National Aeronautics and Space Administration

Orbital Debris and Future Environment Remediation

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St Hubert, Quebec, Canada, 28 March 2012

Outline (1/2)

- **Part 1: The Near-Earth Orbital Debris Environment**
  - Overview of the orbital debris populations
  - Optical, radar, and in-situ measurements
  - Orbital debris modeling

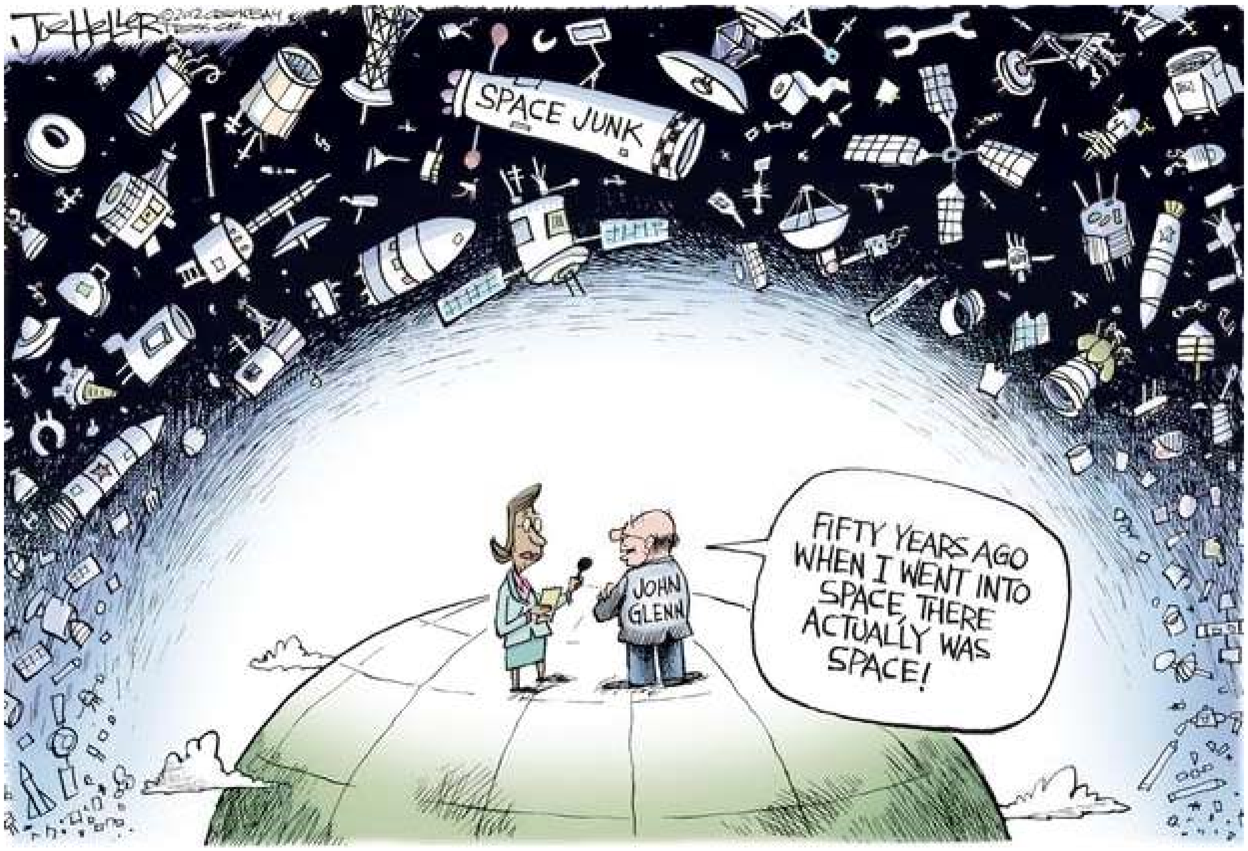
- **Part 2: Orbital Debris Modeling**
  - The NASA OD engineering model
  - The NASA OD evolutionary model
  - The NASA standard satellite breakup model

Outline (2/2)

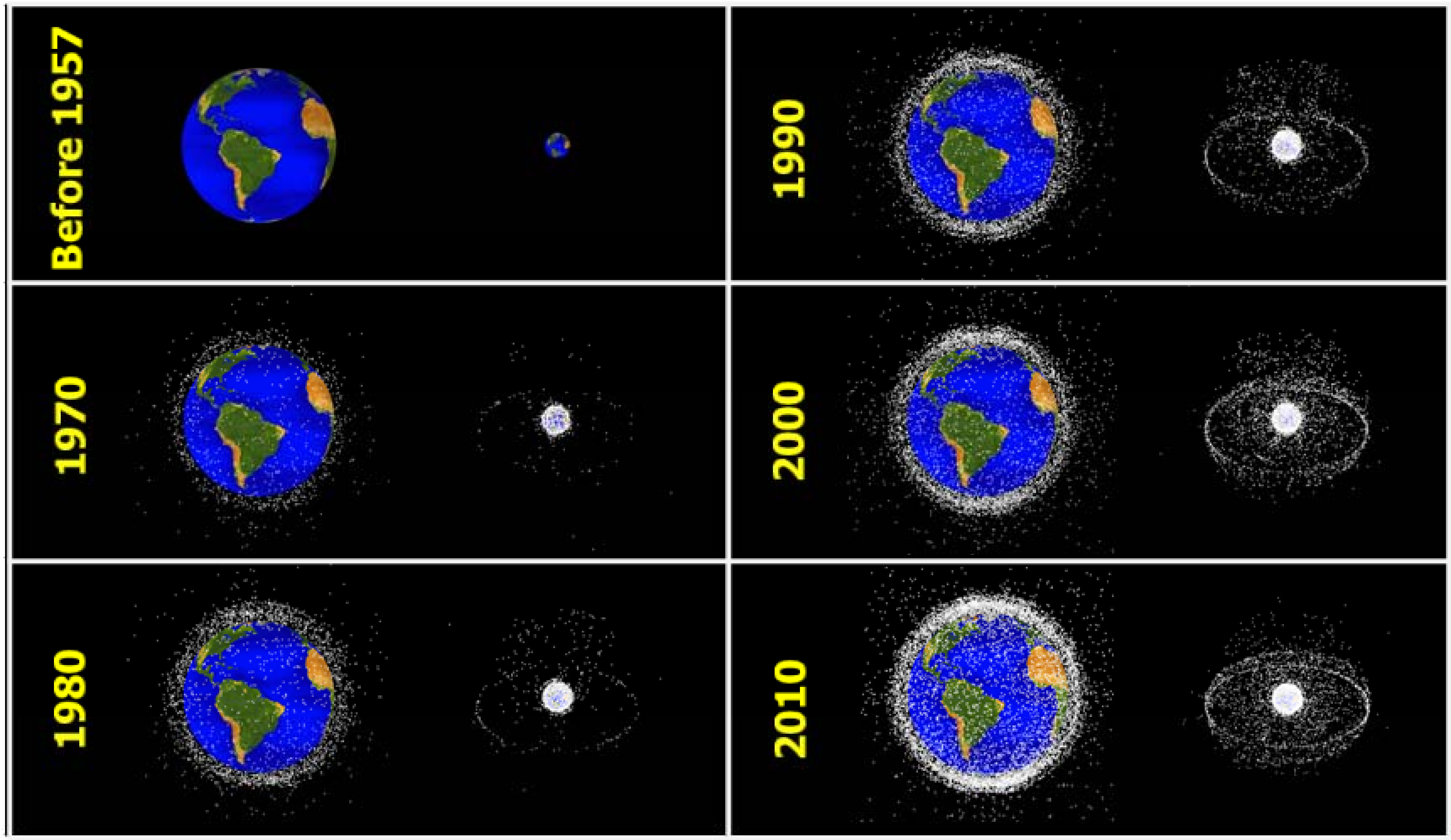
- **Part 3: Options and Challenges for Environment Remediation**
  - Target the root cause of the population growth
  - Target the main threat to operational satellites
  - Prevent major debris generating collisions
  - The challenges

Part 1: The Near-Earth Orbital Debris Environment

Overview of the Orbital Debris Environment



The Near-Earth Environment (1957-2010)



- Only objects in the US Space Surveillance Network (SSN) catalog are shown
- Sizes of the dots are not to scale

