

The background of the slide is a composite image of space exploration. On the left, a large, detailed Earth's moon is shown in a light blue-grey color. Above it and to the left is a smaller, reddish-orange planet, likely Mars. A small spacecraft is depicted in the distance, moving from left to right and leaving a bright blue, glowing trail behind it. The sky is a deep, dark blue filled with numerous white stars. In the bottom right corner, there is a dark silhouette of a person's head and shoulders, looking towards the left. The bottom of the slide shows a dark, silhouetted horizon line with some light clouds visible just above it.

EXPLORESpace TECH

TECHNOLOGY DRIVES EXPLORATION

HPSC – Driving Demand Into the Ecosystem

Wesley Powell – NASA STMD Principal Technologist for Advanced Avionics
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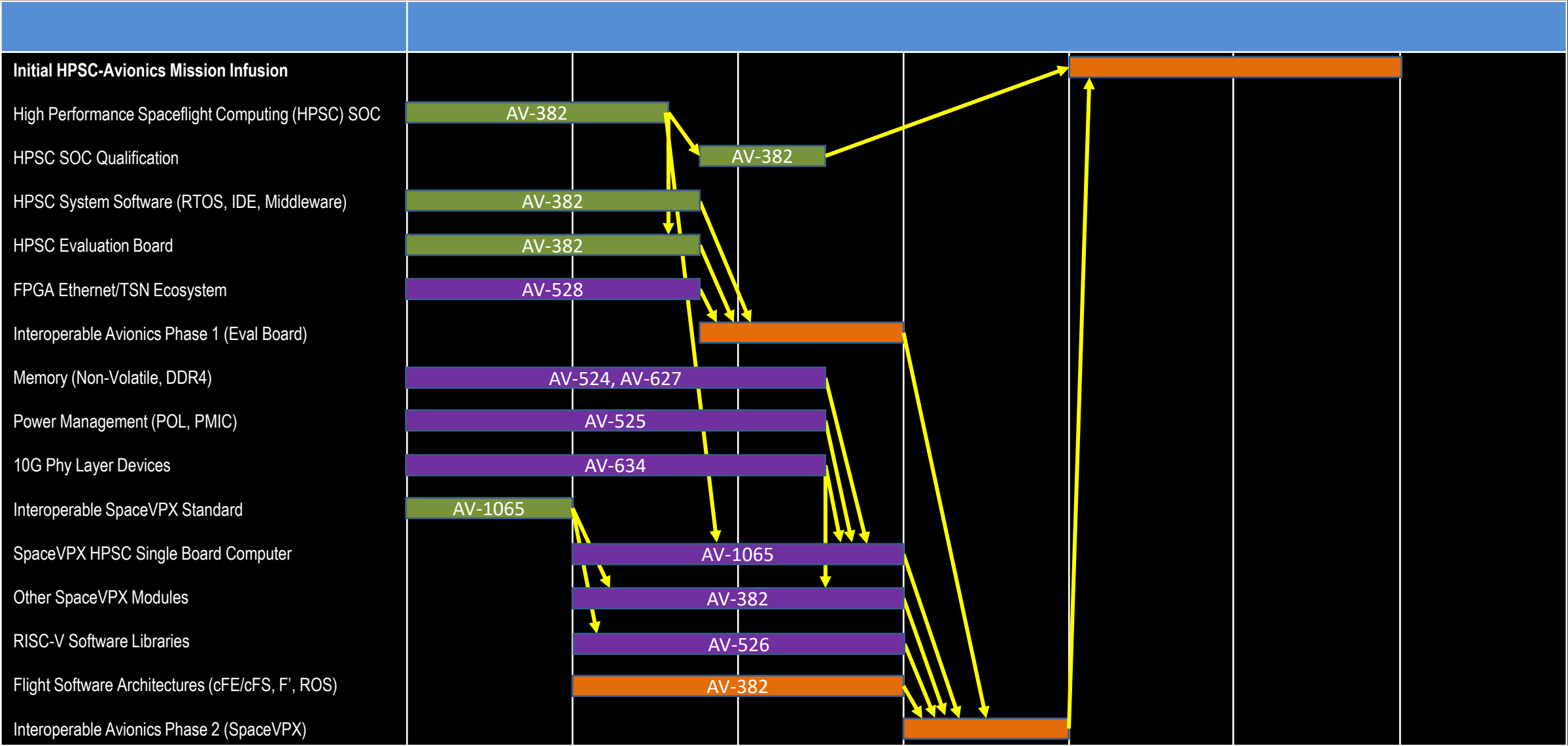
To be presented at the 2024
High Performance
Spaceflight Computing
(HPSC) Technical
Interchange Meeting (TIM),
NASA MSFC, February 13 –
14, 2024

Agenda



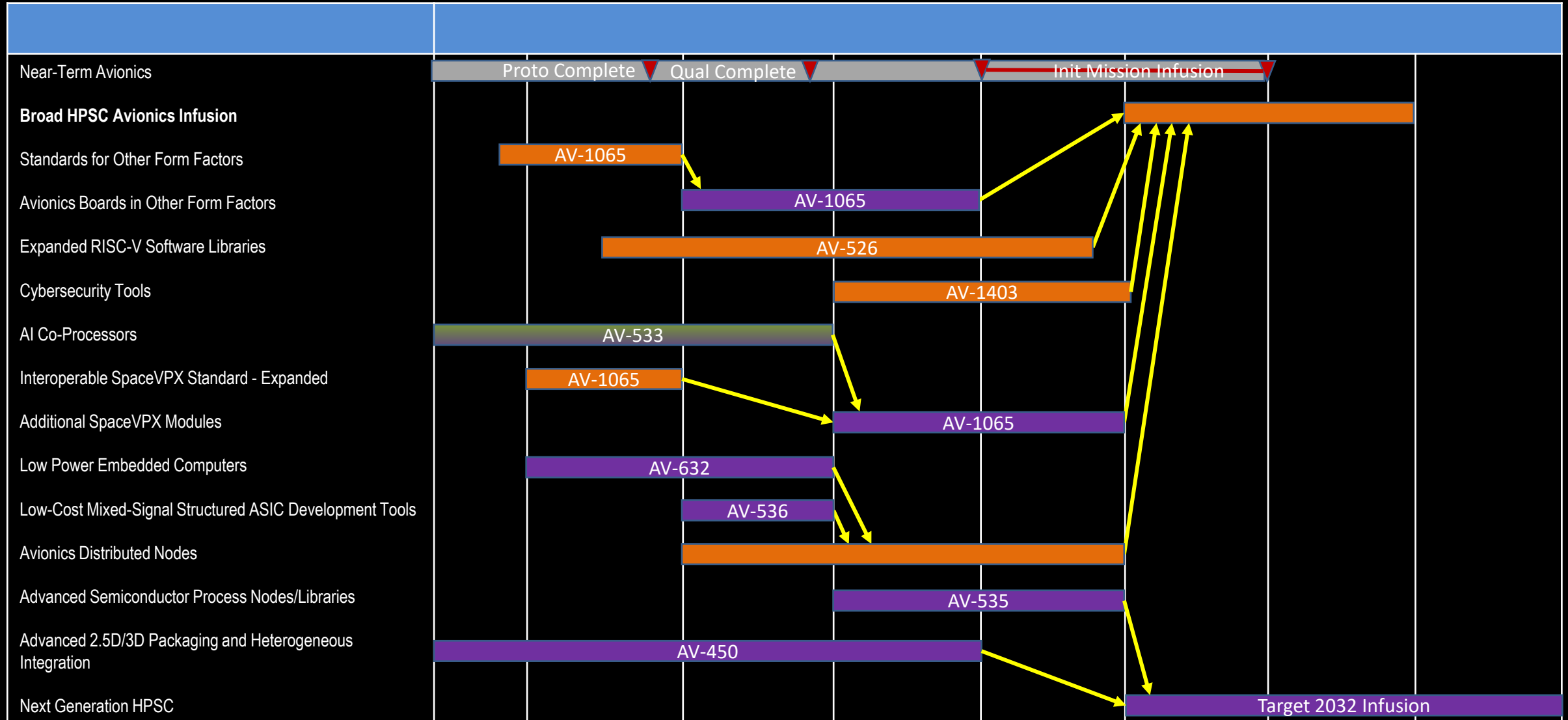
- NASA Spaceflight Computing Roadmaps
- Engaging Industry to Develop HPSC Ecosystem
- NASA Avionics Technology Investments
- HPSC Ecosystem – A Deep Dive
 - Components
 - IP Cores
 - Software
 - Boards
- Conclusion

Near-Term Onboard Computing Roadmap



■ NASA + Industry Funded ■ Expected from Industry ■ NASA (Unfunded)

