# ORBITAL DEBRIS 101

**Compiled by the staffs of the**

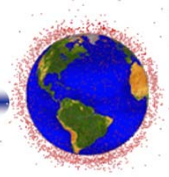
## Orbital Debris Program Office

**&**

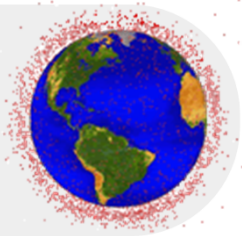
## Orbital Debris Research & Science Operations

**January 2011**





# Orbital Debris

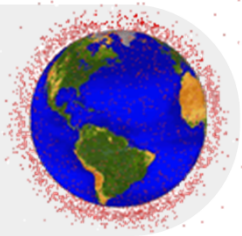


- **What is orbital debris?**
  - Orbital debris is any man-made object in orbit about the Earth which no longer serves a useful purpose.

- **What are examples of orbital debris?**
  - Spent spacecraft and upper stages of launch vehicles, carriers for multiple payloads, debris intentionally released during spacecraft separation from its launch vehicle or during mission operations, debris created as a result of spacecraft or upper stage explosions or collisions, solid rocket motor effluents, and tiny flecks of paint released by thermal stress or small particle impacts.

- **How long will OD remain in orbit?**
  - < 200 km, few days
  - 200 km < x < 600 km, few years
  - 600 km < x < 800 km, decades
  - >800 km, centuries
  - >36,000 km, ∞

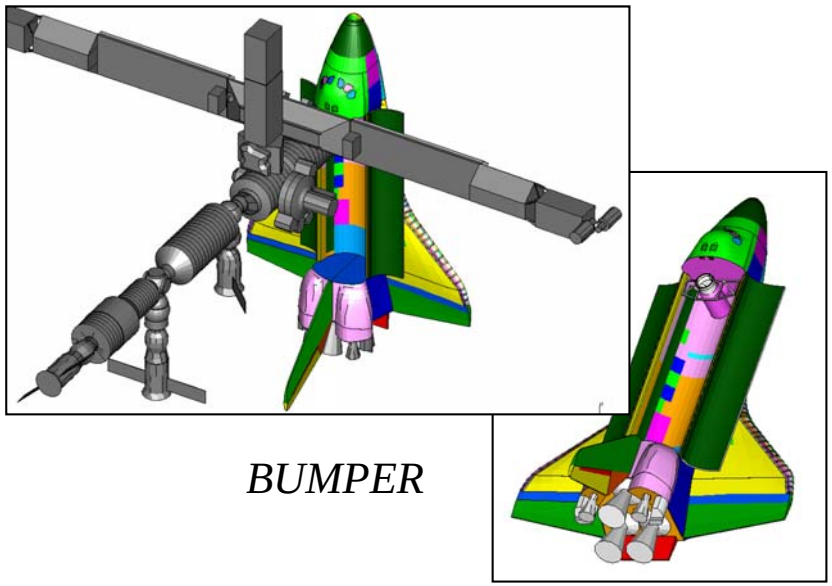
# OD and HITF Groups



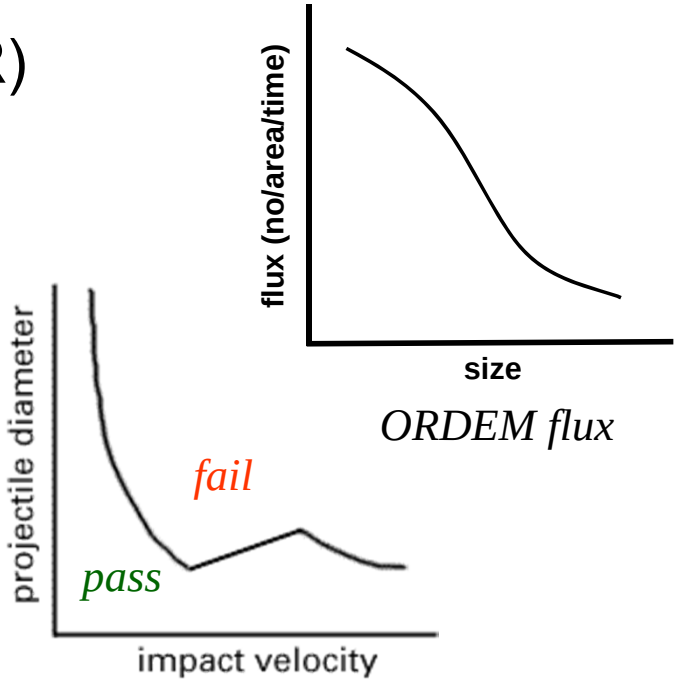
- **Orbital Debris (OD)**
  - Measurements
  - Modeling
  - Environment definition
  - Mitigation and policy
  - Reentry
- **Hypervelocity Impact Technology Facility (HITF)**
  - Low-velocity and hypervelocity impact testing
  - Micrometeoroid and orbital debris (MMOD) impact risk assessments (Shuttle, International Space Station, *etc.*)
  - Impact shielding design
  - Inspection of returned surfaces (*e.g.*, Shuttle windows, radiators, Multi-Purpose Logistics Module)

# OD Damage Assessments for STS/ISS/CEV/others

- **Damage assessments**
  - Environment definition (ORDEM: spatial density, flux, $V_{imp}$, *etc.*)
  - Damage (ballistic limit) equations
  - Finite element modeling (BUMPER)



*BUMPER*




*ORDEM flux*

*ballistic limit equation*

- Loss of Crew and Vehicle (LOCV) risks from MMOD = 1 in 279 (STS-118)
- LOCV risks from MMOD = 1 in 221 (STS-125 HST Servicing Mission)

# Damage Equations: One Example

- **Shuttle window penetration depth (Pd), crack diameter, radiator thermal tape and facesheet hole, depend upon projectile size/density/impact velocity**
  - ➢ *e.g.*, $Pd = 0.53\ \rho^{0.5}\ d^{1.06}\ [V \cos\theta]^{(2/3)}$ (Christiansen 1998)

density, diameter, impact speed, impact angle

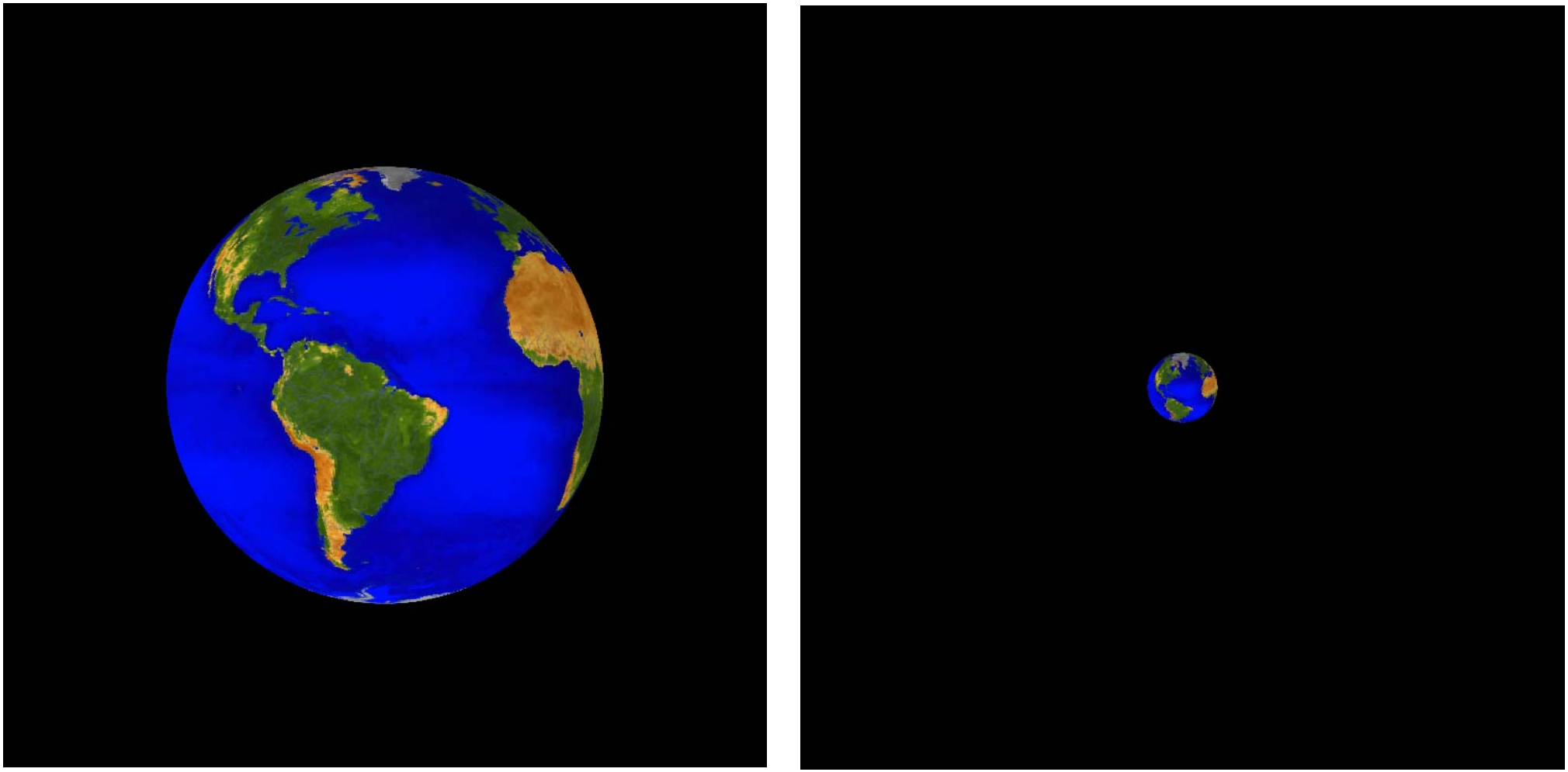
- **Damage also depends on the shape of the projectile and the impact geometry.**

# Outline

- **Orbital Debris Overview**
  - Environment
  - Sources
  - Threat
  - Future
- **Some Details**
  - Measurement
  - Modeling
  - Mitigation and policy
  - Reentry

