Micrometeoroid and Orbital Debris Environment
&
Hypervelocity Shields

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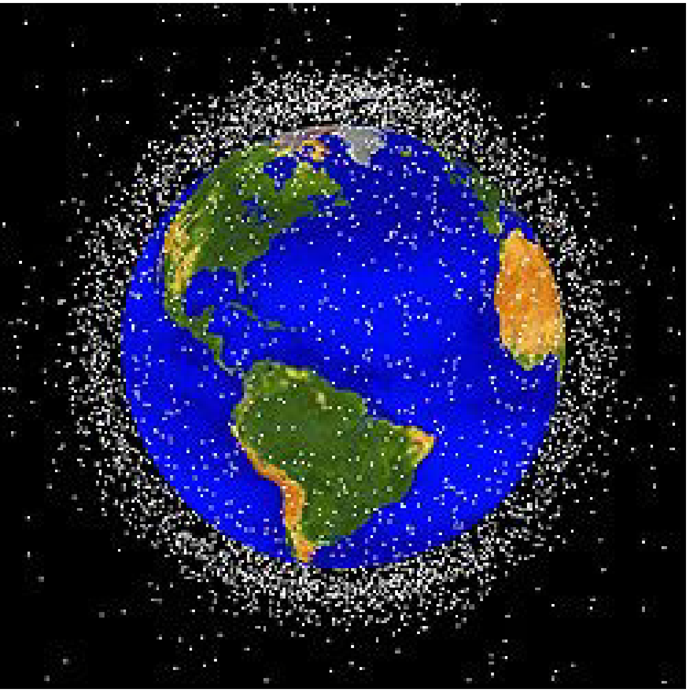
Purpose of this presentation

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

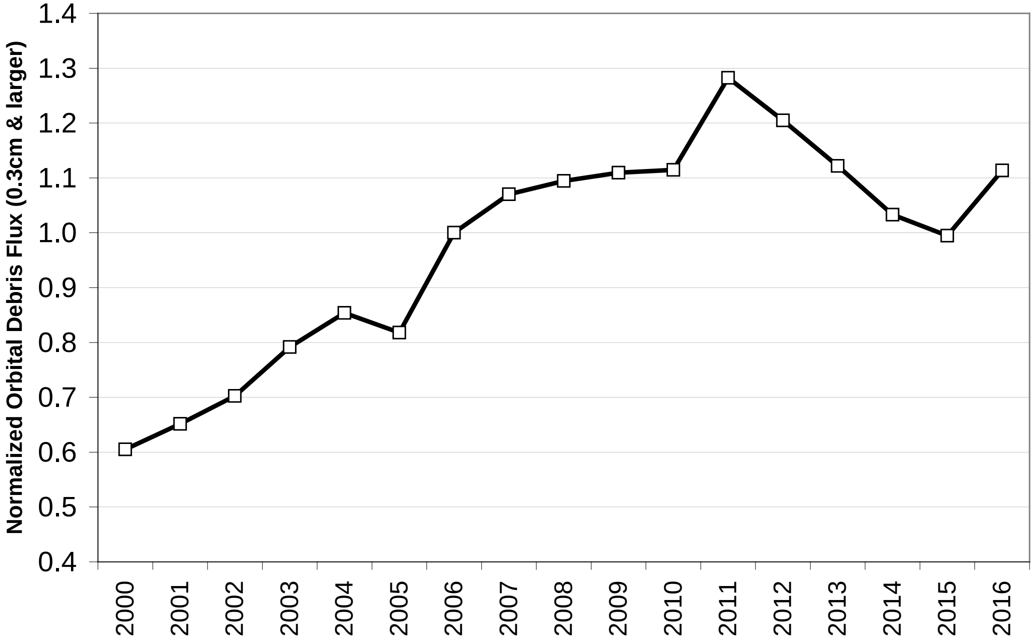
MMOD Environment Models

- 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



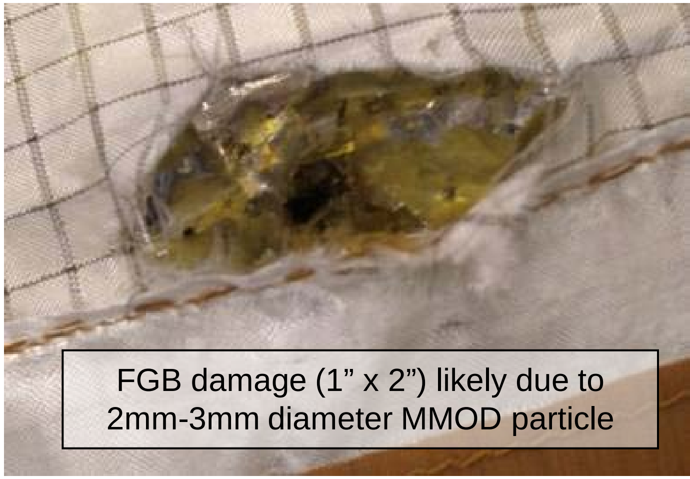
MMOD Environment Models (cont.)

- 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^{rds} 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

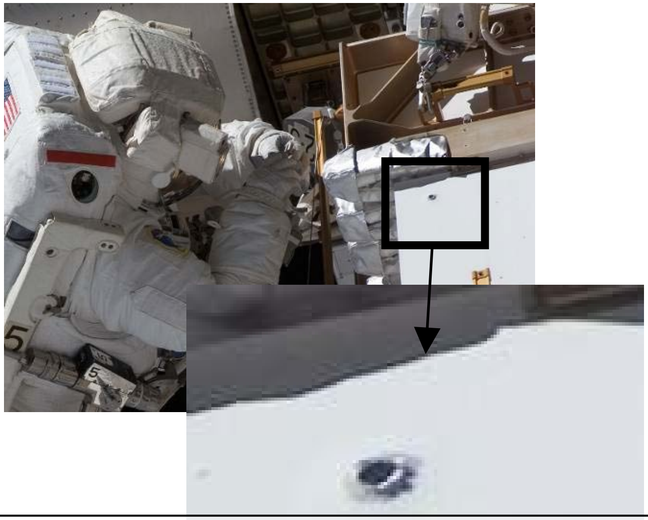
MMOD Damage to spacecraft

- 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)



FGB damage (1” x 2”) likely due to 2mm-3mm diameter MMOD particle



P6 radiator damage noted during STS-118 (0.75” diameter) likely due to 3-5mm diameter x 1mm thick MMOD particle

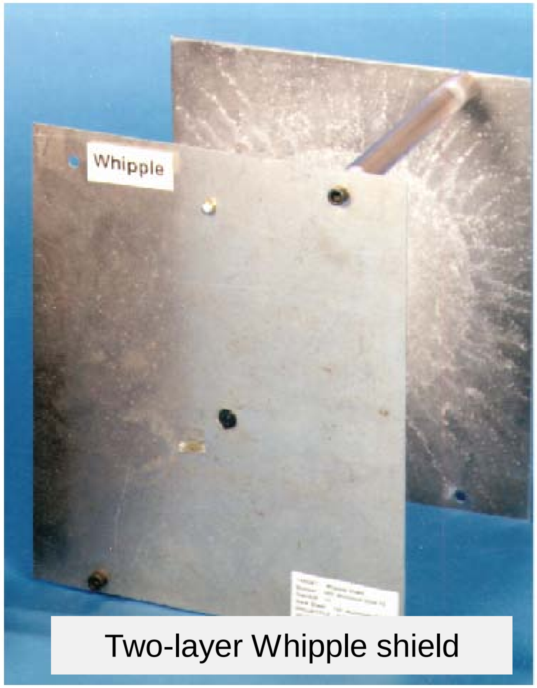
MMOD Shielding

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



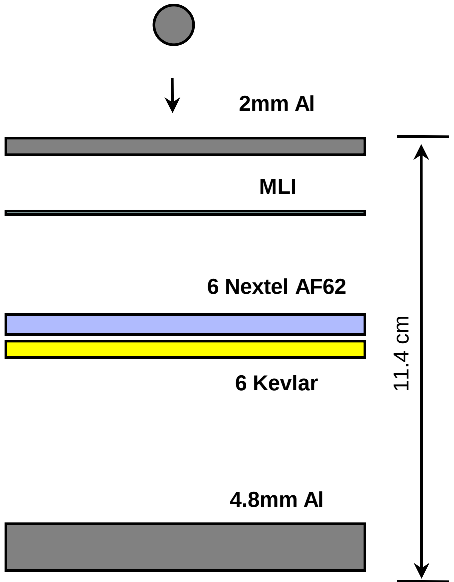
Two-layer Whipple shield

- 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 ≥ 10cm diameter)
  3. **Sensors & crew response to leak if needed**
     - Leak detection, isolation, repair

