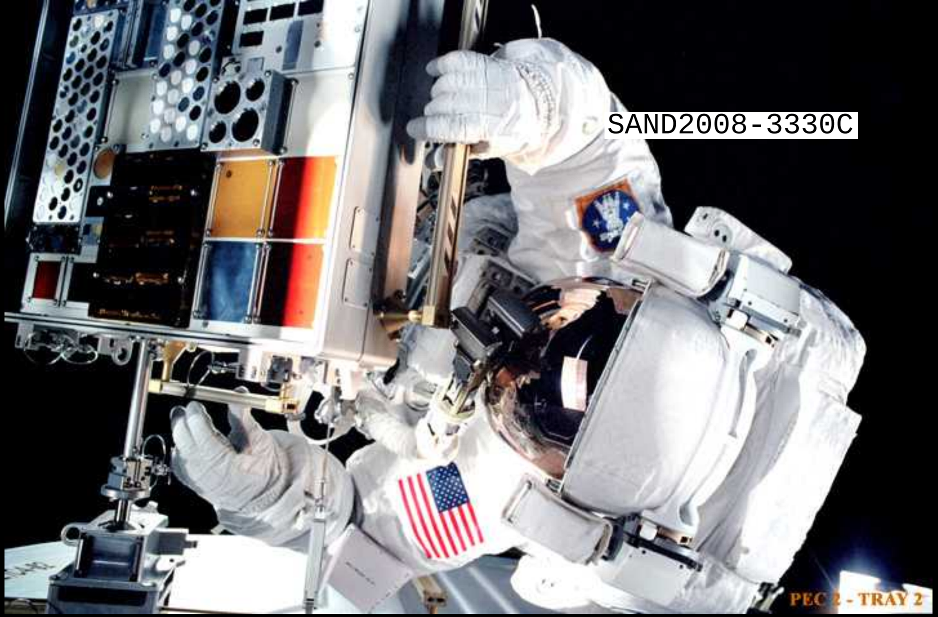
SAND2008-3330C

# Single Event Upset Xilinx-Sandia Expt. (SEUXSE)

# &

# Sandia Passive ISS Research Experiment (SPIRE)



**Gayle Thayer**

**Ethan Blansett, Dave Bullington, Dennis Clingan, Tracie Durbin, Jeff Kalb, MyThi To, and Brandon Witcher**

**May 21, 2008**

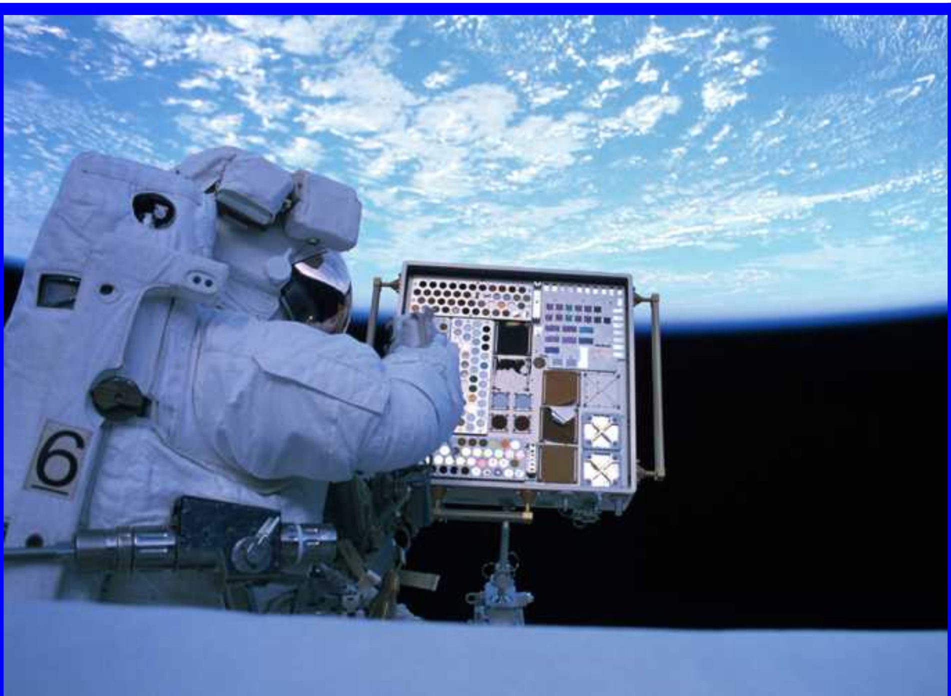
*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.*

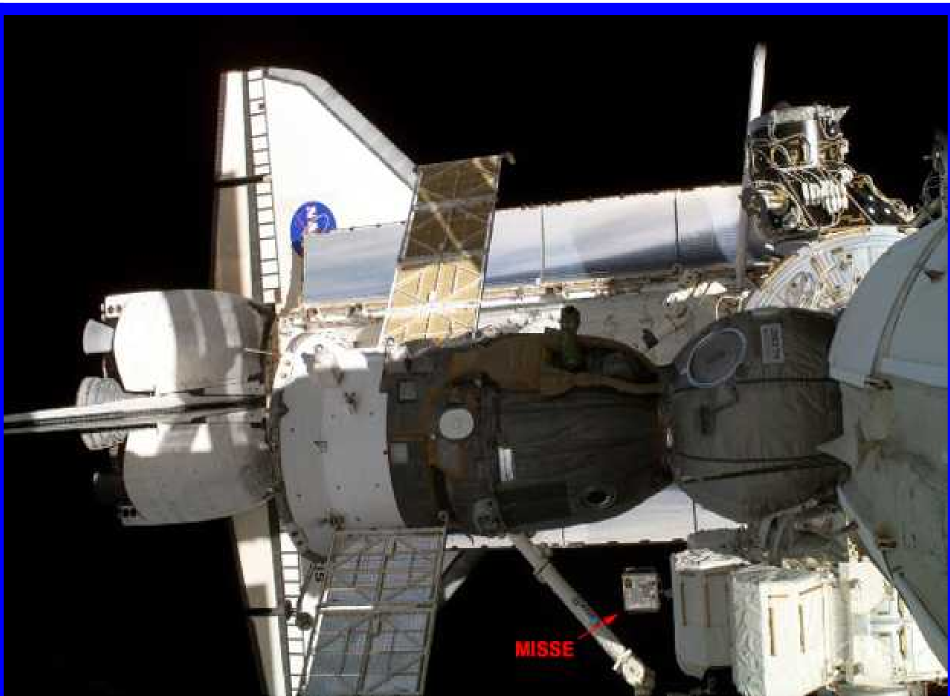
# Outline

**Background**

**Active Experiments (SEUXSE)**

**Passive Experiments (SPIRE)**





# MISSE

- MISSE = Materials on International Space Station Expt.
- Expts spend 1-2 years on ISS – returned via Shuttle.
- Initially passive experiments only – combined UV, AO, radiation.

- MISSE-1,-2 (AFRL/BPW)
  - passive material exposures
  - launched 2001, returned 2005
- MISSE-3,-4 (AFRL/BPW)
  - 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, returned Sept 2006
- MISSE-6 (AFOSR/BPW)
  - Entering I+T (AFRL-0510)
  - Scheduled launch June 2008
- MISSE-7A (NRL), 7B (AFRL/BPW)
  - Being built (NRL-0602)
  - Launch scheduled July 2009

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# 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*

# MISSE-7 Network

**U.S. Naval Research Laboratory**
MISSE-7 Lead

**DoD Space Test Program (STP) (SMC/OLAW)**
Shuttle/ISS Payload Integration and Operations
Launch Vehicle Integrator

**PEC-A**
NRL Lead

- Sandia National Lab
- Lockheed Martin
- Tylera
- AFRL/VS
- Assurance Technologies
- U.S. Naval Academy
- AFRL
- Aerospace Corp.
- Sharp Corp.
- JAXA
- DOD Payloads Office, NASA JSC
- Boeing Phantom Works
- NASA LaRC, GRC

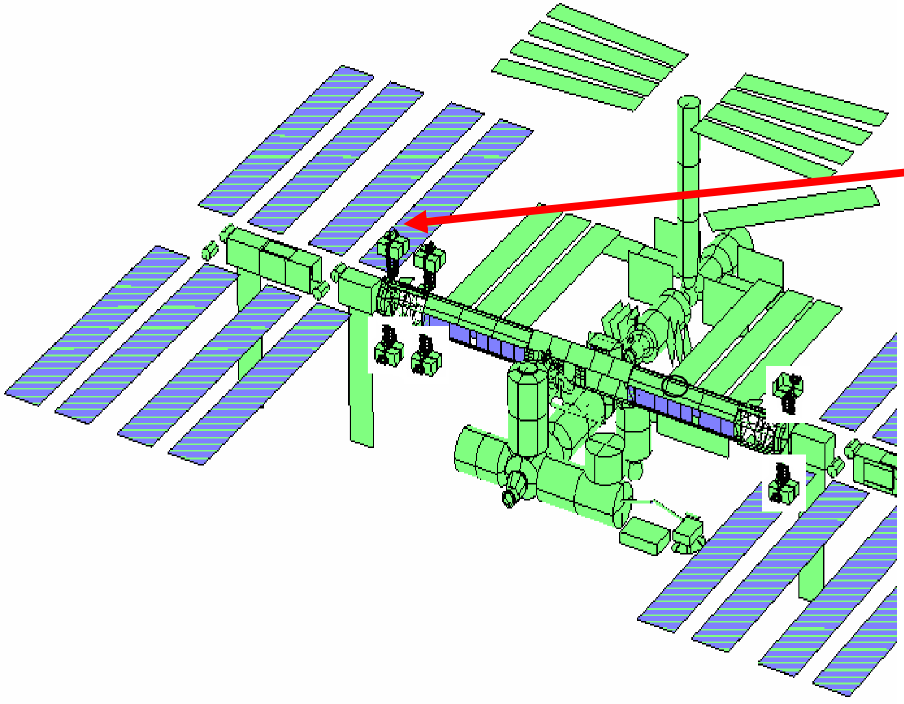
**PEC-B**
Air Force Research Laboratory (AFRL/ML)
Boeing Phantom Works

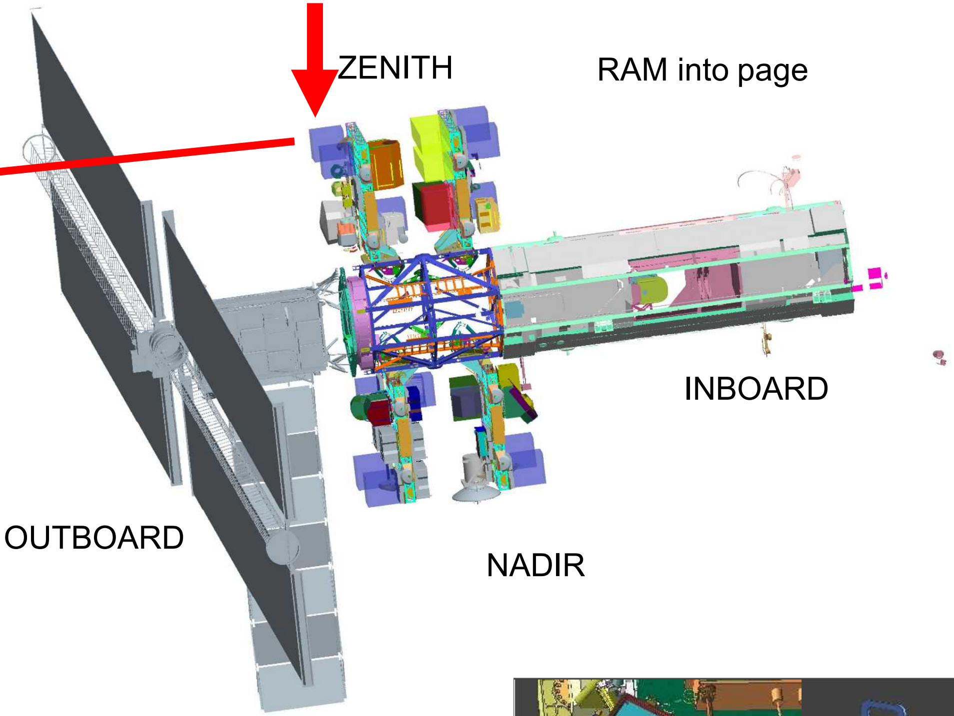
**NASA Centers**
- LaRC
- GRC
- MSFC
- JSC
- ARC

