Overview: Space Debris and Reentry Hazards

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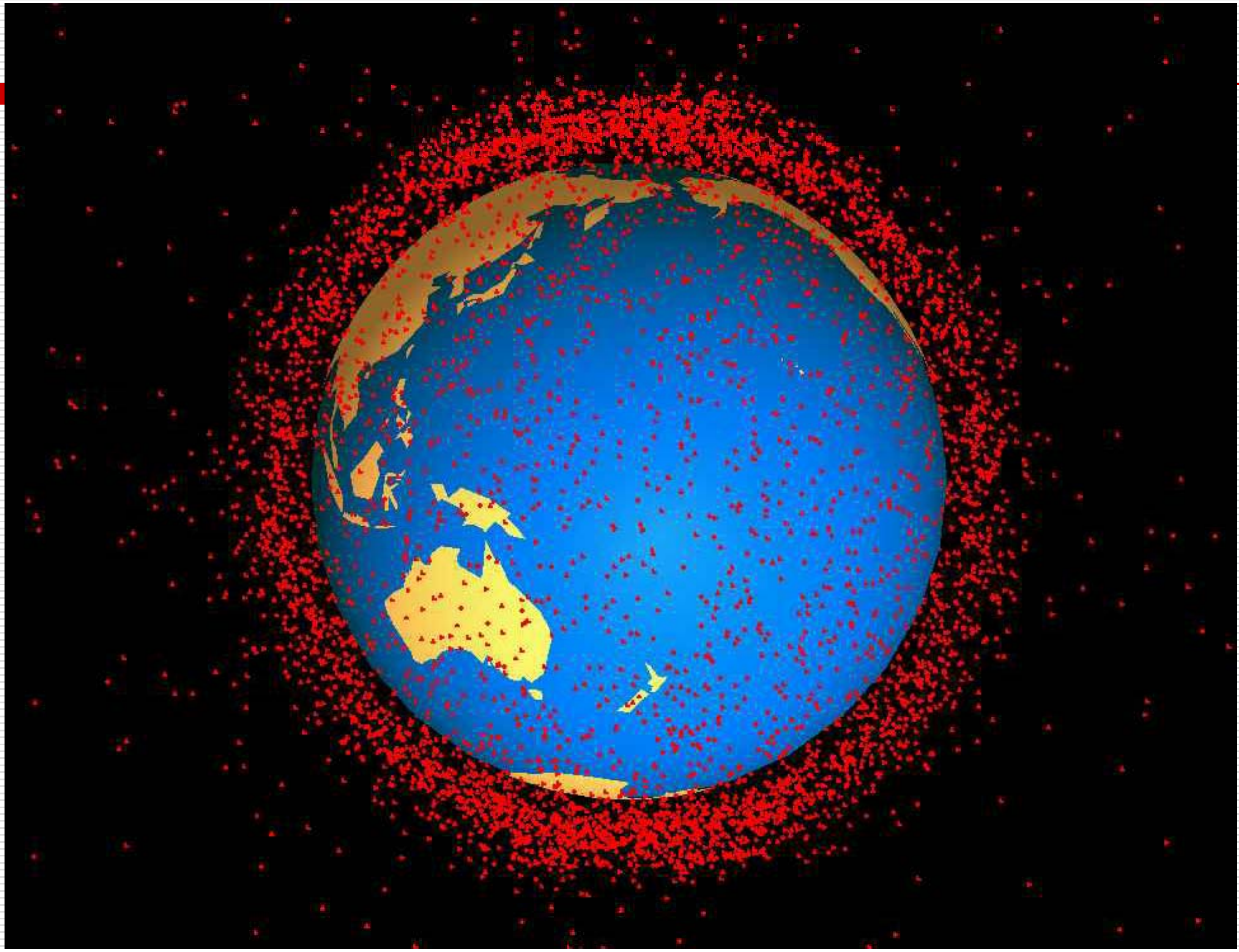
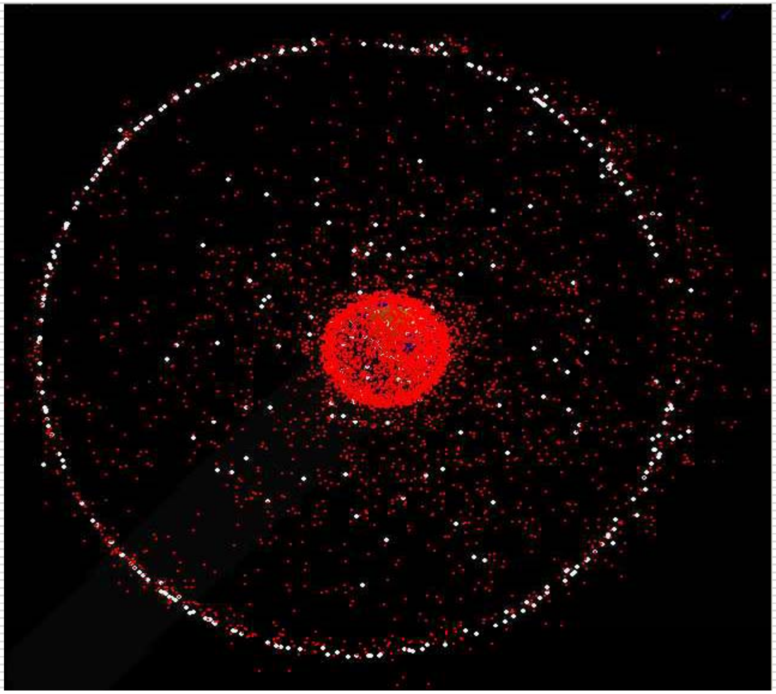
Space Debris

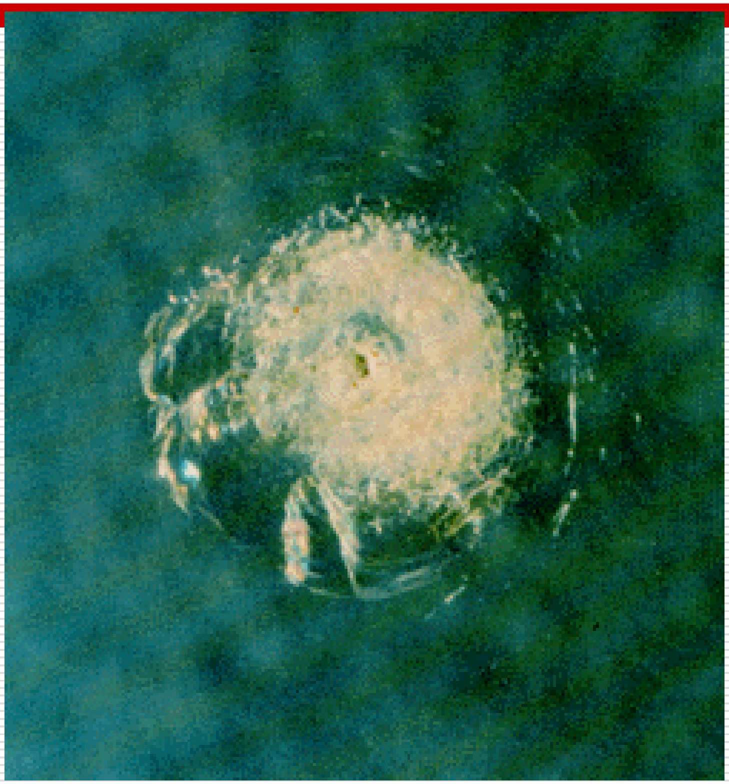


Space Debris Overview



- **Man-made objects**
  - Debris from exploded satellites and rocket stages
  - Dead satellites
  - Debris from normal operations
  - Astronaut's glove
- **Have about 700 operating satellites**
  - Over 12,000 pieces of tracked debris
  - Over 100,000 pieces of debris large enough to cause loss of a satellite

Why the concern with small debris?



