National Aeronautics and Space Administration

Measuring small debris – what you can't see can hurt you

Mark Matney, Ph.D.

Orbital Debris Program Office

NASA Johnson Space Center

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

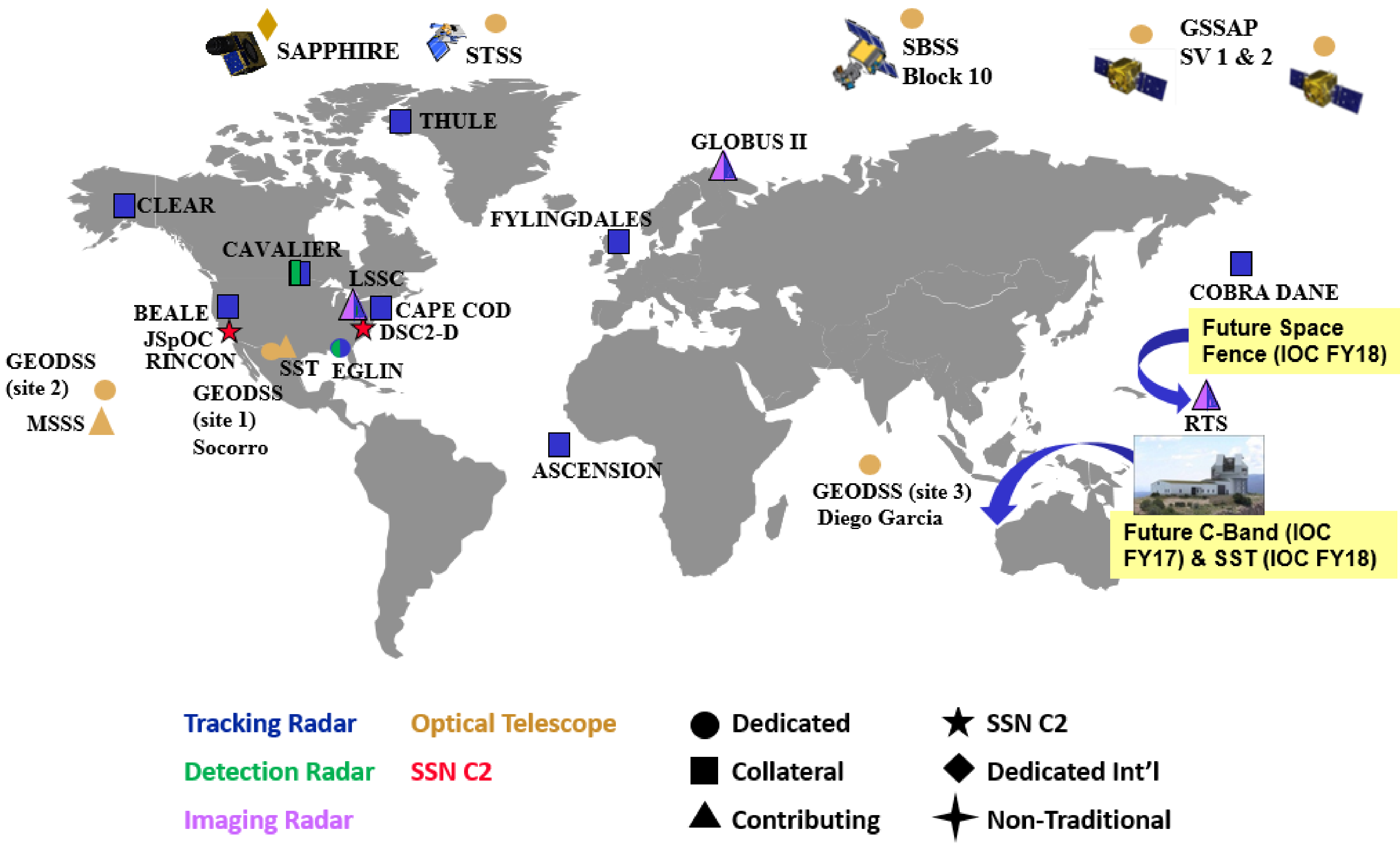
Brewster Rockit on Debris Sources

SSN

- **Almost all 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**

Space Surveillance Network



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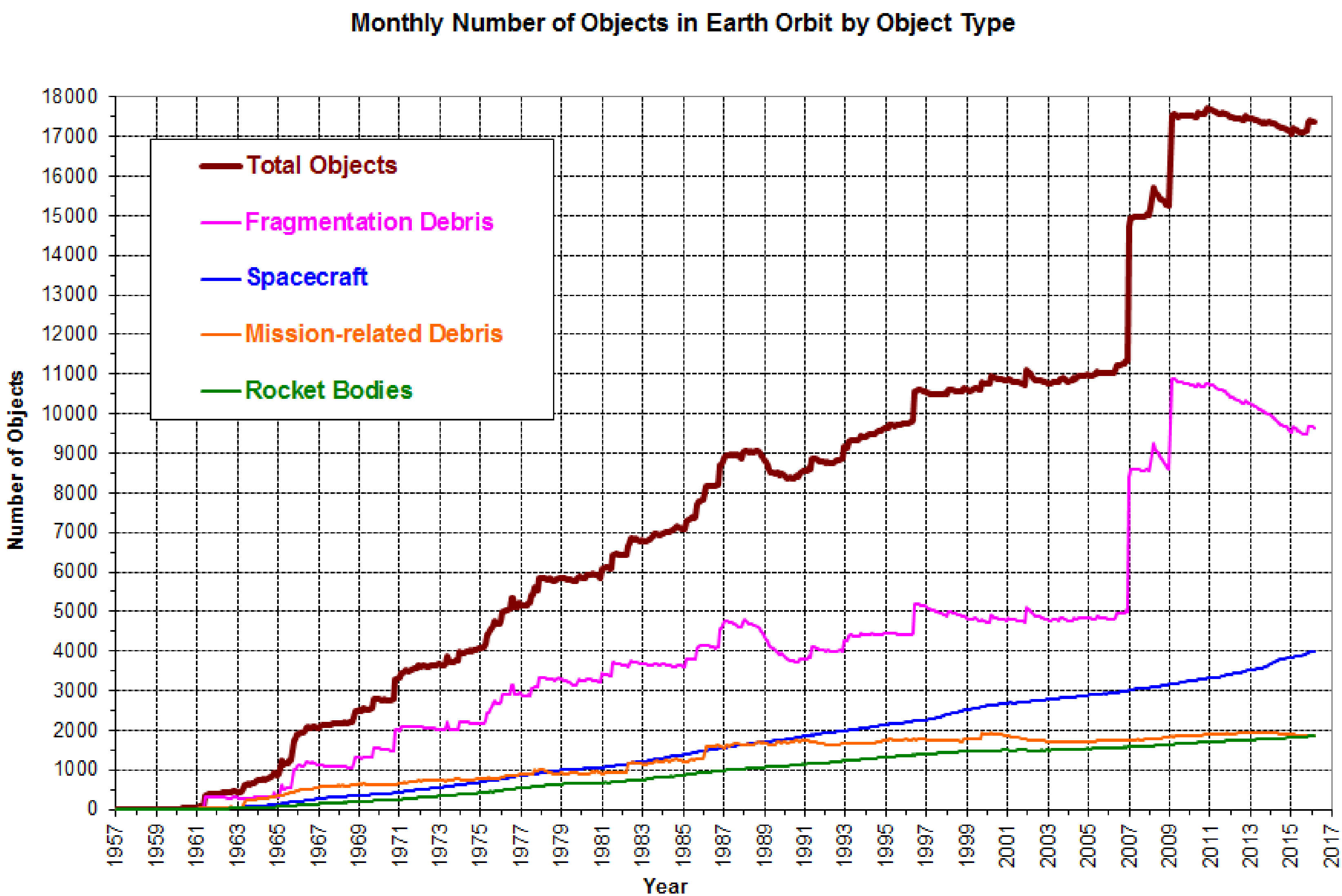
Evolution of the Cataloged Satellite Population



