

National Science Foundation's



Industry/University Cooperative Research (I/UCRC) Program

VANTAGE

Visual And Neuromorphic Tracking And Geosensing Experiment



Mission-Critical Computing
NSF CENTER FOR SPACE, HIGH-PERFORMANCE,
AND RESILIENT COMPUTING (SHREC)

Mission Overview



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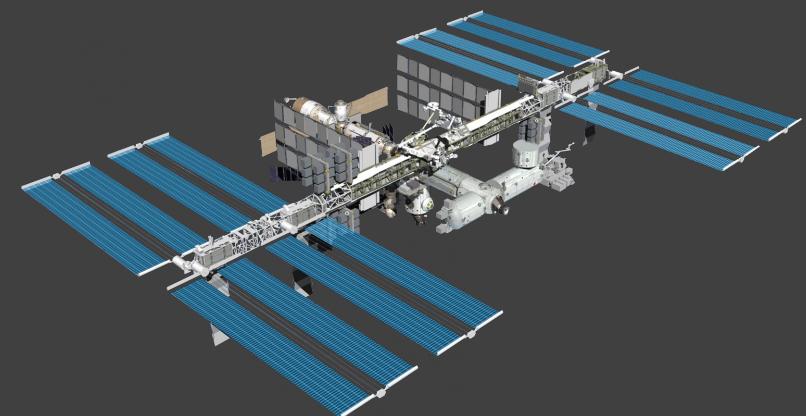
Michael Cannizzaro

Payload Manager
Research Student
University of Pittsburgh



Outline

- Introduction
- Technologies
- Mission Design
- Hardware
- Apps and Services
- Timeline
- Conclusions





Introduction





Acknowledgements

- **VANTAGE is an NSF SHREC Research Mission**

- NSF Center for Space, High-Performance, and Resilient Computing
 - Founded in 2017
 - Formerly CHREC (2007-2017)
 - Comprised of four universities and 25+ industry and government partners
- Hosted at University of Pittsburgh

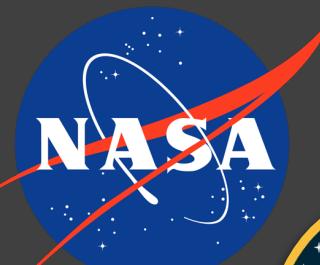
- **VANTAGE Builds Upon Past Success**

- STP-H5-CSP, STP-H6-SSIVP, and STP-H7-CASPR

- **Key Development Partners**

- Department of Defense
- Air Force Research Laboratory
- Space Test Program
- Texas Instruments
- NASA

BAE SYSTEMS



JOHNS HOPKINS
APPLIED PHYSICS LABORATORY



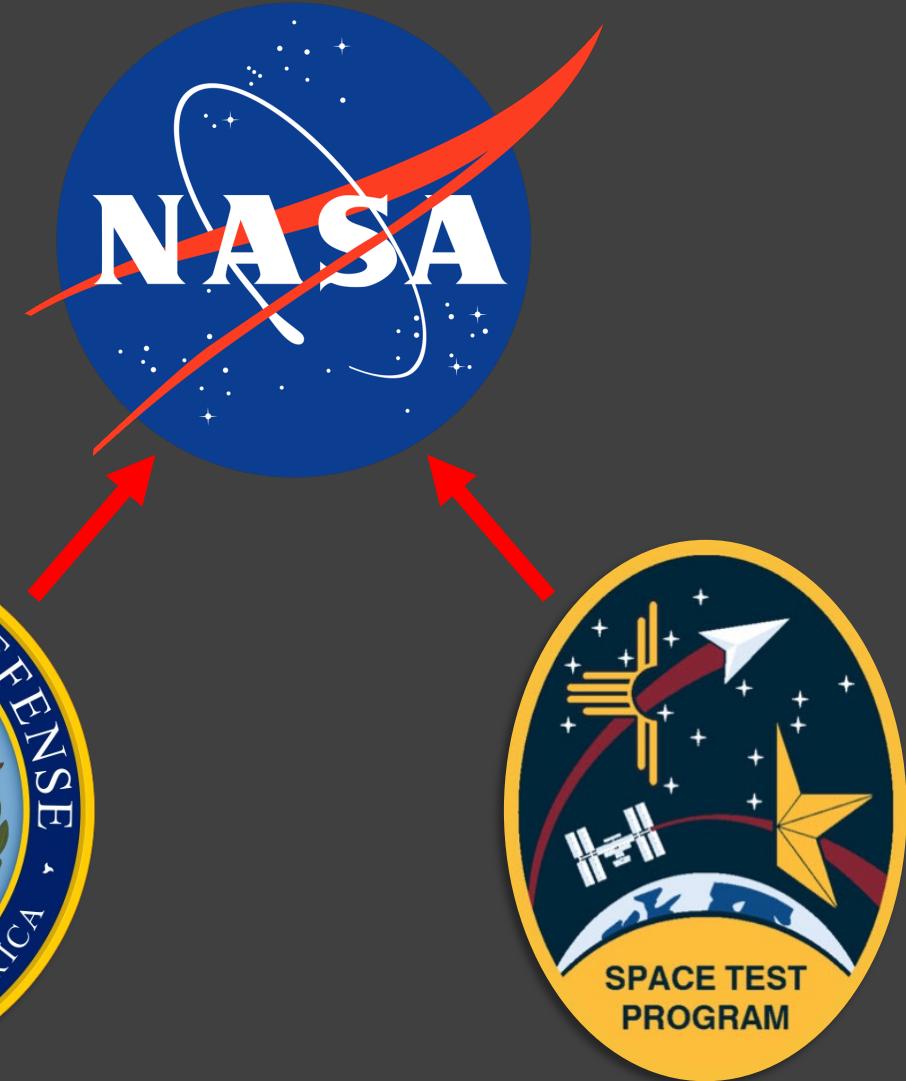
U.S. NAVAL
RESEARCH
LABORATORY





Space Test Program

- **Space Test Program – Houston (STP-Hx)**
 - Managed by United States Space Force
 - “Driving force in DoD space technology advancement”
 - Sole interface to NASA for all DoD payloads on International Space Station (ISS)
 - Provides:
 - Spaceflight opportunities (payloads and launches)
 - Readiness assistance (documentation, reviews, etc.)
 - Management (operations infrastructure)
 - Technical support





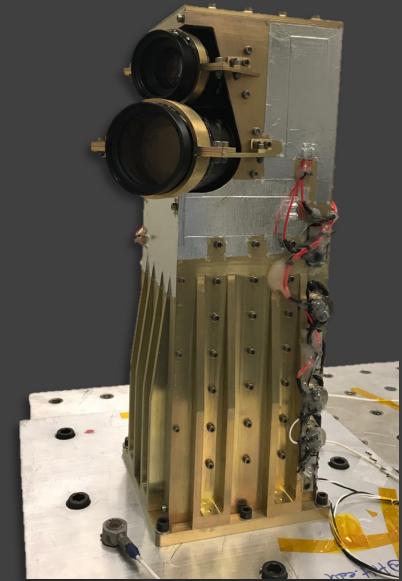
SHREC Mission Heritage

- **Three Successful Missions**

- STP-H5-CSP
 - CHREC Space Processor
 - Demonstration of CSP and hybrid COTS + rad-hard architecture
 - 5 MP Sony camera for Earth observation
- STP-H6-SSIVP
 - Spacecraft Supercomputing for Image and Video Processing
 - Parallel and distributed computing with CSP cluster
 - Two 5 MP cameras (differing field-of-view) for Earth observation
- STP-H7-CASPR
 - Configurable and Autonomous Sensor Processing Research
 - Enable onboard processing for next-generation sensors and apps
 - Satlantis iSIM-90 high-resolution, hyperspectral imager (GRD ~3.0 meters/pixel)



