Patching Spacecraft using GMSEC and cFS

Assured Micropatching – January 2021 PI Meeting

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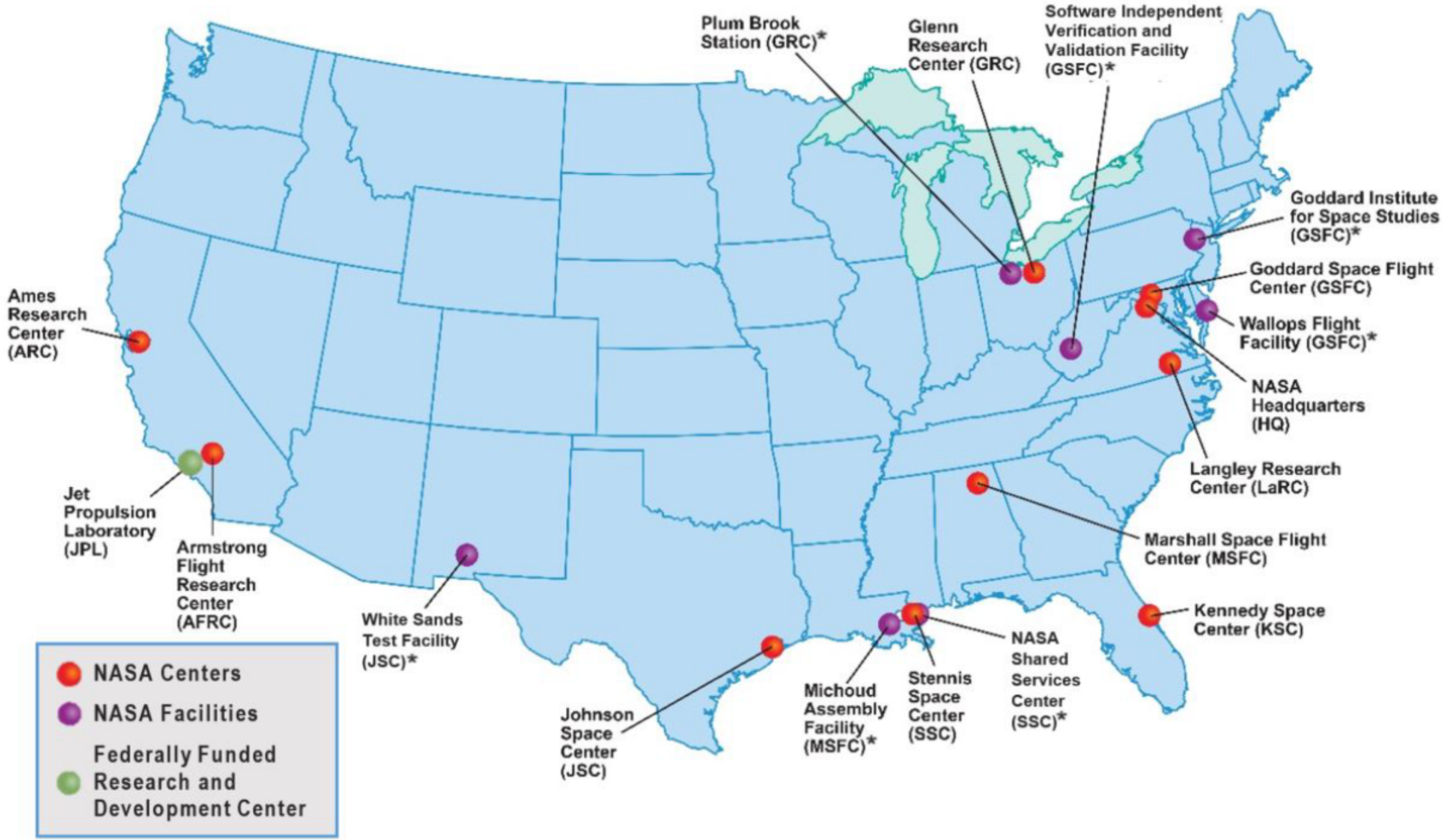
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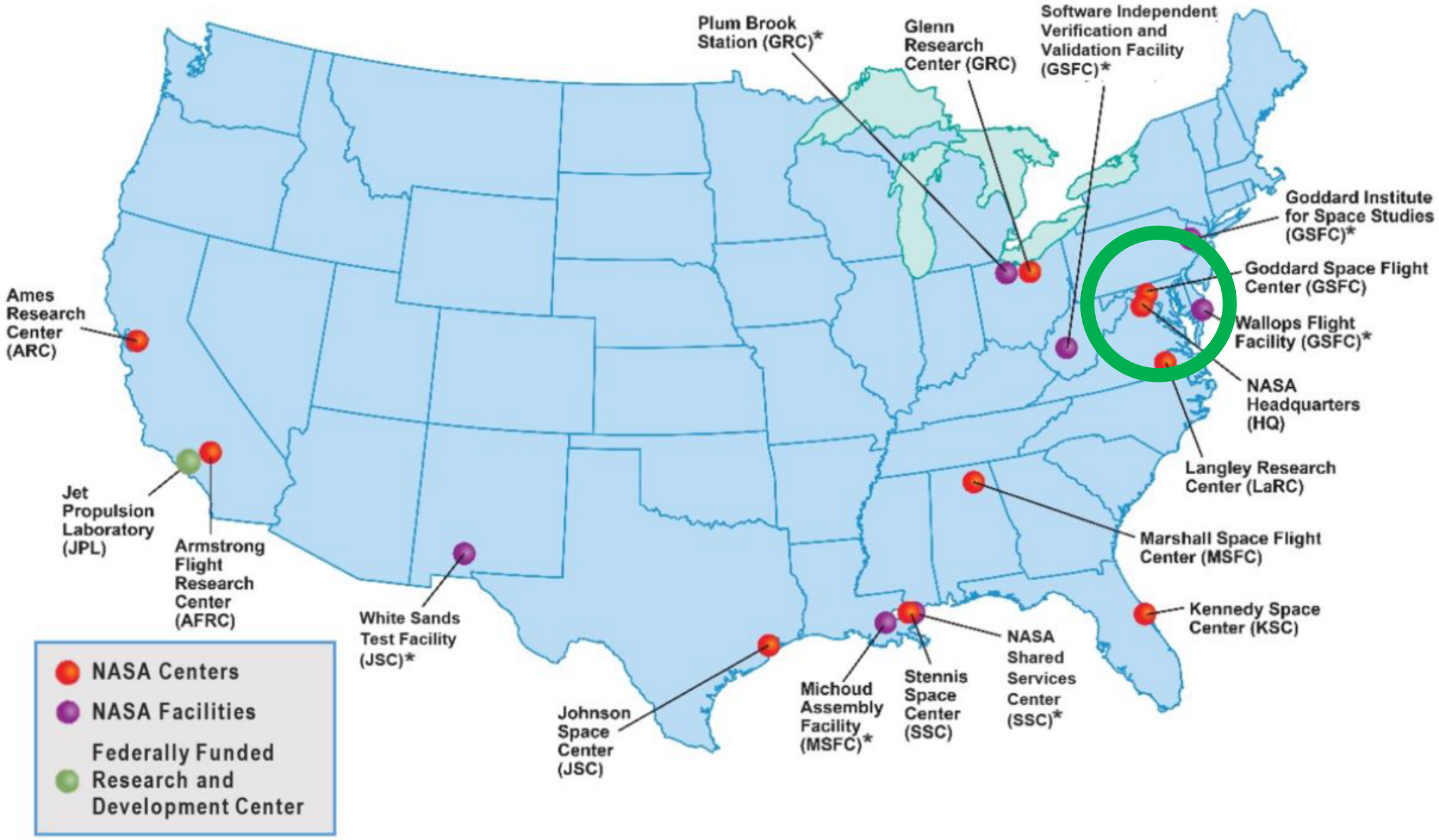
Glenn Research Center (GRC)
Software Independent Verification and Validation Facility (GSFC)*
Goddard Institute for Space Studies (GSFC)*
Goddard Space Flight Center (GSFC)
Wallops Flight Facility (GSFC)*
NASA Headquarters (HQ)
Langley Research Center (LaRC)
Marshall Space Flight Center (MSFC)
Kennedy Space Center (KSC)
NASA Shared Services Center (SSC)*
Stennis Space Center (SSC)
Michoud Assembly Facility (MSFC)*
Johnson Space Center (JSC)
White Sands Test Facility (JSC)*
Armstrong Flight Research Center (AFRC)
Jet Propulsion Laboratory (JPL)
Ames Research Center (ARC)
NASA Centers
NASA Facilities
Federally Funded Research and Development Center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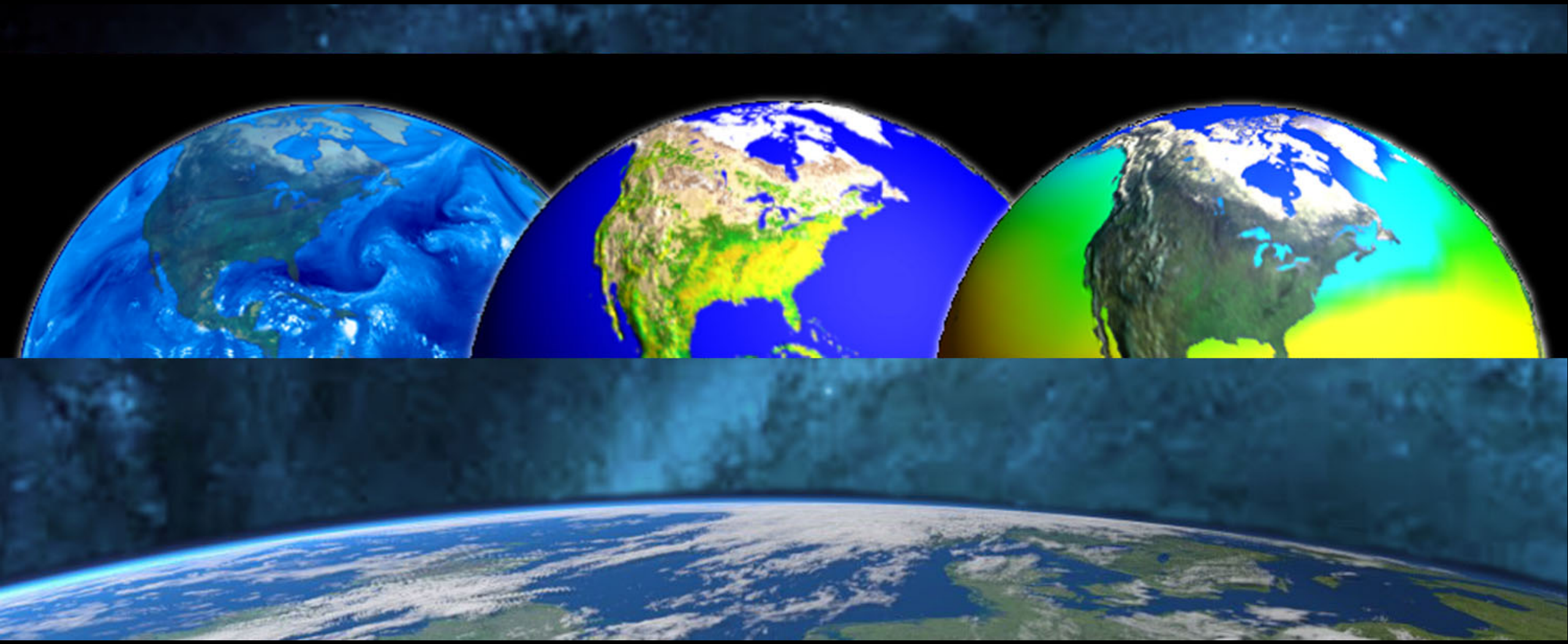
Did You Know That NASA-GSFC:



is home to the Nation's largest organization of earth scientists?

