

# SPHERES

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



## SPHERES/Astrobee Working Group (SAWG) Quarterly Meeting

Aug 23rd, 2017





## 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

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- |     |         |                    |          |                    |
|-----|---------|--------------------|----------|--------------------|
| 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

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## □ 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

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## □ Team

- Jose Benavides, [Jose.V.Benavides@nasa.gov](mailto:Jose.V.Benavides@nasa.gov), PM
- Aric Katterhagen, [aric.j.katterhagen@nasa.gov](mailto:aric.j.katterhagen@nasa.gov), Ops Lead
- Jonathan Barlow, [jonathan.s.barlow@nasa.gov](mailto:jonathan.s.barlow@nasa.gov), Eng Lead
- Jose Cortez, [jose.cortez@nasa.gov](mailto:jose.cortez@nasa.gov)
- Robert Hanson, [robert.s.hanson@nasa.gov](mailto:robert.s.hanson@nasa.gov)
- Simeon Kanis, [simeon.i.kanis@nasa.gov](mailto:simeon.i.kanis@nasa.gov)
- Don Soloway, [Donald.i.soloway@nasa.gov](mailto:Donald.i.soloway@nasa.gov)
- Andres Mora Vargas, [amora@meicompany.com](mailto: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 21<sup>st</sup>
- ❑ Successful Zero Robotics Field Day at Ames, July 7<sup>th</sup>
- ❑ Successful Zero Robotics Finals competition on Aug. 11<sup>th</sup>



**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.**

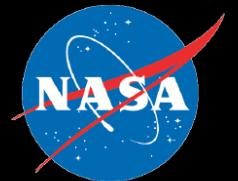


# Program News & Highlights 3/3

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- ❑ Tether-SLOSH kickoff May 23<sup>rd</sup>
- ❑ Vertigo/"Smoothing-Based Relative Navigation" Kickoff
- ❑ Astrobeer project support continues
  - ❑ Astrobeer 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"

National Aeronautics and Space Administration



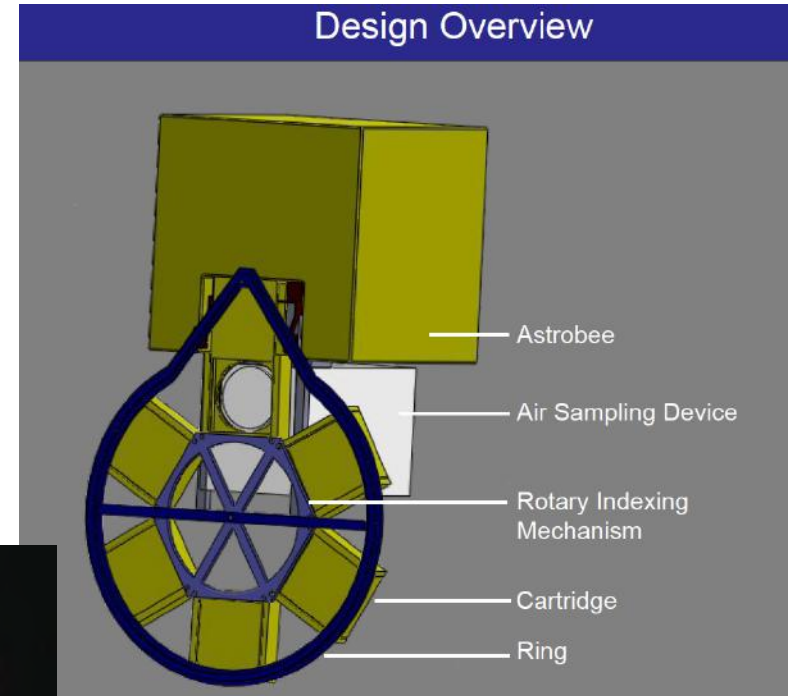
## NASA Ames K-12 STEM CHALLENGES

Ames Office of Education and Public Outreach Challenge Team,  
Sponsored by Tom Clausen (HE)



# Summer 2017 Interns: Qty 8

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



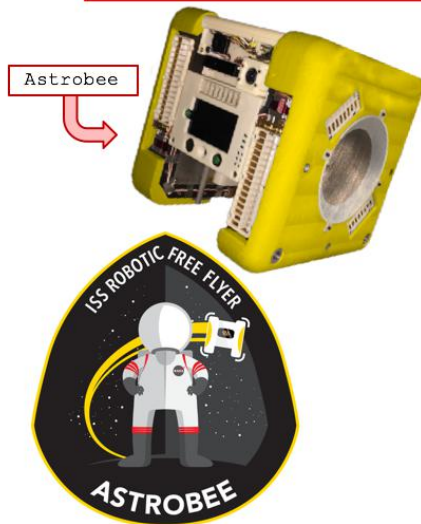
- Eddy Meza: SSLA Shade





# Summer 2017 Interns: Qty 8

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



## BASIC DESIGN REQUIREMENTS

- The system shall establish USB connection with the Astrobee using the USB data pins on the payload interface.
  - The system should identify the Astrobee as a USB device.
  - The Astrobee should identify the payload as a device.
  - The system should be able to transmit and receive data.
- The system shall test and demonstrate current and voltage outputs
  - The system should show a possible current draw of 3A.
  - The system should show voltage levels of ~14.4 volts.
  - The system should limit the current draw of the payload.
- The system shall be able to attach to the payload interface using both the lever method and the screw method.
- The system should have on board computing capabilities for guest science/test software.
- 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

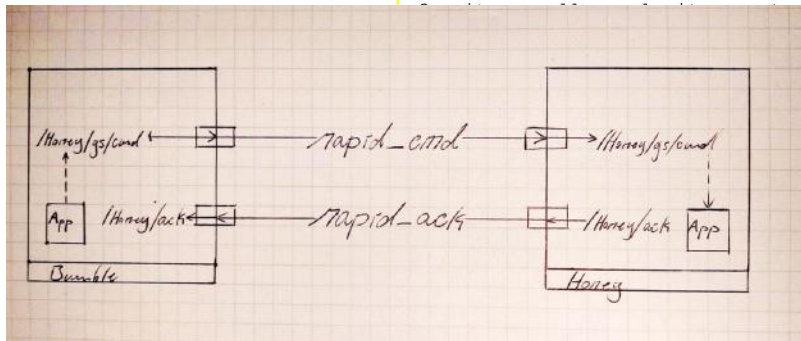
HLP USB D+/-

Reserve Pins [ I2C/UART ]

## APEPT HARDWARE DEV

### I. Electrical

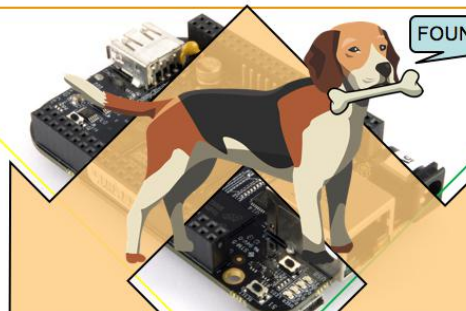
The development of the hardware for the APEPT was centered around the use of the BeagleBone Black (BBB) - a single-board computer/microcontroller: chosen



Custom PCB layout was for the BBB to organize and additions to run the port

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

FOUND THE BONE.



## APEPT SOFTWARE DEV

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

- Robot Operating System (ROS)
- Android OS APK development
- 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.

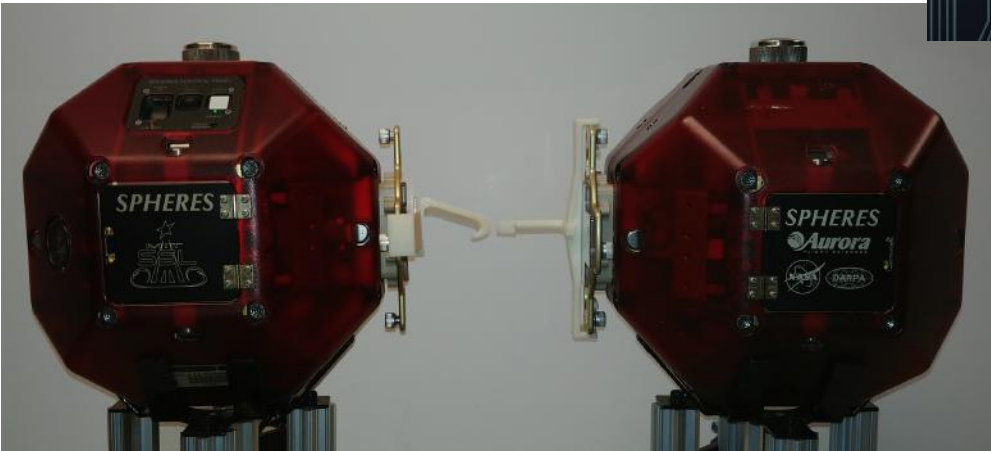
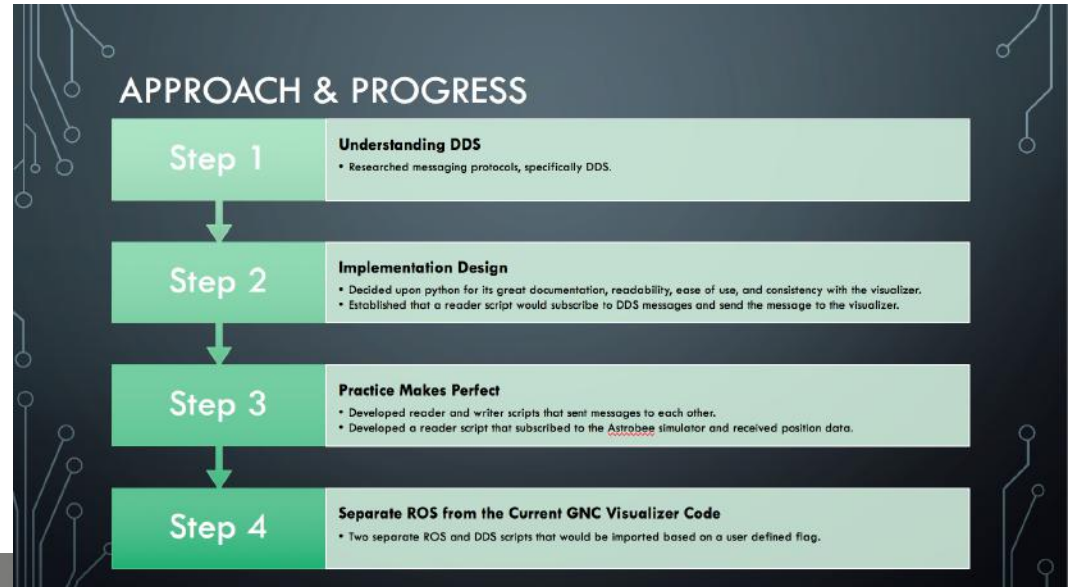
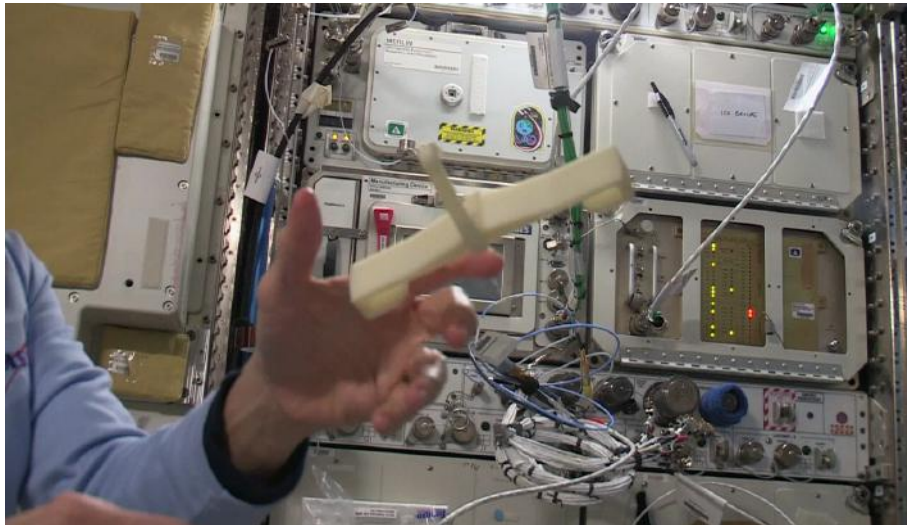
Each of these frameworks are implemented on either the APEPT or Astrobee to conduct the port tests and serve as example use cases/implementation guides for guest science.