# Orbital Debris Growth

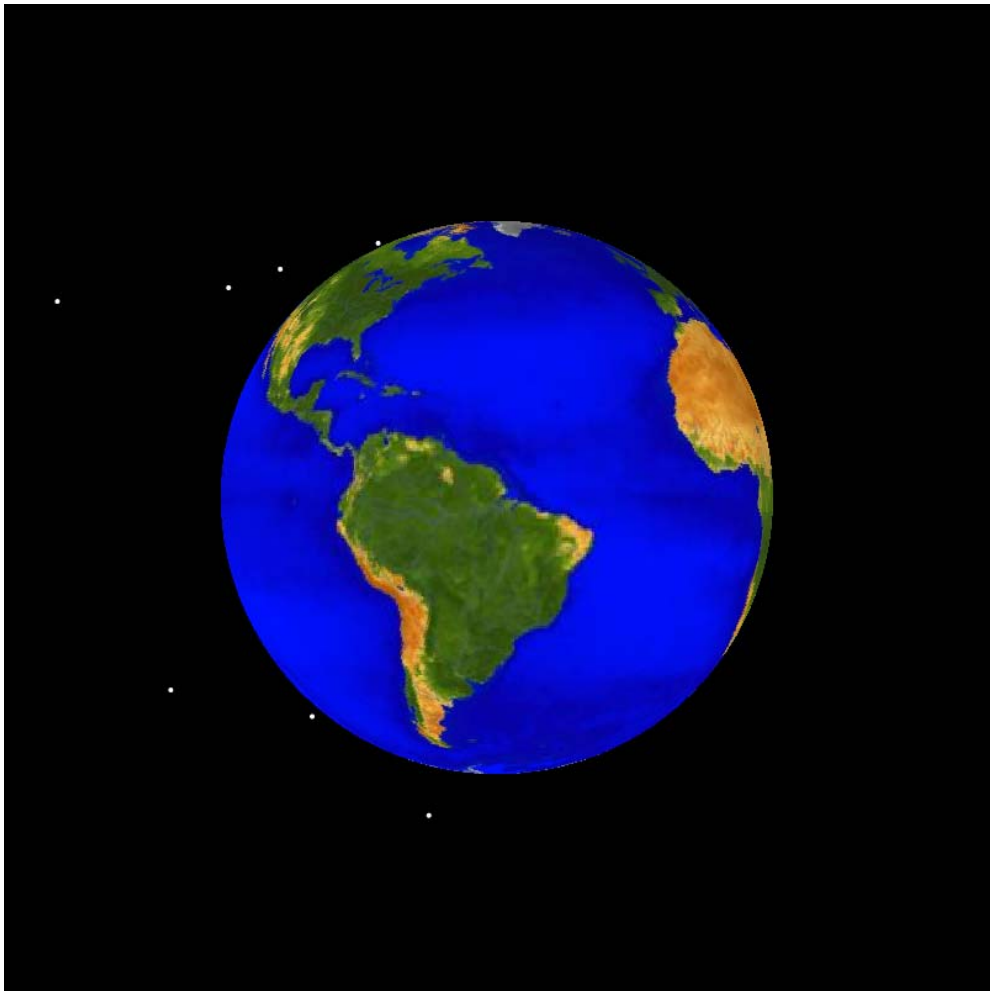
**Before 1957**

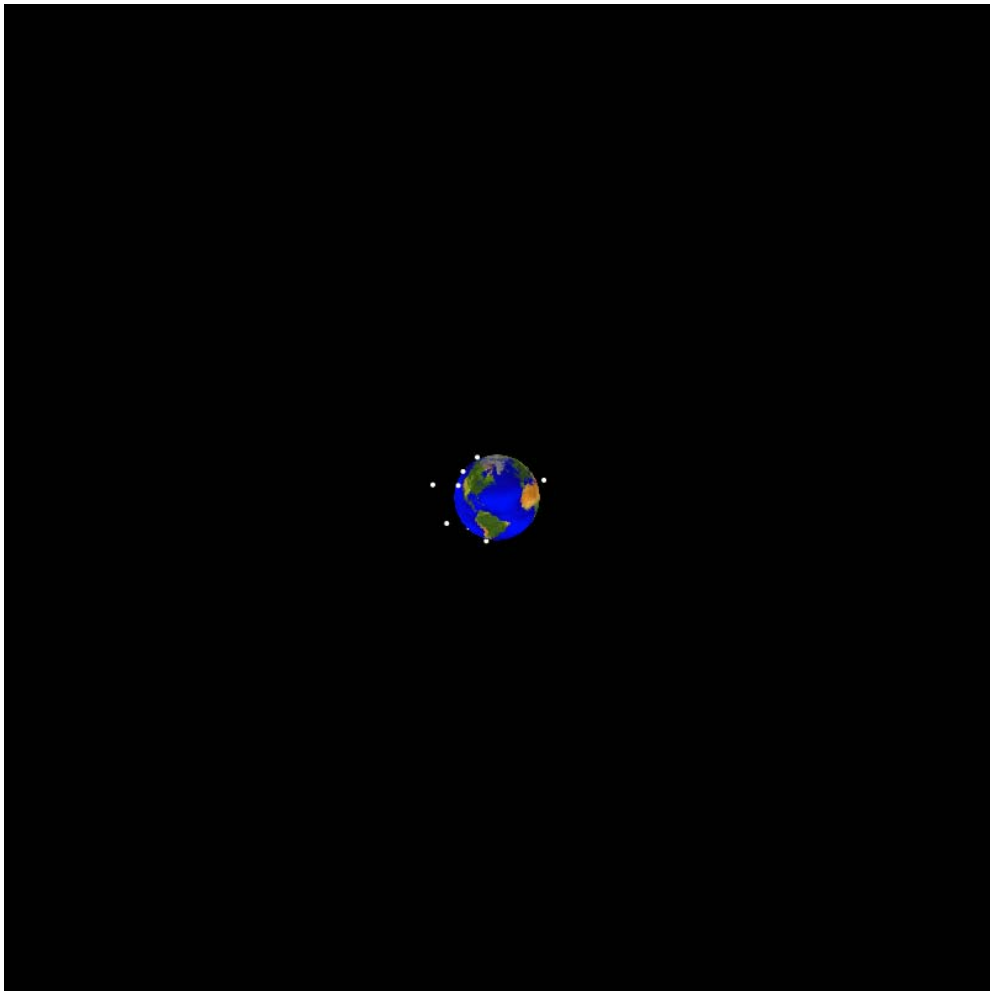


**Cataloged objects (>10 cm diameter) represented by white dots**

# Orbital Debris Growth

**1960**

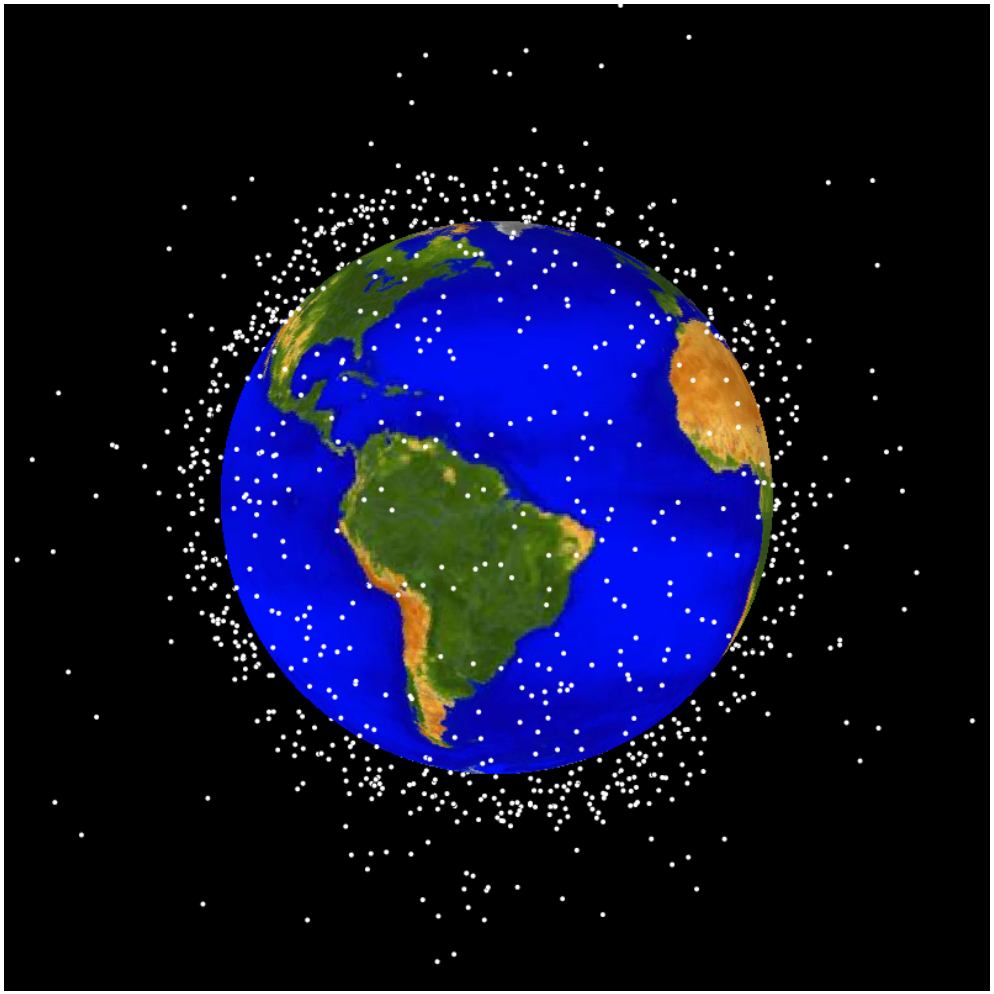


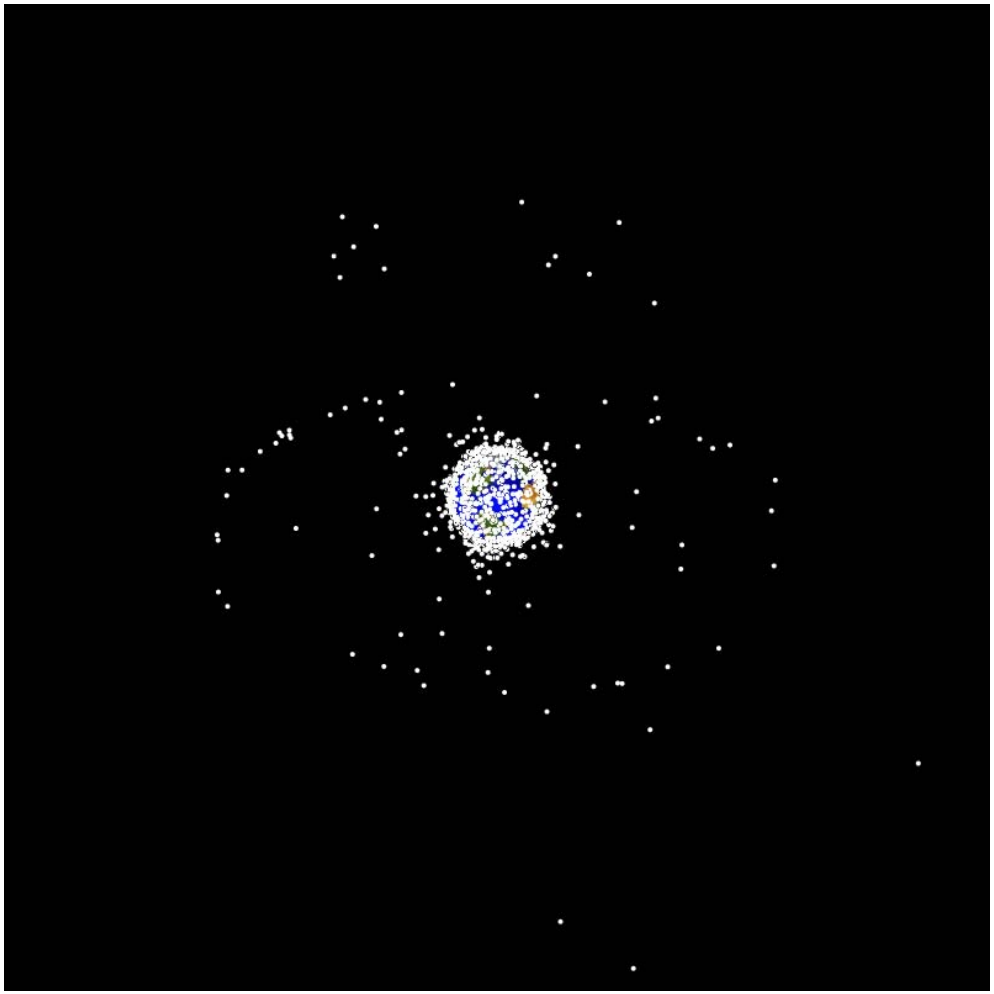


**Cataloged objects (>10 cm diameter)**

# Orbital Debris Growth

**1970**

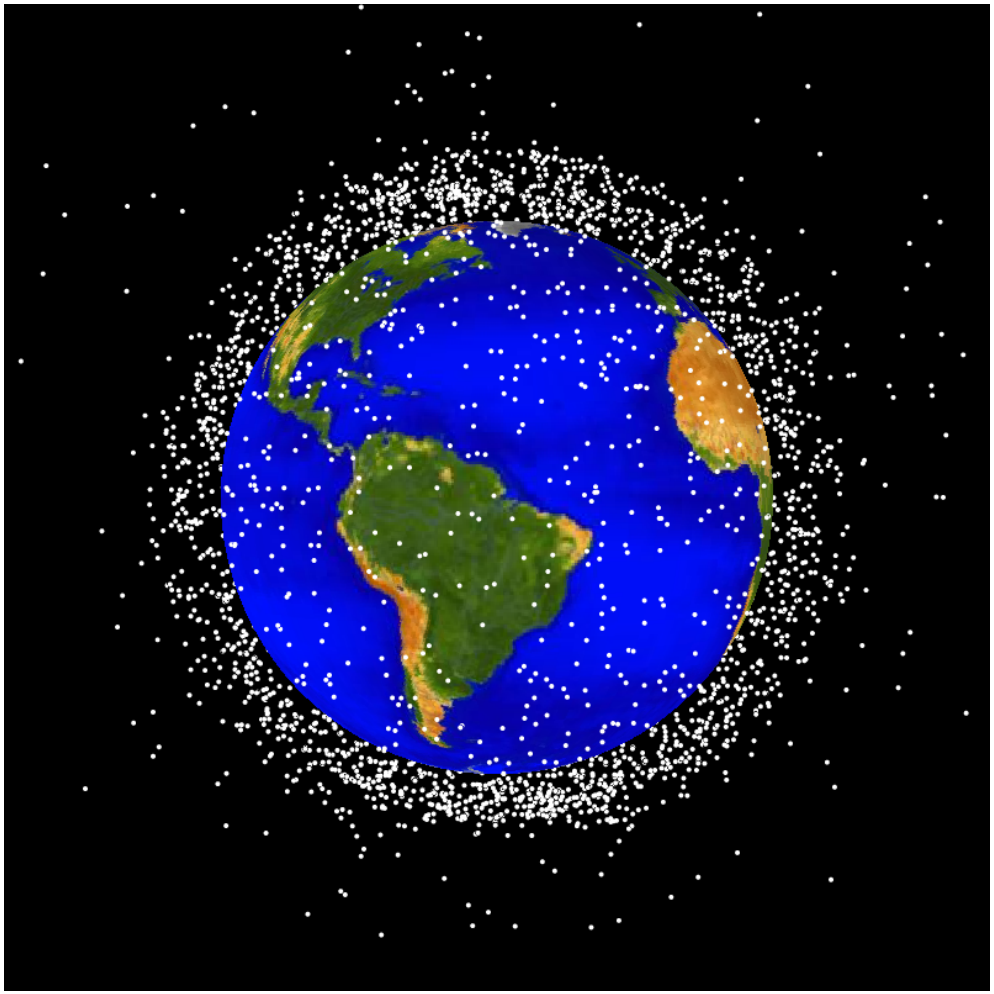


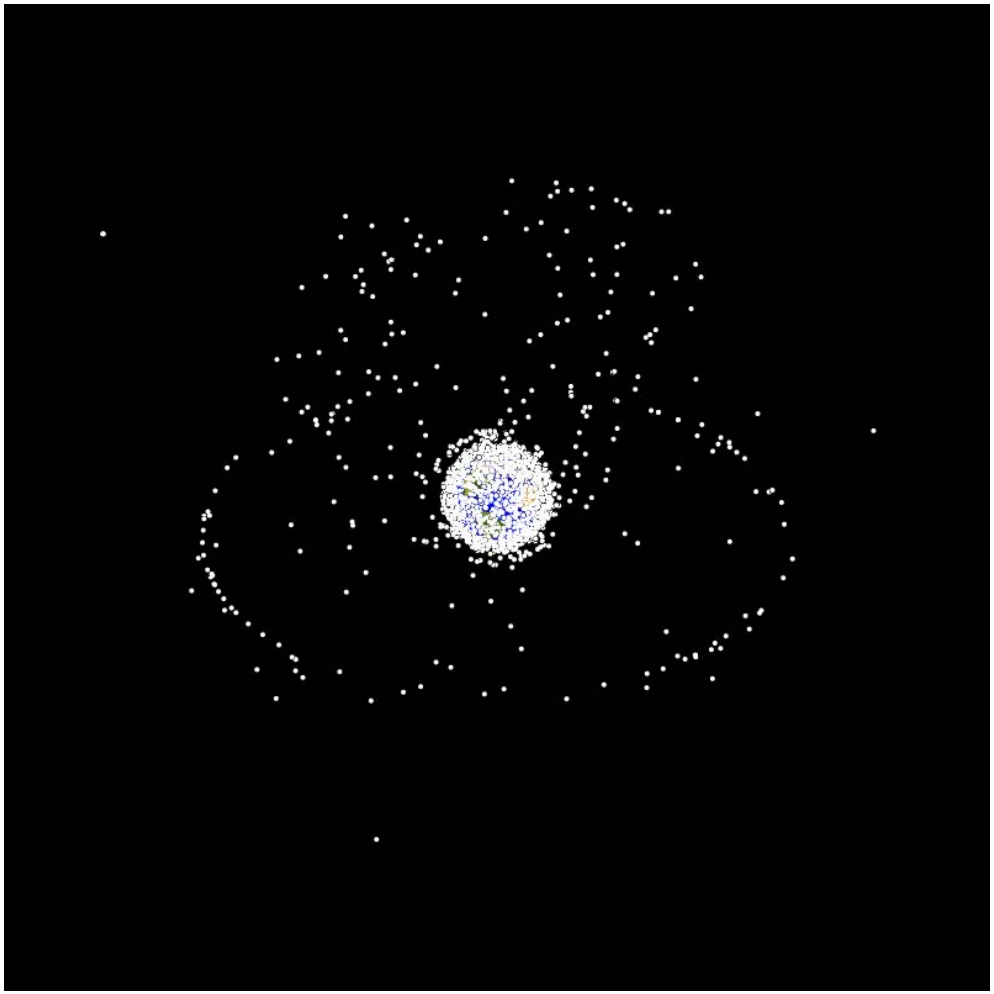


