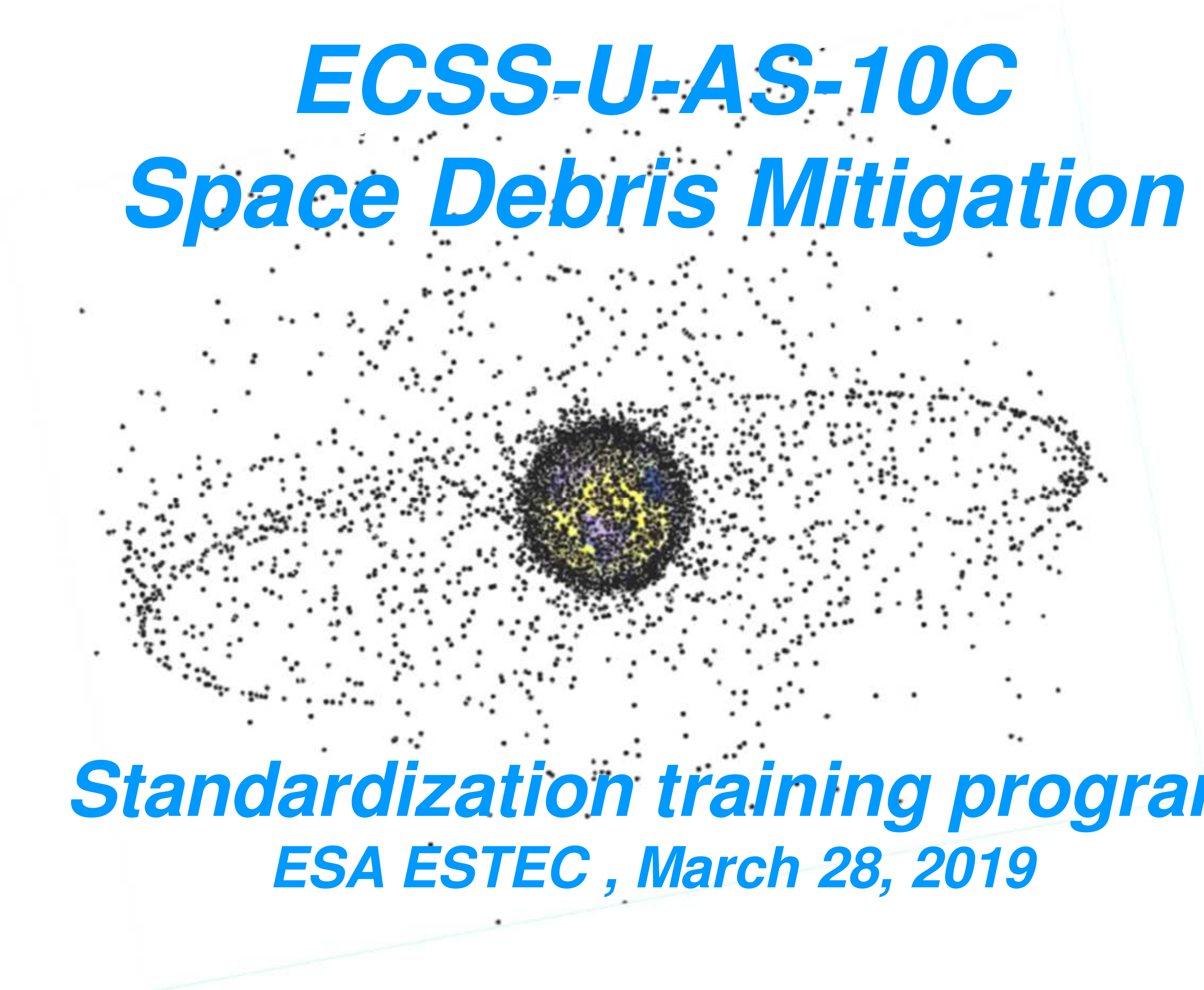
ECSS-U-AS-10C
Space Debris Mitigation



Standardization training program
ESA ESTEC , March 28, 2019

Training Course Instructor

ECSS-U-AS-10C - Space Debris Mitigation

Standardization training program

ESA ESTEC , March 28, 2019

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Representative for ECSS within the ISO TC20/SC14 – WG7 (Orbital Debris Working Group)

Audience ?

Outline

28 March 2018 - 9:00-12:30

Introduction

- Rationale of the course and area addressed

Space Debris Overview

- Space Debris: An increasing issue. Definitions (identified, catalogued, PL, RB), genesis (break ups), evolution
- Space Debris Environment and Critical Events: Iridium 33 – Cosmos 2251 Collision (2009), Fengyun-1C (FY-1C) Anti-Satellite Test (2007), Break-ups
- Environmental data & status
- Effects of Space Debris on Space Systems: hypervelocity impacts, collision avoidance
- Re-entry Risk
- Global Perspective for Space Sustainability

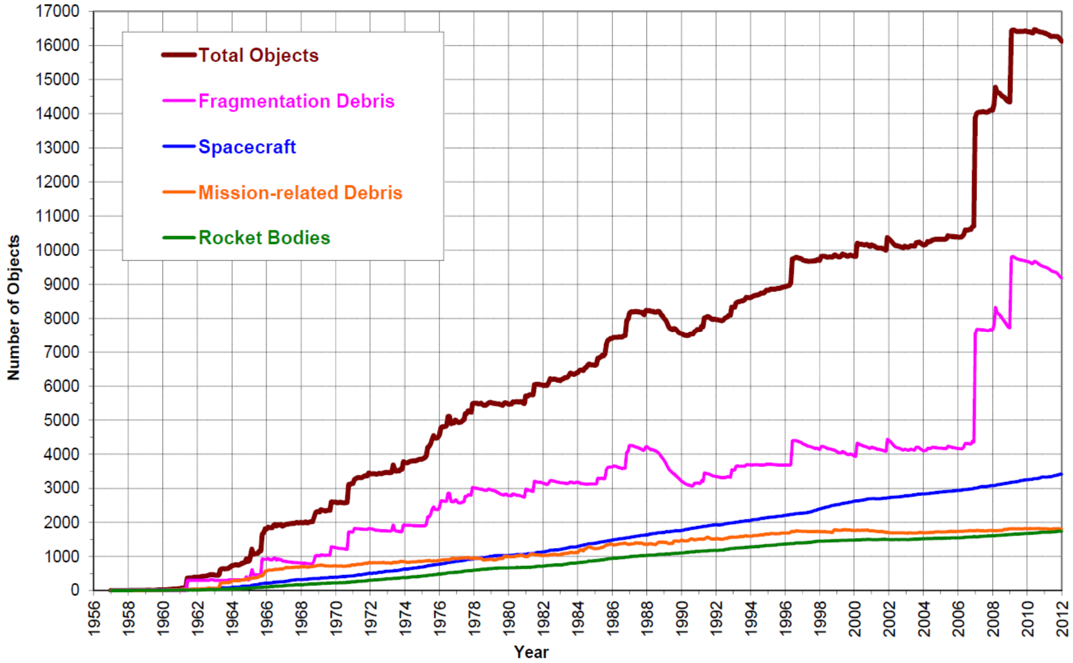
Space Debris Mitigation

- Space Debris Mitigation Guidelines and Standards
- ECSS & ISO TC20/SC14 (& CEN) Space Debris Mitigation Standards
- ESA Space Debris Requirements (ESA/ADMIN/IPOL 2014)
- French Space Law
- ECSS Space Debris Requirements Discussion (with as example Sentinel-1)
- SDM Handbooks and Supporting Studies
- Evolution of Space Debris Requirements: Large constellations, “small” satellites and evolution of requirements

Conclusions

Space Debris Overview

Space Debris: An Increasing Issue



Gravity (Theatrical Trailer) HD(videoming.in)

Space debris / orbital debris (IADC / ISO current definition):

- "man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional" (IADC / ISO definition)

Space debris (new ISO proposed definition):

- Deprecated: orbital debris
- objects of human origin in Earth orbit or re-entering the atmosphere, including fragments and elements thereof, that no longer serve a useful purpose
- Note 1 to entry: Spacecraft in reserve or standby modes awaiting possible reactivation are considered to serve a useful purpose.

Identified Objects (ESA SDO classification, simplified):

- can be traced back to a launch event and for which the nature can be identified. They can be categorized as:
  - Payloads (PL), designed to perform specific function in space excluding launch functionality (including operational satellites).
  - Payload (PL) Debris: Mission Related Objects and fragmentation / released debris with either a genesis traced back to a unique event or an unclear identified genesis (but correlated to a source)
  - Rocket Body (RB), designed to perform launch related functionality (e.g., orbital stages of launch vehicles)
  - Rocket Body (RB) Debris: Mission Related Objects, fragmentation / released debris with either a genesis traced back to a unique event or an unclear identified genesis (but correlated to a source)
  - Unknown (UI) assigned whenever there is lacking evidence to support a more specific classification.

Catalogued Objects:

- objects whose orbital elements are maintained for prolonged periods of time in a catalogue created by a space surveillance system

Space Debris

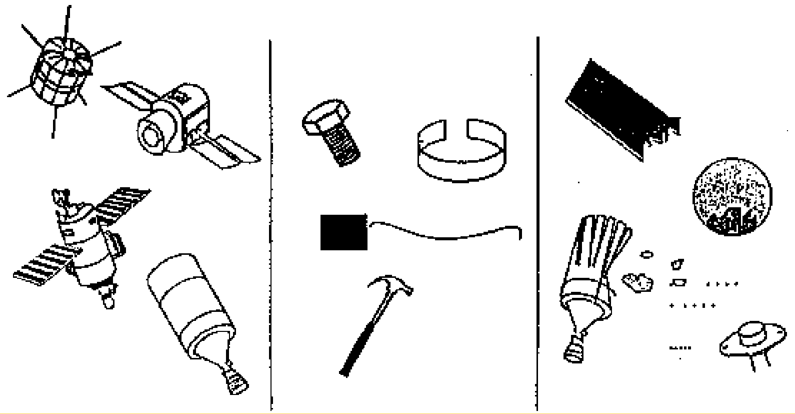
Identified Objects, listed (by type) in the ESA's Annual Space Environment Report - DISCOS Database (as of end of 2018: ~22037 objects):

- PL: ~23% (of which operational/functioning PL ~9%, "retired satellites" ~14%)
- PL Debris (incl. PF PD PM) ~34%
- RB: ~9% (e.g., spent orbital stages)
- RB Debris (incl. RF RD RM): ~24%
- Unknown Objects: ~19%

Catalogued objects:

- Listed in the U.S. SPACE SURVEILLANCE NETWORK "TLE" catalogue, with assigned origin, regular tracking **19173 objects, as of 4 October 2018** (other ≈ 5000 are unpublished for various reasons).

Extrapolations lead to more than 30000 objects > 10 cm; 800,000 - 1,000,000 between 1 and 10 cm; > 100 million between 0.1 and 1 cm



Space Debris

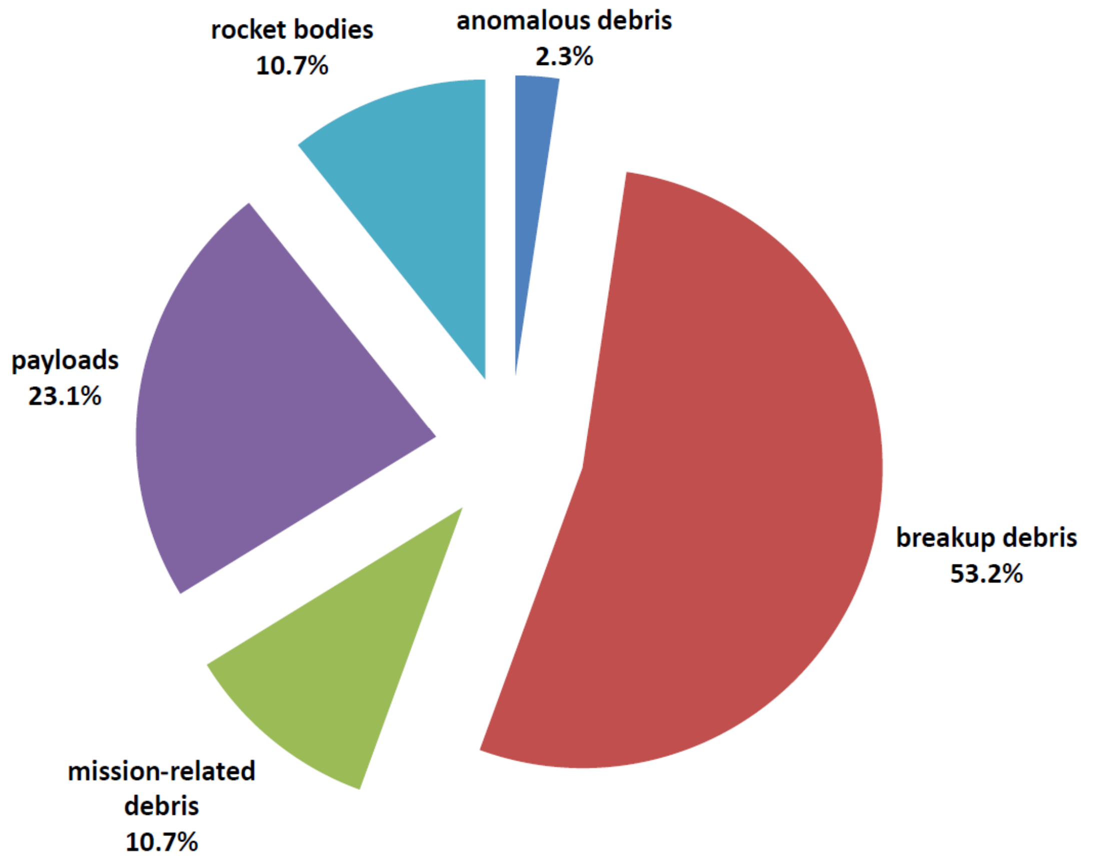
As of January 2019: ~5450 launches had placed ~8950 satellites into orbit, of which ~5000 remain in space (ESA Space Debris Office).

A small fraction ~1950 are still operational today, orbiting with ~ 2000 spent orbital rocket bodies and a large number of mission related objects and fragmentation debris, caused by more than 500 break-ups, explosions, collisions, or anomalous events

Data from ESA Debris Office

Figure: Relative proportions of the cataloged in-orbit Earth satellite population as of 4 January 2016 (ODQN Volume 21, Issue 2, May 2017)

3_Space_Debris_total

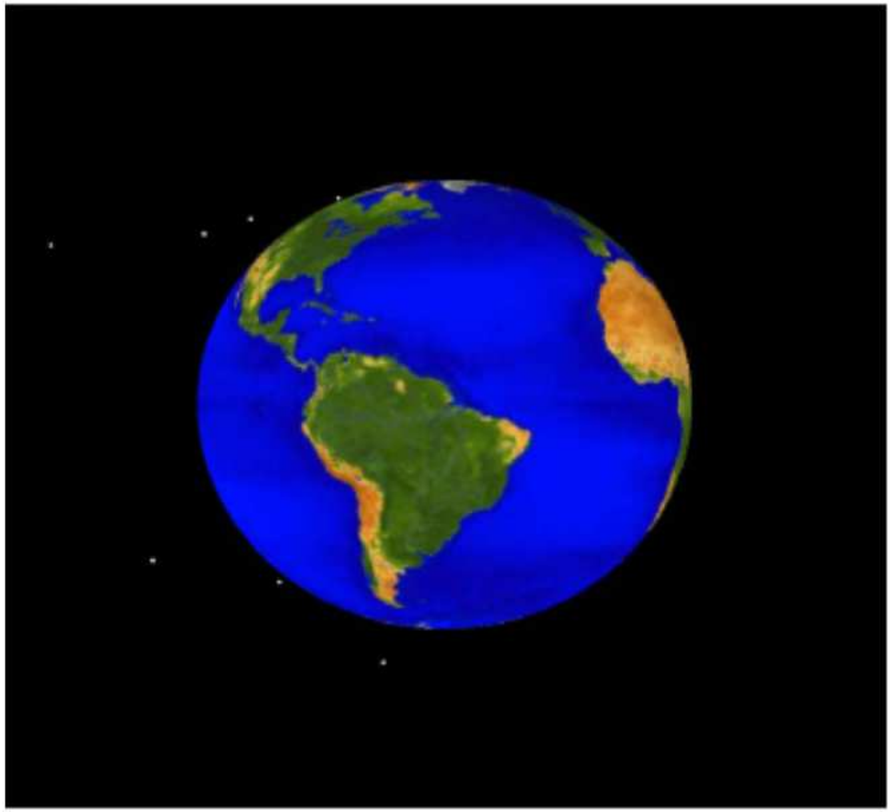


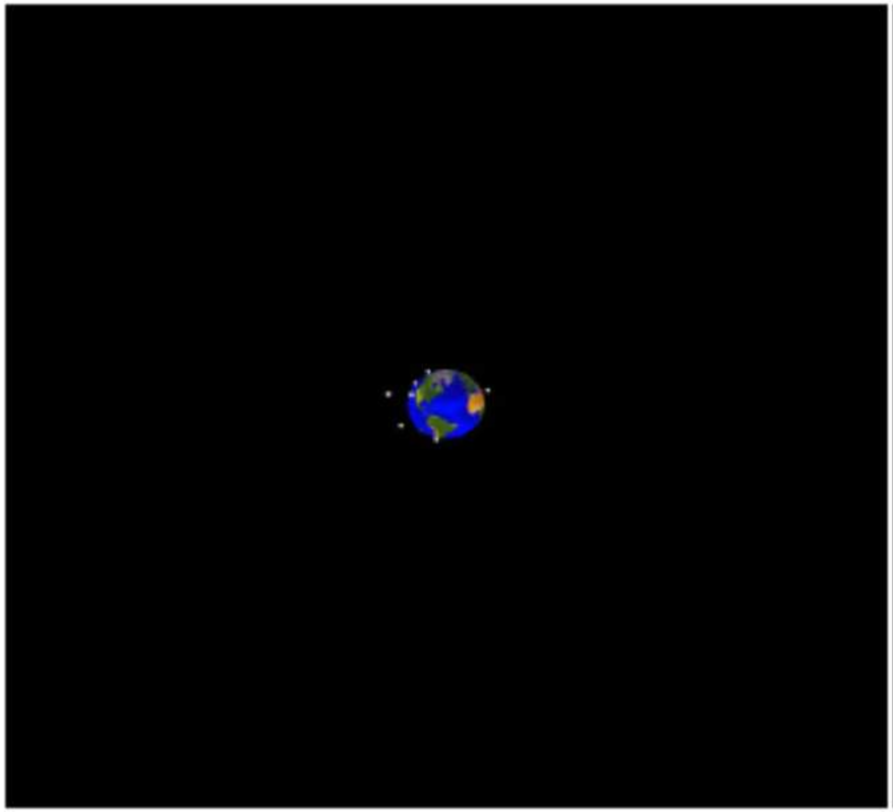
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

Note: object size not to scale (increased for visualization purpose)

http://www.rigb.org/docs/debris/

1960



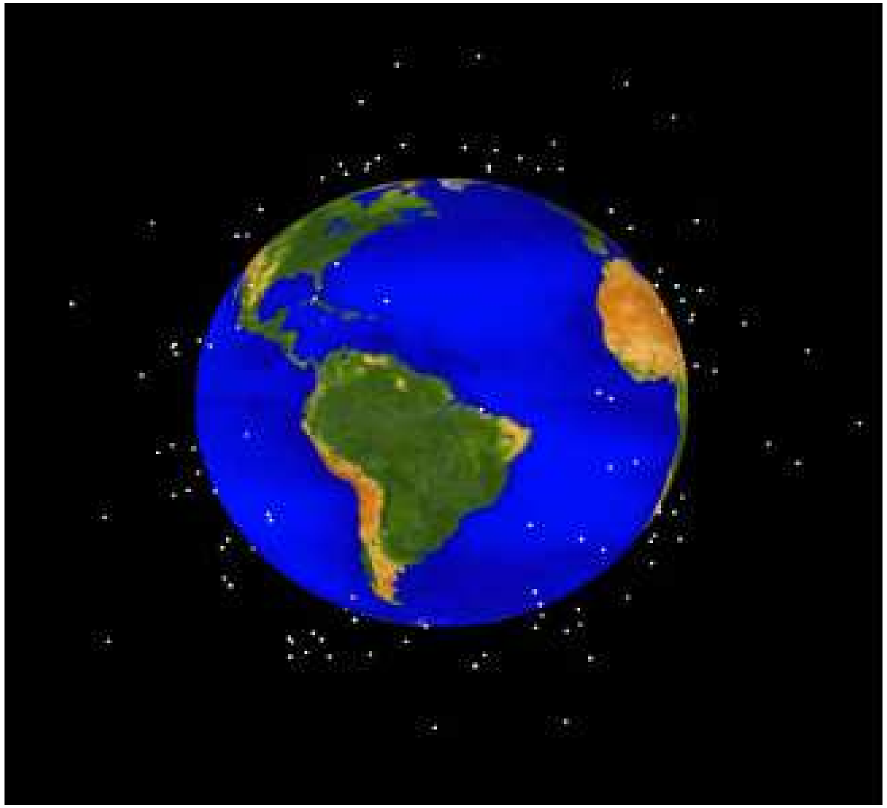


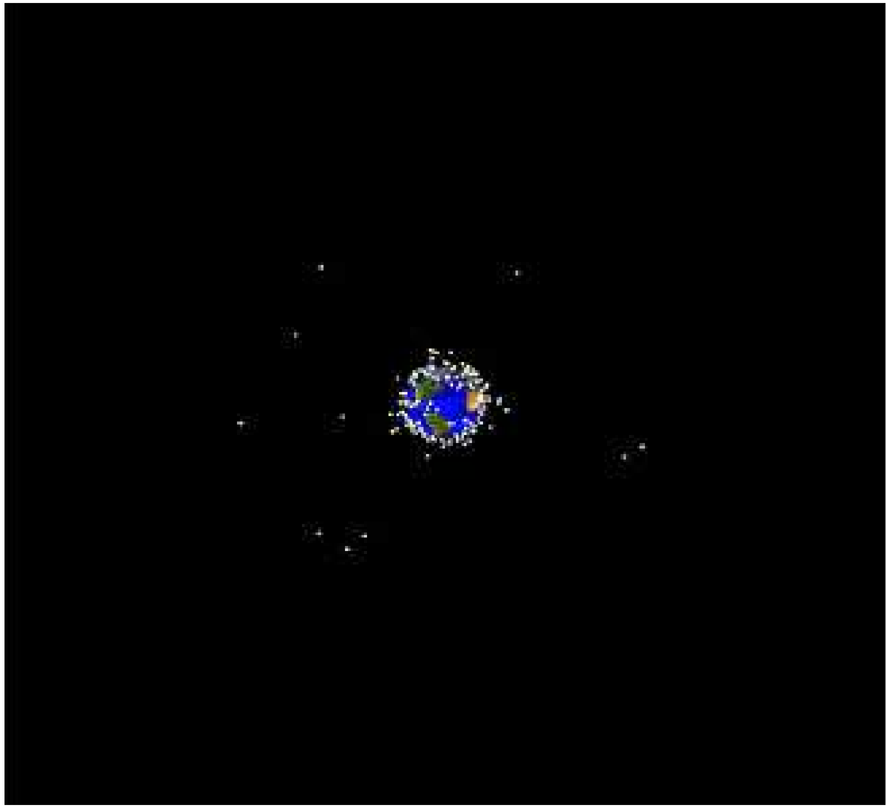
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

https://www.youtube.com/watch?v=wPXCk85wMSQ

https://www.youtube.com/watch?v=9cd0-4qOvb0

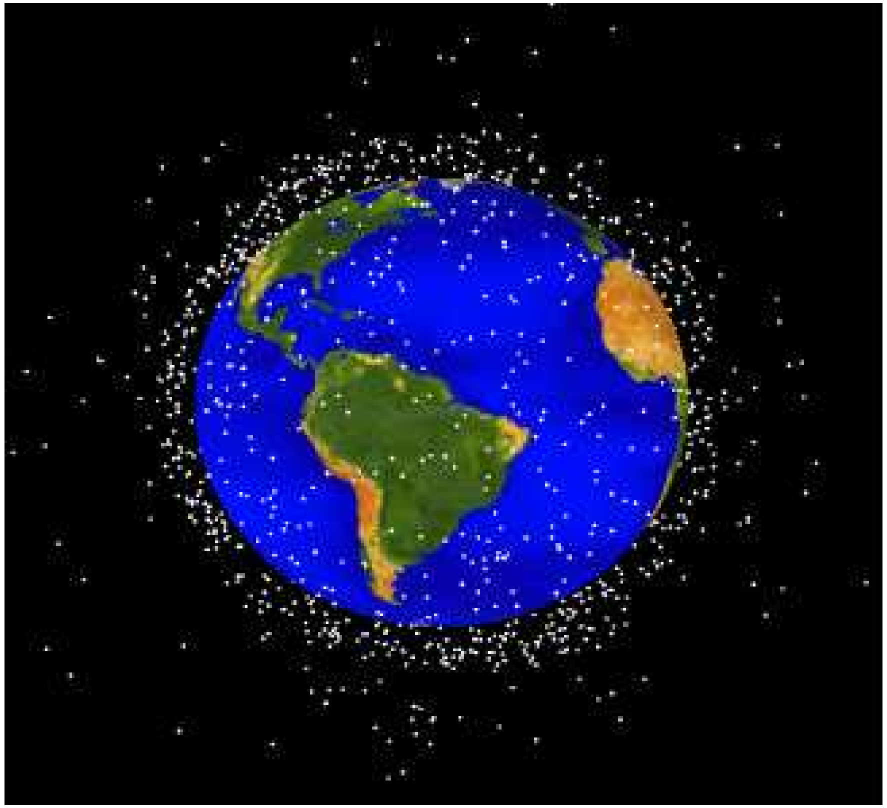
1965

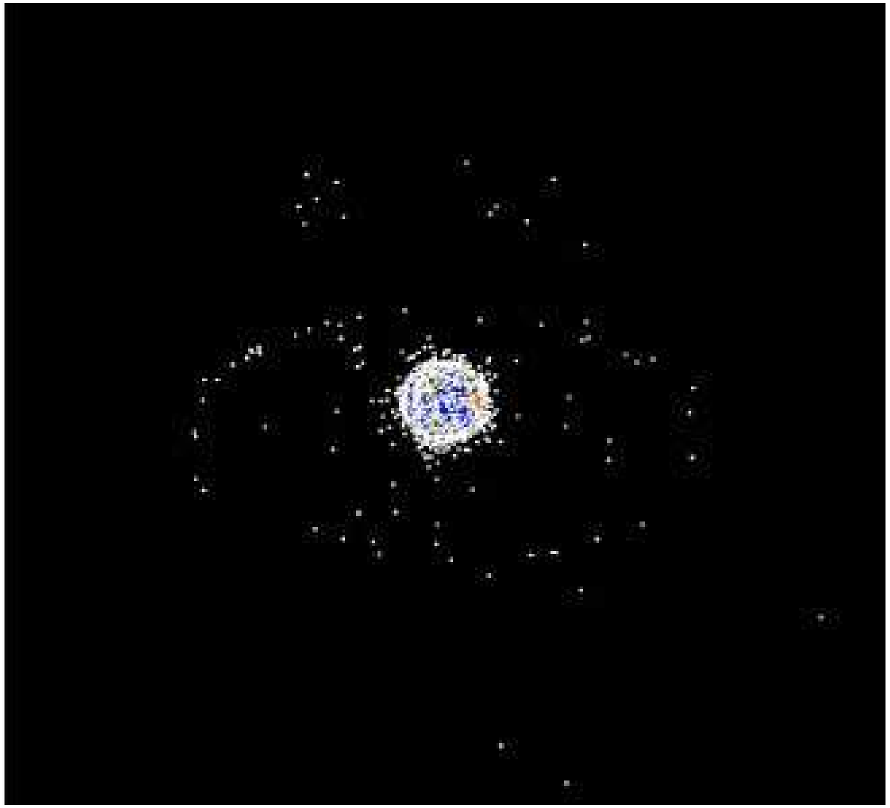




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

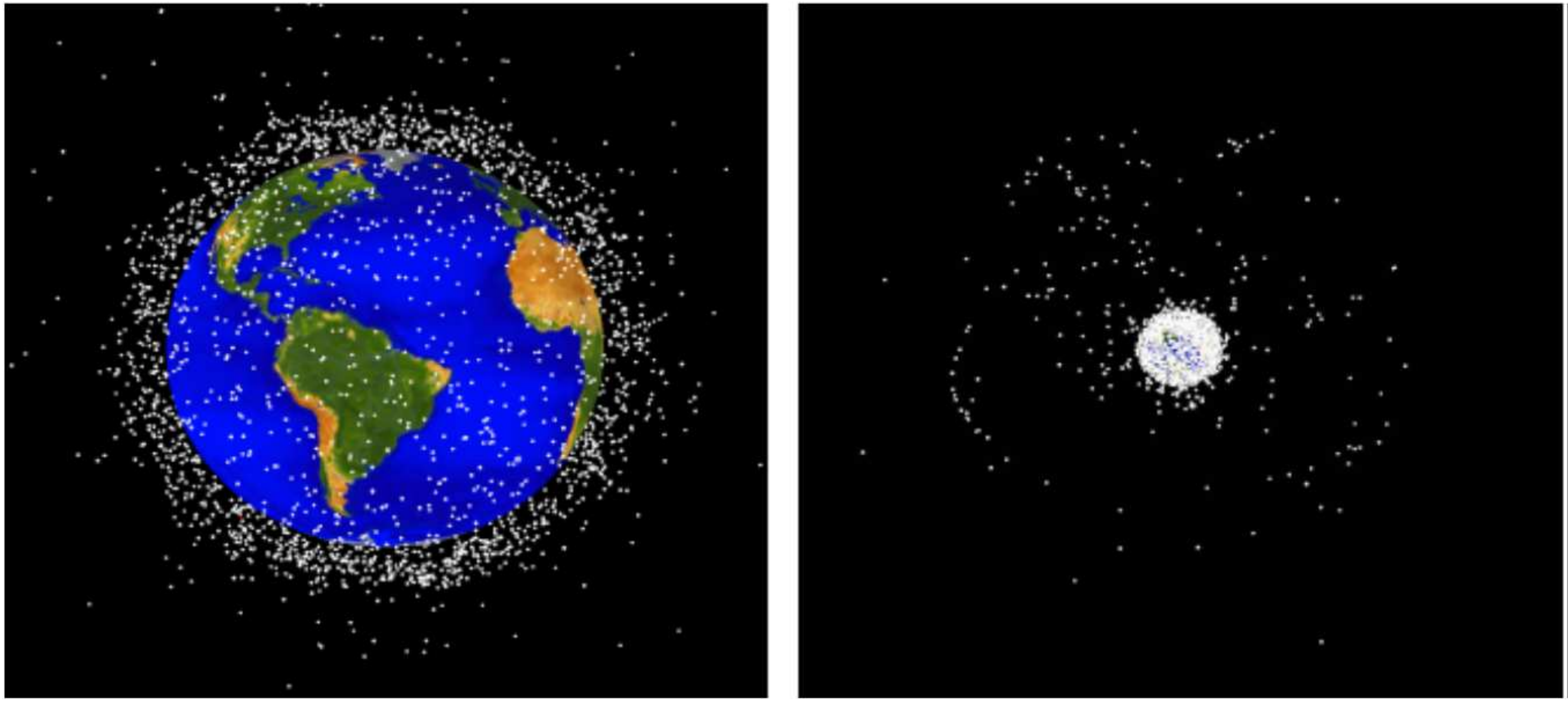
1970





Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

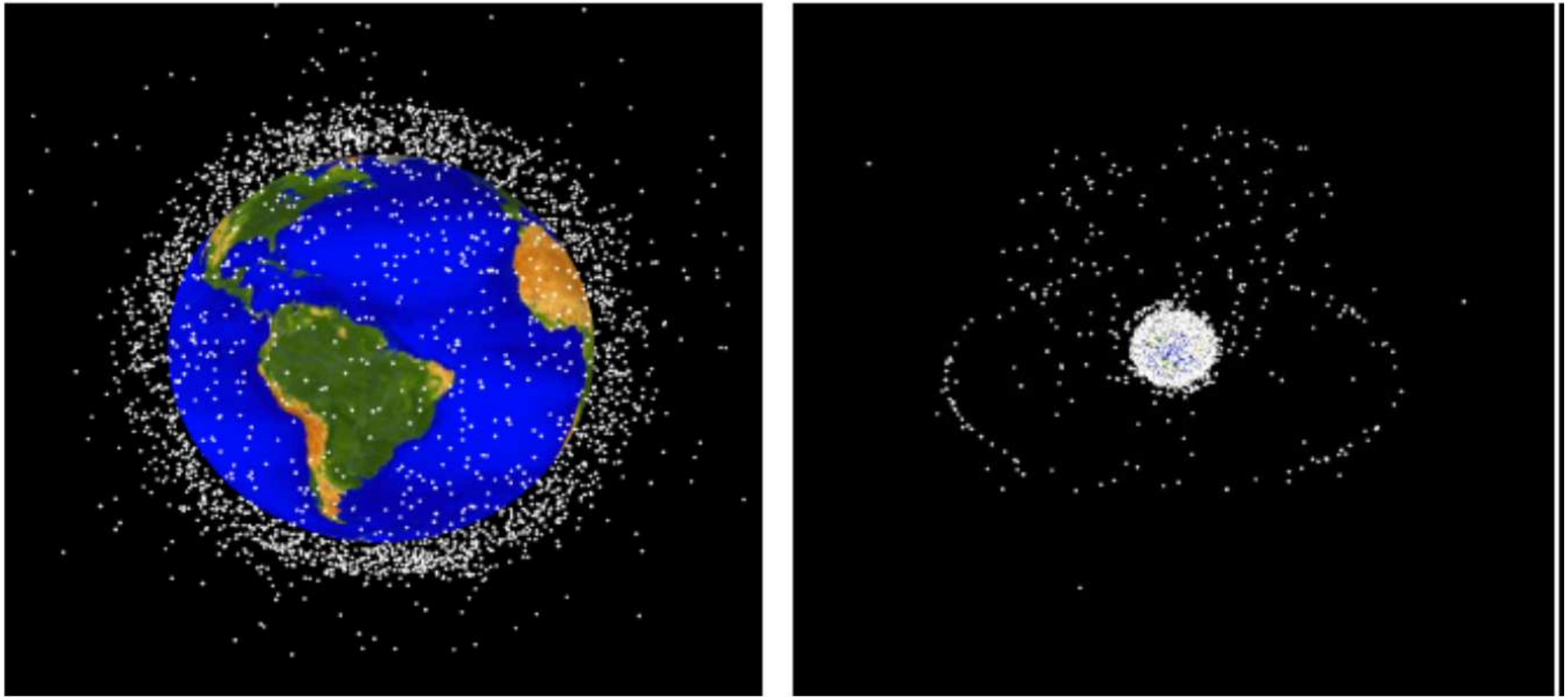
1975



EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

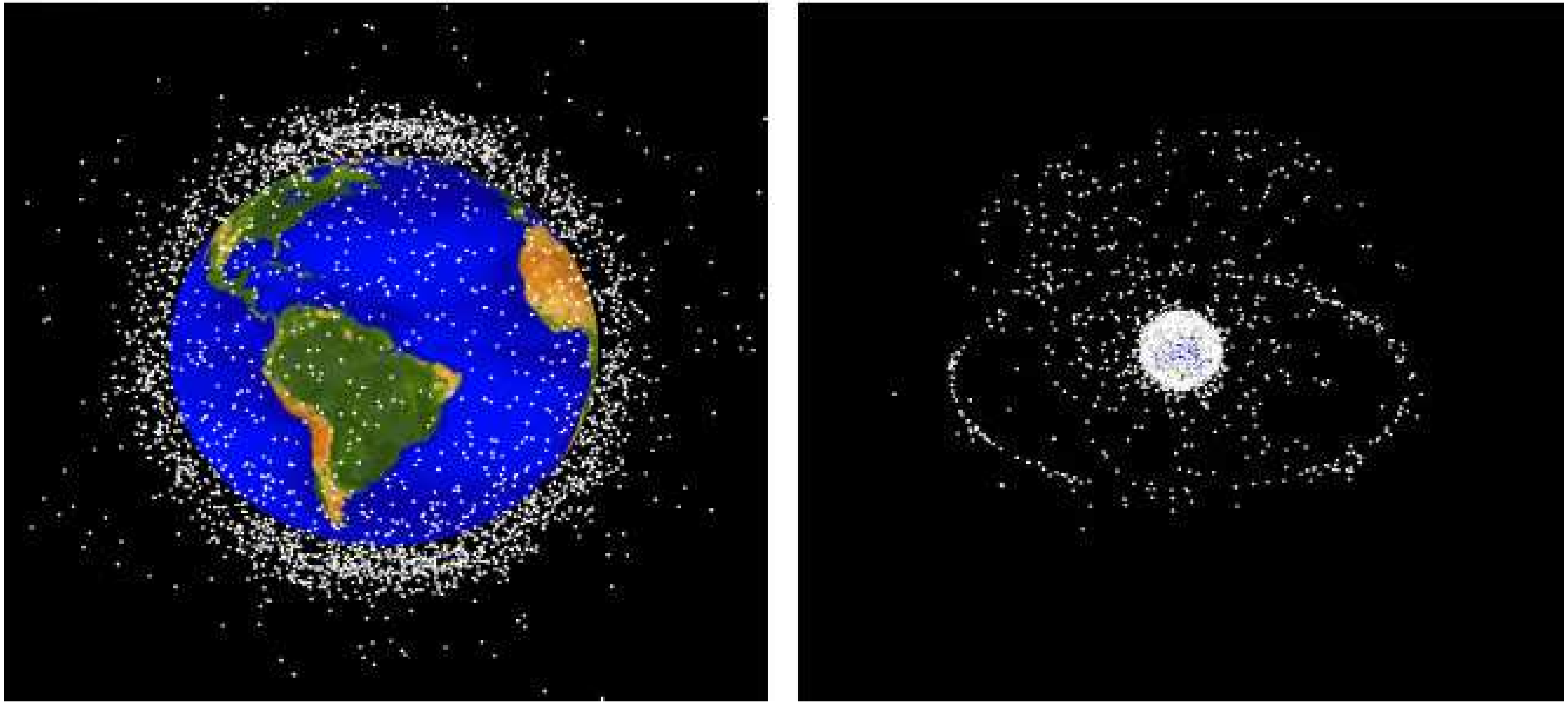
1980



EUROPEAN COOPERATION FOR SPACE STANDARDIZATION

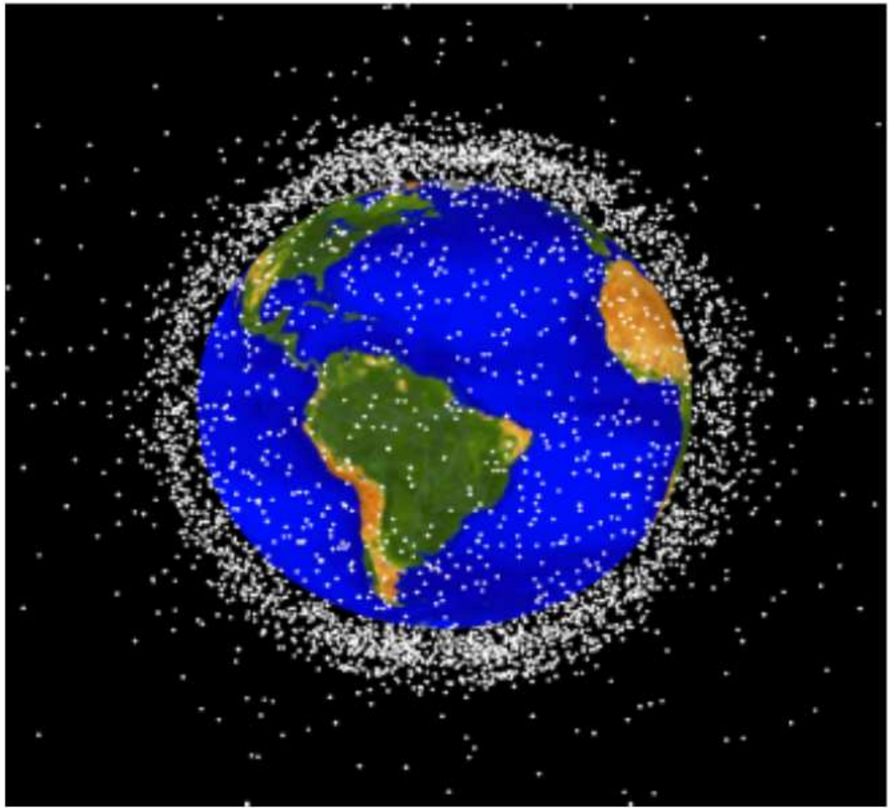
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

