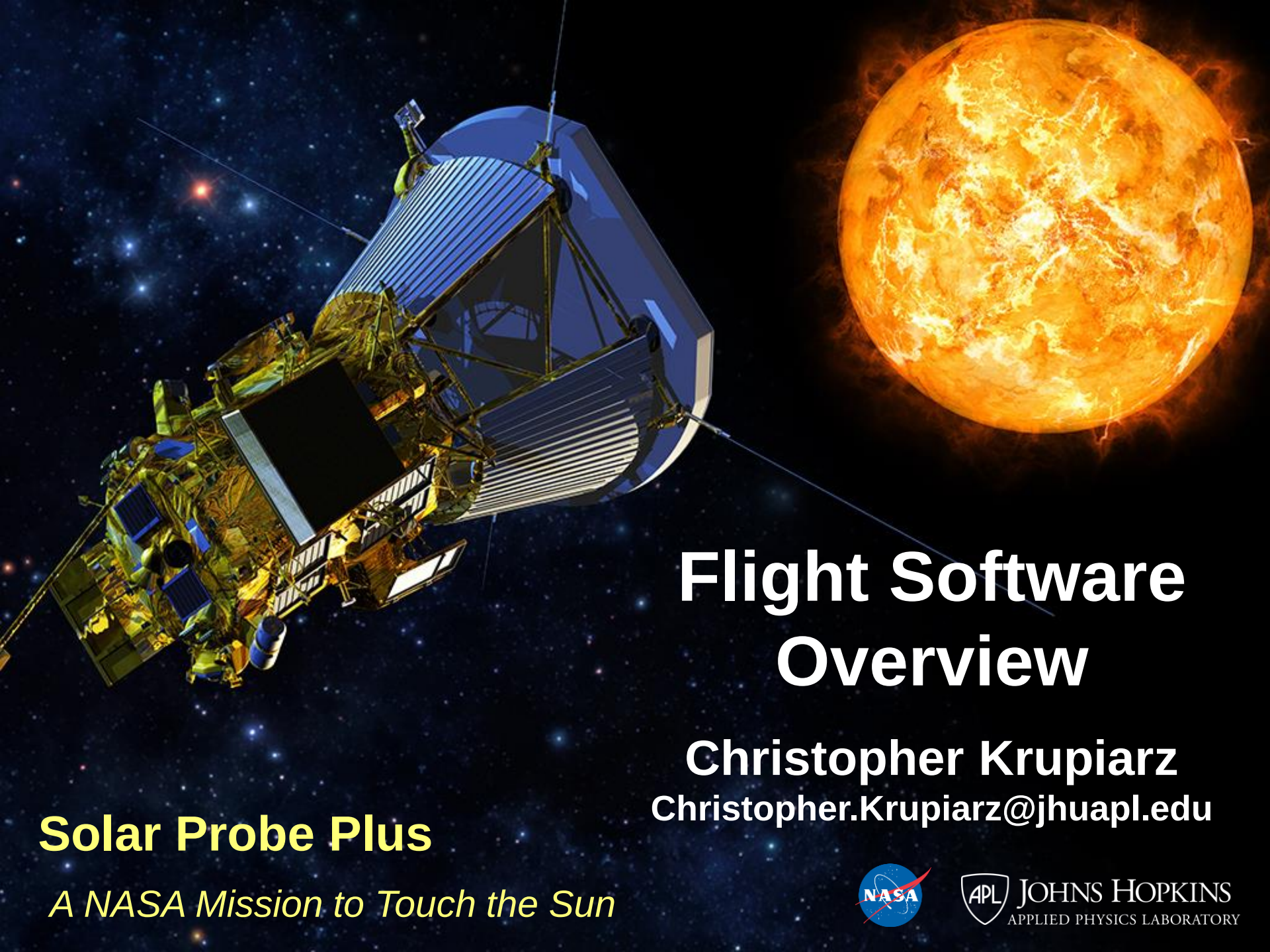

Flight Software Overview

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Solar Probe Plus

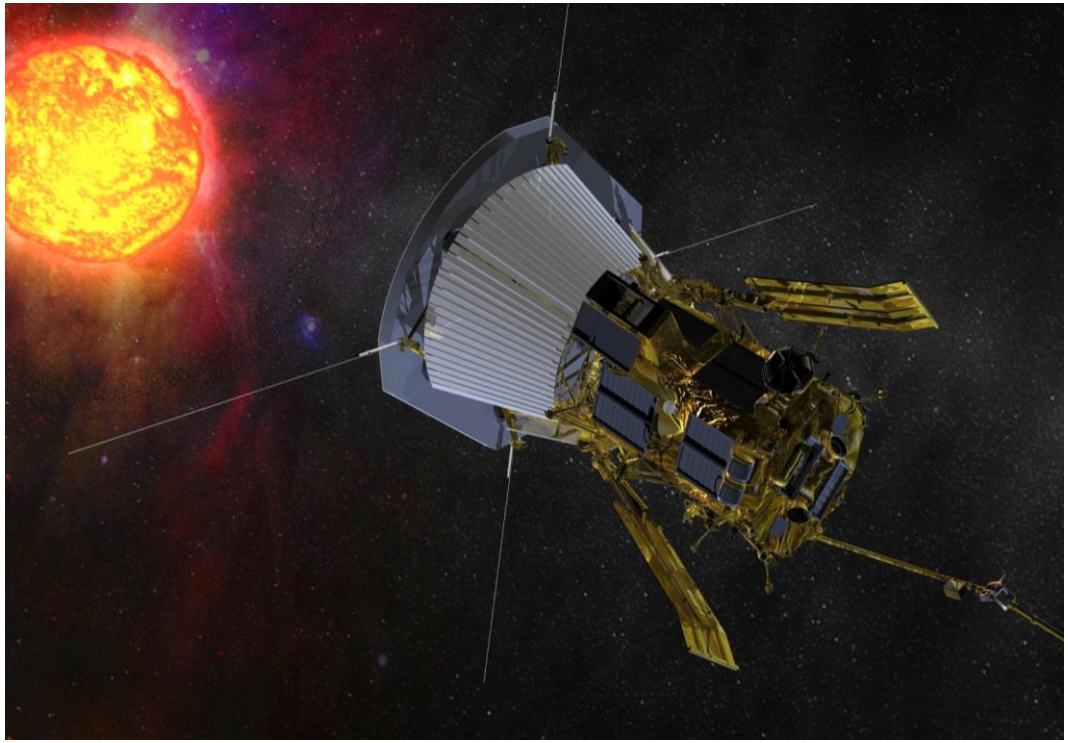
