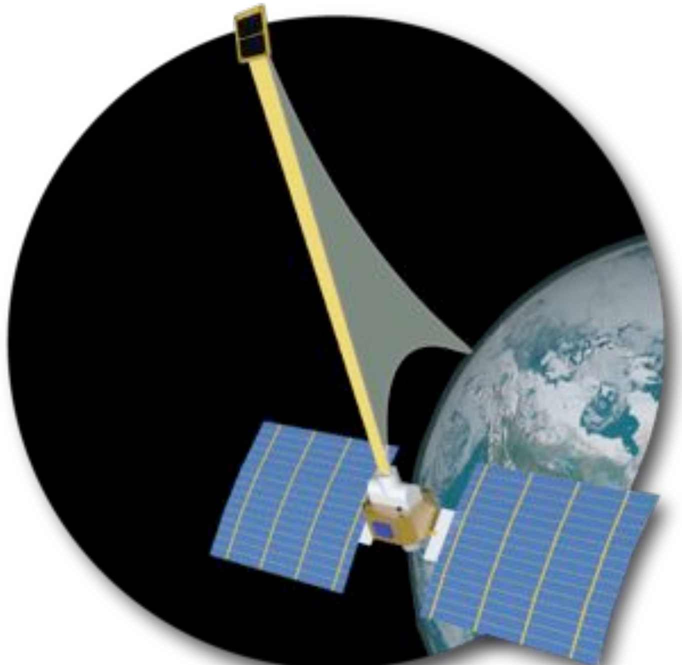
Orbital Debris and CubeSats



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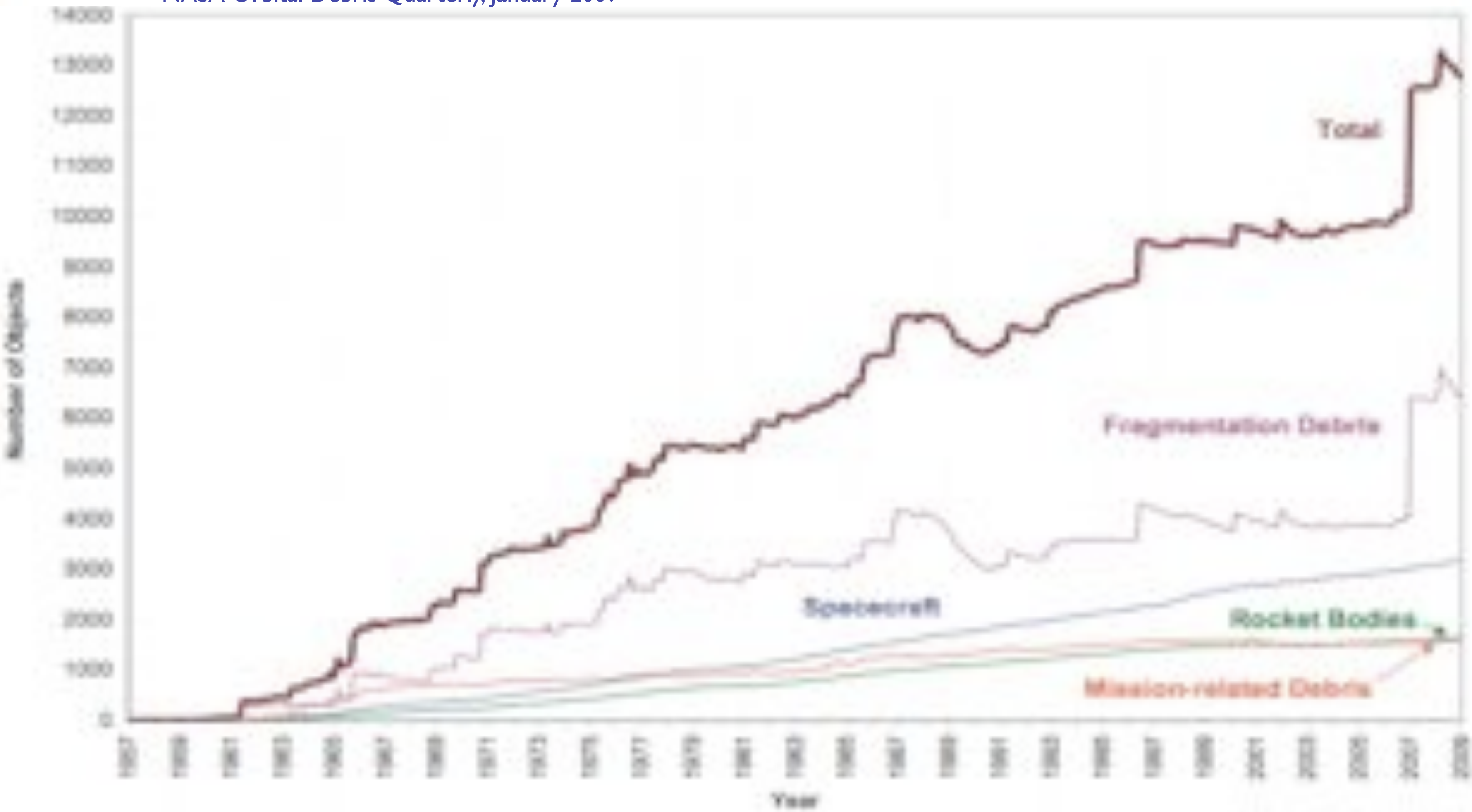
Is Orbital Debris a Problem?

