SpaceCube: Success on Hubble SM4, Current Missions and Ongoing Platform Advancements

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9/30/2009

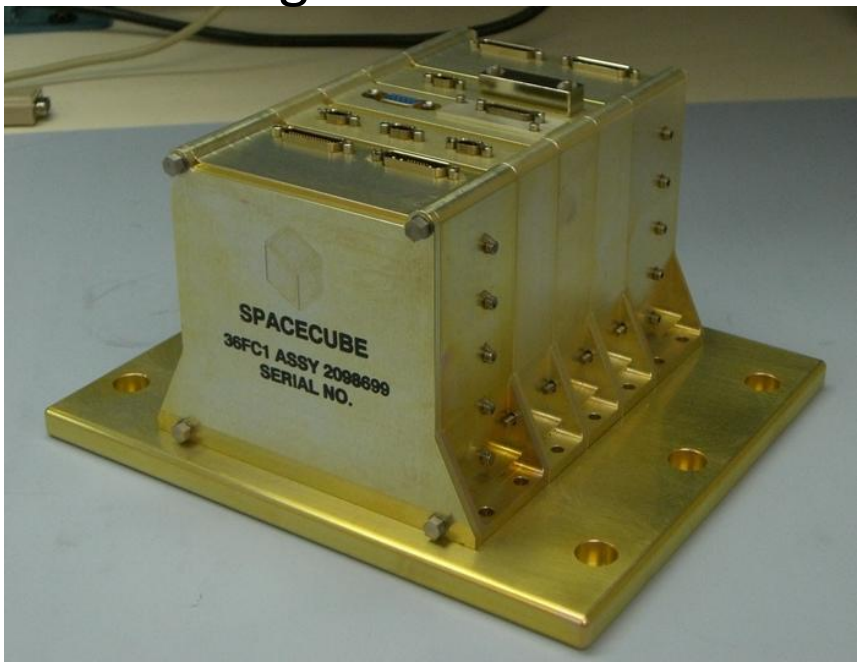
GSFC SpaceCube

- Small, light-weight, reconfigurable multi-processor platform for space flight applications demanding extreme processing capabilities
- Stackable architecture
- Based on Xilinx Virtex 4 FX60 FPGAs, 2 per processor card
- **Successful flight demonstration on STS-125**

Processor Card

2 Xilinx FPGAs, 2 Aeroflex FPGAs
1GB SDRAM, 1GB Flash

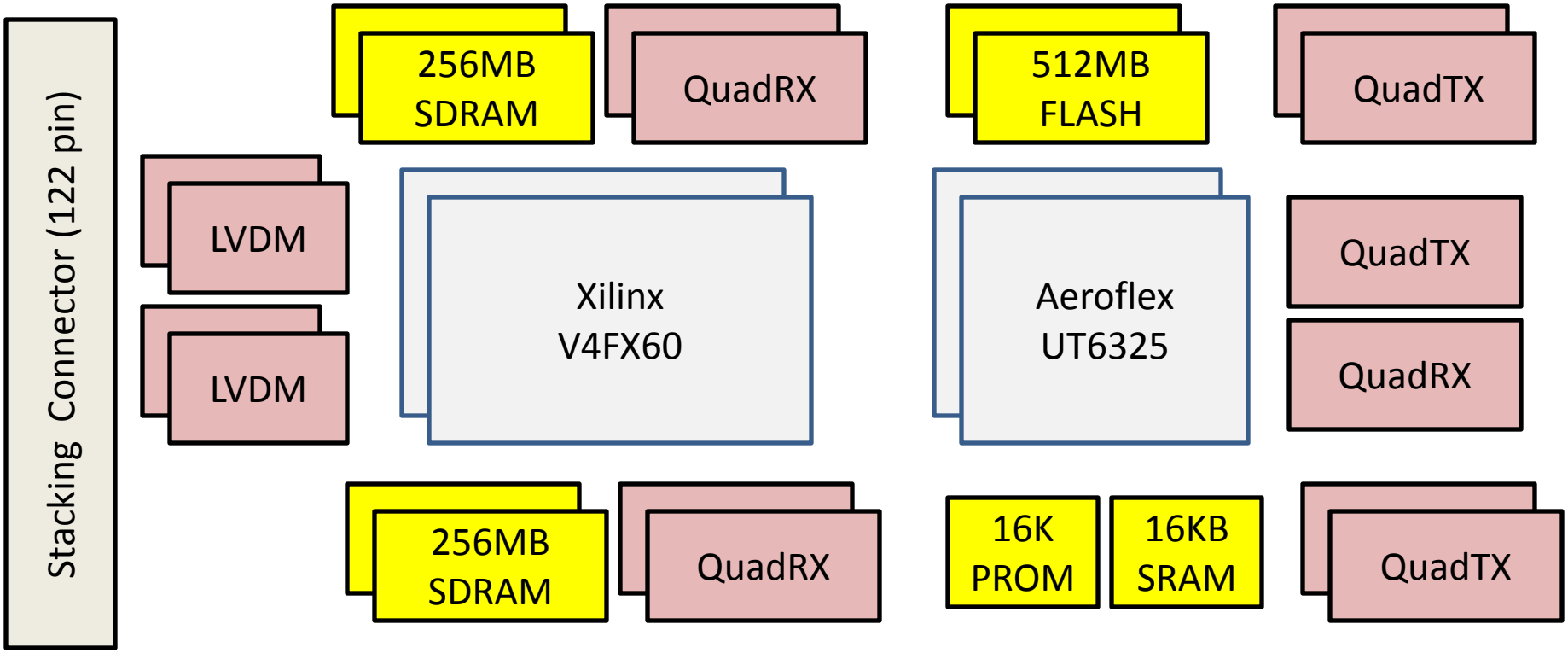
Flight Box



Mechanical: 7.5-lbs, 5”x5”x7”
Power: 37W (STS-125 Application)

SpaceCube Processor Card

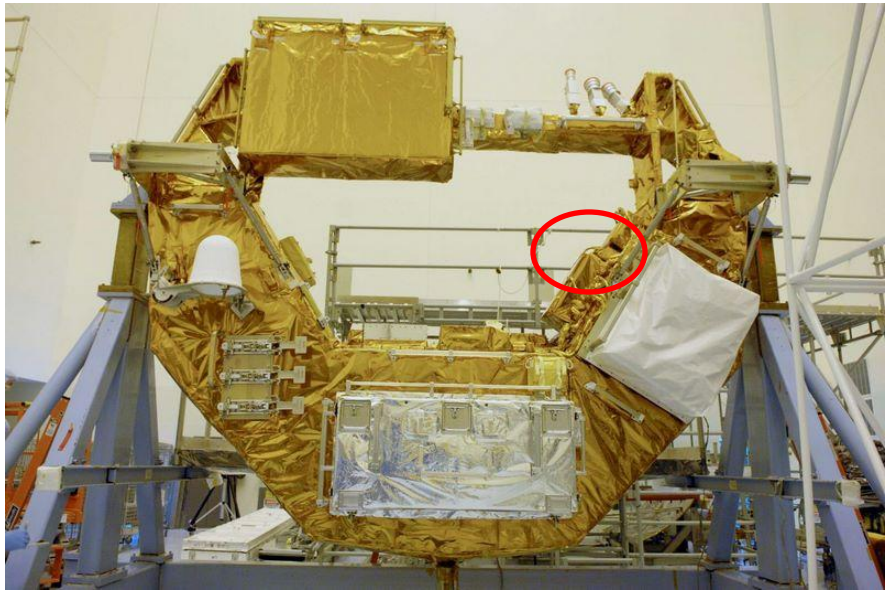
- General: 4”x4” card, Back-to-Back FPGAs (x2), 7W typical power
- Memory: 1GB SDRAM, 1GB Flash, 16KB SRAM, 16KB PROM
- Interfaces: 20 bi-dir differential signals, JTAG
- Backplane: Power, 42 single-ended, 8 LVDM, 2 I2C, POR