4-mm-diameter crater on windshield of Space Shuttle Orbiter made by 0.2 mm fleck of white paint; relative velocity at impact: 3-6 km/sec (NASA Photo)

- Average impact velocity ~20,000 miles/hour at LEO
- High relative velocities means small particles can do much damage
- 795 window craters over 24 Shuttle missions (3.56 m^2 total area)

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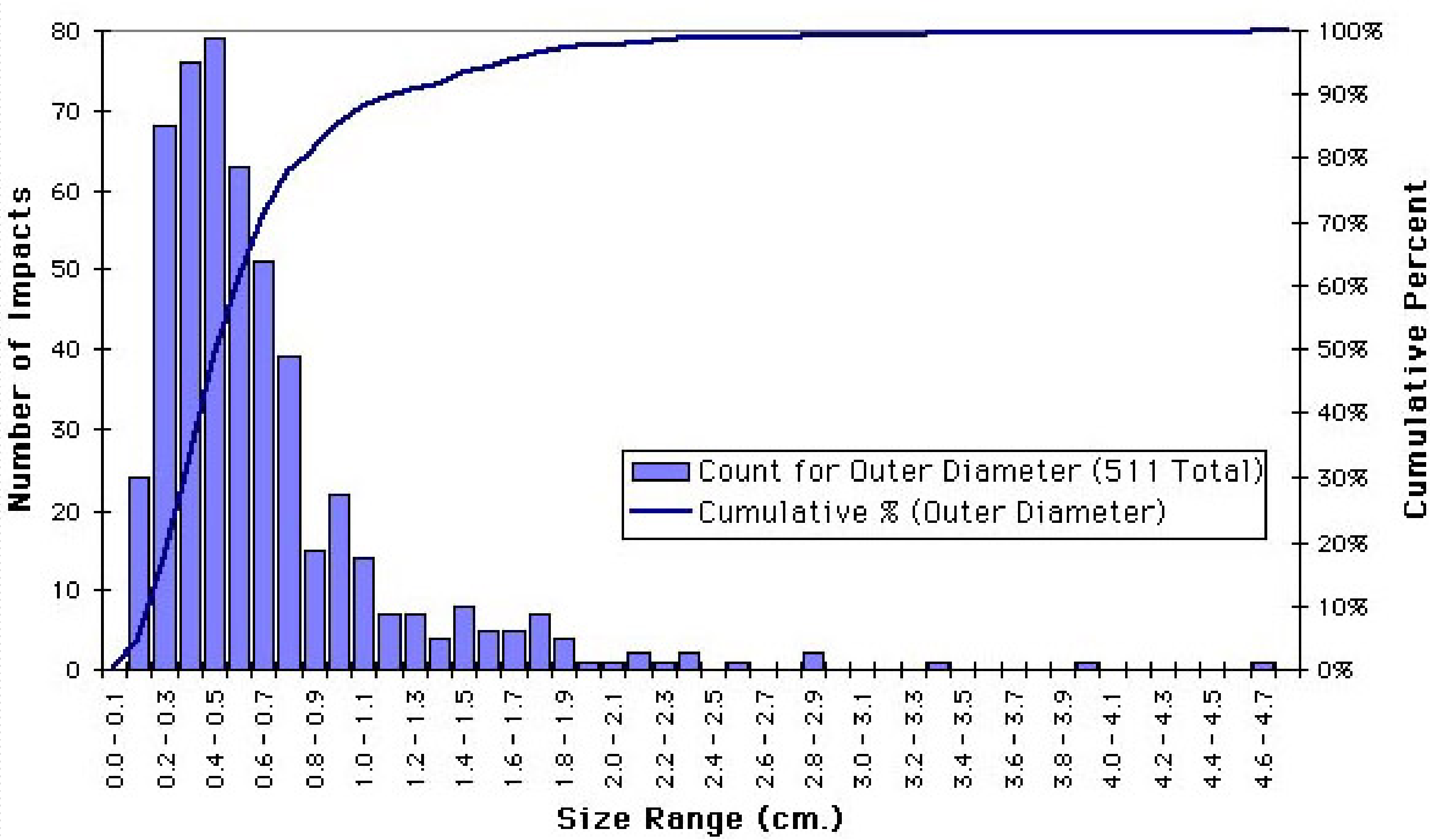
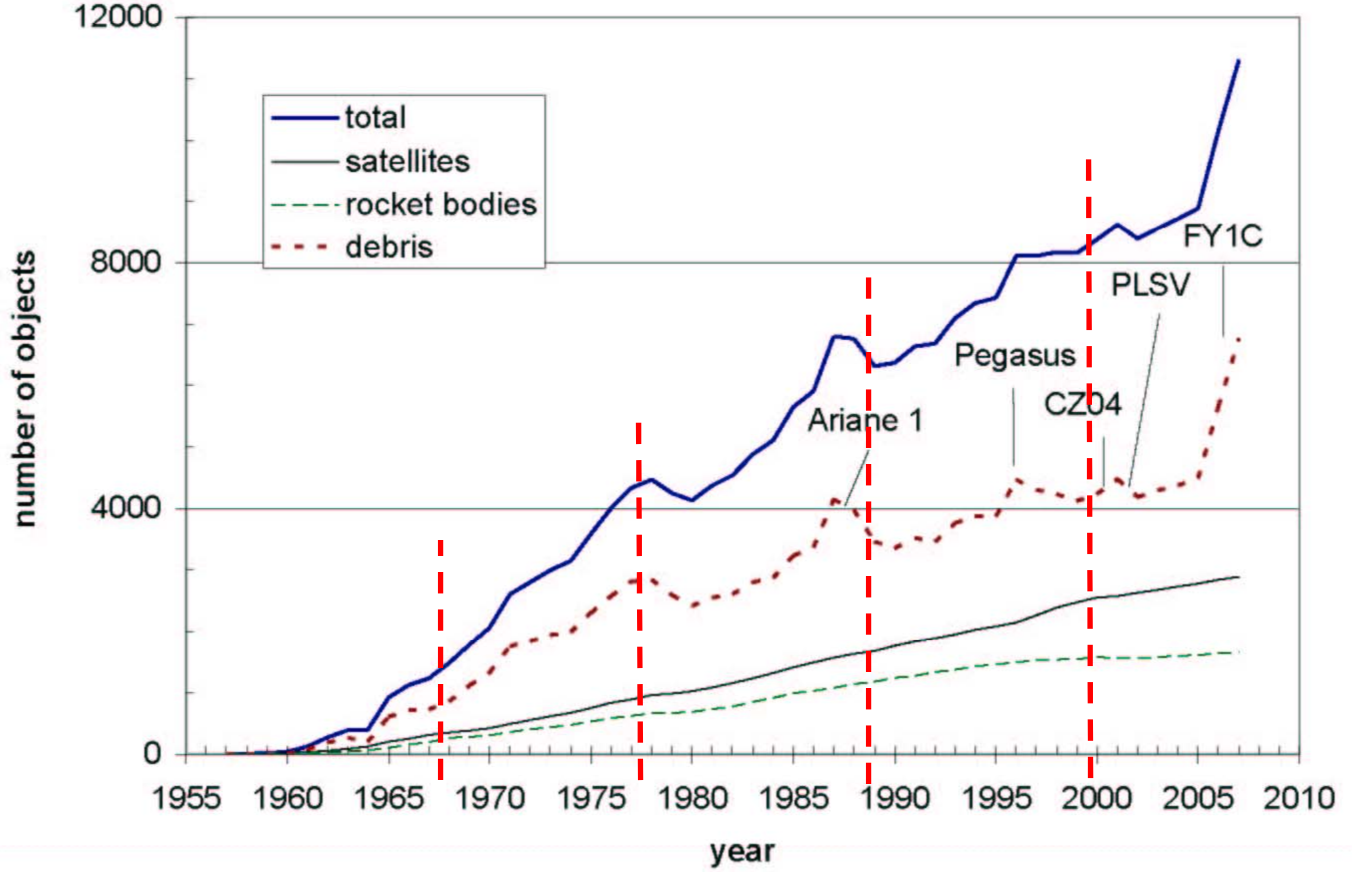
Impacts on Hubble Space Telescope by Non-Tracked Objects



