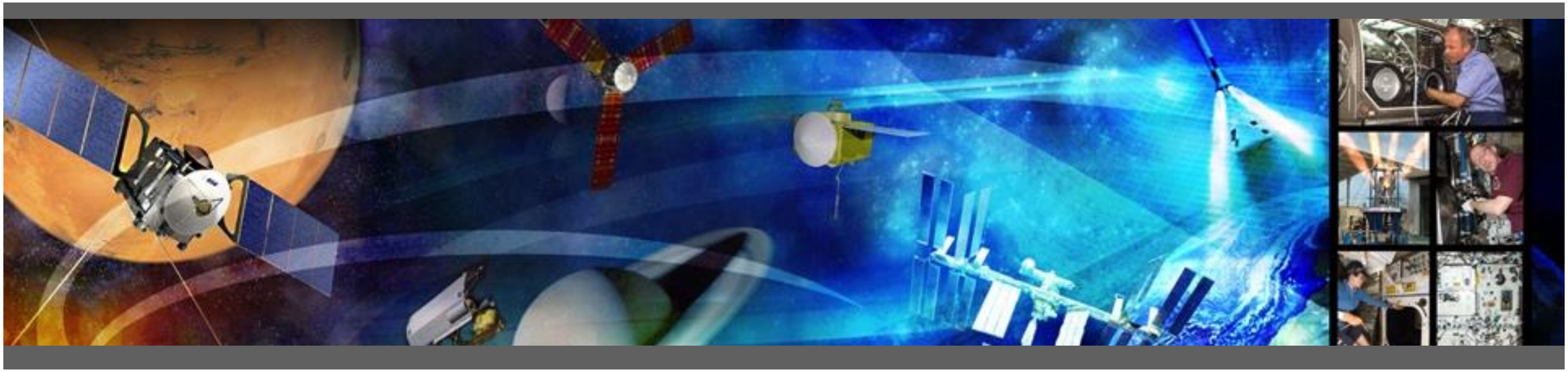
National Aeronautics and Space Administration



NASA MSFC Technology Capabilities for use in SSA Activities

June 2018

Larry Gagliano
Todd Macleod
Mary Hovater
Elizabeth Esther

MSFC ISSAAM

➢ISSAAM (Integrated Space Situational Awareness and Asset Management)

- Initiative to identify existing and proposed capabilities, skills, and activities at MSFC that are applicable to *Space Situational Awareness (SSA)* and *Space Asset Management (SAM)* and functionally organize them according to SSA focus areas
- ISSAAM, under various names, has been in existence at MSFC since 2009

➢Vision

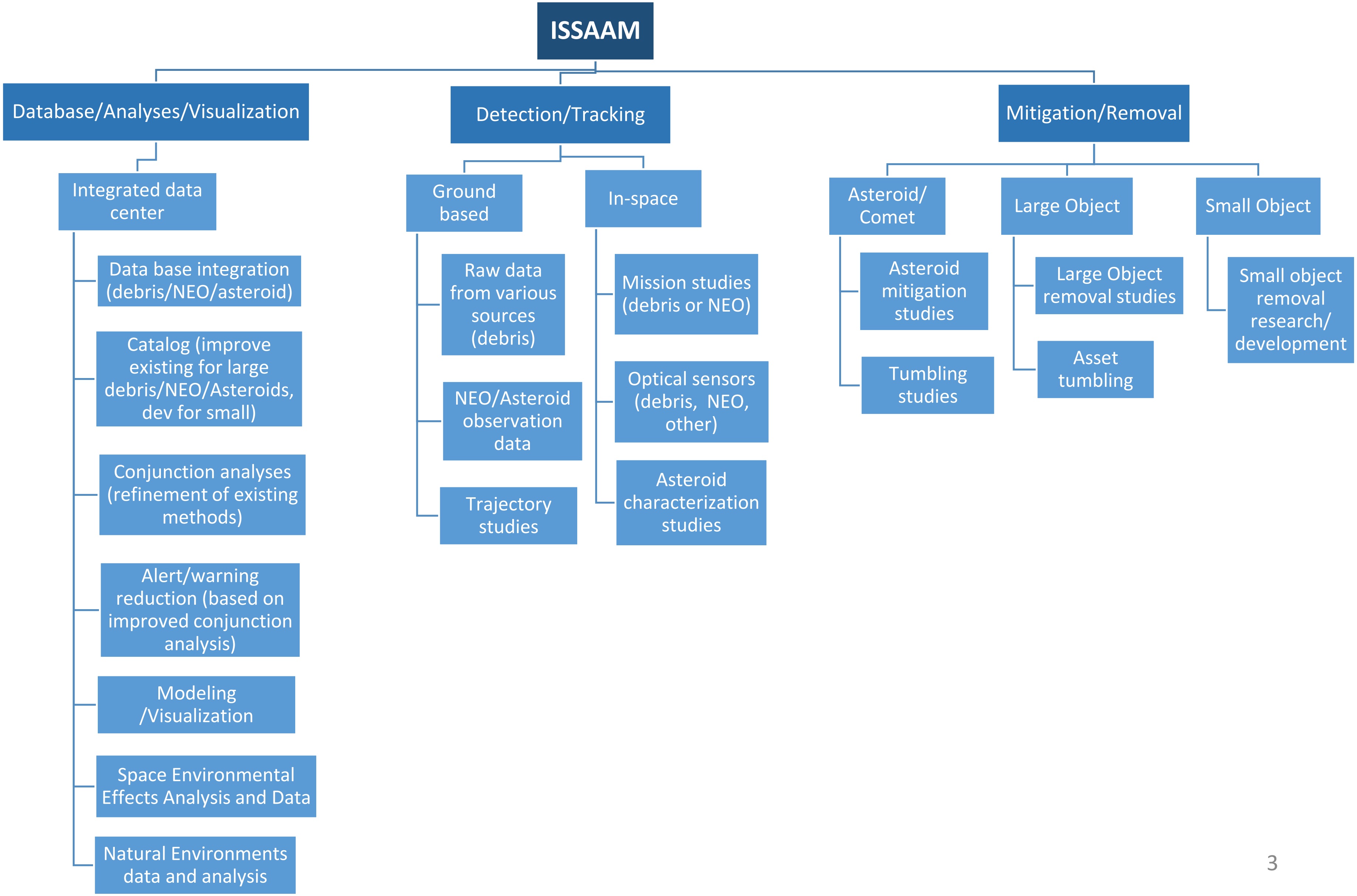
- To establish MSFC as a viable technical partner for SSA/SAM related needs, through technical innovation, collaboration, and cooperation with other U.S. Government Agencies and commercial companies, academia and international Space Community.

➢GOALS

- Integrate activities across Center for stronger more relevant capabilities that potential partners seek
- Support NASA's STMD, OSMA and OCT as needed
- Maintain engagement in SSA community activities and programs
- Foster partnerships with DoD and other SSA involved organizations
- Find and implement solutions to gaps within SSA/SAM

ISSAAM provides Marshall coordinated approach to SSA

ISSAAM Functional Structure

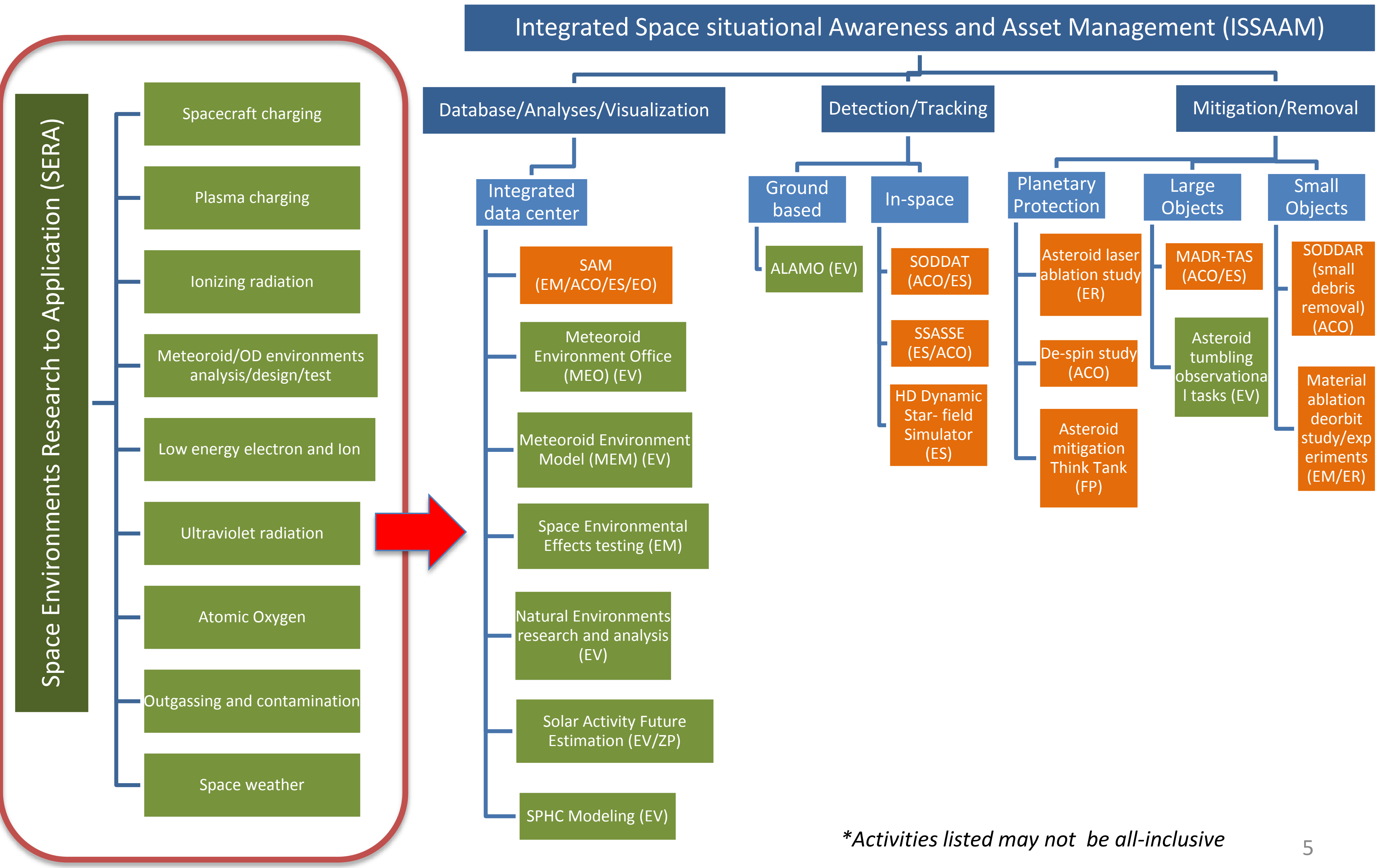


ISSAAM Functional Structure Mapped to Marshall Activities

- **ISSAAM**
  - Database/Analyses/Visualization
    - Integrated data center
      - SAM (EM/ACO/ES/EO)
      - Meteoroid Environment Office (MEO) (EV)
      - Meteoroid Environment Model (MEM) (EV)
      - Space Environmental Effects testing (EM)
      - Natural Environments research and analysis (EV)
      - Solar Activity Future Estimation (EV/ZP)
      - SPHC Modeling (EV)
  - Detection/Tracking
    - Ground based
      - ALAMO (EV)
    - In-space
      - SODDAT (ACO/ES)
      - SSASSE (ES/ACO)
      - HD Dynamic Star- field Simulator (ES)
  - Mitigation/Removal
    - Asteroid/ comet
      - Asteroid laser ablation study (ER)
      - De-spin study (ACO)
      - Asteroid mitigation Think Tank (FP)
      - Asteroid deflection w/ BAE (part of D3I) (CS10)
    - Large Objects
      - FASTSAT recovery mission
      - MADR-TAS (ACO/ES)
      - Asteroid tumbling observational tasks (EV)
    - Small Objects
      - SODDAR (small debris removal) (ACO)
      - Material ablation deorbit study/experiments (EM/ER)

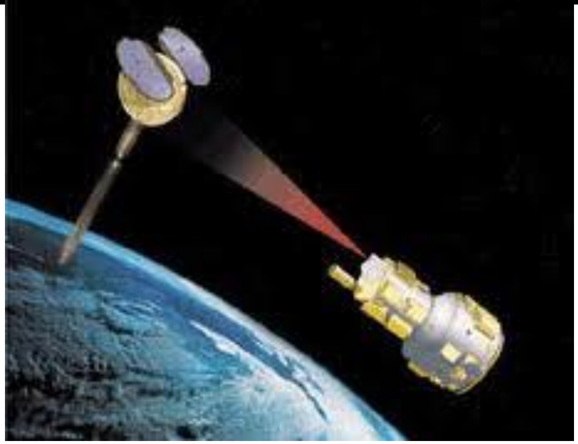
**Activities listed may not be all-inclusive*

ISSAAM Functional Structure Mapped to Marshall Activities

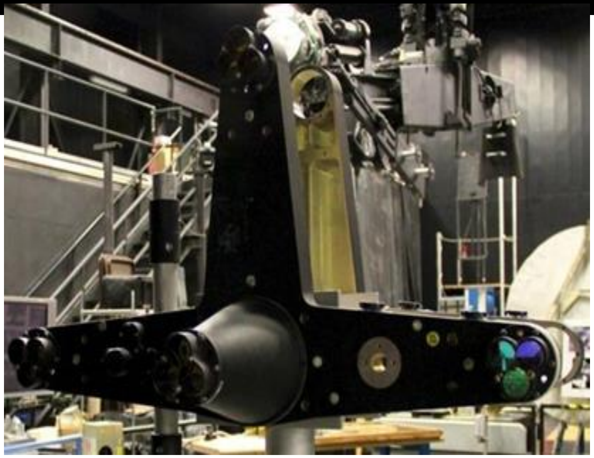


**Activities listed may not be all-inclusive*

MSFC CAPABILITIES AND EXPERIENCE RELATED TO SATELLITE PROXIMITY OPERATIONS

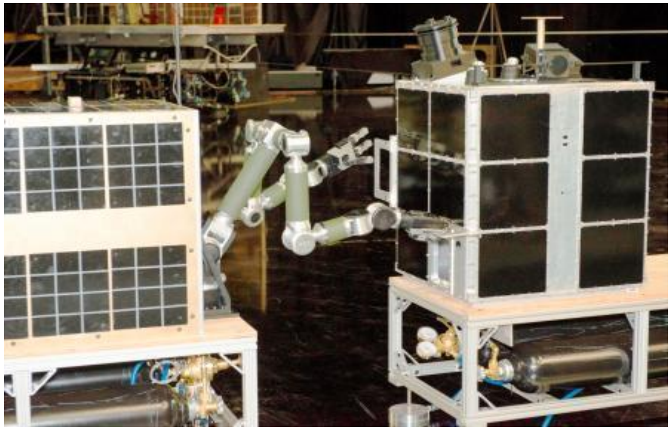


Demonstration for Autonomous Rendezvous Technology
MSFC lead the DART Project and Developed the AR&C Sensors and Software

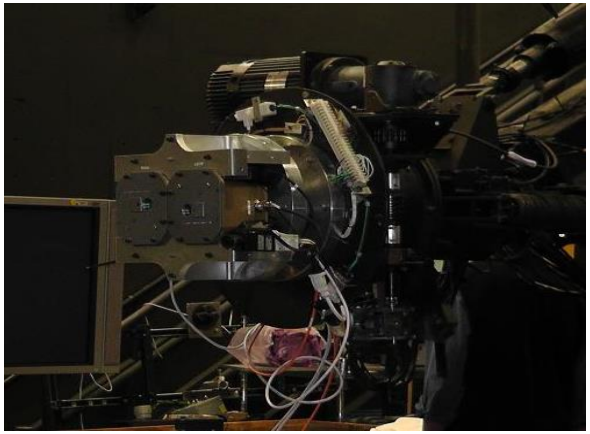


Video Guidance Sensor shuttle flight target
MSFC Developed AR&C System

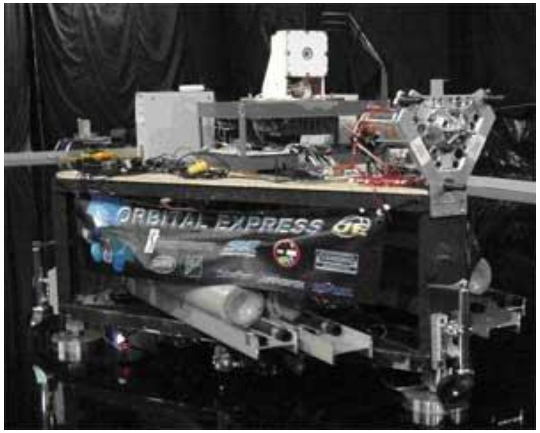
Satellite Thruster Development Testing
MSFC developed future satellite thruster system



Tele-robotic small satellite capture demonstration
MSFC test on Flight Robotics Lab Flat Floor

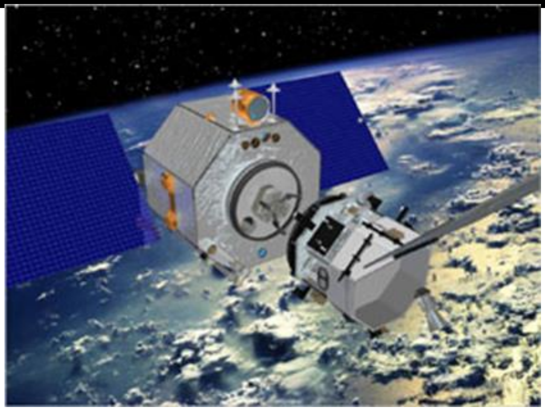


Dragon Eye sensor testing
3-D Flash LIDAR System



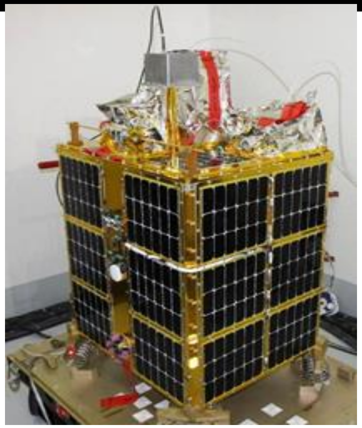
AR&C and docking mechanism test in MSFC Flight Robotics Lab

MSFC Capabilities and Experience in Satellite Proximity Operations

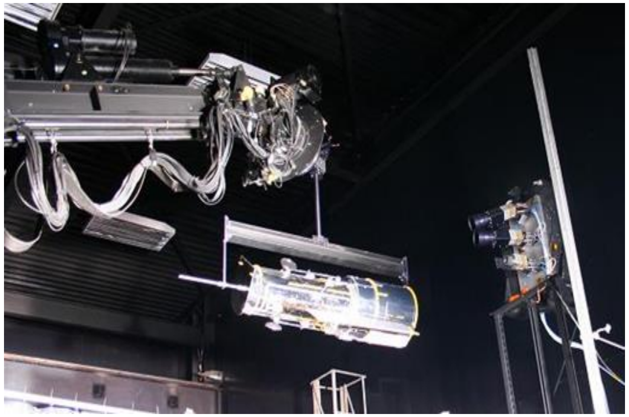


Orbital Express
MSFC Developed flight hardware and software for the mission

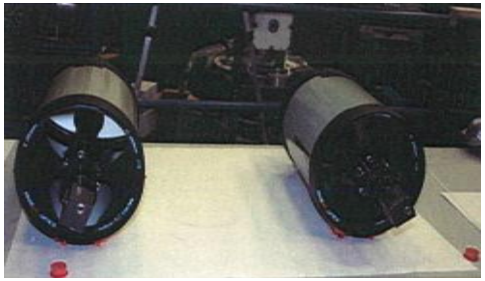
System Integration Laboratory
MSFC developed Hardware-in-the-loop Mission simulations



