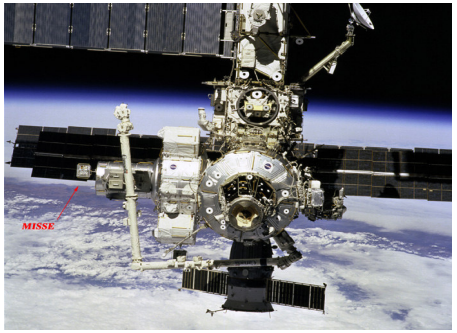
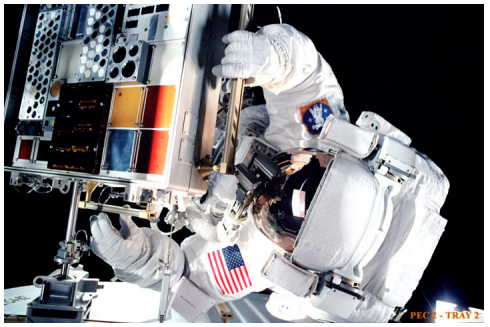




Sandia-Xilinx Virtex FPGA SEU Experiment on the International Space Station

Ethan Blansett

Dave Bullington, Dennis Clingan, Tracie Durbin, Jeff Kalb, Gayle Thayer, MyThi To, and Brandon Witcher, Sandia National Labs

in collaboration with

Rob Walters, Phil Jenkins, U.S. Naval Research Laboratory

Gary Swift, Carl Carmichael, Chen Wei Tseng, Greg Miller, Xilinx, Inc.

Greg Allen, Jet Propulsion Laboratory

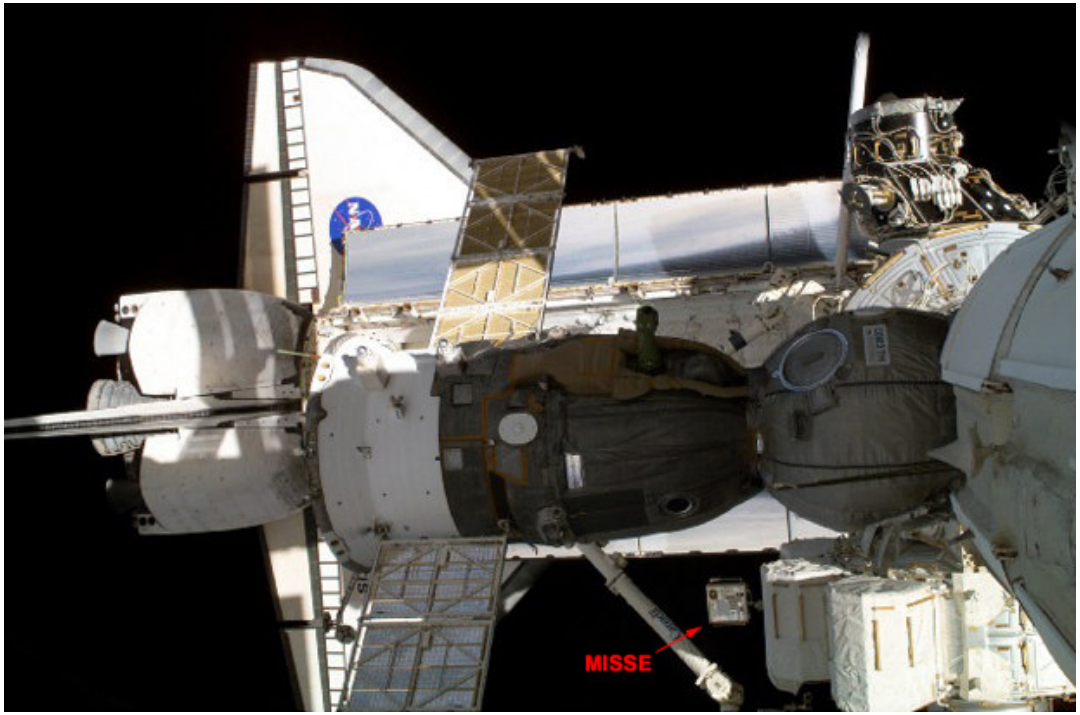
Heather Quinn, Los Alamos National Labs

Robert Reed, Vanderbilt University

-- Thanks to Xilinx Radiation Testing Consortium!! --

MISSE

- **MISSE = Materials on the International Space Station Experiment**
- **Experiments spend 1 to 2 years on the ISS – returned by Shuttle.**
- **Initially passive experiments only – combined UV, AO, radiation.**



- **MISSE-1,-2 (AFRL/ML)**
  - **passive material exposures**
  - **launched 2001, returned 2005**
- **MISSE-3,-4 (AFRL/ML)**
  - **passive material exposures**
  - **launched 2006, returned 2007**
- **MISSE-5 (NRL)**
  - **self-powered with on-board, two-way comm**
  - **Active solar cell and passive material experiments**
  - **Launch Aug 2005, retuned Sept 2006**
- **MISSE-6 (AFOSR)**
  - **Entering I+T (AFRL-0510)**
  - **Scheduled launch Feb 2008**
- **MISSE-7 (NRL)**
  - **Being built (NRL-0602)**
  - **Launch scheduled July 2009**

Sandia National Laboratories

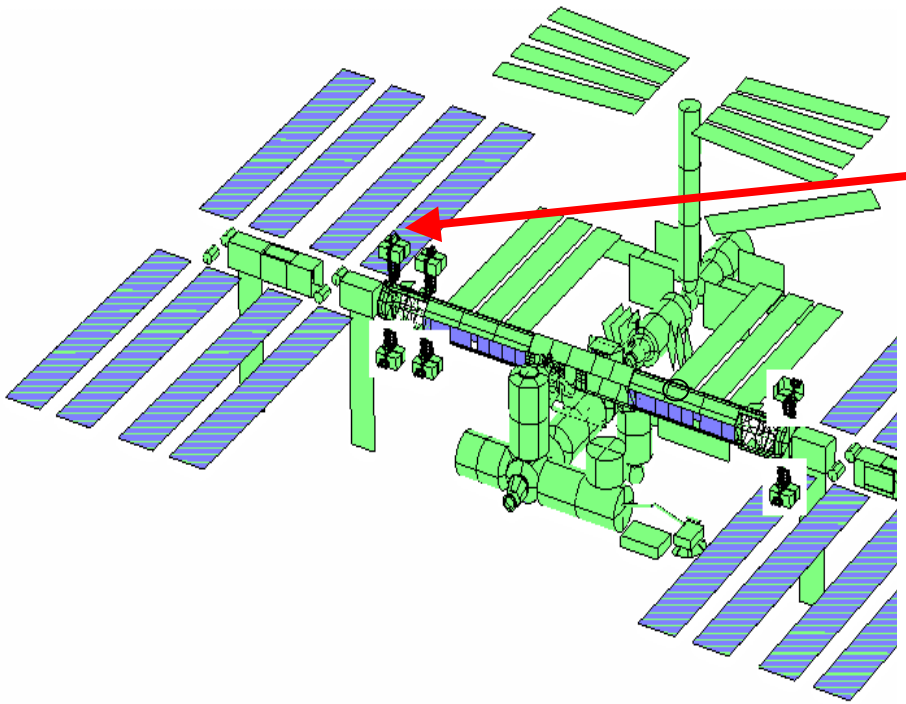
MISSE-7 Overview

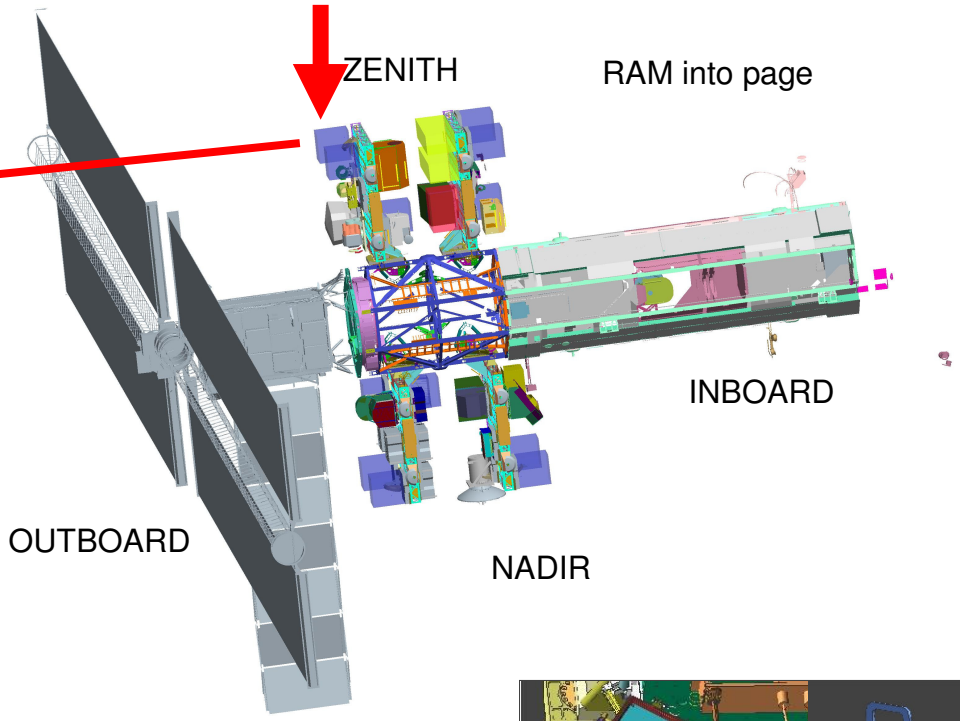
- Leveraging MISSE-6 design
- Will consist of two Passive Experiment Containers (PECs)
  - NRL responsible for PEC-A
    - » Reuse MISSE-5 PEC, resides at NRL
  - AFRL/ML and Boeing Phantom Works responsible for PEC-B
    - » Gary Pippin is BPW POC
    - » PEC 3 or 4 (Returned from orbit on last Shuttle Mission)
- Will draw power from ISS
  - Use MISSE-6 design
  - About 75% of experiments will be active
- Will connect to ISS data to allow active commanding and telemetry
  - 1st for a MISSE
  - Using low data rate, 1553 bus
- Is a Navy SERB Experiment
  - MOA between NRL and STP is signed
- Planning for STS-129 (ULF3), July 2009 Launch

