

DEBRISAT FRAGMENT CHARACTERIZATION SYSTEM AND PROCESSING STATUS

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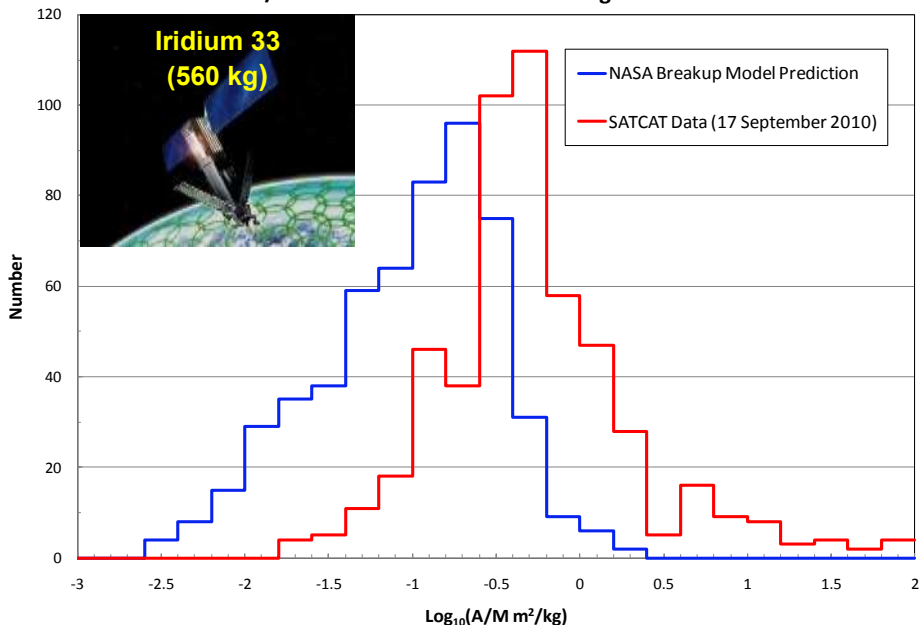
The DebrisSat Team

- **NASA Orbital Debris Program Office (ODPO):** J.-C. Liou, J. Opiela, H. Cowardin, P. Krisko, P. Anz-Meador, E. Christiansen, J. Bacon, *et al.*
 - Co-sponsor, project and technical oversight, data collection, data analyses, NASA model improvements
- **USAF Space and Missile Systems Center (SMC):** T. Huynh, J. Edwards, J. Torres-Ramos, *et al.*
 - Co-sponsor, technical oversight
- **The Aerospace Corporation (Aerospace):** M. Sorge, B. Brady, P. Adams, G. Radhakrishnan, P. Sheaffer, *et al.*
 - Design of DebrisSat, design/fabrication of DebrisLV, data collection, data analyses, DoD model improvements
- **University of Florida (UF):** N. Fitz-Coy and the student team
 - Design/fabrication of DebrisSat, data collection, fragment processing and characterization
- **USAF Arnold Engineering Development Complex (AEDC):** R. Rushing, B. Hoff, M. Nolen, B. Roebuck, D. Woods, M. Polk, *et al.*
 - Hypervelocity impact tests

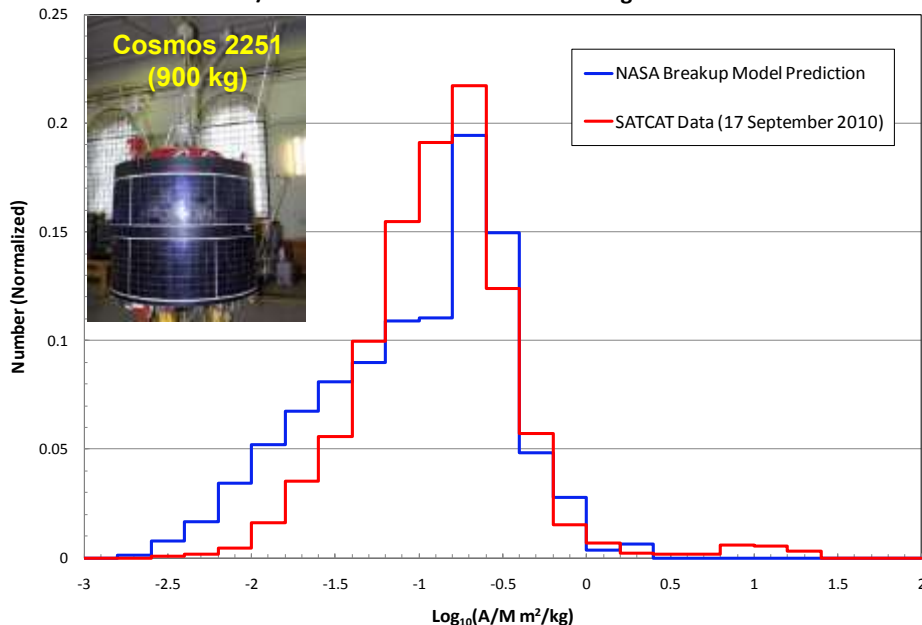
Background

- **Current DoD and NASA satellite breakup models are based on 1992 Satellite Orbital debris Characterization Impact Test (SOCIT) which used a U.S. Navy Transit satellite**
- **Collision in 2009 between Iridium 33 and Cosmos 2251 generated 2000+ trackable fragments and tens of thousands of small untrackable yet potentially damaging/lethal debris (as small as 1 mm)**
- **Newer materials and construction techniques utilized in modern satellites**
 → need for updates to the existing satellite breakup models