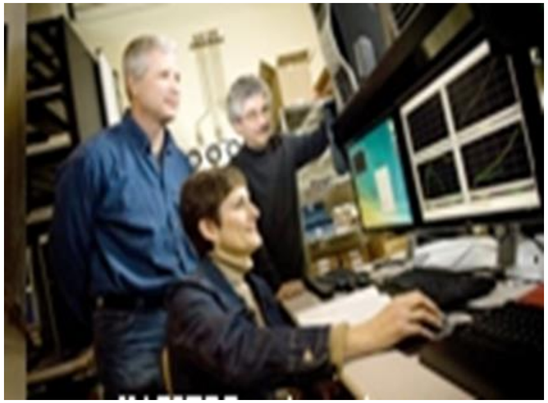
FASTSAT-HSV01
Developed and Flown by MSFC



HST Docking Testing at MSFC
Utilizing the MSFC Contact Dynamics Simulator



High Fidelity Dynamic Star Field Simulator



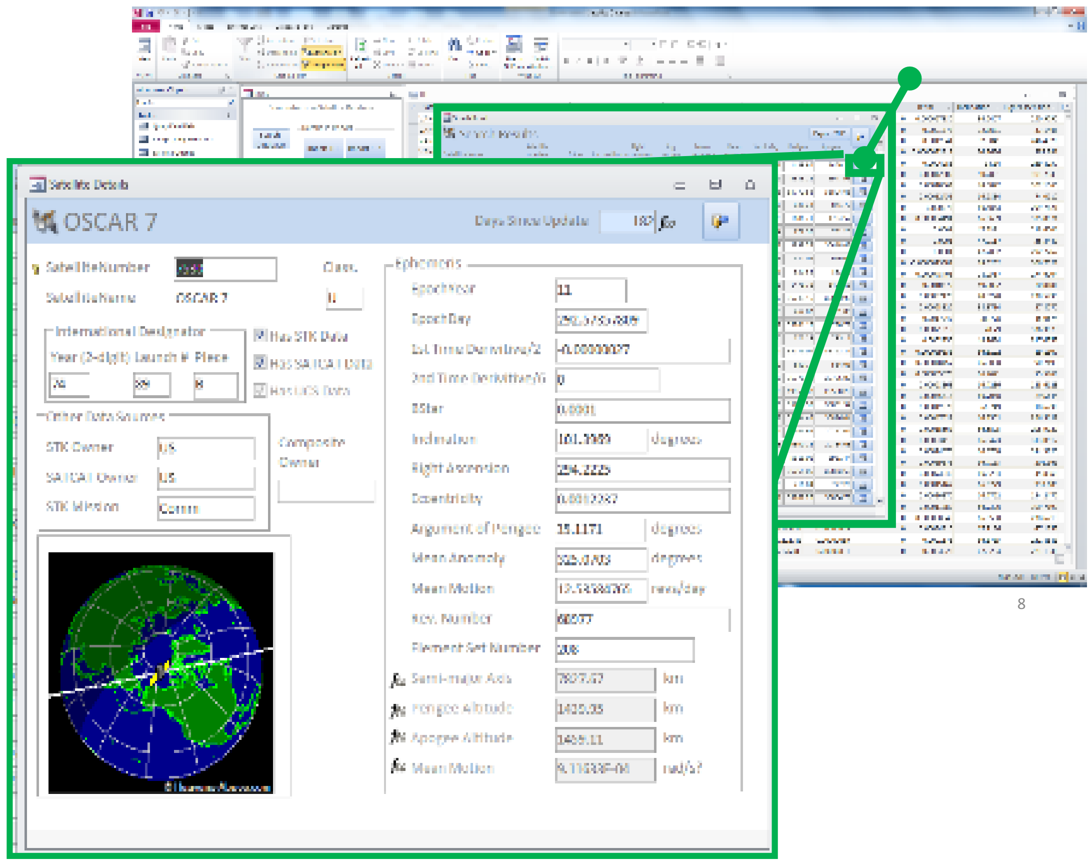
SIL Software Development
MSFC developed Real-Time simulation environment

SAM-D Tech Dev

Overview

In conjunction with the development of our comprehensive data collection effort (SAM-D), SRI and MSFC plan to develop a integrated set of models and simulations that can address the totality of the analysis issues faced by the development and use of space situational awareness systems.

We intend to develop such an integrated analysis system that takes advantage of existing capabilities where possible, develops capabilities that cannot be used in the open environment envisioned for the space situational system we are developing, and provides new capabilities for systems analysis, planning, systems engineering, and situational awareness prediction where none currently exist.



Meteoroid Environment Office (MEO)

MEO, based at Marshall, is the NASA organization responsible for meteoroid environments pertaining to spacecraft engineering and operations. The MEO leads NASA technical work on the meteoroid environment and coordinates the existing meteoroid expertise at NASA centers.

The objective of the MEO is to understand the flux and the associated risk of meteoroids impacting spacecraft traveling in and beyond Earth's orbit. Meteoroids impacting spacecraft are a quantifiable risk as they can puncture pressurized volumes (i.e. space station modules, propellant tanks) or destroy components (i.e. engines, electronics).

2001 Leonid Fireball recorded from Hawaii

Meteoroid Environment Model (MEM) — Given a state vector, MEM outputs mass-limited or penetrating fluxes and average impact speeds and distributions on the surfaces of a cube-like structure with the ram face oriented along the spacecraft velocity. Some of the revolutionary aspects of MEM are a) identification of the sporadic radiants with real sources of meteoroids, such as comets, b) a physics-based approach which yields accurate fluxes and directionality for interplanetary space-craft anywhere from .2 AU to 2 AU, and c) velocity distributions obtained from theory and validated against observation.

Automated Lunar and Meteor Observatory (ALaMO)

- Lunar Telescopes
  - Three 14" (0.35m)
    1 Meade, 2 Celestron
    Paramount (2 ME, 1 MX)

- Detectors
  - Watec 902H2 Ultimate
  - Goodrich SU640 Near-IR (InGaAs)

Huntsville, Alabama

Mayhill, New Mexico

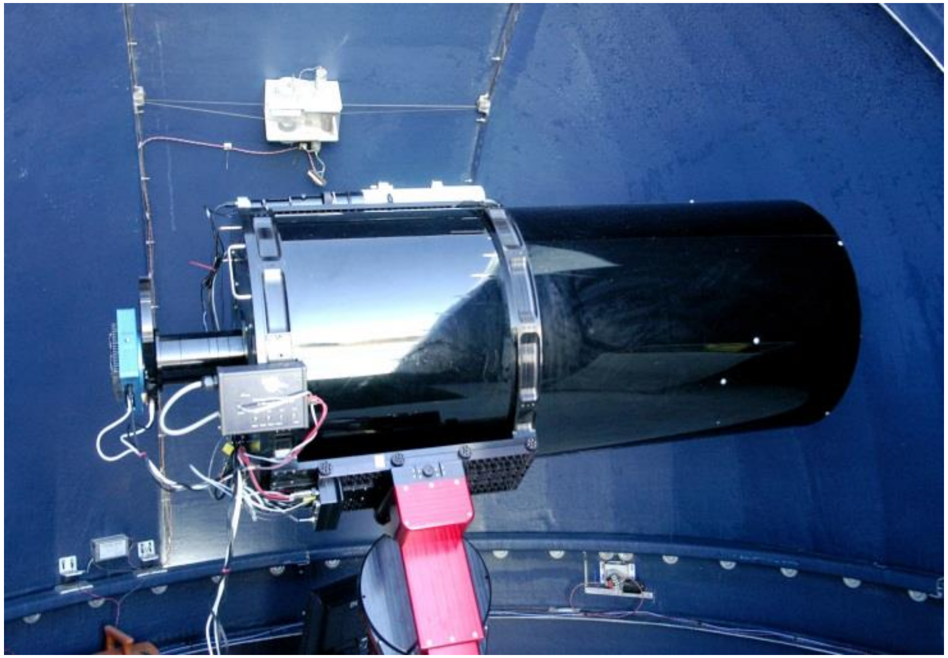
MSFC’s 0.5m Telescope

Mayhill, NM

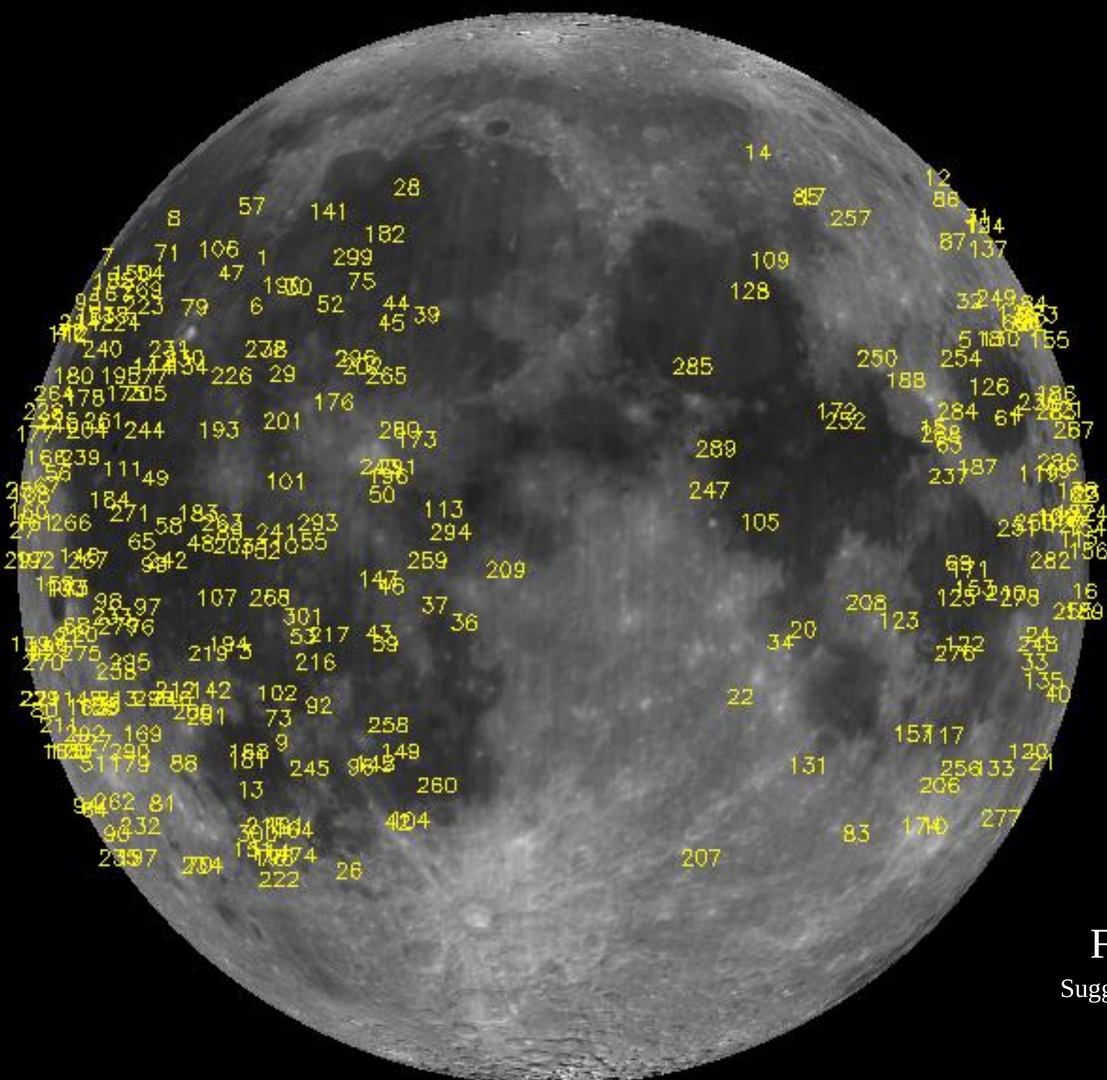
2k x 2k U42 back-illuminated CCD

Johnson-Cousins and Sloan Filters

Fully Automated



300+ lunar impacts observed 2005-present

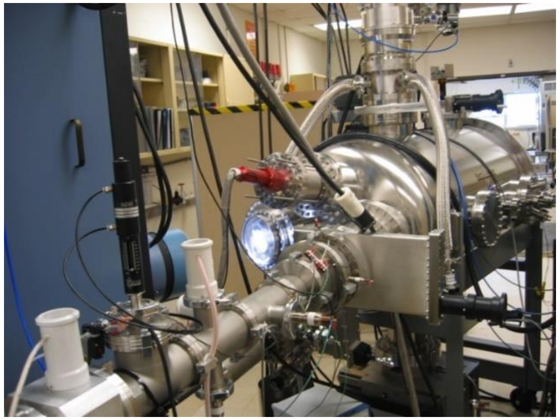


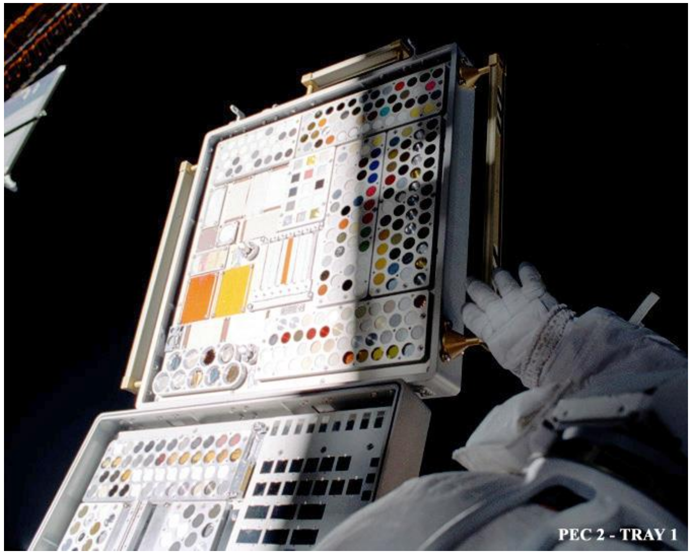
For more info:

Suggs et al. (2013) submitted
Suggs et al. (2011)
Suggs et al. (2007)

Space Environmental Effects Test Capabilities

- Ionizing Radiation – Combined Effects
- Space Plasma Interactions
- Ultraviolet Radiation
- Atomic Oxygen (AO)
- Lunar Environments
- Micro-Meteoroid and Orbital Debris (MMOD) Hypervelocity Impact
- Thermal Vacuum Outgassing
- High Temperature Materials Characterization
- High Temperature Emissivity Measurement System
- Materials Flight Experiments

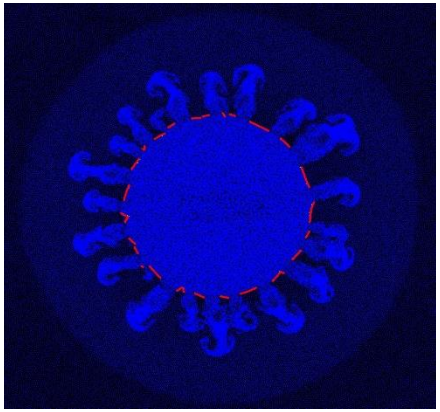




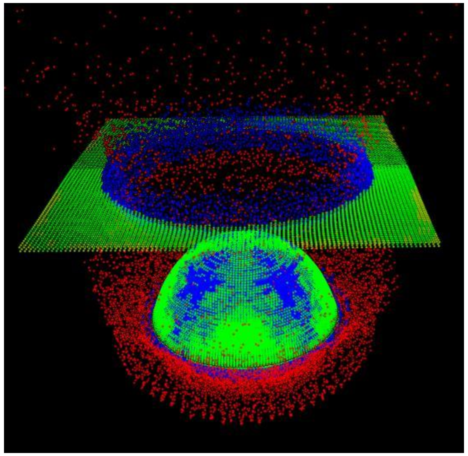
SPHC - Smooth Particle Hydrodynamic Code

This software code that can handle one-, two-, or three-dimensional versions of a problem to support high-velocity impact simulation/modeling. It accommodates any material for which a specified set of properties is known, using any of ten equations of state and seven material strength models. SPHC has flexible geometric modeling capabilities, allowing it to simulate a wide range of articles. Impacts can be modeled at any speed below ≈50 km/s using initial temperatures, densities, porosities, and user-specified internal pressures. Complex objects can be built up from simple geometric constructs, then duplicated and moved as desired in the simulation space.

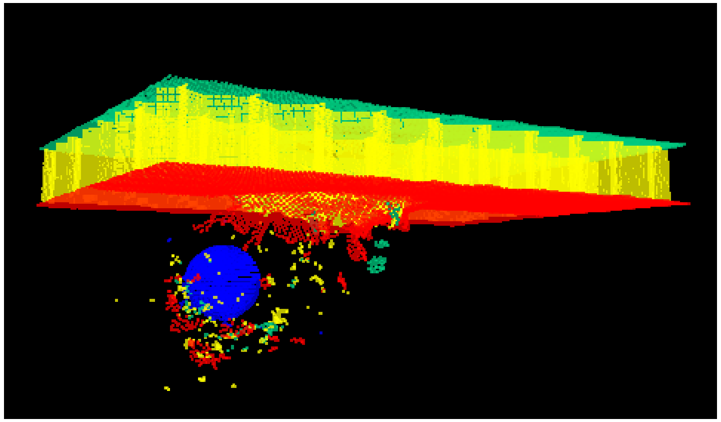
- Grid-Free Lagrangian Hydro / Material Strength / Diffusion
- Conserves Mass, Energy, Momentum, Angular Momentum
- Ideal for problems with large mass distortion/mixing
- 1D, 2D, or 3D….High velocity impact with phase changes
- Extensively validated for space debris impact modeling
- VSP strength technique eliminates tensile instability
- Weibull fracture model



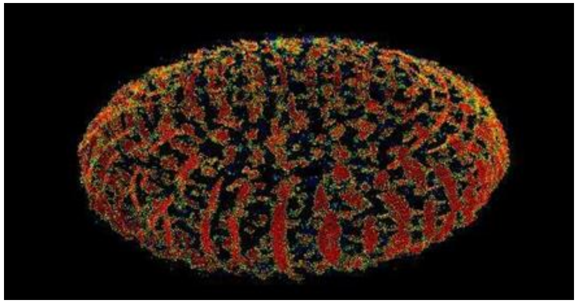
Fracture/mixing patterns for ruptured steel cylinder



6.7 km/s impact of an Al sphere on an Al plate target



1 km/s impact of an Al sphere on an Al hex-honeycomb target



Fracture pattern for rotating steel shell

SLS Modeling Tech Dev

The team is developing tools to support the assessment of crew survivability for the SLS program and MPCV programs. The focus is on the near field environments around the vehicle during catastrophic explosions. Efforts to date have shown that fragments produced by the explosions are the most significant risk to the crew and crew systems. The current research has been focused on pad and near pad explosions. The data available to the team to assess the generation and acceleration of fragments in a vacuum is very limited.

The Blast team is developing these near field models to support the risk assessments for SLS. In order to develop these models the team needs to understand how liquids or the pressurized gases affect the fragment velocities. The impact testing of these COPV tanks can provide the team near field fragment velocities for either liquid or gas contained in the tanks. In turn this data can be used to assess crew risk and to provide for future data to aid in the design of the next generation of MPCV vehicles.