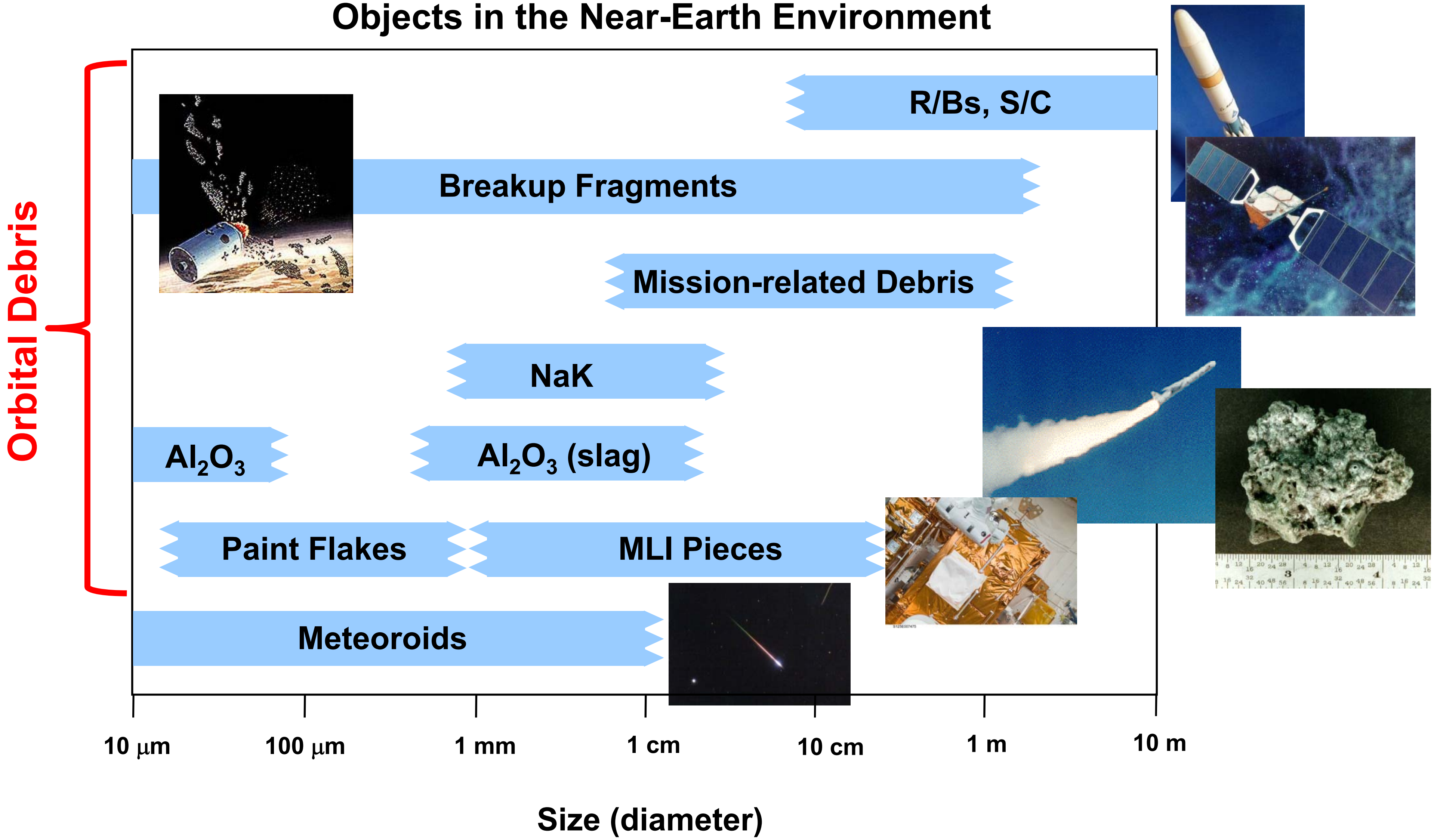
What Is Orbital Debris?

- **Orbital debris is any man-made object in orbit about the Earth that no longer serves a useful purpose**

- **Examples**
  - Intact objects: spent rocket bodies (R/Bs, *i.e*., upper stages) and retired spacecraft (S/C, *i.e*., payloads)
  - Breakup fragments (via explosions or collisions)
  - Mission-related debris: objects released during normal mission operations (engine covers, yo-yo de-spin weights, *etc.*)
  - Solid rocket motor effluents (Al_2O_3 slag and dust particles)
  - NaK droplets (coolant leaked from Russian nuclear reactors)
  - Surface degradation debris (paint flakes, *etc.*)

The Orbital Debris Family

Objects in the Near-Earth Environment



How Much Junk Is Currently Up There?

Softball size or larger (≥10 cm): ~22,000 (tracked by the Space Surveillance Network)

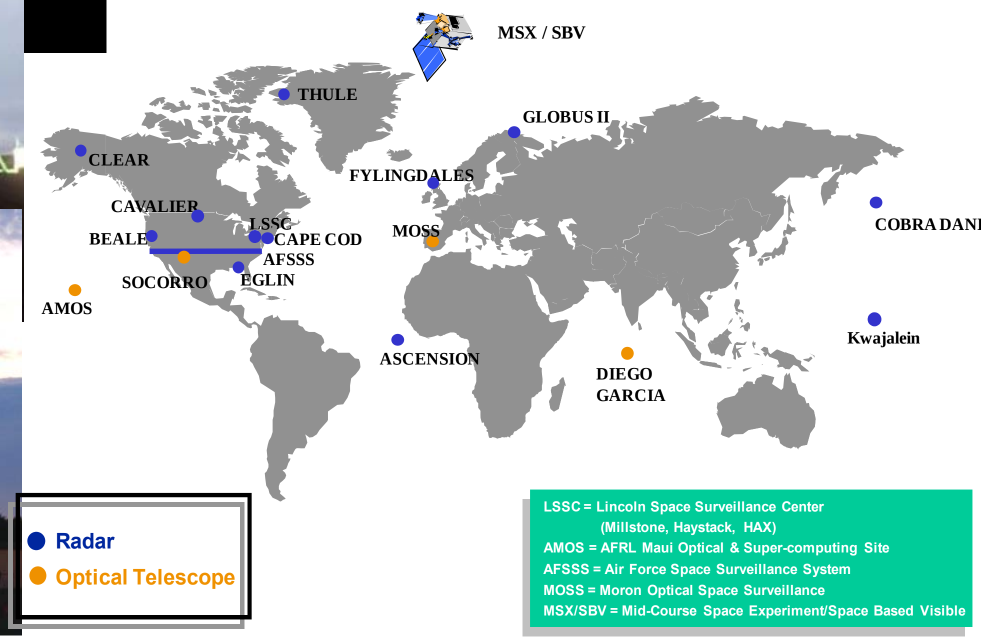
Marble size or larger (≥1 cm): ~500,000

Dot or larger (≥1 mm): ~100,000,000 (a grain of salt)

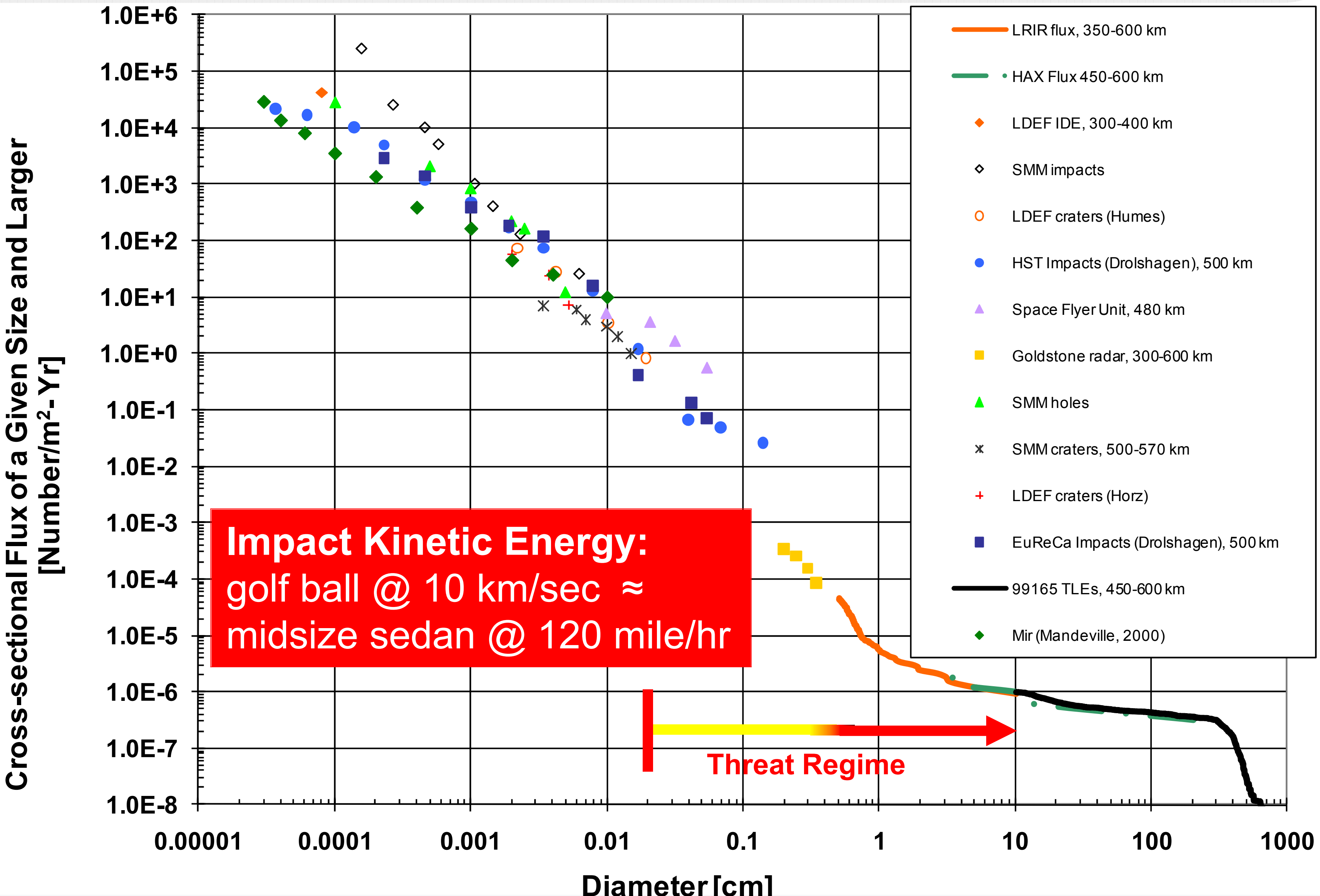
- **Total mass: ~6300 tons LEO-to-GEO (~2700 tons in LEO)**
- **Due to high impact speed in space (~10 km/s in LEO), even sub-mm debris pose a realistic threat to human spaceflight and robotic missions**

