National Aeronautics and Space Administration

The Challenge of Orbital Debris

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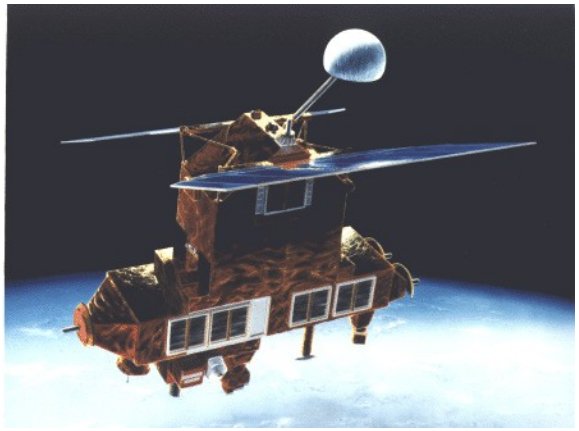
What is Orbital Debris?

- **Space debris encompasses both natural (meteoroid) and artificial (man-made) particles.**
  - **Meteoroids are natural objects in orbit about the Sun**
  - **Any man-made object in Earth orbit that no longer serves a useful purpose**
  - **All man-made objects in orbit are destined to become debris, in one way or another**



Non-operational Spacecraft

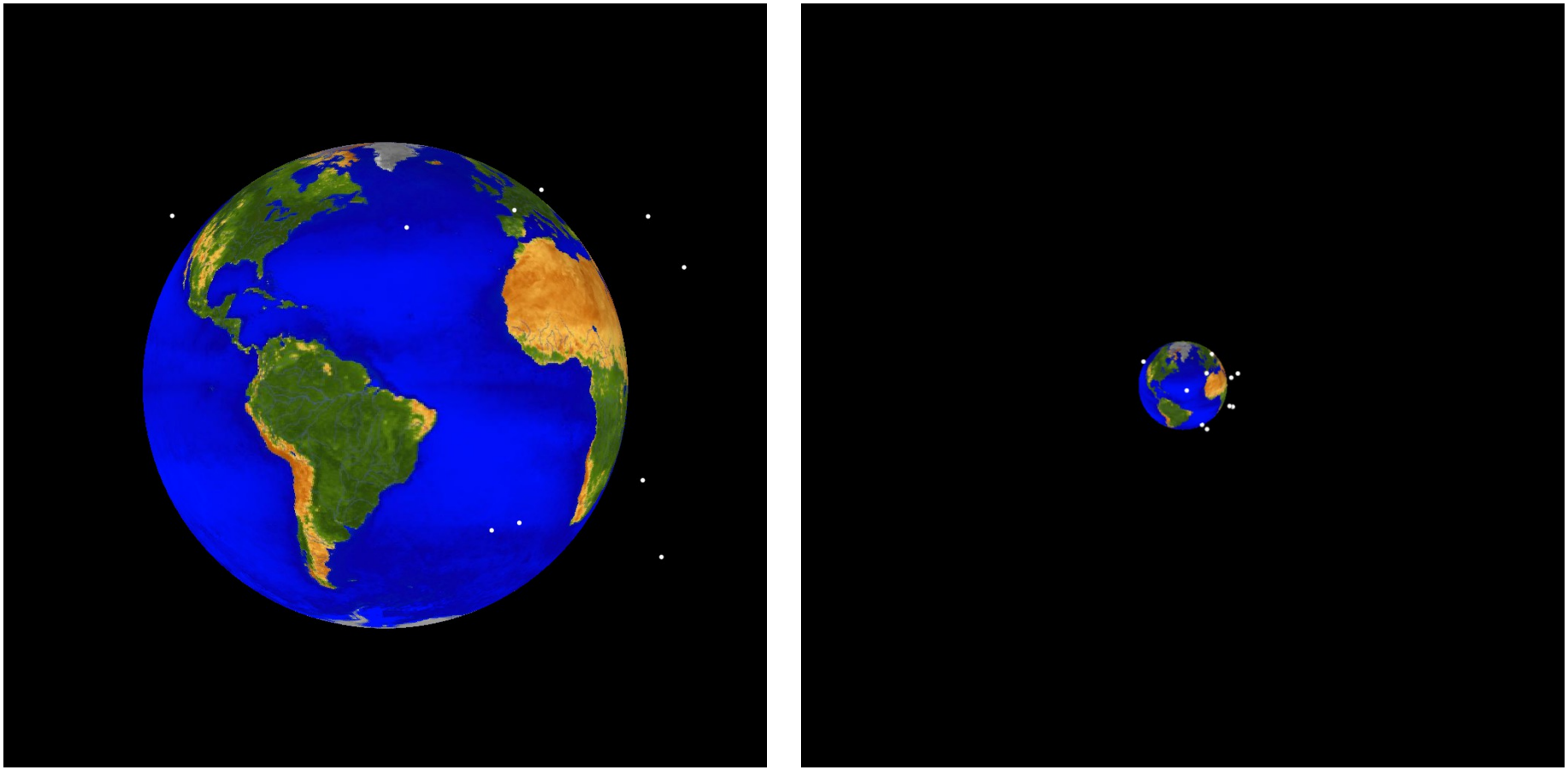
Derelict Launch Vehicle Stages

Fragmentation and Mission-related Debris

Brewster Rockit on Debris Sources

Growth of the Earth Satellite Population

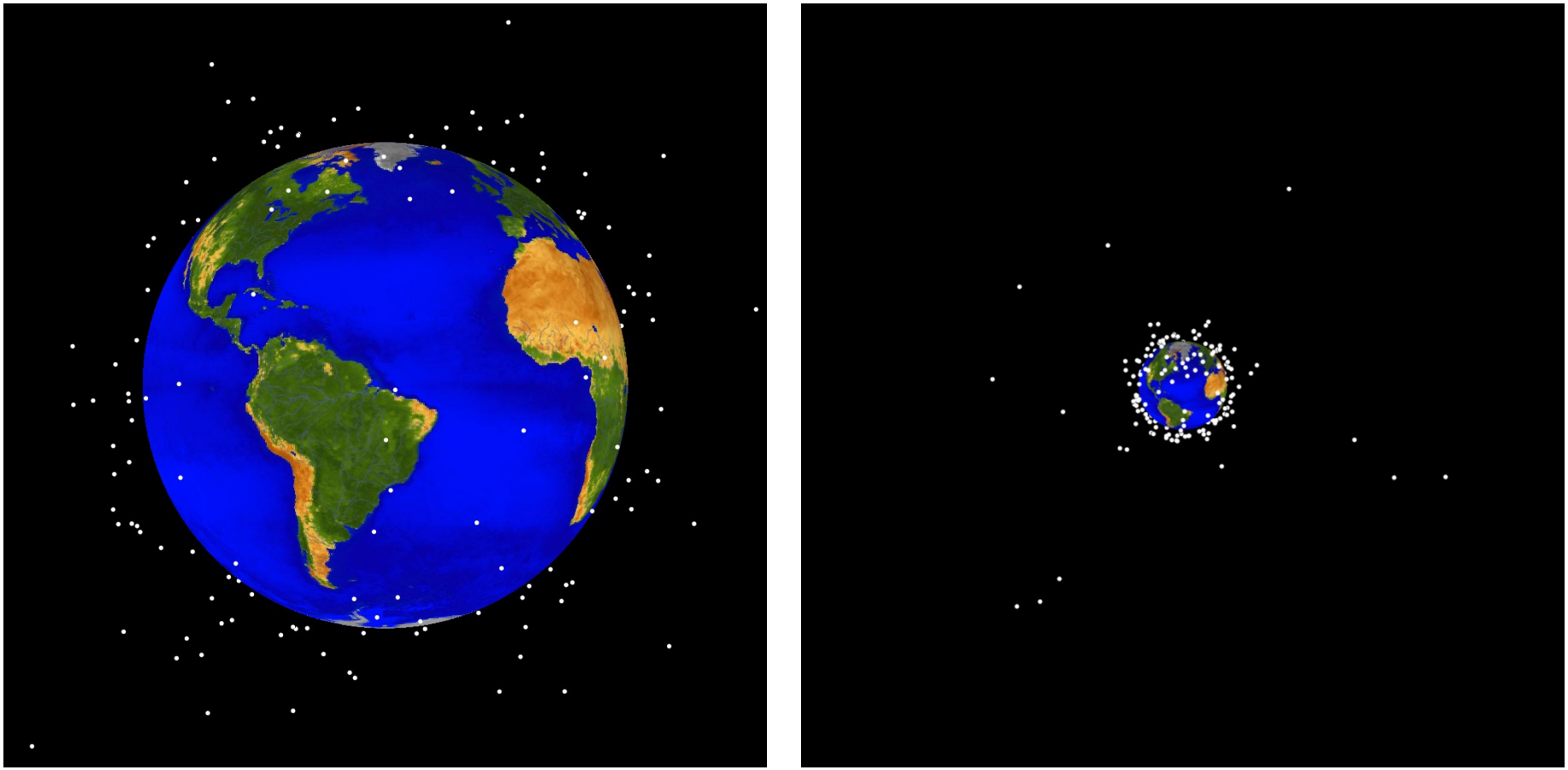
1960



Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

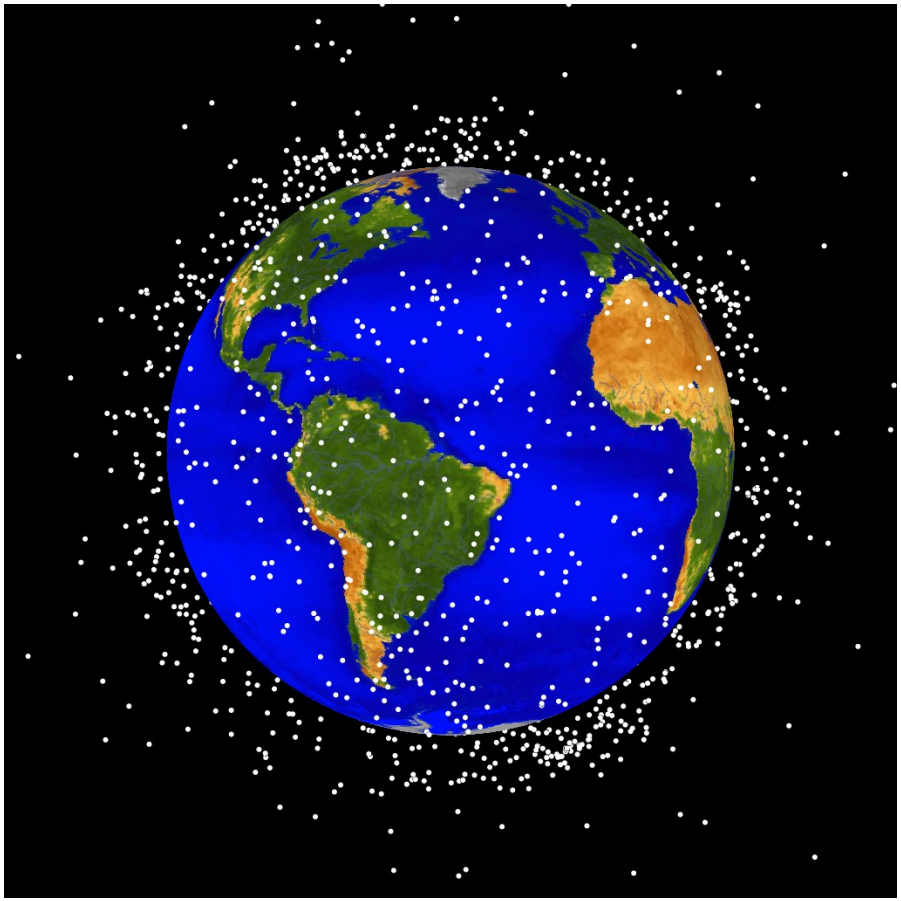
