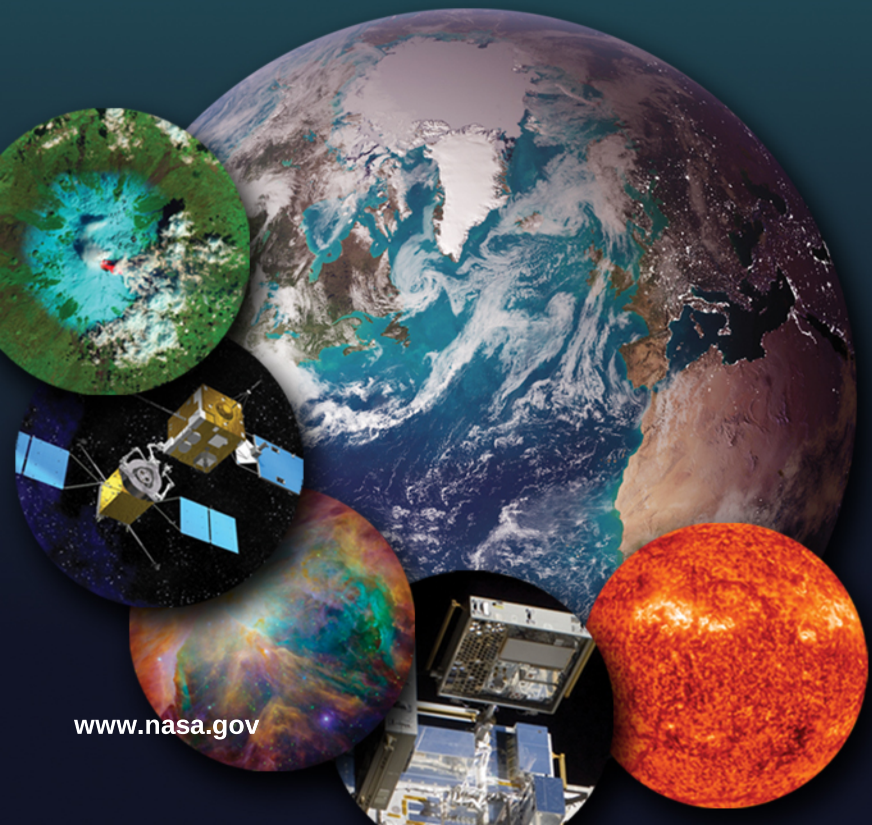
National Aeronautics and Space Administration

Adapting the SpaceCube v2.0 Data Processing System for Mission-Unique Application Requirements

SpaceCube



2015 AHS Conference
Montreal, Canada
June 16, 2015

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Principal Engineer

SCIENCE DATA PROCESSING BRANCH
Code 587 • NASA GSFC

www.nasa.gov

SpaceCube, Target Applications

- Small, light-weight, reconfigurable multi-processor platform for space flight applications demanding extreme processing capabilities
  - Reconfigurable components: FPGA, Software, Mechanical
  - Promote reuse between applications
- Hybrid Flight Computing: hardware acceleration of algorithms to enable onboard data processing and increased mission capabilities
- Example Applications: Instrument Data Interfacing and On-Board Processing, Autonomous Operations, Situational Awareness, Scalable Computing Architectures

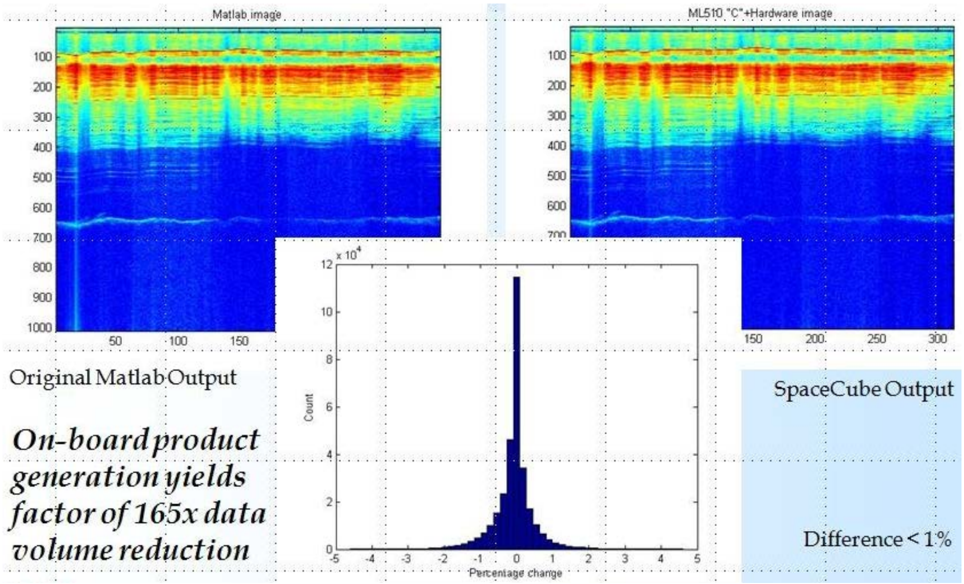
Hardware Algorithm Acceleration

Application	Xilinx Device	Acceleration vs CPU
SAR Altimeter	Virtex-4 FX60	**79x** vs PowerPC 405 (250MHz, 300 MIPS)
RNS GNFIR FPU, Edge	Virtex-4 FX60	**25x** vs PowerPC 405 (250MHz, 300 MIPS)
HHT EMD, Spline	Virtex-1 2000	**3x** vs Xeon Dual-Core (2.4GHz, 3000 MIPS)
Hyperspectral Data Compression	Virtex-1 1000	**2x** vs Xeon Dual-Core (2.4GHz, 3000 MIPS)
GOES-8 GndSys Sun correction	Virtex-1 300E	**6x** vs Xeon Dual-Core (2.4GHz, 3000 MIPS)

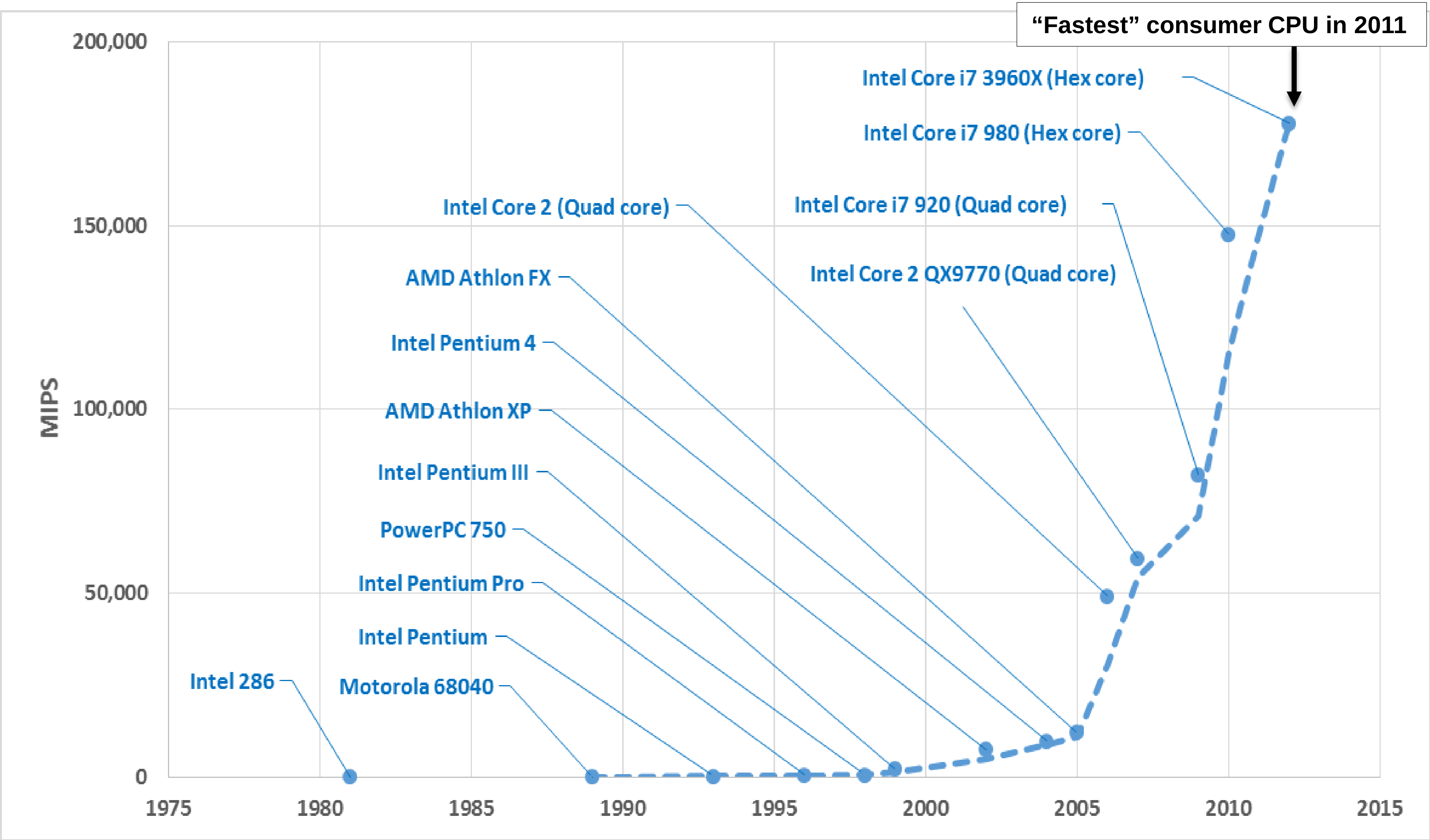
Notes:

1) **All functions involve processing large data sets (1MB+)**
2) **All timing includes moving data to/from FPGA**
3) **SpaceCube 2.0 is 4x to 20x more capable than these earlier systems**