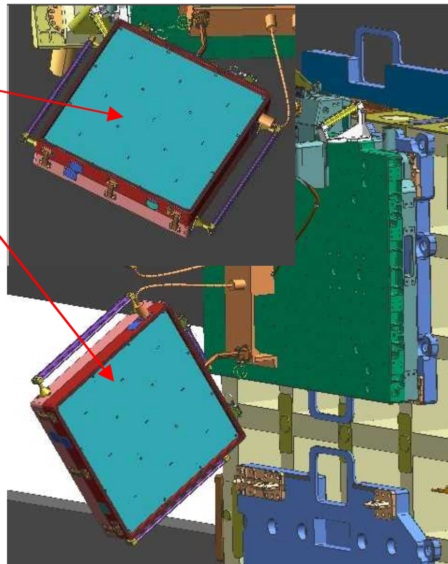
**Industry Partners**
- Boeing
- AMSENG
- CRG

**Academic Partners**
- Air Force Academy
- Montana State U.
- U. of Florida

# MISSE-7 Deployment Configuration

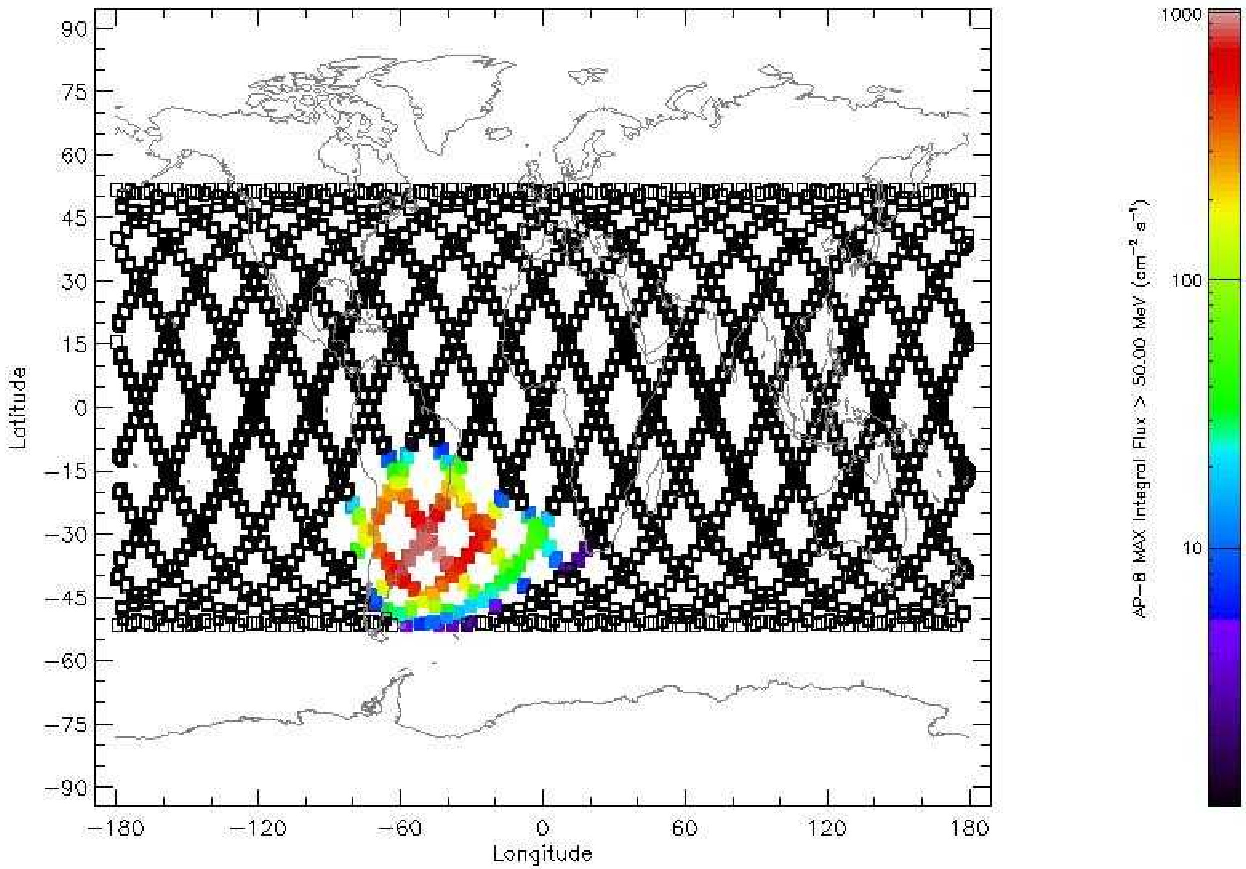





- **MISSE-7 is planned for ELC2**
  - **S3 zenith, outboard of ISS**

# ISS Orbit-- SAA




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

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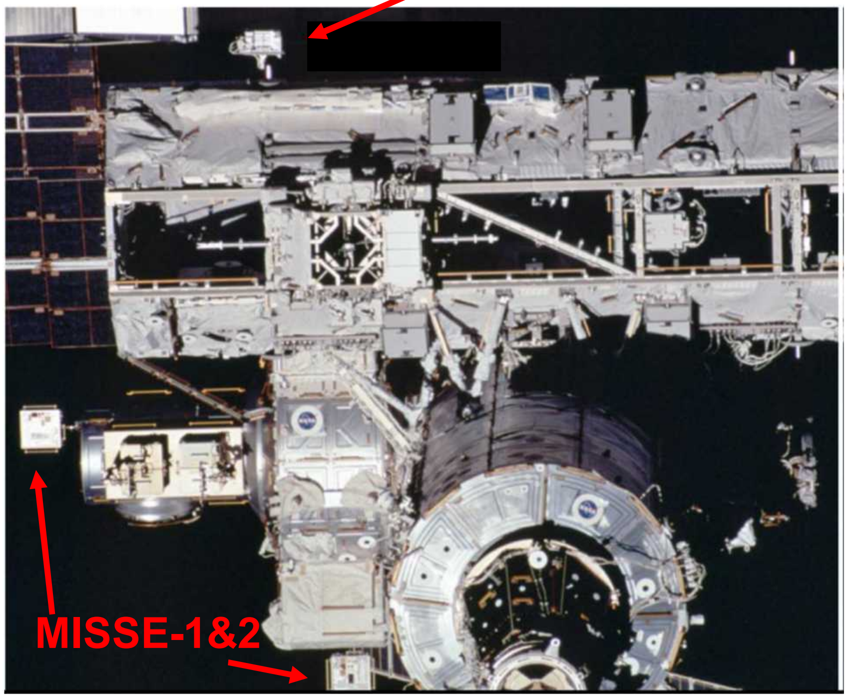
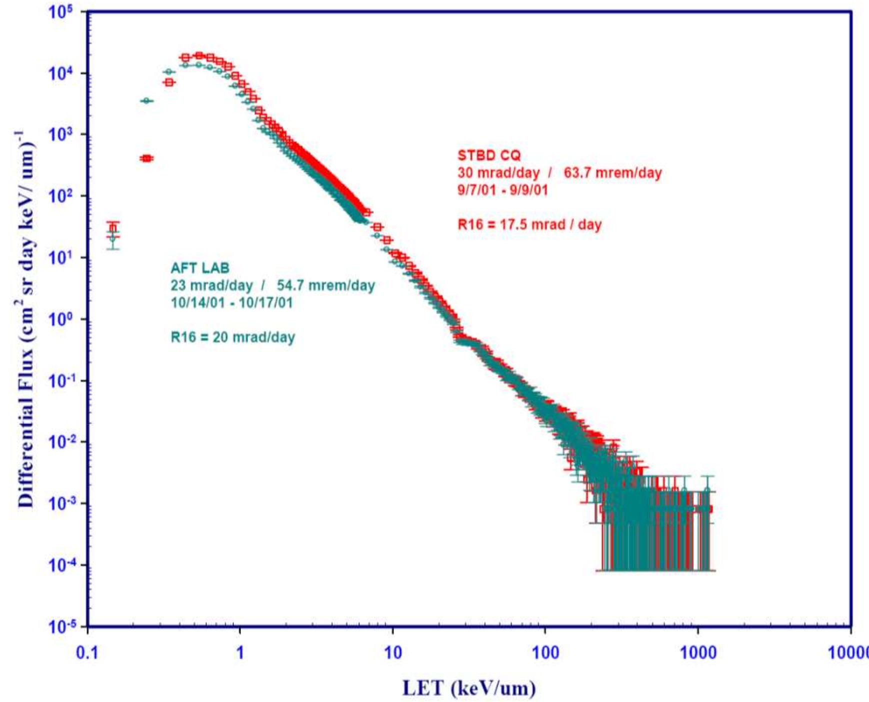
# ISS Radiation Detection

Extra-Vehicular Charged Particle Spectrometer (EV-CPDS)




- **MISSE-7 will have RadFETs on-board as dosimeters.**
- **ISS has several 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**

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# Active Experiment

## Single Event Upset Xilinx-Sandia Experiment (SEUXSE)


**Jeff Kalb**

**Dave Bullington, Dennis Clingan, Tracie Durbin, Ethan Blansett, 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!! --**


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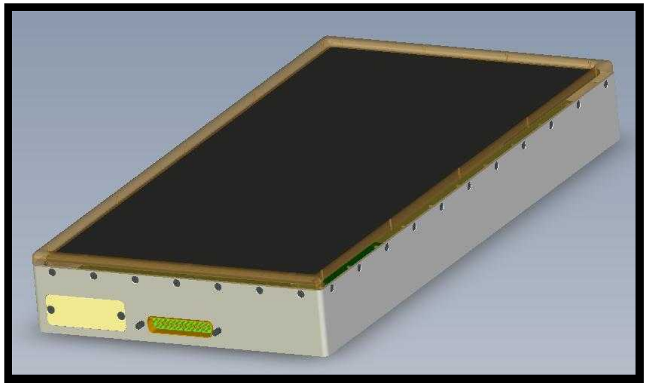
# Active FPGA Expt

- Hardware Delivery September, 2008.
- Incorporates newest Xilinx FPGA Technology:
  - Virtex 4 FX60 (1152 pin BGA, 1.0 mm spacing).
  - Virtex 5 LX330T (1738 pin BGA, 1.0 mm spacing).
- Point of Load Power Converters and support structure.
- Light-weight composite box enclosures.
- Benefits of the project:
  - Demonstration of Technology Opportunity:
    - » Capabilities of Self-Contained Reconfig node.
      - Configuration
      - Mitigation
      - Soft-Core Processors
      - Power Conversion
    - » PCB Fabrication with Current Device Form Factors.
  - Re-establishing SNL as a collaborator in the Reconfigurable Space Computing Arena.
  - Validation test of Space Environment Models and Ground Testing.