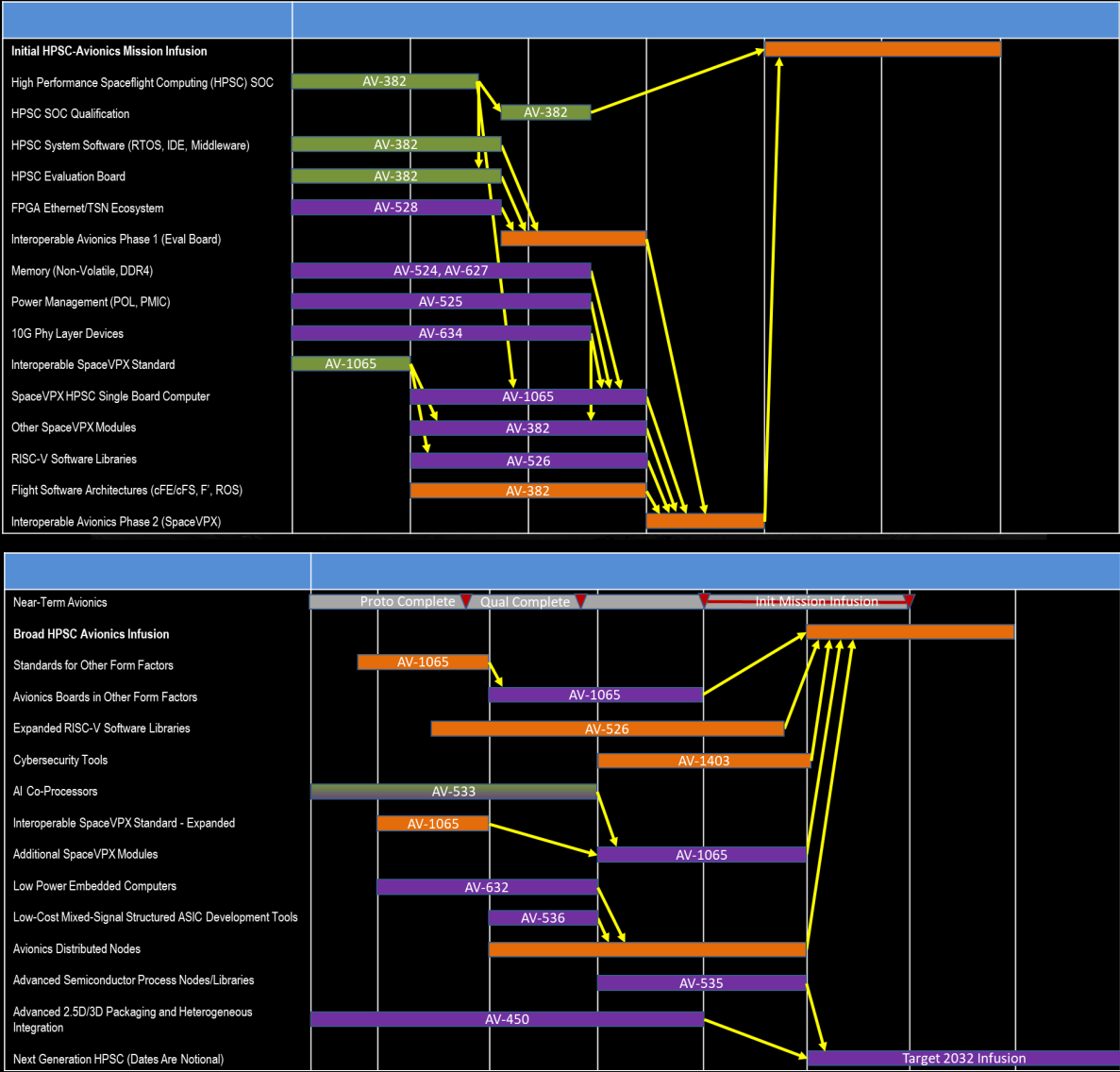
Longer-Term Onboard Computing Roadmap



Engaging Industry to Develop HPSC Ecosystem



- The roadmaps above rely heavily on industry to develop the HPSC ecosystem

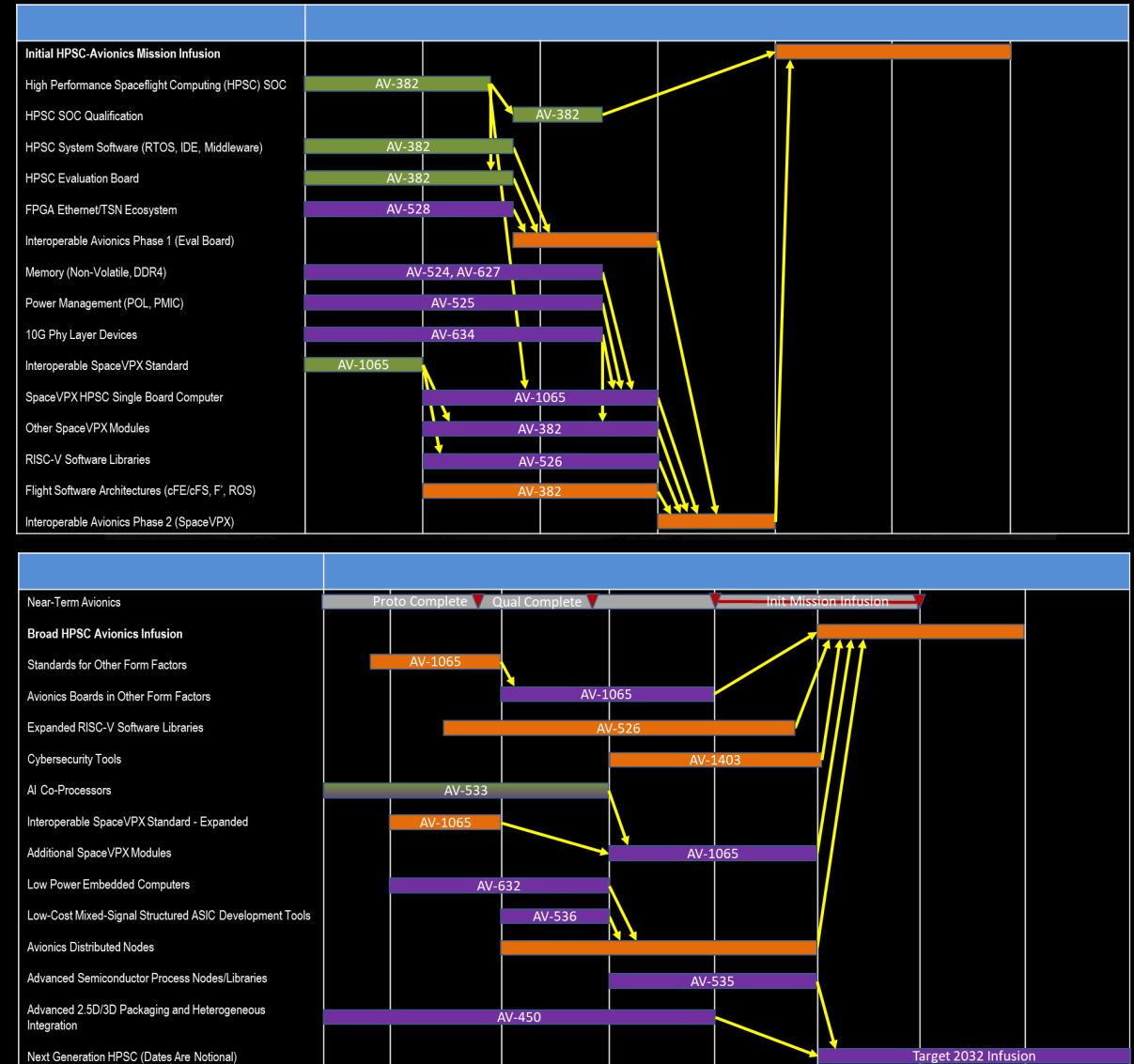


Engaging Industry to Develop HPSC Ecosystem



- The roadmaps above rely heavily on industry to develop the HPSC ecosystem

Everything in purple



Engaging Industry to Develop HPSC Ecosystem



- NASA STMD acquisition vehicles
 - Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR)
 - Has the benefit of leveraging set aside funding
 - Can take time to go through development phases
 - Phase 1
 - Phase 2
 - Phase 3 (project funded)
 - SBIR Phase 2 Sequential
 - Advances selected SBIR projects that have completed Phase 2
 - SBIR Ignite
 - Limited pilot program focused on technologies with a strong commercial pull
 - Topic areas of interest for this solicitation specifically selected for their commercial relevance
 - Offerors must demonstrate their understanding of the market and provide a strong plan for commercialization of the technology to be competitive for award

Engaging Industry to Develop HPSC Ecosystem



- NASA STMD acquisition vehicles
 - Tipping Point
 - NASA funding of partnerships with industry to develop technologies that are at a “tipping point”
 - Tipping point criteria The proposed technology system is at a Technology Readiness Level (TRL) of approximately 4 or higher at time of submission of the Mini Proposal
 - An investment in a ground demonstration or flight demonstration will result in:
 - A significant advancement of the technology’s maturation to at least TRL of 6, and
 - A significant improvement in the Lead Entity’s ability to successfully bring the technology to market
 - The partner has a robust plan for commercialization
 - Announcement of Collaboration Opportunity (ACO)
 - NASA partnerships advancing commercially-developed technologies (through use of NASA unique resources on a no-exchange-of-funds basis) that can benefit both the commercial and government use of space
 - Allows industry access to technical expertise, test facilities, hardware, and software from across NASA Centers to accelerate the development and availability of these technologies and reduce costs associated with their implementation and use

Engaging Industry to Develop HPSC Ecosystem



- NASA STMD acquisition vehicles
 - Space Technology Research Grant (STRG)
 - Low TRL technology portfolio of groundbreaking research in advanced space technology
 - Challenges the spectrum of academic researchers – from graduate students to tenured faculty members – to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable
 - Funding opportunities
 - NASA Space Technology Graduate Research Opportunities (NSTGRO)
 - Early Career Faculty (ECF)
 - Early Stage Innovations (ESI)
 - Lunar Surface Technology Research LuSTR
 - Space Technology Research Institutes (STRI)

Engaging Industry to Develop HPSC Ecosystem



- The Envisioned Future Priorities (EFP) inform STMD acquisitions
- The EFPs are developed in consultation with SMEs across NASA and with stakeholders from the NASA Science Mission Directorate (SMD) and Exploration Systems Development Mission Directorate (ESDMD)

Engaging Industry to Develop HPSC Ecosystem



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- Ensure American global leadership in Space Technology
 - Advance US space technology innovation and competitiveness in a global context
 - Encourage technology-driven economic growth with an emphasis on the expanding space economy
 - Inspire and develop a diverse and powerful U.S. aerospace technology community

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 - Space Nuclear Propulsion
 - Cryogenic Fluid Management
 - Advanced Propulsion

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- Expanded Access to Diverse Surface Destinations
 - Precision Landing and Hazard Avoidance
 - Entry, Descent, and Landing to Enable Science Missions
 - 20t and Lunar/Mars Global Access

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- Sustainable Living and Working Farther from Earth
 - Advanced Habitation Systems (AHS)
 - In-Situ Resource Utilization
 - Power and Energy Storage Systems
 - Thermal Management Systems
 - Excavation, Construction, and Outfitting (ECO)
 - Surface Systems

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- Transformative Missions and Discoveries
 - Advanced Avionics
 - Advanced Manufacturing
 - Autonomous Systems and Robotics
 - Communications and Navigation
 - In-space Servicing, Assembly, and Manufacturing (ISAM) and Rendezvous, Proximity Operations, and Capture (RPOC)
 - Small Spacecraft Technologies
 - Sensors, Instruments, and Observatories

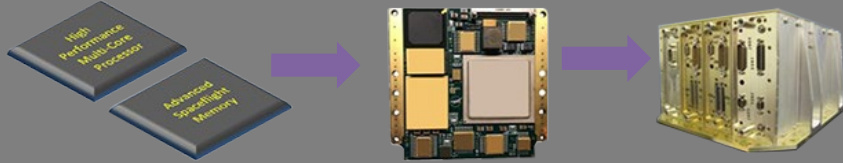
Engaging Industry to Develop HPSC Ecosystem



- Standards organization engagement
 - Allows NASA to guide development and updating of industry standards to meet our specific needs
 - Collaborative effort with other industry and government participants
 - Industry standards then drive industry technology development
 - Ongoing efforts within avionics
 - SOSA SpaceVPX
 - IEEE TSN
- Product purchases
 - In cases where a specific products with needed features does not yet exist, purchase orders may stimulate their development

Benefits	Caveats
• A relatively small NASA investment can yield significant result	• Required dedicated, sustained labor support • This process can take time

