

The background of the slide is a space-themed image. On the left, a large, detailed view of the Moon is shown. To its upper left, a smaller, reddish planet (Mars) is visible. A rocket is depicted in the center, moving from right to left towards the Moon, with a bright blue and white exhaust trail. The sky is dark blue and black, filled with numerous white stars. In the bottom right corner, there is a black silhouette of a person's head and shoulders, looking towards the left.

EXPLORESPACE TECH

TECHNOLOGY DRIVES EXPLORATION

High Performance Spaceflight Computing (HPSC) for Lunar and Planetary Missions

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To be presented at the Lunar and
Planetary Science Conference
(LPSC), Woodlands, TX,
March 12, 2025



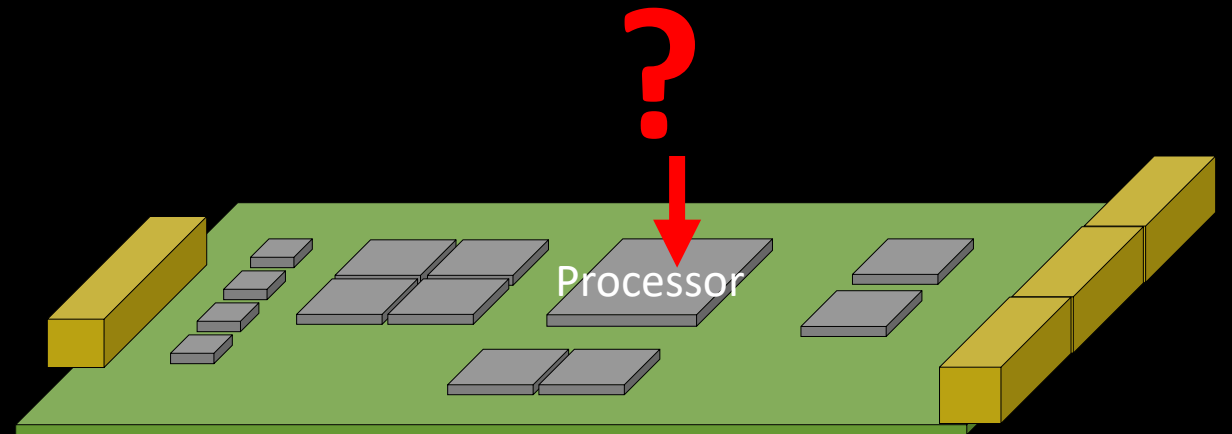
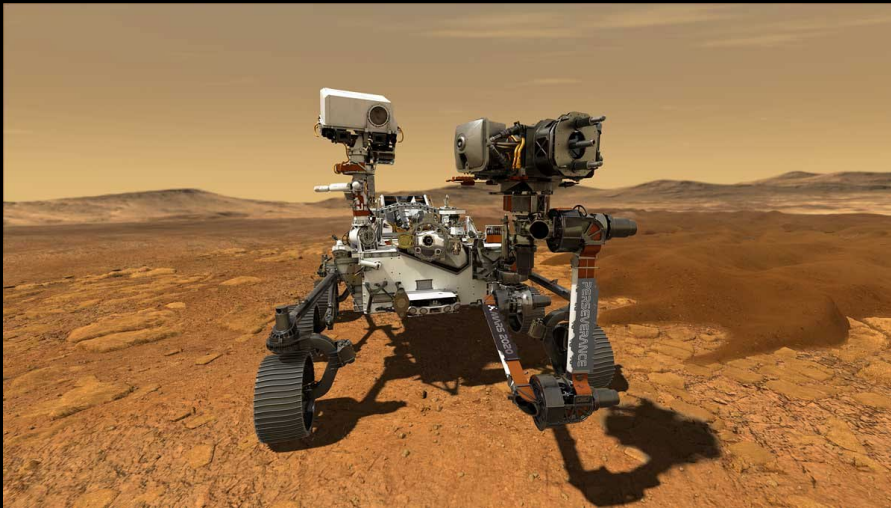
Agenda

- The “Why” for advanced computing
- What is HPSC?
- HPSC Performance, Flexibility and Robustness
- The HPSC Ecosystem
- NASA Use Cases for HPSC
- What HPSC Can Do for The LPSC Community
- Status and Availability
- Conclusion

Introduction

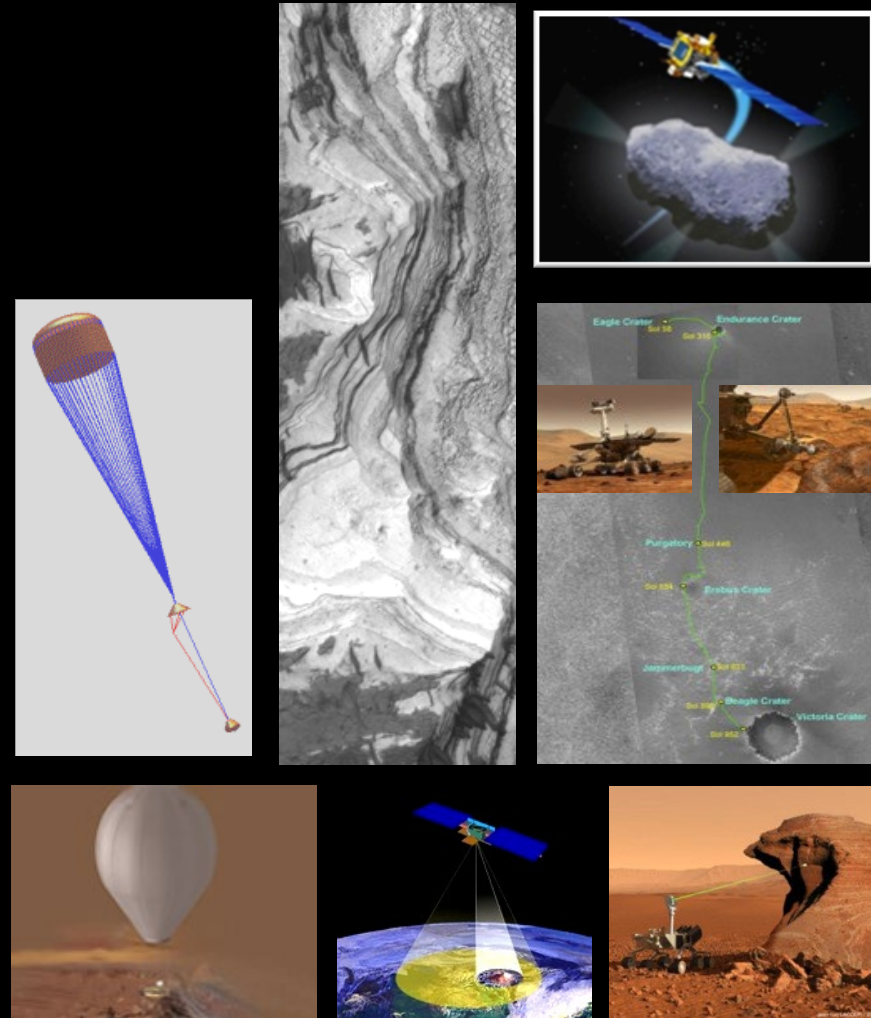


- The spacecraft avionics system: likened to the “brain and central nervous system”
- The BAE RAD750 has been the enduring workhorse for nearly two decades
- What’s next?



The “Why” for Advanced Computing

- Future mission objectives are ambitious
 - Increased sensor data rates
 - Far flung destinations
 - Increased autonomy
- Computing is needed across a very wide range of mission sizes and classes
 - Flagships to cubesats
 - Risk tolerance for crew safety critical
- As compared to terrestrial computing, NASA has some unique challenges
 - Tolerance to harsh environments
 - Extreme needs for low power and energy management, efficiency, fault tolerance, and resilience



Developing HPSC to meet the computing needs of future space missions

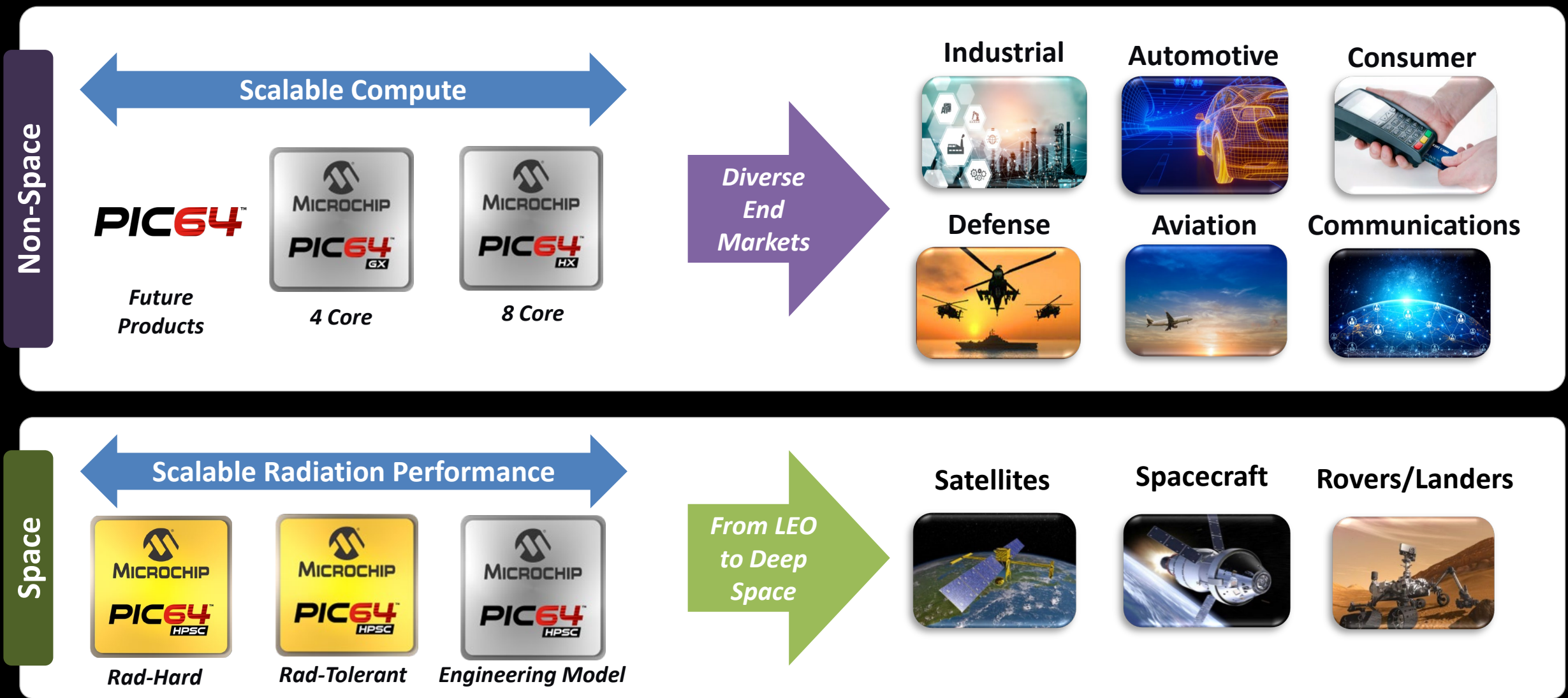


What is HPSC?



- **NASA and Microchip Collaboration.** HPSC Delivers High-Performance computing required for space environments. Infusion targets across human, robotic, and science missions.
- **Fault-tolerant 10-core RISC-V System-on-Chip (SoC).** Vector Processing, AI Processing, Ethernet connectivity, Security, Extensibility, Dynamic Power Management, Broad HPSC Product Portfolio: Cost/Functionality/Schedule: Time To Flight
- **Industry Eco-System.** Industry-funded. Multiple, HPSC-compatible SOCs, hardware (SBCs, Systems), software (OS, Libs, Tools) roadmap benefits NASA for decades to come.
- **Capability Advances. Cost, Schedule, Risk reduction.** Software-based flexibility. Mission and science autonomy, intelligent vehicles, flagship science, Instruments, crew assist.

