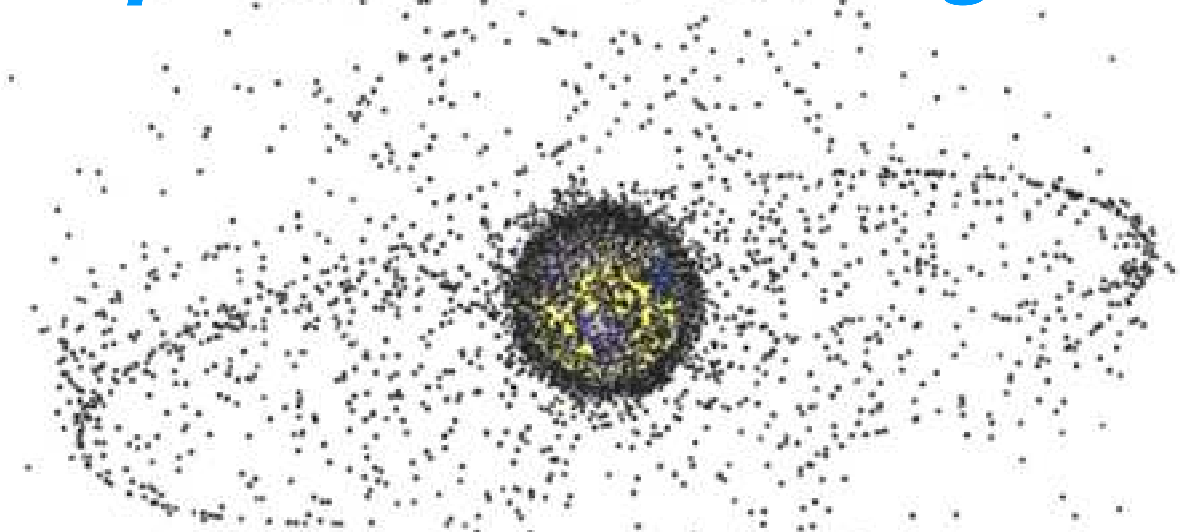
ECSS-U-AS-10C
Space Debris Mitigation



Standardization training program
ESA ESTEC , June 27, 2016
- PART 1 -

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Training Course Instructor

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Head of Space Environment and Debris Unit, Thales Alenia Space - Domain Exploration and Science Italia

Discipline focal point for ECSS for Space Debris and convenor of the ECSS Space Debris Working Group

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

Outline

Introduction

- Rationale of the course and area addressed

Space Debris Overview

- Space Debris: An Increasing Issue
- Space Debris Environment and Critical Events
- Effects of Space Debris on Space Systems
- Re-entry Risk
- Global Perspective for Space Sustainability

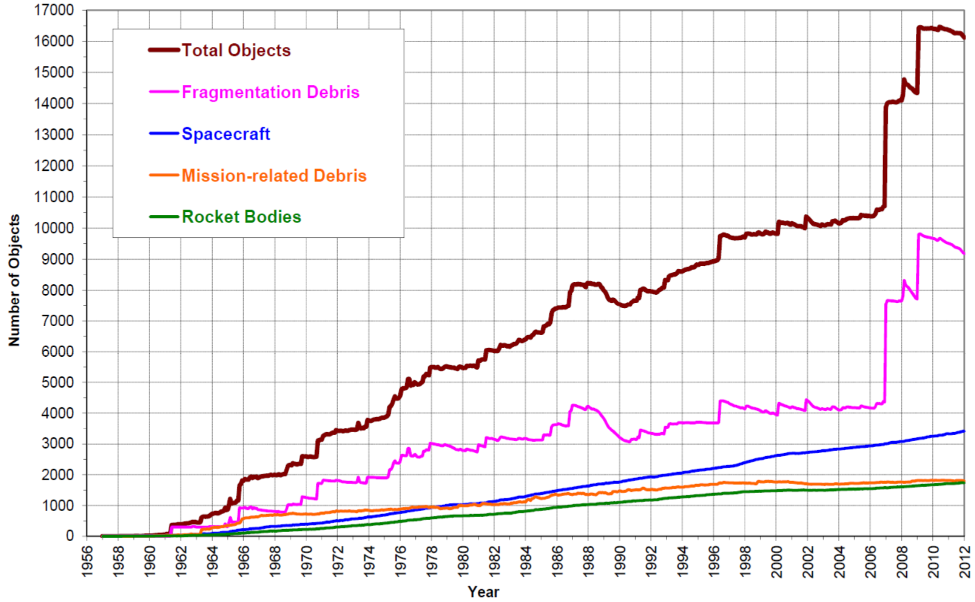
Space Debris Mitigation

- Space Debris Mitigation Guidelines and Standards
- ECSS & ISO TC20/SC14 Space Debris Mitigation Standards
- ESA Space Debris Requirements (ESA/ADMIN/IPOL 2014)
- French Space Law
- ECSS Space Debris Requirements Discussion
- Application of SDM Requirements: Sentinel-1A Case Study
- SDM Handbooks and Supporting Studies
- Evolution of Space Debris Requirements

Conclusions / Feedback / Questions and Answer

Space Debris Overview

Space Debris: An Increasing Issue



Gravity (Theatrical Trailer) HD(videoming.in)

Space Debris

Space debris / orbital debris:

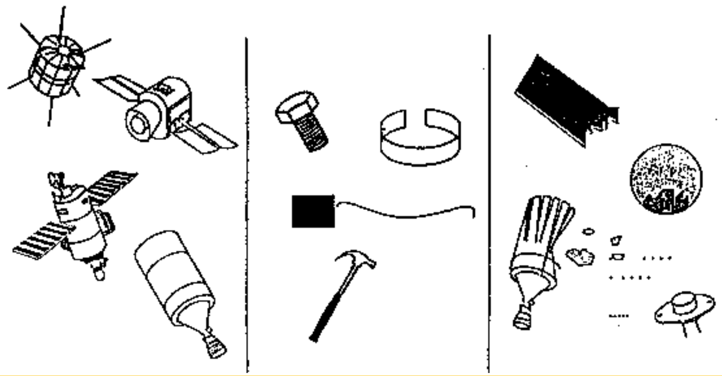
- "man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional" (IADC / ISO)

Catalogued objects:

- Listed in the U.S. SPACE SURVEILLANCE NETWORK "TLE" catalogue, with assigned origin, regular tracking **17385 as of 6 April 2016**, but extrapolations lead to more than 29,000 objects > 10 cm and 750,000 between 1 and 10 cm.

Objects origin:

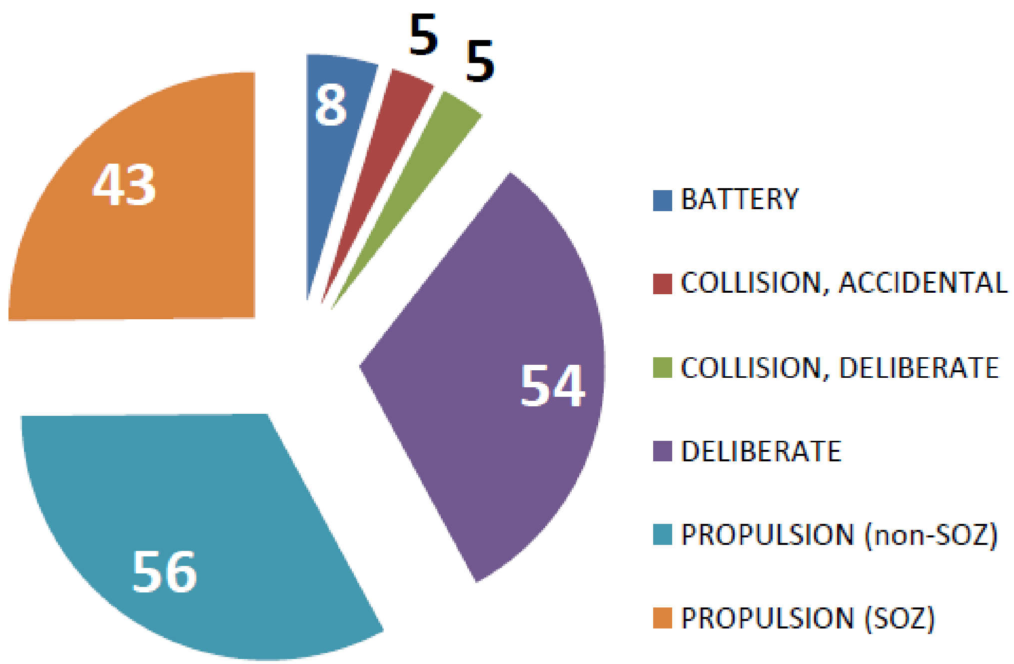
- Active satellites (~6%), retired satellites (~13%), spent orbital stages (~11%), mission related objects (~5%), break up of satellites or rockets and orbital collisions (~60%, ~250 events)



Space Debris

About ~60% of objects, ~240 break-up events (according to ESA DISCOS database as of May 2014):

- 31% due to propulsion system
- 3% due to battery
- 5% due to collision
- 24% due to deliberate break-up
- 36% unidentified causes

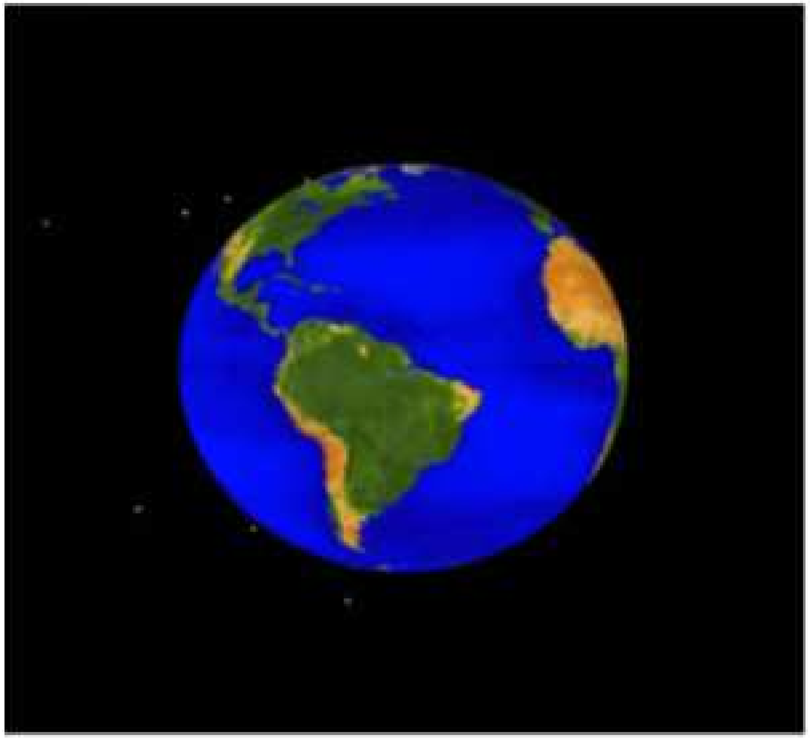


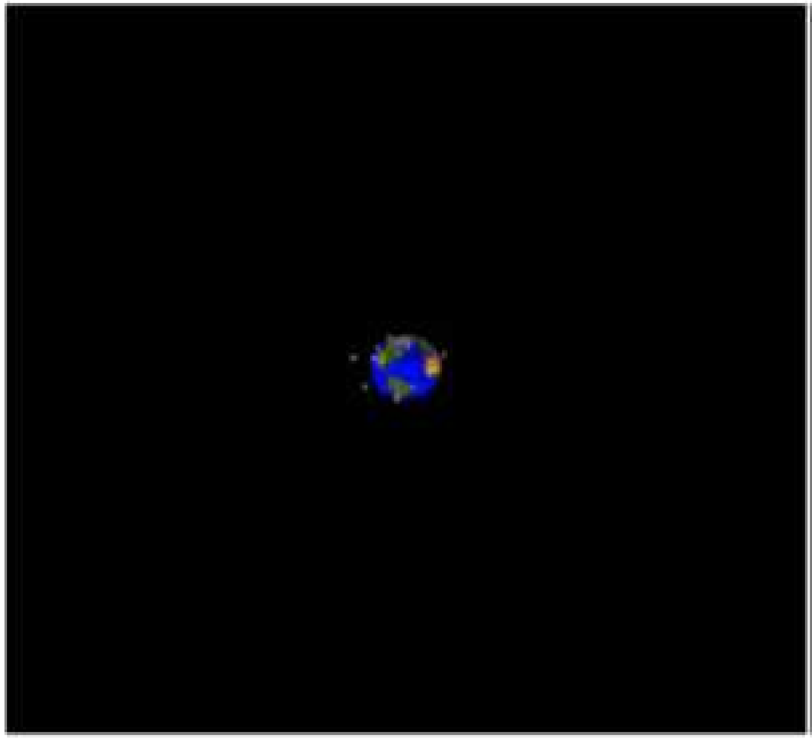
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

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

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

1960



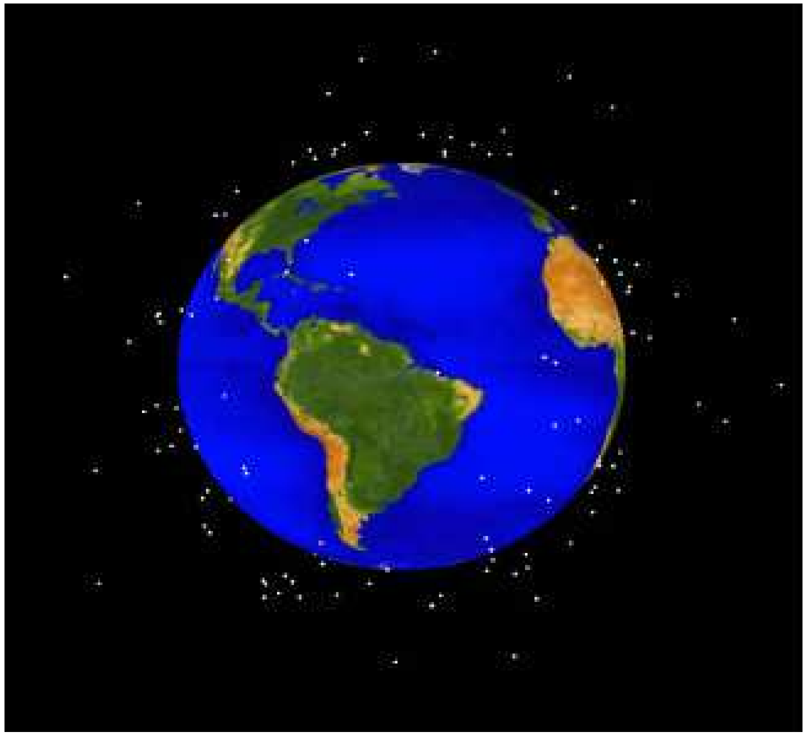


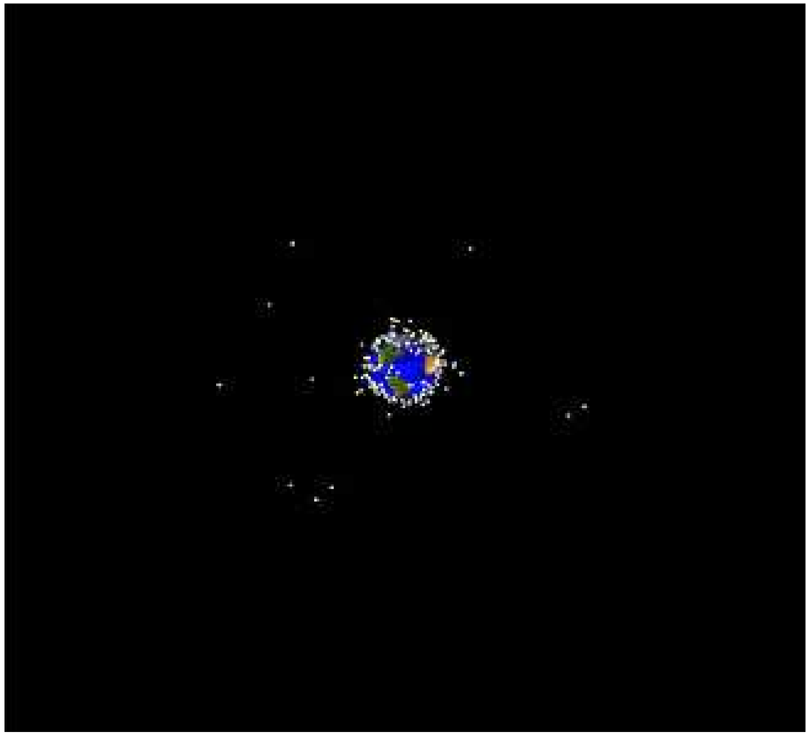
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

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

1965

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

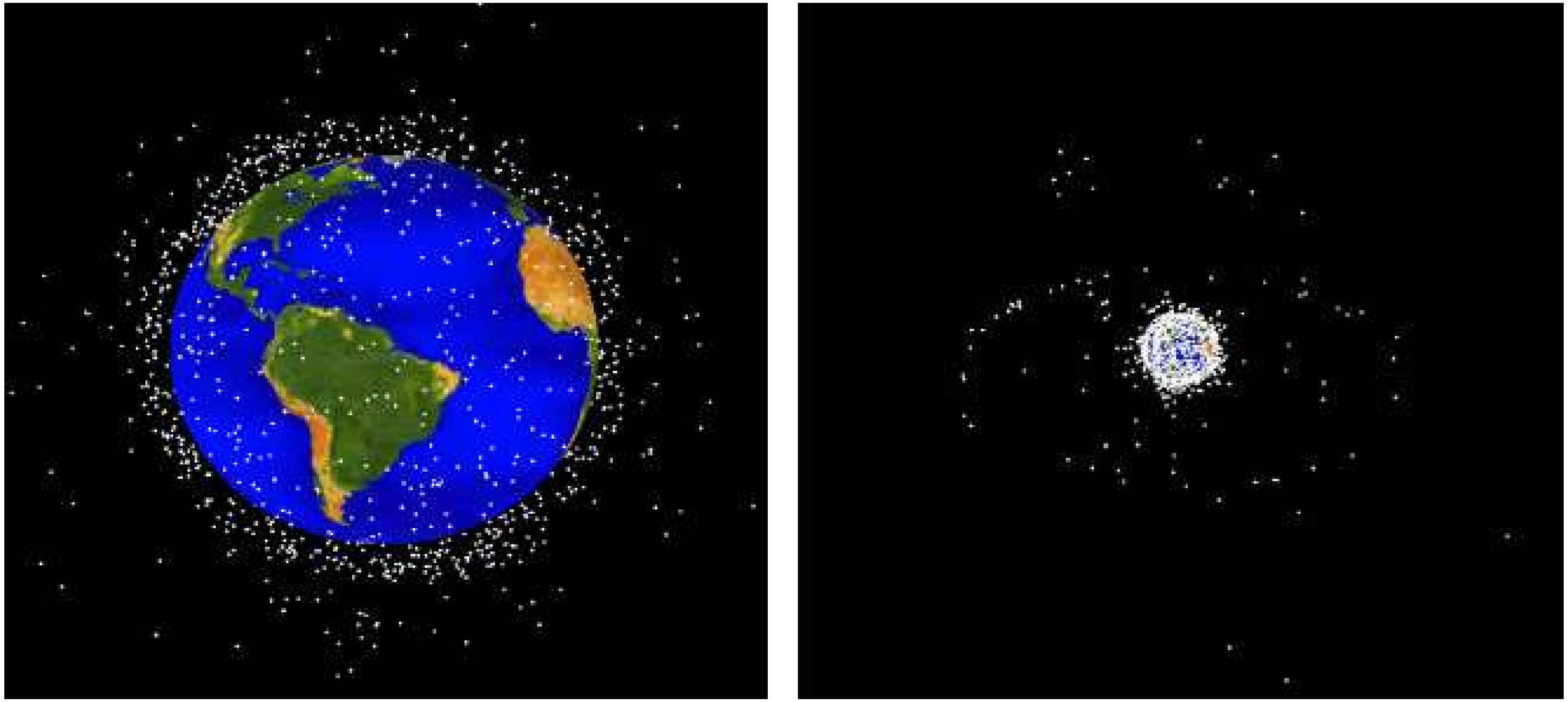




Space & Debris: Our Past , Our Future

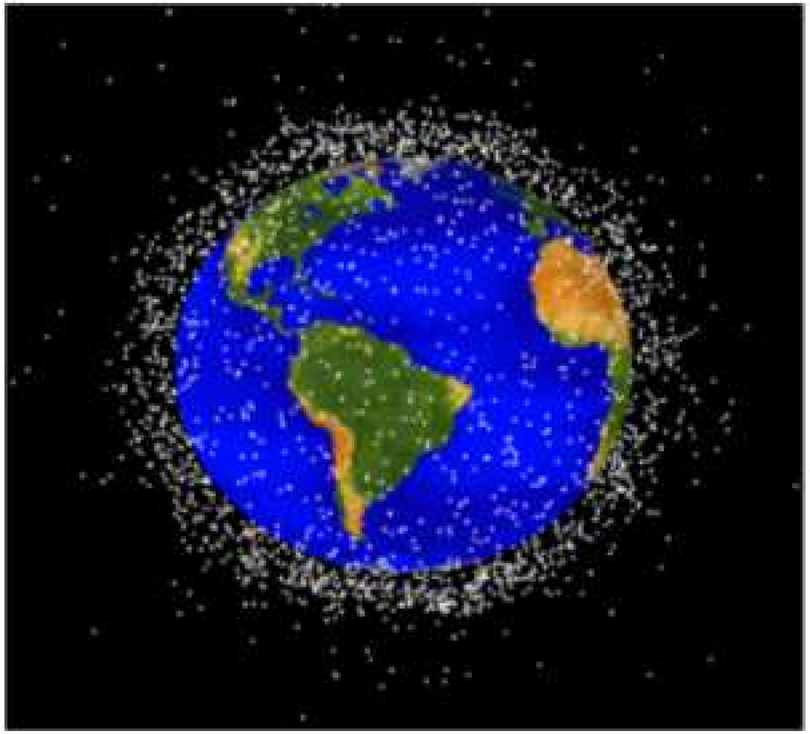
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