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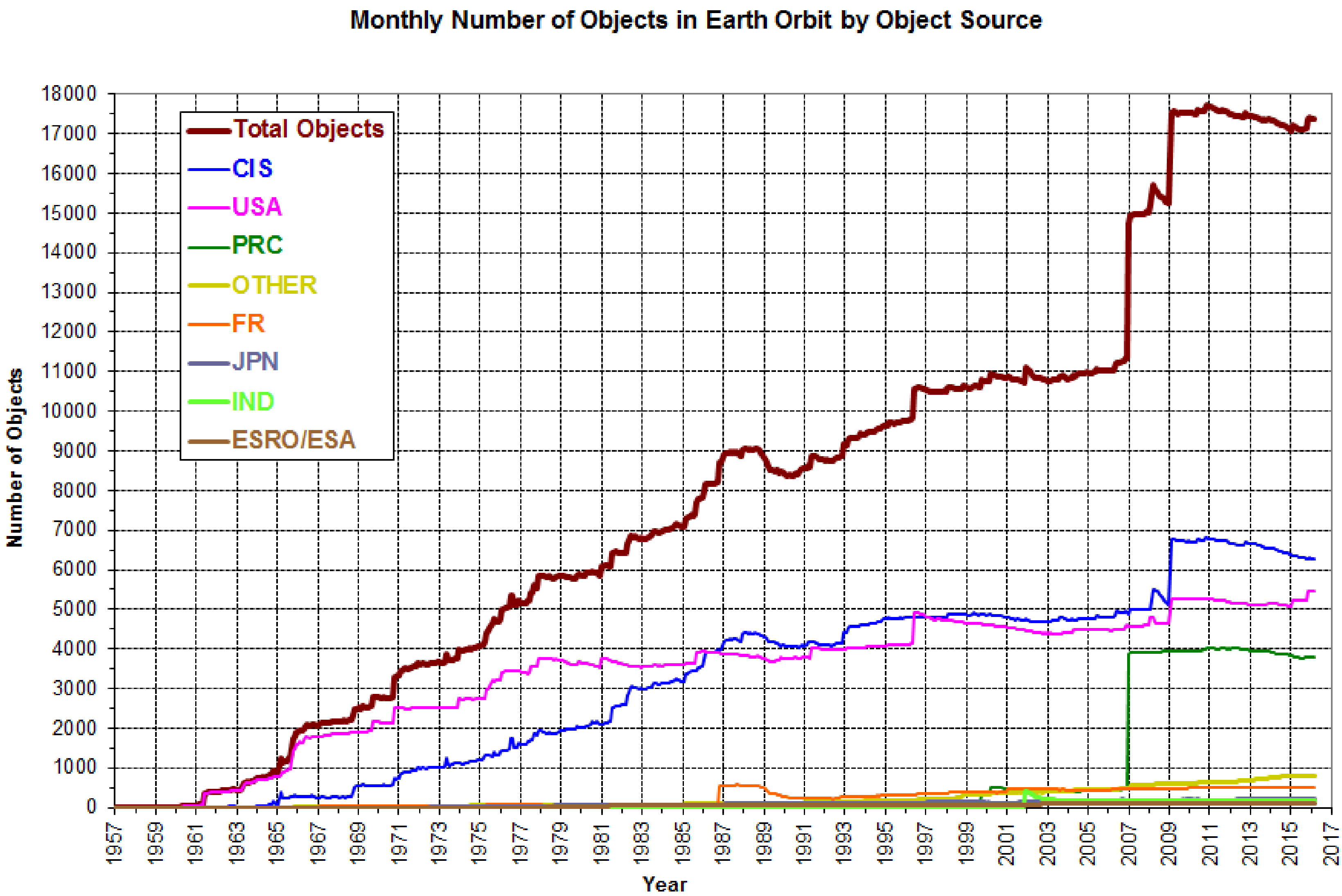
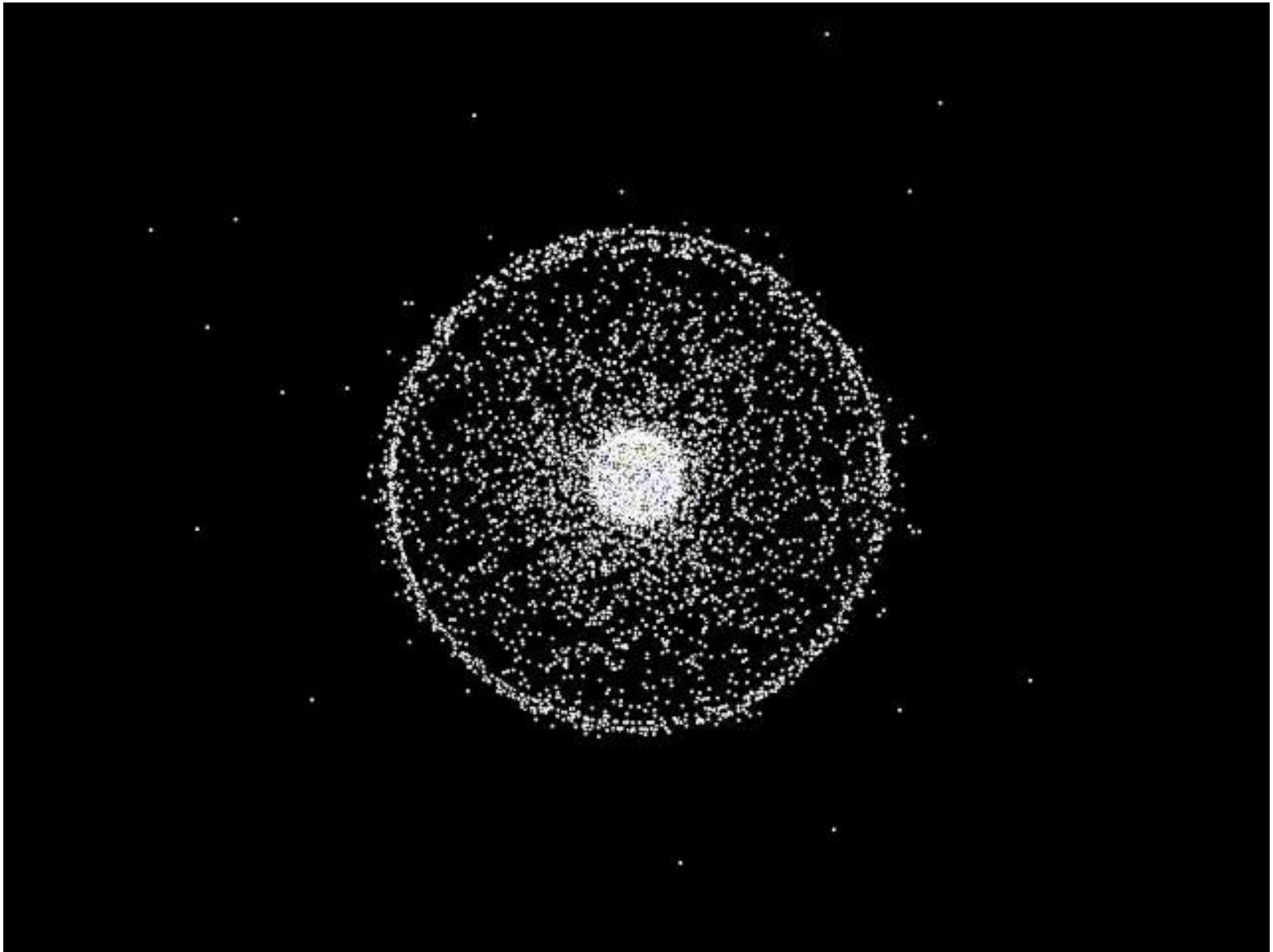
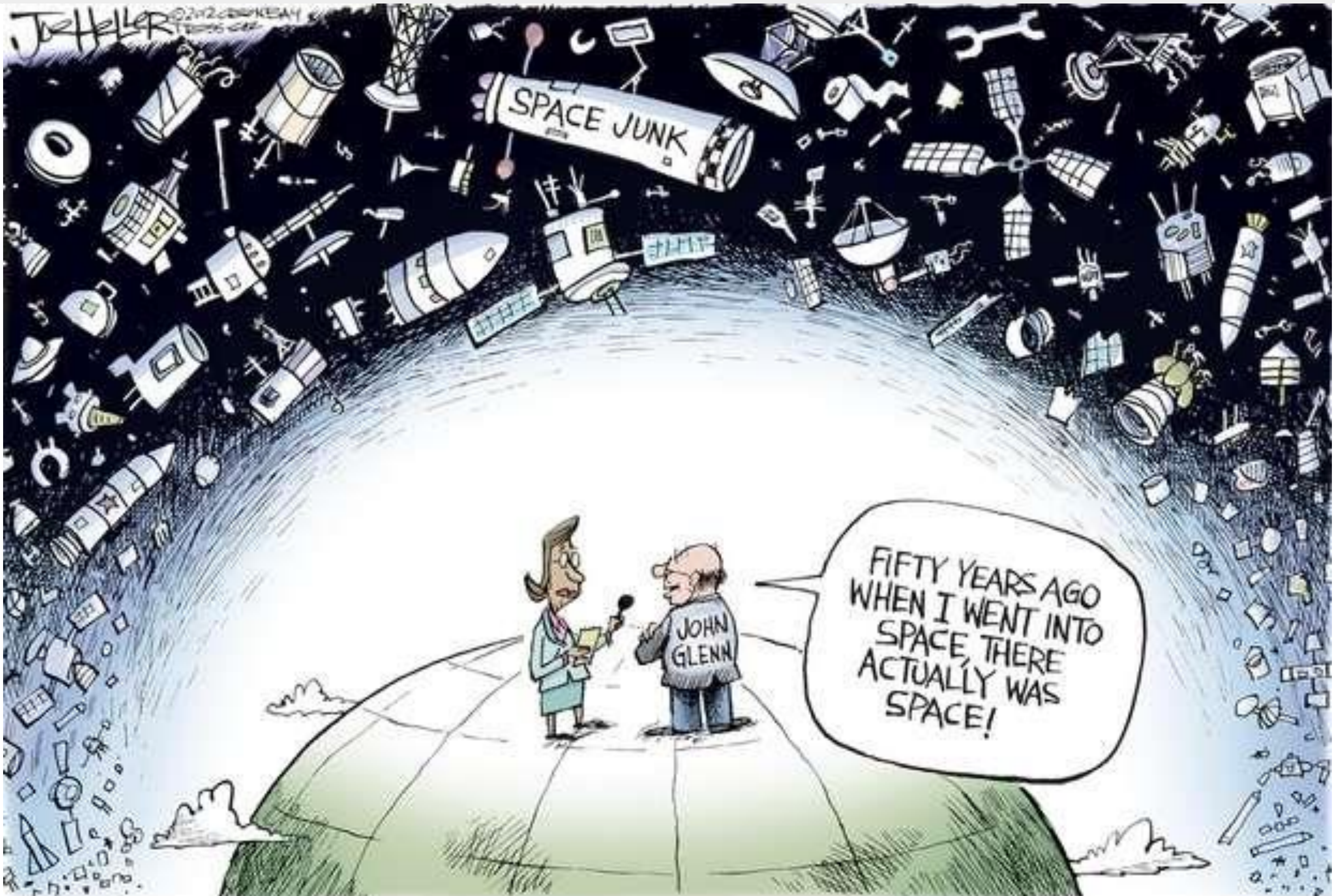
Evolution of the Cataloged Satellite Population



SSN Catalogue Orbital Environment




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

JSpOC

- **The Joint Space Operations Center (JSpOC) 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 determine their orbits with sufficient accuracy to recover the object on a future pass over an SSN sensor**
  - **This tracking capability allows the JSpOC 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**

- **NASA and the DoD have established complementary areas of expertise in order to understand the debris environment in Earth space**
  - **DoD concentrates on the part of the environment large enough to track, identifying and tracking individual objects**
  - **NASA concentrates on the part of the environment too small to track, and uses statistical tools to understand what is going on**

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**

- **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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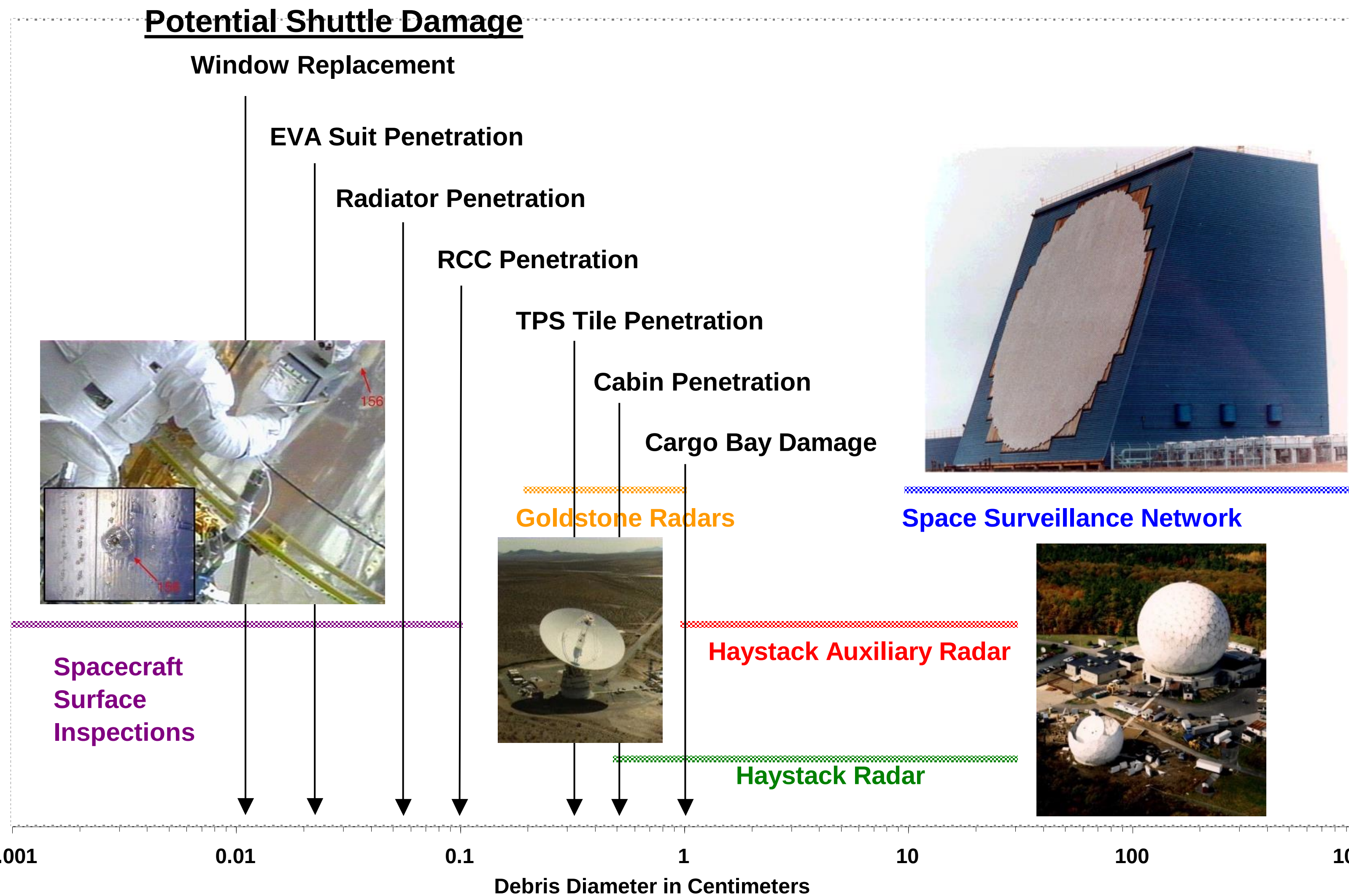
Principal Orbital Debris Data Sources



HUSIR/HAX Radars

- **Located in Massachusetts – 42.6° latitude**

- **Haystack Ultrawide Satellite Imaging Radar (HUSIR – previously known as Haystack)**
  - **36 m diameter**
  - **3 cm wavelength (X-band)**
  - **Can detect 5 mm – 1 cm debris in LEO**

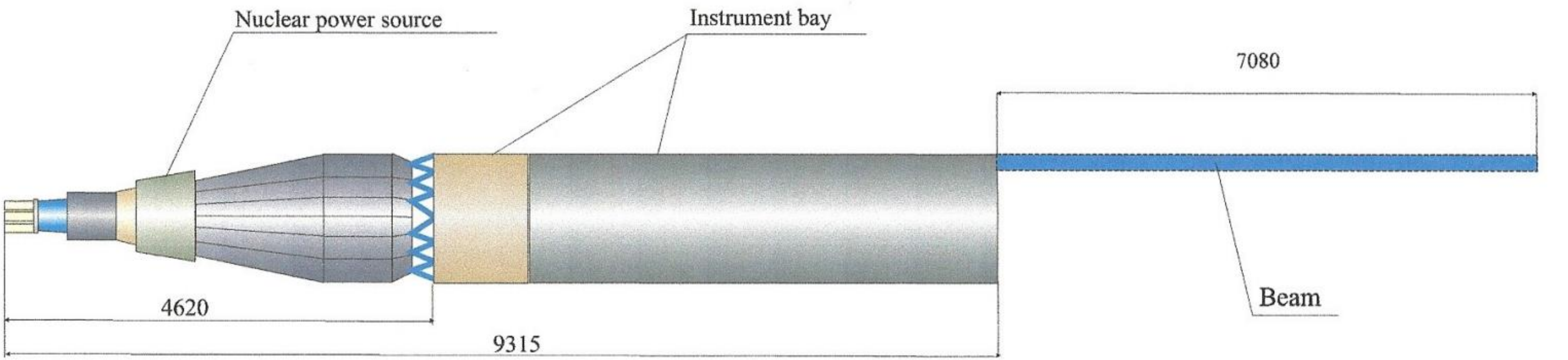
- **Haystack Auxiliary Radar (HAX)**
  - **15 m diameter**
  - **1.8 cm wavelength (Ku-band)**
  - **Can detect 1 – 3 cm debris in LEO**