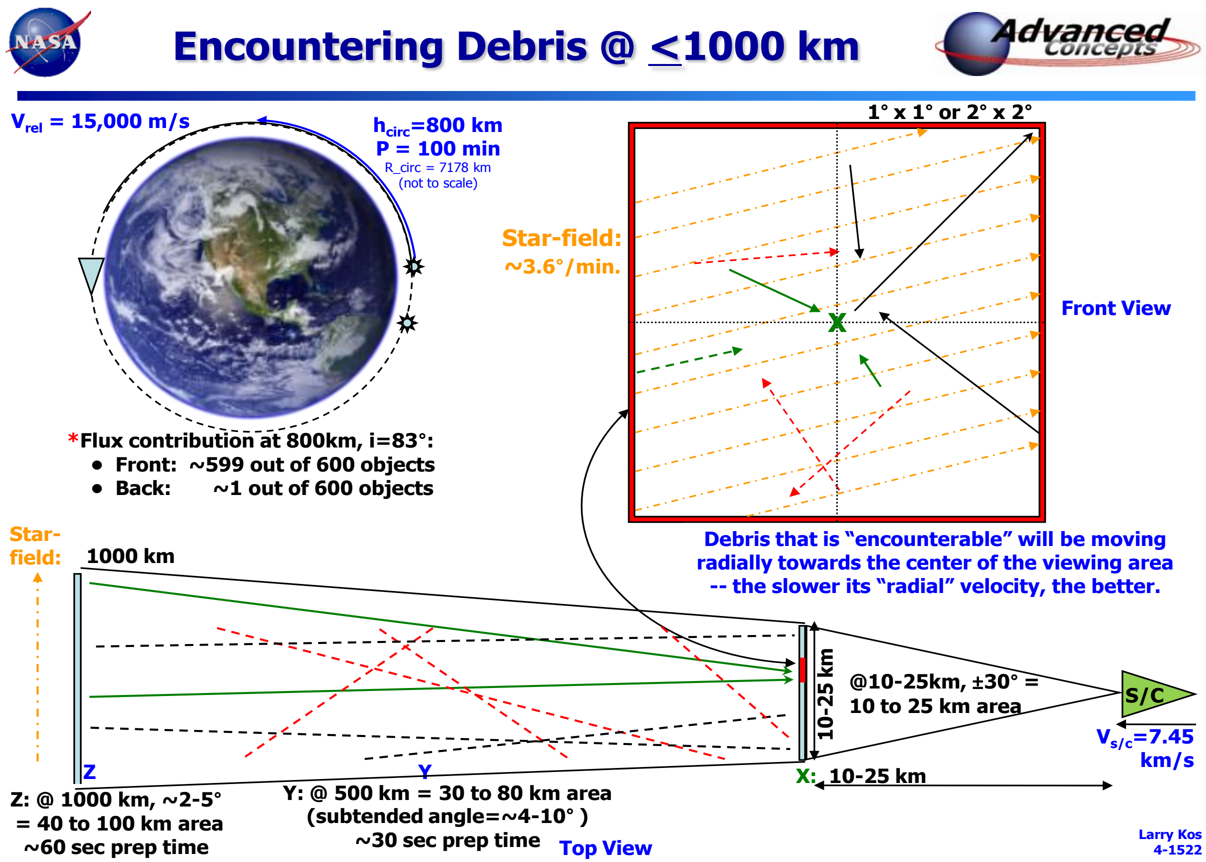
A series of test activities raised some concerns about the generation of orbital debris caused by failures of composite over wrapped pressure vessels (COPVs). These tests have indicated that a large number of composite fragments can be produced by either pressure/burst failures or by high-speed impacts.

A review of prior high-speed tests with COPV indicates that other tests have produced large numbers of composite fragments. As was the case with the test referenced here, the tests tended to produce a large number of small composite fragments with relatively low velocities induced by the impact and/or gas expansion.

Orbital Debris STEREO Tracking Camera Dev

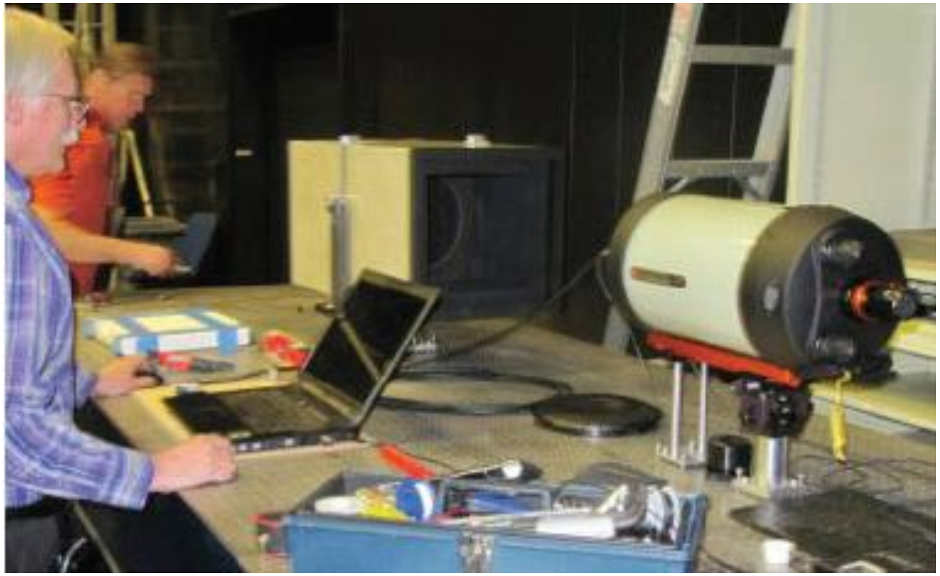
The Problem:
Traditional orbital trackers looking for small, dim orbital derelicts and debris typically will stare at the stars and let any reflected light off the debris integrate in the imager for seconds, thus creating a streak across the image.

The Solution:
By combining off-the-shelf digital video technology, telescope lenses, and advanced video image Field Programmable Gate Array processing, Marshall is building a breadboard of a passive orbital tracking camera that can track faint objects (including small debris, satellites, rocket bodies, and NEOs) at ranges of tens to hundreds of kilometers and speeds in excess of 15 km/sec.



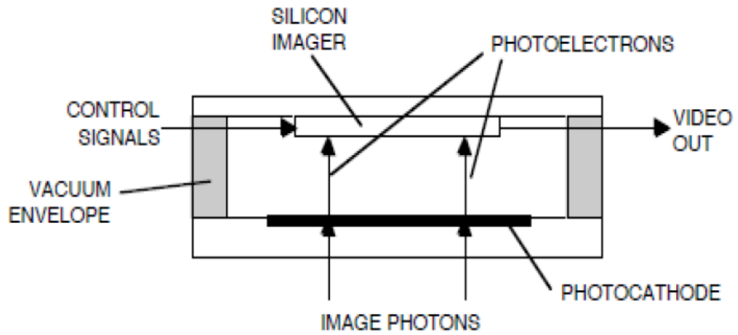
High-Fidelity Dynamic Star Field Simulator

This unique capability was developed in conjunction with Texas A&M University that is now in testing. It has a high resolution large monochrome display and a custom collimator capable of projecting realistic star images with simple orbital debris spots (down to star magnitude 11-12) into a passive orbital tracking camera with simulated real-time angular motions of the vehicle mounted sensor. The simulator can be expanded for multiple sensors, real-time vehicle pointing inputs, and more complex orbital debris images and is adaptable to other sensor optics, missions, and installed sensor testing.



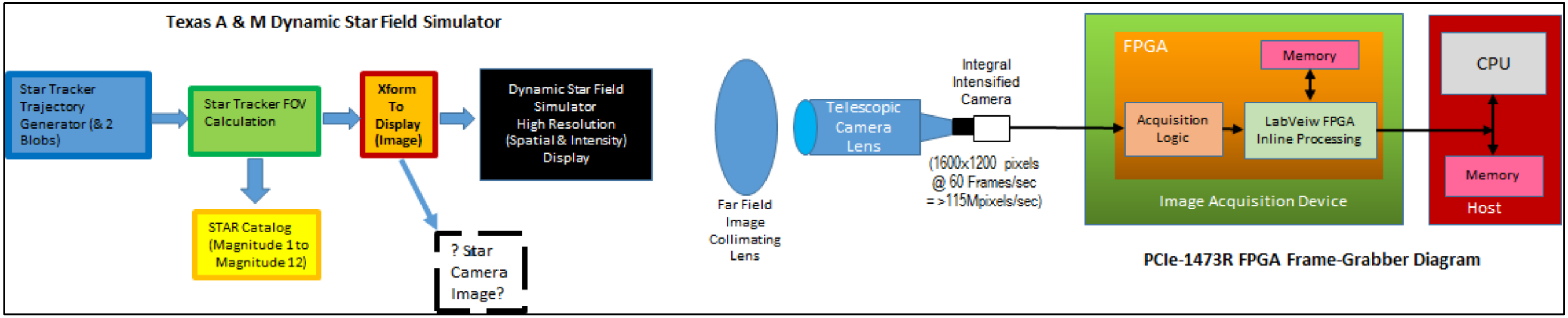
Dr. Tom Pollock (foreground) from Texas A&M begins checkout of the Star Field Simulator

Orbital Debris STEREO Tracking Camera Dev con't



An EBAPS (Electron Bombarded Active Pixel Sensor) sensor will amplify their light with an intensified video imager (as found in the Apache helicopter). For our purposes, we will focus our image to a narrow field of view with a telephoto camera lens that has been ruggedized for launch and outer-space use.

Data Processing: The Small Tracker uses a FPGA (Field-programmable gate array) to convert all lit pixels to spots and identifies the spots NOT moving with the Stars and sends those and star tracker data down for ground processing

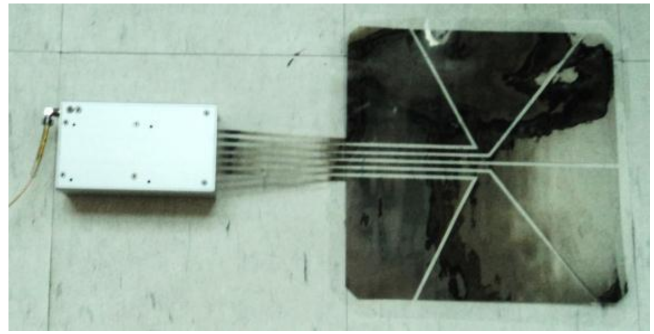


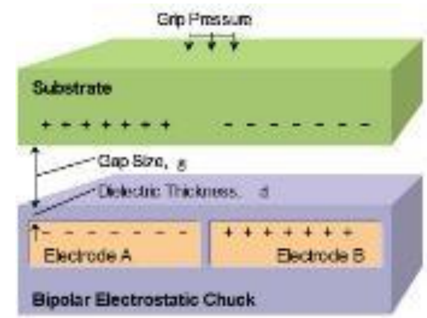
Tests will use the Dynamic Star Field Simulator (developed at MSFC with Texas A&M) which generates a high resolution image of the background stars in motion and one to three small orbital objects to verify the control and performance of the amplified imager, pixel-to-spot FPGA processing, and the orbital object discrimination algorithms.

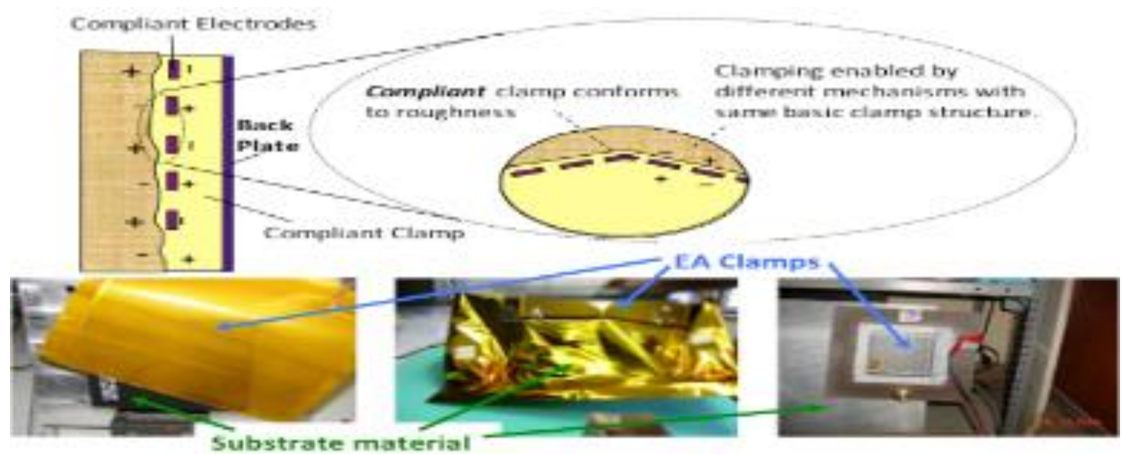
Other tests may mount the Small Tracker to MSFC's Lunar Impact Telescope Observatory to verify real-time star-field processing while tracking ISS from ground then tracking orbital objects from ISS.

Electrostatic Gripper Tech Dev

Specialized Electro-Static grippers (commercially used in Semiconductor Manufacturing and in package handling) will allow gentle and secure Capture, Soft Docking, and Handling of a wide variety of materials and shapes (such as upper-stages, satellites, arrays, asteroids) without requiring physical features or cavities for a pincher or probe or using harpoons or nets. Combined with new rigid boom mechanisms or small agile chaser vehicles, flexible, high speed Electro-Static Grippers can enable compliant capture of *spinning* objects starting from a safe stand-off distance.







Laser-Based Ablation Method to Deorbit Debris

Marshall is working with industry and academia to study the use of laser ablation to deorbit small debris. This concept is being considered for addition to the SODDAT in conjunction with the SSASSE. It would detect, track, and then heat debris with a laser, changing its trajectory to lead to deorbit.

Levitated sample in MSFC ESL

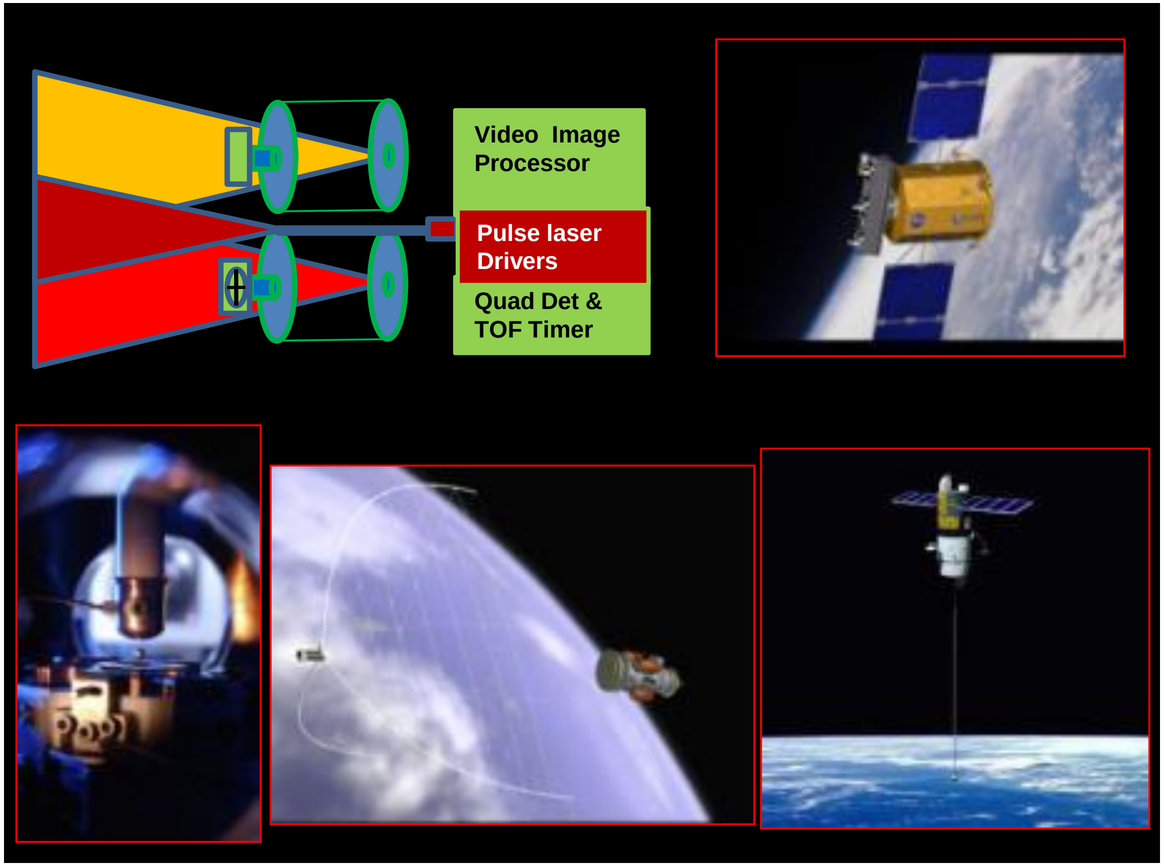
Small Orbital Debris Detection, Acquisition and Tracking

Small Orbital Debris Detection, Acquisition and Tracking (SODDAT) is a conceptual technology demonstration spacecraft was developed to address the challenges of in-situ small orbital debris environment classification including debris observability and instrument requirements for small debris observation.

SODDAT — Artist Conceptual Drawing

Small Orbital Debris Active Removal (SODAR)

An architectural study investigated the overall effectiveness of removing small orbital debris from low-Earth orbit using a satellite-based non-weapons class, low power laser. The results found that a spacecraft with an integrated forward-firing laser is capable of reducing the small orbital debris flux within a 60 to 100 km orbital shell by a significant amount within the one spacecraft's operational lifetime.



Backup

ISSAAM Activities To Date 1/2

<u>Within MSFC:</u>

1. Composite Overwrap Pressure Vessel (COPV) for SLS
   - Hypervelocity impact test and analysis completed
   - The NESC will use the data as part of their Pressure Vessel work
2. Supported troubleshooting Space Debris Sensor (SDS) issue on board ISS in conjunction with JSC
3. Electrostatic Gripper Development
4. Small Orbital Stereo Tracking Camera development
5. Space Asset Management-Database (SAM-D) Tech Dev
6. Small Orbital Debris Data Acquisition and Tracking (SODDAT)
   - Conceptual Design of LEO S/C with passive SSA/OD sensors
   - RFI / OCT TDM Prep
7. Small Orbital Debris Active Removal (SODAR) Architecture Study
8. Support to HQ OCT Active Debris Removal Study in support of Orbital Debris Project Office
9. Approval of MSFC SSA top level goals by SWG (2012)
10. FASTSAT De-orbit Study
11. HQ Orbital Asset Management/Hubble De-orbit study
12. DOCT-R (De-Orbit of a CubeSat via Targeted Re-entry)
13. Small Active Debris Removal (SADR) Phase 1-B to supported ODPO
14. ACO Architectural Studies
    - Conceptual Design of an ADR Chemical Propulsion De-Orbit kit using RS34 (Peacekeeper 4^{th} Stage)
    - Investigate possible opportunities with JAXA on planned JAXA demo mission: "EDT's for ADR"
    - Investigation of Rendezvous & Capture methods with "Large, Tumbling" RSOs

ISSAAM Activities To Date 2/2

With other Gov Agencies:

1. Invited to participate in **NASA HQ debris road mapping** and other SSA meetings
2. SMDC/AMRDEC/MSFC on Space Modeling and Simulation MOA
3. Coordinated hypervelocity tests at AEDC for SLS and Bangham Engineering
   - collaboration between MSFC, AEDC, JSpOC, UAH
4. AMRDEC donated computer clusters, database (Space Asset Management database)
5. AFRL-Continuing to develop partnership opportunities from package of areas seeking Marshall collaboration
6. Collaborate with Rosie Rosenberg (MGen USAF retired) of AF Space Command on space environments need within AF as needed
7. ARC/ISS/MIT-Smartphone Video Guidance Sensor Integrated with SPHERES (SVGS)

With Commercial:

1. SRI international - Flexible Electrostatic gripper and Modeling and simulation as it applies to SSA
2. Southern Aerospace Company (SAC)-SAA in place for 2 years and updating annex 1 currently
3. Bangham Engineering-collaborating on SLS and NESC testing for model verification

With Academia:

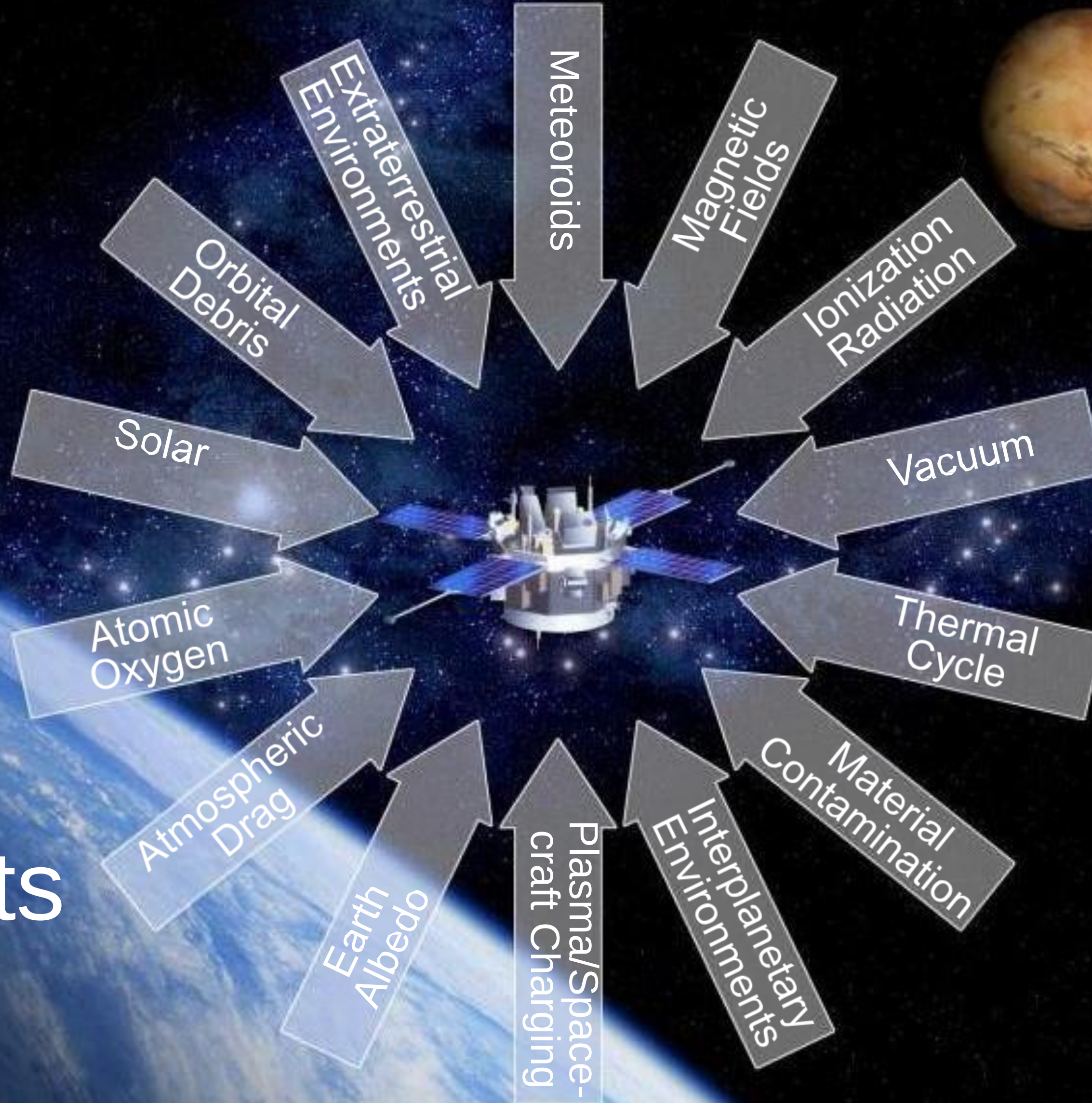
1. UAH
   - Collaborating on Bangham modeling (test validation) for SLS
   - Storing old datasheets from the Impact Test Facility on the Light Gas Gun of which they now house

With International:

1. ESA
   - Wishes to utilize Marshall technologies for various missions
   - Interested mission research out of ACO

Active Engagement with SSA Community

- Center for Orbital Debris Education and Research (CODER) workshop
  - Participated since 2016
- Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference
  - Participated since 2012
  - Invited to present 2015, 2016, 2017, 2018
- AFRL SSA Classified Conference
  - Participated since 2013
  - Invited to present 2016, 2017, 2018
- CNES International Workshop on Space Debris Modelling and Remediation
  - Participated since 2014
  - Invited to present 2016
- HQ mapping activities
  - Invited to attend the regular meetings on debris road mapping lead by Faith Chandler
  - Faith took our functional structure to be the structure for the road map
- IAA Conference on SSA (ICSSA)
  - Participated since 2017 (very first of these)



Space Environments Research to Applications

G–32307

Space Environments Research to Applications (SERA)

- **MSFC in-house SERA working group formed to facilitate information exchange and coordination of space environment activities in MSFC's science and engineering communities:**
  - Science/ZP — heliophysics, space radiation, and plasma environment research
  - Engineering/EV — applied space environments and effects support to NASA programs
  - Engineering/EM — materials in space, space environment testing, NASA program support

- **MSFC interests and activities include:**
  - Space physics research, space radiation detector development, plasma instrument development and calibration for ionosphere to interplanetary space environments
  - Space environment impact on space system design, operations, and anomaly investigations
  - Solar activity predictions and space weather monitoring
  - High voltage solar array interactions with LEO plasma environment
  - Tool development for characterizing and mitigating space environment impacts on space systems (with emphasis on spacecraft charging and ionizing radiation)

- **SERA focus is a product oriented approach for transitioning research results into applications**

- **MSFC, AFRL space environment, space environmental effects, and space situational awareness communities have common interests that would benefit from collaboration**

Current SERA Activities

- **SERA Workshop (November 2013)**
  - Identified technology gaps, prioritized NASA investment needs in space weather forecasting, ionizing radiation, spacecraft charging, materials and processes, and impact physics
  - High priority item identified by multiple disciplines is a materials property database:
    - FY14: data mining and populate data sheets, NASA would benefit from AFRL input
      - FY15: continue data mining and develop database on NASA/MAPTIS web site

- **International Space Station (ISS) Floating Potential Measurement Unit (FPMU)**
  - Instrument suite (WLP, NLP, FPP, PIP) for monitoring ISS charging, plasma environments
  - Characterize US high voltage (160V) solar array interactions with LEO plasma environment
  - Monitor visiting vehicle and payload charging, auroral charging, ISS science payload support including DOD Space Test Program payloads (USAFA iMESA and Canary, NRL RAIDS)
  - Collaborate with science community validating ionosphere models and support development of charging and drag effects tools (FPMU, DMSP charged particles and AFRL HASDM data)

- **Real time space environmental tools**
  - Geostationary orbit single event upset tool (real time version of CREME96)
  - Geostationary orbit internal charging tool

- **AFRL/NASA collaboration on Nascap-2k surface charging model**
  - AFRL currently funds model development, NASA distributes software
  - AFRL support needed to modify ITAR classification of software

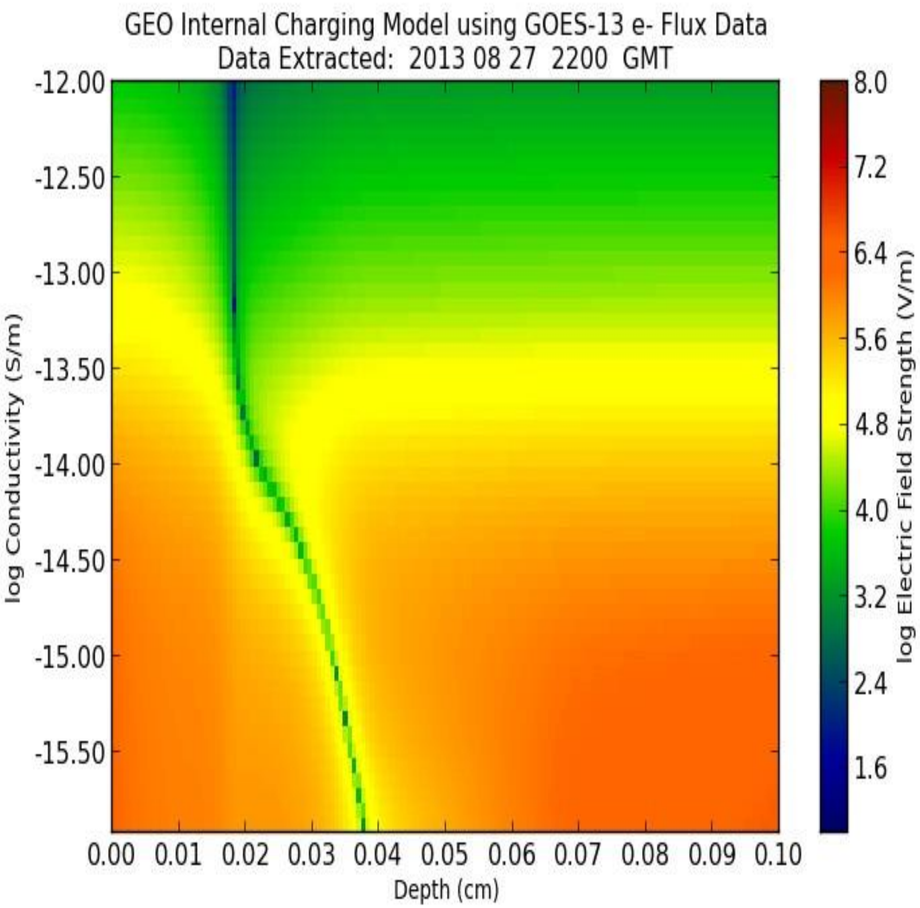
Space Environments Research to Applications (SERA)

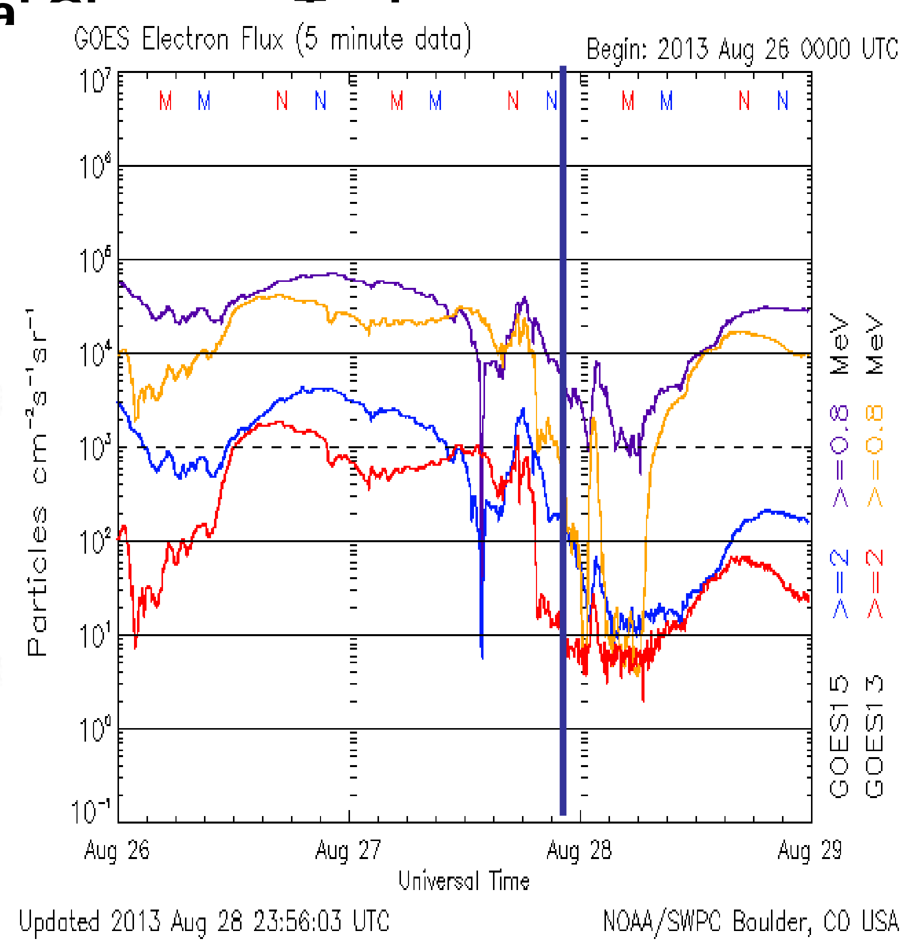
- **Low Energy Ion and Electron Facility (LEIEF)**
  - NASA unique facility designed for calibration of charged particle detectors over complete range of particle energy, mass, flux, and angular acceptance
  - Facility supports iterative design, build, and testing of space plasma instrumentation used in studying dynamic processes of the Sun, Earth, and other planetary space environments
  - Electron source, spatially broad 35 keV ion source, UV source, ISO 7 clean tent and ISO 5 benches, environmental vacuum chamber, 2-D rotation and translation system, beam-imaging diagnostics, and automated data acquisition and analysis capability
  - Completed calibration of 16x2 Dual Ion Spectrometers (DIS) top hats for the Magnetosphere Multiscale (MMS) mission, supporting calibration efforts of the Solar Probe Plus (SPP) Solar Wind Electrons Alpha and Protons (SWEAP) instrument Faraday cup detector

- **DMSP auroral charging, solar array plasma interaction studies**
  - MSFC developed software tools for working with DMSP SSJ and SSIES sensor data (F6 – F18)
  - AFRL provided DMSP Nascap-2k charging model to MSFC (D. Ferguson/AFRL)
  - Developing automated charging event identification algorithms, useful for “charging indices”
  - MSFC would benefit from AFRL contacts to help understand:
    - DMSP spacecraft configuration, power system design, solar array power manipulation strategies, and spacecraft operations that impact on charging behavior
    - SSJ detector calibration information (F6 – F18 and F19, F20 when launched)
    - Insight into Microwave Imager processing unit lockup anomalies (F13, other?)

Backup

Geostationary Orbit Internal

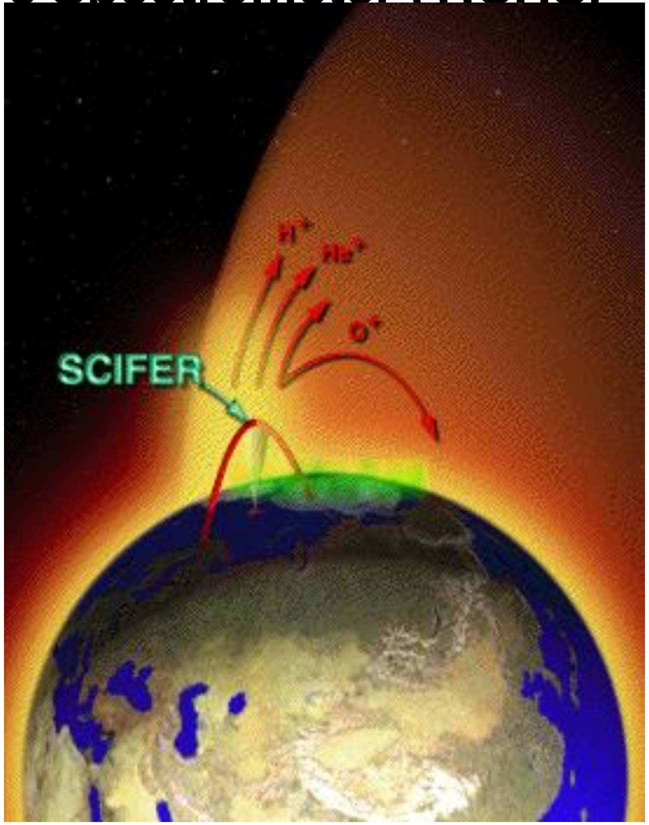




Electric fields resulting from internal (deep dielectric) charging as function of depth in dielectric material and electrical conductivity. Fields are updated at 5 minute intervals using NOAA GOES >0.8 MeV, >2.0 MeV electron data.

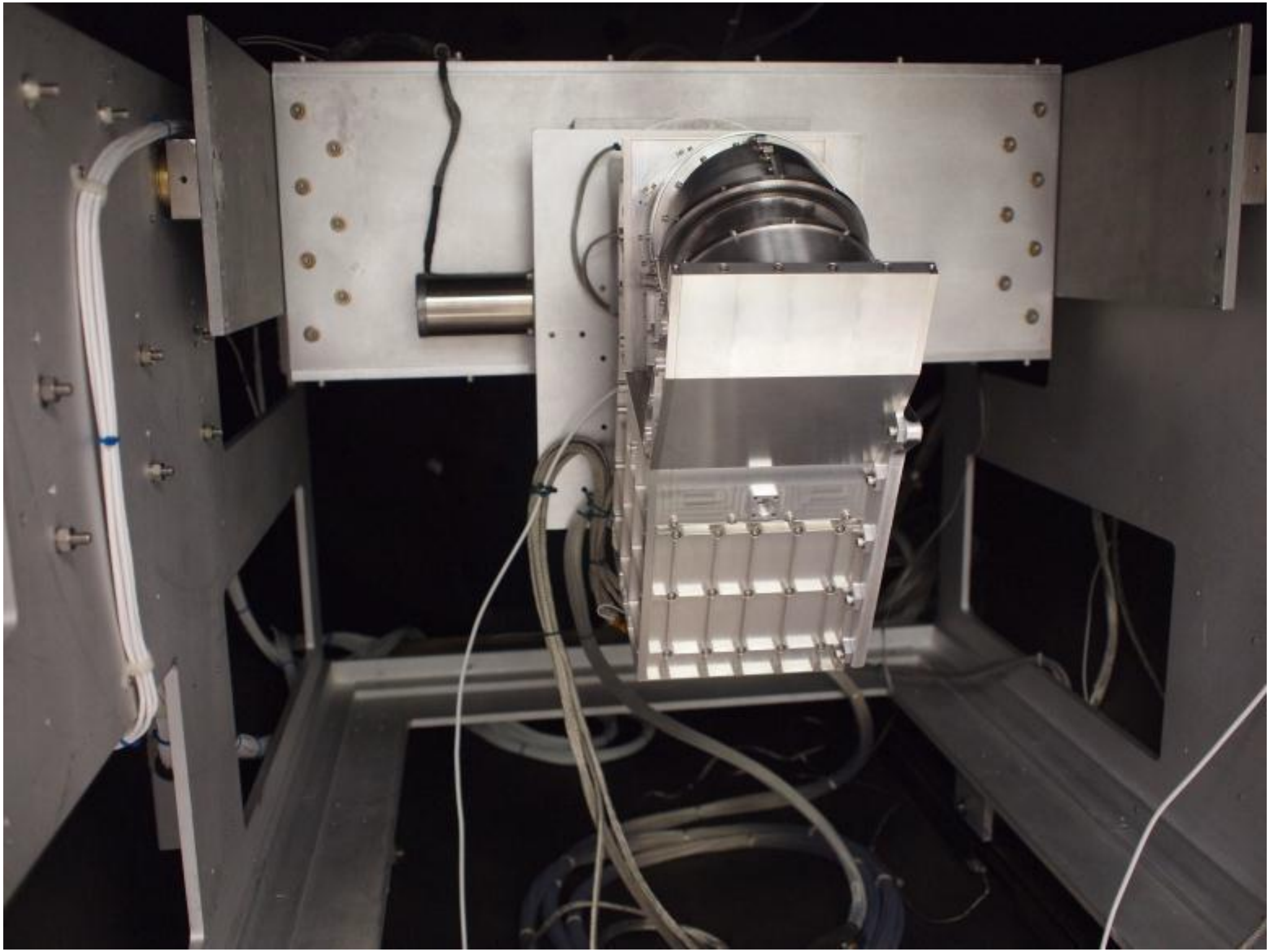
Thermal Ion, Electron Capped Hemispheric Spectrometer (TICHS/TECHS)