~7 years of exposure

NASA

Number of Orbiting Objects



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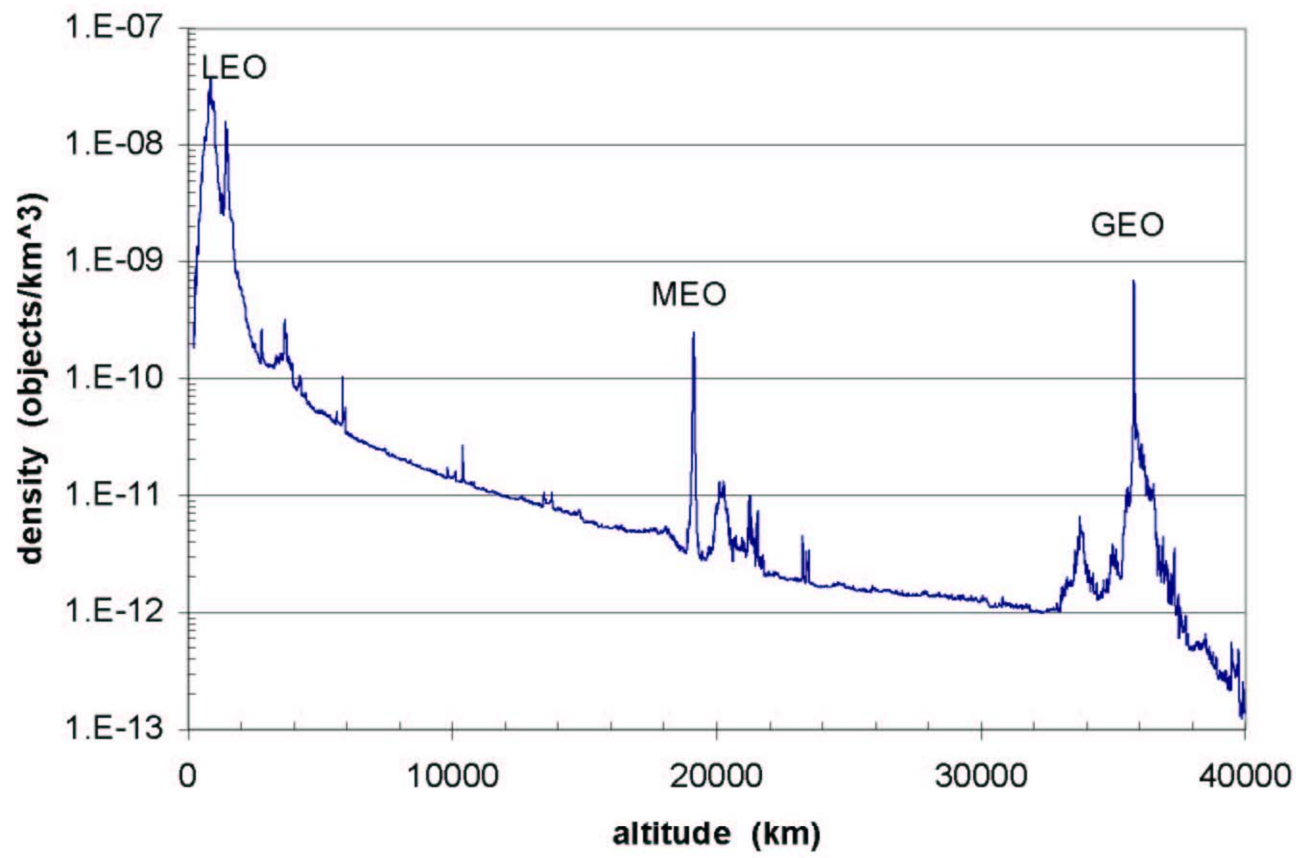
Altitude Distribution



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History of Large Object Interference

- **Three confirmed accidental collisions**
  - Non-operational Russian Cosmos navigational satellite collided with debris from a sister Cosmos satellite (December 1991)
  - French satellite CERISE damaged by fragment from Ariane rocket body (1996)
  - Final stage of a US Thor Burner 2A rocket, launched in 1974, collided with a fragment from the upper stage of a Chinese Long March 4 which exploded in March 2002 (January 2005)
- **Near misses with Space Shuttle, Mir, ISS**
  - NASA moved Space Shuttle at least 8 times, ISS 3 times to avoid close approaches
- **Commercial operators move GEO satellites**

Recent Events

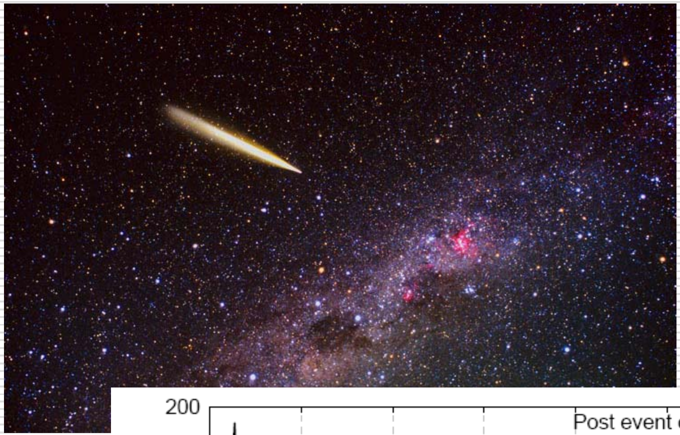
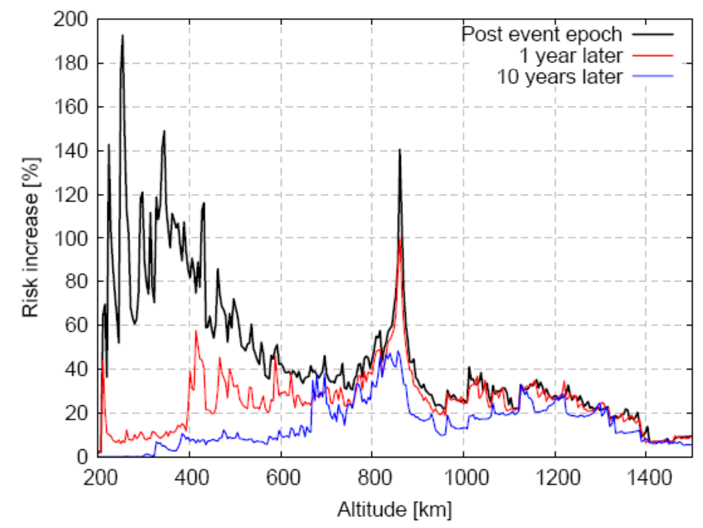


Photo courtesy Western Australian Space Photographer Ray Palmer



- Chinese ASAT test 11 January 2007
  - 958 kg target in 853 km circular orbit, 98.7° inclination
  - Generated 1500 fragments, 200km ≤H ≤4,800km
- Russian rocket stage explosion 19 February 2007
  - 853km ×14712km orbit, 51.5° inclination
  - Similar number of fragments

Courtesy Heiner Klinkrad, ESA

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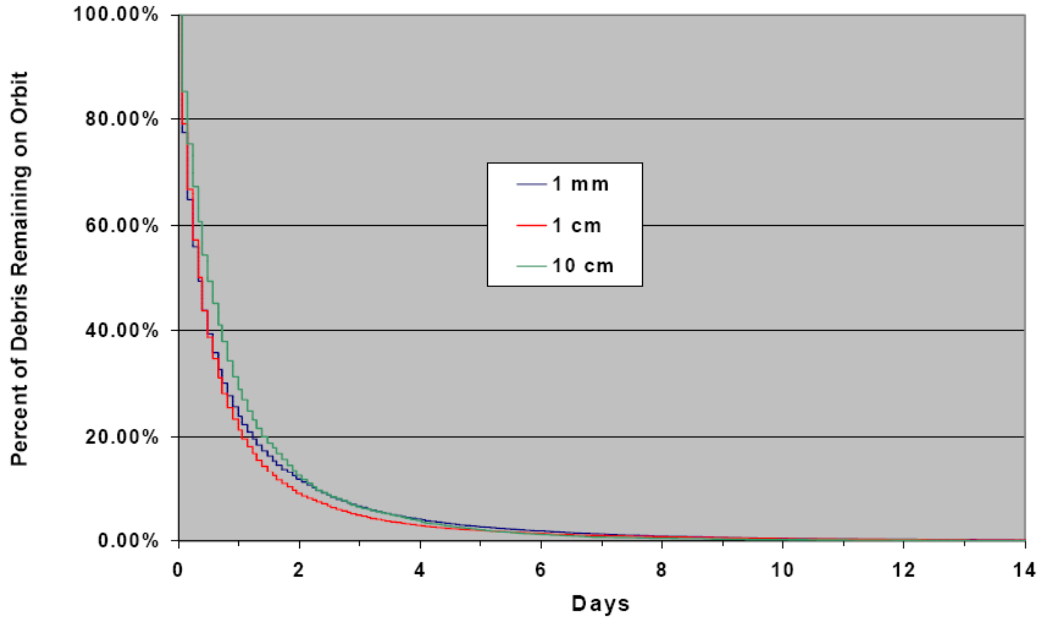
Recent Events: USA-193 Intercept

National Aeronautics and Space Administration

Maximum Longevity of Debris

- **Assuming a worst case scenario of fragmentation at 250 km, 99% of the debris placed in orbit will reenter within one week.**



