



Potential Space Disasters, and What We Can Do to Prevent Them

SCOTT HULL, NASA/GODDARD SPACE FLIGHT CENTER

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Challenges to Operating in Space

- ▶ Remote Location
 - ▶ Difficult or impossible repairs
 - ▶ Difficult or impossible rescue for crew
- ▶ Human Error
- ▶ Radiation
 - ▶ Typical background
 - ▶ Single event effects
- ▶ Orbital Debris
- ▶ Meteoroids
- ▶ Most apply in Earth orbit and beyond

Crewed vs. Robotic Missions

Crewed Missions

- ▶ VERY high visibility
 - ▶ Many \$Billion
- ▶ Lives are at risk
- ▶ Much lower “acceptable” risk
 - ▶ Greater shielding thresholds
 - ▶ Higher threshold for lethal objects
- ▶ More checks in operations
- ▶ More redundancy in design

Robotic Missions

- ▶ Lower visibility, but still important missions
 - ▶ \$100M to couple \$B
- ▶ Science data and knowledge are at risk
- ▶ Risk threshold defined by importance
 - ▶ Also reflected in cost
 - ▶ Lower thresholds for lethal objects
- ▶ Operations are carefully conducted
- ▶ Some single-point-failures allowed

Remote Location Risks

- ▶ Launching a rescue or repair mission takes weeks to years
 - ▶ Launch vehicles aren't just sitting around
 - ▶ Repair materials may need to be developed
- ▶ International Space Station (ISS) is visited frequently
 - ▶ Still could take weeks to re-task a mission (it's much easier in the movies)
 - ▶ "Lifeboats" are attached to the station just in case
- ▶ Robotic Missions have Safehold Mode to provide time for assessment of anomalies
 - ▶ Failure may not be recoverable, though
 - ▶ Hubble Servicing missions fixed failures and upgraded capabilities

Radiation

- ▶ Total Dose Background
 - ▶ The longer you stay, the greater the effect
 - ▶ Accelerated ground testing of parts
 - ▶ Annealing effects usually make ground testing harsher than space
- ▶ Single Event Effects
 - ▶ Cosmic rays, and high energy protons from the Sun
 - ▶ Single Event Upsets (SEUs) are soft errors, and non-destructive: can result in data loss
 - ▶ Single Event Latchup (SEL) results in a high operating current: often destructive
- ▶ Error Detection and Correction circuits are used to mitigate damage

Radiation – Terra example

- ▶ Sometimes we don't know it all before launch...
- ▶ Optocoupler in the emergency shutdown circuit for the science instruments
 - ▶ Uses an LED and a phototransistor to electrically isolate circuits
- ▶ Radiation in the South Atlantic Anomaly caused a reset signal every day
 - ▶ Single event radiation was causing the light pipe to fluoresce: **shutdown signal**
 - ▶ We discovered this effect days before launch; were still writing the trip report
- ▶ New software edit uploaded to look for multiple/continuous reset signals
- ▶ Flexibility in the mission design saved the mission
- ▶ We no longer use that part, or use it knowing this characteristic