PIC64 and HPSC Product Plans



HPSC Performance

Raw numbers ...	HPSC Performance
Scalar processing	~100x Rad750 performance
Vector processing	256 GFLOPS
AI/ML 8-bit processing	2 TOPS
AI/ML 16-bit processing	1 TOPS

Not available with existing spaceflight processors

More representative of onboard science data processing ...

SpaceBench Processing Kernel Suite

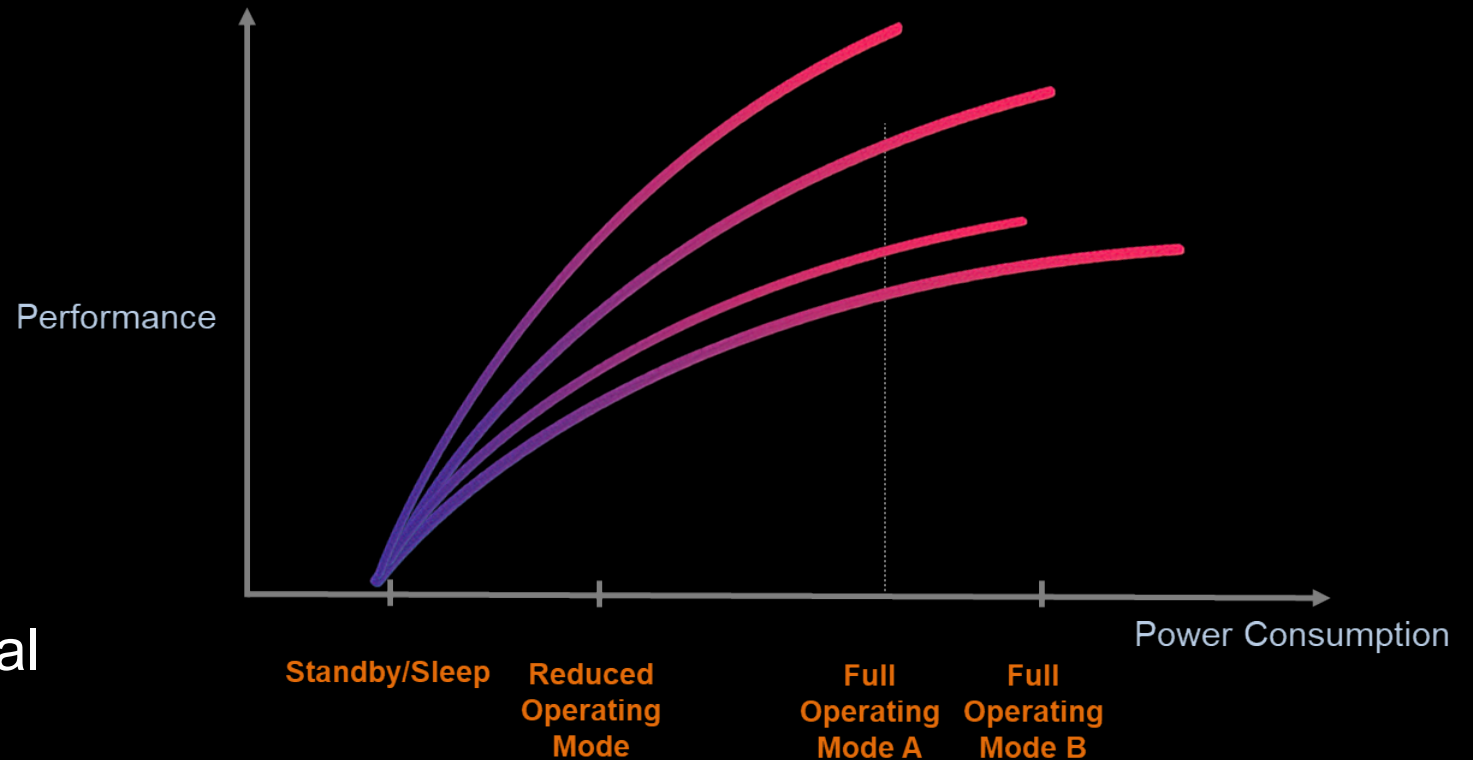
- Matrix math
- Fourier and wavelet transforms
- Orbital equations
- Artificial potential functions
- Reed-Solomon codes
- Advanced Encryption Standard

Emulations show that HPSC has a **1,343 X** speedup over a flight GR740 processor

In layman's terms ... HPSC performance is roughly equivalent to an Intel i7 circa 2022 Windows laptop

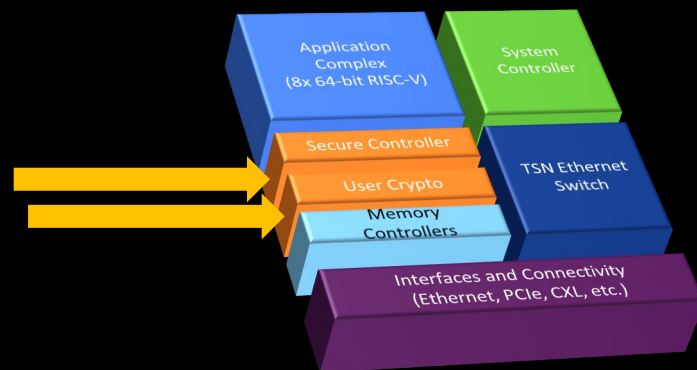
HPSC Flexibility

- HPSC enables scalable performance, fault tolerance, and power to meet mission needs
- HPSC provides run-time architecture adaptability to compute needs
- HPSC partitioning allows mission critical and non-critical code to be run concurrently without risk of interference

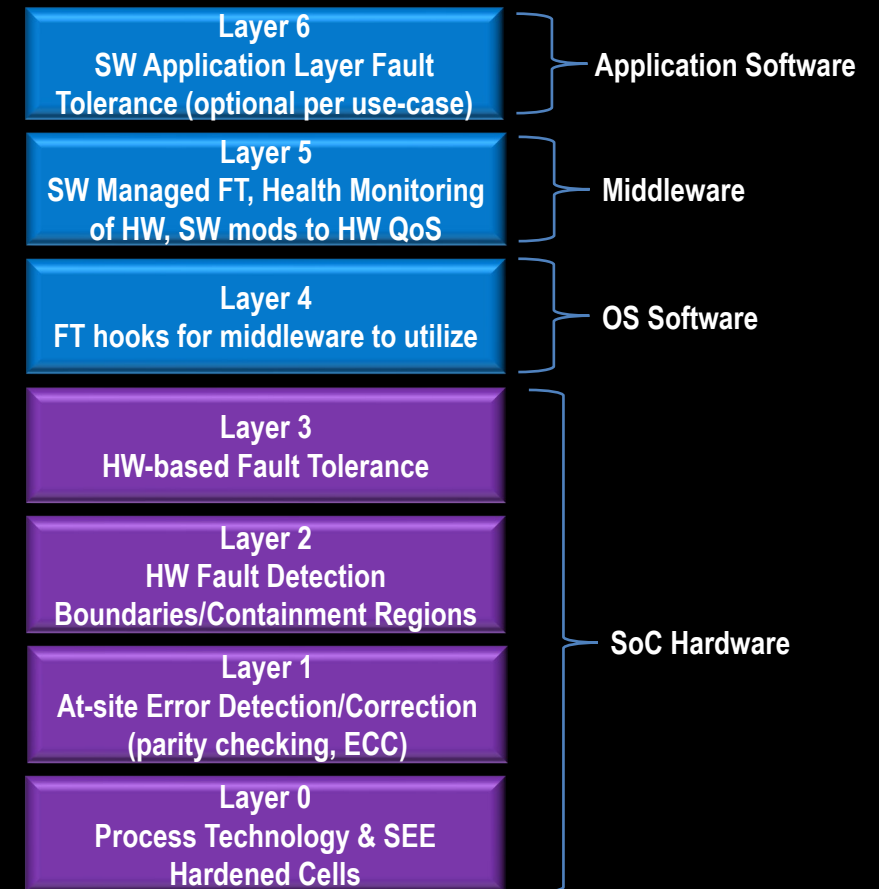


HPSC Robustness

- HPSC is developed specifically for the space radiation environment
 - 200 kRad Total Ionizing Dose (TID) requirement
 - Radiation Hardened By Design (RHBD) mitigations for Single Event Effects (SEE)
- HPSC employs a layered fault tolerance approach
 - Design techniques
 - Hardware fault containment and isolation
 - Optional core-level redundancy
 - Software support
- HPSC provides security via a dedicated Secure Controller and user cryptological services