**Cataloged objects (>10 cm diameter)**

# Orbital Debris Growth

**1980**

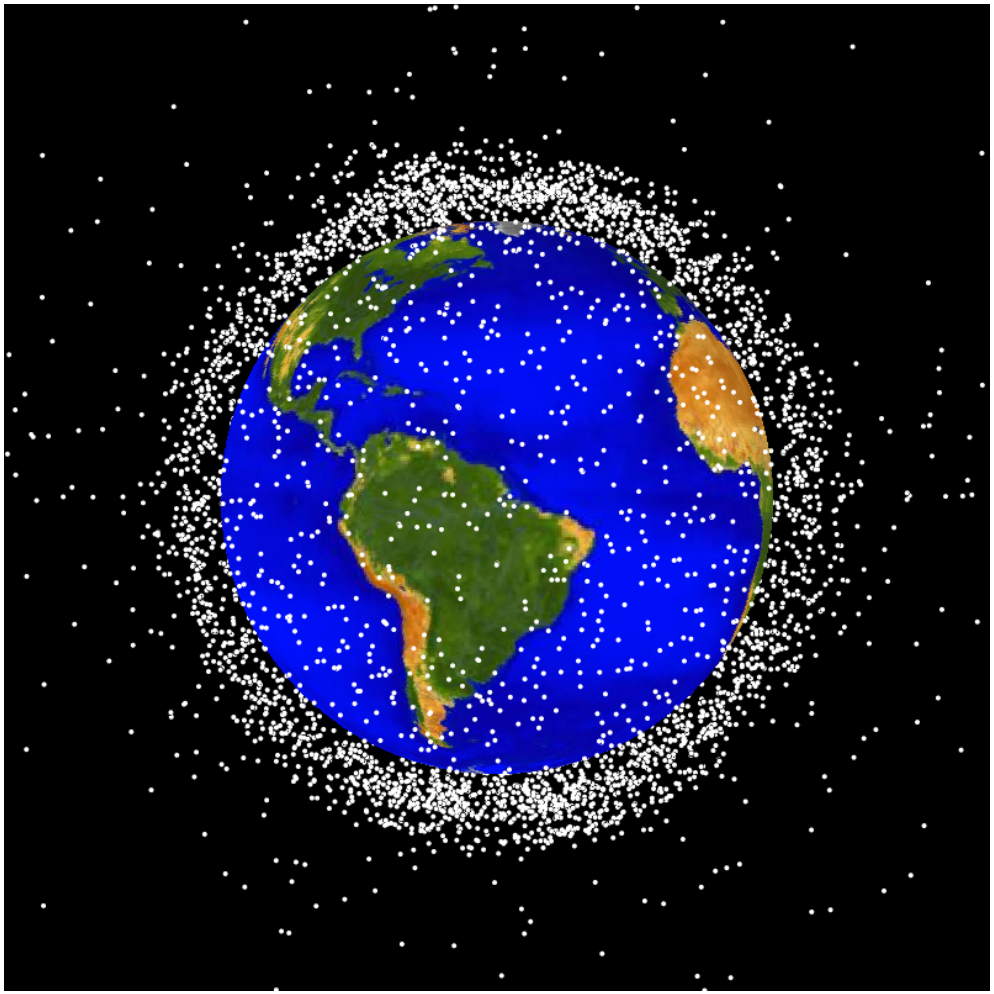


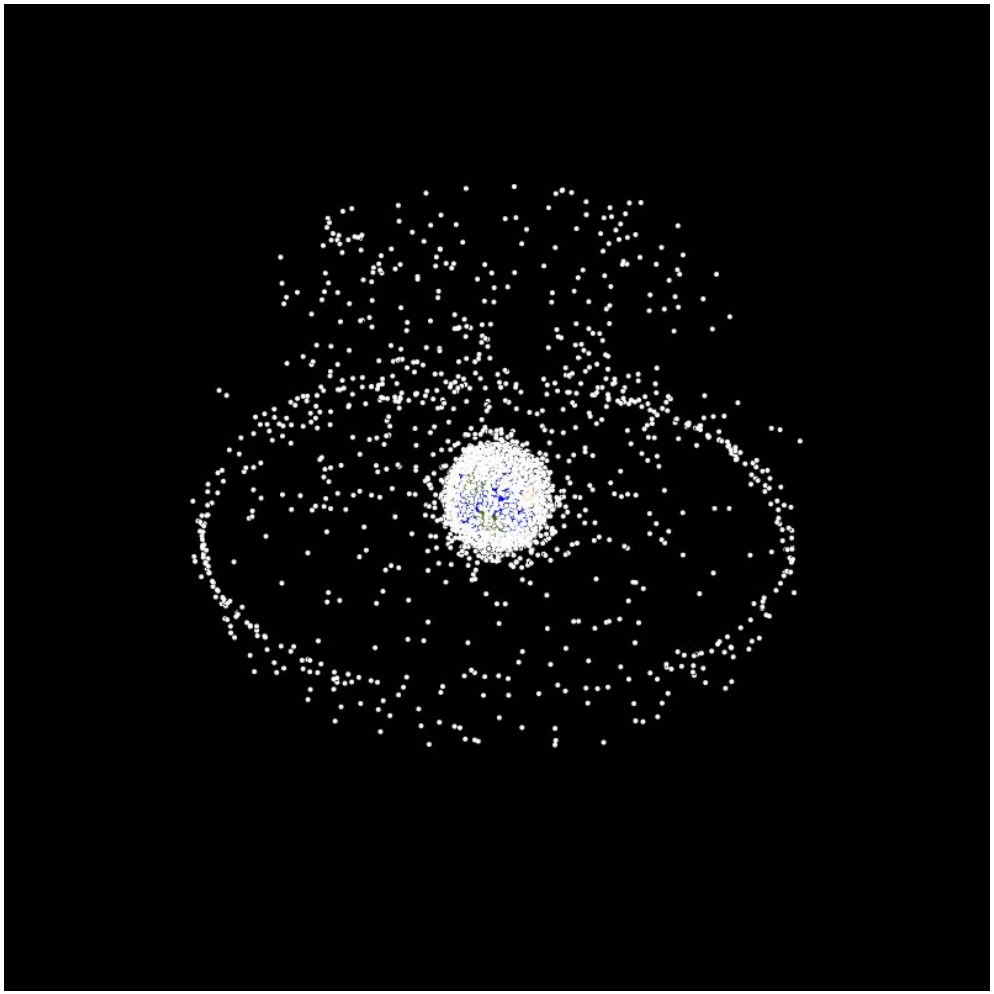


**Cataloged objects (>10 cm diameter)**

# Orbital Debris Growth

**1990**

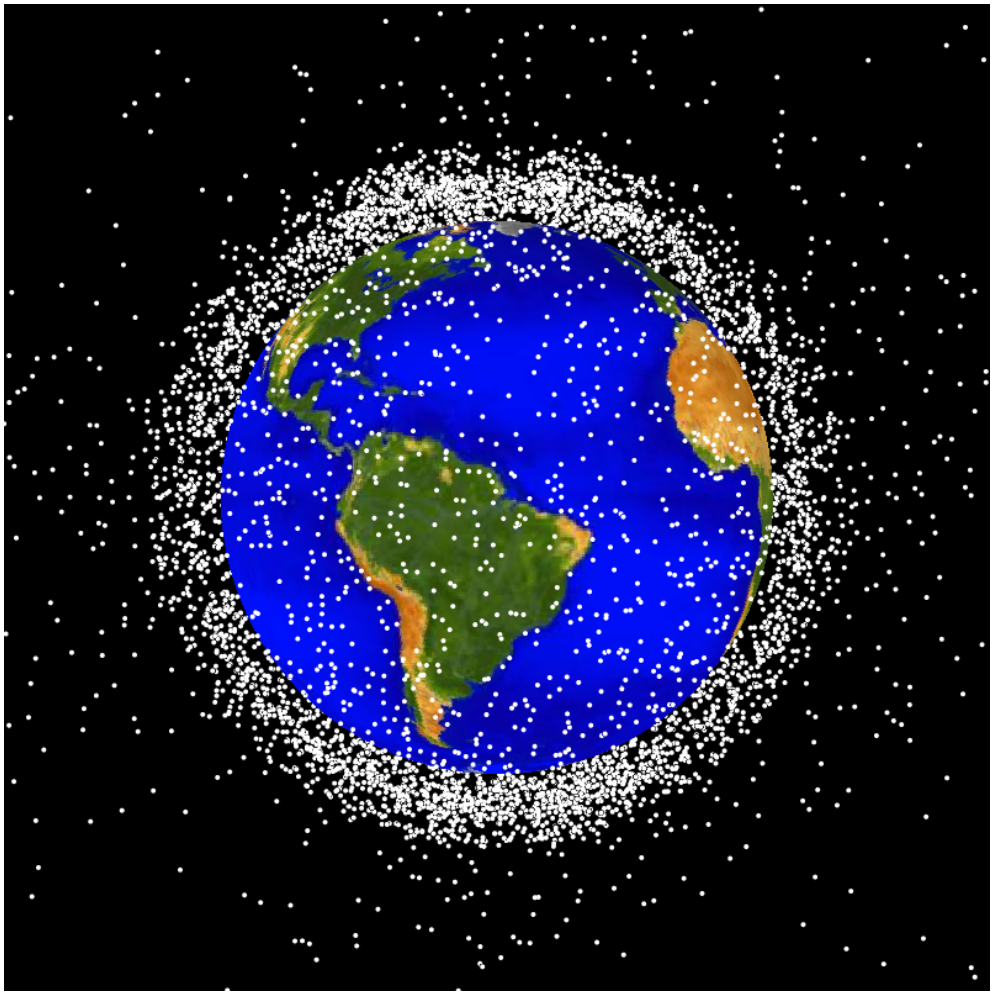


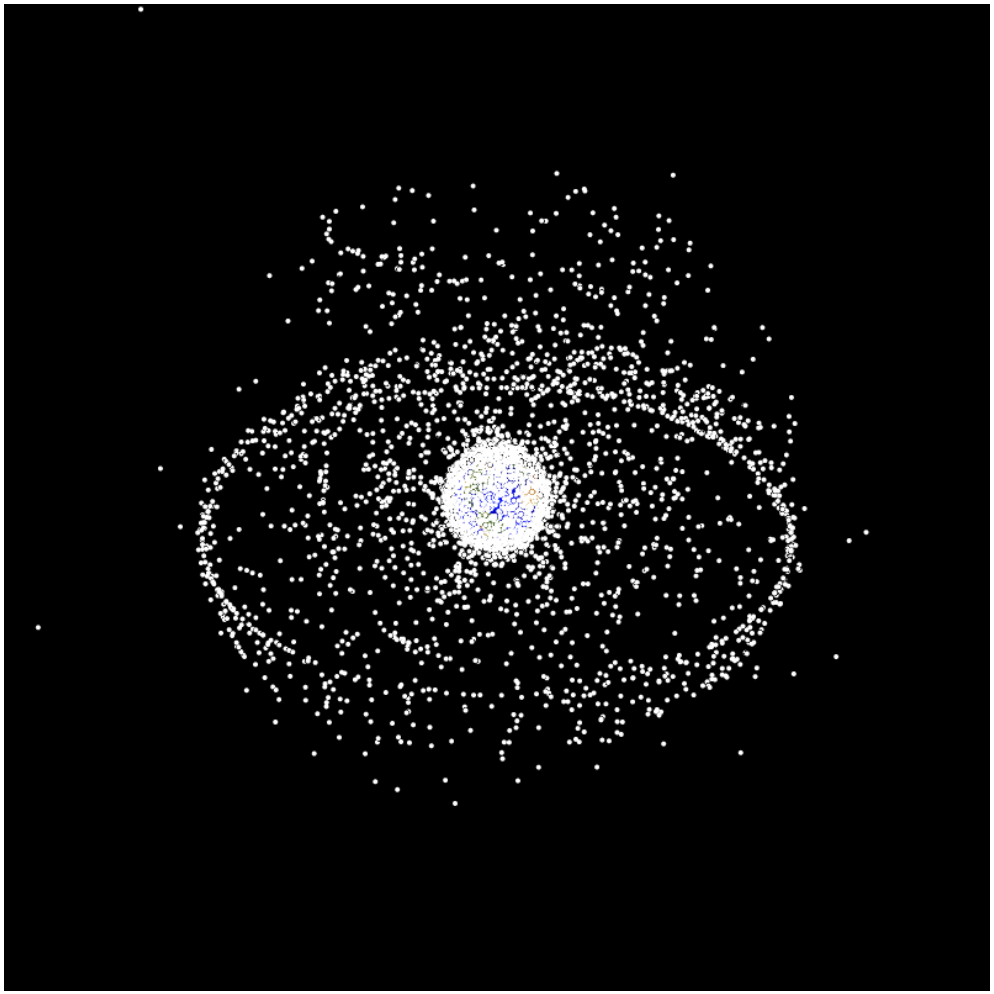


**Cataloged objects (>10 cm diameter)**

# Orbital Debris Growth

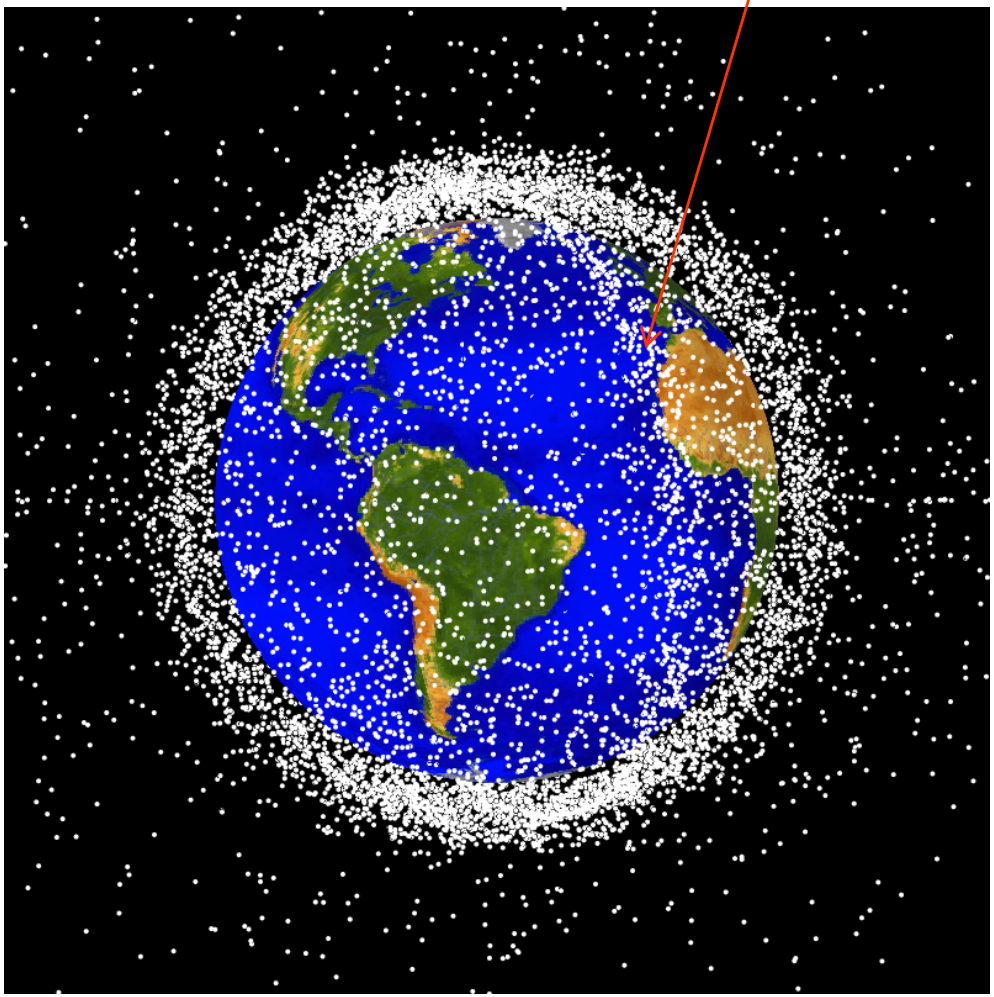
**2000**

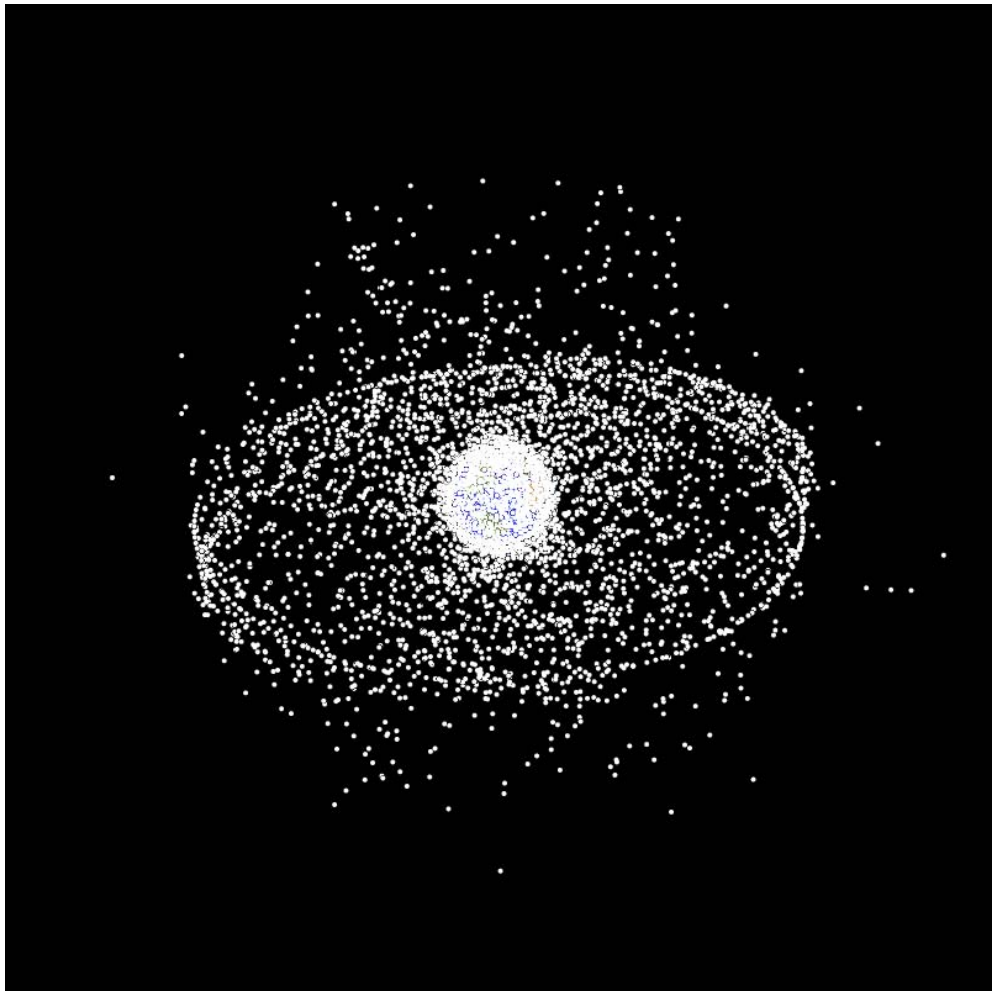