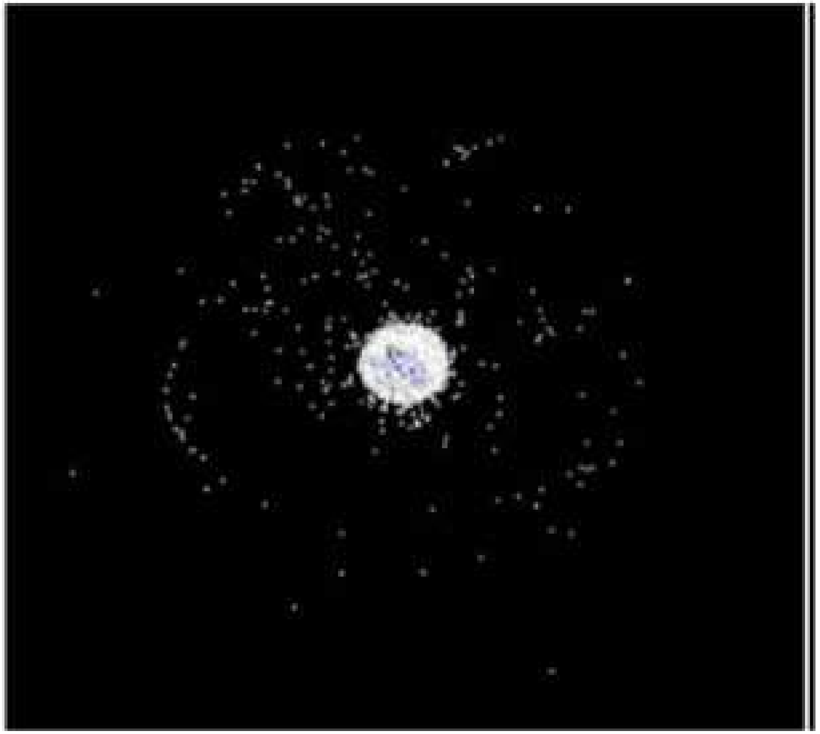
1970



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

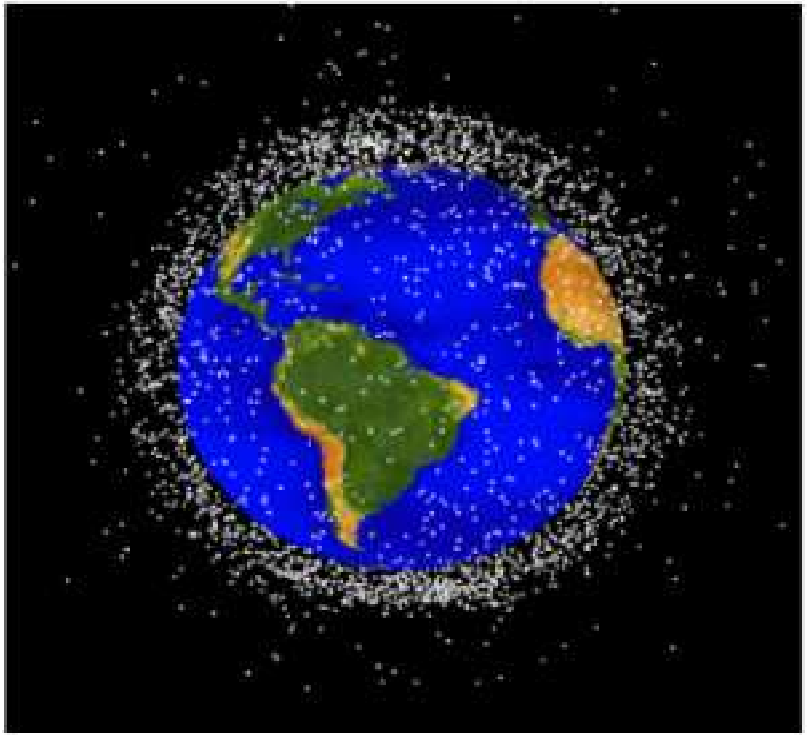
1975

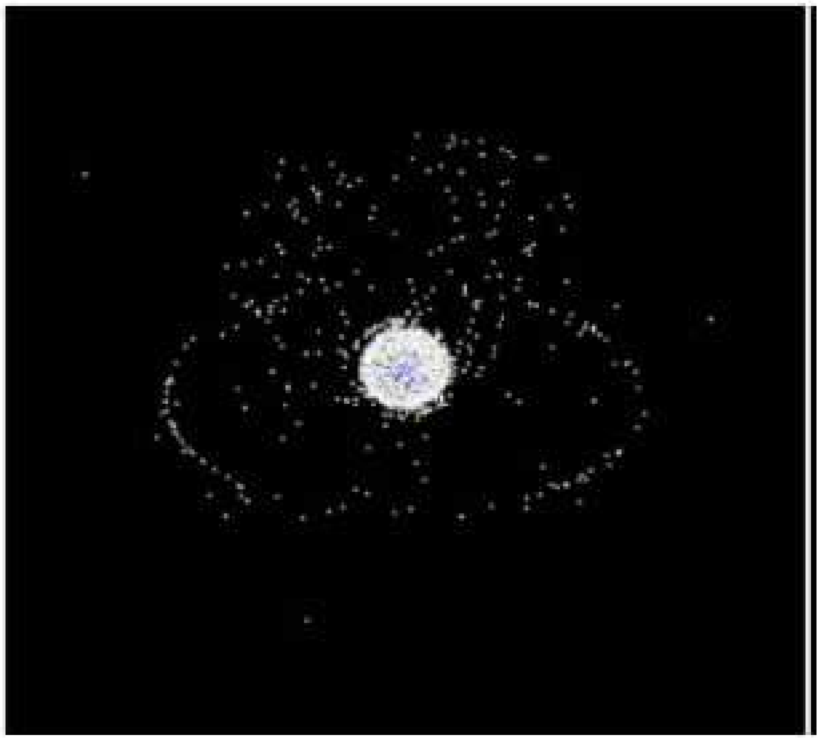




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

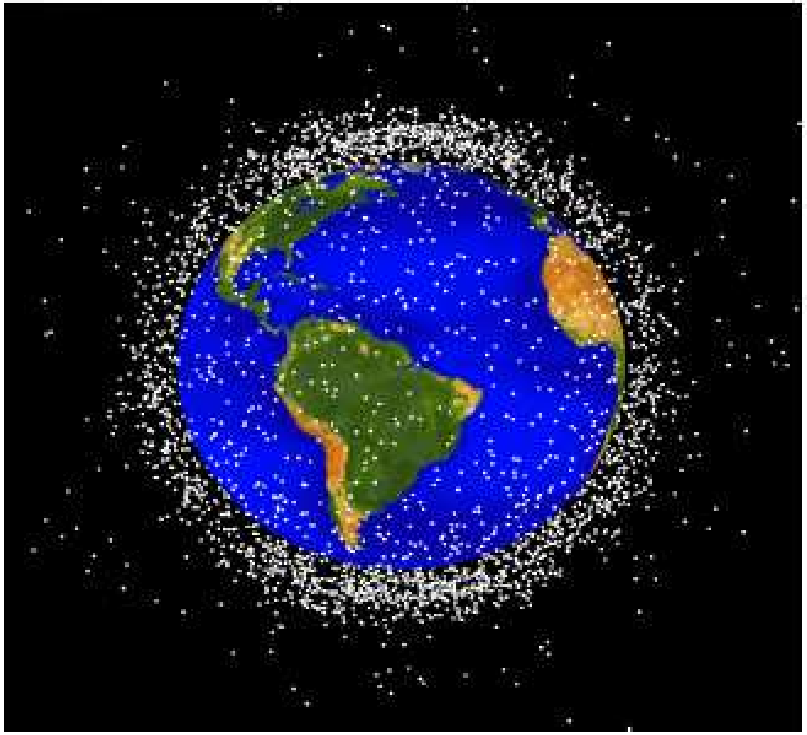
1980

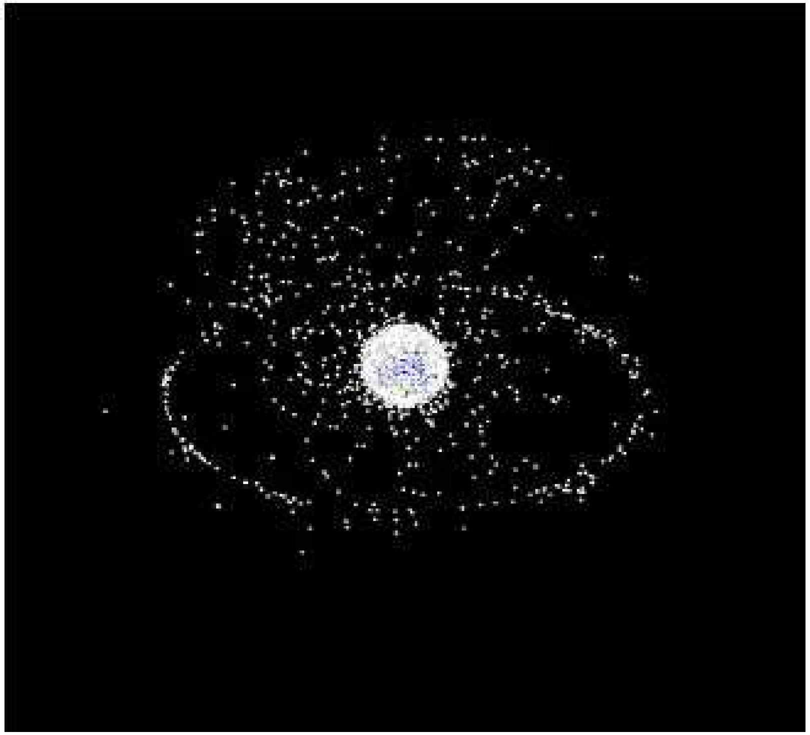




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

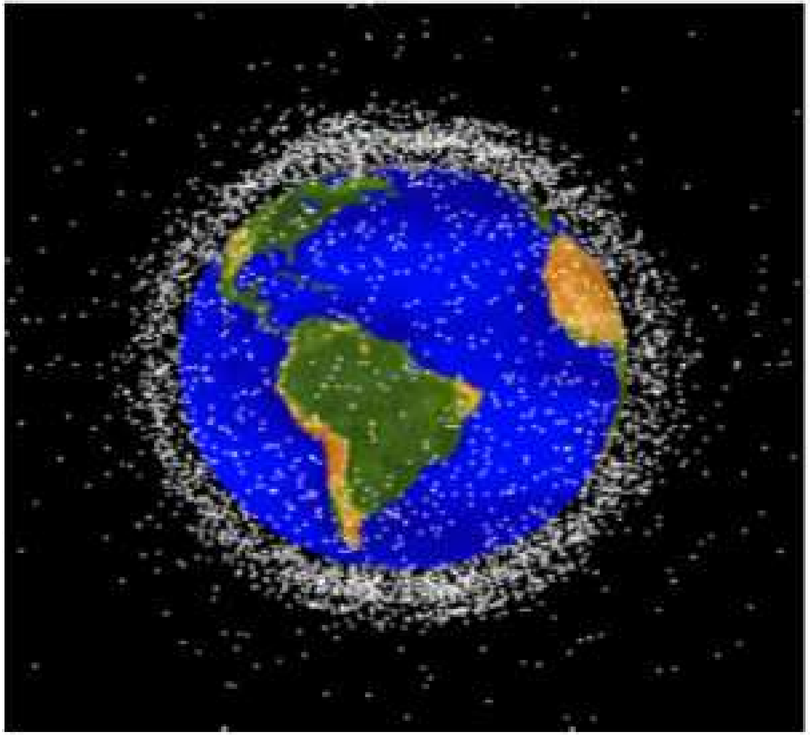
1985

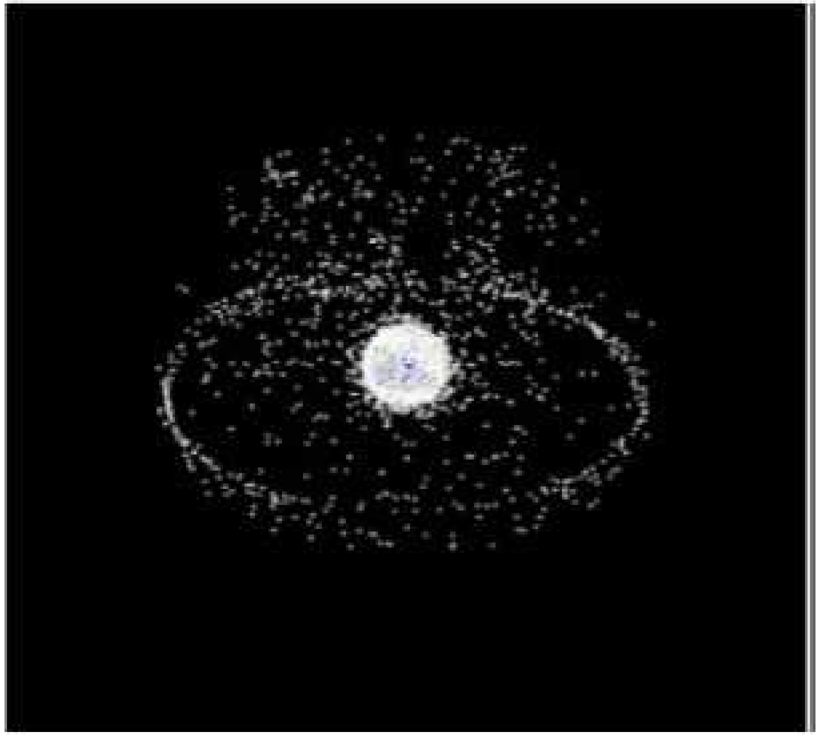




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

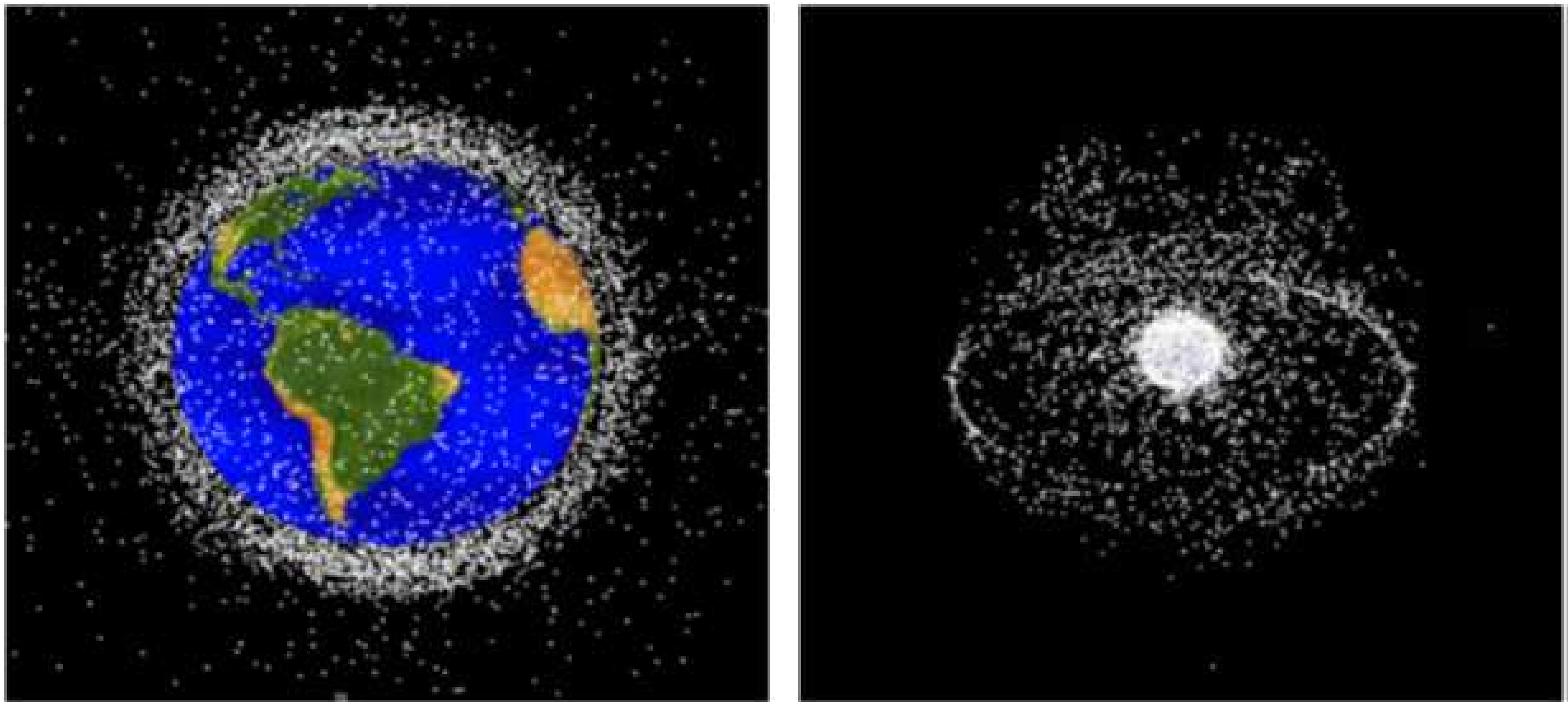
1990





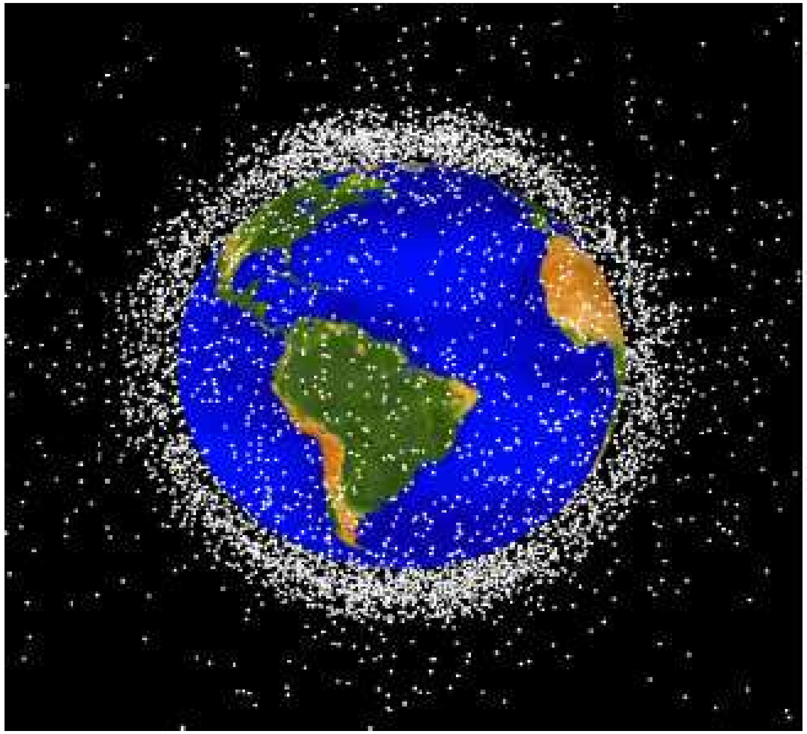
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