1965

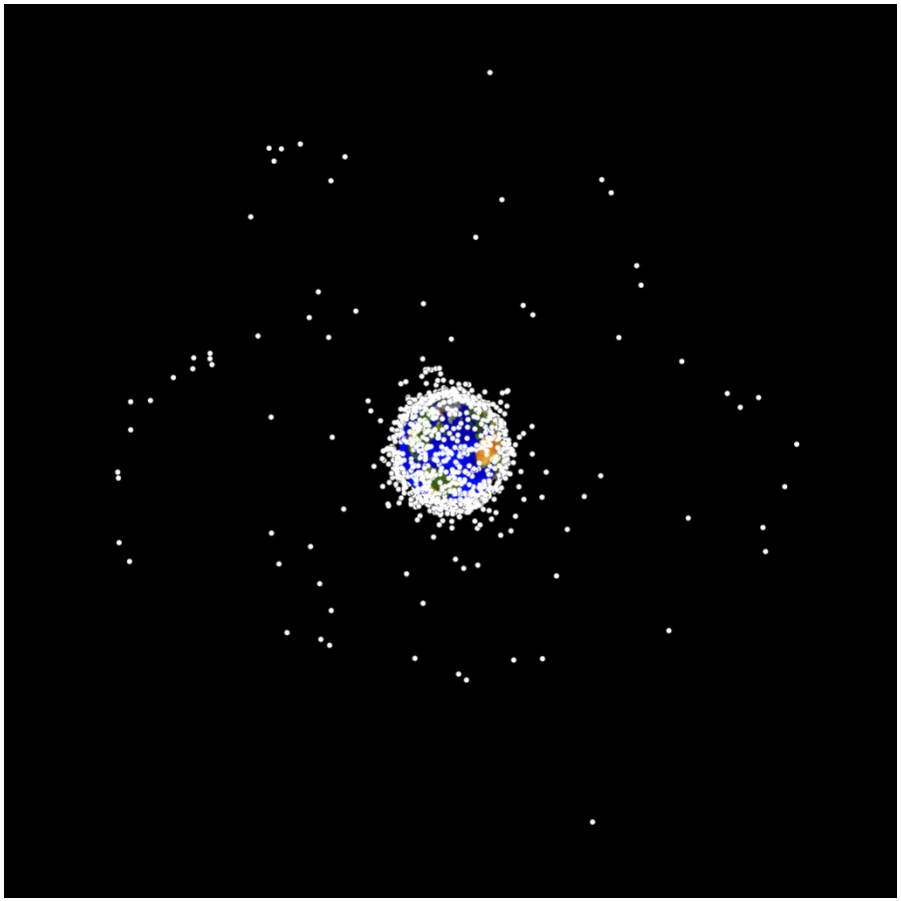


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

1970

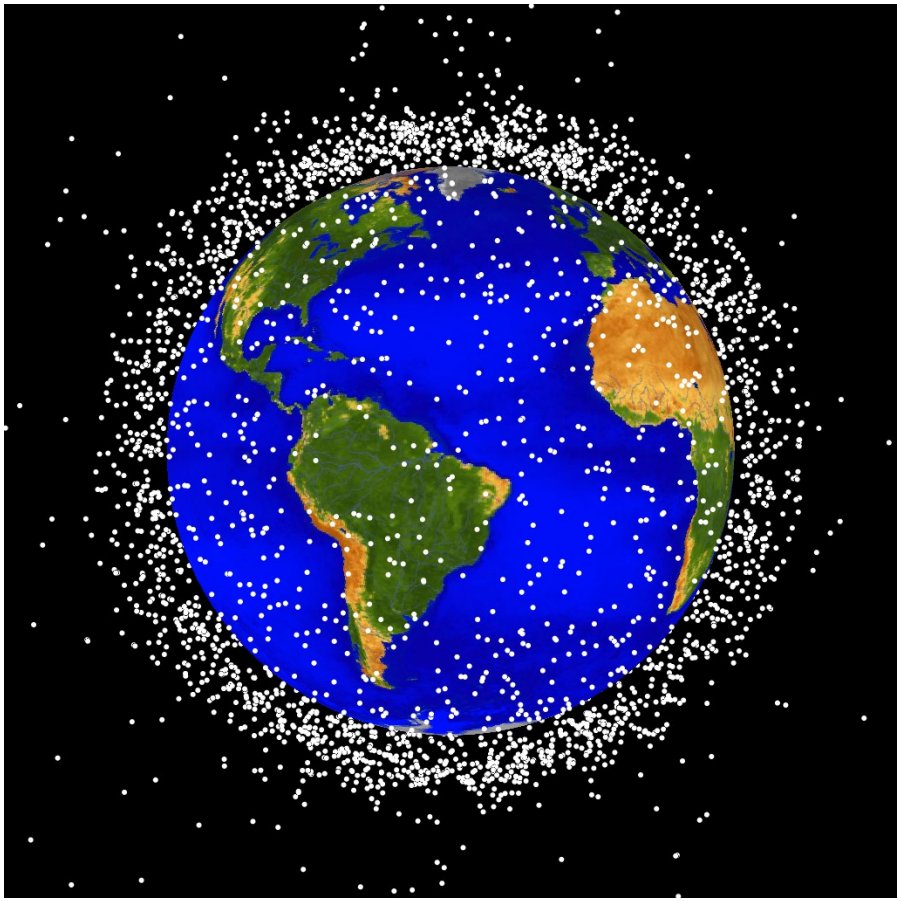


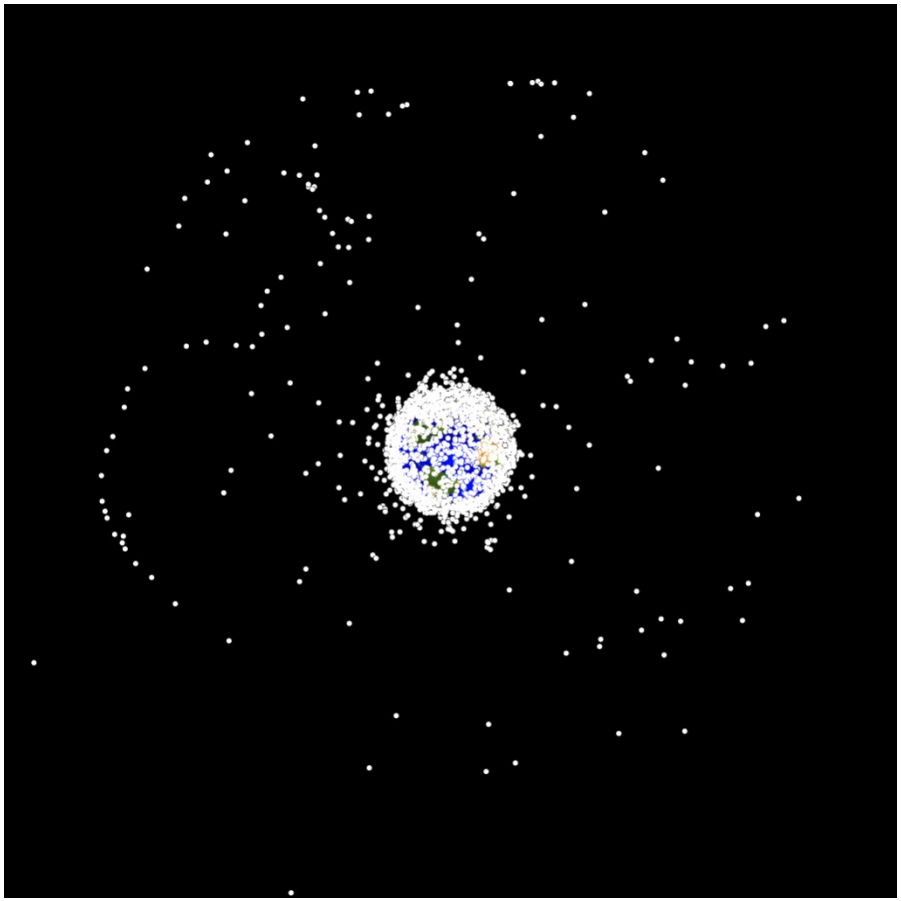


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

1975

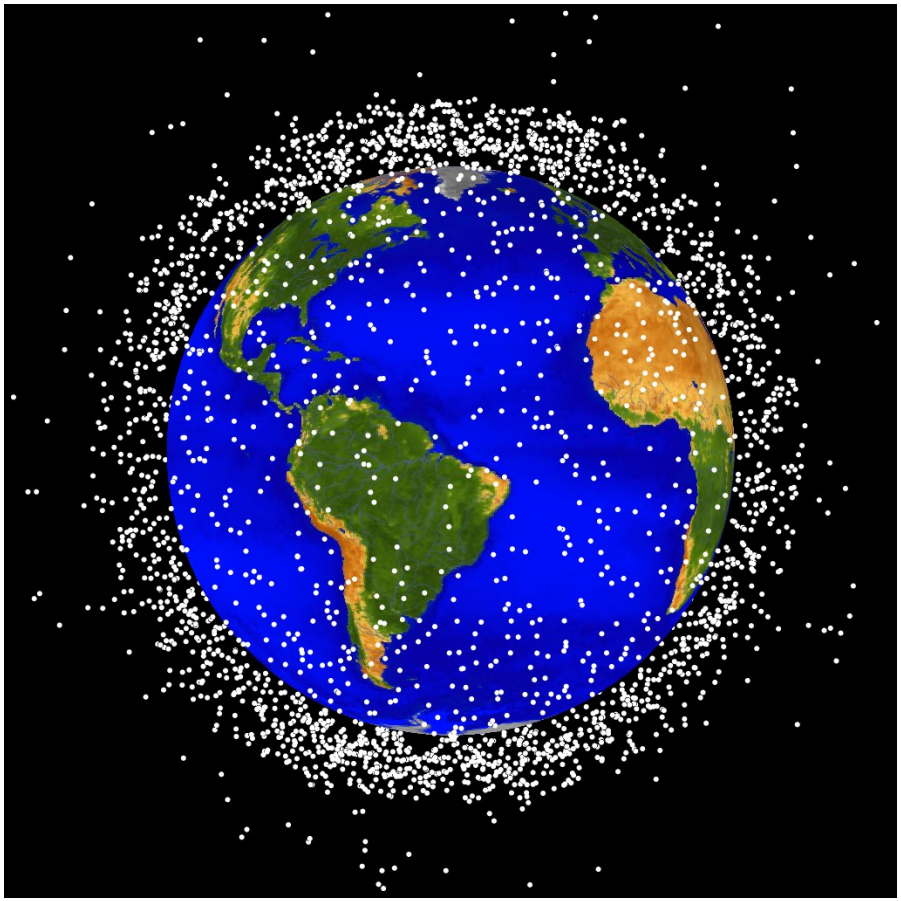


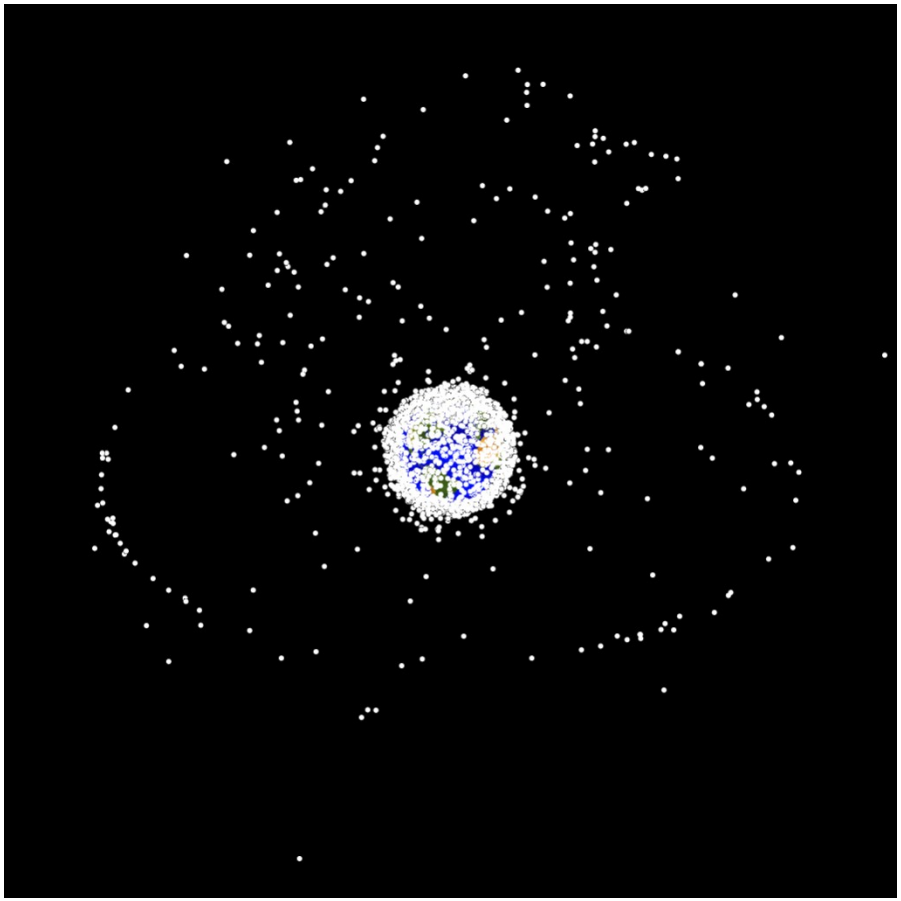


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

1980

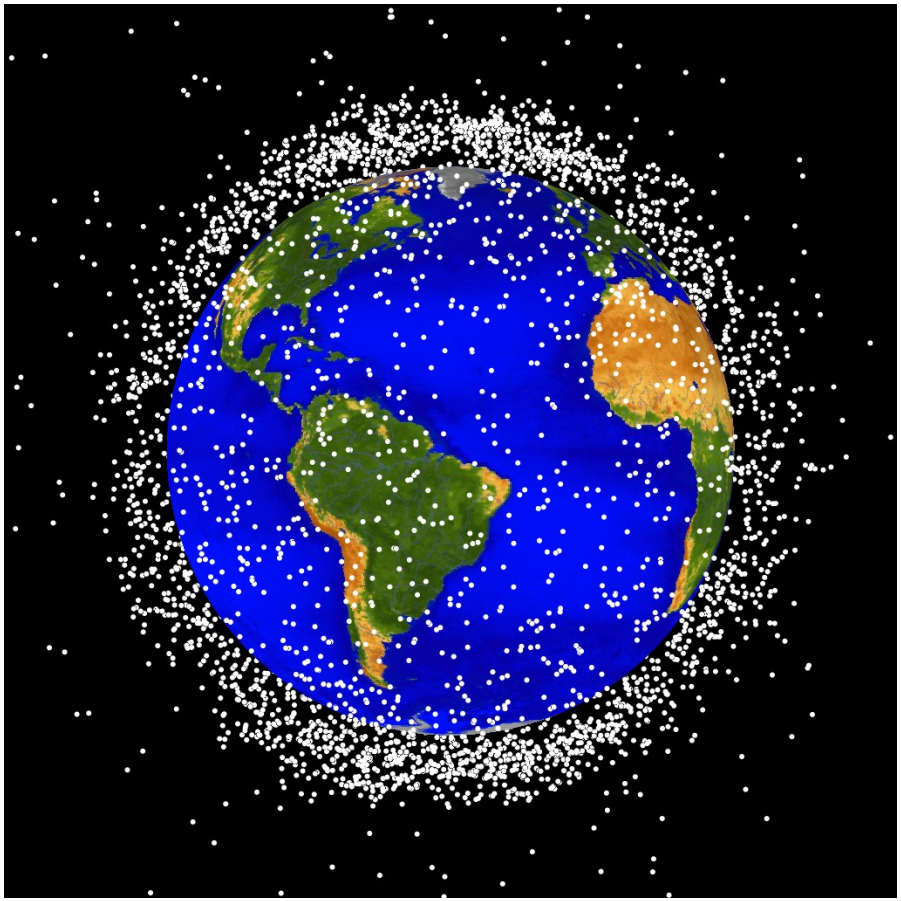


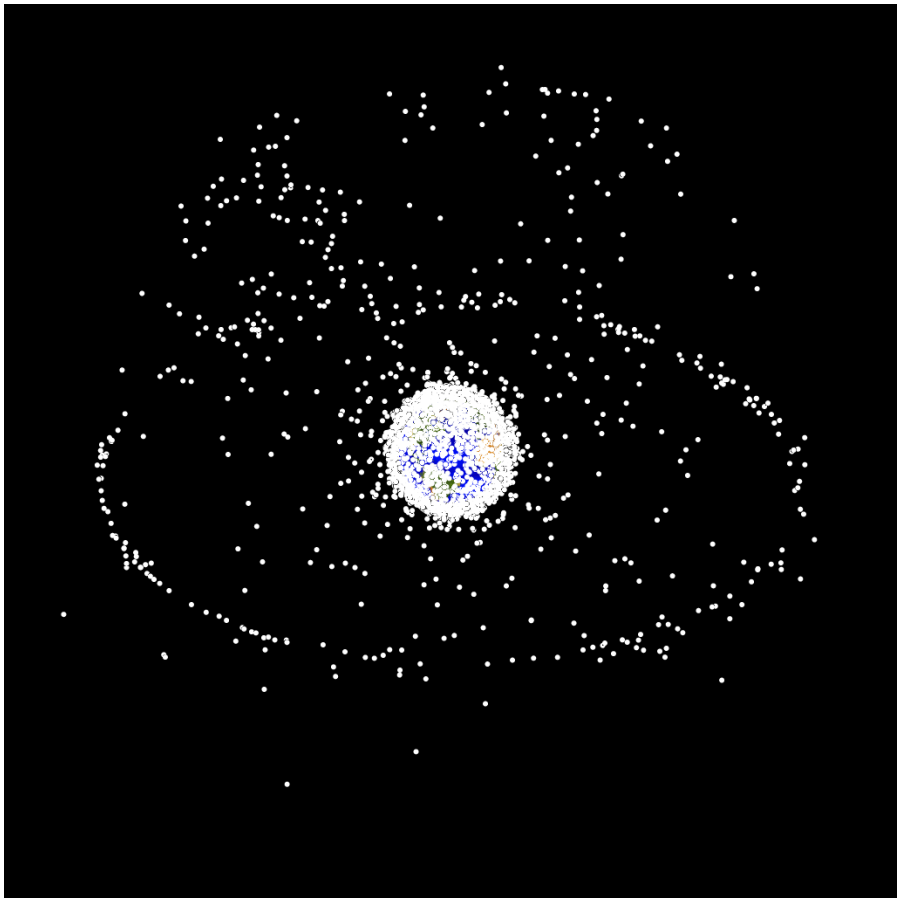


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

1985

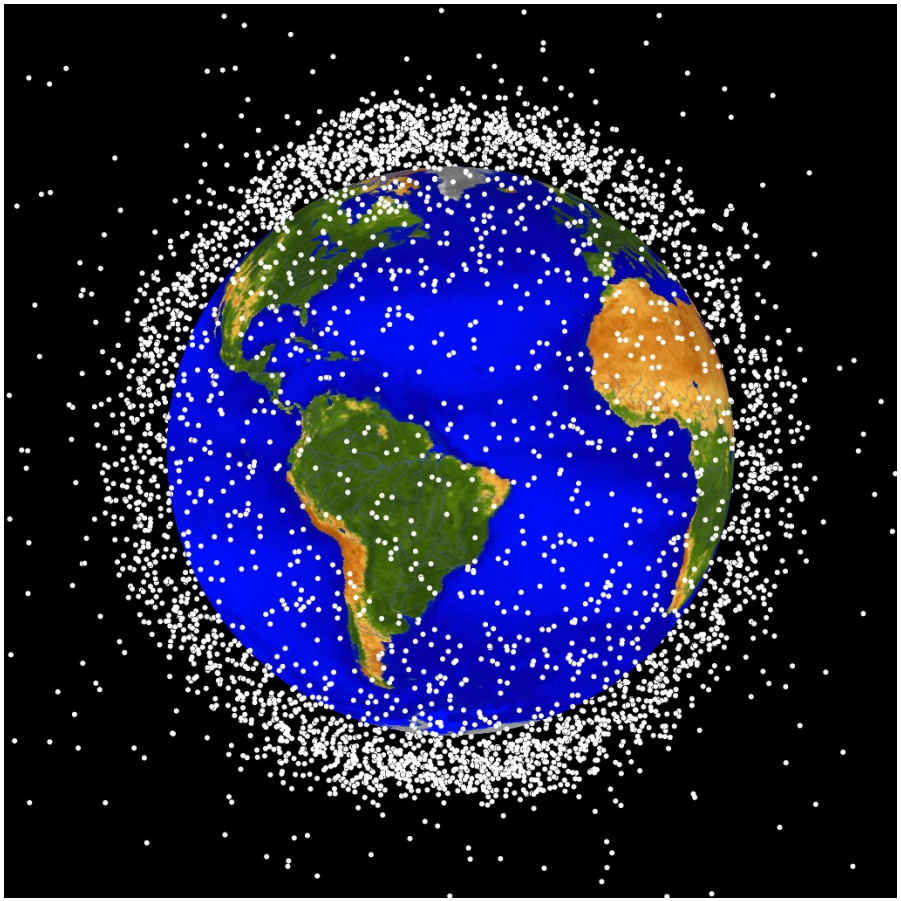


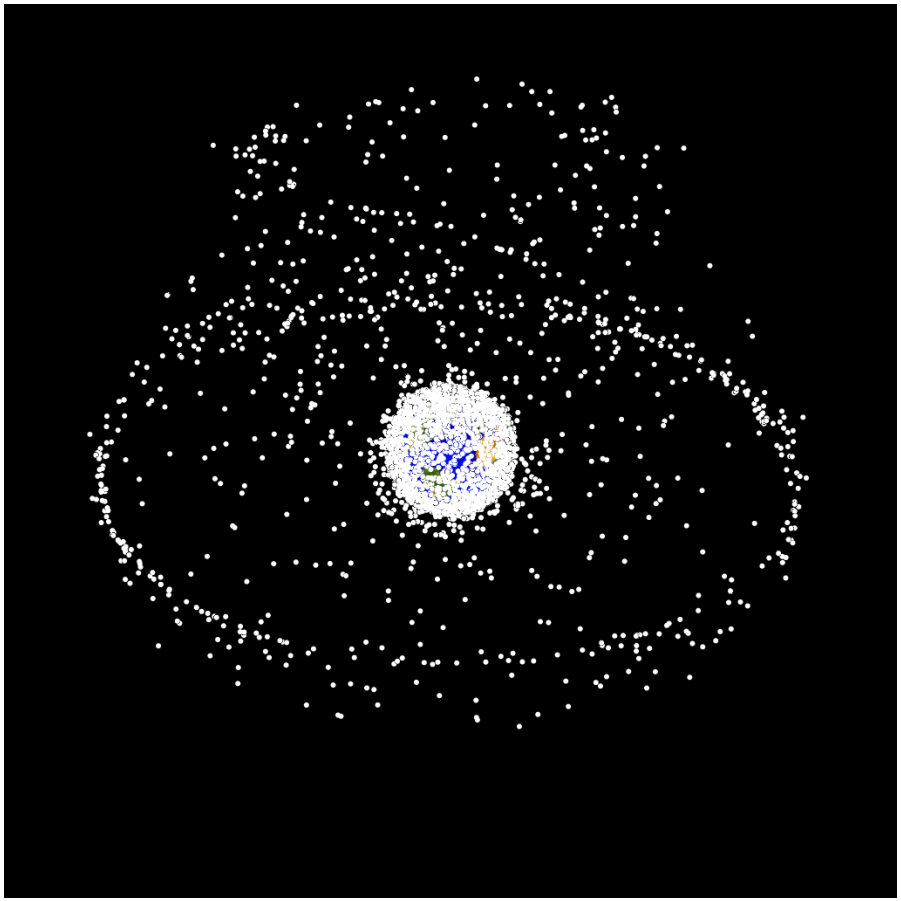


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

1990

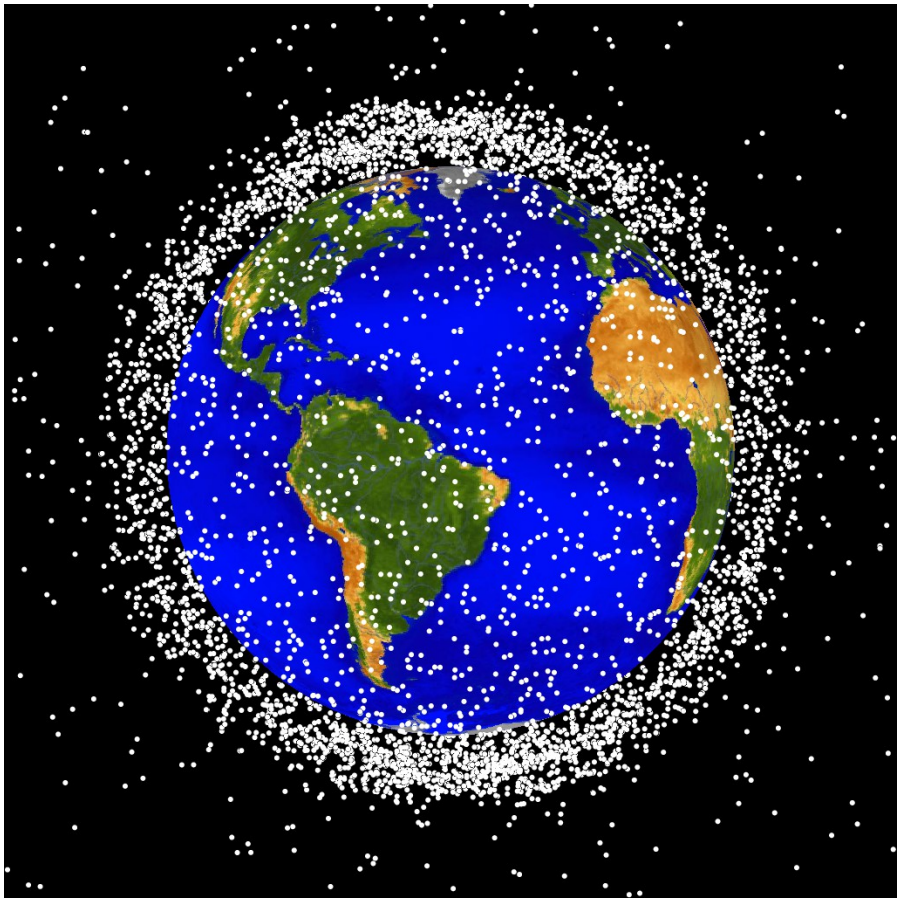


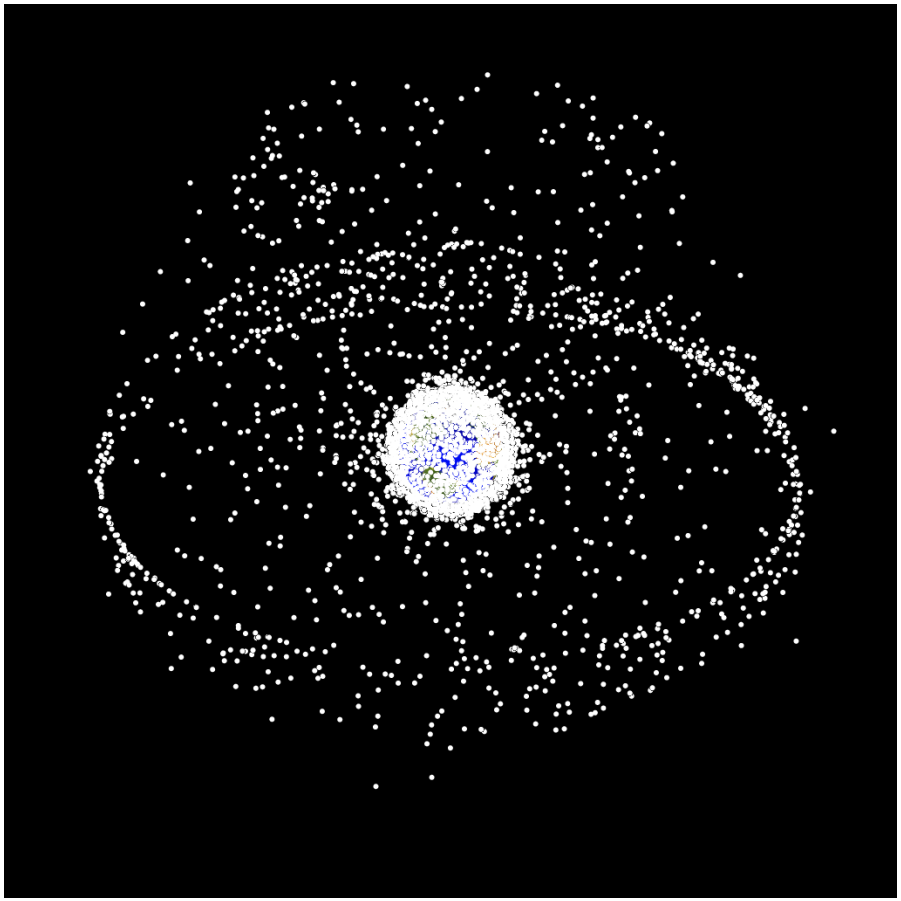


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

1995

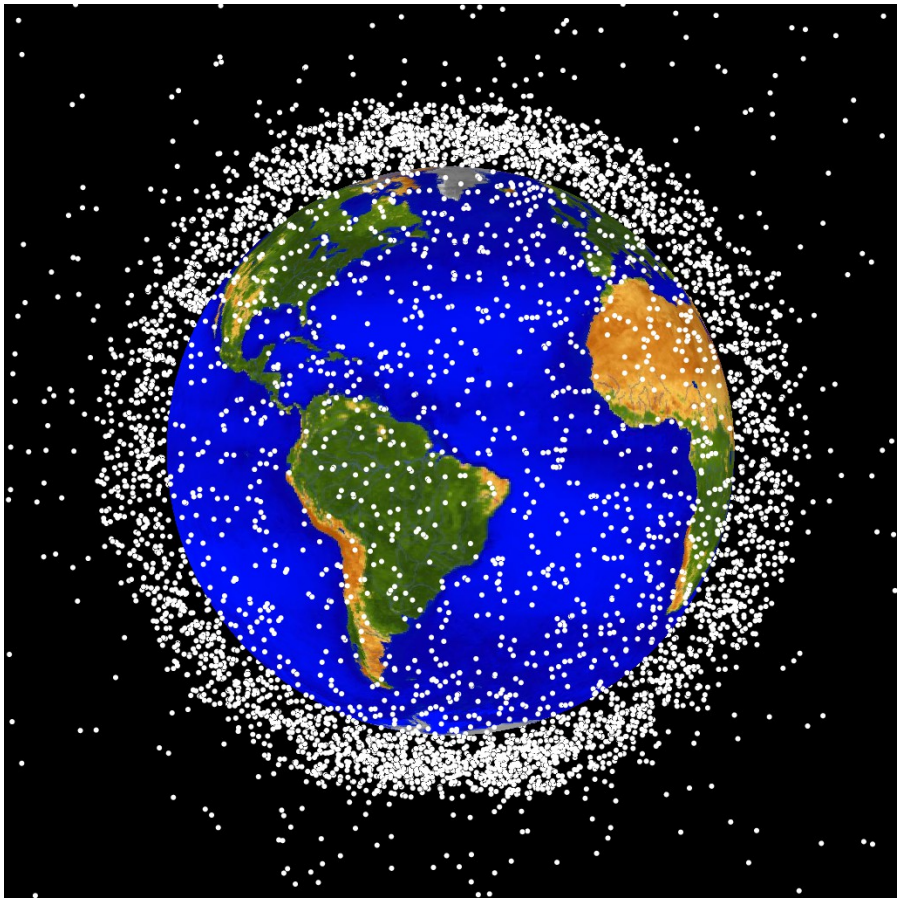


