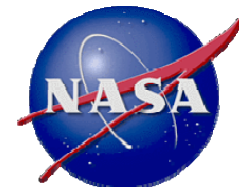
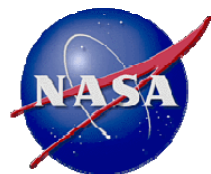


National Aeronautics and Space Administration

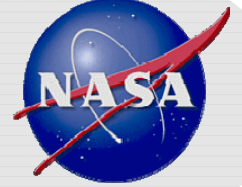


NASA Orbital Debris Program Office and the DebrisSat Project

J.-C. Liou and H. Cowardin

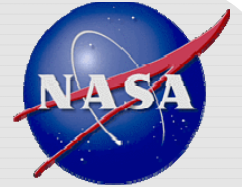


DebrisSat Program Management Review
University of Florida, 21 February 2018



Outline

- **The Orbital Debris (OD) Problem**
- **The NASA Orbital Debris Program Office (ODPO)**
- **DebrisSat Project Overview**



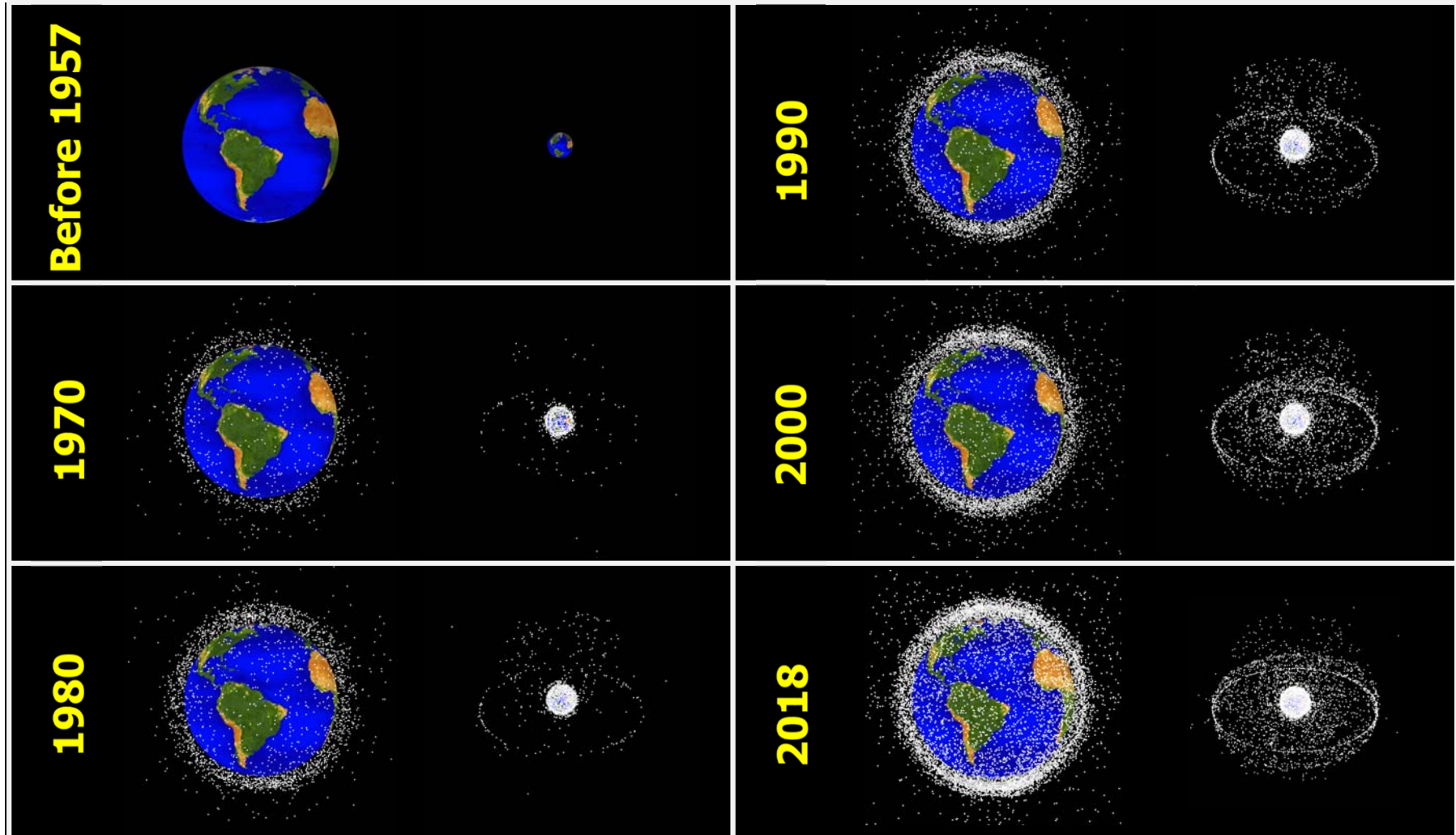
The Orbital Debris Problem



Credit: 1981 painting copyright William K. Hartmann, Senior Scientist Emeritus, Planetary Science Institute, <https://www.psi.edu/about/staff/hartmann/pic-cat/spaceexploration.html>

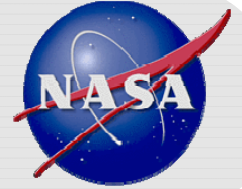


Growth of the Orbital Debris Populations



Credit: NASA ODPO

- Only objects in the US satellite catalog (~ 10 cm and larger) are shown
- Sizes of the dots are not to scale



How Much Junk is Currently Up There?



**Baseball size or larger (≥ 10 cm): ~23,000
(tracked by the U.S. Air Force Space Surveillance Network)**



Credit: public domain images

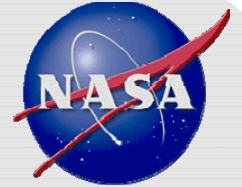
Marble size or larger (≥ 1 cm): ~500,000



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



- **Due to high impact speed in space (~10 km/sec in LEO), even sub-millimeter debris pose a realistic threat to human spaceflight and robotic missions**
 - 10 km/sec = 36,000 km per hour (the speed of a bullet ~2,500 km per hour)
- **Mission-ending threat is dominated by small (mm-to-cm sized) debris impacts**
- **Total mass: >7400 tons LEO-to-GEO (~2700 tons in LEO)**

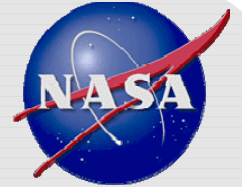


Threat from Orbital Debris - Examples

- **The gravity-gradient boom of an operational French satellite (CERISE) was cut in half by a tracked debris fragment in 1996**
- **The fully operational Iridium 33 was destroyed by a retired Russian satellite (Cosmos 2251) in 2009**
- **Near the end of the Space Shuttle Program, the Loss of Crew and Vehicle risks from MMOD impact damage were in the range of 1-in-250 to 1-in-300 per mission (OD to MM ~2:1 at ISS altitude)**
- **Satellite operators, including the International Space Station (ISS) Program, conduct collision avoidance maneuvers against the tracked objects on a regular basis**
 - ISS has conducted 25 collision avoidance maneuvers and 5 “shelter-in-Soyuz” since 1999
- **Impacts by small, untracked debris could be responsible for many satellite anomalies**