A/M Distribution of Iridium 33 Fragments



A/M Distribution of Cosmos 2251 Fragments



DebrisSat Hypervelocity Test

- **DebrisSat test article designed and fabricated as a “representative” modern LEO satellite with components typically found in modern LEO satellites (utilized materials and design/fabrication procedures commonly associated with modern LEO satellites)**
- **Test performed on April 2014 at AEDC**
 - Test article: 56 kg representative LEO satellite
 - Projectile: 570 g hollow cylinder
 - Impact speed: 6.8 km/s



Post-Impact Goals & Requirements

Overall

- Recover 90% of DebrisSat's original mass
- Collect all debris fragments with at least one dimension ≥ 2 mm
- Damage no more than 1% of collected debris
- Characterize mass, physical size, material, shape of the debris fragments

FY16

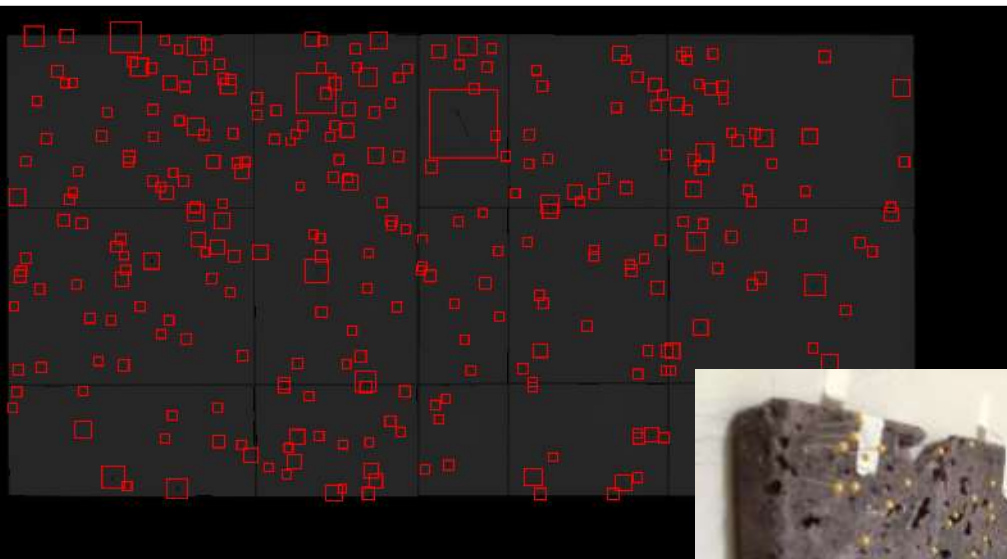
- Characterize fragments collected from Row 3



Detection and Extraction

Detection

- X-ray foam panels
- Use object detection software to identify potential fragment