HUSIR/HAX Radars

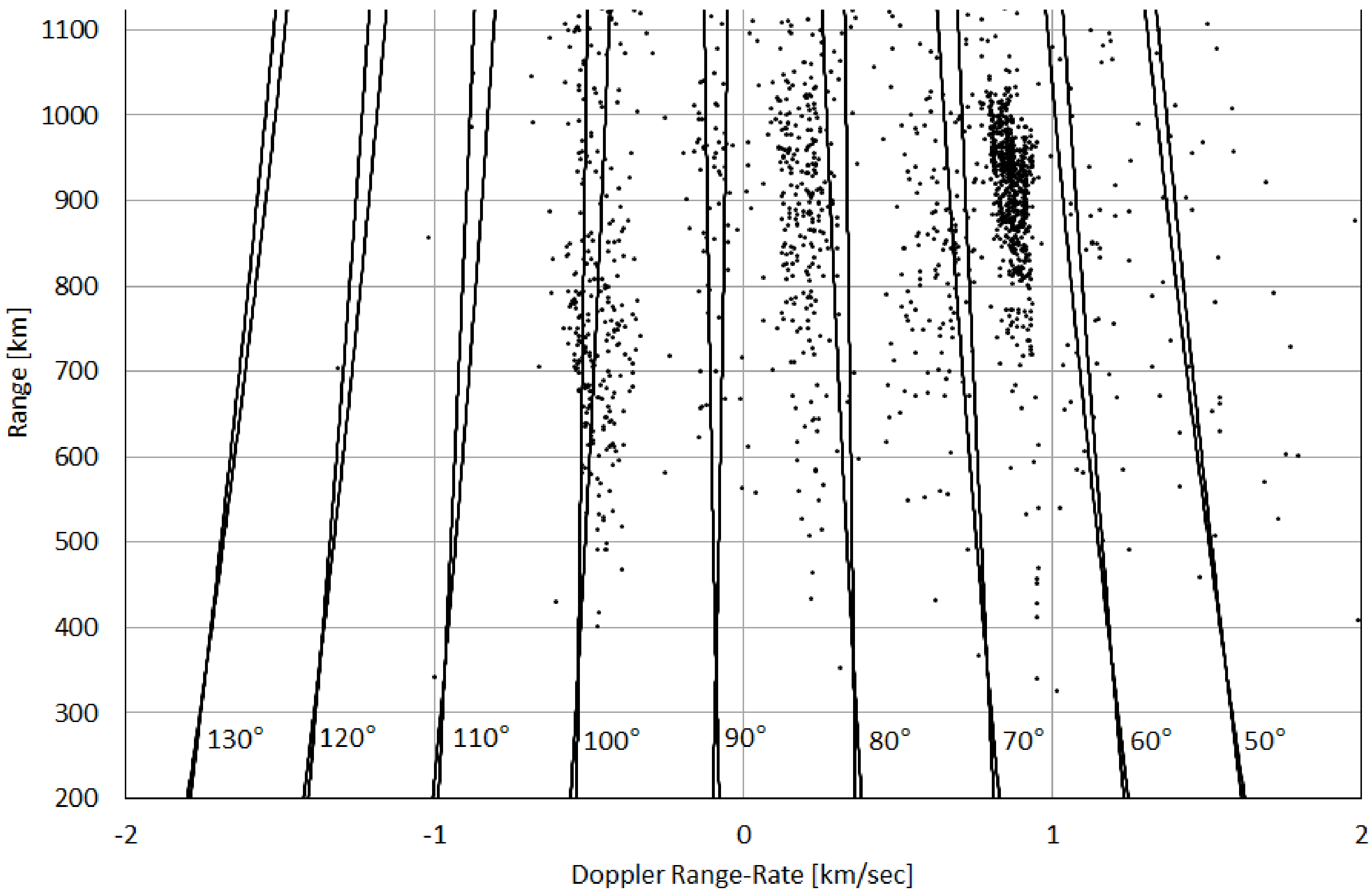
- **HUSIR and HAX measurements**
  - **Range**
  - **Doppler range-rate**
  - **Radar cross section (RCS)**
  - **Circular polarization**

- **Haystack/HUSIR uses several different pointing directions to monitor the environment**
  - **75° East – allows the estimate of the inclination using the Doppler range-rate and assuming a circular orbit**
  - **20° South – can detect objects in orbits with inclinations lower than the latitude**
  - **10° South – can detect objects in even lower inclinations, but with less sensitivity**

- **HAX**
  - **Due to sensitivity limitations, uses only 75° East**
  - **Wider beam gives greater count for >1 cm population than HUSIR**



Nuclear power source
Instrument bay
7080
Beam
4620
9315

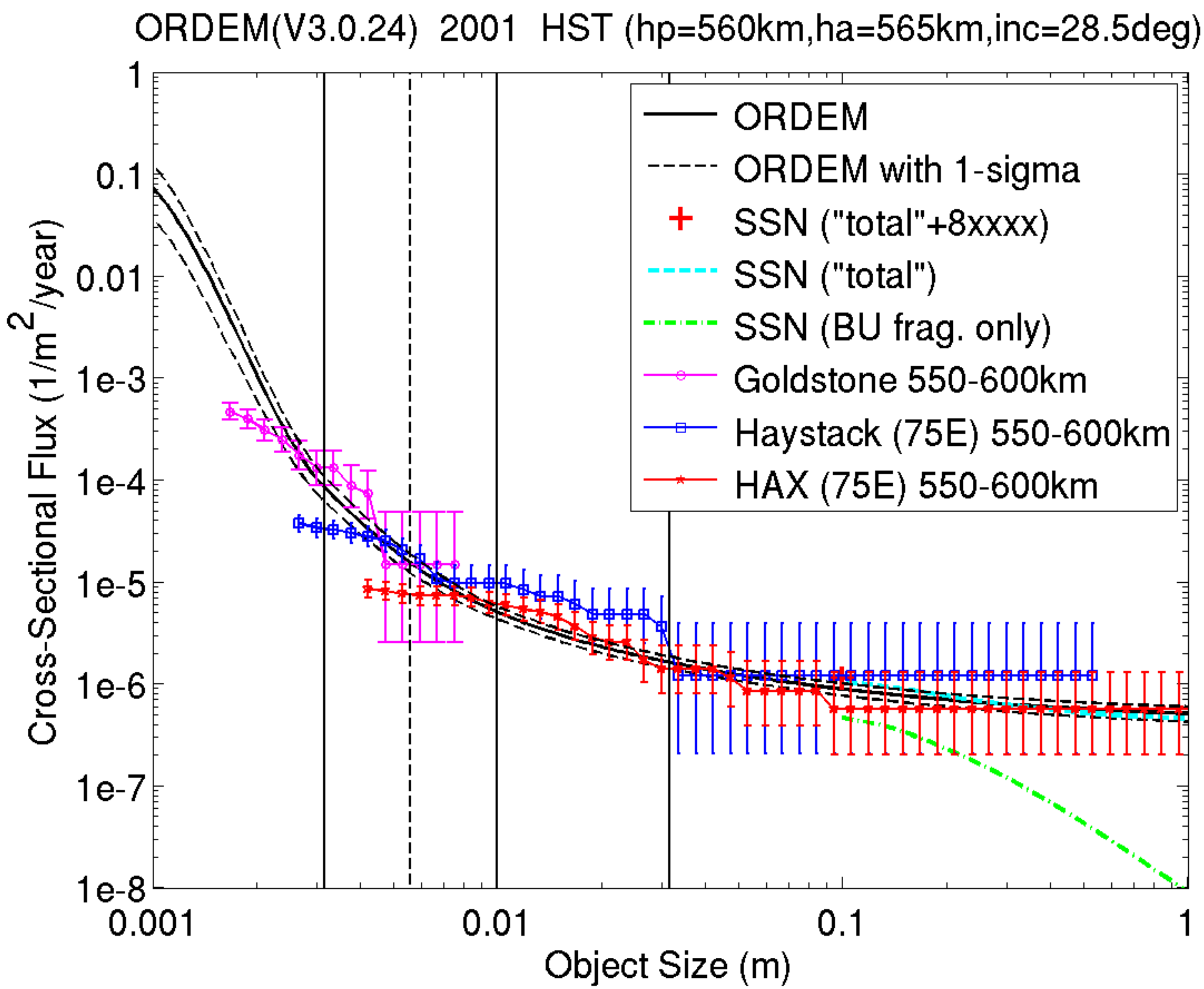


Range [km]
1100
1000
900
800
700
600
500
400
300
200
130°
120°
110°
100°
90°
80°
70°
60°
50°
-2
-1
0
1
2
Doppler Range-Rate [km/sec]

Goldstone Radar

- **Located in southern California – 35.4° latitude**
- **Part of NASA's Deep Space Network**
- **Bistatic system**
  - **70 m dish + 35 m dish**
  - **3.5 cm wavelength (X-band)**
  - **Can detect 2 mm – 5 mm debris in LEO**
- **Limited capability and time available**
- **75° East mode, but recently experimented with 20° South**

