# NASA GSFC Avionics Architectures and Future Directions

**Wesley A. Powell**

**Assistant Chief for Technology**
**NASA Goddard Space Flight Center – Electrical Engineering Division (Code 560)**

**wesley.a.powell@nasa.gov**
**301-286-6069**

# Acronym List

| | | | |
|---|---|---|---|
| AI | Artificial Intelligence | GSFC | Goddard Space Flight Center |
| C&DH | Command and Data Handling | HPSC | High Performance Spaceflight Computing |
| CAN | Controller Area Network | ICESAT-2 | Ice, Cloud, and land Elevation Satellite 2 |
| cFE | Core Flight Executive | I2C | Inter-Integrated Circuit |
| cFS | Core Flight System | IP | Intellectual Property |
| cPCI | Compact Peripheral Component Interconnect | MUSTANG | Modular Unified Space Technology Avionics for Next Generation |
| COTS | Commercial Off the Shelf | NASA | National Aeronautics and Space Administration |
| DET | Direct Energy Transfer | OSAL | Operating System Abstraction Layer |
| DSP | Digital Signal Processing | POL | Point Of Load |
| EMI | Electromagnetic Interference | PSE | Power System Electronics |
| EMC | Electromagnetic Compatibility | PSP | Platform Support Package |
| EO-1 | Earth Observing 1 | RF | Radio Frequency |
| FPGA | Field Programmable Gate Array | RMAP | Remote Memory Access Protocol |
| GEDI | Global Ecosystem Dynamics Investigation | RRM3 | Remote Refueling Mission 3 |
| GHz | Gigahertz | SAR | Synthetic Aperture Radar |
| GMSA | Goddard Modular Smallsat Architecture | SCEB | Smallsat Common Electronics Board |
| GPS | Global Positioning System | SPI | Serial Peripheral Interface |
| GPU | Graphics Processing Unit | SRIO | Serial RapidIO |
| GN&C | Guidance Navigation and Control | UART | Universal Asynchronous Receiver/Transmitter |

# Outline

- NASA GSFC Overview
- Avionics Scope
- Current GSFC Avionics Architectures
- Future Requirements Drivers
- How Future Architectures Can Meet These Needs
- Current Challenges