# Summer 2017 Interns: Qty 8

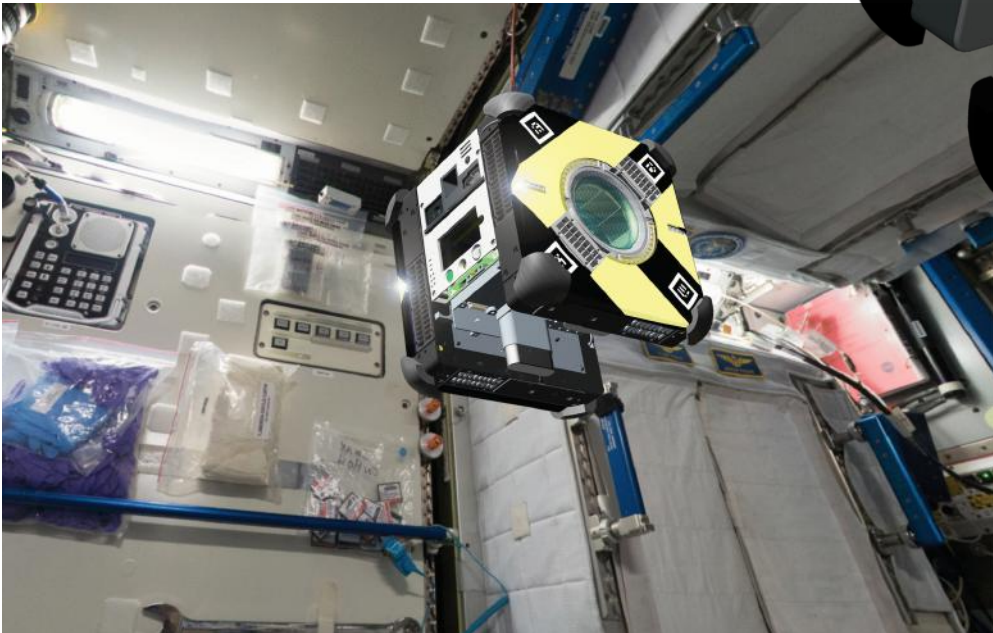
- ❑ Matt Moropoulos: SPHERES-Hook
- ❑ Michael Richardson: MGTG Control Software
- ❑ Rachel Crum: Payload to Ground Communication





# 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

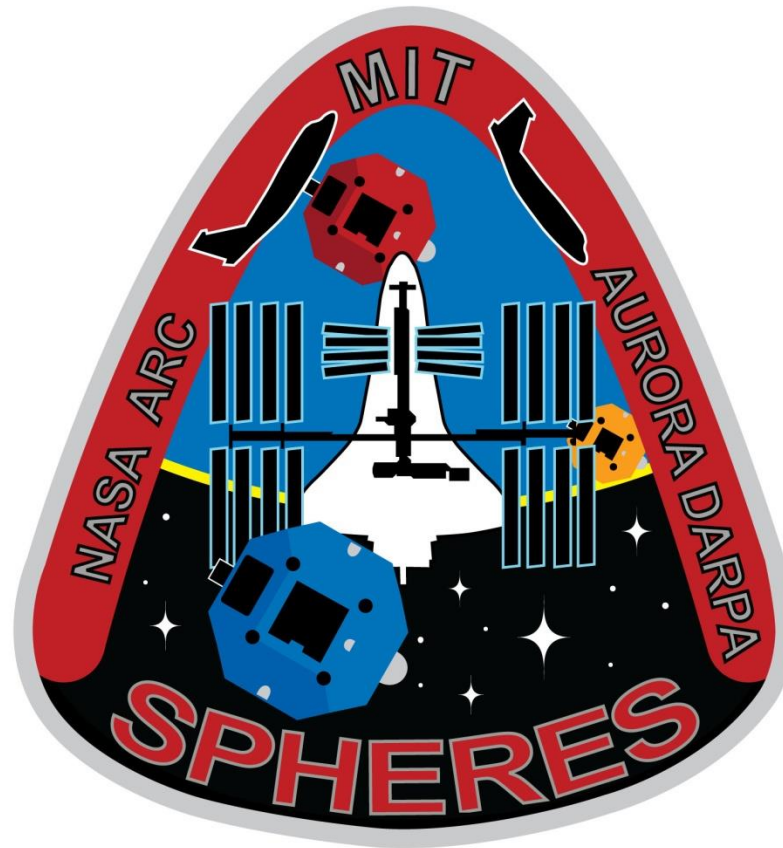




# Guest Science Program (GSP)

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- ❑ **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 & Astrobees Operations





# Operations: Functions

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## 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 (CO2 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

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## 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

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## 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]** =====

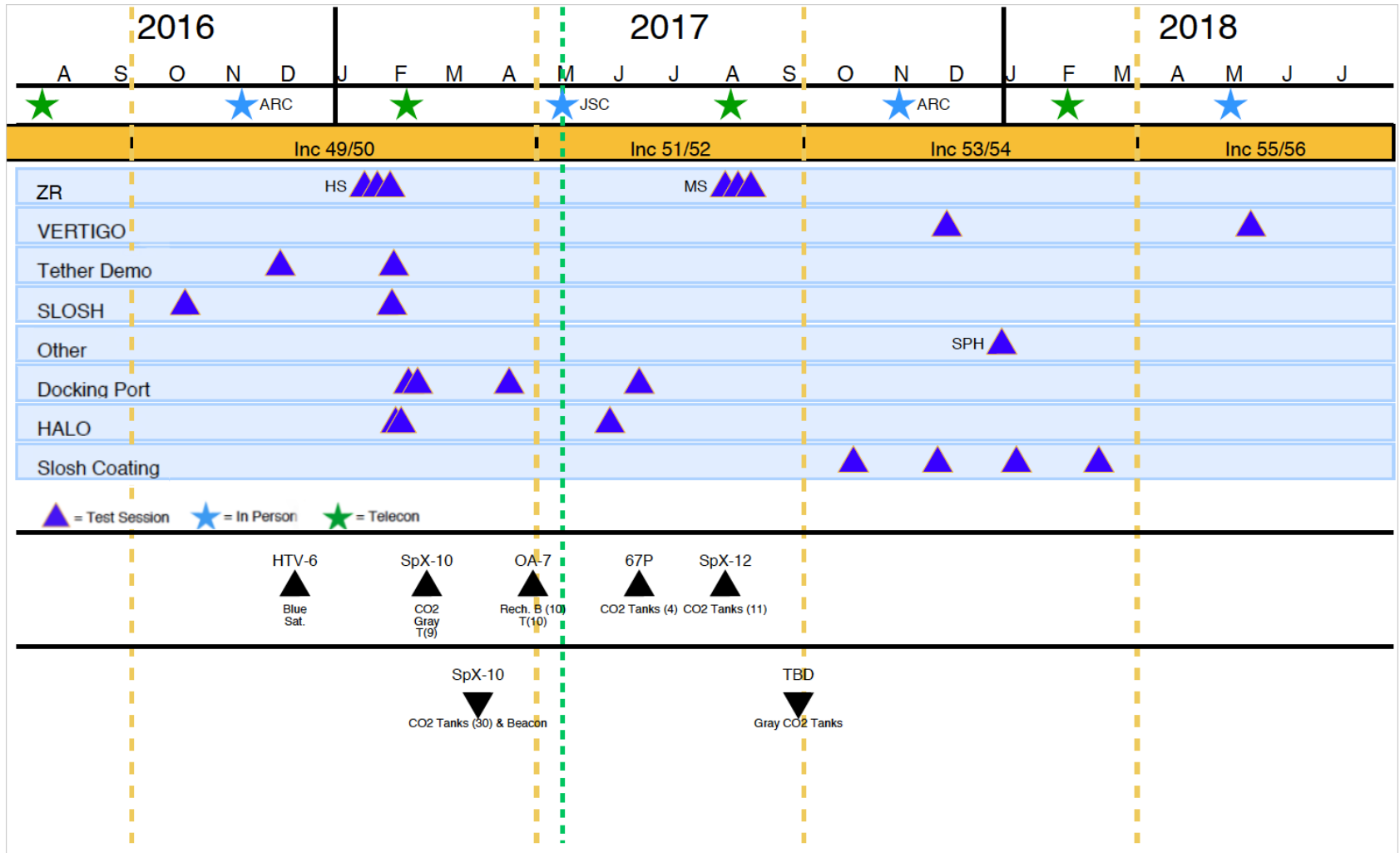
- **Tether-Slosh** **TBD**
- **Smoothing-Based Relative Navigation** **TBD**
- **Zero Robotics High School Units Test** **Nov- Dec 2017**
- **Zero Robotics High School Dry Run** **Jan 2018**
- **Zero Robotics High School Finals** **Jan 2018**

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

- **Additional Docking Port** **TBD**
- **Slosh Coating** **TBD**



# SPHERES Calendar





# Consumables Status

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## 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](https://twitter.com/NASA_SPHERES)

Website

<http://www.nasa.gov/spheres>

The screenshot shows the NASA SPHERES website interface. At the top, there is a navigation bar with links for Topics, Missions, Galleries, NASA TV, Follow NASA, Downloads, About, and NASA Audiences, along with a search bar. Below this is a large banner image of the SPHERES satellites. The main content area is divided into several sections:

- Left Sidebar:** Contains navigation links such as Ames Research Center, Overview, Images, Videos, Media Resources, Follow, social media icons (Facebook, Twitter, Google+, YouTube, Instagram), and a list of site sections including SPHERES Home, Mission Overview, History, Satellites, Facilities, Partners and Affiliates, Guest Scientist Program, SPHERES Publications, FAQ, Archived Science, and Related Topics.
- Main Content Area:**
  - Top Left:** A close-up image of a satellite component with the text "SPHERES Blue Satellite Repair Complete". Below it, a paragraph describes the repair of the "blue" satellite's propulsion subsystem on the Space X 9 Dragon cargo module.
  - Top Right:** A photo of two astronauts with the text "SPHERES Zero Robotics Middle School 2016". To its right is a "What is SPHERES?" section explaining the program's purpose and history.
  - Bottom Left:** A photo of a person working on a satellite component.
  - Bottom Right:** A photo of an astronaut in the ISS with the text "SPHERES Maintenance Test Session". Below it is a "Tweets by @NASA\_SPHERES" section.

