A5

Current Status of Programs and Research within the NASA Orbital Debris Program Office

Jack Bacon
NASA

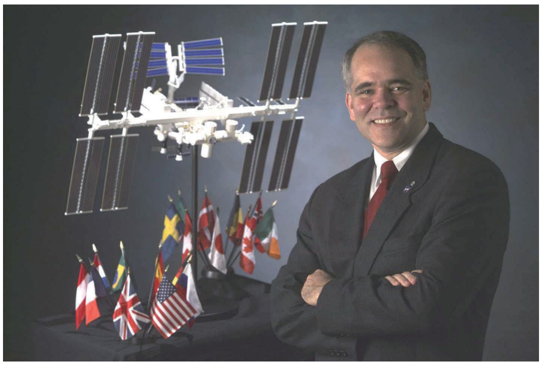
The NASA Orbital Debris Program Office (ODPO) is the world's longest-standing orbital debris research organization. It supports all aspects of international and US national policy-making related to the orbital environment and to spacecraft life cycle requirements. Representing more than just NASA projects, it is the United States' center of expertise in the field. The office continues to advance research in all aspects of orbital debris, including its measurement, modeling, and risk assessment for both orbital and ground safety concerns. This presentation will highlight current activities and recent progress in all aspects of the ODPO's mission.

Time lapse of HTV4 entry, Sept 7, 2013

The creation of a multi-kilometer vortex of mist resulting from fluid release from HTV4

Biography

Jack Bacon



Dr. Jack Bacon is the newest member of the NASA Orbital Debris Program Office. He joins ODPO as its entry safety specialist, after a 26-year career as an international systems integration engineer within the International Space Station Program, where he received two NASA medals and numerous other awards for his work. His doctorate degree in experimental fluid mechanics was awarded in 1984 by the University of Rochester. His Bachelor of Science degree is from the California Institute of Technology, 1976. For fifteen years Jack coordinated the ISS End-of-Life disposal planning, where he researched shallow entry physics and safety issues. He has collaborated with JAXA on a variety of projects, including the highly successful HTV4 entry experiment in 2013. The HTV4 entry remains the best-documented entry ever, and has advanced the science of spacecraft entry. Today Jack leads the development of software tools for entry analysis within the ODPO, and conducts research into numerous facets affecting the safety of ground populations under natural spacecraft entries. He has recently joined the Launch and Entry Safety Technical Subcommittee of the International Association for the Advancement of Space Safety, and is a technical member of the Inter-Agency Space Debris Coordination Committee. He is happily married to Kathleen: the girl he's loved for over 40 years.

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Current Status of Programs and Research
within the
NASA Orbital Debris Program Office

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Background

- **The NASA Orbital Debris Program Office (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, B. Cour-Palais, H. Zook, etc.)
- **ODPO provides technical and policy level support to NASA Headquarters, Office of Science and Technology Policy, other U.S. Government agencies and the commercial sector**
- **ODPO represents the U.S. Government in international fora, including the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations**
- **Work within ODPO continues to develop an improved understanding of the orbital debris environment and measures that can be taken to control debris growth.**

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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**
  - Analytical (Orbital Re-Entry Survivability Analysis Tool (ORSAT)
  - Observational (targeted and natural decays)
- **National and International Debris Policy**

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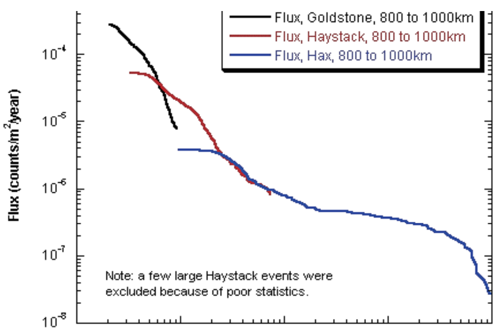
Radar Data Processing and Analysis

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

Goldstone

Haystack and HAX



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Current Radar Status

- **Continuing to use data from:**
  - HUSIR
  - HAYSTACK
  - HAX
  - Goldstone

- **Have obtained access to extensive Arecibo data files**
  - Future data reduction effort

- **Radar processing software update in work**
  - DRADIS replaces ODAS

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Radar Measurement Improvements (1 of 2)

- **Radar Data Processing Software**
  - A new set of radar data processing software, DRADIS, is being built by SIDLUX systems
  - The new software will replace the current ODAS software
  - Delivery of DRADIS is scheduled for the end of September
  - DRADIS is being tested by SIDLUX systems while it is being constructed
  - After delivery to NASA, additional tests will be performed at the ODPO to ensure that the new software meets it performance requirements

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Radar Measurement Improvements (2 of 2)

- **Some New Features in DRADIS**
  - Target detection capability with methods other than 16 pulse noncoherent integration
  - M of N detection will be available in DRADIS and is intended to be the new detection algorithm
  - M of N provides multiple hypothesis testing for various paths through the beam
  - Provides optimal M of N combinations for various paths through the beam
  - Monopulse calculations will be corrected by forcing the cosine θ term to be only ±1
  - Corrected monopulse will result in better path through the beam resulting in more accurate size estimates and trajectory estimates

