Measurement of Satellite Impact Test Fragments for Modeling Orbital Debris

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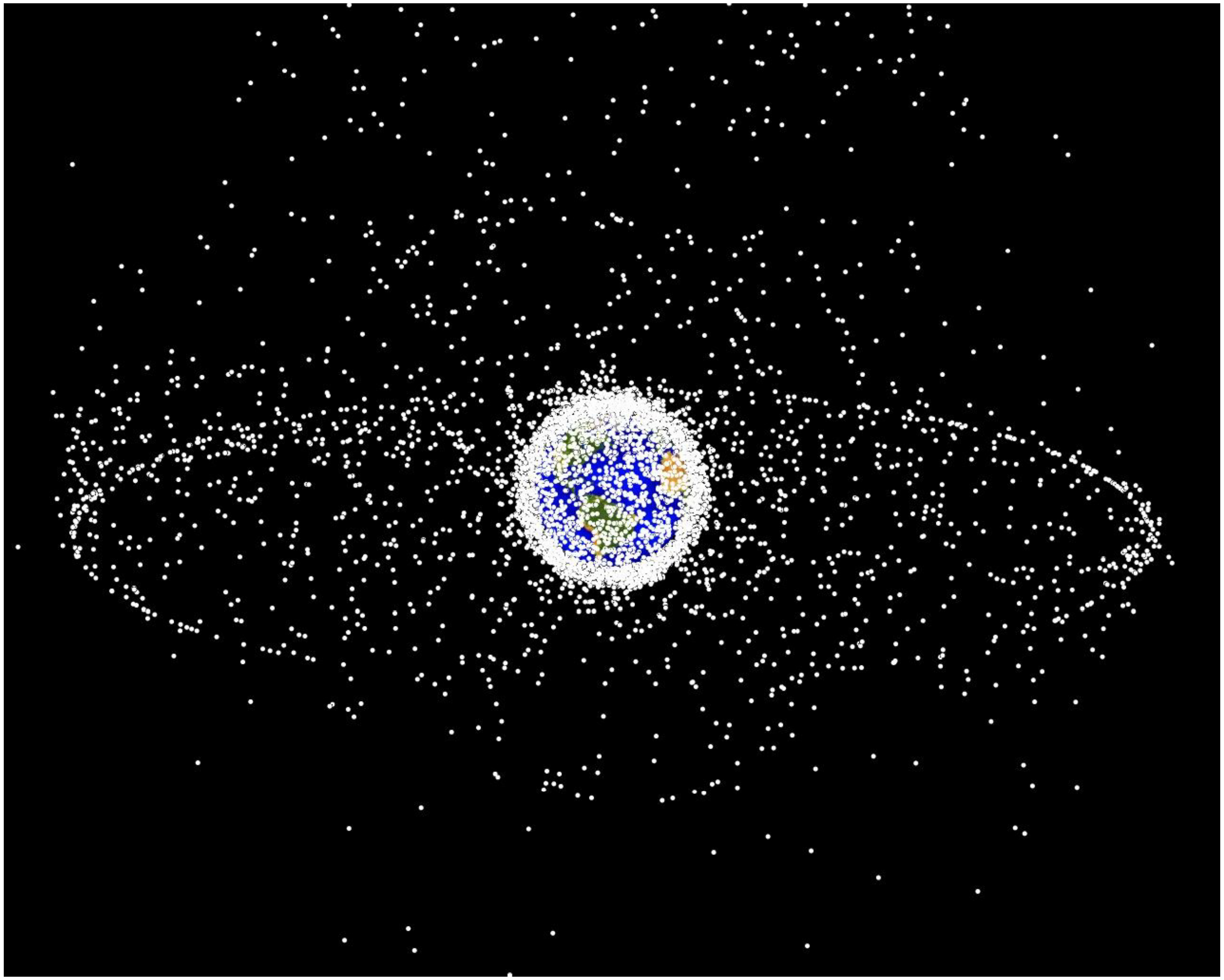
Outline

- Overview of orbital debris
- Purpose of measuring hypervelocity impact test fragments
- Overview of hypervelocity impact testing
- Hand measurement techniques
- Computerized measurement system
- Conclusions
- Questions

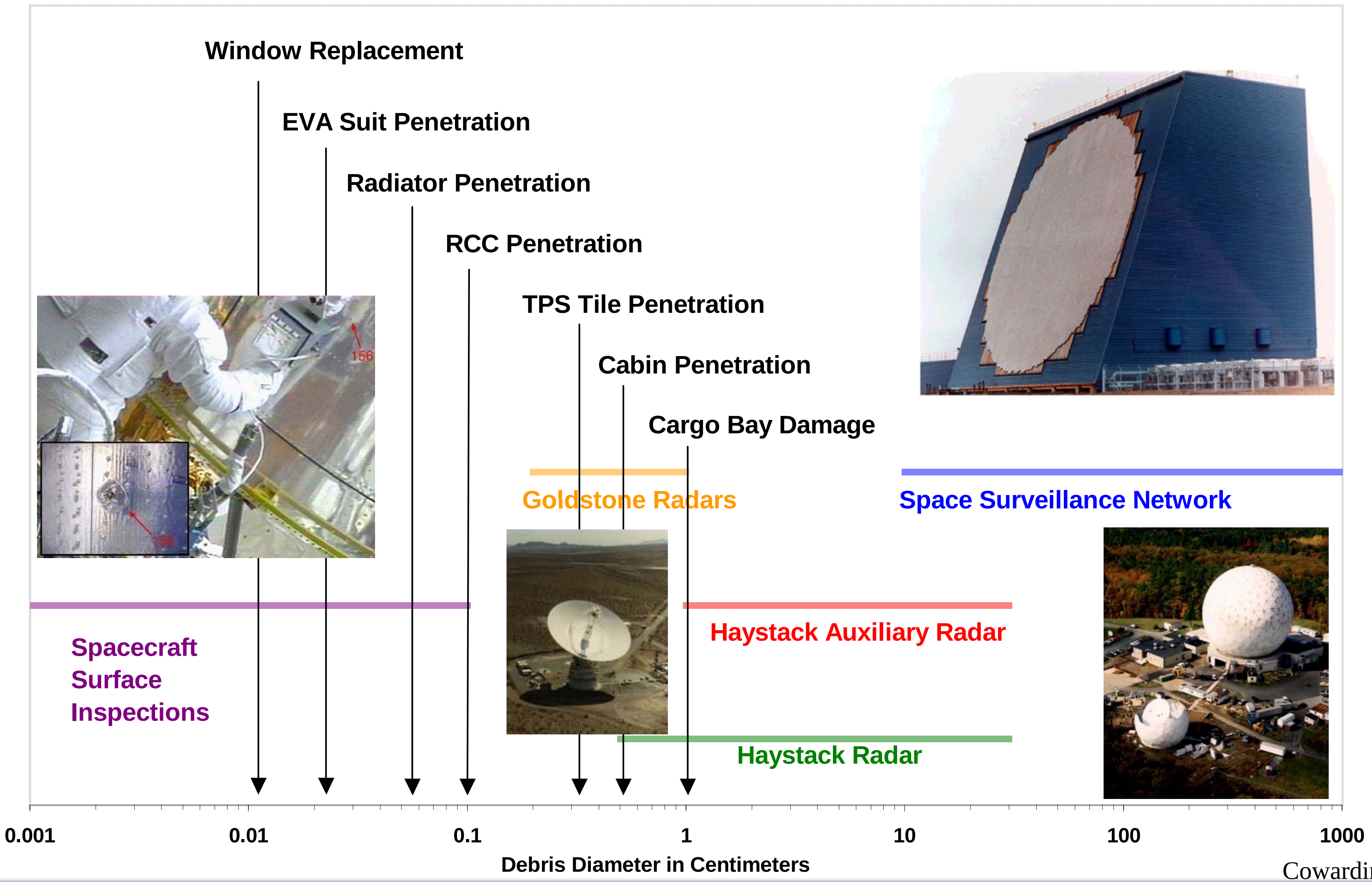
Orbital Debris



Is it safe out there?

Principal Orbital Debris Data Sources

Potential Shuttle Damage

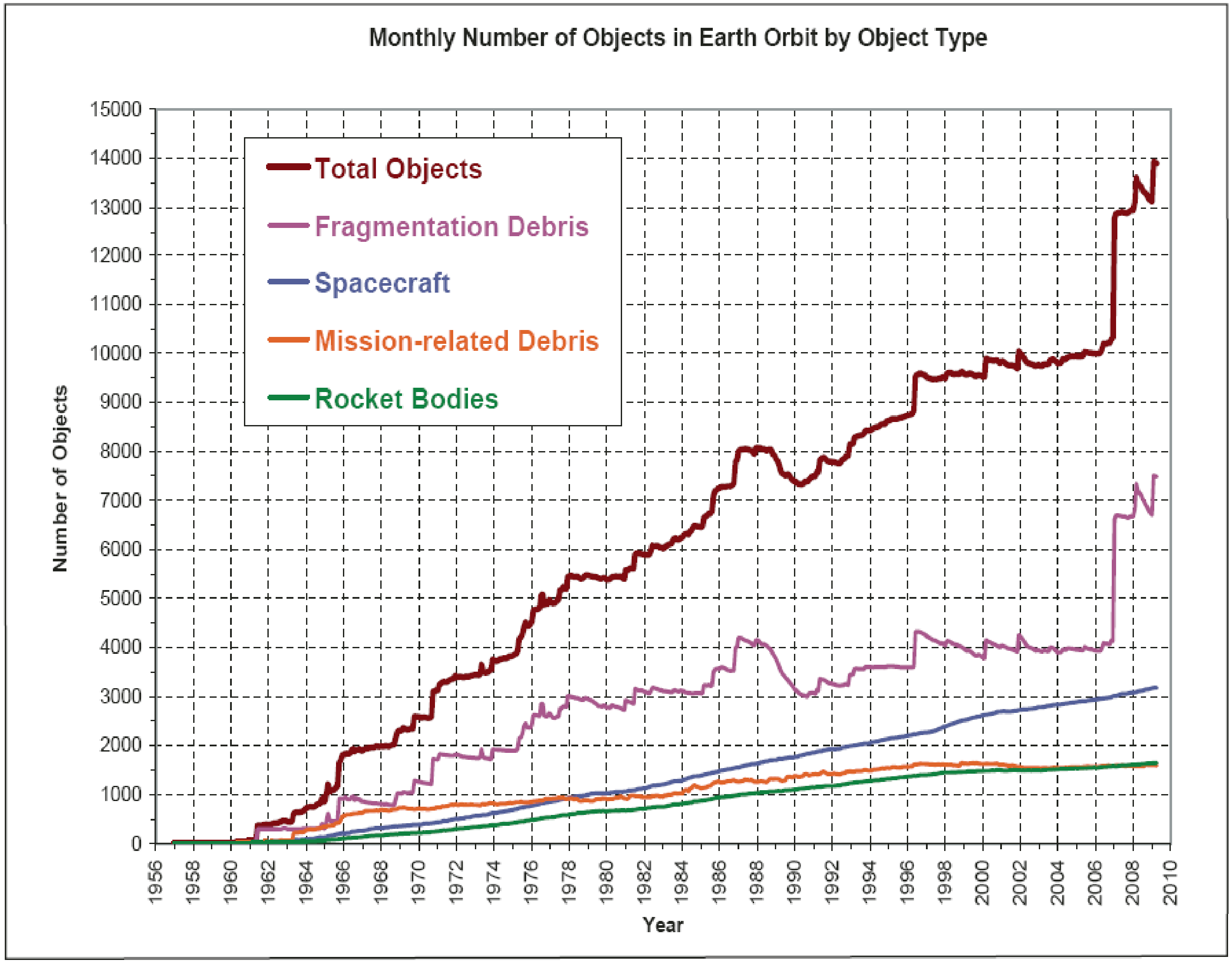


Cowardin, 2008

Orbital Debris Overview

- There are over 13,000 catalogued objects in orbit
- over 18,000 tracked objects >10 cm
- Fragmentation debris are a problem
  - Risk to current and future operating satellites

Orbital Debris Quarterly Newsletter, April 2009



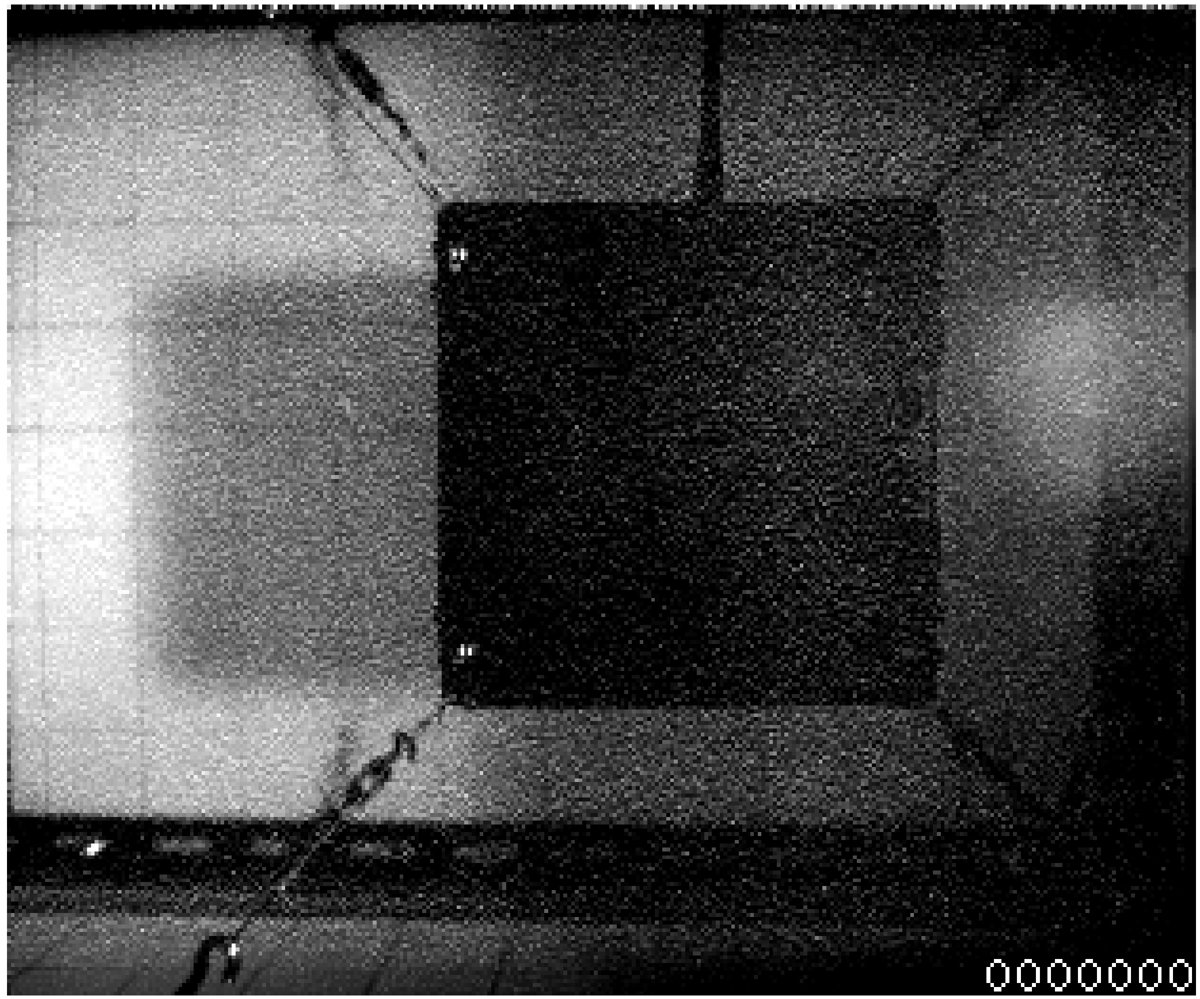
Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially.

