SPHERES and Astrobee
Space Station Robotic Free Flyers

ISS National SPHERES/Astrobee Facility
Date

Jose V. Benavides
With support from SPHERES & Astrobee project teams
NASA Ames Research Center

Agenda

- SPHERES
- Astrobee Project overview
- Current status & upcoming activities
- On-orbit commissioning activities (FY18)
- Free Flyer external appearance
- Integrating with the Astrobee platform

Synchronized Position Hold Engage Reorient Experimental Satellites - SPHERES

- A Facility of the ISS National Laboratory with three IVA nano-satellites designed and delivered by MIT to research estimation, control, and autonomy algorithms
- Installed on ISS in 2006
- Managed by ARC since Fall 2010
- By working aboard ISS under crew supervision, it provides a risk tolerant Testbed Environment for Distributed Satellite & Free-flying Control Algorithms
  - Formation flight, Docking, Proximity Operations
- If anything goes wrong, reset and try again!
- The satellites can be reused
  - ✓ Replenishable consumables
  - ✓ Multiple test sessions assigned per year

Scott Kelly working with SPHERES in the Kibo lab

If you can't bring the space environment to the laboratory, take the laboratory to space!

Over 119 Test Sessions (600+ hrs. of Facility Console activities involving crew)
One of the most used and popular ISS National Lab Facilities

SPHERES Platform Capabilities

•Sensors

- Accelerometers, Gyroscopes, Ultrasonic ranging
- Smartphone Camera

•Actuator

- CO2 Propulsion, 0.2N of force possible

•C&DH

- 115kbps downlink to laptop
- Real-time interface to laptop Matlab runtime
- 400kbps real-time downlink to Mission Operations Center

•Expansion Port

- Provides an interface for integration with additional technologies
- Well documented ICD
- Currently used by several Payloads

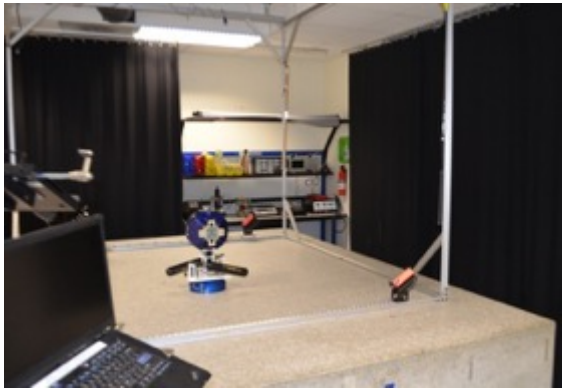
Diameter	8.3 in (0.2 m)
Mass	7.8 lb (3.5 kg)
Thrust (single thruster)	<1 oz (0.2 N)
CO_2 Capacity	6 oz (170g)

SPHERES Facility Labs

Flight Lab

International Space Station

Engineering Evaluation Lab (EEL)



Granite Lab

Mission Operations Center

Micro Gravity Test Facility (MGTF) Lab: Cradle/ Gimbal and Robotic ARM

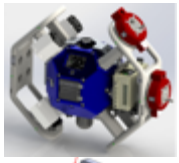
Microgravity Free-Flyer Technologies
past, present, & future

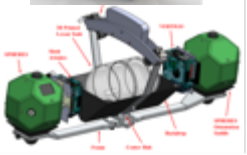
RINGS

SLOSH

Tether

Vertigo





UDP/HALO

SmartSPHERES

Interact

Zero Robotics

AERCam

PSA

SPHERES

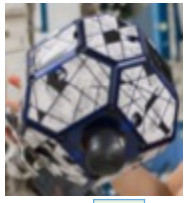
Astrobee

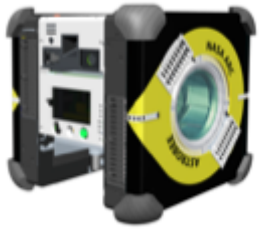
1996 - 2002

2000 - 2008

2006 - 2018

2018





TA02 In-Space Propulsion

TA05 Communication & Navigation

STEM Education

TA04 Robotics, Tele-Robotics & Autonomous

Avionics & Software Risk mitigation

SPHERES Facility Team

❑ Team

- Jose Benavides, Jose.V.Benavides@nasa.gov, PM
- Aric Katterhagen, aric.j.katterhagen@nasa.gov, Ops Lead
- Jonathan Barlow, jonathan.s.barlow@nasa.gov, Eng Lead
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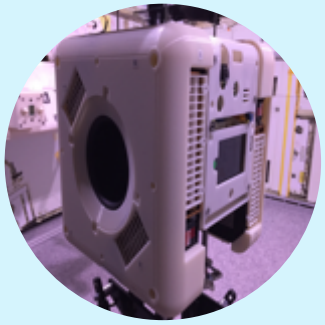
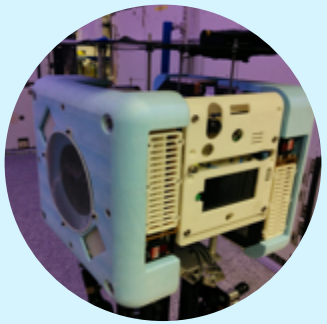
- Jose Cortez, jose.cortez@nasa.gov
- Robert Hanson, robert.s.hanson@nasa.gov
- Simeon Kanis, simeon.i.kanis@nasa.gov
- Don Soloway, Donald.i.soloway@nasa.gov

Facility Transition





SPHERES Operations	Astrobee Development & Build	Astrobee Commissioning	Astrobee Operations
12 Years (Est. 2006 -)	2 Years (CY 16 - 17)	1 year (CY 18)	6 Years (- 2024)
Major Tasks • ISS Operations • Consumables • Maintenance • Payload Support	• Infrastructure & Lab Upgrades • Integration & Test Support • Flight Build Support • Guest Science SW & Processes • Simulator Dev	• Operations Planning Products • On Orbit Install Checkout & Demo	• ISS Operations • Maintenance • Payload Support
SPHERES Support			Astrobee Support

Guest Scientist Program (GSP)

Overview

The GSP provides access to the source code, with examples, a SPHERES software simulator, and Operations support.

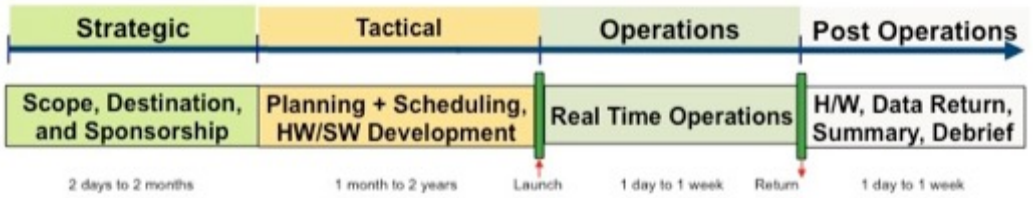
Technical Aspects

1. Download GSP from Sourceforge, including simulator
2. Dev and Test your software on the simulator
3. Test in Ames SPHERES Lab
4. Deliver Software and planning products to SPHERES Operations
5. Conduct test session aboard ISS

Operational Planning Aspects

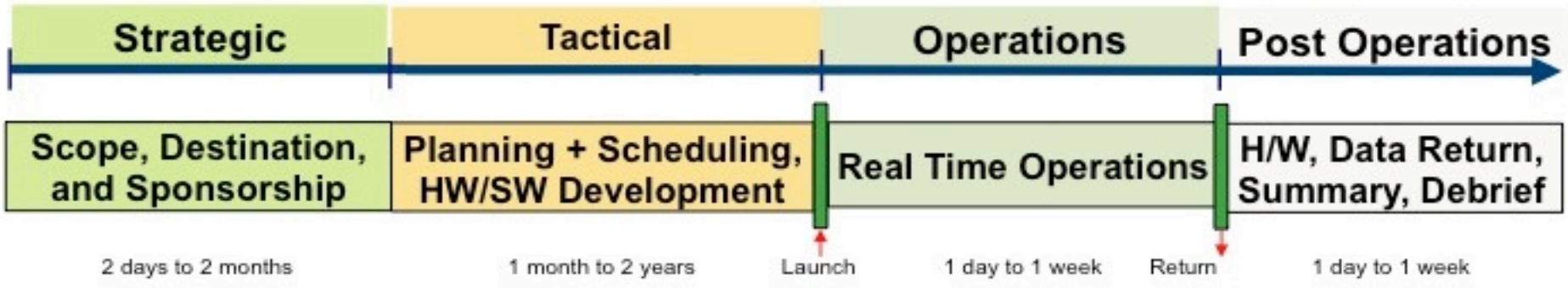
1. Deliver proposed investigation – one pager
2. SPHERES initiates request to schedule ISS Test Session
3. Generate all planning items required by ISS (e.g. Test Plan,)

www.nasa.gov/spheres/gsp



GSP Process

Overview



Operations: Functions

Ensure Facility Readiness for ISS Test Sessions

- All crew training now via Onboard Training (OBT) both English & Russian
- Crew procedure updates
- Coordinate with ISS Lead Increment Scientist and POIC Cadre
- Flight products on orbit (test plan, .spf, on-board training and review, etc.)
- Consumable (CO_2 Tanks and Batteries) refurbishment and resupply
- Support SPHERES directory/file maintenance

Real-Time ISS Test Session support

- Coordinate w/SPHERES investigators product development and delivery
- Support crew and POIC cadre real-time
- Conduct/coordinate crew conferences as needed
- Test session data and video management

Operations: Functions

Increment Planning

- PTP and 2-pager development, review, and update
- CEF support and submittal
- Timeline planning model review and update

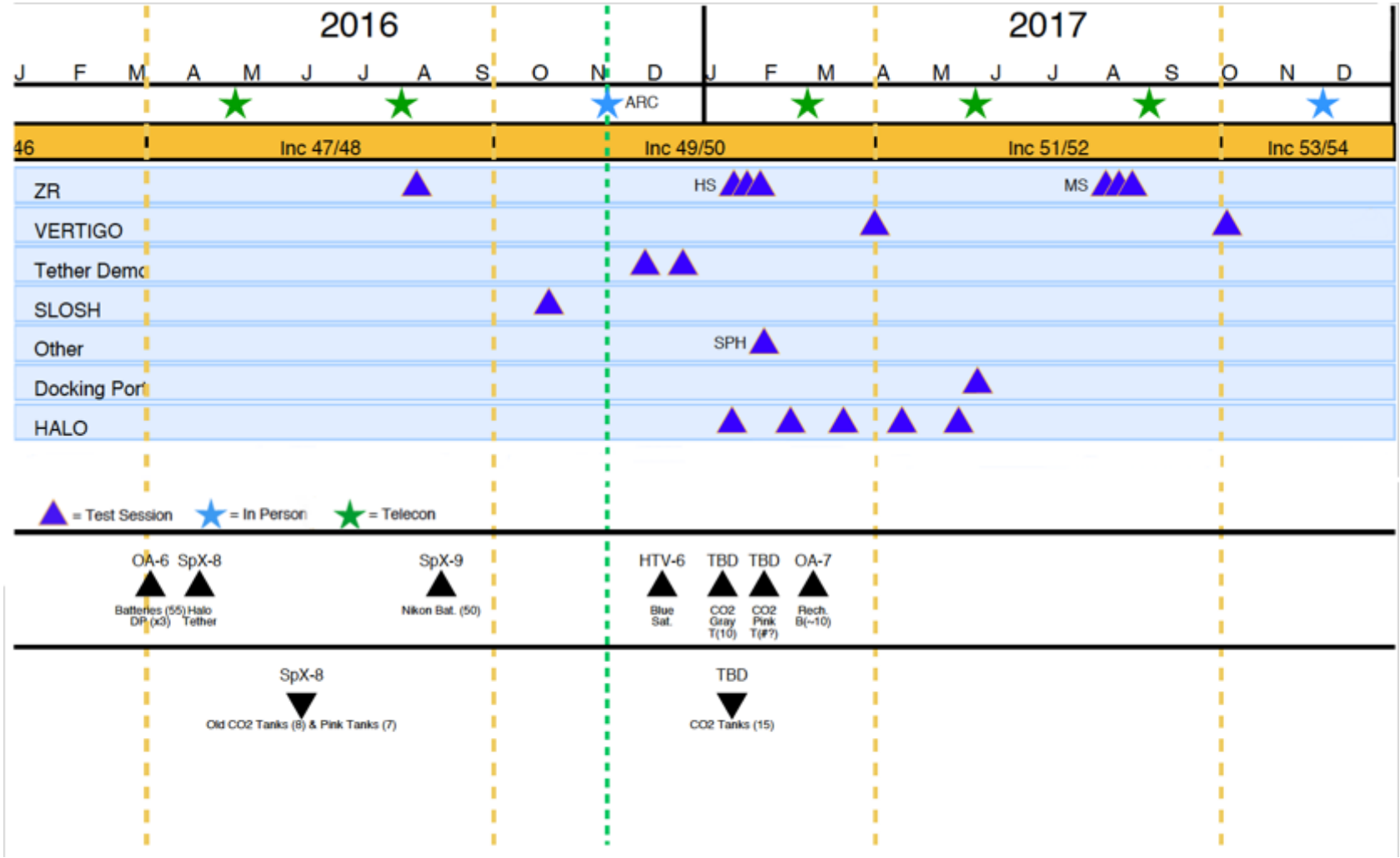
Safety and Verification Assessments

- Conduct Integrated Safety Assessments for all SPHERES payloads
- Conduct Integrated Verification for all SPHERES payloads
- Safety & Verification assessments for Battery/Tank launches/returns
- Complete Certification of Flight Readiness for ground systems and on-orbit hardware and operations products
- Conduct ISS Requirements Change Assessments to SPHERES Facility

Public Relations

- Maintain website, work with ARC PAO office to publish material on site

SPHERES Calendar



Blue Flight Repair

Astrobee Project Overview

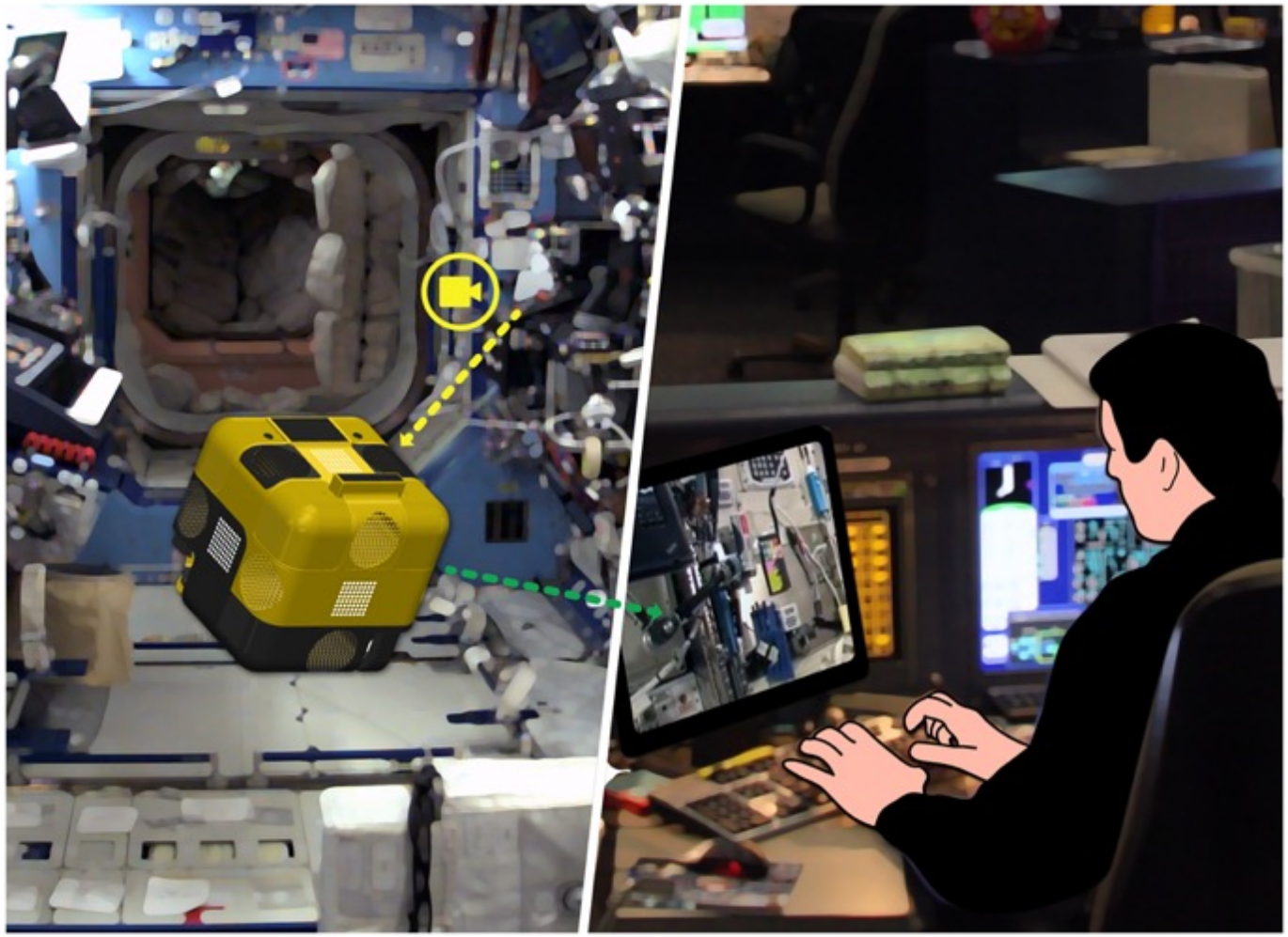
Project Summary

- Develop, test, deliver 2 free flying robots for ISS IVA use
- 3 year project (FY15-FY17) under Human Exploration Telerobotics 2 (HET2)
- 1 year (FY18) extension for on-orbit commissioning (just approved)
- Sponsor: Space Technology Mission Directorate, Game Changing Development Program
- Technology infusion to ISS payloads & operations