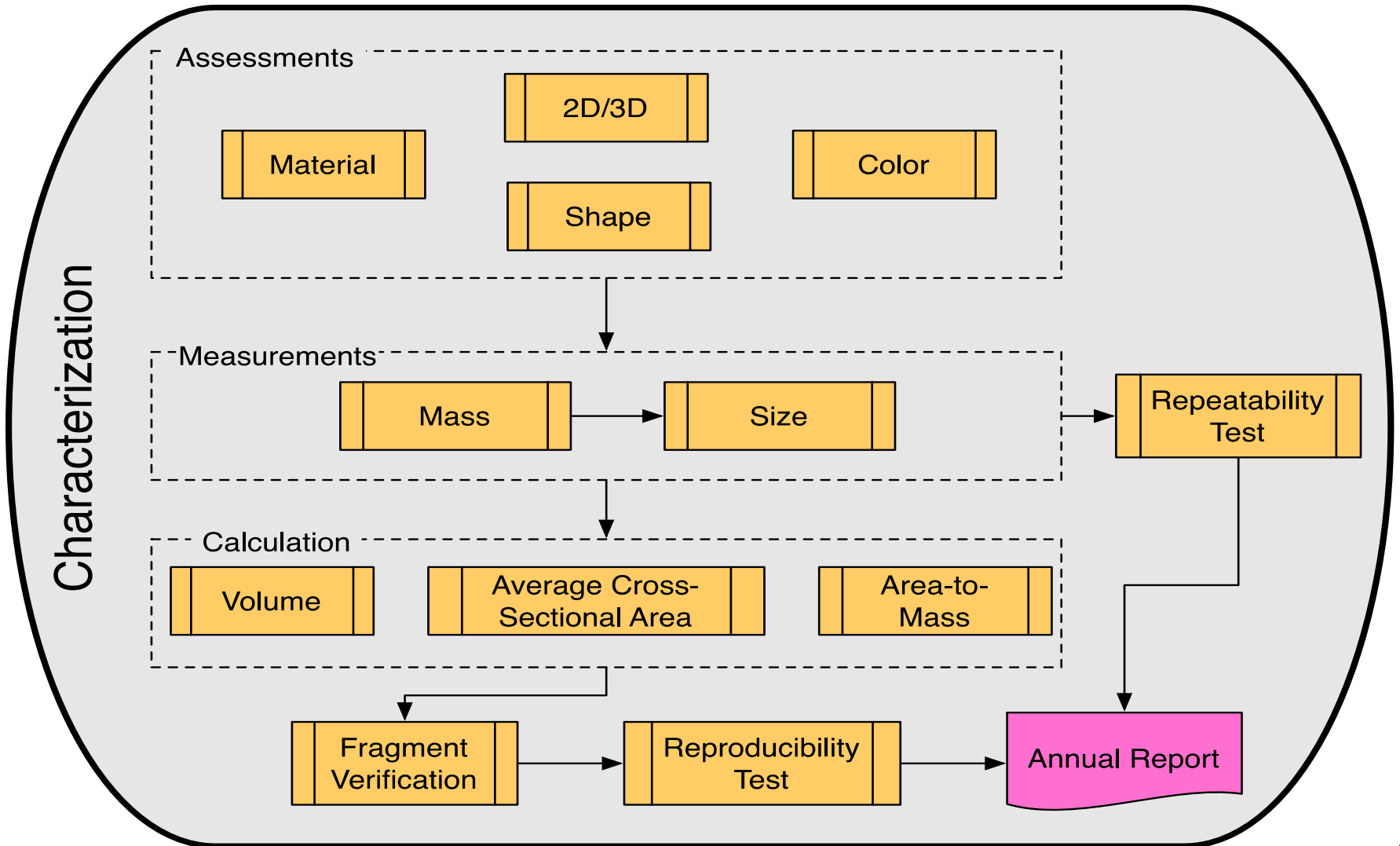


Extraction

- Map fragment location
- Excavate fragments
- Catalog fragments $\geq 2\text{mm}$



Characterization



Characterization: Assessments

Size (2D or 3D)



Materials

- Based on Debrisat components
- Samples used to compare material content

Database designators

-AL- -MLI-
 -CFRP- -SS-

Shape

- Based on inputs from SOCIT and subject matter experts
- Samples used for comparison



Straight Needle



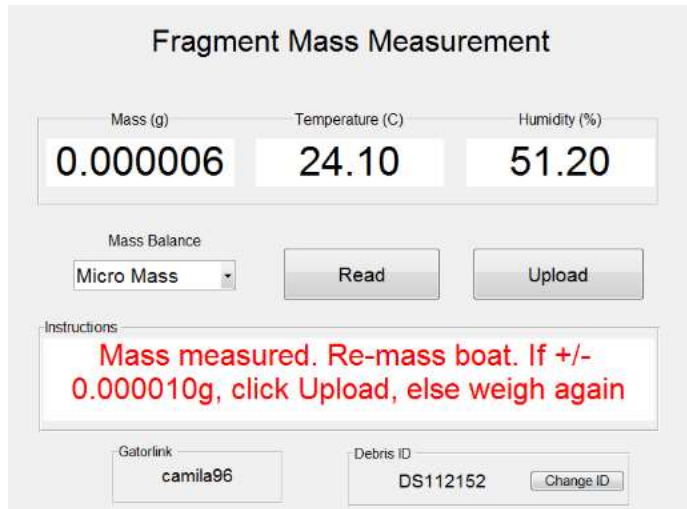
Flat Plate

Color

- Based on Debrisat components
- Aluminum components anodized based on location within satellite

