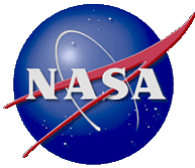


# Micrometeoroid and Orbital Debris Environment & Hypervelocity Shields

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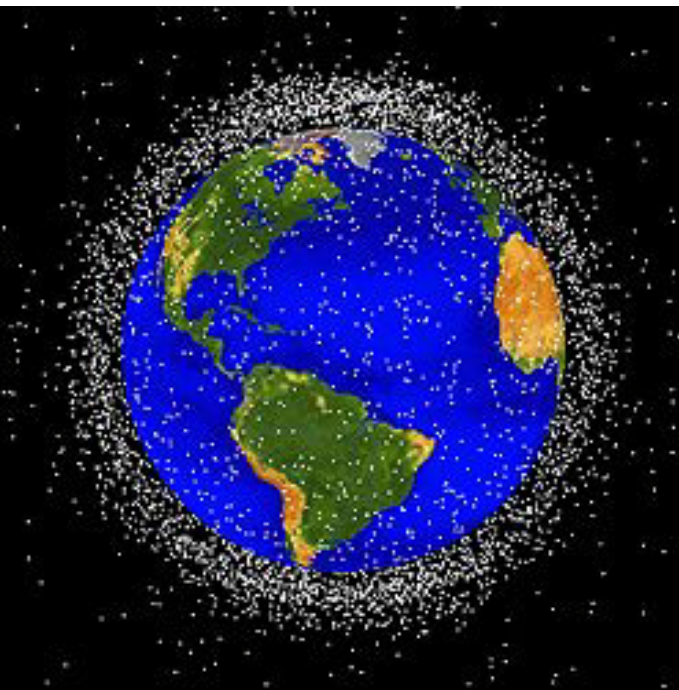
# Purpose of this presentation

- Provide background on micro-meteoroid & orbital debris (MMOD) shielding protection
  - MMOD environment
  - MMOD protection requirements
  - Shielding approaches

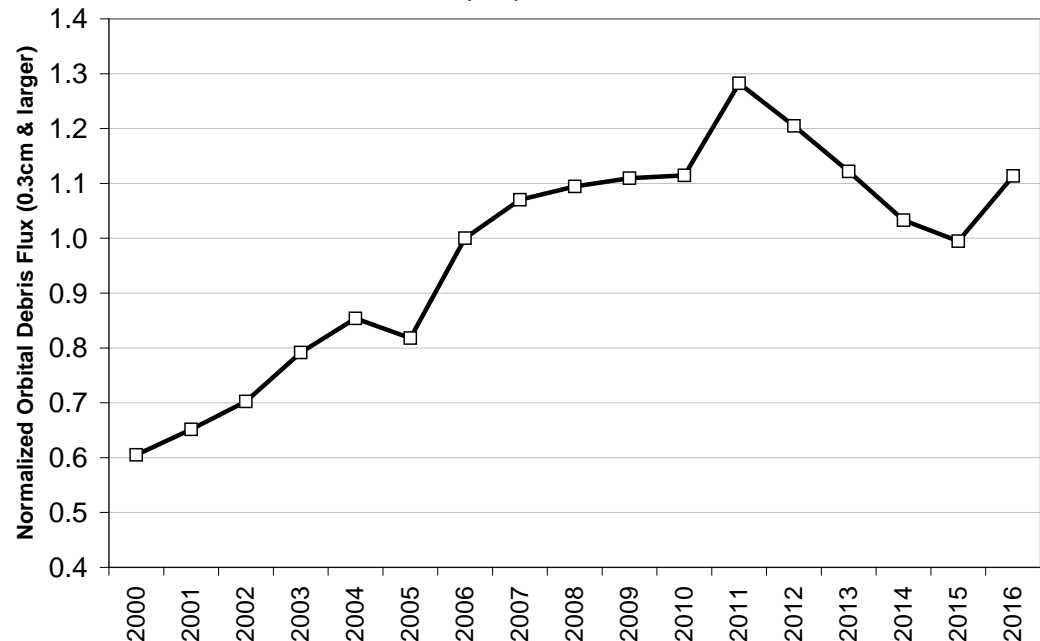
# MMOD Environment Models

- Orbital Debris (OD) environment models
  - Orbital Debris environment (ORDEM2000): 1-17 km/s
    - Debris flux increases with increasing altitude up to about 1500km altitude
    - Debris is not a major factor above GEO altitude (35786km)
  - Debris environment subject to change (ORDEM 3.0 release pending)

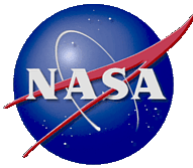
Orbital Debris in Earth Orbit



Normalized Orbital Debris Flux by Year at ISS Altitude  
For Threat Particle Sizes > 0.3cm  
(Normalized to 2006 flux)  
Note OD Risk is proportional to Flux

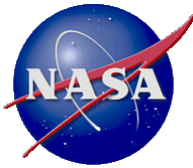


## MMOD Environment Models (cont.)

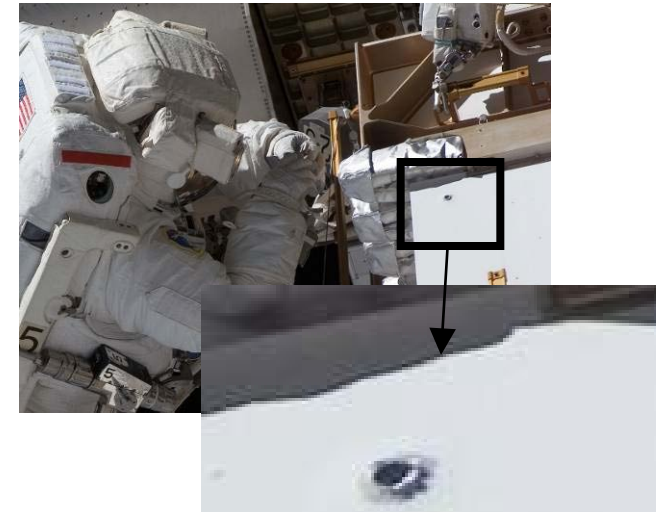
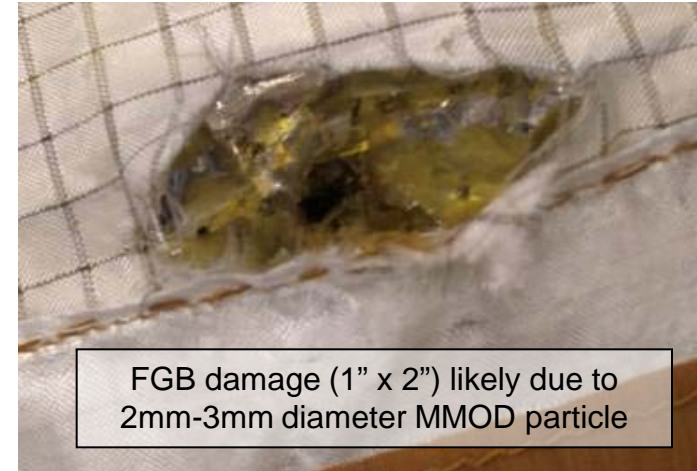


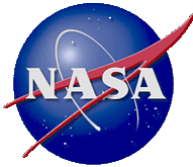
- Meteoroid model (MEM) provided by MSFC
  - <http://www.nasa.gov/offices/meo/home/index.html>
  - Meteoroid environment (MEM): 11-72 km/s
    - Average 22-23 km/s
  - MM environment model is subject to change (new release of MEM is pending)
- Orbital Debris is the predominate threat in low Earth orbit
  - For ISS, debris represents approximately 2/3<sup>rd</sup>s of the MMOD risk
  - For missions to the Moon, L1, or elsewhere, OD risk will need to be assessed for time period spacecraft resides in LEO
- Meteoroid risk is influenced by Earth focusing (gravitational) factor and Earth shadowing while in Earth orbit
  - Meteoroid risk far from Earth is typically less compared to meteoroid risk in LEO

# MMOD Damage to spacecraft

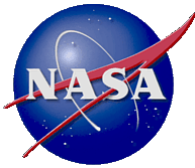


- Several ISS and Shuttle MMOD damages appear to have been caused by >1mm diameter MMOD particles
  - FGB compressor damage due to 2mm-3mm diameter particle
  - P6 radiator damage due to 3mm-5mm particle
  - SM solar array damage due to >2mm particle
  - STS-118 radiator damage due to high density 1mm particle
- Good agreement between actual damage to predictions for ISS Pressurized Logistics Module and Shuttle (damage identified after return to ground)





# MMOD Shielding



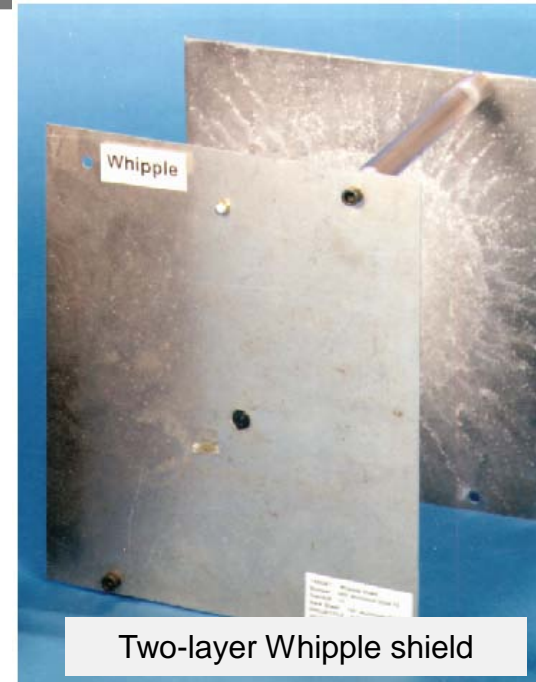
# MMOD Protection Requirements

- MMOD risk is a function of vehicle size, mission duration (time exposed to MMOD), failure criteria, shielding, flight trajectory
- MMOD requirements are key aspect of providing adequate MMOD protection, crew safety and vehicle survivability
- Typically MMOD protection requirements expressed in terms of maximum allowable failure risk over a time period, or a reliability level (probability of no failure)
  - For instance, Orion Lunar sortie (24 day mission) maximum allowable MMOD loss-of-crew (LOC) risk is 1 in 1000 (0.1% risk), and Lunar outpost (210 day mission) maximum allowable MMOD risk is 1 in 500 (0.2% risk)
    - Note, that over many missions, the cumulative MMOD risk increases with the total duration of all missions