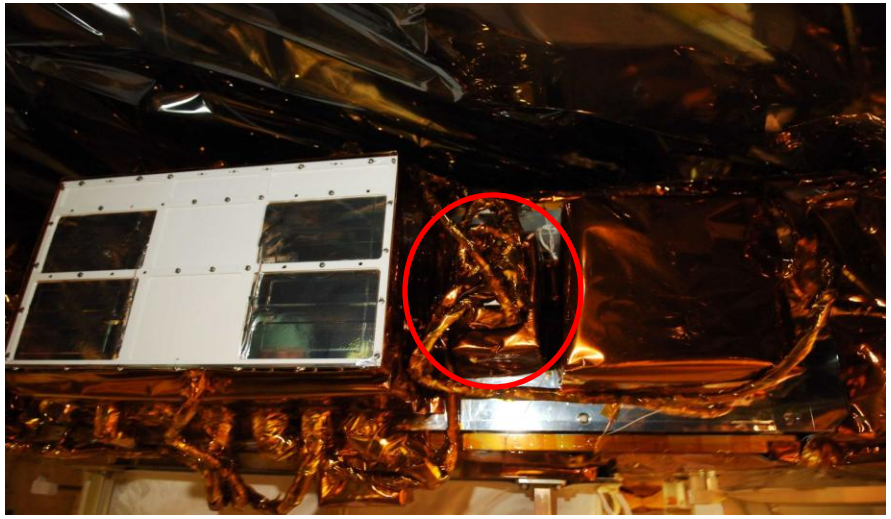
Hubble Servicing Mission 4 (STS-125)

- **R**elative **N**avigation **S**ensors (RNS) – HST Payload
  - Record images of HST during docking and release, in particular the Soft Capture Mechanism
  - Perform on-orbit position and attitude estimation (Pose)
- RNS SpaceCube: Main Avionics Box
  - Controlled 3 cameras, GPS, 960GB memory, telemetry module, shuttle Ku downlink
  - Hosted Linux, VxWorks, C&DH, Automatic Gain and Integration Control, 2 pose image processing algorithms, TMR'd self-configuration scrubber using ICAP
  - Recorded GPS/AGC/POSE flight logs to flash
  - Consisted of 2 processor cards, 2 low-voltage power cards, 1 JPEG2000 compression card (VIM)