0g Robotics Research Facility

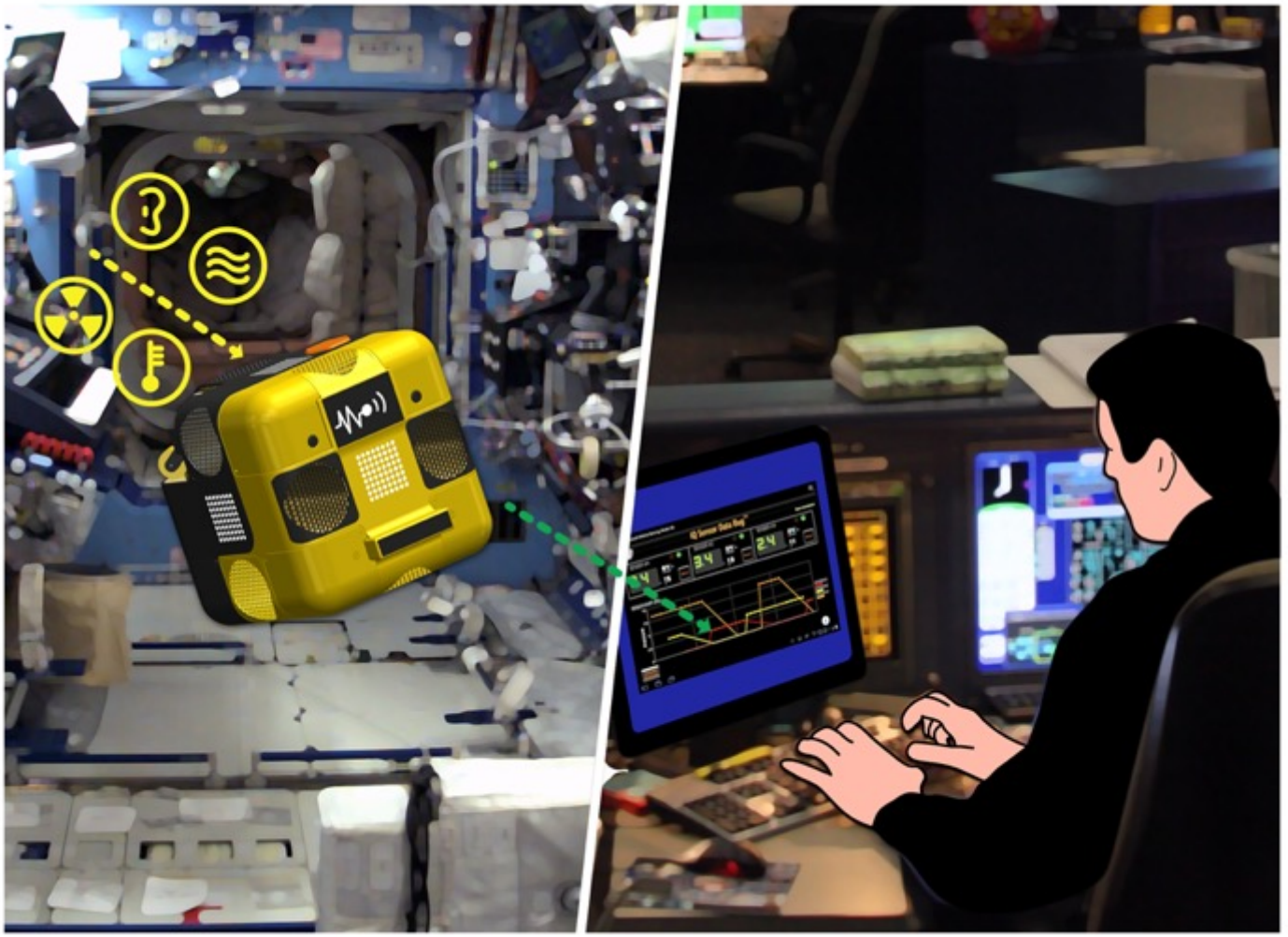
AES, Astrobee/SPHERES Program and users

Mobile Camera Tasks



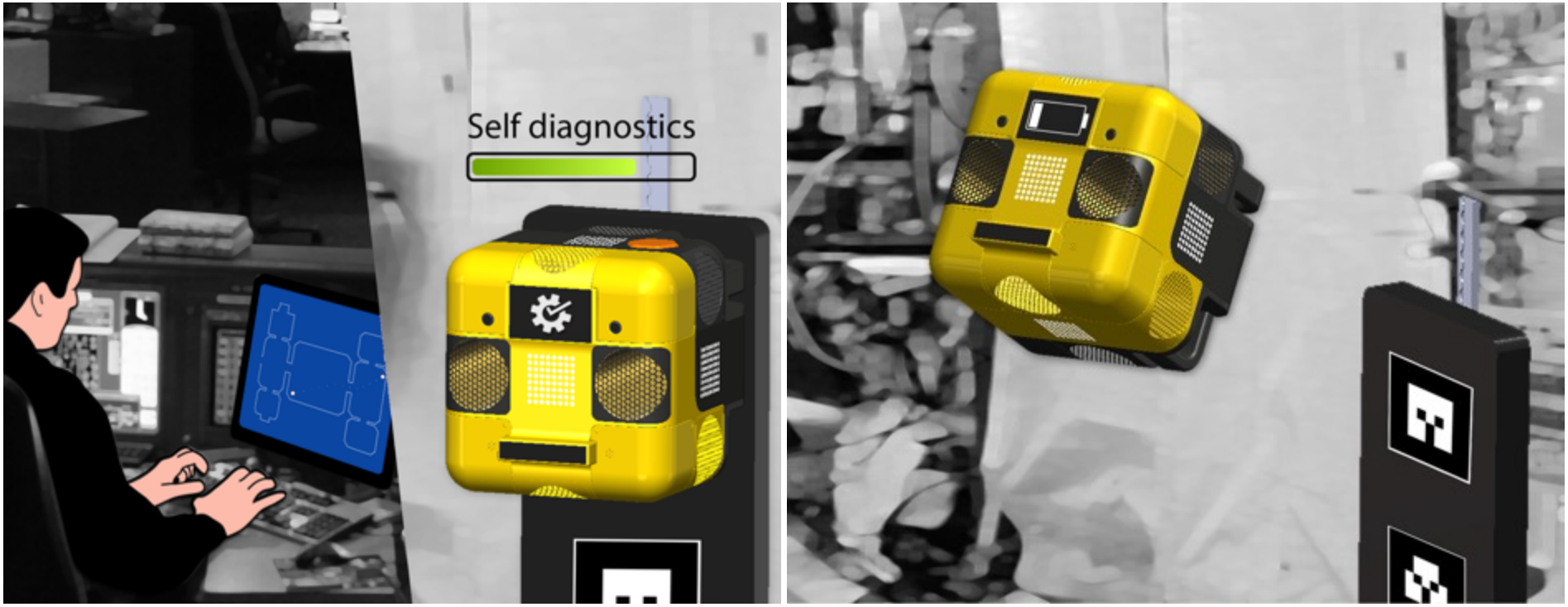
ISS Program, FOD, POIC

Mobile Sensor Tasks



ISS Program

Dock & Resupply

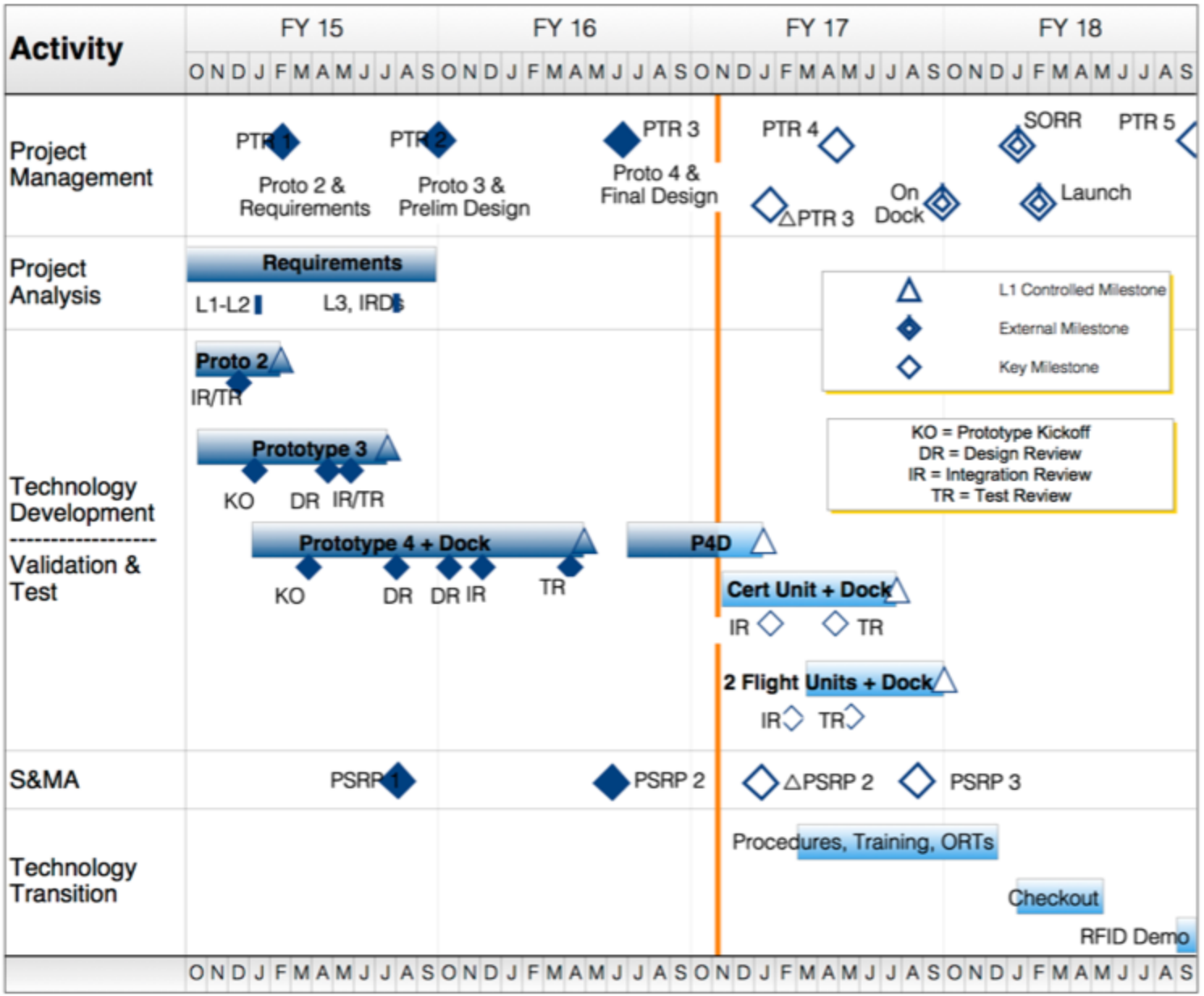


Automate consumable resupply

Minimize crew time

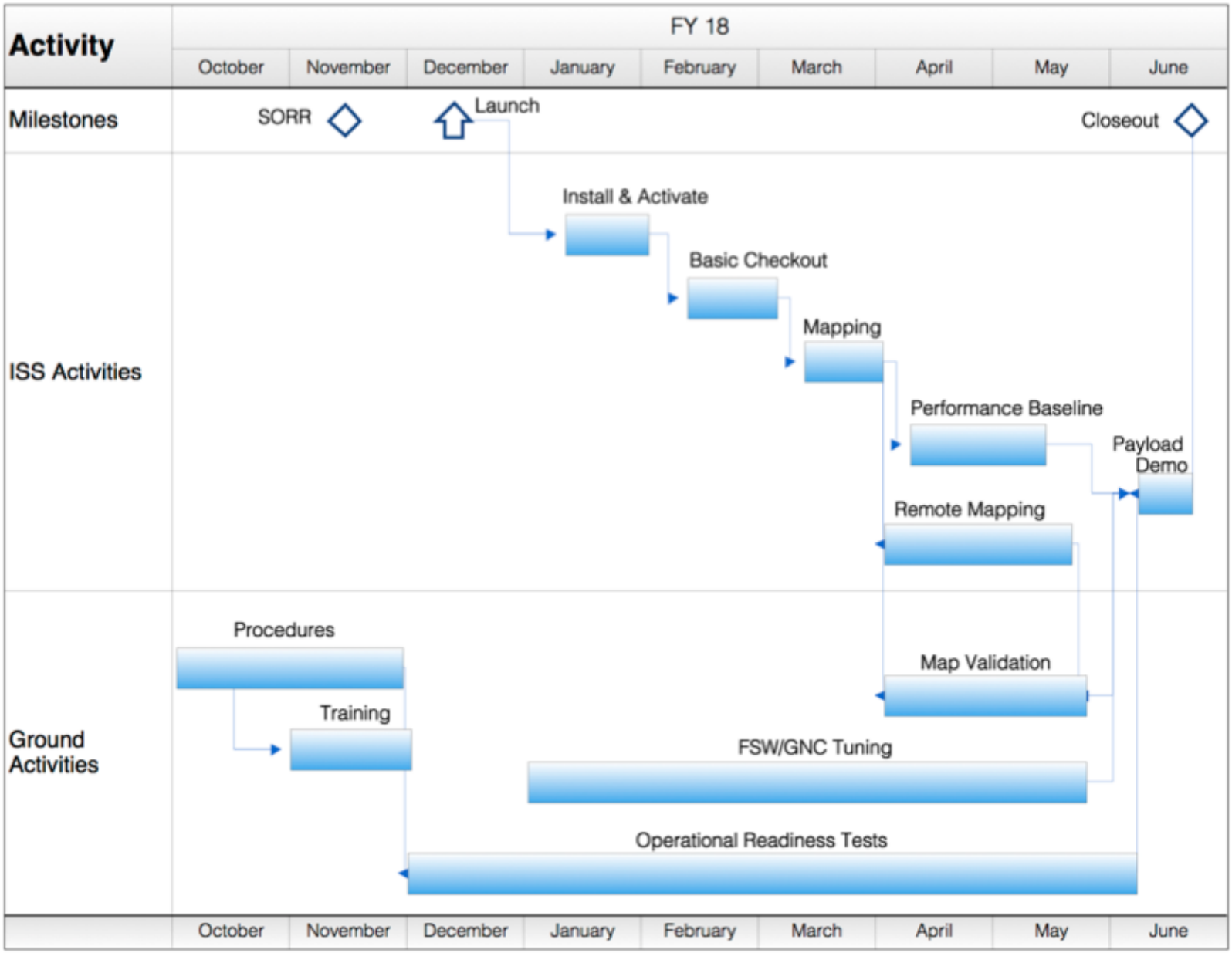
Current Status & Upcoming Activities

Schedule

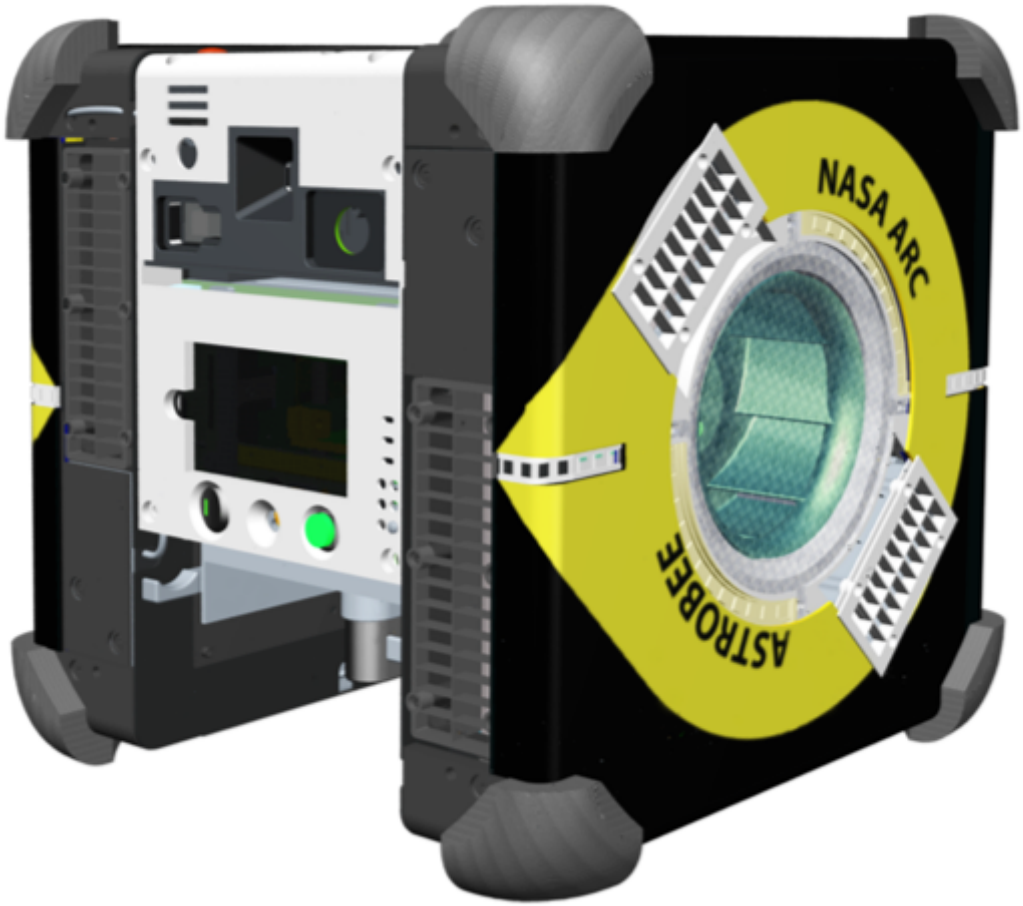

Activity
FY 15
FY 16
FY 17
FY 18
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
Project Management
PTR 1
PTR 2
PTR 3
PTR 4
SORR
PTR 5
Proto 2 & Requirements
Proto 3 & Prelim Design
Proto 4 & Final Design
△PTR 3
On Dock
Launch
Project Analysis
Requirements
L1-L2
L3, IRDs
L1 Controlled Milestone
External Milestone
Key Milestone
Technology Development
Proto 2
IR/TR
Prototype 3
KO
DR
IR/TR
KO = Prototype Kickoff
DR = Design Review
IR = Integration Review
TR = Test Review
Validation & Test
Prototype 4 + Dock
KO
DR
DR
IR
TR
P4D
Cert Unit + Dock
IR
TR
2 Flight Units + Dock
IR
TR
S&MA
PSRP 1
PSRP 2
△PSRP 2
PSRP 3
Technology Transition
Procedures, Training, ORTs
Checkout
RFID Demo
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S