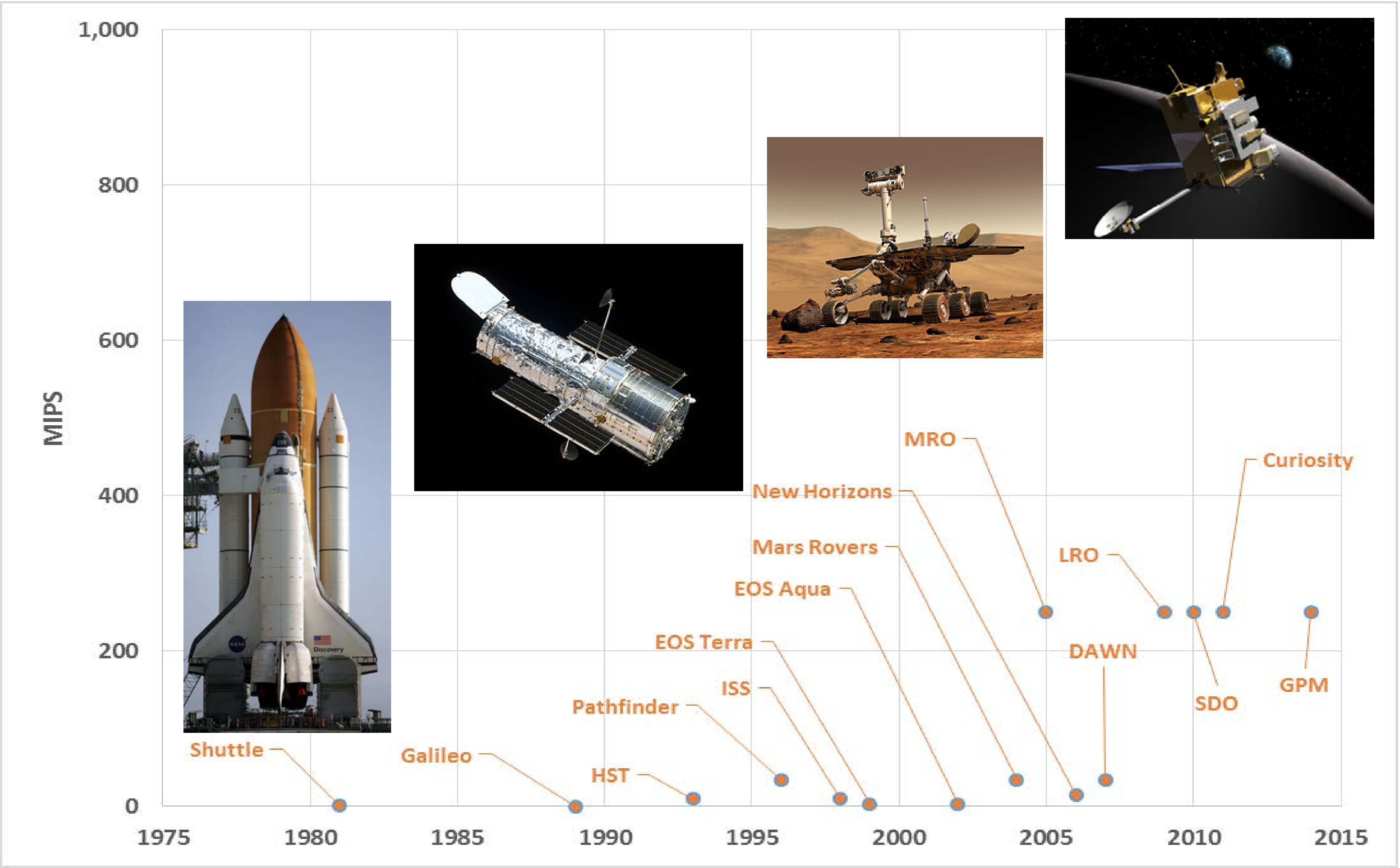
On-Board Data Reduction



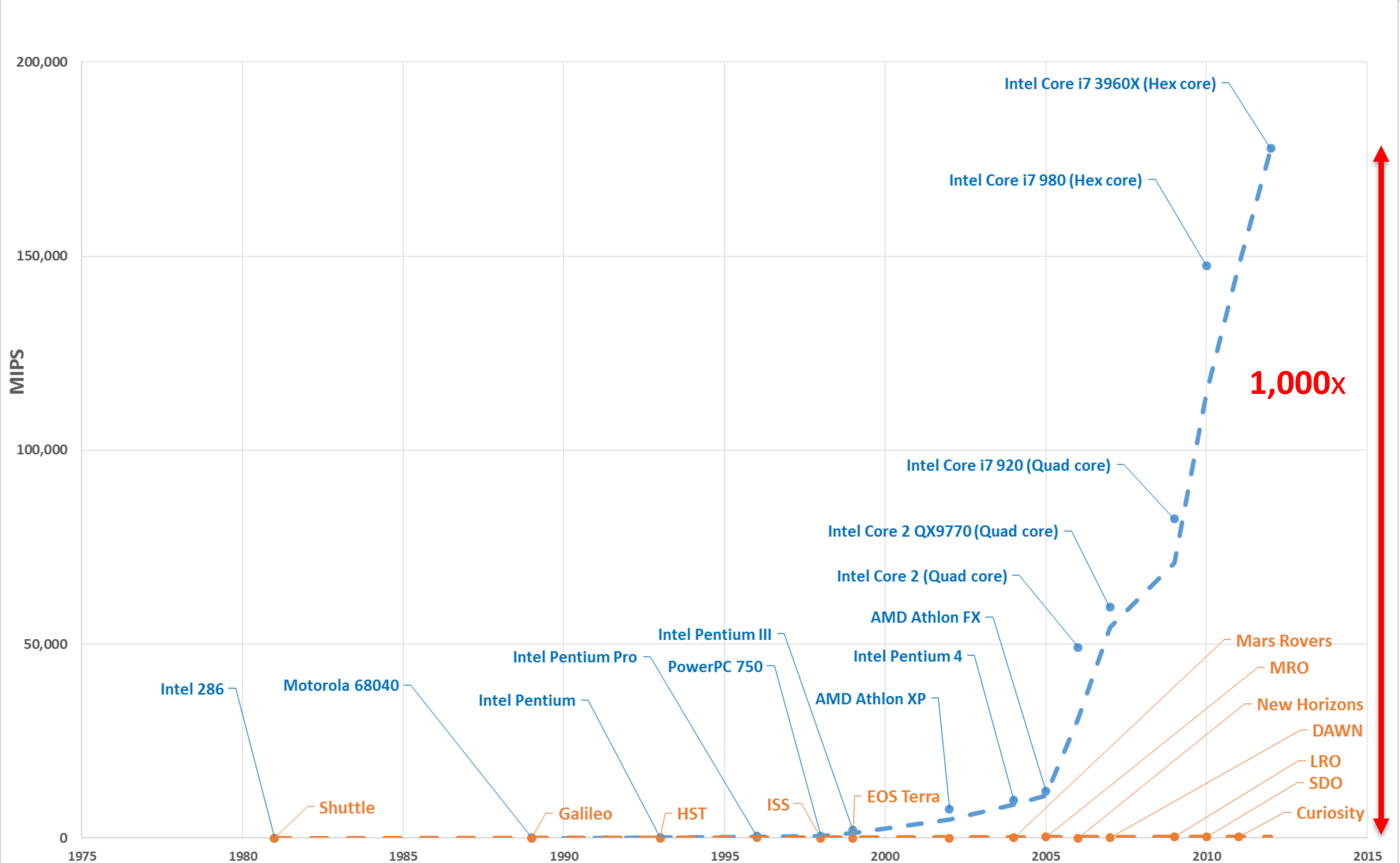
Commercial Processor Trend



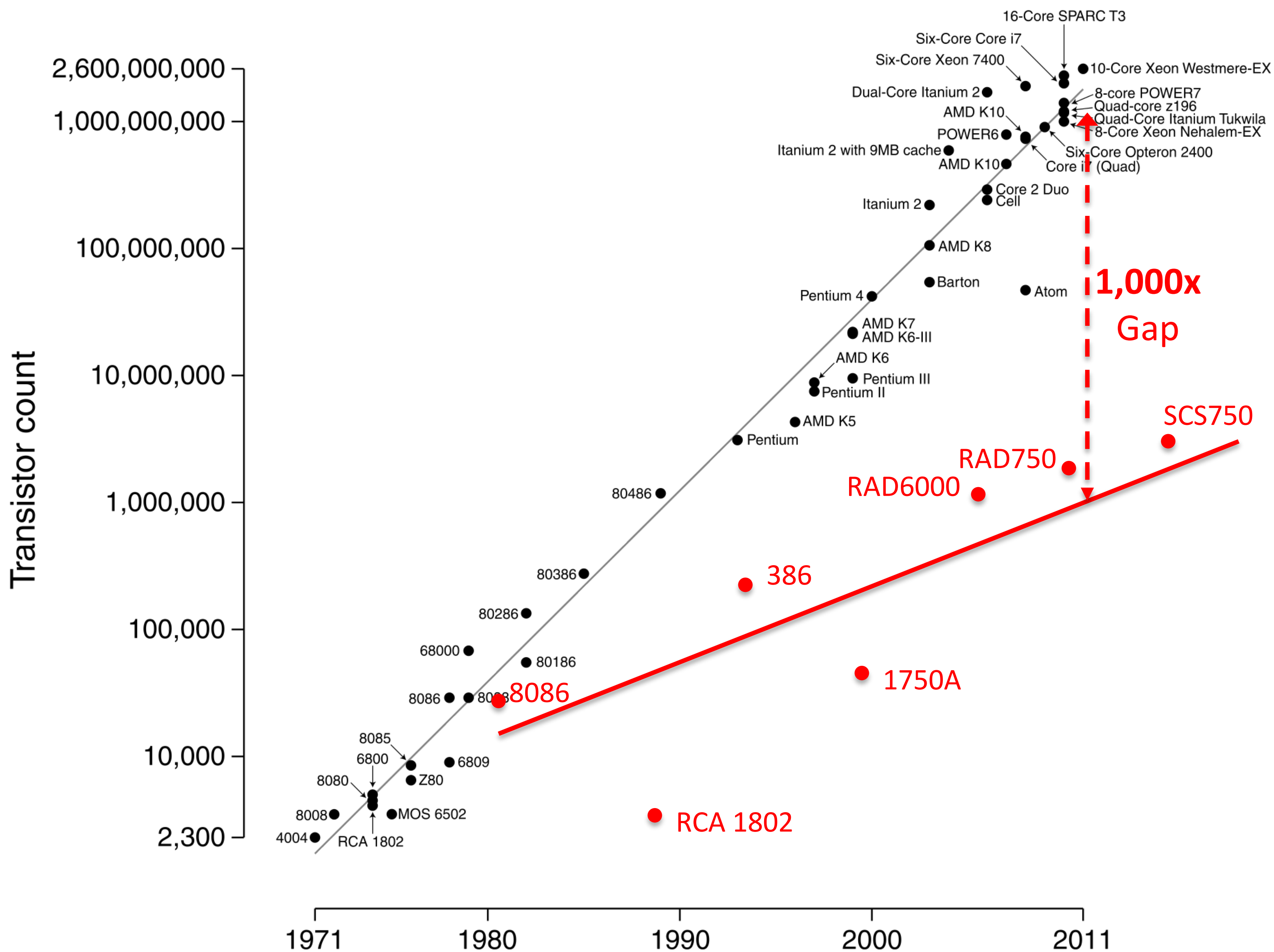
Space Processor Trend



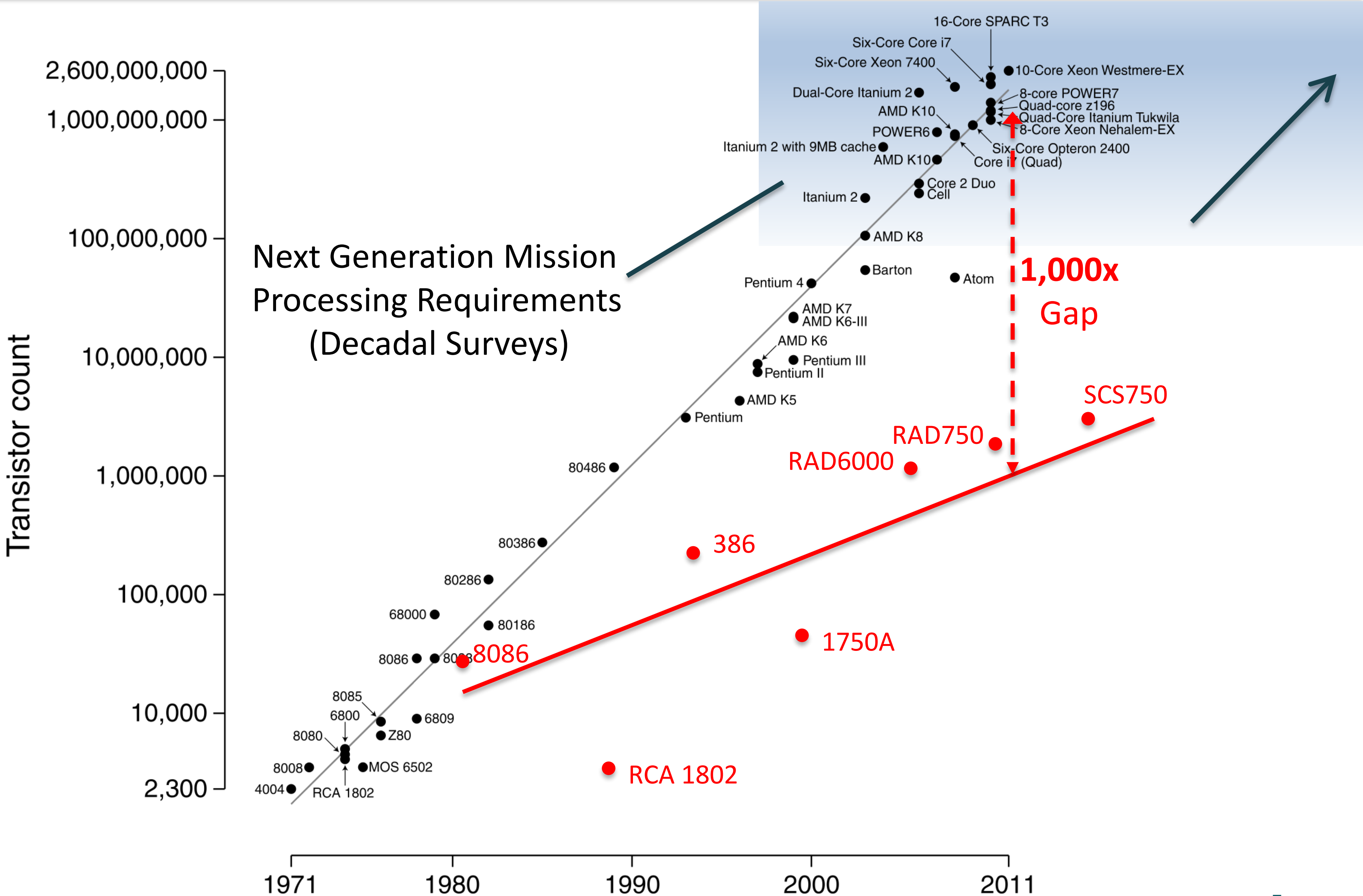
Processor Trend Comparison



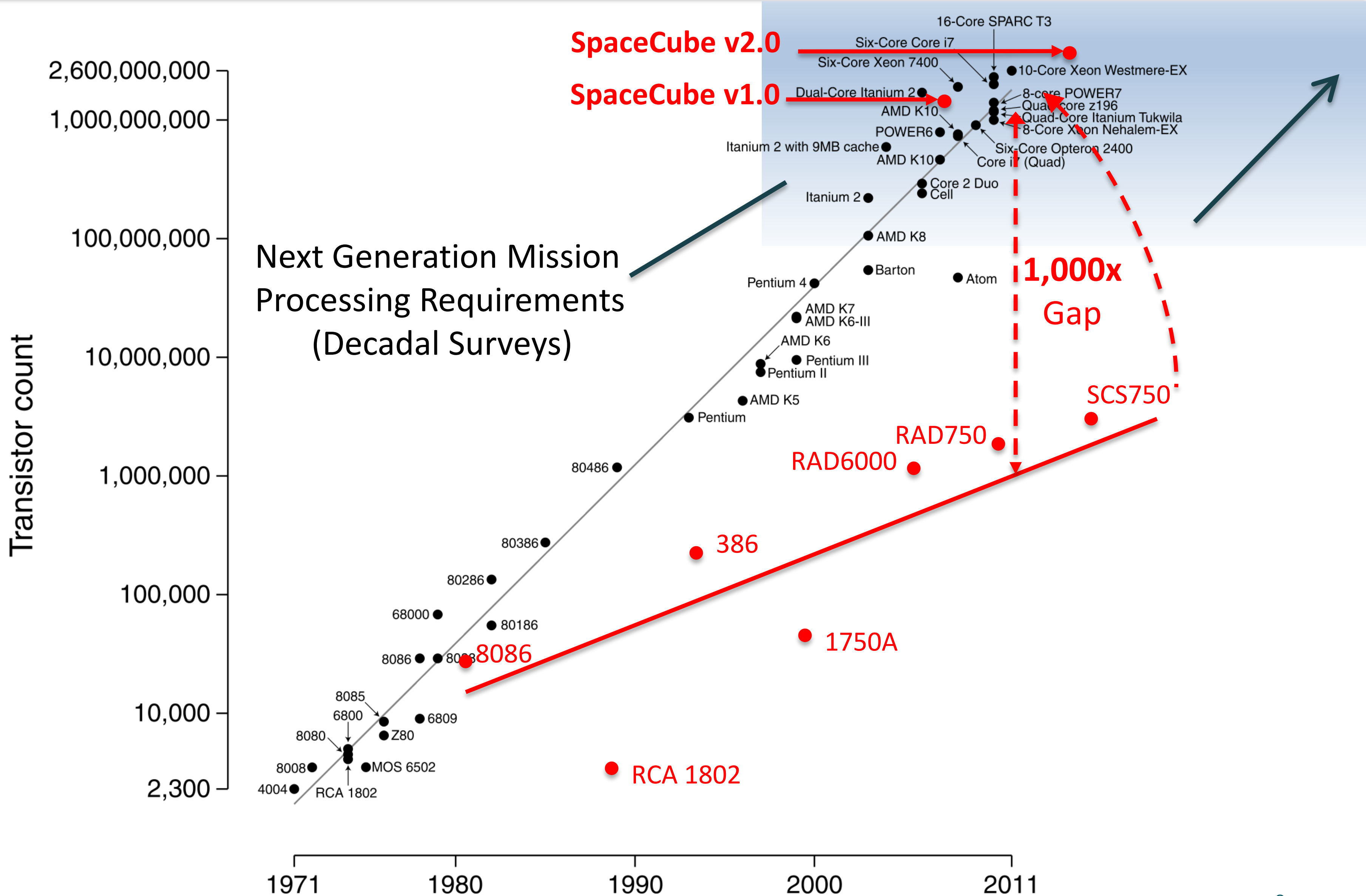
Processor Trend Comparison



Future Space Processing Requirement

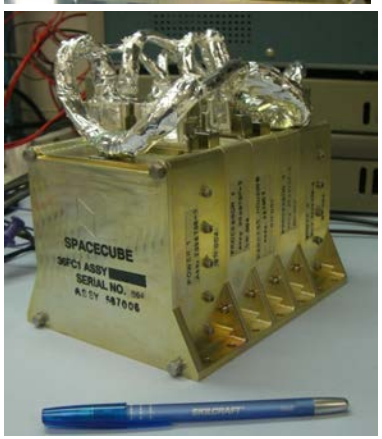


SpaceCube Closes the Gap



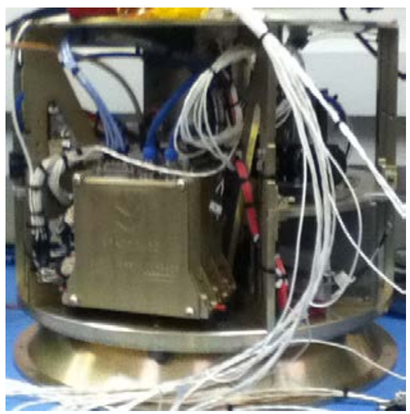
SpaceCube Family Overview

v1.0



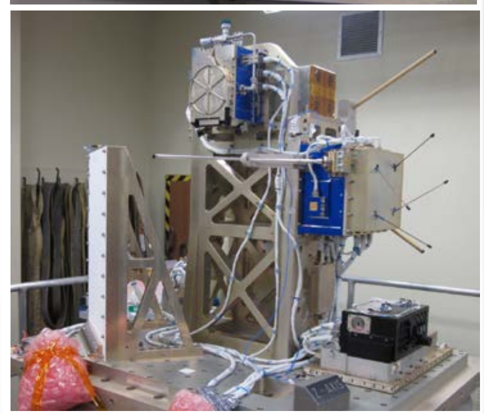
2009 STS-125
2009 MISSE-7
2013 STP-H4
2016 STP-H5

v1.5



2012 SMART

v2.0-EM

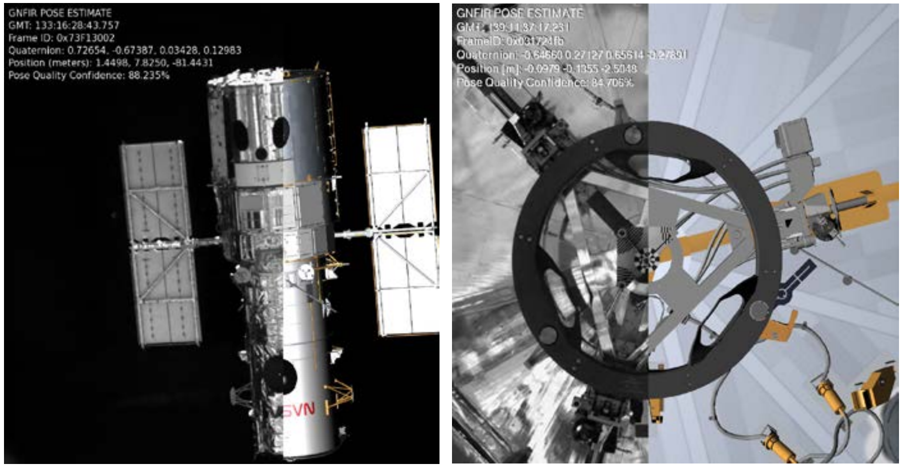


2013 STP-H4
2016 STP-H5