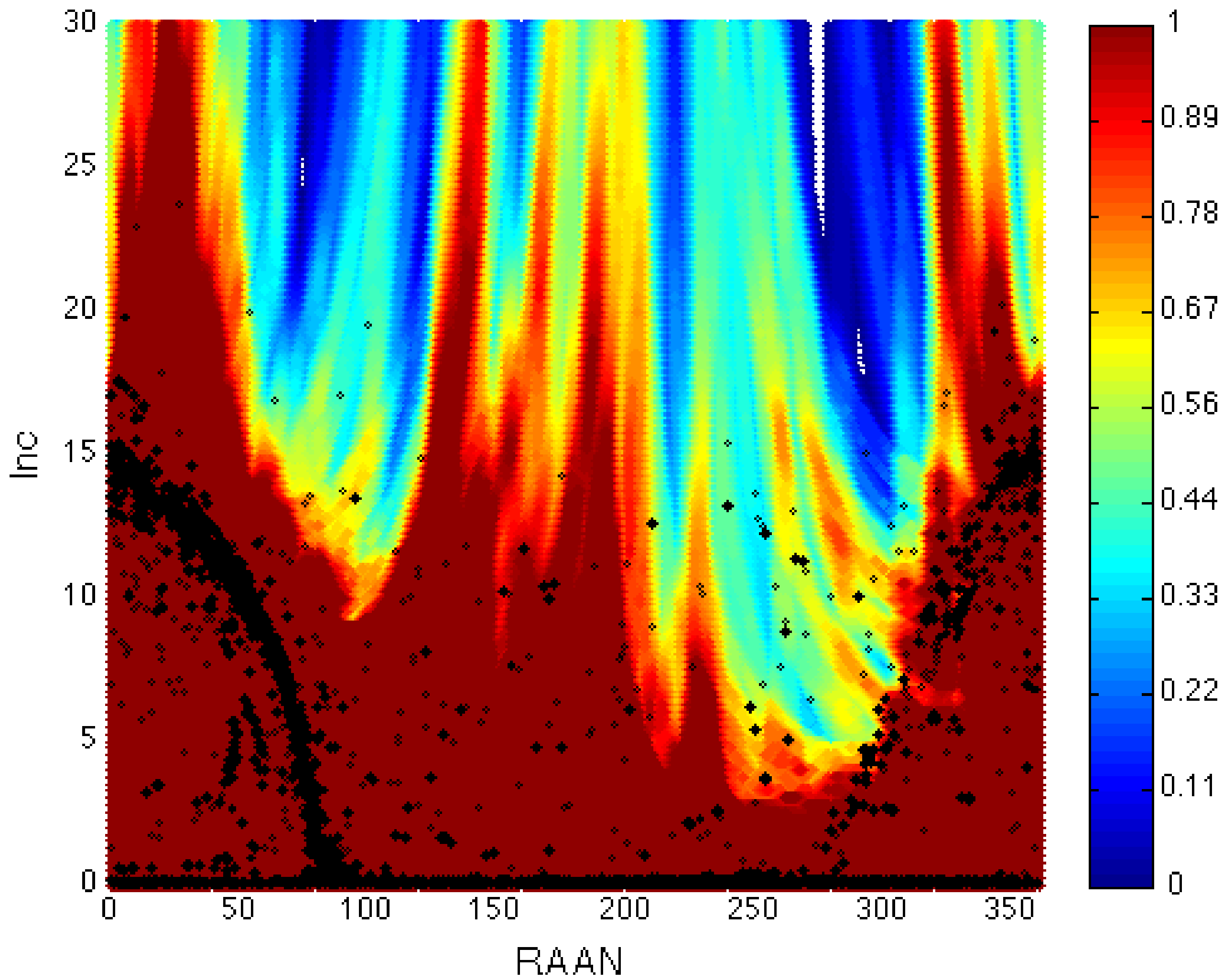
Example of Composite Radar Data



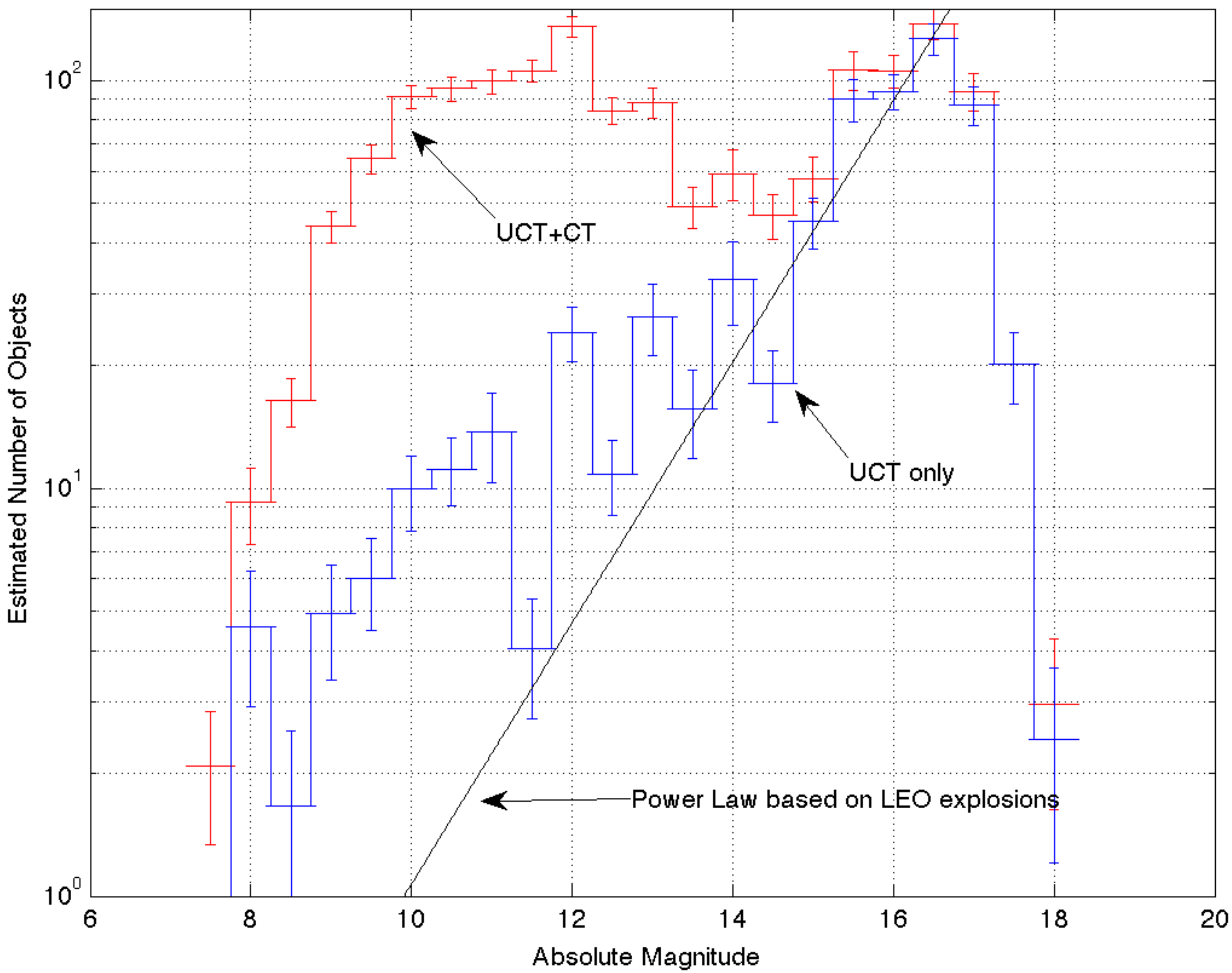
Optical Telescopes

- 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

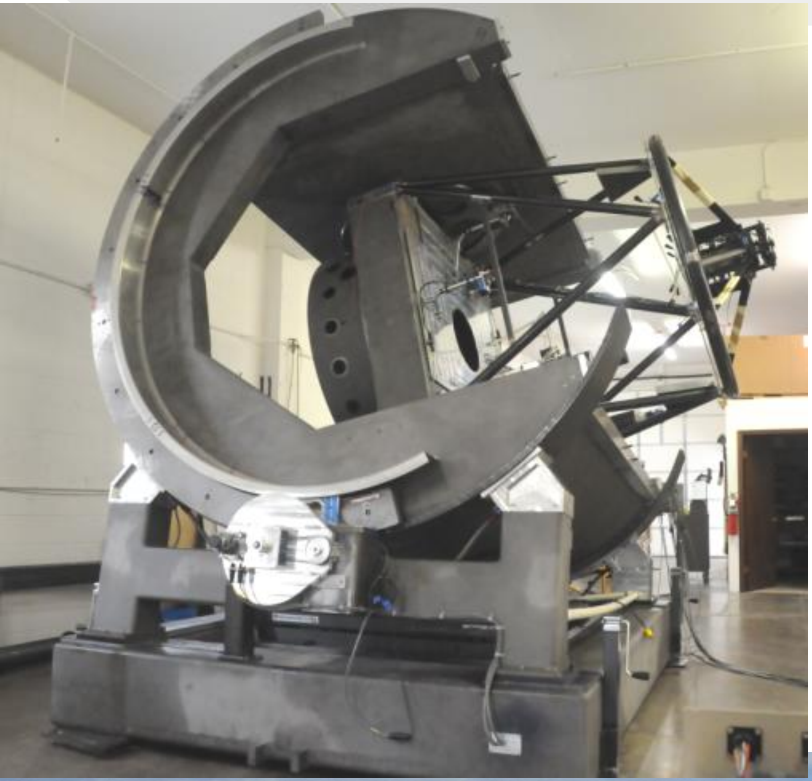
Statistical Survey



Estimated Near-GEO Population



MCAT – Meter Class Autonomous Telescope



- NASA has recently deployed the 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
- Will have the ability to extend statistical surveys in GEO for smaller debris (~ 10 cm)
- Will also have the capability to look for 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 direction 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 residual of impactor, letting us know the material of the particle (e.g., aluminum, steel, meteoroid).
- Use statistical techniques to "back out" debris characteristics

Shuttle Database

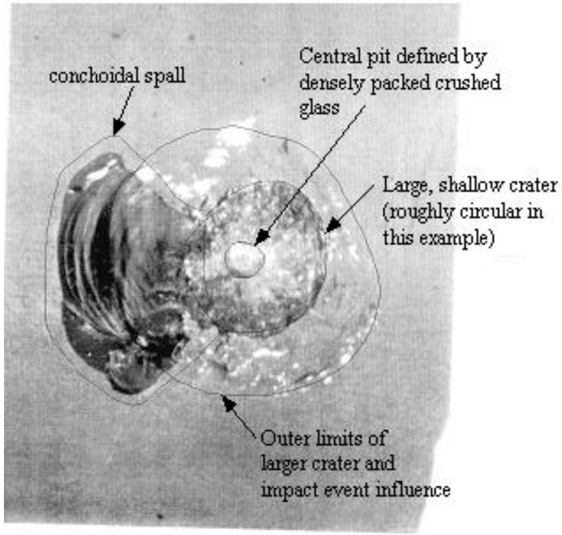
- **Until 2011, the US regularly launched the Space Shuttle into LEO**
  - **Usually to ~400 km altitude**
  - **Occasionally up to 600 km altitude**

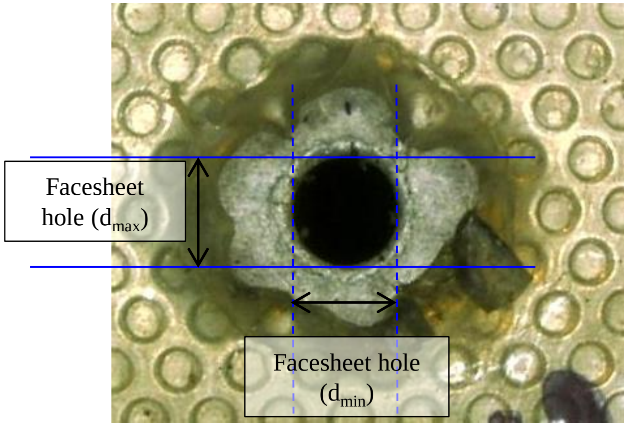
- **While not designed as such, certain surfaces served as excellent debris impact detectors**

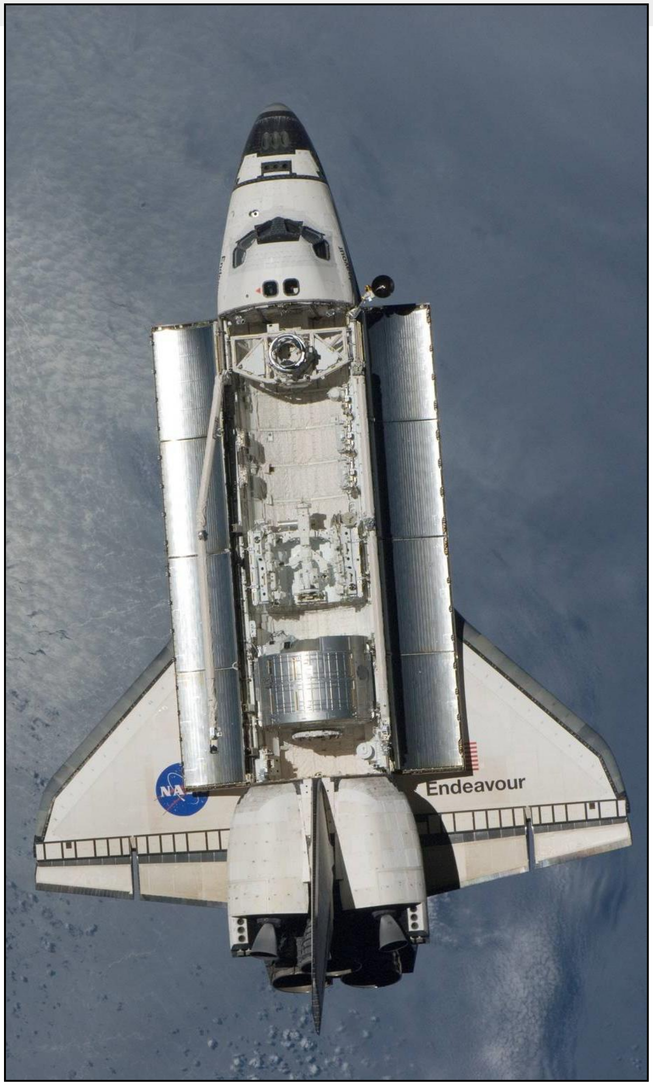
- **Windows**
  - **3.5 m^2**
  - **Detected impactors in 10 µm – 100 µm size range**
  - **Excellent surface for identification of impactor material**

- **Radiators**
  - **120 m^2**
  - **Detected impactors larger than about 100 µm up to ~1 mm in size**
  - **Because made of aluminum, could not readily distinguish aluminum impactors**

Shuttle *In Situ* Data







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

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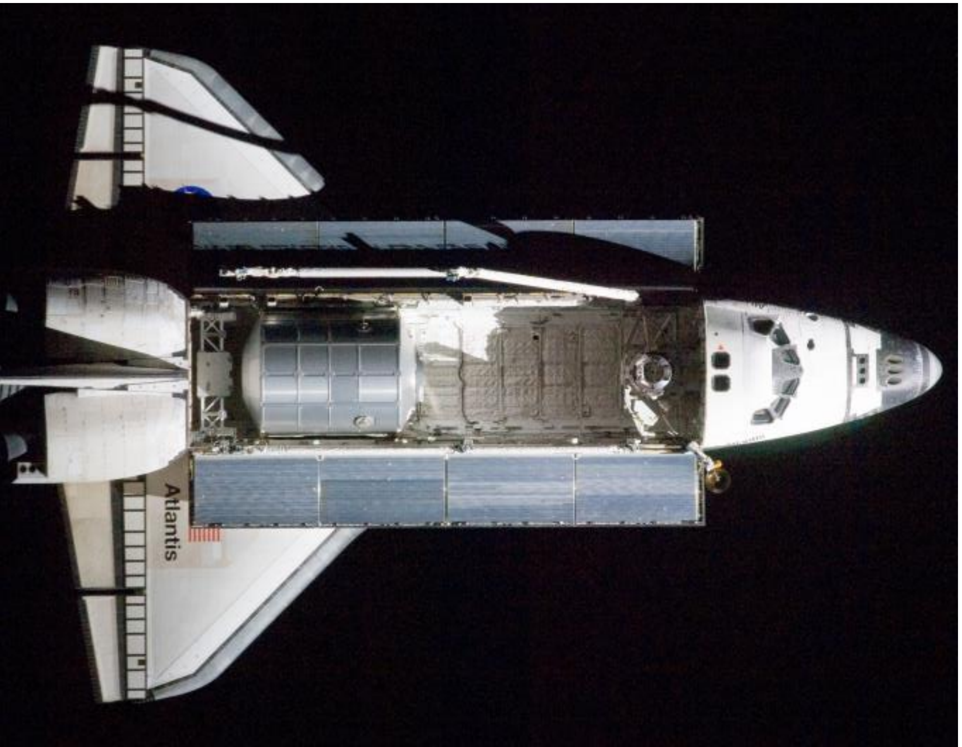
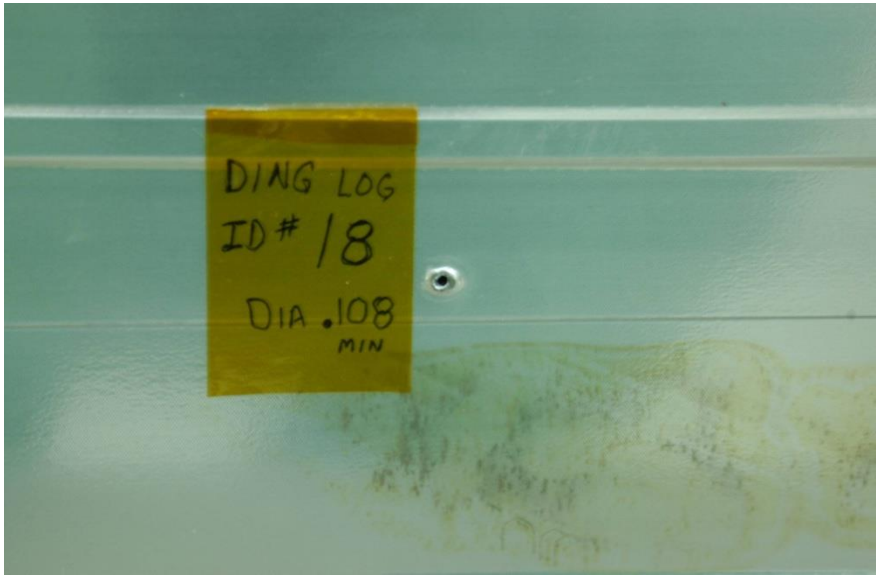
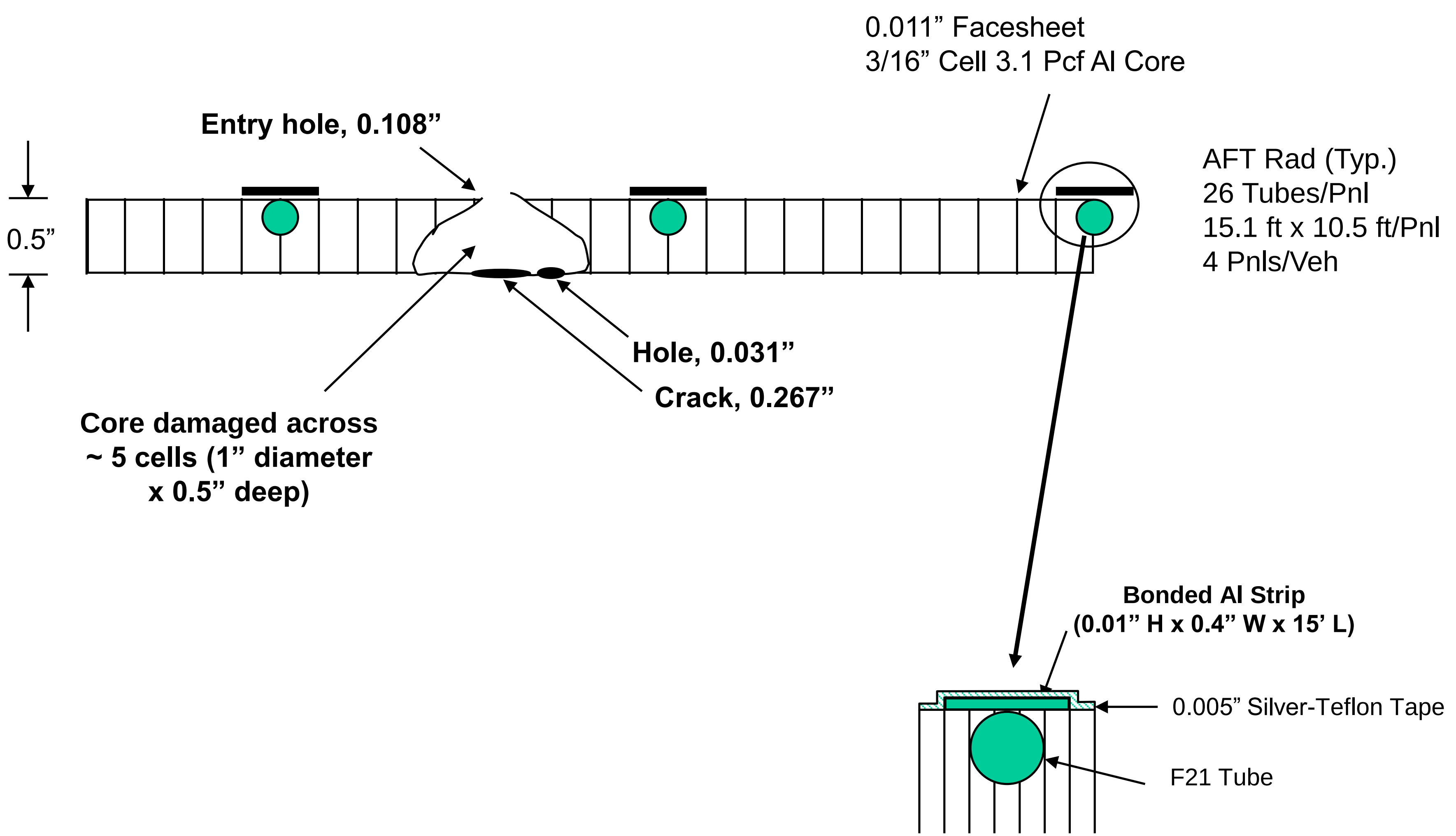
STS-115 MMOD Impact Damage

