National Aeronautics and Space Administration

Micrometeoroid and Orbital Debris (MMOD) Risk Overview

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Agenda

- **Background on micrometeoroid and orbital debris (MMOD) environment**
- **MMOD shielding overview**
- **ISS MMOD risk issues**
  - Radiators
  - Solar arrays
  - Solar array masts
  - EVA Handrails
  - Hardware behind bumpers or covers
  - Return vehicle thermal protection systems (TPS)

MMOD Environment Models

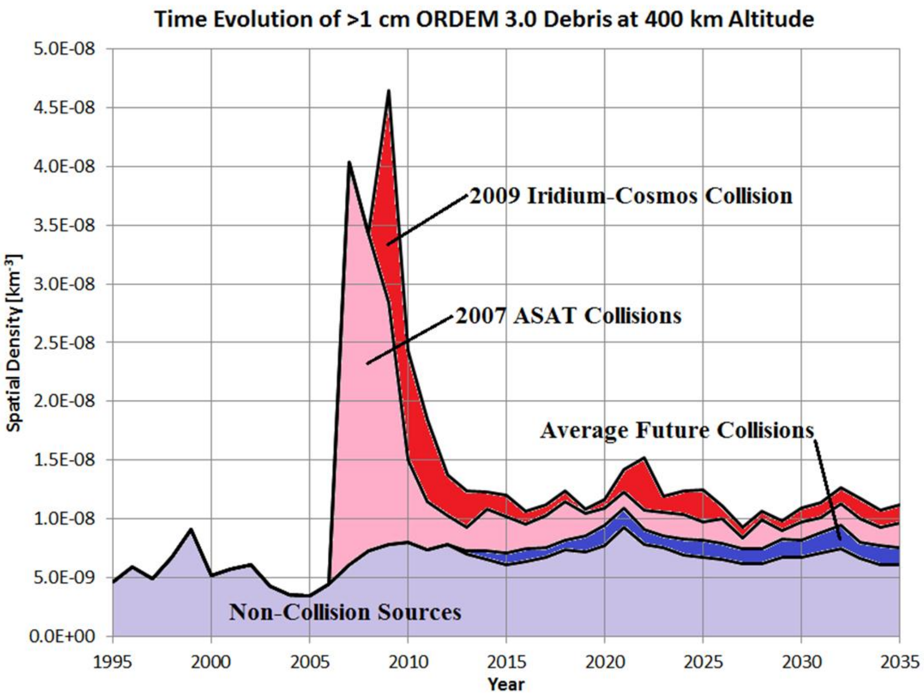
- **Orbital Debris provided by JSC & is the predominate threat in low Earth orbit**
  - ORDEM 3.0 is latest model (released December 2013)
  - Man-made objects in orbit about Earth impacting up to 16 km/s
    - average 9-10 km/s for ISS orbit
  - High-density debris (steel) is major issue
  - http://orbitaldebris.jsc.nasa.gov/

- **Meteoroid model provided by MSFC**
  - MEM-R2 is latest release
  - http://www.nasa.gov/offices/meo/home/index.html
  - Natural particles in orbit about sun
    - Mg-silicates, Ni-Fe, others
  - Meteoroid environment (MEM): 11-72 km/s
    - Average 22-23 km/s

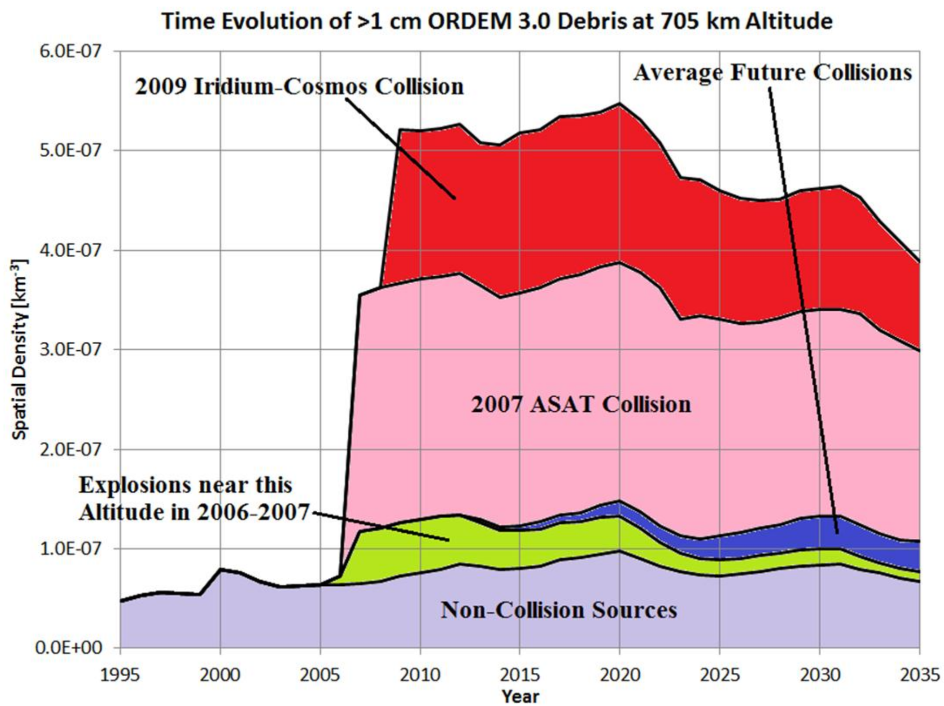
MMOD Environment Models

- **Meteoroids consist of background sporadic flux (static), and streams from meteor showers (variable)**
  - Occasionally, showers can turn into storms
- **Orbital Debris is dynamic, changing as function of the rate of on-orbit explosions & collisions, launch rate and atmospheric drag/solar activity**

