



Towards A Radiation-Tolerant Display System

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Where do we need displays in space?

Spacecraft

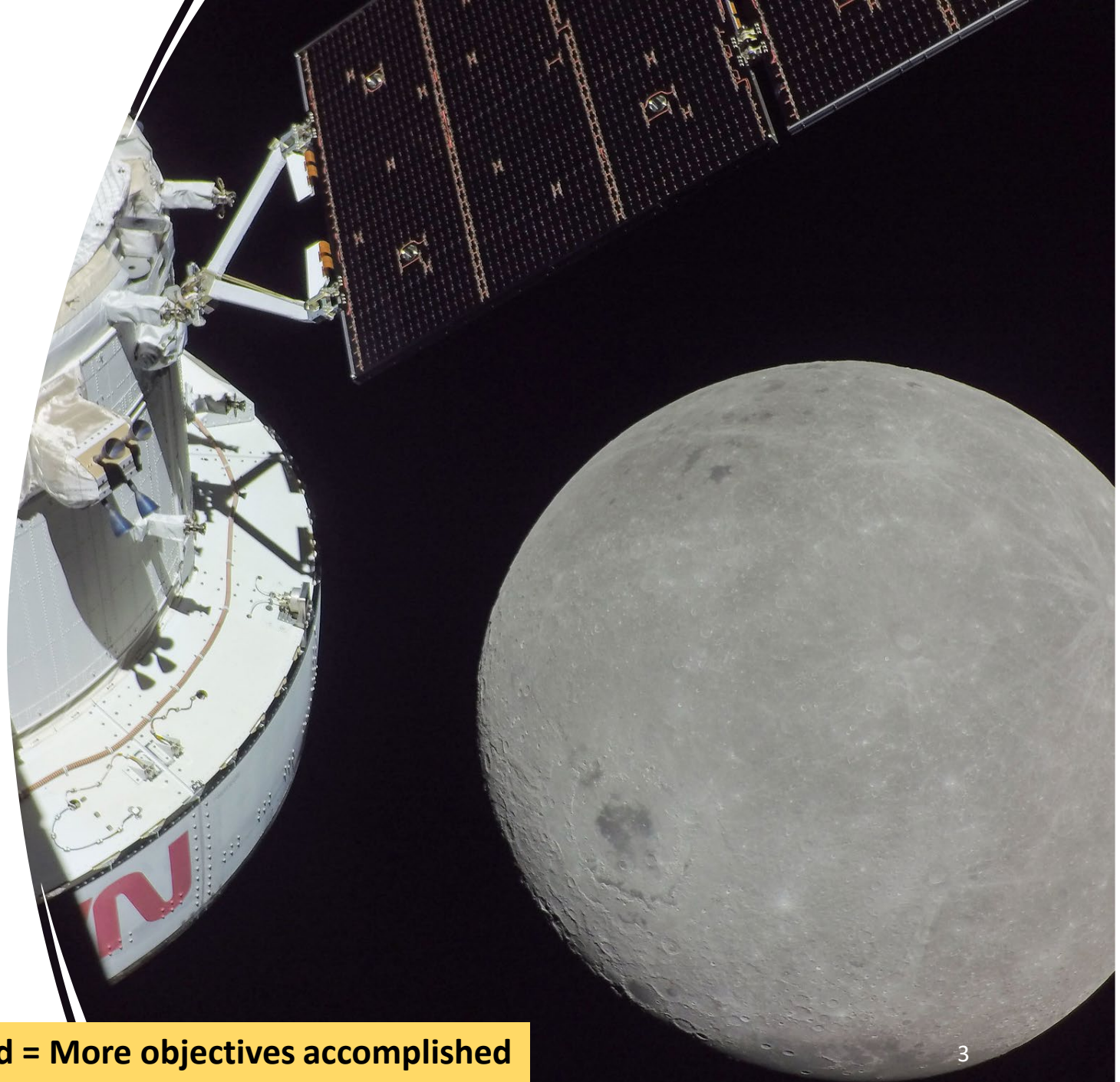
Pressurized Rover

Lunar/Martian Habitat

Extravehicular Activities (EVAs)

Motivation

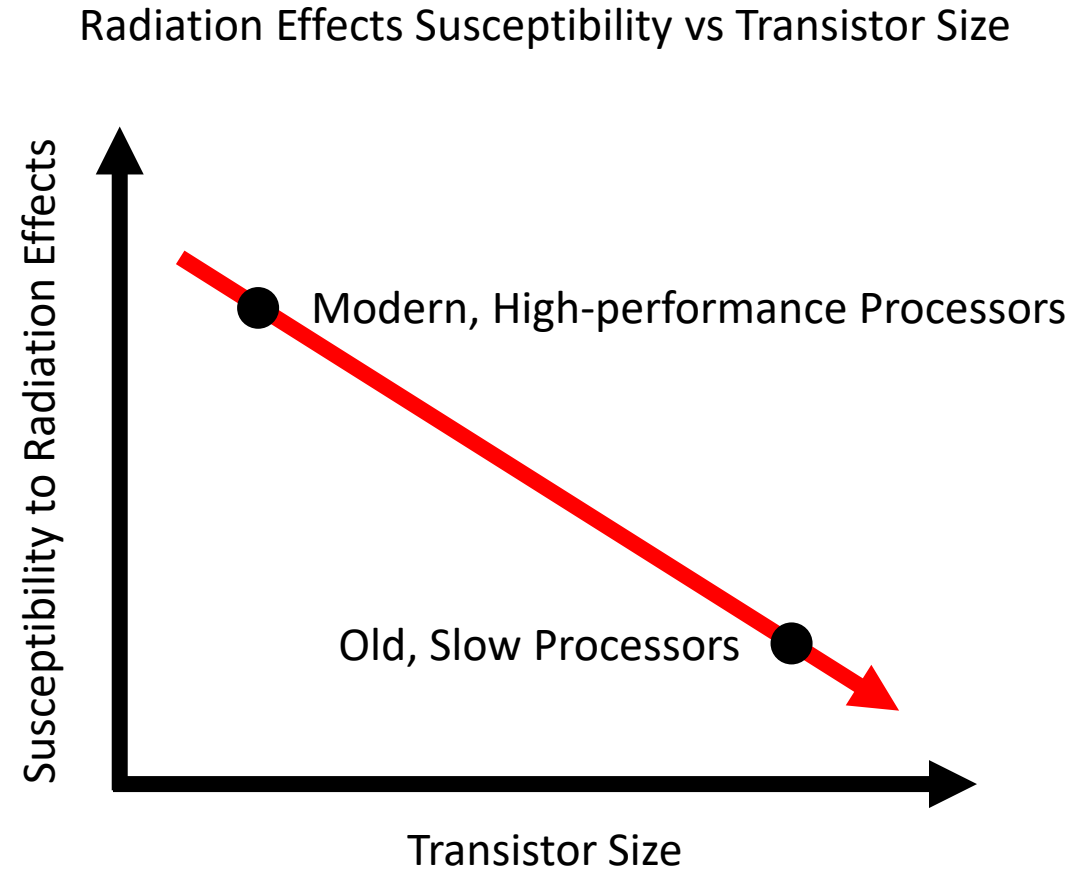
- Displays are a critical piece of NASA's space exploration
- Referenced as part NASA 2020 Taxonomy
- TX02 Flight Computing and Avionics
 - TX02.1 Avionics Component Technologies
 - TX02.1.1 Radiation Hardened Extreme Environment Components and Implementations
 - TX02.1.3 High Performance Processors
 - TX02.2 Avionics Systems and Subsystems
 - TX02.2.1 Spacecraft Command and Data Handling Systems
 - TX02.2.2 Aircraft Avionics Systems
 - TX02.2.3 Vision and Virtual/Augmented Reality Avionics
 - TX02.2.4 Low Power Embedded Computer Systems
- Displays are a unique aspect of human spaceflight avionics
 - Not required in most avionic systems
 - Generate a deliverable for human consumption
 - Only needed for crewed missions
- To date, flight displays fall under two categories:
 1. Simplistic output, generated by slow, flight processors (Orion)
 2. Advanced output, generated by COTS processors not suited for long duration, deep space missions (Crew Dragon)
- Need for a radiation-tolerant display system represents a significant NASA technology gap



