# A Proposal for Standardized MMOD Shielding for Robotic Spacecraft

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# Agenda

- Introduction
- MMOD Penetration Risk Assessment Process
- Orbital Debris Flux Trends
- Component Directionality
- Standardized Blanket Selection Concept
- Summary
- Future Work

# Introduction

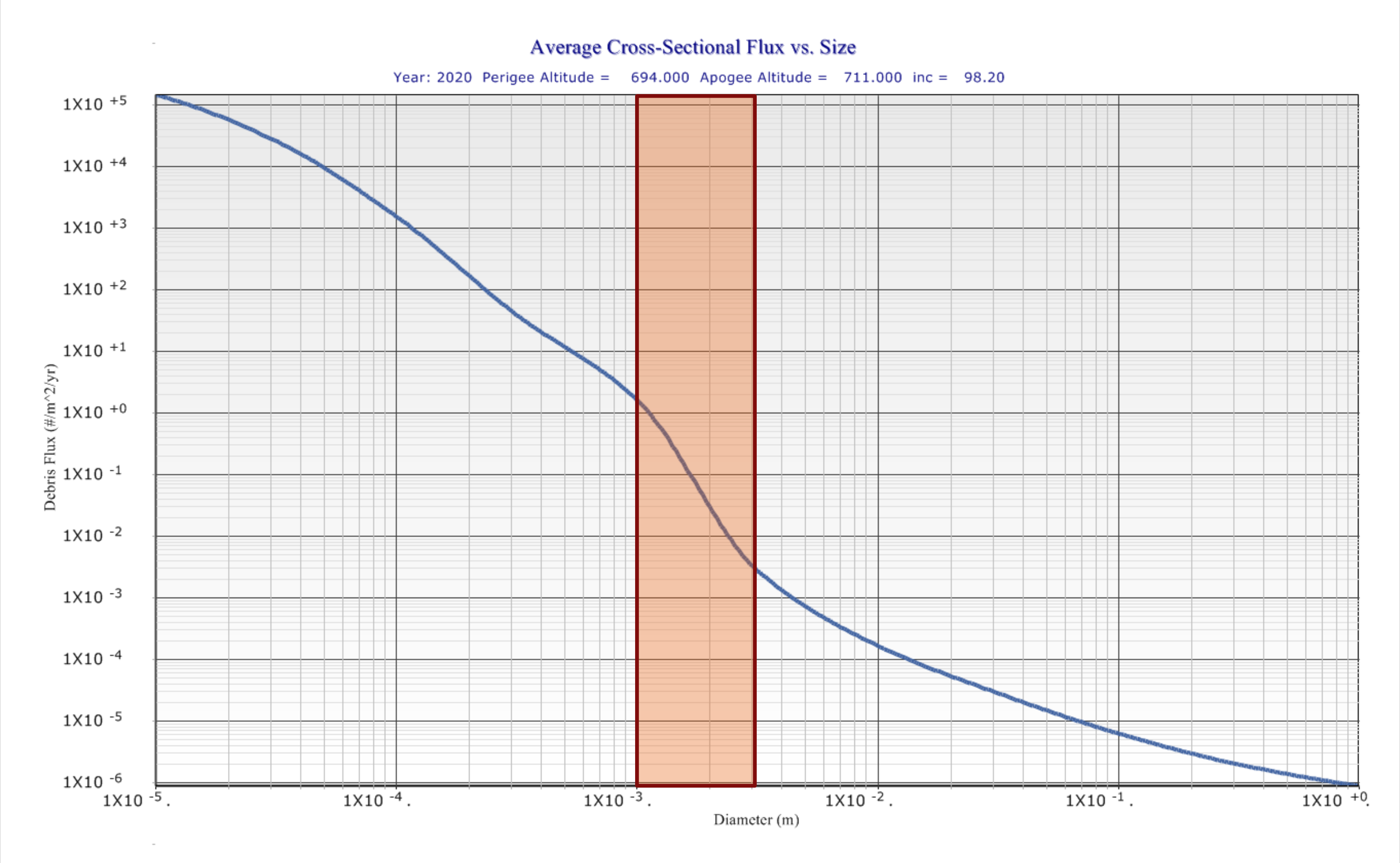
- Micrometeoroids and Orbital Debris (MMOD) are a threat to spacecraft
  - Orbital debris dominates in LEO
- Shield robustness determines the flux of penetrating particles
  - NASA requirement is <0.01 risk per spacecraft of preventing planned disposal
- Traditional risk assessment is performed after design has matured
  - Adequate approach when the risk is low, but increased risks with ORDEM 3.0 model
  - Costs of supplemental shielding rise with spacecraft maturity
- Proactively identifying shield needs early saves time and cost
  - Prevents unexpected thermal and manufacturing difficulties later
  - Not optimized, though; may carry a mass penalty
- This proposal examines the driving factors for proactive shield design