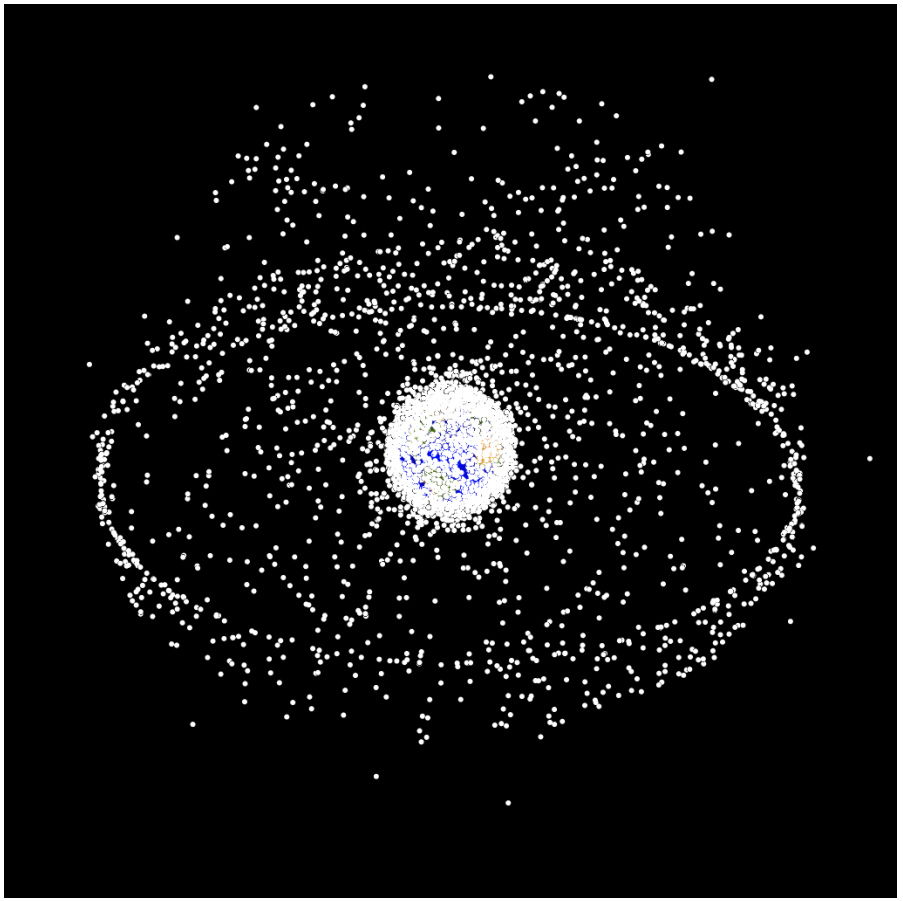


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

2000

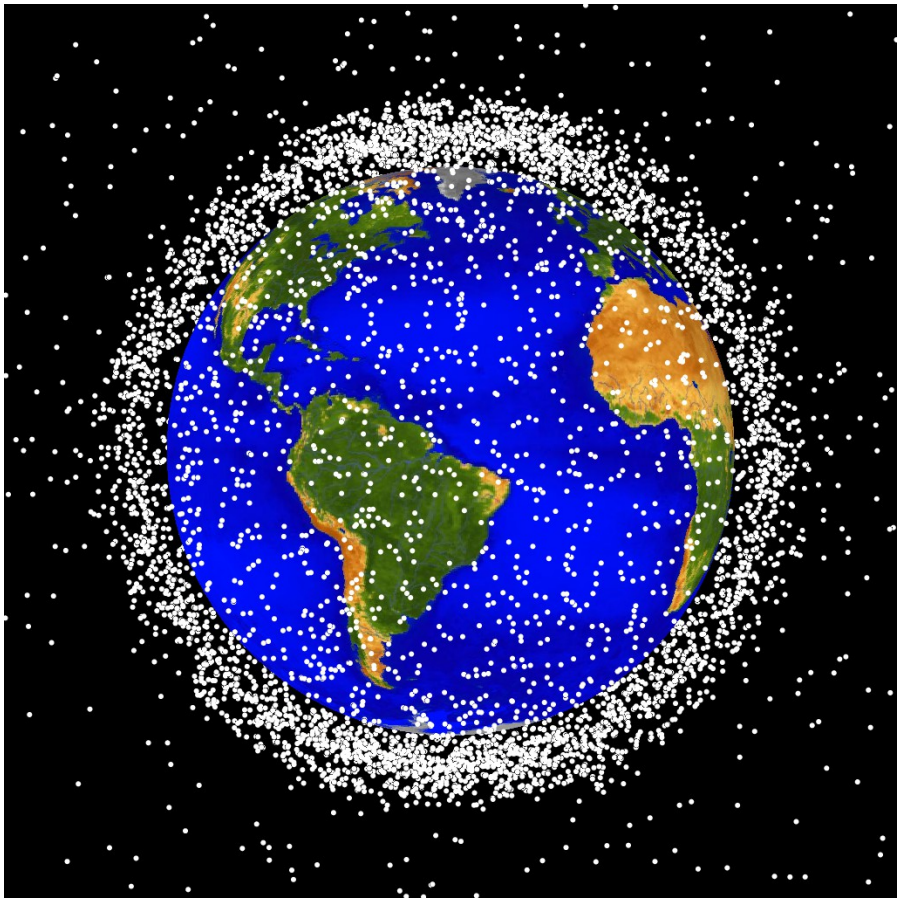


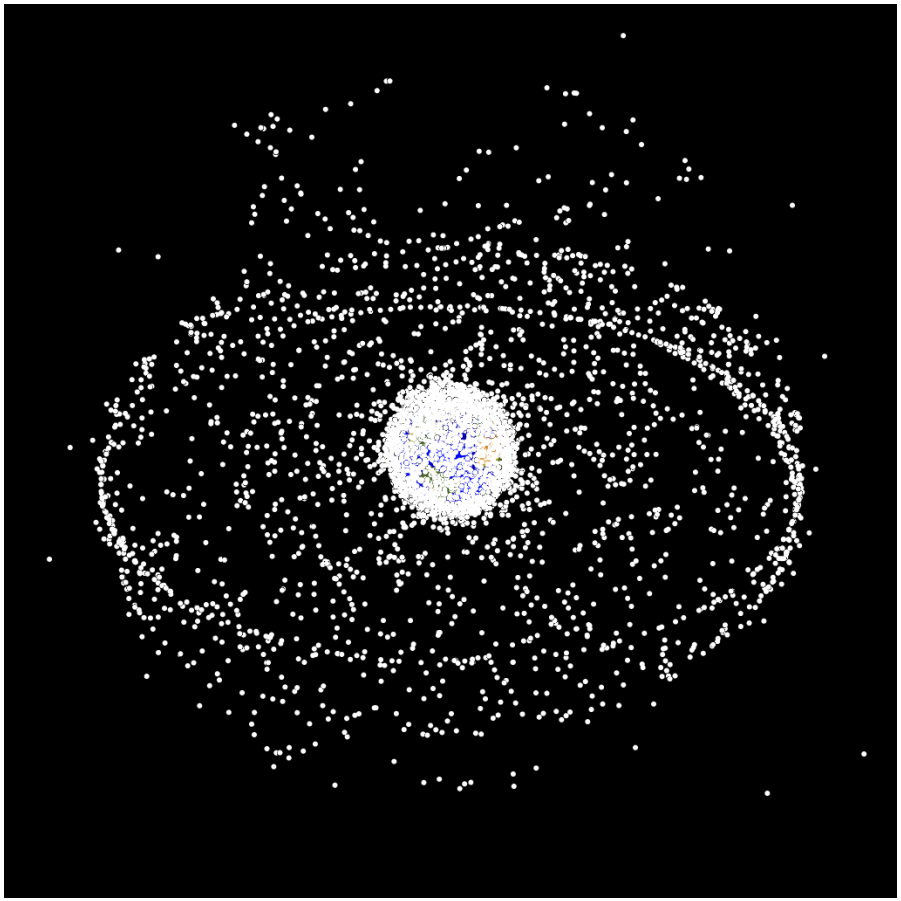


Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

2005

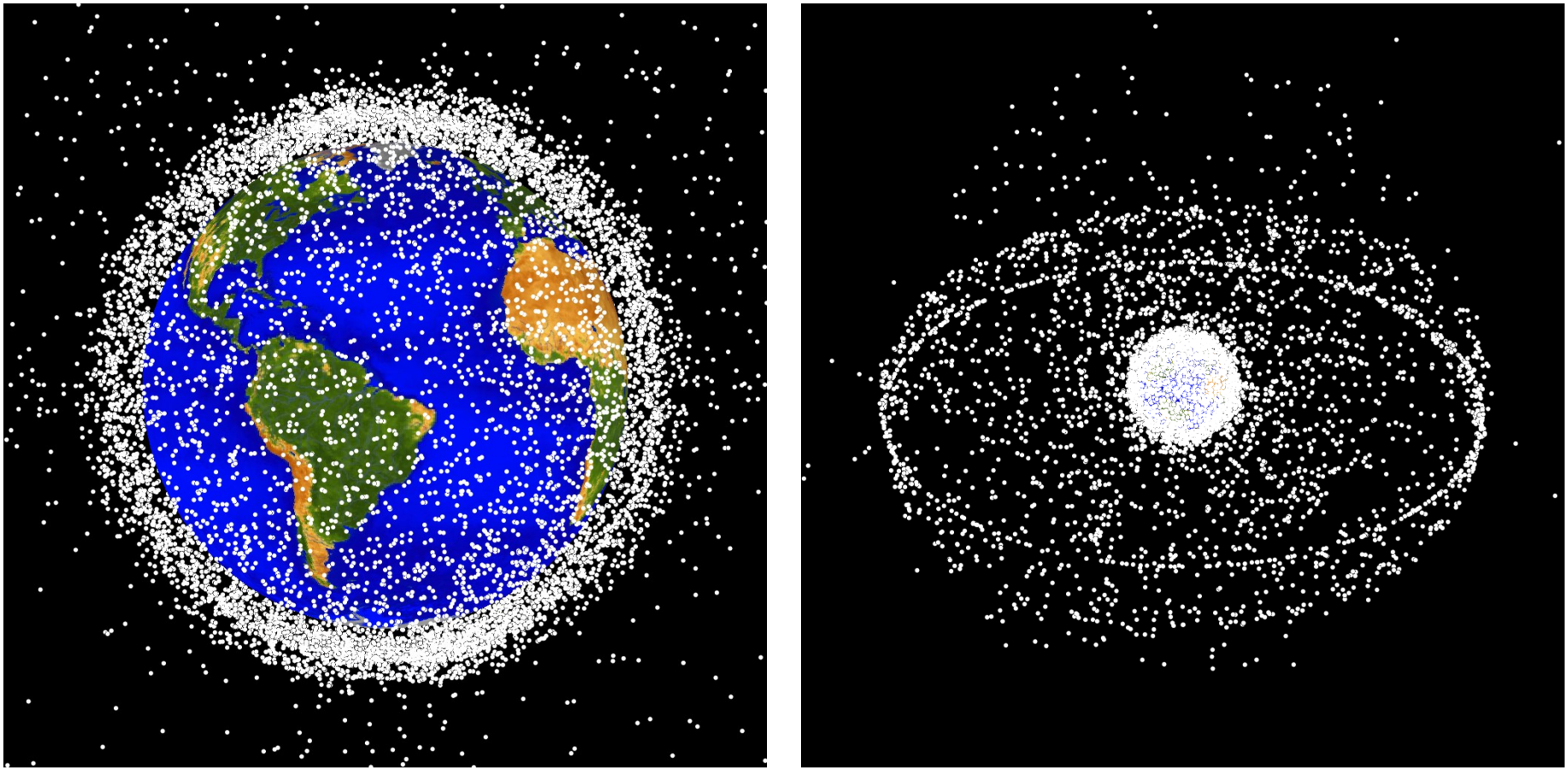




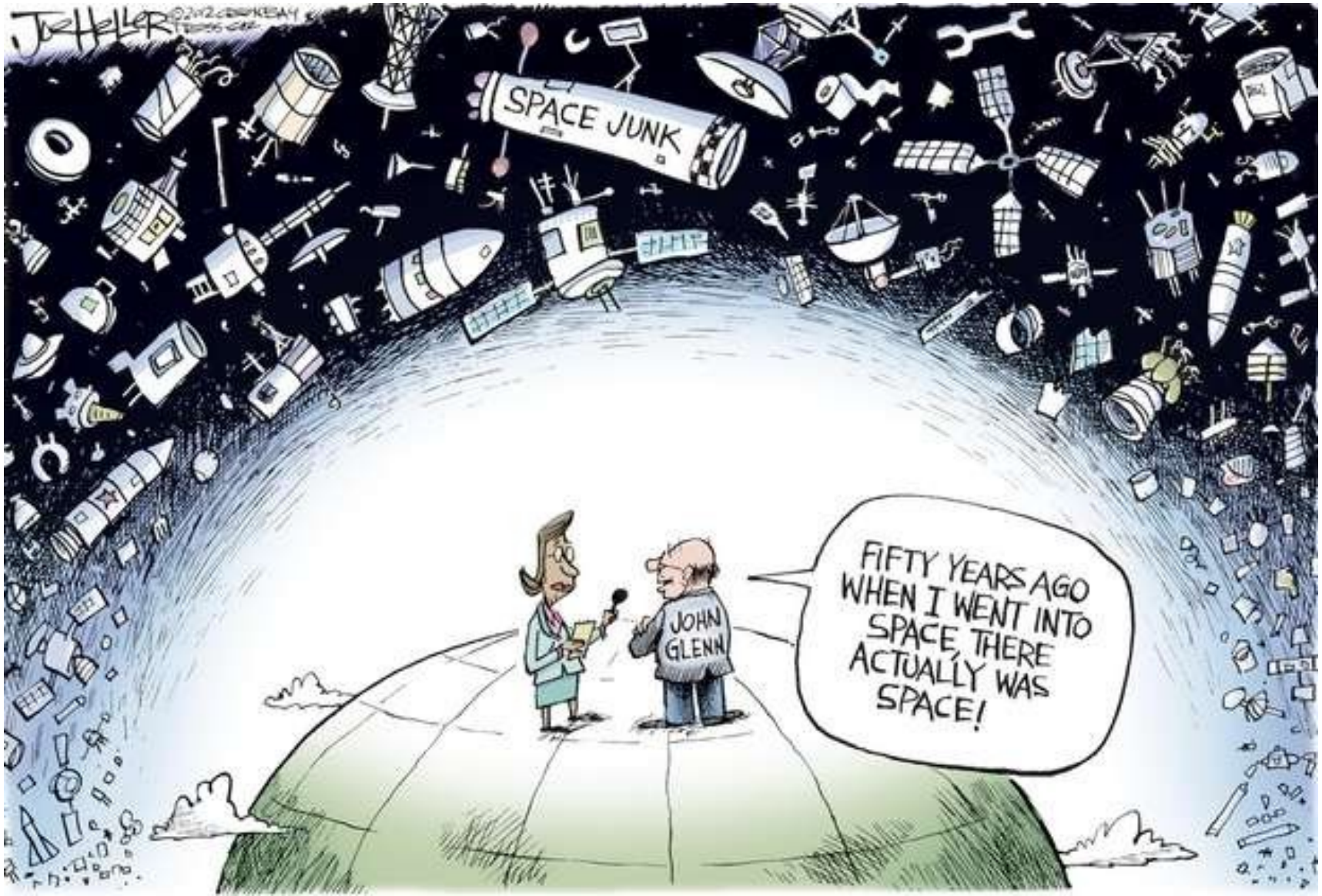
Cataloged objects >10 cm diameter

Growth of the Earth Satellite Population

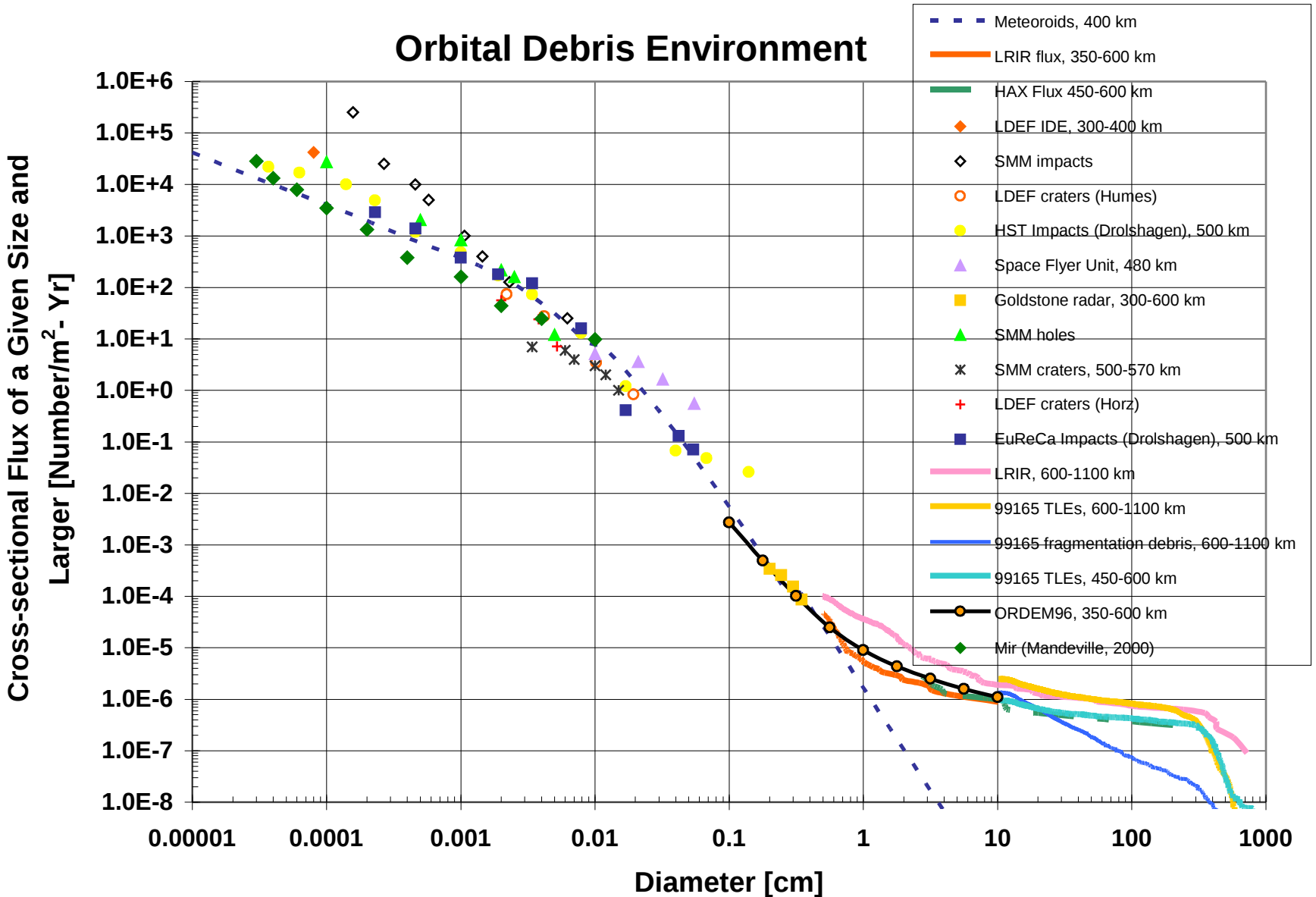
2010



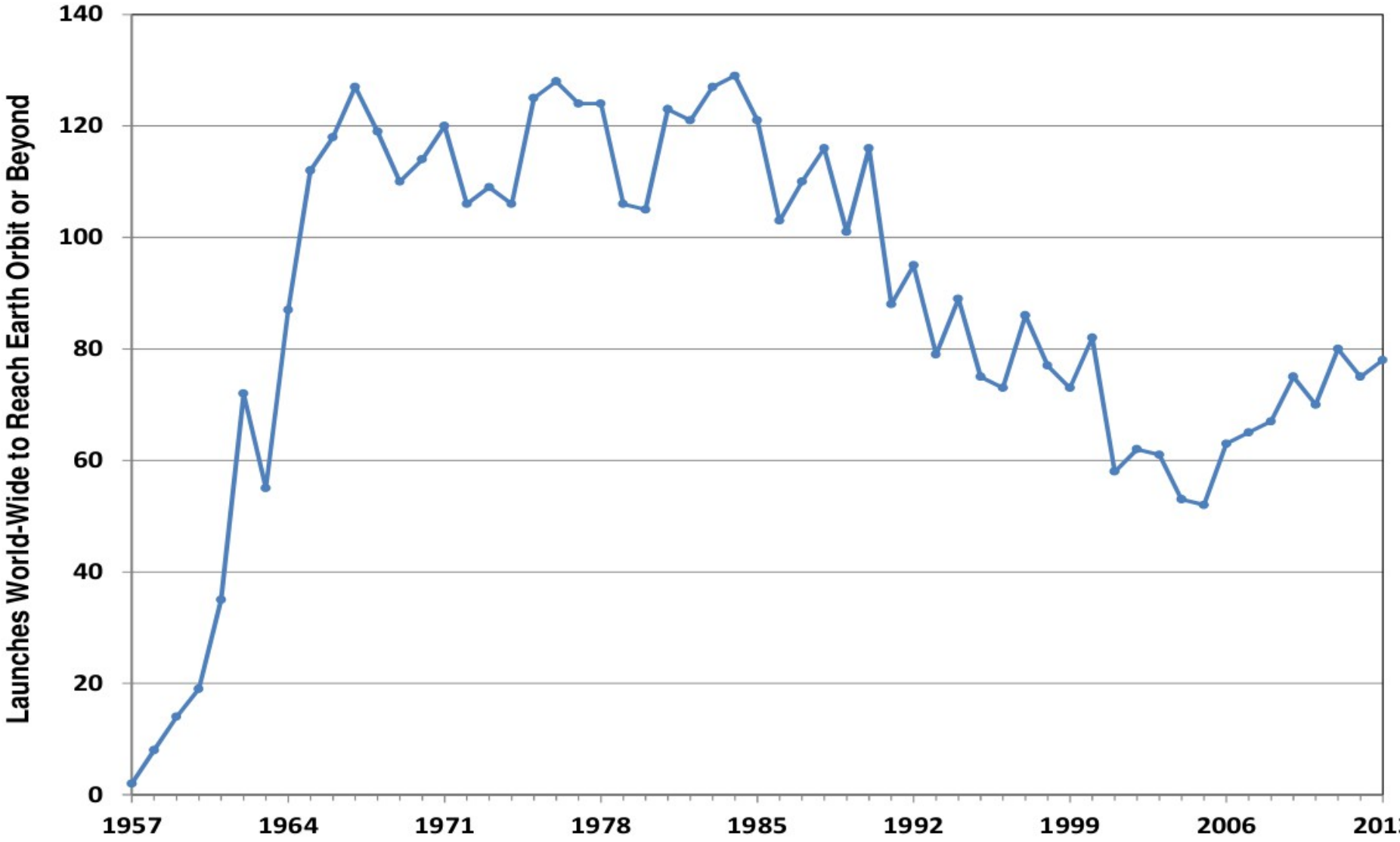
Cataloged objects >10 cm diameter


SPACE JUNK
JOHN GLENN
FIFTY YEARS AGO WHEN I WENT INTO SPACE THERE ACTUALLY WAS SPACE!

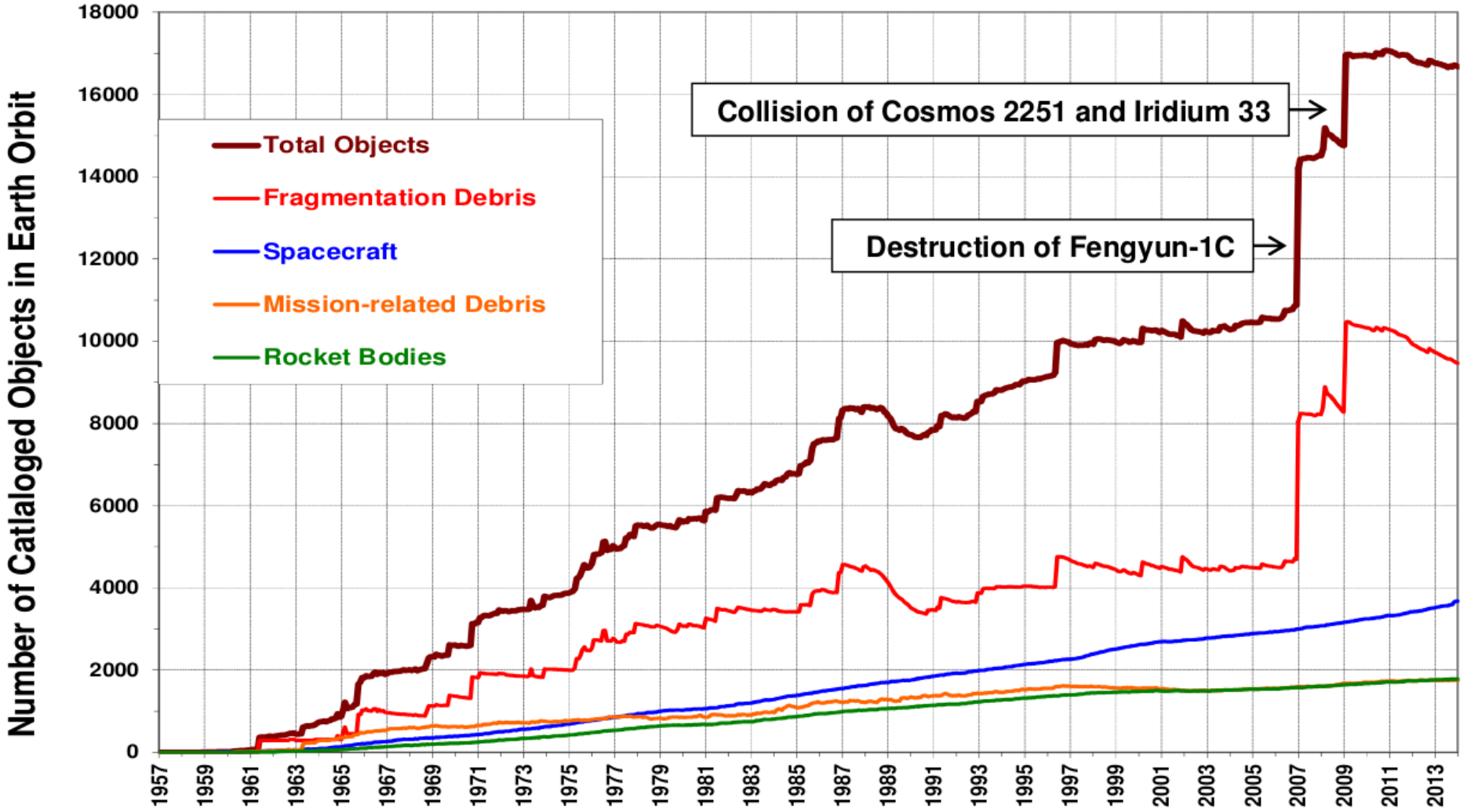
Size – Number Relationship



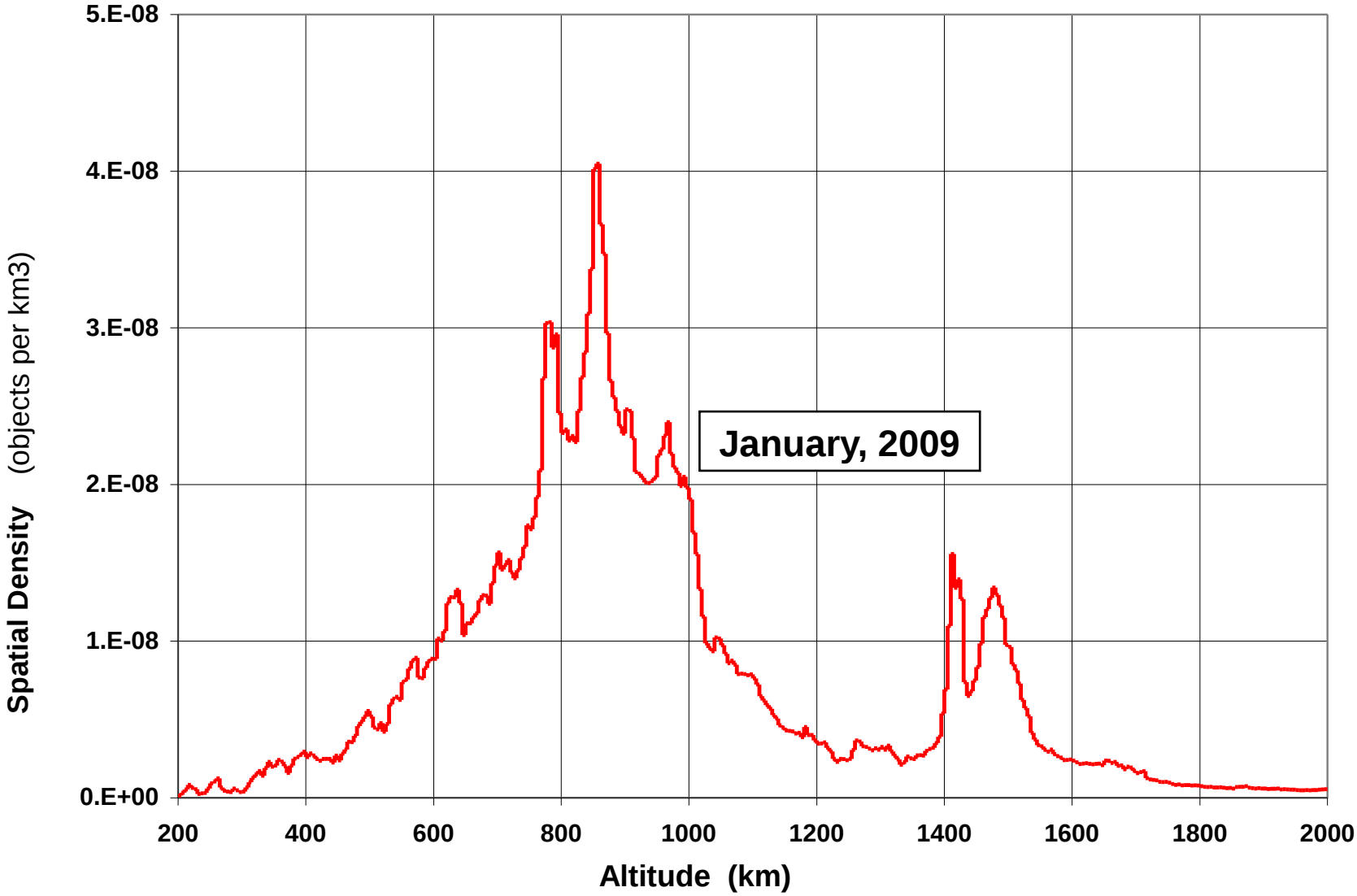
Global Space Launches by Year



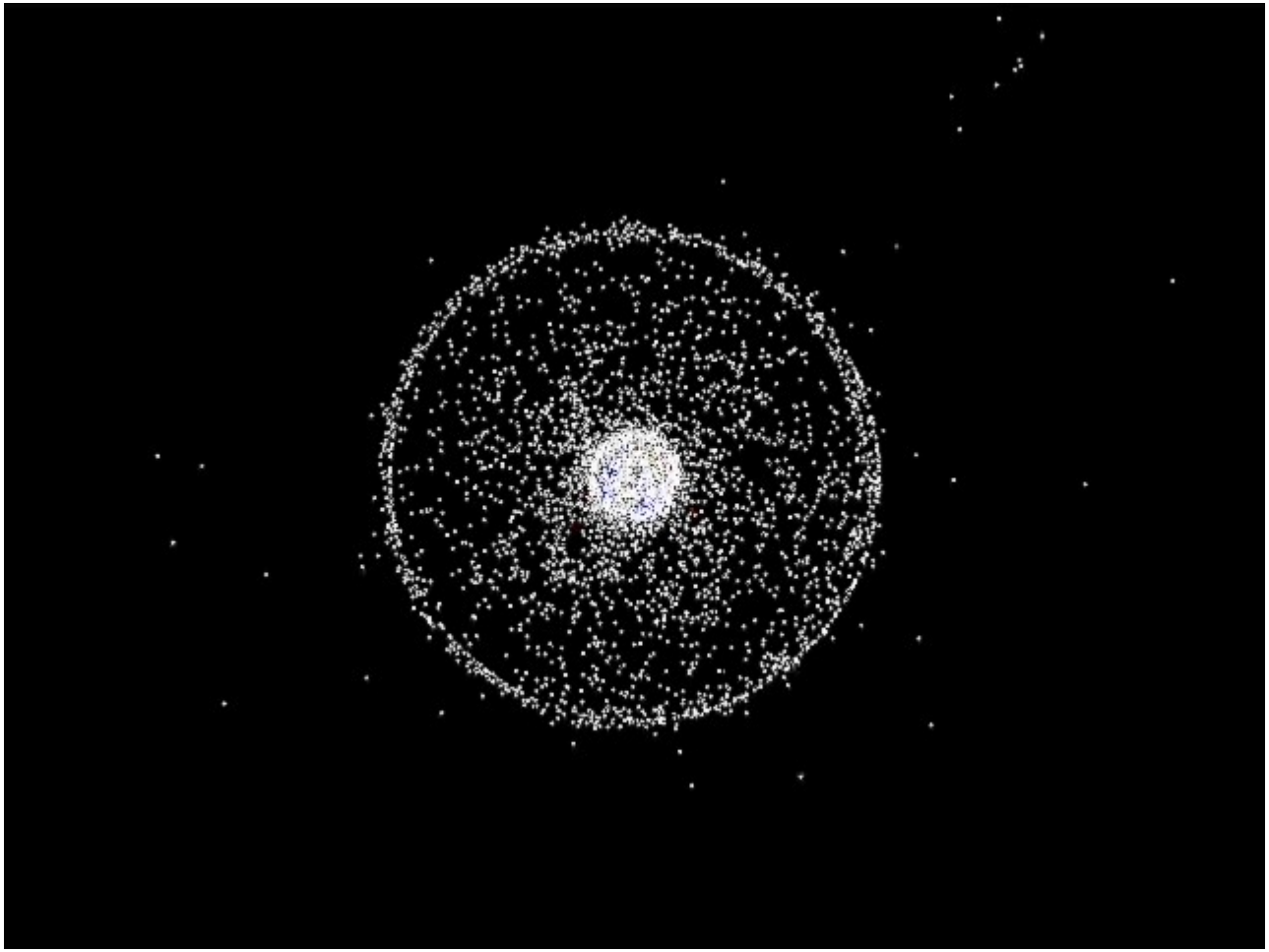
Evolution of the Cataloged Satellite Population