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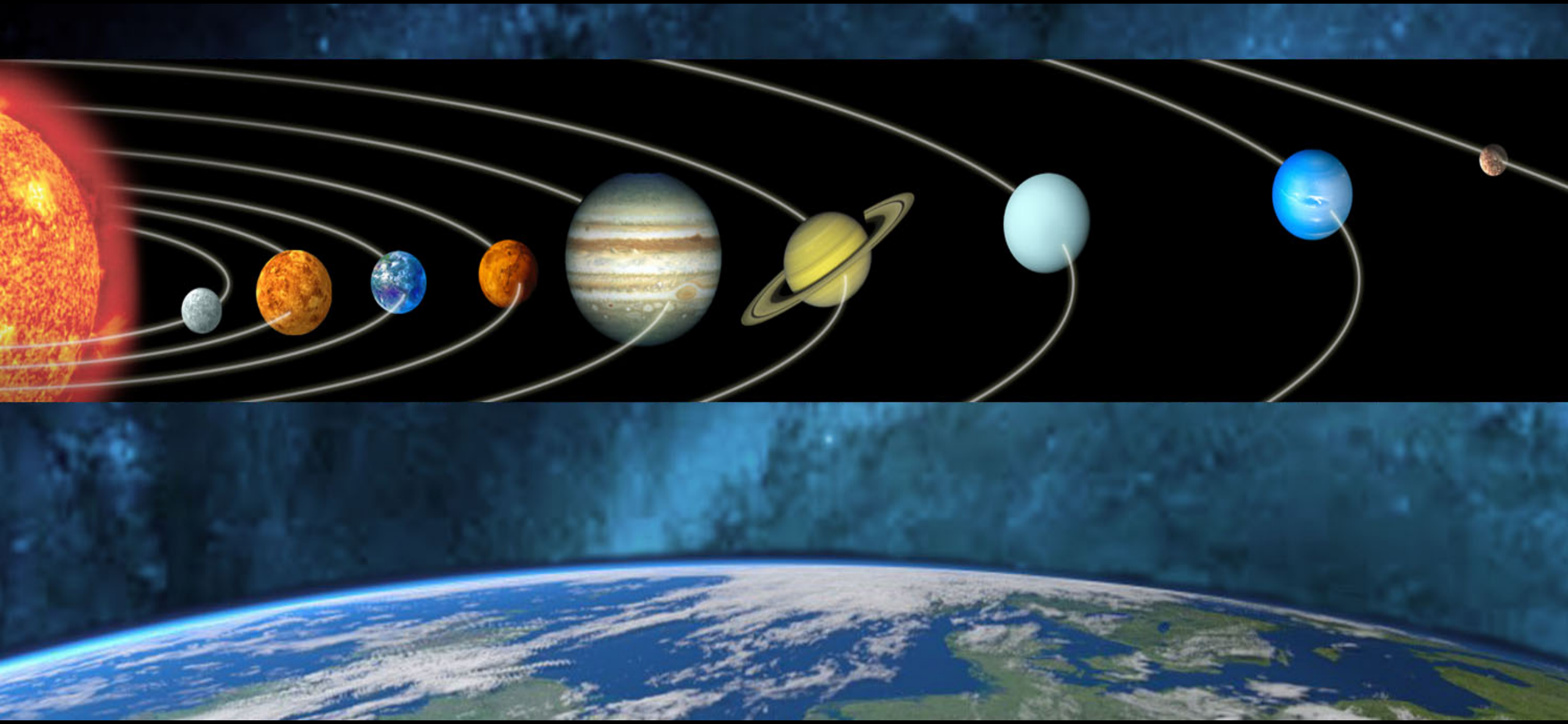

has built instruments on satellites to study every planet in our solar system?

Did You Know That NASA-GSFC:

is developing of comm and nav systems to enable the future human exploration?

Why is NASA interested in AMP?

DISCOVER — EXPAND HUMAN KNOWLEDGE THROUGH NEW SCIENTIFIC DISCOVERIES.

EXPLORE — EXTEND HUMAN PRESENCE DEEPER INTO SPACE AND TO THE MOON FOR SUSTAINABLE LONG-TERM EXPLORATION AND UTILIZATION.

DEVELOP — ADDRESS NATIONAL CHALLENGES AND CATALYZE ECONOMIC GROWTH.

ENABLE — OPTIMIZE CAPABILITIES AND OPERATIONS.

Theme	Strategic Goal	Strategic Objective
DISCOVER	**EXPAND HUMAN KNOWLEDGE THROUGH NEW SCIENTIFIC DISCOVERIES.**	1.1: Understand the Sun, Earth, Solar System, and Universe.
		1.2: Understand Responses of Physical and Biological Systems to Spaceflight.
EXPLORE	**EXTEND HUMAN PRESENCE DEEPER INTO SPACE AND TO THE MOON FOR SUSTAINABLE LONG-TERM EXPLORATION AND UTILIZATION.**	2.1: Lay the Foundation for America to Maintain a Constant Human Presence in Low Earth Orbit Enabled by a Commercial Market.
		2.2: Conduct Exploration in Deep Space, Including to the Surface of the Moon.
DEVELOP	**ADDRESS NATIONAL CHALLENGES AND CATALYZE ECONOMIC GROWTH.**	3.1: Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation.
		3.2: Transform Aviation Through Revolutionary Technology Research, Development, and Transfer.
		3.3: Inspire and Engage the Public in Aeronautics, Space, and Science.
ENABLE	**OPTIMIZE CAPABILITIES AND OPERATIONS.**	4.1: Engage in Partnership Strategies.
		4.2: Enable Space Access and Services.
		4.3: Assure Safety and Mission Success.
		4.4: Manage Human Capital.
		4.5: Ensure Enterprise Protection.
		4.6: Sustain Infrastructure Capabilities and Operations.

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GSFC's Diverse Mission Portfolio

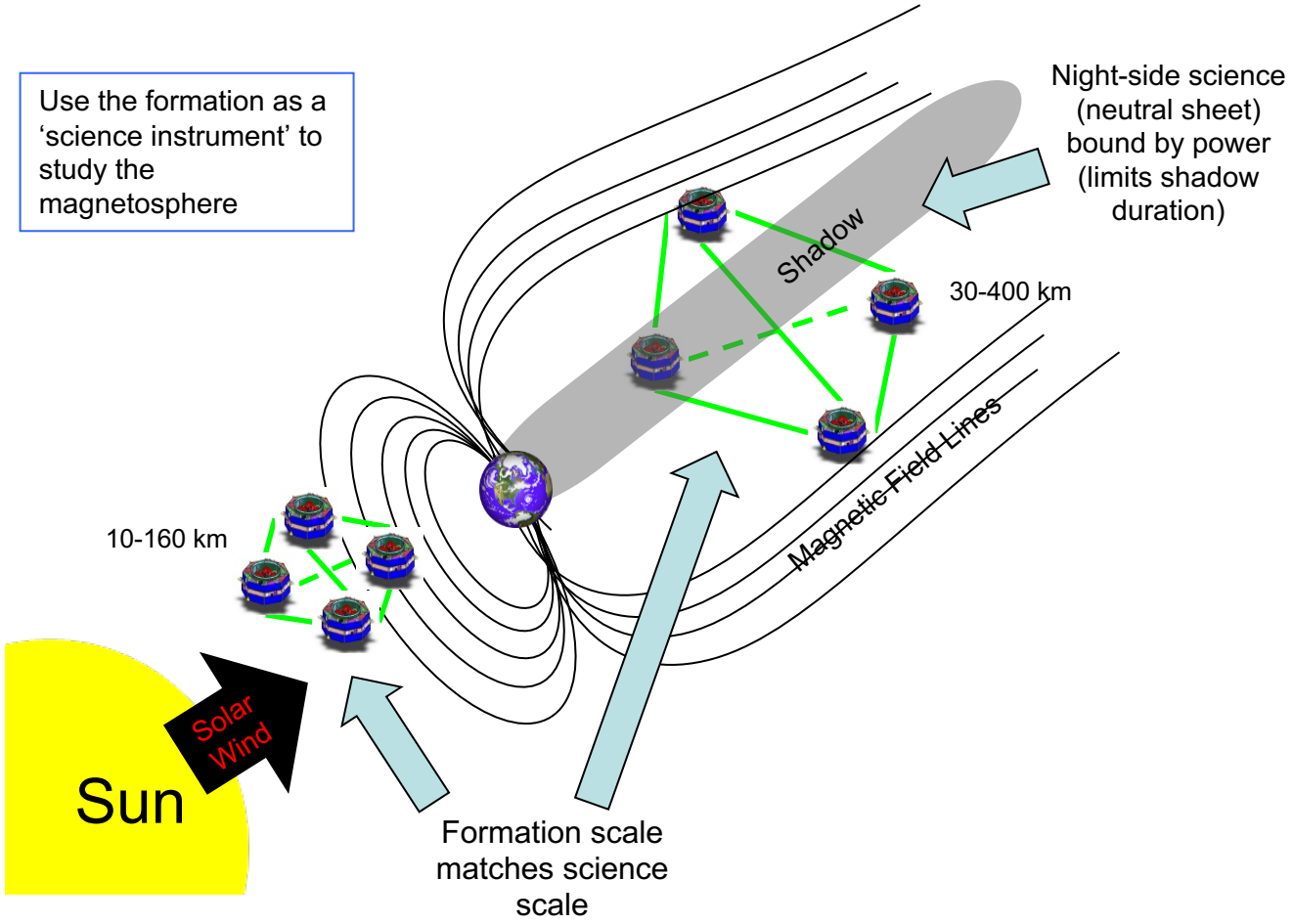
Micropatching Saves the Day:
a real-life example

Music: Moi et Toi by Abdel Ali Slimani
Footage: Aurora Borealis Explained (University of Oslo)
SMV Editing: Conrad Schiff

Introduction to MMS

- The goal of MMS (Magnetospheric MultiScale) Mission is to study the physics of magnetic reconnection in the Sun-solar-wind-Earth interaction
- The applications include power grid protection, mitigating communications disruption, improving magnetic confinement, understanding auroras, and climate change
- MMS is a complex formation flying mission launched by NASA on March 13, 2015
- To accomplish this goal MMS requires a highly integrated and responsive ground system to support the flight operations. Components of the ground system include:
  - Control of the flight
  - Issuance of commands
  - Acknowledgement of the receipt of telemetry
  - Trending and Analysis
  - Communication of with networks (DSN, SN, and NEN)
  - Interoperability between components (e.g. flight dynamics and maneuver command generation and execution

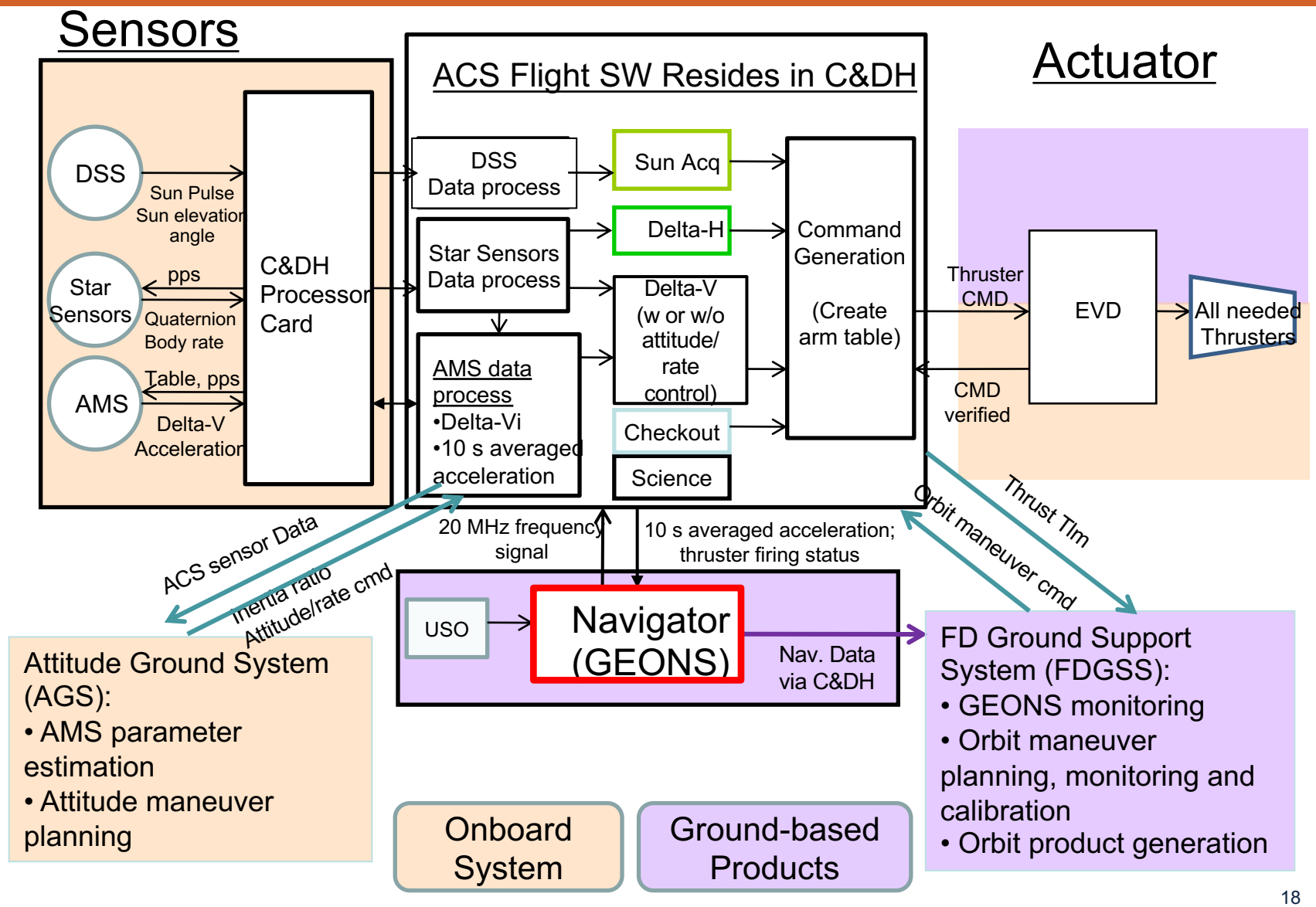
MMS Mission Concept at a Glance



Spacecraft GN&C Block Diagram

- Spacecraft dynamics result from a complex interplay of onboard sensors & actuators with ground-based products