*From "*7th Materials on the International Space Station Experiment (MISSE-7)" *--Robert J. Walters, NRL*

Sandia National Laboratories

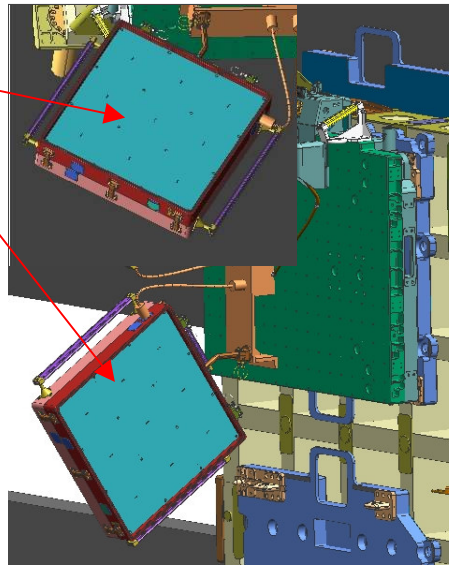
MISSE-7 Deployment Configuration





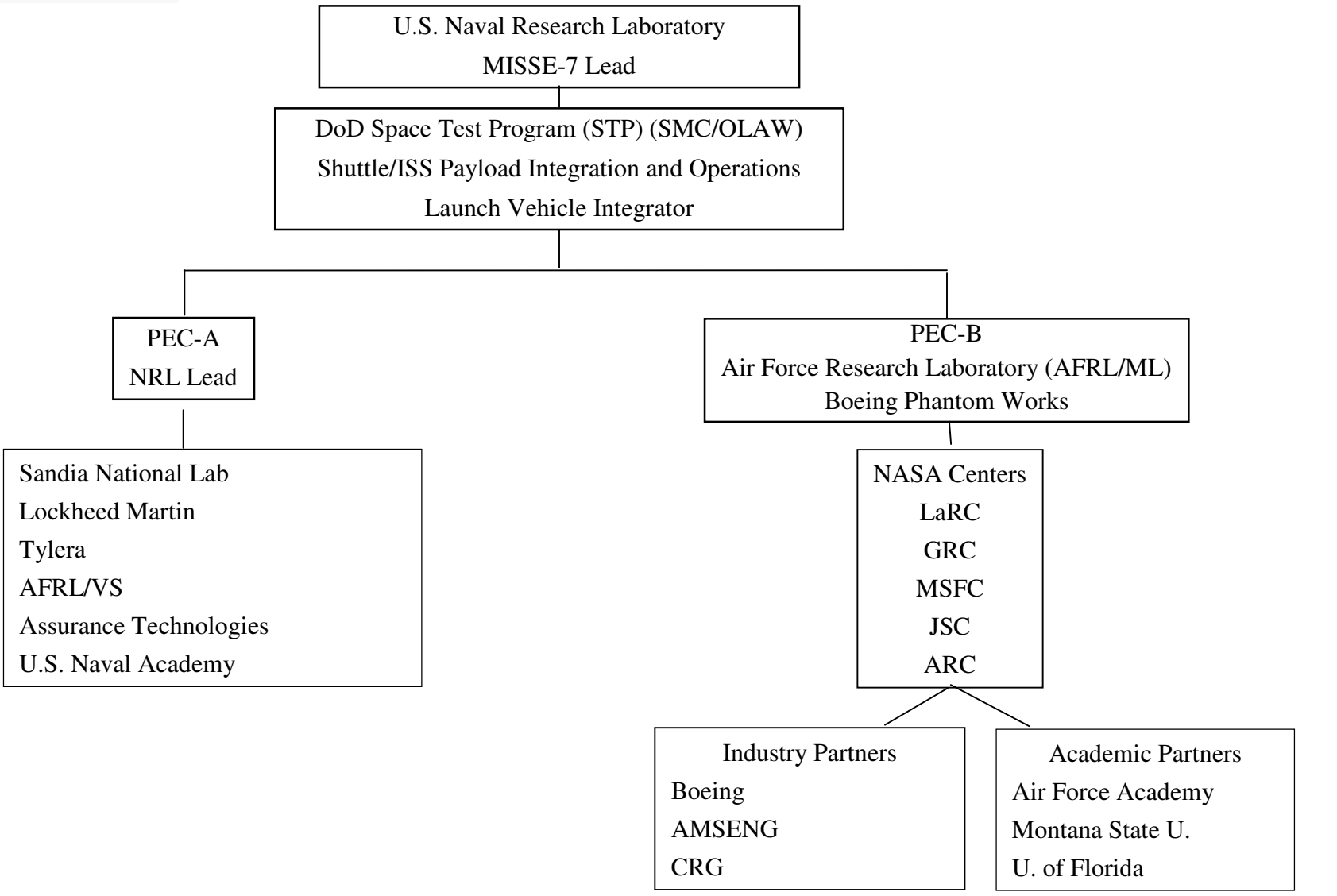
PEC-A, Zenith/Nadir

PEC-B, Ram/Wake



- **MISSE-7 is planned for ELC2**
  - **S3 zenith, outboard of ISS**

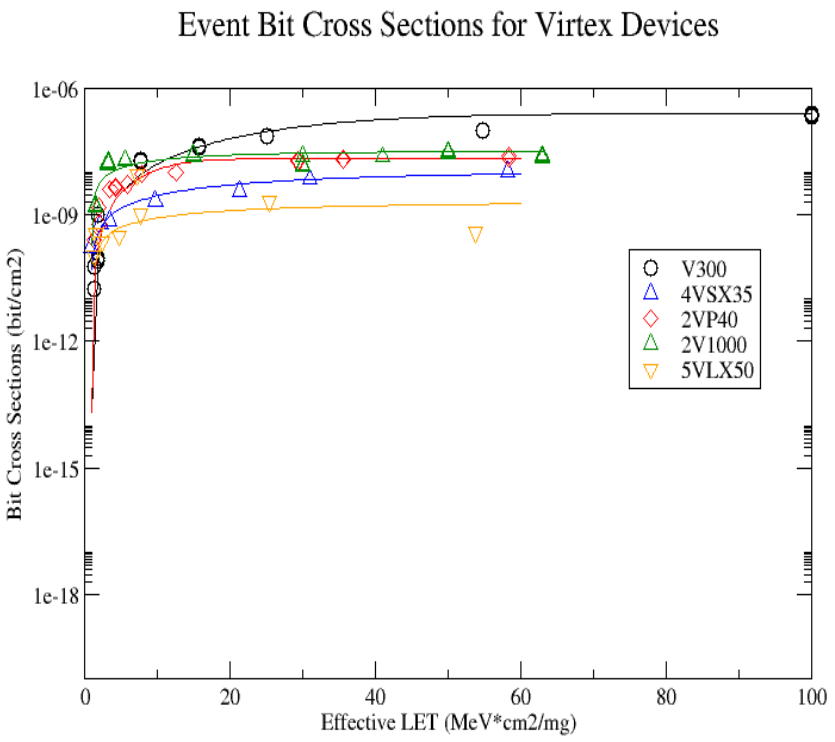
MISSE-7 Team

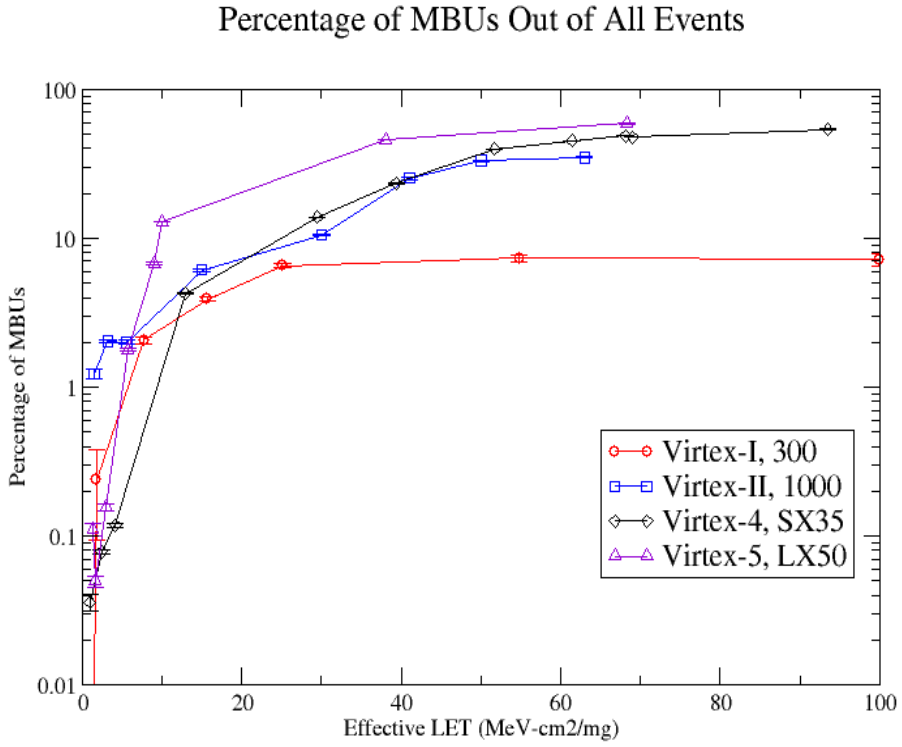


Sandia National Laboratories

Virtex Multiple Bit Upsets

From "Eight Years of MBU Data: What Does It All Mean?", NSREC 2007
--Heather Quinn, Keith Morgan, Paul Graham, Jim Krone, and Michael Caffrey, LANL