# MMOD Penetration Risk Assessment Process

- NASA uses the Bumper software tool
- Bumper determines the exposure from all angles (Geometry module)
  - 3D CAD model: spacecraft and component dimensions and locations
- Bumper determines the penetrating particle diameters and velocities (Response)
  - Damage tolerance and shielding materials, including the chassis wall
  - Built-in ballistic limit equations for shield types
- Bumper predicts the number of penetrations ($N_{pen}$) with the Shield module
  - Environment models for MM (MEMR2) and OD (ORDEM 3.0)
  - $N_{pen}$ used to generate $P_{pen}$
- Comprehensive risk for spacecraft is calculated, including redundancy

# Orbital Debris Flux Trends

## Typical flux vs. particle size curve

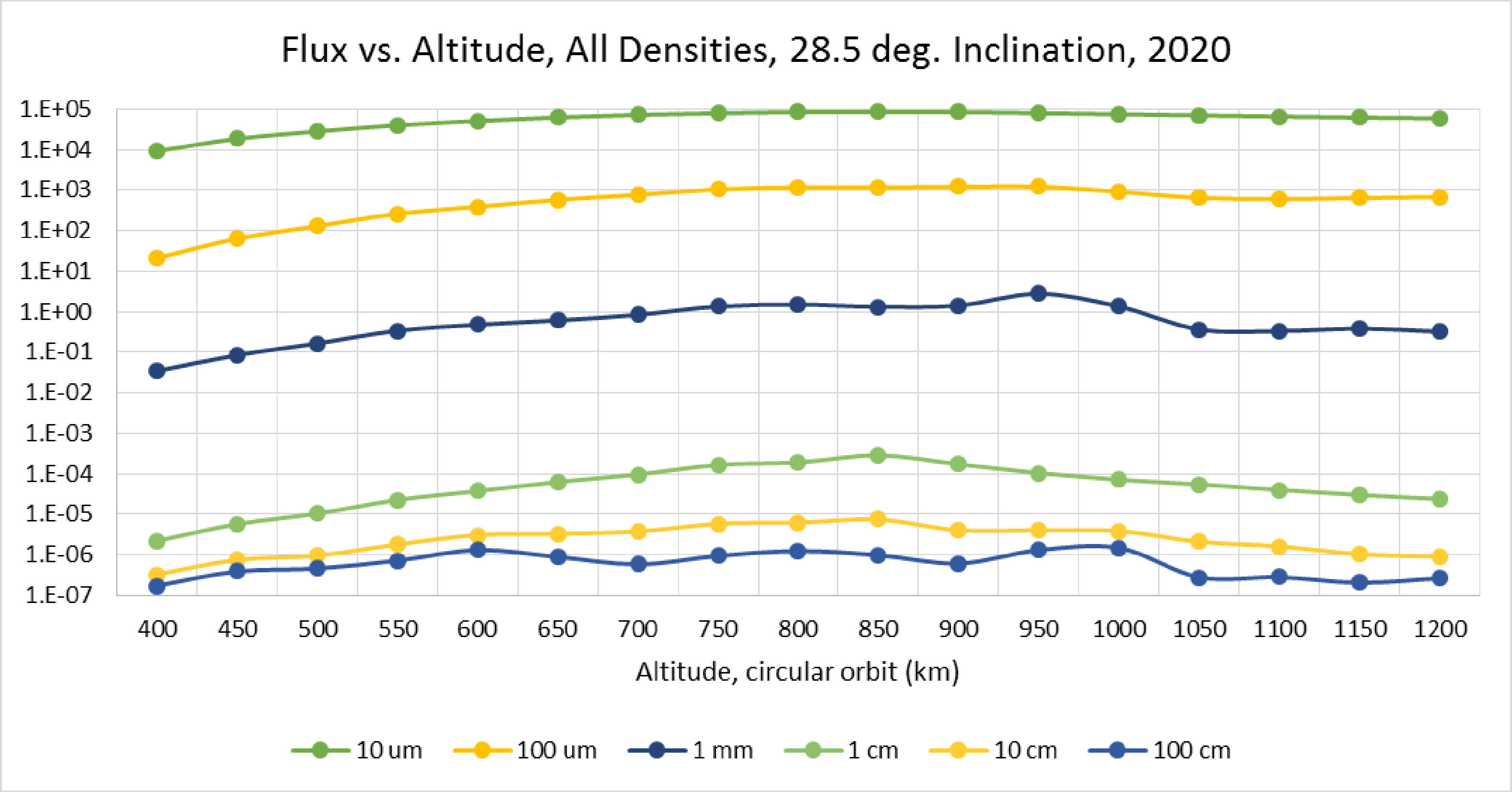


1-3 mm is a <u>critical size range</u>

- < 1 mm: most particles are shielded by the chassis wall
- > 3 mm: flux is very low, and shielding is very difficult
- Steepest part of the curve