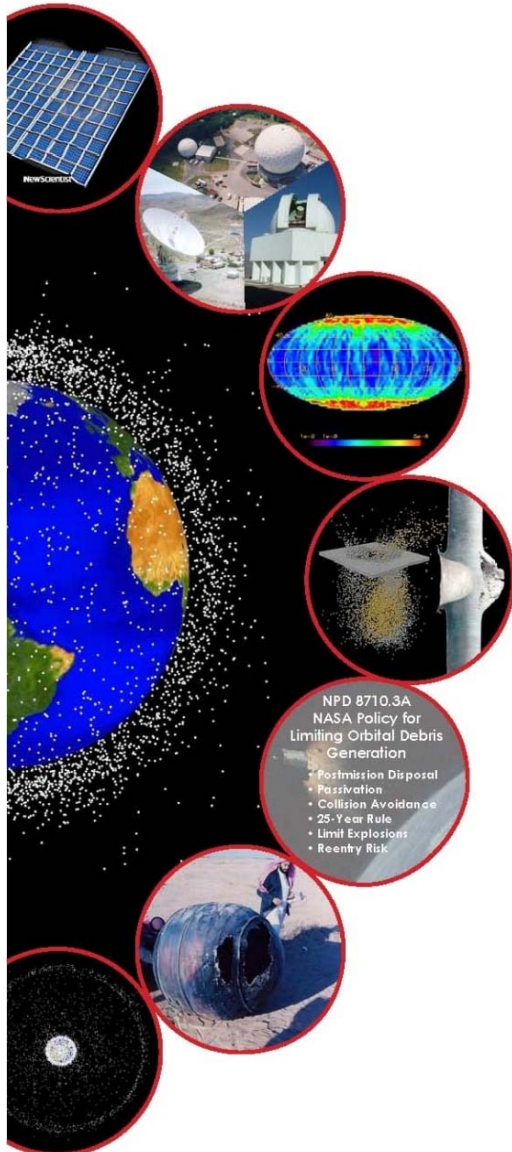
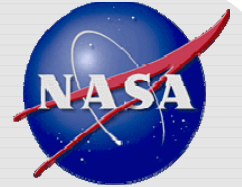


Credit: NASA



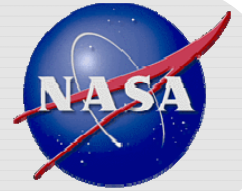
The NASA Orbital Debris Program Office

NASA Orbital Debris Program Office (ODPO)

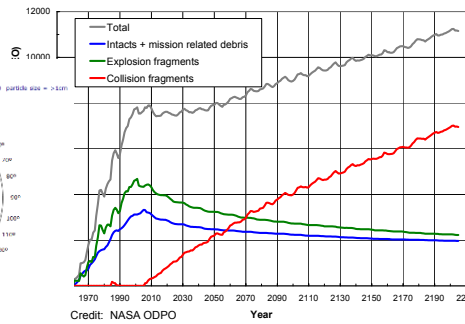
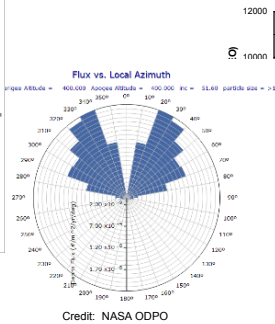
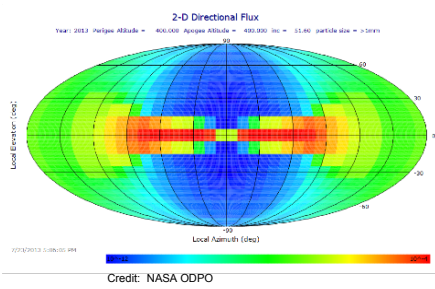


- **The ODPO is the only organization in the U.S. Government conducting a full range of research on orbital debris**
 - This unique NASA capability was established at JSC in 1979 (D. Kessler, J. Loftus, B. Cour-Palais, *etc.*)
 - ODPO's roles and responsibilities are defined in NASA Procedural Requirements NPR 8715.6B
- **ODPO provides technical and policy level support to NASA HQ, OSTP, and other U.S. Government and commercial organizations**
- **ODPO represents the U.S. Government in international fora (IADC, United Nations, *etc.*)**
- **ODPO is recognized as a pioneer and leader in environment definition and modeling, and in mitigation policy development**

Credit: NASA ODPO



ODPO's End-to-End Mission Support



Mission Risk Assessments

OD risk assessment tools for NASA mission (ORDEM, ORSAT, DAS, etc.)

Measurements

Radar
Optical
In-situ
Laboratory

Modeling

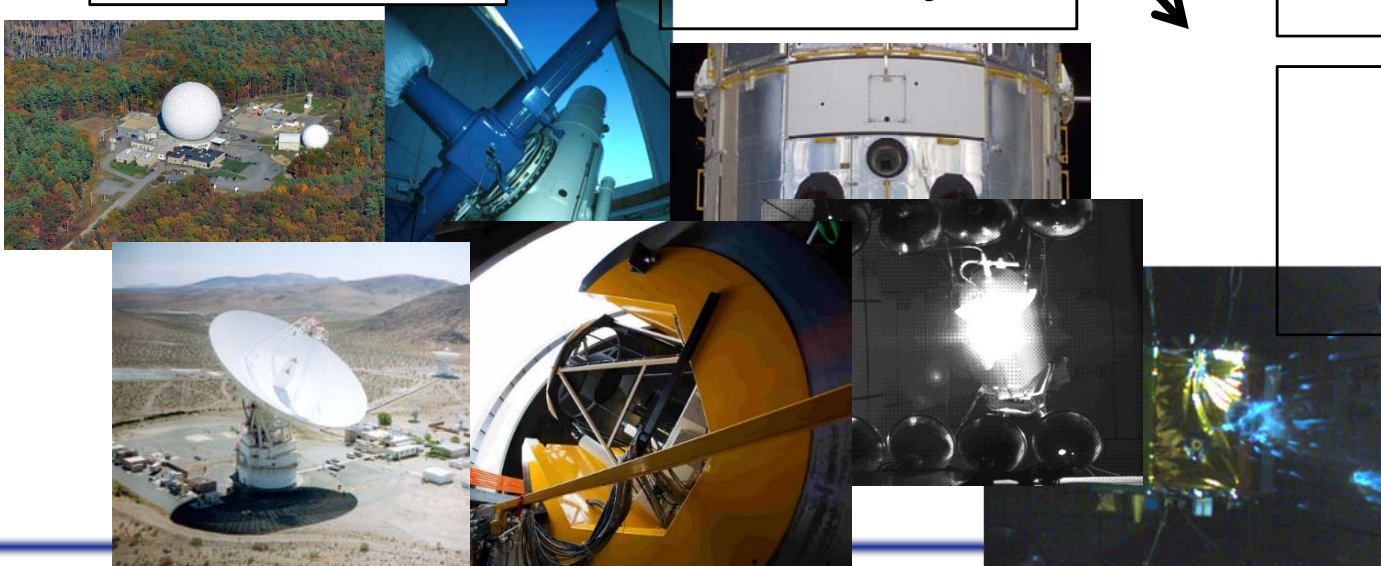
Breakup
Engineering
Evolutionary
Reentry