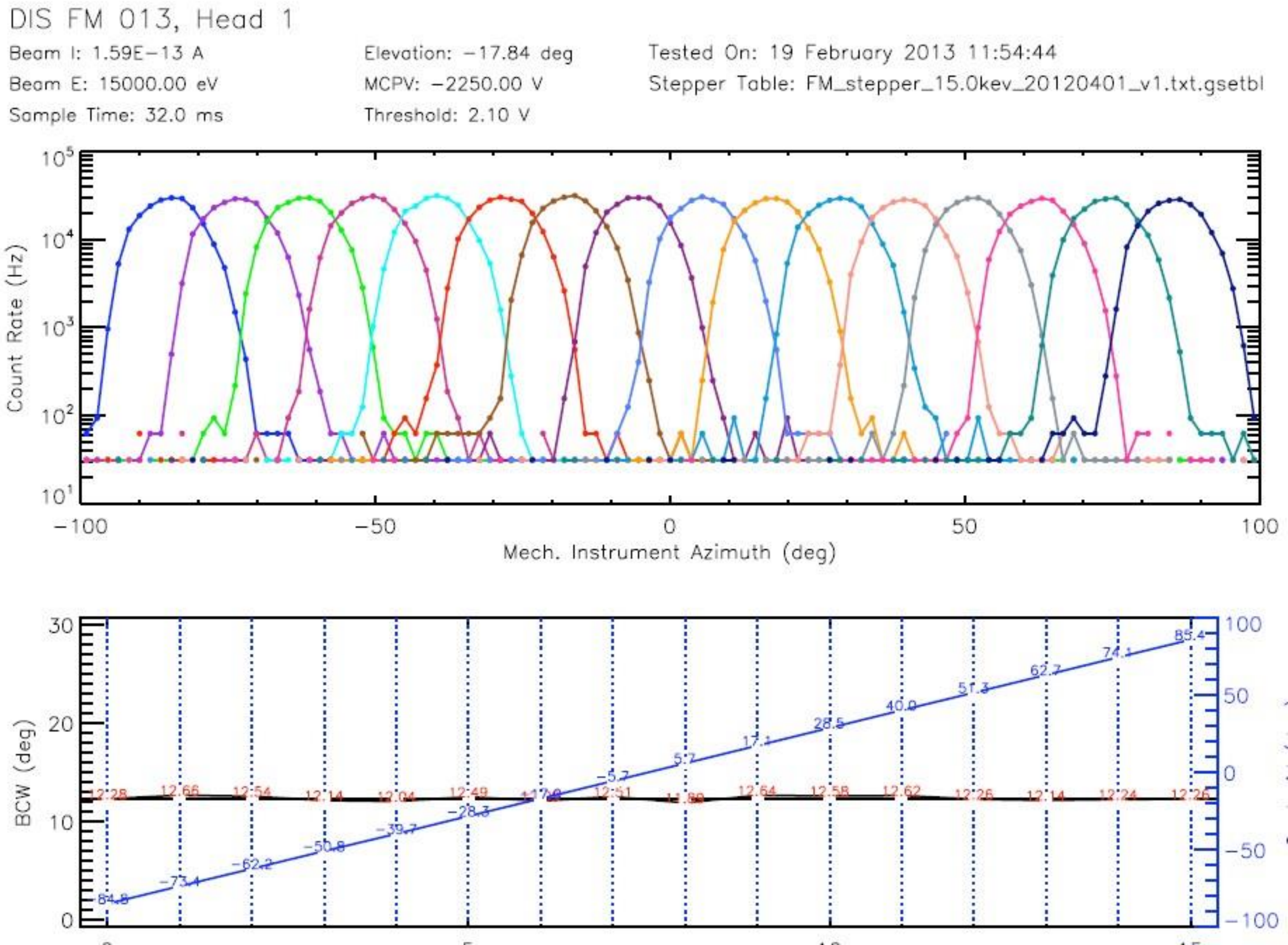
- Small electrostatic analyzer for low energy ions (<30eV)
- Part of the SCIFER, Caper, and SS2 sounding rocket payload for studying ion outflow at high latitudes

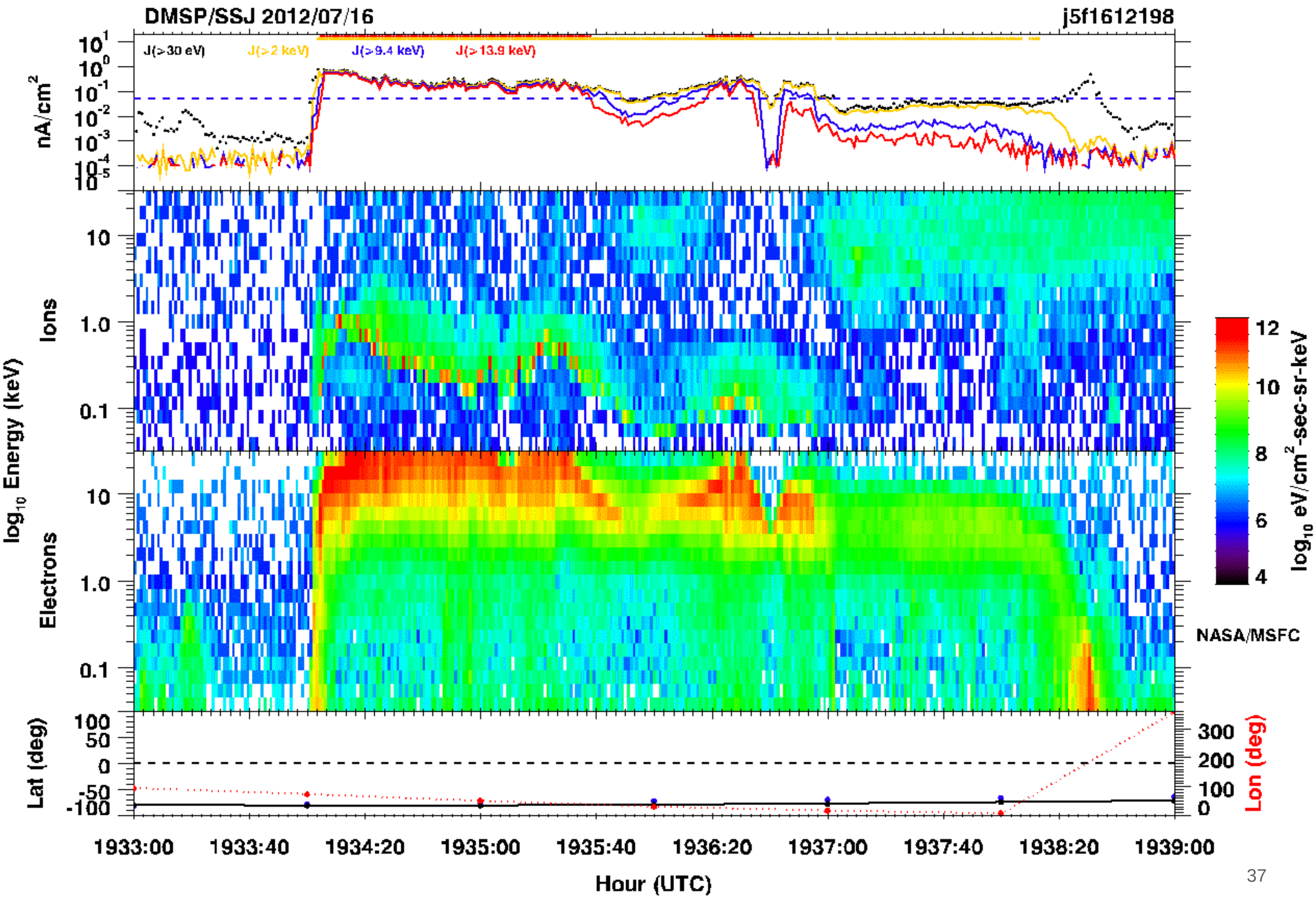


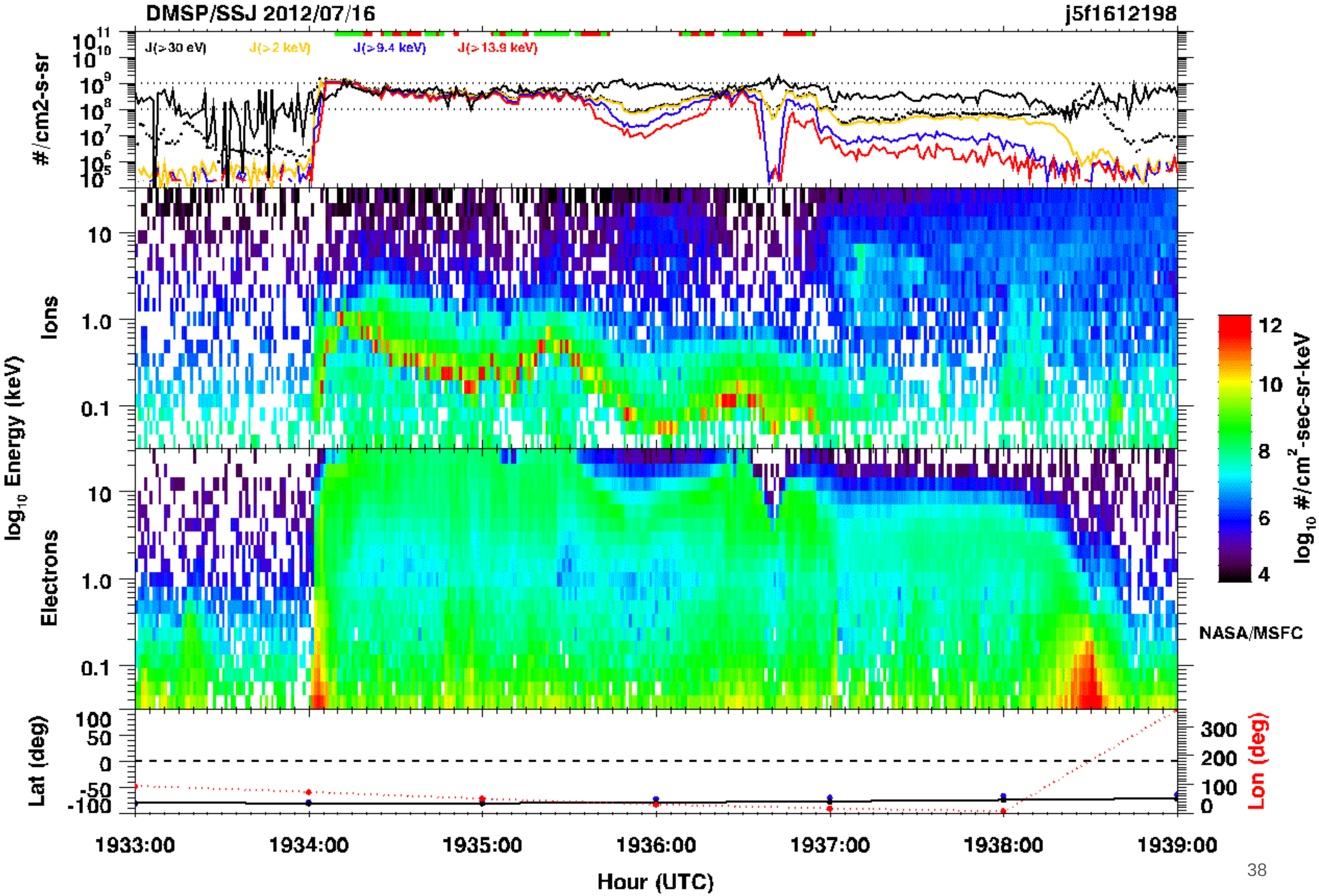
Parameter	Value
Mass and power for sensors/electronics	1.3 kg, 5 W
Volume: electronics box	20.3 x 15.9 x 8.8 cm
each sensor (cylindrical)	5 cm long x 3.0 cm dia.
TICHS energy measurement/resolution	0.3 to 30 eV, ²E/E= 0.06
TICHS polar angle measurement/resolution	320° in 32 bins/10°
TICHS azimuthal angle response	18°
TICHS geometry factor	2.6 x 10^{-5} cm^2 sr eV/eV

Low Energy Electron and Ion Facility (LEEIF)



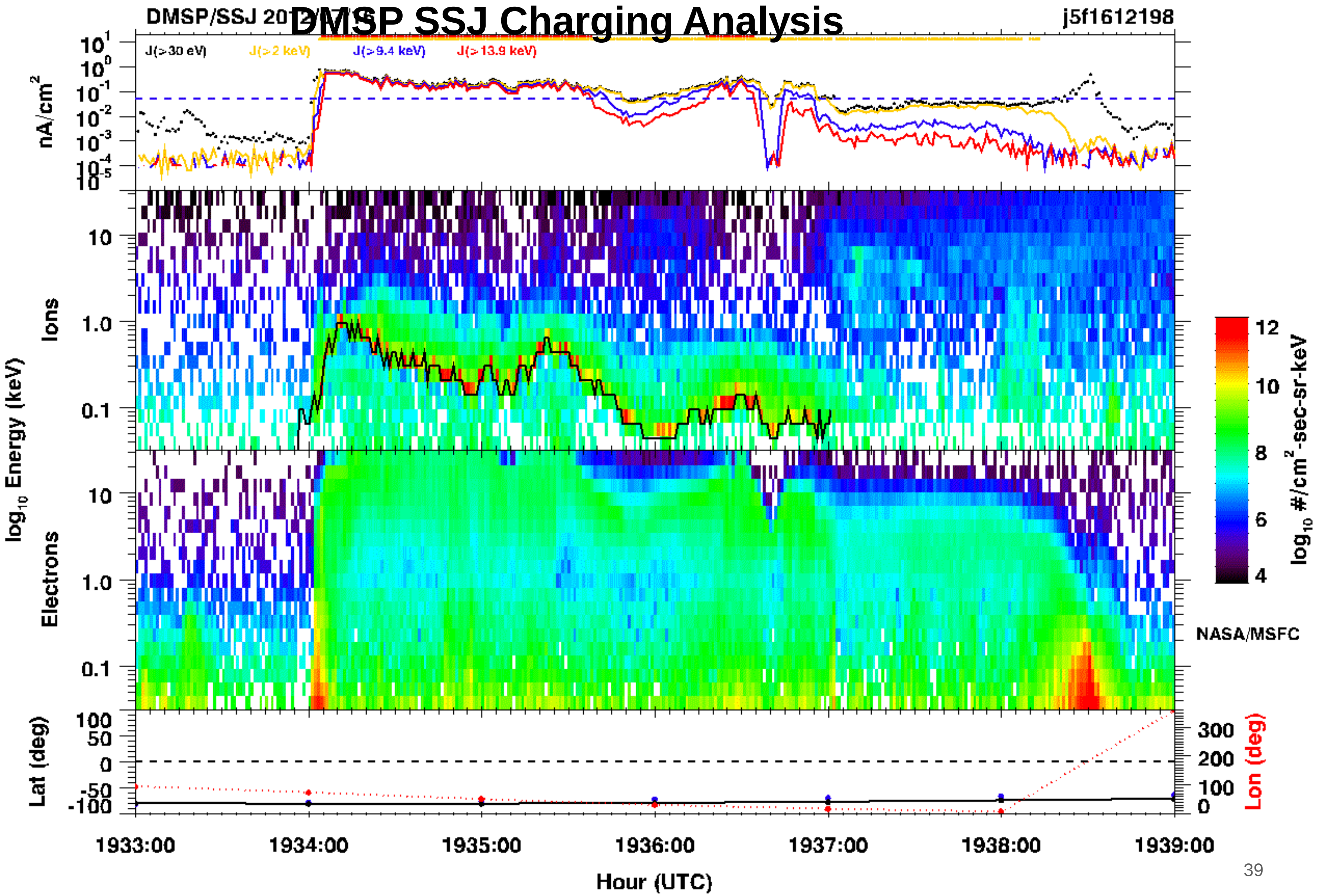

DIS FM 013, Head 1
Beam I: 1.59E−13 A
Beam E: 15000.00 eV
Sample Time: 32.0 ms
Elevation: −17.84 deg
MCPV: −2250.00 V
Threshold: 2.10 V
Tested On: 19 February 2013 11:54:44
Stepper Table: FM_stepper_15.0kev_20120401_v1.txt.gsetbl
Count Rate (Hz)
Mech. Instrument Azimuth (deg)
BCW (deg)

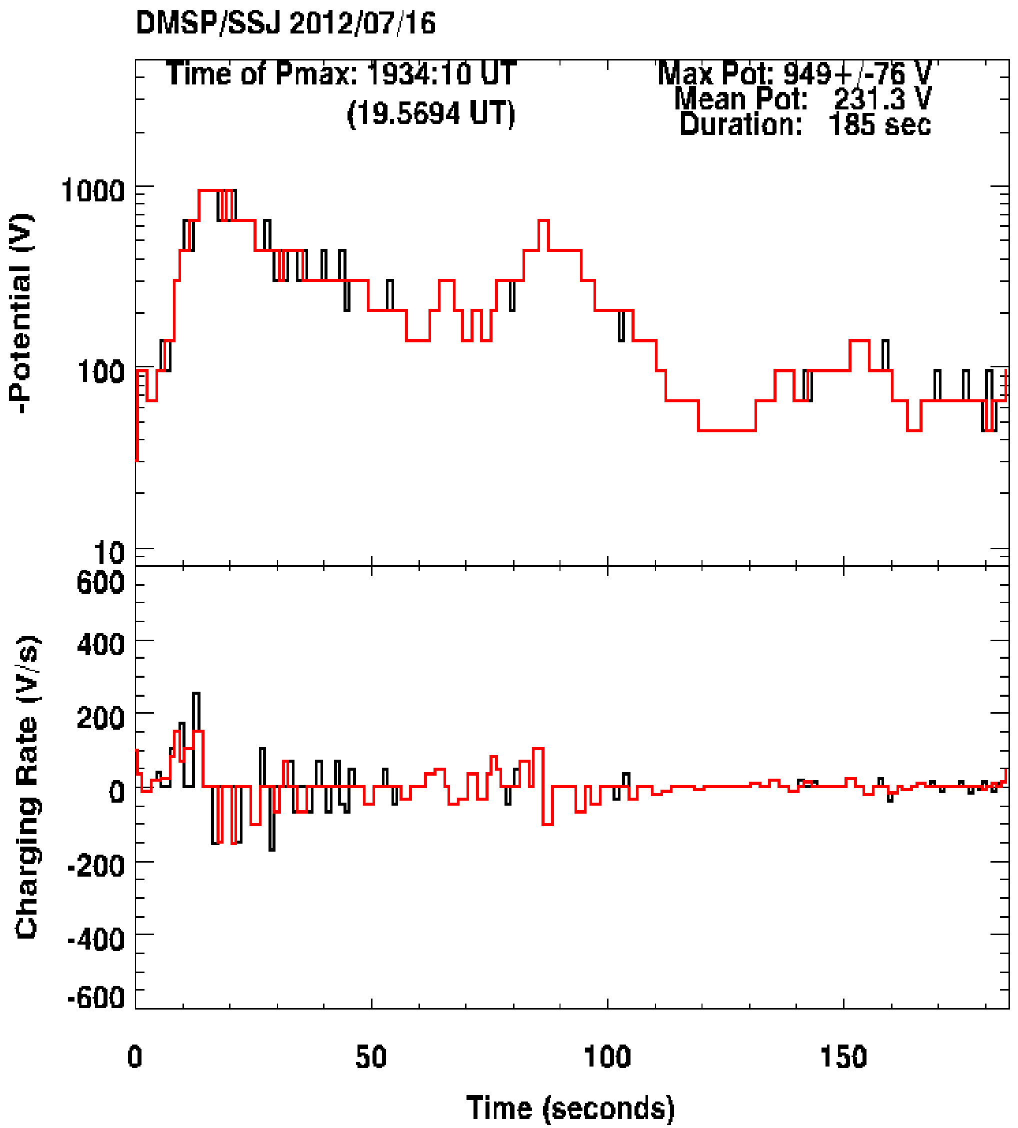

DMSP/SSJ 2012/07/16
j5f1612198
J(>30 eV)
J(>2 keV)
J(>9.4 keV)
J(>13.9 keV)
nA/cm2
Ions
Electrons
log10 Energy (keV)
log10 eV/cm2-sec-sr-keV
NASA/MSFC
Lat (deg)
Lon (deg)
1933:00
1933:40
1934:20
1935:00
1935:40
1936:20
1937:00
1937:40
1938:20
1939:00
Hour (UTC)



DMSP/SSJ 2012/07/16
j5f1612198
J(>30 eV)
J(>2 keV)
J(>9.4 keV)
J(>13.9 keV)
#/cm2-s-sr
Ions
Electrons
log10 Energy (keV)
log10 #/cm2-sec-sr-keV
NASA/MSFC
Lat (deg)
Lon (deg)
1933:00
1934:00
1935:00
1936:00
1937:00
1938:00
1939:00
Hour (UTC)