NASA Avionics Technology Investments

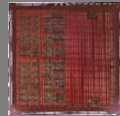


High Performance Spaceflight Computing

- 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



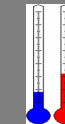
Deterministic Wireless

- 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

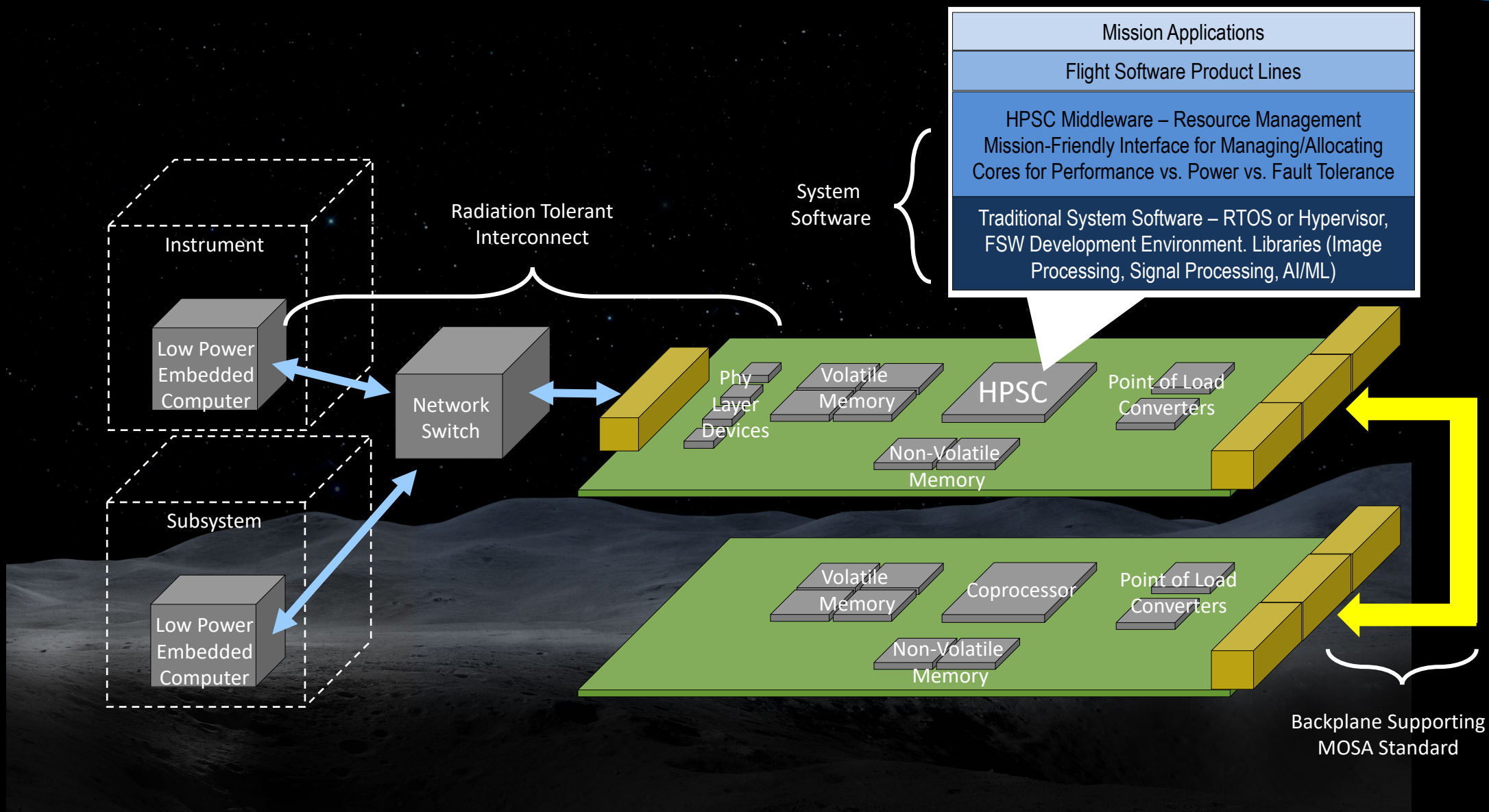
- Radiation effects characterization in display technologies
- Prototyping of crew EVA suit display technology
- NASA JSC/GSFC/LaRC
- NASA ESDMD funded



