NASA's Future Avionics Vision

Wesley Powell – NASA STMD Principal Technologist for Advanced Avionics
Wesley.A.Powell@nasa.gov, 301-286-6069

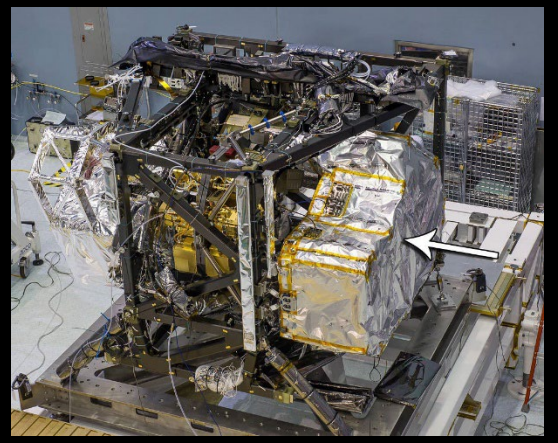
To be presented at the 2023 Radiation Hardened Electronics Technology (RHET) Conference, Allen, TX, November 6-9, 2023

Avionics Scope

- Avionics within NASA's Space Technology Mission Directorate (STMD)
  - Hardware and software infrastructure necessary for the command and control of spacecraft and surface assets, providing the onboard intelligence and interconnection to integrate the functions of other systems and manage their operation as a whole
  - Other elements that are sometimes defined as being with scope of avionics, but are not included within the Advanced Avionics SDP are power systems, communication, and navigation
- As a foundational technology, advanced avionics enables many other technologies being developed within STMD, and avionics technologies can often be used within scientific instruments and subsystems
  - Entry, Descent, and Landing (EDL) Systems
  - Software Defined Radios
  - Smart Sensors (Cameras, Lidar, …)
  - Multispectral/Hyperspectral Imagers
  - Spectrometers
  - Radars

Navigation Doppler Lidar (NDL)


Safe and Precise Landing – Integrated Experiment (SPLICE) Descent and Landing Computer (DLC)


James Webb Space Telescope (JWST) Near Infrared Spectrometer (NIRSpec) Instrument

General use cases driving needs - Science

- Earth Science
  - High performance processing for onboard data reduction, as sensor bandwidth > downlink bandwidth
  - Increased onboard autonomy to enable sensor web
- Planetary Science
  - Increased autonomy, for spacecraft/surface system control and science data collection
  - Harsh thermal and radiation environments
  - High performance processing for onboard data reduction, as sensor bandwidth >>> downlink bandwidth
- Astrophysics
  - High performance processing for adaptive wavefront sensing and control
  - High performance processing for onboard data reduction, as sensor bandwidth > downlink bandwidth
  - Avionics architectures to enable robotic servicing
- Heliophysics
  - Avionics and instrument miniaturization for smallsat constellations enabling multipoint in-situ measurements