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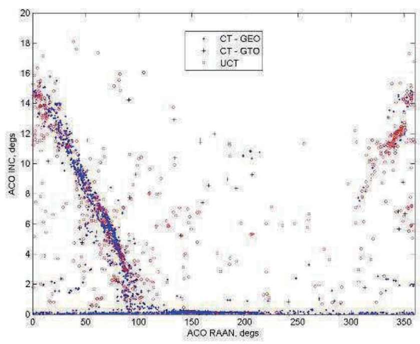
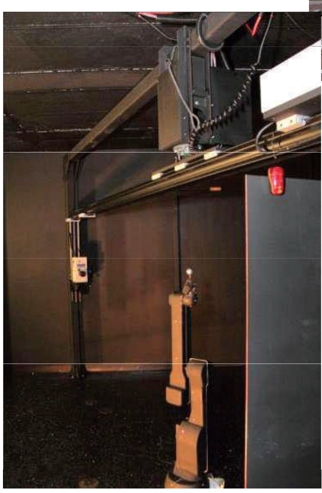
Optical Data Collection, Processing, and Analysis

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





OMC

MODEST

MCAT

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Optical Measurements Group (OMG)

Major Tasks

– JANAODO
  - **J**ohn **A**fricano **NA**SA/**A**FRL **O**rbital **D**ebris **O**bservatory
– MODEST
  - **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope
– UKIRT
  - **U**nited **K**ingdom **I**nfra **R**ed **T**elescope
– OMC/Laboratory Spectroscopy
  - **O**ptical **M**easurements **C**enter (NASA/JSC)
– SST
  - **S**pace **S**urveillance **T**elescope

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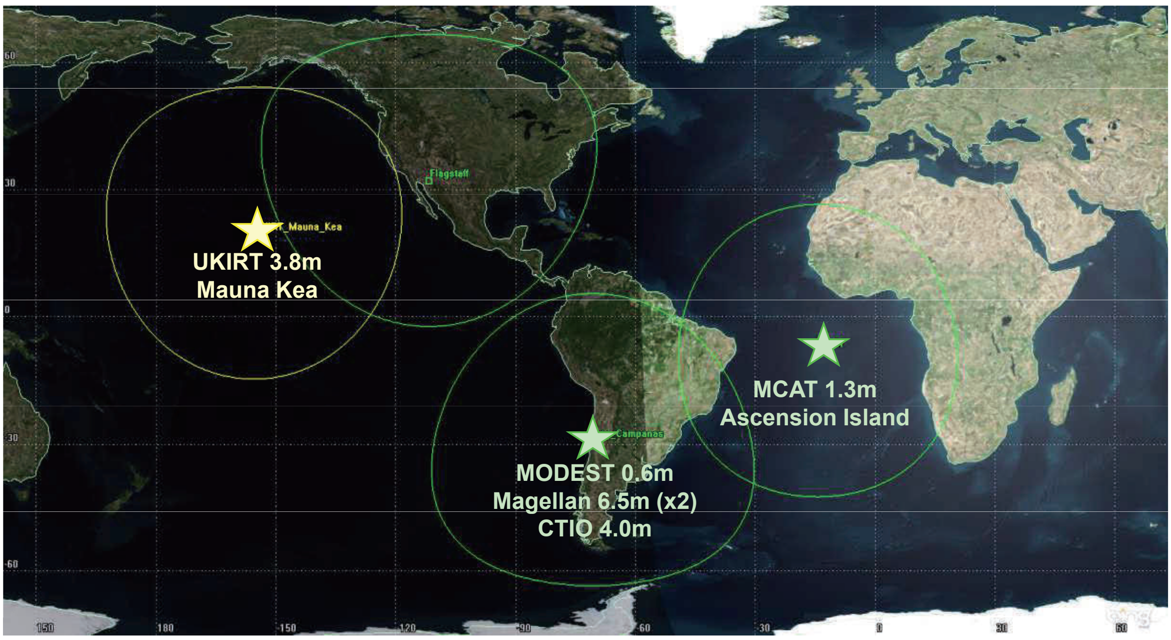
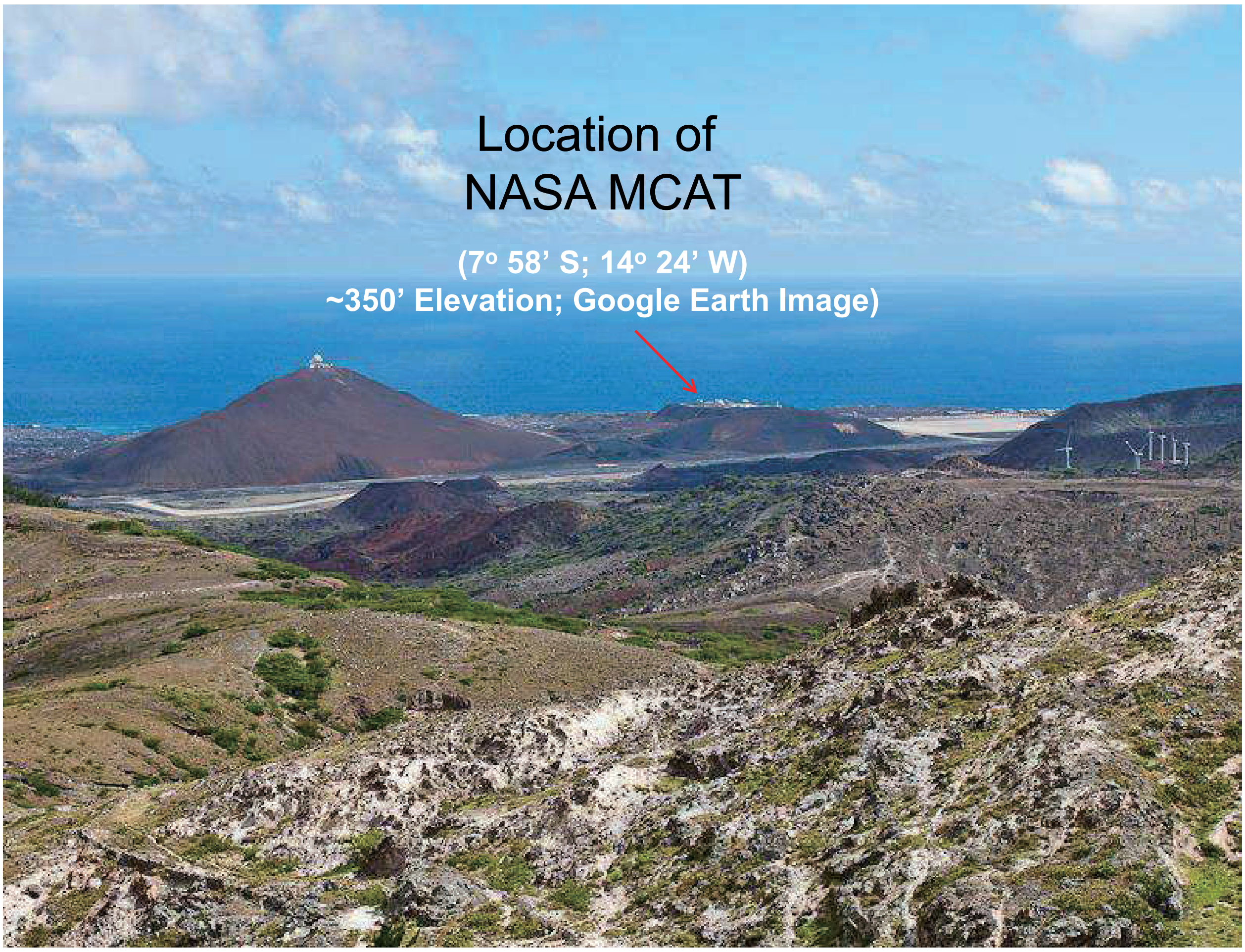
Optical and IR Telescopes used by the NASA debris office