400km altitude

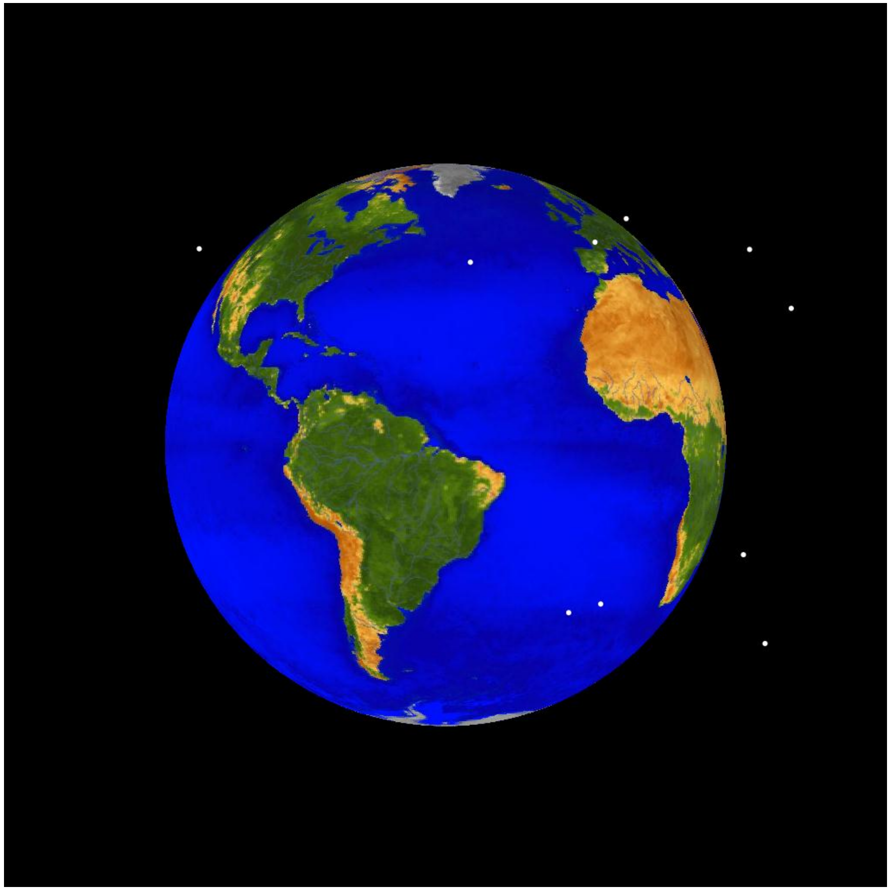


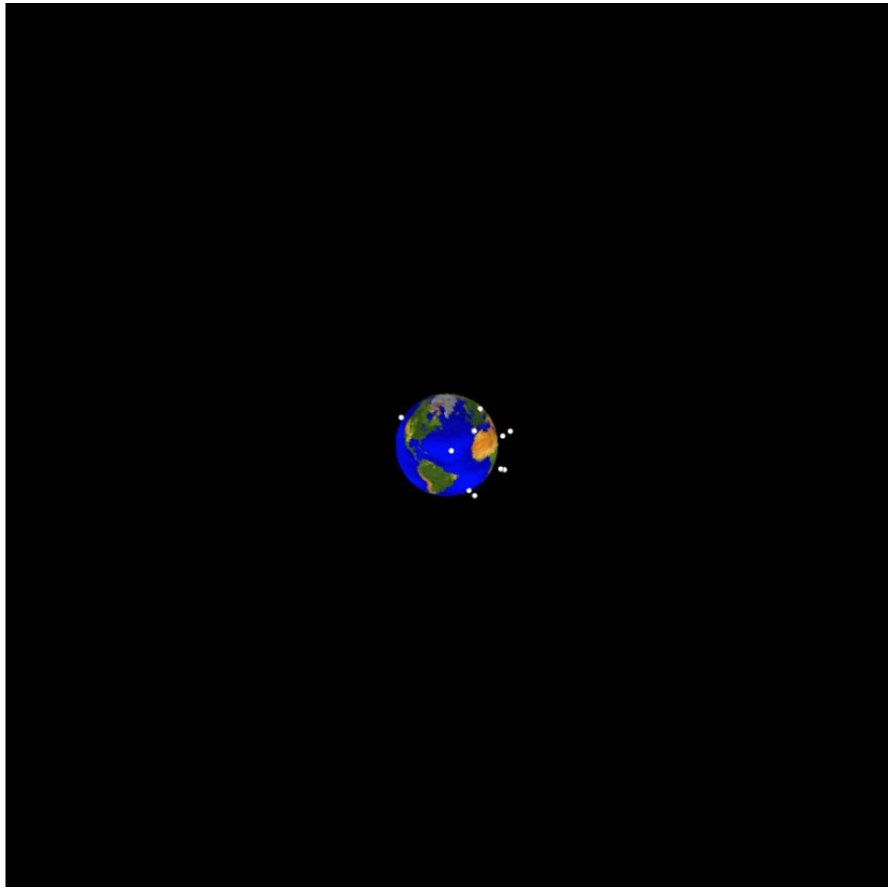
705km altitude



Note, Spatial Density is proportional to impact risk

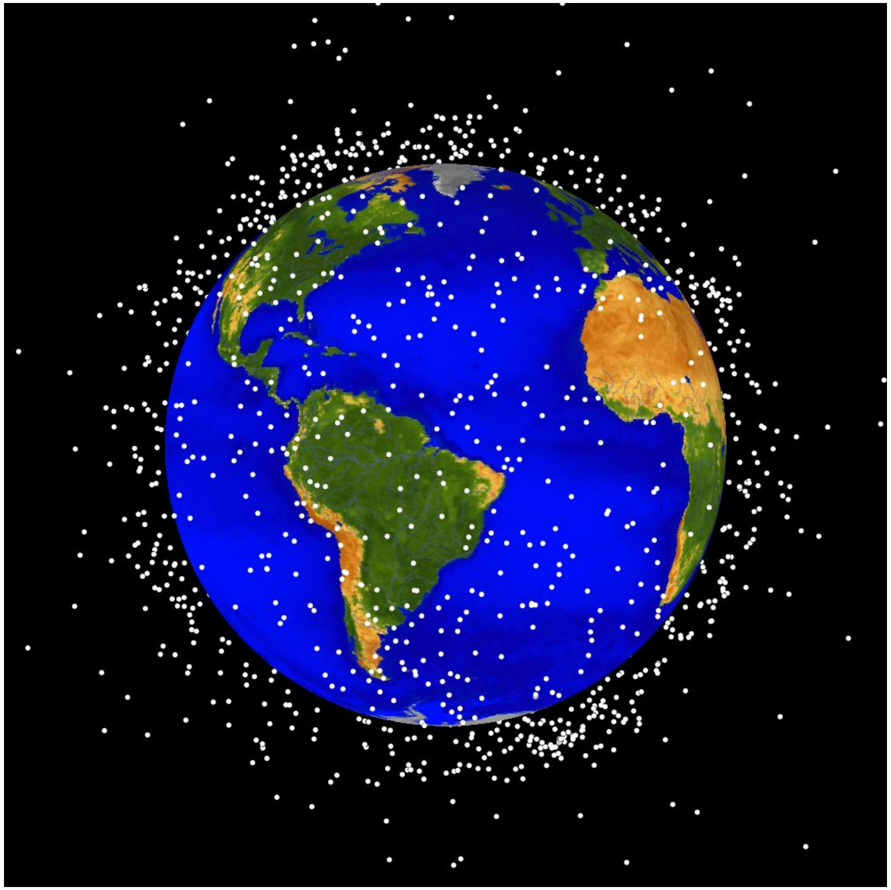
1960

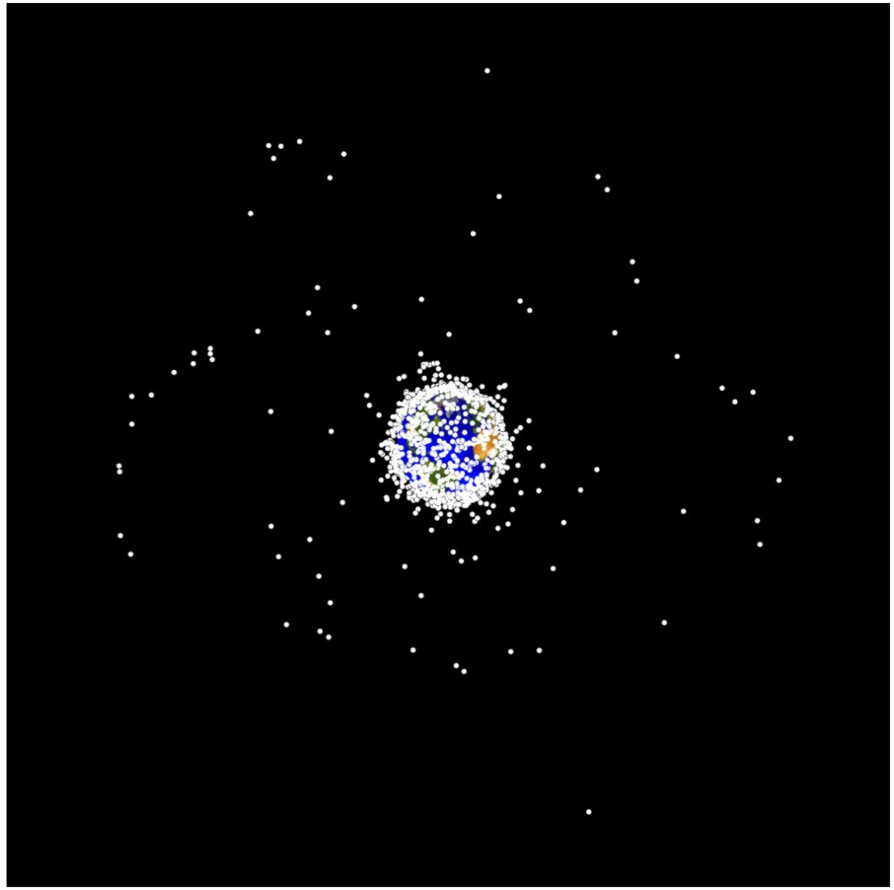




Cataloged objects >10 cm diameter

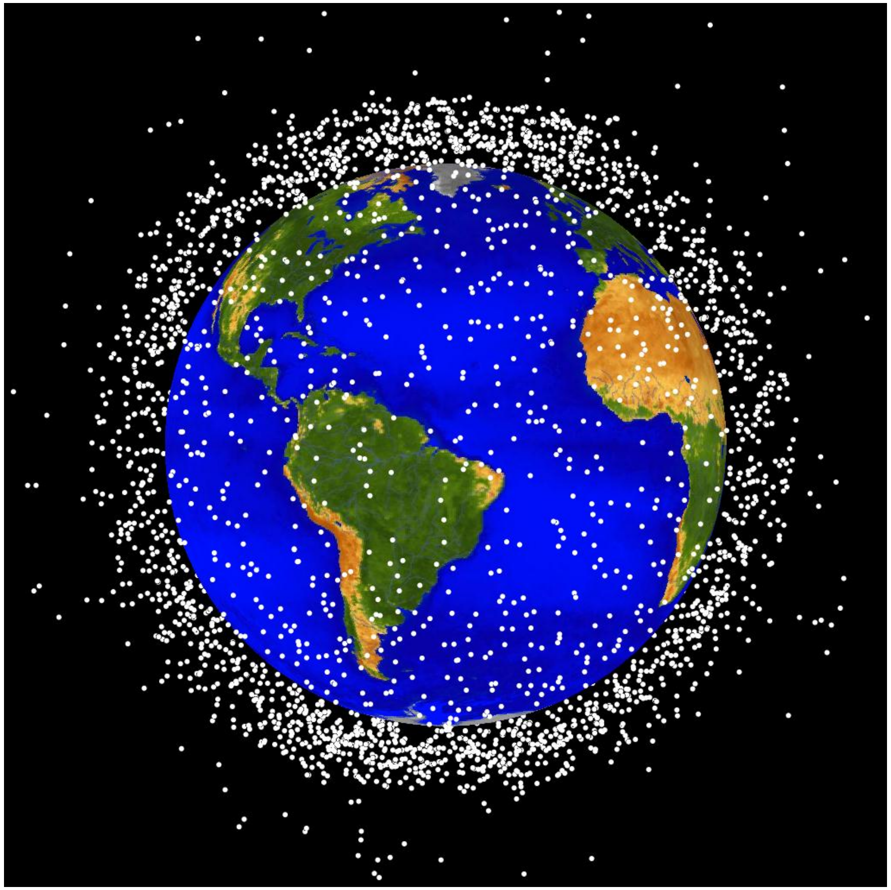
1970

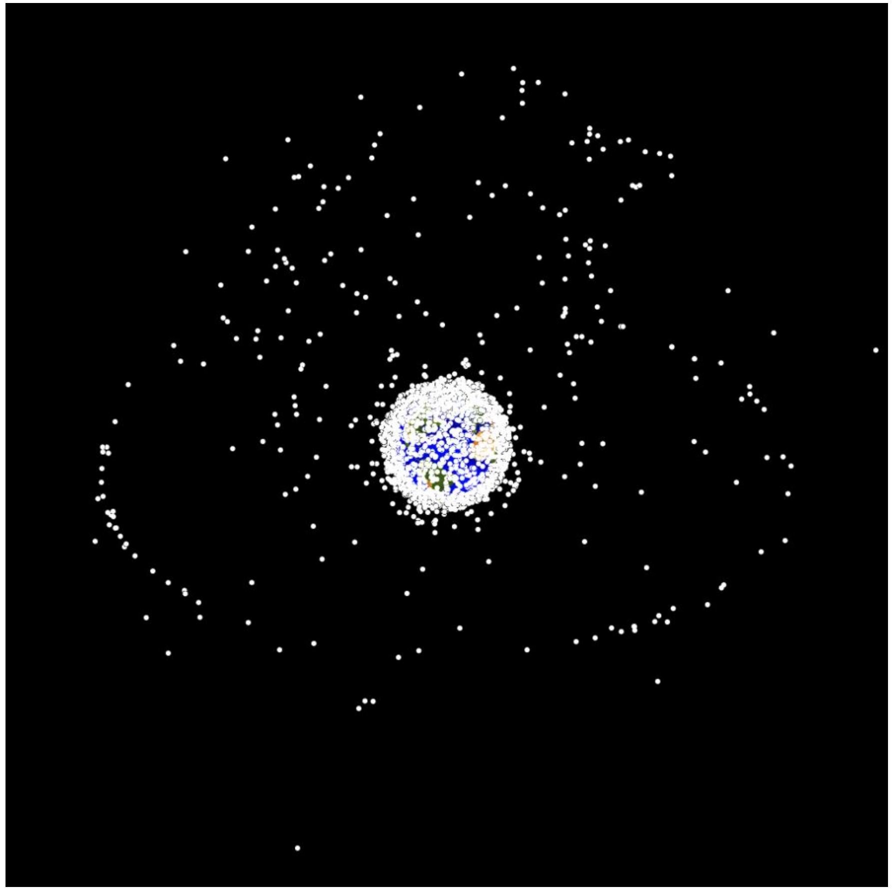




Cataloged objects >10 cm diameter

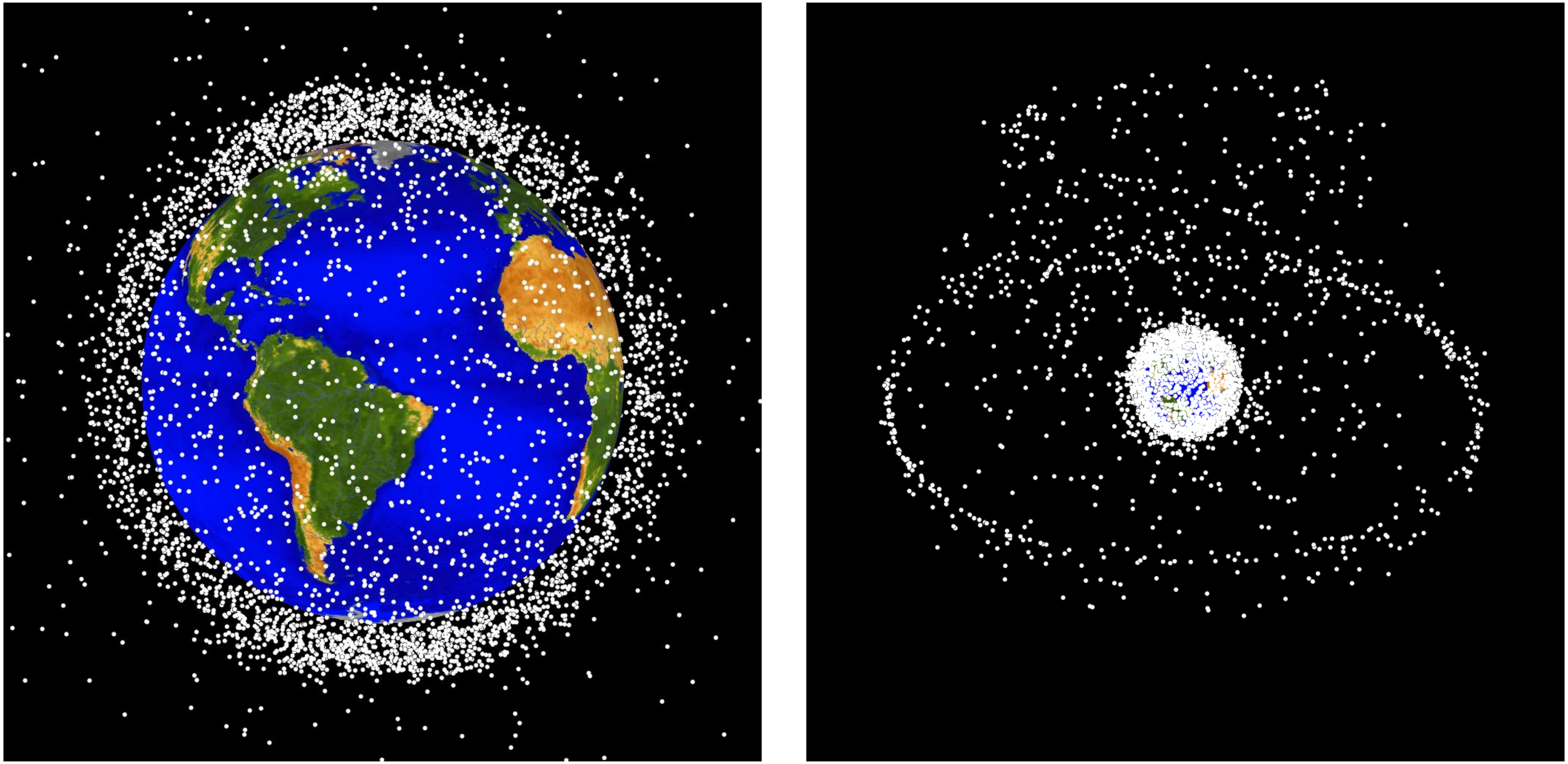
1980





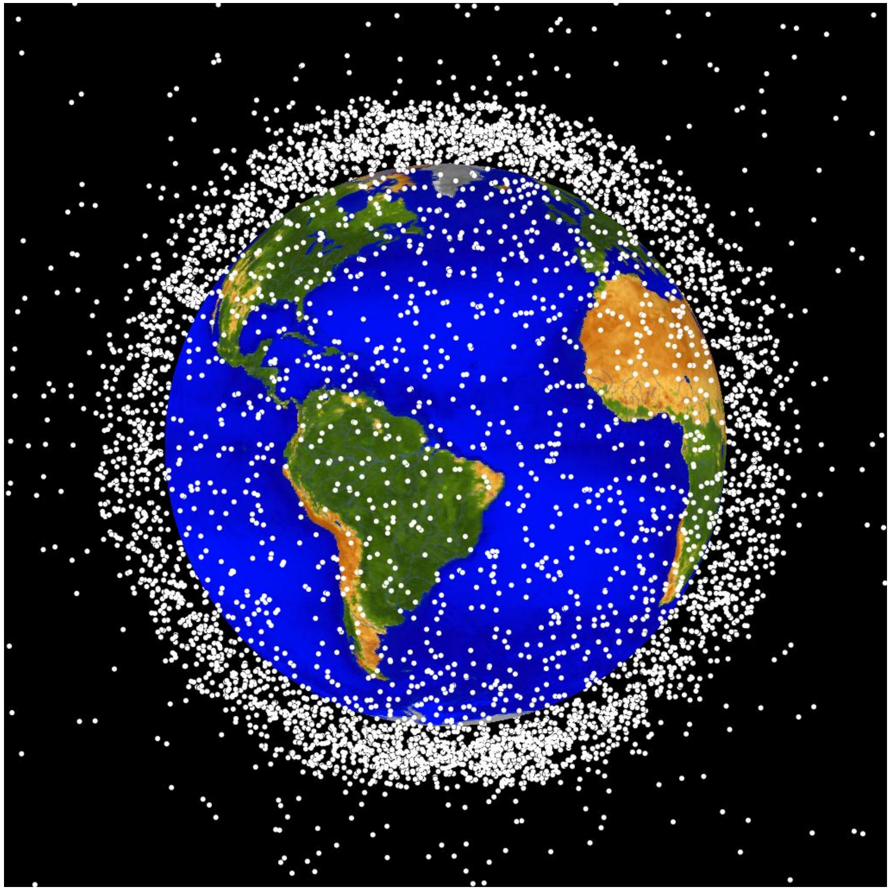
Cataloged objects >10 cm diameter

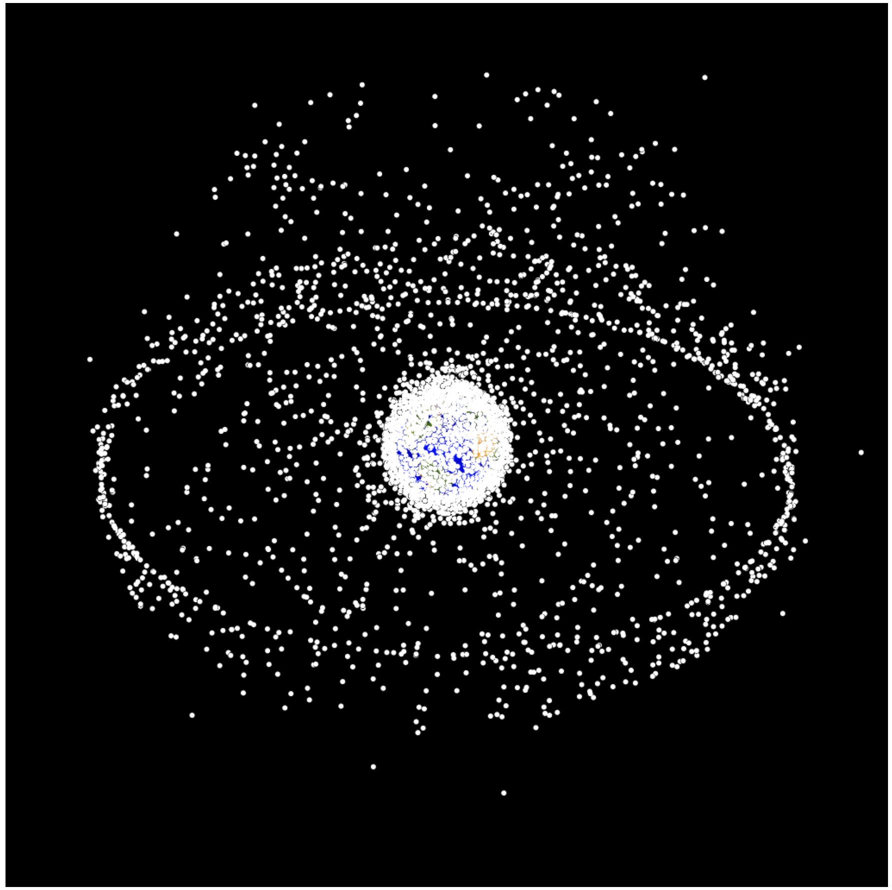
1990



Cataloged objects >10 cm diameter

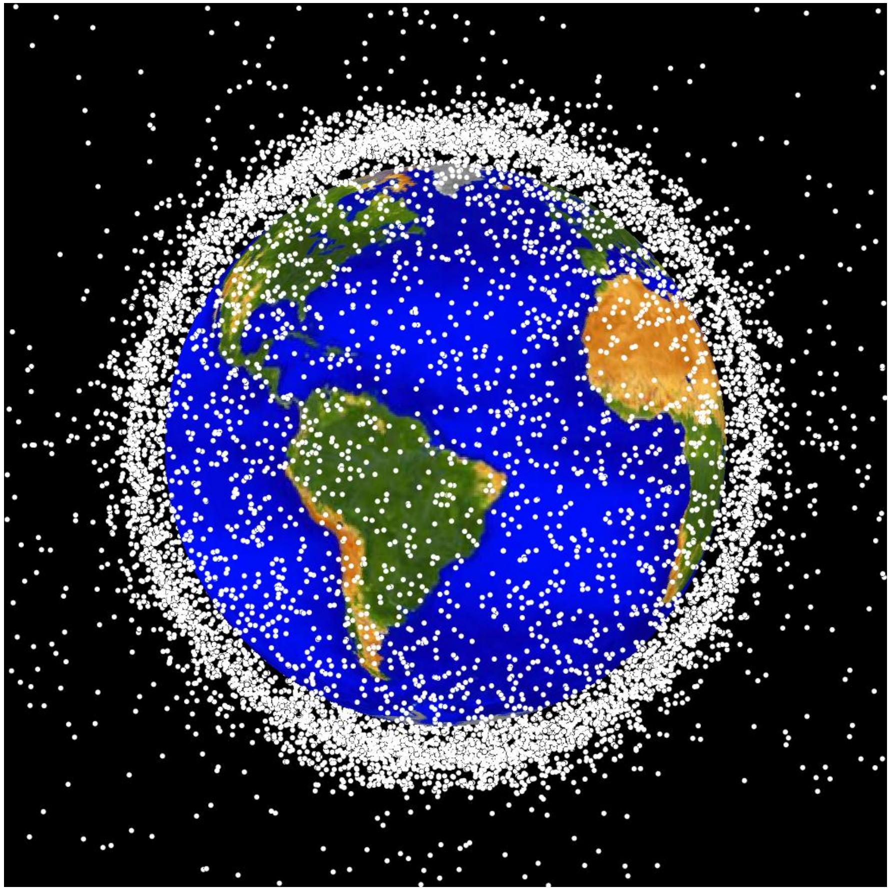
2000

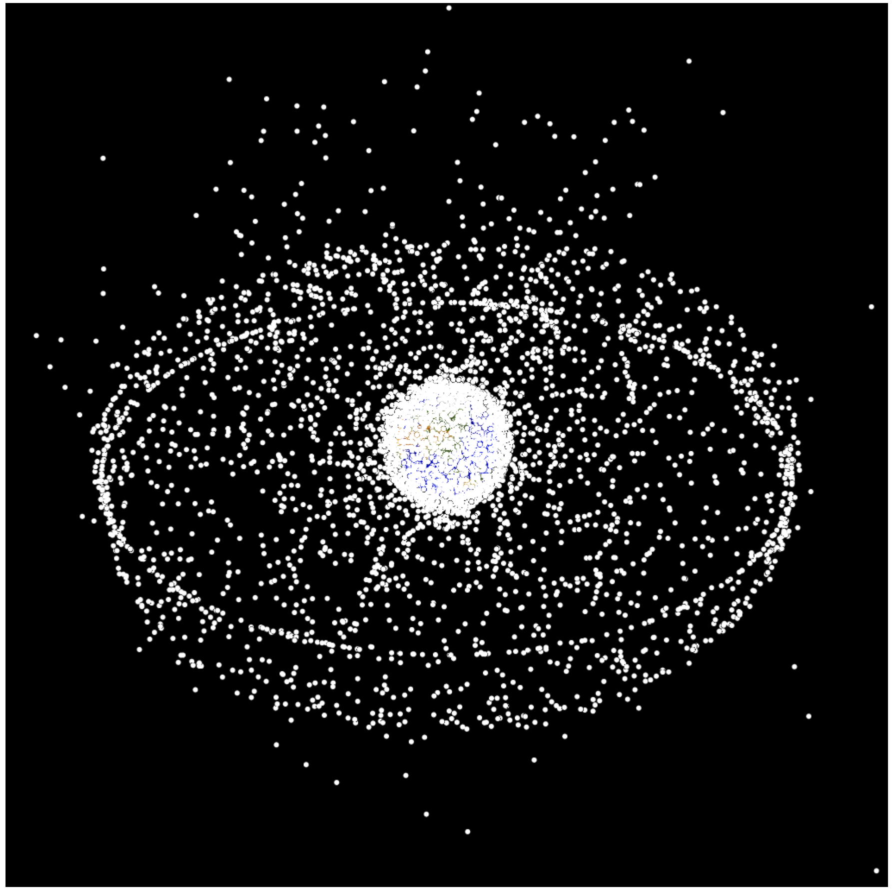