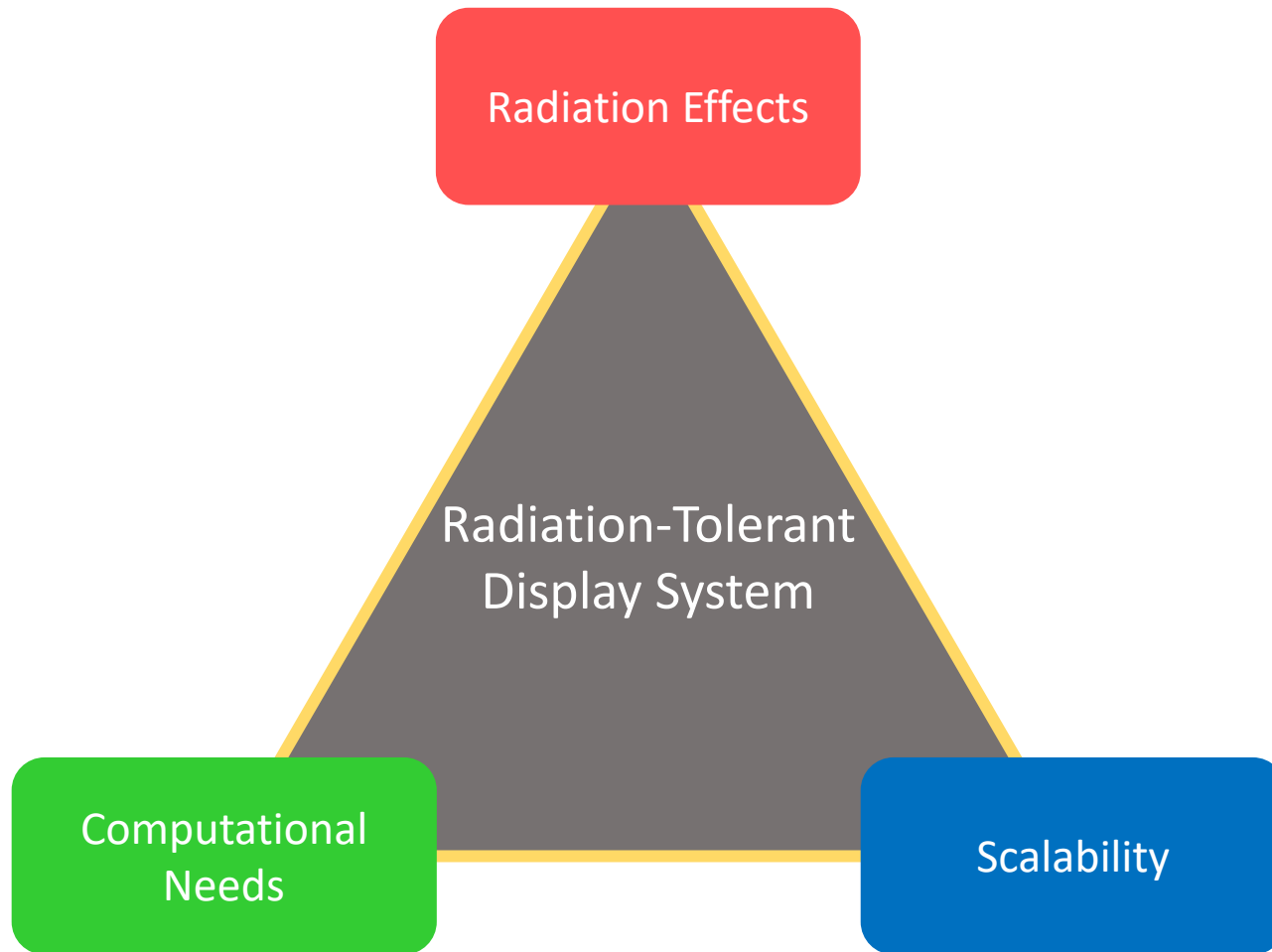
Increased crew autonomy + Decreased cognitive load = More objectives accomplished

Defining the problem

- Current rad-hard processors do **not** provide the necessary **processing capabilities** for desired rendering
- Commercial-off-the-shelf (COTS) processors typically used in graphics rendering (GPUs) are **susceptible** to radiation effects (total dose and single-event effects)
- Development of rad-hard GPUs **not anticipated** any time soon
- Industry **lacks** a commercial display ready for space qualification

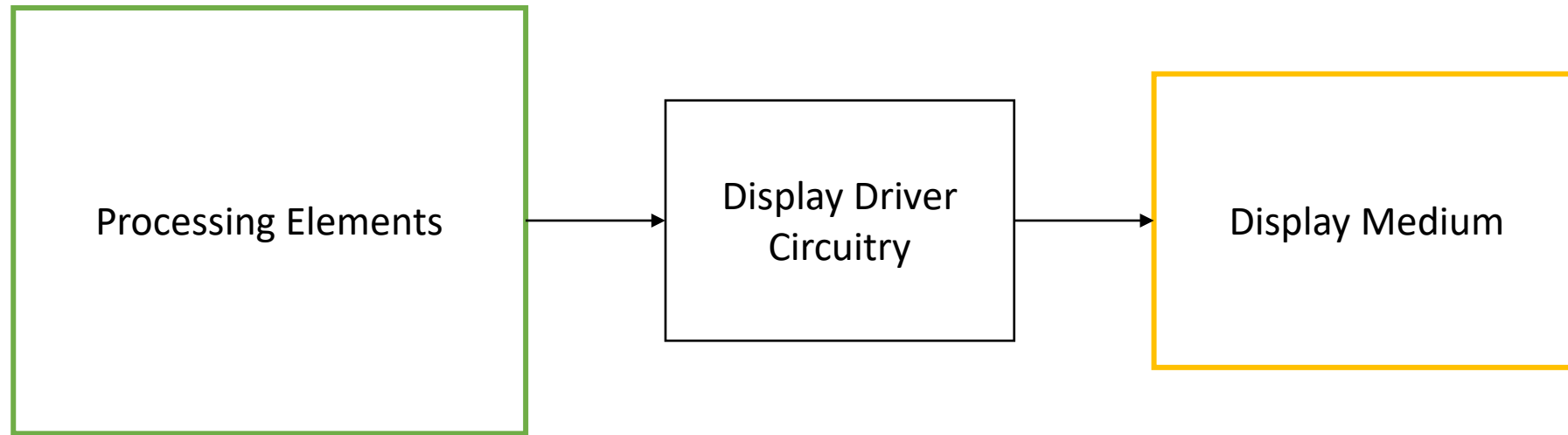


Considerations for System Design



1. Computational Needs
 - Processor and other compute elements must provide the necessary capabilities for the desired applications
2. Radiation Effects
 - Consideration of Total Dose and Single-Event Effects (both destructive and nondestructive)
 - Fault-tolerance: intrinsic and by design
 - Mitigation strategies: supplemental – what can be done externally to increase reliability
3. Scalability
 - Architecture should be scalable to fit various vehicles and requirements
 - Power
 - Form Factor
 - Computational Capacity
 - Modular approach so piece can be easily replaced on long duration mission
 - Multiple Single-Board Computers (SBCs)
 - Enables scaling and replacements

Main Components of a Display System



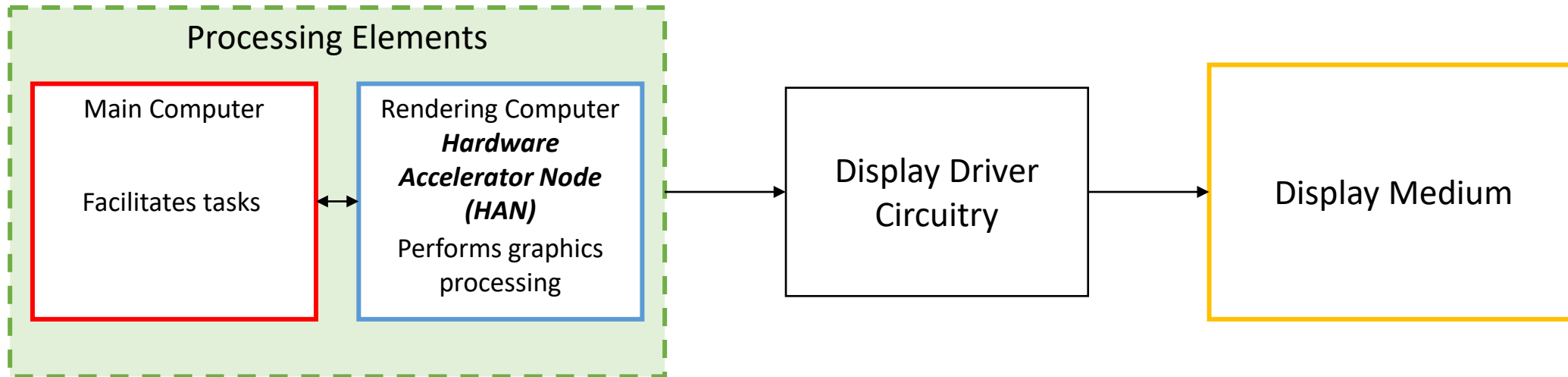
Role:

Produces frames to be displays on screen

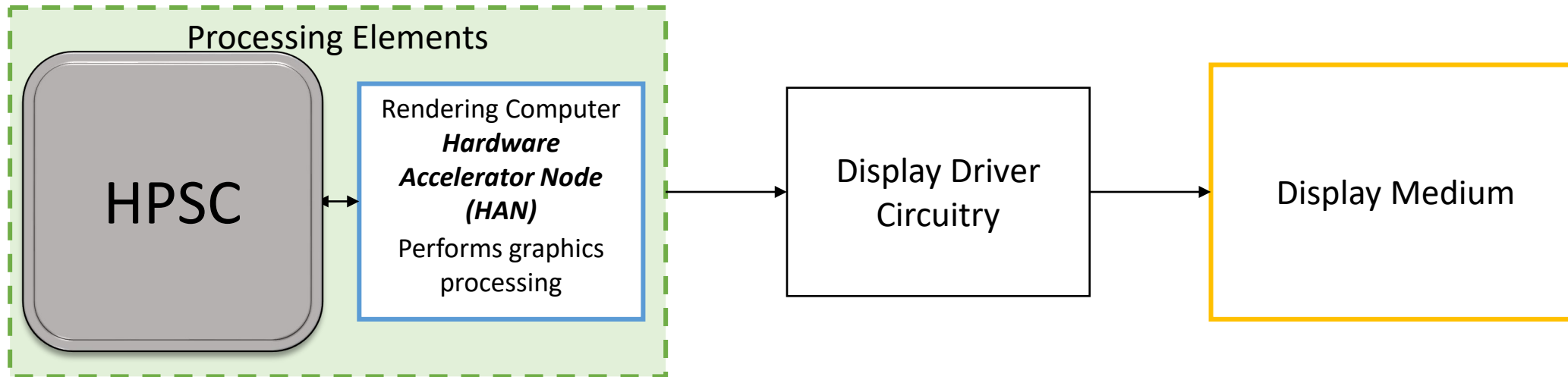
Decodes and translates frame data into control instructions of the physical display

The physical display stack up

System Block Diagram



Project Scope



Processing Elements Options – HPSC (+ Hardware Accelerator Node)

Processing Elements – Option 1

Main Computer/ Rendering Computer
HPSC

- Facilitates tasks
- Performs Graphics Rendering

Processing Elements – Option 2

Main Computer
HPSC

Facilitates tasks

Rendering Computer
HPSC

Performs graphics processing

Processing Elements – Option 3

Main Computer
HPSC

- Facilitates tasks
- Rendering Tasks

Rendering Computer
Discrete GPU

Performs graphics processing

Processing Elements – Option 4

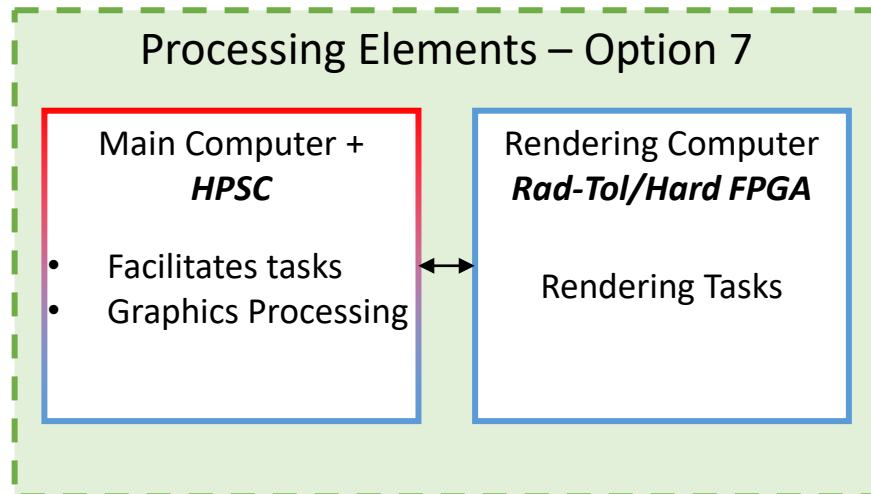
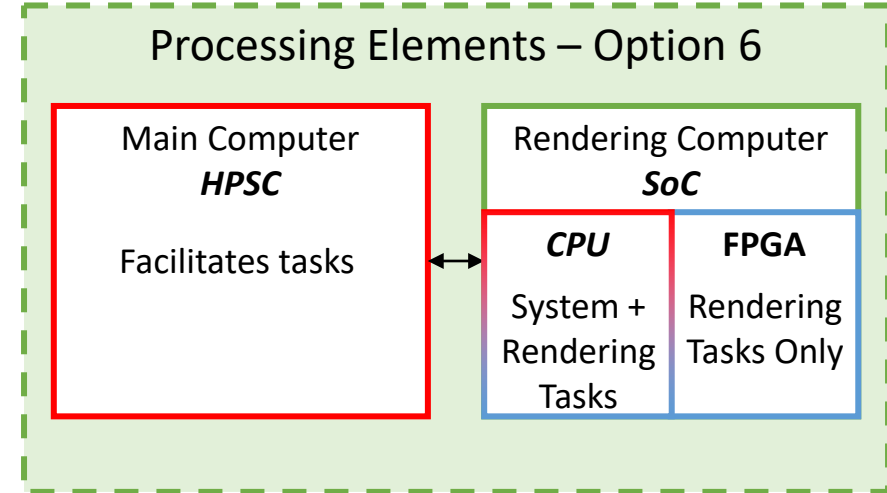
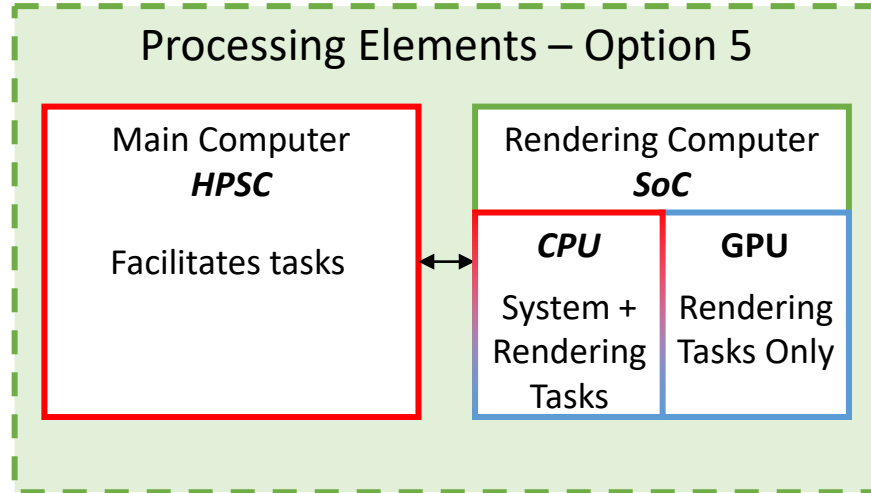
Main Computer
HPSC

- Facilitates tasks
- Rendering Tasks

Rendering Computer
Rad-Tol/Hard FPGA

Performs graphics processing

Processing Elements Options – HPSC (+ Hardware Accelerator Node [SoC])



Radiation Effects

- 1 = All COTS
- 2 = Rad-hard + COTS limited mitigation
- 3 = Rad-hard + COTS w/ mitigation
- 4 = All rad-hard by design

Computational Needs

- 1 = Single device – no acceleration
- 2 = CPU + very little acceleration
- 3 = Main facilitates + some acceleration
- 4 = Main facilitates + graphics acceleration

Scalability

- 1 = Main part of rendering + High SWaP
- 2 = Main part of rendering + low SWaP
- 3 = Dedicated facilitator + Full HAN rendering + high SWaP
- 4 = Dedicated facilitator + Full HAN rendering + low SWaP