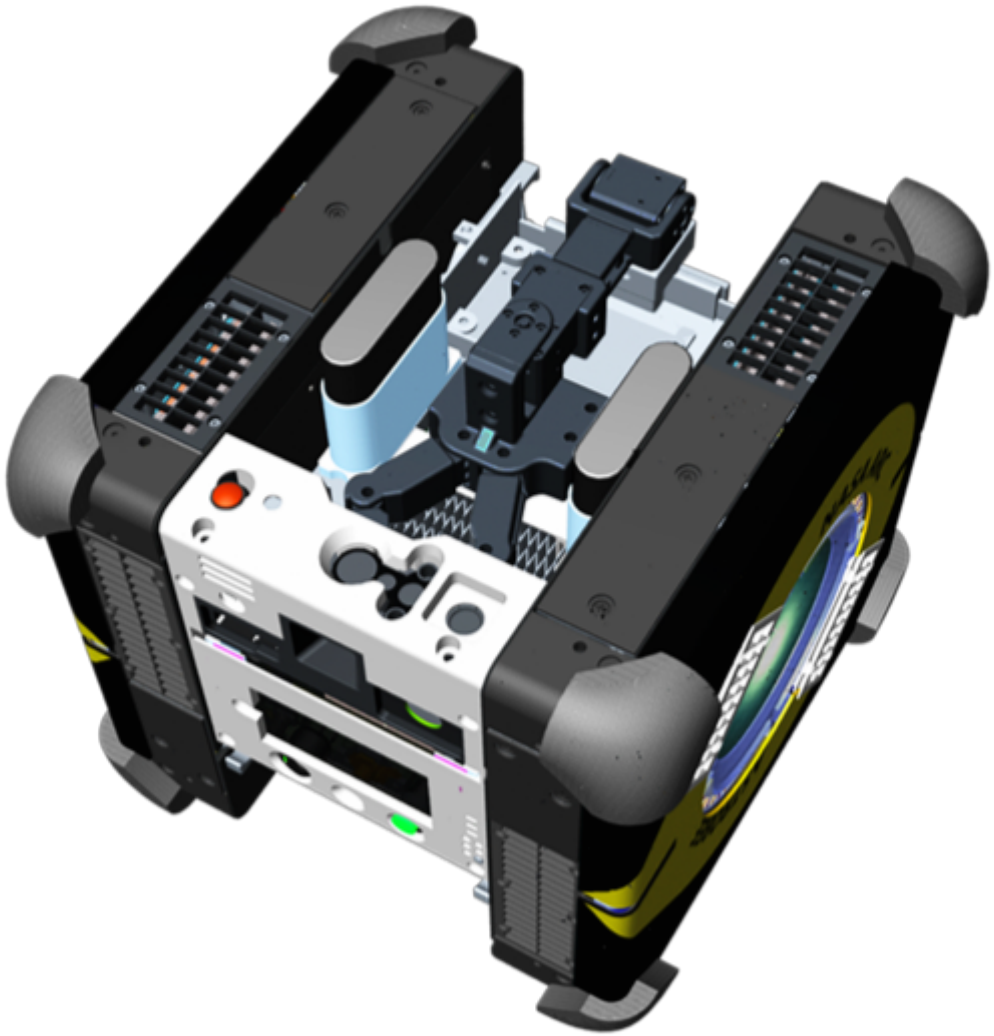
Commissioning Activities

FY18 Activities



External Appearance


NASA ARC
ASTROBEE



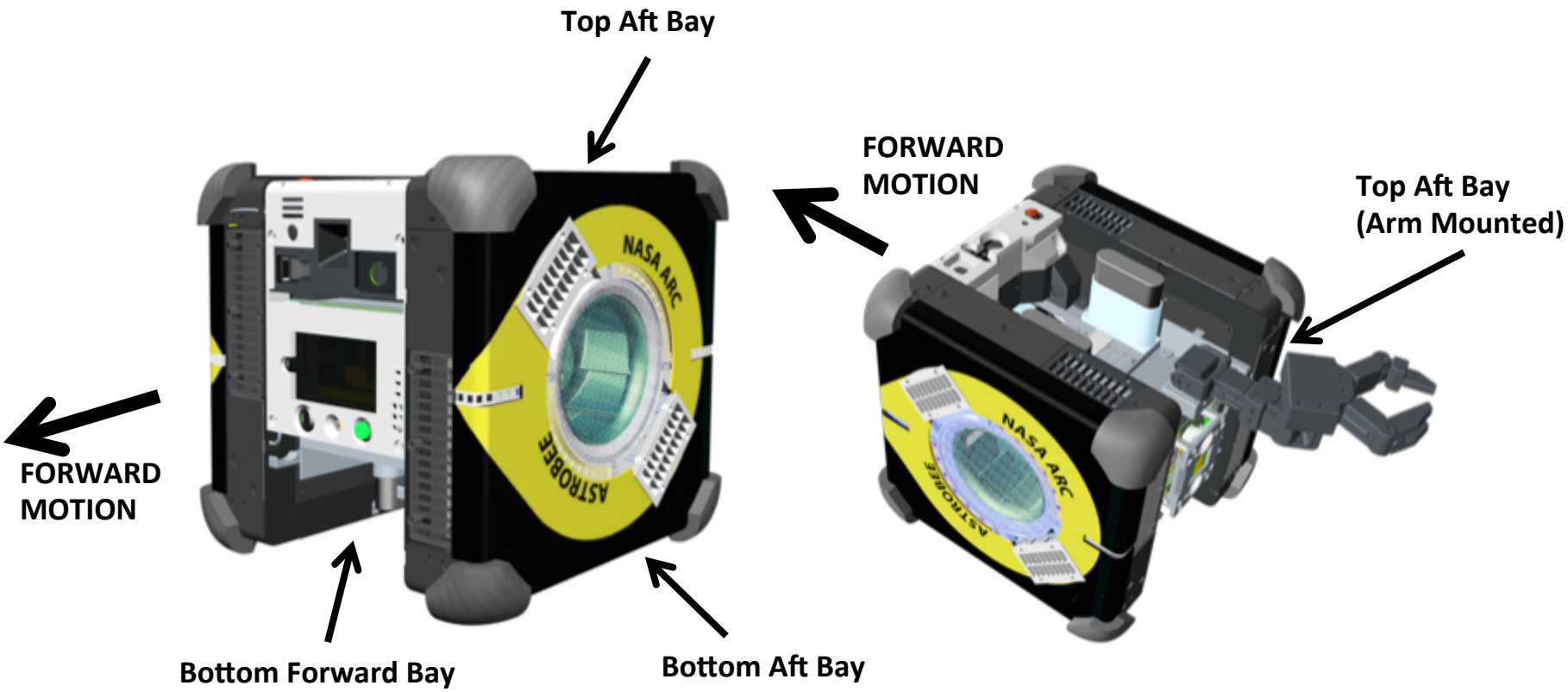

NASA ARC
ASTROBEE

Integrating with the Astrobee Platform

Integration Overview

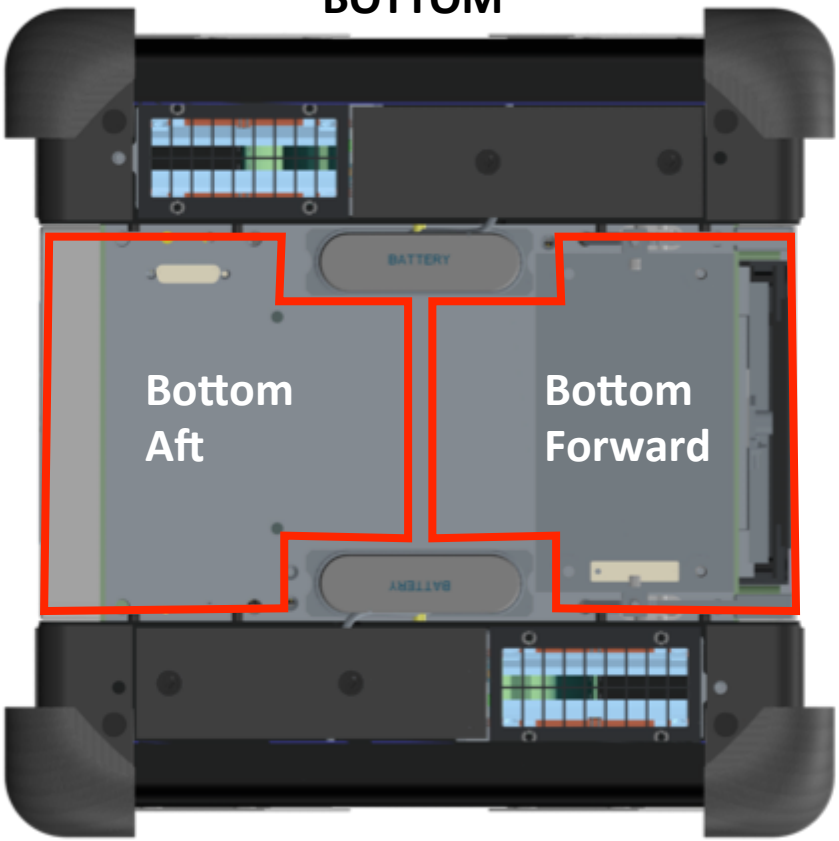
- Look for draft Guest Science Guide document before the end of this year
- Will quickly mention a few points about integration now

Payload Bays

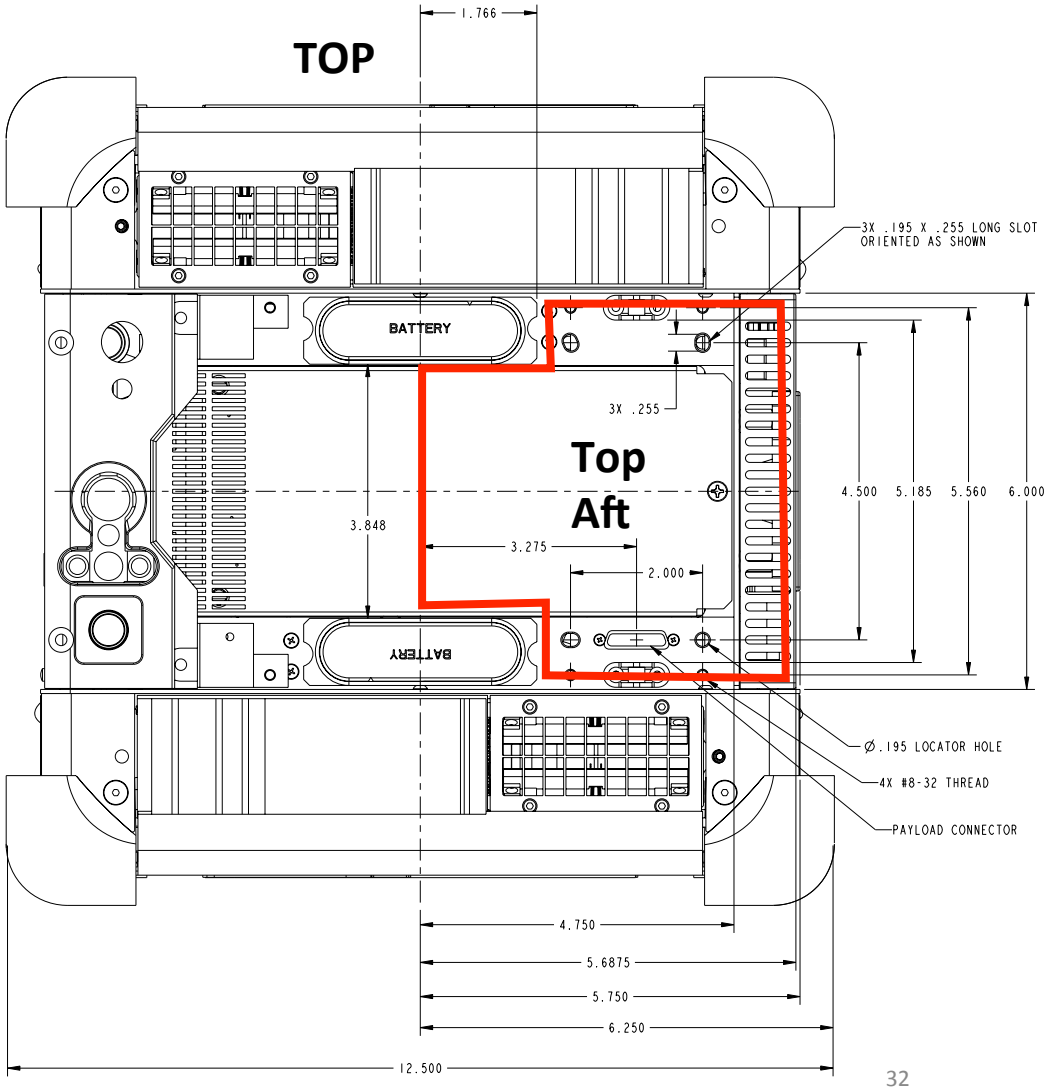


Payload Bays

BOTTOM



TOP



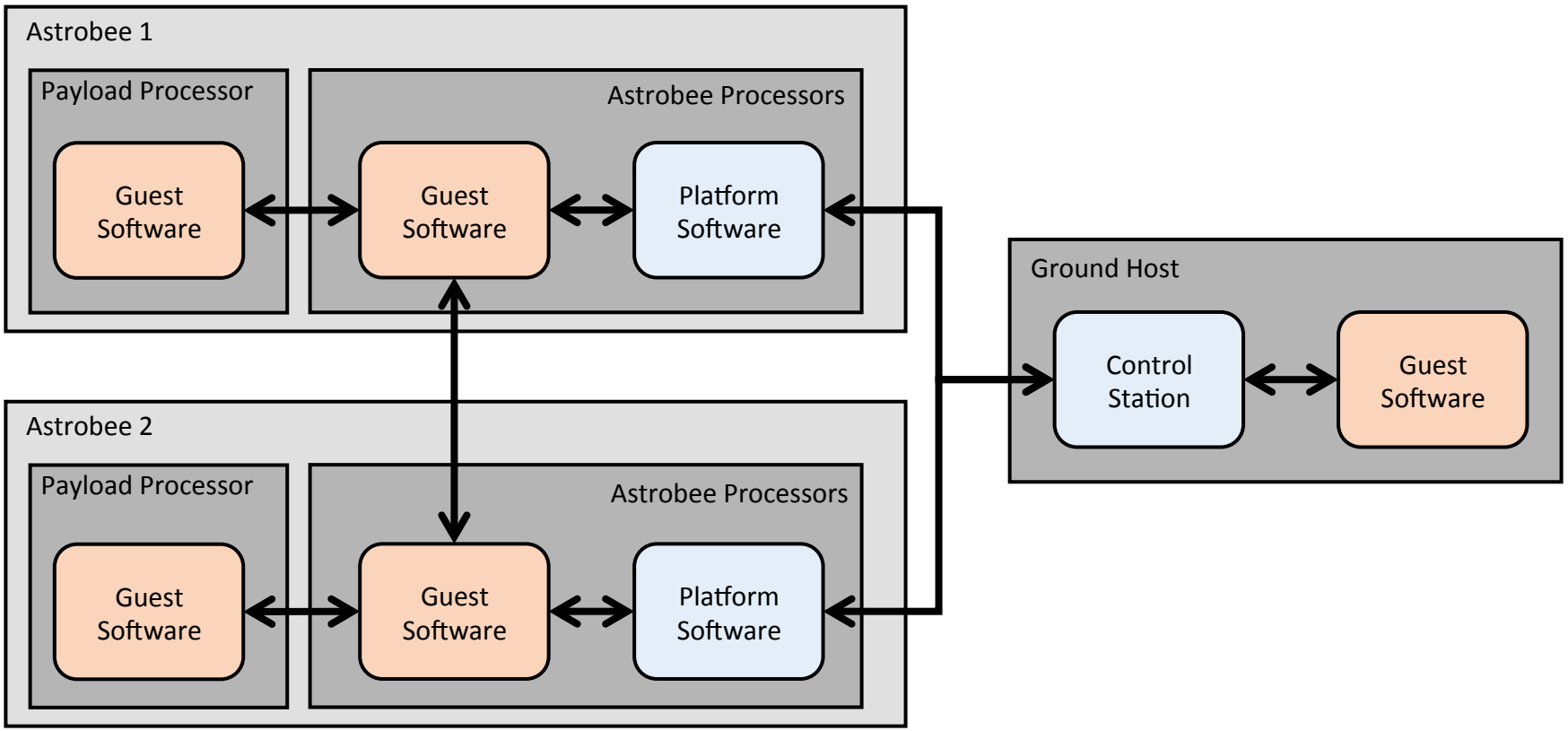
Concept of Operations

- Payload bays: can occupy a single bay, the two adjoining bays on the bottom, or all three
  - (Or use a non-standard mounting approach)
- Primary vs. background experiment
  - Primary experiment controls Astrobee platform
  - Background experiments can run during other activities, as long as they don't interfere
    - Example: Sensor that passively collects data
- Can minimize crew involvement, require crew oversight, or even involve crew in experiment
- Payloads that "play nice" with resources are expected to get more experiment time

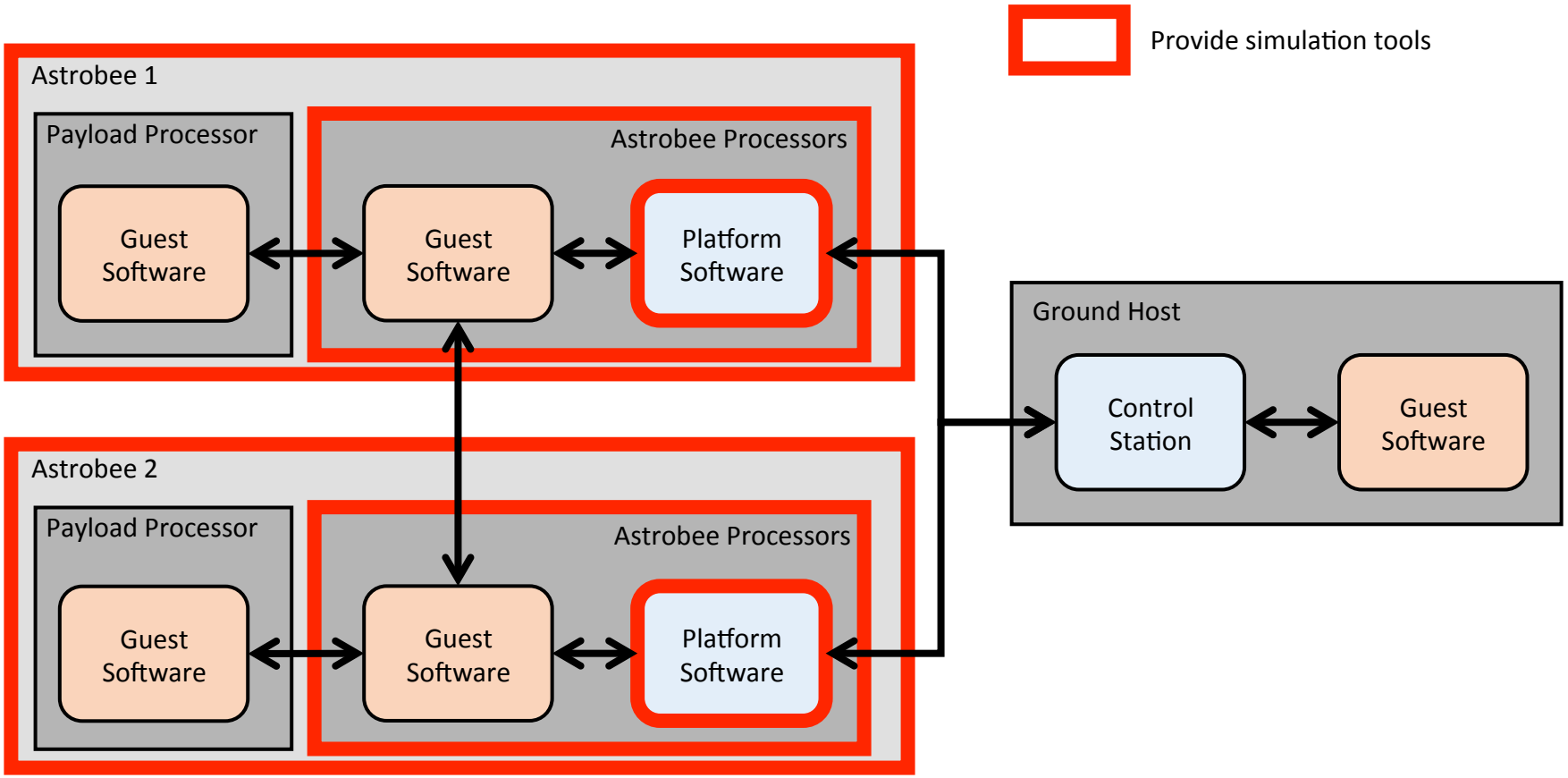
Payload Design Considerations

- Mechanical Interface
  - Payload bay
    - Quick-disconnect levers preferred
    - Four-bolt pattern option also available
  - Odd payloads also possible
    - REALM thin flexible antennas on propulsion modules are our first example
    - Large payloads could potentially connect to dock adapter in “tractor trailer” configuration
- Electrical Interface
  - USB to Astrobee High Level Processor
  - Draw power from 14.4VDC Vbatt (preferred) or USB
  - COTS milspec blind-mate connector
- Inertial properties and forces
  - Guidelines on maximum impact to mass and CG
  - Keep disturbance forces small and steady
    - Thermal air flow exhaust
    - Rotating parts – gyroscopic moment, drag torque, spin-up/spin-down
    - Reaction forces generated by moving articulated parts like arms
- Thermal interface
  - Don’t plan on using Astrobee core as a significant heat rejection path
  - Thermal insulation layer at payload bay surface may be advisable

Software Interfaces



Software Interfaces



Onboard Computing

- **Low Level Processor** (LLP): Linux/ARM, Dual core
  - Runs high frequency control loop
- **Mid Level Processor** (MLP): Linux/ARM, Quad core
  - Runs absolute localization algorithms, obstacle detection, sequencer, communications
  - Heavy processing power used by vision
- **High Level Processor** (HLP): Android/ARM, Quad core
  - Interface with Science Camera and Touch Screen Display
  - Encodes video with dedicated hardware
  - **Runs guest science code**

Astrobee Robot API

- Standard approach
  - Guest science Android/Java app running on HLP communicates via ROS (rosjava) with platform software running on MLP
  - Commanding: Guest app uses restricted vocabulary of high-level commands, sent via ROS to onboard executive
  - Telemetry: Full access to onboard ROS telemetry streams
  - Multi-robot: WiFi network routes are available between the HLPs of different free flyers; all multi-robot coordination is up to guest science software
  - Communication to payload: Your Android app can control USB link to your device
  - Communication to ground: Pack your telemetry data point into a generic ROS guest telemetry message
- Alternatives (more custom -> more effort and more risk)
  - Modify platform software if needed (e.g. tight control loops)
  - Can use Android NDK if C++ is preferred rather than Java
  - Many other possibilities

We Want You!

