Tutorial :
An Overview of the Orbital Debris Environment

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Space Debris

- **Space debris = any man-made object in space that no longer serves a useful purpose**
  – **Note there are also natural debris – meteoroids**

- **Intact objects, > 1 m**
  – **Old rocket bodies and spacecraft**
  – **“Operational” debris – shrouds, mounts, lens caps, etc**

- **Fragmentation debris, 1 mm – 1 m**
  – **Deliberate or accidental explosions from on-board energy sources**
    - Unvented rocket fuel
    - Active batteries
    - Self-destruct mechanisms
  – **Deliberate or accidental collisions**
    - Weapons tests
    - Random collisions
  – **Solid rocket motor slag**

- **Small debris, < 1 mm**
  – **Deterioration of satellite surfaces in space environment**
    - Small debris impact ejecta
    - Deterioration of paint and other materials

Brewster Rockit on Debris Sources

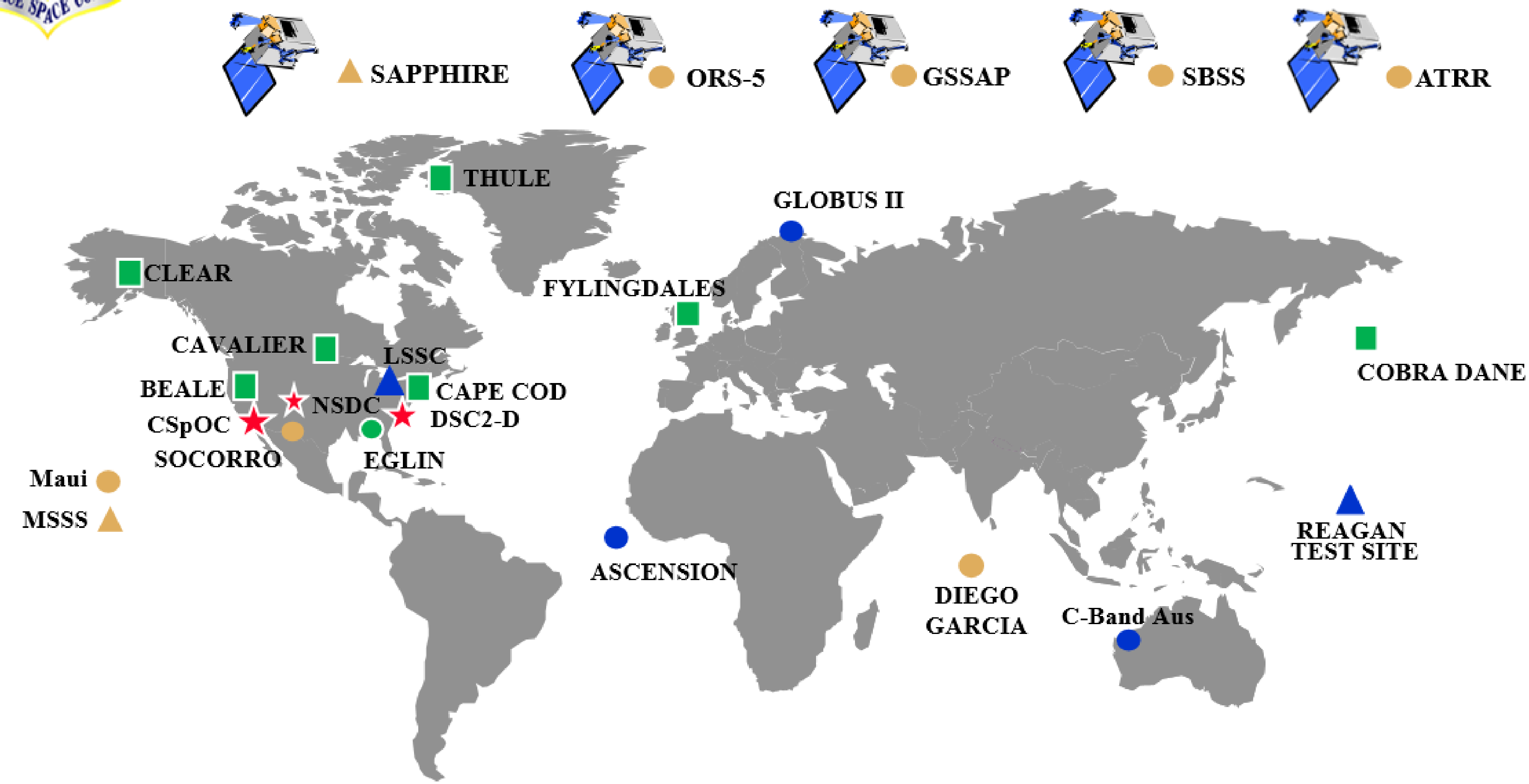
Space Surveillance Network (SSN)

- **Almost all of our operational knowledge of the space environment is from the U.S. Department of Defense's (DoD) Space Surveillance Network (SSN) and its parallels in other countries**

  - **New launches**
    - Payloads
    - Rocket Bodies
    - Operational Debris (brackets, shrouds, etc.)
  - **Breakup events**
    - Anomalous breakups
    - Explosions – both accidental and deliberate
    - Collisions between tracked objects

- **It is through the SSN Catalog that we know the various orbits where humans have launched their satellites and how they have evolved over time**

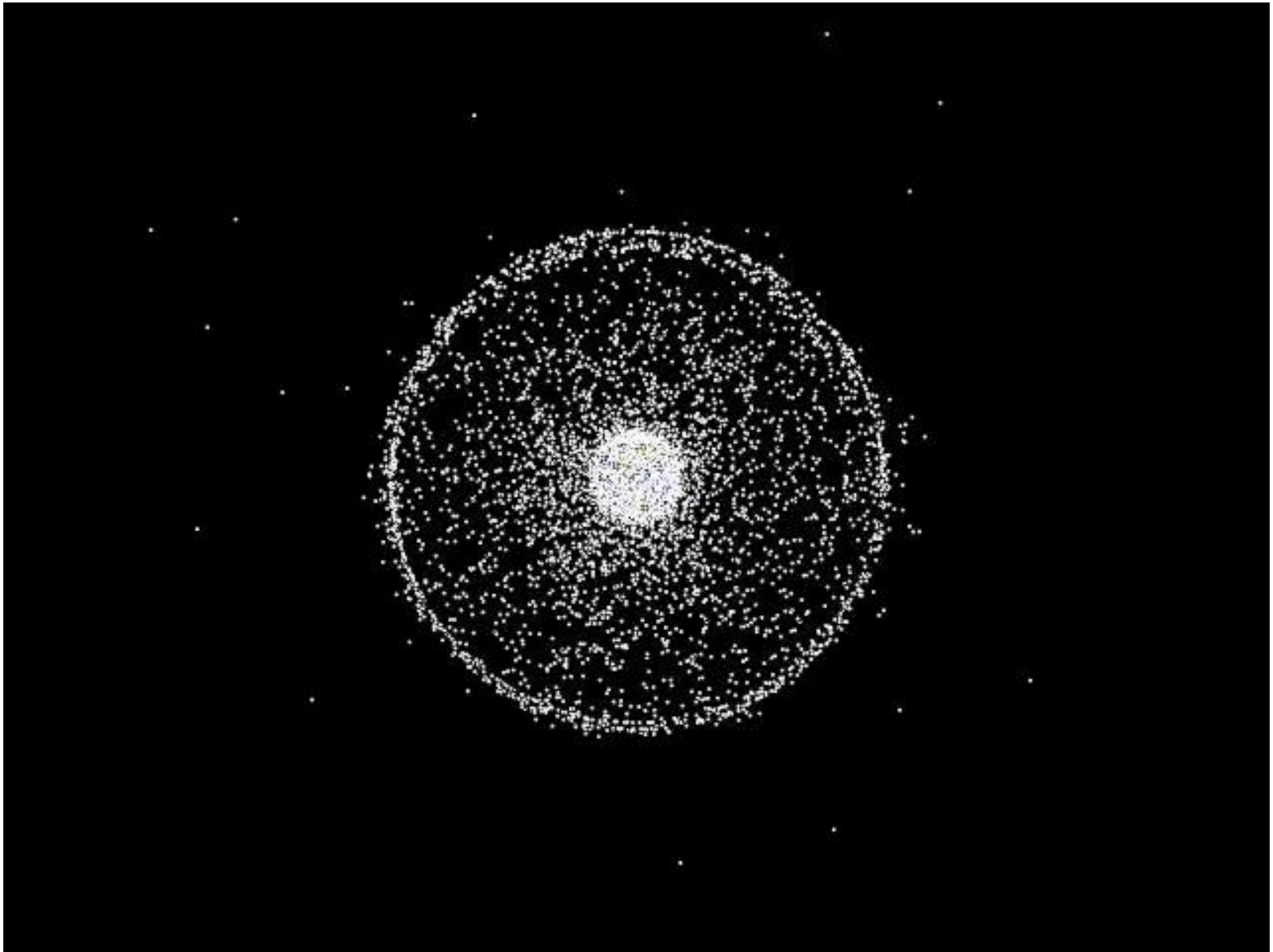
Today's SSN



Phased Array Radar
Mechanical Radar
Optical Systems
SSN C2

- ● Dedicated - subordinate to USSTRATCOM, primary mission of SSA
- ■ Collateral - subordinate to USSTRATCOM, primary mission other than SSA
- ▲ Contributing – under contract or agreement to support SSN
- ★ SSN C2

SSN Catalogue Orbital Environment



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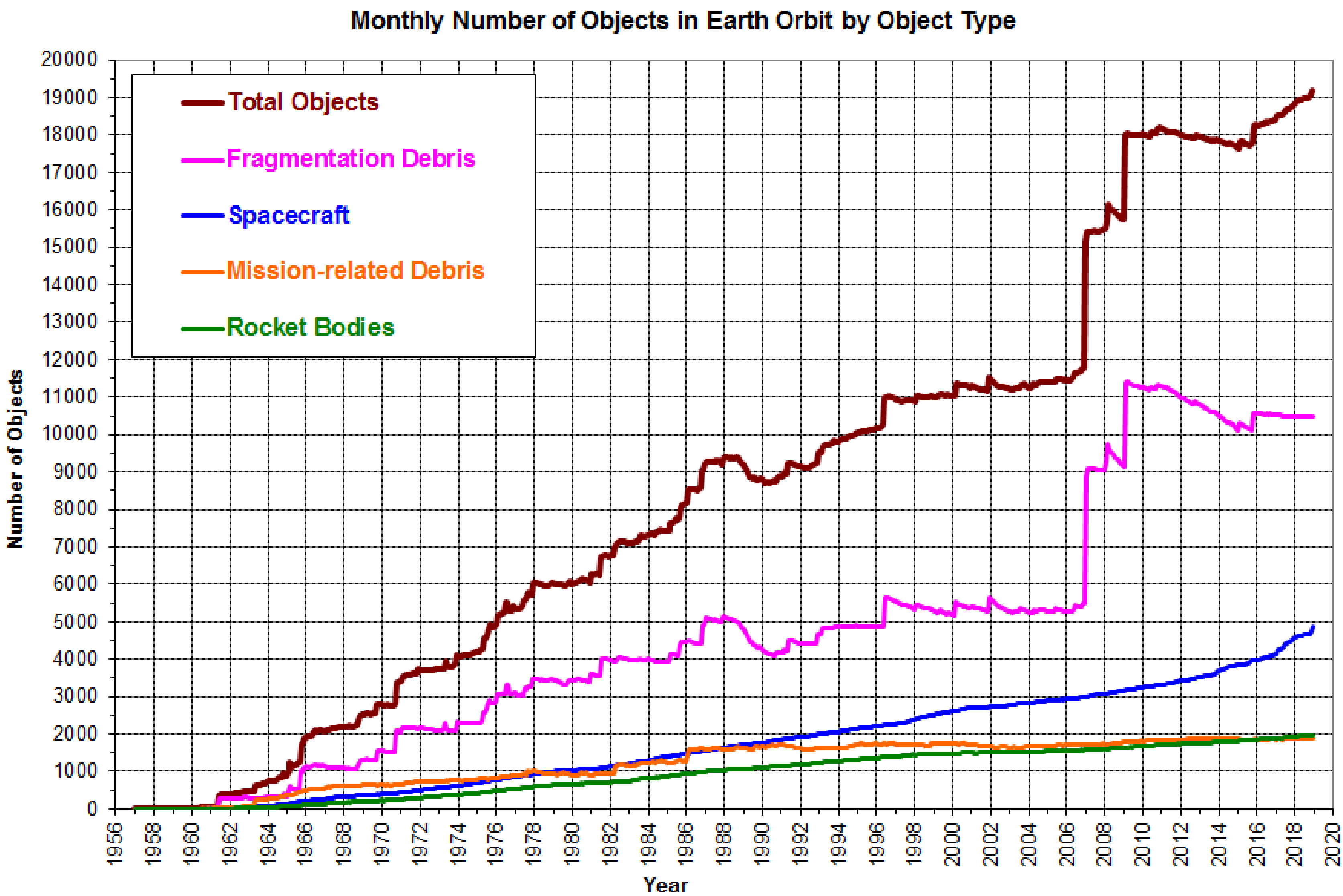
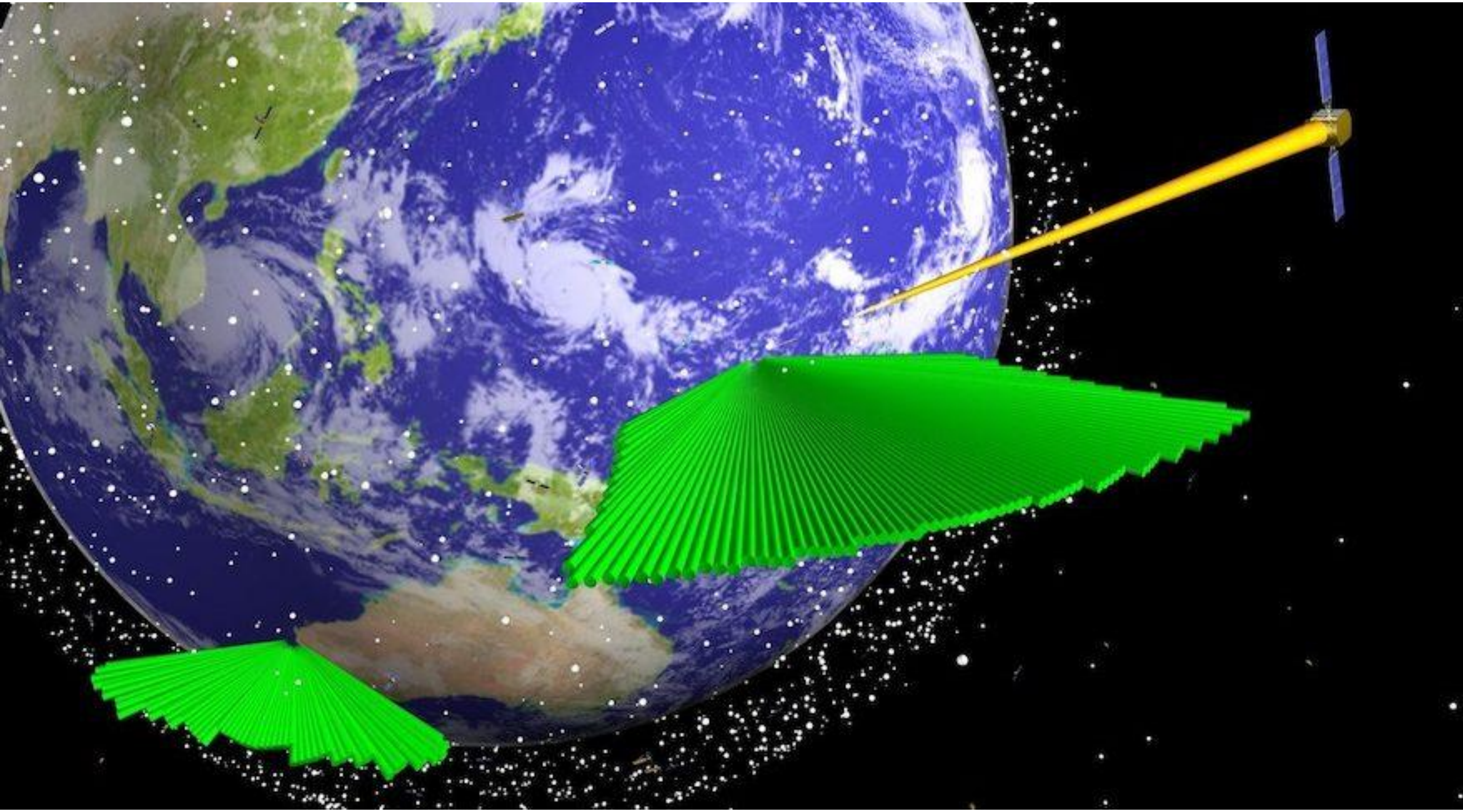
Evolution of the Catalogued (>10 cm) Satellite Population by Number



CSpOC

- The Combined Space Operations Center (CSpOC) is tasked with using the measurement data of the SSN to maintain a Catalog of space objects
  - Catalog consists of objects large enough to be detected by sensors of the SSN and observed often enough to determine their orbits with sufficient accuracy to recover the object on a future pass over an SSN sensor
  - This tracking capability allows the CSpOC to perform conjunction assessment calculations for satellite users
  - There is a sensitivity limit for the SSN sensors, generally given as >10 cm in low-Earth orbit (LEO), and losing sensitivity for deep space objects
  - However, we know there are many debris smaller than 10 cm in size that cannot be tracked

Future Space Fence



Collision Avoidance

- **The current statistical technique used by CSpOC was developed as a joint project by the DoD and NASA originally to ensure the safety of Shuttle and ISS astronauts**

- **Service now provided to any space user**
  - **Possible conjunction warning given to registered user**
  - **Contains the covariance matrix and encounter geometry for each object**
    - Covariance matrix gives uncertainty ellipsoid of the position of each object
    - Information can be used to compute a probability of collision

- **Conjunction assessment for NASA**
  - **Human spaceflight handled by Mission Control in Houston and by their counterparts in Moscow**
  - **Robotic spacecraft handled by NASA's Conjunction Assessment Risk Analysis (CARA) team at GSFC**

Collision Avoidance

- While Collision Avoidance is a prudent thing for a spacecraft operator to do, it is not a cure-all for space debris issues

- While a collision-avoidance maneuver reduces the collision risk, depending on the maneuver threshold chosen and the geometry of a conjunction, it does not mitigate 100% of the collision probability – a (sometimes substantial) residual risk remains

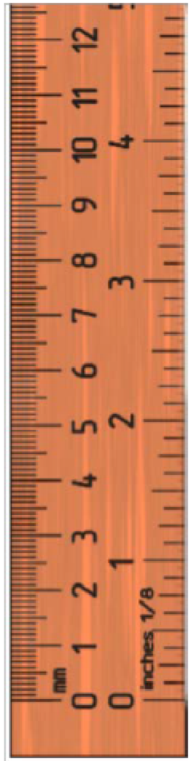
- For every object tracked, there are tens to hundreds of objects we cannot track that can still cause serious damage to a spacecraft

- Vast majority of objects tracked (~95%) are inert and cannot maneuver
  - By itself not a solution for problem of long-term collisional growth of the debris environment

Complementary NASA and DoD MMOD Environment Efforts

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

Debris Sizes



Softball size or larger (≥10 cm): ~23,000
(tracked by U.S. Combined Space Operations Center, CSpOC)

Marble size or larger (≥1 cm): ~500,000

Dot or larger (≥1 mm): >100,000,000
(a grain of salt)

- **Due to high impact speed in space (~10 km/sec in LEO), even sub-millimeter debris pose a realistic threat to human spaceflight and robotic missions**
  - **10 km/sec = 22,000 miles per hour (the speed of a bullet ~1,500 miles per hour)**
- **Mission-ending threat is dominated by small (mm-to-cm sized) debris impacts**
- **Total mass: >7600 tons LEO-to-GEO (~3000 tons in LEO)**

NASA Orbital Debris Program

- **NASA uses a number of assets to monitor the orbital debris environment <10 cm in order to characterize:**
  - **Size distribution**
  - **Orbit distributions (inclination, altitude, eccentricity)**
  - **Possible sources**
  - **Material types**
  - **Shape**

- **NASA uses a statistical sampling technique - a sensor samples the environment over time in order to make statistical conclusions about the debris populations**
  - **Determine how the debris are distributed in orbit**
    - Allows the ability to calculate the collision/damage risk to spacecraft
    - Allows the spacecraft designers to build their spacecraft with better shielding or other techniques to minimize failure risk
  - **Identify new sources and prevent future debris-creating events**
  - **Accurately assess the danger from known sources**
  - **Assess how space activities might be degrading the debris environment**
  - **Monitor for unforeseen new events invisible to the SSN**

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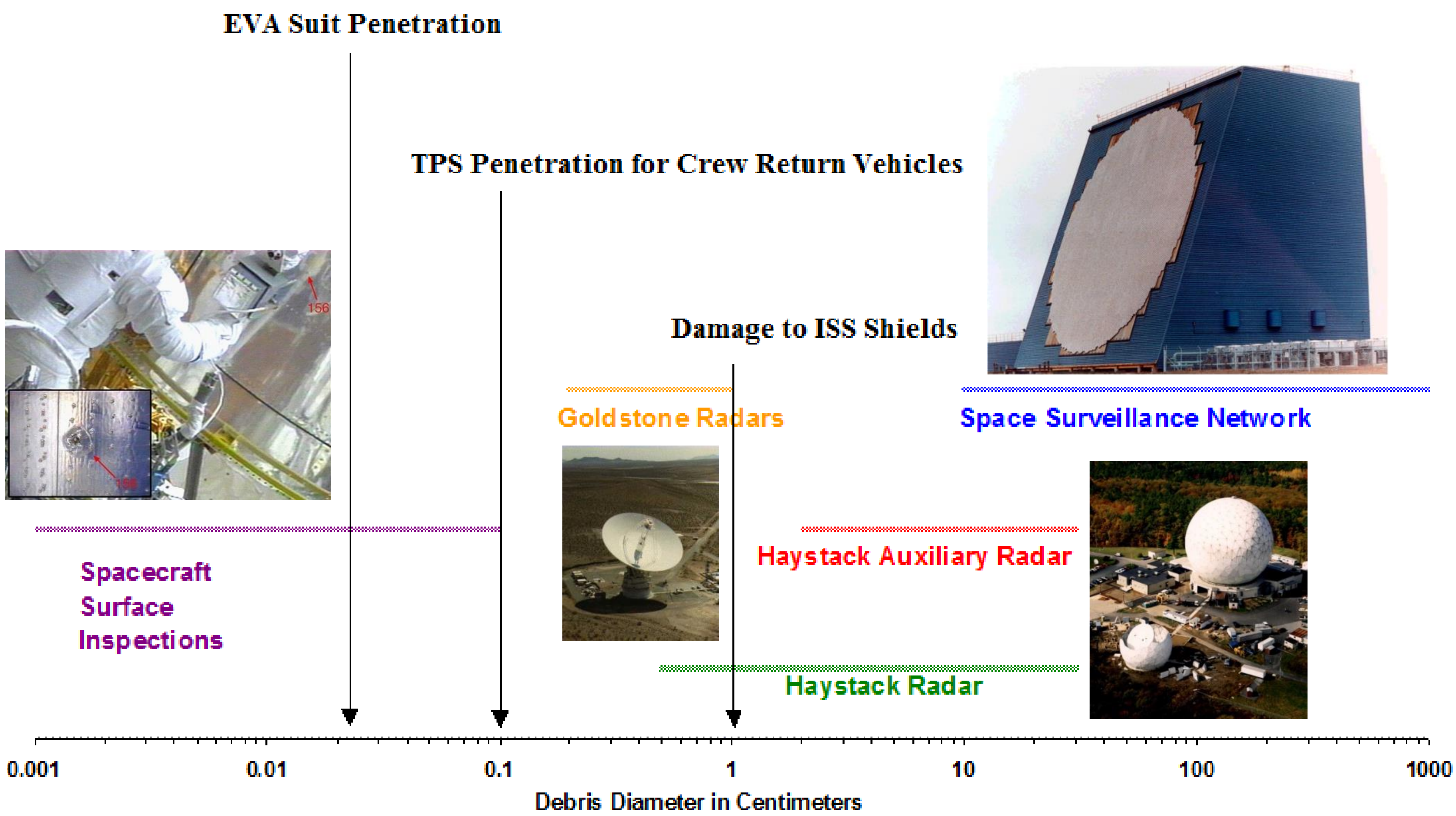
Damage Potential



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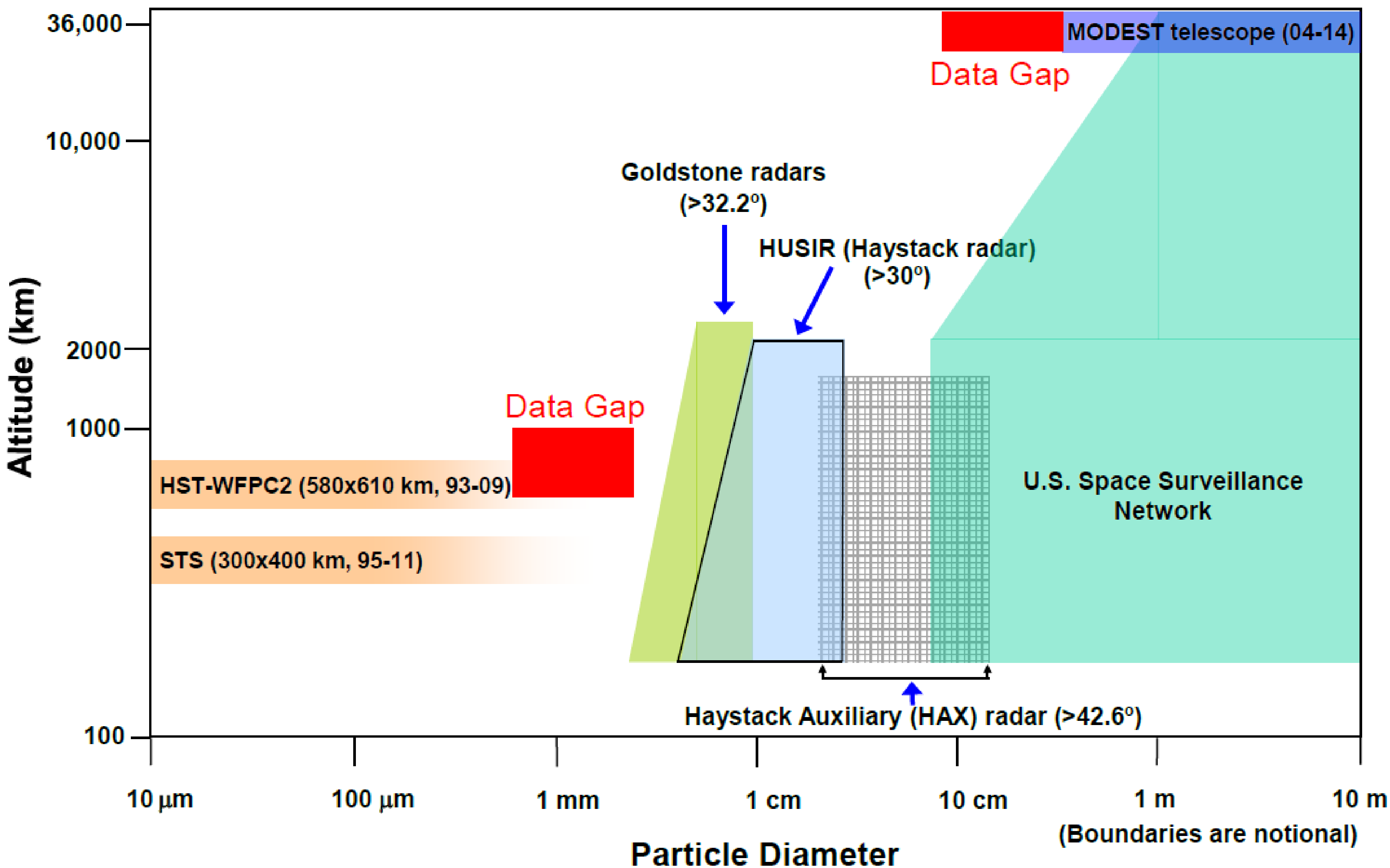
NASA Measurements



HUSIR/HAX Radars

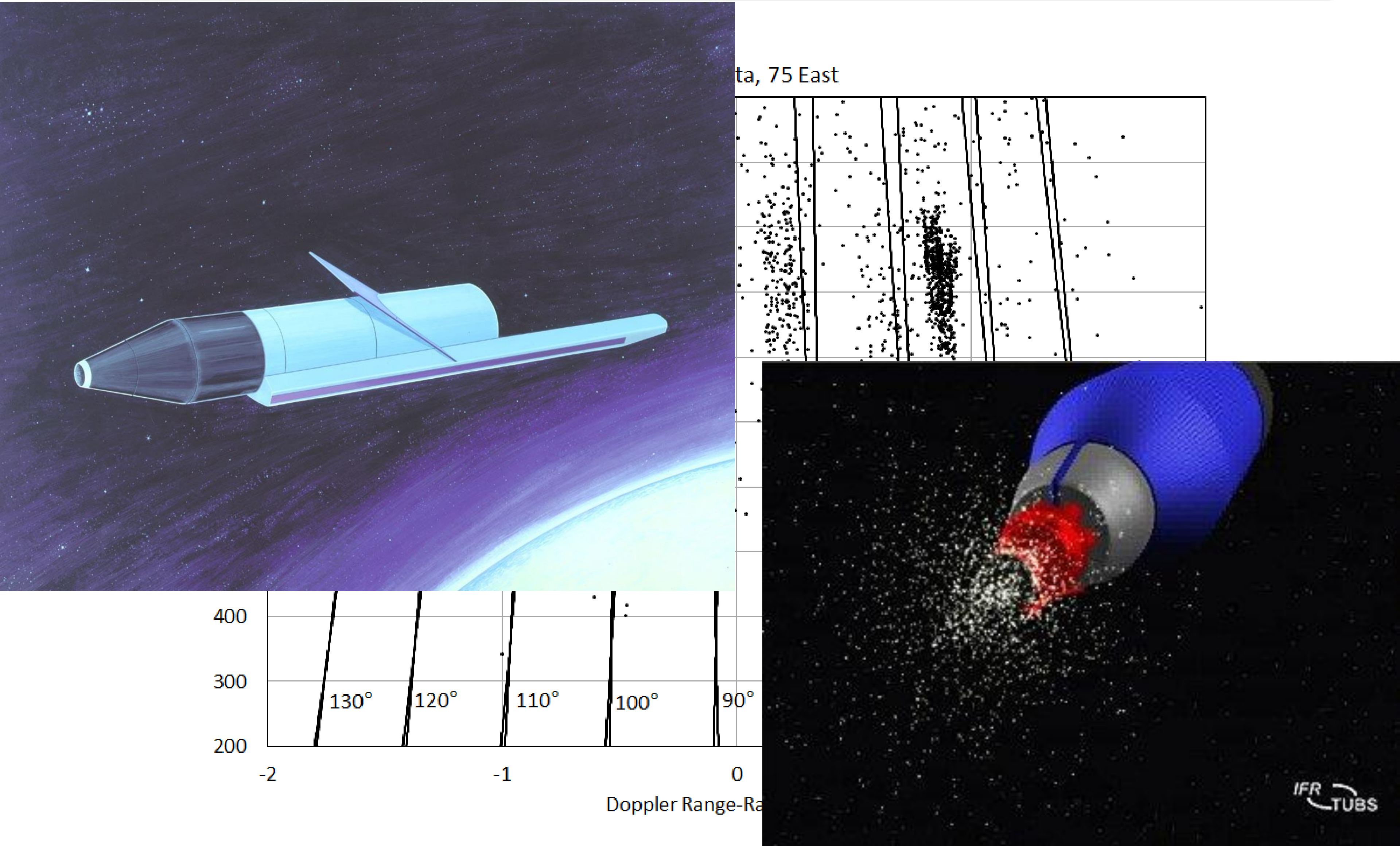
- **Located in Massachusetts – 42.6° latitude, operated by MIT Lincoln Laboratories**

- **Haystack Ultrawide Satellite Imaging Radar (HUSIR – previously known as Haystack)**
  - **36 m diameter**
  - **3 cm wavelength (X-band)**
  - **Can detect debris > 5 mm in LEO**

- **Haystack Auxiliary Radar (HAX)**
  - **15 m diameter**
  - **1.8 cm wavelength (Ku-band)**
  - **Can detect debris > 2 cm in LEO**

- **These radars accurately measure RCS, range, and Doppler velocity along line of sight, but have trouble with other velocity components, so they usually operate in an off-vertical mode (75° East), where Doppler velocity can be used to infer orbit inclination**