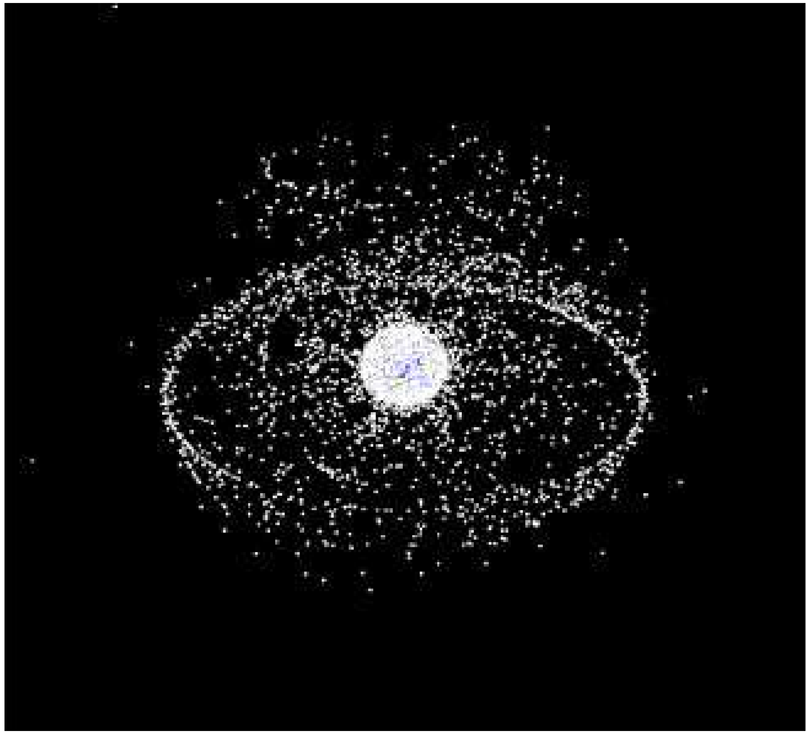
1995



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

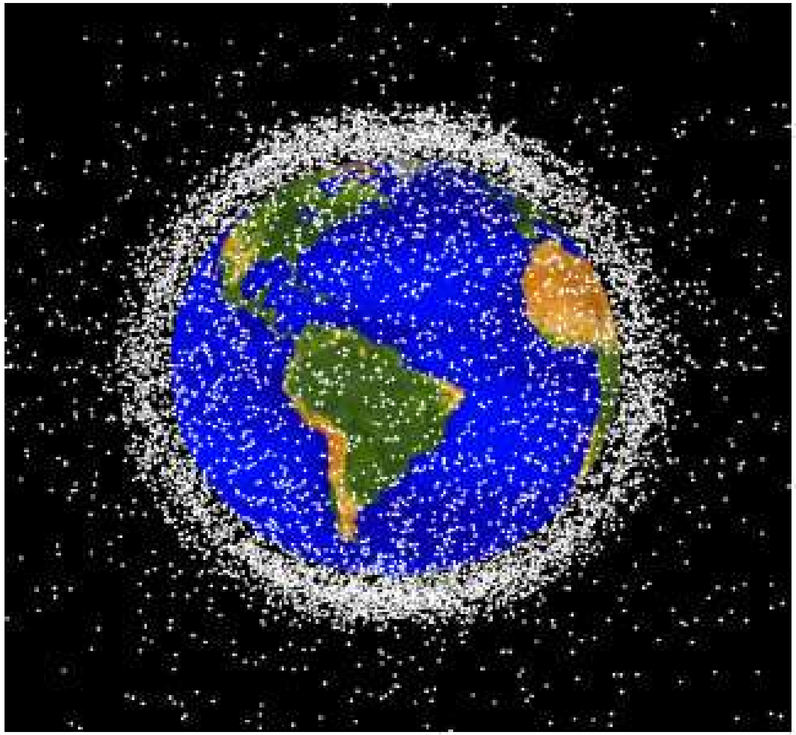
2000

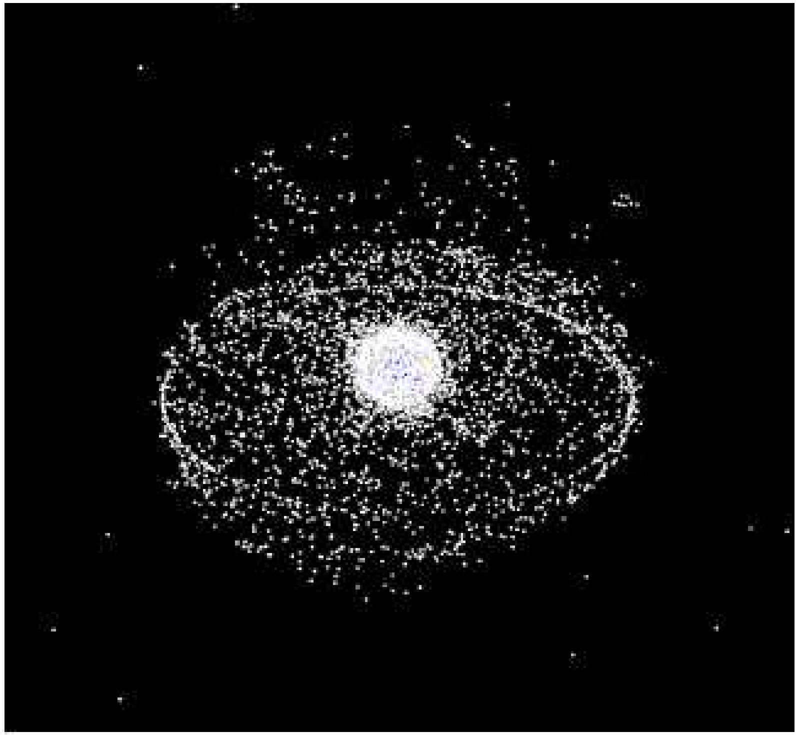




Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

2005

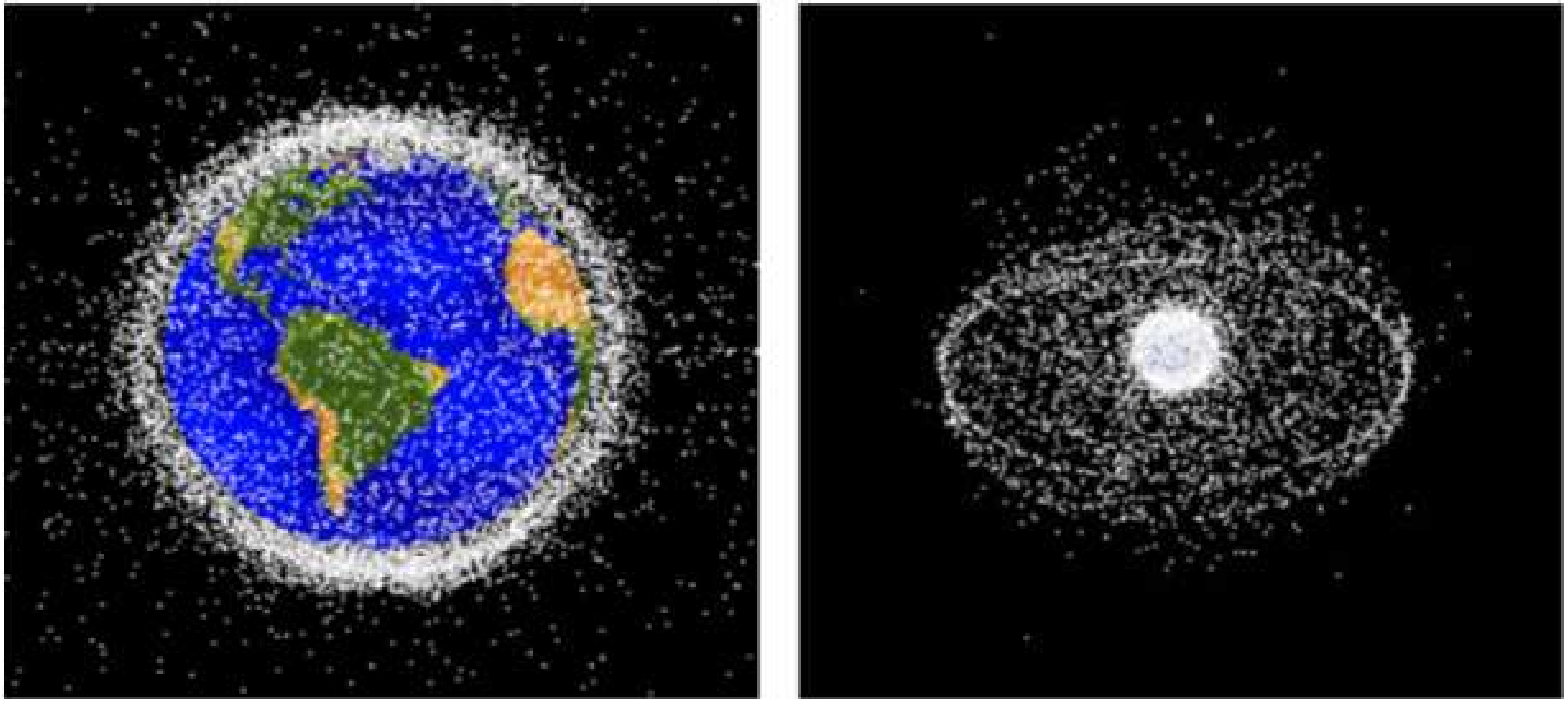




Space & Debris: Our Past , Our Future

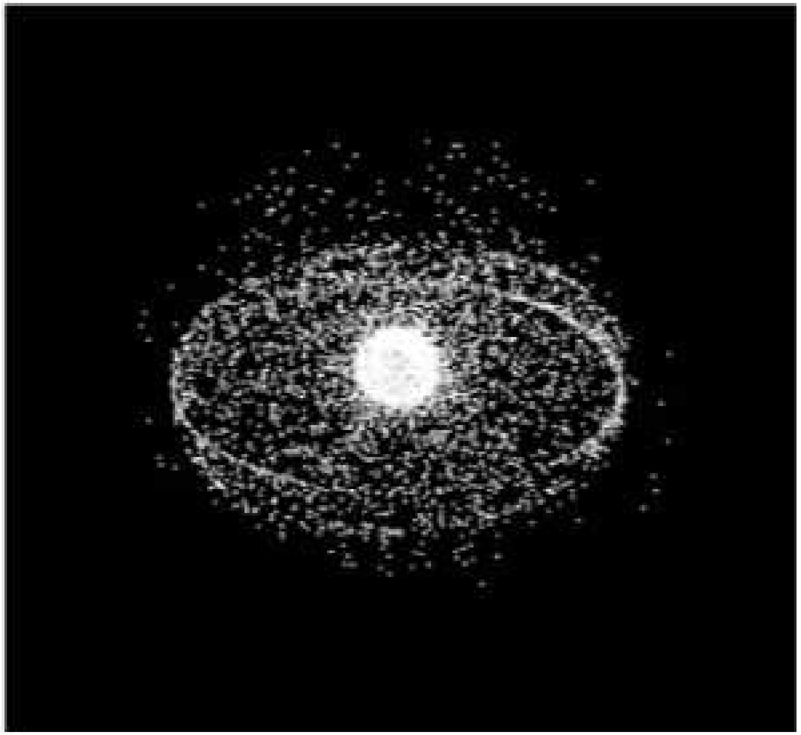
Growth of the Earth orbiting objects population (cataloged objects >10 cm diameter, NASA Space Debris Office / US Space Surveillance Network SSN)

2008



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

2009

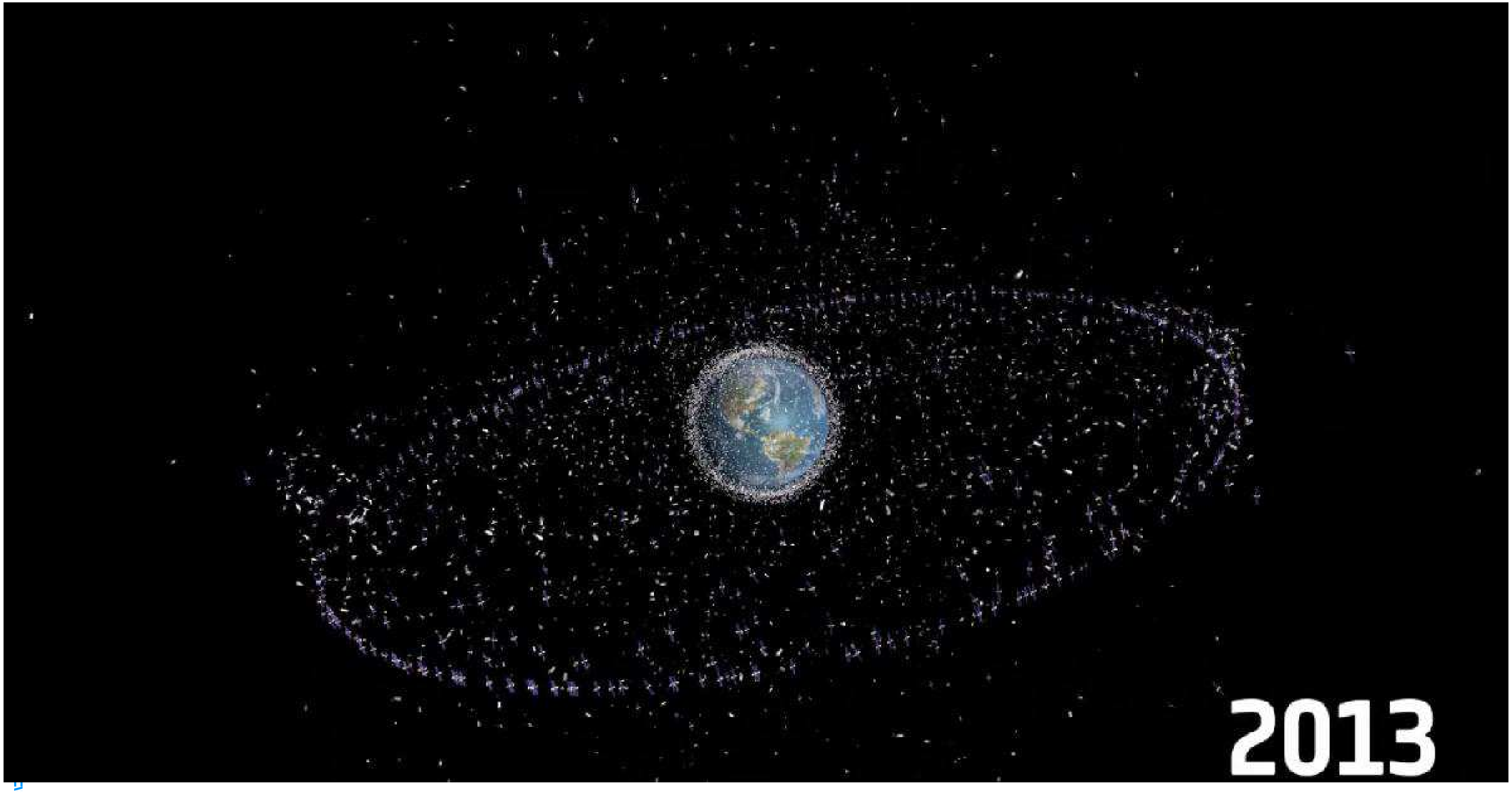


Space Objects > 1cm

Credits: TUBS-ILR

Space Objects (courtesy of ESA)

3_Space_Debris_total.vlc

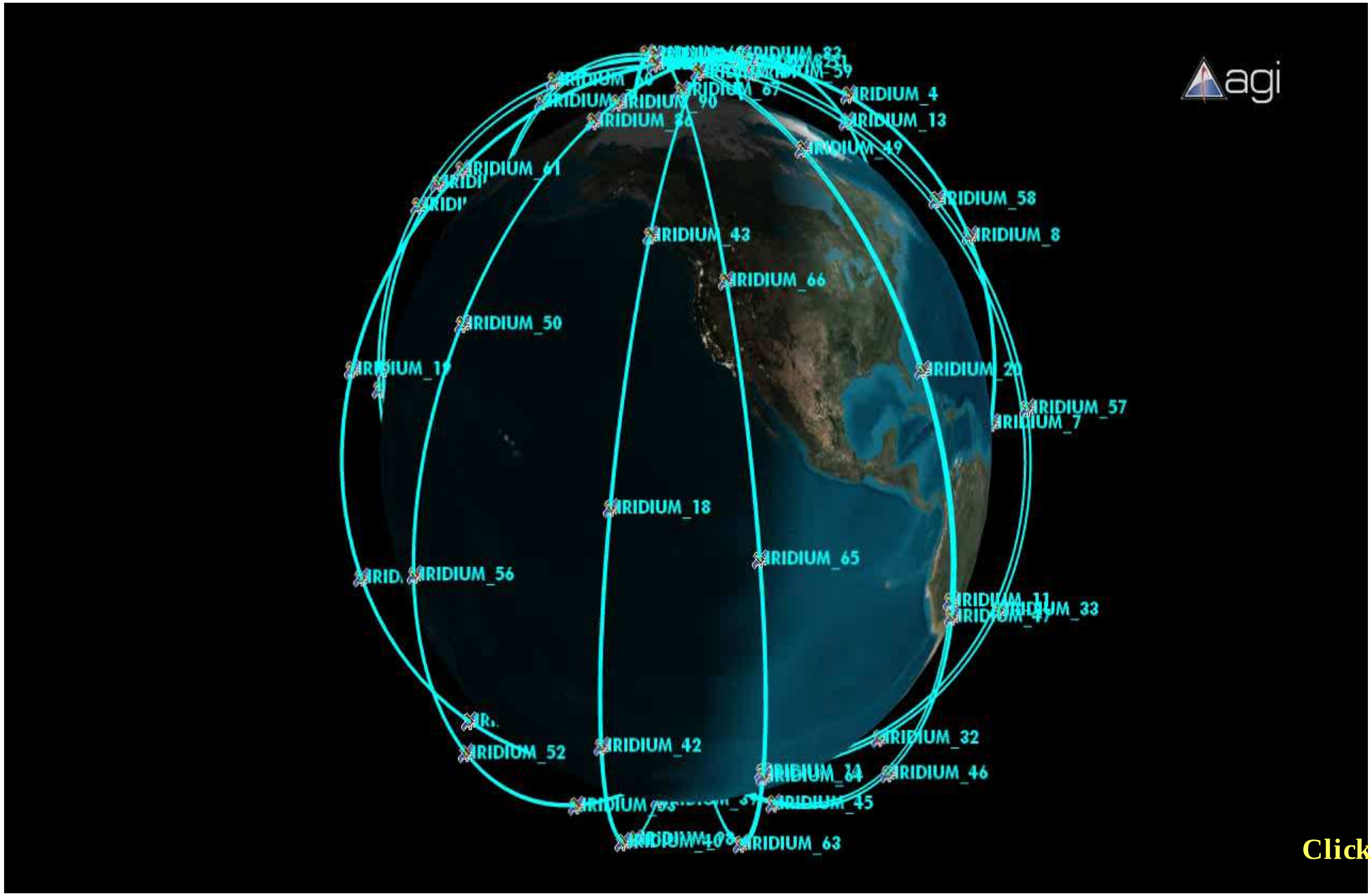


Space Debris Overview

Space Debris Environment
and
Critical Events

Cosmos 2251- US Iridium 33 collision (2009)

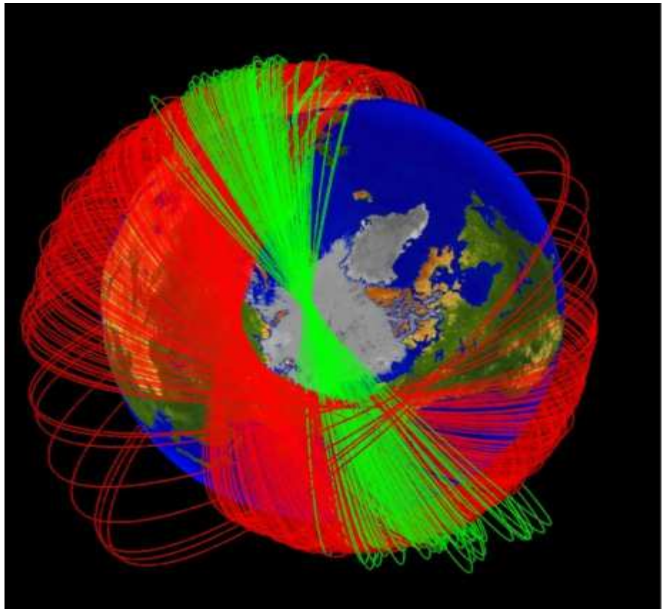
IridiumCosmos_v3



Iridium 33 – Cosmos 2251 Collision (2009)

The first ever accidental collision between two intact satellites occurred on 10/02/2009 at 1656 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

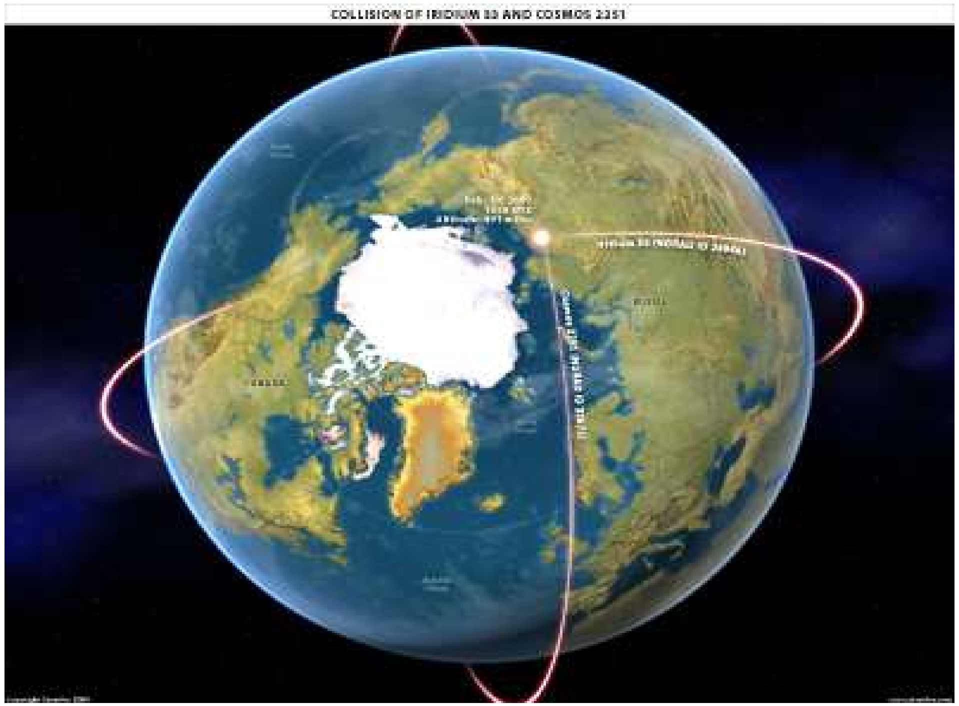
Cosmos:

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

I '= 100:73

Hyper-velocity impact:

- Vimp ' 11:48 km/s
- E 1010 J



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

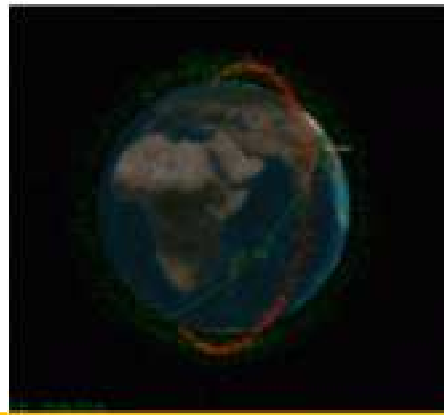
On 11/01/2007, a 958 kg Chinese satellite Feng Yun 1C (1999) was destroyed by a Dong Feng missile in a Chinese anti-satellite test.

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)

More than 5160 space missions conducted since 1957 (as of 1 January 2016)

More than 200 break-up events

The worst event generated almost 20% of the entire population of the catalogued man made debris in Earth Orbit.

Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	Cataloged Debris	Debris in Orbit	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	3428	2880	intentional collision
2	1993	36	Cosmos 2251	2009	790	1668	1141	accidental collision
3	1994	29	STEP-2 Rocket Body	1996	625	754	84	accidental explosion
4	1997	51	Iridium 33	2009	790	628	364	accidental collision
5	2006	26	Cosmos 2421	2008	410	509	0	unknown
6	1986	19	SPOT-1 Rocket Body	1986	805	498	32	accidental explosion
7	1965	82	OV2-1 / LCS 2 Rocket Body	1965	740	473	33	accidental explosion
8	1999	57	CBERS 1 / SACI 1 Rocket Body	2000	740	431	210	accidental explosion
9	1970	25	Nimbus 4 Rocket Body	1970	1075	376	235	accidental explosion
10	2001	49	TES Rocket Body	2001	670	372	80	accidental explosion
						9137	**5059**	

* as of 04 January 2016

Top 10 Breakups, January 2016 (ODQN, P. Anz-Meador)

Critical Events (Collisions / Break up)

More than 5160 space missions conducted since 1957 (as of 1 January 2016)

Only 10 missions account for 1/3 of all catalogued objects currently in Earth orbit

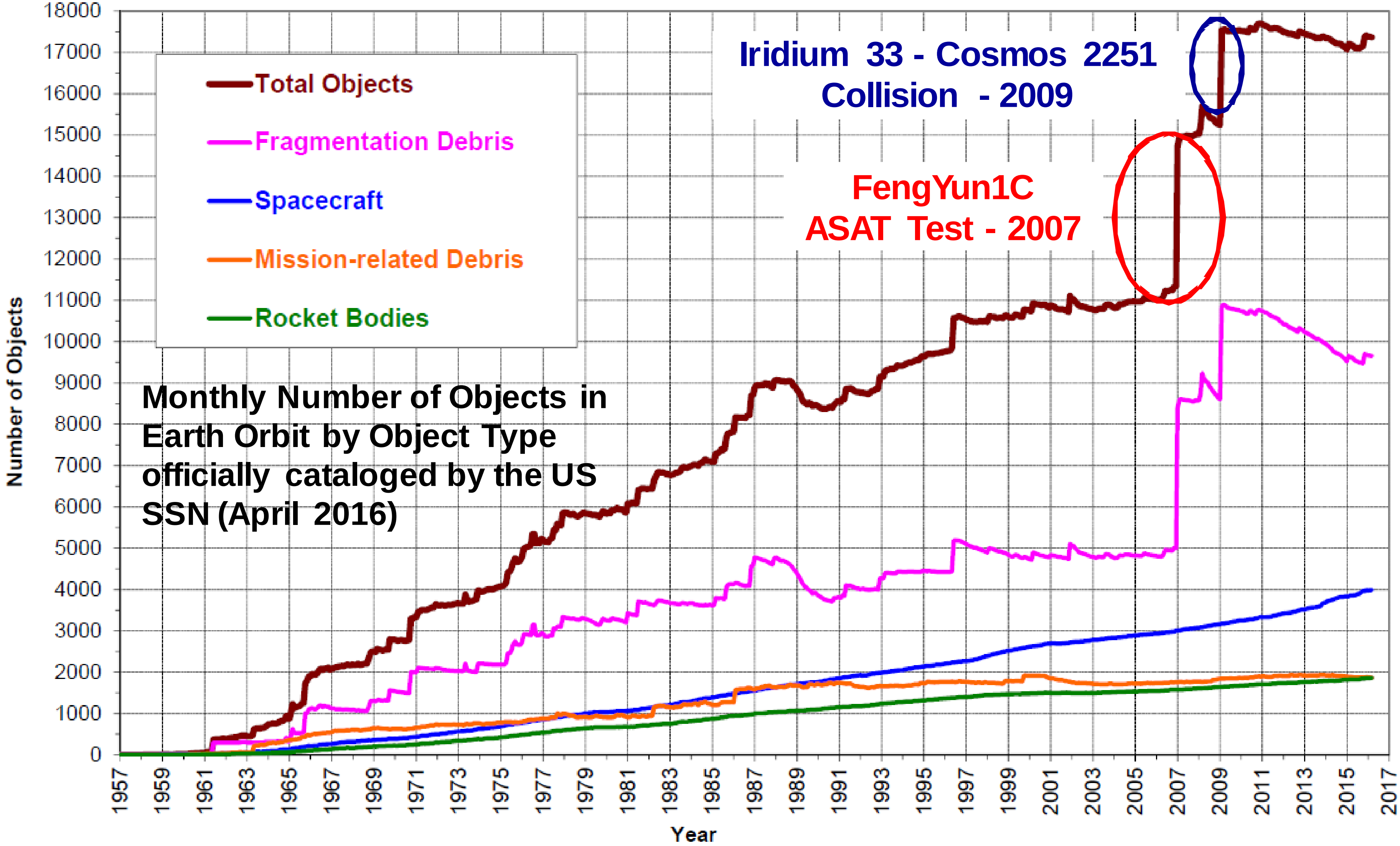
Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	In Orbit*	Total	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	2880	3428	intentional collision
2	1993	36	Cosmos 2251	2009	790	1141	1668	accidental collision
3	1997	51	Iridium 33	2009	790	364	628	accidental collision
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

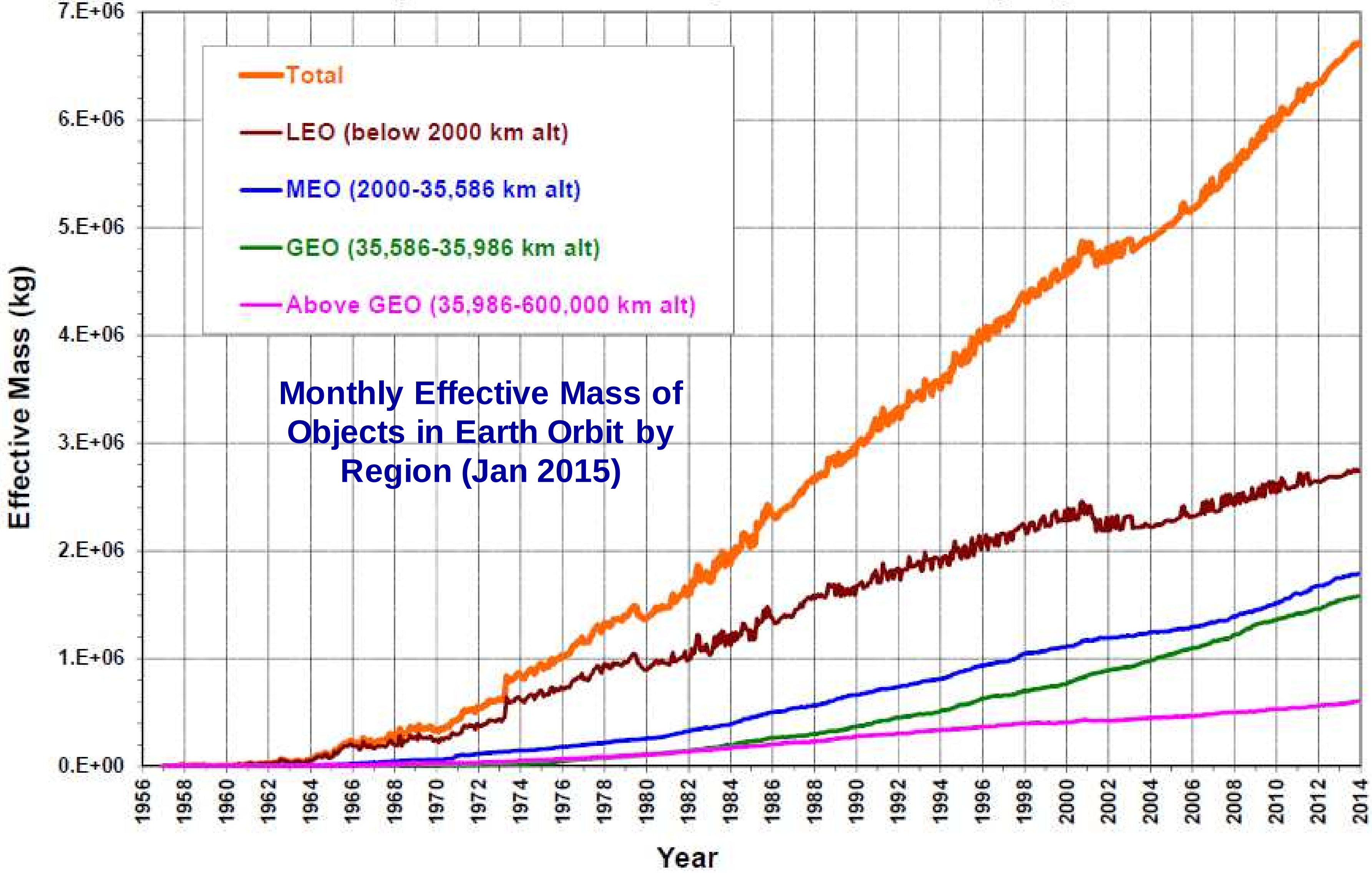
multiple events associated with this SL-16 Zenit second stage

Number of Debris in Orbit, January 2016 (ODQN, P. Anz-Meador)

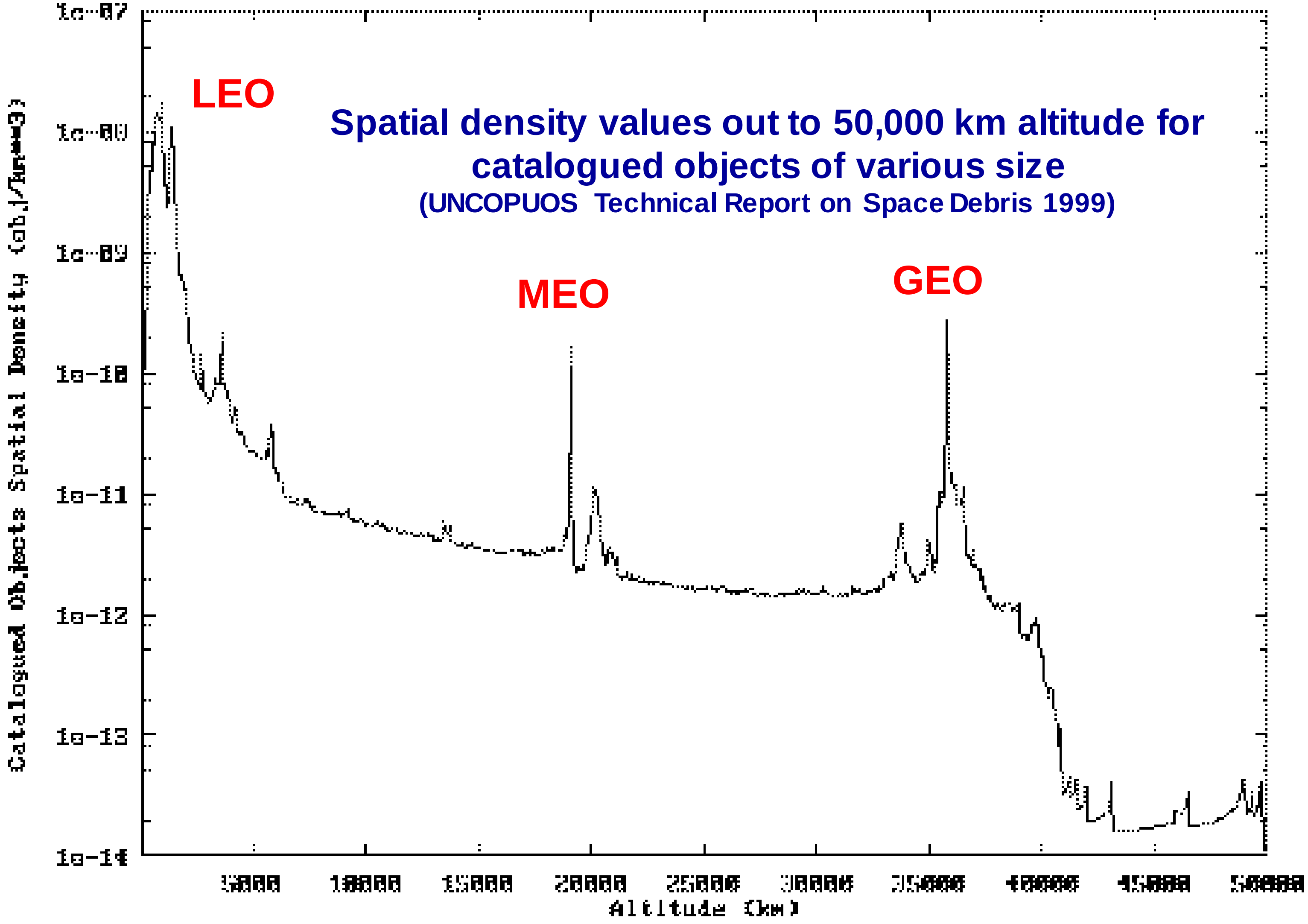
History of On-Orbit Space Objects



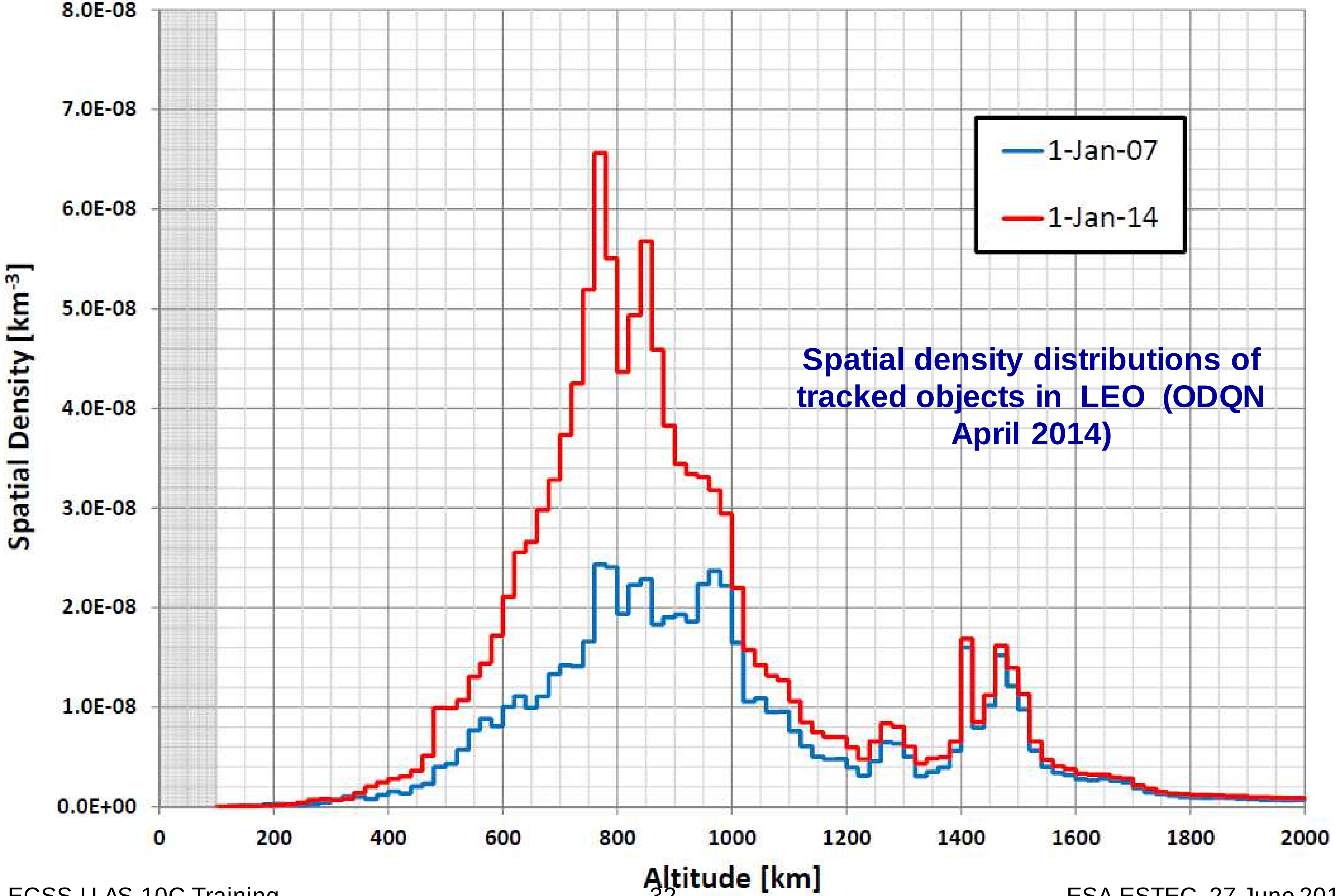
History of On-Orbit Space Objects



Distribution of On-Orbit Space Objects



Distribution of On-Orbit Space Objects



Space Debris Overview

Effects of Space Debris on Space Systems

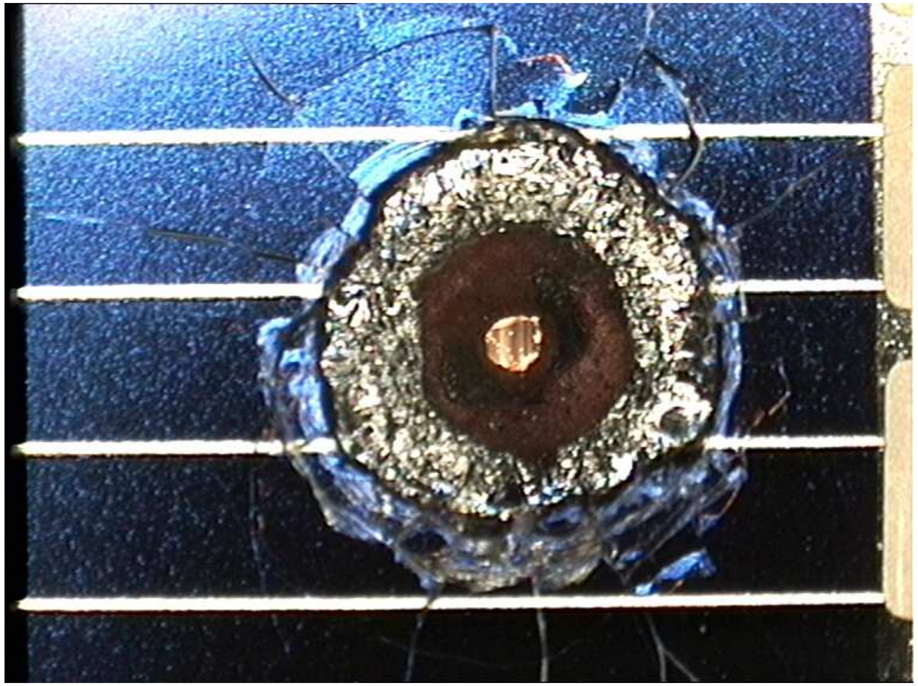
Debris (and meteoroids) impact effects

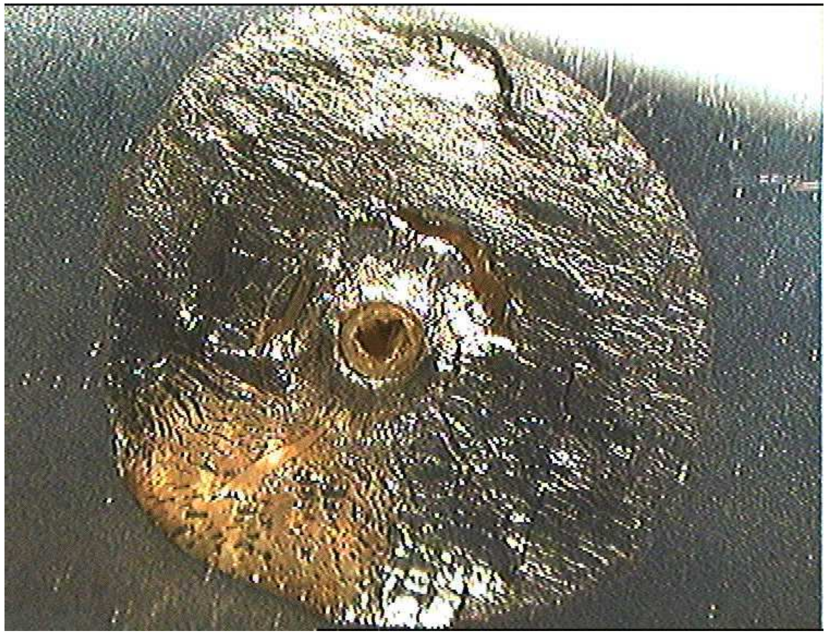
Damage caused by collisions with debris (and meteoroids) depends on size, density, speed and direction of impacting particle, and on the spacecraft shielding. Average impact collisions with the International Space Station are about 19-20 km/s (meteoroids); 10-11 km/s (debris, with significant variations 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 require replacement), penetration of MLI, penetration of solar cells (short circuits, arc burning)

Debris (and meteoroids) impact effects

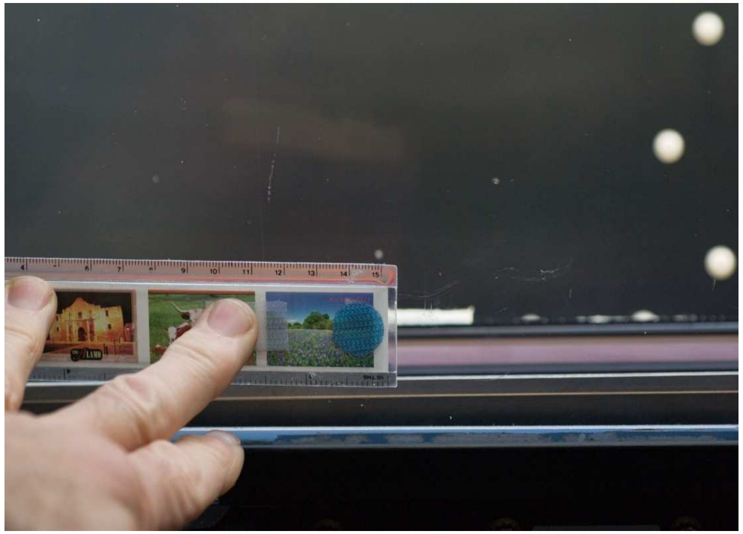
Impact on HST Solar Cell
Crater size: 3.5 mm;
Hole size: 0.5 mm





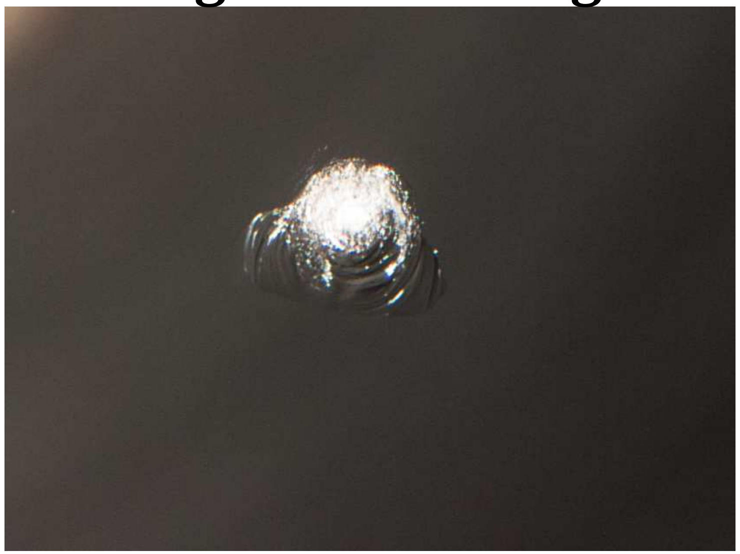
Impact on HST MLI
Outer damage size: 5 mm;
Hole size: 464 um

Debris (and meteoroids) impact effects: Cupola Windows



2012 Ding

August 2014 Ding



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

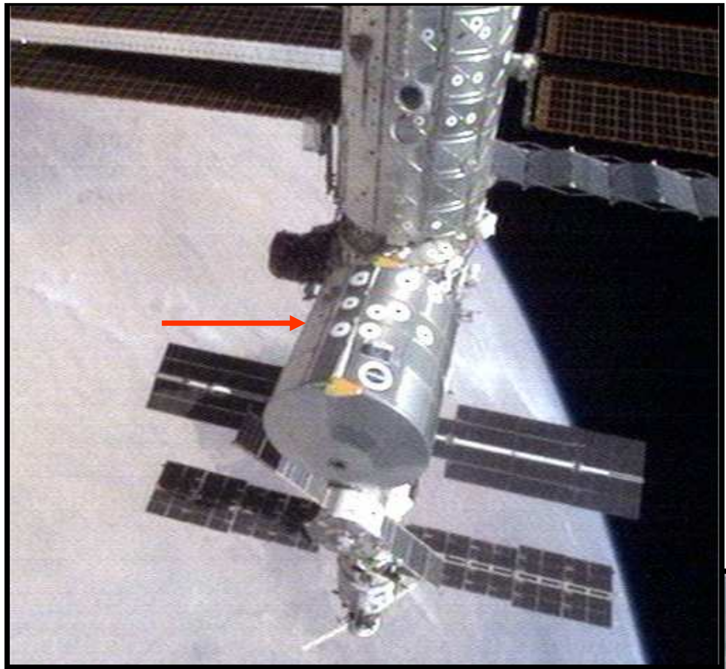
Debris (and meteoroids) impact effects

- **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.