- The primary use of Astrobee is to be a research platform
- It's useless without compelling guest science experiments
- We are here to support you (simulator, facilities, ISS ops development, etc.)

Backup

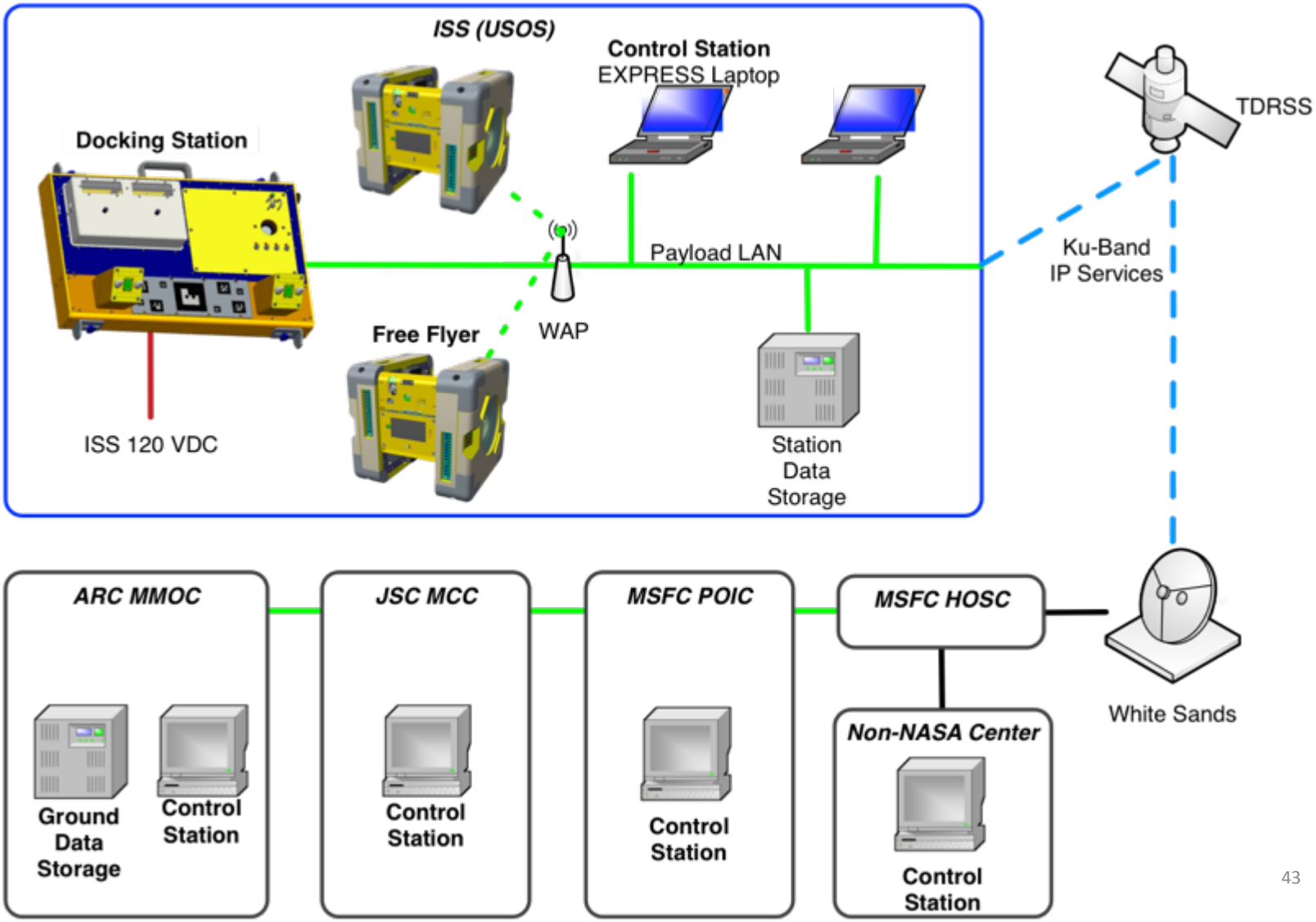
Prototype 4D

- Upgrading existing P4C
  - New central structure
  - EPS board, SpeedCam, crew interfaces, WiFi antenna
  - New prop module servos and PMCs
  - Perching Arm
  - Dock berthing post
  - FM, visual odometry, command dictionary, GNC improvements
  - Control Station

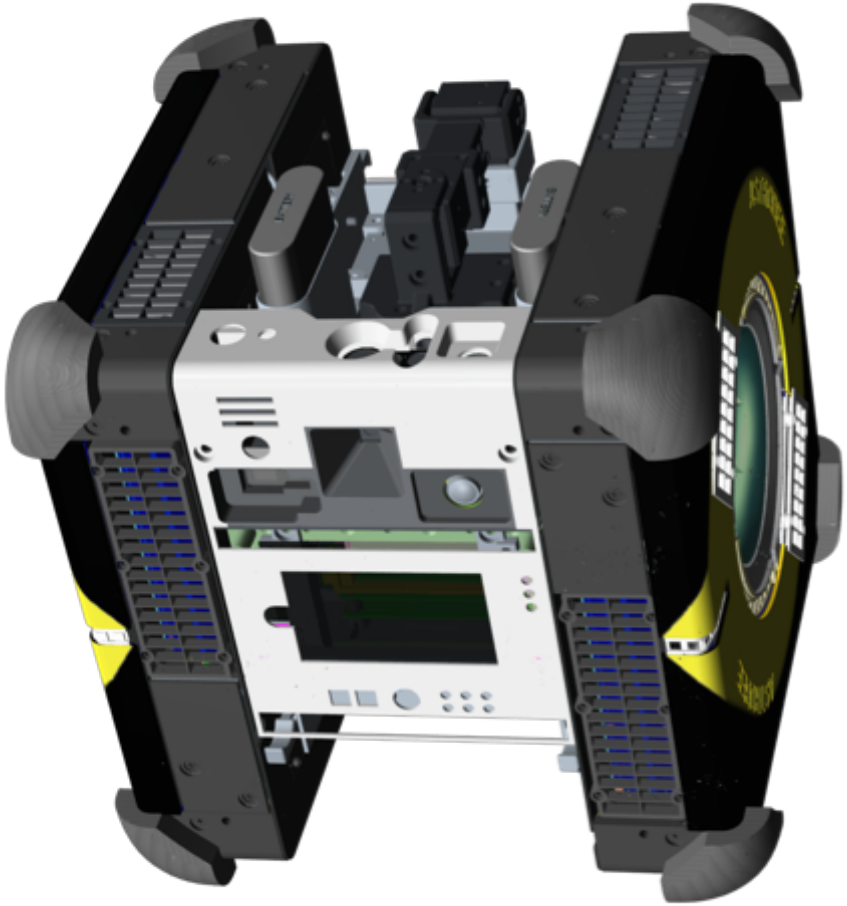
Risk Reduction

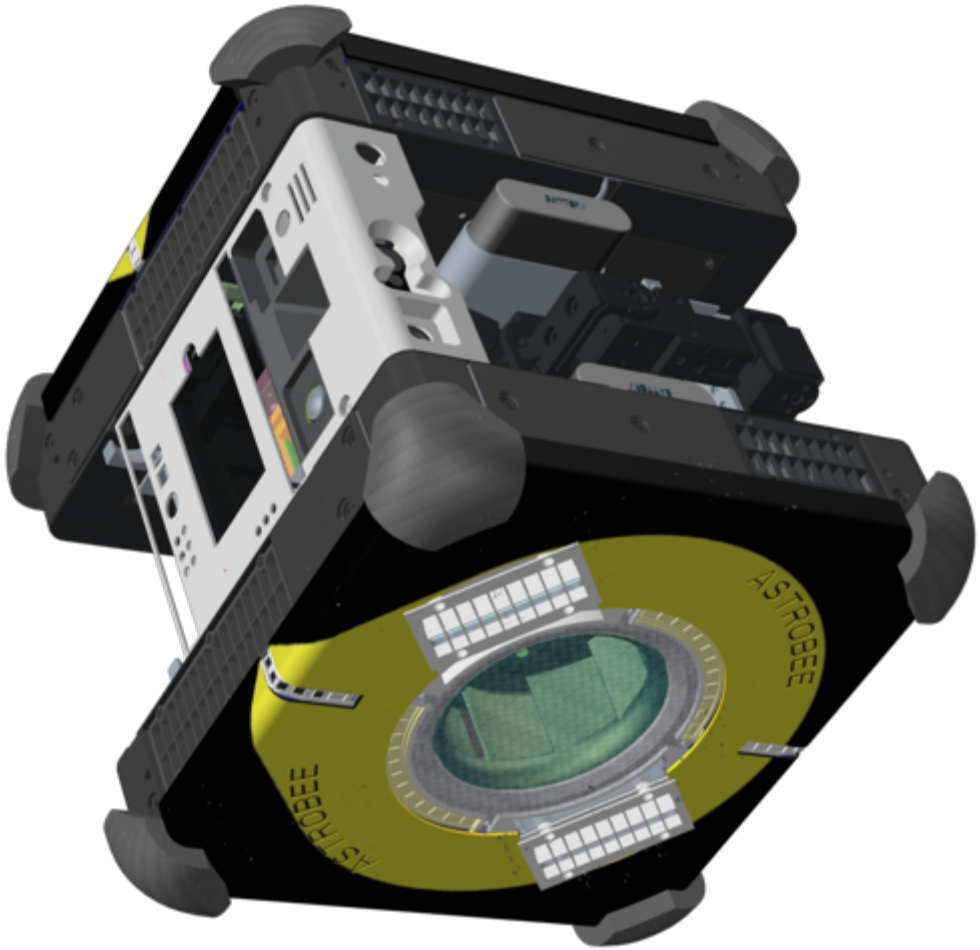
- Single propulsion module not integrated into P4D
  - New nozzles
  - Structural design
  - Bumpers
  - Outer skin
  - Signal LEDs
  - LED control board

