SPHERES

Synchronized, Position, Hold, Engage, Reorient,
Experimental Satellites

SPHERES/Astrobee Working Group (SAWG)
Quarterly Meeting

Aug 23rd, 2017

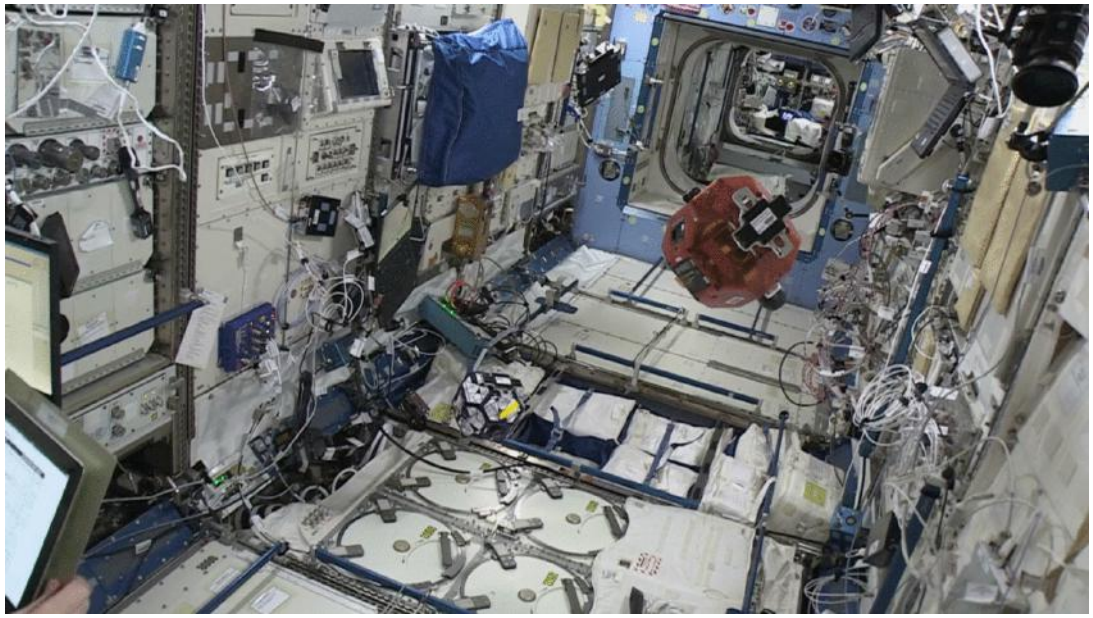
NASA Ames Research Center DARPA MIT SSL SPHERES

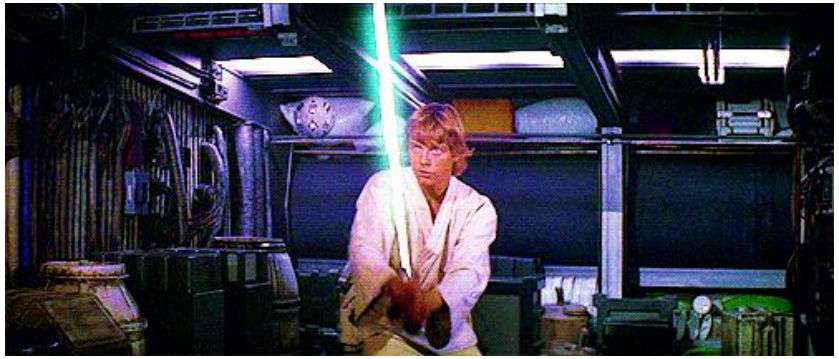
Meeting Kick off

Meeting Logistics

- Topic: SPHERES/Astrobee Working Group (SAWG) Quarterly Meeting
- Purpose: Information sharing across the SPHERES & Astrobee community - not intended to be project reviews!
- Date: Wed, Aug 23rd, 2017
- Location: Virtual
- Time: 8:00 am, PST

- JOIN WEBEX MEETING
- https://nasa.webex.com/nasa/
- Meeting number: 392 669 018
- Meeting password: Astrobee!8
- Join by phone: 1.844.467.6272
- pass code: 445068





Agenda

0.	8:00am	SPHERES Welcome	(2 min) Andres Martinez
1.	8:05am	SPHERES Facility	(10 min) Jose Benavides
2.	8:15am	SPHERES Ops	(15 min) Aric Katterhagen
3.	8:30am	SPHERES Eng	(15 min) Jonathan Barlow
4.	8:45am	SPHERES PIM	(10 min) Melissa Boyer
5.	8:55am	Astrobee	(15 min) Maria Bualat
5.	9:05am	Astrobee Sim	(05 min) Andres Mora Vargas
6.	9:10am	VertigoSmoothing	(10 min) Danilo/Alvar
7.	9:20am	Zero Robotics	(10 min) Katie Magrane
8.	9:30am	SLOSH Lessons	(10 min) Brandon Marsell
9.	9:40am	Tether Slosh	(10 min) Hans Zachrau
10.	9:50am	SVGS-RINGS	(10 min) Hector Gutierrez
11.	10:00am	Metis-RFID	(10 min) Jose Cortez
12.	10:10am	HoneyBee-UDI	(10 min) Jack Wilson
13.	10:20am	Tethers-CobraBee	(10 min) Nathan Britton
14.	10:30am	Altius	(10 min) Jonathan Goff
15.	10:40am	Stanford-Gecko	(05 min) Abhishek Cauligi
16.	10:45am	Illinois-Elecro	(05 min) Matthew Spenko
17.	10:50am	Maryland-Gripper	(05 min) Christine Hartzell
18.	10:55am	Concluding remarks	(05 min) Jose B. Realm

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 **121** Test Sessions (600+ hrs. of Facility Console activities involving crew)

One of the most used and popular ISS National Lab Facilities

SPHERES Community

❑SPHERES Working Group (SWG) Quarterly meeting

- Membership includes MIT, FIT, AFS, DARPA, CASIS, SJSU, Airbus, and NASA (HQ, KSC, JSC, MSFC, and ARC)
- Face-to-Face, twice a year
- Next Face-to-Face will be scheduled in Nov. 2017 at NASA Ames

❑ Purpose:

- Information sharing across the SPHERES/Astrobee community
- Program office shares
  - ✓ National Lab Facility availability
  - ✓ Status of resources (batteries, CO2 tanks, etc.),
  - ✓ Overall Calendar (scheduled Test Sessions, upmass/return), and
  - ✓ Updates on “new” PD, Investigations, and ISS infrastructure.
- Provide the SPHERES/Astrobee community (PD, investigators, etc.) with up-to-date information to determine opportunities to use the NL Facility
- Discuss proposed changes/updates to SPHERES Nat Lab which may be required to support a specific activity or research.
- Discuss specific support requests made to the ISS Office

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
  - 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
  - Andres Mora Vargas, amora@meicompany.com

Program News & Highlights 1/3

- One Man Down

Program News & Highlights 2/3

- Qty 65 gen 2.5 CO2 ready for shipping by 8/31
- Building a light shade for new ISS lighting that allows SPHERES to continue operating in presence of IR noise
- ISS Beacon repair done, launching on OA-8
- Last Inspire-2 MIT Halo Test Session June 23rd
- Inspire-2 investigation completed with workshop on June 21st
- Successful Zero Robotics Field Day at Ames, July 7th
- Successful Zero Robotics Finals competition on Aug. 11th

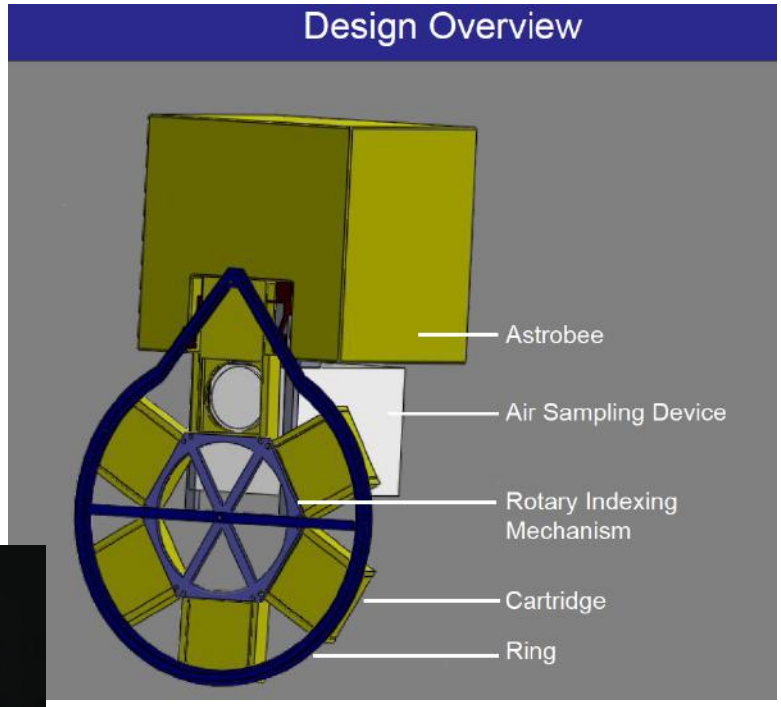
NASA astronaut Jack Fischer helps conduct an in-space competition called SPHERES Zero Robotics that challenges middle and high school students to guide a bowling-ball-sized satellite around the interior of the space station.

Program News & Highlights 3/3

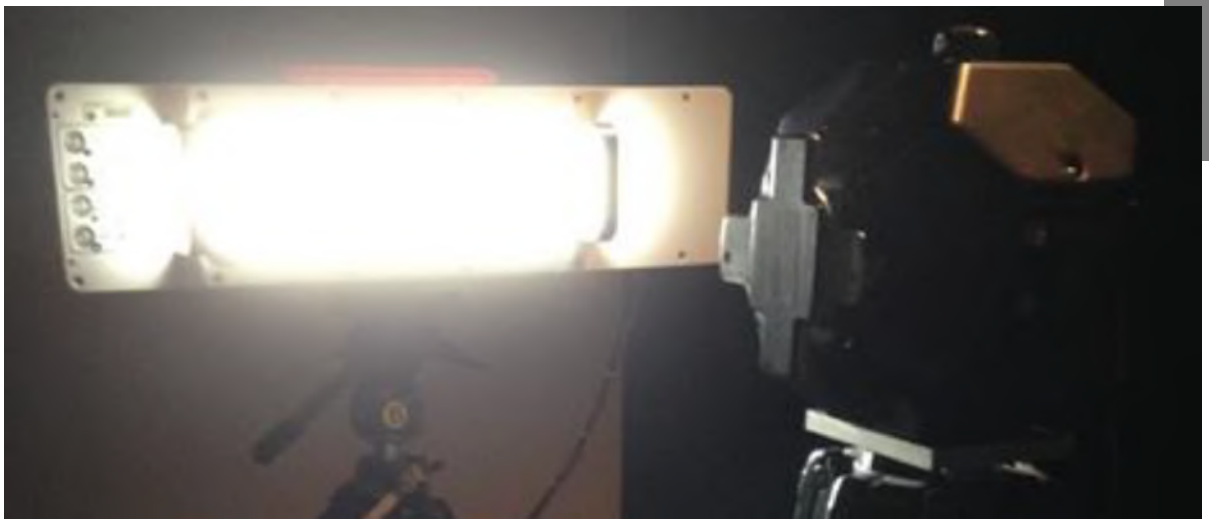
- Tether-SLOSH kickoff May 23rd
- Vertigo/"Smoothing-Based Relative Navigation" Kickoff
- Astrobee project support continues
  - Astrobee Robotics Software Simulator Beta release & open-sourcing targeted 8/31
  - Guest Scientist Guide 8/31
  - Mechanical Payload ICD 8/31
  - Two presentations, ISS R&D conference July 17th
  - Integration & Test
  - Flight Build
- Supported winning poster at Innovation Fair: "Ames K-12 STEM Challenges"

Summer 2017 Interns: Qty 8

- **Aris Koumis & Dean Yuan:** Astrobee Microbial Sampling Payload (AMSP)



- **Eddy Meza: SSLA Shade**



Summer 2017 Interns: Qty 8

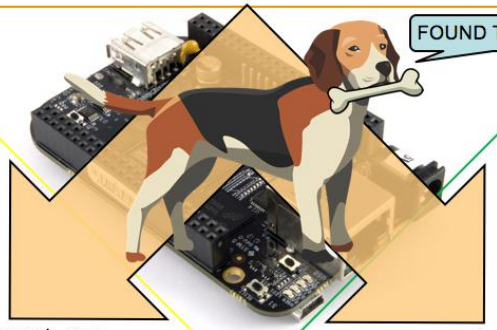
- Elizabeth Nguyen: Astrobee Payload Expansion Port Tester (APEPT)
- Jacob Killelea: Multi-robot Communication

BASIC DESIGN REQUIREMENTS

1. The system shall establish USB connection with the Astrobee using the USB data pins on the payload interface.
   a. The system should identify the Astrobee as a USB device.
   b. The Astrobee should identify the payload as a device.
   c. The system should be able to transmit and receive data.
2. The system shall test and demonstrate current and voltage outputs
   a. The system should show a possible current draw of 3A.
   b. The system should show voltage levels of ~14.4 volts.
   c. The system should limit the current draw of the payload.
3. The system shall be able to attach to the payload interface using both the lever method and the screw method.
4. The system should have on board computing capabilities for guest science/test software.
5. The system should enhance the mechanical mounting of the payload interface to allow for additional attachments. (Bonus)

Payload Connector Pin Types

- Power & Ground
- MLP USB D+/- x 2
- HLP USB D+/-
- Reserve Pins [I2C/UART]



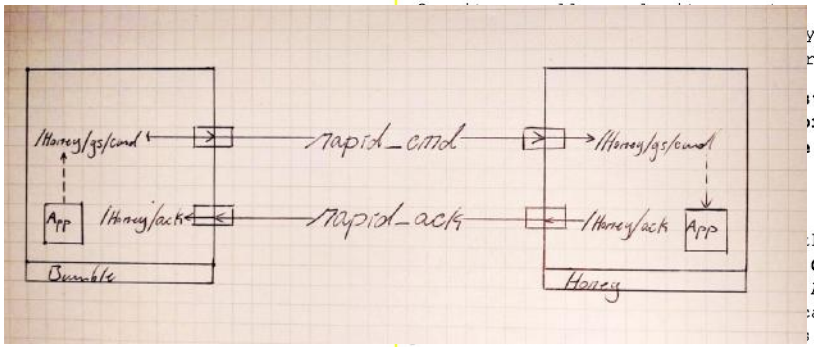
APEPT HARDWARE DEV

I. Electrical

The development of the hardware for the APEPT was **centered around the use of the BeagleBone Black (BBB)** - a single-board computer/microcontroller: chosen

tom PCB layout was
r the BBB to organize and
additions to run the port

he APEPT was
CAD model for the
Astrobee. The model was
al unit, LCD display



APEPT SOFTWARE DEV

For the software development of the APEPT, **several different frameworks** were studied:

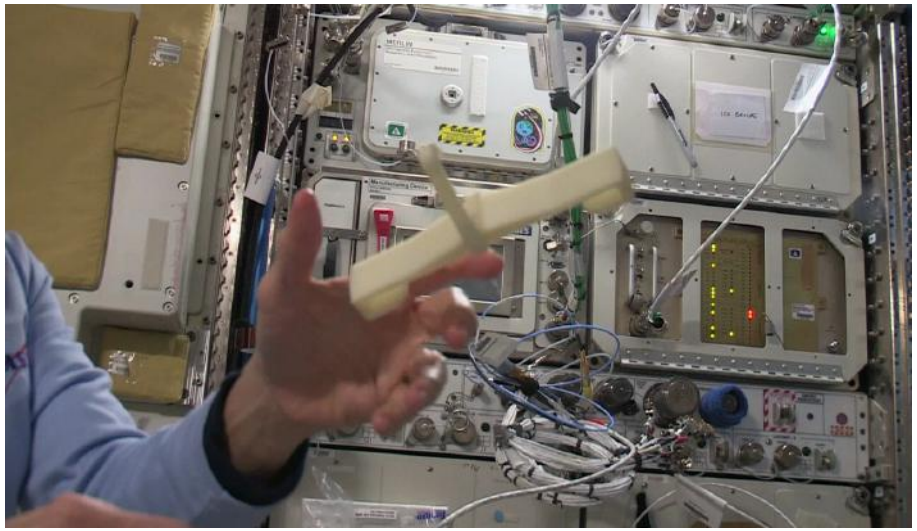
1. **Robot Operating System (ROS)**
2. **Android OS APK development**
3. **JavaScript + BoneScript + NodeJS**

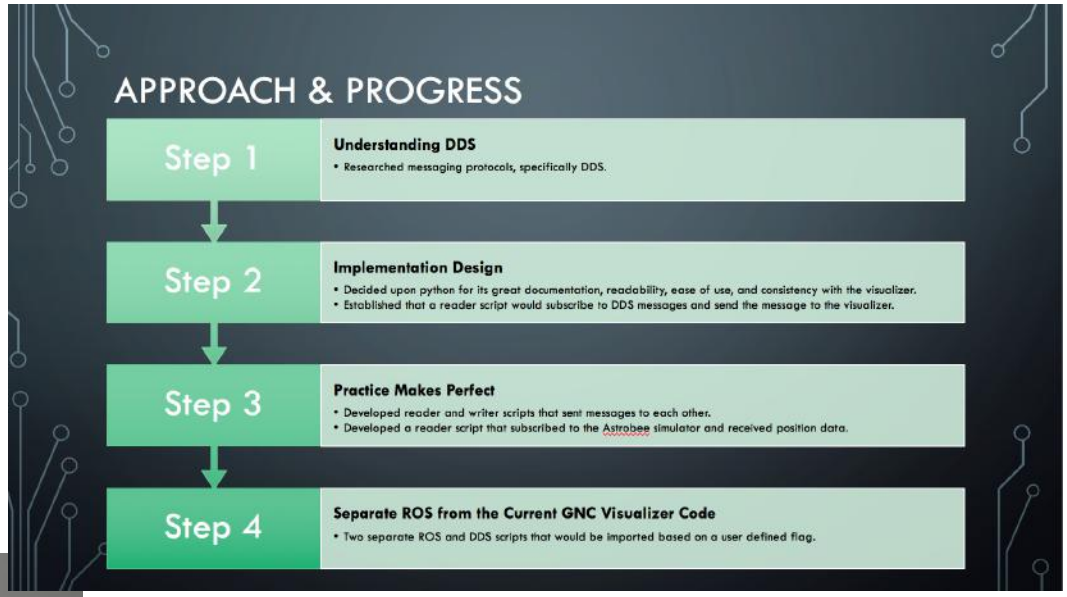
The ROS and Android framework were chosen because Astrobee currently uses these frameworks for operation. The JavaScript + NodeJS was chosen by recommendation and BBB community tutorials.

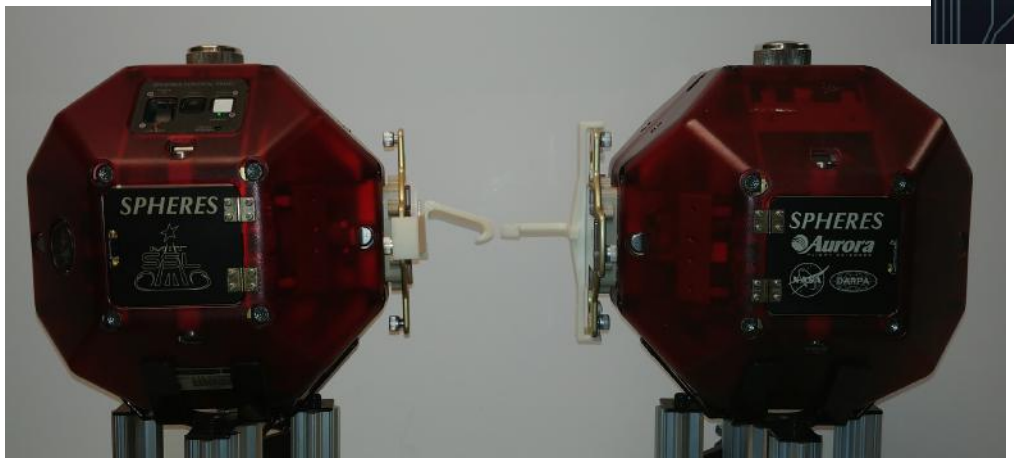
Each of these frameworks are implemented on either the APEPT or Astrobee **to conduct the port tests and serve as example use cases/implementation guides for guest science.**

Summer 2017 Interns: Qty 8

- Matt Moropoulos: SPHERES-Hook
- Michael Richardson: MGTF Control Software
- Rachel Crum: Payload to Ground Communication

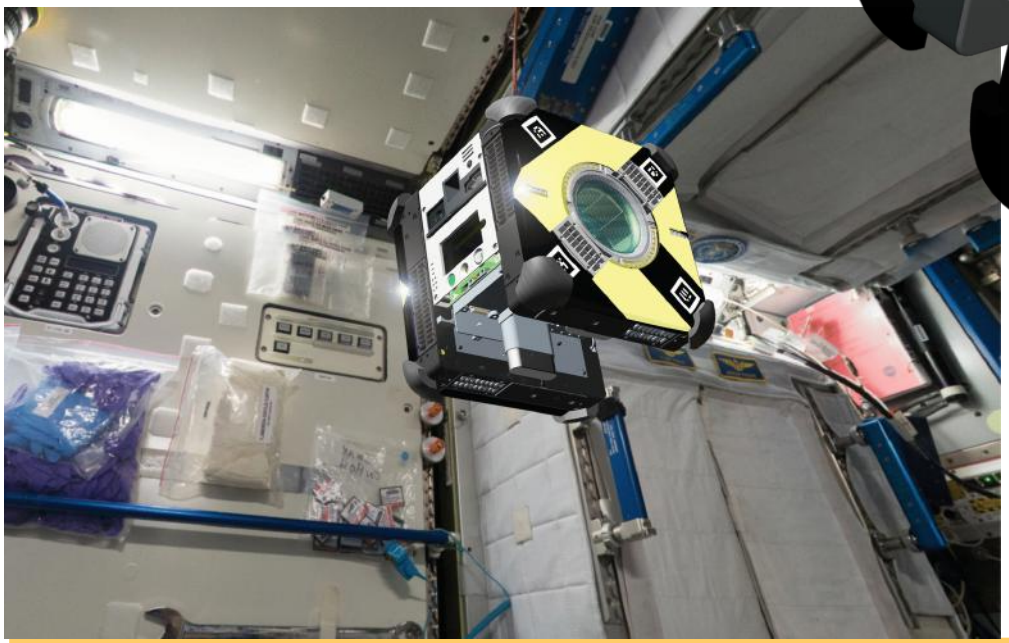






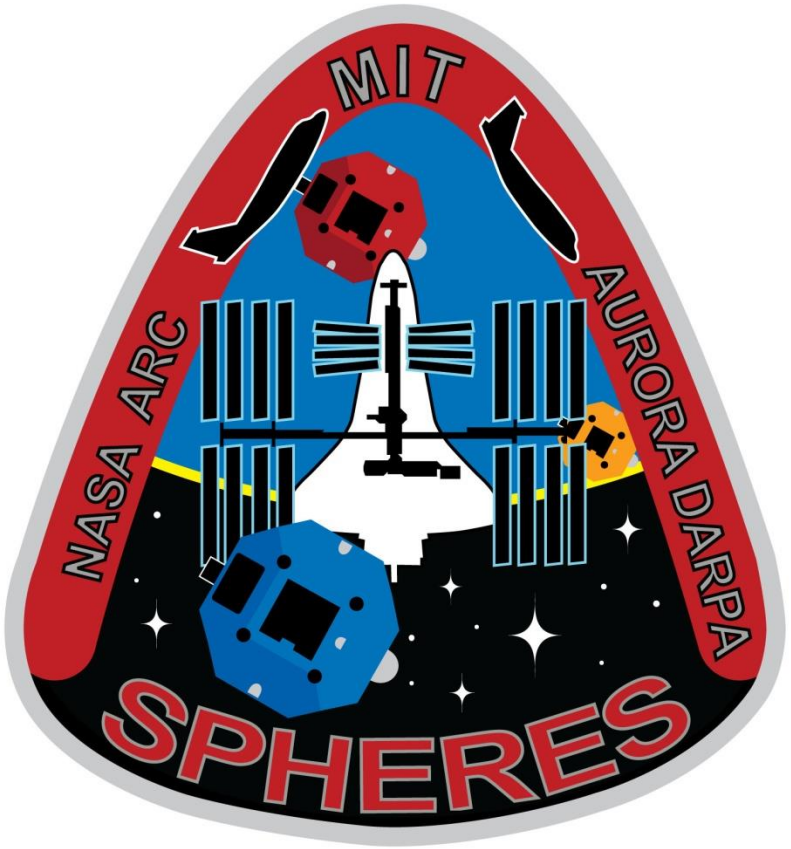
What's next …

- Next ZR competition is under way
- New Vertigo Smooth Navigation research
- Tether-Slosh
- **Continue work transitioning to Astrobee**
  - Goal: Fully operational in 2018



Guest Science Program (GSP)

- What's available from the Astrobee Facility?
  - Astrobee Robotics Software Simulation
  - Ground Hardware: Qty 3 & ”Flat-Sats”
  - Labs: Granite & MGTF
  - Documentation and Training
  - Proposal Support
  - ISS Payload Partner
- How can I use Astrobee and what does it take?
  - Guest Scientist Guide & Mechanical Payload ICD
  - New Hardware or ”just” Software?
  - Ground Demonstration or ISS Operation?
- We want to hear from you!
  - Approximate Scheduling



SPHERES & Astrobee Operations

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

Public Relations

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

Operations: Functions

Increment Planning

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

Safety and Verification Assessments

- Integrated Safety & Verification Assessments 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

Astrobee Ground Ops Development

- On orbit Activity planning and development
- Ground Operations Readiness Test planning and development
- First ISS Ops - Mapping Activity being planned, procedure in final stages

Ops: Increments 51/52 Review

Increments 51/52 (April 2016 to Sept 2017)

- **Increment planning on going for 53/54 (Sept 2017 – March 2017)**
  - **Planning for Tether-Slosh, Smoothing-Based Relative Navigation, Zero Robotics**
- **Planning also for potential Slosh Coating, and follow on Docking Port ongoing**
- **Consumables and hardware manifest support for SpX-11, OA-7, 67P and SpX-12 safety, verification for these flights – summarized on later Ops slide and in PIM presentation**
- **Supported InSPIRE II Workshop at NASA HQ June 21**
- **Procedure and hardware development supported at MIT July 6-7**
- **Supported and presented ISS Conference in Washington D.C.**
-

Ops: Increments 51/52 & 53/54

51/52 (Apr 2017 – Sept 2017) 53/54 (Sept 2017 – March 2017)

- Halo Science 1 — June 23 2017
- Zero Robotics Unit Test/Dry Run — Aug 4, 2017
- Zero Finals — Aug 11, 2017

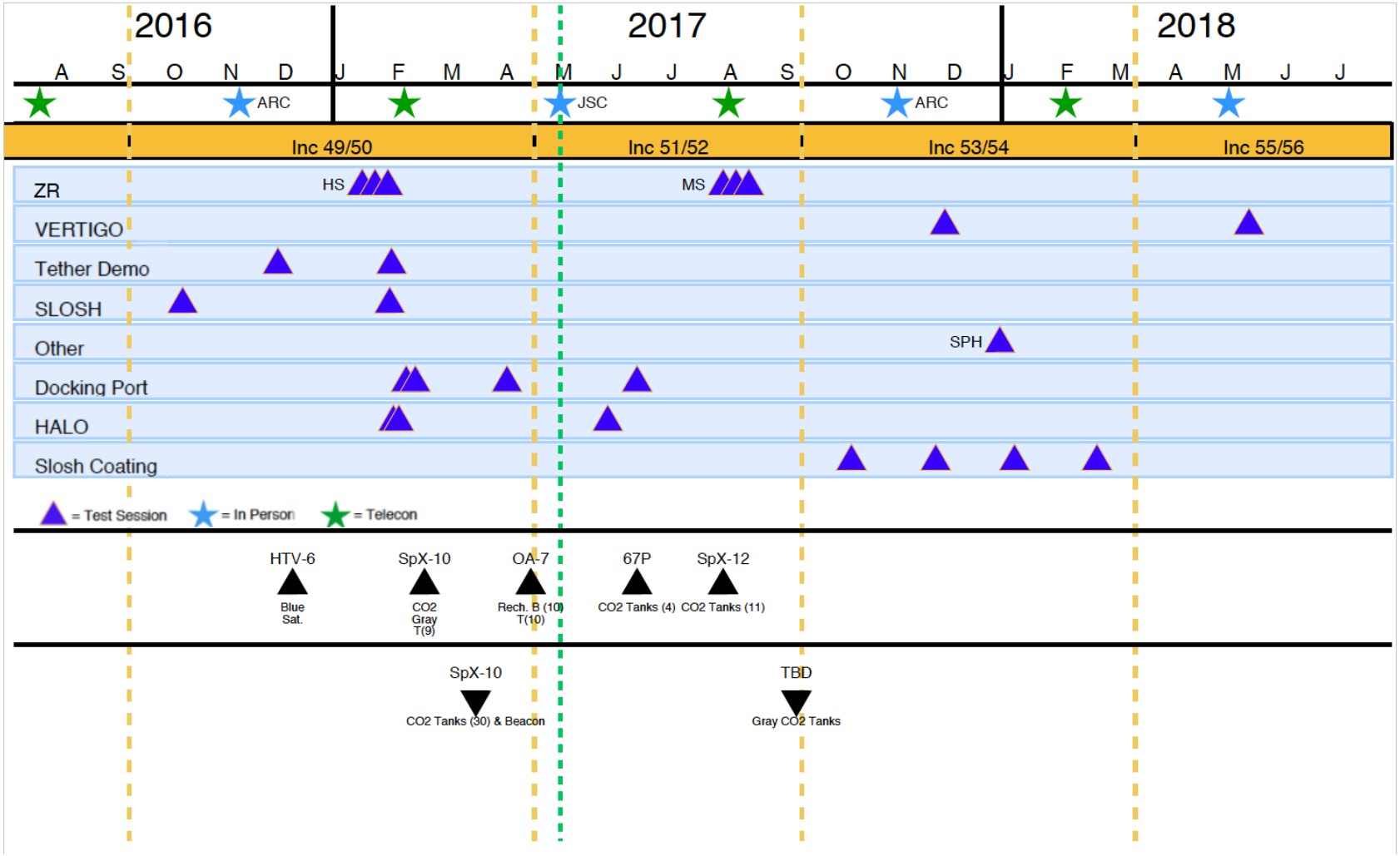
==========[53/54]==========

- Tether-Slosh — TBD
- Smoothing-Based Relative Navigation — TBD
- Zero Robotics High School Units Test — Nov- Dec 2017
- Zero Robotics High School Dry Run — Jan 2018
- Zero Robotics High School Finals — Jan 2018

==========[TBD - possible]==========

- Additional Docking Port — TBD
- Slosh Coating — TBD

SPHERES Calendar



Consumables Status

CO2 Tank Inventory

- **X Tanks on orbit now**
- Planning to up mass pink tanks fall/winter 2017-18 – flight TBD
- **Total: X gray tanks**