- Anecdote – first micropatch on MMS
  - ❑ Navigator box (red outline) showed signs of full CPU use
  - ❑ Code to solve Kepler's equation stuck in infinite loop
  - ❑ Details to follow on next slide



Kepler and Micropatching in Action

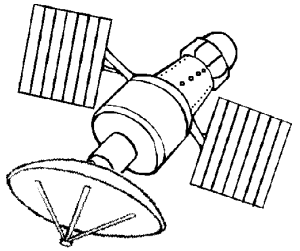
- A typical requirement in any Navigation system is the solution of Kepler's equation

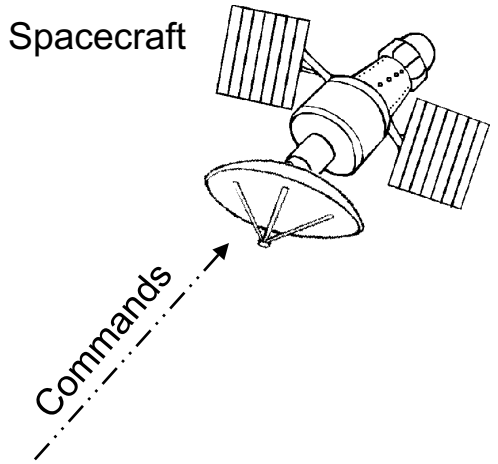
$$M = E - e \sin E$$

- Going from E to M is easy but going from M to E requires a solution to a transcendental equation (numerical iteration)
- The code had a legacy approach that basically, in pseudocode, did the following
  1. Guess a solution E^0
  2. Try it out and compare M^0 to M
  3. use the difference to revise E^1
  4. Repeat until $|M - M^n| < tol$
- The loop had no other exit criterion (e.g. number of trials) and got stuck trying to get $tol = eps$
- Our initial solution was to rewrite the code, recompile, and upload a patch but...
- Our final solution was the (4Ps):
  1. Peek into the memory location storing tol
  2. Poke a new value into the same location
  3. Peek again to make sure
  4. Pray...
- This solution has been flying for years and so far so good

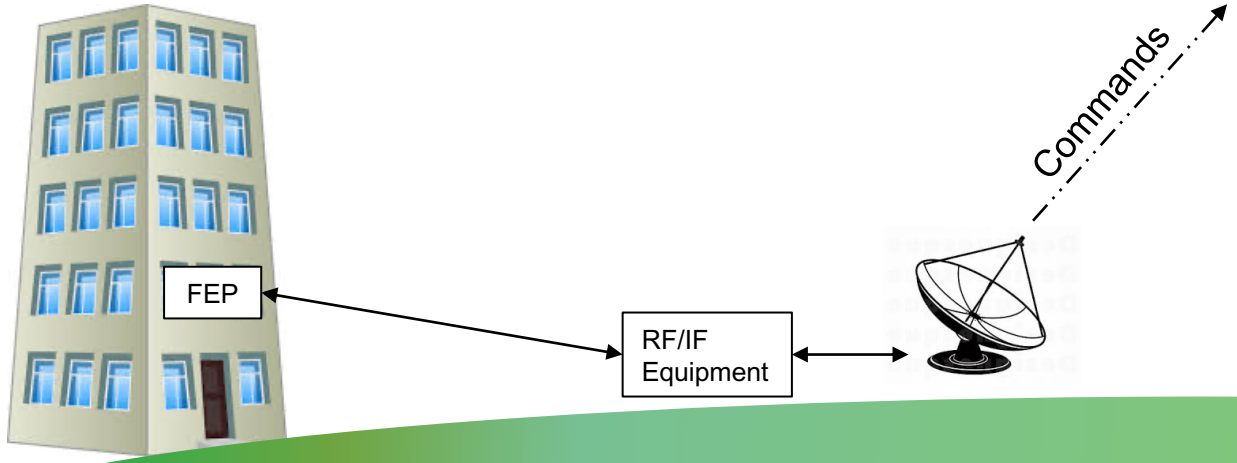
An overview of space mission architecture

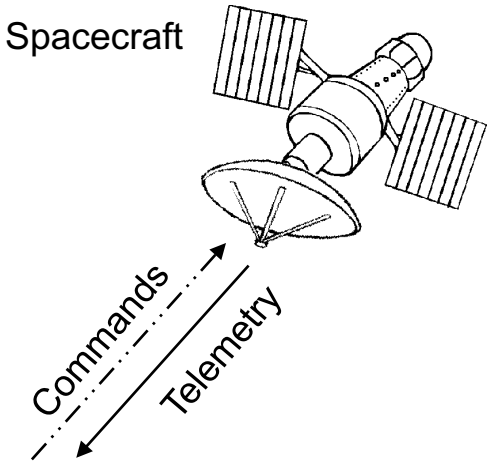
Spacecraft





Mission Operations Center (MOC)





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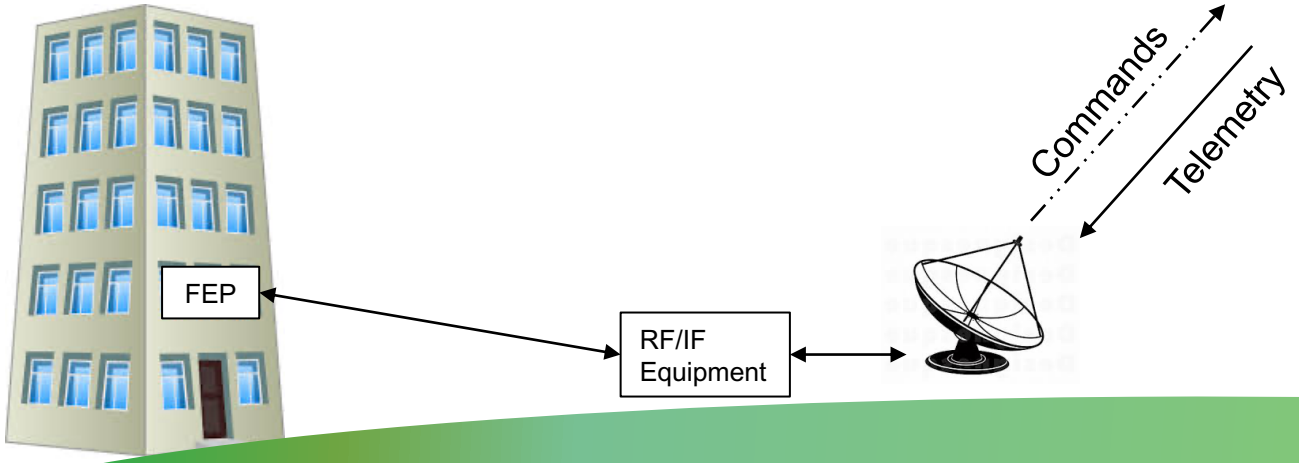

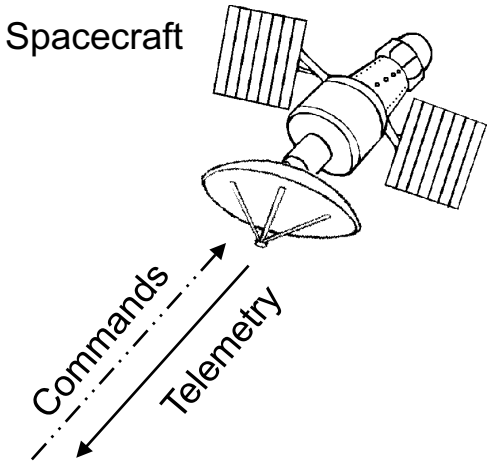

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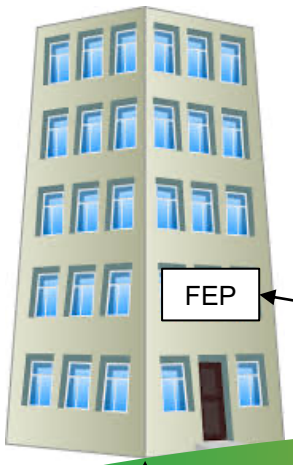
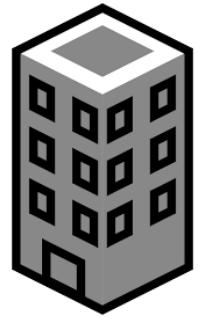


RF/IF Equipment

RF/IF Equipment

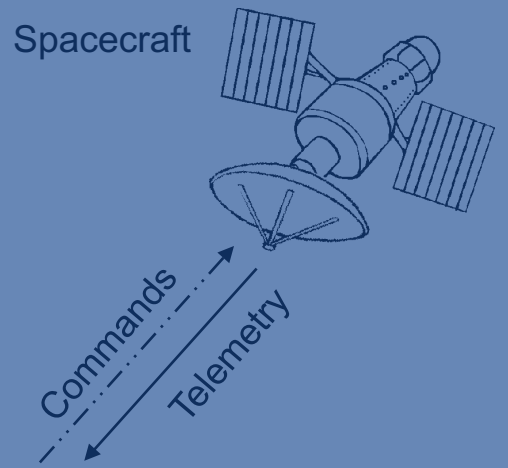
FEP

Backup *MOC*



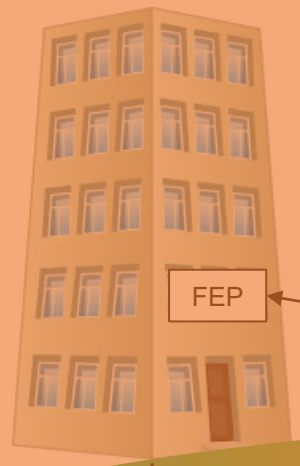
Ground link for synchronization & data delivery

Flight Software (ie. cFS)



Ground Software (ie. GMSEC)

Mission Control Center (MCC)



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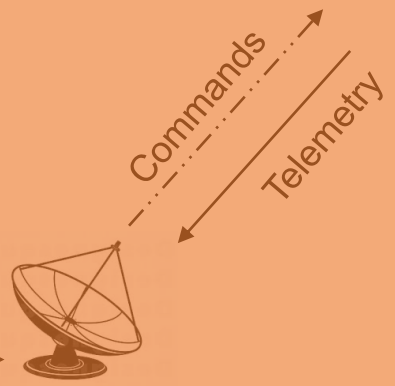