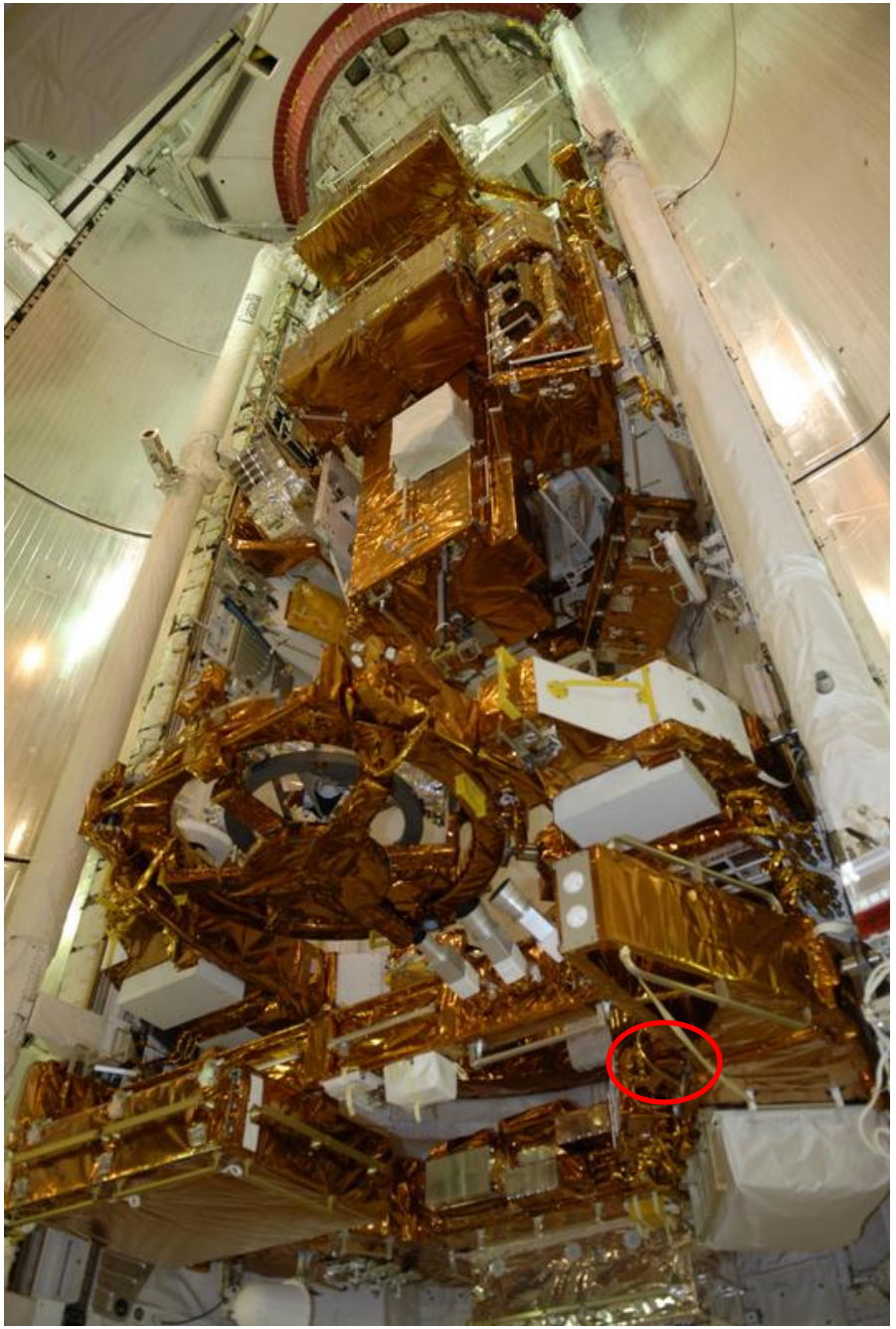
RNS Hardware



MULE Carrier



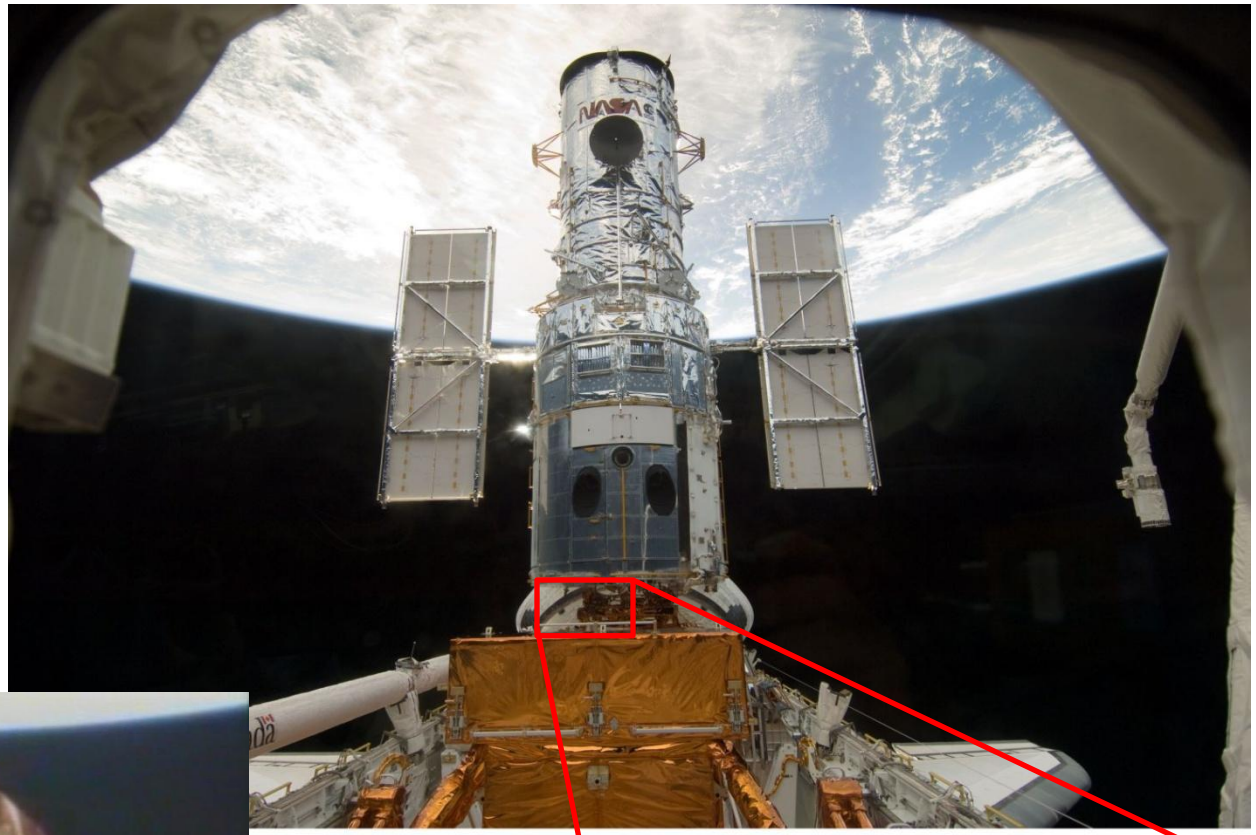
RNS Avionics Panel



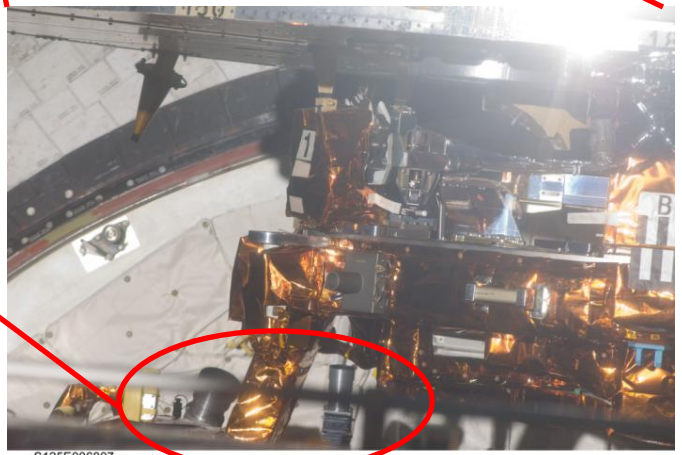
STS-125 Payload Bay

On Orbit

RNS
Cameras

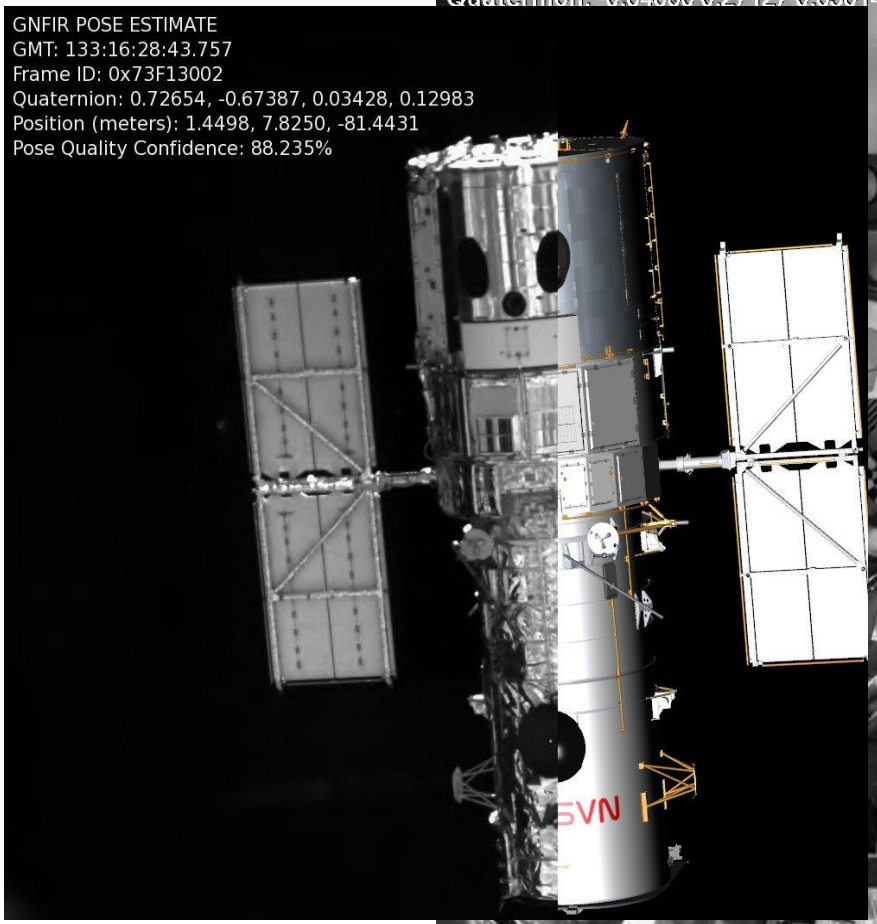


Tough to see,
but our cameras
and SpaceCube
are watching



Tracking Algorithms on SpaceCube

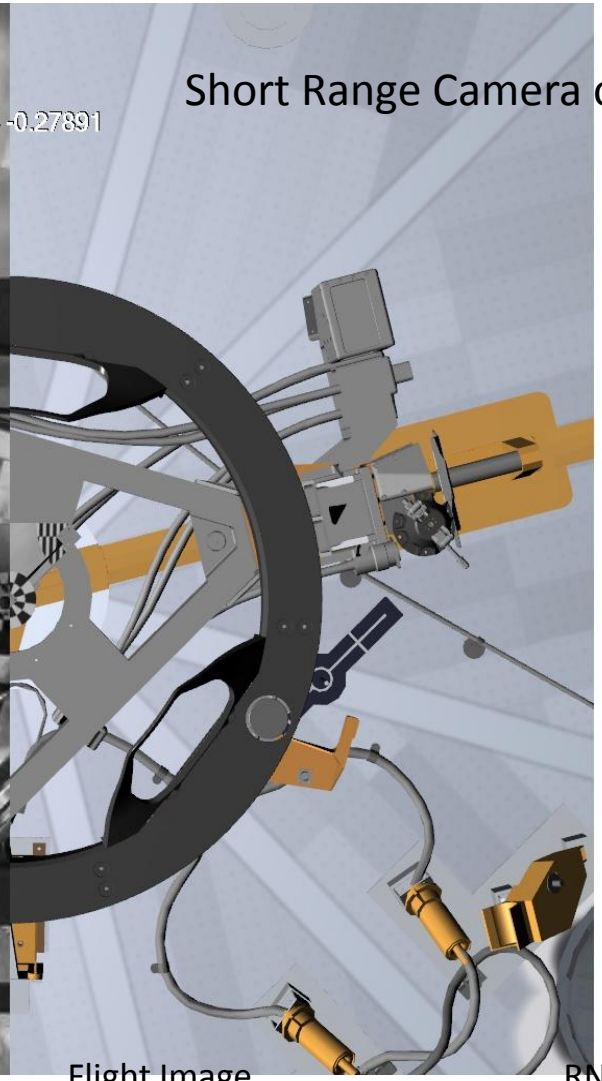
Long Range Camera on Rendezvous



Flight Image

RNS Tracking Solution

Short Range Camera on Deploy



Flight Image

RNS Tracking Solution

RNS Results Summary