Cataloged objects >10 cm diameter

2010



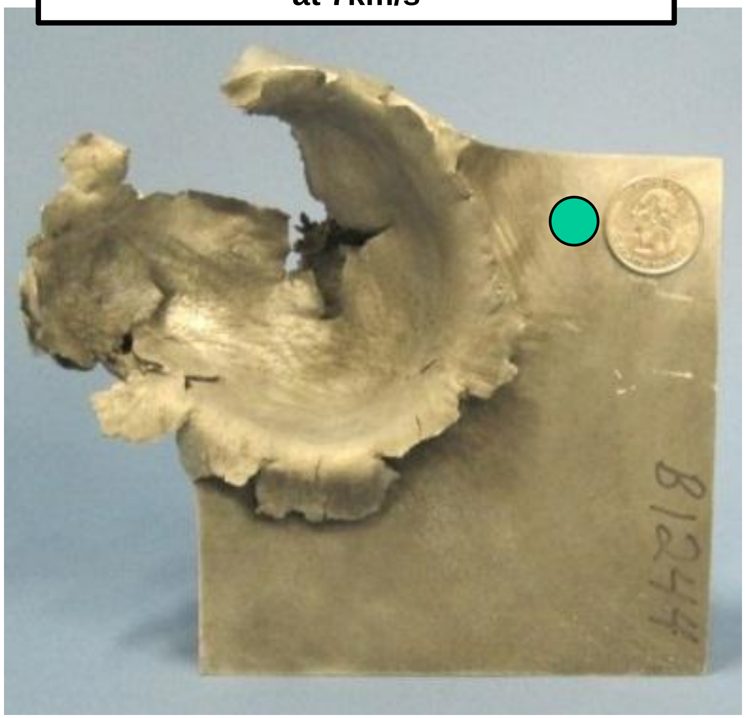


Cataloged objects >10 cm diameter

Effects of Micrometeoroid and Orbital Debris (MMOD) Impacts

- **Even small MMOD impacts can cause a lot of damage**
  - Hypervelocity MMOD impacts represent a substantial threat to spacecraft
  - Rule of thumb: at 7km/s, aluminum sphere can penetrate completely through an aluminum plate 4x the sphere’s diameter

Damage from a 1.3cm diameter sphere at 7km/s

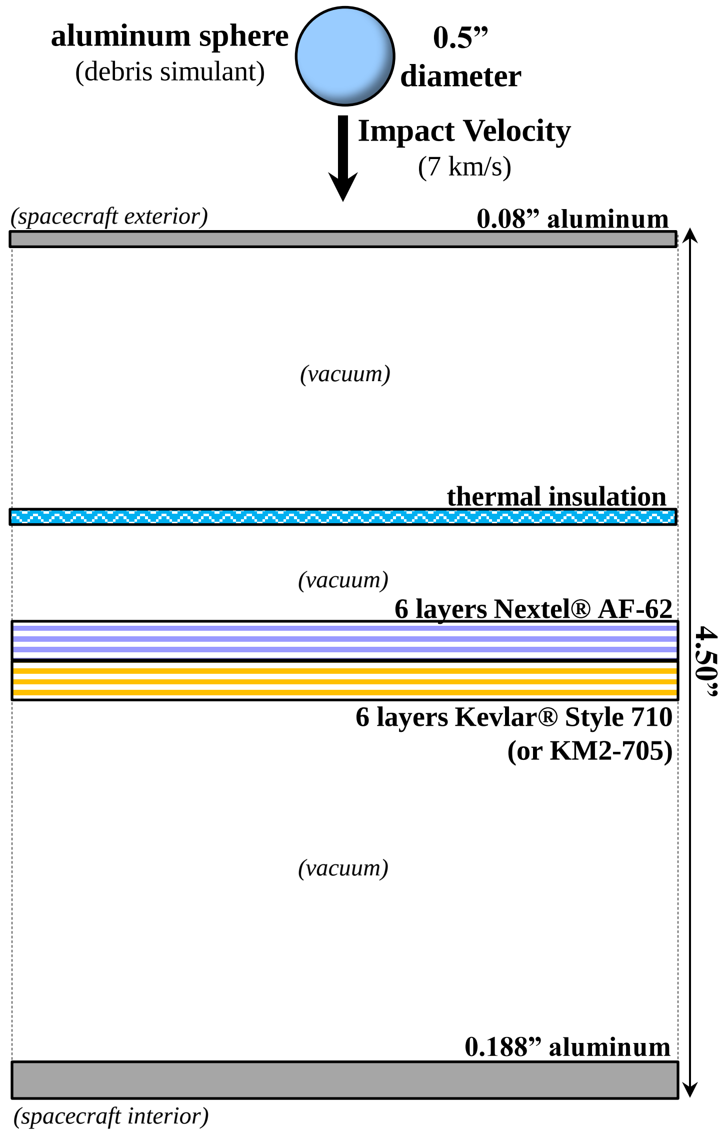


Comparison of size of projectile to size of impact crater

National Aeronautics and Space Administration

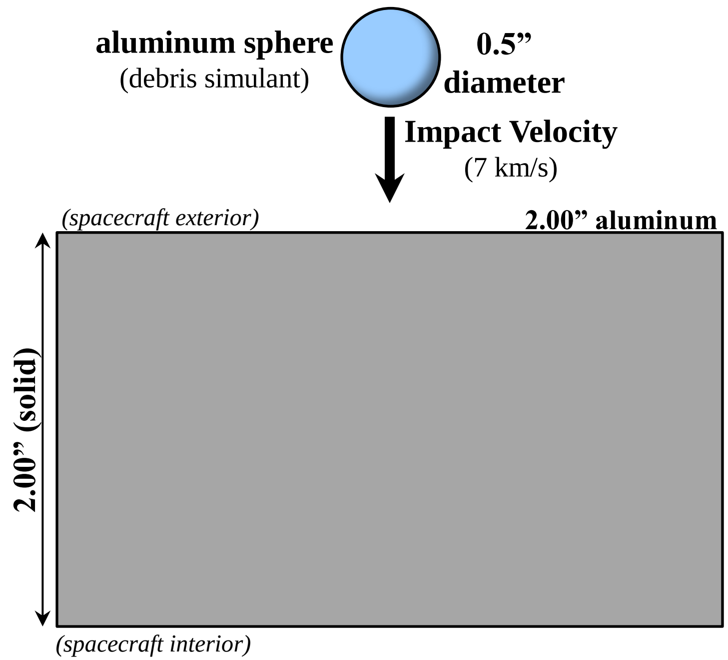
Monolithic versus Stuffed Whipple Shield
Weight Comparison of Equal-Performance Shielding