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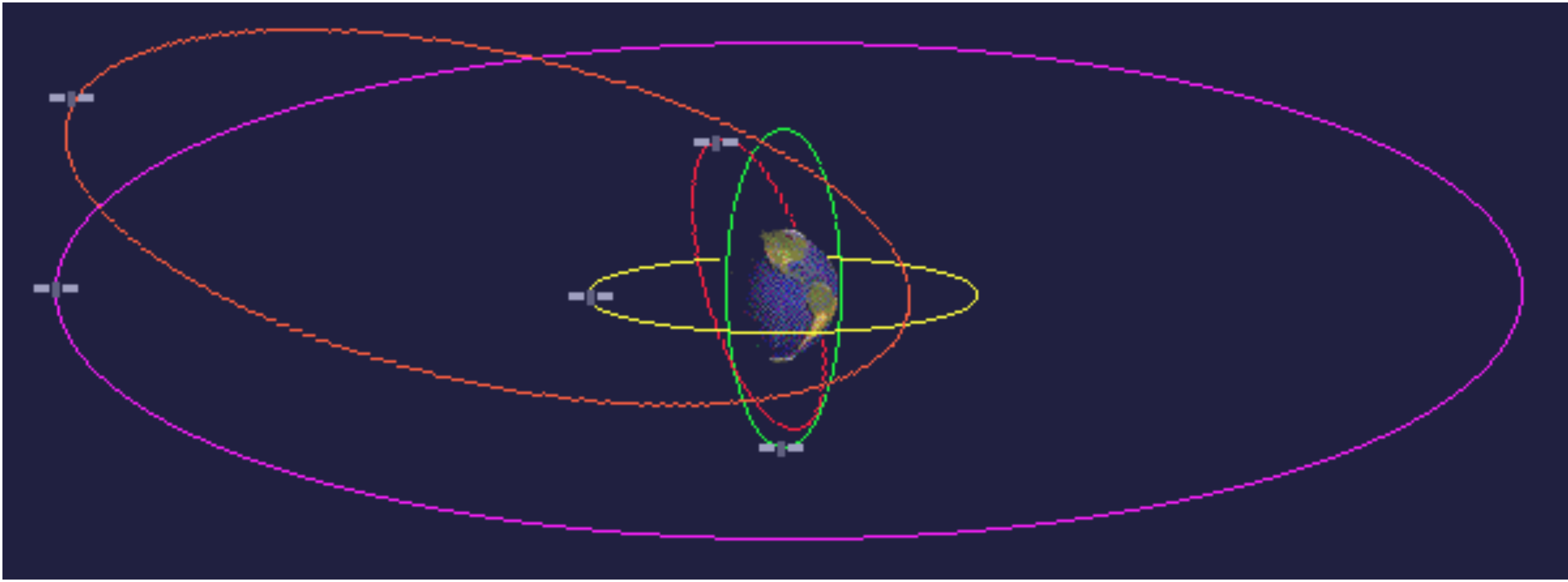
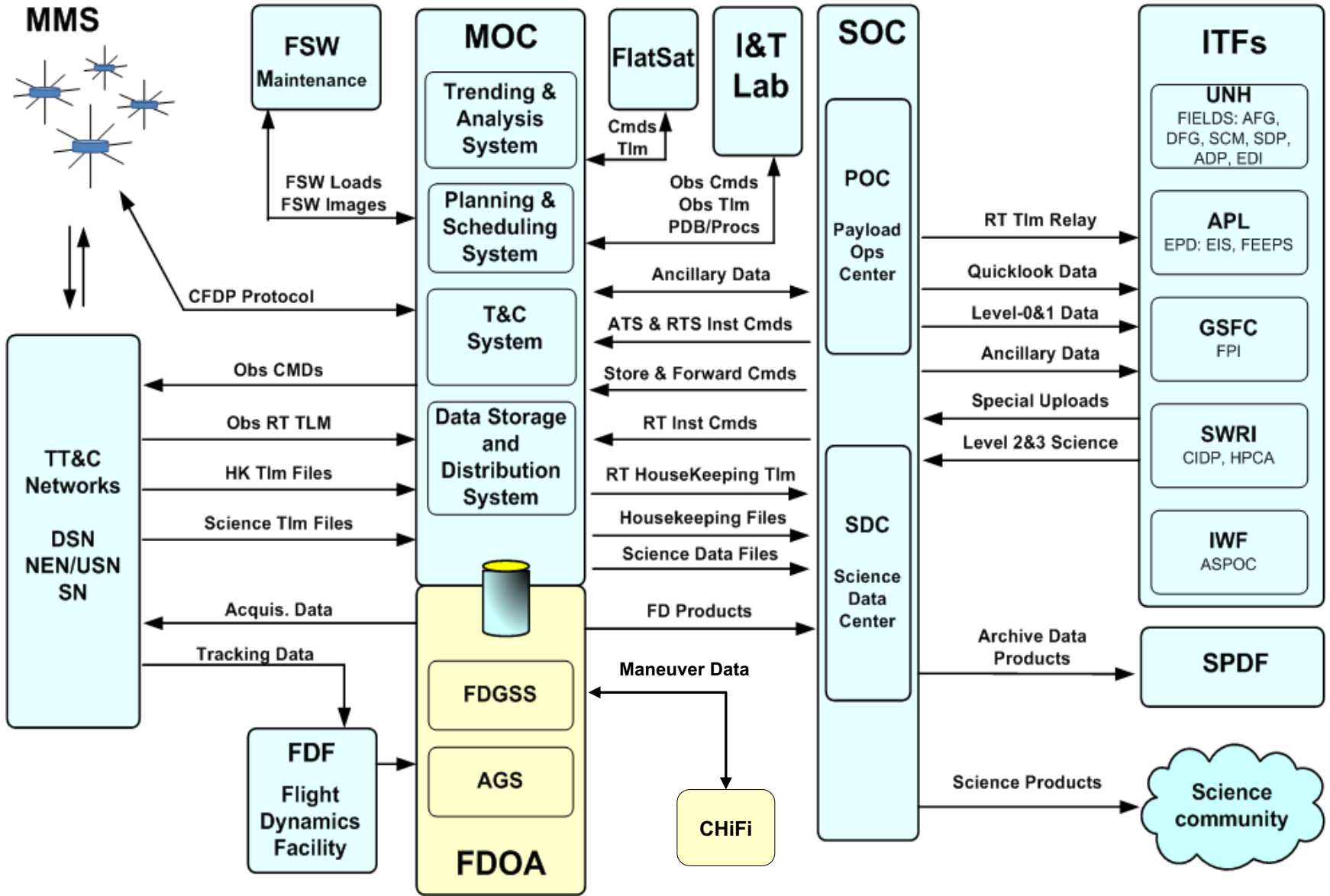
Ground link for synchronization & data delivery

A note on Orbits and Communications

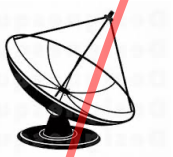


Ground Software and GMSEC

Ground System Architecture



GMSEC: Ground system & mission ops enabler



RF/IF

FEP

CRYPTO

T&C

Trending

Critical technical path

FDS

GSCE

MPS

GMSEC-UTIL

Systems Agent
Resource msg
Installed on all hosts

SA

Communicates
w/other buses

GRASP

Room Alert Adapter
SNMP driver mgmt

RAA

G/S Test
Utilities

CTS

PTU

Triggers action
based on directive
Automation & "brains"

CAT

Email notifications

ANSR

Countdown clock

CC

GMSEC API & Middleware (C2MS)

XTCE

XTCE s/c T&C DB
read, edit, service

GSS

Webservices server & front
end:

- Widgets (single value,
  URL, chart, grid)
- Message viewer
- Message archive
- MVAL request
- NOTE, CC

NOTE

Writes text msg on
bus

GPD

TM table
display

GREAT

Event Archive
Event Analyzer
Event Report

GEDAT

Heartbeat monitor
Trends SA msg

Mission Specific
SW

Ground System Dashboard Concept

Standards

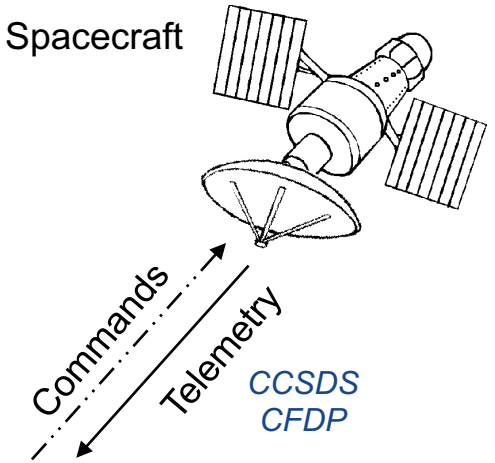
XTCE, XML Telemetry & Command Exchange

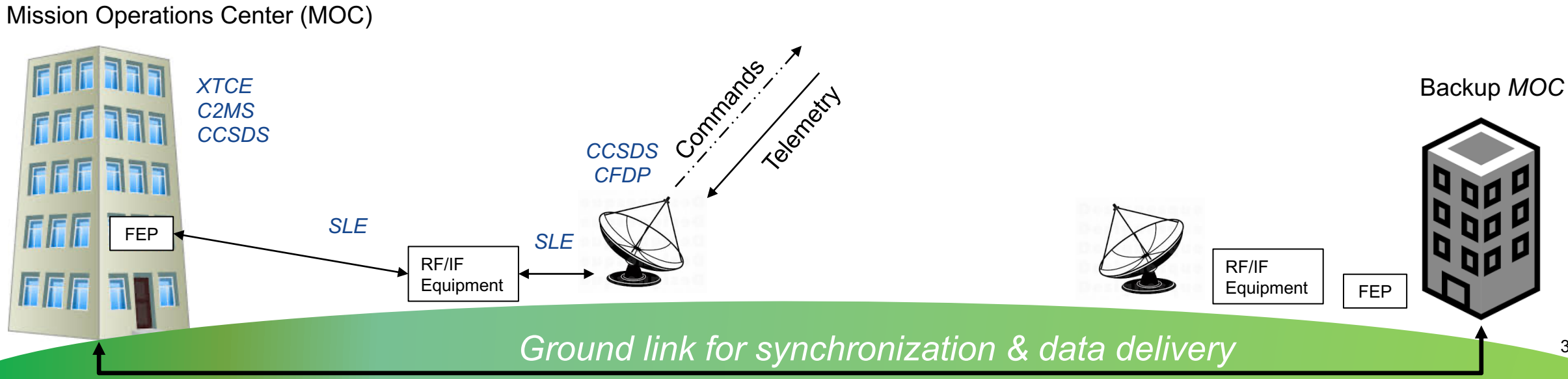
C2MS, Command & Control Message Specification

***CCSDS* packets**, Consultative Committee on Space Data Standards

SLE, Space Link Extension

CFDP, CCSDS File Delivery Protocol

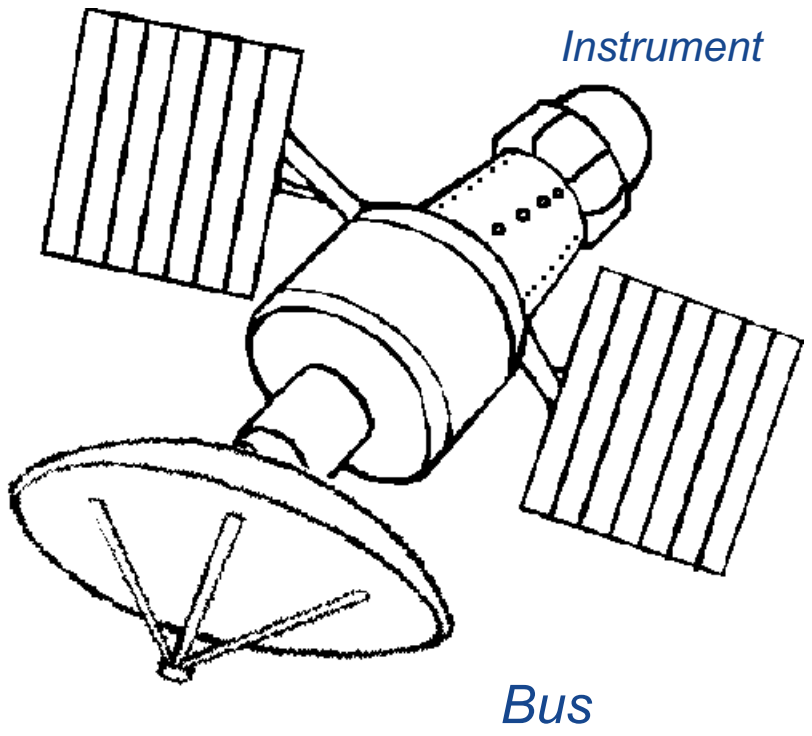




Flight Software and cFS

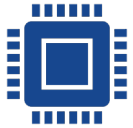
What is Flight Software?