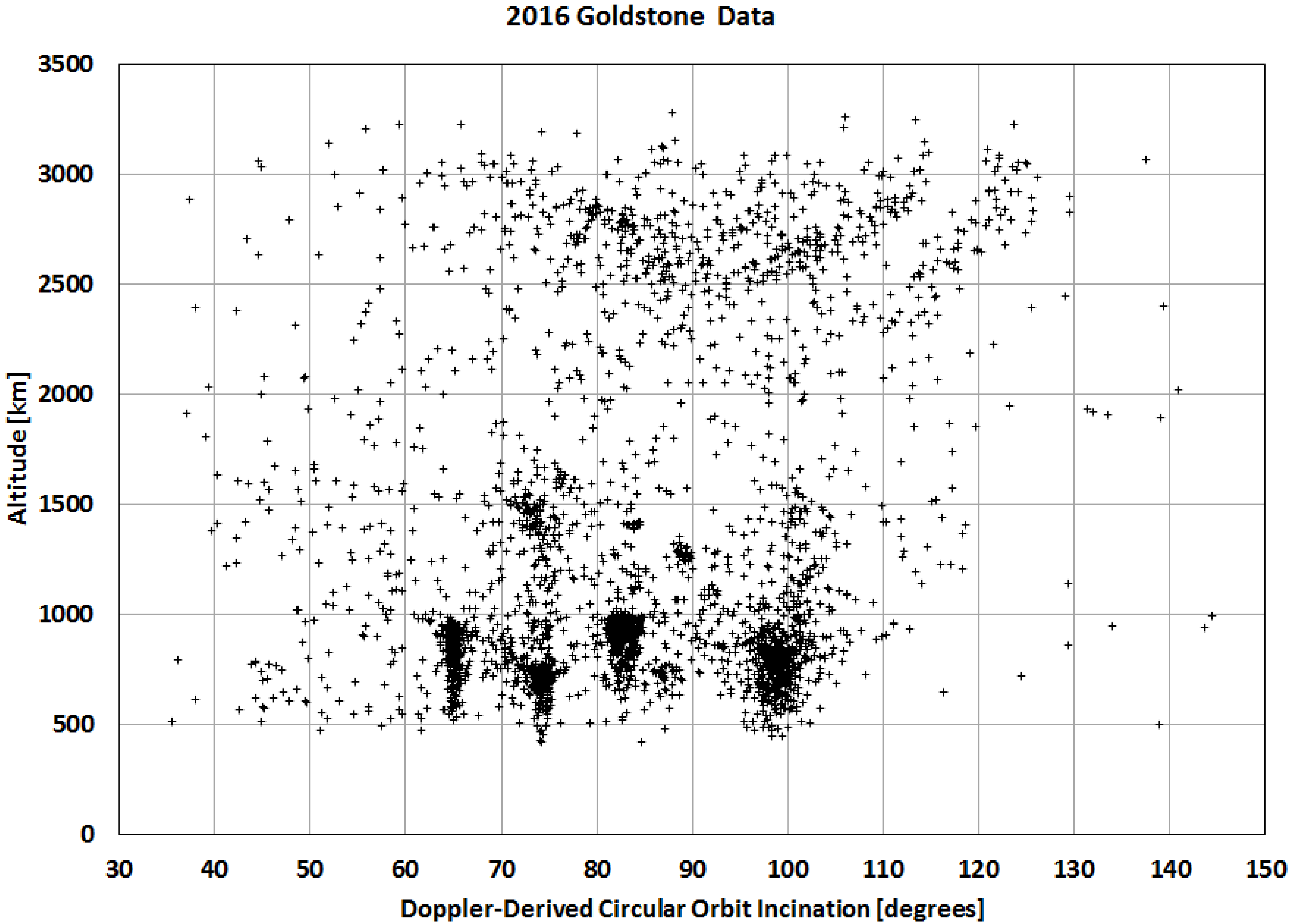
Discovery of RORSAT NaK



Goldstone Radar

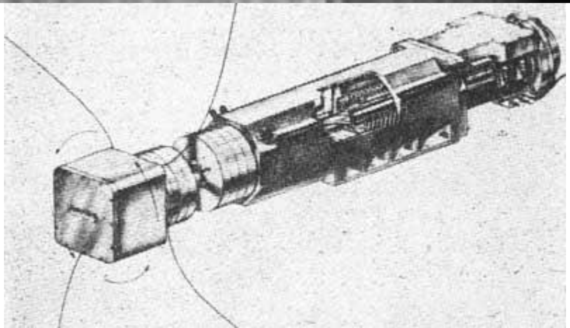
- **Located in southern California – 35.4° latitude**
- **Part of NASA's Deep Space Network**
- **Bistatic system**
  - **70 m dish + 34 m dish**
  - **3.5 cm wavelength (X-band)**
  - **Can detect 2 mm – 5 mm debris in LEO**
- **Limited capability and time available**
- **Due to upgrade of sensors, we lost the 34 m dish close to the 70 m dish (in background)**
- **New longer-baseline configurations have much reduced altitude overlap**

Goldstone Data



West Ford Needles

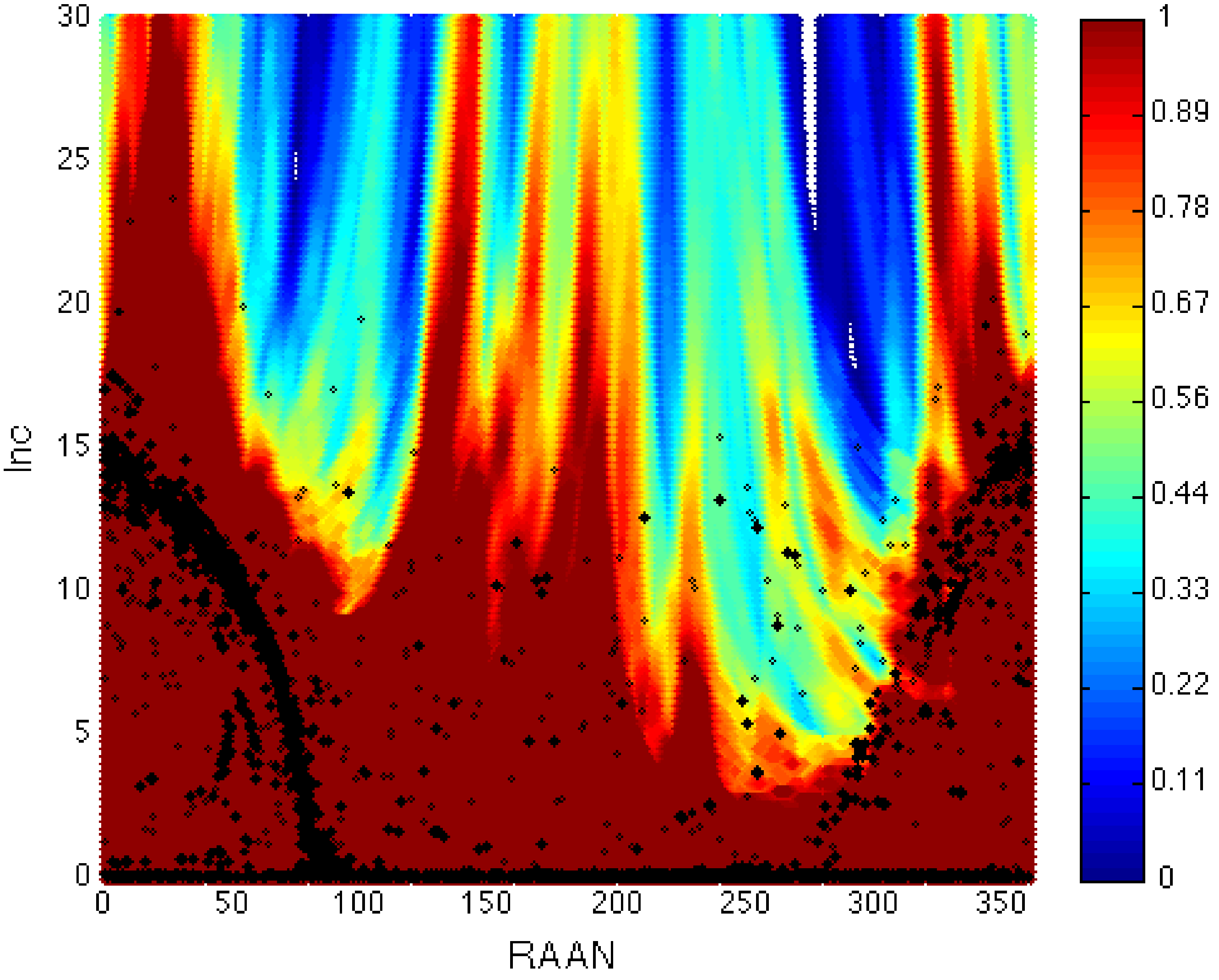
- **The West Ford Needle project was a series of experiments from 1961-1963 to launch hundreds of millions of tiny copper needles (1.78 cm long, thickness of a human hair) into short-lived polar orbits to test ability to bounce signals off the resulting "ring" around the Earth**
- **Solar radiation pressure should have removed individual needles from orbit in a matter of weeks, but many stuck together in large mats that continue to orbit the Earth and are tracked by the SSN**
- **Goldstone data indicates there are also many tiny clumps of needles still in orbit**



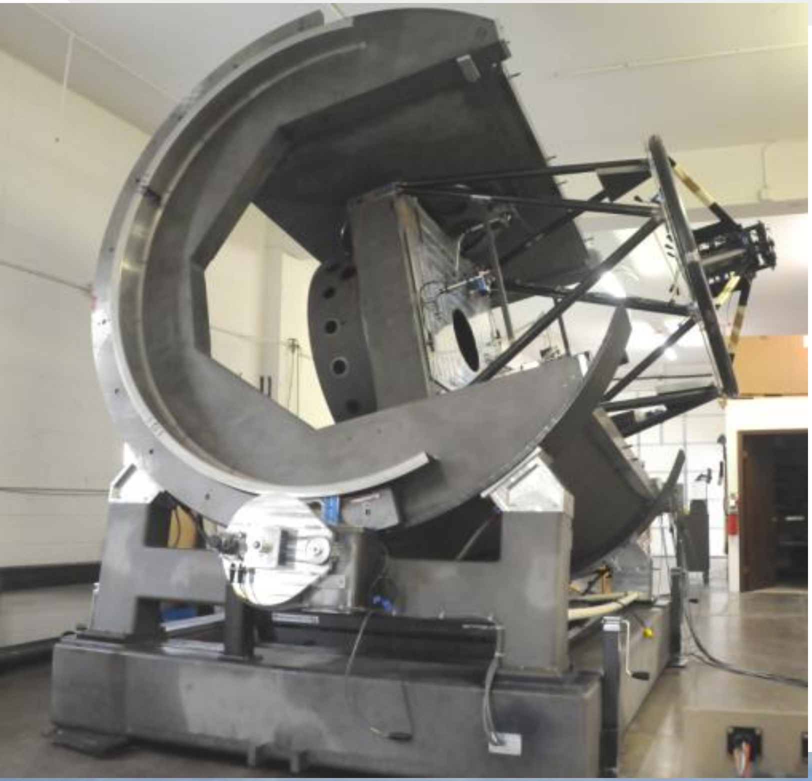
Optical Telescopes

- **Telescopes are the preferred method to observe small debris at Geosynchronous orbit (GEO) altitudes**
- **For more than a decade, NASA has used the Michigan Orbital Debris Survey Telescope (MODEST) to statistically monitor the GEO environment**
  - **0.61 m aperture Curtis Schmidt optical telescope**
  - **Located in Chile, operated by University of Michigan**
- **Observations are conducted near the Earth's shadow to maximize the reflected sunlight from debris**
  - **Can detect objects down to about 30 cm in size**
- **Statistical survey is corrected for probability of detecting an object in a particular orbit**

Statistical Survey



MCAT – Meter Class Autonomous Telescope



- NASA has recently deployed the Eugene Stansbery Meter-Class Autonomous Telescope (MCAT), a 1.3 m aperture Ritchey-Chretien reflecting telescope to Ascension Island (8.0° S), in the Atlantic Ocean near the Equator
- Has the ability to extend statistical surveys in GEO to smaller debris (~ 20 cm)
- Also has the capability to look for low-altitude, low-inclination debris in LEO

In Situ

- **For sizes smaller than ~2-3 mm, we rely on returned spacecraft surfaces**
- **Small impactors leave a damage feature – a hole or crater**
- **Feature size is a function of**
  - **Particle size**
  - **Particle mass**
  - **Particle shape**
  - **Particle density**
  - **Particle speed and angle of impact**
  - **Characteristics of impacted surface**
- **The chief problem is that we do not typically know these things for each particle, all we have is the feature size and position**
  - **Sometimes, electron microscope analysis of feature yields melted residue of impactor, letting us know the material of the particle (e.g., aluminum, steel, meteoroid).**
- **Use statistical techniques to "back out" debris characteristics**

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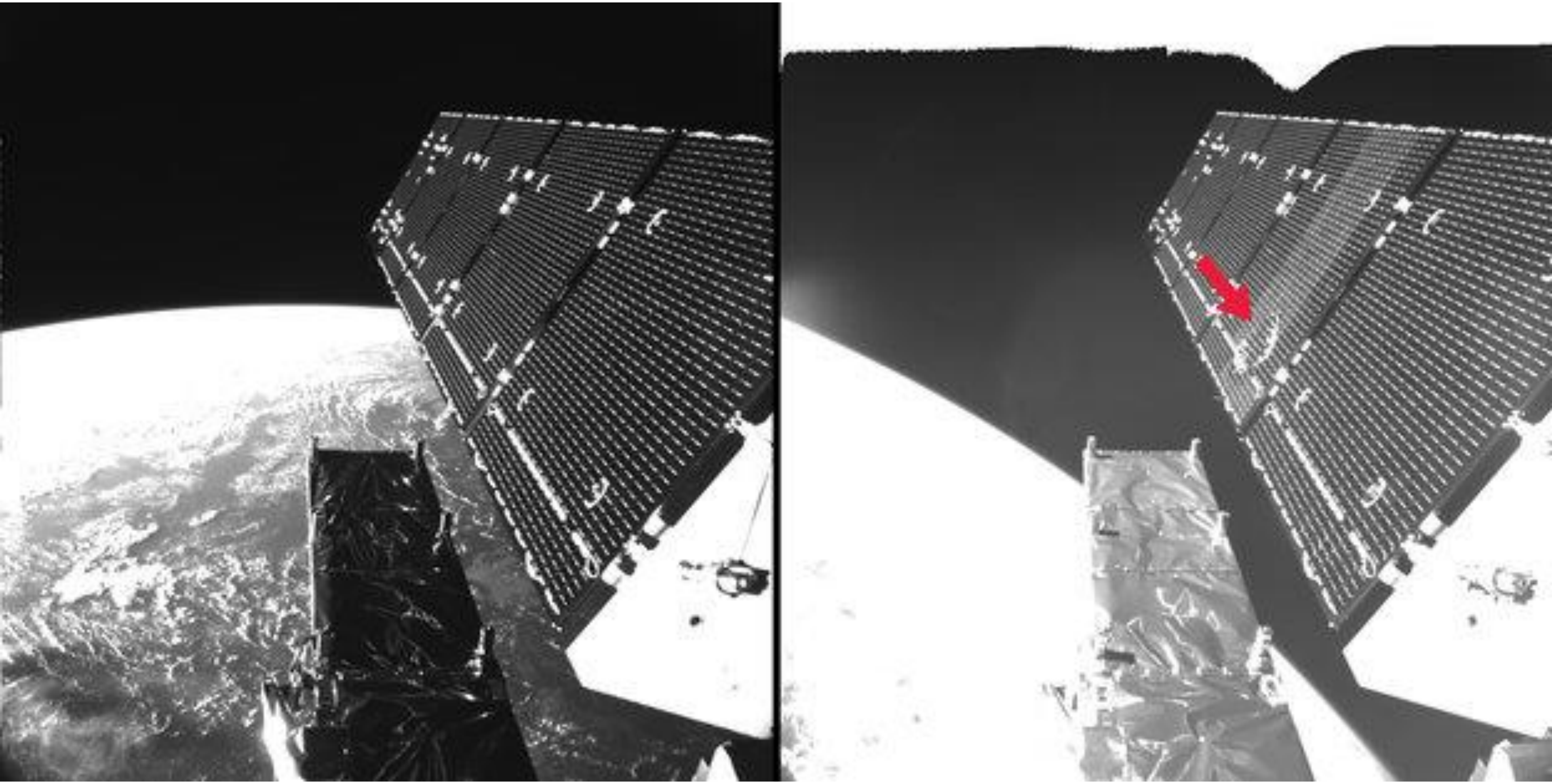
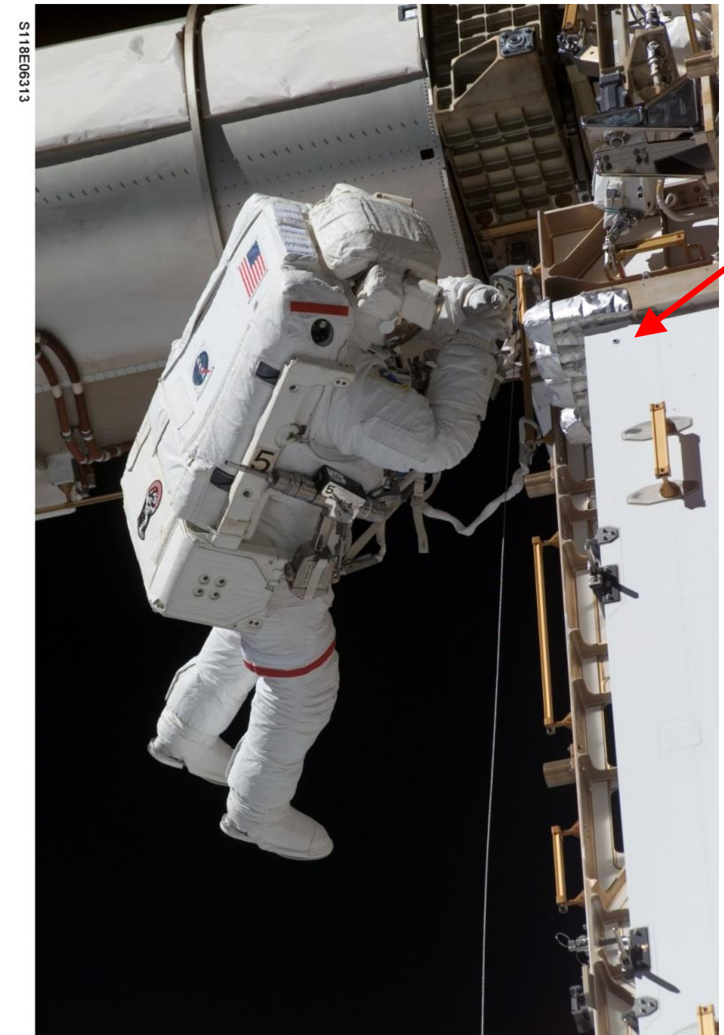
Sentinel-1A Impact 2016/08/23 – Onboard Camera



Debris Impacts Observed during EVA’s

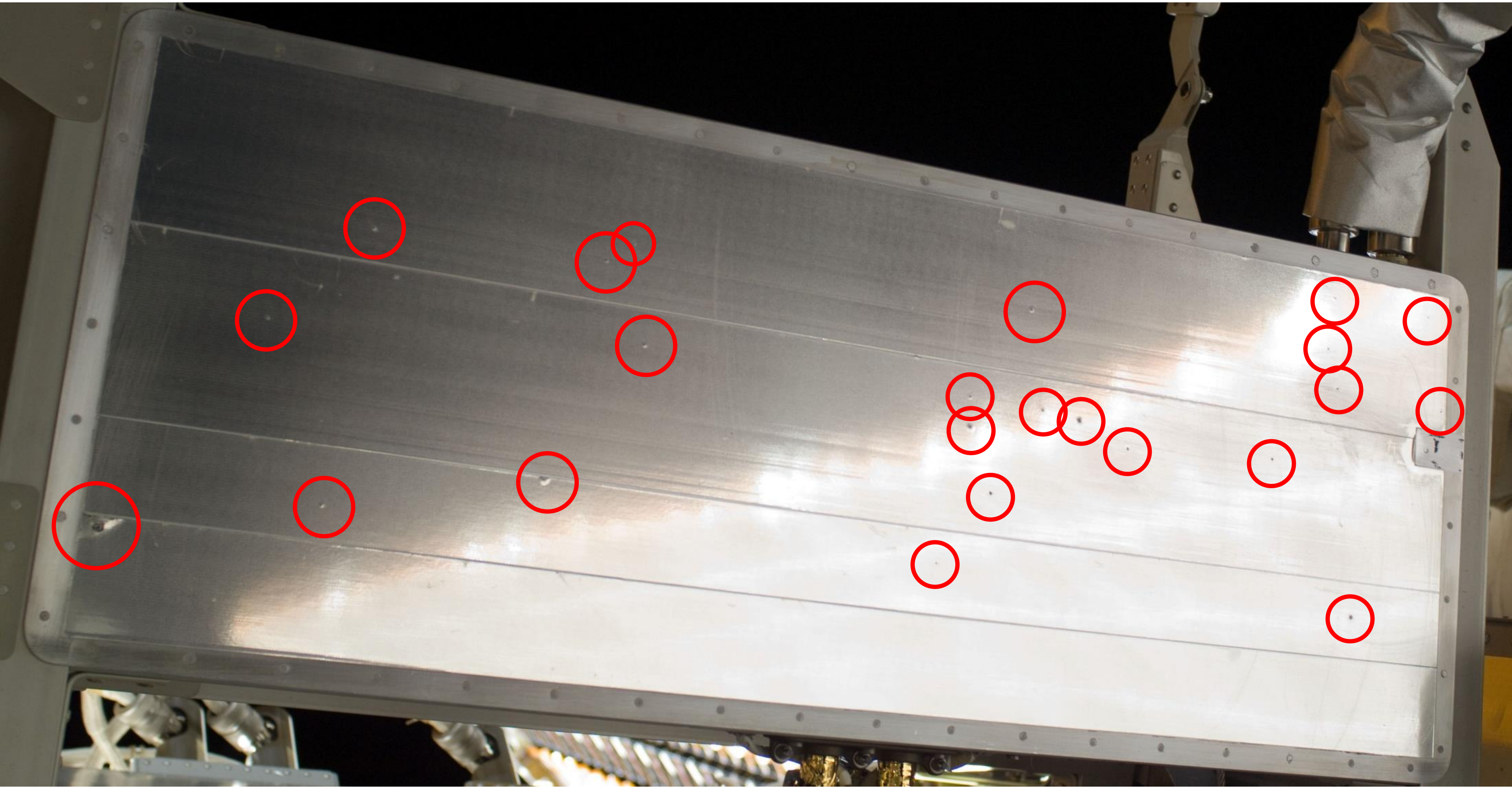
- **Also in 2007, a crew member on EVA noticed a hypervelocity impact crater while working near a large aluminum panel.**



Space debris impact site

MMOD Damage to ISS

- **MMOD impact damages observed to radiator panel during EVA-20 (Nov. 2012)**

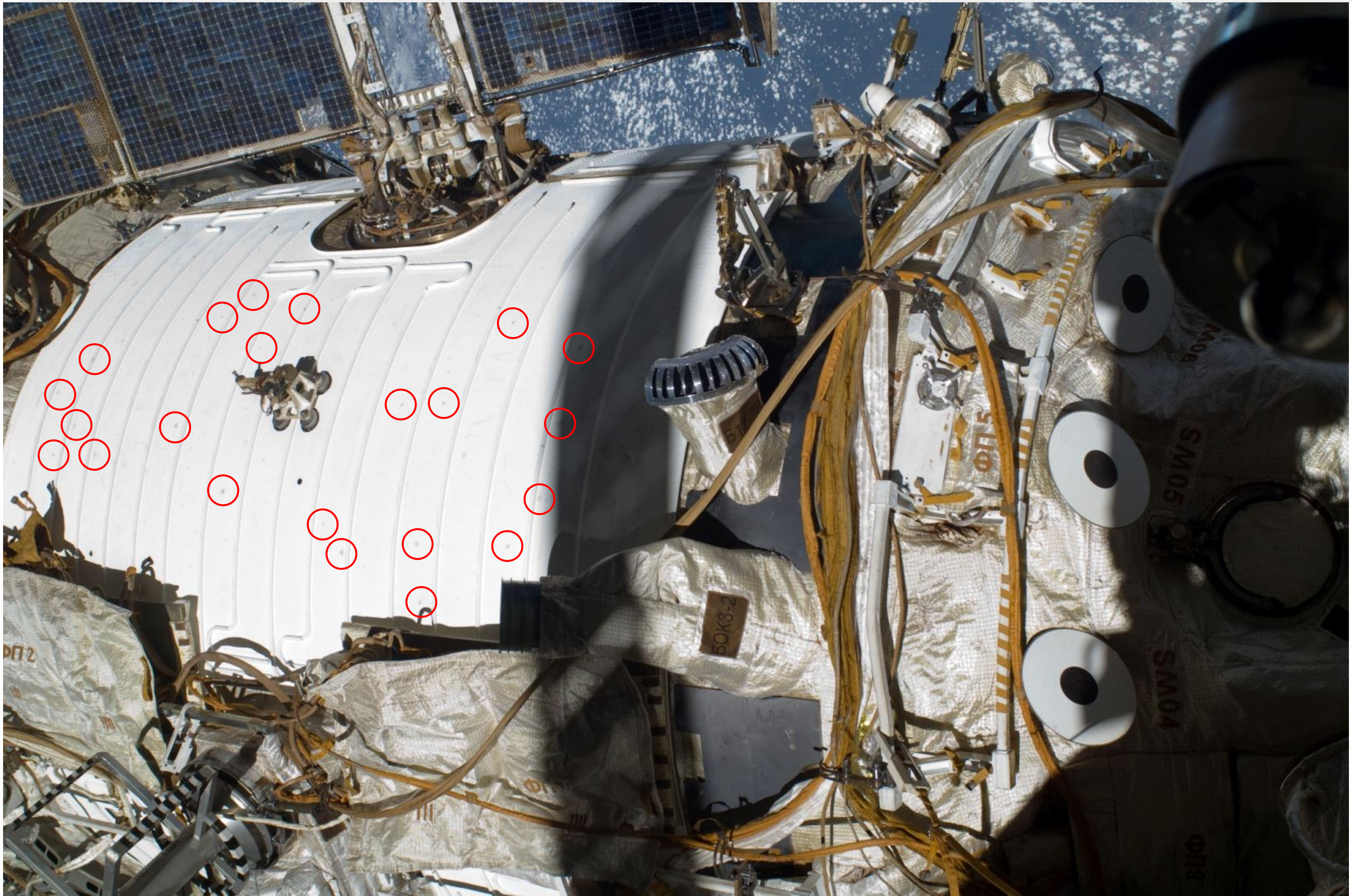


ISS033e017859

MMOD Damage to ISS

ISS032e020579

observed to Service Module during Russian EVA-31 (Aug. 2012)



Close-up of SM radiator damage (1/4)

ISS032e020579

Close-up of SM radiator damage (2/4)

ISS032e020579

Close-up of SM radiator damage (3/4)

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Close-up of SM radiator damage (4/4)

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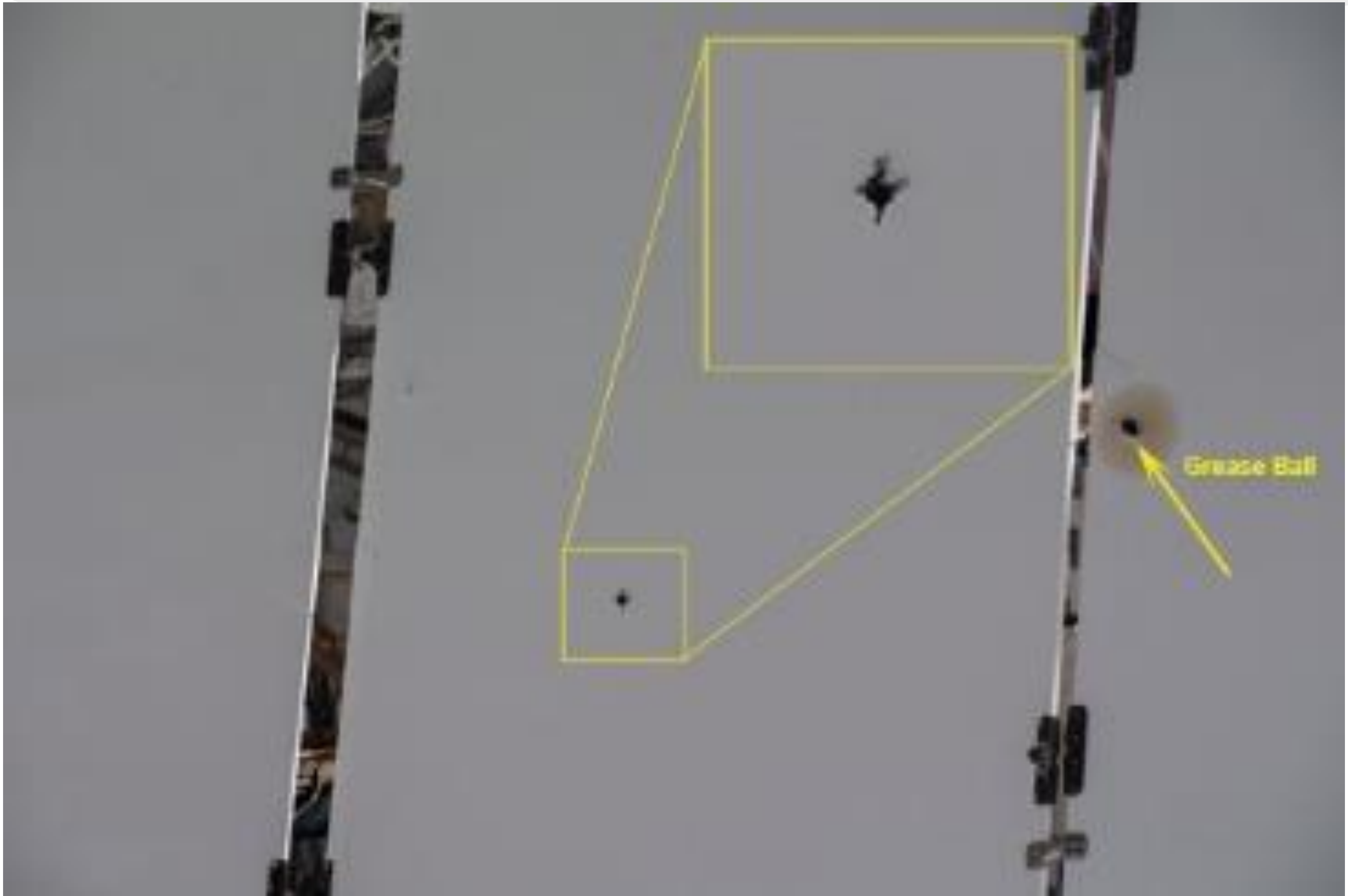
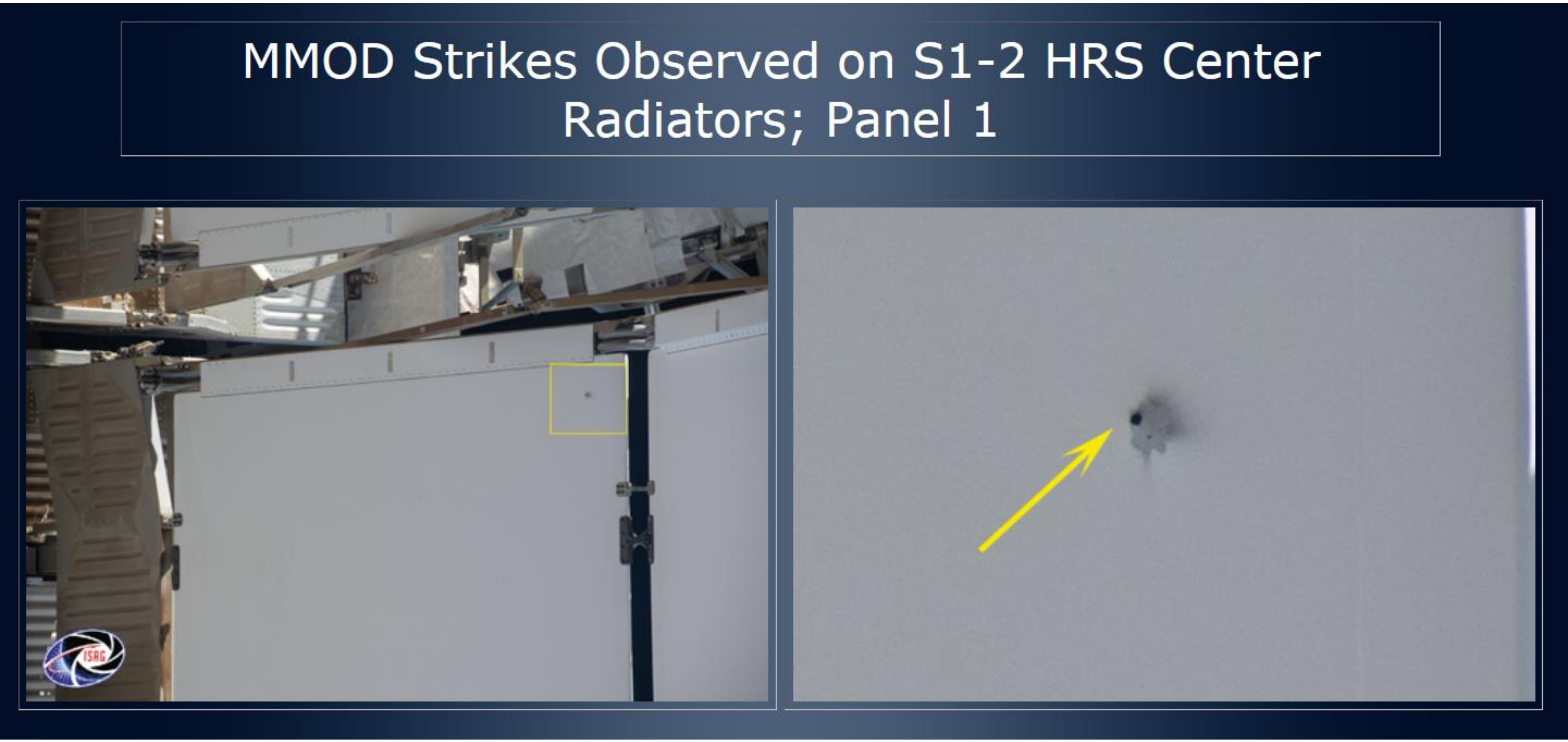
Recent ISS Radiator Imagery