U.S. Satellite Catalog

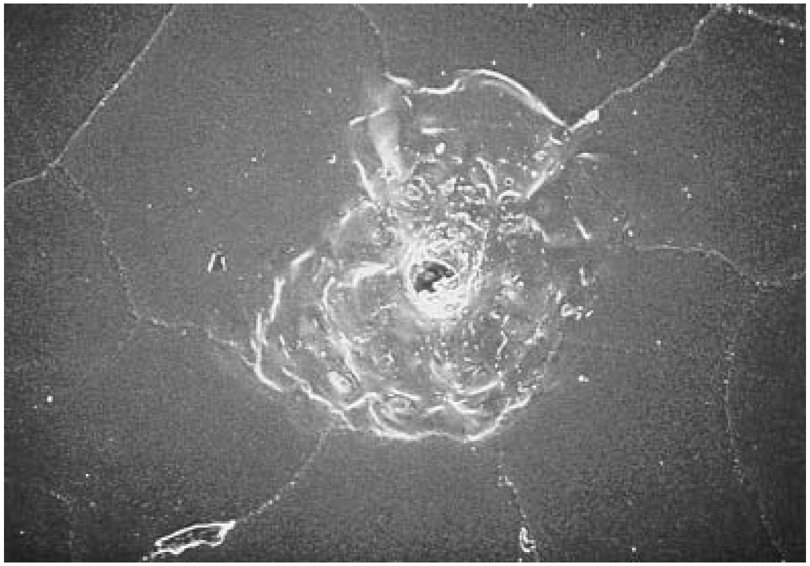
- >22,000 objects tracked by US Space Surveillance Network (SSN) in 2012
- Tracked objects are ~10 cm and larger
- Many more untracked (*i.e.*, smaller) objects in space



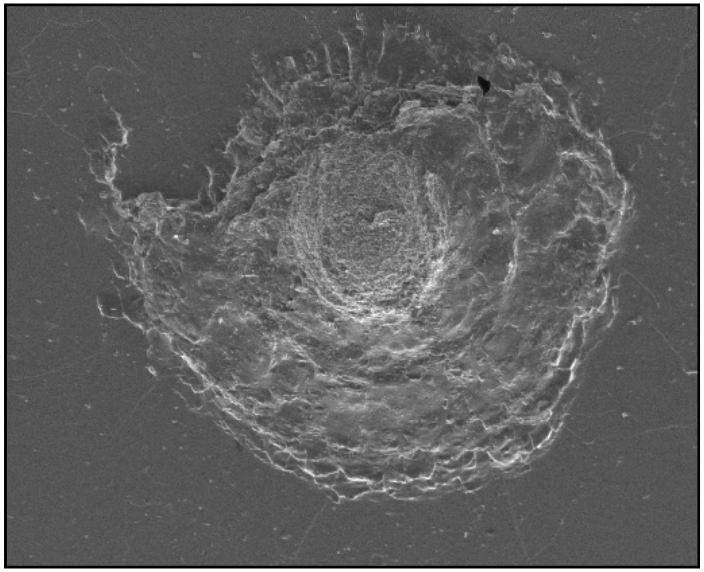
The Environment



Threat from Small Orbital Debris (1/2)



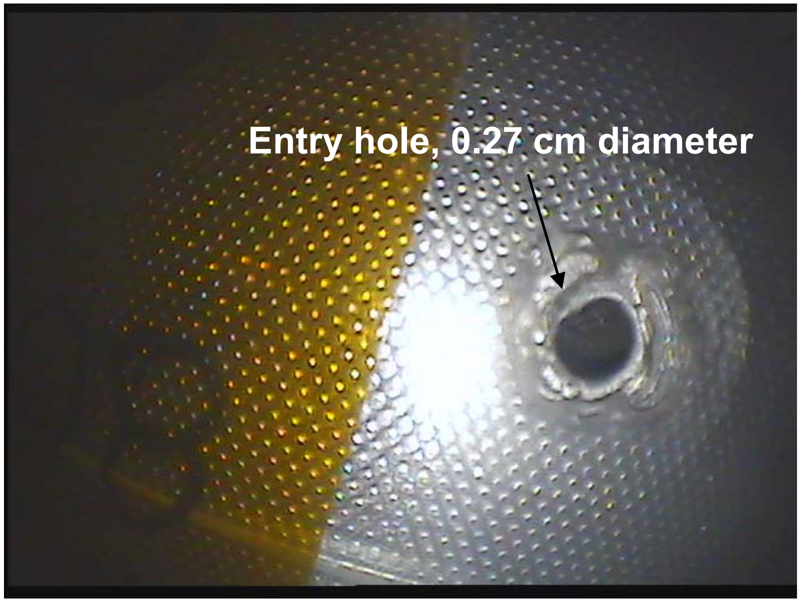
Crater: Dia×Dep ≈ 1.8 mm×0.2 mm
Estimated projectile size ≈ 0.06 mm
(STS-97 window damage, Dec. 2000)

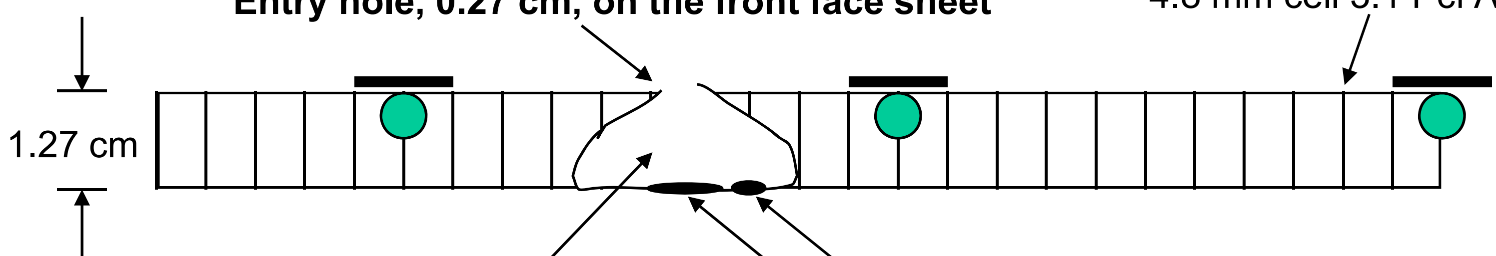


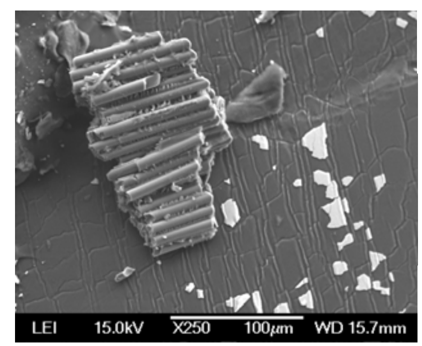
Crater: Dia×Dep ≈ 1 cm×2 mm
Estimated projectile size ≈ 0.5 mm
(STS-92 window damage, Oct. 2000)

→ On average, two shuttle windows were replaced per mission

Threat from Small Orbital Debris (2/2)
(STS-115 Shuttle Radiator Damage, 2006)







Projectile residual

An Example – Shuttle Vulnerabilities

Potential Shuttle Damage

Window Replacement

EVA Suit Penetration

Radiator Penetration

- **Shuttle Loss of Crew and Vehicle (LOCV) risks from MMOD impact damage were in the range of 1 in 250 to 1 in 300 per mission**
  - The risks vary with altitude, mission duration, and attitude
  - OD to MM is about 2:1 at ISS altitude