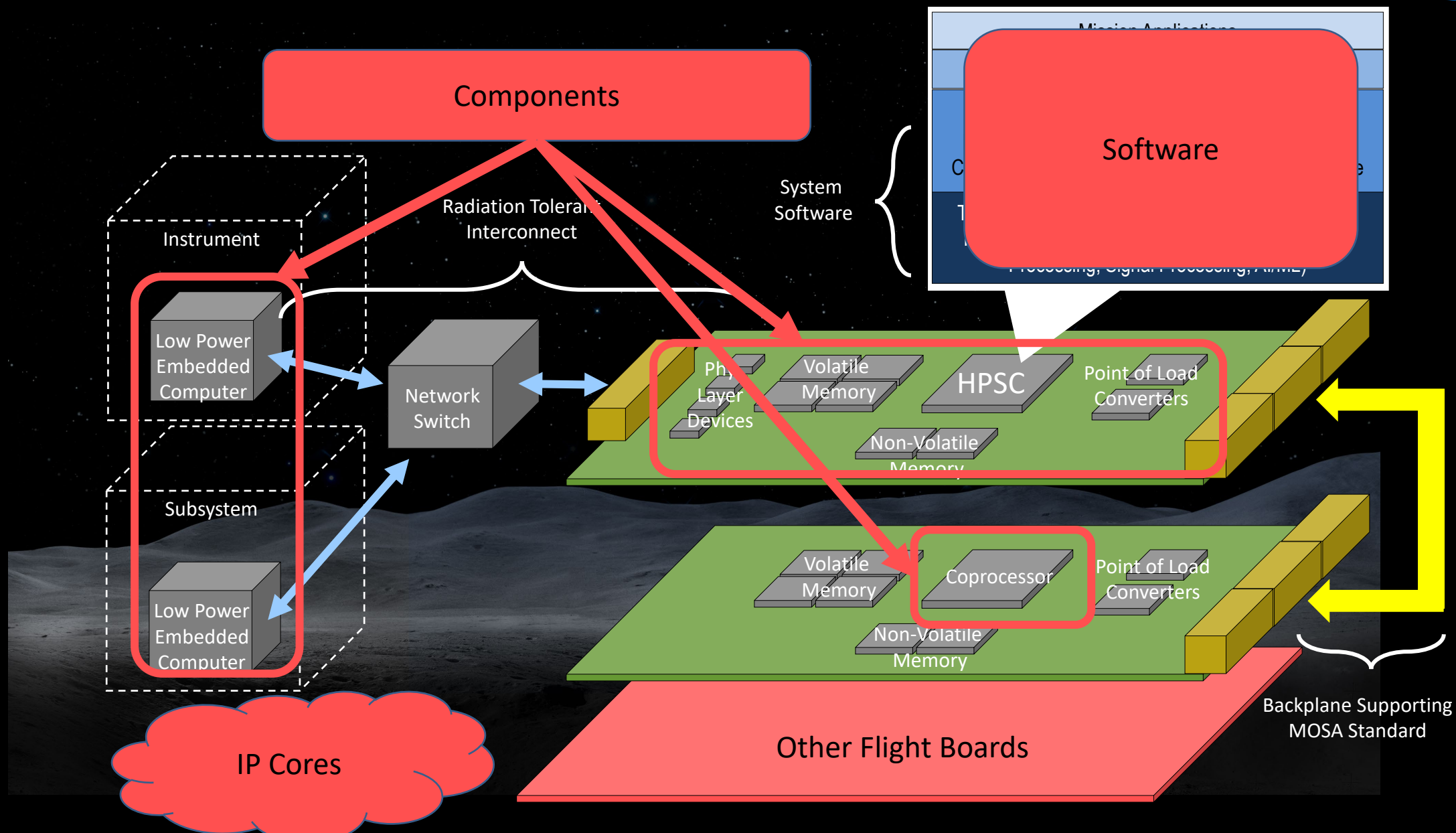
Extreme Environment Electronics

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

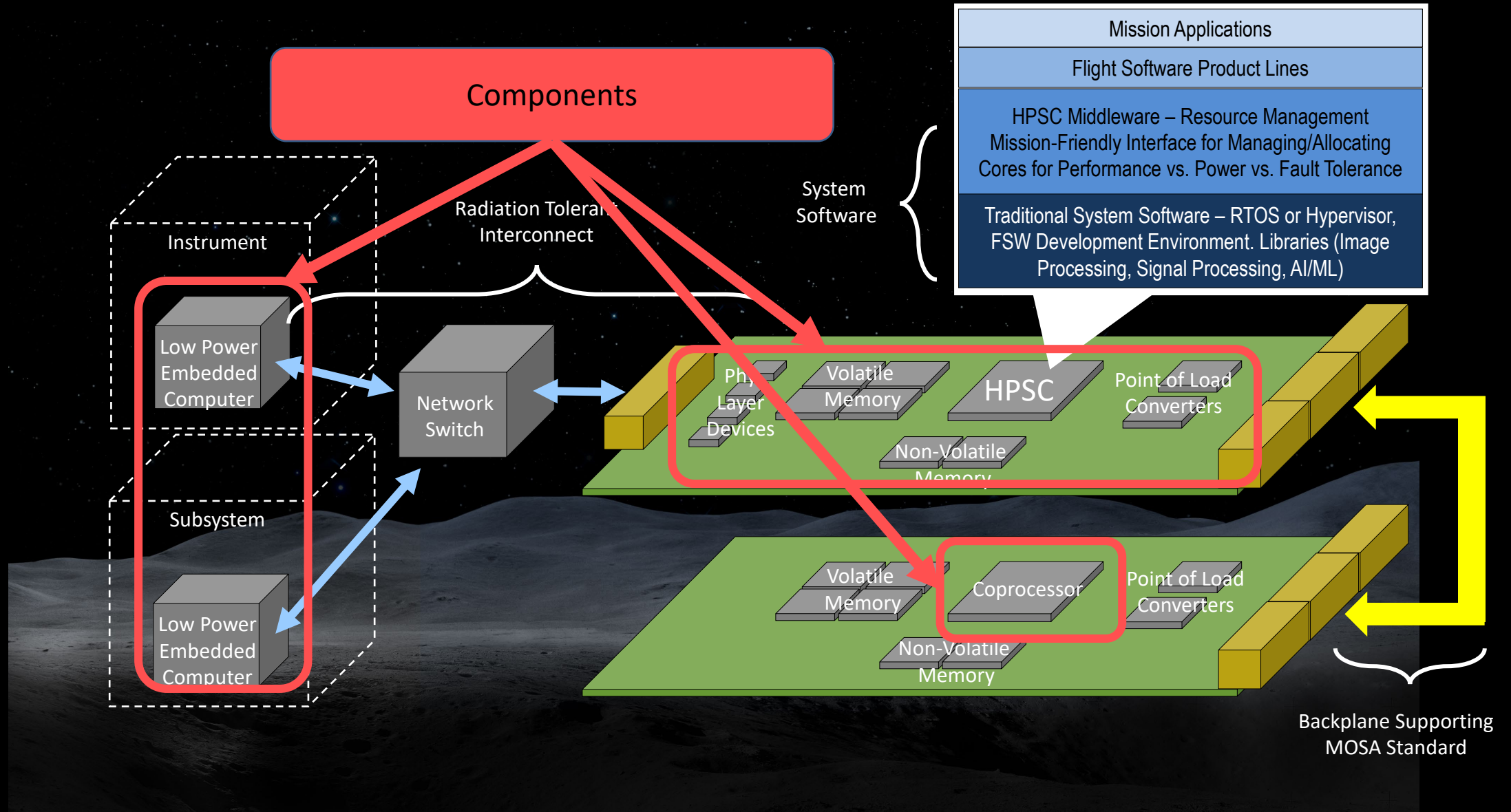
HPSC Ecosystem - A Deep Dive



HPSC Ecosystem - A Deep Dive



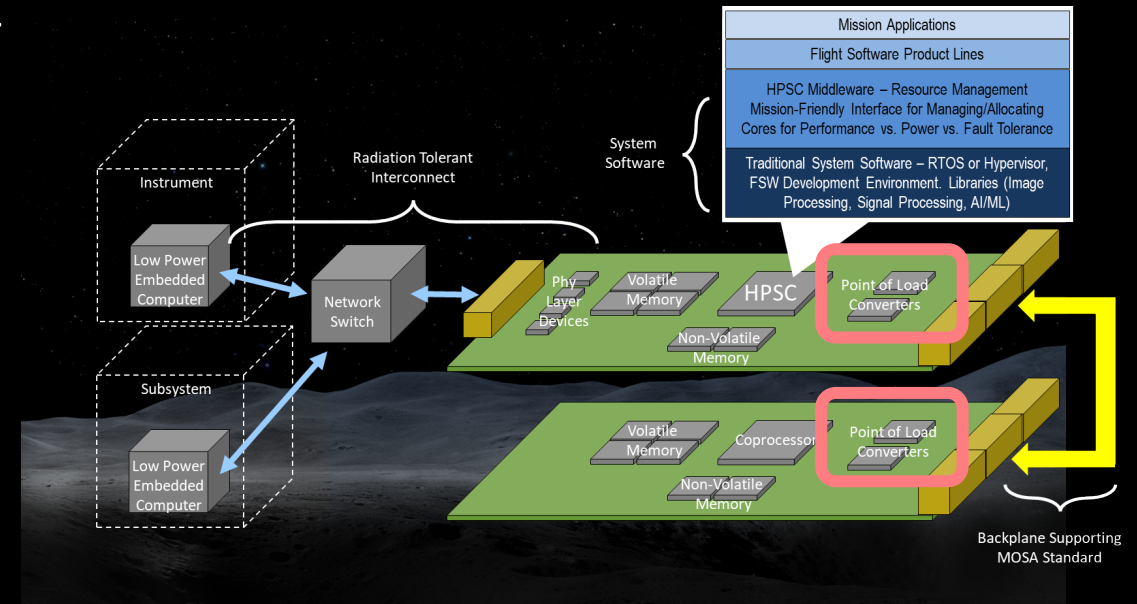
HPSC Ecosystem - Components



HPSC Ecosystem - Components



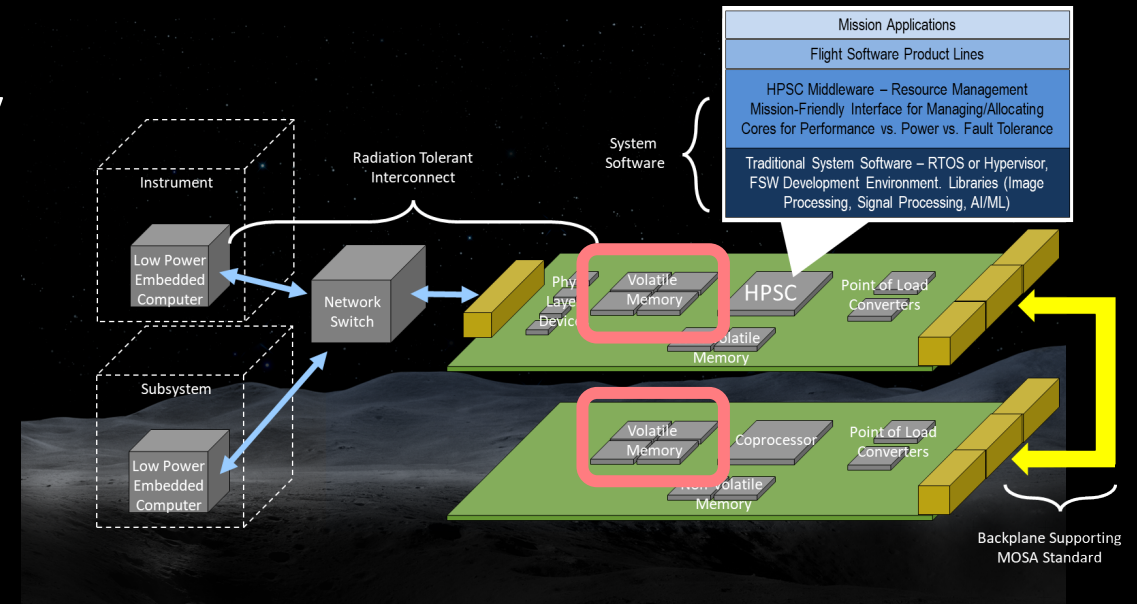
- Power Management
 - Intelligent, efficient, rad hard multiple output Point-Of-Load (POL) direct current (DC) to DC power converters to support current and emerging processor and Field Programmable Gate Array (FPGA) devices
- Goals
 - 3 outputs per converter
 - 12V input
 - Wide output range $\sim 0.5V - 5V$
 - PMBus interface
 - The ability of the device to independently detect and respond to fault conditions



HPSC Ecosystem - Components



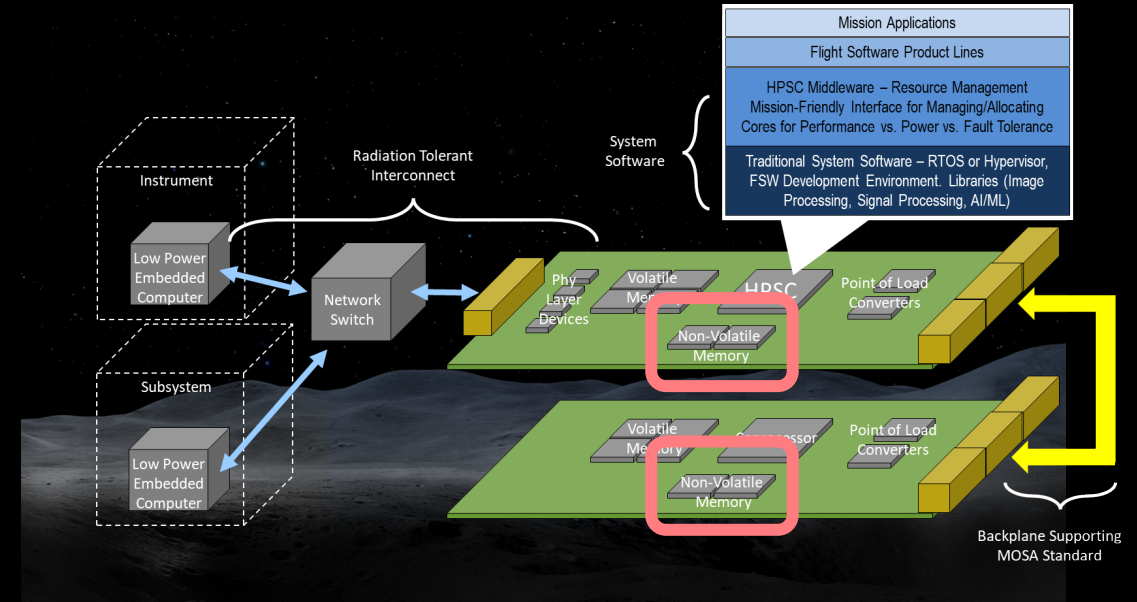
- Volatile Memory
 - Advanced spaceflight volatile memory with industry standard DDR3/4 interfaces with Single Event Functional Interrupt (SEFI) radiation tolerance
- Goals
 - DDR4 interface
 - 80-bit width for packaged parts
 - Stretch goal is capacity approaching current commercial technology



HPSC Ecosystem - Components



- Non-Volatile Memory
 - Advanced spaceflight non-volatile memory with Single Event Functional Interrupt (SEFI) radiation tolerance and industry standard interfaces
- NOR Flash Goals
 - Capacity approaching current commercial technology
 - QSPI interface
- NAND Flash Goals
 - Capacity approaching current commercial technology
- MRAM Goals
 - 4 – 16 Gb capacity
 - DDR3/4 interface

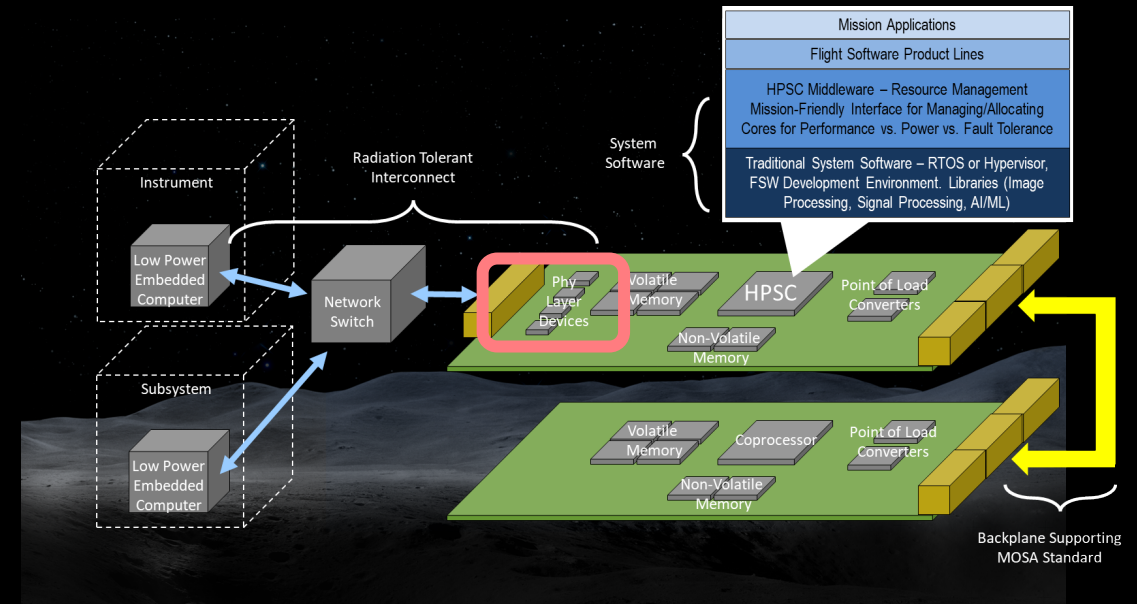


HPSC Ecosystem - Components



- Phy Layer Devices

- Physical layer devices (both copper and optical) are needed to transmit high bandwidth serial links between avionics boxes
- Goals
 - 10 Gbps
 - Both fiber-optic and copper media
- For copper media, an assessment is needed for 10GBASE-T vs. 10GBASE-T1
 - 10GBASE-T = 4 twisted pairs
 - 10GBASE-T1 = 1 twisted pair
 - Choice has implications on connectors, harnessing, drive distance, ...
- For optical media, an assessment is to provide guidance on recommended fiber and connector options