- **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 to that time**

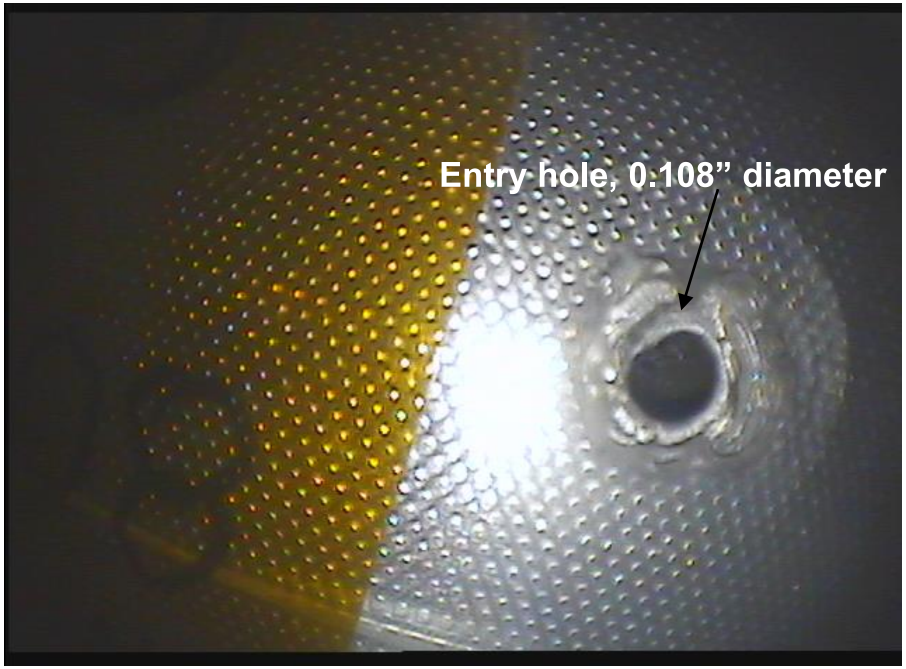




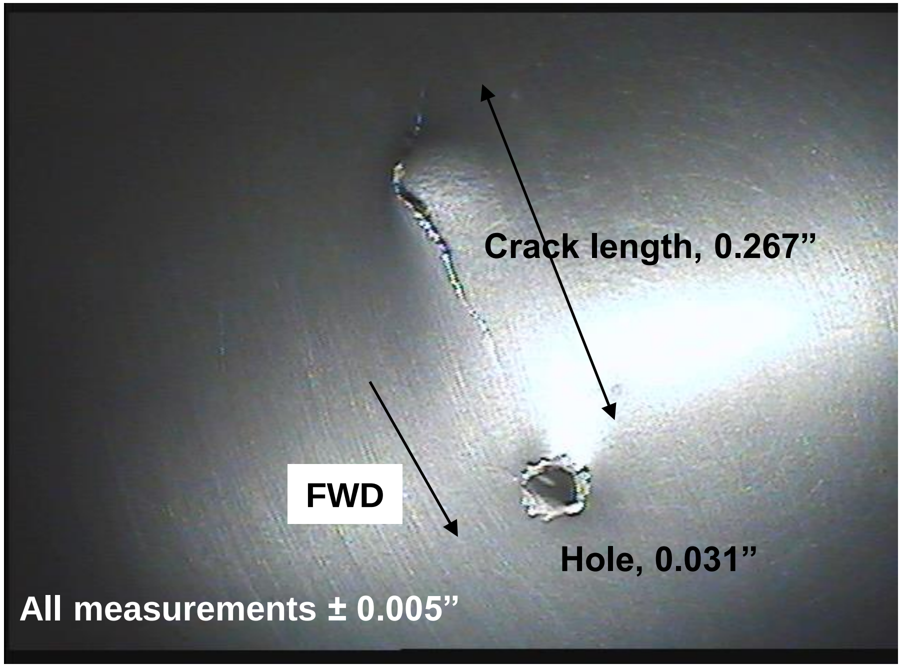
Schematic of Radiator and Sketch of Damage



Additional Images



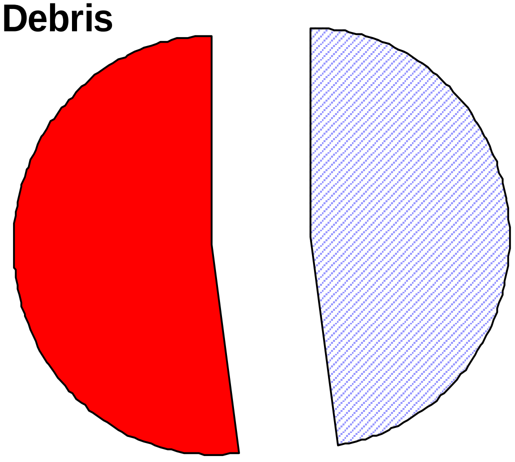
Outer face sheet damage



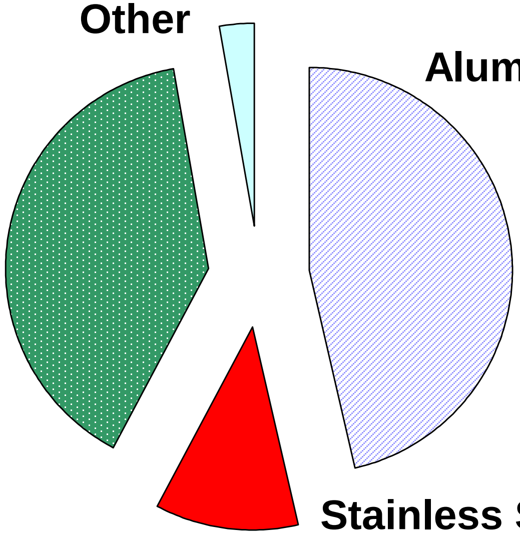
Inner face sheet damage

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

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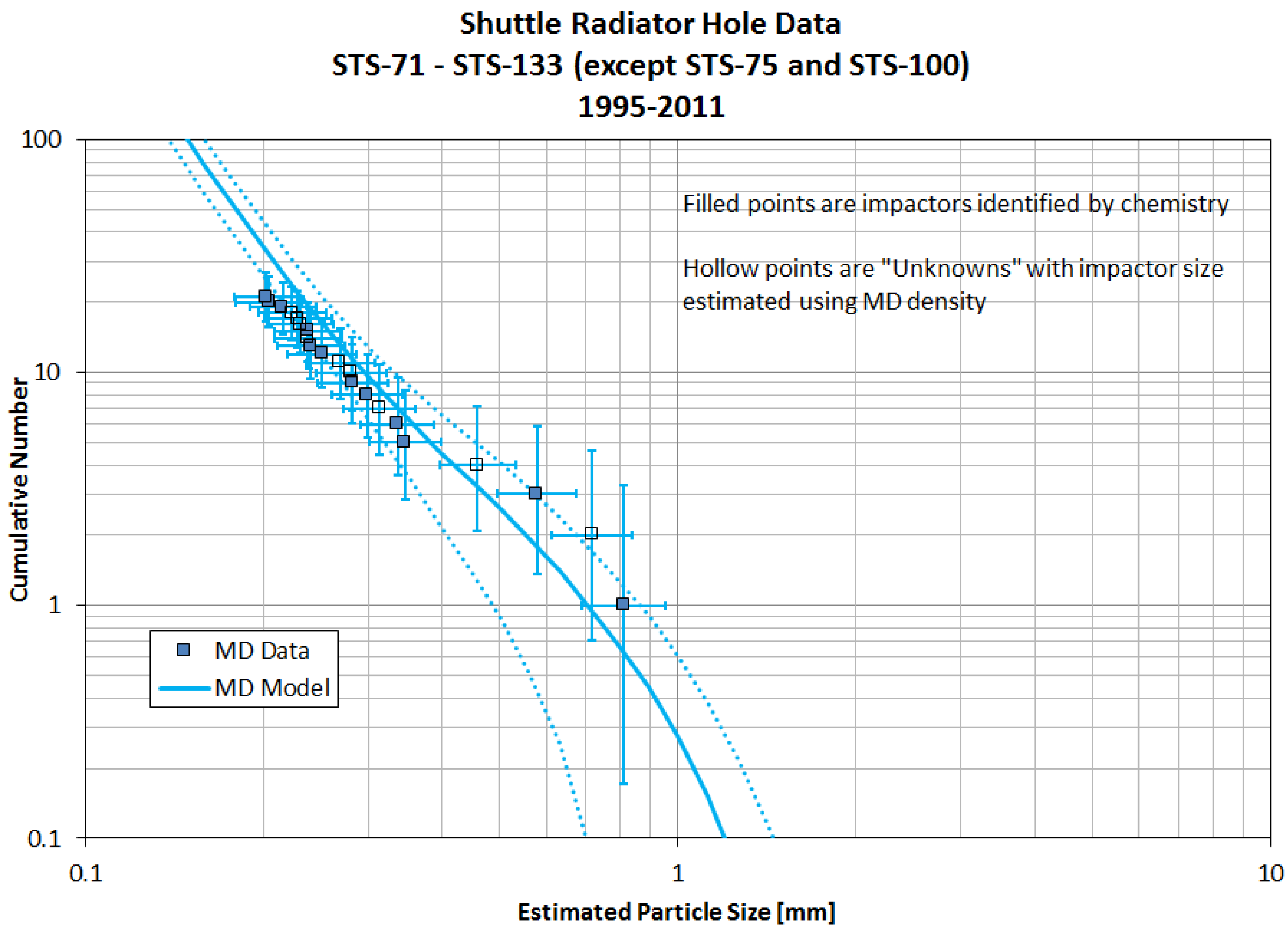
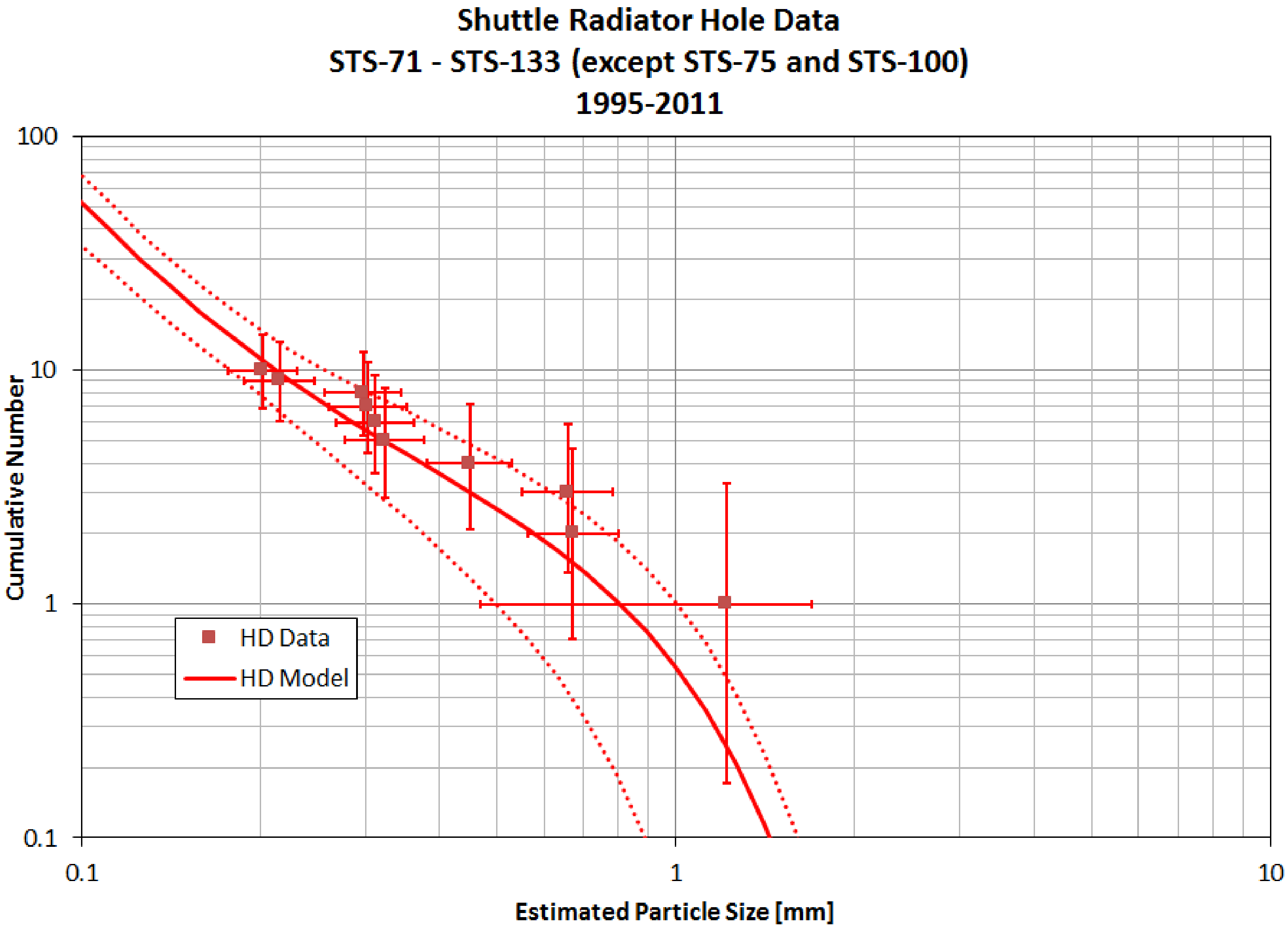
Medium Density (e.g., Aluminum) Shuttle Radiator Impactors