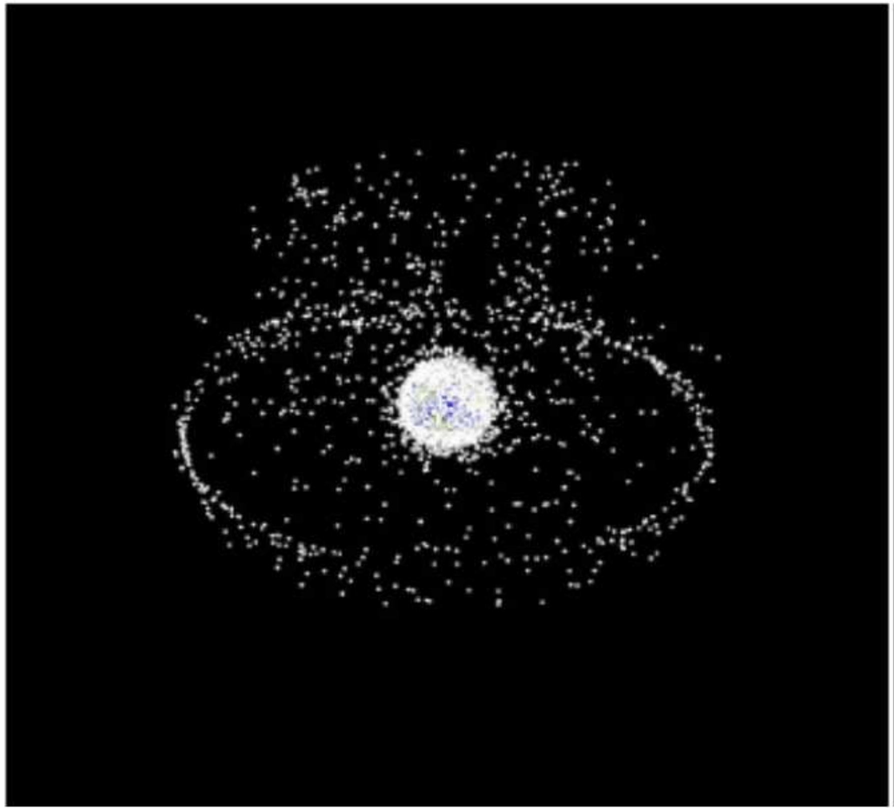
1985



Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

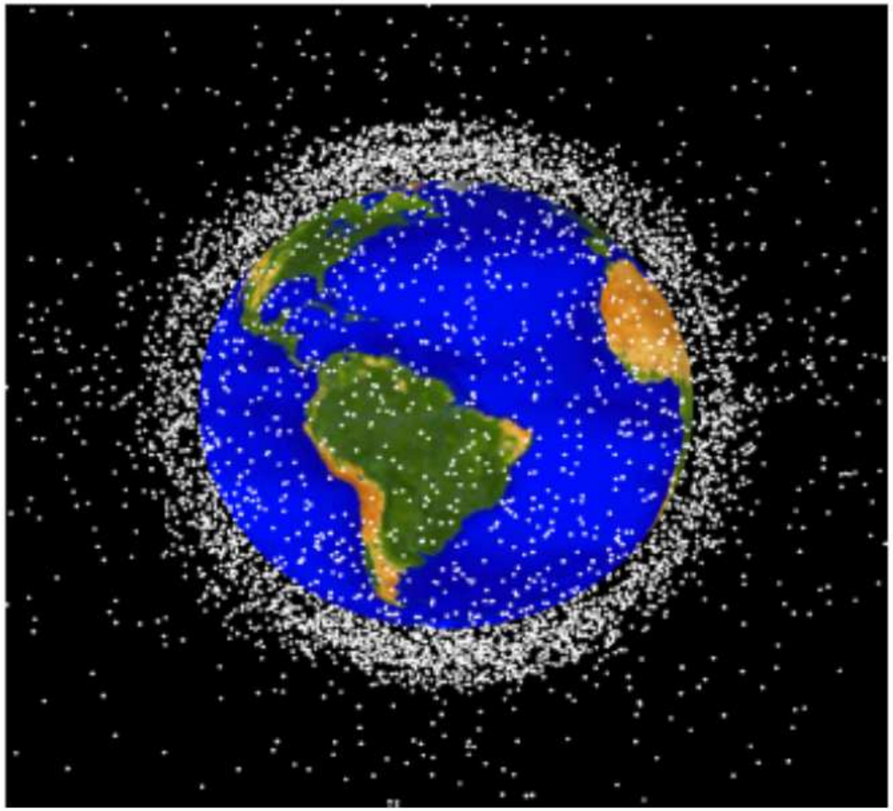
1990

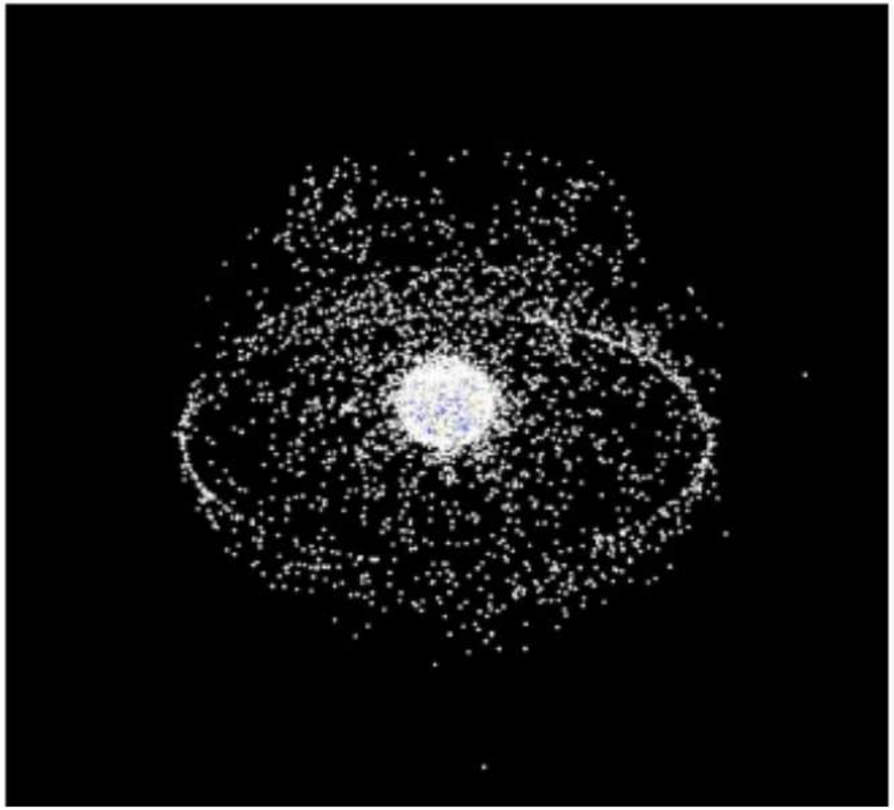




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

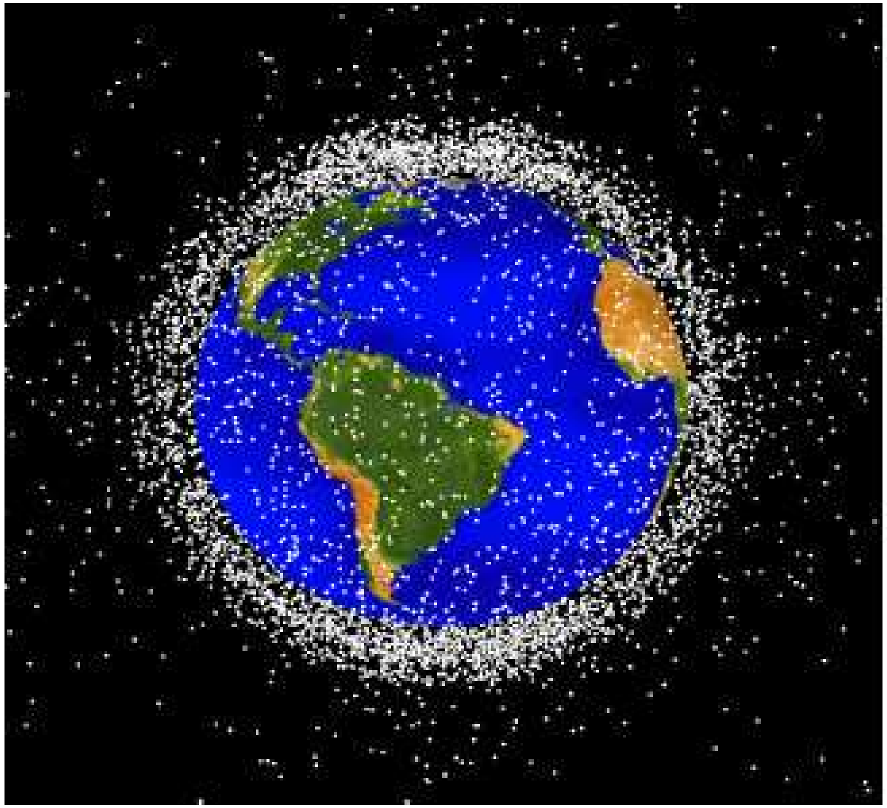
1995

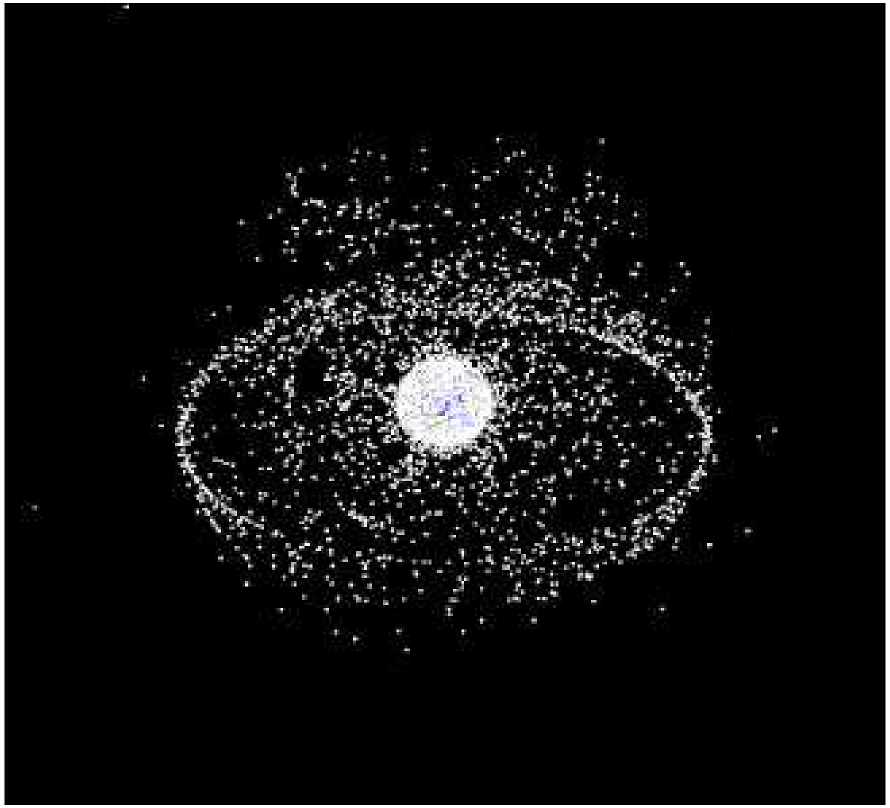




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

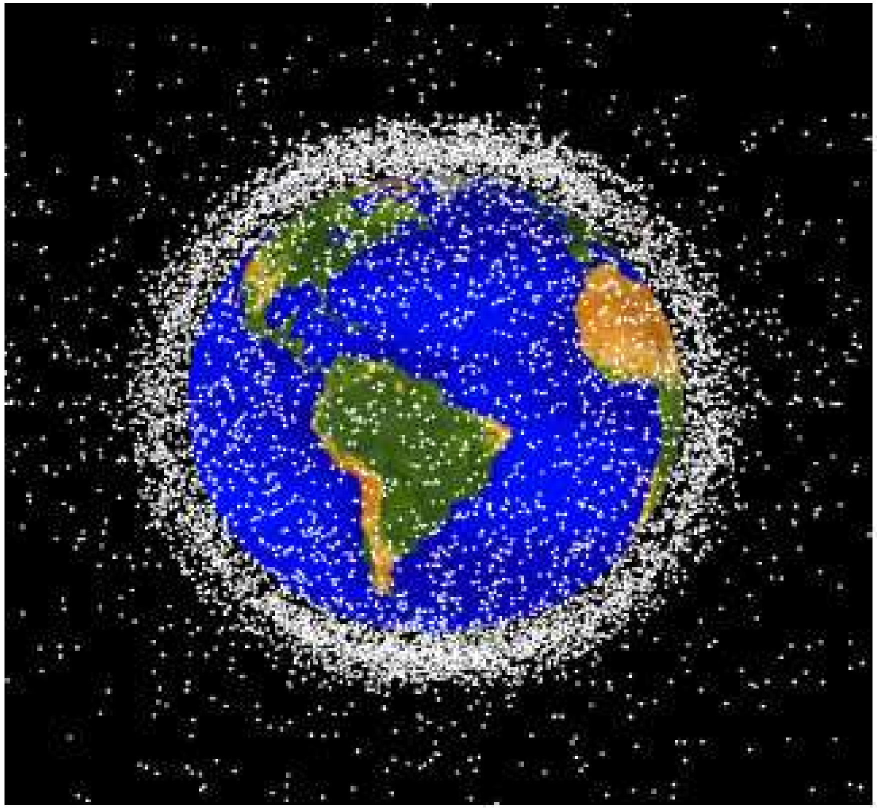
2000

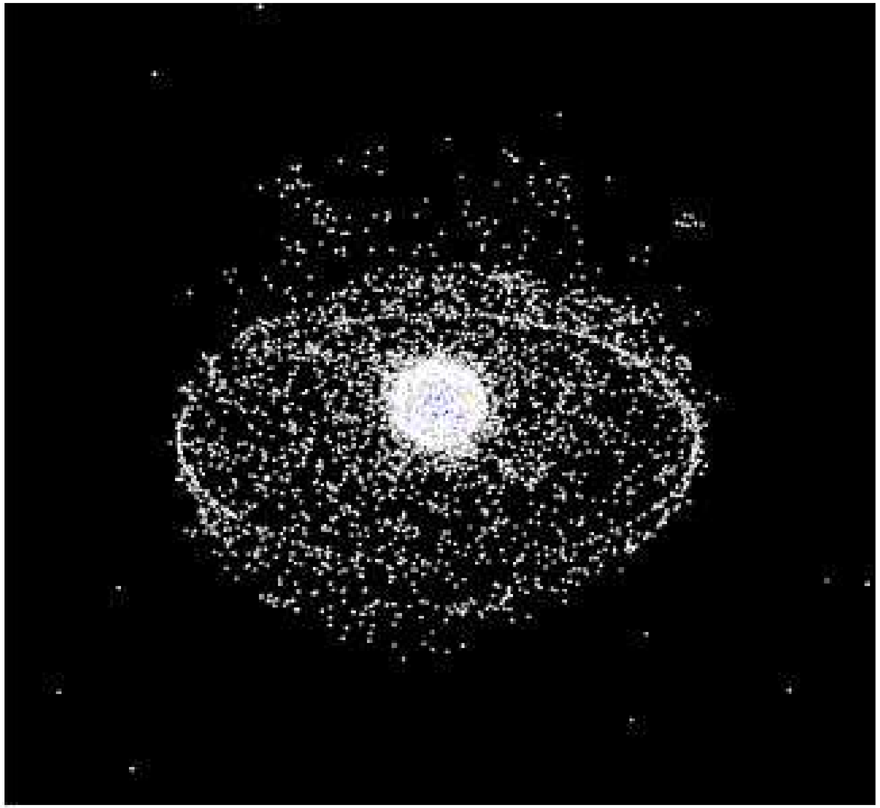




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

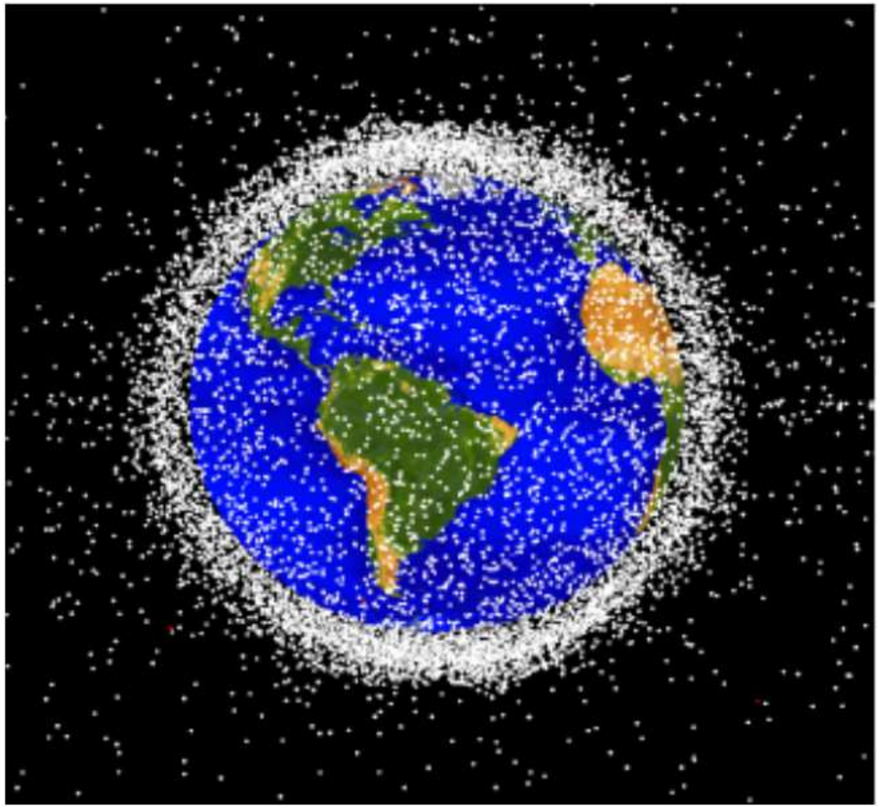
2005

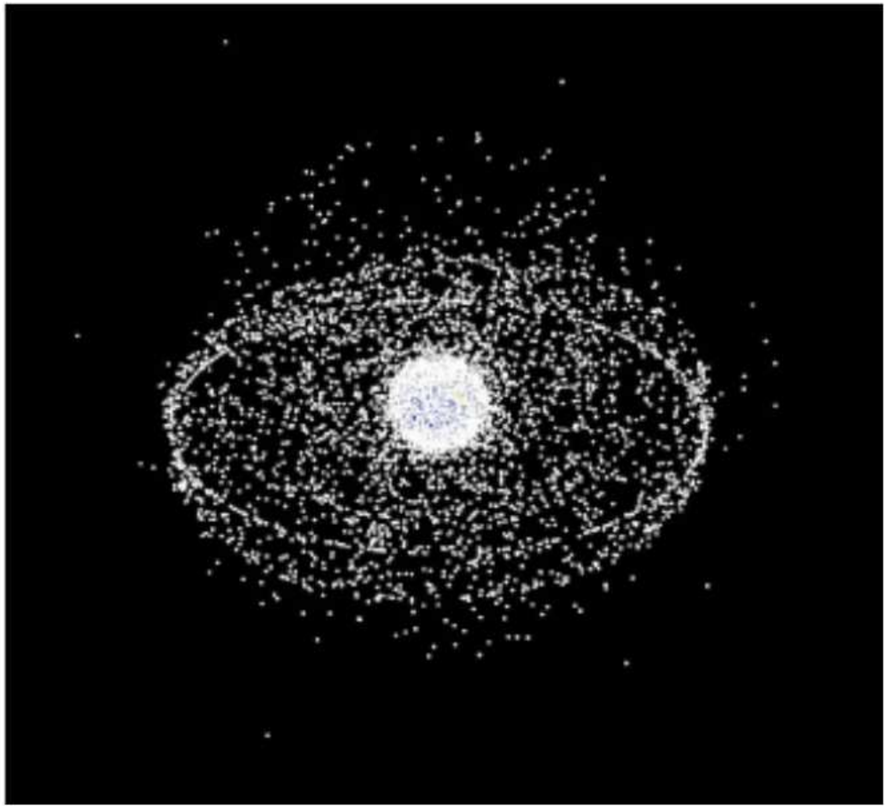




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

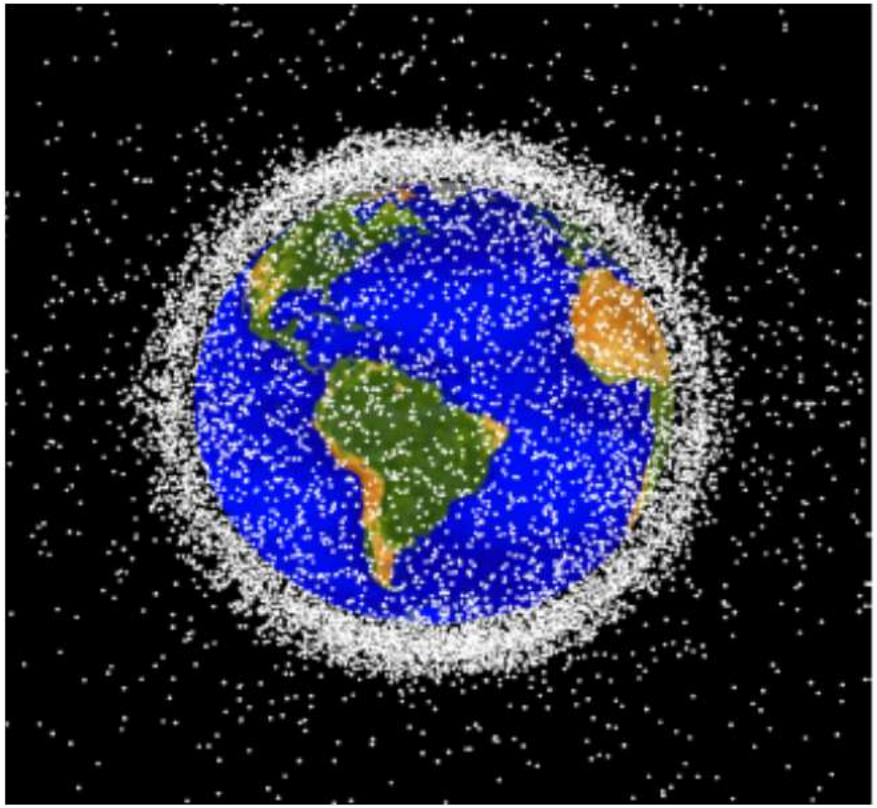
2008

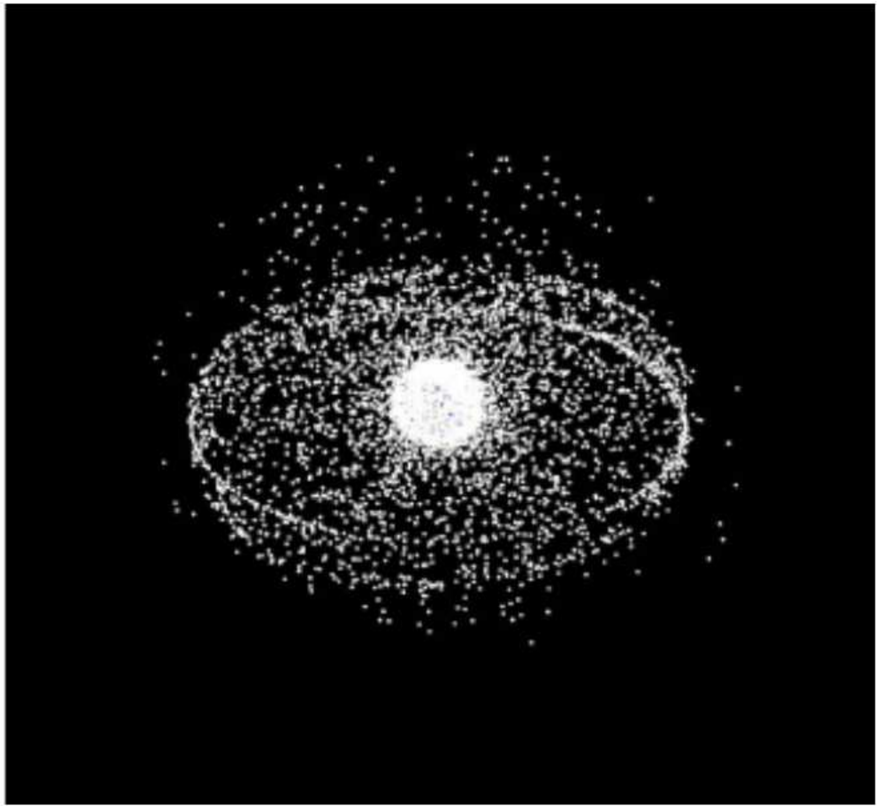




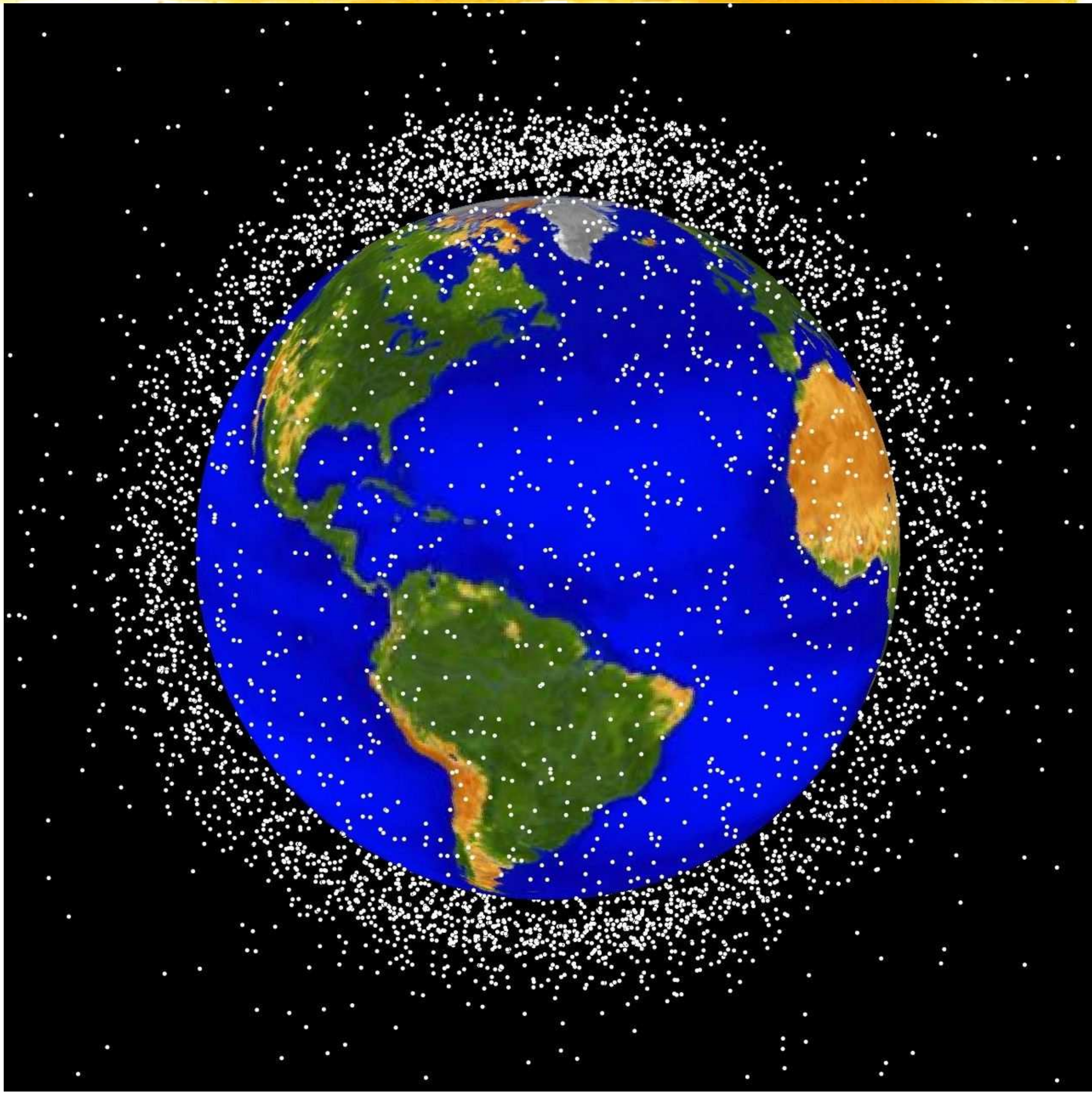
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

2009



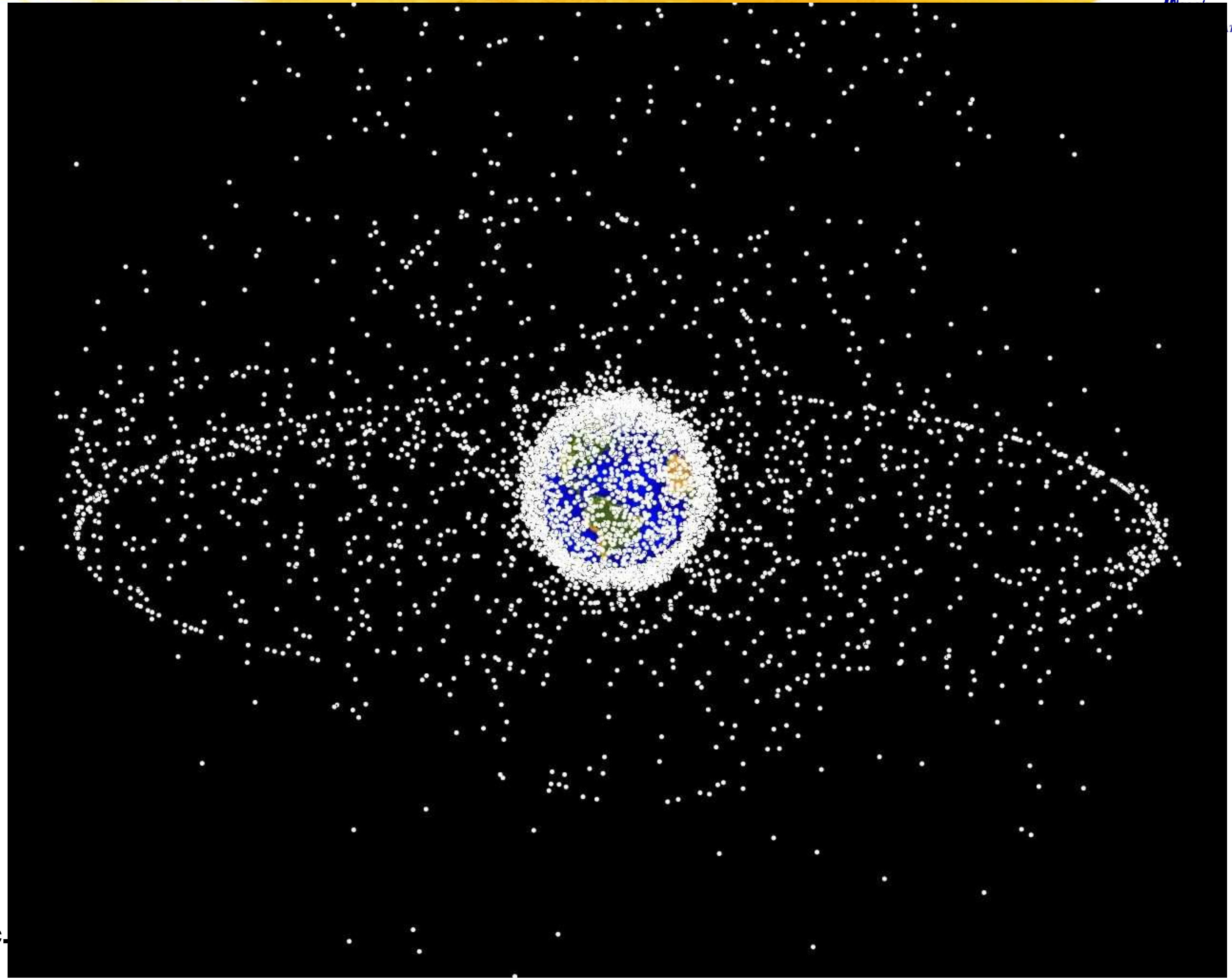


Space Debris in LEO



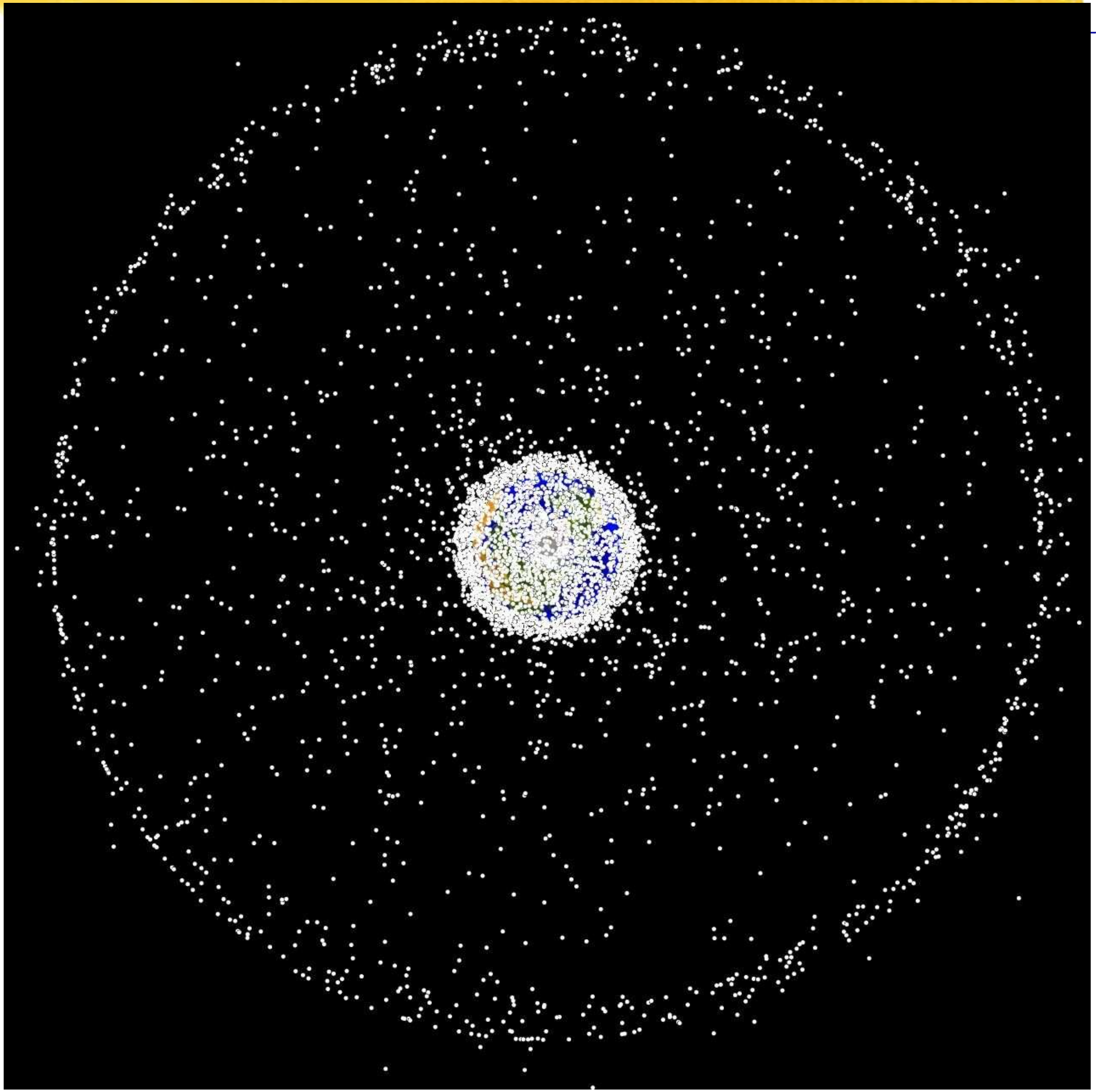
NASA https://orbitaldebris.jsc.nasa.gov/photo-gallery.html

Space Debris – GEO ring



NASA https://orbitaldebris.jsc.nasa.gov/photo-gallery.html

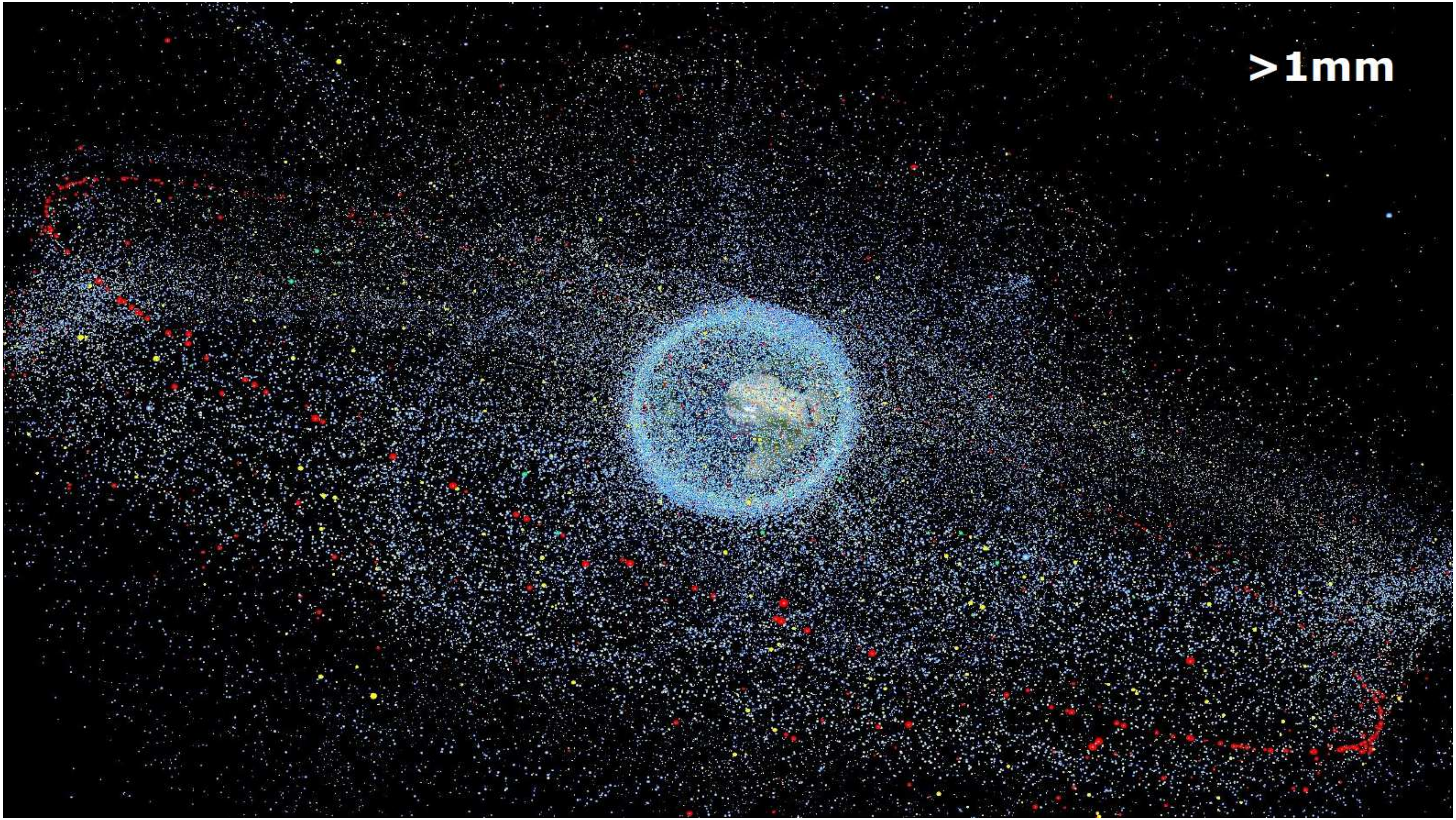
Space Debris – GEO ring (from North pole)



NASA https://orbitaldebris.jsc.nasa.gov/photo-gallery.html

Space Debris

ESA SDO: debris population > 1 mm (based on MASTER model 2009)

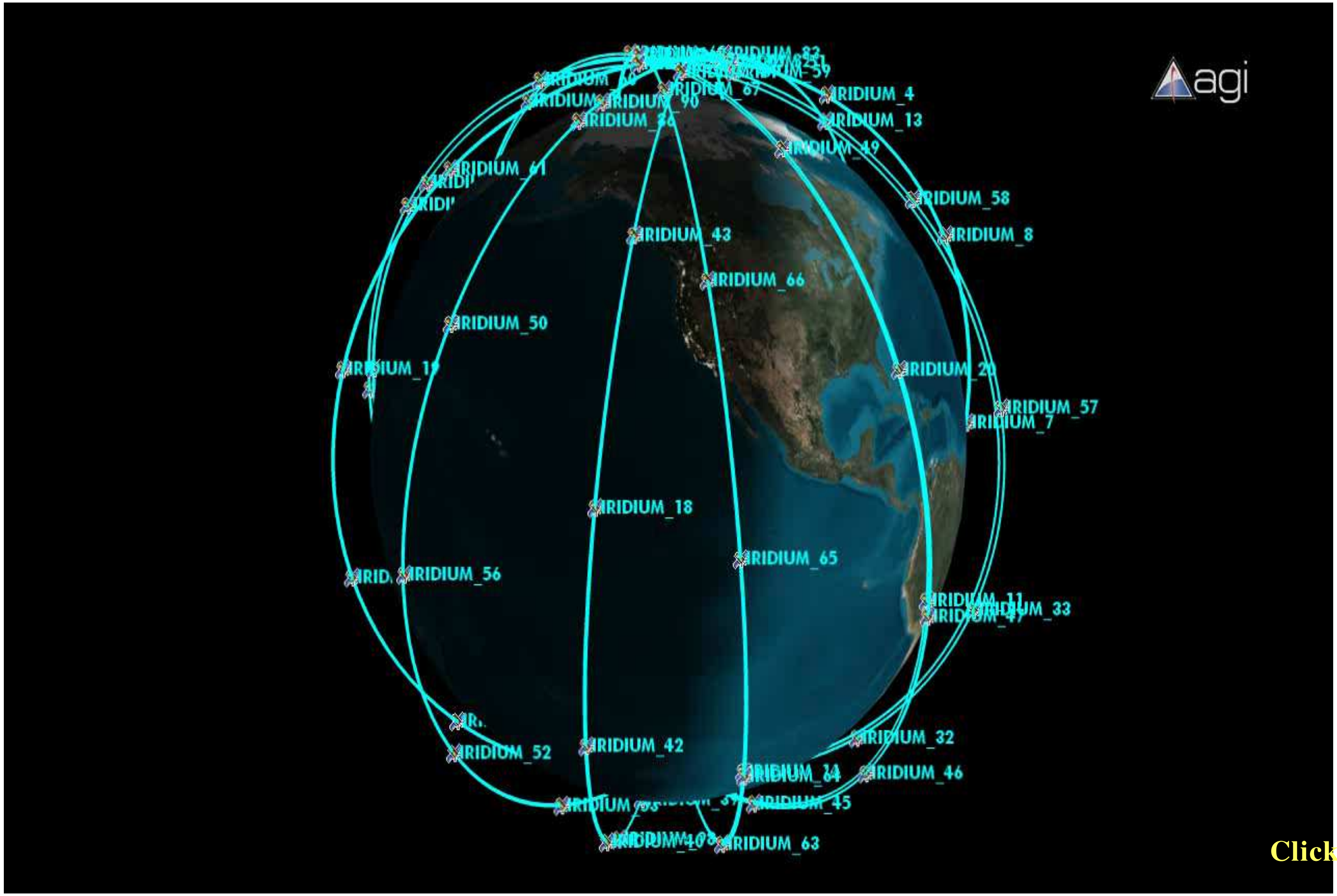


Space Debris Overview

Space Debris Environment
and
Critical Events: ASAT, Collisions, Break-ups

Cosmos 2251- US Iridium 33 collision (2009)

IridiumCosmos_v3



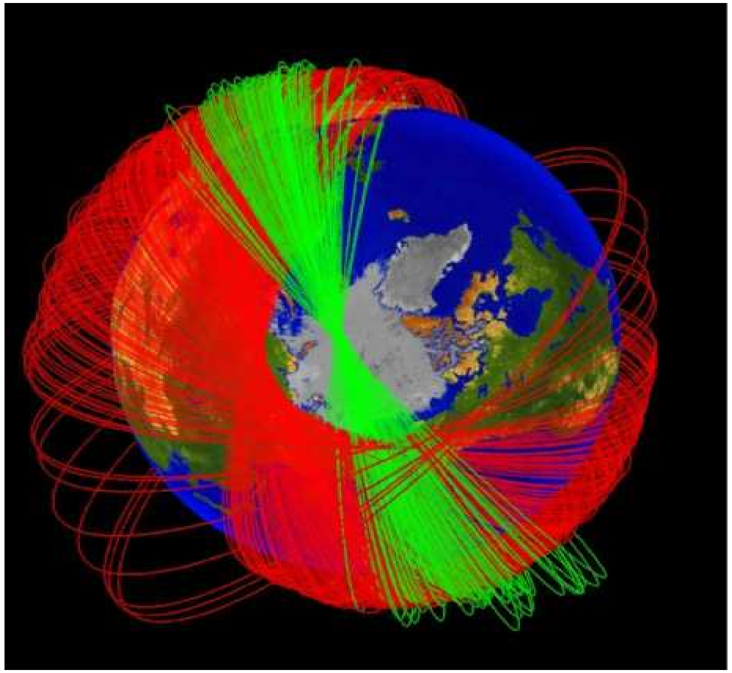
Both cause and consequence.

IRIDIUM satellite constellation consists of 66 main satellites and 6 spares

Iridium 33 – Cosmos 2251 Collision (2009)

The first ever accidental collision between two intact satellites occurred on 10/02/2009 at 16:56 GMT between Iridium 33 (US Operational communication satellite) and Cosmos 2251 (a Russian decommissioned communications satellite) leaving 2 distinct debris clouds in LEO.

- Iridium 33 and Cosmos 2251 mass: 560 kg and 900 kg, respectively
- Collision relative velocity:11.6 km/s, altitude 790 km
- As of January 2016: 628 debris from Iridium 33 and 1668 from Cosmos 2251 were catalogued; 364 and 1141 respectively are still on-orbit
- Highlighted the orbital debris problem in LEO region
- These clouds pose a significant risk both in the short and long-term. Some of the debris is short lived (re-enter within the next 5-10 years), but incidents such as this could potentially lead to an “ablation cascade”



Predicted evolution of the Iridium and Cosmos debris planes by July 10 (six months after the collision)

Iridium 33 – Cosmos 2251 Collision (2009)

From the TLE orbits COSMOS should have passed 400 m far from Iridium.

No collision avoidance procedures implemented: “Iridium was receiving an average of 400 reports per week of objects coming within 5 km of one of their satellites” (66 operational satellites + 6 spares, located on 6 orbital planes)

“Now, once every couple of weeks we do a maneuver” (S. Smith, Iridium EVP, December 2010)

Iridium:

- a = 7174:6984
- e = 0:0002288
- i = 86:399
- Ώ = 121:703

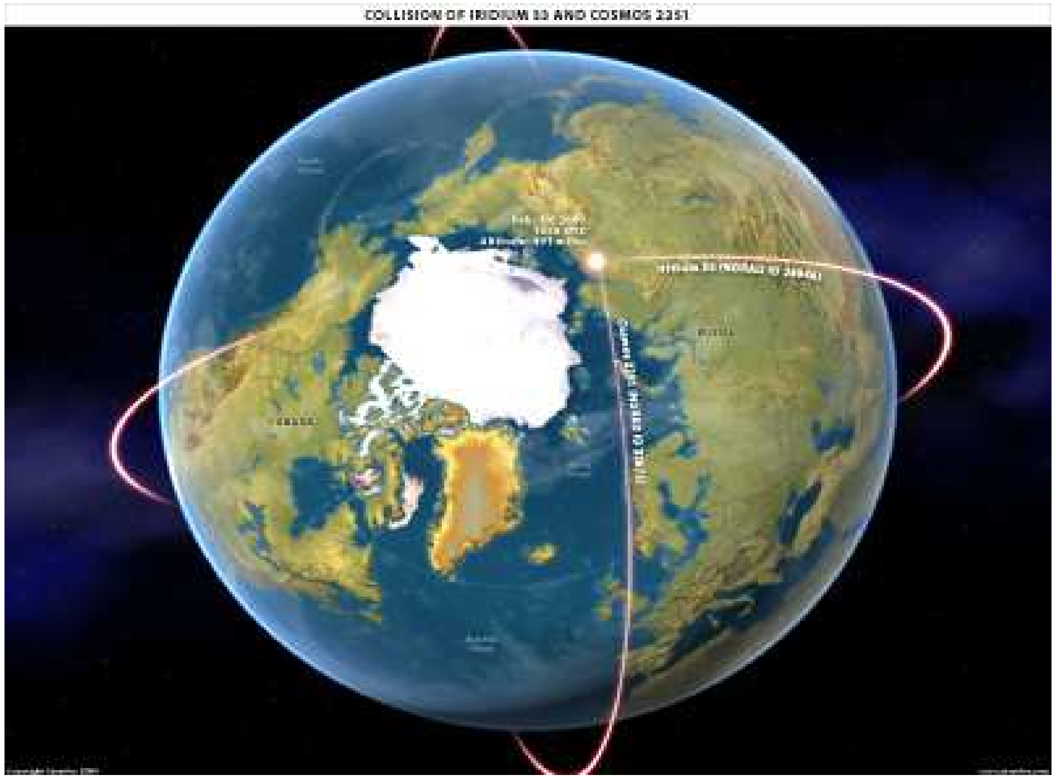
Cosmos:

- a = 7169:649
- e = 0:0016027
- i = 74:0355
- Ώ = 19:4646

I '= 100:73

Hyper-velocity impact:

- Vimp ' 11:48 km/s



Fengyun-1C (FY-1C) Anti-Satellite Test (2007)

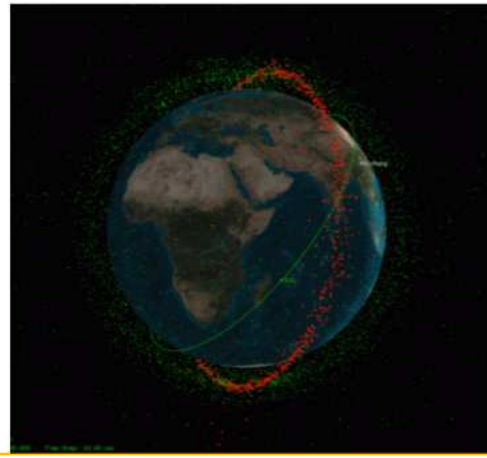
On 11/01/2007, a 958 kg Chinese satellite Feng Yun 1C (1999) was destroyed by a Dong Feng missile in a Chinese anti-satellite test.

The satellite was on a near-circular orbit of ~850 km altitude, inclination 98.65°

A total of 3428 fragments have been officially cataloged by the U.S. SSN from the 1-ton vehicle as of January 2016. Additional debris are being tracked but not yet cataloged. Largest debris-generating event on record, with 2880 objects still on-orbit, (as of January 2016) i.e., almost 20% of the catalog.

The population estimated by the NASA's Orbital Debris Program Office debris larger than 1 cm is greater than 150,000

Since their creation less than 16% of the cataloged debris have fallen back to Earth. Many of the debris will stay in orbit for decades, and some for more than a century.

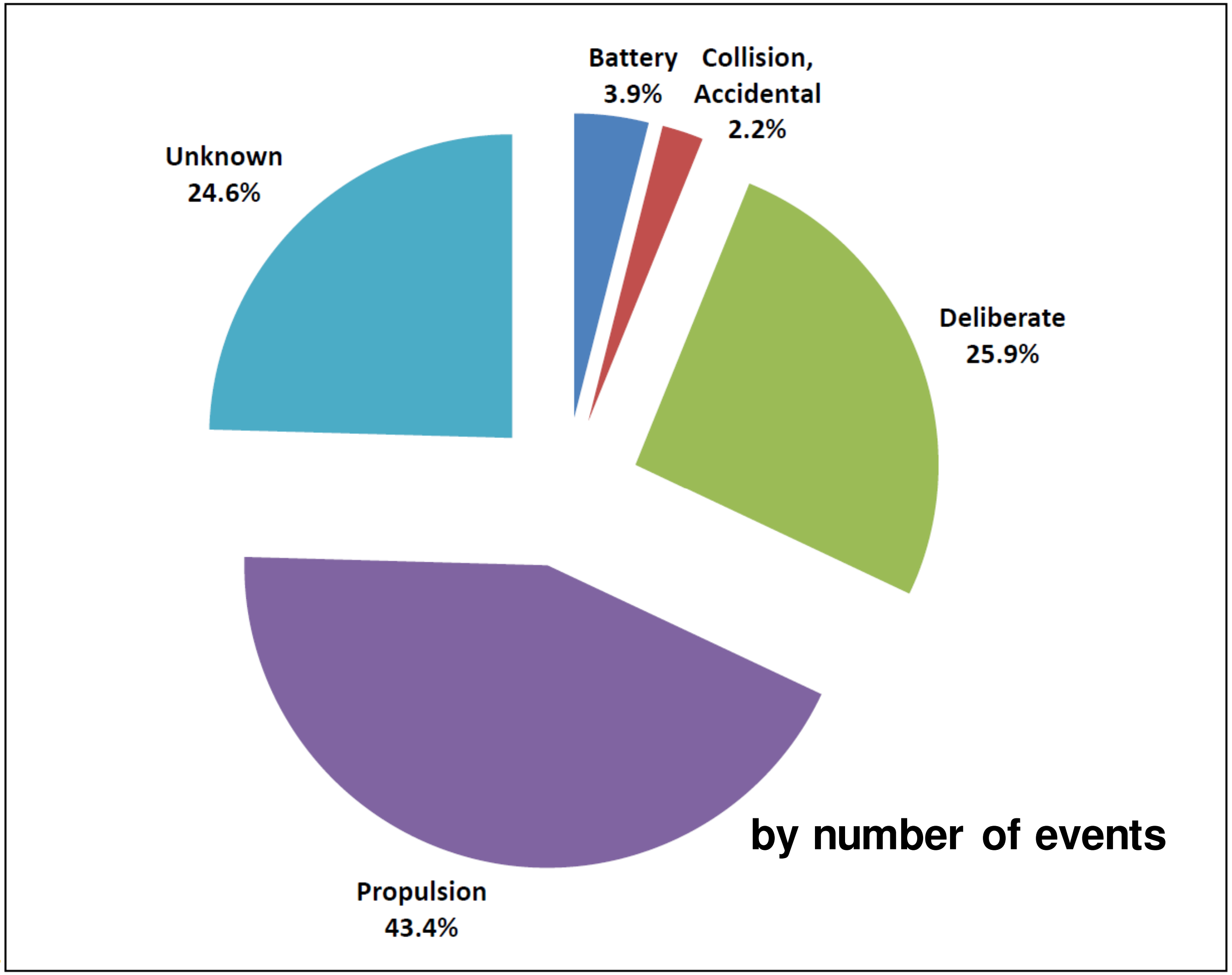


Critical Events (Collisions / Break up by events)

The most important category of man made on-orbit objects is breakups, accounting of > 53% of the total catalog of 17,260 objects as of 1 January 2016 (> 50% of ESA D/B of 19,894 objects as of end 2018)

- The primary causes of satellite breakups are propulsion-related events and deliberate actions.
- The cause for almost 25% of all breakups remains uncertain.

Causes of known satellite breakups as of 4 January 2016 (ODQN, Volume 21, Issue 2)



Critical Events (Collisions / Break up)

More than 5160 space missions conducted since 1957 (as of 1 January 2016, 17,255 objects)

The worst event accounts generated ~ 20% of the population of SSN cataloged man made objects in Earth orbit (~ 40,000) since 1957

Only 10 missions account for 34% of all catalogued objects currently in Earth orbit

6 of these 10 fragmentations were caused by rocket bodies that had operated as designed but later broke up

Number of Debris in Orbit, January 2016 (ODQN, P. Anz-Meador) **UPDATE See ODQN Volume 20, Issues 1 & 2 April 2016**

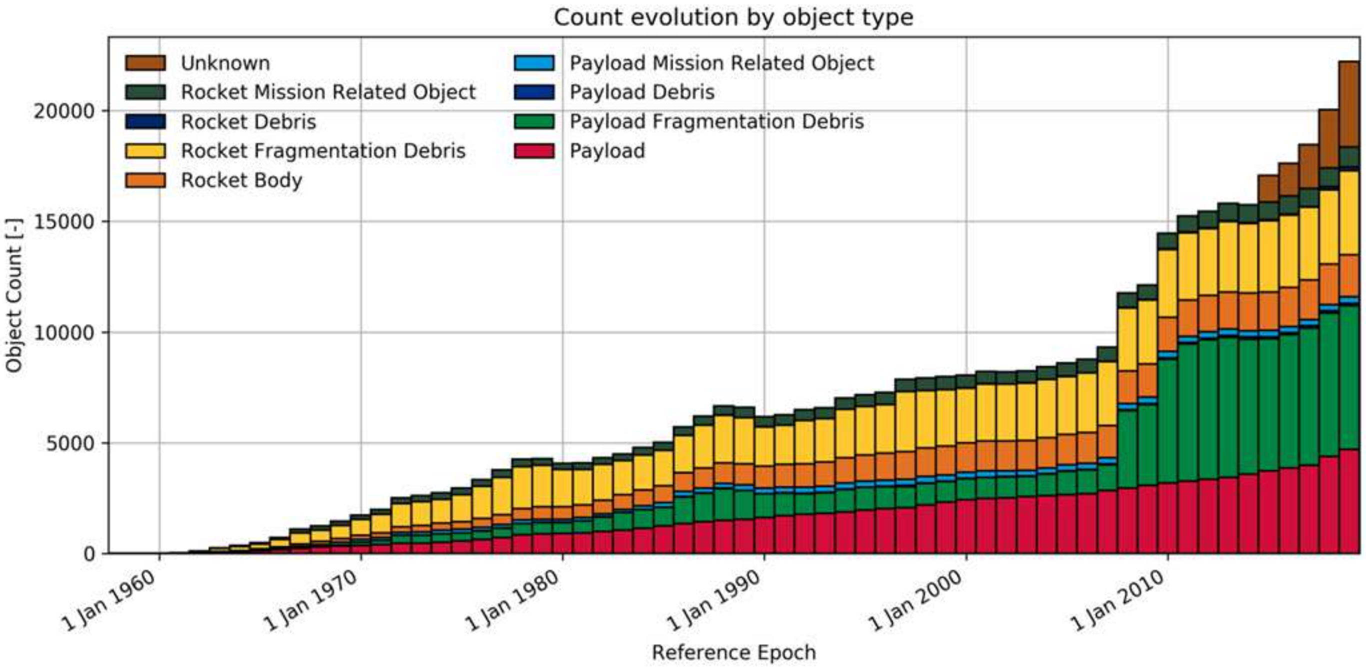
Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	In Orbit*	Total	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	2880	3428	intentional collision
2	1993	36	Cosmos 2251	2009	790	1141	1668	accidental collision
3	1997	51	Iridium 33	2009	790	364	628	accidental collision
4	1981	53	Cosmos 1275	1981	980	289	346	battery explosion
5	1970	25	Nimbus 4 Rocket Body	1970	1075	235	376	accidental explosion
6	1999	57	CBERS 1 / SACI 1 Rocket Body	2000	740	210	431	accidental explosion
7	1992	93	Cosmos 2227 Rocket Body #	1992	830	199	279	accidental explosion
8	1975	52	Nimbus 6 Rocket Body	1991	1090	199	274	accidental explosion
9	1973	86	NOAA 3 Rocket Body	1973	1515	179	201	accidental explosion
10	1976	77	NOAA 5 Rocket Body	1977	1510	174	184	accidental explosion
						5870	**7815**	

* as of 04 January 2016

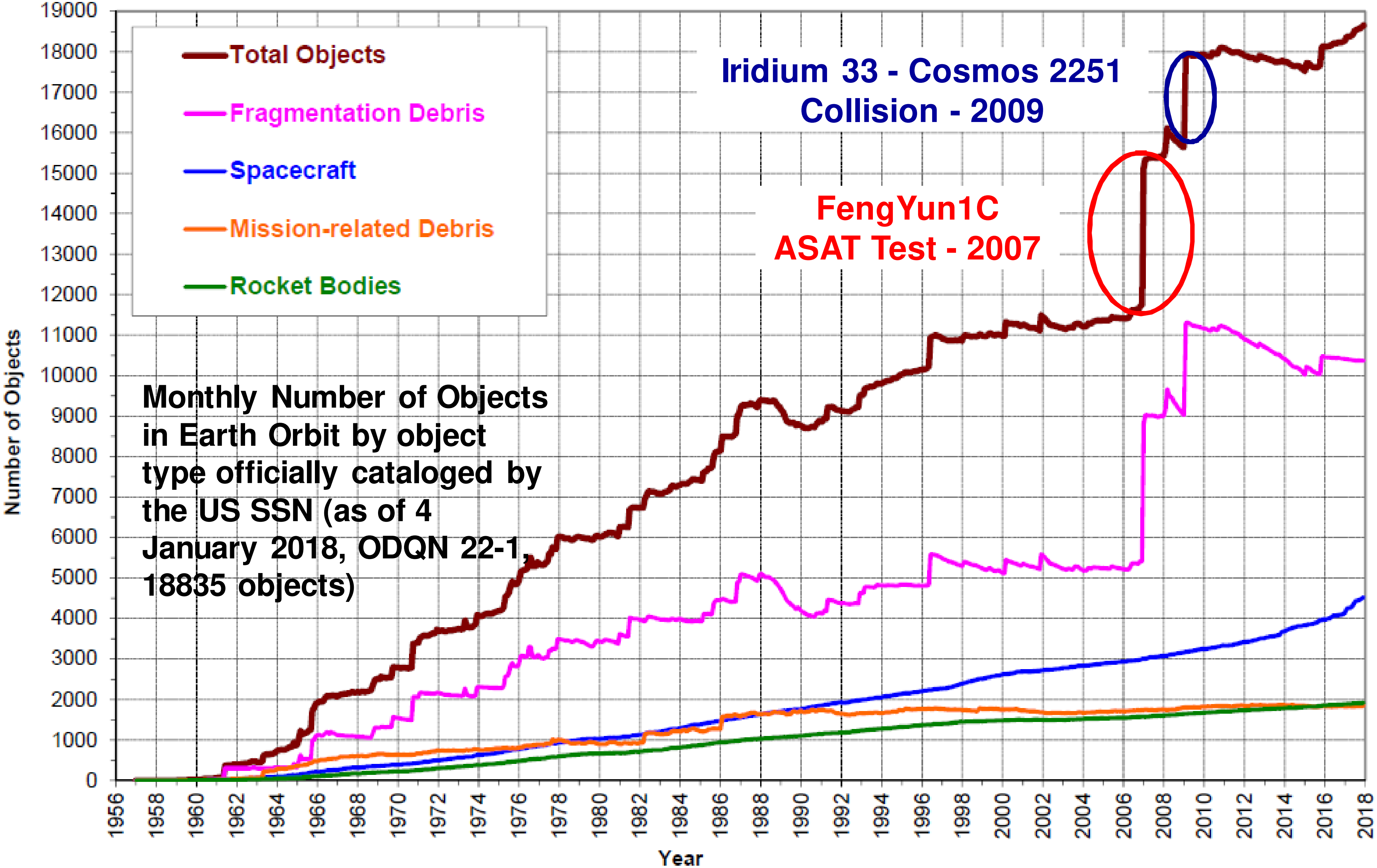
multiple events associated with this SL-16 Zenit second stage