System Architecture

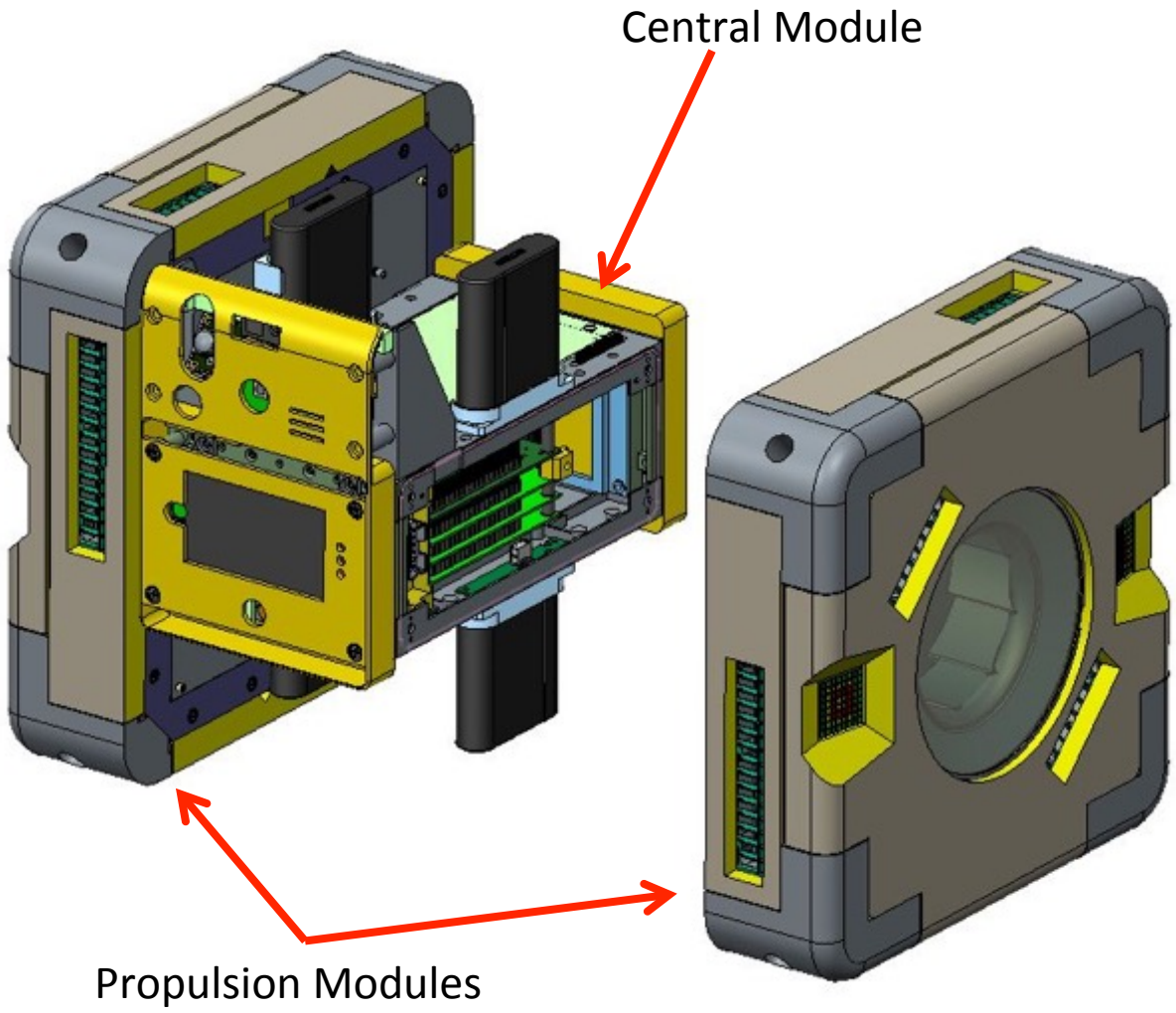


Astrobee

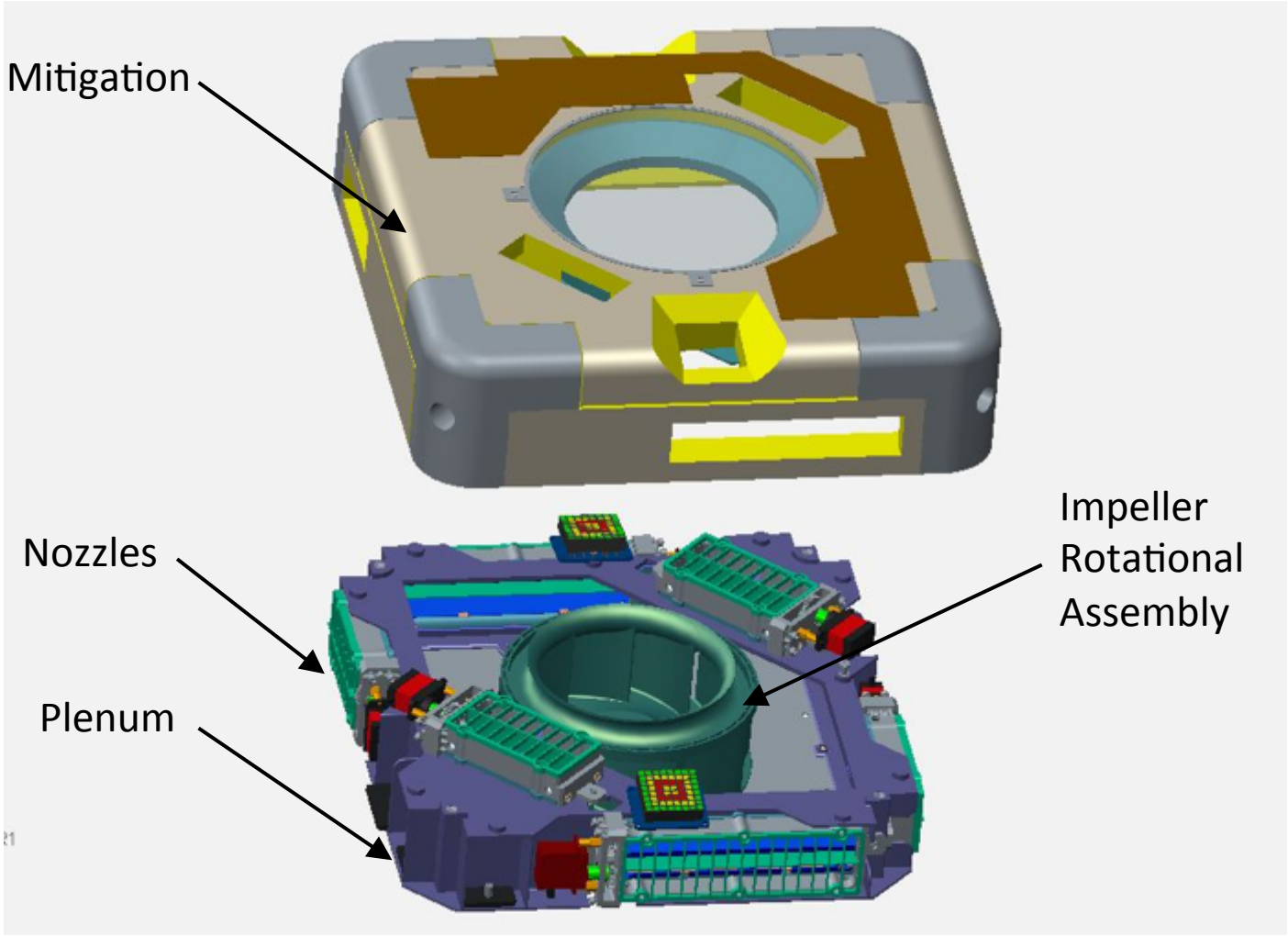




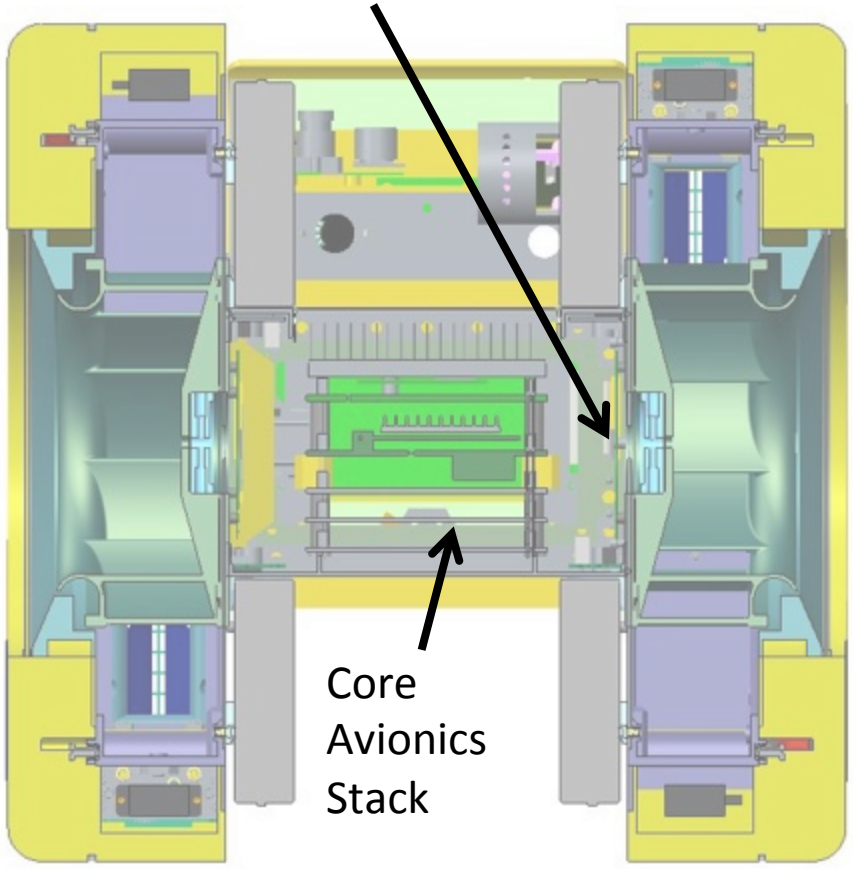
Astrobee Modules



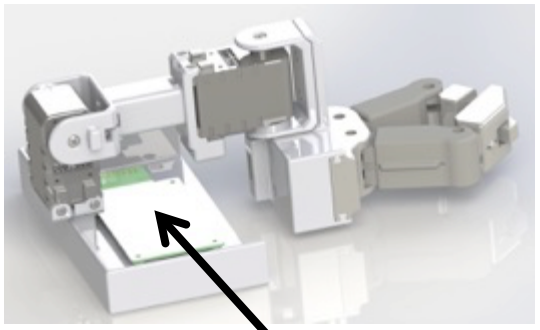
Prop Module Assembly



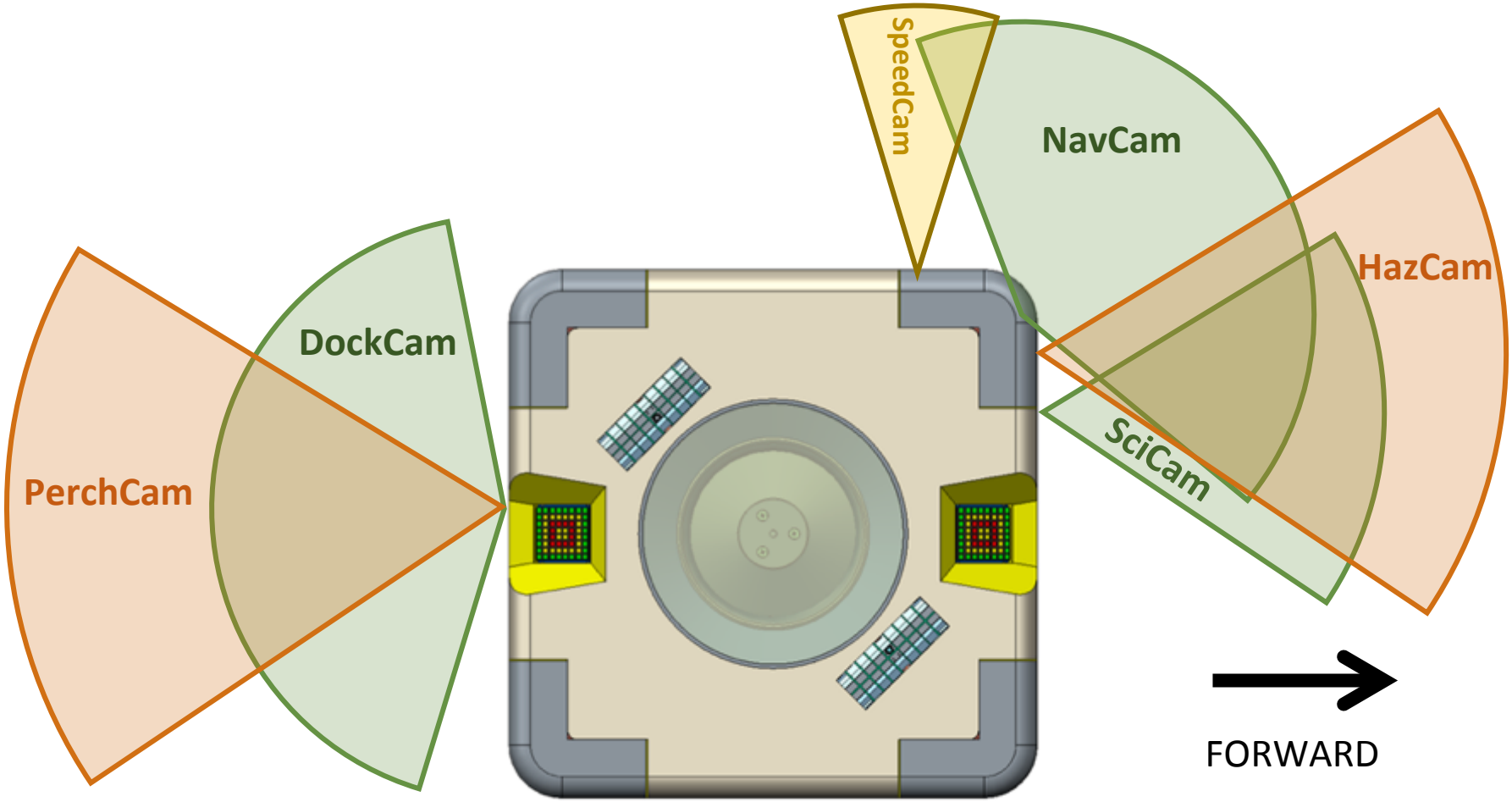
Computing Systems



AFT/CUTAWAY VIEW

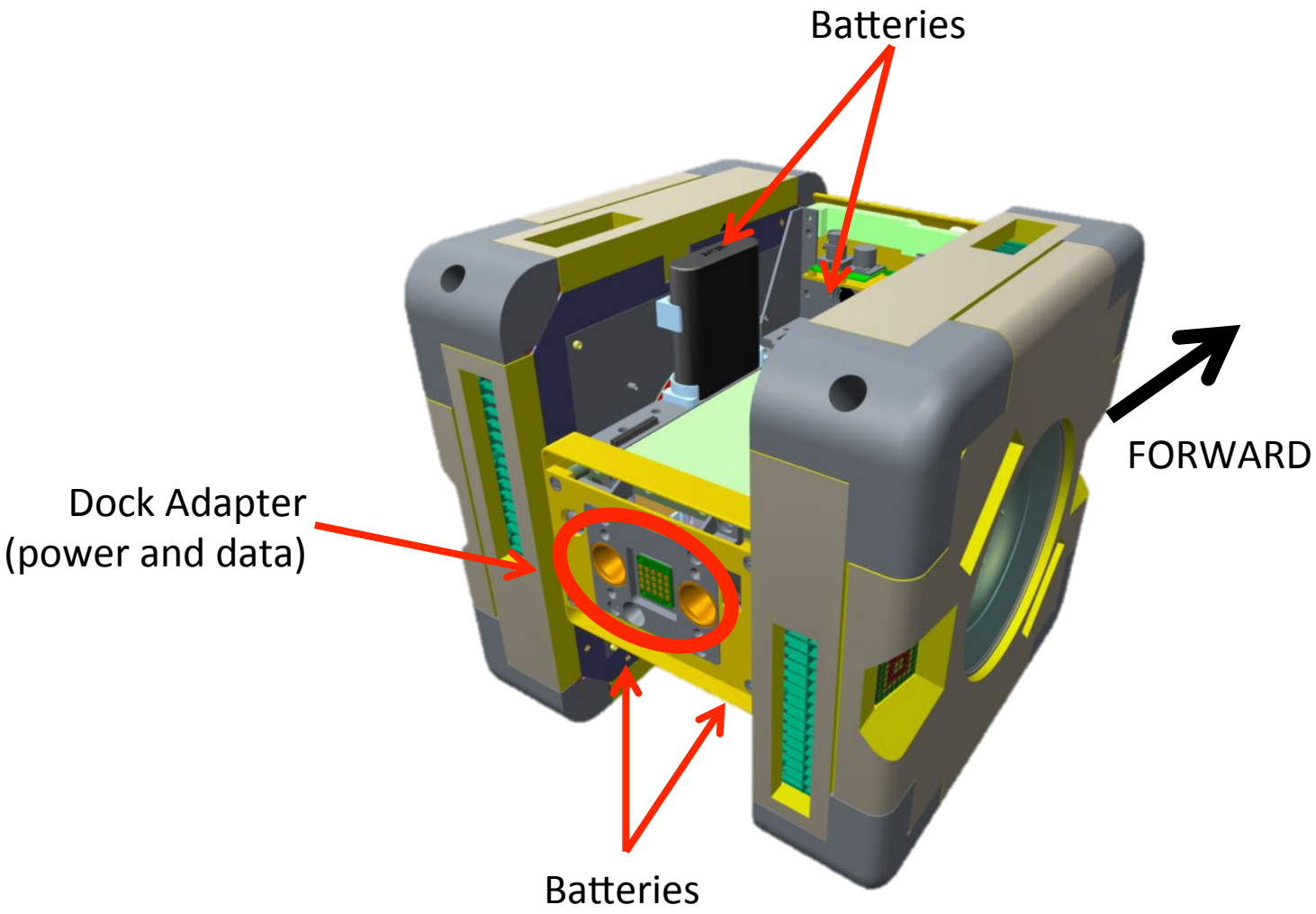


External Sensors

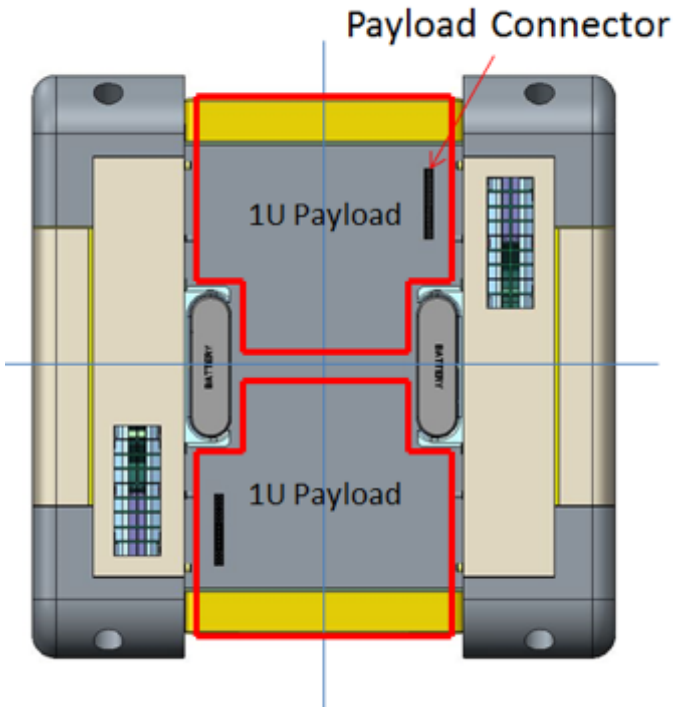


SIDE VIEW

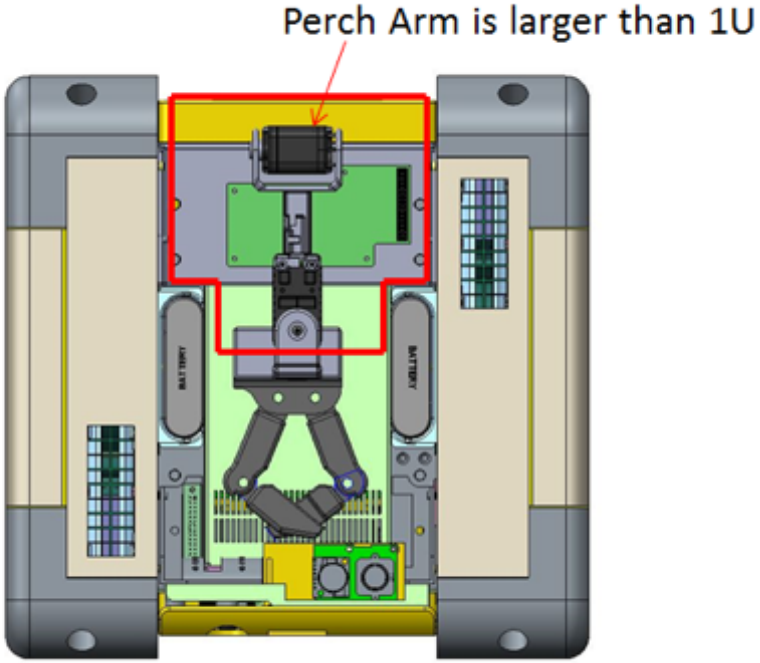
Power Systems



Payload Layout

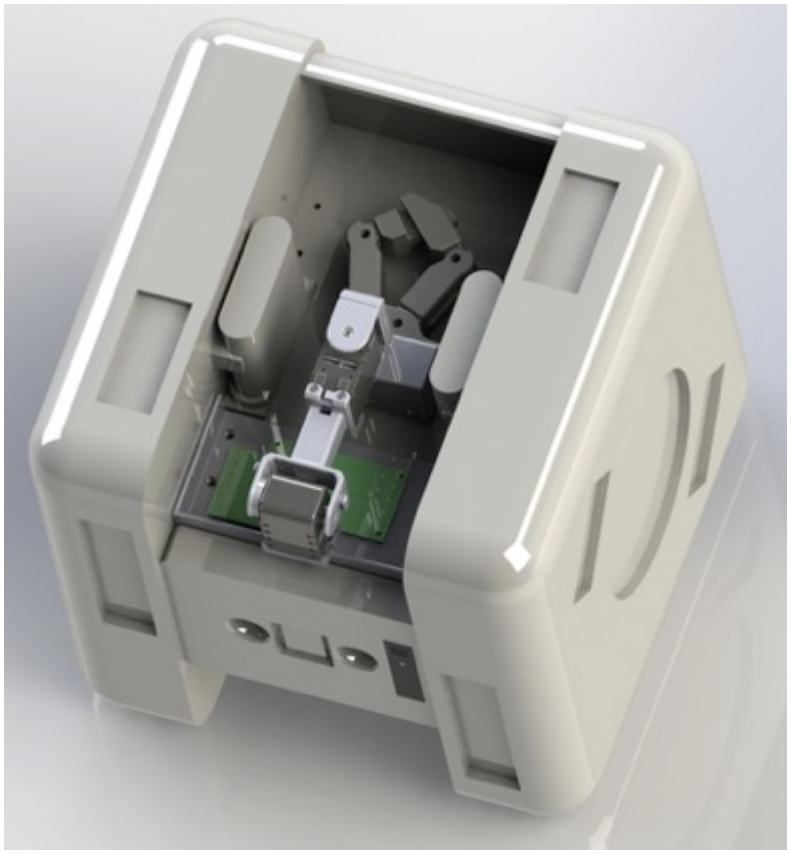


Bottom

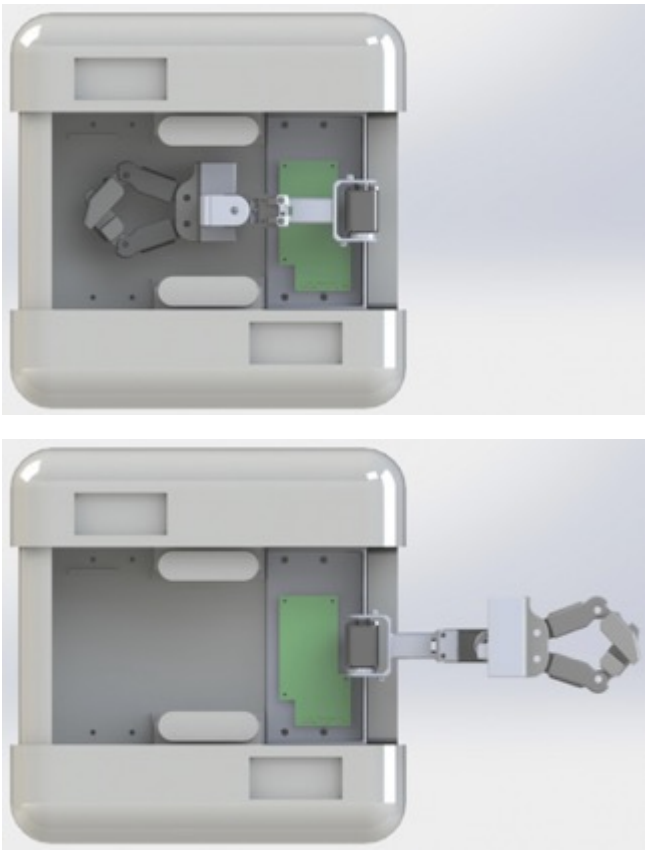


Top

Perching Arm

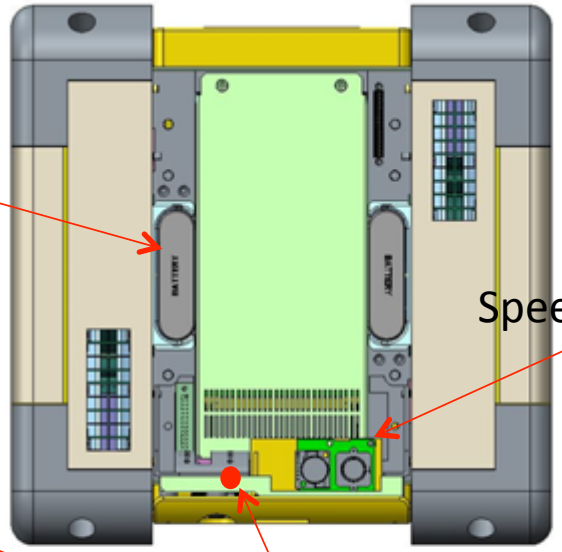


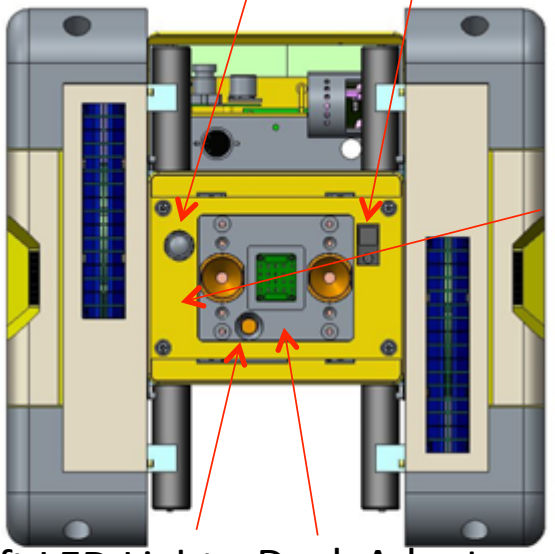
Stowed

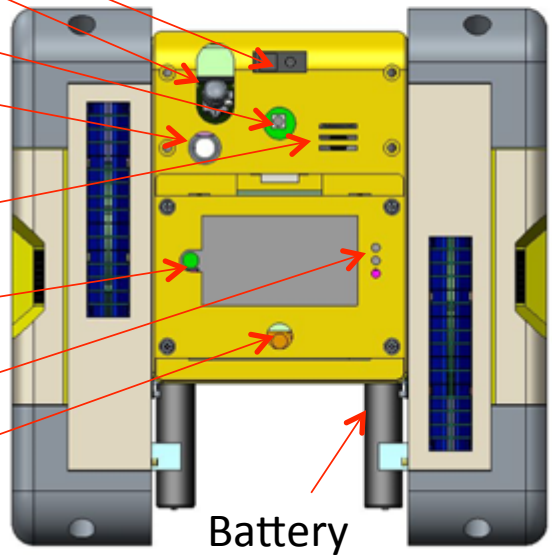


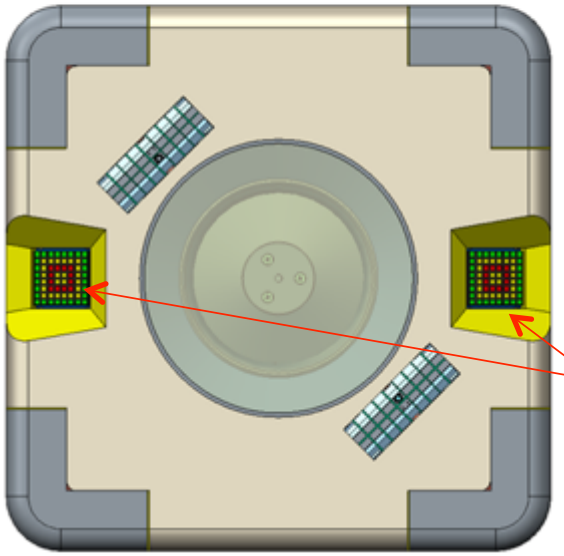
Stowed/Deployed

Base Layout