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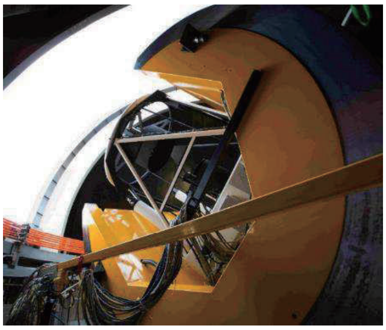
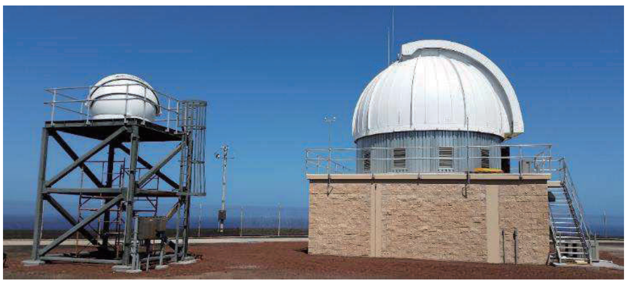
Meter Class Autonomous Telescope (MCAT)

- **1.3-m DFM telescope**
  - 1.3m double horse-shoe DFM telescope
    - Fast tracking smoothly through zenith
  - 7-m fast-tracking Observadome® (GEODSS equivalent)
  - Spectral Instruments camera
    - TDI (time-delay integration) enabled
    - **41' x 41' FOV** (0.957° diagonal)
    - BVRI, g'r'i'z' broadband filters



- **0.4m Benbrook**
- **16" (0.4m) Officina Stellare telescope**
  - ➢ Atlas focuser
  - LEO tracking Astelco mount
  - Finger Lakes Proline camera, e2V chip
    - **44' x 44' FOV**
    - 1.3" per pixel (vs. 0.6"/pix MCAT)
  - Centerline Filterwheel
    - BVRI, g'r'i'z' broadband filters



→ Simultaneous observations with MCAT in 2 filters

(7° 58′ S, 14° 24′ W)

12/39 Orbital Debris Program Office

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MCAT Timeline

Systems Testing	Construction	Acceptance Testing	Full Integration/ Data Collection
• July 2013: Telescope testing • Aug 2013-June 2014: Software/Hardware integration testing	• Sept 2014, Ground-breaking • Sept-March/April 2015: Main facility construction • March-April 2015: Dome installation • April-June 2015: Telescope installation	• June 2, 2015: Engineering First light • June 17: Camera failure • SAT for all except Camera-specific tasks • Aug: 1 Light alt camera for debris tracking, lightcurves • Nov: Si Camera fix • Dec 2015: SI Camera	• Dec 2015: Begin fully integrated systems testing • Jan 2016: Remote Data collection begin • Dec 2016: Benbrook installation testing (16" telescope) • Full operations expected 20+ years