Environment Management

Mitigation
Remediation
Policy
Mission Requirements

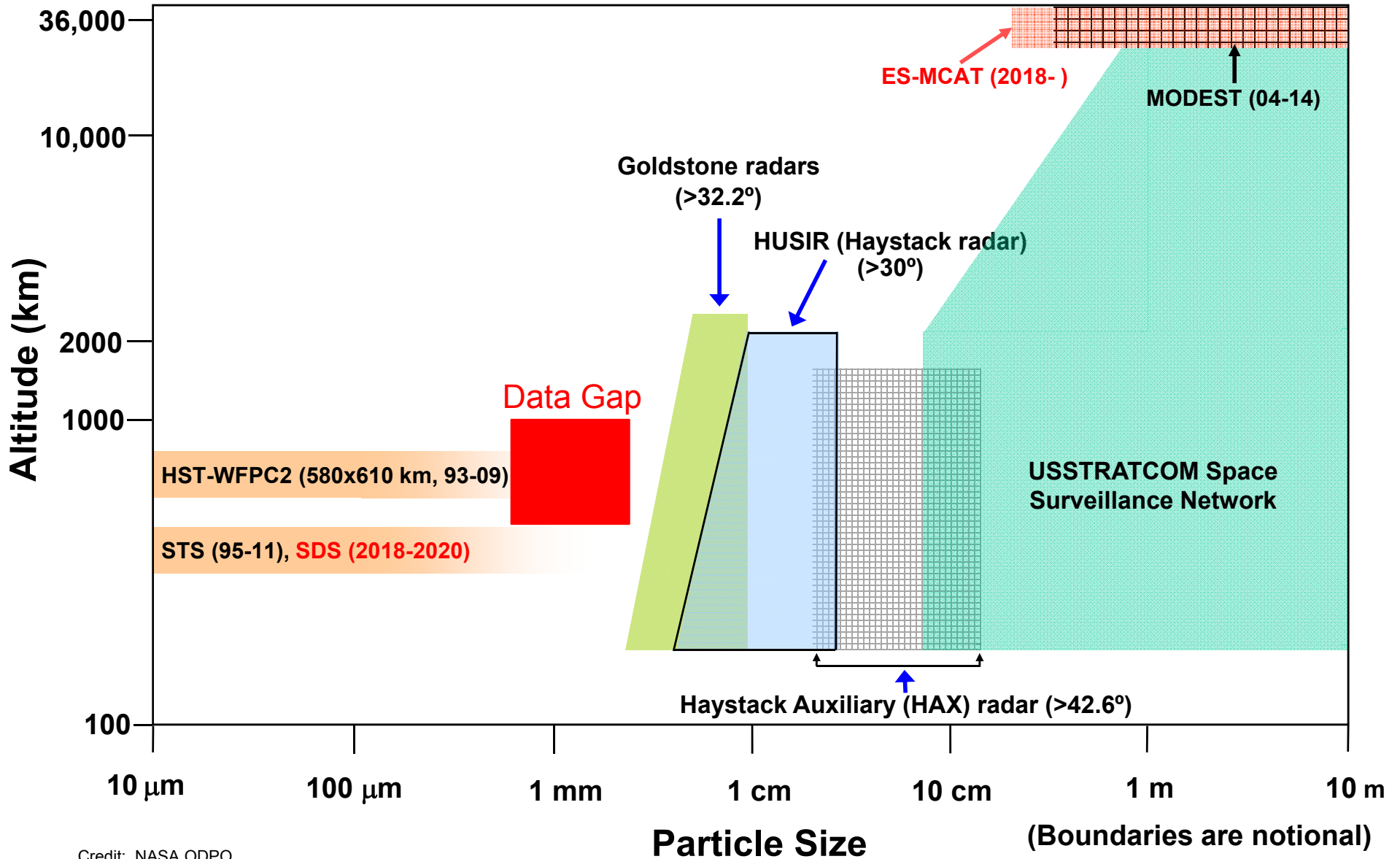
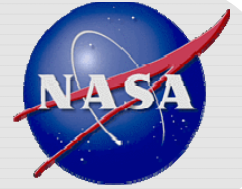
Coordination

U.S. Government
IADC, ISO
United Nations

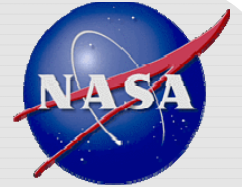


Credits, left-to-right, top: Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts; Patrick Seitzer, University of Michigan; NASA (S125E007413). Left-to-right, bottom: NASA JPL, <https://deepspace.jpl.nasa.gov/galleries/goldstone/#gallery>; Ben Hanna; Arnold Engineering Development Complex/Air Force (2 images)

Space Situational Awareness Coverage in the U.S.

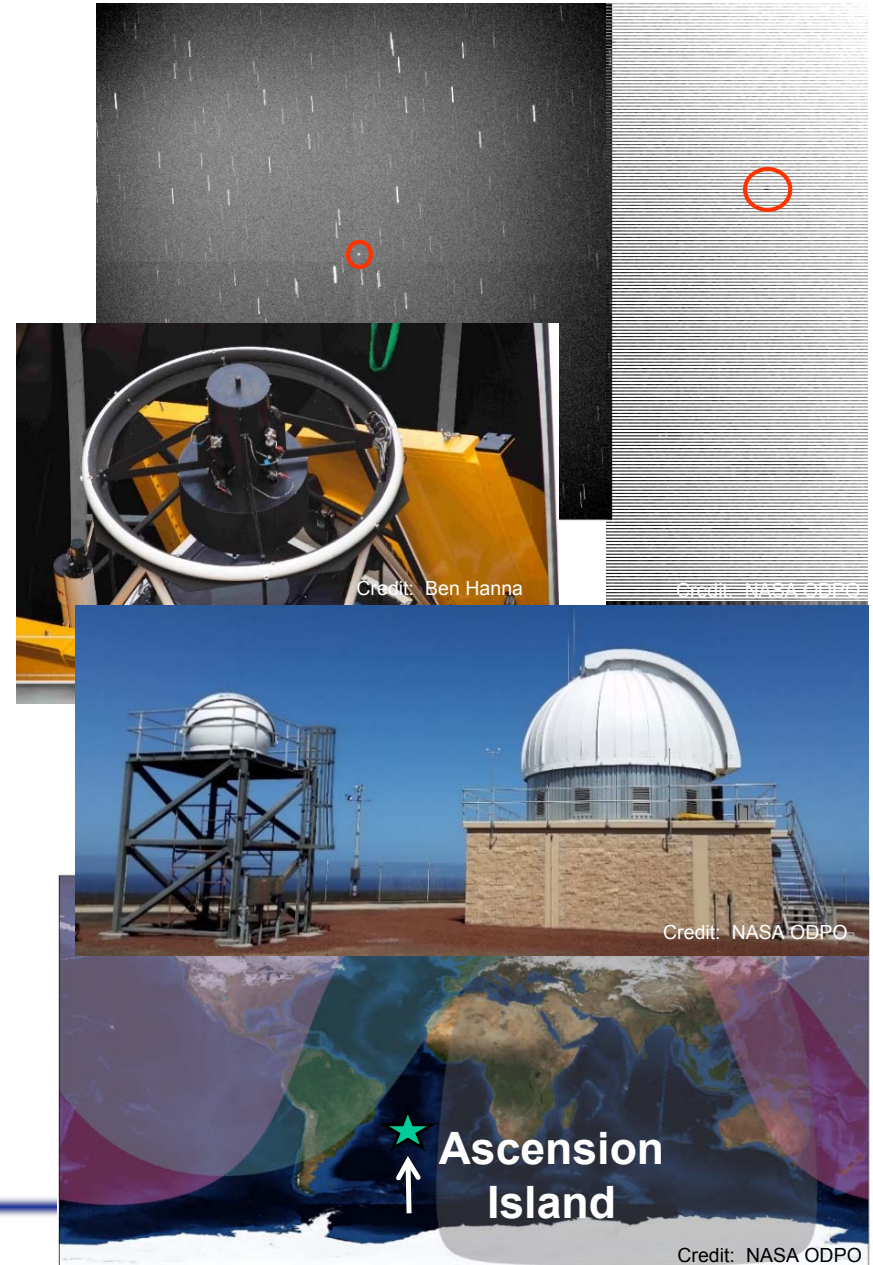


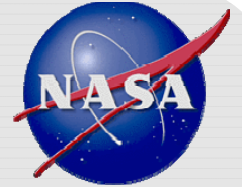
Credit: NASA ODPO



Recent ODPO Highlights - Optical

- **A NASA, Air Force, and Air Force Research Laboratory joint project**
 - Ascension Island (7° 58' S, 14° 24' W)
- **Two instruments at the facility**
 - ES-MCAT: a double horse-shoe 1.3-m DFM telescope with a field-of-view of 41' × 41'
 - Benbrook: a 0.4-m telescope with a similar field-of-view
- **Objectives for operations**
 - Survey faint debris in GEO
 - Characterize low inclination objects in LEO
 - Provide rapid break-up response
 - Support other Space Situational Awareness applications
- **Forward plan**
 - Reach full autonomous operations for routine GEO debris survey by Sep 2018