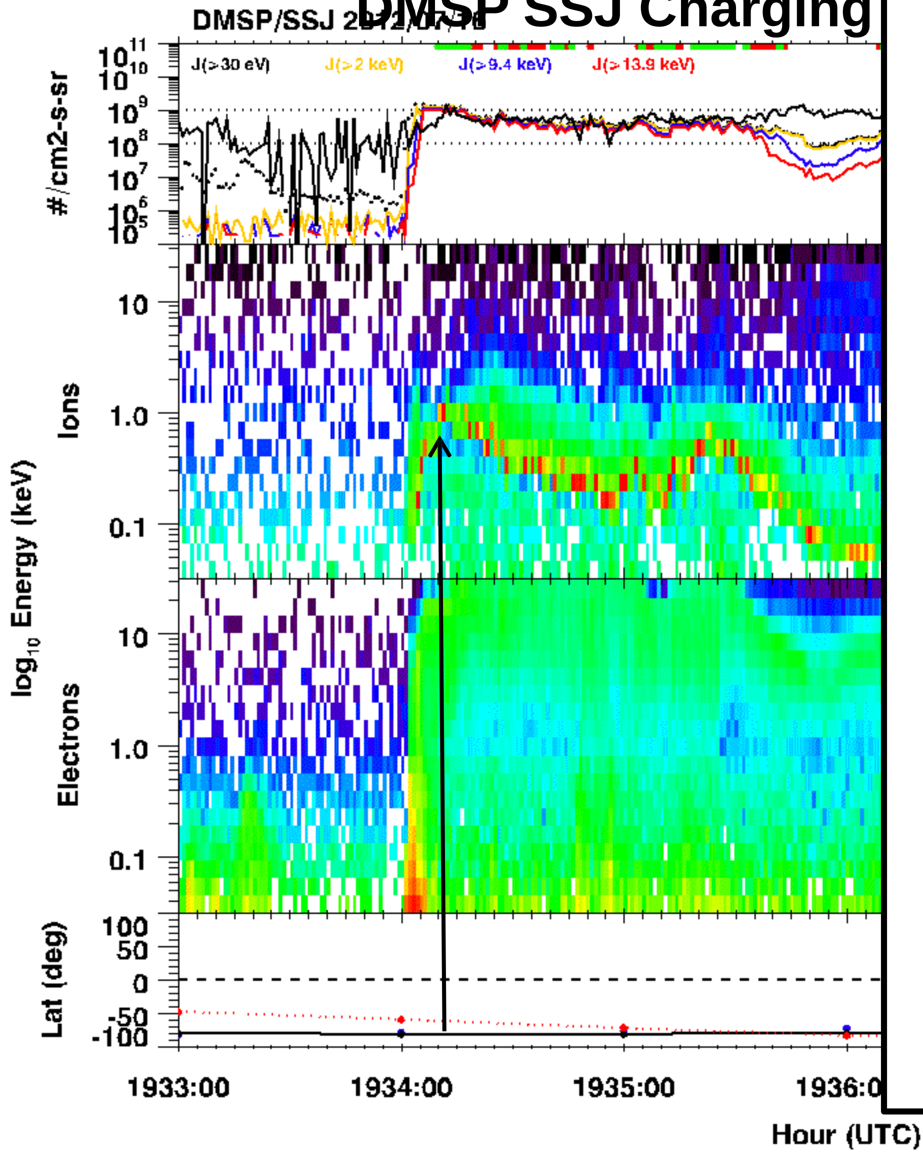
DMSP SSJ Charging Analysis

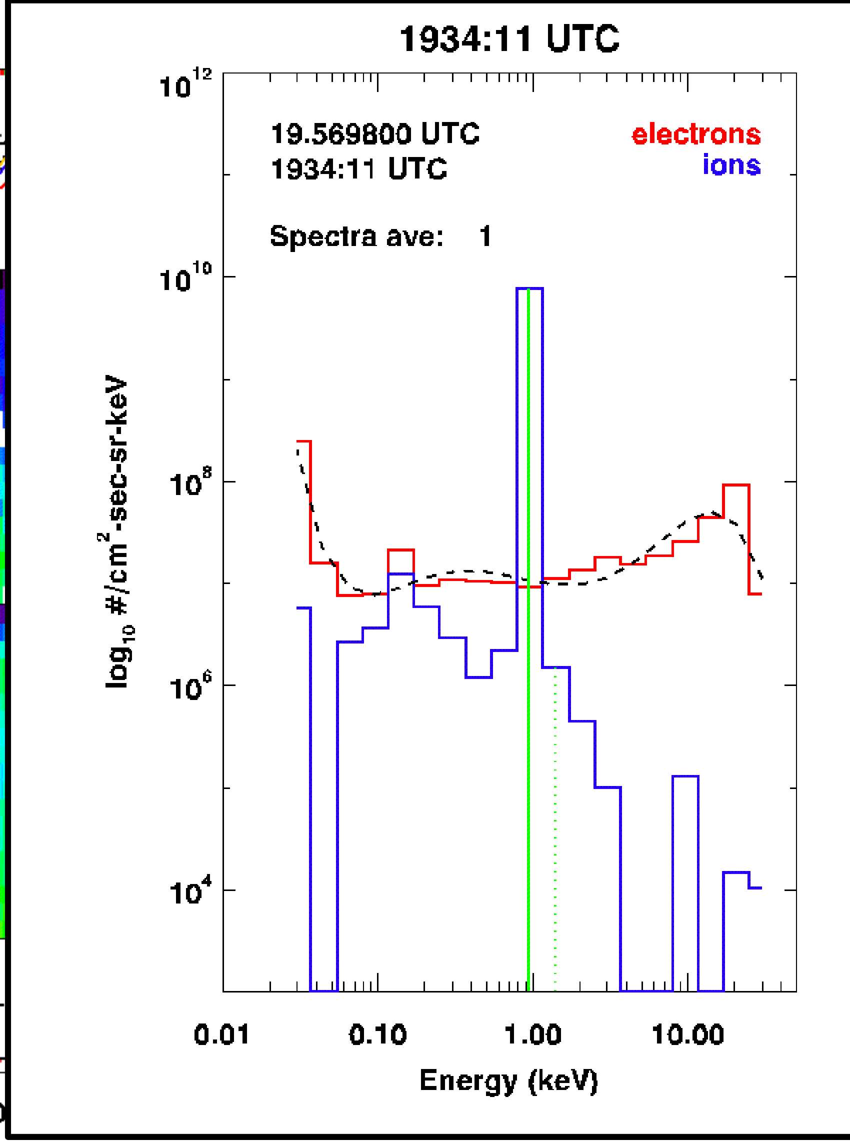


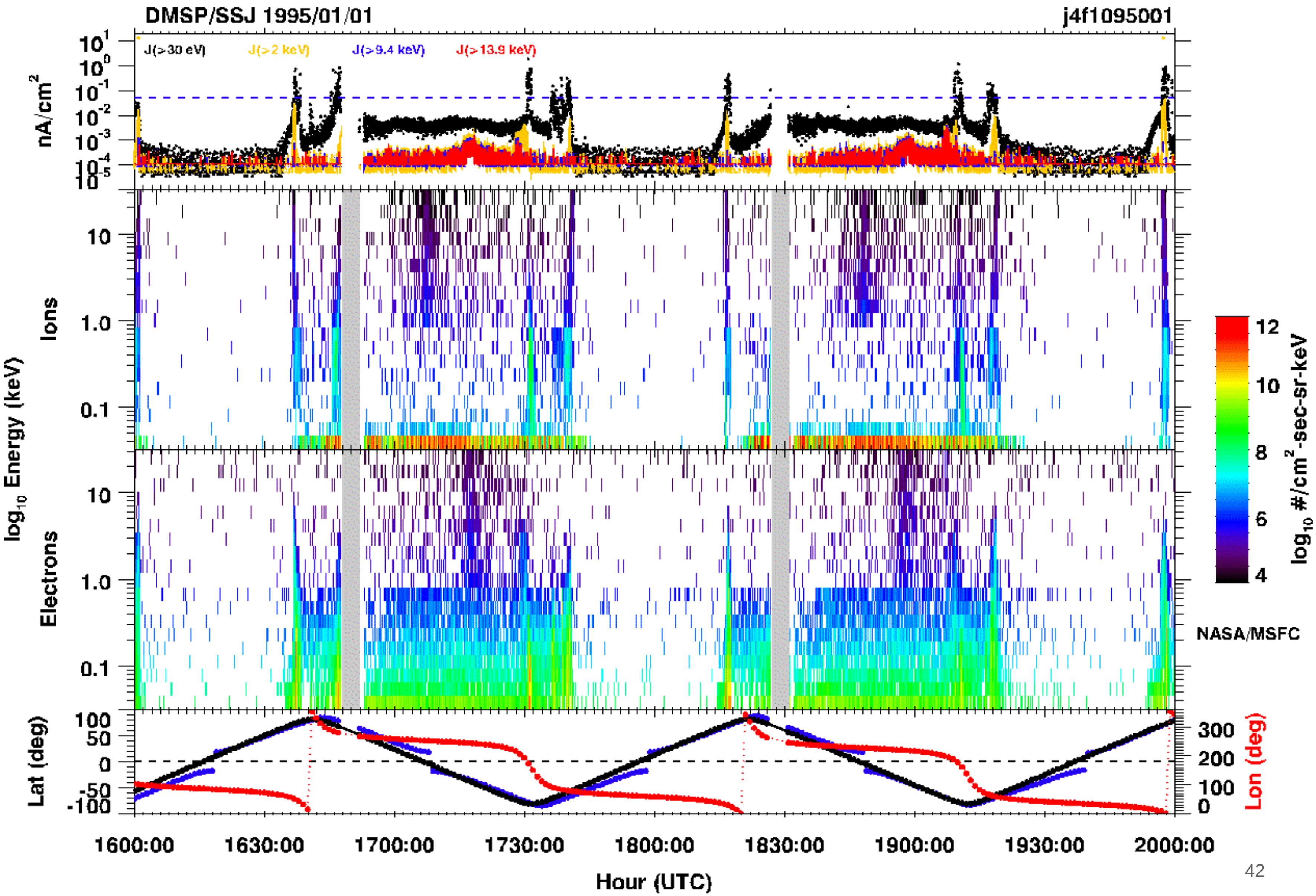


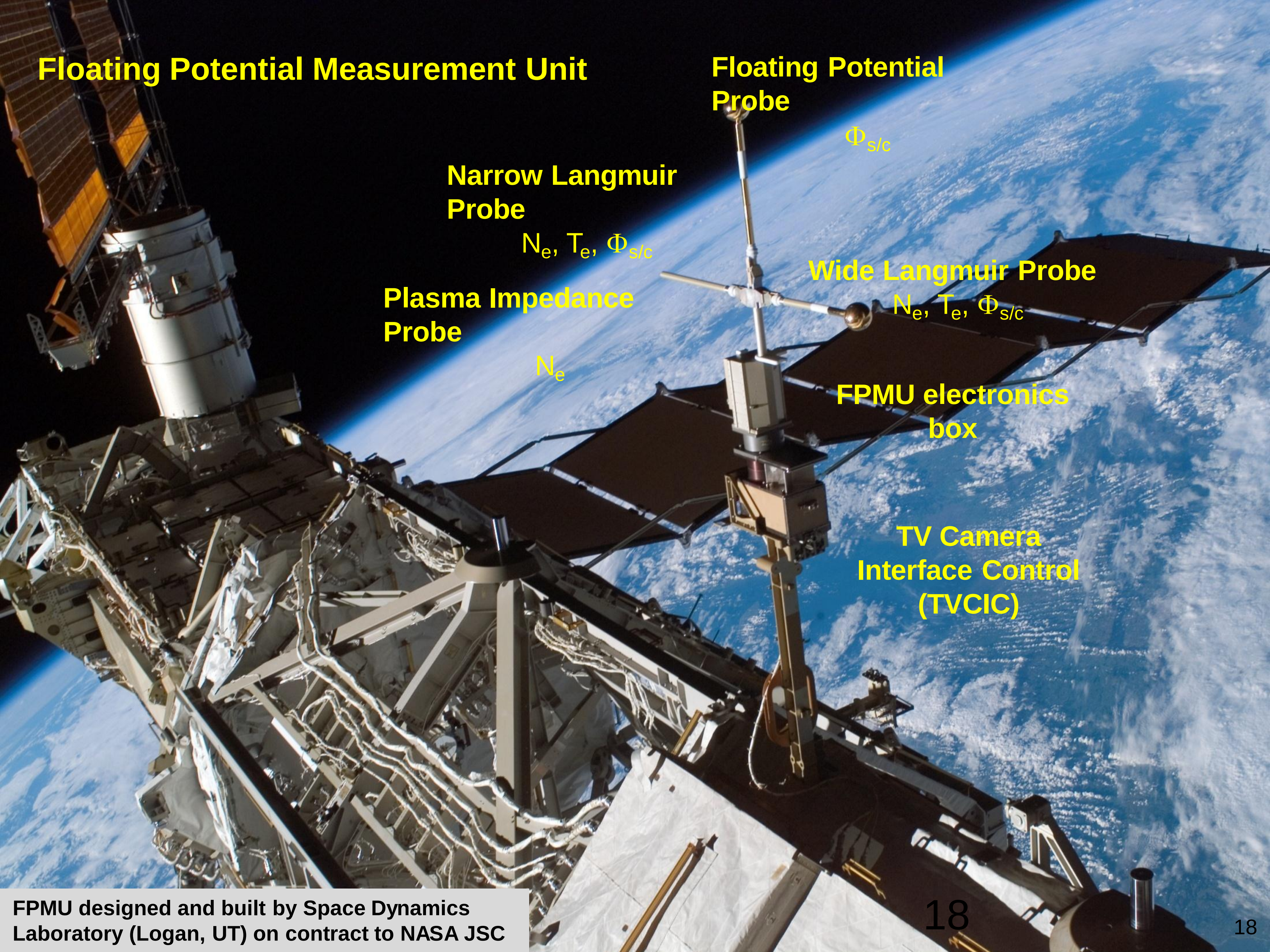

```
#-------------------DMSP Charging Event---------------
# DMSP_CE_f16_2012-07-16_1934:10__949.txt
# Satellite: f16
#      Date: 2012/07/16
# Data file: j5f1612198
#
#     Max V: 949 +/- 76 Volts
#    Mean V:   231.3 Volts
#Time Max V: 1934:10 UT    (19.5694 UT)
#  Duration:    185 sec
# Max V  lat/lon (deg deg -81.383  69.100
# Max V mlat/mlt (deg hr) -78.367  18.264
#
# Number of seconds >= V:
#>=2040 V:             0
#>=1392 V:             0
#>= 949 V:             6
#>= 646 V:            17
#>= 440 V:            38
#>= 300 V:            64
#>= 204 V:            87
#>= 139 V:           109
#>=  95 V:           136
#>=  65 V:           168
#>=  44 V:           185
#>=  30 V:           186
#
#  UT Hr   Seconds  Pot (V)  Rate (V/s)
#-----------------------------------------
  19.5656     0.0       30     97.37
  19.5658     1.0       95     32.31
  19.5661     2.0       95    -14.91
  19.5664     3.0       65    -14.96
  19.5667     4.0       65     15.12
  19.5669     5.0       95     36.99
  19.5672     6.0      139     -0.30
  19.5675     7.0       95     -0.30
  19.5678     8.0      139    102.24
  19.5681     9.0      300    150.57
  19.5683    10.0      440    172.94
  19.5686    11.0      646      0.00
  19.5689    12.0      440      1.42
  19.5692    13.0      646    254.41
  19.5694    14.0      949    151.12
     -----records deleted-----
```

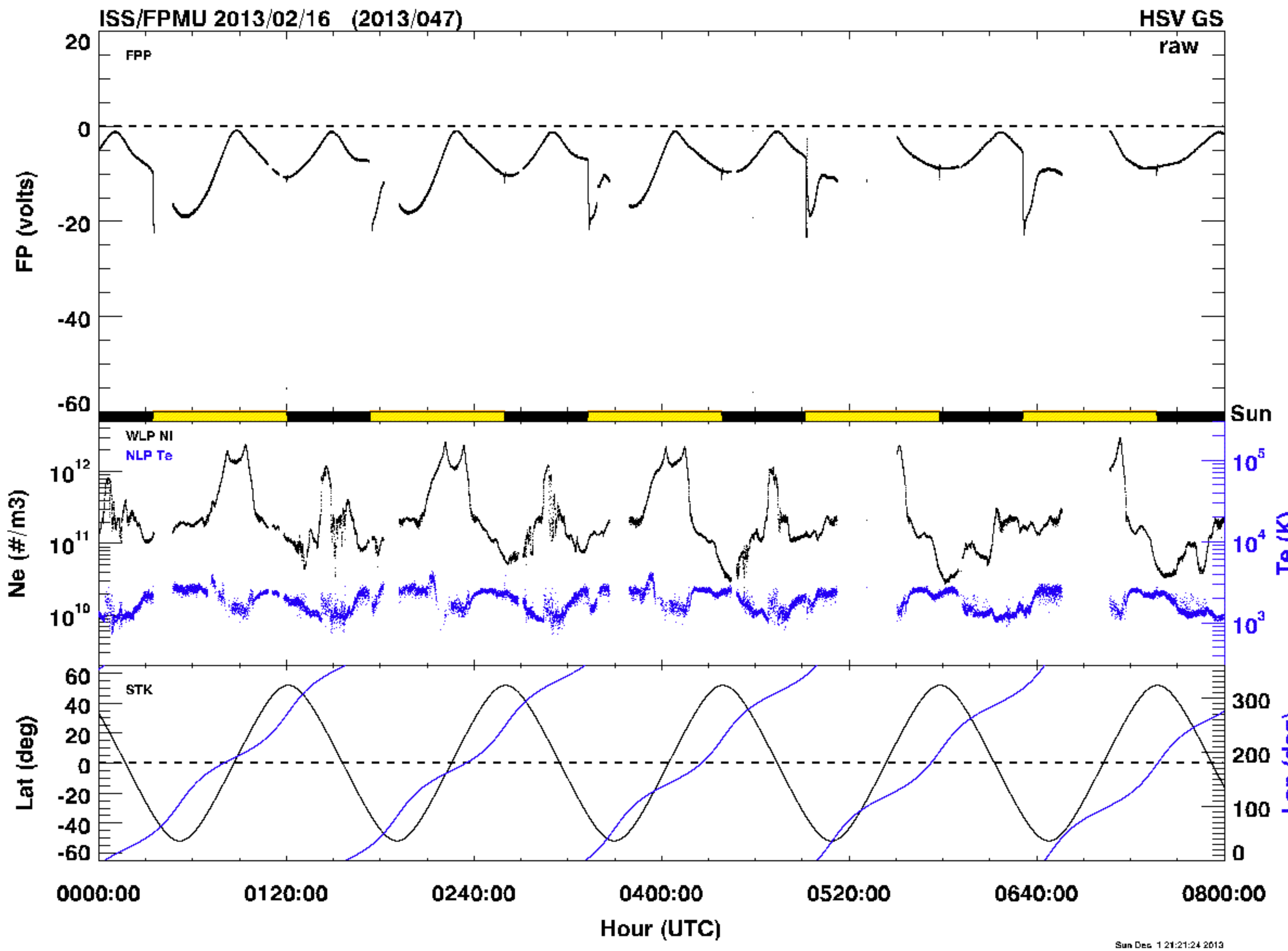
DMSP SSJ Charging



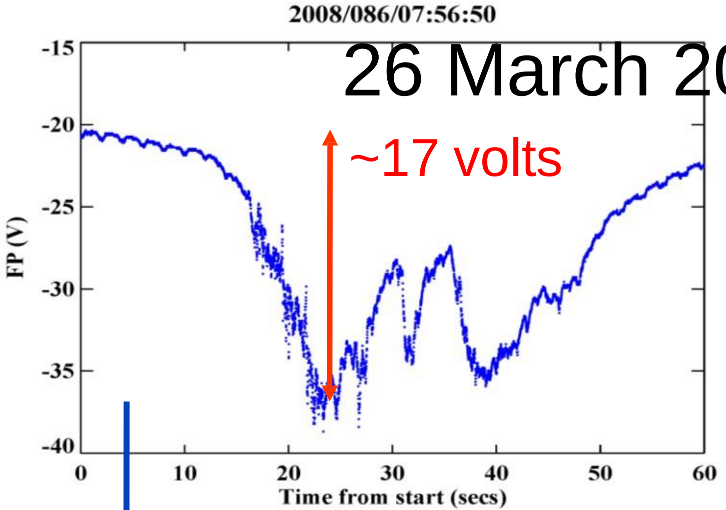



DMSP/SSJ 1995/01/01
j4f1095001
J(>30 eV)
J(>2 keV)
J(>9.4 keV)
J(>13.9 keV)
nA/cm2
Ions
Electrons
log10 Energy (keV)
log10 #/cm2-sec-sr-keV
NASA/MSFC
Lat (deg)
Lon (deg)
1600:00
1630:00
1700:00
1730:00
1800:00
1830:00
1900:00
1930:00
2000:00
Hour (UTC)