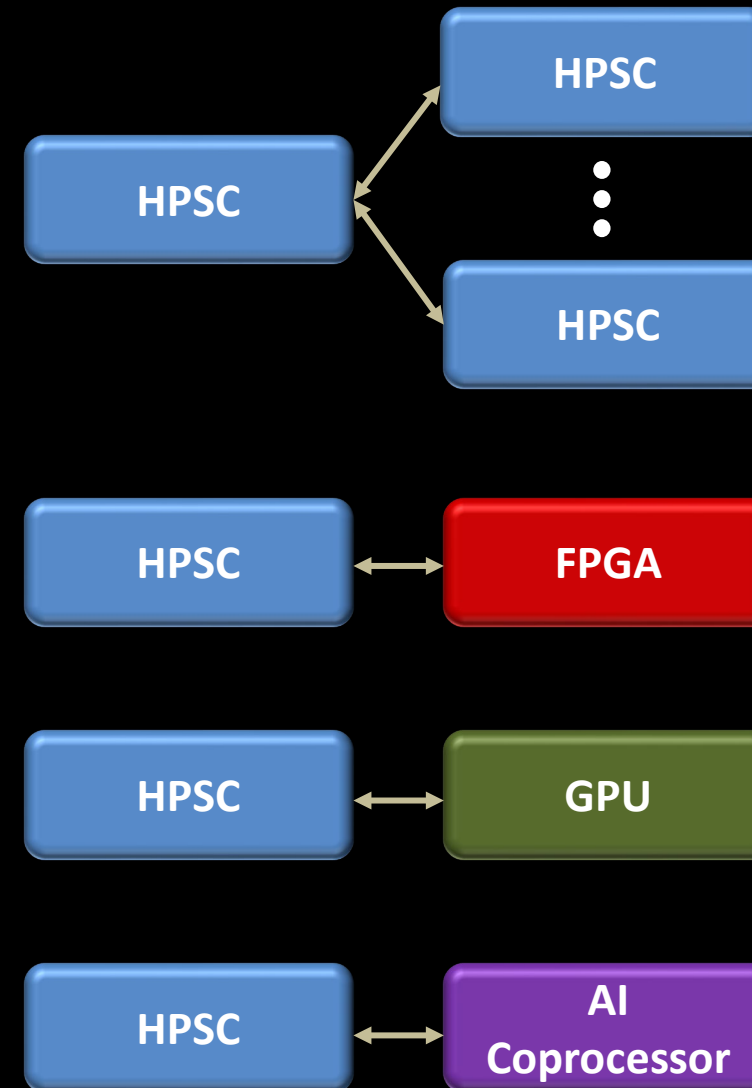
Layered Fault Tolerance



HPSC Expandability and Extensibility

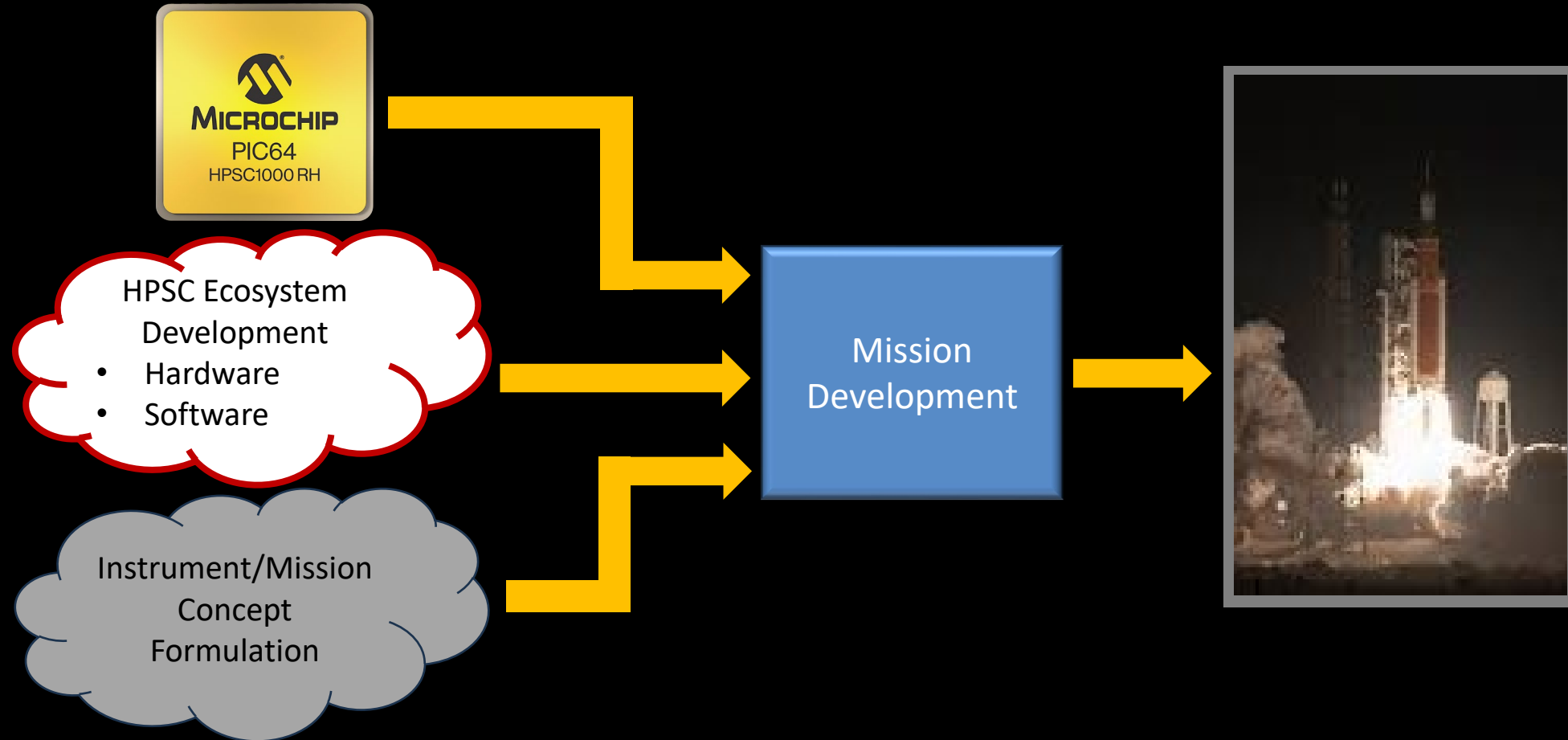
HPSC embraces mission customizable extensibility

- Extend for
 - Performance
 - Increased performance/watt
 - Interface Bridging
 - Mission specific functionality
 - Fault Tolerance



HPSC Ecosystem

- In tandem with the HPSC processor development, NASA is working with industry to establish the HPSC ecosystem to enable mission infusion

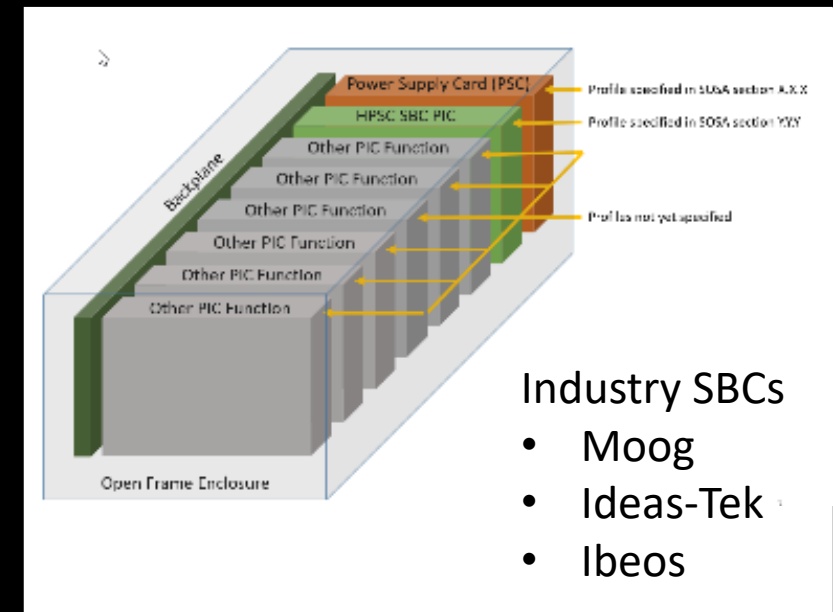


HPSC Ecosystem - Hardware

- HPSC prototyping platforms are being developed by Microchip
- NASA is engaging with industry within the Sensor Open Systems Architecture (SOSA™) consortium to develop interoperable card-level avionics standards
 - System integrators can configure systems consisting of interoperable SOSA SpaceVPX modules from multiple vendors
- Industry has committed to developing HPSC spaceflight card-level products in multiple form factors
- NASA recently released a Request for Information (RFI) to seek industry inputs on developing an “HPSC Test Kit”, which is a non-flight SOSA SpaceVPX system to allow development and test applications on flight-like hardware
 - SOSA SpaceVPX HPSC single board computer (SBC)
 - Other SOSA SpaceVPX cards
 - Power supply
 - Backplane and enclosure
 - Support software



Microchip HPSC Evaluation Boards



Of course, bespoke HPSC flight computers for specific instruments can also be developed



HPSC Ecosystem - Software

- NASA is working with industry to develop a robust standards-based open-source HPSC software ecosystem
 - Multiple Operating Systems
 - Development environment using modern tools and methods
 - High performance libraries
- NASA is also adapting flight software architectures to leverage the capabilities of HPSC

HPSC Enables Desktop to Spaceflight Computing



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Operating Systems

- VxWorks
- RTEMS
- Linux

Hypervisors

- Xen
- KVM

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Compilers

- LLVM
- GCC
- OpenXLA
- IREE

Debuggers

- Lauterbach
- SiFive

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System Libraries

- OpenSBI
- OpenAMP
- OpenMP
- OpenSSL

Performance Libraries

FFTW

POCL

OpenBLAS

AI Frameworks

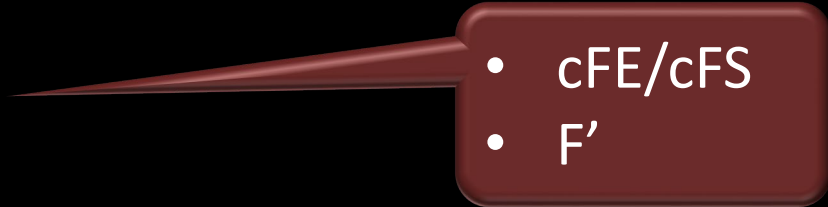
- PyTorch
- Tensorflow
- Tensorflow Lite

HPSC Enables Desktop to Spaceflight Computing



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- A dark red, rounded rectangular callout box with a pointer pointing towards the text "NASA is also adapting flight software architectures to leverage the capabilities of HPSC".
- cFE/cFS
 - F'

HPSC Enables Desktop to Spaceflight Computing



Rovers & Helis

- Vision Processing
- Motion/Motor Control
- Nav Planning
- Science Instruments
- Communication
- Power Management
- Thermal Management
- Fault Detection/recovery



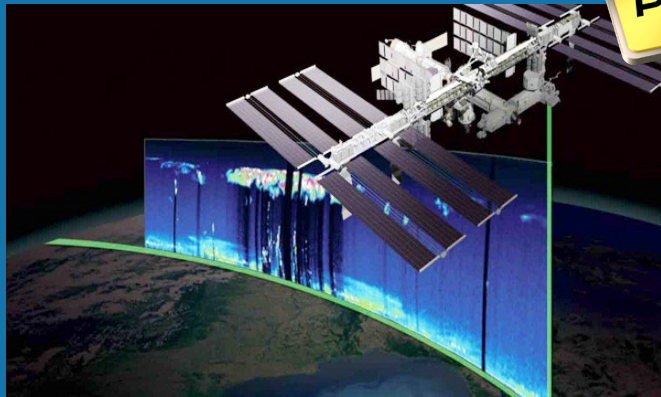
Landers

- Hard real-time compute
- High-rate sensors w/zero data loss
- High level of fault protection/fail over



High Bandwidth Instruments

- Real-time sensor data
- Non-mission critical
- High bandwidth sensors
- Large calibration sets in non-vol memory



Smallsats

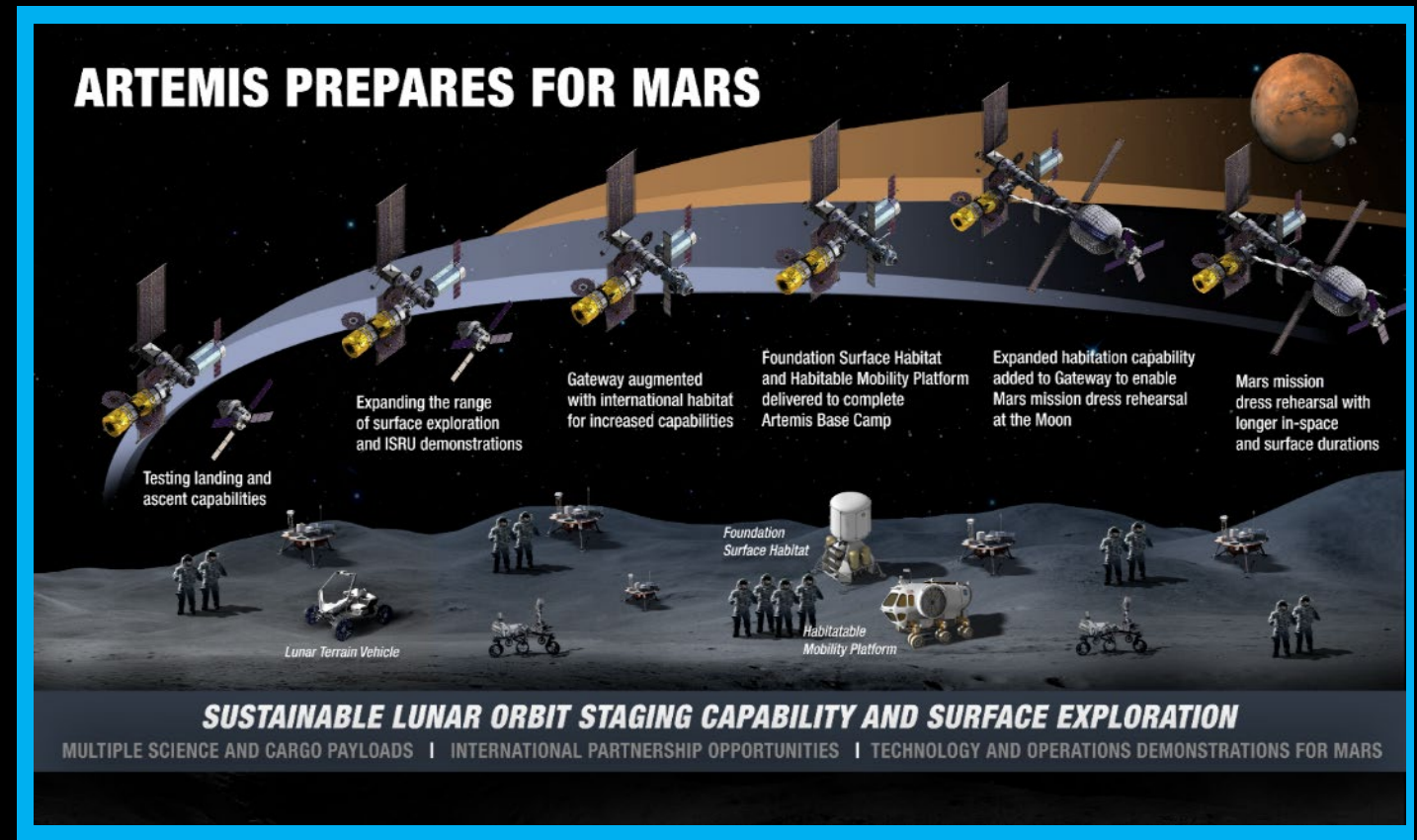
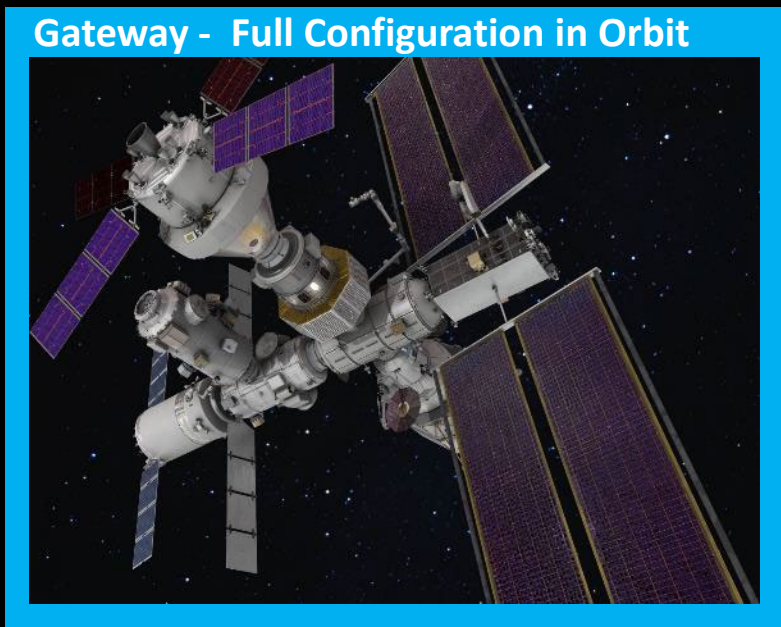
- Hard & soft real-time
- Guidance & Control
- Autonomy & crosslink communication
- Sensor data processing
- Autonomous science