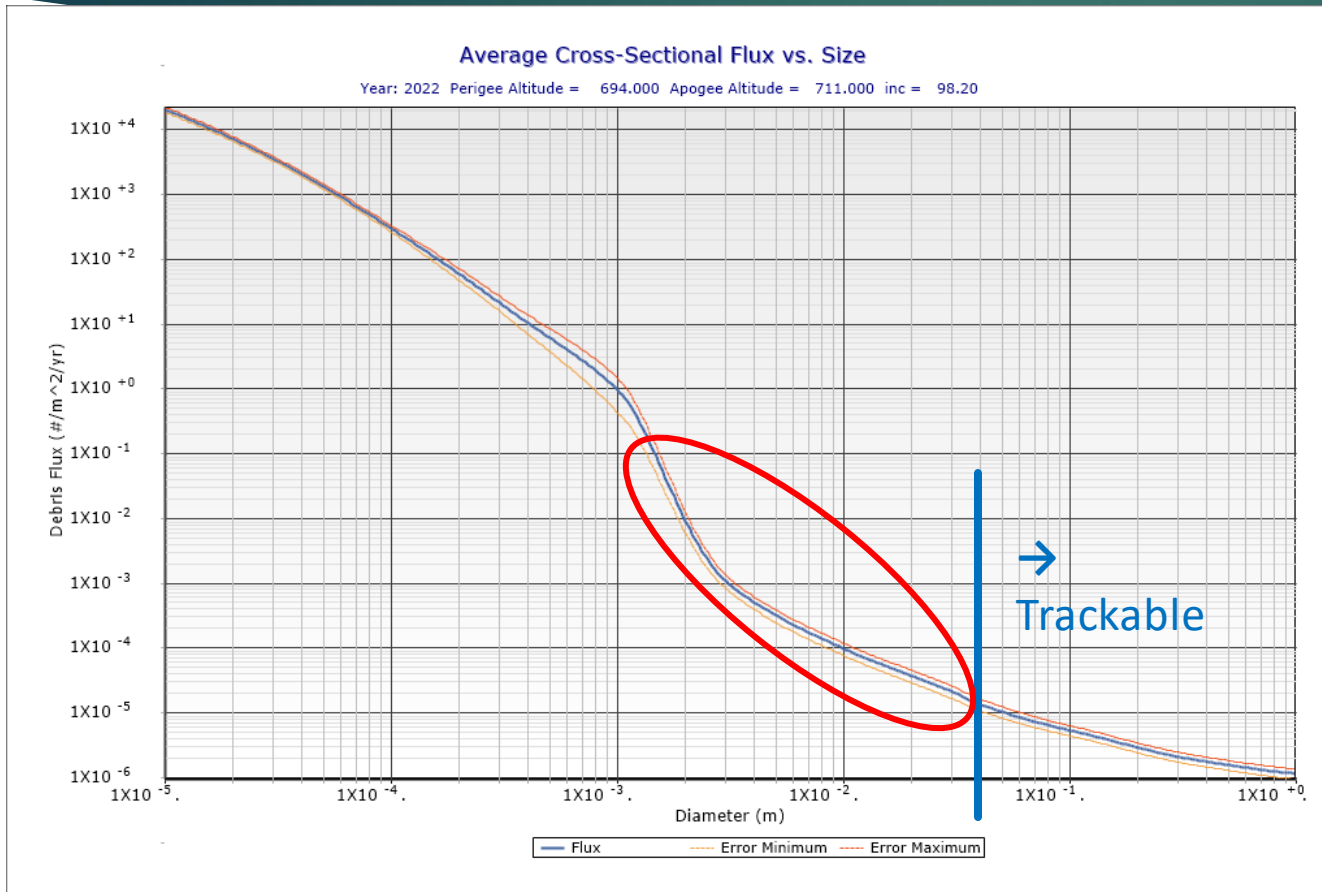
Physical Space Threats

- ▶ Two basic forms of Space Debris
 - ▶ Orbital Debris: 100% human-made; literally orbiting the Earth
 - ▶ Meteoroids: natural debris; not orbiting Earth; essentially random directions
- ▶ Also need to worry about non-debris objects in orbit
 - ▶ Operational satellites used to be a minor concern: ~2500 objects
 - ▶ Now more than twice that number, with a dense cluster at about 550 km
 - ▶ Constellations of literally tens of thousands of satellites EACH are planned
 - ▶ “Space is big” is less and less applicable