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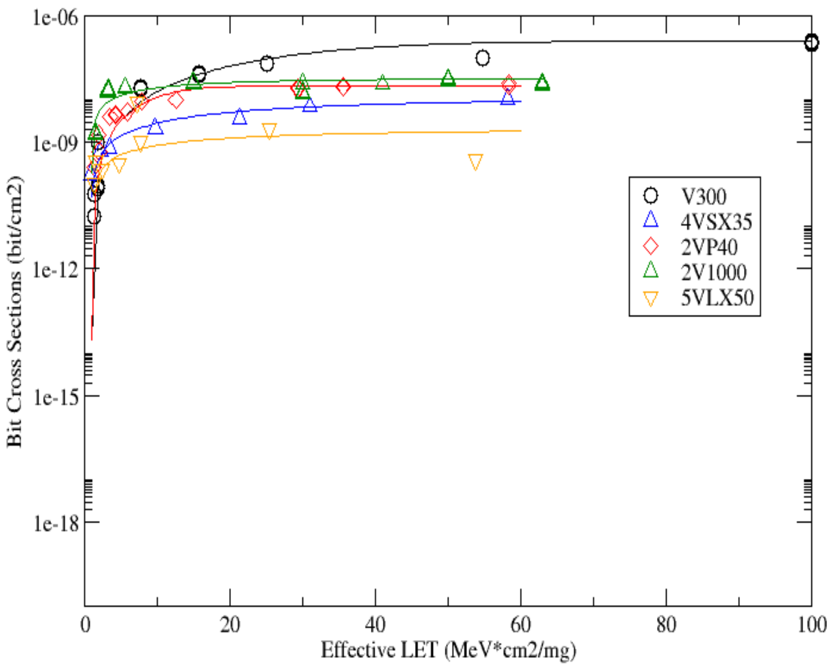
# Partnering with Community


- **NRL, LANL, Vanderbilt, JPL**
- **Xilinx**
  - **SNL is providing designs to XRTC radiation testing set.**
  - **SNL is duplicating exact radiation test setup at SNL (minus the beam).**
  - **SNL is providing support in onsite radiation testing.**
  - **SNL is designing MISSE Architecture similar to Xilinx Test Structure.**
  - **Communicating in Weekly Consortium Telecons.**
  - **Xilinx is providing flight parts for MISSE.**
  - **Xilinx is providing design support and source code for MISSE.**
  - **Xilinx is providing external design review support and validation.**

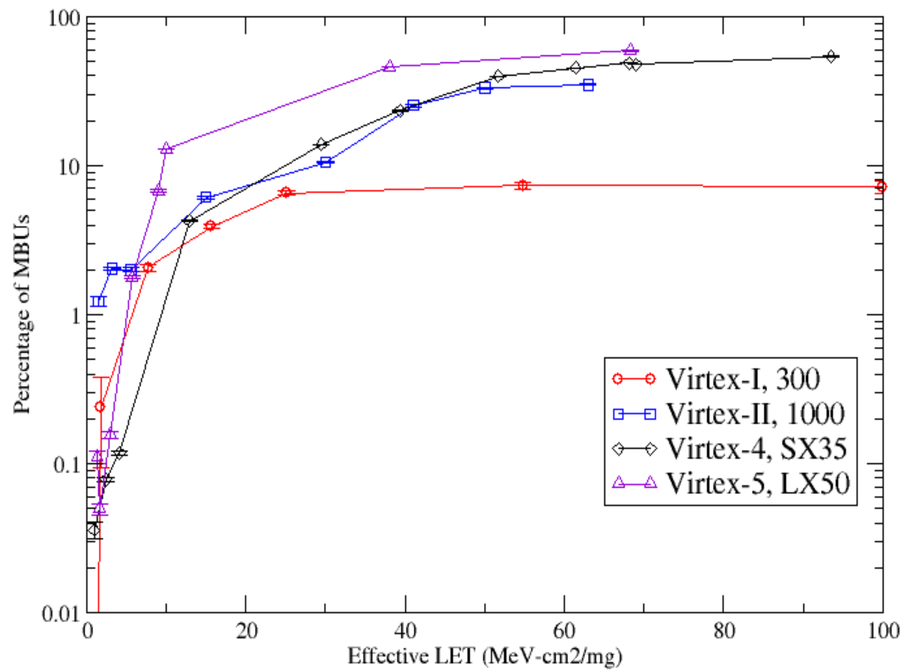
# Virtex Multiple Bit Upsets

*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*

Event Bit Cross Sections for Virtex Devices




Percentage of MBUs Out of All Events




- **Bit Cross Sections Decreasing**
- **% of MBUs Increasing**

- V1 – 220 nm process, 2.5V
- V2 – 130 nm process, 1.5V
- V4 – 90 nm process, 1.2V
- V5 – 65 nm process, 1.0V

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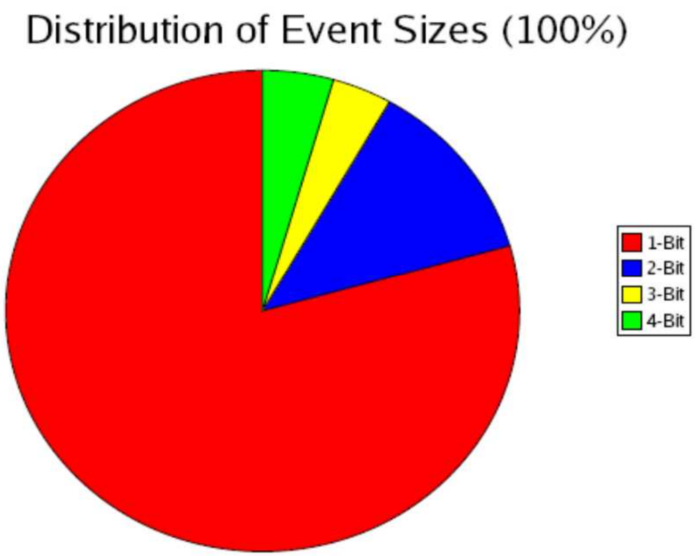
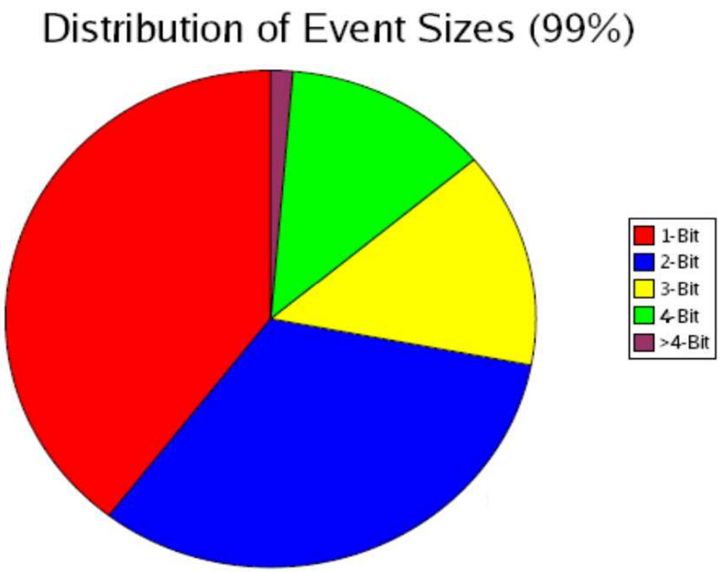
# Distribution of Heavy Ion Events (Normal Incidence)

*From "Domain Crossing Errors", XRTC June, 2007*
*--Heather Quinn, Keith Morgan, Paul Graham, Jim Krone, and Michael Caffrey, LANL*




**Virtex II**

**21% MBU**

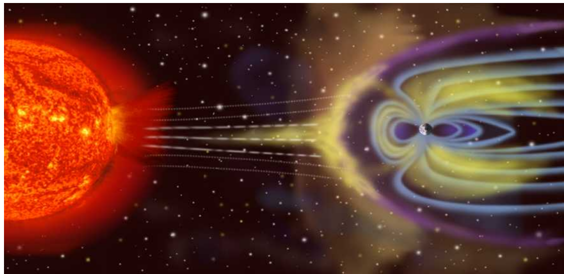



**Virtex 5**

**59% MBU**

# ISS Space Environment

- ISS Orbit: 336 km, 51.6° incl (similar to Cibola orbit: 560km, 35° incl).
- ~300 krad/yr total dose at the surface with no shielding.
- FPGA experiment will get ~30 rad/yr total dose (100 mil Al shield).
- Galactic cosmic rays are predicted to cause ~2 FPGA configuration bit errors/day and ~0.3 BRAM bit 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.
- From LANL Cibola Flight Expt. SEU data with FPGA's, we predict ~4 errors/day. (Cibola: 9 of XQV1000, 54e6 config bits; MISSE: V5LX330T & V4FX60, 104e6 config bits).



- Total errors/year expected to be about 1000/yr.

# Device Resources

| Resource | XQV1000 | V4FX60 | V5LX330T | Total CFE | Total MISSE |
|---|---|---|---|---|---|
| Look Up Tables | 24,576 | 50,560 | 207,360 | 221,184 | 257,920 |
| Flip Flops | 24,576 | 50,560 | 207,360 | 221,184 | 257,920 |
| Block RAM | 32 | 232 | 324 | 288 | 556 |
| Block RAM bits | 128K | 4,176K | 11,664K | 1,152K | 15,840K |
| Digital Clock Manager | 4 | 12 | 12 | 36 | 24 |
| IO Pins | 404 | 576 | 960 | 3,636 | 1,536 |
| Configuration Memory bits | 6.0M | 21.0M | 82.7M | 54.0M | 103.7M |
| DSP blocks | 0 | 128 | 192 | 0 | 320 |
| Gigabit Transceivers | 0 | 16** | 24 | 0 | 40**(24) |
| PowerPC Processors | 0 | 2 | 0 | 0 | 2 |

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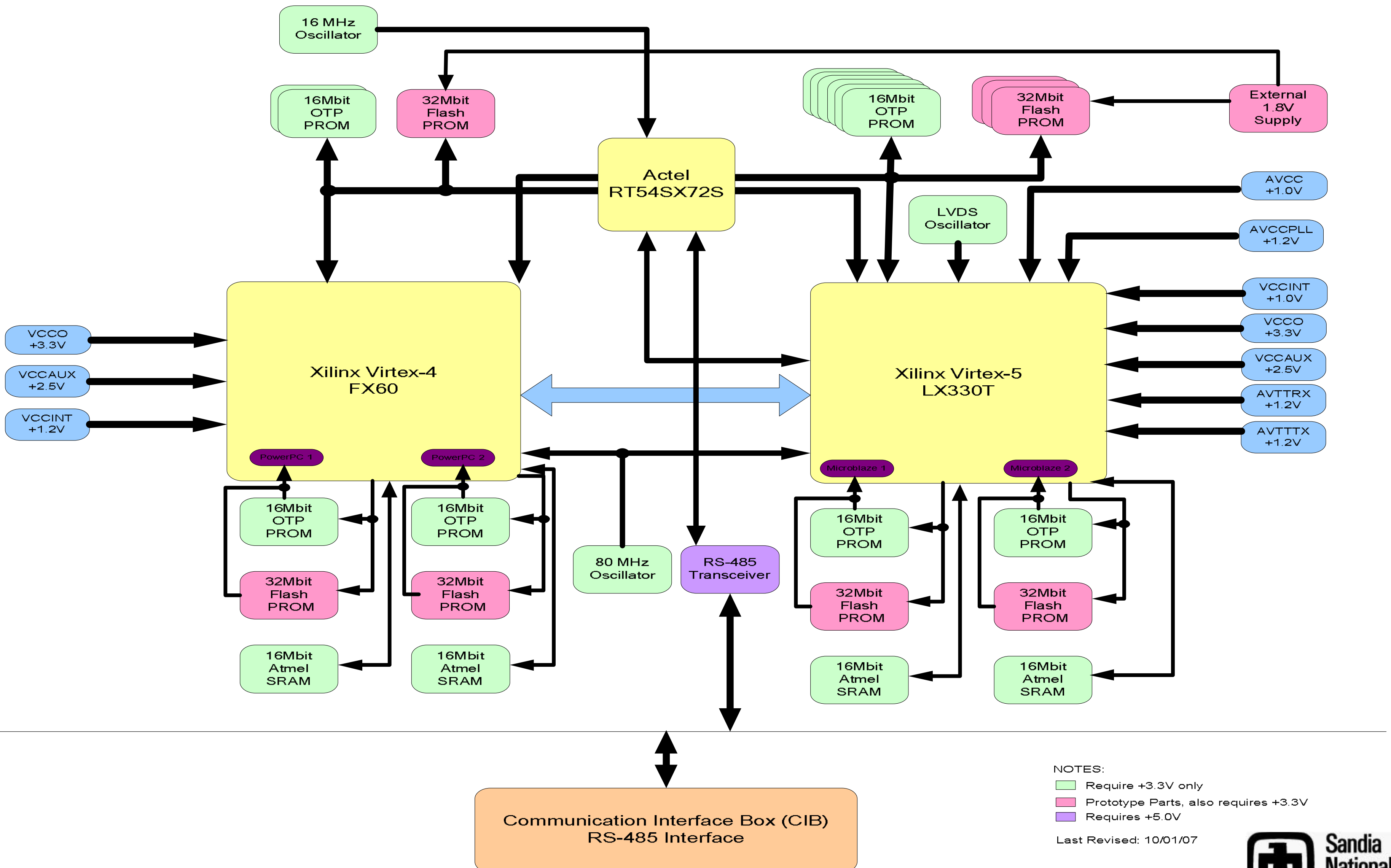
# FPGA Expt Block Diagram

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# Design Highlights

- **Xilinx OTP PROMs:** configuration bit streams and processor software.
  - PROMs boot each device, then accessed by opposite Virtex for cross scrubbing
- **One PPC provides:** software control; self monitor for upsets; and data handling functions for V4-- **second PPC** runs self monitoring algorithms.
- **TMRed MicroBlaze provides:** software control; self monitor for upsets; and data handling functions for V5--non-TMRed MicroBlaze runs self monitoring algorithms.
- **All processors run from external SRAM** including 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.