NASA Crew Exploration: HPSC Use Cases

- Robotics working independently and collaboratively with crew
- Robotics enabling lunar surface infrastructure
- Autonomous landing systems
- Increased autonomy extends missions beyond LEO
- Support for Earth independent operations



Candidate HPSC Applications



Application	Description	Key Challenges
Science spacecraft avionics	<ul style="list-style-type: none"> Spacecraft health/safety management Station keeping Subsystem/instrument control and data handling 	<ul style="list-style-type: none"> Varies by mission size, environment, and class
Crewed vehicles avionics	<ul style="list-style-type: none"> Spacecraft health/safety management Station keeping Environmental Control and Life Support System (ECLSS) management Crew interface Subsystem control and data handling 	<ul style="list-style-type: none"> Fault tolerance, ranging from 2 FT and 1 FT to single string, based on application criticality Mission life Serviceability
Crewed habitat avionics	<ul style="list-style-type: none"> Spacecraft health/safety management Station keeping ECLSS management Crew interface Subsystem control and data handling 	<ul style="list-style-type: none"> Fault tolerance, ranging from 2 FT and 1 FT to single string, based on application criticality Mission life Serviceability High sensor count Earth independent operations



PACE Spacecraft



Gateway



Lunar Habitat Concept

Candidate HPSC Applications



Application	Description	Key Challenges
Rover avionics	<ul style="list-style-type: none"> Rover health/safety management Situational awareness Traverse path planning Mobility control Subsystem/instrument control and data handling Crew interface (for crewed exploration rovers) 	<ul style="list-style-type: none"> Processing performance for autonomous driving Fault tolerance Power efficiency Operational flexibility Harsh environments
Planetary aerobot avionics	<ul style="list-style-type: none"> Aerobot health/safety management Situational awareness Path planning Flight control Subsystem/instrument control and data handling 	<ul style="list-style-type: none"> SWaP efficiency Processing performance for autonomous flight Fault tolerance Operational flexibility Harsh environments
Space suit avionics	<ul style="list-style-type: none"> Suit health/safety management Crew health/safety management Crew interface 	<ul style="list-style-type: none"> SWaP efficiency Resource efficient graphics processing Fault tolerance



Spirit Rover



Mars Ingenuity Helicopter

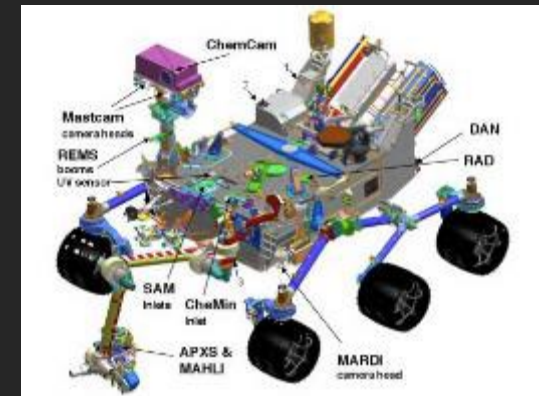


Space Suits

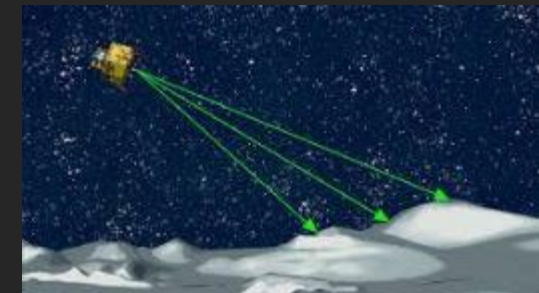
Candidate HPSC Applications



Application	Description	Key Challenges
Science Instrument Data Processing and Control	<ul style="list-style-type: none"> • Land imagers • Telescopes • Mass specs • Lidar • Radar • Cameras • Radiometers • Magnetometers • Biological and physical science experiments 	<ul style="list-style-type: none"> • Varies by instrument, but can include: <ul style="list-style-type: none"> • Adaptive wavefront sensing and control • Data reduction • Low-latency alert generation • SWaP sensitivity • Harsh environments • Autonomous operations
Landing systems	<ul style="list-style-type: none"> • Autonomous landing and hazard avoidance • Terrain relative navigation • Hazard detection and avoidance 	<ul style="list-style-type: none"> • Fault tolerance (based on mission class), ranging from 2 FT to 1 FT • Operate through faults • Performance for terrain mapping and path planning
Communication relay	<ul style="list-style-type: none"> • In-space or surface relays for crewed and/or science missions using Delay Tolerant Networking (DTN) • Navigation and timing signals 	<ul style="list-style-type: none"> • High bandwidth I/O • High bandwidth encryption/decryption • Onboard storage for buffering



Instruments on Curiosity Rover



ALHAT Concept



TDRSS Satellite

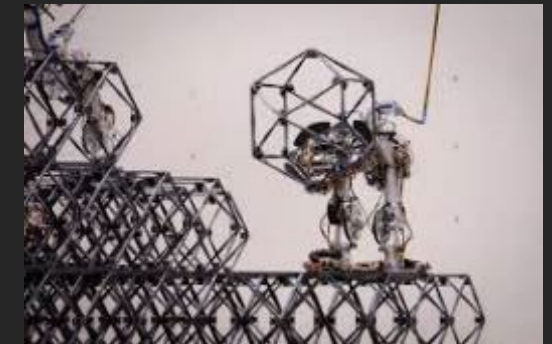
Candidate HPSC Applications



Application	Description	Key Challenges
Robotics	<ul style="list-style-type: none"> In-space and surface robotics, including: <ul style="list-style-type: none"> Rendezvous, Proximity Operations & Capture (RPOC) Servicing Assembly Construction Manufacturing Maintenance 	<ul style="list-style-type: none"> Fault tolerance and safety for crew collaboration Processing performance Leveraging for industry standard interfaces Leveraging for industry standard software tools (ROS support) Mapping robotics applications to avionics requirements Harsh environments
Surface systems and infrastructure for crewed presence	<ul style="list-style-type: none"> Excavation and construction In-Situ Resource Utilization (ISRU) Surface power systems 	<ul style="list-style-type: none"> Processing performance to support robotics Harsh environments
Space cloud computing	<ul style="list-style-type: none"> Disaggregation of onboard processing applications to across multiple spacecraft or surface systems 	<ul style="list-style-type: none"> Communication overhead Use cases identification and analysis needed



Integrated System for Autonomous and Adaptive Caretaking (ISAAC)



Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS)



Fission Surface Power



What HPSC Can Do for The LPSC Community

Onboard
Sensor Data
Processing

Autonomy

Size, Weight,
Power, and
Cost Reduction



Onboard Sensor Data Processing

- Raw sensor data rates for planetary and lunar science instruments can vastly exceed available downlink bandwidth
- Onboard data processing is needed to extract science of interest from the sampled sensor data
- Examples include:

Synthetic Aperture Radar	Image formulation and feature detection from raw RF data
Orbitrap Mass Spectrometer	Species detection from raw time-series data
Hyperspectral Imager	Classification of collected imagery and detection of features
Lidar	Surface and/or object identification from photon counts or sampled waveforms

- Data compression can further reduce data volume to fit within downlink constraints

HPSC can enable this onboard processing

Autonomy



From 2018 Workshop on Autonomy for Future NASA Science Missions

Mission Destination	Autonomy Needs
Mars	<ul style="list-style-type: none">• Individual Agent Task Planning• Collaborative Multi-agent Task Planning• Sample Acquisition and Delivery• Surface Navigation• Scientific Autonomy
Lunar Surface	<ul style="list-style-type: none">• Autonomous Local Navigation• Adaptation (For New Measurement Objectives)• Coordination of Multiple Robots/Assets• Planning and Coordination of Multi-robot and Human-robot Teams
Ocean Worlds	<ul style="list-style-type: none">• Knowledge and Model Building• Hazard Assessment• Execution and Control• Verification and Validation (V&V)• Autonomous Science