A NASA Mission to Touch the Sun

NASA

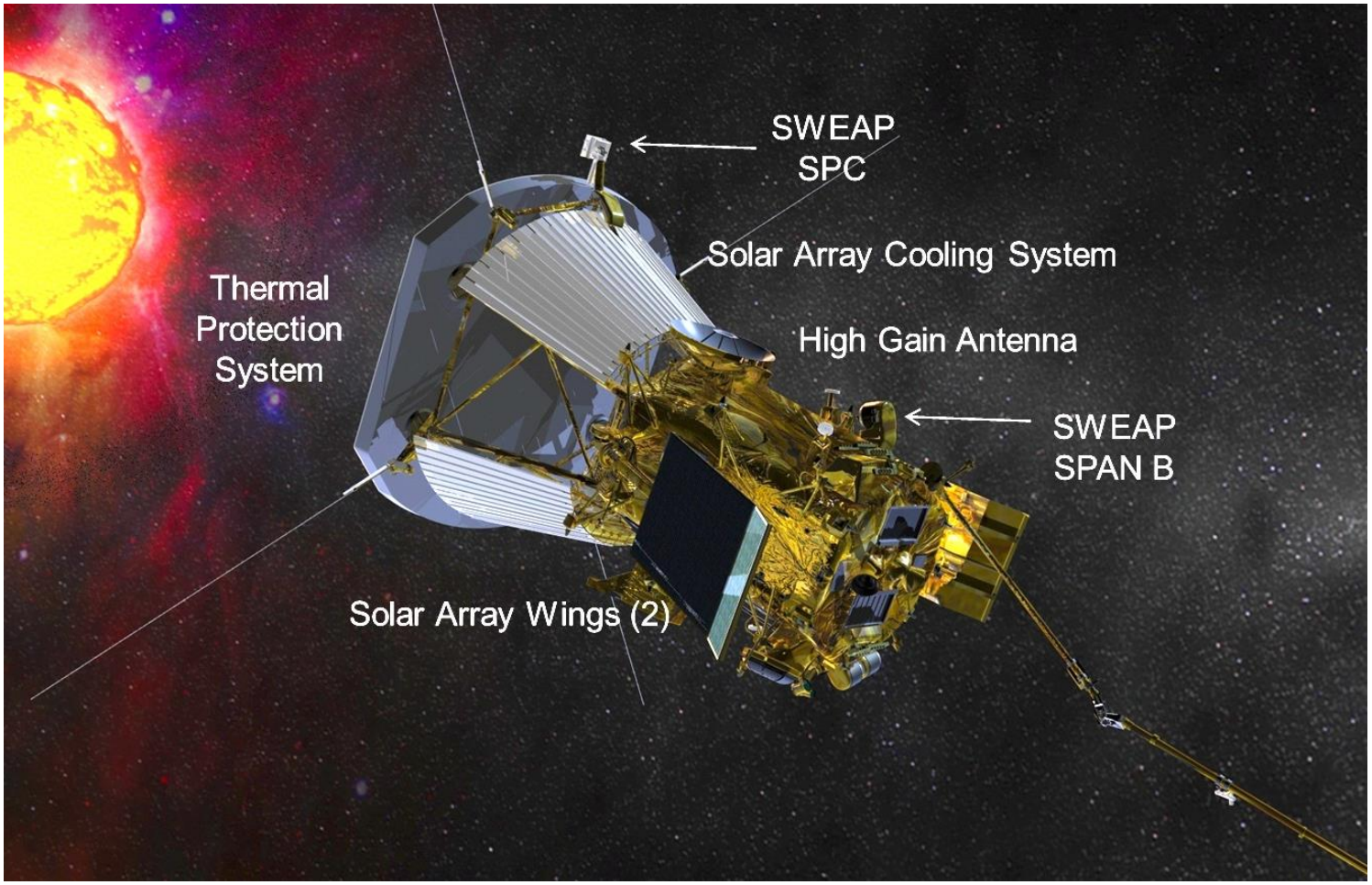
APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Overarching Science Objective