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# Design Highlights (cont'd)

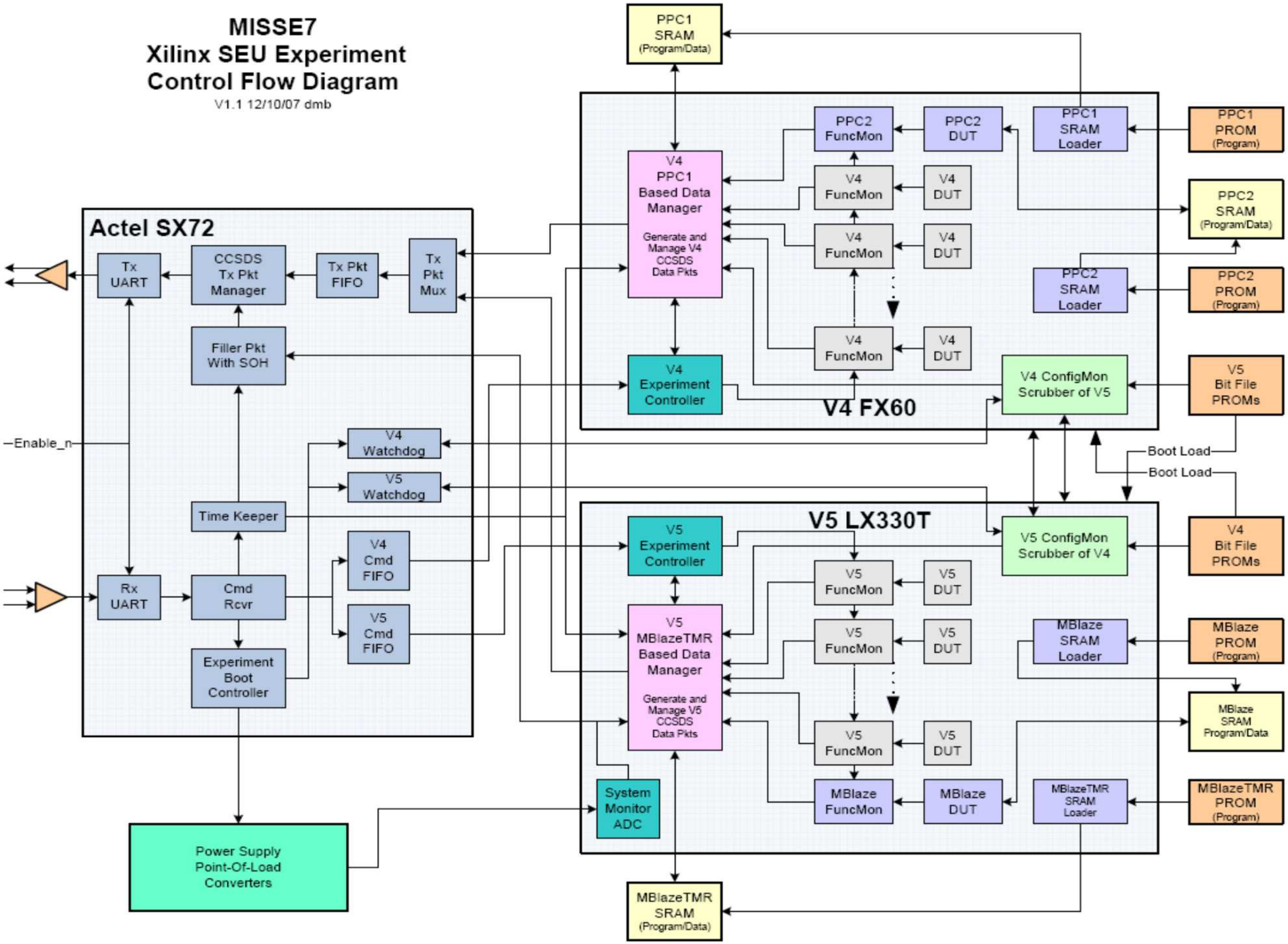
- **Each SEU event record includes:** time, bit location, expected and actual data values.
- **FPGA environment is monitored** with cross correlation to ISS radiation and environmental monitors.
- **Actel FPGA contains external watchdog** monitors of each Xilinx to recover from any SEFI modes.
- **Actel FPGA provides hardware interface** to ISS serial command and data channels.
- **Downlink Allocation** of 0.5 to 10 Mbytes/day.
- **Point-Of-Load (POL) converters**
  - Custom, radiation tolerant.
  - Generates local voltages to simplify ISS power interface (single 5V source).

# On-Orbit Tests

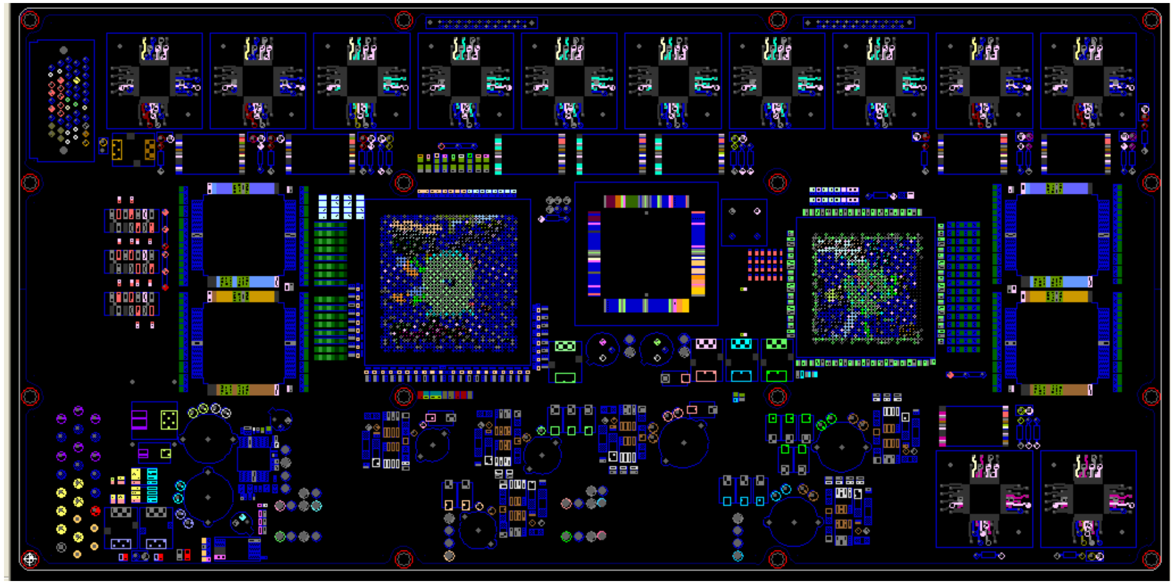
| Test | V4FX60 | V5LX330T |
|---|---|---|
| Configuration/Scrubbing | YES | YES |
| Block RAM | YES | YES |
| PowerPC Cache | YES | NO |
| PowerPC Algorithm | YES | NO |
| Single MicroBlaze | NO | YES |
| TMR MicroBlaze | NO | YES |
| Gigabit Transceiver | NO | YES |
| Digital Clock Manager | YES | YES |
| DSP Blocks | YES | YES |
| IOB | YES | YES |
| IOSERDES | YES | YES |
| SRL16 | YES | YES |

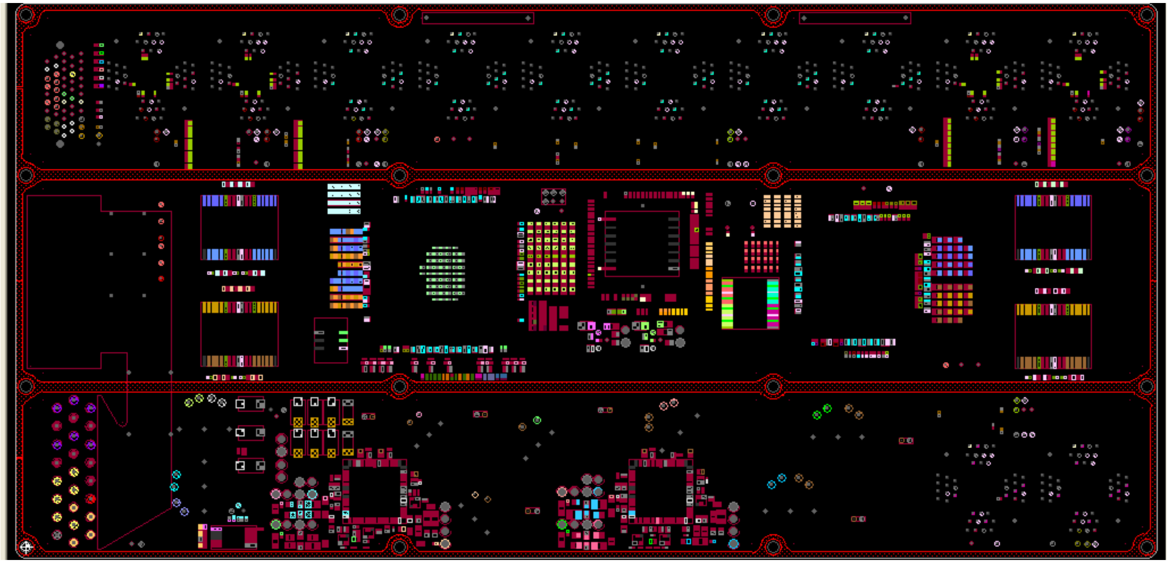
# MISSE7
# Xilinx SEU Experiment
# Control Flow Diagram