HPSC Ecosystem - Components

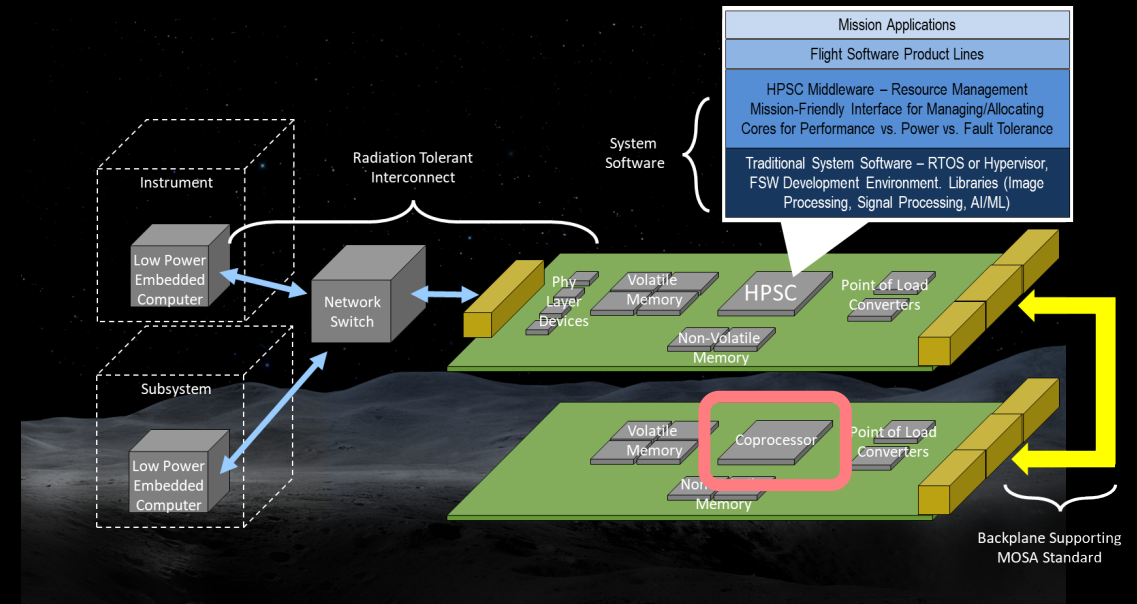


- Co-processors

- Artificial intelligence (AI) coprocessors for deep space missions, including radiation tolerant neuromorphic and machine learning processors, are needed to enable autonomous landing, surface navigation, robotic servicing/assembly, and data processing for lunar surface science instruments.

- Goals

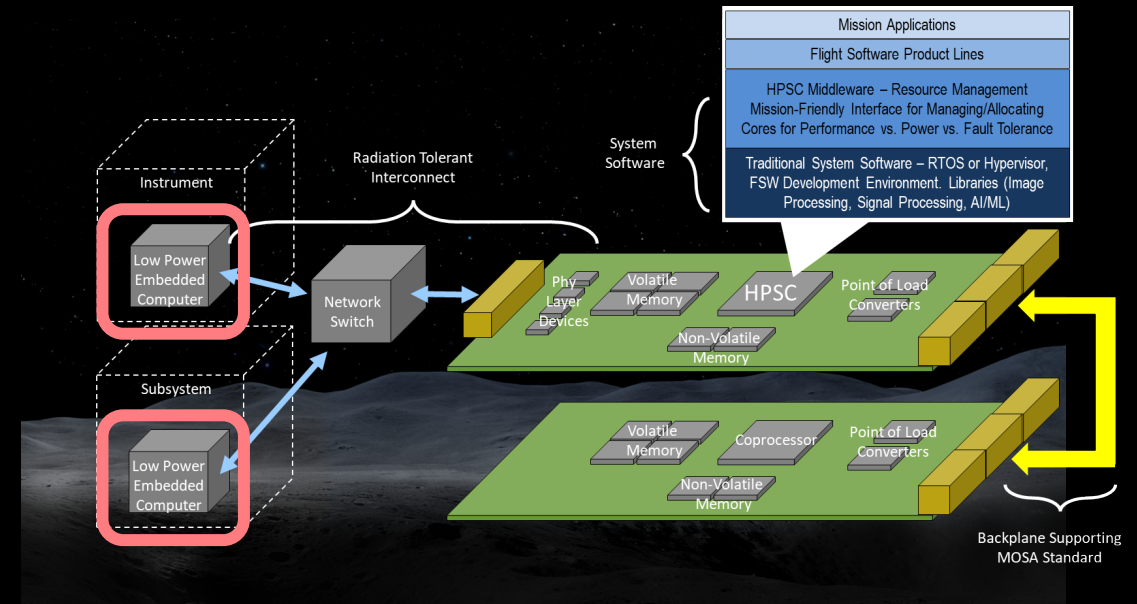
- AI co-processor architectures that map to NASA processing needs
- SEL immune
- PCIe or Ethernet interface
- Notionally 4 TOPS bandwidth (40 TOPS stretch goal), but this is really wide open (the architecture is key)
 - Work is needed to map AI applications to processing requirements



HPSC Ecosystem - Components



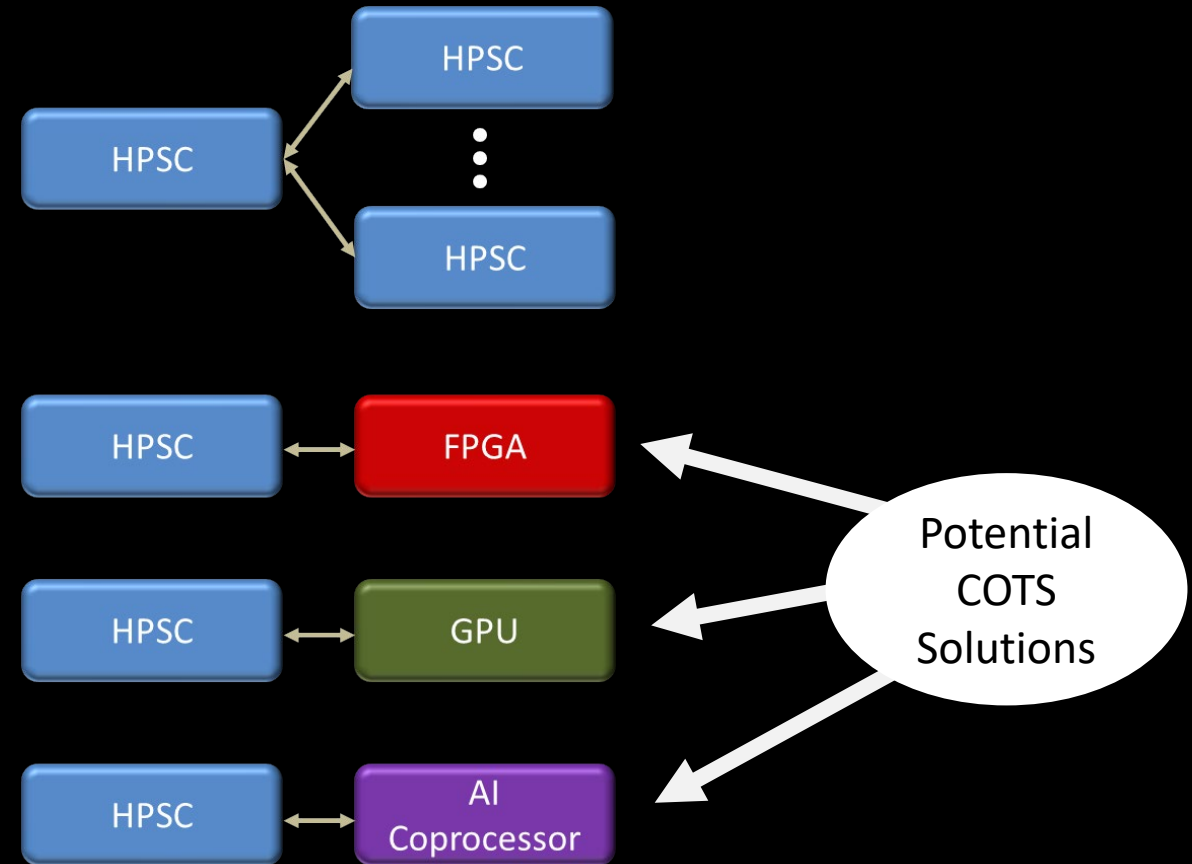
- Low Power Embedded Computers
 - Low power embedded computers to support distributed robotics architectures, smart cameras for autonomous docking and robotics applications, and low-to-medium bandwidth processing within instruments
- Target application goals
 - Support minimum frequency for operating inner control loop for motors > 1kHz
 - Support 5 Hz fiducial tracking performance for smart cameras
- Study is needed to develop
 - Requirements for low power embedded computing applications
 - Distributed avionics architecture to enable modular, interoperable, and reusable robotic systems
 - Low power embedded computer concepts that are consistent with that architecture and can meet SWaP (and potentially extreme environmental) requirements