Space Debris Overview

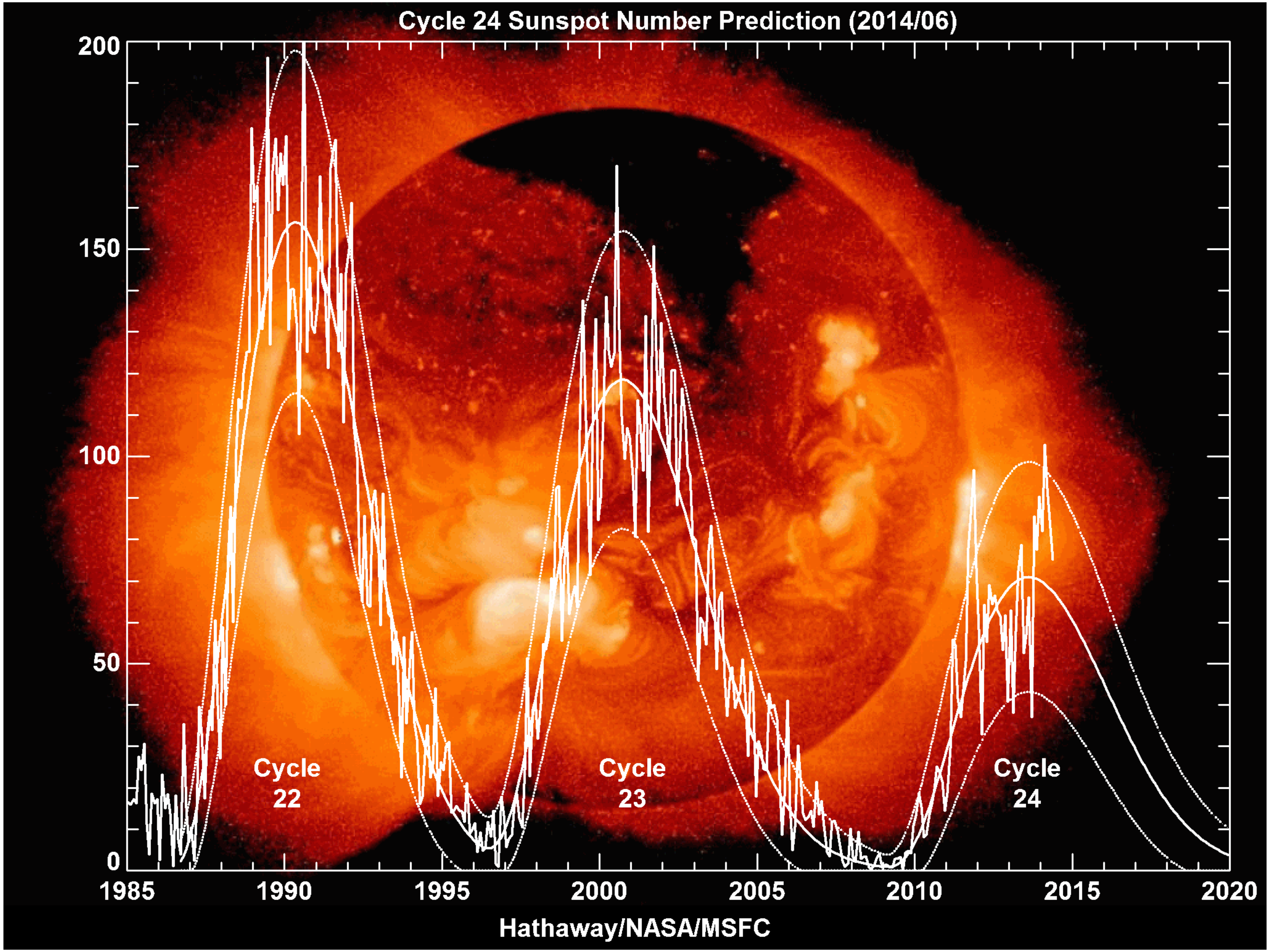
Environmental data & status



Debris Environment - History of On-Orbit Space Objects

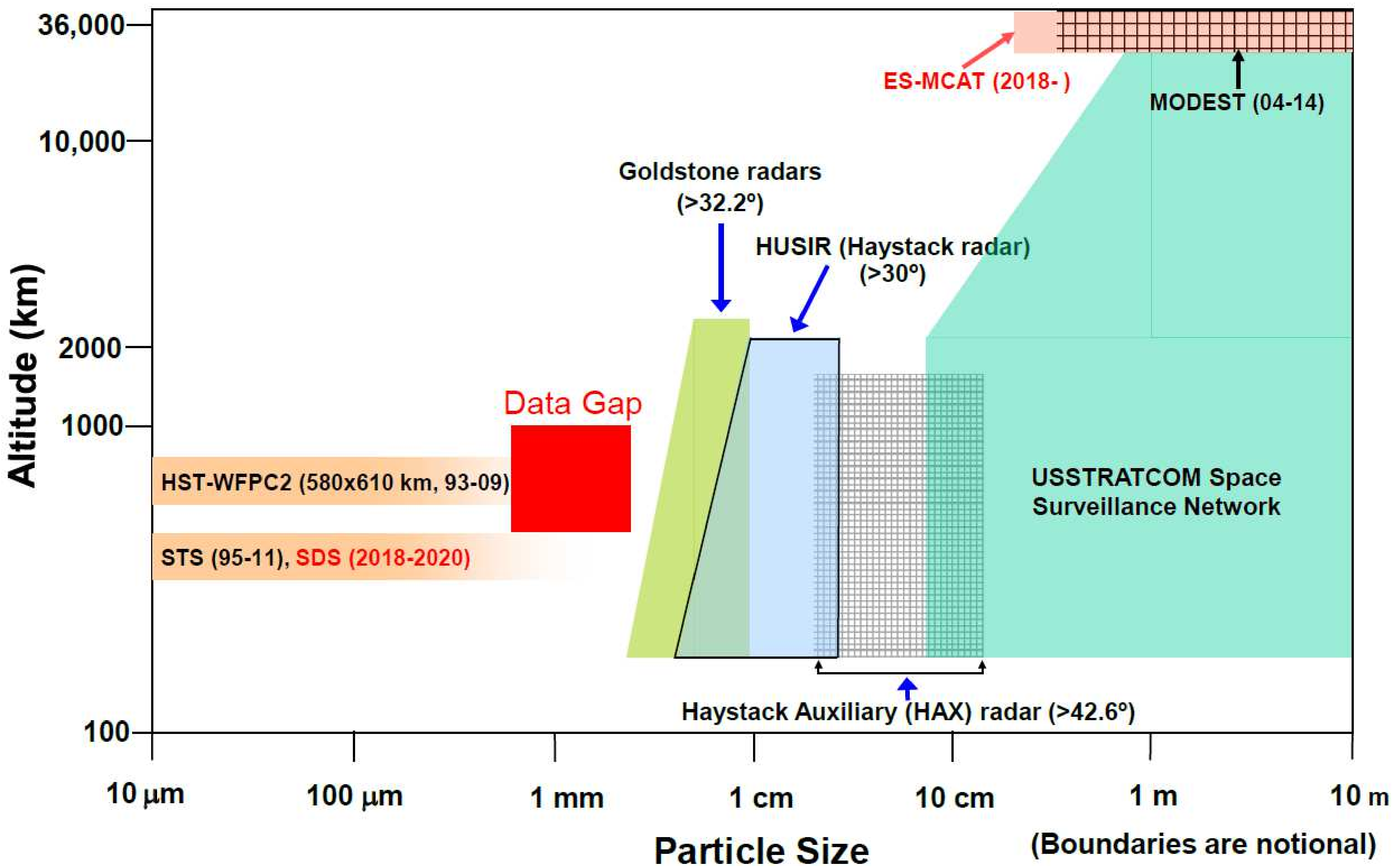


Solar Cycles 22-24



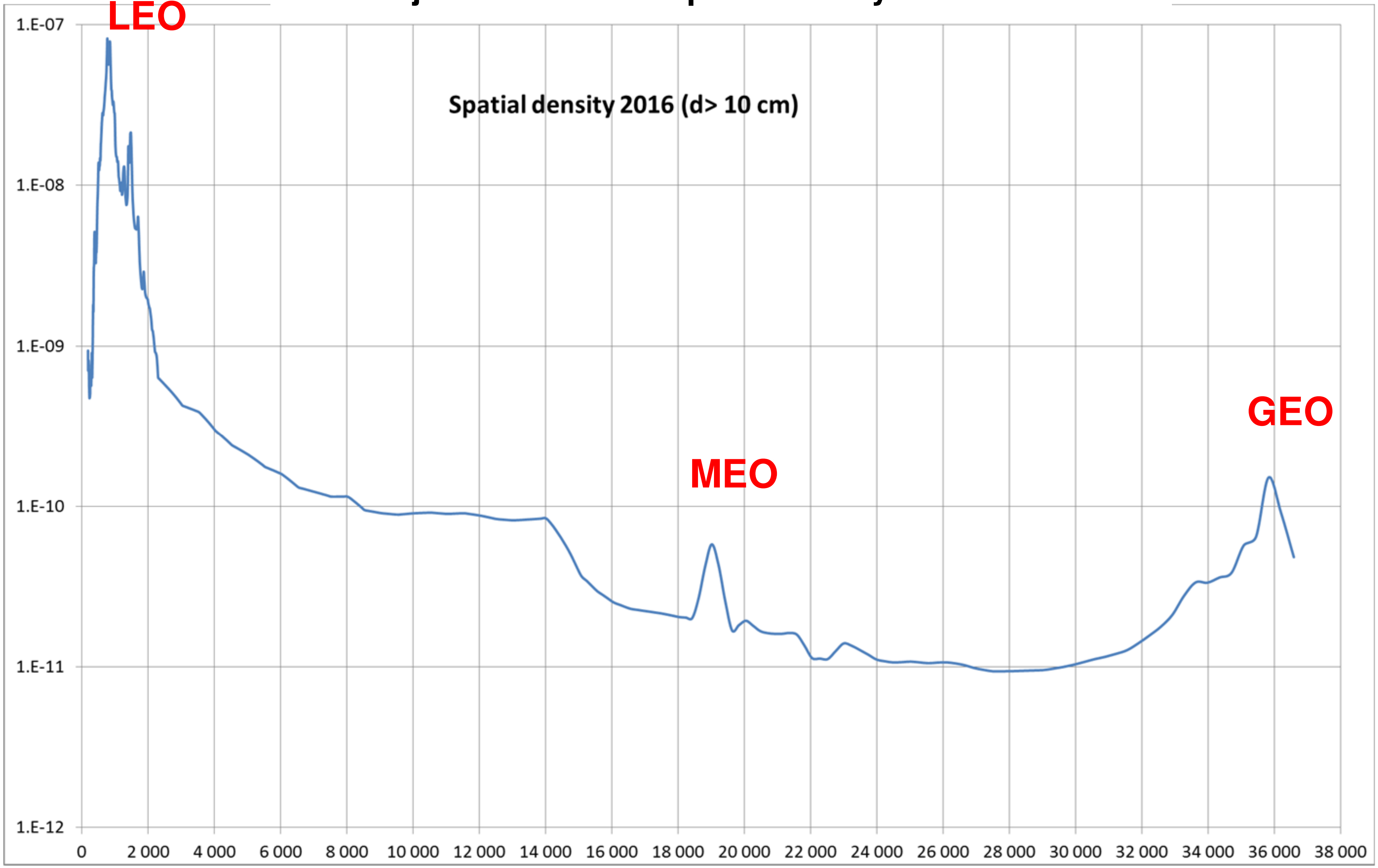
Debris tracking

US Debris tracking (J.-C. Liou, 55th UN COPUOS, 29/01-9/02/2018)

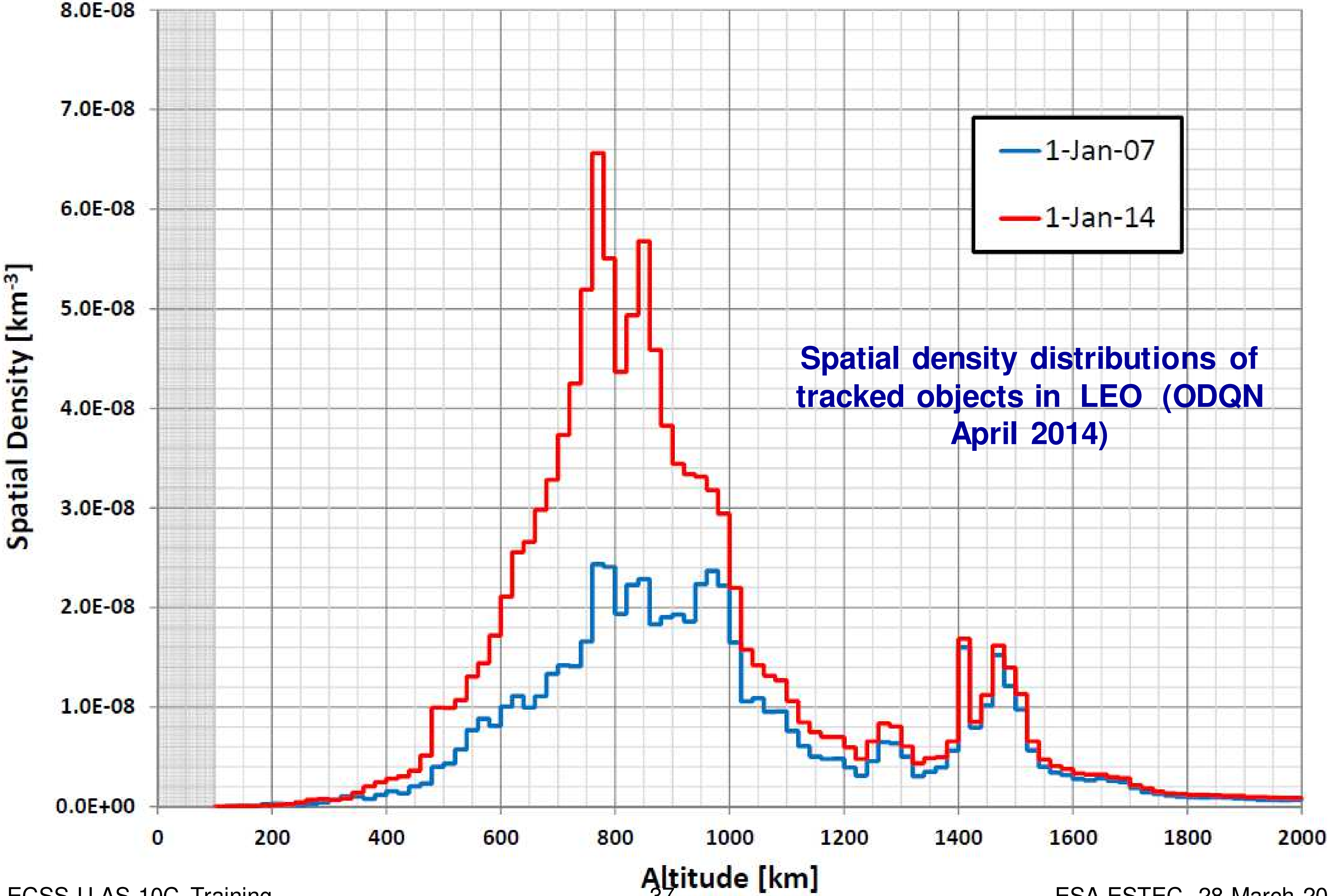


Debris Environment versus altitude

Spatial density v[1/km³] out to 36000 km altitude for objects > 10 cm as predicted by MASTER-8

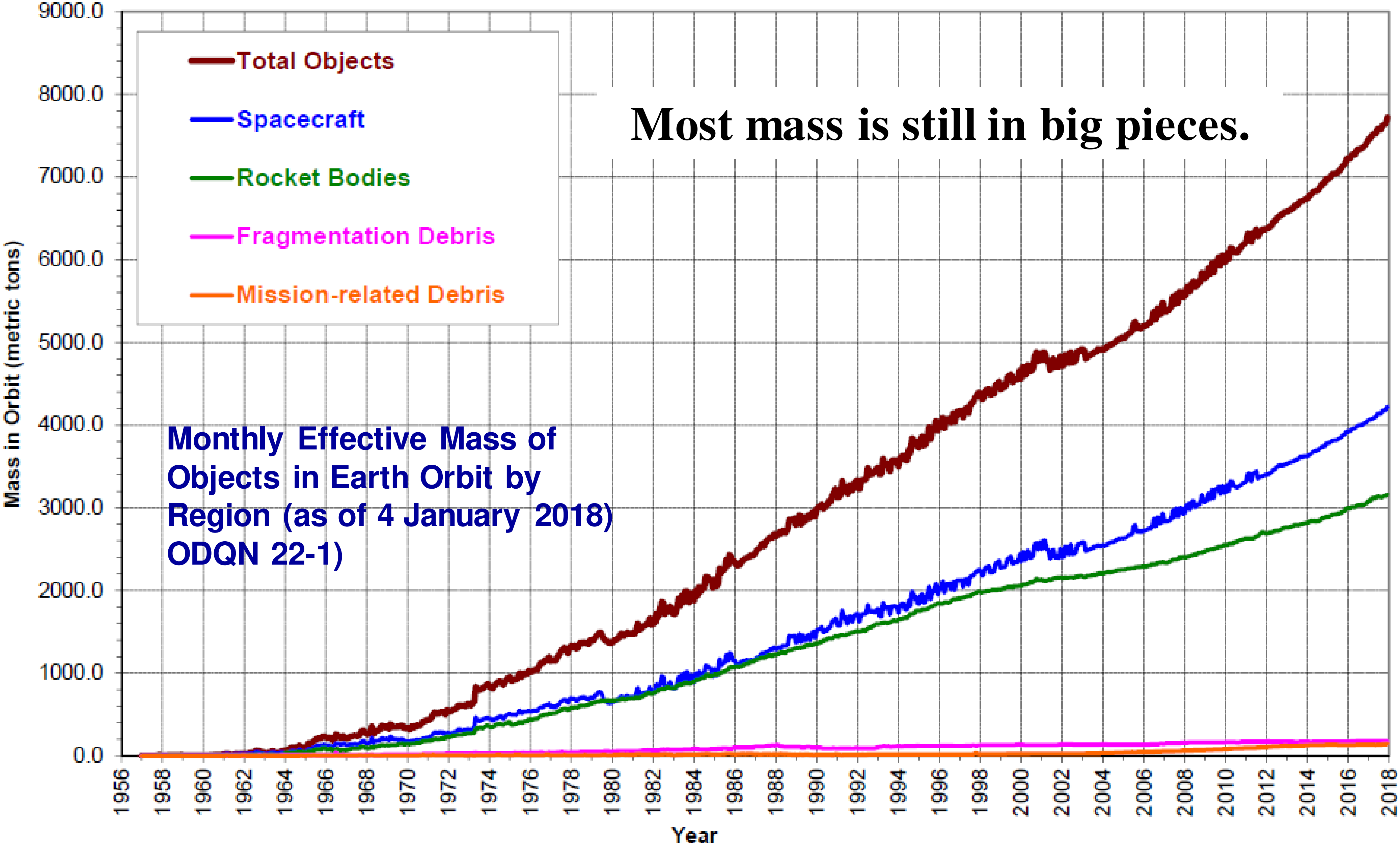


Distribution of On-Orbit Space Objects



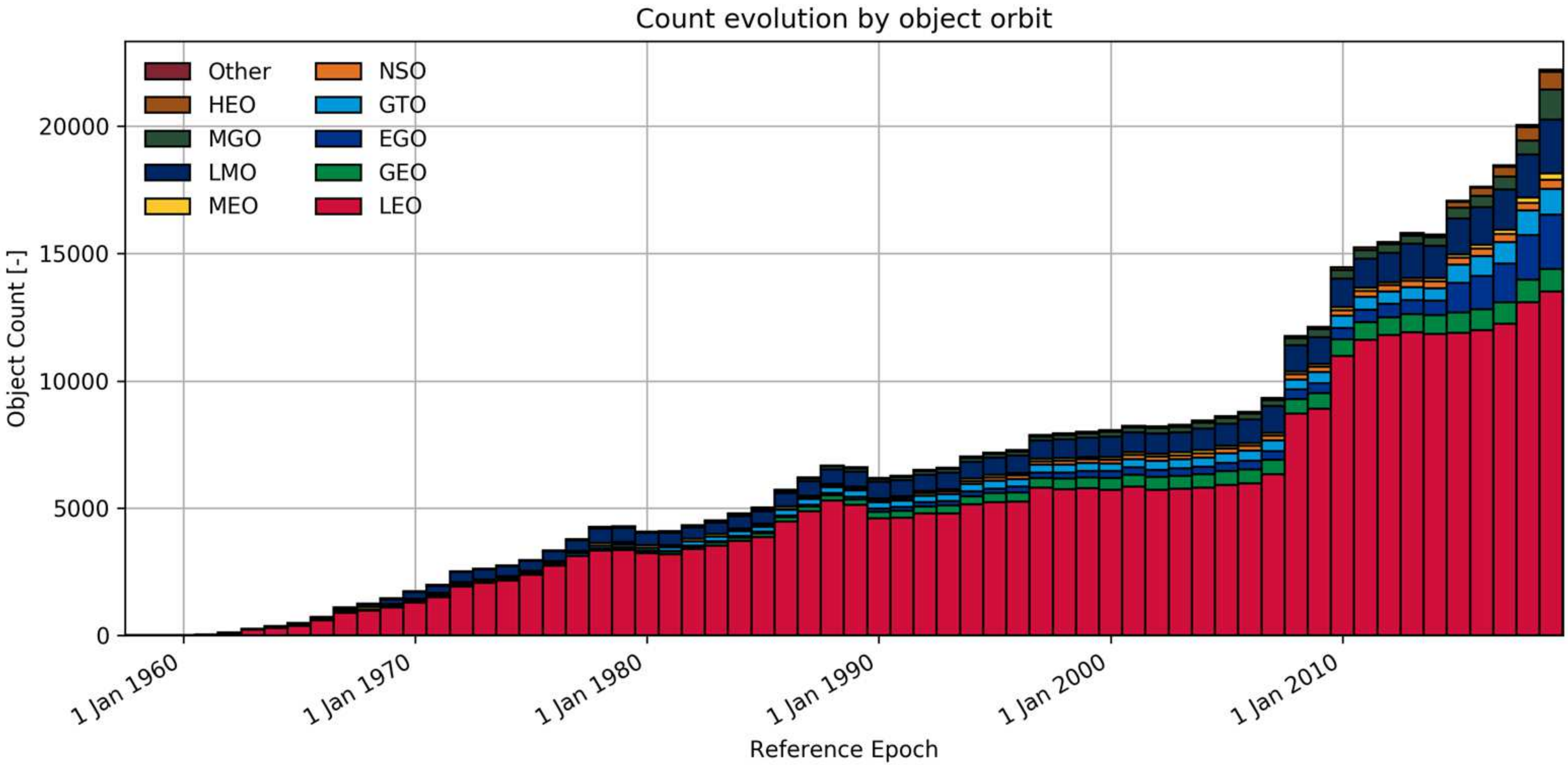
Spatial density distributions of tracked objects in LEO (ODQN April 2014)

History of On-Orbit Space Objects (Mass Jan 2018)



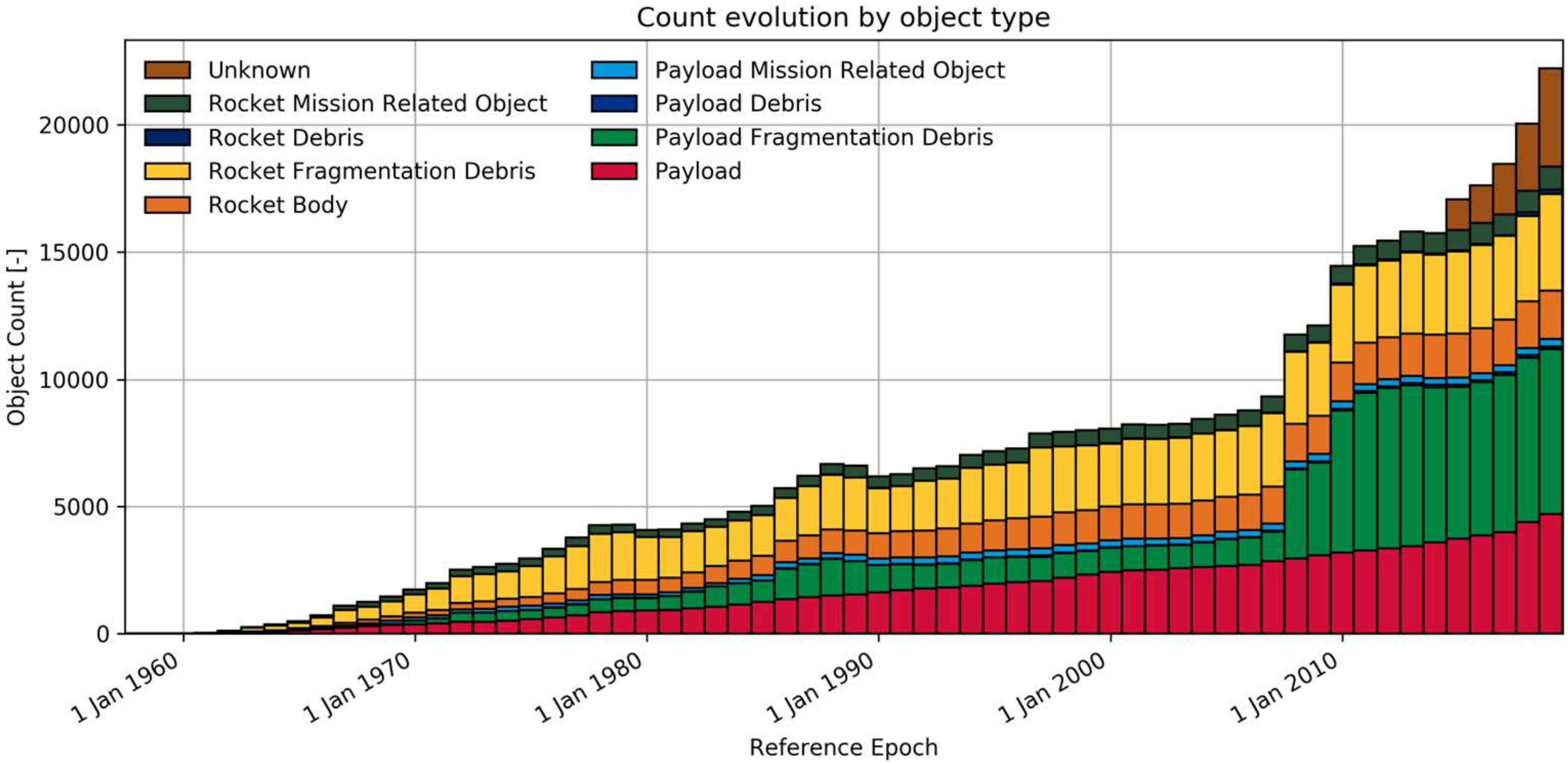
Distribution of On-Orbit Space Objects

Evolution of number of objects by object orbit as of end of 2018 (ESA's Database, https://discosweb.esoc.esa.int/web/guest/statistics, ~22037 catalogued objects)



Distribution of On-Orbit Space Objects

Evolution of number of objects by object type as of end of 2018 (ESA's Database, https://discosweb.esoc.esa.int/web/guest/statistics, ~22037 catalogued objects)



Identified Objects:

- Detailed categories. Payloads (PL) and Payload Debris: Mission Related Objects, fragmentation debris
- Rocket Body (RB) and Rocket Body (RB) Debris: Mission Related Objects, fragmentation debris

Type	Description
PL	Payload
PF	Payload Fragmentation Debris
PD	Payload Debris
PM	Payload Mission Related Object
RB	Rocket Body
RF	Rocket Fragmentation Debris
RD	Rocket Debris
RM	Rocket Mission Related Object
UI	Unknown

Orbital regime	Description
GEO	Geostationary Orbit
IGO	Inclined Geosynchronous Orbit
EGO	Extended Geostationary Orbit
NSO	Navigation Satellites Orbit
GTO	GEO Transfer Orbit
MEO	Medium Earth Orbit
GHO	GEO-superGEO Crossing Orbits
LEO	Low Earth Orbit
HAO	High Altitude Earth Orbit
MGO	MEO-GEO Crossing Orbits
HEO	Highly Eccentric Earth Orbit
LMO	LEO-MEO Crossing Orbits
UFO	Undefined Orbit
ESO	Escape Orbits

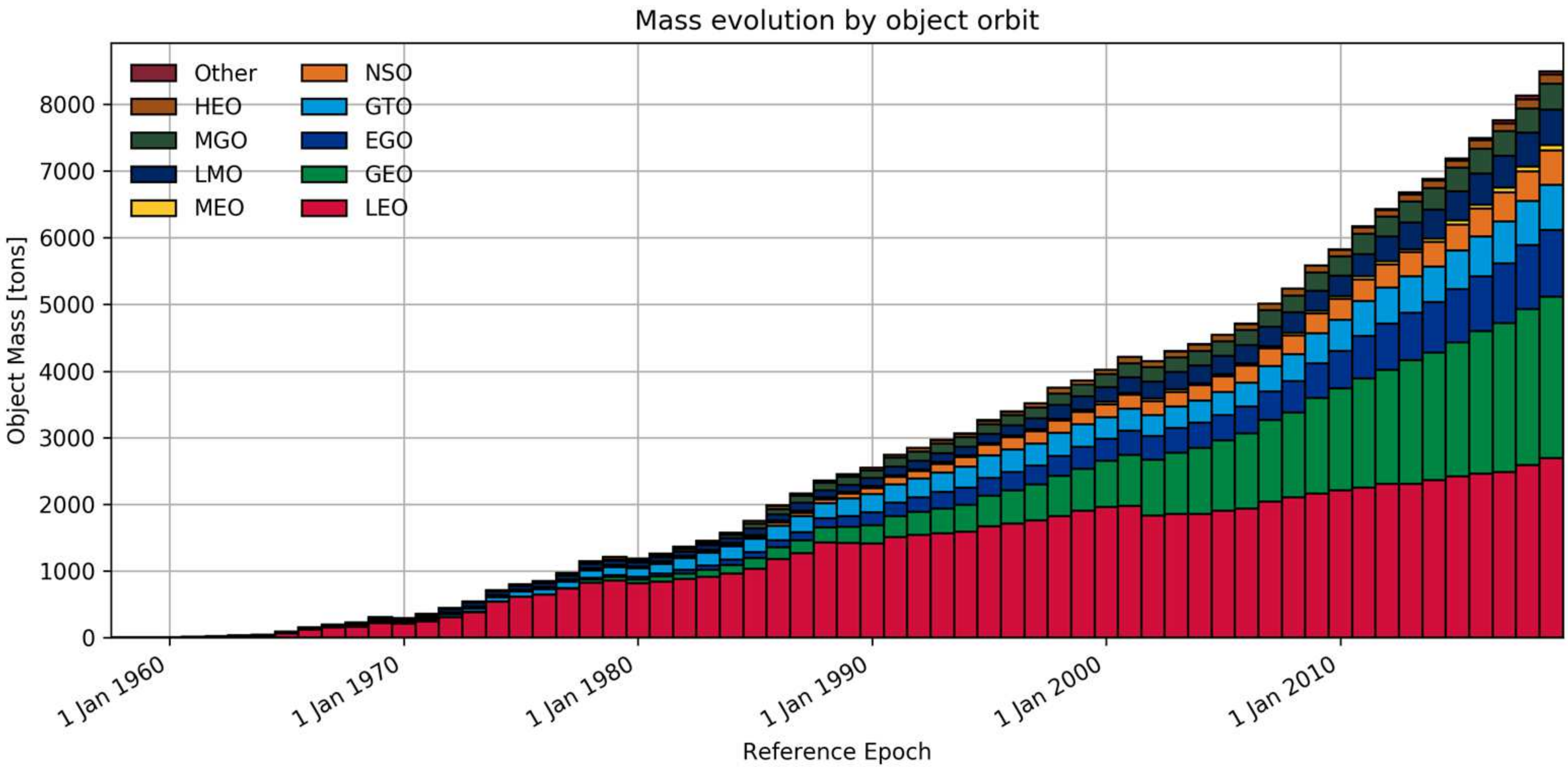
Space Debris Classification (ESA SDO)

Orbit	Description	Definition		
GEO	Geostationary Orbit	$i \in [0, 25]$	$h_p \in [35586, 35986]$	$h_a \in [35586, 35986]$
IGO	Inclined Geosynchronous Orbit	$a \in [37948, 46380]$	$e \in [0.00, 0.25]$	$i \in [25, 180]$
EGO	Extended Geostationary Orbit	$a \in [37948, 46380]$	$e \in [0.00, 0.25]$	$i \in [0, 25]$
NSO	Navigation Satellites Orbit	$i \in [50, 70]$	$h_p \in [18100, 24300]$	$h_a \in [18100, 24300]$
GTO	GEO Transfer Orbit	$i \in [0, 90]$	$h_p \in [0, 2000]$	$h_a \in [31570, 40002]$
MEO	Medium Earth Orbit	$h_p \in [2000, 31570]$	$h_a \in [2000, 31570]$	
GHO	GEO-superGEO Crossing Orbits	$h_p \in [31570, 40002]$	$h_a > 40002$	
LEO	Low Earth Orbit	$h_p \in [0, 2000]$	$h_a \in [0, 2000]$	
HAO	High Altitude Earth Orbit	$h_p > 40002$	$h_a > 40002$	
MGO	MEO-GEO Crossing Orbits	$h_p \in [2000, 31570]$	$h_a \in [31570, 40002]$	
HEO	Highly Eccentric Earth Orbit	$h_p \in [0, 31570]$	$h_a > 40002$	
LMO	LEO-MEO Crossing Orbits	$h_p \in [0, 2000]$	$h_a \in [2000, 31570]$	
UFO	Undefined Orbit			
ESO	Escape Orbits			

Orbit	Description	Definition	
LEO_{IADC}	IADC LEO Protected Region	$h \in [0, 2000]$	
GEO_{IADC}	IADC GEO Protected Region	$h \in [35586, 35986]$	$\delta \in [-15, 15]$

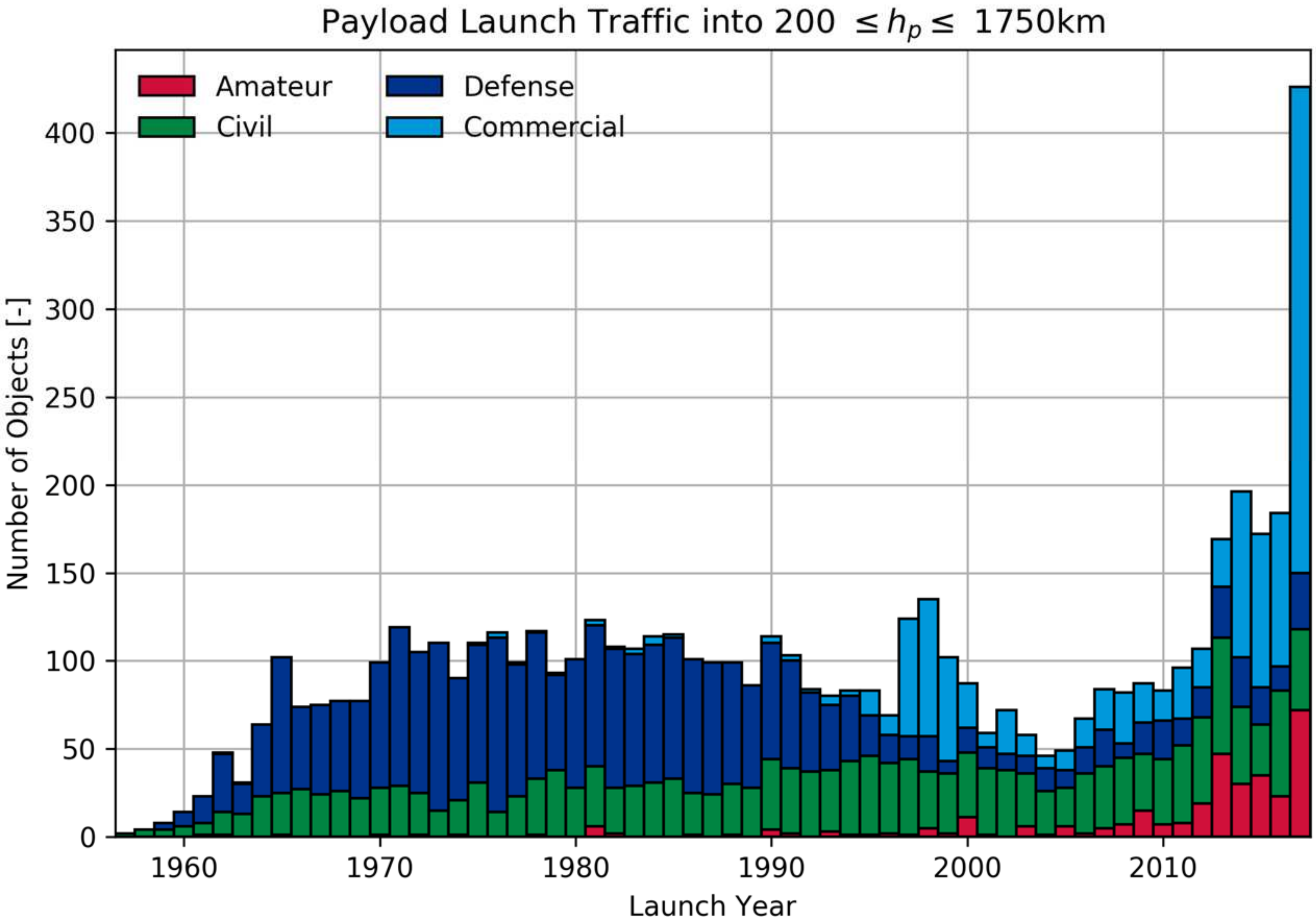
Distribution of On-Orbit Space Objects

Evolution of mass of objects by object orbit as of end of 2018 (ESA's Database, https://discosweb.esoc.esa.int/web/guest/statistics, ~22037 catalogued objects, ~ 8343.4 ton)



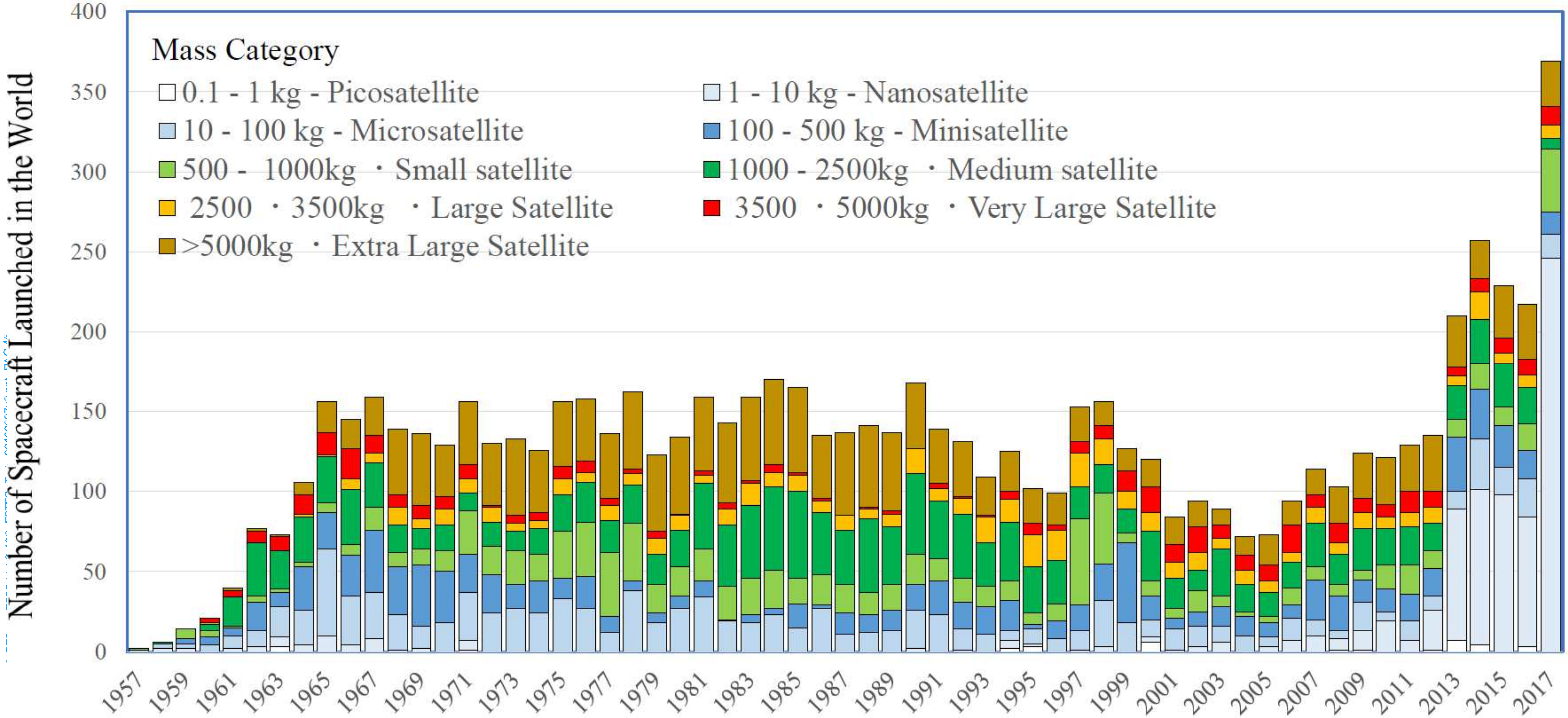
Distribution of On-Orbit Space Objects - LEO

Evolution of the launch traffic near LEO per mission type as of end of 2017 (ESA's D/B, https://discosweb.esoc.esa.int/web/guest/statistics)



Evolution of the launch traffic

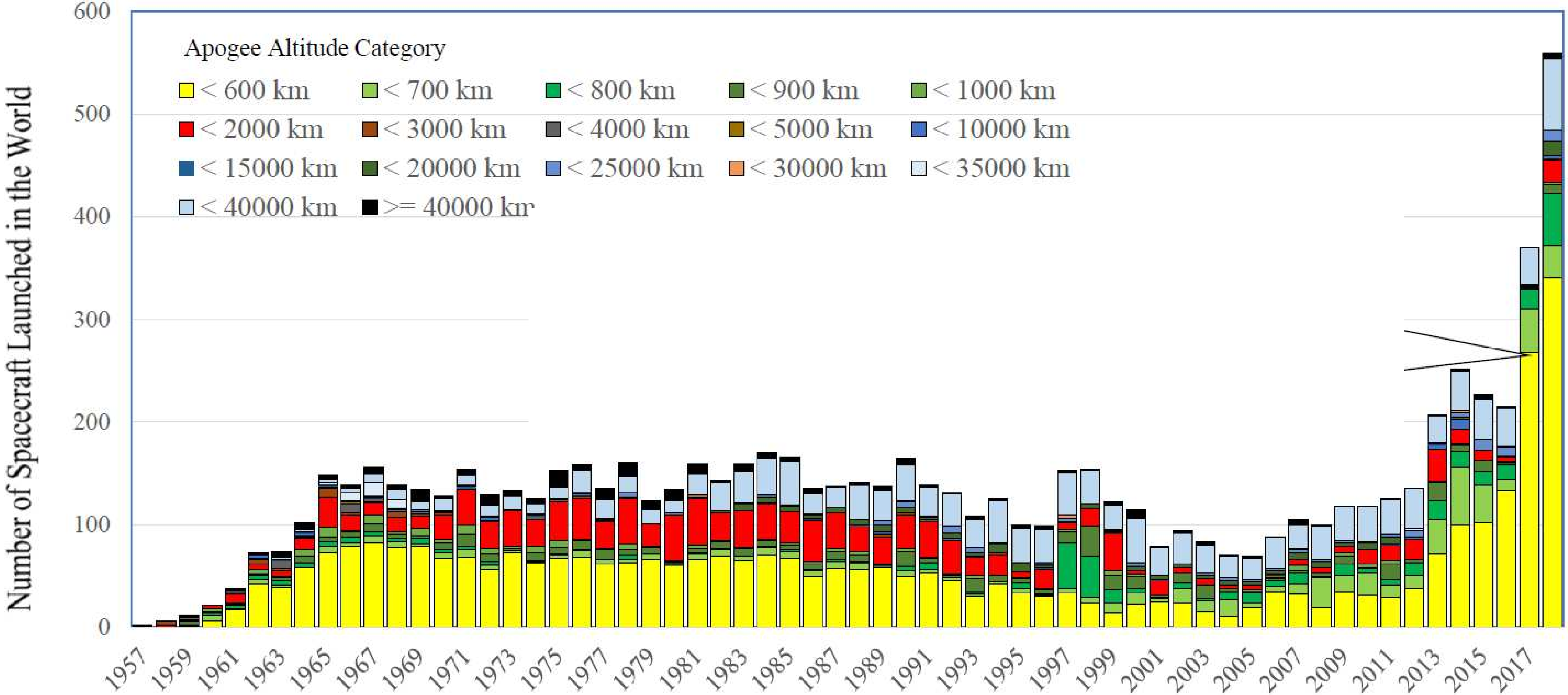
As of end of 2017. Number of SC launched per year per mass category Data source: Seradata Database, elaboration by JAXA.



Evolution of the launch traffic

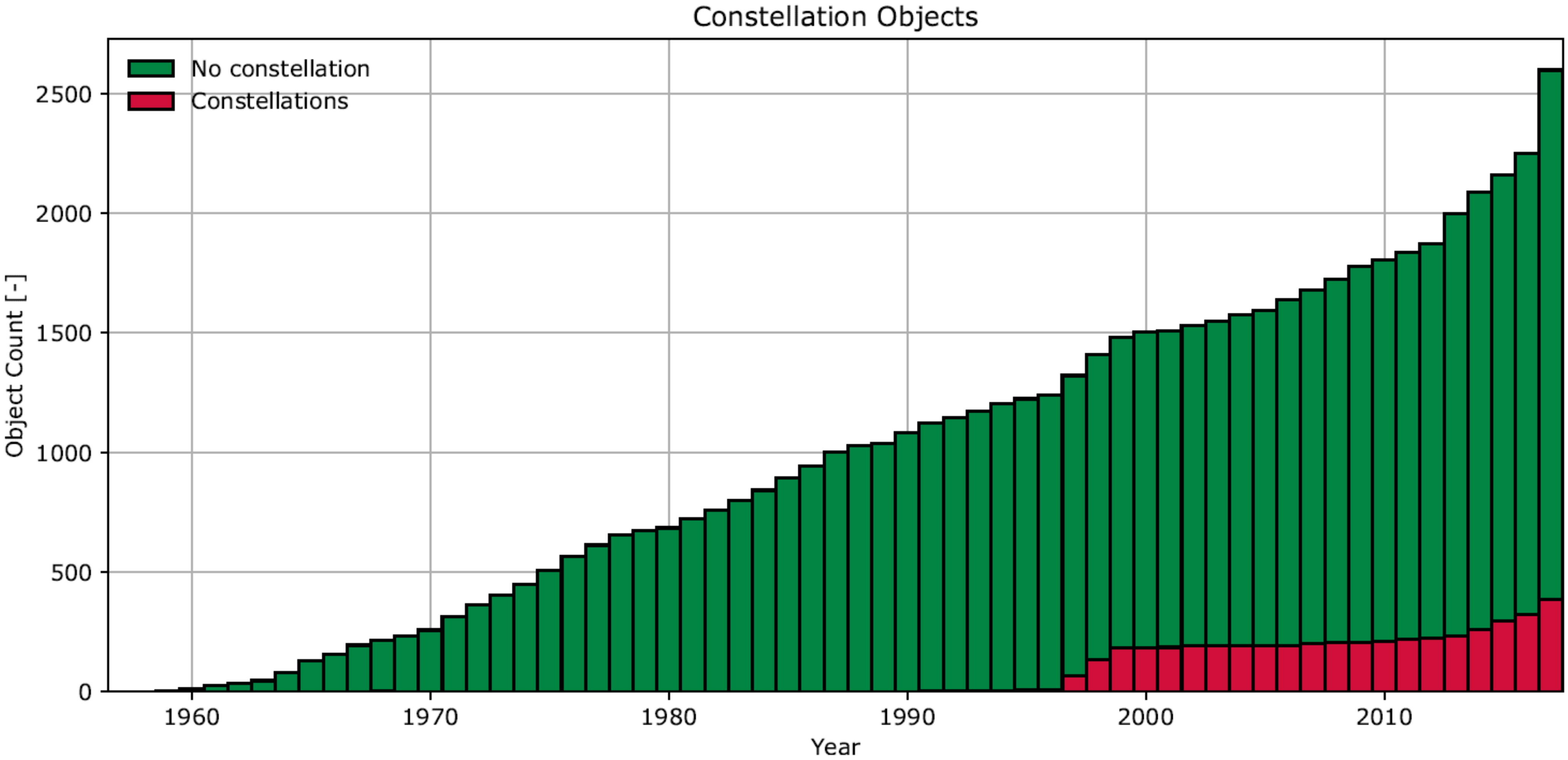
As of end of 2017. Number of SC launched per year per altitude category. Data source: Seradata Database, elaboration by JAXA.