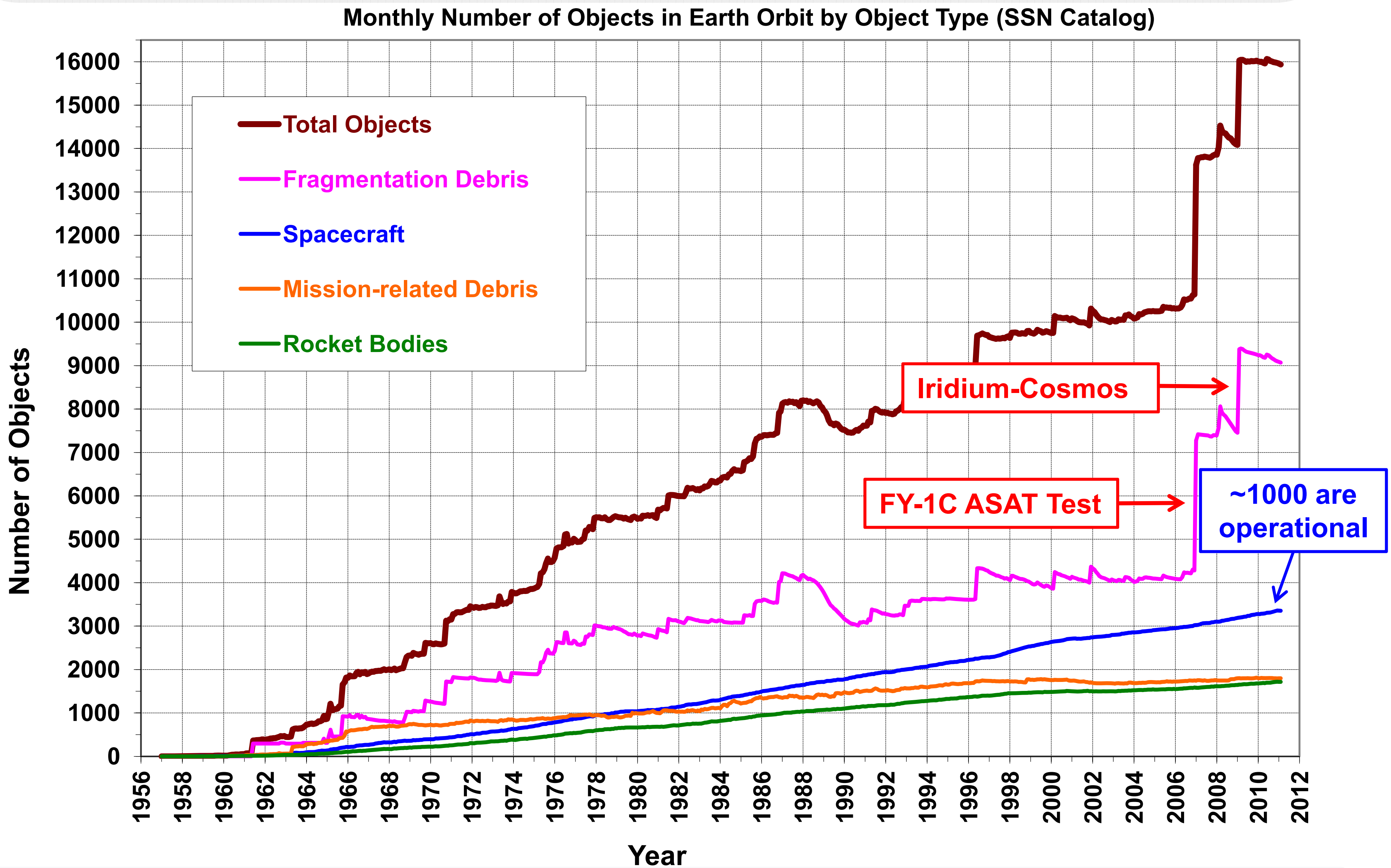
0.001 0.01 0.1 1 10 100 1000

Debris Diameter in Centimeters

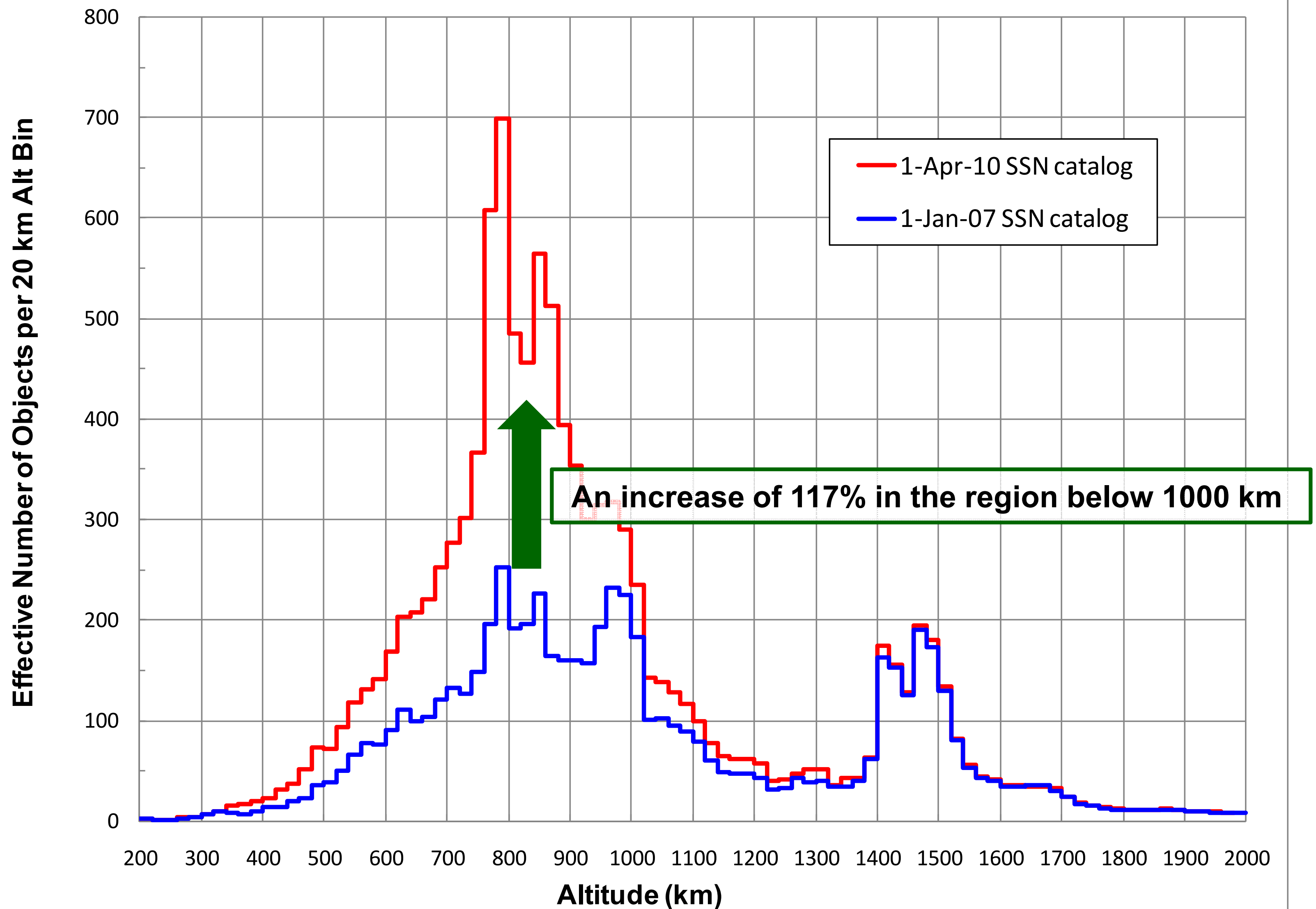
The Big Sky Is Getting Crowded

- **U.S. Air Force's Joint Space Operations Center (JSpOC) provides conjunction assessments for all operational S/C**
  - A warning is issued for LEO S/C when (1) a miss distance is less than 1 km and (2) a radial miss distance is less than 200 m during the forecast period of 72 hours
- **In 2010, JSpOC issued 10 to 30 conjunction warnings on a daily basis, and more than 100 collision avoidance maneuvers were carried out by satellite operators**
- **The ISS has conducted 15 Debris Avoidance Maneuvers (DAM) since 1999**
  - 4 times since last April

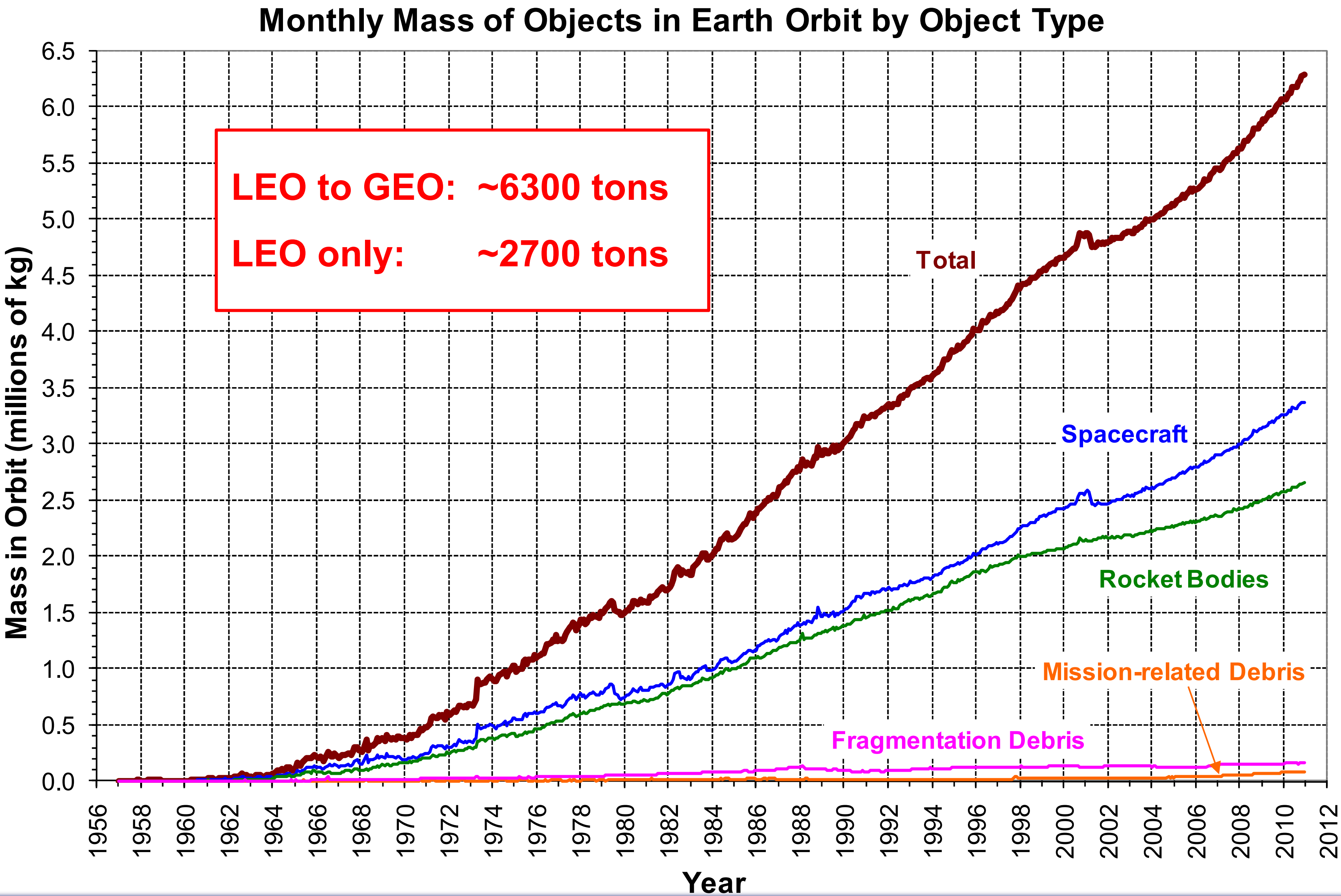
Growth of the Historical Cataloged Populations