STP-H5-CSP



STP-H6-SSIVP



STP-H7-CASPR



STP-H12-VANTAGE

- **In-House Expertise**

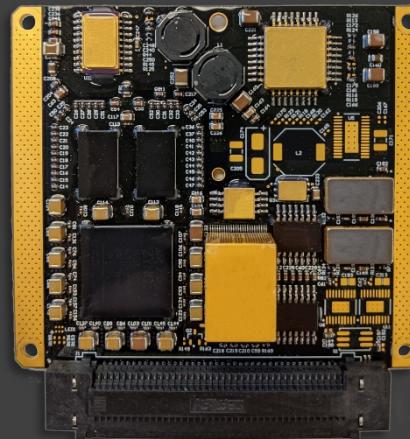
- Earth-observation datasets, classifiers, and compression tools
- Novel edge computing through hybrid (rad-hard + COTS) processing
- Reliable flight hardware, FPGA apps, and software

- **SHREC Flight Computers**

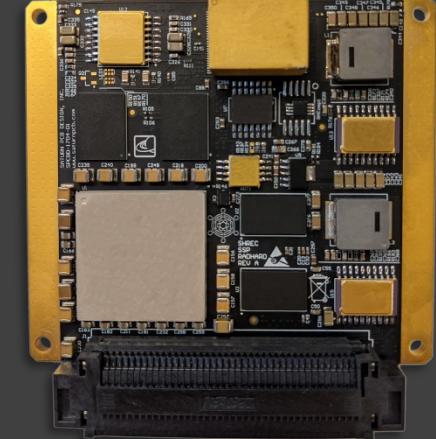
- CHREC Space Processor (CSP) – 22.5+ years of flight heritage (7 devices + 3 missions)
- SHREC Space Processor (SSP) – 4 years of flight heritage (2 devices + 1 mission)
- Space GPU (SGPU) – Accelerate compression, checksums, and image processing

- **Proposed Fourth STP Mission: STP-H12-VANTAGE**

- Leverage SHREC's existing Earth-observation, processing, and system-development expertise
- Introduce overlap of visual and neuromorphic data for novel perception and autonomy research



CSP



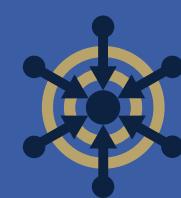
SSP



AMD GX-216 SoM



Technologies

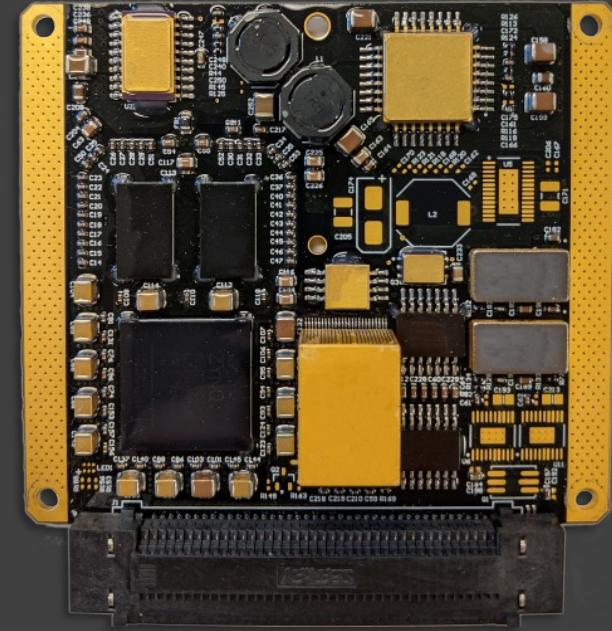


CHREC Space Processor (CSP)

- Hybrid (COTS + Rad-Hard) Single-Board Computer
- Leverages Xilinx Zynq-7020 FPGA SoC
 - Dual-core ARM Cortex-A9 @ 667 MHz
 - Artix-7 FPGA
- Additional Specifications:
 - Radiation-tolerant NAND flash (1 – 4 GB)
 - COTS DDR3 (256 MB – 1 GB)
 - Dedicated watchdog circuitry
 - Onboard power regulation
 - 26 ARM GPIO pins
 - 12 Single-ended FPGA I/O pins
 - 24 High-speed differential pairs
- Extensive Mission Heritage on STP-H5, STP-H6, and STP-H7



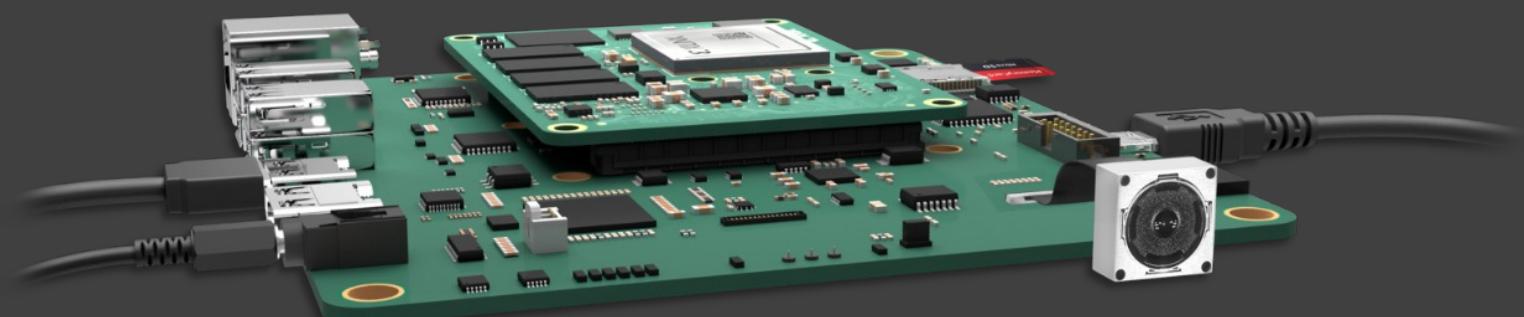
CSP Active
Eval Board



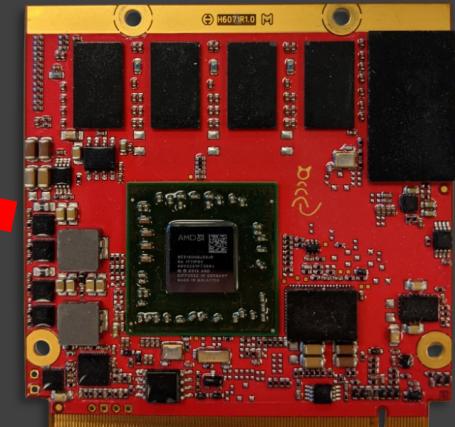
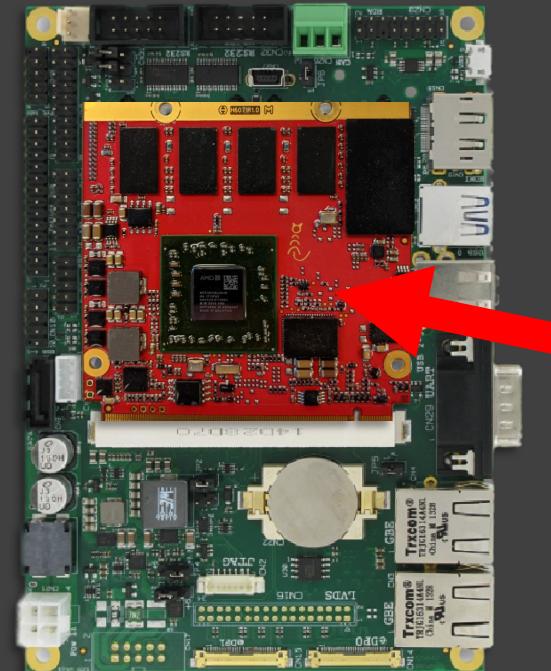


System-on-Module Solutions for Space

- **System-on-Modules (SoMs)**
 - Commercially-available PCB
 - COTS processor, communications interfaces, memory, etc.
 - High-density board connector(s)
 - Vertically mounted to SoM carrier board
 - Carrier provides connection breakouts/other supporting circuitry
 - Successful flight on STP-H7-CASPR!
 - AMD GX-216HC GPU
 - Custom COTS carrier card with Ethernet communication