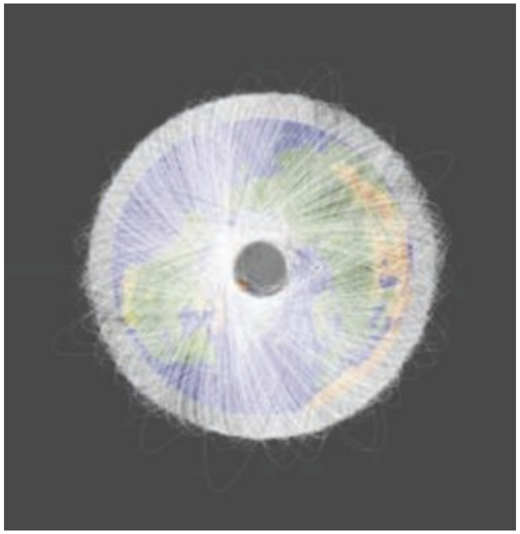
Advanced Propulsion, Power, & Comm. for Space, Sea, & Air

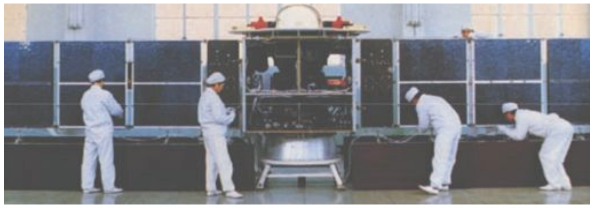
NASA Orbital Debris Quarterly, January 2009

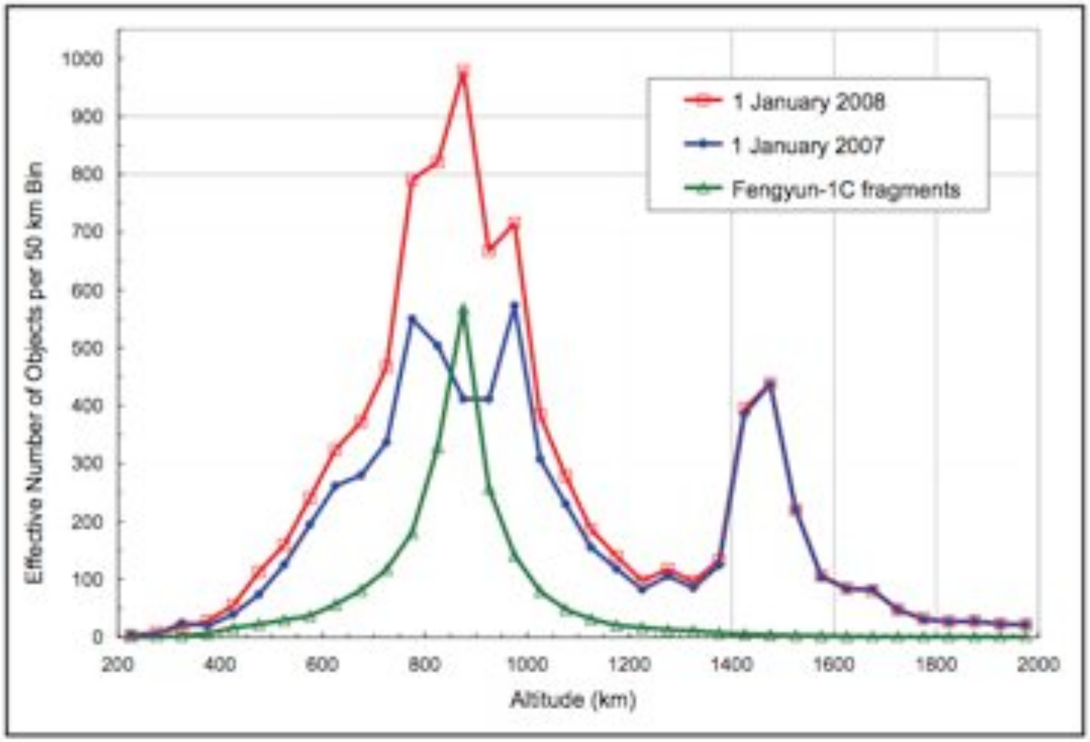


Fengyun 1-C ASAT

- On January 11, 2007 China tested an ASAT device on a retired satellite Fengyun 1-C (863km circular, 98.9˚)
- 2378 fragments greater than 5 cm in diameter have been officially cataloged
- less than 2% of the cataloged bodies have decayed

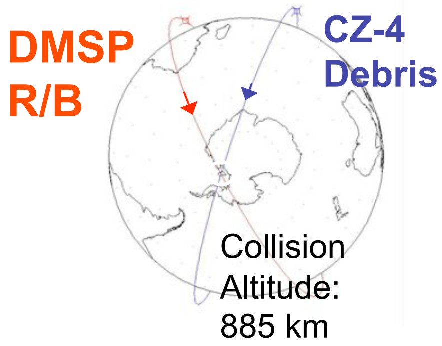




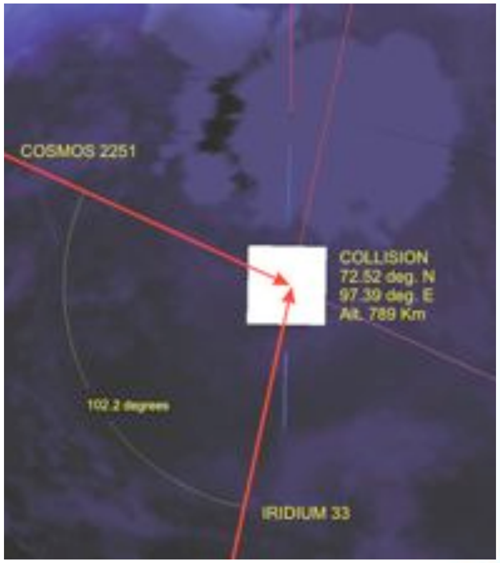


Accidental Collisions

- 24 July 1996 between debris from the 1995 French CERISE spacecraft, and debris from a French rocket body which exploded in November of 1986.
- 17 January 2005 between a 1974 rocket body and debris from a Chinese rocket body which exploded in March 2000
  - Both objects were in similar retrograde orbits at 885 km
  - TWO new pieces of debris (1+1=4??)



- February 10, 2009 Iridium 33 and Cosmos 2251 communications satellites collided over northern Siberia.
  - First observed collision between two intact objects.
  - 1+1 = ??