- Flight Software is embedded software that flies!
- The **real-time** “Brains” of the spacecraft
- Part of the Spacecraft Bus or a Science Payload
- Starts when power is applied to CPU

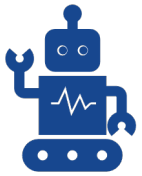


Unique Challenges of Flight Software

EXPECTATIONS



24/7 uptime for years



Complex autonomous/robotic systems

Remote operations and maintenance

REALITY

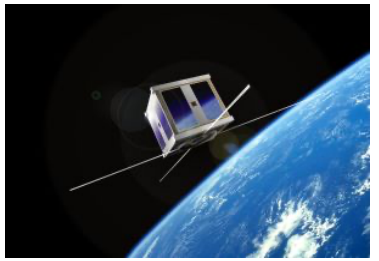
Harsh environments cause transient and permanent faults

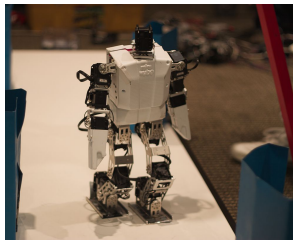
Generations older than consumer electronics

Communications at “dial-up” speeds

An open-source framework for embedded software

Your App



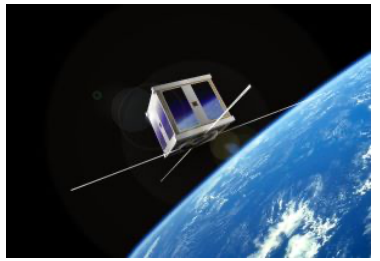


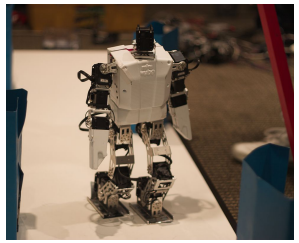
Multiple Embedded, Real-Time
Operating Systems and Platforms

An open-source framework for embedded software

Your App

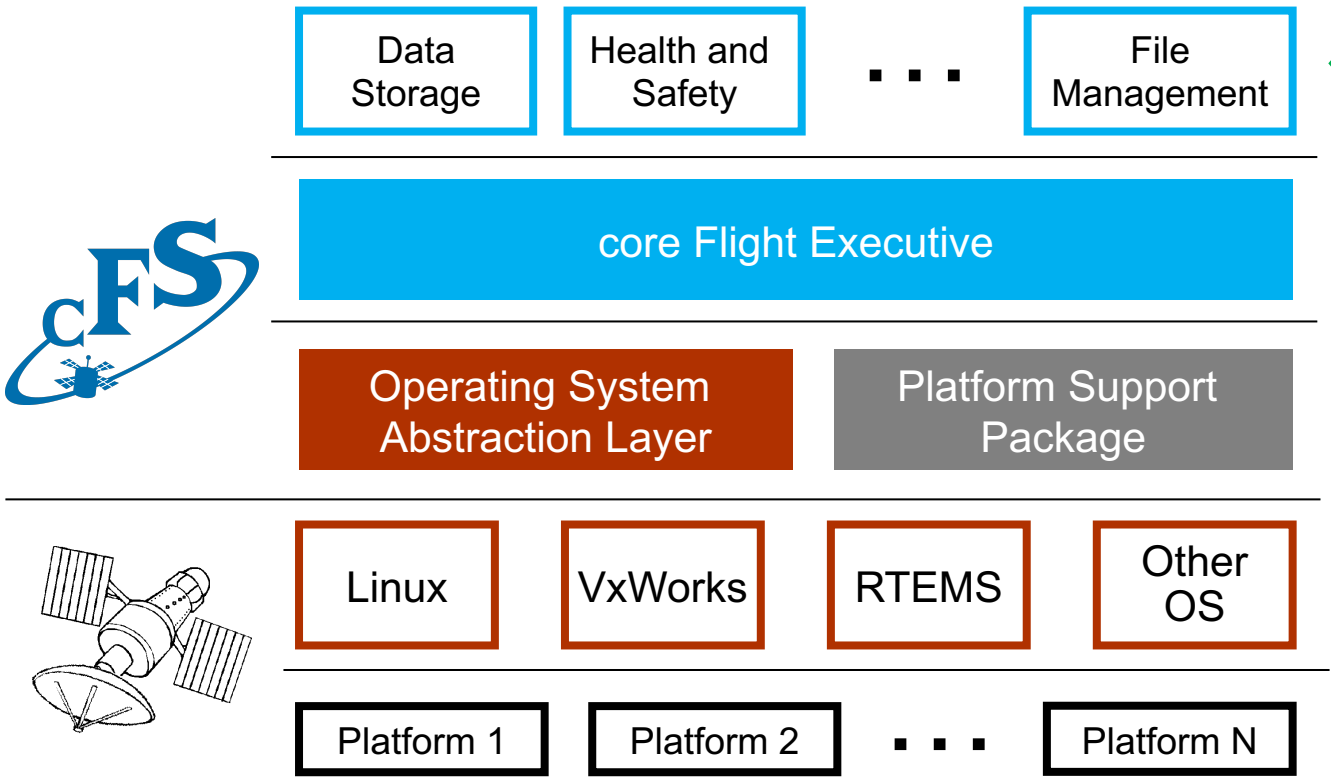
- Software framework bundled with a suite of applications and tools
- Written for flight systems with NASA **reliability and rigor** while being scalable & accessible



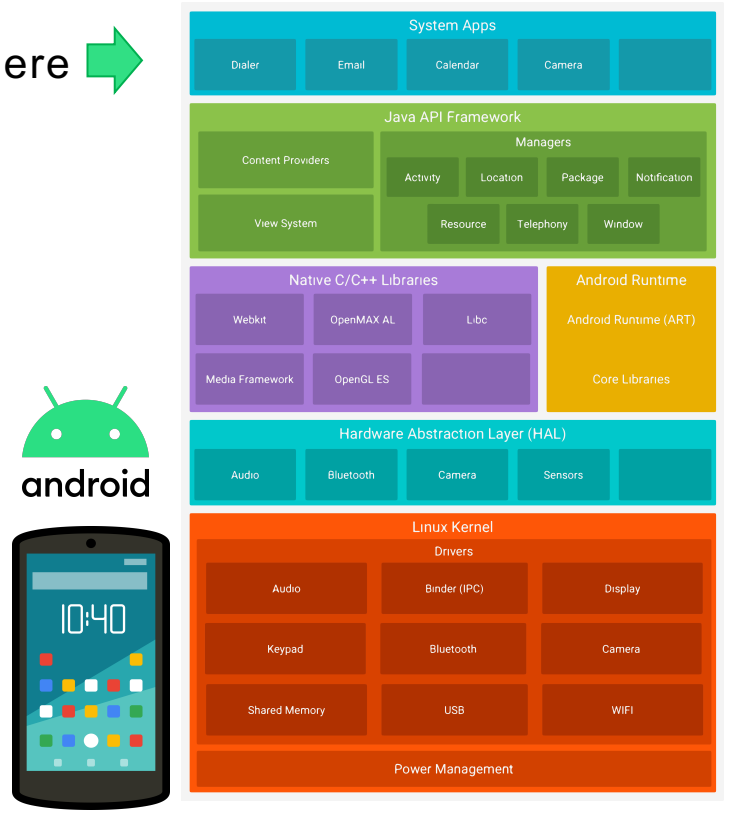


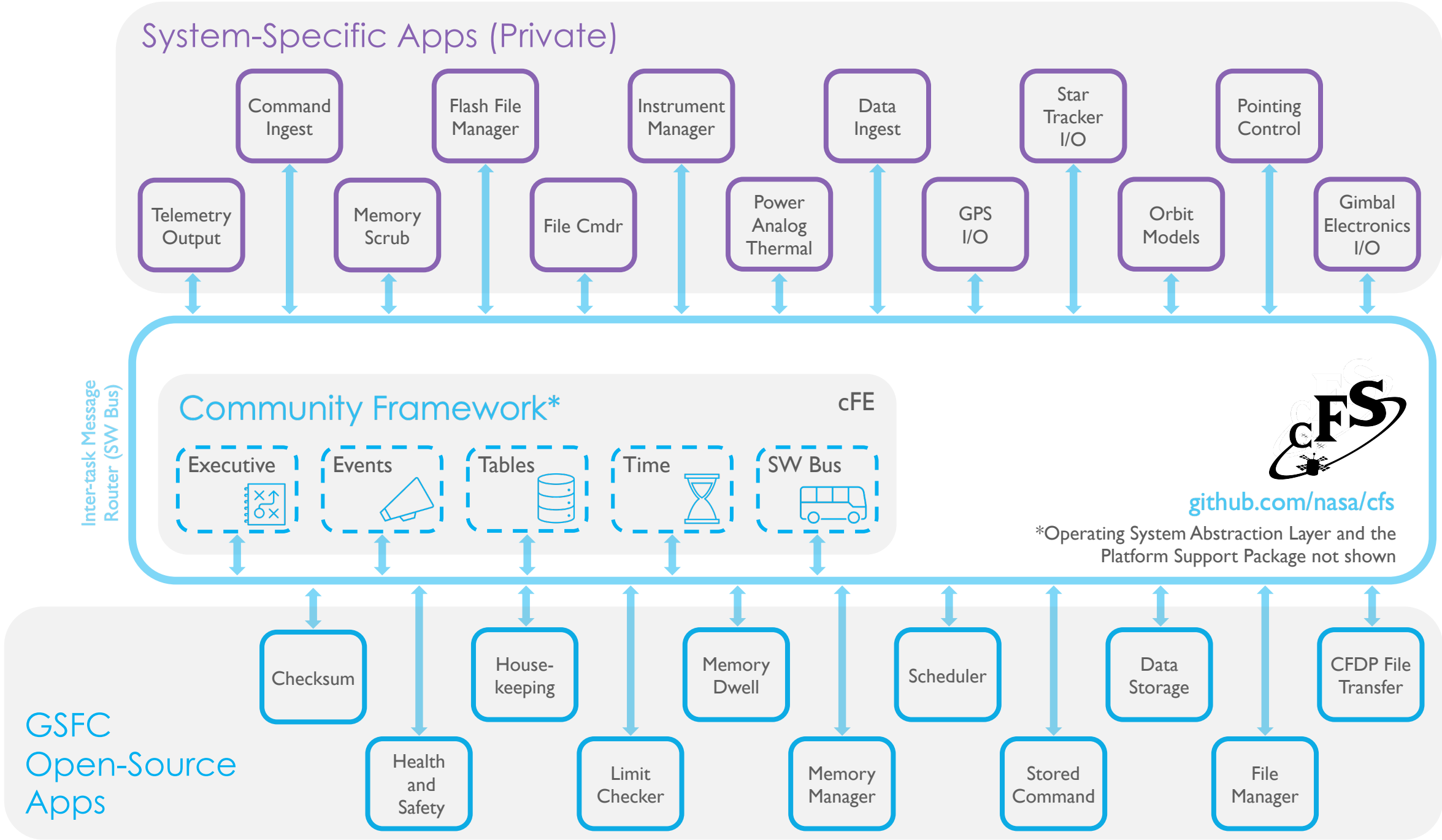
Multiple Embedded, Real-Time Operating Systems and Platforms

Architecture Provides Flexibility



Add YOUR app here

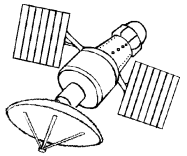


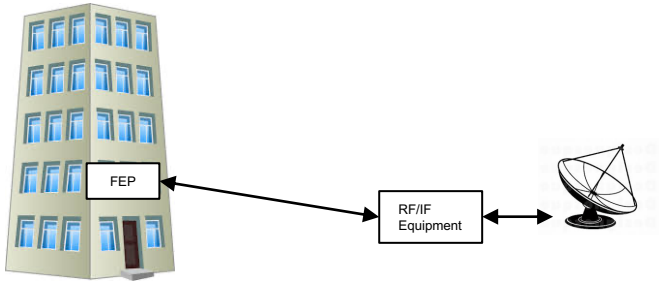

System-Specific Apps (Private)
Command Ingest
Flash File Manager
Instrument Manager
Data Ingest
Star Tracker I/O
Pointing Control
Telemetry Output
Memory Scrub
File Cmdr
Power Analog Thermal
GPS I/O
Orbit Models
Gimbal Electronics I/O
Inter-task Message Router (SW Bus)
Community Framework*
cFE
Executive
Events
Tables
Time
SW Bus
cFS
github.com/nasa/cfs
*Operating System Abstraction Layer and the Platform Support Package not shown
Checksum
House-keeping
Memory Dwell
Scheduler
Data Storage
CFDP File Transfer
GSFC Open-Source Apps
Health and Safety
Limit Checker
Memory Manager
Stored Command
File Manager

AMP Challenge Ideas

AMP Spacecraft Challenge Ideas

- Patch a simulated spacecraft running cFS and an emulated ground system
  - Fix an iterator-based algorithm with a “broken” exit condition (MMS Example)
  - Patch a Kalman Filter algorithm with a runaway covariance matrix
- Patch the firmware of space-like hardware
  - fix parameters such as scale factors and gains
- And more!