- SpaceCube enabled RNS to meet all objectives
  - Recorded 6 hours of camera and GPS data
  - Successfully tracked HST during rendezvous for 21 minutes and deploy for 15 minutes
  - Sent 100,000+ compressed images to ground
- SpaceCube powered for 60 hours (8 in SAA)
  - 2 configuration SEUs in SAA scrubbed out
  - 1 PowerPC SEE that watchdog repaired

What's Next?

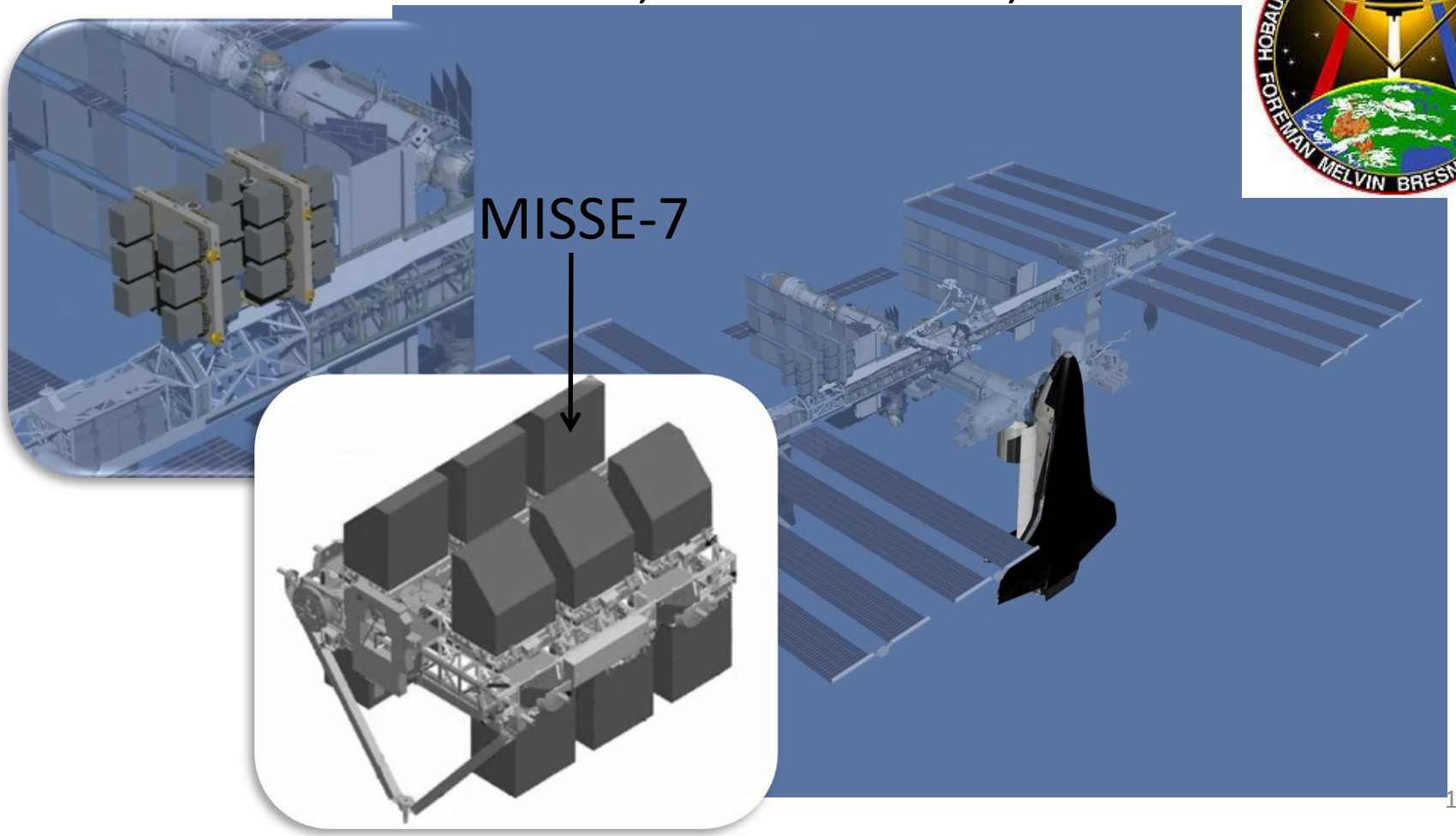
- Just completed raw imagery downloads at GSFC
- Looking for another flight for RNS hardware
  - Possible ISS flight for robotic demonstration
  - Hubble Robotic De-orbit Mission?