# Hypervelocity impact effects



Monolithic target



Two-layer Whipple shield

- At hypervelocity, small particles can cause a lot of damage
  - High velocity MMOD particles represent a substantial threat to spacecraft which typically are constructed with light-weight materials to save mass
  - Rule of thumb: at 7km/s, aluminum sphere can penetrate completely through an aluminum plate with thickness 4 times the sphere's diameter
  - A multi-layer spaced shield provides more effective protection from hypervelocity impact than single layer (total shield thickness < projectile diameter)



# ISS MMOD protection approach

- **Multi-faceted approach to mitigating MMOD Risk on ISS**

1. **Robust shielding**

- ISS has best shielding ever flown: US/ESA/Japan Nextel/Kevlar “stuffed” Whipple shields effective for 1.3cm diameter debris impacting at typical impact conditions
- Redundant & hardened external systems; e.g. US Radiators

2. **Collision avoidance**

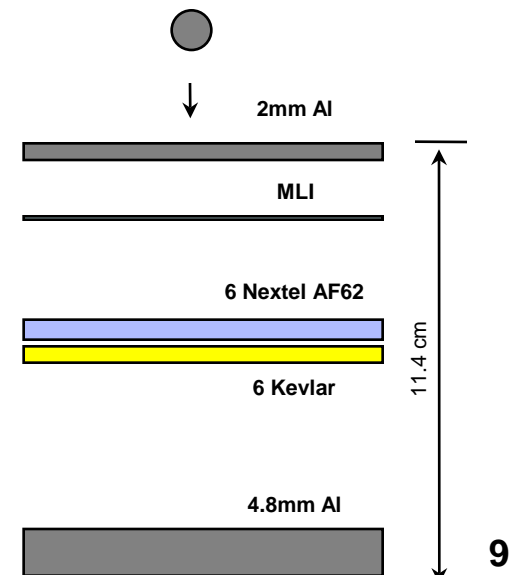
- Maneuver to avoid ground trackable orbital debris (typically  $\geq 10\text{cm}$  diameter)

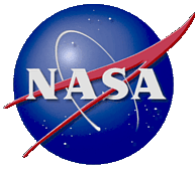
3. **Sensors & crew response to leak if needed**

- Leak detection, isolation, repair



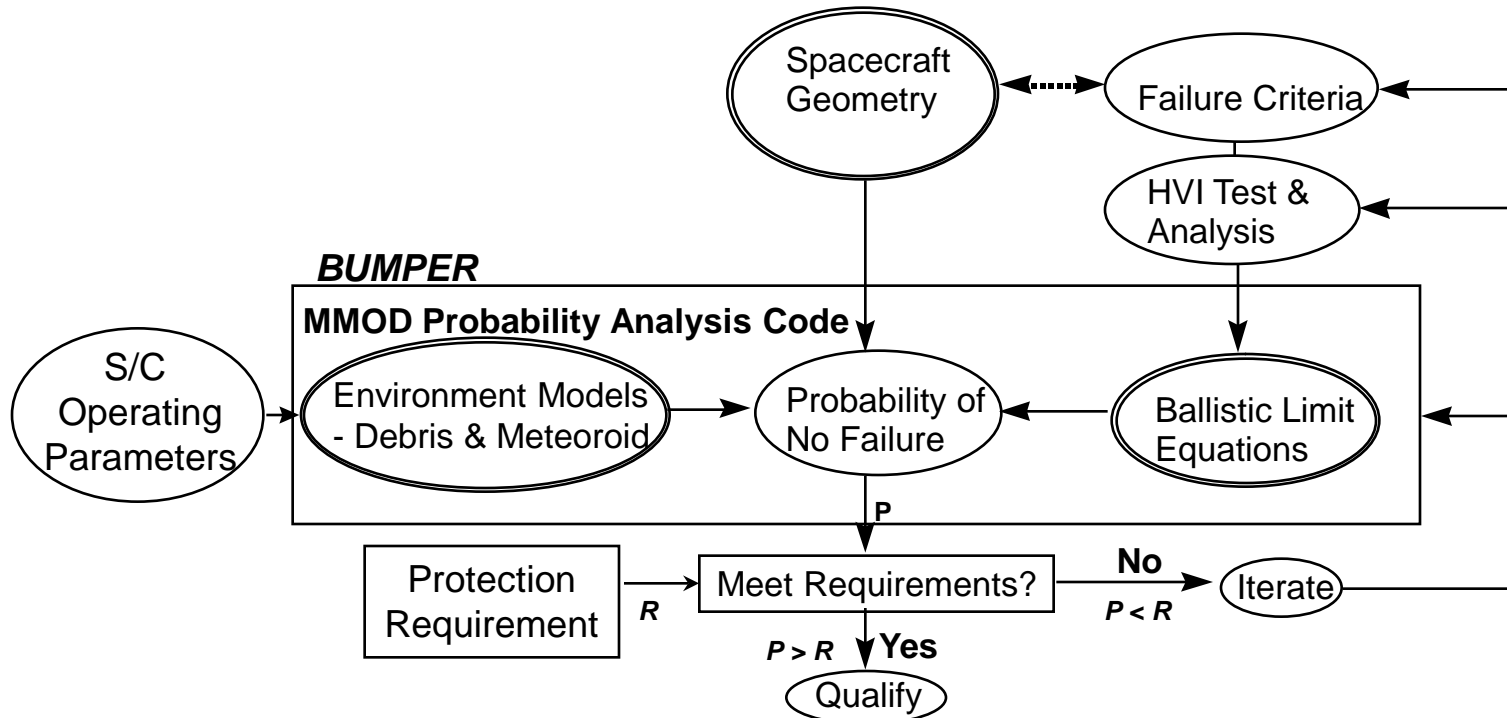
0.5" diameter hypervelocity projectile penetrates nearly 2" thick aluminum block, but is stopped by NASA stuffed Whipple shields which weigh far less (same as 3/8" thick aluminum)



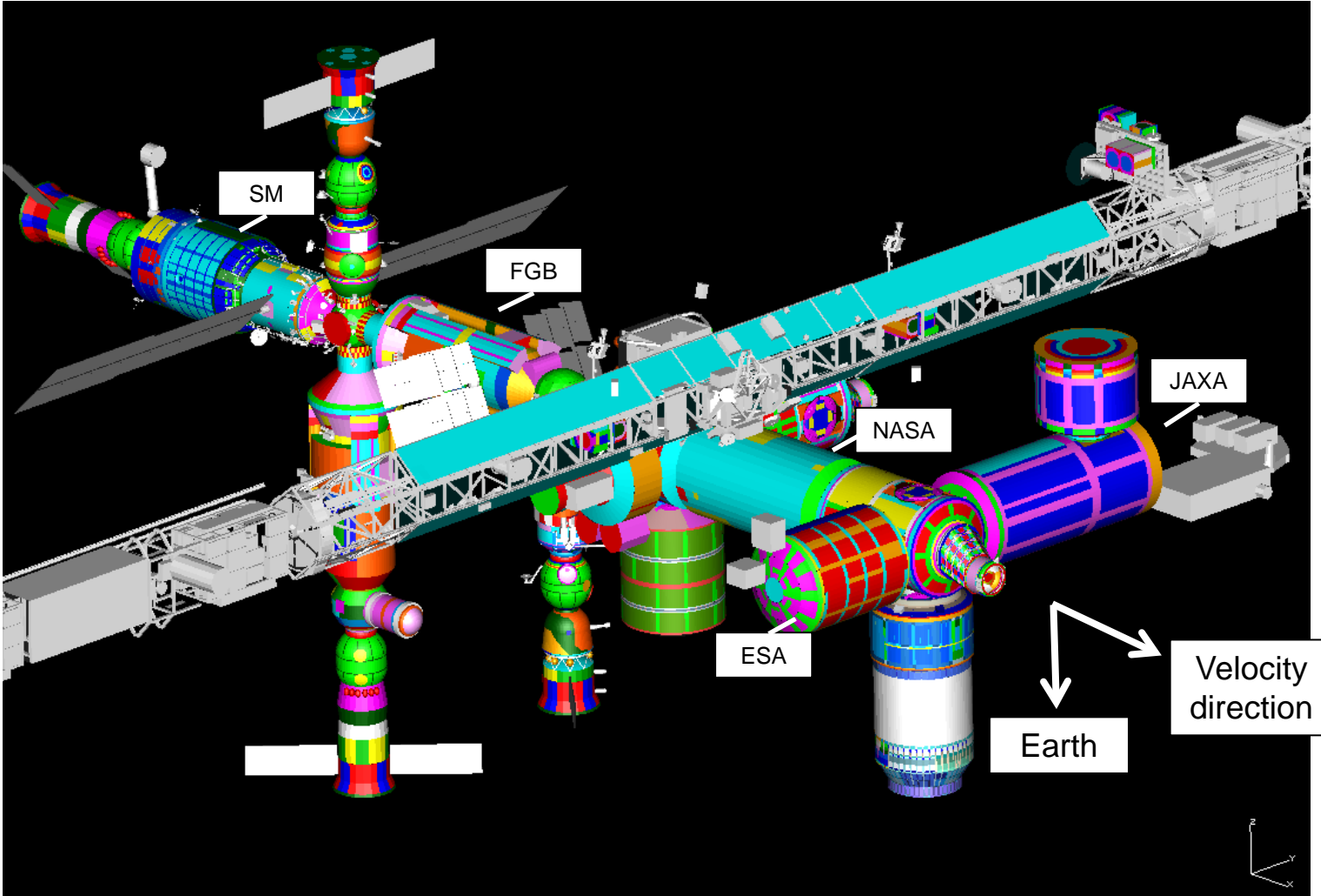
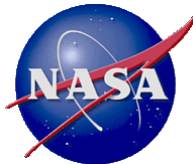


