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# Sagittarius A* Small Satellite Mission: Capabilities and Commissioning Preview

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SSC21-I-05

LOFT ORBITAL

ORBIT LOGIC

20 YEAR ANNIVERSARY 2001–2021 EMERGENT Space Technologies

LeafLabs

Kitware

Raytheon Intelligence & Space

# Mission Overview

- **SSCI is leading a Defense Advanced Research Projects Agency (DARPA)-funded team launching a mission called Sagittarius A* on June 24, 2021 onboard SpaceX Transporter-2**
- **Summary of Mission Objectives**
  - Demonstrate key mission autonomy software technologies
  - Provide a testbed for on-orbit software developmental test & autonomous mission operations
  - Reduce risk for future constellation-level mission autonomy and operations.
- **Payload will fly on Loft Orbital shared-mission spacecraft**
  - Mission Reservation Agreement with Loft Orbital allocates an orbit-average processing time & imaging time per orbit, paid for by contract options
  - Autonomy payload has attitude control authority over the spacecraft bus and command authority of the imaging payload

Onboard mission management software performs fully-autonomous onboard request handling, resource & task allocation, collection execution, ATR, and space-based detection downlinking

# Sagittarius A* Primary Mission CONOPS

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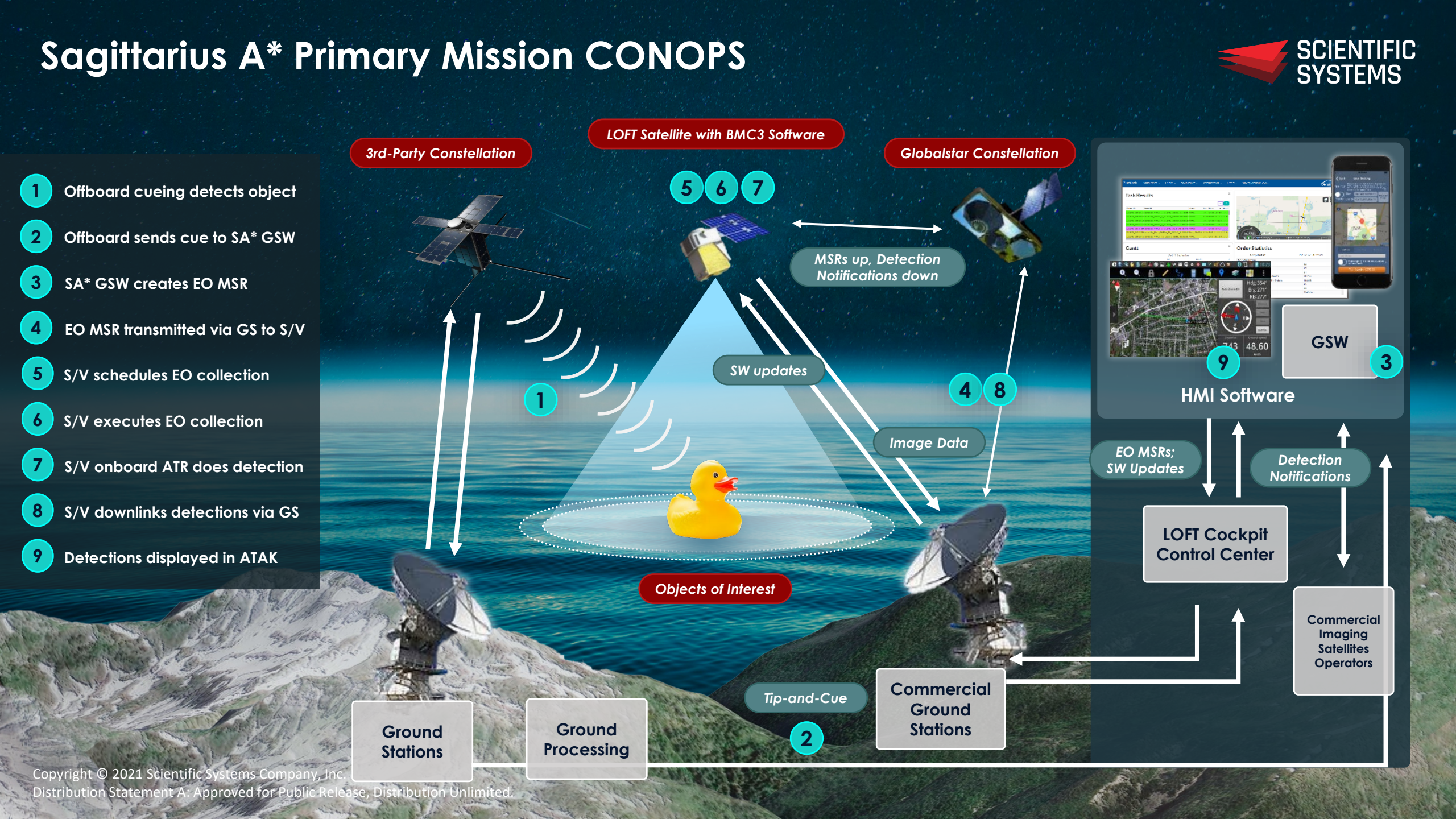
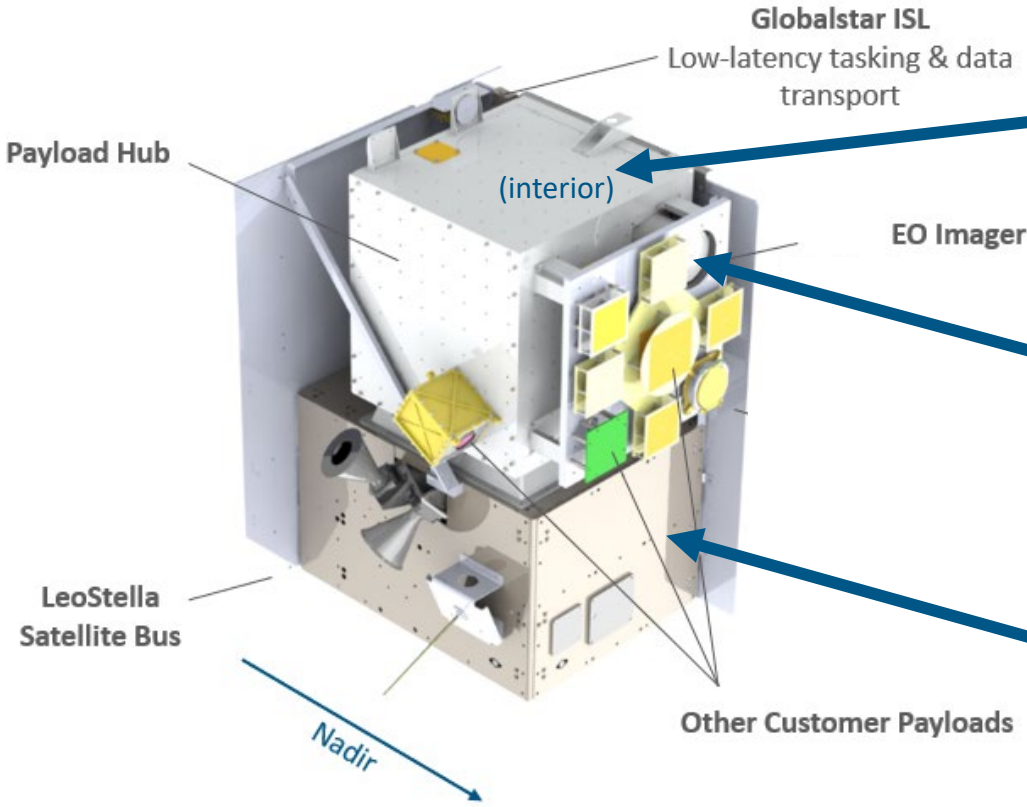
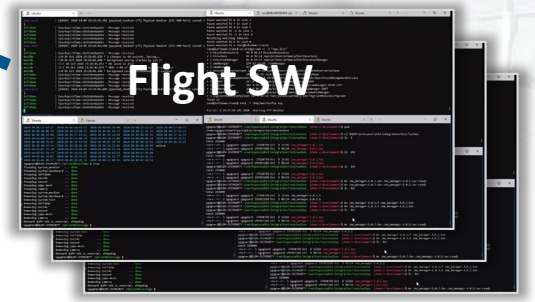
1. Offboard cueing detects object
2. Offboard sends cue to SA* GSW
3. SA* GSW creates EO MSR
4. EO MSR transmitted via GS to S/V
5. S/V schedules EO collection
6. S/V executes EO collection
7. S/V onboard ATR does detection
8. S/V downlinks detections via GS
9. Detections displayed in ATAK