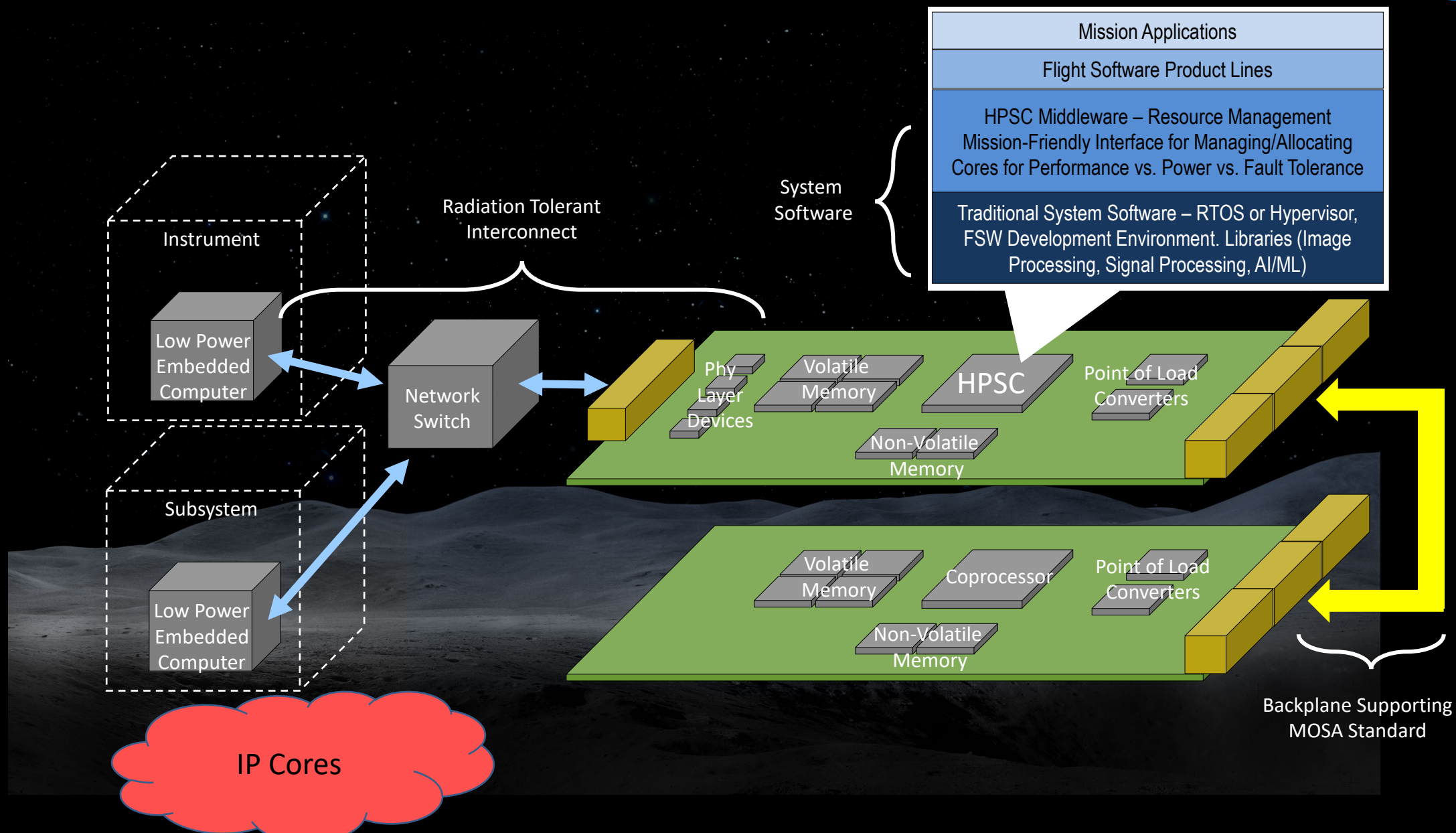
What About COTS?



- 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
- COTS parts from Industry Leading Parts Manufacturer (ILPM) are preferred
- Note that the broader HPSC ecosystem may leverage COTS coprocessors



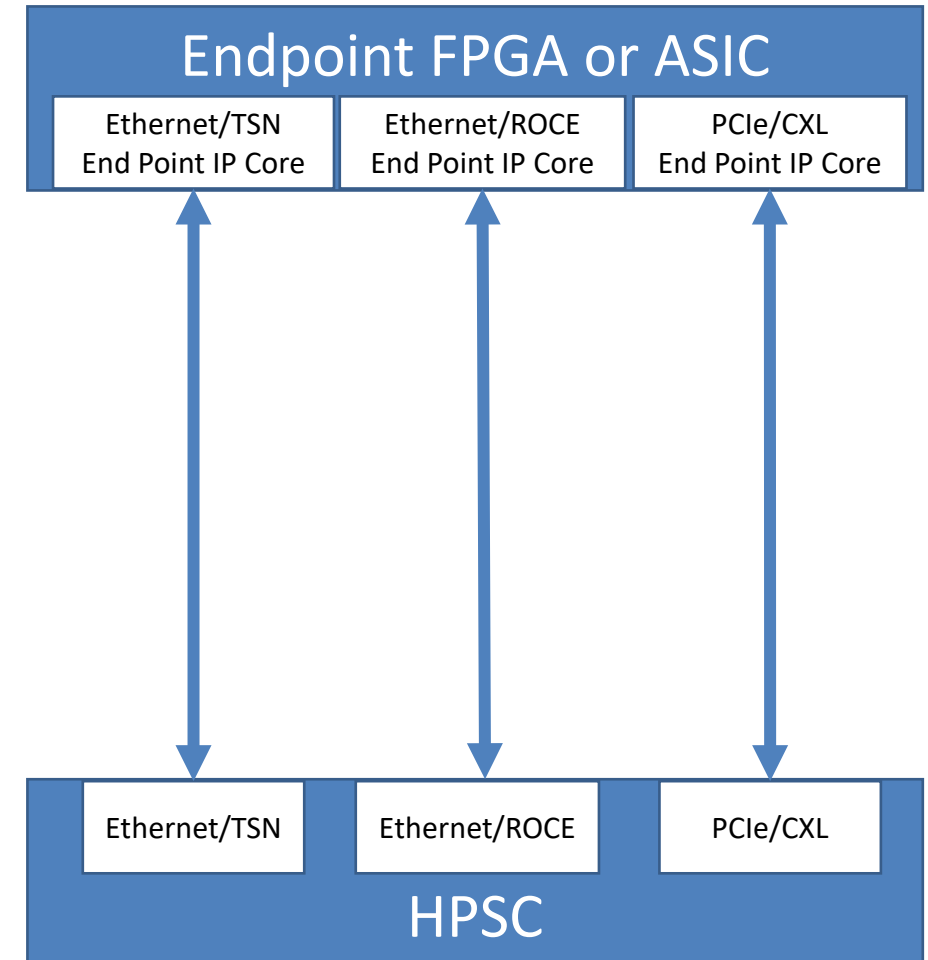
HPSC Ecosystem – IP Cores



HPSC Ecosystem – IP Cores



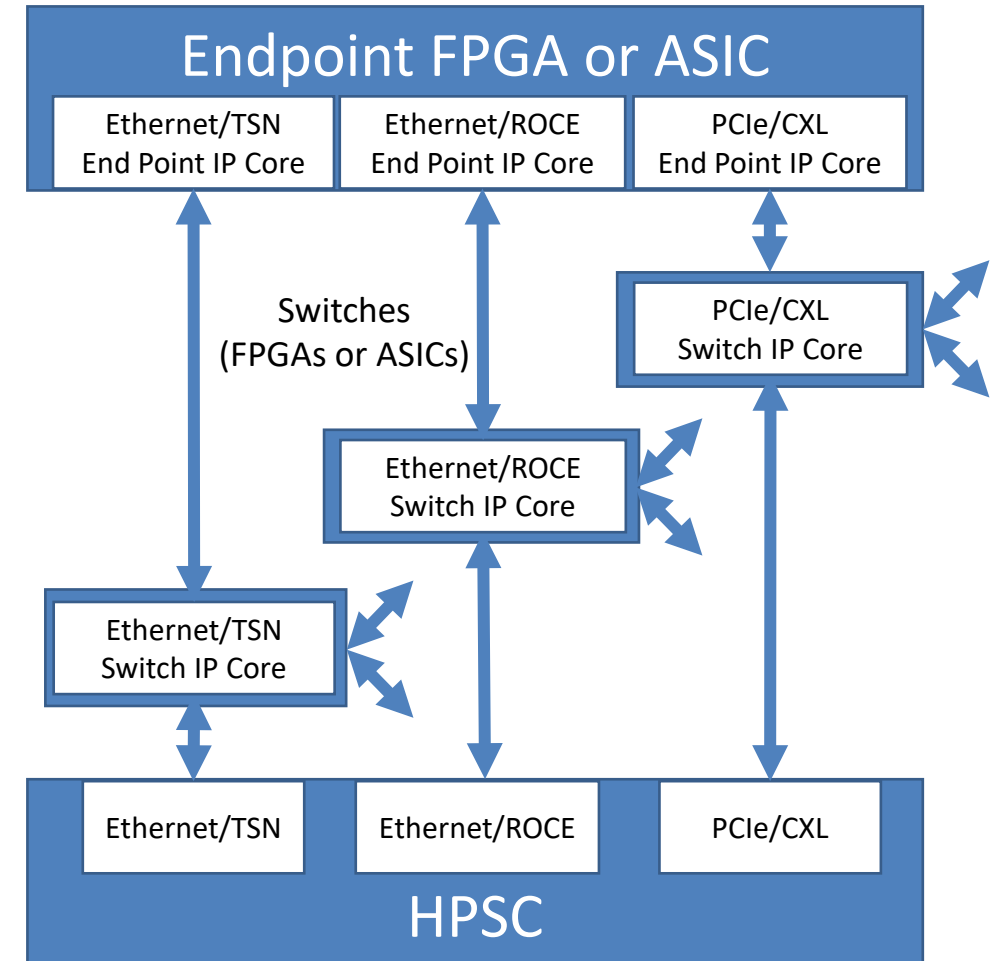
- IP Cores are needed to implement complementary interfaces to HPSC as end points within FPGAs or ASICs
 - Ethernet/TSN
 - ROCE
 - PCIe/CXL



HPSC Ecosystem – IP Cores



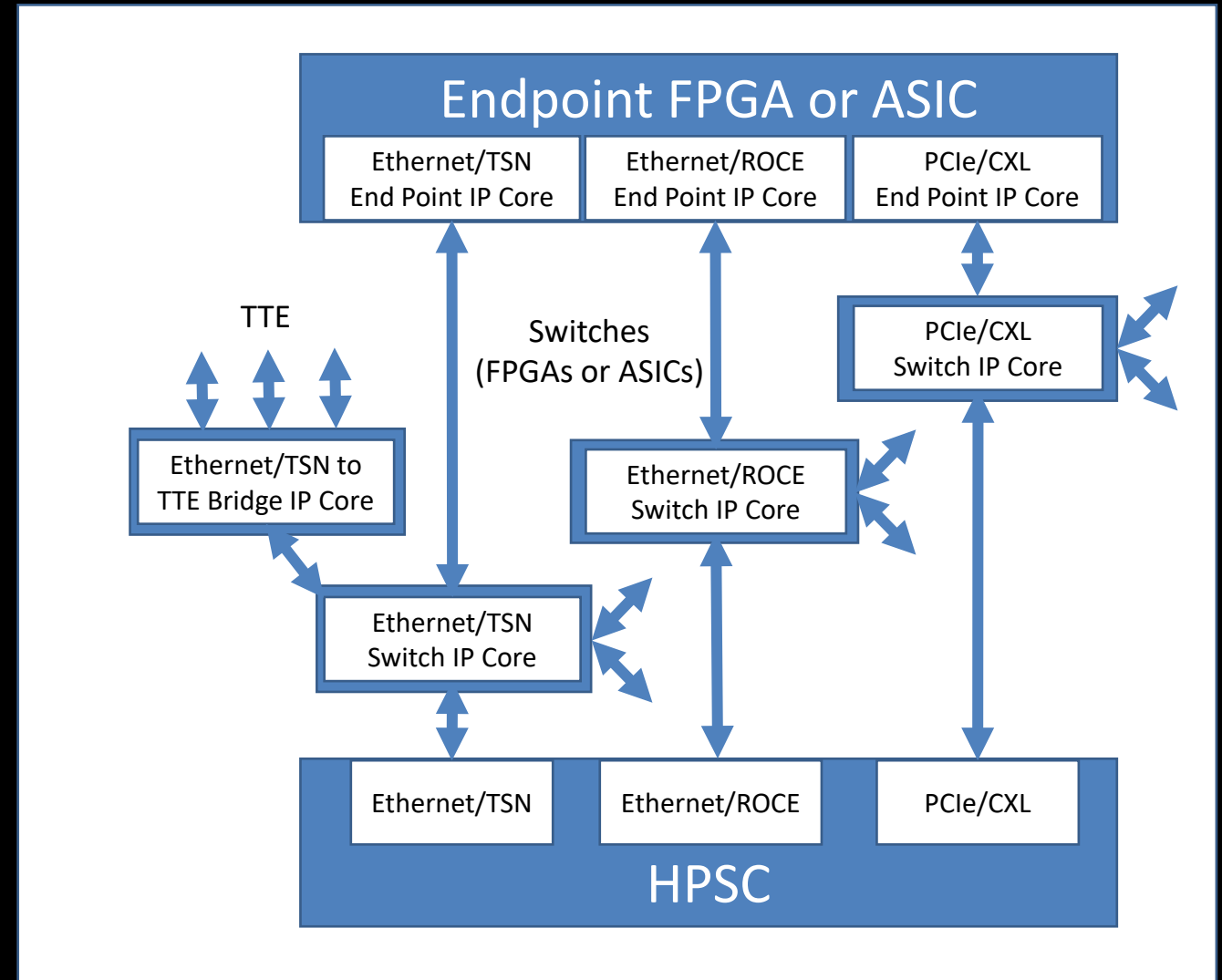
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 - PCIe/CXL
- Switch IP cores are also needed for these interfaces