Stuffed Whipple Shield
4.5 pounds per square foot



Aluminum “Monolith” Shield
29.1 pounds per square foot

Scale: 1” = 1”

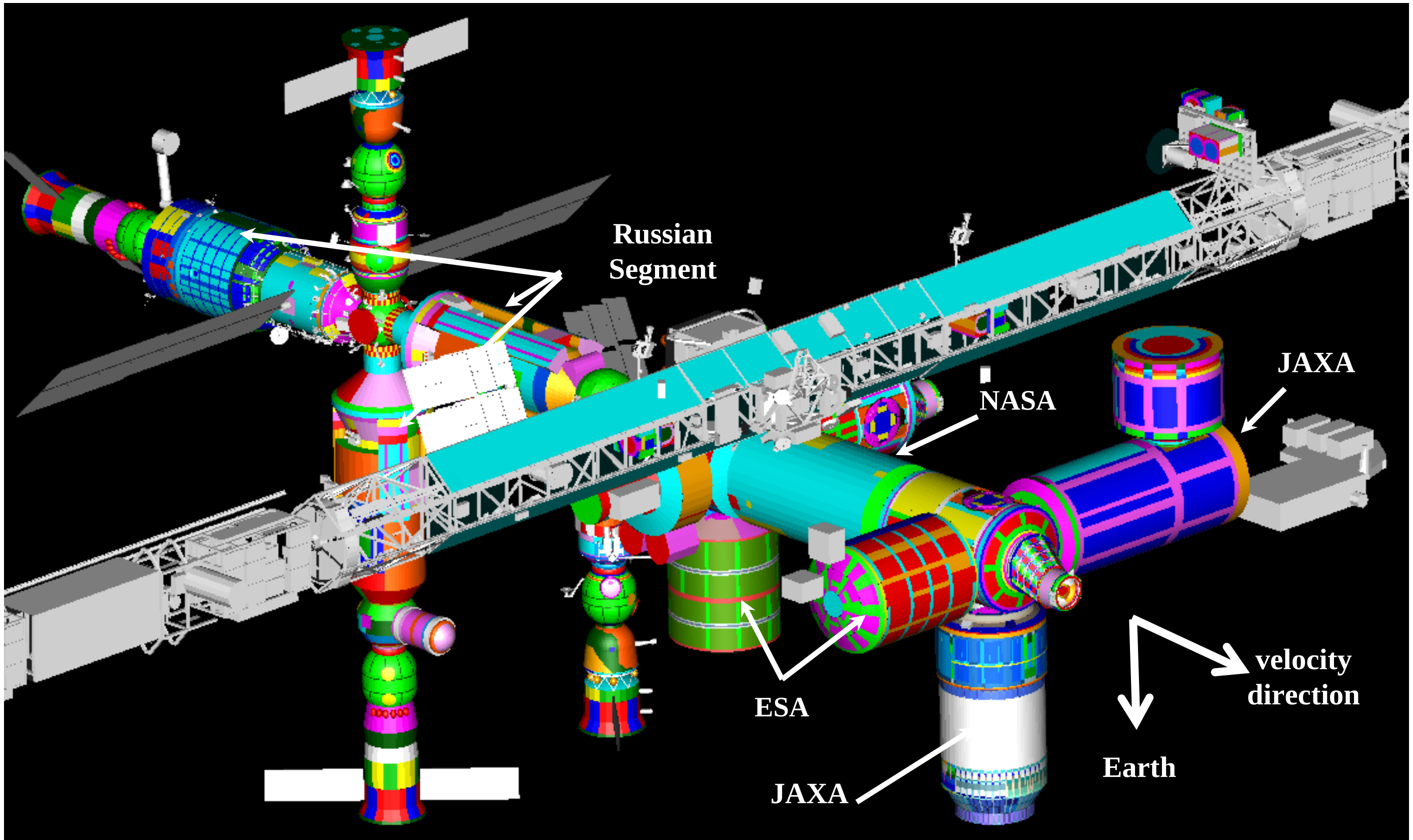


equal performance = 84% weight reduction

These shields can stop a 0.5” diameter aluminum debris projectile impacting at 7km/s, but the Stuffed Whipple shield weighs 84% less (94% if rear wall is excluded) and costs much less to launch to orbit

ISS shielding overview

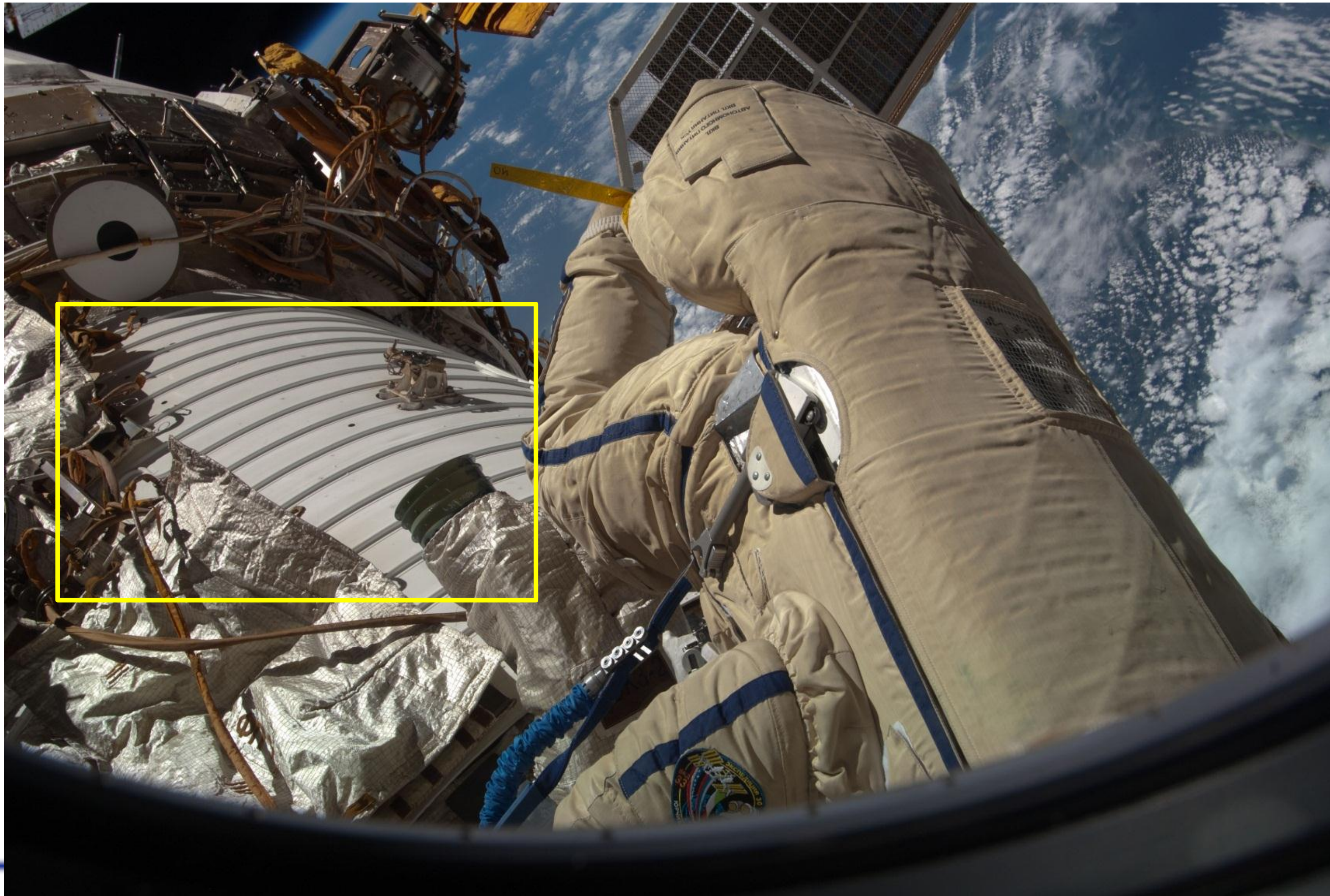
- Several hundred MMOD shields protect ISS, differing by materials, standoff distance, and capability
- Heavier shields on front & sides (where we expect most MMOD impacts), less capable shielding on aft, nadir and visiting vehicles



colors represent different MMOD shield configurations

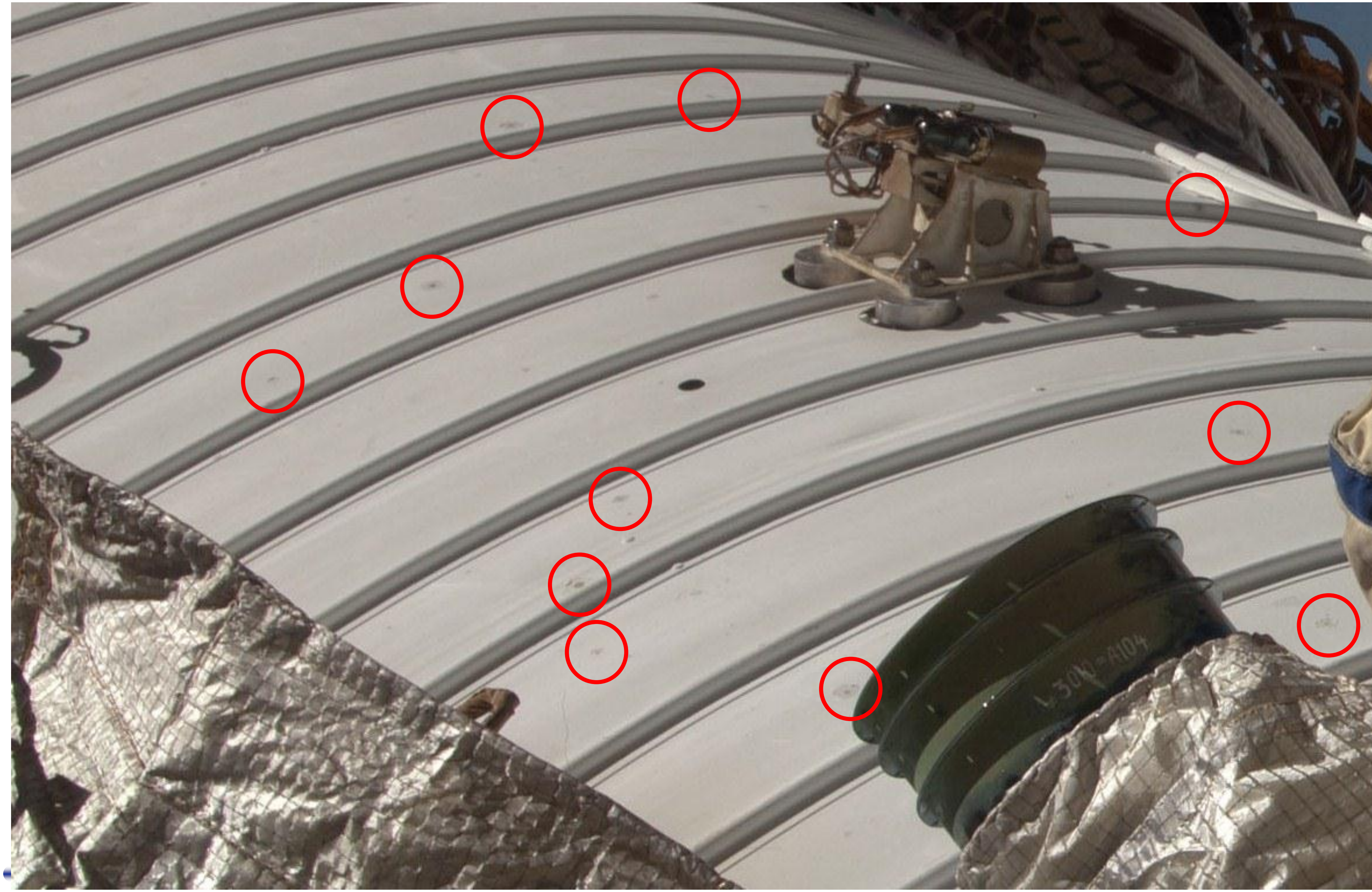
Issues: MMOD Damage to ISS Radiators

- **MMOD impact damages observed to ISS radiator panels during Russian EVA (June 2013)**