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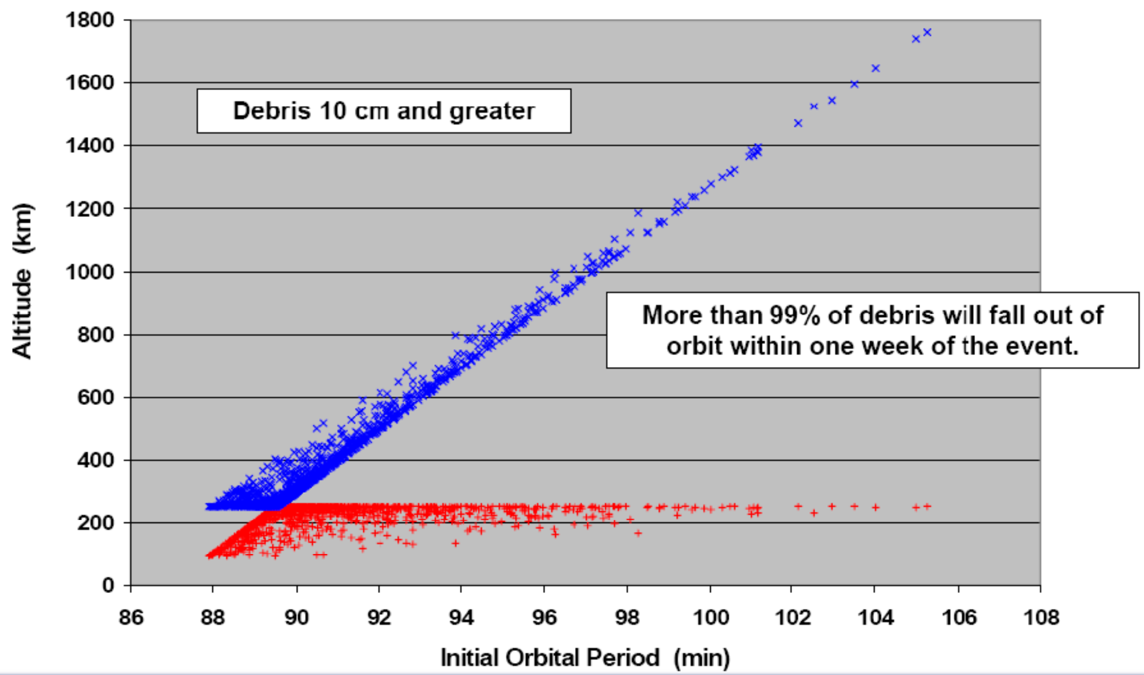
From: "Space Debris Assessment for USA-193," Presentation to the 45th Session of the Scientific and Technical Subcommittee Committee on the Peaceful Uses of Outer Space, United Nations, 11-22 February 2008.

Recent Events: USA-193 Intercept

National Aeronautics and Space Administration

Initial Extent of Debris

- **Again assuming a worst case scenario of a fragmentation at 250 km, the majority of the orbital debris cloud would be confined to low altitudes.**



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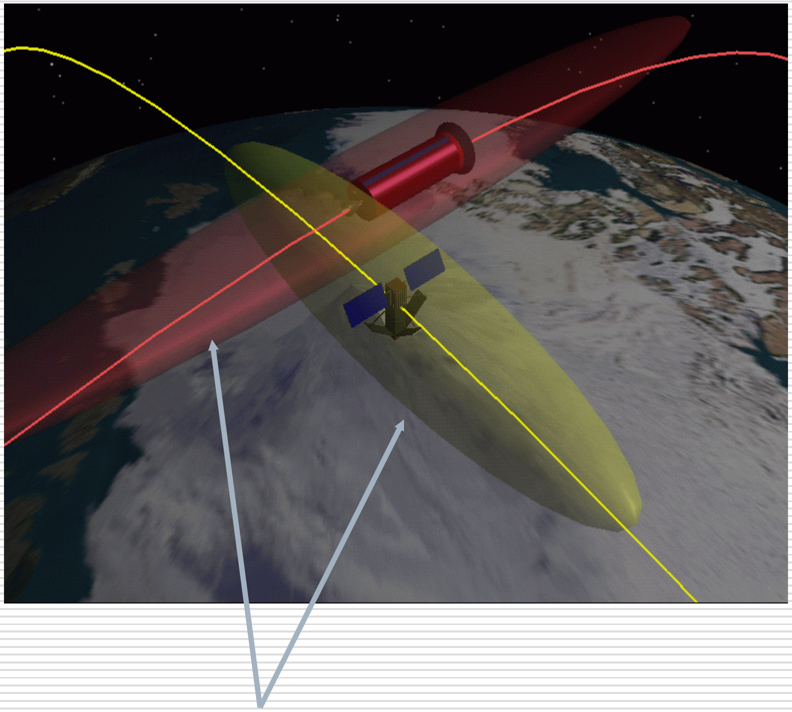
Sources of Debris & Mitigation

- **Source: On-orbit explosions**
  Mitigation:
  - Deplete and/or vent propellants and pressurants at end of life
  - Open-circuit batteries
- **Source: Debris created during injection, normal operations**
  Mitigation:
  - De-orbit stages
  - Tether releasable parts (lens covers, etc.)
  - Capture debris from explosive bolts and mechanisms
  - Avoid environmental degradation of coatings and materials
- **Source: Collisions**
  - Move hardware out of operational regions
  - Reenter, move to disposal orbit
  - Maneuver to avoid collisions

Avoiding Collisions

- Position "known" at time of measurement, degrades until next measurement
- Models estimate probability of impact (or interference)
- "Action" (new measurement or satellite maneuver) taken if probability exceeds threshold
- Models must also look into the future to show proposed action is safe



Covariance ellipsoids indicate possible locations of orbiting object

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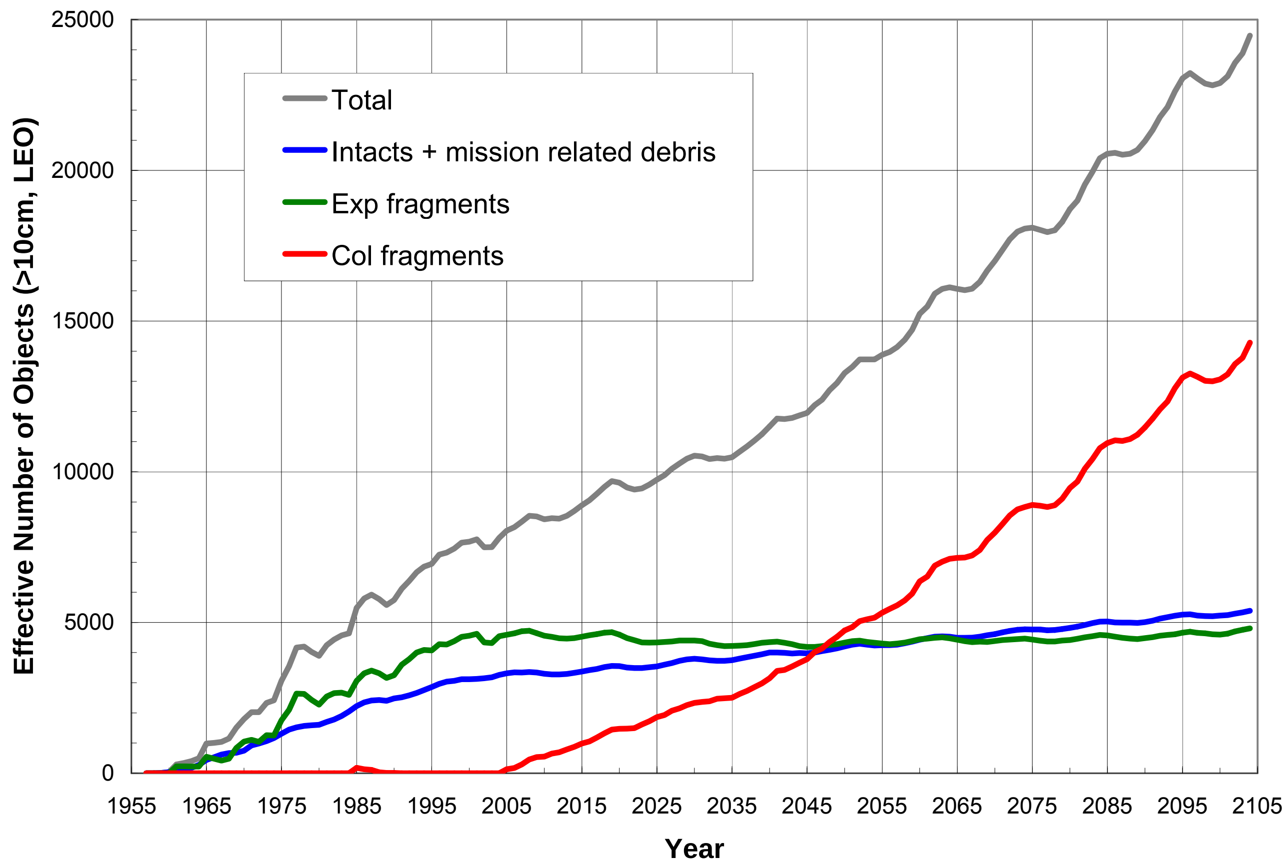
Requirements and Standards