# NASA GSFC Overview

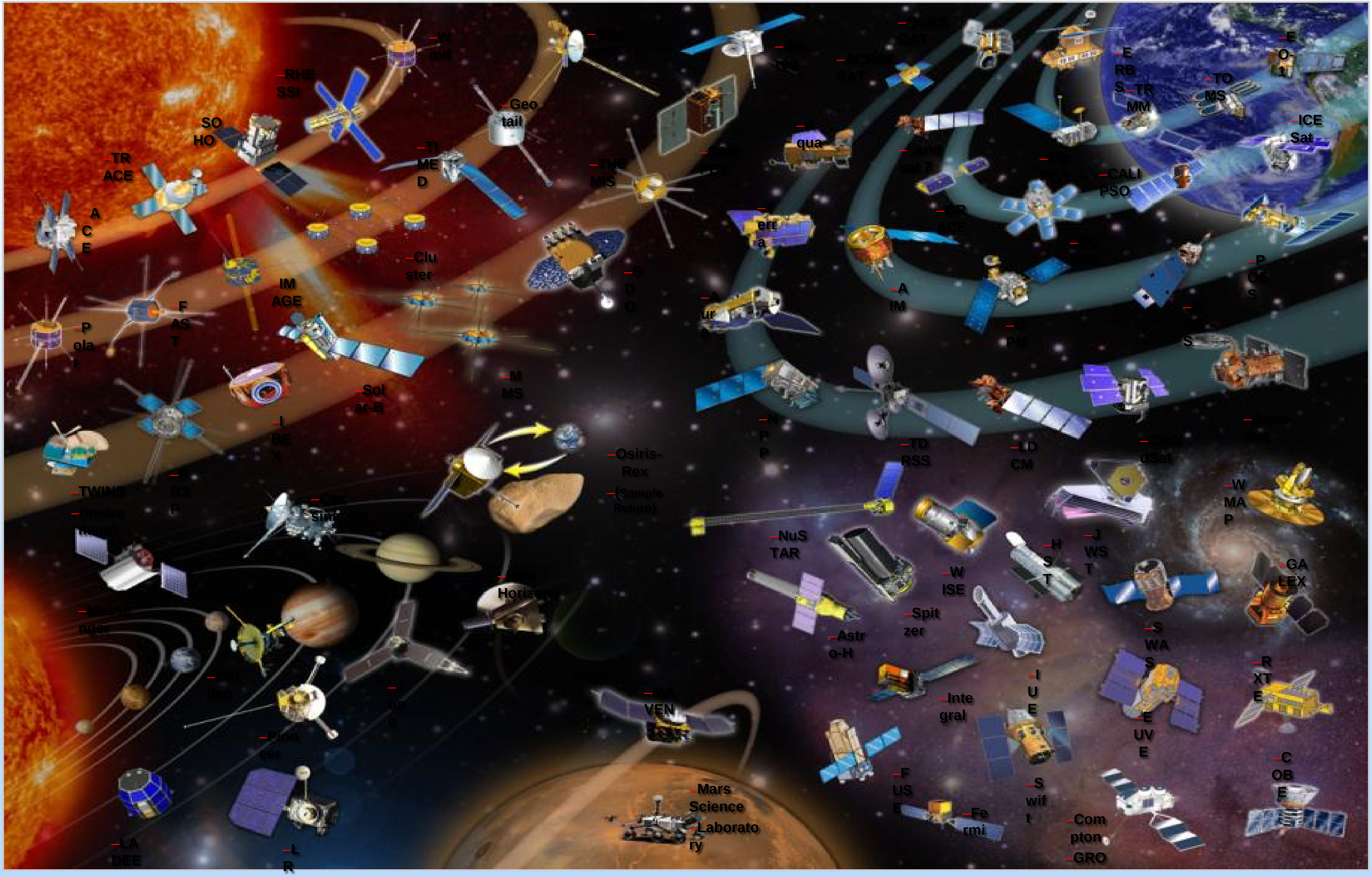
- NASA's first Space Flight Center (established 1959)
- Largest Collection of Scientists & Engineers in the U.S.
- Nearly 300 successful missions including the World's First Weather Satellite and the Hubble Space Telescope
- 2006 Nobel Prize in Physics [Big Bang/Cosmic Background]
- Hubble Space Telescope Supported 2011 Nobel Prize in Physics

**=> *We TRANSFORM Human Understanding of Earth and Space***

# Facilities

- GSFC Greenbelt, MD
- GSFC Wallops Flight Facility, VA
- IV&V Facility, WV
- Goddard Institute for Space Studies, NY
- Ground Stations at White Sands Complex, NM

# A Diverse Mission Portfolio



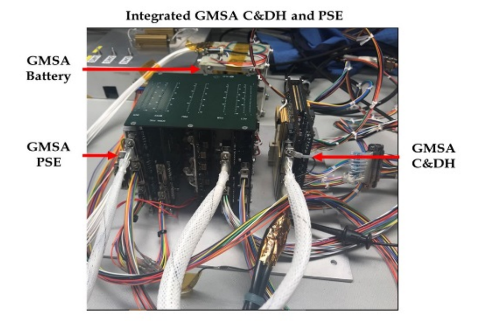
# Avionics Scope

- The scope of avionics can vary widely across organizations
- For the purposes of this presentation, the scope of avionics is considered to include:
  - Command and Data Handling (C&DH)
  - Power System Electronics (PSE)
  - Guidance Navigation and Control (GN&C)
  - Uplink/downlink (but not the full transponder)
  - Onboard Networks
- Avionics scope does not include science instruments
  - However, avionics components often are used within instrument electronics

