SpaceCube: A Family Of Reconfigurable Hybrid On-Board Science Data Processors

Thomas P. Flatley
Head, Science Data Processing Branch
Software Engineering Division
NASA - Goddard Space Flight Center
Greenbelt, MD USA

NASA/ESA Conference on Adaptive Hardware and Systems (AHS-2012)
Nuremberg/Erlangen, Germany June 25-28, 2012

The Challenge

The next generation of NASA science missions will require "order of magnitude" improvements in on-board computing power

Mission Enabling Science Algorithms & Applications

- Real-time Wavefront Sensing and Control
- On-Board Data Volume Reduction
- Real-time Image Processing
- Autonomous Operations
- On-Board Product Generation
- Real-time Event / Feature Detection
- Real-time "Situational Awareness"
- Intelligent Data Compression
- Real-time Calibration / Correction
- On-Board Classification
- Inter-platform Collaboration

Our Approach

- The traditional path of developing radiation hardened flight processor will not work … they are always one or two generations behind
- Science data does not need to be 100% perfect, 100% of the time, especially if you can collect 100x MORE DATA using radiation tolerant* processing components
- Accept that radiation induced upsets will happen occasionally … and just deal with them
- Target 10x to 100x improvement in "MIPS/watt"

*Radiation tolerant – susceptible to radiation induced upsets (bit flips) but not radiation induced destructive failures (latch-up)

Our Solution

SpaceCube: a high performance reconfigurable science data processor based on Xilinx Virtex FPGAs

- **Hybrid processing … CPU, DSP and FPGA logic**
- **Integrated "radiation upset mitigation" techniques**
- **SpaceCube "core software" infrastructure**
- **Small "critical function" manager/watchdog**
- **Standard interfaces**

SpaceCube Family Overview

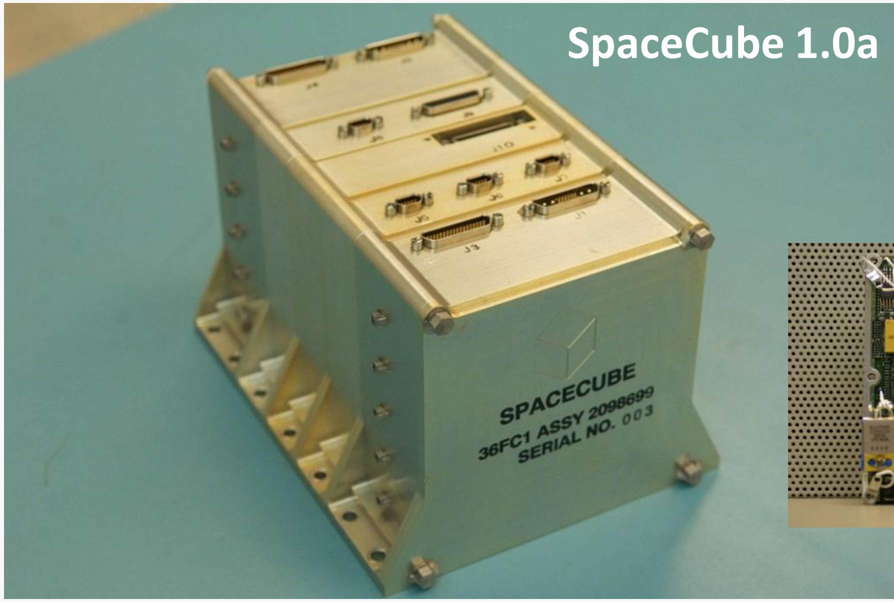
Unit	Mission	Notes	Specs	Stats	Status
SpaceCube 1.0a	Hubble Servicing Mission 4	Relative Navigation Sensors Experiment STS-125 May 2009	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 37W	2009 Flight
SpaceCube 1.0b	MISSE-7 (ISS)	added RS-485, RHBS, STS-129 Nov 2009	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 32W	In Flight
SpaceCube 1.5	SMART (DoD/ORS)	adds GigE & SATA, commercial parts, sounding rocket flight	4"x4" card (1) Virtex5	Size: 5"x5"x4" Wt: 4 lbs Pwr: < 20W	2011 Flight
SpaceCube 1.0c	Argon Ground Demonstration	Original RNS unit, w/added 1553 & Ethernet	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 40W	Software Development
SpaceCube 1.0d	STP-H4 (ISS)	CIB Experiment Interface w/added 1553 & Ethernet	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 40W	2013 Flight
SpaceCube 2.0	Earth/Space Science Exploration missions ISE 2.0 (ISS)	Std 3U form factor, GigE, SATA, Spacewire, cPCI	4"x6" card (2) Virtex5 SIRF	Size: 5"x5"x7" Wt: < 10 lbs Pwr: 15-20W	Under Development (ISE 2.0 2013 Flight)
SpaceCube 2.0 Mini	CubeSats, Sounding Rocket, UAV IPEX Cubesat	"Mini" version of SpaceCube 2.0, CubeSat form factor	2.5"x2.5" cards (1) Virtex5/SIRF (1) Aeroflex Rad-Hard FPGA	Size: 3.5"x3.5"x3.5" Wt: < 3 lbs Pwr: 5-15W	Under Development (IPEX 2014 Flight)

Processor Comparison

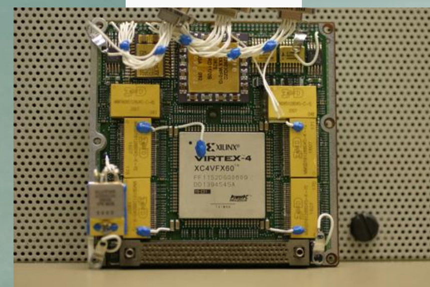
	MIPS	Power	MIPS/ W
MIL-STD-1750A	3	15W	0.2
RAD6000	35	10-20W	2.33_1
RAD750	300	10-20W	20_2
SPARC V8	86	$1W_3$	86_3
LEON 3FT	60	$3\text{-}5W_3$	15_3
GSFC SpaceCube 1.0	3000	5-15W	400_4
GSFC SpaceCube 2.0	5000	10-20W	500_5

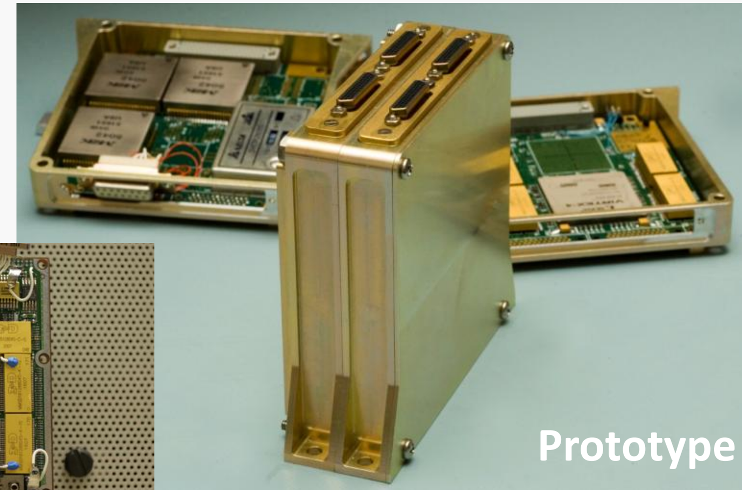
Notes:
1 – typical, 35 MIPS at 15 watts
2 – typical, 300 MIPS at 15 watts
3 – processor device only ... total board power TBD
4 – 3000 MIPS at 7.5 watts (measured)
5 – 5000 MIPS at 10 watts (calculated)

Current SpaceCube Systems



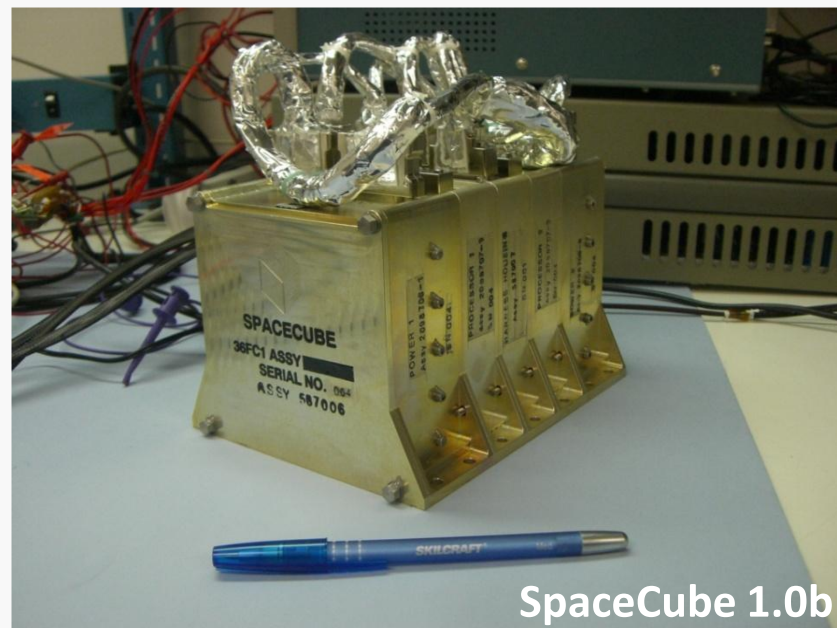
SpaceCube 1.0a





Prototype

SpaceCube 1.5



SpaceCube 1.0b

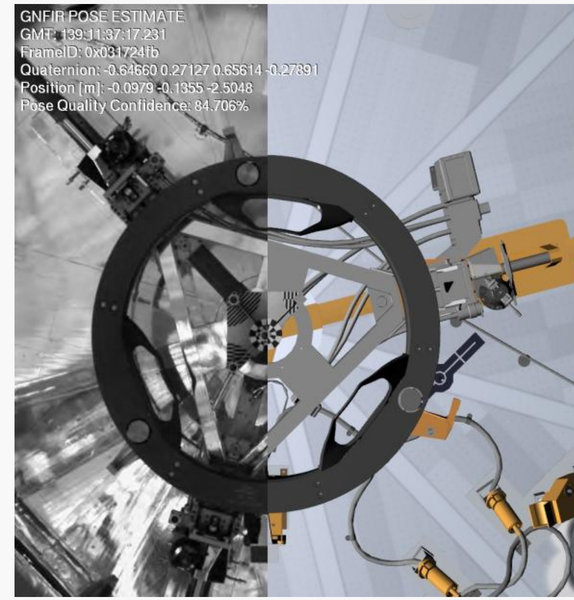
On-Board Image Processing

STS-125 Payload Bay

Long Range Camera on Rendezvous

Flight Image **RNS Tracking Solution**

Short Range Camera on Deploy

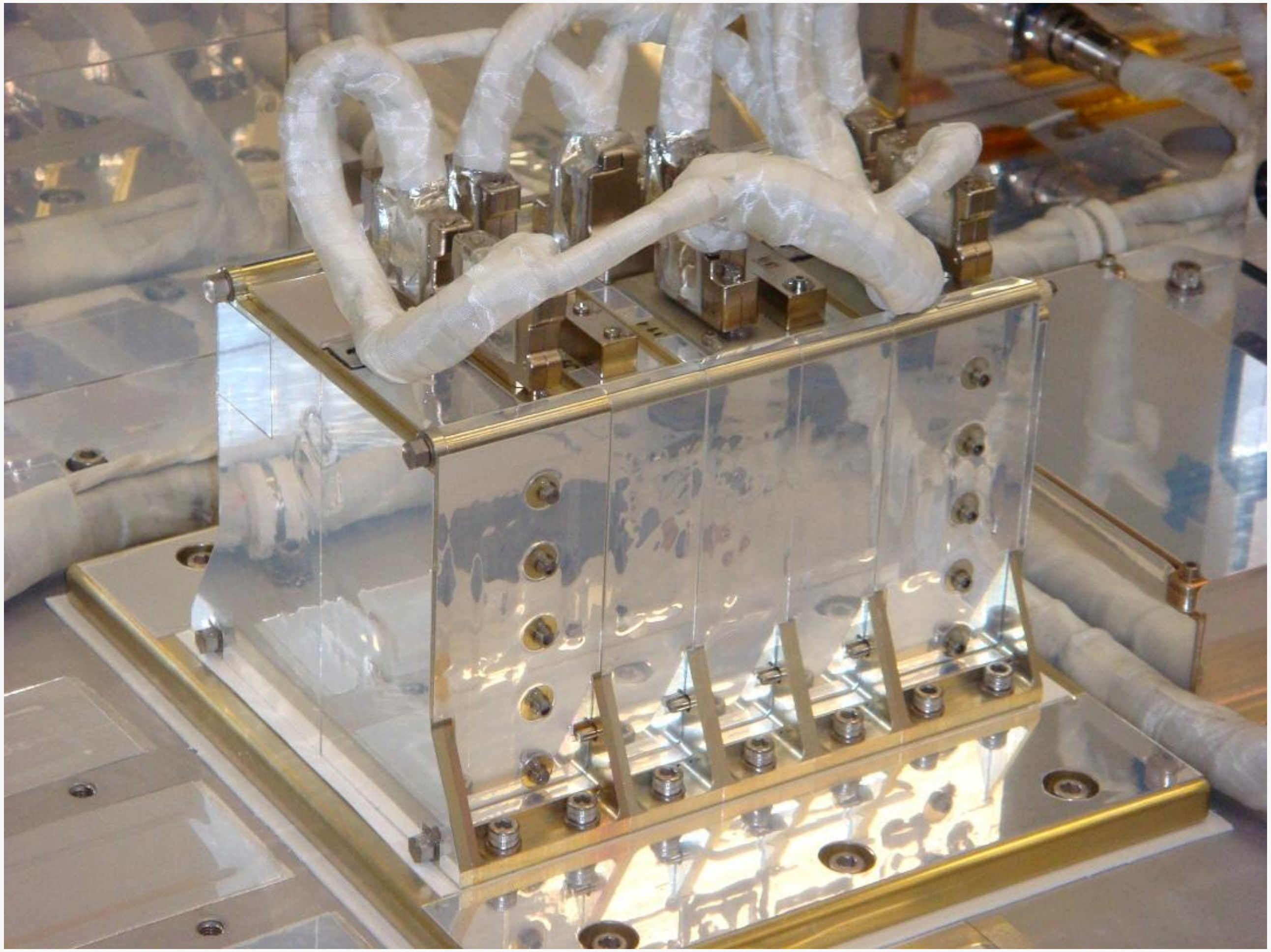


Flight Image **RNS Tracking Solution**

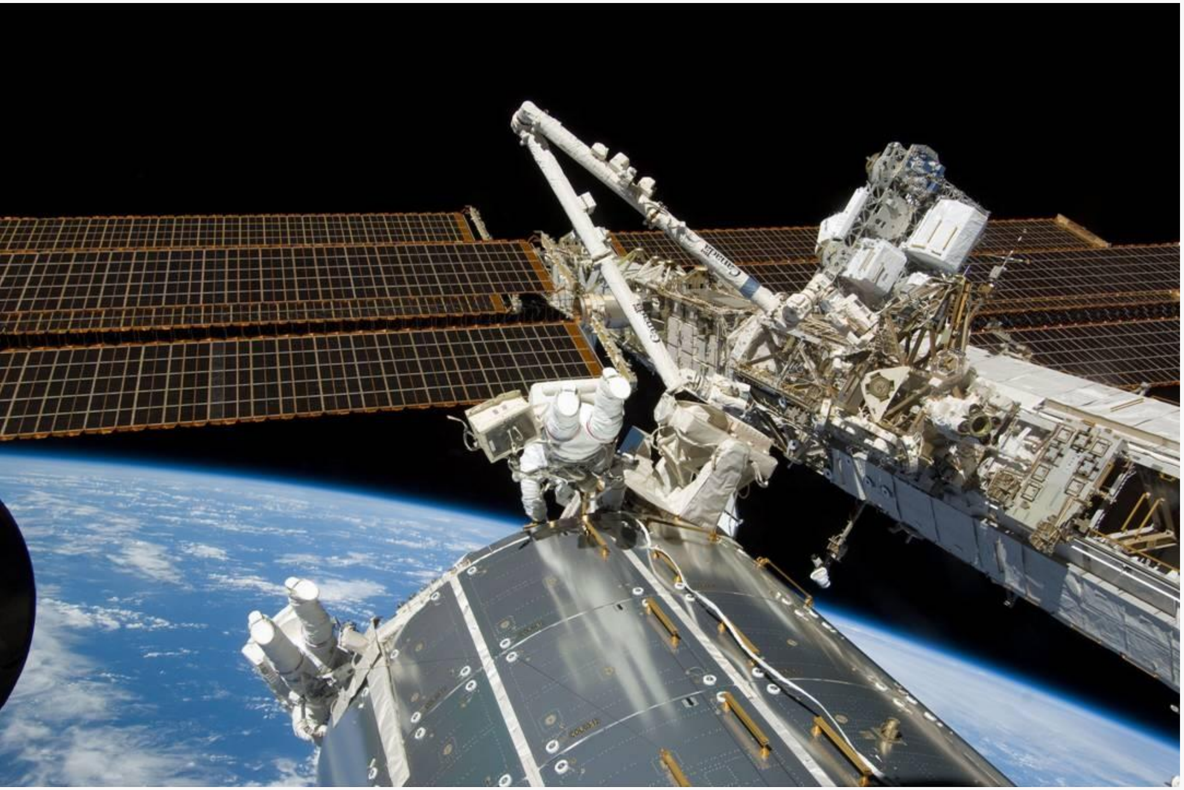
HST-SM4

GSFC SpaceCube 1.0a - Hubble SM 4 (May 2009):
- Autonomous Rendezvous and Docking Experiment
- Hosted camera AGC and two Pose algorithms