- Majority of SC with low altitude, i.e. lifetime < 25 yrs



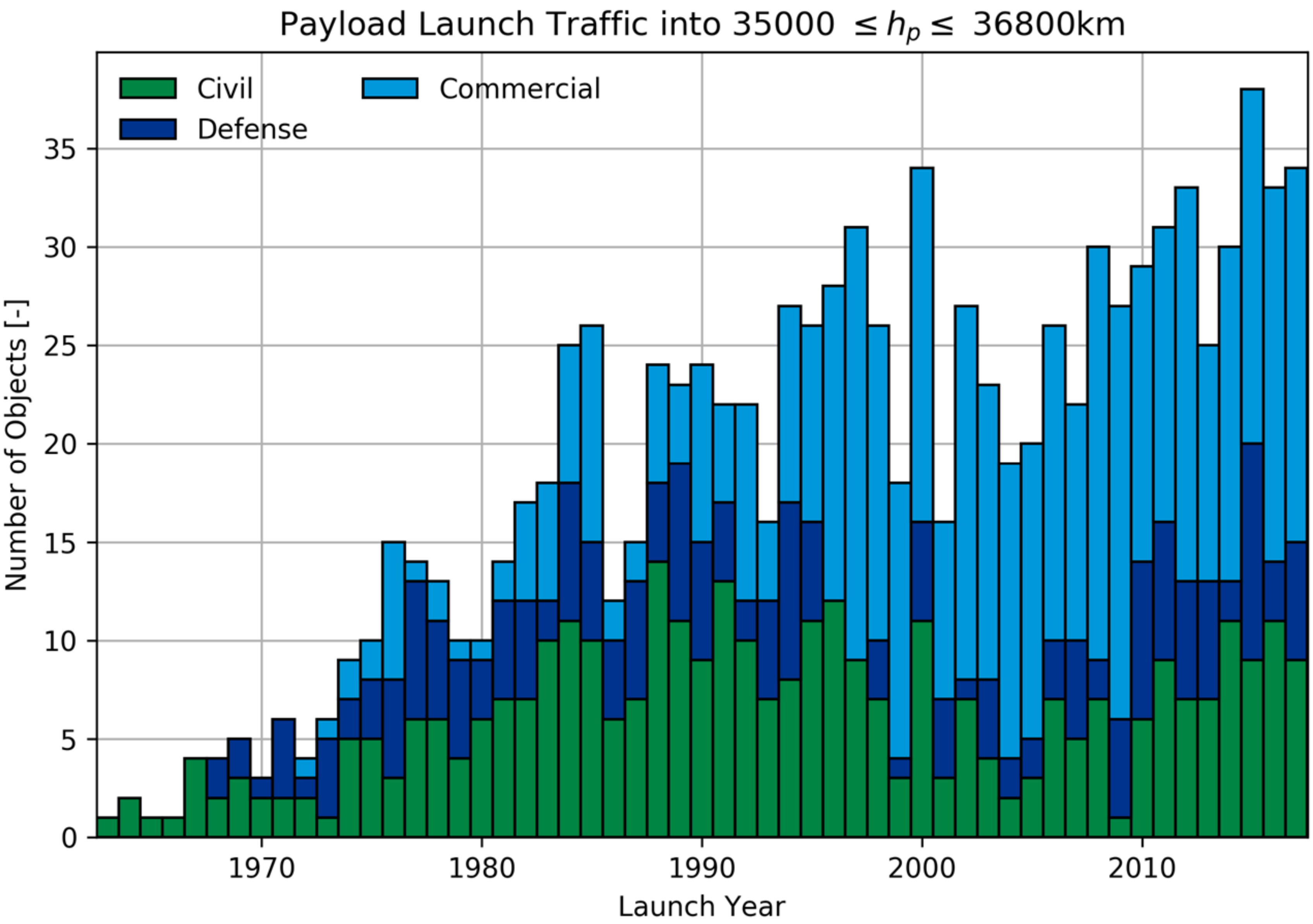
Distribution of On-Orbit Space Objects - LEO

Evolution of the constellation / non constellation launch traffic near LEO as of end of 2017 (ESA's D/B, https://discosweb.esoc.esa.int/web/guest/statistics)

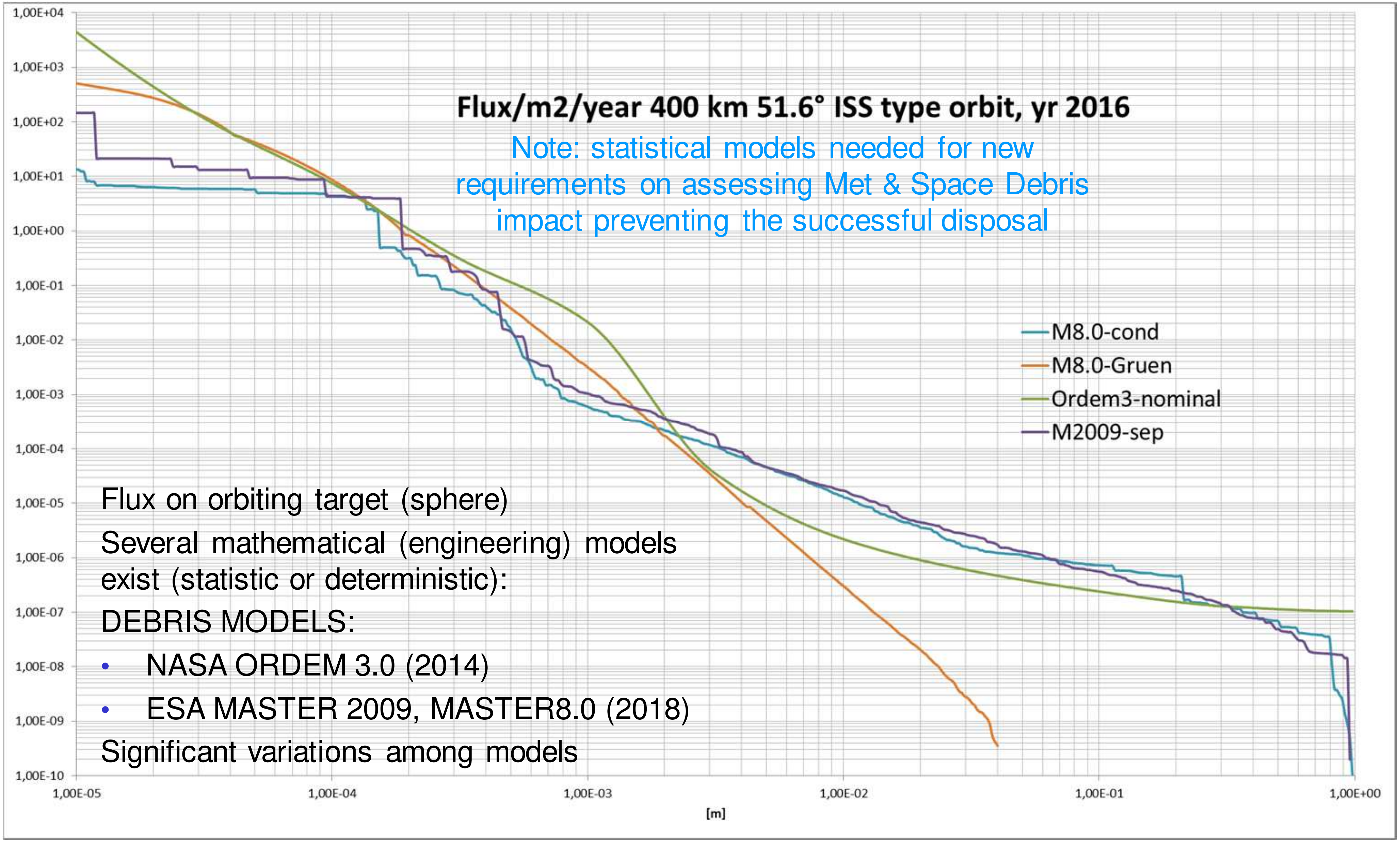


Distribution of On-Orbit Space Objects - GEO

Evolution of the launch traffic near GEO per mission type as of end of 2017 (ESA's D/B, https://discosweb.esoc.esa.int/web/guest/statistics#objects)



Debris Environment Models



Note: statistical models needed for new requirements on assessing Met & Space Debris impact preventing the successful disposal

Flux on orbiting target (sphere)

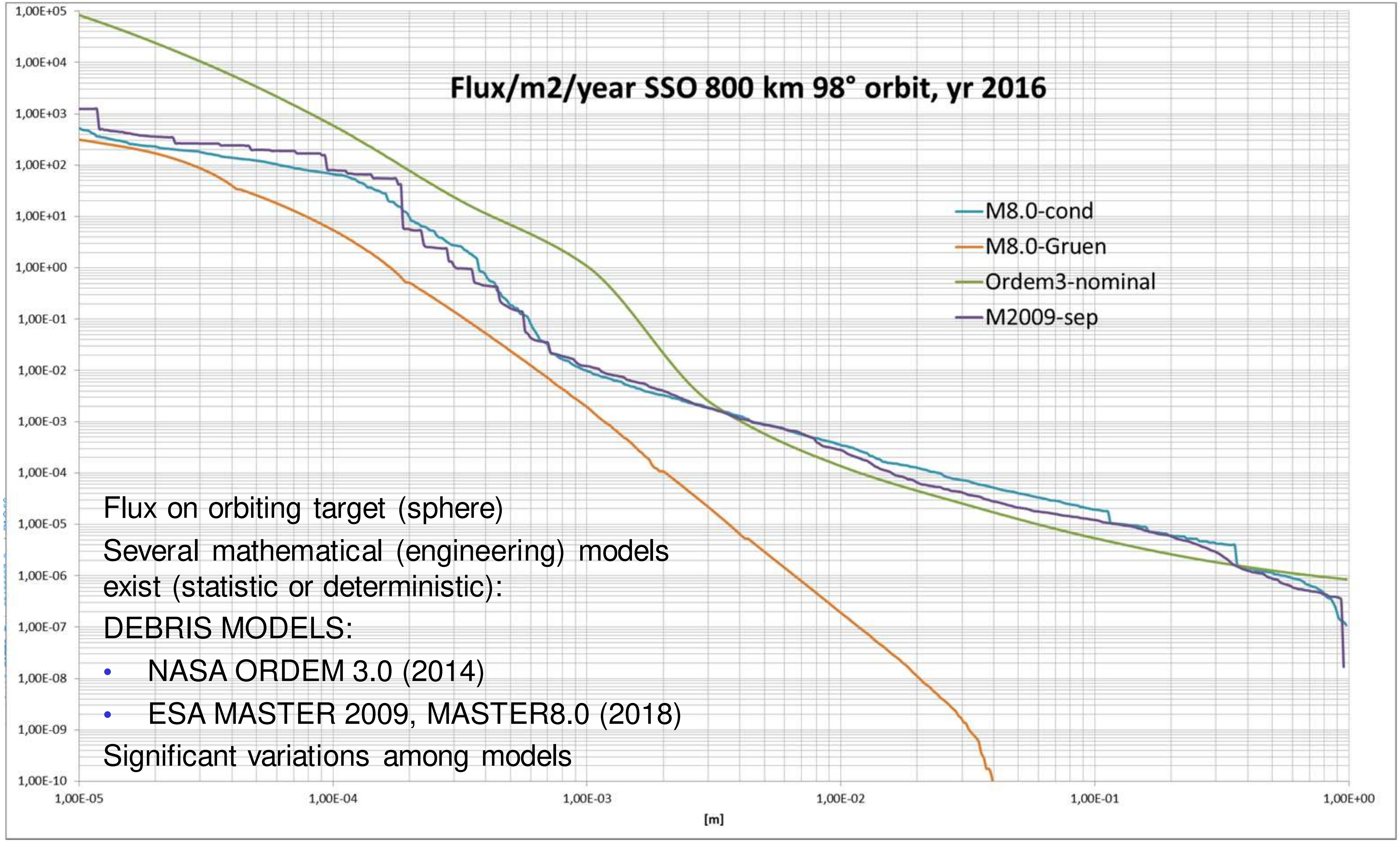
Several mathematical (engineering) models exist (statistic or deterministic):

DEBRIS MODELS:

- NASA ORDEM 3.0 (2014)
- ESA MASTER 2009, MASTER8.0 (2018)

Significant variations among models

Debris Environment Models



Flux on orbiting target (sphere)

Several mathematical (engineering) models exist (statistic or deterministic):

DEBRIS MODELS:

- NASA ORDEM 3.0 (2014)
- ESA MASTER 2009, MASTER8.0 (2018)

Significant variations among models

Space Debris Overview

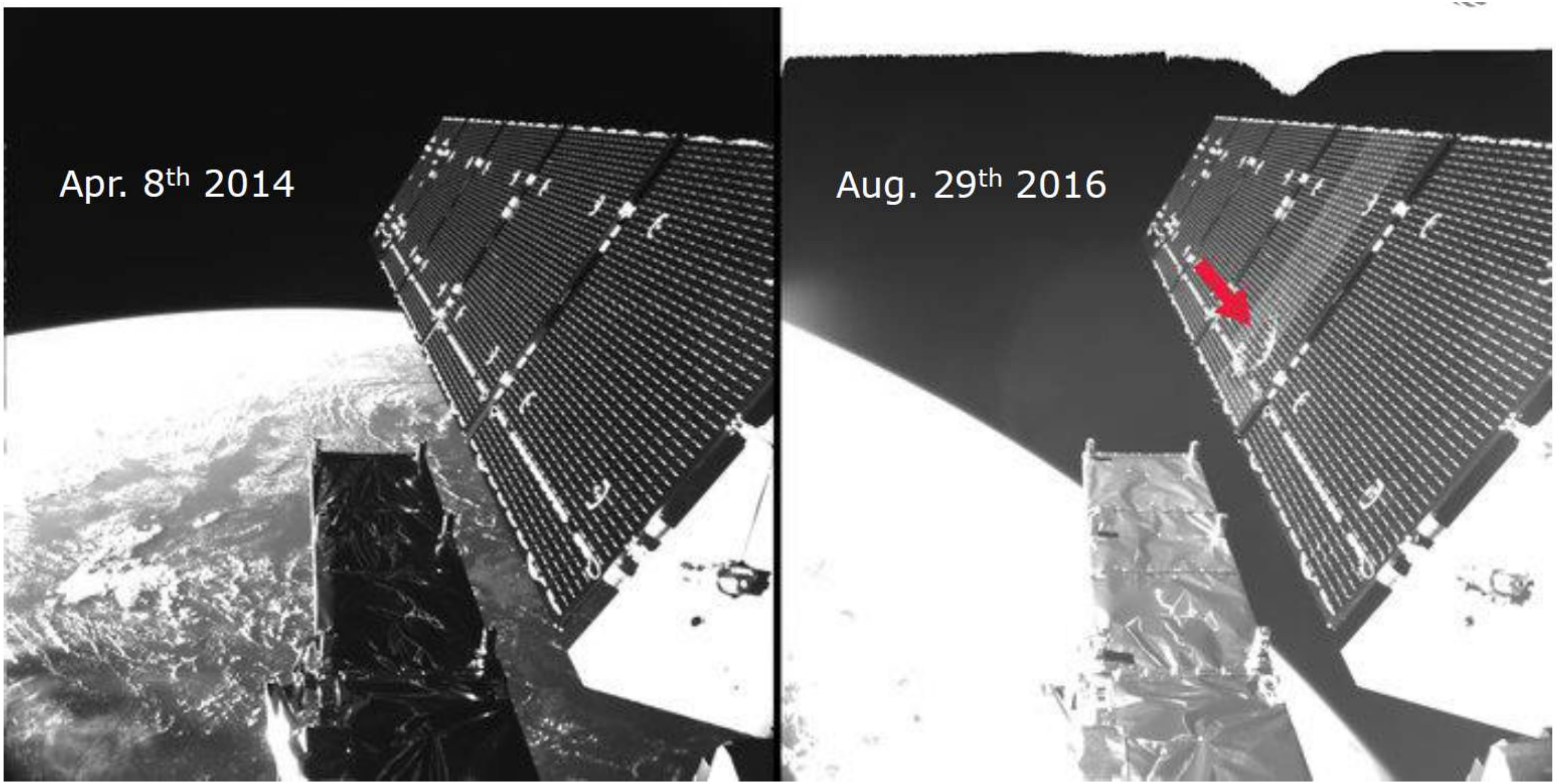
Effects of Space Debris on Space Systems

Sentinel-1A Earth-observation SAR mission (launched 3 April 2014, ID2014-016A)

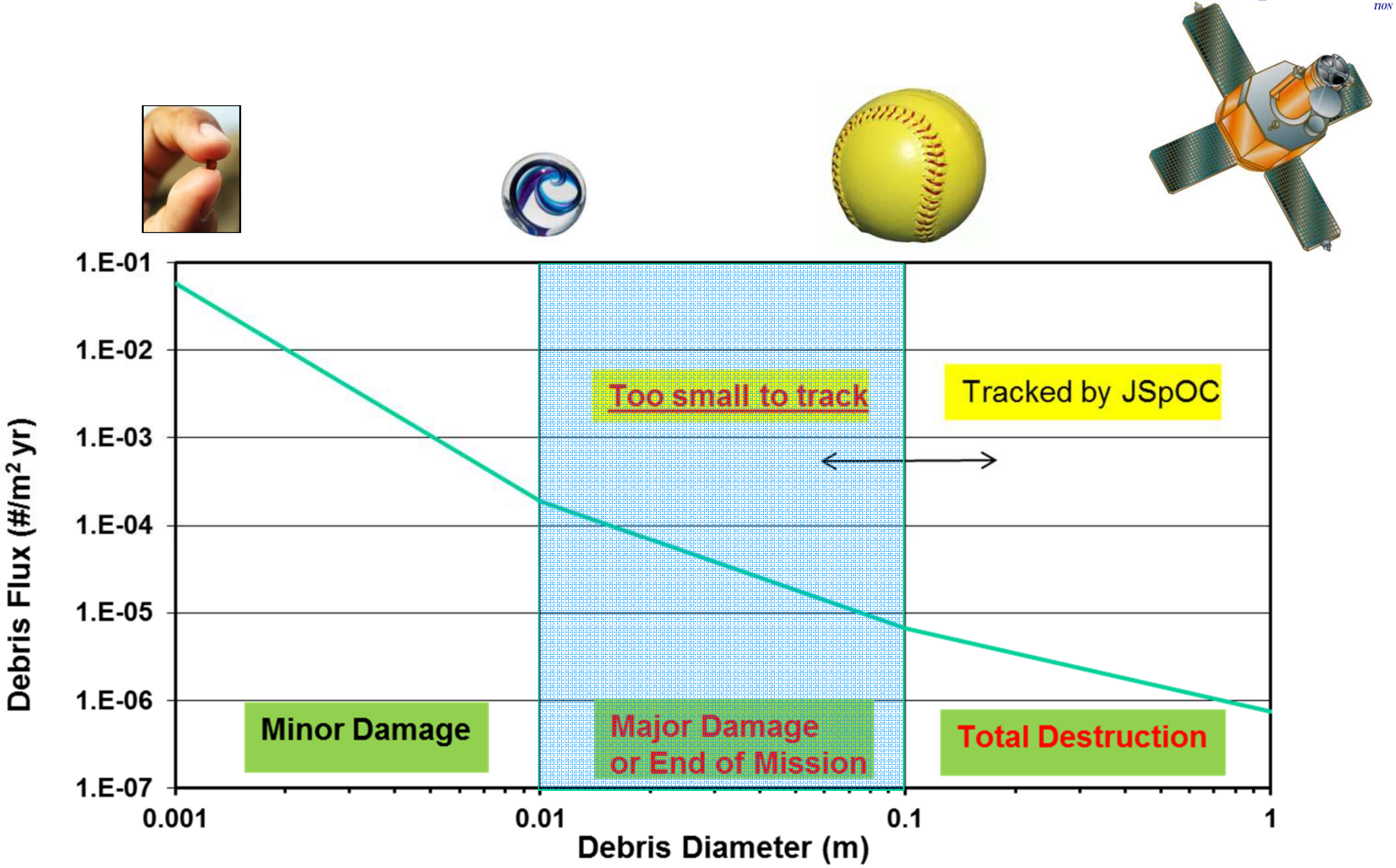
Orbital Parameters		
Semi-major axis	7080	km
Eccentricity	0.00127	
Inclination	98.1	deg
RAAN	308.5	deg
Argument of Perigee	68.9	deg
Mean Anomaly	291.2	deg
Average altitude	693 (almost circular)	km
Orbits	Sun-synchronous, dawn-dusk, Polar	
Epoch	2012/30/10-00:00:00.000	

Debris impact effects

Impact on Sentinel-1A Solar Array (Aug. 23rd 2016) due to a millimetre-size particle (pictures from the onboard camera)



MMOD IMPACT EFFECTS



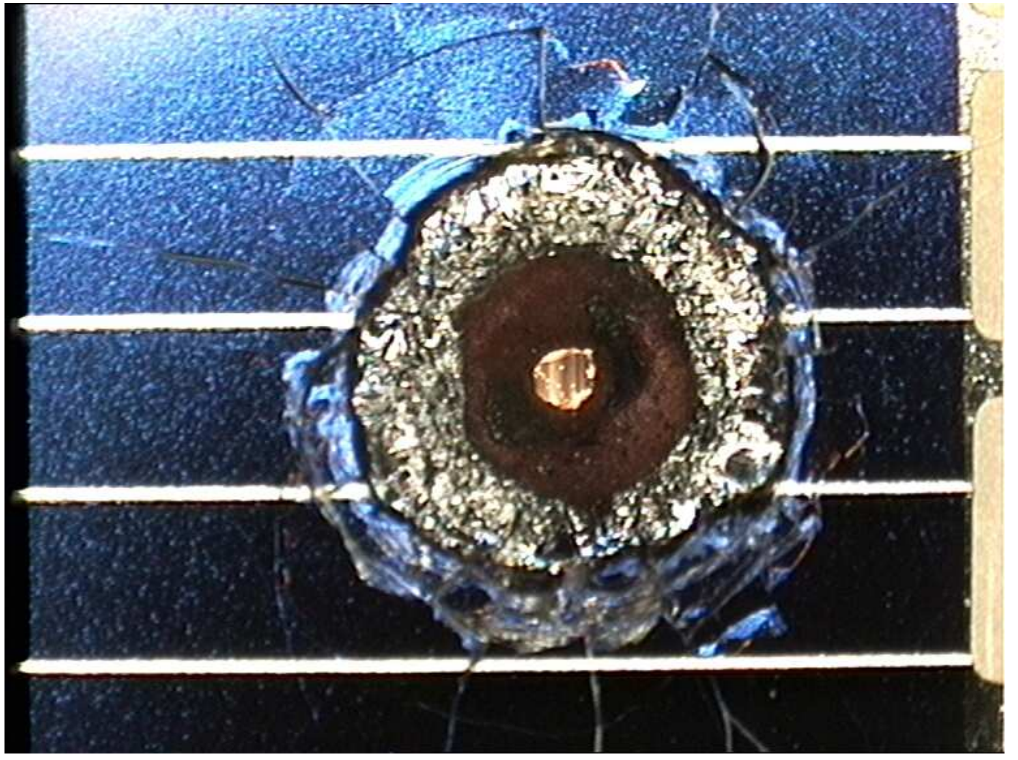
Debris (and meteoroids) impact effects

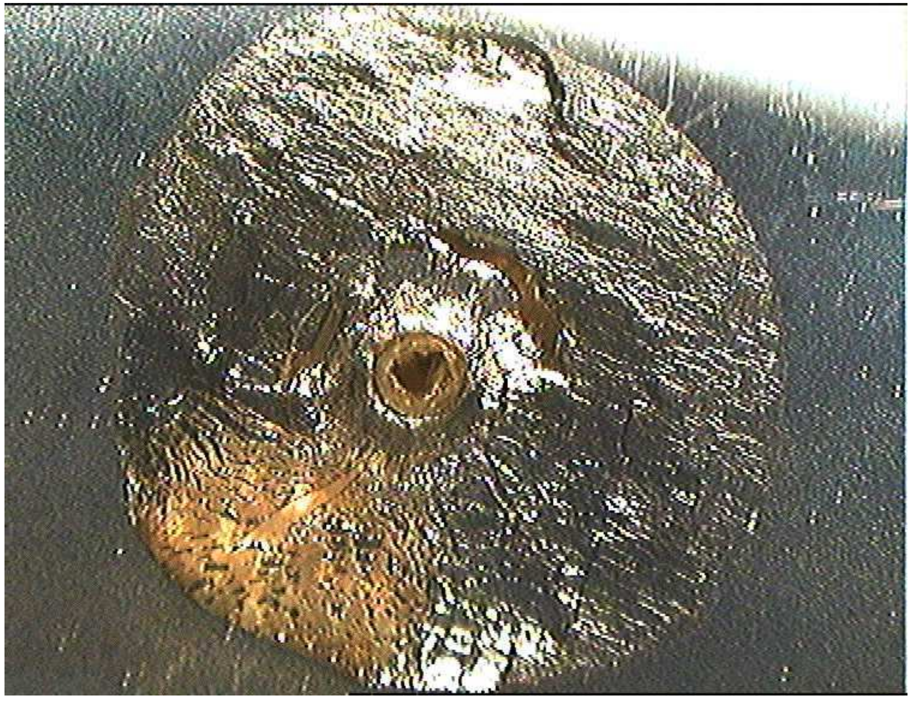
Damage caused by collisions with debris (and meteoroids) depends on size, density, speed and direction of impacting particle, and on the spacecraft shielding. Average impact collisions with the International Space Station are about 19-20 km/s (meteoroids); 10-11 km/s (debris, with significant variations according to the models):

- D ≤ 1 μm: Some surface degradation (sandblasting effect) leading to a change of thermal, optical or electrical properties…
- D = 10 μm: Noticeable individual craters (> 200 μm) on brittle surfaces, electromagnetic interference from impact plasma, optical light flash, impact generated radio waves
- D = 100 μm: Damage on sensitive sensors and surfaces (Shuttle windows required replacement), penetration of MLI, penetration of solar cells (short circuits, arc burning)

Debris (and meteoroids) impact effects

Impact on HST Solar Cell
Crater size: 3.5 mm;
Hole size: 0.5 mm





Impact on HST MLI
Outer damage size: 5 mm;
Hole size: 464 um

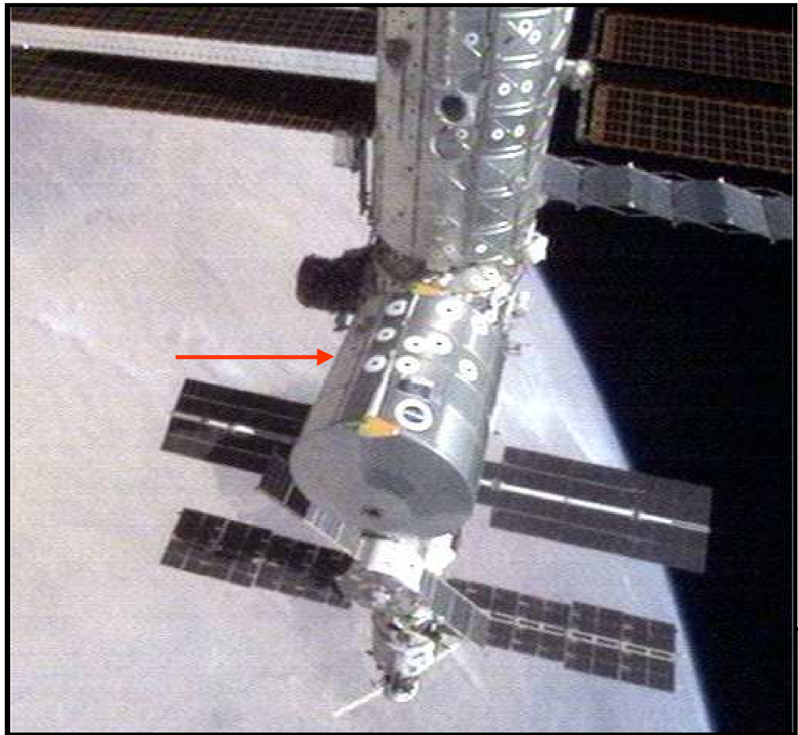
Debris (and meteoroids) impact effects: Cupola Windows

Photo taken by ESA astronaut Tim Peake from inside Cupola in May 2016

- 7 mm-diameter circular chip gouged out by the impact from a tiny piece of space debris
- The background just shows the inky blackness of space

Debris (and meteoroids) impact effects

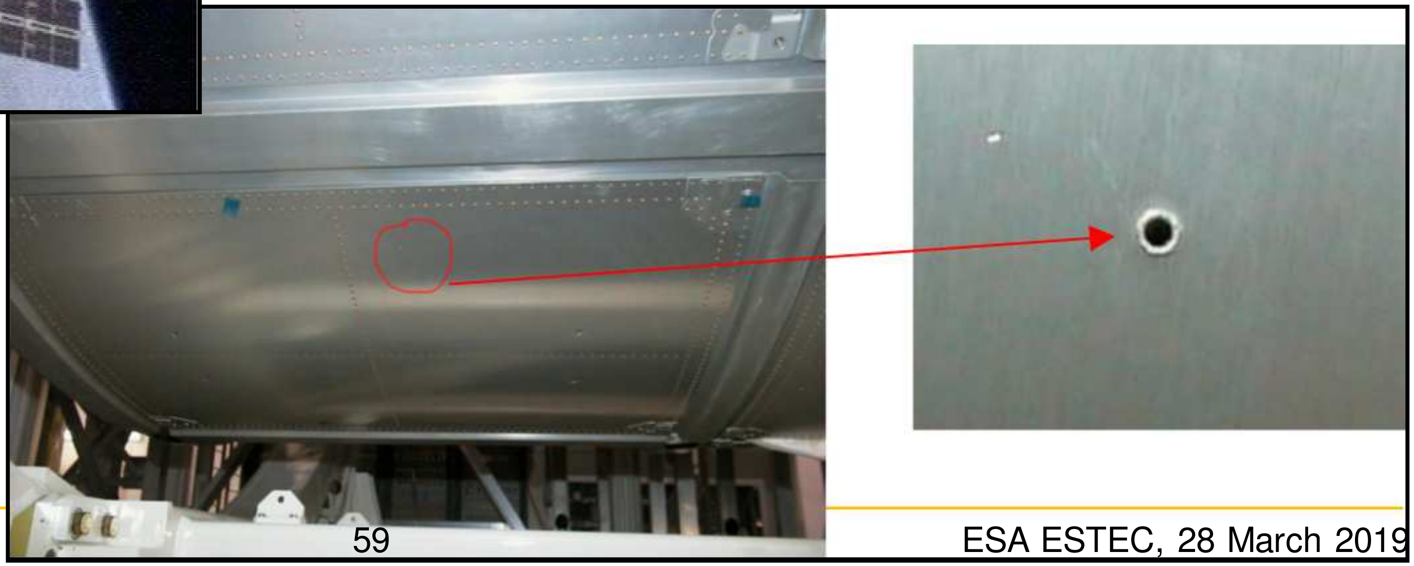
More than 26 impacts reported on MPLM over the first 5 missions



MPLM Leonardo, mission STS-102/5A.1 (March 2001), 3 MMOD impacts.

Largest impact: through hole in bumper shield 1.2 mm diam. According to NASA impactor could be a paint flake about 0.46 mm diam.

No damage to MLI underneath.



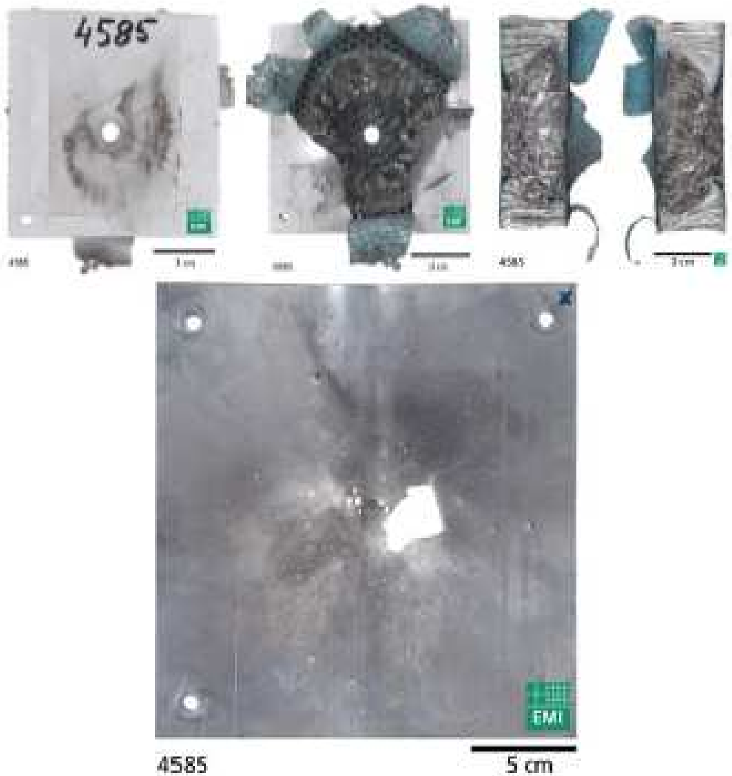
Debris (and meteoroids) impact effects

- **D = 1 mm: Penetration of 3-5 mm wall thickness with damage on equipment behind wall, structural damage of exposed equipment, penetration of tanks, baffles, sun-shields, external cables, etc.**
- **D = 1 cm: Structural damage/ destruction on any spacecraft part hit, penetration of shields protecting manned modules, creation of new large debris pieces.**
- **D = 10 cm: Complete destruction of satellite or subsystem hit. Interference with astronomical observations.**

Al sphere, 12 mm diameter, 2.5 g.
Impact velocity: 6.8 km/s, kinetic energy 56.5 kJoule.
Al slab thickness 18 cm.

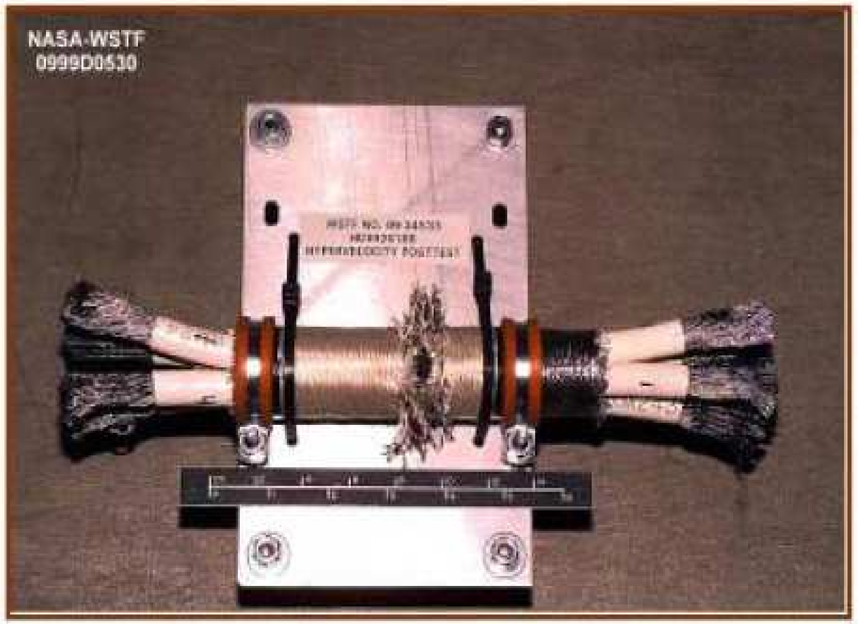
Effects - HVI / Ballistic Limit Equations

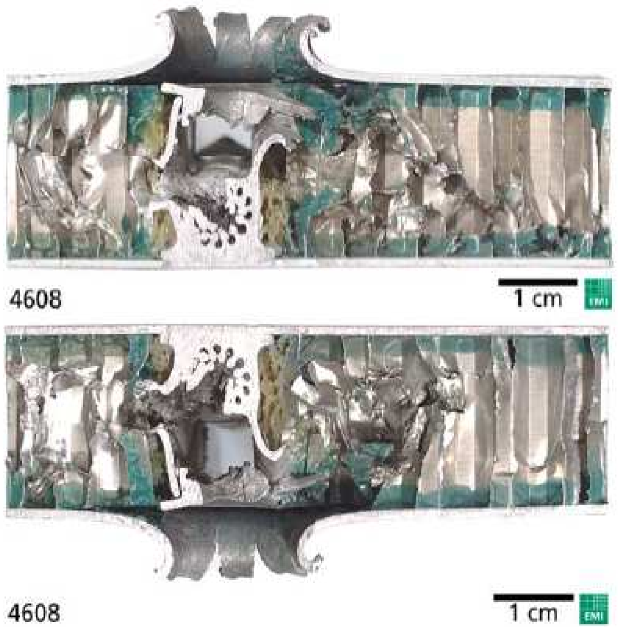
Damage to internal components (piping, pressure vessels, heat pipes, cables, electronic boxes…) tested in the frame of HVI test campaigns

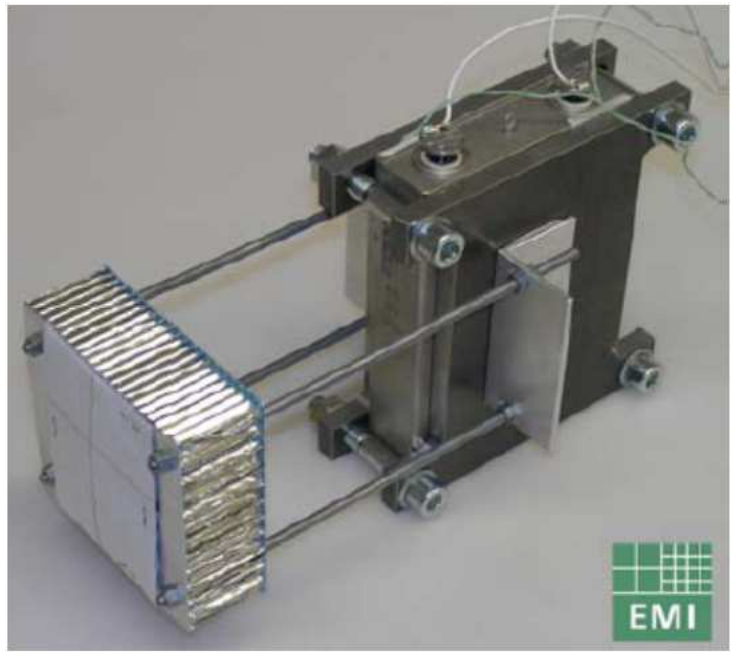


Effects HVI / Ballistic Limit Equations

Needed for every item potentially impacted







Debris (and meteoroids) effects: MMOD Risk Assessment

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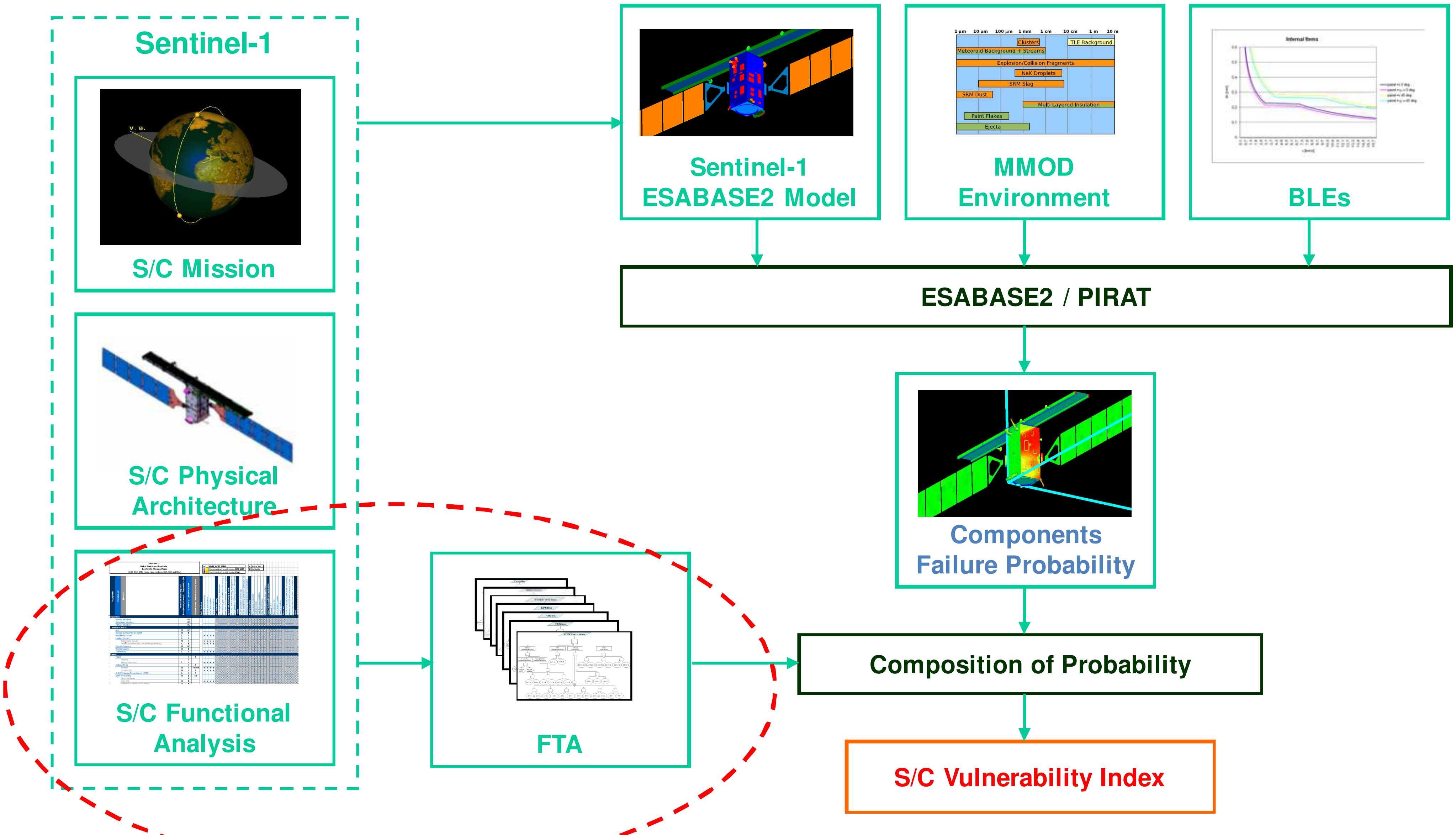
Unmanned SC

Note: debris and meteoroids risk assessment needed for new requirements on assessing Met & Space Debris impact preventing the successful disposal



Debris effects: Collision Avoidance (COLA) Manoeuvres

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25 COLA manoeuvres conducted from 1999 to 2015 (average 1,6 per year)

No COLA manoeuvres in 2016-2017, but an ISS visiting vehicle had 1 COLA maneuver in 2017

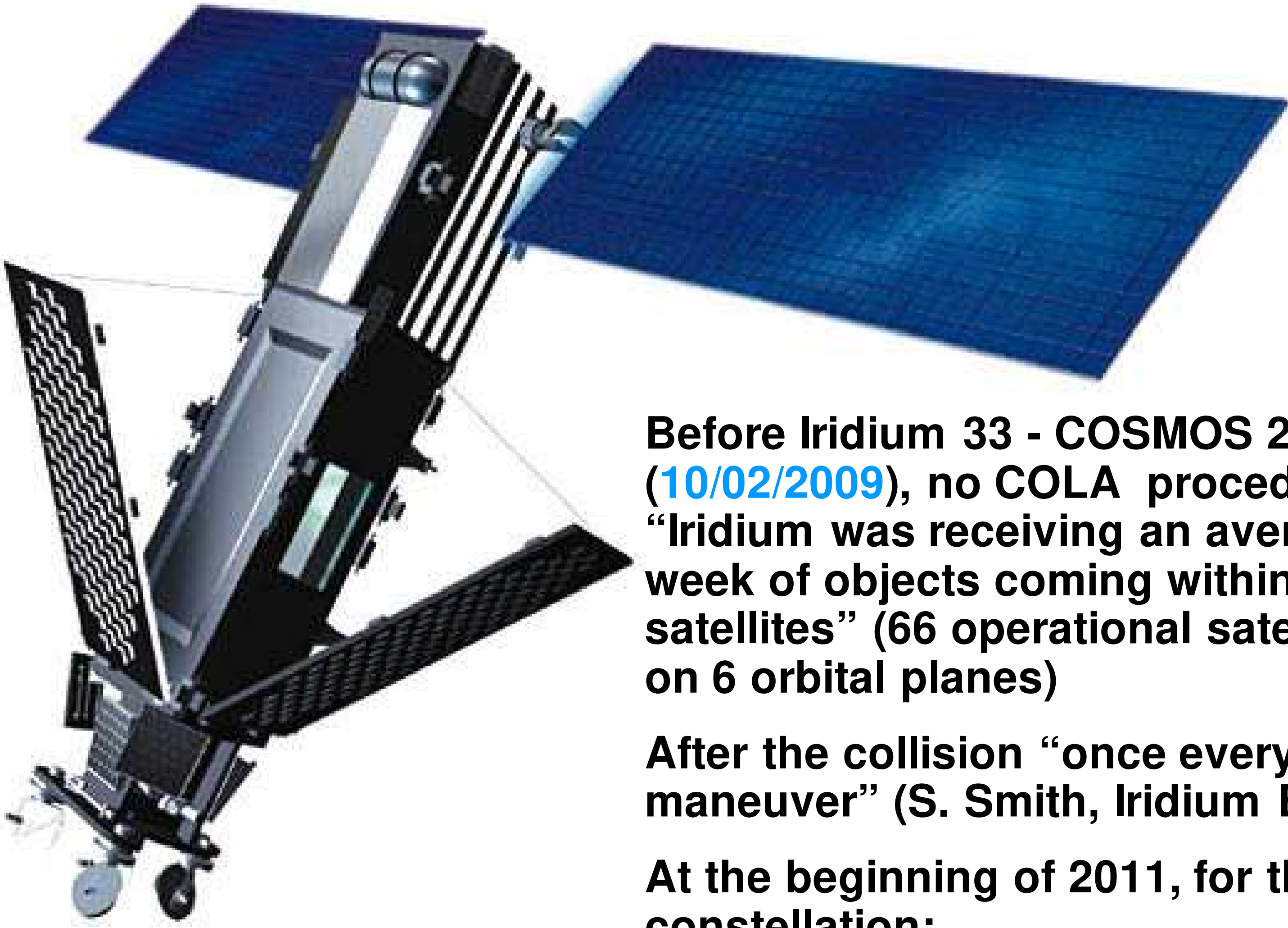
From January to September 2015: 4 COLA manoeuvres

From April 2011 to April 2012: 4 COLA manoeuvres (2 additional would have conducted if warnings had come sooner)

- Solar activity increases, resulting in increased drag and leading to a higher number of debris falling through the ISS orbit

Date of Maneuver or Close Approach	Object Avoided	Action Taken
2-April-2011	Fragmentation debris from Russian Cosmos 2251	Collision Avoidance Maneuver
28-June-2011	Debris apparently from Proton ullage motor breakup	Crew retreated to Soyuz due to insufficient time for maneuver
29-September-2011	Russian Tsyklon rocket body debris	Collision Avoidance Maneuver
13-January-2012	Fragmentation debris from Iridium 33	Collision Avoidance Maneuver
28-January-2012	Fragmentation debris from Fengyun-1C	Collision Avoidance Maneuver
24-March-2012	Fragmentation debris from Russian Cosmos 2251	Crew retreated to Soyuz due to insufficient time for maneuver

Debris effects: Iridium COLA Statistics



Before Iridium 33 - COSMOS 2251 collision (10/02/2009), no COLA procedures implemented: "Iridium was receiving an average of 400 reports per week of objects coming within 5 km of one of their satellites" (66 operational satellites + 6 spares, located on 6 orbital planes)

After the collision "once every couple of weeks we do a maneuver" (S. Smith, Iridium EVP, December 2010)

At the beginning of 2011, for the first IRIDIUM constellation:

- 82 alerts were managed over the last 22 months (≈ 1/ week)
- 32 resulted in mitigation burns (39%), (≈ 1/ 3 weeks)

Note: Iridium replacement

40 new SC "Iridium NEXT" were launched in 2017, to start replacement of the 66 Iridium SC

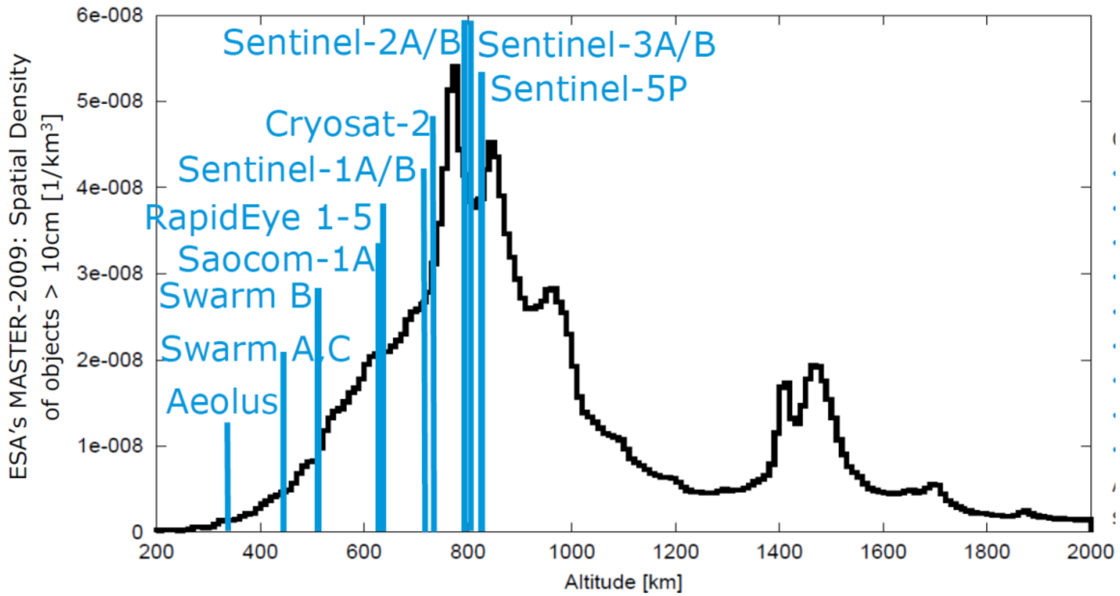
In 2017 13 first-generation SC removed from operational orbits for disposal and passivation

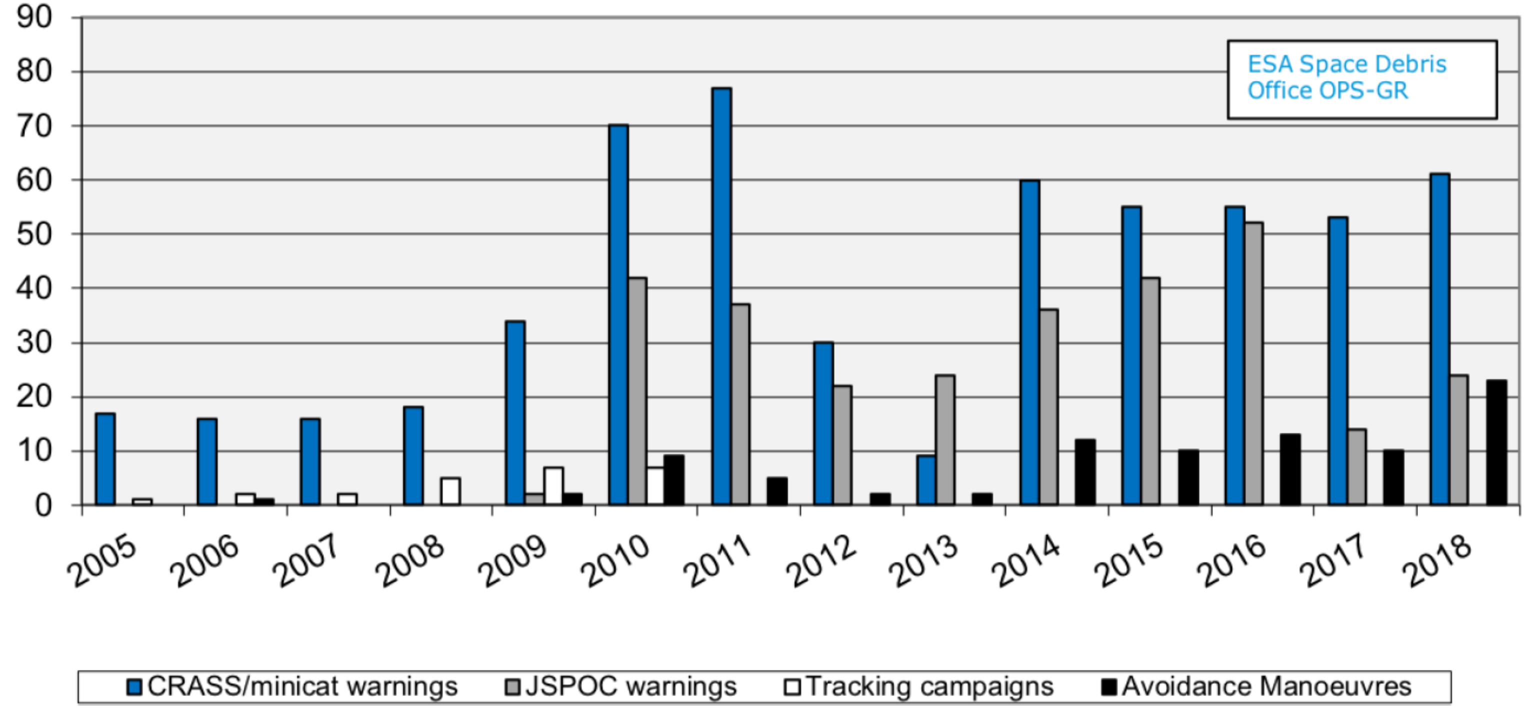
- 6 SC reentered as of February 2018
- 3 SC expected to reenter by 2020
- 4 SC expected to reenter within 25 years

Debris effects: Collision Avoidance (COLA)

Operational collision avoidance at ESOC

(Q. Funke et al. 9/11/2018)





Space Debris Overview

Re-entry Risk

Debris effects: Re-entry Risk

Since the launch of the first artificial satellite (1957), more than 22,000 human-made objects reentered within the Earth atmosphere, with an average of more than 1 human-made objects per day (as of January 2016)

Currently about than 40 large, human-made objects re-enter the Earth's atmosphere every year (more than 90,000 kg/yr)

The majority of these objects do not survive the intense reentry environment (10-40% of a spacecraft mass has been estimated to have survived and impacted the Earth surface).

More than sixty spacecraft uncontrolled re-entry events resulting in the recovery of debris on the ground have been documented.

It has been estimated that, globally, more than 1,400 metric tons of materials have survived re-entry since the beginning of the Space Age.

Apart from high area to mass ratio components (e.g. solar panels), generally lost at an altitude around 100 km, most spacecraft and rocket upper stages mainly disintegrate at an altitude of about 78±10 km.

Debris effects: Re-entry Risk

The survivability of components depends on shape, materials, accommodation, shielding, etc.

The average risk induced by each re-entry is small. It depends from and increases with spacecraft mass and number of fragments which may survive.

Of the MIR mass of 135,000 kg about 25,000 kg in 1,500 fragments survived re-entry.

For major systems such as the MIR station or ATV, performing a safe de-orbit / controlled re-entry is necessary to mitigate the re-entry safety risk.

In 2002 the Columbia accident created 84000 debris, spread out on a 1000x40 km area

Debris effects: Re-entry Risk

Nobody seriously injured so far (but in January 1997 a woman in Oklahoma suffered a slight scratch due to a reentering piece of H/W)

NASA

- Delta 2nd Stage reentry, January 1997
- Dry weight at reentry: 920kg
- Most debris landed in Texas
- Footprint length ~760 km

<.1 kg

Tulsa World (staff photo by Brandi Stafford)

~40 kg

Photo courtesy Aerojet

~30 kg

NASA

~250 kg

NASA

THE AEROSPACE CORPORATION

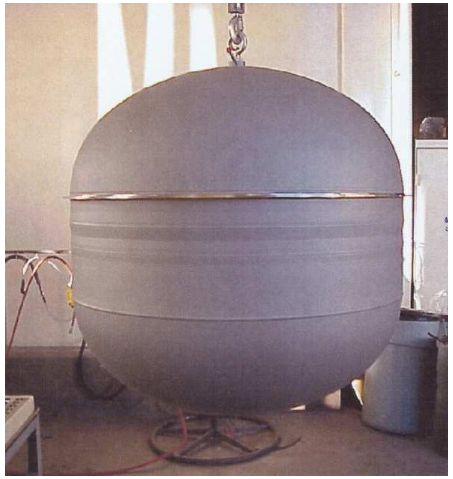

Georgetown USA 1997
Somewhere in the USA
Saudi Arabia about 240 km from Riyadh
21 January 2001
Worcester, about 150 kilometres outside of Cape Town, south Africa in April 2000
Queensland, Australia, in 2008.

Debris effects: Re-entry Risk (Environment)

Typical fuels and other materials used by spacecraft are hazardous should they impact the ground

- Cosmos 954 Accident (Canada, 1978, see dedicated slide)
- The 2003 break-up of space shuttle Columbia resulted in numerous tanks reaching the ground (84,000 debris spreading 1000 x 40 km)
- A Proton launcher failure in September 2007 contaminated a vast swath of agricultural land of Kazakhstan with 200 tons of toxic fuel
- In 2008 USA-193 was destroyed due to the risk of large quantities of fuel reaching the ground

Haz Mat team response to 2003 *Columbia* break-up



Hydrazine tank used on USA-193

Debris effects: Re-entry Risk (Radioactive Material)

As of 2016 there have been 11 cases of failures leading to dispersal of radioactive material, including:

- plutonium payload on board Apollo 13 lunar module which ended up in the Pacific Ocean close to the coast of New Zealand,
- 68 pounds of uranium-235 from the Russian Cosmos 954 which were spread over Canada's Northwest Territories in 1978;
- in 1996, when the Russian MARS96 disintegrated over Chile releasing its plutonium payload which has never been found.