High Density (e.g., Steel) Shuttle Radiator Impactors



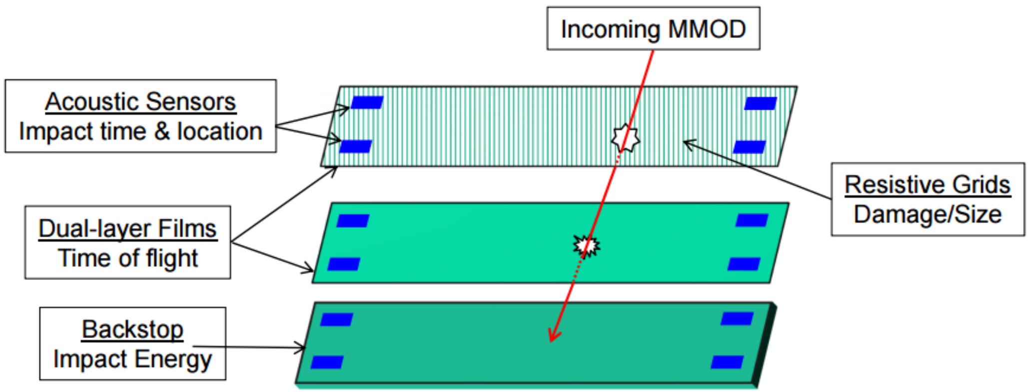
Future of *In Situ*

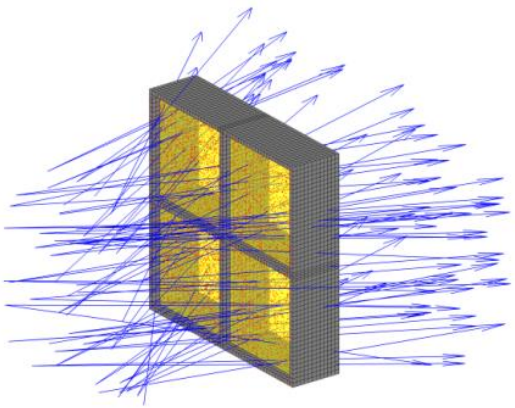
- **The Shuttle no longer flies, so NASA currently has no dedicated sensor to monitor the small particle environment**

- **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**

- **DRAGONS flight demonstration currently manifested to fly on ISS**
- **We hope to find flight opportunities at higher altitudes in the near future**

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**

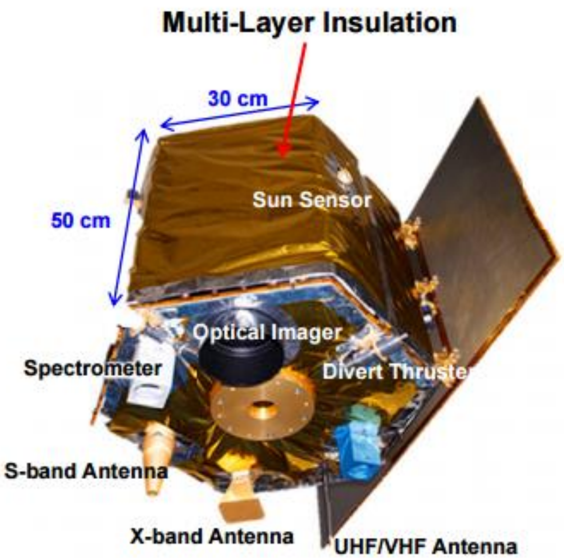
Ground Experiments

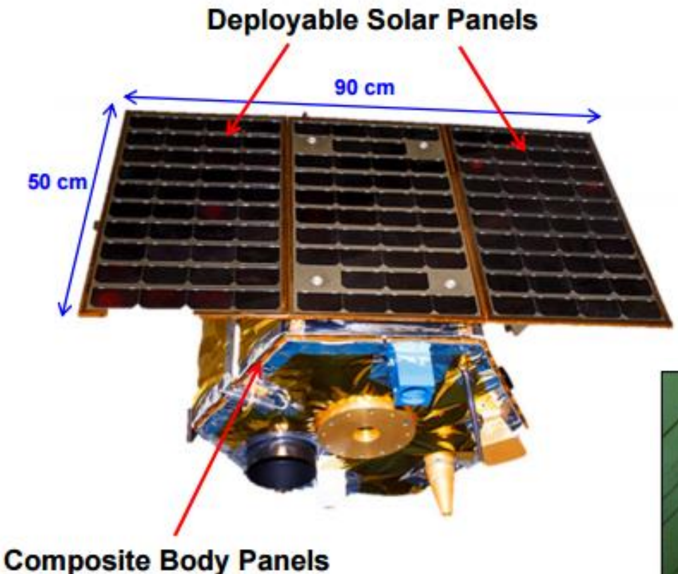
- **However, there have been major changes in spacecraft construction materials over the years, so a need to test the breakup models using more modern spacecraft materials**
- **NASA, in conjunction with US Dept of Defense, conducted the DebriSat impact experiment, using a mock satellite made of modern 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