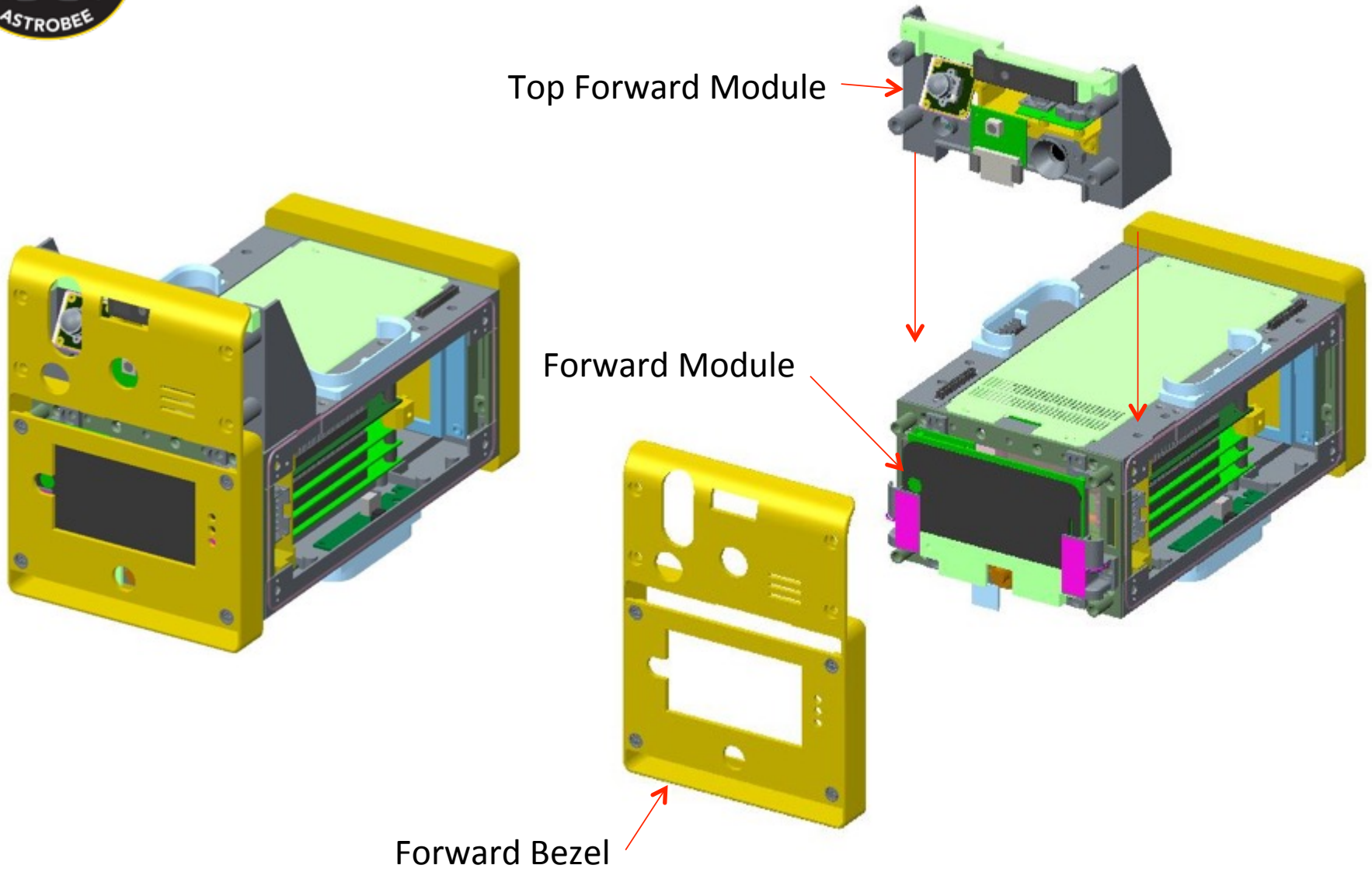

Battery
(1 on top +
1 on bottom)
SpeedCam
Terminate Button


PerchCam
DockCam
Status LEDs
Aft LED Light
Dock Adapter

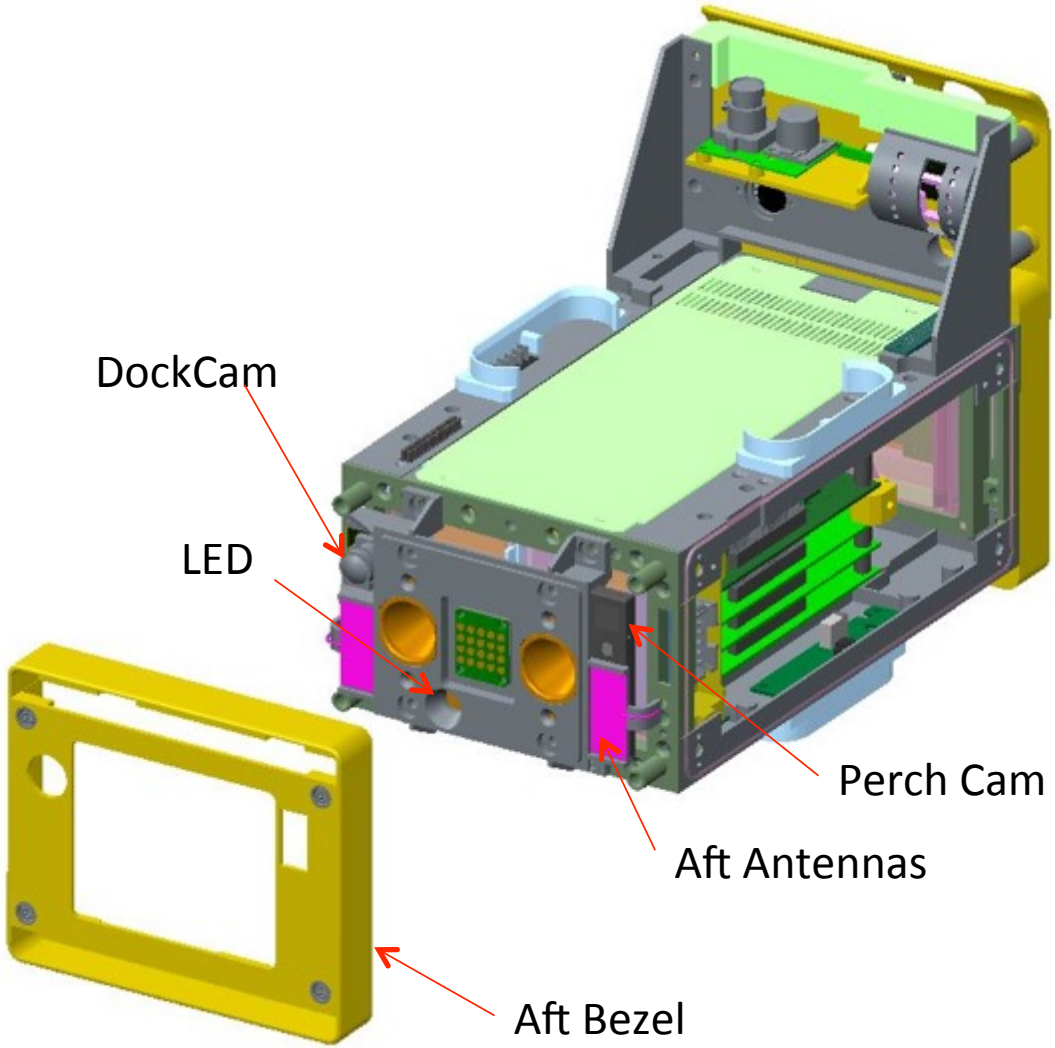

HazCam
NavCam
SciCam
Laser
Microphone /
Speaker
Touch Screen /
Touch Screen Activate Button
Status LEDs
Front LED light
Battery


LED
Indicators

Core and Forward Module



Aft Module

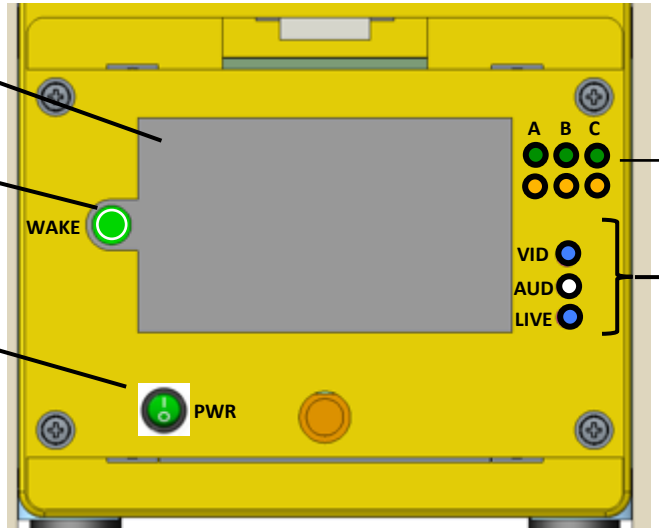


Indicators

Touch Screen Activate Button

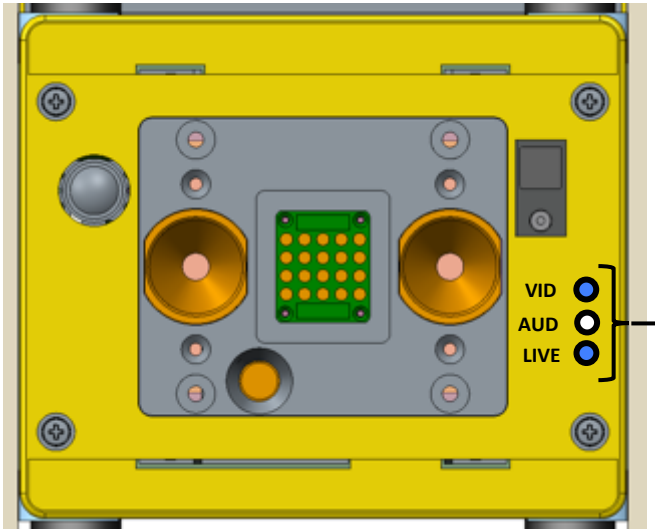
Wake Button (illuminated green when awake)

Power Switch (illuminated green when power is on)



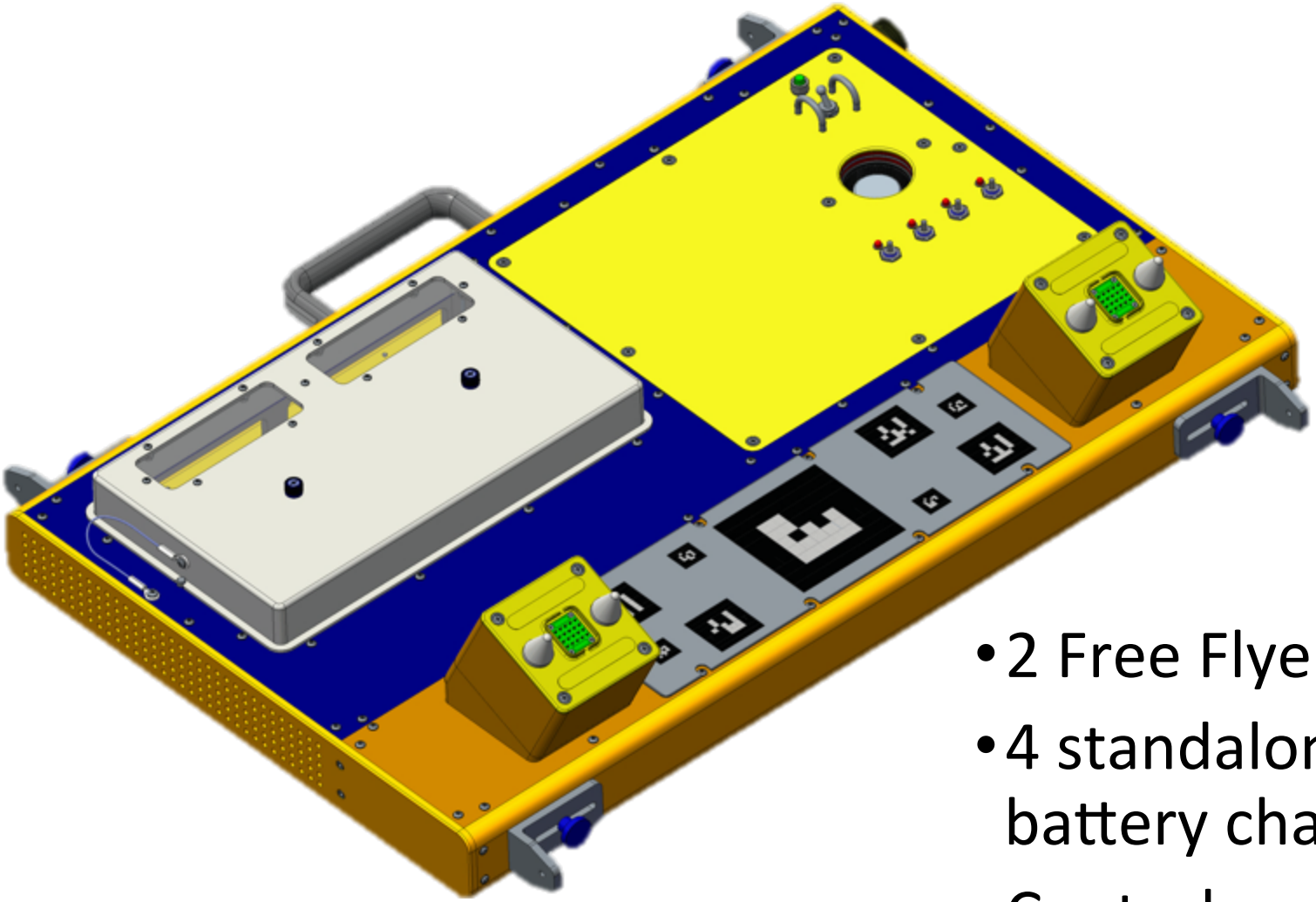
General Status LEDs (crew can call down status in case of errors, like “A is green, B is amber, C is off”)

A/V Mode LEDs (blue, white, blue)



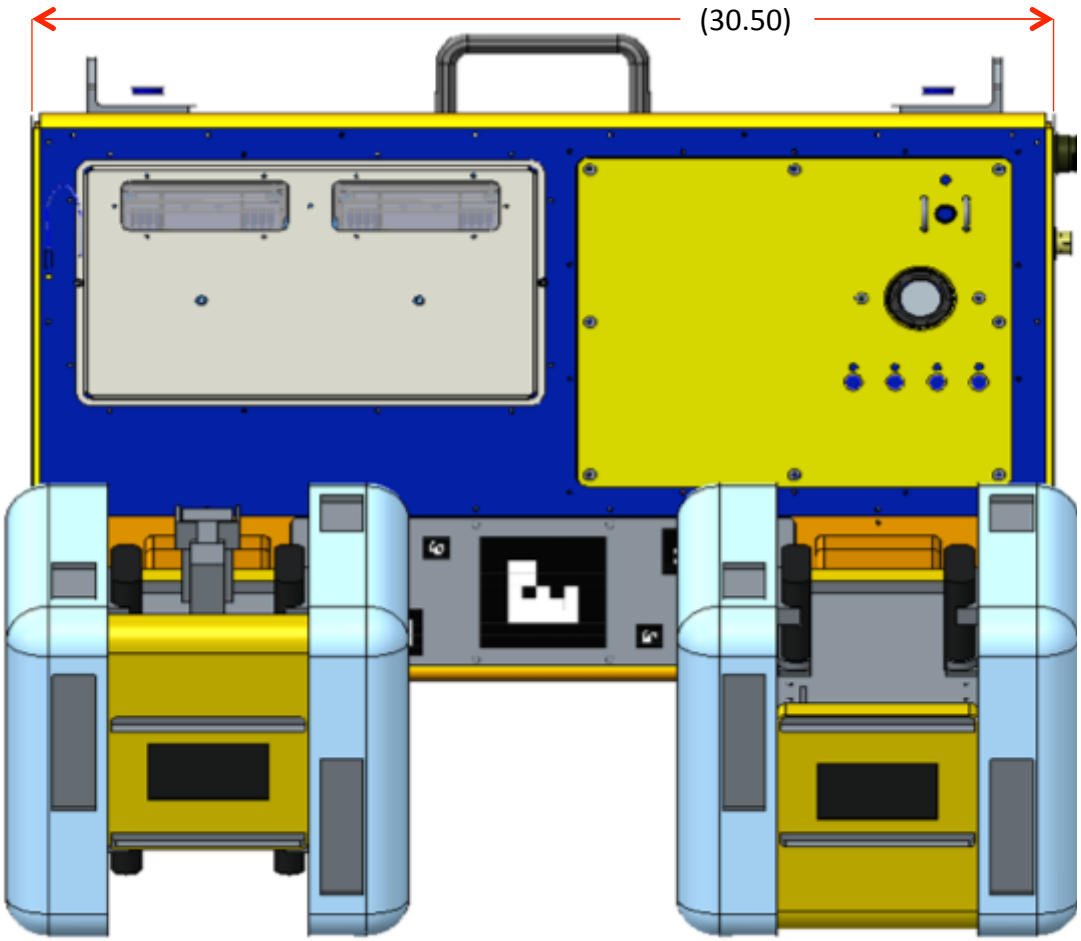
A/V Mode LEDs (blue, white, blue)