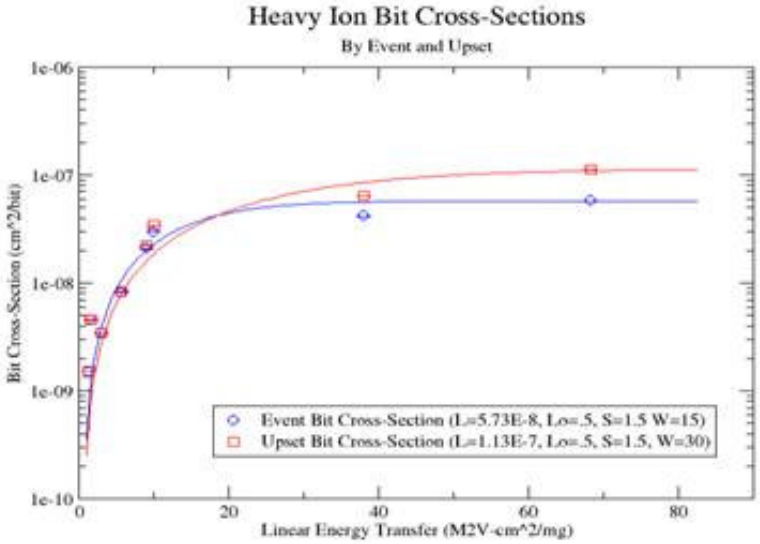


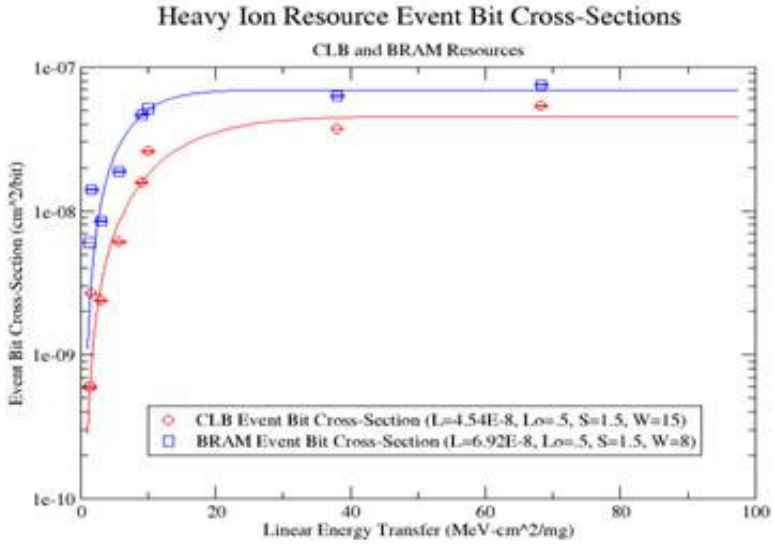
- V4: 1-bit and 2-bits events equally likely.
- V5: 3-bit and 4-bit events 25% of all events.

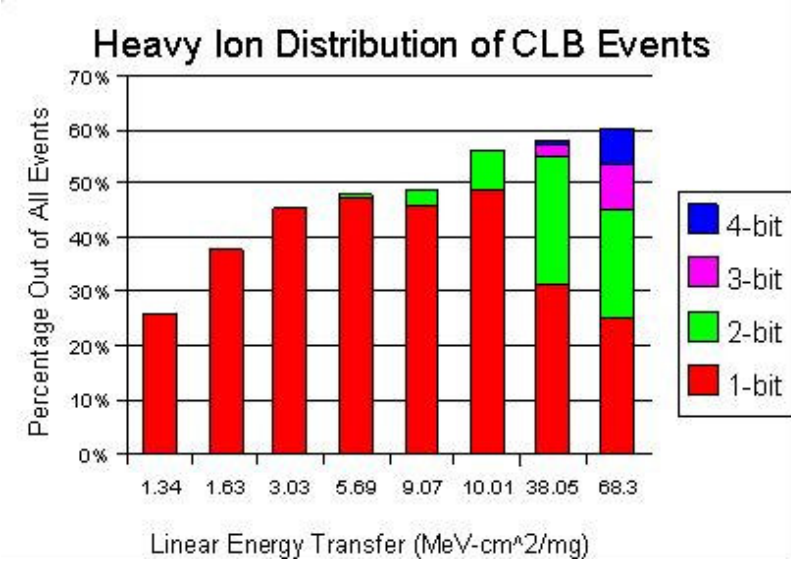
Sandia National Laboratories

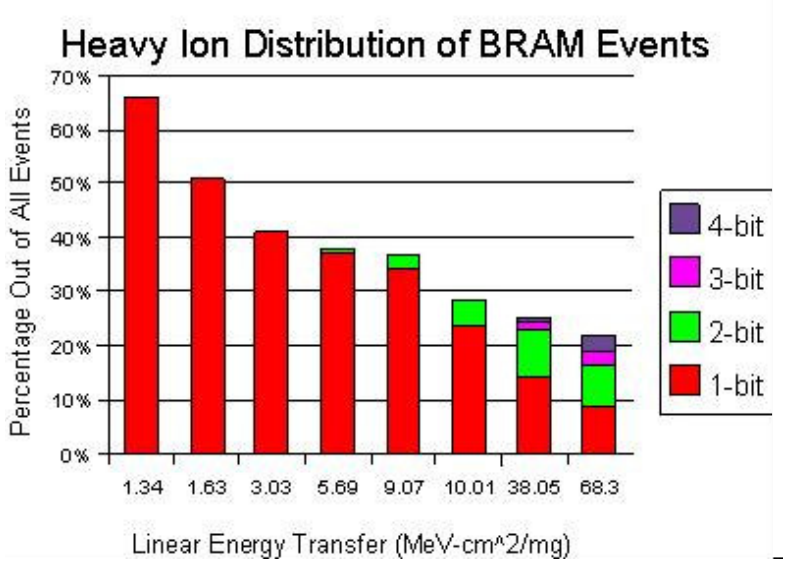
Virtex-5 SEUs

From "Static Proton and Heavy Ion Testing of the Xilinx Virtex-5 Device", NSREC 2007
--Heather Quinn, Keith Morgan, Paul Graham, Jim Krone, and Michael Caffrey, LANL