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MCAT/ JANAODO Project Overview (1 of 2)

- Collaboration between NASA, Air Force 45th Space Wing, and Air Force Research Laboratory (AFRL) Maui Optical Site (AMOS)
- MCAT Goal: Statistically characterize under-sampled orbital regimes
  - Geosynchronous and near GEO altitudes
  - LILO, i.e. Low inclination Low Earth Orbit (LEO)
    - Evening and morning twilight

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MCAT/ JANAODO Project Overview (2 of 2)

- **MCAT Objectives:**
  - Monitor and assess orbital debris environment by ***surveying, detecting***, and ***tracking orbiting objects*** at:
    - **LEO, MEO, GTO, GEO altitudes**
    - **Debris as small as 20-30 cm in GEO should be detectable**
    - **GEO debris surveys**
  - May participate in JSpOC (*Joint Space Operations Center*) follow-up or hand-off activities
- **Ascension Island location enables access to under-sampled low inclination orbits and new GEO longitudes (7° 58′ S, 14° 24′ W)**
    - **Existing technical staff for "caretaker" support**
    - **Automated data analysis at site**
    - **Low data transmission requirements – transmit results, not data**

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Operational Concepts to attain Objectives (BIG PICTURE)

1. GEO Sweep/ GEO Follow-up:	2. Catalog or Object-of-Interest Tracking:	3. Orbit Scan (LEO mode):	4. Stare – Detect – Chase:	5. Coordinated Observations:
TDI mode matches GEO motion to sweep GEO longitudes; follow-up specific targets for further characterization	*Target specific objects for testing or characterization*	*Define rate track by a given expected orbital rate*	*Object crosses Field of View, its motion calculated, chase at calculated rate of motion*	***I. Optical-Optical*** *Benbrook* ***II. Radar-Optical*** *C-band radar on Ascension;*

- **5 Modes of data collection**
- **Survey: Modes 1 & 3**
- **SSA: supported most through modes 2 & 3**
  - Mode 2 to determine individual object characteristics/orbits
  - Mode 3 for rapid follow-up after break-up event

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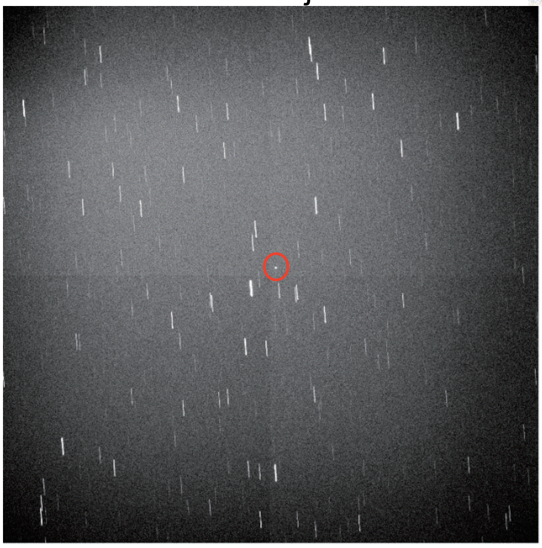
MCAT Object Tracking (TLE)

MEO object

GEO object



- MEO and GEO object tracking with MCAT

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Instrument Commissioning

- **Finger Lakes Fast-read out (alternate camera)**
  - Originally purchased for the DIMM seeing monitor measurements
  - Electronically cooled (55C below ambient)
  - 3' x 3' FOV
    - **Small format, but <u>fast read-out</u>, electronic shutter (4 MHz or 10 MHz)**
    - **Lightcurve studies of known objects**
  - Instrument commissioning Aug 2015
- **SI camera (prime camera)**
  - Cryo-cooled (-110C)
  - Instrument commissioning Dec 2015
  - 41' x 41' FOV
    - **Survey, Object characterization**
- **FLIR Infrared sky-cam mounted on MCAT above secondary mirror**

In-Space Debris Sensing

- **DRAGONS is an impact sensor designed to detect and characterize collisions with small orbital debris.**
  - 50μm to > 1mm debris size detection
  - Characterize debris size, speed, direction, and density
- **The Space Debris Sensor (SDS) is a flight demonstration of DRAGONS on the International Space Station (ISS)**
  - Approximately 1 m^2 of detection area facing the ISS velocity vector
  - To be attached on the ESA Columbus module with minimal obstruction from ISS hardware
  - Minimum two year mission on Columbus External Payloads Facility(EPF)
  - Development is nearing final checkout and integration with the ISS
  - Current launch schedule is SpaceX 13, ~ Sept 2017, or SpaceX 14, ~ Feb 2018

Background

- **DRAGONS concept and technology has been under development with intermittent grants since 2002**
- **The goal of DRAGONS is to provide in-situ statistical data on the debris population that is too small for ground-based remote sensing to accomplish**
  - Results would be used to update the Orbital Debris Engineering Model (ORDEM)
  - Current estimates of the small debris population is based on inspection of exposed surfaces returned on Shuttle (Retired 2011)
- **The DRAGONS team includes the NASA Orbital Debris Program Office, the NASA Hypervelocity Impact Technology group, the NASA/JSC Engineering Directorate, Jacobs, the United States Naval Academy, the Naval Research Lab, Virginia Tech, and the University of Kent**