# Current GSFC Avionics Architectures

- **GSFC uses multiple hardware architectures to implement avionics, each targeted for different use cases**

| Architecture | Purpose |
|---|---|
| MUSTANG (Modular Unified Space Technology Avionics for Next Generation) | Command & Data Handling (C&DH) and Power System Electronics (PSE) for medium to large missions |
| GMSA (Goddard Modular Smallsat Architecture) | Command & Data Handling (C&DH) and Power System Electronics (PSE) for cubesats and smallsats |
| SpaceCube | High performance onboard processing applications |



**Integrated GMSA PSE and C&DH**

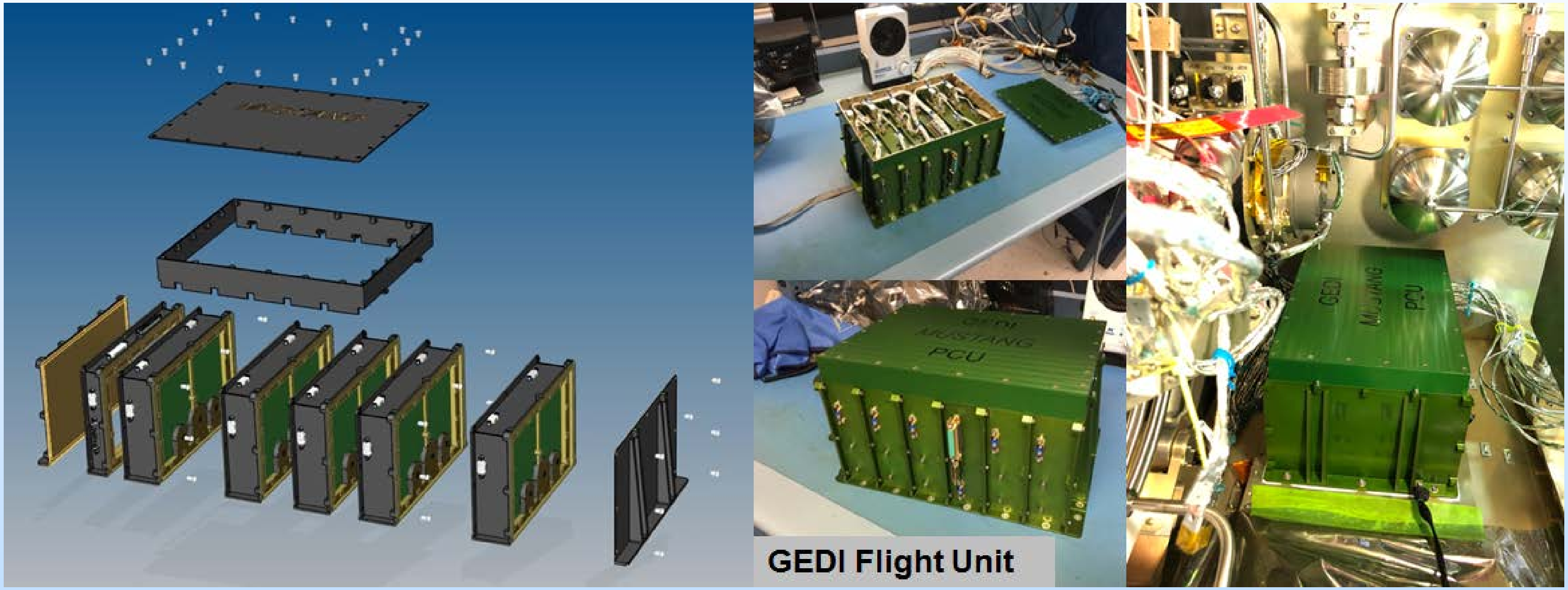
**Global Ecosystem Dynamics Investigation (GEDI) MUSTANG**

**Robotic Refueling Mission 3 (RRM3) SpaceCube**

# MUSTANG

- **Derived from avionics flown on recent flight missions, MUSTANG targets medium to large missions and instruments**
- **Employs slice-based architecture, providing a suite of electronic modules that can implement spacecraft avionics and instrument electronics**
- **Packaging concept has flexibility to accommodate varying slice widths and both single and multi-box configurations**
- **Uses a dual core GR712C as the primary processor**
- **Also uses a LEON3FT soft-core processor embedded within an RTG4 FPGA as an auxiliary processor**
- **Uses SpaceWire/RMAP (Remote Memory Access Protocol) for internal and external communication**