Current Tasks

- SpaceCube 1.0: RNS flight spare to ISS (Nov 09)
  - Platform for testing radiation mitigation techniques starting with Rad-Hard by Software (RHBS)
  - Collaborating with industry and universities
- SpaceCube 1.5: Sounding Rocket Avionics
  - DoD **O**perationally **R**esponsive **S**pace payload funding
  - Feature Xilinx Virtex 5 FX100 with gigabit interfaces
- SpaceCube 2.0: Increased performance over SC1.X
  - ESTO funding → Prototype FY10, Engineering Unit FY12
  - For missions requiring high data rates and/or onboard science data processing

MISSE-7 Overview

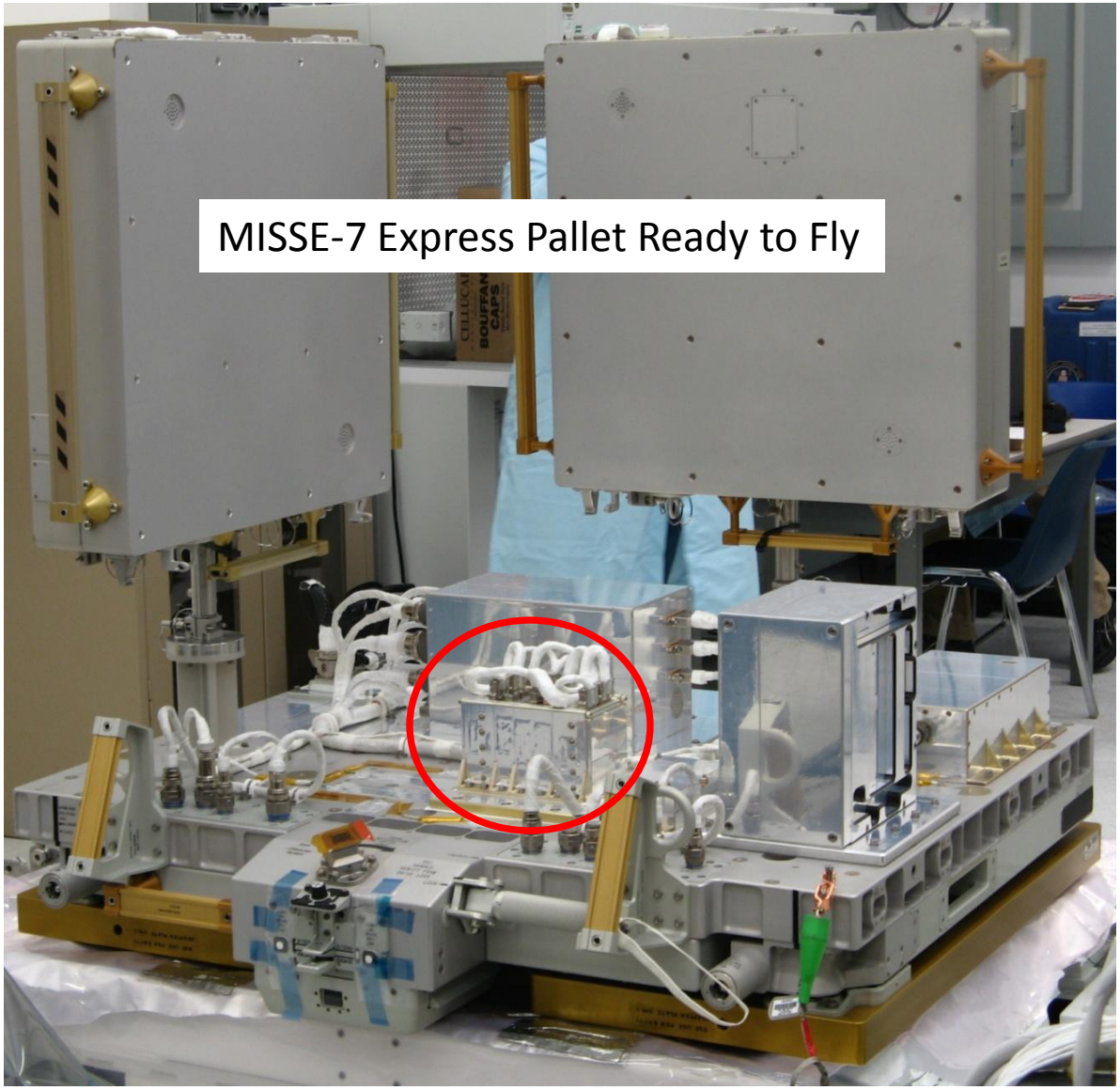
- Materials International Space Station Experiment
- Payload Lead: Naval Research Lab
- STS-129 Shuttle Atlantis, November 12, 2009