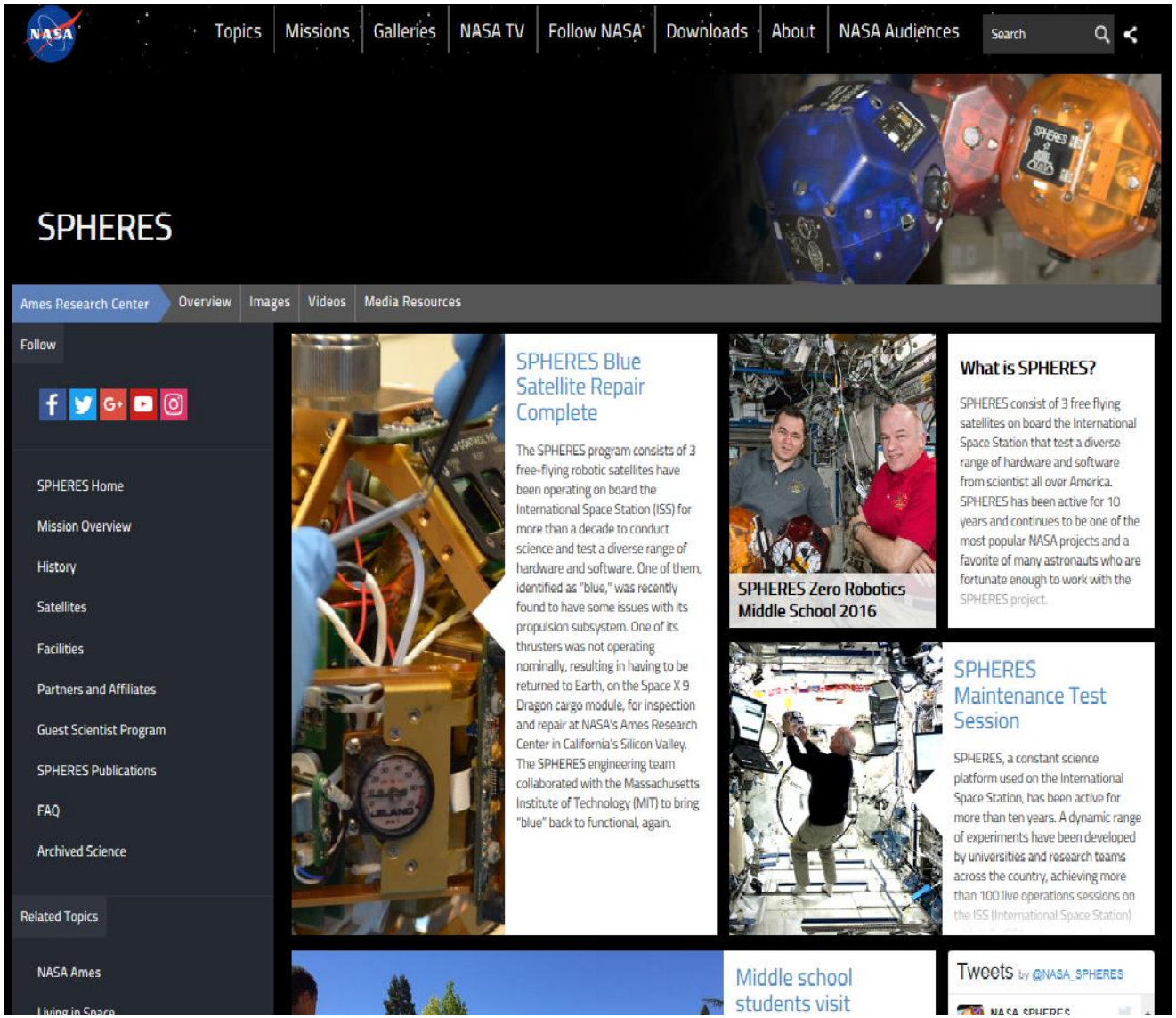
Battery Pack Inventory

- **X Batteries on orbit now**
- 10 SPHERES Rechargeable Batteries arrived on station with OA-7

Consumables downmass

- 13 empty gray tanks to be returned on SpX-12

SPHERES on Social Media



Twitter

https://twitter.com/NASA_SPHERES

Website

http://www.nasa.gov/spheres

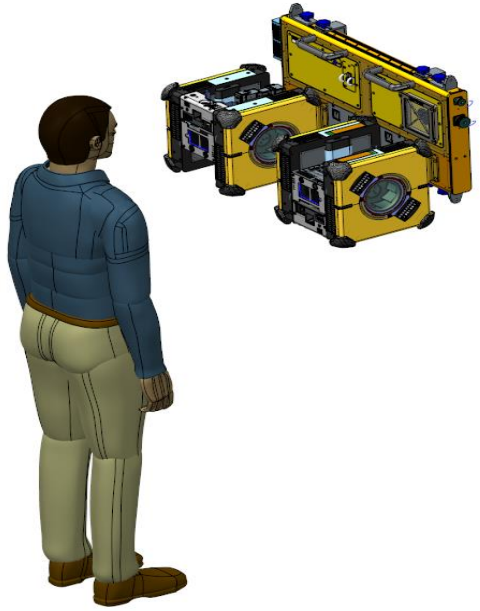
Astrobee System Overview

SPHERES/Astrobee Working Group

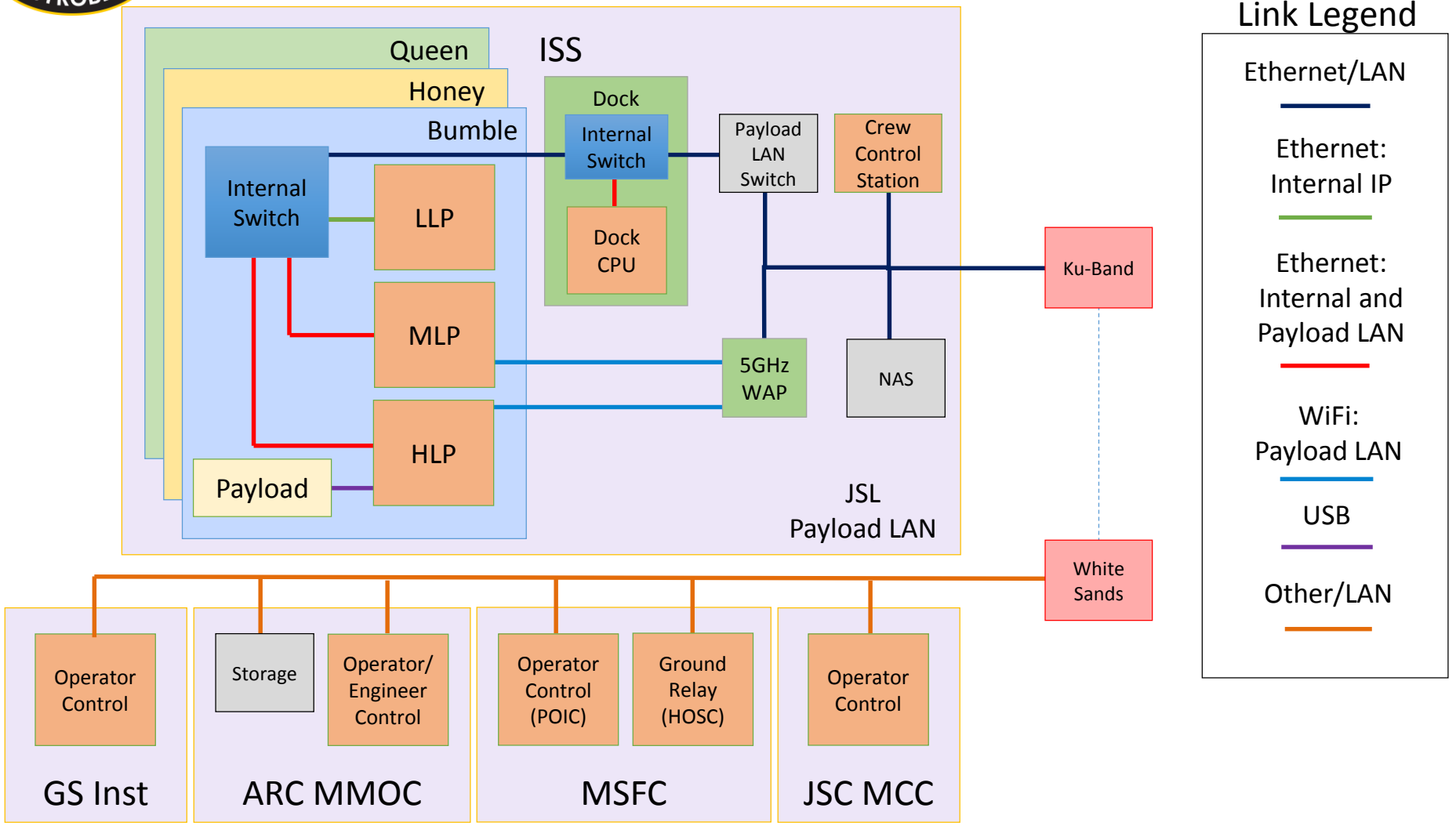
August 23, 2017

Astrobee Elements

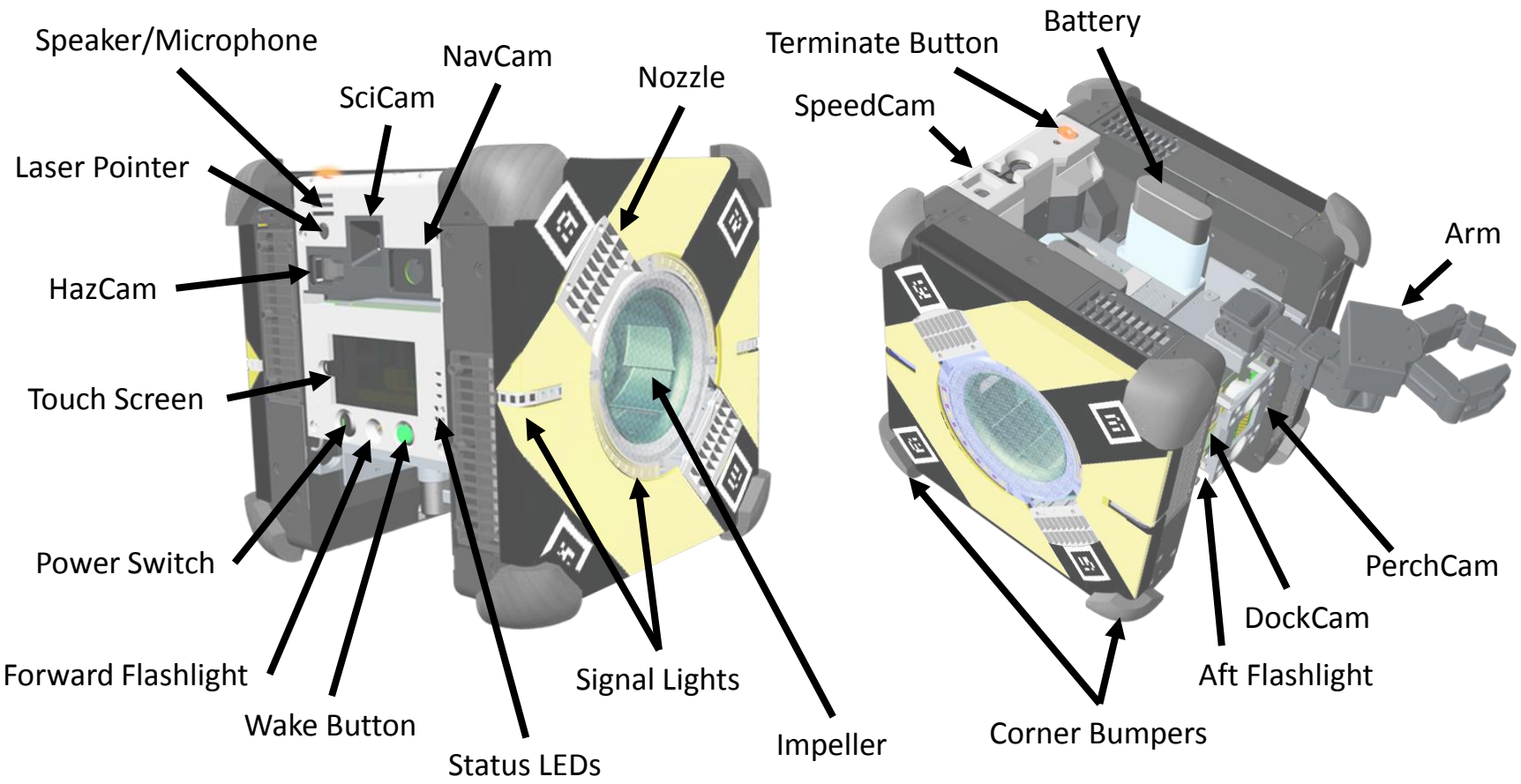
- Astrobee
  - Free Flyer
  - Dock
  - Ground Data System



System Data Flow Diagram



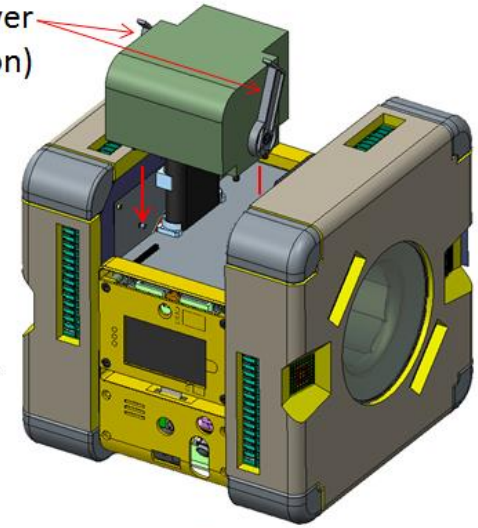
Astrobee


Speaker/Microphone
NavCam
SciCam
Nozzle
Laser Pointer
HazCam
Touch Screen
Power Switch
Forward Flashlight
Wake Button
Status LEDs
Signal Lights
Impeller
Terminate Button
Battery
SpeedCam
Arm
PerchCam
DockCam
Aft Flashlight
Corner Bumpers

Payload Attachment Options

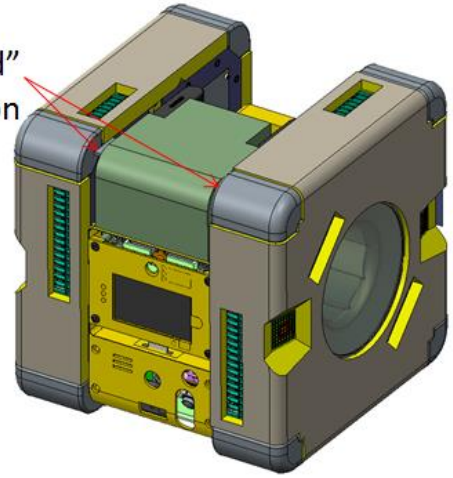
Quick "No Tool" Payload Attachment

2X Lever
(open position)



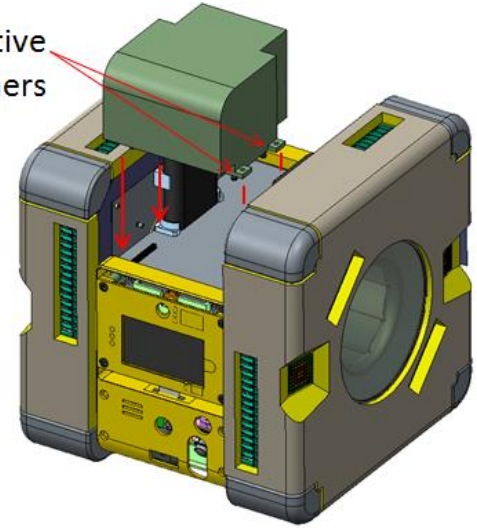
Lever engages and disengages payload connector and provides mechanical attachment