ISS036e011356

MMOD Damage to ISS Radiators



ISS036e011356

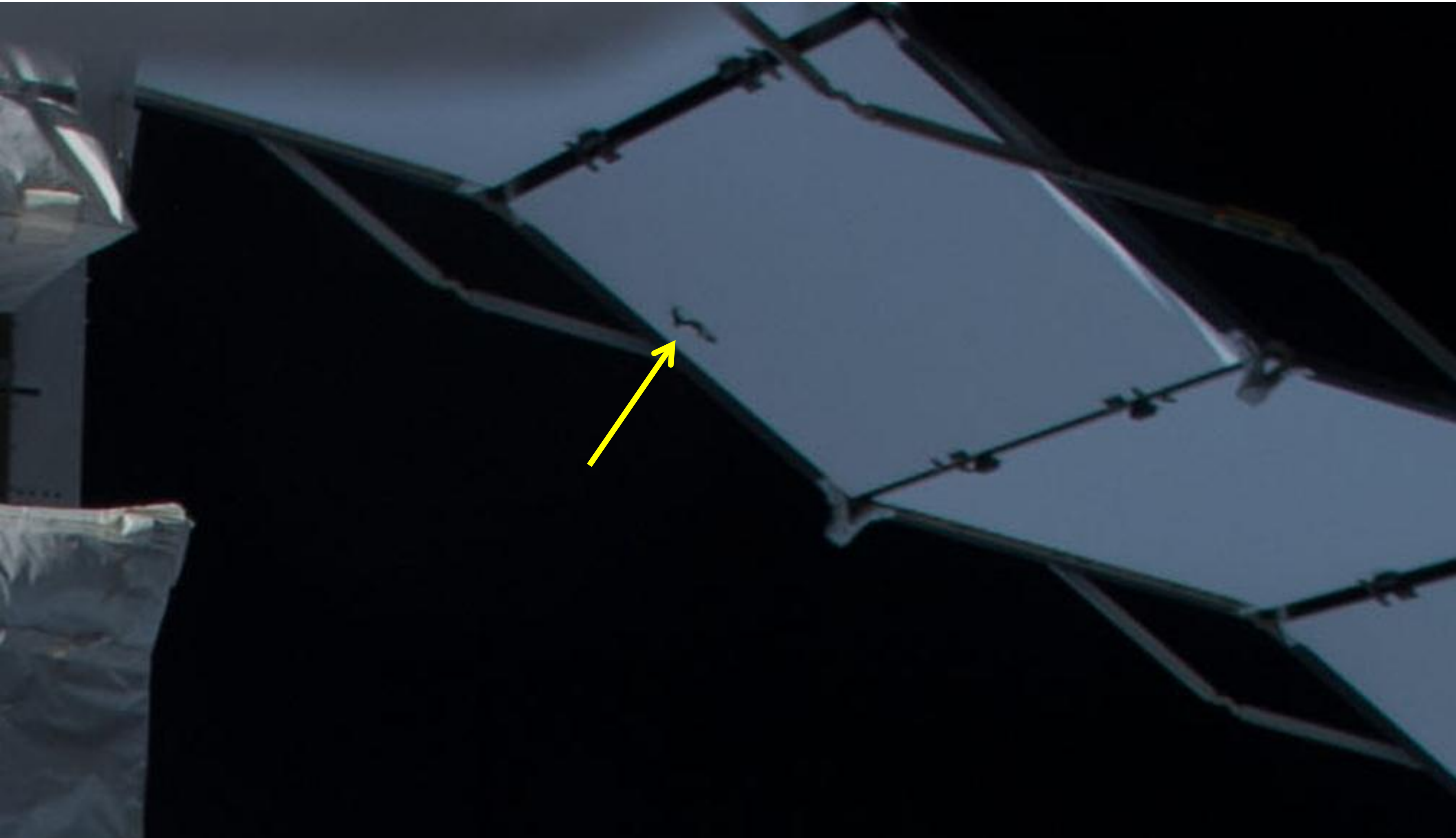
MMOD Damage to ISS Radiators (US)

- **MMOD impact damages observed to ISS radiator panels (Aug. 2013)**

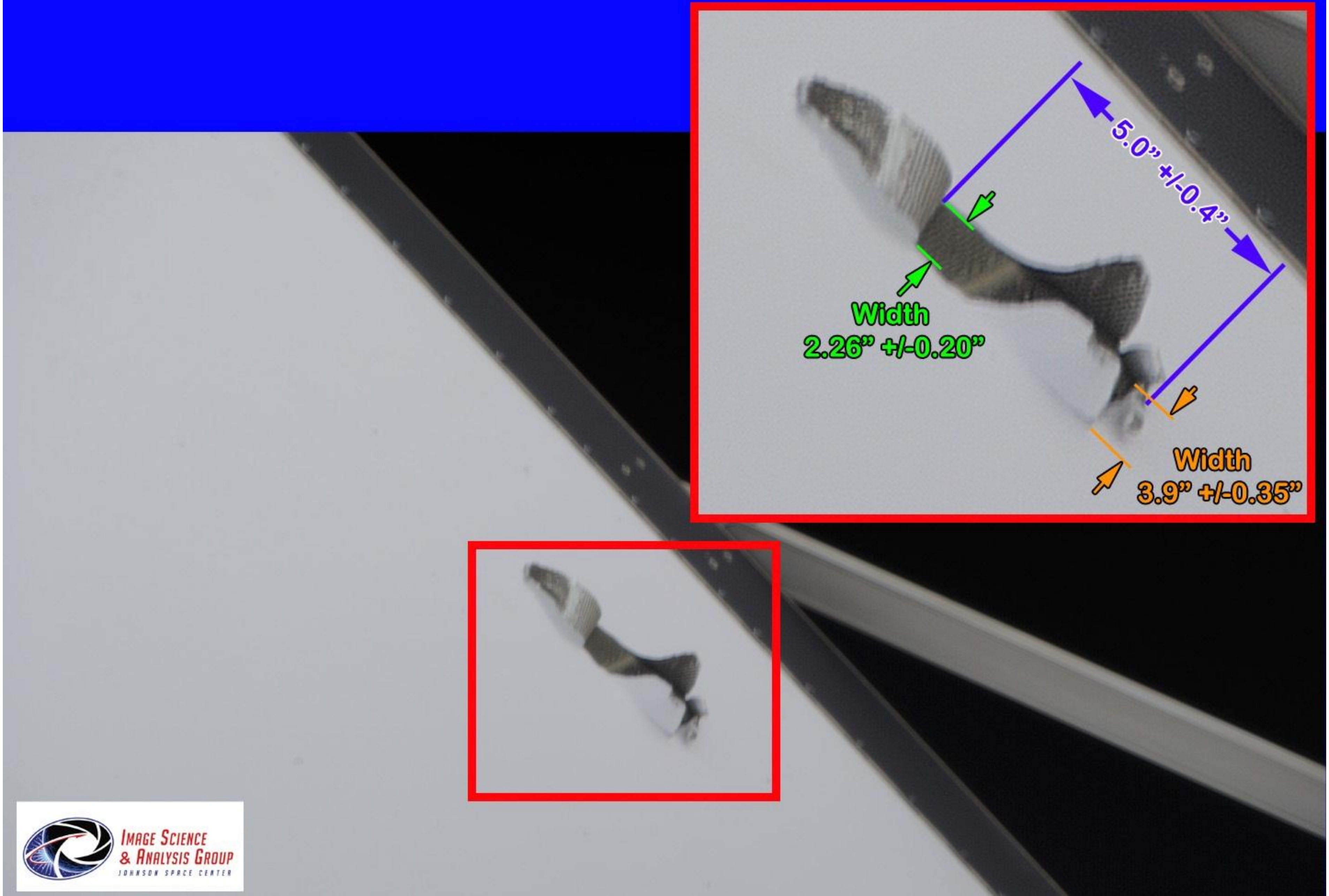
ISS036e037365

P4 photovoltaic radiator

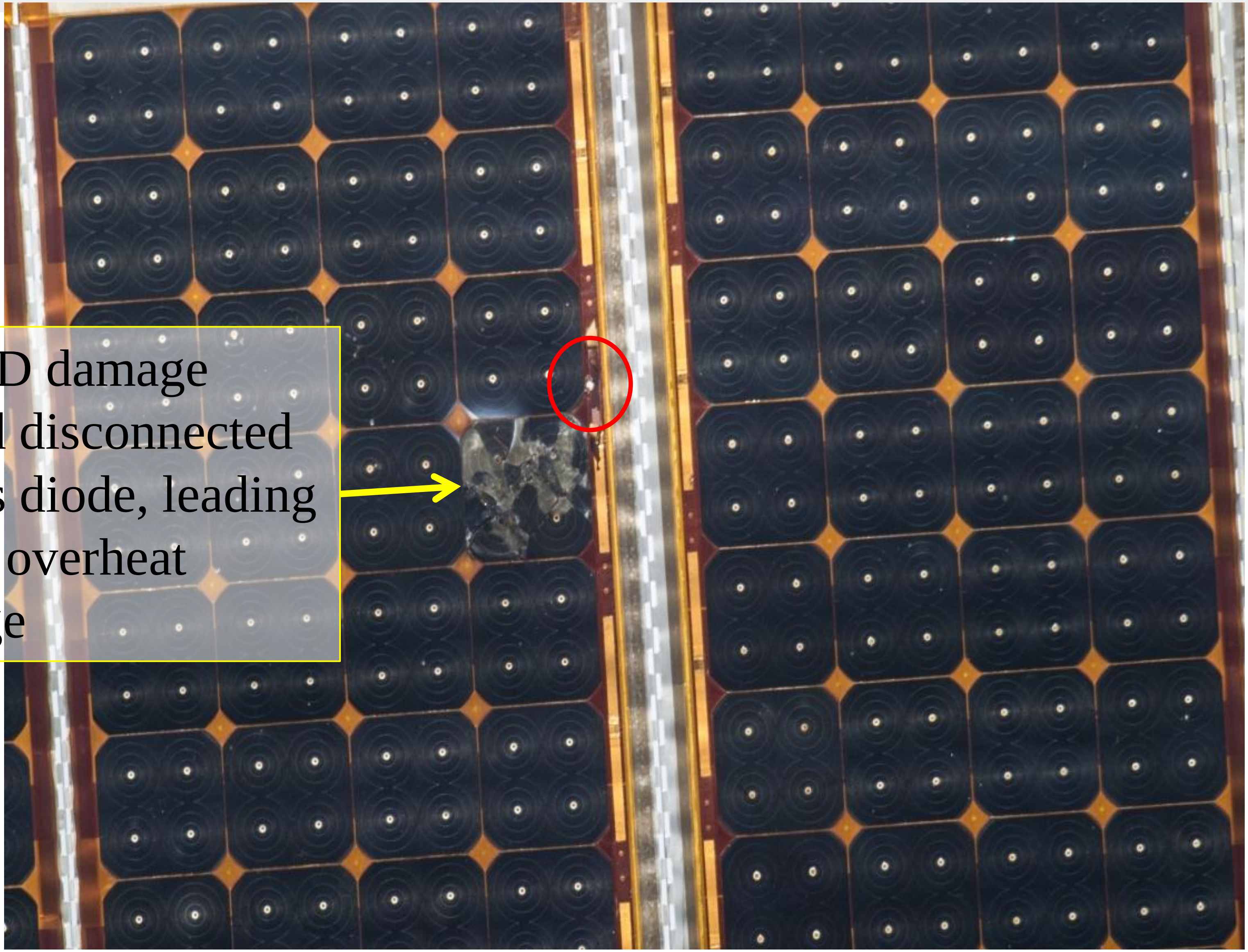
- **Initial indication found on 6/30/2014**