Orbital Debris Environment

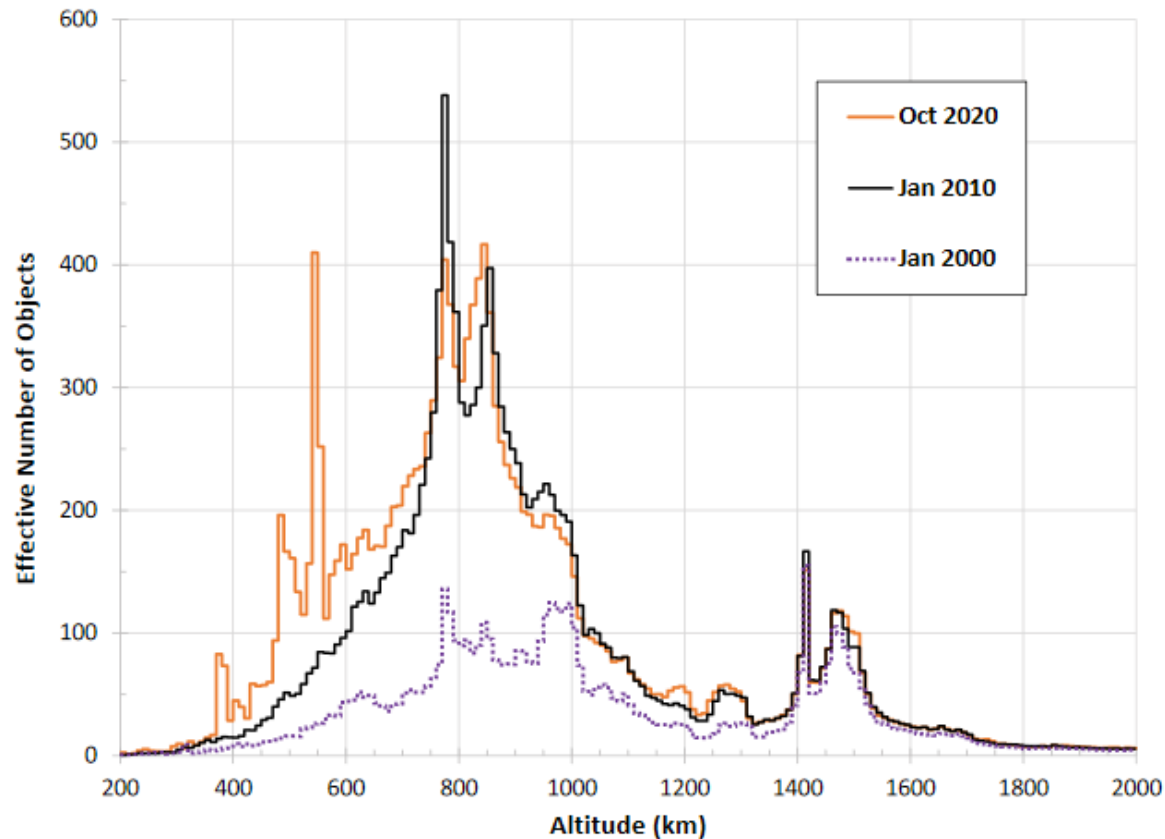
- ▶ Limited to Earth orbit, much denser in Low Earth Orbit than MEO or GEO
- ▶ Sources: rocket bodies, dead satellites, explosions, collisions
- ▶ Follows orbital characteristics
 - ▶ Very fast: up to 14 km/s for head-on collisions
 - ▶ Risk varies by direction, both particle flux and velocity
 - ▶ Typically, relatively low eccentricity (planar; few strikes in nadir and zenith direction)
- ▶ Size distribution (flux) falls off rapidly below about 1 mm
- ▶ ISS is shielded to about 1 cm object impacts
- ▶ Robotic spacecraft are often shielded to about 1.2 to 2 mm penetration

Orbital Debris Distribution - Size



- ▶ 705 km Sun-Synchronous orbit in 2022
- ▶ This is a log-log plot
- ▶ **Can only track individual objects > 4cm**
- ▶ Particles as small as **1.2 mm** can **penetrate components** on this spacecraft
- ▶ Oval indicates **Lethal Non-Trackable debris**
- ▶ The larger they are, the fewer, but still **10,000 times more lethal debris than that which we can track and avoid**