Lever in "Locked" position

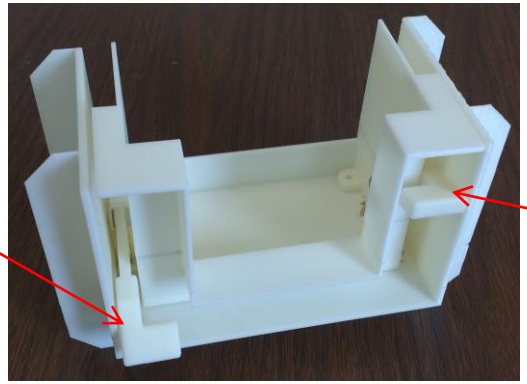


4X Fastener Payload Attachment

4X Captive Fasteners

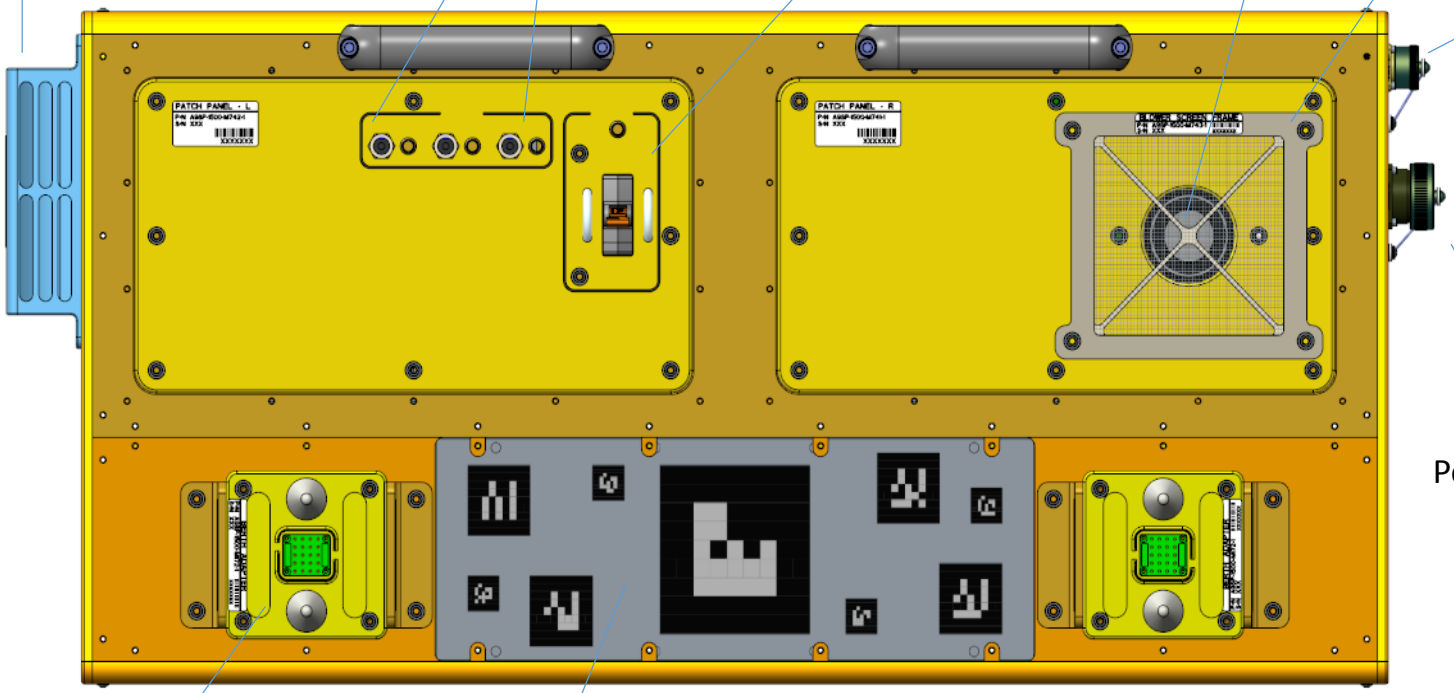


"Un-Lock" Position

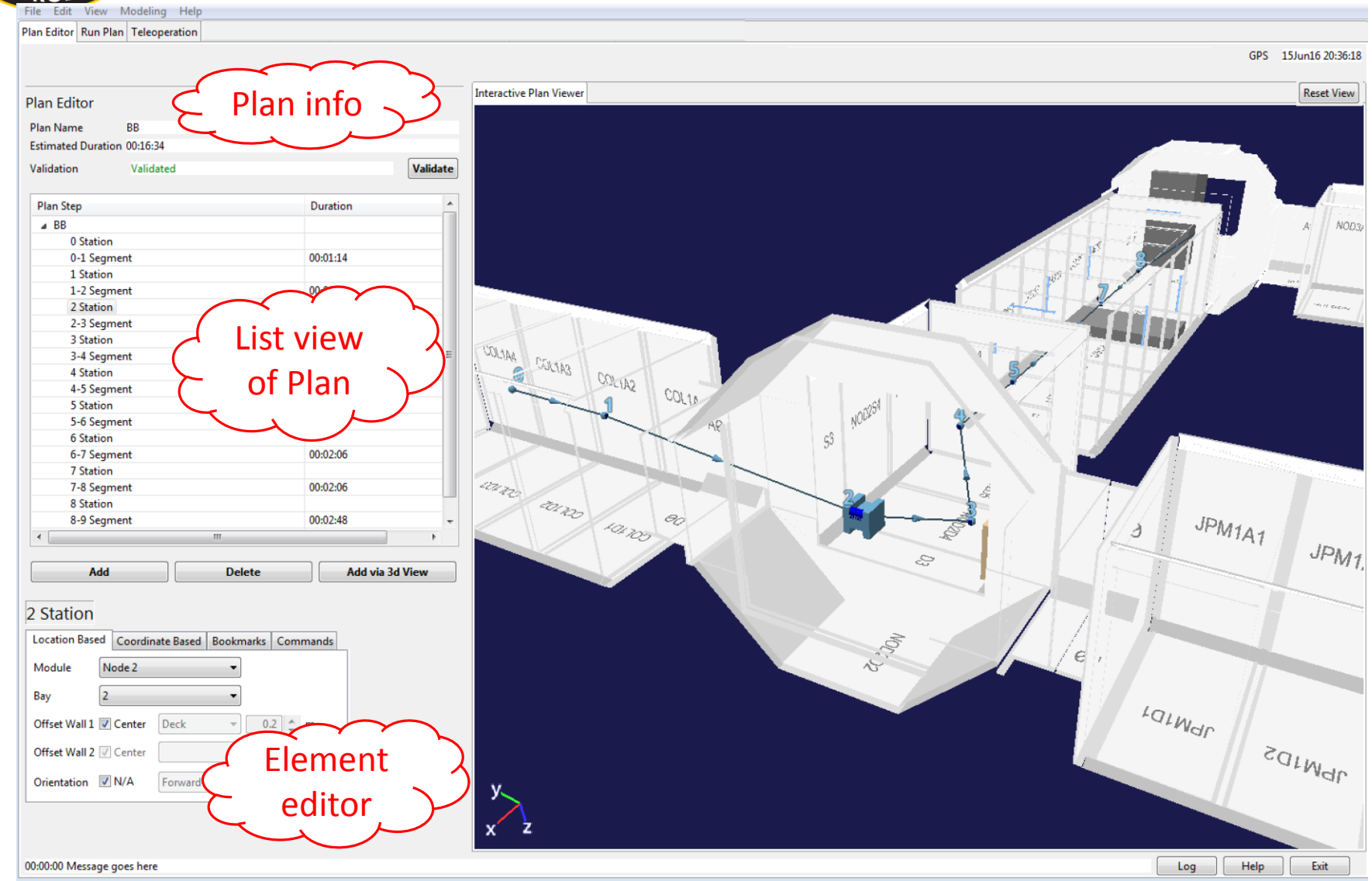


"Lock" Position

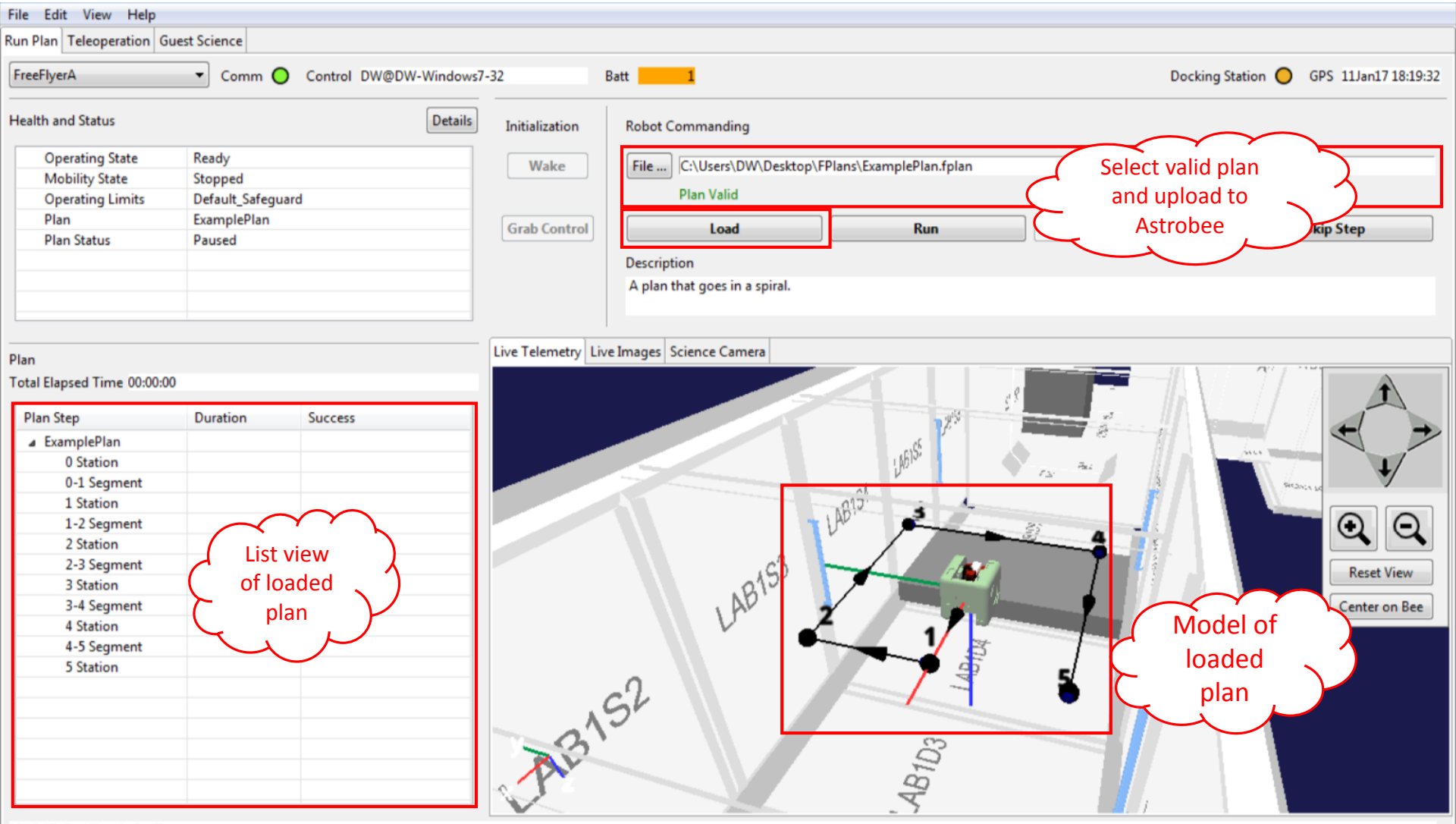
Dock


Air Vent Deflector
Subsystem Breakers
Main Power Breaker
Cooling Fan
Cooling Fan Screen
RJ-45 Connector
Power Connector
Free Flyer Berth
AR Target

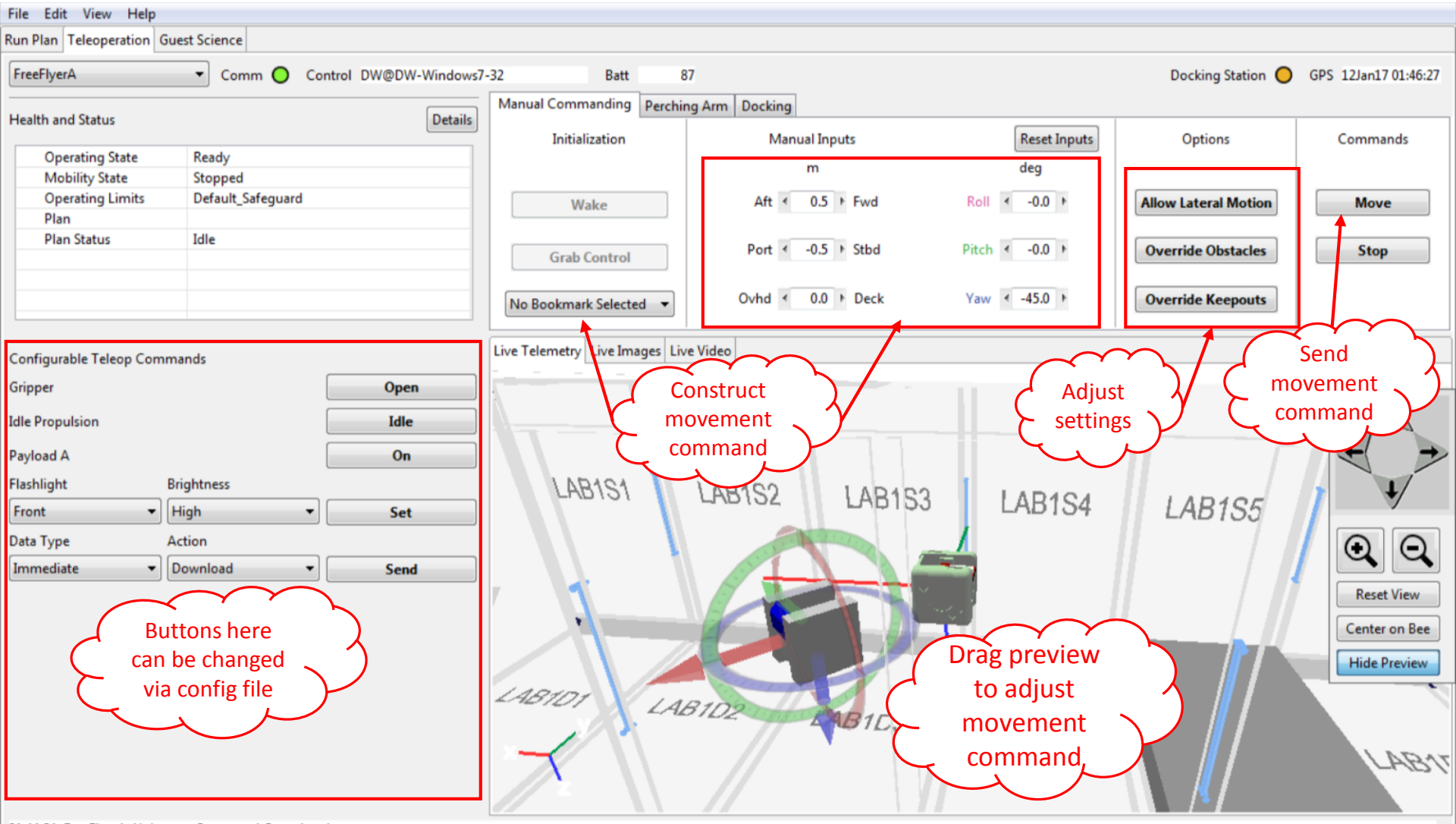
Plan Editor Tab (Operator/Engineering)