Recent ISS Radiator Imagery



National A

Tim Peake
@astro_timpeake

Follow

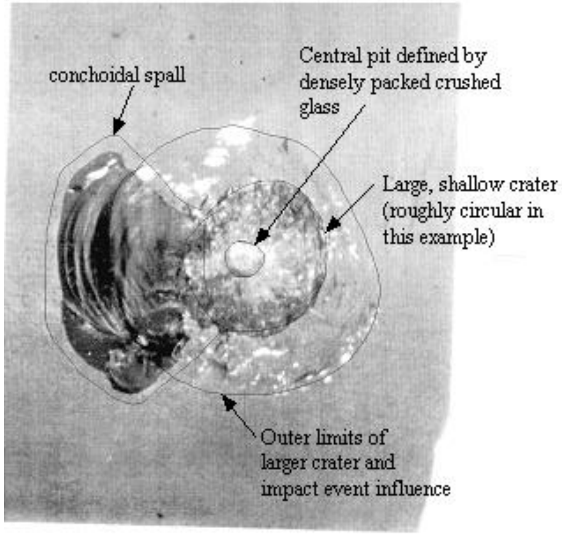
Often asked if @Space_Station is hit by space debris. Yes – this chip is in a Cupola window esa.int/spaceinimages/ …

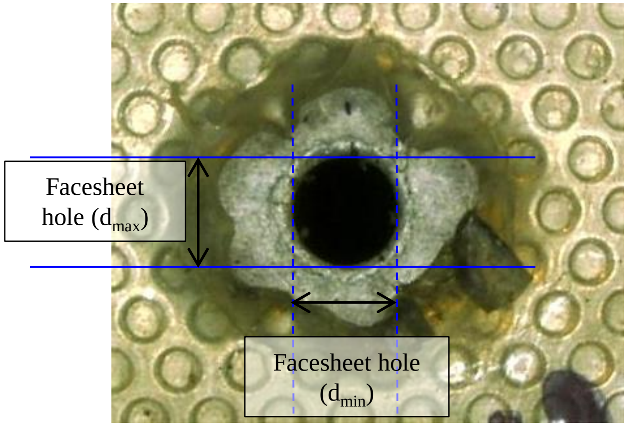
RETWEETS 1,735

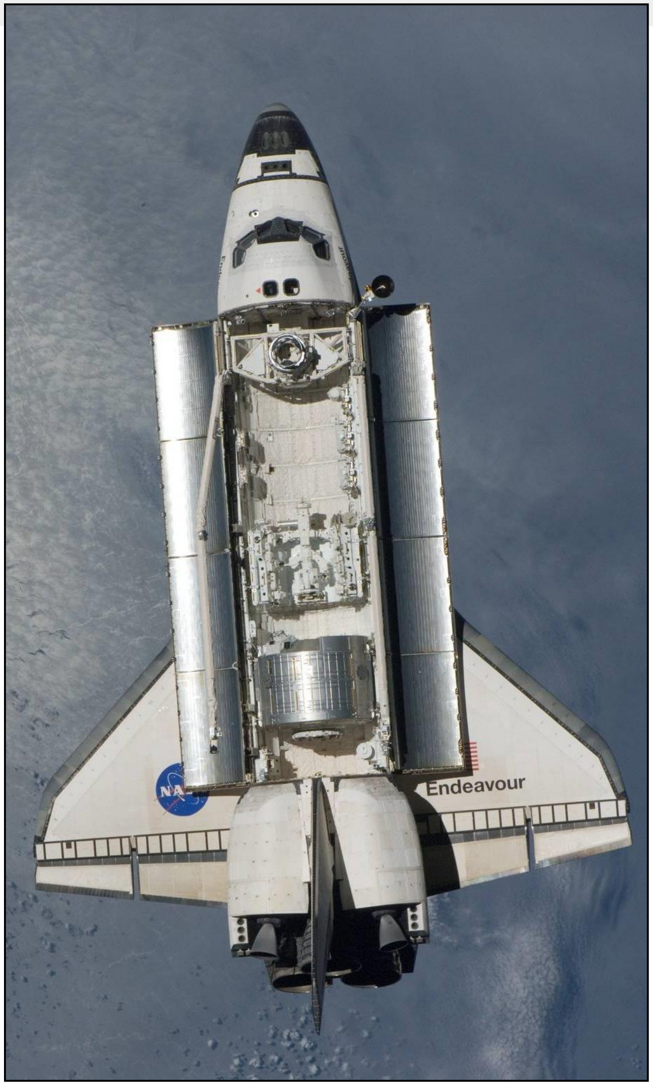
LIKES 2,840

6:07 AM - 12 May 2016

Shuttle *In Situ* Data

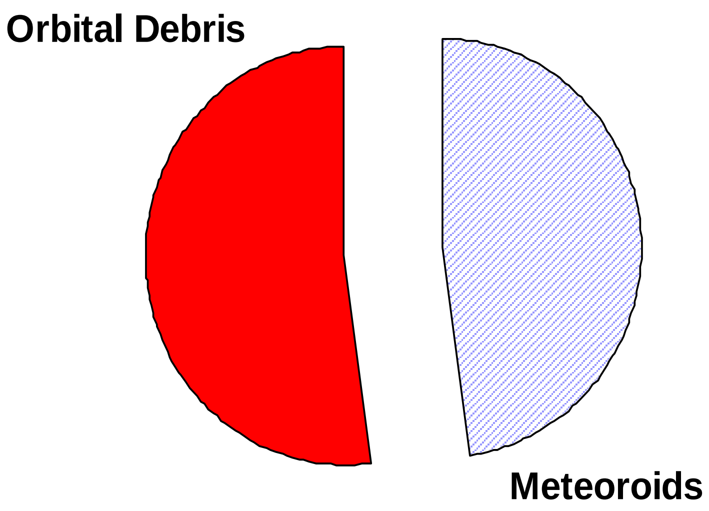




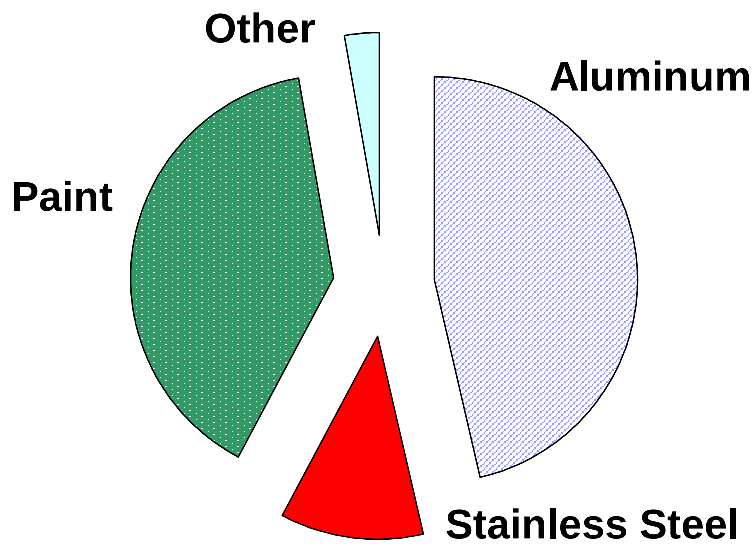


Material Types of Shuttle Window Impacts

- **It is possible to put craters from space-exposed hardware into an electron microscope and identify the material of the impactor**



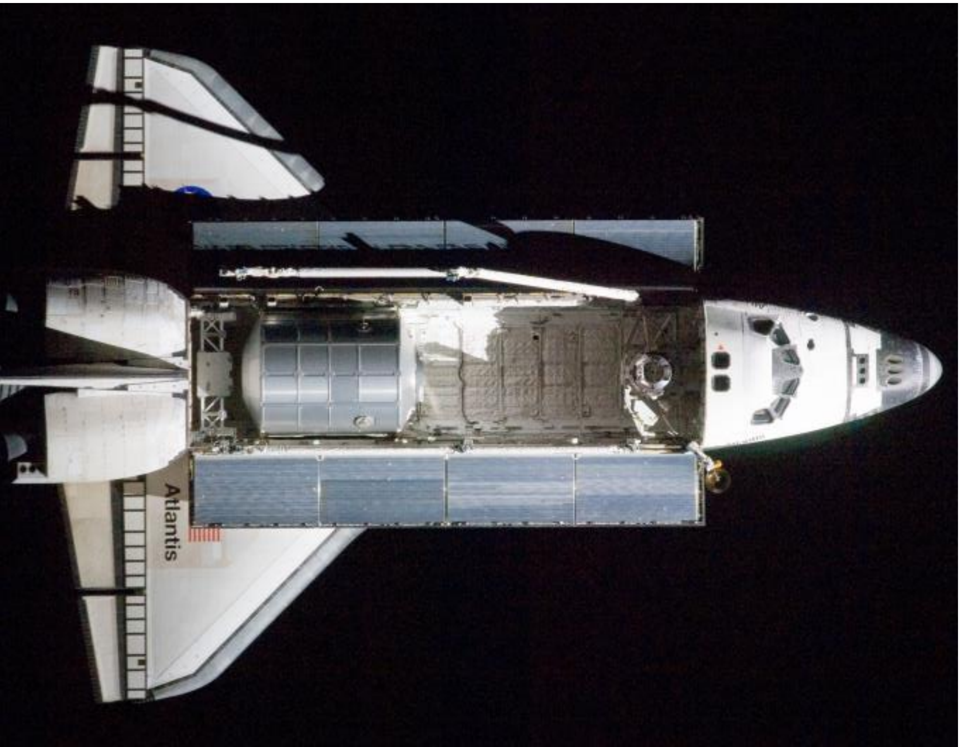
Identified Impactors

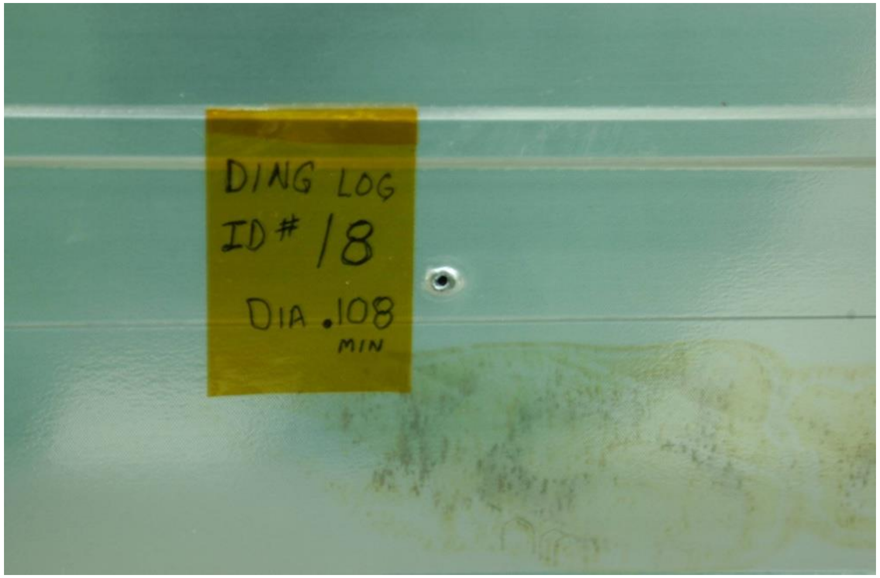


Types of Orbital Debris Impactors

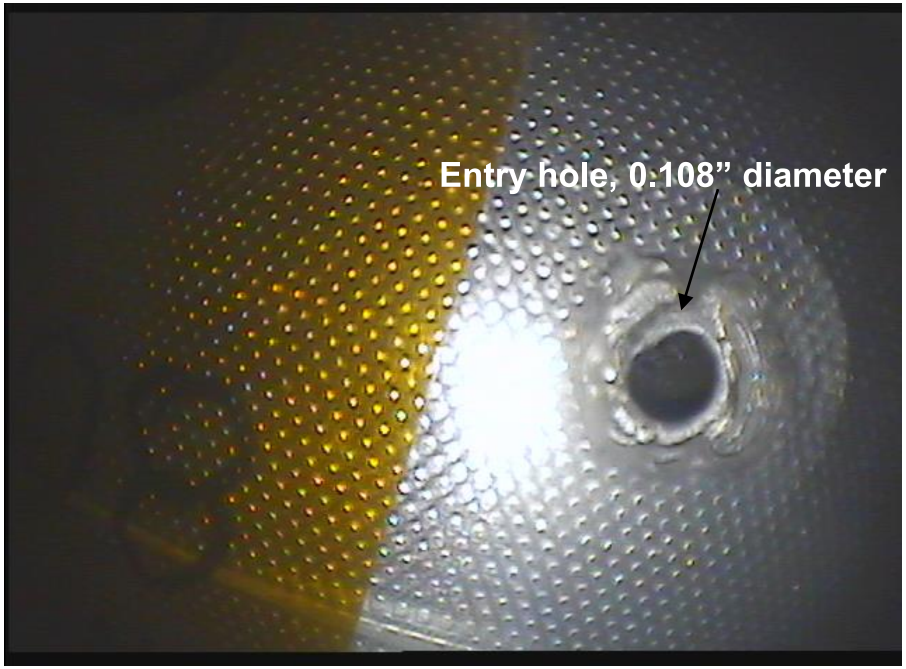
STS-115 MMOD Impact Damage

- **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.**
- **This is the most significant MMOD damage recorded on the Orbiter radiators up to that time**

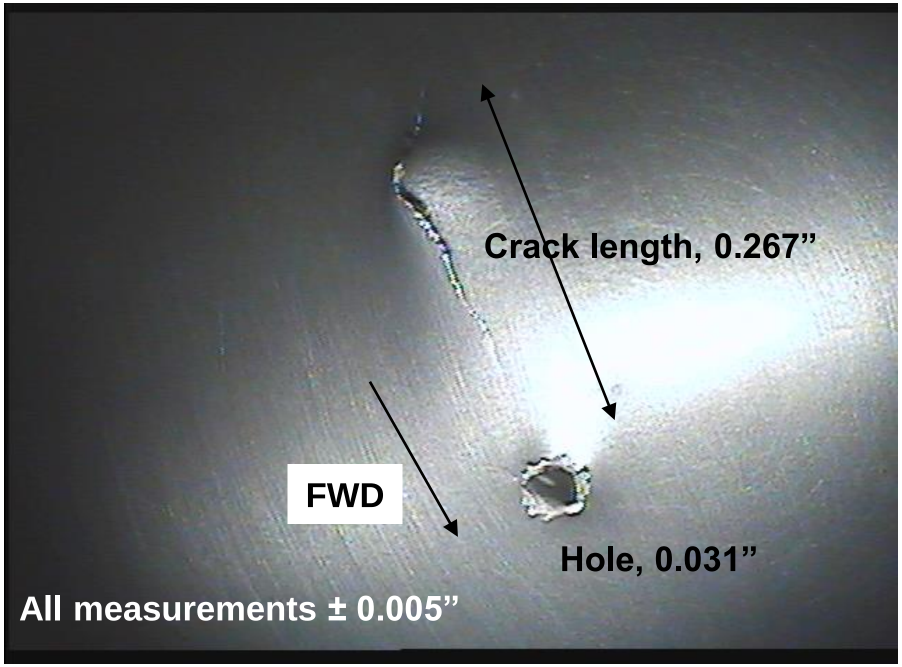




STS-115 MMOD Impact Damage

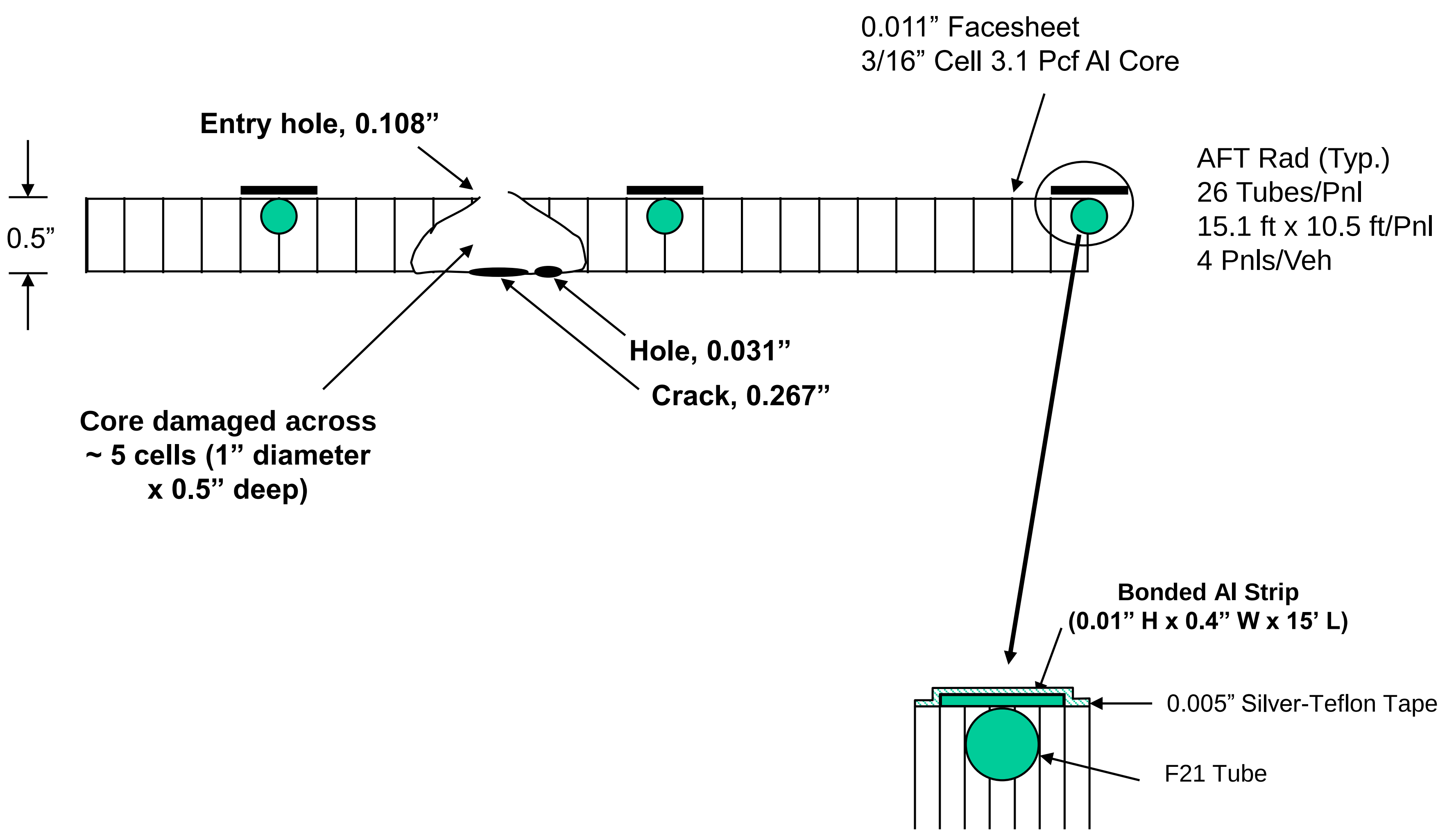


Outer face sheet damage



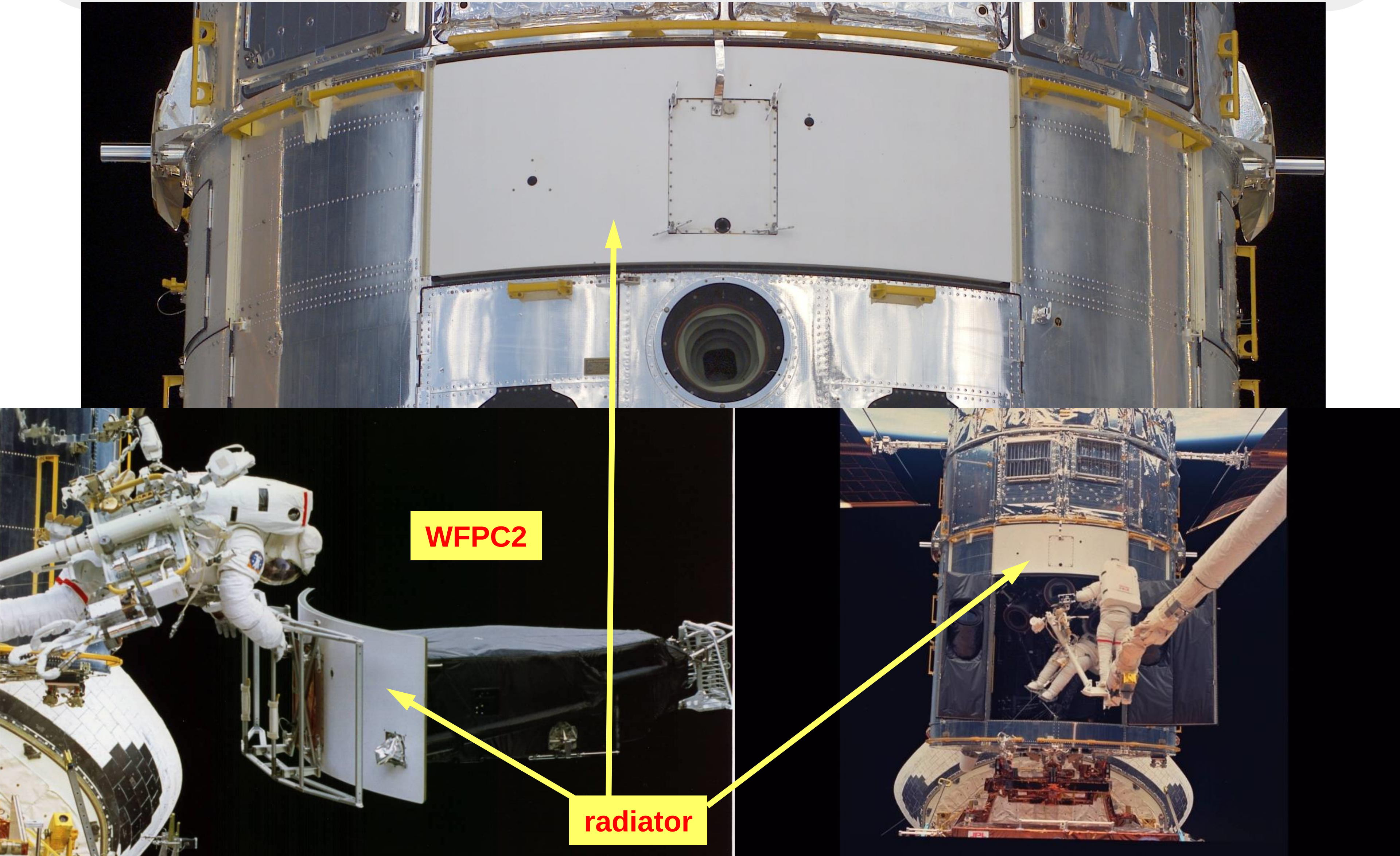
Inner face sheet damage

Schematic of Radiator and Sketch of Damage

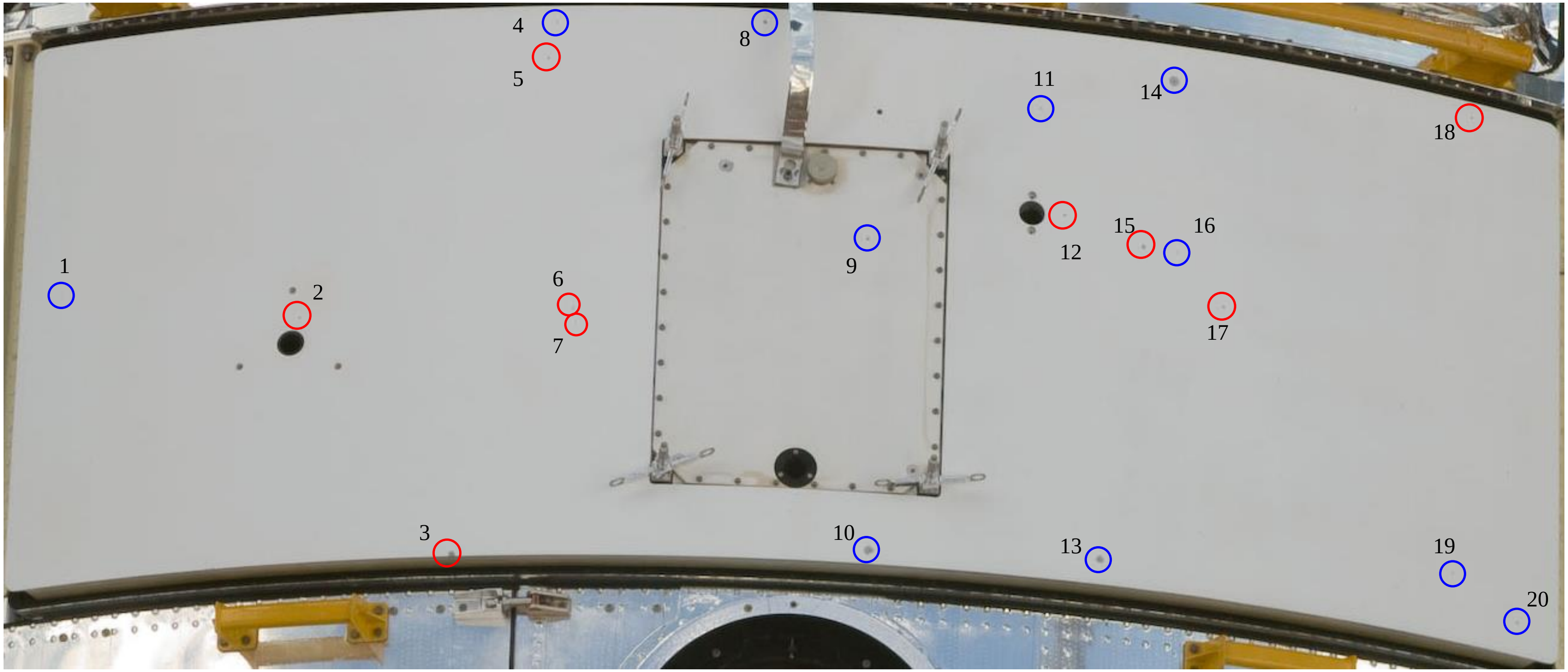


What day is trash pickup around here?