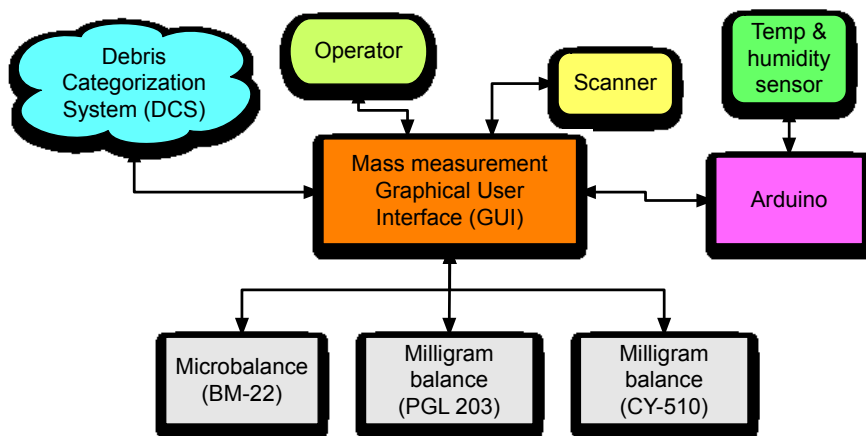
Silver		Gold	
Red		Royal Blue	

Characterization: Mass Measurement

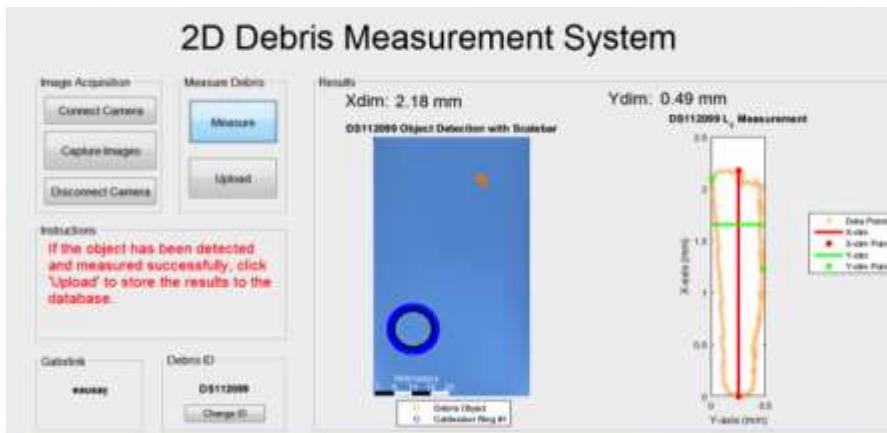


- **Mass Measurement System**

- Integrated system that includes mass balances, temperature, and humidity sensor
- For each mass measurement, the temperature and the humidity of the characterization room is also measured
- Measurements are uploaded to the database through the GUI (i.e., automated system)

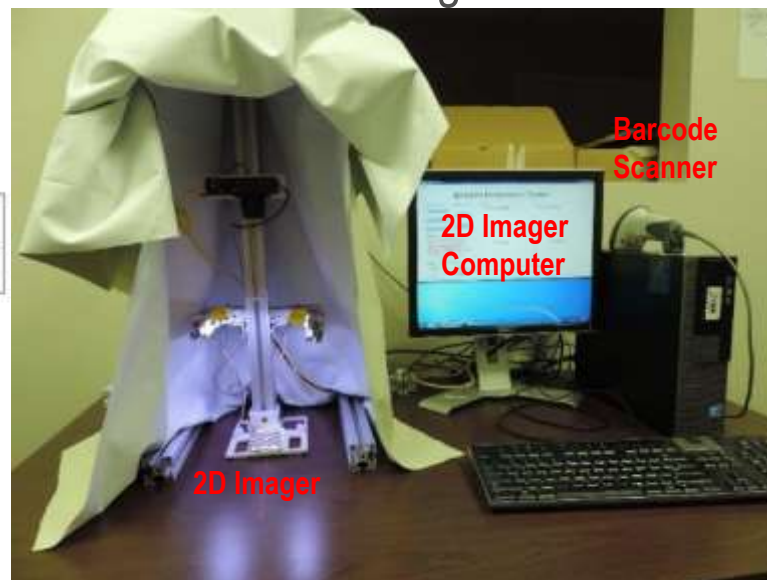
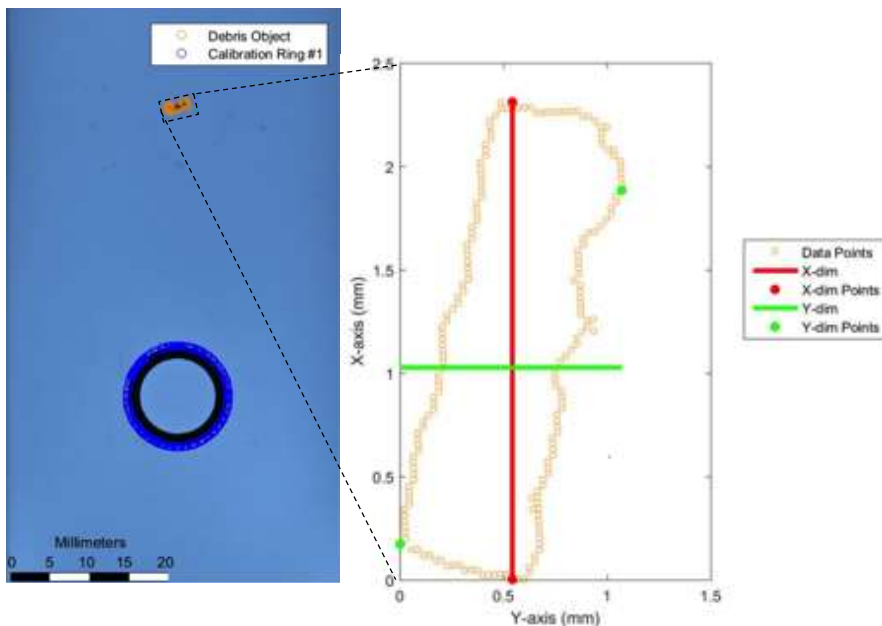