Is Orbital Debris a Problem?

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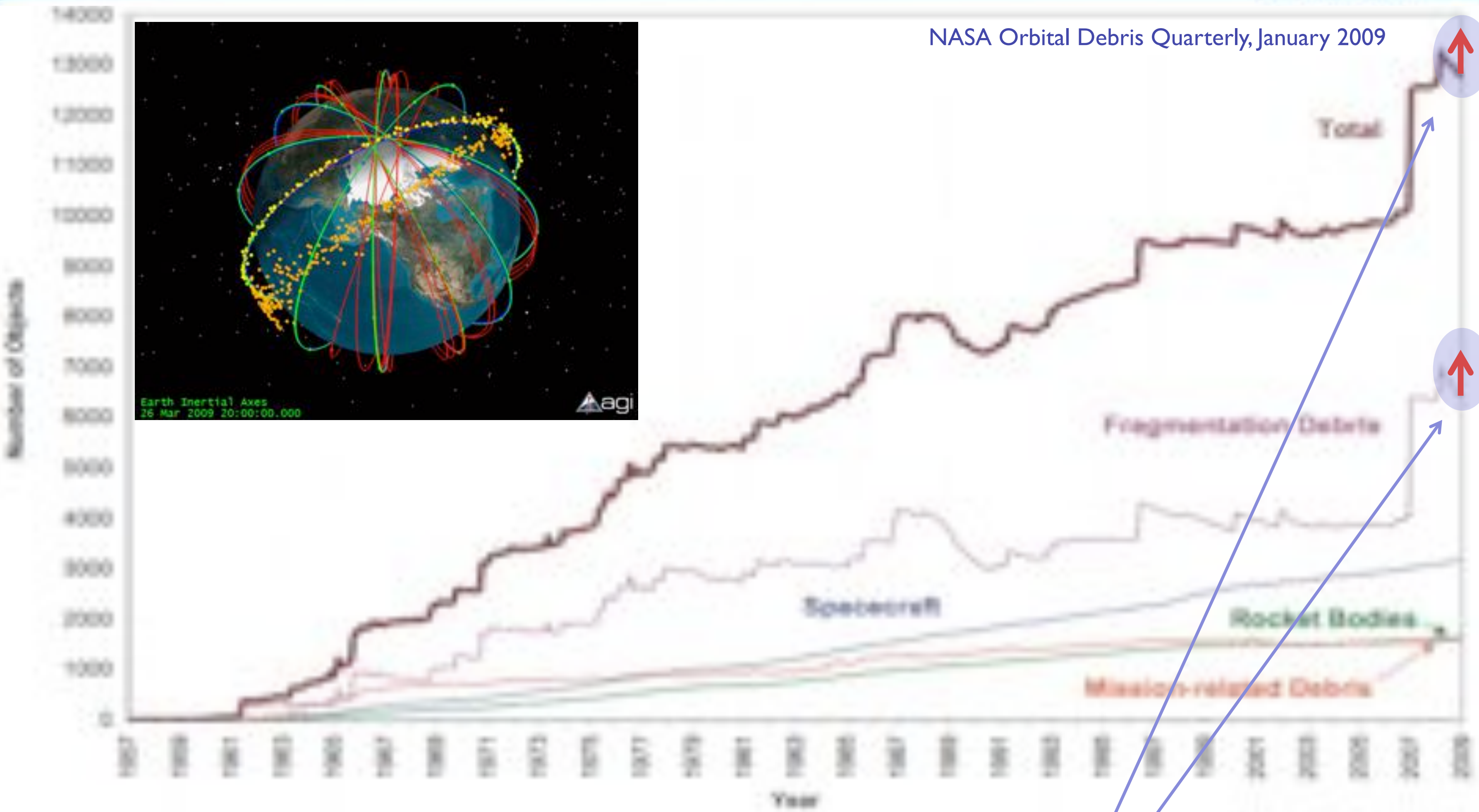
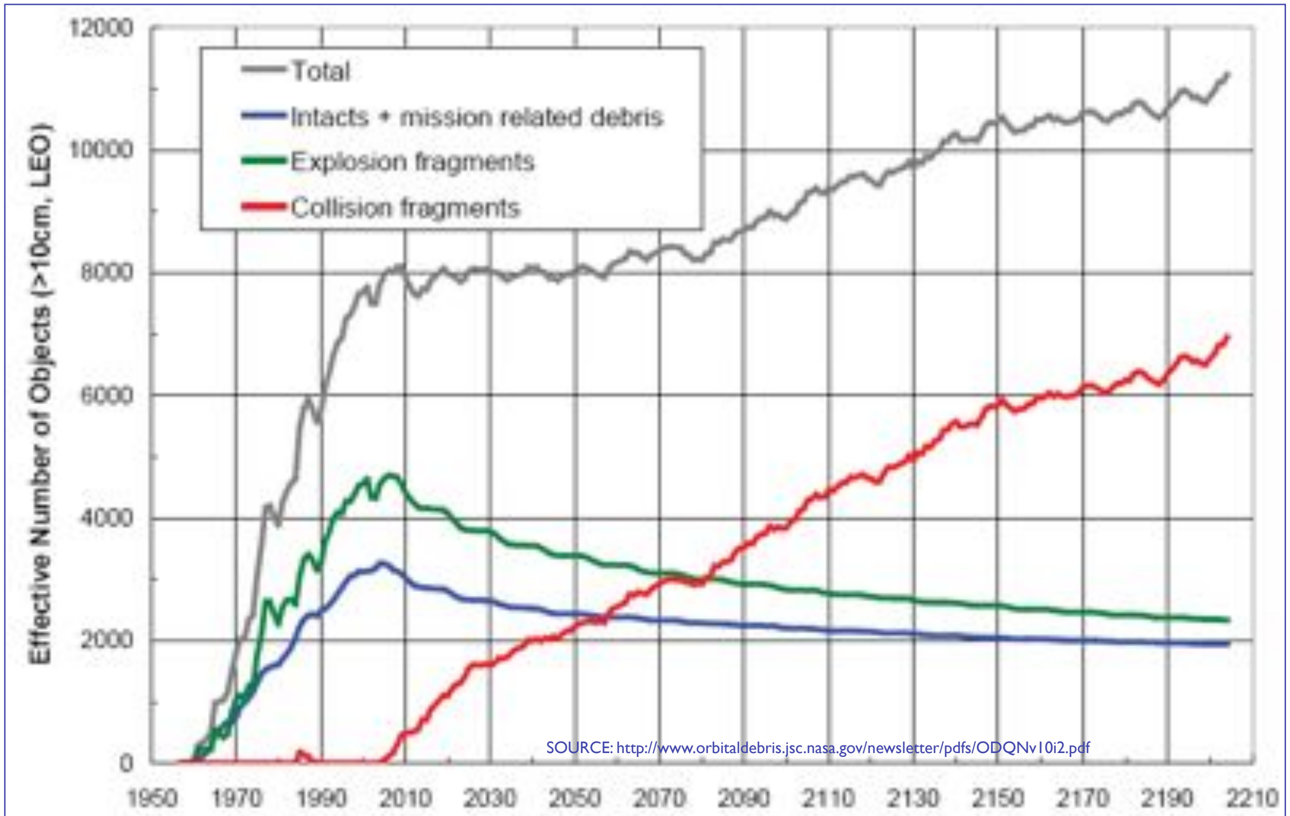