MISSE7/8 SpaceCube

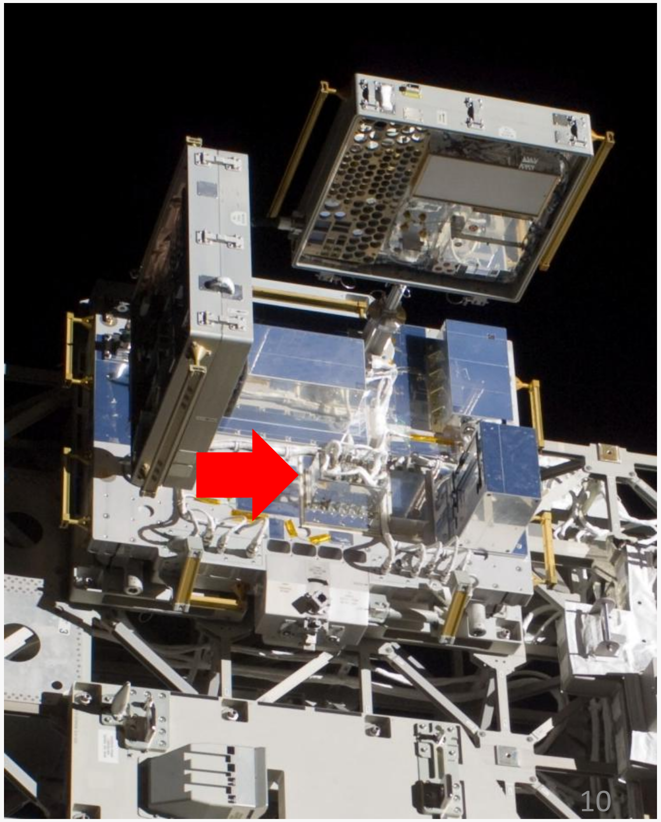


SpaceCube Upset Mitigation



GSFC SpaceCube 1.0b (Nov 2009):

- “Radiation Hardened by Software” Experiment (RHBS)
- Autonomous Landing Application
- Collaboration with NRL and the DoD Space Test Program (STP)

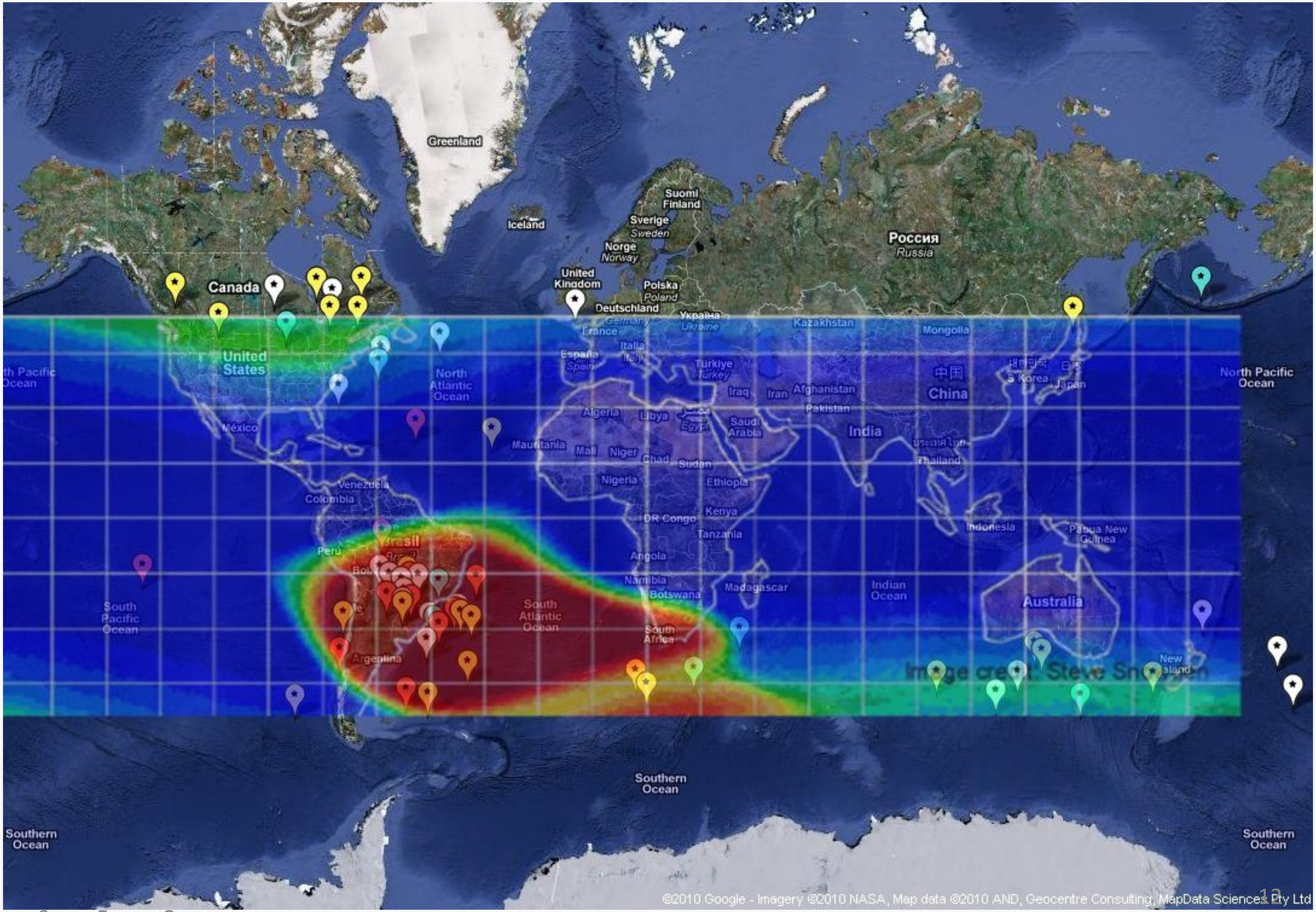


MISSE7/8

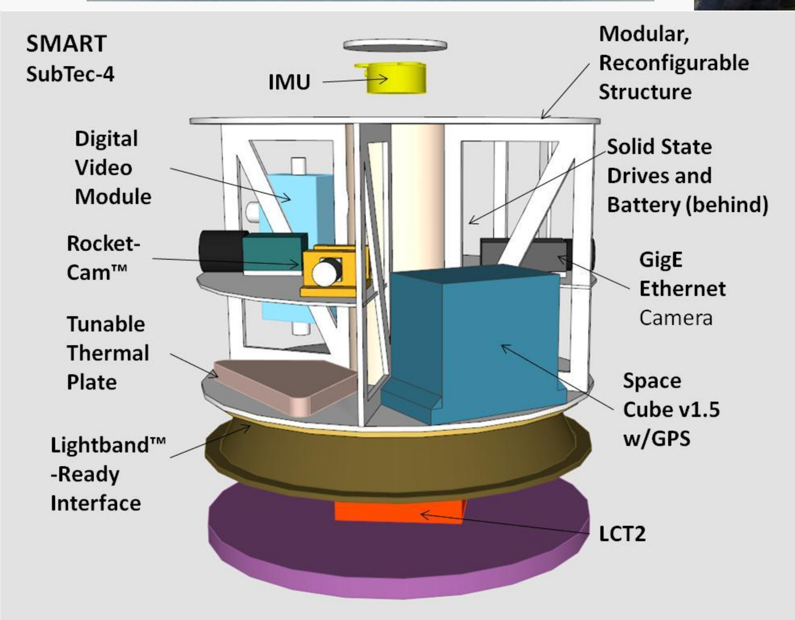
Orbit	ISS
Days in orbit	900+
Total SEUs	175+
Total Errors	0

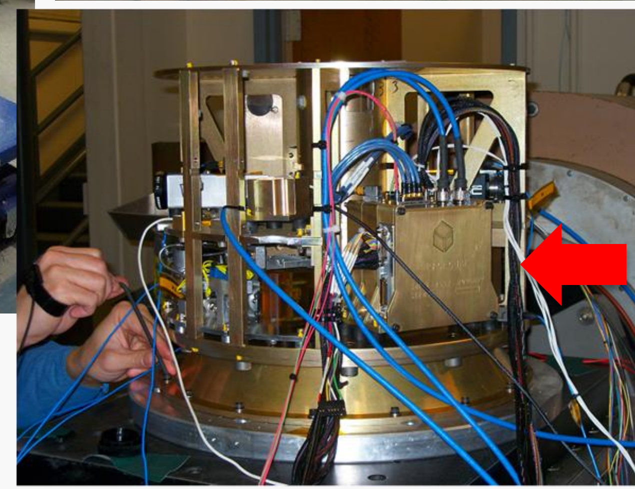
On-Orbit Upset Locations

On-Orbit Upset Locations



SMART Sounding Rocket Experiment

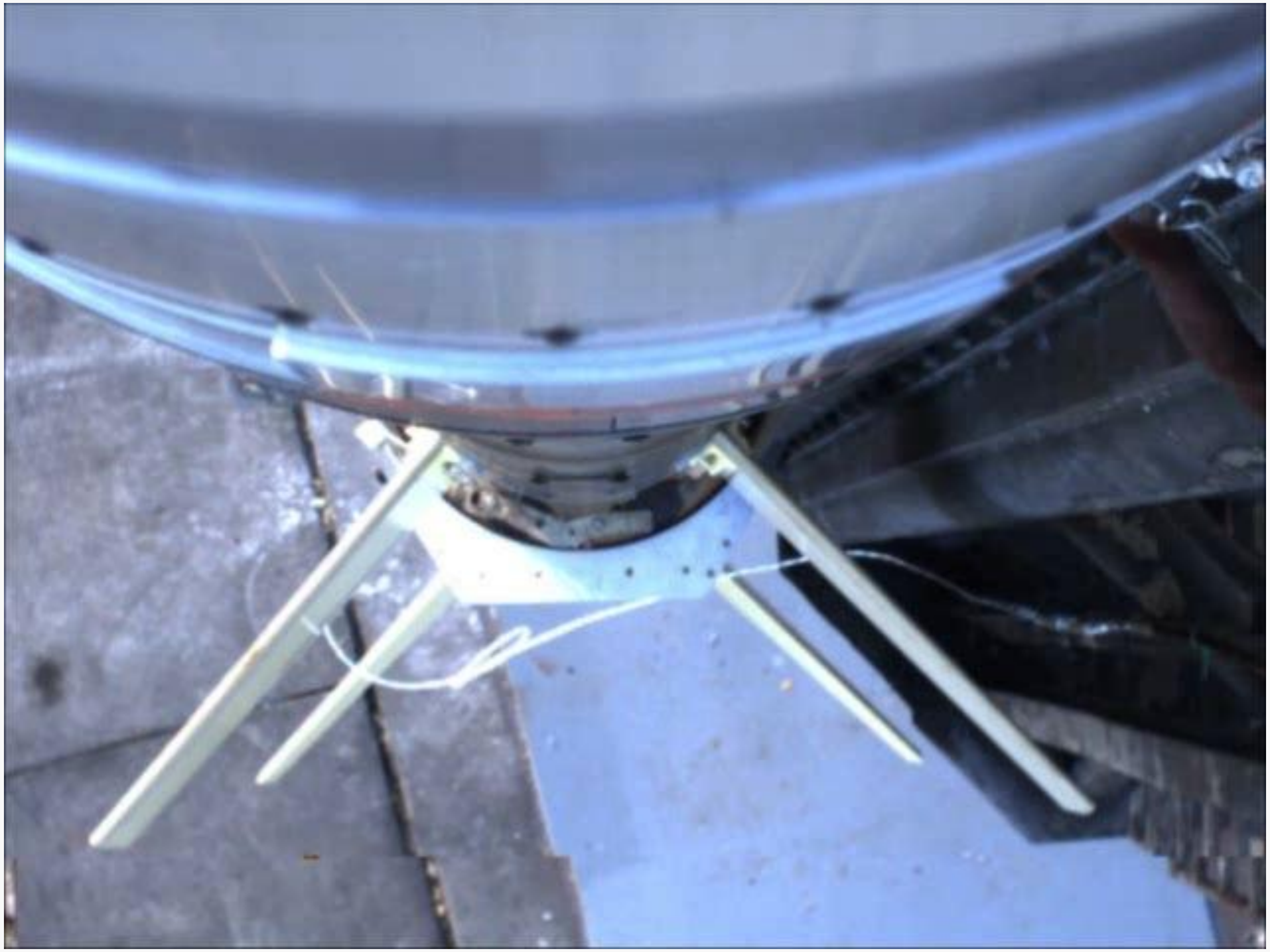




SpaceCube 1.5 on the SMART sounding rocket payload (SubTec-5, launched June 2011):