# Debris Flux vs. Altitude

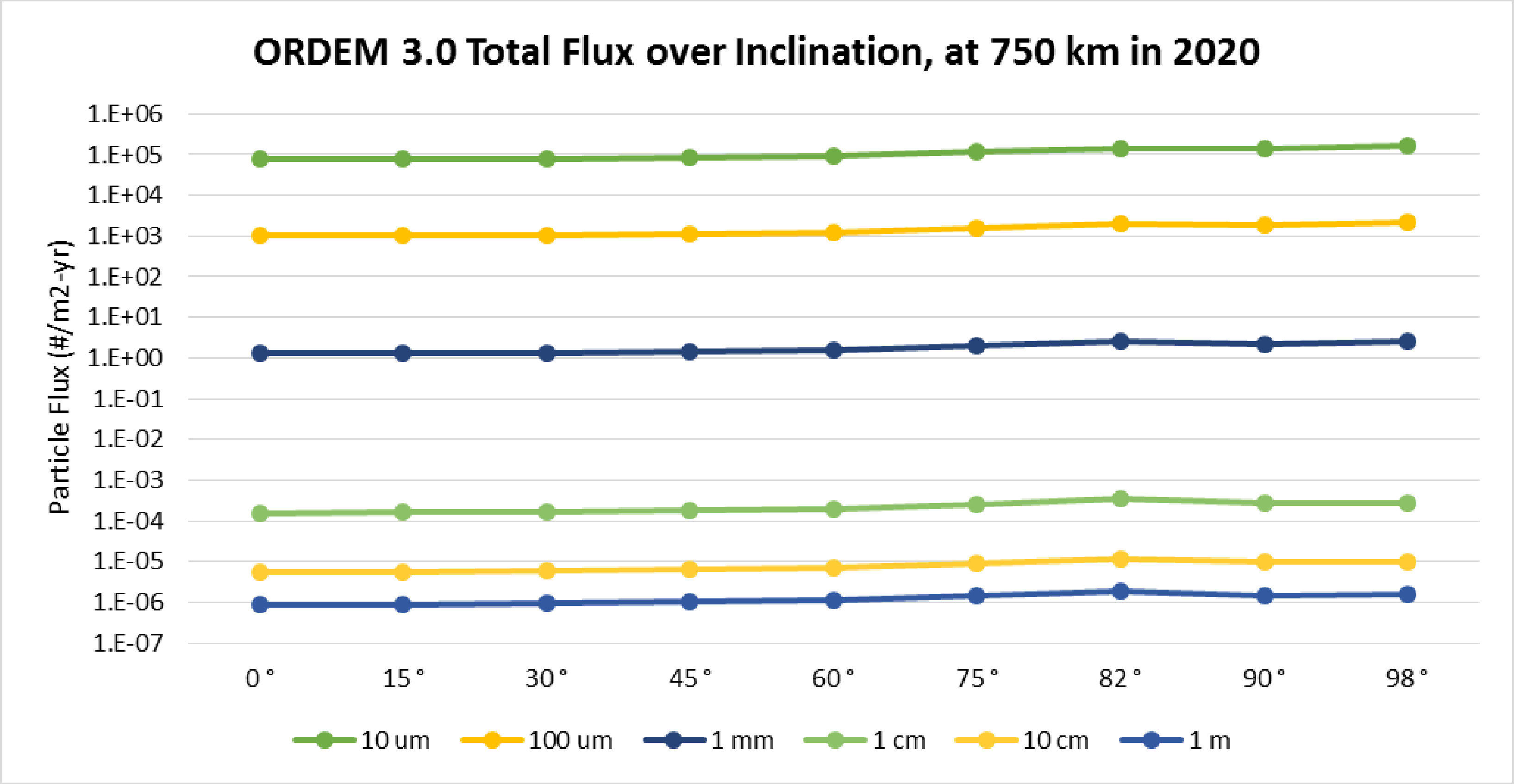
## for Different Particle Sizes



- Orders of magnitude difference between particle sizes
- Up to 2 orders of magnitude range for a specific particle size