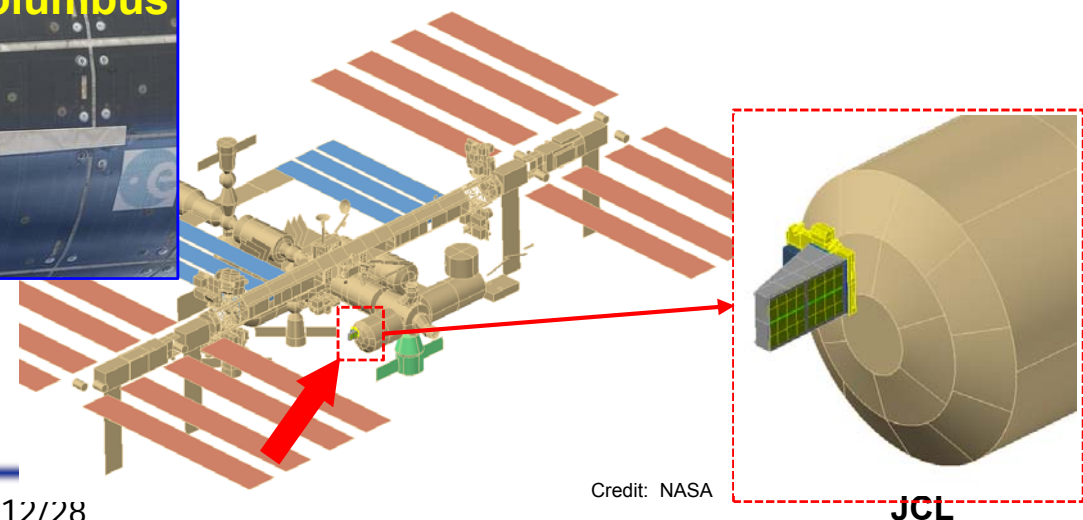


Recent ODPO Highlights – *In Situ* Measurements

- **The International Space Station (ISS) Program funded a DRAGONS technology demonstration mission launched in 2017**
 - Objectives: (1) mature DRAGONS technologies and (2) characterize the sub-millimeter debris environment at the ISS altitude
 - To avoid confusion with the SpaceX Dragon, the mission was renamed Space Debris Sensor (SDS)
- **NASA will continue to seek mission opportunities to deploy DRAGONS to characterize the millimeter-sized orbital debris populations at 600-1000 km altitude**



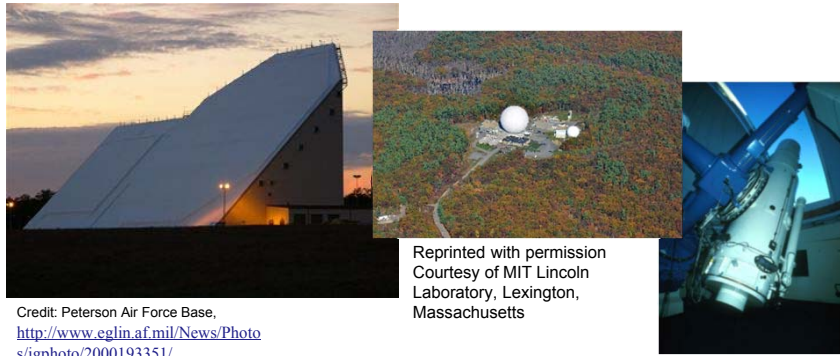
Credit: NASA



Credit: NASA



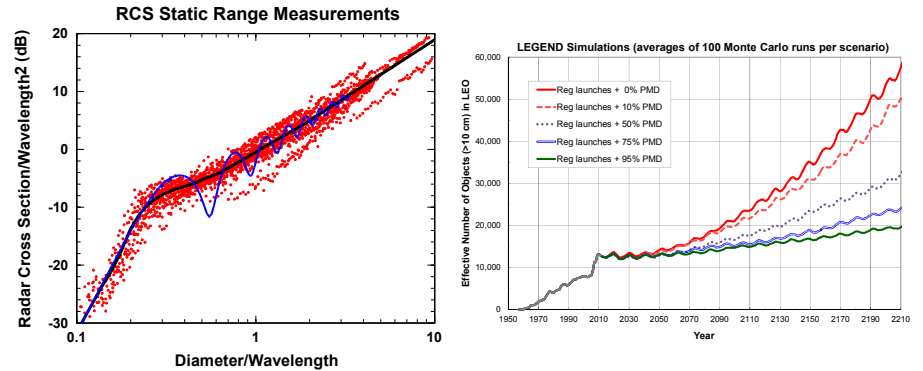
Managing OD Risks for Space Assets



Credit: Peterson Air Force Base, <http://www.eglin.af.mil/News/Photo/s/jgphoto/2000193351/>

Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts

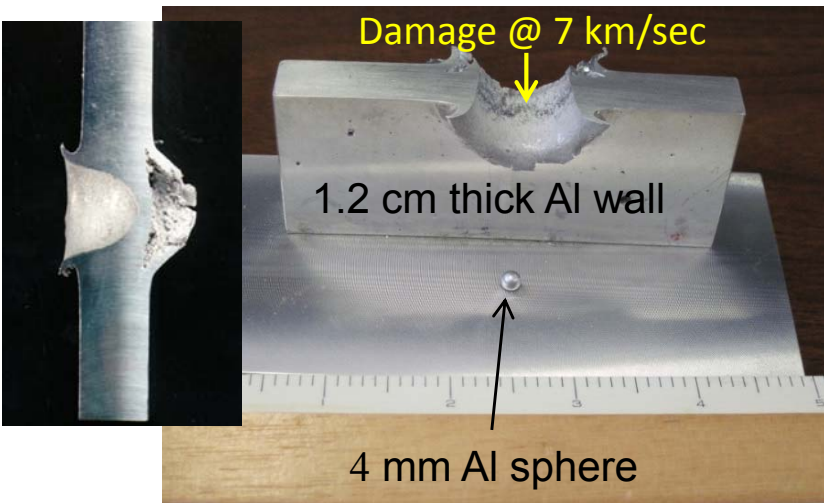
Credit: Patrick Seitzer, University of Michigan



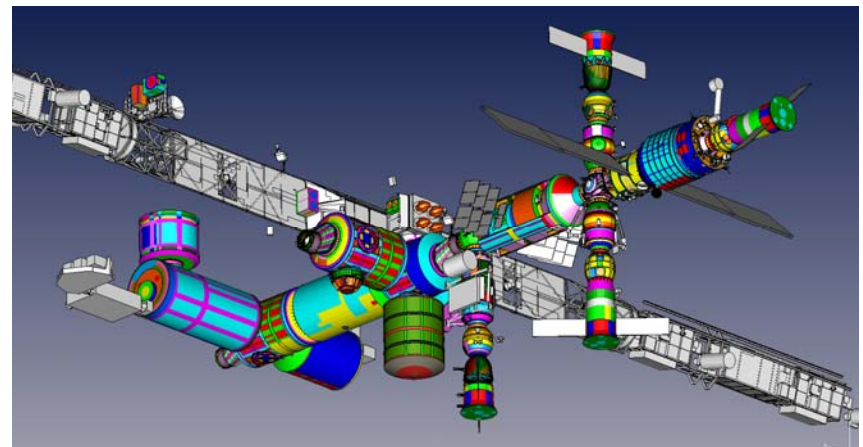
1. **Observe** events, objects/orbits, RCS, brightness, *etc.*
3. **Evaluate** impact consequences