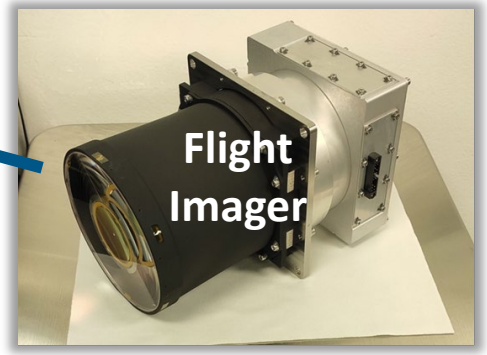
# Loft Orbital YAM-3 Spacecraft








SSCI autonomous Constellation Mission Management software hosted on an onboard processor housed within the Payload Hub





Mission software includes onboard tasking & execution, ML-based Automatic Target Recognition (ATR), and on-orbit software update capabilities

**SSCI system will fly on Loft Orbital YAM-3 shared LEO satellite mission**

**100 kg spacecraft owned and operated by Loft Orbital**

# CFC-400 & Communications Resources

- **Innoflight CFC-400 Onboard Mission Processor**
  - Rad-tolerant MPSoC, 0.5U CubeSat form factor
  - Receives GPS, time, and other data from the bus & imager
- Any app conforming to a C++ / Python SDK can be uploaded, connected to onboard message buses, & operated from ground


Innoflight CFC-400

| Parameter | Baseline Resources |
|---|---|
| Max Power Draw | 15W |
| CPU | Quad-core ARMv8 x64 @ up to 1.2 GHz |
| RAM | 2Gb total, and SSCI apps use about 100Mb-200Mb |
| Persistent Disk Storage | 8Gb/16Gb |
| FPGA | ~550K Flip-Flops, ~4 MB Block RAM, 512 Mb Volatile RAM available |
| Operating System | Commodity Linux |