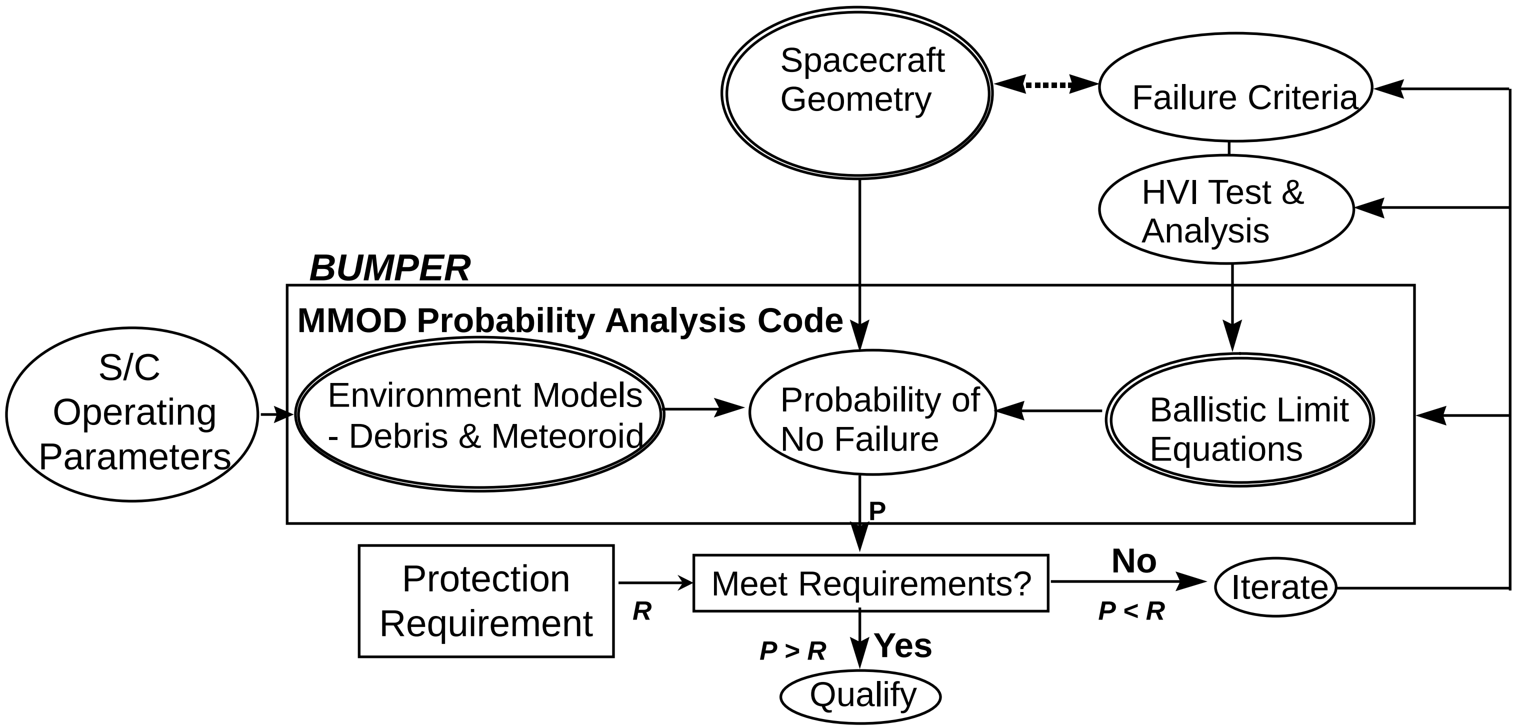
0.5" diameter hypervelocity projectile penetrates nearly 2" thick aluminum block, but is stopped by NASA stuffed Whipple shields which weigh far less (same as 3/8" thick aluminum)



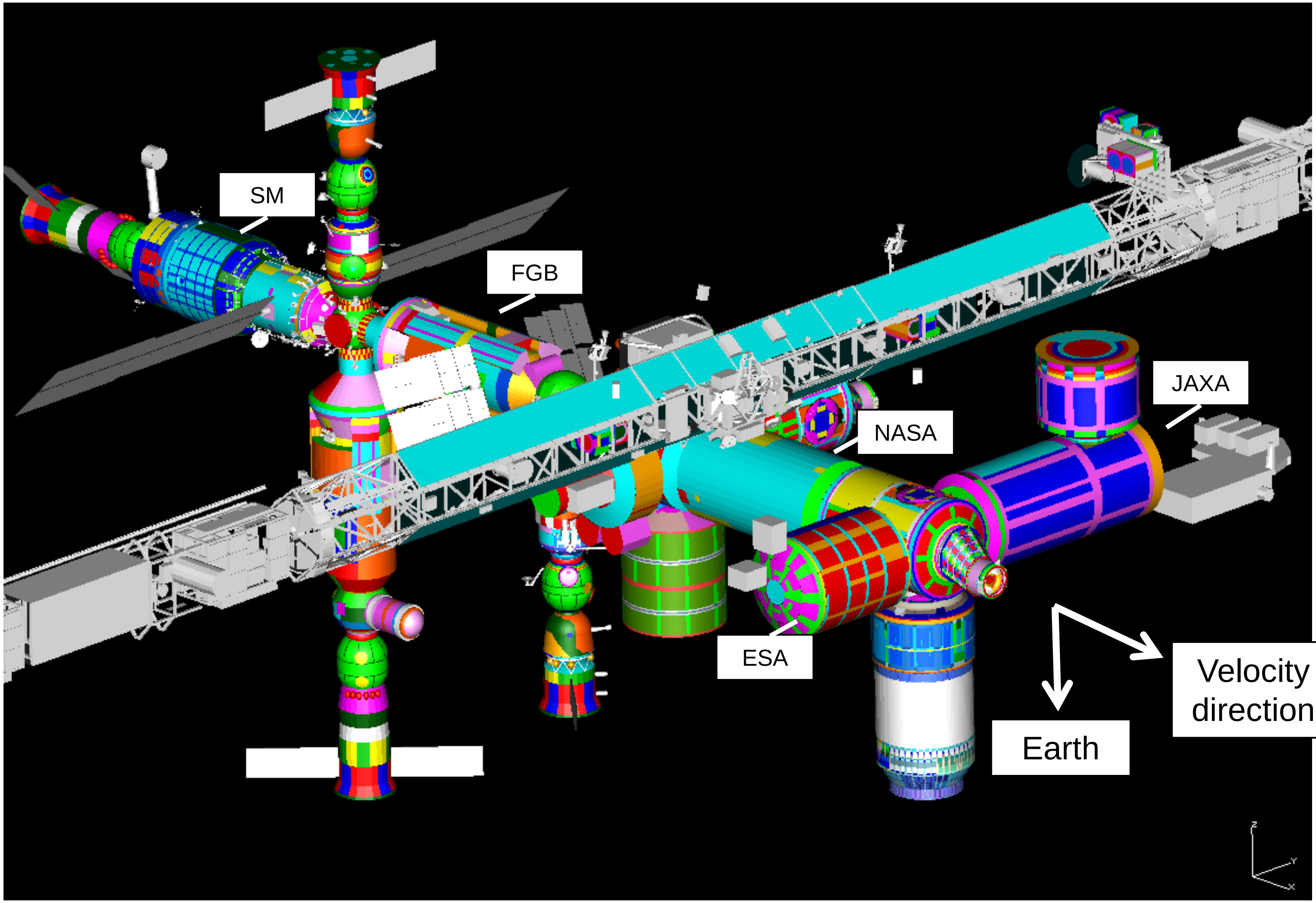
National Aeronautics and Space Administration