# Debris Flux vs. Inclination

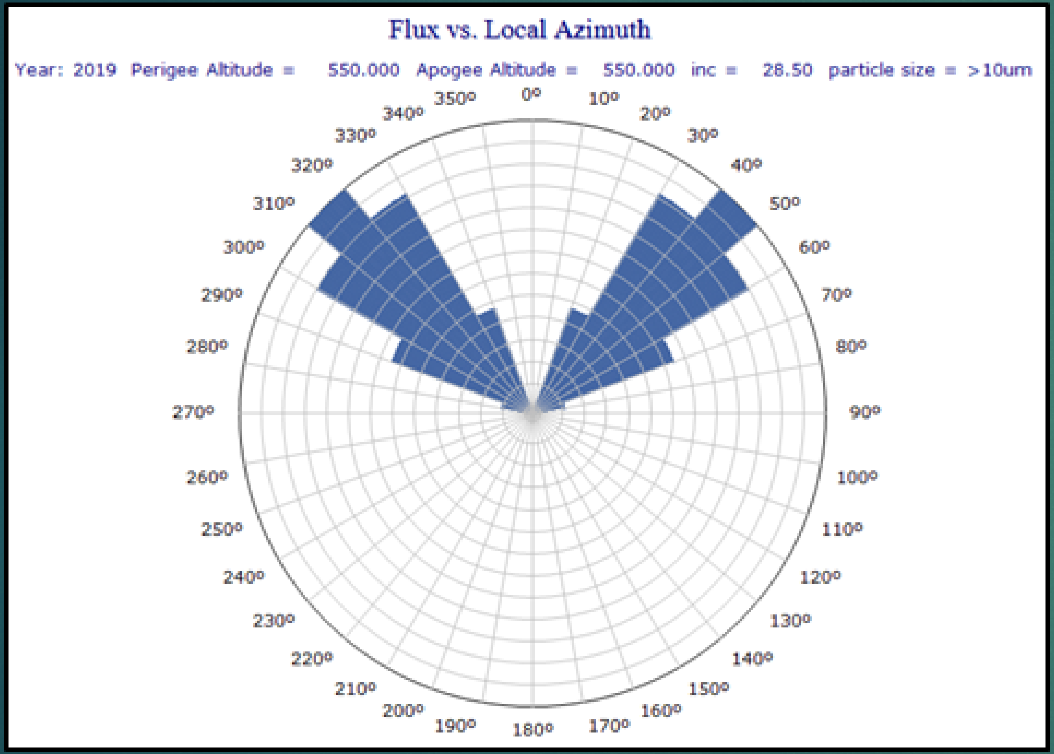
## for Different Particle Sizes



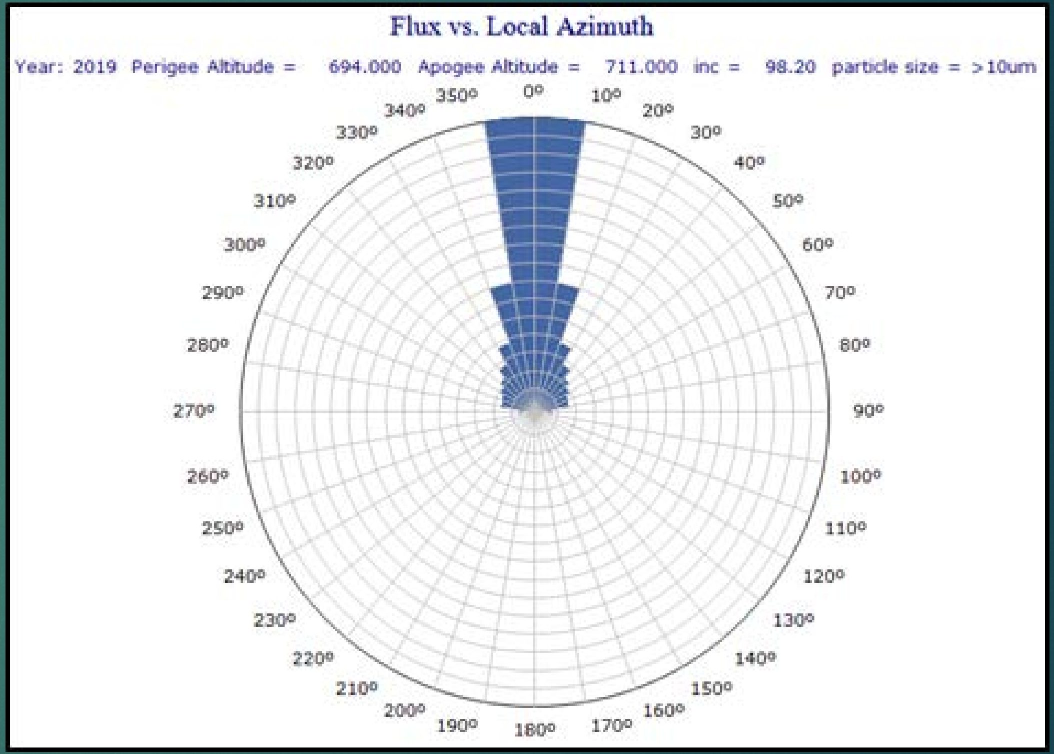
- Variations are within about a factor of 2
- Stronger difference is in the flux direction (next slide)