Debris (and meteoroids) impact effects

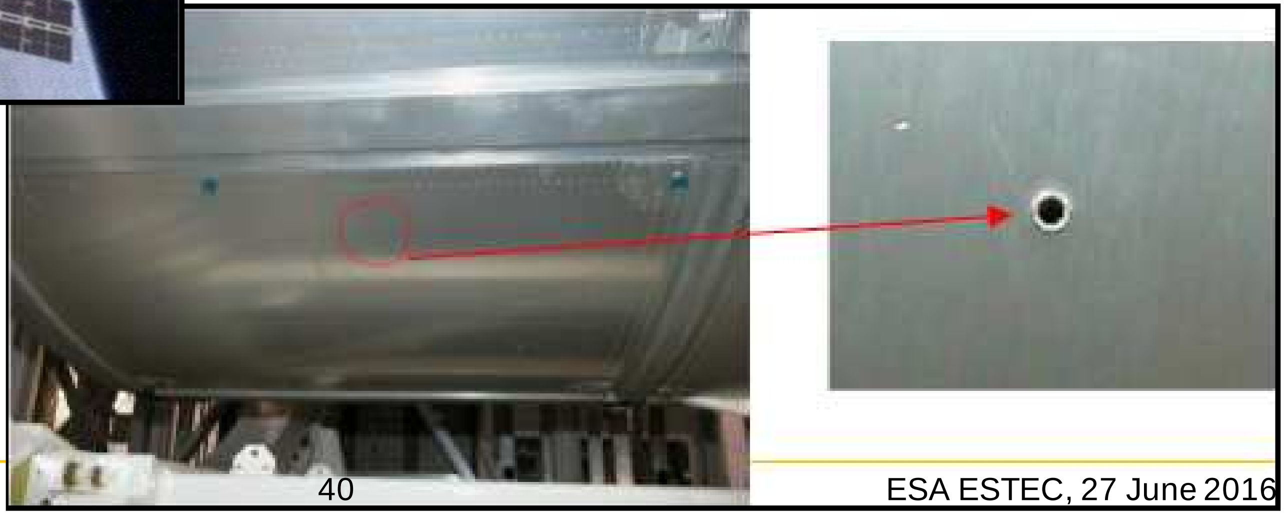
More than 26 impacts reported on MPLM over the first 5 missions



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

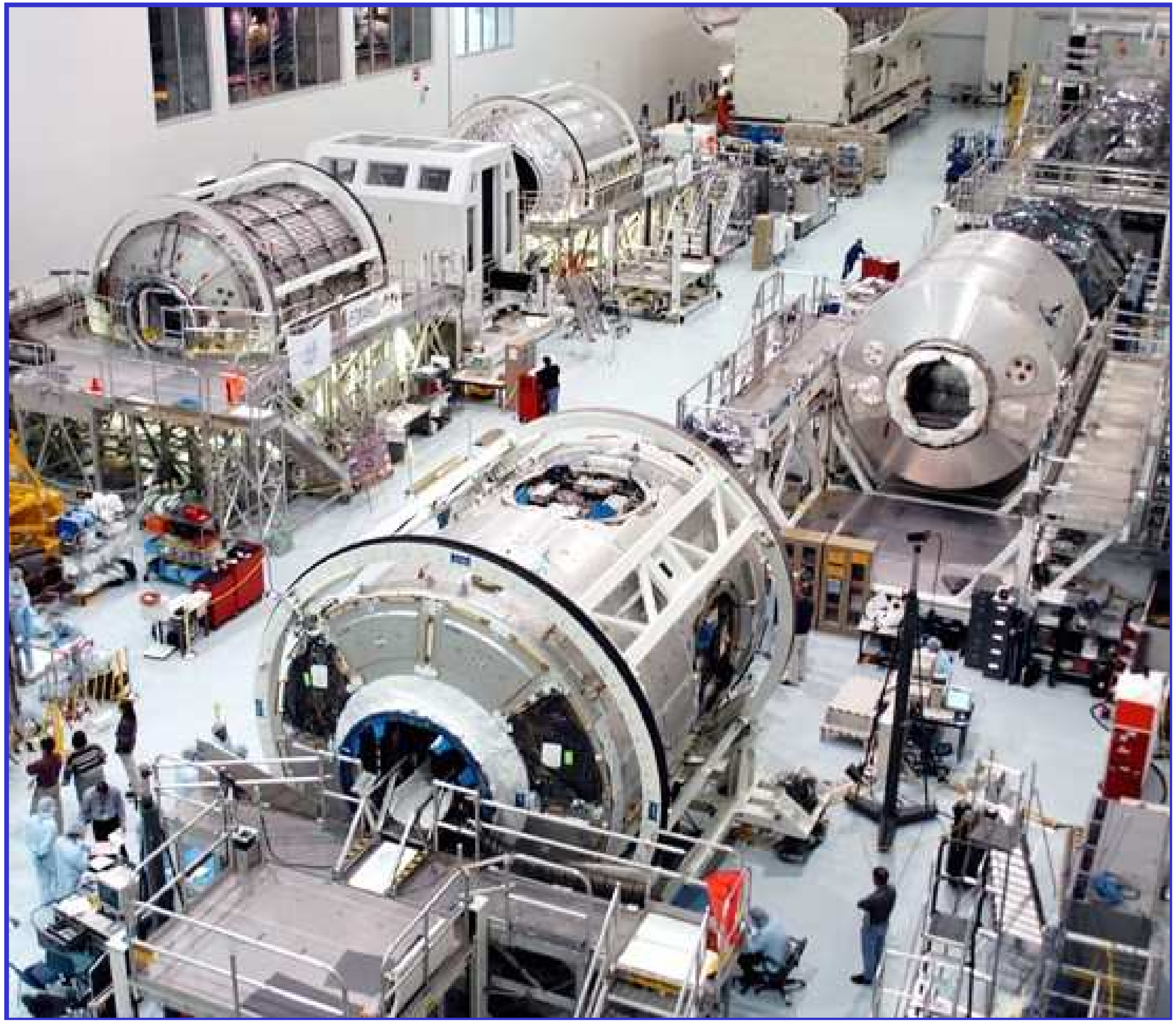
Largest impact: through hole in bumper shield 1.2 mm diam. According to NASA impactor could be a paint flake about 0.46 mm diam.

No damage to MLI underneath.



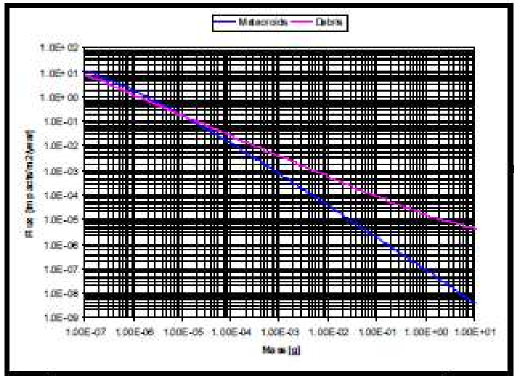
Debris (and meteoroids) effects: MMOD Risk Assessment

TAS-I crewed elements at KSC

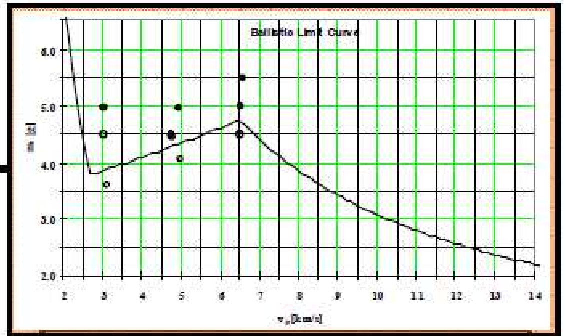


EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Manned SC

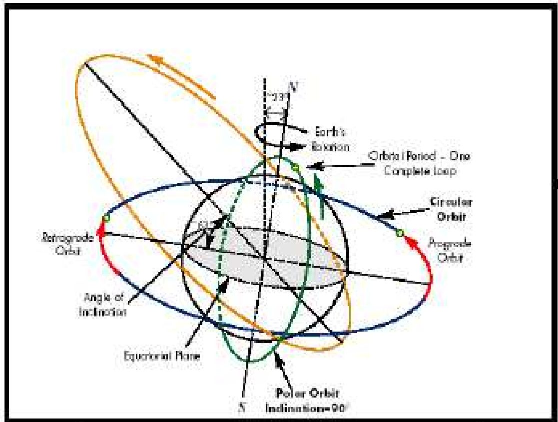


MMOD ENVIRONMENT



BLE (DAMAGE EQUATIONS)

ESABASE/DEBRIS
3D
TOOLS



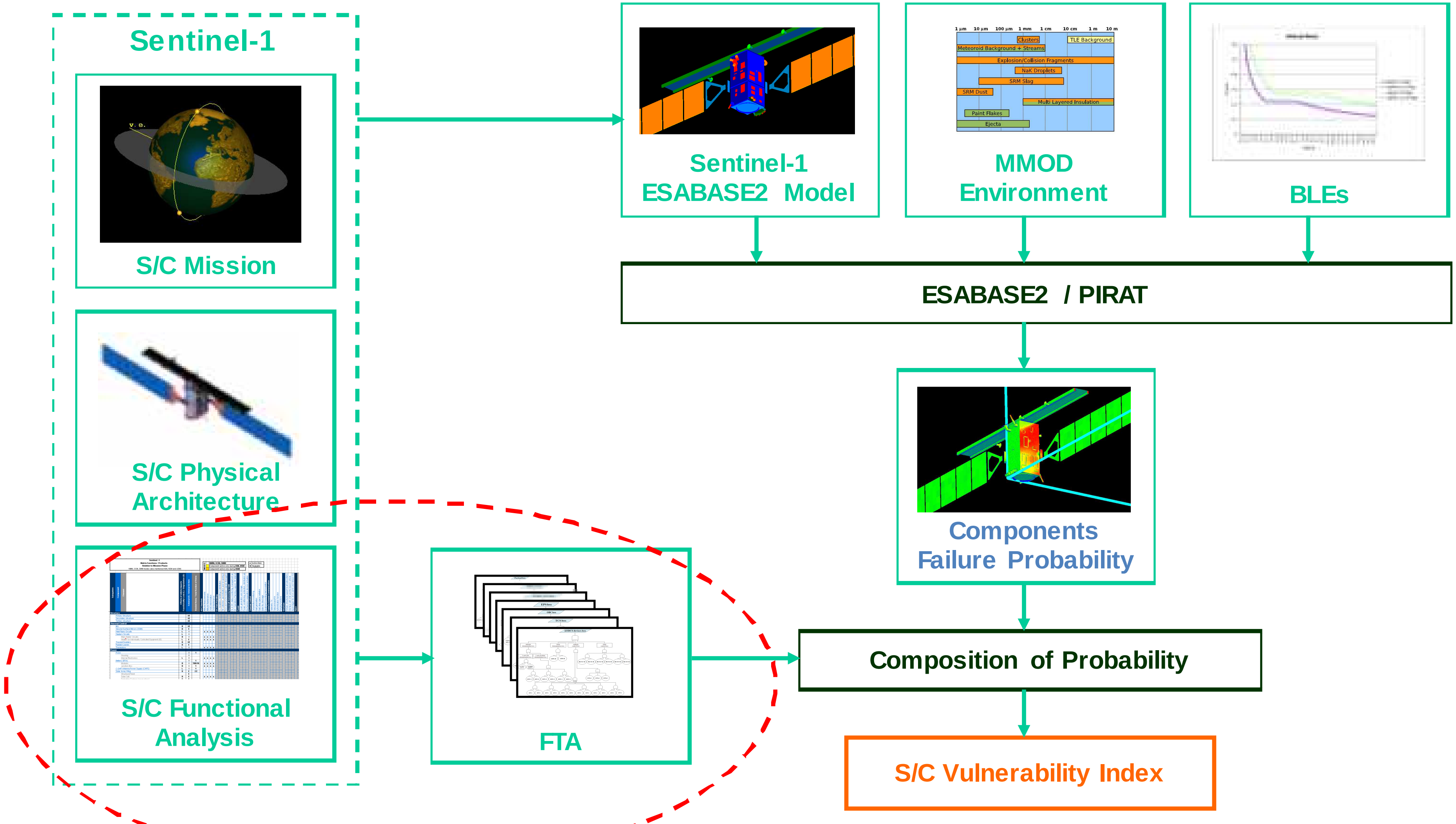
MISSION PROFILE

Number of MMOD
impacts / failures
(Risk level)

SPACECRAFT GEOMETRY

Debris (and meteoroids) effects: MMOD Risk Assessment

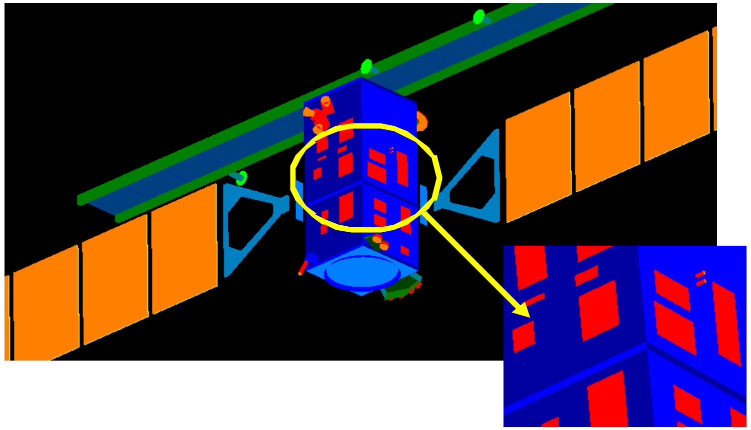
Unmanned SC

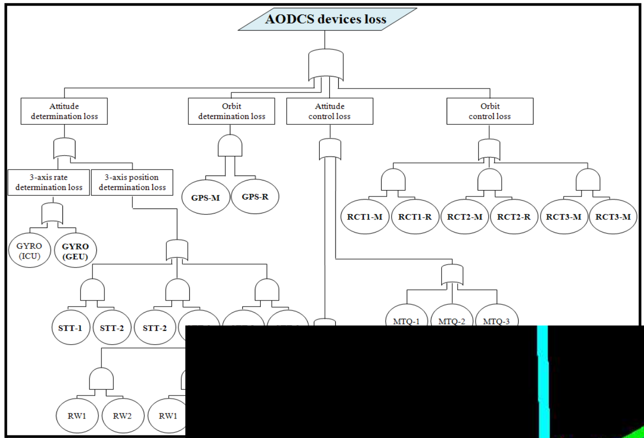


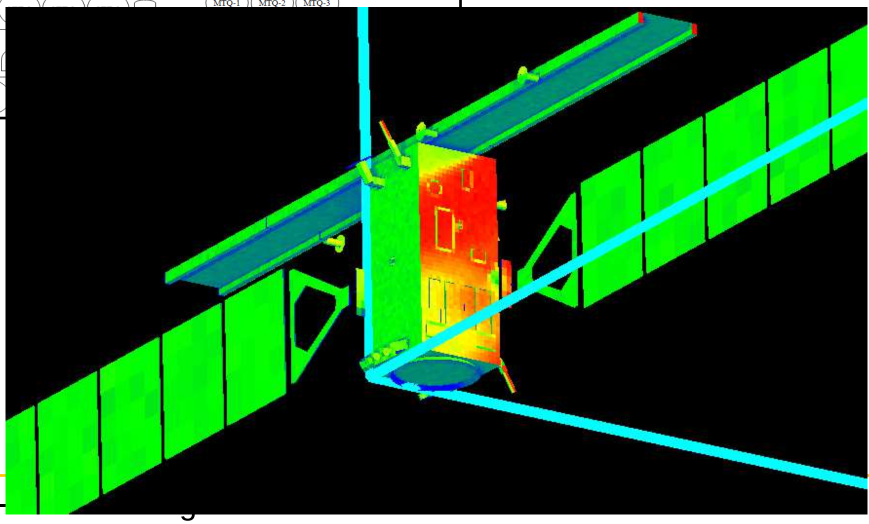
Debris (and meteoroids) effects: MMOD Risk Assessment

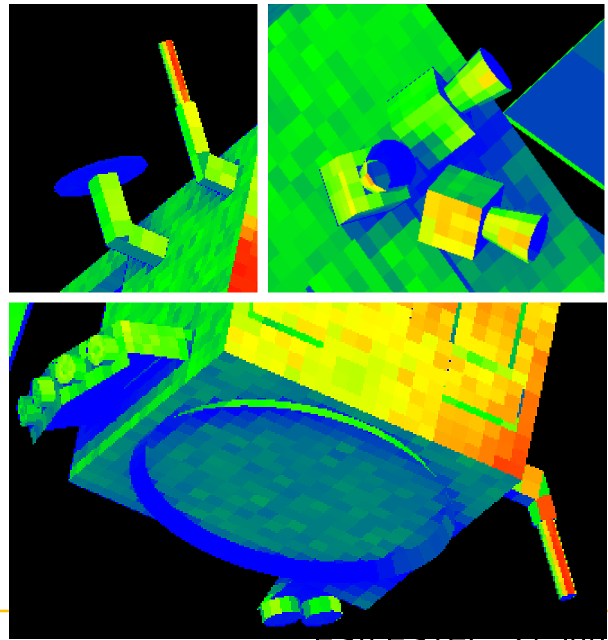
Sentinel 1A

- Orbit: 693 km, 98.11°
- ESABASE2\Debris tool
- MASTER2009 Debris model
- Fault Tree Analysis









Debris effects: Collision Avoidance (COLA) Manoeuvres

25 COLA manoeuvres conducted from 1999 to 2015 Q3 (average 1,6 per year)

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

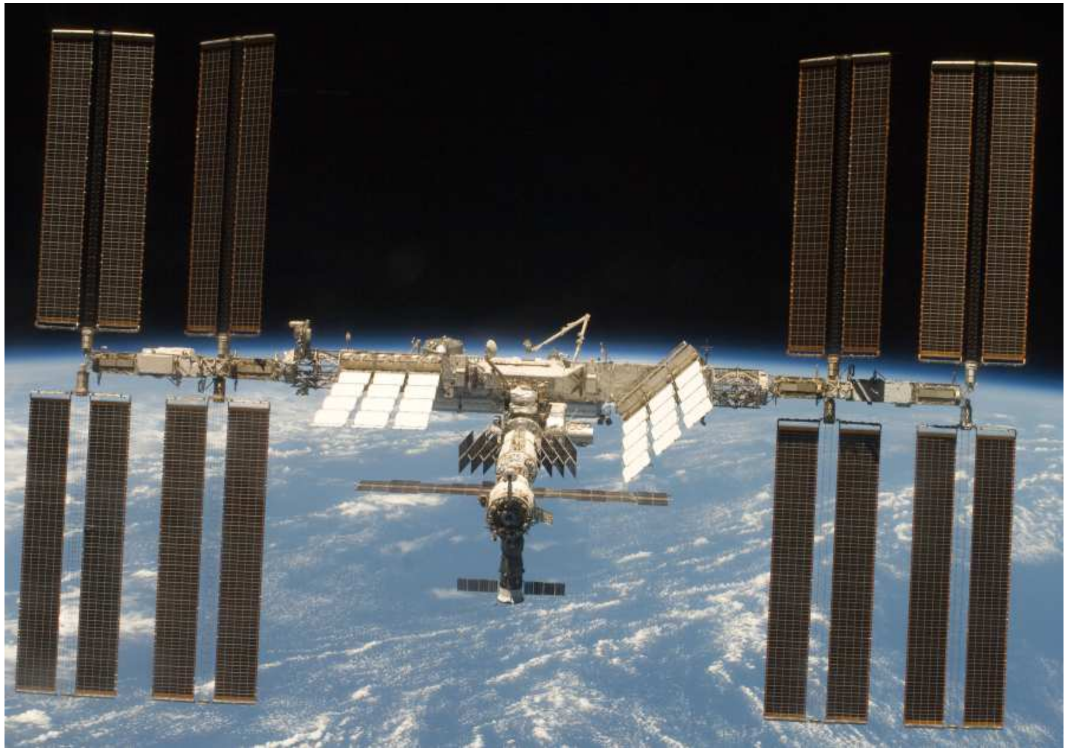
Date of Maneuver or Close Approach	Object Avoided	Action Taken
2-April-2011	Fragmentation debris from Russian Cosmos 2251	Collision Avoidance Maneuver
28-June-2011	Debris apparently from Proton ullage motor breakup	Crew retreated to Soyuz due to insufficient time for maneuver
29-September-2011	Russian 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: Collision Avoidance (COLA) Manoeuvres

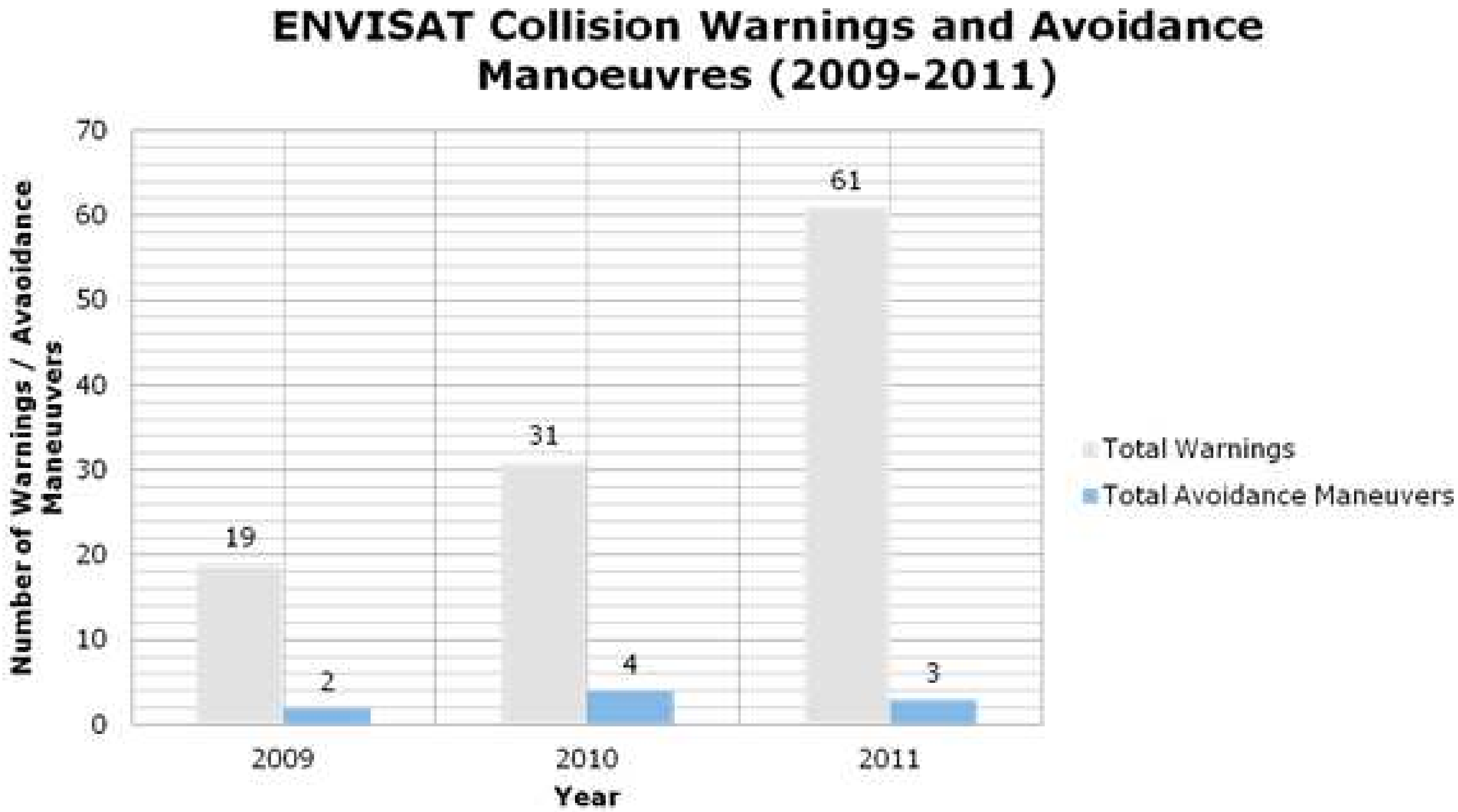
The 24th collision avoidance manoeuvre (Q3 2015) was for a conjunction with an Iridium 33 fragment (from Cosmos 2251 - Iridium 33 collision).