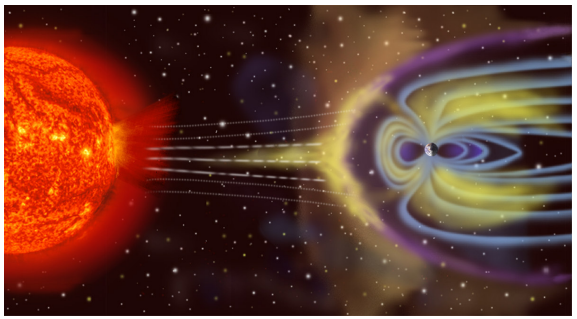




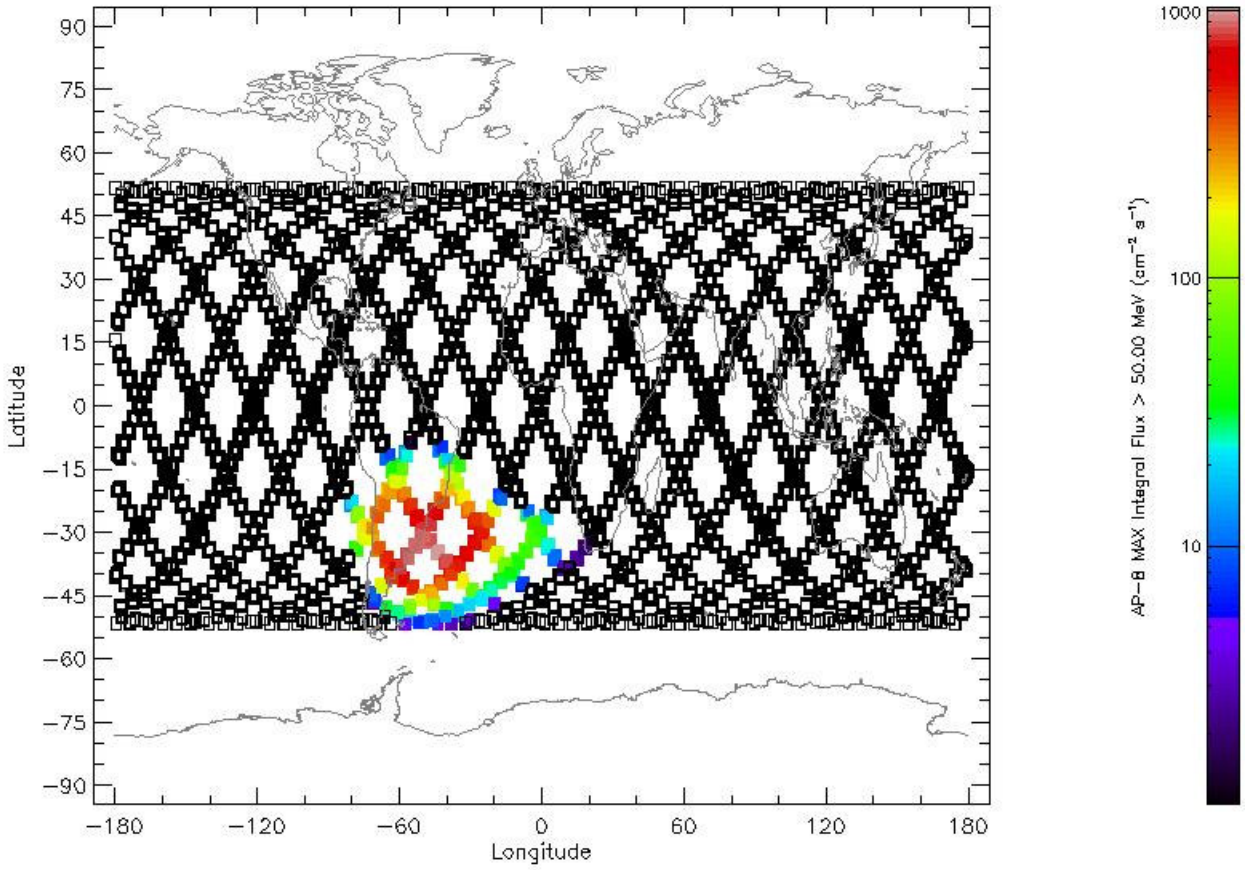
Sandia National Laboratories

ISS Space Environment

- **ISS Orbit: 336 km x 347 km, 51.6 deg. inclination**
- **Passive experiments (no shielding) will get ~30 krad/yr total dose at the surface.**
- **FPGA experiment (100 mil Al shield) will get ~30 rad/yr total dose.**
- **Galactic cosmic rays are predicted to cause ~2 FPGA configuration bit errors/day and ~0.3 BRAM bit errors/day.**
- **From LANL Cibola Flight Expt. SEU data with FPGA's in similar orbit, we predict ~4 errors/day.**
- **About ½ of errors are predicted to be multiple bit upsets.**
- **South Atlantic Anomaly is predicted to cause about 0.2 errors/day.**
- **We predict about 7 flares/year with 4 errors/day and 1 flare/year with 20 errors/day.**
- **Total errors/year expected to be about 1000.**



ISS Orbit-- SAA

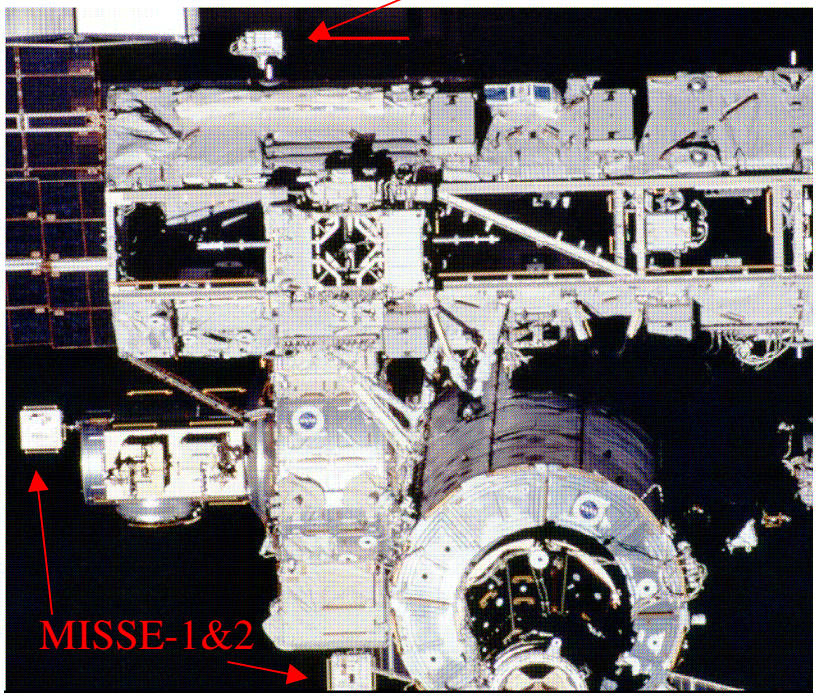


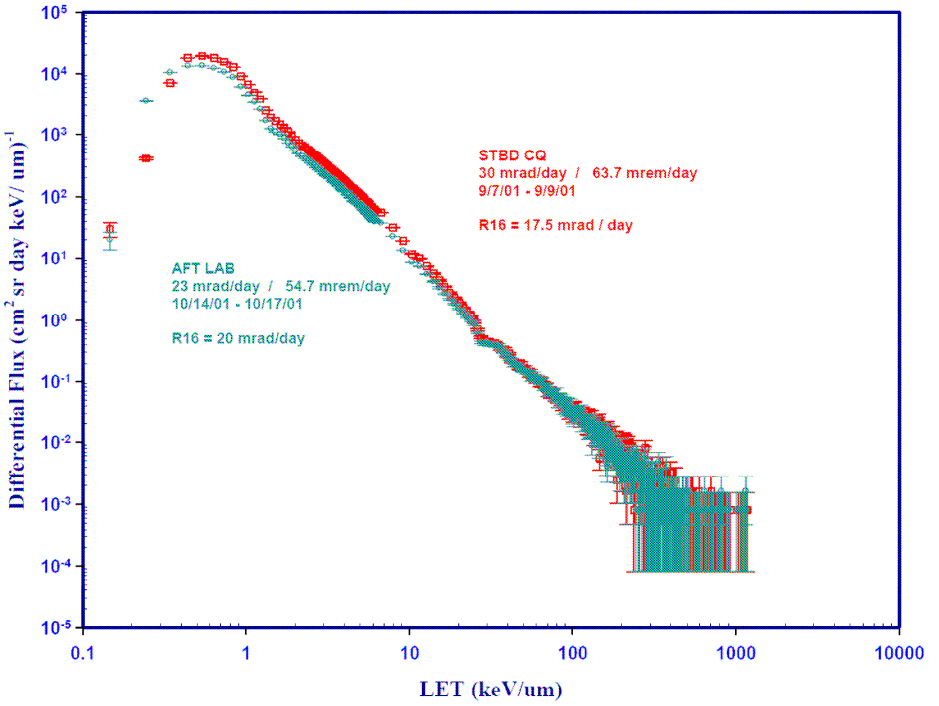
- **ISS proton environment calculated using AP8MAX**
  - **Shown is the integral Flux of protons with energy > 50 MeV**
- **The ISS passes through the SAA**

Sandia National Laboratories

ISS Radiation Measurements

Extra-Vehicular Charged Particle Spectrometer (EV-CPDS)