# Astrobee System Overview



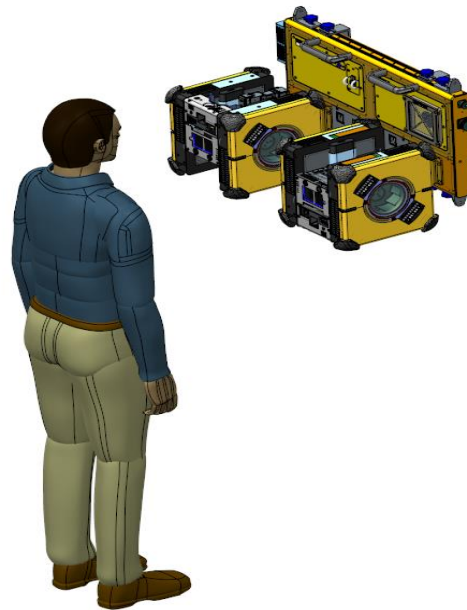
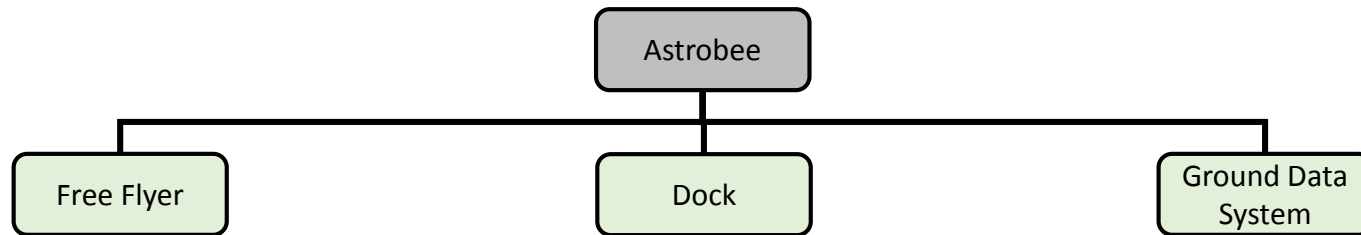
SPHERES/Astrobee Working Group

August 23, 2017



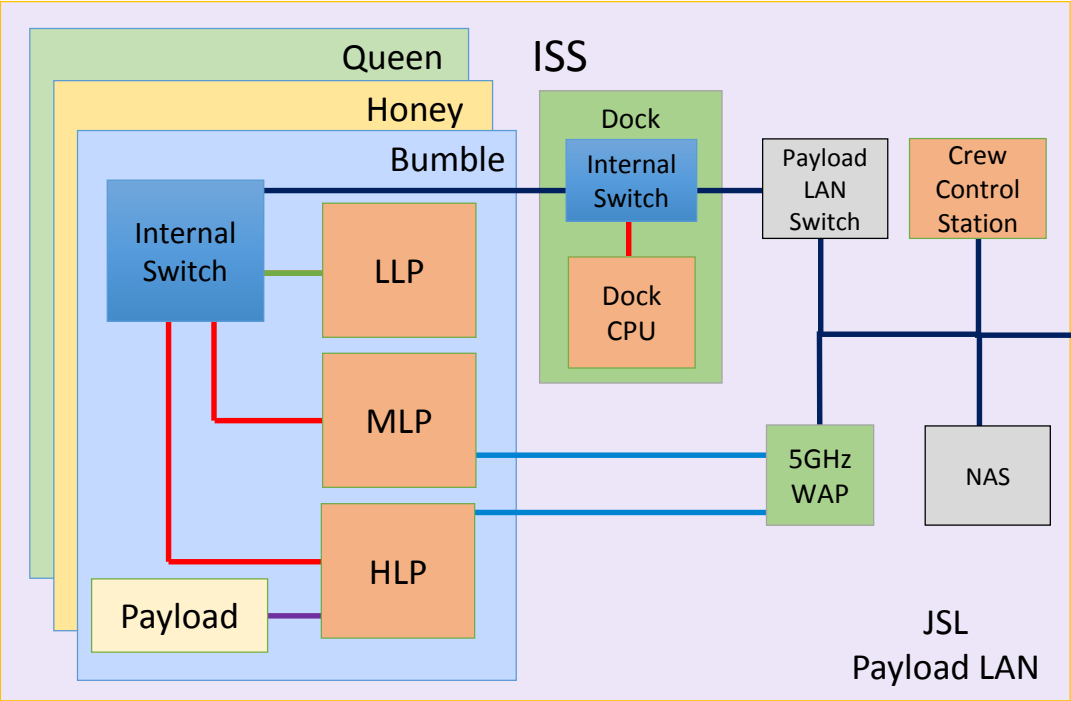


# Astrobee Elements

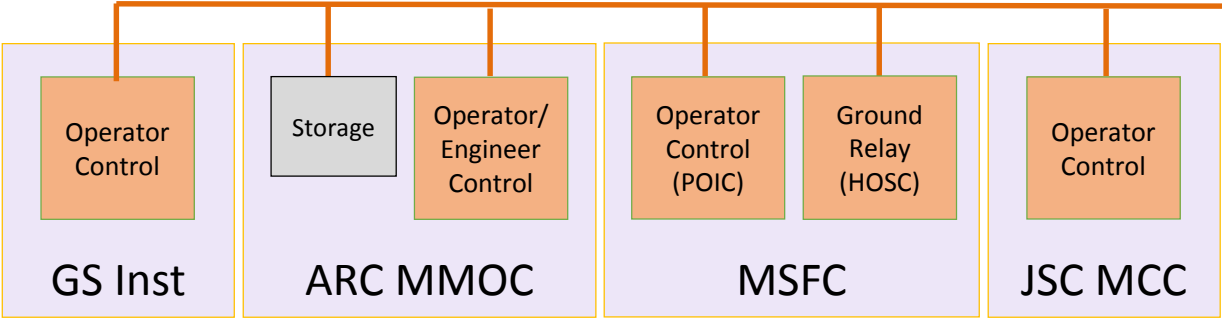
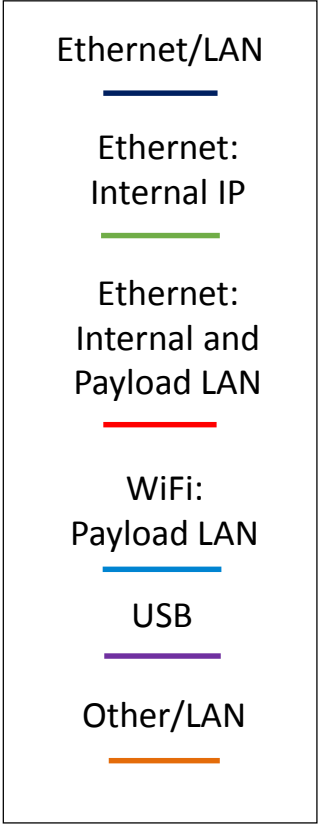