# MUSTANG



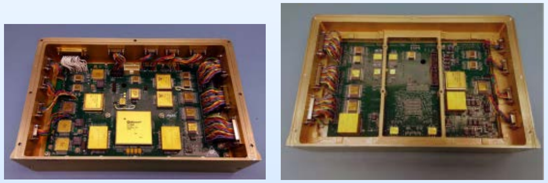
MUSTANG Architecture

# MUSTANG

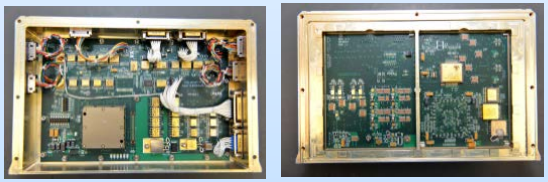
- **Some existing hardware**

**Engine Valve Driver Card**

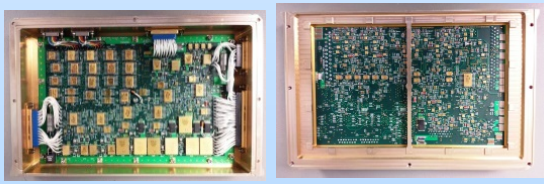
**Digital IO Card**



**PSE Monitor Card**

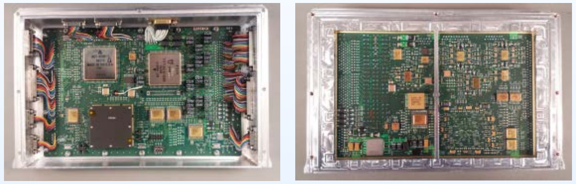


**Output Module Card**

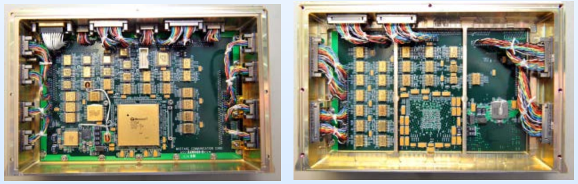


**Mechanism Control Card**

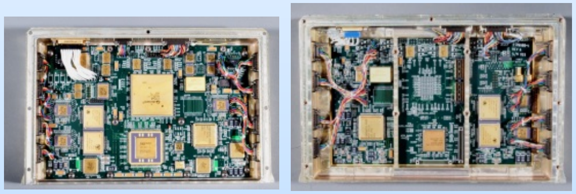
**Housekeeping Card**



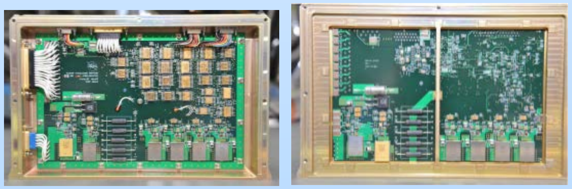
**Communication Card**



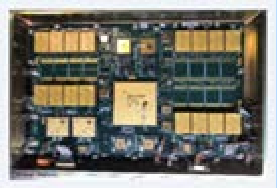
**Processor Card**



**Deployment Card**



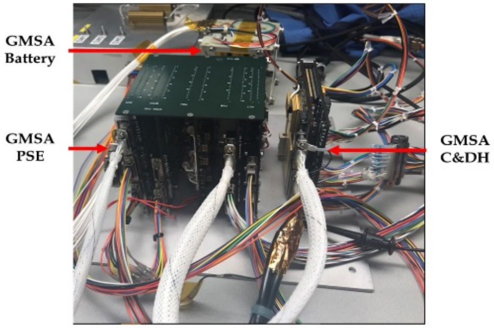
**Data Storage Card (Not Fully Populated) Full Capacity 3.5Tb**