Altitude Distribution of Debris



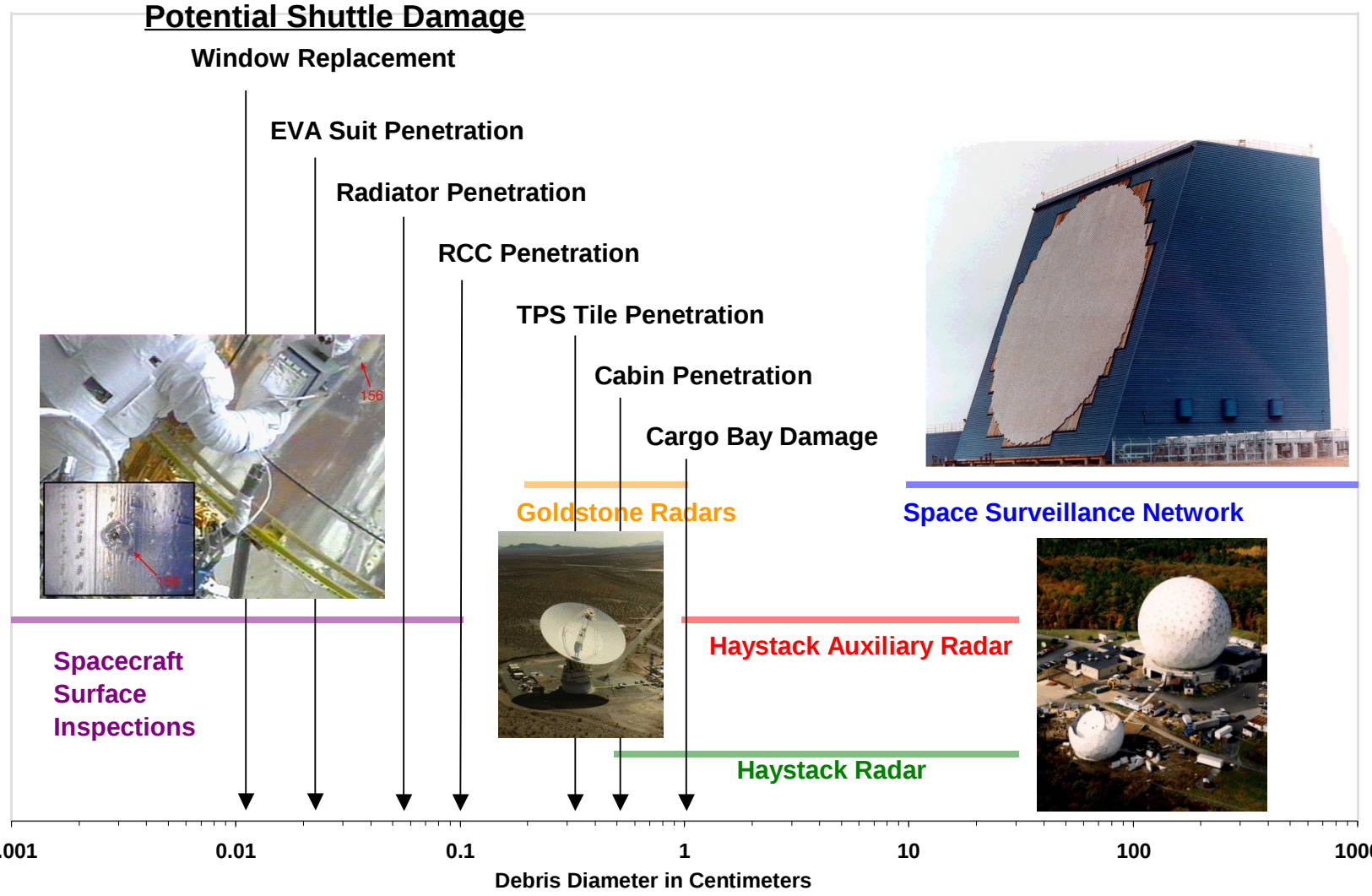
Orbital Environment



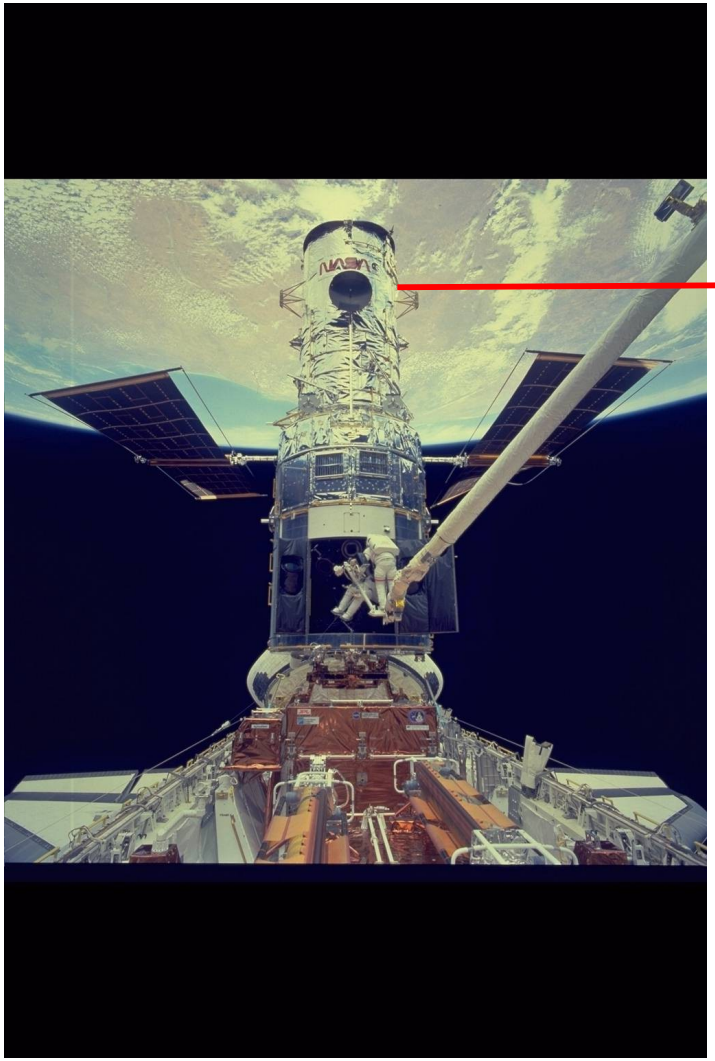
How Do We Know What's Up There?
Complementary NASA and DoD Orbital Debris Efforts

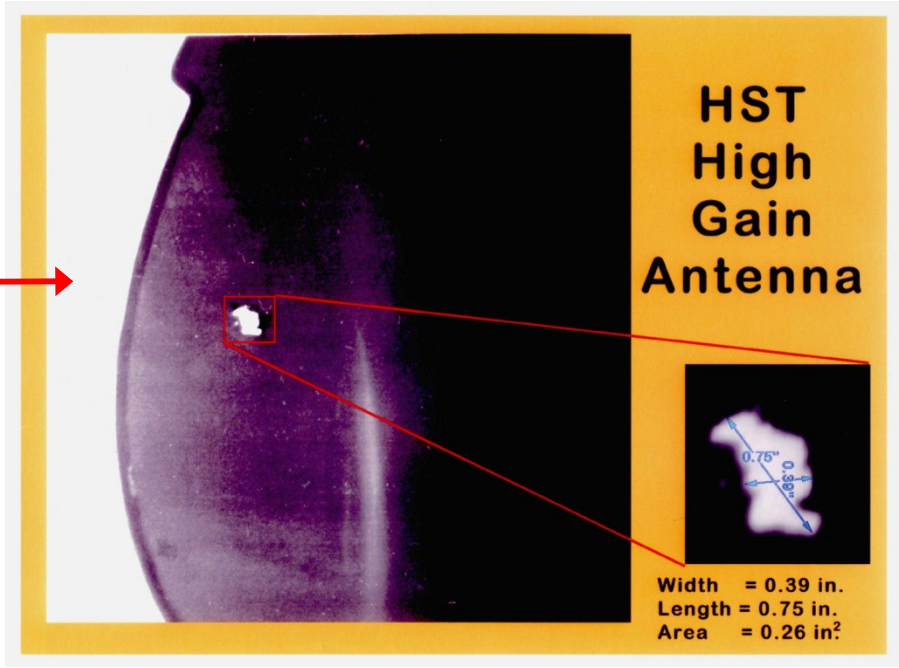
Activity	Lead Agency
Environment Definition (>10 cm)	DoD
Environment Definition (<10 cm)	NASA
Risk Assessments	DoD (>10 cm)
	NASA (<10 cm)
Mitigation Measures	NASA
Environment Projection	NASA

Principal Orbital Debris Data Sources



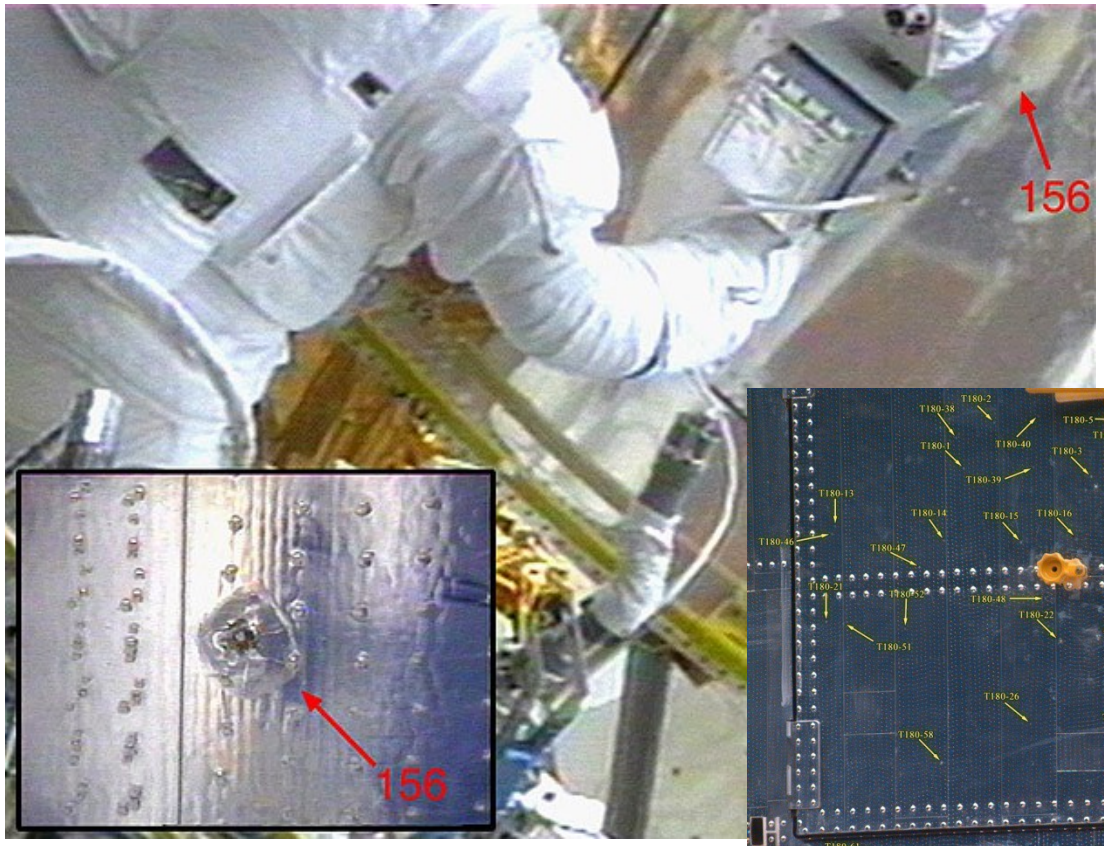
Hubble Space Telescope





- **The Hubble Space Telescope suffered a significant impact in one high gain antenna during its first four years in space.**

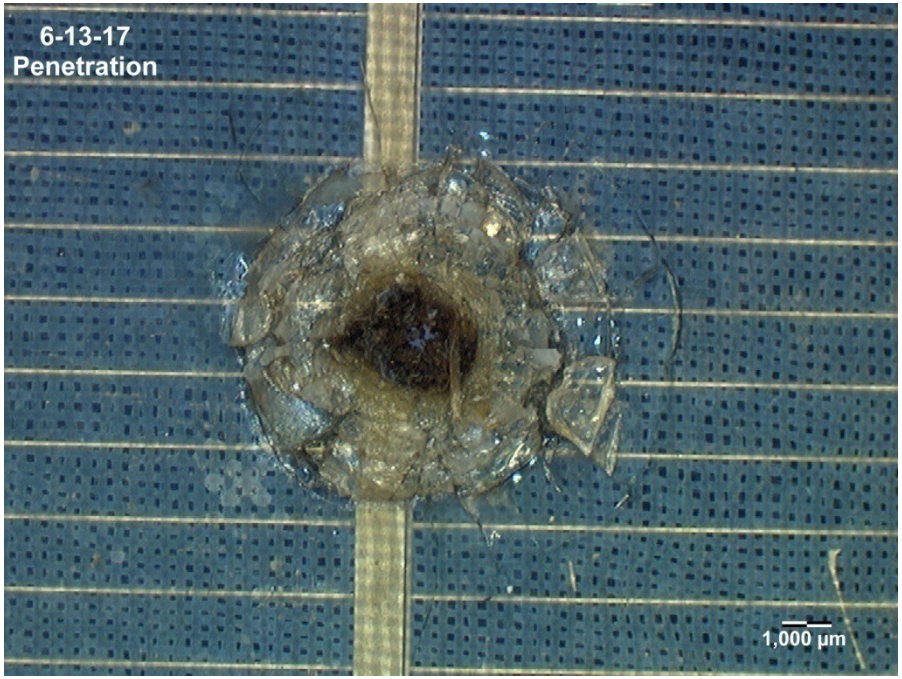
Hubble Space Telescope (continued)



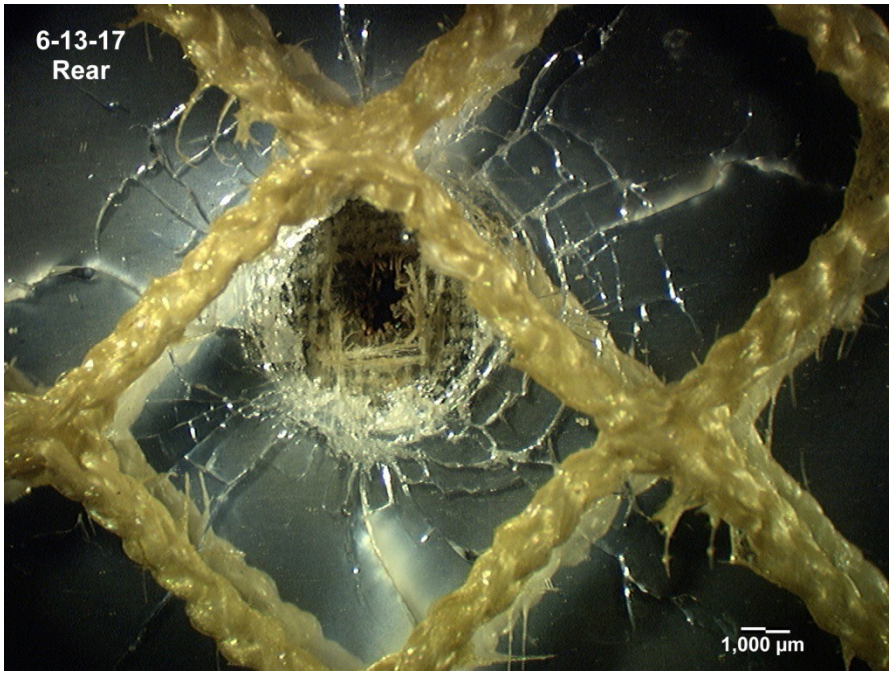
After 7 years in space the Hubble Space Telescope had been peppered with more than 500 craters on its aft shroud

Mir Space Station Solar Array

- **Sample impact from Mir solar array returned in 1998 by Space Shuttle**

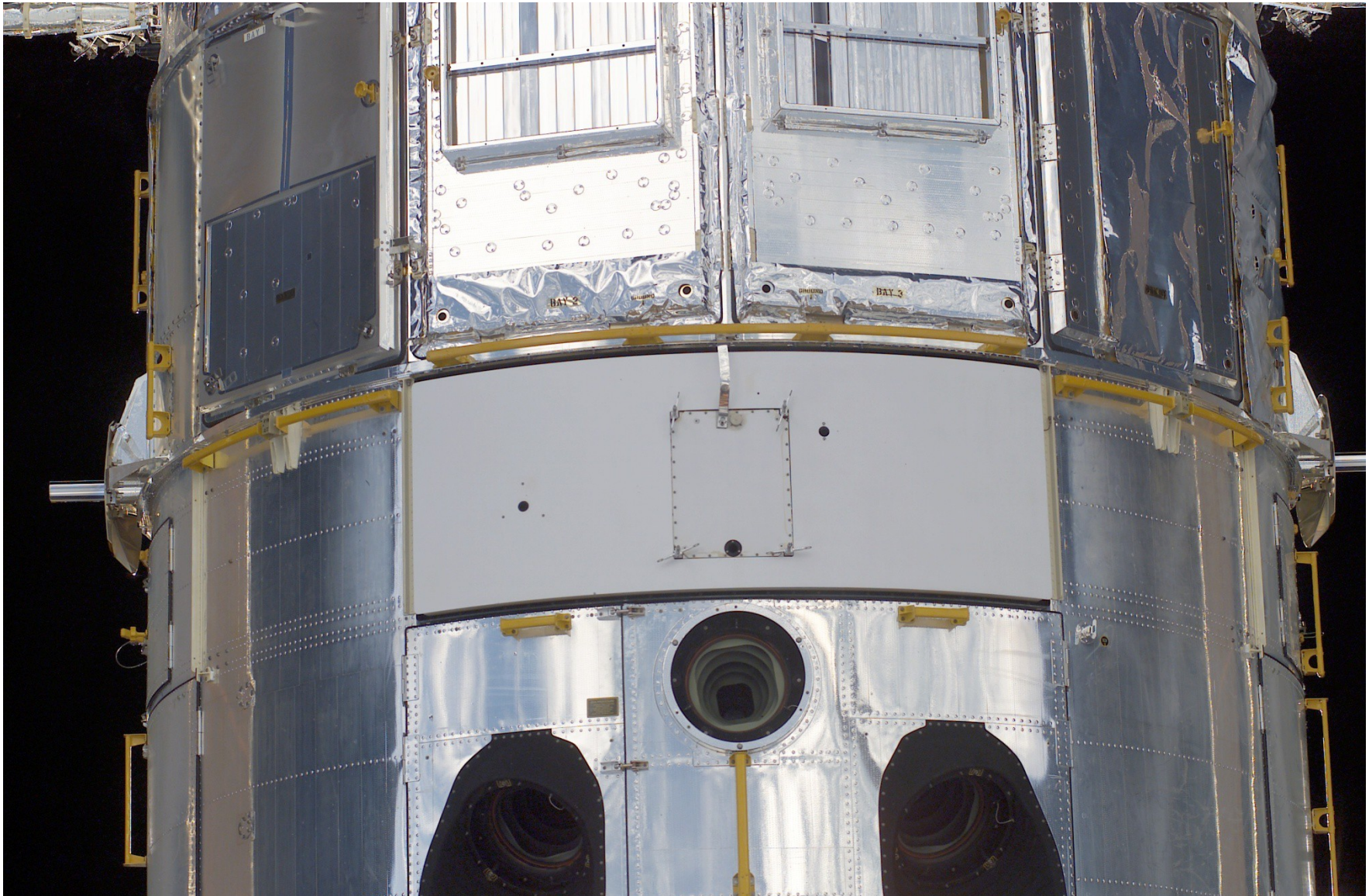


Front of Panel



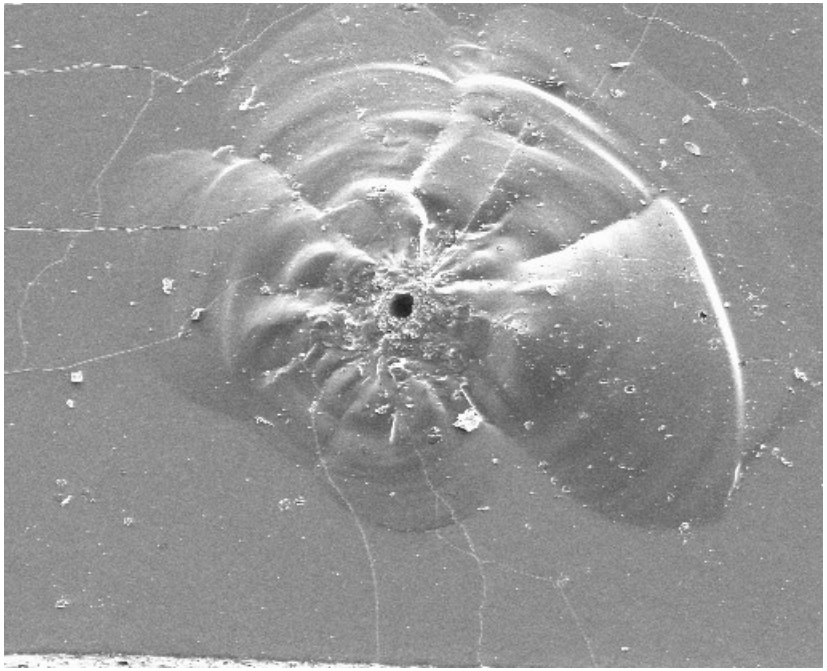
Rear of Panel

WFPC-2
1993-2009



WFPC-2
1993-2009

Sample Space Shuttle Impacts



STS-92 Window Impact

~0.1 mm Aluminum Debris

2 mm diameter crater

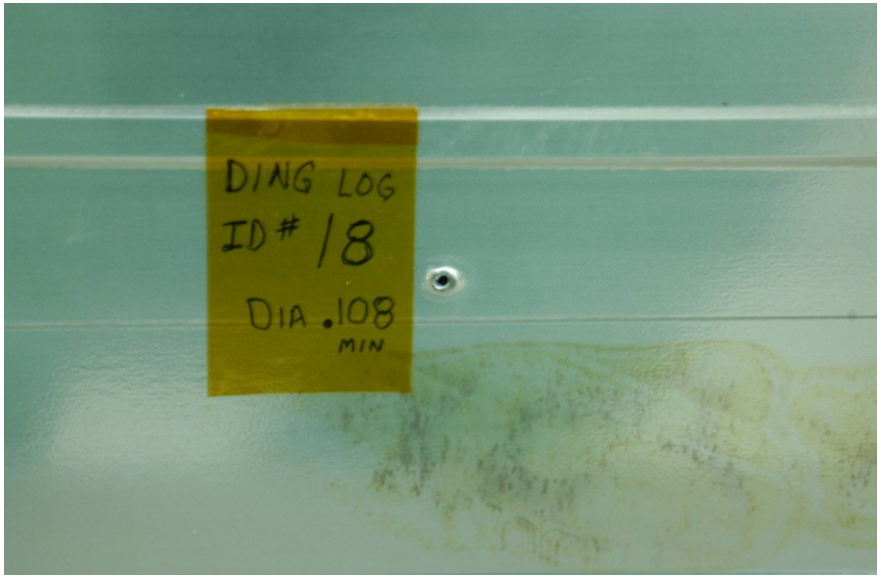
STS-90 Radiator Penetration

~0.3 mm Paint Particle

1 mm diameter hole

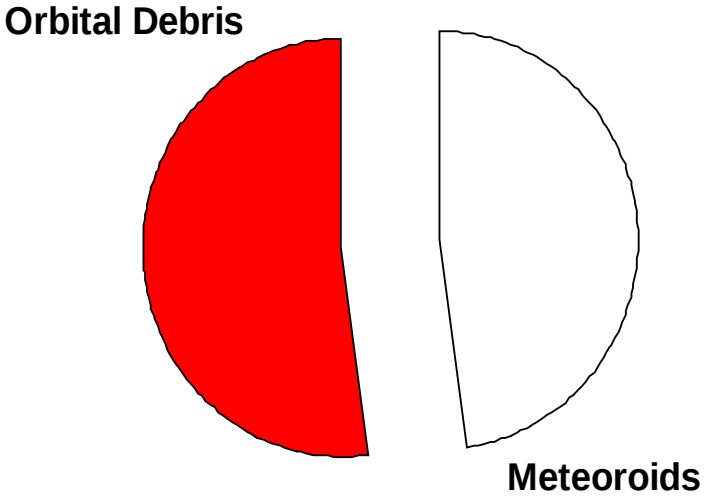
STS-115 MMOD Impact Damage

- The debris punched all the way through the radiator.
- The face sheet hole was 2.8 mm in diameter.
- The core inside the panel was completely destroyed for at least a 2.5 cm diameter below the face sheet damage.
- Impactor was determined from chemical analysis of residue to be orbital debris