# Shielding Design and Verification Methodology

- Identify vulnerable spacecraft components/subsystems
- Assess HVI damage modes
- Determine failure criteria
- Perform HVI test/analysis to define “ballistic limits”
- Conduct meteoroid/debris probability analysis
- Compare MMOD analysis results with requirement
- Updates to design, operations, analysis, test, or failure criteria
- Update/iterate as necessary to meet requirement



# ISS MMOD shielding finite element model for Bumper code MMOD risk assessments

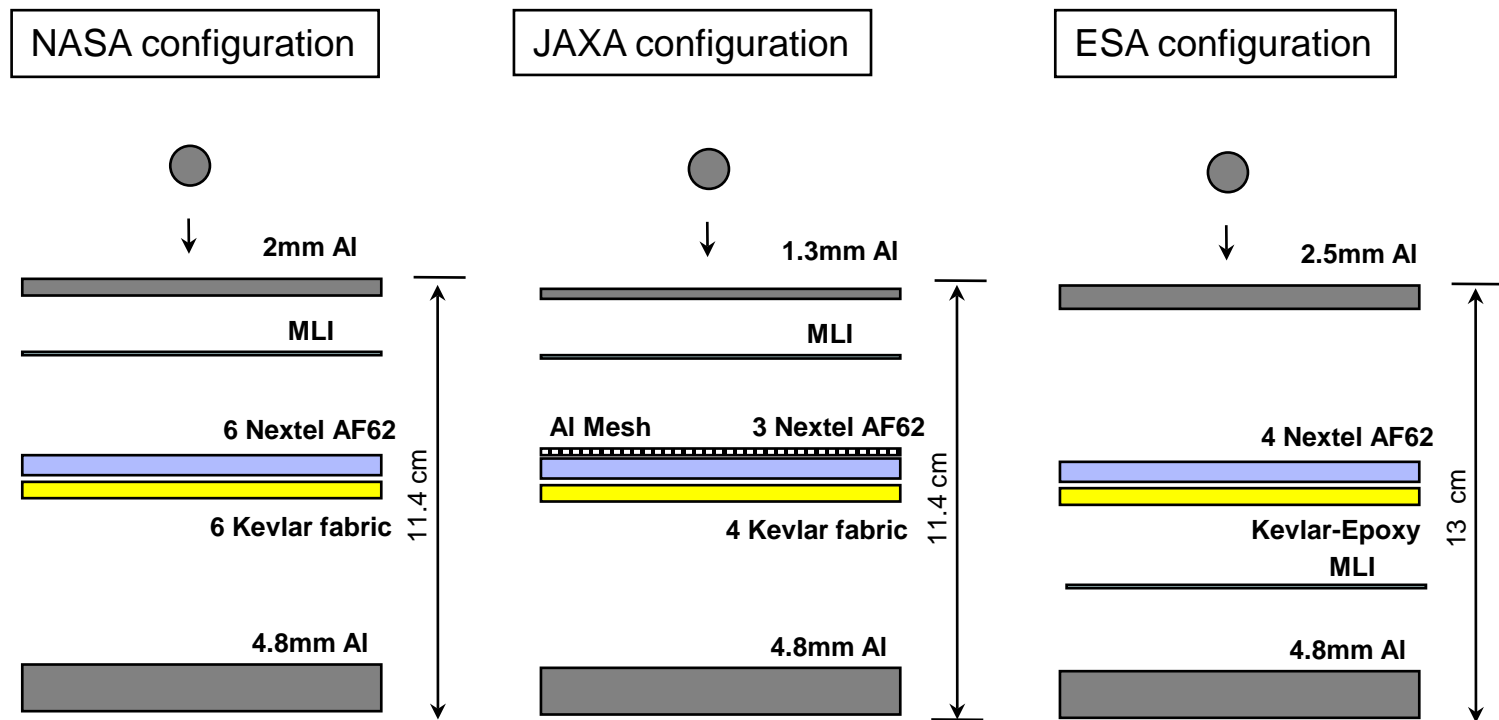


Each color represents a different MMOD shield configuration

# ISS “Stuffed Whipple” Shielding

(Typical Configurations Illustrated)

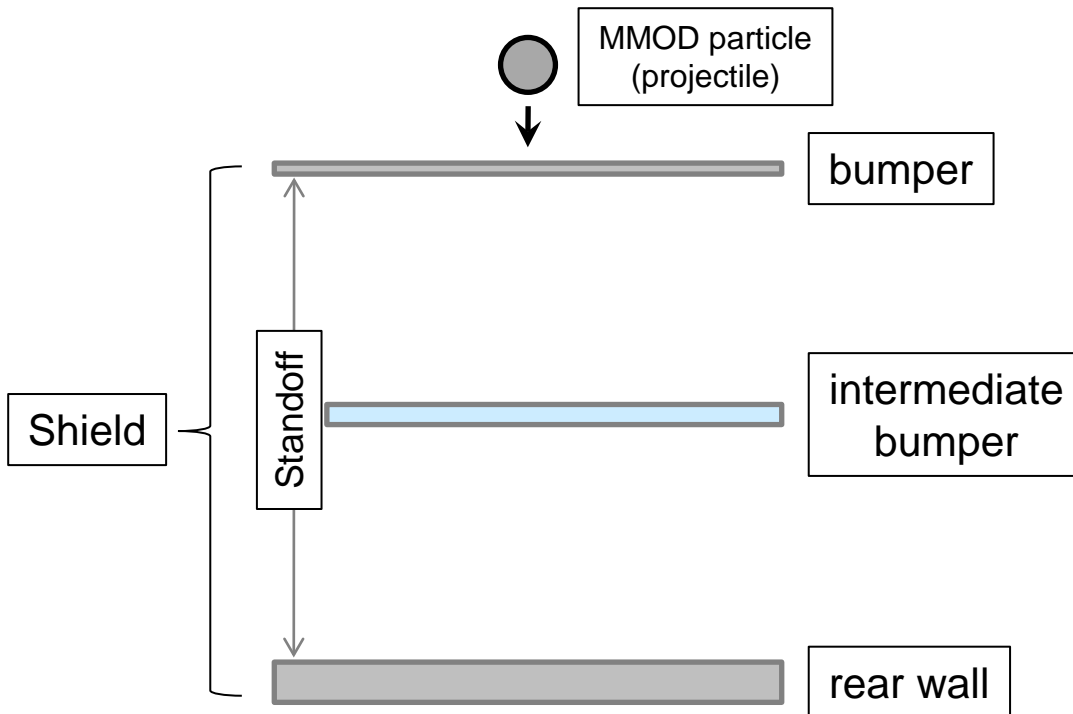
- US, JAXA and ESA employ “Stuffed Whipple” shielding on the areas of their modules exposed to greatest amount of orbital debris & meteoroids impacts
  - Nextel and Kevlar materials used in the intermediate bumper
  - shielding capable of defeating 1.3cm diameter aluminum sphere at 7 km/s, normal impact



Typically, bumpers are Al 6061-T6, rear walls are Al 2219-T87 or Al 2219-T851  
Kevlar 29 style 710 or Kevlar KM2 style 705 fabric are typically used

# MMOD shielding background

- MMOD shields typical composed of bumper(s), standoff, and rear wall (final protection layer)
  - Exclude multi-layer insulation (MLI) thermal blanket