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

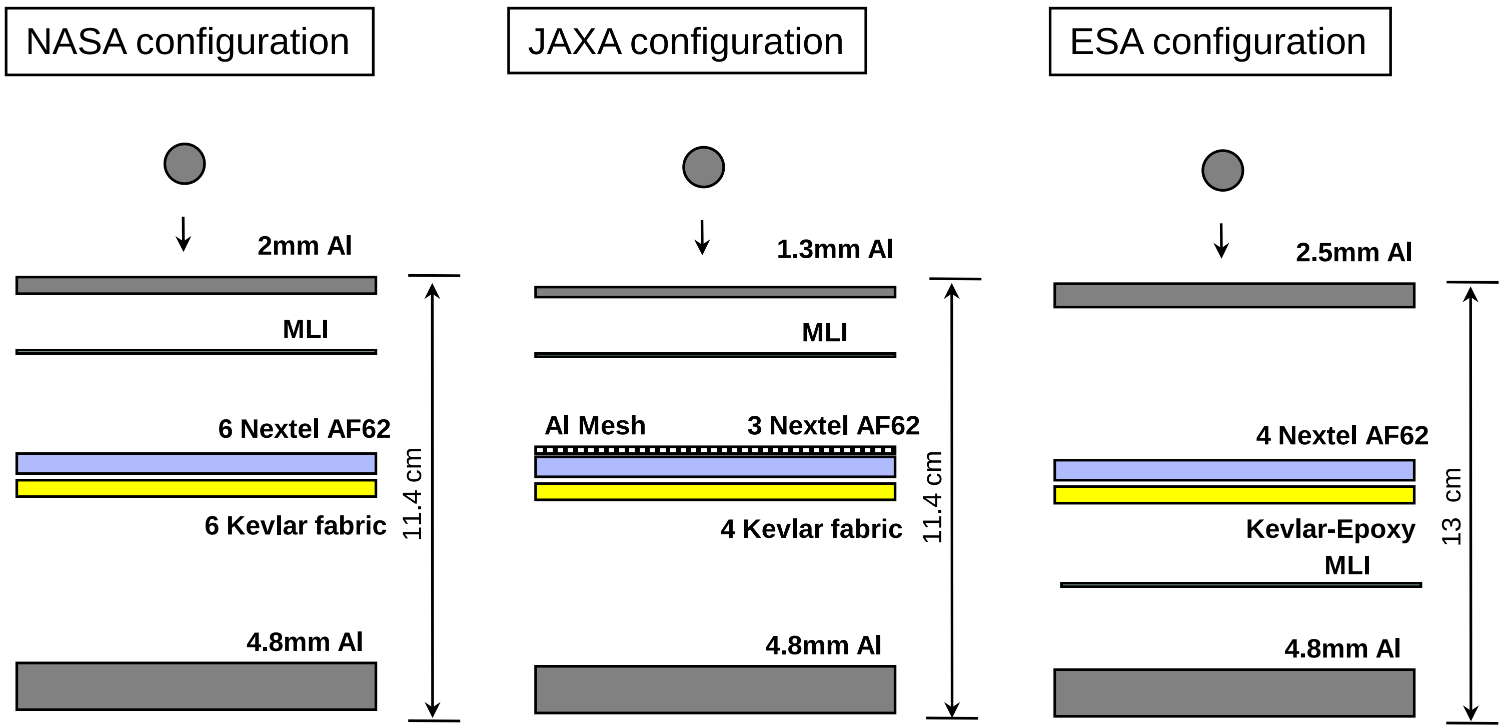


Each color represents a different MMOD shield configuration

ISS "Stuffed Whipple" Shielding

(Typical Configurations Illustrated)

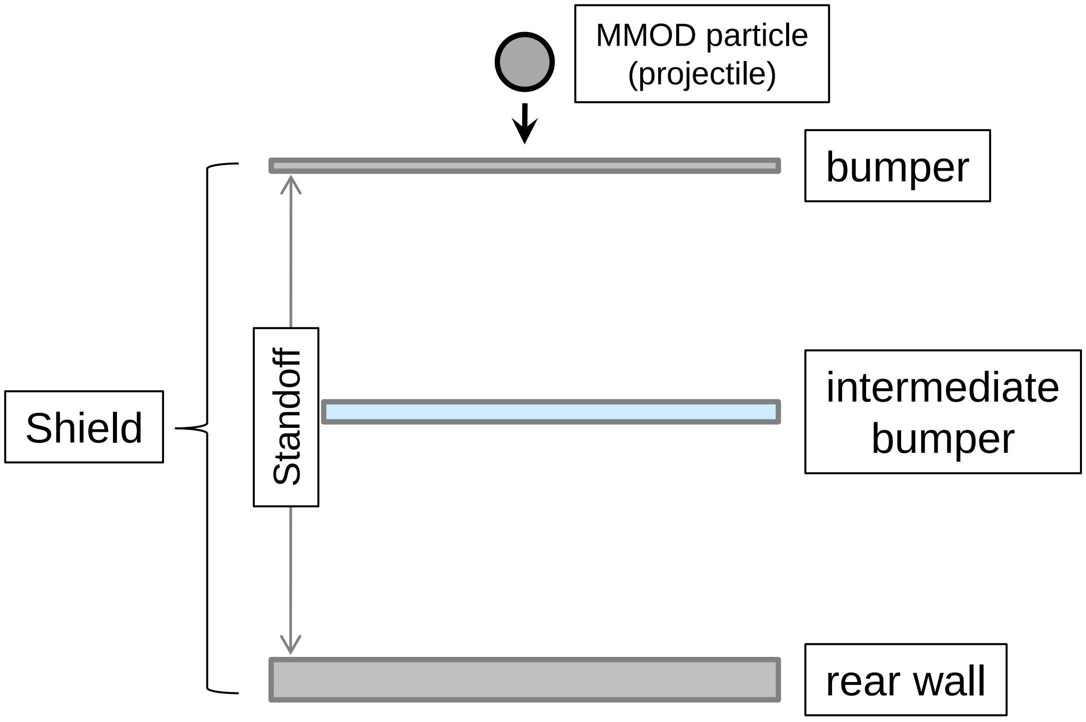
- US, JAXA and ESA employ "Stuffed Whipple" shielding on the areas of their modules exposed to greatest amount of orbital debris & meteoroids impacts
    - Nextel and Kevlar materials used in the intermediate bumper
    - shielding capable of defeating 1.3cm diameter aluminum sphere at 7 km/s, normal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

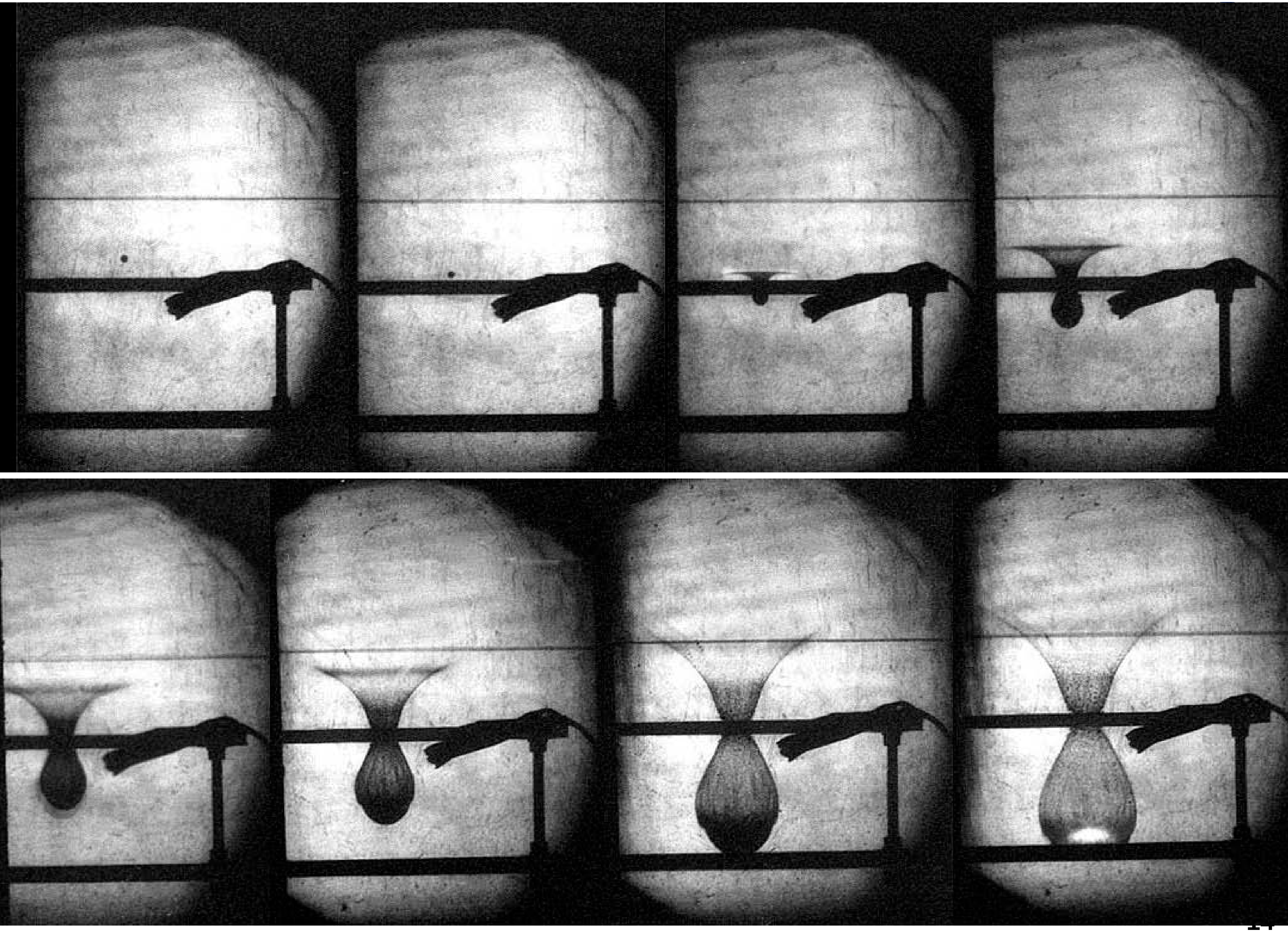
- MMOD shields typical composed of bumper(s), standoff, and rear wall (final protection layer)
  - Exclude multi-layer insulation (MLI) thermal blanket