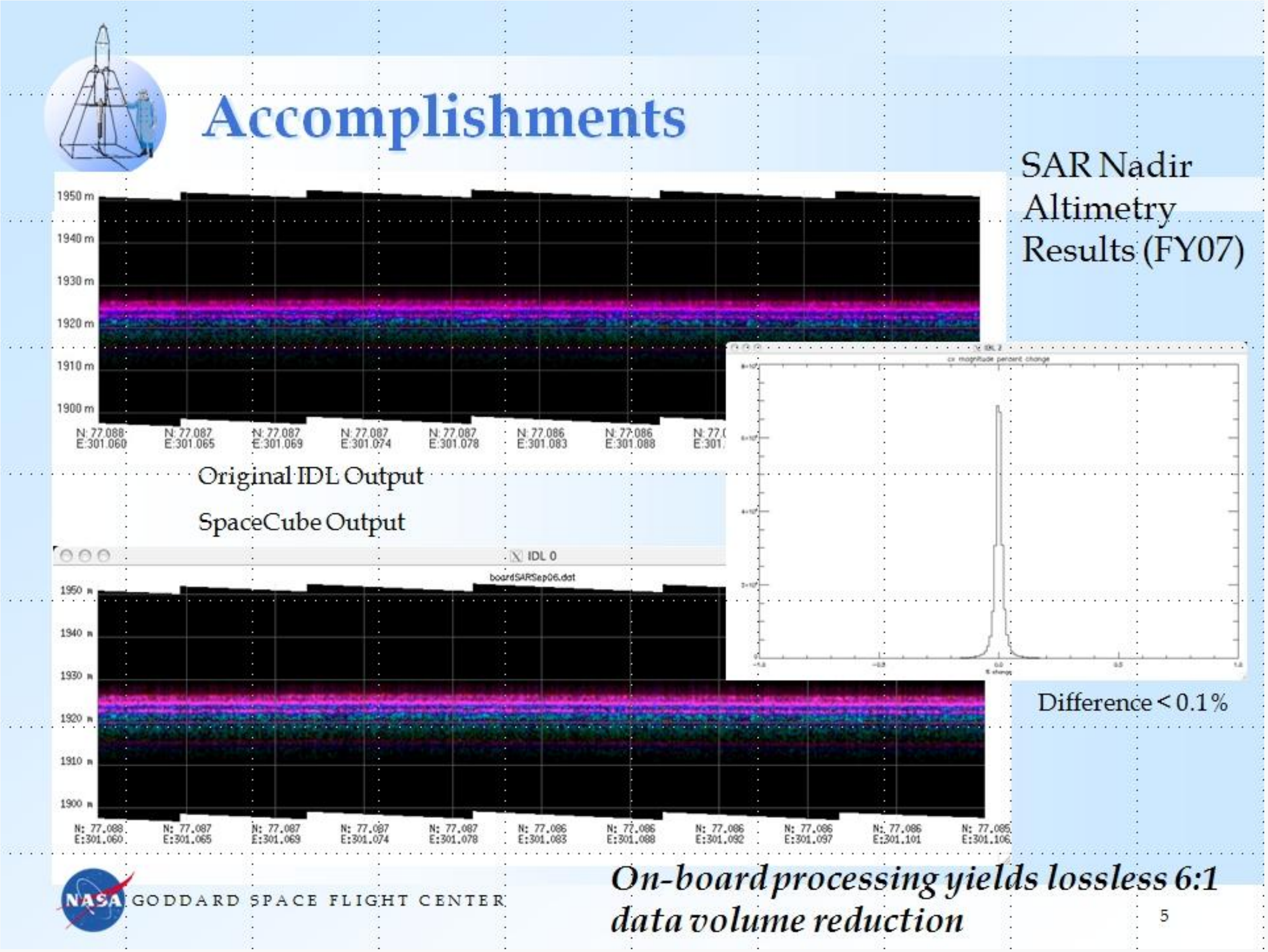
- **Multi-function avionics**
- **Collaboration with ORS**

SMART Real-time Video

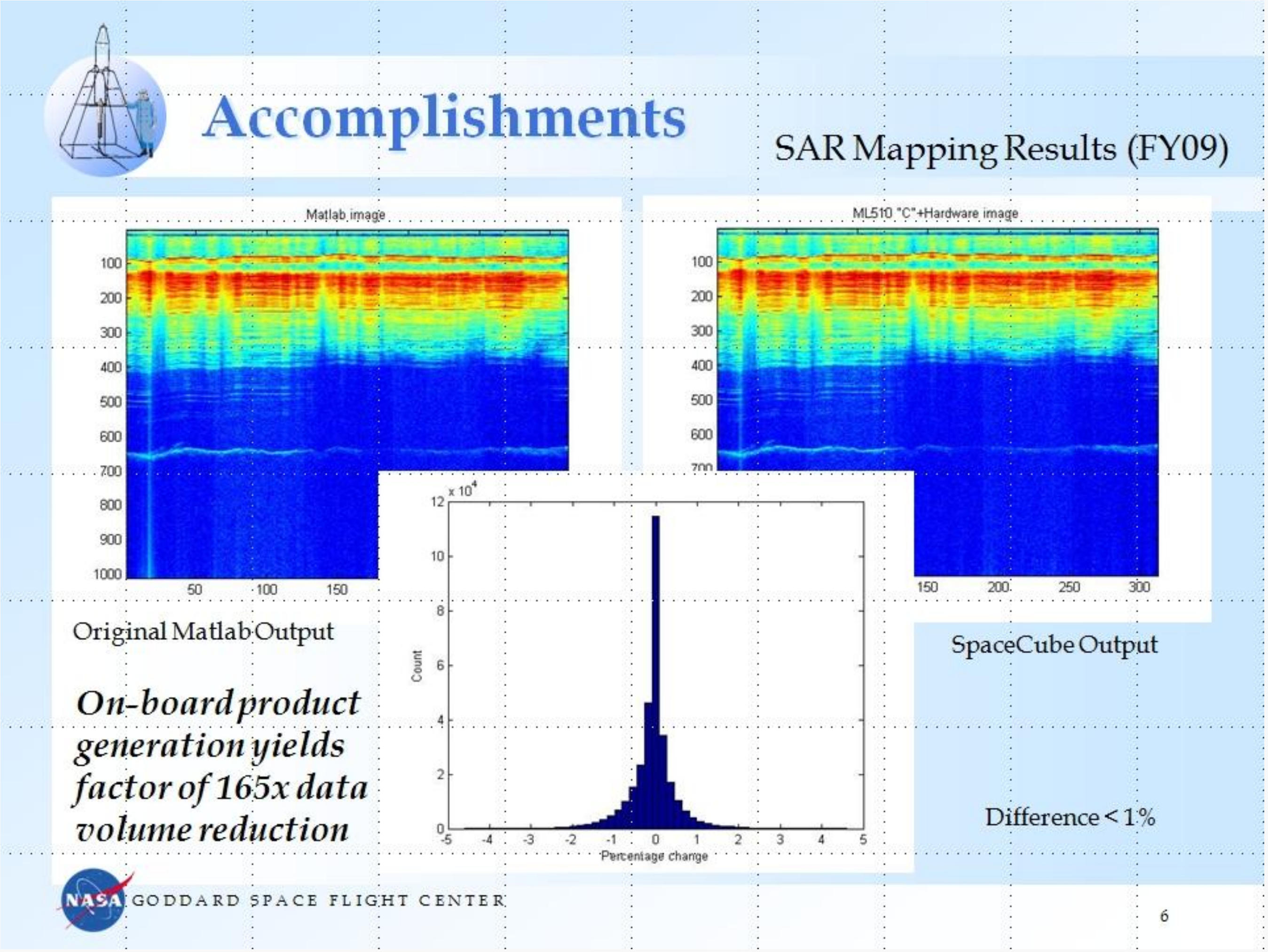


SpaceCube 1.5 - SMART GigE Camera 1 Real-time Downlink at 6 fps – clip
NASA Wallops Flight Facility - June 10, 2011

On-Board Data Reduction



On-Board Data Reduction (cont)



RUSHMAPS IRAD Results

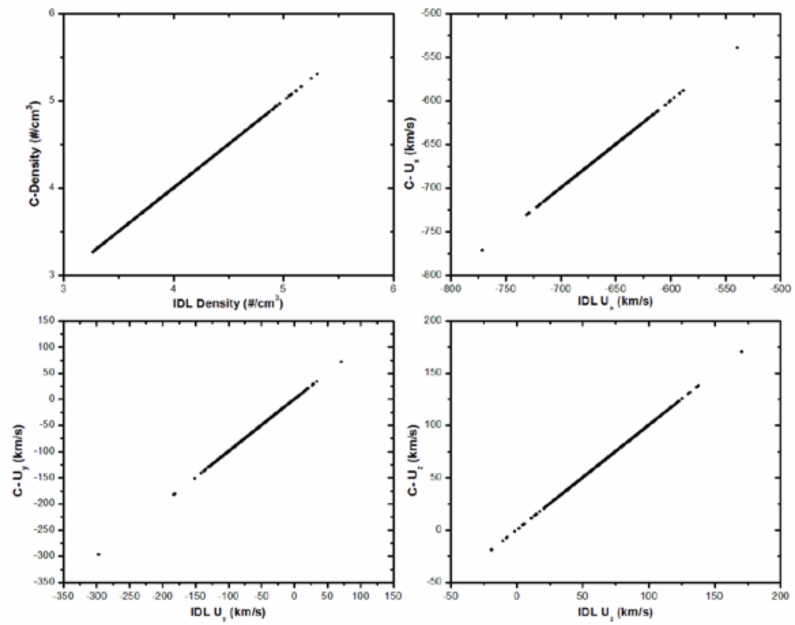
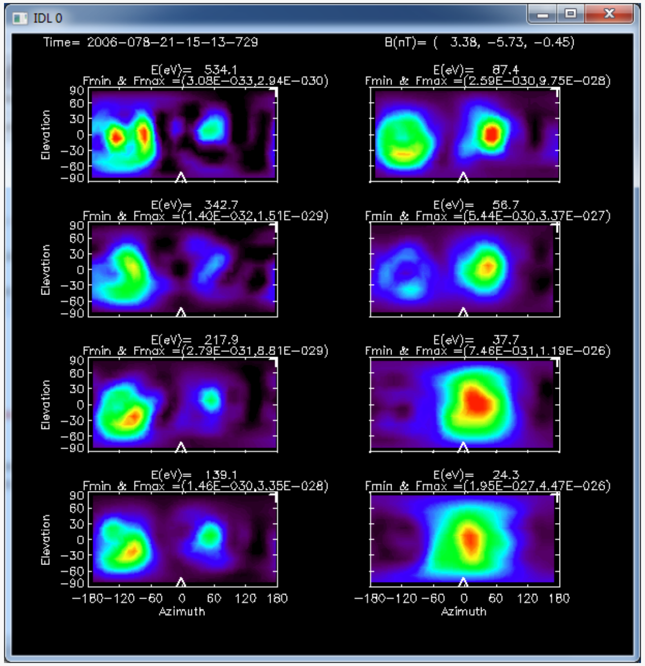


Fig-1. Comparison of Cluster moment density and bulk velocity results implementation of the C-code SpaceCube platform board versus the results from the original IDL code.

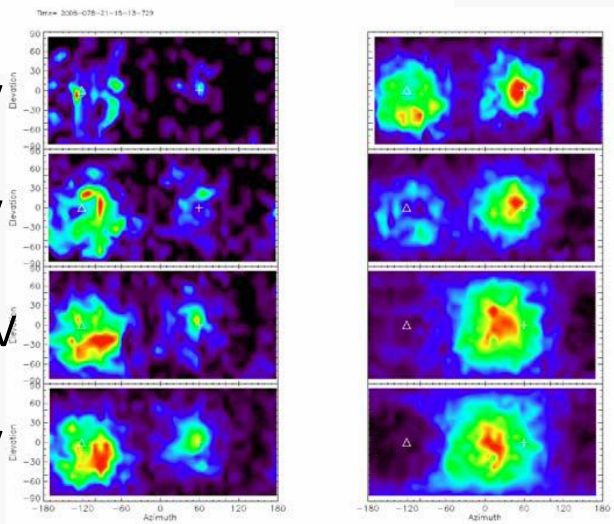


E=534.1 eV

E=342.7 eV

E=217.19eV

E=139.1 eV



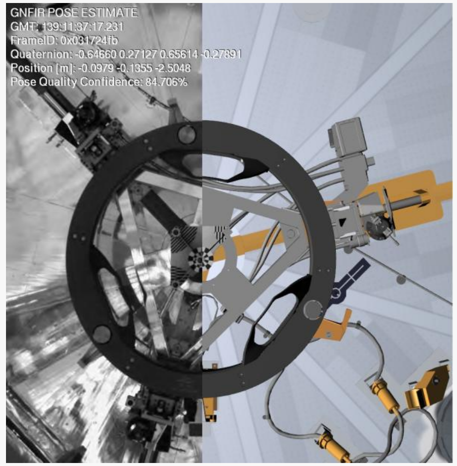
E= 87.4 eV

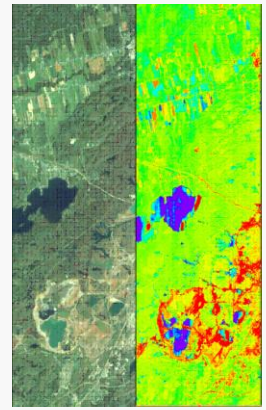
E= 56.7 eV

E= 37.7 eV

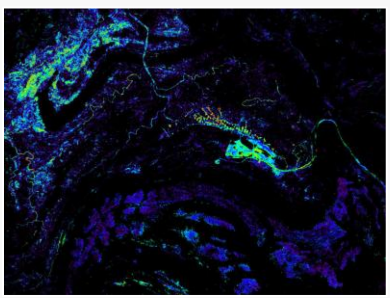
E= 24.3 eV

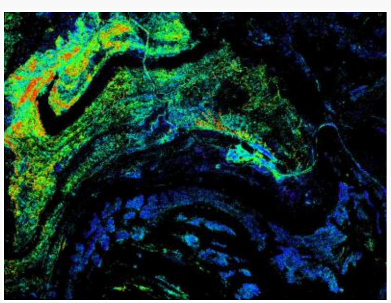
On-Board Product Generation

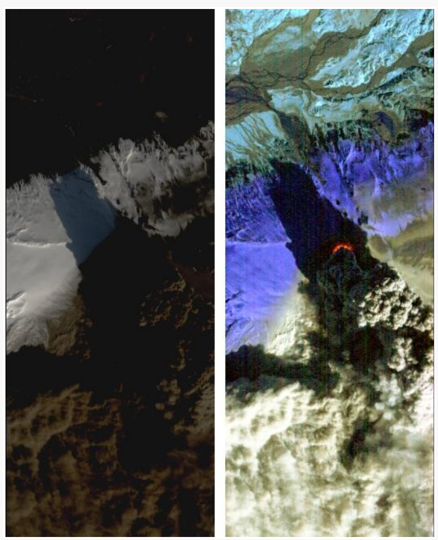


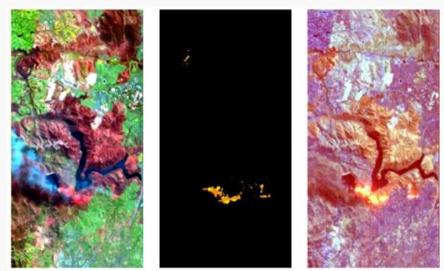


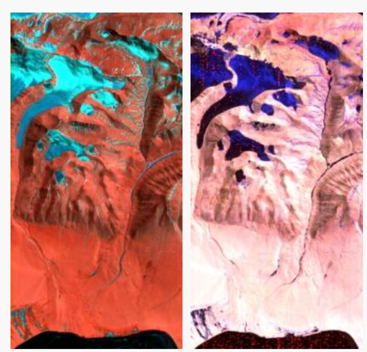
- Classification
- Product Generation
- Event Detection
- Atmospheric Correction