Resources

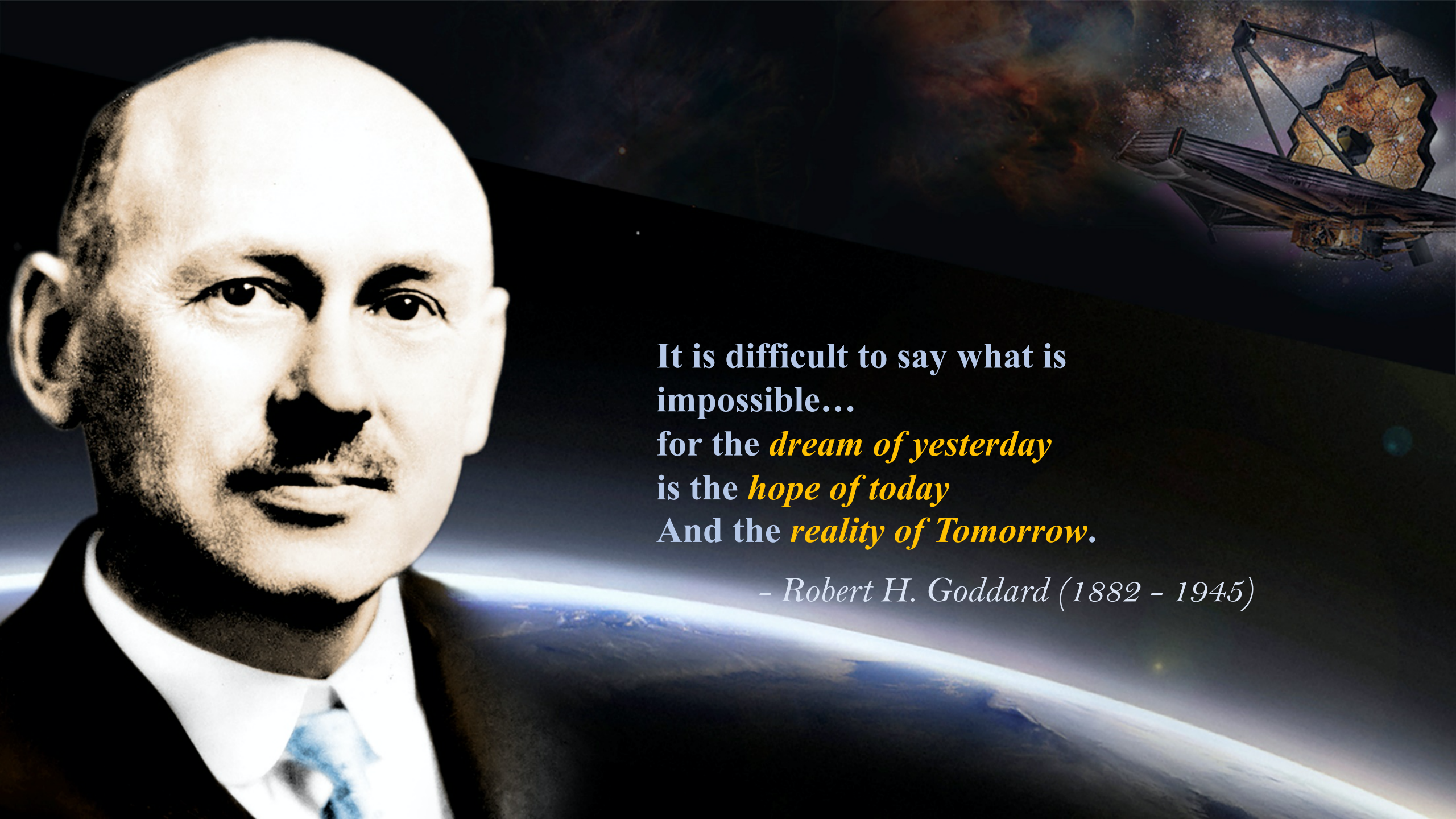
cFS

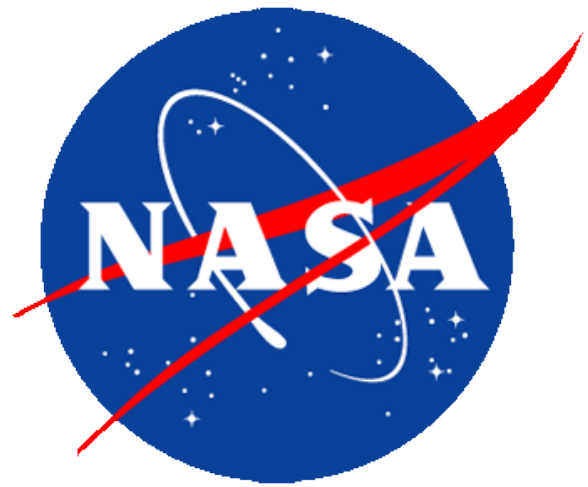
- cFS Framework Bundle
  https://github.com/nasa/cfs
- Training Exercises
  https://ntrs.nasa.gov/citations/20205000691
- OpenSatKit*
  https://github.com/OpenSatKit/OpenSatKit
- Community Mailing List
  https://lists.nasa.gov/mailman/listinfo/cfs-community

GMSEC

- GMSEC Web Site
  https://gmsec.gsfc.nasa.gov
- GMSEC Overview
  https://www.nasa.gov/content/reference-material
- C2MS
  https://www.omg.org/spec/C2MS/

*Not maintained by NASA


It is difficult to say what is
impossible…
for the dream of yesterday
is the hope of today
And the reality of Tomorrow.
- Robert H. Goddard (1882 - 1945)


NASA

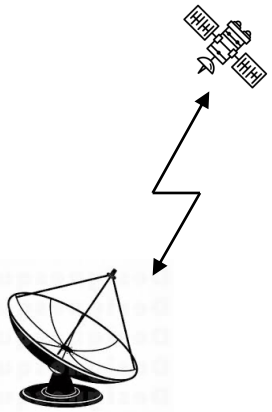
Backup Charts

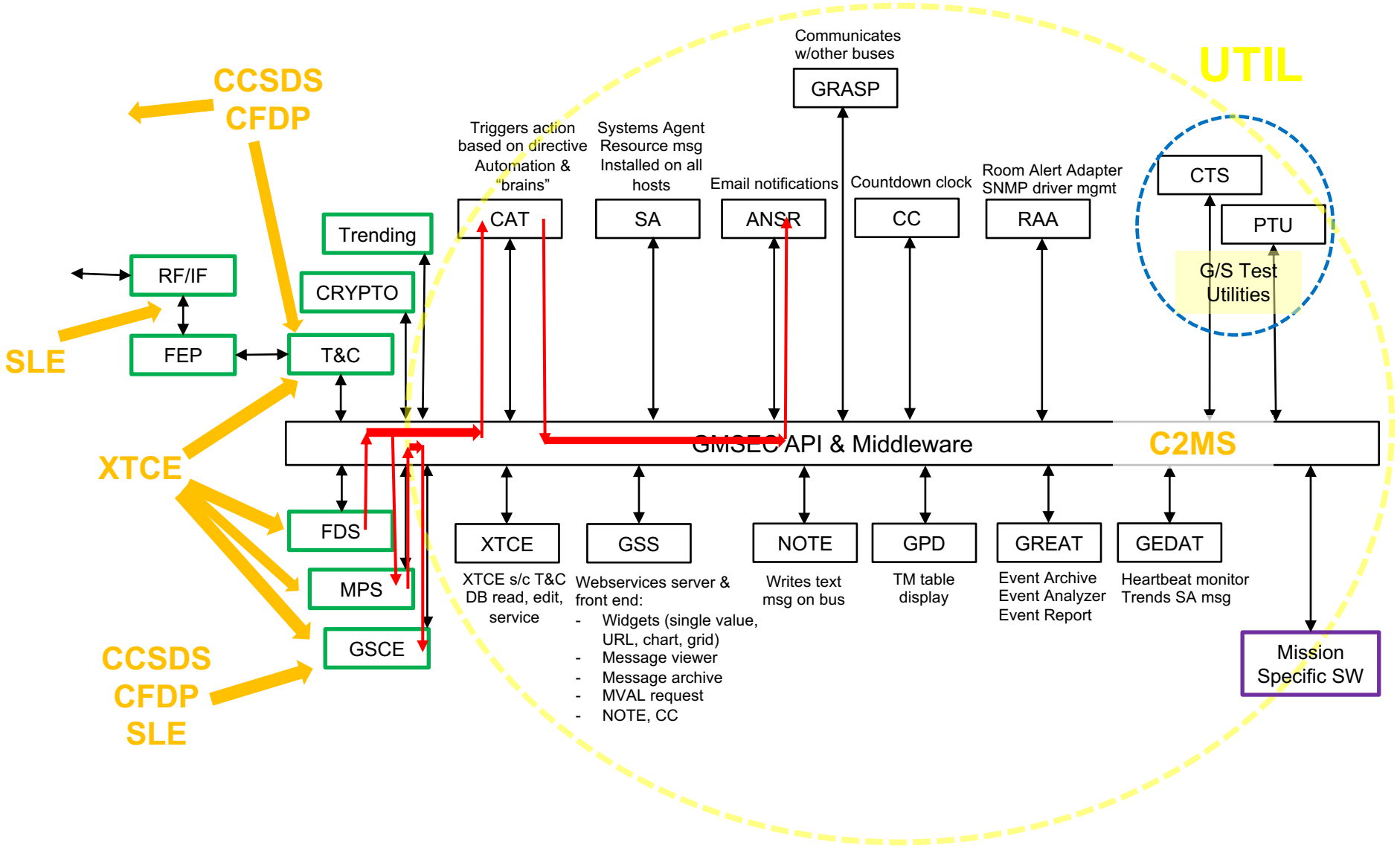
Acronyms

AFRL	Air Force Research Laboratory
AI	Artificial Intelligence
API	application programming interface
APL	Applied Physics Laboratory
App	Software Application
ARC	Ames Research Center
CFDP	CCSDS File Delivery Protocol
cFS	core Flight System
CLPS	Commercial Lunar Payload Service
CSA	Canadian Space Agency
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DTN	Delay/Disruption Tolerant Networking
ESA	European Space Agency
GMSEC	Goddard Mission Services Evolution Center (GMSEC)
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
IOS	Internet Operating System (Apple)

IV&V	NASA's Independent Verification and Validation facility
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KARI	Korea Aerospace Research Institute
KSC	Kennedy Space Center
MMS	Magnetospheric Multiscale
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NPR	NASA Procedural Requirements
RTEMS	Real-Time Executive for Multiprocessor Systems
TRL	Technology Readiness Levels