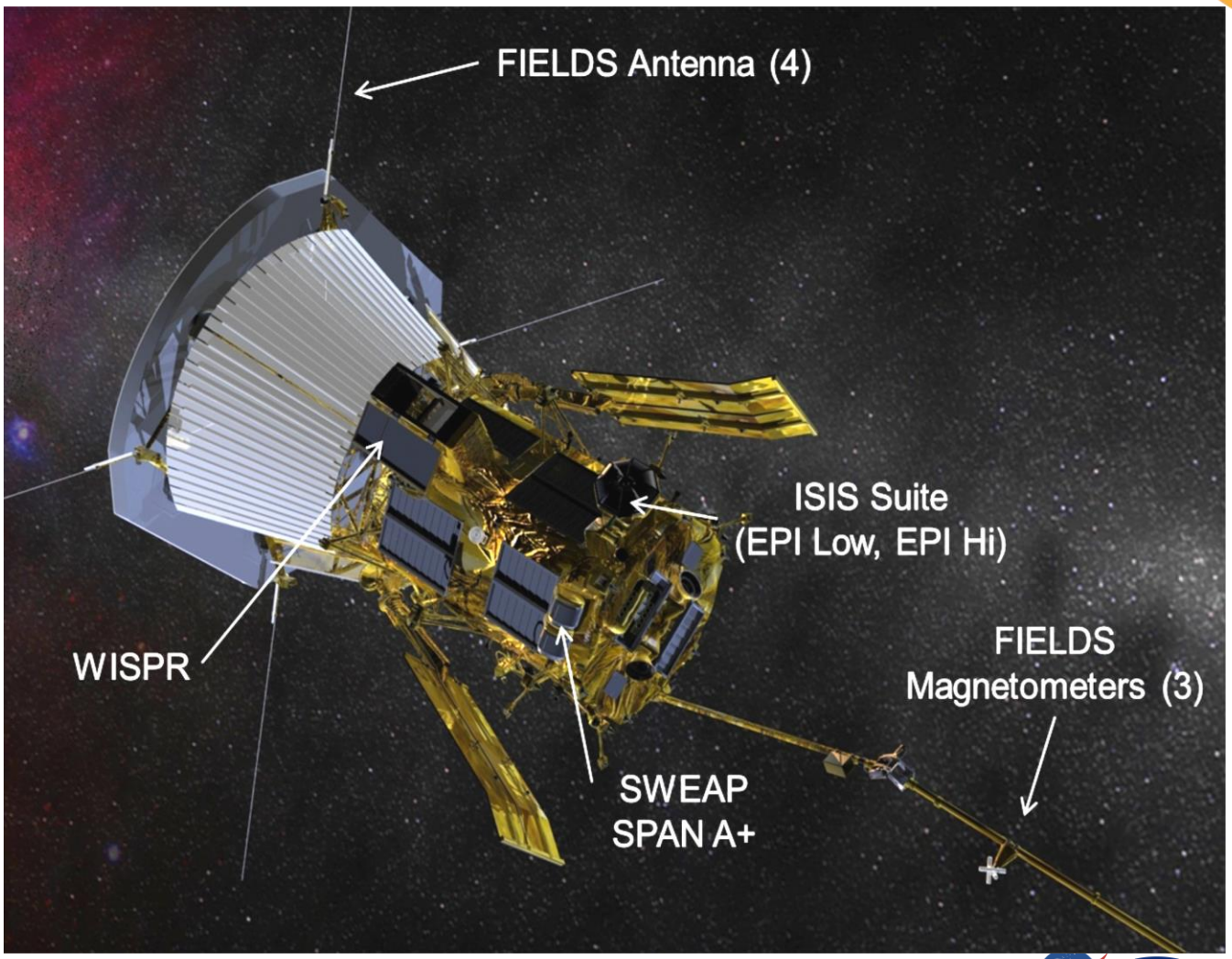
- To determine the structure and dynamics of the Sun's coronal magnetic field, understand how the solar corona and wind are heated and accelerated, and determine what mechanisms accelerate and transport energetic particles.