Purposes of Impact Testing

- **Size and shape distribution of fragments on orbit**
  - Measure size
  - Determine shape
    - Accurate area calculation for irregular shapes
  - Determine cross-sectional area
  - Find area-to-mass (A/M) distributions as functions of size
  - Incorporate into computer codes
- **3-D Model of fragment**
  - Compare with optical lab measurements

Hypervelocity Impact Test Fragments (1)

- **Many impact tests have been performed**
  - Realistic nonfunctional micro-satellites
  - Projectiles
  - Hyper- and low-velocity impacts
  - Differing impact directions



Courtesy of Kyushu University and Simadzu Corporation for the high-speed video camera HyperVision HPV-1

Hypervelocity Impact Test Fragments (2)

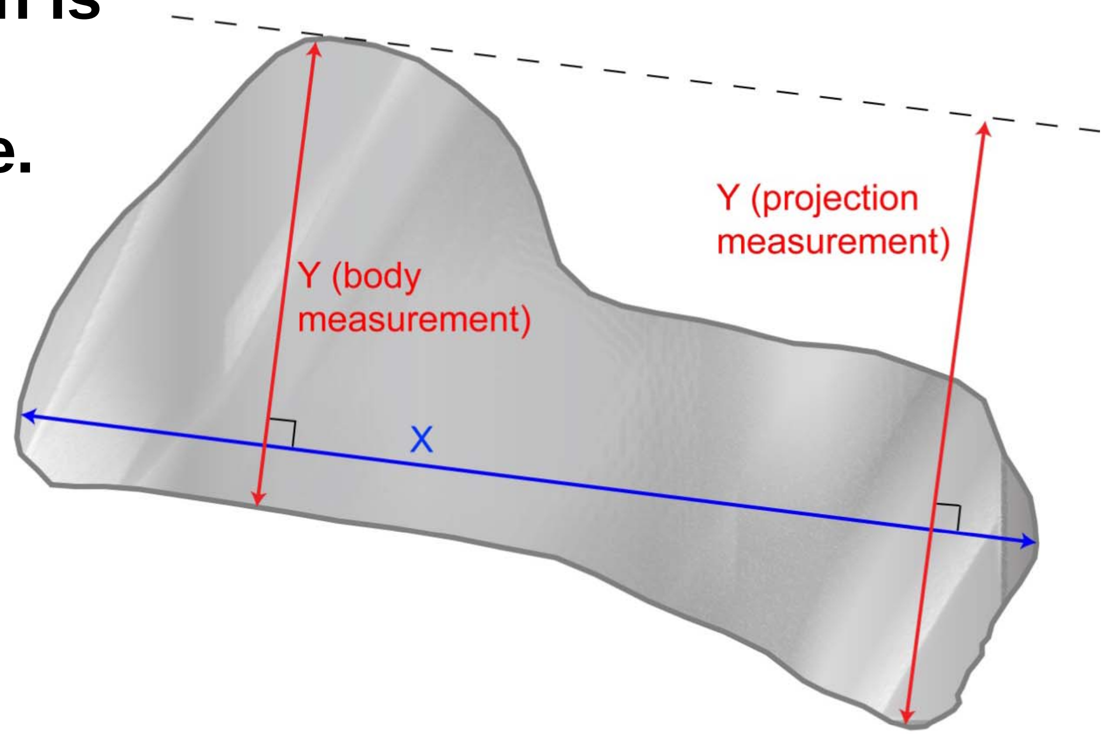
- **Purpose: Improve our ability to predict what debris will result from an on orbit collision or explosion**
  - Size and shape determination of collision debris
    - Standard size determination is Characteristic Length L_c

Shot 3 fragments

Measurement Techniques

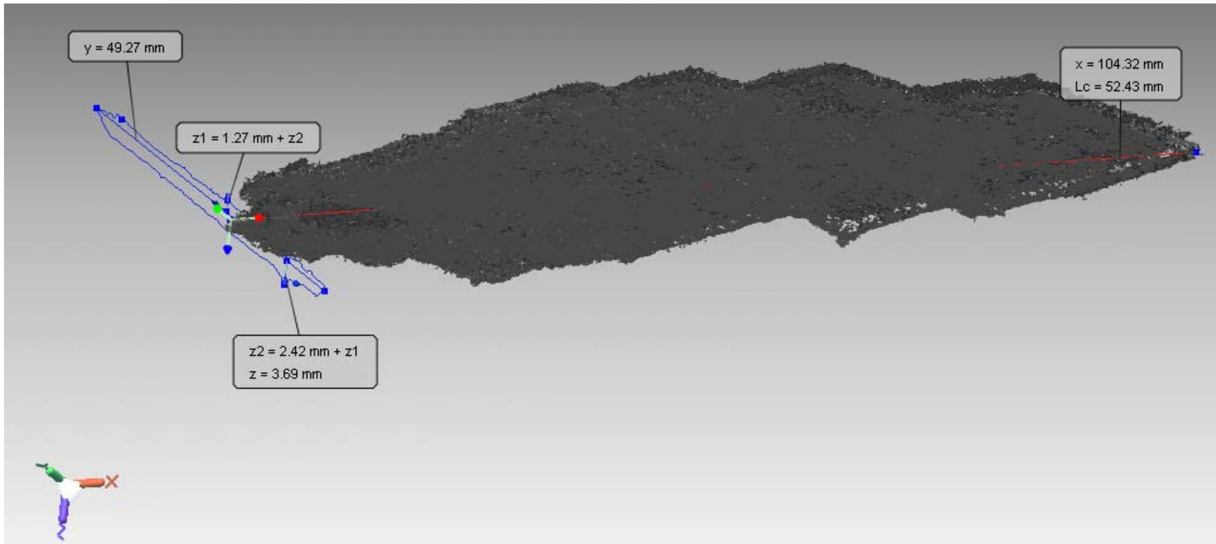
- **x = longest projection dimension**
- **y = longest projection orthogonal to x**
- **z = longest projection orthogonal to both x and y**
- **Characteristic length is the standard size comparison variable.**

$$L_C = \frac{x + y + z}{3}$$

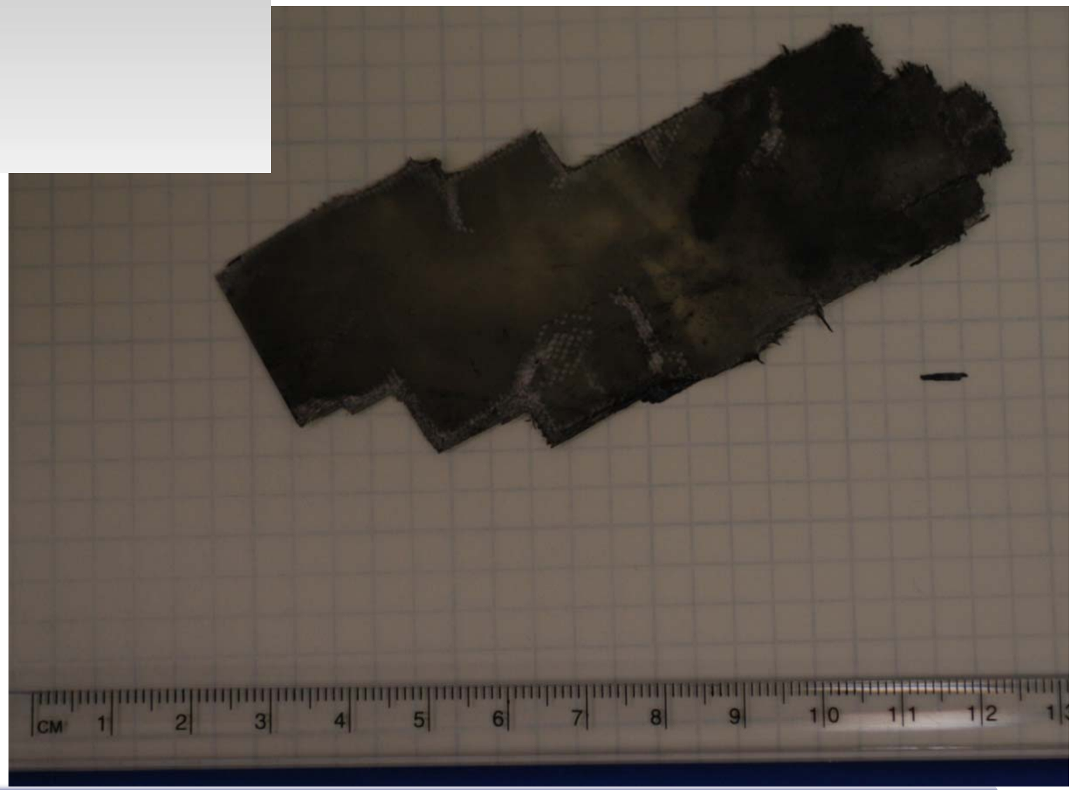


Projection measurements, Hill, Stevens ODQN 2007

Hand Measurement Techniques



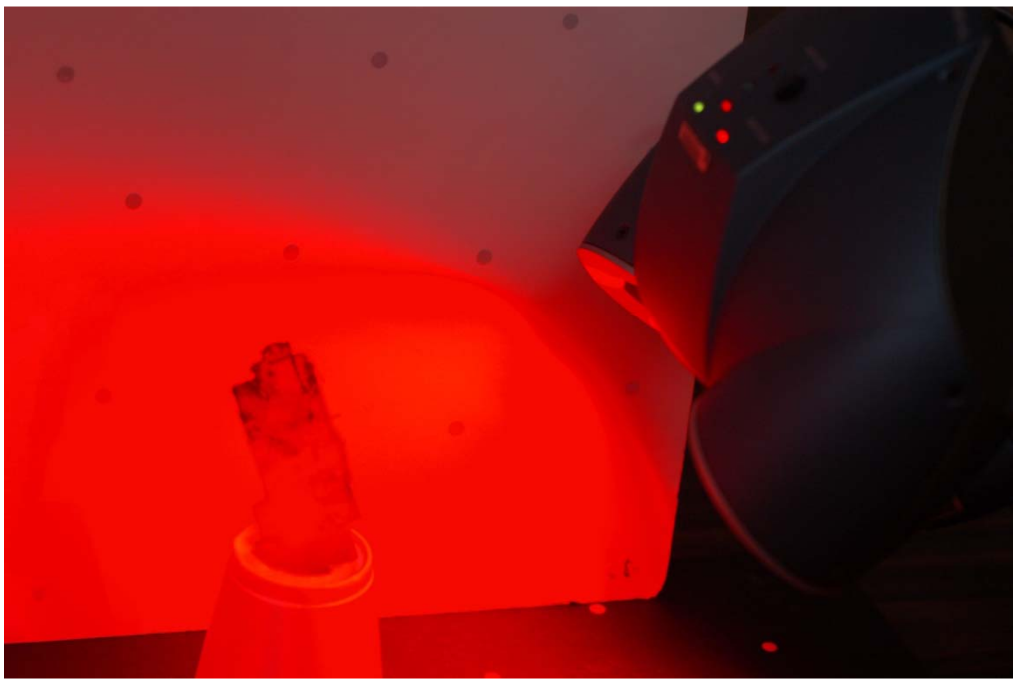
Shot 3 fragment #282, GFRP



- **Ruler and grid paper**
- **Rely on memory and eyes to determine orthogonal directions**
- **Uncertainty unknown**
  - **Variation between users**
- **Not always repeatable**

Computerized Measurement Techniques

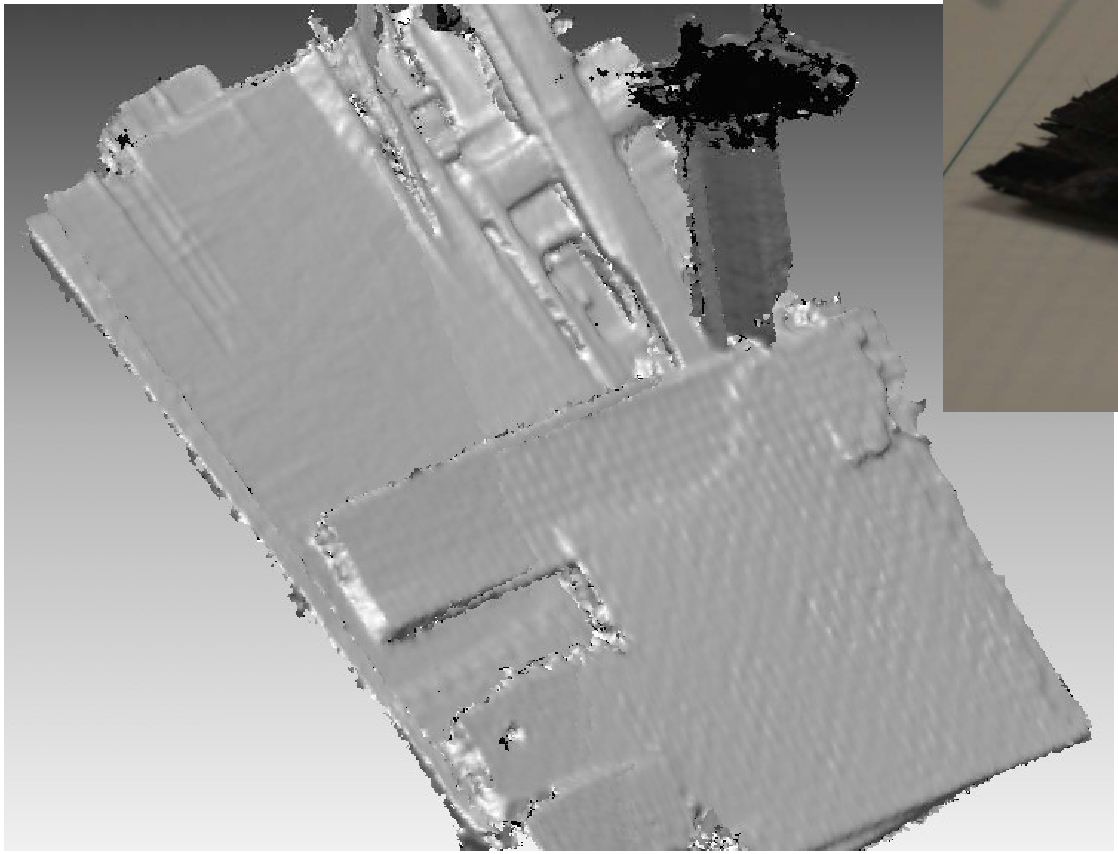
- **Hand held laser scanner**
  - Two cameras triangulate position of object against reference board
  - 8 LEDs to light up reference dots
  - Crosshair lasers