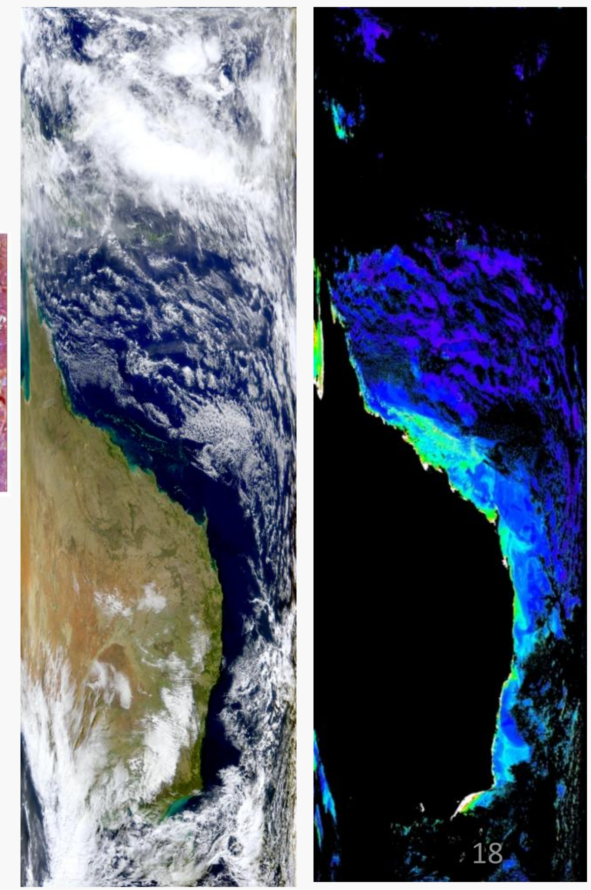




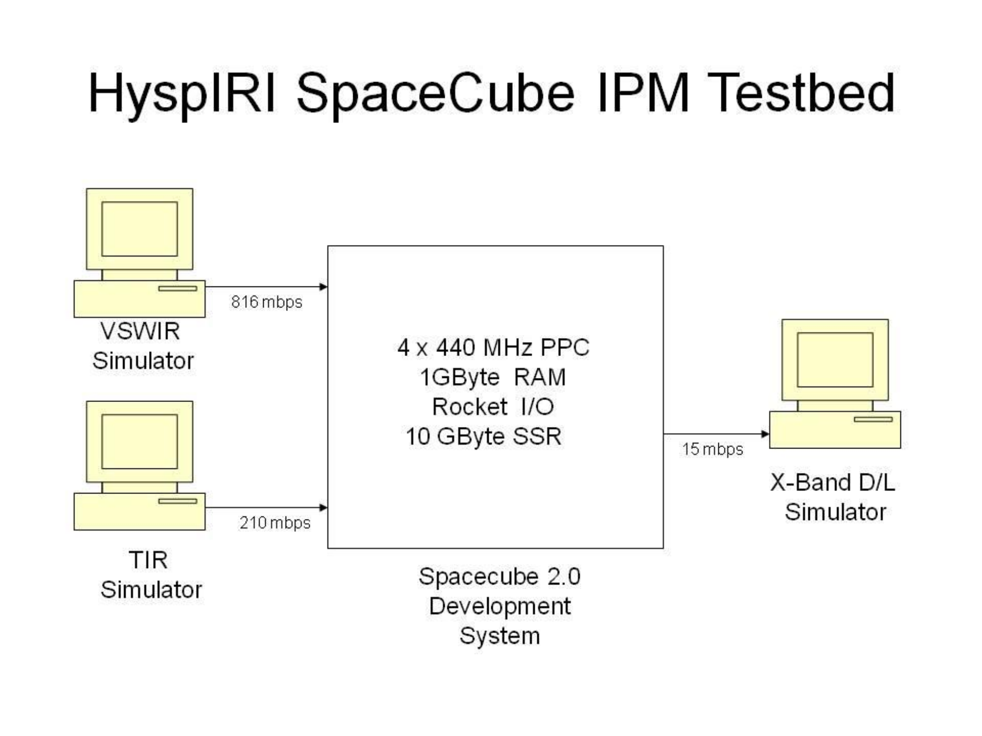


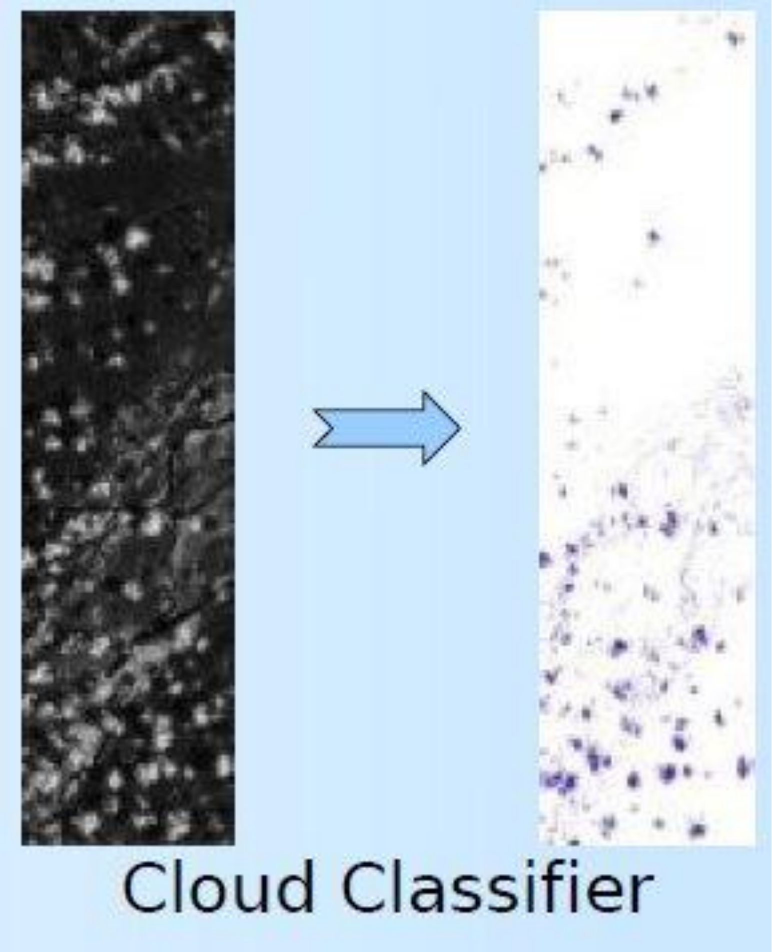






HyspIRI Demonstration Testbed





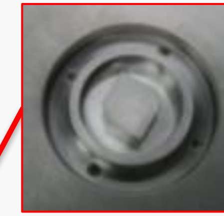
Argon AR&D Test Payload

IR Camera

MDA RNS Cameras And Baffles

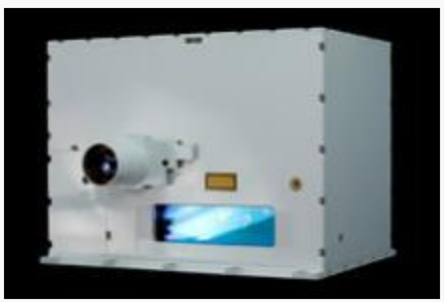
Ball VNS

Power Control Unit (PCU)



Wireless Patch Antennas (x4)

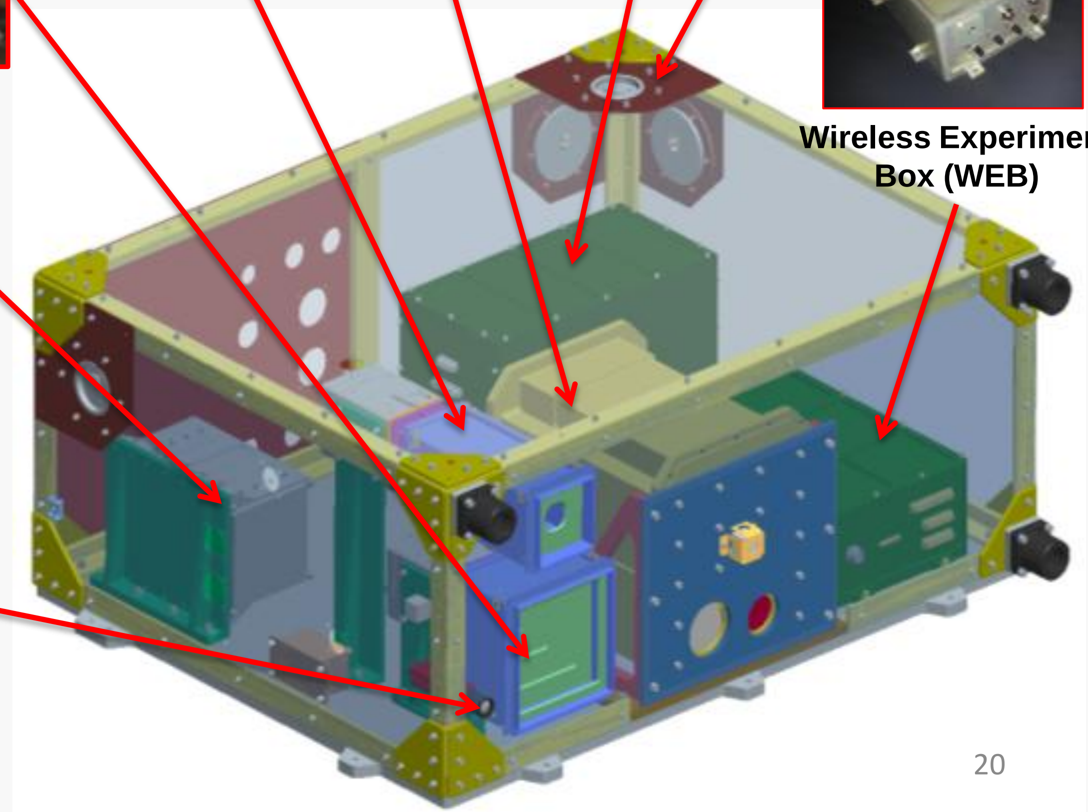
Wireless Experiment Box (WEB)



Neptec TriDAR

SpaceCube (EDU)

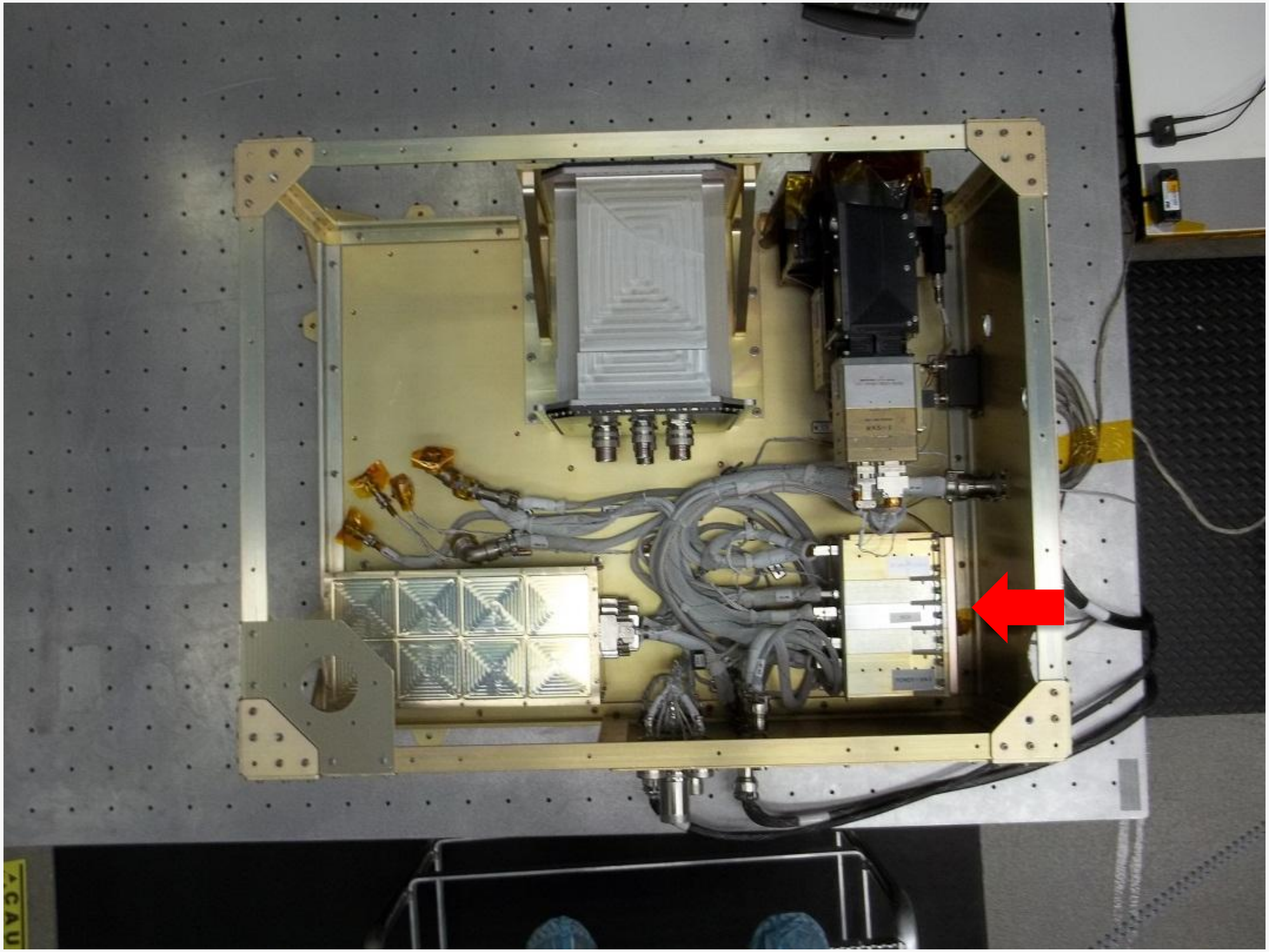
Ecliptic/Sony Situational Awareness Camera



Estimated Mass:
140 lb

Rough Size:
25”x32”x14”

Argon Payload Assembly



GSFC Satellite Servicing Lab

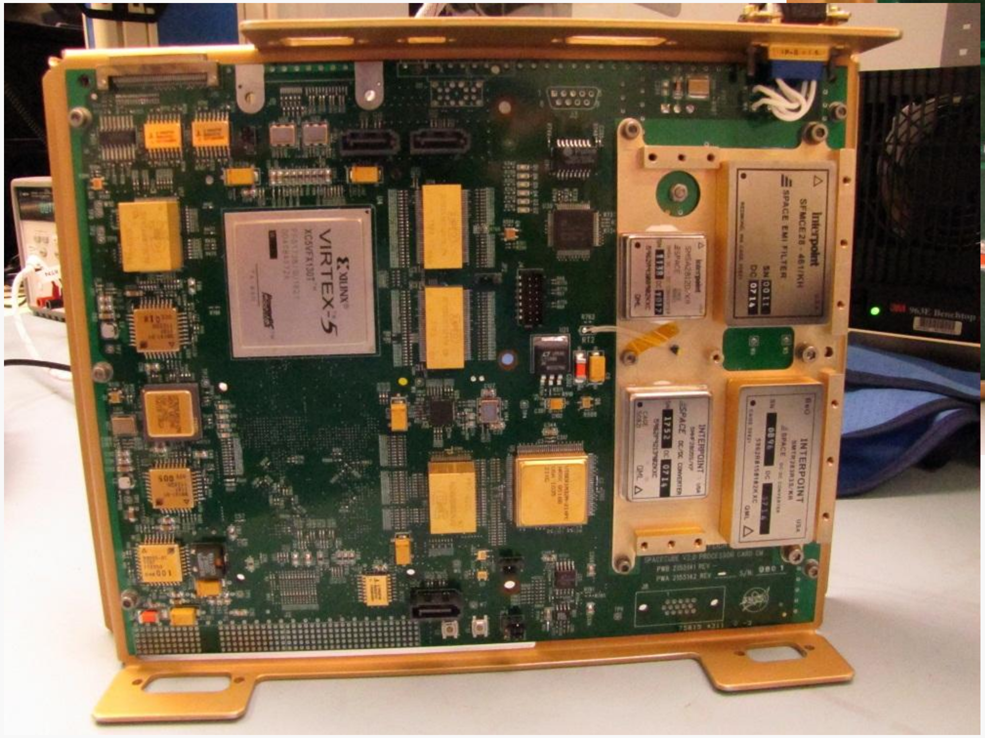
Testing with simulated 6-DOF motion of Argon and Target