Consequences of the Two Major Events



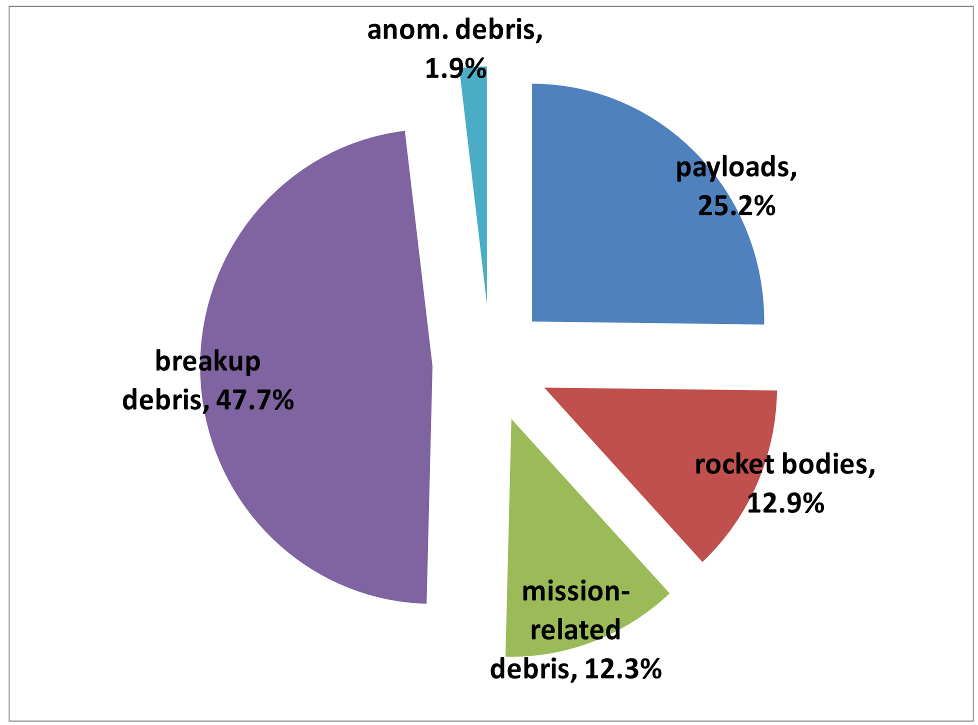
Mass in Orbit



Sources of the Cataloged Populations

- **~4700 launches conducted worldwide since 1957**
- **211 known breakups (thru Jan 2012)**
  - Major events
    - **Titan Transtage (473, 1965)**
    - **Agena D stage (373, 1970)**
    - **Ariane 1 stage (489, 1986)**
    - **Pegasus HAPS (709, 1996)**
    - **Long March 4 stage (316, 2000)**
    - **PSLV (326, 2001)**
    - **Fengyun 1C (~3200, 2007)**
    - **Briz-M (>1000[a], 2007)**
    - **Cosmos 2421 (509, 2008)**
    - **Iridium 33 (>700, 2009)**
    - **Cosmos 2251 (~2000, 2009)**

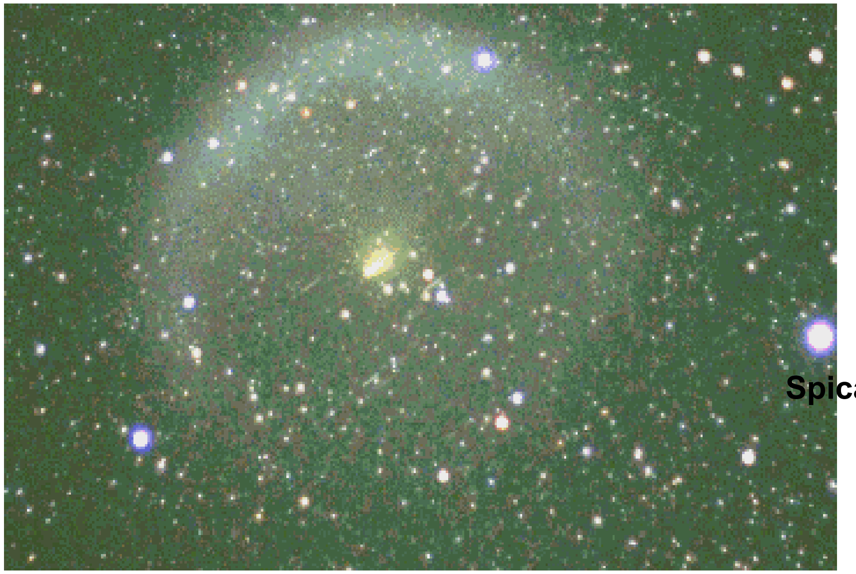
Source Breakdown



[a]initial report

Explosion of Briz-M

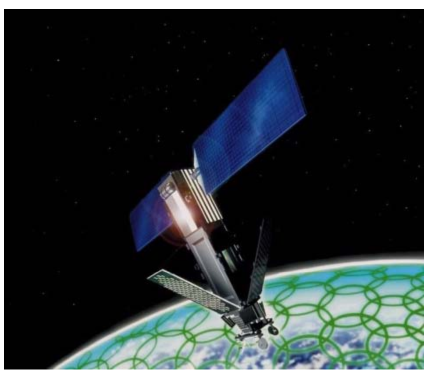
- **Briz-M**
  - 4th stage of a Russian Proton Launch Vehicle
  - 485 km by 14,750 km, inclination = 51.5°
  - Mass ~2000 kg
  - Possible cause of the breakup: explosion of the remaining propellant on board the stage



(R. McNaught, Feb 17, 2007)

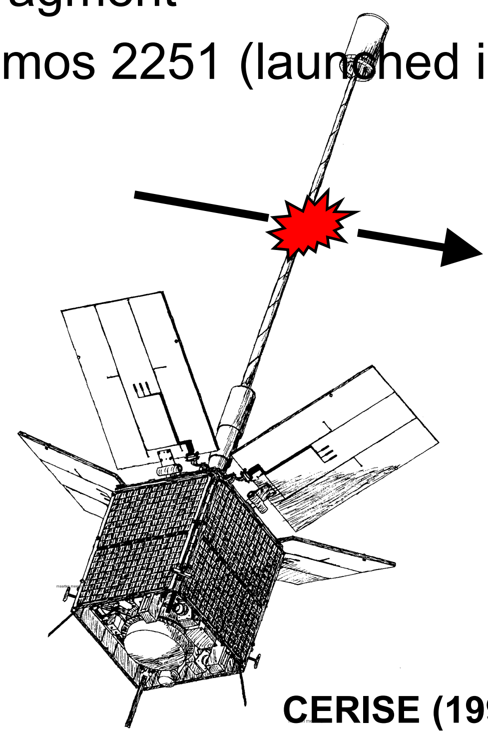
Accidental On-Orbit Collisions

- **Four <u>accidental</u> collisions between <u>cataloged objects</u> have been identified**
  - 1991: Russian Sat (launched in 1988) ↔ Russian fragment
  - 1996: French Sat (launched in 1995) ↔ French fragment
  - 2005: US R/B (launched in 1974) ↔ PRC fragment
  - 2009: Iridium 33 (launched in 1997) ↔ Cosmos 2251 (launched in 1993)



Iridium33 (560 kg)

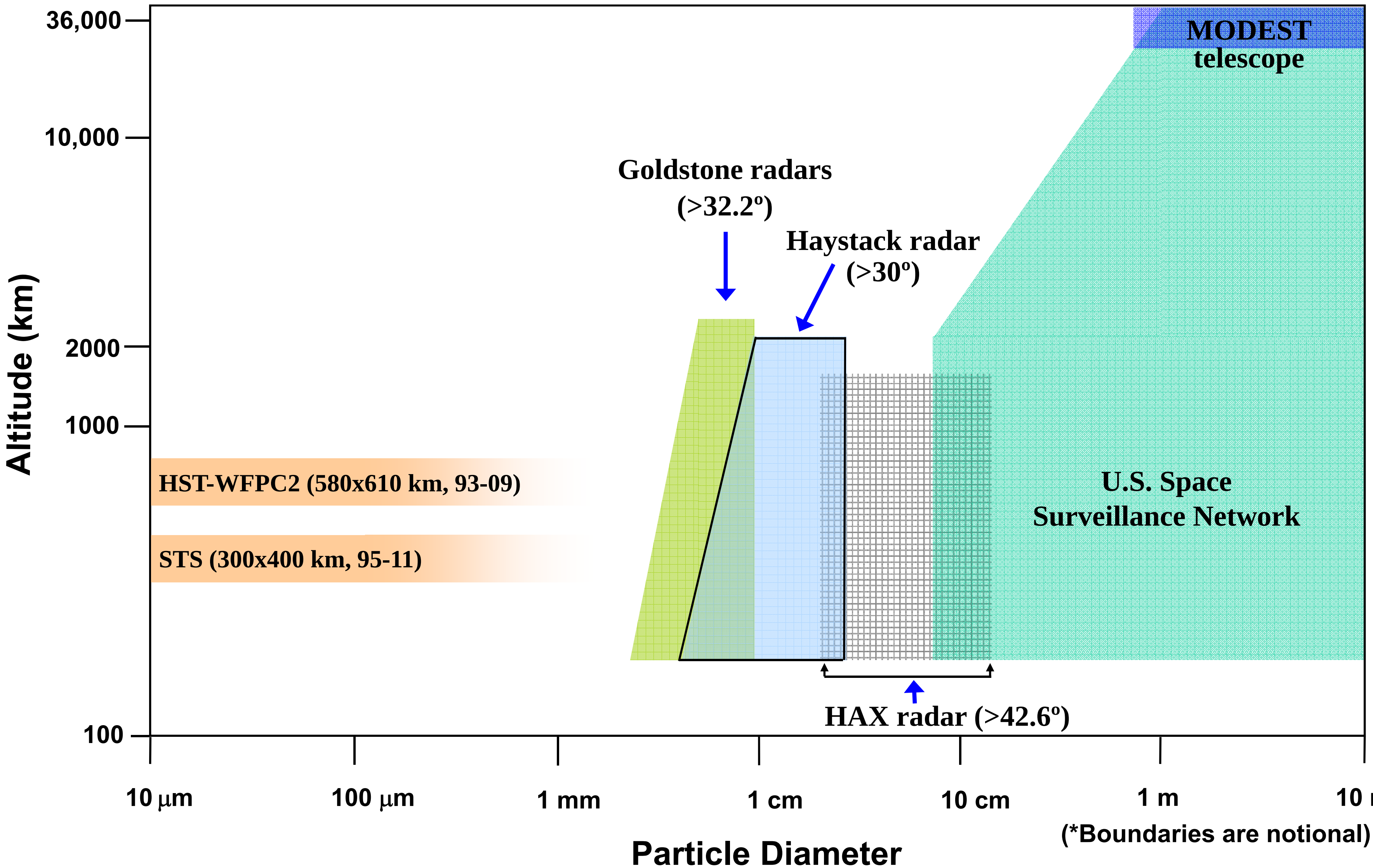
Cosmos 2251 (900 kg)