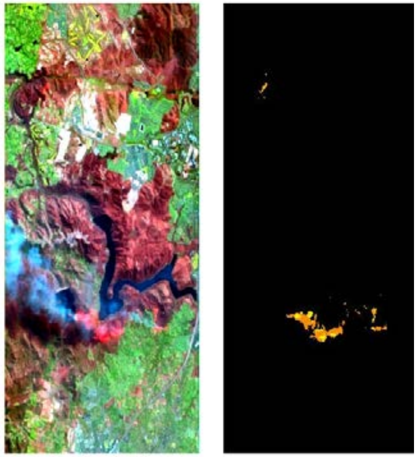
v2.0-FLT

2015 GPS Demo
- Robotic Servicing
- Numerous proposals for Earth/Space/Helio

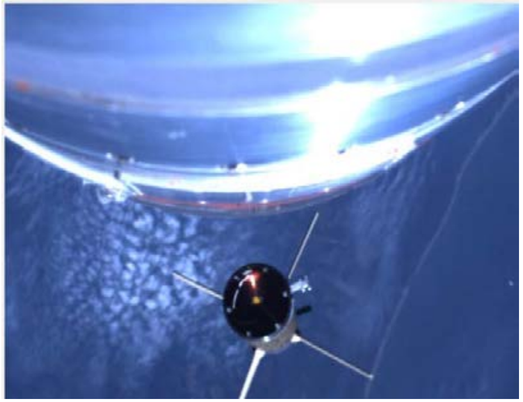
Example SpaceCube Processing



Real-Time Image Tracking of Hubble



Fire Classification



Gigabit Instrument Interfacing

Xilinx ISS Radiation Data

Spectrometer Data Reduction

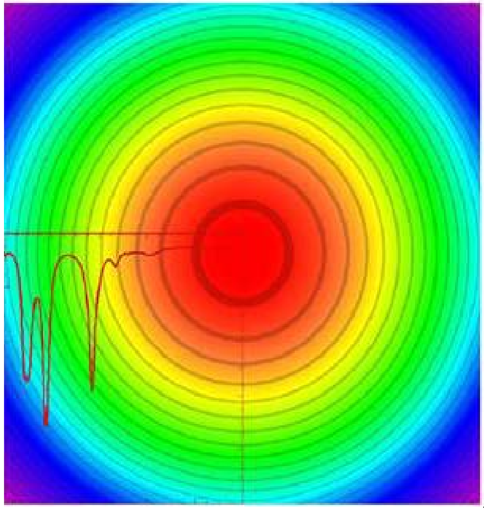
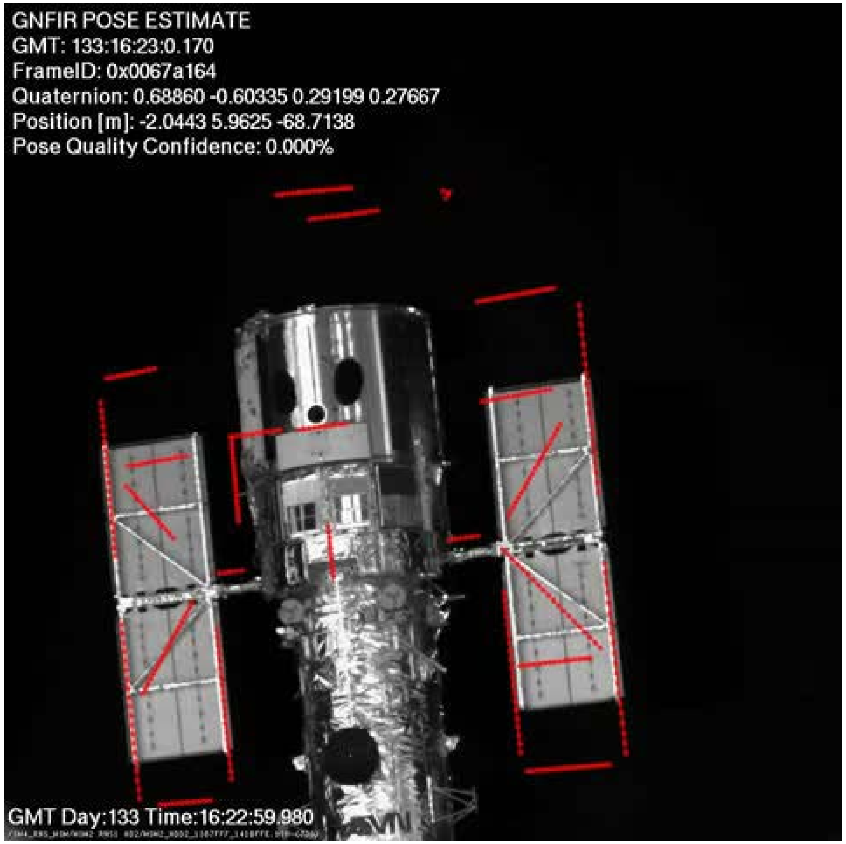


Image Compression

On-Board Image Processing

→ Successfully tracked Hubble position and orientation in real-time operations
→ FPGA Algorithm Acceleration was required to meet 3Hz loop requirement

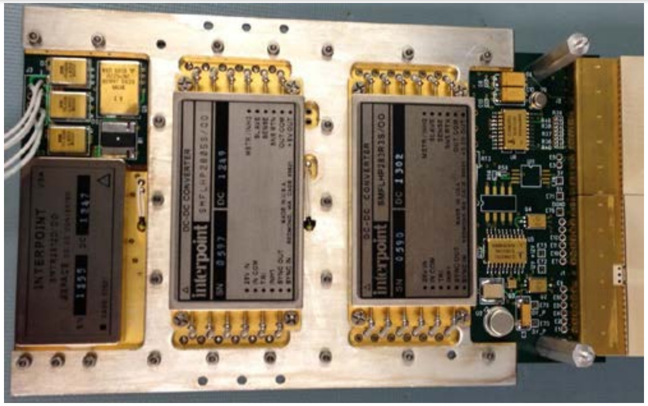


Rendezvous

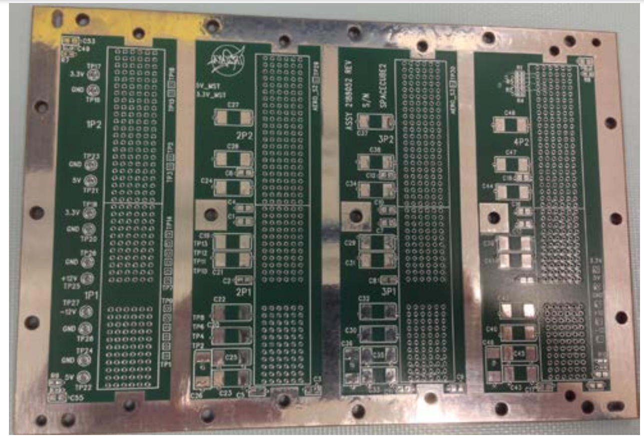
Deploy (Docking Ring)