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

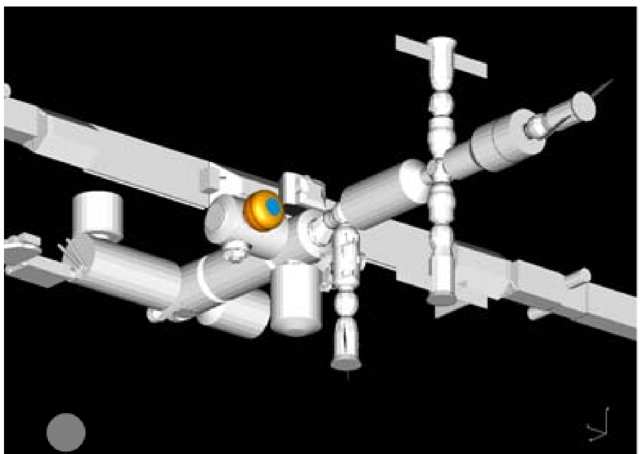
Purpose: Stop debris from MMOD & bumper(s)
Key material & physical parameters ($V \geq 7$ km/s): strength, toughness, thickness

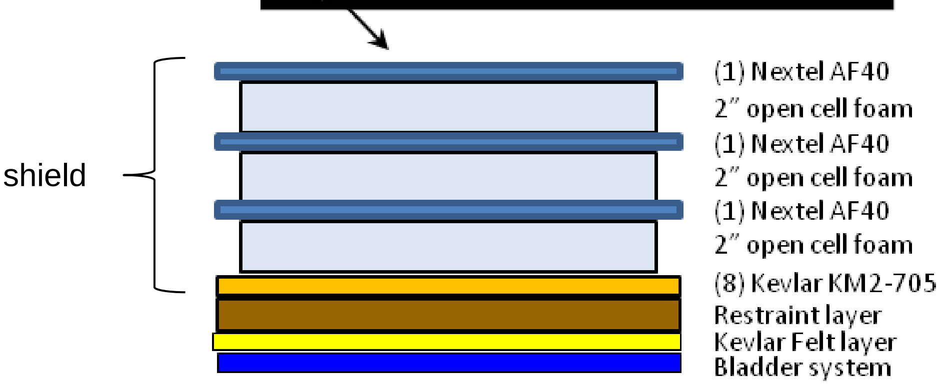


Shielding assessments for inflatables

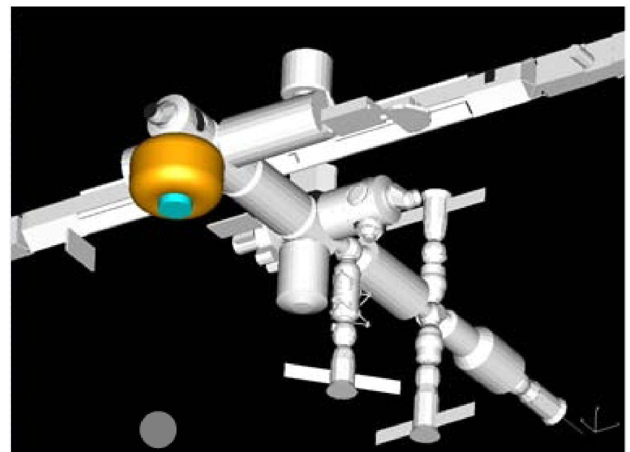
- Hypervelocity impact tests have been performed for MMOD shielding of potential inflatable modules, for two damage modes:
  - (1) Failure of shield protecting restraint layer
  - (2) Failure of shield, restraint and bladder

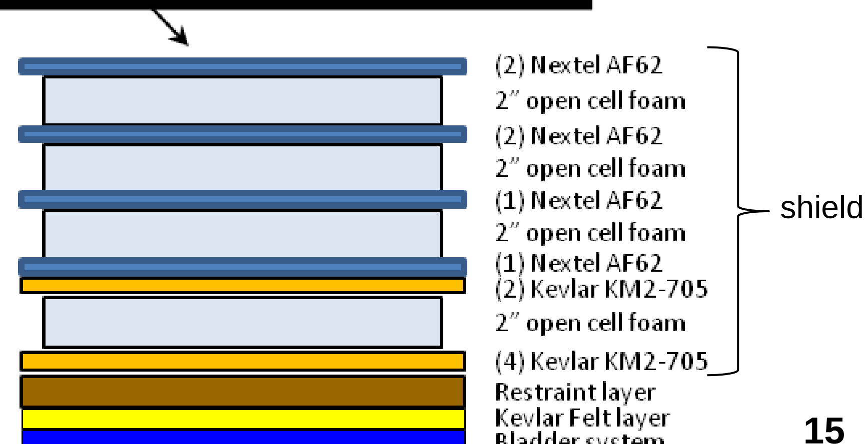
BEAM inflatable on Node 3 aft





Deep Space Habitat inflatable demonstrator on Node 2 nadir





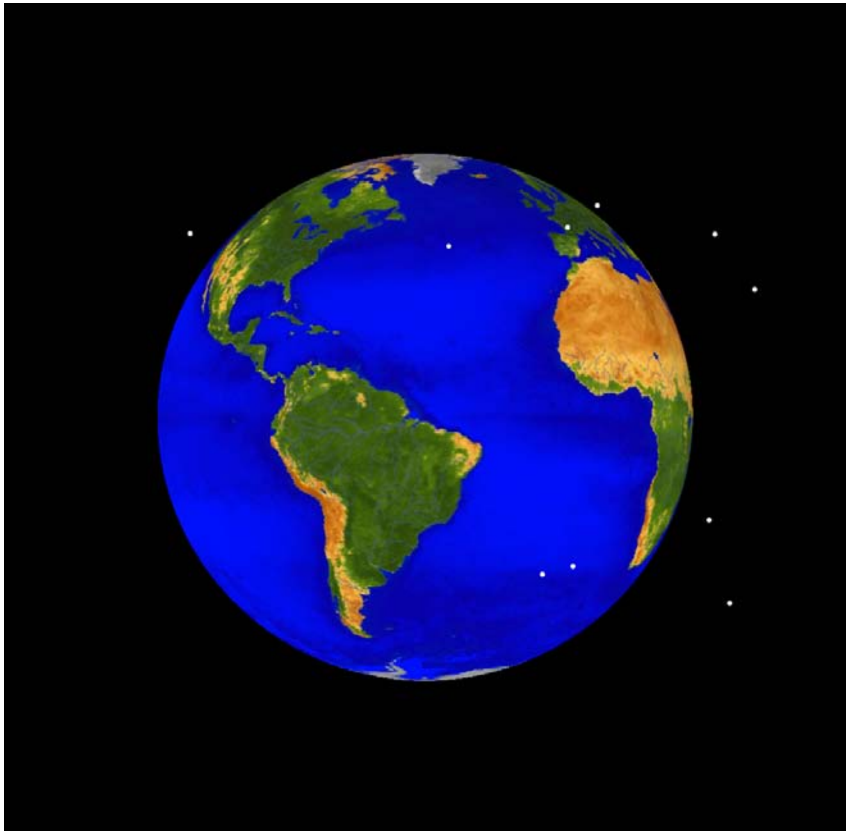
Summary

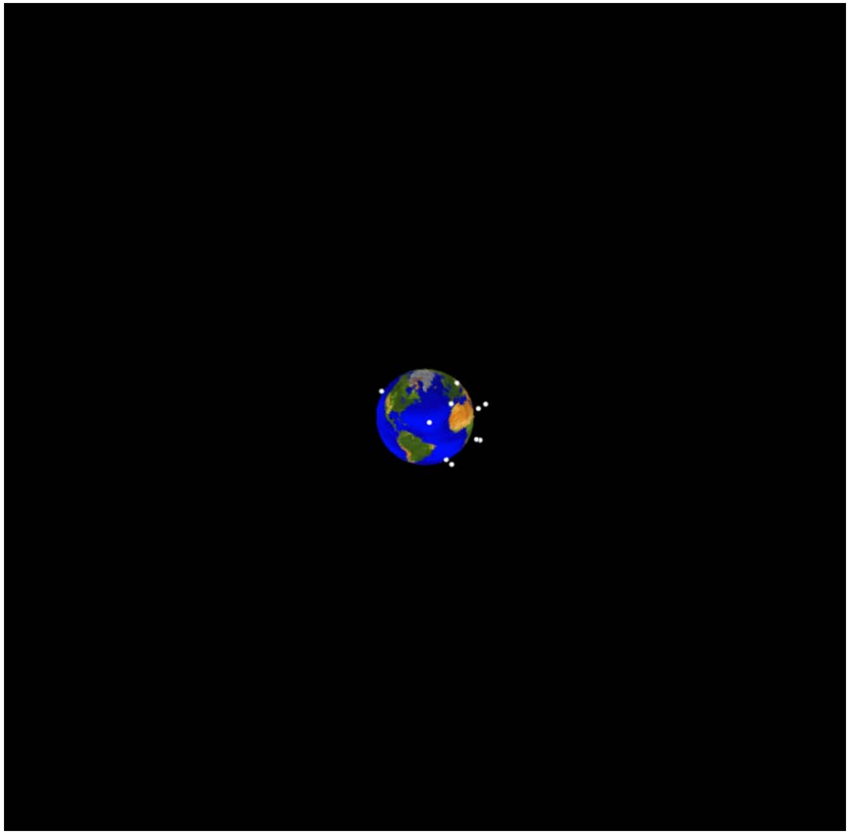
- MMOD shielding capability influenced by both:
  1. Configuration – "standoff" (more is better), number of bumper shield layers
  2. Material selection – ceramics/metals on exterior of shield, high-strength to weight ratio (fabrics & composites) on interior of shield