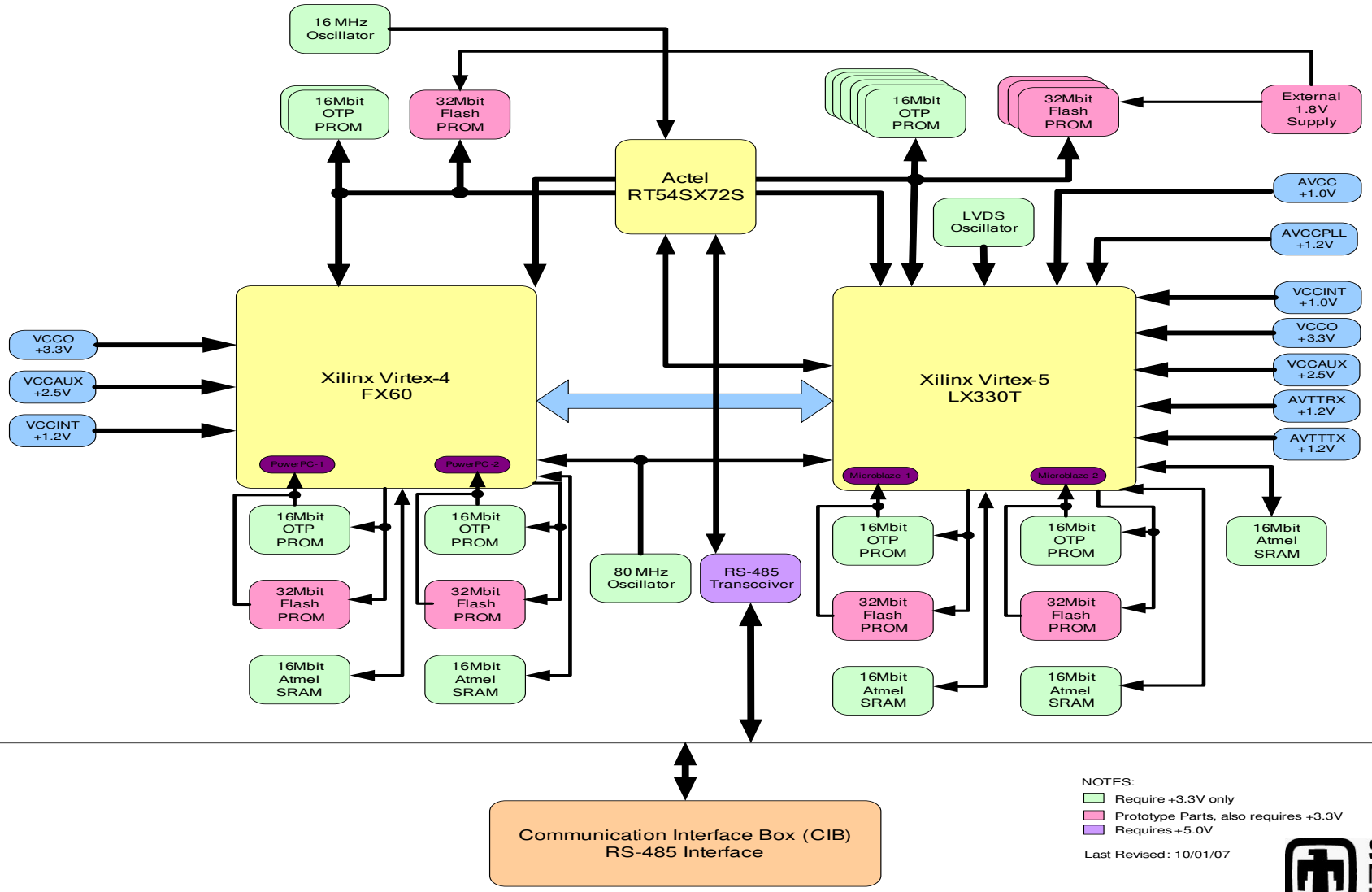




- **MISSE-7 will have on-board dosimeters & particle detectors**
- **Also, ISS has many on-board radiation monitors**
- **The EV-CPDS will provide LET data useful to MISSE-7**
  - **Data available through ISS Radiation Measurement Data Archive: Web-based Data Analysis System**

Sandia National Laboratories

FPGA Experiment Block Diagram



Sandia National Laboratories

Design Details

- Xilinx One-Time-Programmable PROMs will hold separate copies of the configuration bit stream and processor software for each Virtex.
- The configuration PROMs will boot each device and then be accessed by the other Virtex to provide cross scrubbing of each Xilinx FPGA.
- One embedded V4 PPC will provide software control, self monitor for upsets, and data handling functions. While the other embedded V4 PPC runs self monitoring upset codes.
- In the V5, a TMRed MicroBlaze will provide software control, self monitor for upsets, and data handling functions -- the other V5 non-TMRed MicroBlaze runs self monitoring upset codes.
- All processors run from external SRAM program memory that includes local data storage -- protected with Error-Detection-And-Correction (EDAC) circuitry.
- Each Virtex contains many different hardware logic element Device-Under-Test (DUT) units each with associated Functional Monitors (FuncMon) to detect and report SEU events.

Design Details, cont.

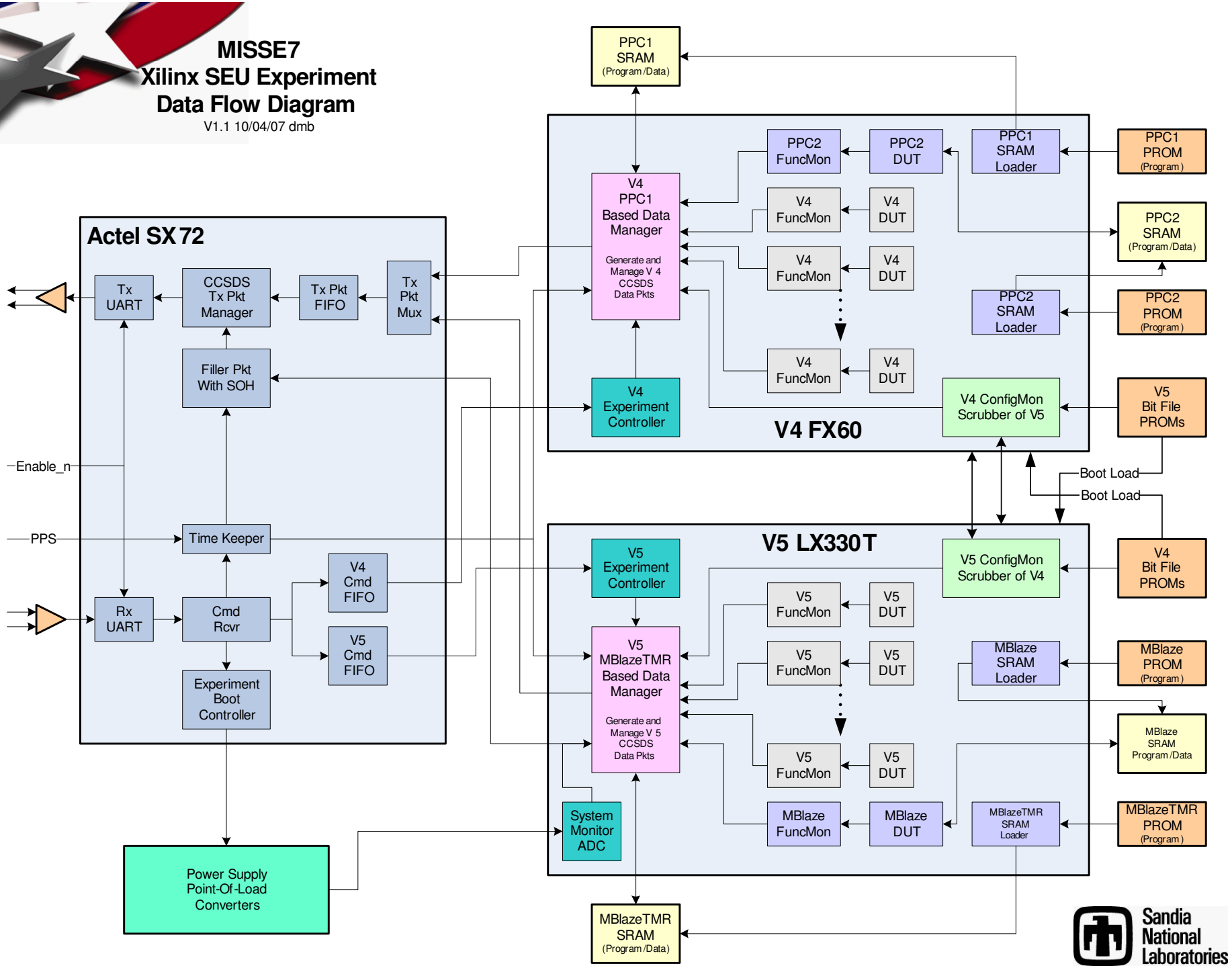
- DUT and Functional Monitor logic elements include: Block RAM, embedded FIFO logic, DCM, DSP48, IOB, V5 MGT, etc.
- Each SEU event data record includes time, bit location, along with expected and actual data values.
- FPGA environment is monitored with cross correlation to ISS radiation and environmental monitors.
- Actel provides non-volatile hardware interface to ISS serial command and data channels.
- Actel also contains external watchdog monitors of each Xilinx FPGAs to recover from any SEFI modes.
- Custom radiation tolerant Point-Of-Load converters are used to generate all Xilinx FPGA voltages.

□□

Sandia National Laboratories

MISSE7
Xilinx SEU Experiment
Data Flow Diagram

V1.1 10/04/07 dmb



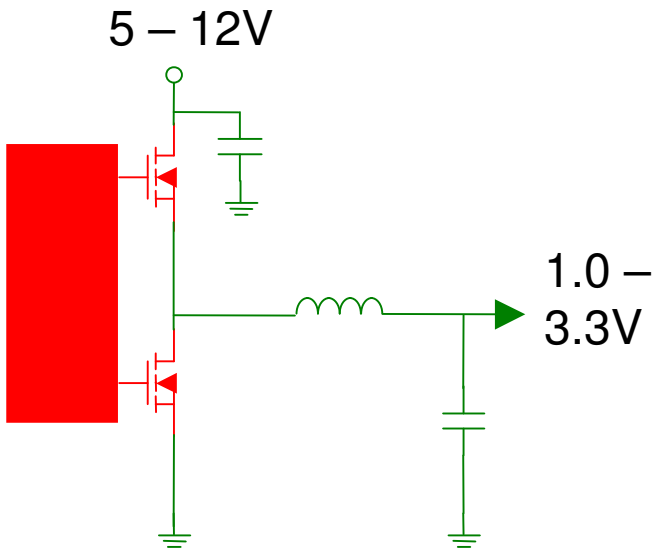
Sandia National Laboratories

Radiation Tolerant POL Converter

Objective - Develop and evaluate the performance of Point-of-Load (POL) power converters for space processor applications

Primary Requirements

- Total dose tolerant to > 100kRad
- Latch-up Immune
- No SEL to LET > 80 MeV-cm^2/mg
- Triple-output
- Switching frequency > 300 kHz each
- Target efficiency > 90%