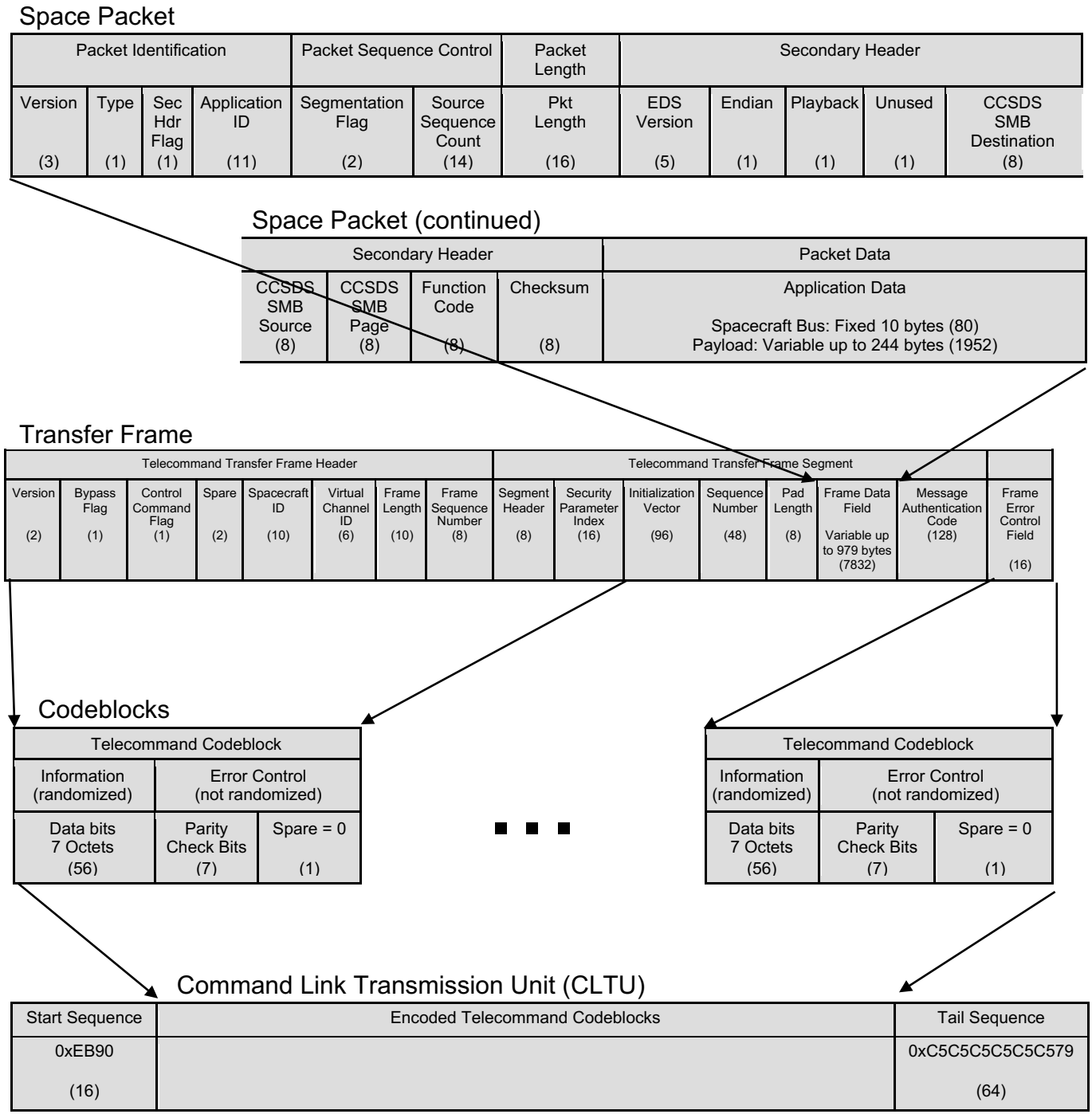
C2MS: Publish/subscribe Mechanics





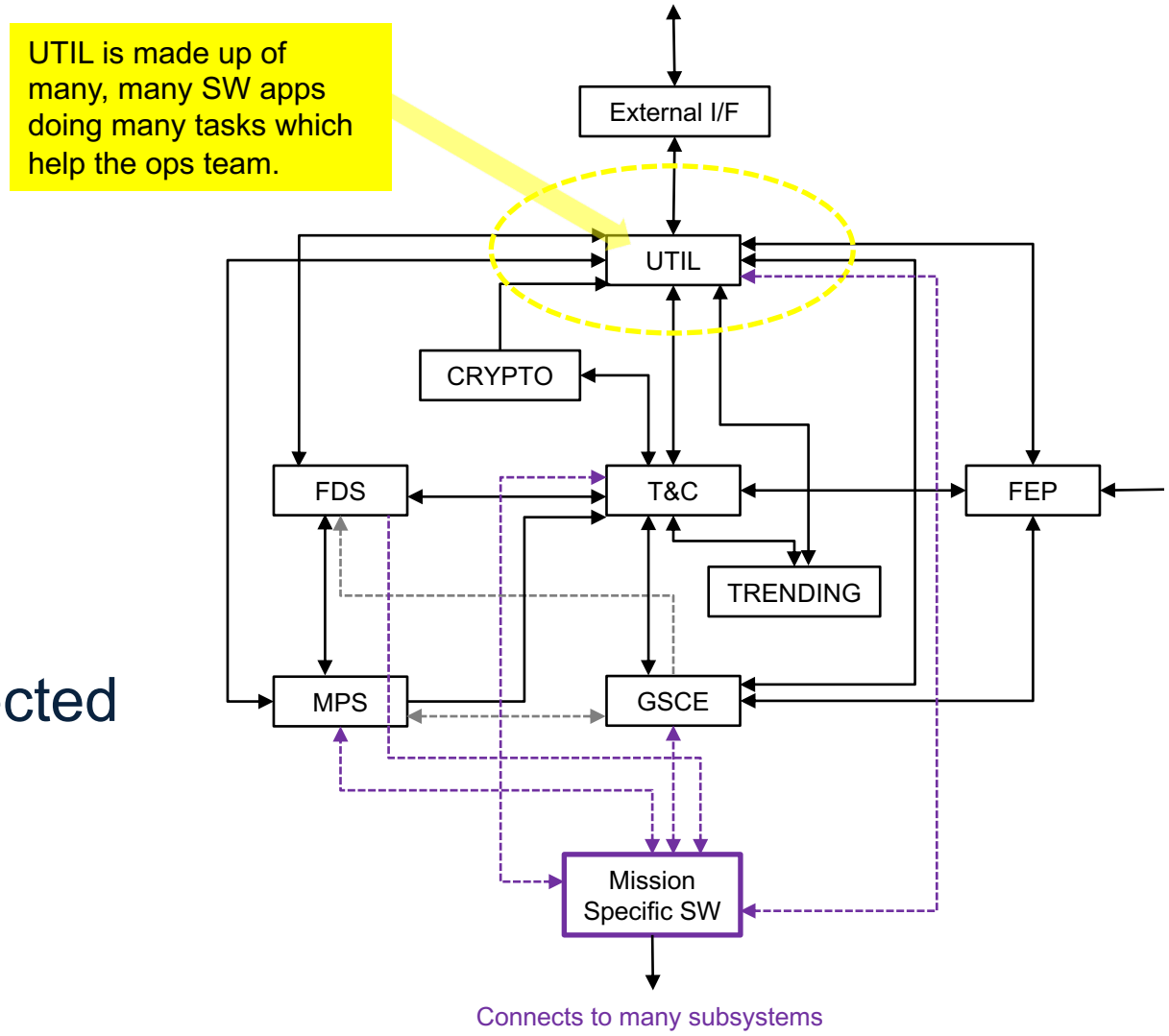
CCSDS

- Consultative Committee on Space Data Standards (CCSDS):
  - International Organization for comm and data standards for spaceflight
  - Published international TM &TC packet standards
    - CCSDS TM and TC packet formats
  - 28 countries
  - 1000+ missions
  - CFDP: CCSDS File Delivery Protocol
  - www.public.ccsds.org



Mission Control: Interfaces

- Socket interfaces
- Custom code
- Difficult to maintain
- Difficult to replace
- Interfaces are a nightmare
- Coordination with 3rd parties is challenging
- Situational awareness is neglected



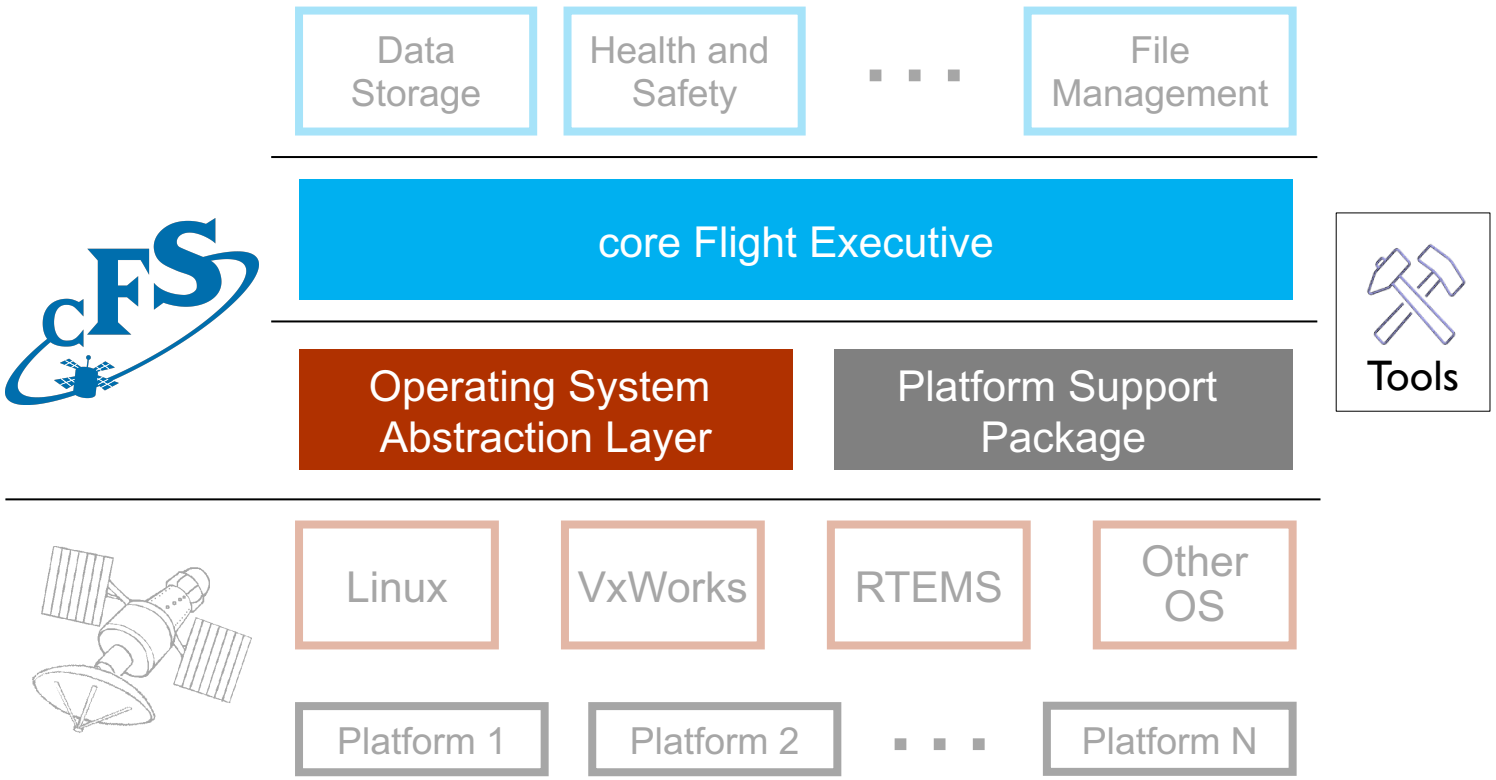
Common Types of Flight Software

- Command & Data Handling (C&DH)
  - Establish startup configuration
  - Manage command and telemetry
  - Control the flow of on-board operations
  - Manage time
  - Manage Fault Detection and Correction
- Attitude Control System (ACS)
  - Control momentum build-up
  - Determine current orbit position, attitude, velocity
  - Control maneuvers
- Instrument Software
  - Configure science instruments
  - Capture/process science data

Key cFS Definitions

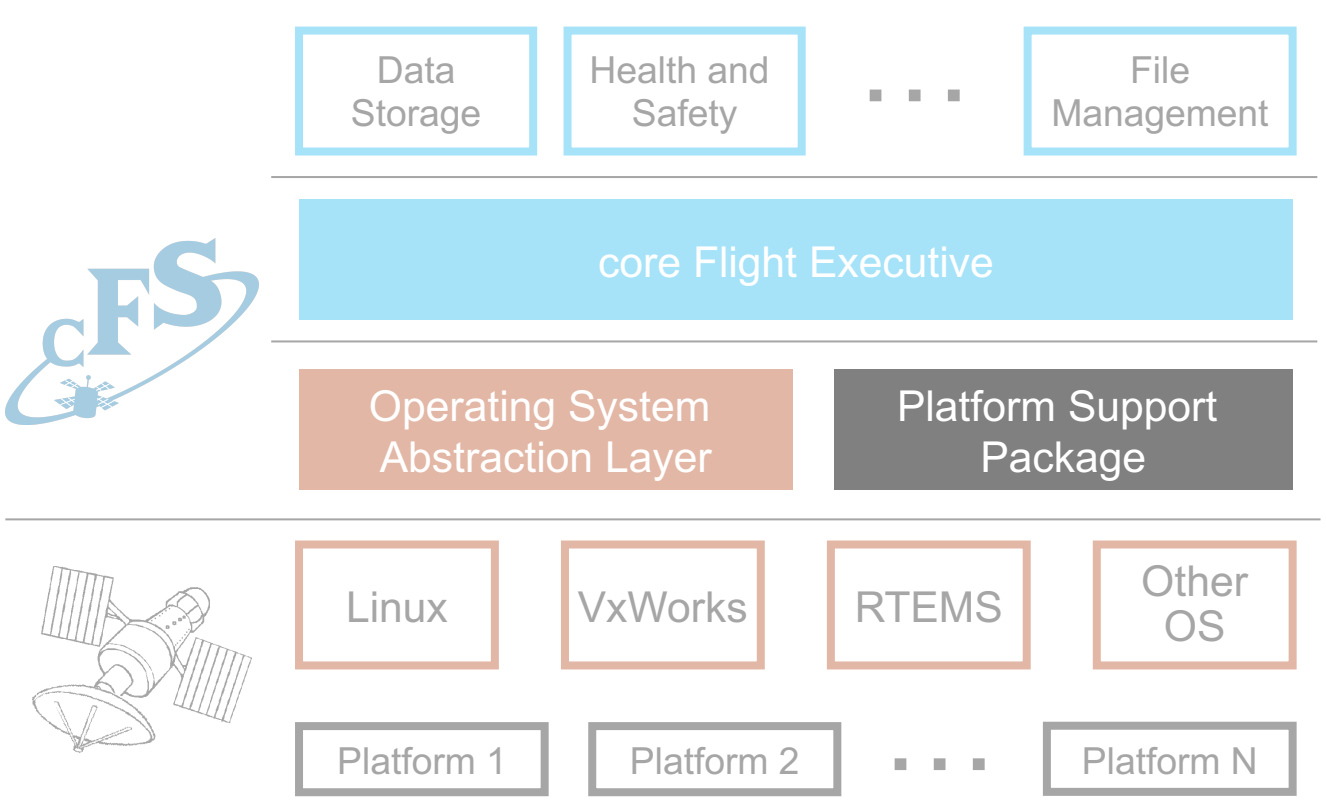
- **cFS Framework** – The set of individual services, applications, tools, and infrastructure supported by the cFS open source community.
- **cFS Component** – An individual application, service, or tool cFS Distribution – A set of custom components packaged together with the framework.
- **cFS Distribution** – A collected combination of apps and components configured to work for a specific system (ie. SmallSats)
- **cFE** or **cFS**?
  - cFE is the core Flight Executive services and API
  - cFS is a general collective term for the framework and the growing set of components