Carrier Board Example



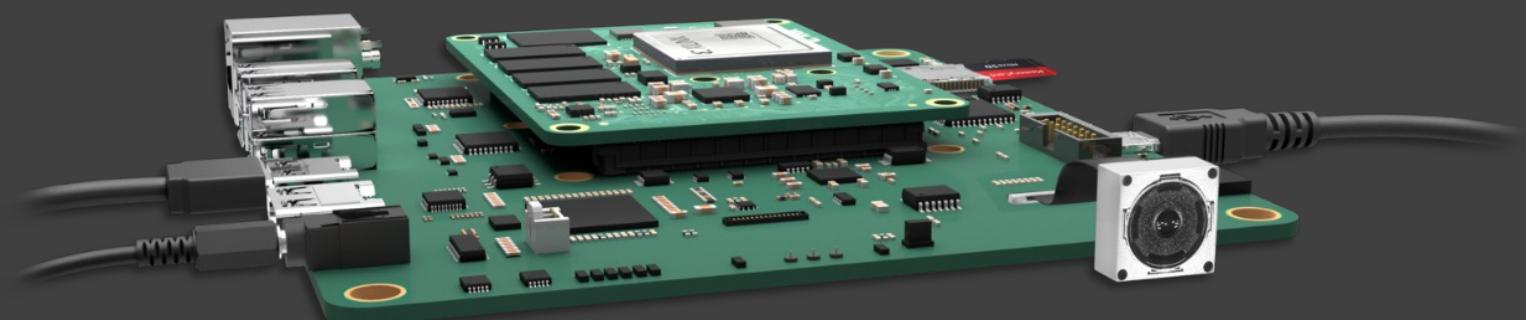
AMD GX-216 SoM



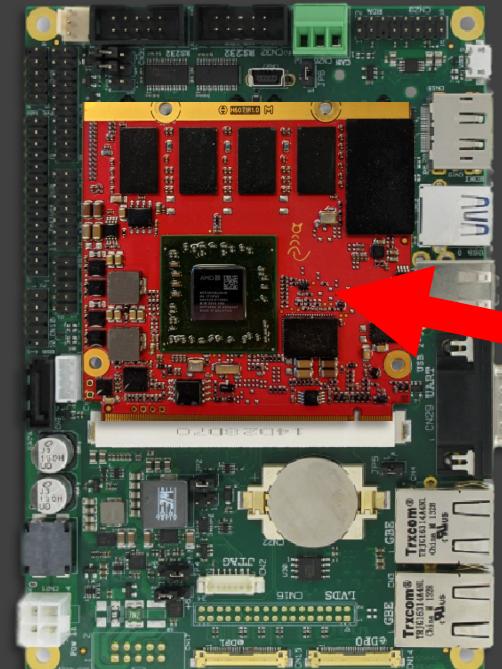


System-on-Module Solutions for Space

- **NEW** – Hybrid Architectures for SoM Carriers
 - COTS SoM enables high performance with desired SoC at minimal cost
 - Custom SoM carrier contains rad-hard supporting components
 - Power, data storage, watchdog timing, etc.
 - Enables low-cost prototyping and iterative design
 - Maximizes system dependability
 - Minimizes time to deployment

