National Aeronautics and Space Administration
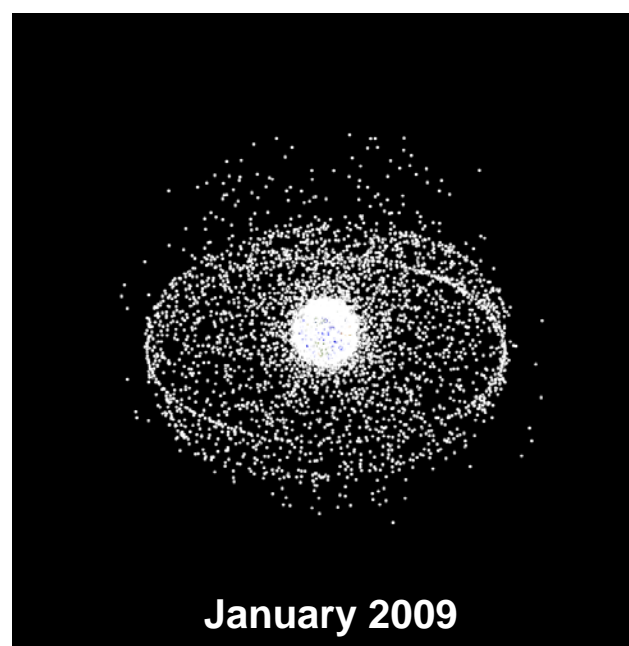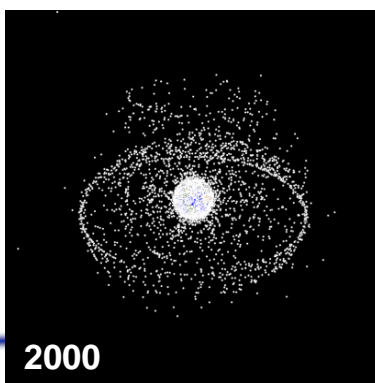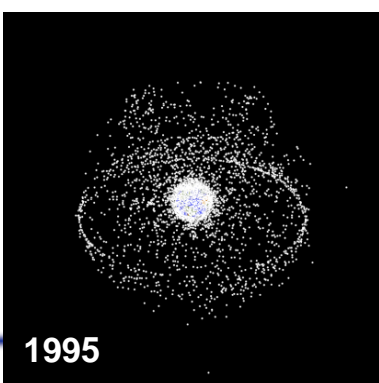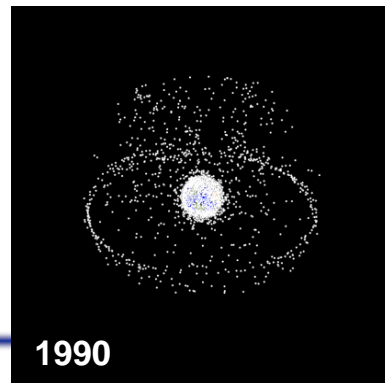
Orbital Debris Research in the United States

Gene Stansbery
Program Manager

NASA Orbital Debris Program Office
Lyndon B. Johnson Space Center

June 2009

Growth of the Satellite Population
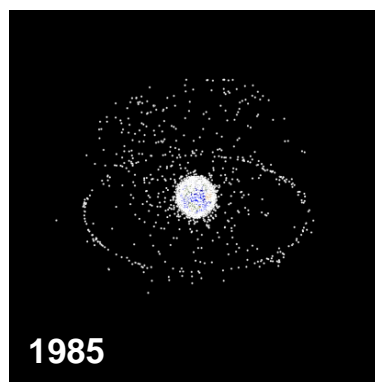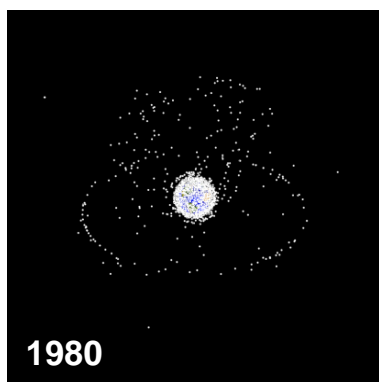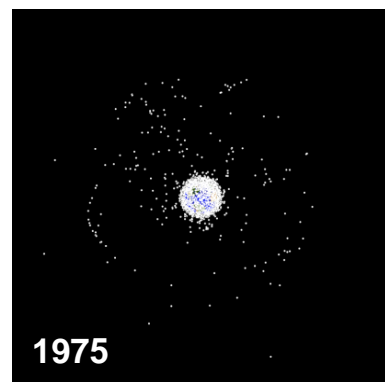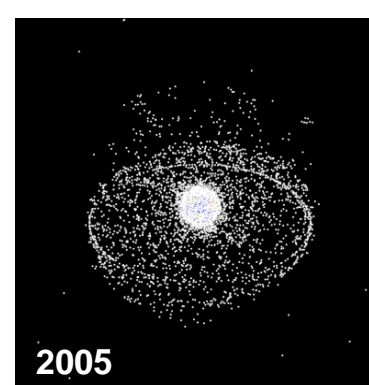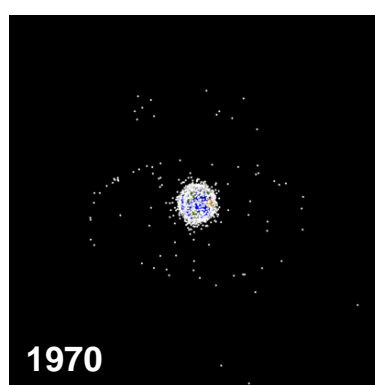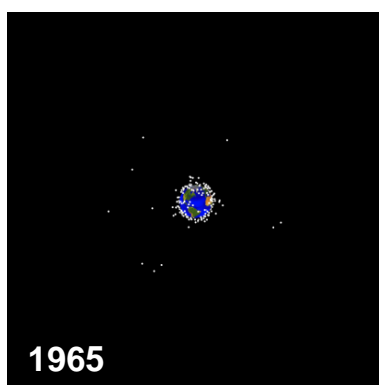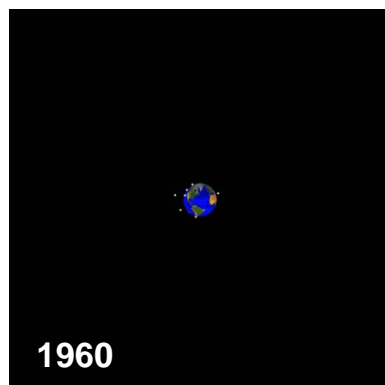
94% of Tracked Object Population are Debris
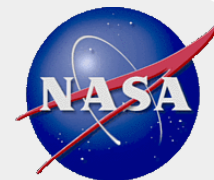
US Space Surveillance Network