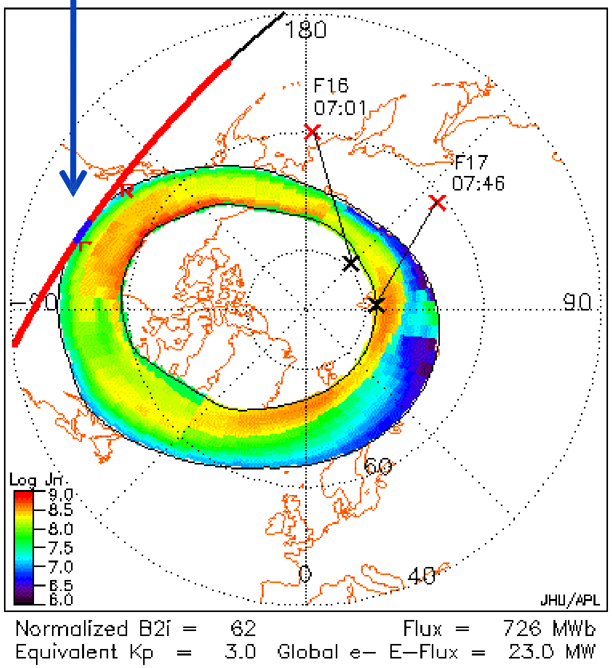

Floating Potential Measurement Unit
Floating Potential Probe
$\Phi_{s/c}$
Narrow Langmuir Probe
N_e, T_e, $\Phi_{s/c}$
Plasma Impedance Probe
N_e
Wide Langmuir Probe
N_e, T_e, $\Phi_{s/c}$
FPMU electronics box
TV Camera Interface Control (TVCIC)
FPMU designed and built by Space Dynamics Laboratory (Logan, UT) on contract to NASA JSC
18

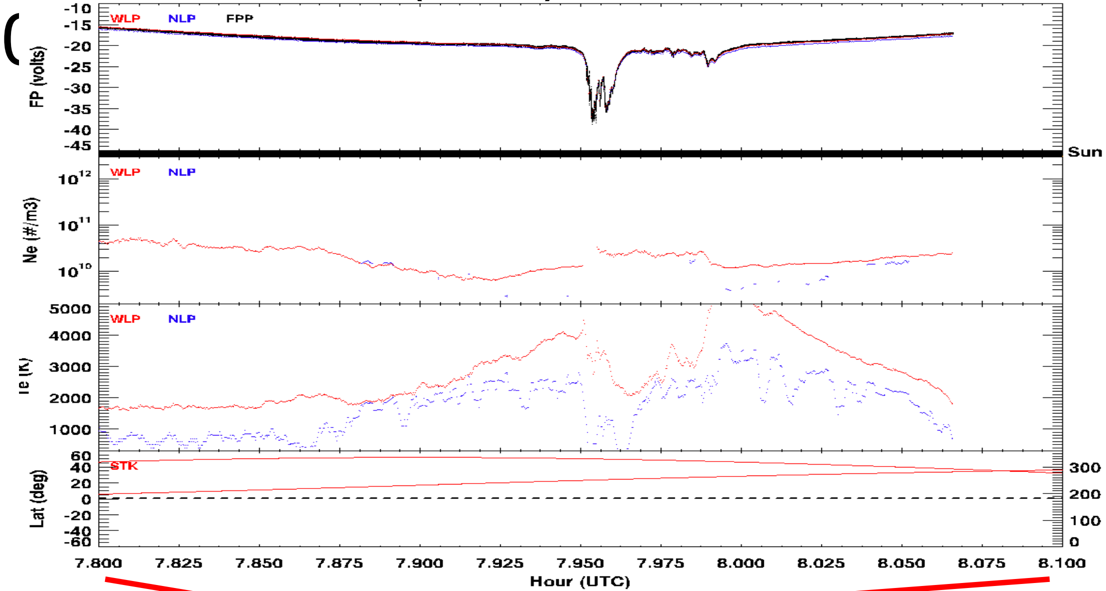

ISS/FPMU 2013/02/16 (2013/047)
HSV GS
raw
FPP
FP (volts)
20
0
-20
-40
-60
Sun
WLP NI
NLP Te
Ne (#/m3)
10^{12}
10^{11}
10^{10}
10^{5}
10^{4}
10^{3}
Te (K)
STK
Lat (deg)
60
40
20
0
-20
-40
-60
300
200
100
0
Lon (deg)
0000:00
0120:00
0240:00
0400:00
0520:00
0640:00
0800:00
Hour (UTC)
Sun Dec 1 21:21:24 2013

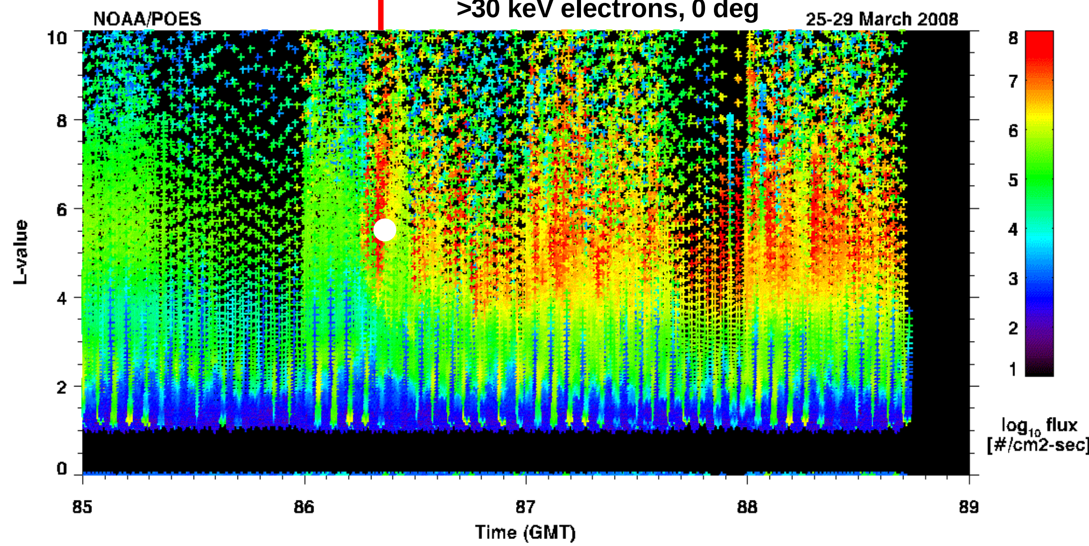
26 March 20(



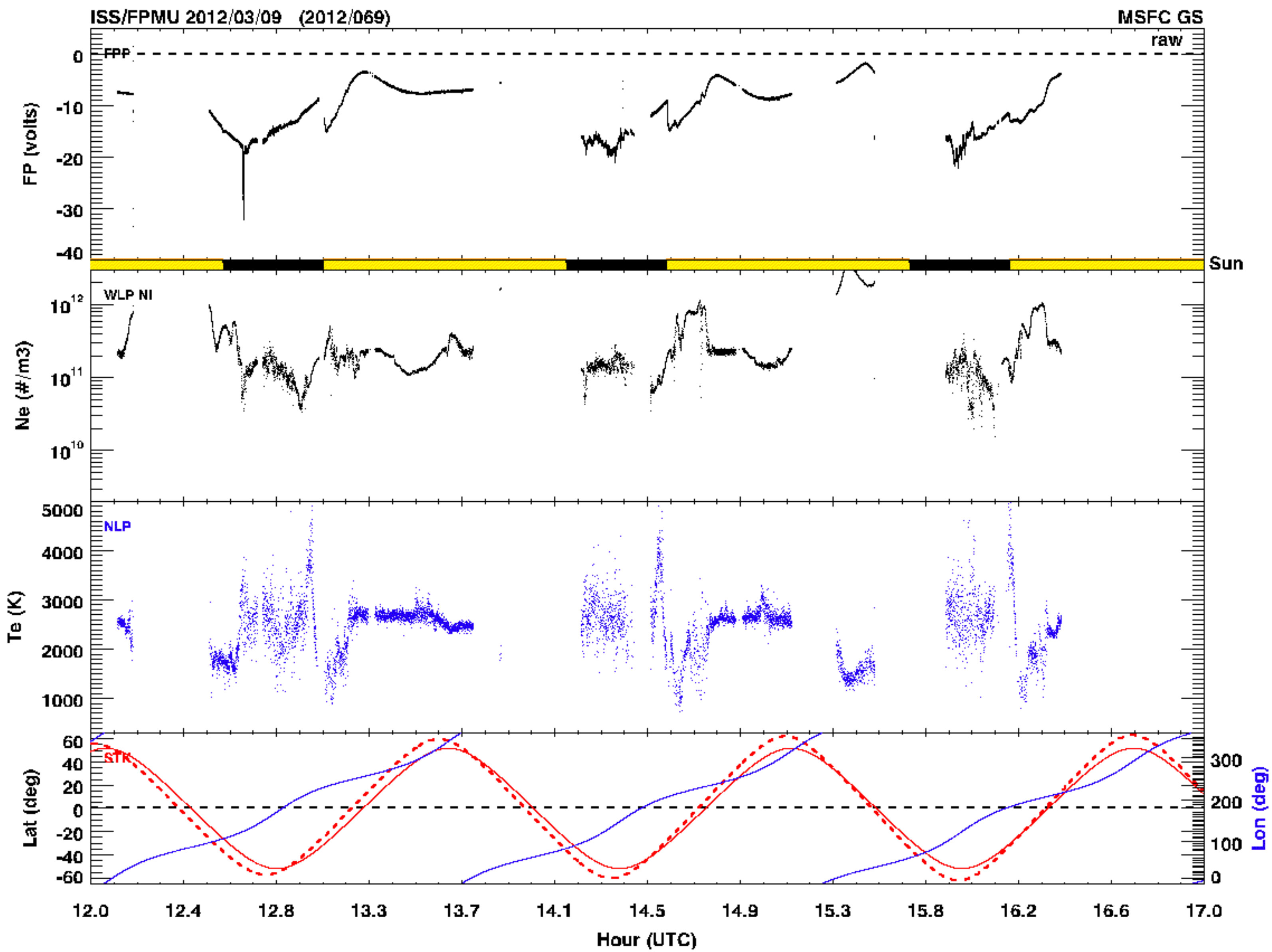
26 Mar 2008 07:30 – 08:00 UT





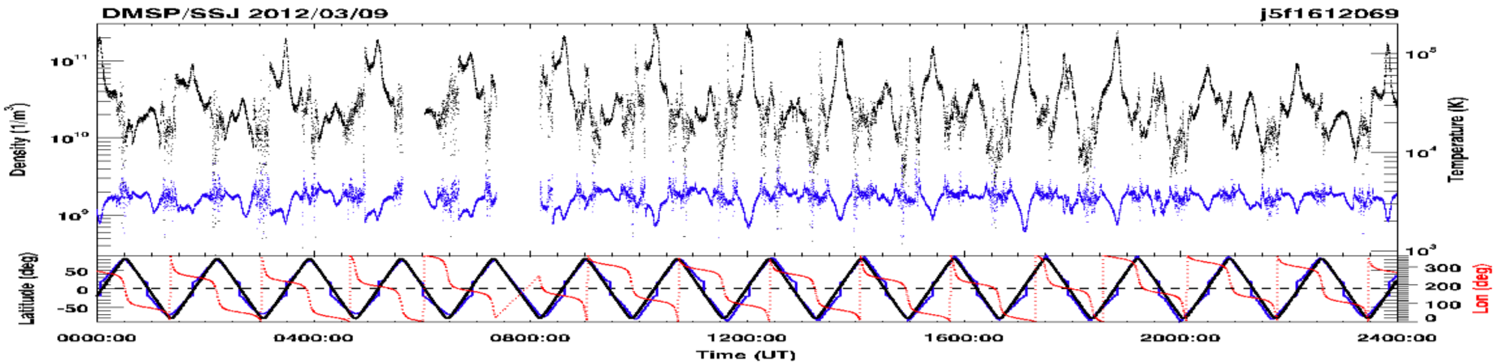


[adapted from *Craven et al.*, 2009]

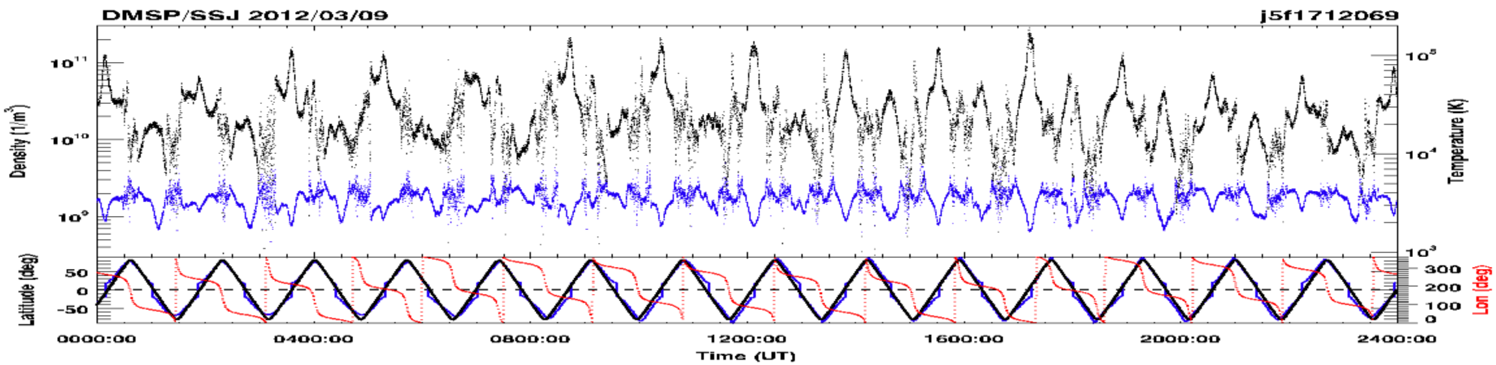


ISS/FPMU 2012/03/09 (2012/069)
MSFC GS
raw
FPP
FP (volts)
0
-10
-20
-30
-40
Sun
WLP NI
Ne (#/m3)
10^{12}
10^{11}
10^{10}
NLP
Te (K)
5000
4000
3000
2000
1000
STK
Lat (deg)
60
40
20
0
-20
-40
-60
Lon (deg)
300
200
100
0
12.0
12.4
12.8
13.3
13.7
14.1
14.5
14.9
15.3
15.8
16.2
16.6
17.0
Hour (UTC)

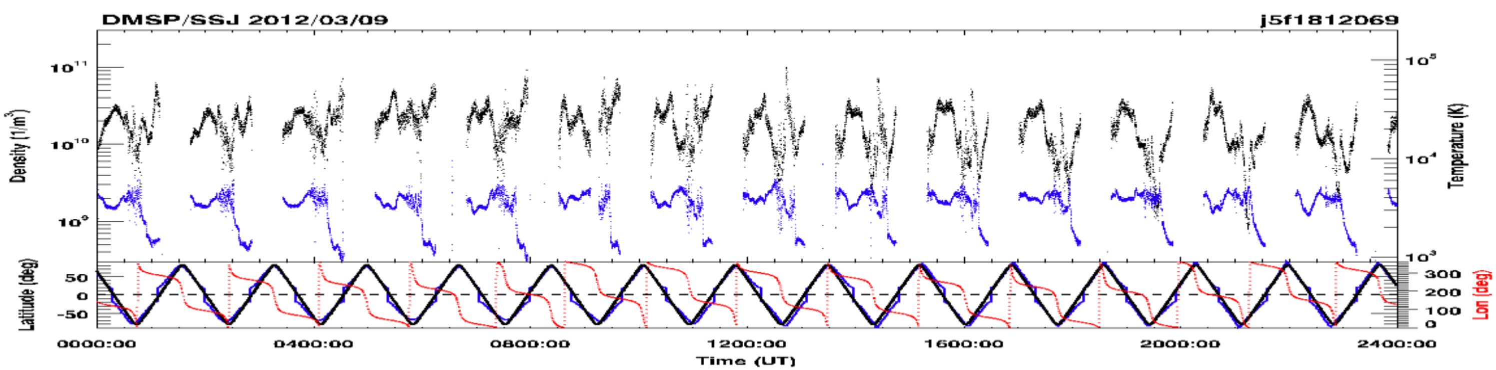
F16
~5-17 LT



F17
~5-17 LT



F18
~9-16 LT



Orbital Debris Problem in Perspective is a 2 by 2 Matrix

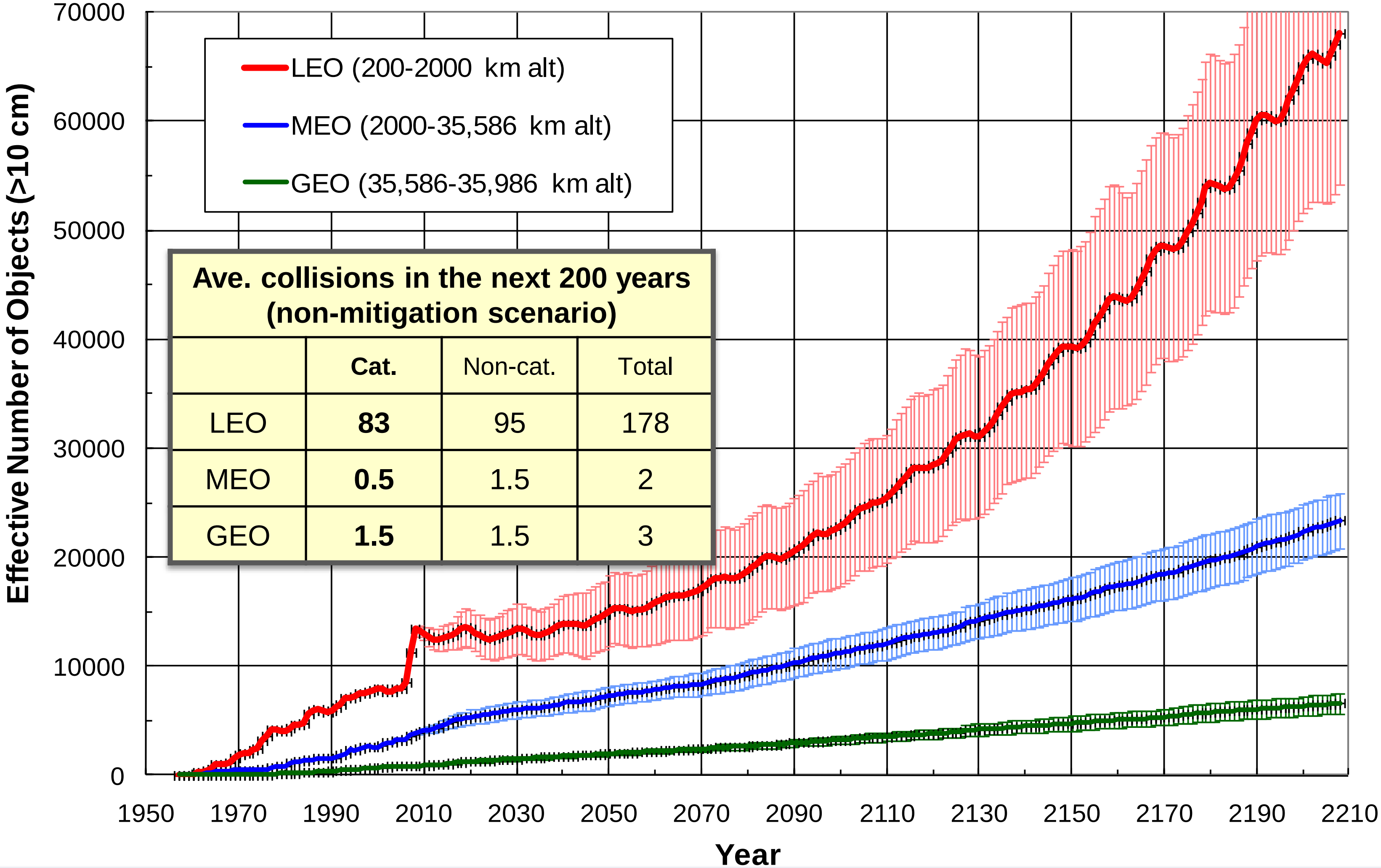
- **Small orbital debris is classified as 1 cm to 10 cm in diameter**
  - In everyday terms this is between the size of an M&M and a softball
- **Small orbital debris is the responsibility of NASA****
  - The USAF (STRATCOM) tracks large debris
  - NASA relies on predictive statistical analysis to quantify small orbital debris

	U.S. AIR FORCE **Large (Tracked)**	NASA **Small (Untracked)**
GEO (Low Velocity 3-7 km/s)	**~4,000 objects** **Low Risk**	**~20,000** **Low Risk**
LEO (High Velocity 13-16 km/s)	**~11,500 objects** **Moderate Risk**	**~500,000 objects** **High Risk**

** NASA APPEL-Orbital Debris and Reentry Risk Management, Slide # 4

Growth of the Orbital Debris Populations

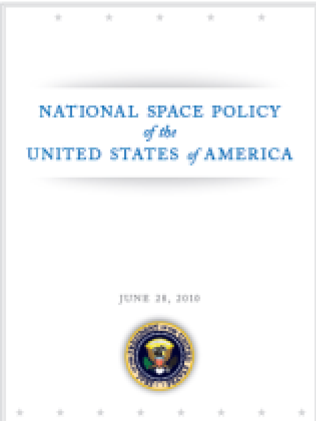
Non-Mitigation Projection (averages and 1-σ from 100 MC runs)



Ave. collisions in the next 200 years (non-mitigation scenario)

	Cat.	Non-cat.	Total
LEO	**83**	95	178
MEO	**0.5**	1.5	2
GEO	**1.5**	1.5	3

Orbital Debris Tasks within the National Space Policy of the USA



Goals

- **Strengthen stability in space** through: domestic and international measures to promote safe and responsible operations in space; improved information collection and sharing for space object collision avoidance; protection of critical space systems and supporting infrastructures, with special attention to the critical interdependence of space and information systems; and strengthening measures to mitigate orbital debris.