ICESat-2

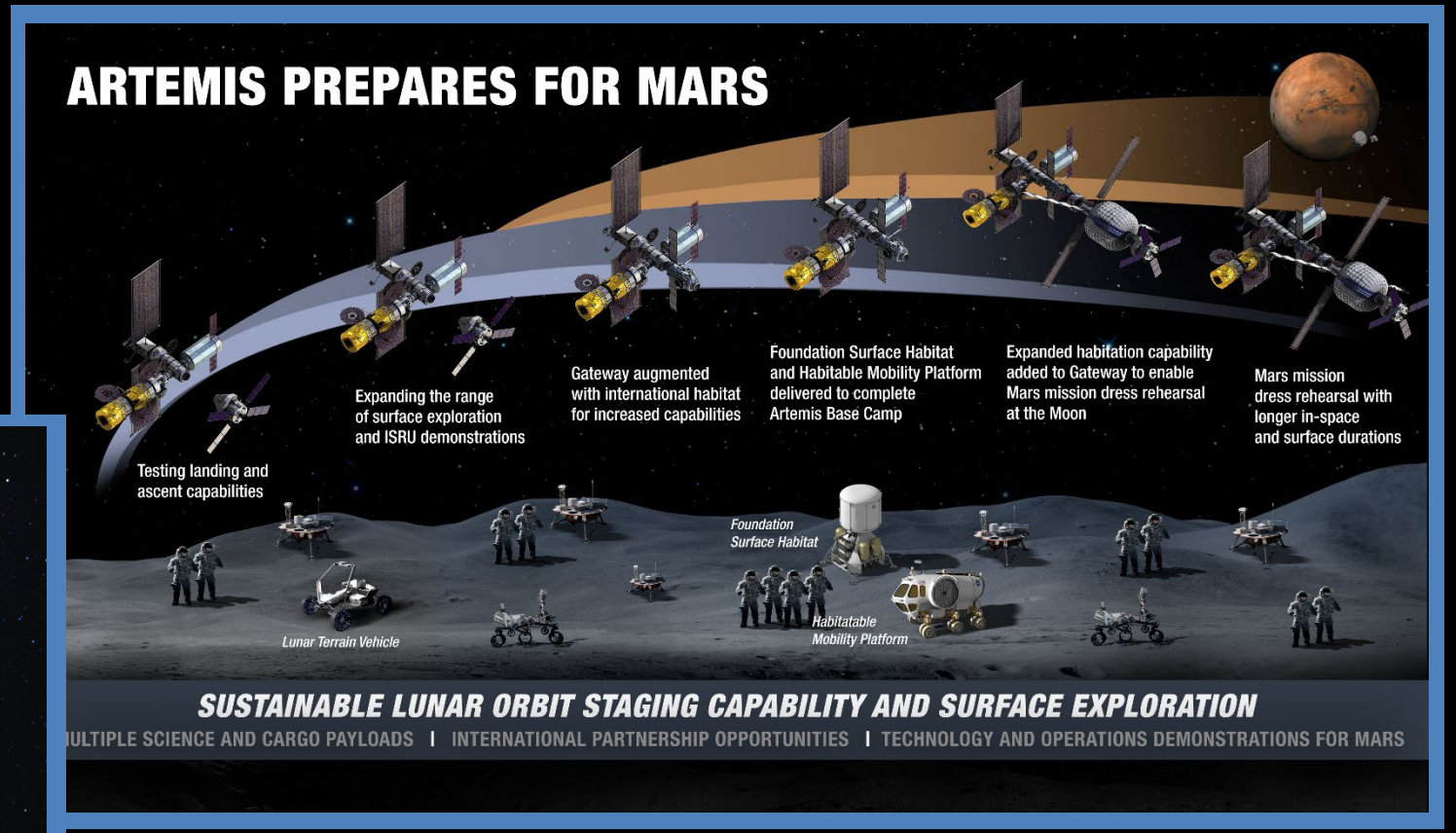

Psyche


Roman Space Telescope


Magnetospheric Multiscale (MMS) Mission

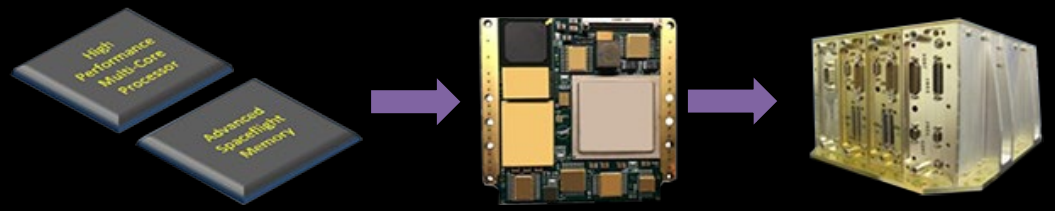
General use cases driving needs - Crewed exploration

- Increased autonomy as missions extend beyond LEO to Cis-Lunar space, and beyond
- Robotics both working independently and collaboratively with crew
- Longer duration missions
- Harsh thermal environments
- Serviceability and maintainability



Gateway - Full Configuration in Orbit

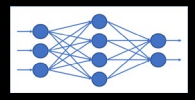
Advanced Avionics – Envisioned Future

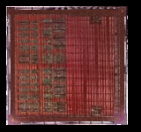


HIGH PERFORMANCE SPACEFLIGHT COMPUTING

- Radiation-hardened general-purpose processor with vector processing, increased performance, and flexibility to adapt to mission specific performance, power, and fault tolerance needs
- Advanced spaceflight memory with radiation tolerance, increased capacity and improved performance
- Intelligent, efficient, multiple output Point-Of-Load (POL) power converters
- High performance Single Board Computer (SBC) incorporating high-performance general-purpose processors, advanced memory, point-of-load converters, and real-time operating system in industry standard form factors and bus architectures
- System software tools with vector support to leverage the capabilities and manage the complexity of advanced multi-core processors

Crewed Exploration | Earth Science | Planetary Science | Astrophysics | Heliophysics





OTHER COMPUTING ARCHITECTURES

- Artificial Intelligence (AI) coprocessors to enable autonomous landing, surface navigation, robotic servicing/assembly, fault detection/mitigation, distributed systems operations, science data processing, and tip and cue for remote sensing missions
- Spaceflight quantum computers
- Low power embedded computers to support distributed robotics architectures

Crewed Exploration | Earth Science | Planetary Science | Astrophysics | Heliophysics

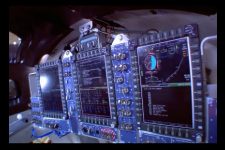
INTERCONNECT

- Radiation-tolerant interconnects to support low latency onboard video, multi-gigabit instruments, onboard science, and enhanced autonomy applications; including end points, switches, physical layer devices, and software support
- Highly reliable, high-bandwidth deterministic wireless networks

Crewed Exploration | Earth Science | Planetary Science | Astrophysics | Heliophysics

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision.

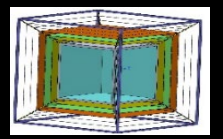
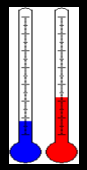
Advanced Avionics – Envisioned Future



CREW INTERFACES

- Radiation-tolerant displays that can operate reliably for long durations mission beyond LEO
- Radiation-tolerant graphics processing that can operate reliably for long mission durations beyond LEO
- Heads Up Displays for Exploration EVA
- Crew voice and audio systems for deep space missions providing efficient compression of multiple streams, acoustic echo and noise cancellation, speech recognition and voice control, and wireless capabilities

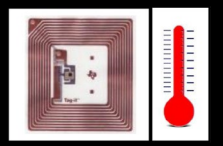
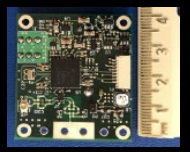
Crewed Exploration

EXTREME ENVIRONMENT AVIONICS

- Extreme temperature electronics capable of operating in environments with both high radiation and wide temperature ranges, including lunar/planetary surfaces or within nuclear systems
- Avionics packaging and thermal management technologies to enable avionics operation in extreme environments
- Dust tolerant connectors to enable interconnect on lunar and planetary surfaces

Crewed Exploration | Planetary Science

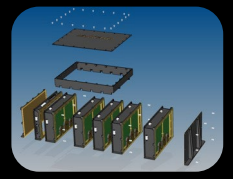
DATA ACQUISITION

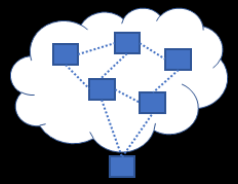
- Wireless sensor networks to reduce harness mass and complexity, simplify integration and test, and improve system flexibility, serviceability, and expandability
- Low-cost, robust, high-accuracy data acquisition systems to enable distributed in situ monitoring of structures and subsystems on cost constrained missions

Crewed Exploration | Earth Science | Planetary Science | Astrophysics | Heliophysics

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision.

Advanced Avionics – Envisioned Future

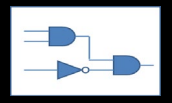
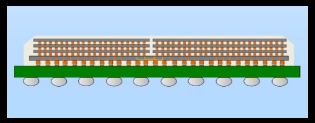




AVIONICS ARCHITECTURES

- Interoperable avionics architectures allowing systems to be composed of standard interoperable modules from multiple vendors
- Cybersecurity tools providing defense-in-depth for spaceflight avionics
- Serviceable avionics architectures to simplify post-deployment servicing of avionics hardware
- Space cloud computing architectures allowing onboard processing to be distributed across multiple spacecraft or surface elements

Crewed Exploration | Earth Science | Planetary Science | Astrophysics | Heliophysics

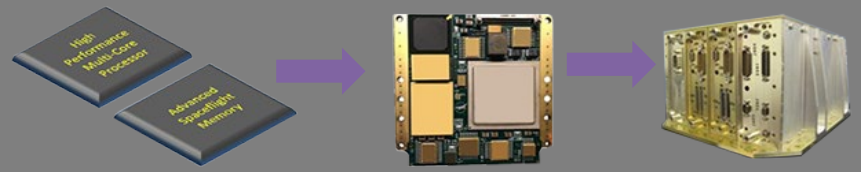
FOUNDATIONAL TECHNOLOGIES

- Advanced 2.5D/3D packaging supporting heterogeneous integration enabling miniaturization and improved performance
- Advanced semiconductor process nodes and libraries to enable next generation radiation hard devices
- Low-cost, radiation-hardened mixed-signal ASICs
- Advanced test systems accelerating radiation and reliability testing of complex COTS microelectronics devices

Crewed Exploration | Earth Science | Planetary Science | Astrophysics | Heliophysics

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision.