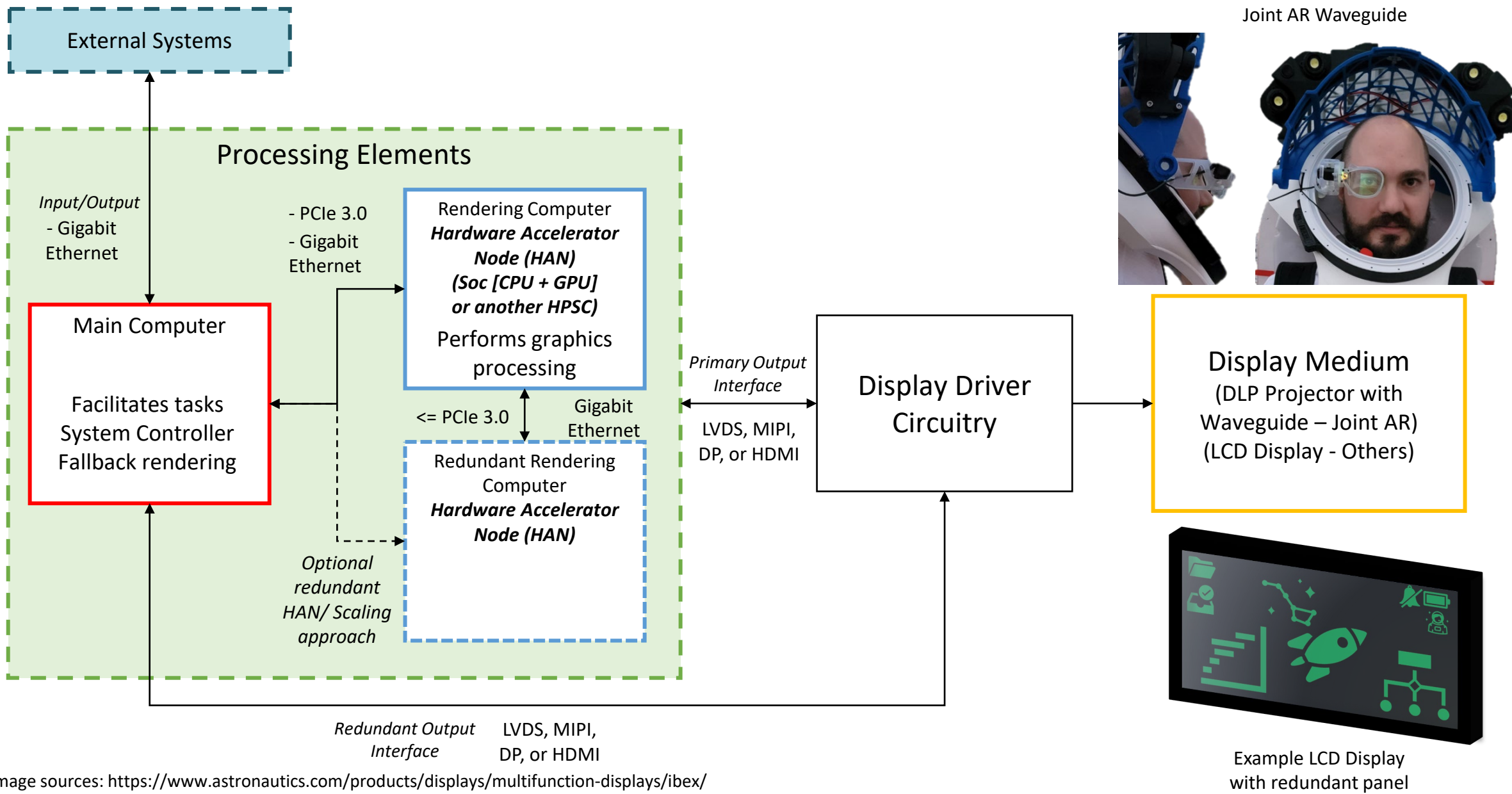
Radiation Effects

Computational Needs

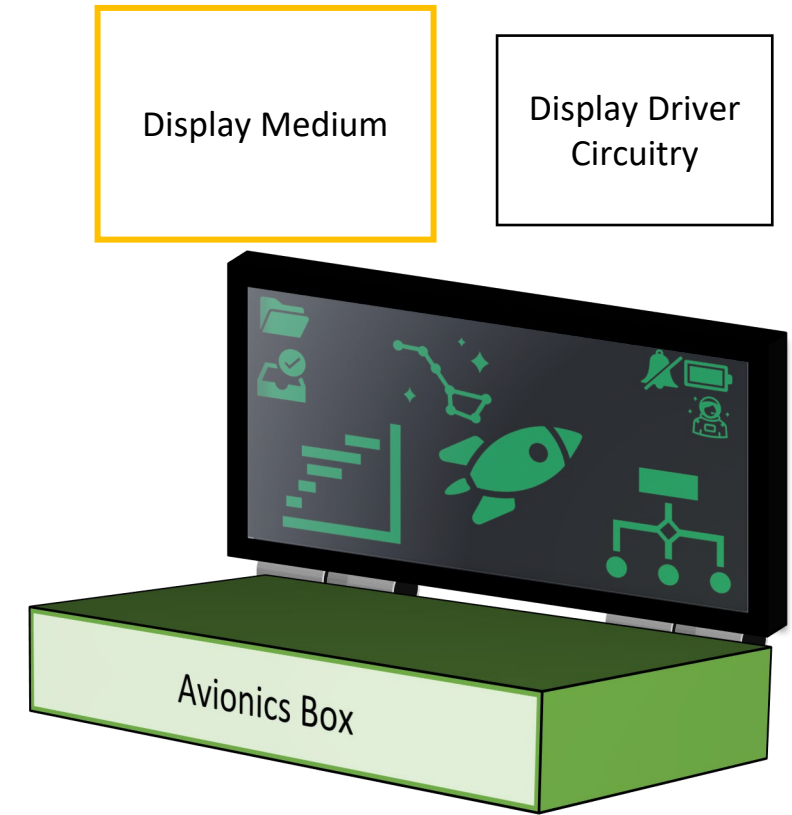
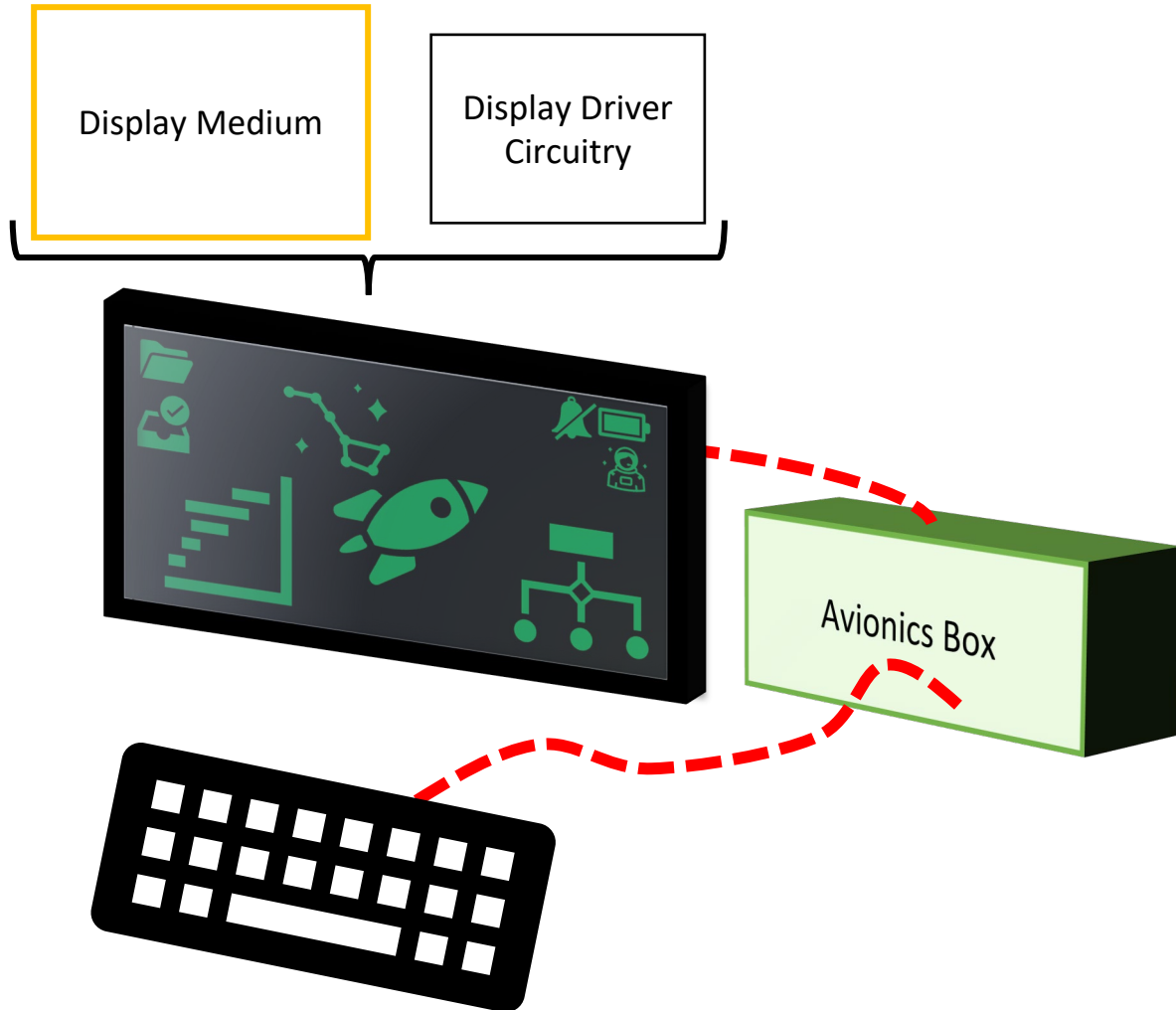
Scalability

Configuration	Main	Rendering				Total
Option 1	HPSC		4	1	2	7
Option 2	HPSC (1)	HPSC (2)	4	2	3	9
Option 3	HPSC	Discrete GPU	2	4	3	9
Option 4	HPSC	Rad-Tol/Hard FPGA	3/4	3	3	9/10
Option 5	HPSC	SoC (CPU + GPU)	3	4	4	11
Option 6	HPSC	SoC (CPU + FPGA)	2	3	3	8
Option 7	HPSC (1)	HPSC (1) + Rad-Tol/Hard FPGA	3/4	2	3	8/9