→ Typical space flight processors are 25-100x too slow for this application

SpaceCube v2.0 Flight System

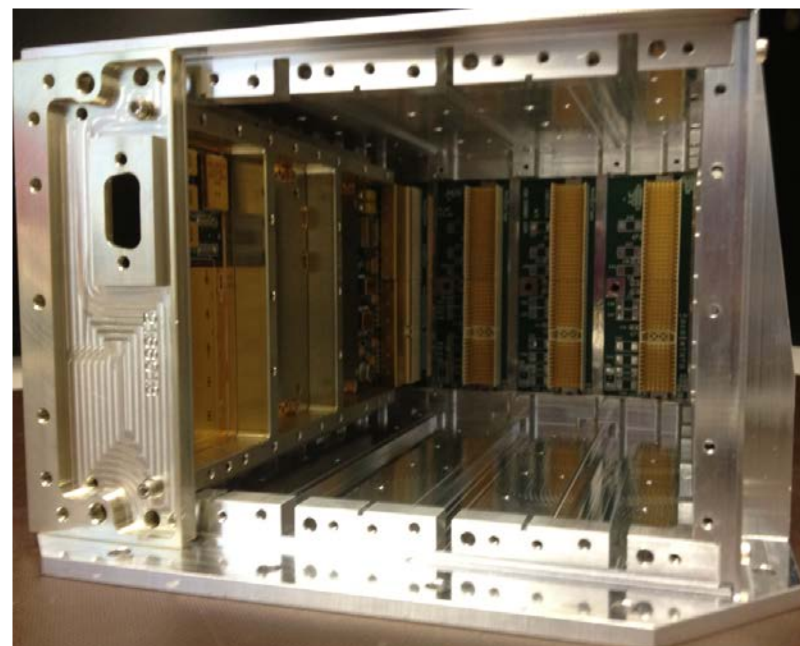


Power Card
- 22-38V Input, 7A limit
- 5V/80W, 3.3V/53W, +/-12V/24W

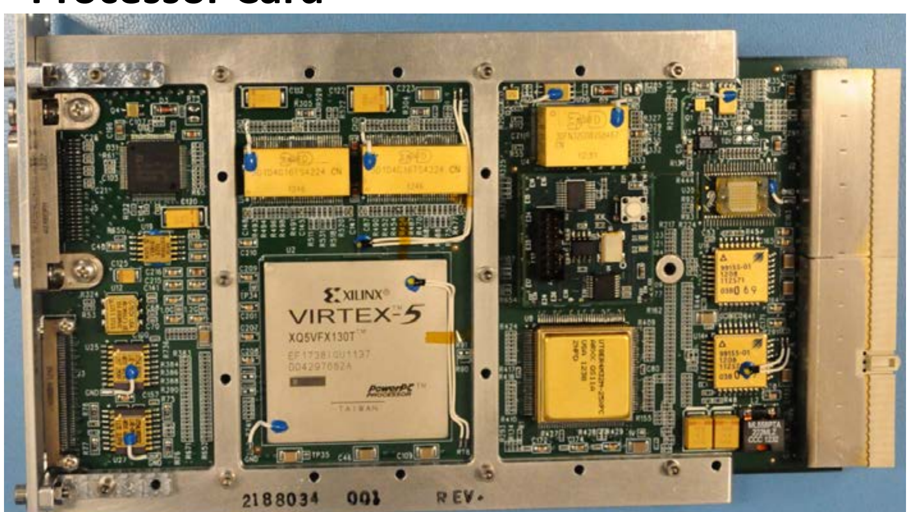


Backplane Card
- 4 slots
- Point-to-Point
- Gigabit SERDES
- 2 processors, 1 I/O
- 3 processors

Chassis: 12.7 x 23 x 27 cm^3

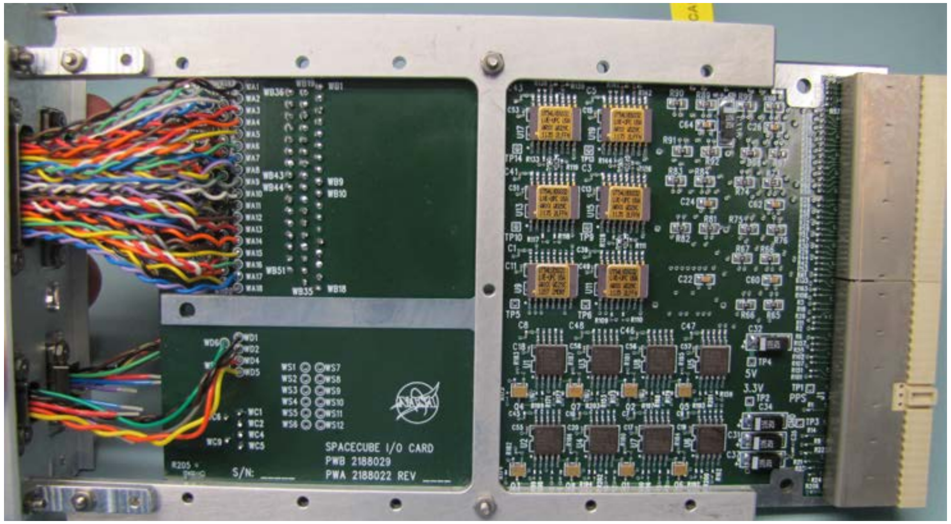


Processor Card



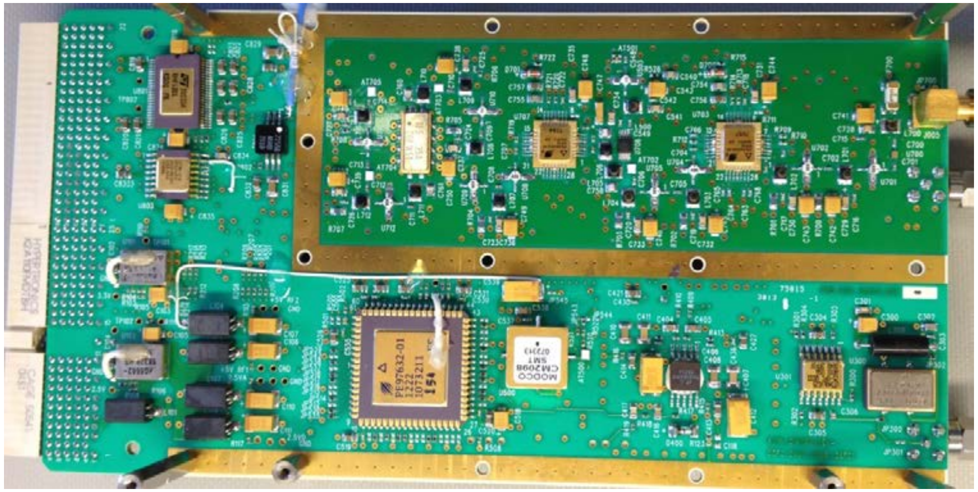
Example Mission-Unique I/O Cards

Video/Spacecraft Interface Card



LIDAR High Speed Digitizer

GPS RF Front-End Interface Card



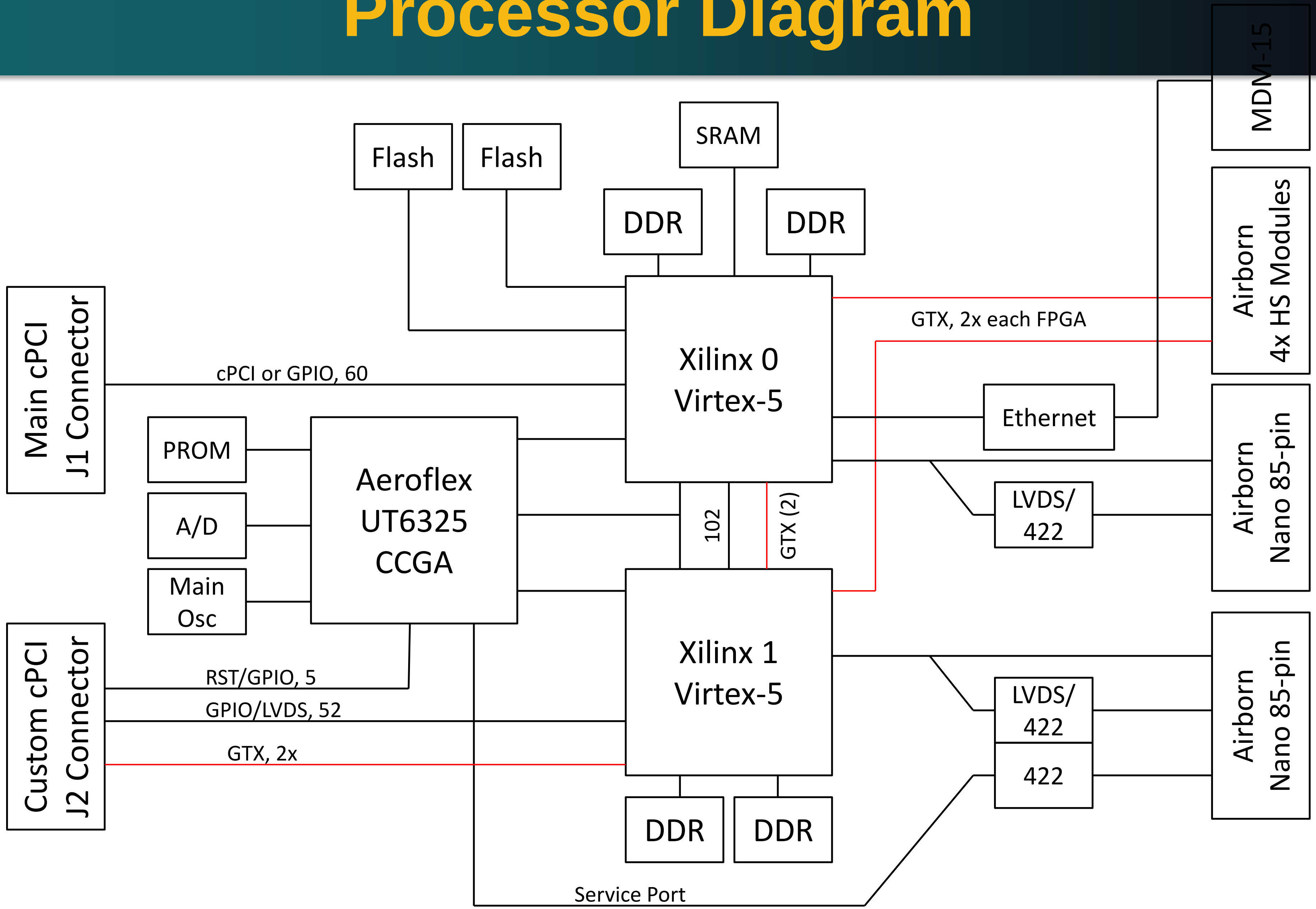
LIDAR Front-End Interface Card

Processor Card

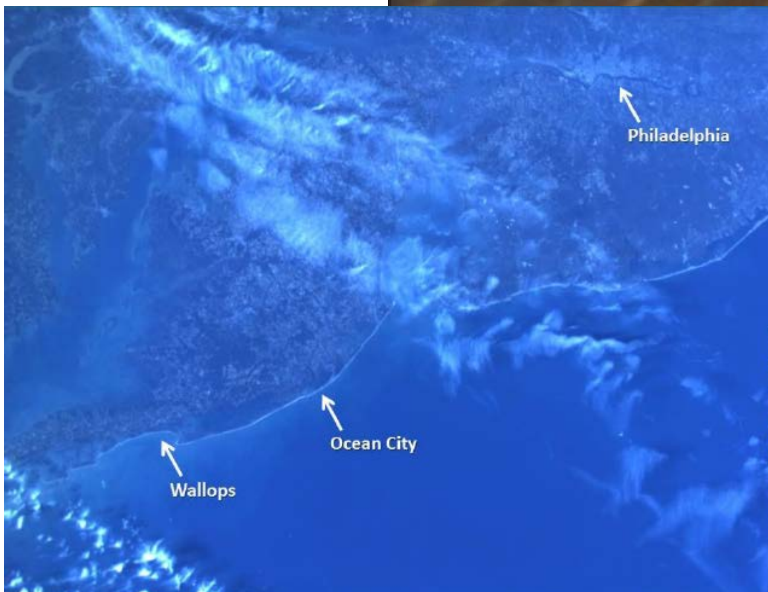
Power Draw: 10-15W
Weight: 0.98-lbs
22 Layers, Via-in-Pad
IPC 6012B Class 3/A

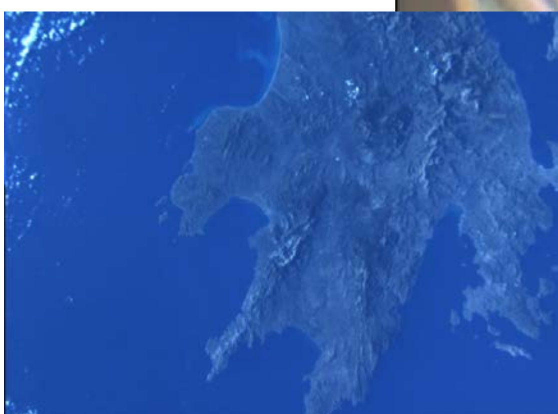
- 2x Xilinx Virtex-5 (QV) FX130T FPGAs
- 1x Aeroflex CCGA FPGA
  - Xilinx Configuration, Watchdog, Timers
  - Auxiliary Command/Telemetry port
- 1x 128Mb PROM, contains initial Xilinx configuration files
- 1x 16MB SRAM, rad-hard with auto EDAC/scrub feature
- 4x 512MB DDR SDRAM
- 2x 4GB NAND Flash
- 16-channel Analog/Digital circuit for system health
- Optional 10/100 Ethernet interface
- Gigabit interfaces: 4x external, 2x on backplane
- 12x Full-Duplex dedicated differential channels
- 88 GPIO/LVDS channels directly to Xilinx FPGAs
- Mechanical support for heat sink options and stiffener for Xilinx devices