# Debris Flux vs. Inclination

## Flux Direction Plots



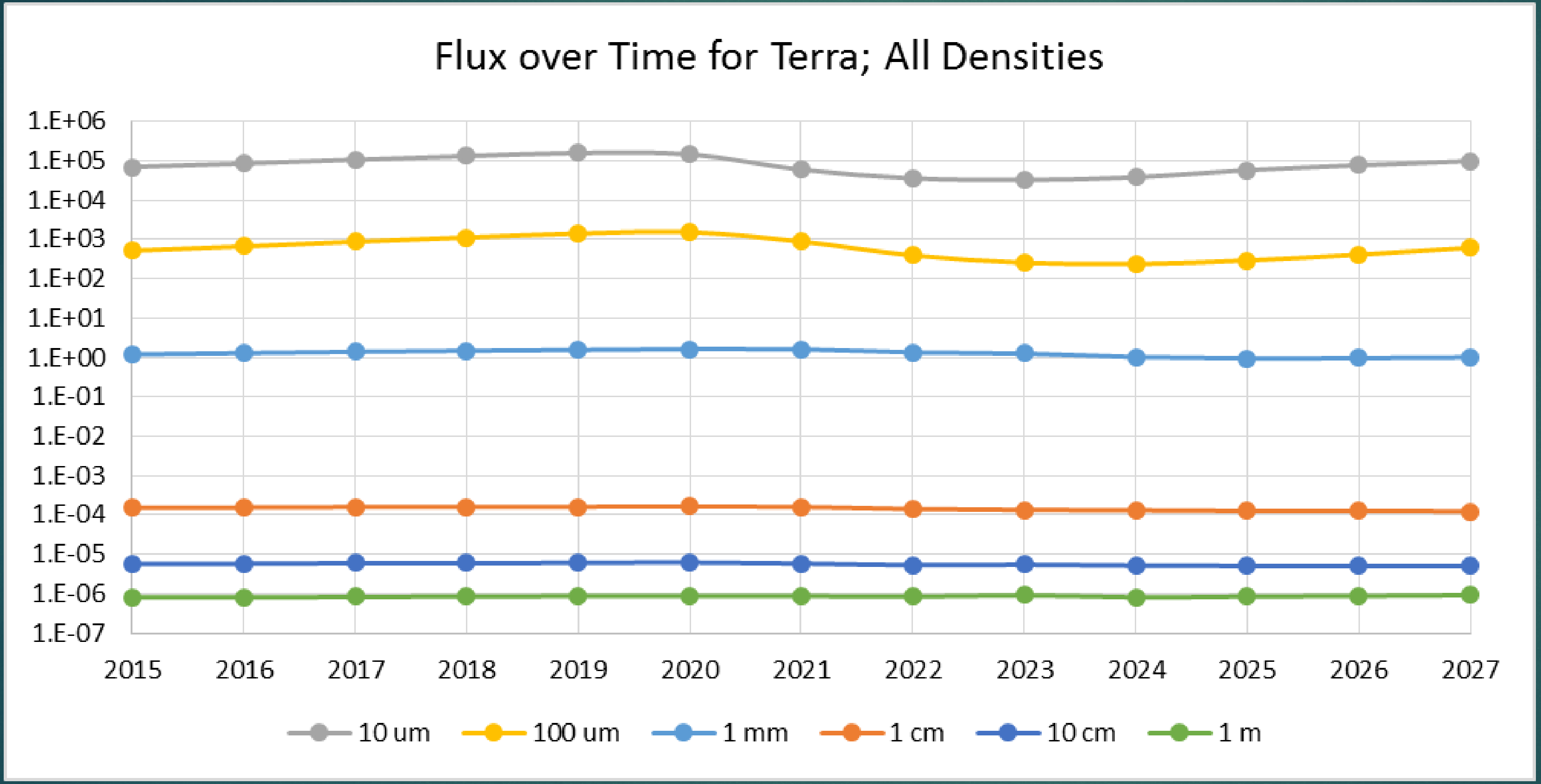
28.5° Inclination



98.2° Inclination

# Debris Flux vs. Time

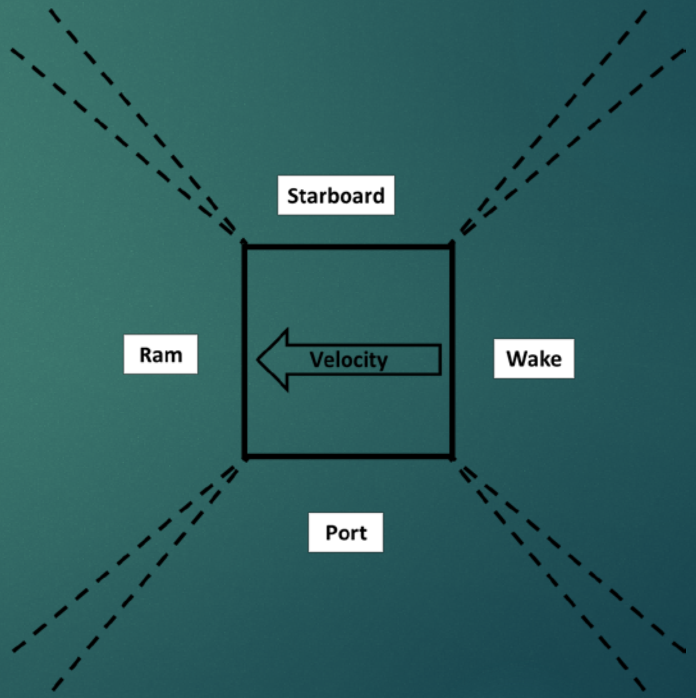
## for Different Particle Sizes



- Variations are within about a factor of 2
- Flux varies with solar cycle, so the start date is important

# Component Directionality

- Threat varies greatly by the direction with respect to velocity
  - Consider each direction separately
  - Could have very different shields for each side of the component
- Baseline categories use +/- 40° azimuth and +/- 5° elevation
  - Includes ~95% of total debris flux
- For missions that vary the velocity direction, consider all exposed directions equally



# Standardized Blanket Selection Concept

- Notional idea – not yet fully developed or tested
- Shields categorized by the total fluence only
  - Impact velocity, impact angle, and projectile density contributions are all factored into the design of the shield
  - Critical surface area is nullified by the blanket area
- Estimate the total debris fluence in each critical direction
  - $\text{Flux}_{\text{Direction}} \times \text{Time} = \text{Fluence}_{\text{Direction}}$
- For ‘omnidirectional pointing’ missions, divide the total particle flux by 5, since there is usually one keep-out direction
- Some engineering judgement will always need to be to be employed