Hardware Architecture – System Block Diagram



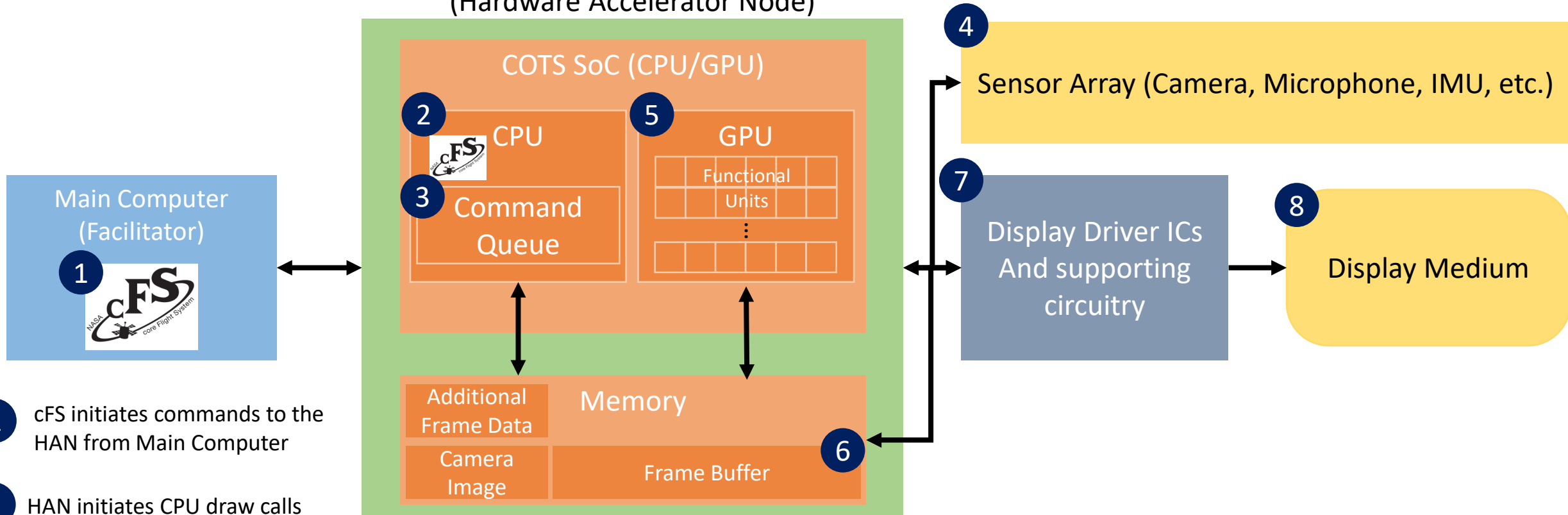
Radiation-Tolerant Portable Crew Interface



Con-Ops

NASA Radiation-Tolerant Display Prototype

HAN
(Hardware Accelerator Node)



1 cFS initiates commands to the HAN from Main Computer

2 HAN initiates CPU draw calls

3 Commands are enqueued to process frame data

4 Sensor data captured

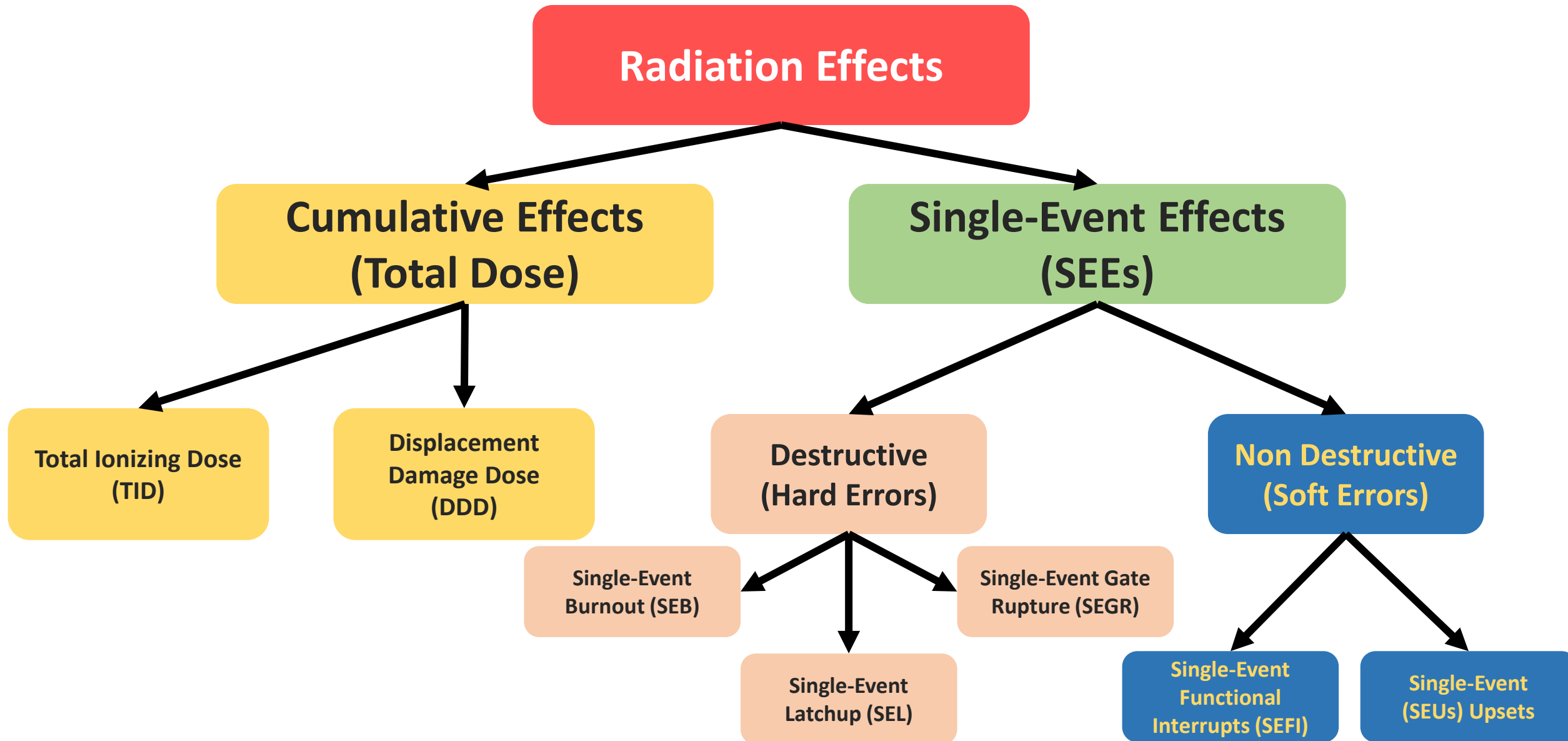
5 GPU accelerates shader calculations

6 Result stored in Frame Buffer

7 Frame data encoded and transmitted to Display Drive ICs

8 Final Image Rendered and Displayed on Screen

Radiation Effects & Fault-Mitigation Strategies



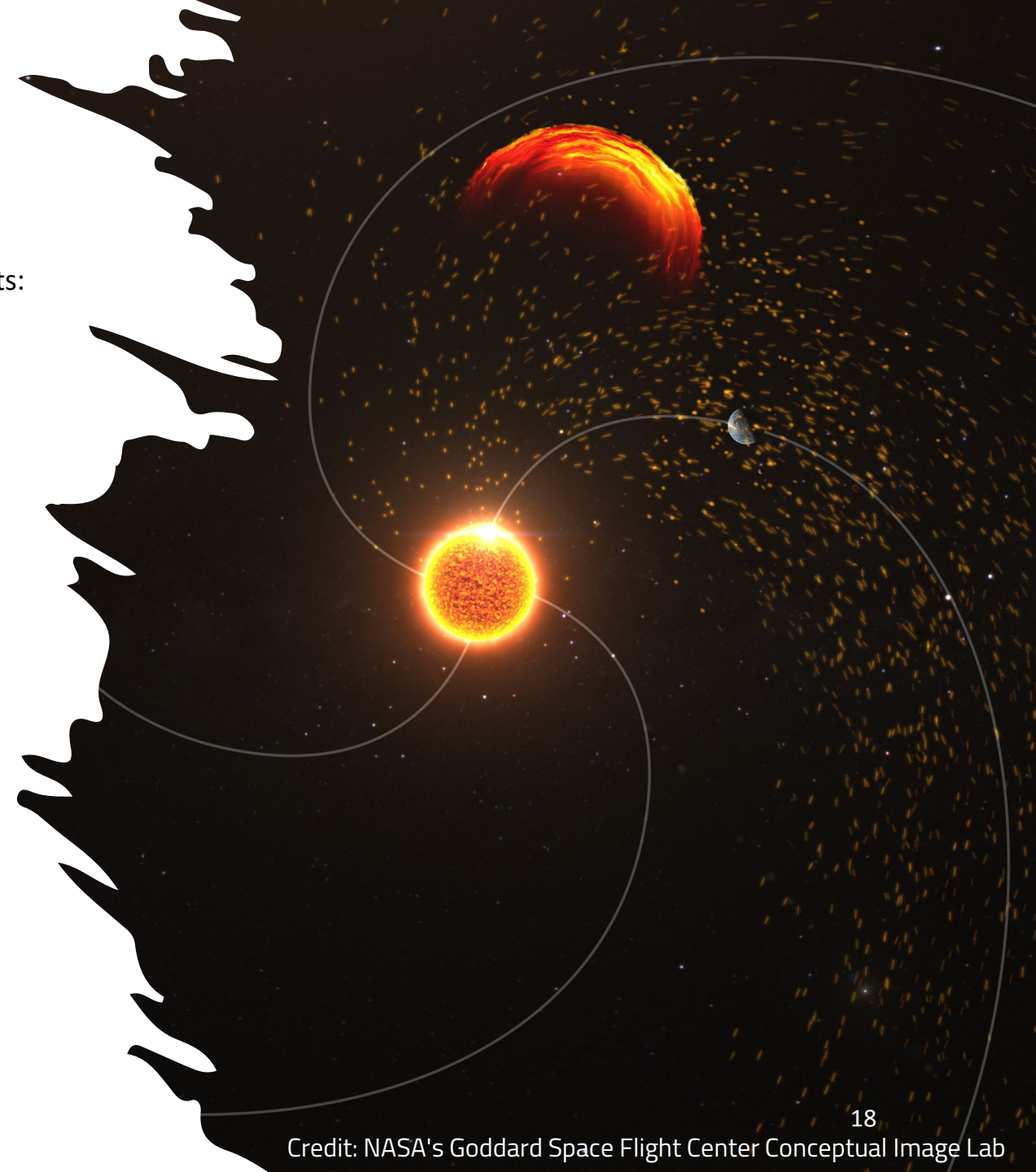
Radiation Effects

Rad-Tolerant Display System needs to consider radiation effects on multiple fronts:

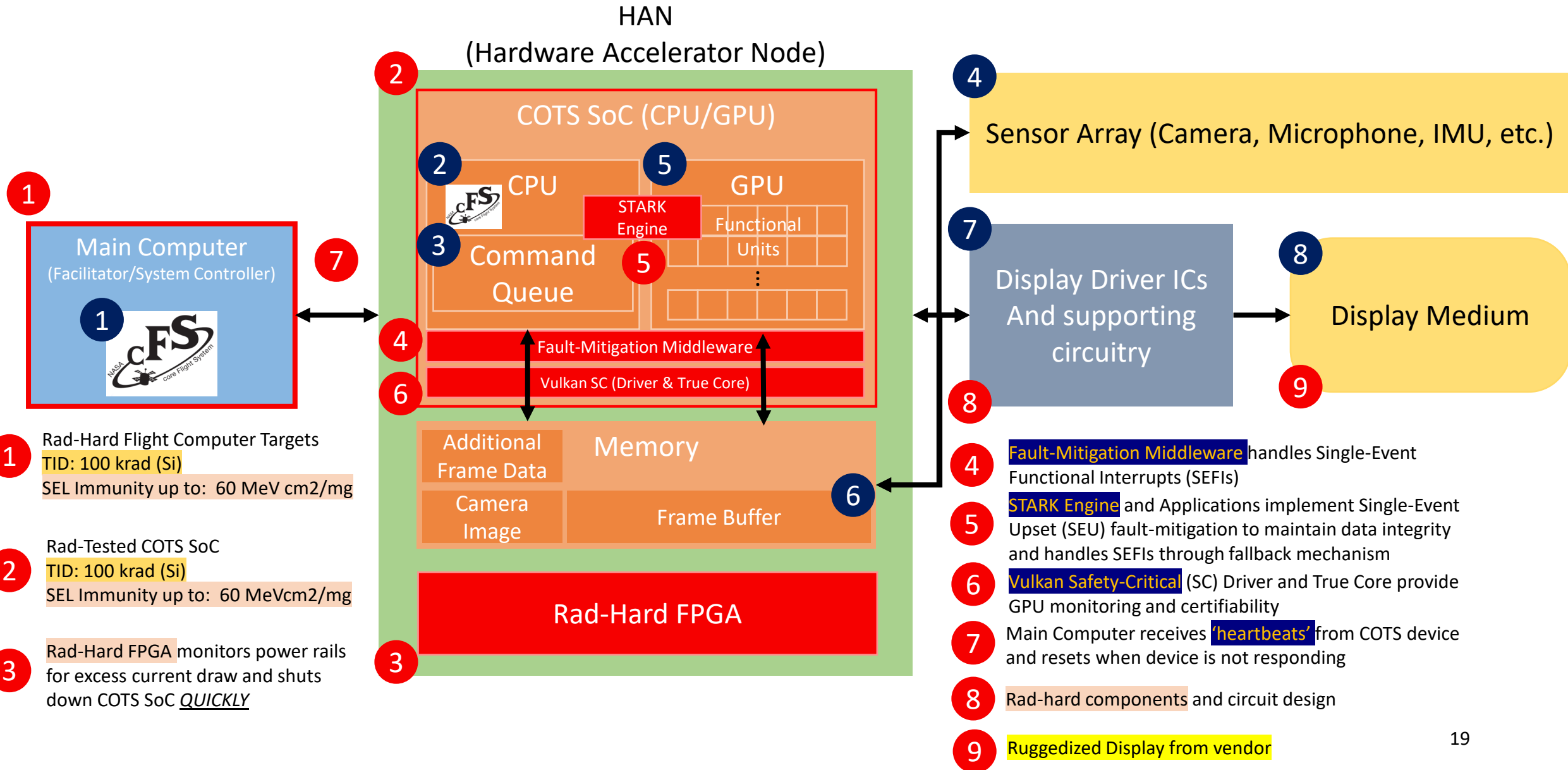
- **Total Ionizing Dose:** Up to n rad
 - Depends on:
 - Environment
 - Material
 - Time dependent
- **Destructive Single-Event Effects (DSEEs) Immunity**
 - Linear Energy Transfer = LET
 - Units: Energy loss per unit path length / material density
- **Single-Event Upset (SEU) Mitigation Strategies**
 - System Availability
 - Are reboots okay?
 - Data reliability

Summary of requirements:

1. Total Dose (Cumulative Effects)
 - Target: **100 krad**
2. Single-Event Effects
 - Target: **LET ≥ 60 MeV-cm²/mg**

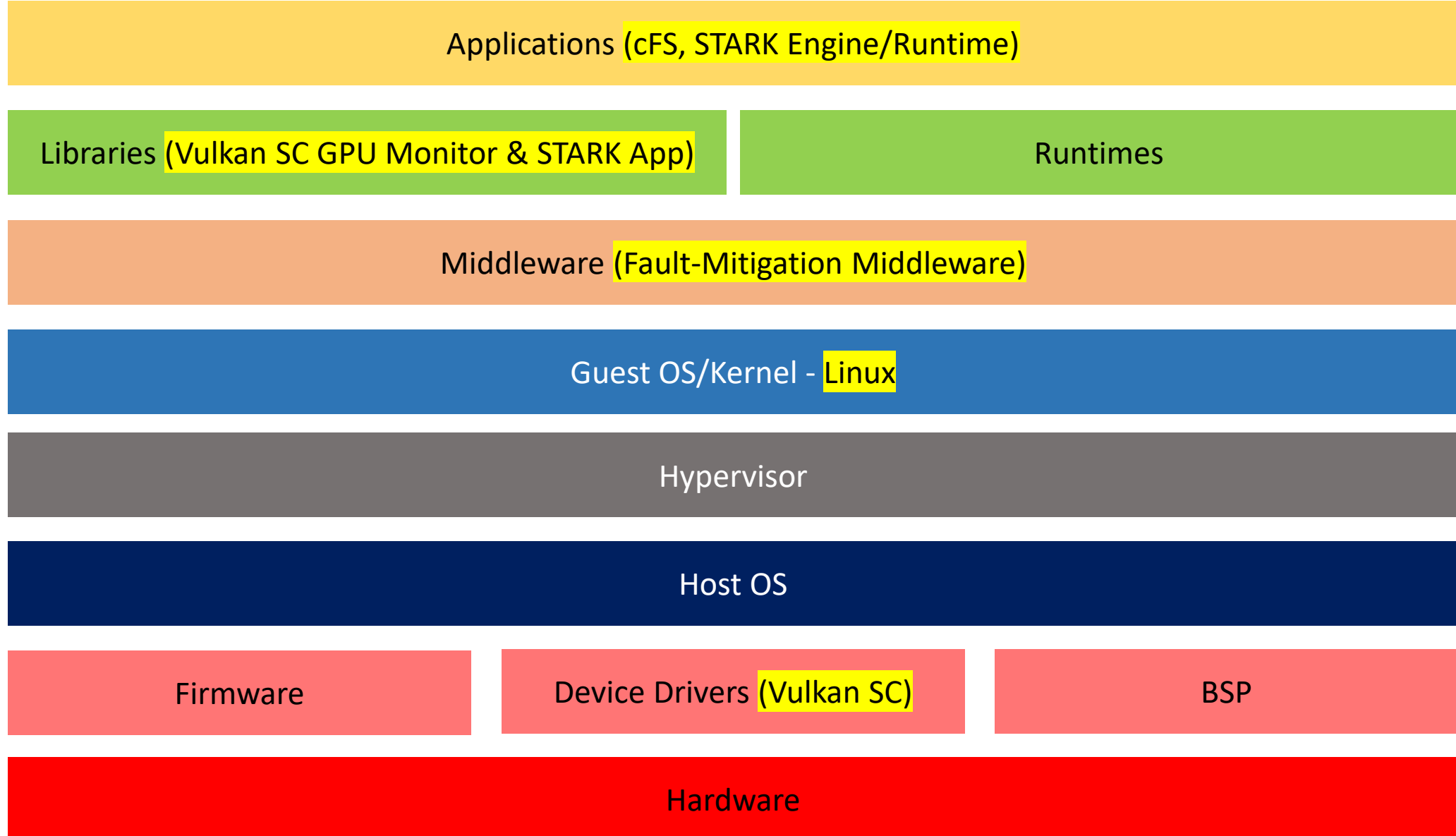


NASA Radiation-Tolerant Display Prototype



Software

Software Stack – Enhanced SW Stack for Reliable Graphics Rendering

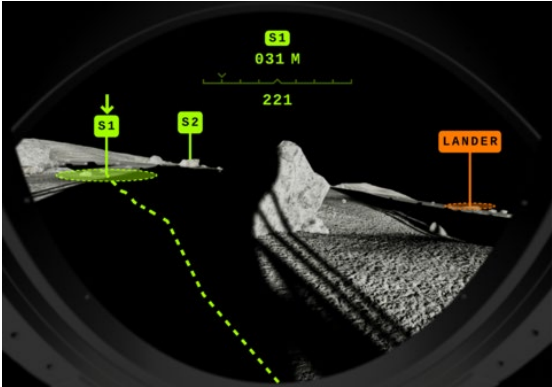


STARK - *Space Technology Application Rendering Kit*

- Goal: Targeting many fault-mitigation strategies
 1. Fallback mechanism for CPU rendering
 2. Fault-Tolerant Computer Shaders
 3. Reinforced graphics pipeline
 4. Redundant texture data
 5. & More
- Shader = Small GPU program; Can be graphics or compute
- stkDNN/stkBLAS – Fault-Tolerant Computer Shaders libraries
 - Similar to cuDNN/cuBLAS
 - Can be used for dependable hardware acceleration of ML models
 - Leverage GPUs many threads to provide thread-level redundancy
 - Thread-level synchronization achieved via Vulkan subgroup voting