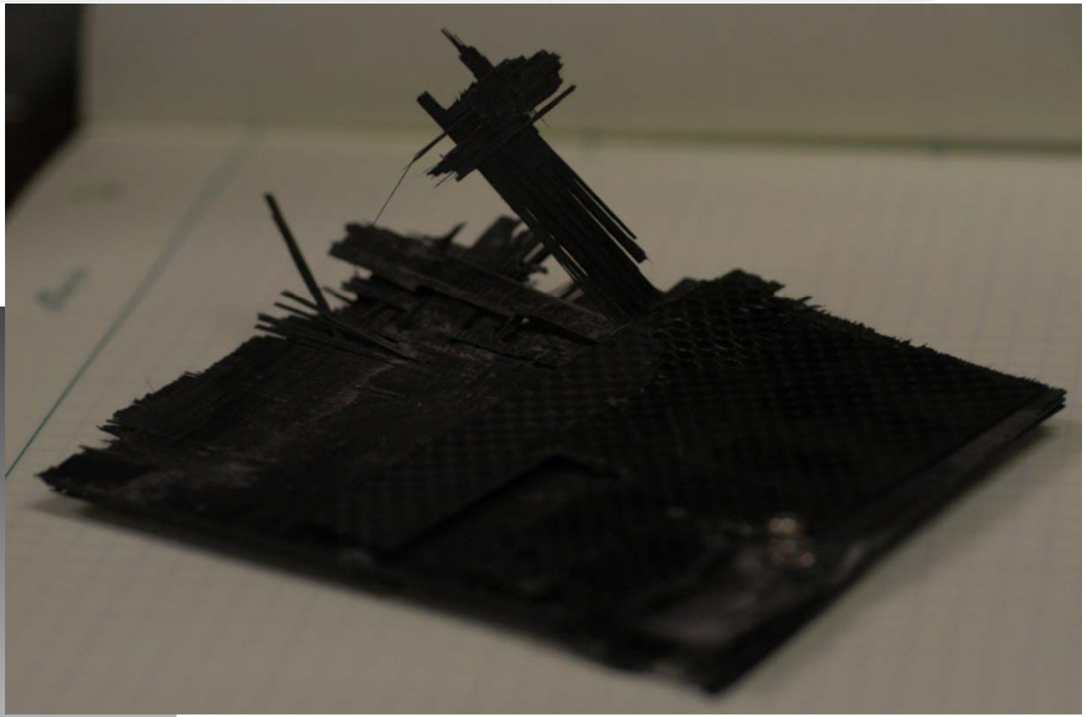


Scanning setup

Hand-held laser scanner

Detail

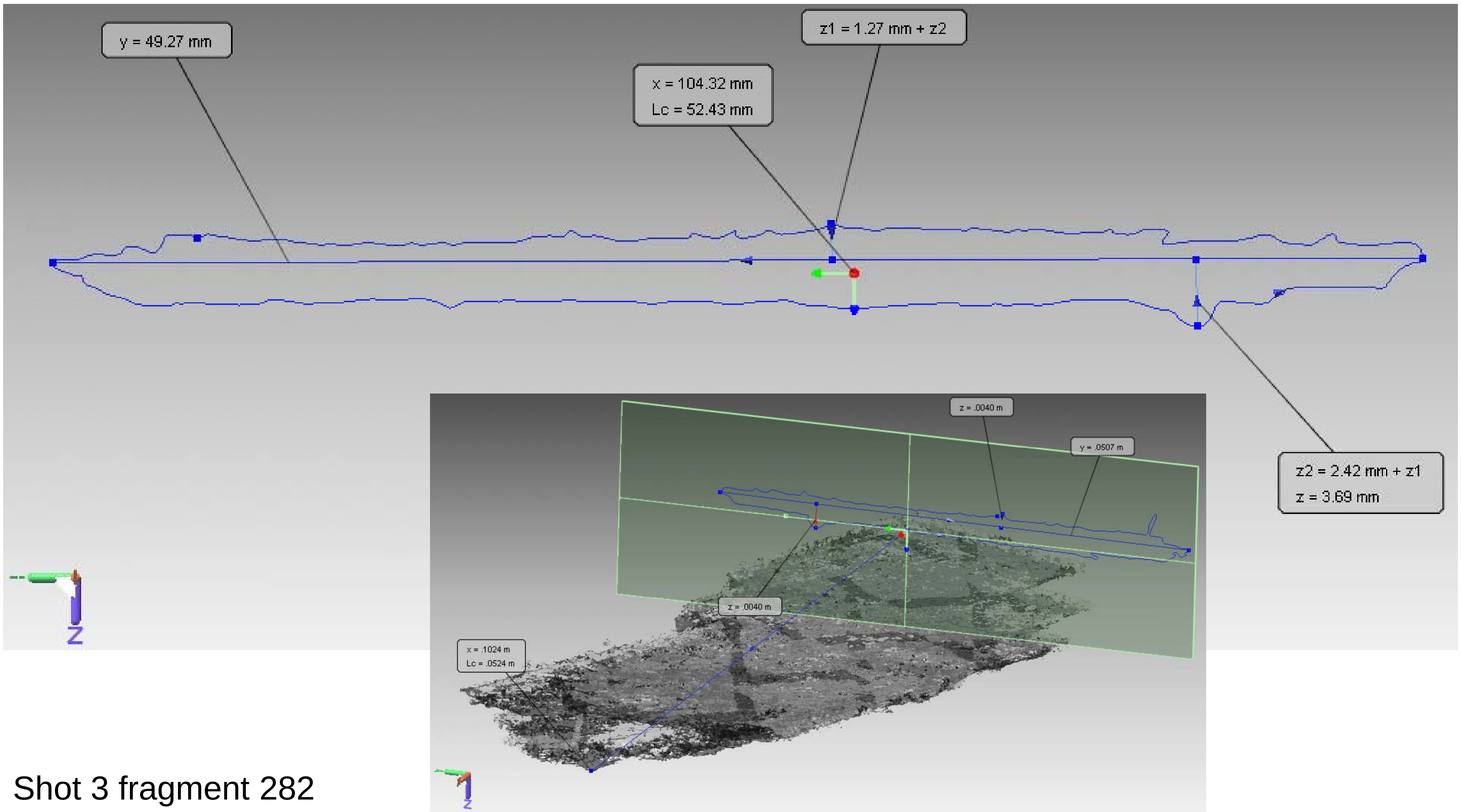




Shot 3 fragment 7

Measurement Software Program

- **Measurement techniques**



Shot 3 fragment 282

Uncertainties

- **Measured three qualitative types of fragments:**
  - Easy
  - Moderate
  - Difficult
- **Performed maximum reasonable human error ranges on each**
- **Compared results**

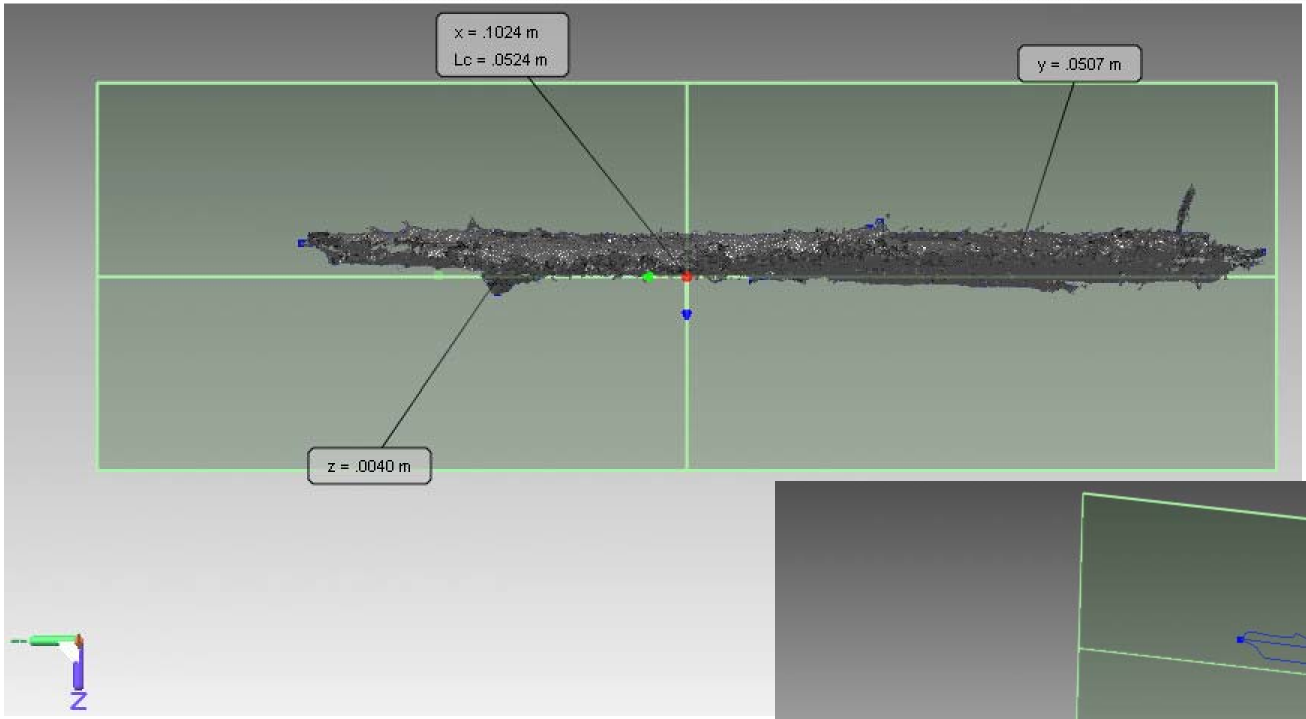
Easy Fragment

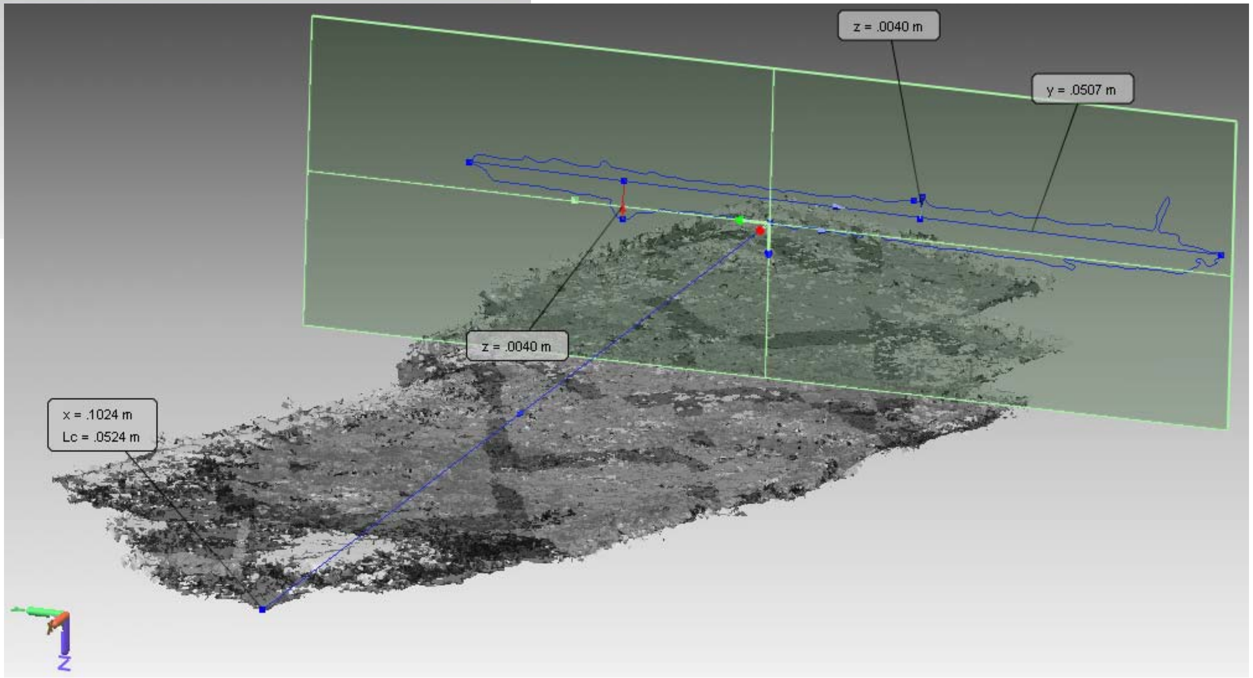
Aluminum Cube

	Initial Measurements	Careful Measurements	Underestimate	Overestimate	Range
x	49.15	49.43	49.12	49.43	0.31
y	46.47	47.35	45.89	47.7	1.81
z	41.27	40.08	40.96	40.29	1.19
L_c	45.63	45.62	45.32	45.81	0.49

- Maximum reasonable human error used for under- and over-estimates
- Range in characteristic length is less than 0.5 mm for an easy fragment

Shot 3 Fragment 282 – Moderate Fragment





Computer vs. Hand Measurement

Shot 3 Fragment 282 *All values reported in millimeters*

**user adjusted to 2.5 giving Lc of 51.6 – computerized technique 'discovered' true curvature*

	Hand user 1	Hand user 2	Hand user 3	Hand user 4	Computer	Computer Underestimate	Computer Overestimate
x	104.35	104	104	104.03	104.32	102.54	105
y	41.7	40	48.4	49.16	49.27	47.66	50.32
z	2.1775	1	1*	1.43	3.69	2.64	4.48
L_C	49.4	48.33	51.1	51.54	52.43	50.95	53.27

Difference in characteristic length:

- Between hand measurements 4.29mm 8.3%
- Between computerized measurements 2.32mm 4.4%
- Between hand and computer 0.83mm 1.6%

Maximum error assessed to be less than 2.5 mm – LESS THAN USER ERROR

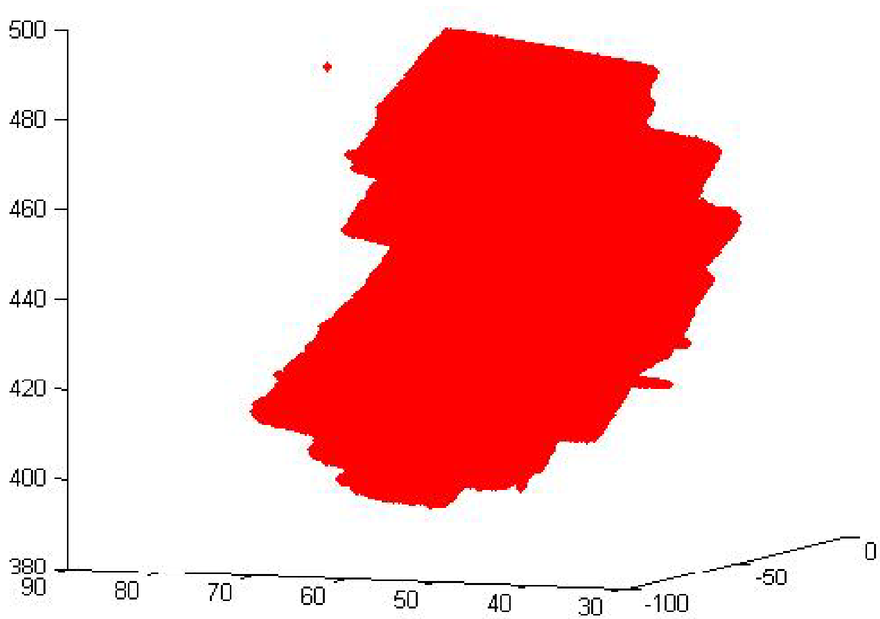
Computerized Measurement Techniques

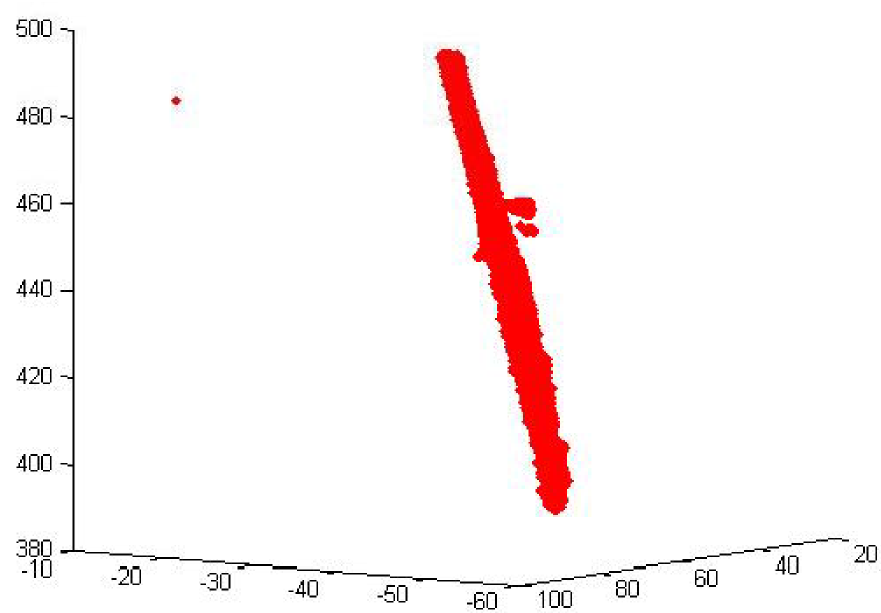
- **Advantages**
  - Uncertainty is more consistent
    - Maximum error ~ 0.25 mm
  - Allows for additional calculations / analysis
    - All calculations are repeatable
  - Decreases the risk of damaging the fragment (less handling)