- 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

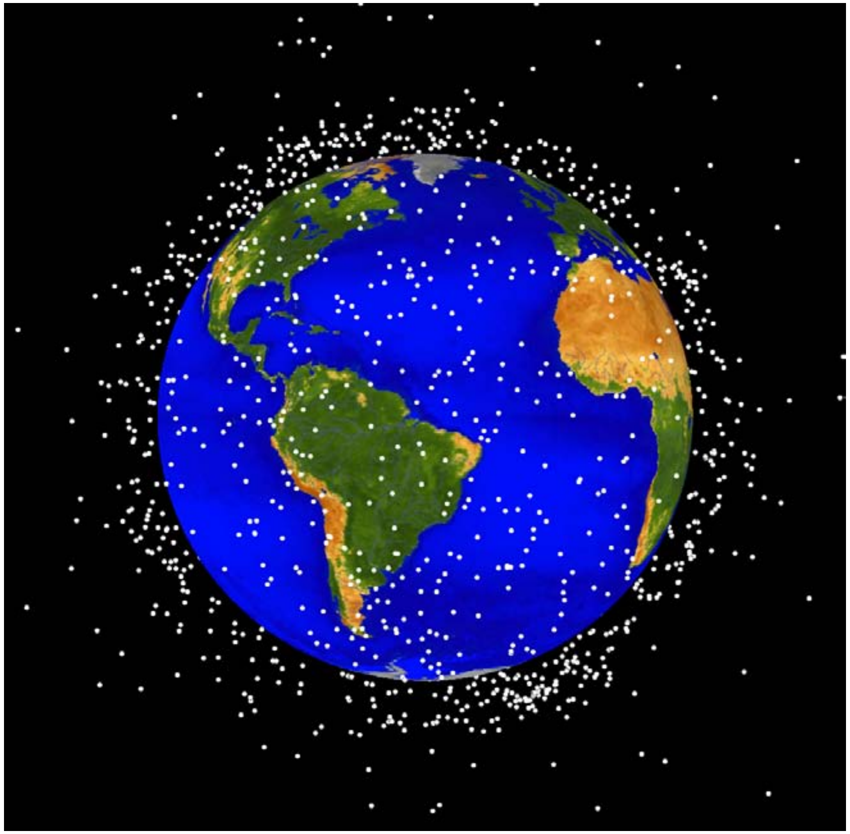
1960

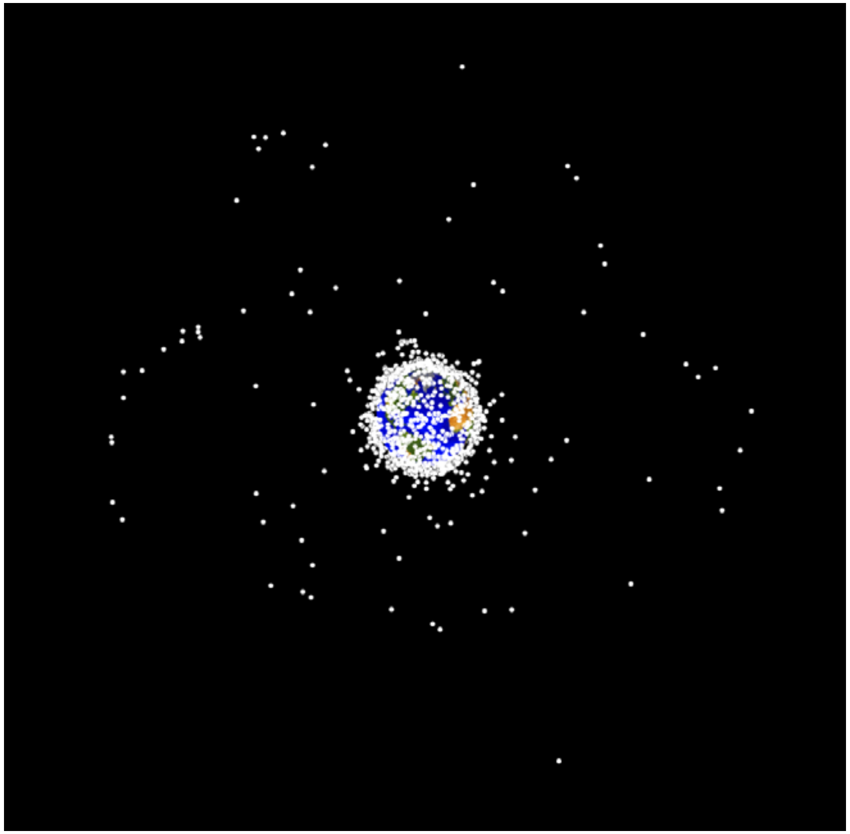




Cataloged objects >10 cm diameter

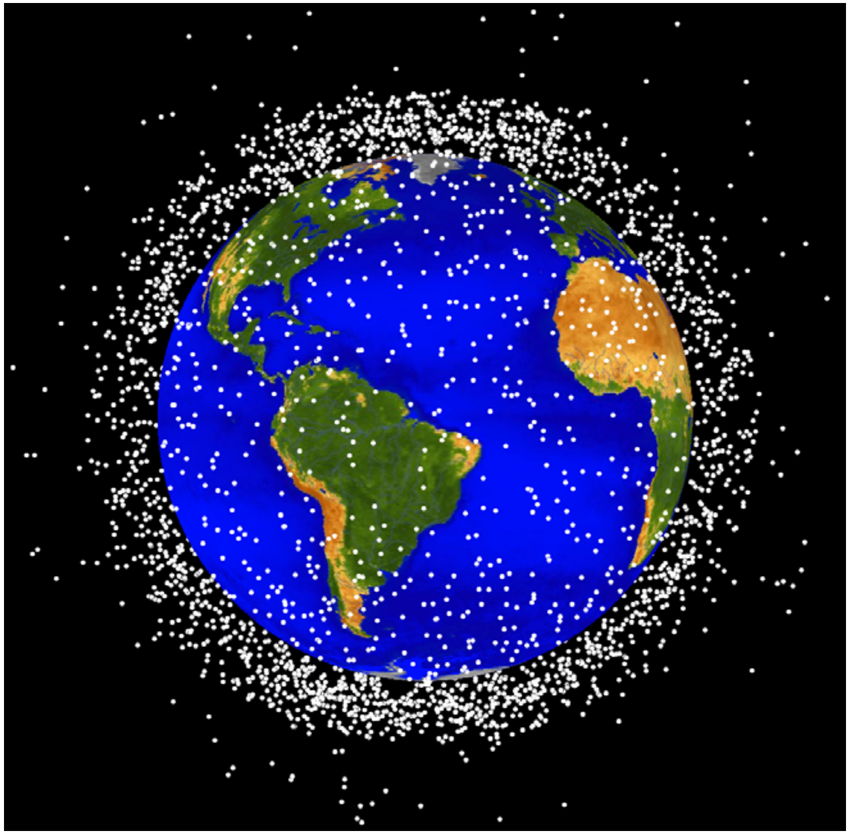
1970

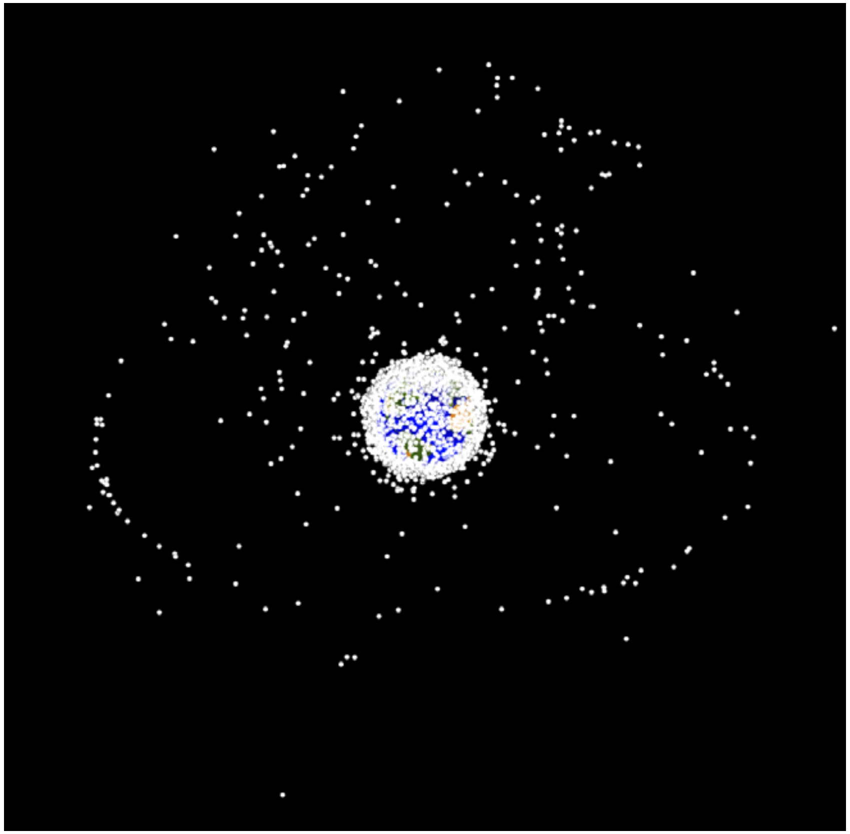




Cataloged objects >10 cm diameter

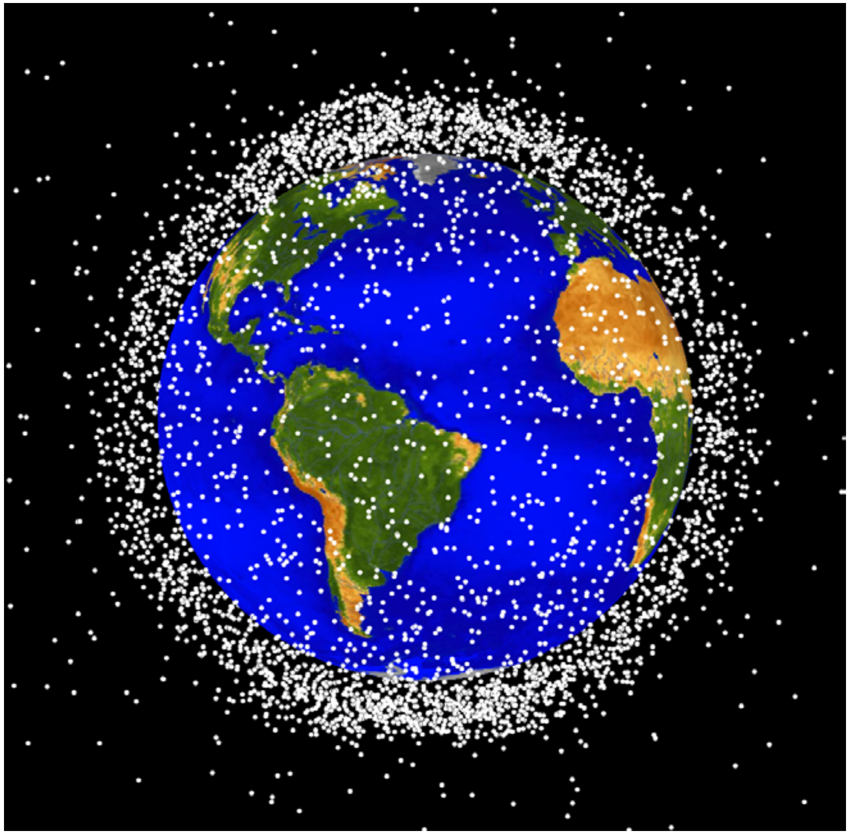