V1.1 12/10/07 dmb



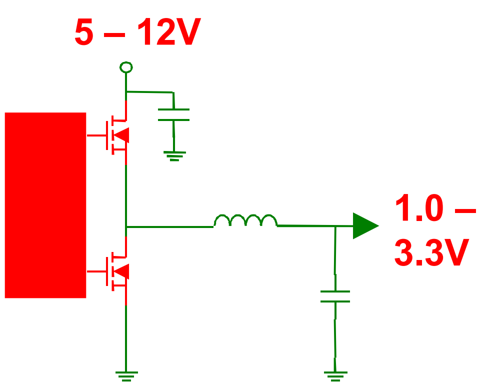
# Board Layout



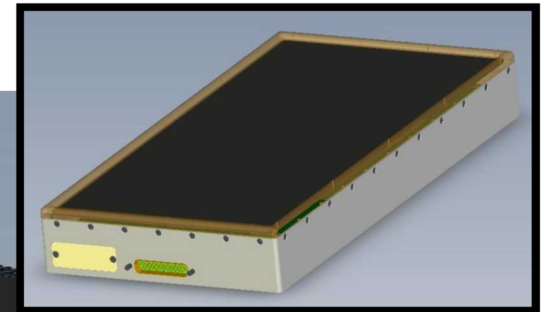


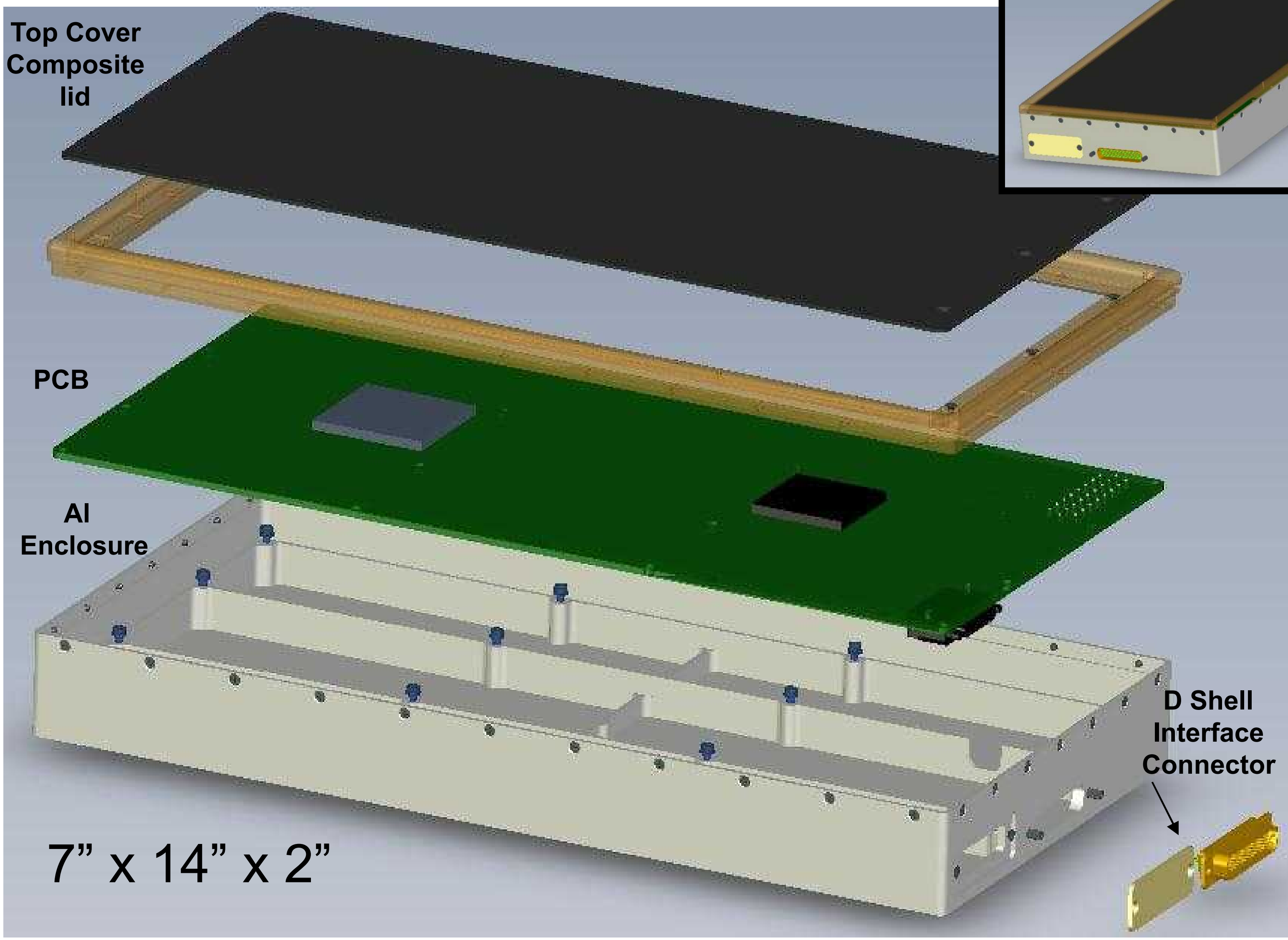
# MISSE FPGA Power System

- **Rad-hard point-of-load (RHPOL) power converters generate required low voltages**
  - 6 POL Converters: +3.3V, +2.5V, 2 at +1.2V, 2 at +1.0V
  - 90% efficiency
- **RHPOL controller IC developed under GPSIIIC**
  - 3 outputs per controller
  - Total-dose tolerant to >1Mrad($SiO_2$)
  - Immune to single-event latchup, burnout, and gate rupture
  - No POL output single-event transients to >80MeV-cm$^2$/mg
- **COTS power FETs tested under GPSIIIC**
  - Total-dose tolerant to >30krad($SiO_2$)
  - Immune to single-event burnout and gate rupture
- **System Advantages to using POL Converters**
  - Simple Power Distribution Design (Single Voltage to Node)
  - Local Conversion provides better regulation for low voltage high current logic
  - Very efficient



# MISSE7 Active Enclosure



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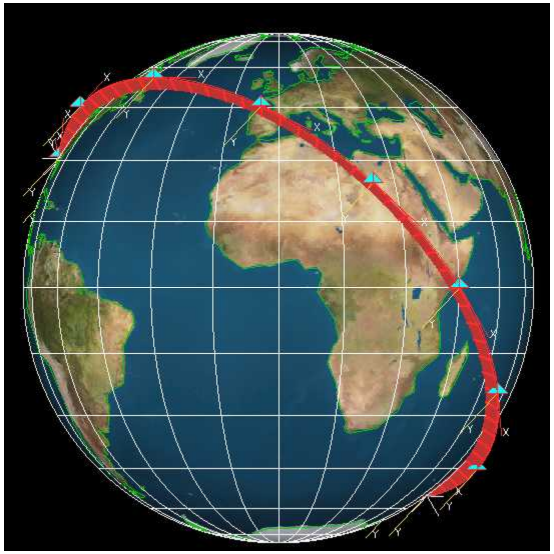
# Thermal Model Assumptions and Orbital Parameters

**Assumptions:**

- Heat conducted from board to walls of housing and through struts beneath Xilinx chips.
- **Two power cases**
  - 40 Watts, PEC temperature = 30C.
  - 30 Watts, PEC temperature = 60 C.
- **Facing nadir (earth)**
- **Orbital Heating Parameters:**
  - Albedo = 0.3
  - Solar Constant=1351 $W/m^2$
  - Earthshine=237 $W/m^2$

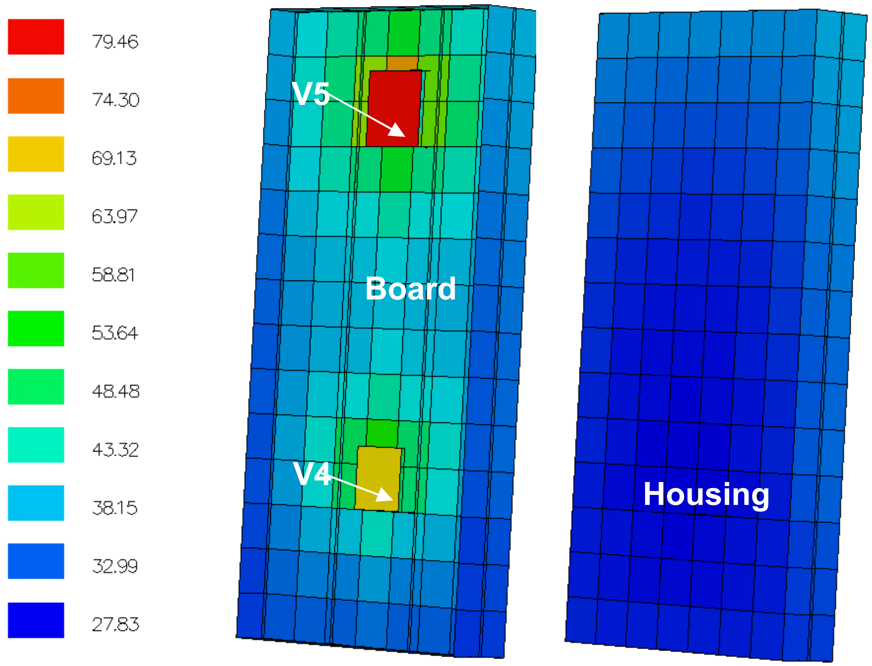


**ISS Orbit:**

- 90 minute period
- Hmin = 184.5 naut miles
- Hmax = 192.1 naut miles
- Inclination = 51.395 deg

# High & Low Component Temperatures for two power cases (40 W & 30 W)

| | T (C)<br>40 W to board, PEC = 30C | | T (C)<br>30 W to board, PEC = 60C | |
|---|---|---|---|---|
| | High | Low | High | Low |
| V4 | 71 | 68 | 84.84 | 81.93 |
| V5 | 83 | 79 | 92.81 | 89.68 |
| PCB | 75.9 | 33.17 | 86.55 | 53.74 |
| Metal Housing | 53.3 | 31.31 | 70.95 | 51.50 |
| Composite Lid | 43.9 | 28.07 | 61.55 | 45.59 |




Temperature (C) after 9.2 hours, High Power Case

# Passive Experiment

## Sandia Passive ISS Research Experiment (SPIRE)


### Gayle Echo Thayer

**Dennis Clingan, Tracie Durbin, Ethan Blansett, Alan Hsu, Troy Olsson, Michael Watts, Mike Baker, Paul Resnick, Dave Baiocchi, Gary Patrizi, and Kenton Childs, Sandia National Labs**

***in collaboration with***

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

**Dahv Kliner, Sandia CA**

**Kelly Simmons Potter, University of Arizona**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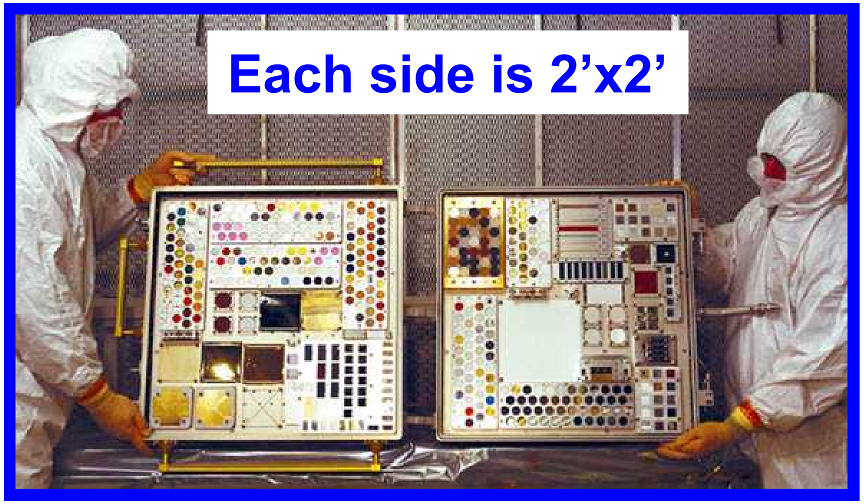
# SNL Passive Allocation

- **Likely Solar Facing:**
- **UV + radiation + thermal + vacuum; but little AO**
- **3” x 7” x 1” working envelope**

**3” x 7”**

# Passive Selection Criteria

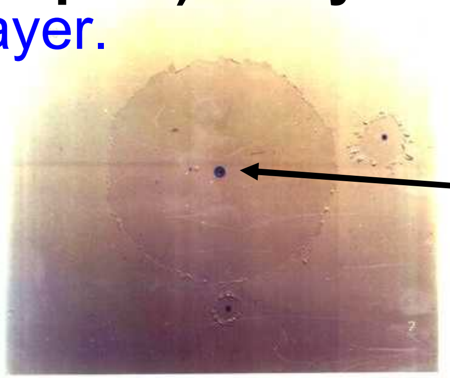
- **Science in Space** -Will the experiment provide useful knowledge that can't be obtained any other way?
- **Engineering** -Will the experiment qual test needed materials or capabilities for future hardware?
- **Allocated Space** -How much will the experiment eat up?
- **Programmatic** -Will the experiment complement other ongoing programs?