Characterization: 2D Size Measurement

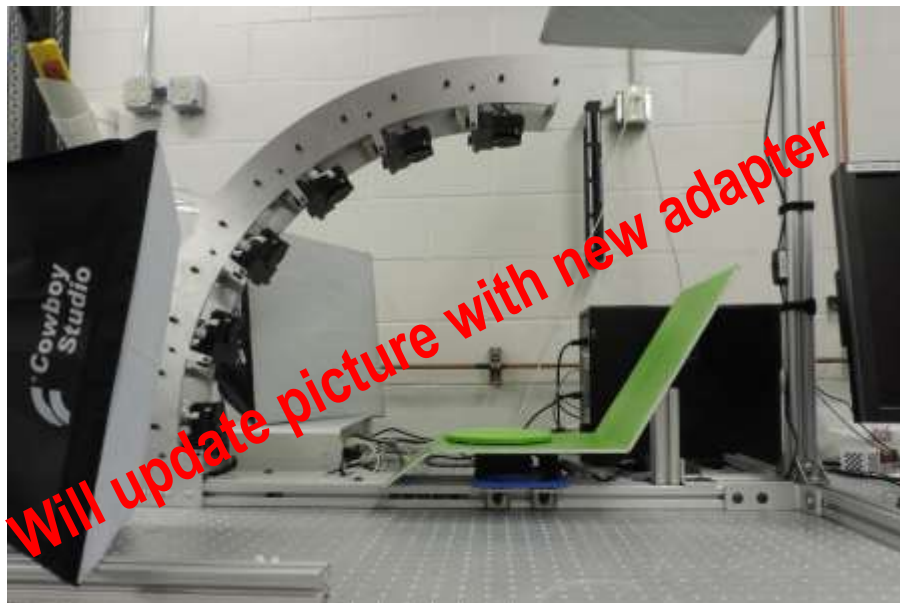


- **2D Imaging System**

- Single camera with front/back lighting
- Generate 2D point cloud from backlit image then compute X-dim, Y-dim, characteristic length (L_c), and area
- Images, 2D point clouds, and computed dimensions are uploaded to the database through the GUI



Characterization: 3D Size Measurement



- **3D Imaging System**

- 6-camera system distributed evenly along a vertical arc
- Green screen turntable
- Constructs a 3D representation from multiple 2D images using space carving technique
- From the 3D representation, the largest three orthogonal dimensions (X_{DIM} , Y_{DIM} , Z_{DIM}) are computed
- Calculated values, images and the 3D point cloud are uploaded to the database through the GUI



Object



3D representation

Characterization: Calculation, Verification, and R&R

- Characteristic length
 - Average of the fragment's largest three orthogonal dimensions
- Volume and bulk density
- Average cross-sectional area
- Area-to-mass ratio
- Verification of fragment characteristics
 - All fragments are independently verified (measurements, images, etc.) and stored in database; cannot be modified once verified
- Measurement system validations performed
 - Repeatability and reproducibility (R&R) tests designed and implemented for data integrity

Current Processing Status

Row 1	2L-101-0 2L-101-1 2L-101-2 2L-101-3 2L-101-4 2L-101-5 2L-101-6 2L-101-7 2L-101-8	2L-101-T	2L-101-0 2L-101-1 2L-101-2 2L-101-3 2L-101-4 2L-101-5 2L-101-6 2L-101-7 2L-101-8	2L-101-T	2L-103-0 2L-103-1 2L-103-2 2L-103-3 2L-103-4 2L-103-5 2L-103-6 2L-103-7 2L-103-8	2L-103-T	2L-103-0 2L-103-1 2L-103-2 2L-103-3 2L-103-4 2L-103-5 2L-103-6 2L-103-7 2L-103-8	2L-103-T	2R-105-0 2R-105-1 2R-105-2 2R-105-3 2R-105-4 2R-105-5 2R-105-6 2R-105-7 2R-105-8	2R-105-T	2R-105-0 2R-105-1 2R-105-2 2R-105-3 2R-105-4 2R-105-5 2R-105-6 2R-105-7 2R-105-8	2R-105-T	2R-107-0 2R-107-1 2R-107-2 2R-107-3 2R-107-4 2R-107-5 2R-107-6 2R-107-7 2R-107-8	2R-107-T	2R-107-0 2R-107-1 2R-107-2 2R-107-3 2R-107-4 2R-107-5 2R-107-6 2R-107-7 2R-107-8	2R-107-T
Row 2	2L-201-0 2L-201-1 2L-201-2 2L-201-3 2L-201-4 2L-201-5 2L-201-6 2L-201-7 2L-201-8 2L-301-0	2L-201-T	2L-201-0 2L-201-1 2L-201-2 2L-201-3 2L-201-4 2L-201-5 2L-201-6 2L-201-7 2L-201-8	2L-201-T	2L-203-0 2L-203-1 2L-203-2 2L-203-3 2L-203-4 2L-203-5 2L-203-6 2L-203-7 2L-203-8 2L-303-0	2L-203-T	2L-203-0 2L-203-1 2L-203-2 2L-203-3 2L-203-4 2L-203-5 2L-203-6 2L-203-7 2L-203-8	2L-203-T	2R-205-0 2R-205-1 2R-205-2 2R-205-3 2R-205-4 2R-205-5 2R-205-6 2R-205-7 2R-205-8	2R-205-T	2R-205-0 2R-205-1 2R-205-2 2R-205-3 2R-205-4 2R-205-5 2R-205-6 2R-205-7 2R-205-8	2R-205-T	2R-207-0 2R-207-1 2R-207-2 2R-207-3 2R-207-4 2R-207-5 2R-207-6 2R-207-7 2R-207-8	2R-207-T	2R-207-0 2R-207-1 2R-207-2 2R-207-3 2R-207-4 2R-207-5 2R-207-6 2R-207-7 2R-207-8	2R-207-T
Row 4	2L-401-0 2L-401-1 2L-401-2 2L-401-3 2L-401-4 2L-401-5 2L-401-6 2L-401-7 2L-401-8	2L-401-T	2L-401-0 2L-401-1 2L-401-2 2L-401-3 2L-401-4 2L-401-5 2L-401-6 2L-401-7 2L-401-8	2L-401-T	2L-403-0 2L-403-1 2L-403-2 2L-403-3 2L-403-4 2L-403-5 2L-403-6 2L-403-7 2L-403-8	2L-403-T	2L-403-0 2L-403-1 2L-403-2 2L-403-3 2L-403-4 2L-403-5 2L-403-6 2L-403-7 2L-403-8	2L-403-T	2R-405-0 2R-405-1 2R-405-2 2R-405-3 2R-405-4 2R-405-5 2R-405-6 2R-405-7 2R-405-8	2R-405-T	2R-405-0 2R-405-1 2R-405-2 2R-405-3 2R-405-4 2R-405-5 2R-405-6 2R-405-7 2R-405-8	2R-405-T	2R-407-0 2R-407-1 2R-407-2 2R-407-3 2R-407-4 2R-407-5 2R-407-6 2R-407-7 2R-407-8	2R-407-T	2R-407-0 2R-407-1 2R-407-2 2R-407-3 2R-407-4 2R-407-5 2R-407-6 2R-407-7 2R-407-8	2R-407-T
Row 5	2L-501-0 2L-501-1 2L-501-2 2L-501-3 2L-501-4 2L-501-5 2L-501-6 2L-501-7	2L-501-T	2L-501-0 2L-501-1 2L-501-2 2L-501-3 2L-501-4 2L-501-5 2L-501-6 2L-501-7	2L-501-T	2L-503-0 2L-503-1 2L-503-2 2L-503-3 2L-503-4 2L-503-5 2L-503-6 2L-503-7	2L-503-T	2L-503-0 2L-503-1 2L-503-2 2L-503-3 2L-503-4 2L-503-5 2L-503-6 2L-503-7	2L-503-T	2R-505-0 2R-505-1 2R-505-2 2R-505-3 2R-505-4 2R-505-5 2R-505-6 2R-505-7	2R-505-T	2R-505-0 2R-505-1 2R-505-2 2R-505-3 2R-505-4 2R-505-5 2R-505-6 2R-505-7	2R-505-T	2R-507-0 2R-507-1 2R-507-2 2R-507-3 2R-507-4 2R-507-5 2R-507-6 2R-507-7	2R-507-T	2R-507-0 2R-507-1 2R-507-2 2R-507-3 2R-507-4 2R-507-5 2R-507-6 2R-507-7	2R-507-T