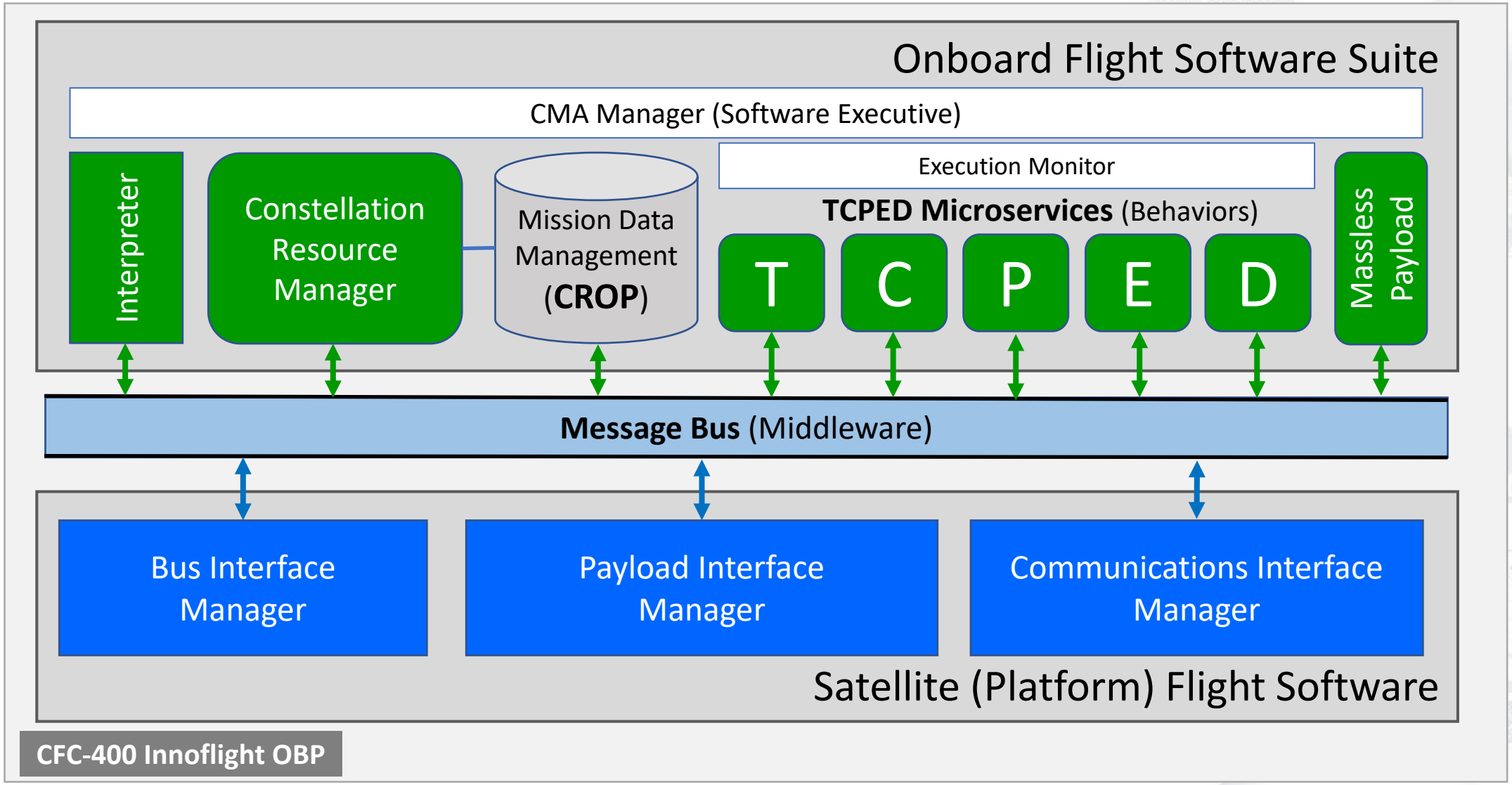
- **Onboard Communications**
  - GlobalStar low-rate duplex inter-satellite link (ISL) for low rate tasking and status monitoring throughout nearly all of the YAM-3 orbit, all 24/7/365
  - Ground station links:
    - S-band for Telecommand (TC)
    - X-band downlink for TC/TM and mission data
    - UHF backup
  - Large files of 10s to 100s of Mb can be uploaded in standard operations via file sharding across multiple passes.
  - Data Latency
    - Payload Data Latency from on-orbit collection to SSCI servers expected to be <= 120 minutes.
    - Globalstar ISL low-rate data is near-real-time

# Mission Management Software

SSCI's Collaborative Mission Autonomy is a fully-decentralized, edge-based, hardware-agnostic, event- and data-driven autonomy architecture & flight software that enables dynamic composition of mission event chains (i.e. pipelines of TCPED-type work items) executed across teams of satellites up to constellation scales

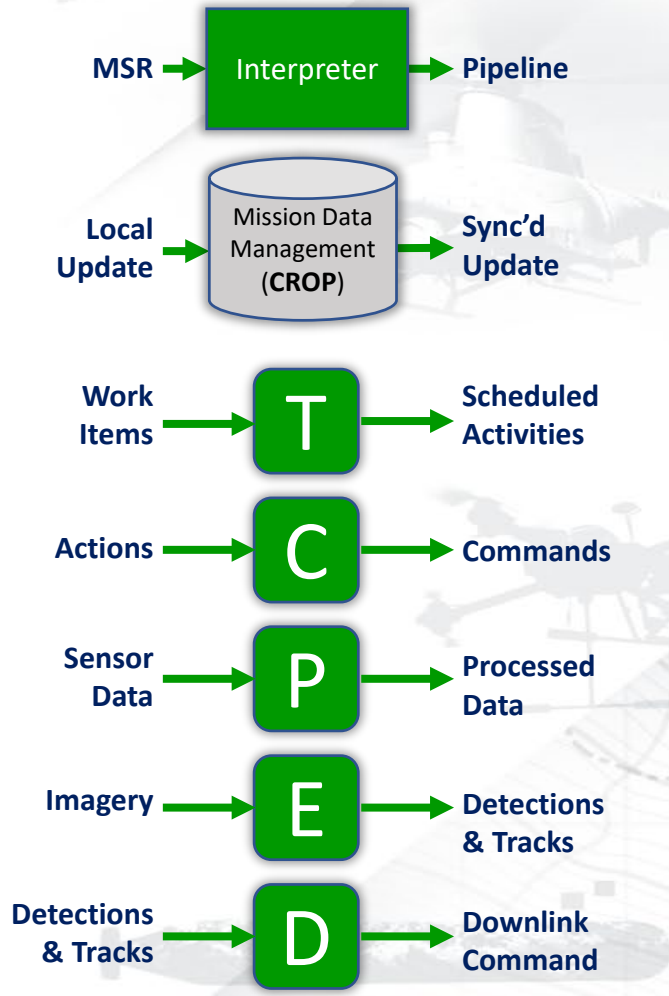
- **Technical Demonstration Objectives**
  - Autonomous management of bus, payload, and processing/exploitation resources to satisfy a user's Mission Service Request
  - Autonomy software benchmarking on COTS, limited-SWAP, commodity onboard mission processors
  - Ability to update mission flight software (FSW) during on-orbit operations.
  - Autonomous tipping and cueing using offboard ISR resources and onboard Machine Learning-based ATR
  - Execution and test of third-party "massless payloads", i.e. software plugins developed using our Software Development Kit
- **Mission Value & Impact**
  - On-orbit demonstration of critical technologies for Proliferated LEO autonomous mission Command, Control, and Communications (C3)
  - Hardware agnostic mission autonomy software flown on this single spacecraft can operate on heterogenous buses & payloads and scale across full satellite constellations
  - Risk reduction for constellation-scale responsive multi-mission self-tasking and resource optimization, product dissemination, multi-domain capabilities, and resiliency