NASA Avionics Technology Investments



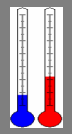
High Performance Spaceflight Computing
- General purpose multi-core processor, system software, and evaluation board development
- Microchip
- NASA STMD funded

Advanced Spaceflight Memory
- Radiation Hardened NOR-Flash device development
- MicroRDC/Infineon
- NASA funding via AFRL contract

Neuromorphic Processor
- Neuromorphic chip development for use in space radiation environments
- Mentium Technologies
- NASA SBIR Sequential funded

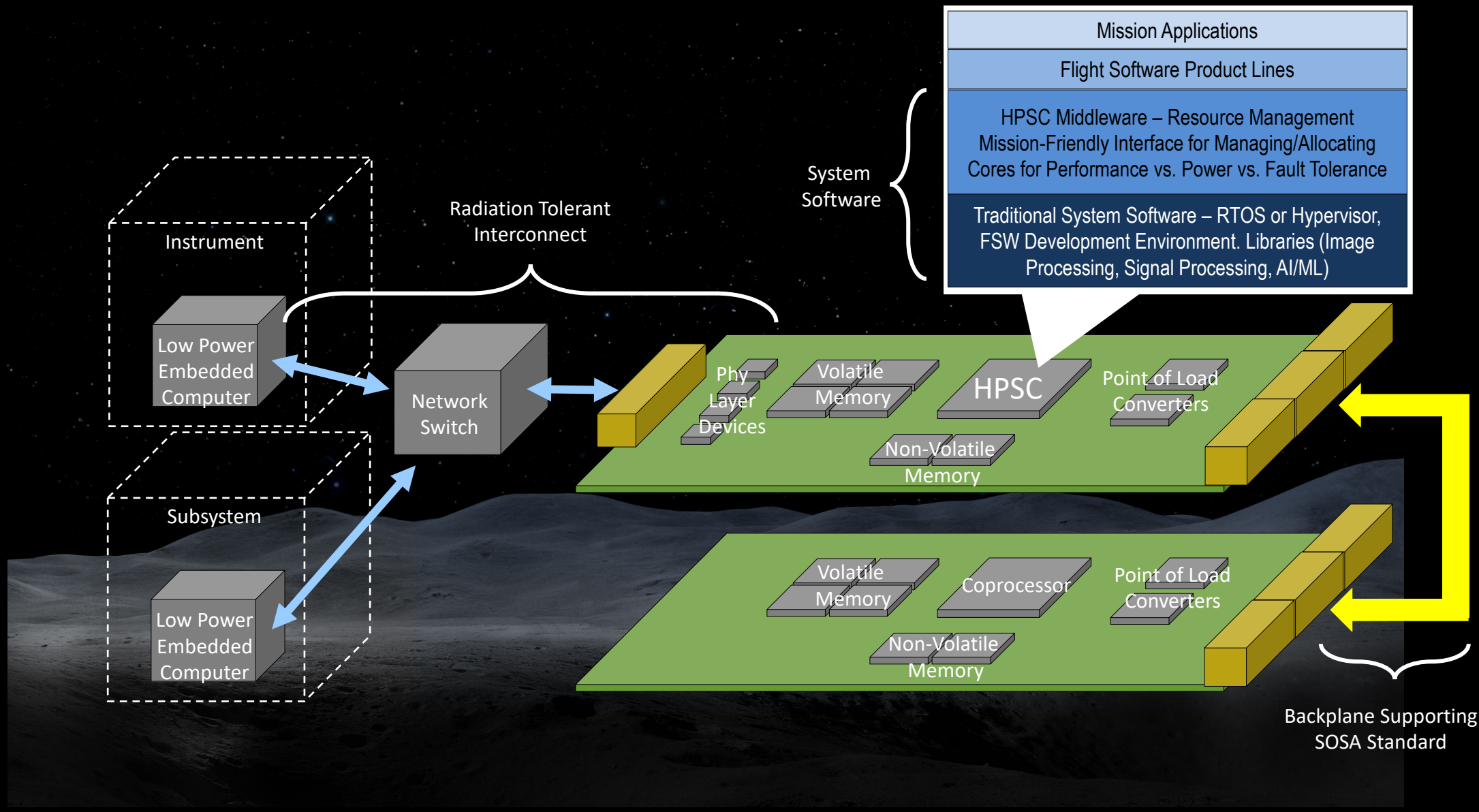
Deterministic Wireless
- Development of space-based wireless network protocol stack supporting MAC-level dynamic resource allocation for real-time prioritized data classes
- North Dakota State University
- NASA Early Stage Innovation (ESI) Funded

Crew Displays
- Radiation effects characterization in display technologies
- Prototyping of crew EVA suit display technology
- NASA JSC/GSFC/LaRC
- NASA ESDMD funded