- **Disadvantages**
  - Some objects are difficult to measure (equally true for hand measurements)
    - Light reflection / scattering
  - Unreliable for small objects
    - Determined Lc=5.2 mm is smallest nugget we can scan
  - Measurements are time-consuming

Future Work

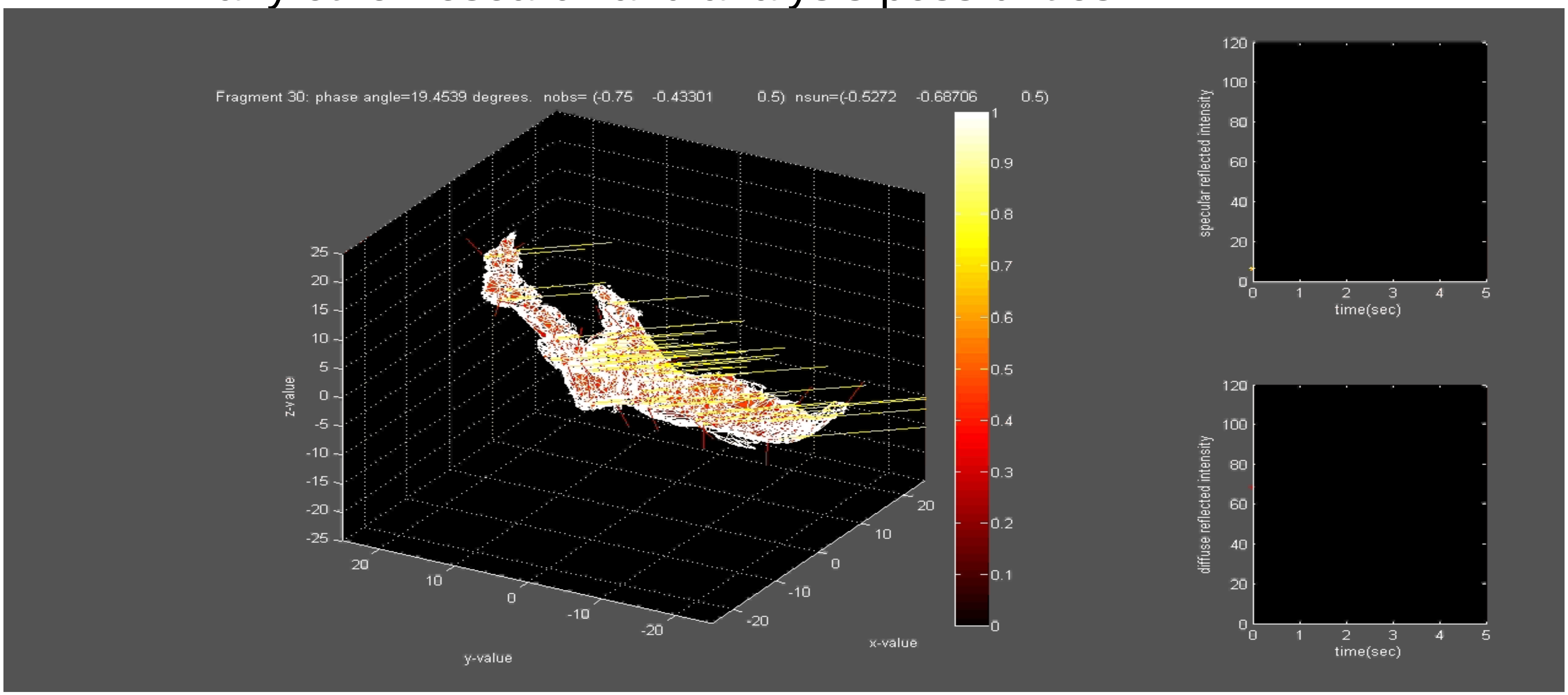
- **MATLAB® model**
  - Measure cross-sectional area at any 2D slice of 3D model
    - A/M results
      - Irregular objects
    - Shape determination
  - Volume





Future Work

- **MATLAB® model**
  - Tumbling model for comparison with photometric studies
    - Establish a model which will support an optical database to aid in the interpretation of telescopic data
  - Many other research and analysis possibilities

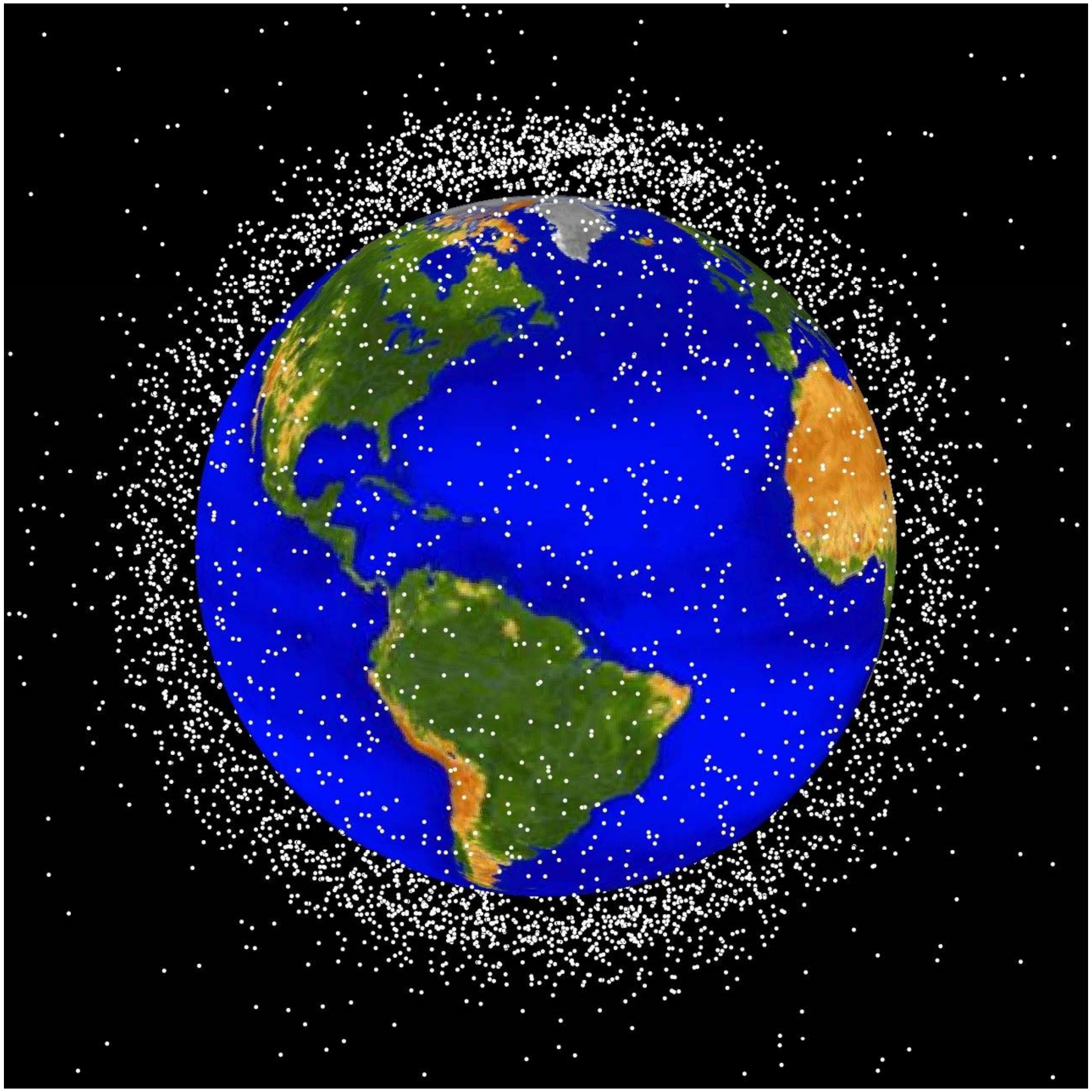


Dr. Ojakangas, Drury University

Conclusions

- The computerized measurement system creates a 3D model of a satellite impact fragment.
- This model is more consistent than hand measurement techniques and is repeatable.
- By manipulation of the saved model, this technique allows for further analyses without having to redo any work with the physical fragment.
- This model supports size and shape determination for the understanding of the corresponding distributions of the on orbit debris population.

Questions?



References

1. NASA Orbital Quarterly News, January 2009, p 12

2. *H. Rodriquez, "Orbital Debris: Past, Present and Future", AIAA Technical Symposium May 2008.*

3. *J.-C. LIOU and N. L. Johnson, "Risks in Space from Orbiting Debris", SCIENCE 20 January 2006: Vol. 311. no. 5759, pp. 340 - 341*
   DOI: 10.1126/SCIENCE.1121337

Back-up: Difficult Fragment

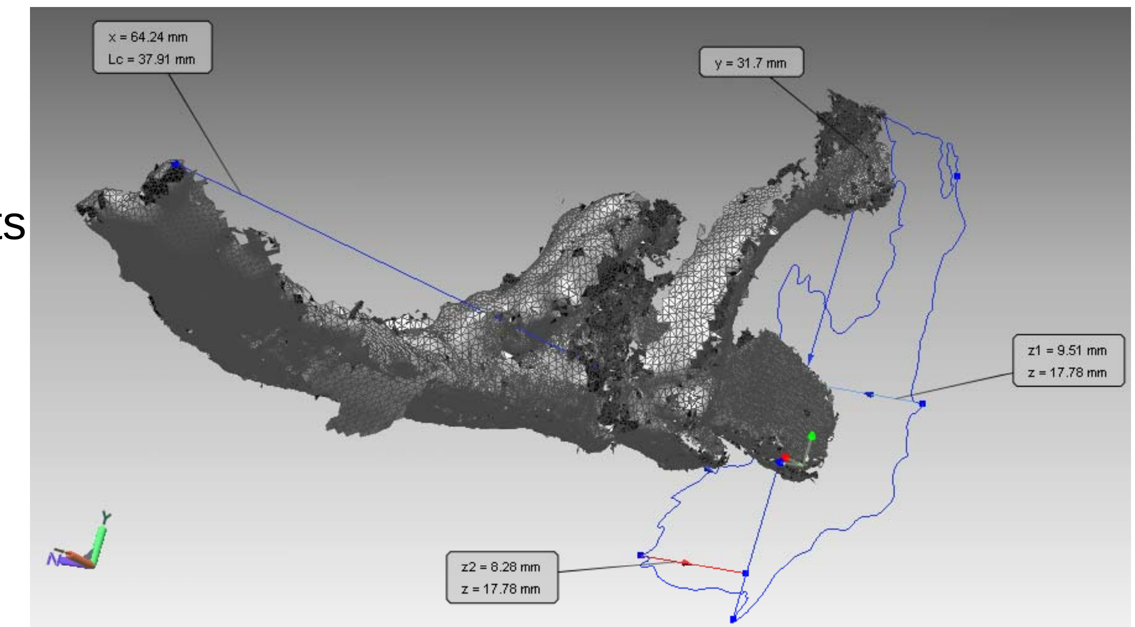
Shot 3 Fragment 30

values reported in millimeters

	Initial computer	Detailed computer	Computer underestimate	Computer overestimate	Hand user 1	Hand user 2
x	63.61	64.24	63.57	64.24	72.25	72.00
y	23.56	31.70	23.30	32.25	33.09	37.50
z	19.84	17.78	19.29	18.04	14.86	19.00
L_C	35.67	37.91	35.39	38.17	40.02	42.83

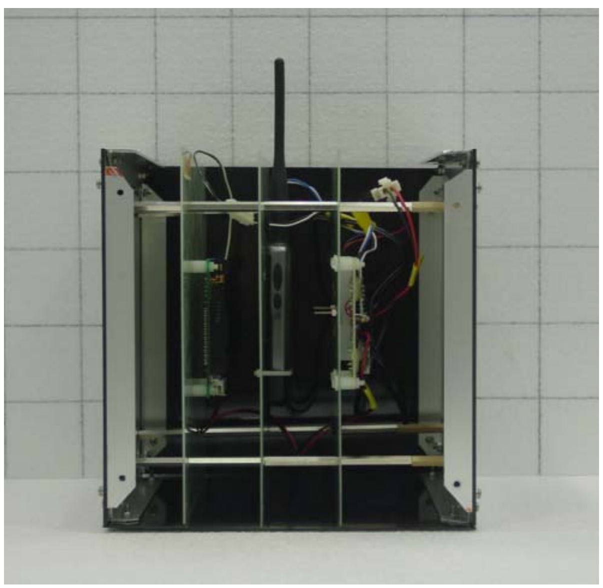
Difference in L_C:

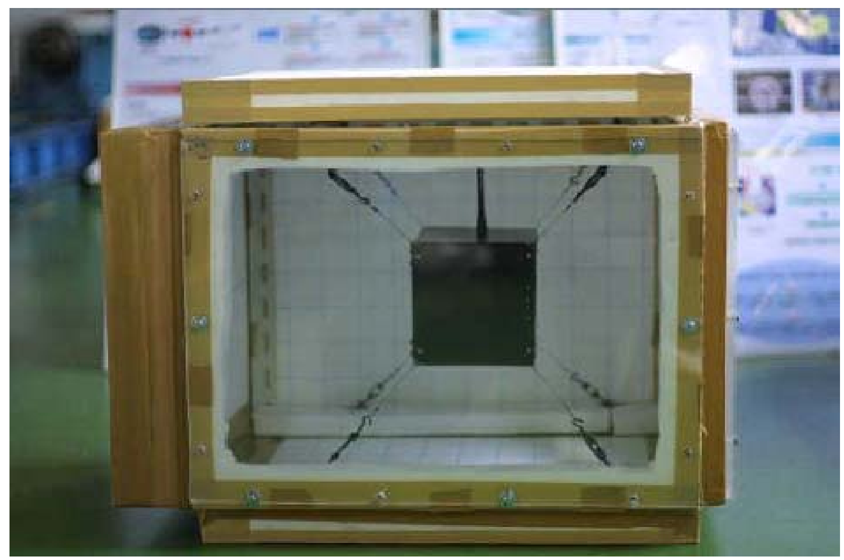
- Between hand measurements
  0.25 mm 0.3%
- Between computerized measurements
  2.78 mm 6.5%
- Between hand and computer
  4.92 mm 11.5%



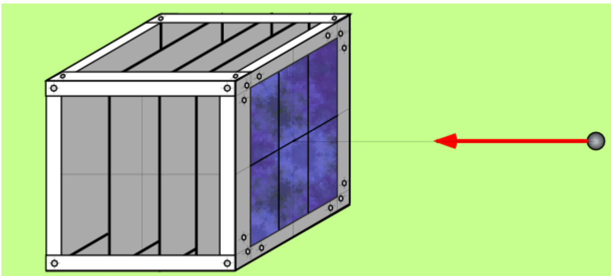
Back-up slides – test satellites

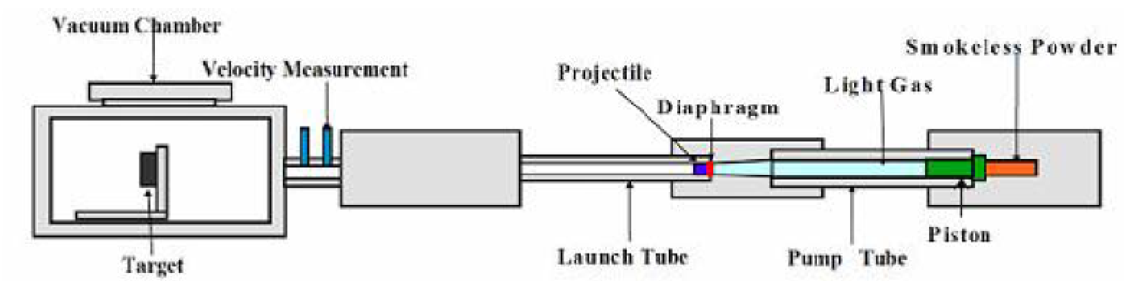
- **Target satellites**
  - Cube-shaped, with 6 Carbon Fiber Reinforced Plastic (CFRP) outer walls and 3 Glass Fiber Reinforced Plastic (GFRP) boards inside
    - Direction of CFRP fiber: (0°, 90°)
    - Thickness of the front and back CFRP walls: 2 mm
    - Thickness of other CFRP and GFRP walls: 1 mm
  - Components: lithium-ion batteries, transmitter, solar cells, power circuit board, communication circuit board, on board computer,