- Most Lethal population: objects 1-10cm(!) in size
- New math: 1+1 = 894 (as of 4/13/09)

Orbital Debris in the Future

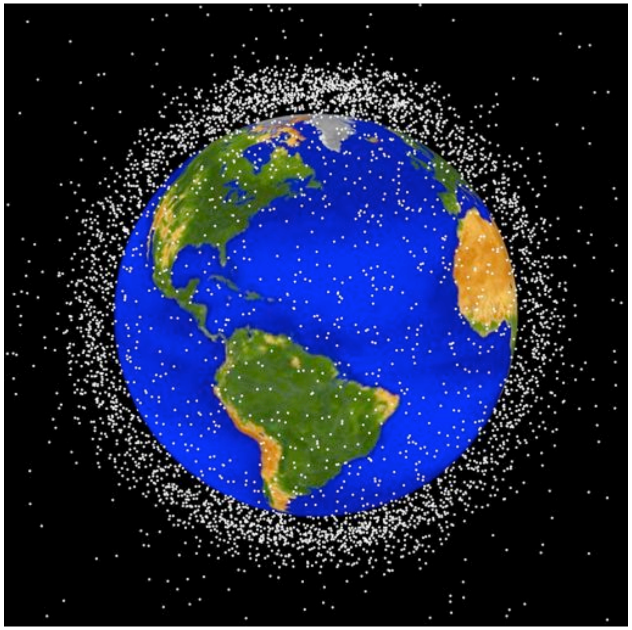
- Random collisions between man-made objects in earth orbit may some day initiate cascading collisions that will exponentially pollute these high-value orbits, rendering them exceedingly hazardous for space ventures.

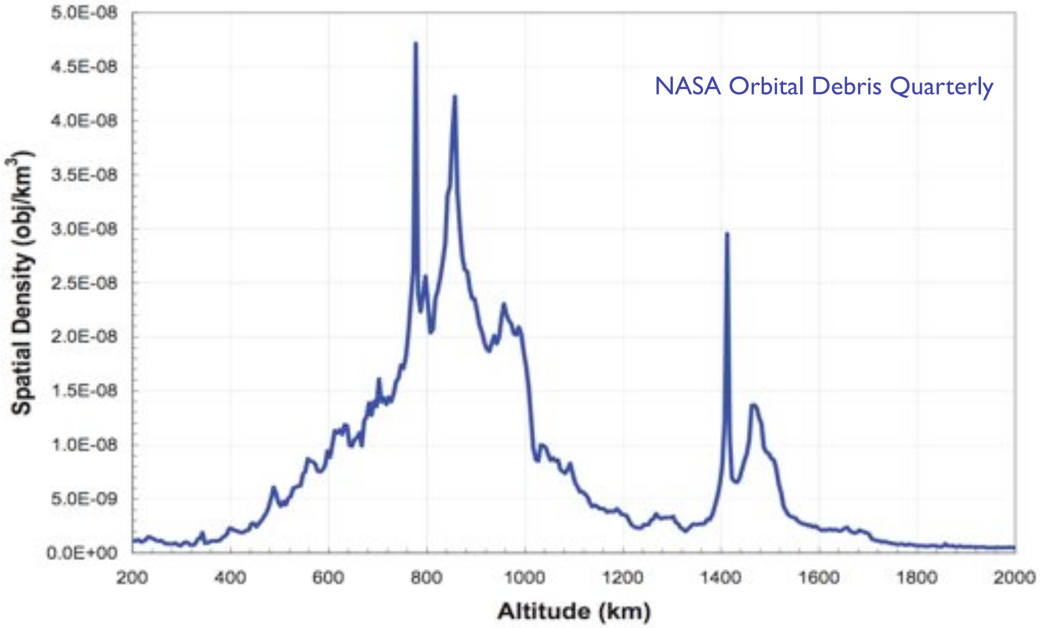


NASA EVOLVE model

Is Orbital Debris a Problem for us?

- Risks to CubeSats are small
- Risks FROM CubeSats....
  - Most lethal debris population: objects 1-10cm(!)
  - Secondary Payloads do not choose target orbits, only launches
    - 89% of all CubeSats launched in sun-sync orbits
    - 50% into heavily populated orbits





How do I/must I react?