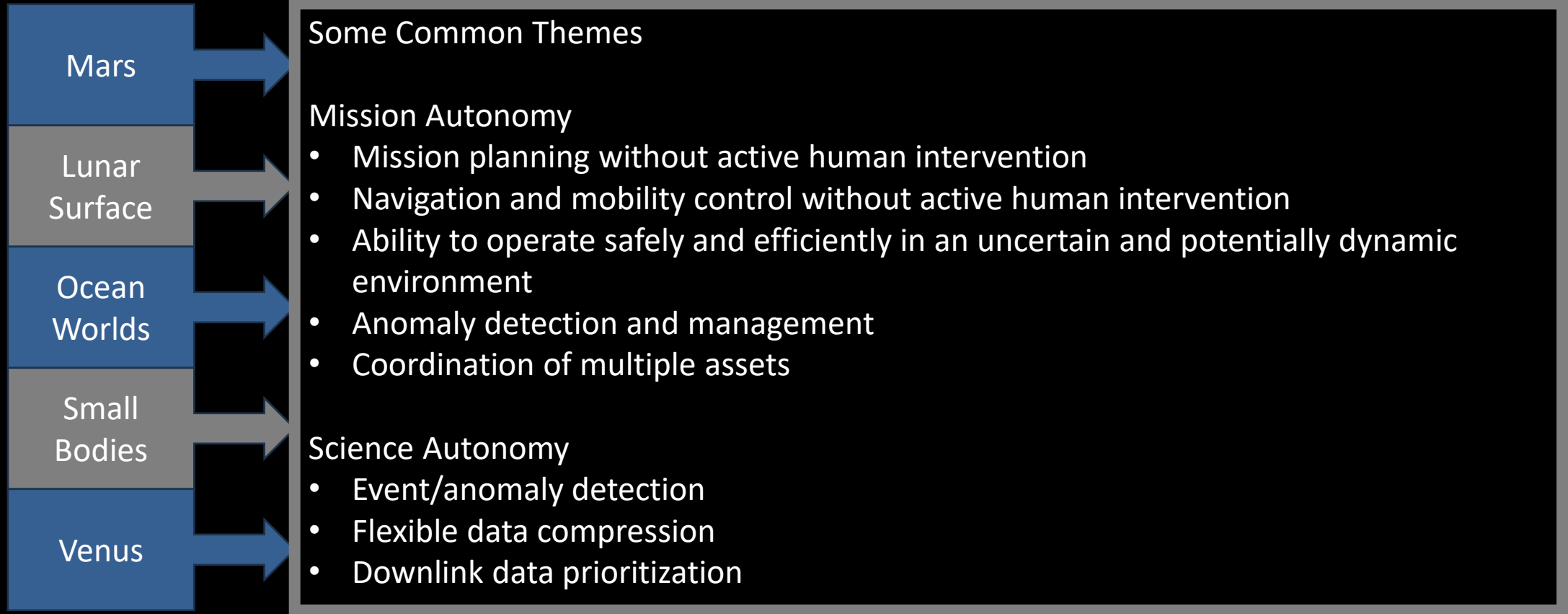
Autonomy



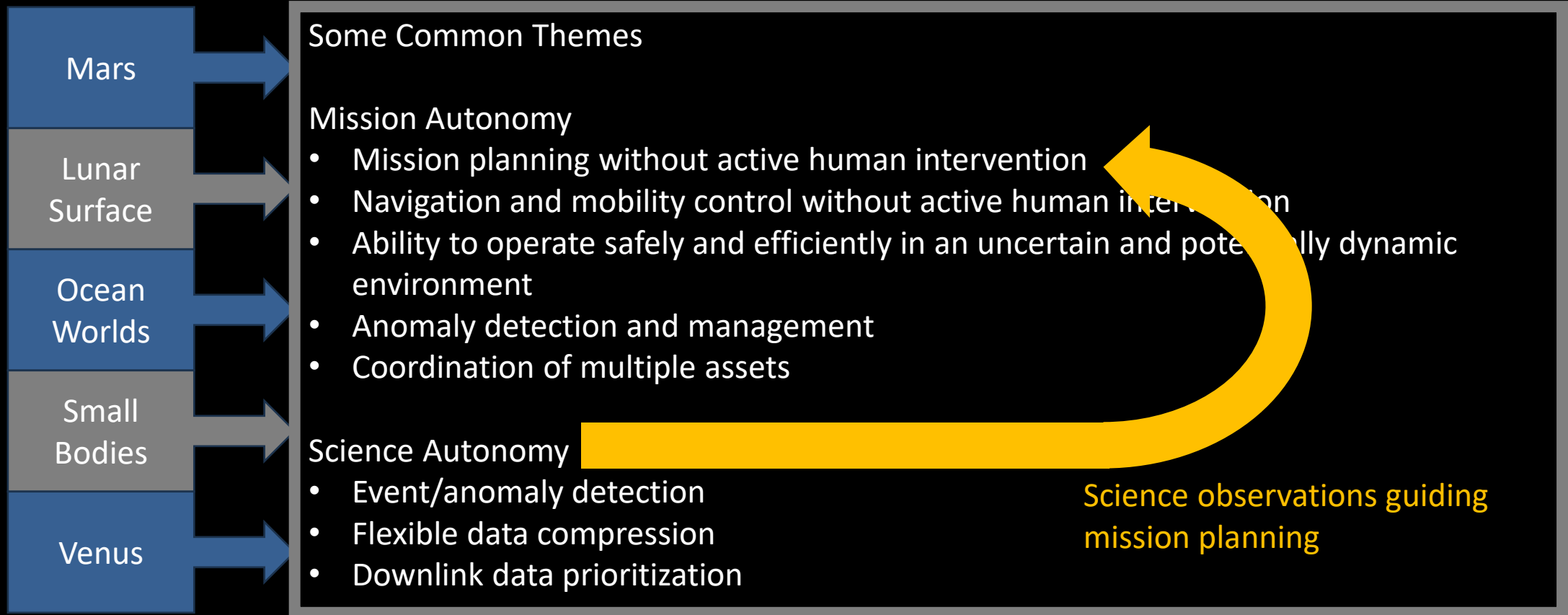
From 2018 Workshop on Autonomy for Future NASA Science Missions

Mission Destination	Autonomy Needs
Small Bodies	<ul style="list-style-type: none">• End-to-end, Long-Duration Autonomy• Approaching and Landing on a Body• Handling the Uncertain and Dynamic Environment• Proximity Interaction• Reaching the Specific Surface Targets• Manipulation Surface/Subsurface• Extracting Resources• Detecting Small Bodies and Coordinating Multiple Spacecraft• Planetary Defense
Venus	<ul style="list-style-type: none">• Networking• Autonomous Navigation• Measuring Altitude• Event Detection and Confirmation with Coordinated Dropsonde Release

Autonomy



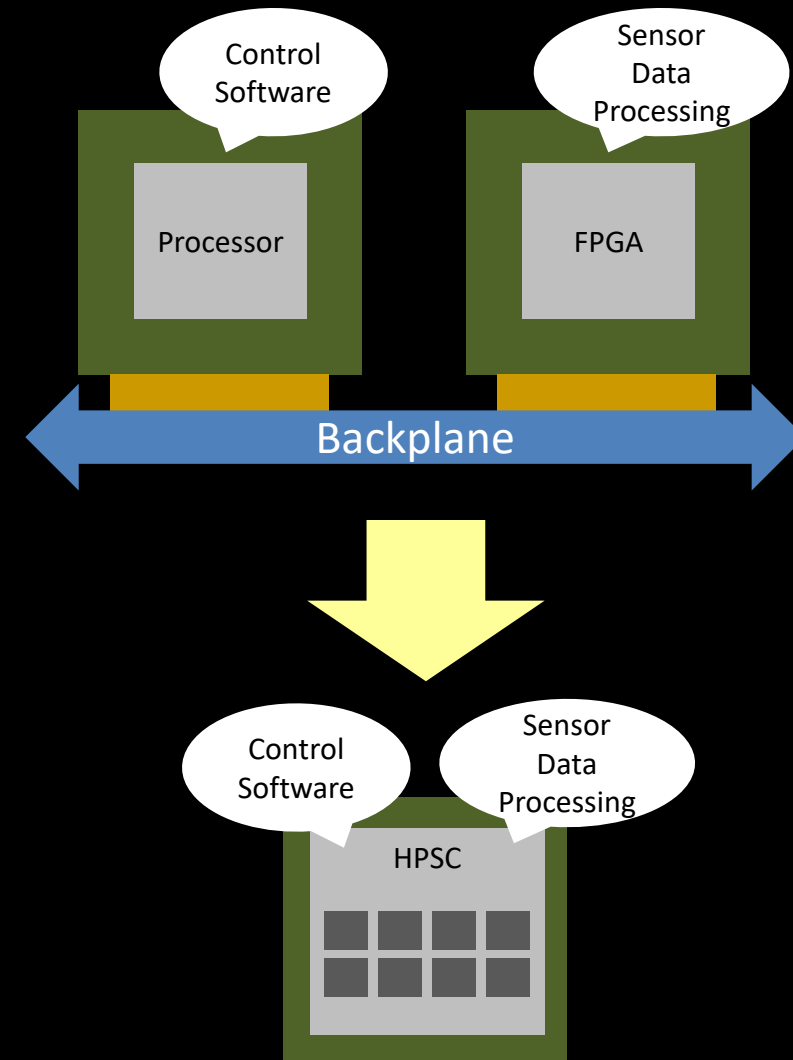
Autonomy



HPSC can enable this autonomy

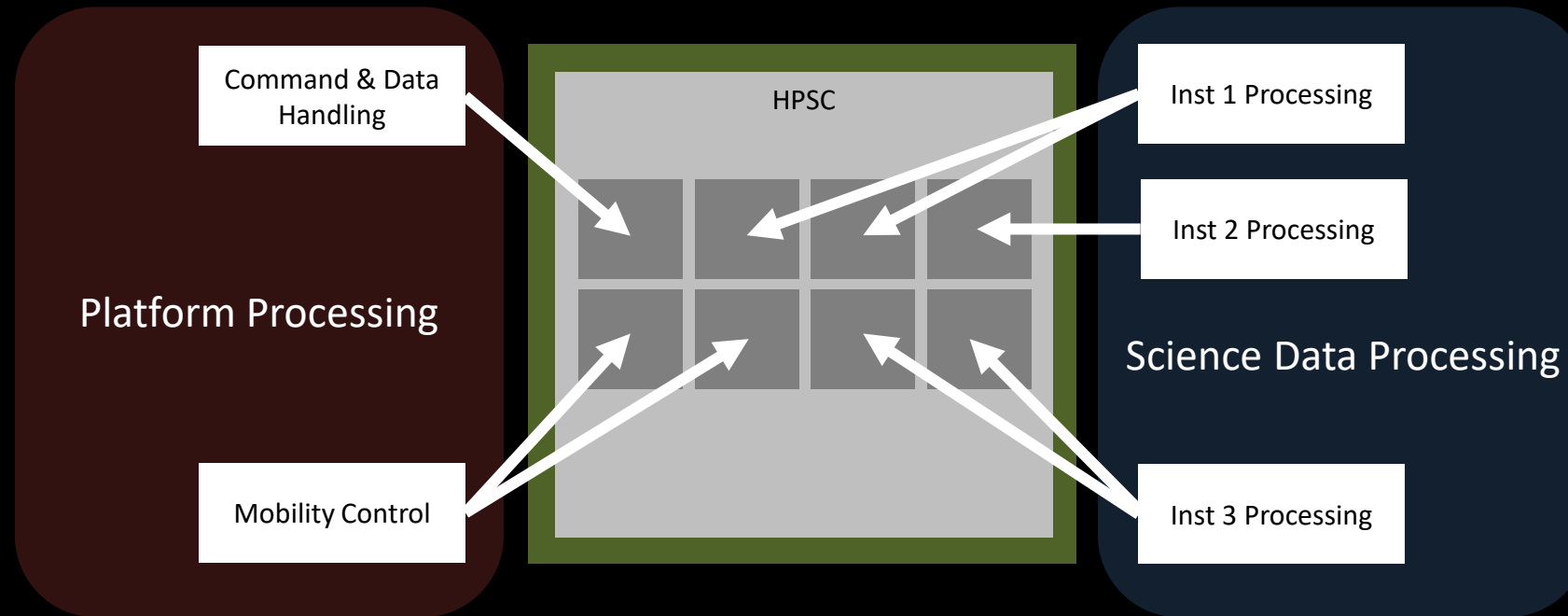
Size, Weight, Power, and Cost (SWaP-C) Reduction

- With the limited performance of existing spaceflight processors, Field Programmable Gate Arrays (FPGAs) has been used for onboard sensor data processing
- This presents several disadvantages
 - Increased size, mass, and power
 - Added complexity of coordination between the processor and the FPGA
 - Performance impact from moving data between the processor and the FPGA
 - Increased design, verification, and validation cost and schedule
 - Need for a specialized skillset for FPGA design
 - Longer iterations for design, implementation, and testing
- With the vector processing capabilities of HPSC, sensor data processing can be migrated back into the processor where it can be implemented with conventional software tools
- In cases where an FPGA (or another coprocessor) is desirable for specific processing tasks, HPSC provides features that simplify data movement and management of those devices