None / Unknown
Inspected
Preparing for X-ray
Ready for X-ray
Ready for Extraction
Extracting Fragments
Completed
Need to re-image
Broken panels

Panel status as of August 2016:

- Prepared
 - 375 panels
- X-rayed
 - 298 panels
- Extracted
 - 66 panels

• Over 125K fragments have been collected to date

Summary

- Post-impact activities continue (i.e., detection, extraction, characterization of fragments with one dimension ≥ 2 mm)
- A systematic characterization process using repeatable procedures and reliable equipment have been established
- FY2016 activities focused on the characterization of fragments from Row 3
 - Preparation: Completed all panels
 - X-ray imaging: 70 out of 71 panels
 - Extraction: 60 out of 71 panels
 - Characterization: 2389 fragments

Questions?



Examples of Fragments



Current Processing Status

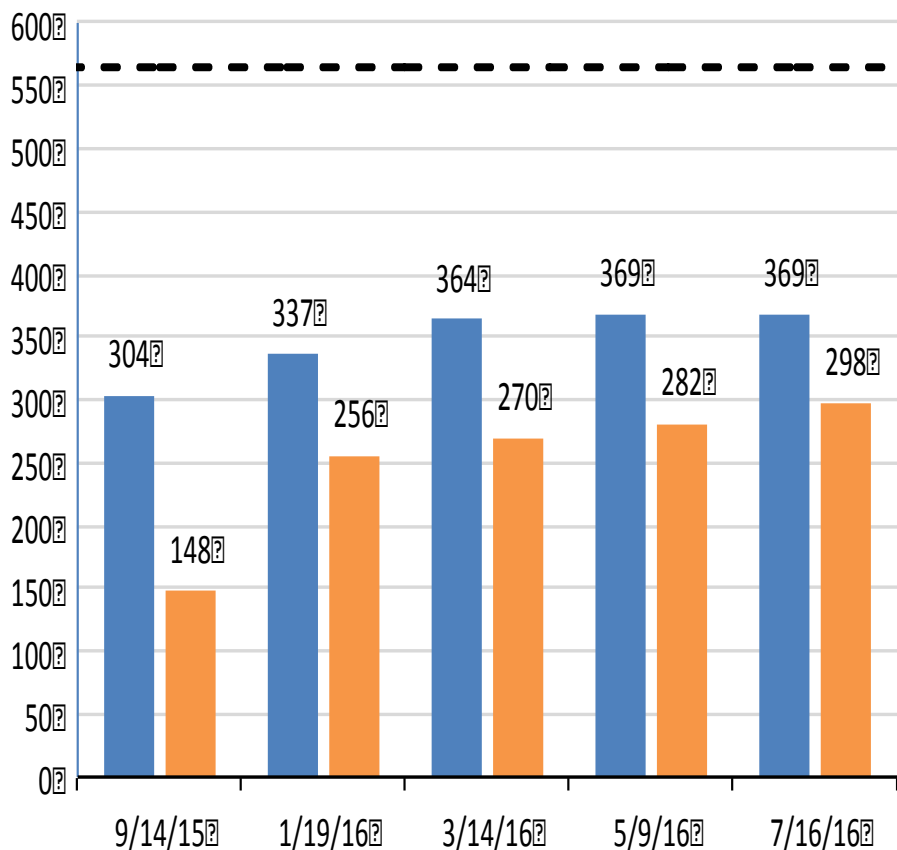
Panels Prepared	369 of 564*
Panels X-rayed	298
Panels Extracted	62
Debris Collected	125 000
* Not all 564 panels remained intact post-impact; processing of broken panels is in planning	