**Cataloged objects (>10 cm diameter)**

# Orbital Debris Growth

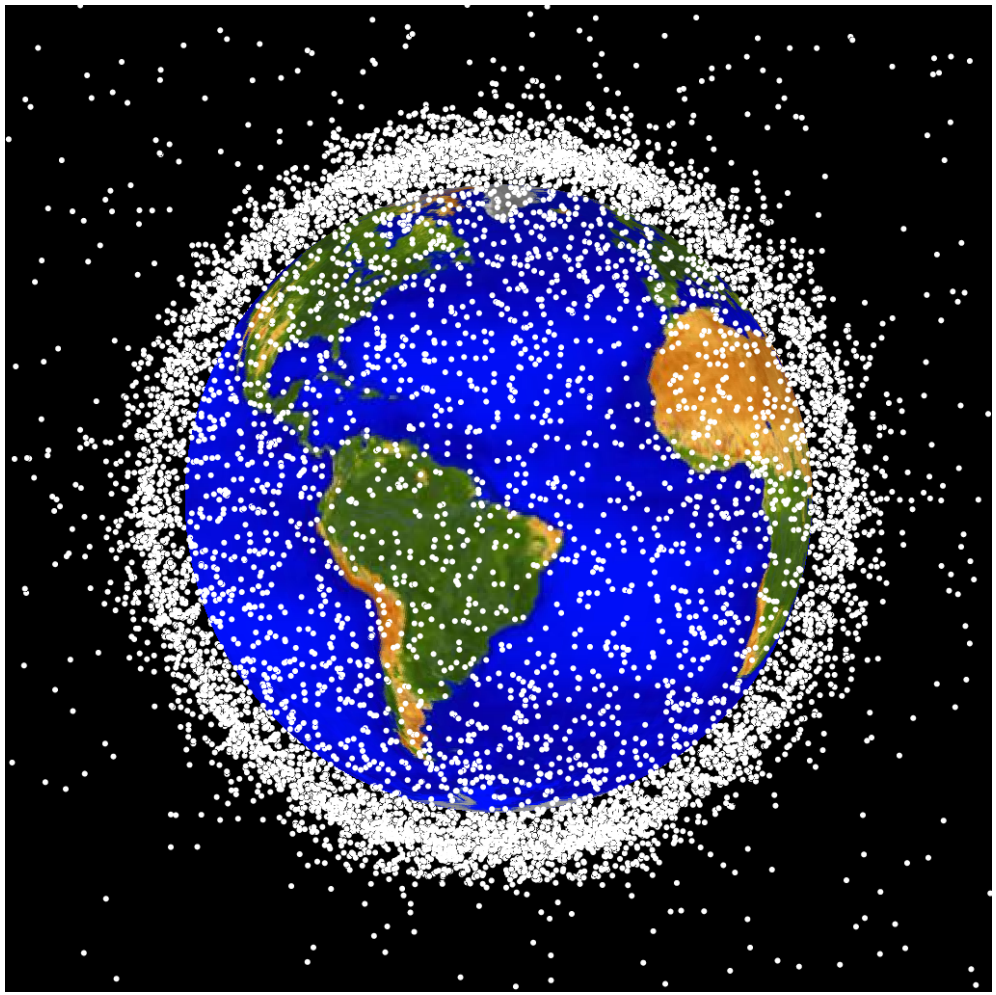


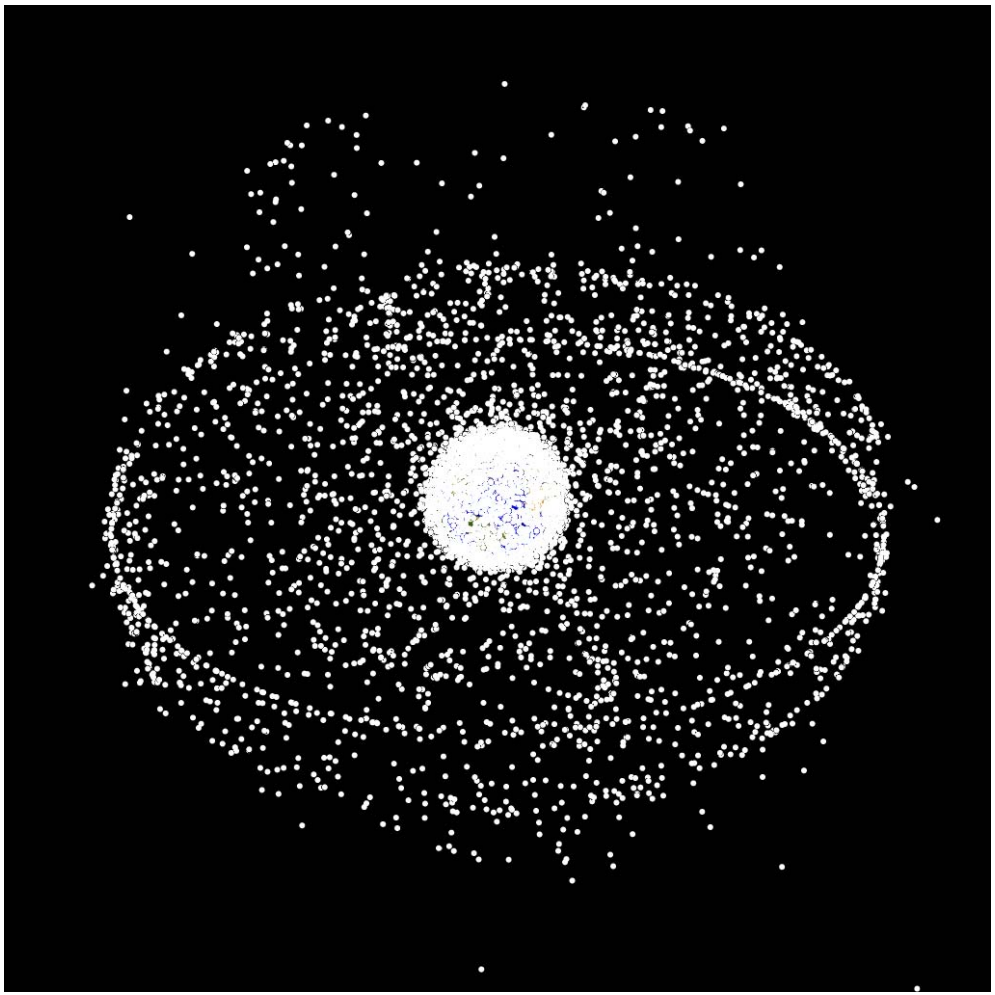



**Cataloged objects (>10 cm diameter)**

# Orbital Debris Growth

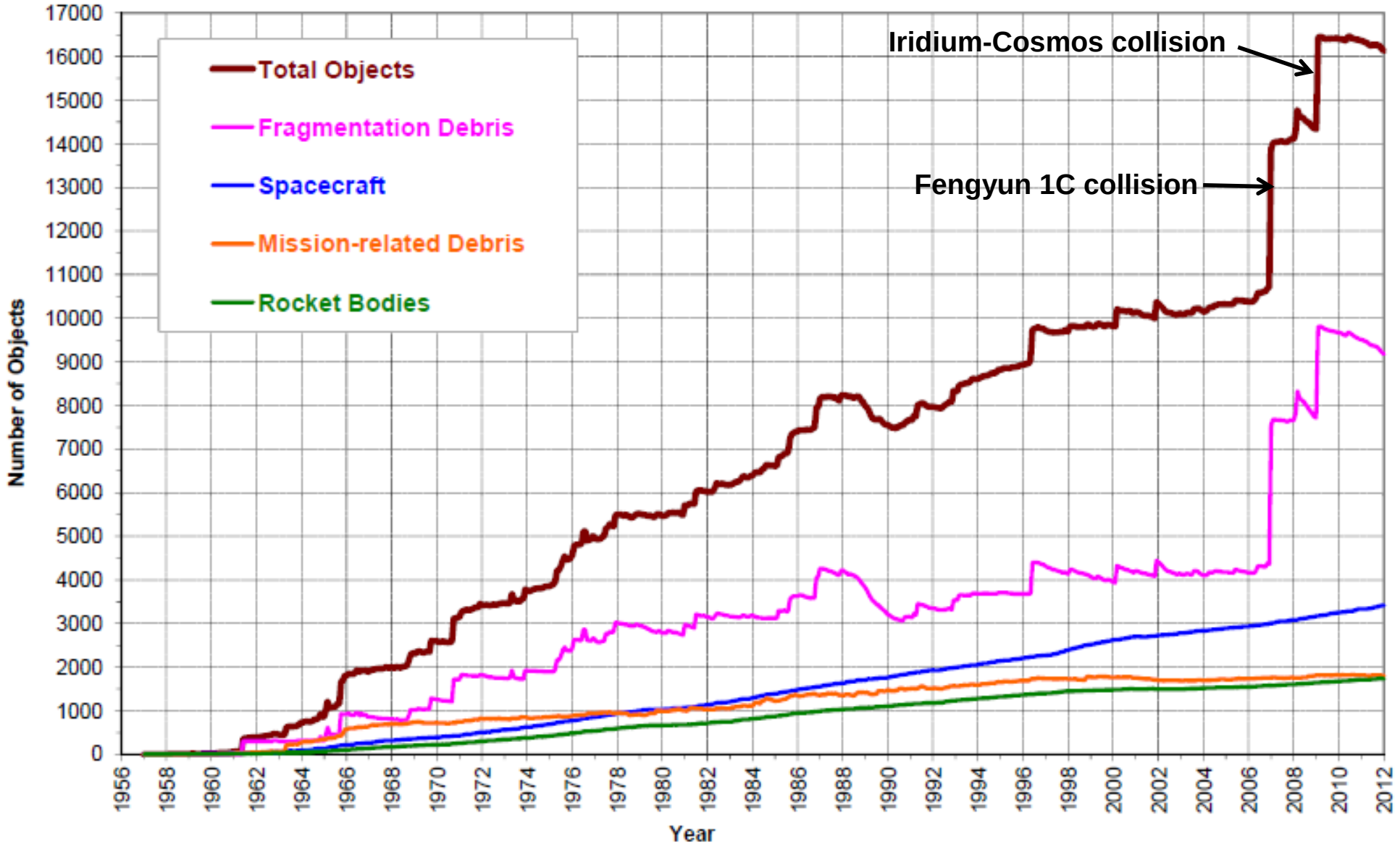
**2012**



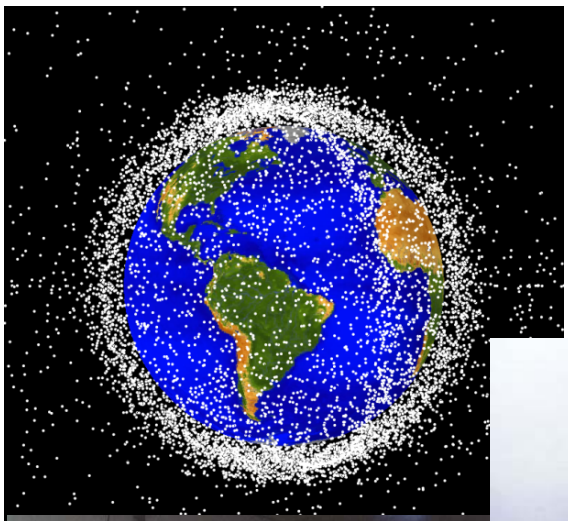


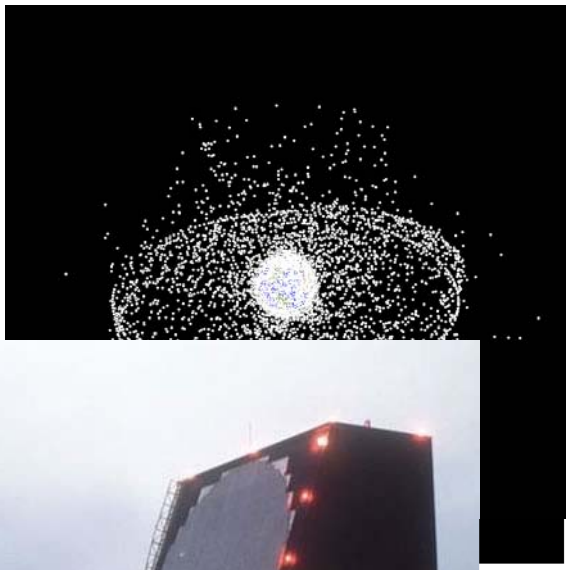
**Cataloged objects (>10 cm diameter)**

# Growth of the Orbital Debris Population



# Satellite/Debris Populations



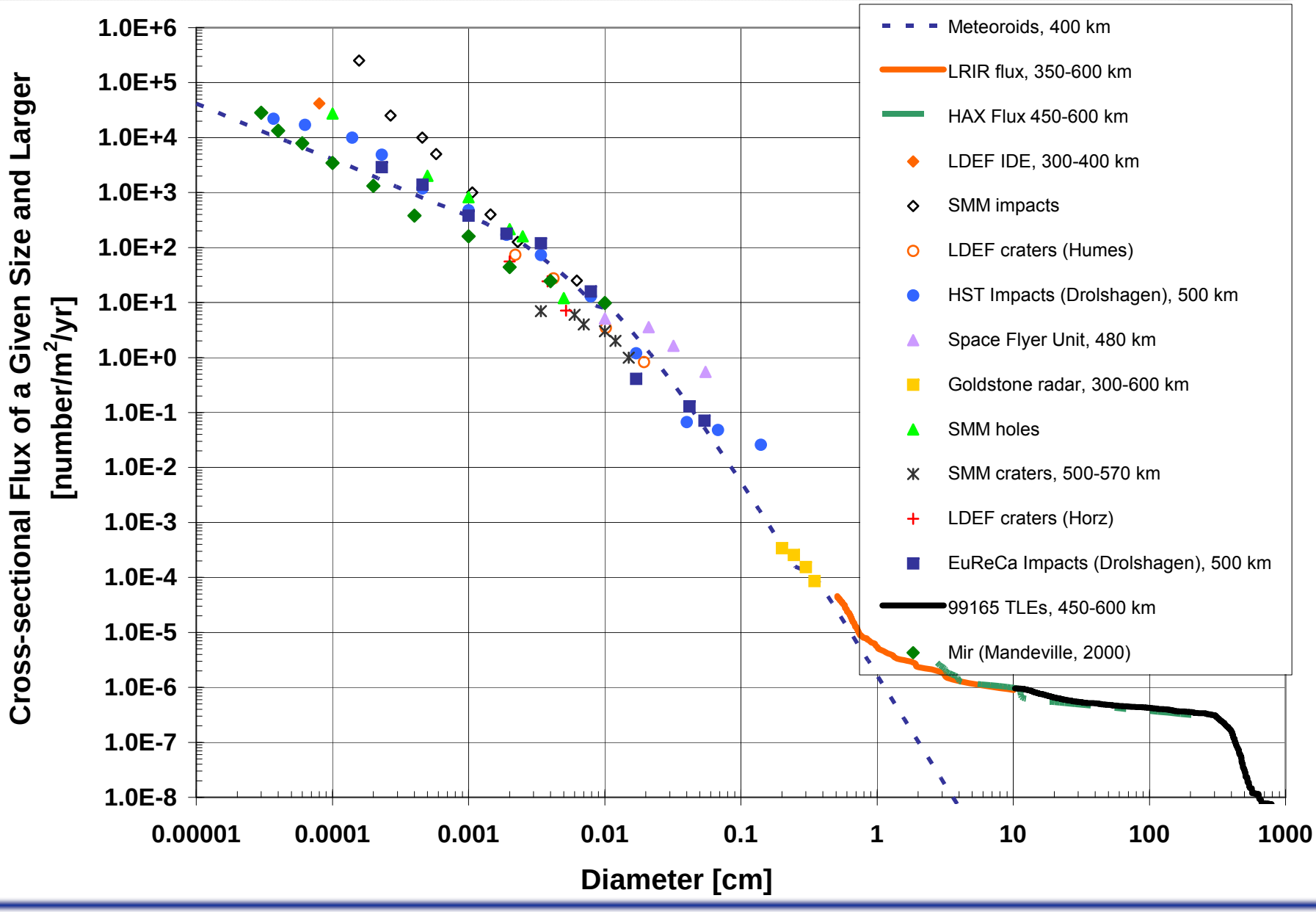