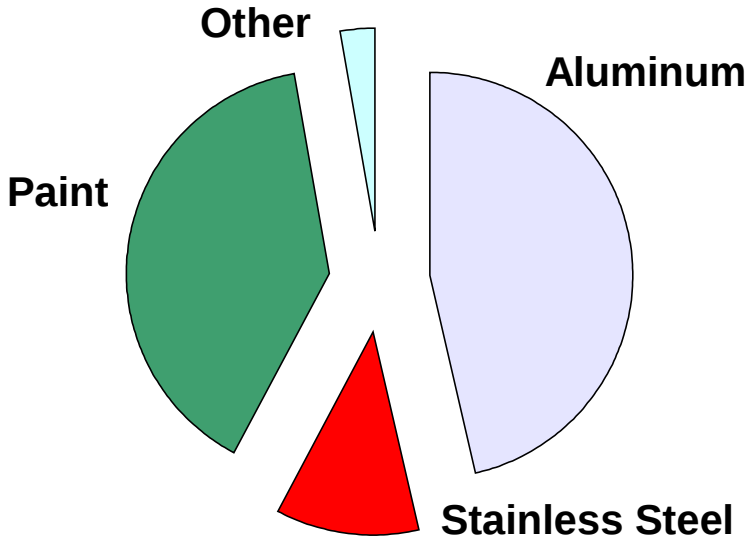


Types of Shuttle Window Impacts

- During 1992-2001 a total of 463 Shuttle window impactors were characterized by type
- Impactors were typically 0.01-0.06 mm in diameter, but some were as large as 0.2 mm in diameter



Identified Impactors



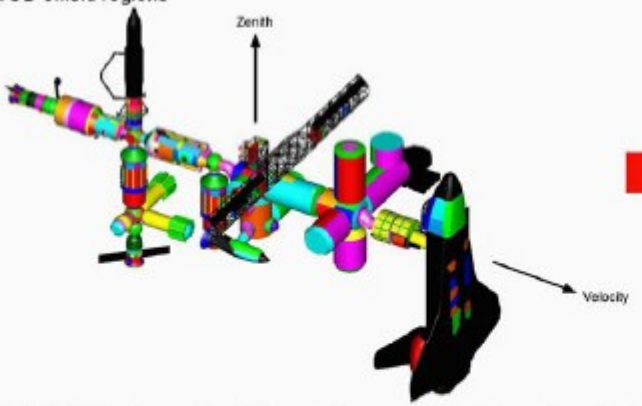
Types of Orbital Debris Impactors

BUMPER

NASA/JSC BUMPER-II Meteoroid/Debris Threat Assessment Code

Spacecraft Configuration (I-DEAS Finite Element Model)

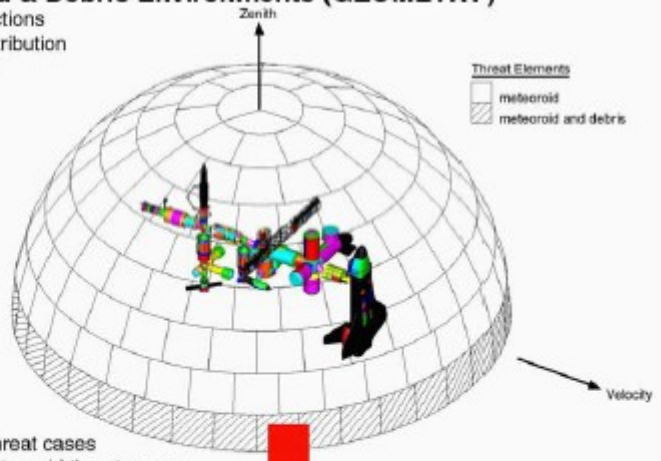
- Describes spatial relationships of spacecraft components
- Defines spacecraft orientation (velocity and zenith directions)
- Defines M/OD shield regions



- Approximately 120,000 elements in ISS assembly complete mated configuration FEM

Meteoroid & Debris Environments (GEOMETRY)

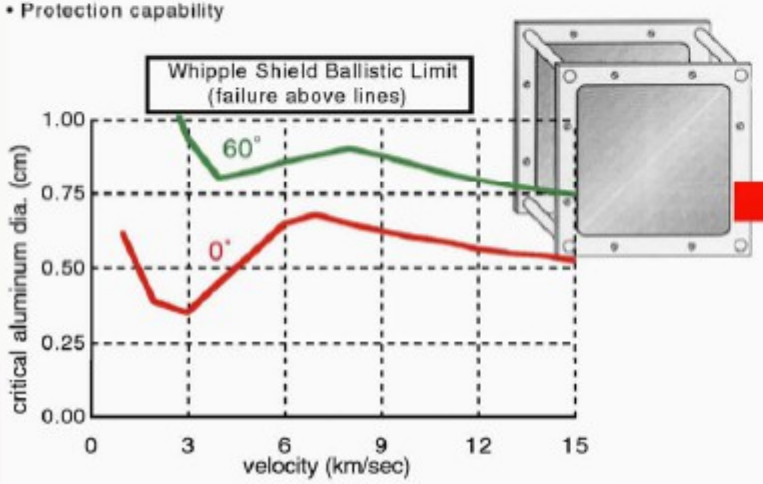
- Threat directions
- Velocity distribution
- Shadowing



- 90 debris threat cases and 149 meteoroid threat cases assessed for each element in the FEM

Critical Particle Diameter Calculation (RESPONSE)

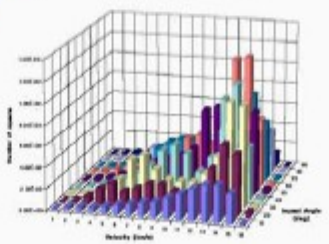
- Protection capability

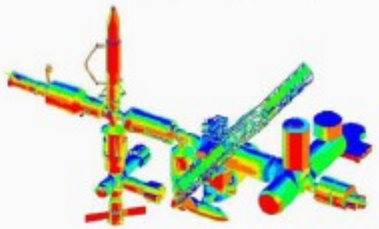


Computation of Penetrating Flux and PNP (SHIELD) Graphical Interpretation of Results (EXCEL & I-DEAS)

Space Station Orbital Debris Threat Assessment

Station Region	Impact Risk From 1 mm Ø Debris: Probability No Impact	Impact Risk From 1 mm Ø Debris: Odds of Impact	Debris Penetration Risk: Probability No Penetration	Debris Penetration Risk: Odds of Penetration
FGB	0.995338	1/214	0.995541	1/224
Service Module	0.999335	1/1505	0.999795	1/4912
Node 2	0.999465	1/1105	0.999998	1/625000
Hab Module	0.995074	1/29	0.996923	1/928
Lab Module	0.995522	1/89	0.999022	1/1023
CRV	0.997445	1/391	0.999839	1/6228
TOTALS	0.934622	1/15	0.993132	1/146

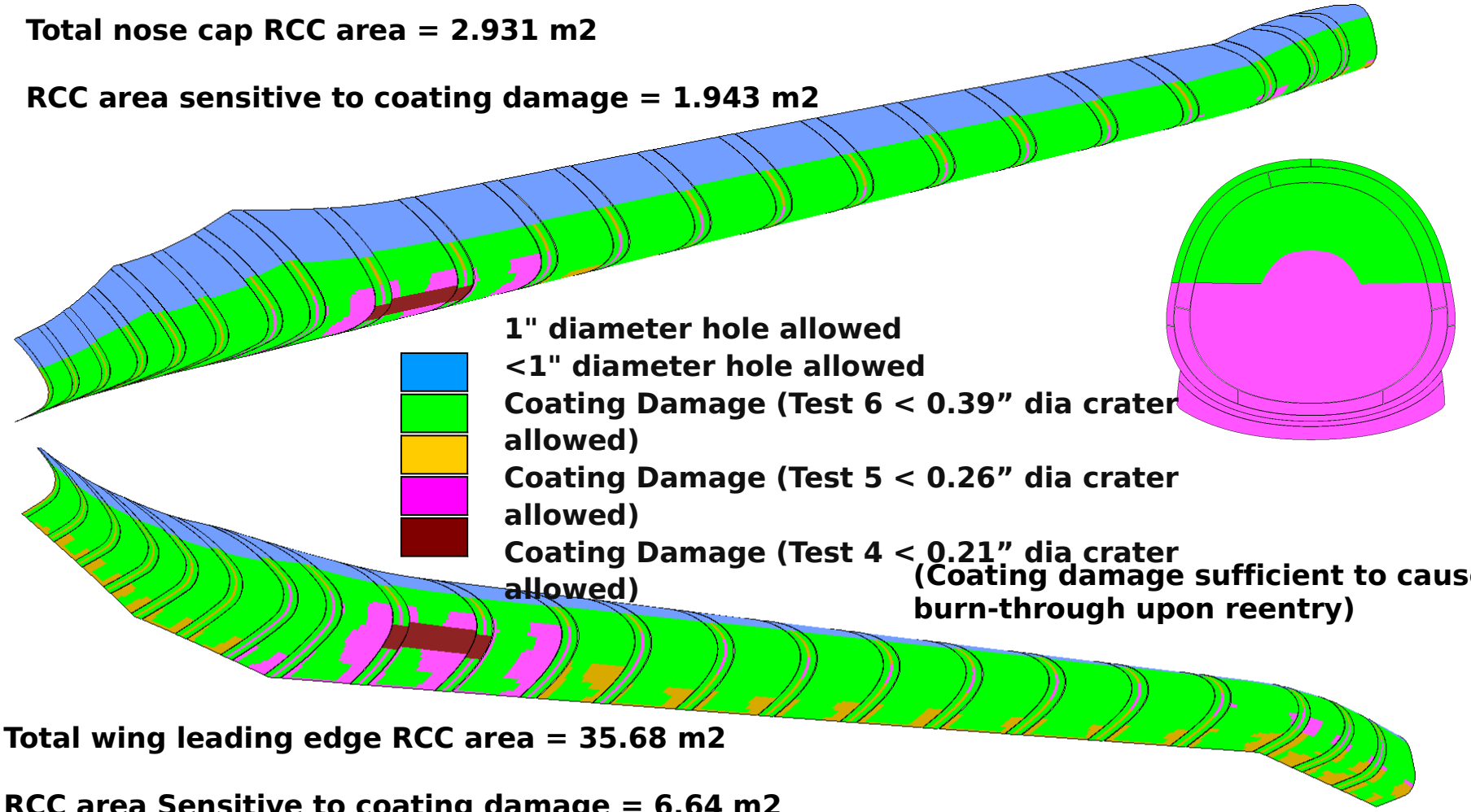




Shuttle RCC

Total nose cap RCC area = 2.931 m2

RCC area sensitive to coating damage = 1.943 m2



1" diameter hole allowed
<1" diameter hole allowed
Coating Damage (Test 6 < 0.39” dia crater allowed)
Coating Damage (Test 5 < 0.26” dia crater allowed)
Coating Damage (Test 4 < 0.21” dia crater allowed)

(Coating damage sufficient to cause burn-through upon reentry)

Total wing leading edge RCC area = 35.68 m2

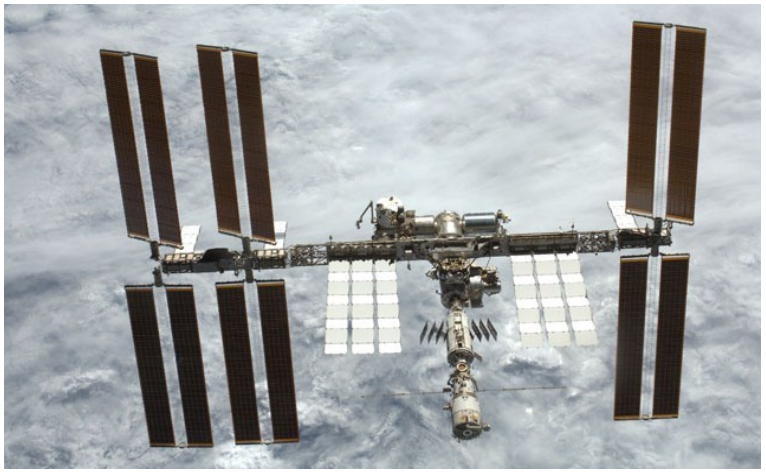
RCC area Sensitive to coating damage = 6.64 m2

Threat of Space Debris to ISS

- **After more than 15 years the ISS has grown from a single 20 metric ton module to a complex laboratory with a span of nearly 100 meters and a mass of almost 500 metric tons.**

- **Despite being the most heavily shielded vehicle ever flown in space, some portions of ISS are vulnerable to space debris particles as small as 3 mm in size, and all critical modules and components are vulnerable to space debris 1 cm and larger.**

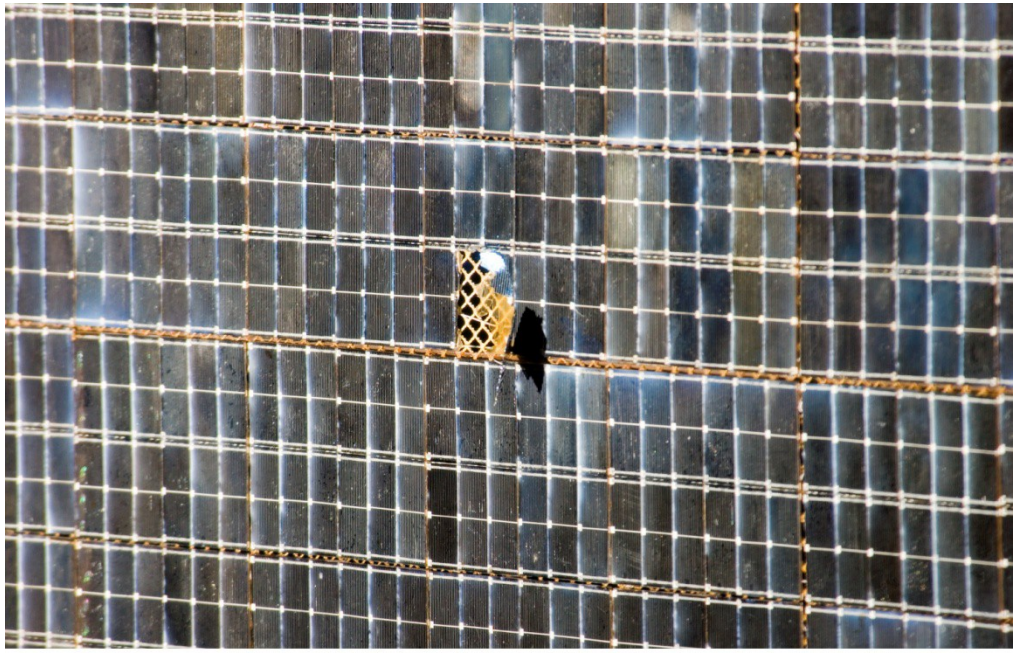
November, 1998



November, 2008

Evidence of Space Debris Impacts on ISS

- **The primary means of detecting space debris impact events are**
  - **(1) crew member observations during space walks,**
  - **(2) photographic surveys of the ISS by externally-mounted cameras or by visiting vehicles, and**
  - **(3) the close examination of components returned to Earth.**

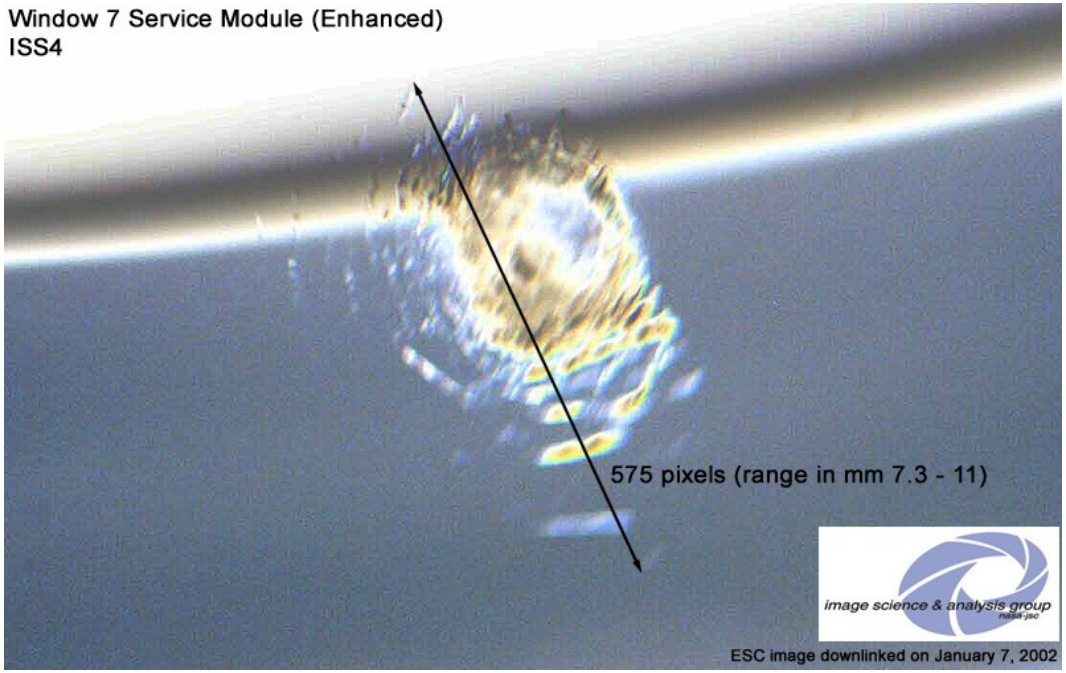


Photograph made in 2006 of solar array damage from an impacting particle.

Space Debris Impacts on ISS Windows

- **The impact of space debris on ISS windows can impede scientific observations and, in the extreme, pose a risk to the ISS and its crew.**

- **One impact on a window in the Zvezda module led to the installation of a protective opaque cover over the window inside the module.**



Particle impact crater recorded in 2002 on one of the windows of the Zvezda module.

Debris Impacts Observed during EVA's

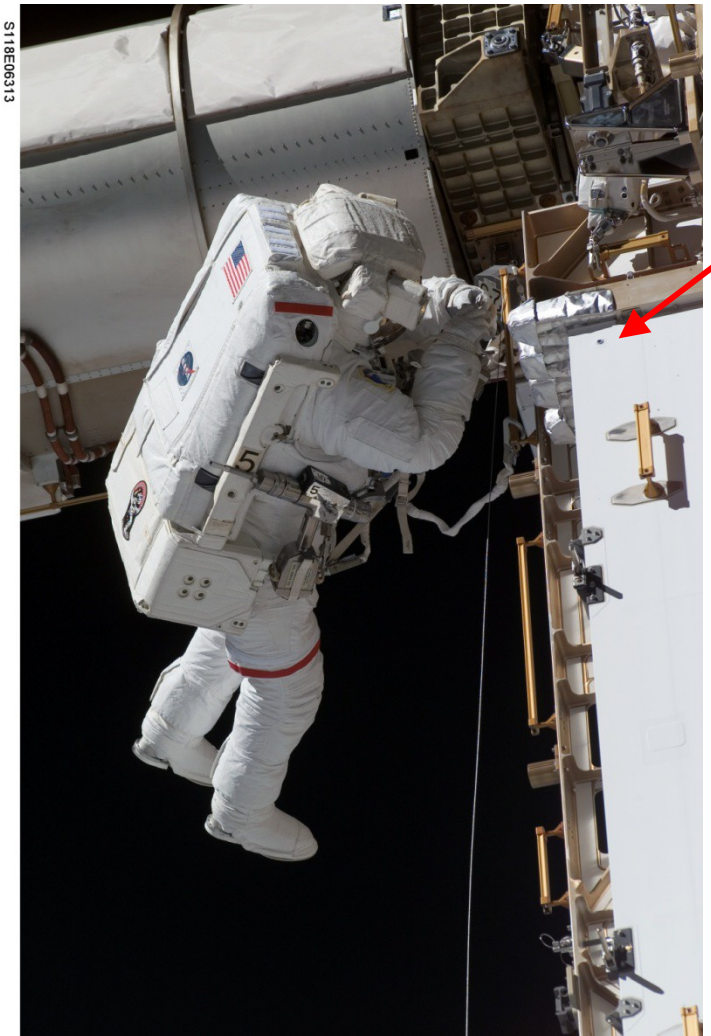
- **The Zarya module was the site of one of the largest space debris impacts on the ISS main structure.**

- **The particle, estimated to be 2-3 mm in diameter, penetrated the module's thermal blanket and the underlying steel mesh, fiberglass, and aluminum honeycomb layers, but did not damage the compressor immediately below.**

Tear, 6.7 cm long and 3.3 cm wide, was discovered in 2007.

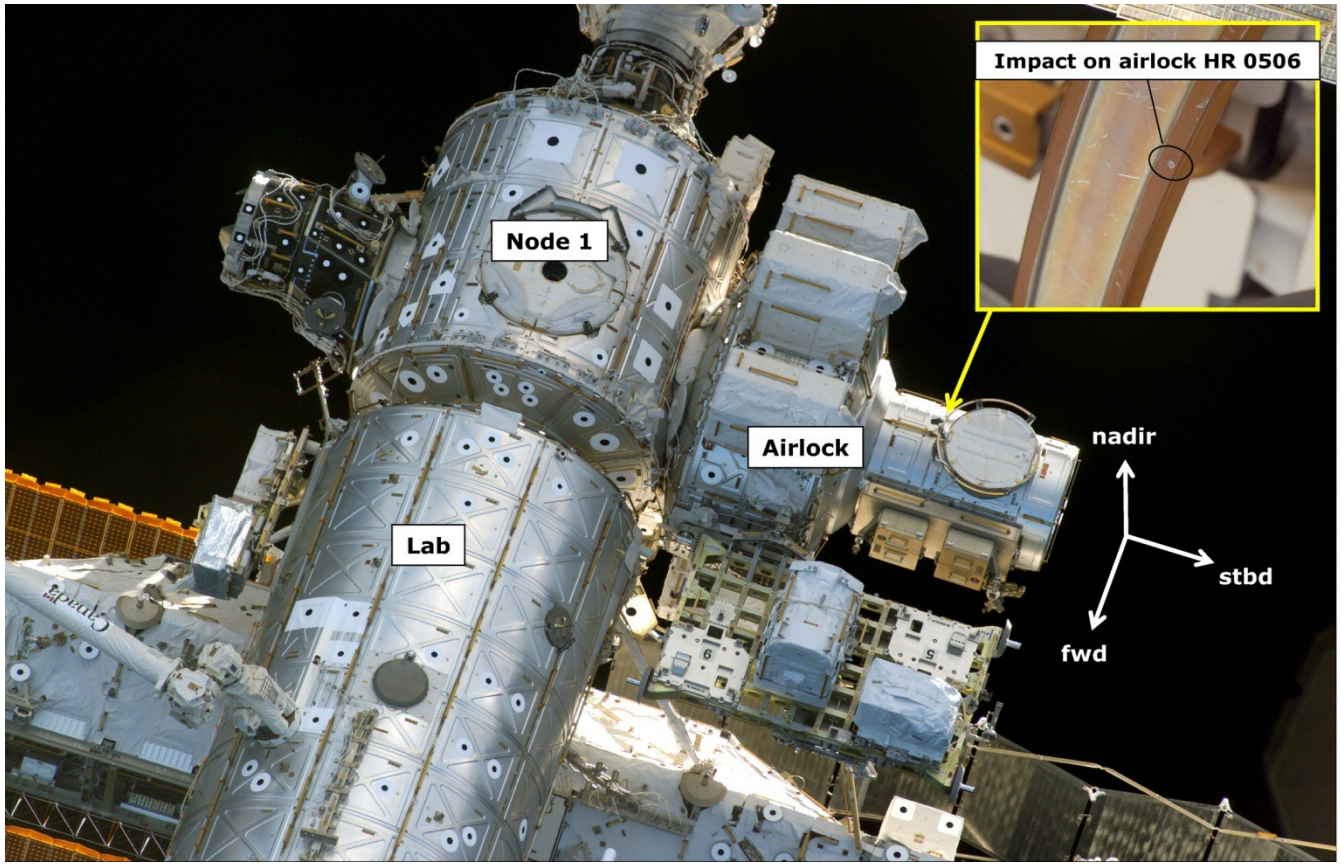
Debris Impacts Observed during EVA's (continued)

- **Also in 2007, a crew member on EVA noticed a hypervelocity impact crater while working near a large aluminum panel.**