Activity	# of Panels	Avg. Time/Panel (hr)
Preparation	369	3.0
X-ray imaging	298	0.5
Extraction	62	
Low Density Panels	12	15.2
Medium Density Panels	43	11.6
High Density Panels	7	9.4

Expectations and Progress

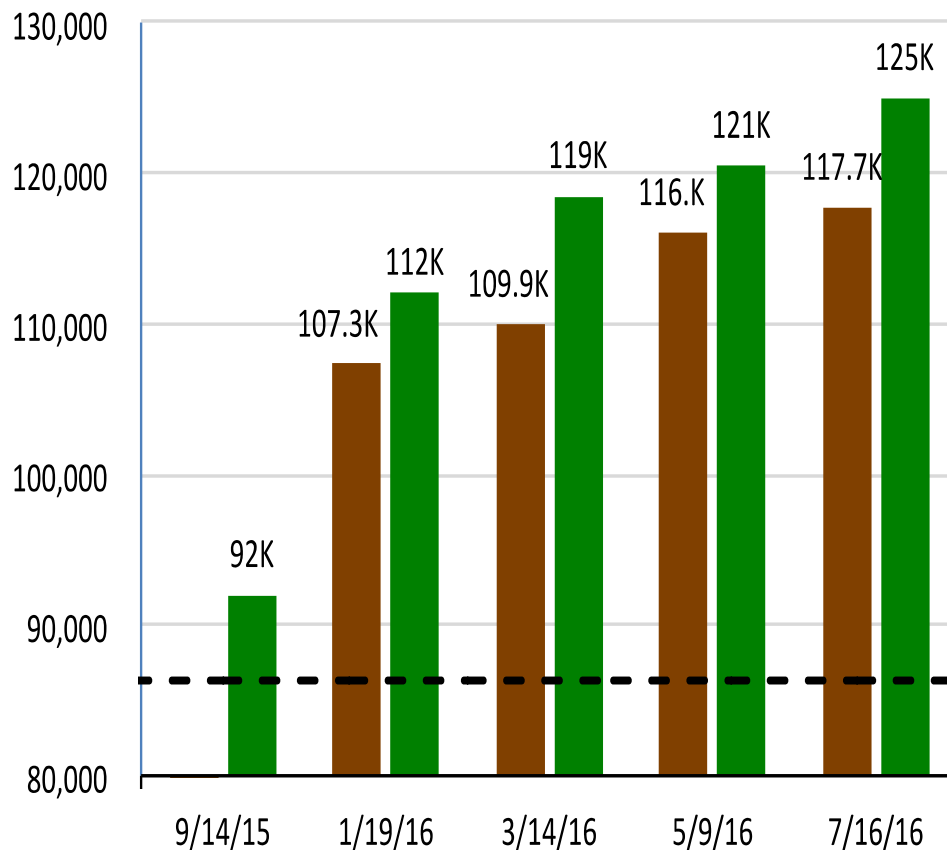
Panel Summary FY2016

Prepared X-rayed Total Panels Installed



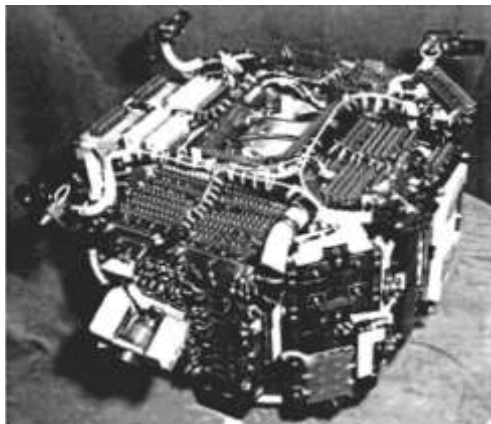
Fragment Summary FY2016

Recorded Collected (Estimate) Predicted Fragments



Background

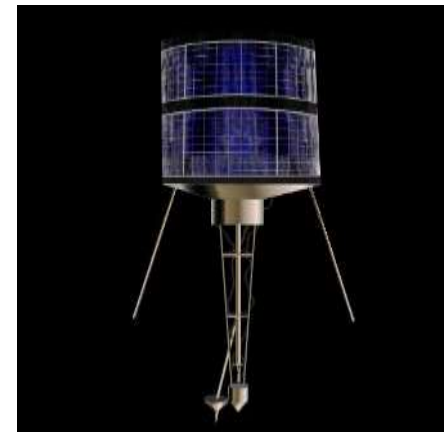
- **1992 Satellite Orbital debris Characterization Impact Test (SOCIT) used U.S. Navy Transit navigation satellite to develop the DoD and NASA satellite breakup models**
 - 34.5 kg target fabricated in the 1960s
 - 150 g Al sphere projectile
- **The accidental collision between Iridium 33 and Cosmos 2251 in 2009 generated 2000+ trackable fragments and tens of thousands of small untrackable-yet-potentially-damaging/lethal debris (as small as 1 mm)**