# Mission Management Software



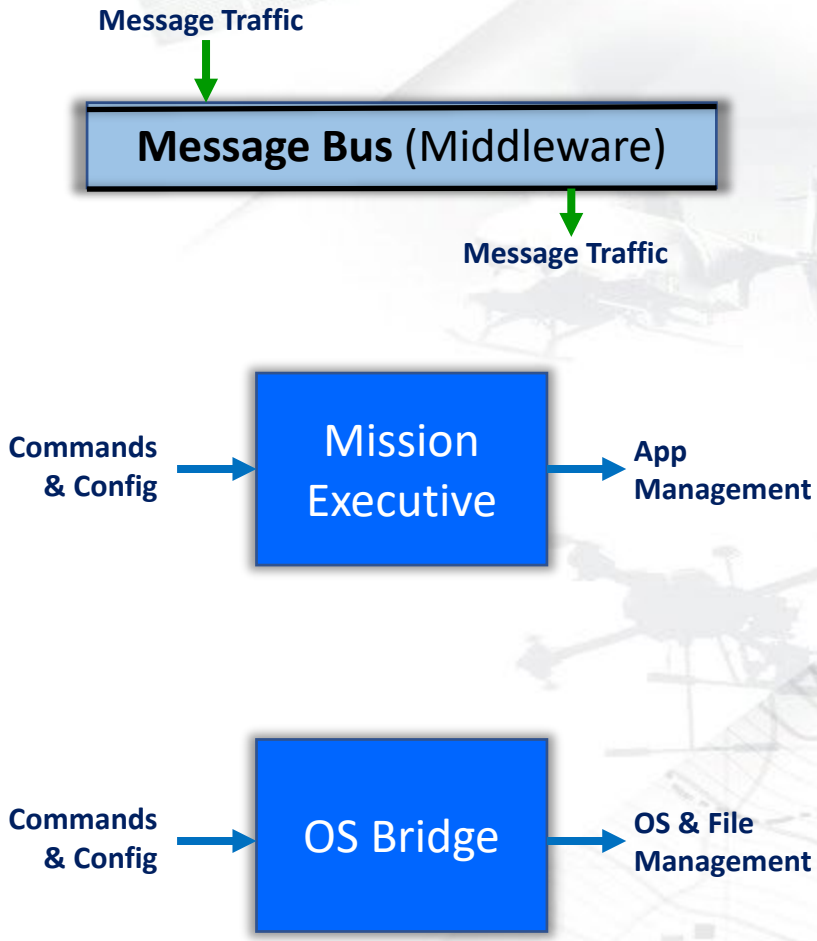
# Mission Management Software Microservices