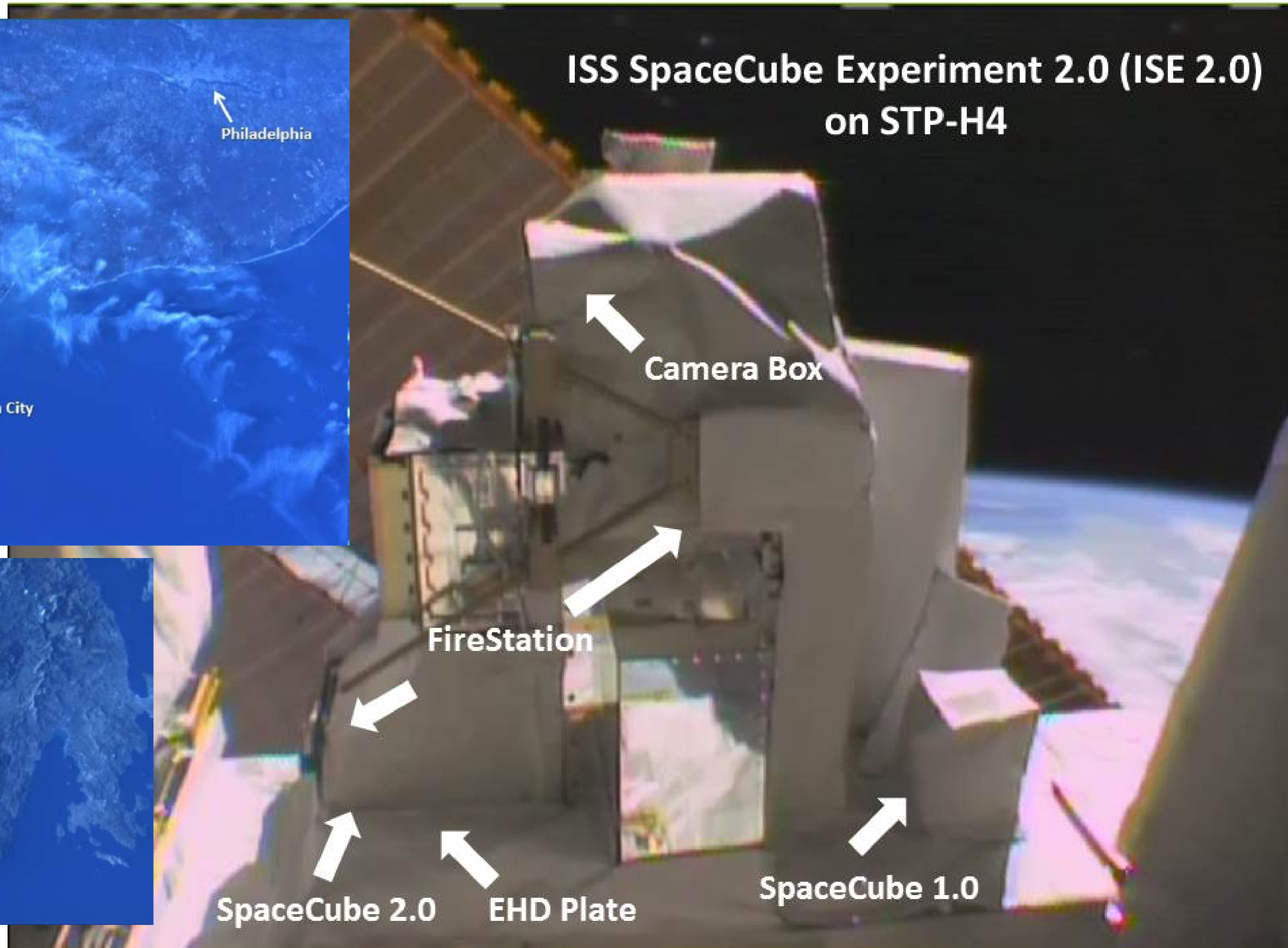
Processor Diagram



STP-H4 Operational on ISS







Next Up: STP-H5 in 2016

Adapting the SpaceCube Platform

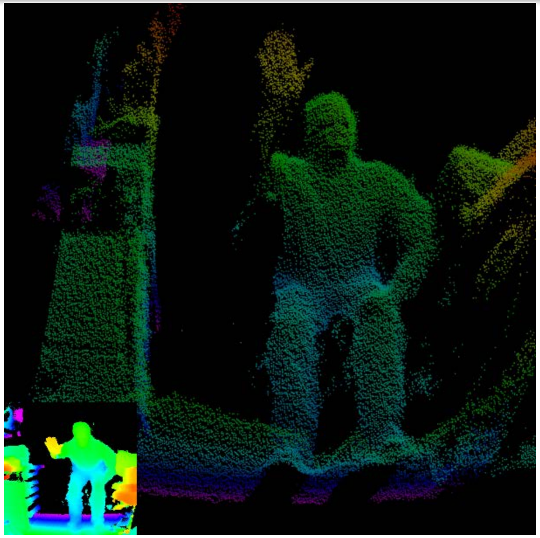
1) SpaceCube-based Lidar
   - Goddard Reconfigurable Solid State Lidar (GRSSLi)

2) SpaceCube-based GPS
   - Based on NASA/GSFC Heritage “Navigator” Technology

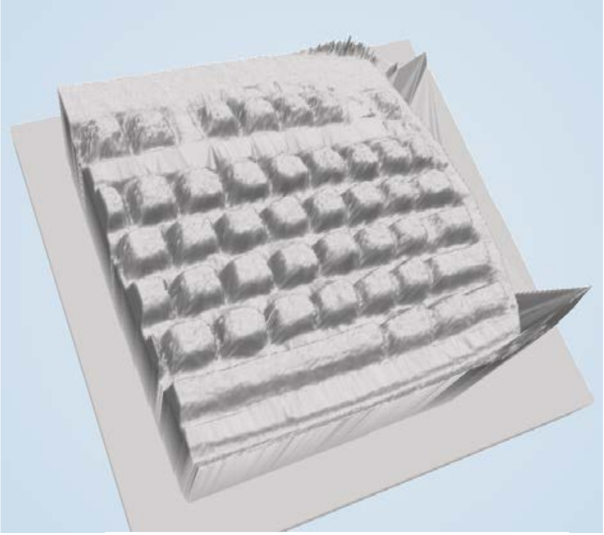
3) ISS Robotic Avionics
   - Robotic Refueling Mission 3 (RRM3)

LiDAR Application (GRSSLi)

- Imaging LiDAR based on MEMS Scanning Mirror
- What can it do?
  - High quality & high rate proximity operations range imaging
    - 6mm range resolution, <1cm noise 1σ, 5µs per pixel
    - Variable rate/ spatial resolution
      - 3Hz @ 256x256 pixels, 12Hz @128x128pixels
    - Variable field of view, +/- 20° max (currently)
    - Variable fiber laser to extend dynamic range
      - <0.5m to 50 meter range max with 2µJ laser
  - Science quality sub-millimeter range resolution scans
    - Demonstrated 380µm resolution, 480µm noise 1σ
    - Geophysical science
    - Model building and reconnaissance
  - Range finding
    - 182 meters demonstrated with 1 second average
- All capabilities listed **<u>do not</u>** require hardware modifications
  - Software configurable



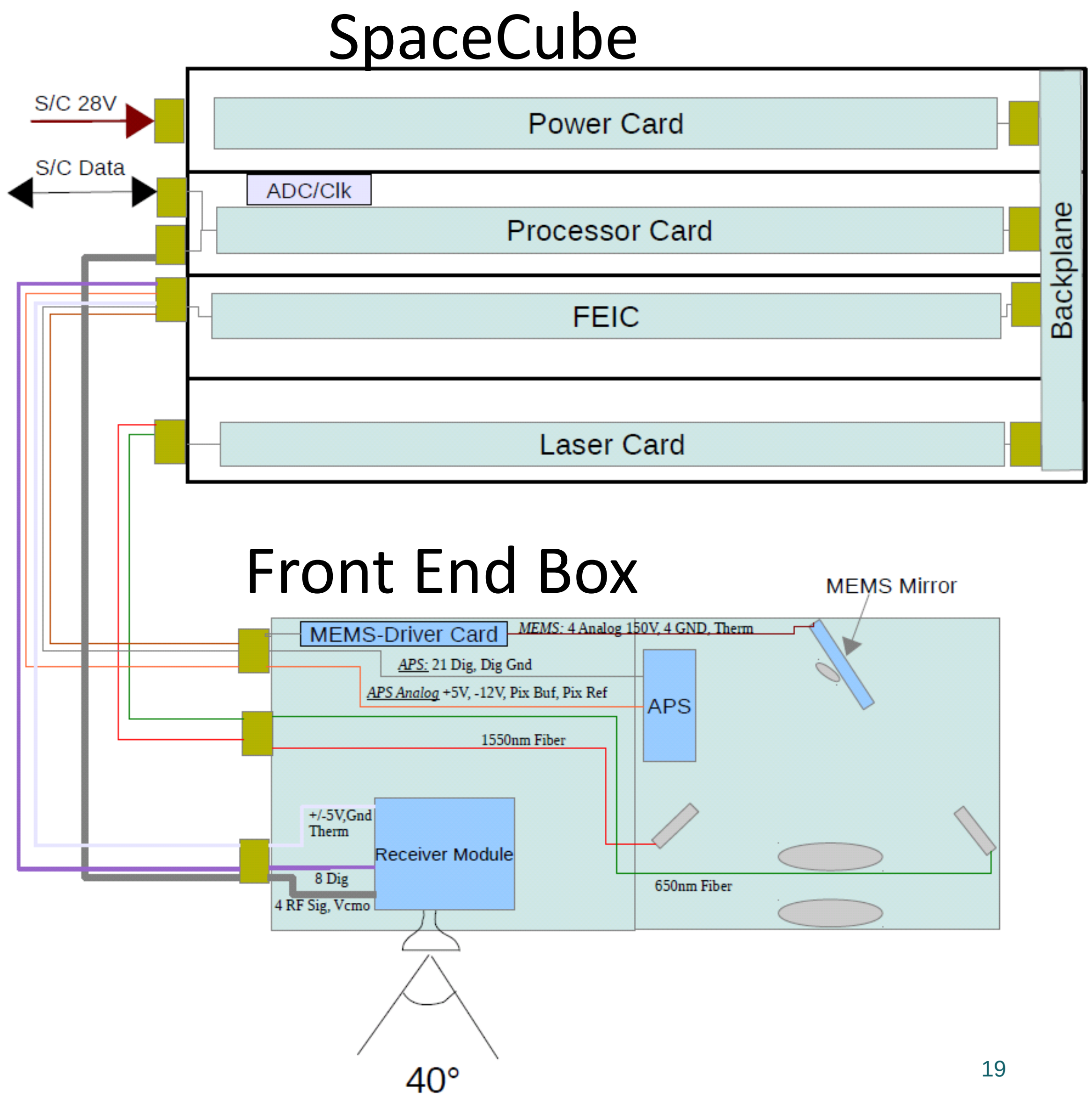
3D image of person waving



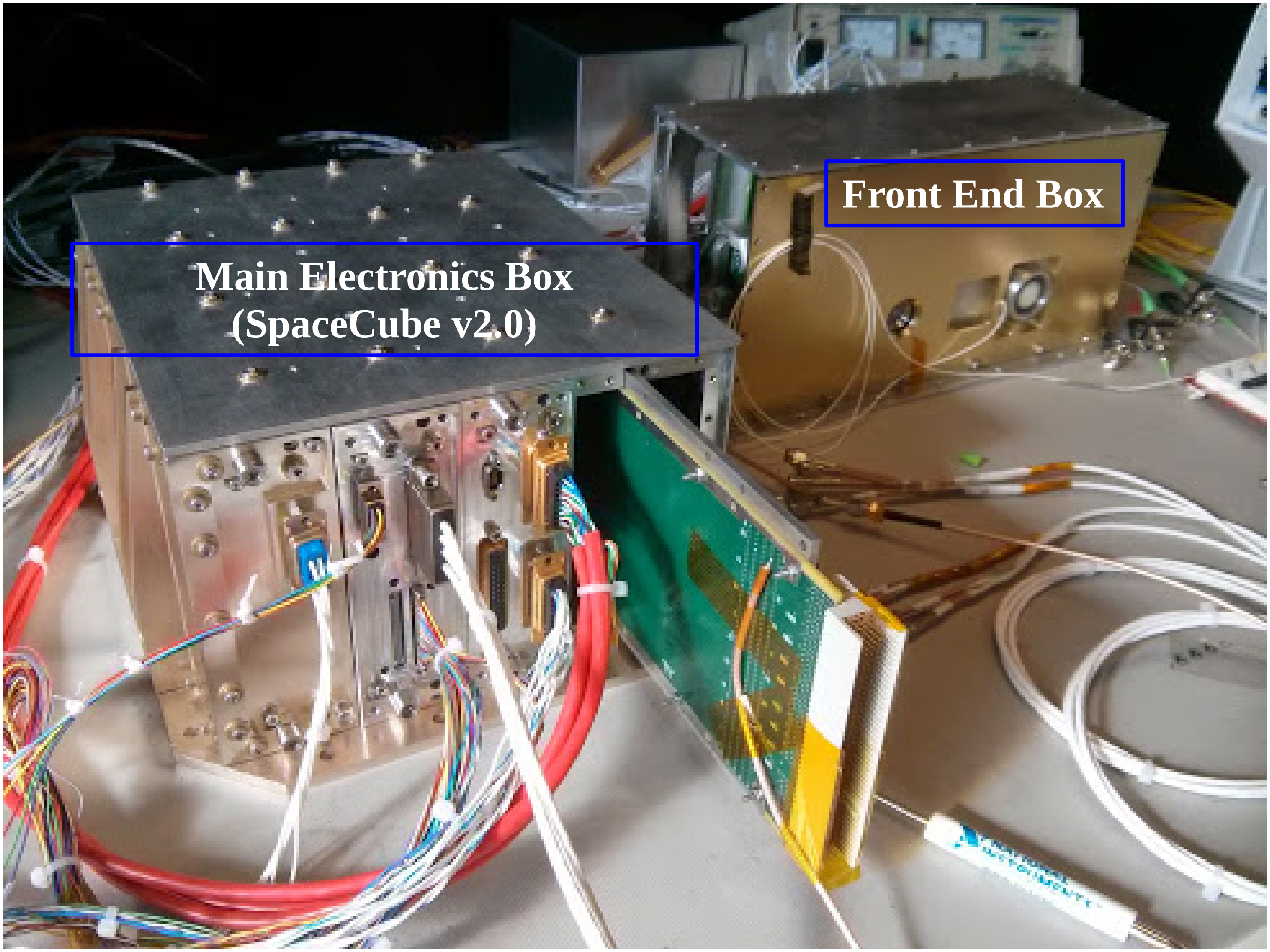
Hires 3D model of computer keyboard from single GRSSLi "science mode" scan