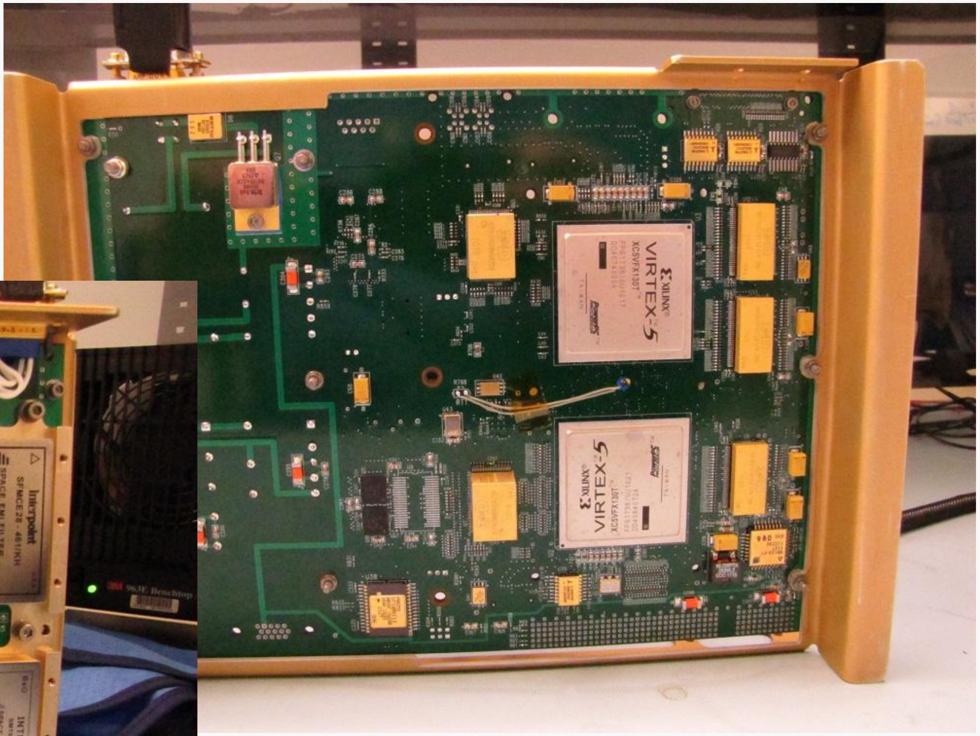
- Rotopod and FANUC motion platforms simulate target-sensor dynamics
- Up to 13 m separation possible

Testing conducted at GSFC in January-February 2012

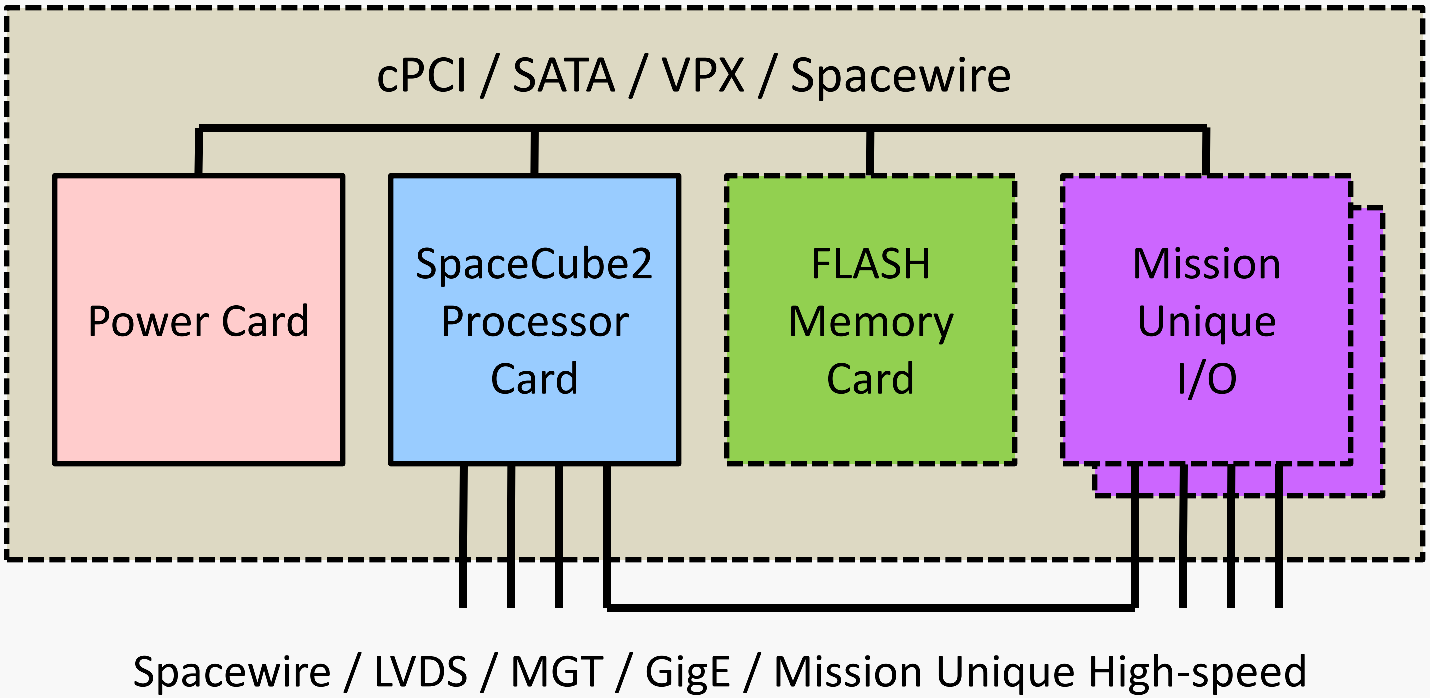
- Motion includes closed-loop approach and non-cooperative “tumble”
- Open loop testing to characterize sensor/algorithm performance
- Closed-loop tests - evaluate end-to-end system (sensors, algorithms, control law) in real time

SpaceCube 2.0 Prototype



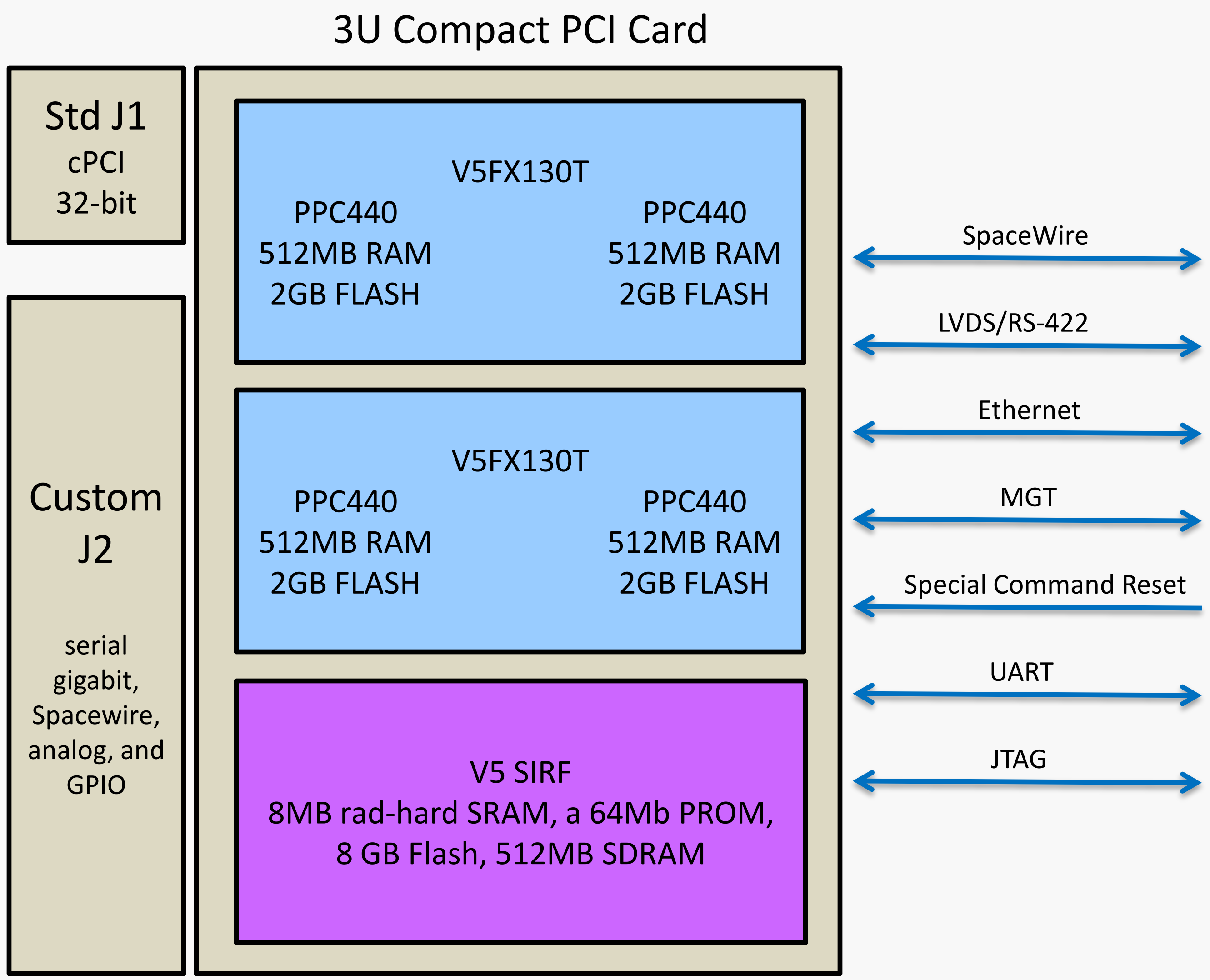


SpaceCube 2.0 Block Diagram

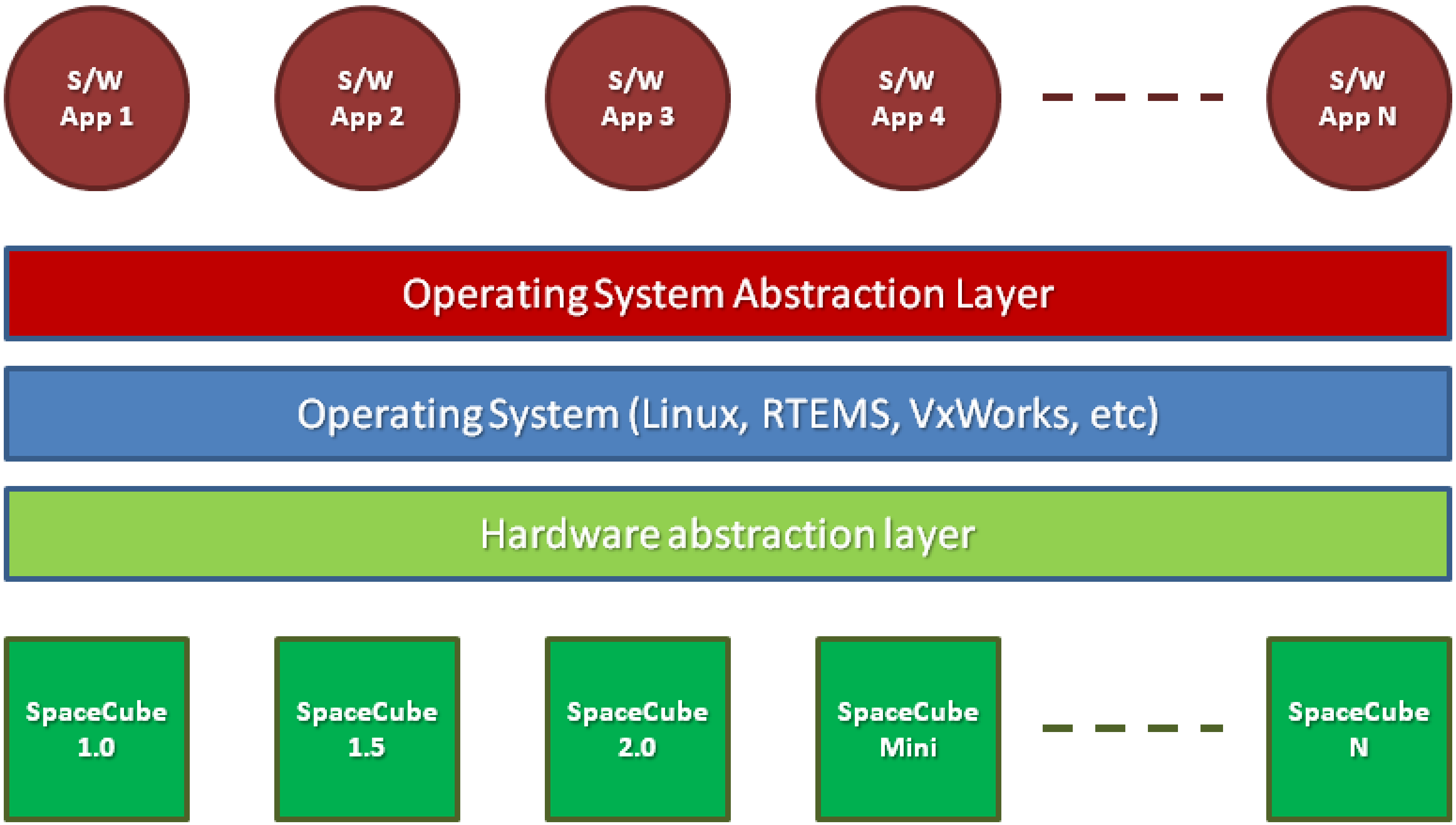


Standard 3U Card Form Factor
Nominal Box Level Parameters:
Size 5”x5”x7”, Weight 10-15 lbs, Power 10-20 watts