**Purpose:** Breakup MMOD particle, laterally disperse resulting debris

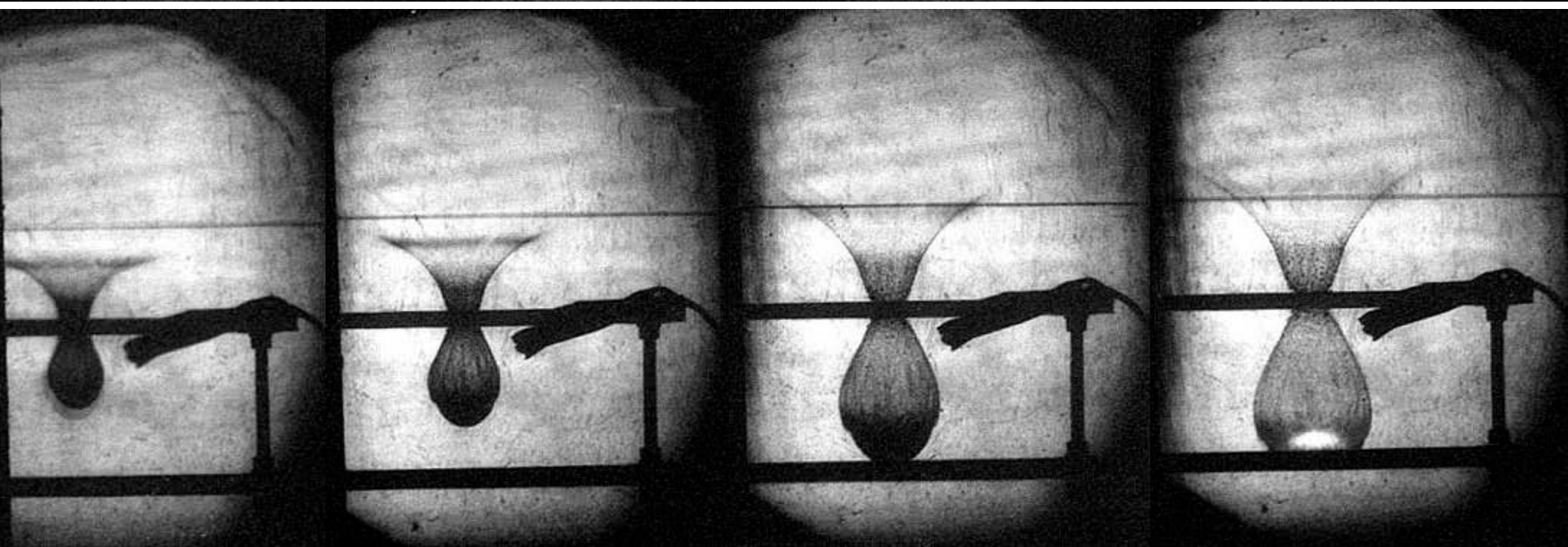
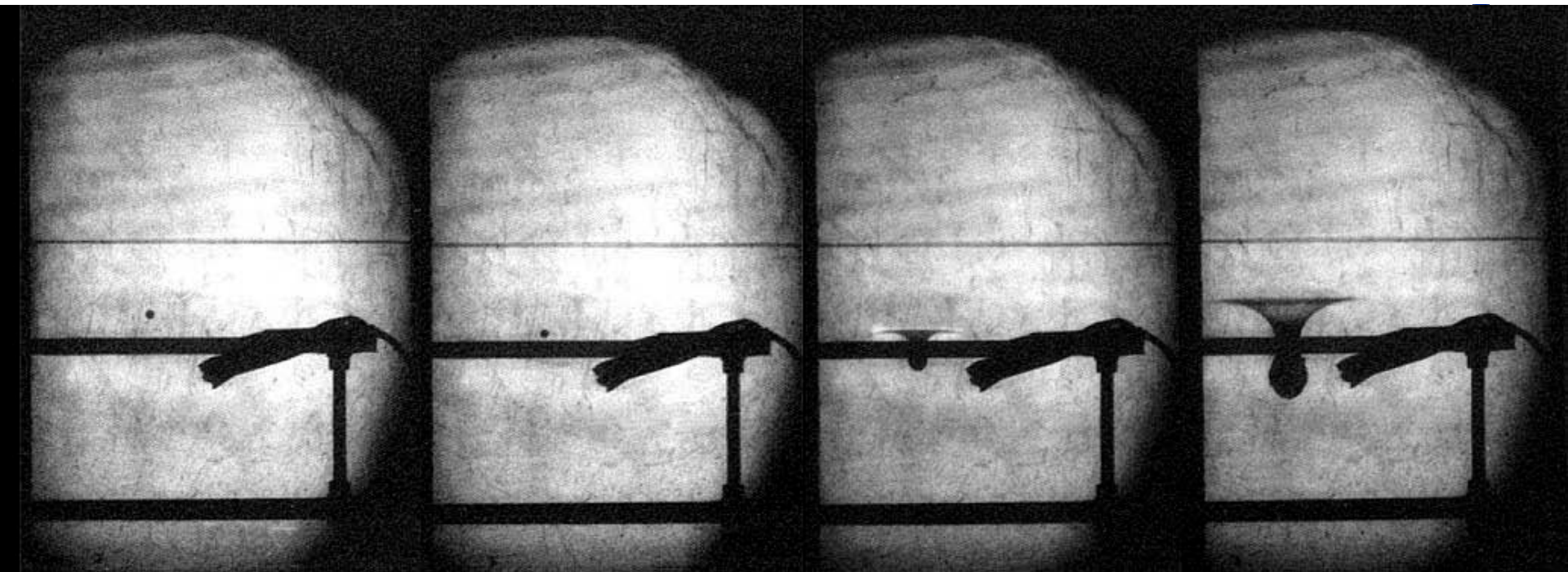
**Key material & physical parameters ( $V \geq 7$  km/s):** density, thickness to projectile diameter ratio, thermal properties

**Purpose:** Further breakup debris from first impact, slow expansion of debris cloud

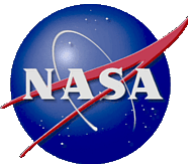
**Key material & physical parameters ( $V \geq 7$  km/s):** combination of first bumper and rear wall properties

**Purpose:** Stop debris from MMOD & bumper(s)

**Key material & physical parameters ( $V \geq 7$  km/s):** strength, toughness, thickness

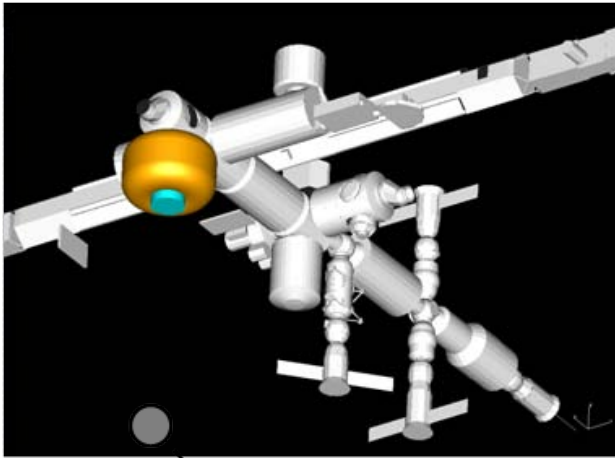
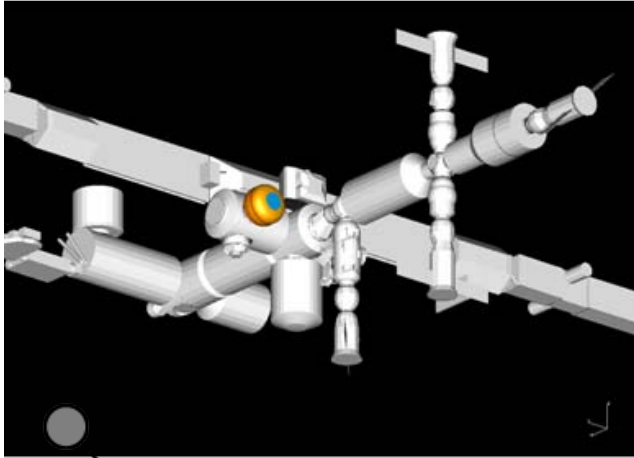


# Shielding assessments for inflatables



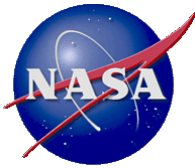
- Hypervelocity impact tests have been performed for MMOD shielding of potential inflatable modules, for two damage modes:
  - (1) Failure of shield protecting restraint layer
  - (2) Failure of shield, restraint and bladder

BEAM inflatable on Node 3 aft



Deep Space Habitat inflatable demonstrator on Node 2 nadir

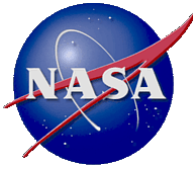




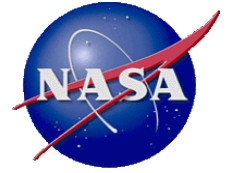
# Summary

- MMOD shielding capability influenced by both:
  1. Configuration – “standoff” (more is better), number of bumper shield layers
  2. Material selection – ceramics/metals on exterior of shield, high-strength to weight ratio (fabrics & composites) on interior of shield
- More information available:
  - NASA TP-2003-210788, Meteoroid/Debris Shielding
  - NASA TM-2009-214785, Handbook for Designing MMOD Protection
  - NASA TM-2003-212065, Integration of MMOD Impact Protection Strategies into Conceptual Spacecraft Design
  - NASA TM-2009-214789, MMOD Shield Ballistic Limit Analysis Program