MSX / SBV

THULE

GLOBUS II

CLEAR

FYLINGDALES

CAVALIER

LSSC

BEALE CAPE COD

MOSS

COBRA DANE

AFSSS

SOCORRO EGLIN

AMOS

ASCENSION

DIEGO GARCIA

Kwajalein
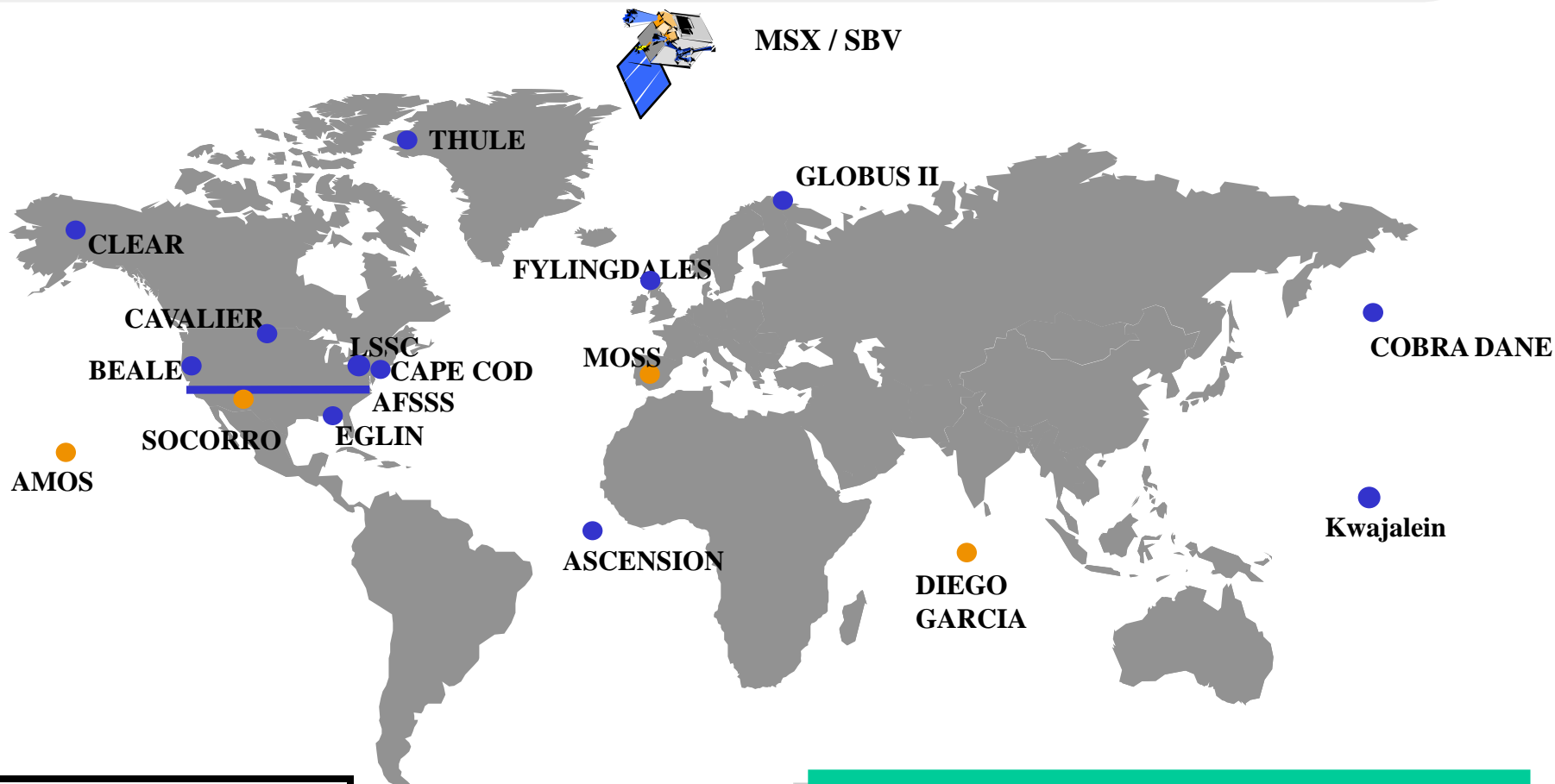
● **Radar**

● **Optical Telescope**

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

Tracking and Catalog Maintenance

- **The US Department of Defense maintains a worldwide network of sensors which catalogs and tracks man-made orbital debris**
  - Although some cataloged debris is as small as 5 cm diameter, the nominal size of debris in the catalog is 10 cm in low earth orbit and 1 m at geosynchronous altitudes
  - Catalog currently has approximately 14,000 objects in orbit
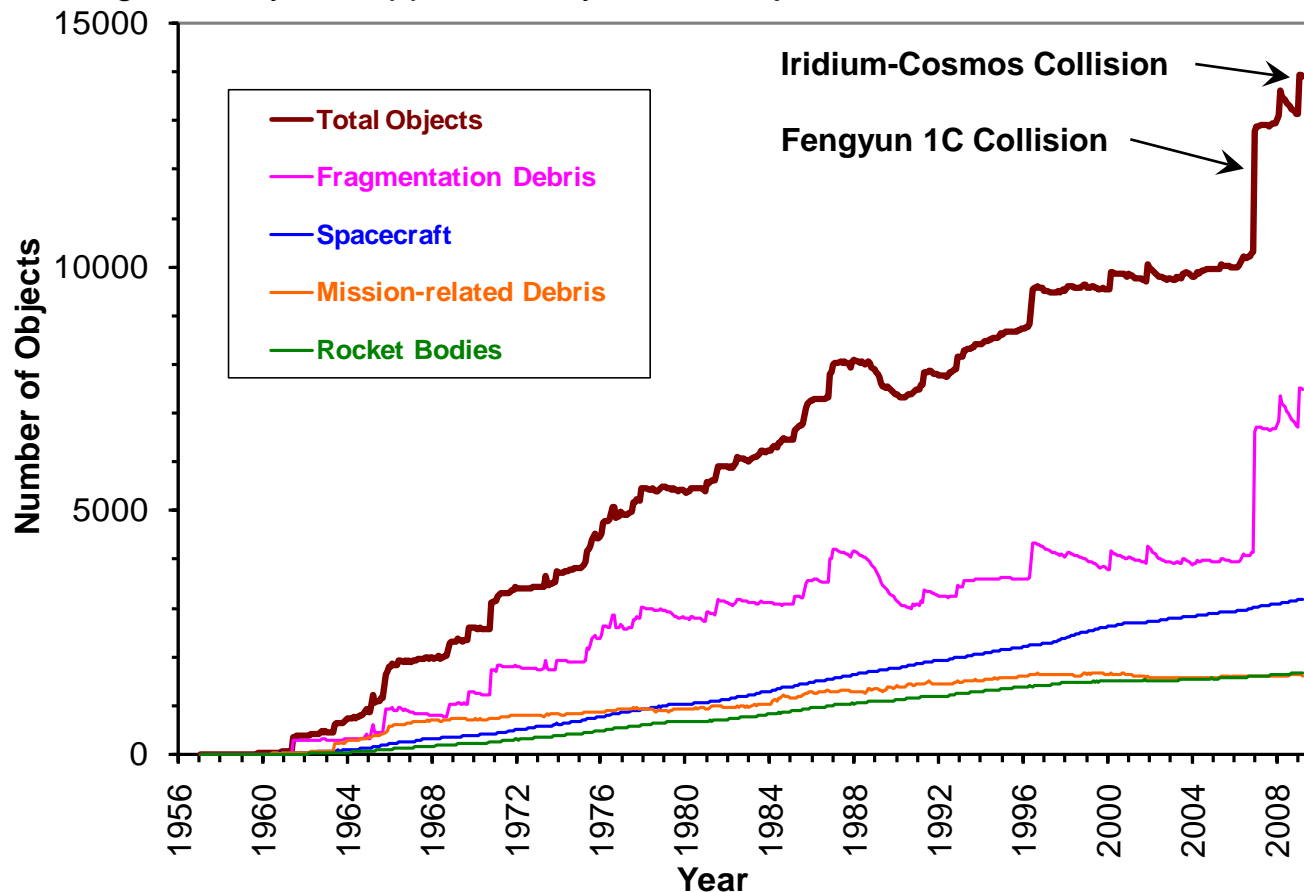
Haystack and HAX Radars

- **Orbital Debris Radar Observations – Objective**

  – Haystack and HAX are the prime sources of data for orbital debris smaller than 10cm. Haystack and HAX collect debris data in the critical size region between 1cm and 10cm.
  – Both radars annually collect between 500 hours to 700 hours of debris observation data which provides enough statistics for developing orbital debris models.

- **Radar Description**

  – Collocated in Tygsboro, Massachusetts at a latitude of 42.6 .
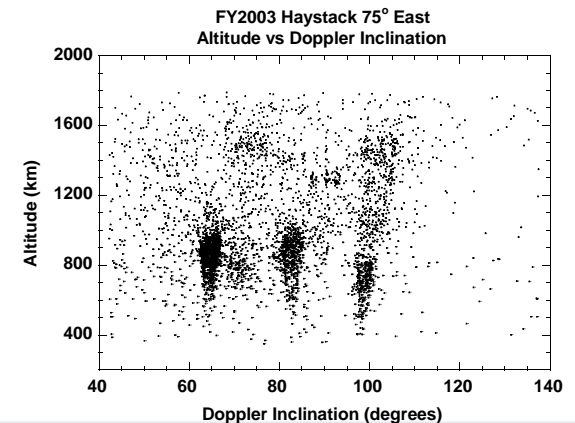 – The main reflector of the Haystack and HAX radars are 36.6m and 12.2m diameter, respectively.
  – A pulsed continuous wave (CW) single frequency waveform is used for debris detection. Haystack transmits X-band and HAX transmits K-band.
  – Both radars observe a range window of ~ 300 to 1900 km.
  – Haystack can observe debris down to 5 mm and HAX can observe down to 2cm for LEO observations.

- **Data Collection and Processing**

  – NASA conducted the Orbital DEbris RAdar Calibration Spheres (ODERACS) experiments on two space shuttle missions in 1994 and 1995 to validate data processing at NASA JSC.
  – The experiments showed that the Haystack radar is calibrated within nominal limits, with measured RCS values accurate to ±1.5dB.