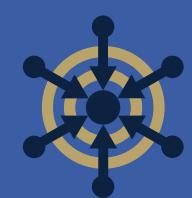


Carrier Board Example



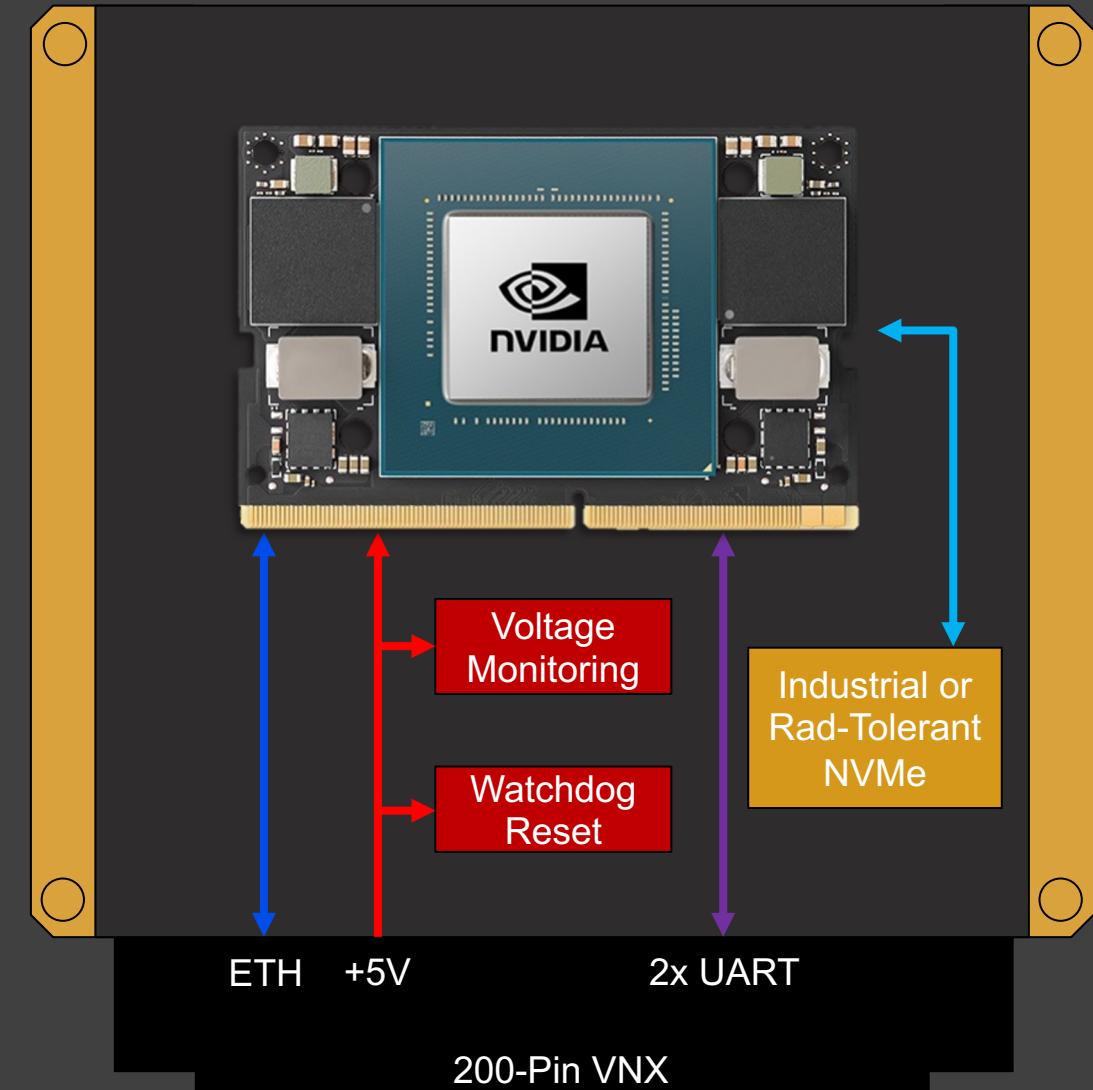
AMD GX-216 SoM





System-on-Module Solutions for Space

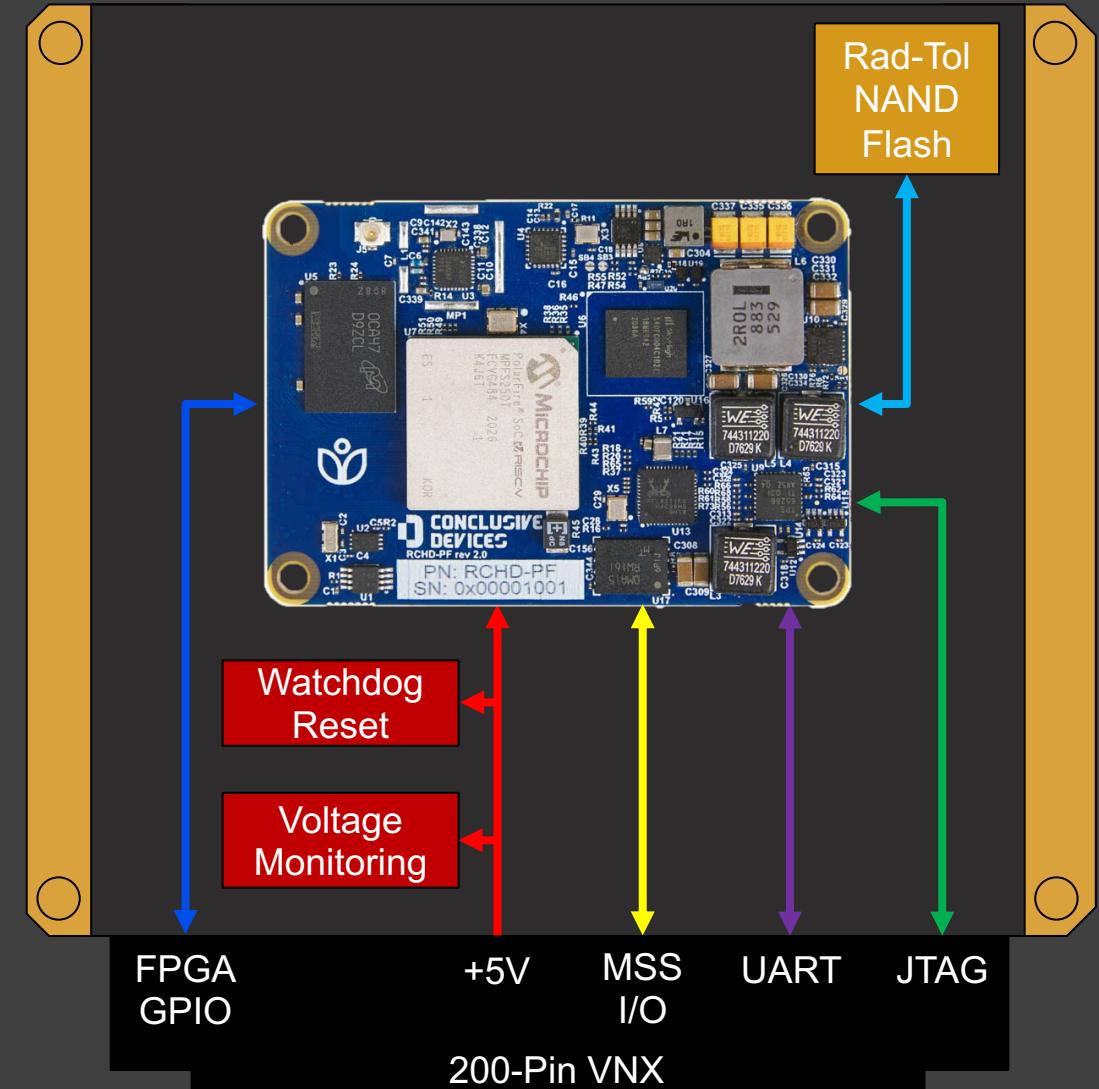
- Hybrid NVIDIA GPU SoM Carrier
- COTS NVIDIA Jetson Orin NX 16GB SoM
 - 1024-core NVIDIA Ampere GPU architecture @ 918 MHz
 - 8-core 64-bit ARM Cortex-A78AE CPU @ 2.2 GHz
 - 16 GB COTS LPDDR5
- SoM Carrier Incorporates:
 - UART and Ethernet communications
 - Dependable onboard power regulation
 - Dedicated watchdog circuitry
 - Fault-tolerant non-volatile data storage





System-on-Module Solutions for Space

- Hybrid Microchip PolarFire SoC SoM Carrier
- COTS Microchip PolarFire SoC (MPFS250T) SoM
 - 4-core 64-bit RISC-V GC (SiFive U54) CPU @ 600 MHz
 - PolarFire FPGA fabric
 - 254K logic elements (4-input LUT + DFF)
 - 784 math blocks (18x18 MACC)
- SoM Carrier Incorporates:
 - Processor I/O (UART, Ethernet, etc.)
 - FPGA I/O
 - Dependable onboard power regulation
 - Dedicated watchdog circuitry
 - Radiation-tolerant NAND flash





Neuromorphic Event-Based Sensing

- **Mimics Function and Efficiency of Biological Eye**

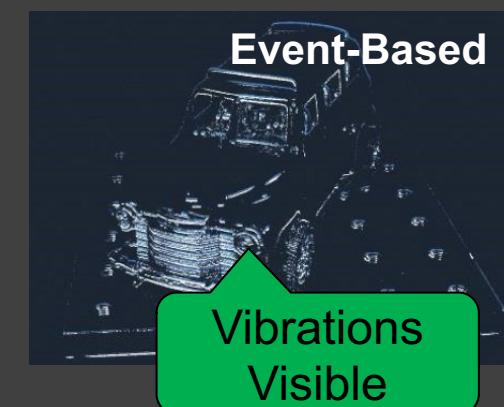
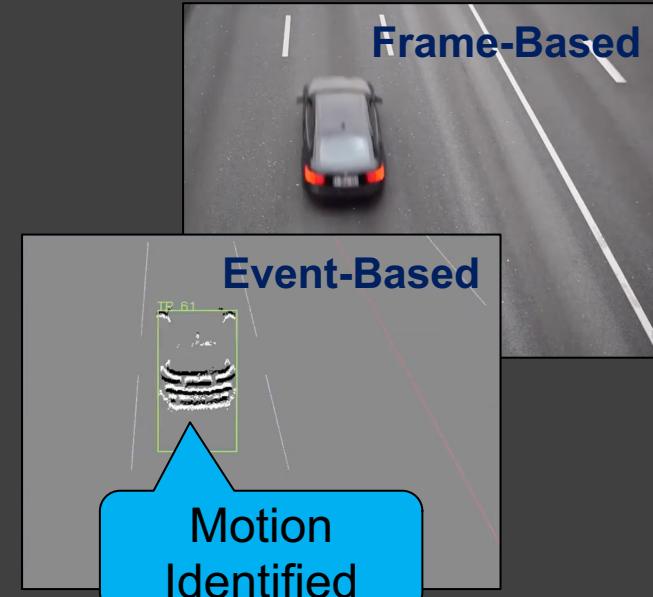
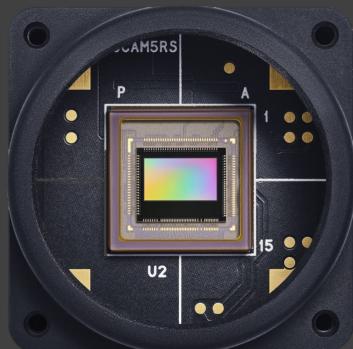
- Only responds when changes (“events”) detected
- Low data rate → data is only produced if events occur
- Efficient output → Only changes in scene are transmitted

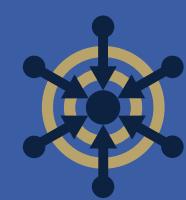
- **High Temporal Resolution**

- Beneficial for counting/measuring objects, calculating trajectories, identifying onboard vibrations, and more

- **Prophesee + Sony IMX636 Event-Based Sensor**

- High-definition (1280 x 720 pixels)
- Sensor peak power consumption <100mW





COTS Catadioptric Lenses

- **Compact and Cost-Effective Telescope-Like Design**
 - Cluster of mirrors and glass lenses place long focal lengths into small and lightweight package
 - Most lenses available for <\$500
- **Low-GRD Imaging Opportunities**
 - Estimated ~2.5 meter/pixel imaging with 500mm lens and 4K Sony industrial sensor
 - Lens on neuromorphic sensor will have differing GRD to ensure sufficient swath coverage for data acquisition and triggering
- **Some Challenges**
 - COTS lenses will require either environmental and mechanical testing, or custom mechanical modification, for flight assurance



Tokina SZ SUPER TELE 500mm
(Candidate)