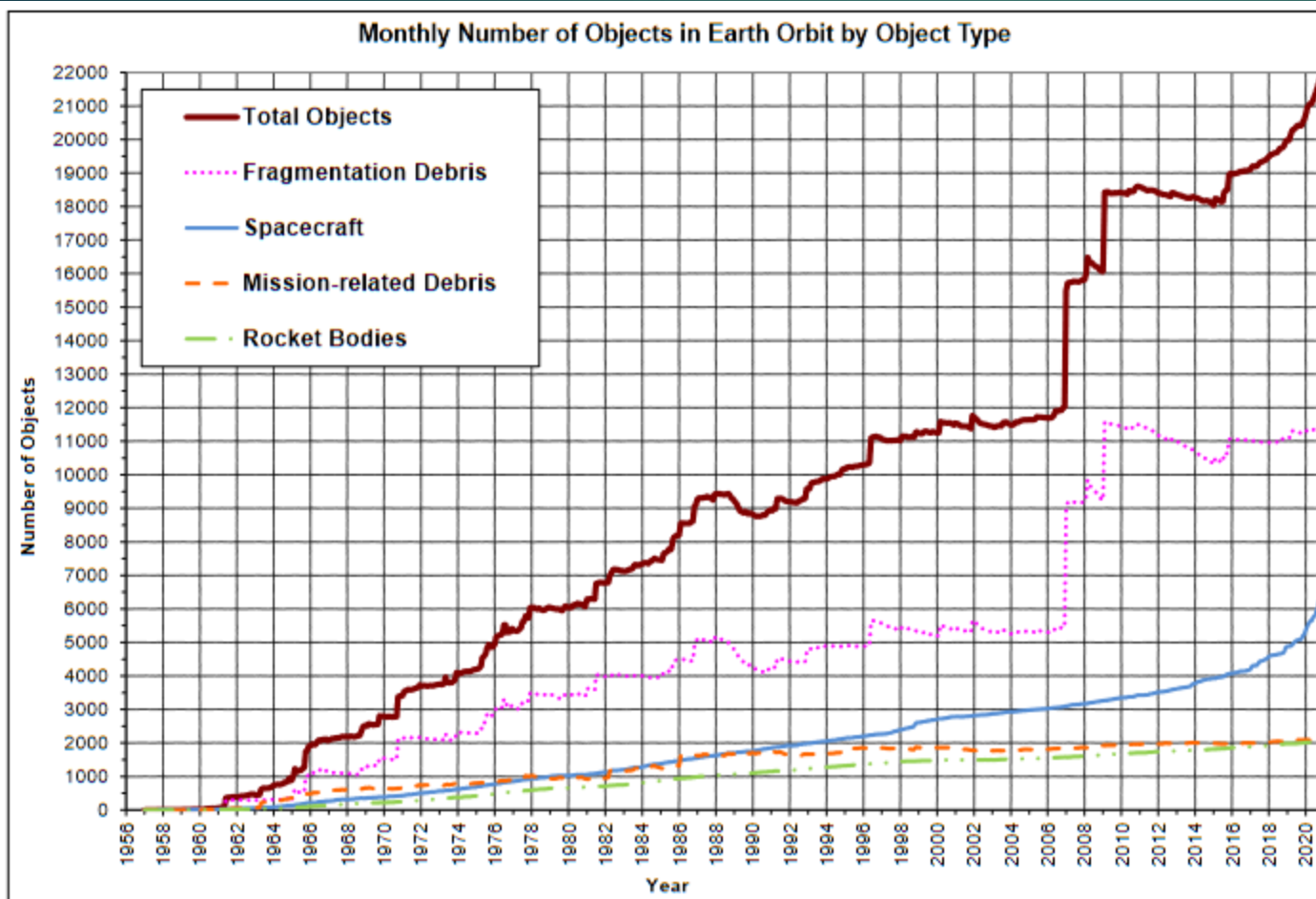
Orbital Objects Distribution - Altitude



- ▶ Shows the concentrations of all **tracked** orbital objects (> 10 cm)
 - ▶ Big peaks at ~780 and ~850 km
 - ▶ Modest peaks at 1400 and 1500 km
- ▶ Also shows changes over time
 - ▶ **New peak at 550 km** for Starlink
 - ▶ Bulk of 600 km debris dragging down to 500 km