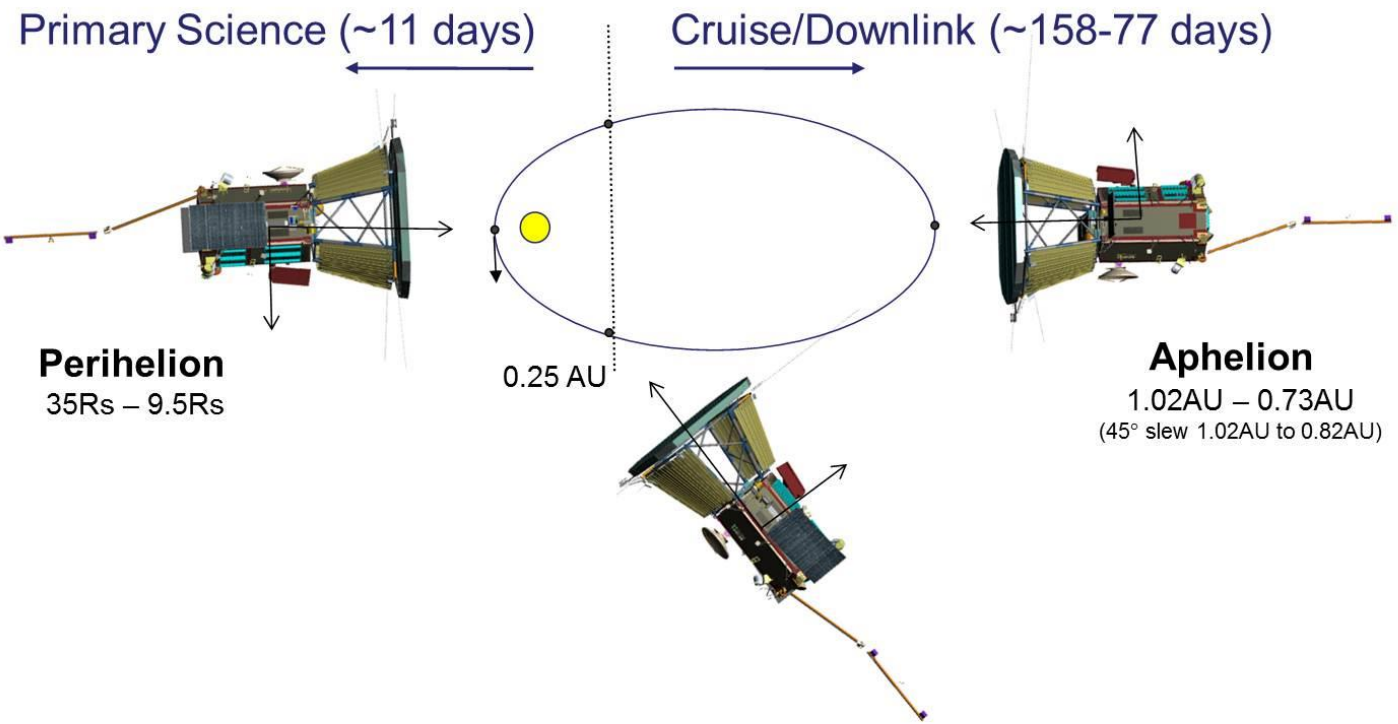
Observatory: Anti-Ram Facing View



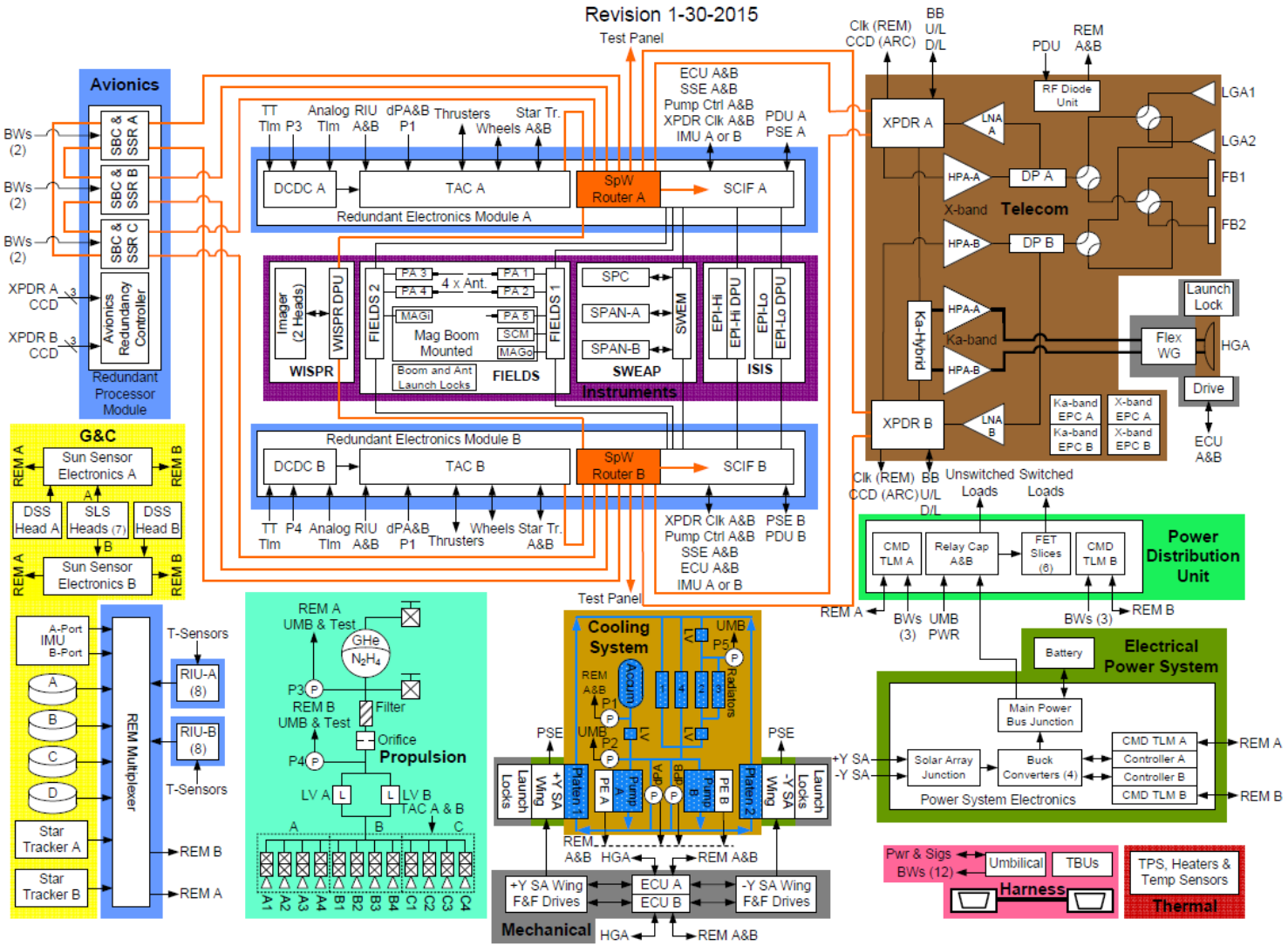
Observatory: Ram Facing View



High Level Concept of Operations



Block Diagram



FSW Design
Hardware Environment

- **APL Developed Single Board Computer (x3):**
  - **UT699E LEON3FT (Sparc V8 architecture) 80MHz from Cobham Colorado Springs**
  - **32 MB SRAM with EDAC**
  - **8 MB of MRAM (Non-Volatile Memory) 6.4 MB usable**
    - **3.2 MB per logical bank**
  - **FPGA facilitates NVM image verification during boot**
  - **Boot loader executes out of NVM**
  - **256Gbits (32GBytes) NAND Flash Bulk Memory (SSR) on processor board**
    - **Memory mapped I/O**
  - **SBC interfaces**
    - **UARTs to Avionics Redundancy Controller (ARC)**
    - **SpaceWire to spacecraft and instrument subsystems as well as other single board computers**

Flight Software Driving Requirements (1 of 2)

- Manage software operations on three processors
- Uplink command data files using CFDP
  - Provide additional uplink in BD mode
- Management of files on the SSR (256Gbit)
- Allow for reset in sufficient time for Solar Array Safing
- Retention of critical spacecraft information through processor resets
- Communicate to spacecraft elements external to computer
  - SpaceWire transactions
- Boot time

Flight Software Driving Requirements (2 of 2)

- Operate a 3-axis stabilized spacecraft
- Uplink data range of 7.125bps to 2Kbps
- Downlink frames at rates from 10bps up to 1Mbps
- Downlink recorded data files using CFDP
- Distribution of time and status
- Manage spacecraft time tagged commands
- Collect instrument data
- Manage spacecraft subsystem commands and collect spacecraft housekeeping data
- Record and downlink spacecraft housekeeping and instrument data
- Support fault protection & limited autonomous instrument safing

FSW Design
FSW Functionality (1 of 2)

- **Boot**
  - Simple boot loader; no commanding/telemetry
- **Command and Data Handling (C&DH)**
  - Command management
    - Uplink: receive transfer frames from transponder
    - Commands: real-time, macros, time tags, autonomy
    - Packets extracted and distributed locally or to a S/C subsystem
  - Telemetry
    - Receive telemetry from subsystems/individual applications
  - SSR management
    - Record/playback spacecraft and instrument data to/from a file system