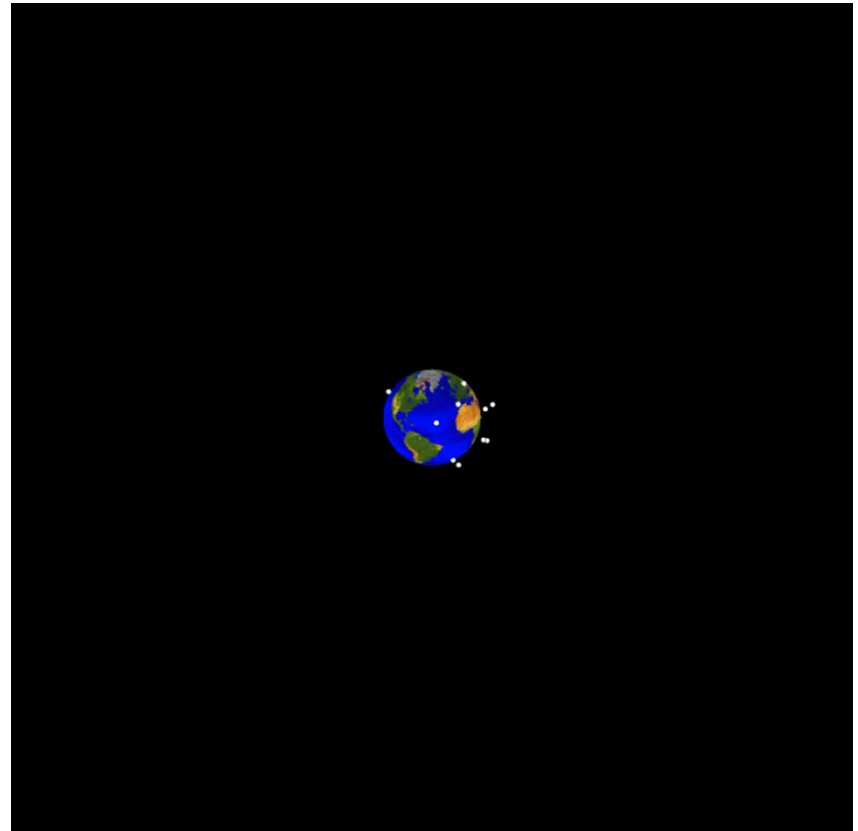
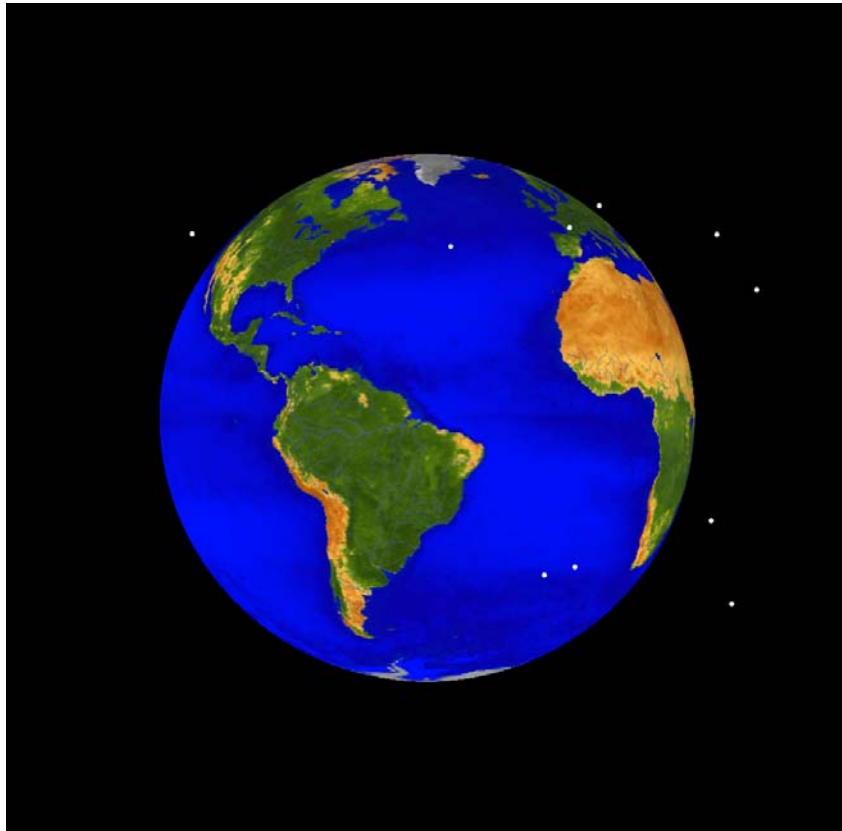




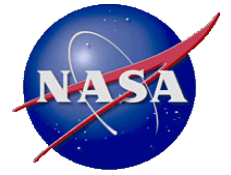
# Backup Charts



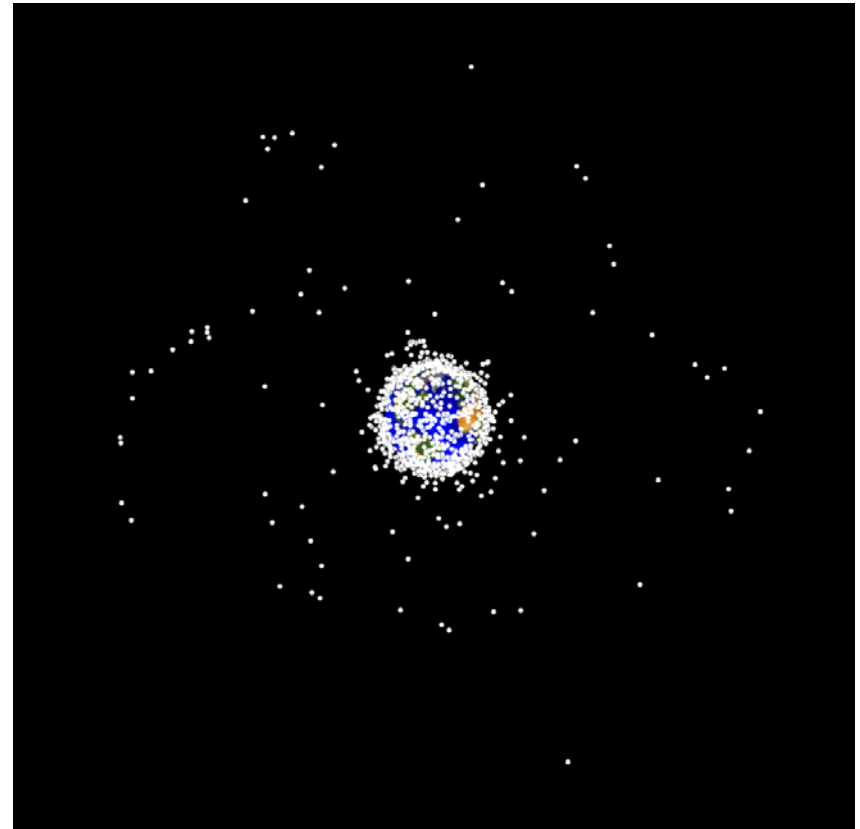
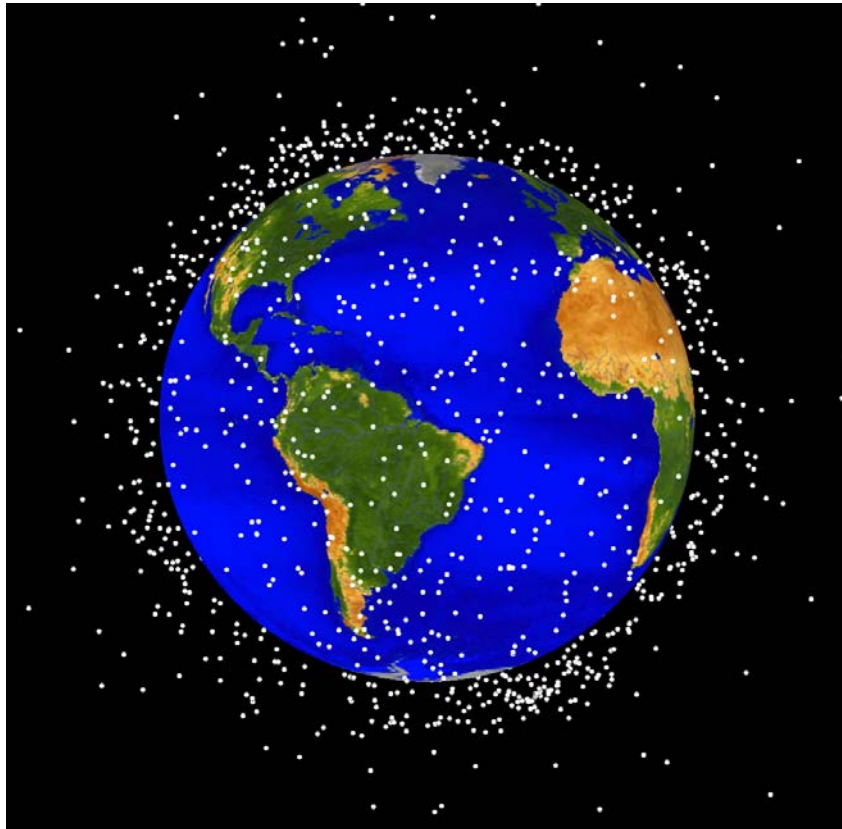
1960



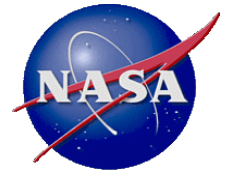
Cataloged objects >10 cm diameter



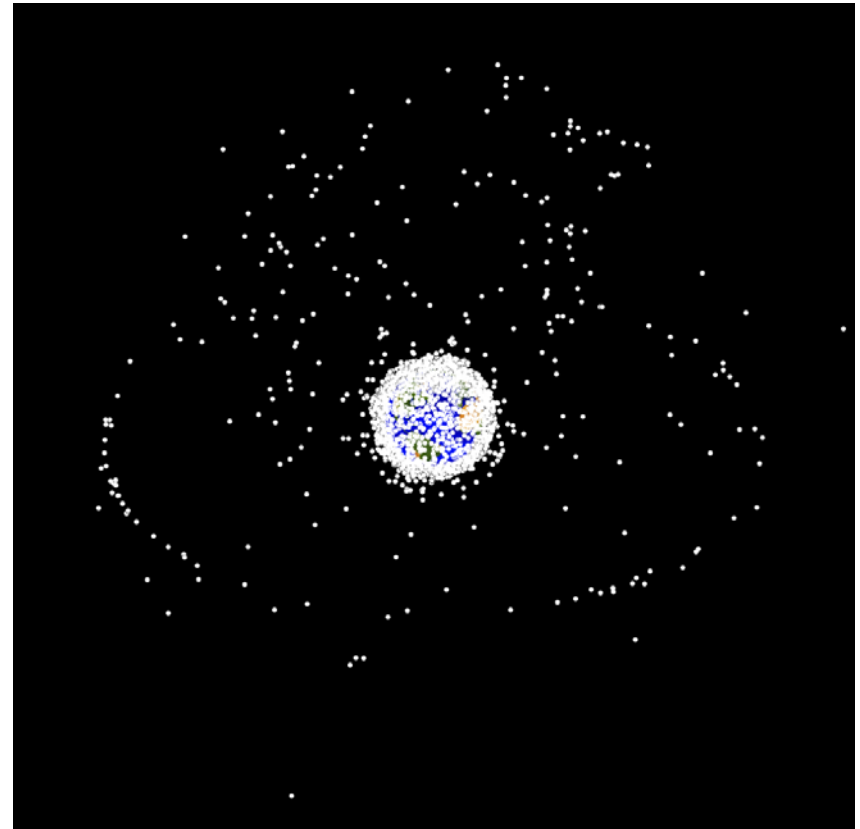
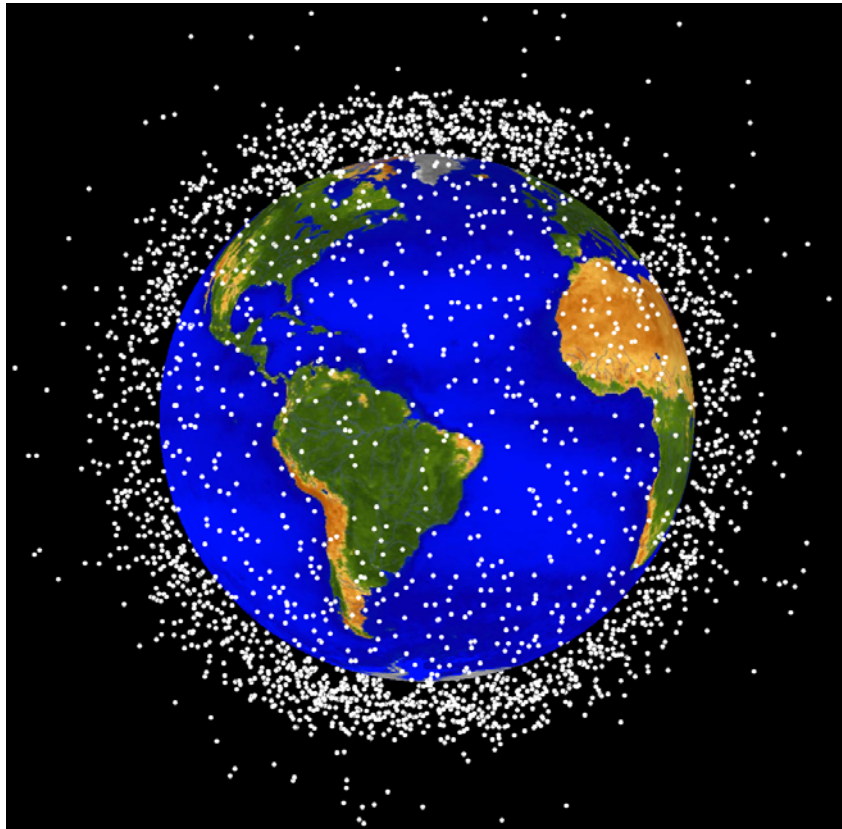
1970