Currently there are 32 defunct nuclear reactors, 13 reactor fuel cores and at least eight radio-thermal generators (RTGs) circling Earth.

The total mass of RTG nuclear fuel is about 150kg, while there are 1,000kg of radioactive fuel from nuclear reactors.

Operation *Morning Lights* -Canada 1978

Debris effects: Re-entry (COSMOS 954 Accident)

On 24 January 1978, COSMOS 954 nuclear-powered surveillance satellite, crashed in the Northwest Territories, scattering a large amount of radioactivity over a 124,000 square kilometre area in Canada's north, stretching southward from Great Slave Lake into northern Alberta and Saskatchewan.

The clean-up operation (coordinated between US and Canada) continued into October 1978 and resulted in the estimated recovery of about 0.1 percent of COSMOS 954's power source.

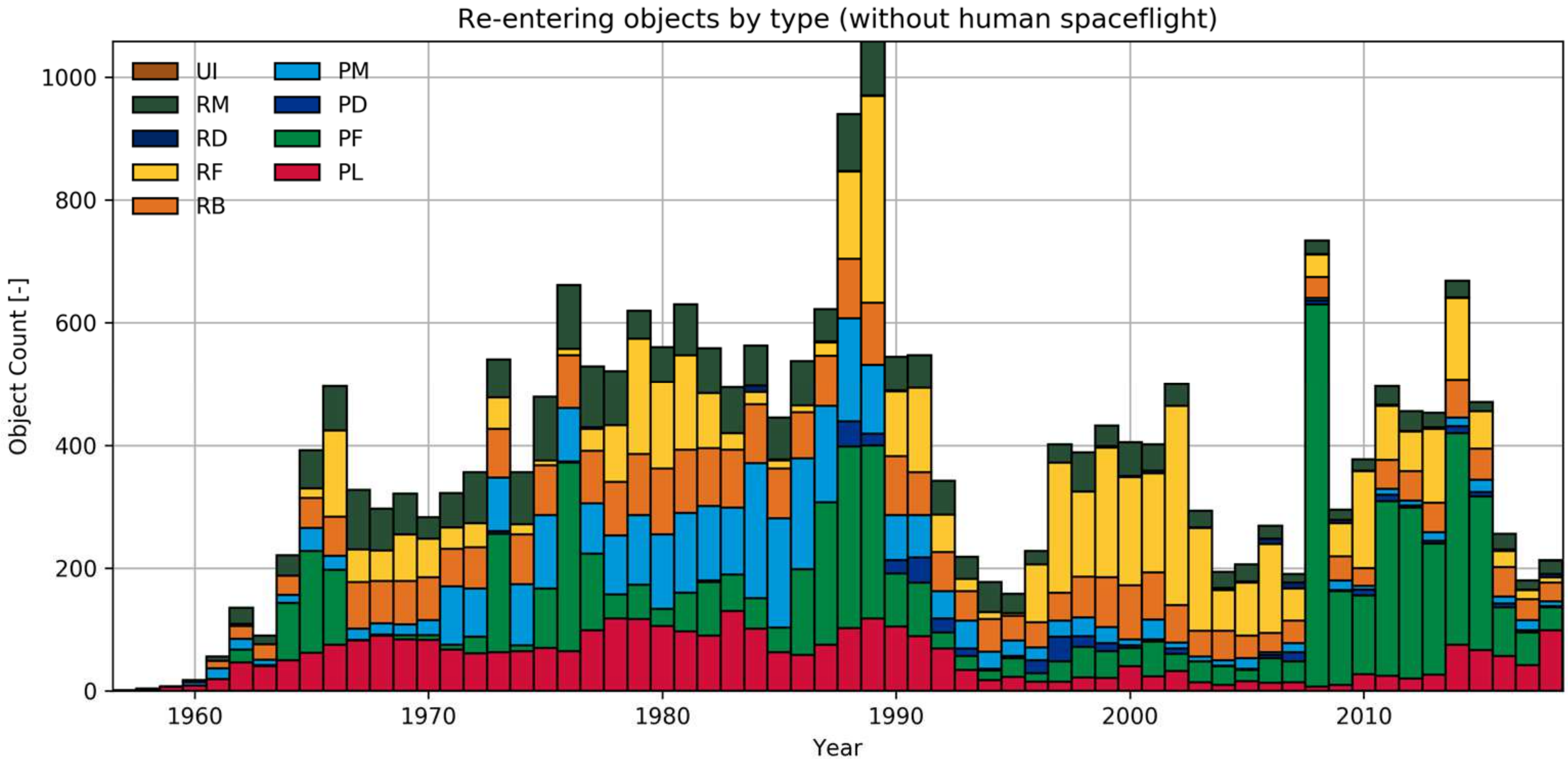
Settlement of Claim between Canada and USSR for Damage Caused by "Cosmos 954" (Released on April 2, 1981) for the sum C$ 3,000,000.00

First piece of debris found from the crashed Cosmos-954 Soviet satellite

Debris effects: Re-entry

Objects removed from the Space Environment

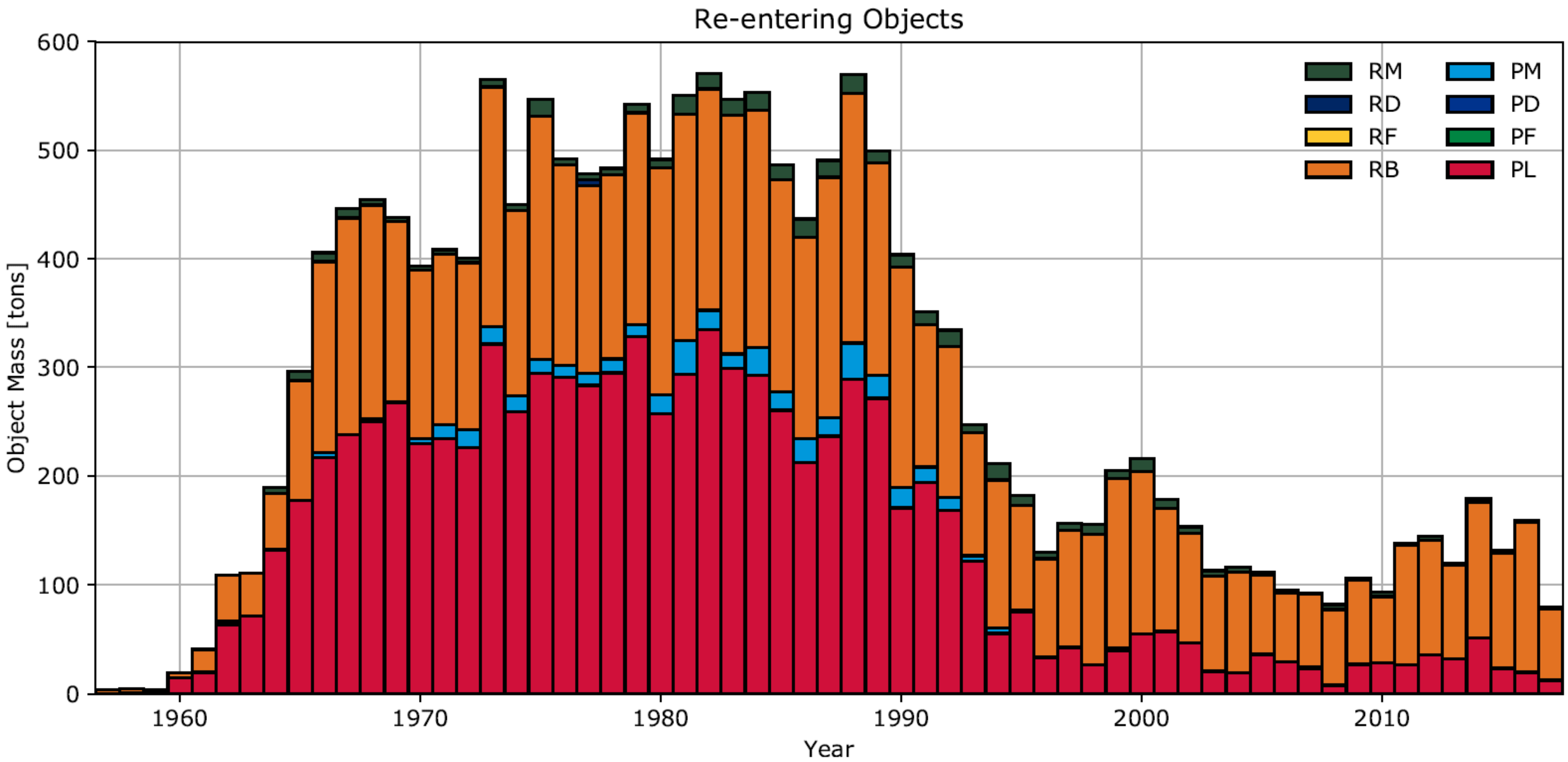
- Evolution as of end of 2018 (ESA's Database, https://discosweb.esoc.esa.int/web/guest/statistics, ~22037 catalogued objects)



Debris effects: Re-entry

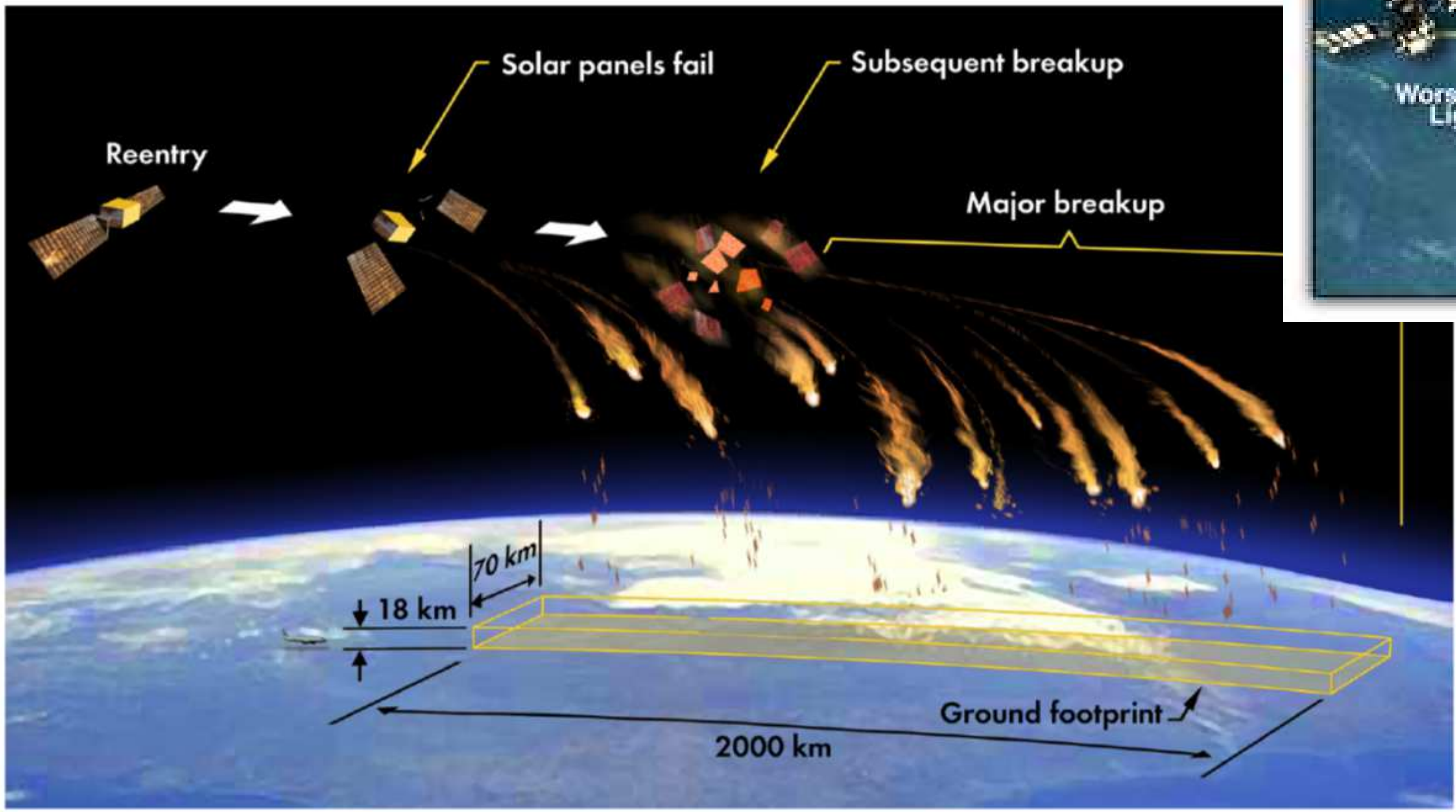
Objects mass removed from the Space Environment

- Evolution as of end of 2017 (ESA's Annual Space Environment Report - DISCOS Database, 19894 catalogued objects)



Debris effects: Re-entry Footprint (Example)

- **Compton Gamma Ray Observatory (CGRO), NASA**
- **Launched in 1991, ~ 11 Ton**
- **Re-entered into the Pacific Ocean (June, 2000)**



Debris effects: Re-entry Risk (UARS)

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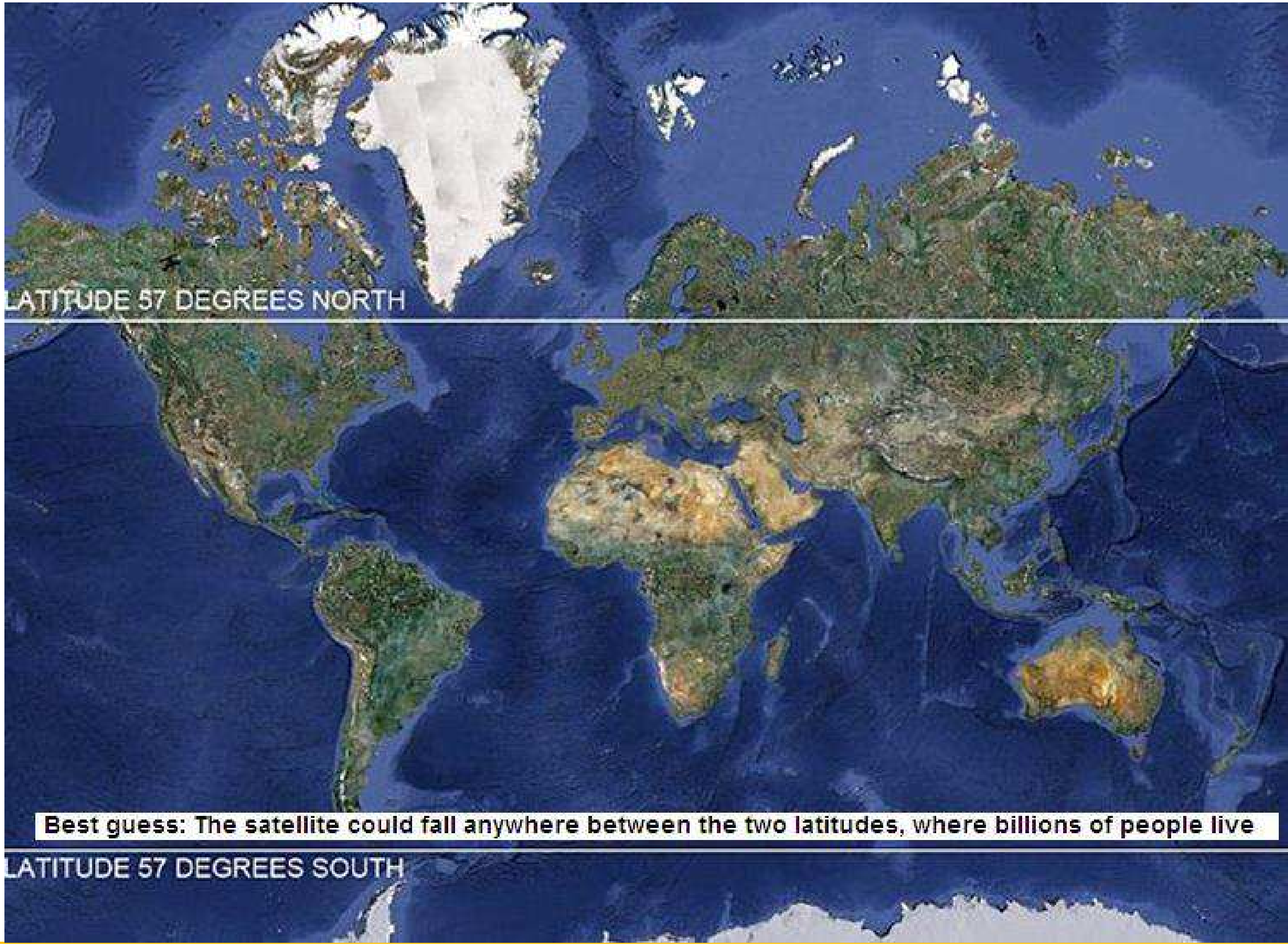
UARS (Upper Atmosphere Research Satellite) mass 5,668 kg re-entered 23/09/2011. It could have fallen anywhere between ± 57° latitude



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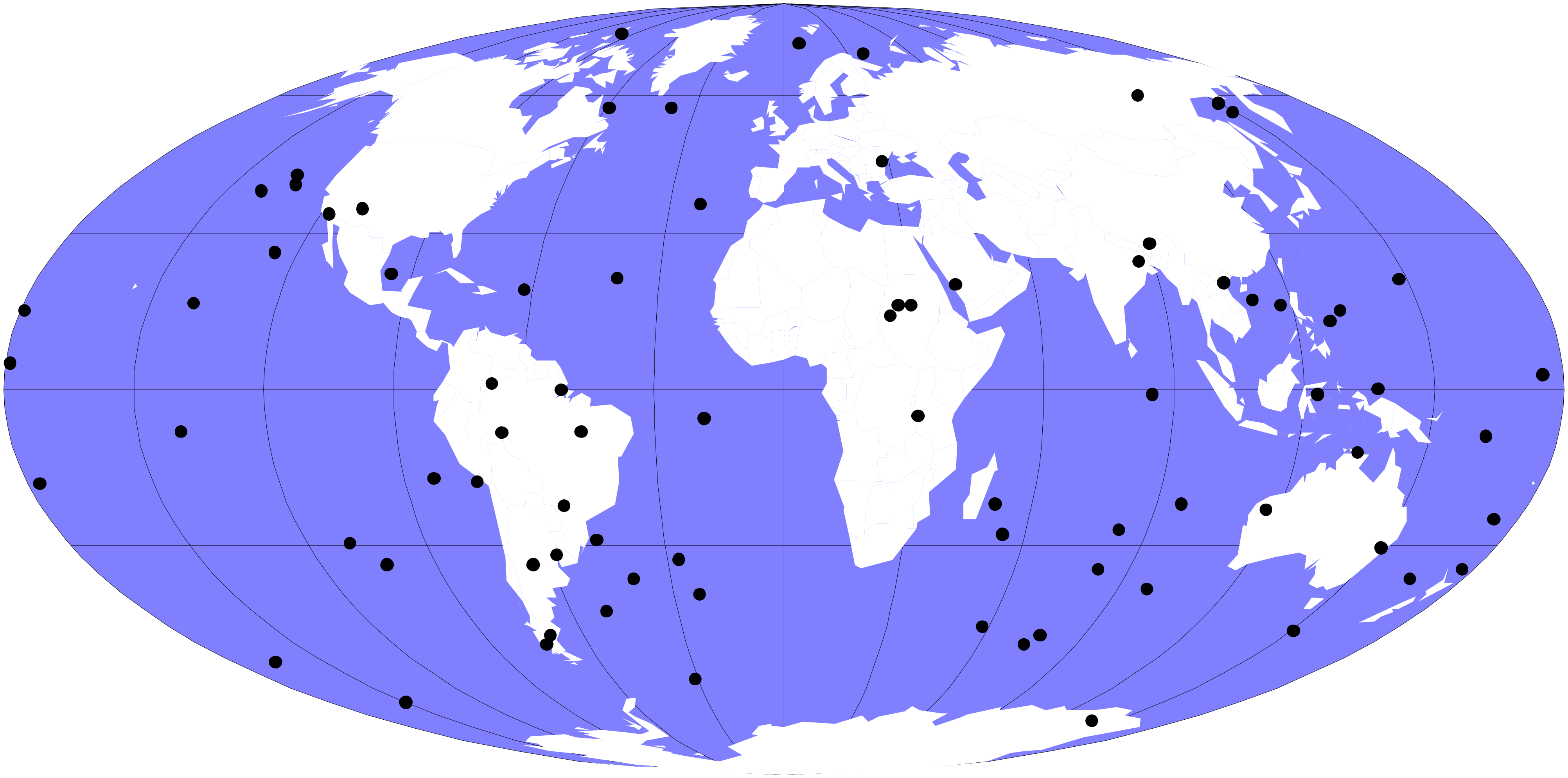
Debris effects: Re-entry Risk

Global Distribution of Circular Orbit Reentries

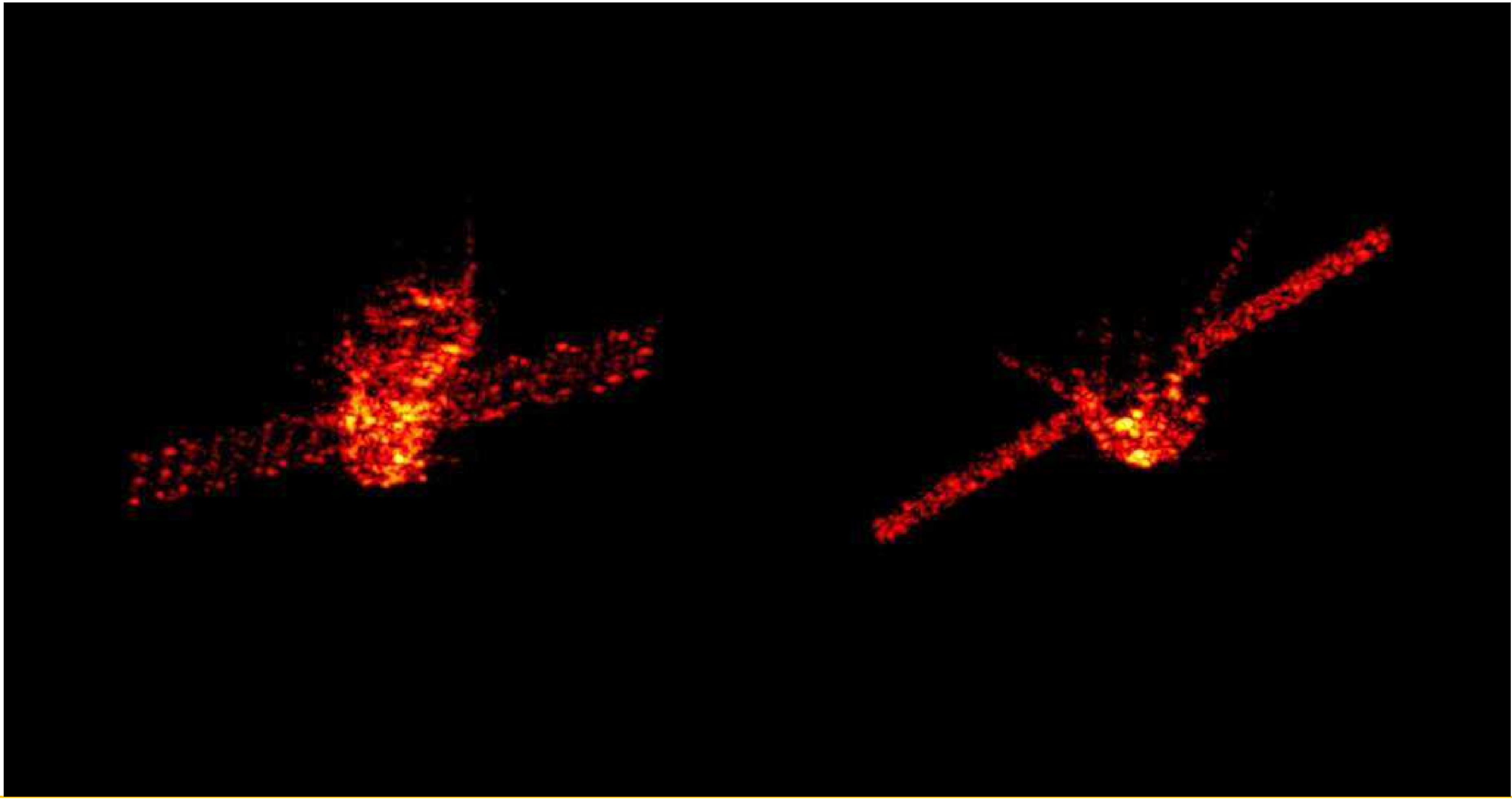


81 intact satellites (both rocket bodies and spacecraft) that reentered between 2003 and 2011 (including UARS)

Source: Matney, M., "Empirical test of the predicted footprint for uncontrolled satellite reentry hazards", Proceedings 5th IAASS Conference, Oct. 2011.

Tiangong-1 altitude at 270 km altitude, radar image © Fraunhofer FHR, Wachtberg, Germany

Tiangong-1 completed a destructive uncontrolled re-entry on 2 April 2018 00:15 UTC



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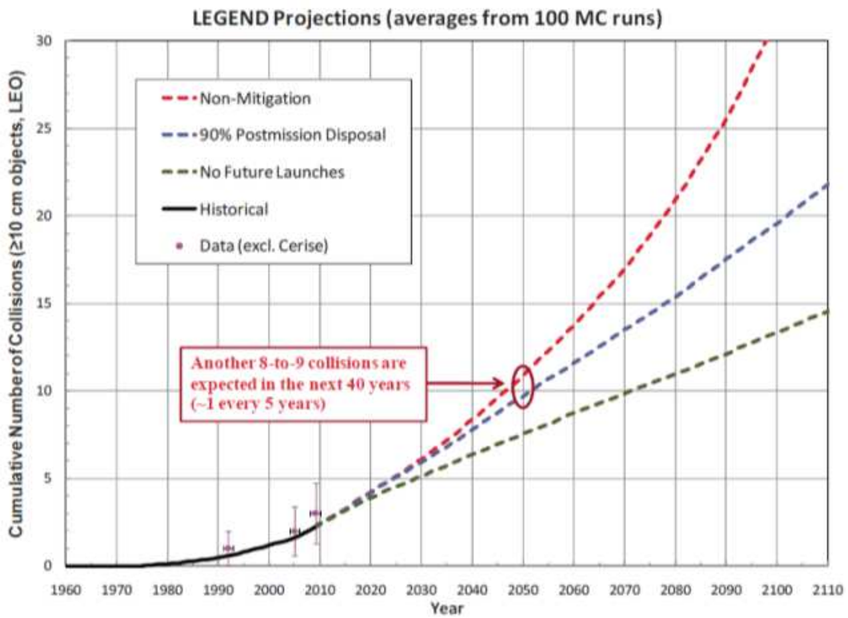
D4D

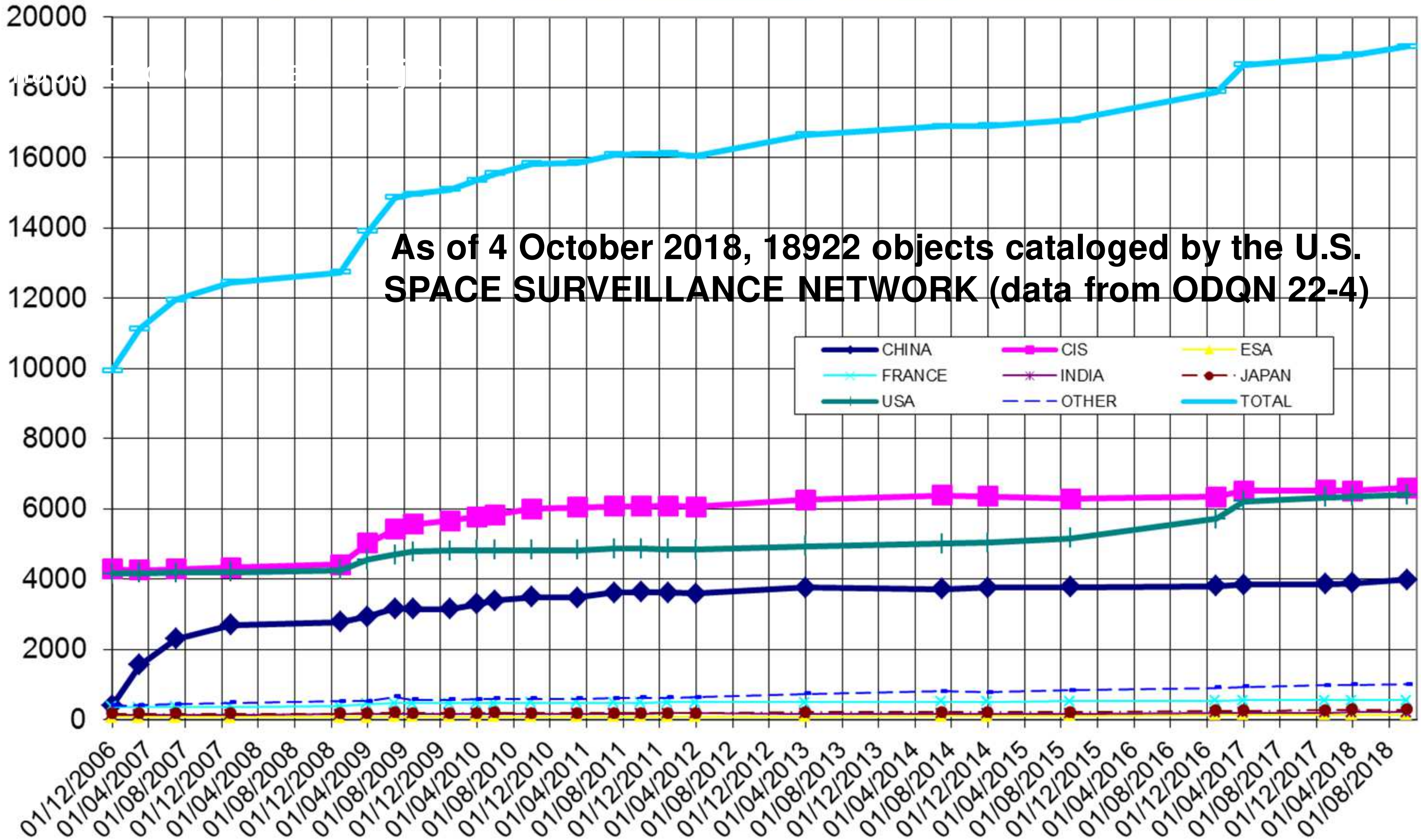
The intentional design of space hardware to burn up during atmospheric reentry. Design for Demise applies both at equipment and system level and developments at these two levels are necessary.

Space Debris Overview

A Global Perspective for Space Sustainability



Space Debris: A Global Issue



Space Debris: Kessler Syndrome

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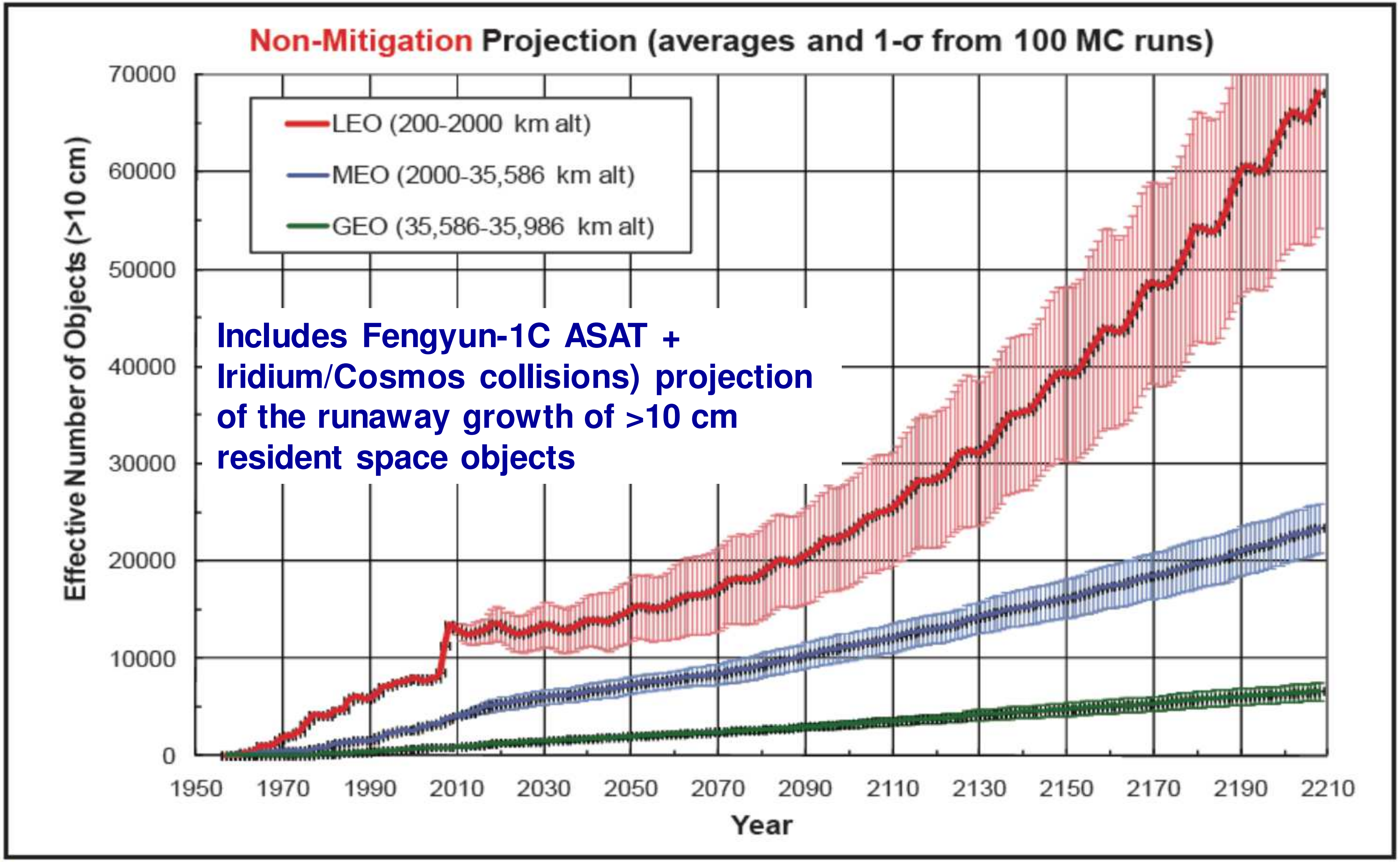
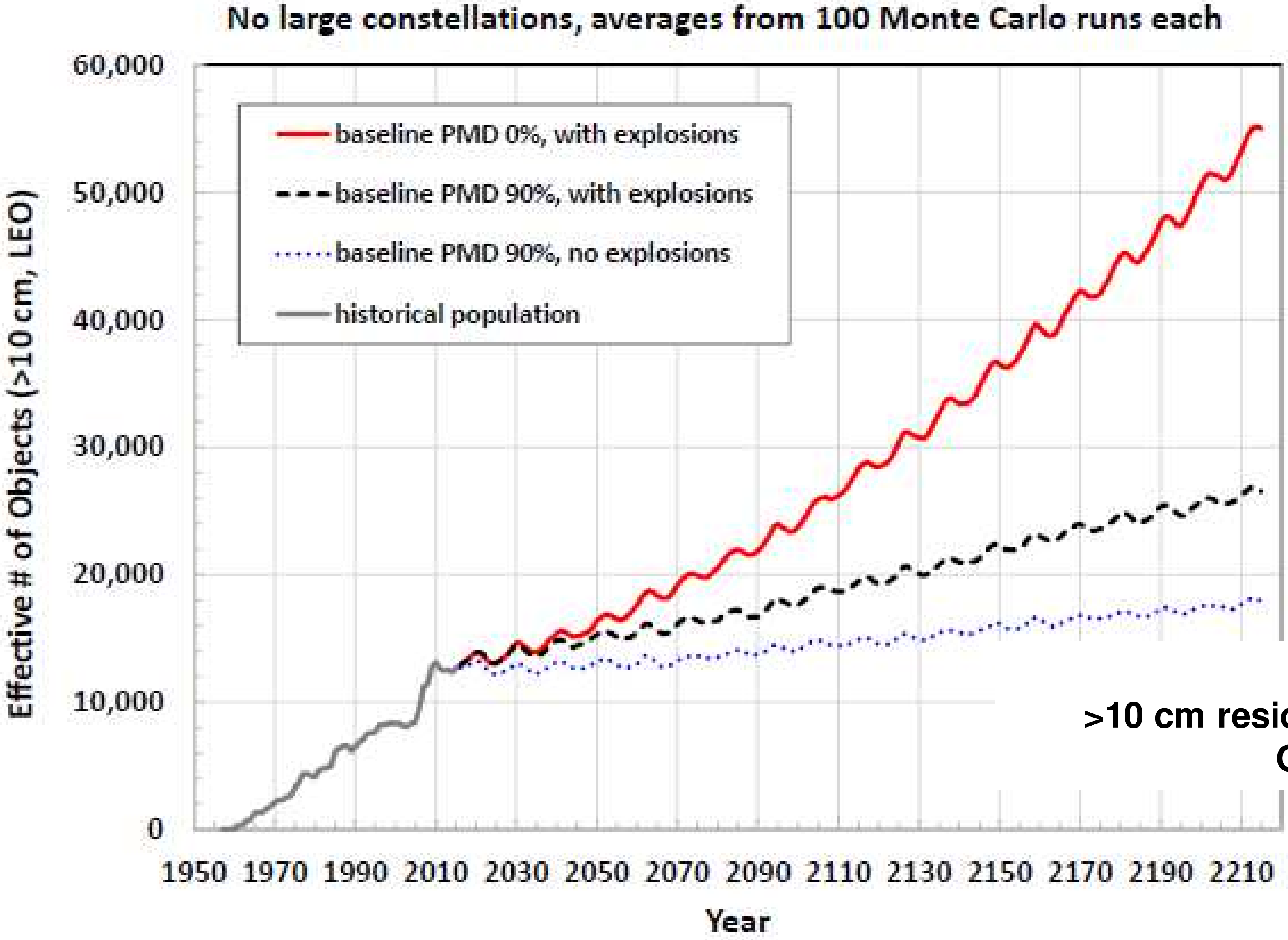
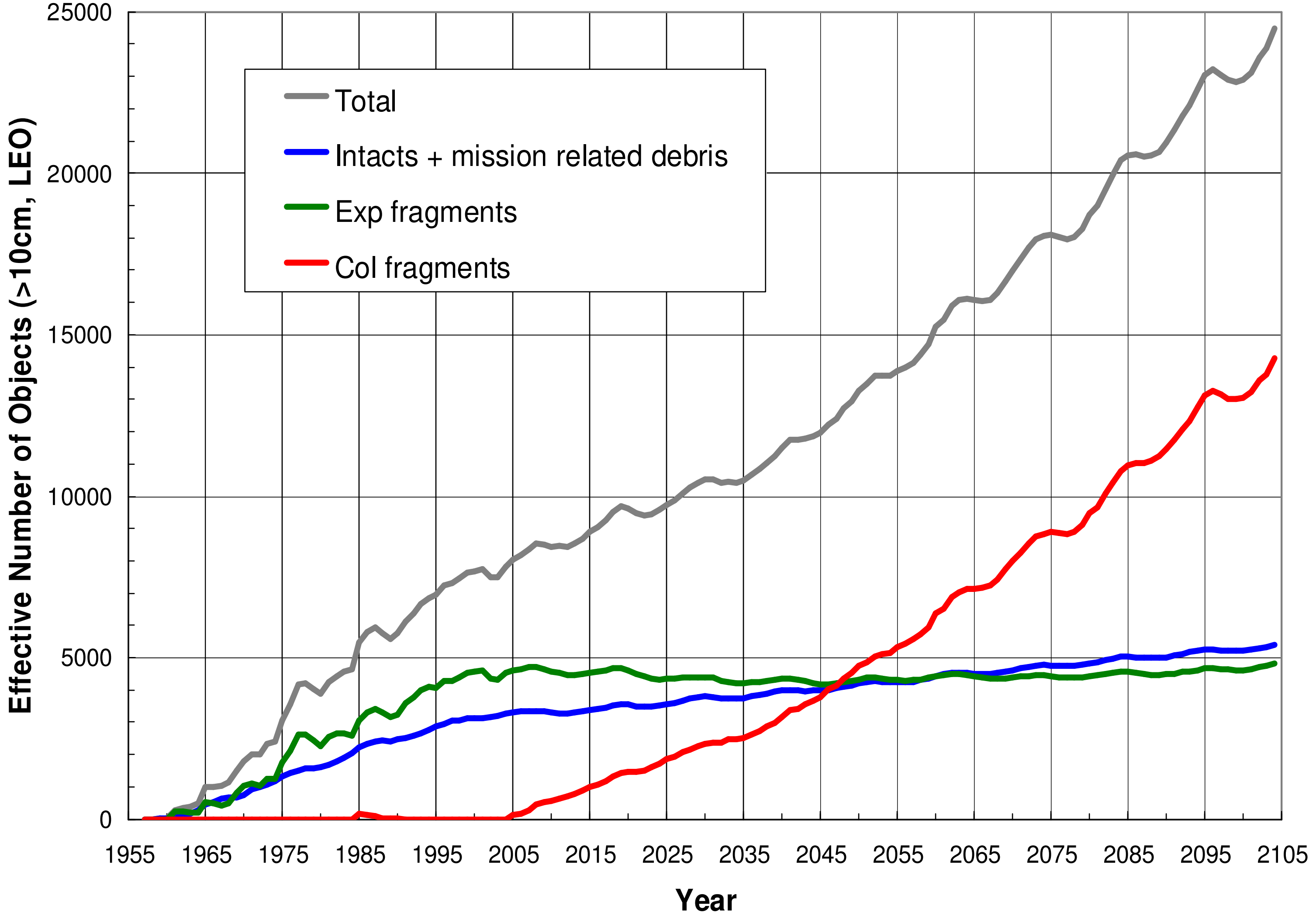


Space Debris: Kessler Syndrome



In LEO
>10 cm resident space objects
ODQN 22-3 09/2018

Space Debris: Kessler Syndrome



Assumptions:

- **200 to 2000 km altitude orbits**
- **No mitigation (no post-mission maneuvers to dispose of hardware)**
- **1997-2004 launch cycle**

Predictions:

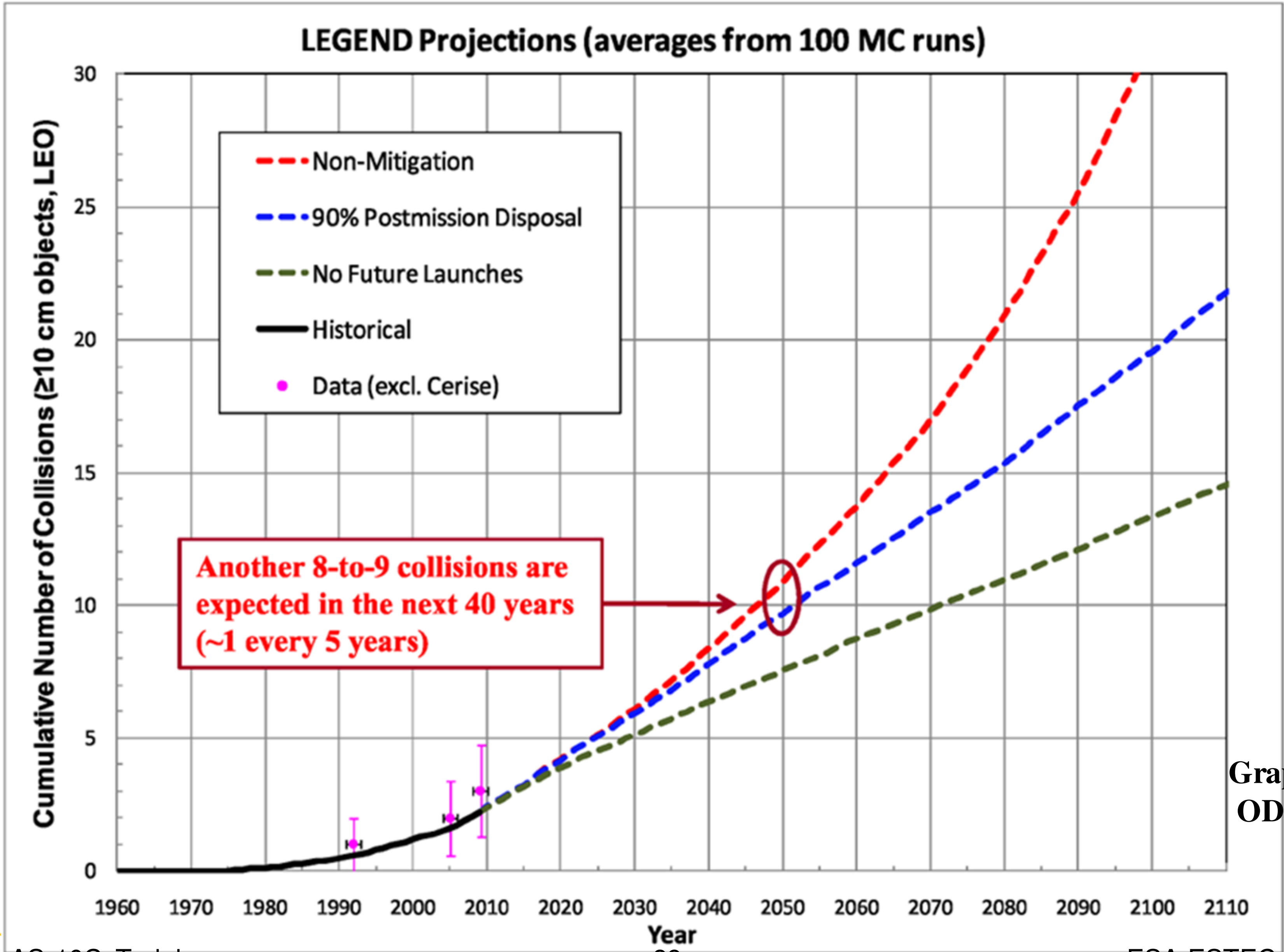
~24 collisions in next 100 years

J.-C. Liou, "A statistical analysis of the future debris environment," ***Acta Astronautica*** **62 (2008) 264 – 271.**

Space Debris: Kessler Syndrome (with and w/o disposal efforts)

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

NASA predicted collisions in LEO: an average of about 1 / 5 years expected for the next 40 years.



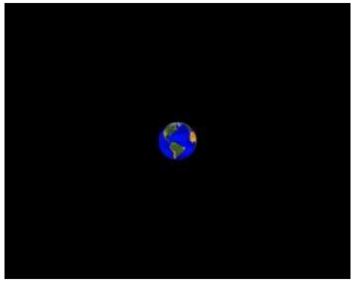
Graph: NASA ODPO, 2017

C:\DES\.... ECSS-U-AS-10C ESTEC Train 20160627v2.ppt PAG.89

Space Debris– A Global Issue

REMEDIATION:

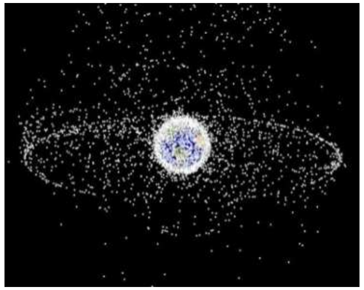
- Removing existing, non-cooperative objects is extremely difficult and expensive. Investigated techniques suffer from lack of development and testing, economic and legal viability:
  - Ground based laser cleansing
  - Active Debris Removal



Pre 1957

Only current option: MITIGATION

- Avoid the intentional release of space debris (Mission Related Objects MRO) into Earth orbit during normal operations
- Avoid break-ups in Earth orbit (including passivation at the End of Mission)
- Remove spacecraft and launch vehicle orbital stages from the protected regions:
  - GEO to a graveyard orbit (GEO + 200 km)
  - LEO within 25 years after End of Mission (re-entry controlled or uncontrolled, higher orbit)



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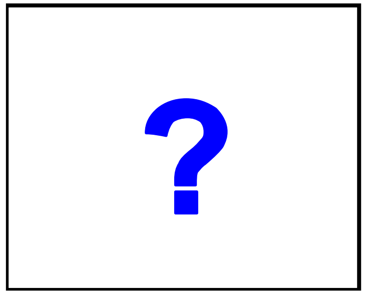

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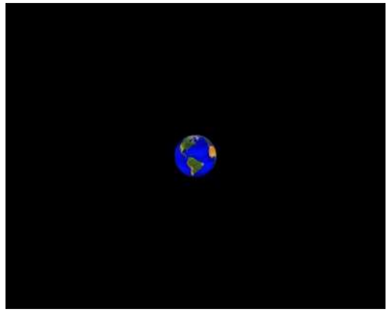
Space Debris – A Global Issue

Only current option: MITIGATION

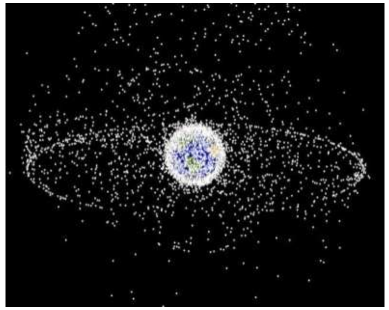
- [Perform the necessary actions to minimize the risk of collision with other space objects]
- [Assess the risk that a space debris or meteoroid impact causes a SC to break-up / prevents its successful disposal]
- [Monitor periodically the conditions of SC]
- [Evaluate and control of Re-entry Risk]

A global issue requires international solutions:

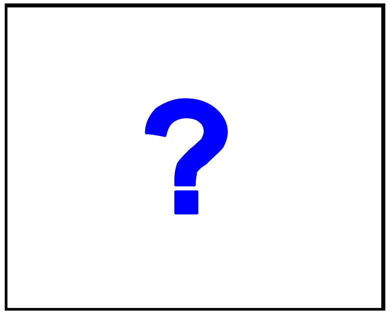
GUIDELINES AND STANDARDS



Pre 1957



2008



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Space Debris Mitigation

Space Debris Mitigation Guidelines and Standards

United Nations
Office for Outer Space Affairs

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

SDM: Standards and Guidelines I

In the last 25 years, Space Debris Mitigation Standards, Guidelines or Handbooks have been issued by several national, regional and international organizations.

Since the mid-1990s, space agencies in Europe have developed guidelines.

In 1993, the Inter-Agency Debris Coordination Committee (IADC) was formed (now composed of 13 national Space Agencies).

In 2002, IADC published the "Space Debris Mitigation Guidelines" which were presented to the UN-COPUOS STSC (Scientific & Technical Subcommittee) and served as a baseline for the "UN Space Debris Mitigation Guidelines". The IADC guidelines were updated in 2007 (IADC-02-01, Revision 1, September 2007)

IADC

United Nations
Office for Outer Space Affairs

SDM: Standards and Guidelines II

In 2006, the "European Code of Conduct" was signed by ESA, ASI, BNSC, CNES and DLR.

In 2007, UN-COPUOS STSC "UN Space Debris Mitigation Guidelines“ approved by the 63 STSC member nations as voluntary high-level space debris mitigation measures

In 2007, NASA policy was established to control the generation of orbital debris: NASA Procedural Requirements 8715.6A, NASA Technical Standard 8719.14 (2007). All NASA projects are required to provide debris assessments and End of Mission (EoM) planning.

In 2008, ESA “Space Debris Mitigation for Agency Projects” was published. The requirements were made applicable to all space vehicles, including launchers, satellites and inhabited objects. The document was updated in 2014 (ESA/ADMIN/IPOL(2014)2).

SDM: Standards and Guidelines III

In June 2008, Space Debris Mitigation requirements are also part of the French Loi relative aux Opérations Spatiales (LOS, N°2008-518). The French LOS has been updated on July 11th, 2017

ISO International debris standards were developed from 2003 by TC20/SC14 committee "Space systems and operations", with the participation of 12 nations (now 13).

The ISO key document is "ISO 24113 - Space Debris Mitigation". This standard (published July 2010, 1st ed., May 2011, 2nd ed.) is based on the IADC and UN guidelines, and aims at translating the existing recommendations into quantitative implementation requirements.

The European Cooperation for Space Standardisation (ECSS) supports ISO TC20/SC14 development through ECSS SDWG.

ECSS-U-AS-10C Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements published February 10, 2012

SDM: Standards and Guidelines IV

The European Committee for Standardization (CEN) published the ECSS-U-AS-10C Adoption Notice of ISO 24113 as EN 16604-10 in 2014

National standards are used by several agencies (ROSCOSMOS, JAXA,…)

UNCOPUOS published a set of internationally agreed guidelines for the long-term sustainability of outer space activities in 2018, addressing recommendations on

- the policy and regulatory frameworks for space activities,
- the safety of space operations,
- rules of engagement for international cooperation,
- capacity-building and awareness, and
- scientific and technical research and development.