- **Interpreter**
  - Semantic-level Mission Service Requests (MSRs) are sent to the satellite and decomposed onboard into Pipelines of sub-tasks (Work Items), in a very different manner from traditional collection planning task decks
  - Pipelines are dynamic, inherently handle task dependency trees, and can spawn additional Pipelines
- **Common Relevant Operating Picture (CROP)**
  - Pipelines are stored onboard in the Common Relevant Operating Picture (CROP) database with their status
  - Pipelines are distributed among offboard sources (and future additional satellite nodes) via lightweight CROP synchronization algorithms to enable tip-and-cue, distributed processing, and decentralized planning and execution.
- **Tasking (Planning)**
  - Performs access computations, resource & task self-allocation/self-optimization, and can be configured to account for priorities & resource limitations including satellite access, power management, storage, and comms availability.
  - Performs receding horizon planning based on latest CROP data at each cycle
- **Execution**
  - Performs collection, including health- & status-aware commanding to specific bus & payload interfaces
- **Processing**
  - Entails sensor data reformatting, transfer, and publication to other onboard systems including potential filtering & thresholding
- **Exploitation**
  - Exploits processed data, and includes Machine Learning-based ATR, and can easily integrate other exploitation algorithms
- **Dissemination**
  - Handles mission data & product dissemination, including for ISL-based downlinking over Globalstar