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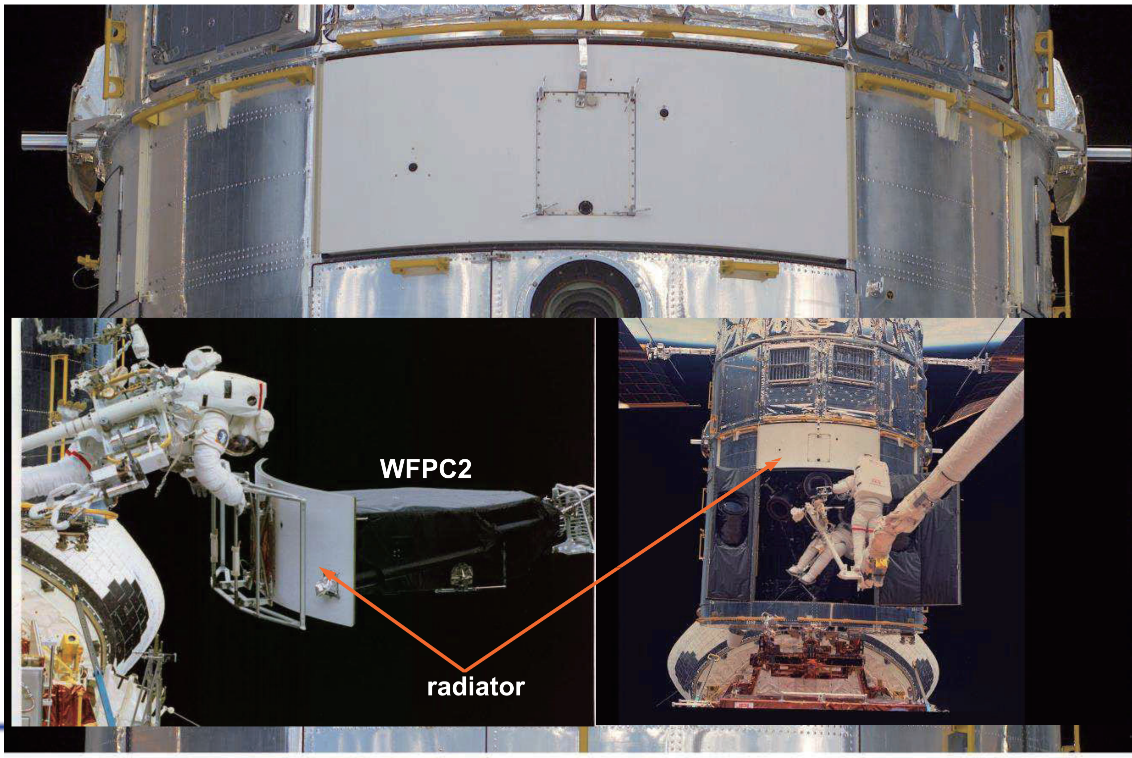
MMOD Inspection of the HST WFPC2 Radiator



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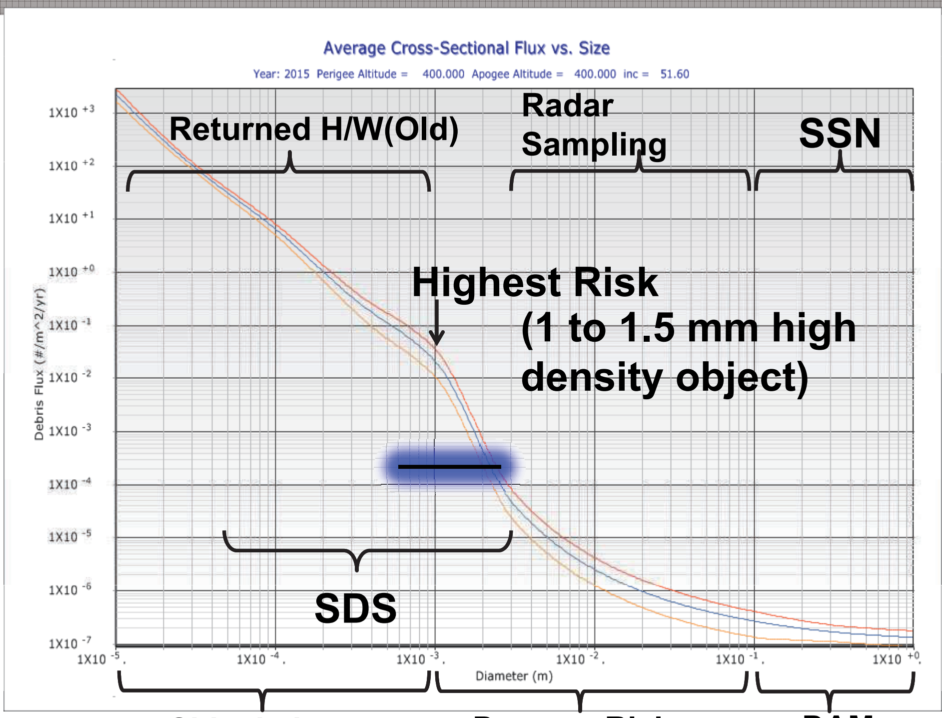
ORDEM 3.0 ISS Debris Environment 2015 Prediction