Run Plan Tab (All)



Teleoperation Tab (All)



Construct movement command

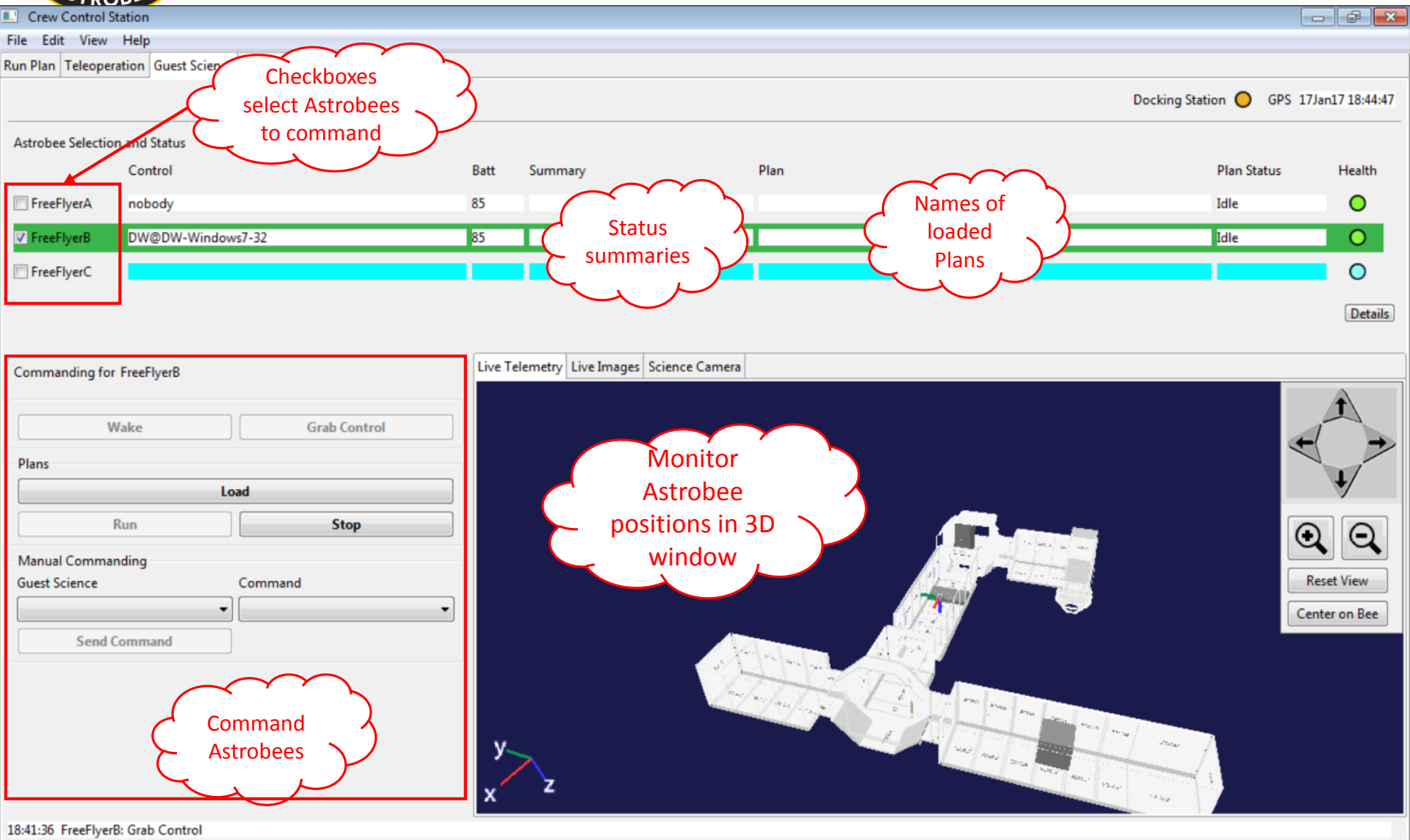
Adjust settings

Send movement command

Buttons here can be changed via config file

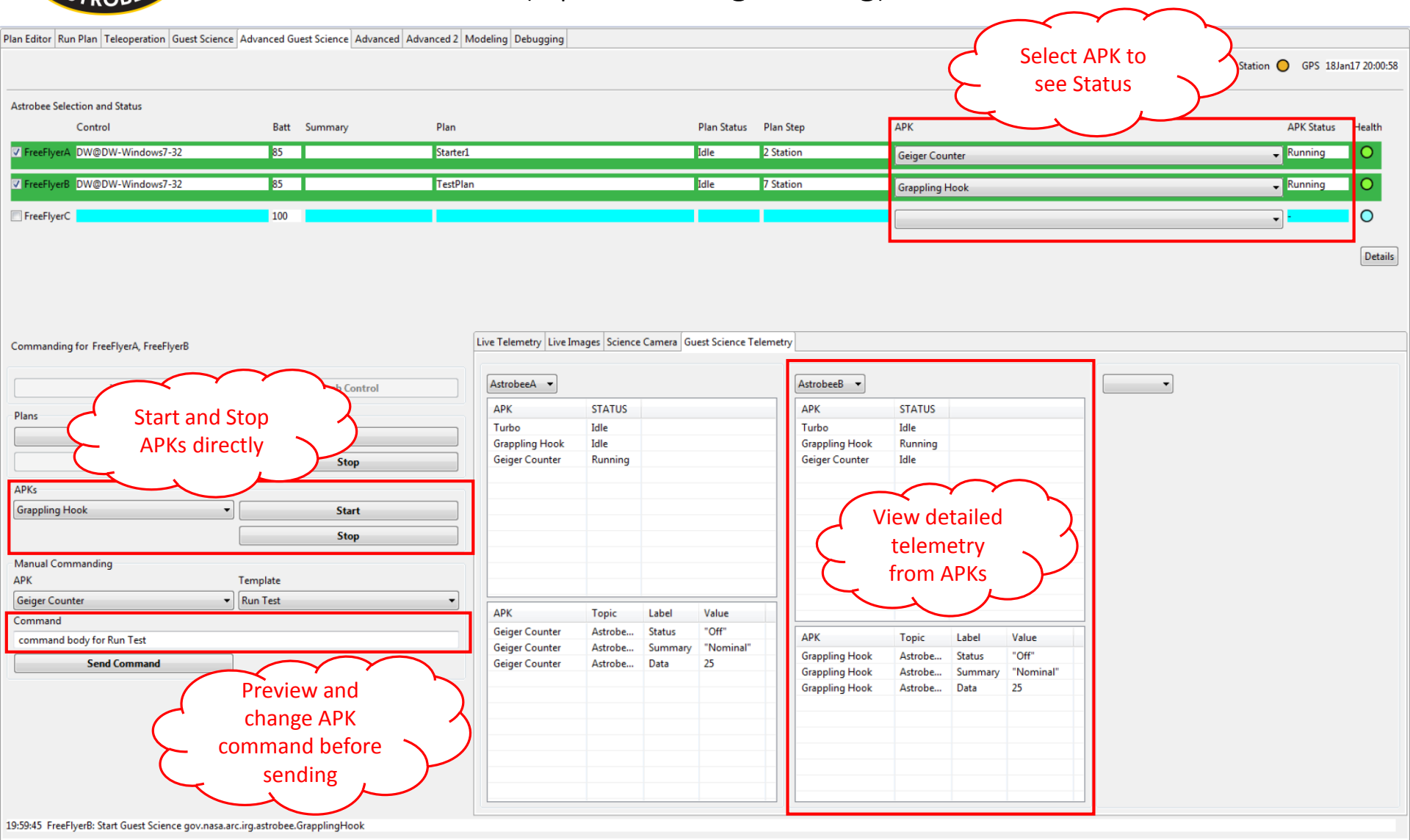
Drag preview to adjust movement command

Guest Science Tab (Crew)

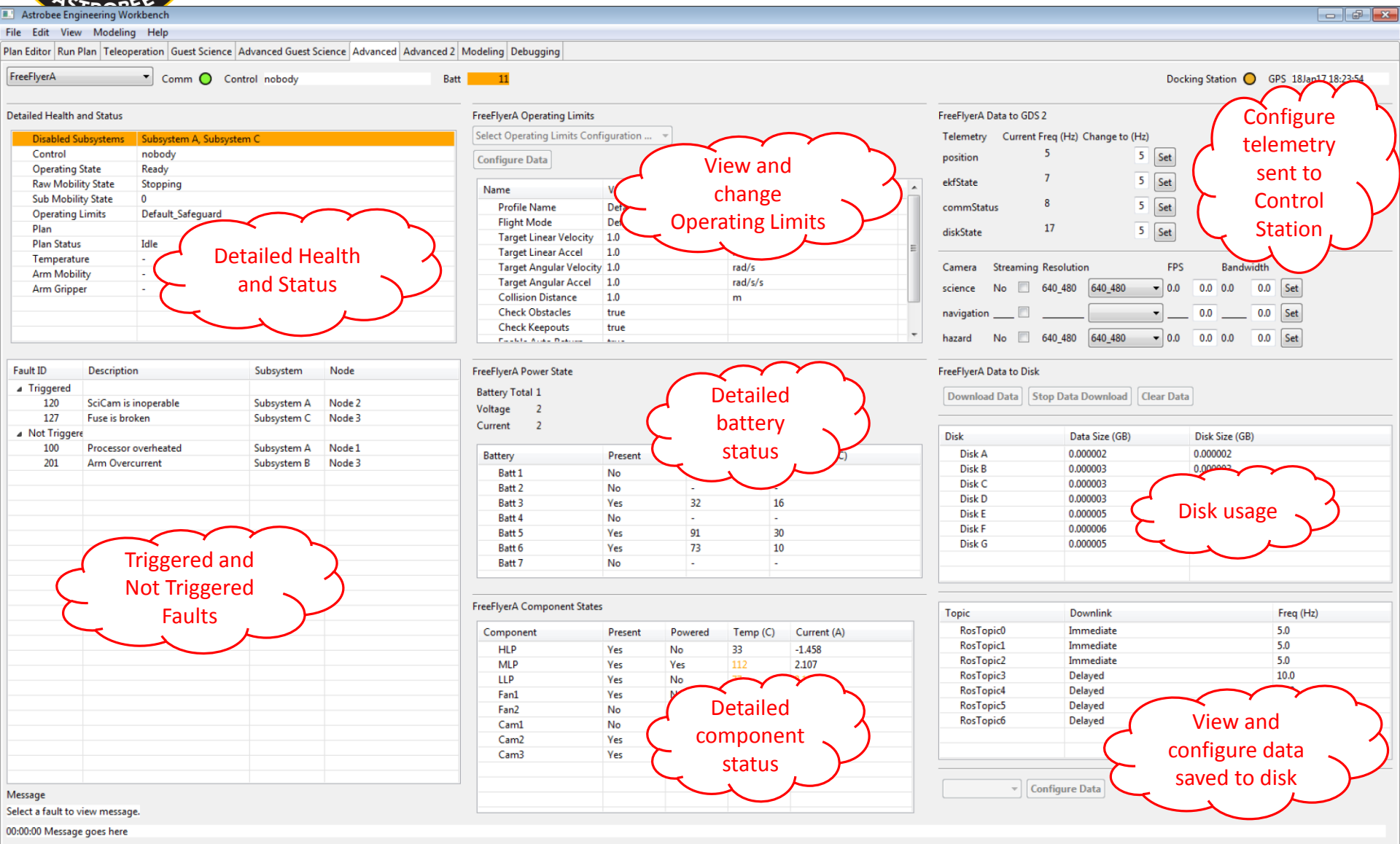


Advanced Guest Science Tab

(Operator/Engineering)



Advanced Tab (Engineering)



Astrobee Status

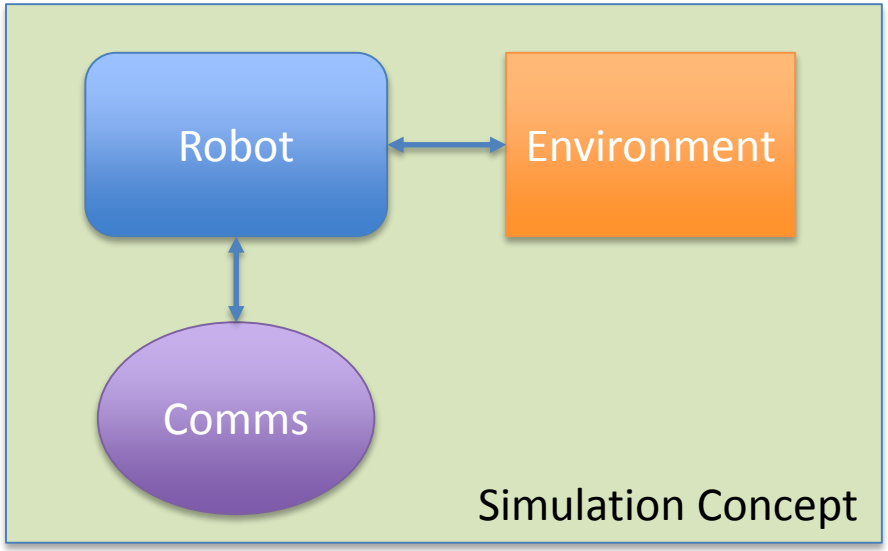
- Finalizing drawings
- Procurement has begun
- On track for August 31st delivery:
  - Beta release of Flight Software/Simulator
  - Mechanical Payload ICD drawings
  - Initial draft of the Guest Science Guide

Guest Science and Simulator Integration

Andres Mora

Simulator

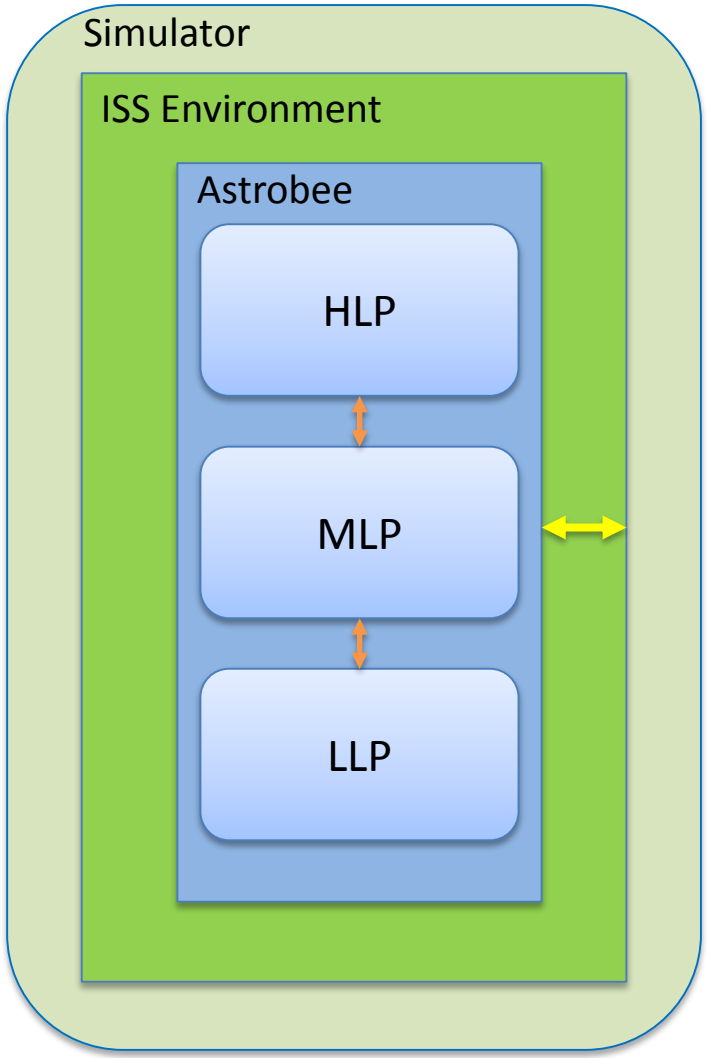
- Robot:
  - Hardware includes multiple cameras, processors, actuators, and mobility mechanisms.
  - Software allows localization within ISS, communication, grasping, actuation, locomotion.
  - Runs Guest Science payload (both hardware and software)
- Simulator:
  - Has the same code base as that in the robot
  - Adds components to simulate the environment inside the ISS and the communication with ground control
  - Allows users (Guest Scientists) to quickly test their experiments and understand how the robot would behave.