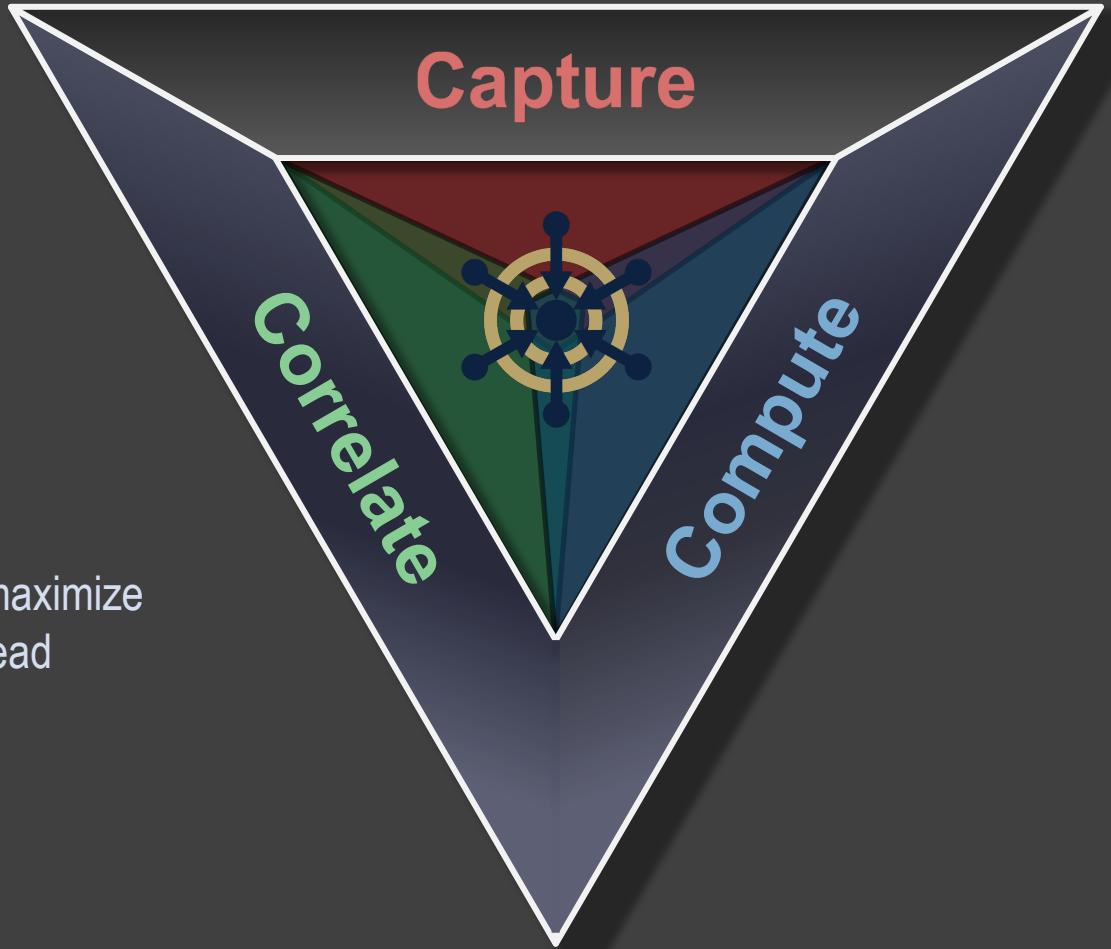
Mission Design

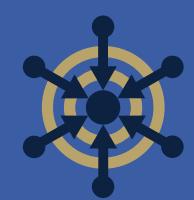




Mission Objectives

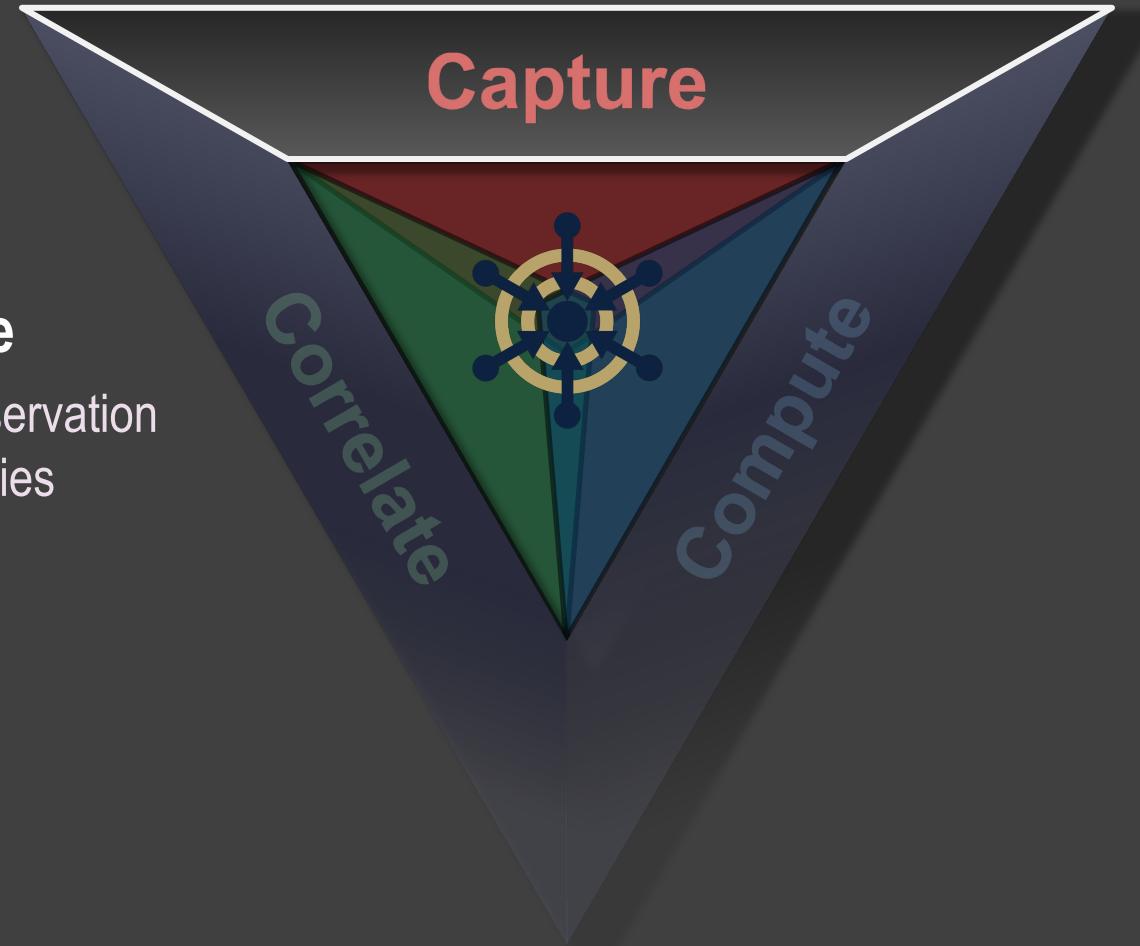
- **Three Key Objective Categories**
 - Capture
 - Demonstrate core onboard sensor features and capabilities for Earth observation data capture
 - Correlate
 - Verify sensor correlation operations and begin identification, tracking, and additional science
 - Compute
 - Leverage next-generation hybrid space computing systems to maximize system performance and reliability with minimal cost and overhead