Measurement of P4-PVR Radiator Damage
“2A” Side of Panel 3



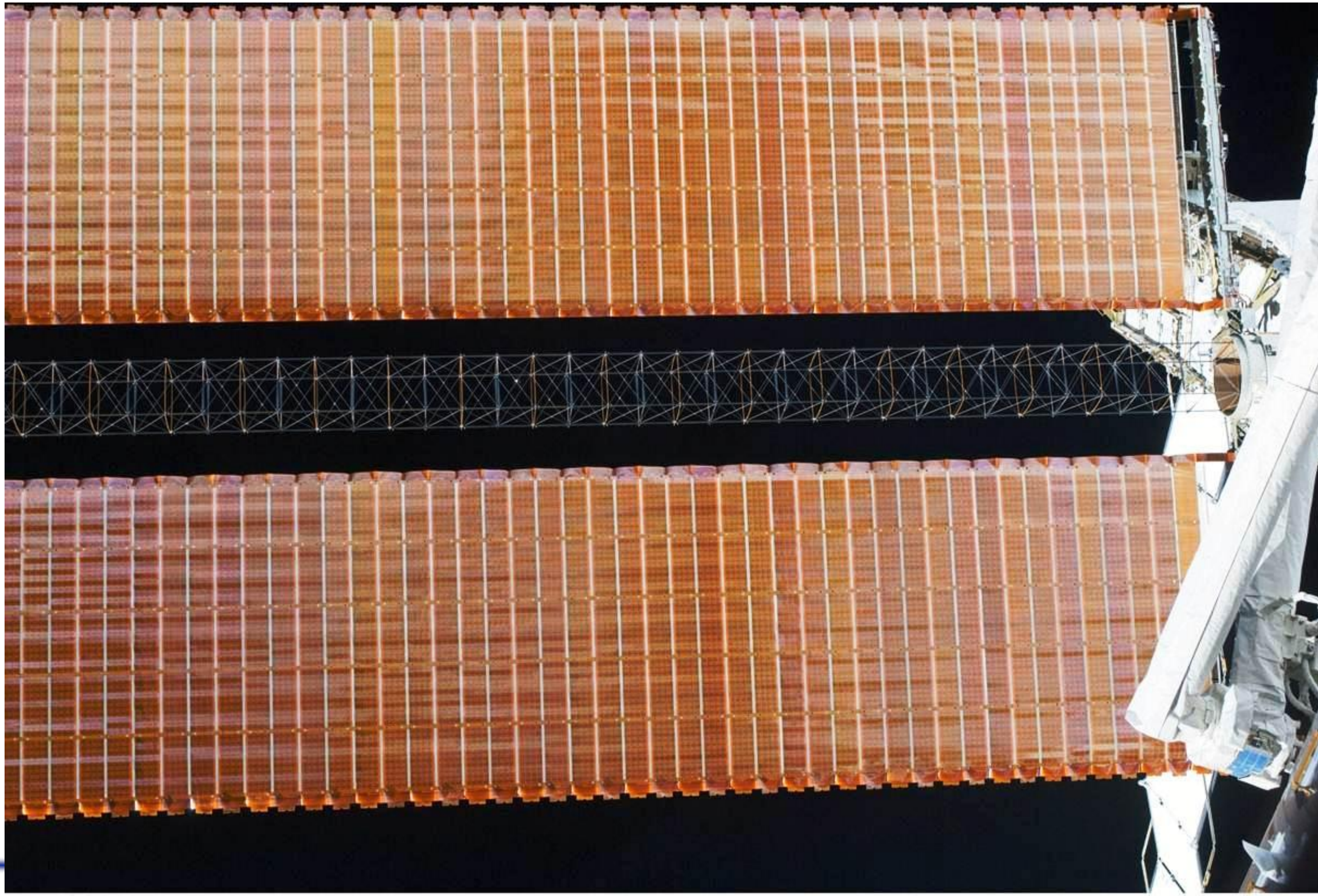
ISS Solar Array Damage



MMOD damage caused disconnected bypass diode, leading to cell overheat damage

ISS Solar Array Mast

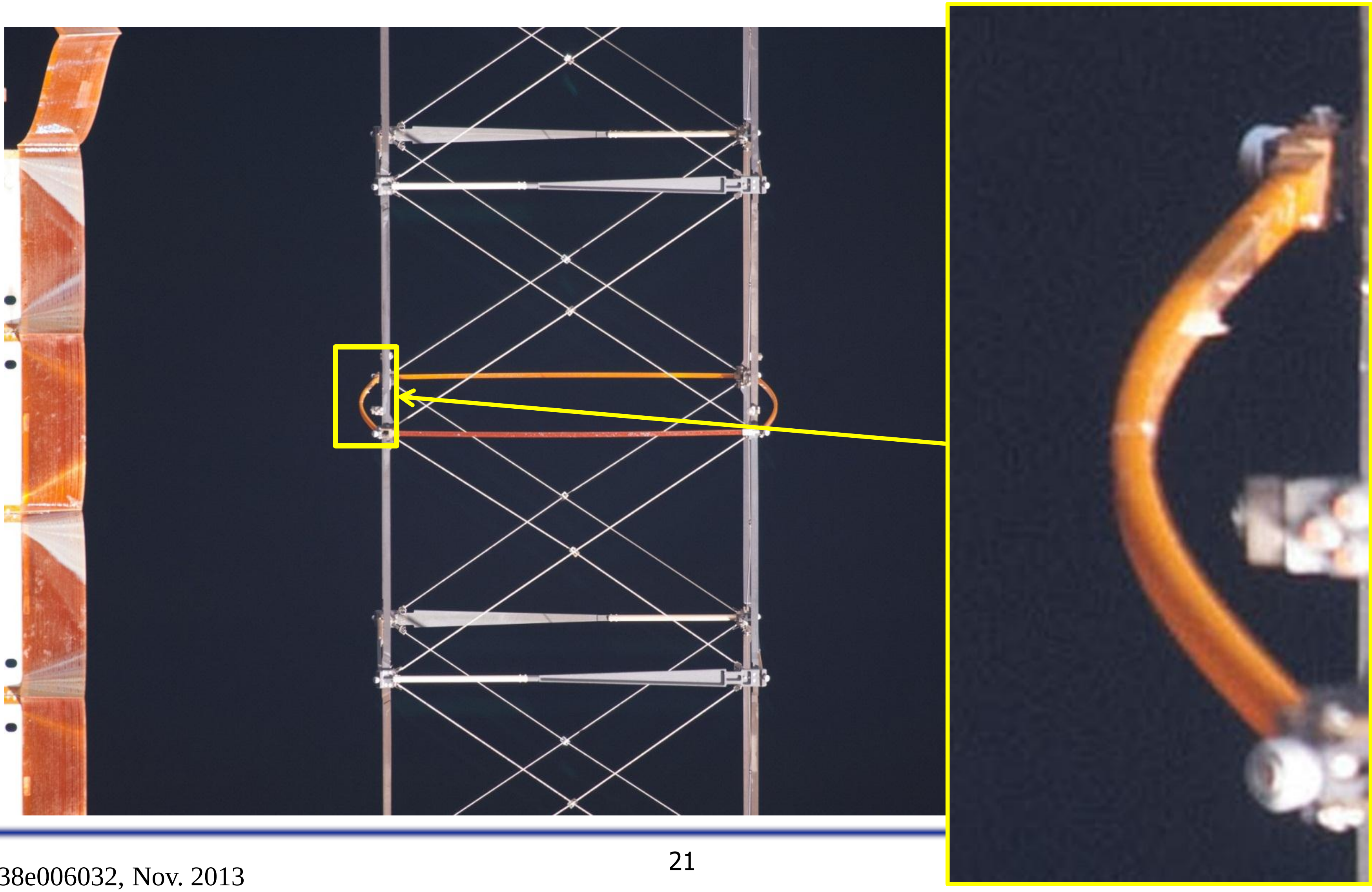
- **Deployable structural booms or masts used to support ISS solar arrays**



ISS022E067792

MMOD Damage to ISS Solar Array Masts

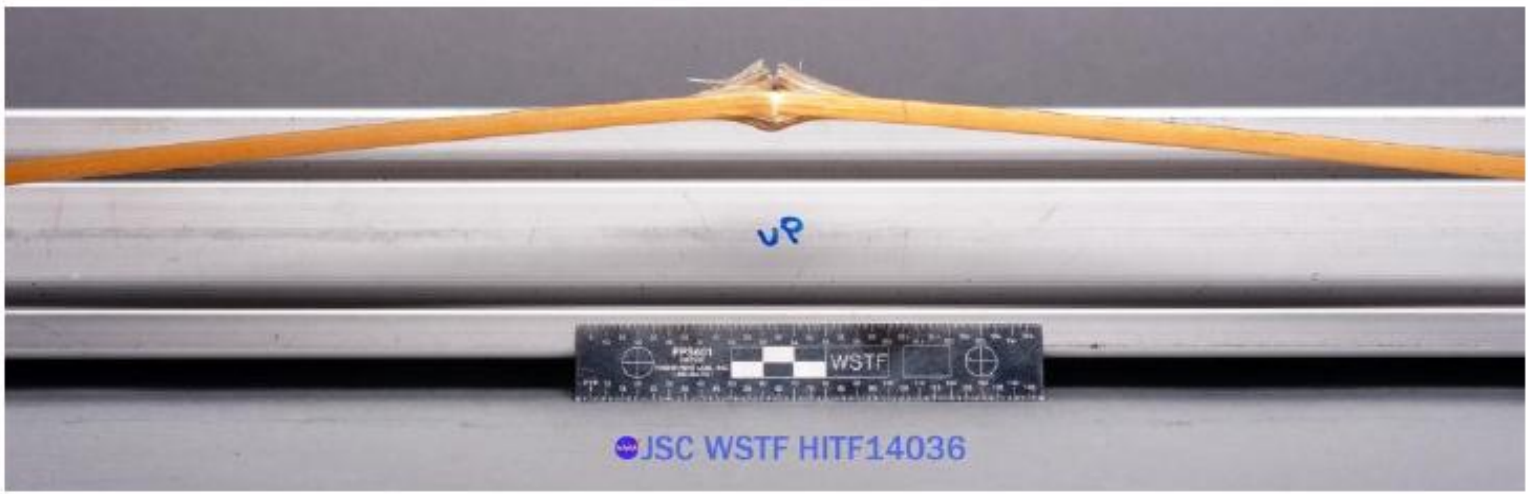
- **Elements of the solar array masts have been damaged from MMOD impacts**



ISS038e006032, Nov. 2013

Hypervelocity impact tests

- **Mast elements have been hypervelocity impact tested and structurally tested to assess residual strength for ISS life extension**

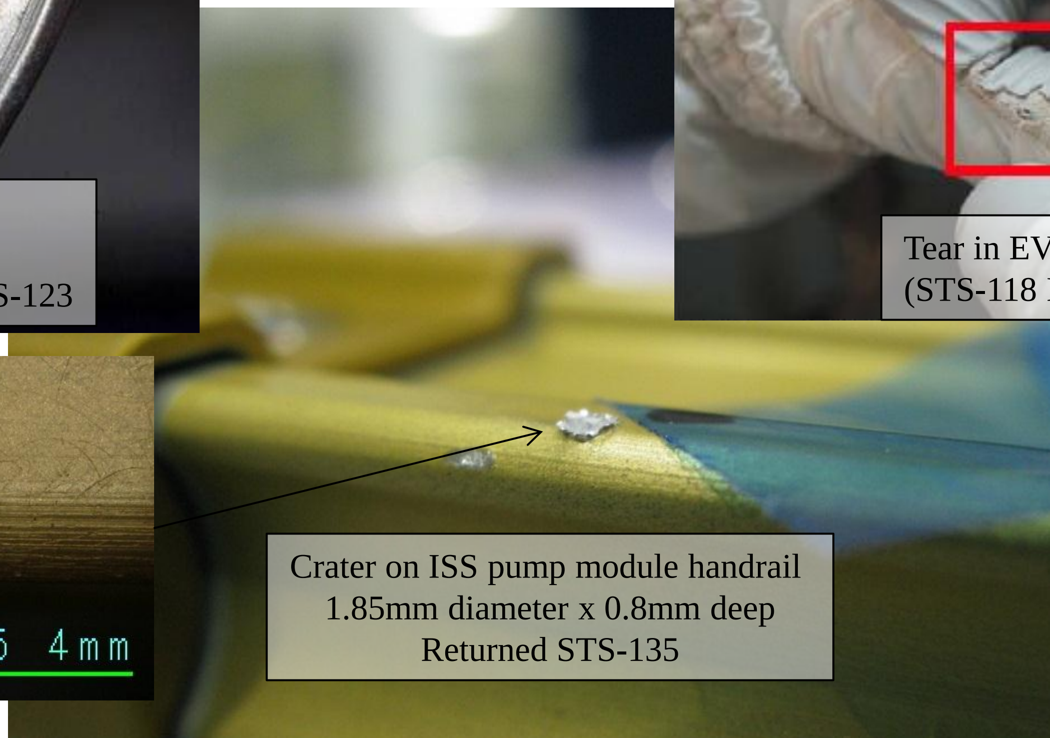


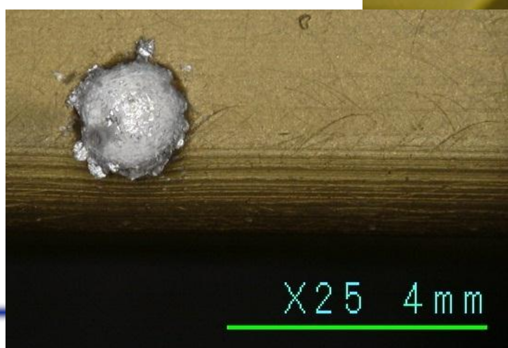
Handrail and EVA tool MMOD damage

- Many craters noted to ISS handrails and EVA tools
- Sharp crater lips have lead to cuts on EVA gloves
- EVA terminated early on STS-118 due to glove cuts
- Modifications to EVA suit and ISS EVA procedures necessary to reduce cut glove risk from MMOD damage

Crater on D-handle tool
5mm diameter
Repaired on-orbit during STS-123

Tear in EVA glove
(STS-118 EVA#3)