Space Debris Mitigation

European Cooperation for Space Standardisation (ECSS) & ISO TC20/SC14 Space Debris Mitigation Standards

ECSS Membership

ECSS Membership

European Space Agency

esa

European Space Industry
represented by
ASD-EUROSPACE
The Space group in ASD

Some organizations have an Observer role on ECSS, e.g.
- CEN-CENELEC
- EUMETSAT
- EDA

National Space Agencies

Agency	Country
agenzia spaziale italiana	**Italy**
cnes	**France**
DLR	**Germany**
Netherlands Space Office	**The Netherlands**
Norsk Romsenter	**Norway**
UK Space Agency	**United Kingdom**
CSA ASC	Canada

Voting | Associate | Observers

European Cooperation for Space Standardization (ECSS)

- ECSS-E-ST-31-02C Rev.1 DIR1: Start of Public Review (Due: 22 July 2016)
- ECSS-E-ST-33-01C Rev.1 DIR1: Start of Public Review (Due: 30 June 2016)
- ECSS-E-ST-20-20C, ECSS-E-HB-20-20A and ECSS-E-ST-70-41C published (15 April 2016)
- ECSS-E-ST-10C Rev.1 DIR1: Extension of Public Review (New due date: 24 June 2016)
- ECSS-Q-ST-30C Rev.1, -40C Rev.1 and -80C Rev.1: Start of Public Review (Due: 3 June 2016)
- ECSS-Q-ST-10C Rev.1 "Product assurance management" (15 March 2016) published
- ECSS-E-HB-11A DIR1: Start of Public Review (Due: 22 April 2016)
- ECSS-E-ST-60-21C DIR1: Start of Public Review (Due: 31 March 2016)
- ECSS-Q-ST-70-54C DIR1: Start of Public Review (Due: 31 March 2016)
- ECSS-E-ST-50-12C Rev.1 DIR3: Start of Public Review (Due: 30 January 2016) --> Extended until 19 Feb 2016

ECSS Branch Structure

ECSS content:

128 active standards:
(2S, 1P, 6M, 60Q, 58E, 1U)

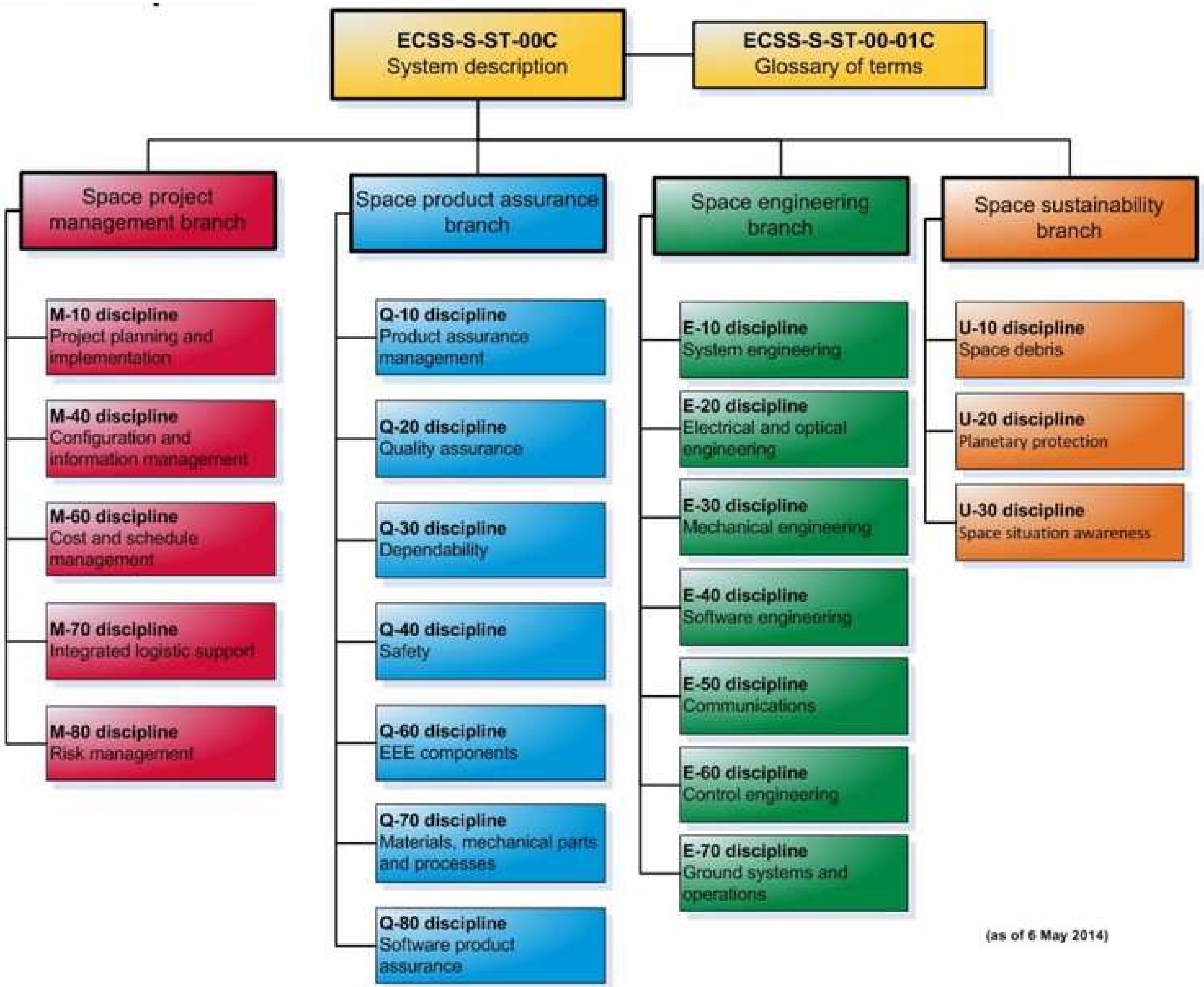
Also published through DOORS Data base modules (V06- 17 October 2017)

Systematically transferred in EN

52 active handbooks

On-going activities: more efficient to save resources

- 22 active Working Groups
- 31 new or to be updated documents (1M, 6Q, 23E, 1U)



ISO (International Organization for Standardization)

ISO is a network of the national standards institutes of 163 countries, on the basis of one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system.

- Established in 1947 to promote standards in international trade, communications, and manufacturing
- Over 200 Technical Committees, each administered by a designated Secretariat

ISO/TC20 Aircraft and Space Vehicles

TC 20/SC 14 Space systems and operations (13 members / countries)

Secretariat: ANSI (US)/AIAA

- Chair: Paul Gill (US)
- Secretary: Nick Tongson (US)

Participating Members

- Brazil (ABNT)
- China (SAC)
- Finland (SFS)
- France (AFNOR)
- Germany (DIN)
- India (BIS)
- Italy (UNI)
- Japan (JISC)
- Norway (SN)
- Russian Federation (GOST R)
- Ukraine (DSTU)
- United Kingdom (BSI)
- United States (ANSI)

Observing Members (9); Liaisons (7) (ECSS is a Liaison Member)

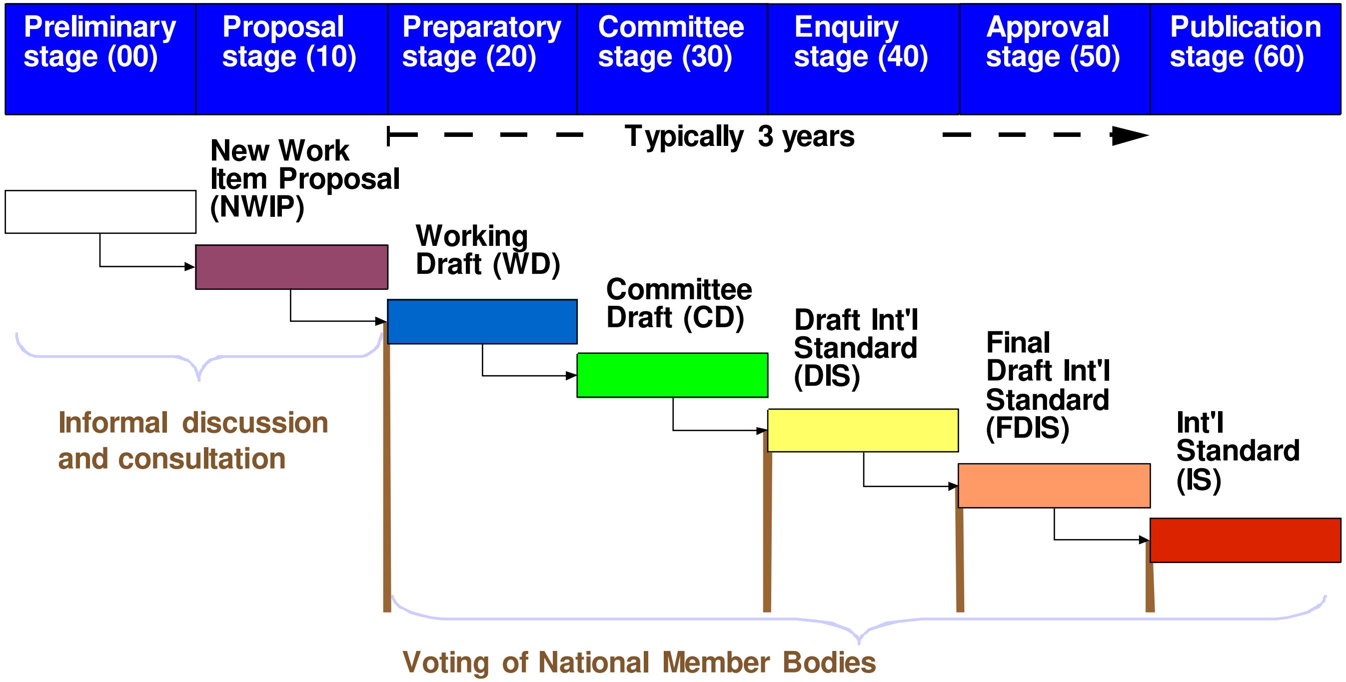
TC 20/SC 14 - Space systems and operations WG

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Working Group	Convener	Leadership
WG 1 : Design, Engineering & Production	Japan	Keiichiro Eishima
WG 2 : Interfaces, Integration and Test	United States	James Houghton
WG 3 : Operations and Ground Support	Germany	Andre Lacroix
WG 4 : Space Environment (Natural and Artificial)	Russia	M.I. Panasyuk
WG 5 : Programme Management and Quality	France	Severin Drogoul
WG 6 : Materials and Processes	Japan	Naoko Baba
WG7: Orbital Debris Coordination Working Group	United Kingdom	Hedley Stokes

ISO TC20 SC14

- Level playing field: development of key standards in the international arena
- Long development process (typically 3 years or more)
- Unstructured set of standards, many items related to space debris issue, content variable both in terms of quality and usefulness:
- WG7 (ODWG) attempt to develop and coordinate a framework of SDM standards, consolidating the debris standards into a smaller more coherent set of documents



ECSS Approach to Space Debris Mitigation

ECSS decided in 2003 to set up a ECSS Space Debris Working Group (SDWG) to:

- Contribute to the development of worldwide space debris implementation standards in the framework of the ISO TC20/SC14 ODCWG

ECSS relies on ISO to produce norms related to SD:

- SDWG members participate to ISO WGs / ODCWG meetings and activities
- Inputs and comments to ISO SDM documents provided through SDWG

Key standards adopted by ECSS:

- ISO 24113: Space systems - Space debris mitigation requirements, Second Edition, May 2011
- ECSS-U-AS-10C Adoption Notice of ISO 24113: Space mitigation requirements, February 10, 2012
- Decision on a case-by-case basis
- Modifications, delta requirements, interpretations, as necessary

ECSS –U-AS-10C modifications of ISO 24113 :

- deleted limitation of applicability to unmanned systems
- added requirement on max number of space debris that can be release during launch operations
- modified requirement to include maximum size of solid combustion products that can be released in GEO protected region (1mm)

Ref: www.ecss.nl


ECSS-U-AS-10C
10 February 2012

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space sustainability

Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ISO / ECSS / EU - Space Debris Mitigation

EUROPEAN COOPERATION

European Committee for Standardization (CEN, Comité Européen de Normalisation)

- Founded in 1961; has 34 national members
- Develop European Standards (ENs) to build a European internal market
- It is officially recognised as a European standards body by the European Union (together with the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI).
- The ECSS-U-AS-10C Adoption Notice of ISO 24113 has been published as EN 16604-10 in 2014

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

CSN EN 16604-10

English Version

Space sustainability - Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space Debris Mitigation

ESA Requirements on Space Debris Mitigation

esa space for europe

European Space Agency

ESA Policy on Space Debris Mitigation

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Since 2008 , ESA has adopted a Space Debris Mitigation Policy based on the "European Code of Conduct for Space Debris Mitigation"

A new ESA Space Debris Mitigation Policy has entered into force on 28 March 2014: ESA/ADMIN/IPOL (2014)2 " Space Debris Mitigation Policy for Agency Projects "

ESA
Director General's Office

ESA/ADMIN/IPOL(2014)2
Att.: Annexes 2
Paris, 28 March 2014
(Original: English)

Distribution: all staff
ESA unclassified – "Releasable to the Public"

__Space Debris Mitigation Policy for Agency Projects__

1. INTRODUCTION

As a consequence of spaceflight activities, the number of functional and non-functional (i.e.: space debris) human-made objects in Earth orbit continues to grow. To minimise the impact of space operations on the orbital environment, to reduce the risk of collision on orbit and to ensure the safety of the public on ground during re-entry, mitigation and safety measures must be anticipated as from the conception of a space system.

In May 2011, the 2nd edition of ISO 24113 "Space Systems – Space Debris Mitigation Requirements" was issued as the international standard which establishes the design and operations requirements to minimise the impact of space operations on the orbital environment. On 10th February, 2012, this standard was adopted by the European Coordination on Space Standardisation (ECSS) as the ECSS-U-AS-10C standard (Adoption Notice of ISO 24113: Space Systems – Space debris mitigation requirements).

The present Instruction establishes the ESA standard for the technical requirements on space debris mitigation for Agency projects, it sets out the principles governing its implementation and the definition of responsibilities.

2. POLICY

In order to ensure a corporate approach on space debris mitigation, it is the Agency's policy that the ECSS-U-AS-10C is established as the ESA standard ("the standard") for the technical requirements on space debris mitigation for Agency projects.

As the standard foresees that in cases of re-entry the maximum acceptable casualty risk shall be determined by the approving agents, it is the Agency's policy to define that the maximum acceptable casualty risk for ESA space systems shall be as follows:

a) For ESA Space Systems for which the System Requirements Review has already been kicked off at the time of entry into force of this Instruction, casualty risk minimisation shall be implemented on a best effort basis and documented in the Space Debris Mitigation Report.

b) For ESA Space Systems for which the System Requirements Review has not yet been kicked off at the time of entry into force of this Instruction, the casualty risk shall not exceed 1 in 10,000 for any re-entry event (controlled or uncontrolled). If the predicted casualty risk for an uncontrolled re-entry exceeds this value, an uncontrolled re-entry is not allowed and a targeted controlled re-entry shall be performed in order not to exceed a risk level of 1 in 10,000.

2014-0520

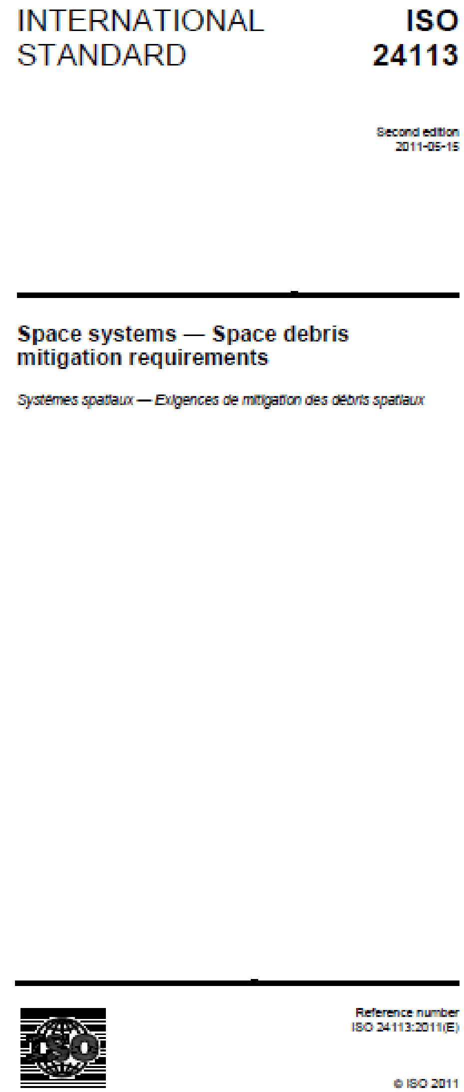
ESA/ADMIN/IPOL(2014)2 and ECSS / ISO

The ESA/ADMIN/IPOL(2014)2 established the ECSS-U-AS-10C (Adoption Notice of ISO 24113: Space Systems – Space debris mitigation requirements) as "the ESA standard for the technical requirements on space debris mitigation for Agency projects"

De facto, the ESA/ADMIN/IPOL(2014)2 includes the requirements addressed in ISO 24113 "Space Systems - Space Debris Mitigation Requirements" together with the modifications described in ECSS-U-AS-10-C.

In addition, ESA/ADMIN/IPOL(2014)2 contains several ESA specific provisions, e.g.,:

- the casualty risk for any re-entry shall not exceed 1 in 10,000 for any re-entry event. In case the predicted casualty risk for uncontrolled re-entry exceeds this value, a targeted controlled re-entry shall be performed.



SDM Document flow

IADC Guidelines: 2002, 2007

↓

UN General Assembly Space Debris Mitigation Guidelines: 2007

↓

ISO 24113 Space Debris Mitigation: 2010, 2011

↓

ECSS-U-AS-10C Adoption Notice of ISO 24113: 2012

↓

ESA/ADMIN/IPOL(2014)2 Space Debris Mitigation for Agency Projects

↓

EN 16604-10 publication of ECSS-U-AS-10C as EN: 2014

Space Debris Mitigation

Technical Regulation in the Frame of the Loi Operations Spatiales / French Space Operations Act (LOS / FSOA)

cnes

LOS

French Space Law (FSL - LOS)

LOIS

LOI n° 2008-518 du 3 juin 2008 relative aux opérations spatiales (1)

NOR : *ESRX0700048L*

L'Assemblée nationale et le Sénat ont adopté,

Le Président de la République promulgue la loi dont la teneur suit :

TITRE I[er]

DÉFINITIONS

French Space Law (FSL - LOS)

The French Space Law (FSL - LOS) entered into force on December 10th, 2010. The associated Technical Regulation ministerial order published on March 31st, 2011

It is based on a principle of prior authorisation for:

- Operators, irrespective of nationality, intending to launch or bring back to Earth a space object on French territory.
- French operators intending to launch or bring back to Earth a space object
- Persons of French nationality intending to launch a space object
- French operators intending to control such an object in space

4 juin 2008 JOURNAL OFFICIEL DE LA RÉPUBLIQUE FRANÇAISE Texte 1 sur 129

LOIS

LOI n° 2008-518 du 3 juin 2008
relative aux opérations spatiales (1)

NOR : ESRX0700048L

L'Assemblée nationale et le Sénat ont adopté,
Le Président de la République promulgue la loi dont la teneur suit :

TITRE Ier

DÉFINITIONS

Article 1er

Pour l'application de la présente loi, on entend par :
1° « Dommage » : toute atteinte aux personnes, aux biens, et notamment à la santé publique ou à l'environnement directement causée par un objet spatial dans le cadre d'une opération spatiale, à l'exclusion des conséquences de l'utilisation du signal émis par cet objet pour les utilisateurs ;

French Space Law (FSL - LOS)

The French Space Law (FSL - LOS) Technical Regulation was updated on July 11th, 2017

- **Arrêté du 11 juillet 2017 modifiant l'arrêté du 31 mars 2011 relatif à la réglementation technique en application du décret n° 2009-643 du 9 juin 2009 relatif aux autorisations délivrées en application de la loi n° 2008-518 du 3 juin 2008 relative aux opérations spatiales**
- **Published JORF n°0181 du 4 août 2017 texte n° 30**

JORF n°0181 du 4 août 2017
texte n° 30

Arrêté du 11 juillet 2017 modifiant l'arrêté du 31 mars 2011 relatif à la réglementation technique en application du décret n° 2009-643 du 9 juin 2009 relatif aux autorisations délivrées en application de la loi n° 2008-518 du 3 juin 2008 relative aux opérations spatiales

French Space Law : Other Safety Objectives

Protection of public health and the environment

Mitigating risk of dangerous contamination during launch or re-entry

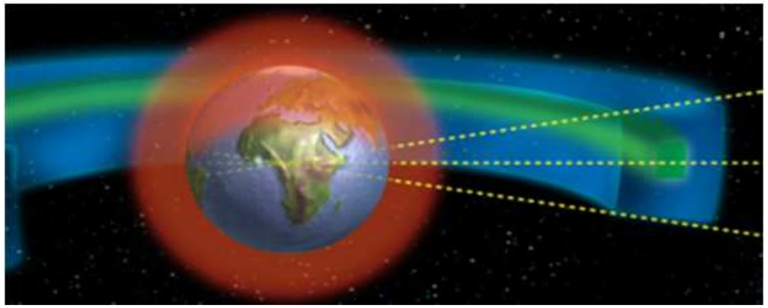
Mitigating space debris:

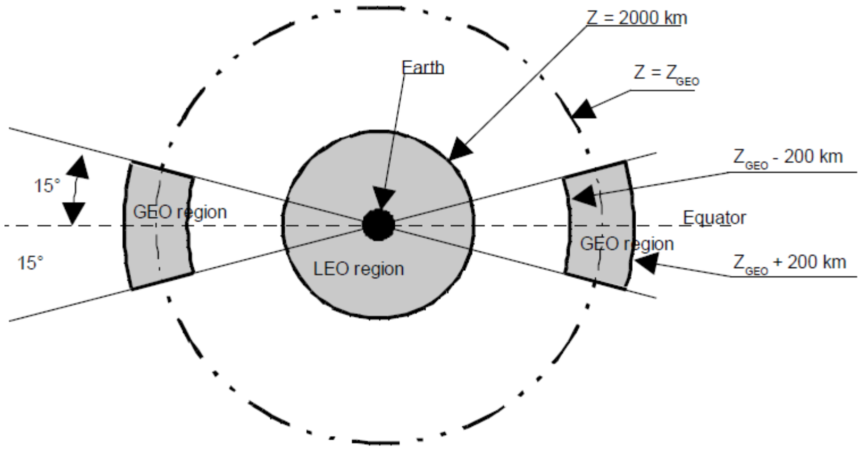
- Do not generate debris during nominal operations
- Minimise the probability of accidental break down
- Remove space vehicles and orbital stages from protected regions after the end of the mission
- Prevent collisions with GEO satellites whose orbital parameters are known

At the beginning of 2019, 65 SC operated under LOS / FSOA license

Space Debris Mitigation

Space Debris Mitigation Requirements Discussion





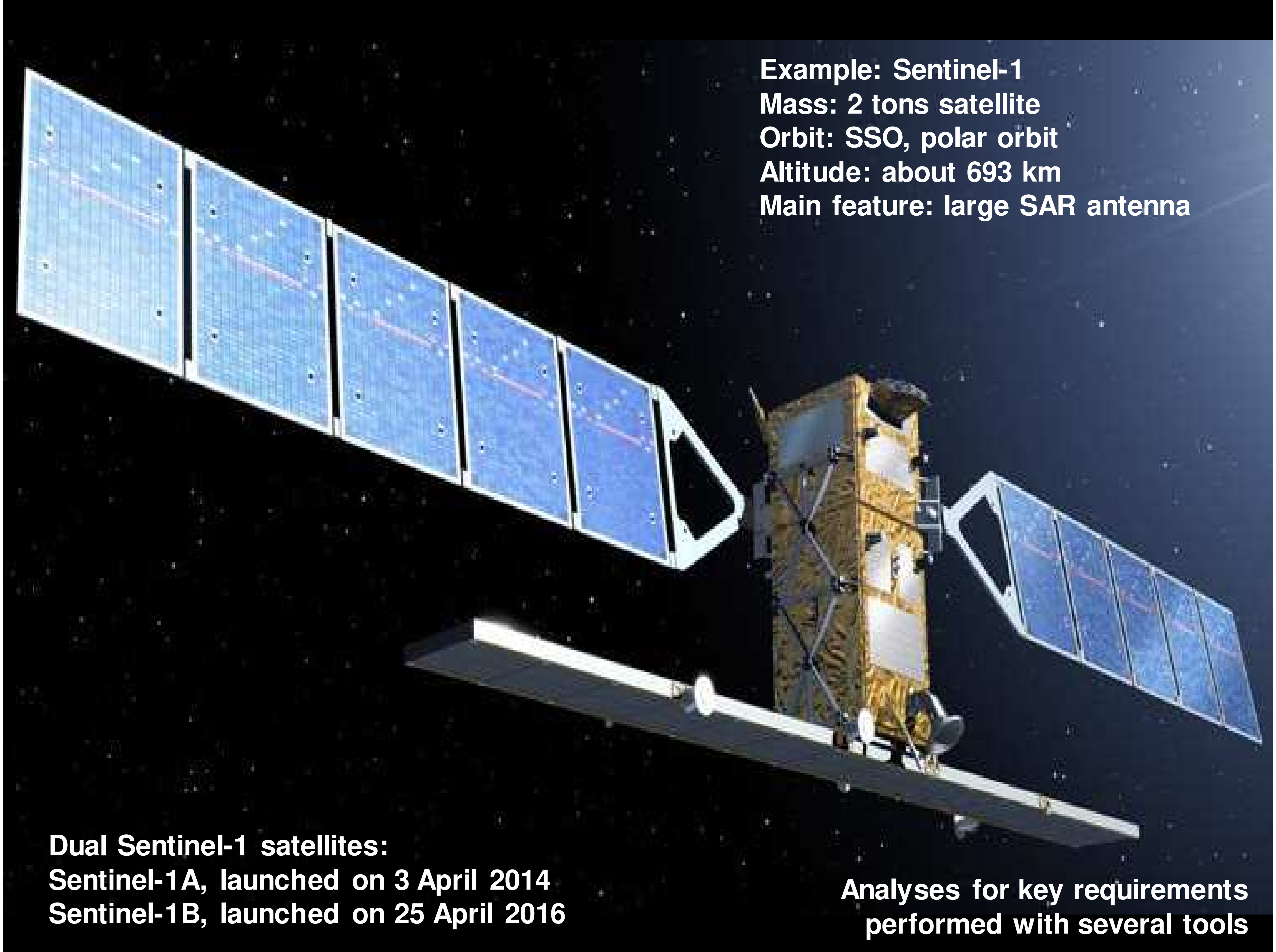
Space Debris Mitigation – Main Measures

Requirements considered:

- **ECSS-U-AS-10C Adoption Notice of ISO 24113 Space debris mitigation requirements (2012) / ESA/ADMIN/IPOL(2014)2**
  - ISO 24113:2011 (second edition) Space debris mitigation requirements
  - French Space Law (FSL - LOS) Technical Regulation, updated 2017

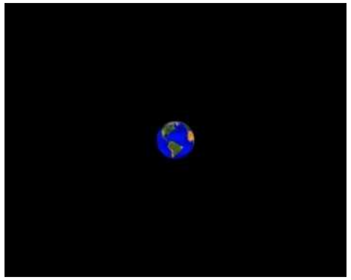
New requirements under publication:

- **ISO/DIS 24113, Third edition (ISO24113 ed3)**
  - Submitted to ballot to become FDIS (ballot ended 2018-12-13, 10/10 positive votes, 7 with comments, 4 abstentions)
  - Expected publication ~ September 2019


Example: Sentinel-1
Mass: 2 tons satellite
Orbit: SSO, polar orbit
Altitude: about 693 km
Main feature: large SAR antenna
Dual Sentinel-1 satellites:
Sentinel-1A, launched on 3 April 2014
Sentinel-1B, launched on 25 April 2016
Analyses for key requirements
performed with several tools

Space Debris Mitigation – Main Measures

For Spacecraft and Launch Vehicle orbital stages:



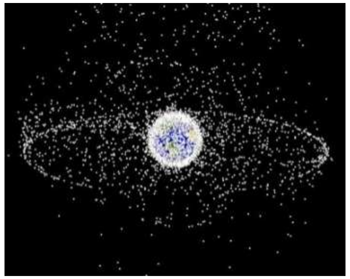
Pre 1957

Avoid the intentional release of space debris (Mission Related Objects MRO) into Earth orbit during normal operations

Avoid break-ups in Earth orbit (including passivation at the End of Mission)

Remove spacecraft and launch vehicle orbital stages from the protected regions:

- GEO to a graveyard orbit (GEO + 200 km)
- LEO within 25 years after End of Mission (re-entry controlled or uncontrolled, higher orbit)



2008

[Perform the necessary actions to minimize the risk of collision with other space objects]

[Assess the risk that a space debris or meteoroid impact causes a SC to break-up / prevents its successful disposal]

[Monitor periodically the conditions of SC]

[Evaluate and control of Re-entry Risk]

?

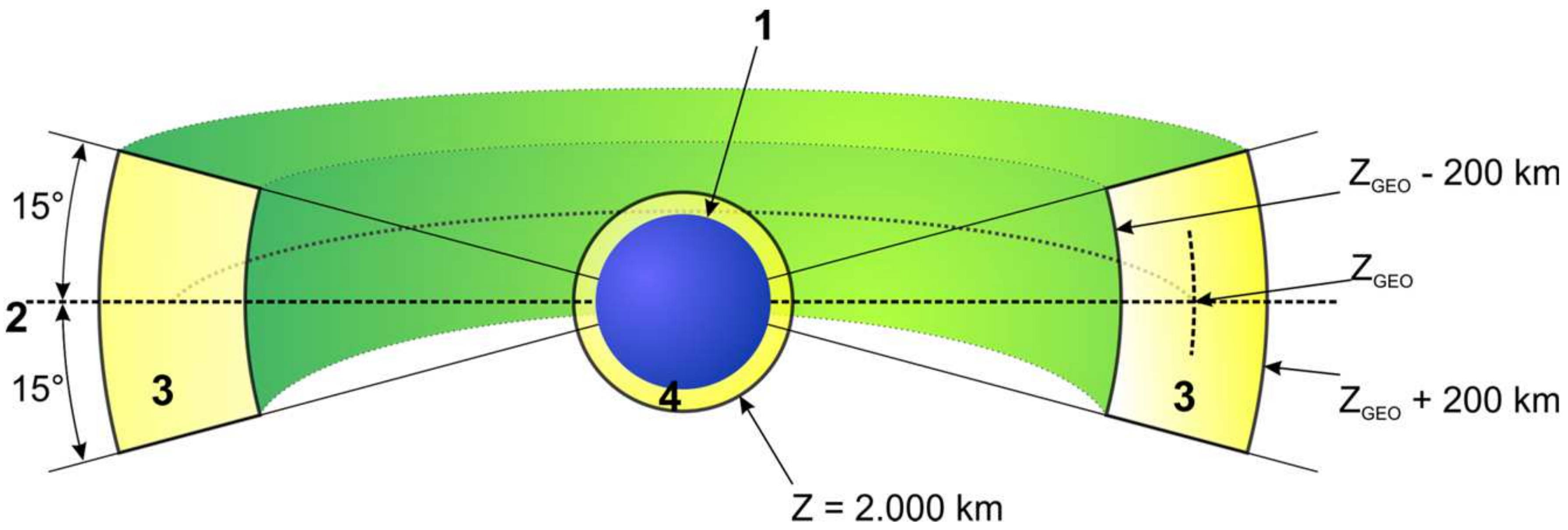
2019+

Rqmt's: protected regions - ch.5

LEO protected region: a shell that extends from the surface of a spherical Earth with an equatorial radius of 6 378 km up to an altitude, Z, of 2 000 km.

GEO protected region: a segment of a spherical shell with :

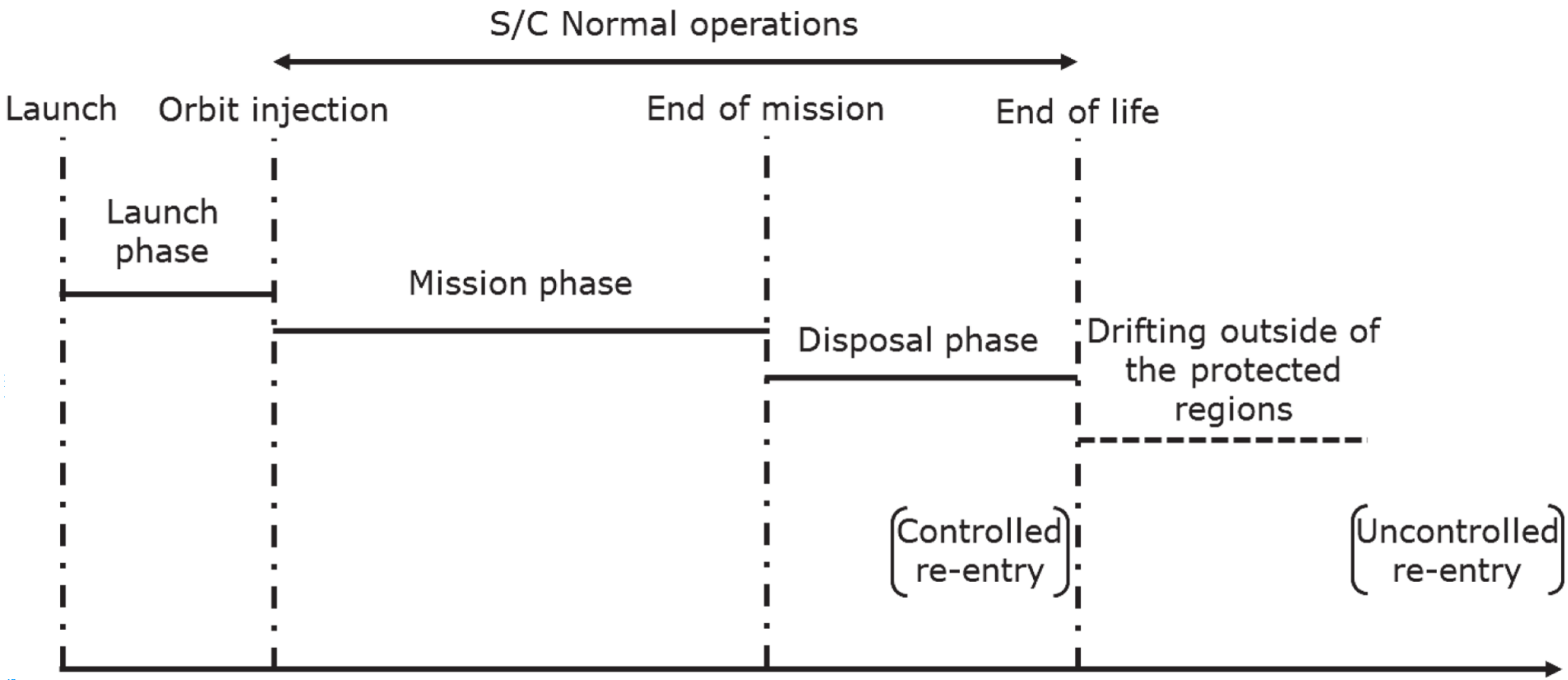
- lower altitude: geostationary altitude minus 200 km;
- upper altitude: geostationary altitude plus 200 km;
- latitude sector: 15° South ≤ latitude ≤ 15° North,
- ZGEO ~ approximately 35 786 km



Note: some requirements apply to Earth Orbit

Post-launch life cycle phase

Life cycle phases of an Earth-orbiting spacecraft (S/C)



Space Debris Mitigation

Space Debris Mitigation Requirements Discussion:

Chapter 6.1

Avoid the intentional release of space debris (Mission Related Objects MRO) into Earth orbit during normal operations

Release of space debris during normal operations into Earth orbit to be avoided

Non-combustion debris: no objects are released as part of the nominal mission (review of design)

- Debris released during launch operations shall not exceed:
  - a. One, for the launch of a single spacecraft
  - b. Two, for the launch of multiple spacecraft

  (ECSS-U-AS-10C and LOS only, but also next ISO24113 ed3. This is to limits the possibility during launch operations to release adapters or dispensers in case of single or multiple launches.)
- Debris identification: objects released as part of the nominal mission (if any) identified and listed (*e.g., with dimensions, mass, material, phase of the mission, time and orbit of the expected release*)
- Lifetime data / calculation for each space debris:
  - If in (or crossing) LEO protected region: presence limited to < 25 years after release (*demonstration using a rapid semi-analytic propagators*).
  - If MRO close to GEO protected region: show that it remains outside the GEO region > 100 years (*with a rapid semi-analytic propagators*).

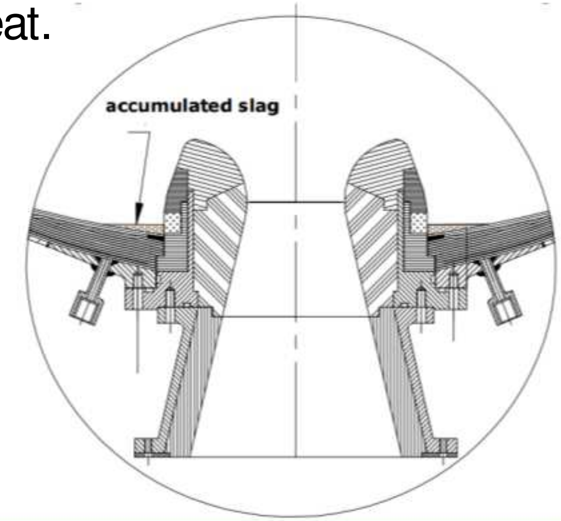
Rqmt’s : Avoid MRO into Earth orbit - ch.6.1

Pyrotechnic devices: Review of design to screen pyros and to show that they do not release into orbit any particles > 1 mm in Earth orbit.

Solid rocket motors

- SRM products in GEO and LEO:
  - ISO24113 requires that no solid combustion products are released in GEO and that methods to avoid the release are considered in LEO protected region
  - ECSS requires no solid combustion products larger than 1 mm are released into the GEO protected region.
  - ISO24113 ed3 will require SRM not to release debris > 1 mm in LEO and GEO

Combustion or pyrotechnic related particles < 1 mm contribute to the debris environment but are not considered a threat.



Sentinel 1 – Requirements ch.6.1

Mission Related Objects (MRO)

- Launchers: requirement on procurement of launch service
- Spacecraft: no objects released as part of the nominal mission

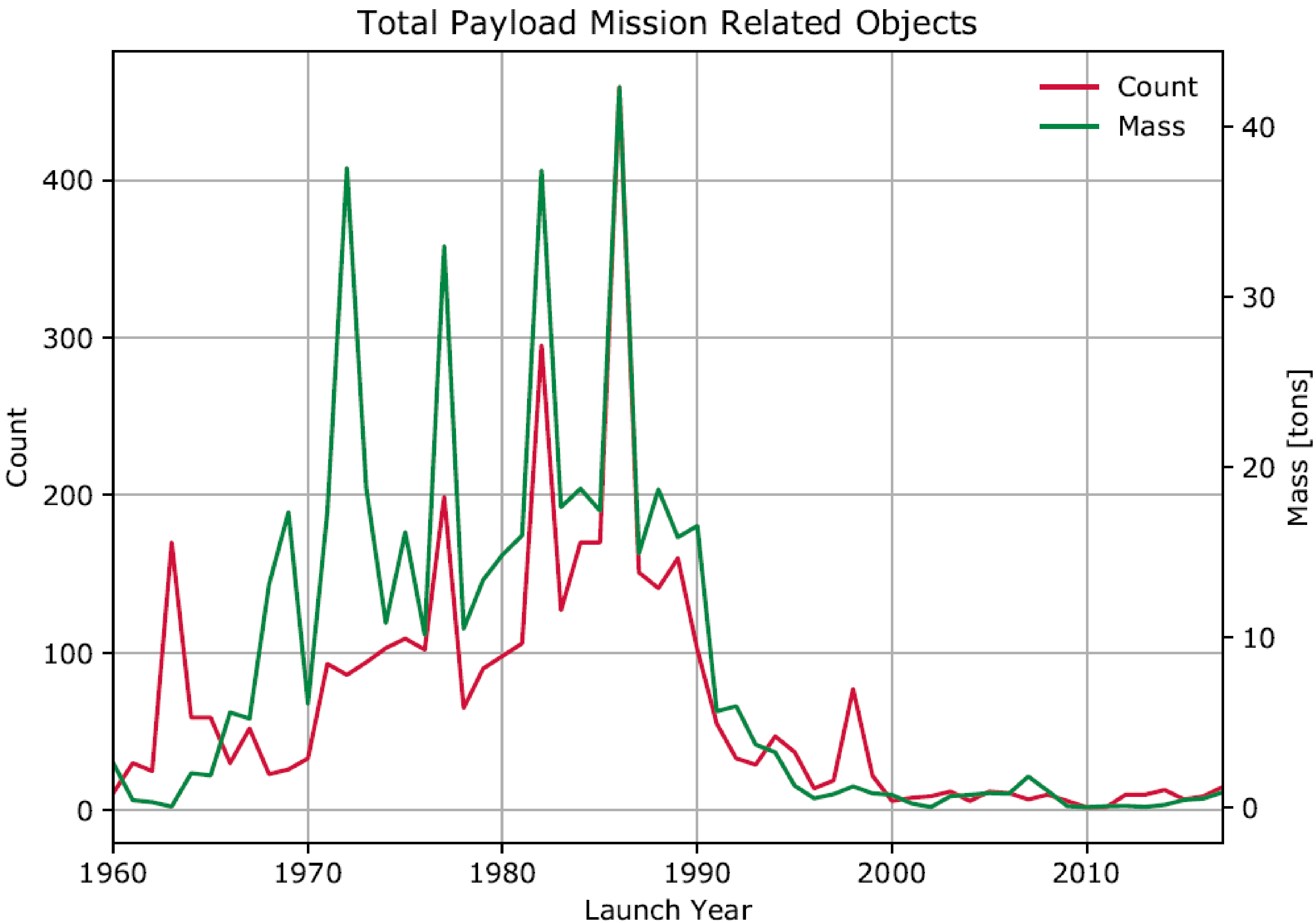
Fragmentation

- No intentional destruction envisaged

Solid propellant and pyrotechnics

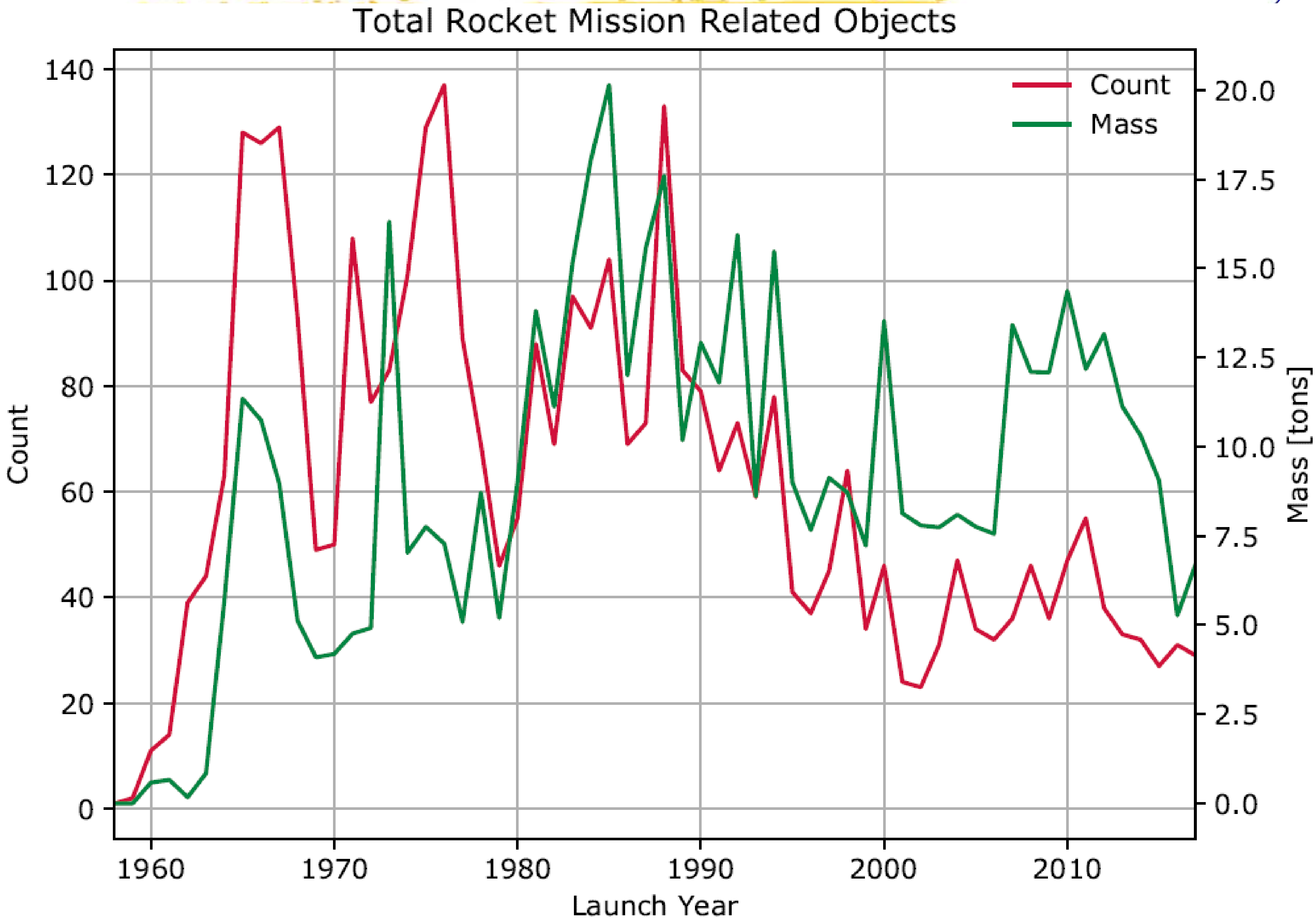
- Solid rocket motors: no solid propellant used
- Pyrotechnics: no particles > 1 mm released
  - Self contained cable capture Thermal Knife for SAW
  - Non Explosive Actuators (NEA) for SAR antenna

Rqmt's : Avoid MRO into Earth orbit - ch.6.1



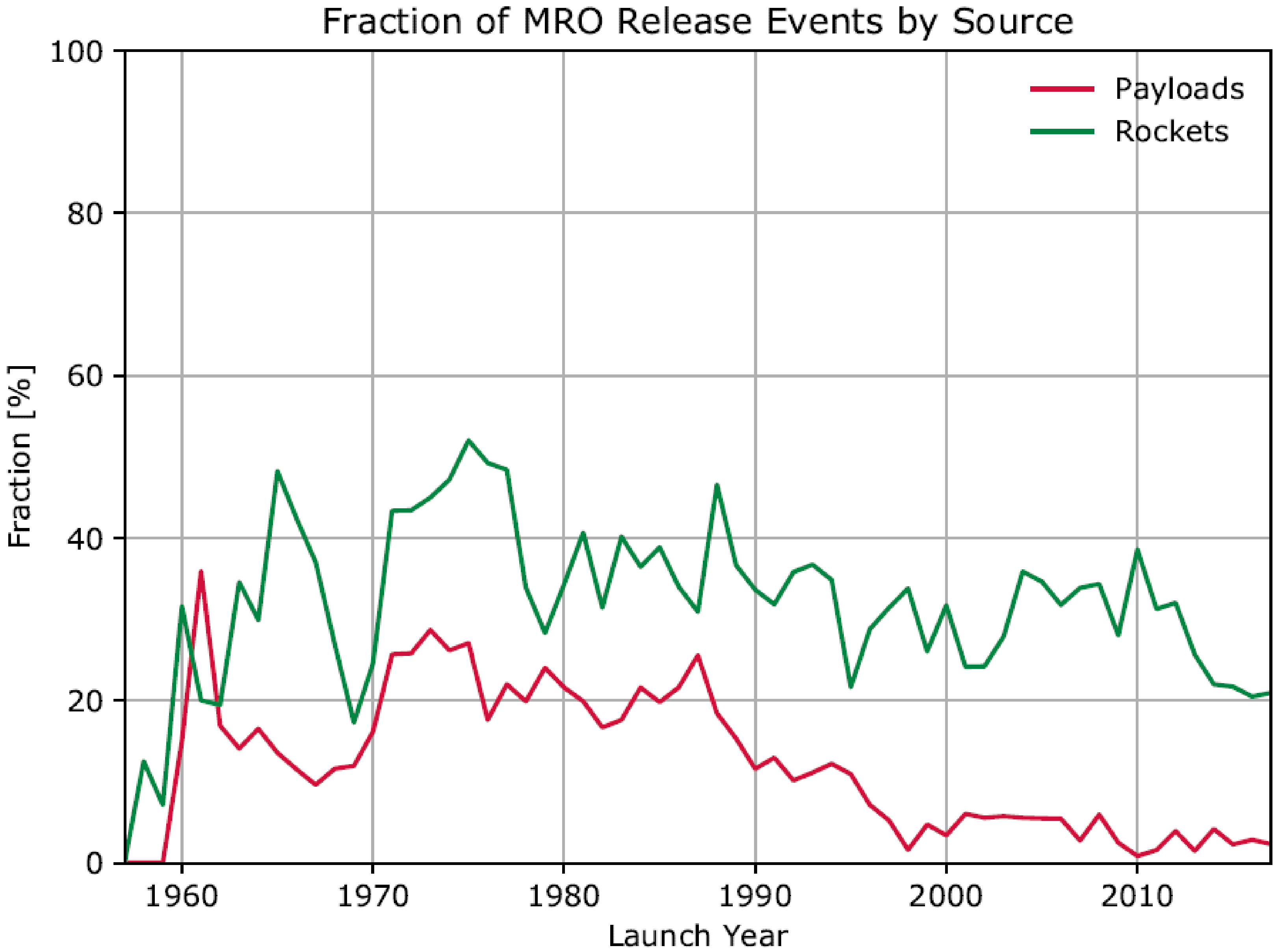
Total number and mass of catalogued mission related objects released from payloads (ESA's Annual Space Environment Report – 2018)

Rqmt's : Avoid MRO into Earth orbit - ch.6.1



Total number and mass of catalogued mission related objects released from rocket bodies (ESA's Annual Space Environment Report – 2018)

Rqmt's : Avoid MRO into Earth orbit - ch.6.1



Fraction of MRO releases per year w.r.t. the total amount of PL and RB injected into the space environment during that year (ESA's Annual Space Environment Report – 2018)

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Space Debris Mitigation

Space Debris Mitigation Requirements Discussion:

Chapter 6.2

Avoid break-ups in Earth orbit (including passivation at the End of Mission)

[Perform actions to minimize the risk of collision with other space objects] & [Assess the risk that a space debris or meteoroid impact causes a SC to break-up]

Rqmt's: Avoiding break-up in Earth orbit - ch.6.2

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Intentional break-up

- Declaration that no intentional break-up of a spacecraft is planned (<u>in Earth Orbit</u>).

Accidental break-up caused by an on-board source of energy

- The probability of S/C accidental on-orbit break-up < 10–3 until EoL, in <u>Earth orbit</u>. (*Develop a break-up prevention plan, to be reviewed / updated as part of the normal spacecraft design review process and during the operation phase*).
- System level failure analysis considering each source of stored energy, potential failure modes resulting in a break-up to be performed (and risk mitigation measures, in the design, operational and disposal phases).
- After the S/C end of operations (and before its end of life), proper actions are to be taken in order to deplete or make safe all remaining on-board sources of stored energy in a controlled sequence in order to avoid break-ups after the end of life (passivation).
  - Note: link with EoM disposal.
  - In LOS and <u>ISO24113 ed3</u> "passivation" only if controlled re-entry is not planned. If planned but not performed, "passivation" shall occur.

Rqmt's: Avoiding break-up in Earth orbit - ch.6.2

Accidental break-up caused by an on-board source of energy – new provisions ISO24113 ed3:

- SC condition to be monitored periodically during operation to detect any anomalies that could lead to an accidental break-up.
- If SC anomaly detected during operations which could lead to an accidental break-up then a contingency plan to be implemented to mitigate this risk

Accidental break-up caused by a collision – new provisions ISO24113 ed3:

- SC operating in the GEO protected region to have a recurrent manoeuvre capability.
- SC operating in Earth orbit with a recurrent manoeuvre capability to be designed and operated to actively manage collision risk until EoL
- SC capable to actively manage collision risk, if the risk with other space objects is assessed to be above a risk threshold (set by an approving agent) then collision avoidance manoeuvres to be conducted to reduce the risk of collision below the threshold.
- During the SC design an assessment to be made of the risk that a space debris or meteoroid impact will cause the SC to break-up before its end of life (to improve SC design against impacts).