SpaceCube-Based Lidar (GRSSLi)

- Main Goal: **Forge Path to Flight**
  - All designs spec flight parts (where possible)
  - TRL5 box built with engineering/commercial versions of flight parts
- 2 Box design
  - Quickest path to working flight prototype
  - Allows separation of heavier and hotter MEB, putting just front end box(FEE) on optical bench.
  - Easier to modify for varying mission requirements (range/power, etc)
  - Allows easy integration of additional sensors like cameras, vision algorithms, or additional cards like GPS



GRSSLi System Integration



GRSSLi Sub-millimeter Scans

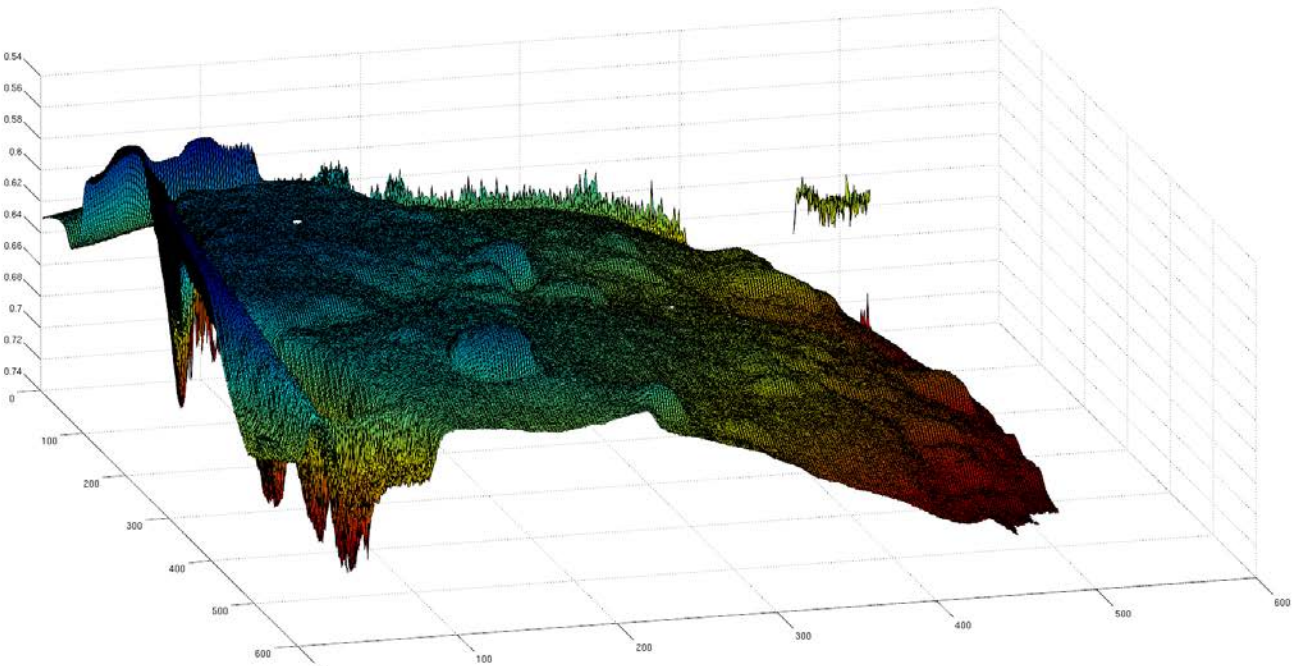
Science LiDAR Requirements

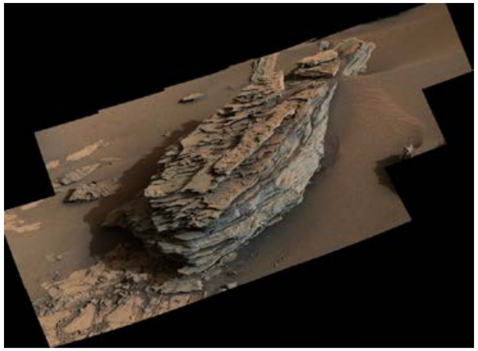
- Range resolution:
  - < 0.001 m
- Max Range: 10m
- Pixel Scale
  - 1cm Spatial Resolution @1m range

Demonstrated Capability

- Range resolution: 0.000380 m
- Range noise: 0.00480 m 1σ
- Laser Divergence: 2 mRad
  - At 1m: 4mm spot dia
  - At 10m: 4cm spot dia

3D Scan of “FeSS” Sandstone clearly exhibiting biologically derived textures

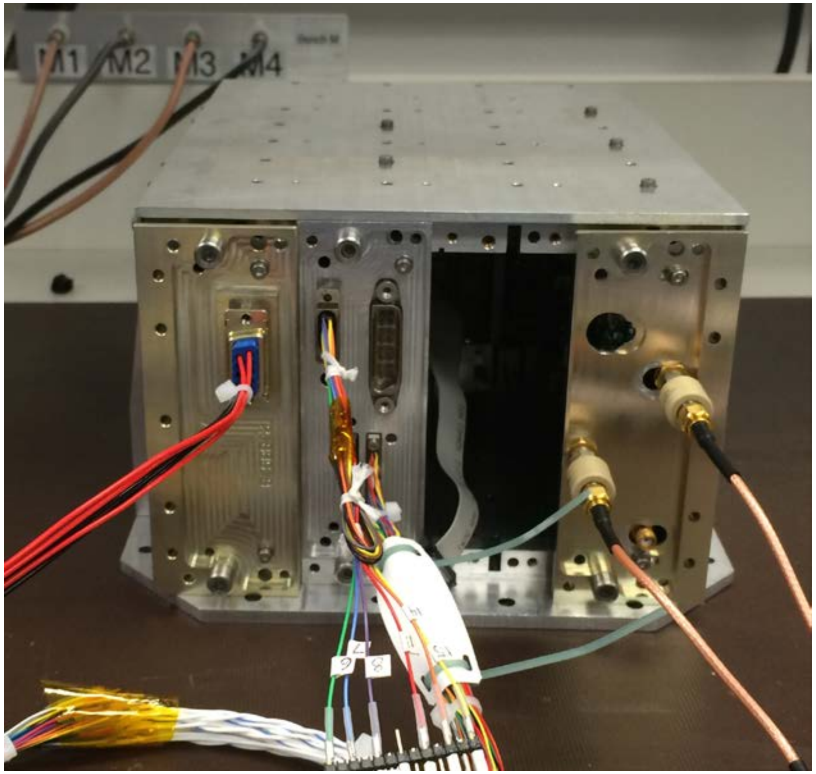




Mars Rock in Gale Crater with < 1 cm thick layers GRSSLi could measure the 3D arrangement of layered materials to understand depositional environments and textures associated with biosignature preservation potential.
Curiosity MastCam mosaic (100mm images, NASA/JPL/MSSS)

SpaceCube-Based GPS

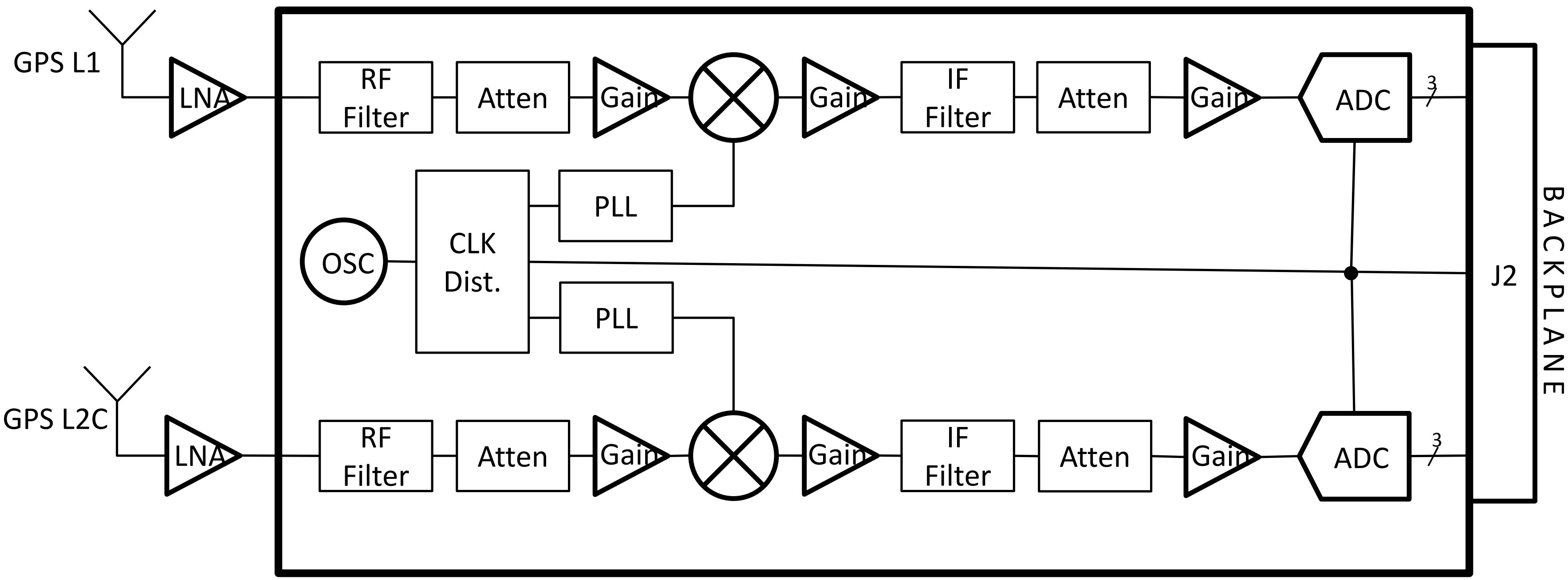
Merges NASA GSFC SpaceCube avionics and “Navigator” technologies