FY2003 Haystack 75° East
Altitude Distribution, 100 km bins, Diameter > 0.01 m

Flux (counts/m² / year) vs Altitude (km)

FY2003 Haystack 75° East
Altitude vs Doppler Inclination

Altitude (km) vs Doppler Inclination (degrees)
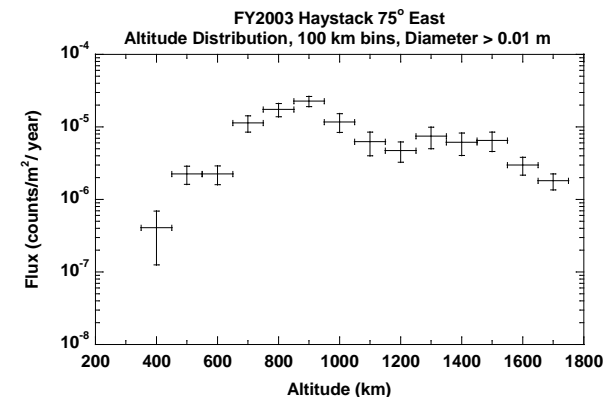
Goldstone Radar

- **Goldstone Radar Overview**
  - The NASA Jet Propulsion Laboratory Goldstone radar is used on a limited basis to supplement orbital debris observations made by Haystack and HAX.
  - Collects nearly 100 hours of data annually
  - Goldstone provides a measurement of the debris environment between 2 mm and 1 cm.
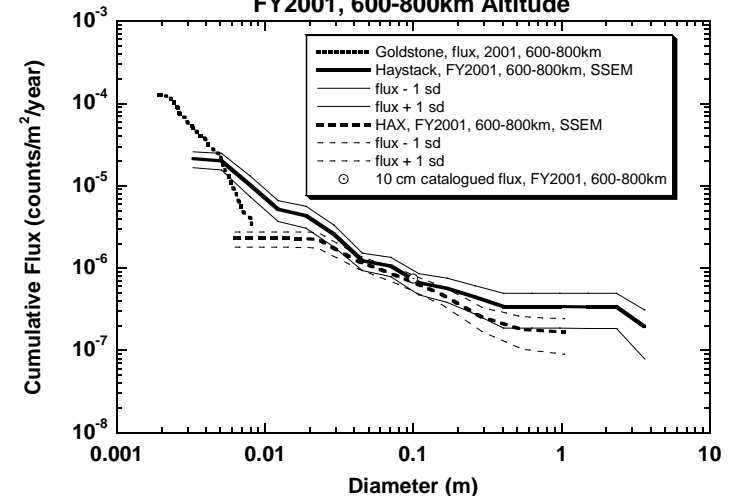
- **Radar Description**
  - Collocated in southern California's Mojave desert at a latitude of 35.2 .
  - Pairs of up chirp and down chirp X-band pulses are used for debris detection.
  - Observable range window of ~ 350 to 3300km.
  - Observable range rates of 0.85km/s.
    - This dictates a staring observation mode near the zenith which makes Doppler inclination measurements unreliable.
    - Upgrades to the data acquisition system are currently being tested to increase the observable range rates. This would allow pointing away from the zenith and hence a reliable Doppler inclination measurement.
  - The radar cross section measurements have greater uncertainties than that of Haystack or HAX since the Goldstone radar:
    - does not calibrate using a calibration satellite
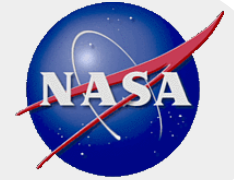   - does not have a monopulse system to determine the position of the debris within the radar beam.

- **Data Collection and Processing**
  - The data collected at the radar is processed at JSC using software supplied by JPL.
  - The processed data is thoroughly inspected at JSC for quality control before subsequent extensive analysis.

Goldstone, Haystack, HAX, and 10cm Catalogued Flux FY2001, 600-800km Altitude

Legend:
- Goldstone, flux, 2001, 600-800km
- Haystack, FY2001, 600-800km, SSEM
- flux - 1 sd
- flux + 1 sd
- HAX, FY2001, 600-800km, SSEM
- flux - 1 sd
- flux + 1 sd
- ⊙ 10 cm catalogued flux, FY2001, 600-800km

Y-axis: Cumulative Flux (counts/m^2/year)
X-axis: Diameter (m)

Michigan Orbital Debris Survey Telescope (MODEST)