Orbital Debris Quarterly News
November 2020

Orbital Debris Growth



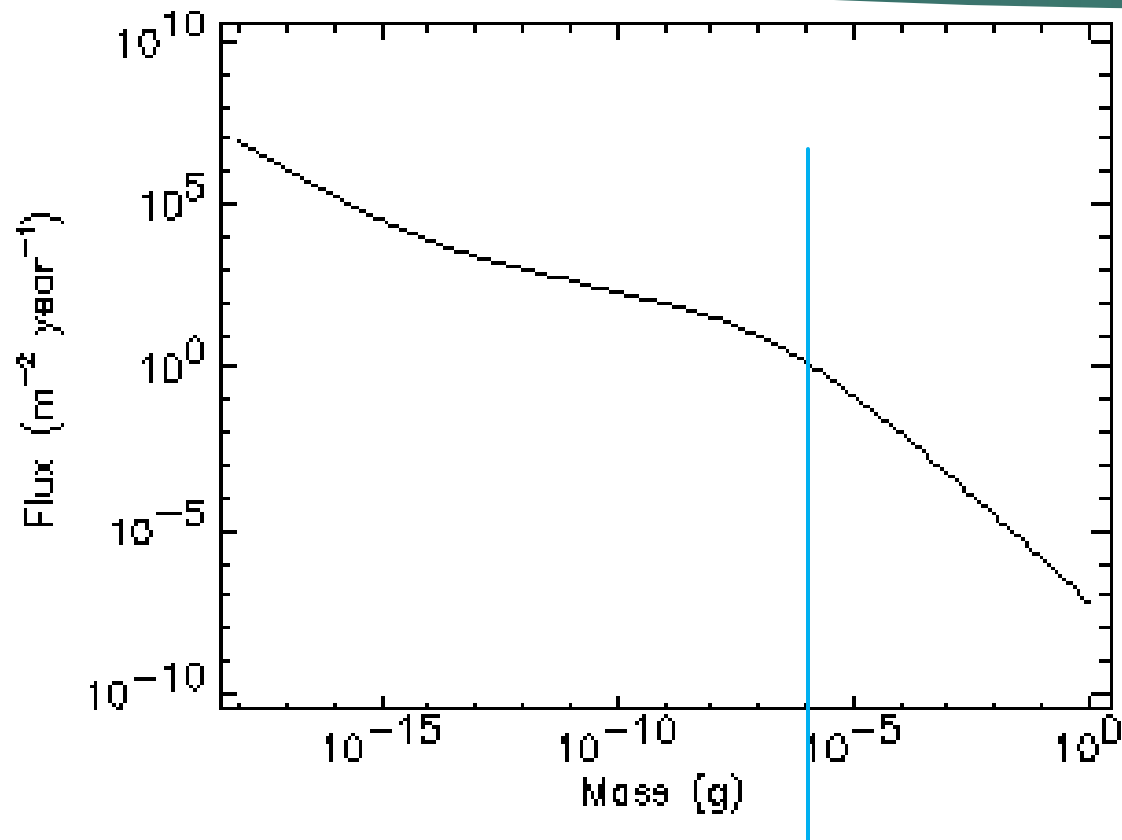
- ▶ Object count is increasing dramatically
- ▶ “Fragmentation” includes accidental and intentional collisions
 - ▶ One additional ASAT test since this plot was published
- ▶ Collisions are believed to be self-sustaining in future models
 - ▶ Even if we were to stop launching, debris still increases

Orbital Debris Quarterly News
February 2021

Meteoroids

- ▶ Present throughout space
- ▶ Natural debris
 - ▶ Cometary debris has density close to water
 - ▶ Rocky asteroid debris has higher density
- ▶ Not orbiting the Earth
 - ▶ Collisions to zenith and nadir spacecraft faces are more common than with orbital debris
 - ▶ Generally much faster: 30 to 70 km/s
 - ▶ Rotation rate and orbital velocity of the Earth contribute to the velocity
 - ▶ Can be faster on one side of the Earth than the other
 - ▶ But generally smaller/lighter than orbital debris
 - ▶ Impact energy, though, is $\frac{1}{2} mv^2$

Meteoroids Size Distribution



- ▶ This is a log-log plot over 18 orders of magnitude of mass
 - ▶ 10^{-6} g $\approx$ 0.1 mm diameter
- ▶ Mostly from six sporadic sources
- ▶ Flux and velocity vary by direction

Spennvis Grün model background information

Space Debris Risk Mitigation

- ▶ Shielding
 - ▶ Ceramic breakup layers separated from Kevlar stopping layers
 - ▶ Can be built into existing thermal blankets in some cases
 - ▶ Difficult to shield against meteoroids
 - ▶ Carries a mass penalty, and can get very thick for large separations
- ▶ Redundancy
 - ▶ Multiple components in case one fails
 - ▶ Carries a mass and complexity penalty, though
- ▶ Fail safely
 - ▶ Plan for failures to occur
 - ▶ Design in a spacecraft Safehold Mode

Shielding Design Considerations



- ▶ **First establish the acceptable risk**
 - ▶ Based on cost, mass, importance, etc.
 - ▶ Risk is expressed in terms or impacts per area and time (10^{-2} strikes $/\text{m}^2\text{-yr}$ in this example)
- ▶ Risk determines the **minimum particle size you need to shield against**
 - ▶ 2 mm in this example
 - ▶ Larger particles will likely penetrate
- ▶ Design a shield that will just stop particles that size and velocity
 - ▶ Velocity is a function of direction/side
 - ▶ Increased separation between layers helps spread the impact energy

What else Can We Do to Mitigate Debris Risks?

- ▶ Prevention of future debris
 - ▶ Passivation: depleting all stored energy
 - ▶ Batteries
 - ▶ Propulsion subsystems
- ▶ Responsible Disposal
 - ▶ < 25 years in LEO after the mission
 - ▶ GEO graveyard orbit
- ▶ Tracking of larger pieces (> ~4 cm)
 - ▶ Conjunction Assessments



Questions?

SCOTT.HULL@NASA.GOV