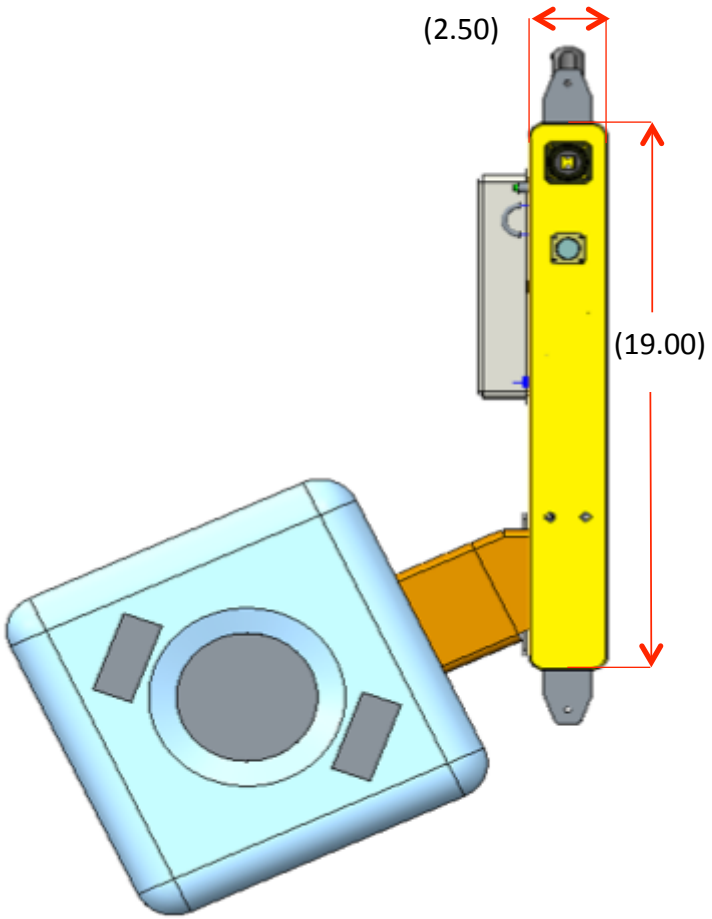
Docking Station



- 2 Free Flyer berths
- 4 standalone battery chargers
- Control panel

Docking Station
Front and Side View

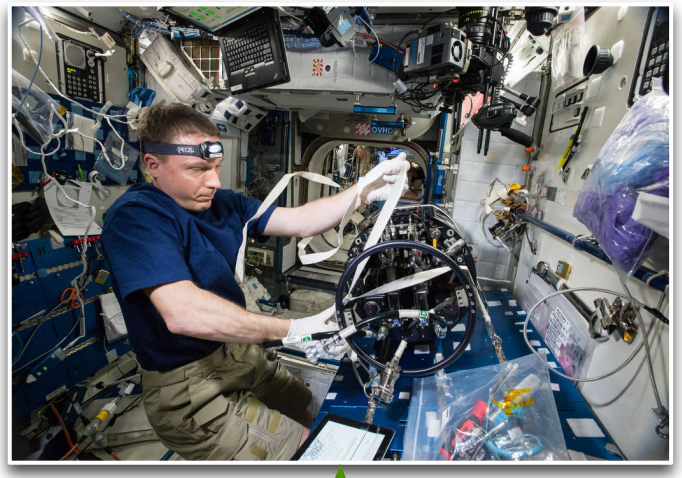


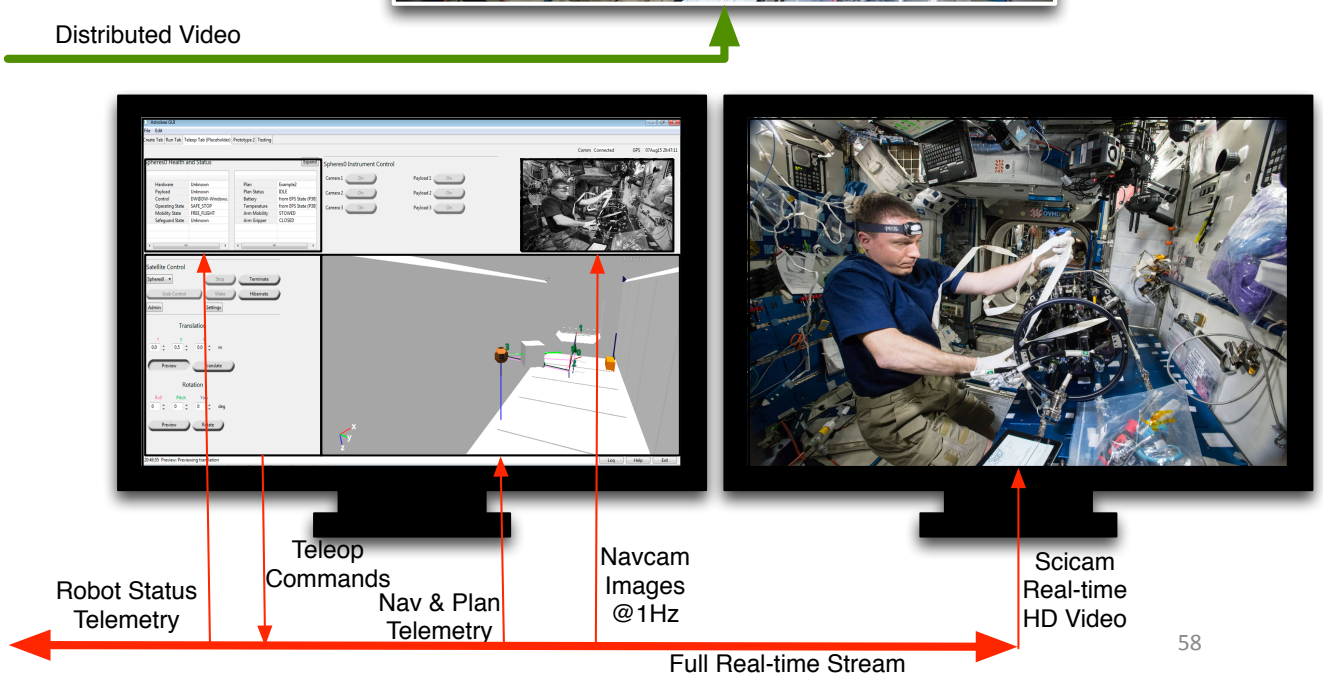


NOTE: Dimensions are in inches

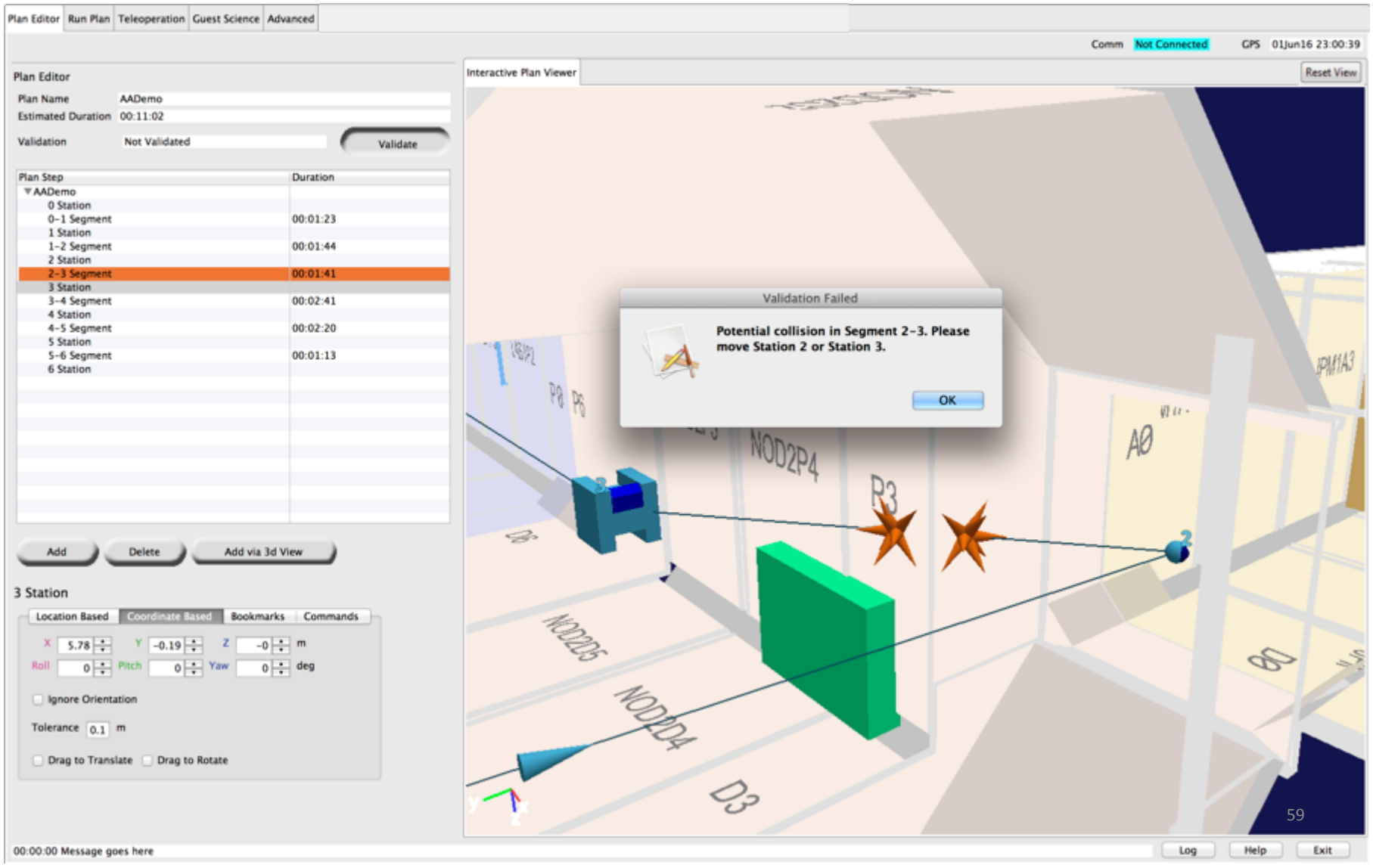
Control Station

- Eclipse based GUI
- Create, run, tele-op plans
- Run guest science
- Administration
- Separate ground UI for file transfer, software updates and diagnostics

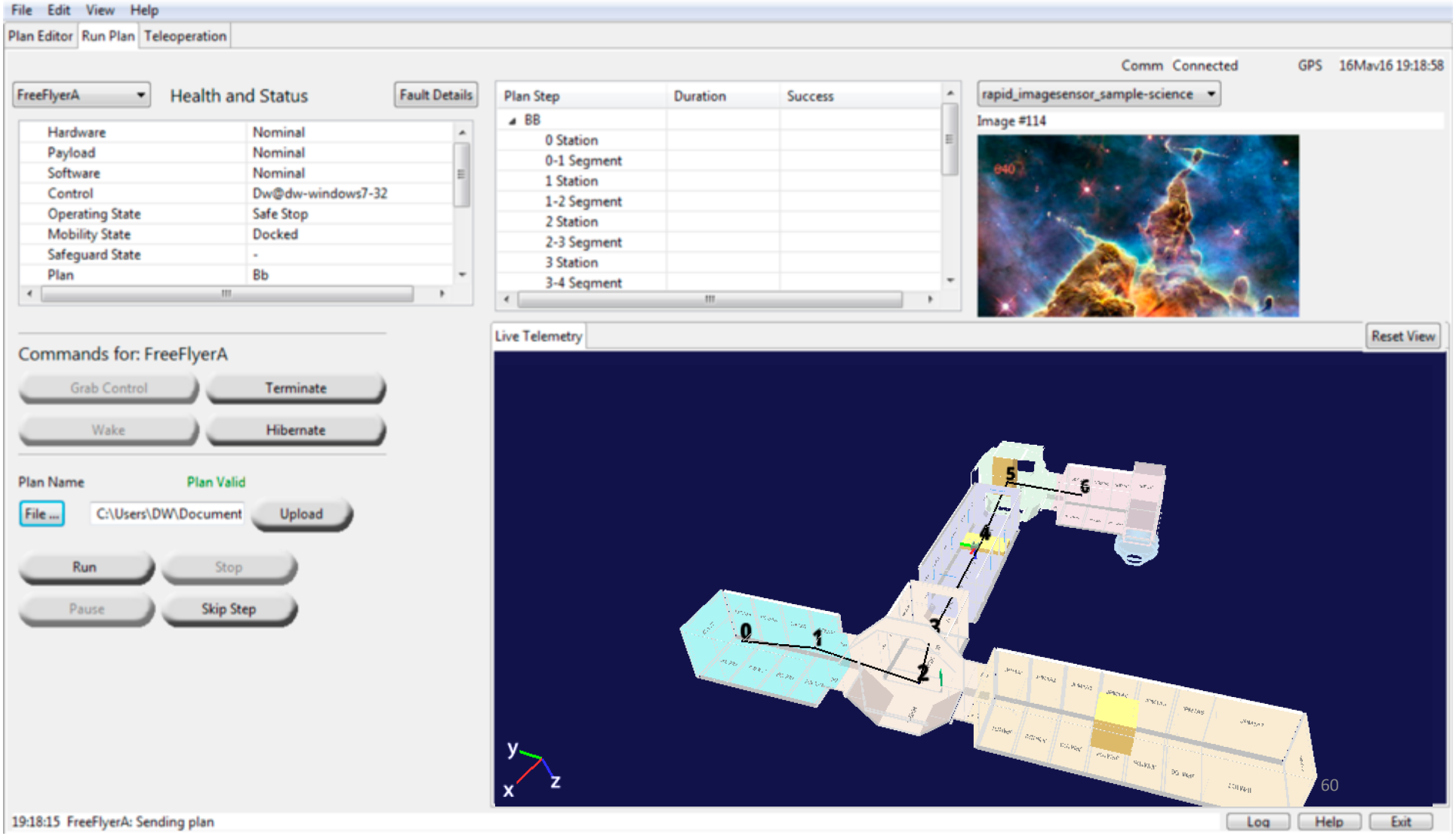




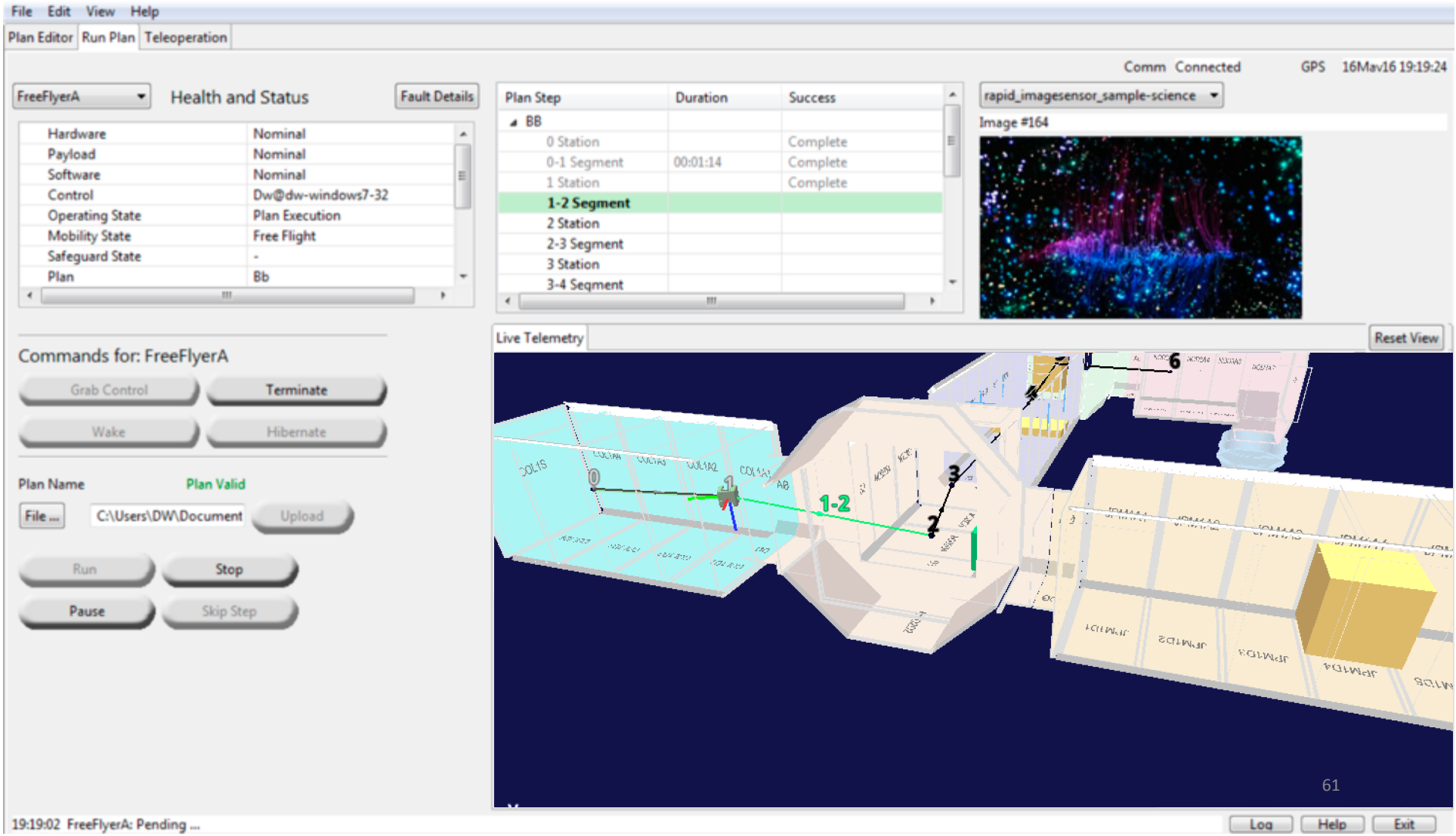
Plan Validation



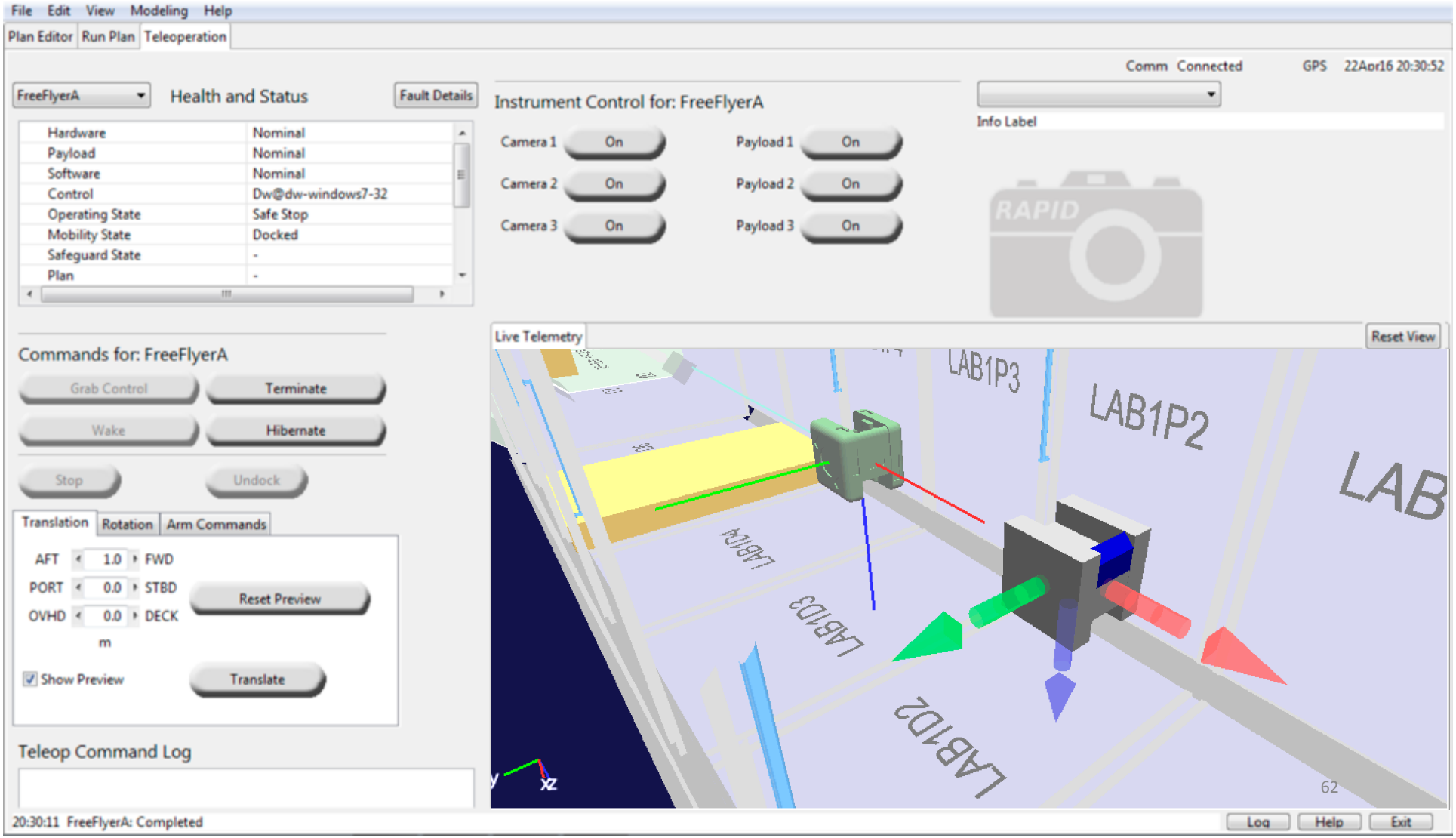
Run Plan Tab


File Edit View Help
Plan Editor
Run Plan
Teleoperation
Comm Connected
GPS 16May16 19:18:58
FreeFlyerA
Health and Status
Fault Details
Hardware Nominal
Payload Nominal
Software Nominal
Control Dw@dw-windows7-32
Operating State Safe Stop
Mobility State Docked
Safeguard State -
Plan Bb
Plan Step
Duration
Success
BB
0 Station
0-1 Segment
1 Station
1-2 Segment
2 Station
2-3 Segment
3 Station
3-4 Segment
rapid_imagesensor_sample-science
Image #114
Commands for: FreeFlyerA
Grab Control
Terminate
Wake
Hibernate
Plan Name
Plan Valid
File ...
C:\Users\DW\Document
Upload
Run
Stop
Pause
Skip Step
Live Telemetry
Reset View
0
1
2
3
4
5
6
y
x
z
60
19:18:15 FreeFlyerA: Sending plan
Log
Help
Exit