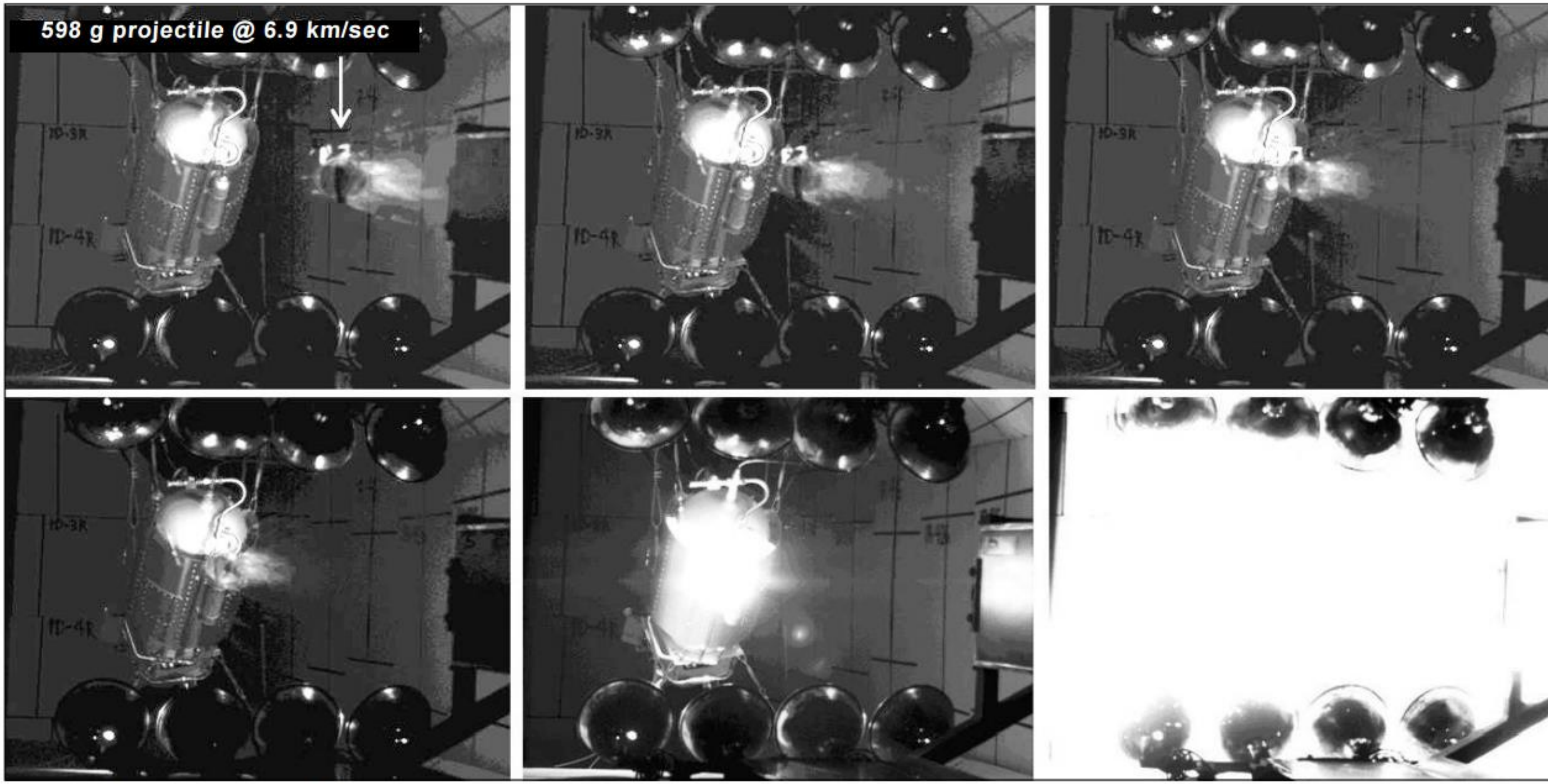




DebriSat

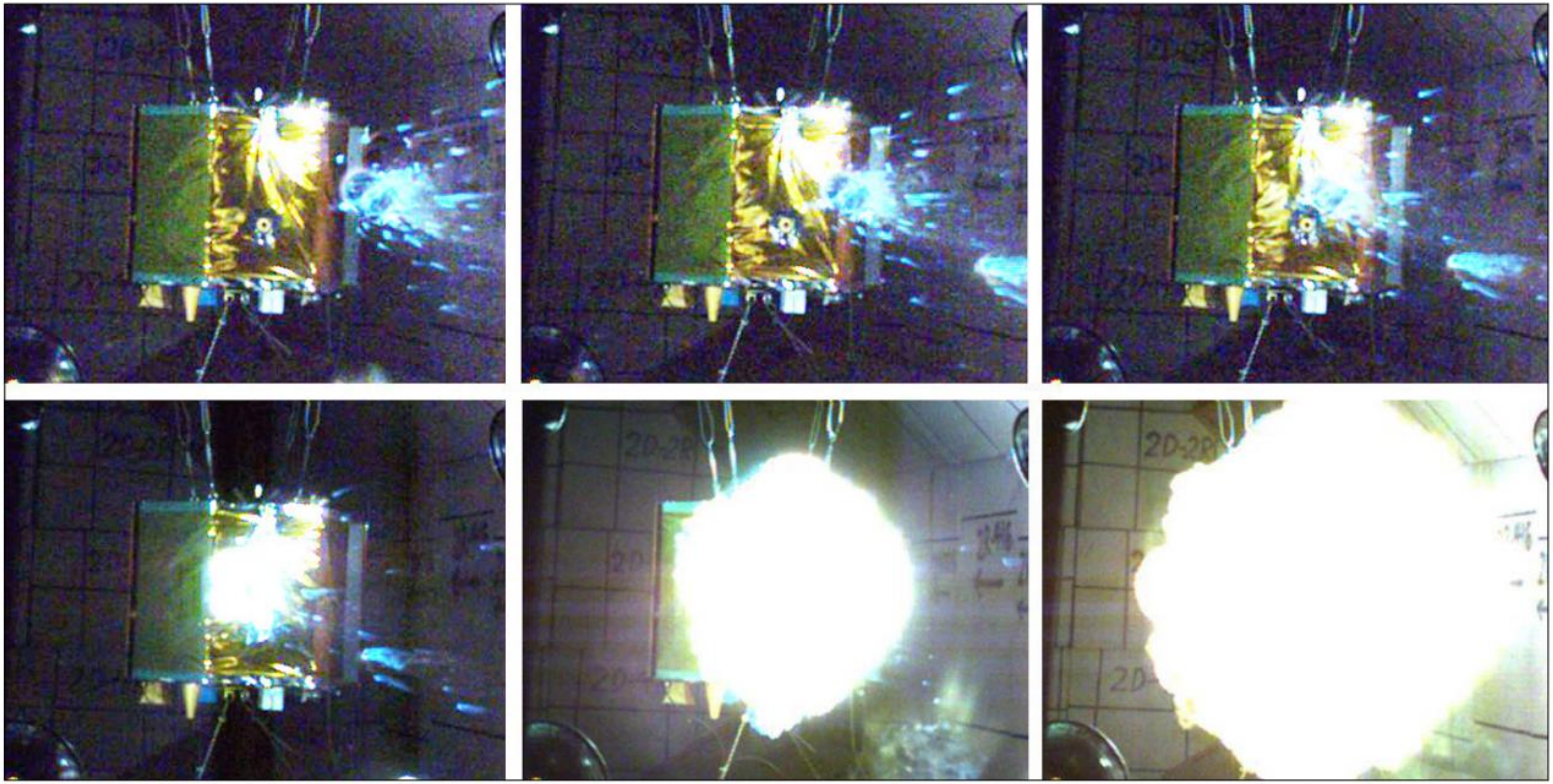
DebrisLV

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 analyzed to ascertain particle velocities**

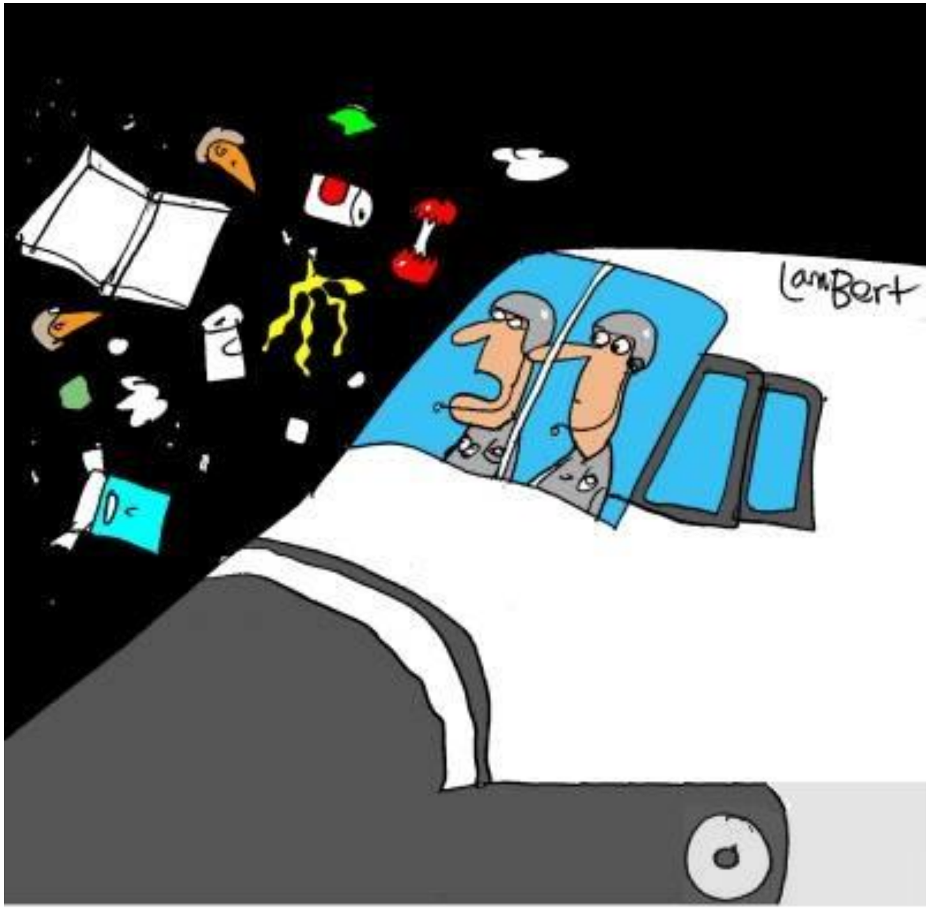
- **More debris were recovered than we anticipated based on previous models**

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

Conclusions

- Monitoring the Earth space environment requires multiple detectors
  - Broad range in size
  - Broad range in altitudes
- Earth environment is dynamic, and needs to be monitored regularly
- With the loss of the Space Shuttle, we need new tools to sample the small particle environment, as well as extend to regions where we have as yet no data
- New detectors will sample sizes and regions previously difficult to see with existing sensors

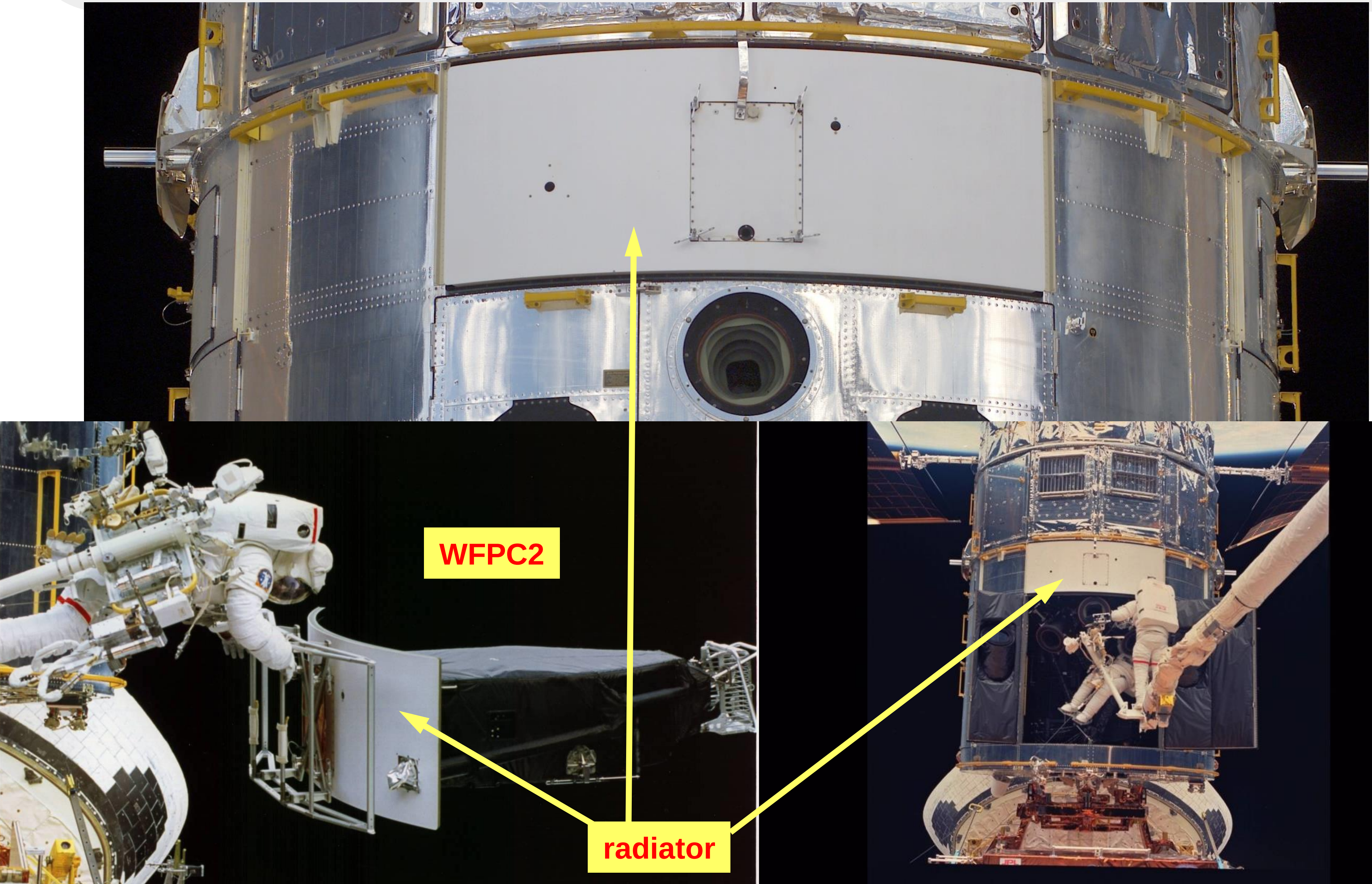
Questions?



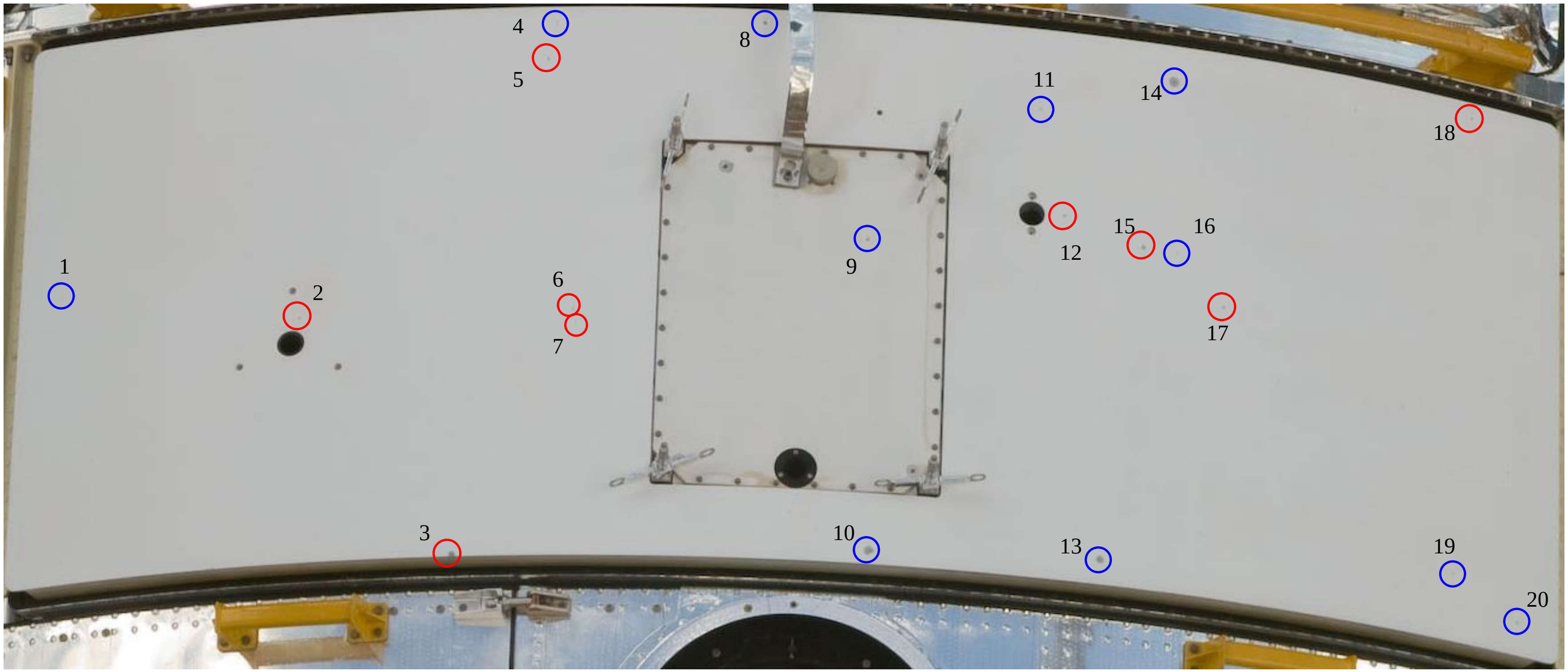
What day is trash pickup around here?