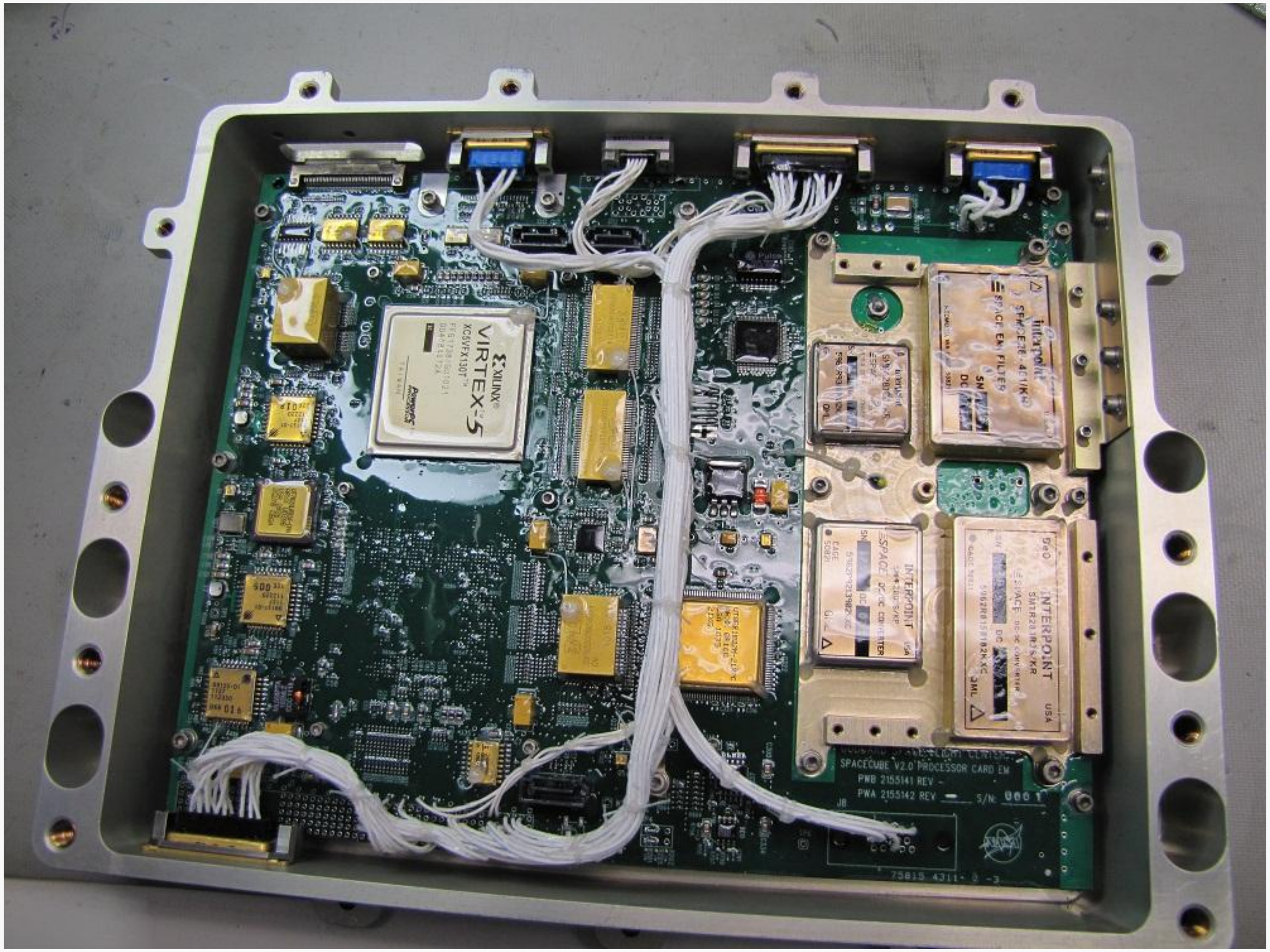
SpaceCube 2.0 Processor Card



SpaceCube Core Software

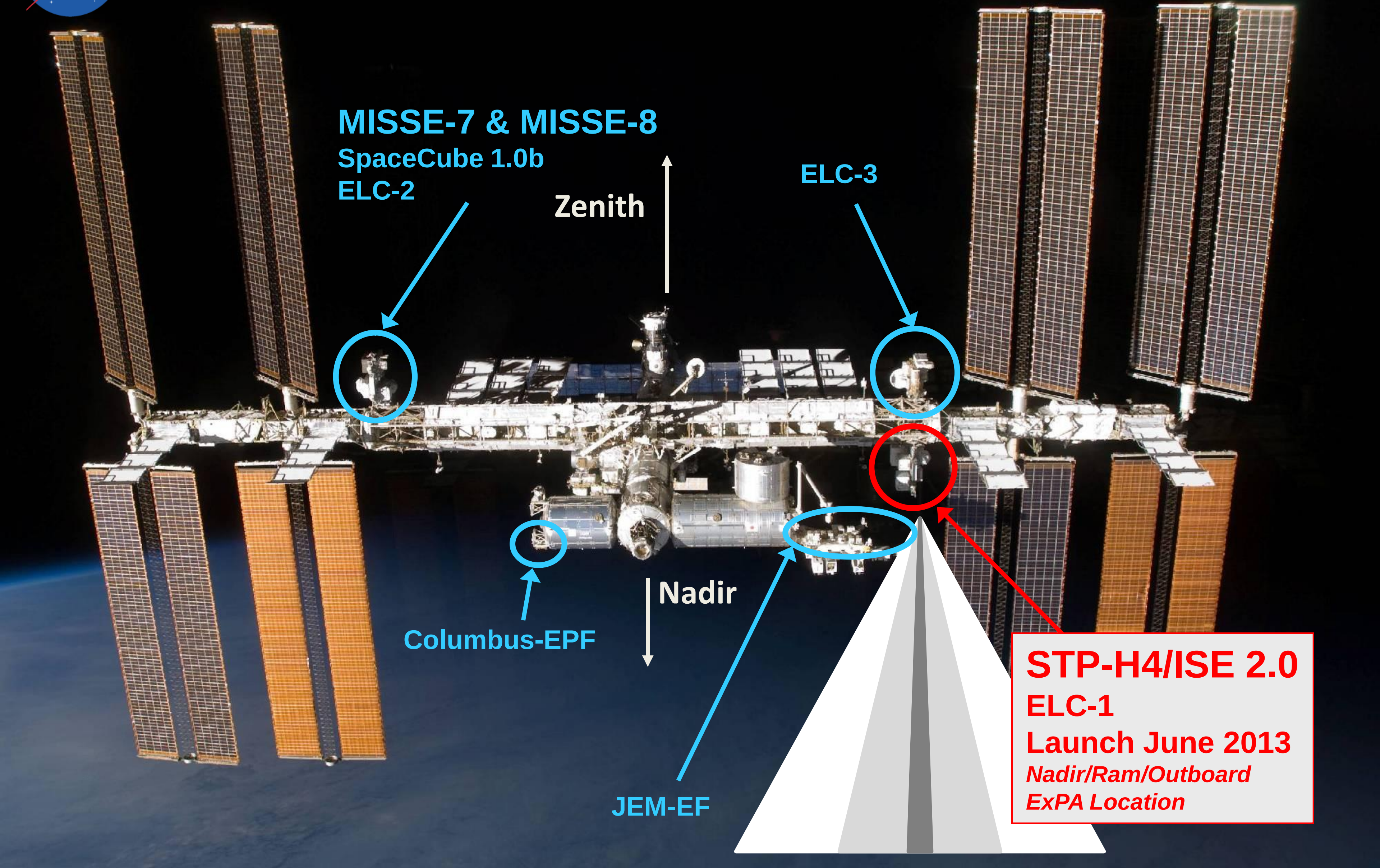


SpaceCube 2.0 EM for STP-H4



STP-H4 is a DoD Space Test Program payload/experiment pallet on the ISS

STP-H4 / ISE 2.0 Location & FOV

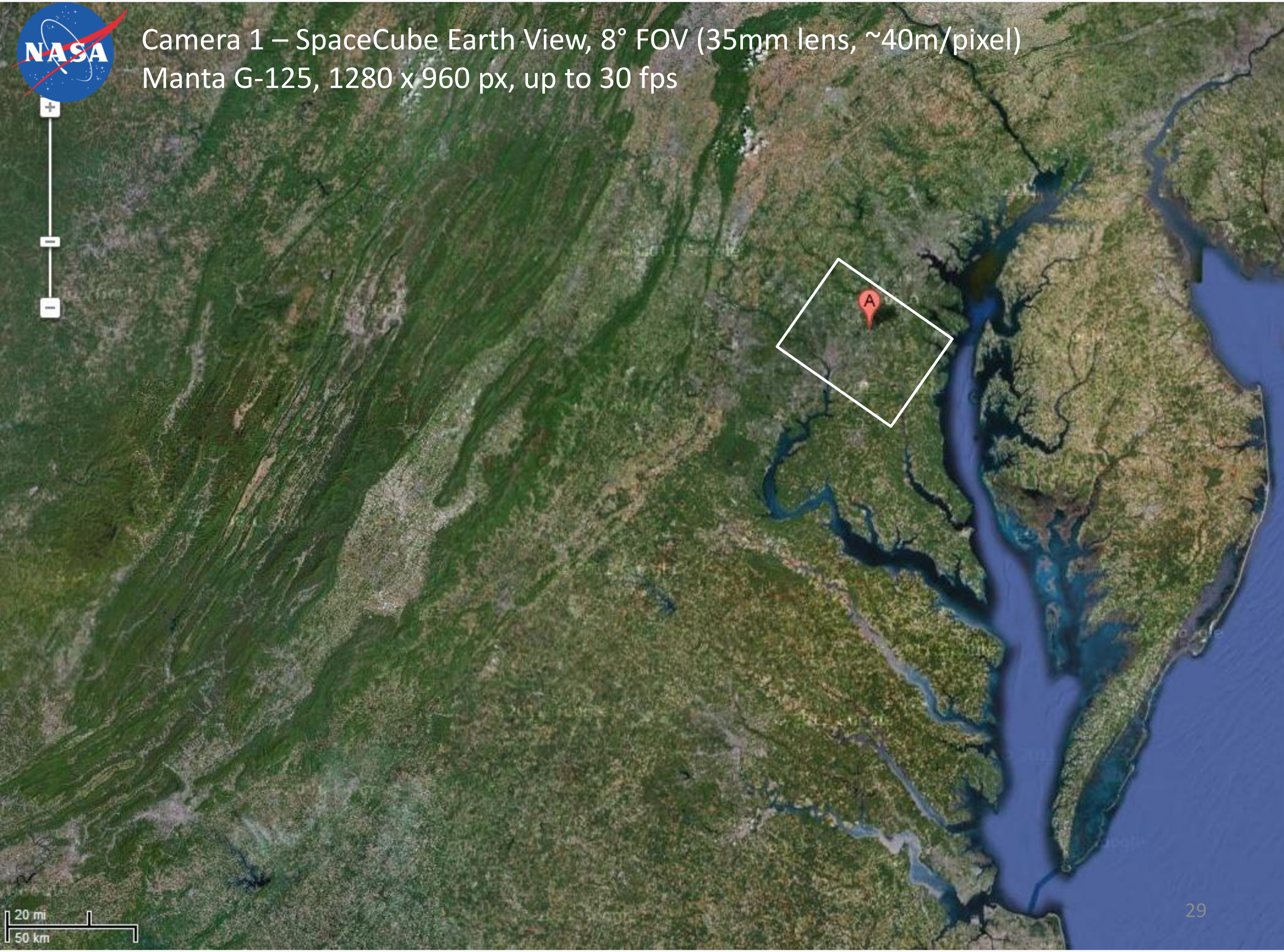


ISS Flying Towards You

Image Credit: DoD Space Test Program

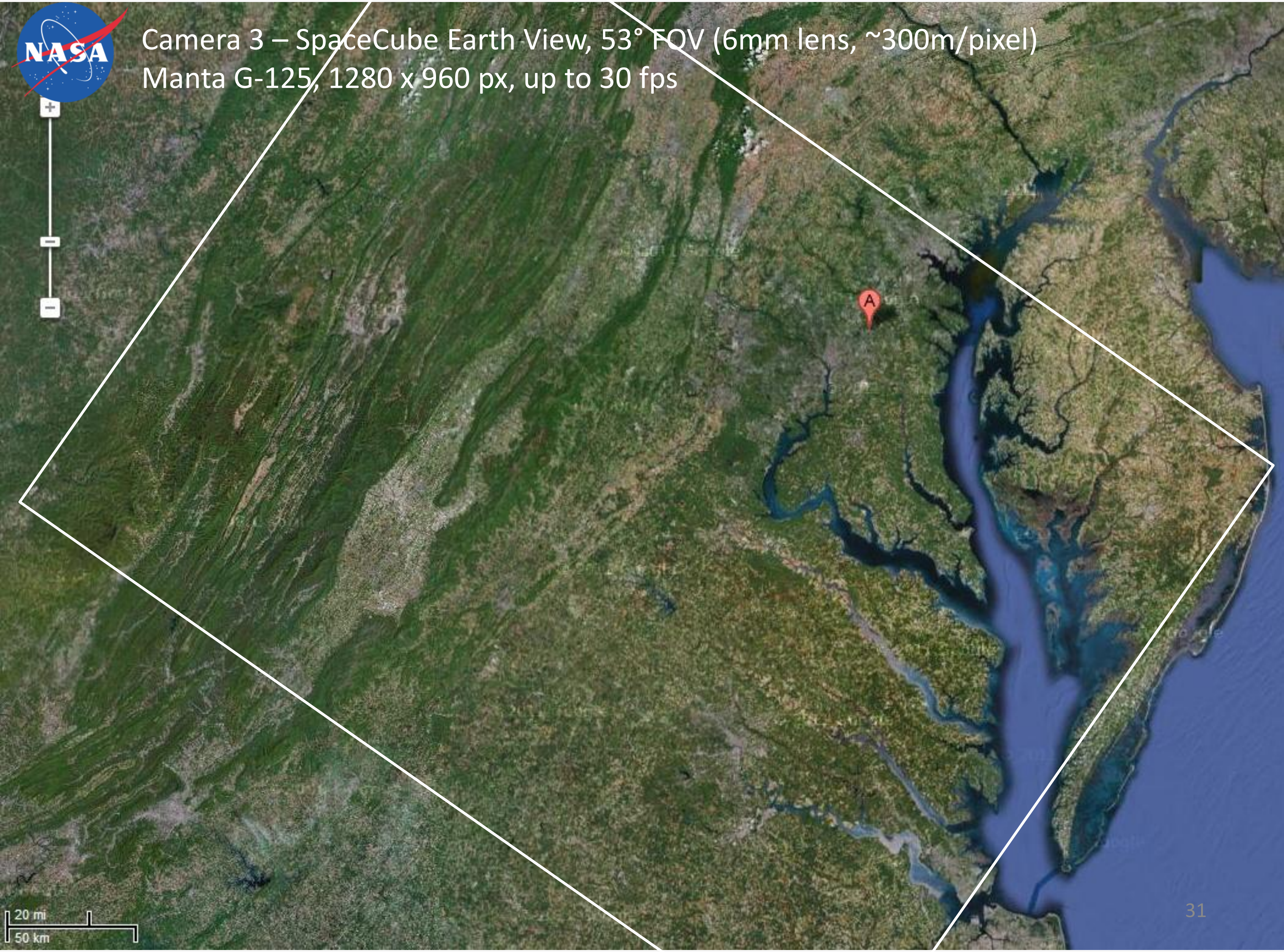
28

Camera 1 – SpaceCube Earth View, 8° FOV (35mm lens, ~40m/pixel)
Manta G-125, 1280 x 960 px, up to 30 fps



Camera 2 – SpaceCube Earth View, 32° FOV (8.5mm lens, ~175m/pixel)
Manta G-125, 1280 x 960 px, up to 30 fps

Camera 3 – SpaceCube Earth View, 53° FOV (6mm lens, ~300m/pixel)
Manta G-125, 1280 x 960 px, up to 30 fps