# Passive Experiments

**(These do not require our passive space allocation)**

1. **Passive Thermal Control Materials (Coatings, underfills -active expt),** Ron Akau.
2. **Finer BGA patterns; Via in Pad (active expt),** Steve Garrett.
3. **Rare-earth-doped optic fiber lasers (wrapped inside the PEC),** Dahv Kliner.
   - High band-width secure communications, chemical and physical sensing in space, high efficiency and beam quality, rugged.
4. **HMPI (high velocity micro particle impact) analysis (PEC analysis on return),** Gayle Thayer.



**HMPIs from LDEF**

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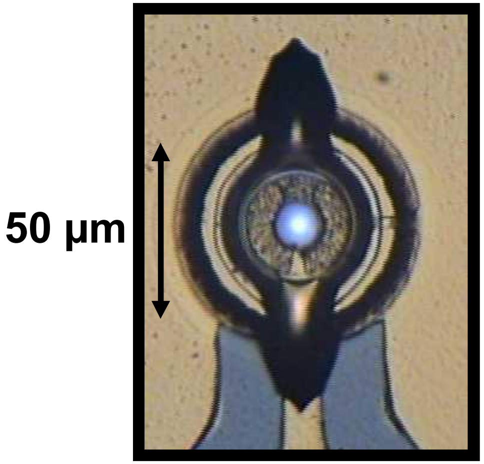
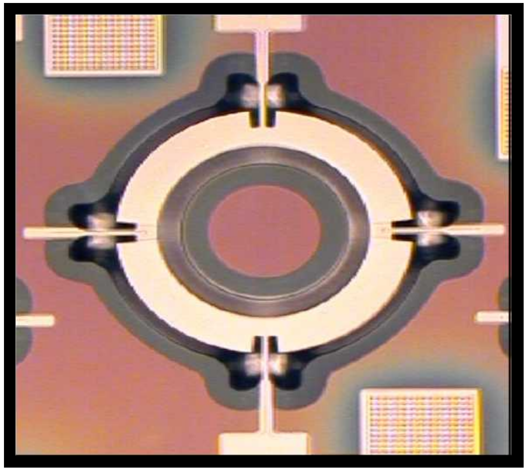
# Passives

## (In order of space needed)

Lasing VCSEL




AlN MEMs 110MHz Filter

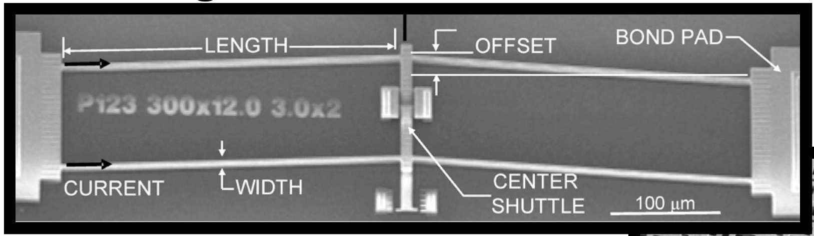


5. VCSELs = Vertical Cavity Surface Emitting Laser (fiber optic tranceivers -FOTs), Alan Hsu.
6. GaAs Photodiodes (FOTs), Ethan Blansett.
7. AlNi microResonators (RF filters), Troy Olsson.
8. Micro Photonic chips (IR FPAs and gyrometers), Michael Watts.

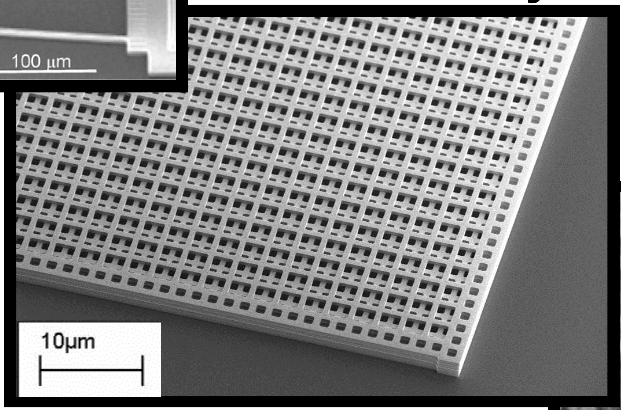
# Passives

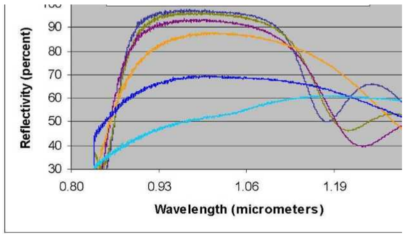
## (In order of space needed)

### Latching Sensor

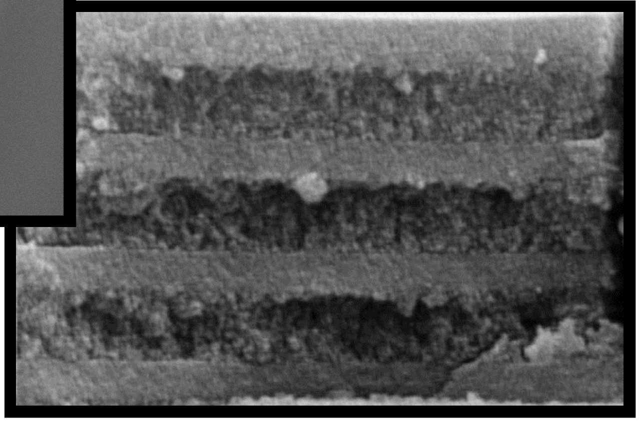



### W Photonic Crystal




### Nanoparticle IR Mirror



5. **MEMs latching impact sensors,** Mike Baker.
6. **W MEMs Photonic crystals (selective emitters or filters),** Paul Resnick.
7. **High voltage Photovoltaics,** Kenton Childs.
8. **Nano-particle thin film mirrors (IR adaptive optics),** Hongyou Fan.

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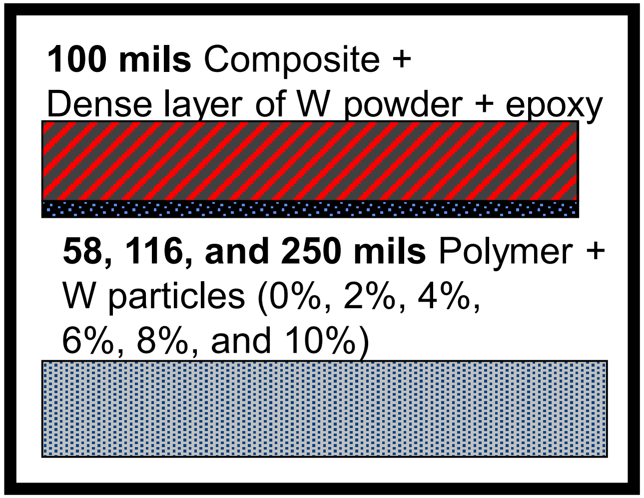
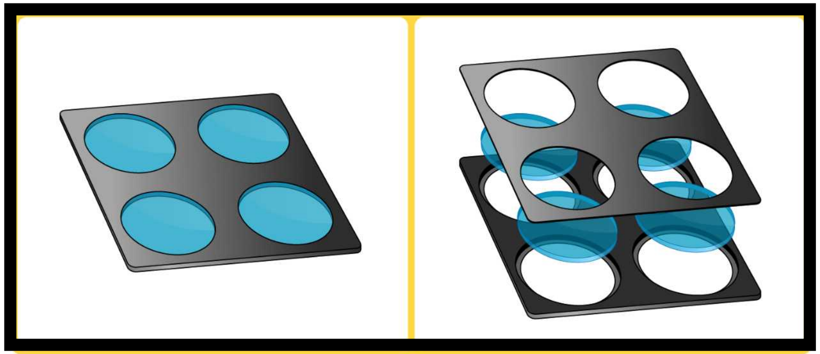
# Passives

## (Additional expts on ORMATE II -Aerospace Corp. collaboration)

**Rad Shielding Composites**



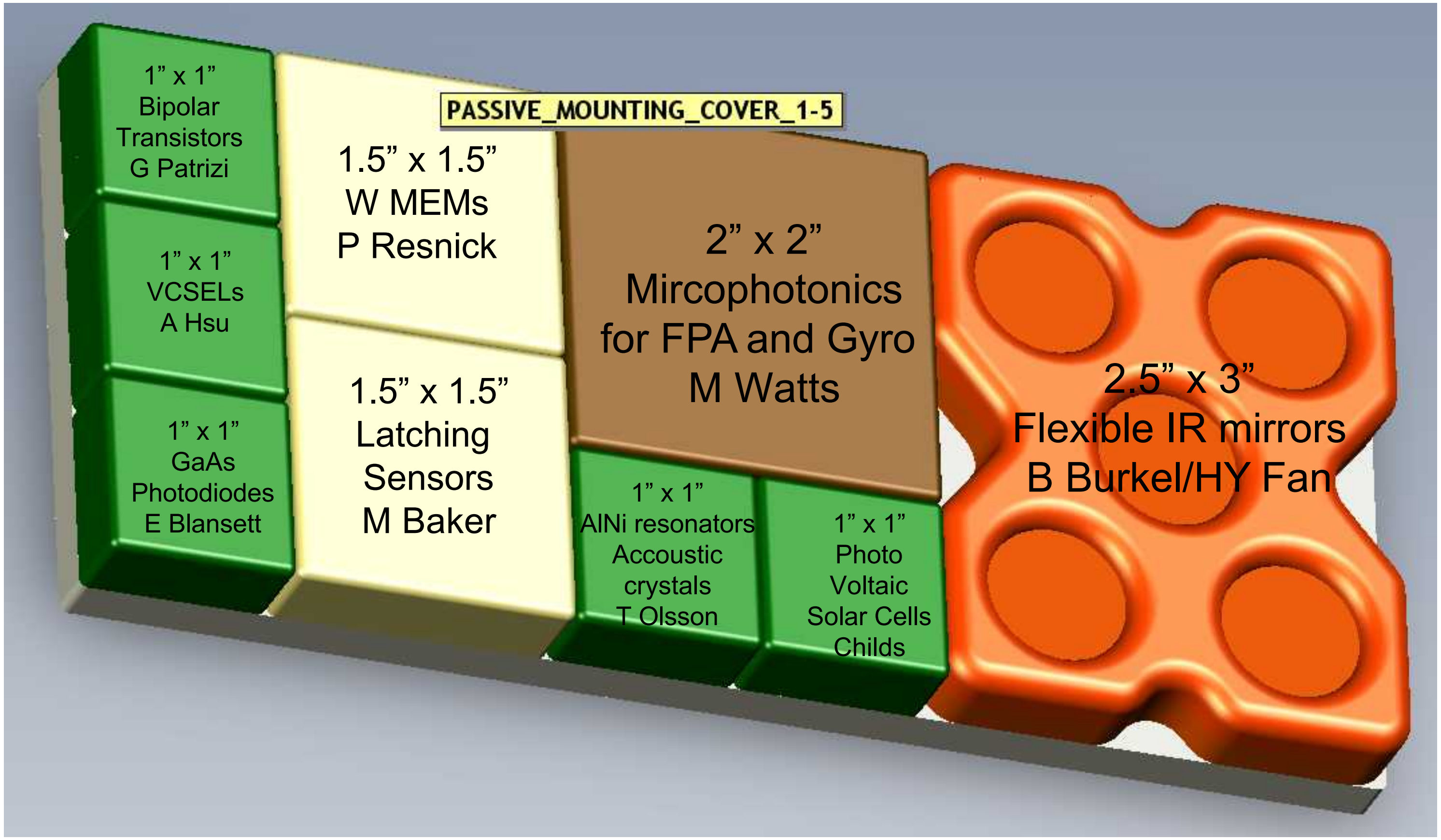

**AR Optic Lens Coatings**



13. **Light weight rad shielding composites + RadFETs**, Joe Lenhart & Gayle Thayer.
14. **Optical lens coatings**, Dave Baiocchi.
15. **Tribological low-friction coatings**, Somuri Prasad.