- **GEO debris survey telescope (0.6/0.9 Schmidt Telescope)**
- **Located near La Serena, Chile at the Cerro Tololo Inter-American Observatory (CTIO)**
- **Collecting data since 2002**
- **Data used in modeling of the future environment (sample data shown middle right)**
- **Limiting Magnitude ~ 19 M_v in R (corresponding to a size of 30 cm if you assume 0.13 albedo)**
- **Figure (bottom right) shows a probability map of where we have looked and the detections seen**
  - Red shows the orbit planes that were the most visible, while blue shows the orbit planes that were the least visible
  - Solid diamonds are correlated targets and the open circles are uncorrelated targets
- **Status of Survey Project**
  - Collecting survey data every observing run
  - Collecting light curve data in specific photometric bands on uncorrelated targets
  - Use of two telescopes to refine orbits and the orbit determination process
- **Special Projects – High Area-to-Mass (A/m)**
  - Joint project through IADC for objects of high A/m
  - Following IADC high A/m objects at sites around the world for a more complete orbit
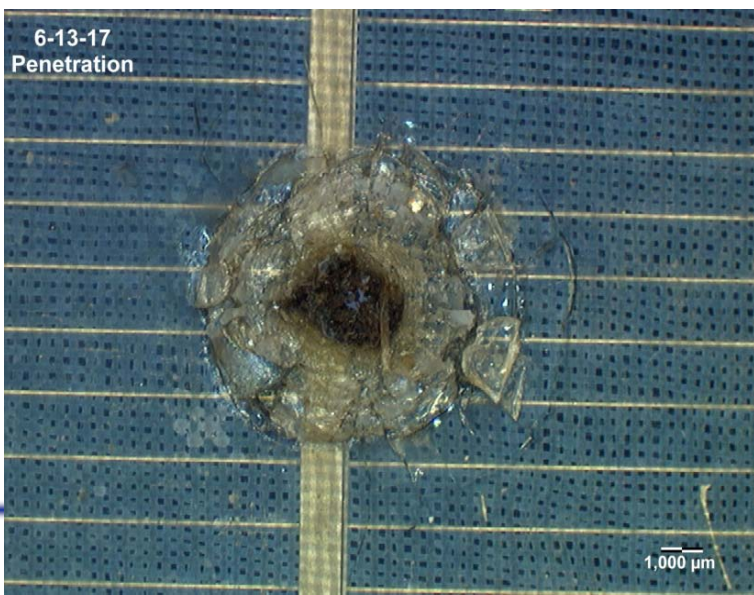 - Efforts being made to determine source and material of these objects
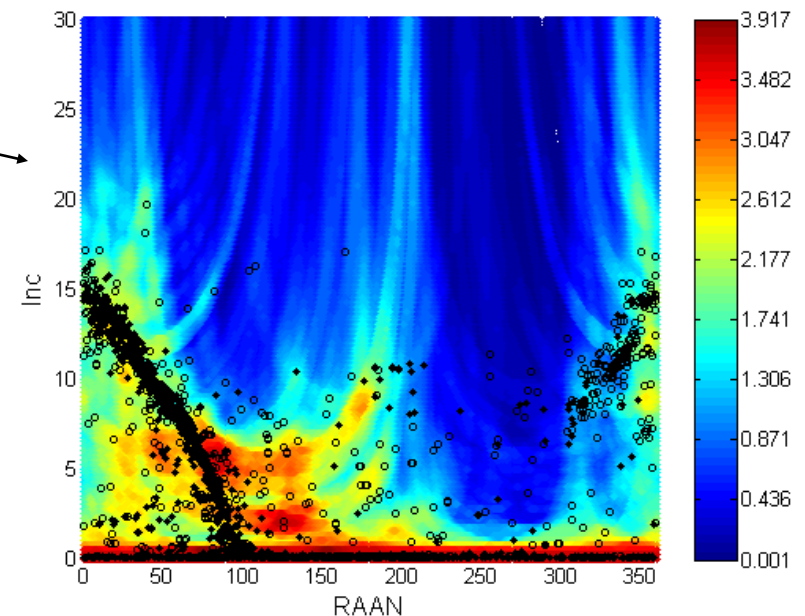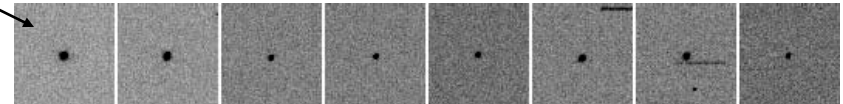
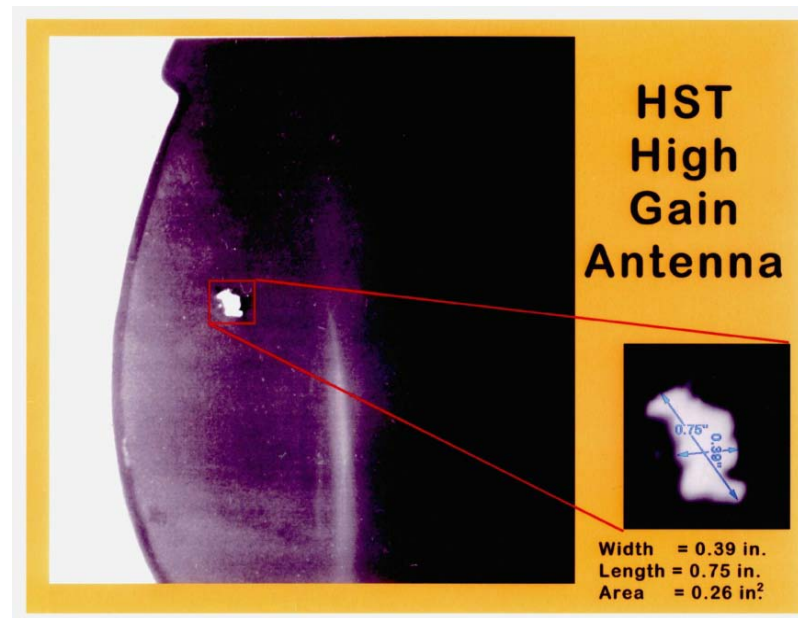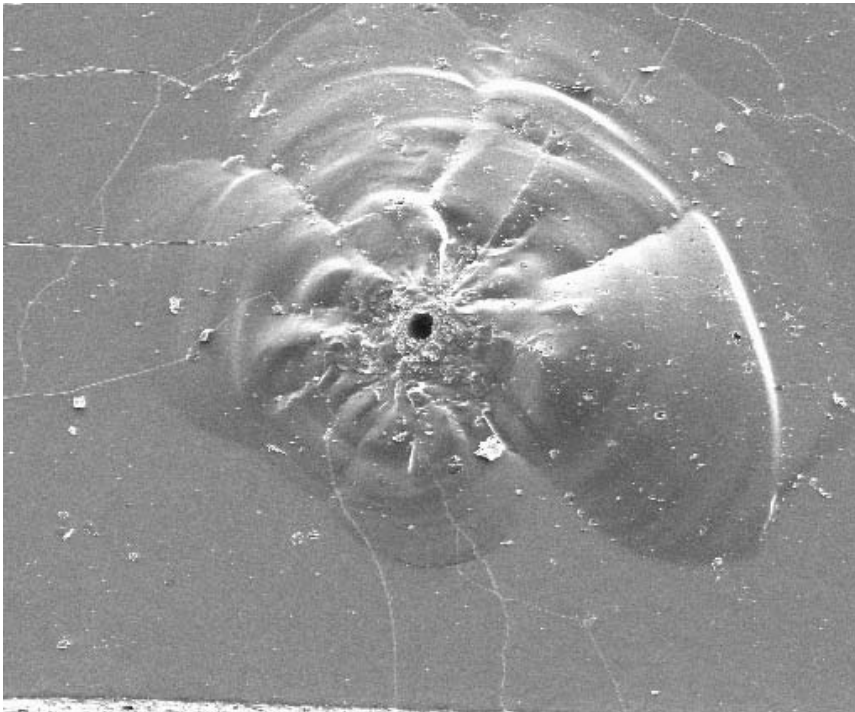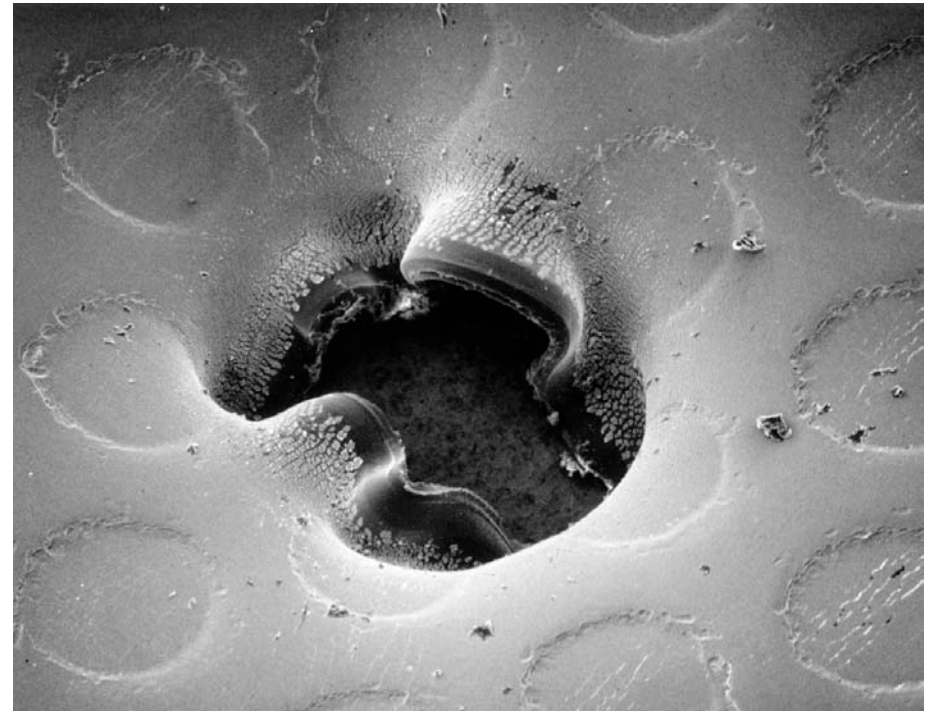# Spacecraft Surface Examinations
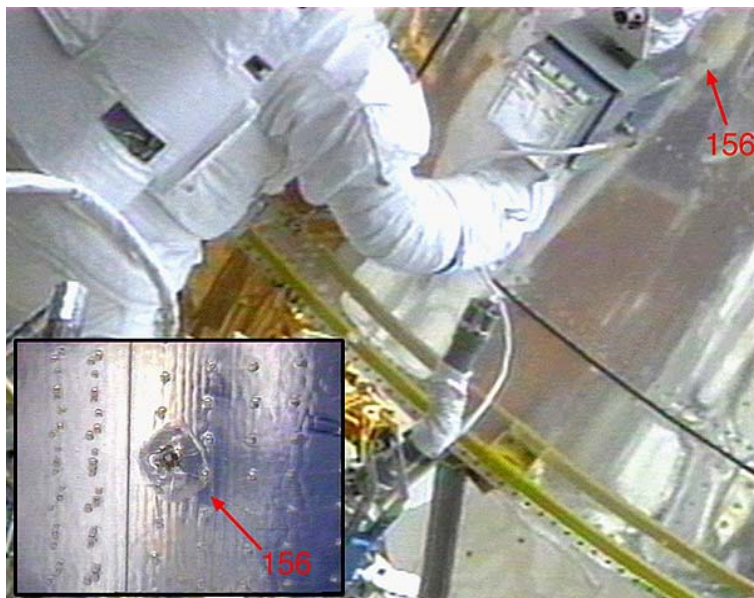
HST

Mir

ISS
MPLM

Sample Space Shuttle Impacts

STS-92 Window Impact

~0.1 mm Aluminum Debris

2 mm diameter crater

STS-90 Radiator Penetration

~0.3 mm Paint Particle

1 mm diameter hole

STS-115 Radiator Impact

Outer Face Sheet Damage

Inner Face Sheet Damage

0.011" Facesheet
3/16" Cell 3.1 Pcf Al Core

Entry hole, 0.108"

0.5"

AFT Rad (Typ.)
26 Tubes/Pnl
15.1 ft x 10.5 ft/Pnl
4 Pnls/Veh

Hole, 0.031"
Crack, 0.267"

Core damaged across
~ 5 cells (1" diameter
x 0.5" deep)

Bonded Al Strip
(0.01" H x 0.4" W x 15' L)