On March 12, 2009, threat by a small debris: #25090 PAM-D debris (a “yo-tumble” of a Delta II PAM-D stage, launched in 1993) with 0.0092 m2 radar cross section, estimated size/mass about 2 inches/1 kg.

- Due to late notification, no Debris Avoidance Manoeuvre was performed
- The 3 crew members of Expedition 18 carried out a contingency “evacuation” into the Soyuz
- #25090 debris orbit: 4230 km x 143 km, 34.7° inclination, 0.24 eccentricity
- Closest distance was 2.4 km, relative velocity 9.43 km/s



Debris effects: Collision Avoidance (COLA) Manoeuvres



<u>collision warning</u> ~ probability > 1 in 10,000 or crossing distance below 300m
<u>collision avoidance maneuver (CAM)</u>~ probability of collision > 1 in 1,000
threshold for preparing the CAM is 1/3,000

Space Debris Overview

Re-entry Risk

Debris effects: Re-entry Risk

Since the launch of the first artificial satellite (1957), approximately 20,000 human-made objects reentered within the Earth atmosphere, with an average of 1.1 human-made objects per day

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.

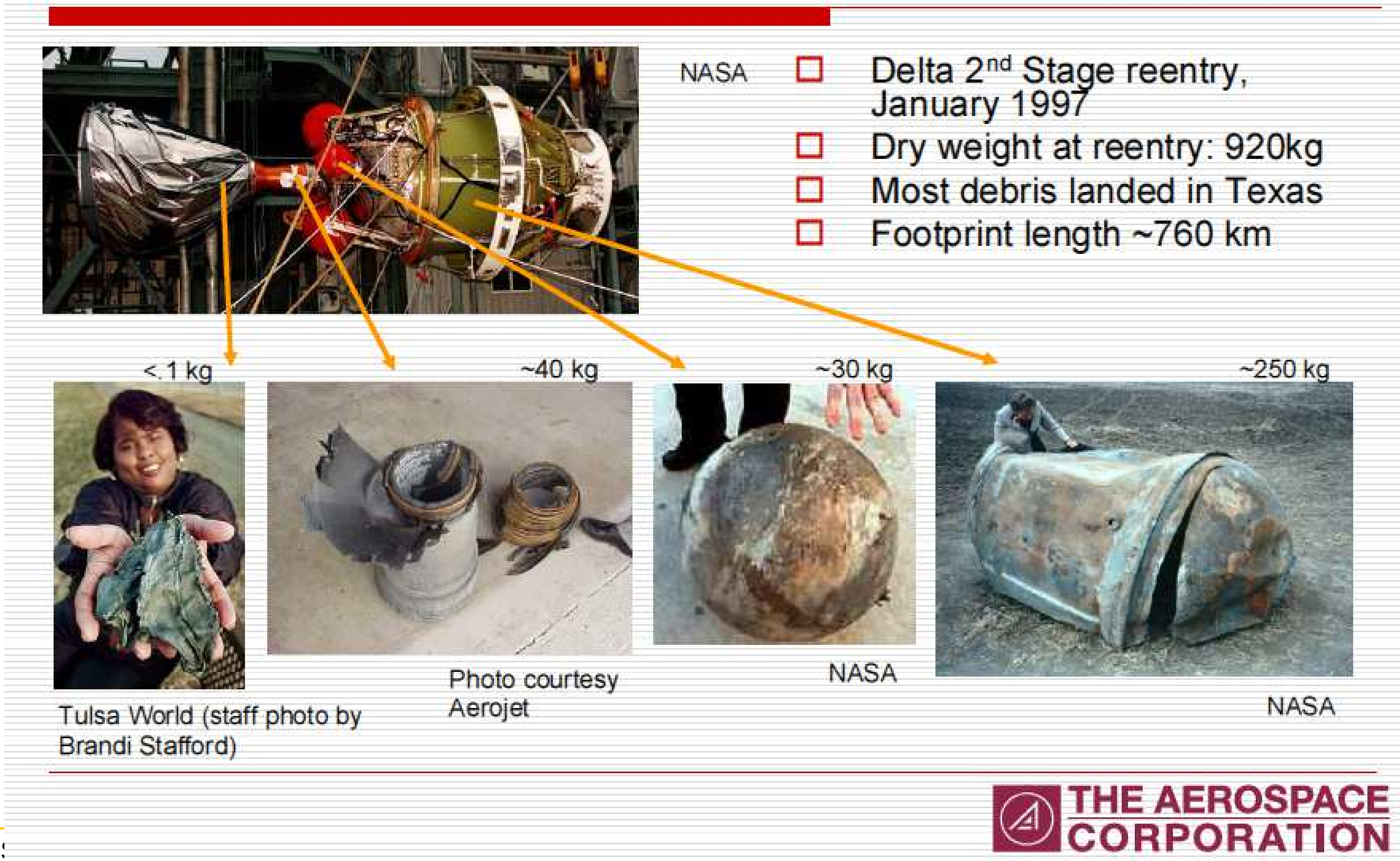
Of the MIR mass of 135,000 kg about 25,000 kg in 1,500 fragments survived re-entry.

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)



Debris effects: Re-entry Risk (Environment)

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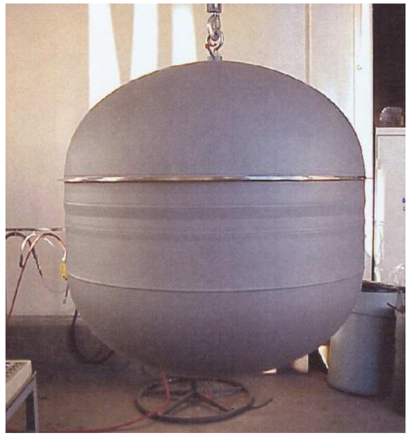
Typical fuels used by spacecraft are hazardous should they impact the ground

- 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 today 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)

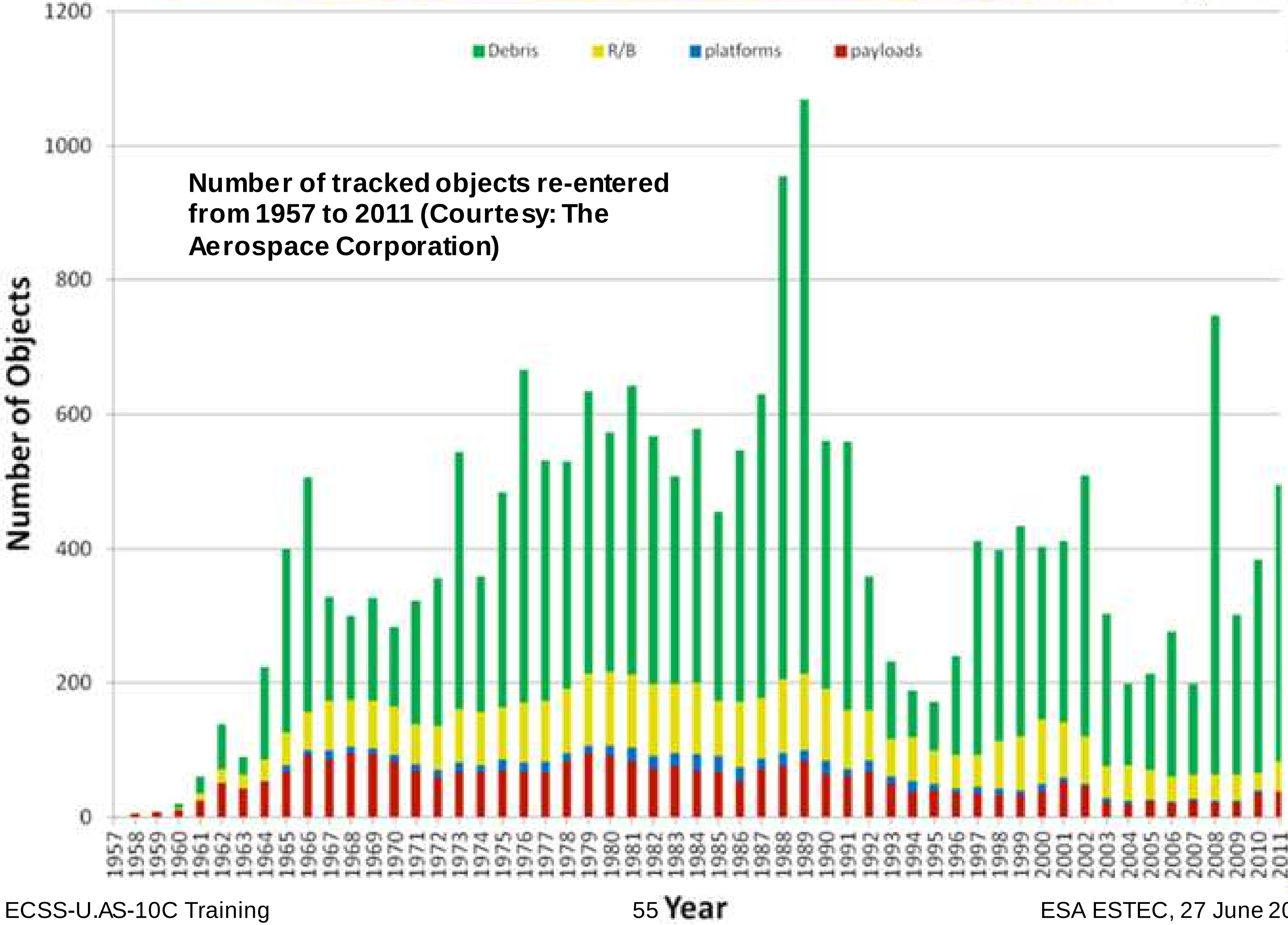
On 24 January 1978, COSMOS 954 nuclear-powered surveillance satellite, crashed in the Northwest Territories, scattering a large amount of radioactivity over a 124,000 square kilometre area in Canada's north, stretching southward from Great Slave Lake into northern Alberta and Saskatchewan.

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



Debris effects: Re-entry (Fuel tanks)

A number of fuel tanks have been recovered after surviving reentry, these pose a risk of casualty or property damage.

South Africa, 2000

Texas, 2001

Saudi Arabia, 2001

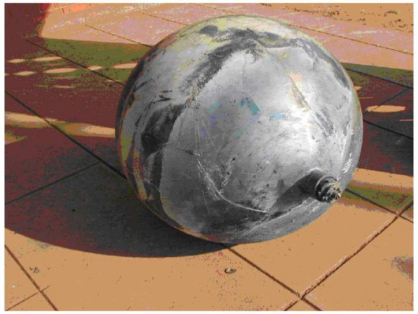
Guatemala, 2003

Australia, 2007

Fuel tanks present impact risk to people, property (should they survive the re-entry) as well as environmental risk due to toxic fuels.

Debris effects: Re-entry LV Orbital Stages

In January 1997, a 30 kg titanium pressurant tank survived the reentry of the Delta 2 second stage. It was found near Seguin, TX



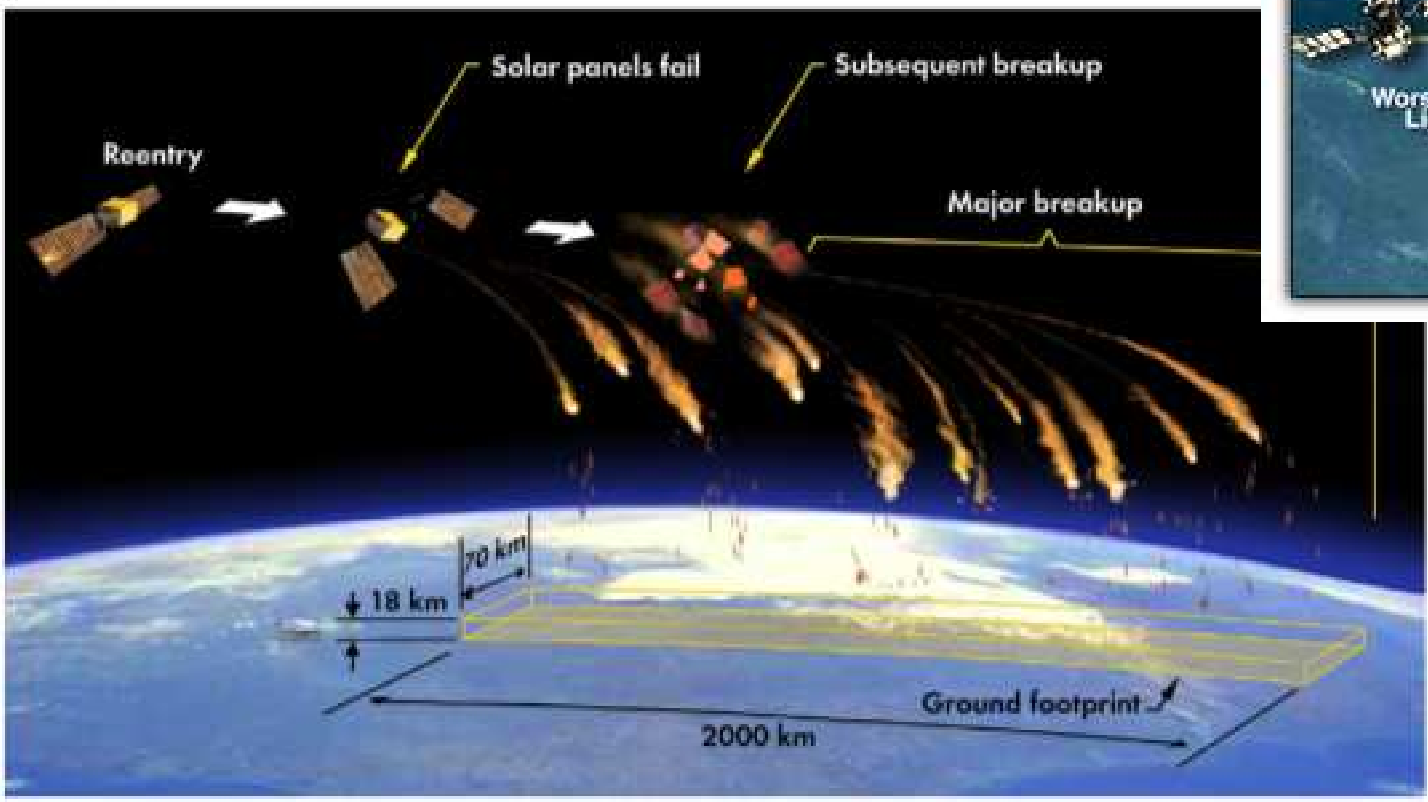
In March 2002, a titanium pressure sphere fell near a home in Kasambya, Uganda. It was Identified as debris from 3rd stage of Ariane launch on May 1985

In Feb 2012, an Ariane 4 3rd-stage rocket body (launch 1997) re-entered in Brazil

The larger part of uncontrolled re-entry debris (60 or 70%) come from Launch Vehicles Orbital Stages

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)

Early Sept. 2011, NASA warned of the risk of a falling satellite (Upper Atmosphere Research Satellite, UARS) to re-enter the atmosphere on Sept. 23 ±1 day.

The satellite was launched in Sept, 1991 and decommissioned on 15th Dec. 2005.

Dry mass = 5,668 kg.

As of 18th Sept. 2011, the orbit was 215 km by 240 km.

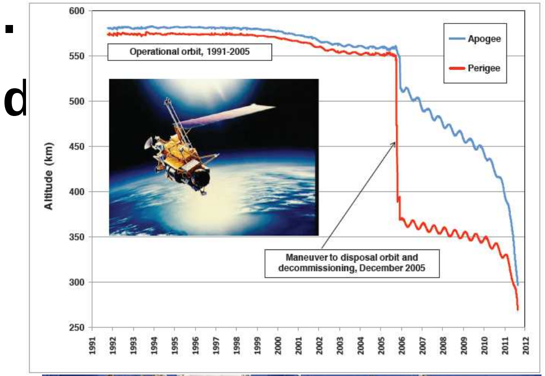
The number of “potential” hazardous objects expected to survive was 26 with a total mass of approx. 532 kg.

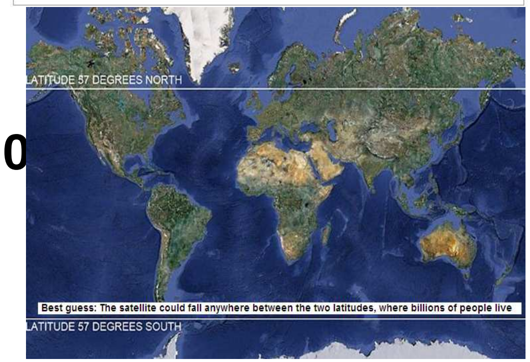
Estimated human causality risk = ~1 in 3200

Any surviving components of UARS were expected to land within a zone between 57º north latitude and 57º south latitude.

The debris field was located between 300 miles and 800 miles downrange, or generally northeast of re-entry point.

Final re-entry date was 23rd Sept. 2011.





Debris effects: Re-entry Risk (UARS)

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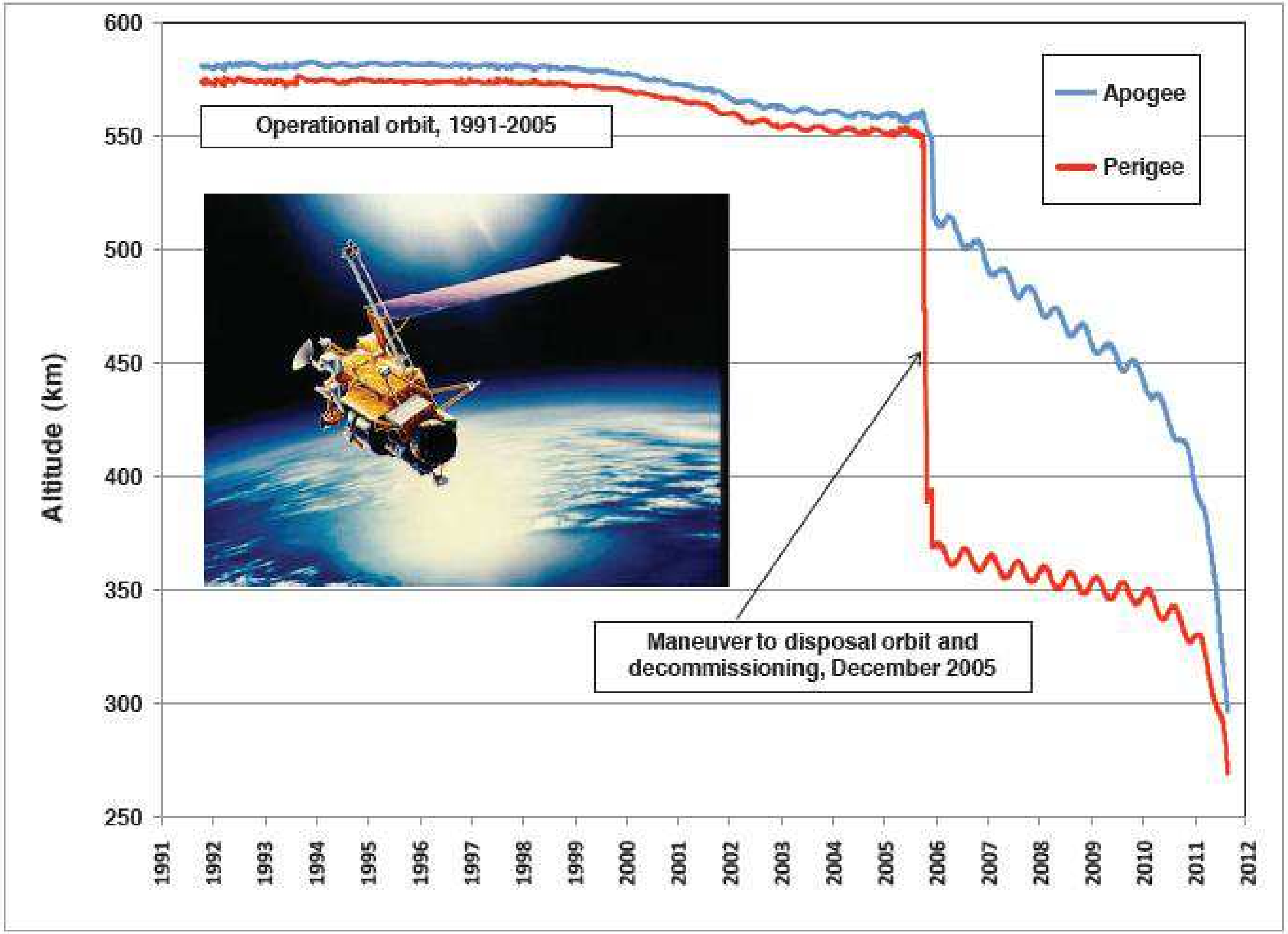
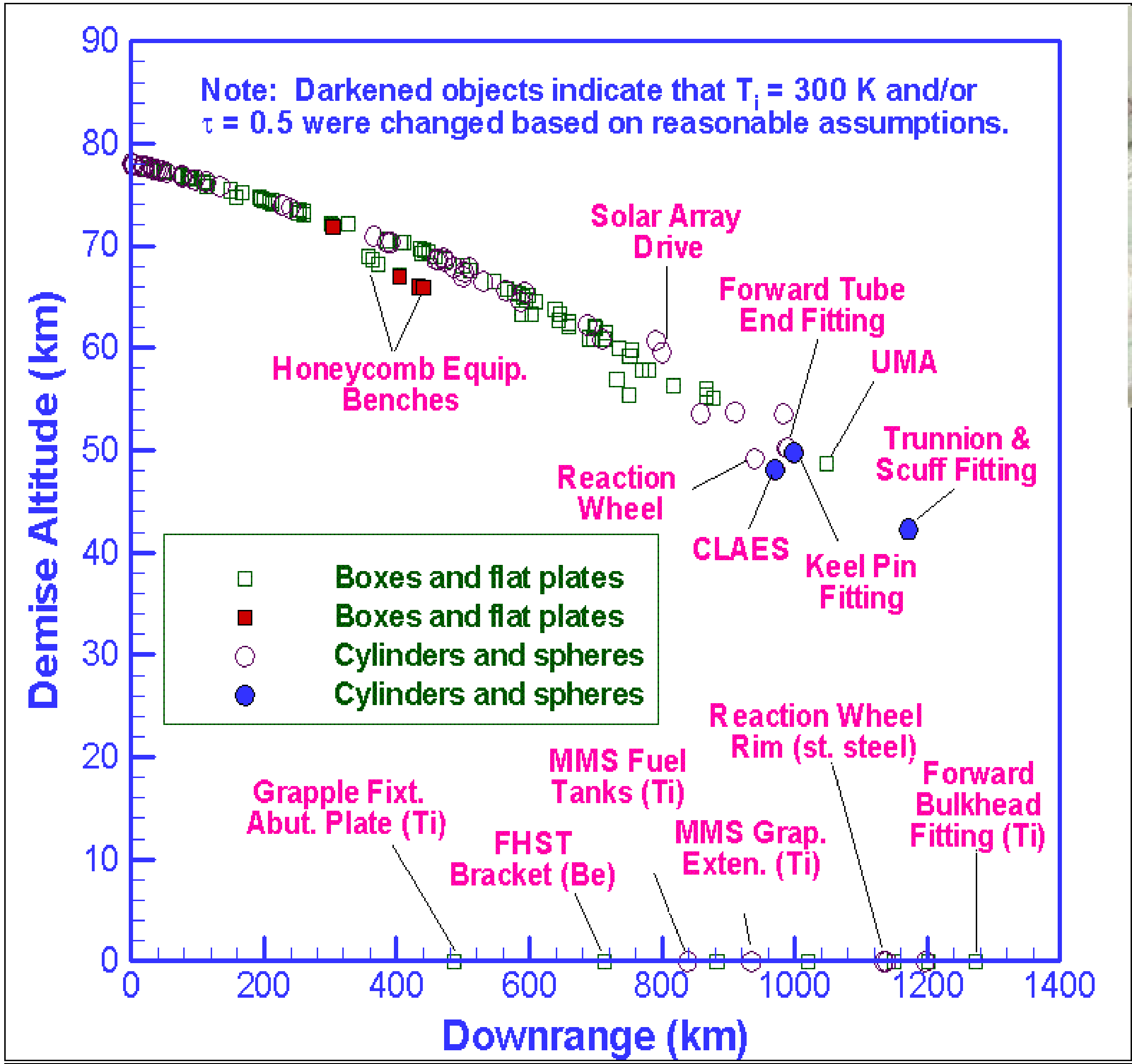