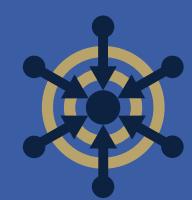




Mission Objectives

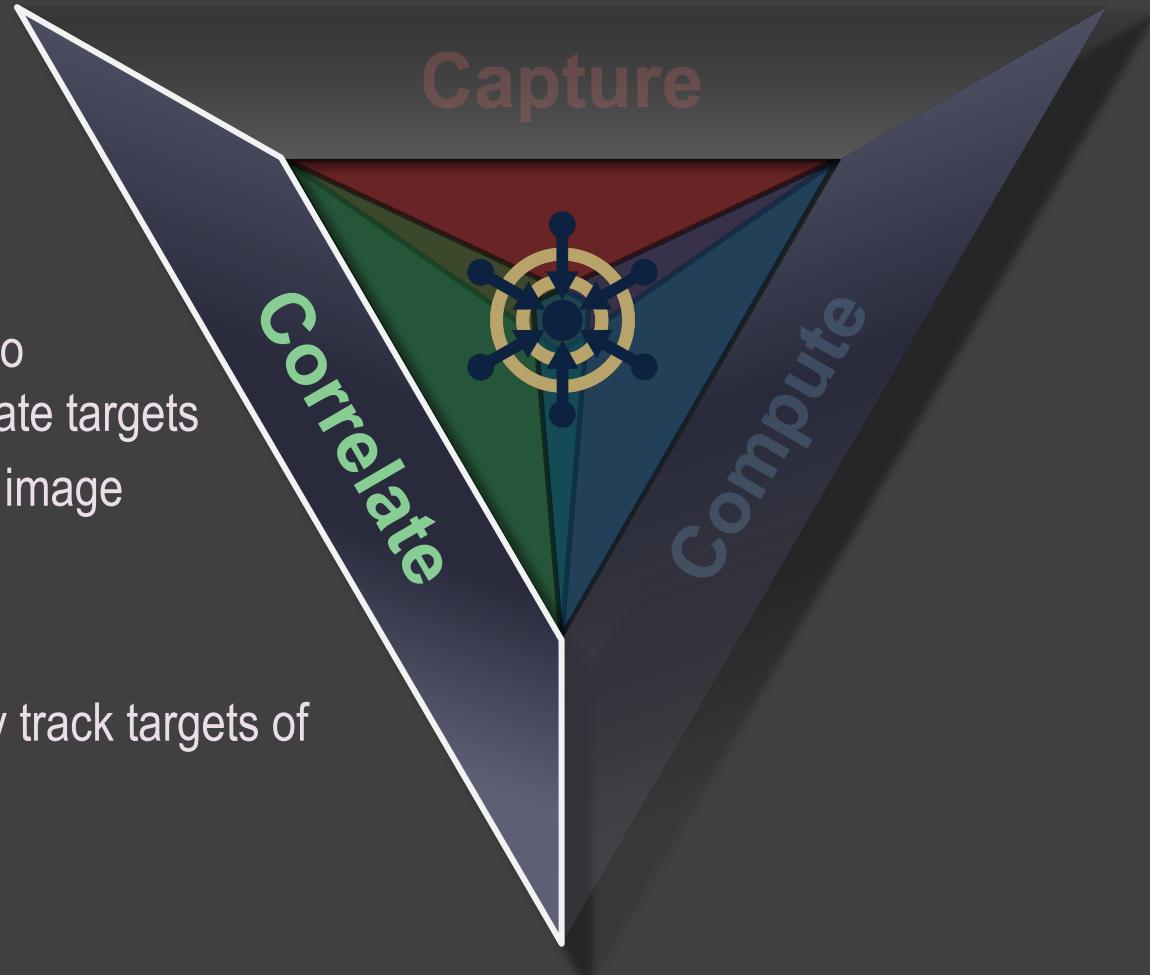
- **Mission Objective #1: Low-GRD Image Capture**
 - Experiment with industrial cameras and low-cost optics for low-GRD Earth observation image capture and onboard processing
- **Mission Objective #2: Event-Based Data Capture**
 - Leverage neuromorphic event-based sensors for Earth observation applications and demonstrate onboard processing capabilities





Mission Objectives

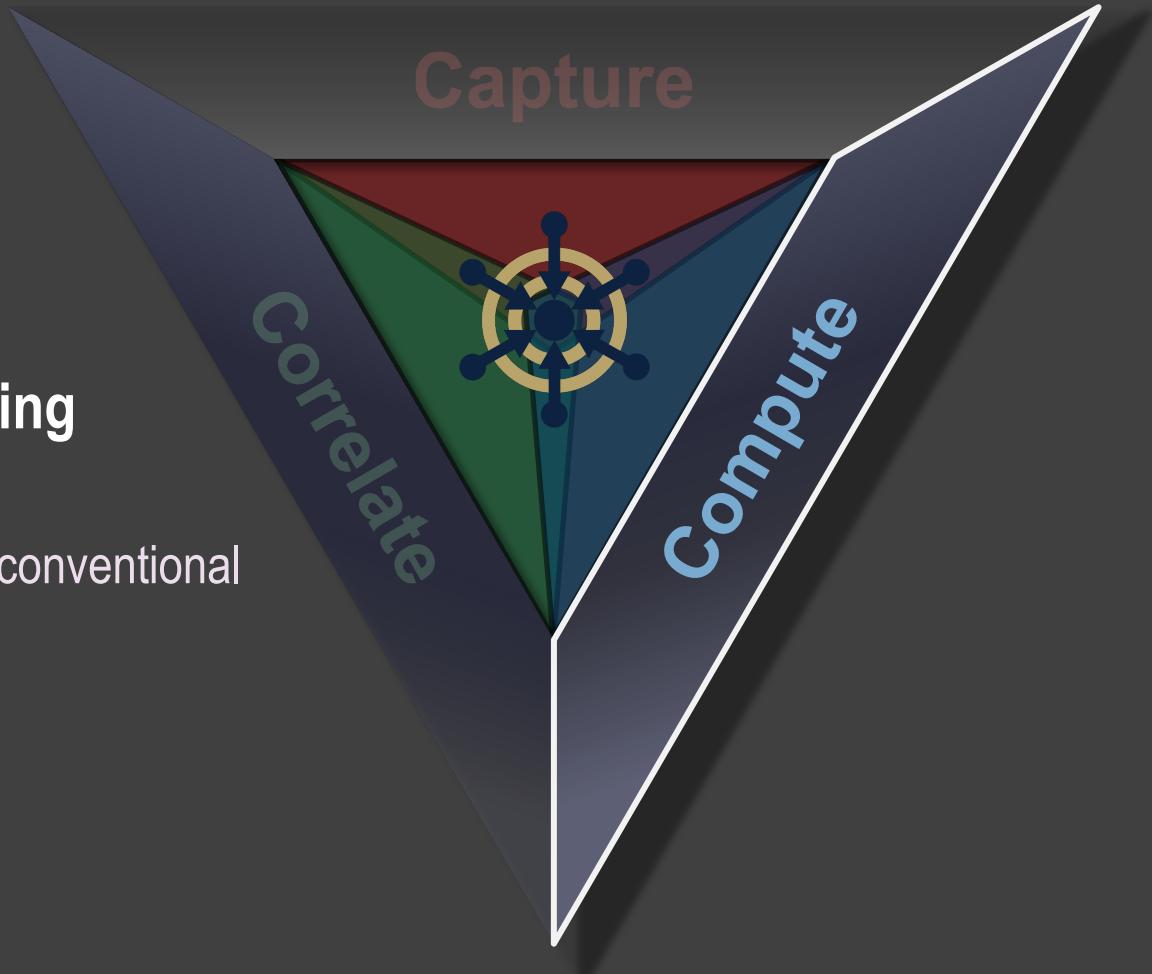
- **Mission Objective #3: Sensor Correlation**
 - Demonstrate simultaneous image and neuromorphic data captures and verify overlapping sensor fields of view
- **Mission Objective #4: Intelligent Target Capture**
 - Experiment with overlapping fields of view of both sensors to intelligently trigger the capture of images featuring appropriate targets
 - Record and downlink data to create dataset with correlated image and neuromorphic event-based data
- **Mission Objective #5: Effective Target Tracking**
 - Using onboard sensor suite, enable system to automatically track targets of interest and capture and downlink relevant data