HST SM1 (STS-61, 1993)



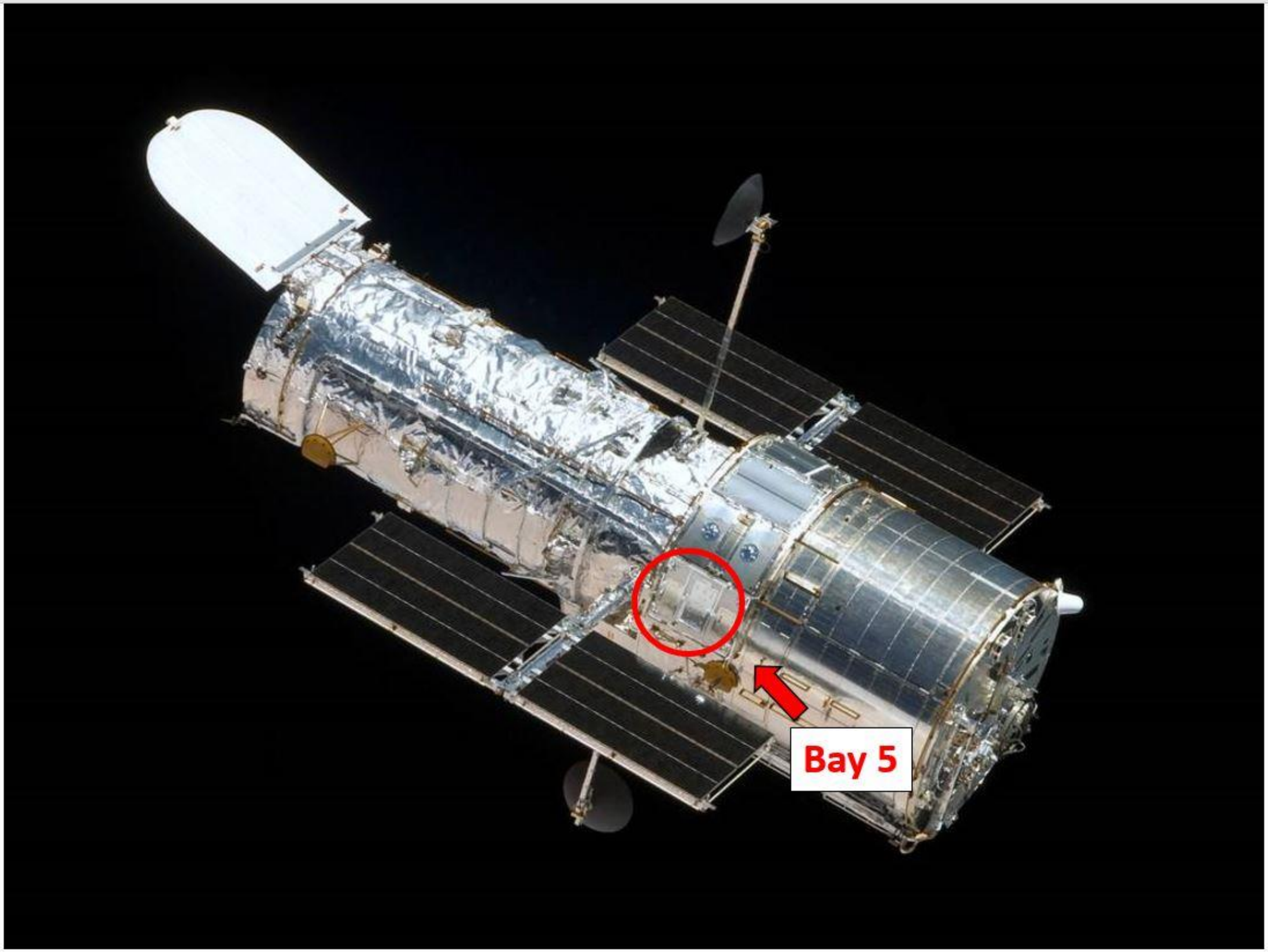
Visible MMOD Impact Damage on WFPC2 Radiator from the On-orbit Imagery Survey



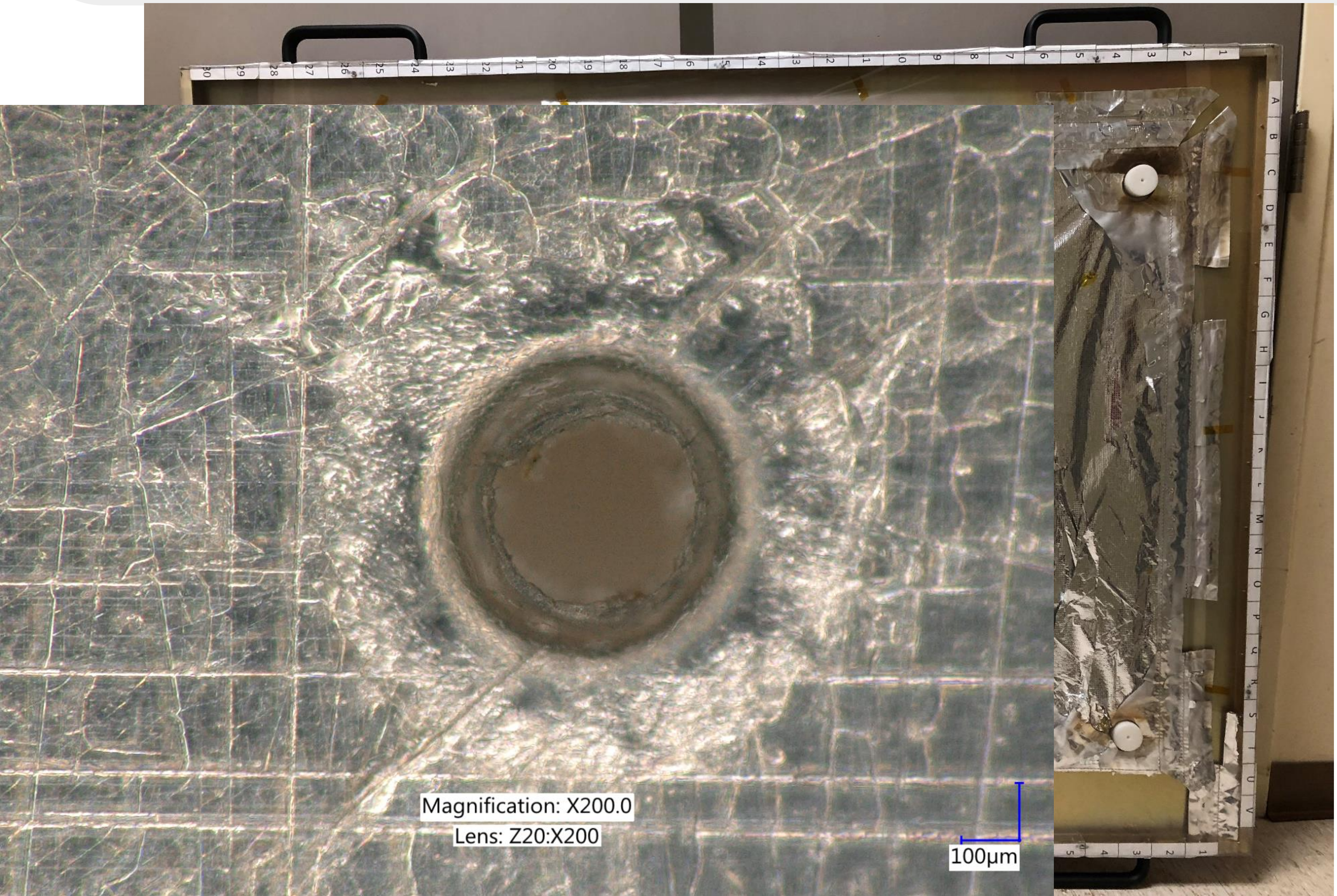
S125e006995.jpg (edited)

- Red circles: Impacts identified from SM3B images (2002)
- Blue circles: Additional impacts identified from SM4 images (2009)

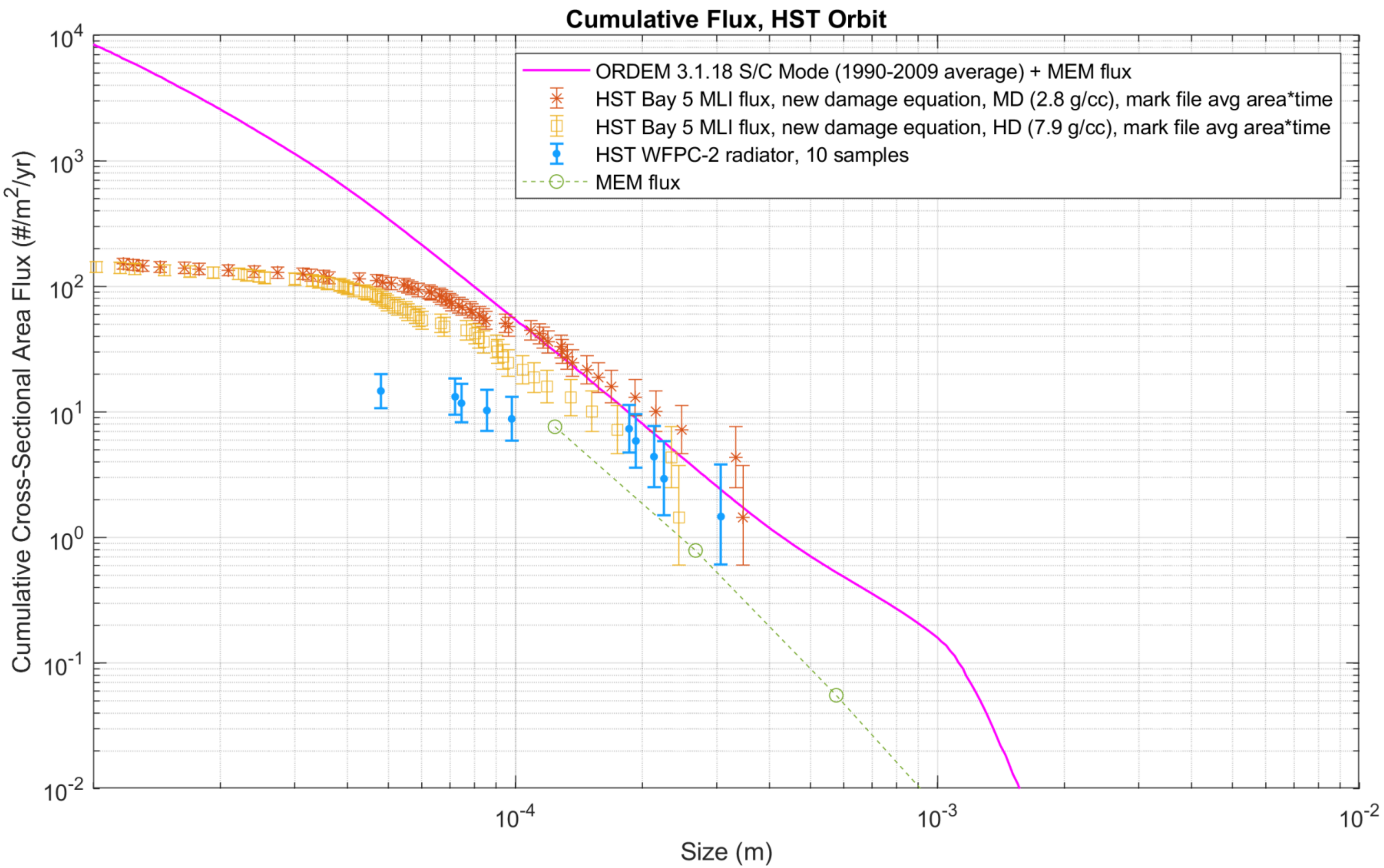
Bay 5 MLI



Bay 5 MLI



HST Crater Data



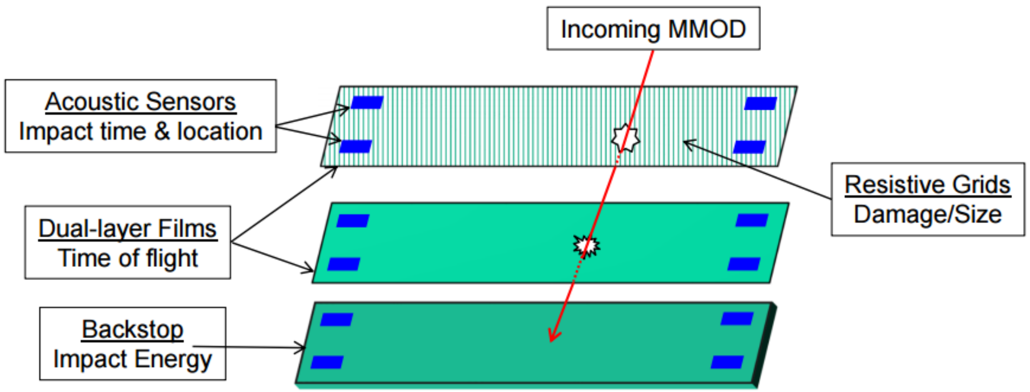
Future of *In Situ*

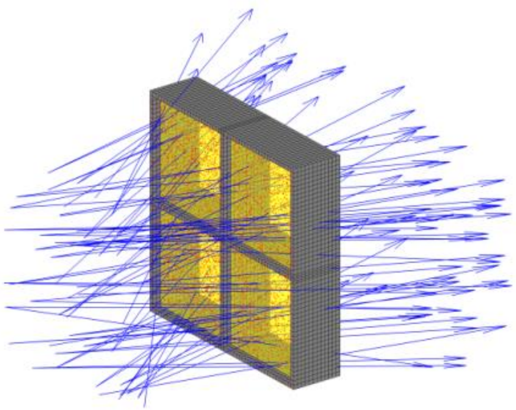
- The Shuttle no longer flies, so NASA currently has no dedicated sensor to monitor the small particle environment

- The best way to measure small particles is by using a dedicated, calibrated sensor, designed to measure the impactor properties of most interest
  - Size
  - Shape
  - Material Density
  - Speed and Direction
  - Time of Impact (combined with position of sensor, can be used to determine particle orbit)

DRAGONS

- **The Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor (DRAGONS) is a new technology initiative to measure *in situ* debris**



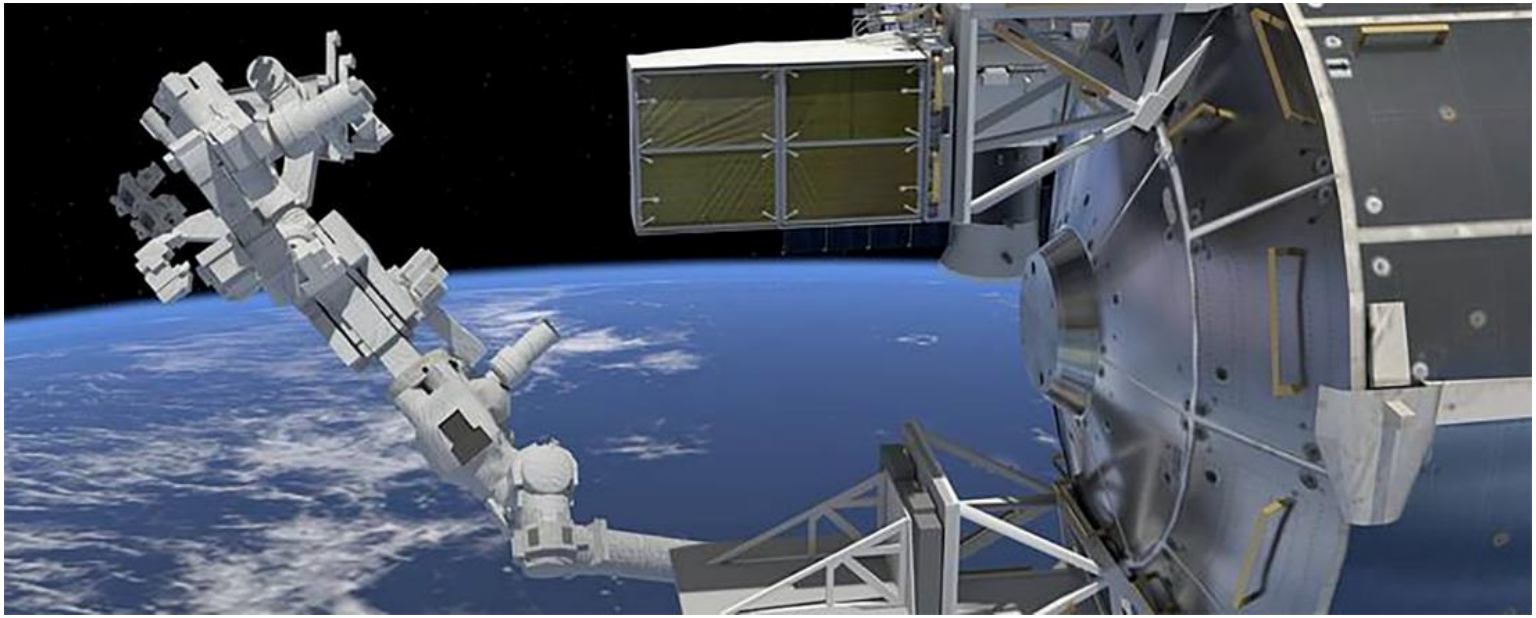


- **The resistive grid on the first layer used to estimate the particle size**
- **Acoustic sensors at each layer to measure path and time-of-flight**
- **Backstop to record total energy**
- **Using velocity, energy, and size, should be able to estimate mass and material density**
- **Impact time to compute debris orbit**

Space Debris Sensor

- **The technology had a flight technology demonstration on the Space Debris Sensor (SDS) aboard the ISS**

- **While some engineering data was obtained, the instrument suffered a fatal failure and is no longer operational**



Future DRAGONS

- **We are currently awaiting flight opportunities of the DRAGONS technology, especially at higher orbit altitudes**
  - **Debris environment is predicted to be worse at altitudes between 700 and 1000 km altitude**
  - **NASA and other spacecraft are spending money and resources to mitigate the predicted risk**
  - **We have little to no data on these small particles – we are relying on models to extrapolate the risk from lower altitudes**

Ground Experiments

- **Sometimes it is not enough to measure events in space, they need to be studied in the laboratory under controlled conditions**

- **There is a long history of studying collision or explosion debris on the ground by picking up the pieces afterwards**
  - **Number of debris**
  - **Size distribution**
  - **Shapes**
  - **Delta-velocities**

- **The primary source of data has been the Satellite Orbital debris Characterization Impact Test (SOCIT), which used an intact Transit satellite built in the 1960's for the target of a hypervelocity impact test**

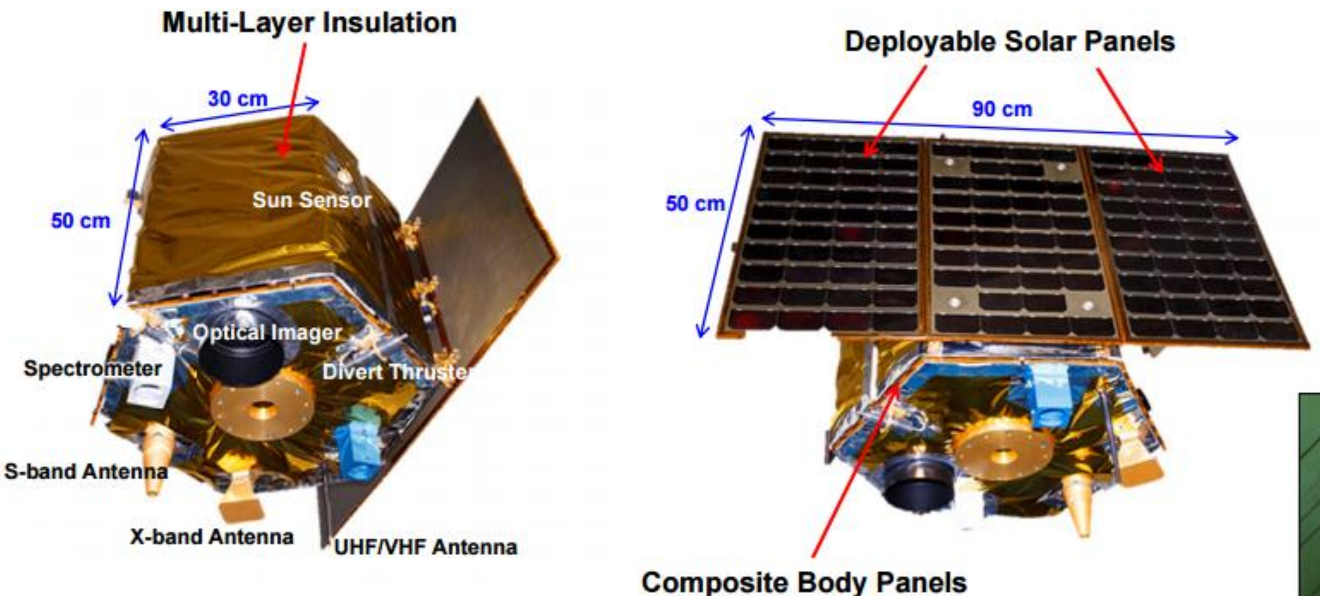
Ground Experiments

- **However, there have been major changes in spacecraft construction materials over the years, so a need to test the breakup models using more modern spacecraft materials**
- **NASA, in conjunction with US DoD and the Aerospace Corporation, conducted the DebriSat impact experiment, using a mock satellite made of modern materials**
  - **Included a test of a mock tank, designated DebrisLV**

A comparison between Transit and DebriSat

	Transit (SOCIT)	DebriSat
Target body dimensions	46 cm (dia) × 30 cm (ht)	60 cm (dia) × 50 cm (ht)
Target mass	34.5 kg	56 kg
MLI and solar panel	No	Yes
Projectile	Al sphere	Hollow Al cylinder
Projectile dimension, mass	4.7 cm (dia), 150 g	8.6 cm × 9 cm, 570 g
Impact speed	6.1 km/sec	6.8 km/sec
Impact energy to target mass ratio	78 J/g (2.7 MJ total impact energy)	235 J/g (13.2 MJ total impact energy)

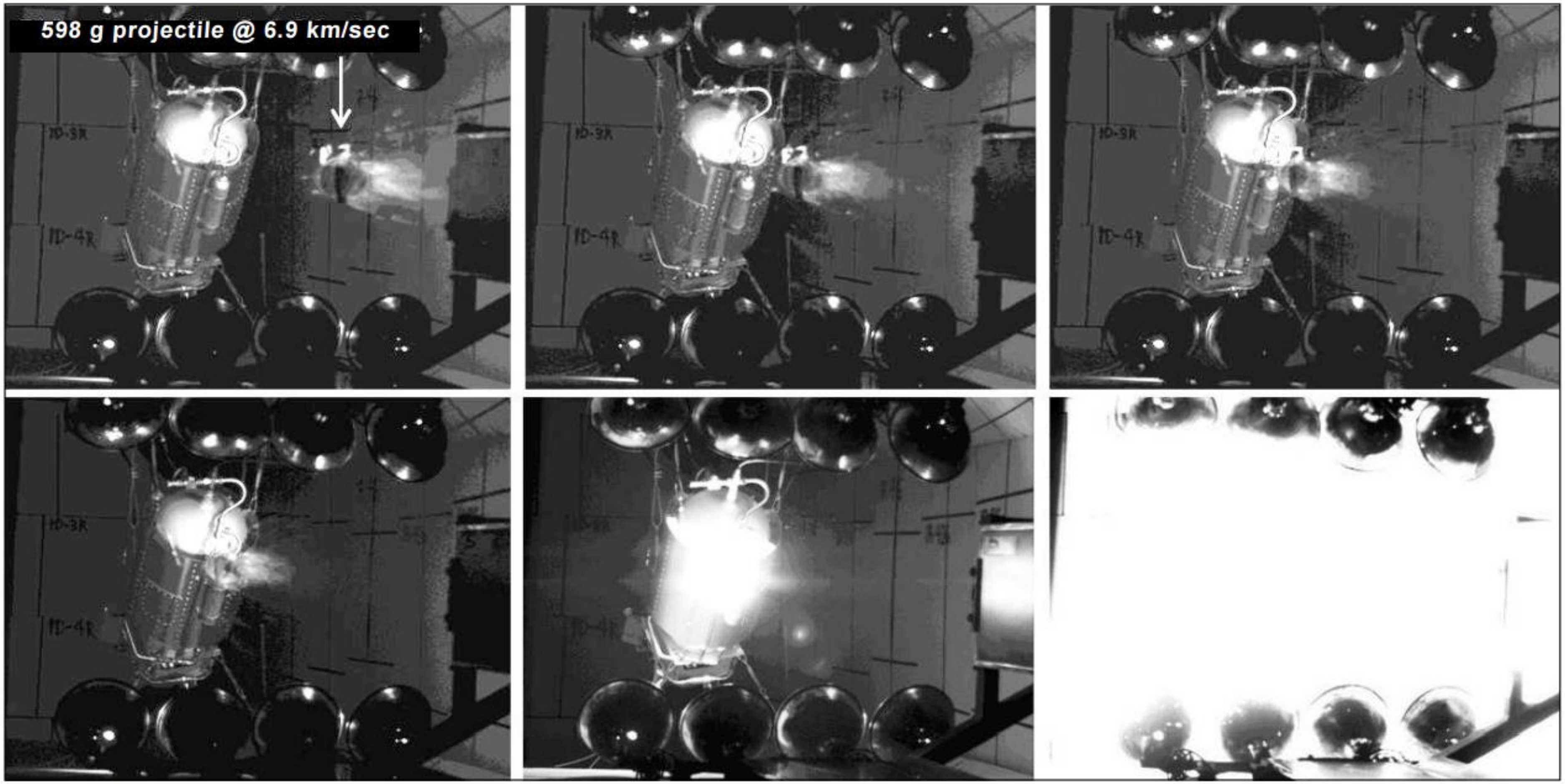
DebriSat



DebriSat

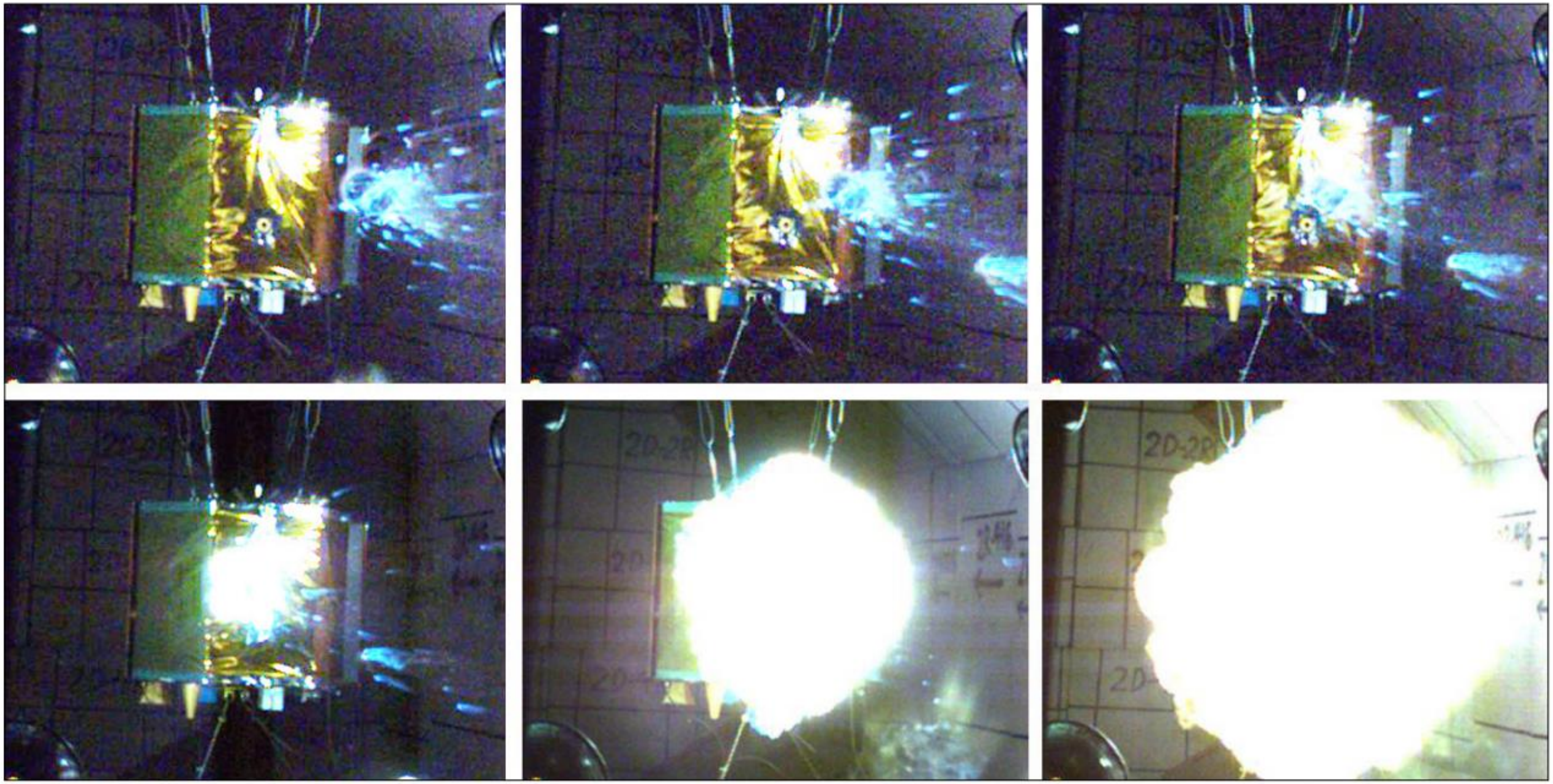
DebrisLV

DebrisLV



Impact sequences of DebrisLV

DebriSat



Impact sequences of DebrisSat

DebriSat

- **The debris from the impacts have all been collected, and are being carefully analyzed by a team from the University of Florida**
  - **Digital photos of each object**
  - **Mass, 3D dimensions**
  - **Material components identified**
  - **Soft-catch material being x-rayed to ascertain particle velocities and particle shapes**

- **More debris were recovered than we anticipated based on previous models**

- **Final dataset will be a detailed resource**
  - **Shape studies**
  - **RCS studies**
  - **Material distributions**
  - **Size distributions**

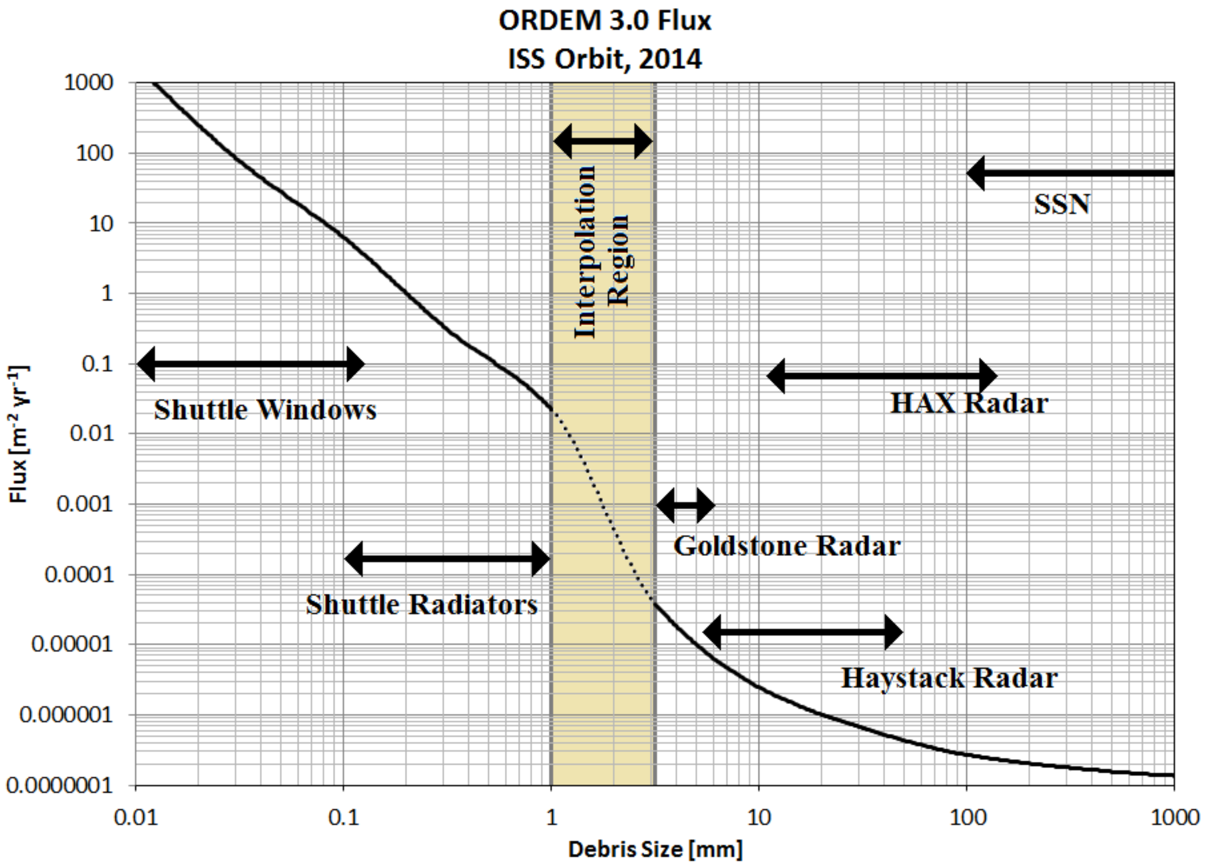
ORDEM 3.1

- **An Engineering Model is a tool (primarily) for spacecraft designers and users to understand the long-term risks of debris collisions with their spacecraft**
- **NASA's Orbital Debris Engineering Model ORDEM represents NASA's best estimate of the current and near future orbital debris environment**
  - **The environment is dynamic and must be updated periodically**
  - **Populations based on empirical data as much as possible**
- **The ORDEM 3 series of models have significant new capabilities over previous ORDEM models**
  - **Uncertainties**
  - **Material density categories**
  - **Model extended to GEO**
  - **Can easily calculate flux for satellites in highly elliptical orbit**
- **ORDEM 3.1 is an update of the environment based on the latest data, but with minimal changes to the model structure**
  - **Model completed and is undergoing review**
  - **Should be available later in 2019**

Data Sources for ORDEM Models

Data Source	Data Type	Size Limits	ORDEM 3.0	ORDEM 3.1
STS Windows and Radiators	*In situ*	10 µm - 1 mm	1995-2011	1995-2011
HST WFPC-2 Radiator	*In situ*	50 µm - 300 µm		1990-2009
HST Bay 5 MLI	*In situ*	10 µm - 300 µm		1990-2009
HUSIR/Haystack	Radar	>5.5 mm	1999-2003, 2007-2009	2013-2017
HAX	Radar	>1 cm	1999-2003, 2007-2009	
Goldstone	Radar	2 mm - 8 mm	2001, 2005-2007, 2009	2016-2017
SSN Catalog	Radar	>10 cm	1957-2007	1957-2017
MODEST (GEO)	Optical	>30 cm	2004-2006	2004-2009, 2013-2014

Data and Size Regimes



- **Small particle populations are fit separately from large particle populations**