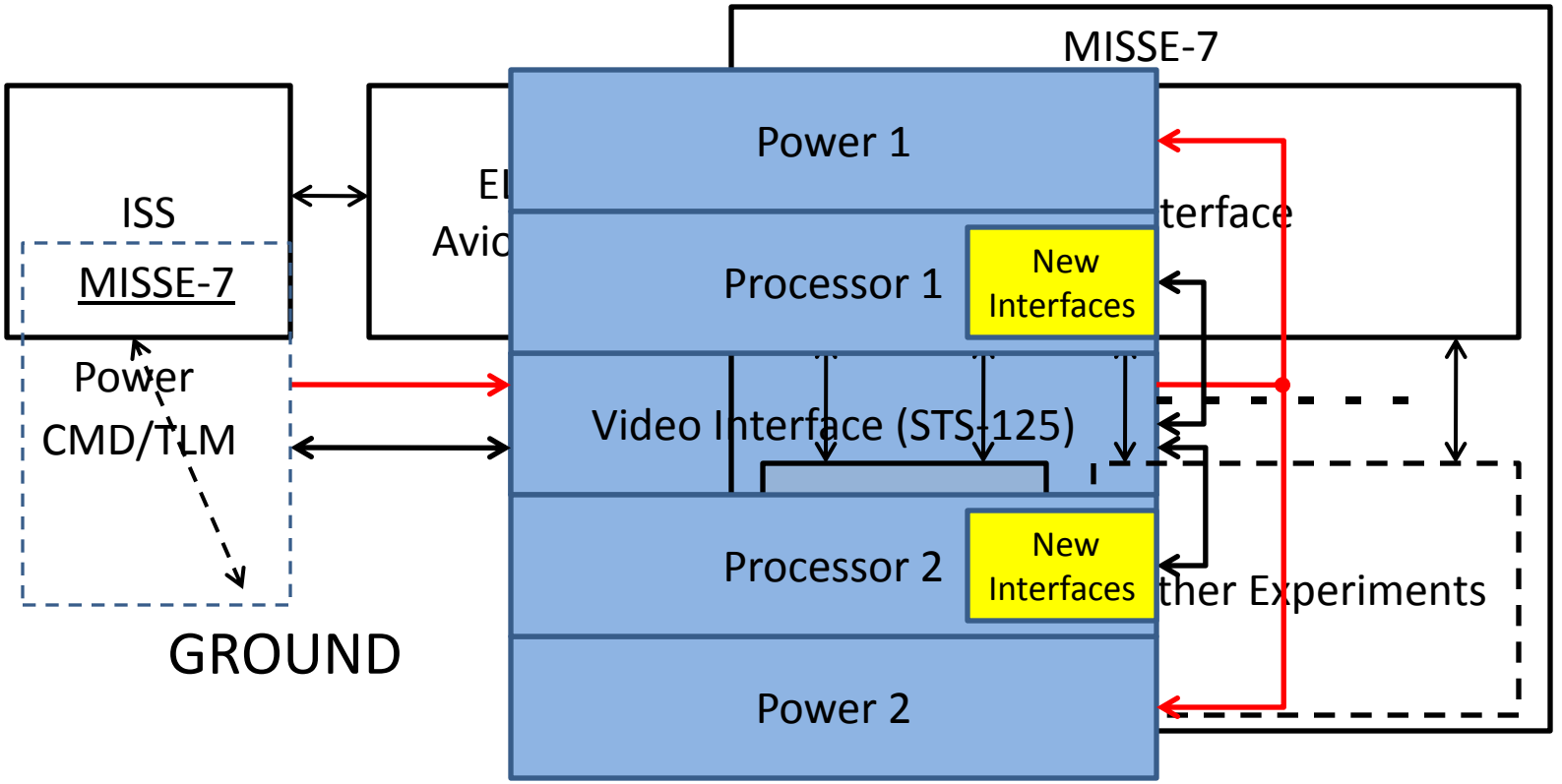
MISSE-7 SpaceCube

- Flight spare SpaceCube from HST SM4, STS-125
  - Re-engineered box for MISSE-7/ELC interface
  - Built adapter plate, custom harness, new software
  - Delivered box to NRL in 9 months!
- Test bed for radiation mitigation techniques
  - Start with “Radiation-Hardened by Software”
- Supports compressed file uploads
- Operations from a laptop

MISSE-7 SpaceCube



MISSE-7 SpaceCube Block Diagrams



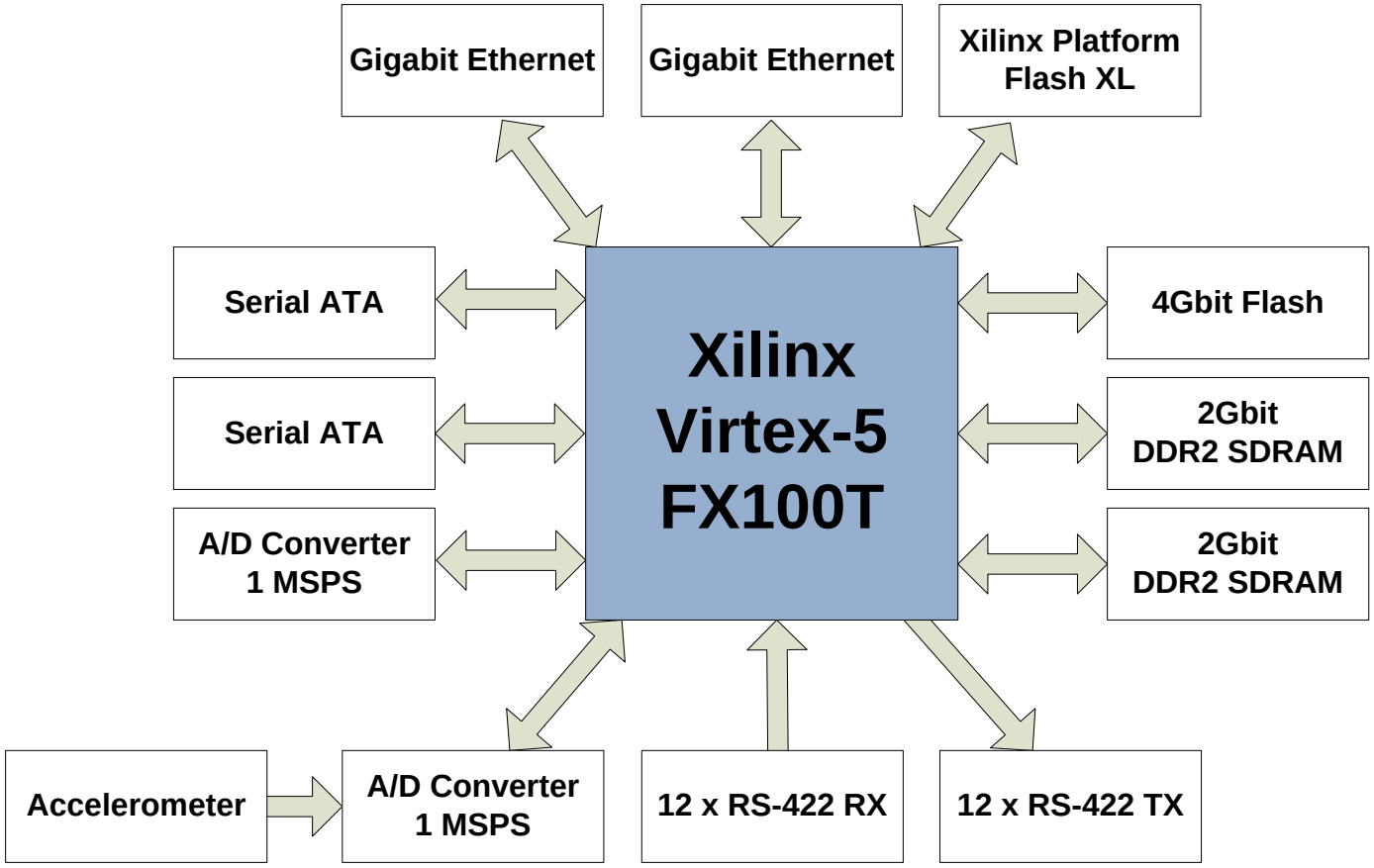
MISSE7 SpaceCube Future Work

- IRAD to continue work just approved!
- Collaboration with industry partners and universities
  - NSF Center for High-Performance Reconfigurable Computing
    - University of Florida
    - Brigham Young University
- Conduct ops and analyze radiation data
- Improve RHBS algorithms
- Upload improved FPGA/SW designs
- Roll in results to on-going SpaceCube advancements

SpaceCube 1.5 Overview

- SpaceCube 1.5 Processor Card
  - Collaboration with DoD **O**perationally **R**esponsive **S**pace (ORS)
  - COTS components
    - Targets small-scale, responsive missions
    - Short-duration suborbital, near-space, and orbital flights
  - Features inherited from SpaceCube 1.0
    - 4” x 4” Form-Factor
    - Stackable Architecture
    - Legacy flight interfaces (RS-422/LVDS)
    - Power card compatibility
  - Bridge to SpaceCube 2.0
    - Transition to Xilinx Virtex-5 FPGA
    - “Plug and Play” Gigabit interfaces (SATA, Ethernet)
    - High-speed DDR2 SDRAM memories