# SNL Passive Area

**3" x 7" x1**

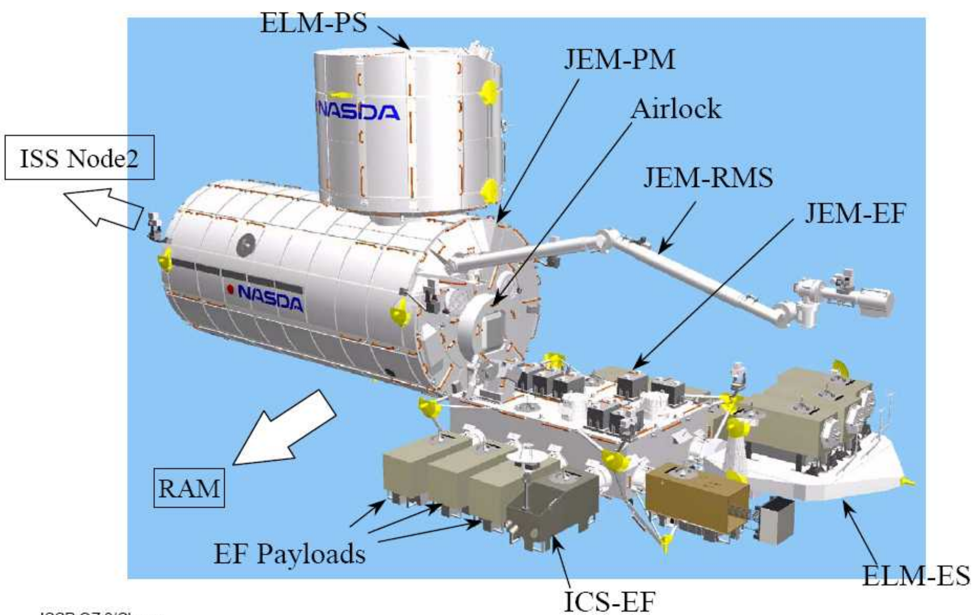



PLUS 3 materials expts on ORMATE II
(Aerospace + NRL Passive Allocation)

# Future MISSE, PRELSE

**PRELSE = Platform for Retrievable Experiments in a LEO Space Environment**

- **Submitted to SERB (Space Experiment Review Board), 10/07.**
- **A JEM-EF (Japanese Experiment Module - Exposed Facility) Payload (JAXA).**
- **A platform supporting modular experiments.**
- **Small, self-contained expts returned via crew vehicle.**




Slide courtesy of Rob Walters (NRL)

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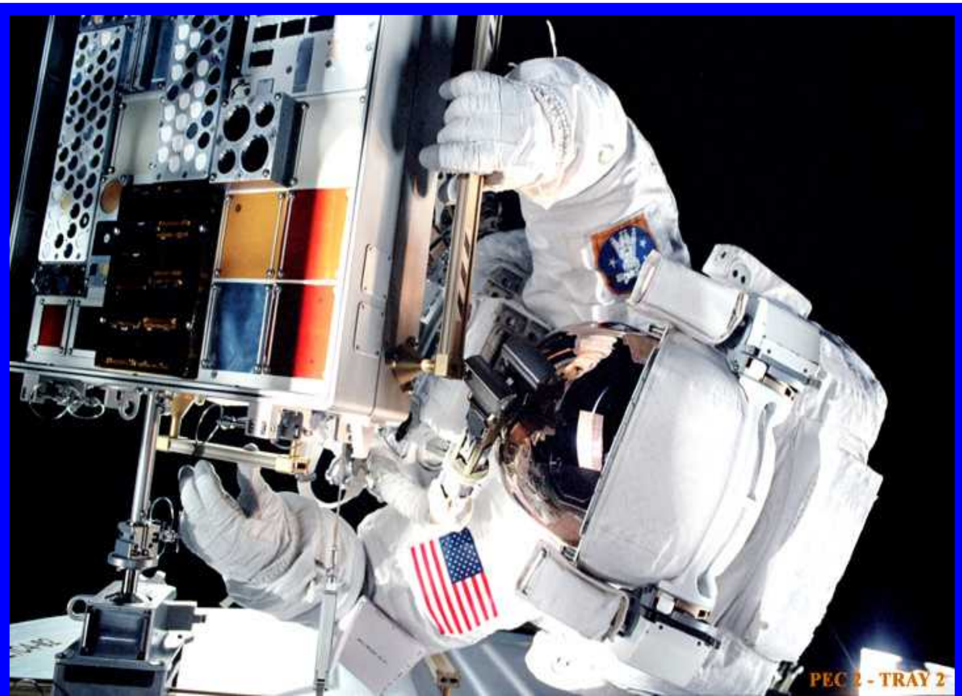
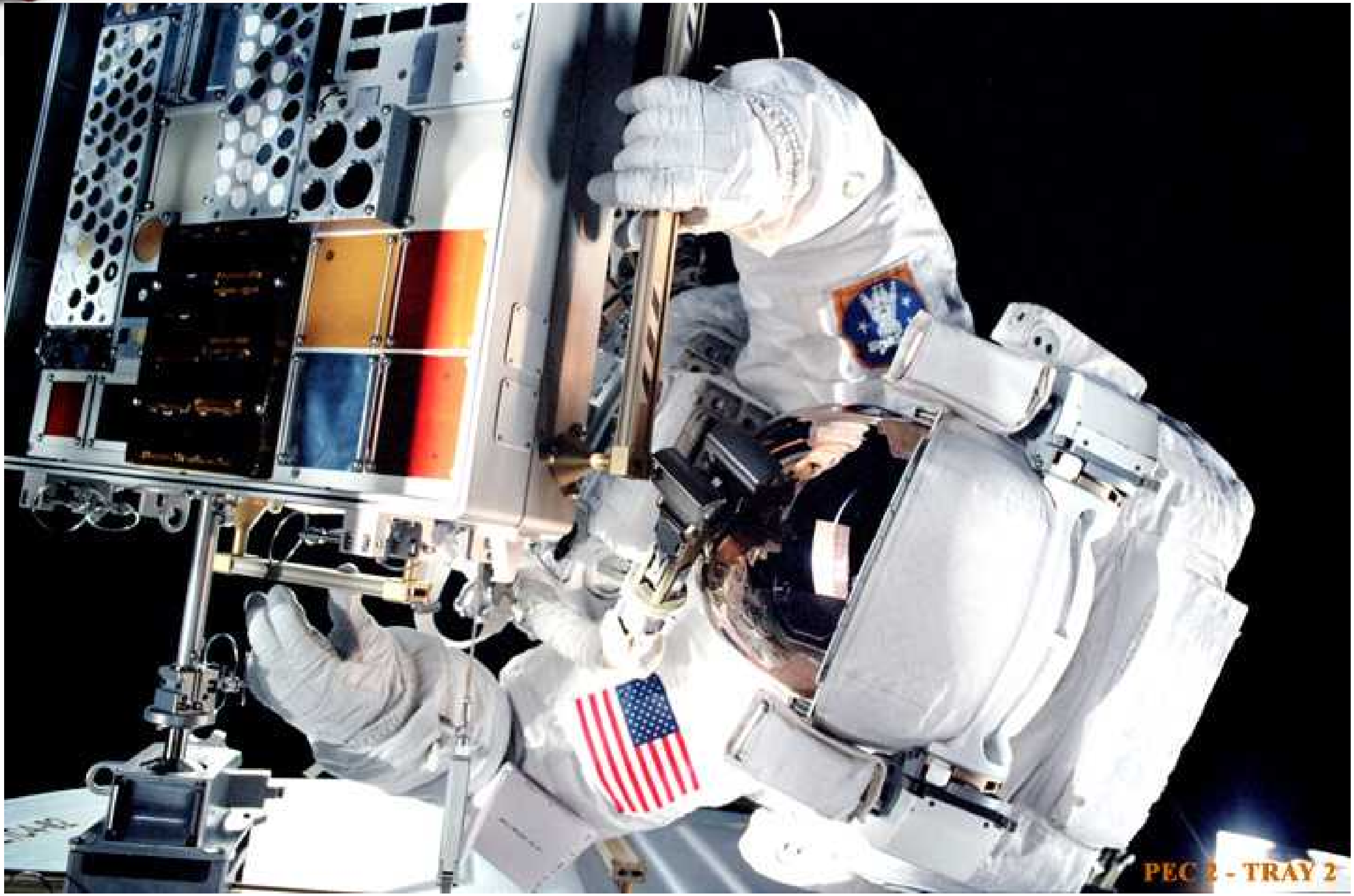
# Summary

- MISSE is a large collaboration opportunity.
- MISSE will increase TRL level of high functionality and SWaP reducing technologies (FPGAs, POL converter, composites, radiation shielding materials, mirror coatings).
- Low cost, correlation to ISS rad detectors, quick deployment, with return analysis of the experiment.