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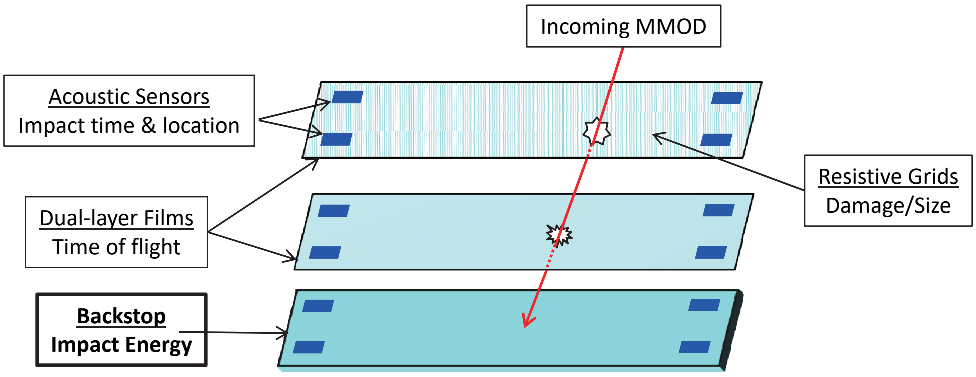
Detection Principles

- **SDS combines dual-layer thin films, an acoustic sensor system, a resistive grid sensor system, and sensored backstop**
- **Impact detection and recording capability**
  - Impact time, particle size, impact speed, impact direction, and impact energy/particle density



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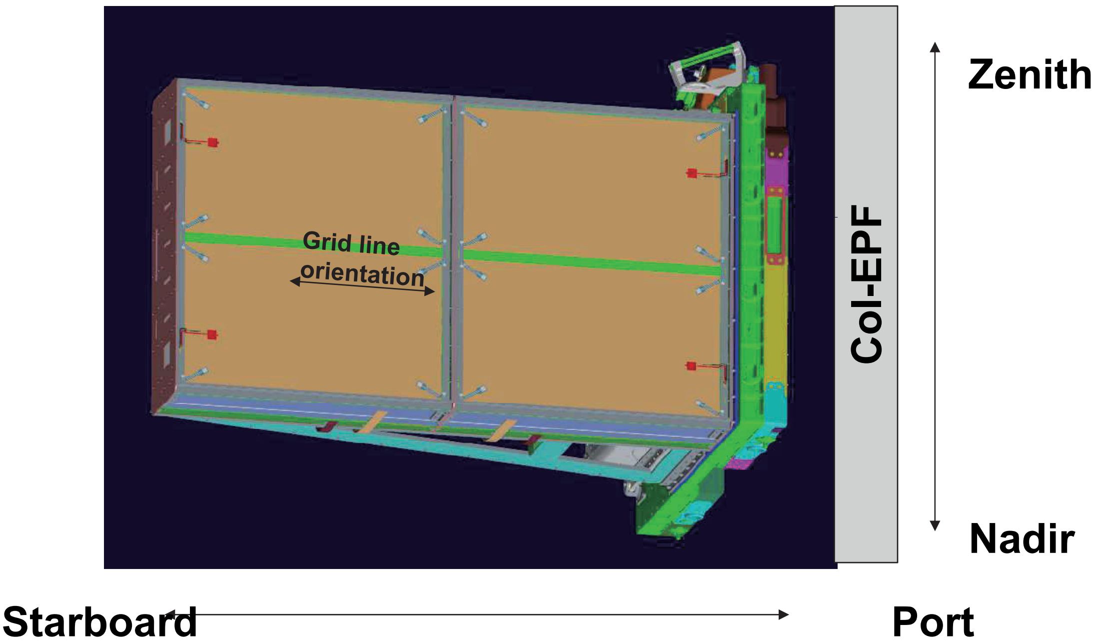
SDS ISS Orientation



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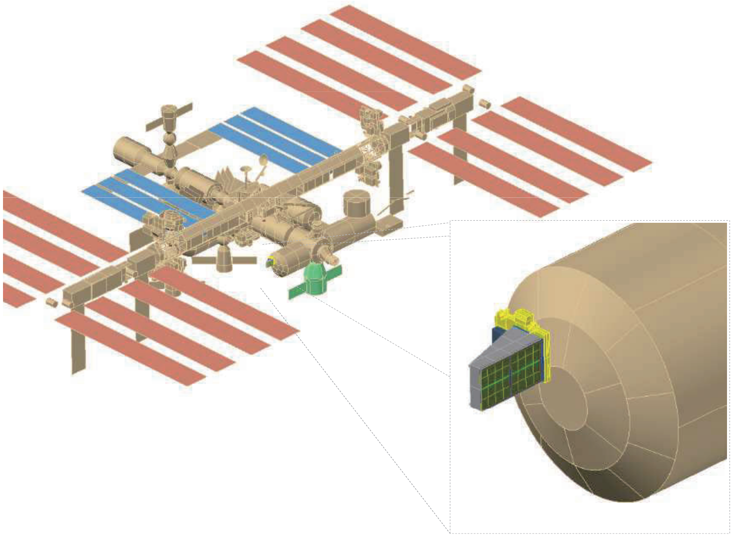
SDS Installed on Columbus-EPF