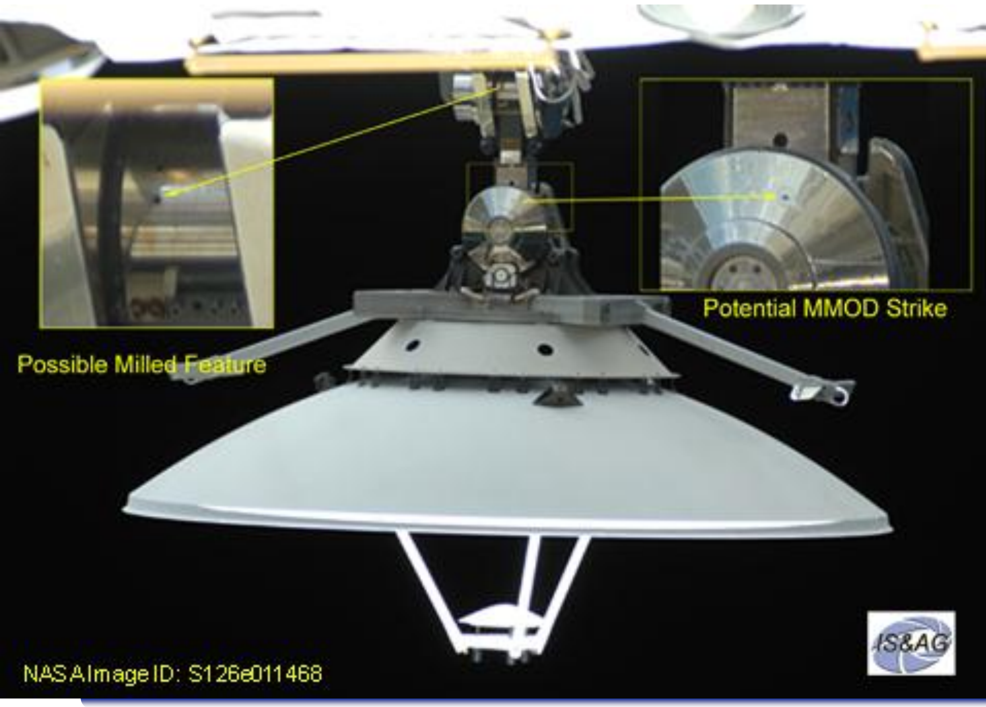


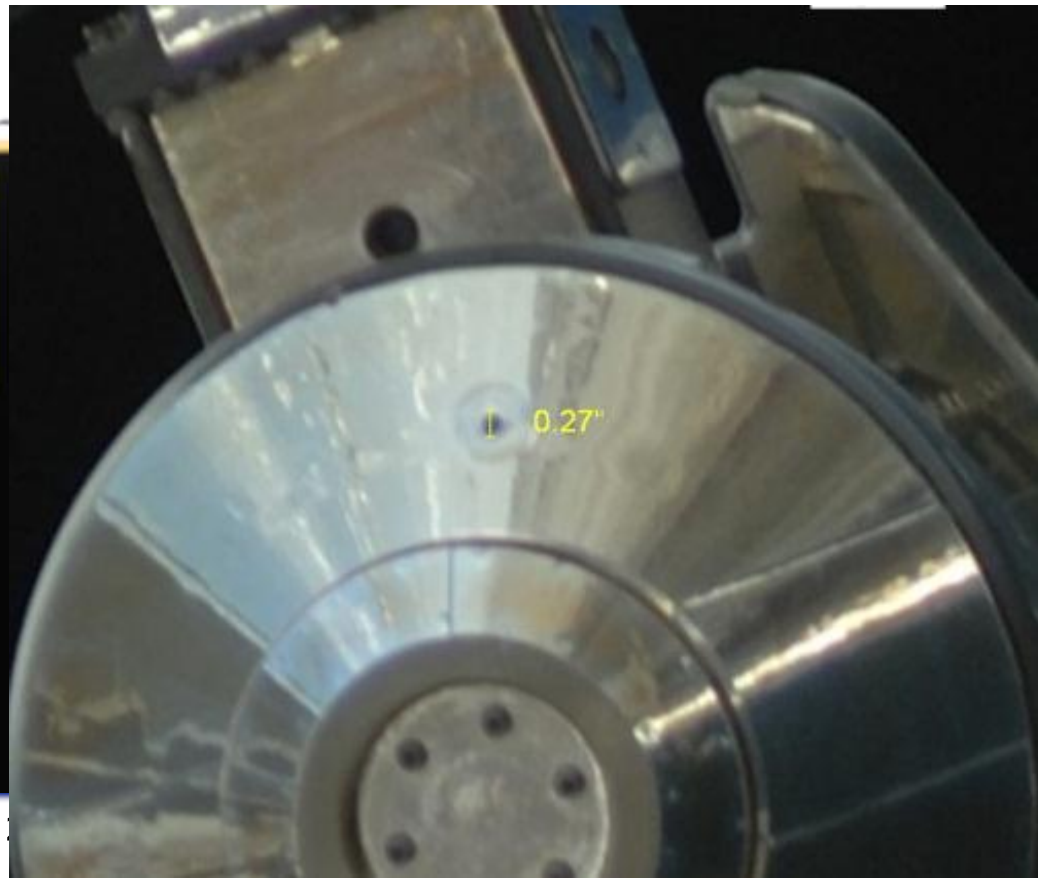


Crater on ISS pump module handrail
1.85mm diameter x 0.8mm deep
Returned STS-135

Ku-band antenna

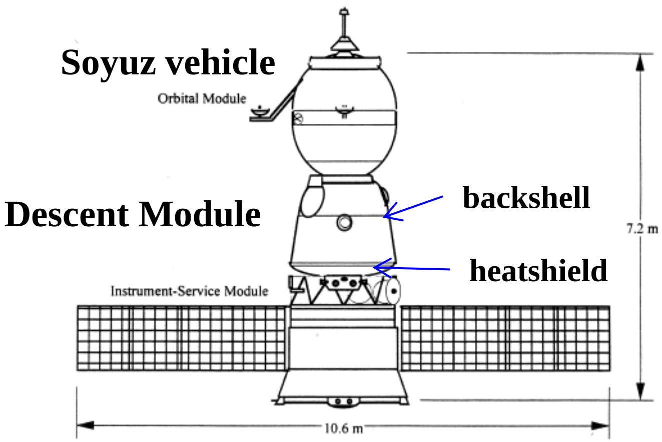
- **An MMOD Strike was seen on the ISS Ku Antenna Gimbal Gear Cover. The image was captured during Mission ULF2 / STS-126.**
- **Interior damage?**





Thermal protection systems (TPS) for crew return vehicles

- **MMOD risk to thermal protection system (TPS) of ISS crew return vehicles (Soyuz, Commercial vehicles) is high**
  - Concern is TPS damage that can lead to loss-of-vehicle during reentry
  - Issue can be mitigated by inspection and repair or safe-haven (not Program baseline)

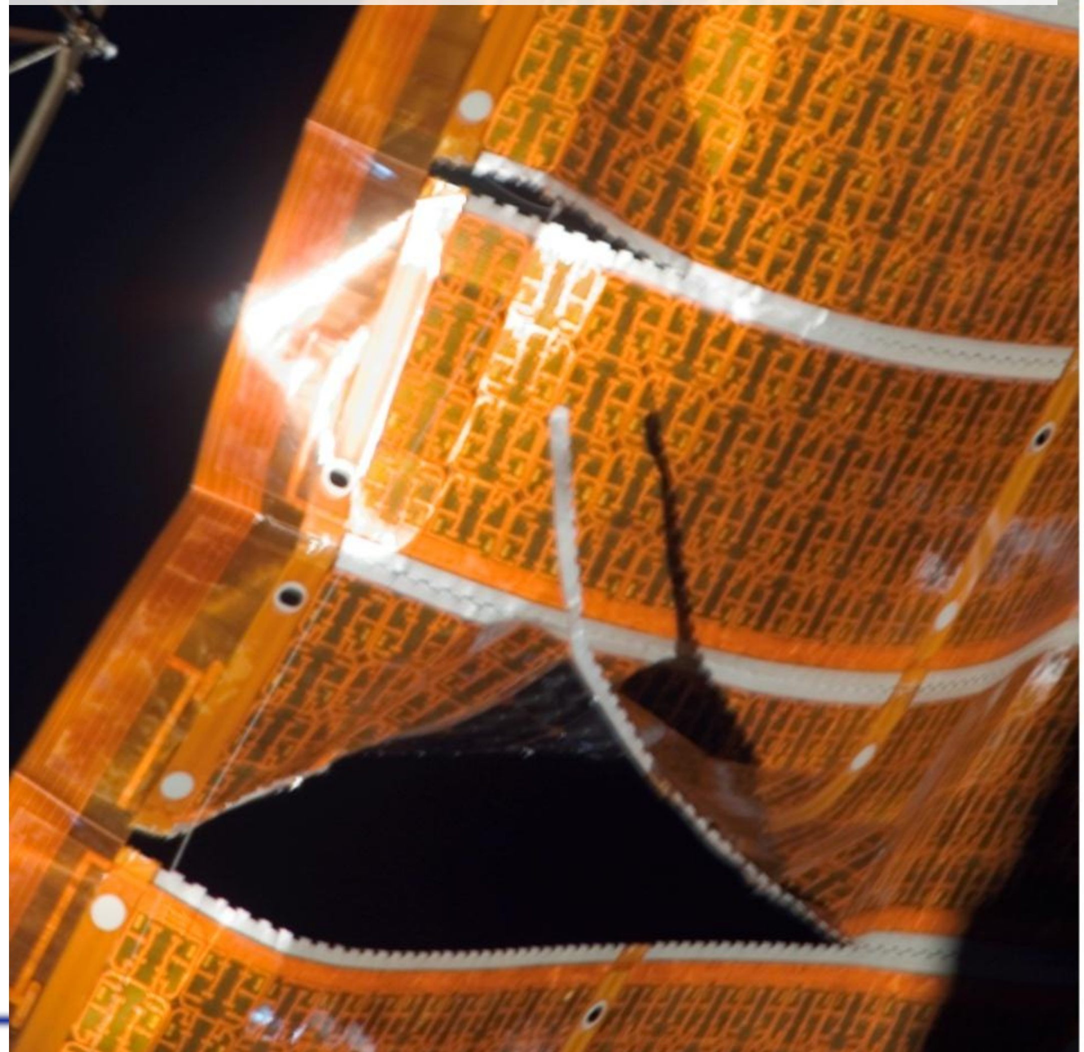


BACKUP CHARTS

STS-120 Solar Array Wing (SAW) EVA repair was caused by MMOD impact damage

During STS-120 two solar array wings were removed from Z1 truss and relocated to P6 location. During re-deployment, the 4B solar array wing was torn in two places, due to a snagged guide wire. The guide wire was removed and "cuff-links" added to stabilize the array.

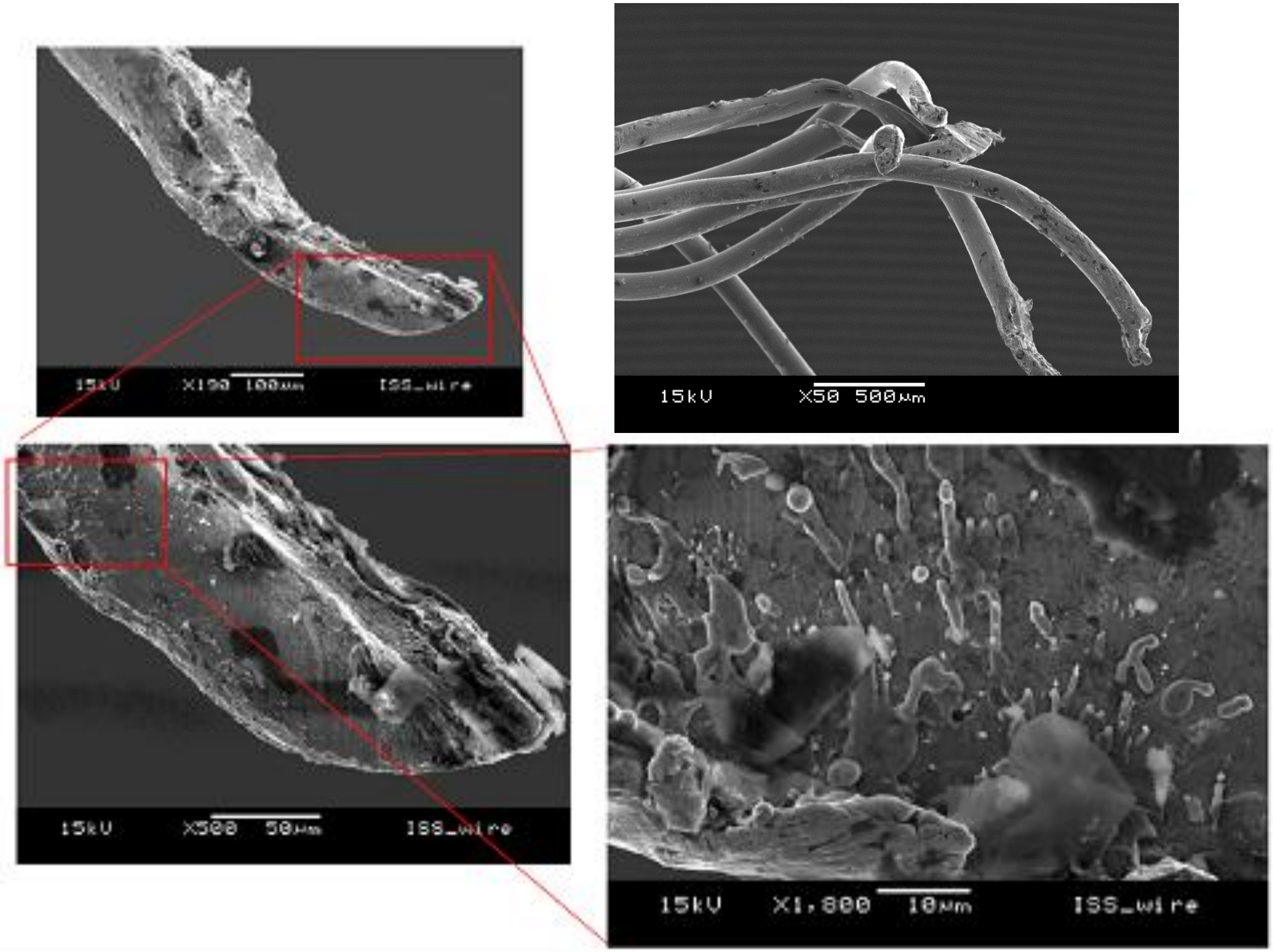
ISS016E009184



S120E008247

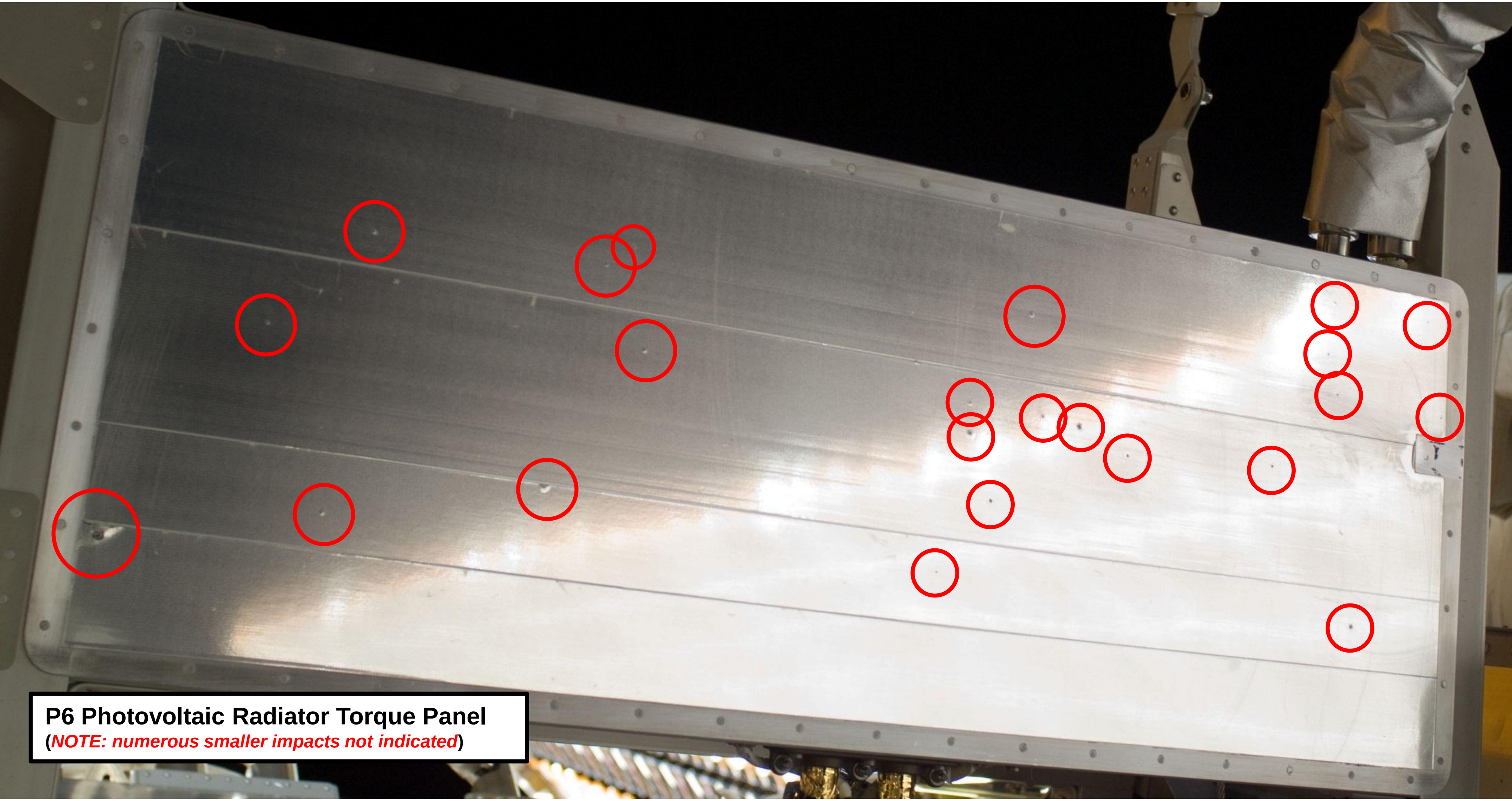
Scanning Electron Microscope EDXA Evaluation of retrieved guide wire