Rqmt’s: Avoiding break-up in Earth orbit- ch.6.2

S/S / items to be screened for potential S/C break-up:

- Electrical systems, especially batteries
- Propulsion systems and associated components
- Pressurized systems
- Rotating mechanisms

Industry best practice. Consider environmental extremes & potential mechanical degradation or chemical decomposition (during mission and following passivation)

After the end of operations, passivation to be performed to avoid break-ups after the end of life:

- Energy sources on board to be depleted
- Onboard energy generation systems to be permanently deactivated.
- List of components to be passivated at the end of disposal phase (example)

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

List of components to be passivated at the end of disposal phase

Passivation strongly design dependent. It may be impossible to completely deplete some energy sources (residual ergols or pressurizers, battery disconnect, etc.).

Item	Passivation actions
Batteries (BTA)	-Interrupt power supply (switch off PCDU) -Limit batteries re-charging (*)
-Electro-explosive devices -Pyrotechnic devices -Actuators (e.g., NEAs, TKFs)	Deactivate if not already used during mission / remove electrical power (switch off PCDU)
-Reaction Wheels (RW) -GYRO -C-GYRO	Remove electrical energy inputs (switch off PCDU)
-Propellant tank (propellant and pressurant) -Propulsion PRP S/S lines	-Depressurizing tank (as far as possible) -Empty tank (as far as possible) (**) -Empty propellant lines (as far as possible)
Heat Pipe	Demonstrate low probability of rupture

Sentinel 1 – Requirements ch 6.2

Passivation:

- Strongly design dependent.
- Specific passivation operations depend on EoL S/C effective status and configuration
- It may be impossible to completely deplete some energy sources (residual ergols or pressurizers, battery disconnect, etc.).

Sentinel-1 battery passivation:

- 240 Ah battery manufactured by ABSL based on Sony Li-Ion 186590HC cells.
- At EoL battery to be left in low charge conditions and the solar arrays rotated to minimize re-charging.
- Partial battery re-charging can not be prevented after S/C switch off (with no S/C attitude control) because battery management is HW implemented with the SAW directly connected to the battery.
- Cells equipped with systems to avoid cells overcharge and protection against short-circuits.
- Cells are protected against over temperature and over pressure to reduce in controlled way the pressure build up and to avoid explosion risks (leak before burst).

Sentinel 1 – Requirements ch 6.2

Tanks passivation: drain of propellant and pressurant gas

Propellant stored in a tank pressurized with helium, equipped with a diaphragm for N2H4 expulsion.

- To remove propellant: fire the thrusters until maximum depletion of N2H4.
- Low quantity of hydrazine remaining in the tank and piping.

About 200g of helium pressurizer at low pressure will remain within the tank at the end of the lowering perigee manouvers.

- Limited helium quantity / pressure left in the MLI insulated tank not expected to lead to any break-up risk
- Typical design (also for TLC SC: Helium part / pressurant is isolated at end of transfer phase, for reliability of on-station phase)
- Pyro valves in the propellant lines plus dedicated draining lines not implemented (require major design changes).

Heat pipes left pressurized. Maximum working pressure and pressure after EoL significantly lower than burst pressure.

S1 - COLA Manœuvres ch 6.2 new provisions

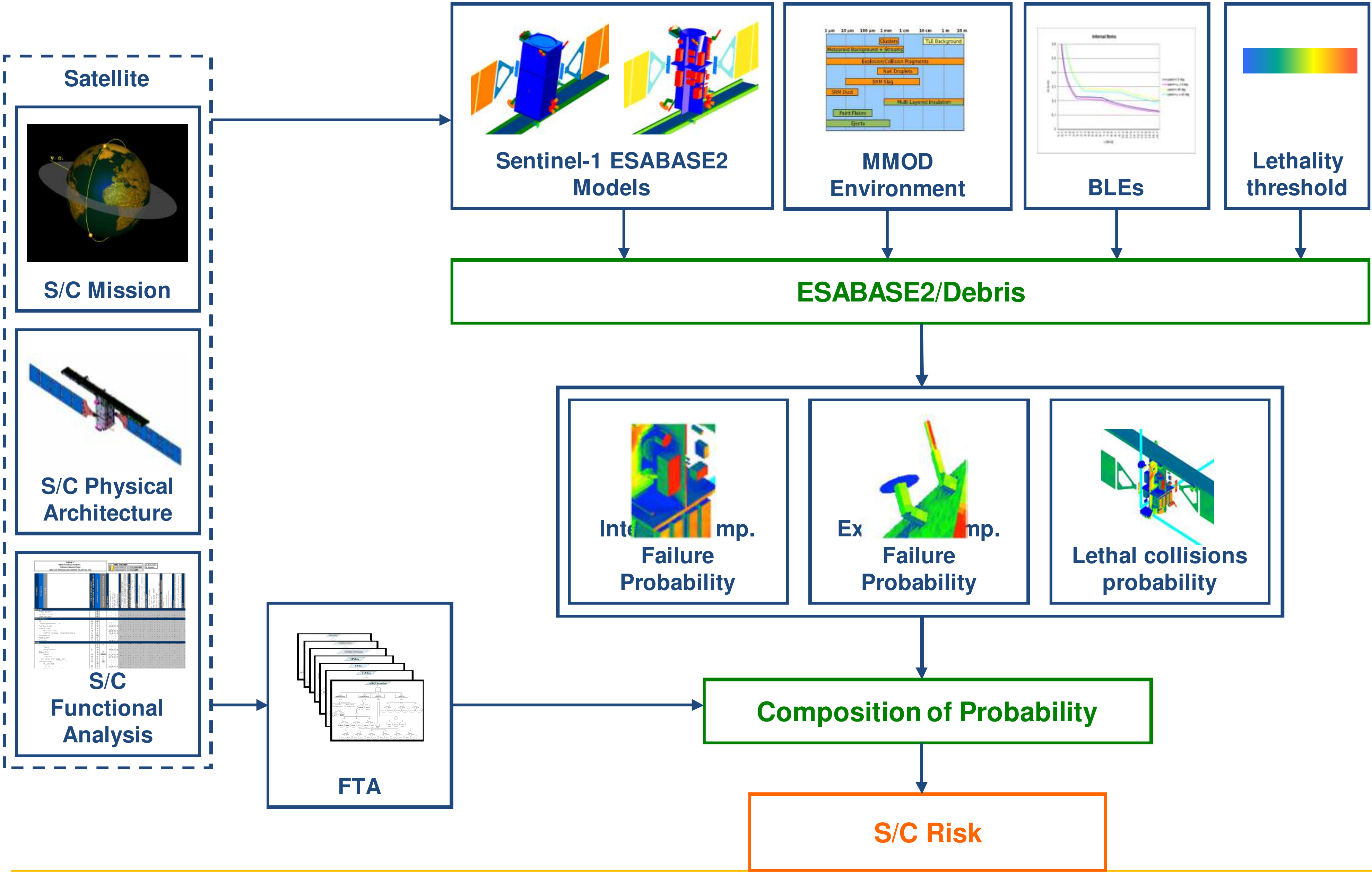
Sentinel-1A (lauched 03 April 2014) and Sentinel-1B (launched 25 April 2016) Debris Close approaches and COLA Manouvers (CAM), as of October 2017

- **S-1A CAM: 18**
  - 1 during LEOP
  - 6 before reaching the reference orbit
- **S-1A close approaches (no CAM): 31**
- **S-1B CAM: 3**
  - 1 before reaching the reference orbit
- **S-1B close approaches (no CAM): 1**

Additional recent CAM executed on Sentinel-1A on:

- 25 September 2018
- 4 January 2019
- 3 February 2019
- 18 March 2019

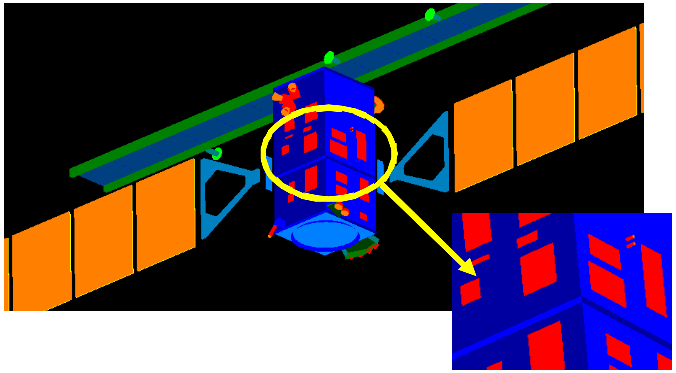
Sentinel 1 – Requirements ch 6.2 / 6.3 new provisions

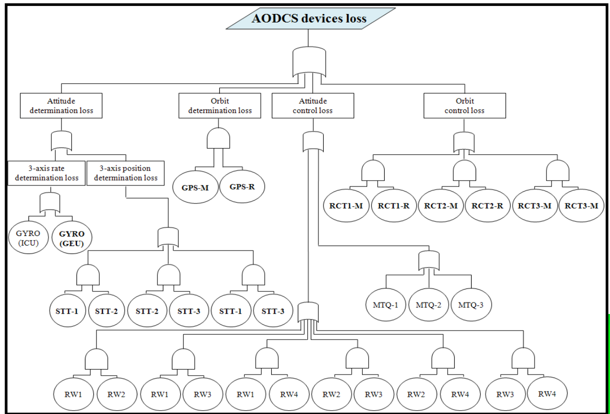


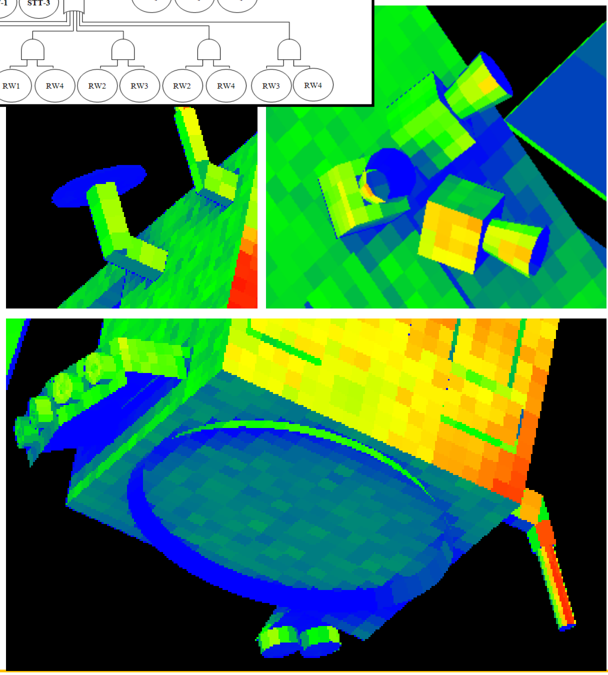
Sentinel 1 – Requirements ch 6.2 / 6.3 new provisions

Sentinel 1A

- Orbit: 693 km, 98.11°
- ESABASE2\Debris tool
- MASTER2009 Debris model
- Fault Tree Analysis
- Results depending on many assumptions







Sentinel-1 mission loss
> 4.51E-02

Payload devices loss
4.02E-07

AODCS devices loss
2.04E-03

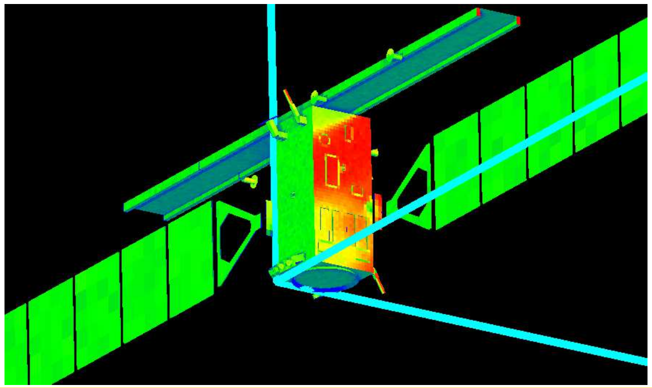
EPS devices loss
2.81E-02

TT&C S/S devices loss
2.80E-05

PDHT S/S devices loss
2.42E-03

OBC devices loss
4.75E-10

Satellite loss (lethal collisions)
1.31E-02



Rqmt's: Avoiding break-up in Earth orbit - ch.6.2

The most important category of man made on-orbit objects is breakups:

- Accounting of > 53% of the total SSN catalog (of 17,260 objects as of 1 January 2016)
- Accounting of > 50% of ESA D/B (of 19,894 objects as of end 2018, considering the 489 confirmed on-orbit fragmentation events)

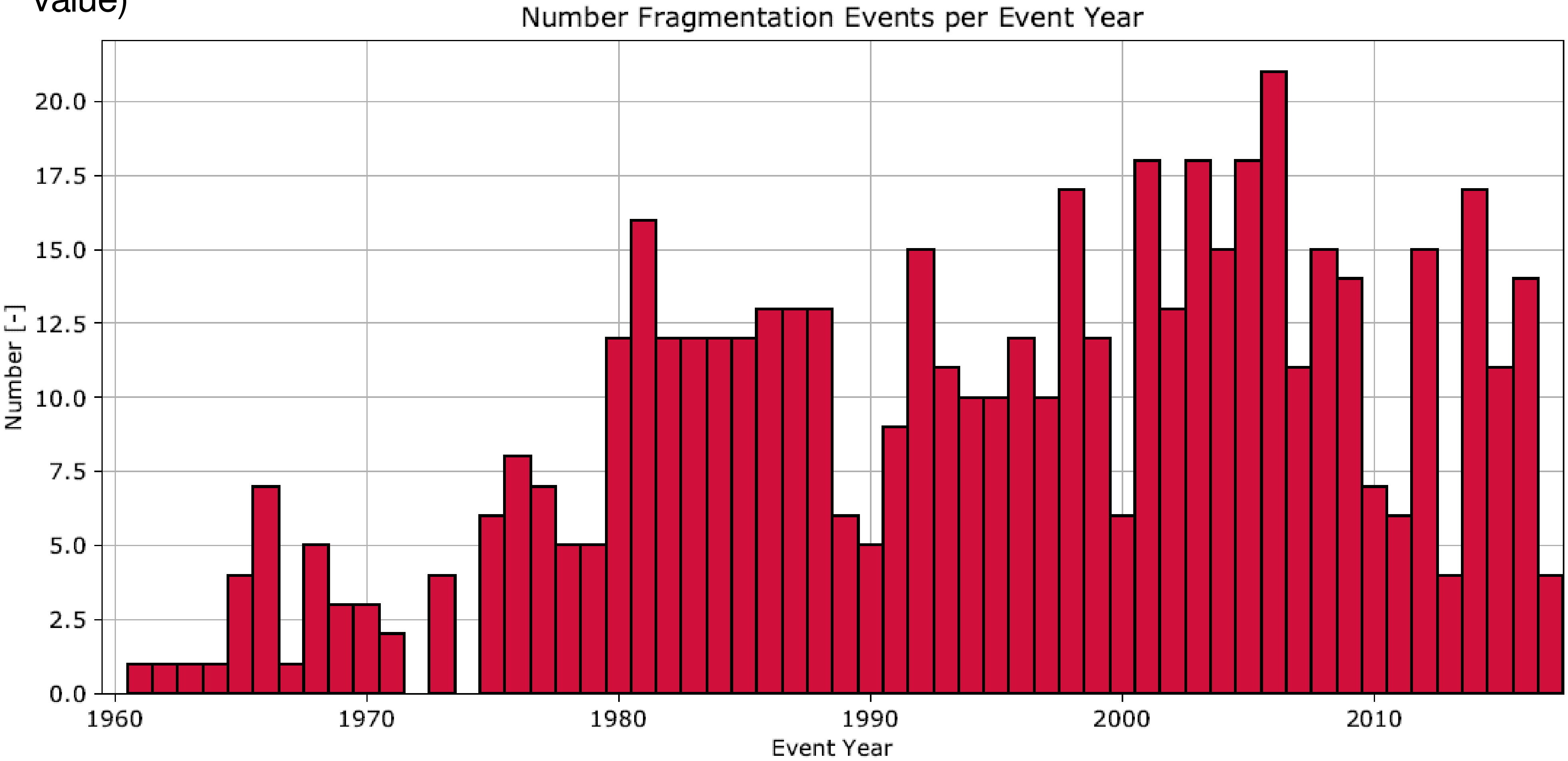
ESA classification of fragmentation events:

- Well known break-up cause:
  - Accidental
  - Aerodynamics
  - Collision
  - Deliberate
  - Electrical
  - Propulsion
- Cause not well established, yet:
  - Anomalous: .
  - Assumed
  - Unconfirmed
  - Unknown

Break-up / Fragmentation events

Number of fragmentations in orbit as of end of 2017 (ESA's Database, based on 489 confirmed on-orbit fragmentation events):

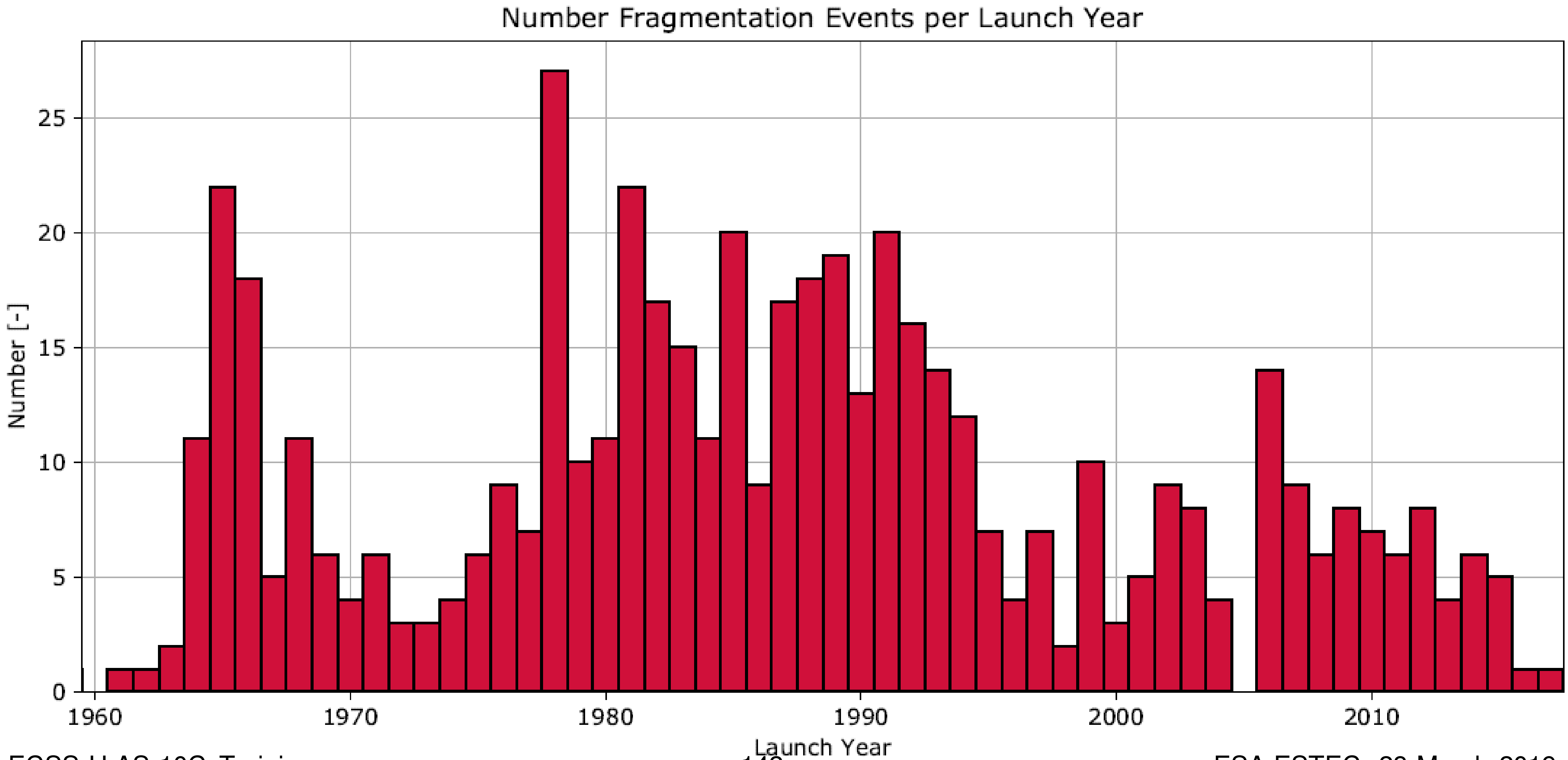
- Considering the past 20 years, 8.1 non-deliberate events per year in Earth orbits (mean value)
- Considering events where 90% of the fragments have lifetime > 25 years, the annual rate of events is 2.4
- Considering the past 20 years, for a fragmentation event to occur, it takes ~11.6 years (mean value)



Break-up / Fragmentation events

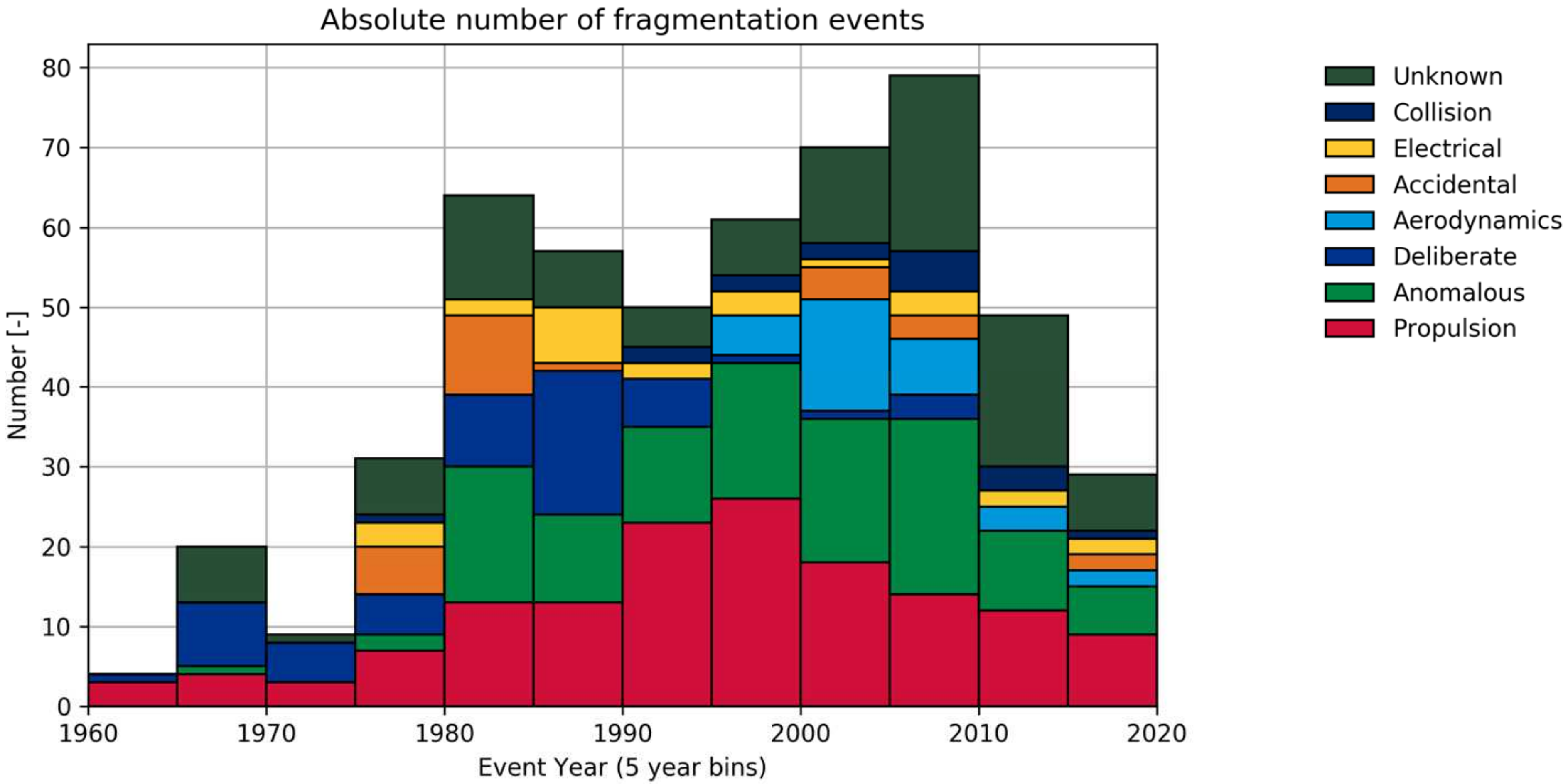
Number of fragmentations in orbit as of end of 2017 (ESA's Database, based on 489 confirmed on-orbit fragmentation events):

- Modern SC still prone to fragmentation events



Break-up / Fragmentation events

Evolution of number of fragmentations in orbit as of end of 2017 (ESA's Database, https://discosweb.esoc.esa.int/web/guest/statistics, 19894 catalogued objects; based on 489 confirmed on-orbit fragmentation events).



Space Debris Mitigation

Space Debris Mitigation Requirements Discussion:

Chapter 6.3

Remove spacecraft and launch vehicle orbital stages from the GEO protected regions

Rqmt's: GEO disposal – ch.6.3

At End of Mission S/C or LV to be removed from GEO protected region. Disposal actions to be completed before S/C EoL.

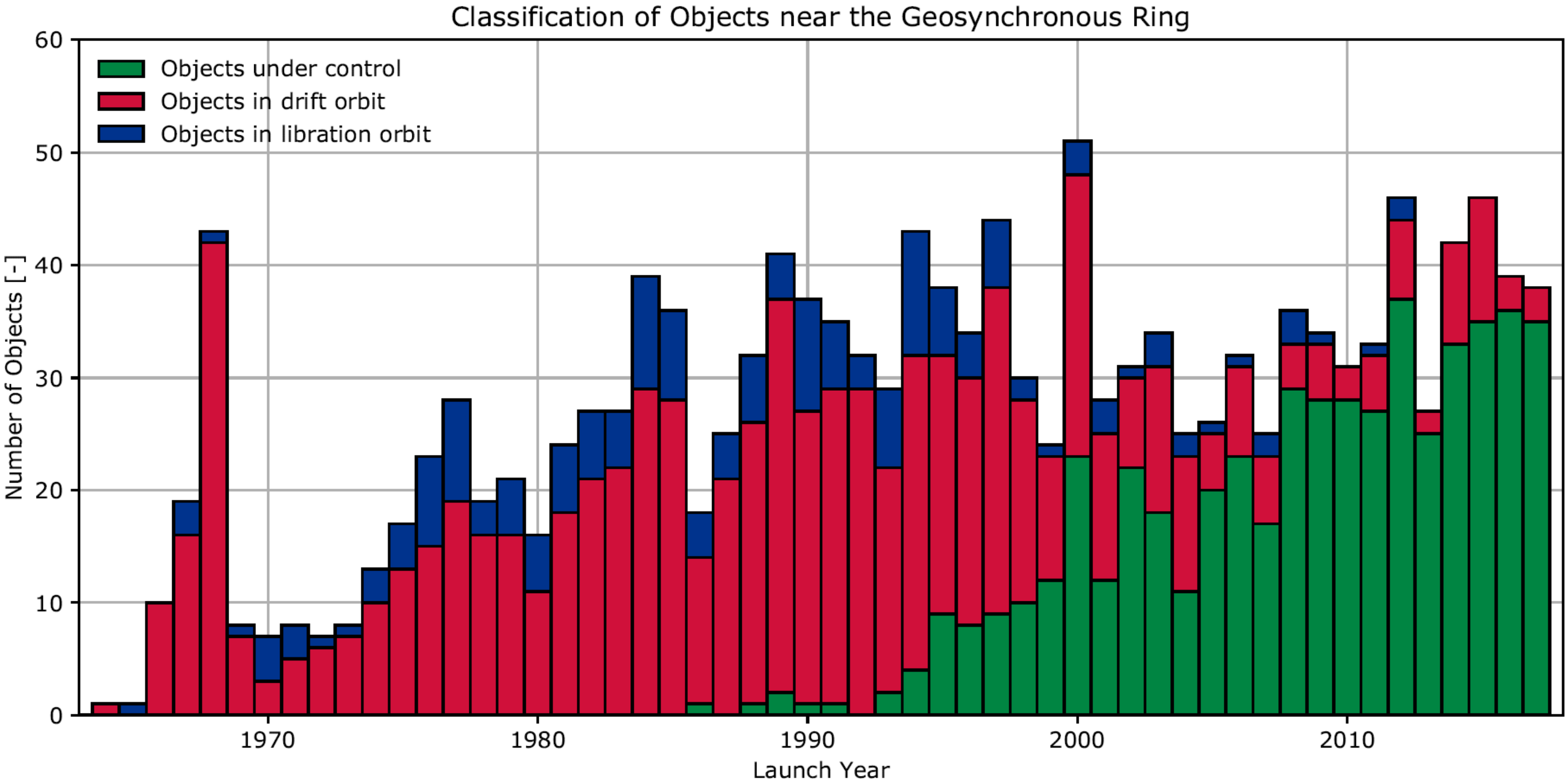
- GEO S/C shall perform disposal manoeuvres. During the design phase, provisions and resources (e.g., propellant) for GEO disposal manœuvres to be allocated.
- GEO disposal - IADC formula. A "simple" method to comply with the requirement using the so called IADC formula:

$$\Delta H = 235 + (1\,000 \times CR \times A/m) \text{ [km]}; \quad \text{eccentricity} < 0.003$$

- GEO disposal - 100 years rule. More complex method, using a long-term semi-analytic orbit propagator to show the S/C not to re-enter GEO region within 100 years
- The operator may require / need to implement specific GEO disposal strategies, with impacts on the design (e.g., use of pressurizer)
- The passivation activities (e.g., tanks and piping venting) may influence the final orbital parameters in the disposal orbit.

GEO Classification of Objects near the Geosynchronous Ring (ESA's Annual Space Environment Report 2018)

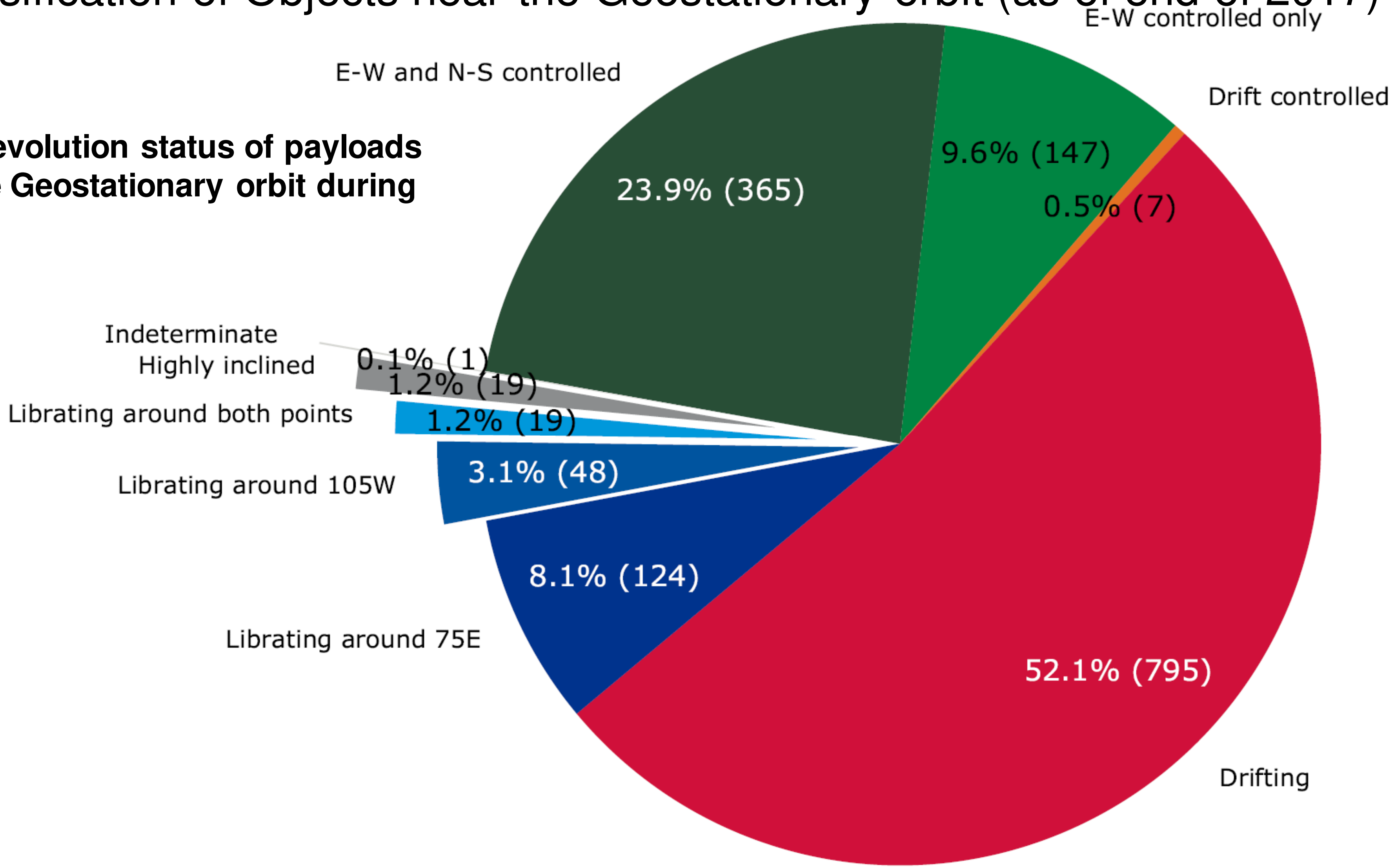
- Orbital evolution status of payloads near the Geostationary orbit during 2017



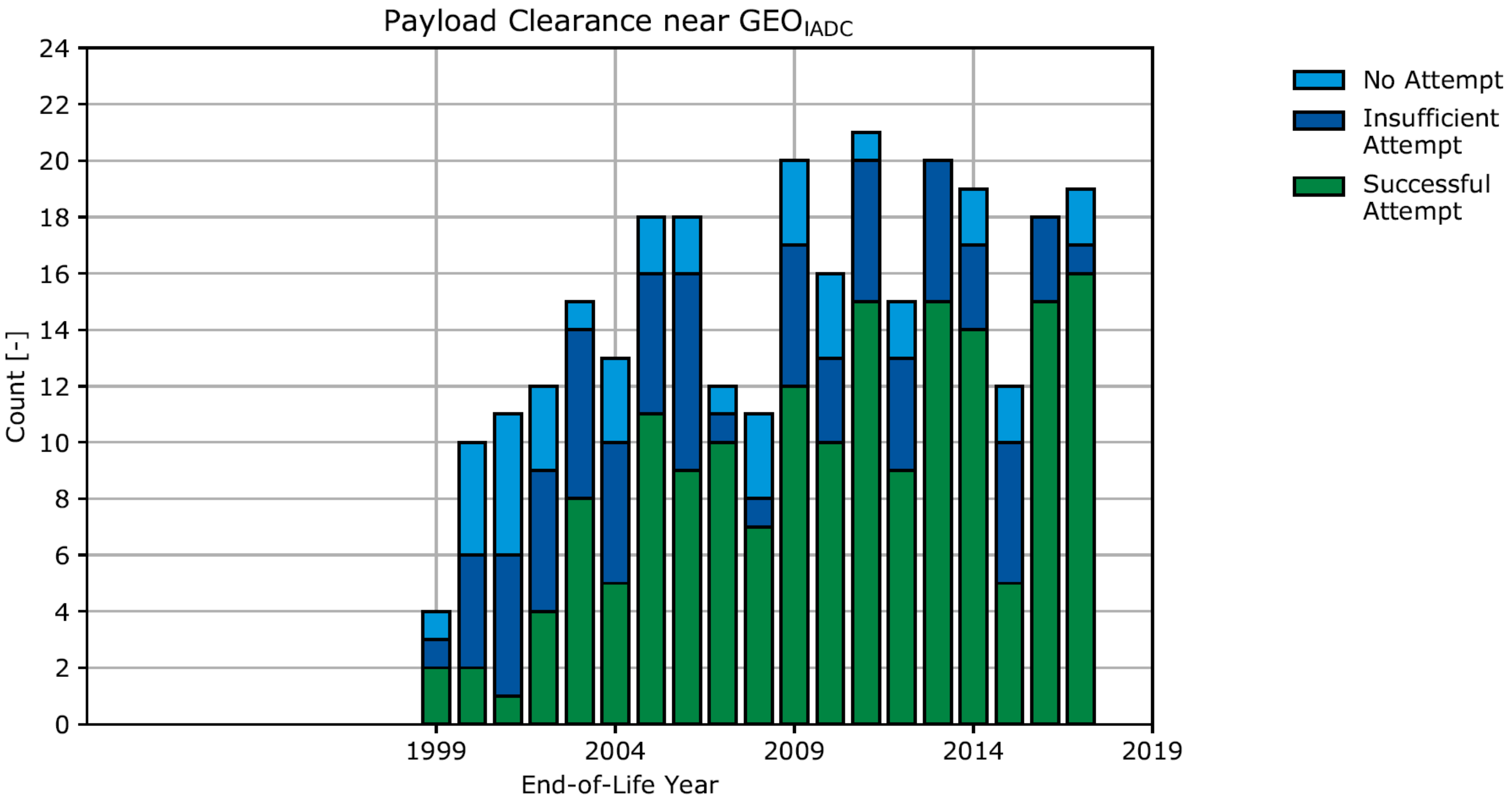
GEO Classification of Objects near the Geosynchronous Ring (ESA's Annual Space Environment Report 2018)

- Classification of Objects near the Geostationary orbit (as of end of 2017)

Orbital evolution status of payloads near the Geostationary orbit during 2017



Absolute EoL clearance near GEO up to 2017 (ESA's Annual Space Environment Report 2018)



Space Debris Mitigation

Space Debris Mitigation Requirements Discussion:

Chapter 6.3

Remove spacecraft and launch vehicle orbital stages from the LEO protected regions

Rqmt's: LEO disposal – ch.6.3

For LEO missions, if re-entry safety requirement is satisfied, LEO S/C shall demonstrate compliance with the 25 year rule.

At EoM, a LEO S/C shall perform disposal manoeuvres to limit its presence in LEO protected region < 25 years (from EoM) by (ISO / ECSS) in order of preference:

- retrieving it and performing a controlled re-entry to Earth
- manoeuvring it in a controlled manner into a targeted re-entry
- manoeuvring it to an orbit with a lifetime < 25 years
- augmenting its orbital decay by deploying a device so that the lifetime is < 25 years
- allowing its orbit to decay naturally so that the remaining orbital lifetime is < 25 years
- manoeuvring it to an orbit with a perigee altitude sufficiently above the LEO protected region that long-term perturbation forces do not cause it to re-enter the LEO protected region within 100 years

- In the French Law:
  - Second issue, July 11th, 2017 , the space object must no longer be present in the protected region 25 years after having completed its operational phase
  - First issue, December 10th, 2010 the requirement asked for "rentrée atmosphérique, de manière contrôlée" except "en cas d'impossibilité, dûment justifiée"

Rqmt's: LEO disposal – ch.6.3

LEO disposal new provisions <u>ISO24113 ed3</u>:

Orbit lifetime to be < 25 years starting from:

- Orbit injection epoch, for SC operating continuously or periodically in LEO protected region w/o capability to perform collision avoidance manoeuvres,
- EoM, for SC operaing continuously or periodically in LEO protected region with the capability to perform collision avoidance manoeuvres,
- Epoch of first intersection with LEO protected region within 100 years after the EoL, for SC operating continuously outside LEO protected region.

Order of precedence with a few modifications wrt previous edition:

- retrieving to Earth
- manoeuvring it in a controlled manner with a targeted re-entry footprint
- allowing its orbit to decay naturally so that the remaining orbital lifetime is < 25 years
- manoeuvring it to an orbit with a lifetime < 25 years
- augmenting its orbital decay by deploying a device so that the lifetime is < 25 years
- note: manoeuvring it to an orbit with a perigee altitude sufficiently above the LEO protected region no longer allowed

Rqmt's: LEO disposal – ch.6.3

For most of LEO missions (orbit < 1300-1400 km), a perigee lowering option can be selected:

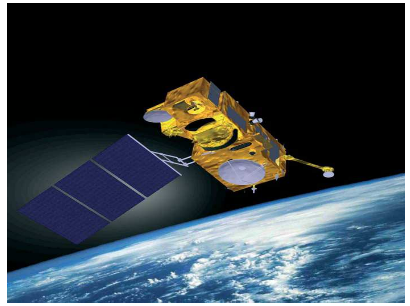
- Compute the orbital lifetime (rapid semi-analytic propagator). If lifetime > 25 years, define an orbit with lifetime < 25 years to be reached at the EoM
- Determine the delta-v and/or propellant necessary
- Allocate propellant in the resource budget.

LEO S/C with perigee > 1300-1400 km a manoeuvres to an orbit with a perigee >> LEO protected region allowed

- This option will not be allowed in the new ISO24113 ed3
- Show that long-term perturbation forces do not cause the S/C to re-enter LEO protected region within 100 years.

Proper assumptions for the evaluation of lifetime &/or propagation to be justified, e.g.:

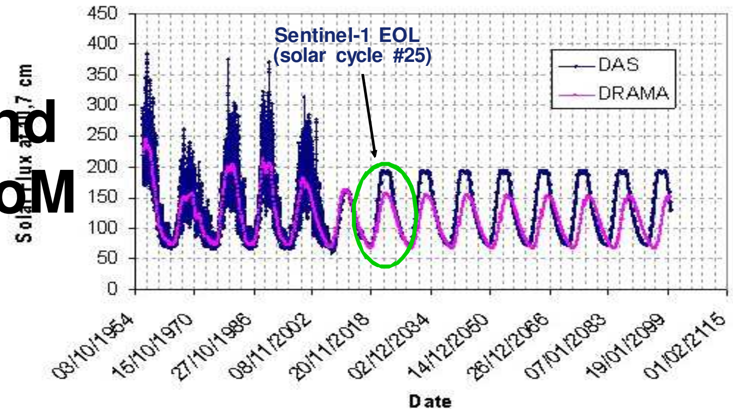
- Initial orbit parameters and epoch, S/C cross-sectional area, drag coefficient, Atmosphere model, Earth gravity models, Solar radiation pressure, Third body perturbations, Solar proxies, etc.)



Sentinel 1 – Requirements ch 6.3

LEO 25-year Orbit Lifetime

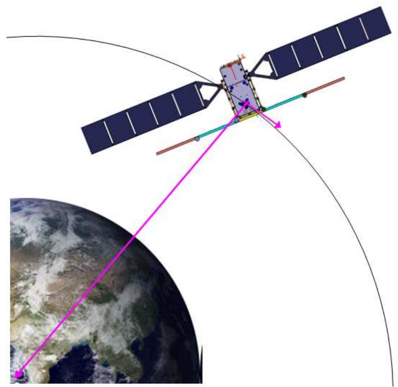
EoL computed with several tools (DAS 2.0.1, DRAMA 1.0, STELA 1.4.2). High variability due to tools and assumptions: 7.25 or 12 yrs mission duration, fix / variable: solar flux, CD, attitude, atmospheric models, etc.



Parameters for perigee lowering maneuvers and amount of propellant for 25-year disposal at EoM determined:

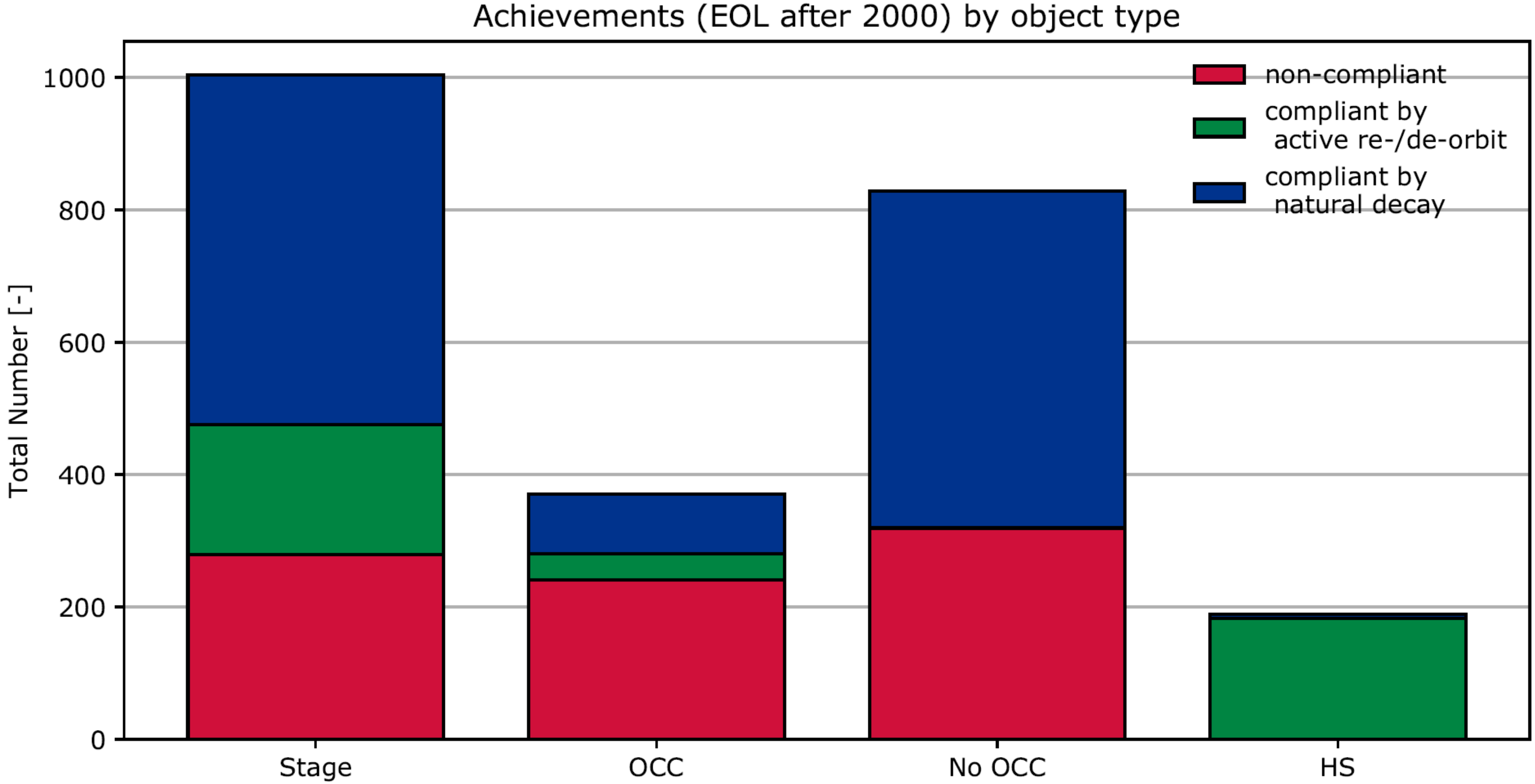
> 23 kg (for disposal in 2020)

> 30 kg (for disposal in 2024)



Rqmt's: LEO disposal – ch.6.3

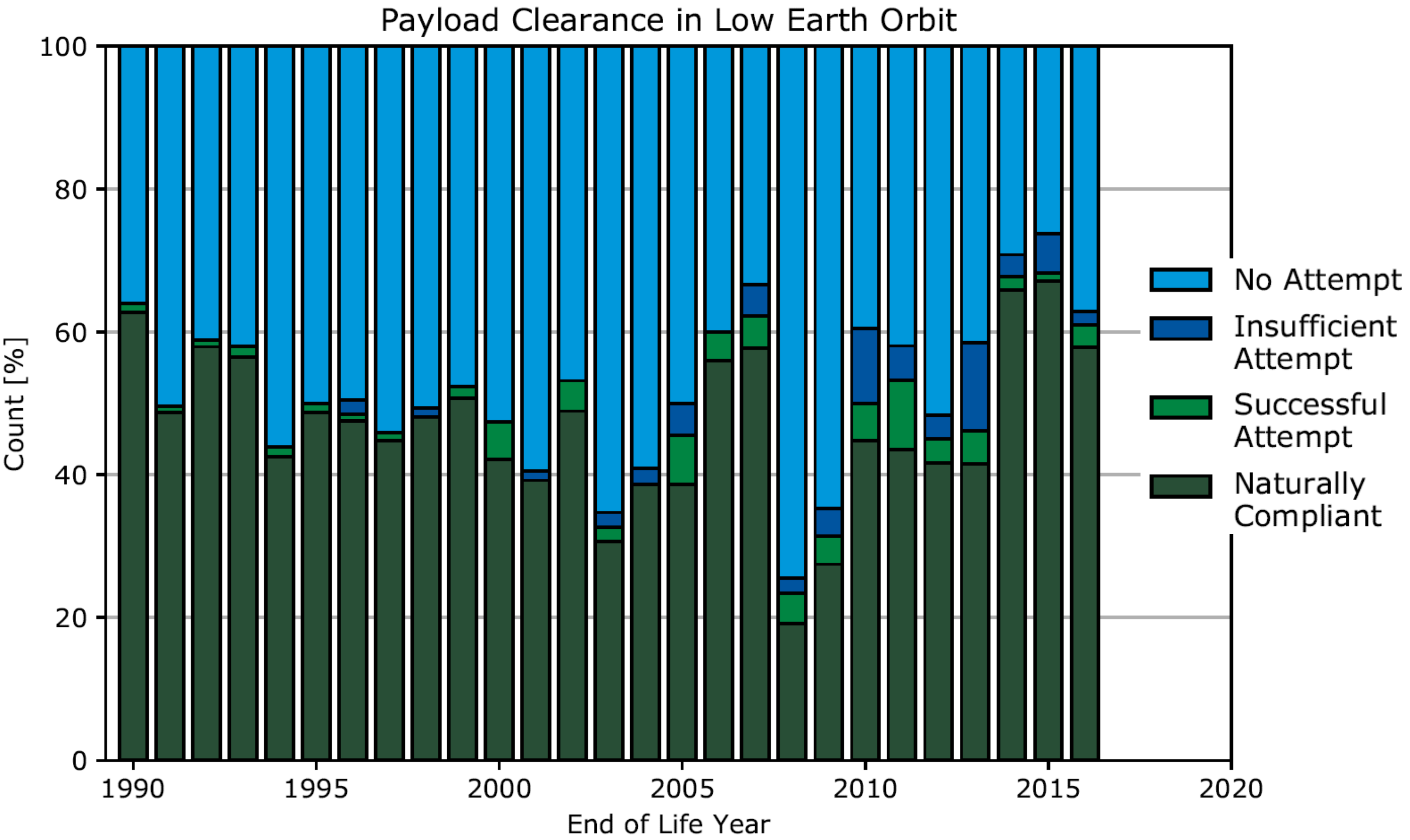
Compliance with LEO disposal (25-yr rule) from 2000 up to 2016 for Payloads, up to 2017 for Rocket Bodies [ESA's Annual Space Environment Report 2018]



Stage: Launch vehicle orbital stage
No OCC: w/o Orbital Control Capability
OCC: SC with Orbital Control Capability
HS: Human mission related sys (ATV, Dragon, etc.)