ISS Experiment Pallet: STP-H4

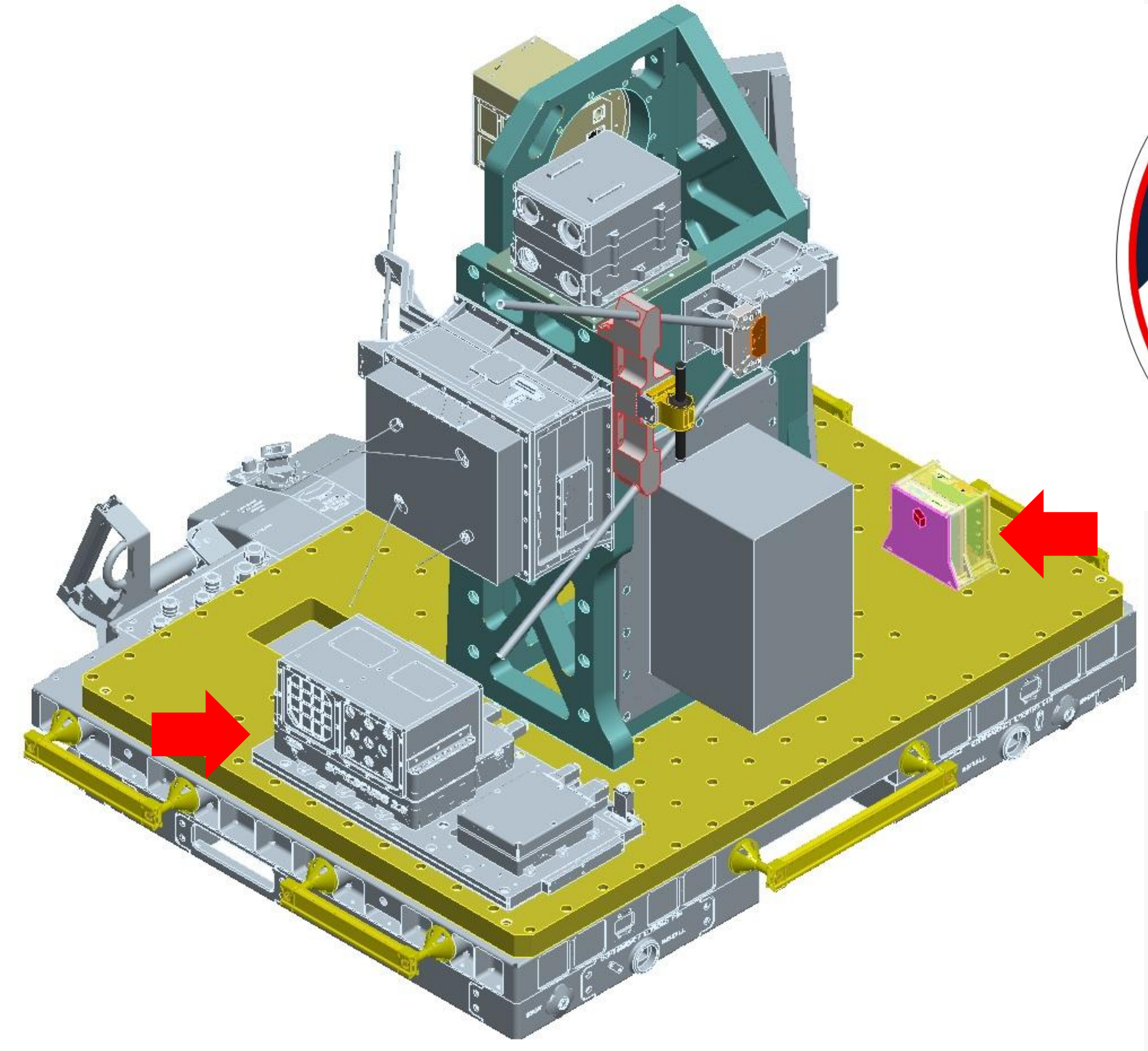


Image Credit: DoD Space Test Program

ISS SpaceCube Experiment 2.0

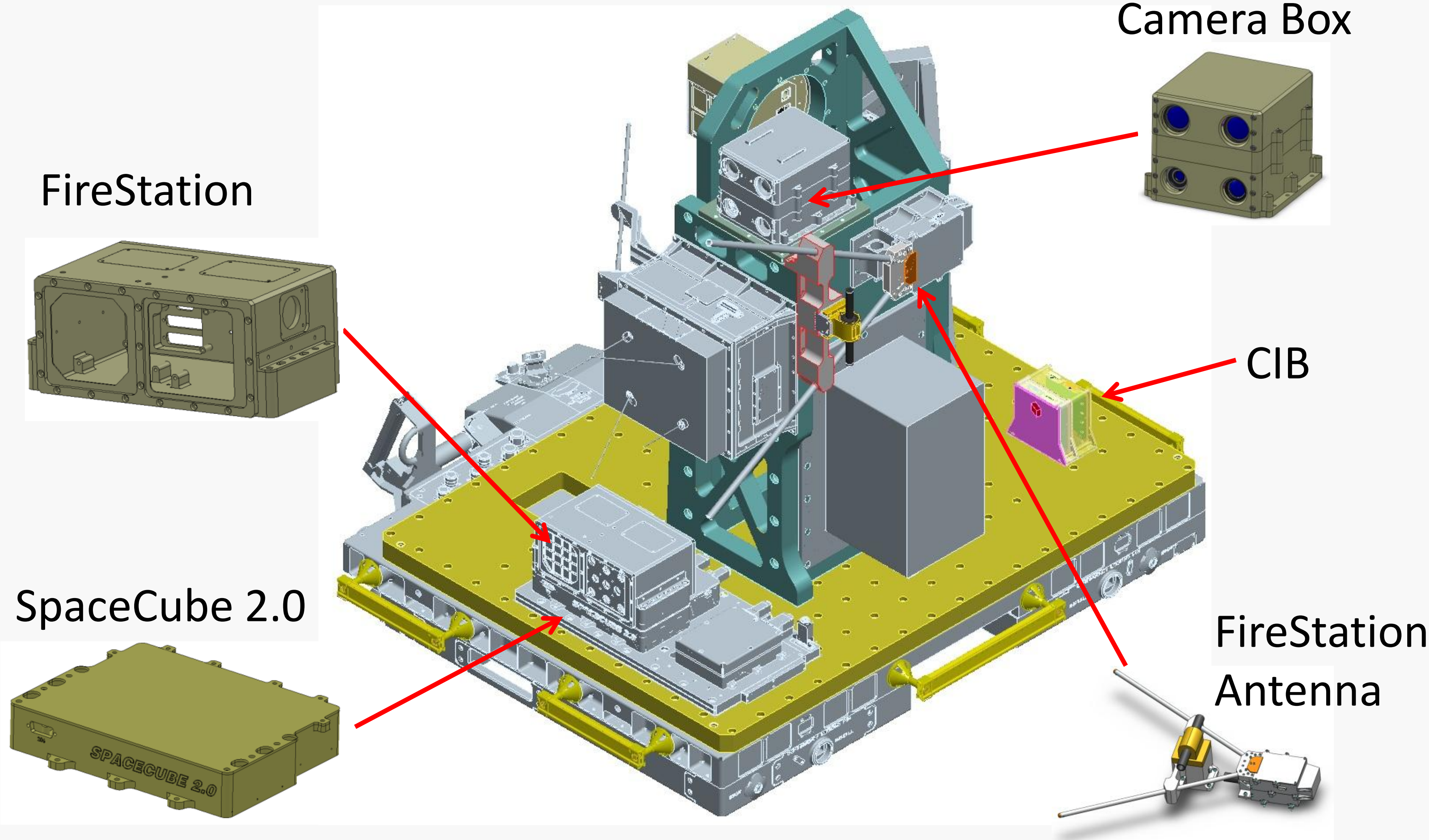
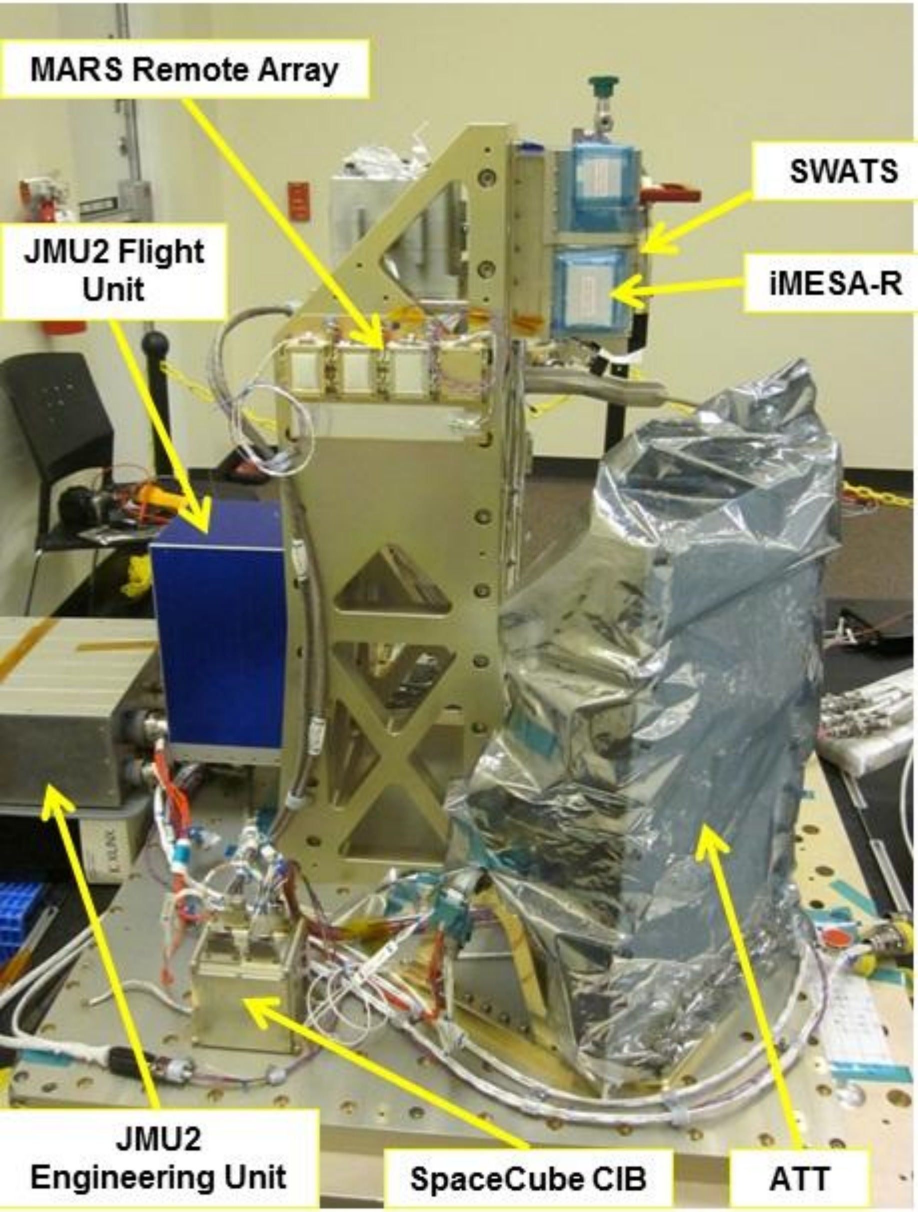
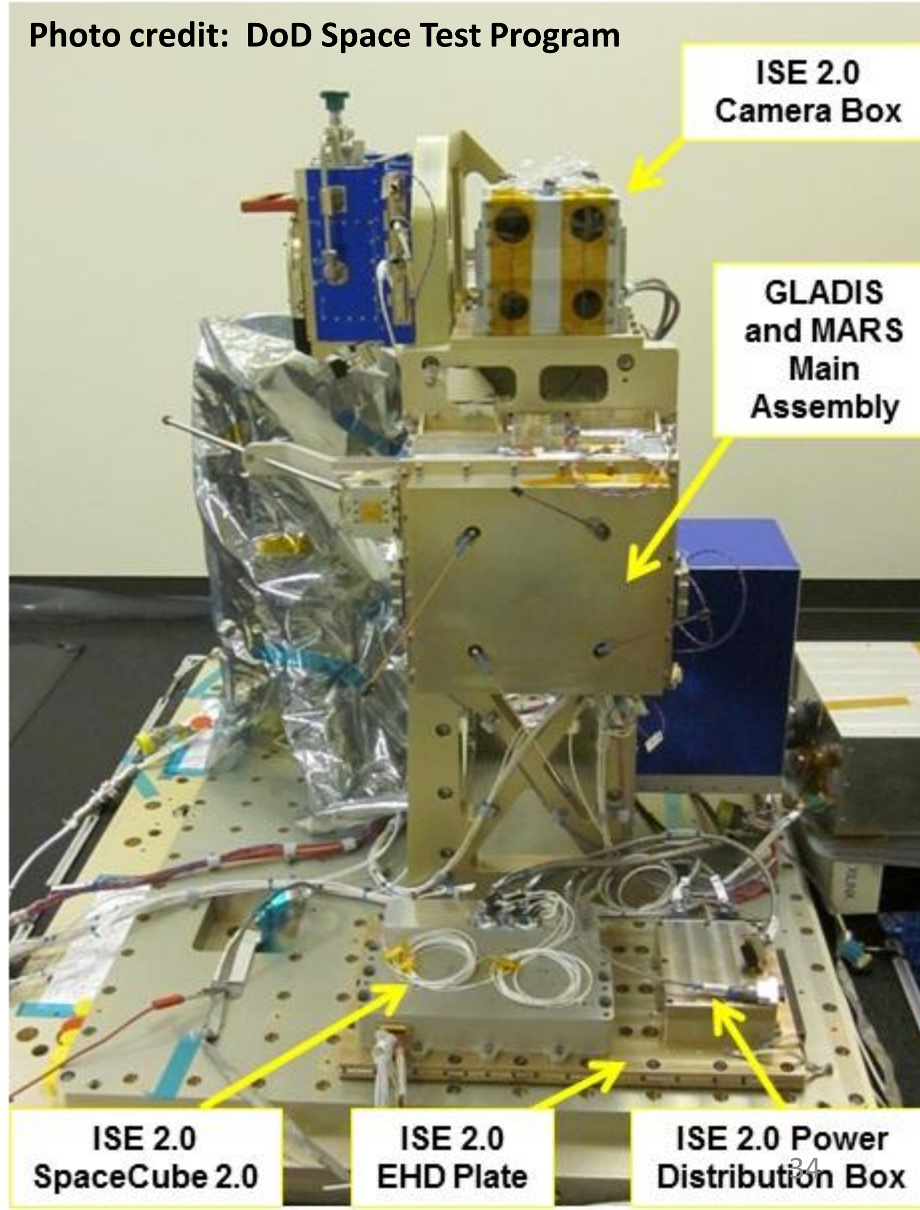