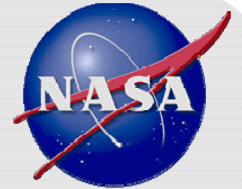
2. **Assess** population, debris size, mass, density, shape, velocity, lifetime, *etc.*
4. **Mitigate** risks in a cost effective manner



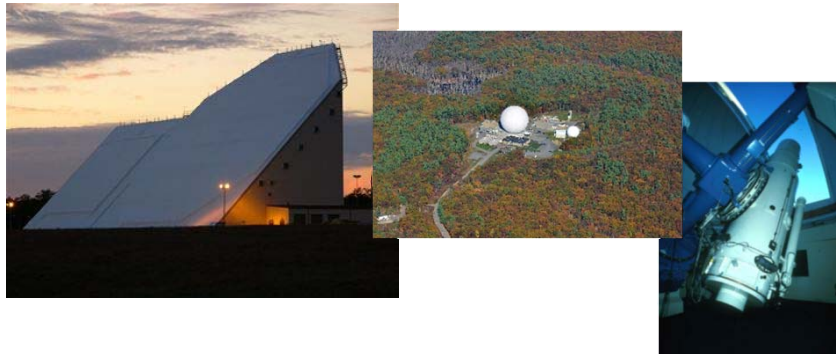
Credit: NASA HVIT Group



Credit: NASA HVIT Group

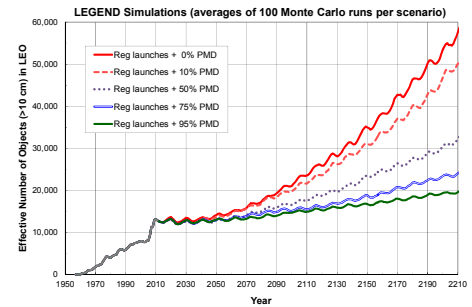
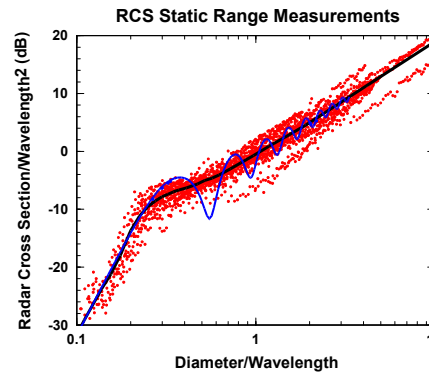
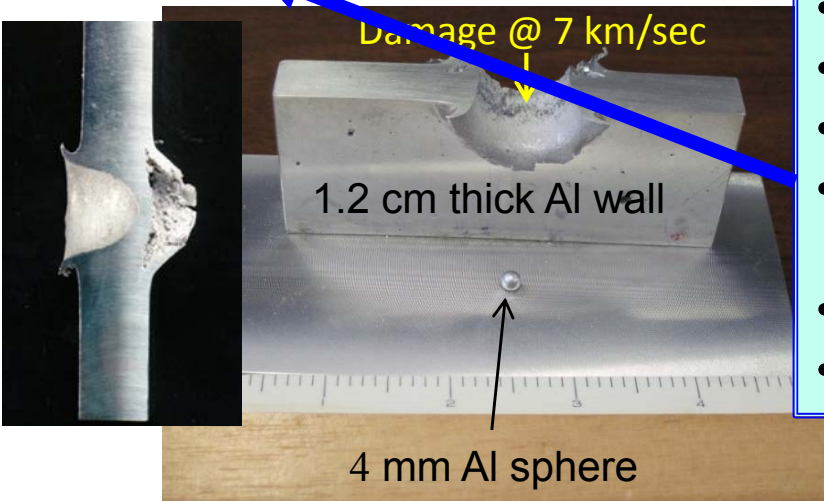


Managing OD Risks for Space Assets



1. **Observe** events, objects/orbits, RCS, brightness, *etc.*

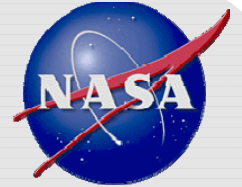
3. **Evaluate** impact consequences



2. **Assess** population, debris size, mass, density, shape, velocity, lifetime, *etc.*

Need lab-based satellite impact test data for

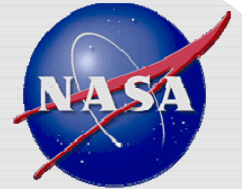
- RCS-to-size conversion
- Optical magnitude-to-size conversion
- Fragment area-to-mass ratio distribution (to ~mm)
- Population characterization (including MLI and solar panel pieces)
- Fragment size and mass distributions (to ~mm)
- Fragment density and shape distributions (to ~mm)



DebrisSat Project Overview

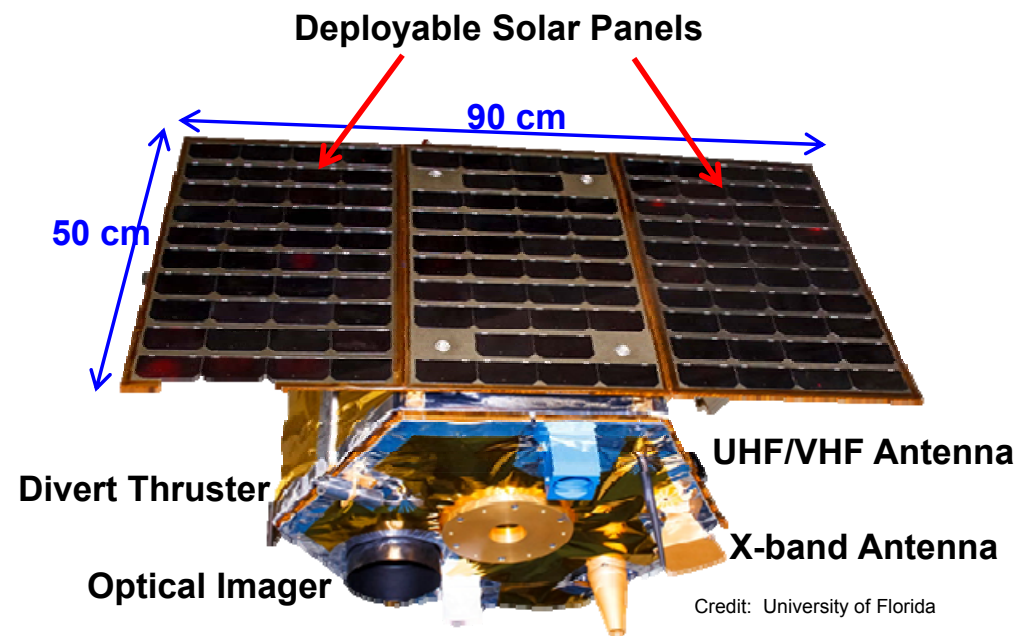
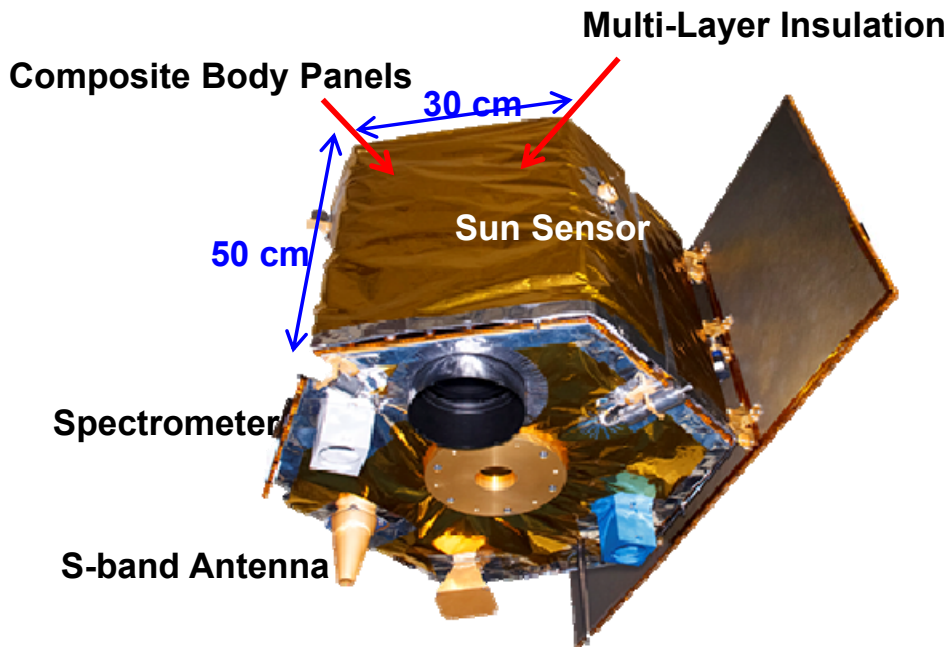