HPSC Ecosystem – IP Cores



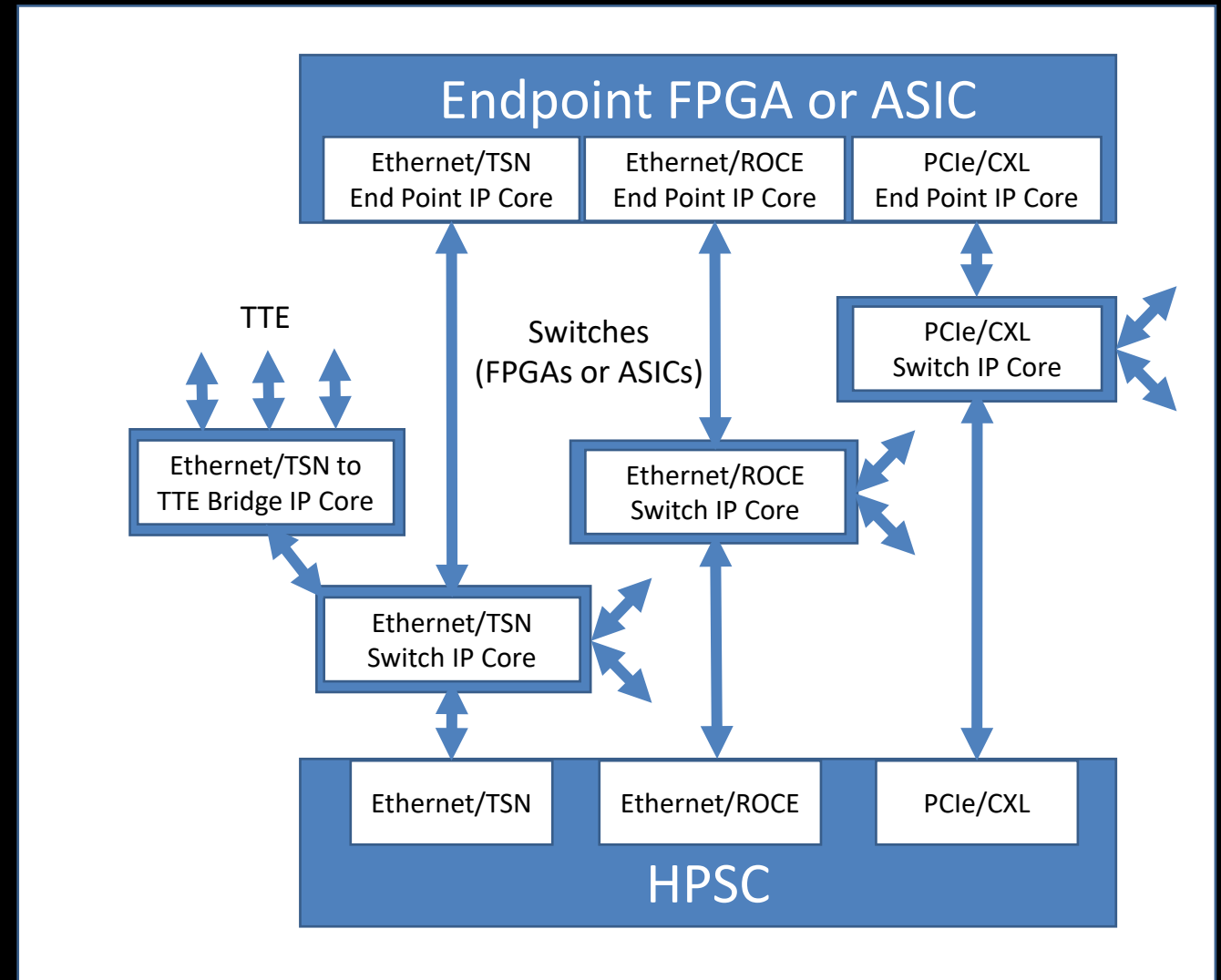
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- Switch IP cores are also needed for these interfaces
- “Bridging” IP cores are support legacy interconnect standards
 - 1553
 - TTE
 - Others



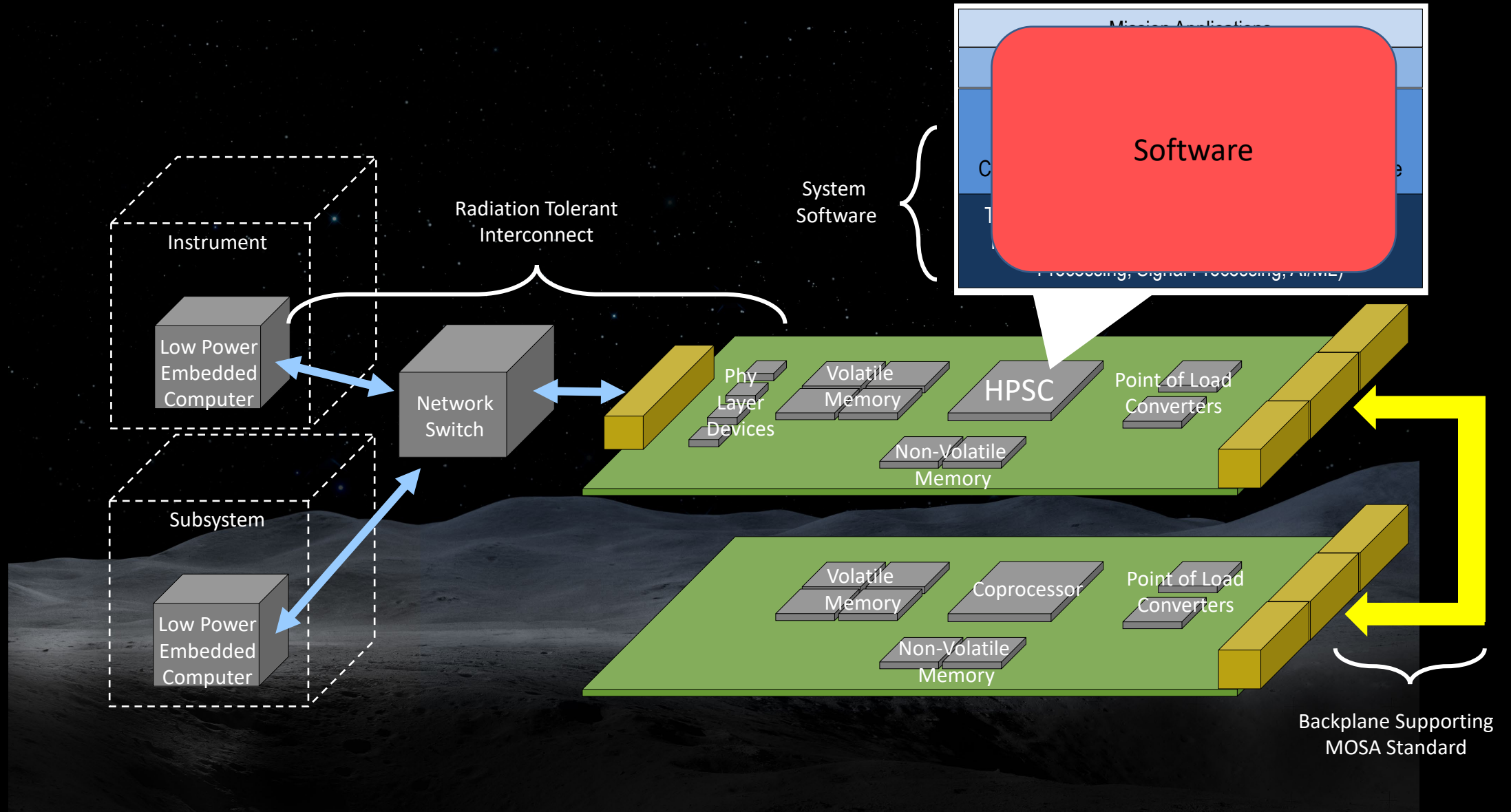
HPSC Ecosystem – IP Cores



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 - Ethernet/TSN
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- Switch IP cores are also needed for these interfaces
- “Bridging” IP cores are support legacy interconnect standards
 - 1553
 - TTE
 - Others
- These IP Cores are needed across the full range of spaceflight FPGA families
- Additionally, IP cores may be needed to support development of supporting ASICs
 - Coprocessors
 - Switches
 - Low power embedded computers