U.S. Navy Transit satellite from SOCIT4



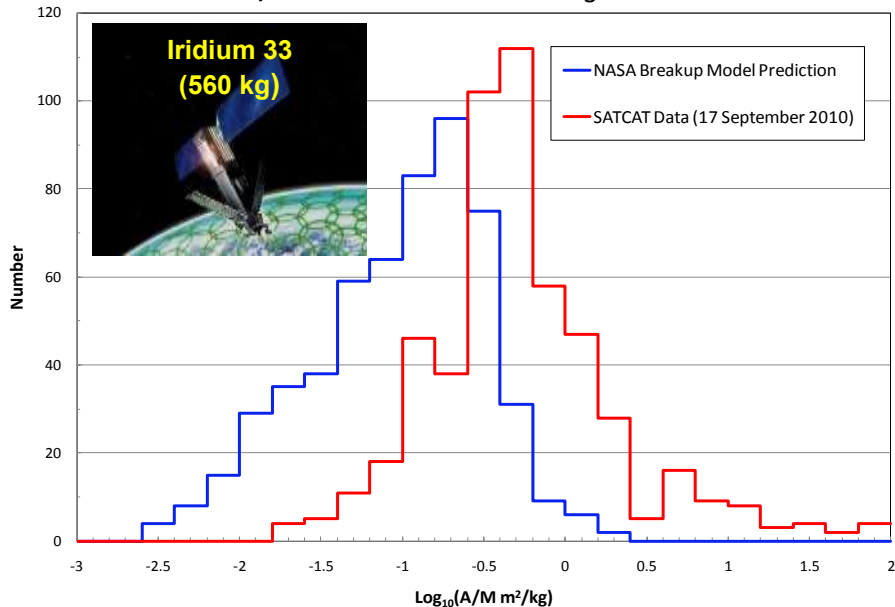
Iridium-33
https://en.wikipedia.org/wiki/Iridium_33



Strela-2M satellite similar to Cosmos-2251
https://en.wikipedia.org/wiki/Kosmos_2251

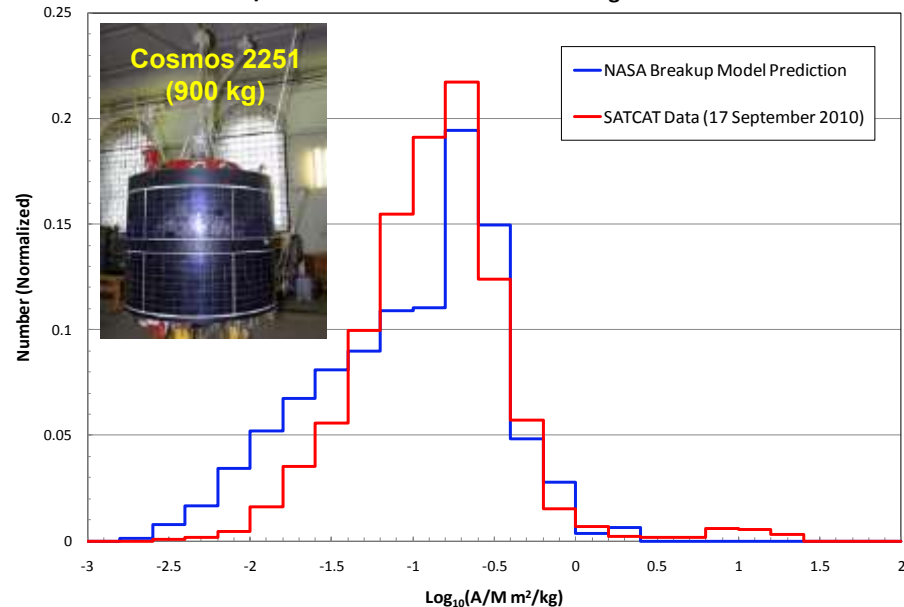
Background

A/M Distribution of Iridium 33 Fragments



- The A/M distribution of the Iridium 33 fragments appears to be systematically higher than the NASA model prediction
- Lightweight composite materials were extensively used in the construction of the vehicle

A/M Distribution of Cosmos 2251 Fragments



- The A/M distribution of the Cosmos 2251 fragments matches well with the NASA model prediction

As new materials and construction techniques are developed for modern satellites, there is a need for new laboratory-based tests to improve the existing DoD and NASA breakup models.