- Inter-Agency Space Debris Coordinating Committee (IADC) guidelines
- NASA, DoD, FCC have adopted policies on debris mitigation
- ISO developing international standards for mission and hardware design to minimize creation of orbital debris
  - End-of-mission disposal of GEO satellites
  - Prediction of reentry hazards
  - Estimating residual propellant

The Future



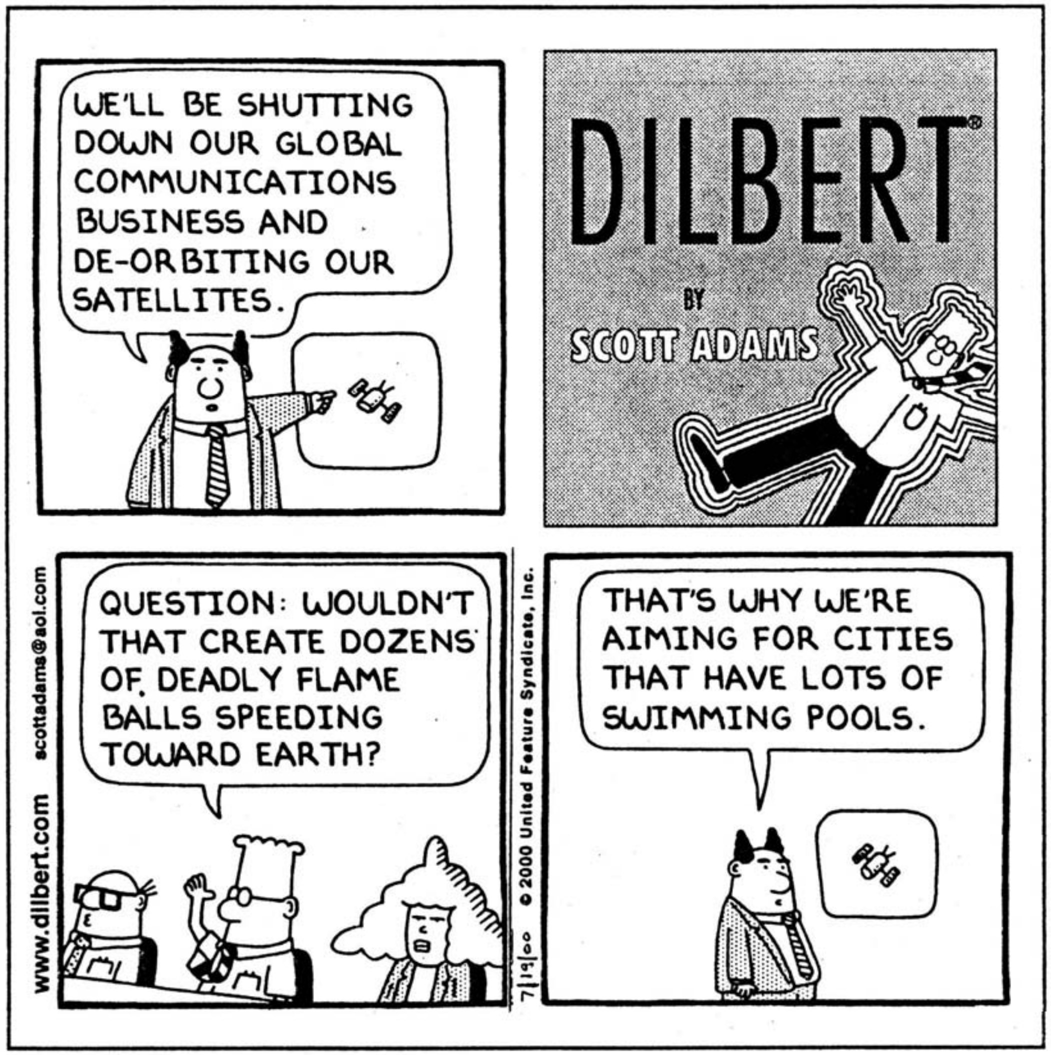
Assumes

- **200 to 2000 km altitude orbits**
- **No mitigation (no post-mission maneuvers to dispose of hardware)**
- **1997-2004 launch cycle**

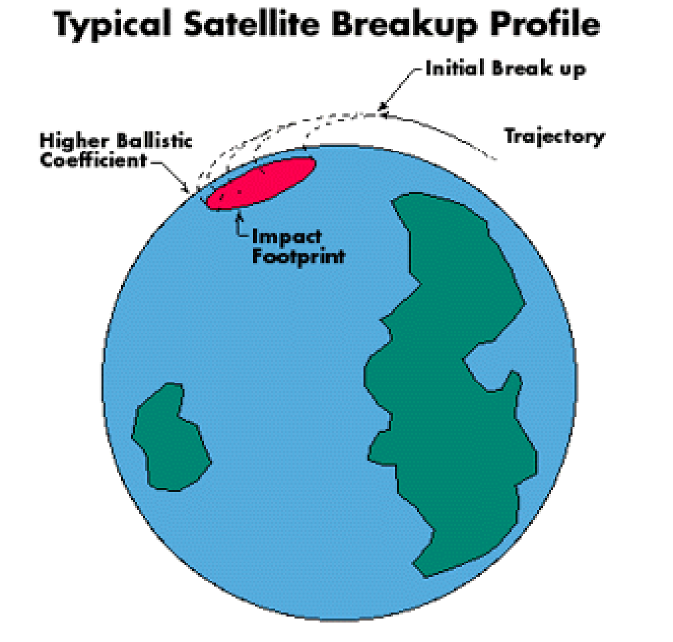
Predicts ~24 collisions in next 100 years

J.-C. Liou, "A statistical analysis of the future debris environment," *Acta Astronautica* 62 (2008) 264 – 271.

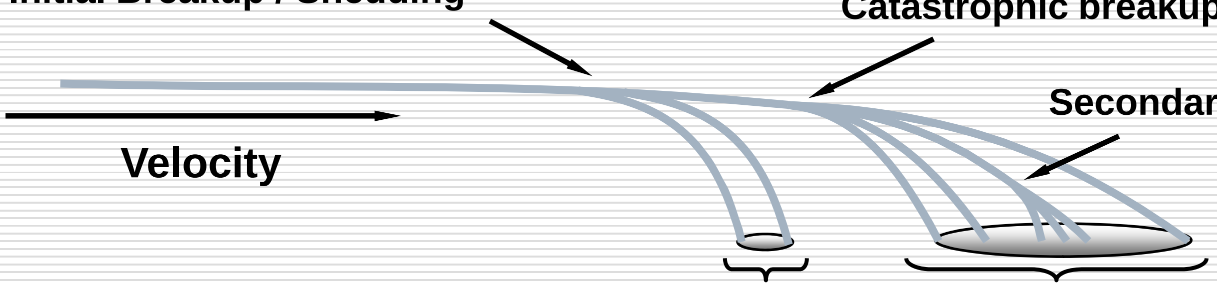
What happens when debris comes back to earth?