- Various guidelines and processes exist
  - NASA
    - NASA Procedural Requirements for Limiting Orbital Debris (NPR-8715.6A)
    - Process for Limiting Orbital Debris (NASA-STD 8719.14)
    - Handbook for Limiting Orbital Debris (NASA-HBK 8719.14a)
  - U.S. Government Orbital Debris Mitigation Standard Practices
  - IADC Space Debris Mitigation Guidelines
    - Guidelines adopted by the 11 members of the Inter-Agency Space Debris Coordination Committee (IADC)
  - UN Space Debris Mitigation Guidelines
    - Guidelines adopted by the Scientific and Technical Subcommittee (STSC) of the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS)
- For US spacecraft, FCC is the orbital debris enforcer

FCC Requirements

- As described in 47 CFR §97.207 (Amateur Radio Service – Space Station)
  - A pre-space notification within 30 days after the date of launch vehicle determination, but no later than 90 days before integration of the space station into the launch vehicle.
  - Notification must also include a description of the design and operational strategies that the space station will use to mitigate orbital debris, including the following information*:

** Same requirements outlined in 47 CFR §5.63 Experimental Radio Service - Supplementary statements required*

FCC Requirements (2)

- Statement that the space station licensee has assessed and limited:
  - Amount of debris released in a planned manner during normal operations,
  - Probability of the space station becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal;
  - Probability of accidental explosions during and after completion of mission operations. This statement must include a demonstration that debris generation will not result from the conversion of energy sources on board the spacecraft into energy that fragments the spacecraft. Energy sources include chemical, pressure, and kinetic energy. This demonstration should address whether stored energy will be removed at the spacecraft's end of life, by depleting residual fuel and leaving all fuel line valves open, venting any pressurized system, leaving all batteries in a permanent discharge state, and removing any remaining source of stored energy, or through other equivalent procedures specifically disclosed in the application;
  - Probability of the space station becoming a source of debris by collisions with large debris or other operational space stations
- A statement detailing the post-mission disposal plans for the space station at end of life
  - The statement must also include a casualty risk assessment if planned post-mission disposal involves atmospheric re-entry of the space station

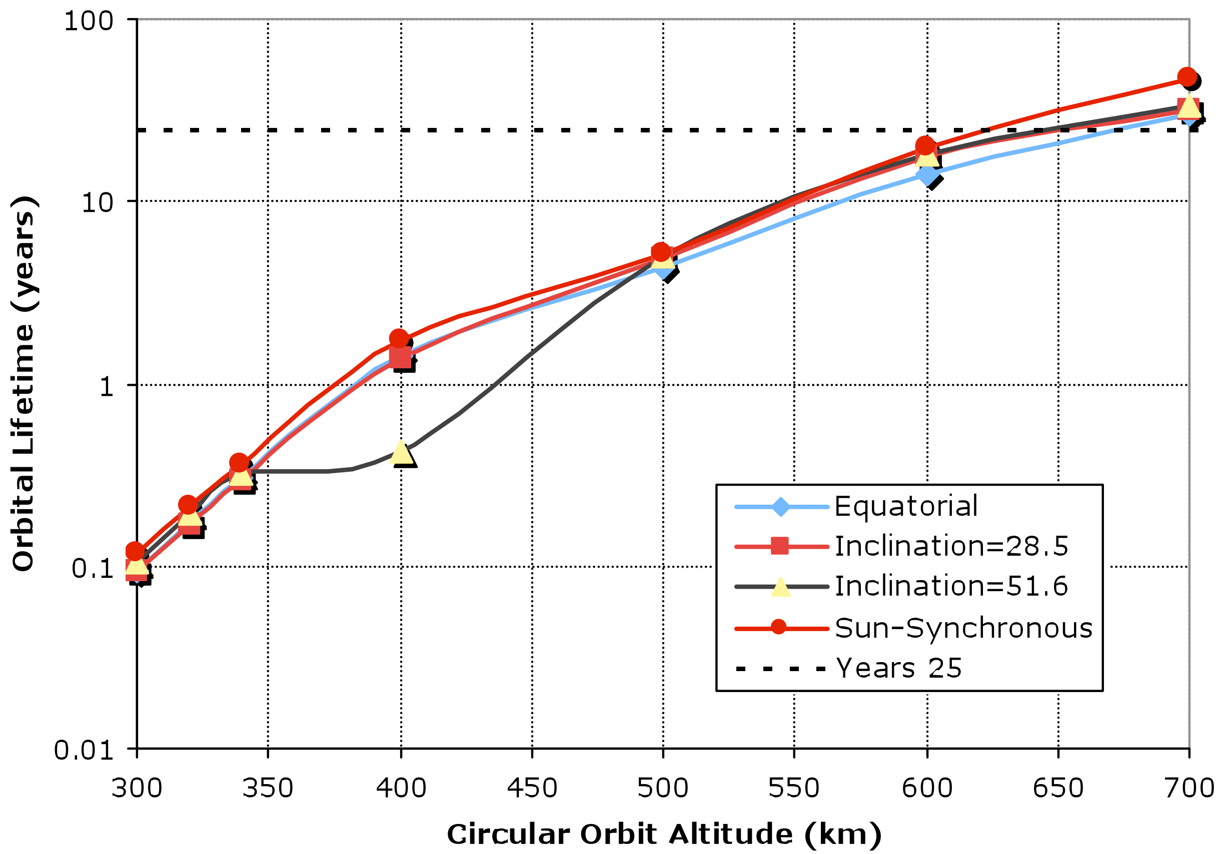
Orbital Debris Assesment Tools

- Orbital Lifetime Analysis
  - STK
- Orbital Debris Assesment
  - NASA's Debris Assessment Tool (DAS) assists in performing orbital debris assessments (ODA), as described in NASA Technical Standard 8719.14, *Process for Limiting Orbital Debris.*

Post-Mission Disposal Options

- Direct Retrieval
- Atmospheric Re-entry
  - If spacecraft left in an orbit without propulsion the spacecraft will remain in orbit less than 25 years after mission completion
- Storage Orbit
  - Between LEO & MEO (2000 - 19,700 km)
  - Between MEO & GEO (20,700- 35,300 km)
  - Above GEO (> 36,100 km)