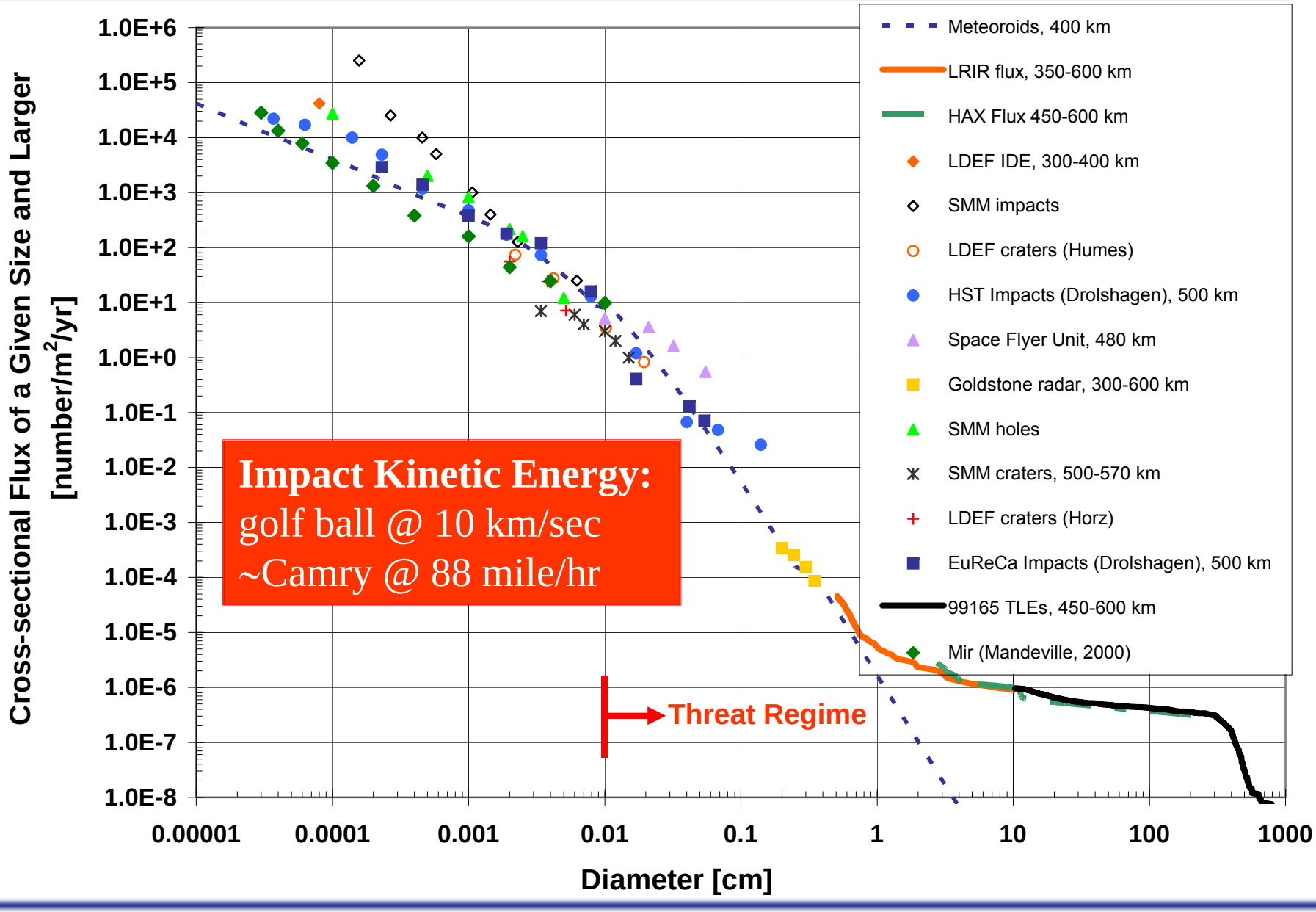
- **>19,000 objects <u>tracked</u> by US Space Surveillance Network (SSN) in 2009**
- **Most tracked objects are ~10 cm and larger**
- **Many more untracked (*i.e.*, smaller) objects in space**


LSSC = Lincoln Space Surveillance Center
(Millstone, Haystack, HAX)
AMOS = AFRL Maui Optical & Super-computing Site
AFSSS = Air Force Space Surveillance System
MOSS = Moron Optical Space Surveillance
MSX/SBV = Mid-Course Space Experiment/Space Based Visible