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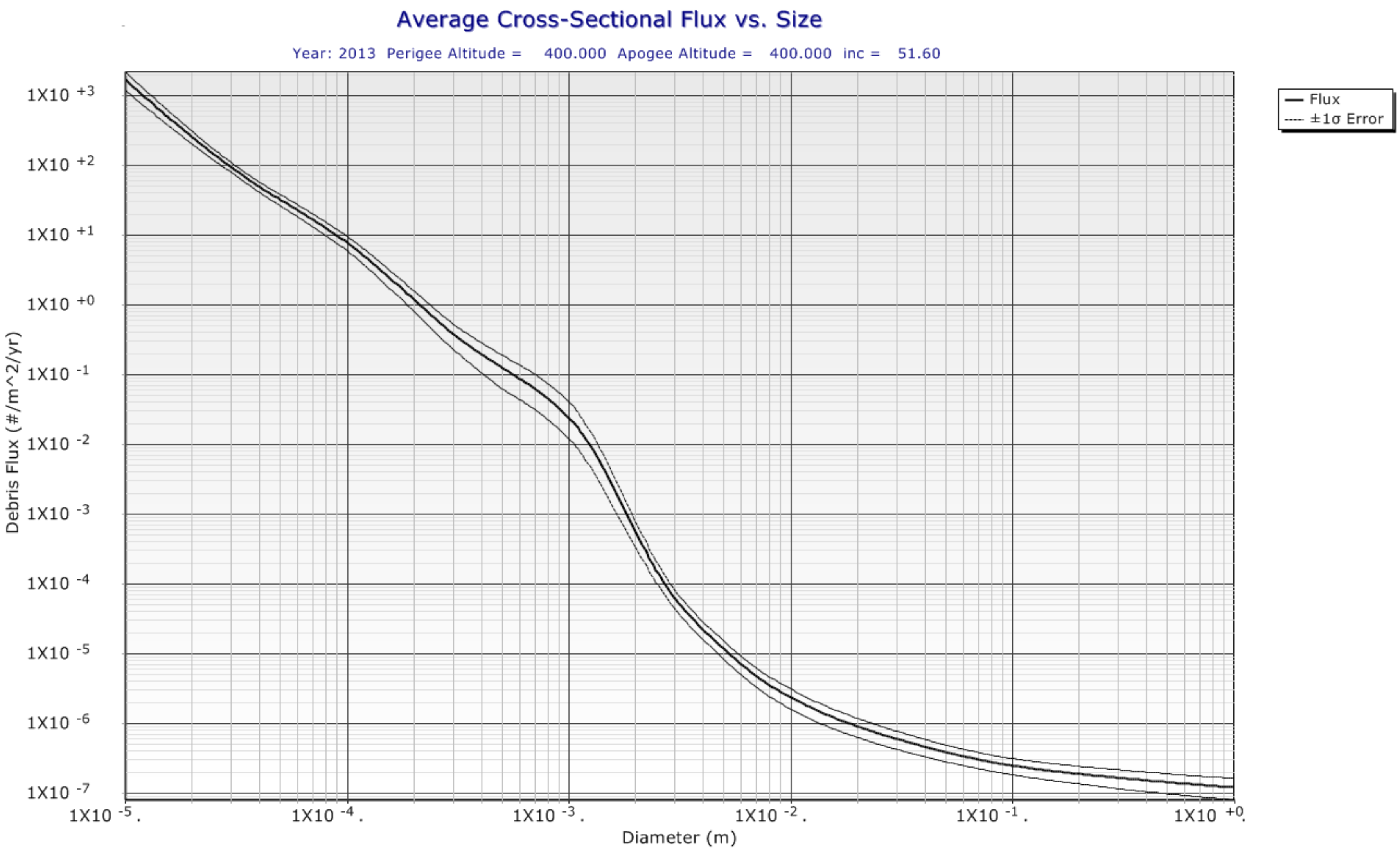
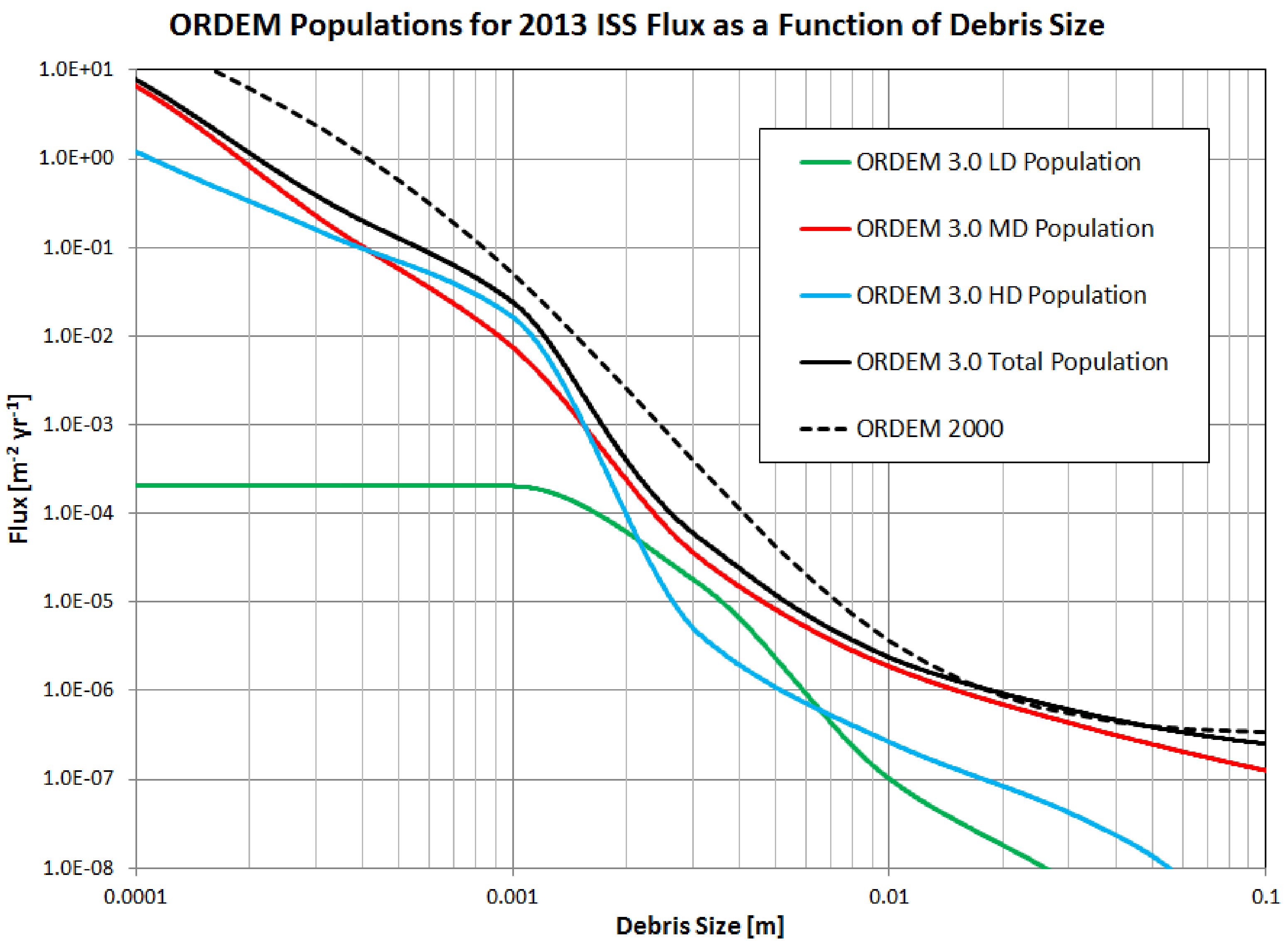
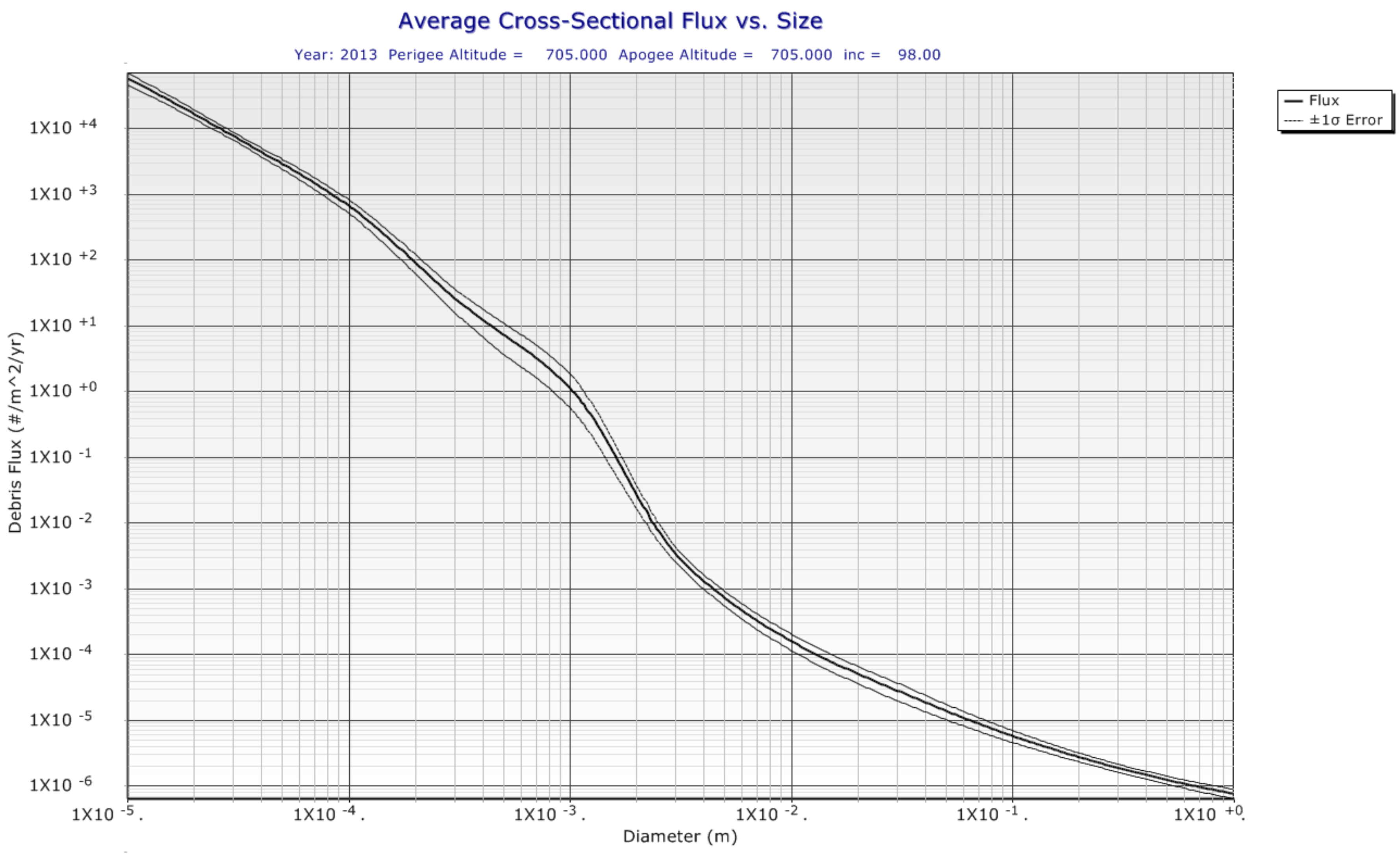
ORDEM 3.0 Flux for ISS 400km



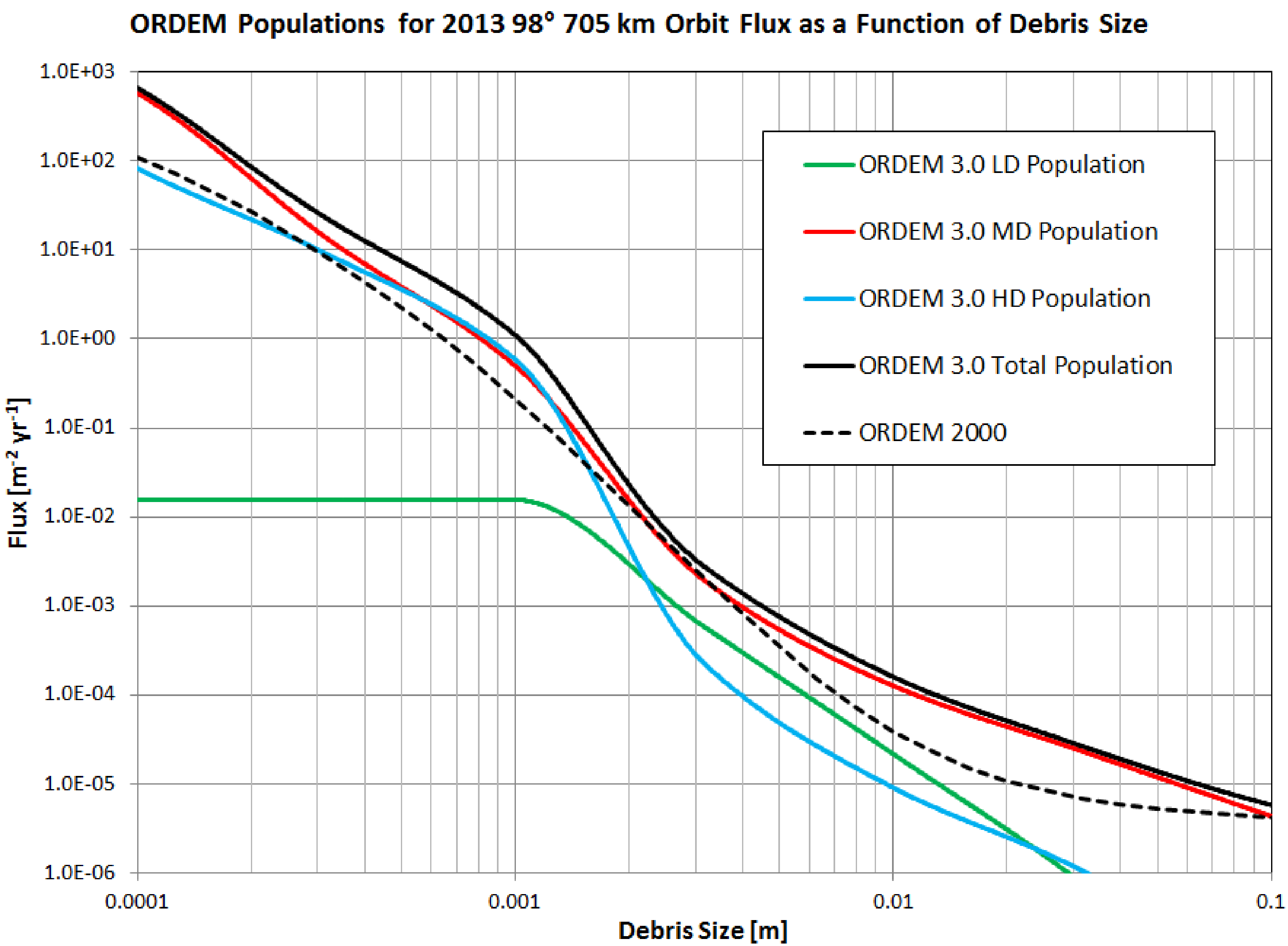
Material Distributions - ISS



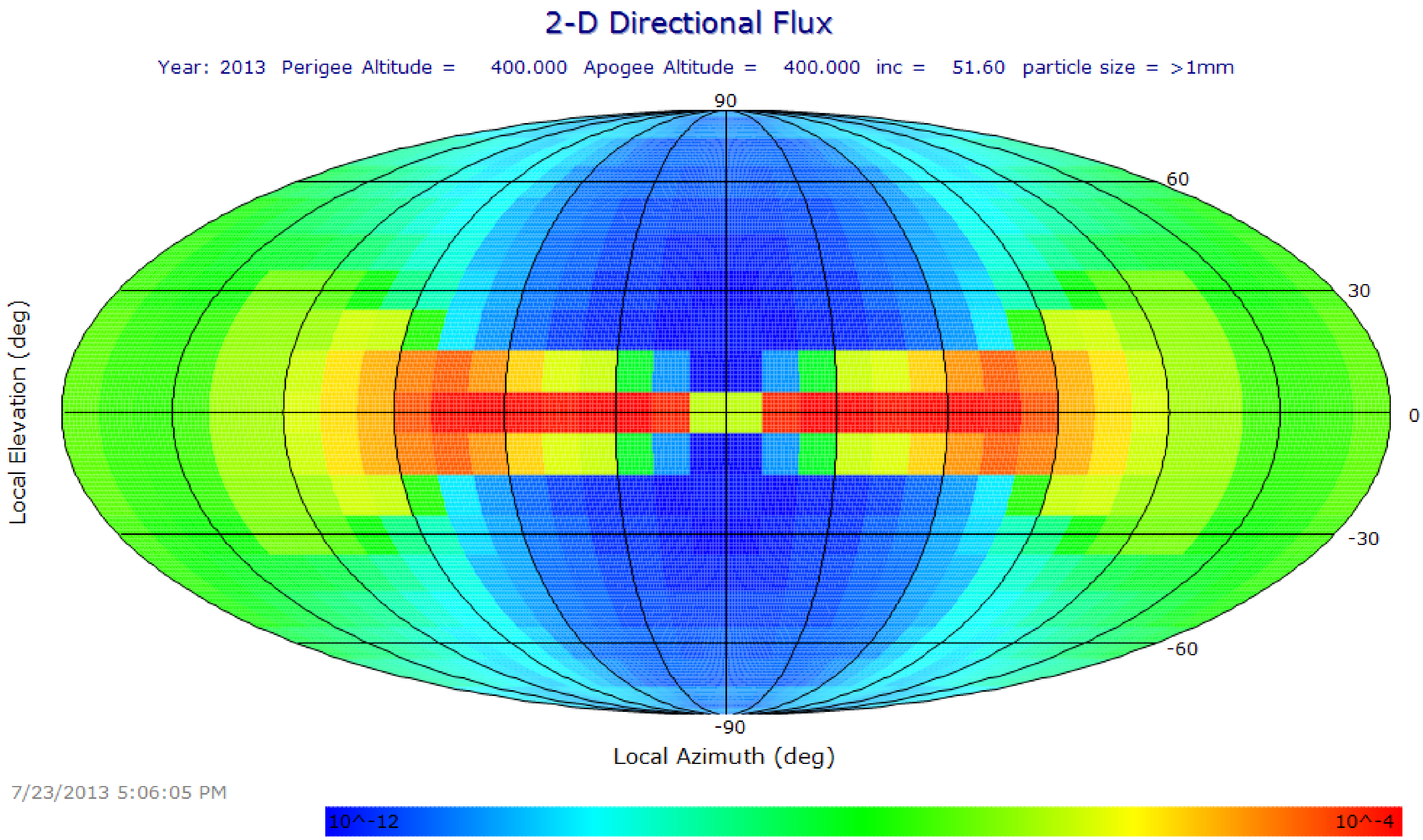
ORDEM 3.0 Flux for A-Train 705km



Material Distribution – A-Train



2D Flux Distribution



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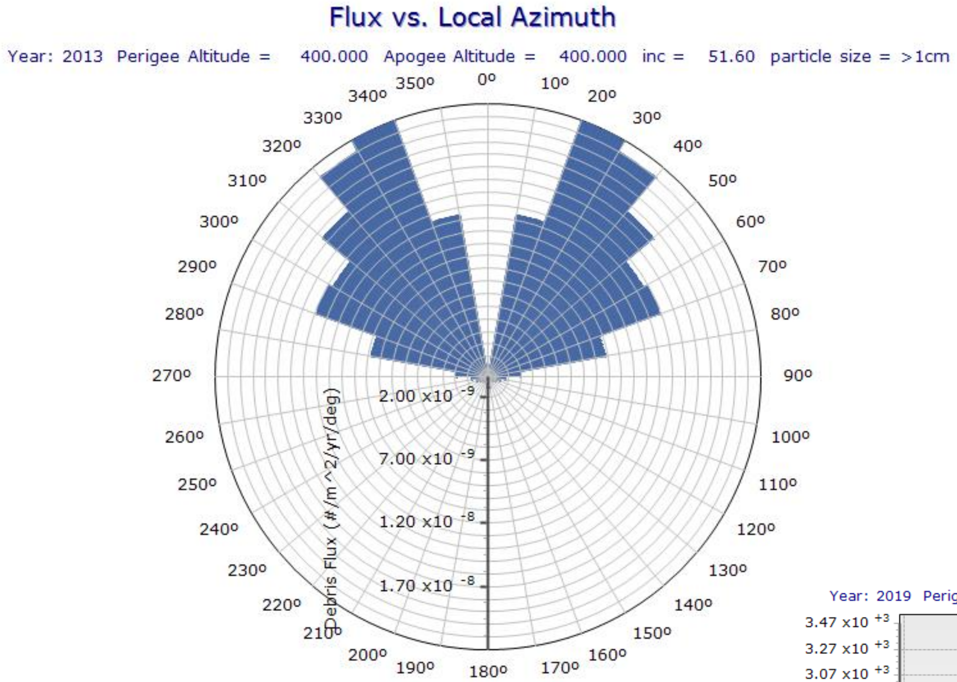
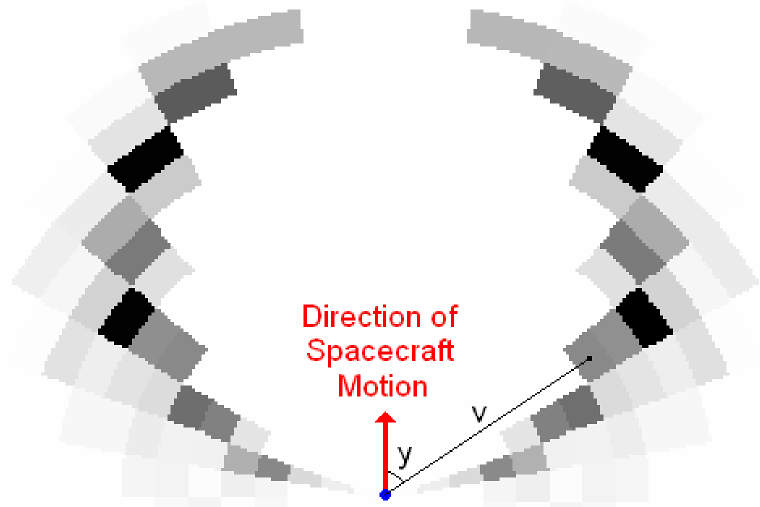
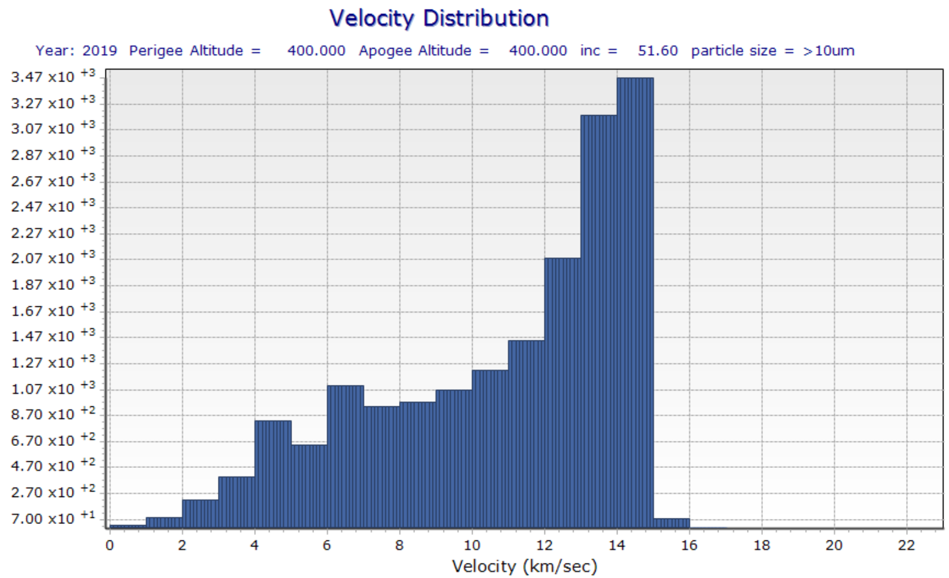
Flux Dependence on Velocity and Direction





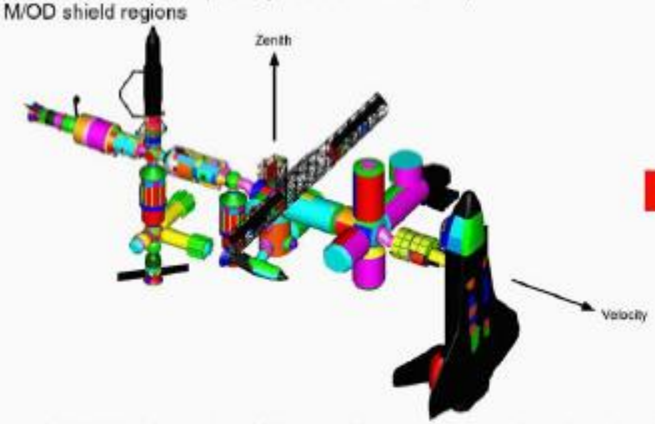


BUMPER

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

Spacecraft Configuration (I-DEAS Finite Element Model)

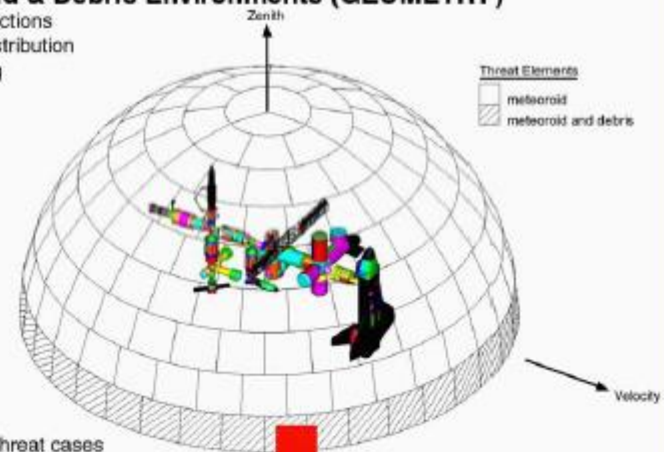
- Describes spatial relationships of spacecraft components
- Defines spacecraft orientation (velocity and zenith directions)
- Defines M/OD shield regions



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

Meteoroid & Debris Environments (GEOMETRY)

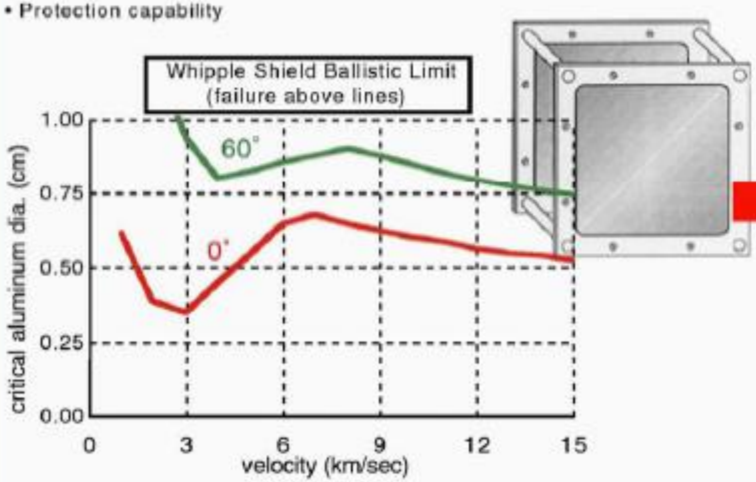
- Threat directions
- Velocity distribution
- Shadowing



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

Critical Particle Diameter Calculation (RESPONSE)

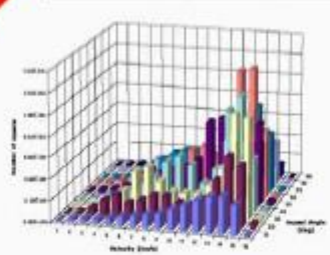
- Protection capability

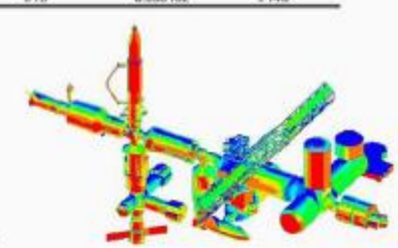


Computation of Penetrating Flux and PNP (SHIELD)
Graphical Interpretation of Results (EXCEL & I-DEAS)

Space Station Orbital Debris Threat Assessment

Station Region	Impact Risk From 1mm Ø Debris: Probability No Impact	Impact Risk From 1mm 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	0.999796	1/4912
Node 2	0.990465	1/105	0.999998	1/625000
Hab Module	0.965074	1/29	0.998923	1/928
Lab Module	0.985522	1/69	0.999022	1/1023
CRV	0.997446	1/391	0.999839	1/6228
TOTALS	0.934622	1/15	0.993132	1/146





Spacecraft Environment Considerations

- Orbital debris fluxes are a function of spacecraft orbit inclination and altitude
- Debris flux and velocity are direction-dependent
  - Custom multi-layer shields work best when optimized for particular velocities and directions
- Debris flux from different material types can skew the risk
  - High-density (e.g., steel) debris have a disproportionate effect on risk
- Spacecraft must design for the long-haul
  - A spacecraft will hopefully operate for many years
  - Risk is primarily a function of exposed area and exposed time

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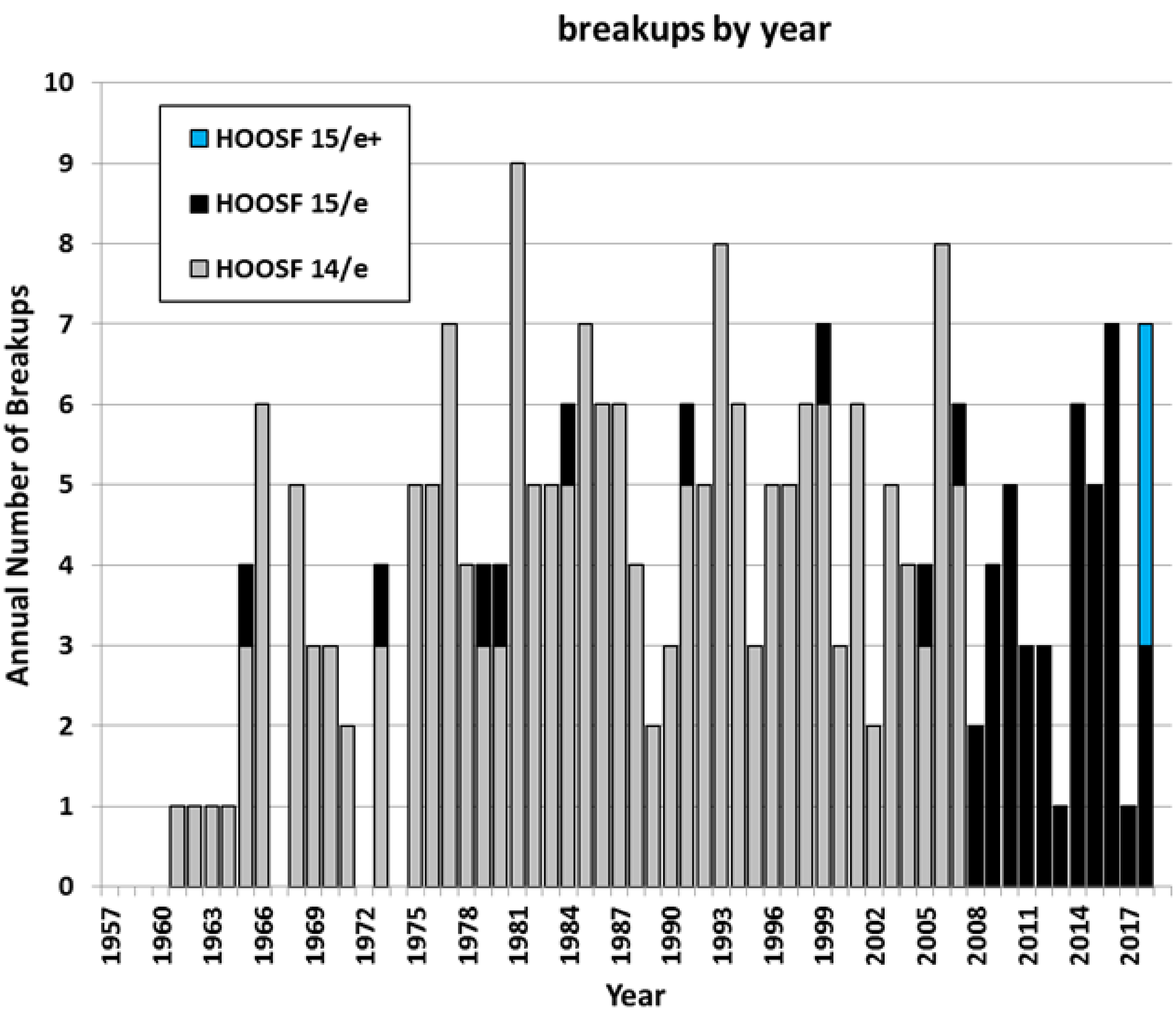
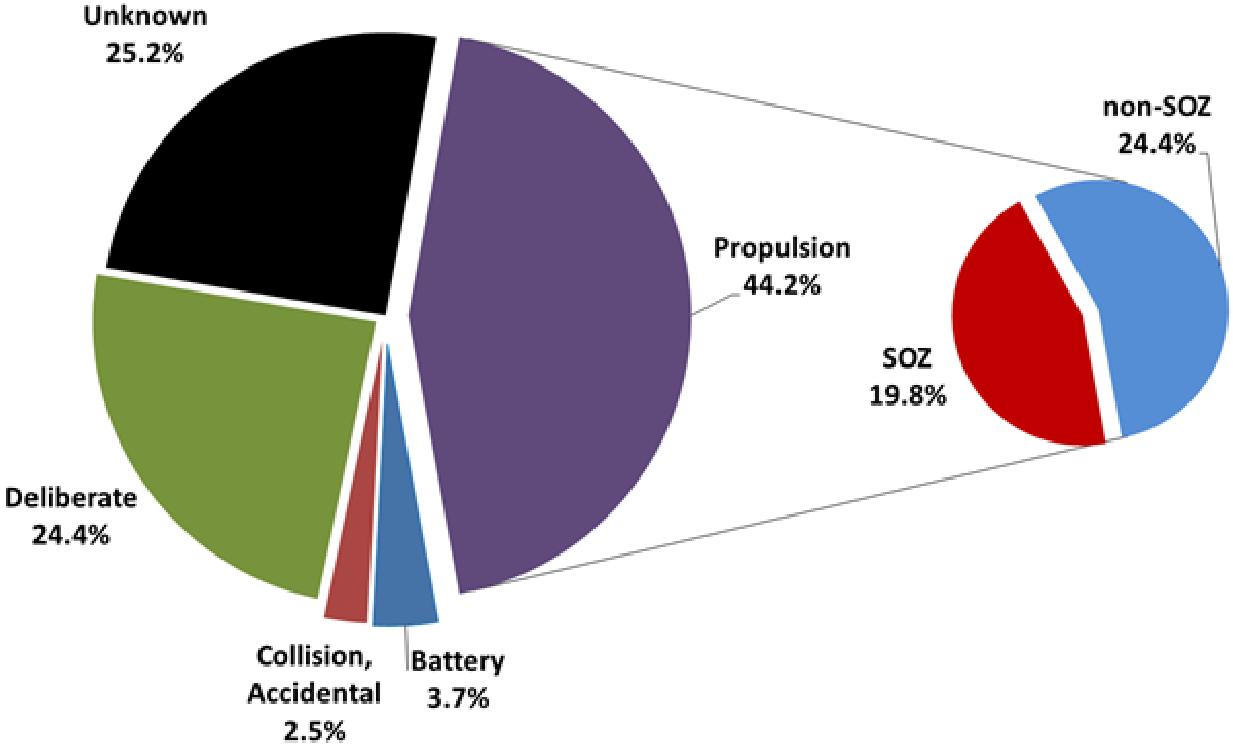
Breakups by year: 246 1961-date