Credit: University of Florida



Brief Intro

- The purpose of the DebrisSat project is to replicate a hyper-velocity fragmentation event using modern-day spacecraft materials and construction techniques to better improve the existing DoD and NASA breakup models

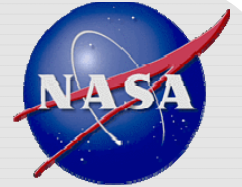


Credit: University of Florida



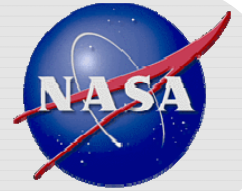
570 g projectile @ 6.8 km/sec

Credit: Arnold Engineering Development Complex/Air Force



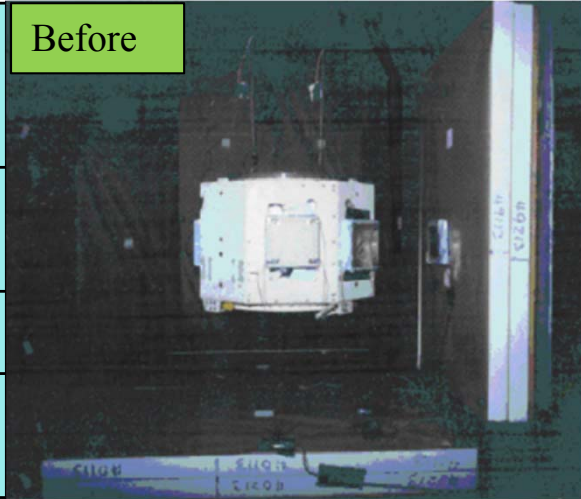

DebrisSat Project Motivation (1/2)

- **The need for laboratory-based impact tests was recognized by DoD and NASA decades ago**
- **Key impact test series, Satellite Orbital Debris Characterization Impact Test (SOCIT) was conducted by the Department of Defense (DOD) and NASA at AEDC in 1992 to support the development of satellite breakup models**
- **Breakup models based on SOCIT have supported many applications over the years**



Previous Laboratory Impact Test

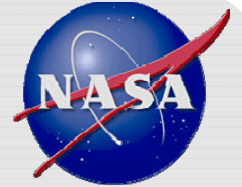
SOCIT vs DebrisSat

	SOCIT U.S. Navy Transit 1960's era satellite	DebrisSat Representative modern spacecraft in LEO	Before
Target body dimensions	46 cm (dia) × 30 cm (ht)	60 cm (dia) × 50 cm (ht)	
Target mass	34.5 kg	56 kg	
MLI and solar panel	No	Yes	
Projectile material	Al sphere	Hollow Al cylinder with attached nylon bore-rider	
Projectile dimension/mass	4.7 cm diameter, 150 g	8.6 cm × 9 cm, 570 g	Before
Impact speed	6.1 km/sec	6.8 km/sec	
Impact Energy to Target Mass ratio (EMR)	81 J/g (2.8 MJ total)	235 J/g (13.2 MJ total)	

Credit: US Government.

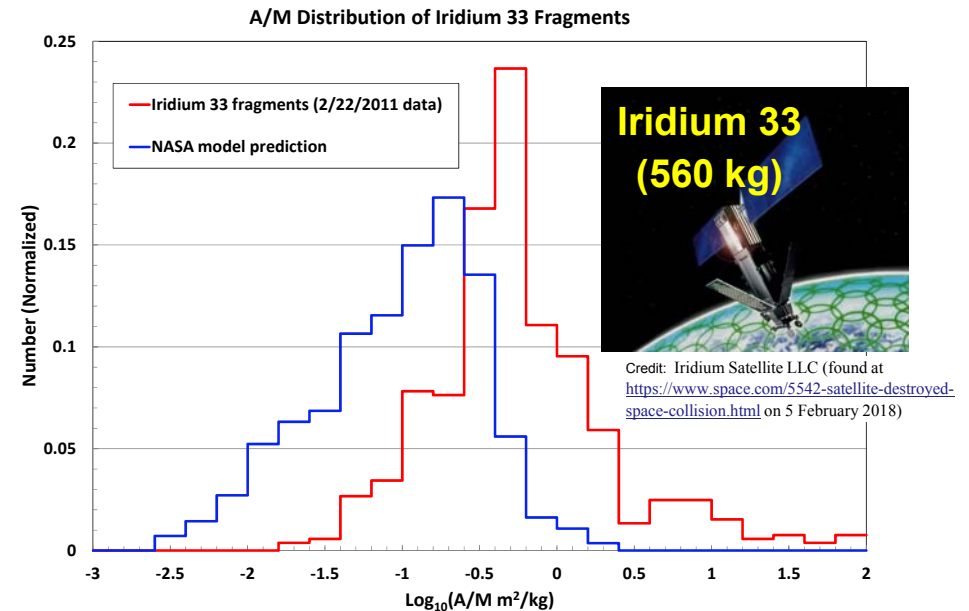
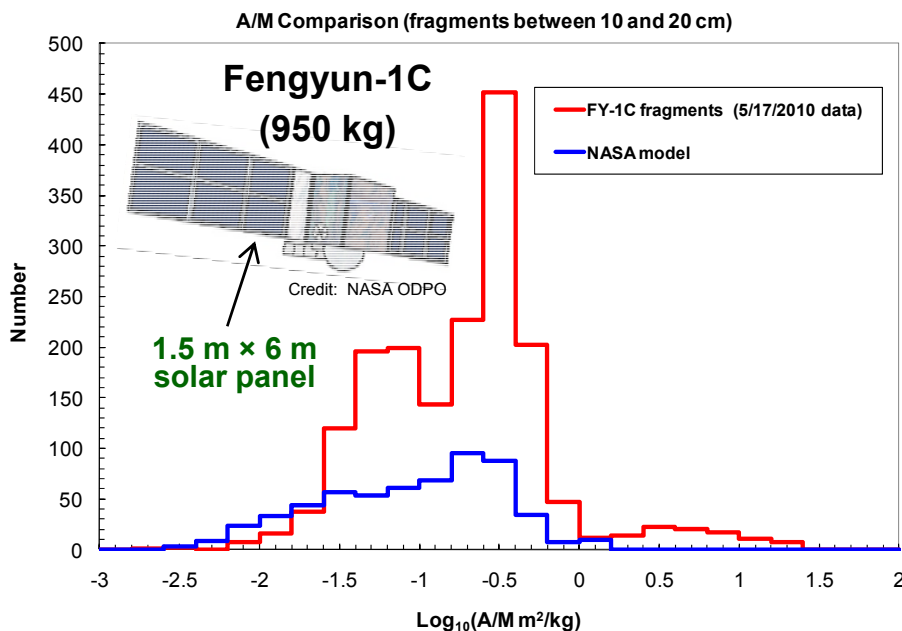
Credit: Arnold Engineering Development Complex/Air Force

See Ausay, E., "A Comparison of the SOCIT and DebrisSat Experiments"

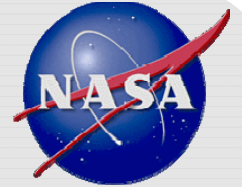


DebrisSat Project Motivation (2/2)

- As new materials and construction techniques are developed for modern satellites, there is a need for new laboratory-based tests to acquire data to improve the existing DoD and NASA breakup models and support space situational awareness (SSA) applications

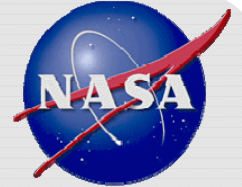


NASA model predictions match well fragments from the breakups of old satellites, but are noticeably different from fragments generated by modern satellites, such as FY-1C (left) and Iridium (right).