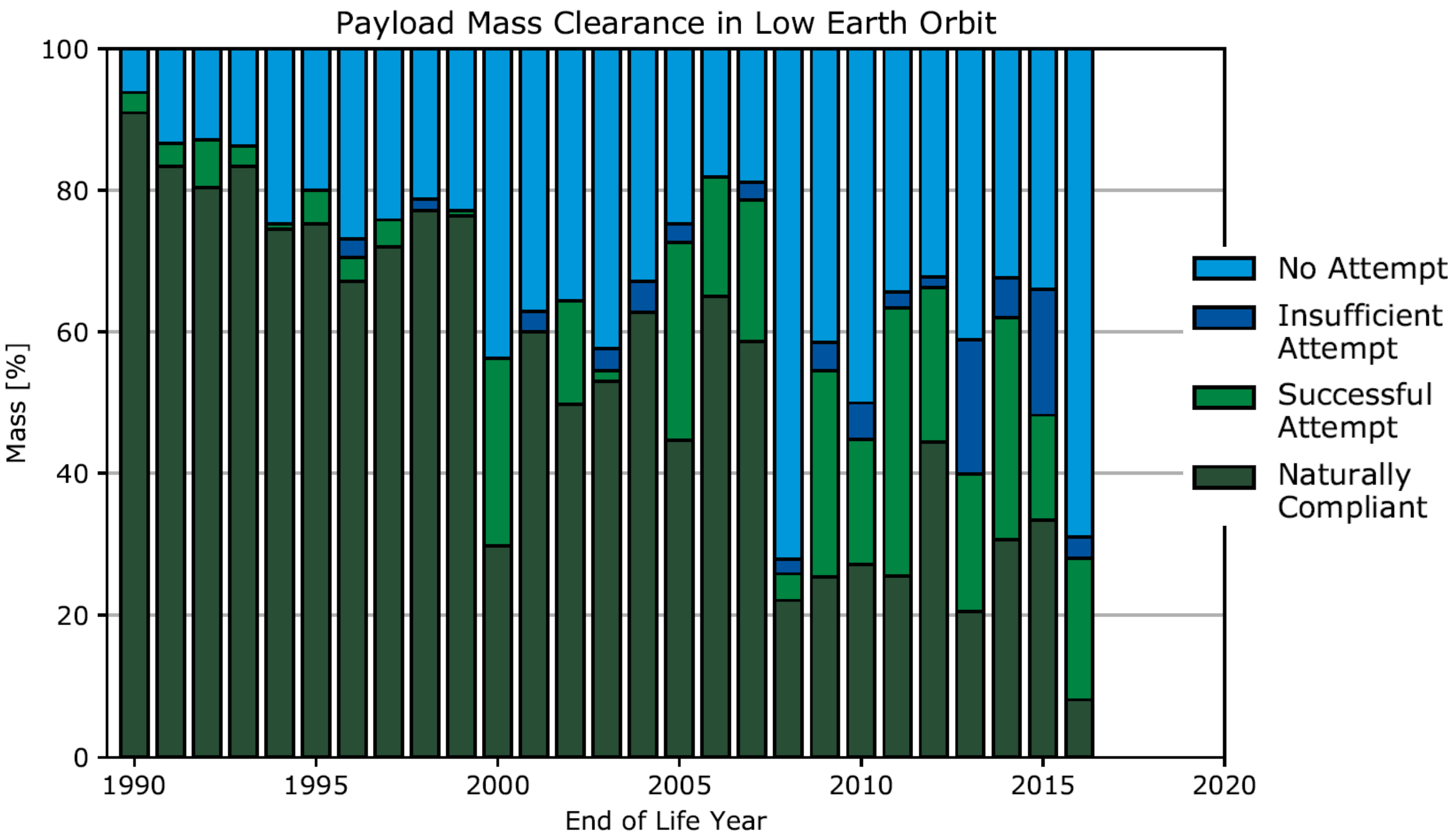
Rqmt's: LEO disposal – ch.6.3

Compliance in terms of clearing the LEO protected region (25-yr rule) for SC up to 2016 [ESA's Annual Space Environment Report 2018]



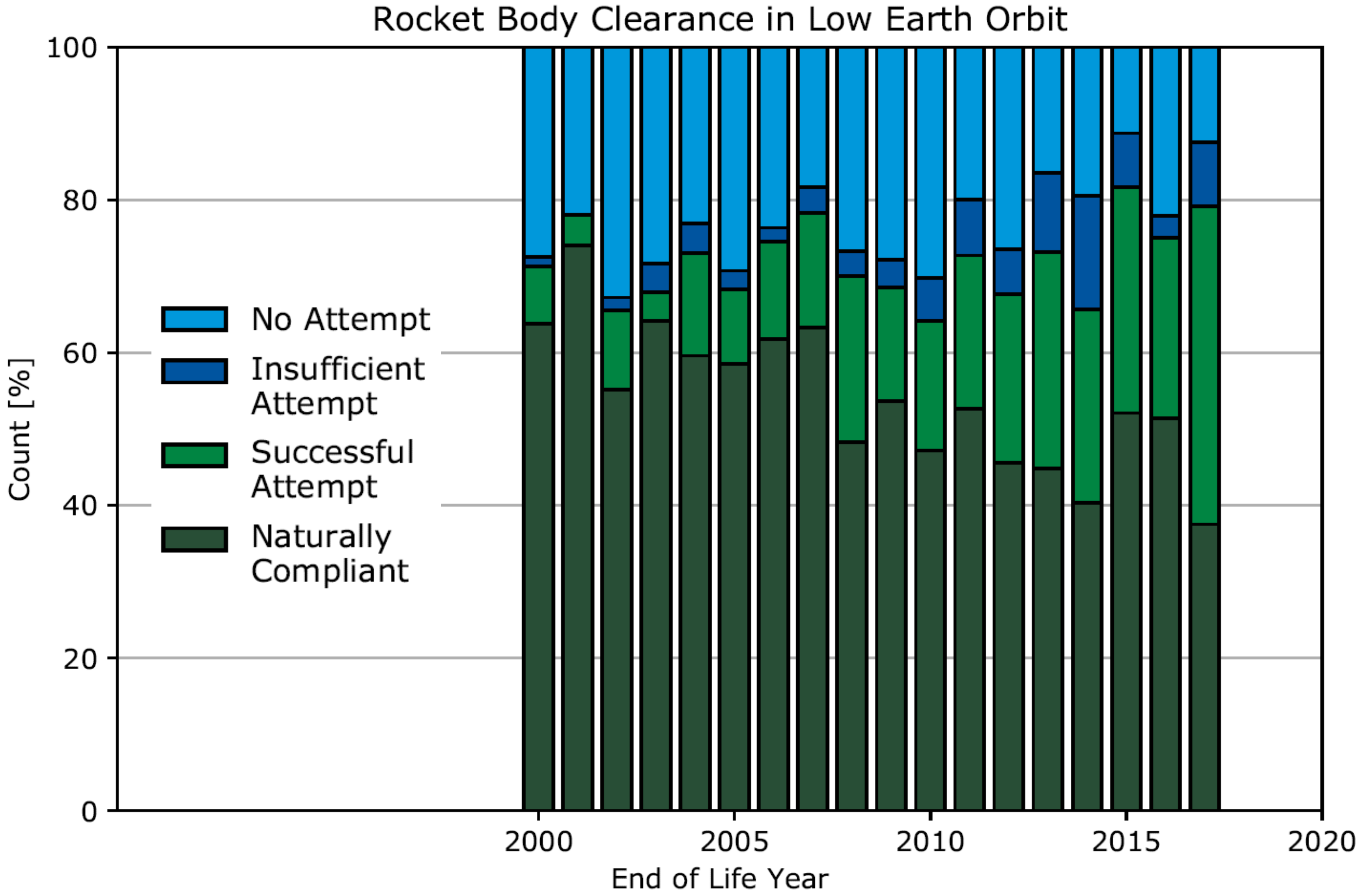
Rqmt's: LEO disposal – ch.6.3

Compliance in terms of clearing the LEO protected region (25-yr rule) for SC up to 2016, excluding Human Systems, by % mass [ESA's Annual Space Environment Report 2018]



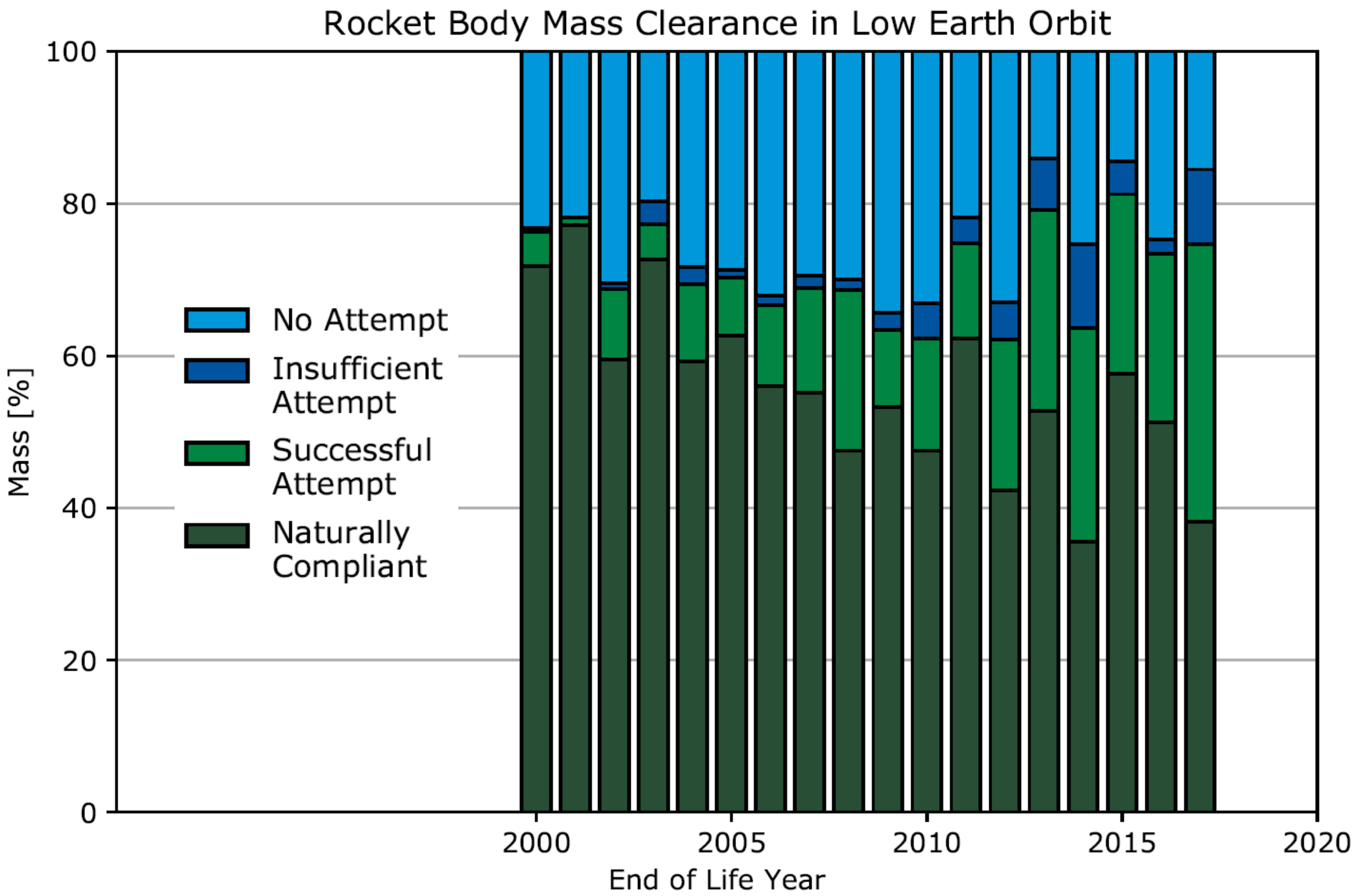
Rqmt's: LEO disposal – ch.6.3

Compliance in terms of clearing the LEO protected region (25-yr rule) for Rocket Bodies up to 2017 [ESA's Annual Space Environment Report 2018]



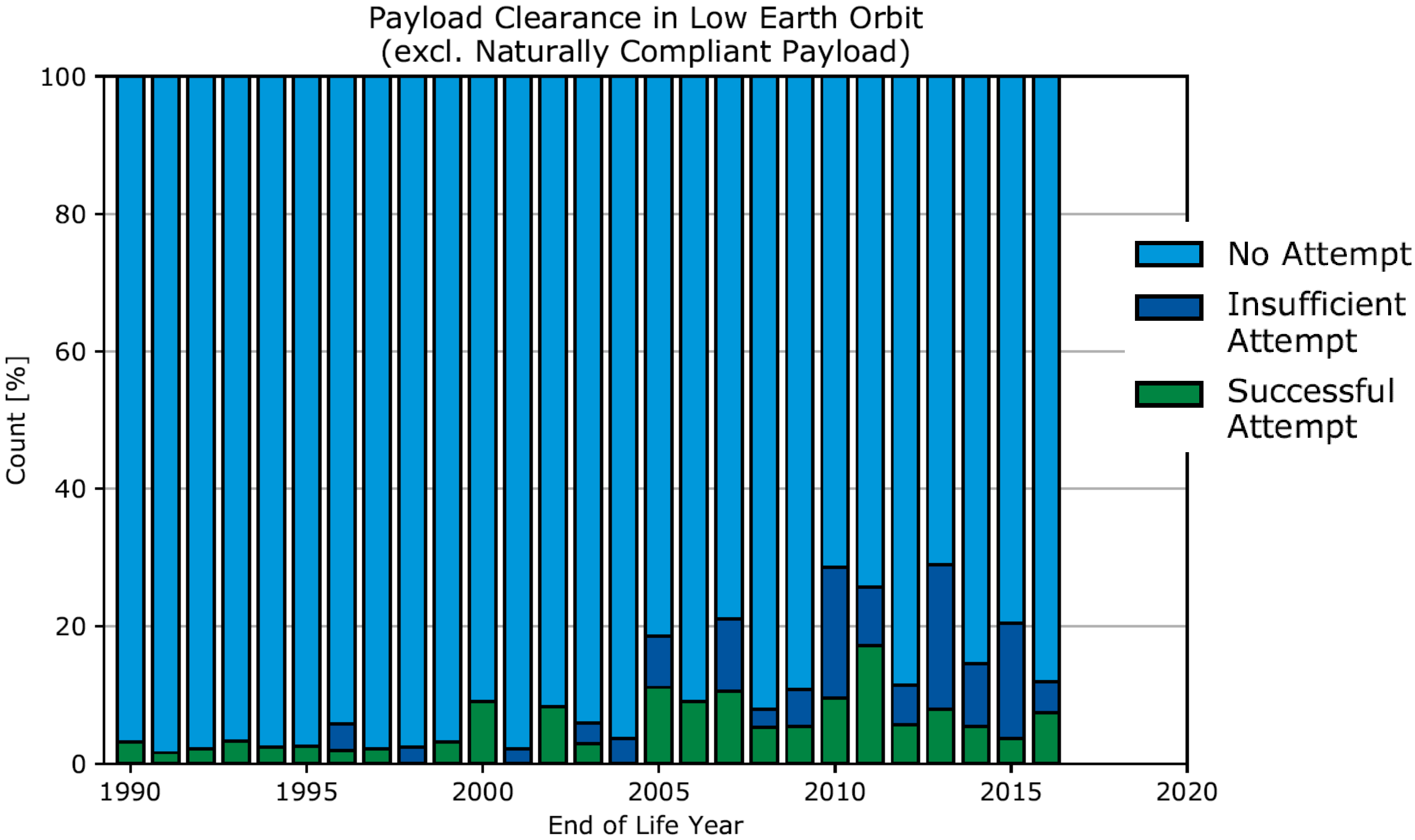
Rqmt's: LEO disposal – ch.6.3

Compliance in terms of clearing the LEO protected region (25-yr rule) for Rocket Bodies up to 2017 [ESA's Annual Space Environment Report 2018]



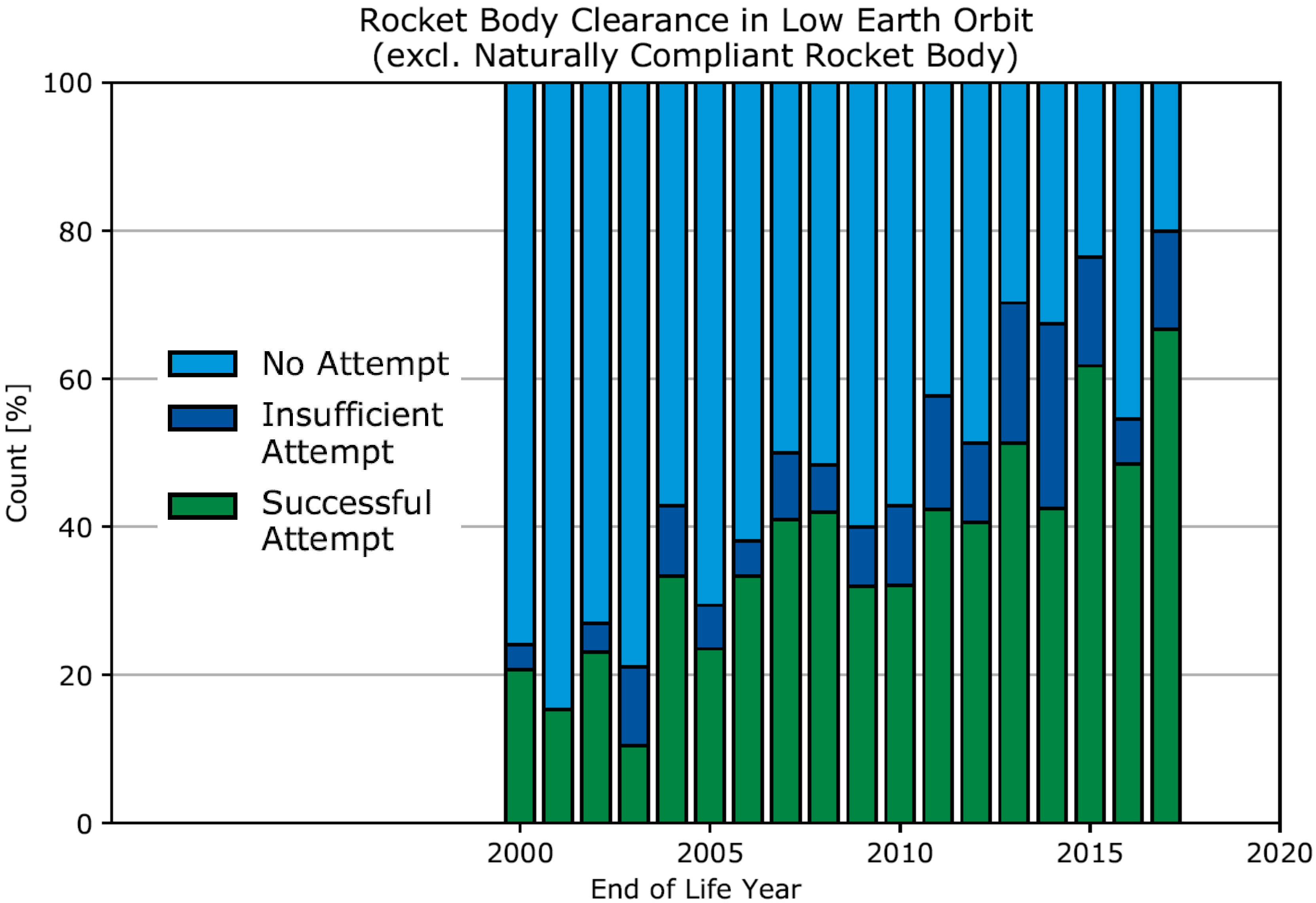
Rqmt's: LEO disposal – ch.6.3

Compliance in terms of clearing the LEO protected region (25-yr rule) for SC (excluding Naturally Compliant SC, e.g. below ≈650km) [ESA's Annual Space Environment Report 2018]



Rqmt's: LEO disposal – ch.6.3

Compliance in terms of clearing the LEO protected region (25-yr rule) for Rocket Bodies (excluding Naturally Compliant RB, e.g. below ≈650km) [ESA's Annual Space Environment Report 2018]



EUROPEAN COOPERATION FOR SPACE STANDARDIZATION

Space Debris Mitigation

Space Debris Mitigation Requirements Discussion:

Chapter 6.3

Successful disposal

[Monitoring periodically the conditions of SC]

Rqmt's: successful disposal – ch.6.3

Probability of successful disposal of the S/C in LEO or GEO to be computed and a probability > 0.9 has to be reached

- Note "disposal" definition: actions performed by a S/C or LV orbital stage to permanently reduce its chance of accidental break-up and to achieve its required long-term clearance of the protected regions

The probability has to be evaluated as a conditional probability weighted on the mission success at the time disposal is executed

$$P(D|M) = \frac{R'_{\text{system}}(T_{\text{mission}} + T_{\text{disposal}})}{R_{\text{system}}(T_{\text{mission}})} \times P_{\text{propellant}}$$

- Note1: new requirements ISO24113 ed3: non-conditional probability > 0.9
- In the French Law:
  - Second issue, July 11th, 2017, the probability of conducting with success disposal maneuvers shall be at last 85% (non-conditional probability), without considering availability of propellants, to be available for disposal maneuvers with a probability of 99%.
  - First issue, December 10th, 2010 the requirement was only related to the necessary resources, to be available with a probability > 0.9.

Rqmt's: successful disposal – ch.6.3

Probability of successful disposal of the S/C in LEO or GEO

- Identification of scenario and resources for disposal: start from nominal mission reliability evaluations; include estimation and availability of amount of propellant
- Identification of S/S for disposal and disposal reliability calculations
  - S/C bus, excluding P/L
  - Remove unnecessary S/S / equipment
  - Reliability figures composed at functional level
- Evaluation of "passivation" reliability calculations
  - Note that passivation may be very S/C dependent
  - Note that level of passivation has to be evaluated wrt consequences
- Obtained reliability is composed with the availability of the resources (e.g., propellant) at the time disposal is executed
- Passivation is not applicable in case of controlled re-entry
- Note that start and end of the disposal phase to be chosen ensuring compliance with the probability of successful disposal requirement

Rqmt's: successful disposal – ch.6.3

Probability of successful disposal of the S/C in LEO or GEO new provisions ISO24113 ed3:

- **The probability of successful disposal of a SC or launch vehicle orbital stage to be > 0,9 through to the EoL (e.g., no longer conditional)**
- **For SC for which a disposal manoeuvre has been planned, the risk of space debris or meteoroid impact preventing the successful disposal to be assessed**
- **Specific criteria for initiating the disposal to be developed, evaluated during the mission and, if met, consequent actions executed**
- **The condition of a SC to be monitored periodically during operation to detect any anomalies that could affect its successful disposal**
- **If an anomaly is detected during the SC operations which could affect its successful disposal then a contingency plan shall be developed and implemented to mitigate this risk.**
- **In case of mission lifetime extension, the capability of a SC to perform successful disposal shall be reassessed considering the status of the SC at the beginning of the mission lifetime extension**

Reliability of successful EoL disposal evaluation based on S/S needed for disposal:

- @ 7.25 yrs = 0.864
- @ 7.25 yrs + 2 mo's = 0.863

Space System EoL Measures

- Propellant accuracy: 2 σ (probability > 99.7%) margins recommended for the propellant reserve measurement

Evolution of the launch traffic ch 6.3 successful disposal

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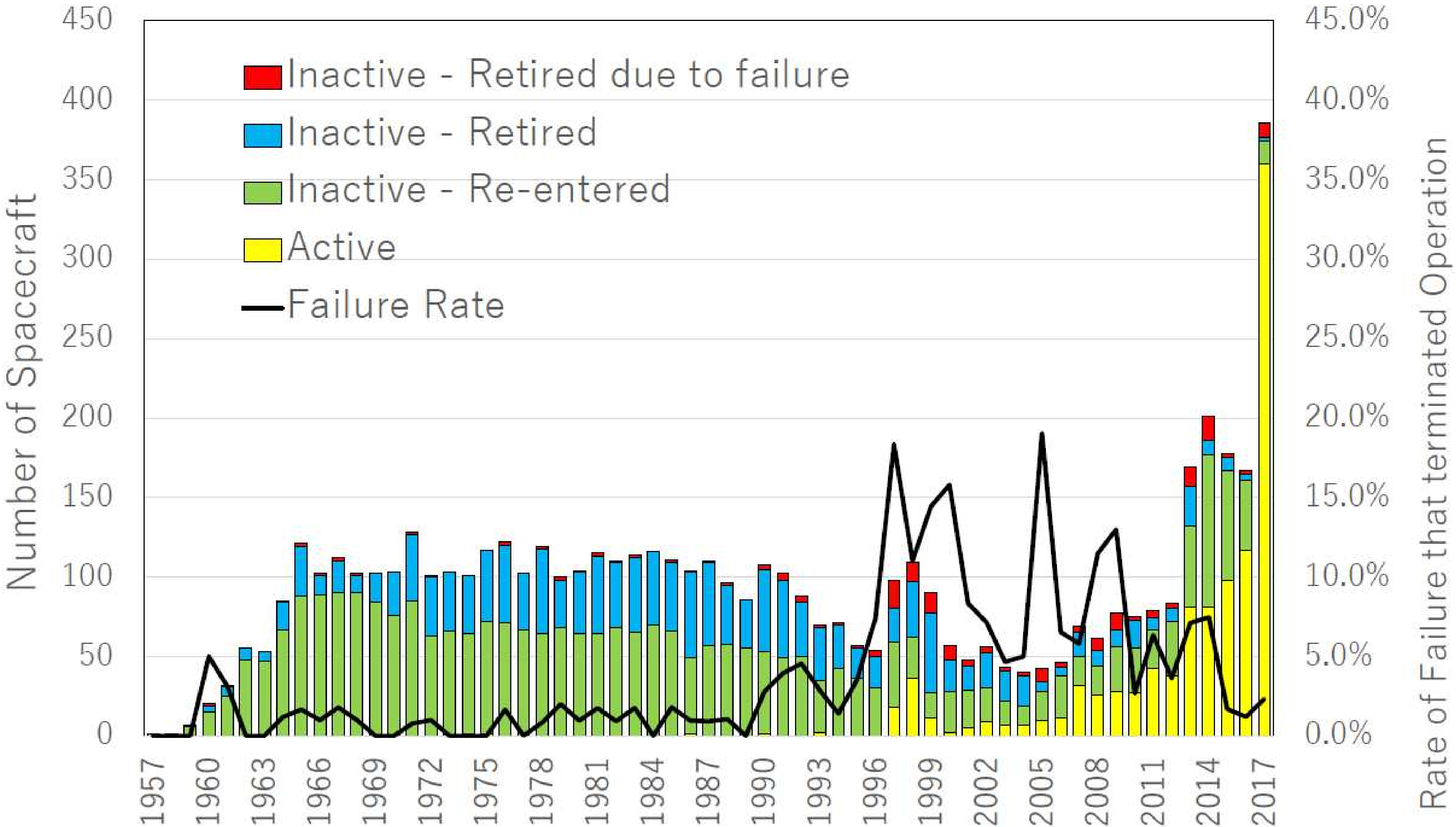
As of end of 2017. Number of SC launched per year with status compared to failure rate. Data source: Seradata Database, elaboration by JAXA. Rate of failure interrupting operations lower than non-compliance with disposal requirements.



Rqmt's: successful disposal – ch.6.3

- A value of at least 0.9 for SC in LEO is rather challenging
- To demonstrate compliance, it will be probably necessary to reassess the SC reliability, tuning the standard models (e.g. taking into account on orbit temperature, failure rate DB FIDES vs MIL, in orbit REX etc.), considering the minimum set of equipment of the subsystems needed for disposal (and also the potential flexibility of the avionics).

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Space Debris Mitigation

Space Debris Mitigation Requirements Discussion:

Chapter 6.3.4

[Evaluate and control of Re-entry Risk]

Rqmt's: Re-entry risk ch.6.3.4

For the re-entry of a spacecraft or launch vehicle orbital stage (or any part thereof), ISO 24113 / ECSS-U-AS-10C do not specify S/C reentry maximum acceptable casualty risk, but ask for this value to be set in accordance with norms issued by approving agents and the re-entry to comply with it.

Re-entry risk assessments (analyses, reports, etc.) are to be performed to show compliance with proper processes, methods, tools, models and data.

In case the total casualty risk is larger than 10^{-4}, uncontrolled re-entry is not allowed. Instead, a controlled re-entry must be performed.

- A number of existing guidelines use 10-4 as the upper limit for the casualty risk threshold per re-entry (e.g., ESA, NASA); ESA/ADMIN/IPOL(2014)2: the casualty risk shall not exceed 1 in 10,000 for any re-entry event (controlled or uncontrolled).

Texas, 2001

Saudi Arabia, 2001

Rqmt's: Re-entry risk ch.6.3.4

In the French Law:

- Second issue, July 11th, 2017, the quantitative safety objectives, expressed as the maximum probability of causing at least one casualty (collective risk) is 10^{-4}
- First issue, December 10th, 2010 the maximum acceptable total casualty risk (probabilité maximale admissible de faire au moins une victime (risque collectif) was:
  - 2*10-5 pour un retour intègre
  - 2*10-5 pour une rentrée atmosphérique contrôlée avec destruction de l'objet spatial
- If a controlled reentry is impossible "en cas d'impossibilité, dûment justifiée"):
  - 10^{-4} pour une rentrée non contrôlée avec destruction de l'objet spatial

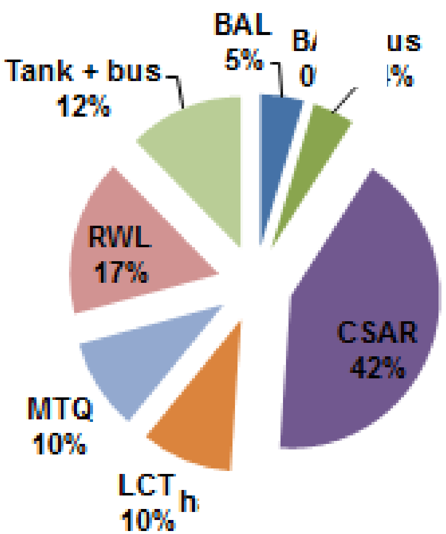
Lottie Williams struck by a fragment possibly from the re-entry of a Delta II rocket body (Tulsa, Oklahoma, January 1997)

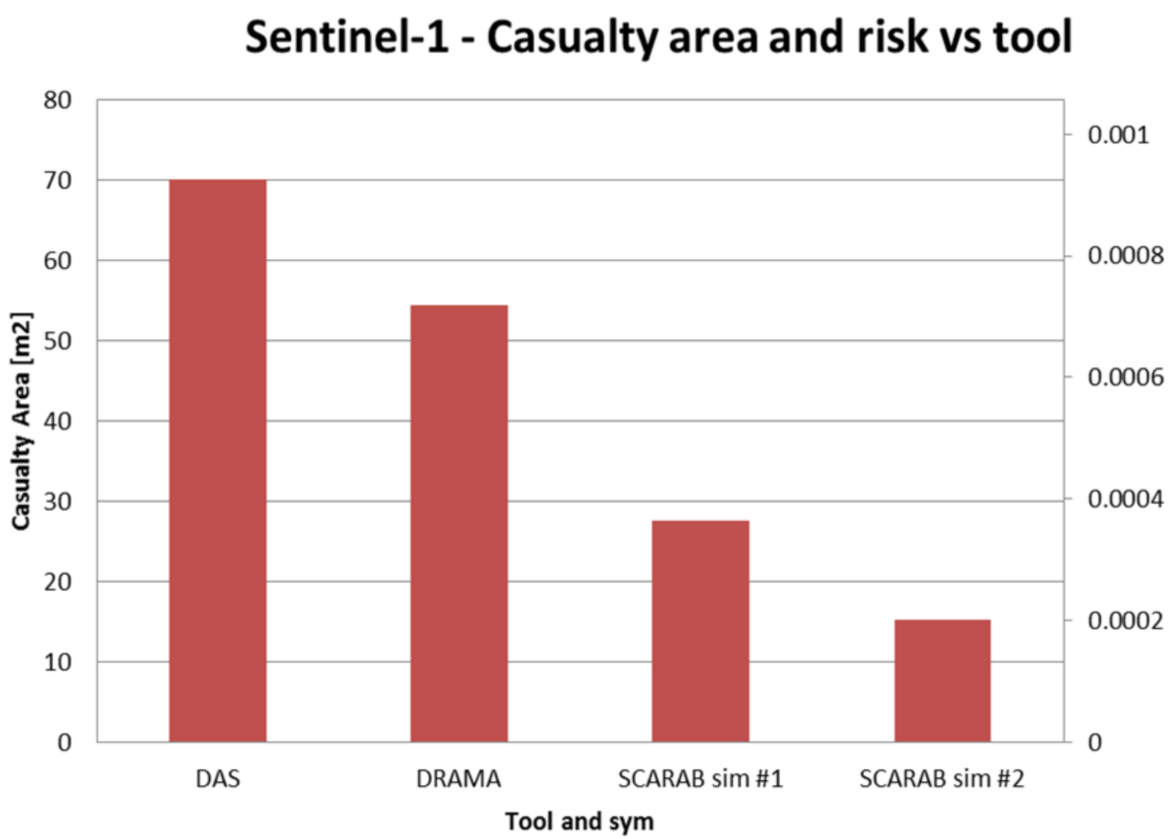
Sentinel 1 – Requirements ch 6.3.4

Re-entry casualty risk assessment (re-entry risk < 10^{-4}):

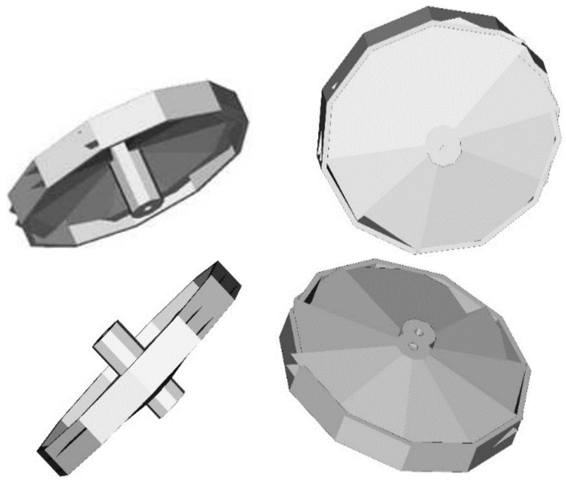
- Preliminary assessment performed with DAS & DRAMA tools, but Casualty Re-entry Risk always significantly above the 10-4 requirement:
  - 9 E-04 (1:1100) according to DAS
  - 7.19 E-04 (1:1391) according to DRAMA
- Additional analysis performed with SCARAB 6-DoF showed iImpact of tools and impact of granularity: Casualty Area decreases (may it increase too?)

Average value of 53 SCARAB simulations:
Casualty Area = 15.2 ± 2.6 m^2
≈ 2E-4 casualty risk





Sentinel 1 – Requirements ch 6.3.4



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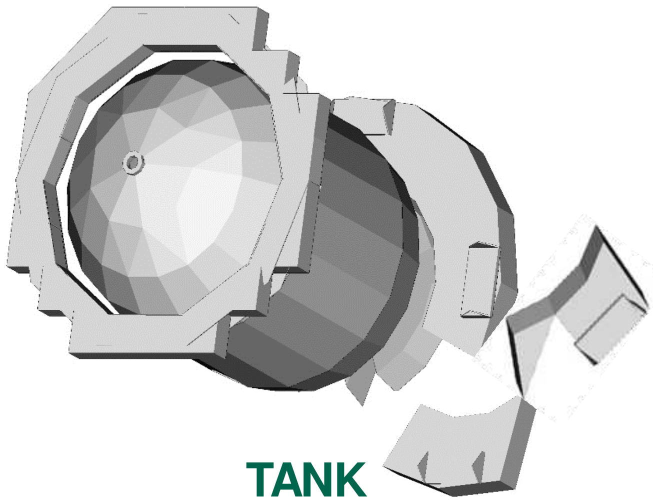

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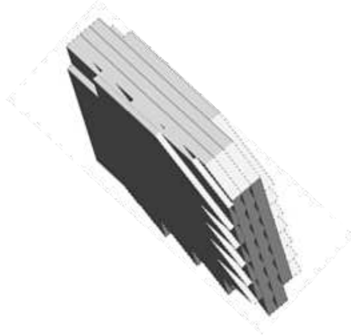
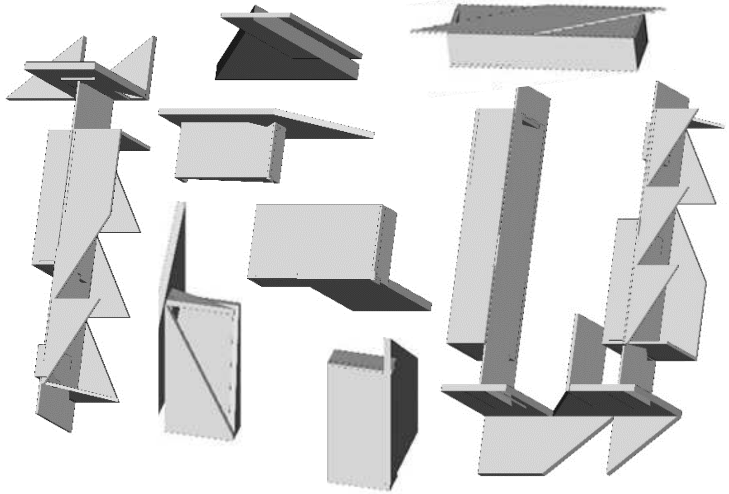
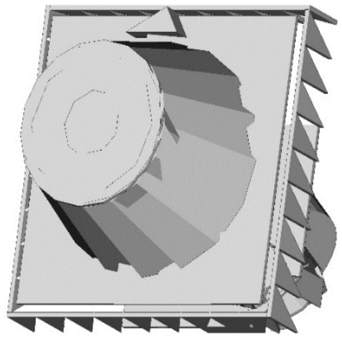


Balance Mass

MTQs



SAR Central panel



LCT

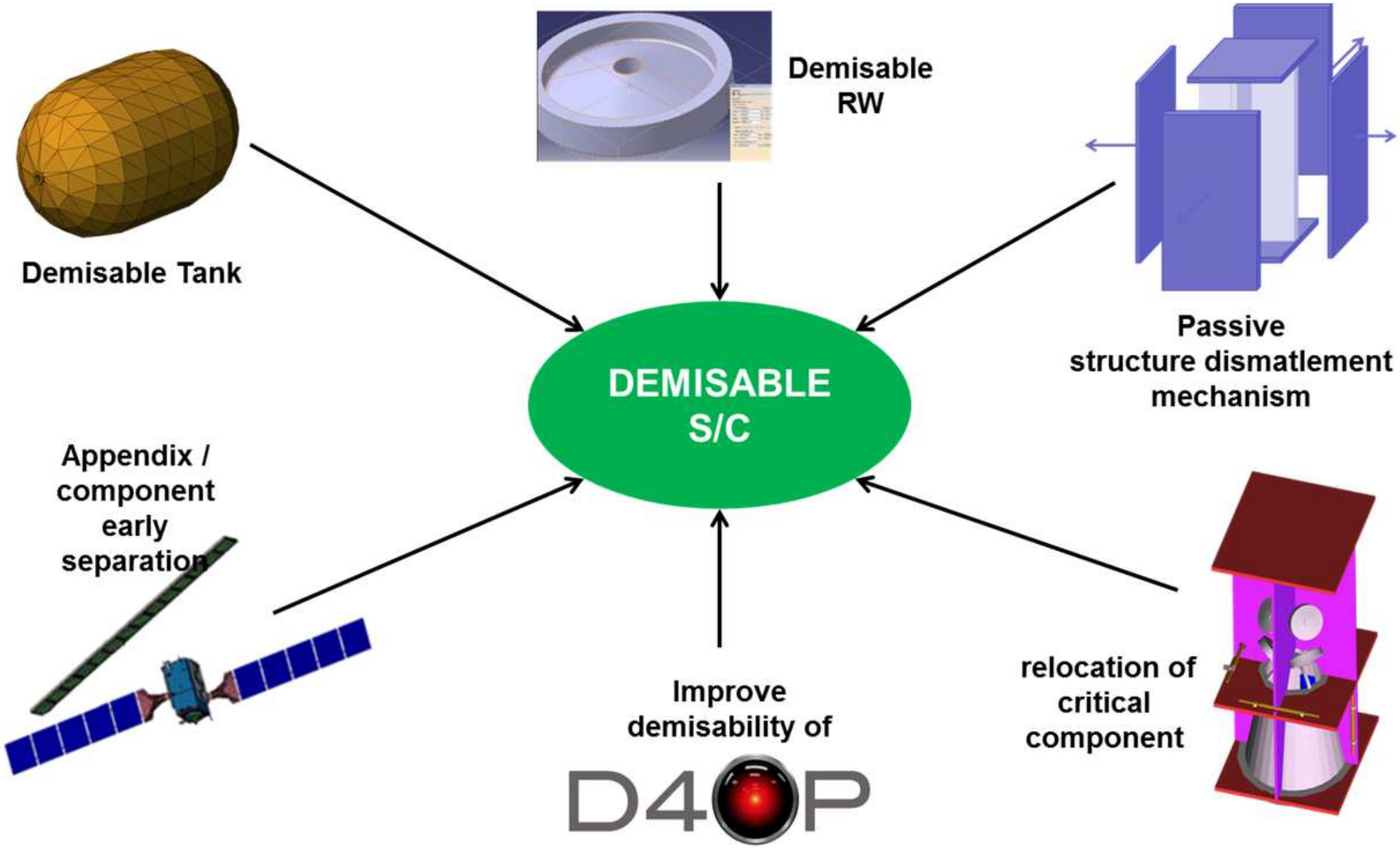
→ **Identify critical items and define the reason of survivability is the first step to identify and tune D4D techniques**

Application of D4D techniques to critical components

Baseline Design
Casualty Area = 15.2 ± 2.6 m^2

→

Demisable Design (best combination)
Casualty Area = 6.3 m^2



Rqmt's: Space debris mitigation plan ch.7

A space debris mitigation plan (SDMP) shall be prepared with the following minimum content:

- the applicable space debris mitigation requirements;
- the verification and validation means to assess compliance with the applicable space debris mitigation requirements;
- a compliance matrix;
- justifications for non-compliance.

The SDMP shall be approved by approving agents

The SDMP shall be reviewed / updated / implemented during the design, manufacturing, launch, operations and disposal phases

Space Debris Mitigation

SDM Handbooks and Supporting Studies

clean space

Inter–Agency Space Debris Coordination Committee

SDM HBs

- Useful reference documents:
  - ESA, ESA ESSB-HB-U-002 , “ESA Space Debris Mitigation Compliance Verification Guidelines “
  - CNES Guide de Bonne Pratique – Maitrise d’un Objet Spatial
  - ISO 18146: TR - Space Debris Mitigation Design and Operation Manual for Spacecraft
  - IADC-04-06, Rev 5.5, May 2014, Support to the IADC Space Debris Mitigation Guidelines
- ESA, CNES and ISO Handbook on SD Mitigation with different purpose and approaches:
  - ESA HB focused on verification methods and techniques to show compliance with SDM requirements within ECSS/ISO24113
  - CNES HB necessary for the implementation of the French law with indications, documentation required, compliance matrix, to provide verification of the requirements. (However, text of rqmts in French LOS / RT rather different from ECSS/ISO)
  - ISO HB more general and procedural, considers SC life-cycle and S/Ss, provides linking to the various SDM lower level ISO Standards

Space Debris Mitigation:

Evolution of Space Debris Requirements

Large constellations and “small” satellites

Potential evolution of Space Debris Scenario

Debris Environment – Evolution

Several proposed concepts for large constellations in LEO

- Targeting operational altitudes above 1000km.
- For typical SC average orbital lifetimes above 1000 km are quasi-eternal.

“Small” satellites / *en masse* deployement in LEO

- On 15 February 2017, the Indian Space Research Organisation (ISRO) PSLV-C37 successfully carried and deployed a record 104 satellites in sun-synchronous orbits
  - 3 Indian satellites (e.g., Cartosat-2D, 714 kg) and 101 international satellites from several countries (96 US, Kazakhistan, Israel, UAE, Switzerland, Belgium, Germany, Netherlands, with orbits ≈492x505km, 97,5°) for a total payload mass of 1,378 kg
  - It is the largest number of satellites launched on a single flight surpassing the previous record of Russia, which in 2014 launched 37 satellites using Dnepr rocket.
- On 23 June 2017, ISRO PSLV-C38 successfully carried and deployed 31 satellites in sun-synchronous orbits
  - 2 Indian satellites (e.g., mapping satellite Cartosat-2E, 712 kg) and 29 smaller foreign satellites as secondary payload

The first of OneWeb's 21 Soyuz launches took place February 27, 2019

- First 6 SC of OneWeb SC injected into LEO
- Next missions expected to carry >30 SC at a time (on Soyuz rockets and on other launchers) to build out a constellation of 600 operational and 48 SC
- About 150 SC expected to be launched in 2019, other ~150 in 2020

Other constellations planned / under development

Constellation Name	Number of satellites	Orbital altitude [km]
Samsung	4600	1400
SpaceX	4000	1100
Oneweb	650	1200
Leosat LLC	140	1800
Yalini	135	600

Source: various media

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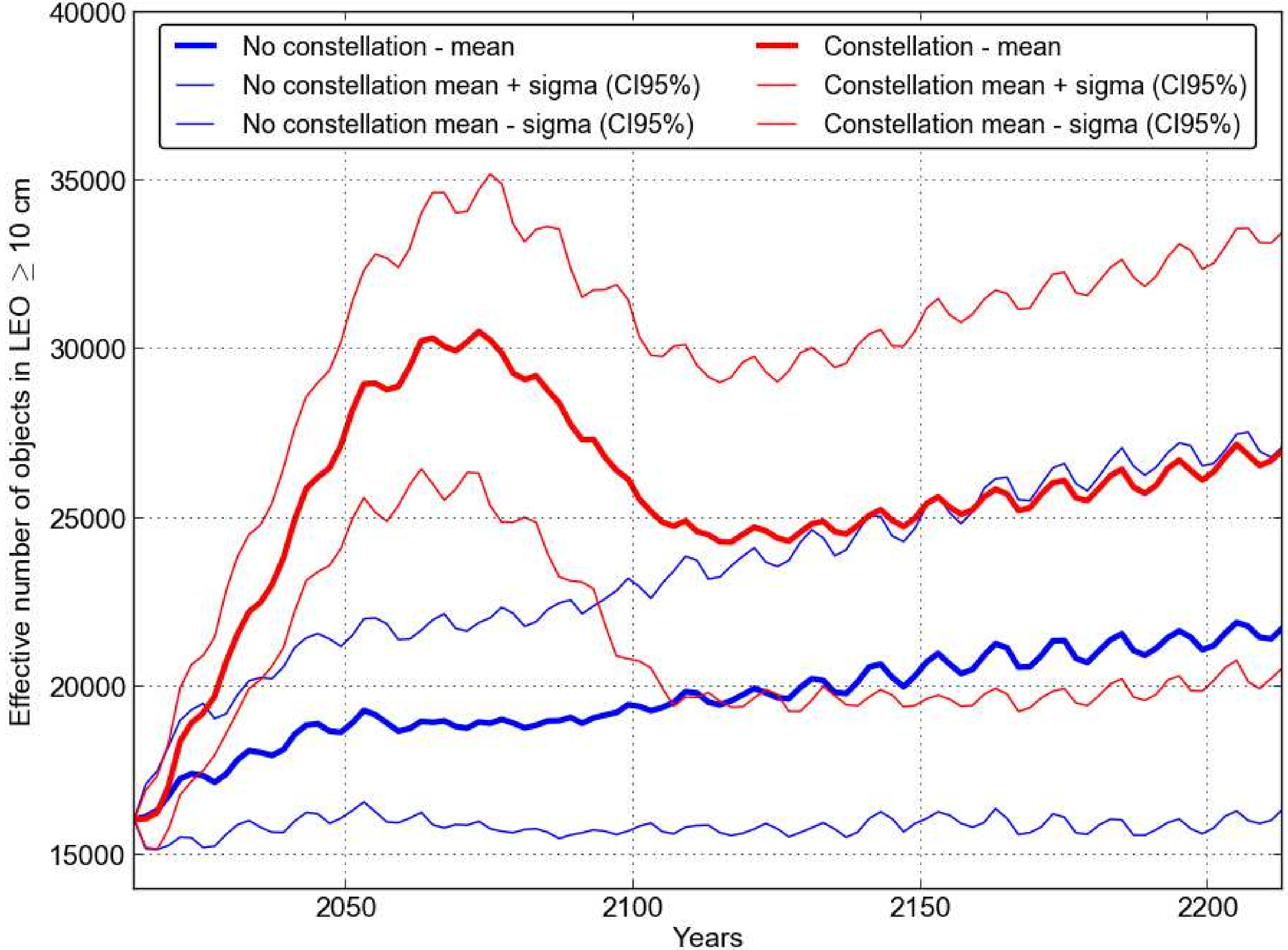
Environmental Effects of a Large Constellation. Assumptions.

(Megaconstellation End of Life Operations. Clean Space Study Report: ESA-TEC-SC-FR-2016-001, May 2016)

Constellation	1080 satellites 1100km altitude 20 orbital planes 85deg inclination
Mission	Jan 2021 to Jan 2071
Satellite	200kg mass 1m² effective cross-section 5 years of mission lifetime
Constellation build-up	2018-2010 20 launches per year 18 satellites per launch
Constellation maintenance	2021-2071 18 objects per launch 12 launches per year
Mitigation behaviour	Launcher stages perform a direct re-entry No mission-related objects are released

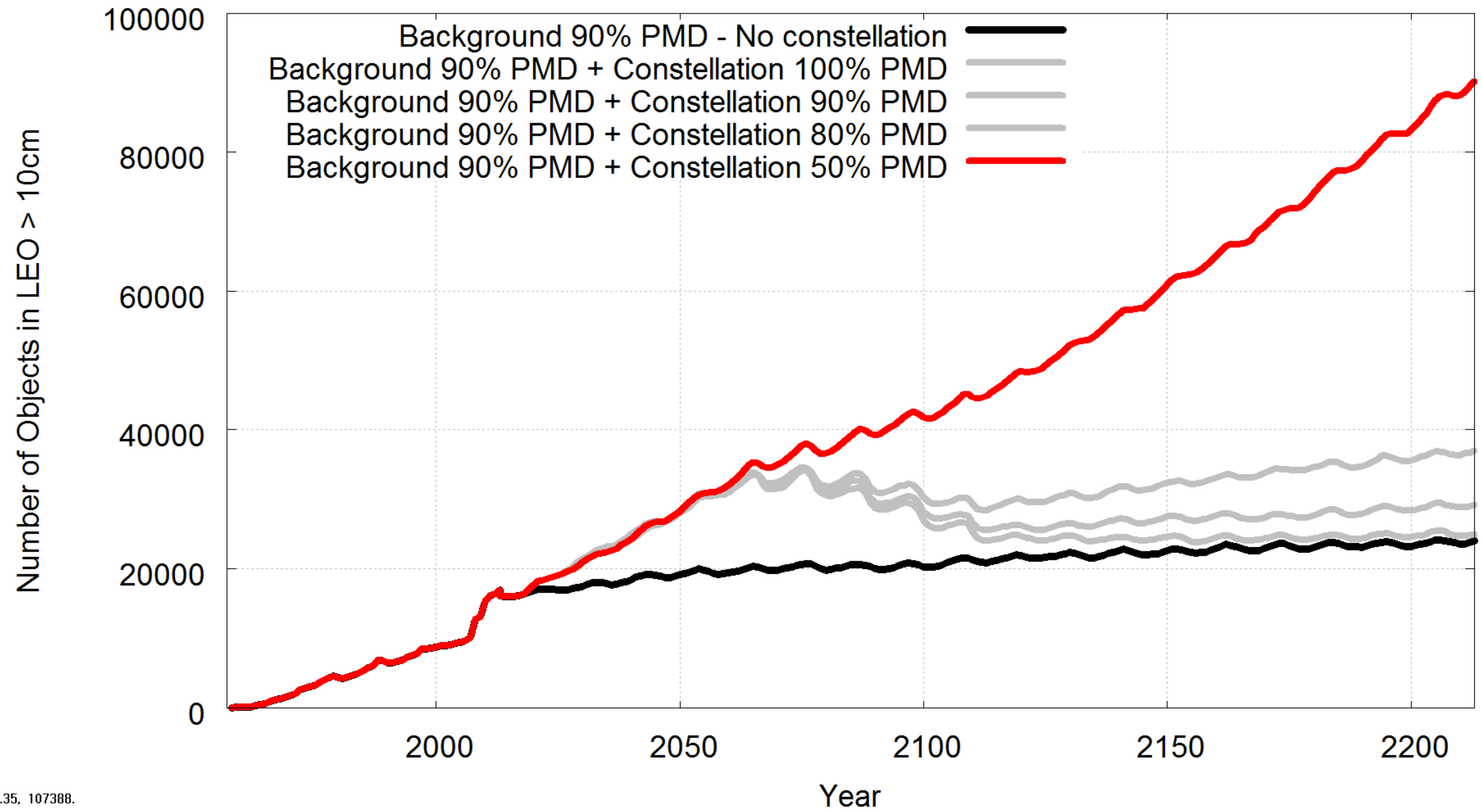
Debris Environment – Evolution

Environmental Effects of a Large Constellation. Results for **90% successful implementation of post-mission disposal** (25 years orbital lifetime after disposal)



Debris Environment – Evolution

Environmental Effects of a Large Constellation



2076.35, 107388.

Debris Environment – Evolution

Environmental Effects of Large Constellations:

- The post mission disposal success-rate (also of Rocket Bodies) is the most significant environmental driver
- Effects grow over-proportionally with area and geometric cross-section
- The presence of more than one mega-constellation in LEO generates more than double of the effect
- Reduction of orbital lifetime to < 25 years has only a minor effect
- Accumulation of on-ground risk is an issue to be studied

Launch, deployment, operation and the disposal of large number of S/C raises issues wrt usage of space: "low cost SC cannot be translated to low quality ones, with a loose management":

- Potential for debris creation and impact on debris population stability
- Main driver for long term stability of the environment is the probability of successful disposal
- Are «low cost» SC compatible with high probability of successful disposal?

Space Debris Mitigation

Evolution of SDM Requirements

&

Conclusions

Space Debris Mitigation – Requirements evolution

ECSS is concerned about the evolution of the space debris population and the potential impact induced by the future LEO large-constellations and the increased number of "small SC"

- The evolving scenario to be careful monitored and analysed, to preserve the environment without limiting access to space and innovation
- At present, no dedicated Space Debris Mitigation requirements for large-constellations / "small SC" are envisaged
- The update of Space Debris Mitigation requirements (on-going with the updated ISO 24113 3rd Edition / ECSS-U-AS-10C) is felt necessary and urgent
- A strict compliance with the SDM updated requirements is a mandatory request, with no relaxation for any specific class of SC

Thank you

Questions ?