1980

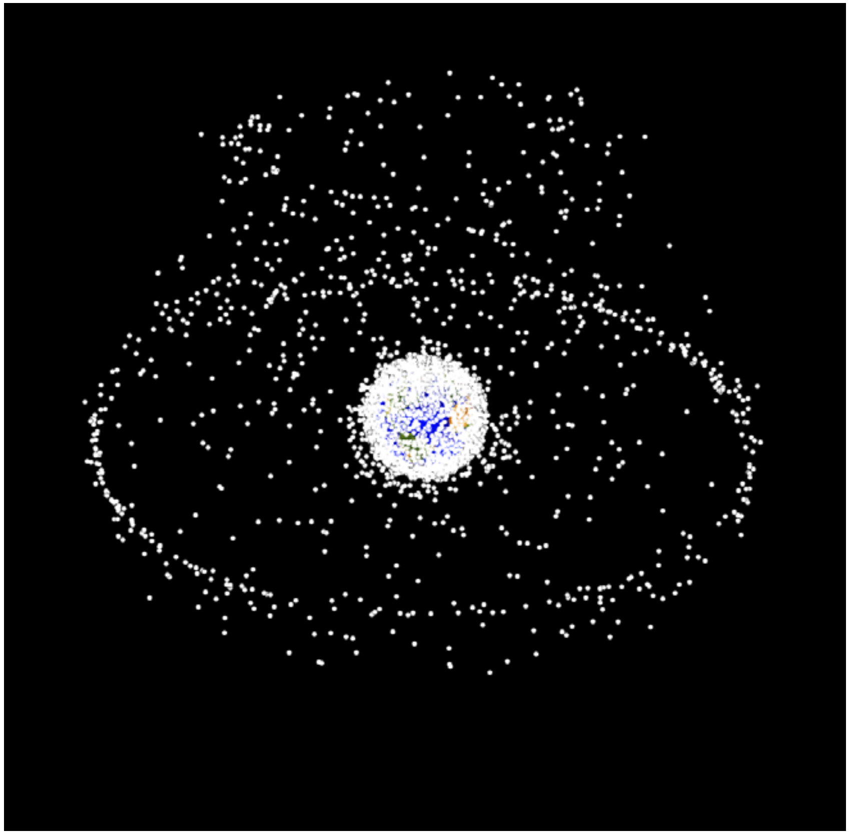




Cataloged objects >10 cm diameter

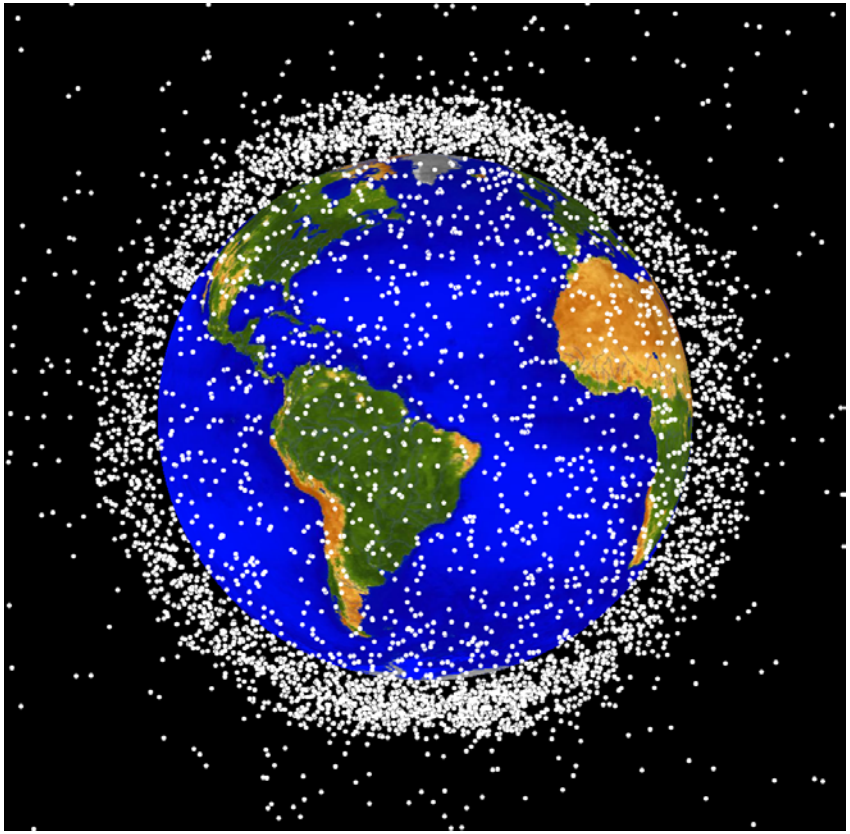
1990

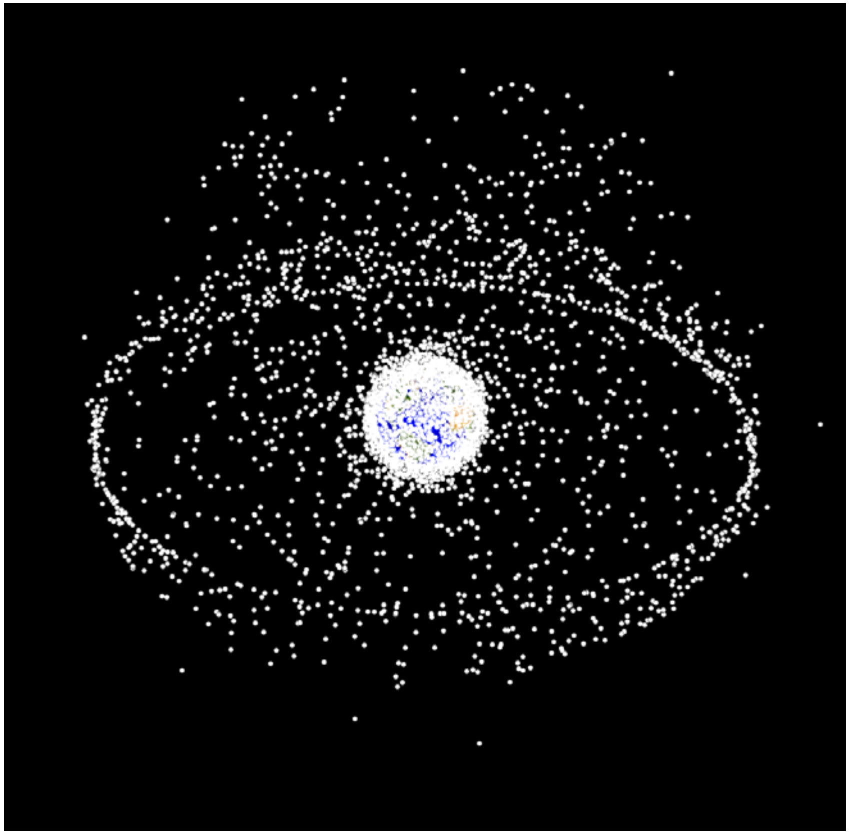




Cataloged objects >10 cm diameter

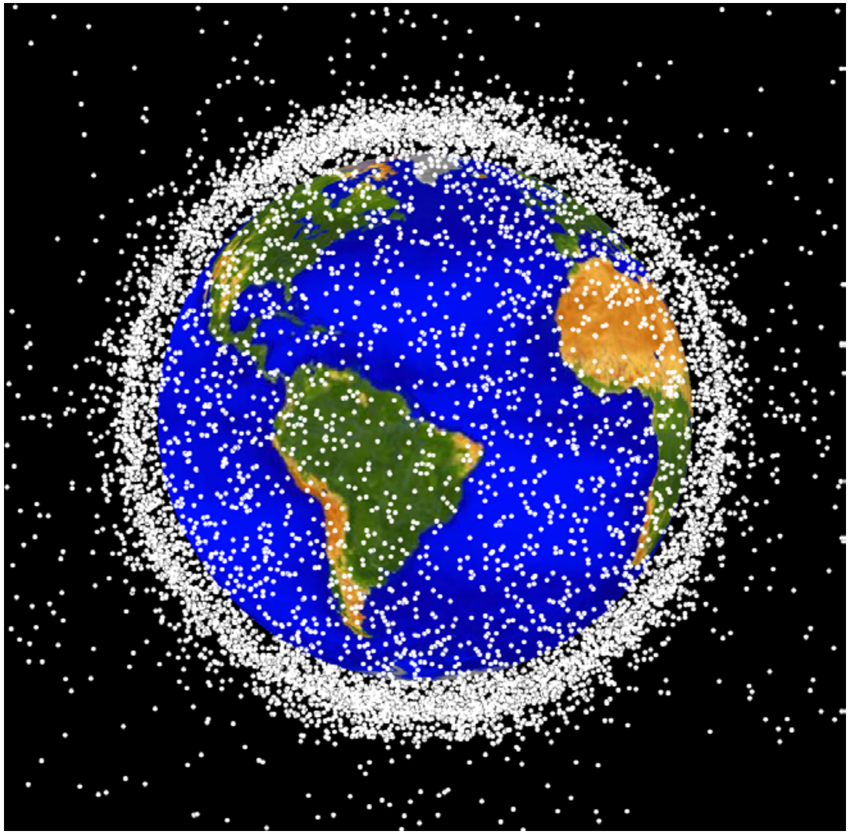
2000

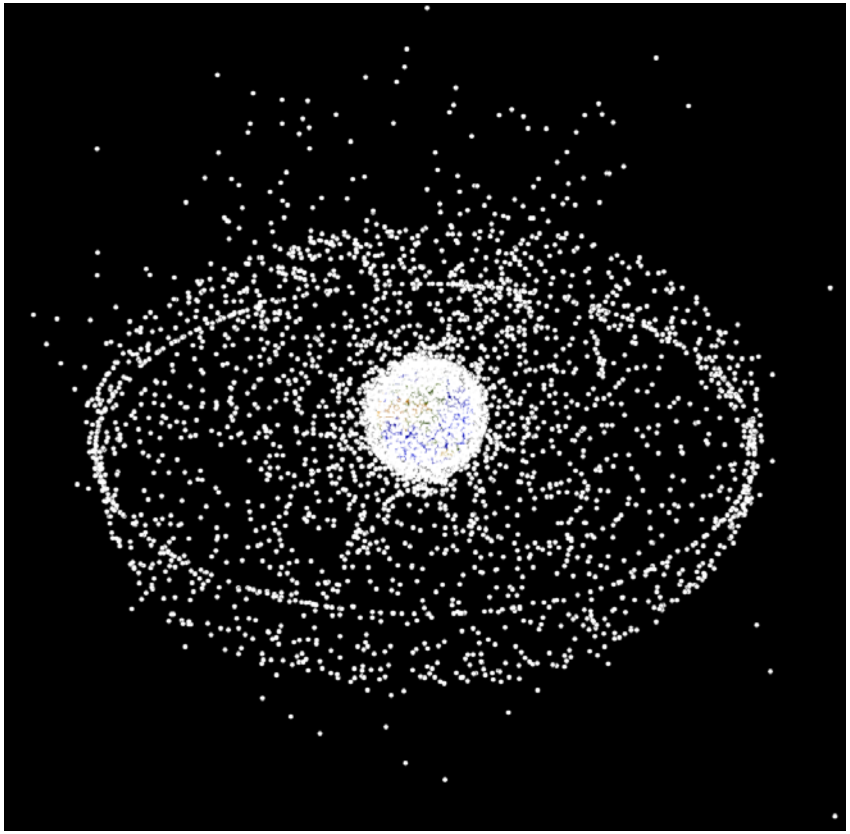




Cataloged objects >10 cm diameter