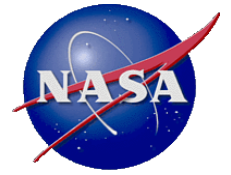
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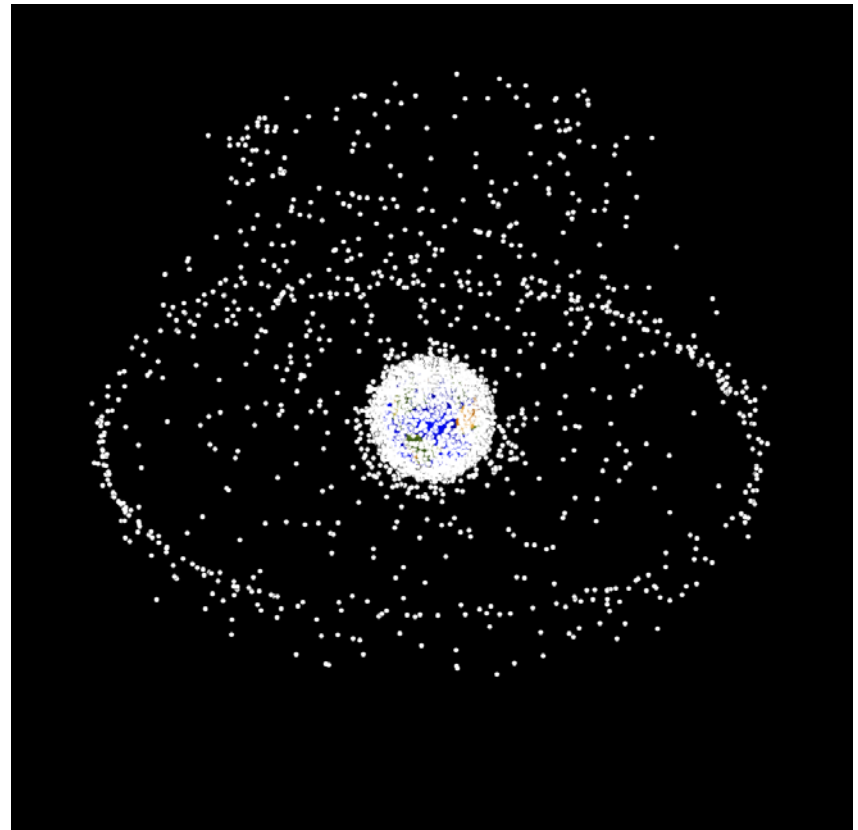
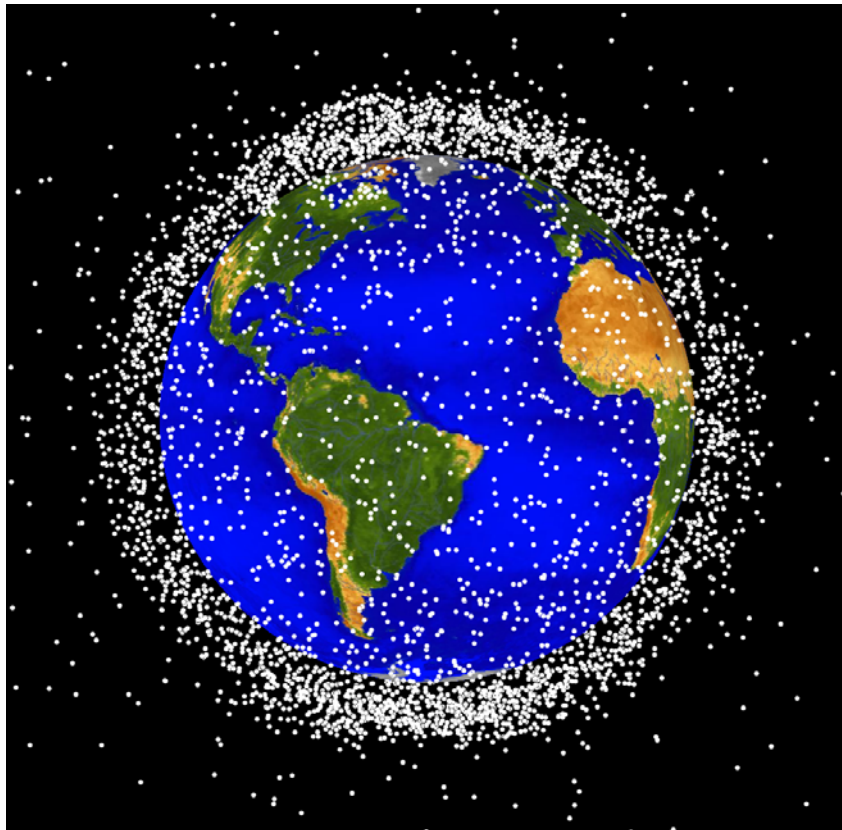
1980



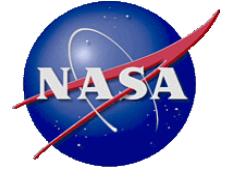
Cataloged objects  $>10$  cm diameter



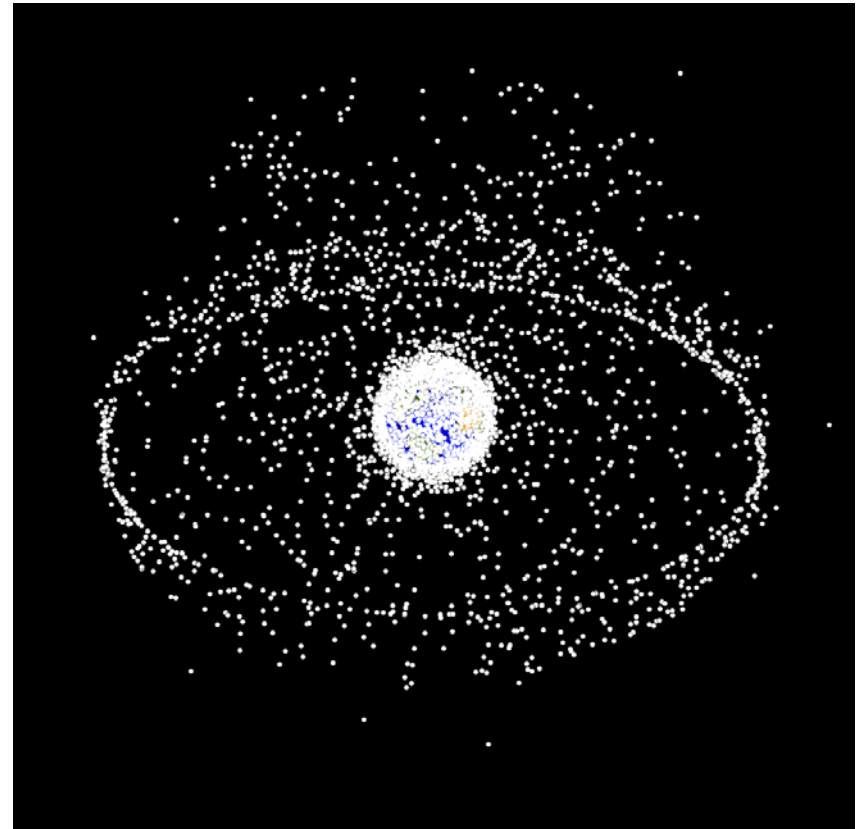
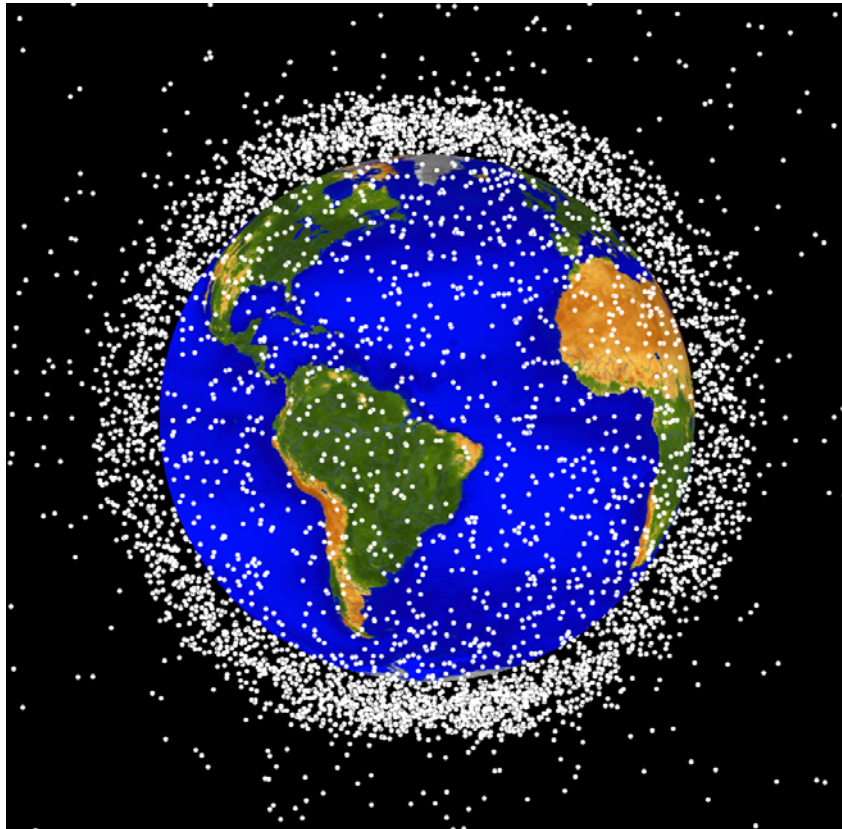
1990