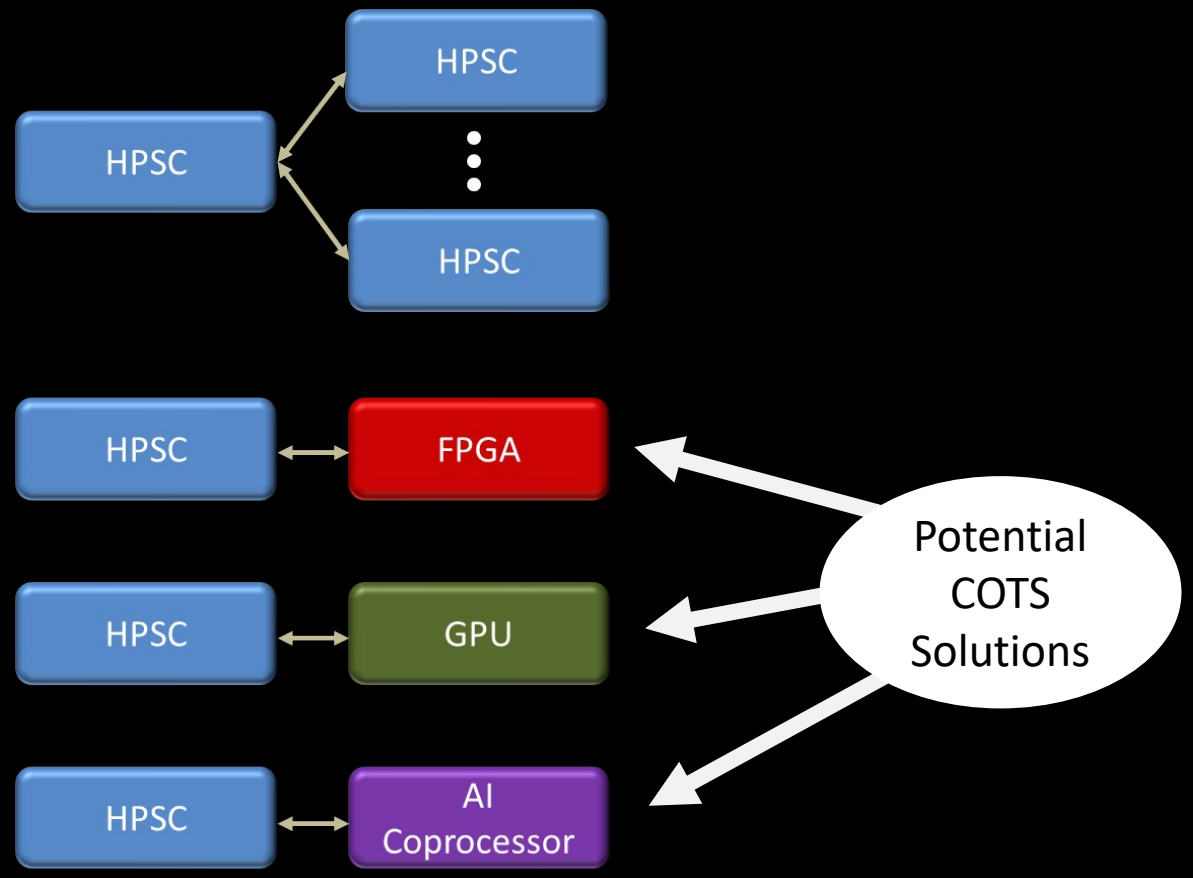
Extreme Environment Electronics
- Low temperature devices (ADC, analog, RF), design library, and packaging development
- Auburn University, Georgia Tech, Vanderbilt and University of Tennessee
- NASA STMD/SMD funded

Enabling an HPSC-Based Computing Ecosystem



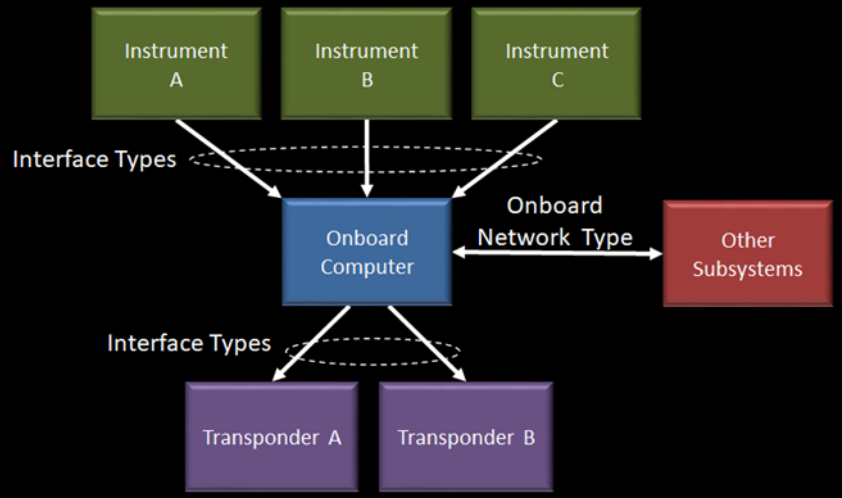
What About COTS?

- While much of NASA's emphasis within avionics is on HPSC, there is also a role for COTS processing solutions
- Use of COTS computing technologies must be guided by Mission, mission Environment, Application, and Lifetime (MEAL) principles
- The NASA Engineering and Safety Center (NESC) has conducted assessments on COTS parts usage
- COTS parts from Industry Leading Parts Manufacturer (ILPM) are preferred
- Advances in test systems are needed to accelerate radiation and reliability testing of complex COTS microelectronics devices