0.005" Silver-Teflon Tape
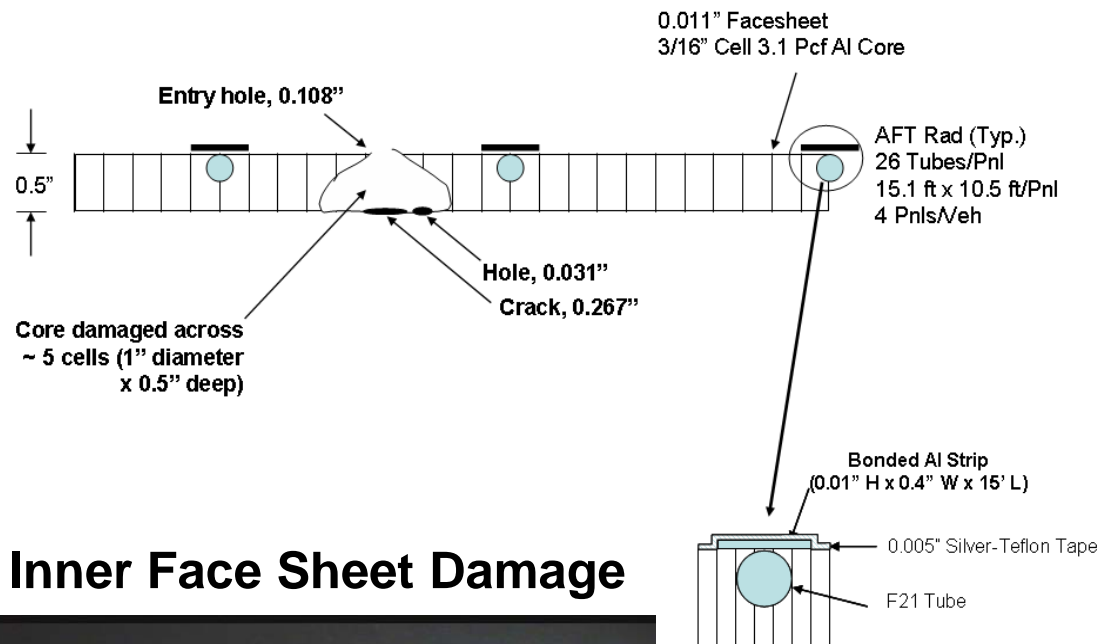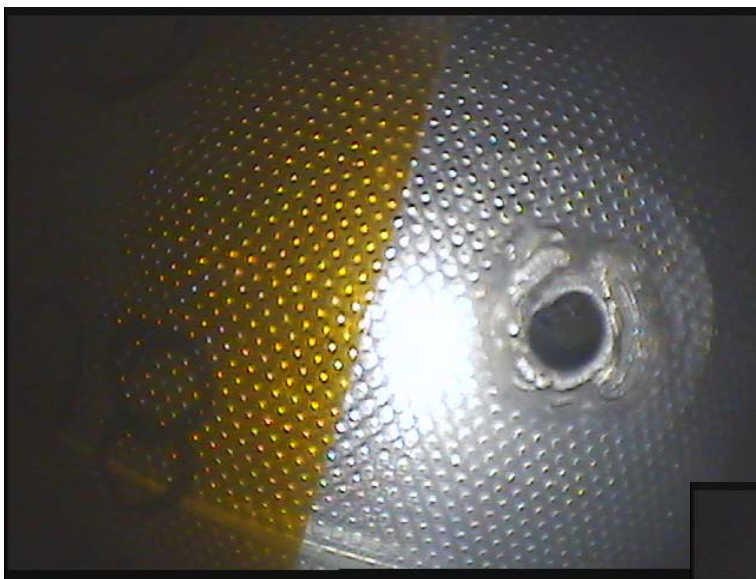
F21 Tube
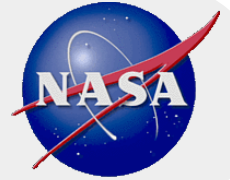
GEO/LEO Observations from Kwajalein Atoll

- **GEO**
  - Comprehensive assessment of debris environment
    - High A/m debris
    - Determination of orbital parameters as inputs to NASA's environment model
  - Current capability
    - Broadband color photometry of targets to 16th magnitude (~50 cm diameter) via an autonomous 0.35 m telescope (an element of the AFRL High Accuracy Network Determination System – HANDS).
  - Planned capability
    - Designing a 1.3 m, 0.96 deg FOV autonomous survey telescope (Meter Class Autonomous Telescope - MCAT to be installed 3Q 2010) for detection and multi-spectral (Optical/NIR) photometry of targets to 20th magnitude (10 cm diameter)

- **LEO**
  - MCAT will detect new LEO debris and enable a statistical assessment of the low-inclination (0-20 deg) debris environment in the 1-10 cm diameter size regime
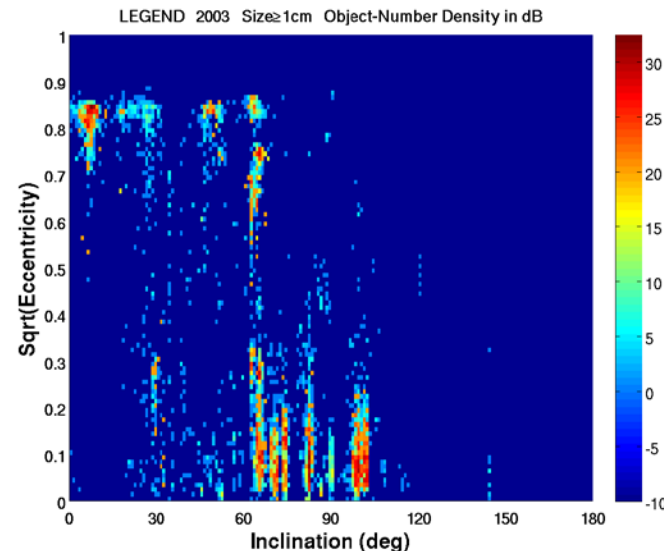
# NASA Orbital Debris Engineering Model: ORDEM2008

- **The ORDEM series of models is in the process of an upgrade to ORDEM2008**
  - Time range – 1995 to 2035
  - Altitude range – 200 km to 38000 km
  - Size range – 10 μm to 1 m
- **Main Datasets and complementary Models**
  - SSN, Haystack, STS window impacts, MODEST
  - LEGEND, NaKModule, SRMSlag, Degradation/Ejecta
- **Statistical estimation of ORDEM2007 OD populations**
  - The Bayesian algorithm developed in the statistical size estimation model (SSEM) is used throughout
    - **Particularly suitable for data in the form of counts**
    - **Allows propagation of uncertainties**
  - Based on reference populations such as LEGEND, NaK Module, SRM slag model …
  - Populations estimated for each year from 1995 to 2035

NoNak(NoCat.) 2003 Haystack 75°East WFC4
obs.hrs: 633.3   counts: 1346 (range: -100km; size>0.01m)
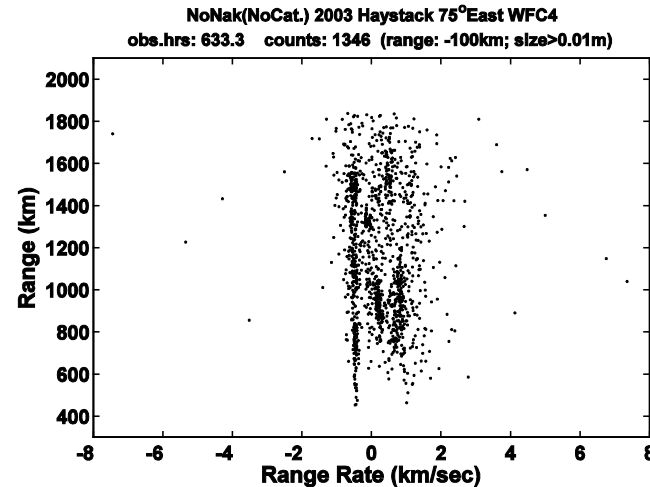
Haystack Detections: Fragments size $\geq$ 1 cm FY2003

LEGEND 2003 Size≥1cm Object-Number Density in dB


Estimated Population: (orbital distribution) Fragments size $\geq$ 1 cm FY2003
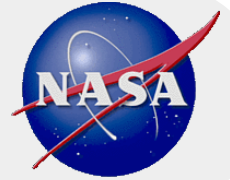
LEGEND
(A <u>LE</u>O-to-<u>GE</u>O <u>En</u>vironment <u>D</u>ebris Model)

- **A state-of-the-art orbital debris evolutionary model**

  - Can mimic the historical environment, and project it into the future (based on user-selected scenarios)

  - Has a fast pair-wise comparison algorithm to estimate P_{col} among orbiting objects