	OpenGL	CUDA	OpenCL	Vulkan
Graphics Processing	X	-	-	X
Cross-Platform	X	-	X	X
General Purpose Compute	-	X	X	X
Driver with More Direct GPU Control	-	-	-	X

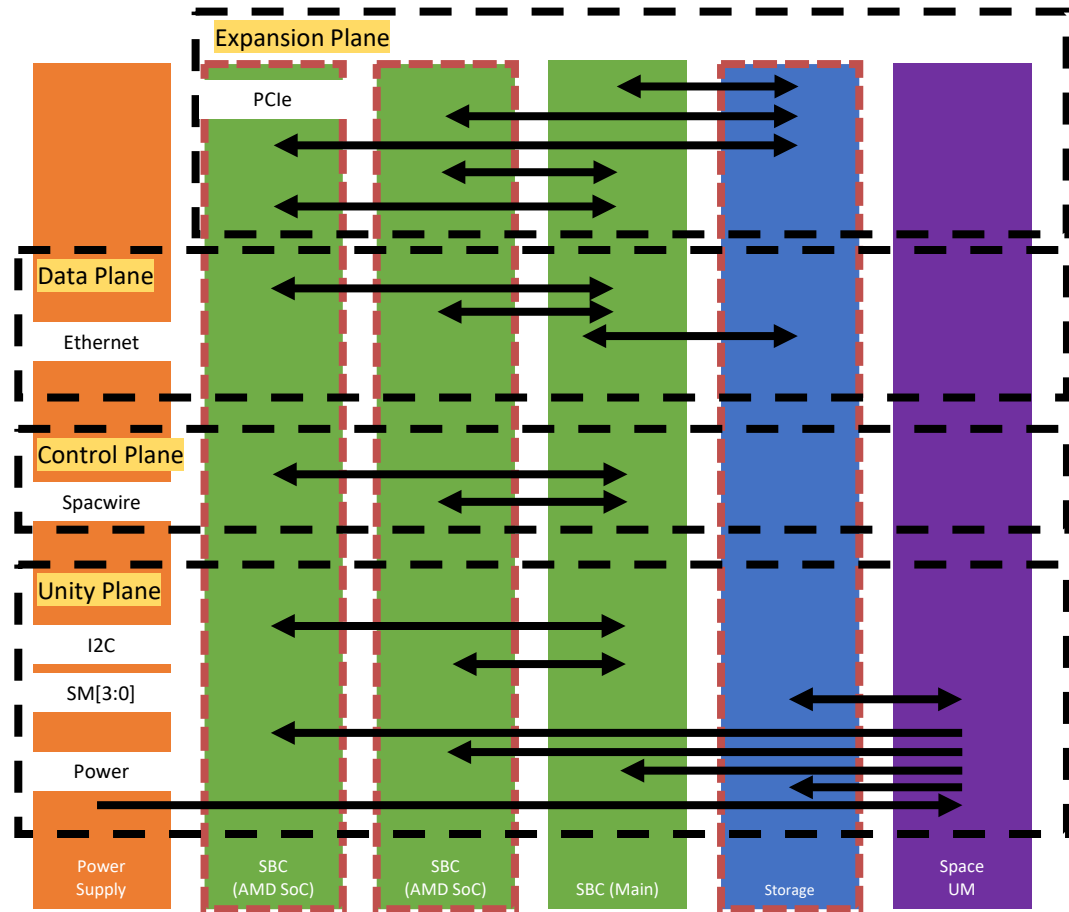
Example 2D UI



Example 3D UI – VR Overlay

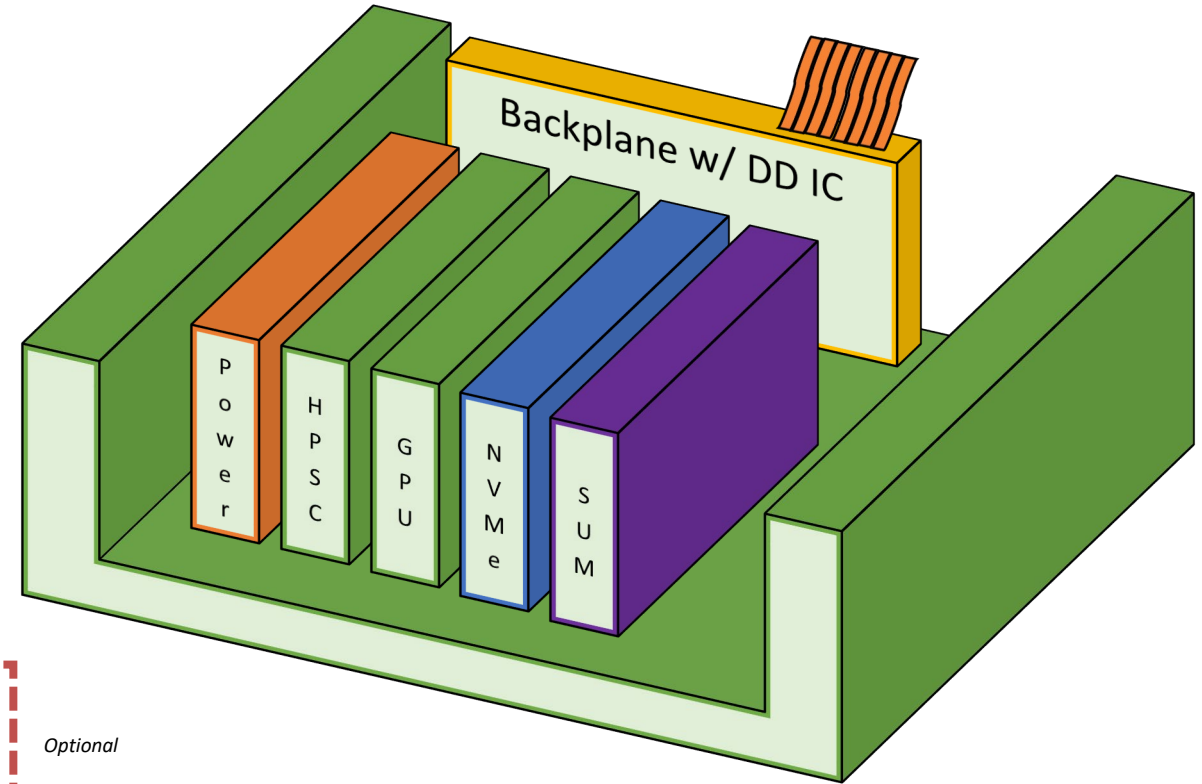
Avionics

Proposed Avionics Box

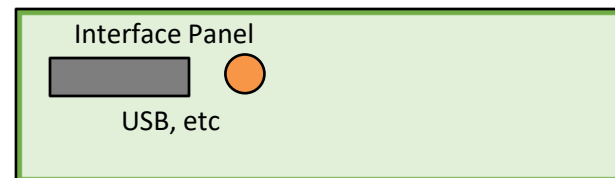


SpaceVPX 3U Single-String Display System Avionics

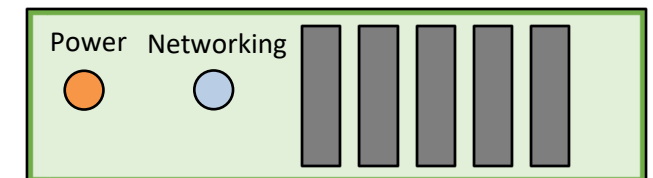
SpaceVPX Compliant Avionics Box



Front

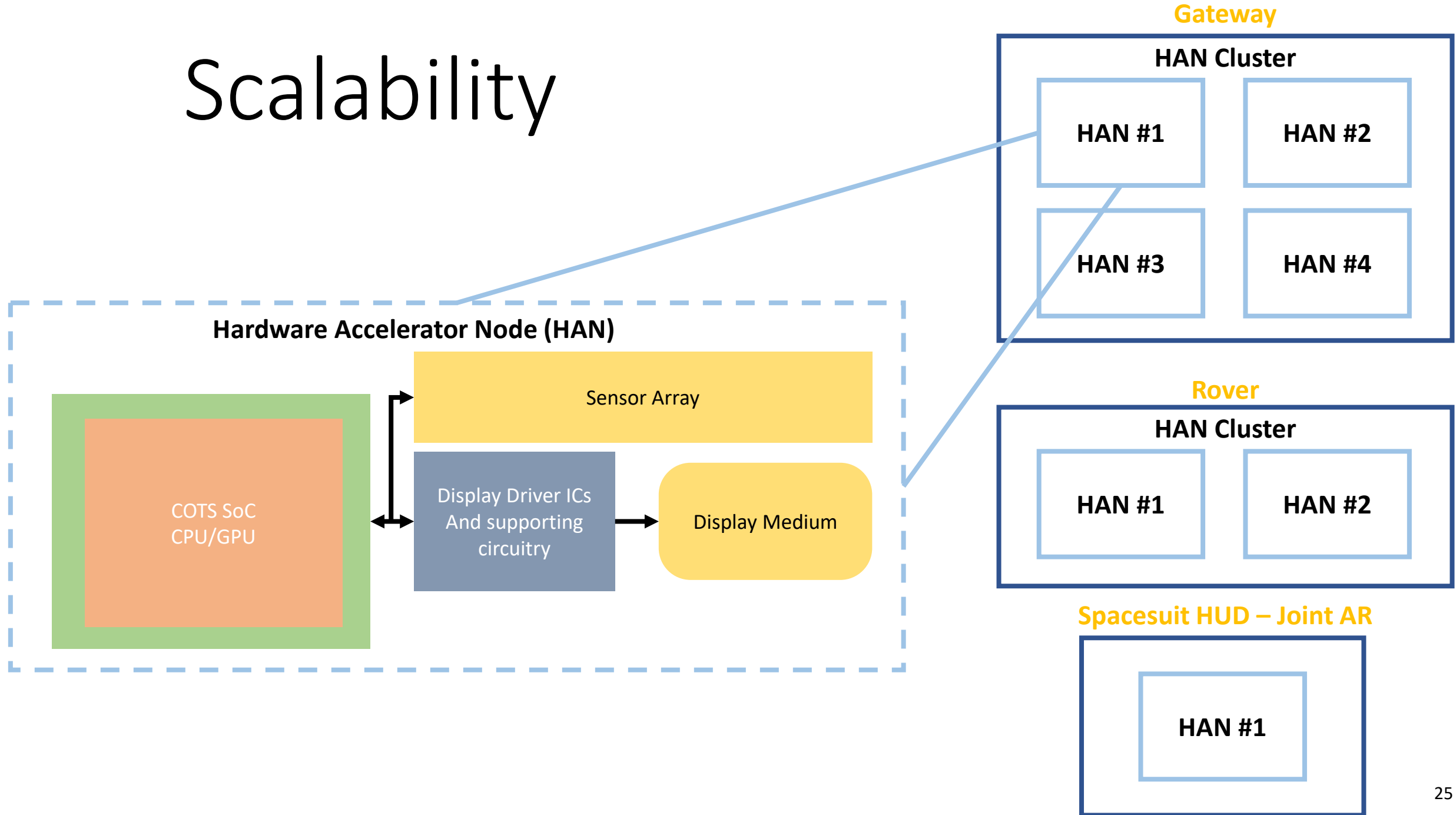


Rear



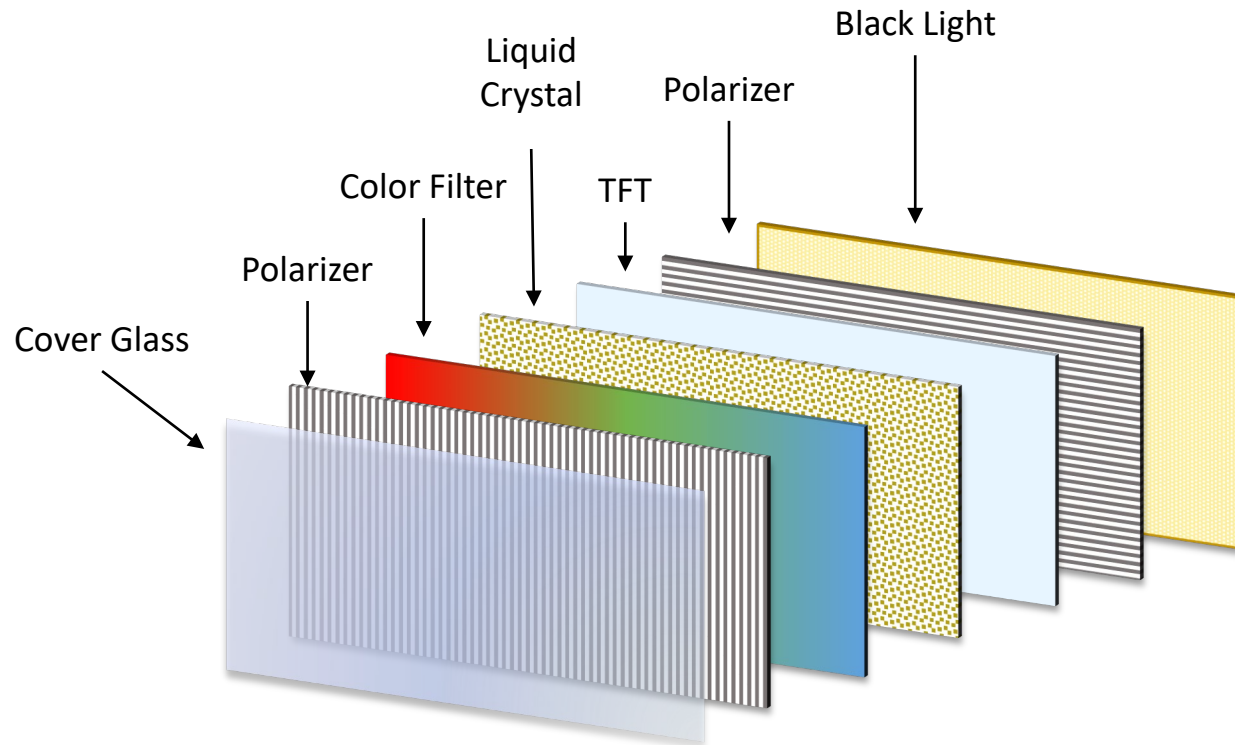