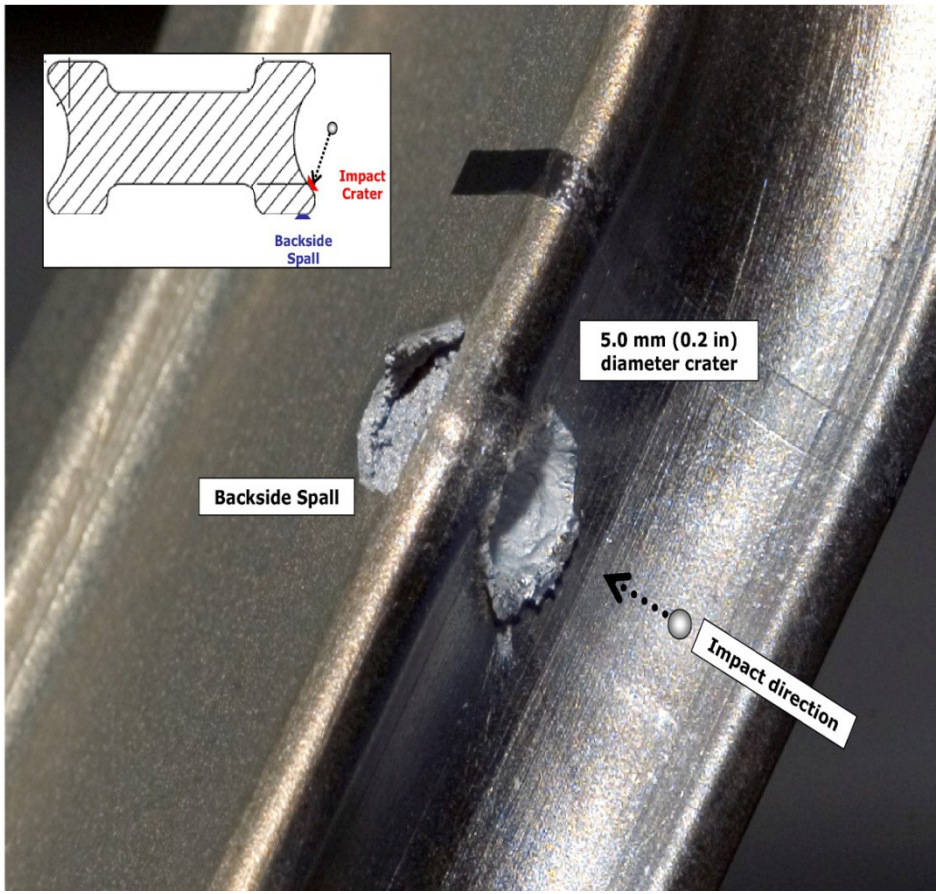
Debris Impacts Observed during EVA's (continued)

- **In early 2008 a space debris impact crater on a handrail (~ 2 mm in diameter) was found with sharp edges, now thought to have possibly been the source of cuts found previously on the gloves of crew conducting EVA's from that airlock.**



Debris Impacts Observed during EVA's (concluded)

- **A space debris particle, estimated to have been slightly less than 1 mm in diameter, struck an EVA tool, which had been stored externally on the Z1 truss of the ISS.**

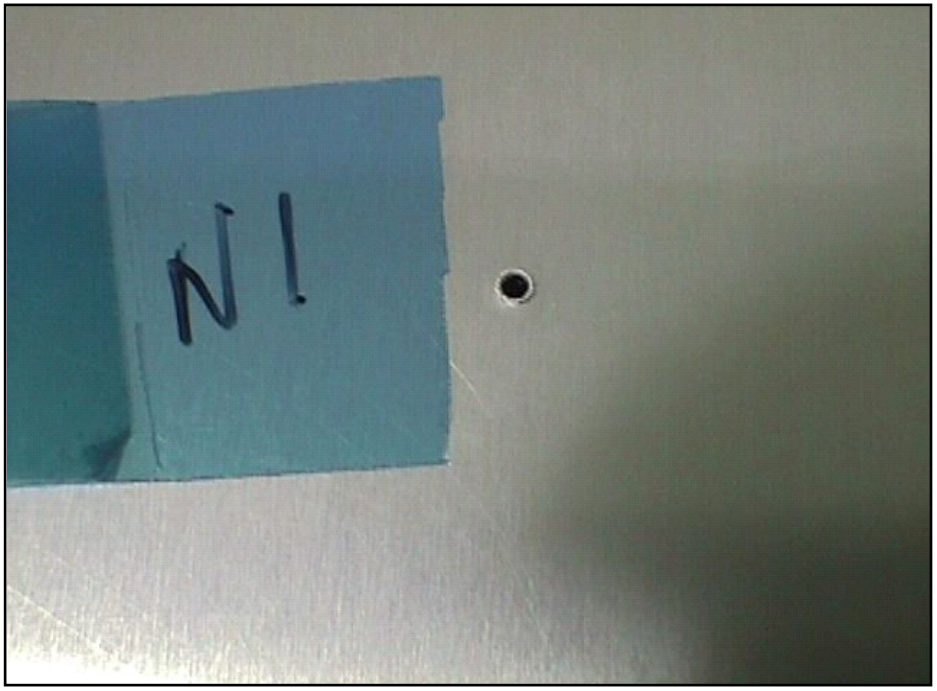


Impact crater and backside spall found on an externally stored EVA tool

Examination of Returned Components

- **Although rarely are components of the ISS returned to Earth, the large Multi-Purpose Logistics Modules (MPLM's), which occasionally ferry equipment to and from the ISS, offer just such an opportunity.**

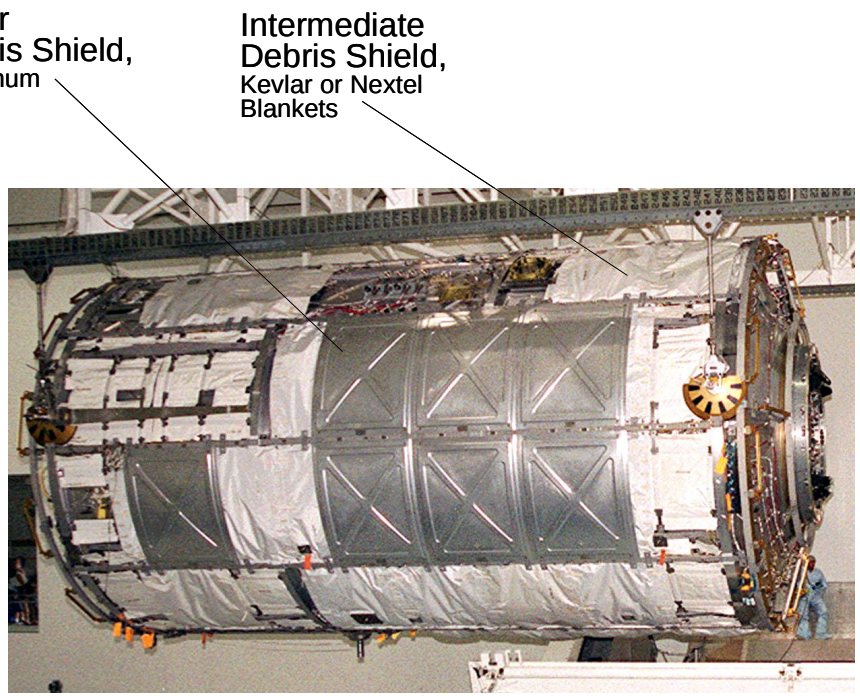
- **By the end of 2008, a total of eight MPLM missions had been conducted, and nearly 200 instances of space debris impacts had been identified.**



Hole found in the space debris shield after the first flight of an MPLM to the ISS in 2001.

ISS Space Debris Countermeasures Strategy

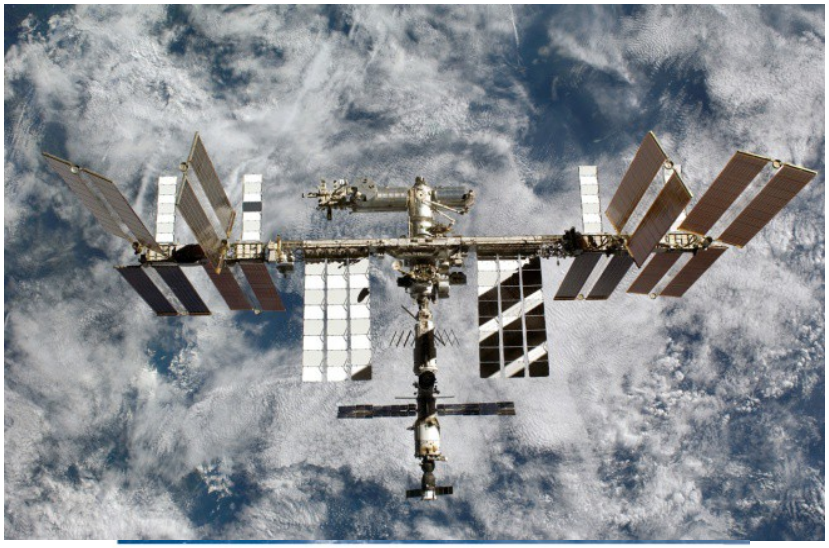
- **Debris smaller than 3 mm: Protect against by inherent structure and specially-designed debris shields.**
- **Debris larger than 10 cm: Conduct collision avoidance maneuvers.**
- **Residual risk lies with debris between 3 mm and 10 cm.**

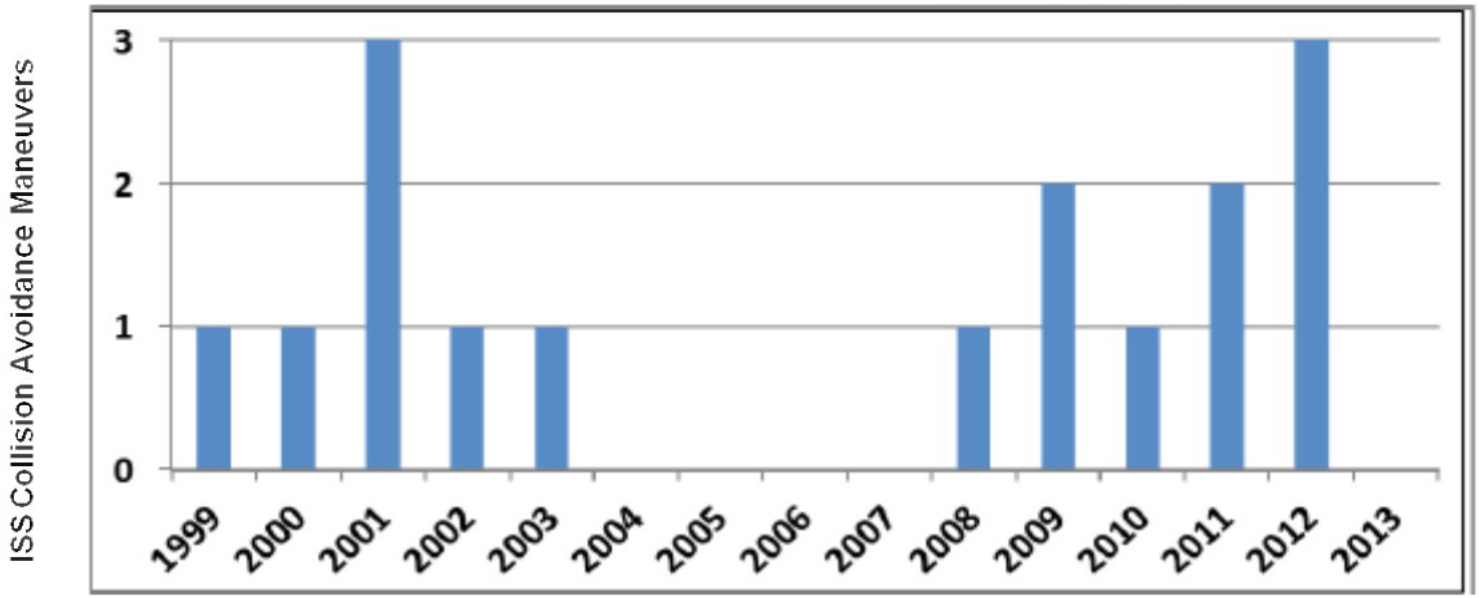


US Laboratory Module during installation of Space Debris Shielding.

ISS Collision Avoidance Maneuvers

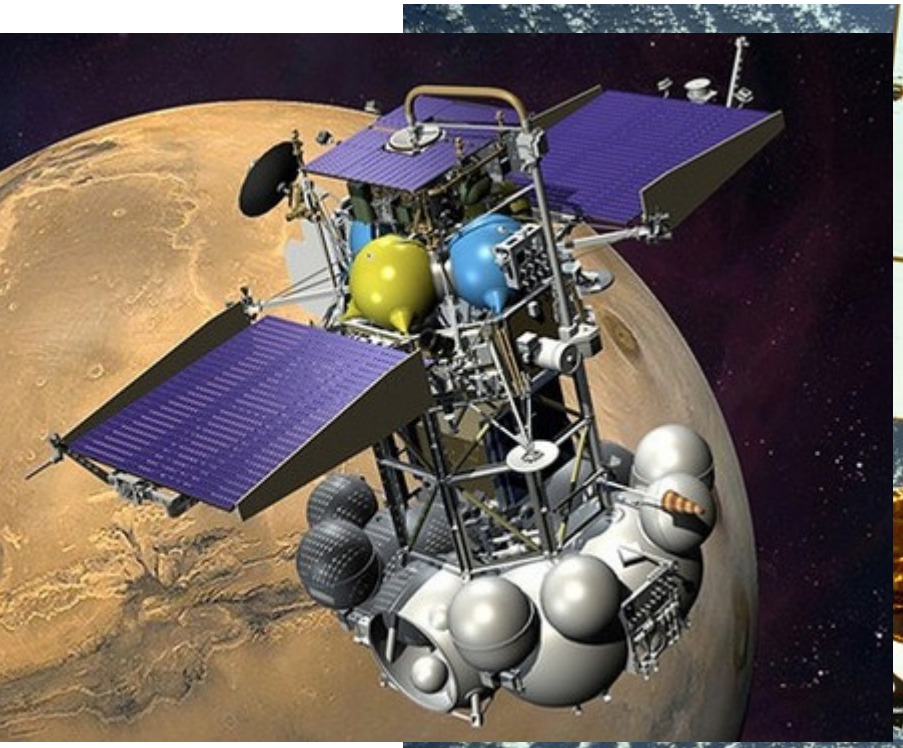
- **The International Space Station has been performing collision avoidance maneuvers since 1999**
  - **Conjunction assessments are evaluated three times each day.**

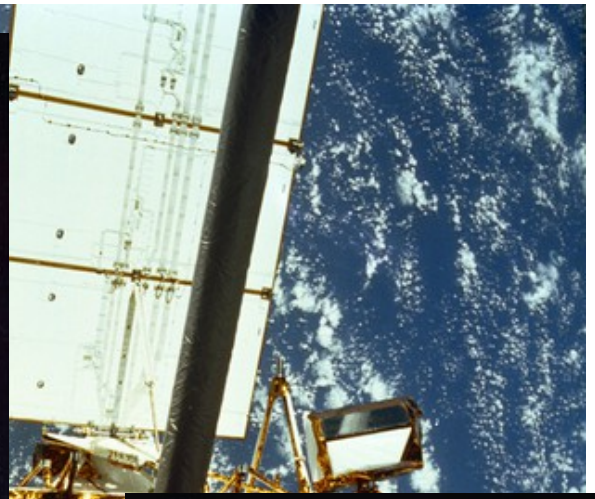




What happens when those big things come down?

Recent Reentries
UARS, ROSAT, Phobos-Grunt





UARS Reentry in the Popular Imagination

Reentry Survivability

- **ORSAT (Object Reentry Survival Analysis Tool) is a high-fidelity model to predict reentering satellite behavior and to aid in determining casualty risks to the world population.**

Texas, 1997

South Africa, 2000

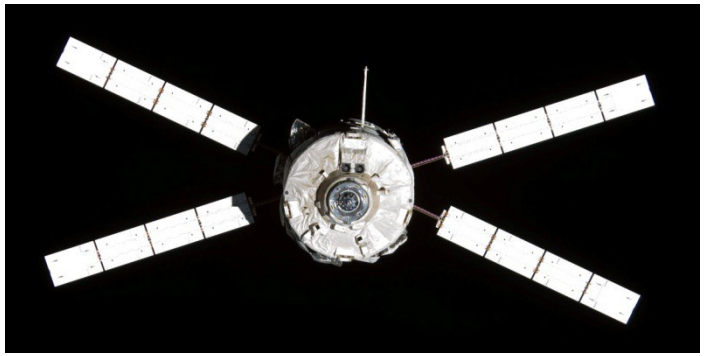
Saudi Arabia, 2001

Guatemala, 2003

Argentina, 2004

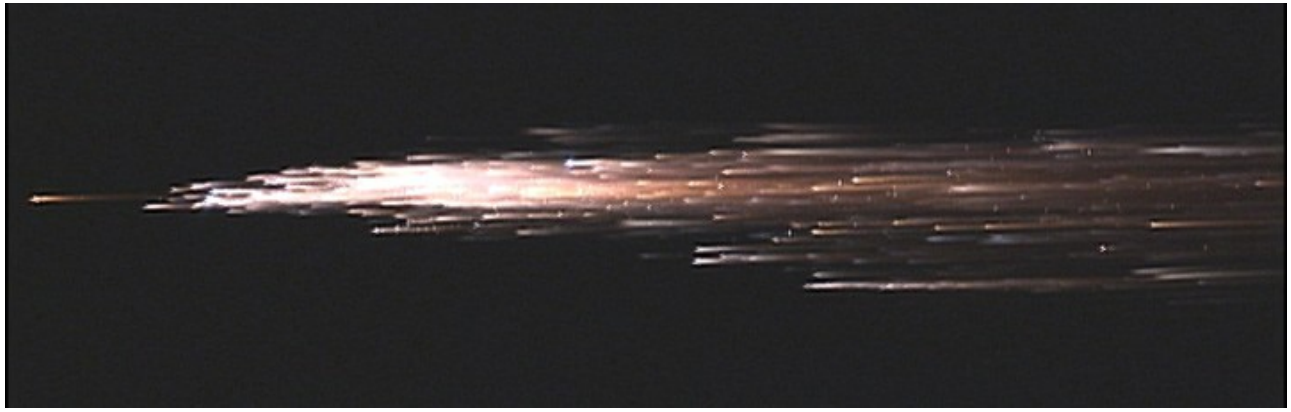
Reentry of the Jules Verne ATV

- **NASA and ESA conducted a joint observation campaign of the reentry of the Jules Verne ATV on 29 September 2008.**
  - **Two aircraft collected a wide variety of data from vantage points over the Pacific Ocean near the reentry path of the Jules Verne.**