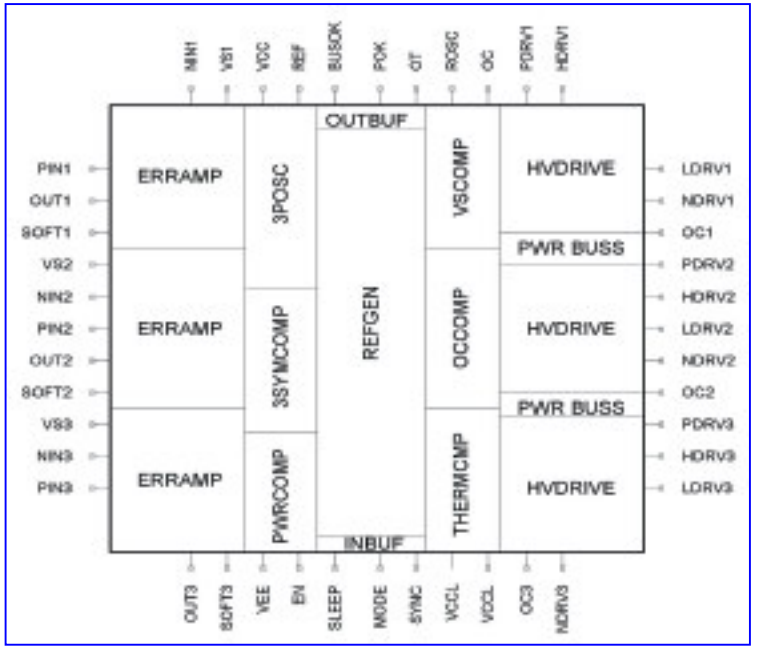
Synchronous Buck

From Brandon Witcher, SNL

Sandia National Laboratories

POL Controller Development

- 3-Output
  - **Multi-rail digital parts (e.g. FPGAs)**
- Synchronous Buck topology
  - **High efficiency > 90%**
- High frequency > 300kHz per phase
  - **Reduced size**
- High gain-bandwidth > 3MHz
  - **Improved transient response**
- Phase interleaving
  - **Reduced size and stresses**
- Flexible for varying applications
  - **V_{IN} from 4.5 – 13.2 volts**
  - **V_{OUT} from 0.6 – 5 volts**
- Fully protected
  - **Over-current**
  - **Under/Over-voltage**
  - **Over-temperature**



Basic Controller Architecture

- Radiation-Hardened
  - **Total-dose > 100krad(SiO_2)**
  - **SEL, SEGR, SEB immune to LET > 80 MeV-cm^2/mg**

Sandia National Laboratories

Schedule

- PCB Design – October-November, 2007
- FPGA Design – Sept. 2007 – June 2008
- Layout – December, 2007
- Manufacturing & Assembly – March, 2008
- Mechanical – May, 2008
- Hardware Testing – June-August, 2008
- Hardware Delivery – September, 2008
- Planning for STS-129 (ULF3), July 2009 Launch
- Return on last Shuttle mission?

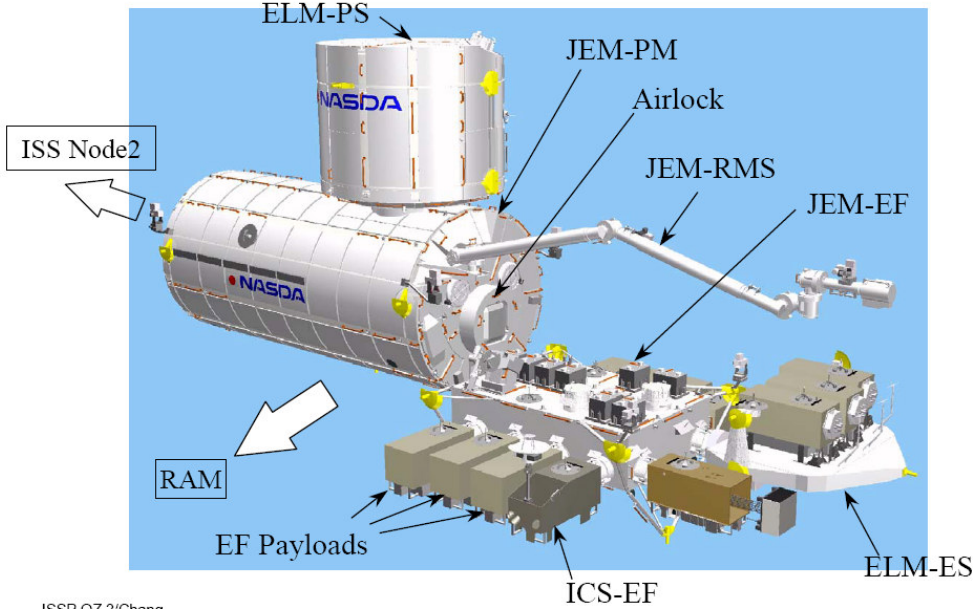
- 3-D Radiation Transport & Device Physics Simulation
  - Robert Reed, Vanderbilt Univ.

Sandia National Laboratories

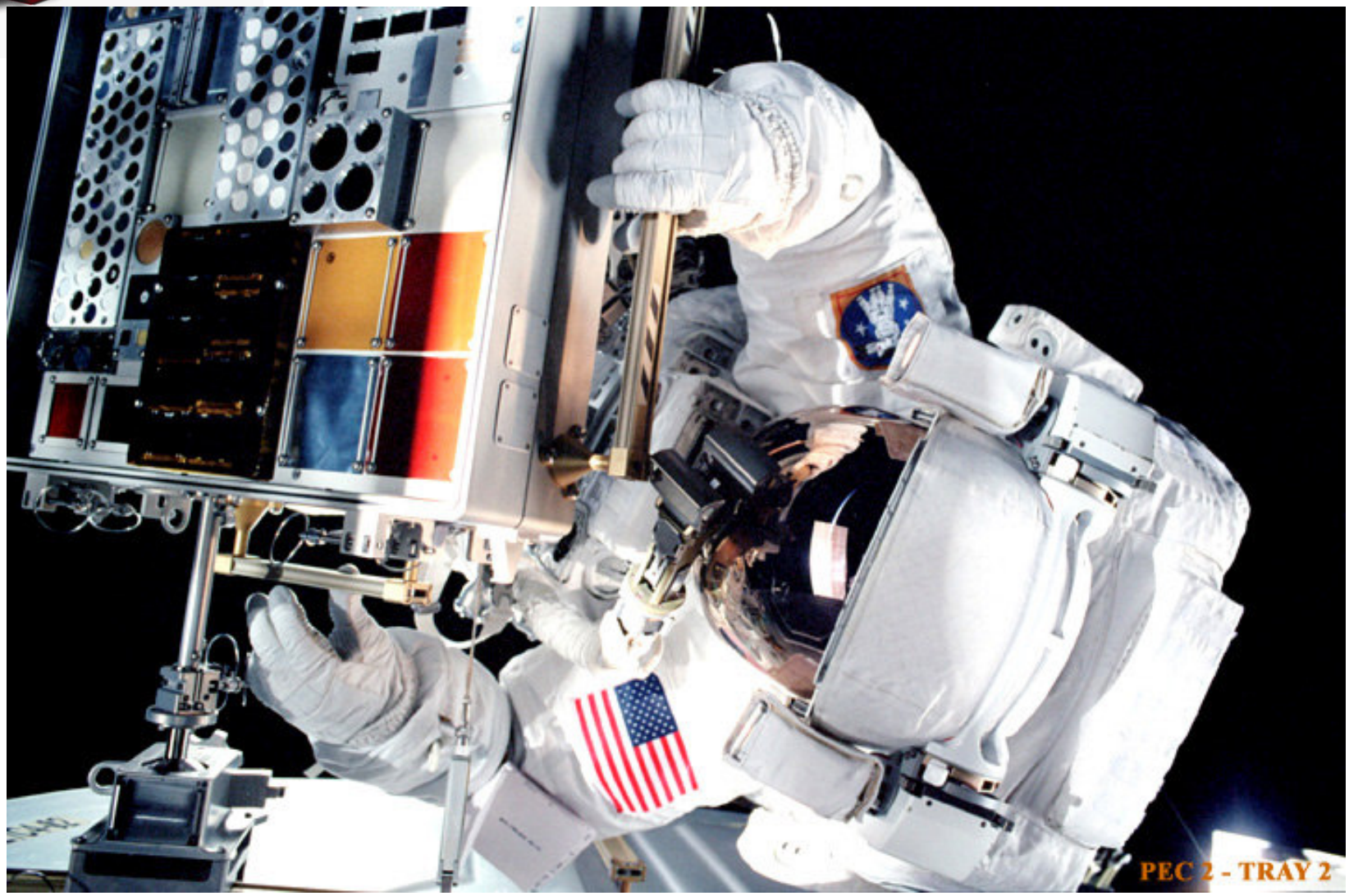
Future of MISSE?

NRL-0714: Platform for Retrievable Experiments in a LEO Space Environment (PRELSE)