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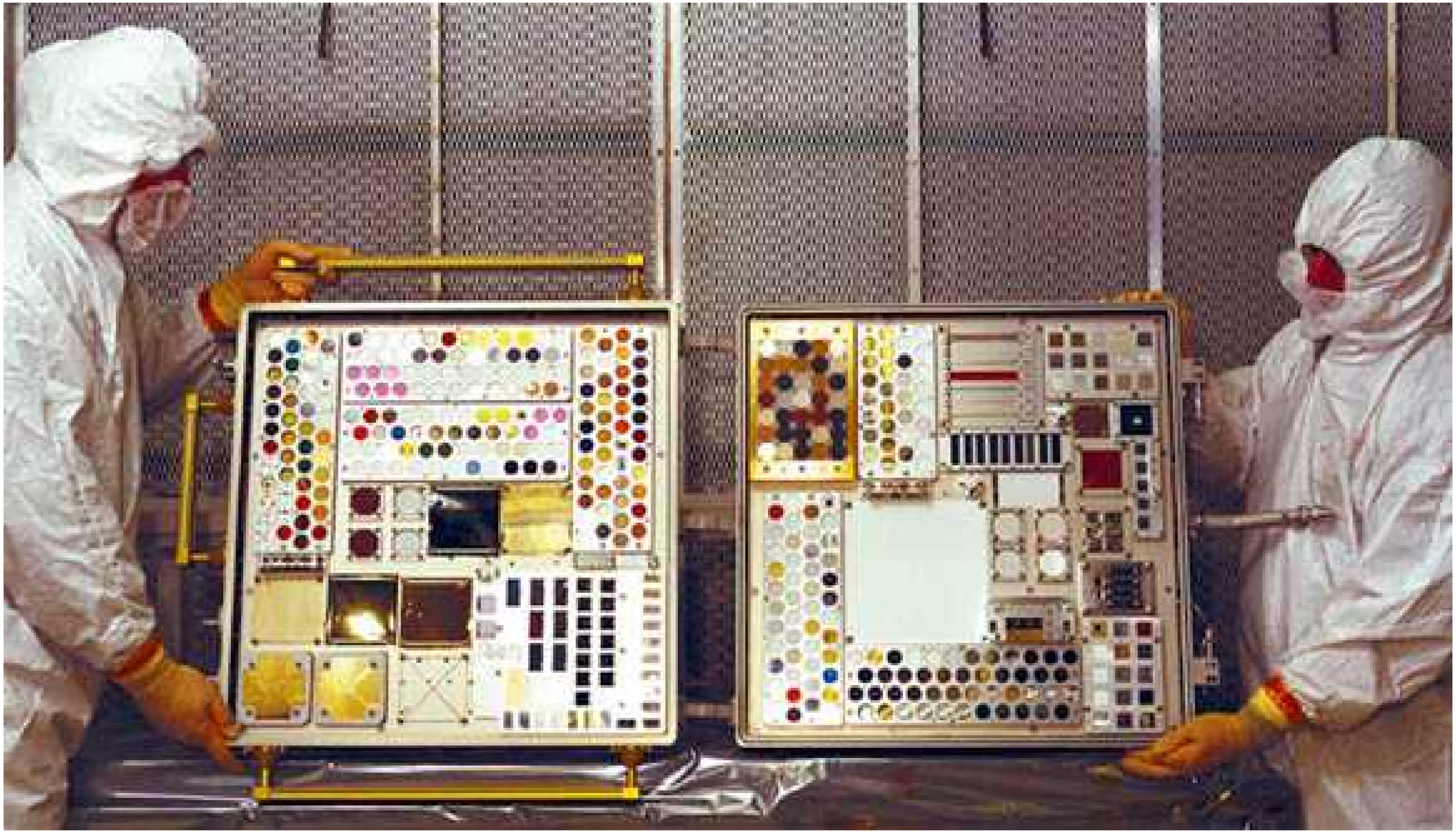
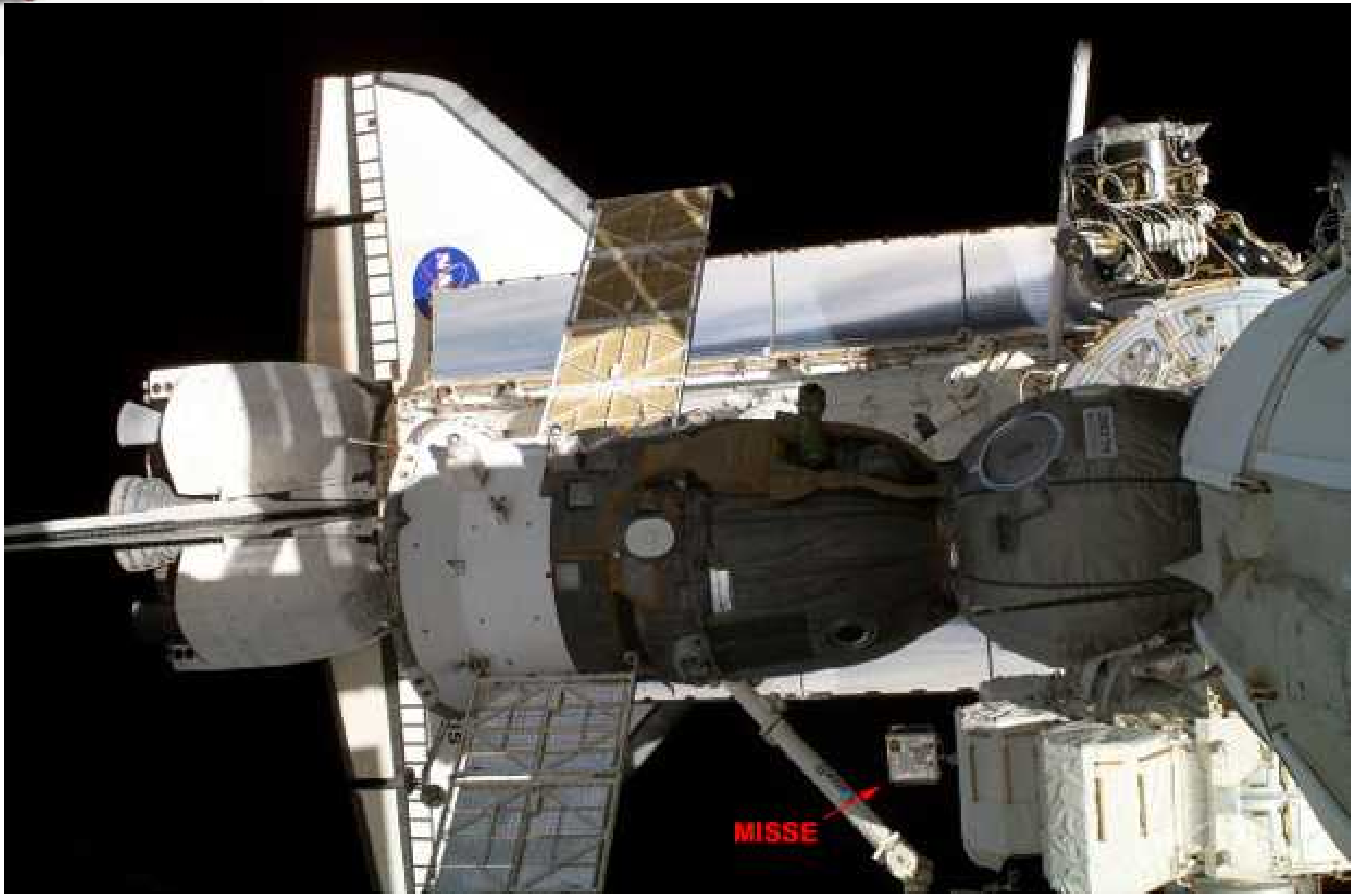
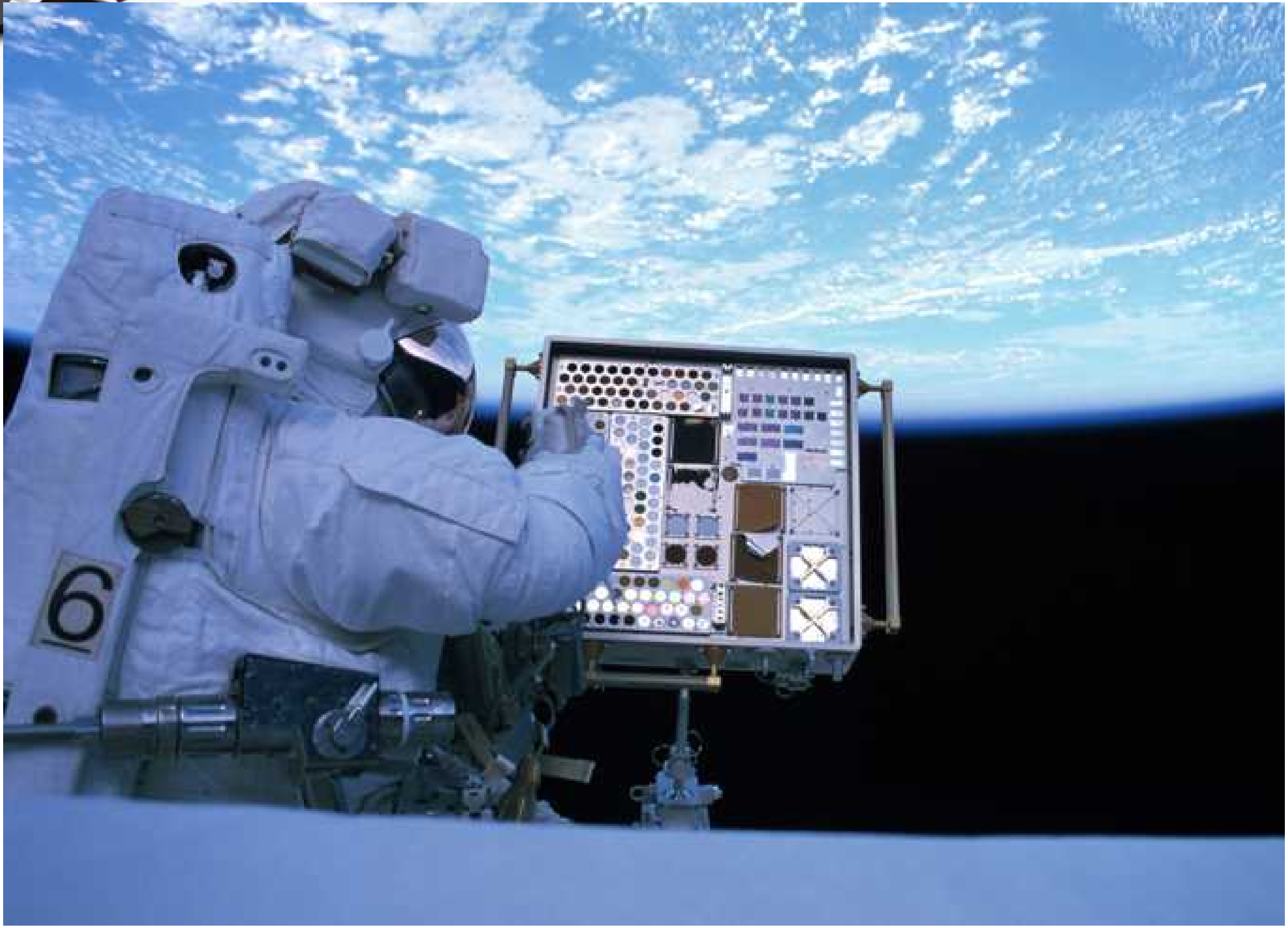
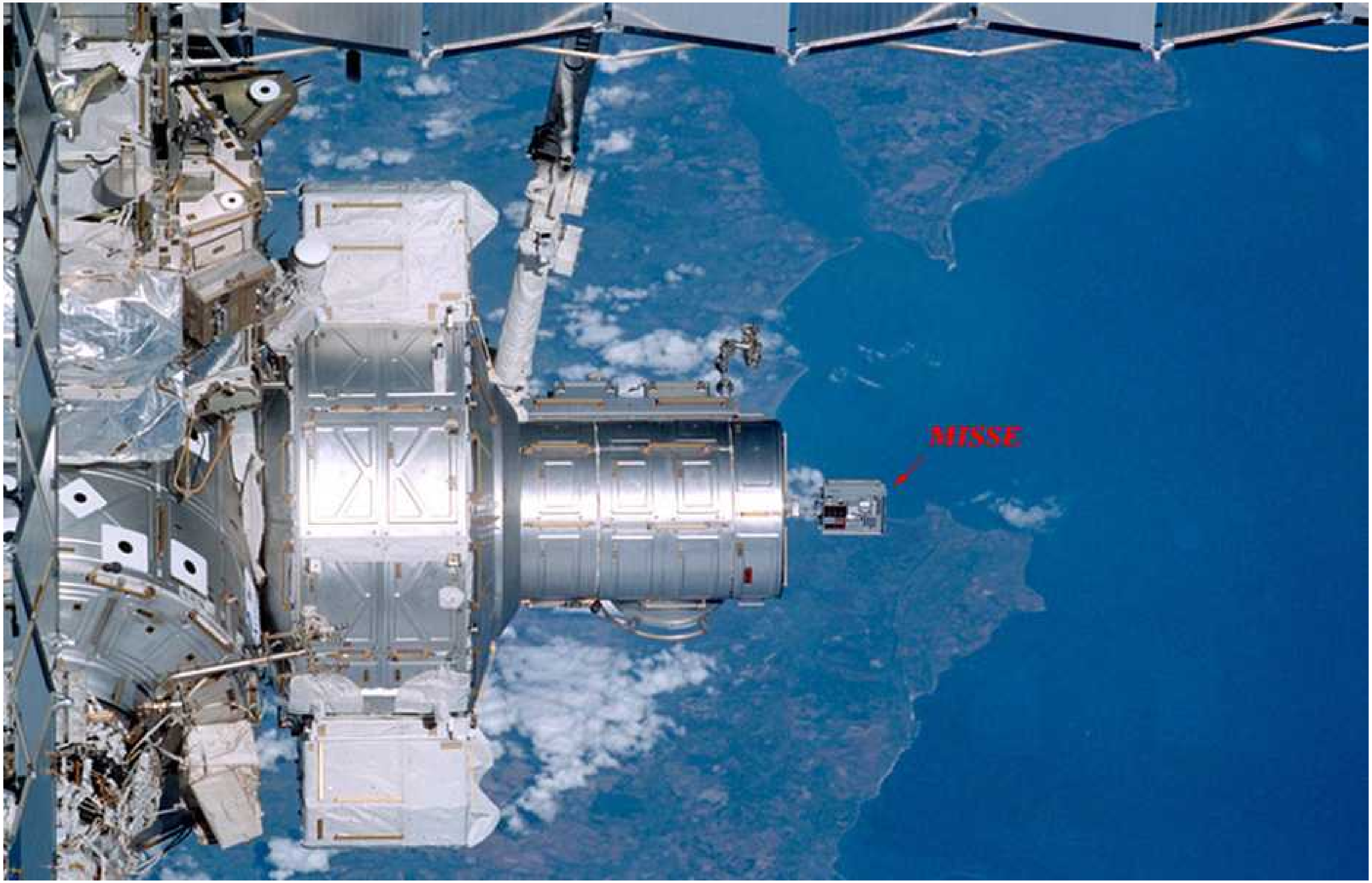



MISSE


6

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