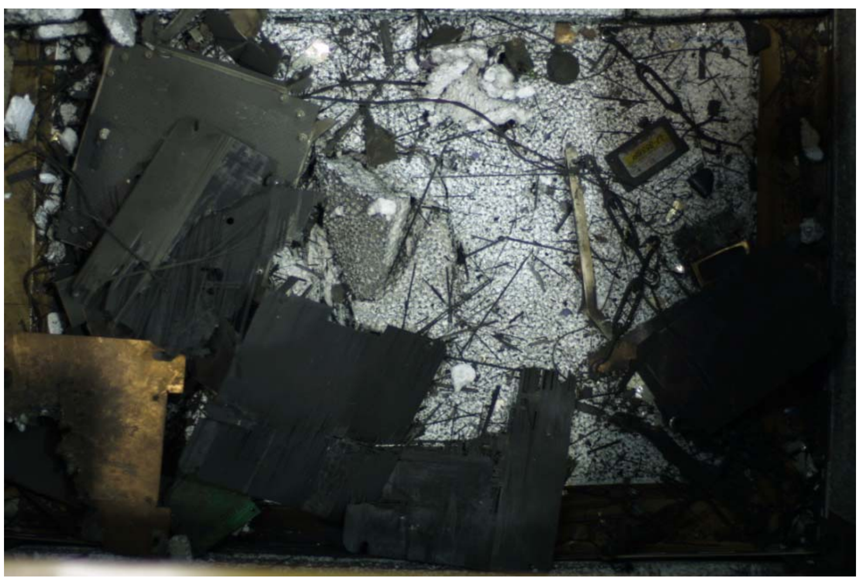




Back up slide - Impact Test





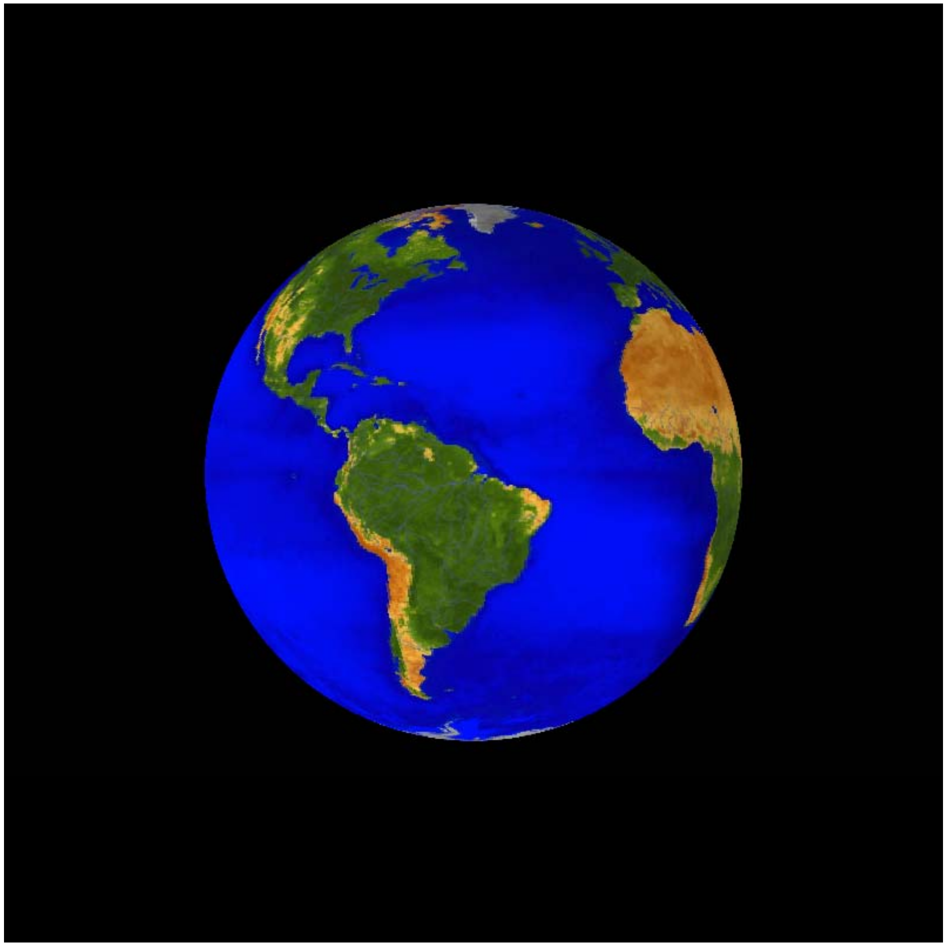


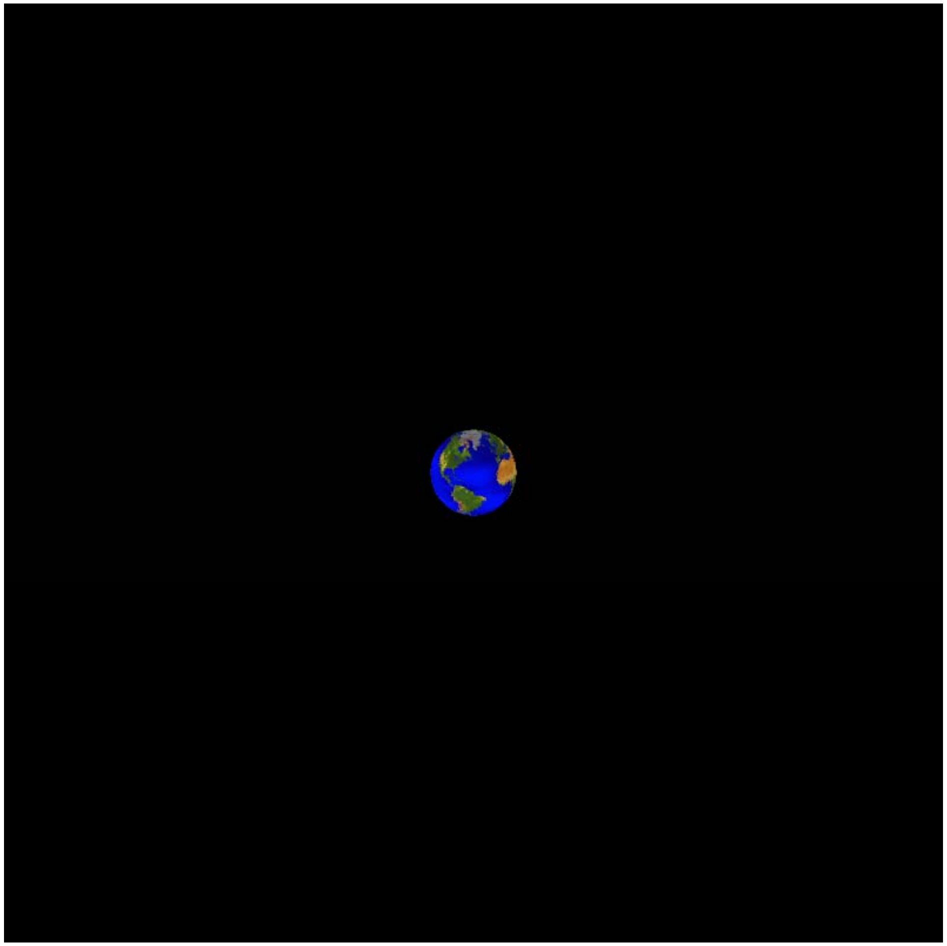
Back up slide - Impact Tests

	Size (cm)	M_t (g)	M_p (g) / D_p (cm)	V_{imp} (km/s)	EMR (J/g)	Impact Angle
0501H	15	740	4.03 / 1.4	4.44	53.7	⊥
0502L	15	740	39.2 / 3.0	1.45	55.7	⊥
0701L	20	1300	39.2 / 3.0	1.66	41.5	⊥
0702L	20	1285	39.2 / 3.0	1.66	42.0	//
0703L	20	1285	39.2 / 3.0	1.72	45.1	⊥

Back up slide - Orbital Debris Growth

Before 1957 = 0 objects

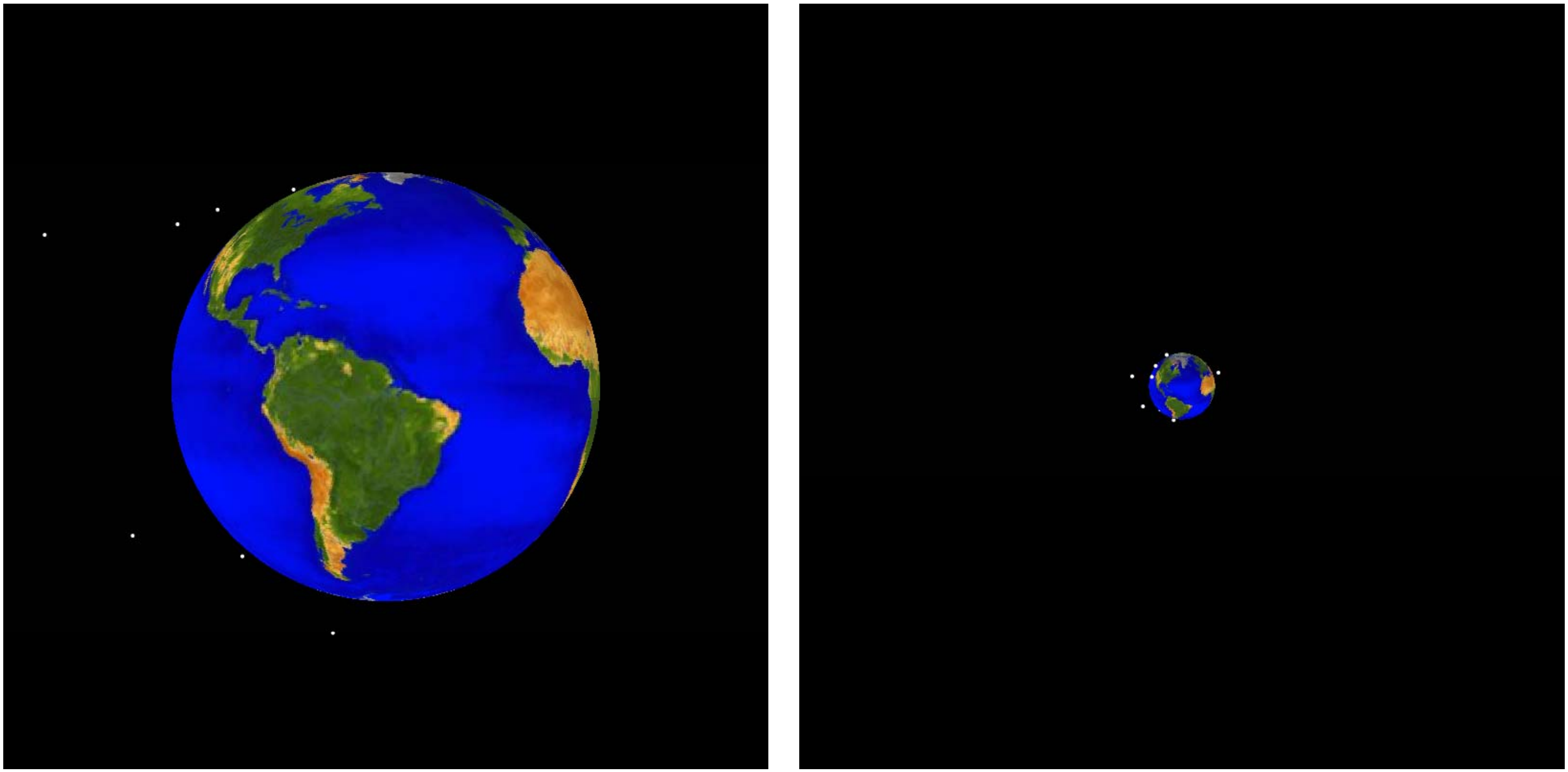




Cataloged objects (>10 cm diameter) represented by white dots ***(not to scale)***