  - Includes two reliable orbit propagators for GEO and LEO/GTO objects

  - Uses the NASA Standard Breakup Model to create simulated breakup fragments

  - Is the tool for the study published in *Science*, and the latest active debris removal analysis
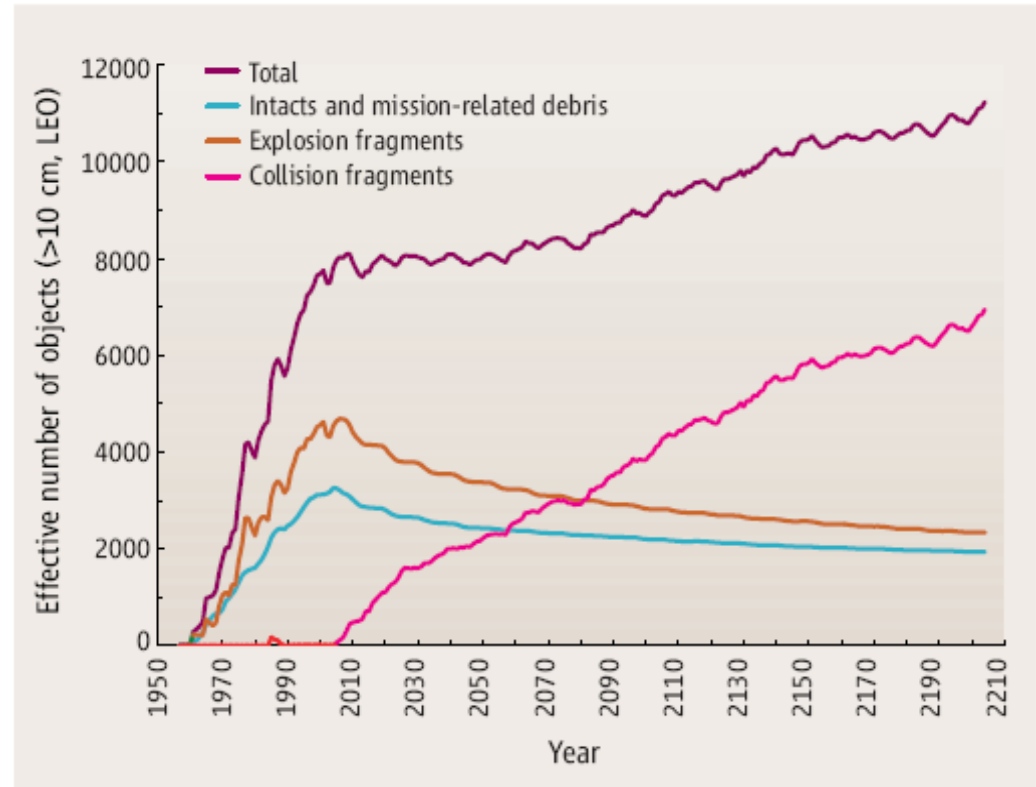

Growth of future debris populations. Effective number of LEO objects, 10 cm and larger, from the LEGEND simulation. The effective number is defined as the fractional time, per orbital period, an object spends between 200- and 2000-km altitudes. Intacts are rocket bodies and spacecraft that have not experienced breakups.

Debris Assessment Software (DAS) 2.0

- **NASA's DAS 2.0 is designed to assist NASA programs in performing orbital debris assessments.**
    - Assessment requirements are described in NASA-STD 8719.14 "Process for Limiting Orbital Debris"
    - DAS 2.0 addresses most requirements point-by-point

- **Recent upgrades to DAS for the 2.0 version include:**
    - Improvements to the orbit propagators and debris environment model
    - Improvements to the reentry survivability model and casualty estimation method
    - Improvements to the user interface and documentation
    - Recommendations from users of the current DAS (1.5.3)
    - Changes in the debris mitigation guidelines
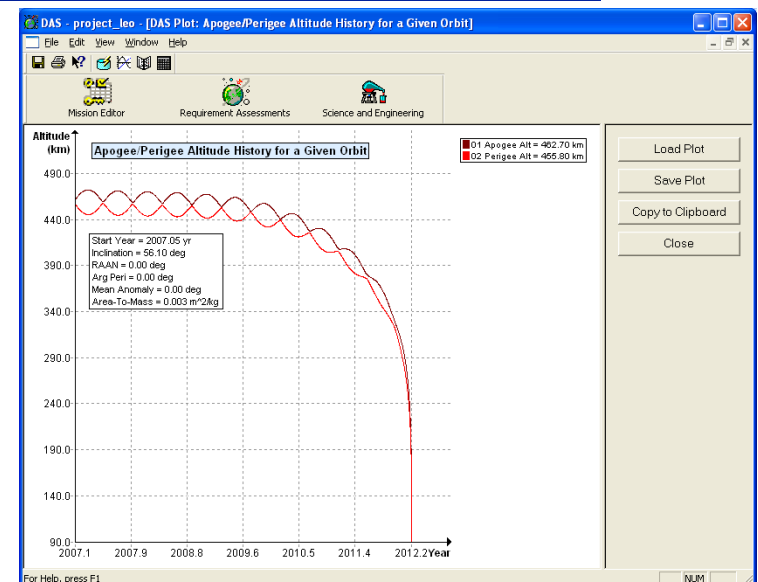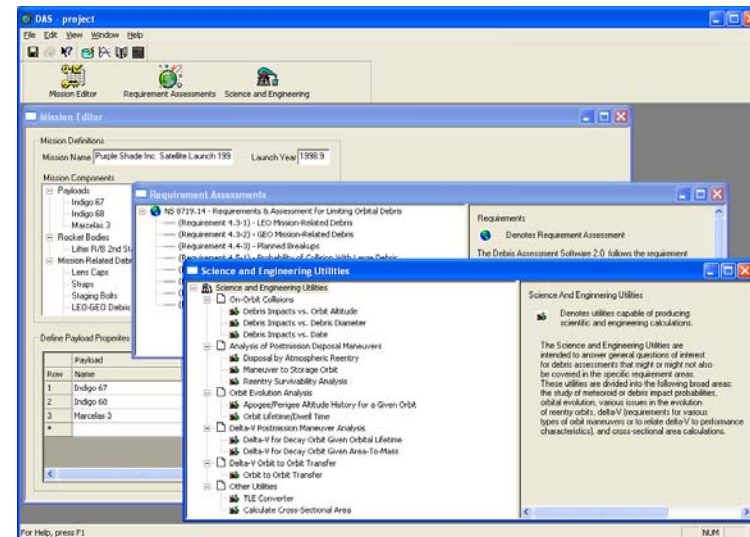
NASA/JSC BUMPER-II Meteoroid/Debris Threat Assessment Code

Spacecraft Configuration (I-DEAS Finite Element Model)
• Describes spatial relationships of spacecraft components
• Defines spacecraft orientation (velocity and zenith directions)
• Defines M/OD shield regions

Zenith
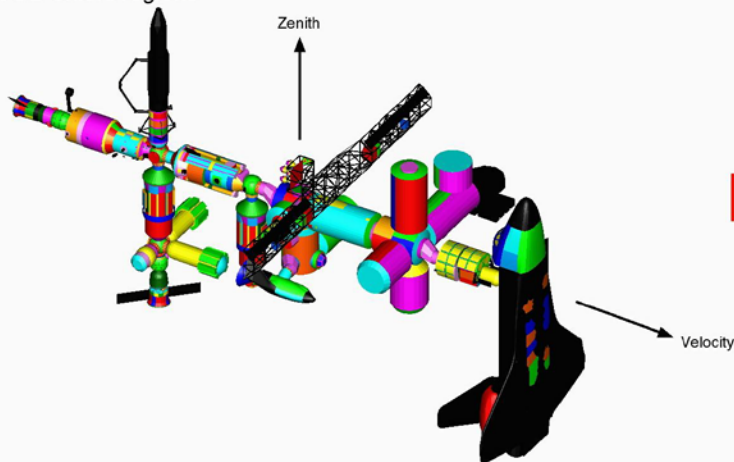
Velocity

• Approximately 120,000 elements in ISS assembly complete mated configuration FEM