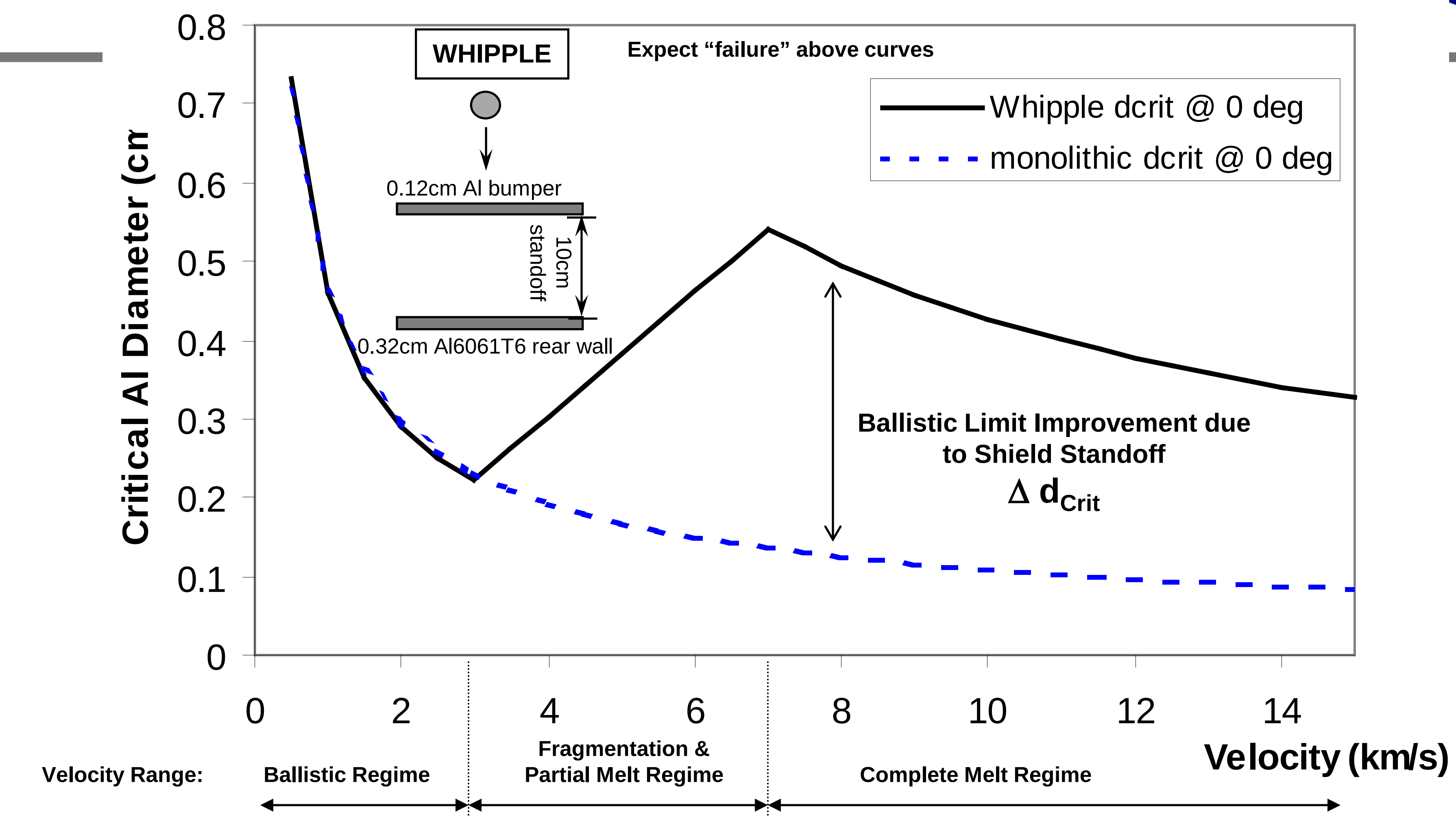
August 2009





Cataloged objects >10 cm diameter

Ballistic Limits for Whipple Shield & equal mass Monolithic



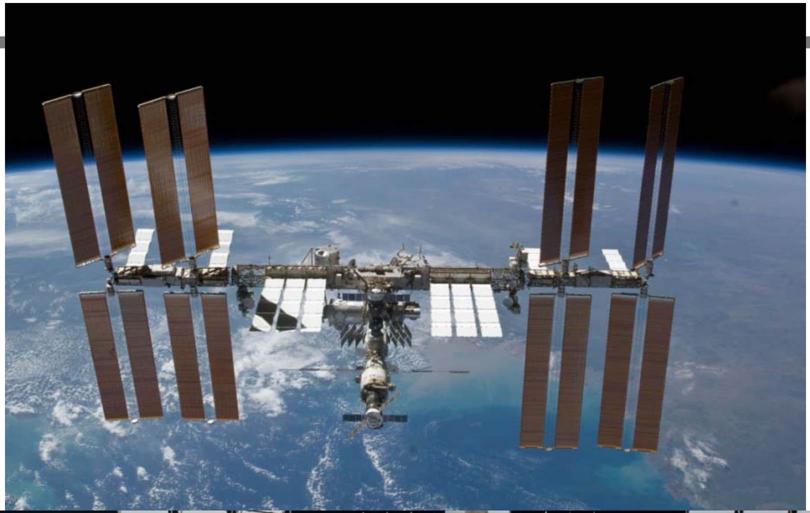
State of Debris Cloud: Few solid fragments
(for Al on Al impacts)

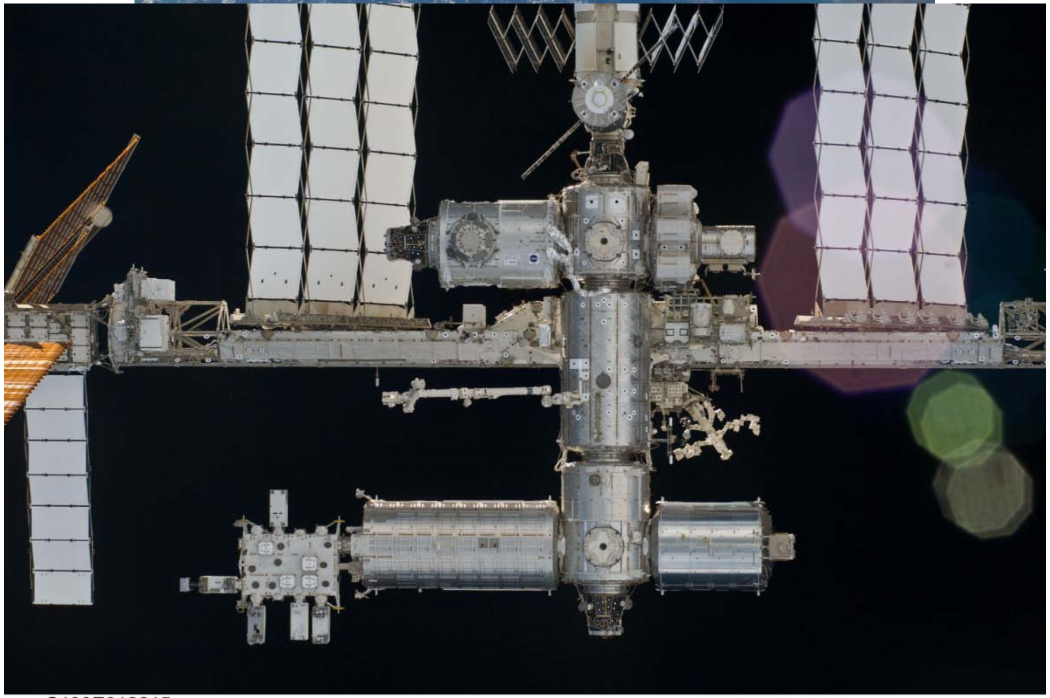