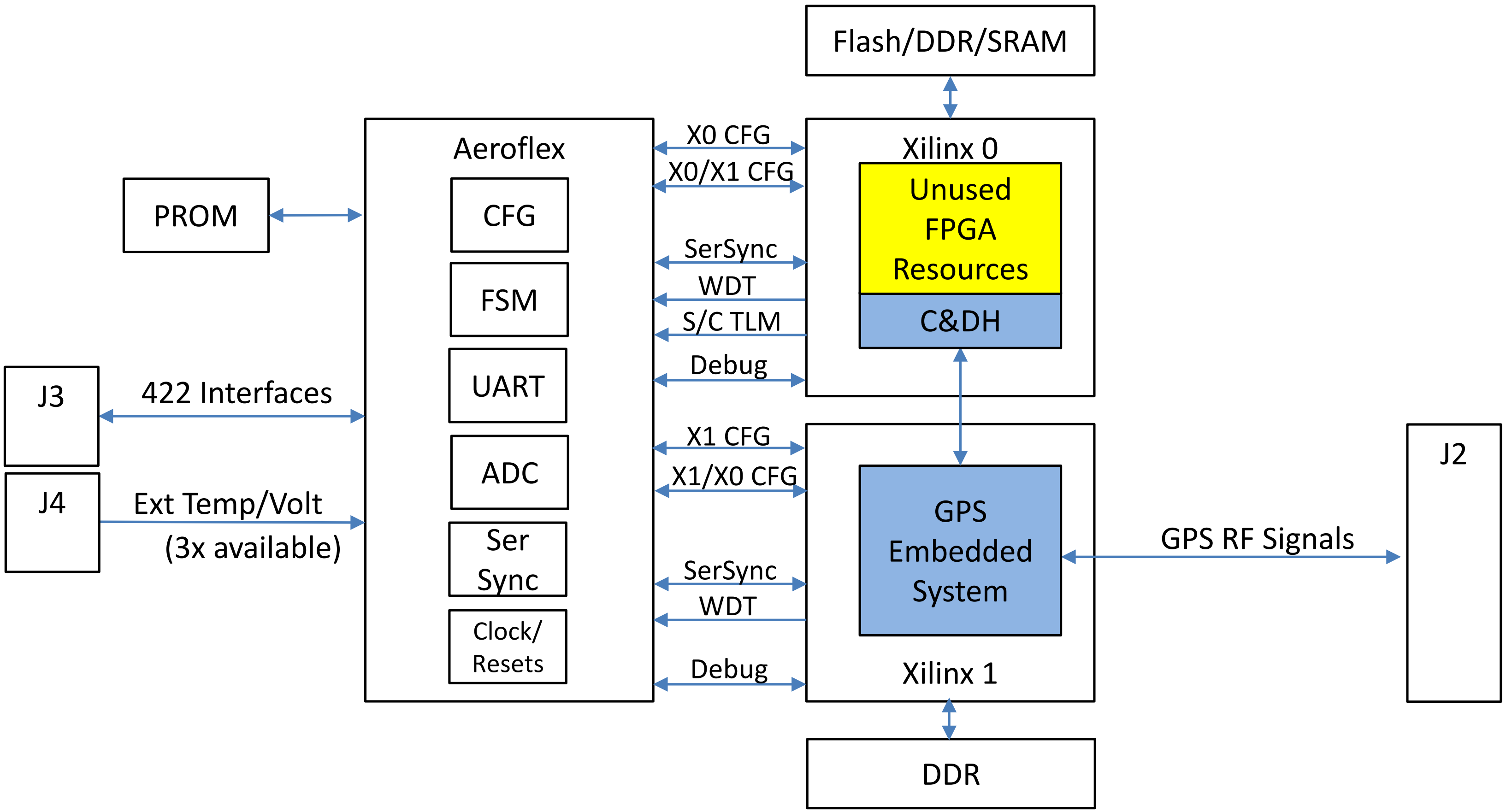
NavCube with dual frequency RF card

Spirent GPS simulators

High Level
GPS RF Card Diagram



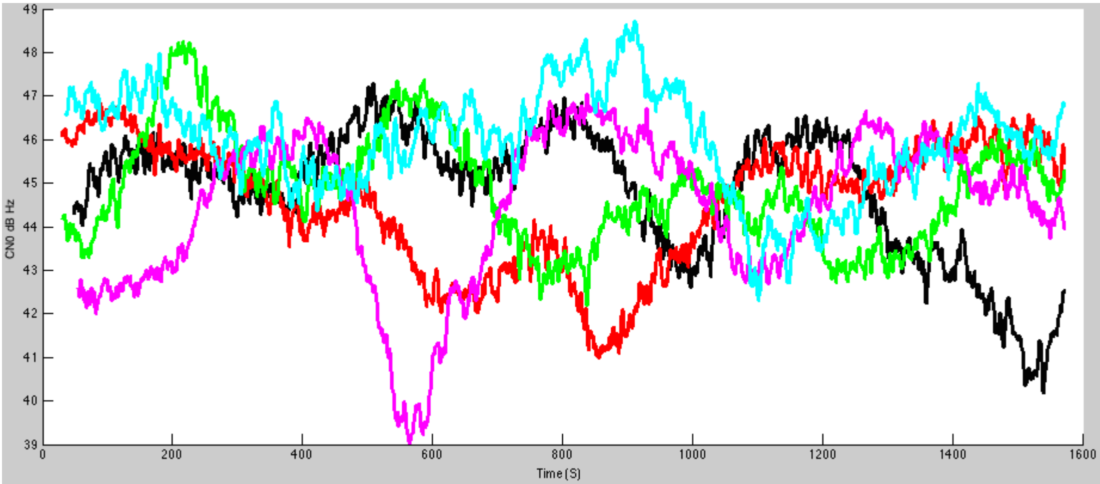
High Level GPS Processor Card Diagram



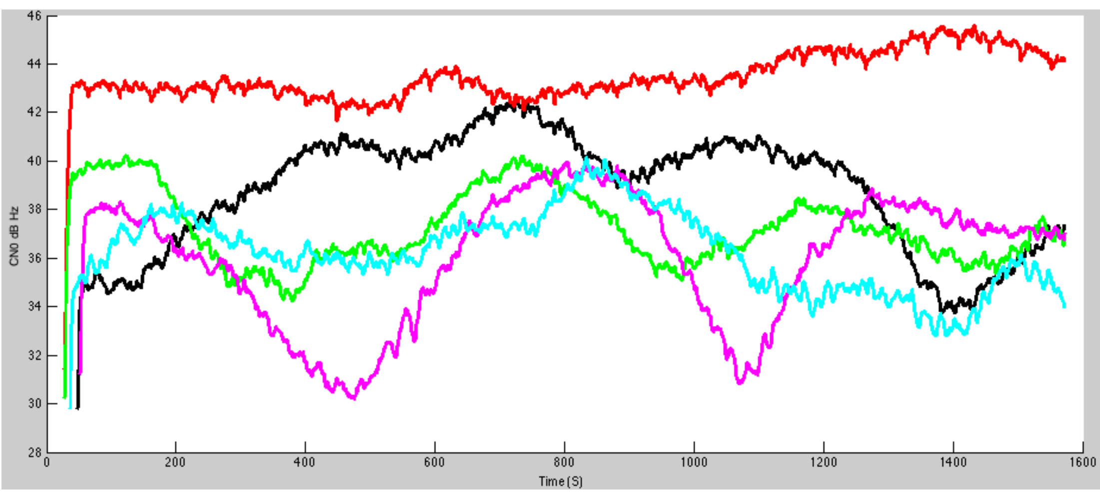
SpaceCube GPS Tracking Data

Tracking GPS L1 and L2C signals

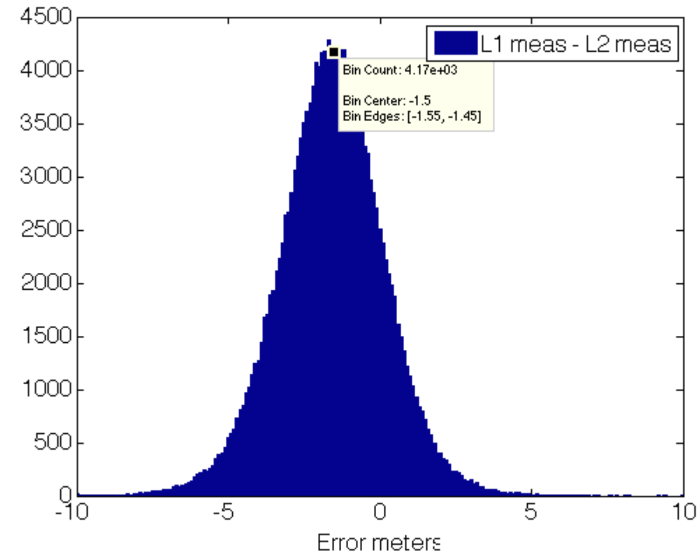
CN0 - GPS L1 signals



CN0 - GPS L2C signals



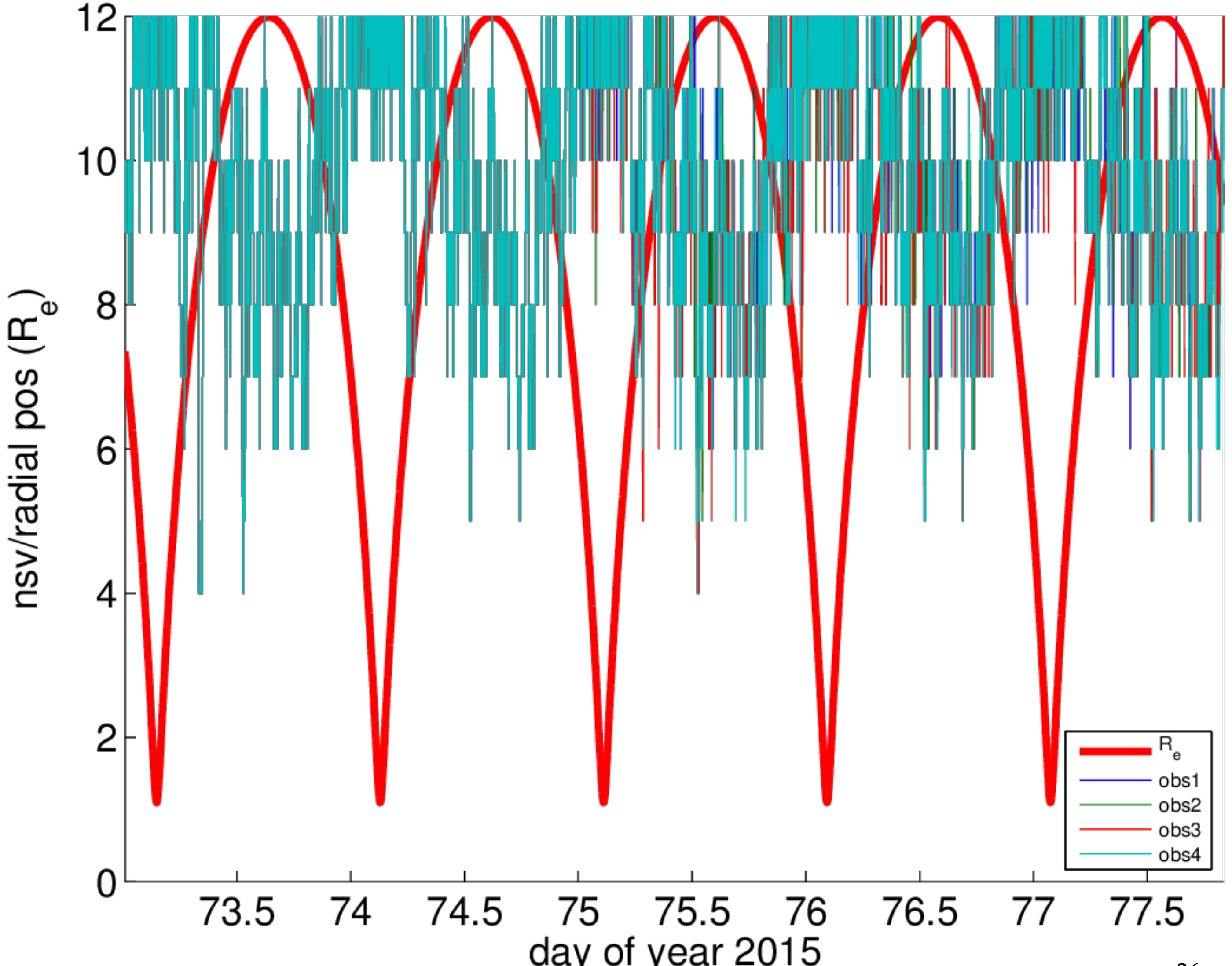
L1 measurements – L2 measurements



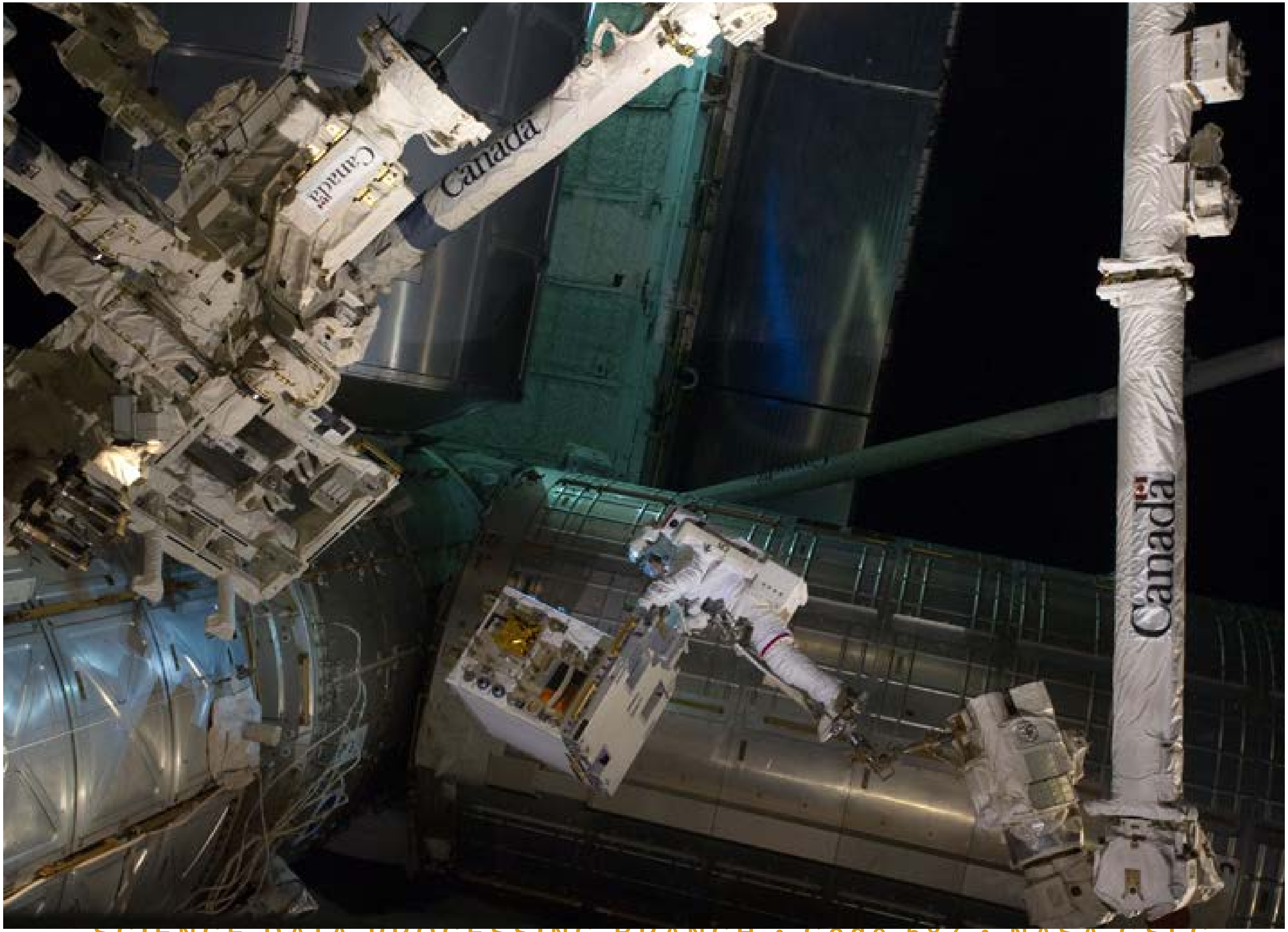
MMS Mission On-Orbit Performance of GPS Navigator