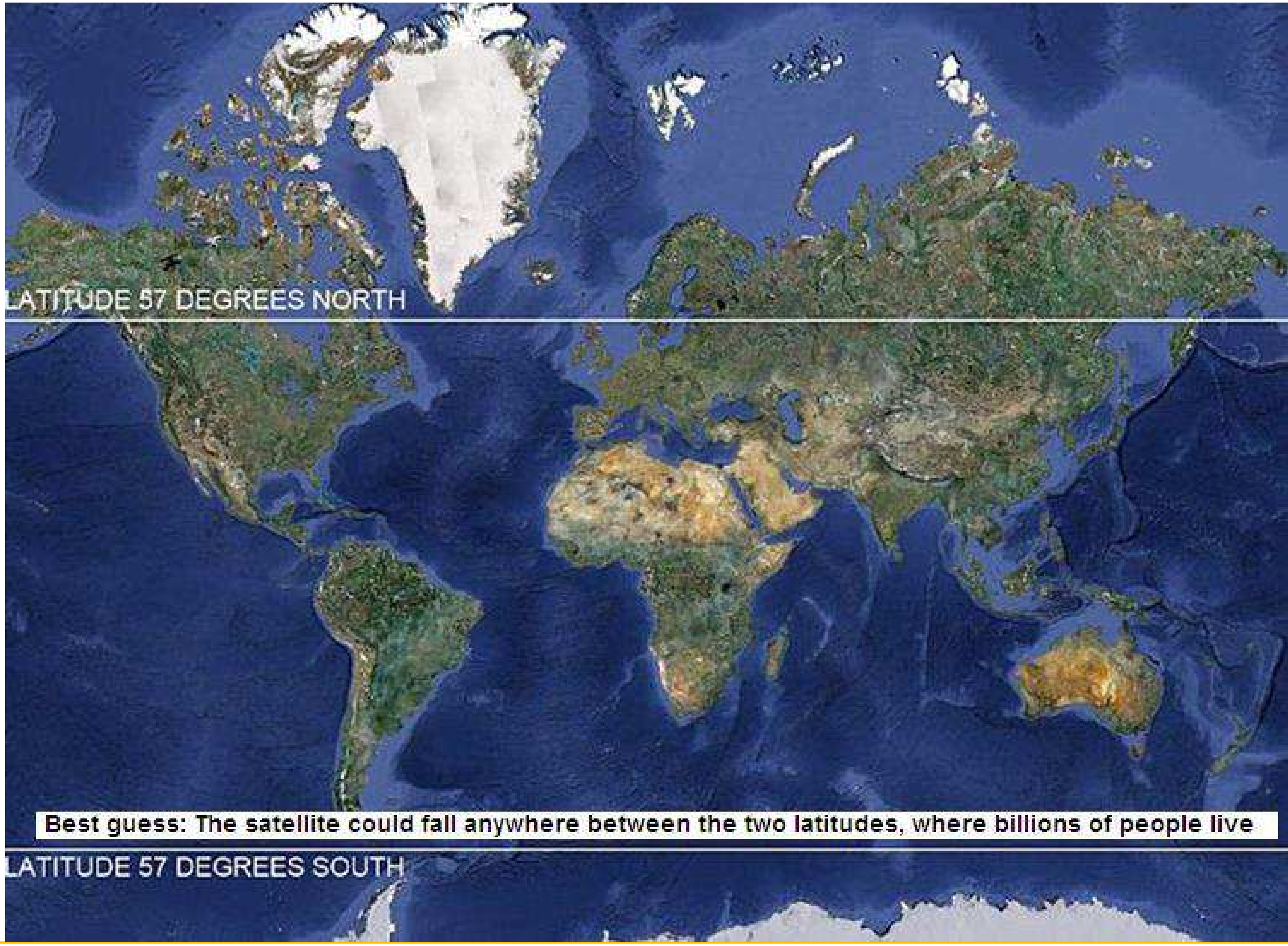
UARS predicted Fragmentation & Footprint



Demise altitude vs. downrange evaluated for nearly all of the UARS components.

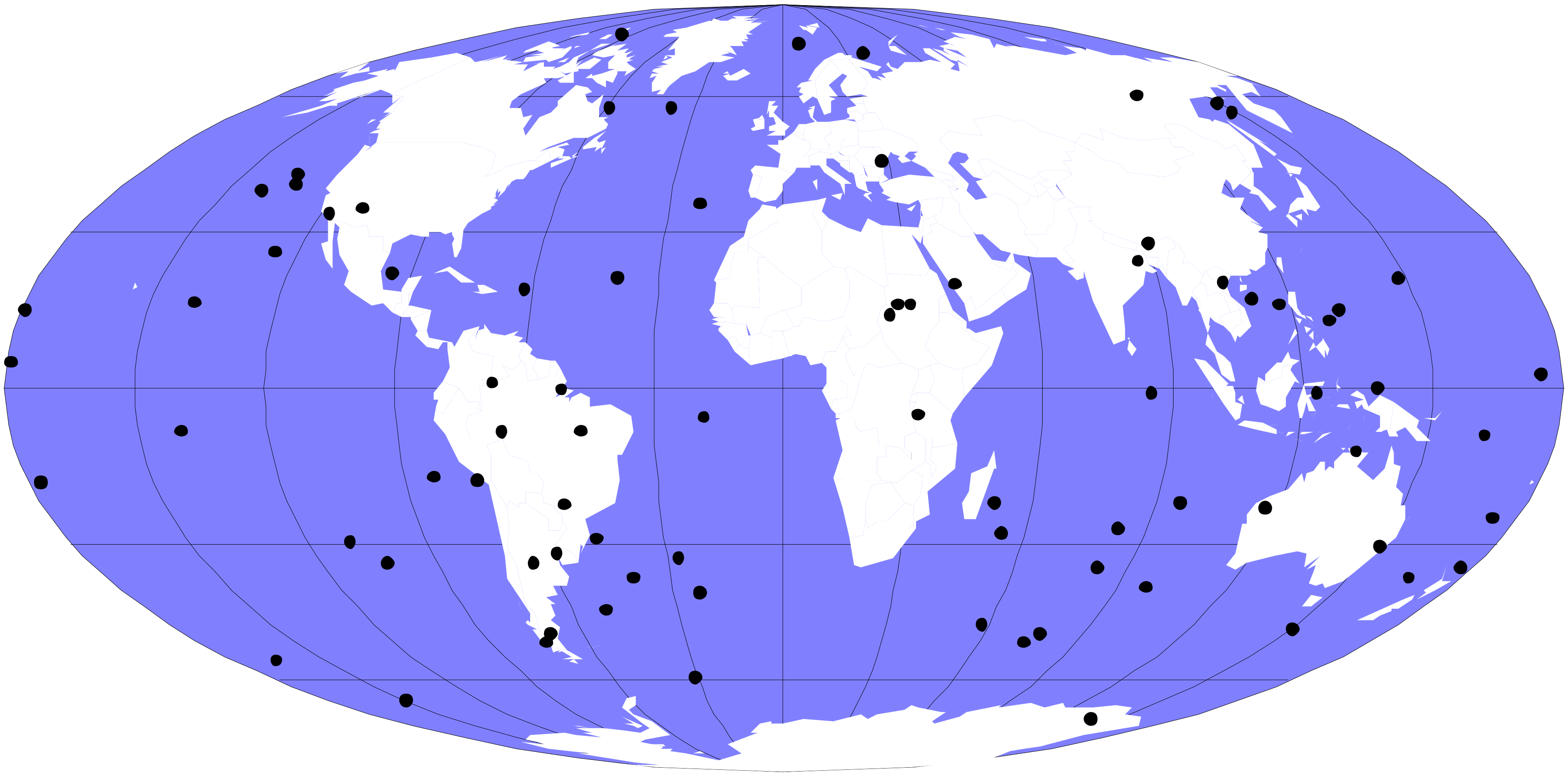
Debris effects: Re-entry Risk (UARS)

Where does UARS could have fallen?



Debris effects: Re-entry Risk

Global Distribution of Circular Orbit Reentries

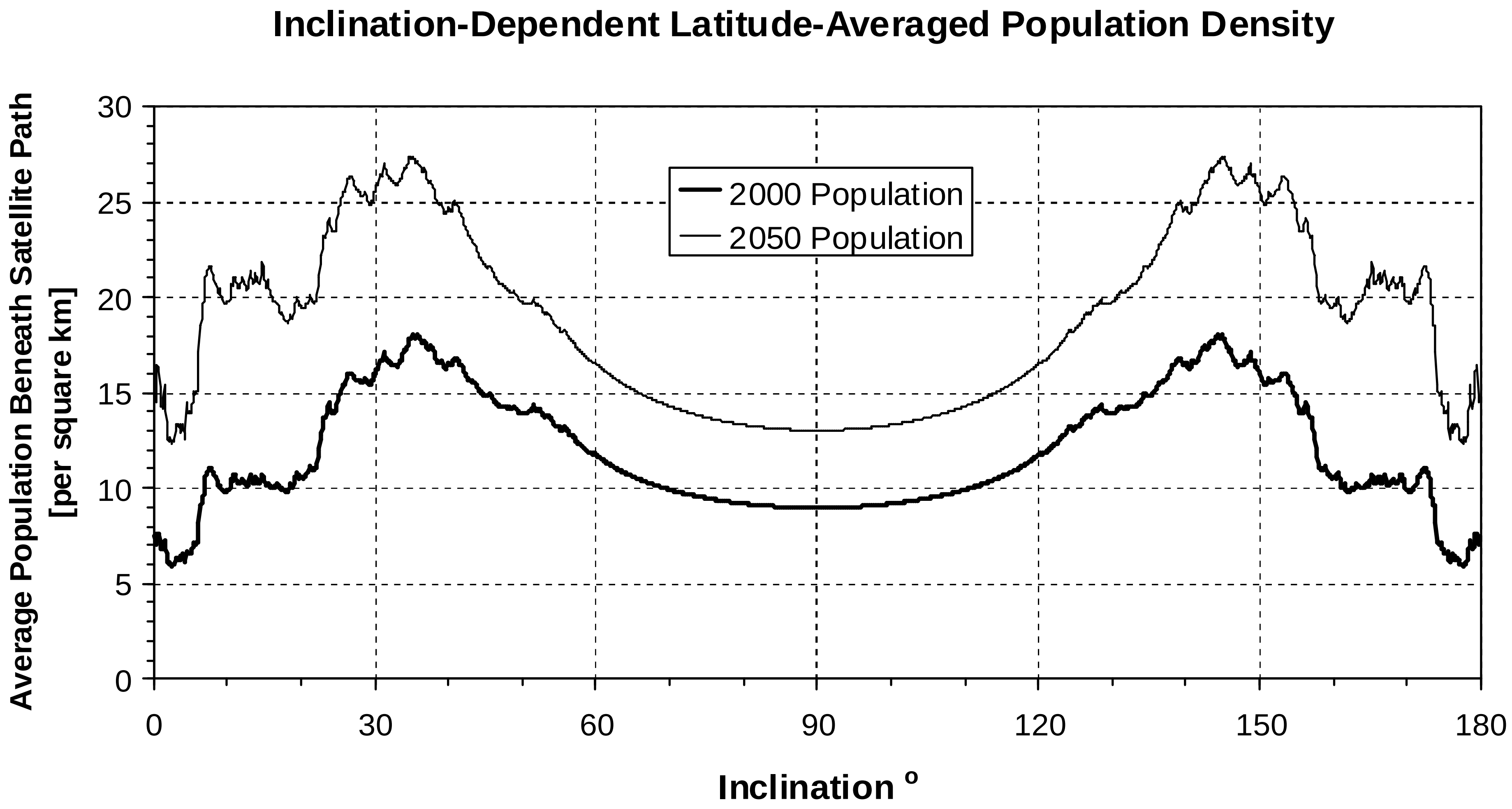


81 intact satellites (both rocket bodies and spacecraft) that reentered between 2003 and 2011 (including UARS)

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

Debris effects: Re-entry Risk

Average Density of People Below Satellite Path

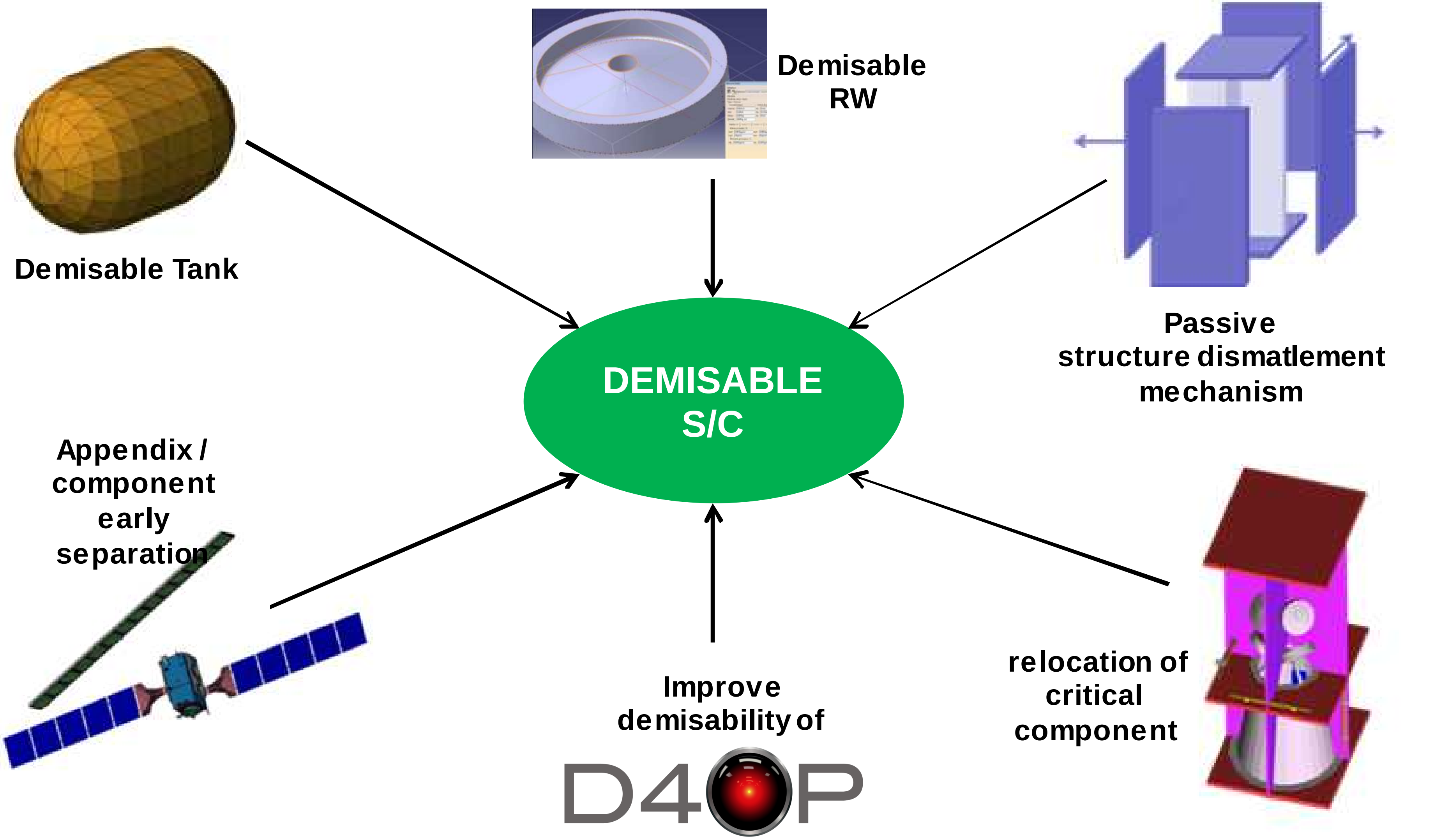


Source: Matney, M., "Empirical test of the predicted footprint for uncontrolled satellite reentry hazards", Proceedings 5th IAASS Conference, 2011.

D4D

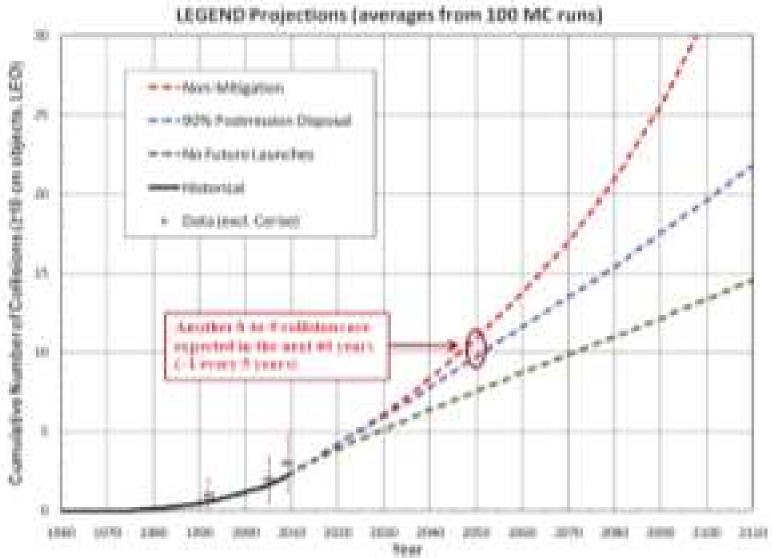
The intentional design of space hardware to burn up during atmospheric reentry. Design for Demise applies both at equipment and system level and developments at these two levels are necessary.