Meteoroid & Debris Environments (GEOMETRY)
• Threat directions
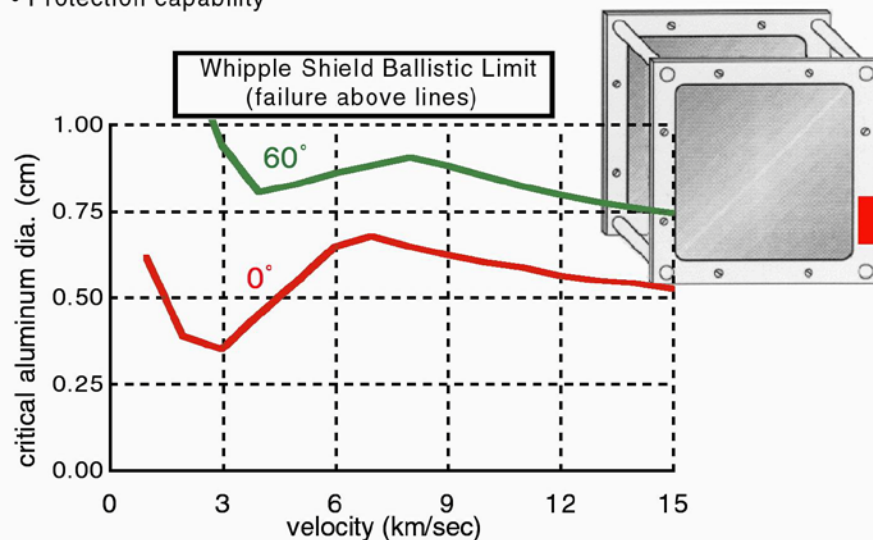• Velocity distribution
• Shadowing

Zenith

Threat Elements
☐ meteoroid
▨ meteoroid and debris

Velocity
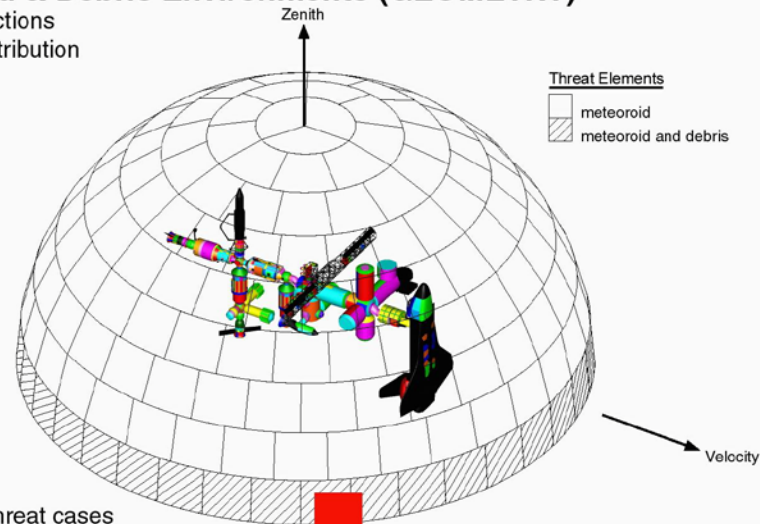
• 90 debris threat cases
  and 149 meteoroid threat cases
  assessed for each element in the FEM

Critical Particle Diameter Calculation (RESPONSE)
• Protection capability

Whipple Shield Ballistic Limit
(failure above lines)

60°

0°

critical aluminum dia. (cm)
velocity (km/sec)

Computation of Penetrating Flux and PNP (SHIELD)
Graphical Interpretation of Results (EXCEL & I-DEAS)

| Space Station Orbital Debris Threat Assessment				
	Impact Risk From 1mm Ø Debris		Debris Penetration Risk	
Station Region	Probability No Impact	Odds of Impact	Probability No Penetration	Odds of Penetration
FGB	0.995338	1/214	0.995541	1/224
Service Module	0.999335	1/1505	0.999796	1/4912
Node 2	0.990465	1/105	0.999998	1/625000
Hab Module	0.965074	1/29	0.998923	1/928
Lab Module	0.985522	1/69	0.999022	1/1023
CRV	0.997443	1/391	0.999839	1/6223
TOTALS	0.934622	1/15	0.993132	1/146
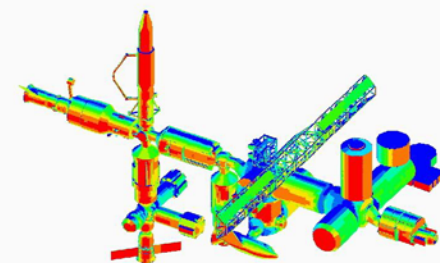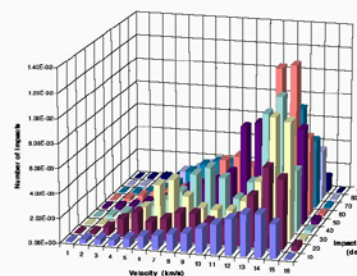
Satellite Reentry Risk Assessment

Object Reentry Survivability Analysis Tool (ORSAT)

− **This code is used to generate trajectory, atmosphere, aerodynamics, aeroheating, thermal, and ablation response of objects during a simulated Earth reentry**

  • Predict demise altitude of objects which burn-up during reentry

  • Computes footprint and debris casualty area of items which do not burn up

− **ORSAT Debris Assessments of note**

  • Hubble Space Telescope

  • Atlas V and Delta IV Rocket Bodies

  • Tropical Rainfall Measuring Mission (TRMM)

  • National Polar-orbiting Operational Environment Satellite System (NPOESS)

  • Compton Gamma Ray Observatory (CGRO)

 • Early Ammonia Servicer (EAS) (ISS Jettison)

EAS Demise Altitude vs. Downrange
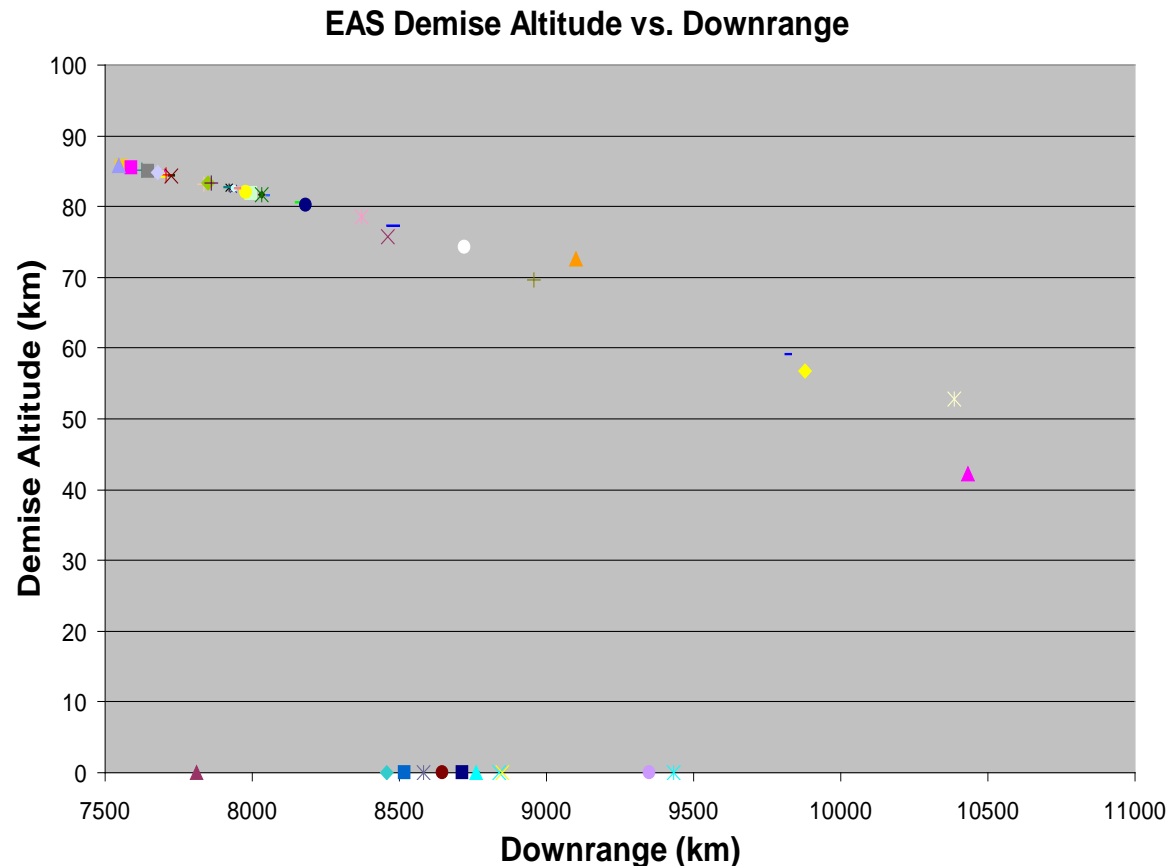
Optical Size and Shape Determination

- **Goal**
  - To develop a optical size estimation model comparable to the existing radar size estimation model .