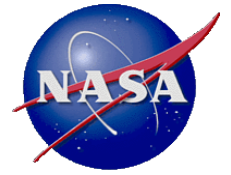
Cataloged objects  $>10$  cm diameter



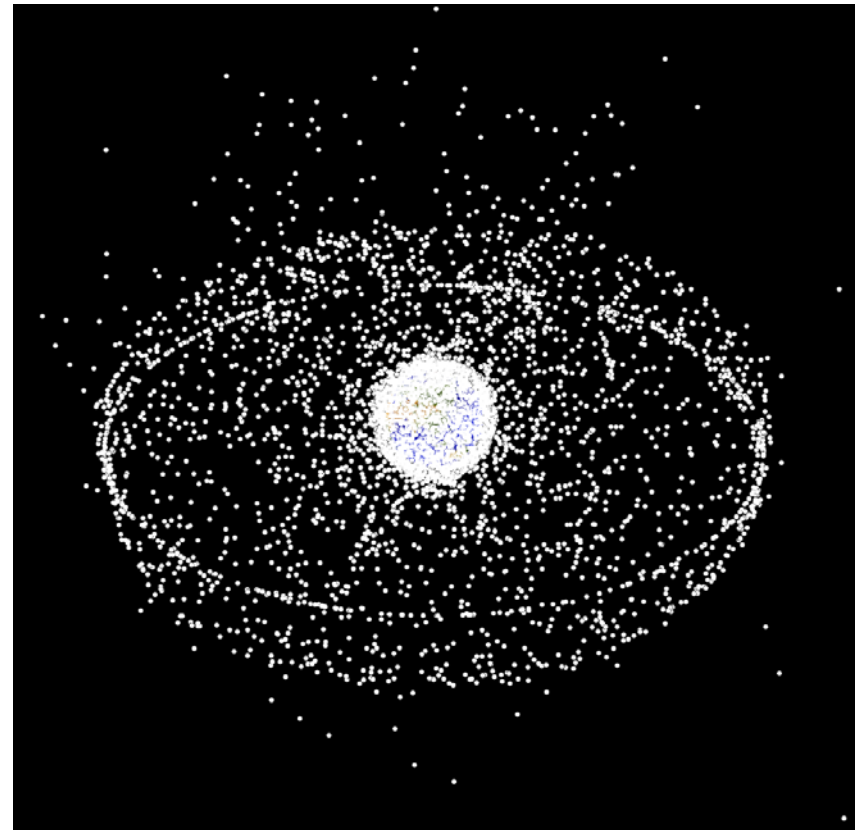
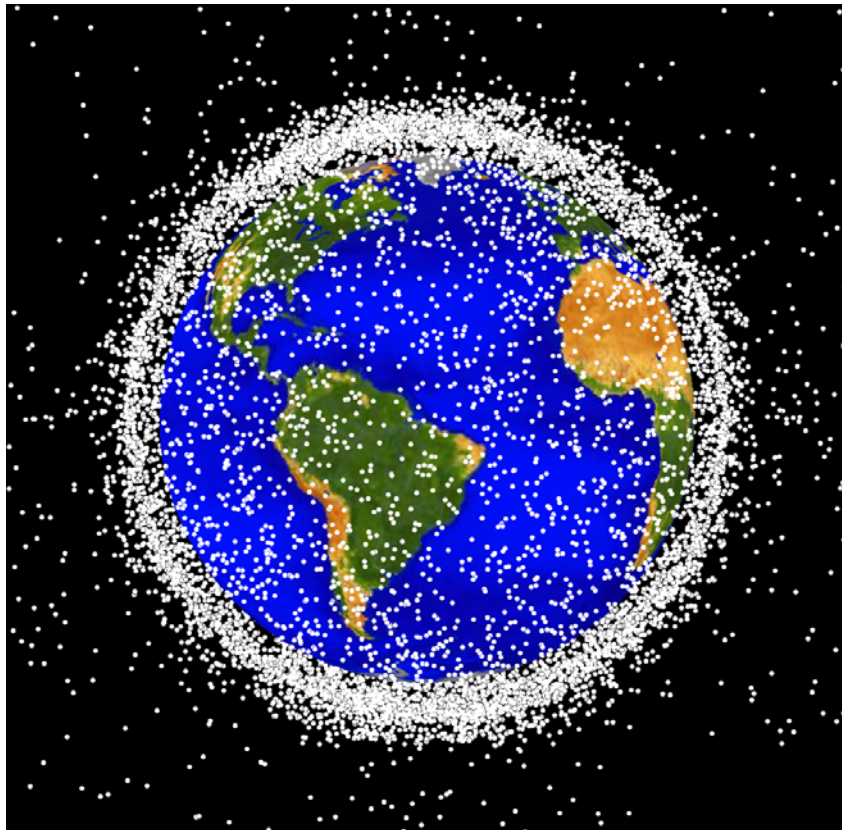
2000