FSW Design
FSW Functionality (2 of 2)

- **Command and Data Handling (C&DH) (Continued)**
  - **Autonomy**
    - **Autonomous fault detection and safing/switchover on Prime**
  - **Software management**
    - **Memory object loading, CPU utilization, etc.**
- **Guidance and Control (G&C)**
  - **G&C sensor interface management, Three-axis control, momentum maintenance**
  - **Cruise phase & thruster control, 50 Hz attitude control, 1 Hz attitude estimation**

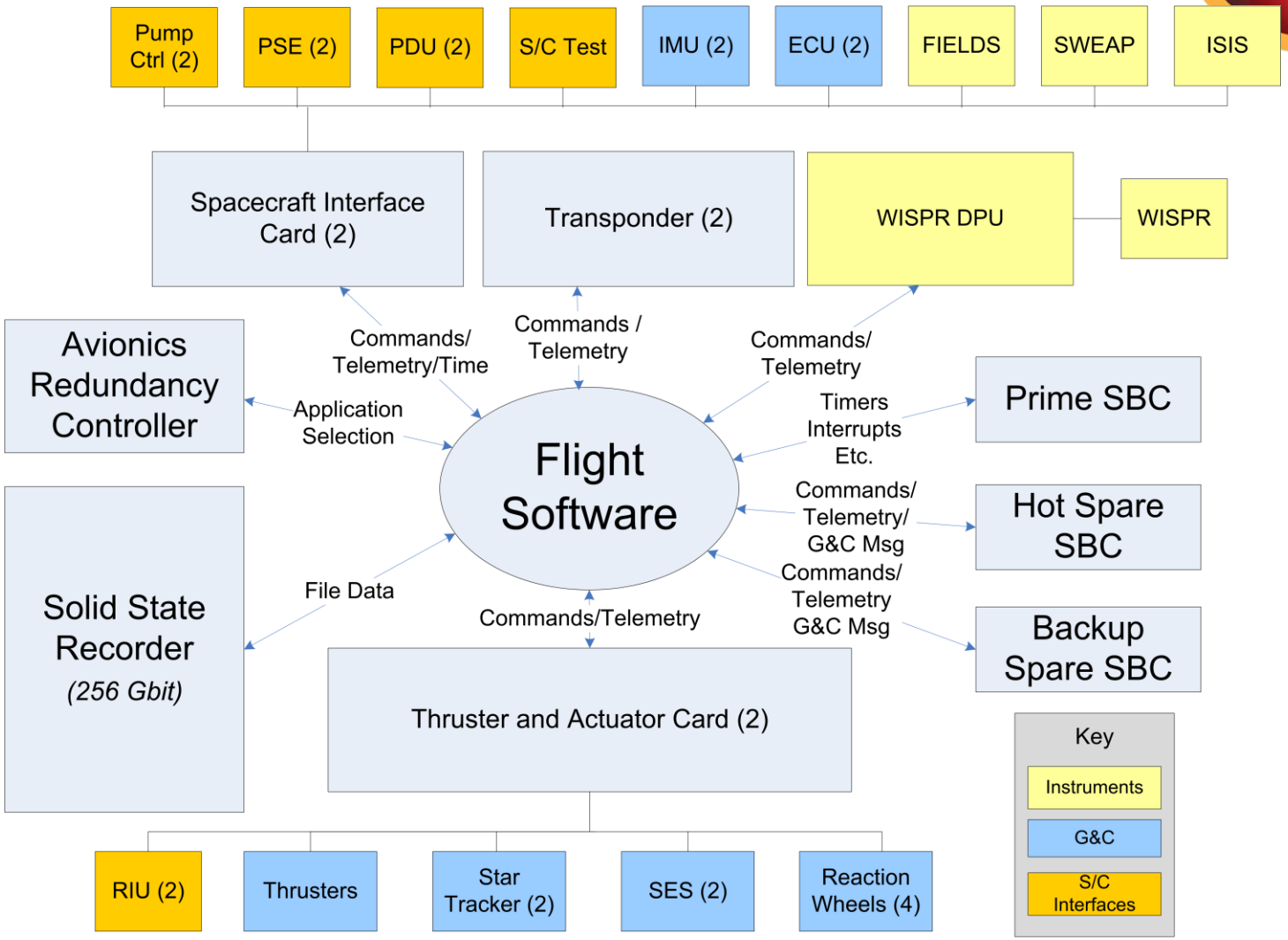
FSW Design
Software on Three Processors

- **Prime, Hot Spare, Backup Spare are all running the same software**
  - **Applications are controlled by Scheduler messages**
    - **Messages drive degree of application functionality**
  - **Some applications have knowledge of SBC logical state**
  - **Reduce power consumption and processor loading**