Nsv: number of GPS satellites tracked

Radial pos: radial distance from center of Earth

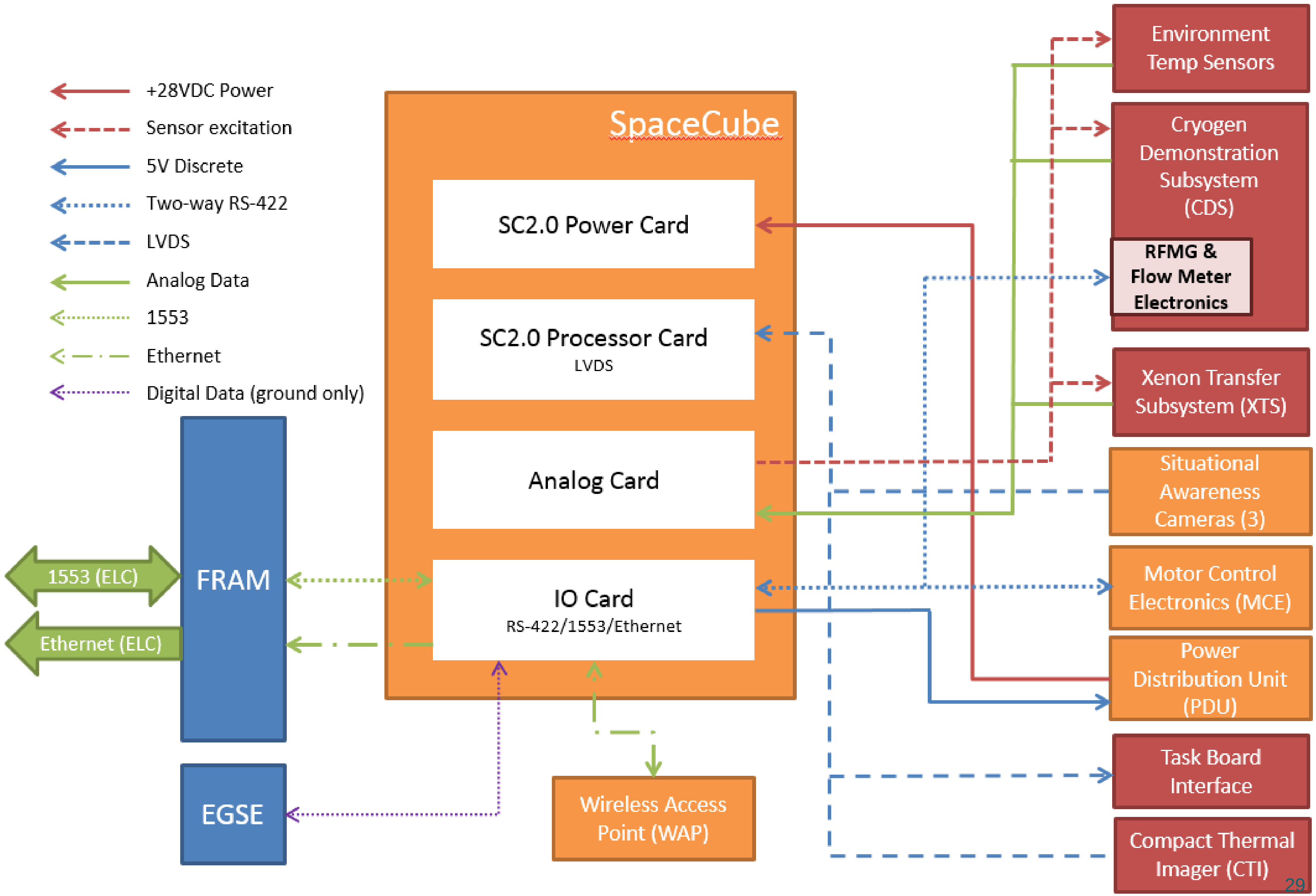


Robotic Refueling Mission (RRM)



RRM Operations

RRM3 SpaceCube Preliminary Diagram



SpaceCube on the ISS

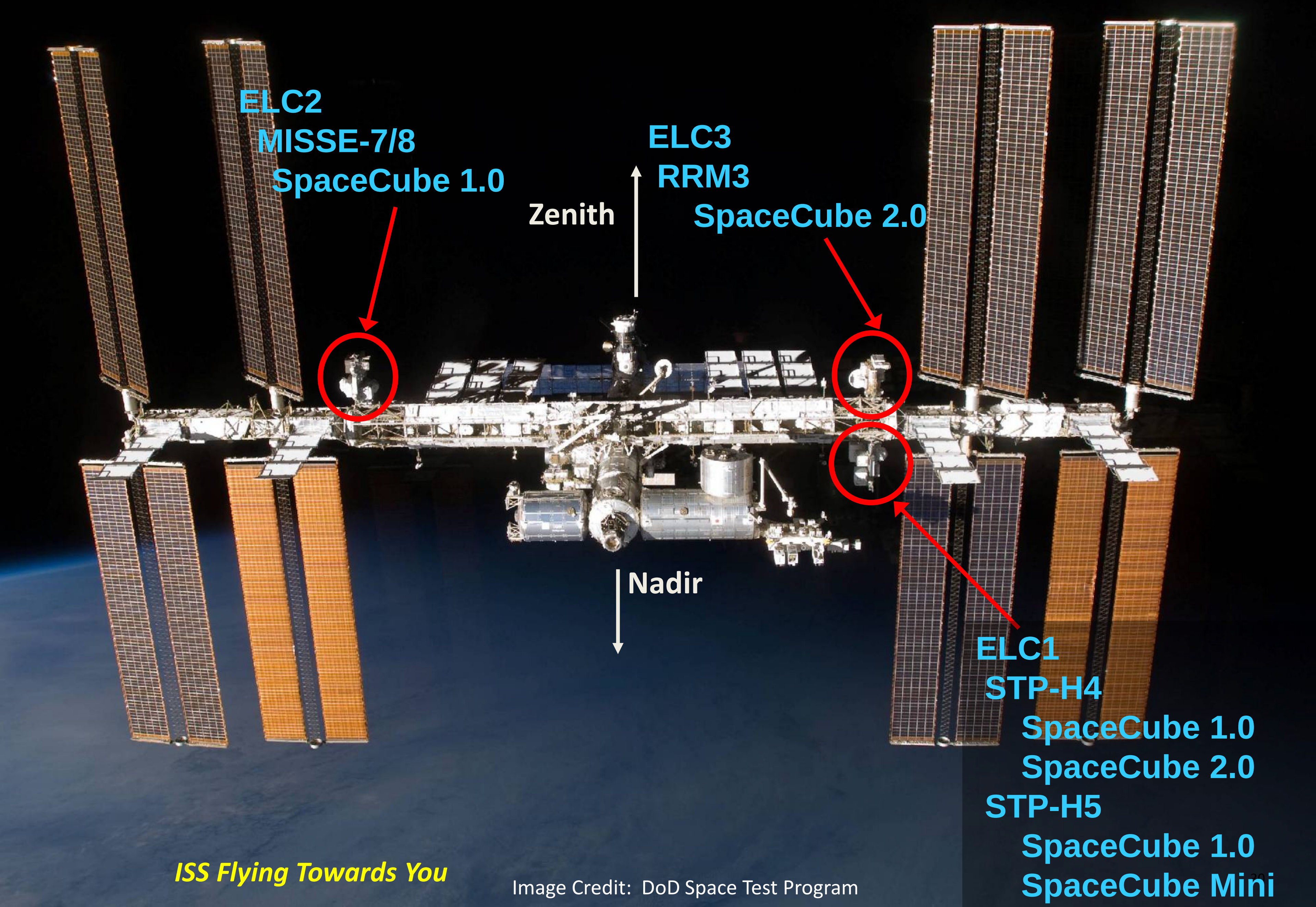
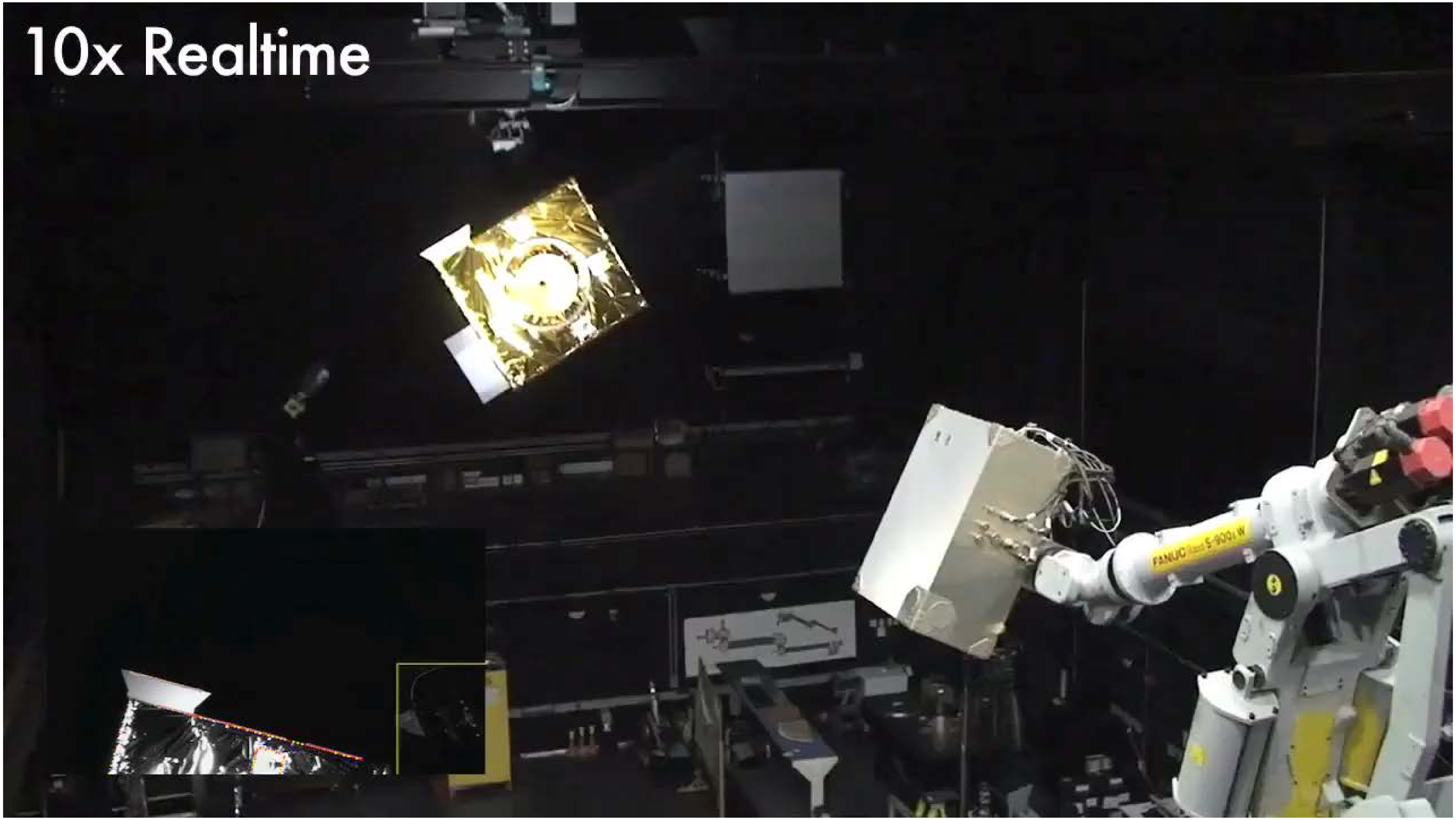


Image Credit: DoD Space Test Program

Enabling Satellite Servicing



Questions?