Run Plan Tab


File Edit View Help
Plan Editor
Run Plan
Teleoperation
Comm Connected
GPS 16May16 19:19:24
FreeFlyerA
Health and Status
Fault Details
Hardware Nominal
Payload Nominal
Software Nominal
Control Dw@dw-windows7-32
Operating State Plan Execution
Mobility State Free Flight
Safeguard State -
Plan Bb
Plan Step
Duration
Success
BB
0 Station Complete
0-1 Segment 00:01:14 Complete
1 Station Complete
1-2 Segment
2 Station
2-3 Segment
3 Station
3-4 Segment
rapid_imagesensor_sample-science
Image #164
Commands for: FreeFlyerA
Grab Control
Terminate
Wake
Hibernate
Plan Name
Plan Valid
File ...
C:\Users\DW\Document
Upload
Run
Stop
Pause
Skip Step
Live Telemetry
Reset View
1-2
19:19:02 FreeFlyerA: Pending ...
Log
Help
Exit

Teleoperation Tab



Free Flyer Key Requirements

- Holonomic control
- Navigate USOS
- Multiple peripheral ports
- Reconfigure parameters per payload
- Open API for payloads
- Position: +/- 20 cm, +/- 2 cm
- Angle: +/- 20 deg, +/- 8 deg
- Max acceleration: 10 cm/sec^2
- Max velocity: 50 cm/sec
- Avoid hitting unexpected obstacles
- Avoid keep out zones
- Validate path against map
- Monitor battery charge
- Noise requirements
- Tolerate collisions
- Size: 30 cm x 30 cm x 30 cm
- Mass: 6 kg
- Stream and record HD video
- Sortie durations & energy storage
- Perch on handrails
- Autonomous docking
- Replaceable modules
- Upgradeable software
- ISS ICD & Safety

Docking Station Key Requirements

- Free flyer and dock must be able to complete all physical connections without crew assistance
  - AR target to assist free flyer localization during dock approach
- Recharge batteries
- Provide free flyer with high bandwidth wired connection to ISS LAN
- Dock provides two free flyer berths
- ISS ICD & Safety

Ground Data Systems Key Requirements

- Ground Control
- Manual Control
- Plan authoring
- Plan control (select, upload, run, pause, abort, skip)
- Provide PIs access to science data
- Software install (guest science)
- Monitor multiple robots
- Identify free flyer being controlled
- Remote Terminate
- Real-time telemetry display
- 2D and/or 3D telemetry visualization
- Simulation for plan visualization
- Control station health & status
- Provide data storage
- Minimal UI training for Crew and Operatory Stations
- Upgradable hardware/software
- ISS ICD

ISS Free Flyer Science:
SPHERES Today, Astrobee Tomorrow

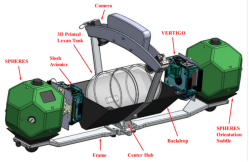
Google Talk

Jose V. Benavides

Presentation Outline

- Free Flyer Evolution
- SPHERES Facility Overview
- SPHERES Guest Scientist Program
- Astrobee Overview
- Astrobee Guest Science Examples
- How to Utilize the SPHERES/Astrobee Facilities
- PD ST&E Process

Free Flyer Evolution

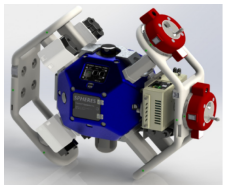


RINGS | UDP/HALO

SLOSH | SmartSPHERES

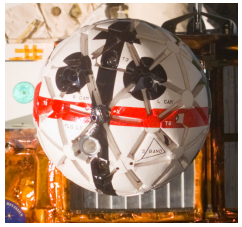
Tether | Interact

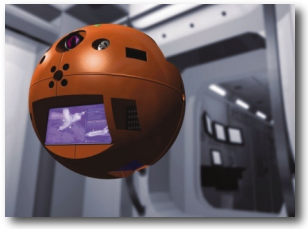
Vertigo | ZeroRobotics

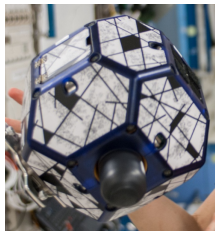


AeroCAM | PSA | SPHERES | AstroBee

1996 - 2002 | 2000 - 2008 | 2006 - 2017 | 2018







Visual Nav | Propulsion | Human Robot Interaction | In-space Manufacturing | GNC | Avionics | Automation

SPHERES Facility

- A Facility of the ISS National Laboratory with three IVA nano-satellites designed by MIT to research estimation, control, and autonomy algorithms
- Installed on ISS in 2006
- Managed by ARC since Fall 2010
- By working aboard ISS under crew supervision, it provides a risk tolerant Testbed Environment for Distributed Satellite & Free-flying Control Algorithms
  - Formation flight,
  - Docking,
  - Close proximity operations
- If anything goes wrong, reset and try again!
- The satellites can be reused
  - ✓ Replenishable consumables
  - ✓ Multiple test sessions assigned per year

Scott Kelly working with SPHERES in the Kibo lab

SPHERES ISS National Lab Facility

- Program Executive: Jason Crusan (HQ)
- Program Manager: Jose Benavides (ARC / TI)
- Chief Engineer: Jonthan Barlow (ARC / TI)
- Operations Lead: Aric Katterhagen (ARC / TI)

131+ Test Sessions (Over 700 hrs) & 45+ individual ISS Crew Members have operated SPHERES (many multiple times) - one of the most used and popular ISS National Lab Facilities

SPHERES Guest Scientist Program

- There are several avenues which can lead to integrating science on the SPHERE Facility:
  - ISS Technology Demonstration Office
  - CASIS (Center for the Advancement of Science In Space)
  - Defense(DOD)/DARPA/
  - SPHERES PM/Engineering/Ops/ POCs (Jose Benavides / Jonathan Barlow / Aric Katterhagen)
  - ESA??

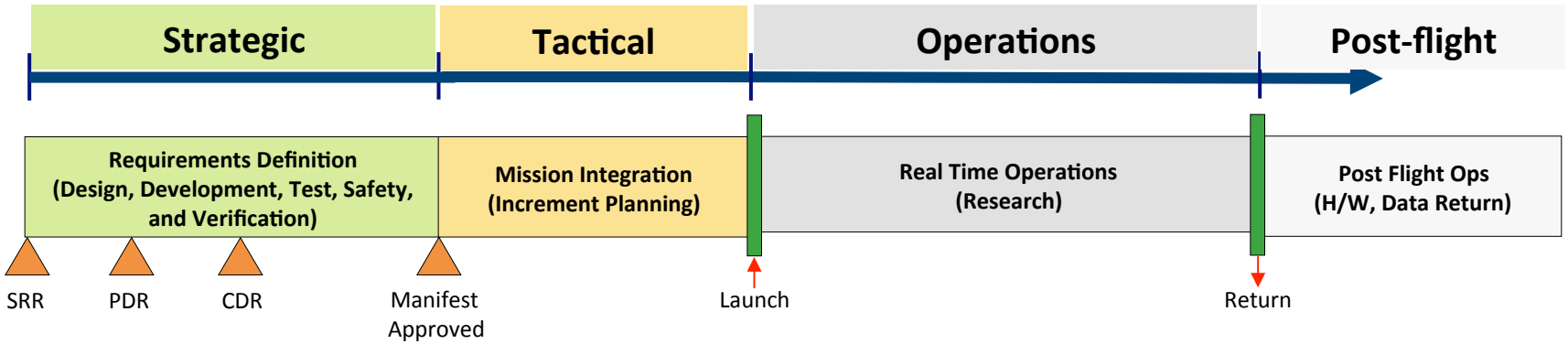
- The SPHERES program (and Astrobee) welcomes scientist from around the world.
- Contacting a party above in addition to reading about the GSP in the pdfs on the SPHERES homepage can assist you in getting started. The GSP Interface Documents are updated as needed so keep checking back.

  https://www.nasa.gov/spheres/guest-scientist-program

- Also available for download below is the SPHERES Simulator. It's hosted by the ISS SPHERES project on Source Forge.

- **NOTE: These processes (this and the following slide) are also being developed for Astrobee so continue to follow the Astrobee homepage (see last slide).**

SPHERES Guest Scientist Program



PIMs provide integration leadership during all phases of the payload's life cycle

- Strategic – facilitate definition of ISS integration requirements, products, and schedule development to ensure that an ISS compatible payload is built; support manifest process (payload data collection and feasibility assessments)
- Tactical – represent PD interests to Increment and Flight-specific teams to ensure that integration and operations requirements are addressed; coordinate verification submittals and payload Certificate of Flight Readiness (CoFR)
- Operations – coordinate payload resupply or return requirements; coordinate verification submittals and payload CoFR during payload lifetime on-orbit
- Post-flight – coordinate vehicle de-integration requirements; assure return of payload hardware/samples from the landing site to the PD; support Lessons Learned submittals

SPHERES Guest Scientist Program

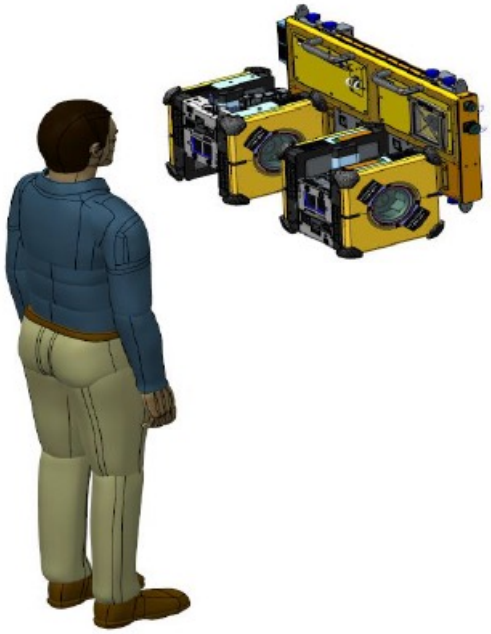
- Current SPHERES Hardware on ISS
- [This slide needs to be updated with photos}
  - Three sats
  - Halo
  - DP
  - VERTIOG
  - Tether-Slosh
  - ZR

Astrobee Overview

- Three free flyers on ISS starting spring 2018
- Docking station for recharge and wired communication
- Built in perching arm using payload interface
- 6 total cameras for various purposes, including one cellphone class HD camera.
- Main purposes:
  - Host guest science payload (GSP payloads)
  - Serve as mobile camera for ISS situational awareness
  - Serve as mobile sensor platform
- First GSP Payloads
  - REALM RFID reader
  - Zero Robotics High School and Middle School competitions
- **Guest Scientist opportunities as early as fall 2018**

Astrobee Overview

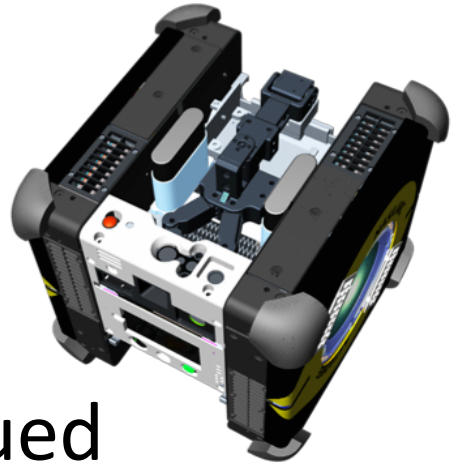
- Astrobee
  - Free Flyer
  - Dock
  - Ground Data System



Astrobee
Guest Science Examples

- Examples of Potential Science
  - REALM (current project in works)
  - RFID Applicator (Phase 1 SBIR)
  - Other RFID capabilities
  - Zero Robotics (current user of SPHERES)
  - All other current and past users of SPHERES
    - VBN
    - EMF studies
    - Docking
    - Human-Robotic interaction (Interact)
    - Fluid Dynamics
    - Tether
  - Free Flyers with Gecko-Inspired Adhesive Appendages
  - CO2 Monitors
  - Crew Radiation Exposure Modeling
  - 3D camera payloads

Astrobee
Guest Science Examples



- Examples of Potential Science Continued
  - Orbital Robot Control for Enhanced Autonomy
  - In-Space Rendezvous and Servicing
  - Components with Exotic Dynamics
  - Formation Flight beyond what SPHERES has done
  - Robotic Manipulation
  - Human-Robot Interaction beyond what Interact has done

How to Utilize the SPHERES Or Astrobee Facilities

- From a high level there are four main ways to utilize the current SPHERES Facility or Future Astrobee Facility. Some examples are more applicable to one research Facility over the other.
  - From easiest to more resource intense
    - Software only science (utilize existing software)
    - Software only science (test new software)
    - Use existing software with existing hardware
    - Create new software for use with existing hardware
    - Create new software and new hardware

- Regardless of the path, there is a general path to working with the ISS program that, depending on the funding and support of the project, the NASA Ames SPHERES/Astrobee team can help with.

PD ST&E Process

(How is this applicable to SPHERES & Astrobee?)

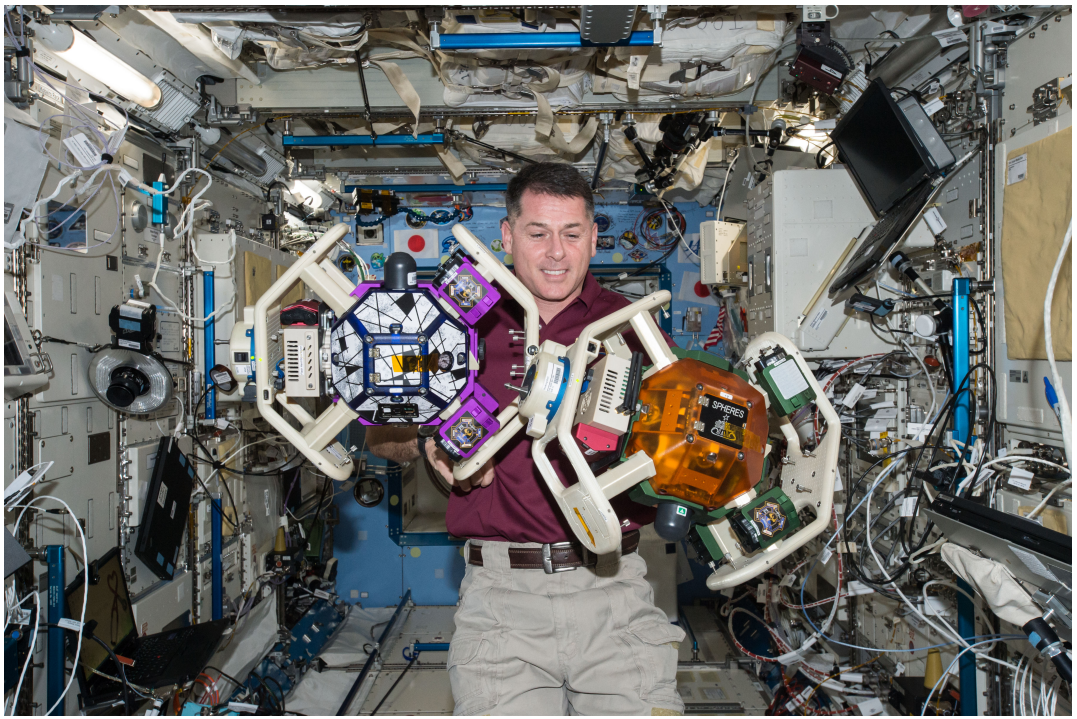
CONCEPTION PHASE	PLAN & PREPARE PHASE	DESIGN & ANALYZE PHASE	VERIFY PHASE	DELIVER PHASE	OPERATE & POST OPS PHASE
Understand what the PD needs from the ISS Program	ISSP collaborates with the PD to provide items required to design the experiment or payload	Understand maturity of design and forward risk as integration process moves into fabrication & verification	Fabricate & complete verification in prep for shipment and launch vehicle integration	Perform launch vehicle integration, & deliver to ISS	Operate the experiment and complete post ops integration
DRIVEN BY PAYLOAD DEVELOPMENT SCHEDULE					
PD receives NASA IT access PD provides Initial Data set • Initial Ops Concept • Initial assessment of Interfaces and services needed from ISS • Project schedule PIA created PIM Schedule developed Kickoff	Complete Phase 0 Safety TIM Complete Phase I Safety Review ISSP develops baseline requirements (ISS and VV) C&DH/GDS Coordination Meeting Identify NASA Test Facility Needs ISSP provides operational constraints PD provides payload readiness date	ISSP/PD define NCR approach (if required) Complete Phase II Safety Review ISSP/PD identifies crew training needs PD completes PDR/CDR (ISSP support as requested by PD) PD submits C&DH inputs PD receives training ops integration products, tools, and documents PD provides inputs to initial ops and planning products PD delivers cargo analytical products	Complete Phase III Safety Review PD conducts verification testing and submit verification data to NASA • Hardware • Software • Science • Operations PD/ISSP updates ops & planning products, pld regs, flight rules, and conducts review C&DH inputs finalized PD identifies part level flight **manifest** data ISSP approves interface verification data and NCRs (if required) PD receives operations console training PD conducts training for crew and visiting vehicle team PD provides ground facility requirements ISSP hosts Science Symposium	PD defines Time-critical Ground Handling Requirements and launch campaign constraints PD delivers hardware and processes at launch site PD provides final inputs to ops and planning products ISS communicates Launch campaign information PD participates in OWTL meeting to report non-standard open work ISSP provides CoFR	PD operates experiment Sample and data return Collect and Evaluate Lessons Learned Crew debrief ISSP ends HOSC services PI publications ISSP shares science with the world
FUTURE STATE: ONE ST&E INTEGRATION FLOW DATA ENTRY POINT (I.E., EMBARK) FOR PAYLOAD DEVELOPER					

Testing Resources Available

- **{PHOTOS of the labs at ARC}**
-

Questions?

SPPHERES/Astrobee Social Media



http://www.nasa.gov/spheres
https://twitter.com/NASA_SPHERES
https://cms.nasa.gov/astrobee