Intersector Guidelines

International Cooperation

Identify Areas for Potential International Cooperation. Departments and agencies shall identify potential areas for international cooperation that may include, but are not limited to: space science; space exploration, including human space flight activities; space nuclear power to support space science and exploration; space transportation; space surveillance for debris monitoring and awareness; missile warning; Earth science and observation; environmental monitoring; satellite communications; GNSS; geospatial information products and services; disaster mitigation and relief; search and rescue; use of space for maritime domain awareness; and long-term preservation of the space environment for human activity and use.

The Secretary of State, after consultation with the heads of appropriate departments and agencies, shall carry out diplomatic and public diplomacy efforts to strengthen understanding of, and support for, U.S. national space policies and programs and to encourage the foreign use of U.S. space capabilities, systems, and services.

Preserving the Space Environment and the Responsible Use of Space

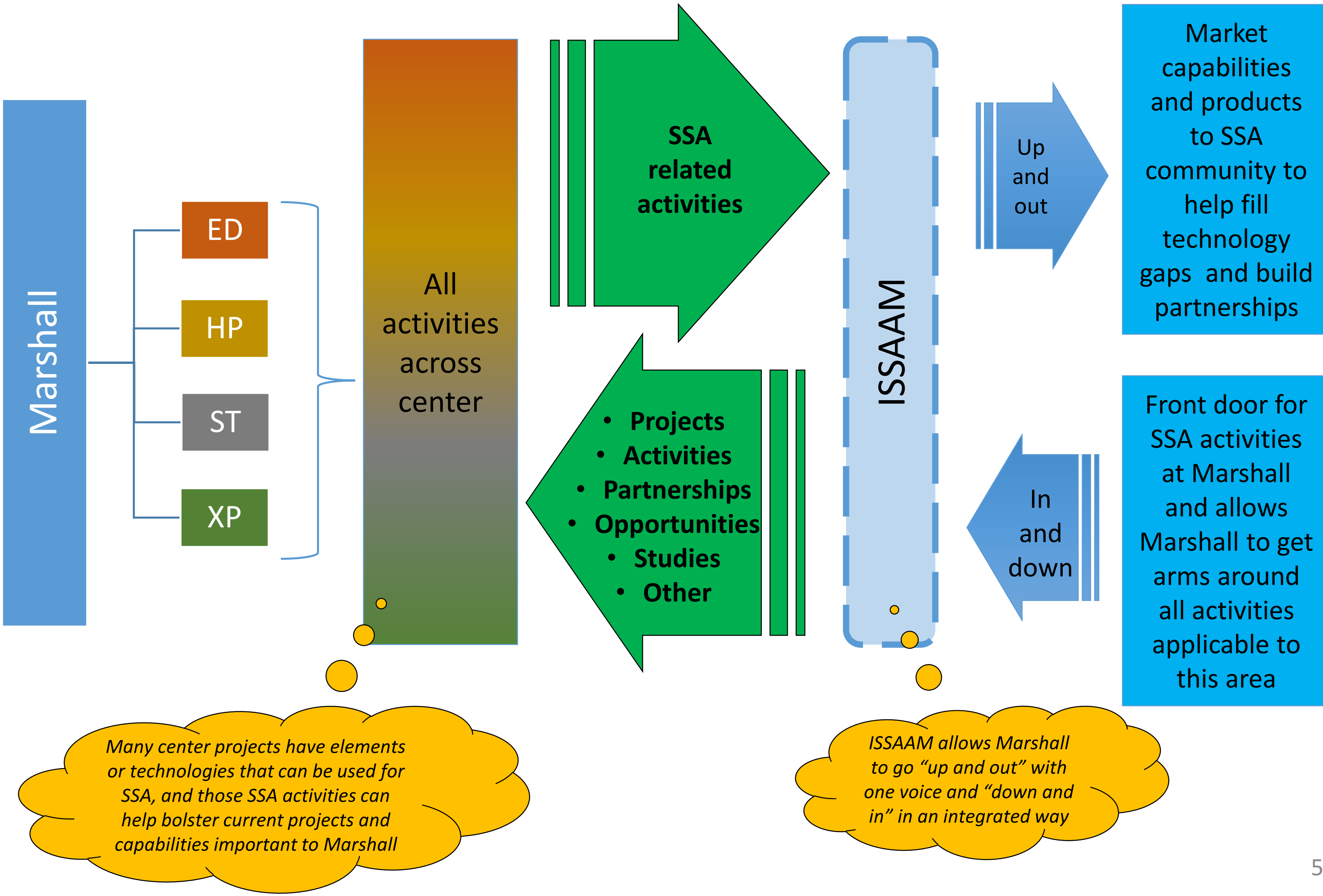
Preserve the Space Environment. For the purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall:

- Lead the continued development and adoption of international and industry standards and policies to minimize debris, such as the United Nations Space Debris Mitigation Guidelines;
- Develop, maintain, and use space situational awareness (SSA) information from commercial, civil, and national security sources to detect, identify, and attribute actions in space that are contrary to responsible use and the long-term sustainability of the space environment;
- Continue to follow the United States Government Orbital Debris Mitigation Standard Practices, consistent with mission requirements and cost effectiveness, in the procurement and operation of spacecraft, launch services, and the conduct of tests and experiments in space;
- 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; and

Is NASA doing anything directly in support of this new policy?
If so, who is orchestrating this effort for the agency (OSMA or OCT)?
How are NASA & DoD working together (inter agency teams, etc.)?

How ISSAAM Helps Marshall

"To enable Marshal projects the synergy to enhance and fill technology gaps for improved SSA/SAM"



MSFC SAA Tech Dev Mapping

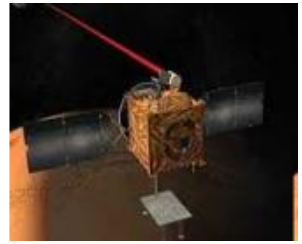
Discipline Technologies

- Real-time Mega-pixel Video Processing
- Narrow Field Staring Arrays
- High Speed Data Processors
- High-Speed, Multi-Axis Gimbals
- Telephoto Megapixel Video Tracking
- High speed Stereo Video Tracking
- Directional Wide Angle Range-Finder
- High Power Pulse Laser Diodes
- Quad Detector Laser Spot Tracker
- Video Spot Data Processing & Spot Telemetry Encoding
- Ablation of materials by use of pulse laser
- Pulse laser technology

Capability Technologies

- Asset Detection
- Asset Tracking
- Other capabilities

Mission Technologies



Orbital Debris Identification, Classification & Engagement

Proximity Operations with Uncooperative Targets

Space Situational Awareness

Missions (Commercial & Government)

NASA / DoD / Commercial

- Orbital Debris Early Warning Sentry
- Earth Orbiting Asset Safety & Mission Assurance
- GEO Satellite Rendezvous for Servicing
- Large Orbital Debris Rendezvous for De-Orbit
- Large Orbital Debris Catalogue Refinement
- Pico-Satellite Detection
- Small Orbital Debris Removal
- Small Orbital Debris Catalogue
- NEO Rendezvous

Benefits

- Verification of Space Environment Model for LEO
- Development of Space Environment Models for GEO
- Decreases the current uncertainties that are associated with Space Situational Network (SSN) two line equivalents (TLE)
- Reduction of number of conjunction alerts and warnings
- Advancement in ADR technologies
- Reduction in large and small debris
- .
- .
- .
- ….

Discipline Technologies → Capability Technologies → Mission Technologies → Missions (Commercial & Government) → Benefits

ISSAAM Functional Areas Map to Strategic Vectors

ISSAAM

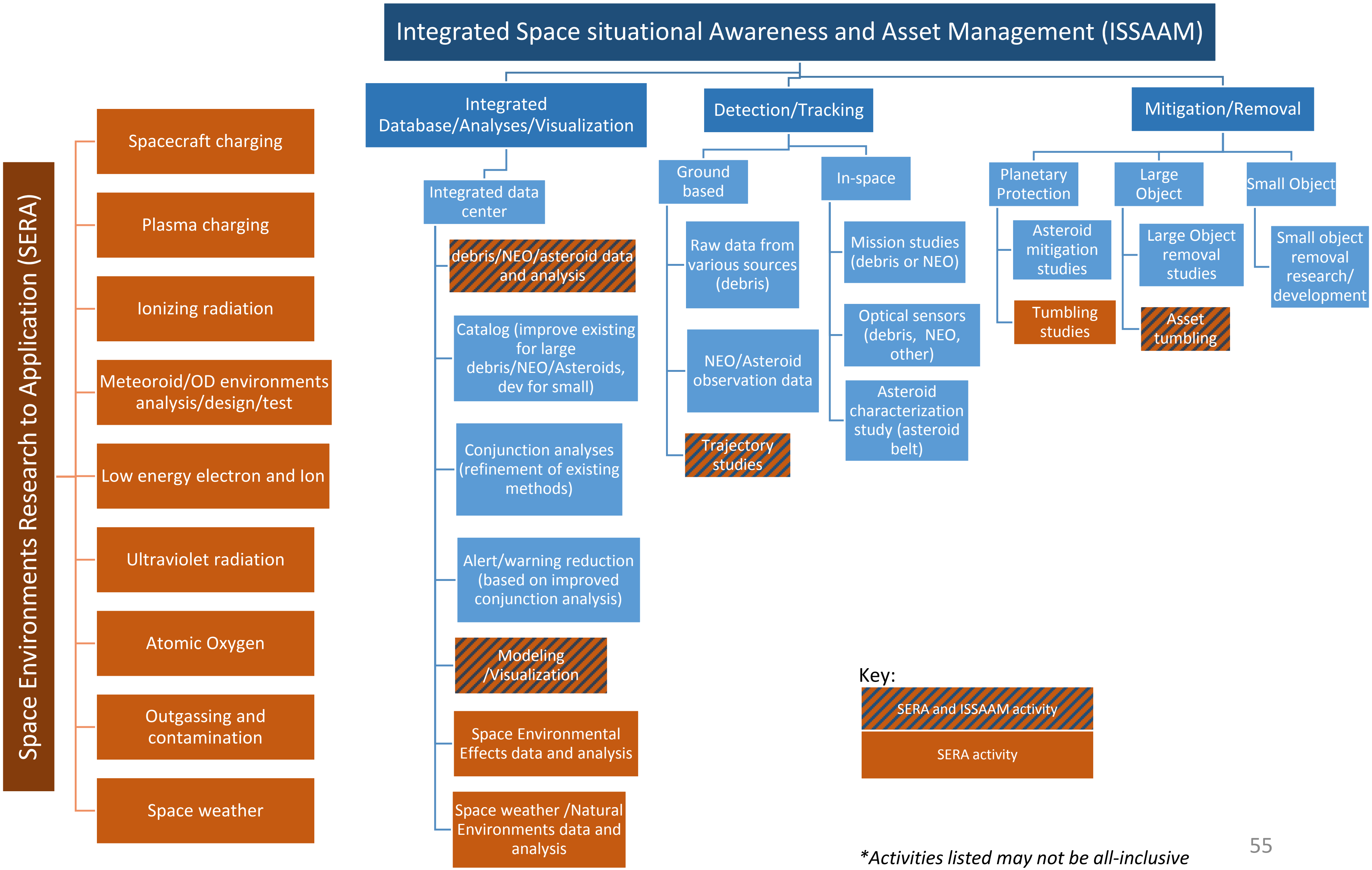
- **Database/Analyses/ Visualization/Modeling**
  - This area captures all work being done to gather, analyze, model and visualize data for SSA. As data grows with exploration, the need for ever growing and real time data processing and modeling will be needed.
  - These are unique Marshall capabilities requested frequently, and are vital to understanding human safety.
  - Data retrieved from planetary science and exploration missions can be processed real time, and all data kept in one portal for future analyses and modeling
- **Detection/Tracking**
  - This area covers both in-space and ground aspects of detection and tracking for SSA. This is particularly an important to small spacecraft used for science/exploration missions.
  - The ability to see an object and track it is used for rendezvous and capture and also for tracking the threat of objects close to our assets.
  - Data retrieved from this tracking can be used as inputs in the large databases mentioned above.
- **Mitigation/Removal**
  - This area is for all the technologies for either mitigation or removal of an asset or NEO. In-space as well as ground.
  - Many of these technologies are unique to Marshall, and current research is being done with several partners
  - In doing so, we gain an understanding of how objects behave, and other characterizations

SSA/OD Activity Alignment

- **Database/Analyses/ Visualization**
  - SAM (EM/ACO/ES/EO)
  - Meteoroid Environment Office (MEO) (EV)
  - Meteoroid Environment Model (MEM) (EV)
  - Space Environmental Effects testing (EM)
  - Natural Environments research and analysis (EV)
  - Solar Activity Future Estimation (EV/ZP)
  - SPHC Modeling (EV)
- **Detection/Tracking**
  - ALAMO (EV)
  - SODDAT (ACO/ES)
  - SSASSE (ES/ACO)
  - HD Dynamic Star- field Simulator (ES)
- **Mitigation/Removal**
  - Asteroid laser ablation study (ER)
  - De-spin study (ACO)
  - Asteroid mitigation Think Tank (FP)
  - Asteroid deflection (CS10)
  - FASTSAT recovery mission (ES)
  - MADR-TAS (ACO/ES)
  - Asteroid tumbling observational tasks (EV)
  - SODDAR (small debris removal) (ACO)
  - Material ablation deorbit study/experiments (EM/ER)

**Activities listed may not be all-inclusive*

ISSAAM Functional Structure Alignment



**Activities listed may not be all-inclusive*

Marshall Activities Brief Description (1/3)

SAM (EM/ACO/ES/EO)	• SAM is a project that collects and integrates data from across the globe on space assets, debris, etc. into one database that can be accessed by interested parties, and used for countless activities in the SSA and Asset Management arena.
Meteoroid Environment Office (MEO) (EV)	• This Marshall office holds the Agency-level responsibility for meteoroid environments models (sporadic and shower meteors). Data out of this office includes the Meteoroid Environment Model (MEM) data.
Meteoroid Environment Model (MEM) (EV)	• Some of the revolutionary aspects of MEM are a) identification of the sporadic radiants with real sources of meteoroids, such as comets, b) a physics-based approach which yields accurate fluxes and directionality for interplanetary spacecraft anywhere from .2 AU to 2 AU, and c) velocity distributions obtained from theory and validated against observation.
Space Environmental Effects Testing (EM)	• The Space Environments Effects (SEE) team studies material's behaviors in the space environment. Laboratory capabilities include simulation of orbital atomic oxygen, ultraviolet radiation, electron and proton radiation, plasma, thermal vacuum, and meteoroid and space debris impacts.
Natural Environments Research and Analysis (EV)	• This group leads the development of natural environment definition for both terrestrial and planetary missions including : ionizing radiation, plasmas, meteoroids, neutral thermosphere, thermal environment, solar activity forecasting. They also do environments data reduction and analysis and environments model development
Marshall Solar Activity Future Estimation (MSAFE) (EV/ZP)	• Each month the Natural Environments Branch uses the most recent monthly mean data as input to the Marshall Solar Activity Future Estimation (MSAFE) model to produce the current monthly report on expected 13-month Zurich smoothed solar and geomagnetic activity.

Marshall Activities Brief Description (2/3)

Smooth Particle Hydrodynamic Code (SPHC) model (EV)	• Smooth Particle Hydrodynamic Code (SPHC) is a software code that can handle one-, two-, or three-dimensional versions of a problem to support high-velocity impact simulation/modeling. It accommodates any material for which a specified set of properties is known, using any of 10 equations of state and 7 material strength models. SPHC has flexible geometric modeling capabilities, allowing it to simulate a wide range of articles. Impacts can be modeled at any speed below ≈50 km/s using initial temperatures, densities, porosities, and user-specified internal pressures. Complex objects can be built up from simple geometric constructs, then duplicated and moved as desired in the simulation space.
Automated Lunar and Meteor Observatory (EV)	• The ALaMO is an observatory here at Marshall that observes and tracks meteoroids entering the atmosphere.
SODDAT (ACO/ES)	• Small Orbital Debris Detection, Acquisition and Tracking. Will enable an in-space view of debris and track the hypervelocity particles. Looking for opportunity to dev and flight demo
SSASSE (ES/ACO)	• Space Situational Awareness Sensor Suite Experiment: this is the sensor that will fly on SODDAT: By combining off the shelf digital video technology, telescope lenses, and advanced video image FPGA processing, MSFC is building a breadboard of a passive orbital tracking camera that can track faint objects (including small debris, satellites, rocket bodies, and NEOs) at ranges of tens to hundreds of kilometers and speeds in excess of 15 km/sec.
High-def Dynamic Star- field Simulator (ES)	• This is a brand new and unique capability, developed in conjunction with Texas A&M University. It has a high resolution large monochrome display and a custom collimator capable of projecting realistic star images with simple orbital debris spots (down to star magnitude 11-12) into a passive orbital tracking camera with simulated real-time angular motions of the vehicle mounted sensor. The dynamic star field simulator can be expanded for multiple sensors, real-time vehicle pointing inputs, more complex orbital debris images and is adaptable to other sensor optics, missions, and installed sensor testing.

Marshall Activities Brief Description (3/3)

Asteroid laser ablation study (ER)	• This is a proposal as an outcome of the Asteroid Think Tank effort.
De-spin study (ED/ACO)	• This is a proposal as an outcome of the Asteroid Think Tank effort. It is a tether concept for de-spin of an Asteroid.
Asteroid mitigation Think Tank (FP)	• This effort was led by FP in an order to gather thoughts on asteroid mitigation
MADR-TAS (ACO/ES)	• This task is to gather an understanding of Large debris/objects and how to most effectively remove them: get more bang for your buck, as in one mission might remove several large objects.
Asteroid tumbling observational tasks (EV)	• This is a current study on how to determine asteroid tumbling rates from limited ground observations.
Material ablation (laser ablation) deorbit study/experiments (EM/ER)	• Current effort in conjunction with UAH and Miltec looking at using laser ablation to deorbit small debris. This concept is being considered for addition to the SODDAT to work in conjunction with the SSASSE so a piece of debris can be detected, tracked, and then engaged to ablate material to change the debris trajectory and lead to its deorbit.