- **SDS installed on ISS Columbus-EPF (External Payload Facility)**



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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**

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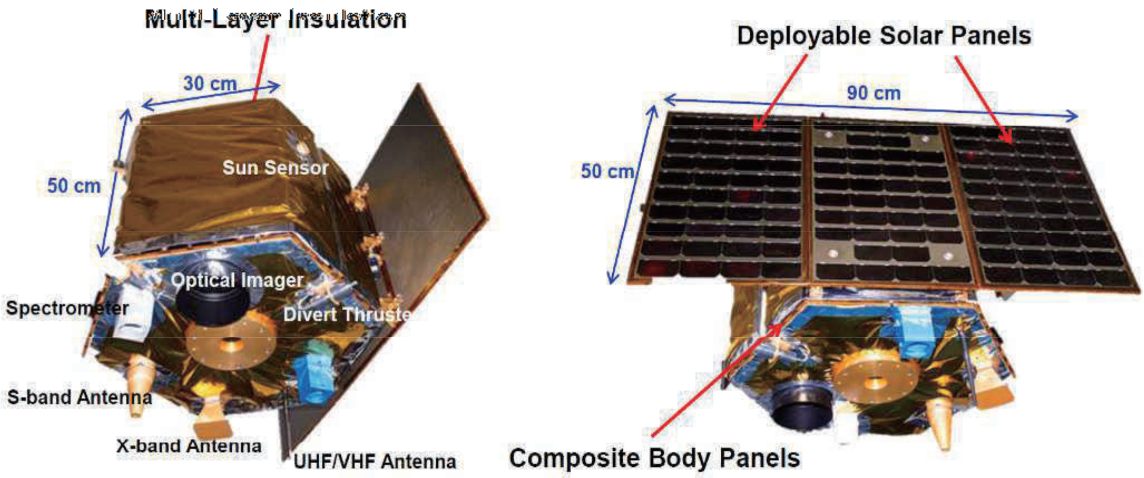
DebriSat



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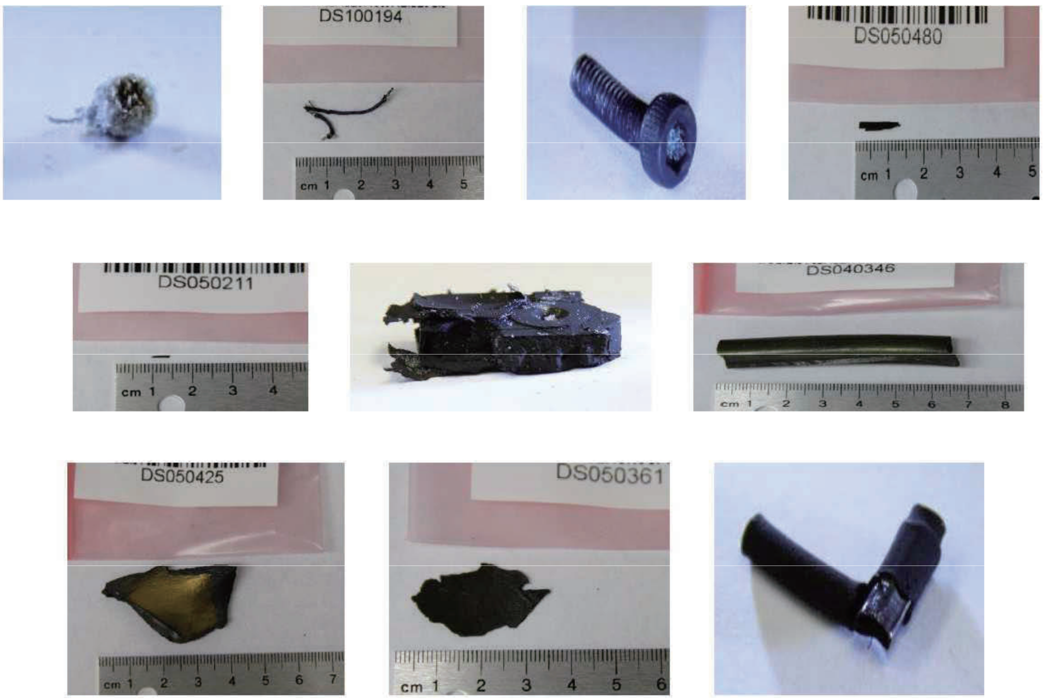
DebriSat Fragments



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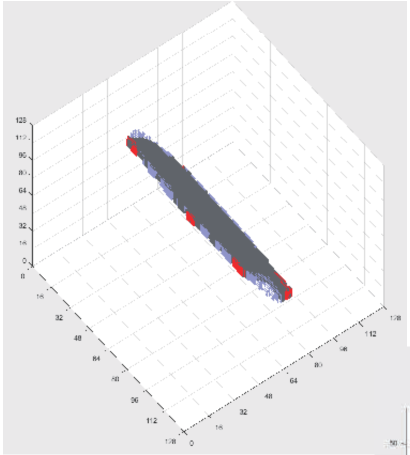
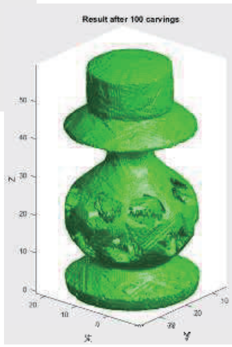
Current DebriSat Status

- **Thousands of (2D) pieces:**
  - Weighed,
  - Imaged,
  - Boundaries measured,
  - Generic “bins” of debris type assigned
    - **“bent rod”, “flat plate”, “nugget/block/sphere”, etc.**
- **ODPO research Hundreds of thousands left to go**
- **University of Florida is recording the data**
- **3D imaging about to start**
- **is under way on additional data mining and indexing techniques**
  - Common-size voxel indexing
  - Spherical harmonic fitting
  - Looking for statistical patterns in 3D shapes, mass properties, material detection, and optical properties.