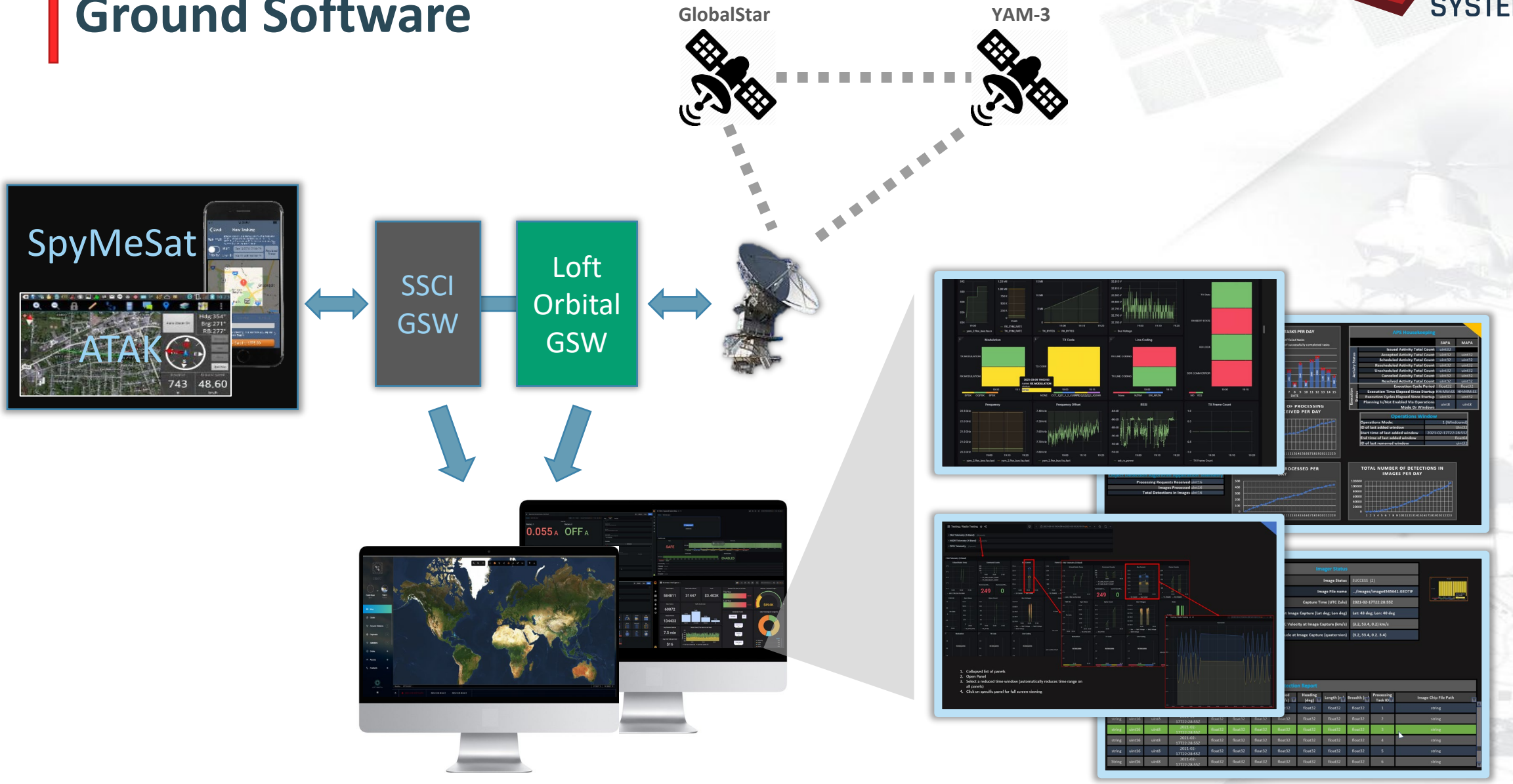


# Infrastructural Flight Software

- **Software Development Kit & Middleware**
  - Mission Management Software is implemented as a set of microservices communicating via an onboard middleware message bus
  - Middleware includes a Software Development Kit (SDK), which allows 3rd-parties to develop applications and upload for full interoperability with the satellite & mission autonomy
- **Mission Executive**
  - Manages the applications on the mission processor, and is responsible for starting, stopping, and monitoring applications
  - Enables onboard software update configuration control via configuration settings that specify the multiple OS & mission software application installations
  - Runs at boot, and performs Fault Detection & Correction (FDC) behavior, including app monitoring and response to app failures
- **OS Bridge & FTP server**
  - Critical enabler for updating the FSW & OS on-orbit
  - Enables an innovative shell-like command capability (termed Direct Mode) by SSCI operators on the ground during ground contact
  - Responsible for fielding commands from operators to interact with the CFC-400 OS and file system and to execute predefined scripts
  - Monitors compute resource usage



# Ground Software



# Integration & Test Approach

Component Subteam

Component Subteam

Component Subteam

Component Subteam

Component Subteam

Component Subteam

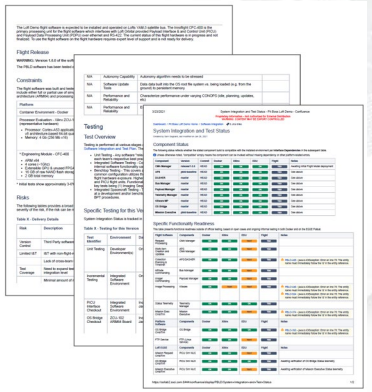
Scrum-of-Scrums

ATLASSIAN

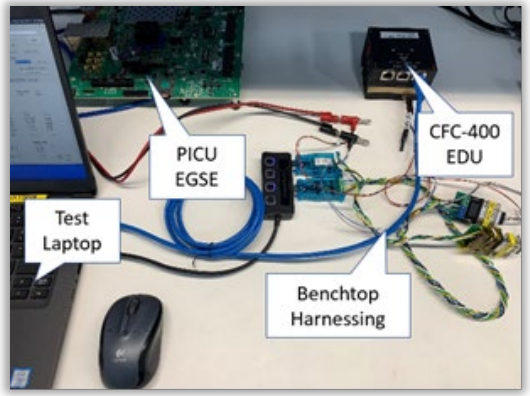
Integration Repo

docker

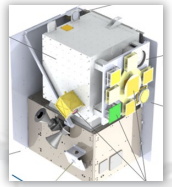
ARM Development Board



Qualification Test Plans




Benchtop Test Environment



YAM-3 and CFC-400 FLT

Increasing Test Environment Fidelity

# Status and Path Forward

- **Testing Status & Qualification**
  - Mission Management flight software was qualified on various test environments & test sets
  - Bus, Imager, interfacing hardware & software qualified at bus provider & Loft Orbital locations
- **Launch & Commissioning**
  - Spacecraft shipped 5/21/21, integrated to LV stack 5/28, and will be launched 6/24 on SpaceX Transporter-2 from Cape Canaveral
- **Flight Operations**
  - Initial operations performed by Loft Orbital for contact, checkouts, and bus commissioning
  - Follow-on operations for SSCI payload checkout & mission software checkout
- **Demonstrations**
  - On-orbit demonstrations will include imaging, onboard ATR space-based detections, tip-and-cue from commercial data sources, and on-orbit software updates for additional applications
  - Additional demonstration & on-orbit testbed opportunities exist for variety of missions