# System Data Flow Diagram

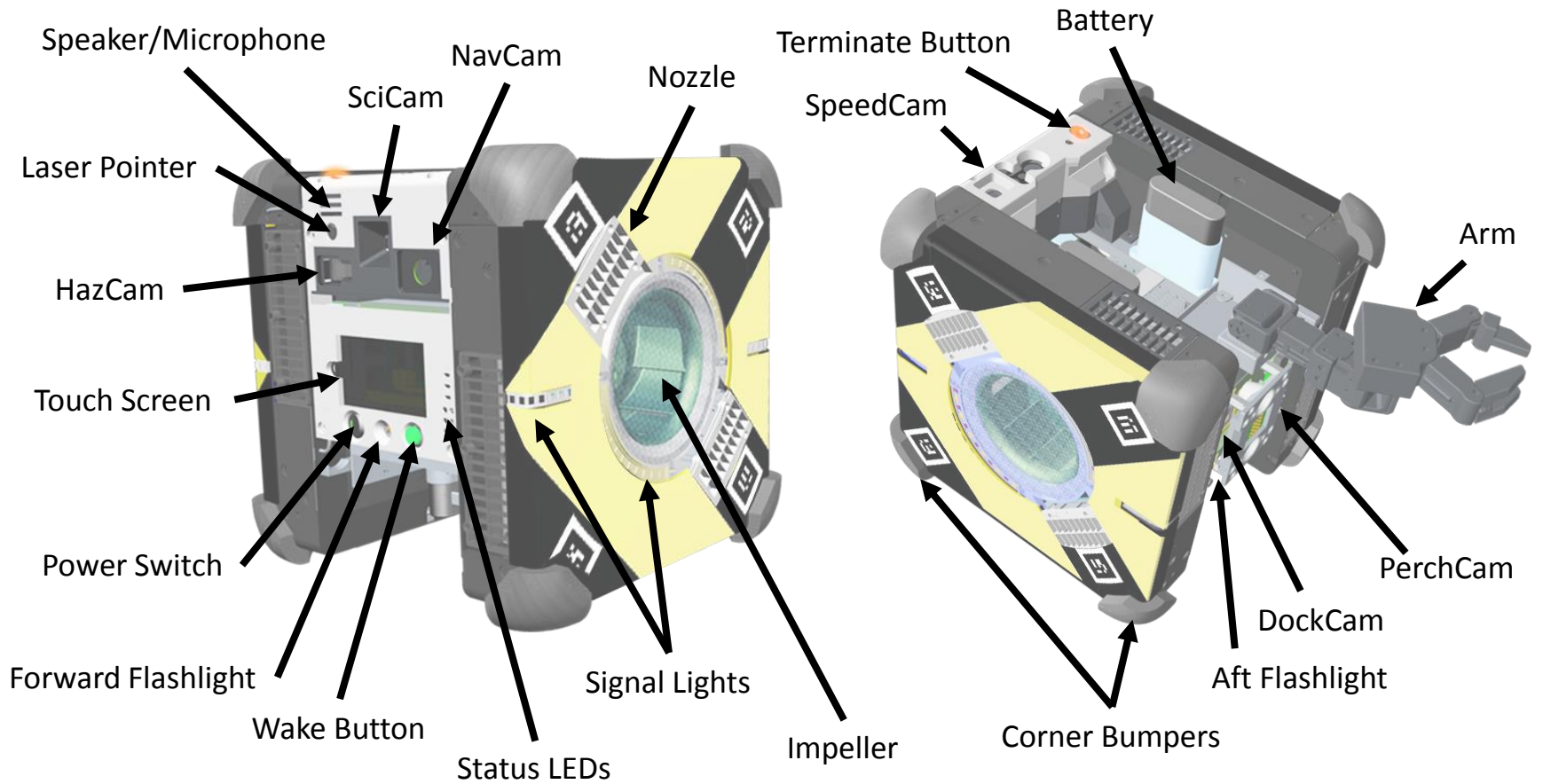


## Link Legend





# Astrobee

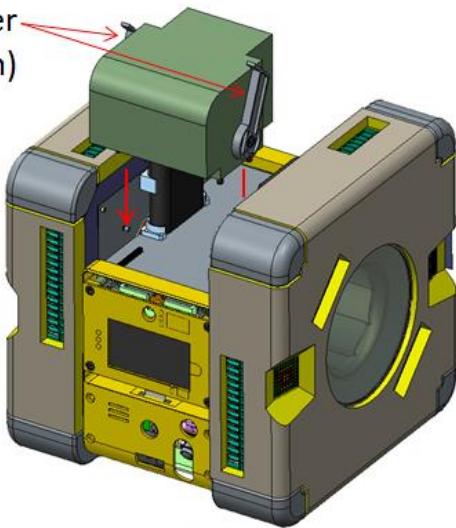




# Payload Attachment Options

## Quick "No Tool" Payload Attachment

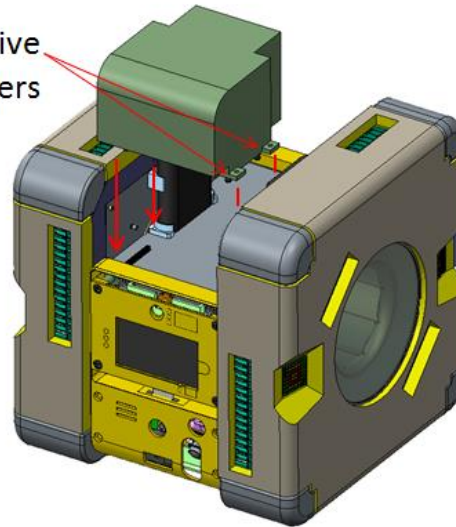
2X Lever  
(open position)



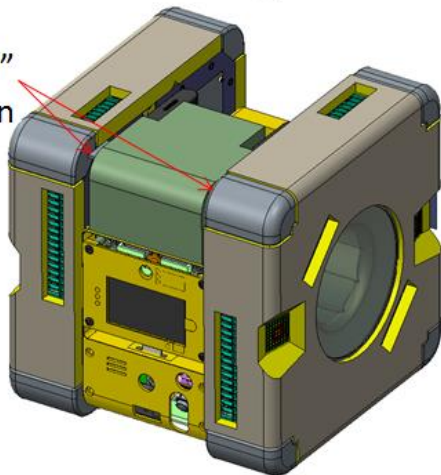
Lever engages and disengages payload connector and provides mechanical attachment

## 4X Fastener Payload Attachment

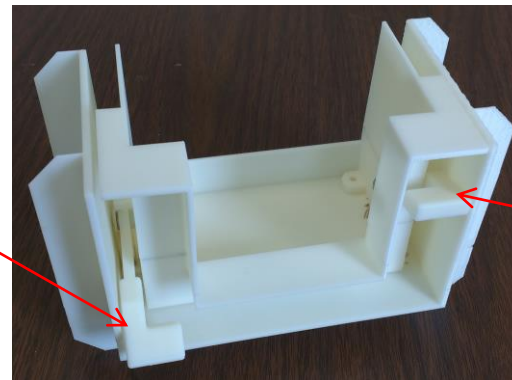
4X Captive Fasteners



Lever in "Locked" position



"Un-Lock" Position



"Lock" Position



# Dock

Air Vent Deflector

Subsystem Breakers

Main Power Breaker

Cooling Fan

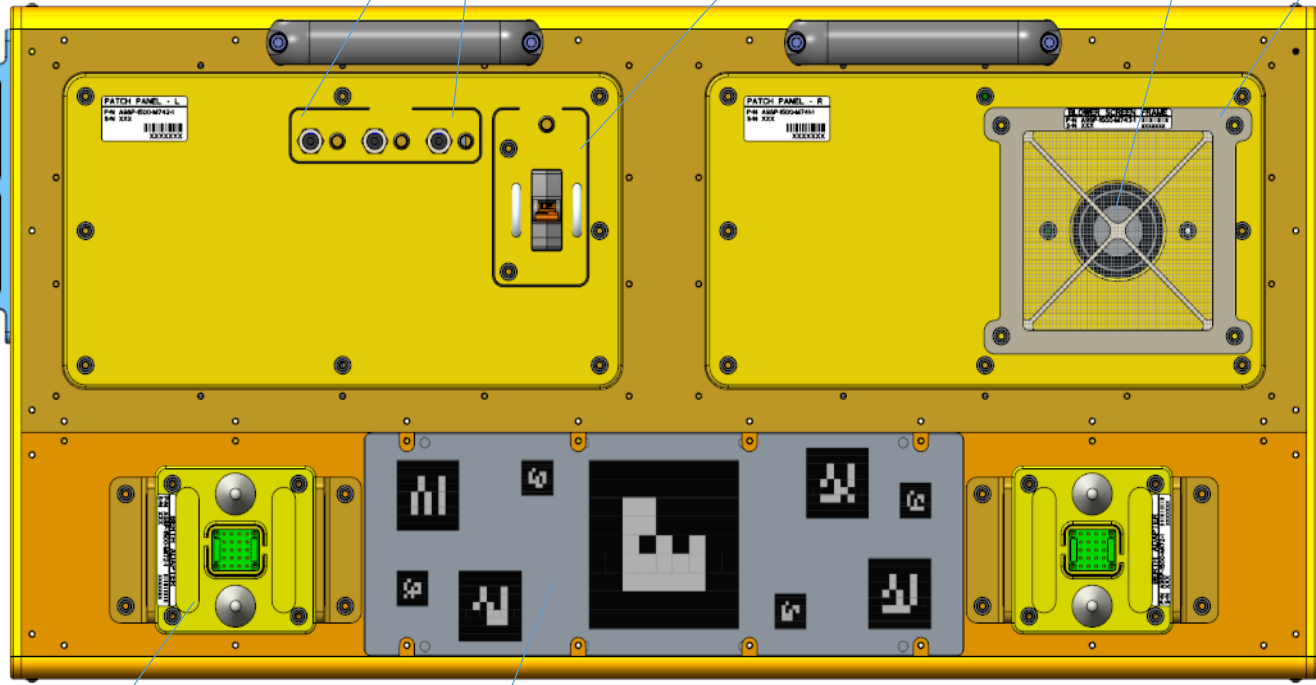
Cooling Fan Screen

RJ-45 Connector

Power Connector

Free Flyer Berth

AR Target





# Plan Editor Tab (Operator/Engineering)

File Edit View Modeling Help  
Plan Editor Run Plan Teleoperation

GPS 15Jun16 20:36:18

Plan Editor

Plan Name BB  
Estimated Duration 00:16:34  
Validation Validated Validate

Plan Step Duration

| Plan Step   | Duration |
|-------------|----------|
| BB          |          |
| 0 Station   |          |
| 0-1 Segment | 00:01:14 |
| 1 Station   |          |
| 1-2 Segment | 00:02:06 |
| 2 Station   |          |
| 2-3 Segment | 00:02:06 |
| 3 Station   |          |
| 3-4 Segment | 00:02:06 |
| 4 Station   |          |
| 4-5 Segment | 00:02:06 |
| 5 Station   |          |
| 5-6 Segment | 00:02:06 |
| 6 Station   |          |
| 6-7 Segment | 00:02:06 |
| 7 Station   |          |
| 7-8 Segment | 00:02:06 |
| 8 Station   |          |
| 8-9 Segment | 00:02:48 |

Add Delete Add via 3d View

2 Station

Location Based Coordinate Based Bookmarks Commands

Module Node 2  
Bay 2  
Offset Wall 1  Center Deck 0.2  
Offset Wall 2  Center  
Orientation  N/A Forward

00:00:00 Message goes here

Log Help Exit

Interactive Plan Viewer Reset View

Plan info

List view of Plan

Element editor



# Run Plan Tab (All)

File Edit View Help  
Run Plan | Teleoperation | Guest Science

FreeFlyerA Comm ● Control DW@DW-Windows7-32 Batt 1 Docking Station ● GPS 11Jan17 18:19:32

**Health and Status** Details

|                  |                   |
|------------------|-------------------|
| Operating State  | Ready             |
| Mobility State   | Stopped           |
| Operating Limits | Default_Safeguard |
| Plan             | ExamplePlan       |
| Plan Status      | Paused            |

**Robot Commanding**

File ... C:\Users\DW\Desktop\FPlans\ExamplePlan.fplan  
Plan Valid

Load Run Skip Step

Description  
A plan that goes in a spiral.