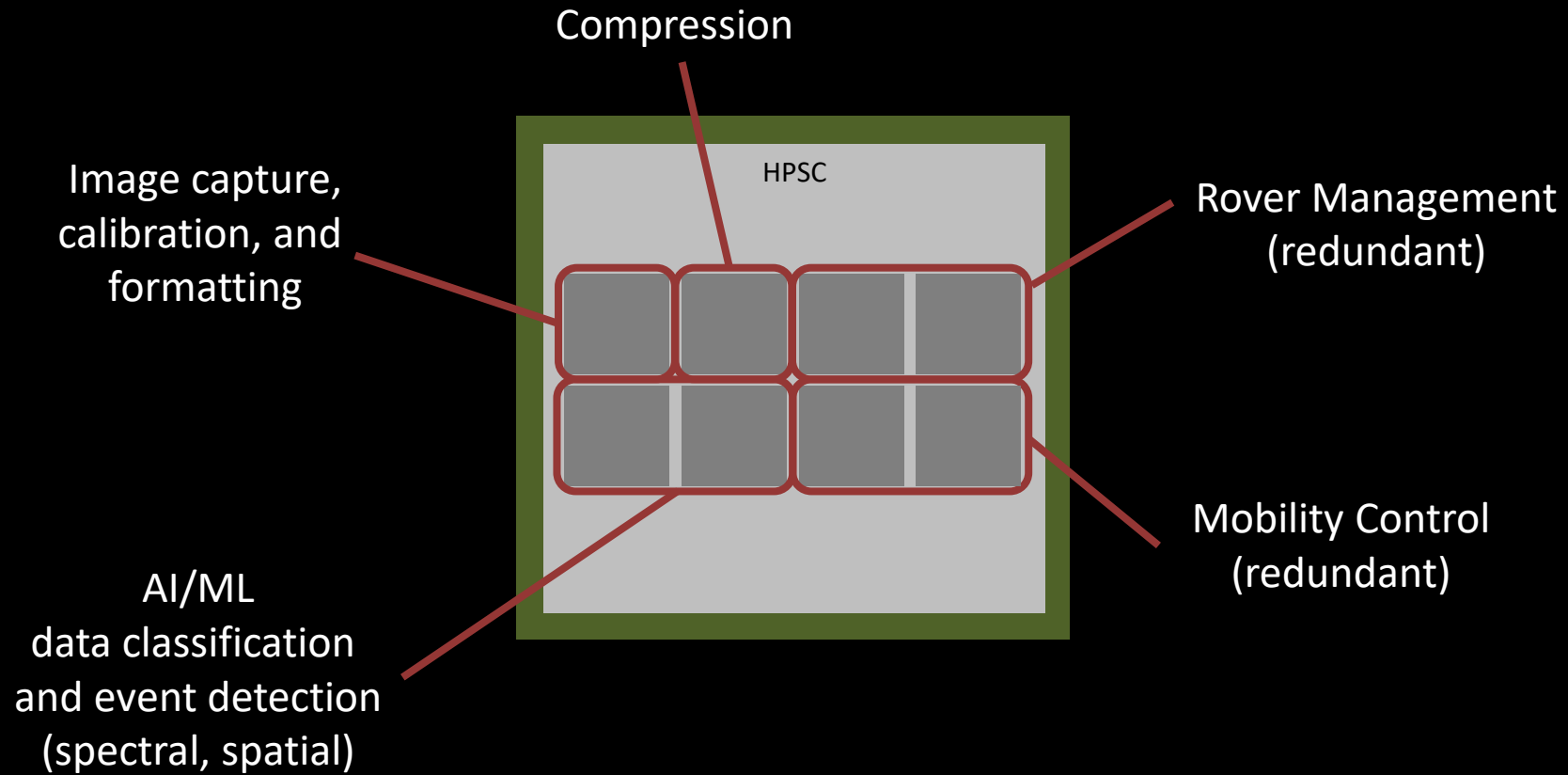


Size, Weight, Power, and Cost (SWaP-C) Reduction

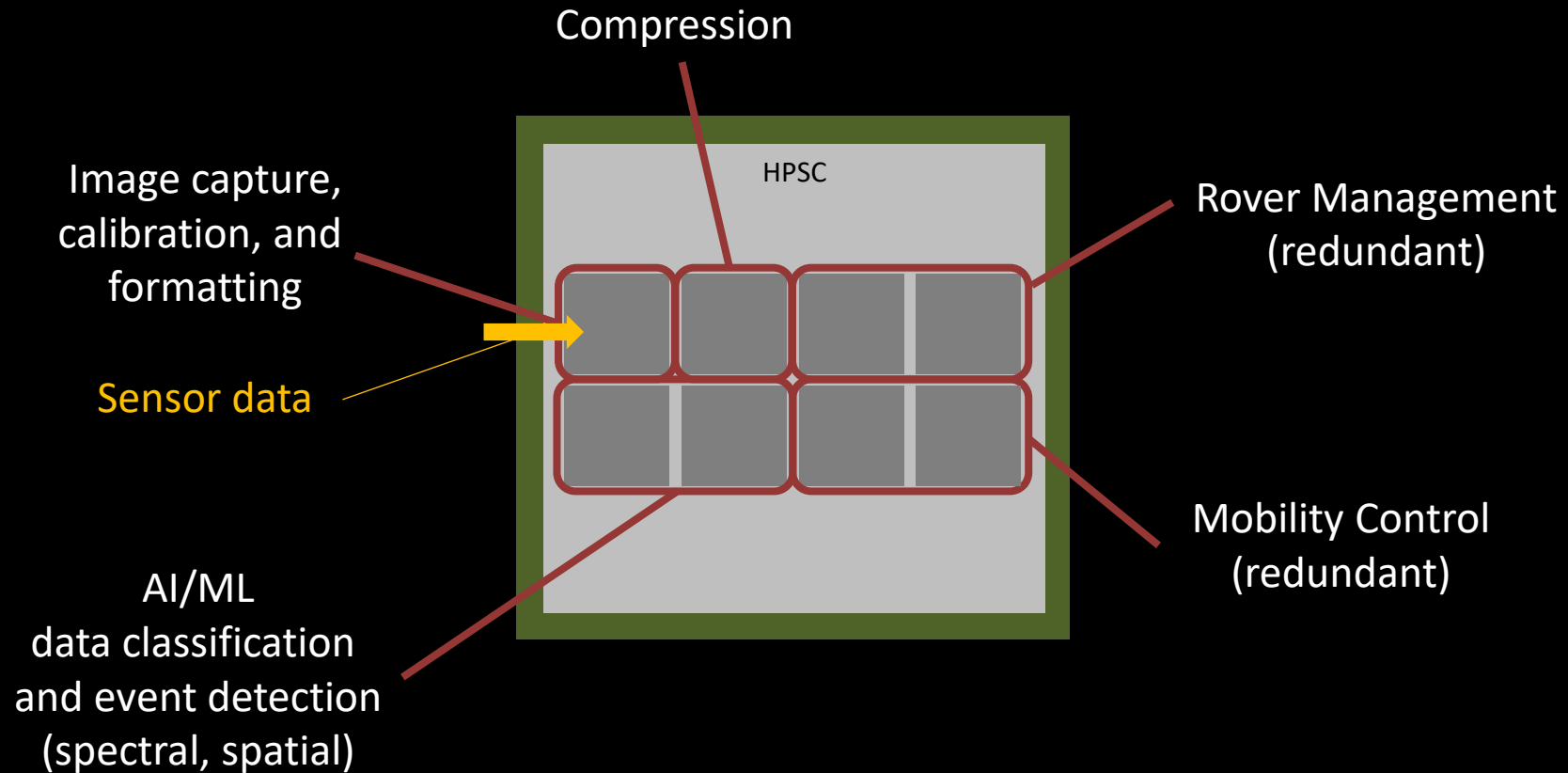
- In the future, platform processing (spacecraft, rover, aerobot) could be combined with instrument processing on a single flight computer
- HPSC's hardware partitioning can isolate platform control and instrument applications, thereby simplifying development and verification & validation
- For a given instrument, science data processing could potentially leverage data products from other instruments



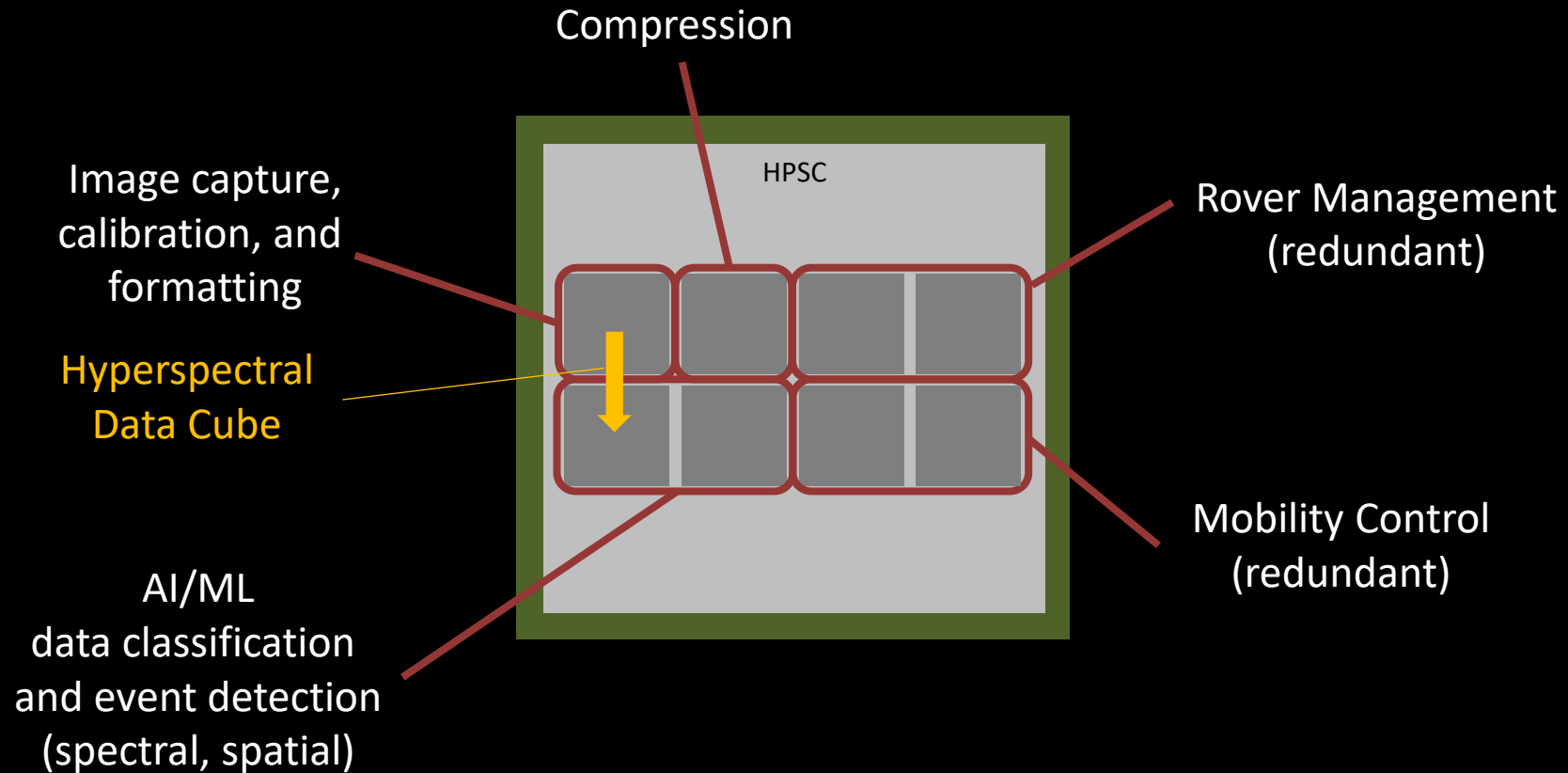
Example - Hyperspectral Imager on Surface Rover