# GMSA

- GMSA targets smallsat and cubesat missions that must operate reliably for long durations in harsh radiation environments
- The GSMA C&DH consists of a Smallsat Common Electronics Board (SCEB) and a mission specific adapter card interconnected via stacking connectors
- The SCEB implements the flight processor as a soft core LEON3FT within a reprogrammable FPGA
- The SCEB also provides UART, I2C, SPI, CAN, and SpaceWire interfaces
- The GSMA PSE consists of 5 cards interconnected via a backplane and uses Direct Energy Transfer (DET) and can support both 3-axis and spin-stabilized spacecraft

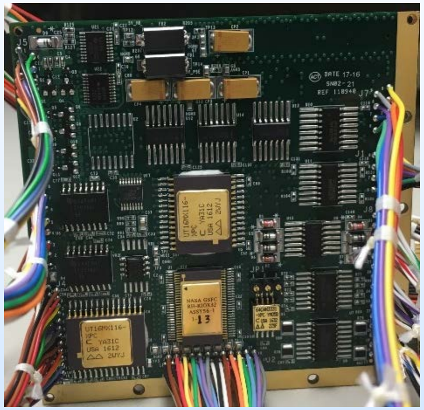
Integrated GMSA C&DH and PSE



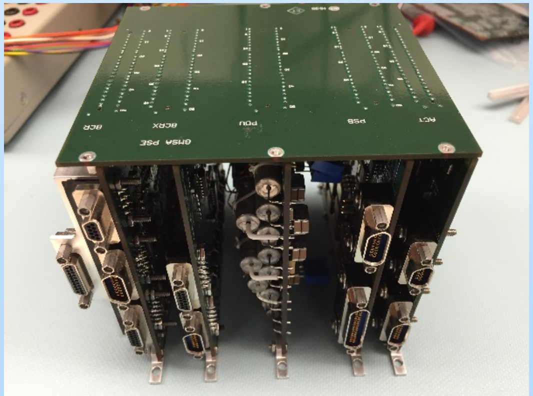
# GMSA

- **Existing hardware**

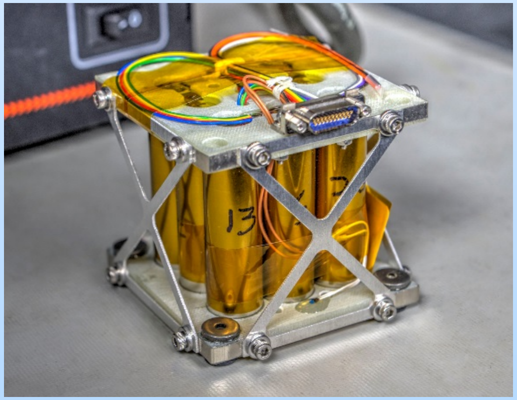
**SCEB**



**Adapter Board**



**PSE**



**Battery Assembly**

# SpaceCube

- **SpaceCube is a high performance reconfigurable science/mission data processor based on Xilinx Virtex FPGAs (Field Programmable Gate Arrays)**
- **The current SpaceCube version 2.0 processor is based on the Virtex-5 FPGA and is implemented as a 3U cPCI board**
- **Mission specific SpaceCube implementations consist of a processor board along with necessary I/O boards**
- **SpaceCube allows hybrid processing within the FPGAs**
  - **Embedded processor cores**
  - **DSP (Digital Signal Processing) function blocks**
  - **FPGA logic**

- **Radiation upset mitigation techniques are employed, including the use of a small “critical function” manager/watchdog**
- **Multi-gigabit serial interfaces from the FPGAs are brought out as I/O**
- **SpaceCube “core software” infrastructure includes cFS (Core Flight System) and “SpaceCube Linux” (with Xenomai)**