Simulator

- Developers require:
  - Simulator able to run in a medium to high-end laptop (e.g. Nvidia Quadro K1100M – Dedicated Video Memory 2048MB GDDR5)
  - Linux environment (Currently Ubuntu distribution, LTS 16.04)
  - Integrate ROS, Android (Android Studio) operating systems
  - Simulator is based on C++, Simulink deployed C blocks
  - Developers in Android extensively use multiple programming languages: Java, XML
  - Provides 3D representation of the robot via Rviz and/or Gazebo
  - Provides dynamical, sensor models via Gazebo

Software Architecture



- *Three ARM processors to isolate guest scientist code, vision based localization and GNC loop, connected by 100Mbps network switch*

- **High Level Processor** (HLP) – Android, Quad core
  - Interface with Science Camera and Display
  - Encodes video with dedicated hardware
  - Runs guest science code

- **Mid Level Processor** (MLP) – Linux, Quad core
  - Runs absolute localization algorithms, obstacle detection, communications
  - Heavy processing power used by vision

- **Low Level Processor** (LLP) – Linux, Dual core
  - Runs 62.5 Hz: EKF and propulsion control loop

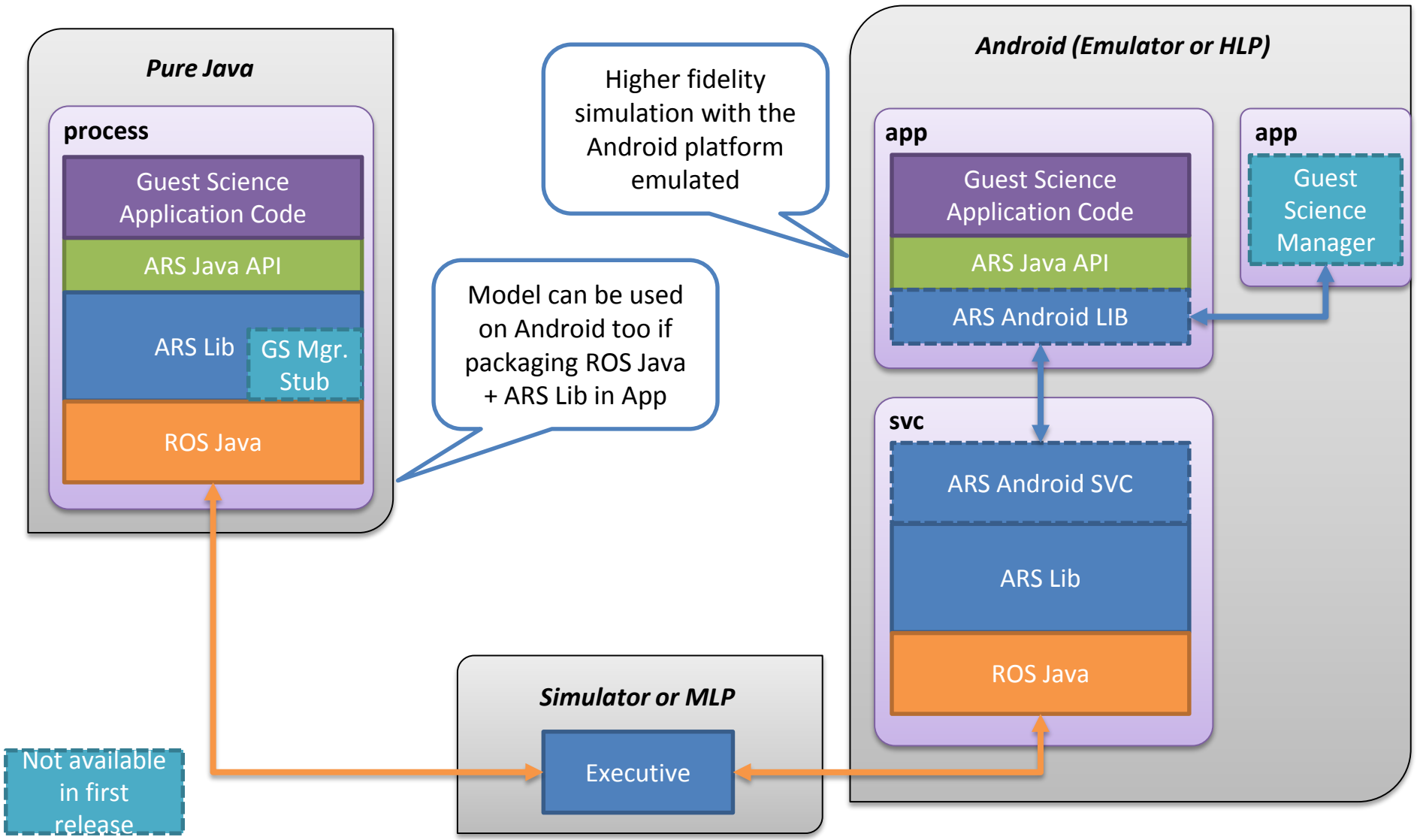
ROS messages:
Sensing/Actuation:

Guest Science

- Guest Science interface scenarios

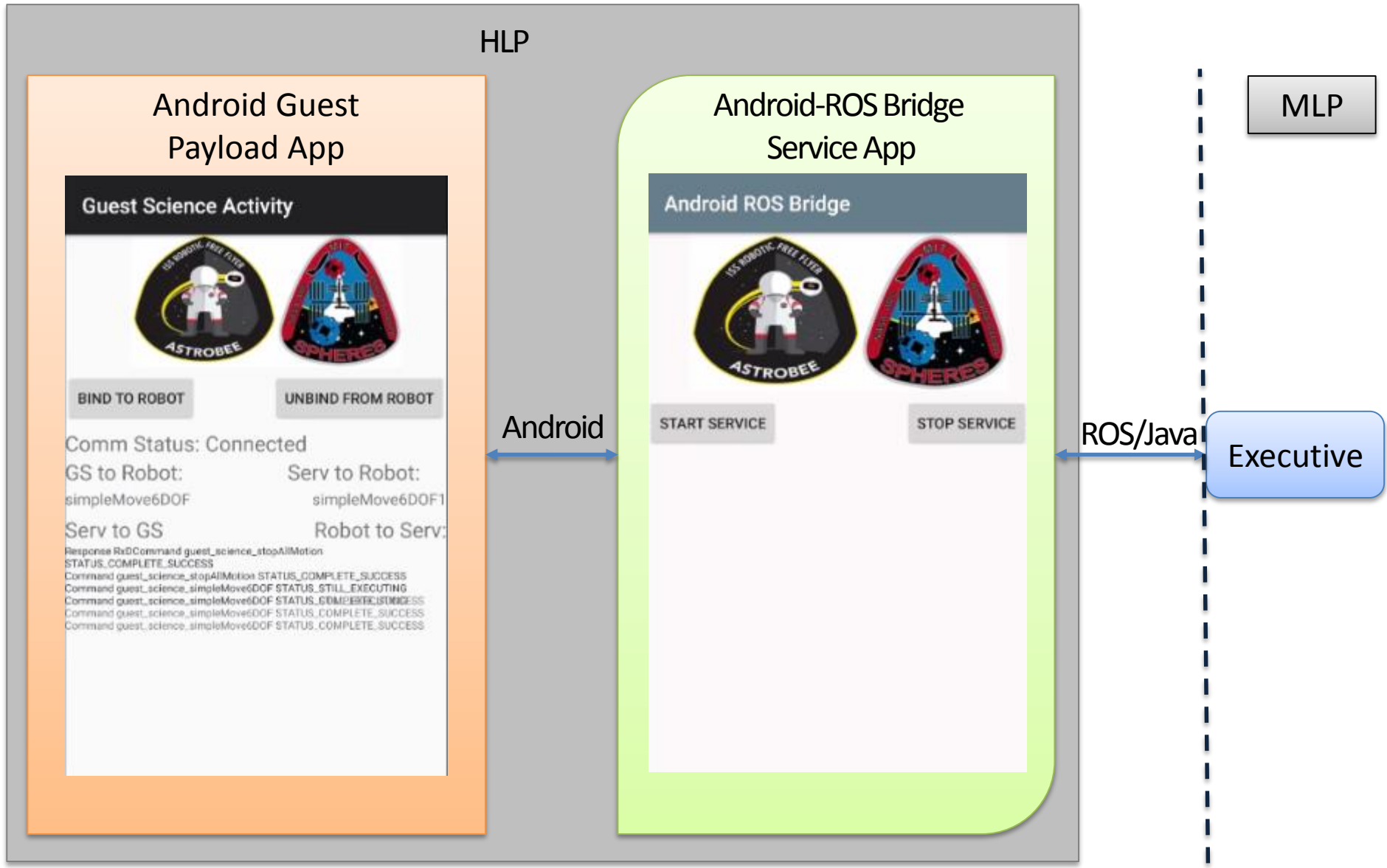
1. Basic API (Zero Robotics): handles high-level commands and uses Android environment only
2. Intermediate API (Zero Robotics, University researchers): high-level to mid-level commands by-passing Android-ROS bridge but still using Java-ROS framework. Telemetry is accessible.
3. Advanced API (University researchers): By-passes completely provided Java-ROS framework.

Guest Science Implementation



Android Guest Science

- Communication between different processes/threads
- Intercommunication Process (IPC)
- Services:
  - Scheduled
  - Started
  - Bound
- Messenger class to avoid complex AIDL implementations



Astrobee Robot Software (ARS)

SPHERES/Astrobee Working Group, 08/23/2017

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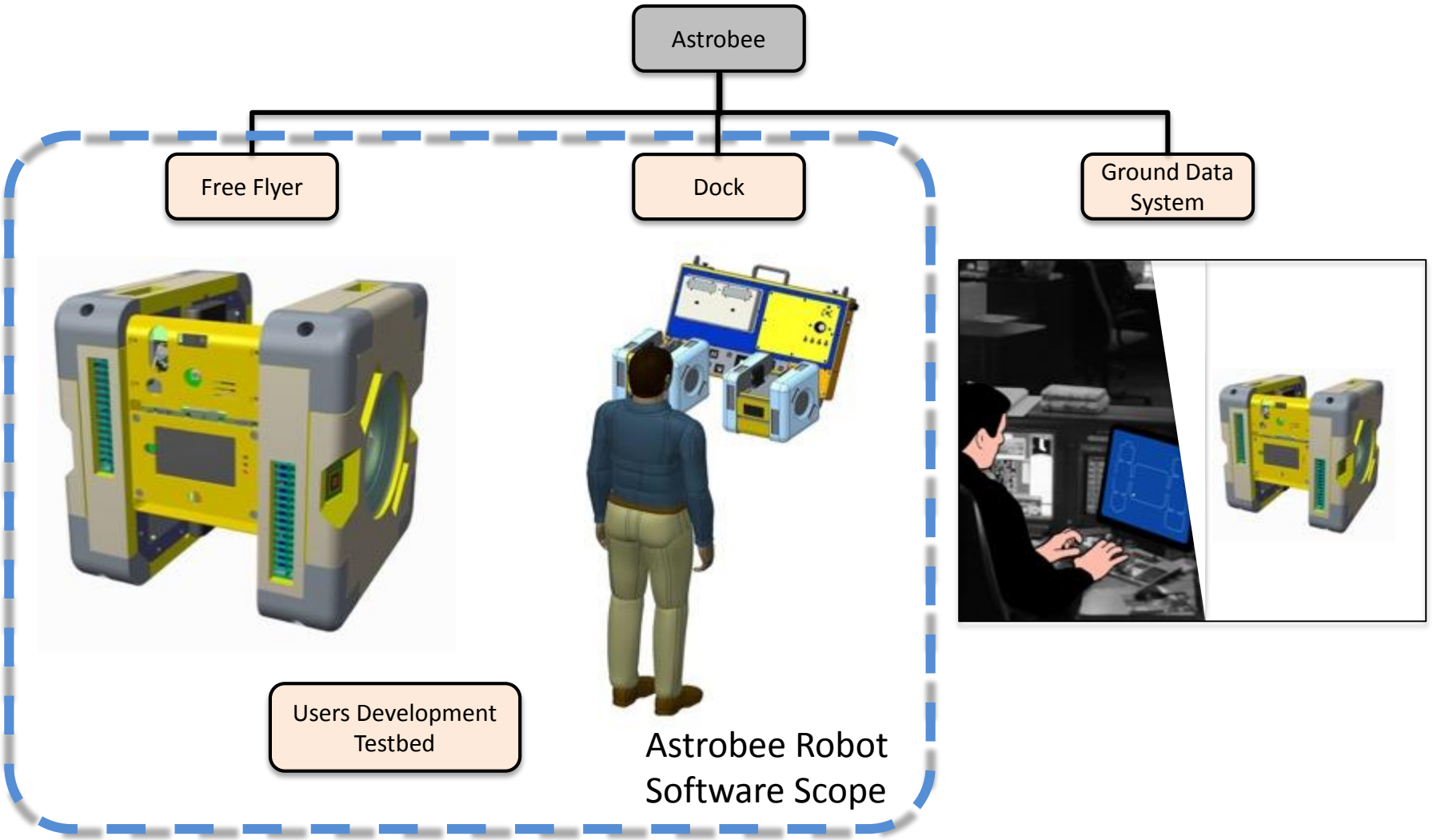
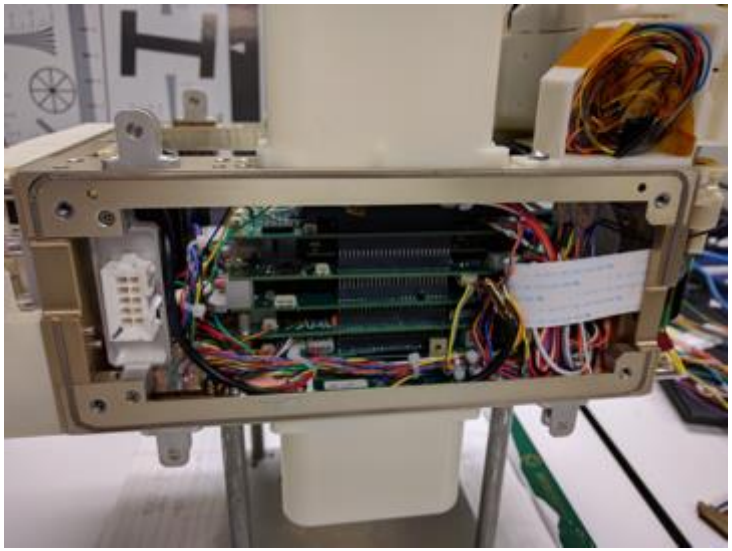
Astrobee Elements / ARS