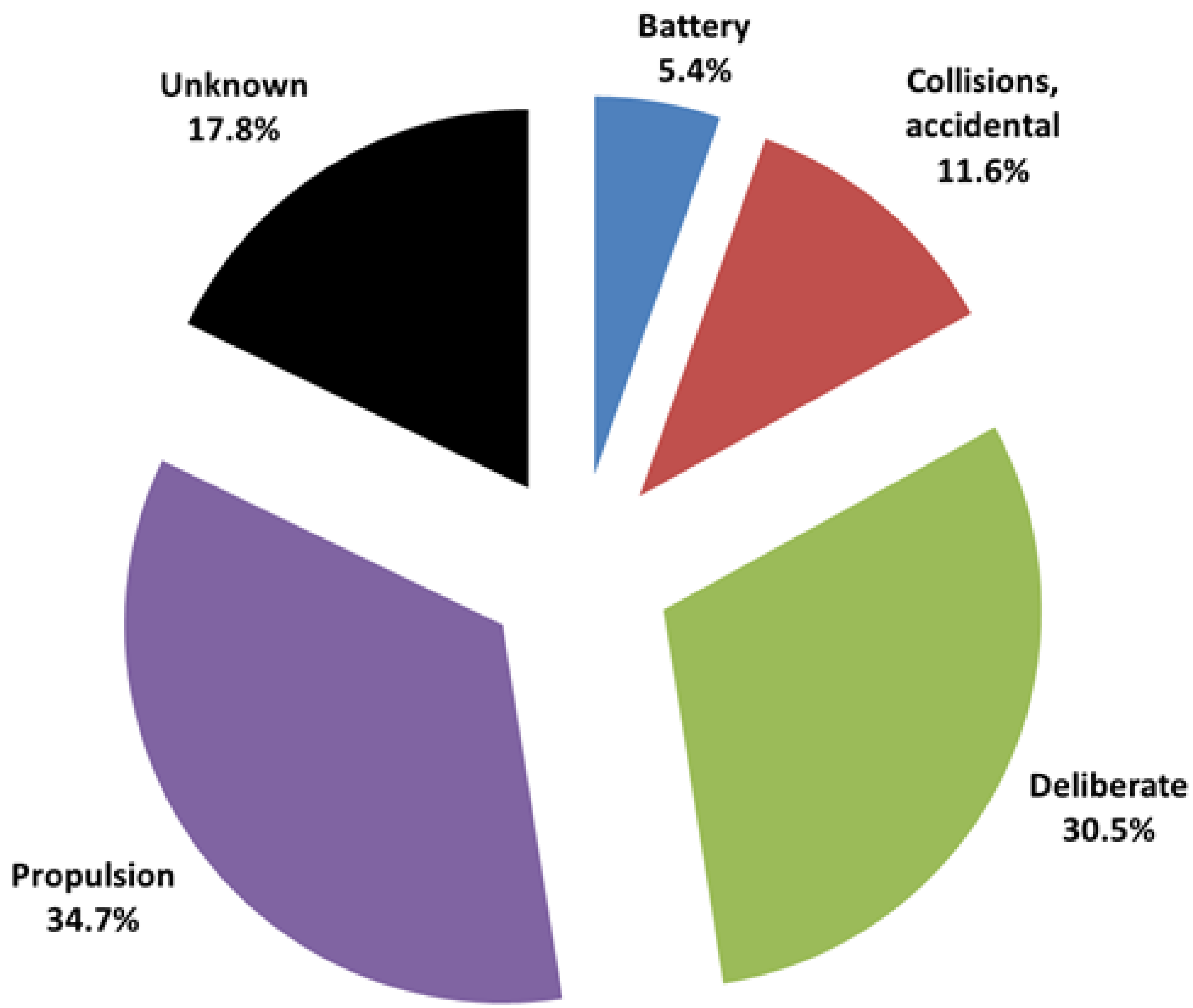
- **The primary source of larger debris (> 1 cm) is from explosive breakups of spacecraft and rocket bodies**
- **HOOSF: the NASA ODPO <u>History of On-orbit Satellite Fragmentations</u>**
  - **14th ed. published 2008**
  - **15th ed. published 2018**
  - **Four events occurred in 2018 *after* information cut-off for 15th ed.**
  - **More have already occurred in 2019**

Breakups by cause: 246 1961-date



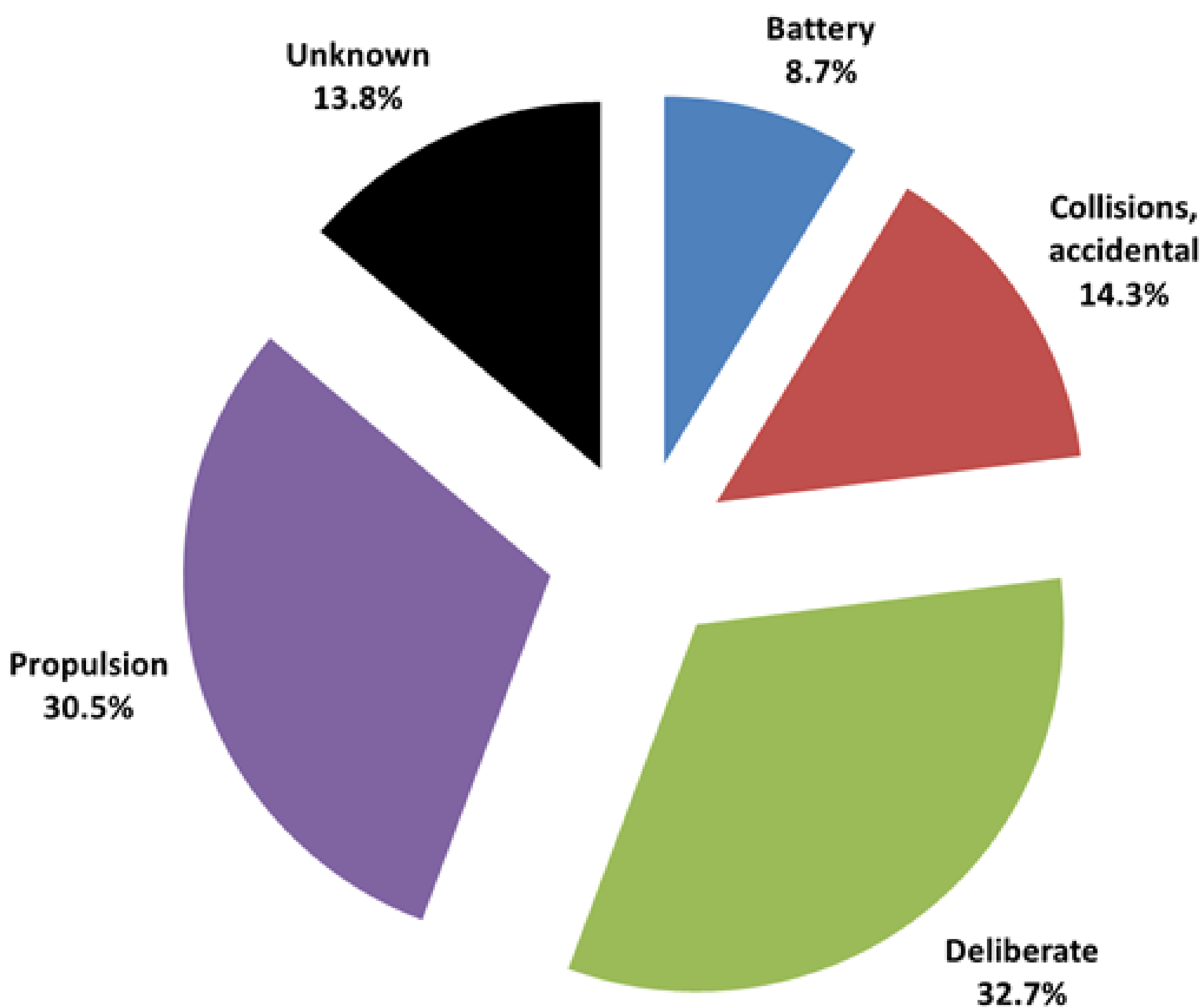
- Propulsion category accounts for majority of breakup events
- *SOZ units* are Proton 4th stage ullage motors
- When *SOZ* breakups are segregated, % of propulsion breakups equals historical deliberate breakup events
- Unknown category includes events whose root cause has not been uniquely identified or the breakup mechanism is unknown

Cataloged breakup debris, 1961-date



- Multiply by 20044, the total number of breakup debris cataloged, to get absolute number in any category
- Propulsion category accounts for majority of breakup debris cataloged
- While *SOZ* breakups typically result in few cataloged fragments, their eccentric parent orbits pose challenges to cataloging

On-orbit Cataloged breakup debris, 1961-date

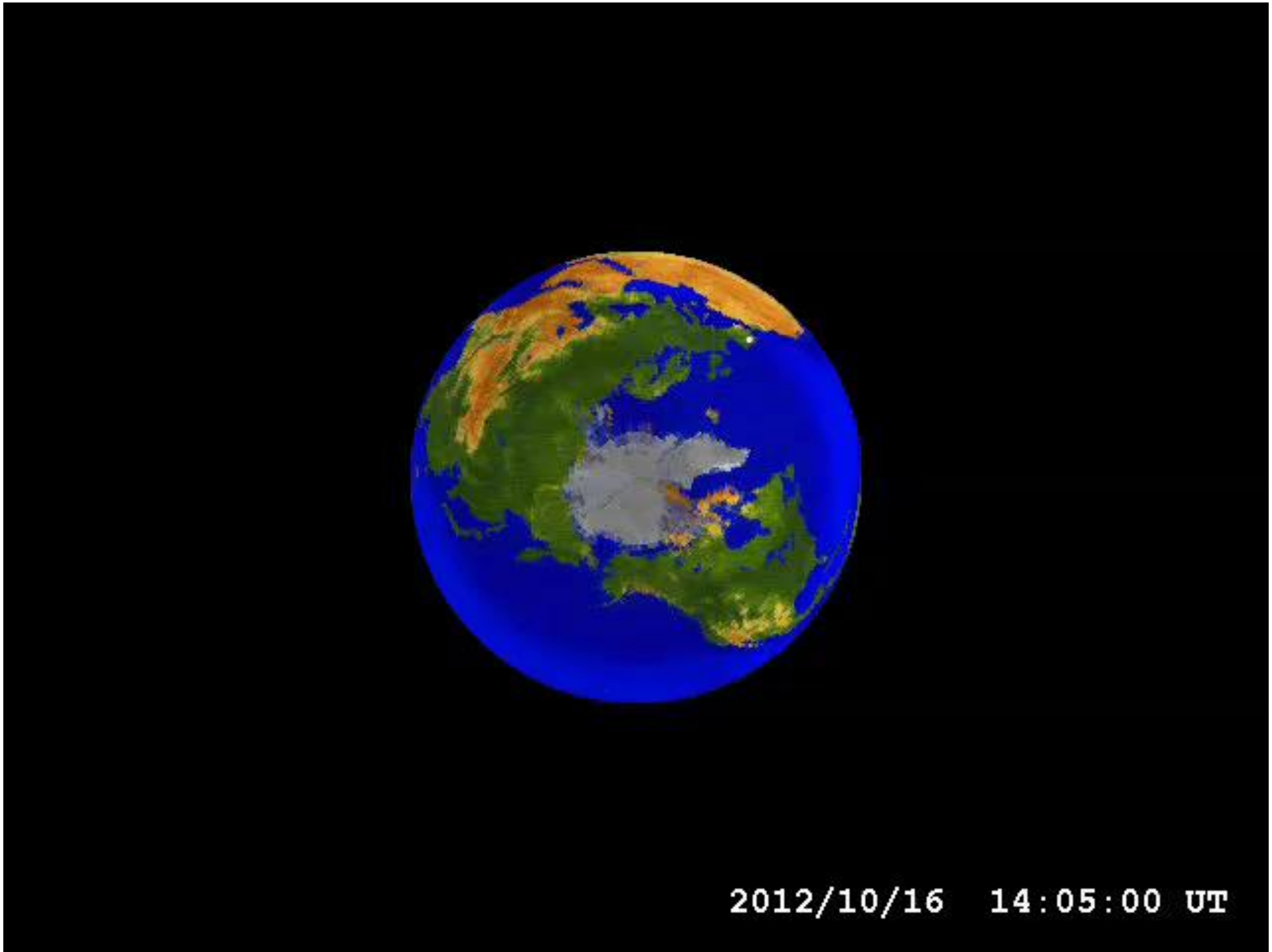


- Multiply by 9953, the total number of cataloged breakup debris *remaining on orbit*, to get absolute number in any category
- Deliberate category accounts for majority of breakup debris on orbit due to intentional FY-1C Anti-Satellite (ASAT) weapon test in 2007
- While *SOZ* breakups typically result in few cataloged fragments, their eccentric parent orbits pose challenges to cataloging

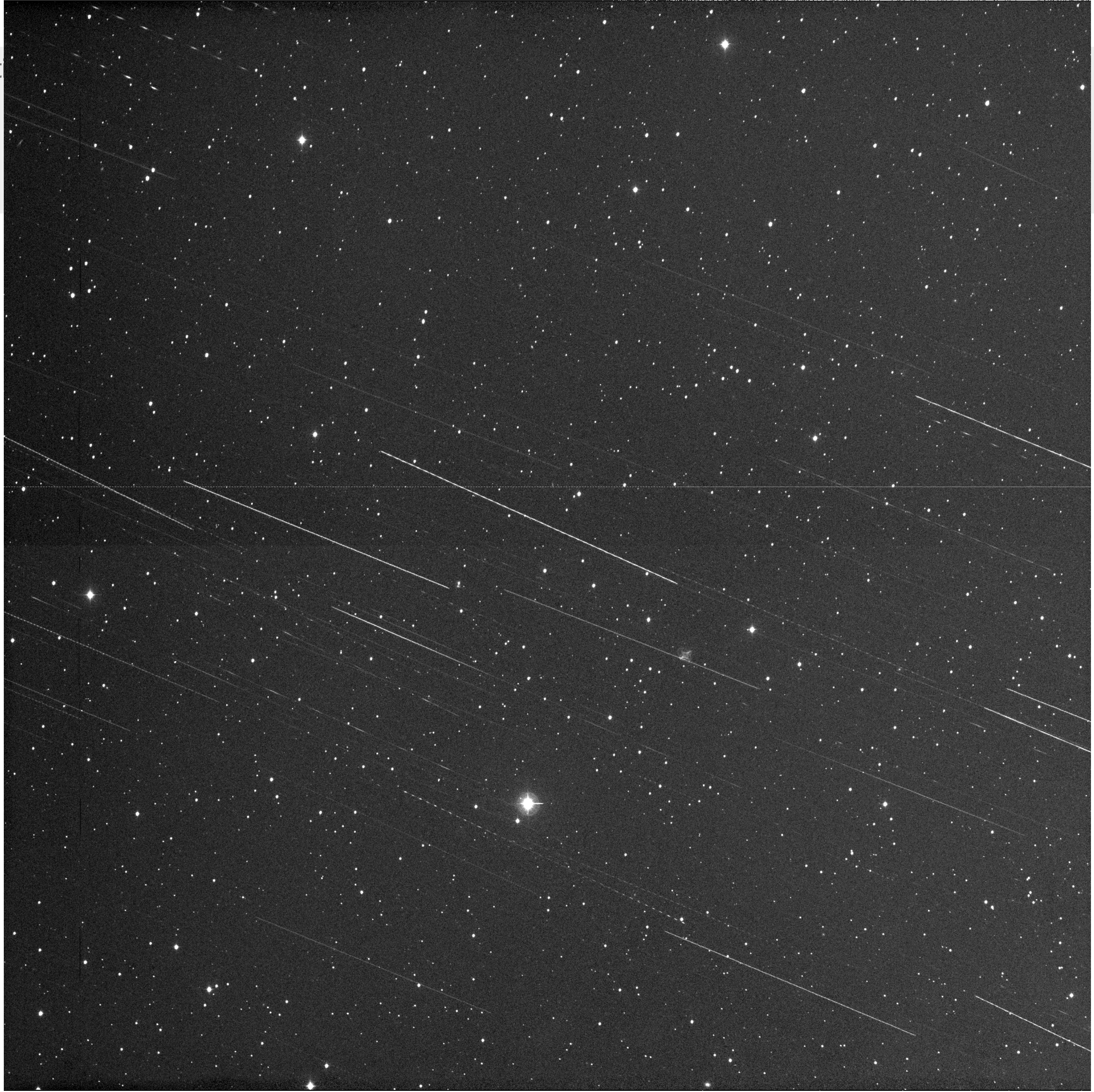
Example Breakup - BRIZ-M

- **On August 6, 2012, the Russians attempted to launch two communications satellites using a Proton rocket**
- **The BRIZ-M upper stage failed to burn properly, and was left stranded in an elliptical orbit with about 5 metric tons of its propellant still aboard**
- **On October 16, the rocket body exploded, creating at least 700 trackable pieces of debris (and probably many more too small to be tracked) in orbits that cross ISS altitude**
- **Observed by astronomers at the Siding Springs Observatory**

BRIZ-M Breakup



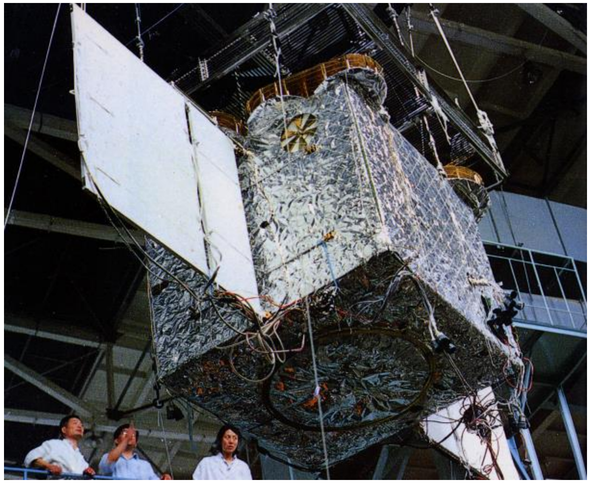
Nati



Previous Briz-M explosion – Feb 19, 2007

Rob McNaught,
Siding Springs Observatory

Chinese ASAT - 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**

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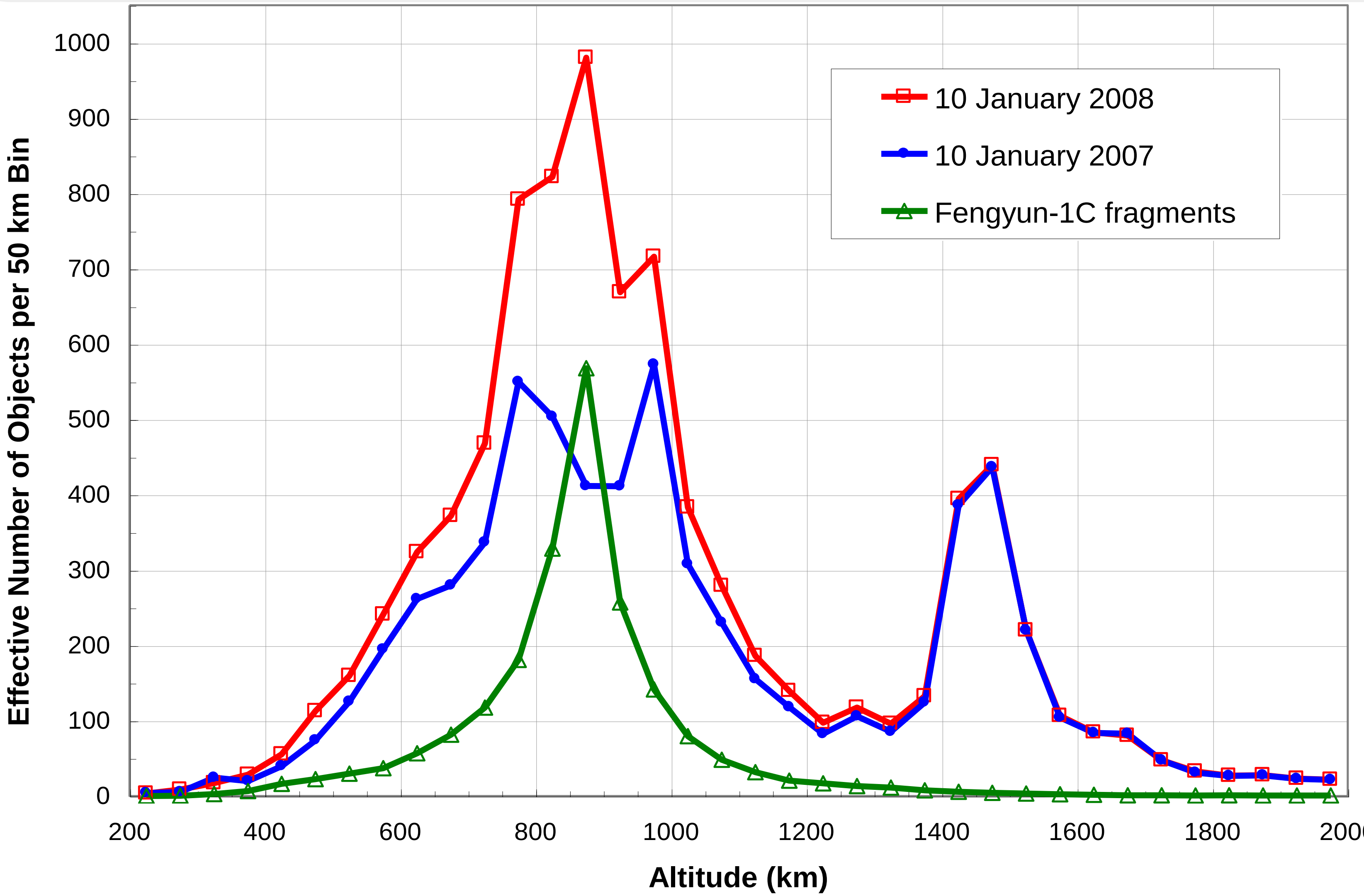
Effect of a Single Event
(Catalog Populations in LEO)



Indian ASAT

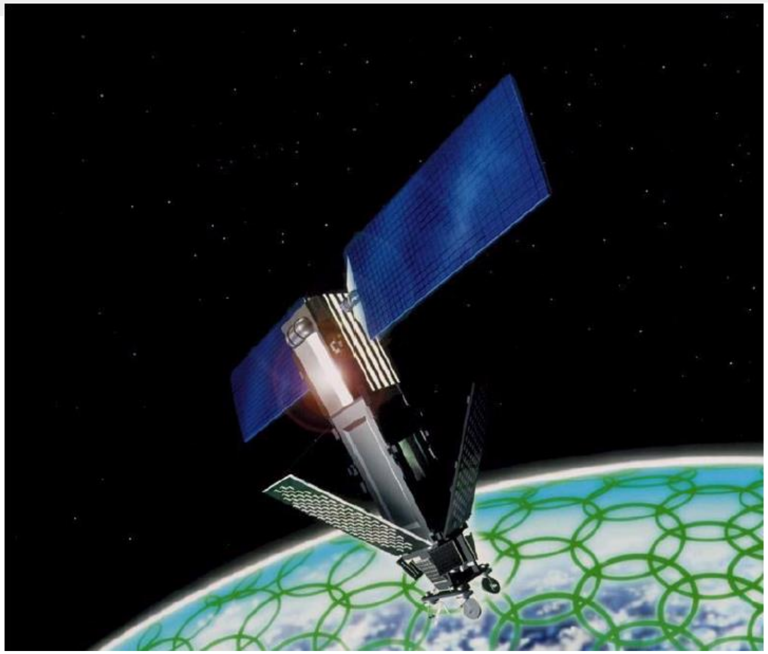
- **On March 27, 2019, Indian announced it had successfully destroyed one of its own satellites with an ASAT weapon**

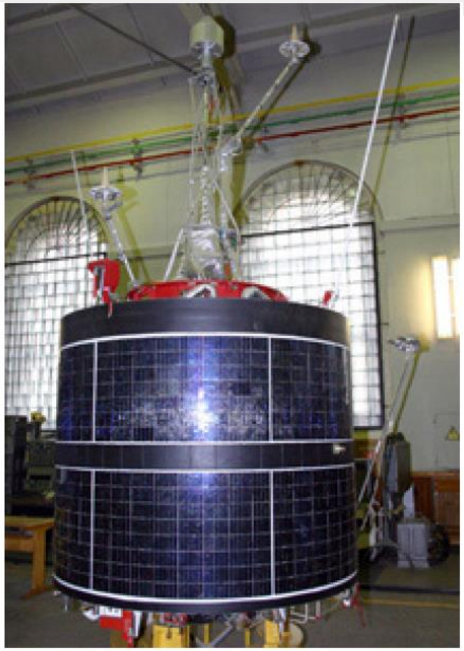
- **The target was destroyed at an altitude where most of the debris would likely reentry in a few weeks to months**

- **90 debris catalogued so far**

- **Microsat-R**
  - **96.6° inclination**
  - **291x252 km**
  - **740 kg**

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

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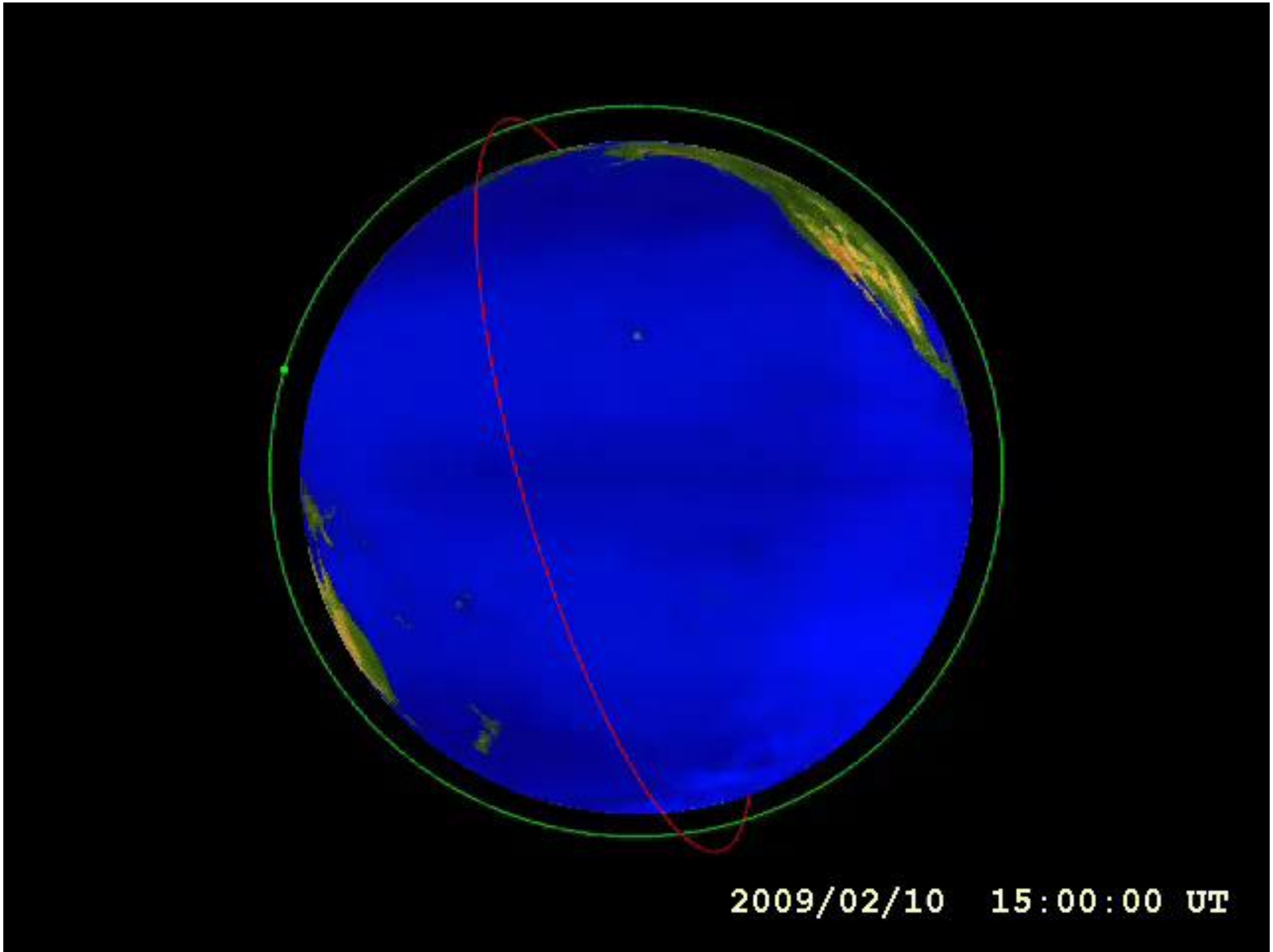
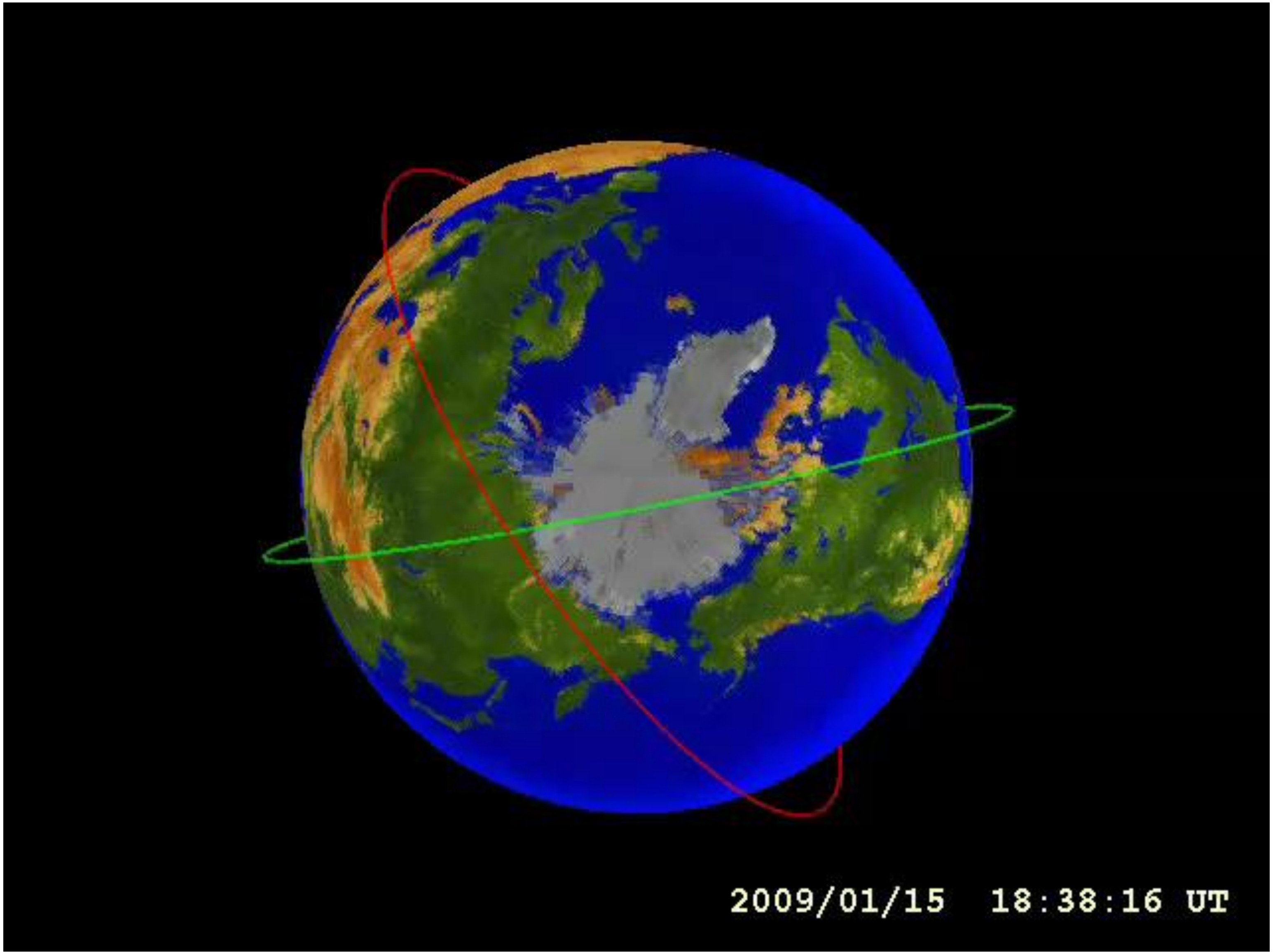
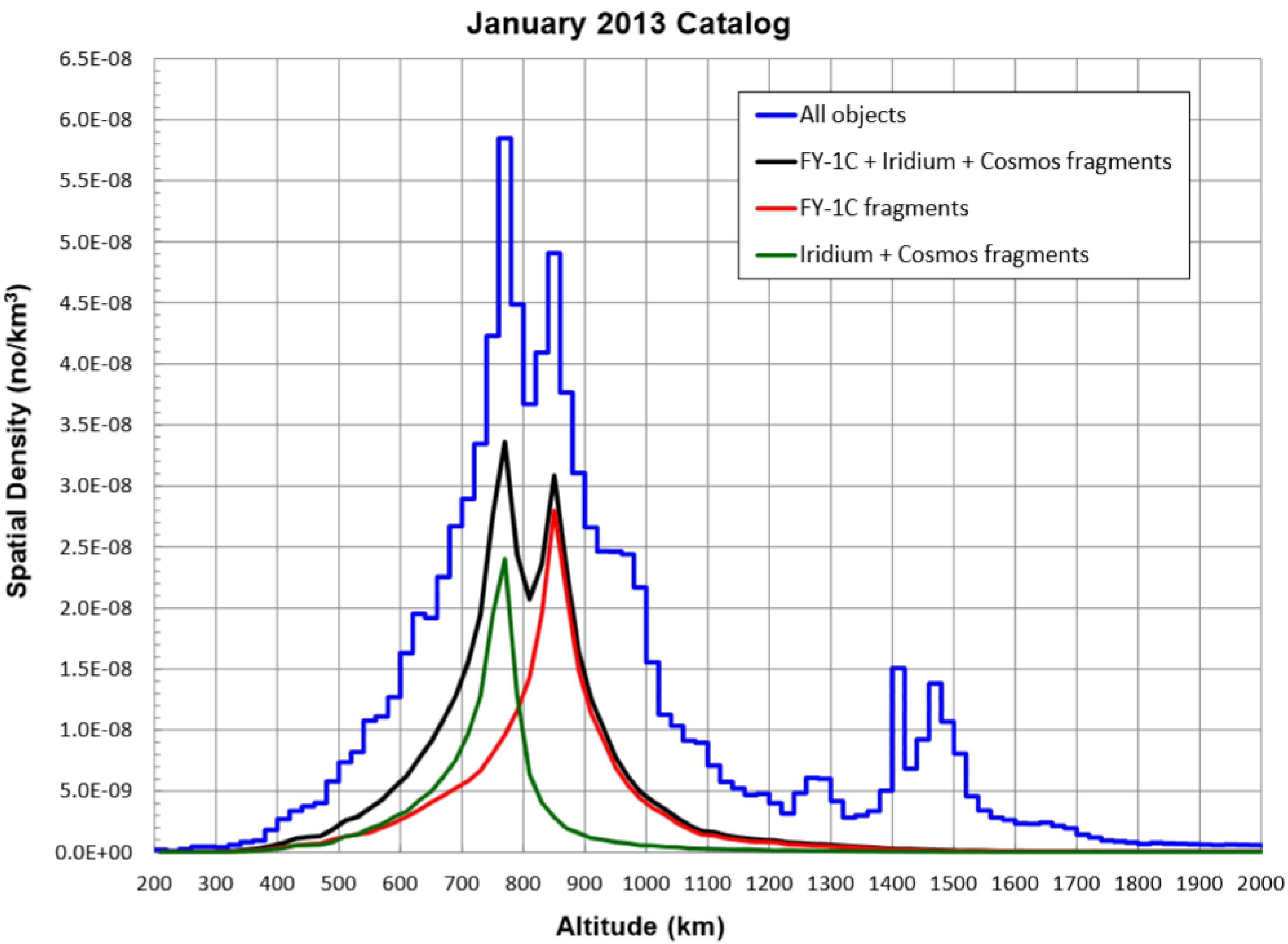
Iridium Collision