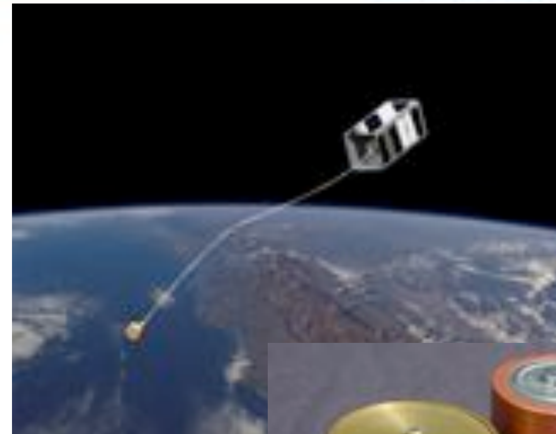
Nanosatellite Orbital Lifetime

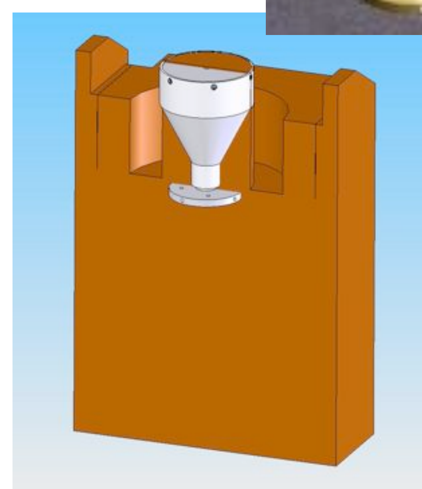


- Orbital Lifetime simulation for a CubeSat ***without*** deployables
  - Single (1U) CubeSat has 1kg mass, $0.01m^2$ cross sectional area, ballistic coefficient ≈ 45 kg/m^2

TUI's 1st Generation Solution: nanoTerminator™

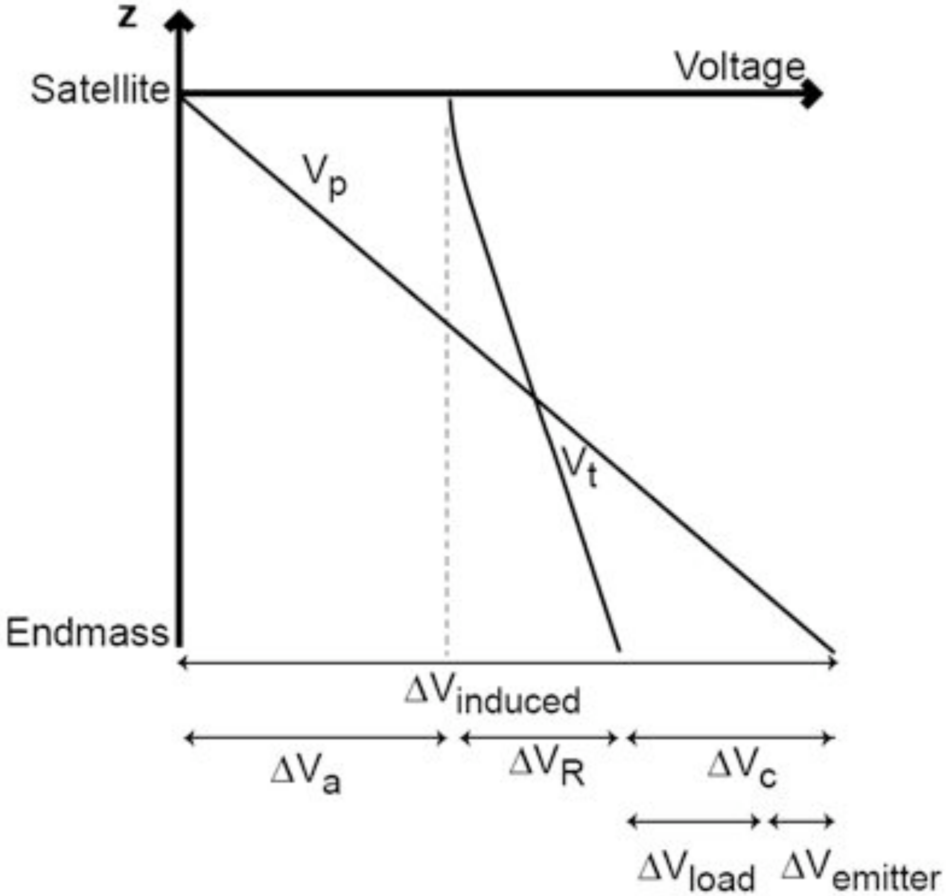
- Introduced in 2005 and targeted RocketPod CubeSat Plus (2kg, 100x100x164mm) and standard CubeSats
- nanoTerminator™ envelope: 54.5 x 38 mm diameter
- nanoTerminator™ mass: 56g
- Consists of 100m of conductive tether spindle & shroud, spring ejection deployer & mount
- A completely passive deorbit system
- Low mass, volume, and power deorbit system that simply meets 25 year lifetime requirement/ recommendation for orbital debris mitigation