Select valid plan  
and upload to  
Astrobee

**Plan**  
Total Elapsed Time 00:00:00

| Plan Step   | Duration | Success |
|-------------|----------|---------|
| ExamplePlan |          |         |
| 0 Station   |          |         |
| 0-1 Segment |          |         |
| 1 Station   |          |         |
| 1-2 Segment |          |         |
| 2 Station   |          |         |
| 2-3 Segment |          |         |
| 3 Station   |          |         |
| 3-4 Segment |          |         |
| 4 Station   |          |         |
| 4-5 Segment |          |         |
| 5 Station   |          |         |

List view  
of loaded  
plan

Live Telemetry | Live Images | Science Camera

Model of  
loaded  
plan



# Teleoperation Tab (All)

File Edit View Help

Run Plan Teleoperation Guest Science

FreeFlyerA Comm ● Control DW@DW-Windows7-32 Batt 87 Docking Station ● GPS 12Jan17 01:46:27

Health and Status Details

|                  |                   |
|------------------|-------------------|
| Operating State  | Ready             |
| Mobility State   | Stopped           |
| Operating Limits | Default_Safeguard |
| Plan             |                   |
| Plan Status      | Idle              |

Manual Commanding Perching Arm Docking

Initialization Reset Inputs

Manual Inputs

|      |      |      |            |
|------|------|------|------------|
| m    |      | deg  |            |
| Aft  | 0.5  | Fwd  | Roll -0.0  |
| Port | -0.5 | Stbd | Pitch -0.0 |
| Ovhd | 0.0  | Deck | Yaw -45.0  |

Options

Allow Lateral Motion

Override Obstacles

Override Keepouts

Commands

Move

Stop

Configurable Teleop Commands

Gripper Open

Idle Propulsion Idle

Payload A On

Flashlight Brightness

Front High Set

Data Type Action

Immediate Download Send

Buttons here can be changed via config file

Construct movement command

Adjust settings

Drag preview to adjust movement command

Send movement command

LAB1S1 LAB1S2 LAB1S3 LAB1S4 LAB1S5

LAB1D1 LAB1D2 LAB1D3

01:44:24 FreeFlyerA: Unknown Command Completed





# Guest Science Tab (Crew)

Crew Control Station

File Edit View Help

Run Plan Teleoperation Guest Science

Docking Station ● GPS 17Jan17 18:44:47

Astrobee Selection and Status

| Control  | Batt              | Summary | Plan | Plan Status | Health |
|--|-------------------|---------|------|-------------|--------|
| <input type="checkbox"/> FreeFlyerA            | nobody            |         |      | Idle        | ●      |
| <input checked="" type="checkbox"/> FreeFlyerB | DW@DW-Windows7-32 |         |      | Idle        | ●      |
| <input type="checkbox"/> FreeFlyerC            |                   |         |      |             | ○      |

Details

Checkboxes select Astrobees to command

Status summaries

Names of loaded Plans

Commanding for FreeFlyerB

Wake Grab Control

Plans

Load

Run Stop

Manual Commanding

Guest Science Command

Send Command

Command Astrobees

Live Telemetry Live Images Science Camera

Monitor Astrobee positions in 3D window



# Advanced Guest Science Tab

## (Operator/Engineering)

Plan Editor | Run Plan | Teleoperation | Guest Science | **Advanced Guest Science** | Advanced | Advanced 2 | Modeling | Debugging

Station ● GPS 18Jan17 20:00:58

Select APK to see Status

### Astrobee Selection and Status

| Control  | Batt              | Summary | Plan     | Plan Status | Plan Step | APK            | APK Status | Health |
|--|-------------------|---------|----------|-------------|-----------|----------------|------------|--------|
| <input checked="" type="checkbox"/> FreeFlyerA | DW@DW-Windows7-32 | 85      | Starter1 | Idle        | 2 Station | Geiger Counter | Running    | ●      |
| <input checked="" type="checkbox"/> FreeFlyerB | DW@DW-Windows7-32 | 85      | TestPlan | Idle        | 7 Station | Grappling Hook | Running    | ●      |
| <input type="checkbox"/> FreeFlyerC            | 100               |         |          |             |           |                |            | ○      |

Details

### Commanding for FreeFlyerA, FreeFlyerB

Start and Stop APKs directly

Control

Plans

APKs

Grappling Hook [Start] [Stop]

Manual Commanding

APK: Geiger Counter | Template: Run Test

Command: command body for Run Test

[Send Command]

Preview and change APK command before sending

### Live Telemetry | Live Images | Science Camera | Guest Science Telemetry

AstrobeeA

| APK            | STATUS  |
|----------------|---------|
| Turbo          | Idle    |
| Grappling Hook | Idle    |
| Geiger Counter | Running |

| APK            | Topic       | Label   | Value     |
|----------------|-------------|---------|-----------|
| Geiger Counter | Astrobee... | Status  | "Off"     |
| Geiger Counter | Astrobee... | Summary | "Nominal" |
| Geiger Counter | Astrobee... | Data    | 25        |

AstrobeeB

| APK            | STATUS  |
|----------------|---------|
| Turbo          | Idle    |
| Grappling Hook | Running |
| Geiger Counter | Idle    |

| APK            | Topic       | Label   | Value     |
|----------------|-------------|---------|-----------|
| Grappling Hook | Astrobee... | Status  | "Off"     |
| Grappling Hook | Astrobee... | Summary | "Nominal" |
| Grappling Hook | Astrobee... | Data    | 25        |

View detailed telemetry from APKs



# Advanced Tab (Engineering)

Astrobee Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

FreeFlyerA Comm Control nobody Batt 11 Docking Station GPS 18Jan17 18:23:54

### Detailed Health and Status

| Disabled Subsystems | Subsystem A, Subsystem C |
|---------------------|--------------------------|
| Control             | nobody                   |
| Operating State     | Ready                    |
| Raw Mobility State  | Stopping                 |
| Sub Mobility State  | 0                        |
| Operating Limits    | Default_Safeguard        |
| Plan                |                          |
| Plan Status         | Idle                     |
| Temperature         | -                        |
| Arm Mobility        | -                        |
| Arm Gripper         | -                        |

**Detailed Health and Status**

### FreeFlyerA Operating Limits

Select Operating Limits Configuration ...

Configure Data

| Name                    | Value | Units   |
|-------------------------|-------|---------|
| Profile Name            | Def   |         |
| Flight Mode             | De    |         |
| Target Linear Velocity  | 1.0   |         |
| Target Linear Accel     | 1.0   |         |
| Target Angular Velocity | 1.0   | rad/s   |
| Target Angular Accel    | 1.0   | rad/s/s |
| Collision Distance      | 1.0   | m       |
| Check Obstacles         | true  |         |
| Check Keepouts          | true  |         |

**View and change Operating Limits**

### FreeFlyerA Data to GDS 2

| Telemetry  | Current Freq (Hz) | Change to (Hz) |
|------------|-------------------|----------------|
| position   | 5                 | 5 Set          |
| ekfState   | 7                 | 5 Set          |
| commStatus | 8                 | 5 Set          |
| diskState  | 17                | 5 Set          |

**Configure telemetry sent to Control Station**

| Fault ID      | Description          | Subsystem   | Node   |
|---------------|----------------------|-------------|--------|
| Triggered     |                      |             |        |
| 120           | SciCam is inoperable | Subsystem A | Node 2 |
| 127           | Fuse is broken       | Subsystem C | Node 3 |
| Not Triggered |                      |             |        |
| 100           | Processor overheated | Subsystem A | Node 1 |
| 201           | Arm Overcurrent      | Subsystem B | Node 3 |

**Triggered and Not Triggered Faults**

### FreeFlyerA Power State

Battery Total 1

Voltage 2

Current 2

| Battery | Present | Temp (C) | Current (A) |
|---------|---------|----------|-------------|
| Batt 1  | No      | -        | -           |
| Batt 2  | No      | -        | -           |
| Batt 3  | Yes     | 32       | 16          |
| Batt 4  | No      | -        | -           |
| Batt 5  | Yes     | 91       | 30          |
| Batt 6  | Yes     | 73       | 10          |
| Batt 7  | No      | -        | -           |

**Detailed battery status**

### FreeFlyerA Data to Disk

Download Data Stop Data Download Clear Data

| Disk   | Data Size (GB) | Disk Size (GB) |
|--------|----------------|----------------|
| Disk A | 0.000002       | 0.000002       |
| Disk B | 0.000003       | 0.000003       |
| Disk C | 0.000003       | 0.000003       |
| Disk D | 0.000003       | 0.000003       |
| Disk E | 0.000005       | 0.000005       |
| Disk F | 0.000006       | 0.000006       |
| Disk G | 0.000005       | 0.000005       |

**Disk usage**

### FreeFlyerA Component States

| Component | Present | Powered | Temp (C) | Current (A) |
|-----------|---------|---------|----------|-------------|
| HLP       | Yes     | No      | 33       | -1.458      |
| MLP       | Yes     | Yes     | 112      | 2.107       |
| LLP       | Yes     | No      | -        | -           |
| Fan1      | Yes     | No      | -        | -           |
| Fan2      | No      | No      | -        | -           |
| Cam1      | No      | No      | -        | -           |
| Cam2      | Yes     | No      | -        | -           |
| Cam3      | Yes     | No      | -        | -           |

**Detailed component status**

| Topic     | Downlink  | Freq (Hz) |
|-----------|-----------|-----------|
| RosTopic0 | Immediate | 5.0       |
| RosTopic1 | Immediate | 5.0       |
| RosTopic2 | Immediate | 5.0       |
| RosTopic3 | Delayed   | 10.0      |
| RosTopic4 | Delayed   |           |
| RosTopic5 | Delayed   |           |
| RosTopic6 | Delayed   |           |

Configure Data

**View and configure data saved to disk**

Message

Select a fault to view message.

00:00:00 Message goes here



# Astrobee Status

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

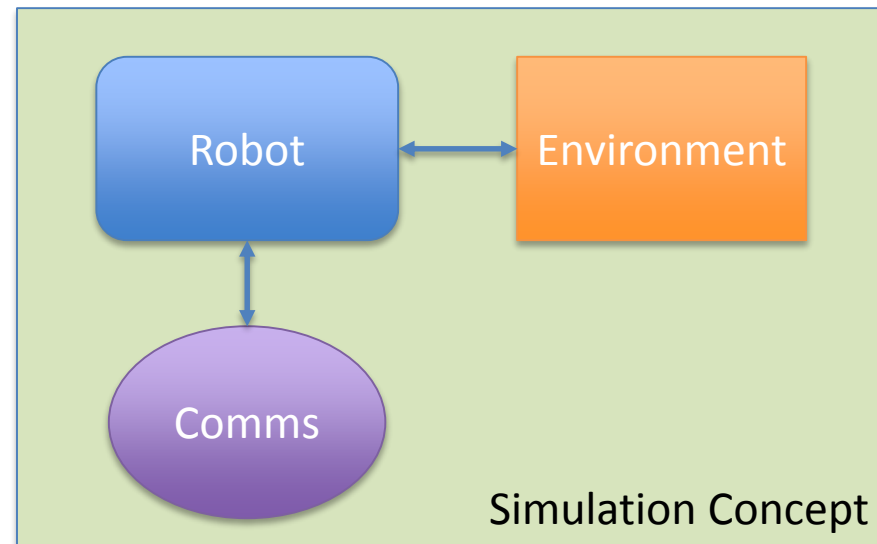
# Guest Science and Simulator Integration

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.