# The Environment



# The Environment



# Shuttle Vulnerabilities

**Potential Shuttle Damage**

**Window Replacement**

**EVA Suit Penetration**

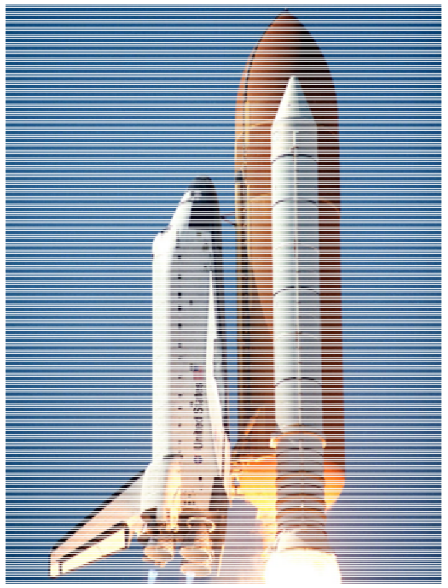
**Radiator Penetration**

**RCC Penetration**

**TPS Tile Penetration**

**Cabin Penetration**

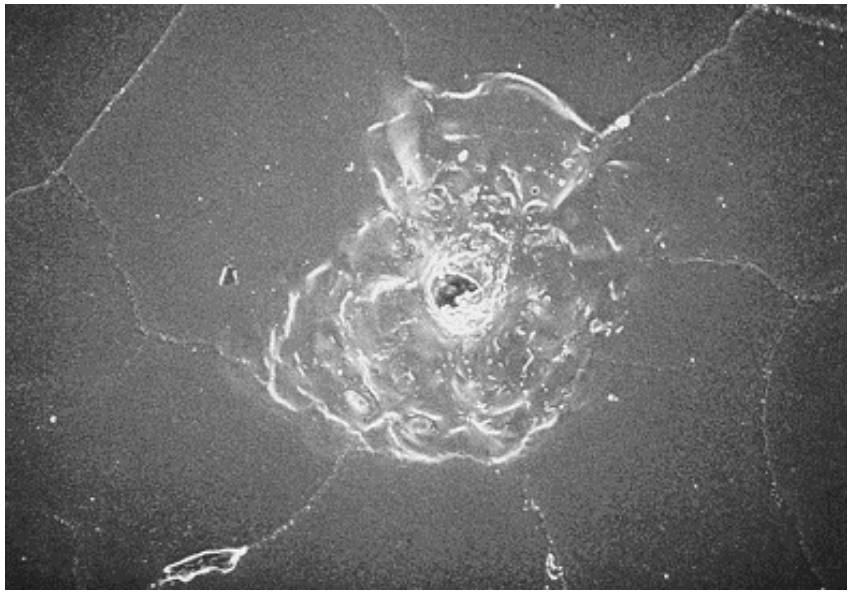
**Cargo Bay Damage**



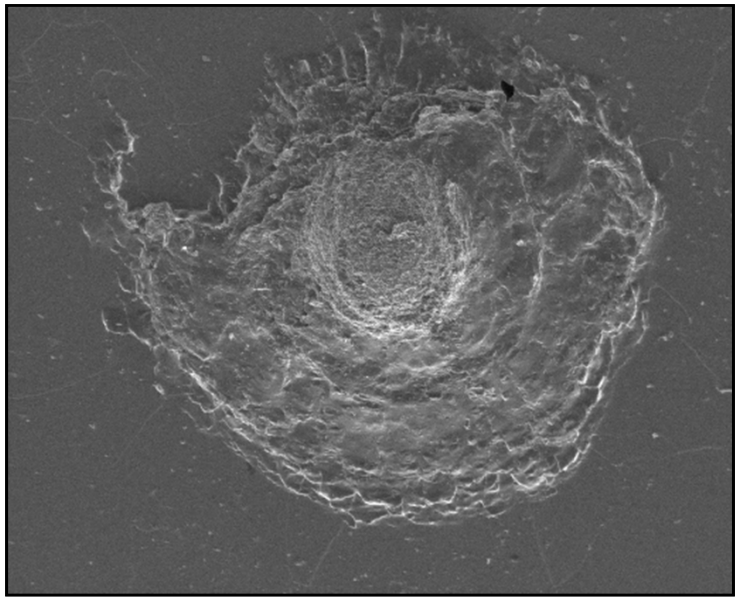

0.001 0.01 0.1 1 10 100 1000

**Debris Diameter in Centimeters**

# The Threat to ISS/Shuttle/Satellites from Orbital Debris Is Real



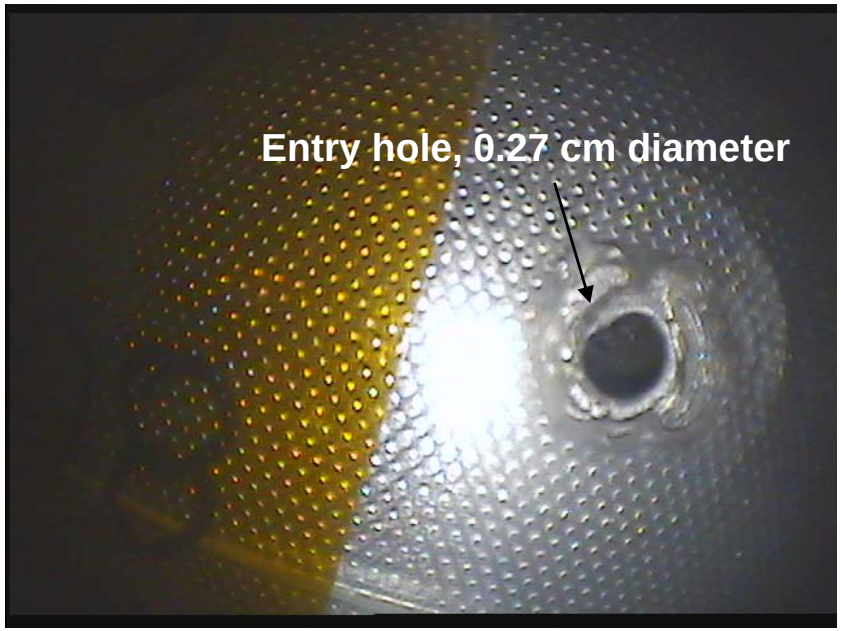
Crater: Dia×Dep ≈ 1.8 mm×0.2 mm
Estimated projectile size ≈ 0.06 mm
(STS-97 window damage, Dec. 2000)



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

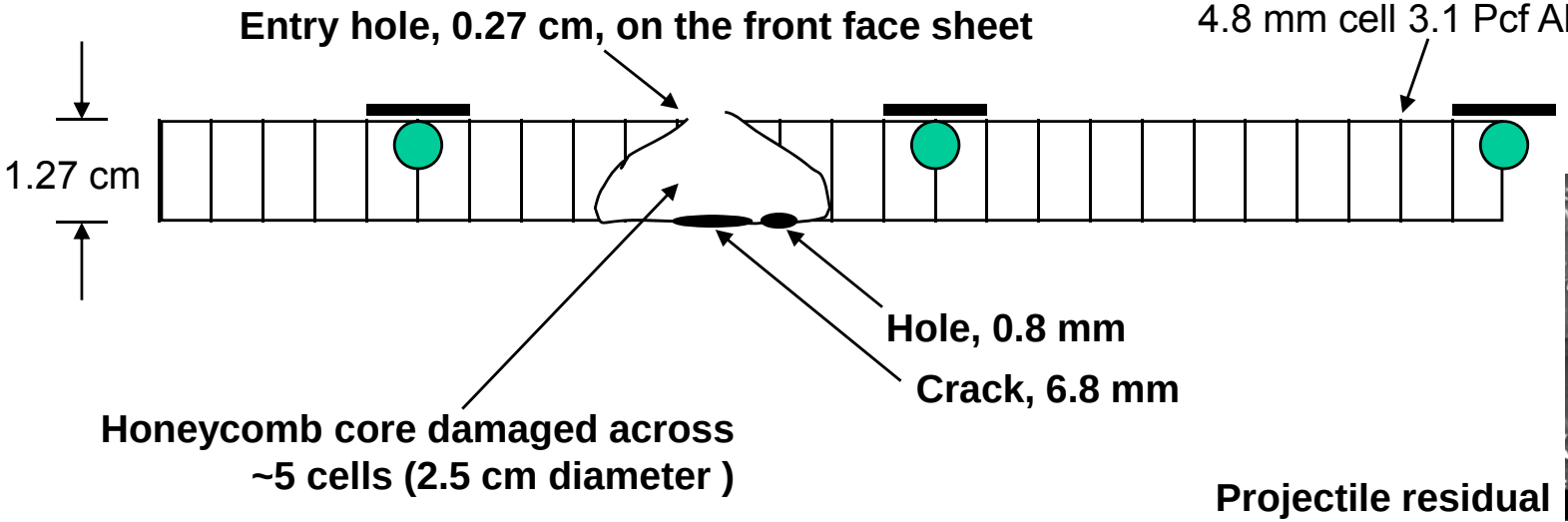
→ On average, two shuttle windows are replaced per mission
→ 8 ISS collision avoidance maneuvers conducted since 1999

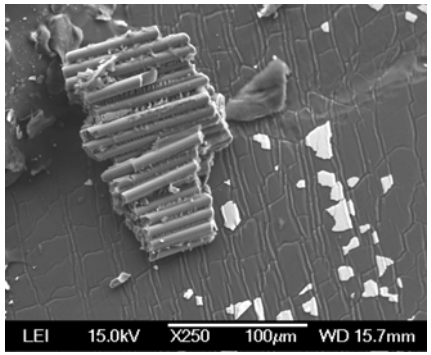
# STS-115 Shuttle Radiator Damage (2006)





0.28 mm facesheet
4.8 mm cell 3.1 Pcf Al Core




Projectile residual

# Population Breakdown

S/Cs, R/Bs

Breakup Fragments

Mission-related Debris

NaK

$Al_2O_3$

$Al_2O_3$ (slag)

Paint Flakes

MLI Pieces

Meteoroids

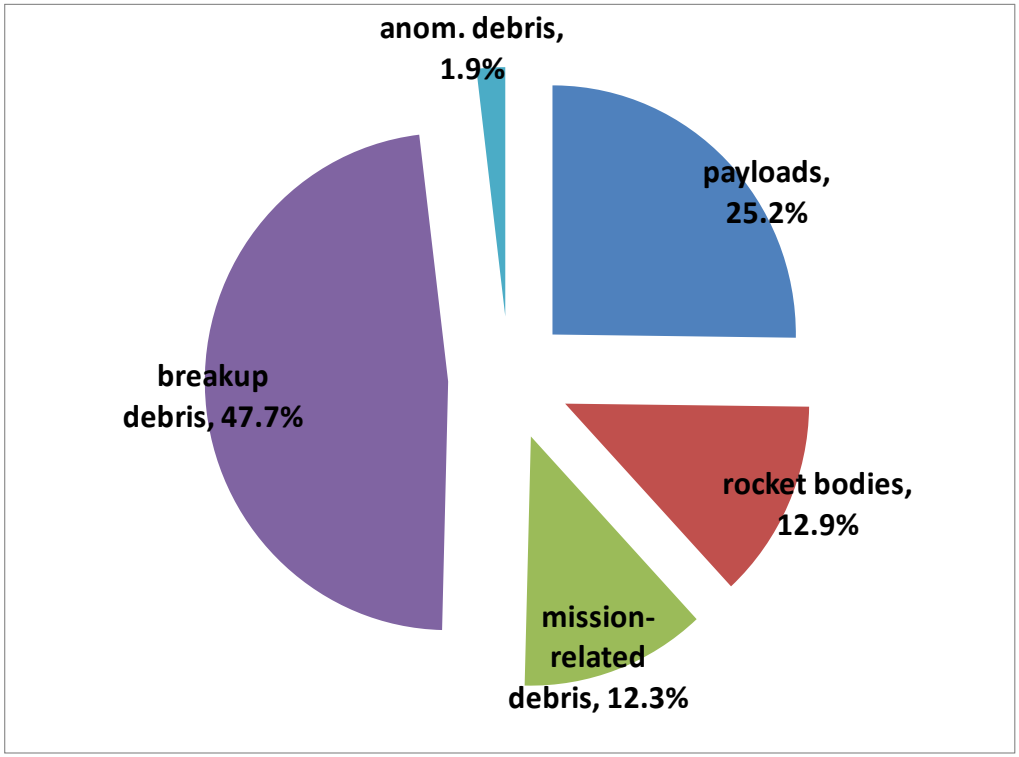
10 μm | 100 μm | 1 mm | 1 cm | 10 cm | 1 m | 10 m

Size (diameter)

# Sources of the Catalog Population

- **~4600 launches conducted worldwide since 1957**
- **211 known breakups through end of 2011, *excluding anomalous or aerodynamic events***

Source Breakdown

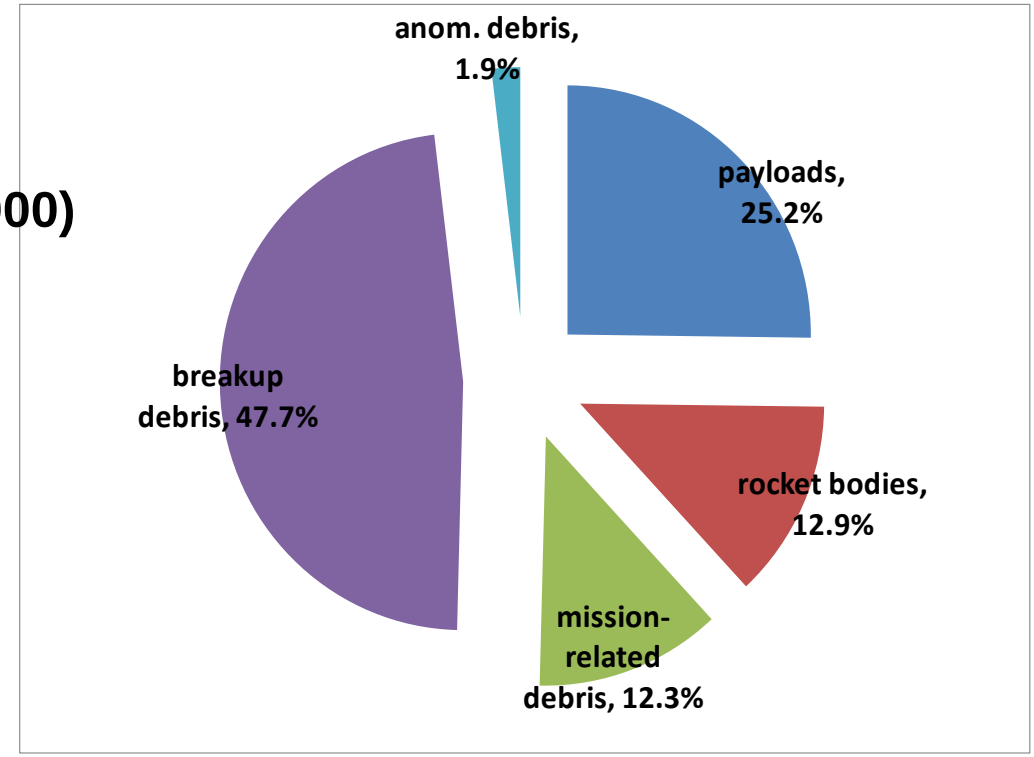


# Sources of the SSN Catalog Population

- **~4600 launches conducted worldwide since 1957**
- **211 known breakups through end of 2011**
  - 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 (~2500, 2007)**
    - **Briz-M (>1000[a], 2007)**
    - **Cosmos 2421 (509, 2008)**
    - **Iridium 33 (>300[b], 2009)**
    - **Cosmos 2251 (>700[b], 2009)**

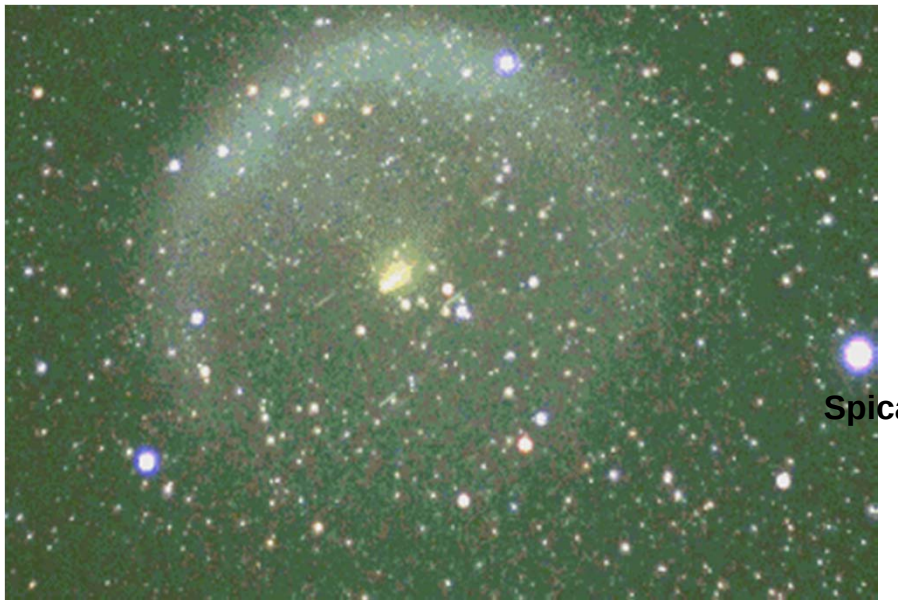
[a]initial report; [b]on-going;

Source Breakdown



# Explosion of Briz-M

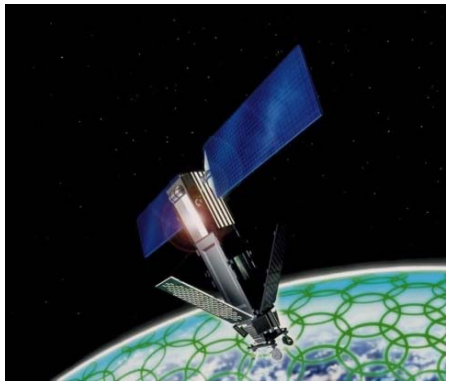
- **Briz-M**
  - 4th stage of a Russian Proton Launch Vehicle
  - 485 km by 14,750 km, inclination = 51.5°
  - Mass ~2000 kg
  - Possible cause of the breakup: explosion of the remaining propellant on board the stage