Backups

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)

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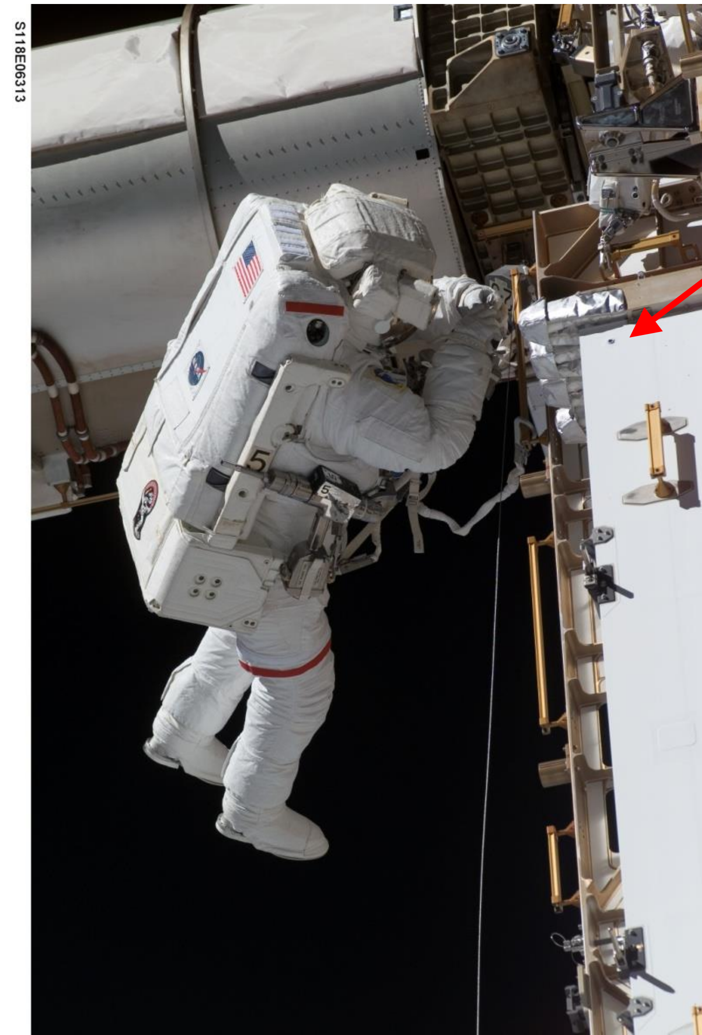
Debris Impacts Observed during EVA’s

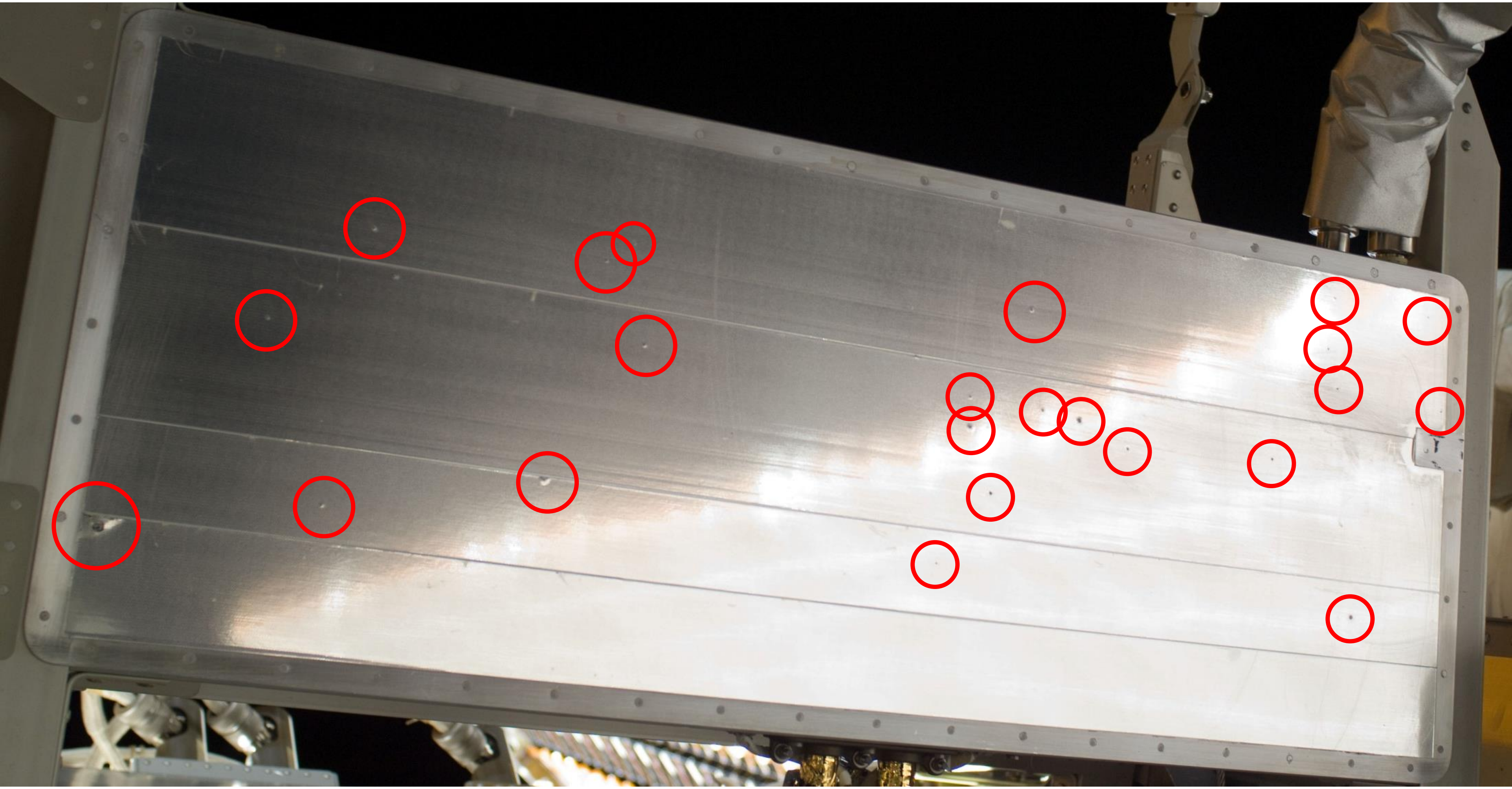
- **Also in 2007, a crew member on EVA noticed a hypervelocity impact crater while working near a large aluminum panel.**



Space debris impact site

MMOD Damage to ISS

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

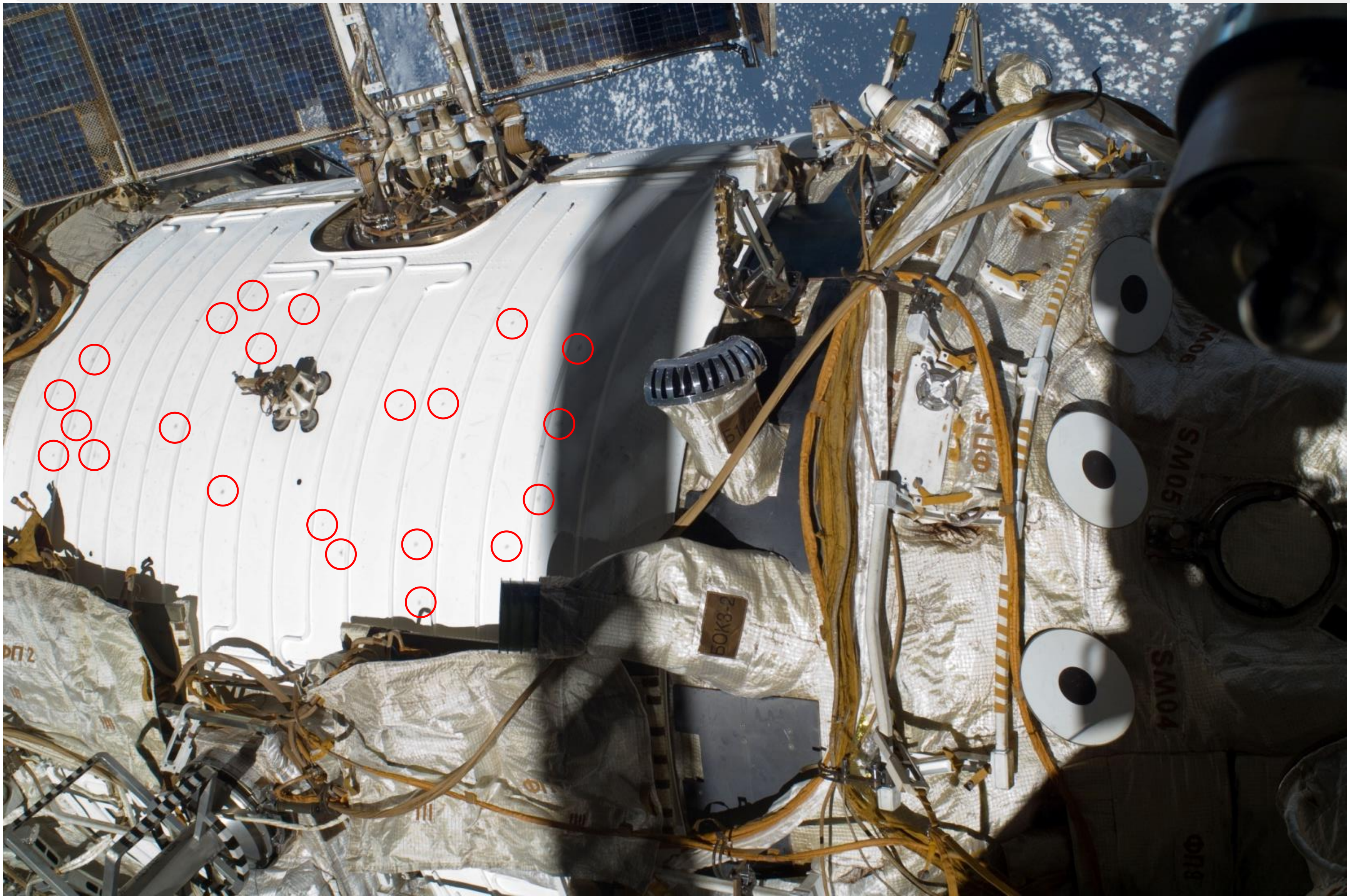


ISS033e017859

MMOD Damage to ISS

ISS032e020579

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



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

ISS032e020579

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

ISS032e020579

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

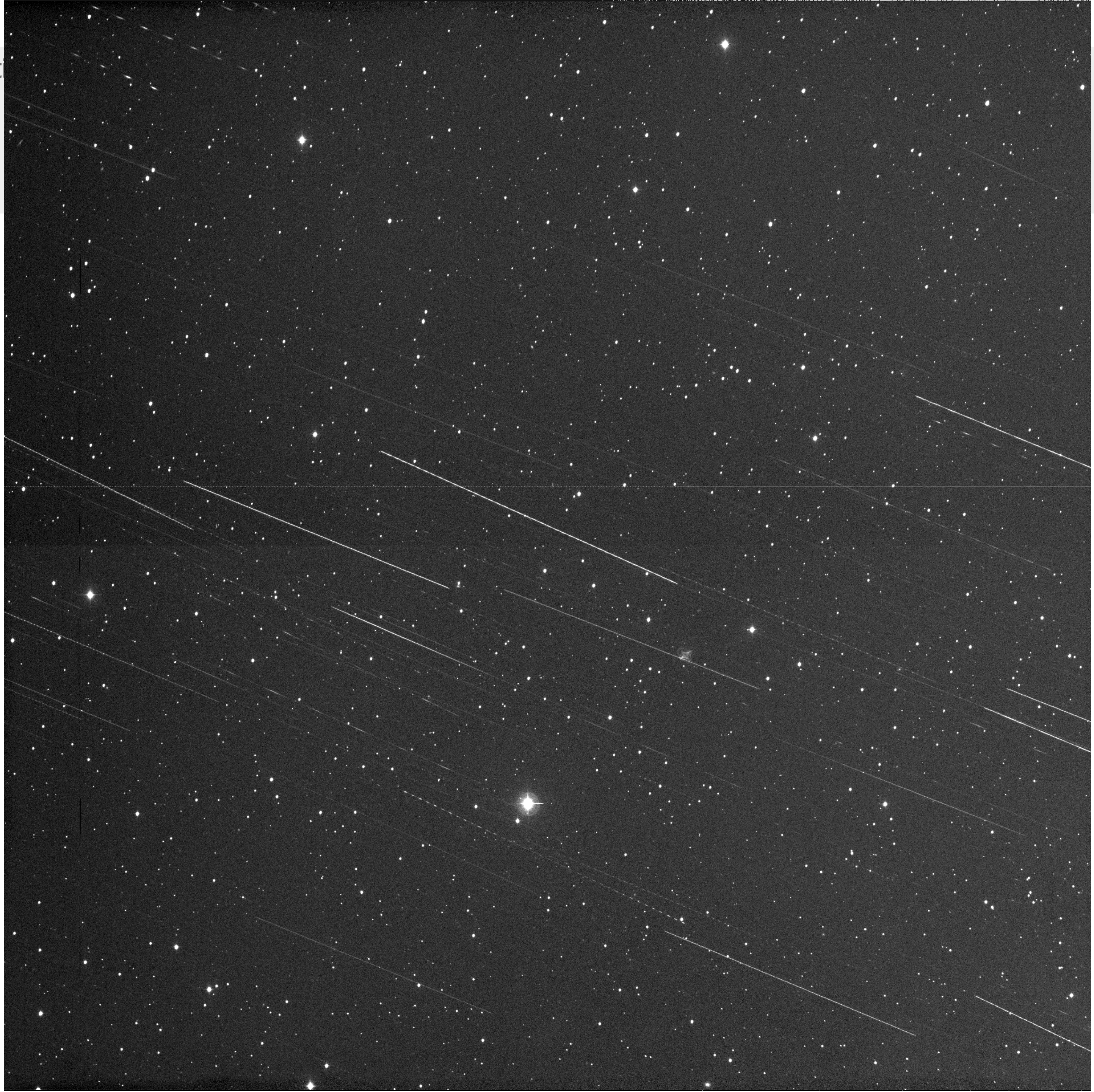
ISS032e020579

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

ISS032e020579

Breakups - 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**



Previous Briz-M explosion – Feb 19, 2007

Rob McNaught,
Siding Springs Observatory