 - To look for difference sin the optical probability distributions of different classes of objects.

- **Current work**
  - Complex 3-D shapes cannot be easily desribed mathematically although they can be grouped into broad catagories such as nuggets, flakes, etc.

  - Scanner can take many realistic shapes which can be grouped into these shape classes.

  - Characteristic length of each sample is measured, where X,Y, Z are the three orthogonal projections of a object as seen in top figure.
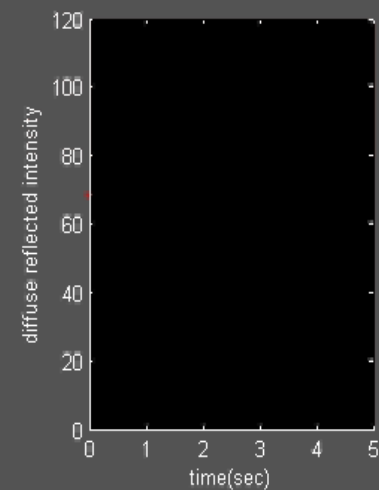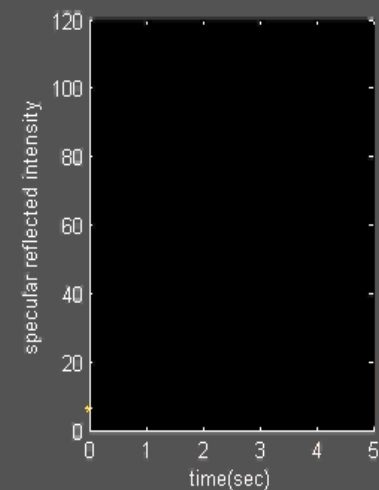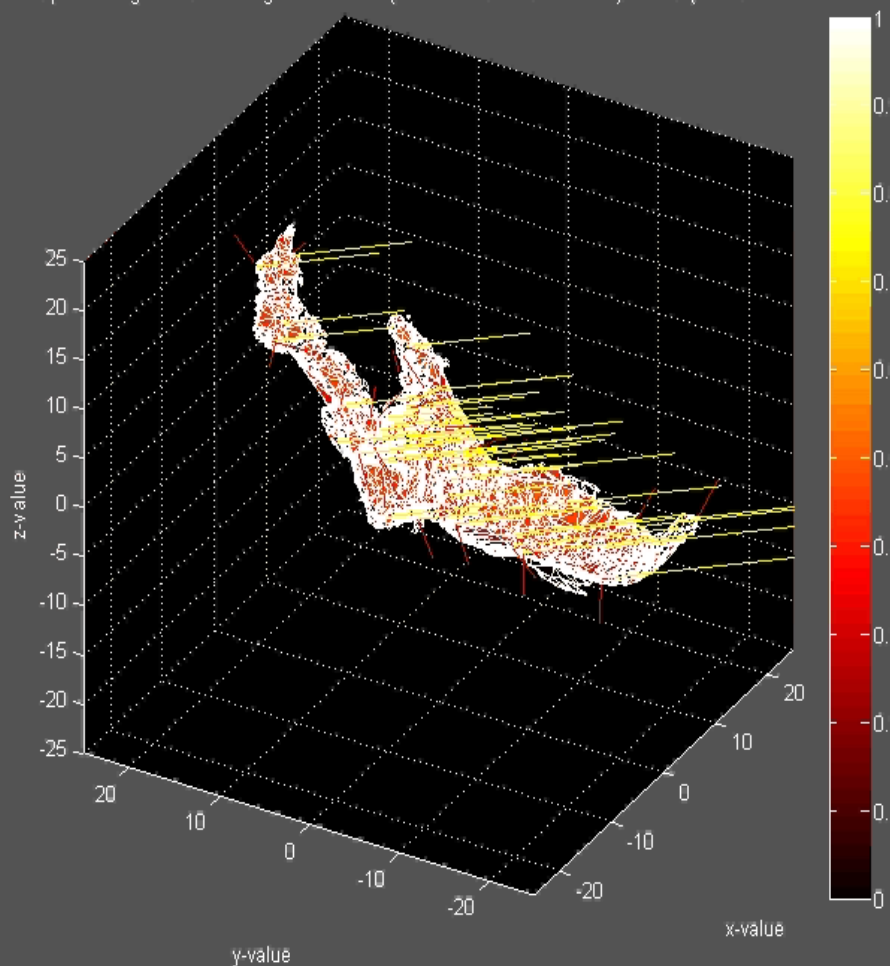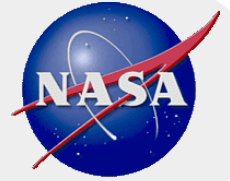   - $L_c = 1/3(X+Y+Z)$
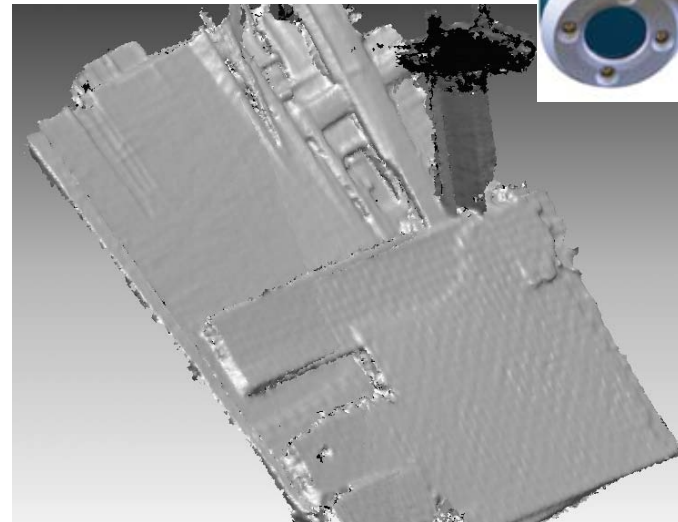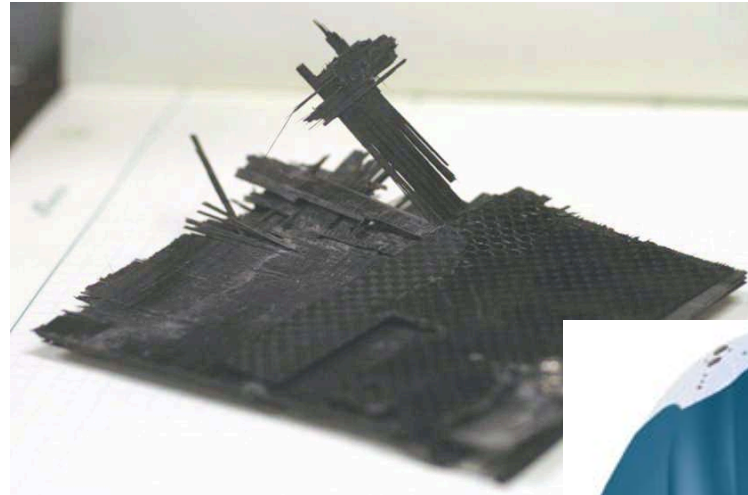
- **Future work**

  - Shapes can be manipulated in software to produce photometric response as a function of viewing geometry for all orientations of the object.

  - Calibration of the photometric response and the specular, diffuse ratio can be calibrated in the laboratory.
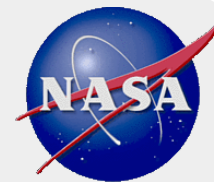
Work on More Complicated Fragments

Spectral Studies

- **Use reflectance spectroscopy in the visible and near-infrared to determine the surface material of space objects**
  - Knowledge of material yields better size estimation data
- **Each material has specific absorption features that make it unique**
  - Using those features, as well as slope, creates a model for materials that best fits the spectrum taken of the object in space
- **Results**
  - Placed objects into categories based on spectral response
    - See example on top right, where the object was thought to be either an asteroid or a human-made object
    - Determined to be human-made due to spectral signature of white paint
  - Measured pristine spacecraft prior to launch and looked at space weathering of materials
    - See example at the bottom right, where the model is based on pre-flight measurements showing great agreement in slope and absorption features
  - Received first data on debris objects (all large pieces)
- **Status of the project – Work in Progress**
  - Continued material modeling
  - Determine cause of the unexpected increase in slope for remote measurements as compared to laboratory measurements
  - Taking ground truth data on spacecraft prior to launch to get better idea of changes in material spectra
  - Obtain more remote measurements of cataloged objects and debris

Reflectance Spectra for a satellite