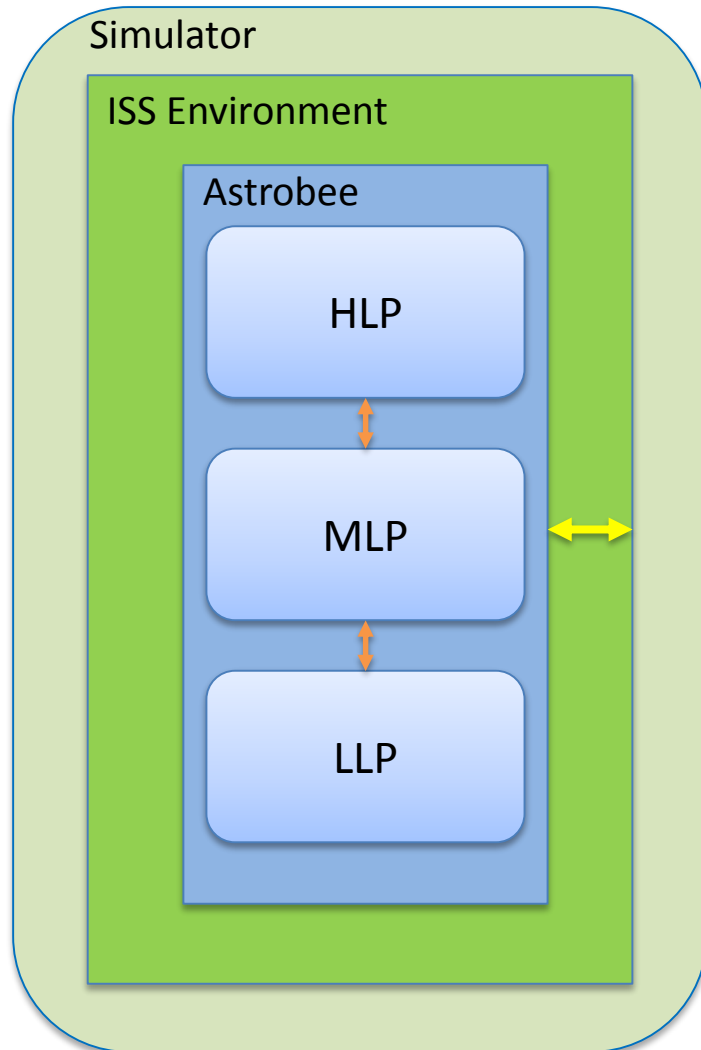


# Simulator



- 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: 



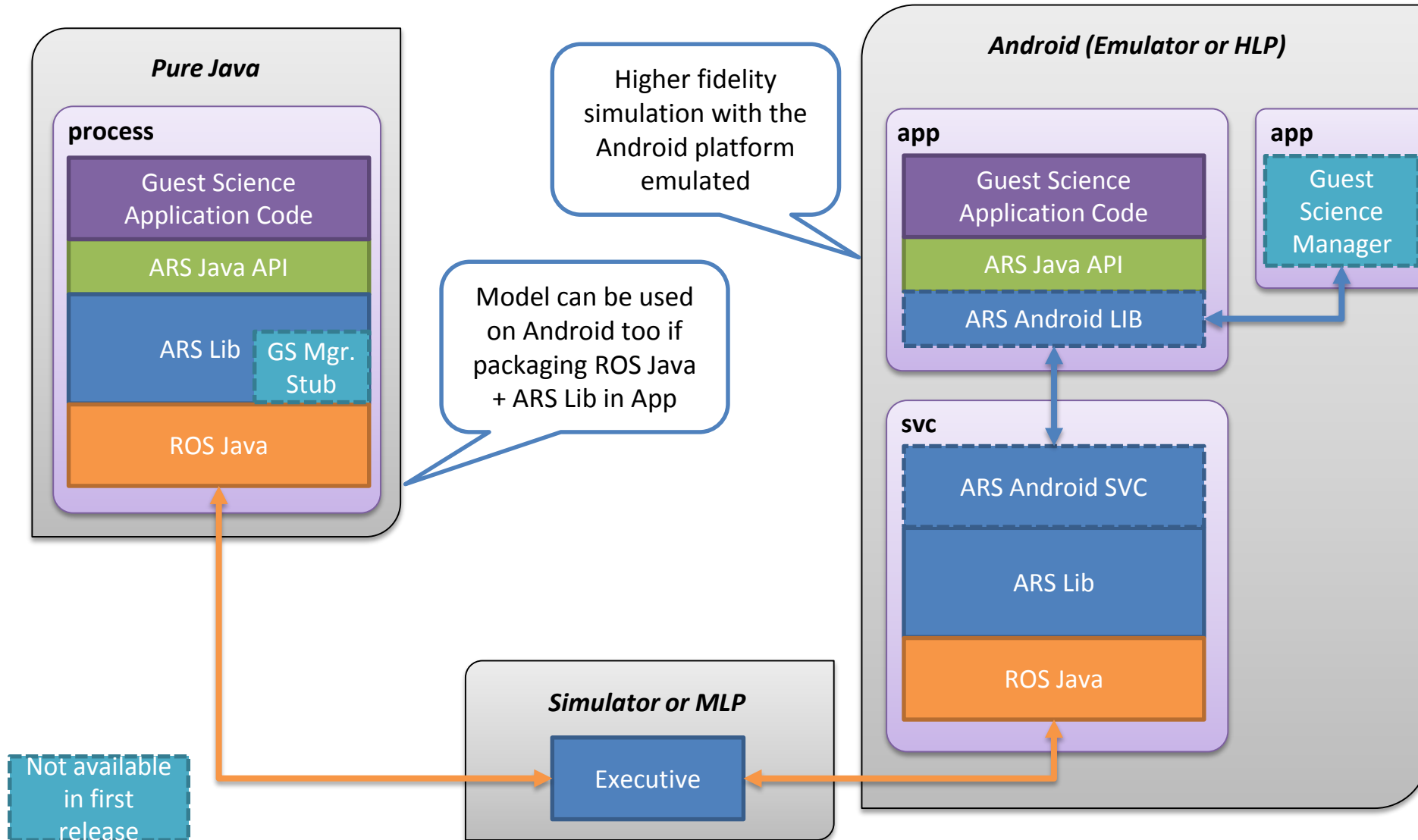


# Guest Science

- 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 bypassing Android-ROS bridge but still using Java-ROS framework. Telemetry is accessible.
  3. Advanced API (University researchers): By-passes completely provided Java-ROS framework.