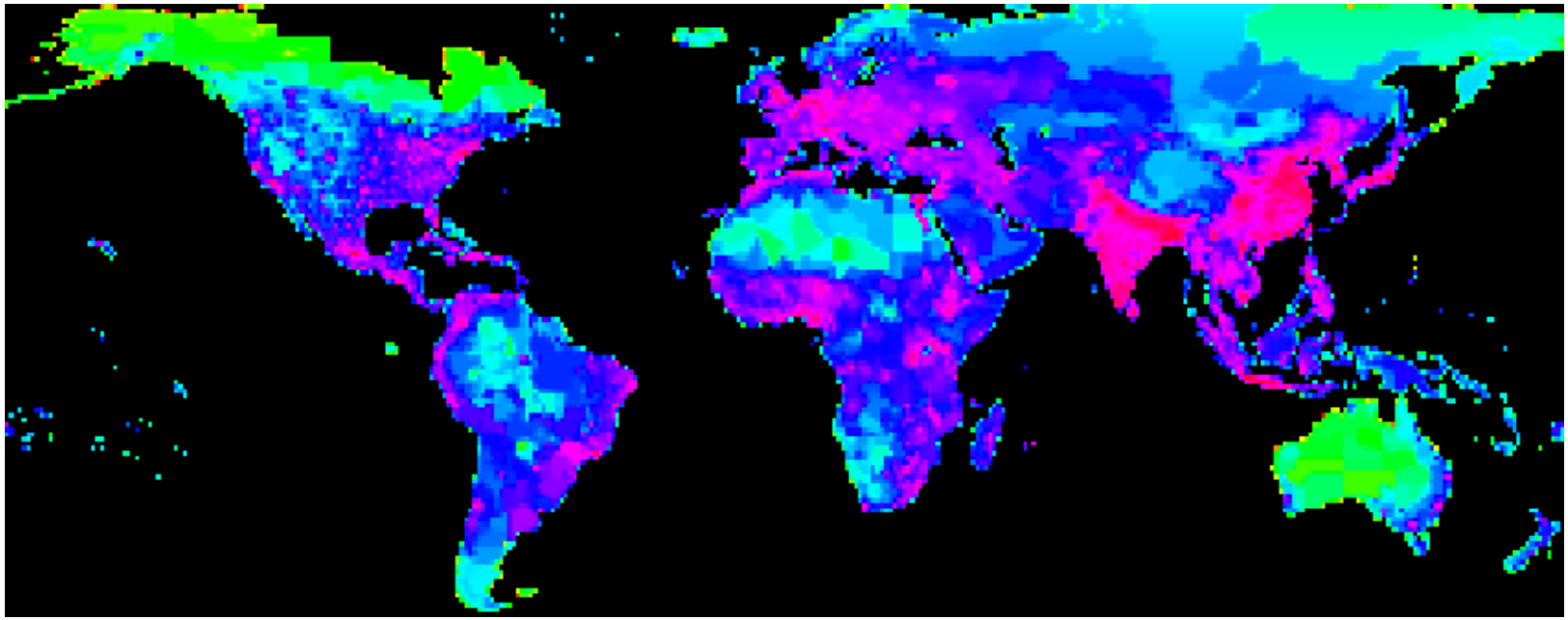


Jules Verne undocking on 5 September 2008

Reentry over Pacific Ocean

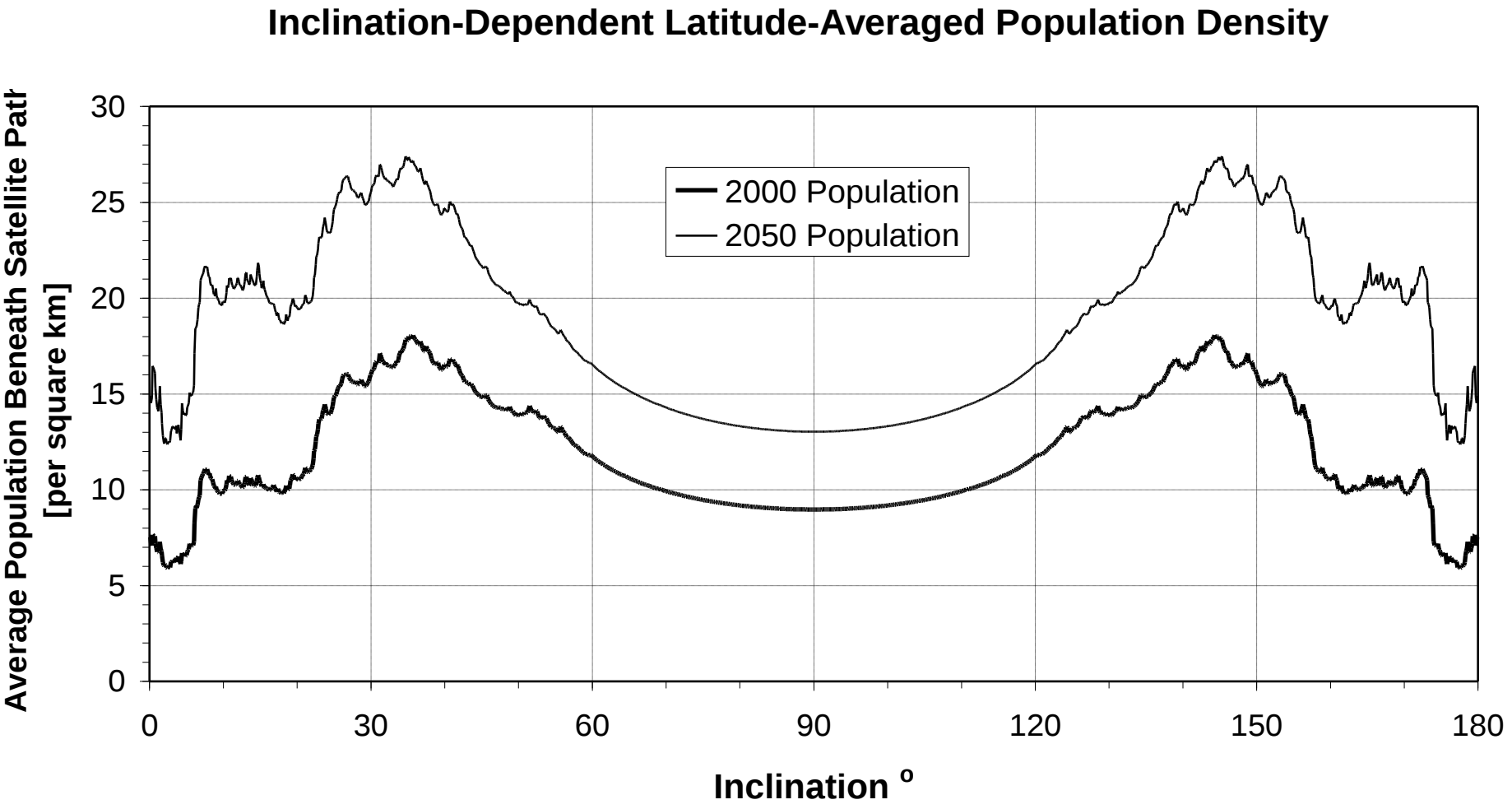


Population Distribution on the Earth



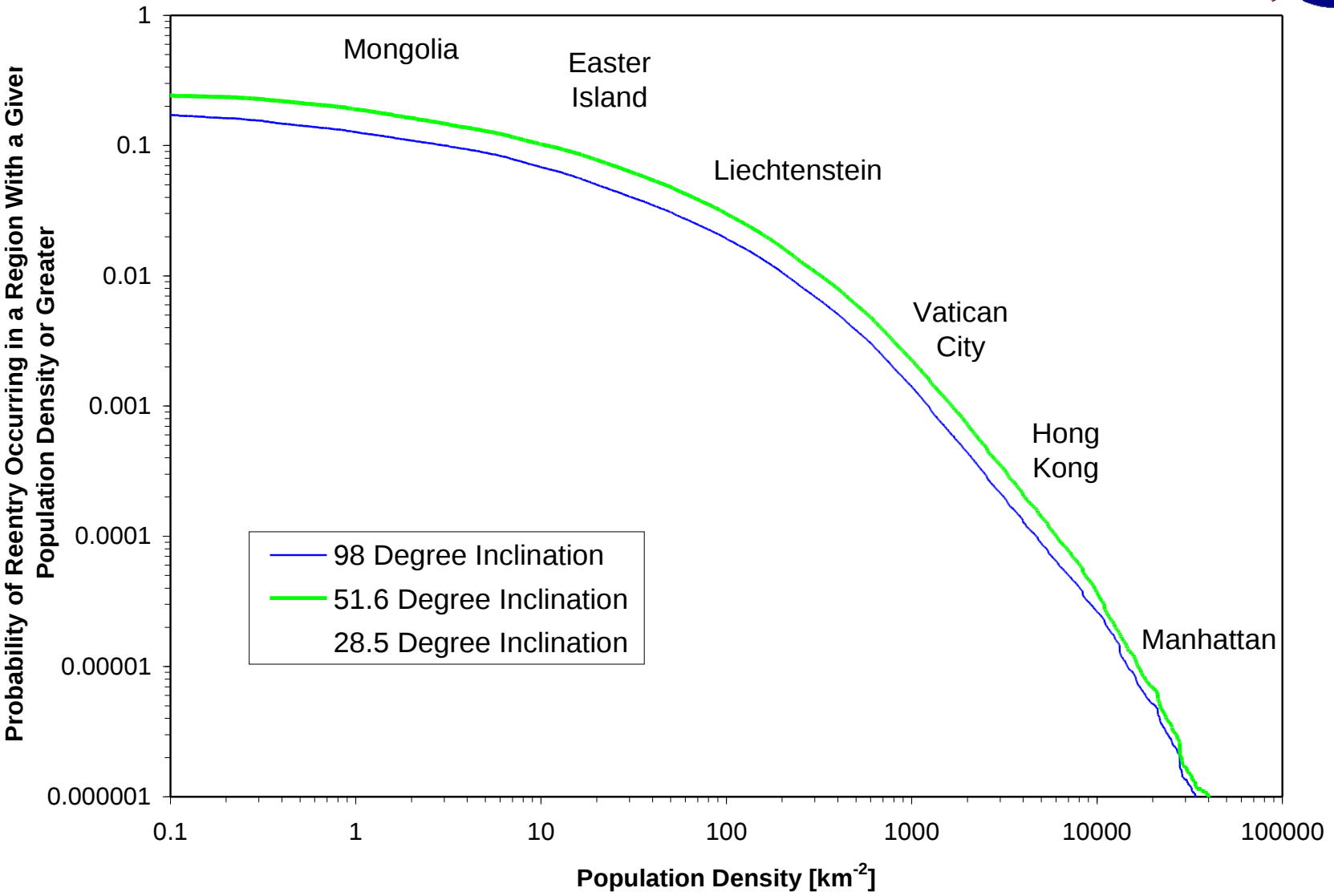
- Gridded Population of the World, version 3 (GPWv3)
- Socioeconomic Data and Applications Center (SEDAC) at Columbia University
- 2.5×2.5 arc minute cells = 4.6 km×4.6 km cells at the Equator
- Reference years 1990-2015 in 5-year intervals

Average Density of People Below Satellite Path

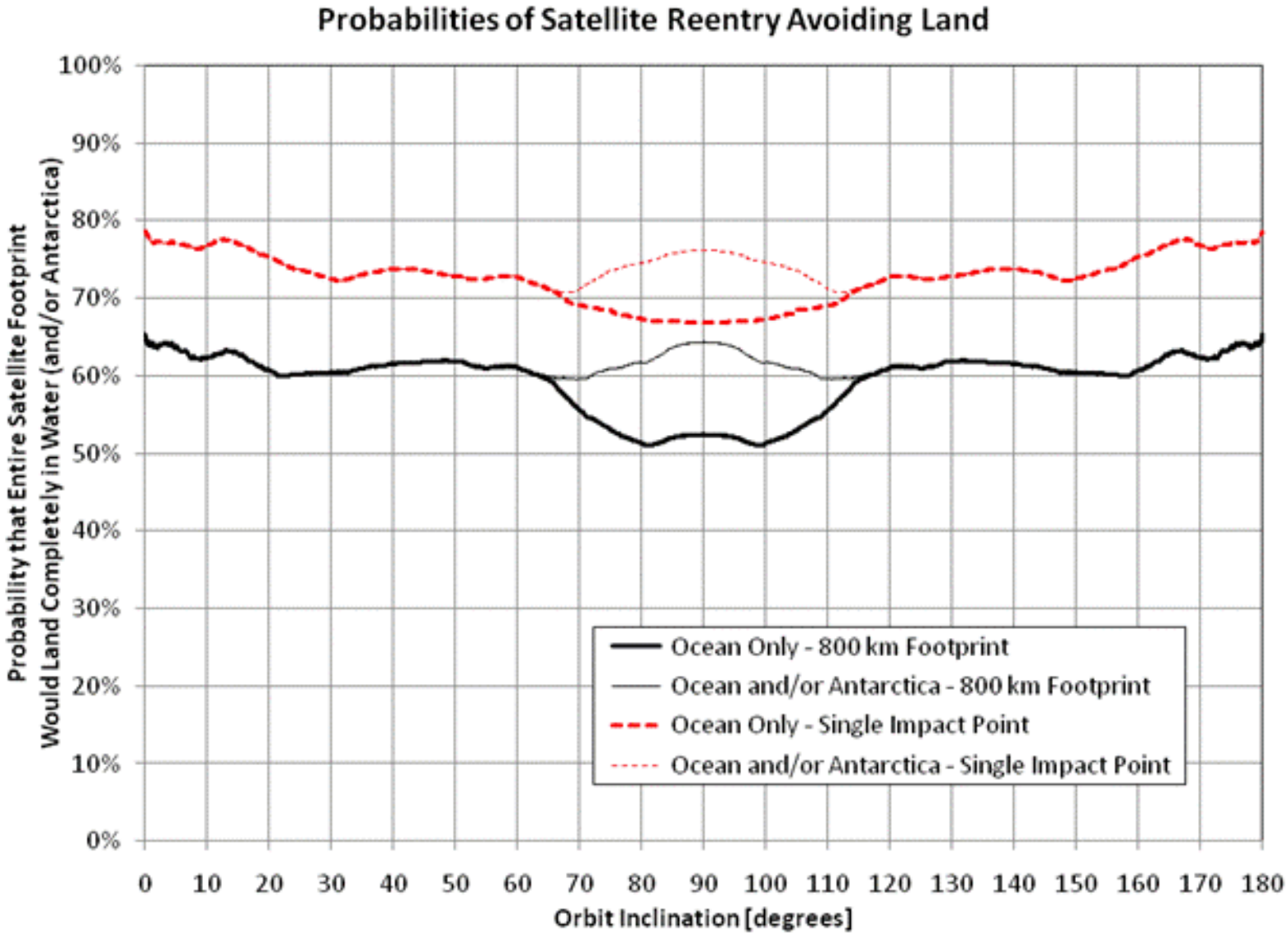


Brewster Rockit on Reentry Risks

Probability of Falling in Populated Areas



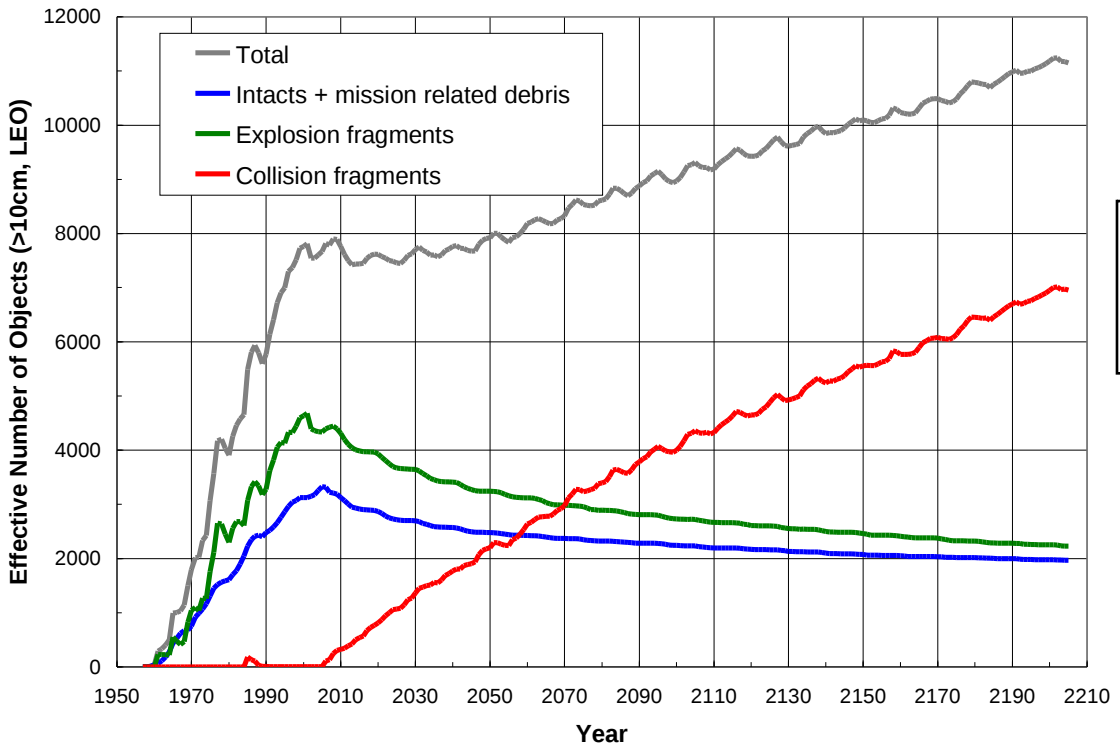
Probability of Ocean Reentry



Near-Term and Far-Term Threats to the Space Environment

- **Historically, the greatest source of hazardous debris has been from the explosions of spacecraft and launch vehicle stages.**
  - **Most of these events have been accidental and preventable**

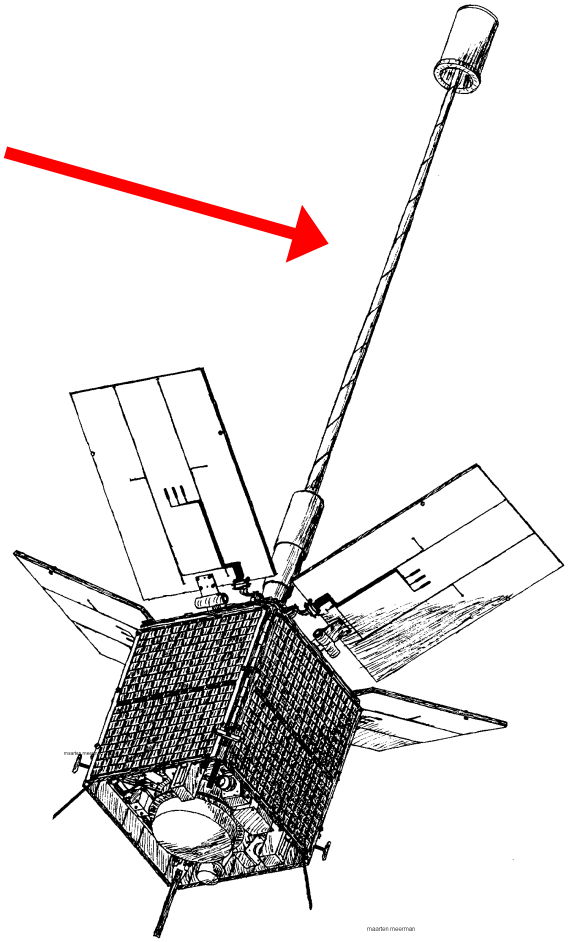
- **In the future accidental collisions will dominate the growth of debris population.**



No new launch scenario

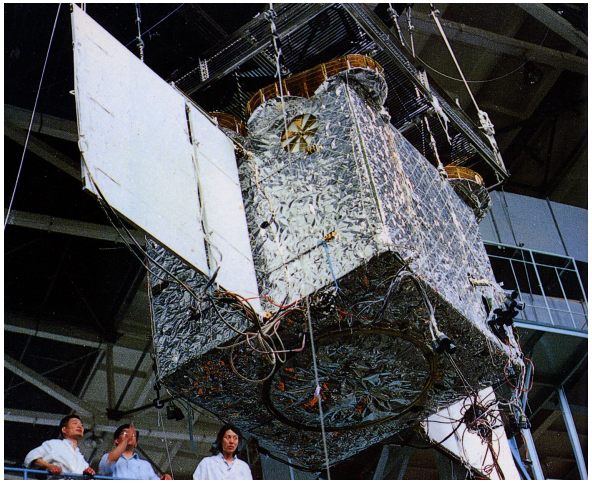
Collisions Have Already Begun

- **1991: Russian non-operational spacecraft struck by debris from a 10-year-older sister spacecraft**
- **1996: French CERISE spacecraft struck by a fragment of a French launch vehicle which had exploded 10 years earlier**
- **2005: U.S. derelict rocket body struck by a fragment of a Chinese launch vehicle which had exploded 5 years earlier**



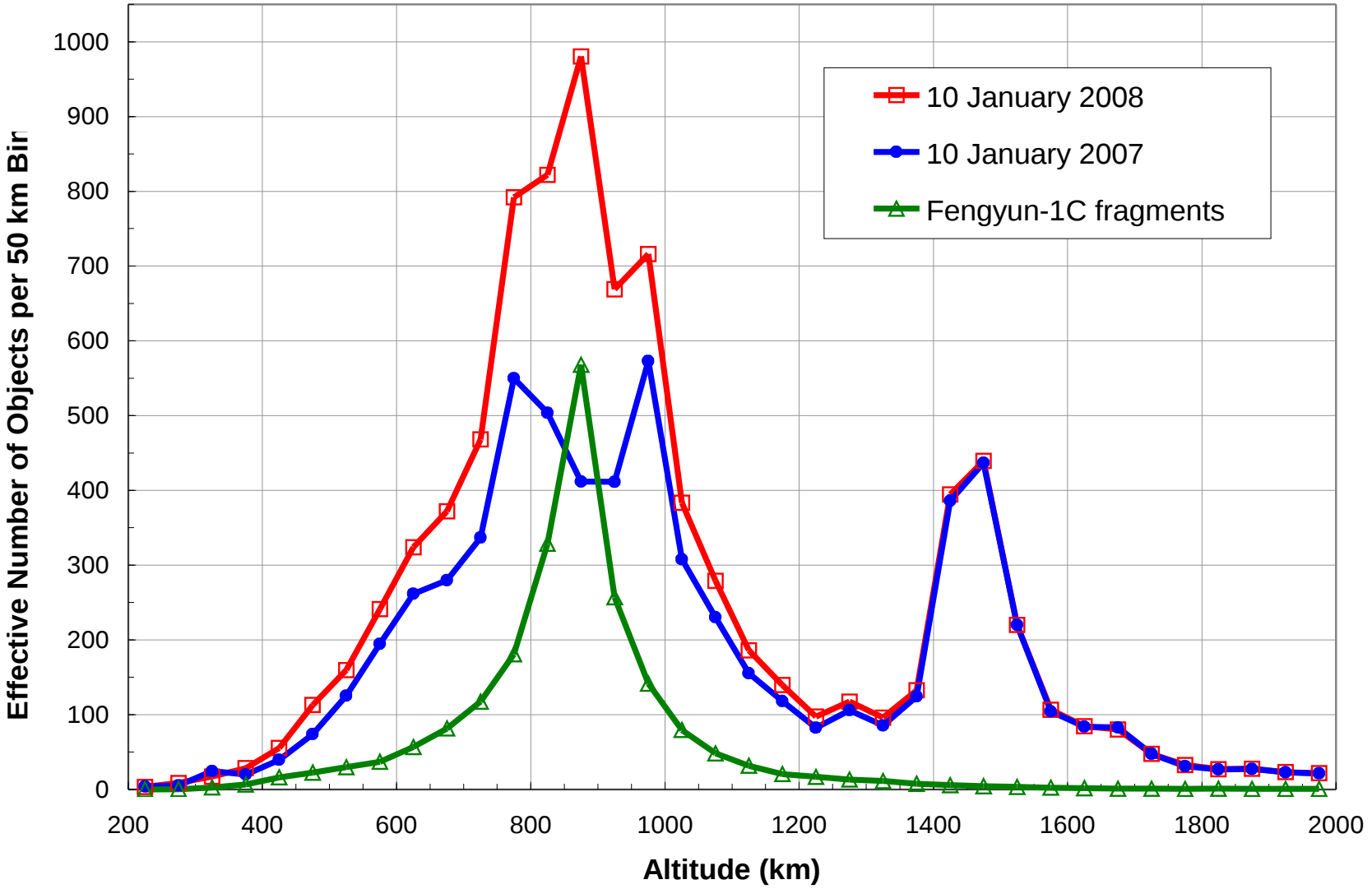
CERISE Spacecraft

Fengyun-1C

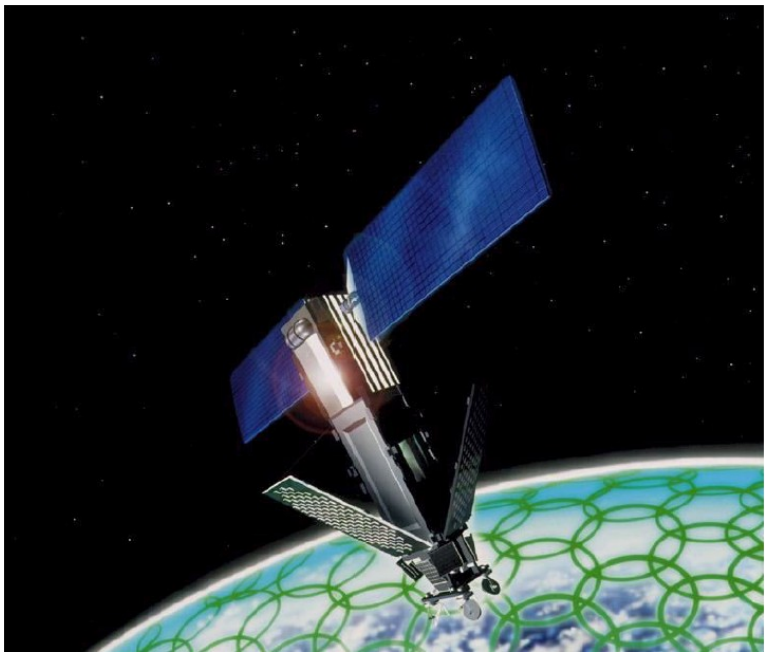


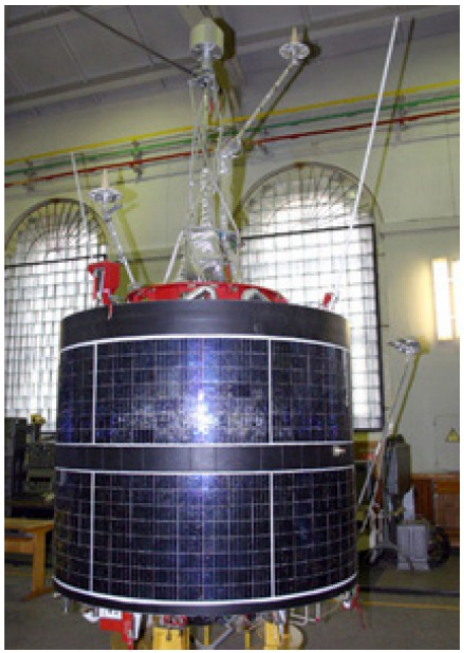
- 950 kg Chinese weather satellite
- 865 km x 845 km, 98.6º orbit
- Destroyed by Chinese military using a ground-based anti-satellite (ASAT) missile on January 11, 2007
- Created an unprecedented number of tracked debris

Effect of a Single Event
(Catalog Populations in LEO)



2009 Collision





February 10, 16:56 GMT two satellites collided near 789 km altitude

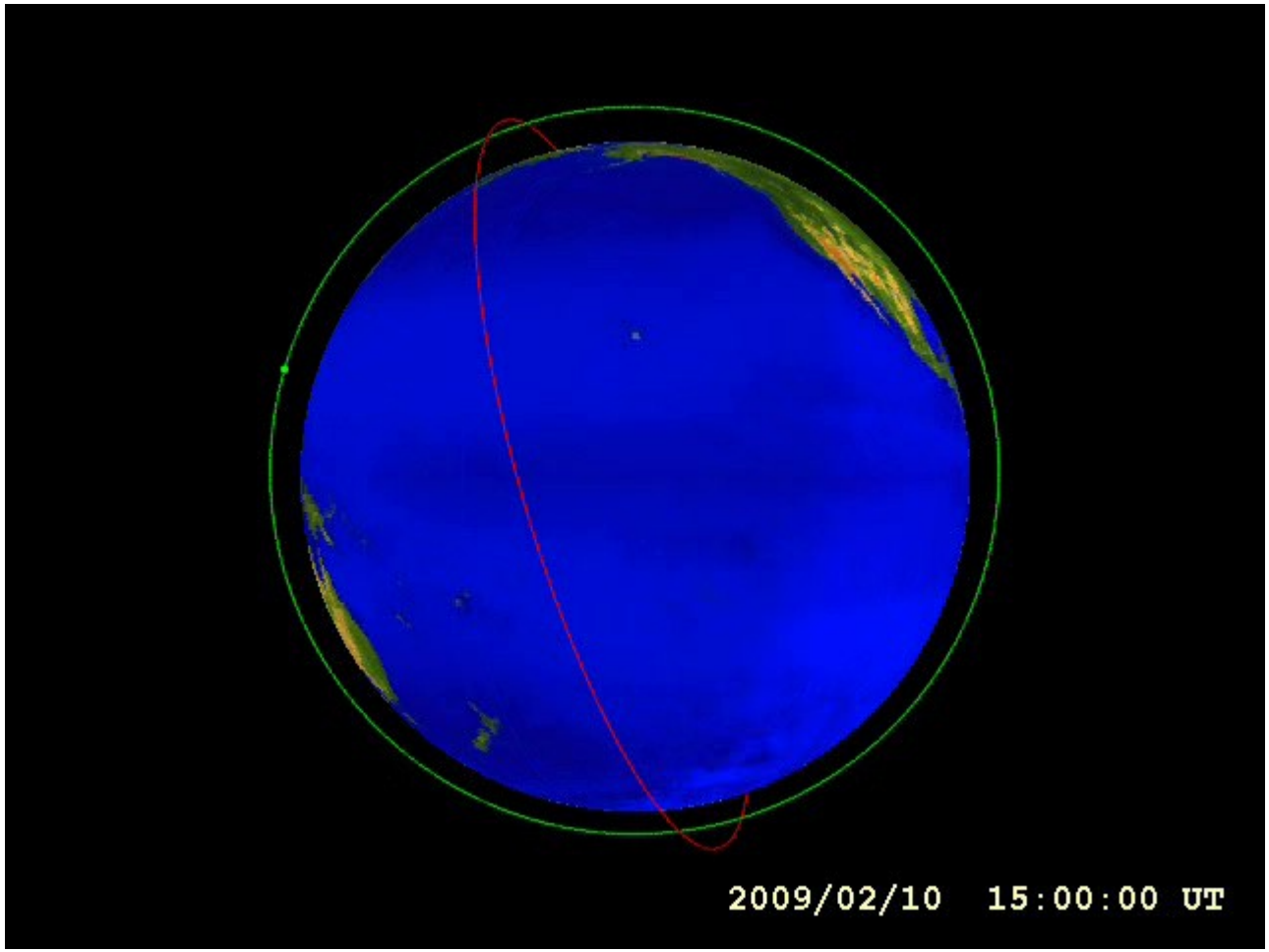
Iridium 33 (24946, 97051C)

- 779 x 808 km, 86.4 orbit, 556 kg
- Operational US Commercial Communication Satellite

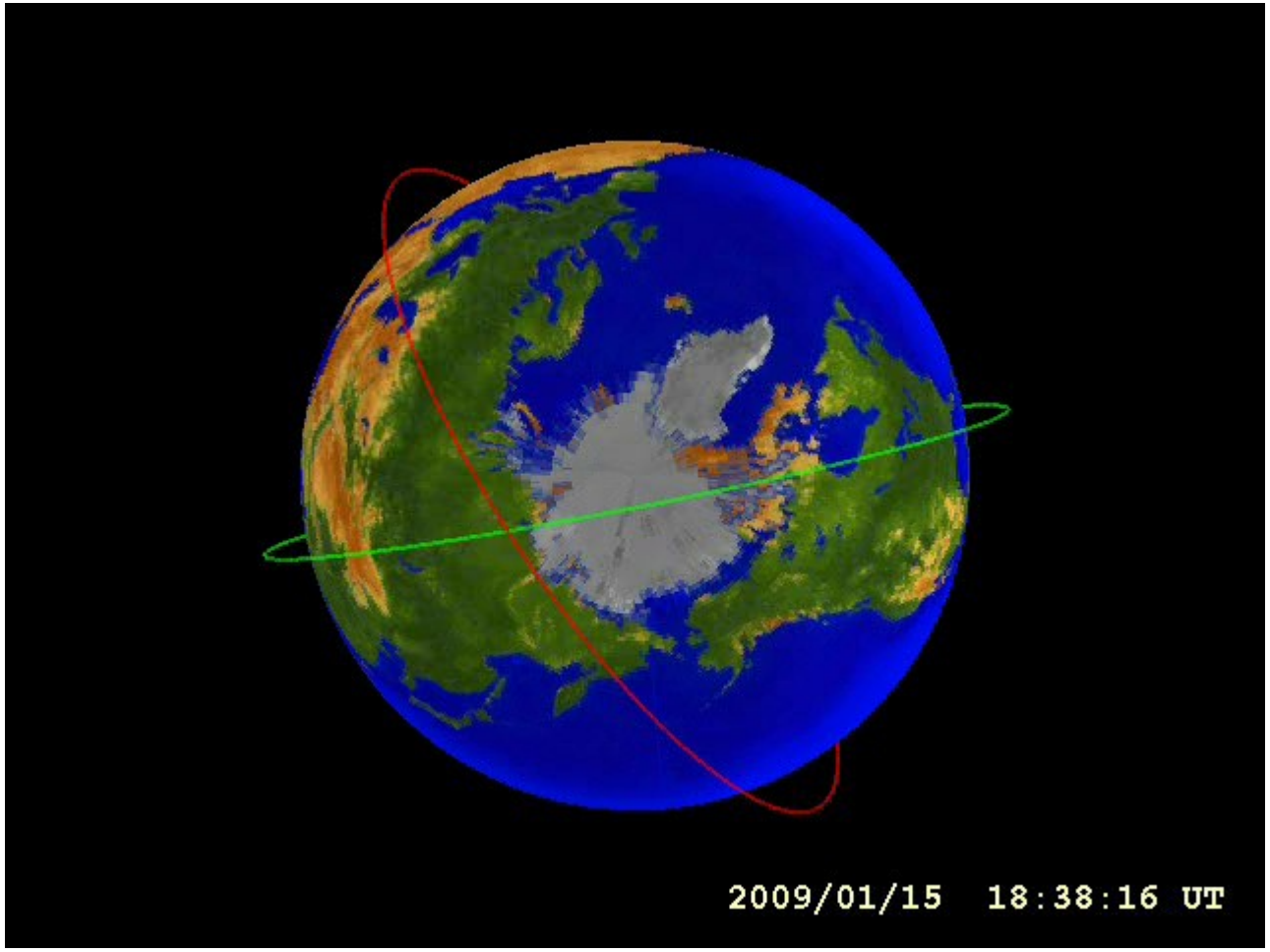
Kosmos 2251 (22675, 93036A)

- 786 x 826 km, 74.0 orbit, 900 kg
- Non-operational Russian Communication Satellite

Iridium Collision



Iridium Collision



Iridium Collision Fallout

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Published online 17 February 2009 | Nature | doi:10.1038/457940a

News

Kaputnik chaos could kill Hubble

Worst-ever orbital collision leads to calls for tighter regulation.