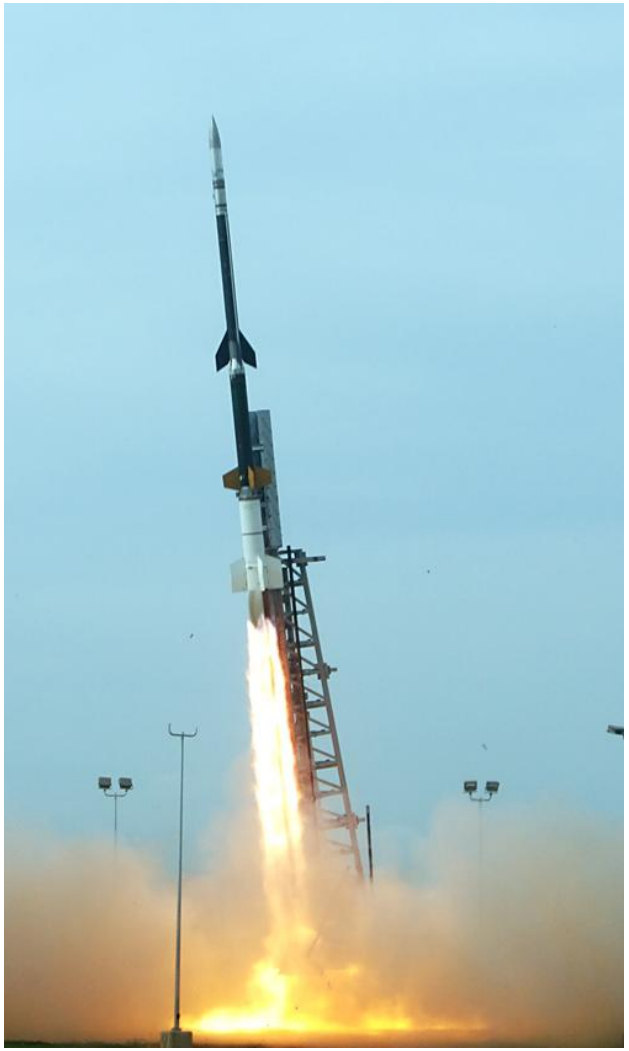
SpaceCube 1.5: Processor Card



SpaceCube 1.5: SMART/ORS

- **Sma**ll **R**ocket/Spacecraft **T**echnologies (SMART)
  - Joint program between NASA and ORS
- Objectives
  - Develop faster, leaner, and more efficient approach to space flight
  - Maturation of miniaturized avionics for small launch vehicles, flight safety, and spacecraft applications
  - Reconfigurable payload structure for accommodating various subsystems
  - Demonstration of technologies applicable to future rocket balloon flights
- Series of sounding rocket flights
  - **First launch: Summer 2010** on a Terrier Improved-Orion sounding rocket

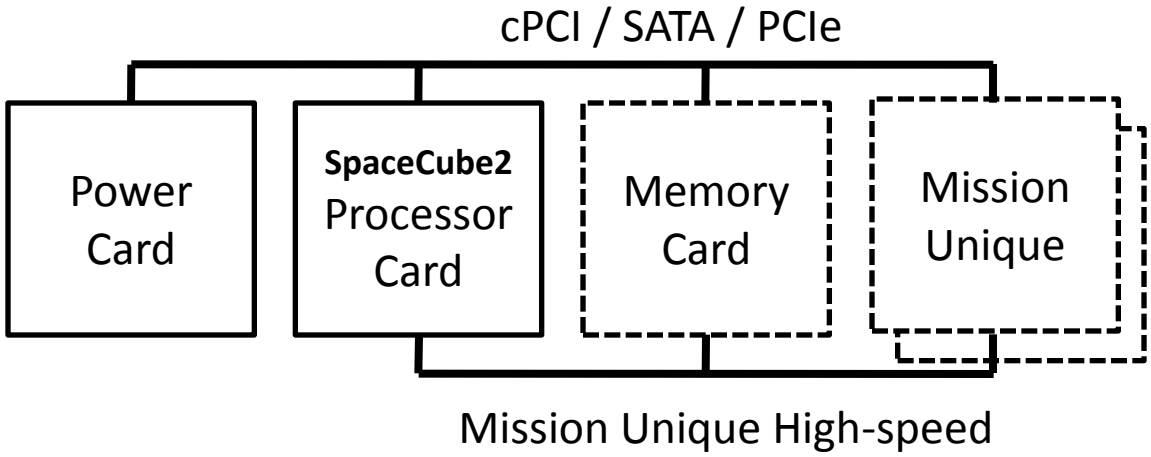
- Micro-satellite platform with **SpaceCube 1.5** as payload avionics
  - Ingest data from
    - RocketCam
    - 2 x GigE Industrial Cameras
    - Inertial Measurement Unit (IMU)
    - GPS
    - Sensors (pressure, thermal, acceleration)
  - Cameras validate interfaces and document flight and deployment of parachute
  - Record data telemetry on two commercial SATA Solid State Drives (SSD)
  - Downlink reduced telemetry through transponder (10Mb/s)



SpaceCube 1.5 Status

- Challenges:
  - Small Form Factor requires careful device selection and constrains I/O resources
  - Finding SATA solution (chose SATA IP Core)
- Improvements:
  - Compact/Rugged gigabit connectors capable of meeting **ALL** SATA specifications
- Status:
  - Completing schematic phase, initiating layout phase
  - FPGA/Software implementation of key interfaces proceeding on development boards