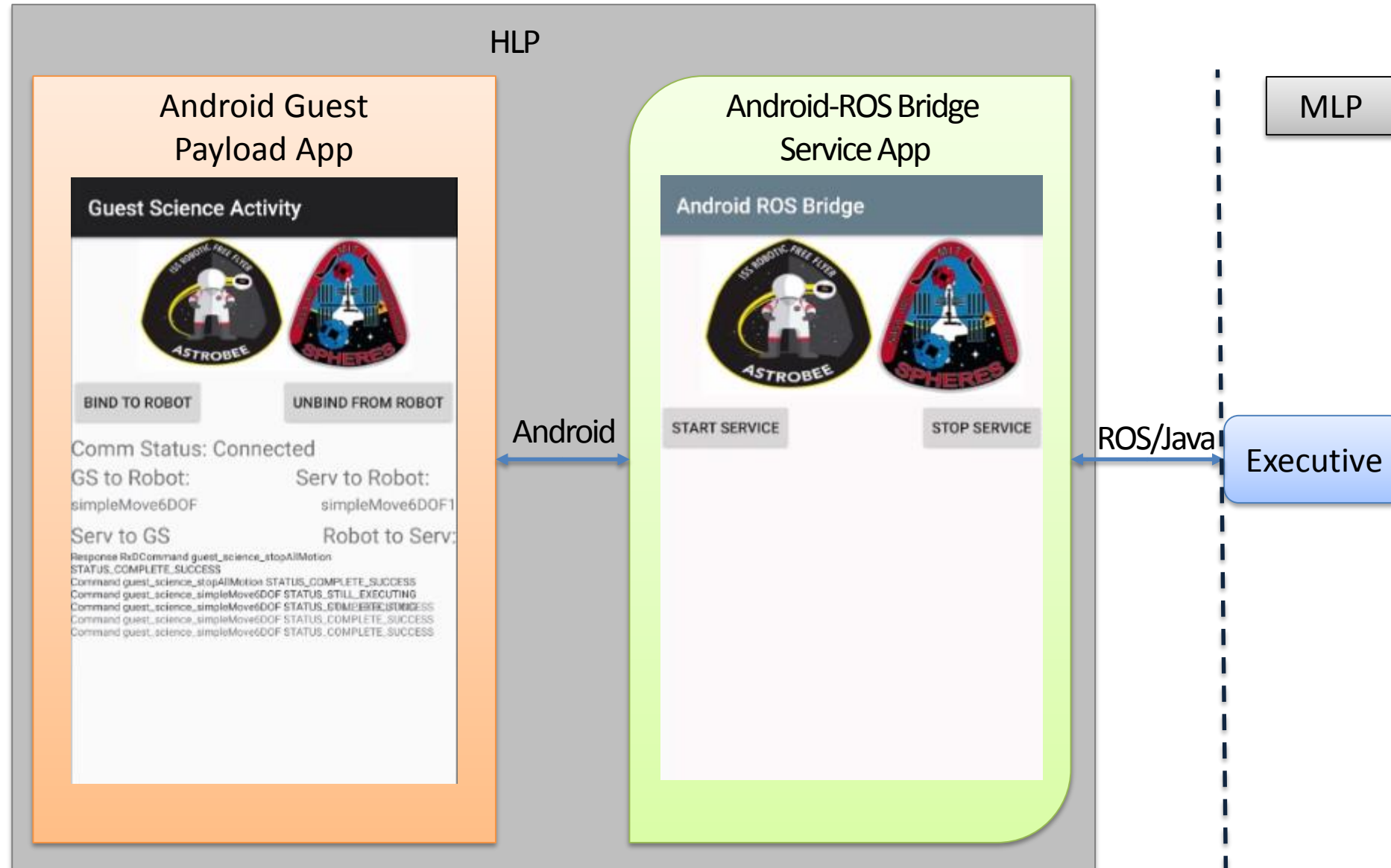
# Guest Science Implementation





# 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)

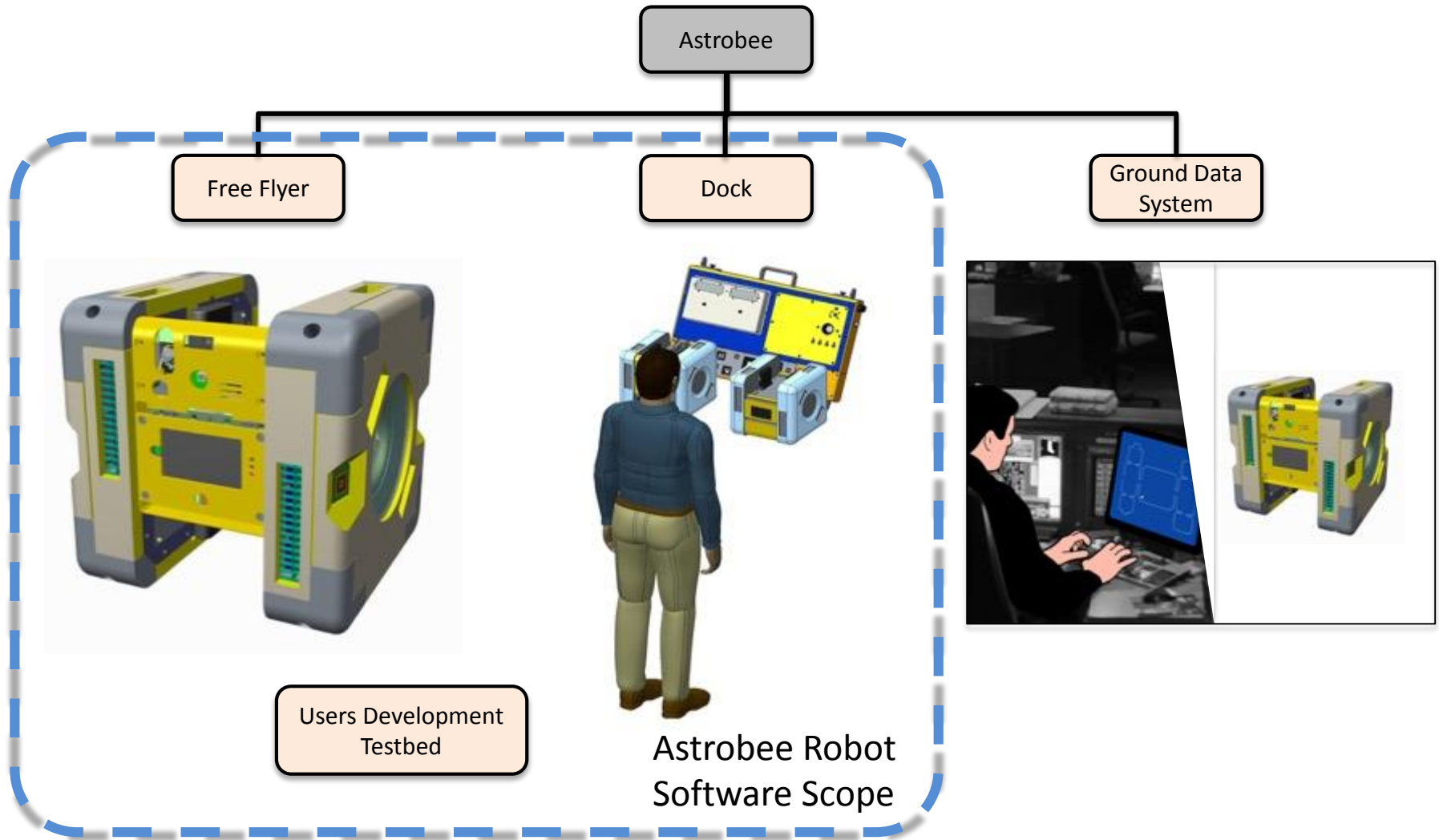
SPHERES/Astrobee Working Group, 08/23/2017



**Lorenzo Flückiger**  
**Maria Bualat**

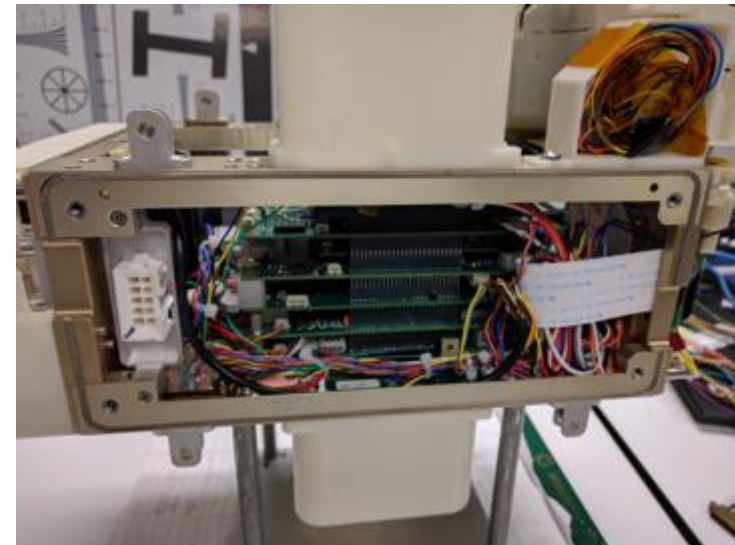
Intelligent Robotics Group  
NASA Ames Research Center  
[Lorenzo.Fluckiger@nasa.gov](mailto:Lorenzo.Fluckiger@nasa.gov)

# Astrobee Elements / ARS



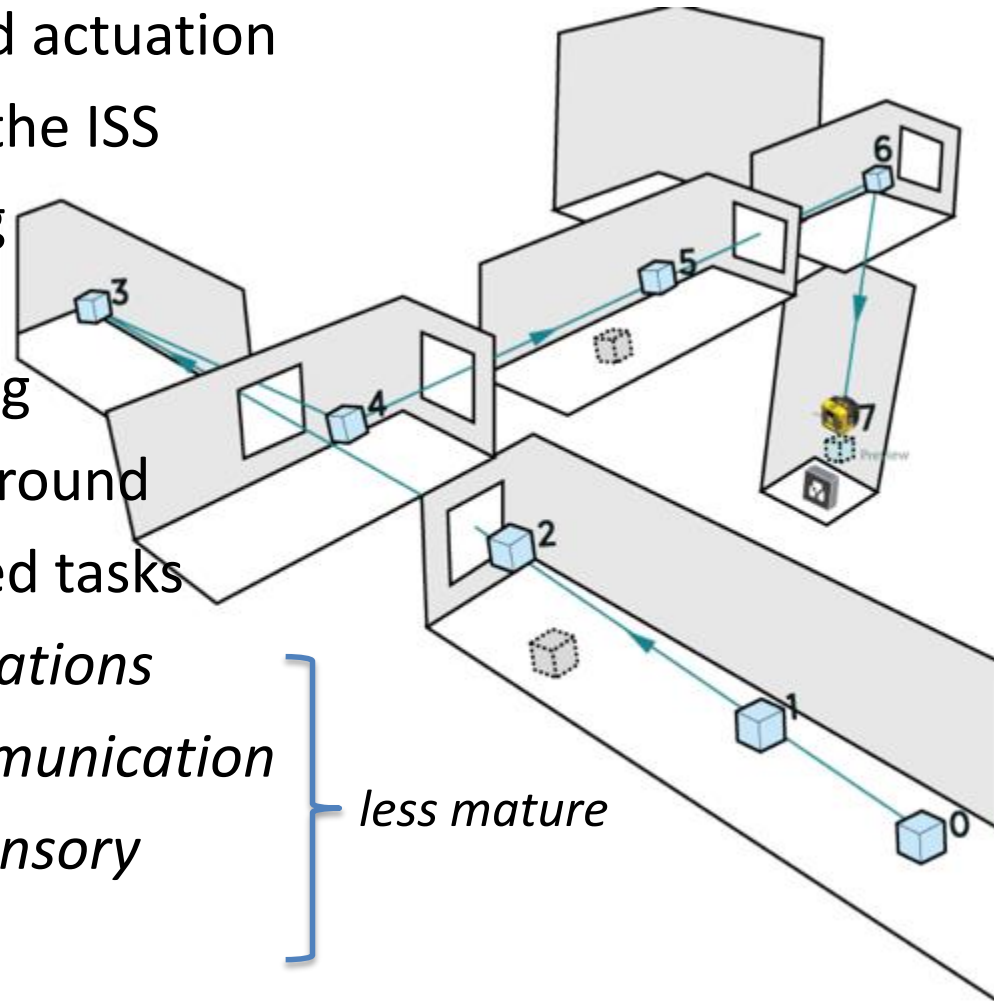
# ARS (Astrobee Robot Software) Overview

- 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 Astrobees 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*



# 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              |

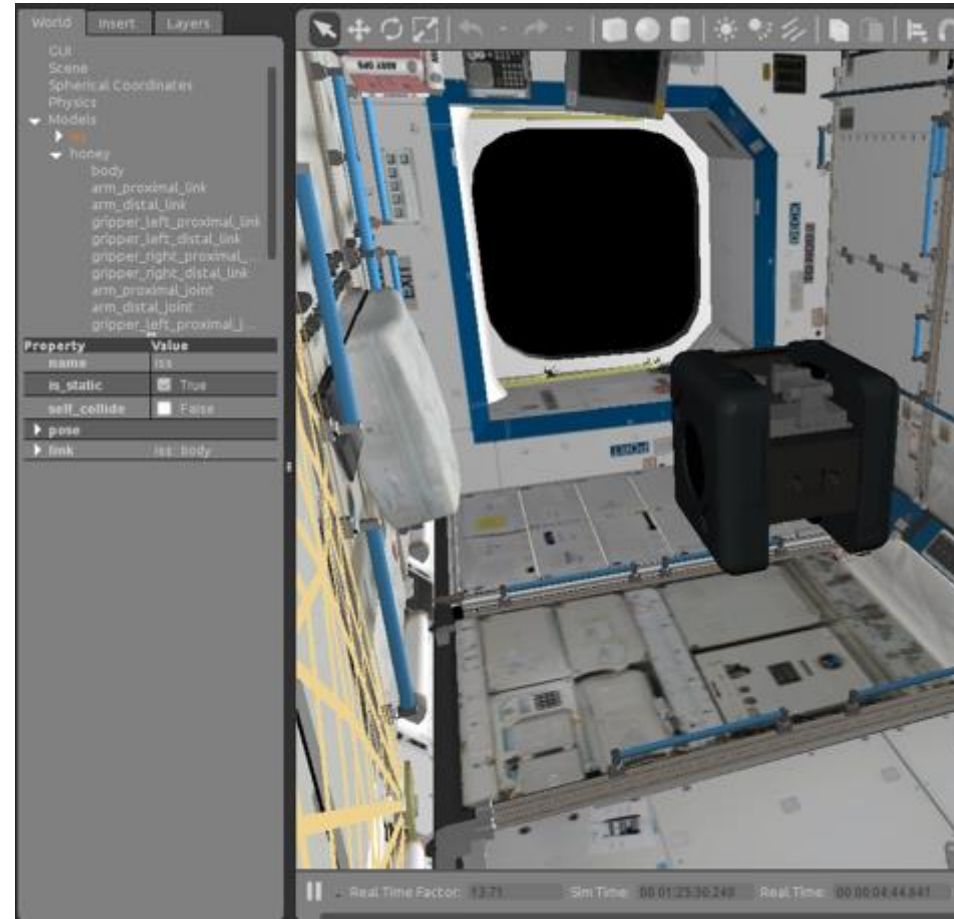
## Totals grouped by language:

|                  |                  |
|------------------|------------------|
| cpp:             | 1422365 (96.05%) |
| without autogen: | <b>58305</b>     |
| ansic:           | 21455 (1.45%)    |
| xml:             | 14956 (1.01%)    |
| python:          | 9792 (0.66%)     |
| java:            | 7963 (0.54%)     |
| sh:              | 2867 (0.19%)     |



