion that in a domino effect can hit other objects
- In a similar scenario the LEO regions will become a physically impenetrable barrier



SD projects

Recently, many projects have started at national, European and international level.

❖National projects:

- Italian ASI-INAF agreement

❖European projects:

- ESA Space Situational Awareness Programme
- EU Space Surveillance and Tracking (SST) → next lecture

❖ Mitigation guidelines:

- COPUOS, Inter-Agency Space Debris Coordination Committee (IADC) → next lecture
- "Long-Term Sustanaibility" (LTS) guidelines for outer space by UNOOSA → next lecture