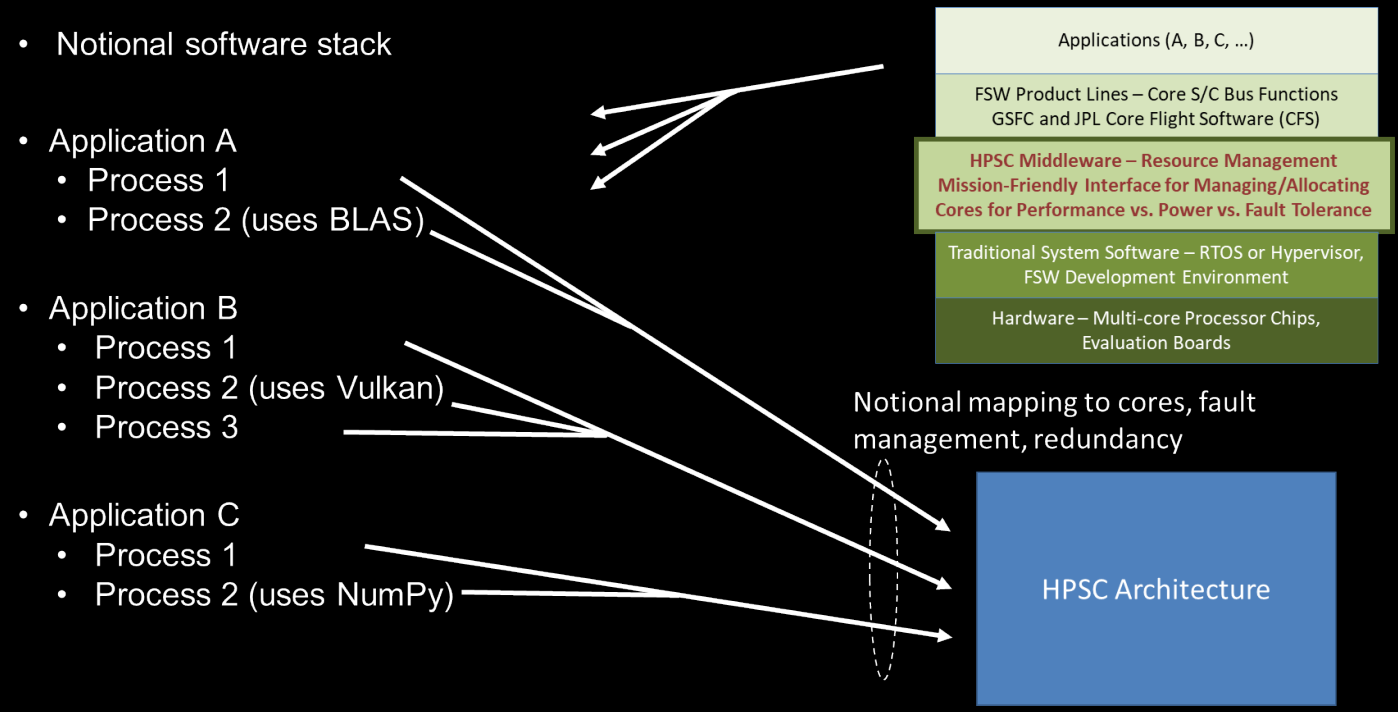
NASA HPSC Use Cases

- NASA-internal workshops have been conducted to identify use cases for HPSC
- 6 NASA Centers participated and provides 20 use cases
  - Crewed missions
  - Earth science
  - Planetary science
  - Astrophysics



NASA HPSC Use Cases

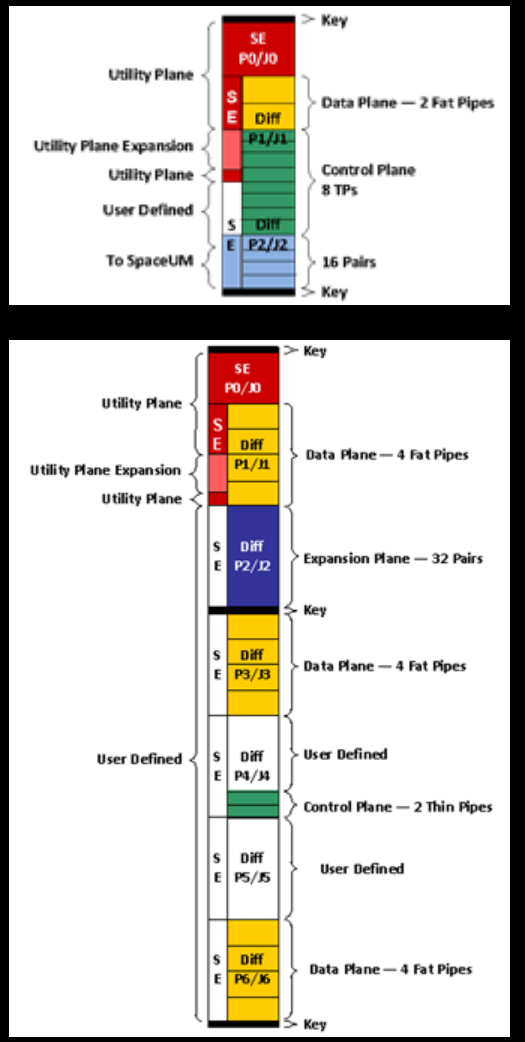
- Key Takeaways
  - Broad HPSC interest within NASA
  - Many use cases map to SpaceVPX, with needs for common module types identified (Power Supply, SpaceUM, SBC, Data Storage, I/O, Coprocessor)
  - Several use cases point to a need for a smaller form factor
  - Software needs for HPSC use cases largely map to ongoing development
- Work is continuing to further define and refine use case needs



NASA and SpaceVPX

- As NASA missions become more frequent, interconnected, ambitious, varied and complex, the need for an ecosystem of interoperable avionics modules becomes more important due to the cost, complexity, and the need to maintain distant systems for long durations
- The previous NASA-developed and widely adopted standard for backplane-based chassis interconnect, cPCI is over 20 years old and no longer supports modern architectures. cPCI has fallen by the wayside and no other standard has risen to replace it
- Stacked-card avionics, including MUSTANG, have arisen that address applications that require limited bandwidth communication between modules
- However, no standard architecture supporting high-bandwidth, tightly coupled modules, has emerged, resulting in ad hoc, non-optimal box level avionics, with attendant impact on cost, risk, schedule

- The existing SpaceVPX industry standard, as specified in VITA-78, addresses some of the needs of the space avionics community, but falls short of an interoperability standard that would enable reuse and common sparing on long duration missions and reduce non-recurring engineering (NRE) for missions in general



3U and 6U Slot Profiles [VITA-78]

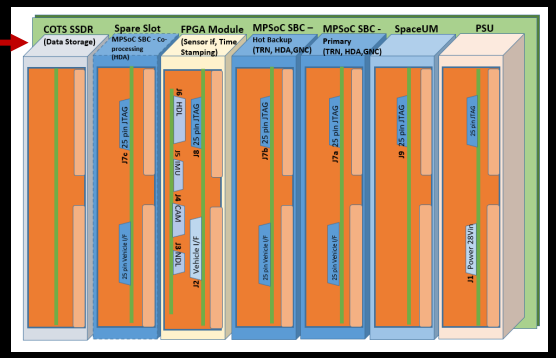
SpaceVPX Overview

SpaceVPX is an architecture standard that defines modules, backplanes, and chassis for spaceflight avionics boxes (the SpaceVPX standard is managed by VMEbus International Trade Association (VITA) as VITA-78)

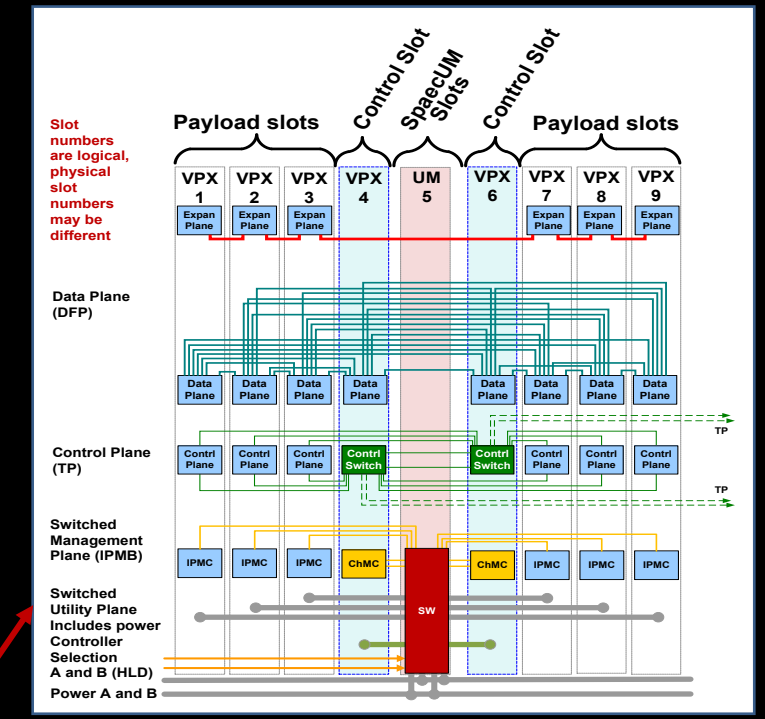
SpaceVPX adapts a Modular Open System Approach (MOSA), derived from VPX and OpenVPX (VITA-65), for space