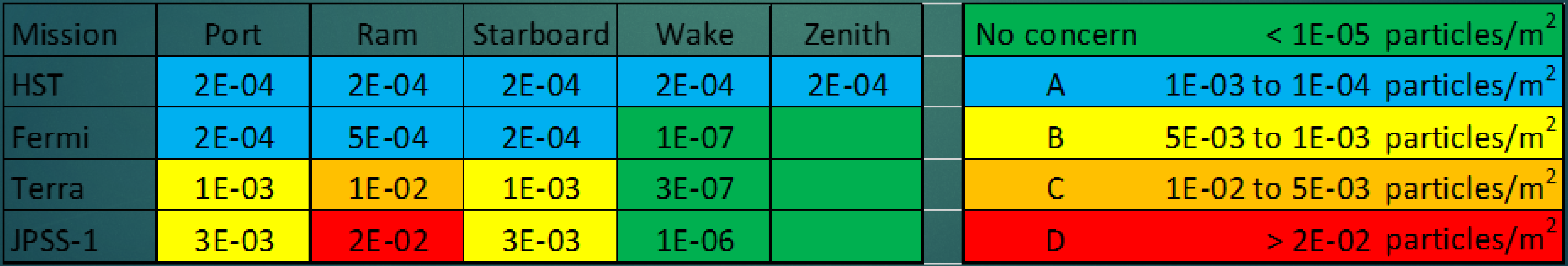
# Notional Blanket Categories

| Mission | Perigee (km) | Apogee (km) | Inclination (degrees) | Design Mission Lifetime (years) |
|---|---|---|---|---|
| **HST** | 550 | 550 | 28.5 | 15 |
| **Fermi** | 524 | 541 | 25.6 | 5 |
| **Terra** | 694 | 711 | 98.2 | 5 |
| **JPSS-1** | 825 | 825 | 98.8 | 7 |

- Total fluence categorized as A-D
- Standardized blanket designs created for each threat category
  - Already tested, with customized BLEs
- Adjust the basic approach for specific mission needs

Total Fluence (particles/m$^2$) per Mission and Direction

Notional Blanket Categories



| Mission | Port | Ram | Starboard | Wake | Zenith |
|---|---|---|---|---|---|
| HST | 2E-04 | 2E-04 | 2E-04 | 2E-04 | 2E-04 |
| Fermi | 2E-04 | 5E-04 | 2E-04 | 1E-07 | |
| Terra | 1E-03 | 1E-02 | 1E-03 | 3E-07 | |
| JPSS-1 | 3E-03 | 2E-02 | 3E-03 | 1E-06 | |

| | |
|---|---|
| No concern | < 1E-05 particles/m$^2$ |
| A | 1E-03 to 1E-04 particles/m$^2$ |
| B | 5E-03 to 1E-03 particles/m$^2$ |
| C | 1E-02 to 5E-03 particles/m$^2$ |
| D | > 2E-02 particles/m$^2$ |

# Standardized Blankets

- Landsat 9 has developed and tested blankets recently
  - Very similar to the Terra orbit and duration
  - From those designs, Level B and C blankets can be selected
  - Existing test data has been used to generate custom BLEs
- JPSS-2 is currently developing and testing blanket solutions
  - Should be useable to develop a Level D blanket design
- Level A blanket remains to be designed and tested
- Chassis wall thickness variations
  - Kevlar can be used to supplement the chassis layer stopping capacity
  - NASA HVIT has developed an Al equivalence formula for Kevlar

# Summary

- A notional concept for a proactive MMOD shielding design is discussed
- Variations in the orbital debris environment are a major driver
  - Examined in terms of altitude, inclination, and time aspects
  - Orbit altitude has the greatest effect on the debris threat
  - Mission duration and start date is also an important consideration
- Five categories of pre-tested shields are proposed
  - Based on directional debris fluence over the baseline mission duration
- Identifying the shielding needs early will minimize the cost and schedule impact, and provide predictable thermal performance

# Future Work

- Identify candidate shield blankets for all categories
  - Complete the hypervelocity testing for Level A shields
- Estimate the effectiveness and practicality of this approach
  - Use actual NASA past missions as case studies
  - Estimate the resulting penetration risk for each case
  - Estimate the mass if these shields had been used
  - Confirm that the shield designs would physically fit into the structures
- Perform thermal testing to characterize shield A-D performance in place of multi-layer insulation
- Confirm manufacturability of the shield candidates
  - Particularly the spacers between layers