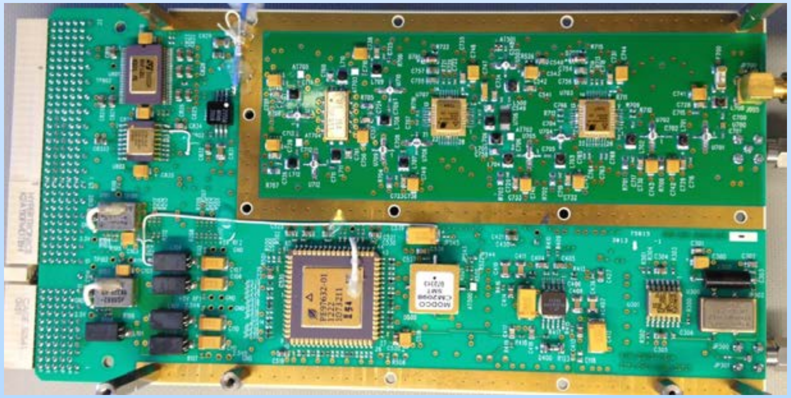
# SpaceCube

- **Some existing hardware**

**SpaceCube V2.0**

**SpaceCube V2.0 Processor Card**

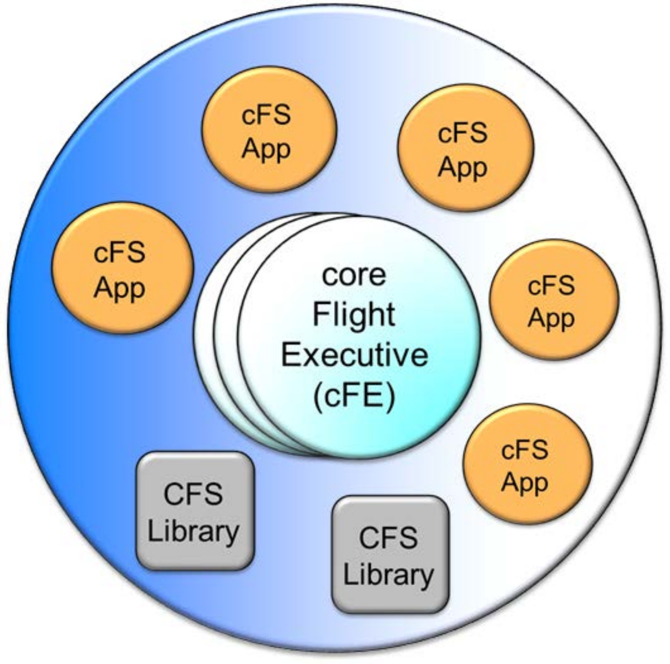
**Restore-L Video/Spacecraft Interface Card**



**GPS RF Front-End Interface Card**

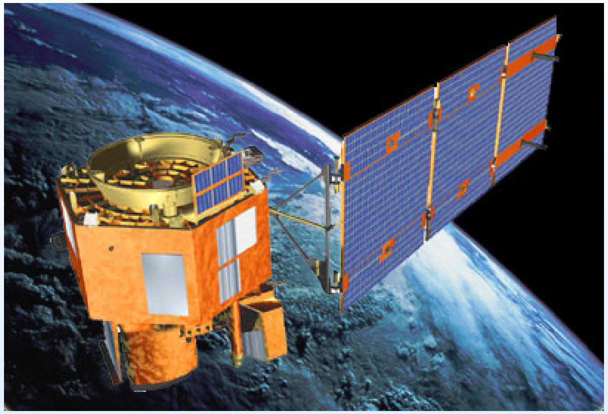
# Core Flight System (cFS)

- Across these architectures, GSFC uses Core Flight System (cFS) for flight software
  - A Flight Software Architecture consisting of an OS Abstraction Layer (OSAL), Platform Support Package (PSP), cFE Core, cFS Libraries, and one or more cFS Applications
- core Flight Executive (cFE)
  - A framework of mission independent, re-usable, core flight software services and operating environment
  - Layered on top of, and linked with the OSAL, PSP, and OS
- cFS App
  - Loosely coupled component using only OSAL, PSP and cFE defined interfaces
- cFS Library
  - Collection of common application services using only OSAL, PSP, and cFE defined interfaces