SpaceCube 2.0 Overview

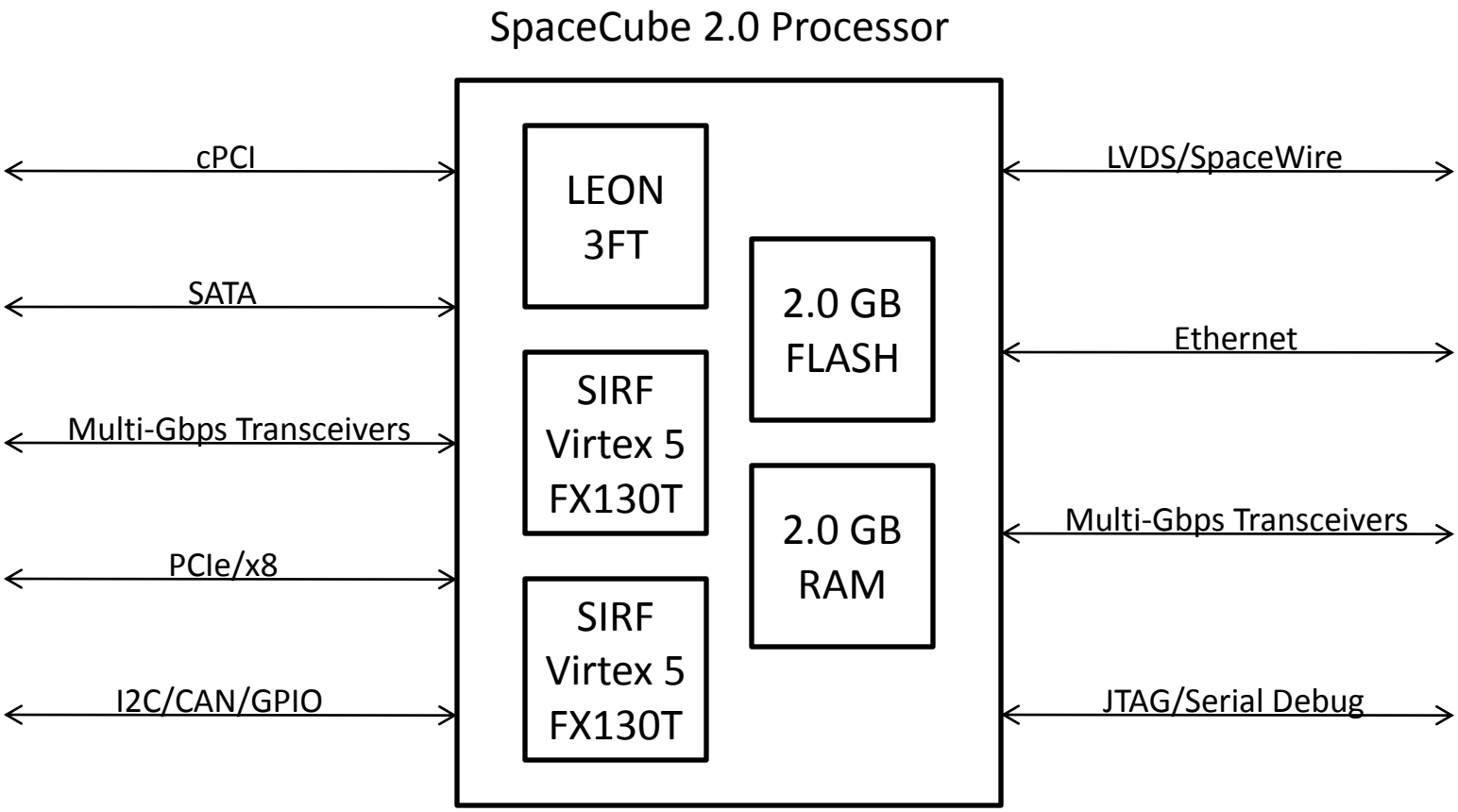


Flight Processor Comparison

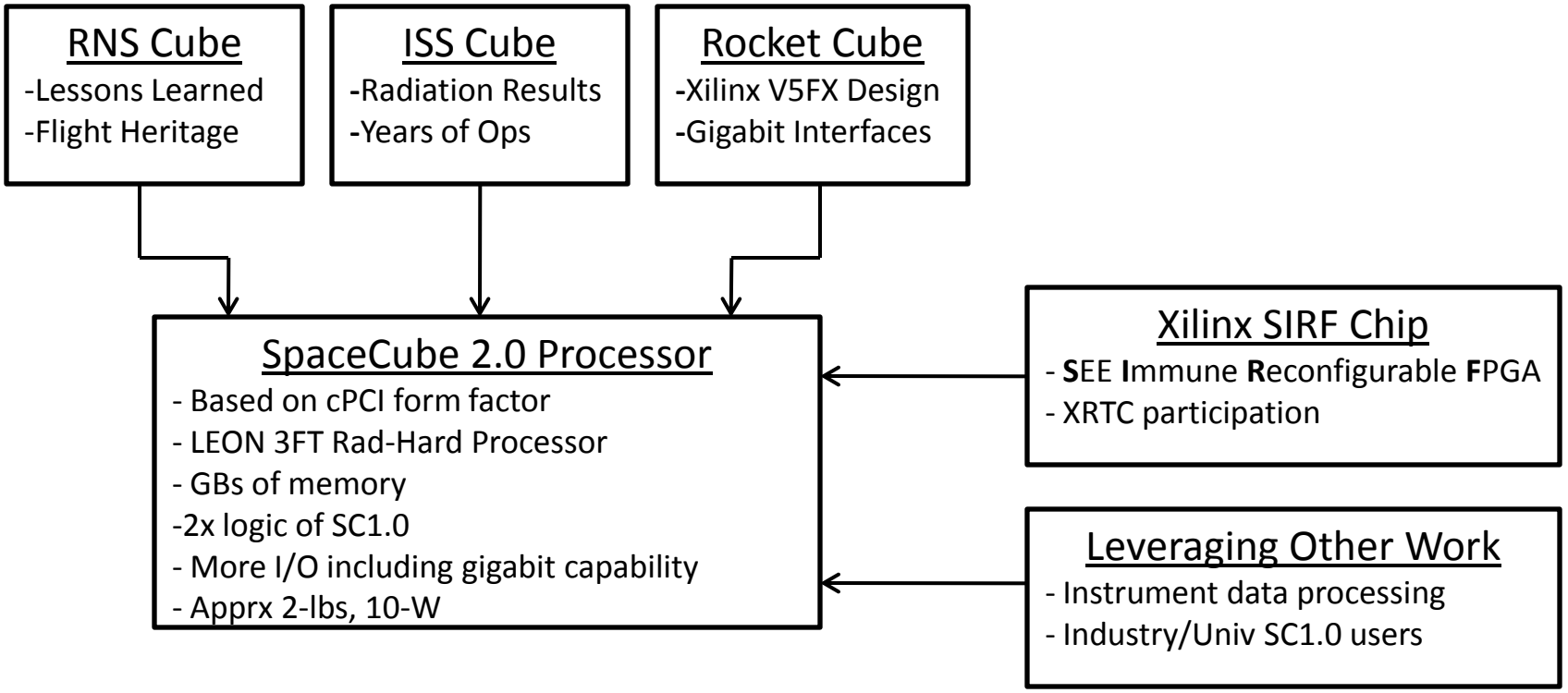
	MIPS	Cost	Power	MIPS/W
MIL-STD-1750A	3	-	15W	0.2
RAD6000	35	$250K	10-20W	2.33[1]
RAD750	< 500	$200K	10-20W	30[2]
SpaceCube 1.0	3000	$60K	5-15W	400[3]
SpaceCube 2.0	5000	$75K	10-20W	500[4]

Notes:
1 – typical, 35 MIPS at 15 watts
2 – typical, 450 MIPS at 15 watts
3 – 3000 MIPS at 7.5 watts (measured)
4 – 5000 MIPS at 10 watts (calculated)

SpaceCube 2.0 Processor Interfaces



SpaceCube 2.0 Development Paths



Main Goals:

- Retain processing power of SpaceCube 1.0
- Add gigabit interfaces
- Improving overall reliability

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CRI