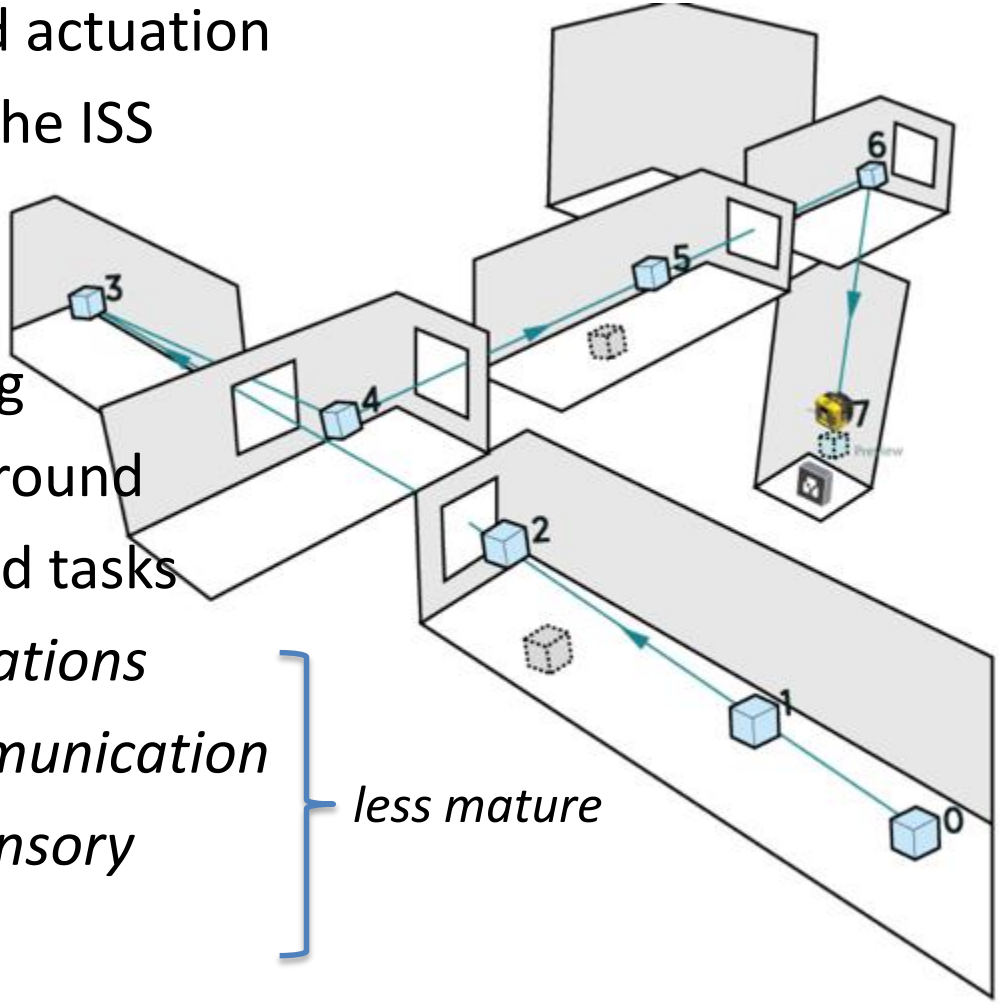
ARS (Astrobee Robot Software) Overview

- ARS is deployed on 4 cell phone type processors (Astrobee + Dock) running Linux and Android
- Astrobee contains 7 distinct microprocessors with custom firmware + several microprocessors with COTS firmware
- Software deliverables includes:
  - Custom firmware(s)
  - Custom tailored Linux kernels
  - Linux and Android Operating Systems
  - ARS dependencies (third-party libraries)
  - **ARS Source Code** ← **Open Source**



ARS Features

- Manage Astrobee sensing and actuation
- Localize and Navigate within the ISS
- Perform autonomous docking (+ return to dock)
- Perform autonomous perching
- Support teleoperation from ground
- Support plan based automated tasks
- *Support "Guest Science" operations*
- *Support multi Astrobees communication*
- *Support hardware for multisensory human interaction*



less mature

ARS Components

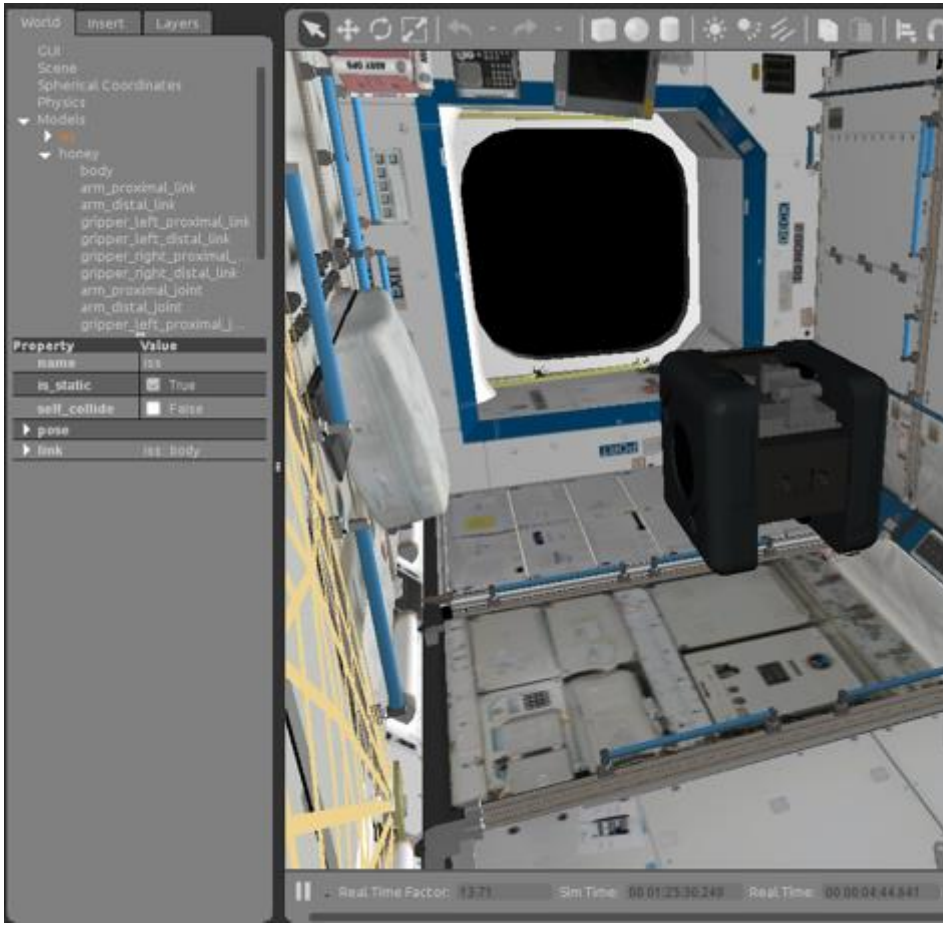
- OS (Communication Framework)
- Localization
  - Marker less Flying
  - Docking
  - Perching
- Offline mapping for localization
- Pose Estimation + Propulsion Control (GNC)
- Executive
  - Mode Management
  - Sequencer (Plan Execution)
- Mobility
  - Generates and validates trajectories
  - Performs collision detection
- Fault Management
- Guest Science
- User Interfaces Support
- Simulator
- Platform Management and development tools

SLOC Directory SLOC-by-Language
1367376 gnc cpp=1367280
45474 submodules ansic=20471,java=7963
14262 mobility cpp=14015
12351 localization cpp=11923
9803 hardware cpp=9366
6760 scripts python=3527,sh=1844
6393 shared cpp=6344
6279 management cpp=6090
4778 tools cpp=2290,ansic=984
3600 communications cpp=3524

Totals grouped by language:
cpp: 1422365 (96.05%)
without autogen: **58305**
ansic: 21455 (1.45%)
xml: 14956 (1.01%)
python: 9792 (0.66%)
java: 7963 (0.54%)
sh: 2867 (0.19%)

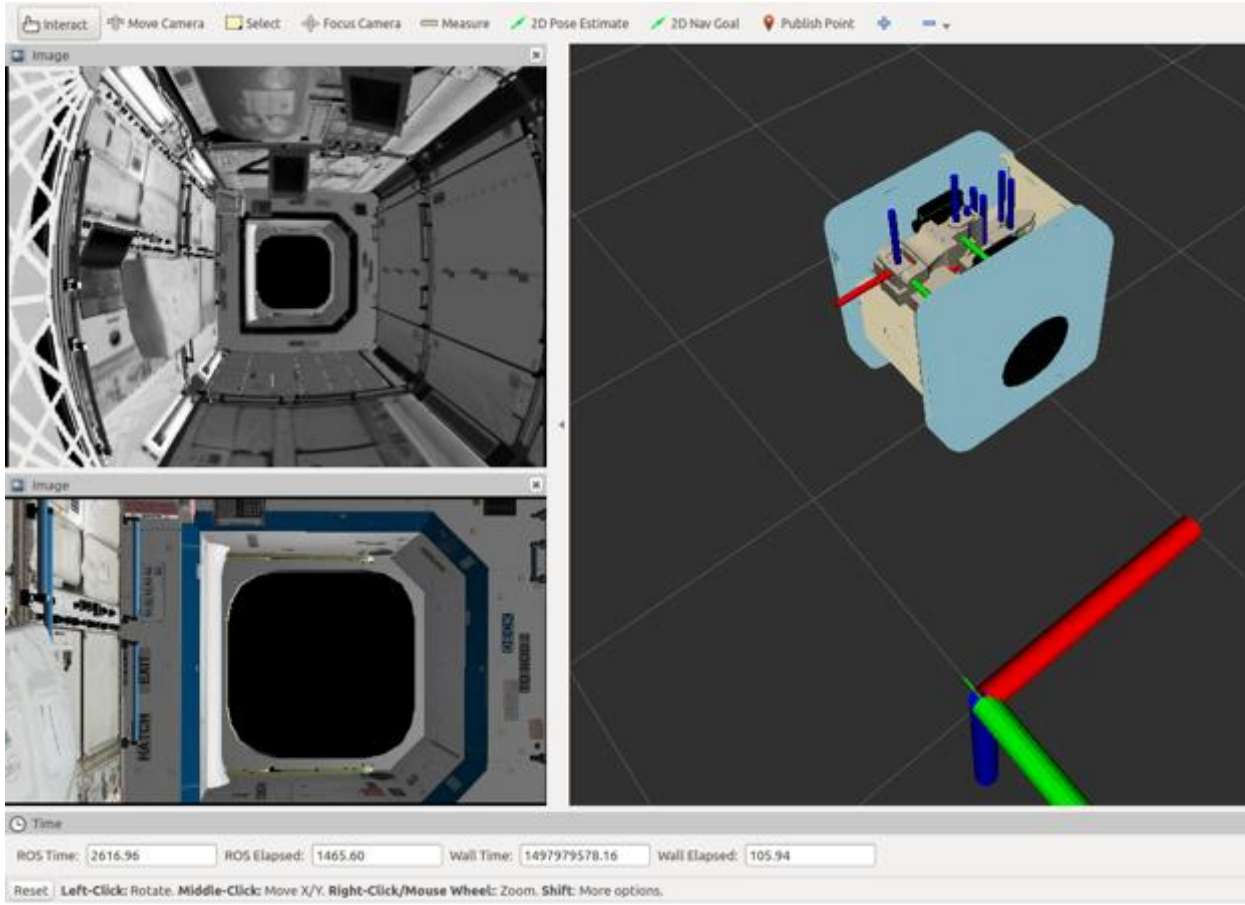
ARS and ROS

- ARS makes extensive use of the open-source Robot Operating System (ROS):
  - Communication framework linking all “nodes” running on the target platform
  - Try to maximize the re-use of existing ROS messages benefit from existing ROS packages
  - Use ROS introspections tools to rapid debugging
  - Use ROS facilities to record/replay/analyze data
  - Use some ROS/Gazebo components for the simulator



Simulator

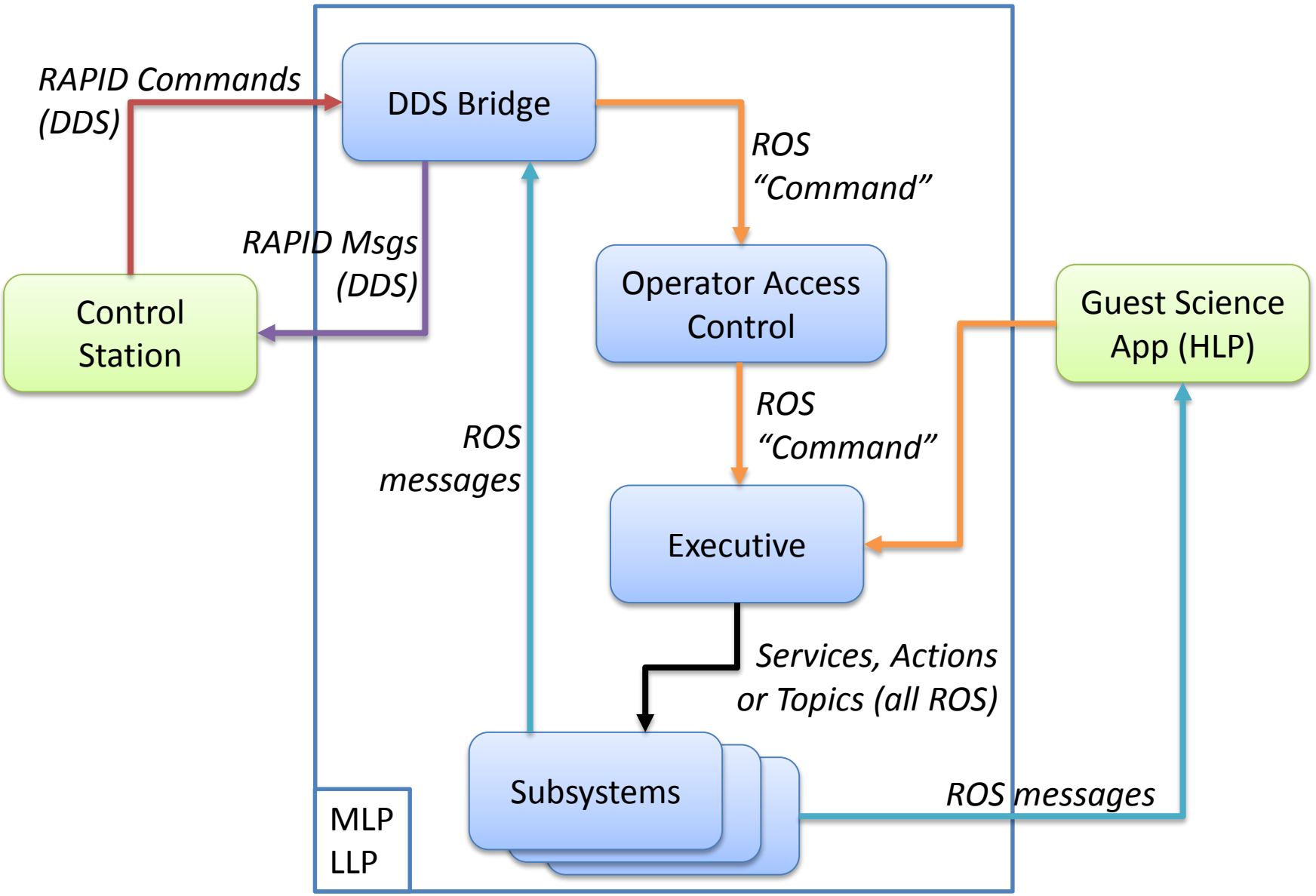
- Custom propulsion system and some localization sensors
- Gazebo based dynamics model, imagers, arm, lights and ISS model
- Can run all nodes on desktop or some nodes on target development board