**(R. McNaught, Feb 17, 2007)**

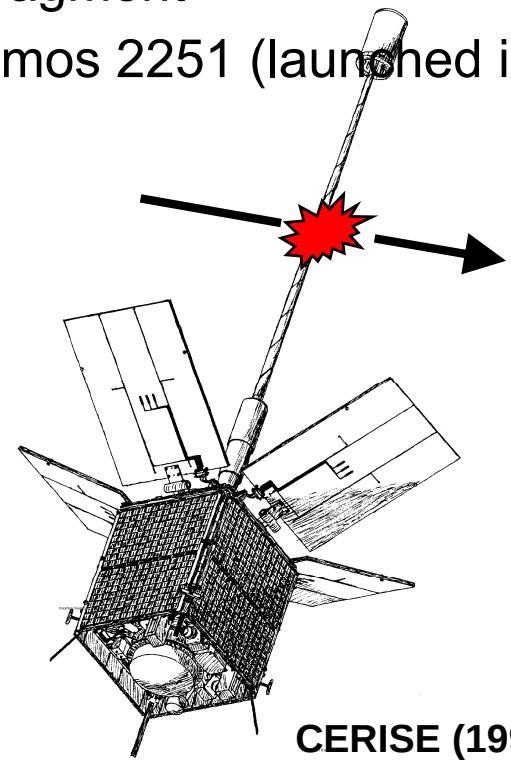
# On-Orbit Collisions

- **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)**

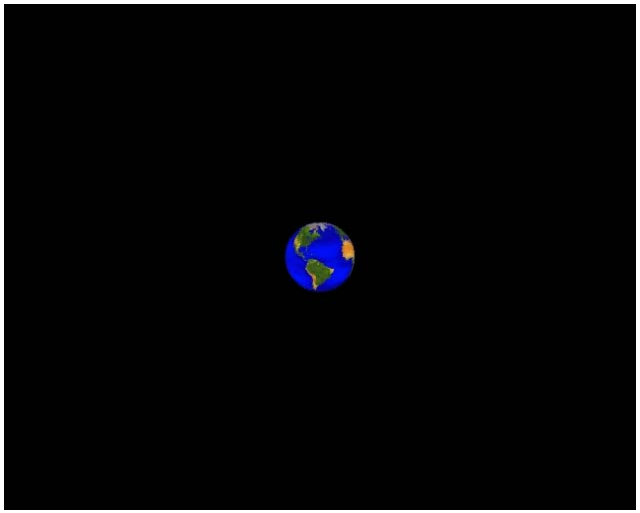
**Cosmos 2251 (900 kg)**



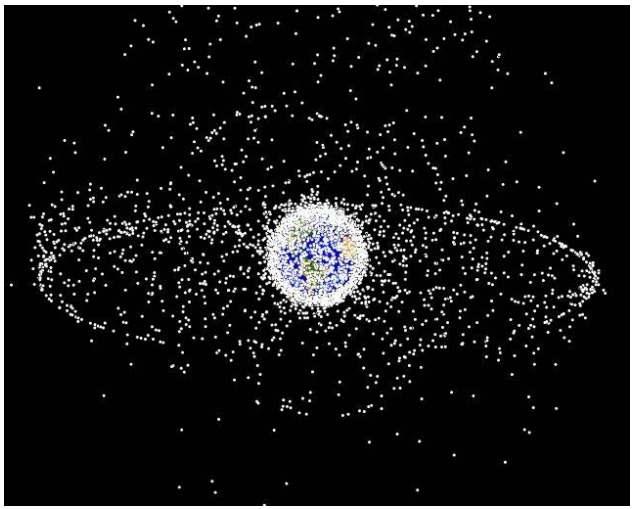
**CERISE (1996)**

# The Question – How Bad Is It?

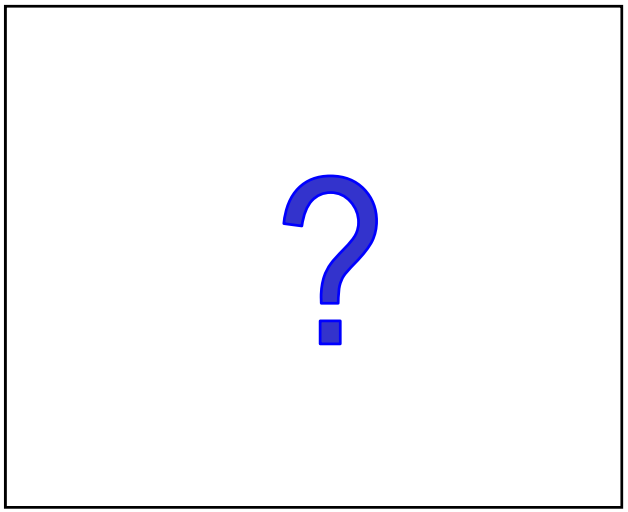
- **Has the current LEO debris population reached the point where the environment is unstable and population growth may be inevitable?**



Pre-1957



2009

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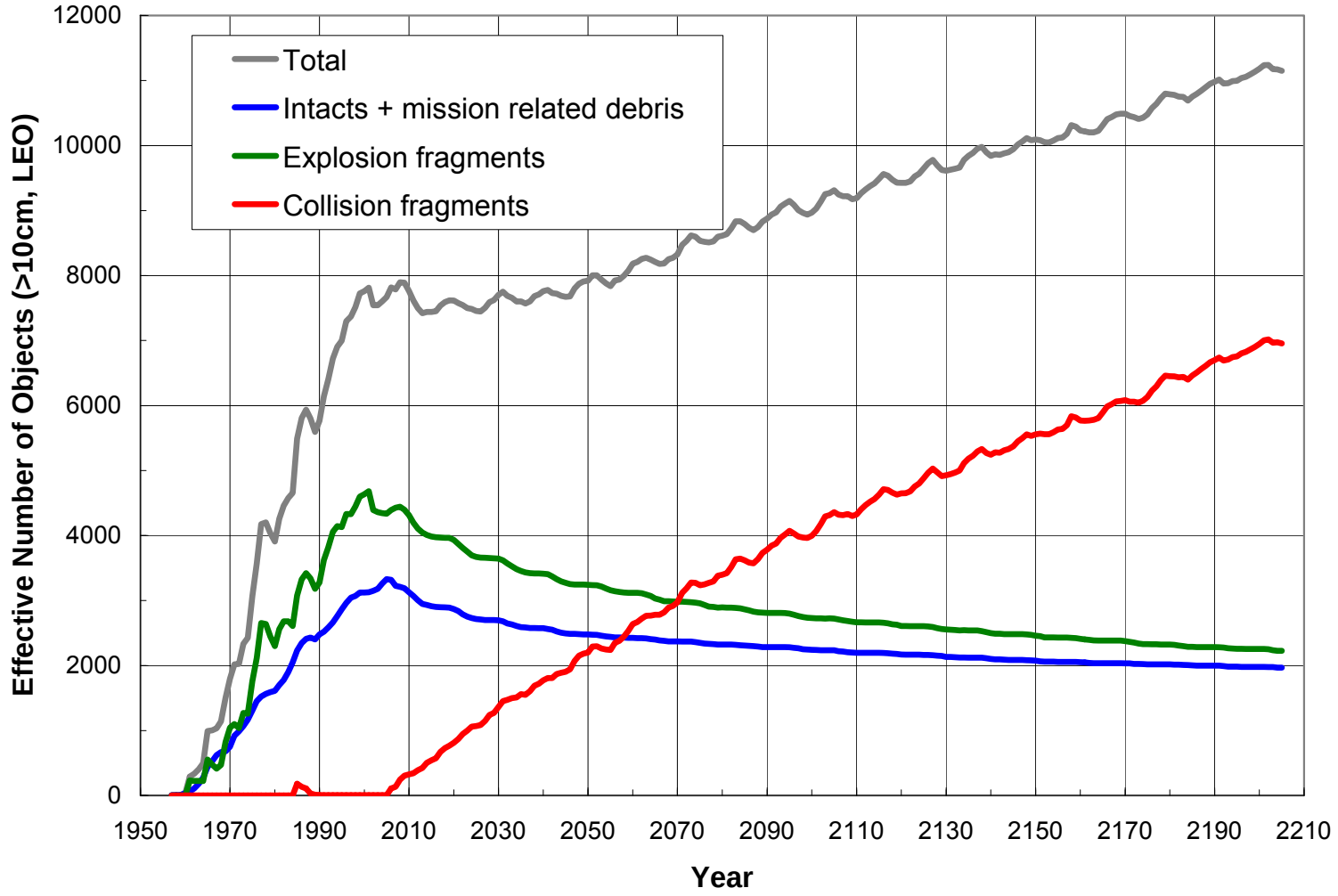
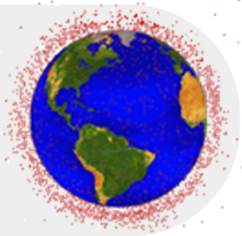
# The Growth of LEO Populations
## ("no future launches" scenario)



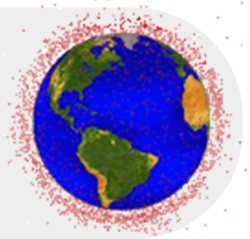

- **Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant**
- **Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions**


# What is the Future?



- **In reality, the situation will be worse than the "no new launches" scenario as**
  - satellites continue to be launched into space
  - unexpected major breakups continue to occur
- **Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient to prevent the self-generating phenomenon from happening**
- **To better limit the growth of the future debris population, active removal of existing objects from orbit should be considered**

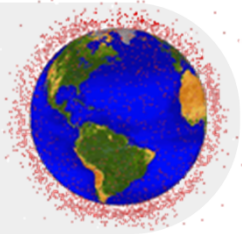
# *How is NASA working to address the OD issues?*



- **The NASA Orbital Debris Program Office has taken the international lead in conducting measurements of the environment and in developing the technical consensus for adopting mitigation measures to protect users of the orbital environment.**

- **Work at the Center continues with developing an improved understanding of the orbital debris environment and measures that can be taken to control debris growth.**

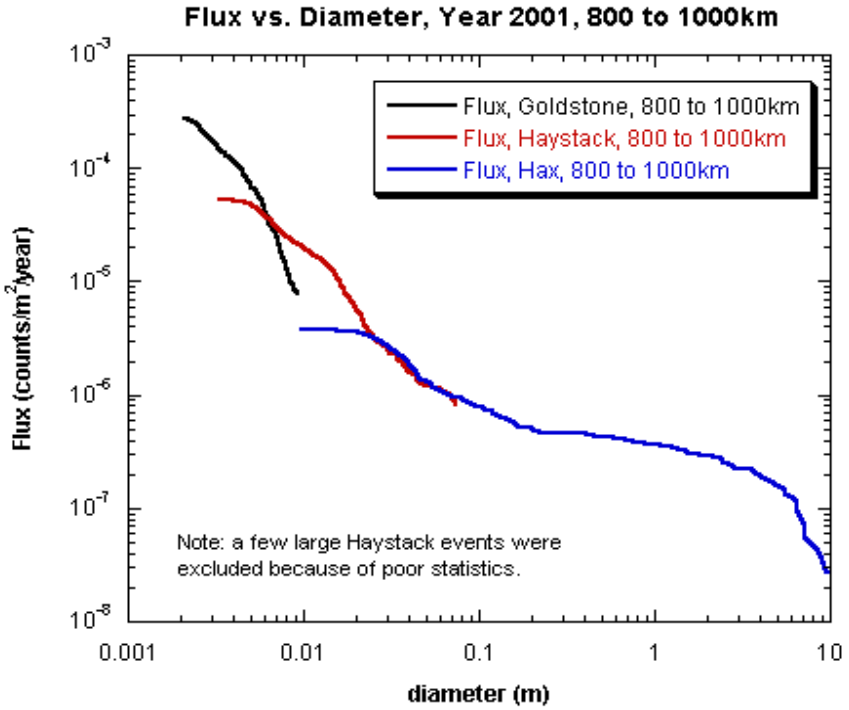
# Tasks of OD Project Team



- **Measurements**
  - Radar Data Processing and Analysis
  - Optical Data Collection, Processing, and Analysis
  - *In Situ* Measurements and Analysis
- **Modeling**
  - Long-Term Environment Modeling
  - Engineering Modeling
  - Short-Term Risk Assessments
- **Safety Standards & Compliance Assessments**
  - Debris Assessment Software (DAS)
- **Reentry Analysis**

# Radar Data Processing and Analysis

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




Goldstone

Haystack and HAX

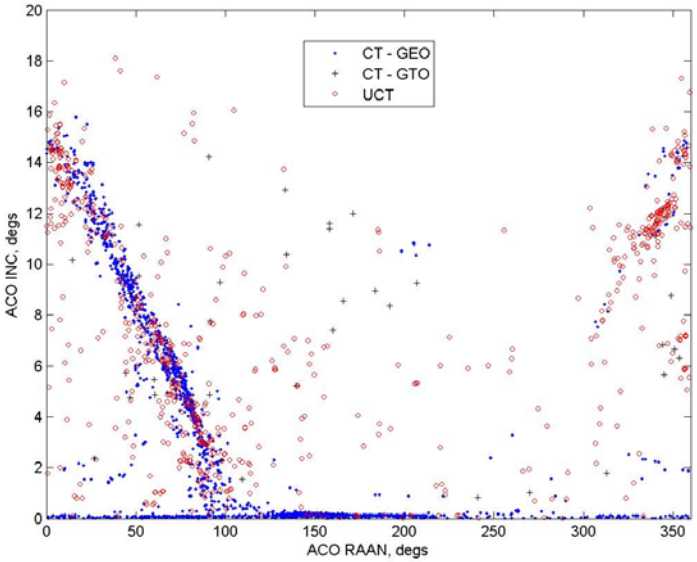
# Optical Data Collection, Processing, and Analysis