Module Access Panels

Scalability

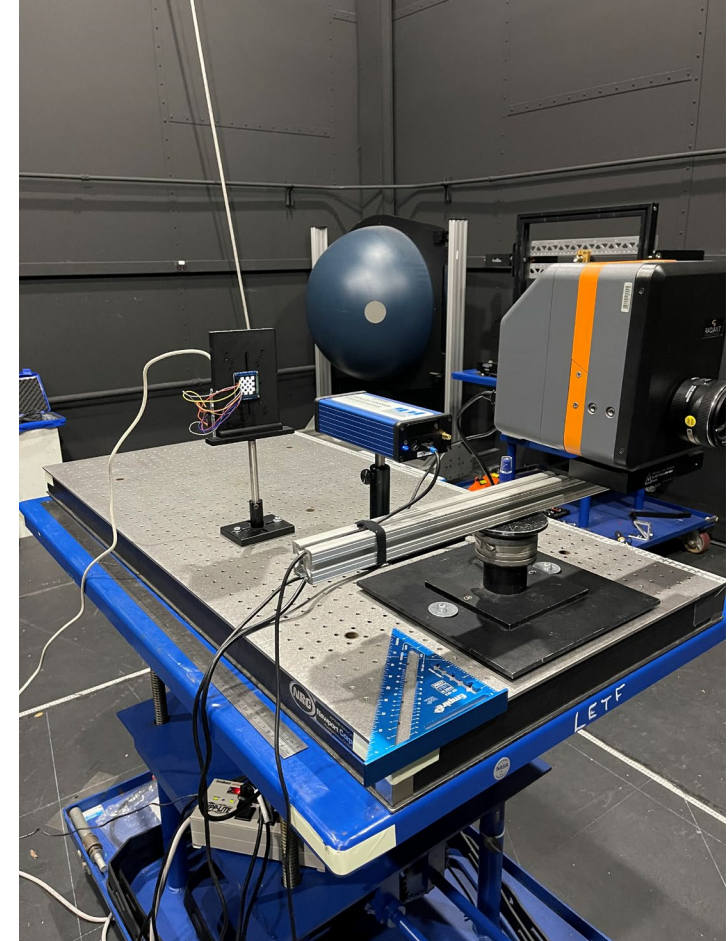


Display Medium

Example Display Stack up (LCD)



Post-Radiation Test Measurements



- NASA has identified Radiation-Tolerant Displays as a significant technology gap for near- and long-term crewed missions
- **Today**, we present a path towards a Radiation-Tolerant Display System through three design corner stones:
 1. Computational Needs
 2. Radiation Tolerance
 3. Scalability
- **Goal and Next Steps**: Work with industry partners to develop, test, validate, and deploy a Radiation-Tolerant Display System



Questions?