7 of 21 wires in the guide wire cable were broken, causing the guide wire to hang-up in a solar array grommet.
3 of the 7 cut wires exhibited evidence of extensive melt at broken ends, indicative of MMOD impact.



MMOD Damage to ISS

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

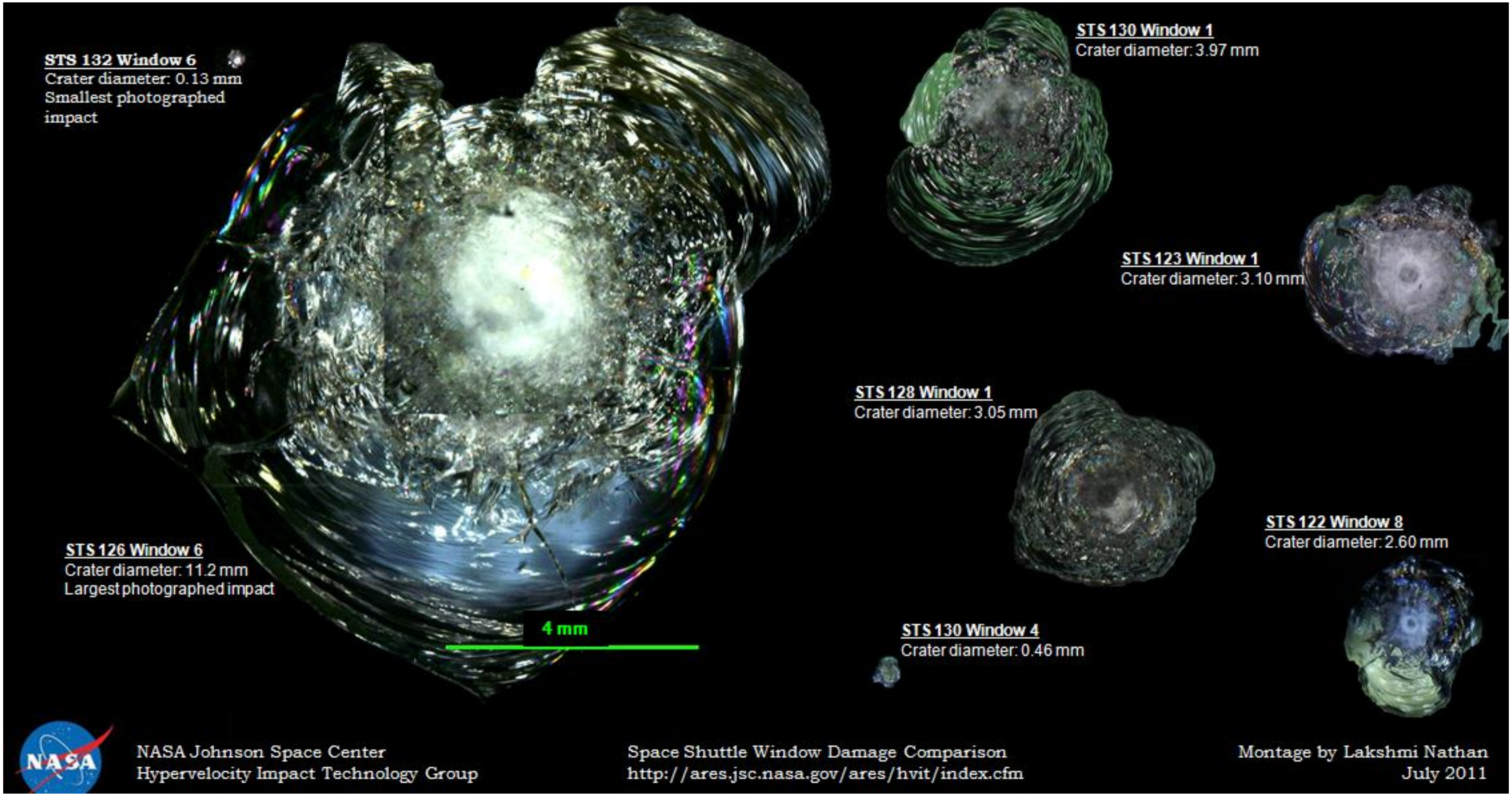


P6 Photovoltaic Radiator Torque Panel
(*NOTE: numerous smaller impacts not indicated*)

ISS033e017859

Observed Spacecraft MMOD Impacts

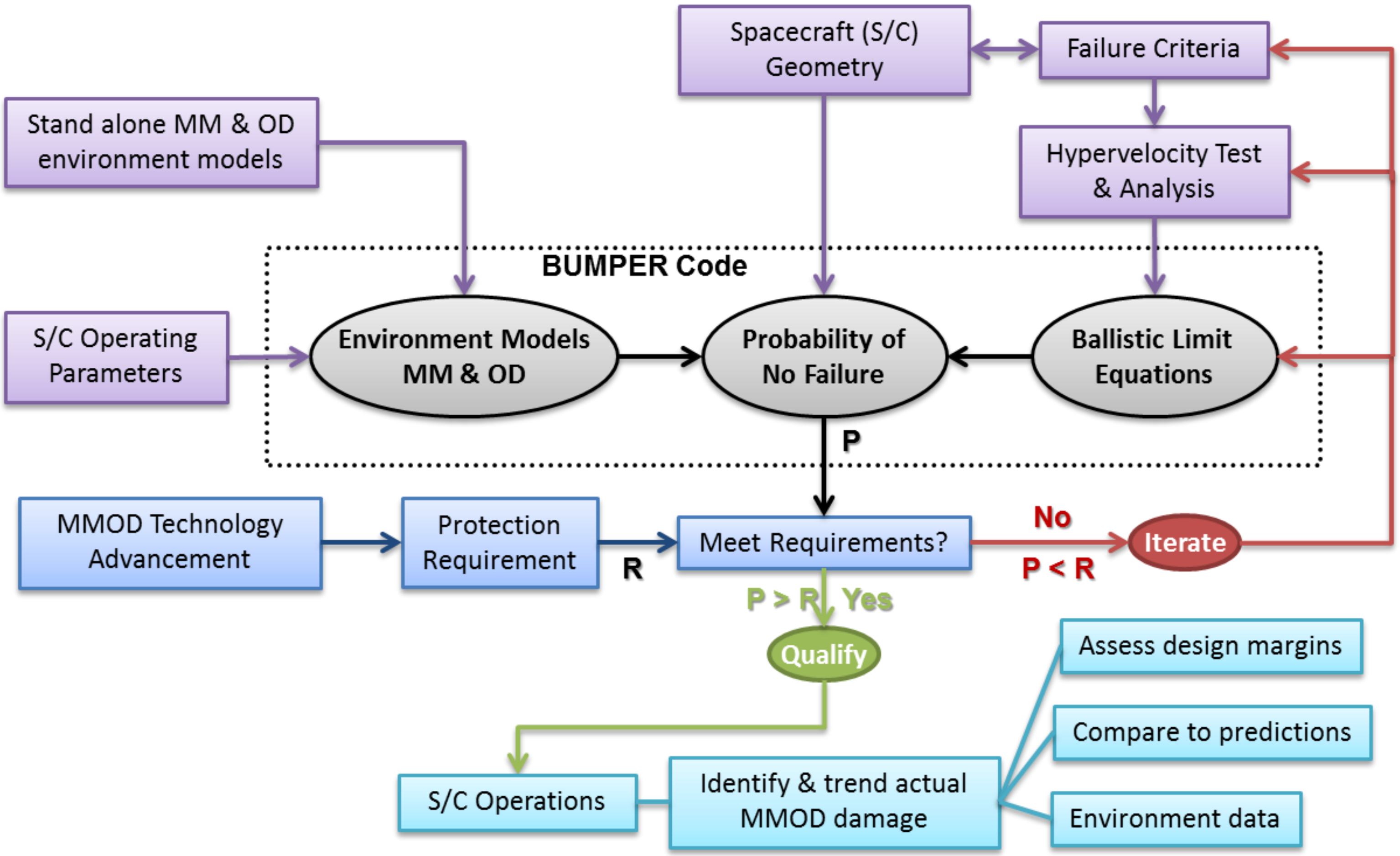
Shuttle Windows



Sampling of Shuttle Window MMOD Impact Craters
(all displayed on same dimensional scale)

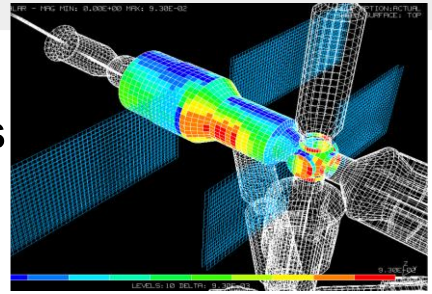
MMOD Risk Assessment Process

- **Process used to identify MMOD risk drivers, evaluate risk mitigation options & optimization, verify compliance with protection requirements**



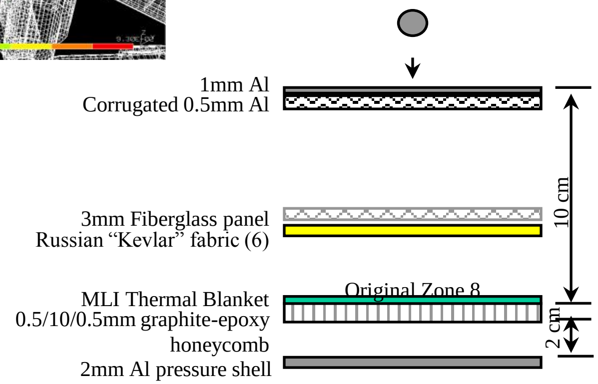
ISS Service Module Shielding

- **Service Module (SM) identified as high penetration risk using Bumper risk analysis**
  - large cone region
  - forward sides of small diameter cylinder
- **Shields designed and tested, EVA installed**
  - 23 augmentation shields for the cone region
  - 5 augmentation shields for the cylinder region
- **28 shields reduced SM MMOD risk by 30%**

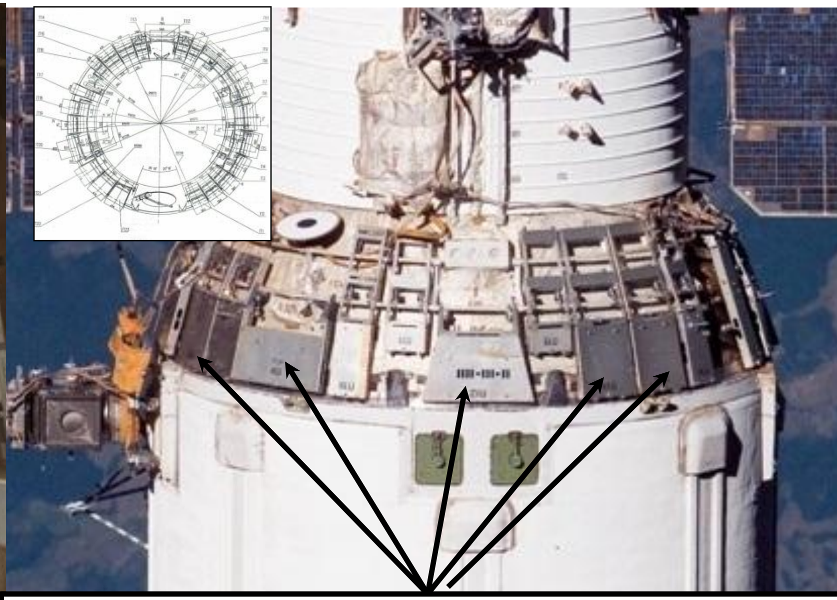


High-risk (red)
Low-risk (blue)

SM "conformal" augmentation shield



EVA Installation



23 "conformal" panels on cone region

5 panels on small diameter cylinder