Reentry Breakup Process



- Aerodynamic heating and loads on a reentering satellite will gradually break the hardware apart
- Some materials will survive reentry
  - Steel, glass, titanium, sheltered parts
- Some melted or shredded away
  - Aluminum, Mylar sheets
- Once separated from the parent body, debris follows new trajectory
- Debris pieces impact within a “footprint” on the ground



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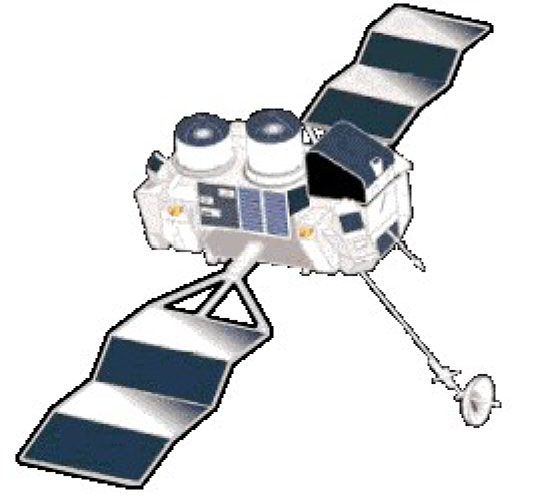
Reentry of Compton Gamma Ray Observatory



- **NASA satellite**
- **12,000 kg**
- **Launched in 1991**
- **Reentered into the Pacific Ocean on June 4, 2000**

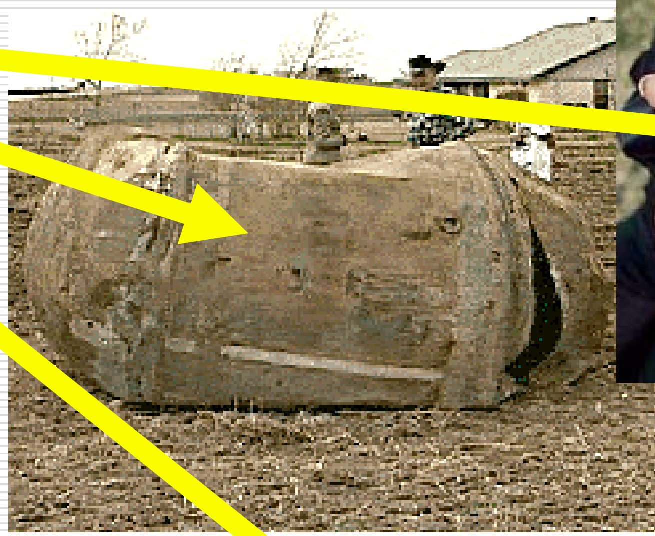
Reentry Disposal

- Reentry will "burn-up" reentering hardware--but not completely
- Must be done carefully--may pose hazard to people and property on the ground
- Have been several examples
  - Cosmos 954
  - Skylab
  - Russian Mars 96
  - Delta 2s (Texas and South Africa)
  - Disposal of Mir space station
  - Recent Shuttle Columbia disaster
- Can include reentry disposal in design of hardware and mission

Delta II Recovered Debris

January 22, 1997

NASA Photo

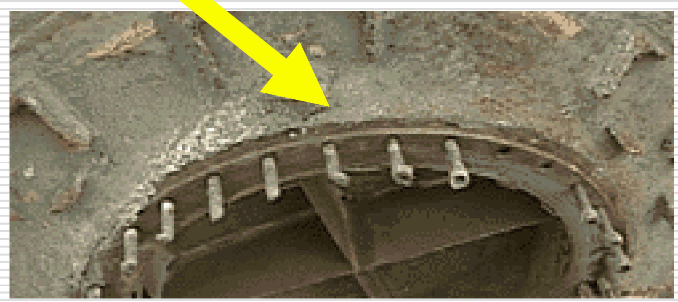


NASA Photo

World Staff Photo by Brandi Stafford

NASA Photo

NASA Photo



NASA Photo

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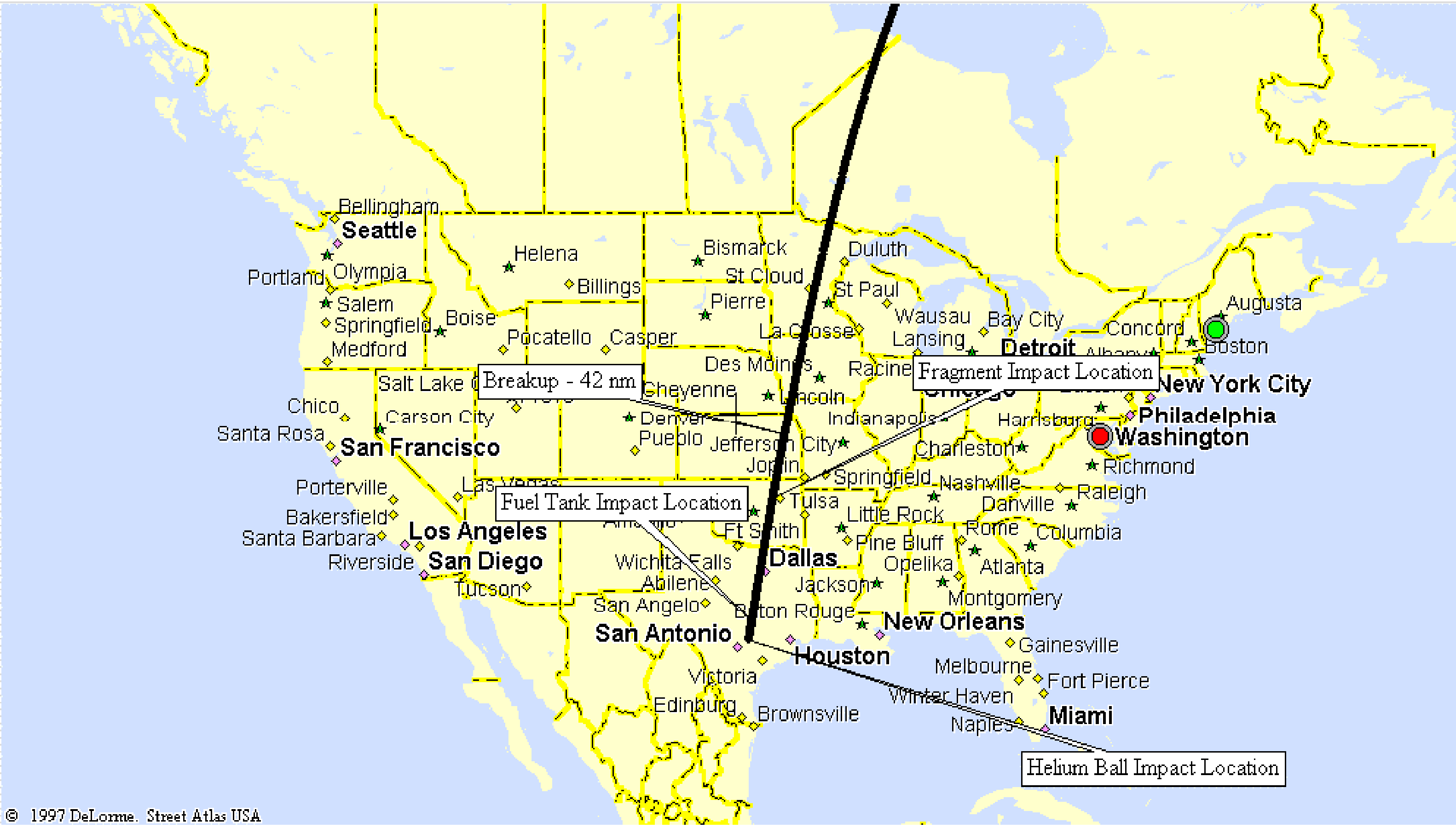
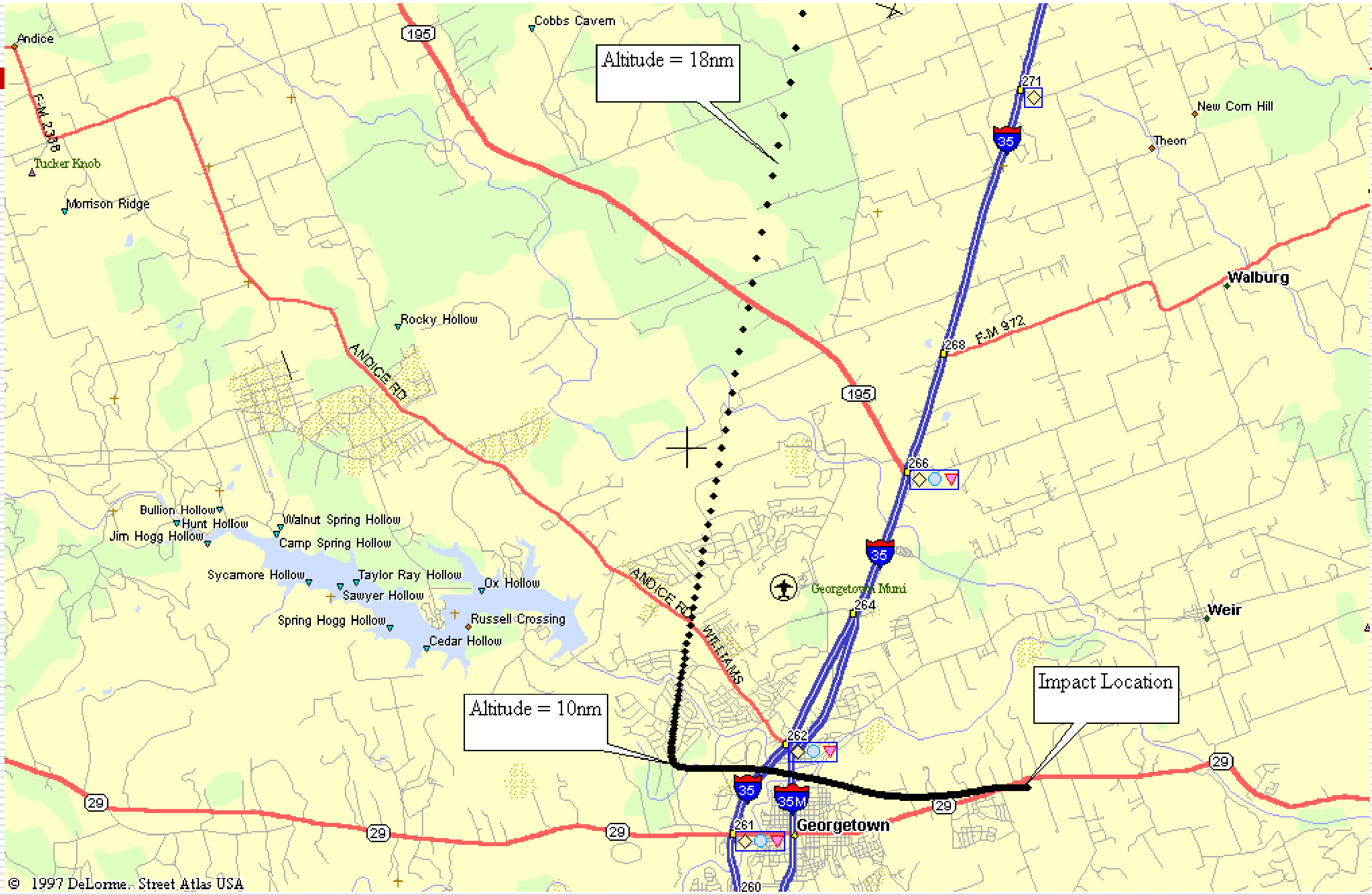
Reentry Trajectory