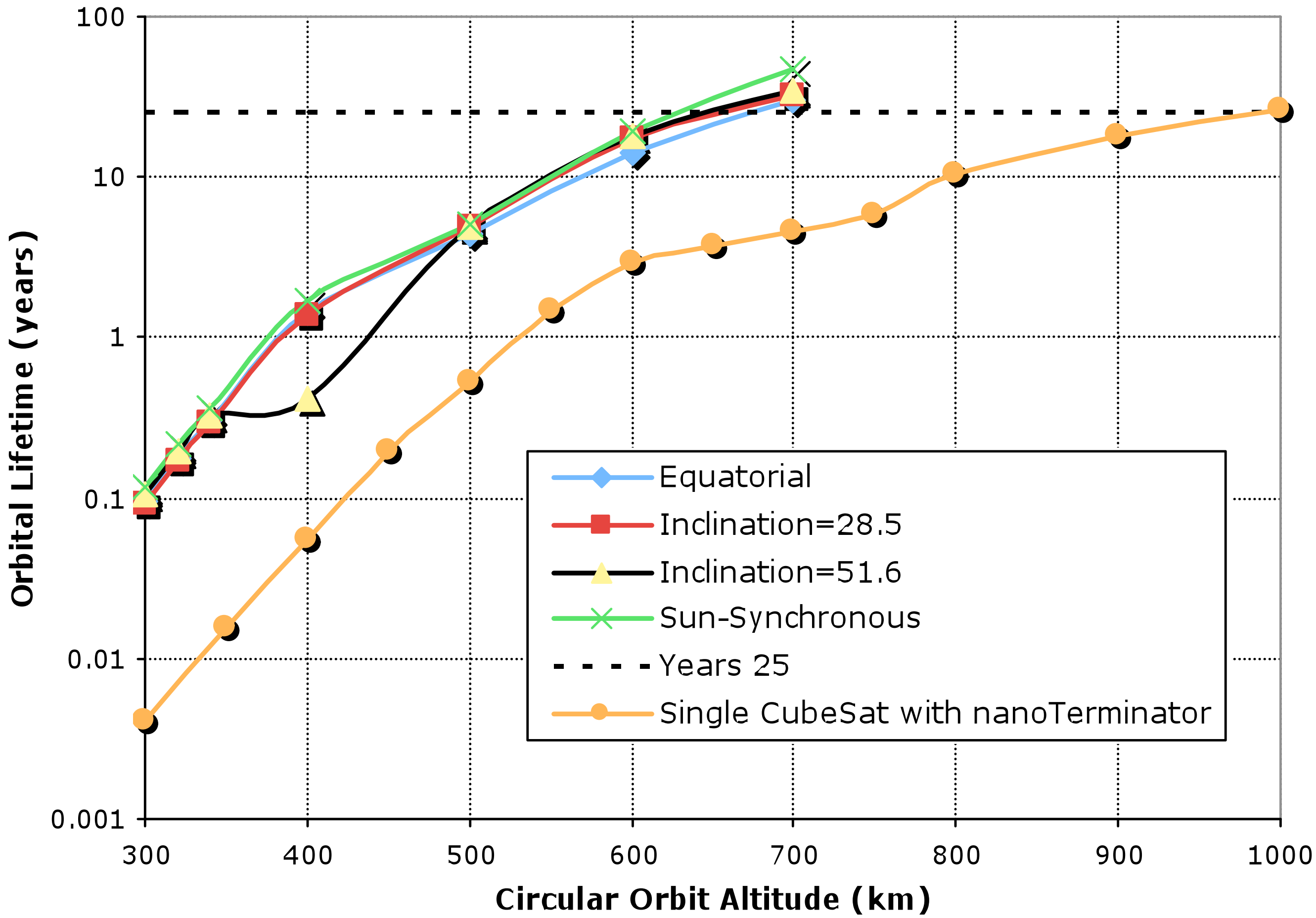


Bare ED Tether Physics (DragMode)

- Bare tether provides large collector area as bare anode
  - Where $V_p > V_t$ e^- collected
  - Where $V_t > V_p$ O^+ collected
- Performance limited by ion collection capabilities
- Electrodynamic Drag is important at higher altitudes where atmospheric drag is lower
- At lower altitudes, aerodynamic drag dominates



nanoTerminator™ Deorbit Times



Orbital Lifetime simulation for a CubeSat with nanoTerminator™

Terminator Tape Deorbit Module

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Objective:

- Meet 25-year lifetime restriction with bare minimum of mass, unit cost, integration complexity, & risk

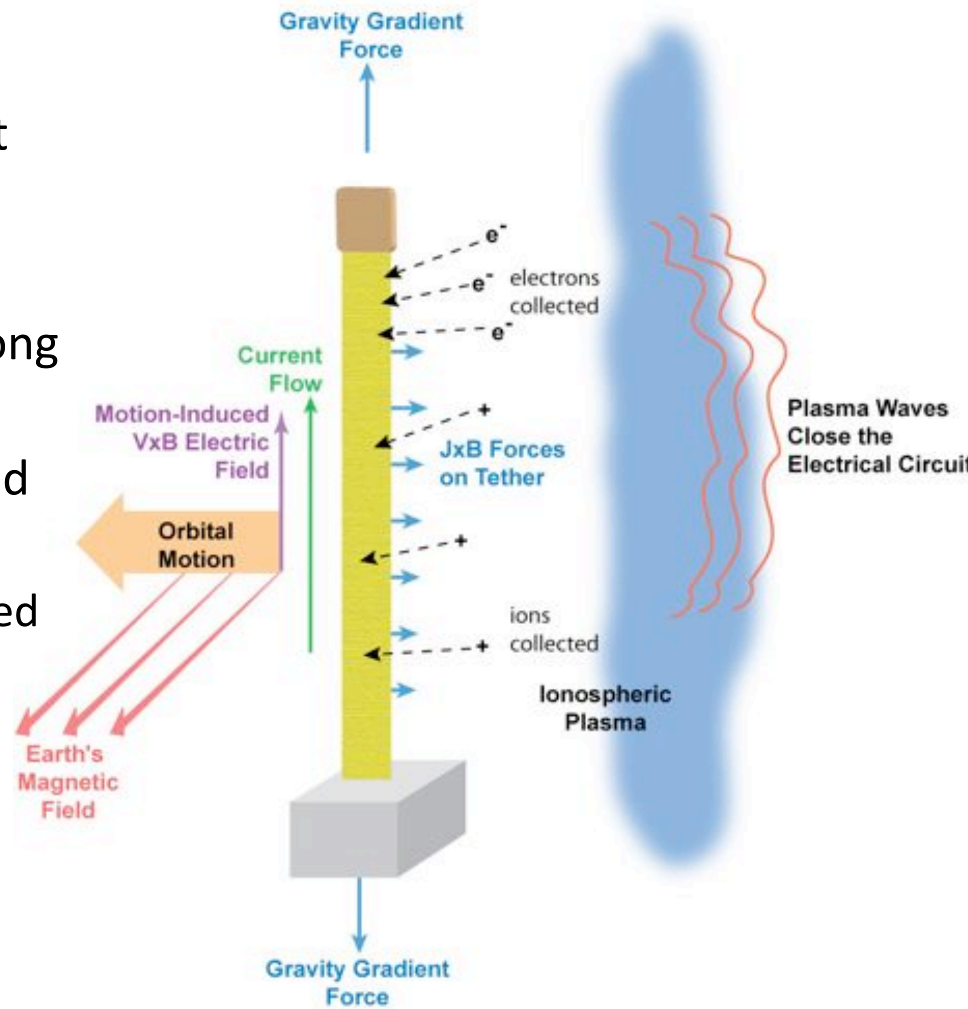
Solution:

- At spacecraft end-of-life, deploy a conducting tape structure from spacecraft
- Deployment initiated by electrical signal from host spacecraft
- Gravity gradient forces align tape along local vertical
- Tape dramatically increases aerodynamic drag area of spacecraft
- Conducting tape also generates <u>passive</u> electro-dynamic drag through interactions with Earth's magnetic field and ionospheric plasma

Terminator Tape Deorbit Module

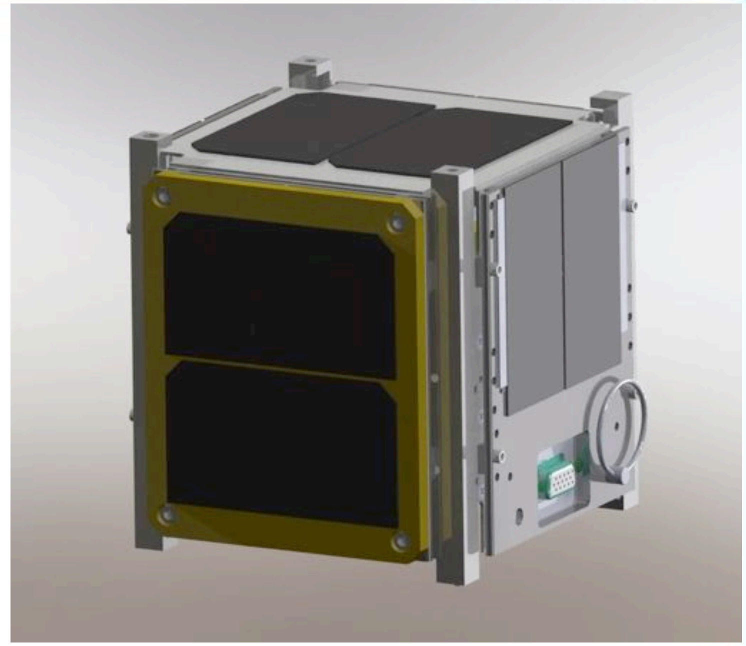
Concept of Operations

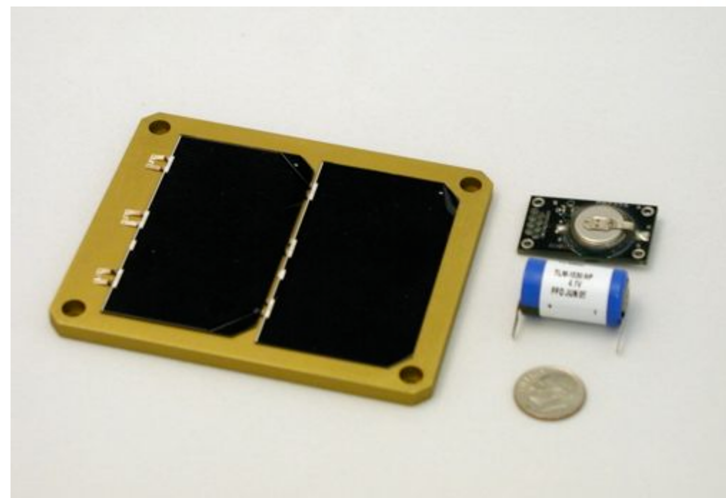
- Terminator Tape Module is entirely dormant during satellite's mission
- Once mission is complete, spacecraft activates module with
- Module deploys conductive tape
- Gravity gradient force aligns tape along local vertical
- Tape enhances aerodynamic drag and generates passive
  - Passive electrodynamic drag observed in Echo balloon tests
- Aero & ED drag de-orbits satellite within 25 years



nanoTerminator for CubeSats

- Enables CubeSats to meet 25-year post-mission lifetime requirements up to 1000 km initial altitude
- Pass-throughs (breakaway) for surface-mounted solar cells
- Can use TUI's Nanosat Release Mechanism for activation
  - Activated by signal from host
  - Deadman Timer for DOA cubesats
- Deploys ≈ 30m x 8 cm conductive tape
- Estimated Volume: 100x83x5 mm
- Estimated Mass: < 80 g





Summary

- Do key analyses early in your development
  - Orbital Lifetime
  - Debris Mitigation
  - Collision Probability
- Design your spacecraft and mission with debris mitigation in mind
  - Component & Subsystem selection design
  - Minimize debris generation and likelihood of explosion
  - Operational Constraints
  - Passivation at end of mission
  - Appropriate levels of redundancy with suitable failsafe
  - Select launch opportunity to lower altitude/density orbits

Bottom Line: Clean up your space when done!


Terminator Tape™
What Goes Up... Must Come Down
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References

- NASA Orbital Debris Mitigation Information
  - http://orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html
- NASA Debris Assessment Software Tool
  - http://orbitaldebris.jsc.nasa.gov/mitigate/das.html
- "In the Matter of Mitigation of Orbital Debris", Second Report and Order, FCC 04-130A1
  - http://fjallfoss.fcc.gov/edocs_public/attachmatch/FCC-04-130A1.pdf