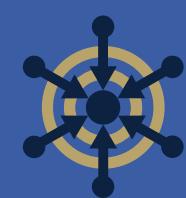




Mission Objectives

- **Mission Objective #6: Accelerated Computer Vision and Machine Learning**
 - Investigate computer vision and machine learning apps on COTS FPGAs, GPUs, and multicore CPUs to evaluate onboard processing capabilities
- **Mission Objective #7: End-to-End Onboard Sensing and Intelligent Processing**
 - Demonstrate end-to-end enterprise capability with onboard conventional and event-based sensing via COTS processing





VANTAGE System Architecture

- **Computing Chassis**

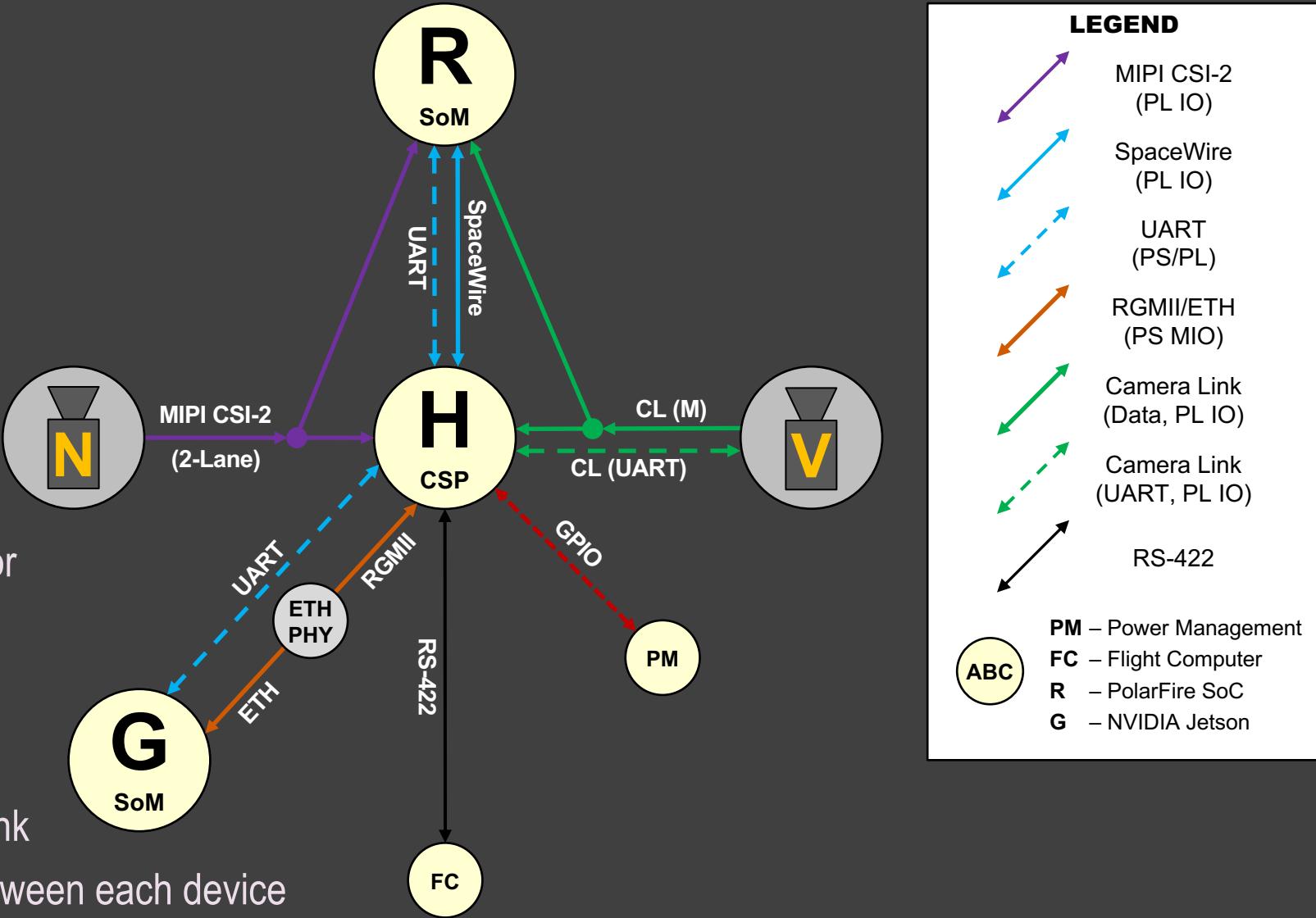
- 1x CSP (main node)
- 2x Hybrid SoM carriers
 - PolarFire SoC SoM
 - NVIDIA Jetson SoM
- 1x SHREC power card

- **Dual-Sensor System**

- 1x Sony IMX636 neuromorphic sensor
- 1x Sony XCL-SG1240C RGB sensor

- **Data Connections**

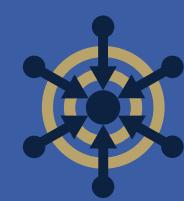
- Ethernet, SpaceWire, and Camera Link
- Redundant UART communication between each device