Cataloged objects >10 cm diameter



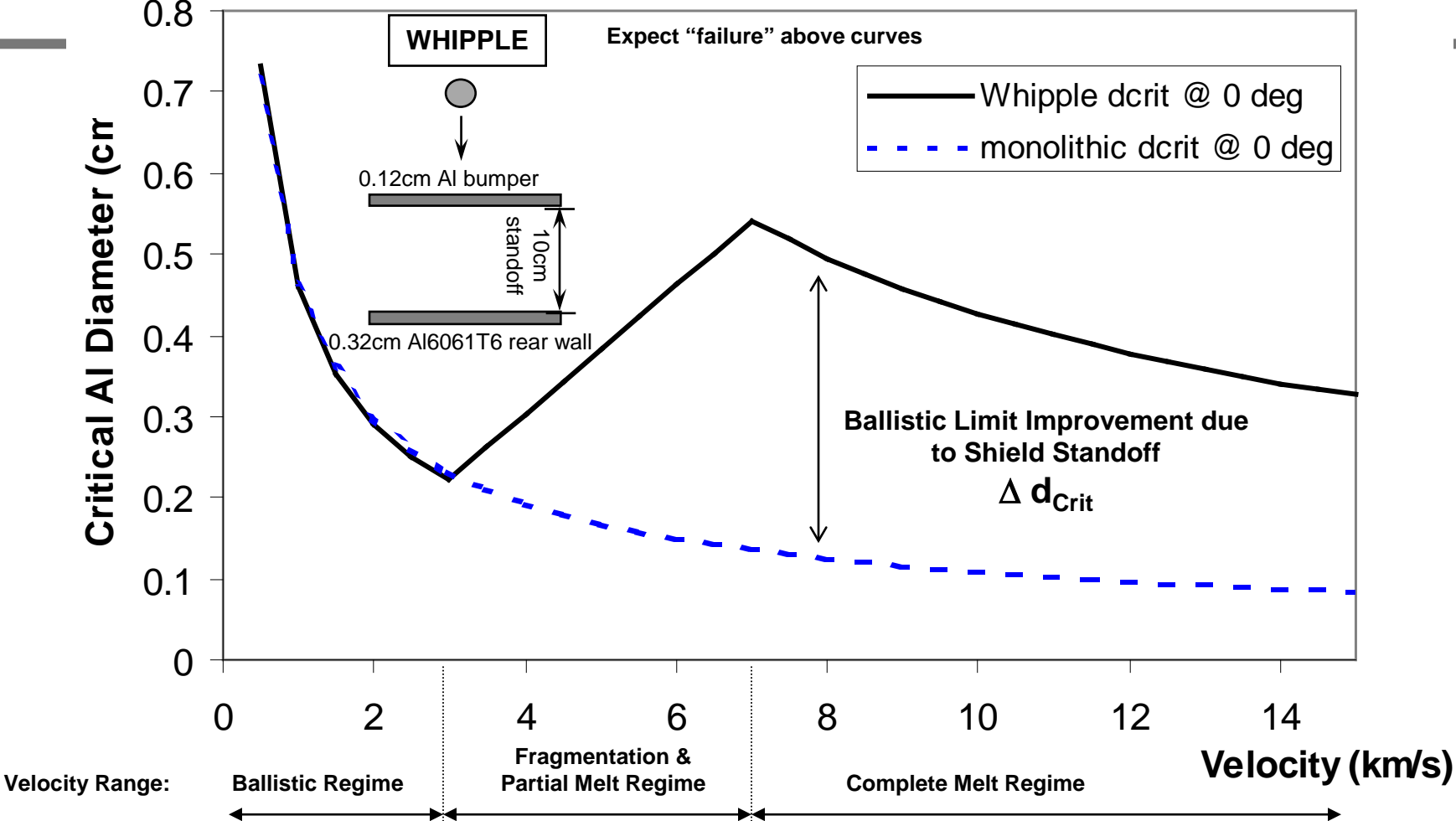
August 2009



Cataloged objects >10 cm diameter



# Ballistic Limits for Whipple Shield & equal mass Monolithic



**State of Debris Cloud:** Few solid fragments  
(for Al on Al impacts)

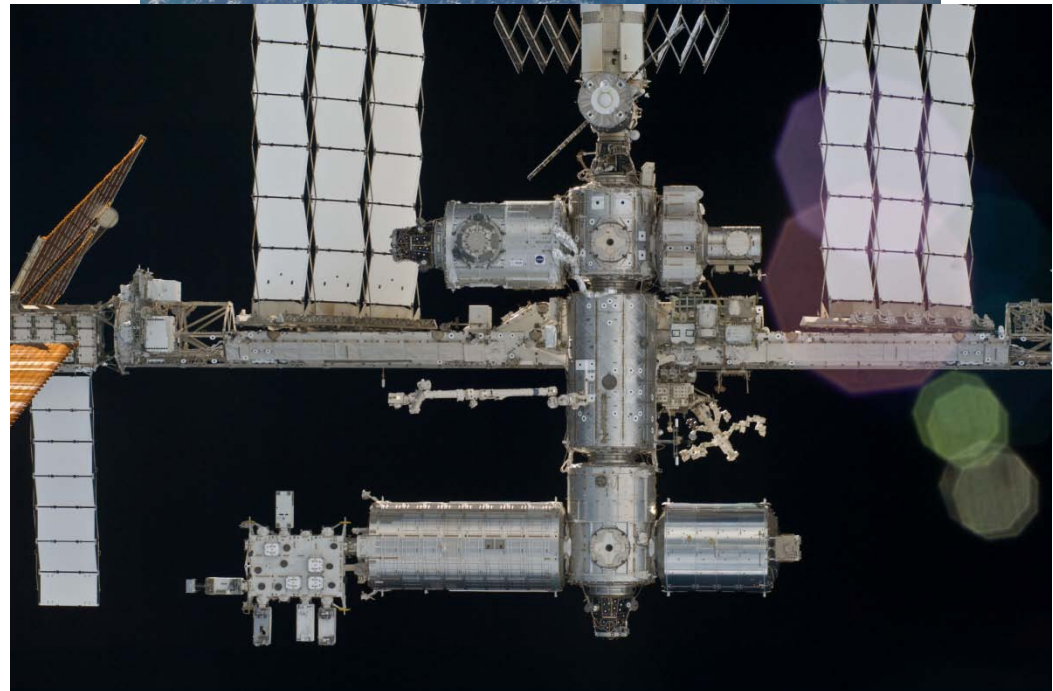
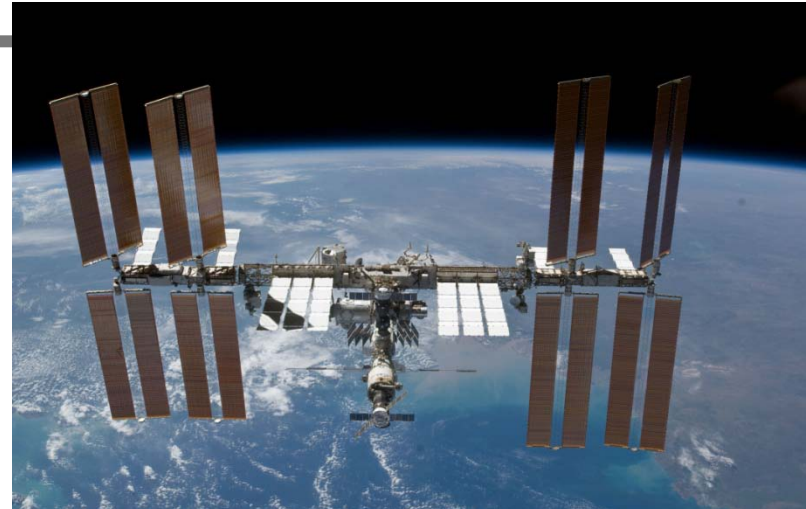
Many (increasing with velocity) solid fragments & liquid droplets

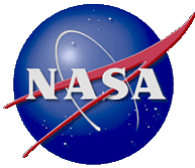
Fine droplets, few solid fragments, some vapor



# ISS MMOD shielding

- Many different shield configurations protect ISS modules, external pressure vessels, gyros, and visiting vehicles from MMOD
  - High risk areas found by analysis
  - More capable shielding (i.e., stopping larger particles) placed where expect greatest amount of MMOD hits





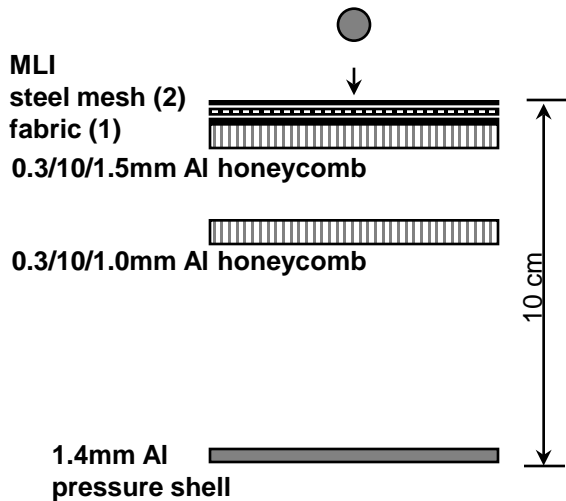
# Shielding materials

- Nextel (3M Inc. trade mark): fabric consisting of alumina-boria-silica ceramic fibers
  - Other ceramic and glass fabrics tested, and will provide adequate MMOD protection (substitute equal mass for Nextel)
- Kevlar aramid fabric: highest hypervelocity protection performance found using Kevlar KM2 fabrics
  - Other high-strength to weight materials incorporated in MMOD shields include Spectra, Vectran, carbon fabric and carbon-composites

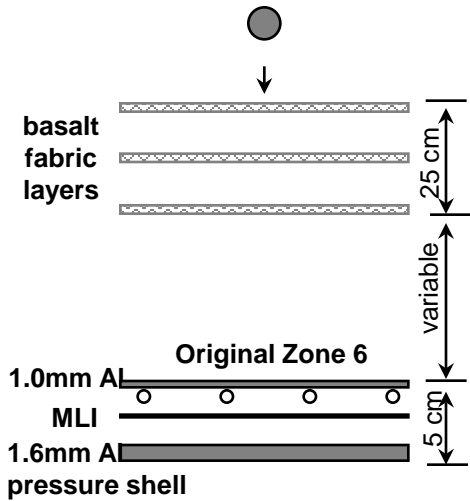
# FGB and Service Module (SM) Mesh & Multi-Shock MMOD Shields

- Majority of FGB shields include 2 or more bumpers spaced in front of the module pressure shell or propellant tank wall (superior to single bumper shields)
  - Metal mesh layers provide additional protection in many FGB shields (a mesh causes greater spread to the debris cloud resulting from high velocity collision)
  - SM augmentation shields rely on multi-shock ceramic fabric layers
- FGB shields & SM augmentation shields provide protection from 1-1.5cm diameter aluminum projectiles (typical).
  - Unaugmented SM shields protect from ~0.3cm aluminum projectiles (typical)

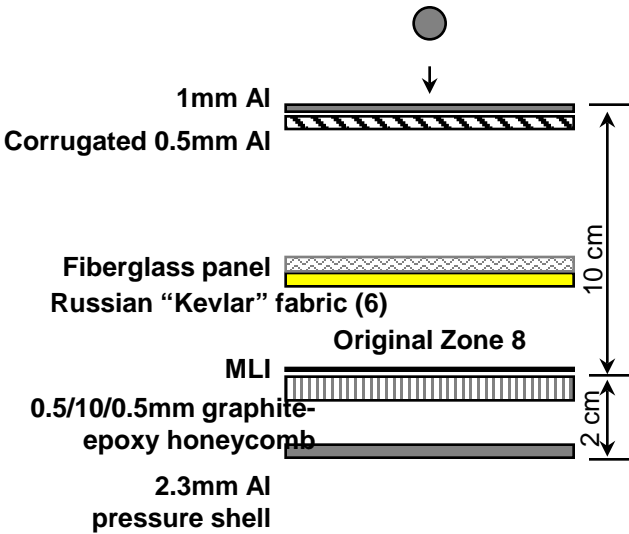
FGB Zone 11c,d,f



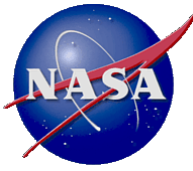
SM deployable shield/zone 6  
orientation of zone 8 not parallel to 4 augmentation bumpers



SM conformal shield/zone 8



# MMOD shields added to Service Module by extravehicular activity (EVA)



Additional MMOD shield panels added by EVA  
(each consist of layers of aluminum, corrugated  
aluminum, fiberglass and Russian Kevlar)