Reconstructed Trajectory for Delta Tank



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South Africa Reentry, April 27, 2000

Photo: Argus/Enver Essop

- Launched March 1996
- Delta second stage used for GPS
- Reentered April 27, 2000
- Debris recovered outside of Cape Town, South Africa

Photo: Die Burger/Antonie Robertson

Photo: Die Burger/Johann van Tonder

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Debris recovered in Bangkok, 2005


NASA Photos

Other Events

NASA Photo

NASA Photo

- Argentina (2004)
  - Delta Stage 3 debris (147 pounds)
  - Debris returned to Aerospace
- Brazil (2004)
  - Debris from NASA launch
- Saudi Arabia (2001)
  - Delta 3rd Stage debris (140 pounds)
  - On display at Aerospace

Other Events

NASA

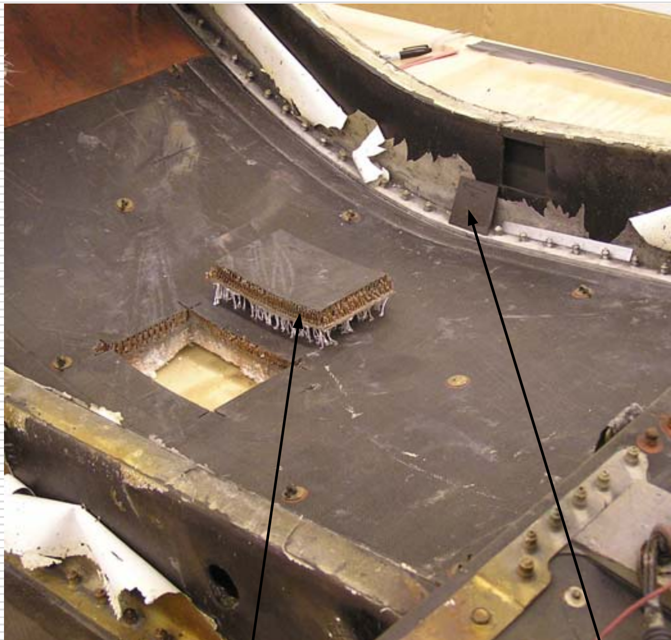
NASA

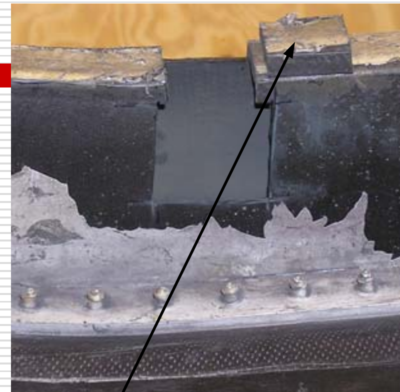
- **Cosmos 954 (1978)**
  - Russian spacecraft
  - Spread radioactive debris in Canada
- **Skylab (1979)**
  - 155,000 lbs
  - Minimal control over entry point
- **Mars 96**
  - Russian spacecraft
  - Debris in Chile
- **Mir (2001)**
  - 280,000 lbs
- ***Columbia* accident (2003)**

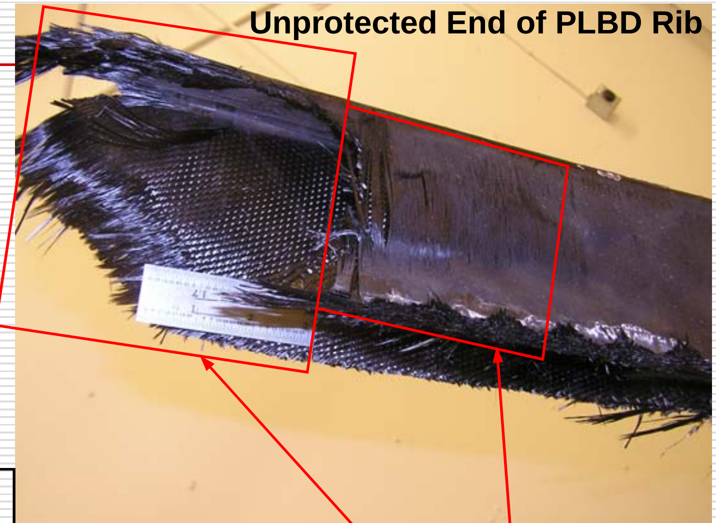
Aerospace Activities

- Examine recovered debris
- Publish best estimates for reentry events
- Improve reentry hazard prediction models
  - Incorporate results of event, material analyses
- Conduct reentry hazard analyses for space hardware
- Developing sensor to collect *in situ* reentry data

Laboratory Analysis: *Columbia* Payload Bay Door Rib & Panel Samples







PLBD Rib Area 2
1.5 in-Long Sample
Cut From 0.25 in-Thick End Wall
Directly Above Area 1

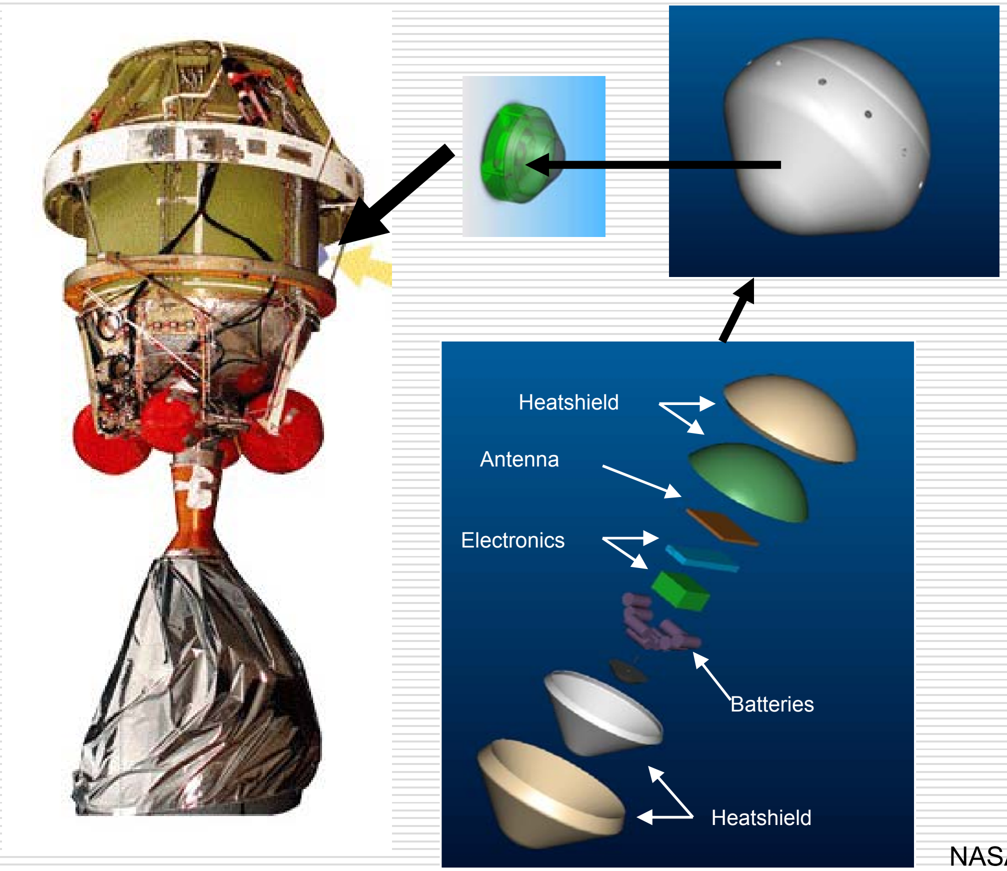
PLBD Panel Area 1
Honeycomb Sandwich
Gr/Epoxy Facesheets & Phenolic Core
Nomex® Insulation on Outside