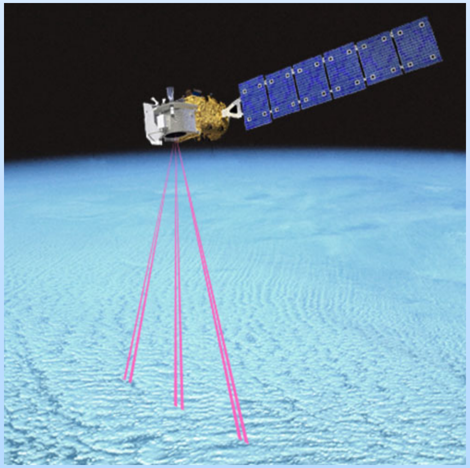


# Future Requirements Drivers

- **Increased sensor data rates**
  - **Synthetic Aperture Radar (SAR)**
  - **Hyperspectral Imagery**
  - **Lidar**
  - **Video**
- **Increased downlink rates**
  - **Ka-Band**
  - **Optical**
  - **Not keeping up with sensor data rates**
- **Increased onboard science data processing**
  - **Real-time event/feature detection**
  - **“Intelligent Instrument” data selection/compression**
  - **On-board data volume deduction**
  - **Real-time calibration/correction**
  - **On-board classification**
  - **On-board product generation**



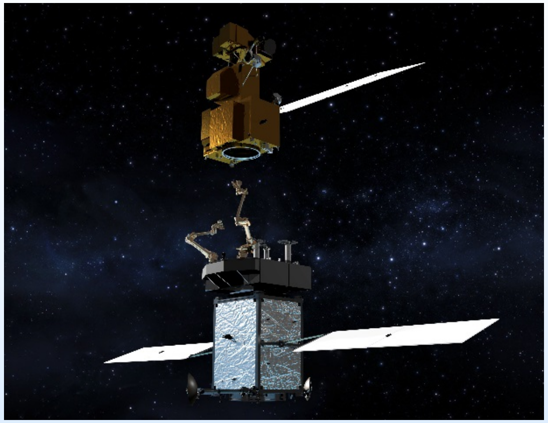
**EO-1 Mission**



**ICESAT-2 Mission**

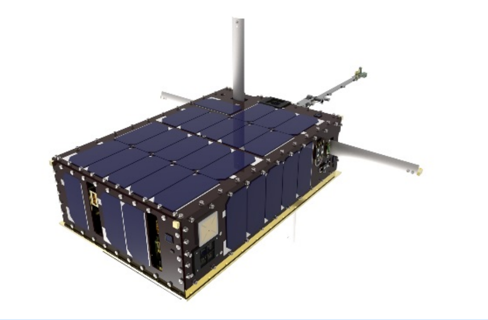
# Future Requirements Drivers

- **Autonomous mission applications requiring high bandwidth processing**
  - Precision formation flying
  - Autonomous navigation
  - Autonomous rendezvous and docking
  - Terrain relative navigation
  - Real-time sensing and control
  - Real-time image processing



Restore-L Mission

- **Improved resource efficiency for small mission classes**
  - Tightly integration of spacecraft and instrument functions
  - Share resources between spacecraft and instrument functions where possible