Iridium Collision



Effect of Collision on Catalog



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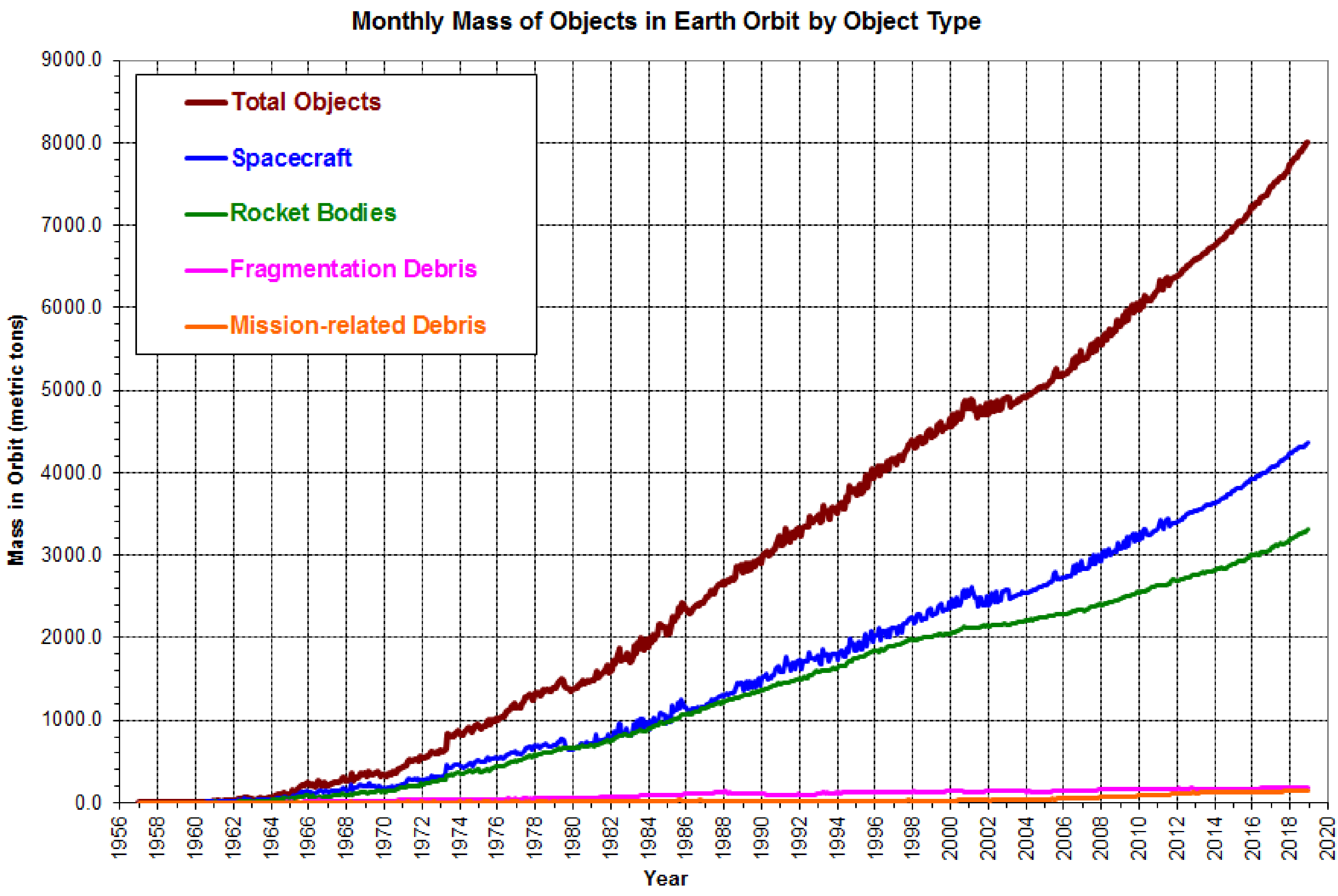
Evolution of the Catalogued (>10 cm) Satellite Population by Mass



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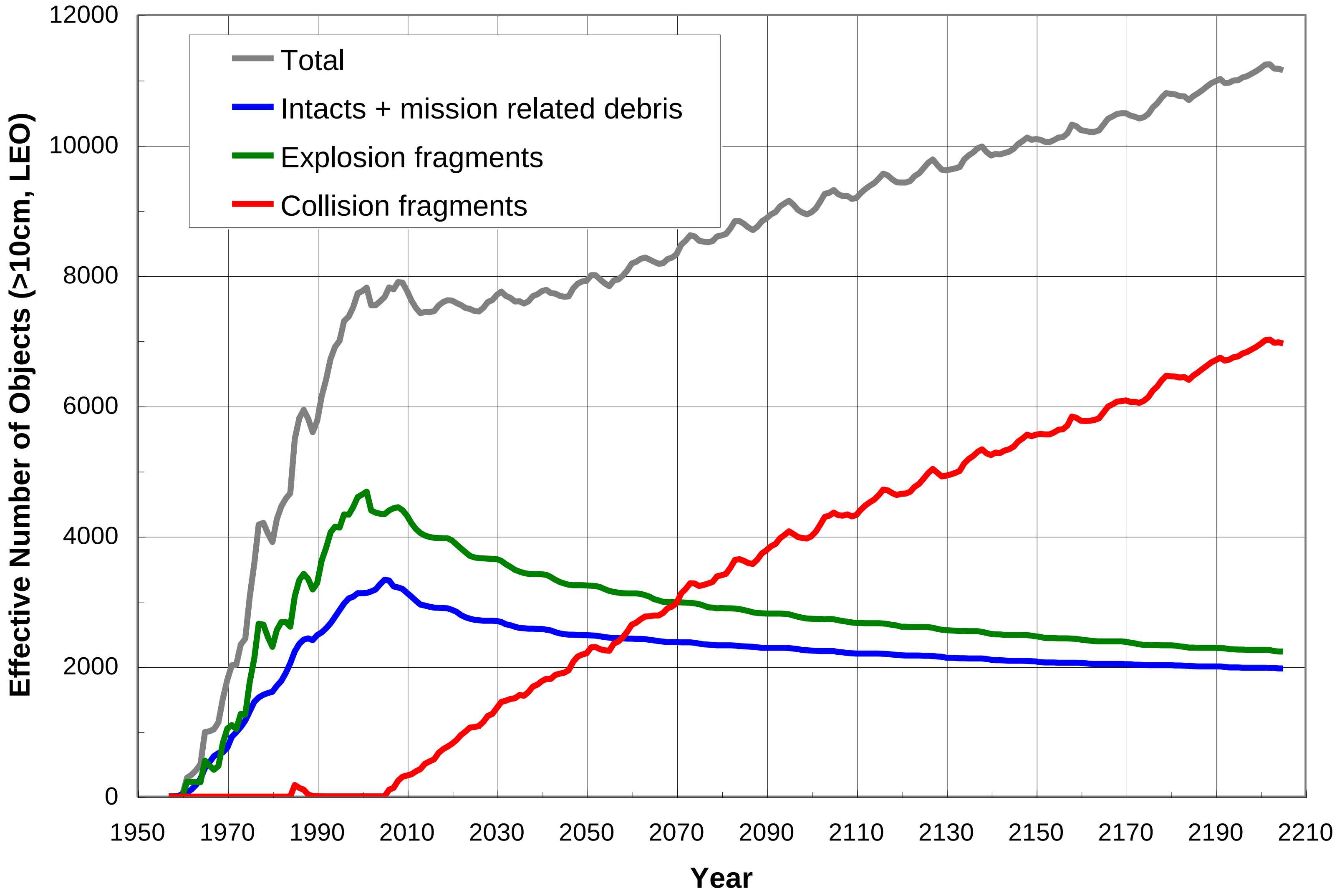
Growth with no future launches
Kessler Syndrome



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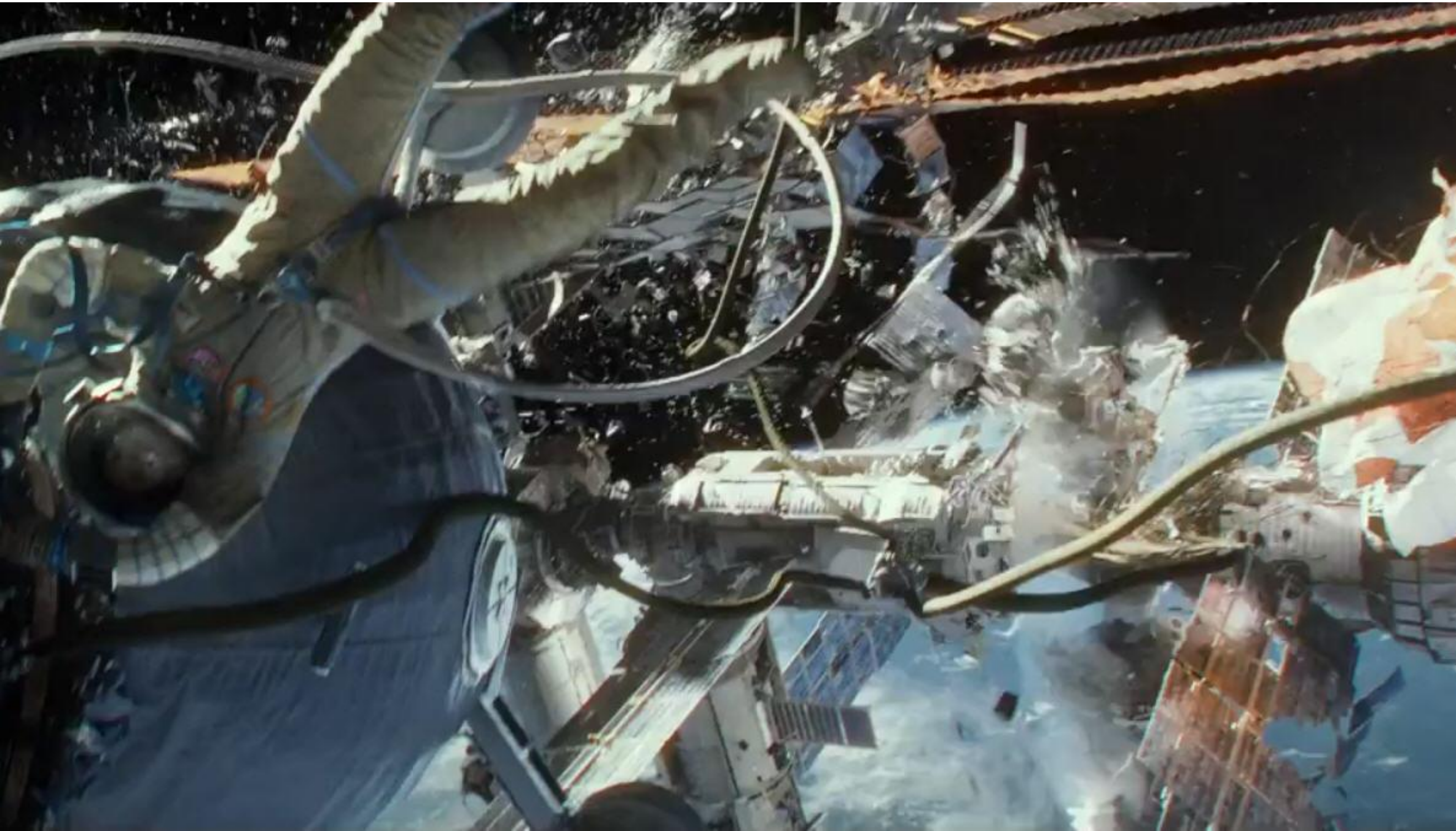
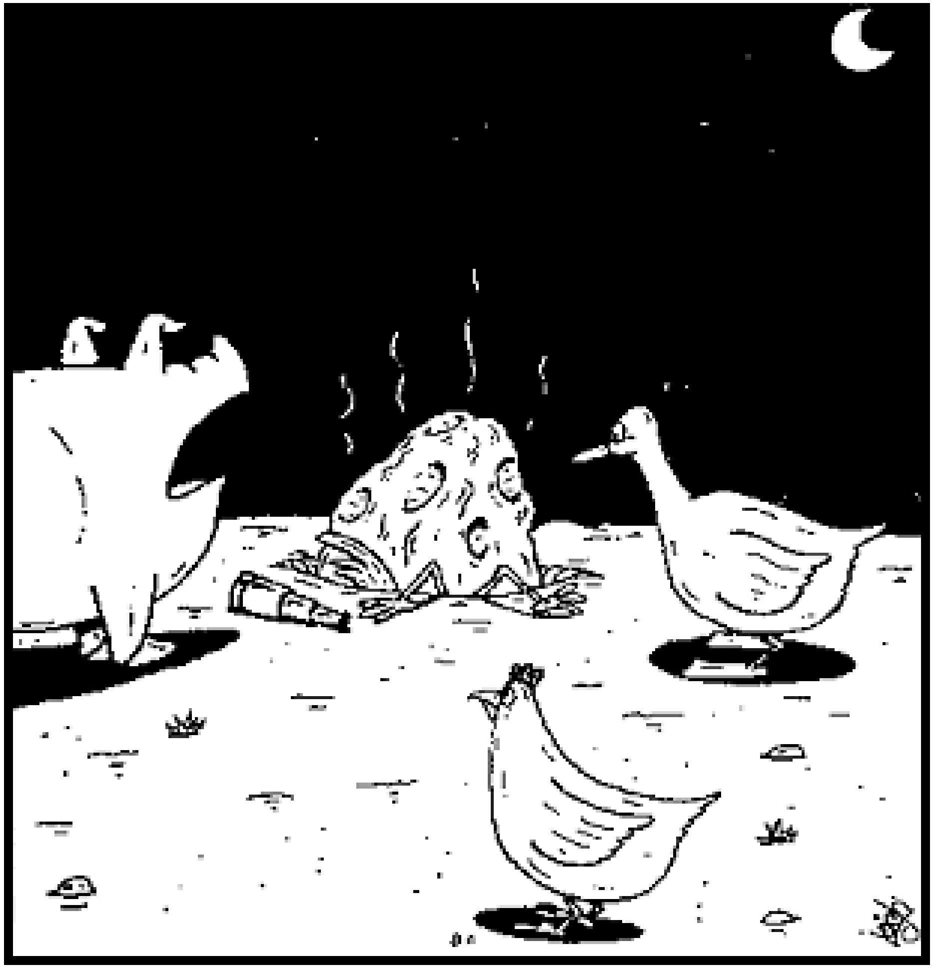
Gravity



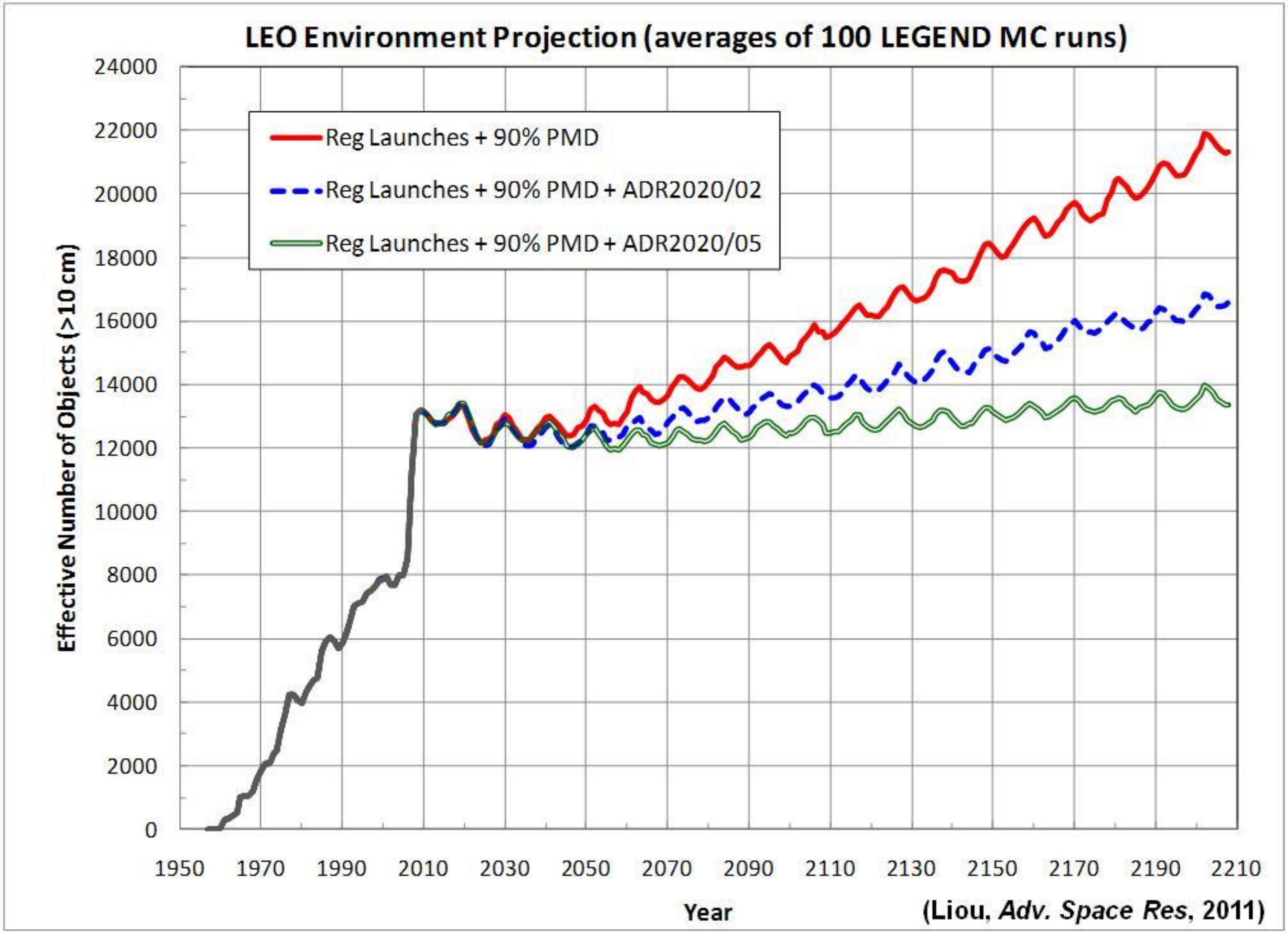
Gravity

Rubes

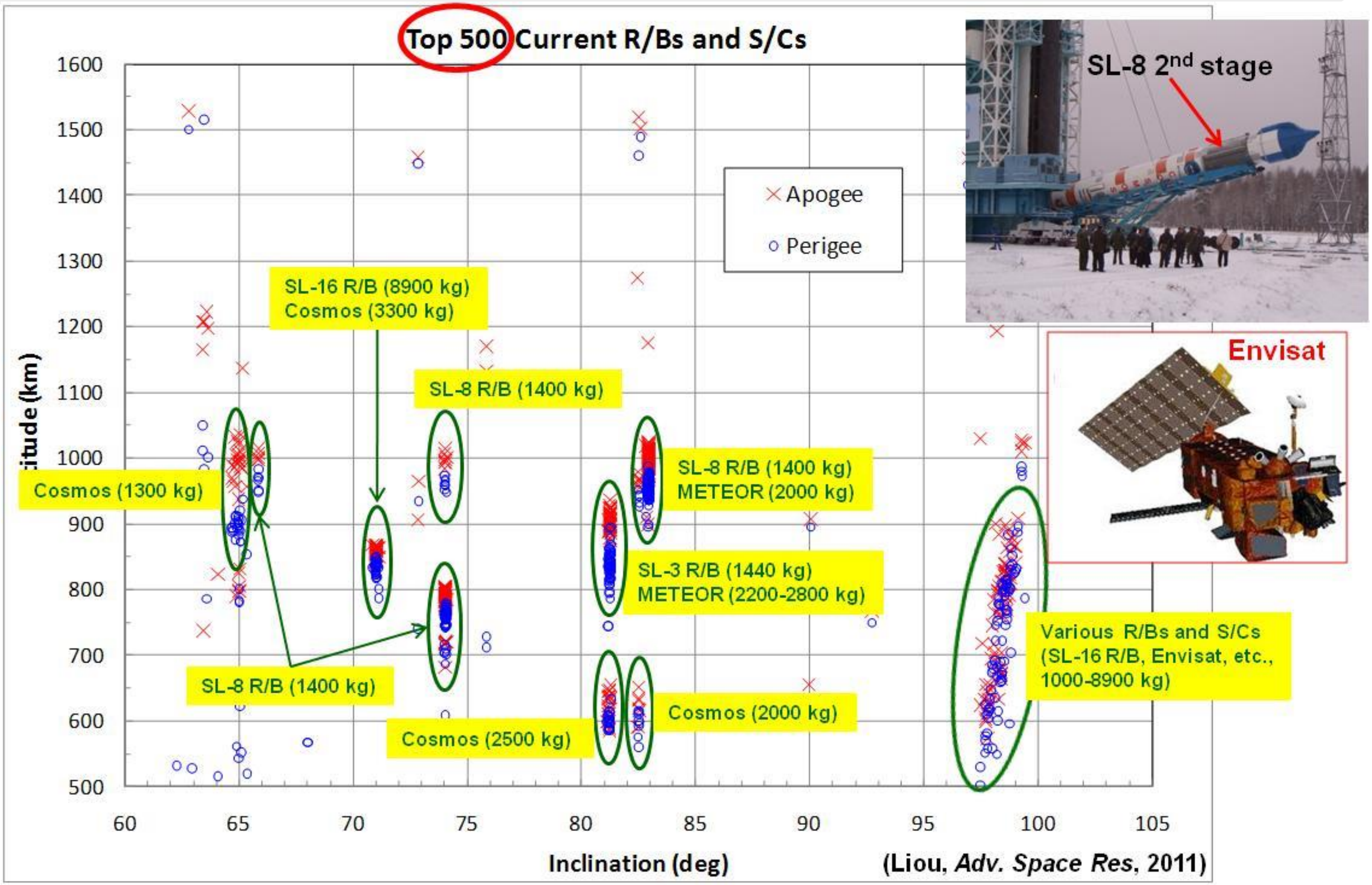


"Well, I'll be ... I guess the little chicken was right."

Fix the Problem? – Remove Mass

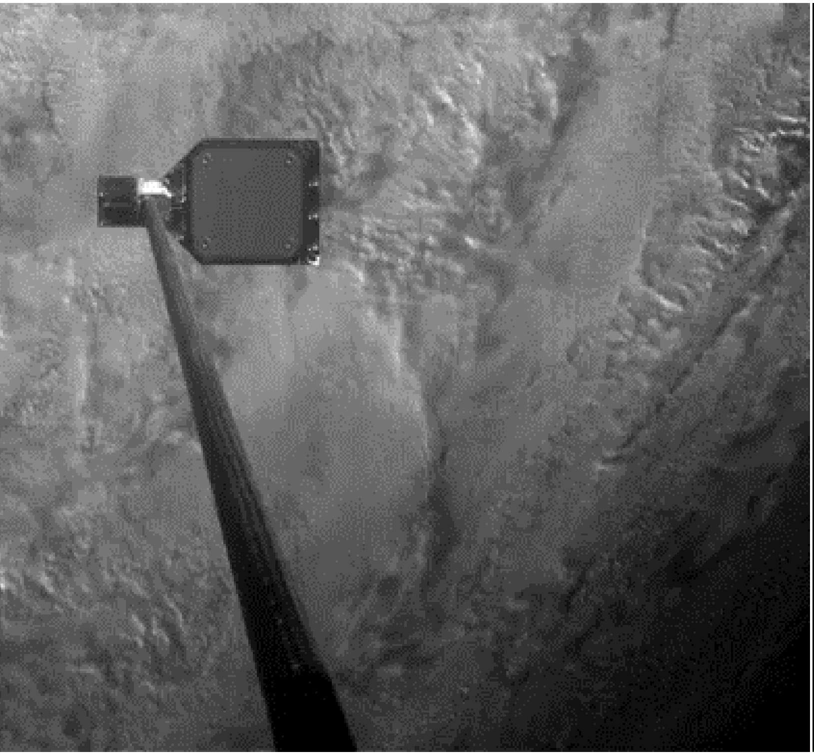


Highest Mass Objects



Active Debris Removal

- **ESA has begun experimenting with technologies that might be used for active debris removal**



Active Debris Removal - 1965 (!)

Active Debris Removal – 2019?