SpaceVPX defines several general module types and how they can be interconnected, using the concept of "profiles"

- Slot Profile – A physical mapping of ports onto a slot's backplane connectors
- Module Profile - Extends a slot profile by mapping protocols to a module's ports and defines physical dimensions
- Backplane Profile - Defines number and types of modules supported and their interconnection topology



Profile Name	Data Plane 4 FP	Expansion Plane P2/J2	Control Plane 2 TP	User Defined
	DP01 to DP04		CPtp01 to CPtp02	P3/J3, P5/J5
MOD6-PAY-4F1Q2T-12.2.1-1-cc	sRIO 2.2 at 3.125 Gbaud per Section 5.2	sRIO 2.1 at 3.125 Gbaud per Section 5.2	SpaceWire per Section 5.2.1	User Defined DIFF pins



[VITA-78]

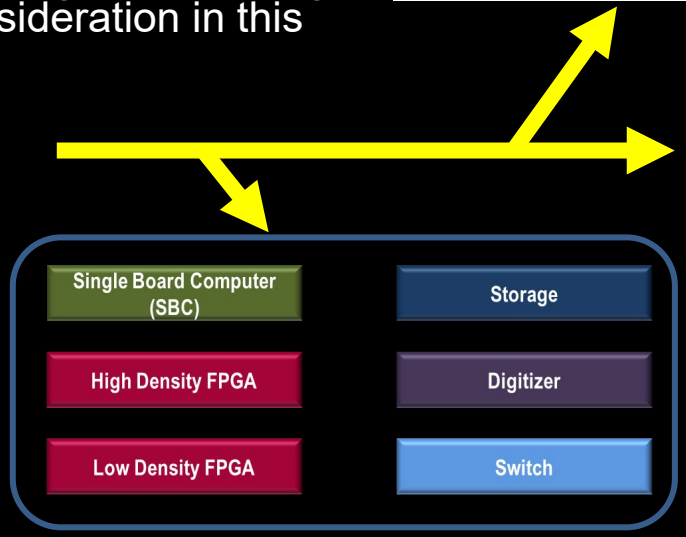
Problem statement – There is so much flexibility within SpaceVPX that it's possible to implement two different modules that are fully compliant with the standard yet cannot interoperate

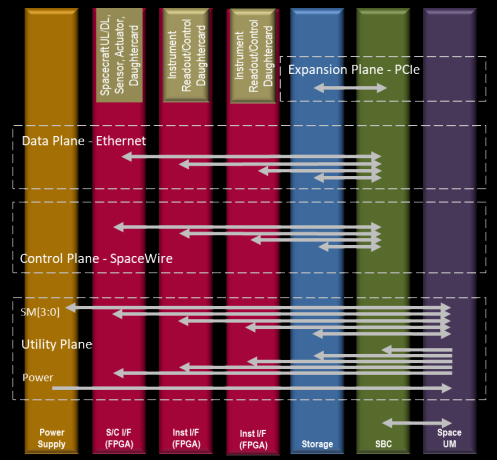
NASA SpaceVPX Interoperability Study

- A NASA Engineering & Safety Center (NESC) study was conducted to address the deficiencies in the SpaceVPX standard for NASA missions and define the recommended use of the SpaceVPX standard within NASA
- The study team was comprised of subject matter experts across NASA (GSFC, JSC, LaRC, JPL)
- The future infusion of NASA's High Performance Spaceflight Computing (HPSC) processor into SpaceVPX systems was a consideration in this study
- Study results included:
  - Proposed interoperable SpaceVPX specification
  - Candidate module types
  - Example systems
- The full study report can be found at:
  - https://ntrs.nasa.gov/citations/20220013983

	Proposed NASA Specification
RT-1	**General** Support dual redundant and single string SpaceVPX systems.
RT-2	**Power distribution and management** Utilize the 5-output SpaceUM (SLT3-SUM-5S1V3A1R1M3C-14.7.2) for 3U implementations with a 5V main power voltage. Utilize the 8-output SpaceUM (SLT6-SUM-8S3V3A1B1R1M4C-10.8.1) for 6U implementations with +12, +5, and +3.3 main supply voltages.

RT-3	**Interconnect**
	Support the following interconnect protocols:
	• Data Plane – Support for Ethernet 10GBASE-KR as specified in IEEE 802.3ap with support for TSN as specified in IEEE 802.1AX, CB, AS, Qbv, Qav, Qci, Qcc, and 802.1Q clauses 8.6.5.1 and 8.6.8.2
	• Control Plane - SpaceWire as defined in ECSS-E-ST-50-12C
	• Expansion Plane – JESD204C
	• Expansion Plane – Support for PCIe Gen 3.1
	• Utility Plane – IPMI and DAP as specified in VITA-78
	• User Defined signals with the requirement that they are user programmable
	  • SERDES - 1600mV peak-to-peak AC-coupled differential signaling; 8b/10b encoding; data rates of 1.25 Gbps, 2.5 Gbps, 3.125 Gbps, 5 Gbps, 6.25 Gbps, and 10 Gbps (note that some modules may not support all of these rates)
	  • Single ended - 2.5V LVCMOS signaling
	• Low-Rate Interconnect – I2C
	• JTAG
	• Provide pin on a front panel to disable JTAG for flight.