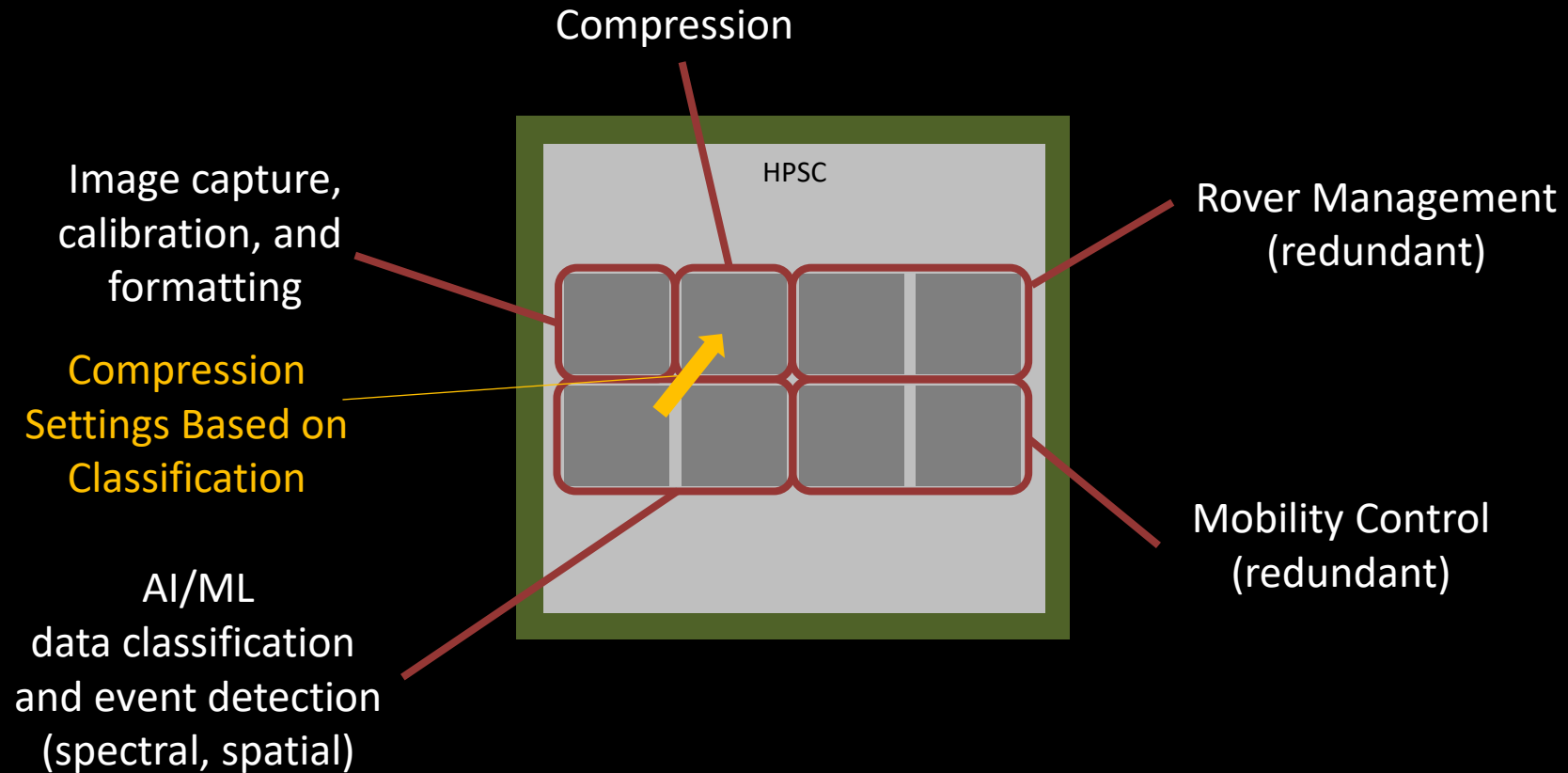
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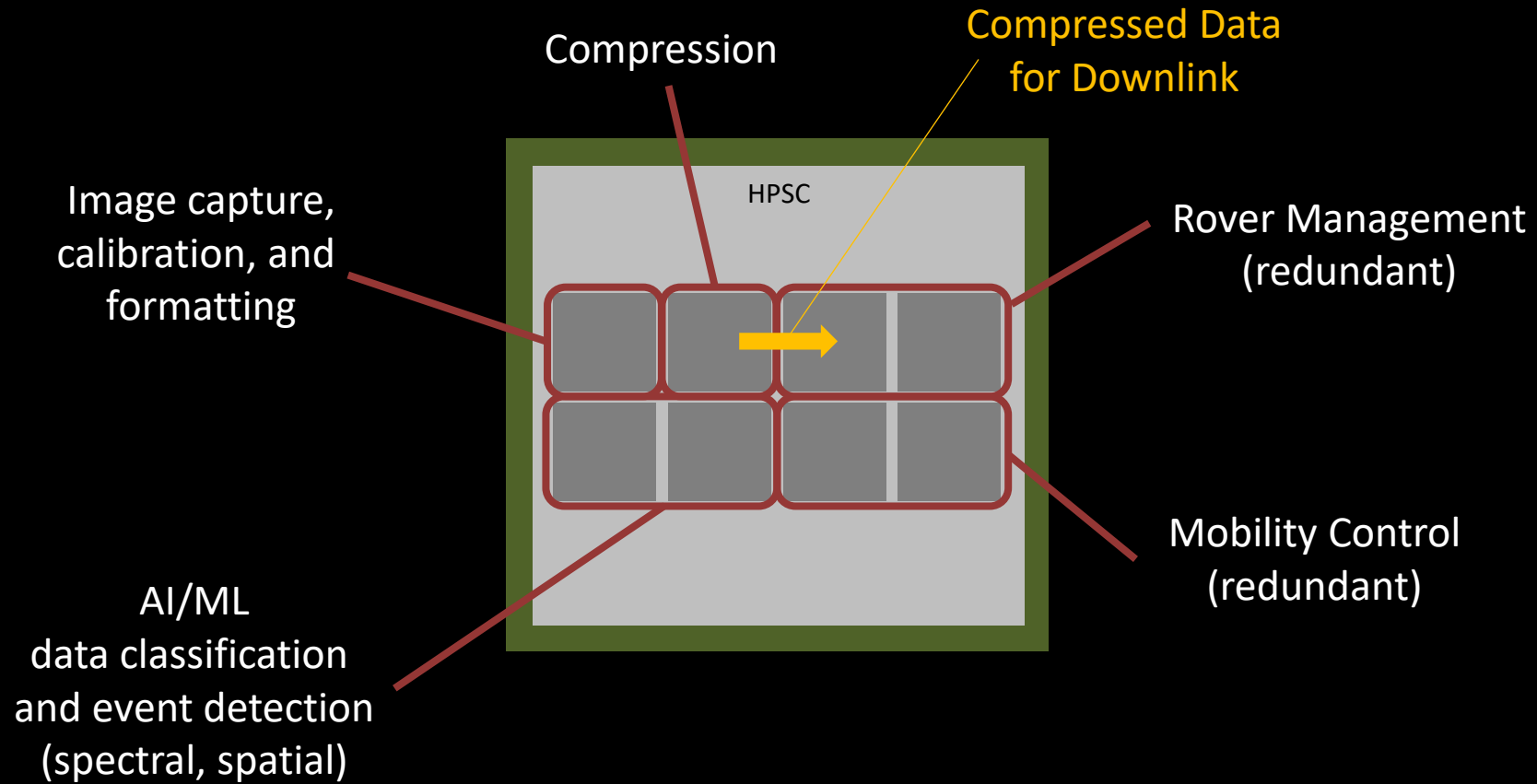
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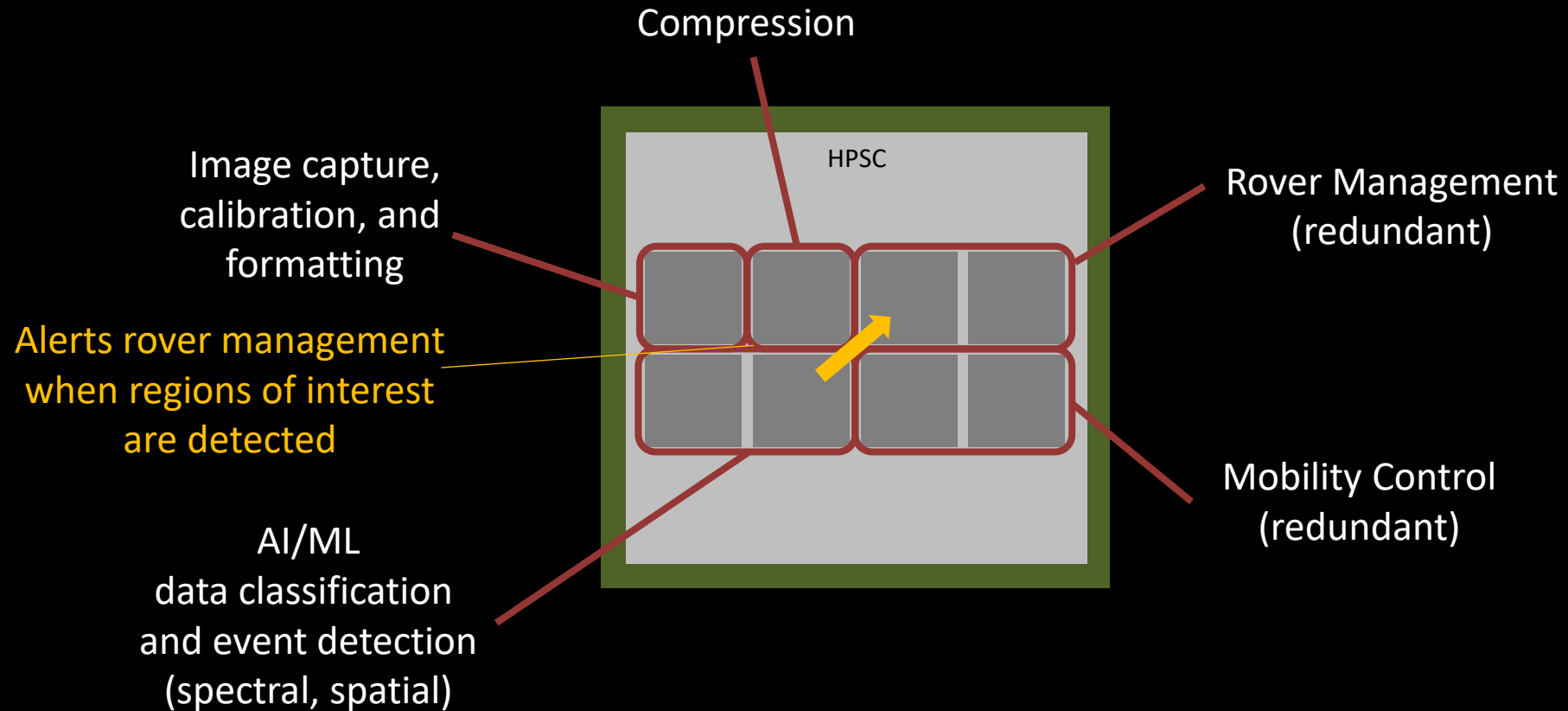
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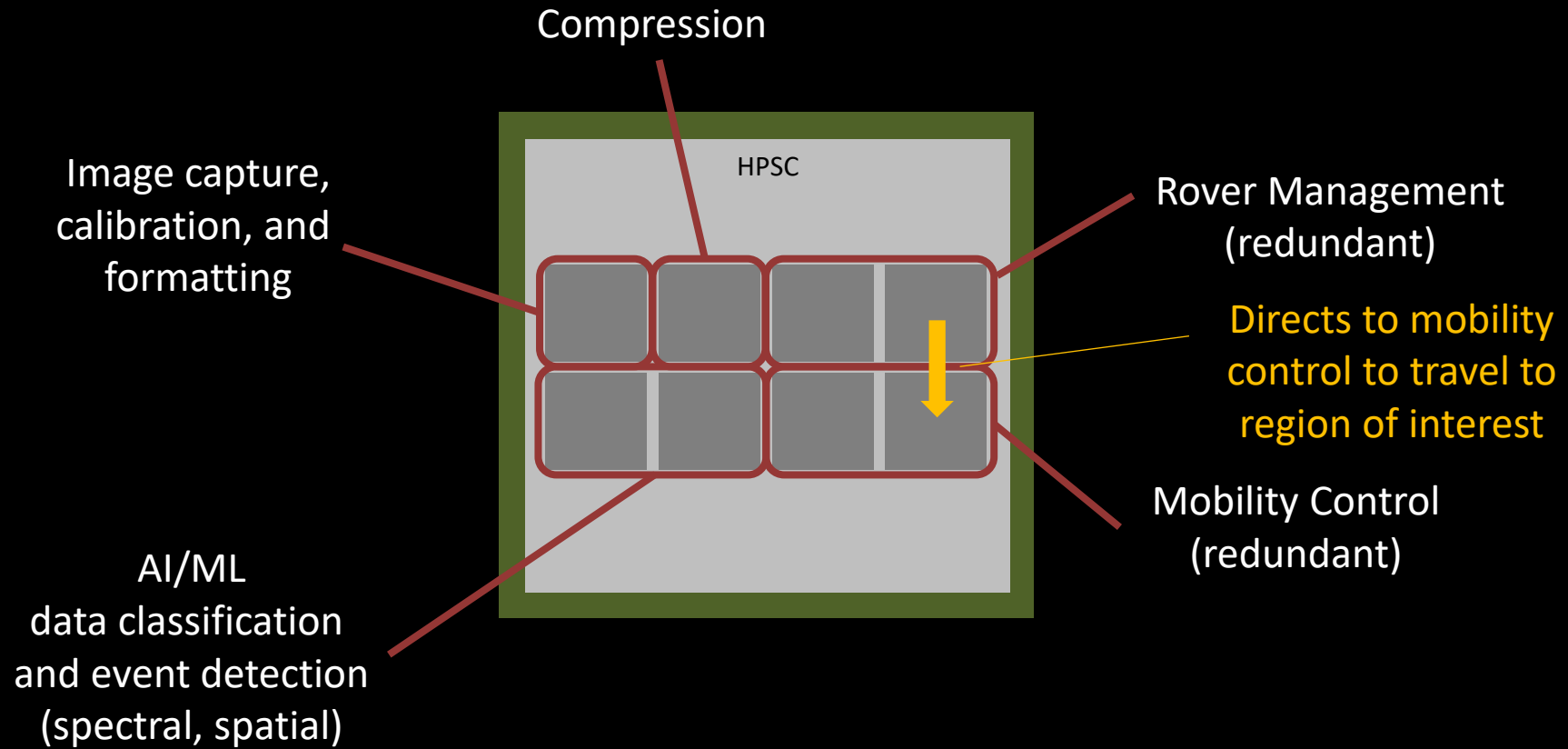
Example - Hyperspectral Imager on Surface Rover