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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

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Current Modeling Status

- **Special study recently completed on debris environment implications of CubeSat population growth:**
  - After their post-mission orbit adjustments, CubeSats accumulate at low altitudes
    - **May pose collision avoidance issues in the long run**
  - As the number of CubeSat deployments increases,
    - **The total number of catastrophic collision events increases**
      - ➢ **which results in an increase in the number of objects**
  - The number of objects in decaying orbits increases
    - **In some cases as much as 90% of the objects in altitude bins < 600km are comprised of CubeSats**
-

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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)

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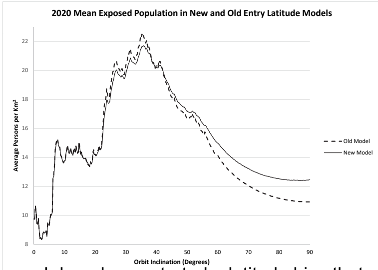
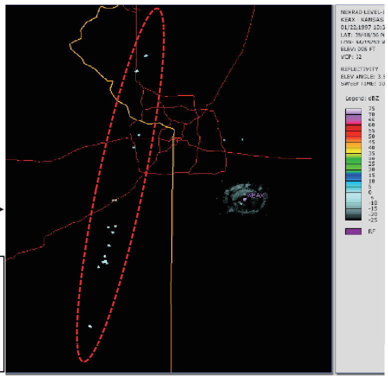
Current Reentry Modeling Efforts

- **ORSAT 7.0 development underway**
- **Oblate Earth effects on decay latitudes**
- **Low dV entry-targeting research**
- **Partnership in entry observation experiments**
- **Data mining of public sources for observed natural decays**



Research has demonstrated a latitude bias that affects the assumption of randomized entry along an orbit path



Weather Radar showing dust clusters under and 60 minutes after Delta II illuminated entry in 1997

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Orbital Debris and U.S. National Space Policy

- **Orbital debris has been addressed in all U.S. national space policies since 1988**
- **National Space Policy (signed 28 June 2010 by President Obama) states:**
  - **For the purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall:**
    - **Lead the continued development and adoption of international and industry standards and policies to minimize debris…**
    - **…Pursue research and development of technologies and techniques, through the Administrator of the National Aeronautics and Space Administration (NASA) and the Secretary of Defense, to mitigate and remove on-orbit debris, reduce hazards, and increase understanding of the current and future debris environment..**
- **Updated NASA Procedural Requirement (NPR 8715.6) and Technical Standard (NS 8719.14) for Limiting Orbital Debris Generation became effective August 2007**

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Current Standards Status

- **NASA Procedural Requirements**
  – Updated NPR 8715.06 revision B is in final review
- **NASA Orbital Debris Technical Standard**
  – NASA STD 8719.14
  – A major review/update in work for Summer 2017 release, reflecting:
    - **Latest US national space policy**
    - **Special requirements evolving from CubeSat proliferation**
    - **Potential extension of risk mitigation standards to lunar, and planetary orbits, and all Lagrange points**

  – Updates to the NASA Orbital Debris Mitigation Handbook and the Debris Assessment Software (DAS) tool will be released concurrently to synchronize to the revised standard.
- **ODPO is coordinating the new revisions with various NASA centers, and is soliciting input from other US agencies engaging in space activities (FAA, USAF, FCC, etc.)**

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Orbital Debris and the International Space Community

- **Inter-Agency Space Debris Coordination Committee (IADC) was established in 1993 (meets annually)**
  – 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
  – Now includes 13 space agencies (China, France, Germany, India, Italy, Japan, Russia, Ukraine, United Kingdom, United States, Canada, South Korea & ESA)
- **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)

Inter-Agency Space Debris Coordination Committee

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Recent International Efforts

- **In 2010, COPUOS established a Working Group on the Long-Term Sustainability of Outer Space Activities (LTS)**
  - Objective: to identify areas of concern for the long-term sustainability of outer-space activities, establish and maintain standards that could enhance sustainability in all of its aspects, including the safe and sustainable use of outer space for peaceful purposes, for the benefit of all countries
  - Topics to be covered: space debris, space weather, space operations, and space situational awareness.

Inter-Agency Space Debris Coordination Committee

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Summary

- **Work within ODPO continues to develop data and models for an improved understanding of the orbital debris environment and measures that can be taken to control debris growth**
- **The NASA Orbital Debris Program Office has a major international role in conducting measurements of the environment and in developing the technical consensus for adopting mitigation measures to protect users of the orbital environment**
- **We are grateful for past, present, and future collaboration and sharing with our partners and fellow researchers in Japan**

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Thank you for your kind attention!