CERISE (1996)

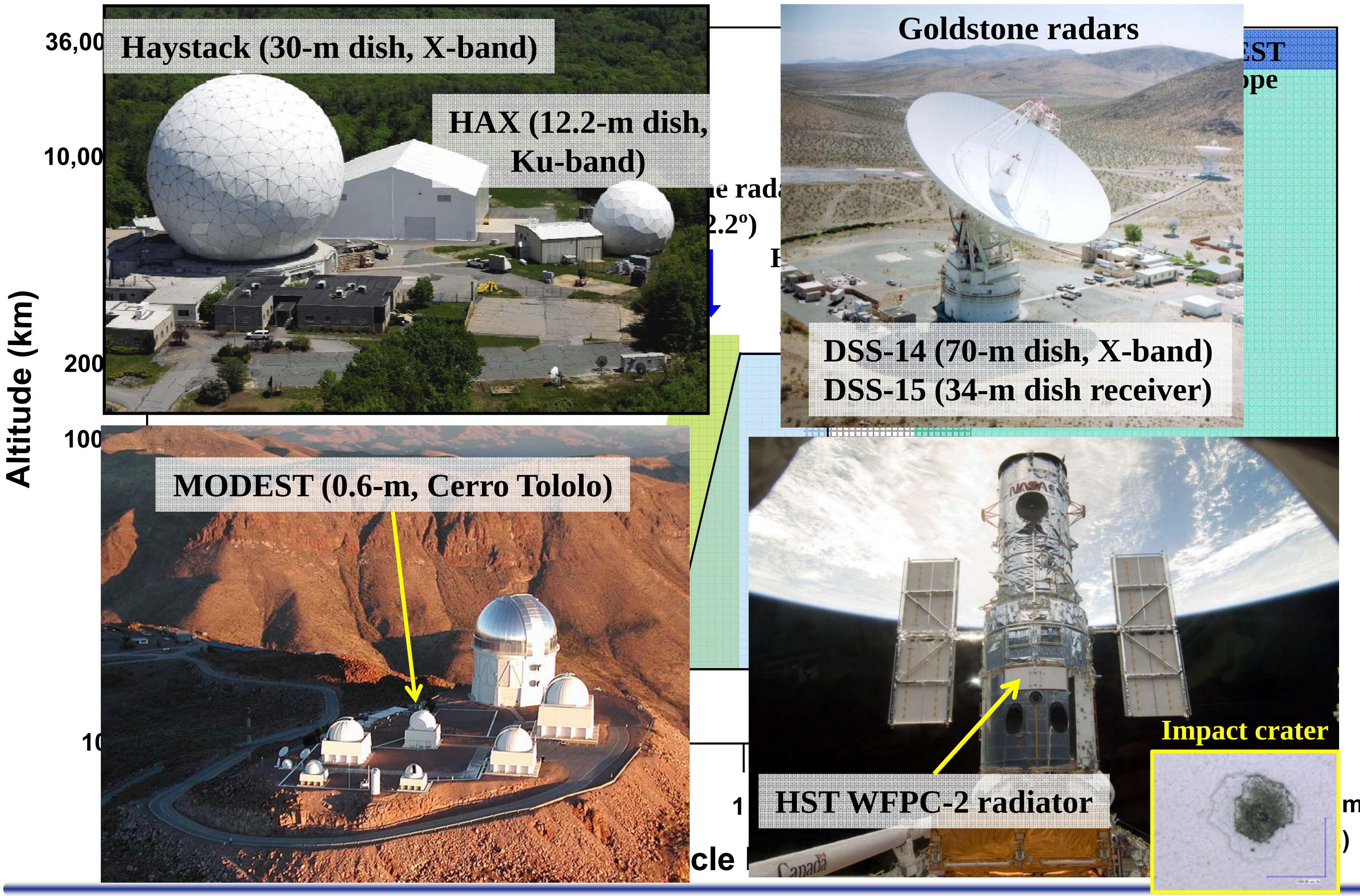
Optical, Radar, and In-Situ Measurements

Current NASA Debris Data (1/2)



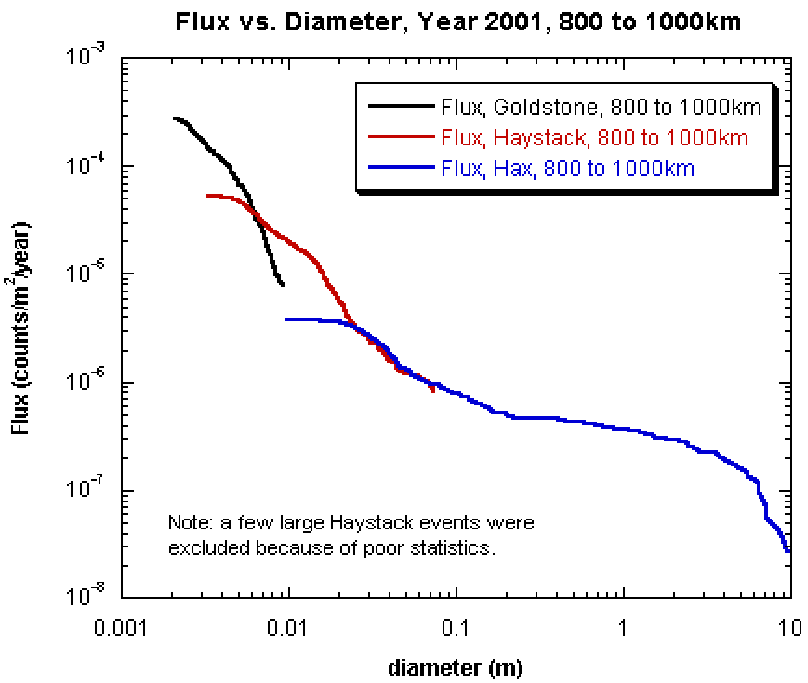
(*Boundaries are notional)

Current NASA Debris Data (2/2)



NASA RADAR Observations

- **Signal processing**
- **Object detection/correlation**
- **Debris size estimation**
- **Orbit determination**
- **Environment definition**



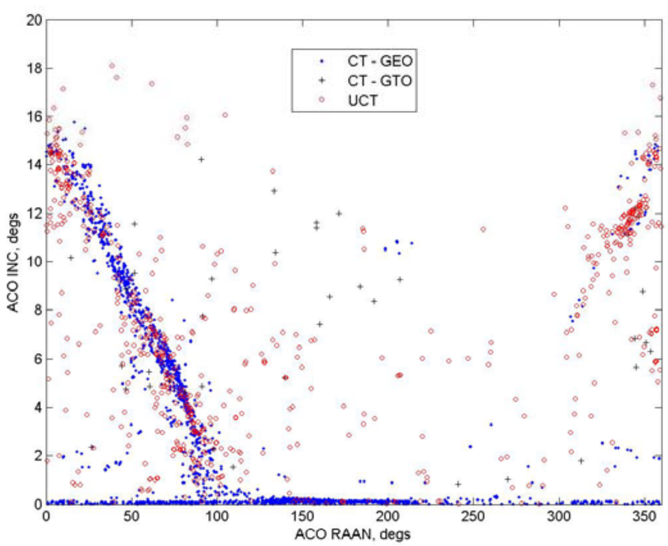
Goldstone

Haystack and HAX

NASA Optical Observations

- Photometric and spectral measurements
- Object detection and correlation
- Optical Measurement Center (OMC)
- Surface material identification
- Orbit determination
- Environment definition