Inter–Agency Space Debris Coordination Committee

- **The Interagency Space Debris Coordination Committee (IADC) is composed of subject matter experts from 13 spacefaring nations, who meet together annually and address technical and policy issues**

- **Space Debris is a regular topic at the UN's Committee on the Peaceful Uses of Outer Space (COPUOS)**

- **NASA has worked closely with the US government, IADC, and UN to come up with non-binding (but taken seriously nevertheless) "guidelines" for what a "good citizen" does in space:**
  - **Don't make any messes you can't clean up – do not create lots of long-lived debris**
  - **Clean up after yourself – make sure to remove satellites and rocket bodies from busy regions of space within 25 years after end of use and passivate them so they don't explode later**
  - **Don't hurt anyone – design your spacecraft and/or mission profile to minimize risk to other missions and people on the ground**

Conclusions

- **Monitoring the Earth space environment is critical**
  - **SSN catalog insufficient to characterize all debris**
  - **Environment is dynamic – even if we get it right today, it will change tomorrow**

- **With the loss of the Space Shuttle, new *in situ* data sources are needed to understand the small particle environment**

- **Models provide spacecraft designers and operators with tools to be able to make informed decisions about the safety of their space activities**

- **Models provide policy makers with tools to be able to make informed decisions about guidelines and regulations concerning space activities**

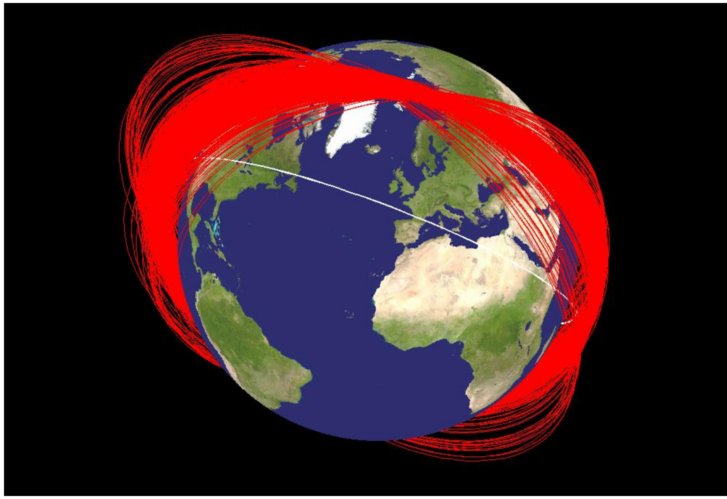
- **However, models are only as good as the assumptions made and the quality of the data behind them**

Challenges Remain

- **Adherence to national and international orbital debris mitigation guidelines is essential if the debris population is to be controlled**

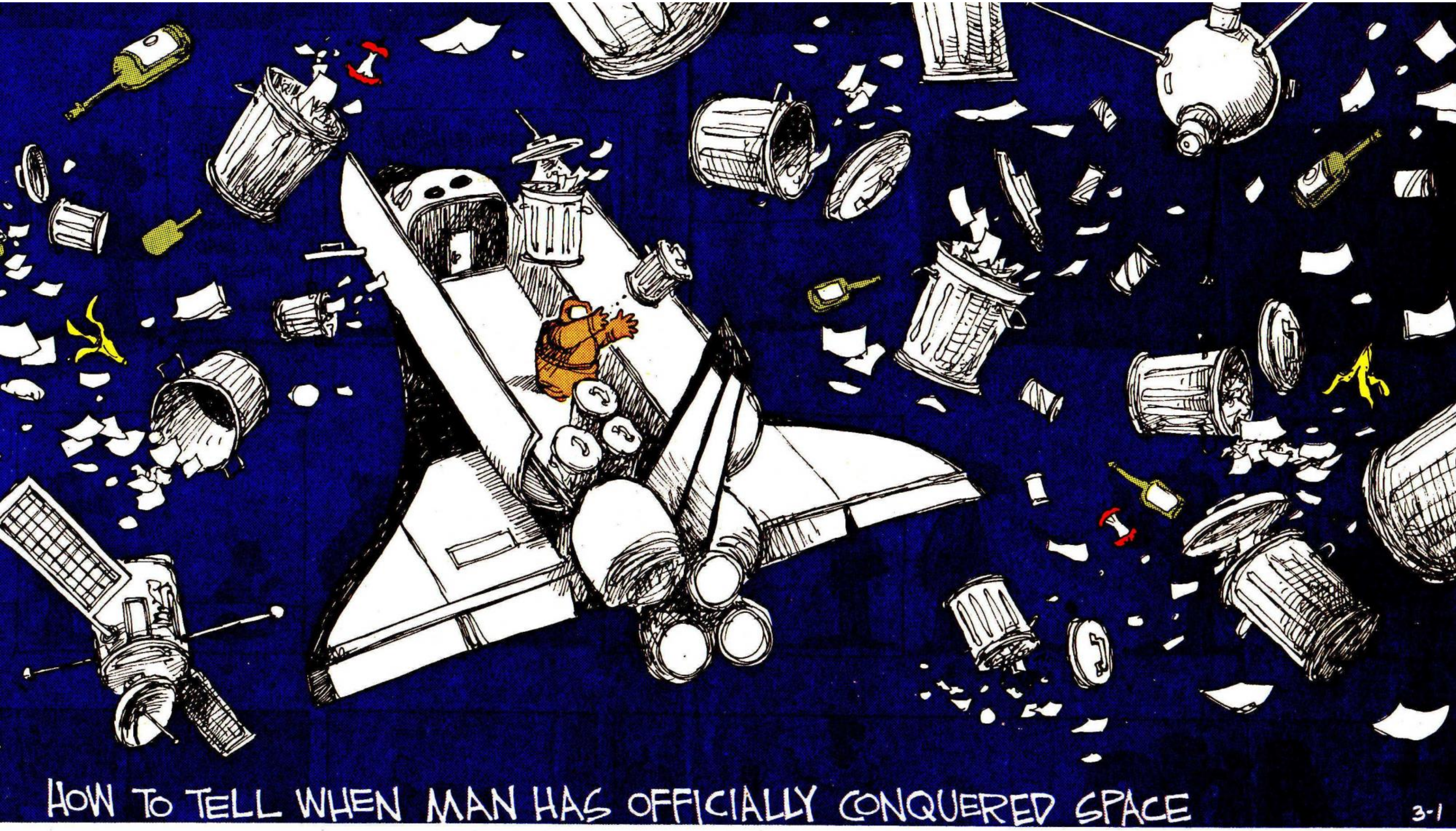
- **Despite efforts to reduce accidental explosions of spacecraft and rocket bodies, such events continue to have dramatic effects in near-Earth space**

- **The deliberate testing of an anti-satellite weapon at high altitude 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 come



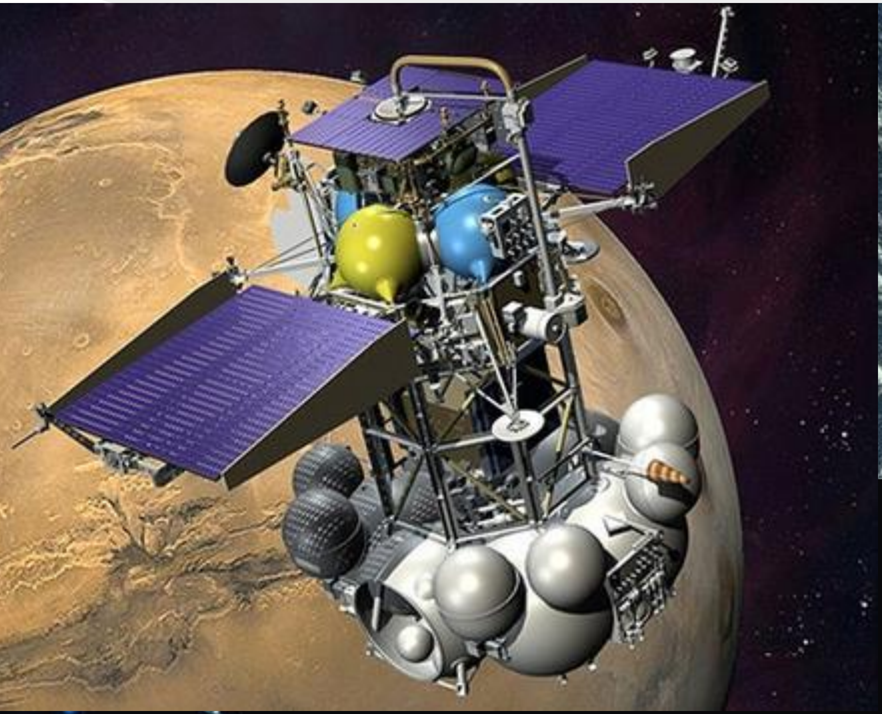
- **The accidental 2009 collision is only the harbinger – collisions are expected to become more common in the future**
  - Growing consensus that we may have to be more proactive in removing large debris

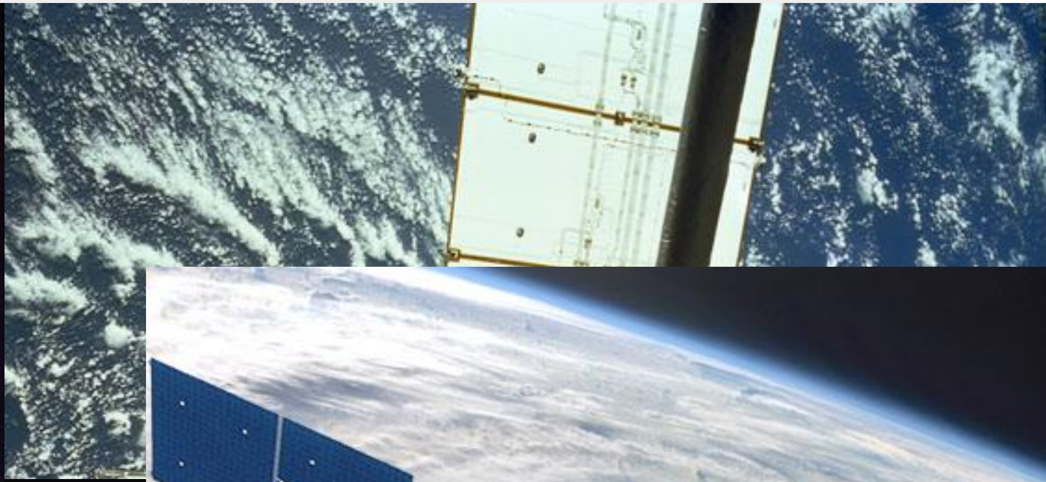
Questions?



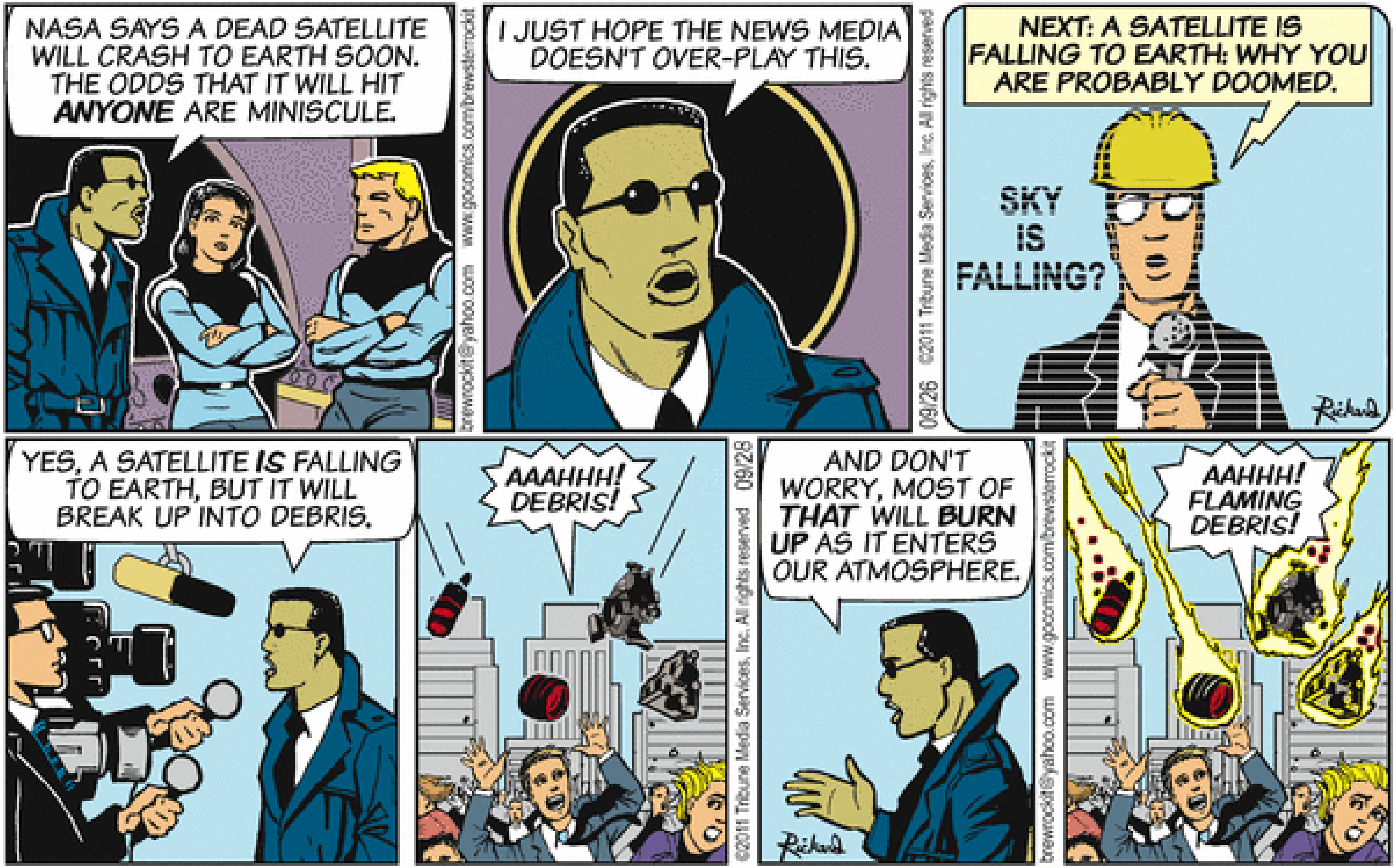
Backups

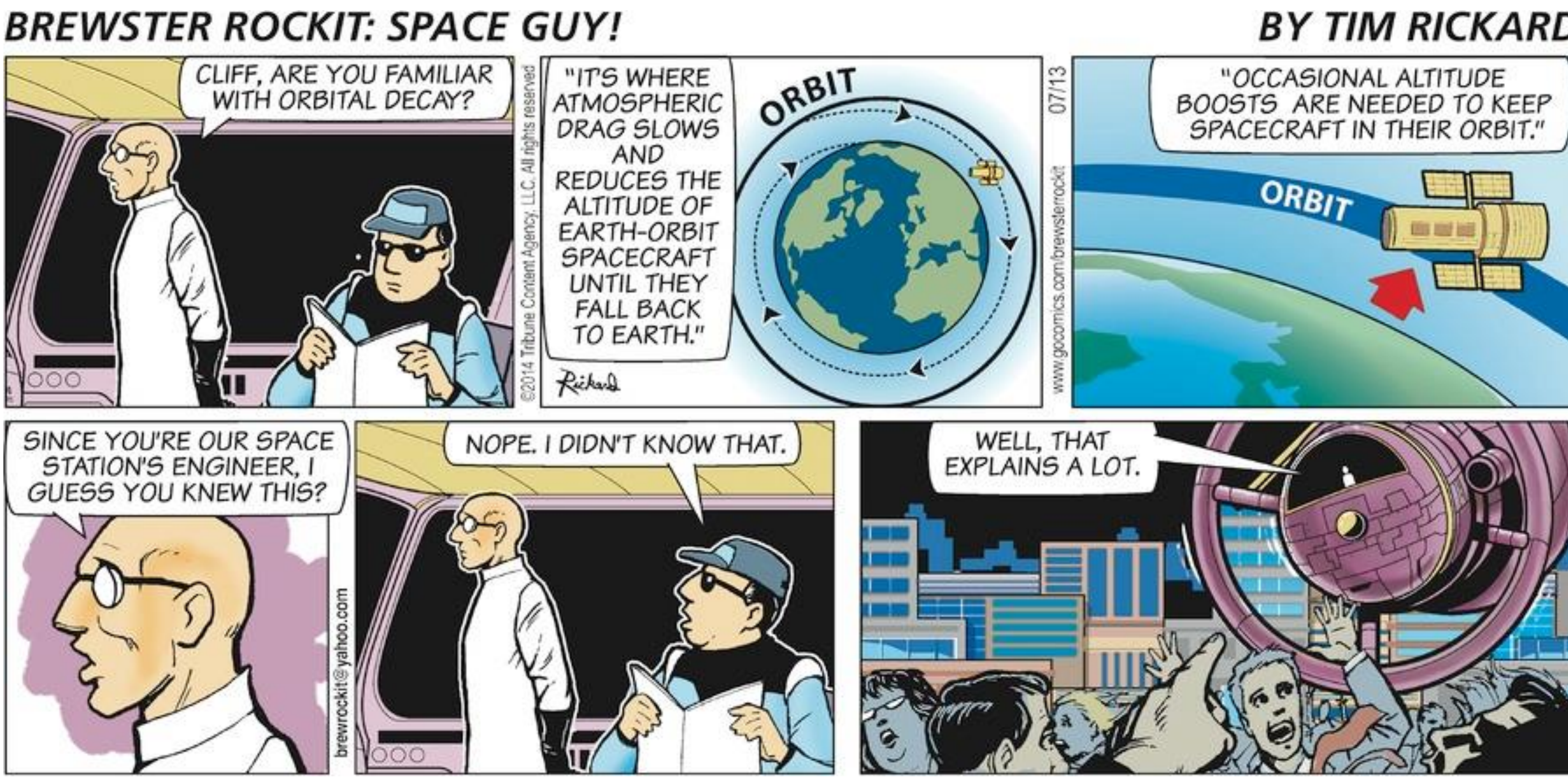
Recent Reentries
UARS, ROSAT, Phobos-Grunt, TRMM





UARS Reentry in the Popular Imagination




BREWSTER ROCKIT: SPACE GUY!
BY TIM RICKARD
CLIFF, ARE YOU FAMILIAR WITH ORBITAL DECAY?
"IT'S WHERE ATMOSPHERIC DRAG SLOWS AND REDUCES THE ALTITUDE OF EARTH-ORBIT SPACECRAFT UNTIL THEY FALL BACK TO EARTH."
ORBIT
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07/13
www.gocomics.com/brewsterrockit
"OCCASIONAL ALTITUDE BOOSTS ARE NEEDED TO KEEP SPACECRAFT IN THEIR ORBIT."
ORBIT
SINCE YOU'RE OUR SPACE STATION'S ENGINEER, I GUESS YOU KNEW THIS?
brewrockit@yahoo.com
NOPE. I DIDN'T KNOW THAT.
WELL, THAT EXPLAINS A LOT.

That Which Survives…

Texas, 1997

South Africa, 2000

Zimbabwe, 2013

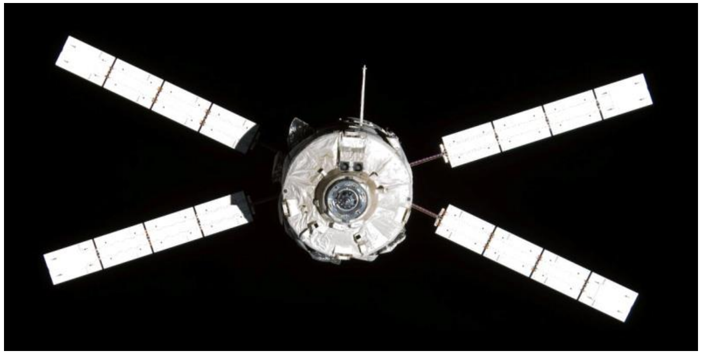
Guatemala, 2003

Argentina, 2004

Saudi Arabia, 2001

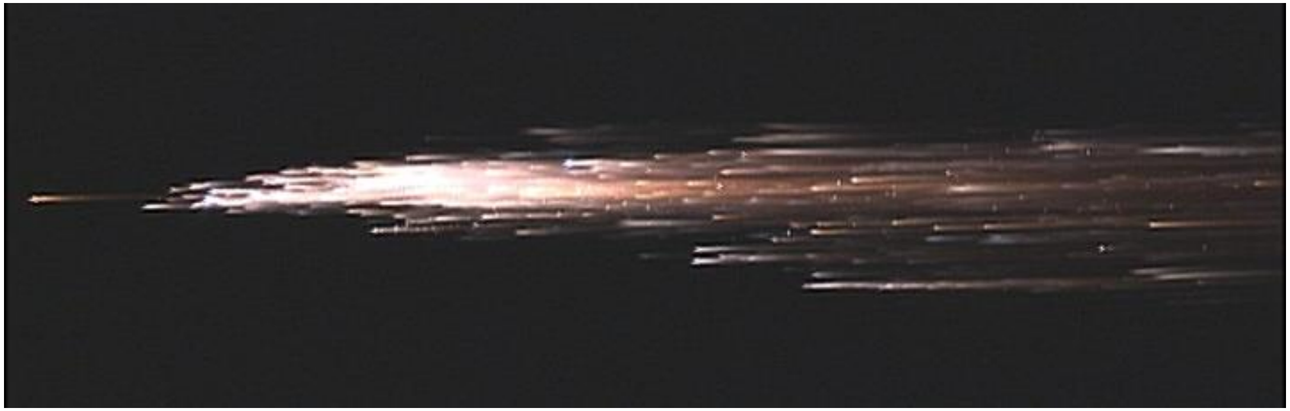
Reentry of the Jules Verne ATV

- **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.**

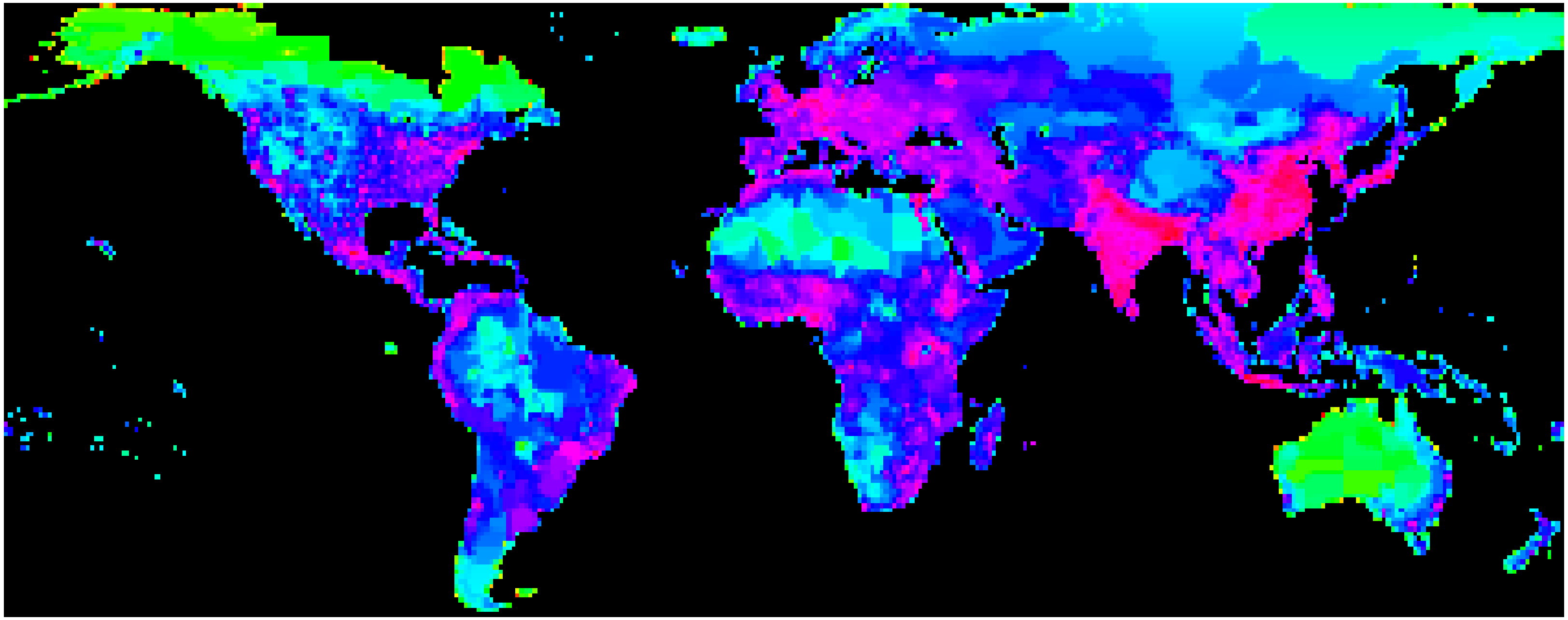


Jules Verne undocking on 5 September 2008

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

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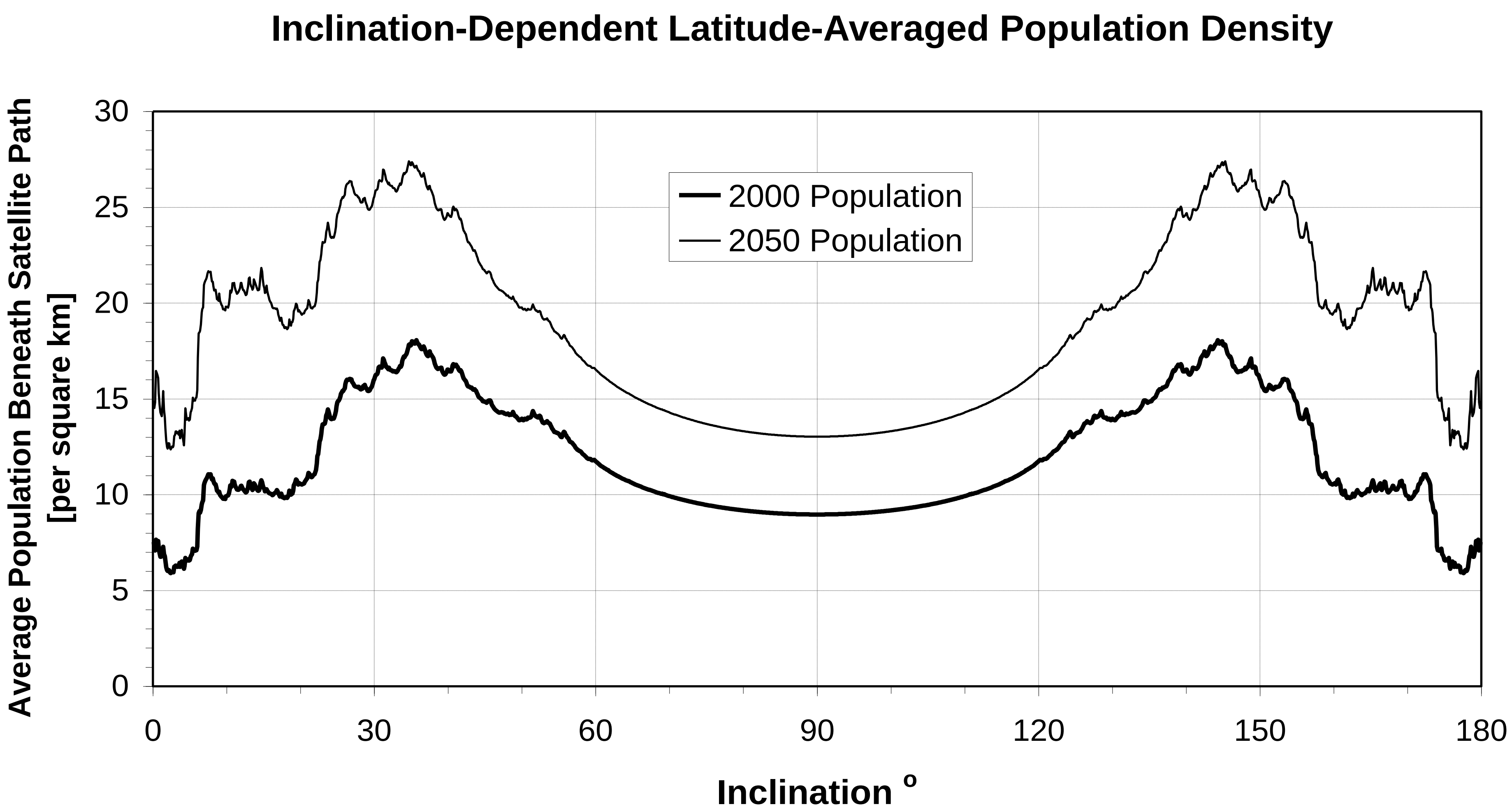
Average Density of People Below Satellite Path



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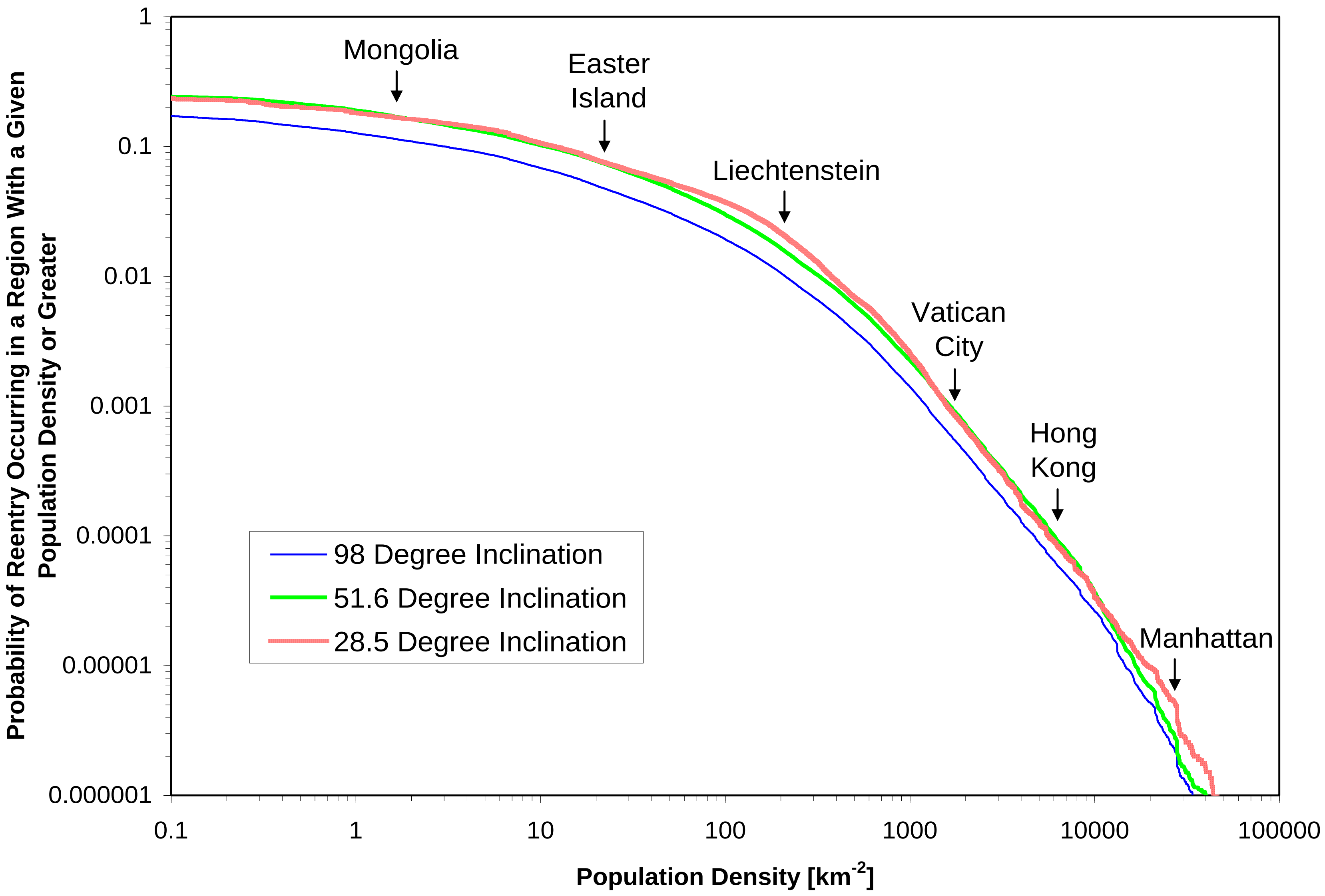
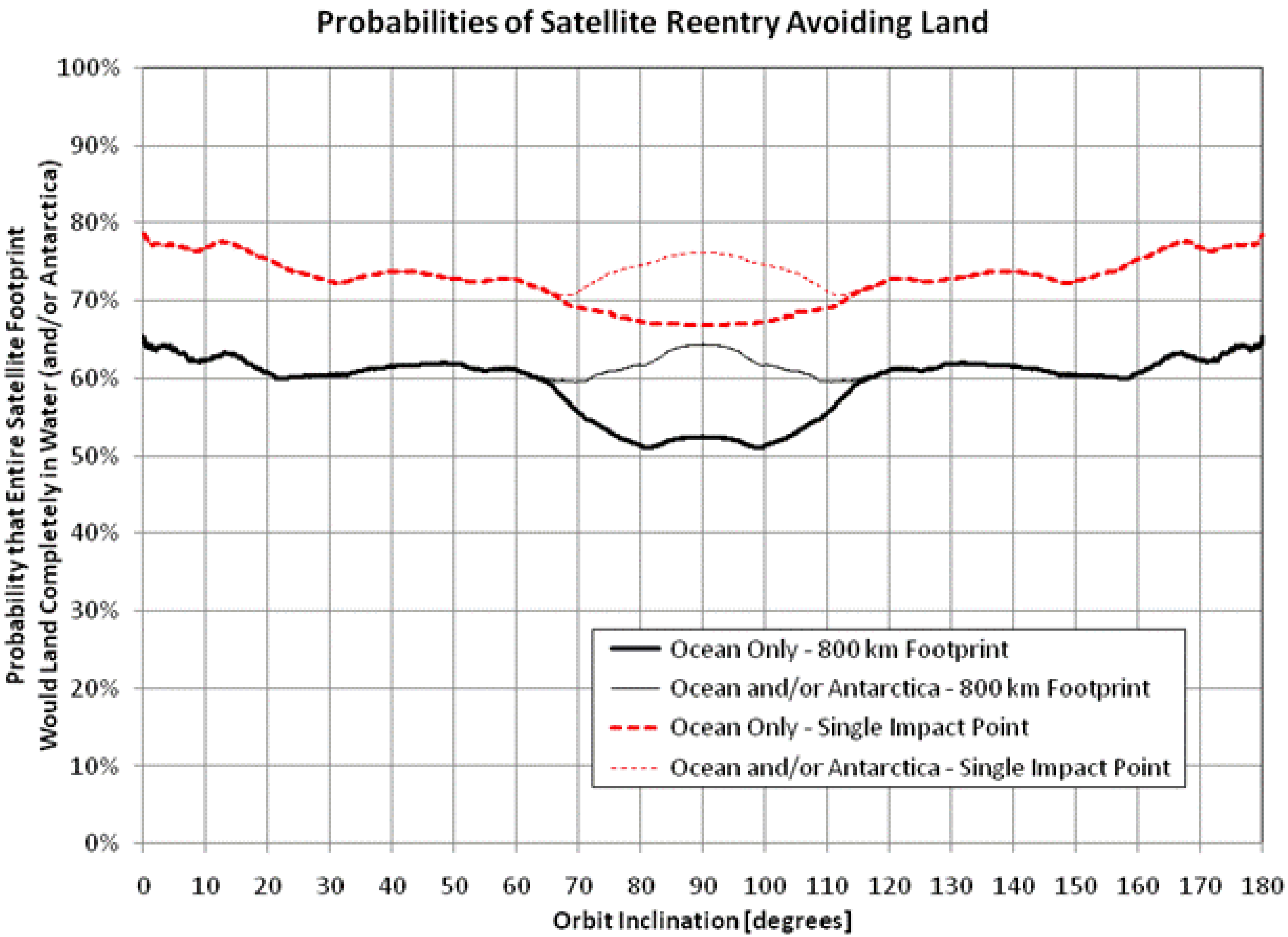
Probability of Falling in Populated Areas



National Aeronautics and Space Administration

Probability of Ocean Reentry



Brewster Rockit on Reentry Risks