HPSC Ecosystem - Software



HPSC Ecosystem - Software



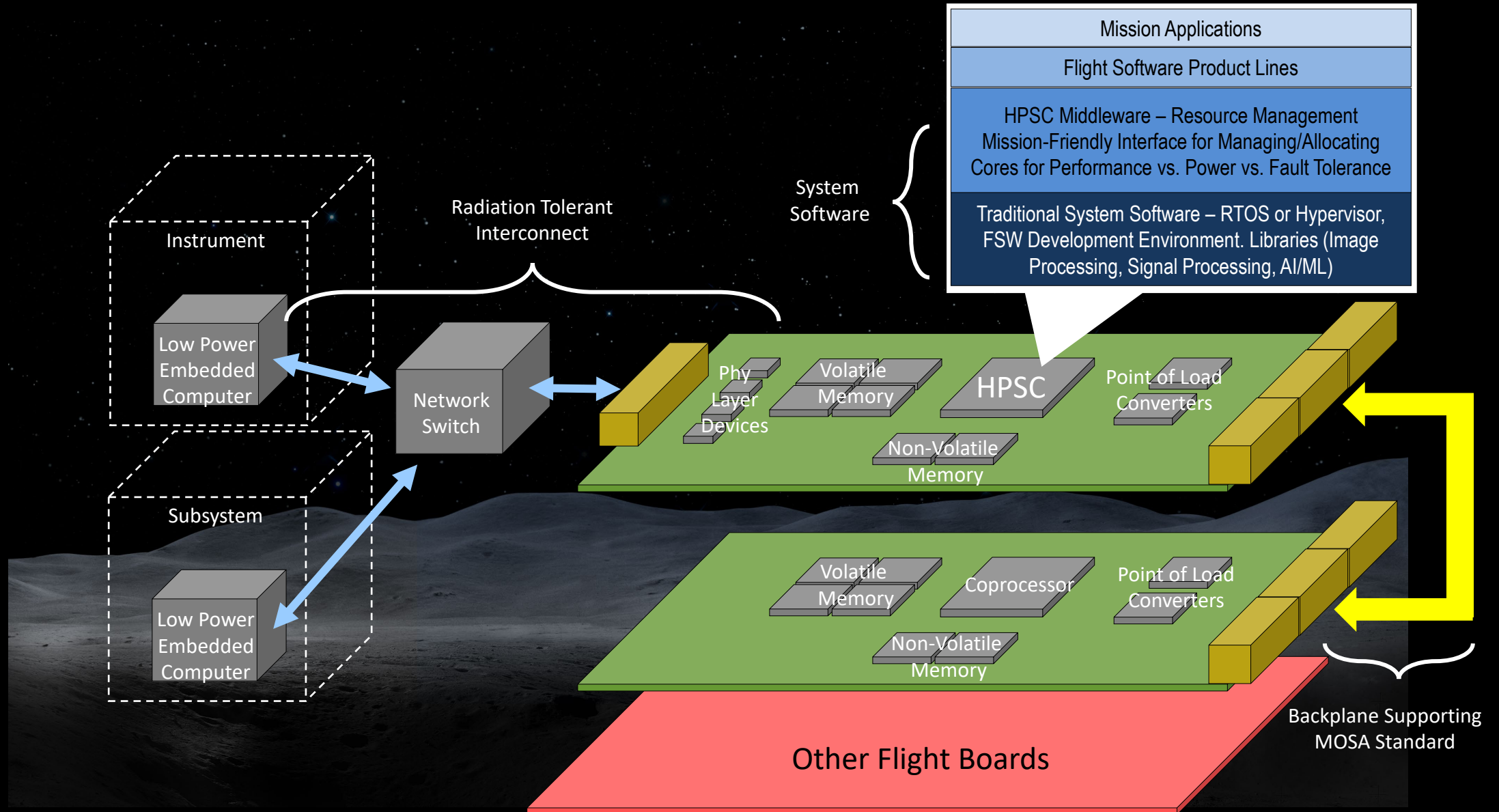
- Flight Software Architectures
 - Assessing adaptations that are needed for cFE/cFS and F' flight software architectures to fully leverage the features and capabilities of HPSC
- Tools
 - OpenXLA
 - OpenXLA is an open-source machine learning compiler that accepts and optimizes models from a variety of ML frameworks and can target execution on a variety of processing platforms
 - Port to HPSC architecture
 - Vulkan
 - Vulkan is a low-level 3D graphics processing API that can target execution on a variety of processing platforms
 - Port to HPSC

HPSC Ecosystem - Software



- SpaceVPX Support Software
 - Chassis Manager
 - Chassis management software is needed to control SpaceVPX chassis
 - IPMC
 - Intelligent Platform Management Interface (IPMI) Controller software is needed for local control of each SpaceVPX PIC
- Multi-Core Verification & Validation (V&V)
 - V&V tools and methodologies are needed for safety critical applications on multi-core processing platforms

HPSC Ecosystem – Boards



HPSC Ecosystem –Boards



- SpaceVPX is planned as the foundation of the HPSC ecosystem
- Board level products (PICs in SOSA terminology) are needed to establish this ecosystem
- PSCs and PICs must support both single-string and cross strapped redundant configurations

Board Types	Description
Power Supply Card (PSC)	Powers SpaceVPX chassis with 3.3V AUX, and combinations of +5V and +12V. Can be implemented as shared or redundant supplies within a chassis
Utility Switch PIC	Provides point-to-point utility plane routing allowing PIC fault isolation.
Single Board Computer (SBC) PIC	Primary processor within chassis. Can optionally serve as system controller and chassis manager.
Co-processor PIC	Processing offload for primary processor. Cannot serve as system controller and chassis manager .
Switch PIC	Expands connectivity for data plane and/or control plane.
External I/O PIC	Provides connectivity outside the SpaceVPX chassis.
Data Storage PIC	Provides network attached storage for bulk memory storage.
SSD PIC	Provides solid state drive with tight coupling to SBC or co-processor.
Radio PIC	Provides uplink and downlink.

HPSC Ecosystem –Boards



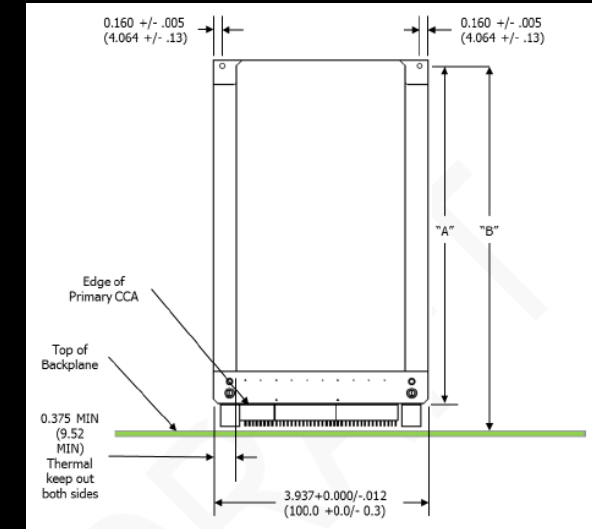
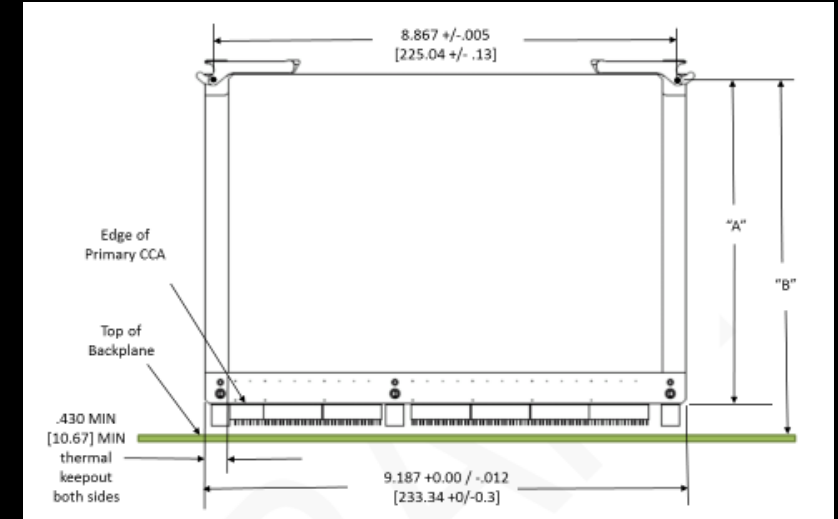
- Standard Products

- It is expected that most of the SpaceVPX PICs would be available as standard products from industry
- The Space External I/O PIC and daughtercards that would implement mission specific interfaces may not initially be standard products
- However, for common interfaces used across multiple missions, standard External I/O PIC and daughtercard products may emerge
 - Camera link
 - External network interfaces (Ethernet/TSN, Spacewire, TTE, ...)
 - Legacy interfaces (1553, ...)
 - Discrete sensor I/O
 - Others

HPSC Ecosystem – Boards



- 3U and 6U
 - The need for both 3U and 6U systems is recognized
 - When the current 3U standardization effort completes, focus will shift to 6U
 - Possibilities for 6U include:
 - Increased number of lanes for control, data, and expansion planes
 - Enhanced fault tolerance
 - Combining PIC functions
- Other form factors
 - Some NASA HPSC use cases point to a need for smaller than 3U SpaceVPX
 - SpaceVNX can be considered as an option for these applications
 - Required board functions will likely be similar to those listed for 3U SpaceVPX



3U and 6U Form Factors [VITA-78]

Conclusions



- The HPSC ecosystem is key to the STMD Advanced Avionics Envisioned Future Priorities
- Roadmaps have been defined for the development of the HPSC ecosystem
- These HPSC ecosystem roadmaps rely heavily on technology development by industry
- There are several paths to help facilitate this industry development
- HPSC ecosystem needs include
 - Components
 - Software
 - Flight boards
 - IP cores
- We look forward to developing the ecosystem and infusing it into our future missions!

Acronyms



- AI – Artificial Intelligence
- ACO – Announcement of Collaboration Opportunity
- ASIC – Application Specific Integrated Circuit
- CAL – Cold Atom Lab
- COTS – Commercial off the shelf
- DAQ – Data Acquisition
- ECLSS – Environmental Control and Life Support System
- EDL – Entry, Descent, and Landing
- EFP - Envisioned Future Priorities
- ESDMD – Exploration Systems Development Mission Directorate
- EVA – Extravehicular Activity
- GPP – General Purpose Processing
- GPU – Graphics Processor Units
- HI – Heterogeneous Integration
- HPSC – High Performance Spaceflight Computing
- HUD – Heads Up Display
- ISRU – In Situ Resource Utilization
- LEO – Low Earth Orbit
- LPEC – Low Power Embedded Computer
- LSII – Lunar Surface Innovation Initiative
- LuSTR – Lunar Surface Technology Research
- ML – Machine Learning
- NEPP - NASA Electronics Parts and Packaging Program
- NESC – NASA Engineering & Safety Center
- NRE – Non-recurring Engineering
- PALETTE – Planetary and Lunar Environment Thermal Toolbox Elements
- PNT – Precision Navigation and Timing
- POL – Point-Of-Load
- REALM – RFID Enabled Autonomous Logistics
- RFID – Radio-frequency Identification
- RHBD – Radiation-Hardened By Design
- SBC – Single Board Computer
- SBIR – Small Business Innovation Research
- SEE – Single Event Effect
- SMD – Science Mission Directorate
- STMD – Space Technology Mission Directorate
- STTR – Small Business Technology Transfer
- SWaP – Size, Weight, and Power
- TSN – Time Sensitive Networking
- TTE – Time Triggered Ethernet
- TX – Taxonomy
- VITA – VMEbus International Trade Association
- V&V – Verification and Validation
- xEMU – eXploration Extravehicular Mobility Unit