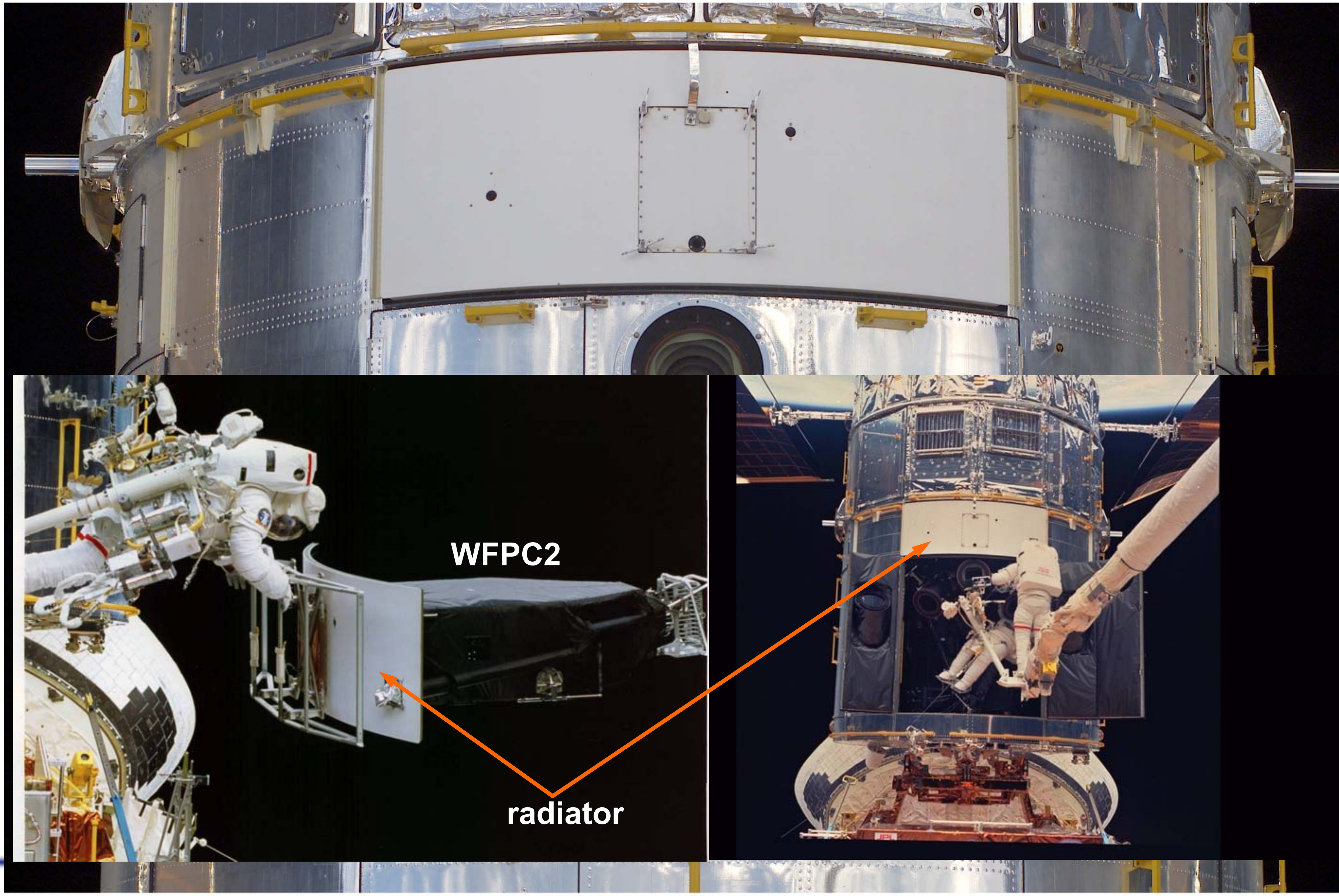
MODEST



OMC

MCAT

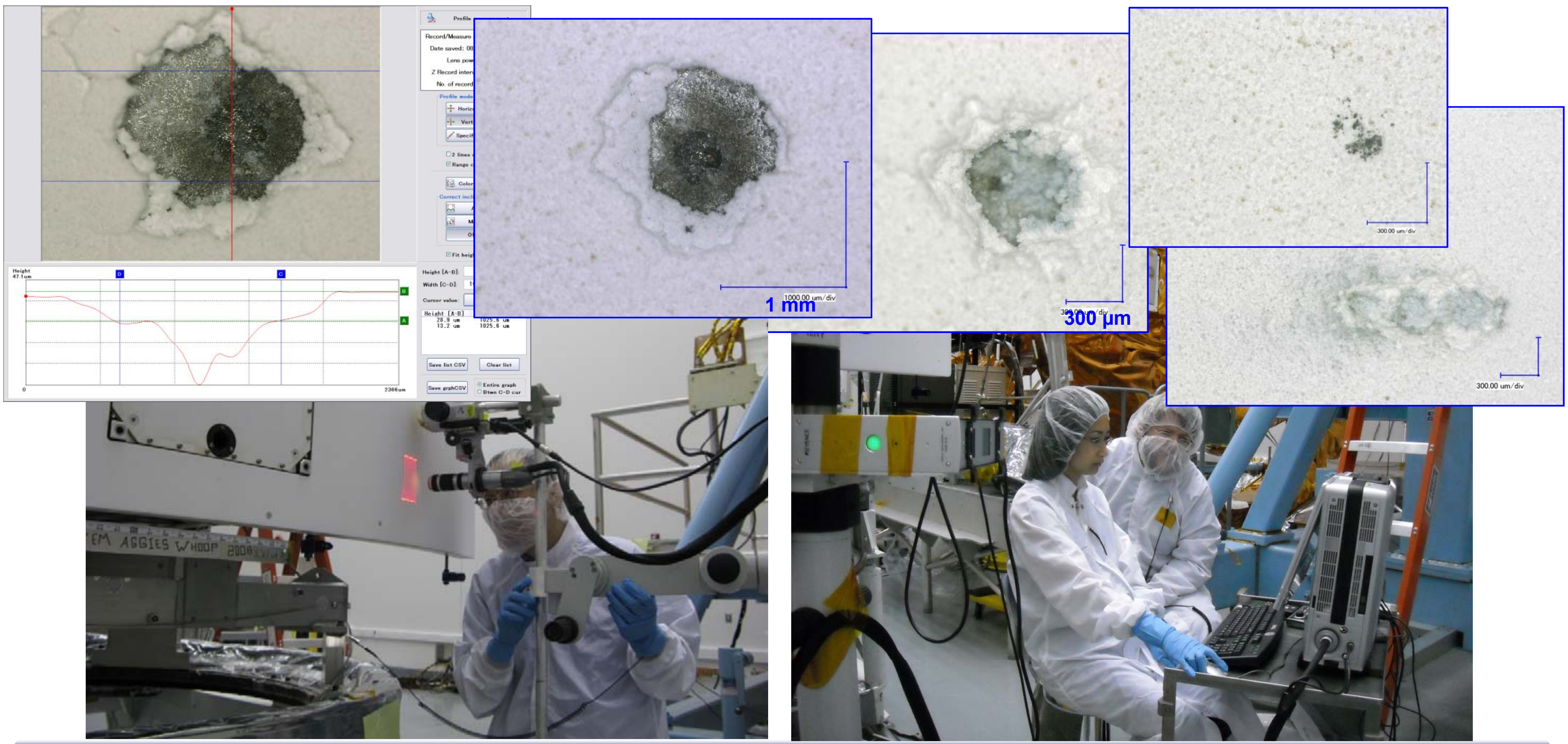
In-Situ Data From Returned Surfaces



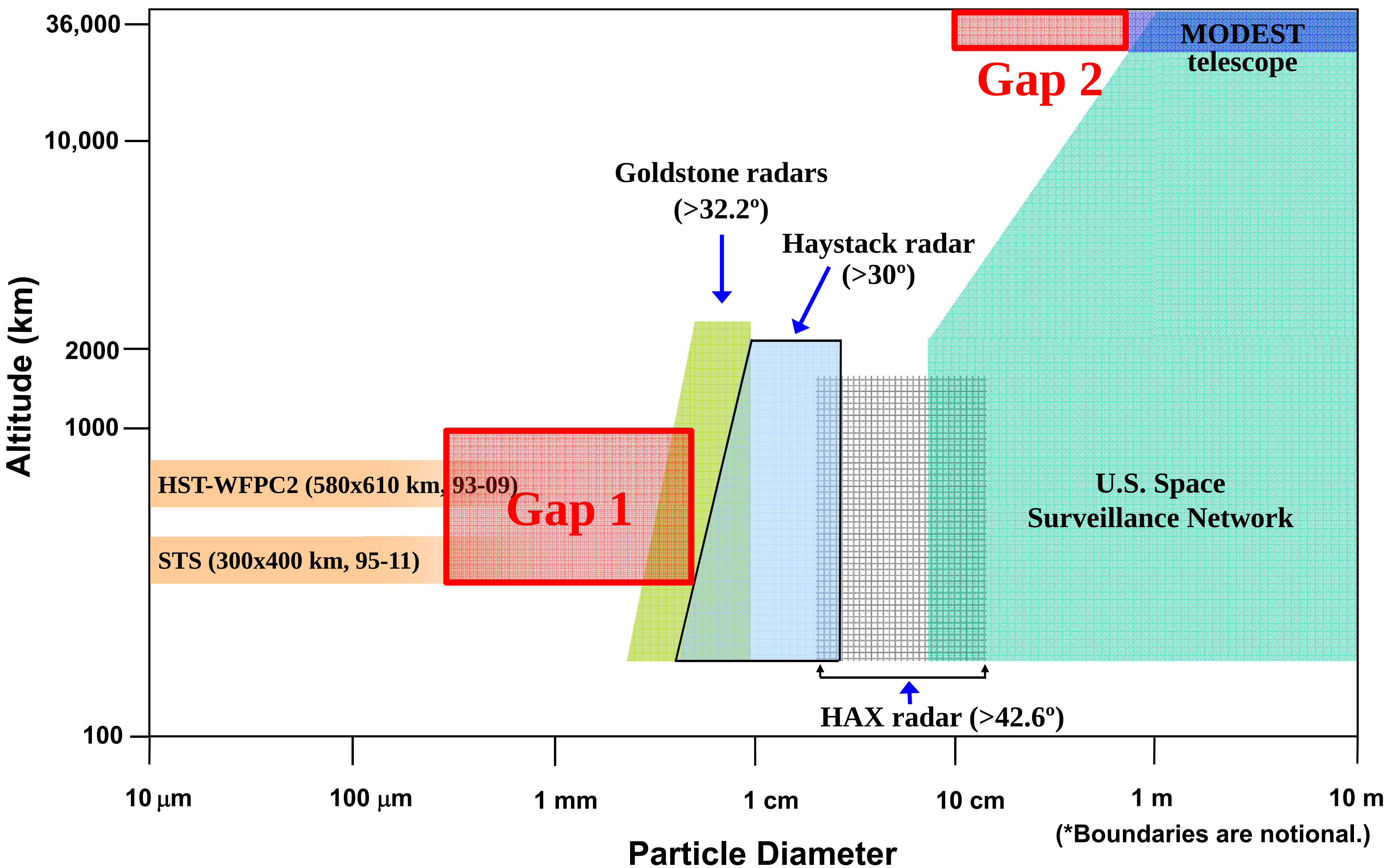
S109E5067

Inspection of the HST WFPC2 Radiator

- **685 impact features (≥300 µm) were identified**
  - Recorded each impact feature's shape, size, depth, and volume