DebrisSat Project Goals

- **Design and fabricate a 60-cm/56-kg class spacecraft (“DebrisSat”), including MLI and solar panels, to be representative of modern payloads in LEO**
- **Conduct a hypervelocity laboratory impact test to simulate a catastrophic fragmentation event**
- **Collect, measure, and characterize all fragments down to 2 mm in size**
- **Use the data to improve space situational awareness applications and satellite breakup models for better orbital debris environment definition**



DebrisSat Project Team



- **NASA Orbital Debris Program Office (ODPO)**
 - Co-sponsor, project and technical oversight, data collection, data analyses, NASA model improvements



- **AF Space and Missile Systems Center (SMC)**
 - Co-sponsor, technical oversight



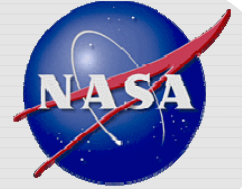
- **The Aerospace Corporation (Aerospace)**
 - DebrisSat design support, DebrisLV design & fabrication, data collection, data analyses, DoD model improvements



- **University of Florida (UF)**
 - DebrisSat design & fabrication, data collection, fragment processing and characterization



- **AF Arnold Engineering Development Complex (AEDC)**
 - Hypervelocity impact tests



DebrisSat Project Milestones

Prep-Test

2009-2011

- Project preparation
 - First ODPO visit to SMC in May 2010
 - Col. Swanson visited ODPO at NASA/JSC in August 2010

Sep 2011

- Project kickoff

Jan 2013

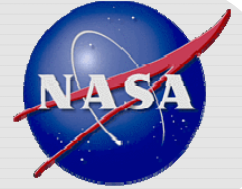
- Final DebrisSat design

Jan 2014

- Complete DebrisSat fabrication

April 2014

- Hypervelocity impacts at AEDC



DebrisSat Project Milestones

Collection-Characterization-Application

2014-present

- Fragment processing and characterization

Sep 2016

- Delivery of 1st set of measurement data

2016-2017

- Initial data analyses for model improvements

2018-2019

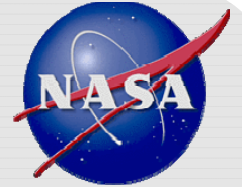
- Fragment radar and optical measurements

Sep 2020

- Complete measurement data

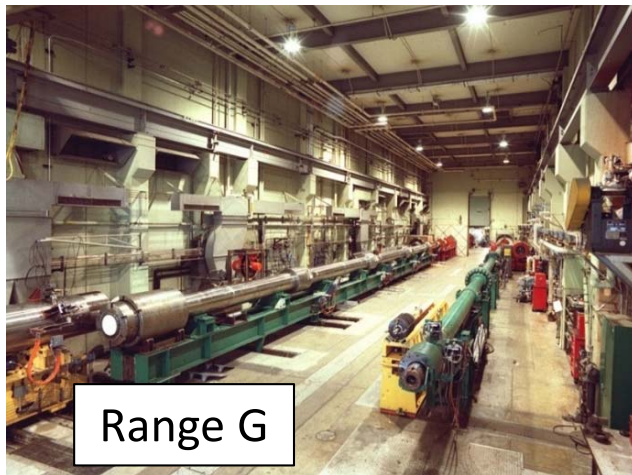
2018-2020

- Debris model and SSA application updates

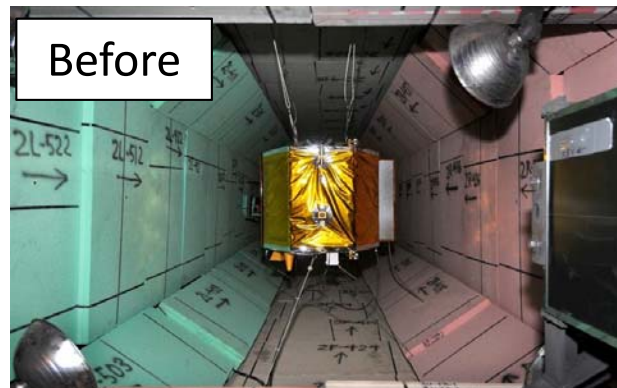


Hypervelocity Impact Facility at AEDC

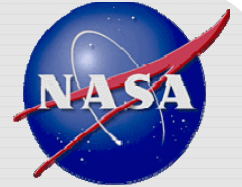
- **Range-G operates the largest two-stage light gas gun in the U.S.**
- **Standard diagnostic instruments include X-rays, high-speed Phantom cameras, and lasers**
 - With additional Aerospace IR cameras, and witness plates
- **Low-density polyurethane foam panels are installed inside target chamber to “soft catch” the fragments**



Credit (all photos): Arnold Engineering Development Complex/Air Force



Examples of the before (without target) and after impact views of the target chamber (10 ft × 20 ft).

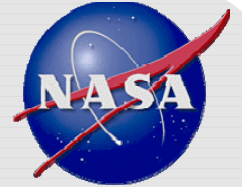


Pre-Test DebrisLV Shot

- **To further increase the benefits of the project, Aerospace built a target resembling a launch vehicle upper stage (“DebrisLV”) for the pre-test shot**
 - DebrisLV: 17.1 kg, body dimensions ~ 88 cm (length) × 35 cm (diameter)
 - Test conditions were identical to the impact on DebrisSat (facility setup, projectile, impact speed, soft catch, etc.)
- **Pre-test shot was successfully conducted on 1 April 2014**
 - Projectile impacted DebrisLV at 6.9 km/sec, completely fragmenting it
 - Fragments and soft catch foam panels/pieces were collected in boxes on 19 pallets for shipment