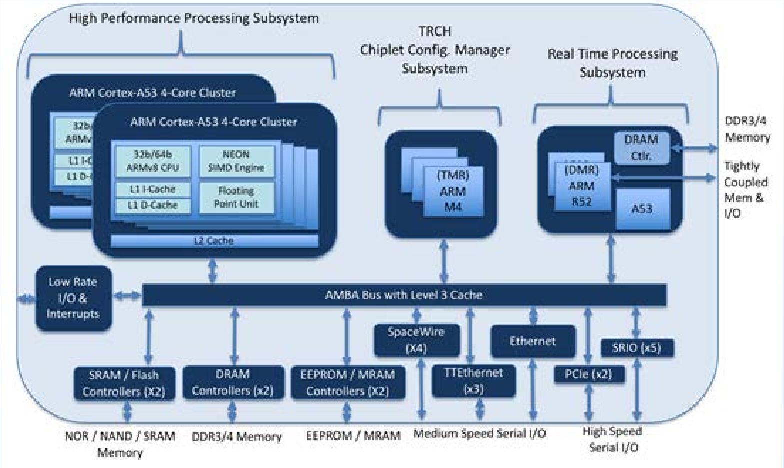


Dellingr Cubesat

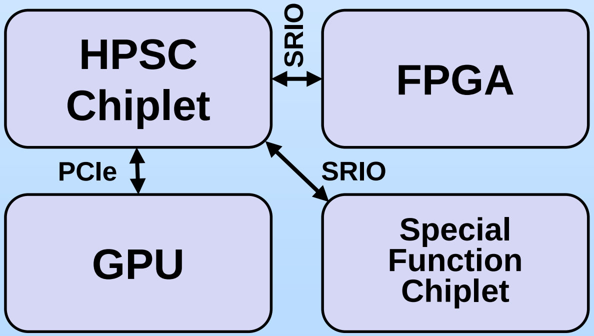
- **Distributed space missions with inter-platform collaboration**

# How Future Architectures Can Meet These Needs

- **Use HPSC widely across mission classes**
  - **Chiplet power, performance, and fault tolerance scalable to meet specific mission needs**
  - **Middleware significantly reduces the complexity of developing applications for the HPSC Chiplet**
- **Employ “hybrid processing architectures”, leveraging different compute devices for what they’re best suited**
  - **HPSC Chiplet**
  - **Graphics Processing Units (GPUs)**
  - **FPGAs**
  - **Special function “chiplets” implemented as ASICs**
- **Increase network bandwidths**
  - **Within boxes and between boxes**
- **Promote IP architectures and standards**
  - **Efficient development of System-On-a-Chip (SOC) devices**
  - **“Software defined spacecraft” for small mission classes**
- **Use “managed COTS” (Commercial Off the Shelf) where appropriate**
  - **Understand radiation susceptibilities**
  - **Determine appropriate mission applications**
  - **Employ “layered” fault tolerance**
  - **Consider resource implications of fault tolerance scheme**



**HPSC Chiplet**



**HPSC Chiplet**

**FPGA**

**GPU**

**Special Function Chiplet**

**SRIO**

**PCIe**

**SRIO**

**Hybrid Processing Architecture**

# Current Challenges

- **How best to leverage HPSC in our hardware architectures**
  - Optimal processing partition between processor elements within hybrid architectures
  - Signal integrity, EMI/EMC (Electromagnetic Interference / Electromagnetic Compatibility) )and management of multiple (up to 24) high frequency (10GHz) interconnects
  - Providing multiple power services and ensuring power/ground quality
  - Adaptation of slice architecture to accommodate high speed networks

- **How best to leverage HPSC in our software architectures**
  - Adaptation of cFS to HPSC
  - Combination of mixed criticality applications in a complex multicore processing environment
  - Image/signal processing libraries ported to HPSC

- **Technology needs**
  - Intelligent, fault tolerant, multi-output Point-of-Load (POL) conversion
  - Advanced spaceflight memories
  - Next generation radiation tolerant FPGAs
  - “Special Function” chiplets with SRIO (Serial RapidIO) connectivity
  - Fault tolerant IP architectures, standards, and libraries

# Current Challenges

- **Smallsat needs**
  - **Smallsat subsystems and components with sufficient reliability and radiation tolerance for long duration missions in harsh environments**
  - **Standard onboard network interfaces**
- **Use of COTS**
  - **Growing reliance on COTS**
  - **Increasing complexity of COTS devices**
  - **Shortened product lifetimes**
  - **Reduced availability of radiation test facilities**
  - **Reliance on board-level or box-level radiation testing**
- **Cybersecurity**
  - **Increased attention within NASA**
  - **But no specific requirements have yet been levied on GSFC avionics**
- **AI and deep learning in space**
  - **Assessing potential onboard AI and deep learning applications**
  - **Defining the optimal flight architectures to implement them**