Geoff Brumfiel

A cloud of debris spreading through low Earth orbit following the collision of two satellites poses a new risk to many scientific missions and may signal the demise of the Hubble Space Telescope. NASA is monitoring the increased threat carefully, and if it is as bad as some fear, the agency may have to cancel the proposed shuttle-servicing mission slated for later this year. Without that mission, the telescope's days are numbered, even if none of the new debris comes anywhere close to it.

At 04:56 GMT on 10 February an active communications satellite owned by Iridium Satellite of Bethesda, Maryland, and a defunct Russian military-communications satellite collided some 800 kilometres above Siberia at more than 10 kilometres per second. The cloud of debris initially consisted of 600 objects large enough to be tracked by the US space-surveillance network, and experts expect that number to grow to more than 1,000 within the coming weeks. Simulations suggest there will be millions more pieces too small to track.

A preliminary analysis by researchers at the University of Southampton in the United Kingdom shows that a head-on collision

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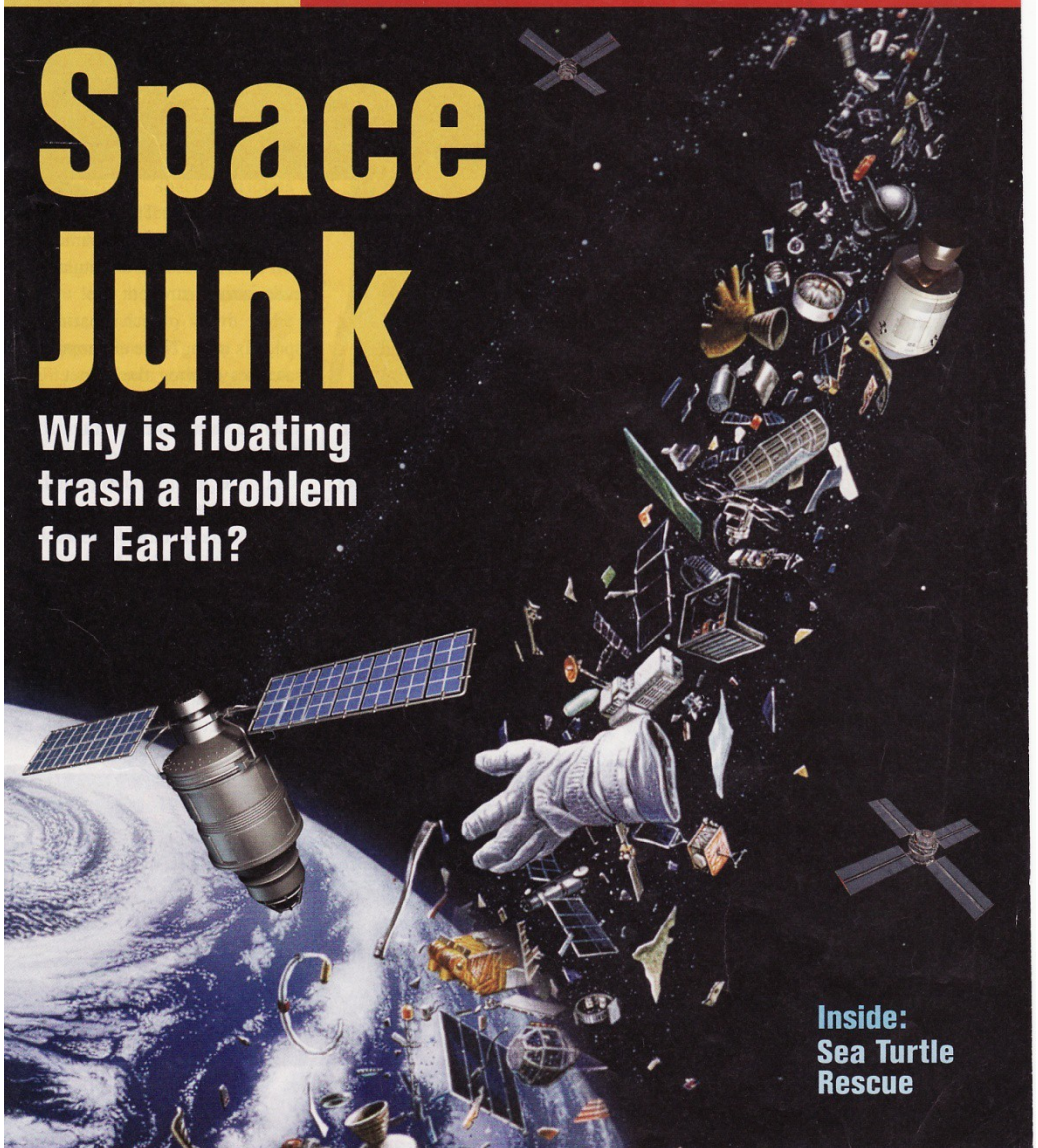
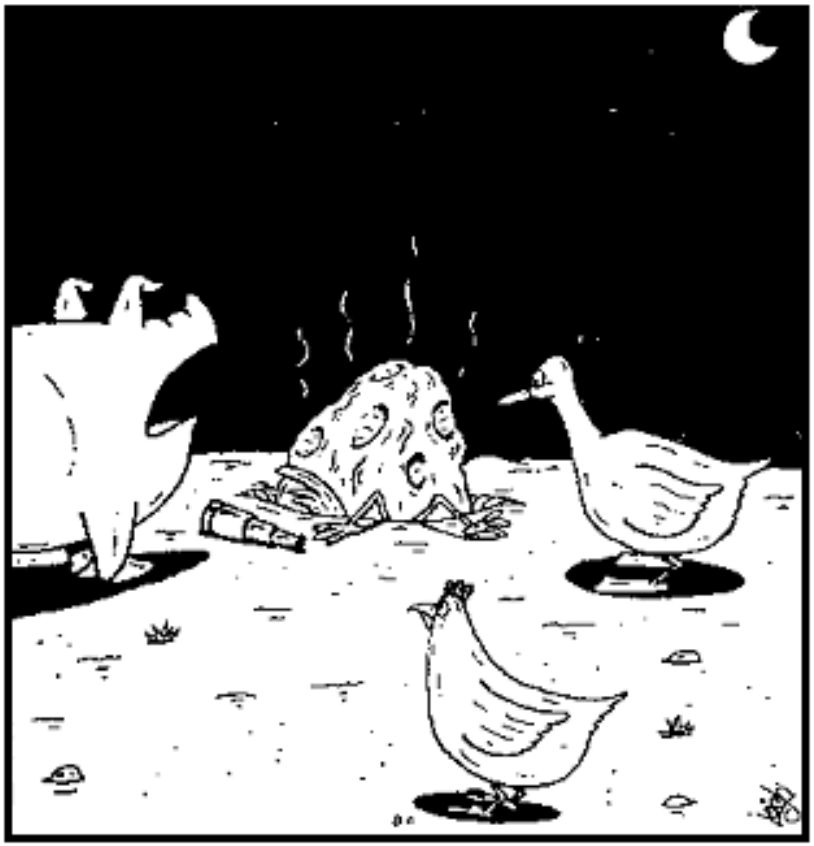


Space Junk

Why is floating trash a problem for Earth?

Inside:
Sea Turtle Rescue



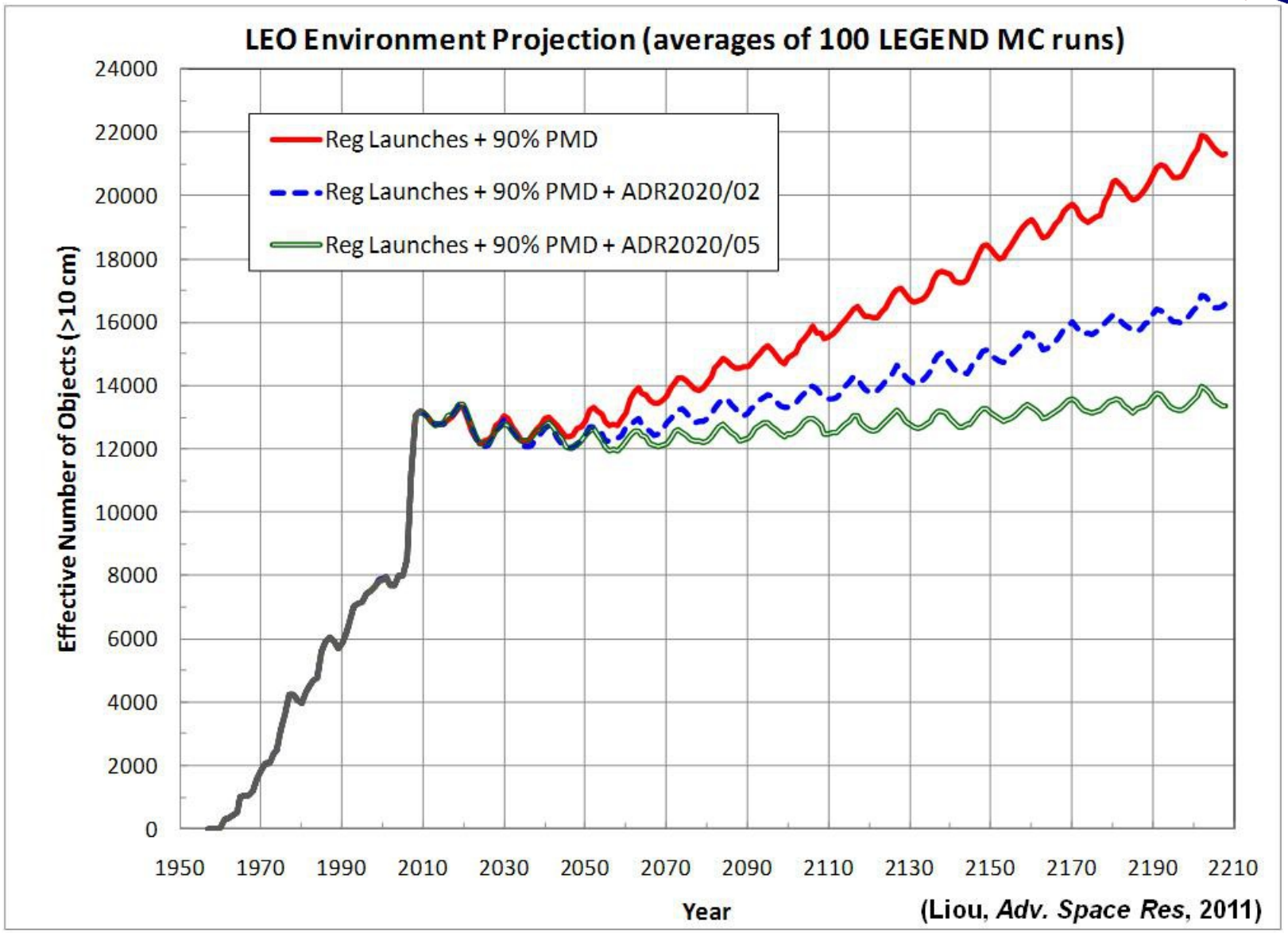
"Well, I'll be ... I guess the little chicken was right."

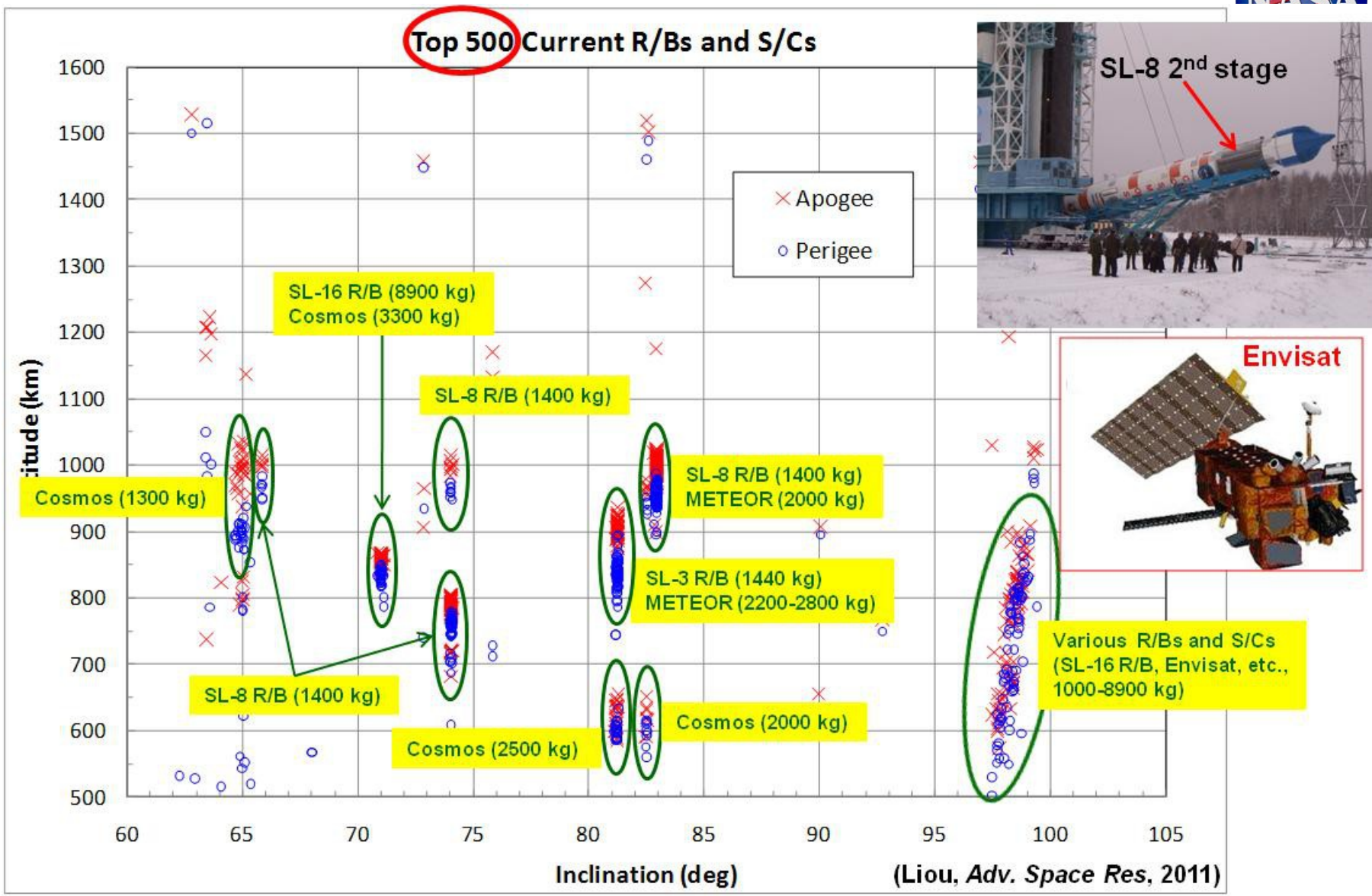
International Arena

- **Space debris is an international problem, not just a US or Russian problem**

- **International mitigation standards have been developed by the Inter-Agency Space Debris Coordination Committee (IADC)**
  - **Composed of the major space-faring agencies, including ASI**
  - **Mitigation Standards include:**
    - **Remove on-board energy sources when mission complete**
      - **Dispose of residual fuel**
      - **Discharge batteries**
    - **Placing satellite or rocket body in final orbit so that it leaves the environment within 25 years (Post-Mission Disposal = PMD)**

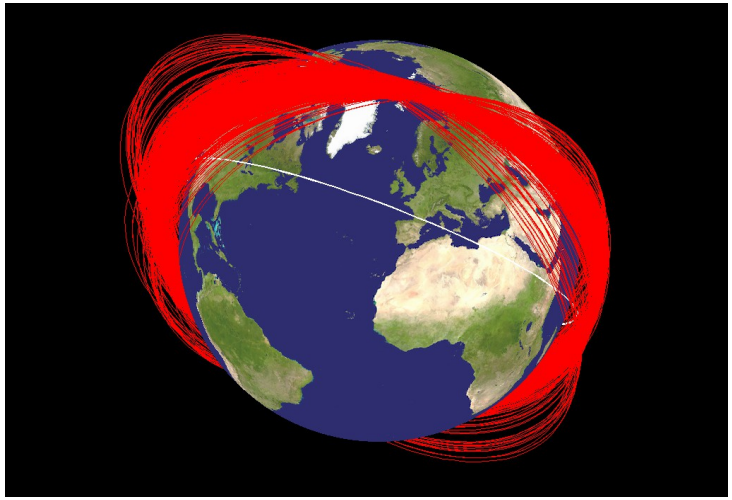
- **IADC Mitigation Guidelines adapted and adopted by the UN Committee on the Peaceful Uses of Outer Space**


LEO Environment Projection (averages of 100 LEGEND MC runs)
Reg Launches + 90% PMD
Reg Launches + 90% PMD + ADR2020/02
Reg Launches + 90% PMD + ADR2020/05
Effective Number of Objects (>10 cm)
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1950
1970
1990
2010
2030
2050
2070
2090
2110
2130
2150
2170
2190
2210
Year
(Liou, Adv. Space Res, 2011)


Top 500 Current R/Bs and S/Cs
Apogee
Perigee
SL-16 R/B (8900 kg)
Cosmos (3300 kg)
SL-8 R/B (1400 kg)
Cosmos (1300 kg)
SL-8 R/B (1400 kg)
SL-8 R/B (1400 kg)
METEOR (2000 kg)
SL-3 R/B (1440 kg)
METEOR (2200-2800 kg)
SL-8 R/B (1400 kg)
Cosmos (2500 kg)
Cosmos (2000 kg)
Various R/Bs and S/Cs
(SL-16 R/B, Envisat, etc.,
1000-8900 kg)
SL-8 2nd stage
Envisat
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
60
65
70
75
80
85
90
95
100
105
Inclination (deg)
(Liou, Adv. Space Res, 2011)

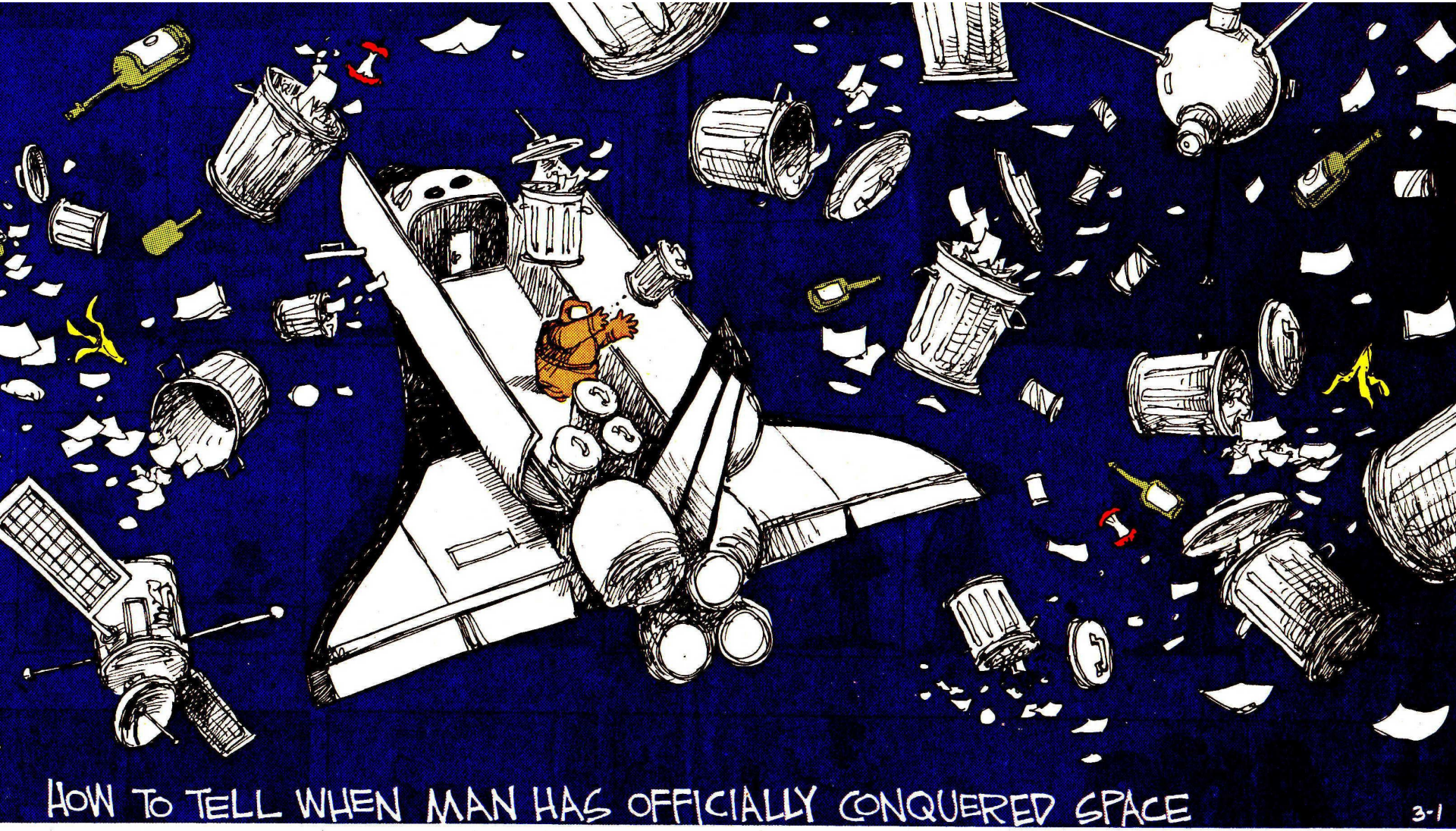
Challenges Remain

- **Adherence to national and international orbital debris mitigation guidelines is essential if the debris population is to be controlled.**
- **Despite efforts to reduce accidental explosions of spacecraft and rocket bodies, such events continue to have dramatic effects in near-Earth space.**
- **The deliberate testing of an anti-satellite weapon by China in January 2007 created the worst orbital debris cloud in history.**
  - The majority of the debris will remain in Earth orbit for decades to centuries



- **The accidental 2009 collision is only the harbinger – collisions are expected to become more common in the future**

The Conquest of Space



Backup Slides

Be Careful What You Drop!