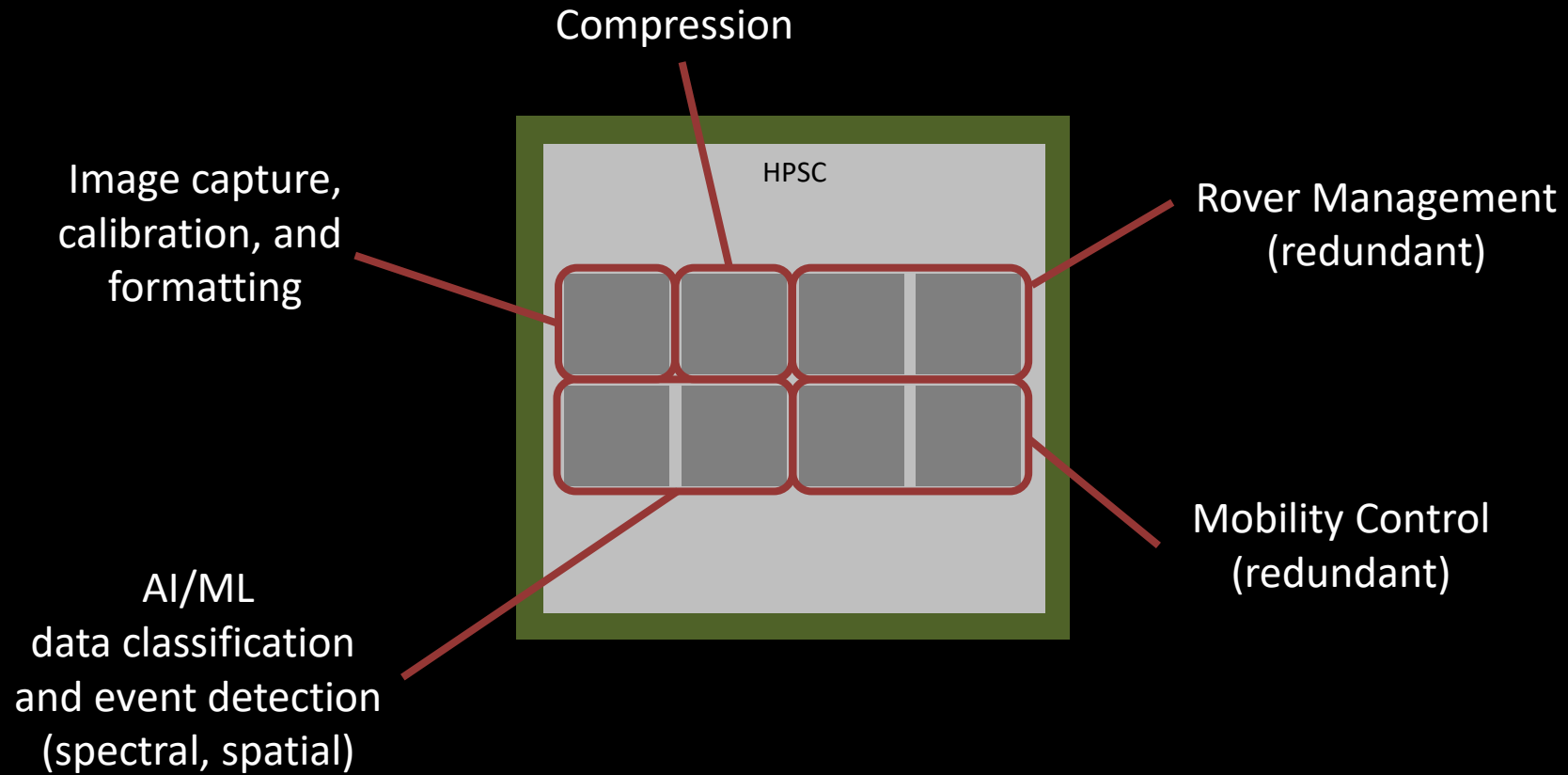
Example - Hyperspectral Imager on Surface Rover



Example - Hyperspectral Imager on Surface Rover



Example - Hyperspectral Imager on Surface Rover





Status and Availability

Current Status

- The HPSC chip development is well underway.
- Industry partners are actively working to develop the HPSC ecosystem.
- A software-based Quick Emulator (QEMU) is currently available for HPSC.

Later This Year

- HPSC chip fabrication will be completed.
- HPSC evaluation boards will be available later in 2025 from Microchip.
- Microchip is also developing a more streamlined HPSC evaluation platform.

2026 Timeframe

- Flight SOSA SpaceVPX HPSC boards are expected from industry.
 - Moog
 - Ideas-Tek
 - Ibeos

In Summary

- NASA and Microchip are developing the HPSC PIC-64 processor to meet future needs of space missions.
- NASA is also working with industry to develop the HPSC ecosystem that will enable broad HPSC mission infusion.
- The compute performance and flexibility of HPSC can enable new possibilities for future missions within the LPSC community.
- HPSC emulators are currently available and HPSC evaluation boards will be available soon for application development and benchmarking within the LPSC community.
- The HPSC team welcomes the opportunity to engage with science community for further discussion.

NASA HPSC Website



Microchip PIC64 Website

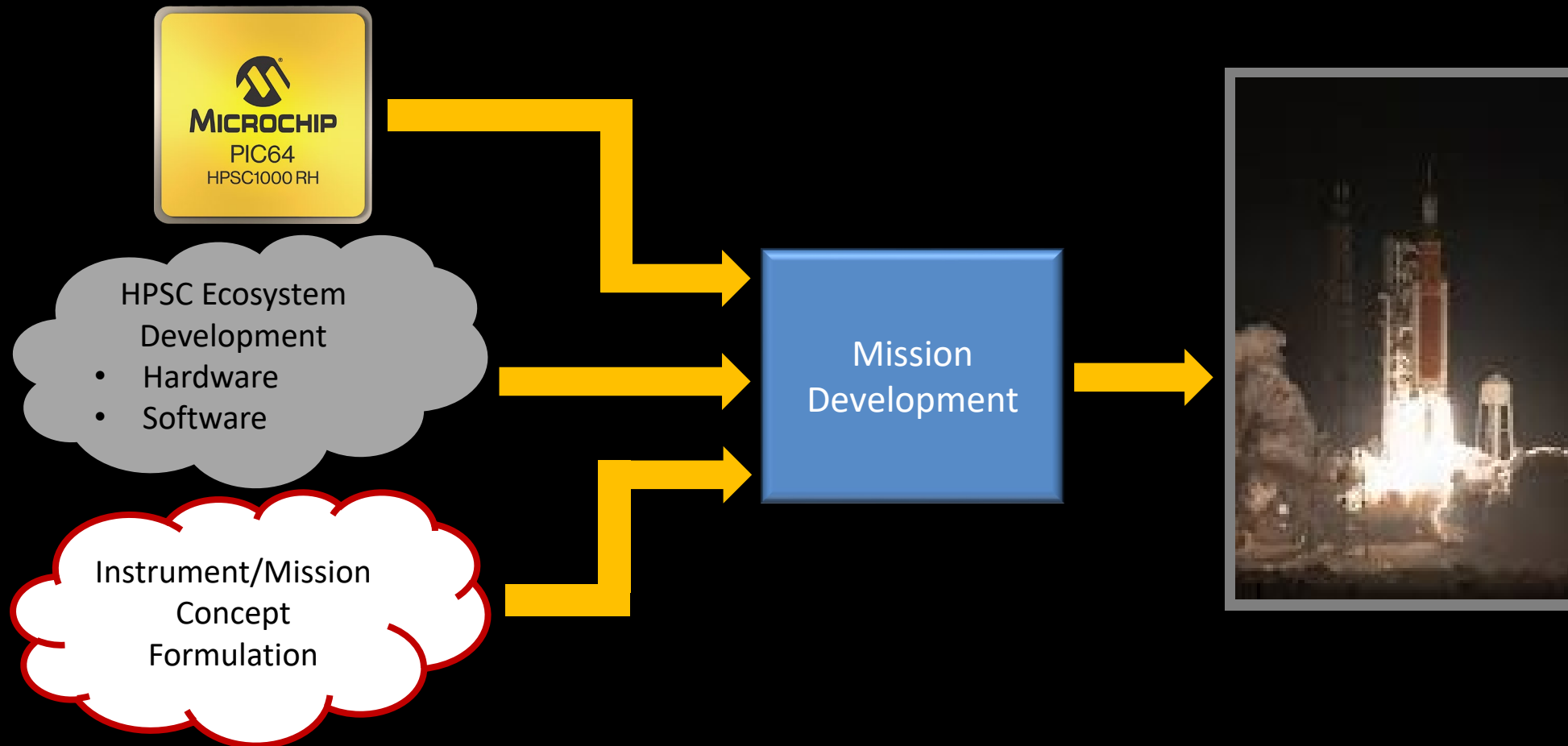


HPSC Ecosystem



Conclusion

- With the currently availability of HPSC emulators and the imminent availability of HPSC development boards, we invite the LPSC community to develop instrument and mission concepts that can leverage the transformational capabilities of HPSC.



Acronym List



AI	Artificial Intelligence	ISRU	In Situ Resource Utilization	RFI	Request For Information
cFE/cFS	Core Flight Executive/Core Flight Software	LEO	Low Earth Orbit	RHBD	Radiation Hardened By Design
DTN	Delay Tolerant Networking	LPSC	Lunar and Planetary Science Conference	RISC	Reduced Instruction Set Computer
ECC	Error Correction Code	ML	Machine Learning	RPOC	Rendezvous, Proximity Operations & Capture
ELCSS	Environmental Control and Life Support System	NASA	National Aeronautics and Space Administration	SBC	Single Board Computer
FFTW	Fastest Fourier Transform in the West	OpenAMP	Open Asymmetric Multi-Processing	SEE	Single Event Effect
FPGA	Field Programmable Gate Array	OpenBLAS	Open Basic Linear Algebra Subprograms	SOC	System-On-a-Chip
FT	Fault Tolerance	OpenSBI	Open Supervisor Binary Interface	SOSA	Sensor Open Systems Architecture
GFLOPS	Giga Floating Point Operations Per Second	OpenSSL	Open Secure Sockets Layer	SW	Software
GPU	Graphics Processing Unit	OS	Operating System	SWaP-C	Size Weight and Power, and Cost
HPSC	High Performance Spaceflight Computing	POCL	Portable Computing Language	TID	Total Ionizing Dose
HW	Hardware	QEMU	Quick Emulator	TOPS	Tera Operations Per Second
I/O	Input/Output	QoS	Quality of Service	V&V	Verification and Validation