Main results of D4D studies (for SC)

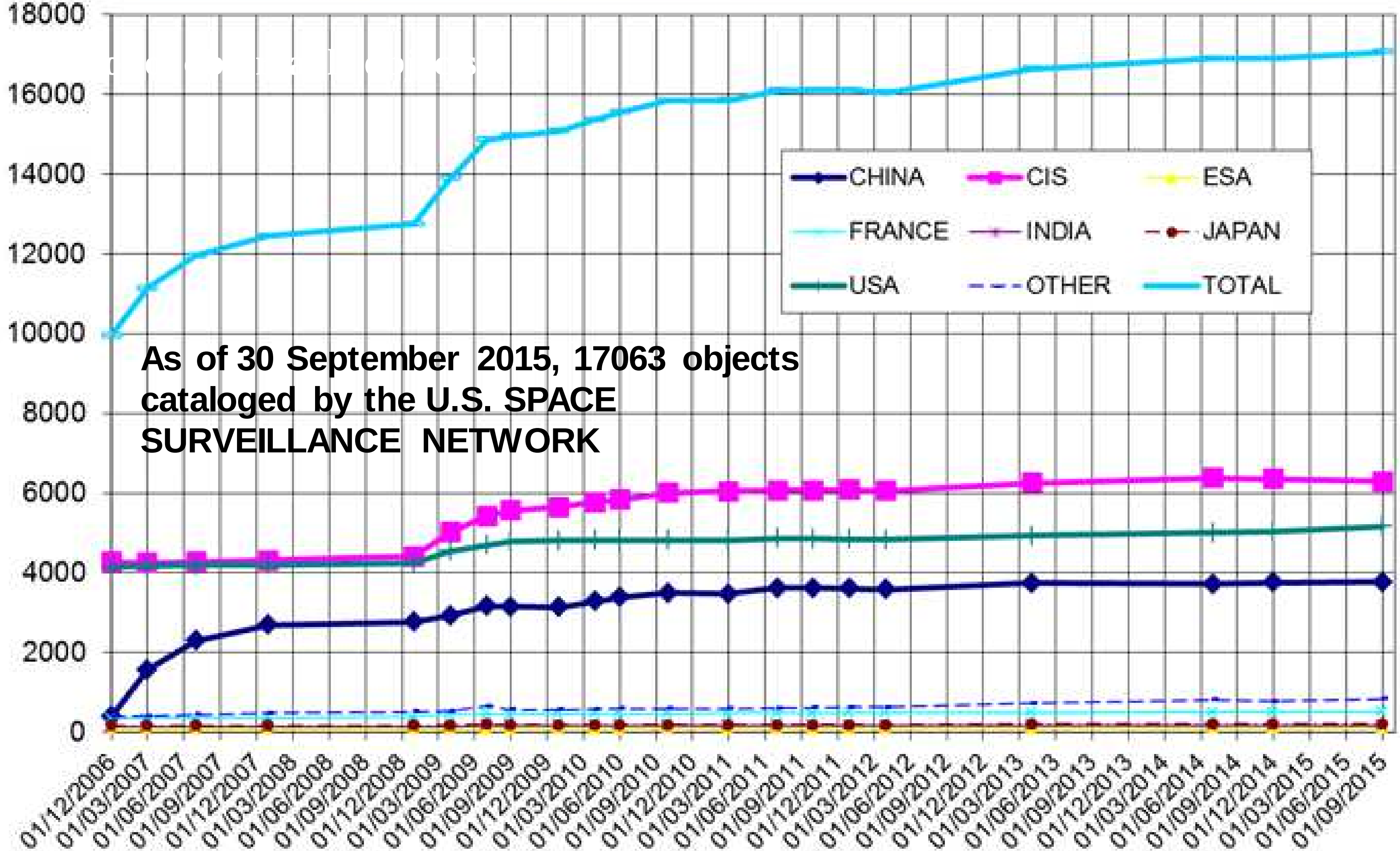


Space Debris Overview

A Global Perspective for Space Sustainability



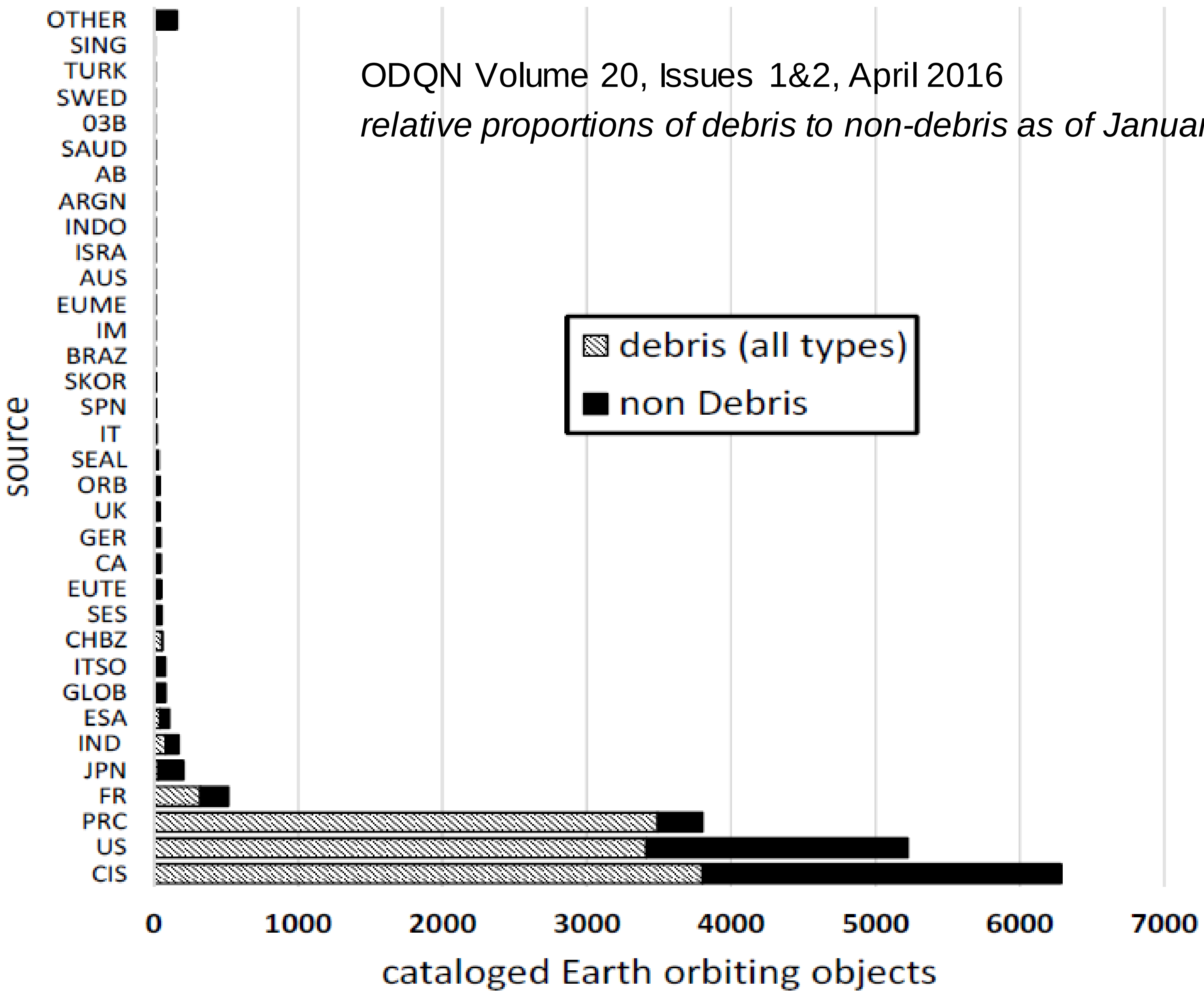
Space Debris: A Global Issue



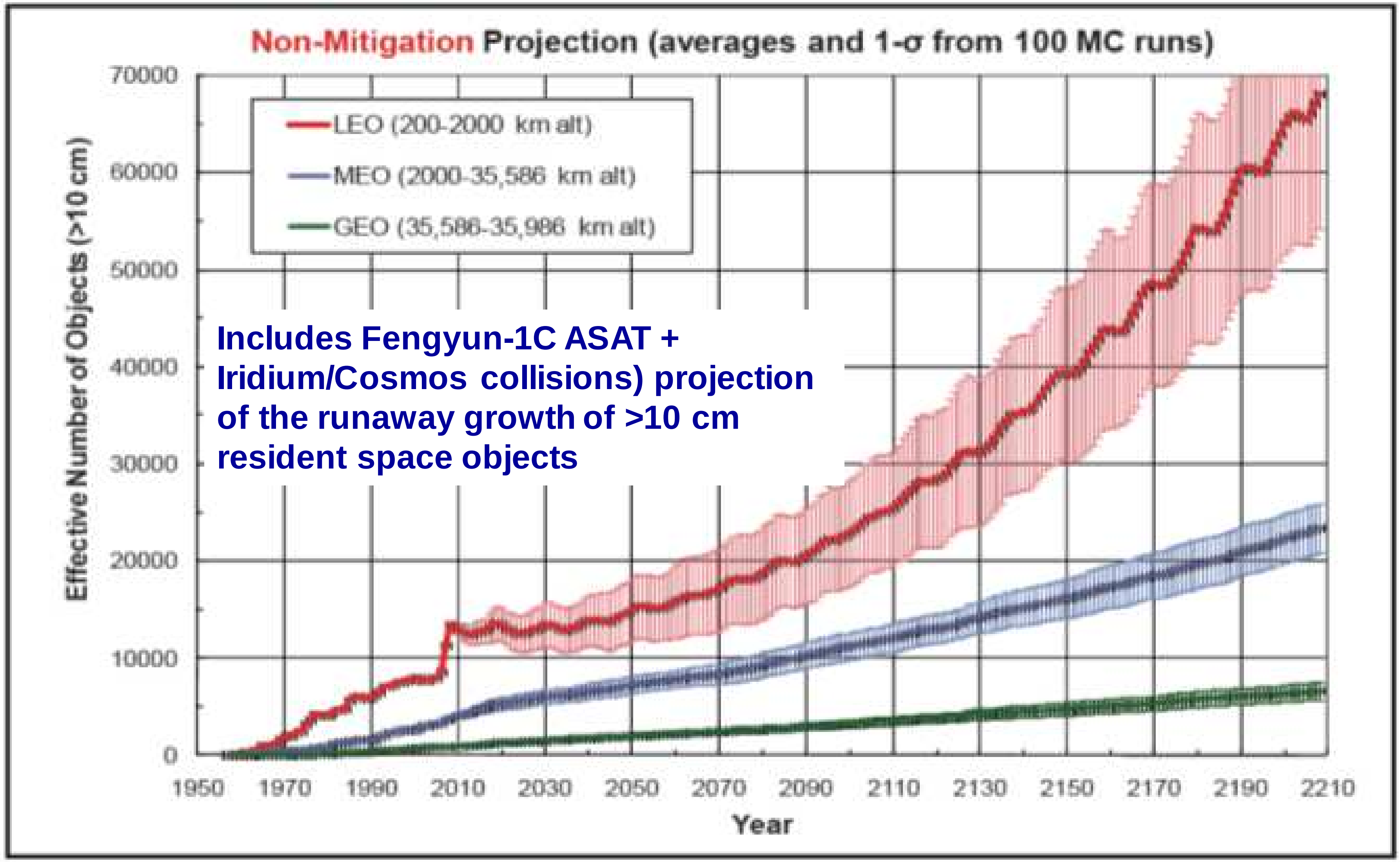
Space Debris: A Global Issue

ODQN Volume 20, Issues 1&2, April 2016

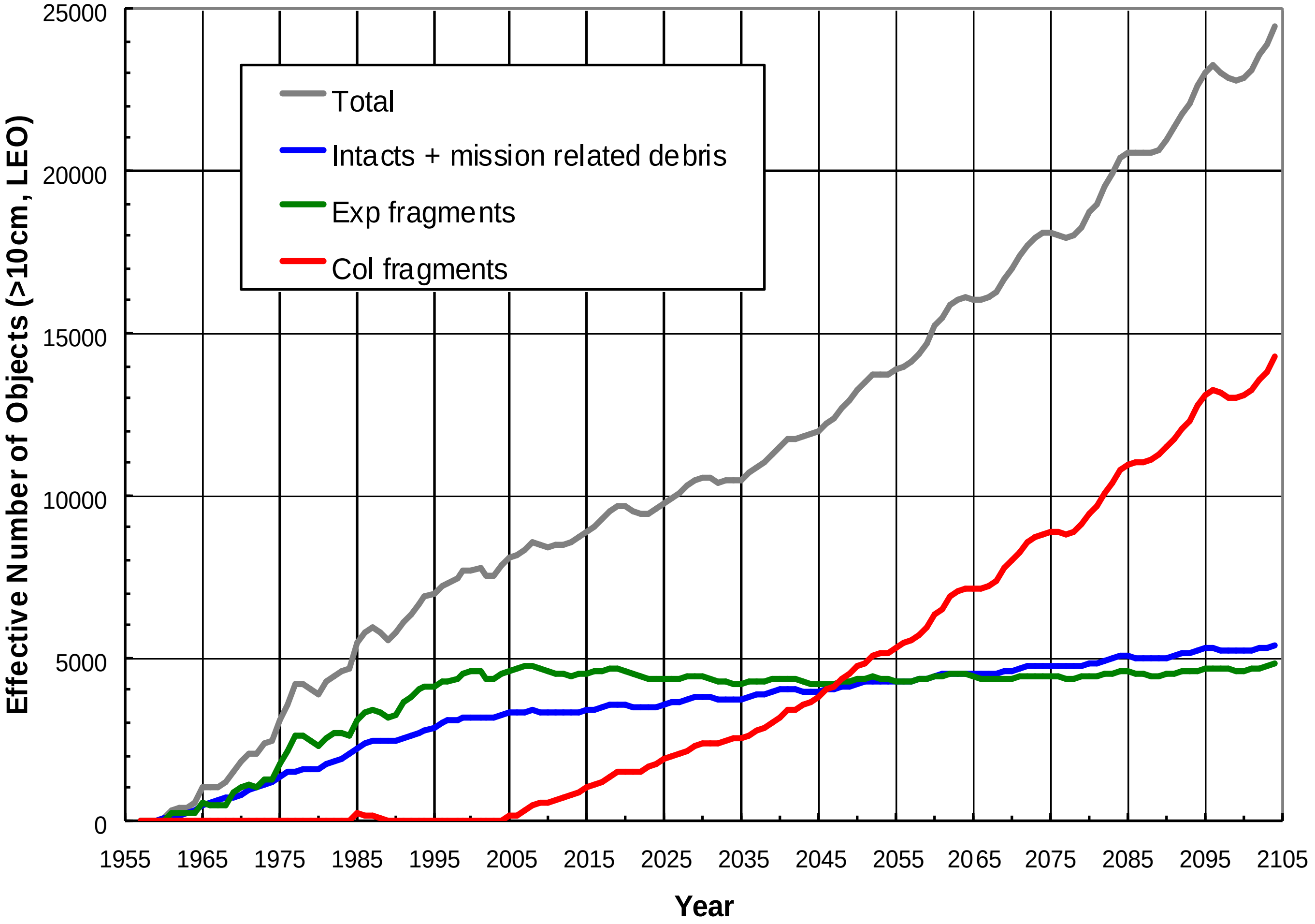
relative proportions of debris to non-debris as of January 2016.



Space Debris: Kessler Syndrome



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, "Astatistical analysis of the future debris environment," ***Acta Astronautica*** **62 (2008) 264 – 271.**

Space Debris: Kessler Syndrome

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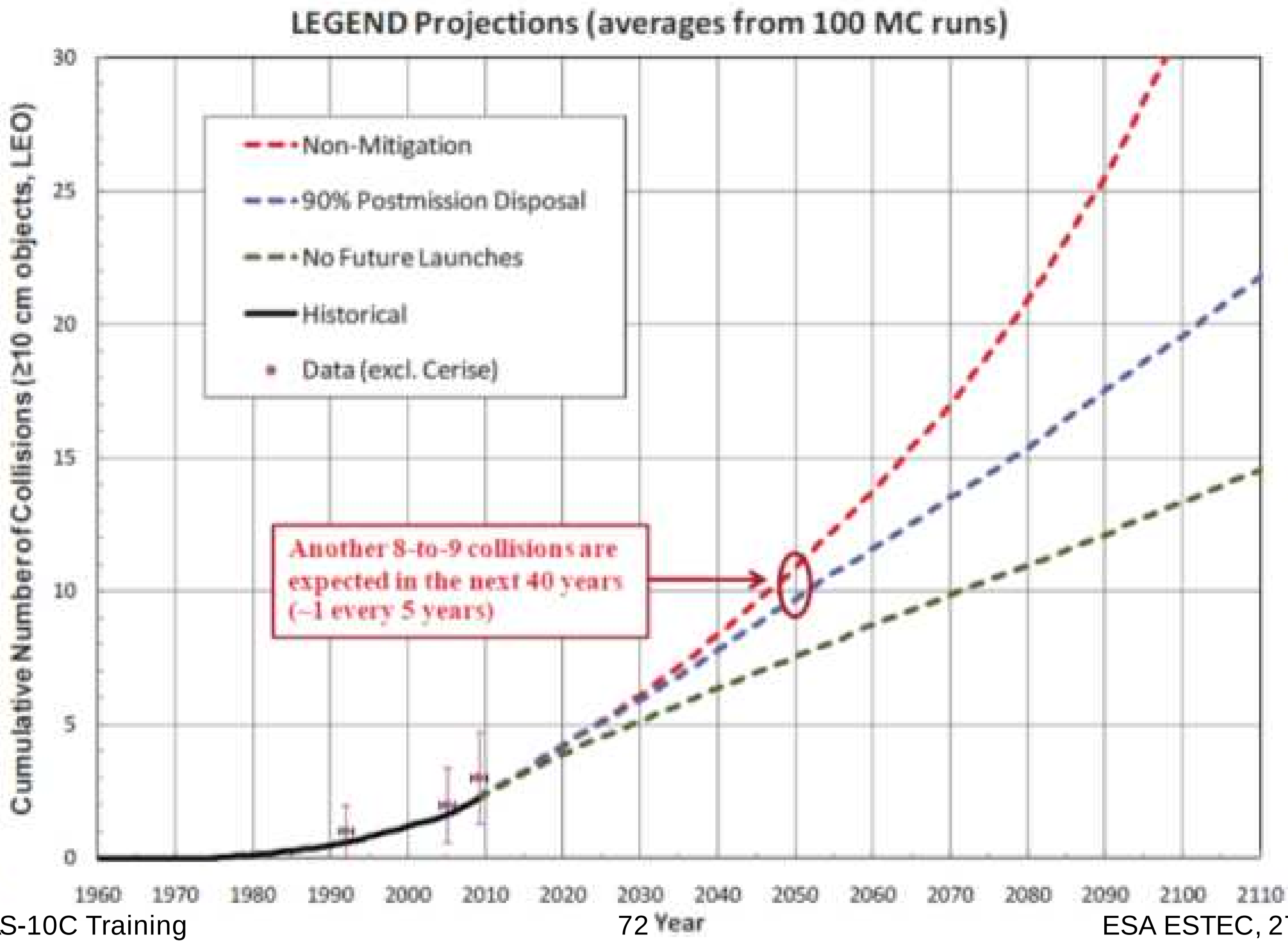
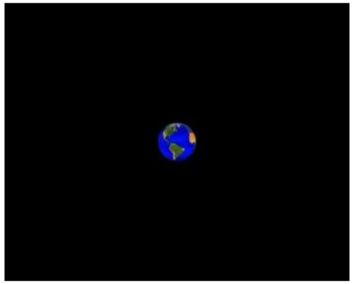
NASA LEGEND-predicted accidental collision activities in LEO. An average of about 1 collision / 5 years expected for the next 40 years.



Space Debris– A Global Issue

REMEDIATION:

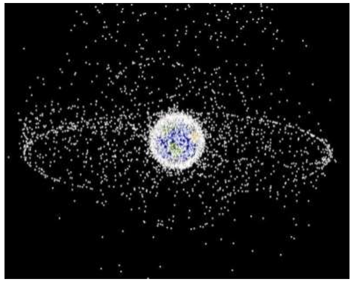
- Removing existing, non-cooperative objects is extremely difficult and expensive. Investigated techniques suffer from lack of development and testing and/or economic viability:
  - Ground based laser cleansing
  - Active Debris Removal



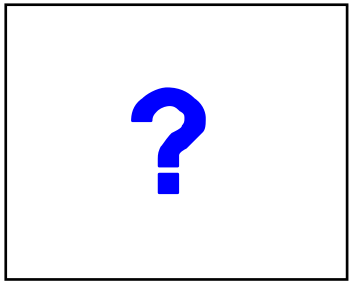
Pre 1957

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)



2008

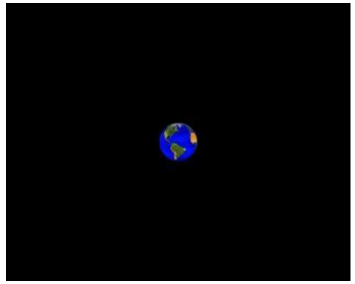


2016+

Space Debris– A Global Issue

Only current option: MITIGATION

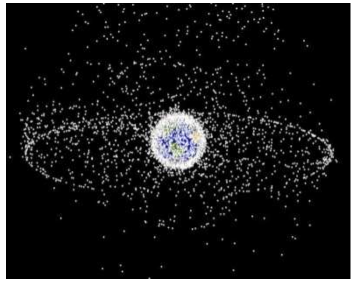
- (Perform the necessary actions to minimize the risk of collision with other space objects (**collision avoidance)**)
- (Evaluate and control of Re-entry Risk)



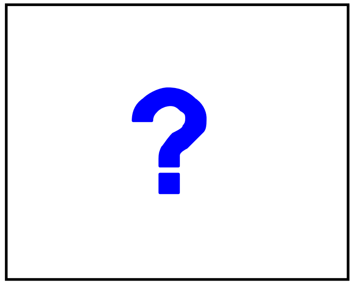
Pre 1957

A global issue requires international solutions:

GUIDELINES AND STANDARDS



2008



2016+

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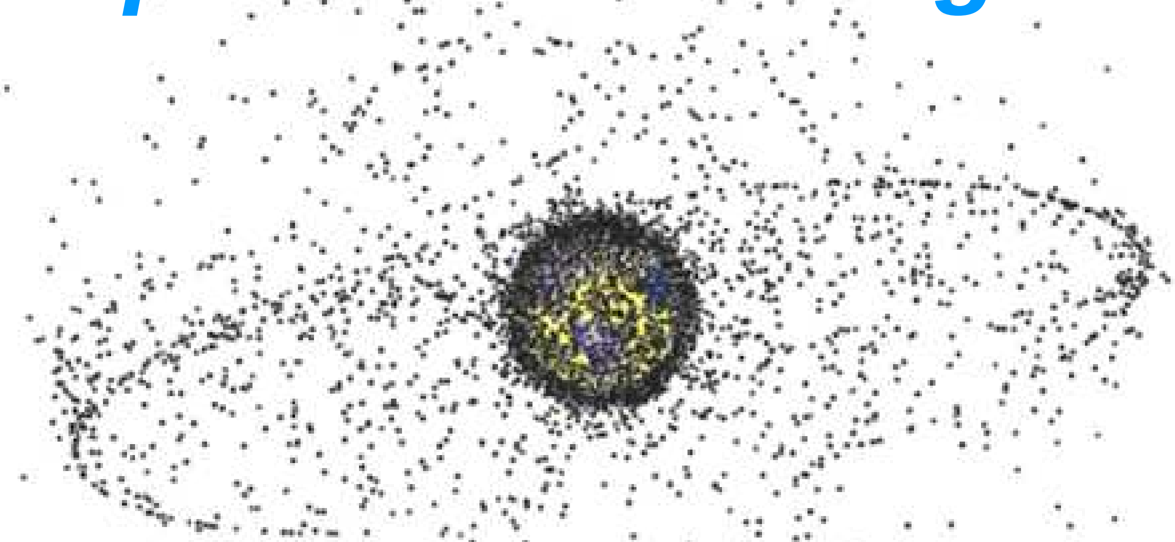
Space Debris Mitigation



Standardization training program

ESA ESTEC , June 27, 2016

- SEE PART 2 -