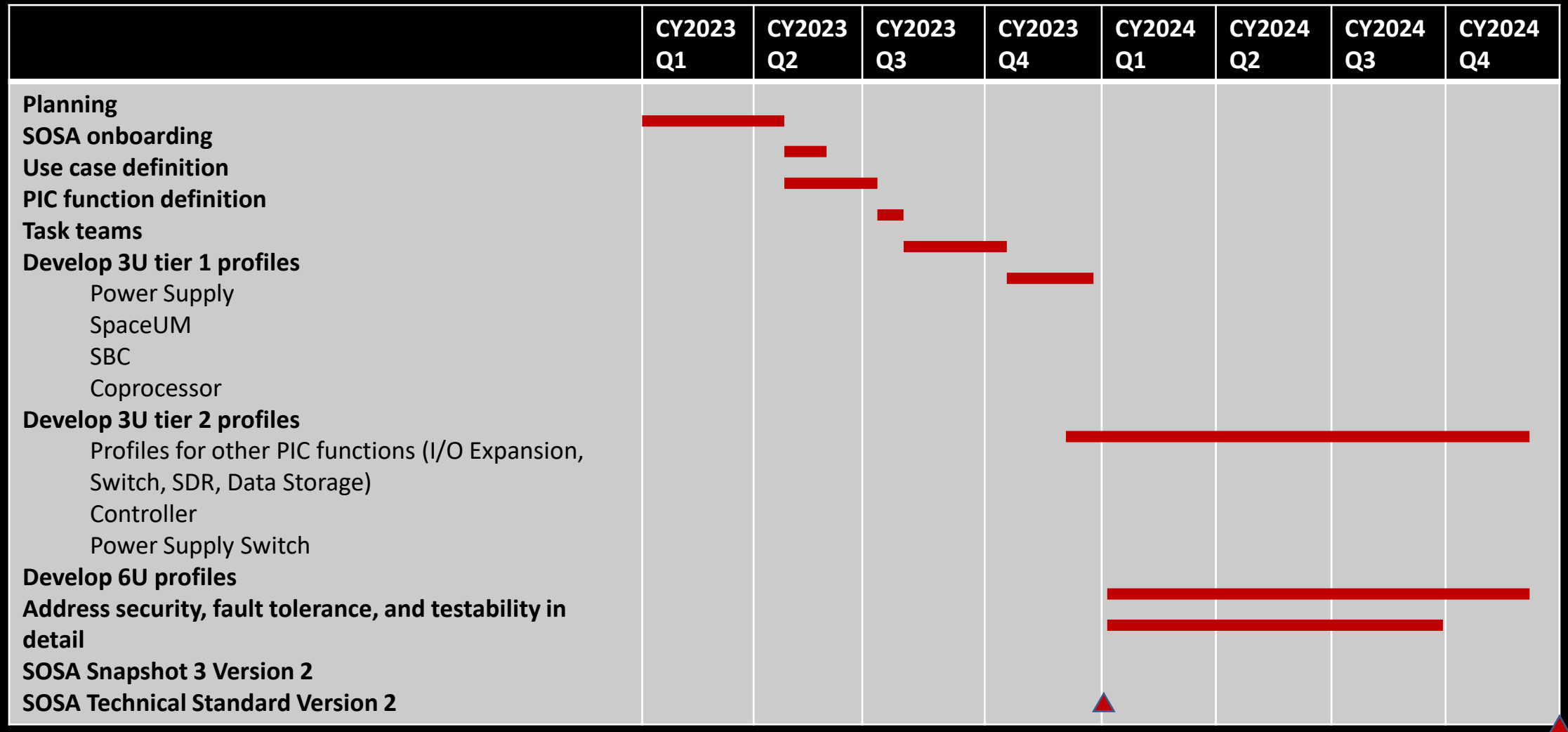


Single String 3U Smallsat Avionics

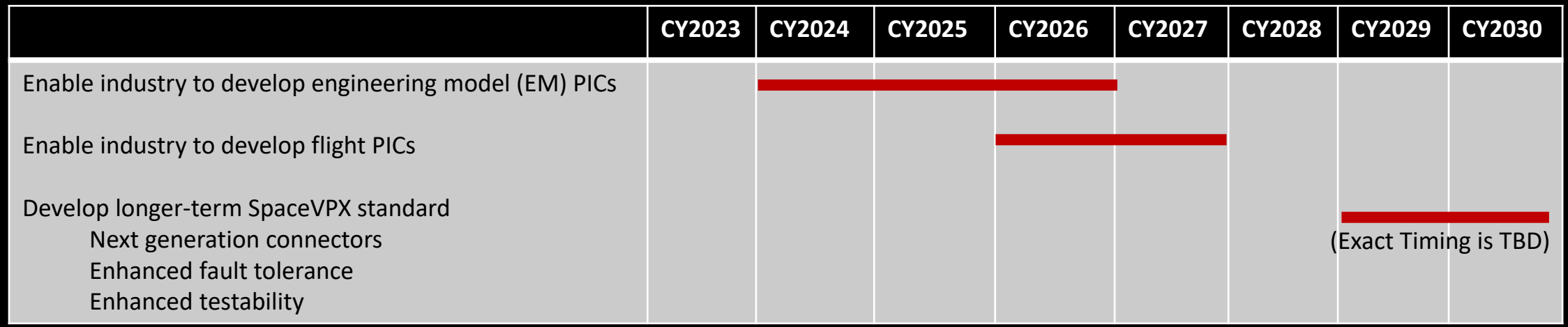
SOSA SpaceVPX Standardization

- A key recommendation of the completed NASA SpaceVPX Interoperability Assessment (R-3) states
  - NESC and STMD should engage with industry, other government agencies, and the SOSA™ Consortium on revision to VITA-78, and refine the module definition and interoperability (see Appendix B) and daughtercard use
- Consistent with this recommendation, a follow-on NESC activity has been initiated to collaborate with industry and other agencies on the development of an interoperable variant of SpaceVPX (currently specified in the VITA-78 standard) within the Sensor Open System Architecture (SOSA) standards organization
- Currently, over 25 industry and OGA participants are engaged on this effort within SOSA
- The expectation is to align content creation with existing SOSA publication schedule, with the specific goal of publishing SpaceVPX content in SOSA Snapshot 3 V2.0 in early 2024
- Content can then be integrated into the VITA-78 standard