- **Prime sends Hot Spare (and Backup Spare during encounter) a status message at 1 Hz**
  - **Data includes:**
    - **Current spacecraft configuration**
    - **Raw star tracker data**
    - **Current time data**
    - **Current accumulated SA flap & feather and HGA step counts**
    - **Current spacecraft FM mode(s)**
    - **Safe Mode – Solar Array entry time**
  - **G&C code on spare will verify raw star tracker data**

- **Hot Spare promoted to Prime on Prime demotion**
  - **G&C primed via previously received message**
  - **Scheduler sends full compliment of messages to applications**

FSW Design
FSW Context Diagram (Prime)



JHU/APL Flight Software

- **1990s/Early 2000s**
  - **NEAR/ACE/TIMED**
    - **Even now, some of our code dates back this era**

- **2000s**
  - **MESSENGER/New Horizons/STEREO**
    - **Modify Last Mission**

JHU/APL Flight Software

- **2000s**
  - **Can we make the code more modular?**
    - **IRAD to make that happen**
  - **Radiation Belt Storm Probes**
    - **Fleshed out many capabilities of using NASA/GSFC Core Flight Executive (cFE)**
    - **Collaboration with NASA/MSFC**
  - **Radiation Belt Storm Probes (Van Allen Probes)**
    - **First full mission adaptation of cFE**
    - **Evolved into Core FSW**
  - **Solar Probe Plus**
    - **First reuse of Core FSW on major mission**

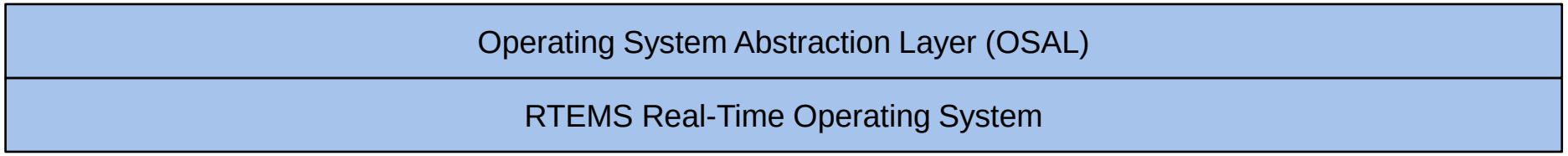
FSW Design
Software Layers (1 of 4)

- **Operating System**
  - **Real-Time Executive for Multiprocessor Systems (RTEMS) with support from OAR Corporation**
  - **Build tools and RTEMS distribution from Cobham Gaisler**

RTEMS Real-Time Operating System

FSW Design
Software Layers (2 of 4)

- **Operation System Abstraction Layer (OSAL)**
  - **Provided by NASA/GSFC**
  - **Enables easy porting of applications that ran over VxWorks on the Van Allen Probes**



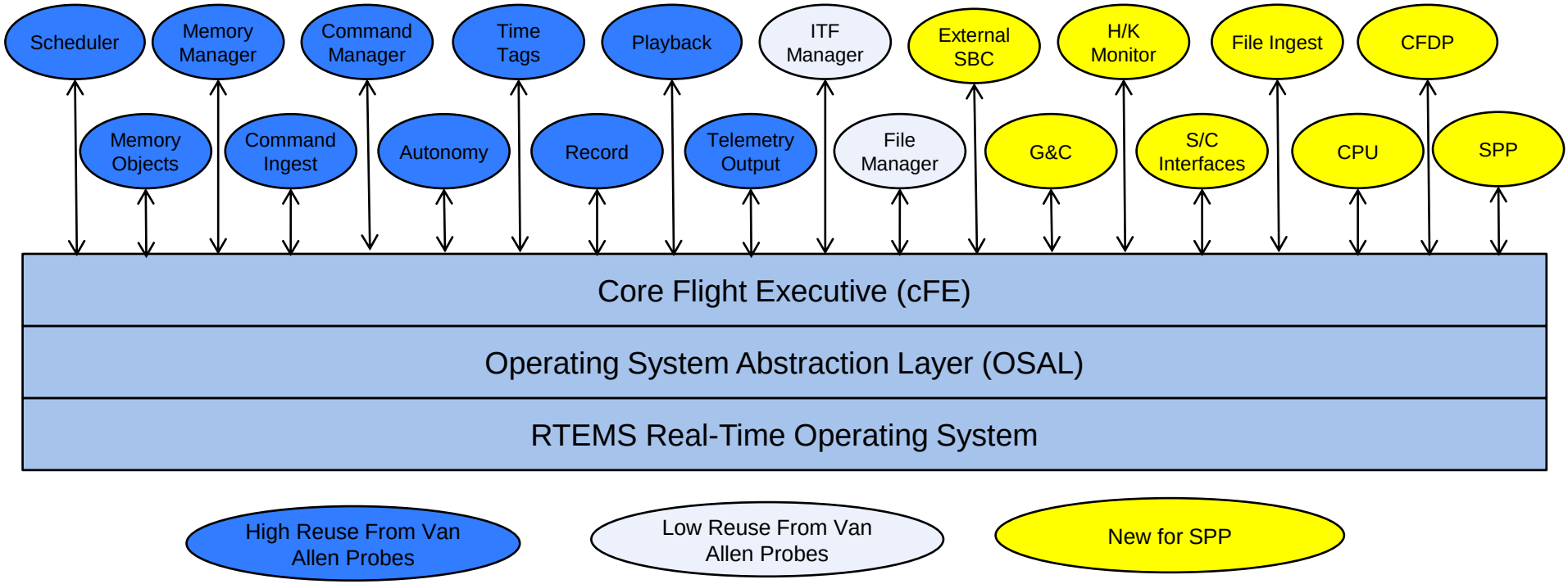
FSW Design
Software Layers (3 of 4)