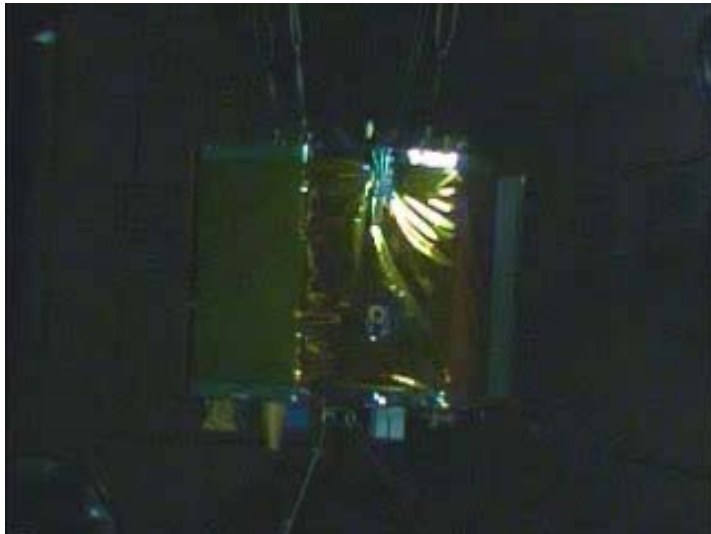
Credit: The Aerospace Corporation



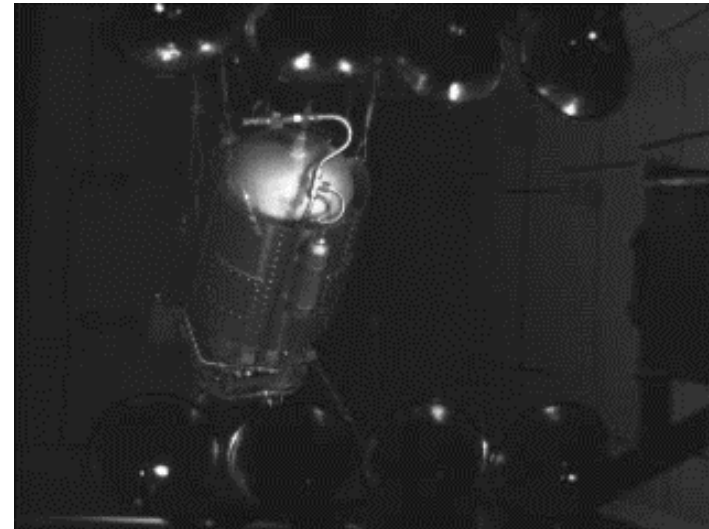
DebrisSat Shot

- **DebrisSat shot was successfully conducted on 15 April 2014**
 - Projectile impacted DebrisSat at 6.8 km/sec, completely fragmenting it
 - Fragments and soft catch foam panels/pieces were collected in boxes on 21 pallets for shipment

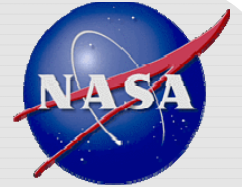
**A ~9 cm, 570-g projectile
impacted DebrisSat at 6.8 km/s**



**A ~9 cm, 598-g projectile
impacted DebrisLV at 6.9 km/s**

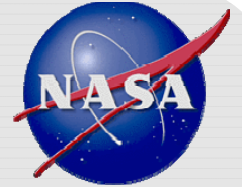


Credit (both videos): Arnold Engineering Development Complex/Air Force



Fragment Characterization Plan

- **Measure fragments, including MLI and solar panel pieces, down to ~2 mm in size**
 - Dimensions, mass, shape, density, composition
- **Obtain 2D and 3D scanning data for fragments**
 - Cross-sectional area, A/m, bulk density
- **Conduct radar, photometric, and spectral measurements for selected fragments**
 - Support improvements to radar and optical size-estimation models



DebrisSat Project Summary

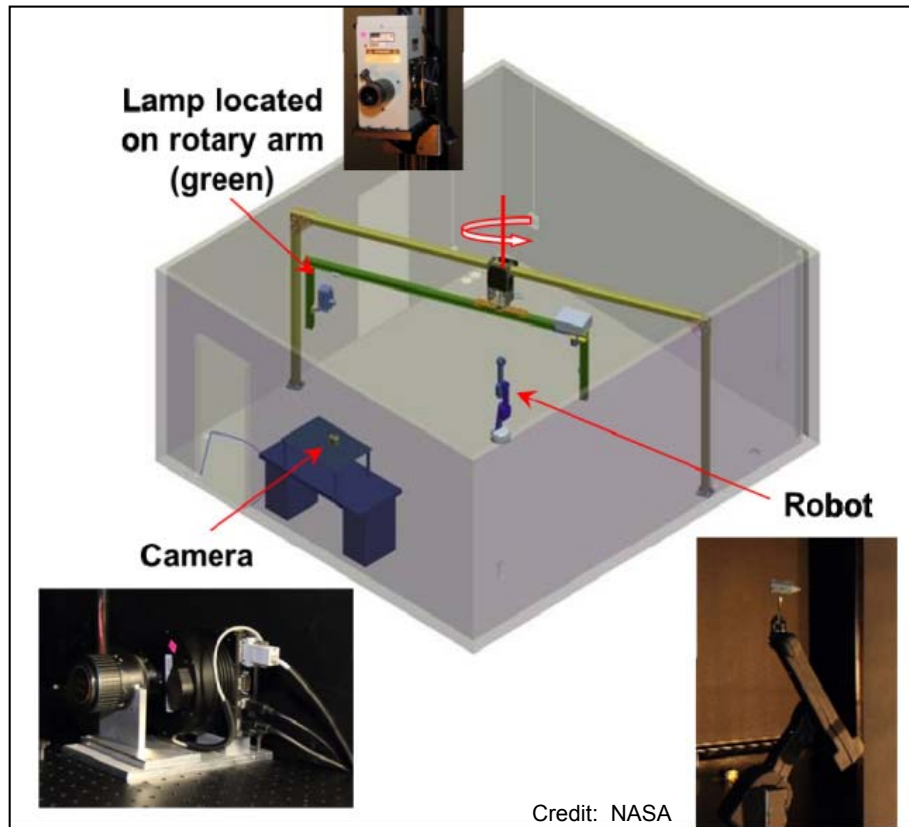
- **Beginning in 2009, significant effort was put into design phase to provide a realistic representation of a modern LEO satellite**
- **Impact test conducted in April 2014; fragments recorded to date have far exceed the initial prediction of 85K**
- **Characterization process involves prepping soft-catch panels, extracting fragments, and acquiring measurements on all fragments ≥ 2 mm in size**
- **Subset of representative fragments will be analyzed in a radar facility and Optical Measurement Center at NASA\JSC to update the current radar-based Size Estimation Model and generate an optical SEM**
- **Goal is to use the data/analysis to update existing breakup models used by NASA and DoD and support future ORDEM development and damage assessments**



Extra Charts



Optical Laboratory Data Analyses: Optical Measurement Center (NASA/JSC)



- **Goal: develop optical size estimation model eliminating need for assumptions in current calculations**

$$d = \frac{2 \cdot R}{[\pi \cdot A_g \cdot \Psi(\alpha)]^{0.5}} \cdot 10^{\left[\frac{M_{\text{abs}}(\nu) + M_{\text{sun}}(\nu)}{-5.0} \right]}$$

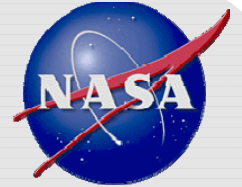
R: 36,000 Km

A_g : geometrical albedo=0.175

$\Psi(\alpha)$, Lambertian Phase Function

- **ASD field spectrometer**: high-resolution reflectance spectrometer .
- **SBIG CCD camera and attached filter wheel**, which uses Johnson/Bessell BVRI and SDSS $g'r'i'z'$
- **75 W Xenon arc lamp**
- **R17 robotic arm (5 DOF)**
- **Rotary arm with potentiometer**

- **Acquire empirical-based bidirectional reflectance distribution function measurements to eliminate need to have aspect angle dependencies**



Radar Facility Data Analyses

Historical:

- 1990s physical measurements acquired (L_c , area, and mass)
- Majority of objects investigated were aluminum or steel
- Radar measurements were taken at multiple angles in order to avoid undersampling the RCS aspect angle variations
- Data were taken at a wide range of frequencies from 2.4 to 18 GHz (S, C, X and Ku bands)

Plan Forward:

- Repeat the 1990s experiment with more modern materials, large frequency sweep, and collect RCS measurements in various aspect angles
- Similar to previous analysis, the physical parameters compared with RCS measurements to investigate the relationships for a broader subset of materials/shapes
- The DebrisSat fragments will provide the opportunity to compare optical measurements against optical inferred sizes and radar cross sections