Image Credit: DoD Space Test Program

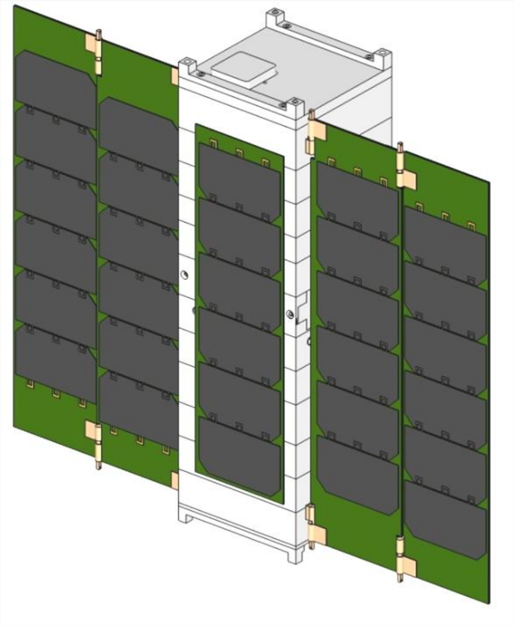
STP-H4 *as of 23 May 2012*

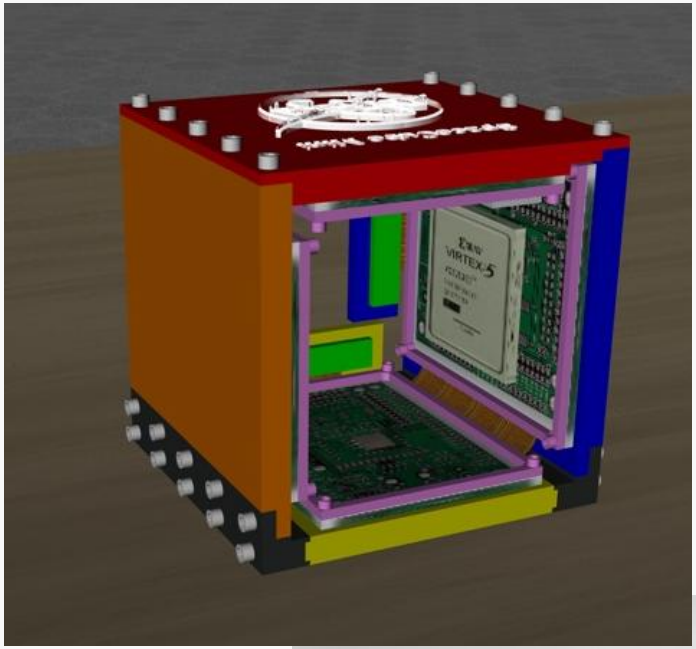
Image Credit: DoD Space Test Program

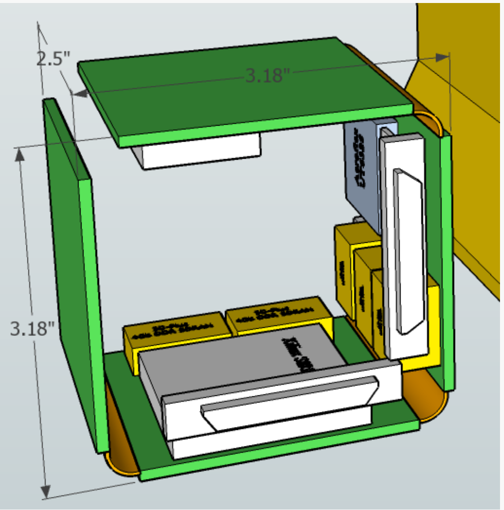


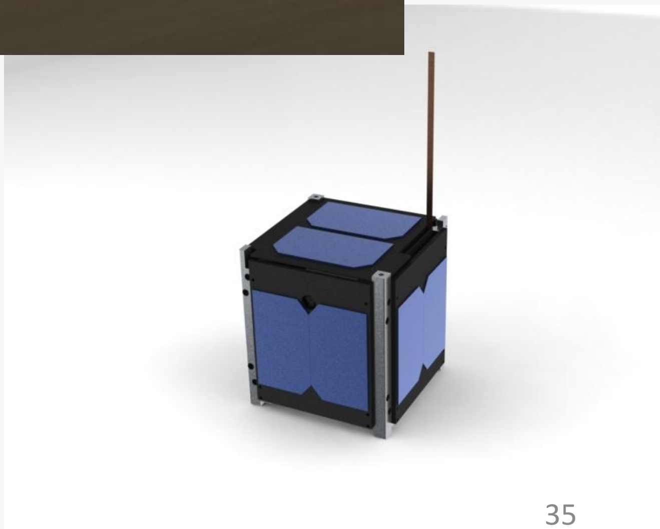


CubeSats: IPEX & TechCube 1

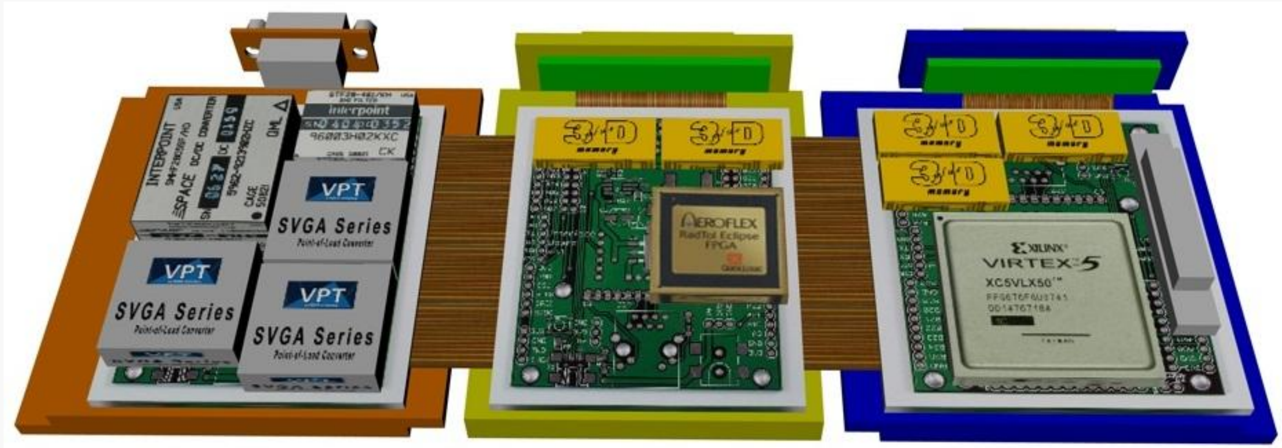


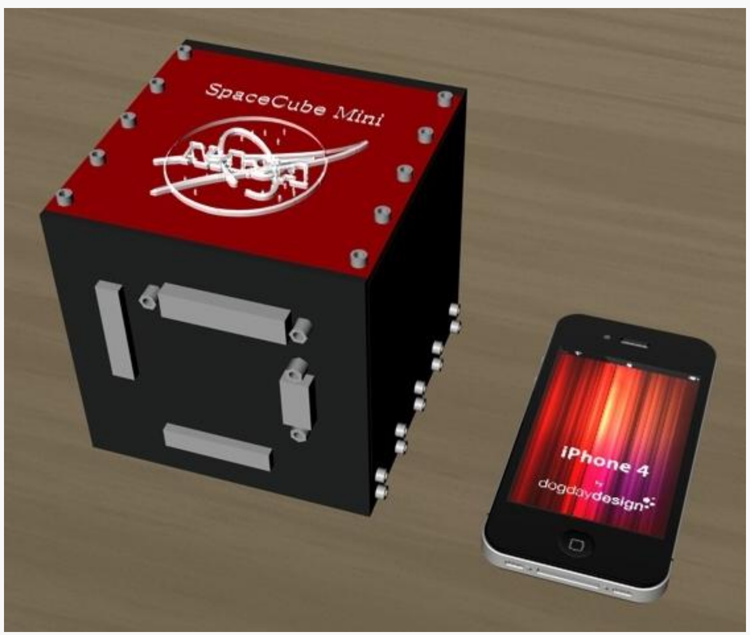


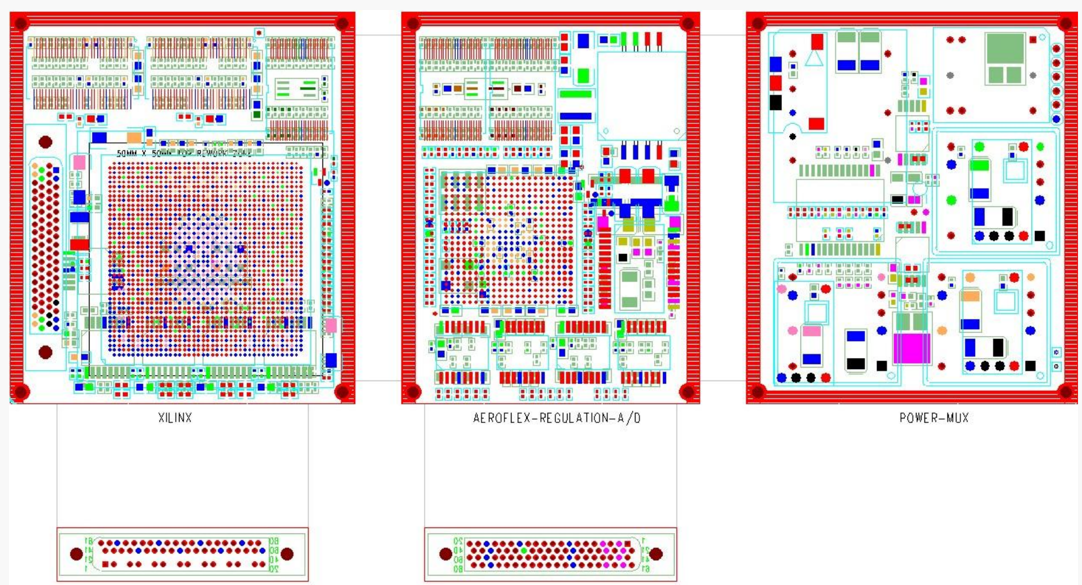




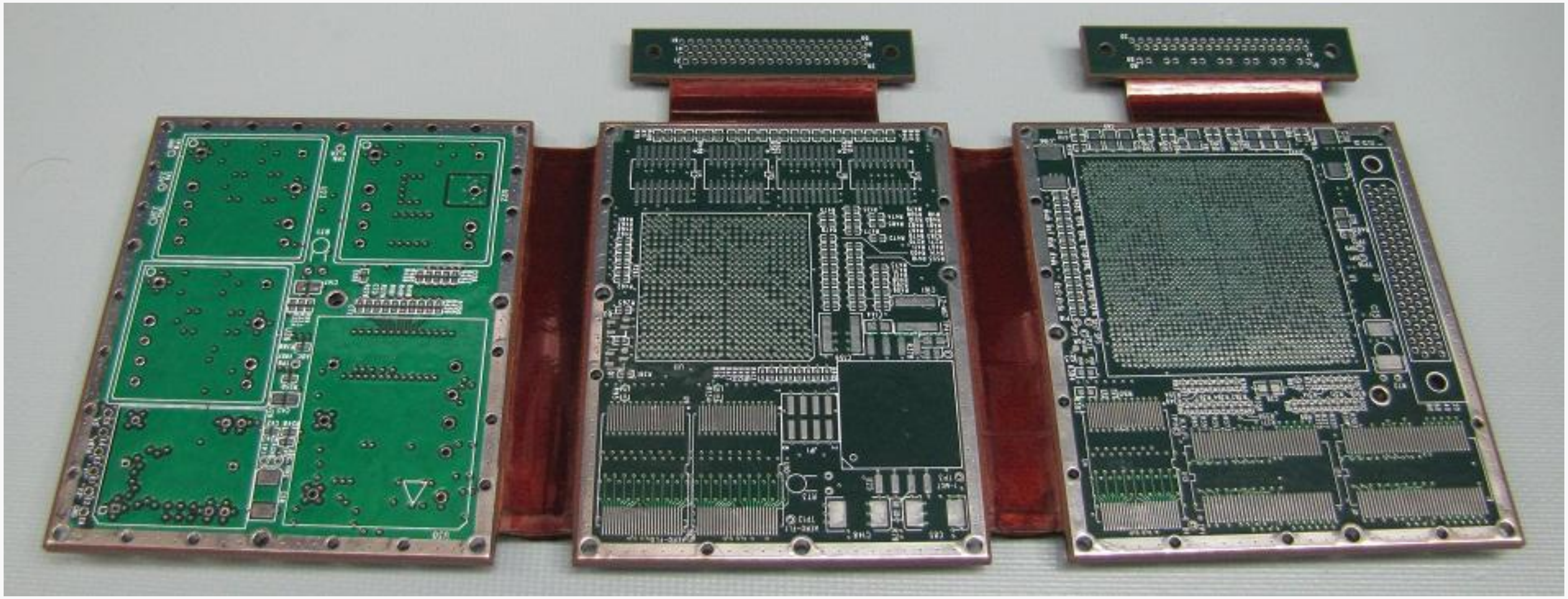
SpaceCube "Mini"



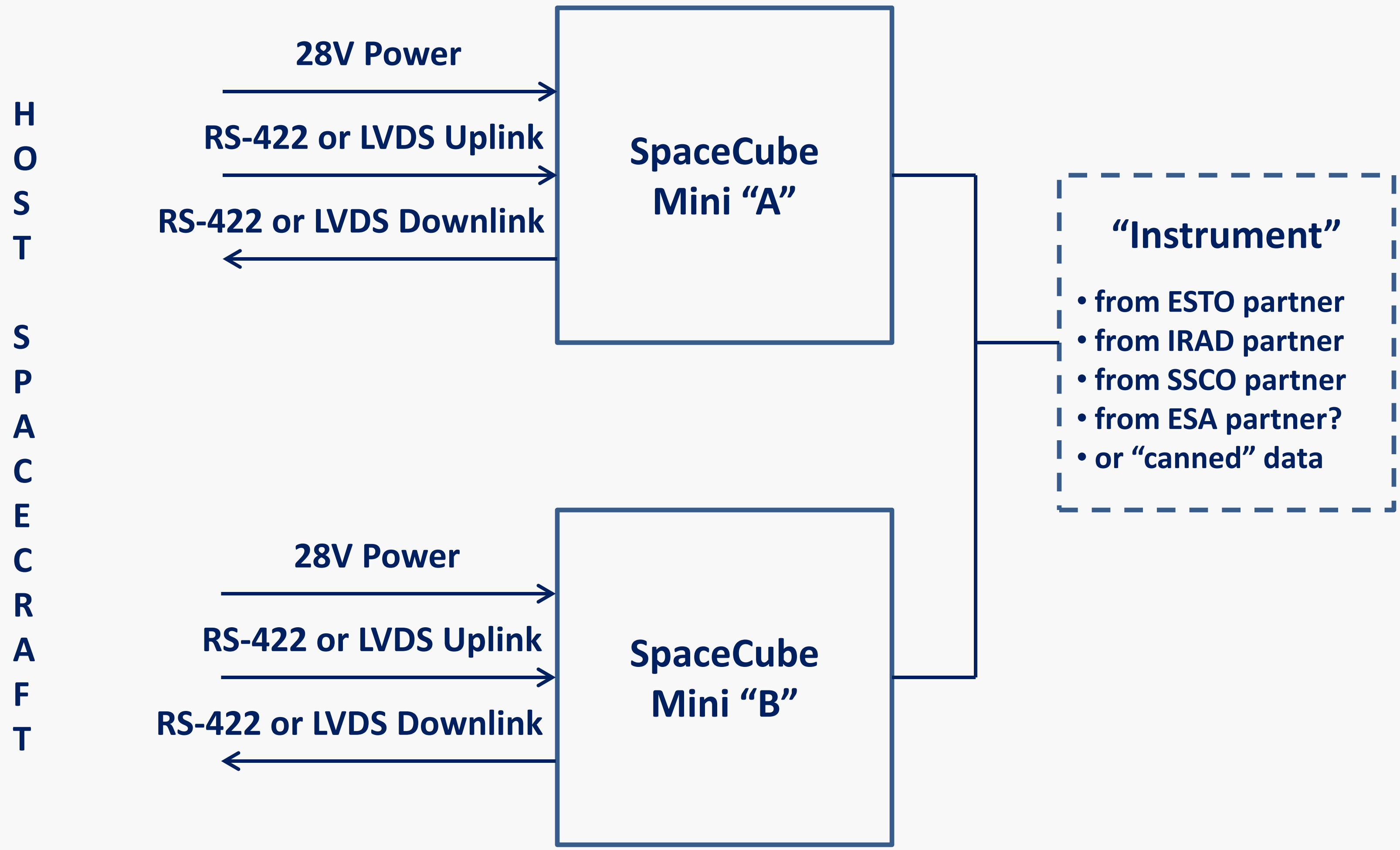




SpaceCube "Mini" for IPEX



SpaceCube At Geo Experiment (SAGE)



The SpaceCube Team

Questions ?

tom.flatley@nasa.gov

http://en.wikipedia.org/wiki/SpaceCube

http://gsfctechnology.gsfc.nasa.gov/SpaceCube.htm

http://esto.nasa.gov/conferences/estf2011/papers/Flatley_ESTF2011.pdf