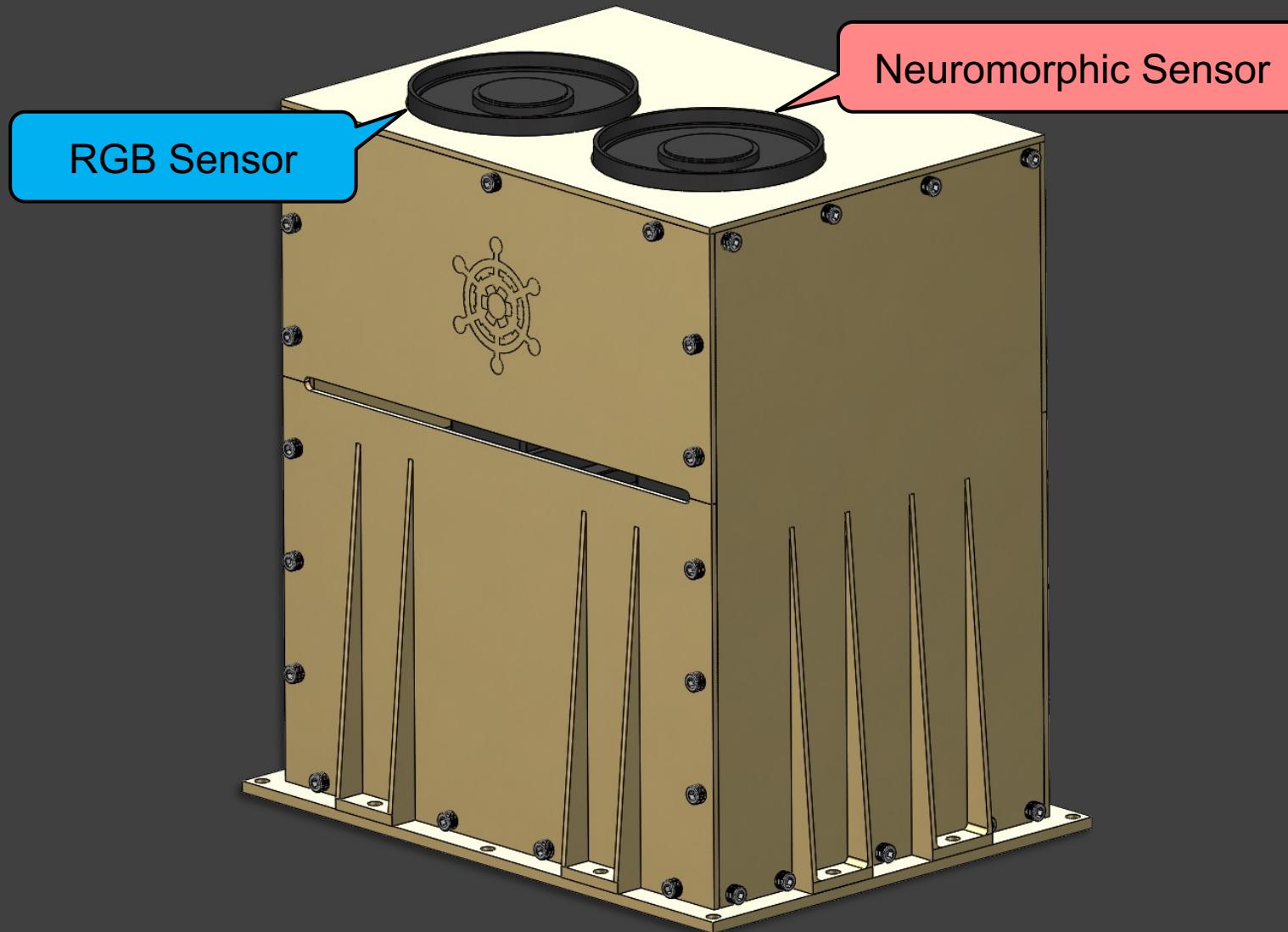


Hardware



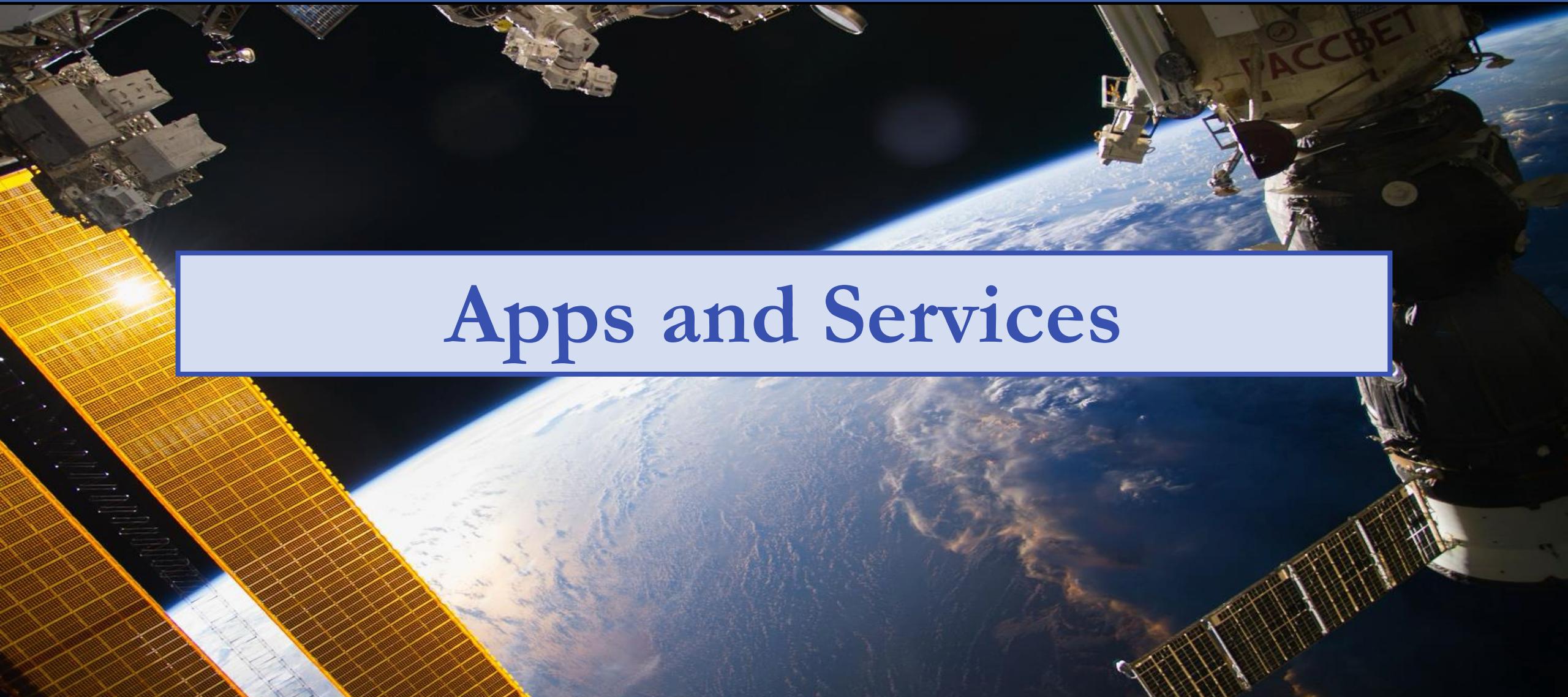


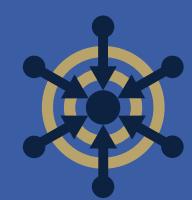
Preliminary Mechanical Model





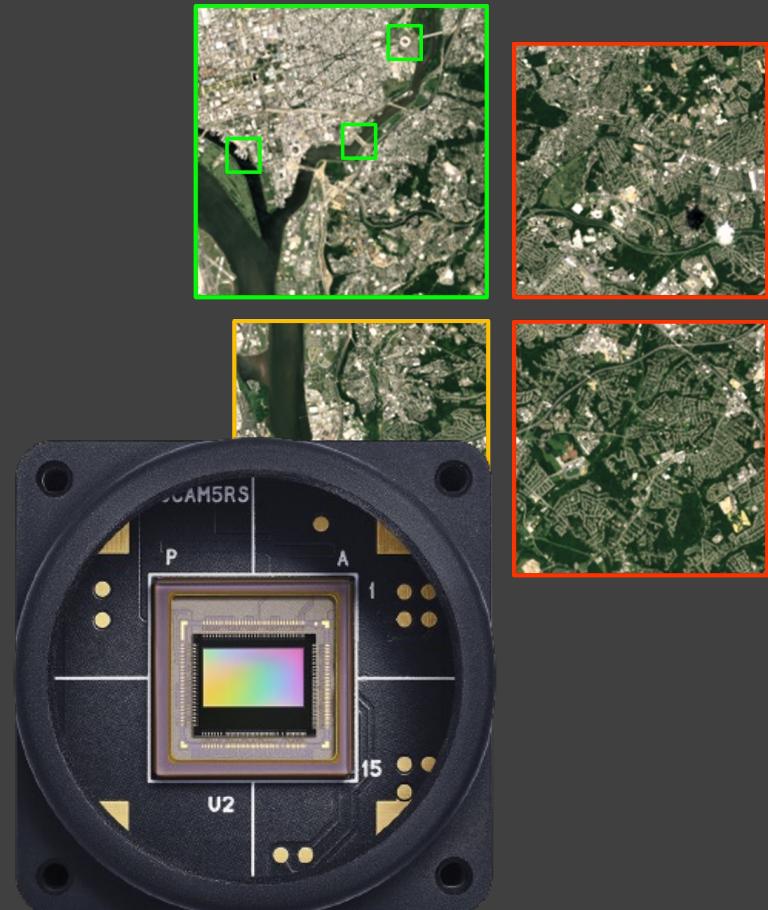
Apps and Services





Apps and Services

- **Next-Generation Autonomous Imaging Pipeline**
 - Tile classification, semantic segmentation, and other deep-learning models
 - CNNJPEG compression, further autonomous app calls, downlink, and storage
- **SHREC Neuromorphic App Suite**
 - Event-based tracking
 - hARMS event-based optical flow algorithms
 - Spiking neural-network framework implemented on FPGA
- **Shared Field of View for Visual and Neuromorphic Sensors**
 - Track objects with neuromorphic sensor and capture visuals at ideal time
 - Gather unique dataset combining advantages of neuro and visual





Timeline





Schedule

Flight
Request
Spring 2024



SERB
Presentations
Spring 2024



STP-H12
Kickoff
Fall 2024



STP-H12
PDR
Winter 2025



STP-H12
CDR
Summer 2025



STP-H12
On-Dock
Early 2026



Estimate
(based on latest
STP guidance)



Conclusions

- **Computing Focus with Scientific Impact**
 - Leverage SHREC expertise in hybrid space computing architectures
 - Integrate ongoing Earth observation and neuromorphic research
- **Simplified Design Without Compromise**
 - Reduced complexity and power compared to CASPR
 - Novel SoM approach enables doing more with less
- **Next Steps**
 - Secure additional funding for parts and manufacturing
 - Complete prototype designs and begin initial fabrication
 - Conduct in-house validation of optical hardware