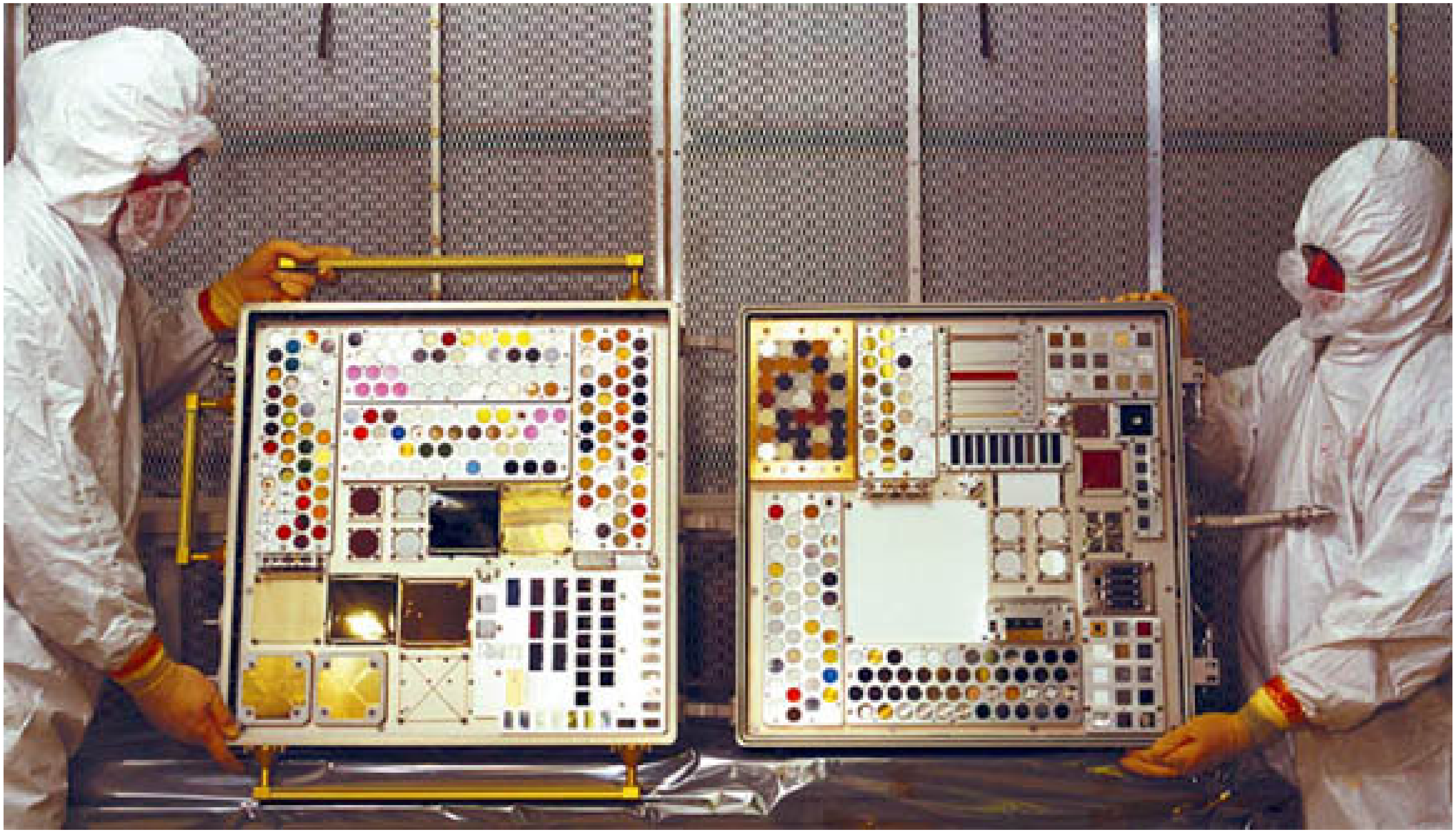
- PRELSE will be a platform supporting modular experiments (analogous to a motherboard and computer cards)
  - Platform will remain on orbit, individual experiments can be retrieved and returned via crew vehicle
- PRELSE will be a JEM-EF Payload
  - Attachment via standard Payload Attach Mechanism-Payload Unit (PAM-PU)
  - Data & electrical connection through Payload Interface Unit (PIU)
  - Will include Grapple Fixture (GF) for connection to the JEM robotic arm for deployment and retrieval
  - Launch on HTV
- Experiments will be small and modular
  - Will plug into standard interface on PRELSE (similar to PCI cards in computer motherboard)
  - PRELSE will provide two-way, high speed data link and power through JEM-EF
  - Will be self-contained for individual launch and return, facilitates return in post-Shuttle era
  - Plan is for continuous rotation of experiments as we did with MISSE but with more capacity and rapid turn around