SOSA SpaceVPX Standardization

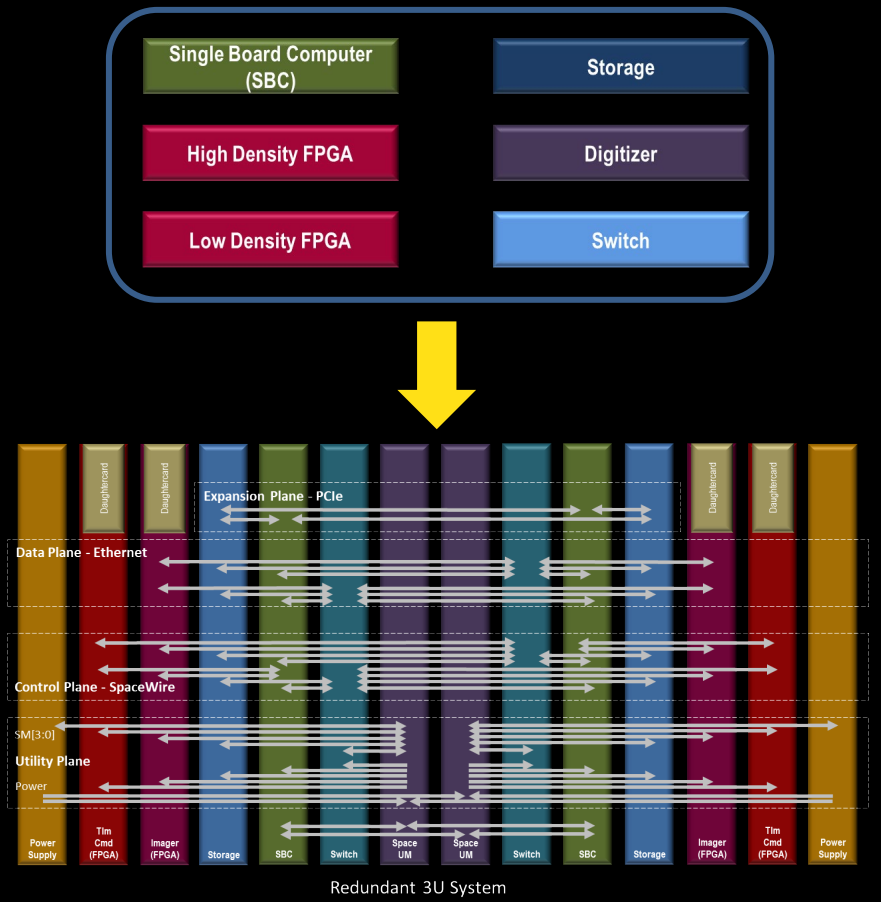


SOSA SpaceVPX Standardization



Benefits of Interoperable SpaceVPX

- Once completed, an interoperable SpaceVPX standard can guide SpaceVPX development within NASA and industry to ensure interoperable avionics for future NASA missions
  - SpaceVPX provides a scalable architecture with the high-bandwidth inter-module communication and inherent fault tolerance to meet the increased onboard computing demands of future missions
  - System integrators can configure systems consisting of SpaceVPX modules from multiple vendors
  - SpaceVPX module vendors can leverage broader markets for their products, which can reduce per unit cost
  - Interoperability provides a key step toward interchangeability that would be needed for common sparing for future crewed missions
- Interoperable SpaceVPX can form the backbone of the HPSC (High Performance Spaceflight Computing) avionics ecosystem
  - SpaceVPX leverages the full capabilities of emerging flight processors



Redundant 3U System

Conclusions

- With the development of HPSC underway, NASA is focusing on the broader HPSC ecosystem to enable mission infusion
  - DDR4 Memory
  - 10G Physical Layer (Transceivers and Connectors)
  - Point of Load Converters (POLs) and Power Management Controllers (PMCs)
  - Coprocessors
  - Software Libraries
- The development of interoperable SpaceVPX Plug-In Cards (PICs) is key to HPSC ecosystem, and the ongoing SOSA SpaceVPX standardization effort is first step toward this goal
- NASA seeks engagement with industry and other government agencies in developing technologies that can address the spaceflight avionics needs of our future crewed and robotic missions

Acronym List

AI	Artificial Intelligence	HW	Hardware	PALETTE	Planetary and Lunar Environment Thermal Toolbox Elements
ASIC	Application Specific Integrated Circuit	ILPM	Industry Leading Parts Manufacturer	PCIe	Peripheral Component Interconnect Express
BSP	Board Support Package	I/O	Intput/Output	PIC	Plug-In Card
cFE/cFS	Core Flight Executive/Core Flight Software	ISA	Instruction Set Architecture	POL	Point of Load
cPCI	Compact Peripheral Component Interconnect	ISRU	In Situ Resource Utilization	QML	Qualified Manufacturers List
COTS	Commercial Off the Shelf	JPL	Jet Propulsion Laboratory	REALM	RFID Enabled Autonomous Logistics
CPU	Central Processing Unit	JSC	Johnson Space Center	RFID	Radio-frequency Identification
C&DH	Command and Data Handling	LaRC	Langley Research Center	RHBD	Radiation-Hardened By Design
DDR	Double Data Rate	LEO	Low Earth Orbit	RISC	Reduced Instruction Set Computer
ECC	Error Correction Code	LLVM	Low Level Virtual Machine	RTOS	Real Time Operating System
ELCSS	Environmental Control and Life Support System	LPEC	Low Power Embedded Computer	SBC	Single Board Computer
EDL	Entry Descent and Landing	LSII	Lunar Surface Innovation Initiative	SBIR	Small Business Innovation Research
ESDMD	Exploration Systems Development Mission Directorate	LuSTR	Lunar Surface Technology Research	SC	Subcommittee
EVA	Extra-Vehicular Activity	MEAL	Mission, mission Environment, Application, and Lifetime	SCC	Space Computing Conference
FET	Field Effect Transistor	ML	Machine Learning	SEE	Single Event Effect
FPGA	Field Programmable Gate Array	MOSA	Modular Open Systems Architecture	SMD	Science Mission Directorate
fps	Frames per Second	MUSTANG	Modular Unified Space Technology Avionics for Next Generation missions	SOC	System-On-a-Chip
FSW	Flight Software	NASA	National Aeronautics and Space Administration	SOSA	Sensor Open Systems Architecture
FT	Fault Tolerance	NEPP	NASA Electronics Parts and Packaging Program	STMD	Space Technology Mission Directorate
GB	Gigabyte	NESC	NASA Engineering & Safety Center	STTR	Small Business Technology Transfer
Gbps	Gigabits Per Second	NRE	Non-Recurring Engineering	SW	Software
GCC	Gnu Compiler Collection	NumPy	Numerical Python	SWaP-C	Size Weight and Power, and Cost
GPP	General Purpose Processing	Open BLAS	Open Basic Linear Algebra Subprograms	TSN	Time-Sensitive Networking
GPU	Graphics Processing Unit	OpenCL	Open Computing Language	TX	Taxonomy
GSFC	Goddard Space Flight Center	OpenCV	Open Source Computer Vision	TWG	Technical Working Group
IEEE	Institute of Electrical and Electronics Engineers	OpenGL	Open Graphics Library	VITA	VMEbus (Versa Module Eurocard Bus) International Trade Association
HI	Heterogeneous Integration	OpenMP	Open Multiprocessing	xEMU	eXploration Extravehicular Mobility Unit
HPSC	High Performance Spaceflight Computing	OS	Operating System		
HUD	Heads Up Display	OSAM	Peripheral Component Interconnect Express		