PLBD Rib Area 1
2.3 by 2.3 in. Square Sample
Cut From 0.1 in-Thick Sidewall

PLBD Rib Areas 3 & 4
Severe Charring on Inside of U-Shaped PLBD Rib
Remaining Sidewall Thickness ≅ 0.075 in.
Remaining End Wall Thickness ≅ 0.185 in.
Bare Fibers on Inside of Sidewalls
Delamination Between Most Plies on Sidewalls
Epoxy Appears Intact on Outside Ply of Sidewalls

- **PLBD Panel Area 1, Rib Area 1, & Rib Area 2 from regions with no apparent damage**
- **PLBD Rib Areas 3 & 4 from severely charred region**

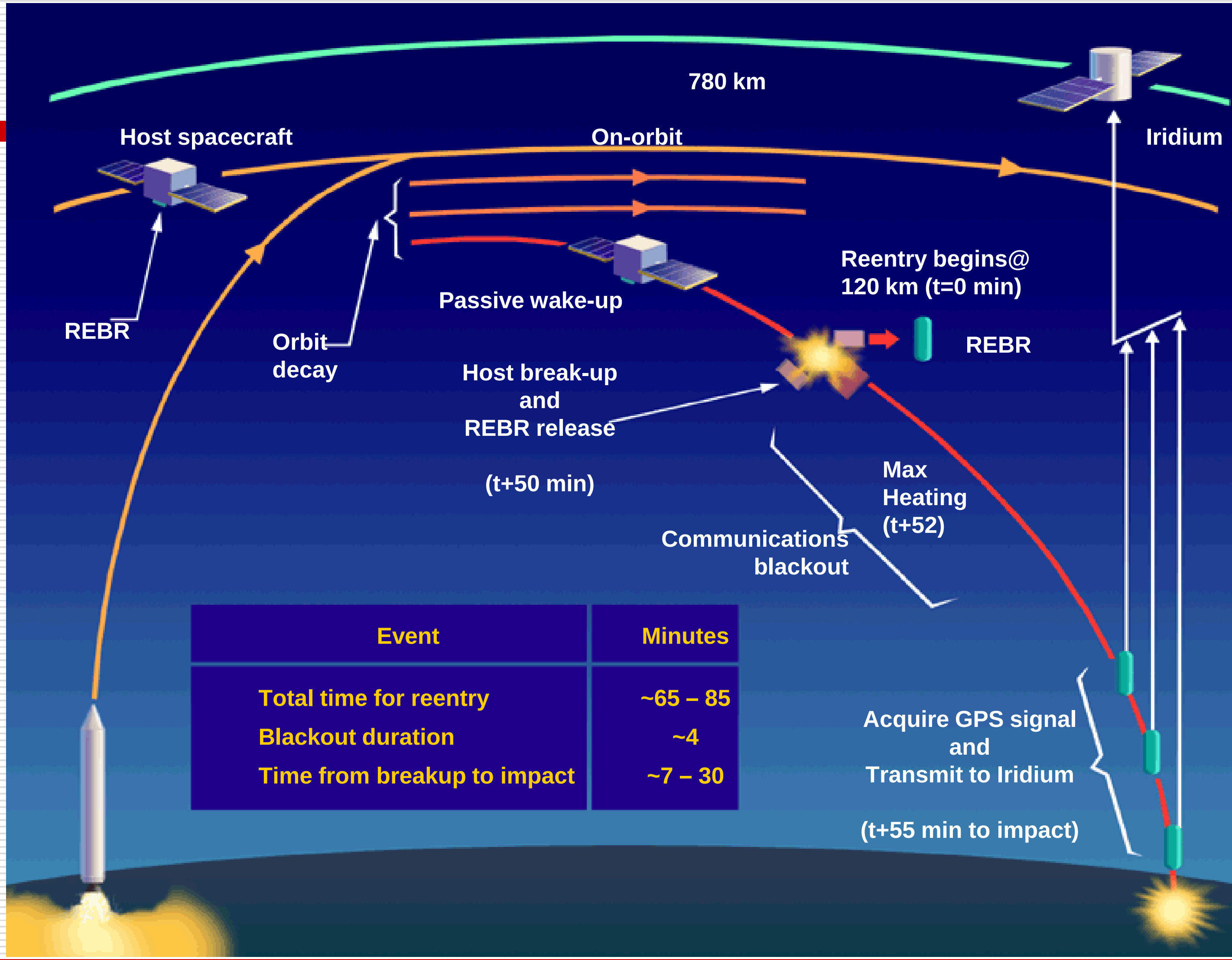
Reentry Breakup Recorder



NASA Ames Research Center illustration

- 2-kg, 12-inch diameter
- GPS, Temperature sensors, Accelerometers, data recorder, batteries, Iridium modem
- Ride of opportunity to space; no services required from host or ground systems
- Probe records data during reentry; phones home data via Iridium prior to impact
- Probe not recovered
- Technology may enable other new systems (launch hardware impact locator, Black Box for reentry vehicles)

Reentry Breakup Recorder (REBR)



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Reentry Predictions

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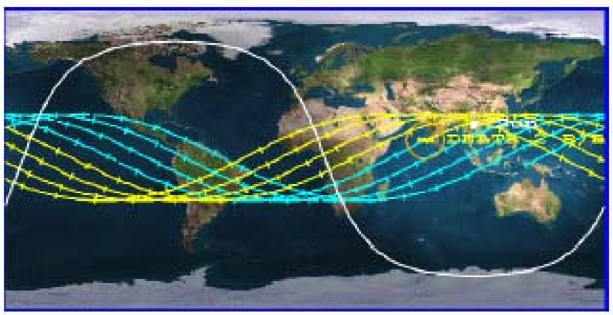
Object Description:

Type:	Delta II Stage 2 Rocket Body
NORAD Name:	DELTA 2 R/B(1)
NORAD Number:	27851
Int'l Designation:	2003 032C
Launched:	08 JUL 2003 @ 04:18 UTC
Site:	Cape Canaveral Air Force Station LC-17B
Mission:	Mars Exploration Rover-B

Reentry Prediction:

Predicted Reentry Time:	25 JUL 2004 @ 05:19 UTC ± 28 hours
Prediction Epoch:	20 JUL 2004 @ 11:49:00.460 UTC

Prediction Ground Track:



For clarity, ground track plot is limited to ± 6 hours (ticks at 5-minute intervals)
Blue Line - ground track uncertainty prior to predicted time
Yellow Line - ground track uncertainty after predicted time
Orange Line - Earth horizon as seen from the reentering body
White Line - day/night terminator (Sun location as indicated)

- Predictions of upcoming reentry events available at www.aero.org/capabilities/cords
- Predictions posted for events in next 5 days
- Worldwide interest and input

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Summary

- Orbital debris and reentry hazards are emerging problems for space operators
- Mitigation policies adopted by U.S. consistent with those being evolved worldwide
- No major collision incidents to date, probability increasing
- Governments, manufacturers, operators taking actions to minimize future threats
- Increased emphasis on space situational awareness for protecting critical assets and capabilities
- Capabilities to predict collision, reentry, related hazards are evolving
- Good data on actual reentry breakups would reduce uncertainty