Back up slide - Orbital Debris Growth

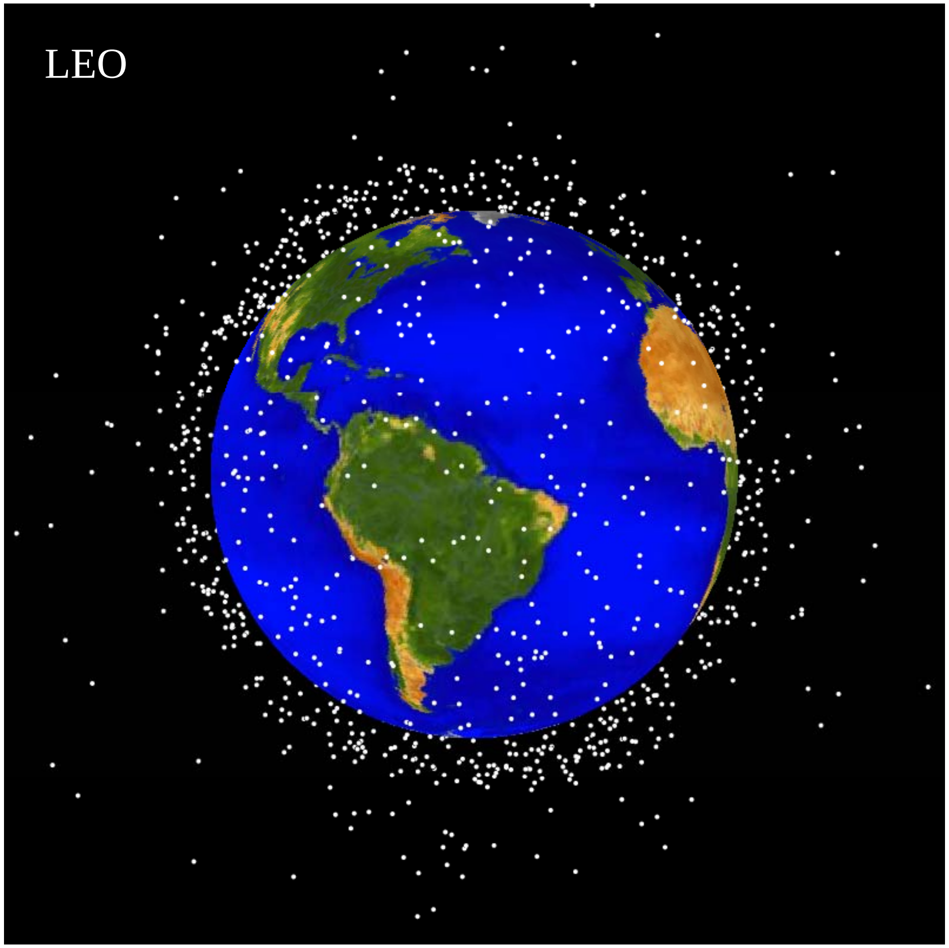
1960 = 10+ objects

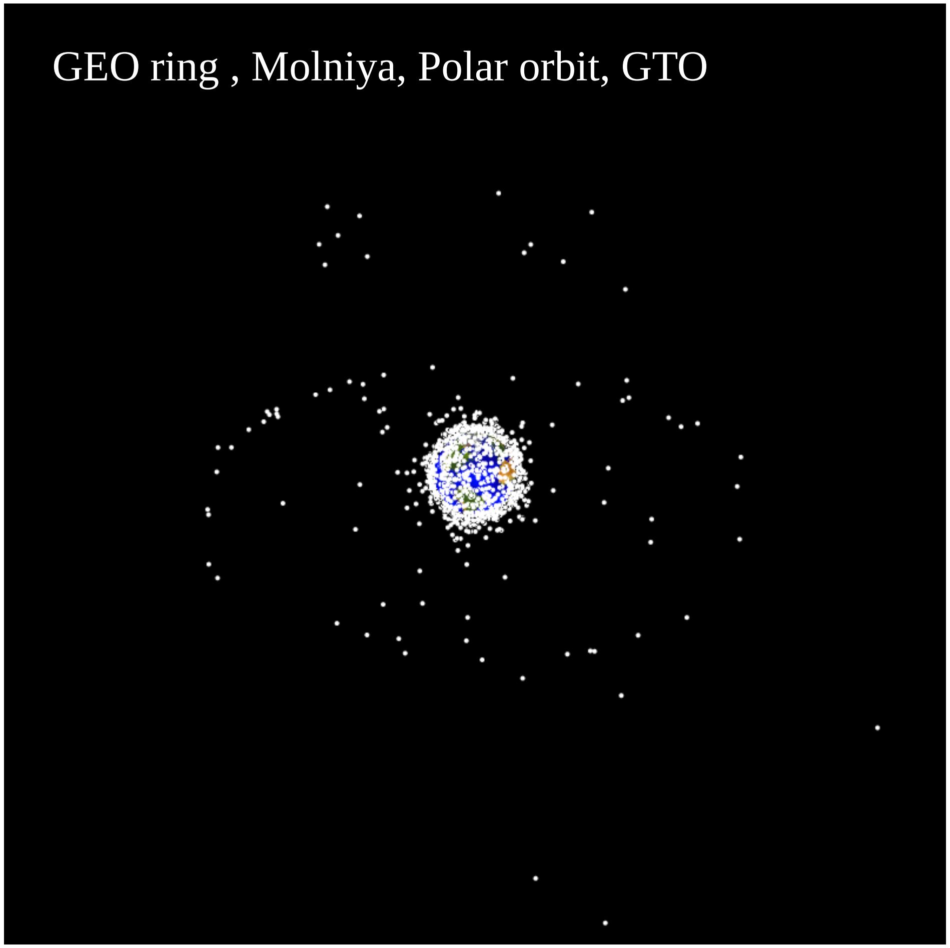


Cataloged objects >10 cm diameter

Back up slide - Orbital Debris Growth

1970 = 1400+ objects

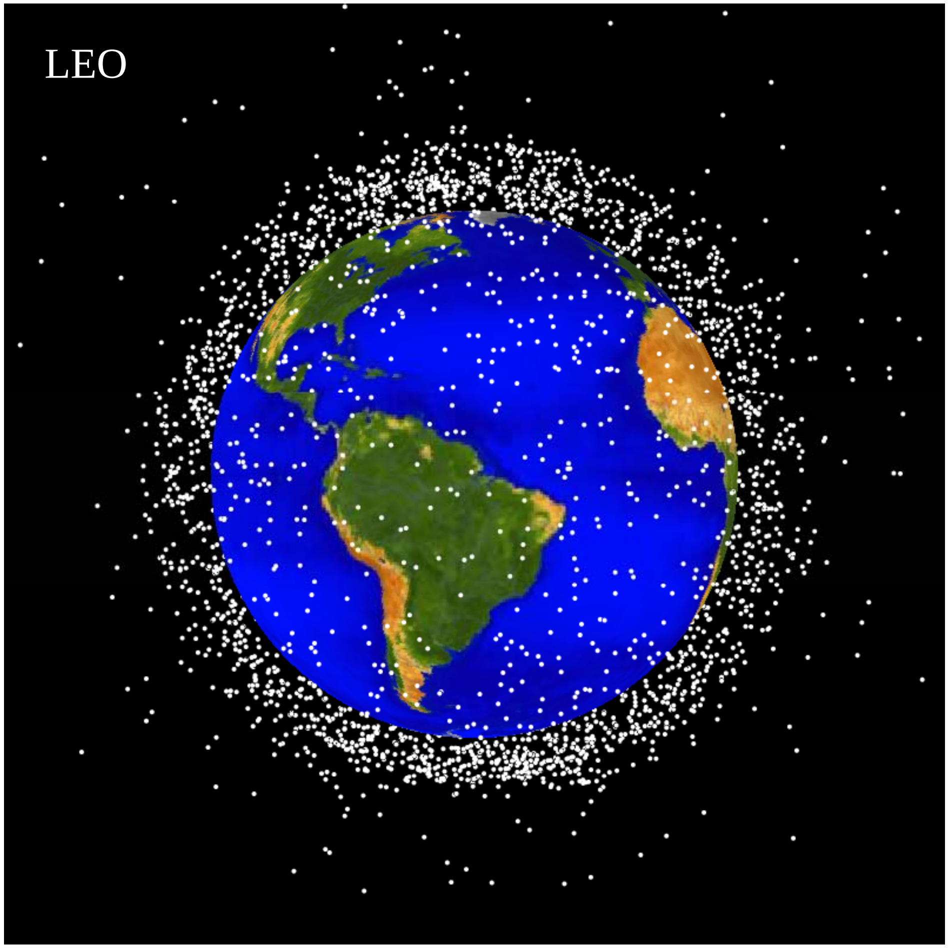


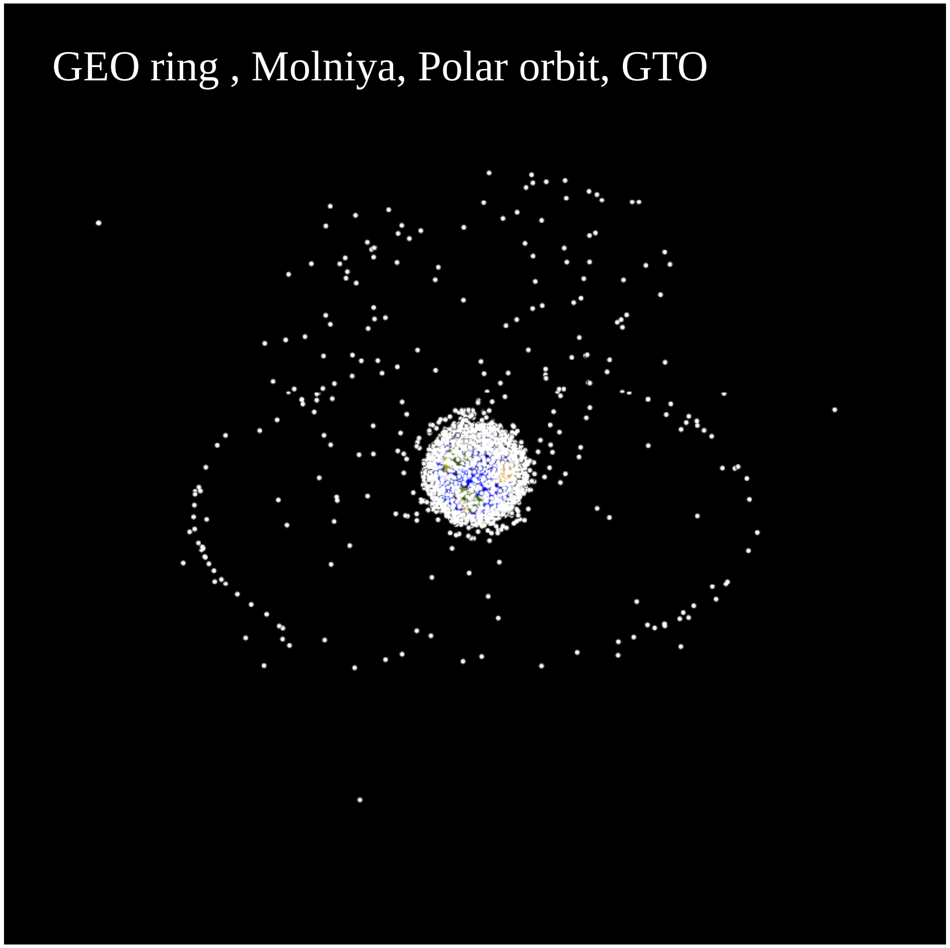


Cataloged objects >10 cm diameter

Back up slide - Orbital Debris Growth

1980 = 3700+ objects

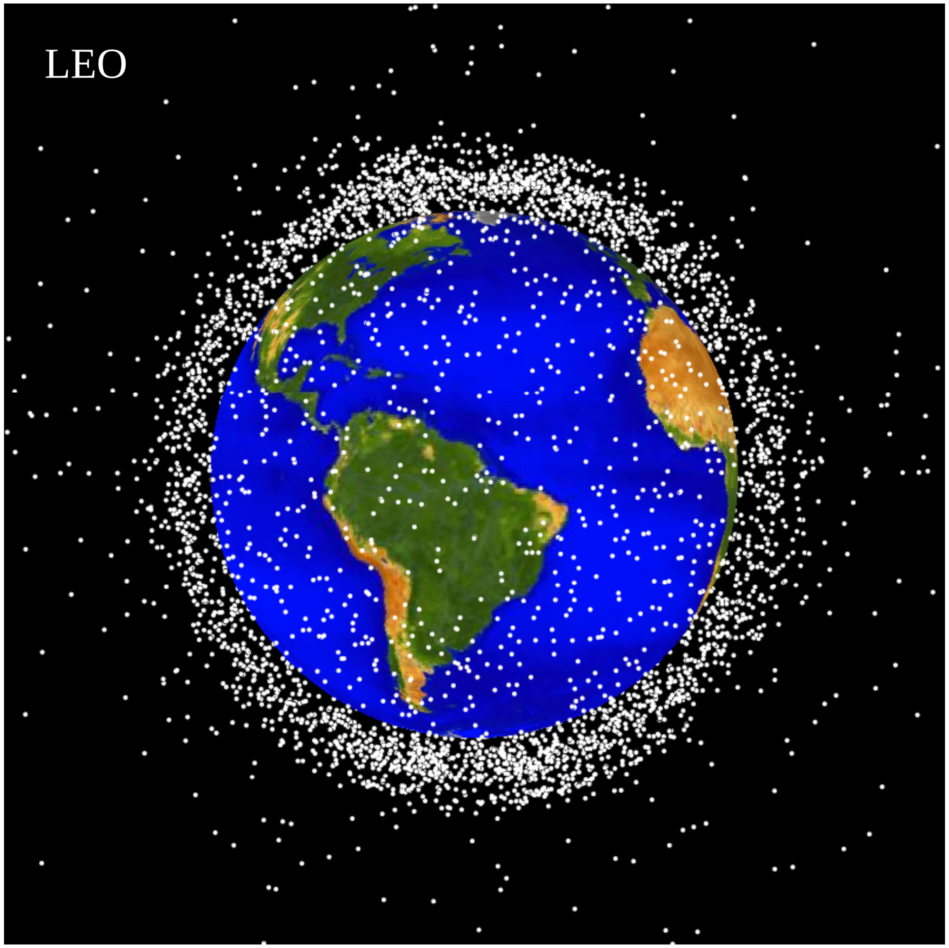


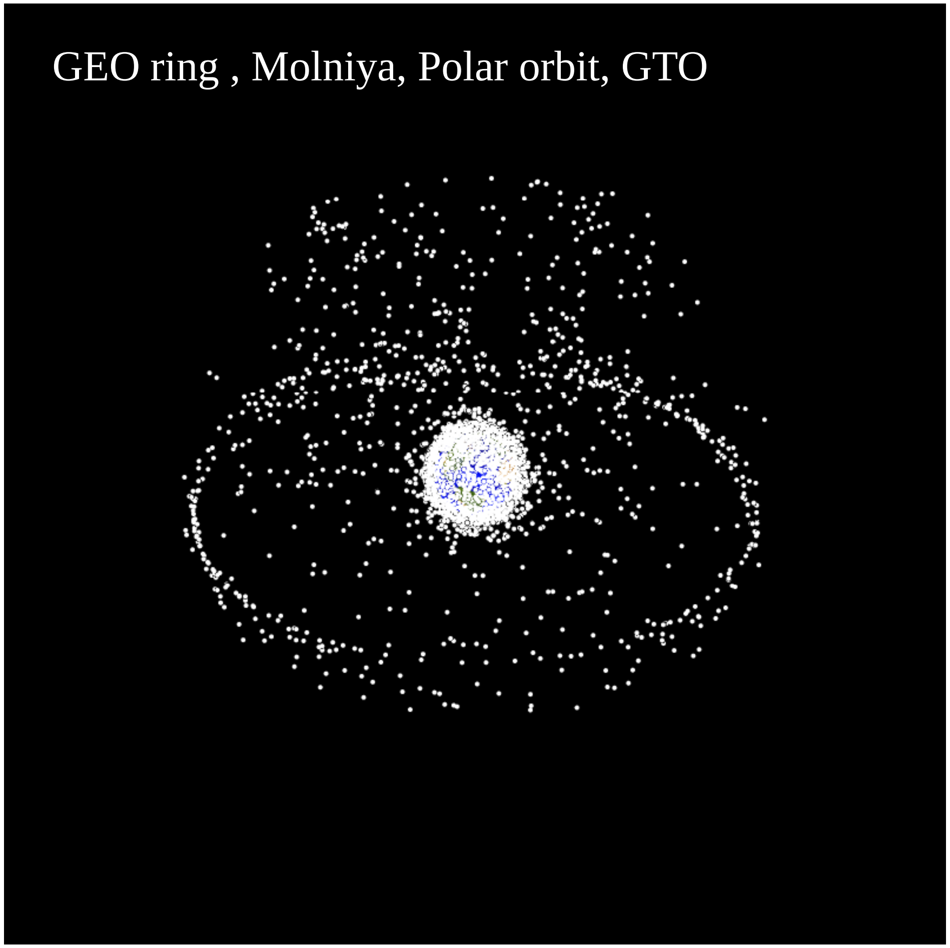


Cataloged objects >10 cm diameter

Back up slide - Orbital Debris Growth

1990 = 6000+ objects

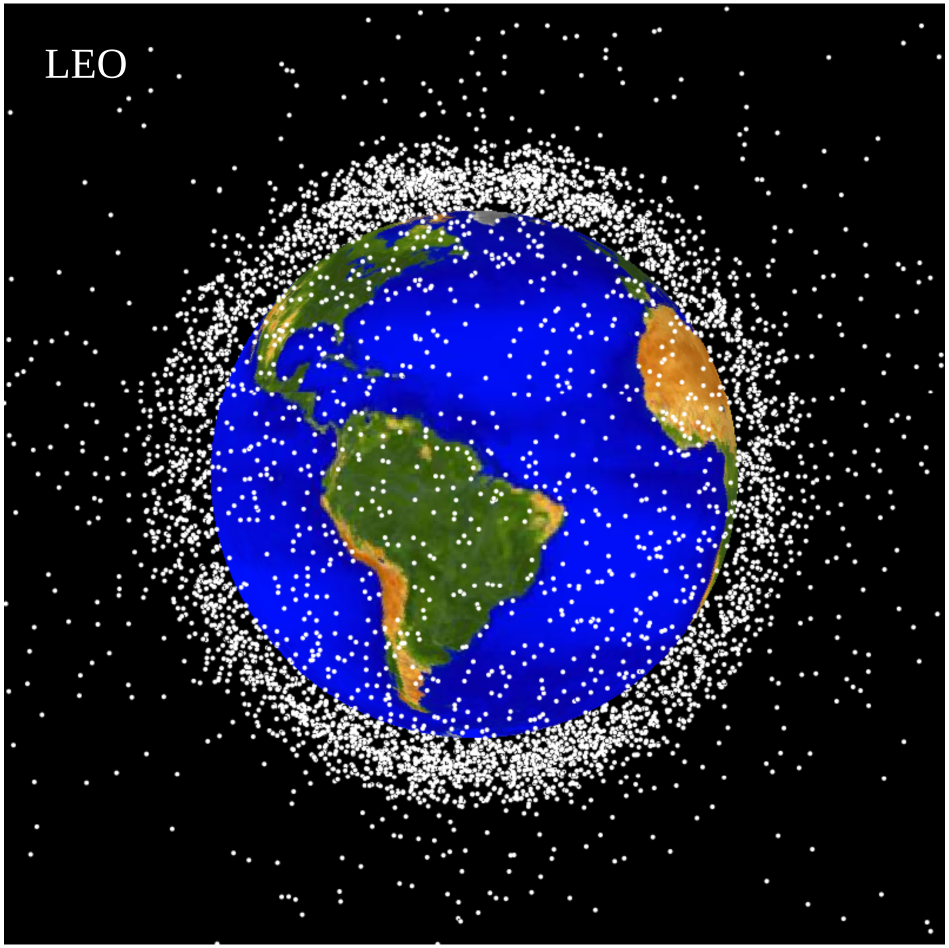


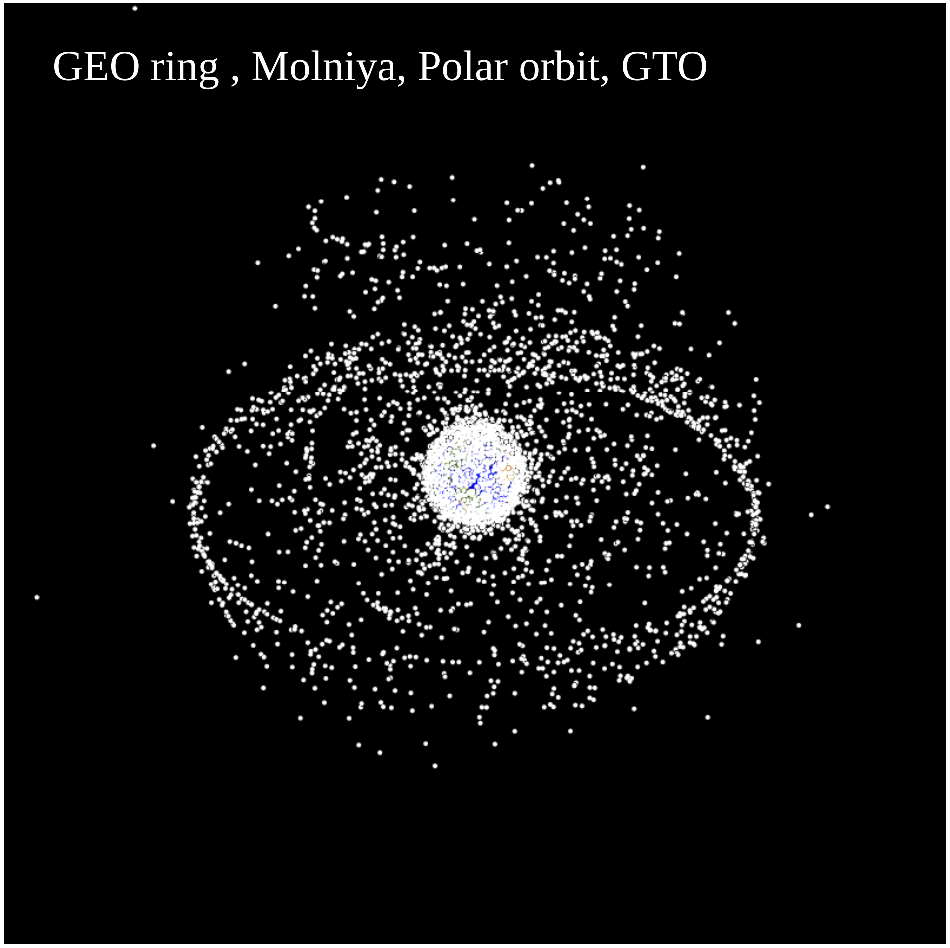


Cataloged objects >10 cm diameter

Back up slide - Orbital Debris Growth

2000 = 8900+ objects





Cataloged objects >10 cm diameter

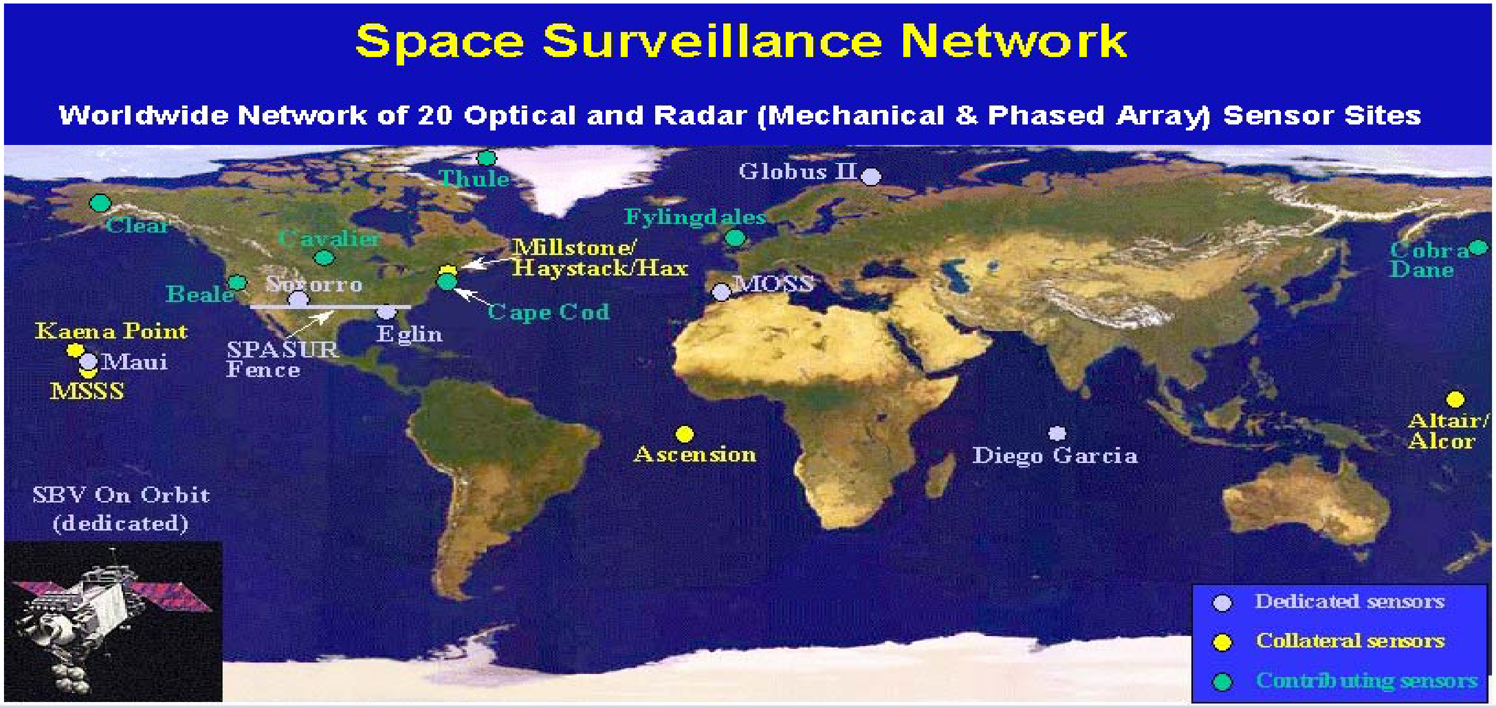
Back up slide - Orbital Debris Background

Orbital Debris = all space objects non-functional and human-made

- First launch in 1957 started growth of the orbital debris population (R/B from Sputnik Launch = SSN 1)
- First satellite break-up in 1961
- Low Earth Orbit (LEO) debris can travel at speeds of ~7 km/s and ~3 km/s in Geosynchronous Earth Orbit (GEO)