Many (increasing with velocity) solid fragments & liquid droplets

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





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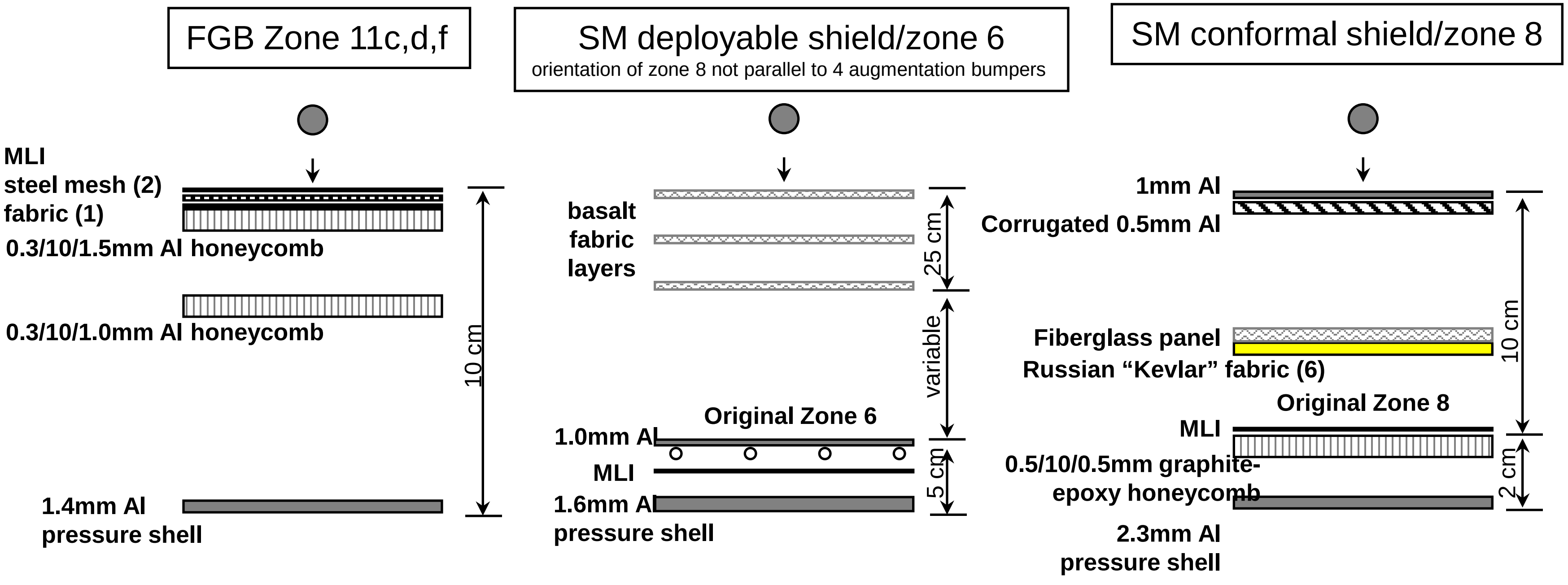
Shielding materials

- 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)



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