ARS APIs Overview

- ARS uses ROS within Astrobee: Messages, Services and Actions define the internal API
- Astrobee & Ground communication uses DDS and the RAPID framework for command and telemetry
- Commands:
  - Commands are defined using XP-JSON schema, tools auto-generates RAPID command dictionary
  - ARS defined a ”ROS Command” mirroring the DDS command structure
  - Onboard Astrobee Guest Science or Ground Applications **share** the **same command dictionary** (some commands unique to one client) with either DDS or ROS transport
- Telemetry:
  - Internal uses ROS Messages (using ROS messages when possible)
  - External uses DDS Messages (subset only, re-using RAPID messages)

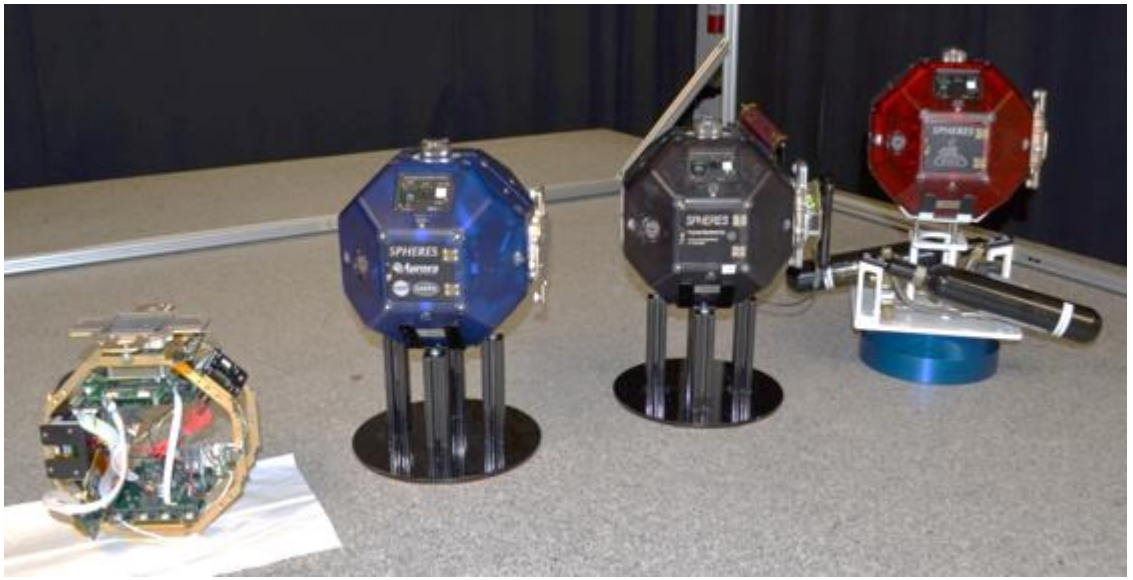
ARS APIs Access

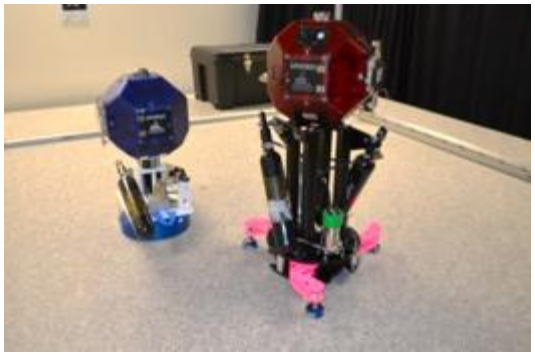


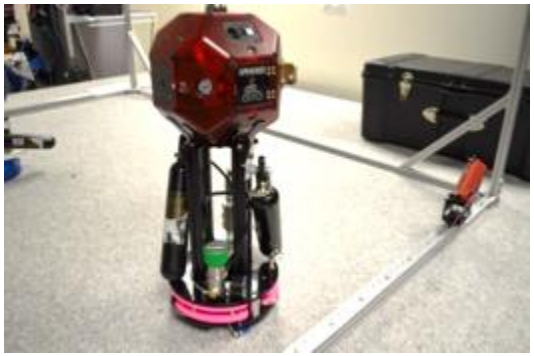
SPHERES Engineering

Hardware Status

- **Hardware status**
  - Red: 100%
  - Blue: 100%
  - Black: 25%
  - Orange: @ MIT
  - Stack: 100%
  - Battery recharger: 4 of 4
  - New air carriage: 3 of 4
    - ✓ Tall 3-puck: 2 of 3
    - ✓ Single puck: 1 of 1
    - ✓ More in work

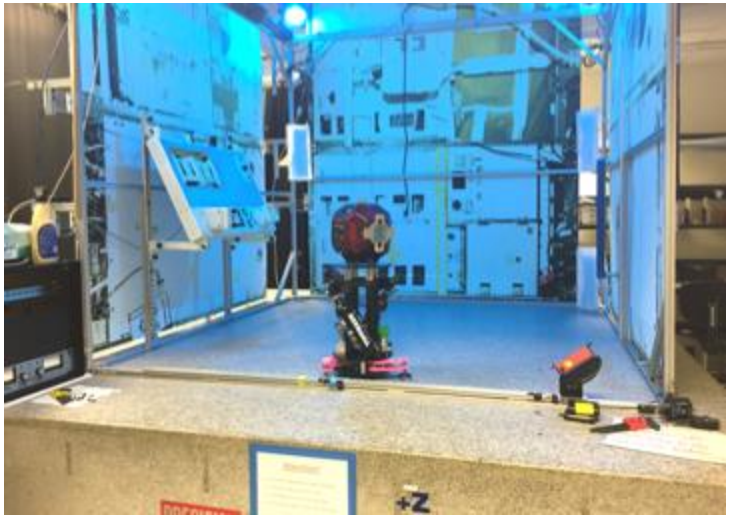






Ground Lab Status

- Granite Lab: Online

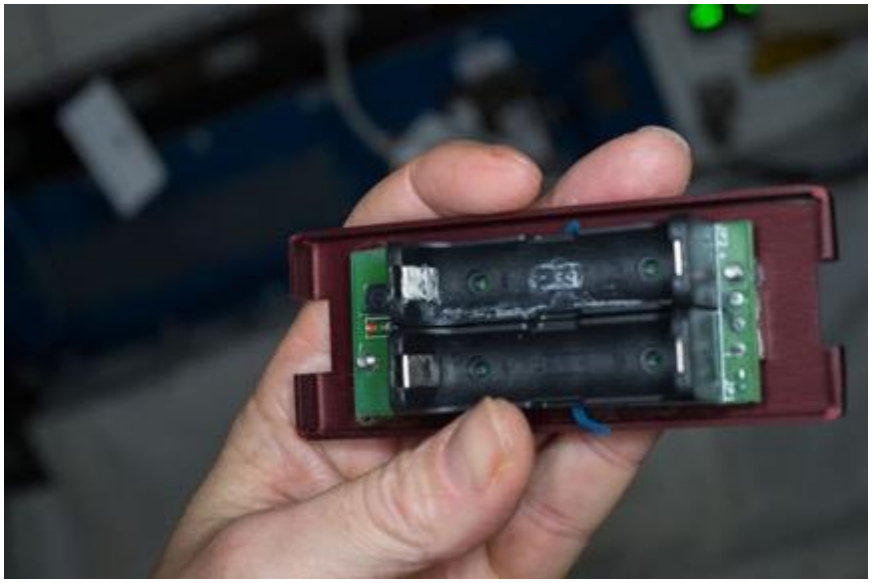


- Flight Lab: Online

- Micro Gravity Test Facility (MGTF) Lab

- Engineering Evaluation Lab (EEL): Available upon request

SPHERES ISS Beacon Repair



Inventory

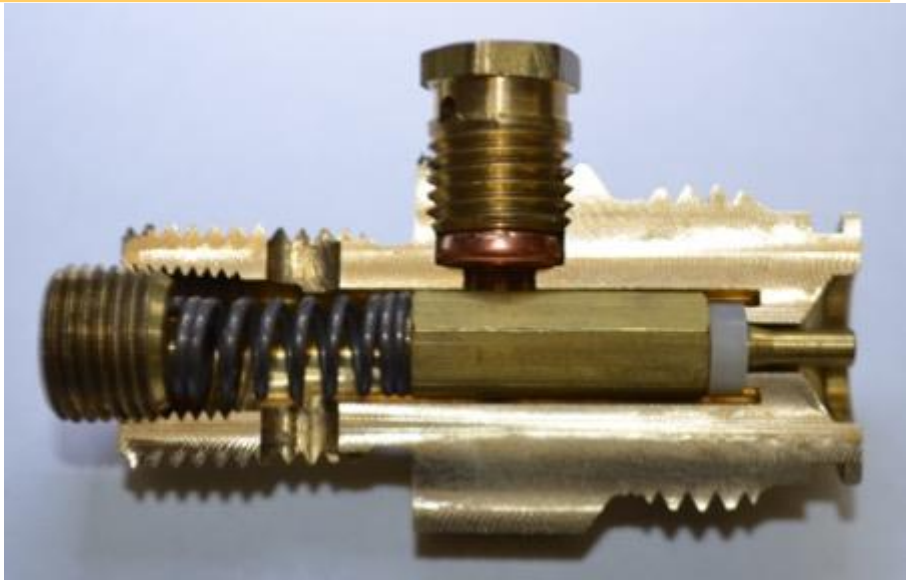
- Corrosion discovered from Batteries
- Discovered by Jeff Williams during TS82 (Maintenance Session)

Results

- Arrived at Ames
- Battery holder replaced, cleaned, and inspected
- Returned to station

Gen 2.5 Pink CO2 Tank Status

- **Inventory Status**
  - ~60 Tanks Ready for Filling
  - Decals Arrived (IMS Barcode / Hazzard waste / Fill Status)
- **Schedule**
  - ~1 week to finalize product (fill, label, bake out) + 1 week Idle leak check
  - Full delivery mid September
- **Notes**
  - Under-Torqued pin-valve issues on Gen 2.0 has been resolved with new oversight and integration at Ames.



Lab Upgrades: MGTF

❑ Environmental effects

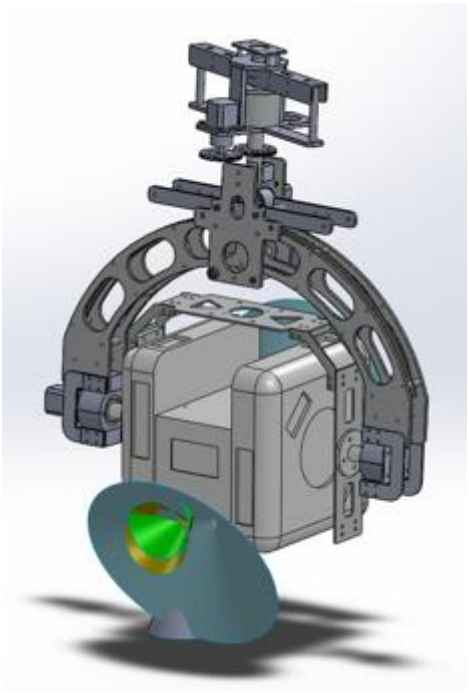
- Background
- Mock ISS Panels
- LED Lighting
- Active Gimbal

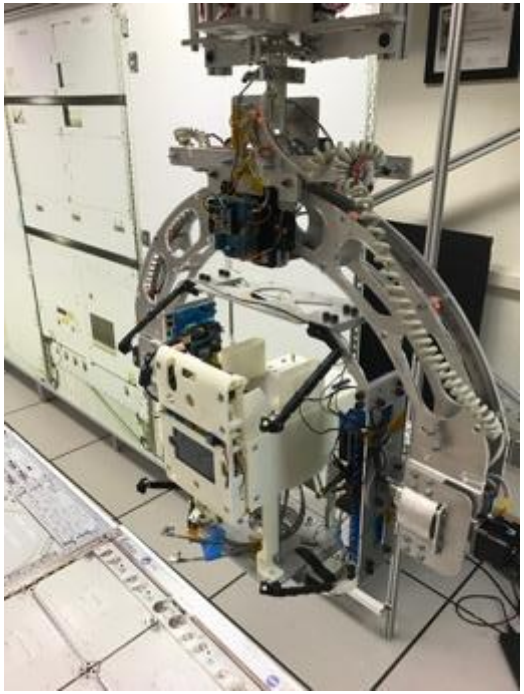
MGTF Gimbal

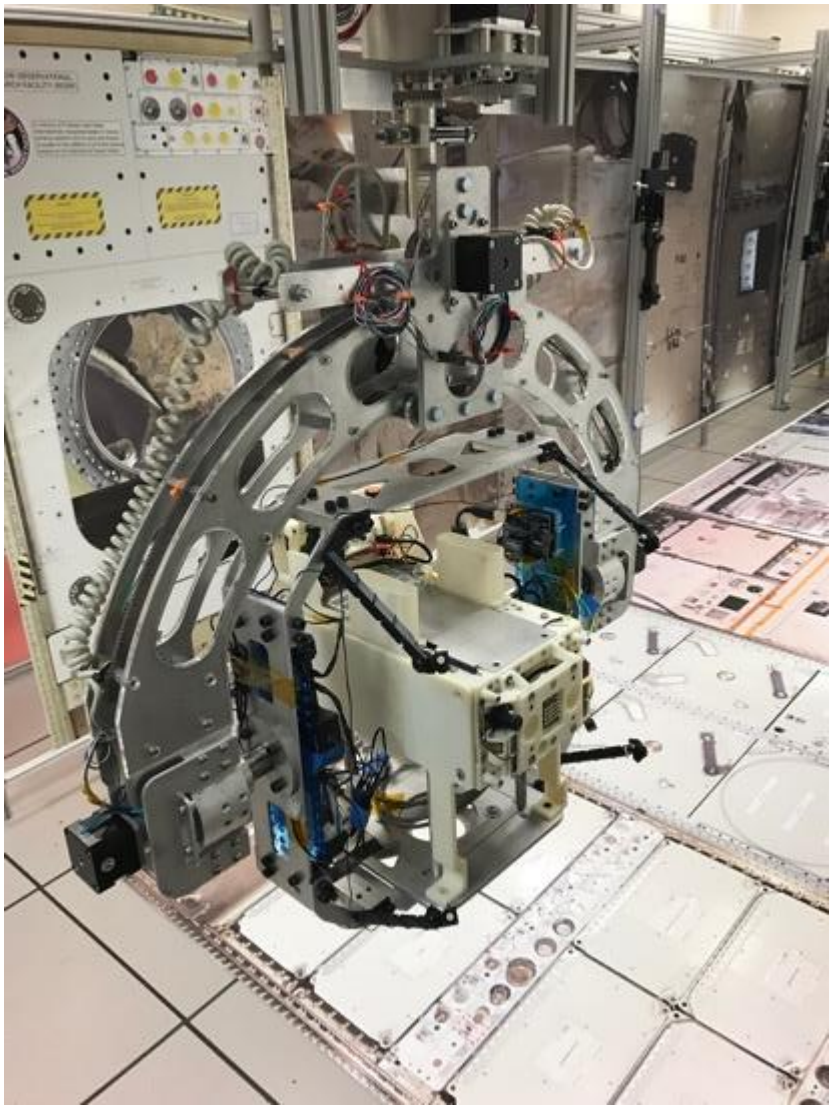
❑ Gimbal Specs

- Active Gimbal

- Yaw 360˚ Roll 126˚ Pitch 180˚
- Weight ~ 30lbs (without satellite)







SSLA Shades (Remember this?)

- JEM GLA lights are planned to be replaced soon by SSLAs
- SSLAs cause IR noise andre sets SPHERES
- Prototype testing at JSC early next month

Software: Gantry Control

6dof Control:

- Matlab control software.
- Position, Velocity, or Acceleration commanding.
- Visualeyez for ground truth
- Real time commands from simulation or from the payload over Xbee.

Status:

- 6-DOF operational.
- Testing in progress