Back-up slide: SSN

- **Space Surveillance Network (SSN) routinely tracks targets >10 cm**
  - Catalogued objects: objects with multiple detections, orbits established (~12,500)
  - Tracked objects: detected at least once, may not be included in catalogue (~17,000)



Back up slide - Other Ground-Based Sensors

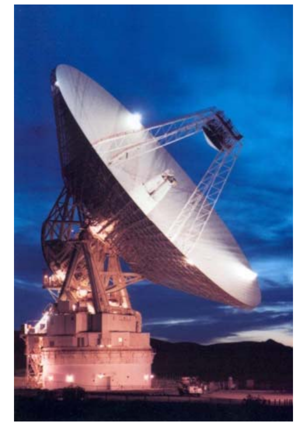
- **Ground-based remote systems able to detect objects as small as 2 mm in LEO and 10 cm in the GEO regime**

ESA 1m telescope

MODEST (0.6 Schmidt) located near La Serena, Chile at the Cerro Tololo Inter-American Observatory

3.67 m Advance Electro-Optical System (AEOS) telescope, Maui, Hawaii

Haystack and HAX radars located in Tyngsboro, MA

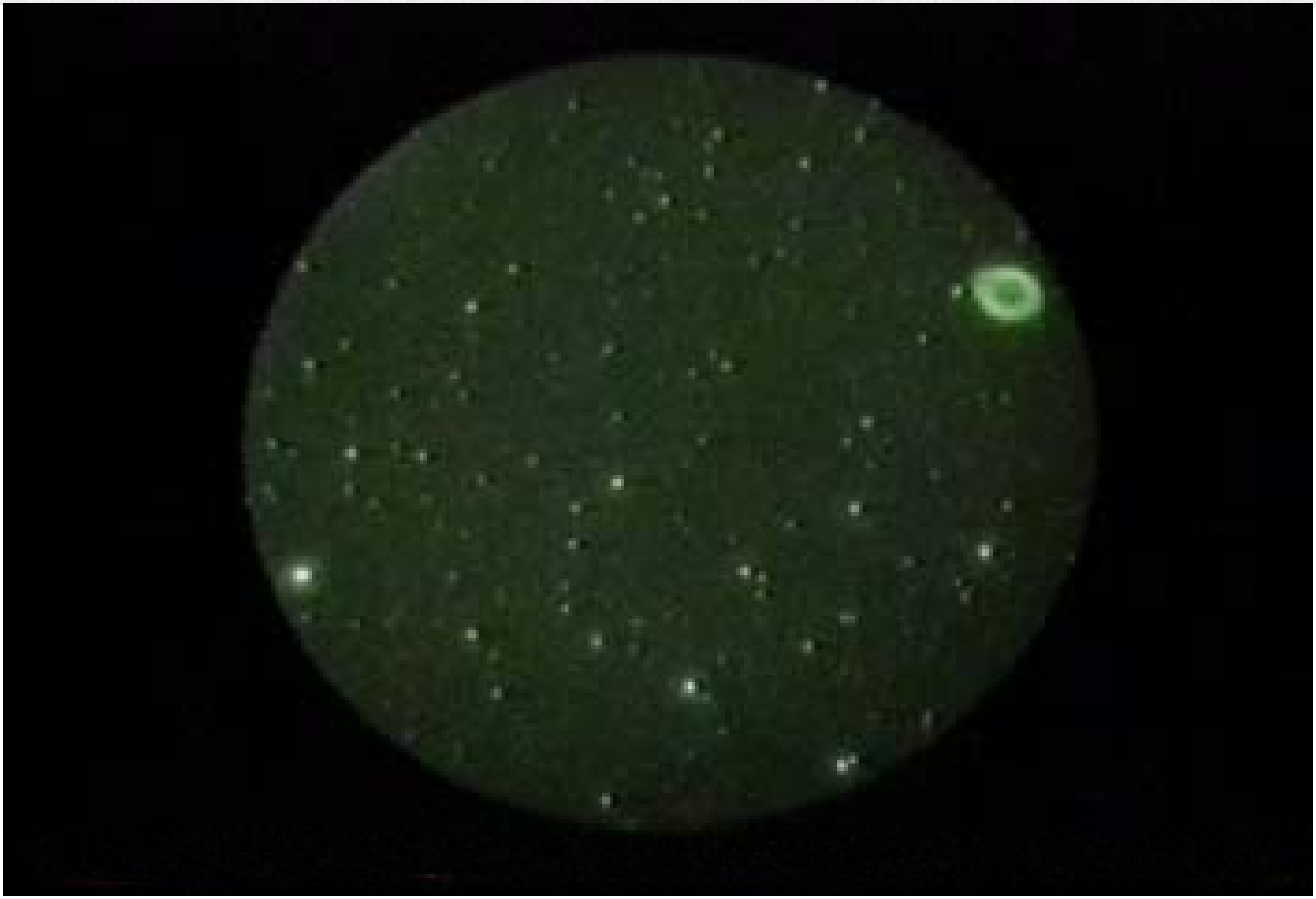


Goldstone-70m dish located in Barstow, CA

Observational Data	Region/Size
SSN catalog (radars, telescopes)	LEO > 10 cm, GEO > 70 cm
Cobra Dane (radar)	LEO > 4 cm
Haystack (radar)	LEO > 1 cm
Goldstone (radar)	LEO >2 mm
STS windows and radiators (returned surfaces)	LEO < 1 mm
HST solar panels (returned surfaces)	LEO < 1 mm
MODEST (telescope)	GEO > 30 cm

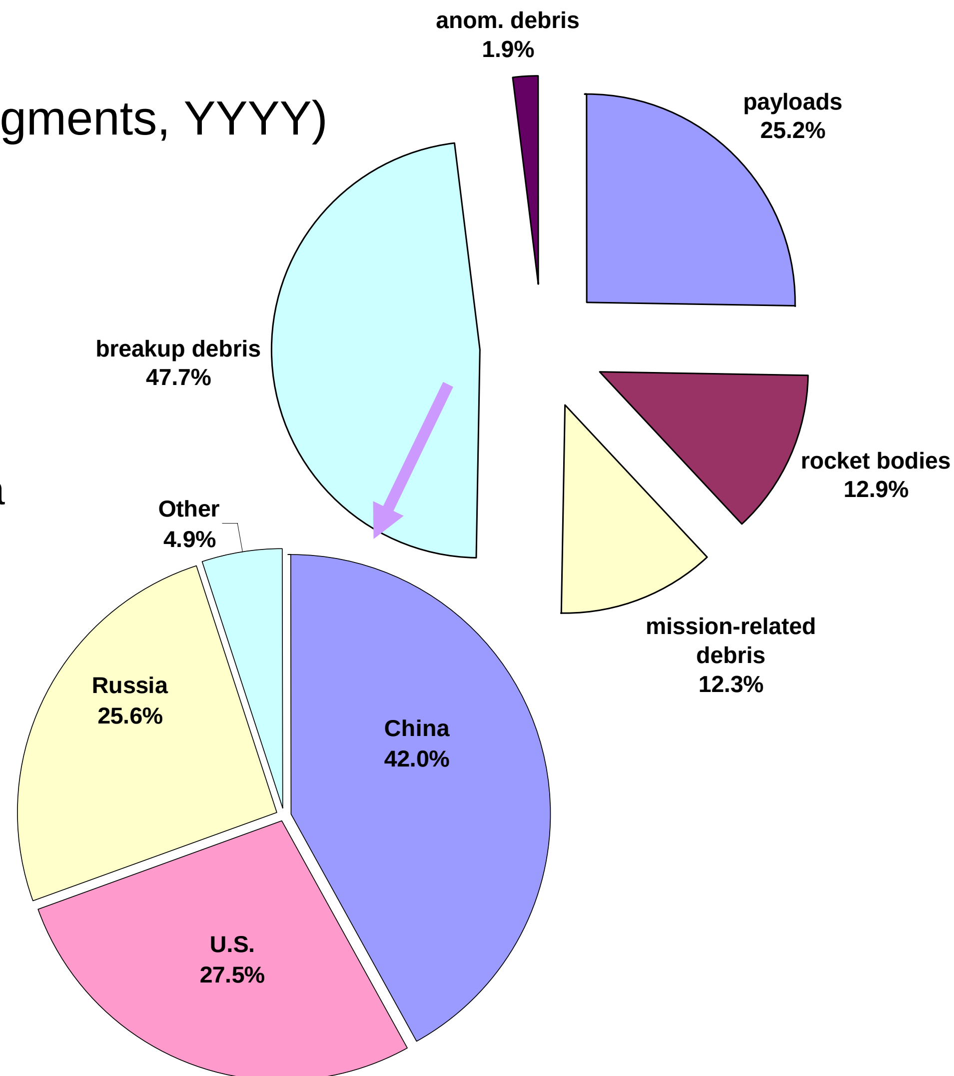
Cobra Dane radar located on Shemya Island, AK