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

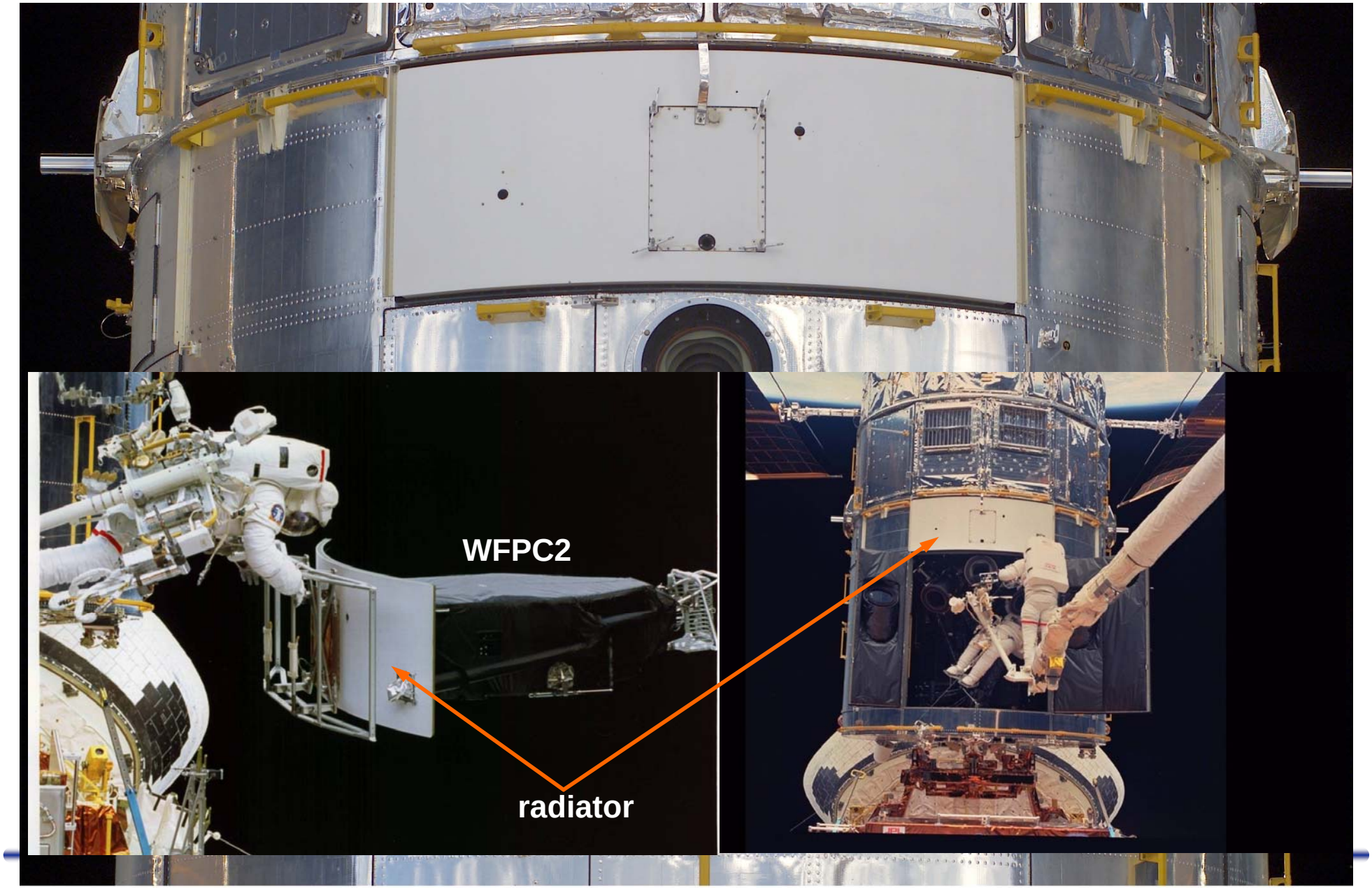
MODEST

MCAT

OMC



# MMOD Inspection of the HST WFPC2 Radiator

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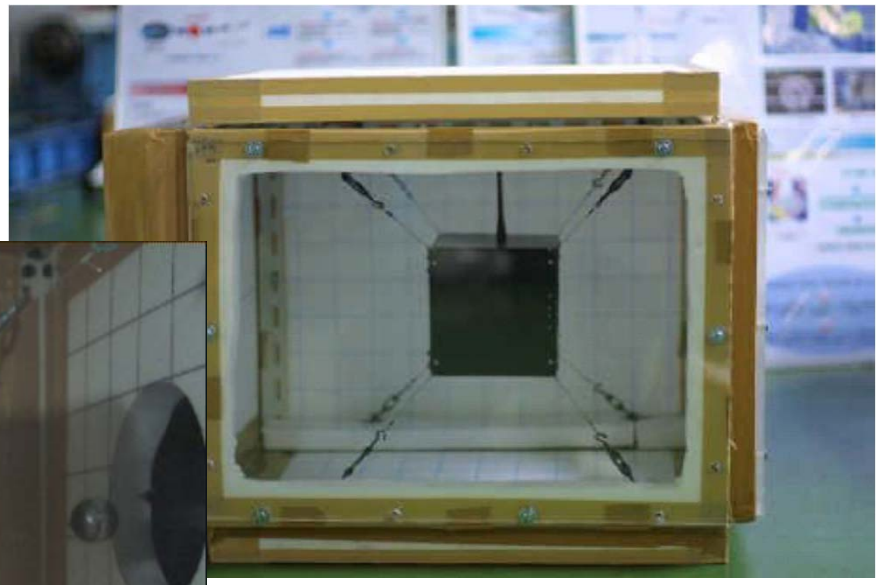
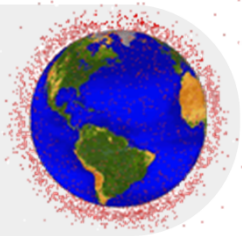
# Satellite Breakup Experiments

- **To better characterize the outcome of a satellite breakup**
  - Fragment size, mass, cross sectional area, area-to-mass (A/m) ratio, aspect ratio, and shape distributions



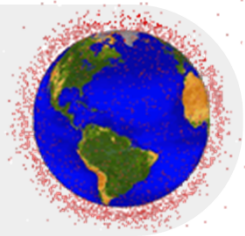
- **Targets**
  - Microsatellites (batteries, solar cells, electronics, circuit boards, *etc*.)
  - Up to 20 cm × 20 cm × 20 cm
  - Mass: up to 1.5 kg
- **Projectiles**
  - Aluminum sphere
  - Diameter: 1.4 to 3 cm
  - Mass: 4 to 40 g
- **$V_{impact}$ = 1.5 to 4.4 km/s**

# Debris Modeling



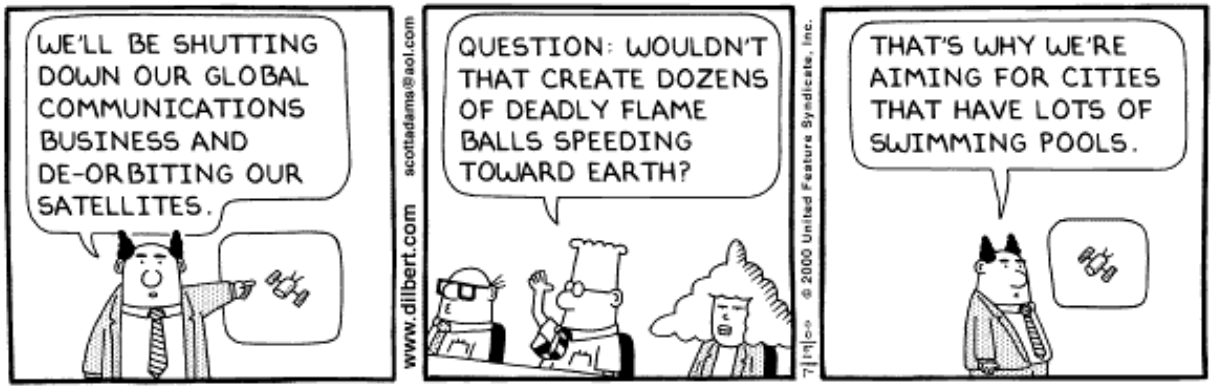
- **Long-Term Environment Modeling**
  - Development of physical models (LEGEND) capable of predicting future debris environment
  - Support the development of US/NASA Debris Mitigation Guidelines and Safety Standards
- **Engineering Modeling**
  - Development of engineering models (ORDEM) capable of predicting OD impact risks (from “debris background”) for ISS, STS, CEV, and other critical space assets
- **Short-Term Risk Assessments**
  - Development of models (SBRAM) capable of predicting impacts risks for ISS, STS, and other critical space assets due to fragments from a new on-orbit breakup

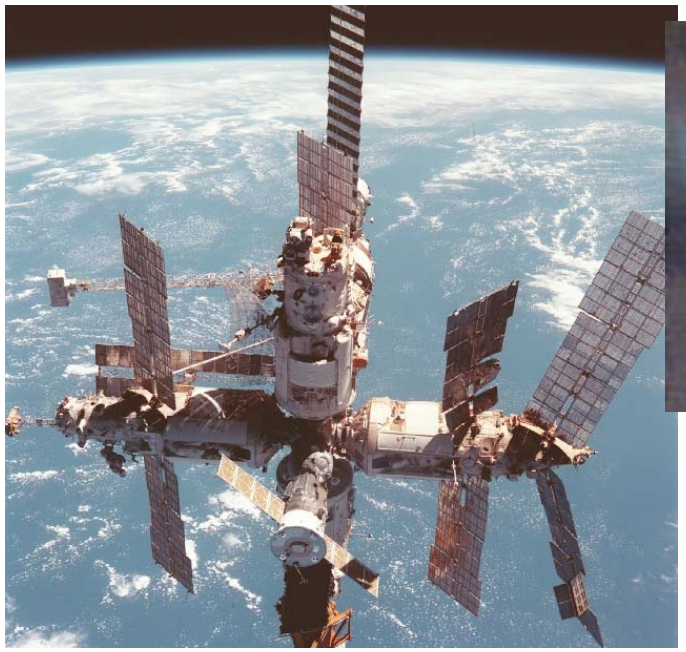
# Safety Standards and Compliance Assessments



- **Safety Standards and Compliance Assessments**
  - Development of models (DAS) to assist NASA programs to ensure mission compliance with NASA Safety Standards
  - Review and provide support for debris assessment reports submitted by NASA mission program offices

# Satellite Reentry



Mir Space Station 2001


Compton Gamma Ray Observatory (2000)

# Reentry Analysis

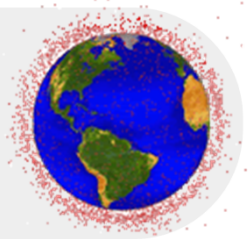
- **Reentry Analysis**
  - Development of models (ORSAT) to evaluate reentry risks
  - Perform satellite reentry risk assessments
  - The risk of human casualty from surviving debris shall not exceed 1 in 10,000 (NASA Standard 8719.14)

**Delta II propellant tank (Georgetown, TX, 1997)**

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

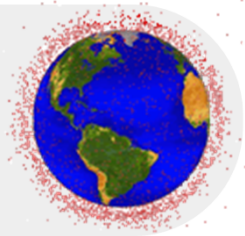
**Titanium casting of STAR-48B SRM (Argentina, 2004)**

# Orbital Debris and U.S. National Space Policy



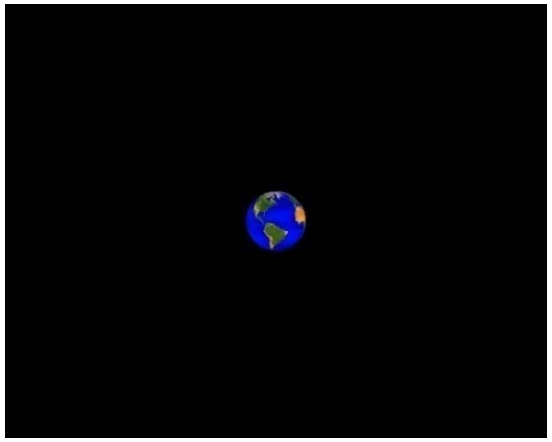
- **Orbital debris has been addressed in all U.S. national space policies since 1988.**
- **New National Space Policy (signed 31 August 2006 by President Bush) states:**
  - "Orbital debris poses a risk to continued reliable use of space-based services and operations and to the safety of persons and property in space and on Earth. The United States shall seek to minimize the creation of orbital debris by government and non-government operations in space in order to preserve the space environment for future generations."
- **Updated NASA Procedural Requirement (NPR 8715.6) and Technical Standard (NS 8719.14) for Limiting Orbital Debris Generation became effective August 2007.**

# Orbital Debris and the International Space Community

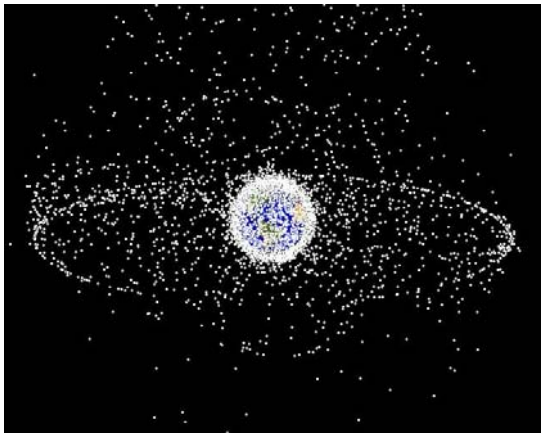


- **Inter-Agency Space Debris Coordination Committee (IADC) was established in 1993 (meet annually)**
  - Includes 11 space agencies (China, France, Germany, India, Italy, Japan, Russia, Ukraine, United Kingdom, United States, & ESA)
  - To exchange information on space debris research activities between member space agencies; to facilitate opportunities for cooperation in space debris research; to review progress of ongoing cooperative activities; and to identify debris mitigation options
- **Since 1994 the subject of orbital debris has been on the agenda of the Scientific and Technical Subcommittee (STSC) of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS)**
  - Adopted a comprehensive set of space debris mitigation guidelines in 2007 (based on the IADC mitigation guidelines adopted in 2004)

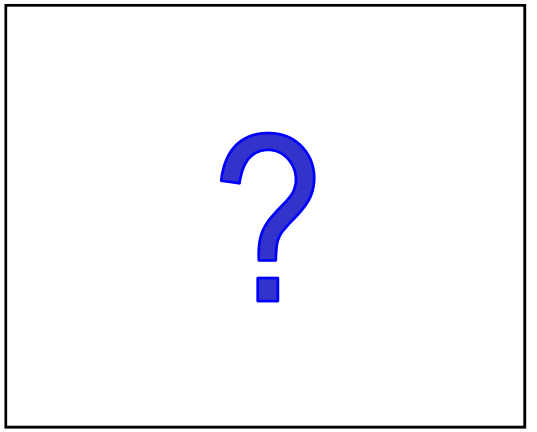
# Questions or Comments?



Pre-1957



2009

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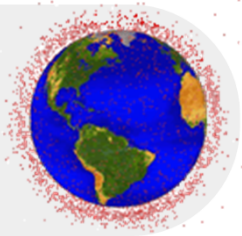
# UN COPUOS STSC Space Debris Mitigation Guidelines



- **The UN COPUOS STSC Space Debris Mitigation Guidelines is four pages long and contains seven numbered guidelines:**
  - Guideline 1: Limit debris released during normal operations
  - Guideline 2: Minimize the potential for break-ups during operational phases
  - Guideline 3: Limit the probability of accidental collision in orbit
  - Guideline 4: Avoid intentional destruction and other harmful activities
  - Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy
  - Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission
  - Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with geosynchronous Earth orbit (GEO) region after the end of their mission