Key cFS Definitions



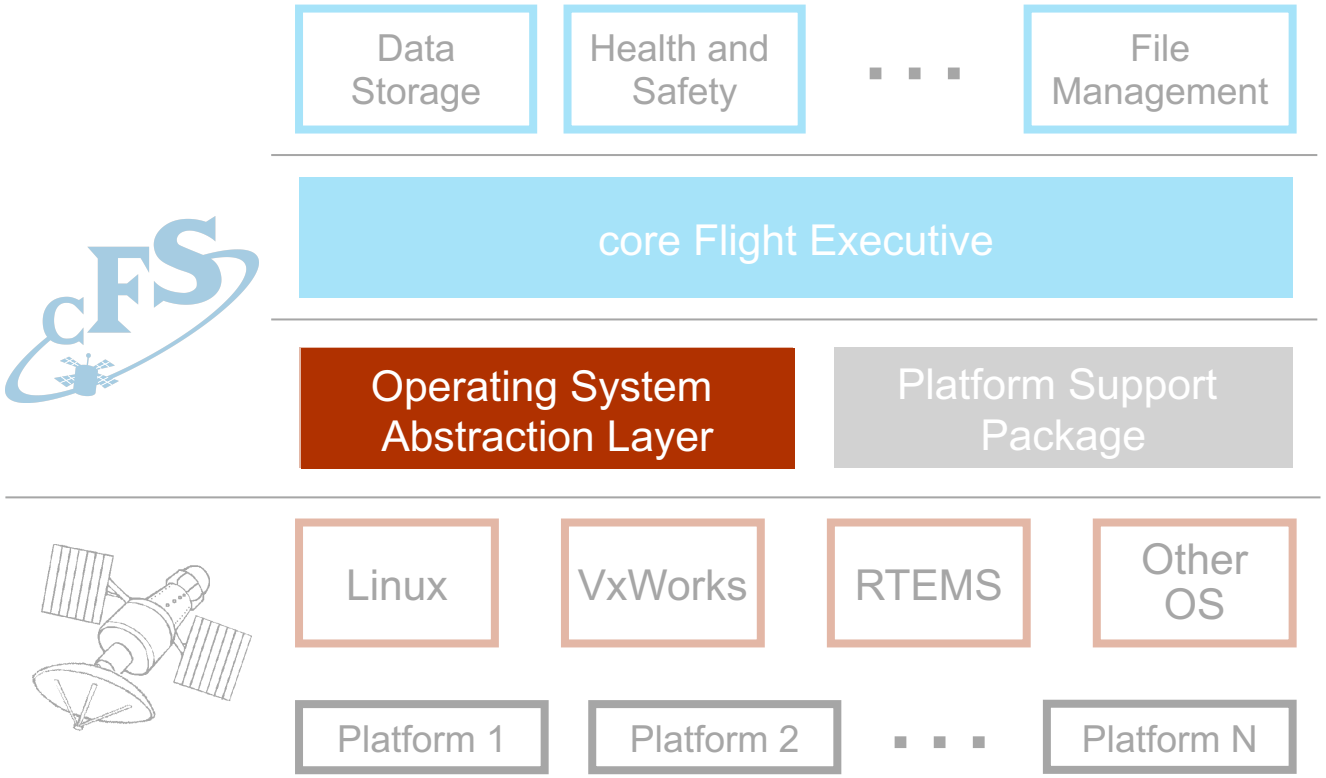
cFS Framework – The set of individual services, applications, tools, and infrastructure supported by the cFS open source community.

Platform Abstraction



The **Platform Support Package (PSP)** is a software library that provides a single Application Program Interface (API) to underlying avionics hardware and board support package.

Operating System Abstraction

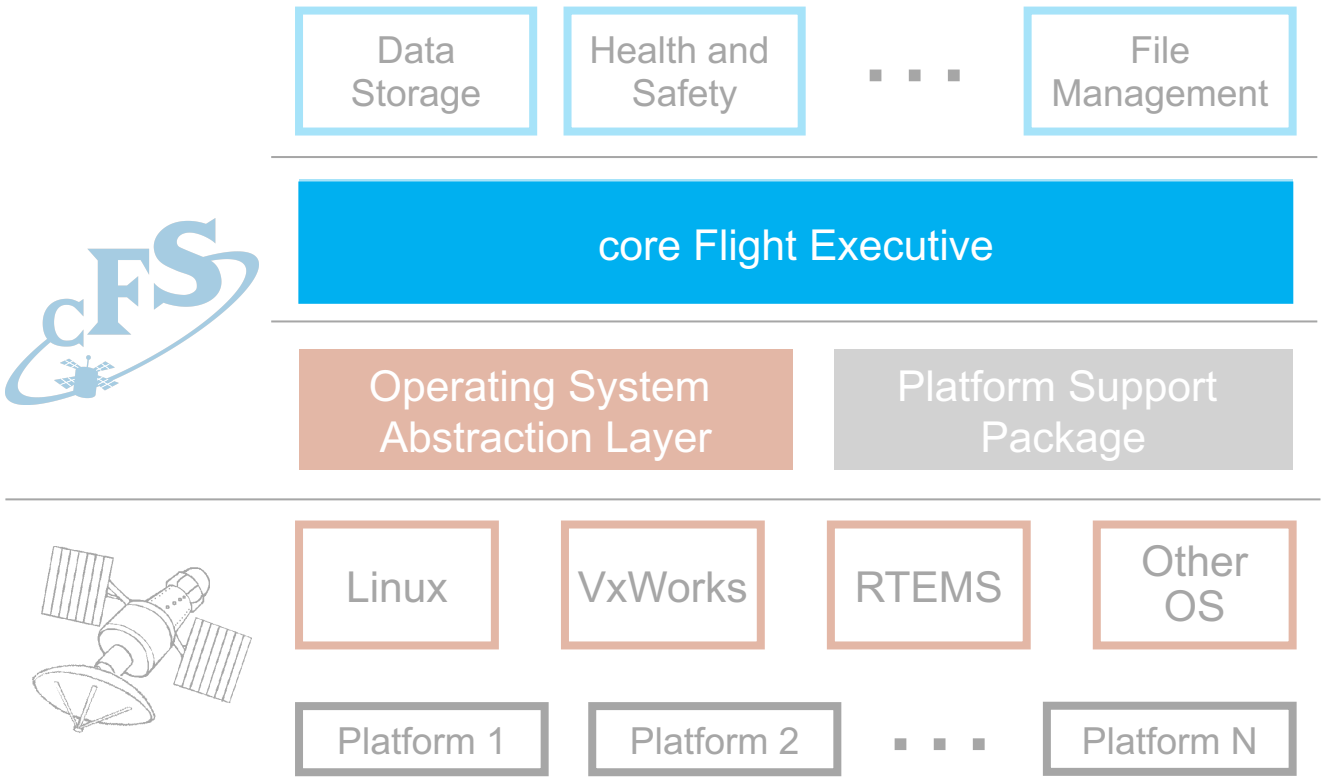


The **OS Abstraction Layer (OSAL)** provides a single Application Program Interface (API) to apps regardless of the underlying real-time operating system.

OSAL supports *Linux, VxWorks, RTEMS, and FreeRTOS**

*FreeRTOS port not maintained by NASA

Core Flight Executive



cFE creates an application runtime environment by providing services that are common to most flight applications:

Executive Services, software management

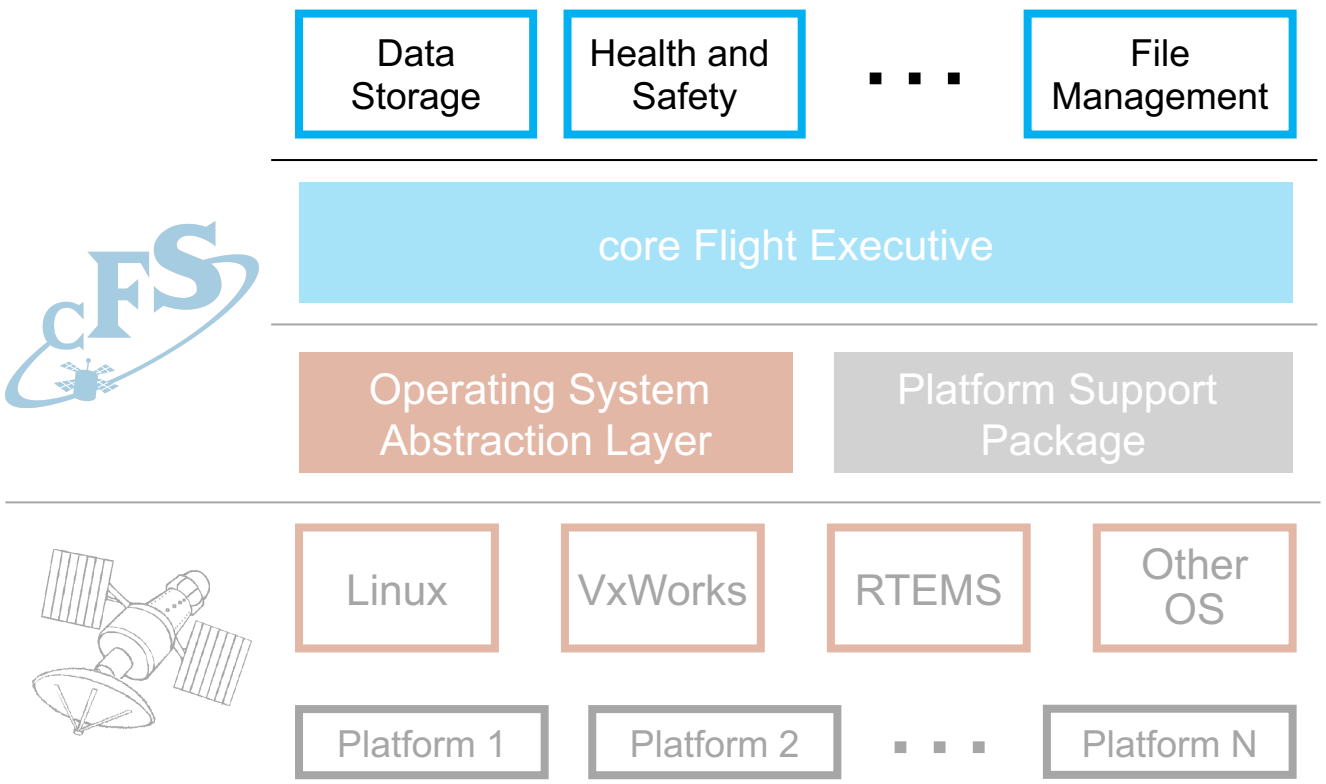
Event Services, onboard logging

Software Bus, pub/sub message bus

Table Services, table management

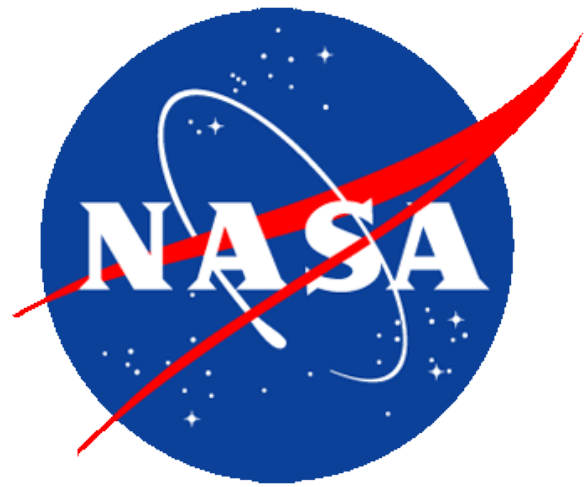
Time Services, time sync and distribution

Application Layer



Applications provide mission functionality using a combination of cFS community apps and mission-specific apps.

11 open-source apps maintained by NASA-GSFC


NASA