Back up - Orbital Debris Seen From LMT



Back up - Sources of the Catalogued Population

- **Approximately 4500 launches conducted worldwide since 1957**
- **Known breakups = 197**
  - Major events: (number of catalogued fragments, YYYY)
    - Titan Transtage (473, 1965) – U.S.
    - Agena D stage (373, 1970) – U.S.
    - COSMOS 1275 (309, 1981) – Russia
    - Ariane 1 stage (489, 1986) – Europe
    - Pegasus HAPS (709, 1996) – US
    - Long March 4 stage (316, 2000) – China
    - PSLV (326, 2001) – India
    - Fengyun 1C (>2500[a], 2007) – China
    - Briz-M (>1000[b], 2007) – Russia



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

Slide 38

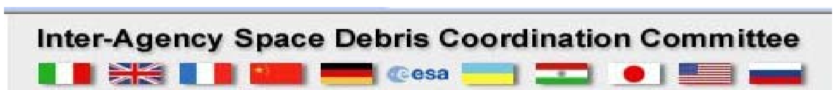
L36 Running into Meatball logo

LMIT-ODIN, 4/21/2009

Back up - Assessing the Problem: Involvement

The orbital debris issue is being addressed at national and international levels

- **U.S.:**
  - U.S. Government Orbital Debris Mitigation Standard Practices
  - NASA Procedural Requirements (NPR) and NASA Technical Standard (NS) on Orbital Debris

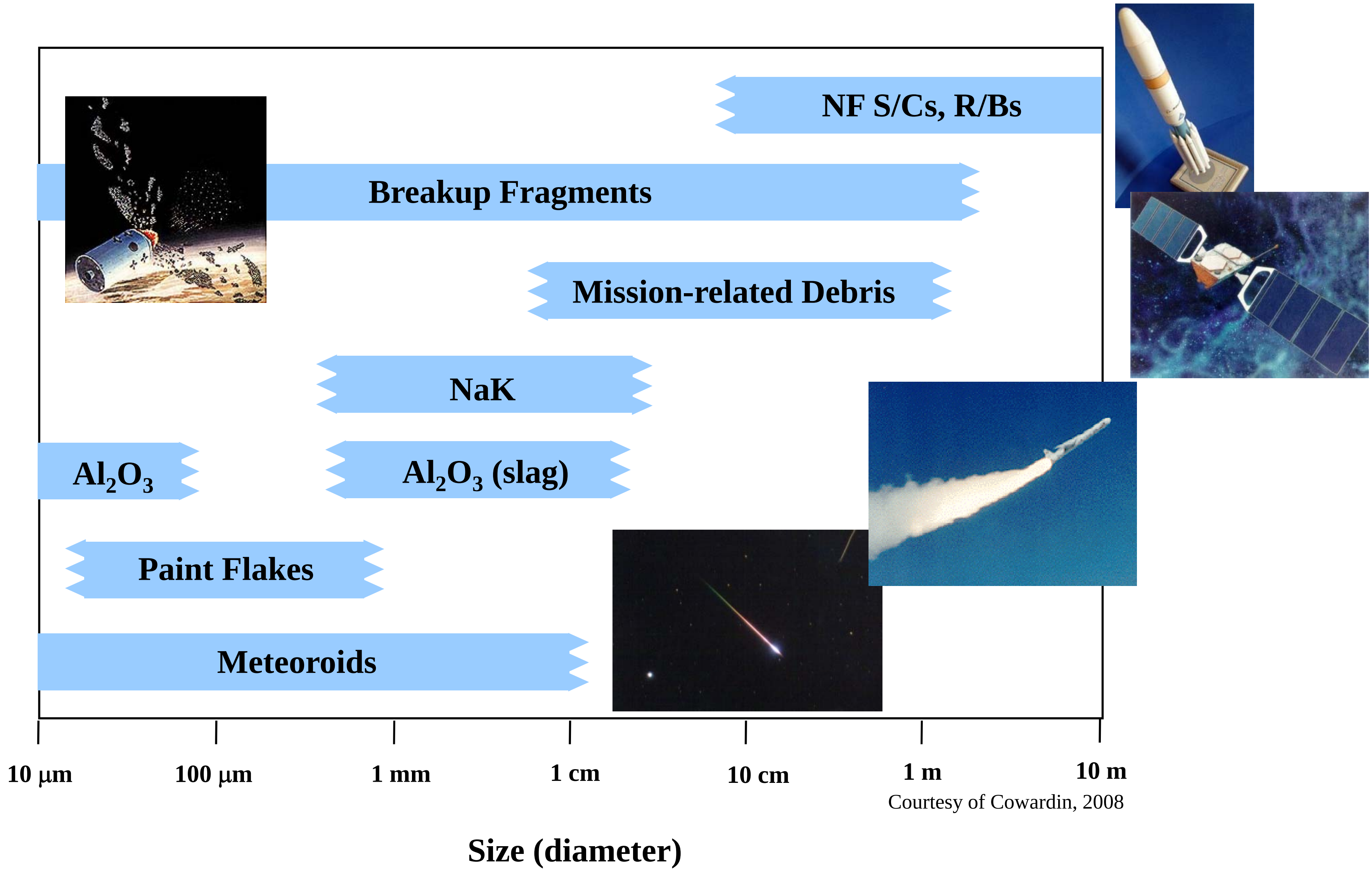


- **IADC:**
  - ASI (Agenzia Spaziale Italiana)
  - BNSC (British National Space Centre)
  - CNES (Centre National d'Etudes Spatiales)
  - CNSA (China National Space Administration)
  - DLR (German Aerospace Center)
  - ESA (European Space Agency)
  - NSAU (National Space Agency of Ukraine)
  - ISRO (Indian Space Research Organisation)
  - JAXA (Japan Aerospace Exploration Agency)
  - NASA (National Aeronautics and Space Administration)
  - ROSCOSMOS (Russian Federal Space Agency)

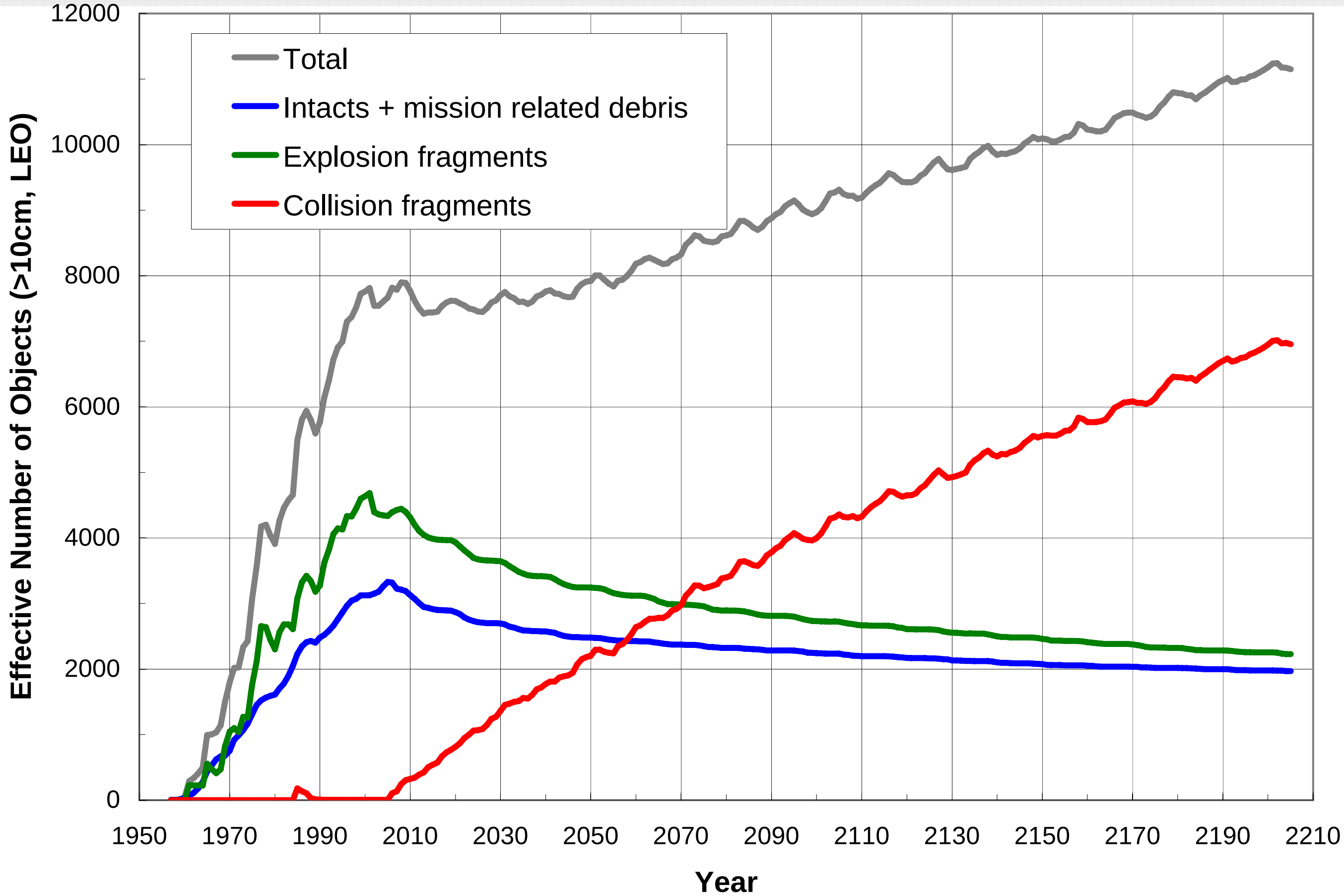
- **COPUOS: United Nations Committee on Peaceful Uses of Outer Space**
  - Started in 1959, currently has *69* member states
  - Albania, Algeria, Argentina, Australia, Austria, Belgium, Benin, Bolivia, Brazil, Bulgaria, Burkina Faso, Cameroon, Canada, Chad, Chile, China, Colombia, Cuba, Czech Republic, Ecuador, Egypt, France, Hungary, Germany, Greece, India, Indonesia, Iran, Iraq, Italy, Japan, Kazakhstan, Kenya, Lebanon, Libyan Arab Jamahiriya, Malaysia, Mexico, Mongolia, Morocco, Netherlands, Nicaragua, Niger, Nigeria, Pakistan, Peru, Philippines, Poland, Portugal, Republic of Korea, Romania, the Russian Federation, Saudi Arabia, Senegal, Sierra Leone, Slovakia, South Africa, Spain, Sudan, Sweden, Switzerland, Syrian Arab Republic, Thailand, Turkey, the United Kingdom of Great Britain and Northern Ireland, the United States of America, Ukraine, Uruguay, Venezuela & Viet Nam

- **ISO**: International Standards Organization Technical Committee "Aircraft And Space Vehicles" Sub-Committee "Space Systems And Operations”
  - Development of standards to address implementation of measures associated with debris mitigation

Orbital Debris Population Breakdown



Back up - The Growth of LEO Populations ("No Future Launches" Scenario)

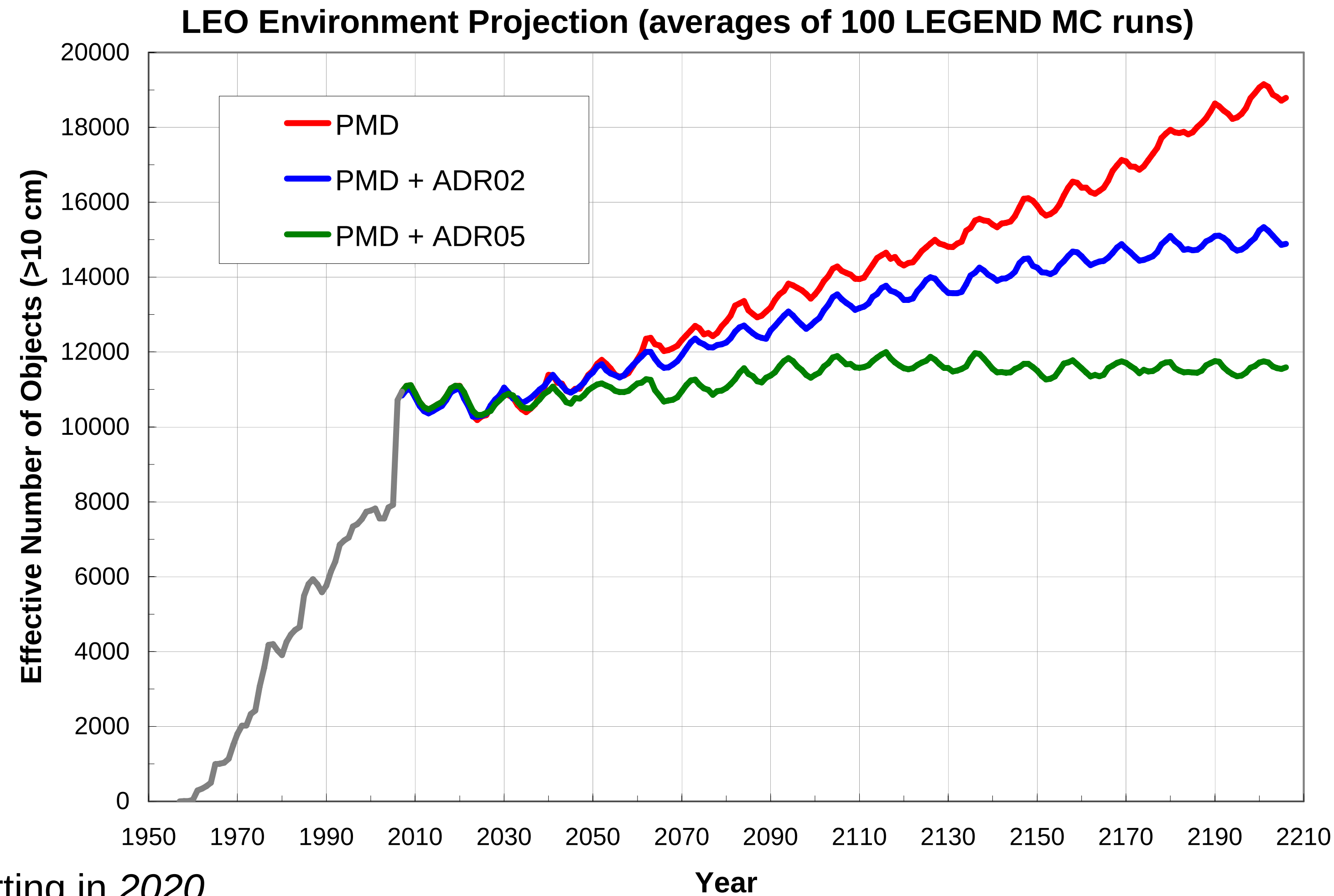


SCIENCE 20 January 2006

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

Back up - Active Debris Removal – The Next Step in LEO Debris Mitigation



Starting in *2020*

PMD scenario predicts the LEO populations would increase by ~75% in 200 years

The population growth could be reduced by half with a removal rate of 2 obj/year

LEO environment could be stabilized with a removal rate of 5 obj/year

Back up – Orbit Propagation