- **NASA GSFC Core Flight Executive (cFE) middleware**
  - **Provided by NASA/GSFC**
  - **Enables common flight executive functions**
  - **Well documented application programmer interface (API)**
  - **Project-independent configuration management**
  - **Applications are modular, independent, and decoupled**

Core Flight Executive (cFE)
Operating System Abstraction Layer (OSAL)
RTEMS Real-Time Operating System

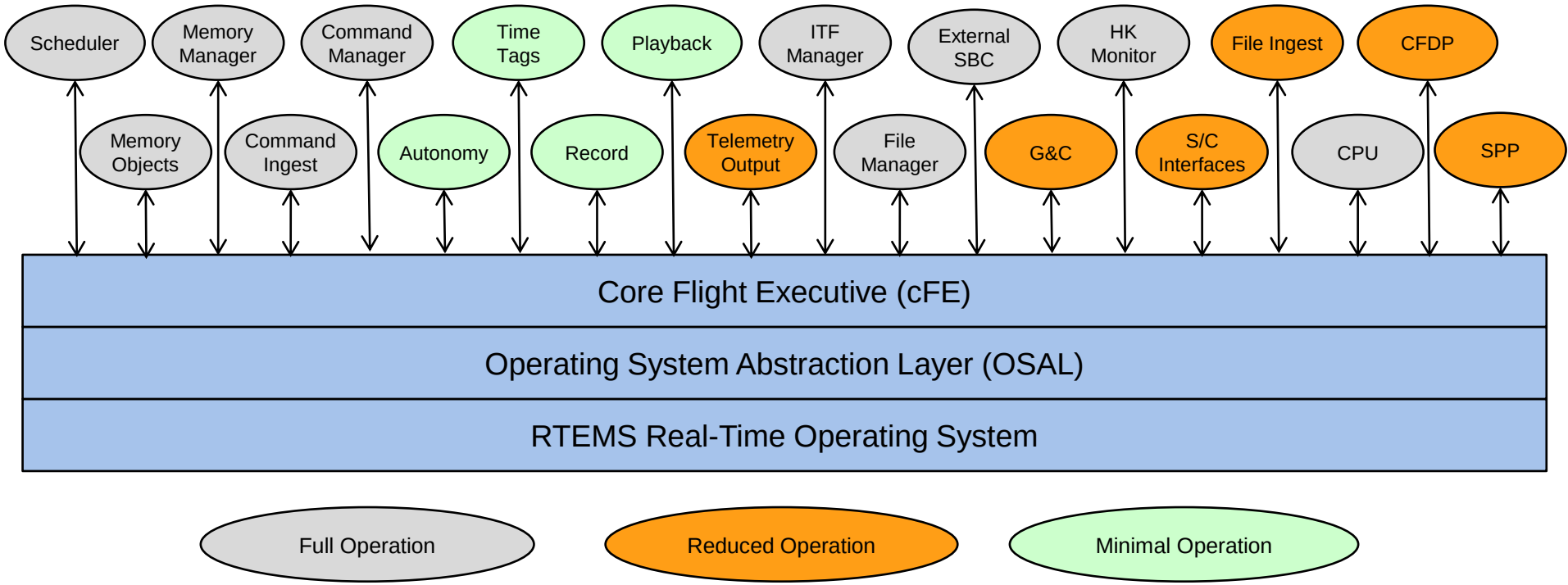
FSW Design
Software Layers (4 of 4)

- **Mission FSW Applications and Libraries**
  - **Significant reuse from Van Allen Probes**
  - **New development**
    - **Includes SpaceWire/CFDP Uplink/Flash file system**



FSW Design
Functionality Across Processors

- **Software Running on Three Processors**
  - **Amount of operation depends upon functionality**
  - **Minimal operation is only receiving commands and producing telemetry**



Solar Probe Plus Flight Software

Questions?