Critical Data Gaps

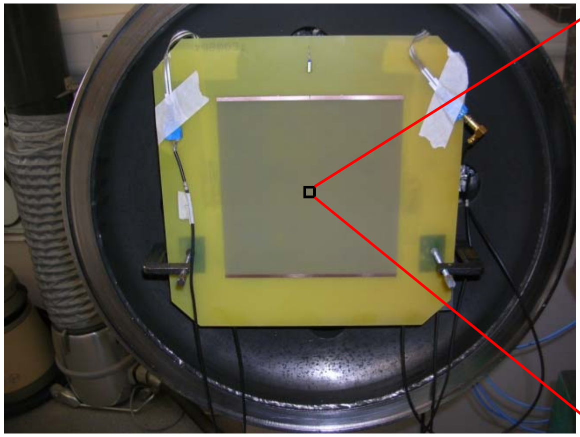


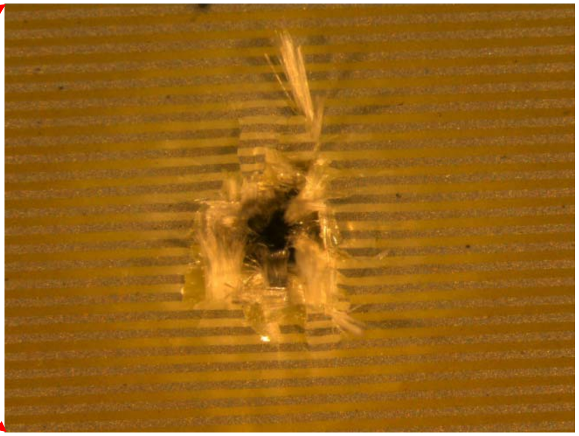
Future NASA Debris Telescope

- **NASA Meter Class Autonomous Telescope (MCAT)**
  - 1.3 m aperture, 0.96° field of view, f/4
  - Located at Kwajalein Atoll (9°N, 168°E)
  - Target detection limits
    - **GEO ~10 cm diameter (20.5 V-mag)**
  - Primary objectives
    - **GEO debris down to ~10 cm**
    - **LEO debris with low inclinations and high eccentricities**
    - **Simultaneous radar-optical observations**
  - Expected operations ~2013

A New Particle Impact Detection Technology

- **Debris Resistive/Acoustic Grid Orbital Navy Sensor (DRAGONS)**
  - Objective: A low-cost/mass/power experiment to detect and characterize 0.1 to 1 mm MMOD particles at 800-1000 km altitude
  - Components: (1) a large surface (≥1 m^2) coated with thin resistive grids, (2) acoustic sensors attached to the backside of the board/film
  - Team: USNA, NASA/ODPO, Kent (UK), NRL, VT
  - Status: Presented to the annual DoD Space Experiment Review Board (SERB) since 2007, a potential flight opportunity in 2015





Hypervelocity Impact Tests

- Resistive grid width: 75 μm
- Projectile: 0.3 mm stainless steel
- Impact speed: 5.06 km/sec
- Impact angle: normal
- Two PVDF acoustic sensors attached to the board

Modeling

General Orbital Debris Modeling (1/2)

- **NASA DO engineering model**
  - Is a mathematical model (such as ORDEM) capable of predicting OD impact risks for critical space assets (ISS, *etc*.)
- **NASA OD evolutionary model**
  - Is a physical model (such as LEGEND) capable of predicting future debris environment
  - Supports the development of US/NASA debris mitigation guidelines and safety standards
- **NASA satellite breakup model**
  - Describes the outcome of a satellite breakup (explosion or collision)

General Orbital Debris Modeling (2/2)

- **Reentry risk assessments**
  - Uses Object Reentry Survival Analysis Tool (ORSAT) to evaluate satellite reentry risks
  - The risk of human casualty from surviving debris shall not exceed 1 in 10,000 (NASA Standard 8719.14)
- **NASA Debris Assessment Software (DAS)**
  - Is designed to assist NASA Programs in performing orbital debris assessments for their planned missions

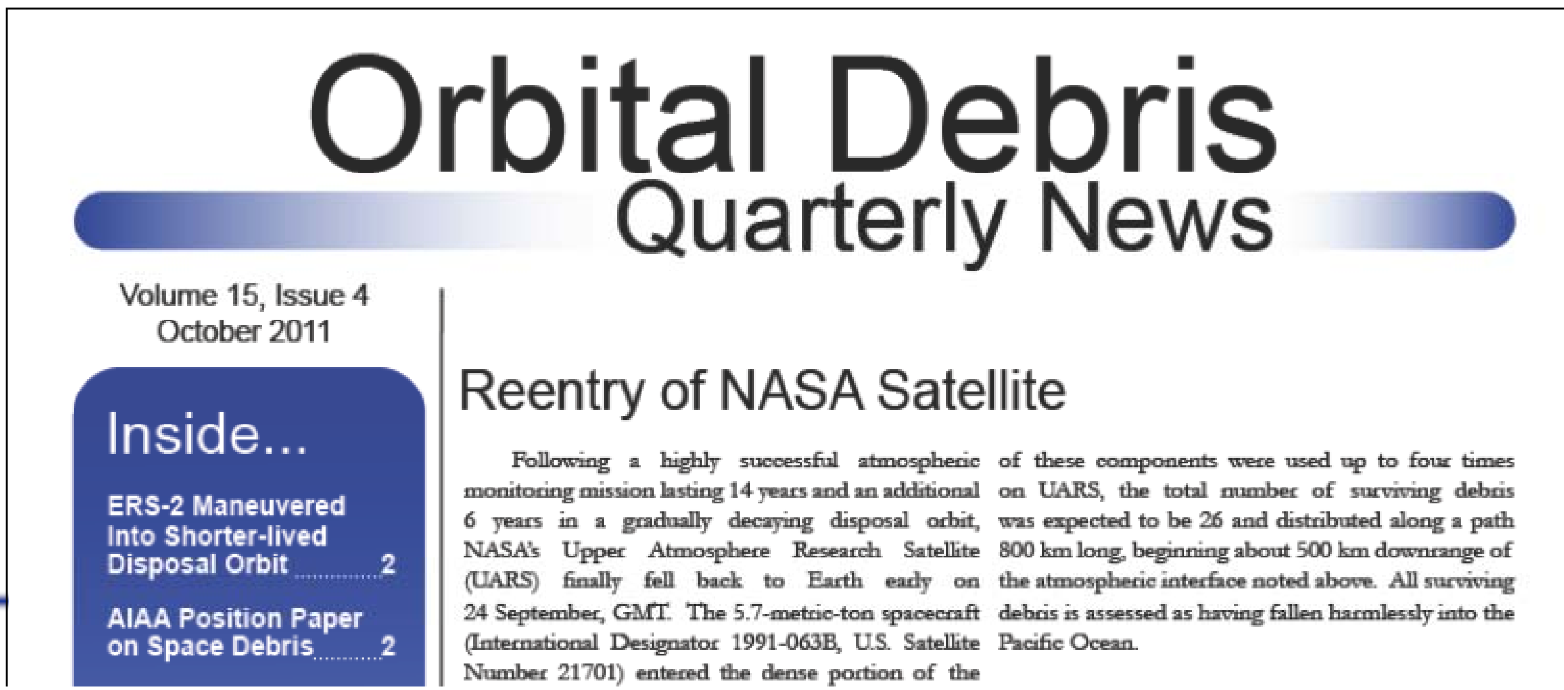
Delta II propellant tank (Georgetown, TX, 1997)

Titanium casting of STAR-48B SRM (Saudi Arabia, 2001)

Titanium casting of STAR-48B SRM (Argentina, 2004)

NASA Orbital Debris Quarterly News

- **ODQN is a quarterly publication of the NASA Orbital Debris Program Office**
  - includes some of the latest events in orbital debris research, news, statistics, project reviews, meeting reports, and upcoming events
  - Is available at http://www.orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html



Orbital Debris Quarterly News

Volume 15, Issue 4
October 2011

Inside...

Reentry of NASA Satellite

Following a highly successful atmospheric monitoring mission lasting 14 years and an additional 6 years in a gradually decaying disposal orbit, NASA's Upper Atmosphere Research Satellite (UARS) finally fell back to Earth early on 24 September, GMT. The 5.7-metric-ton spacecraft (International Designator 1991-063B, U.S. Satellite Number 21701) entered the dense portion of the

of these components were used up to four times on UARS, the total number of surviving debris was expected to be 26 and distributed along a path 800 km long, beginning about 500 km downrange of the atmospheric interface noted above. All surviving debris is assessed as having fallen harmlessly into the Pacific Ocean.

Questions?