Sandia National Laboratories

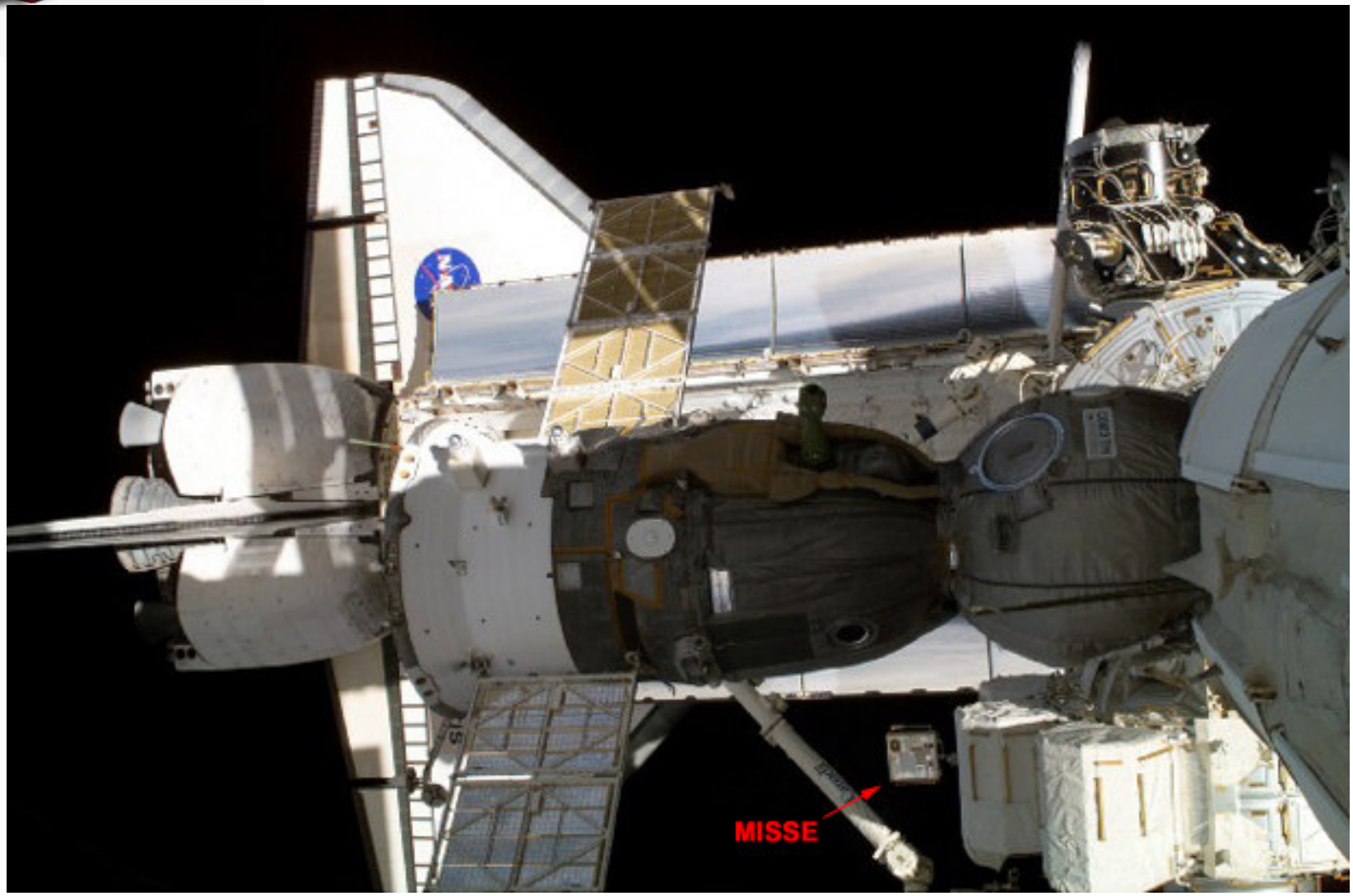


Sandia National Laboratories

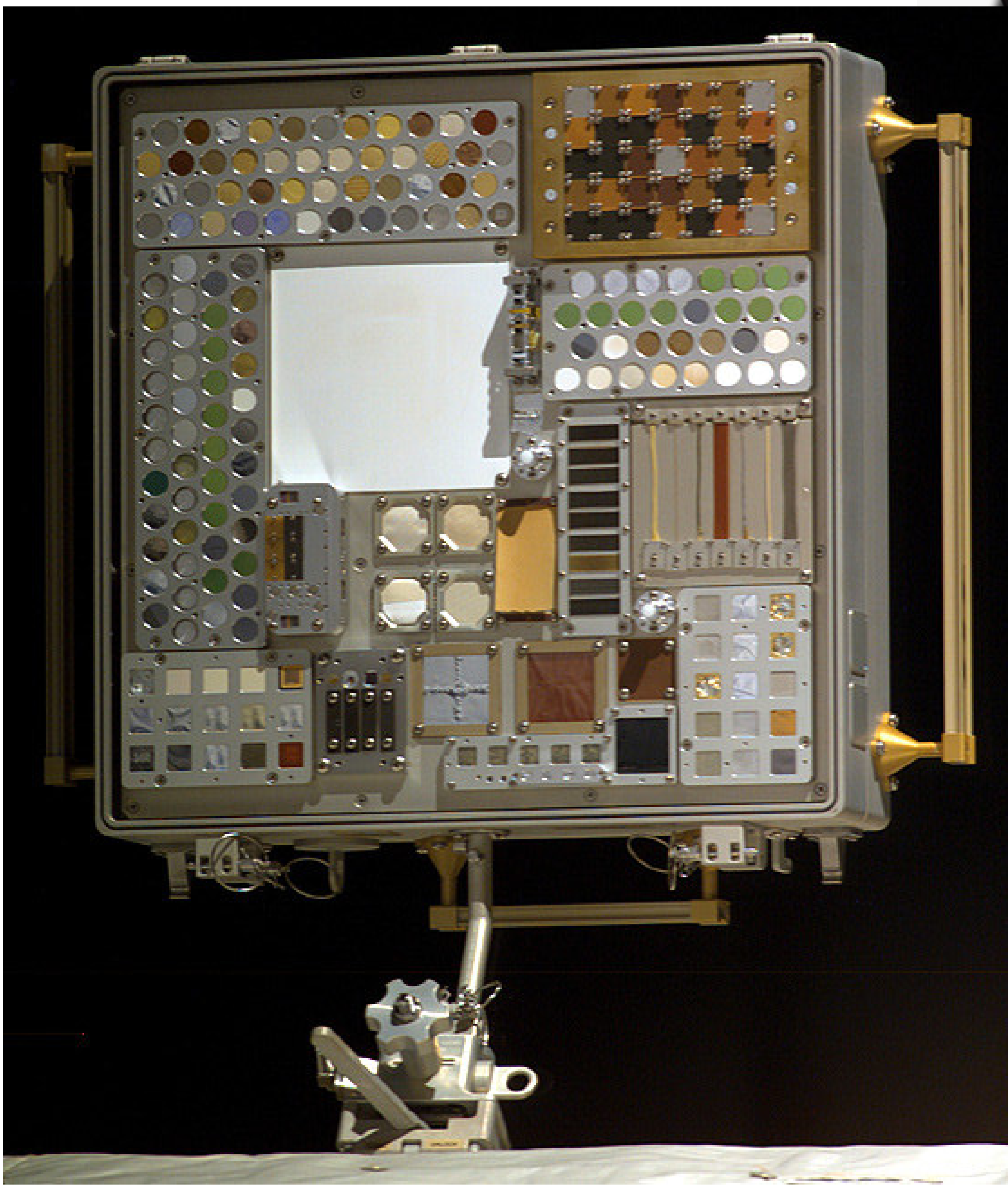


Sandia National Laboratories

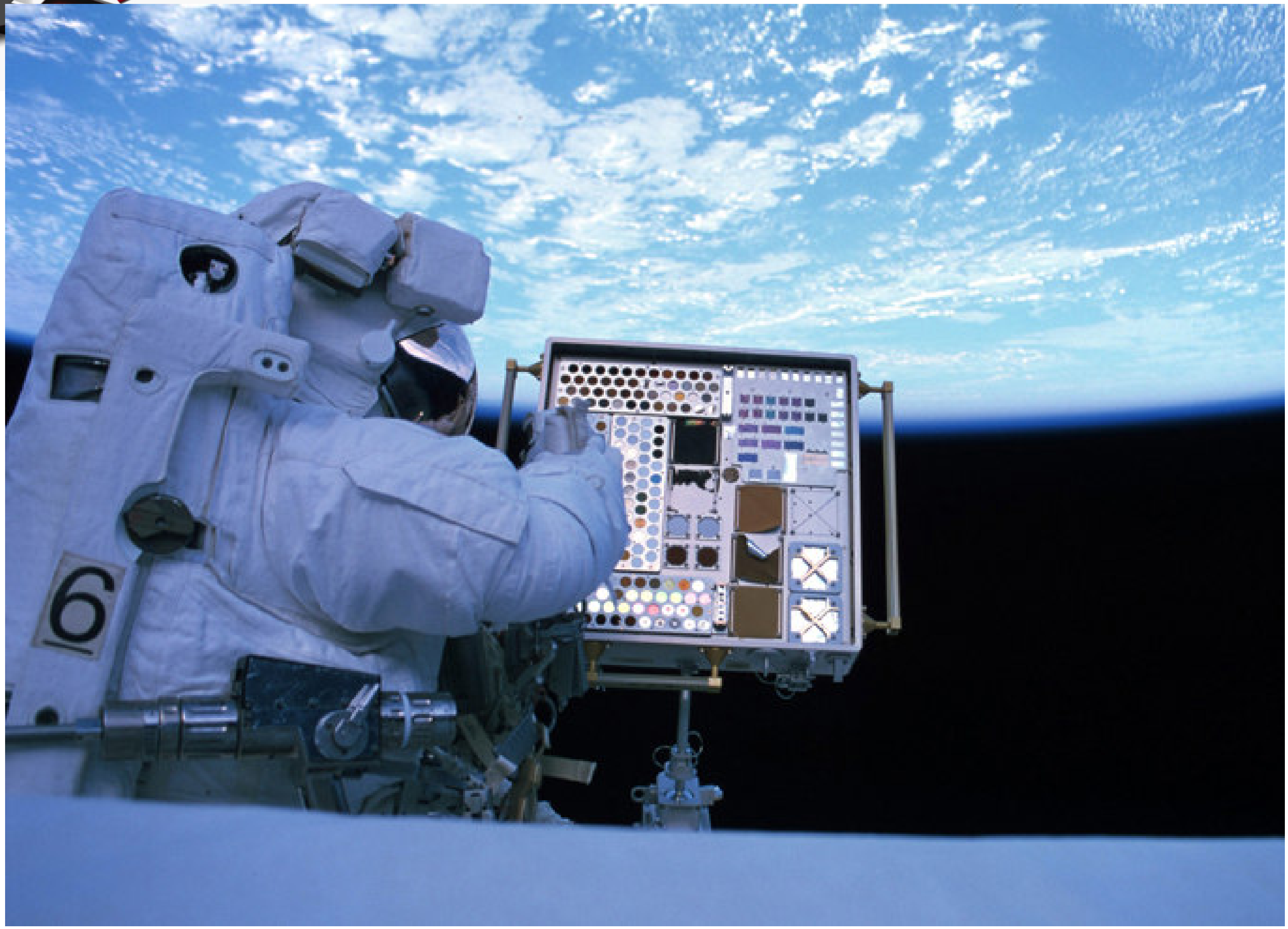
Sandia National Laboratories

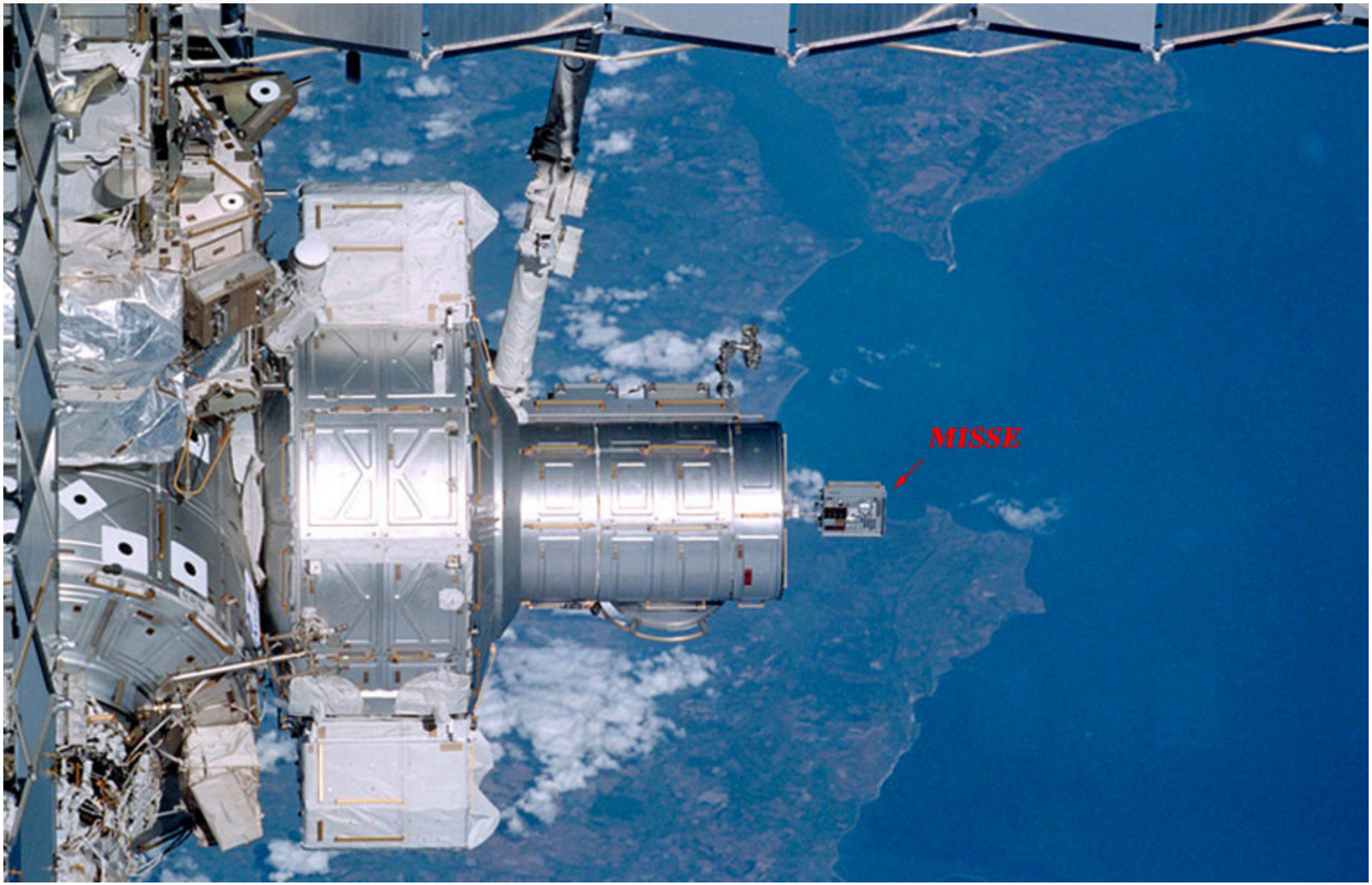


Sandia National Laboratories



Sandia National Laboratories


6



Sandia National Laboratories