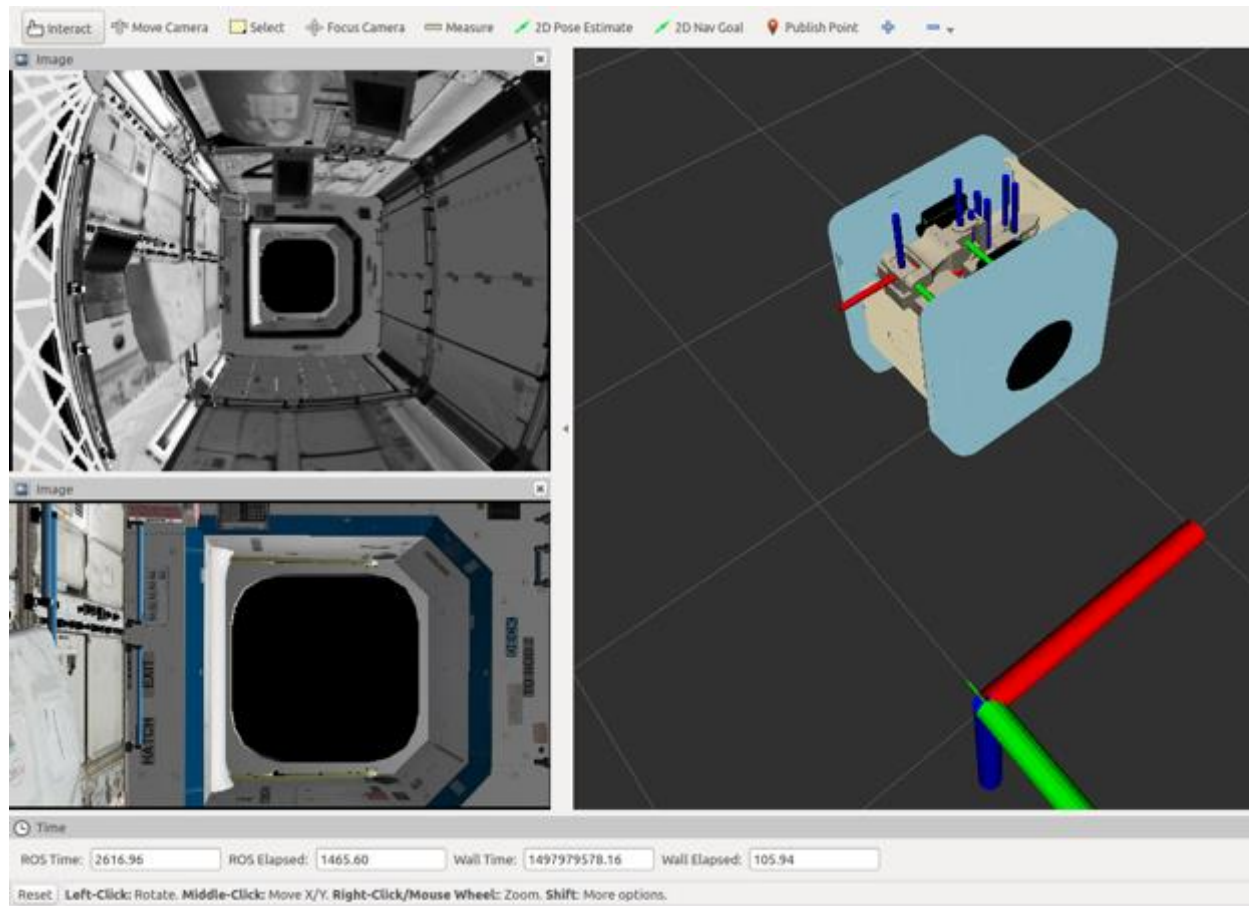
# ARS and ROS

- 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 introspection tools to rapid debugging
  - Use ROS facilities to record/replay/analyze data
  - Use some ROS/Gazebo components for the simulator



# Simulator

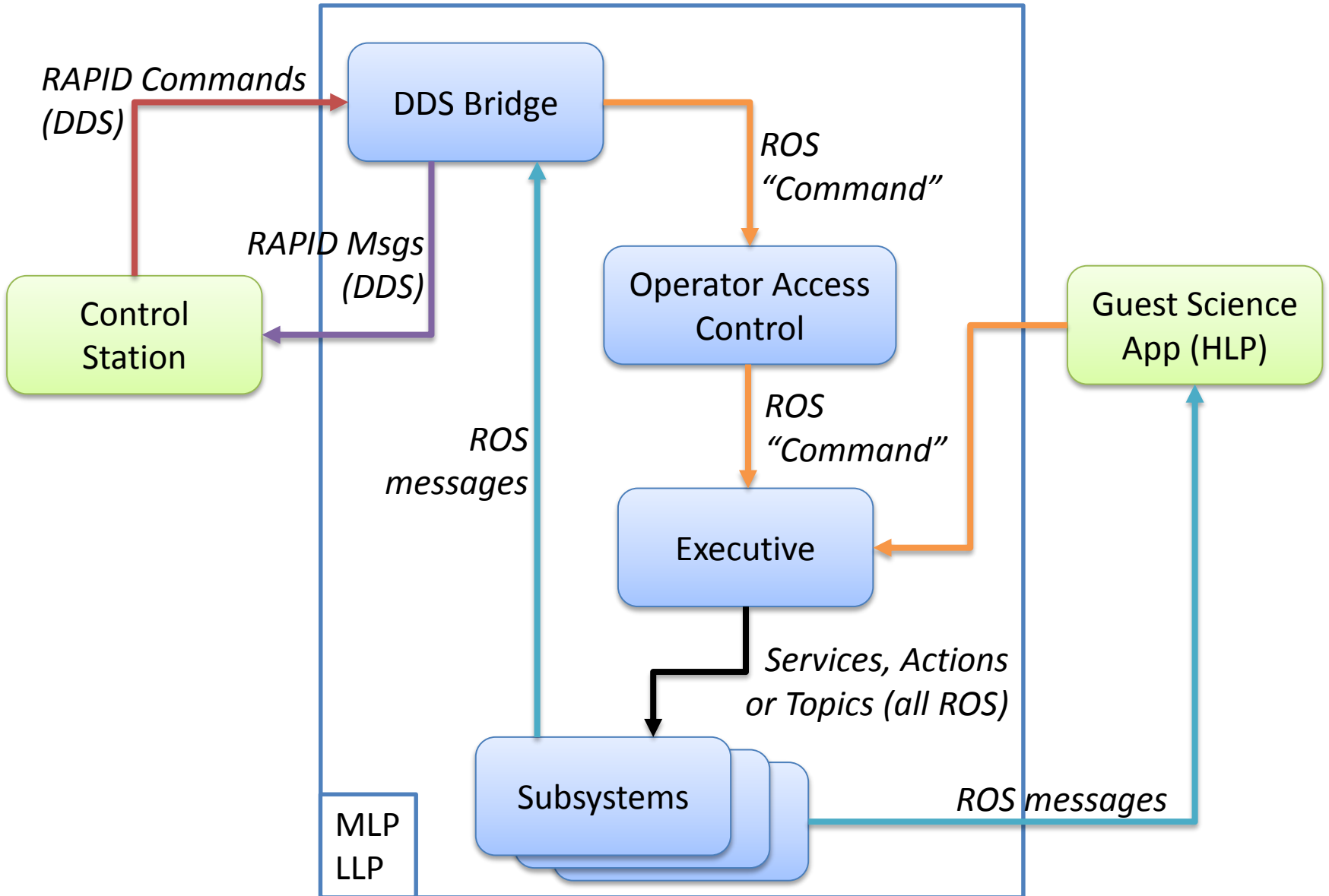
- Custom propulsion system and some localization sensors
- Gazebo based dynamics model, imagers, arm, lights and ISS model
- Can run all nodes on desktop or some nodes on target development board



# ARS APIs Overview

- ARS uses ROS within Astrobeer: Messages, Services and Actions define the internal API
- Astrobeer & 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 Astrobeer 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





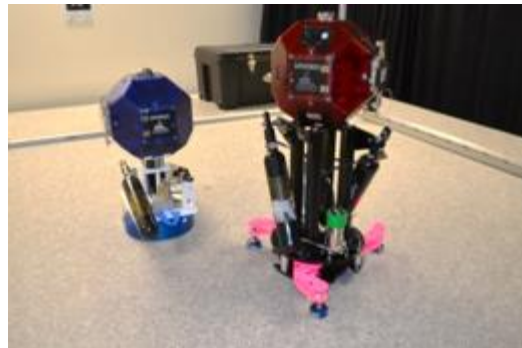
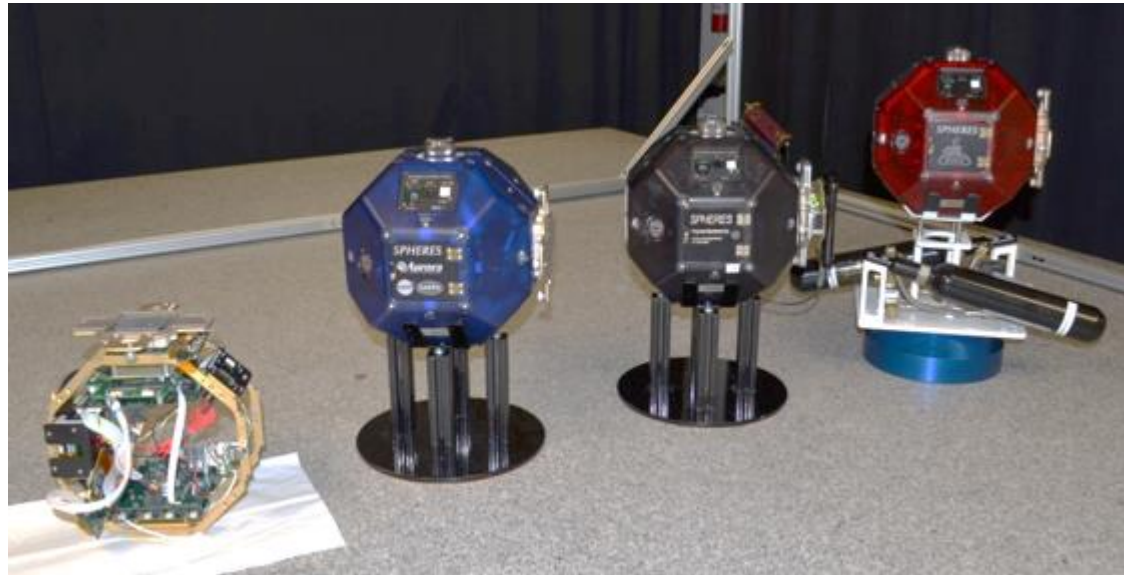
# SPHERES Engineering



# Hardware Status

## ❑ Hardware status

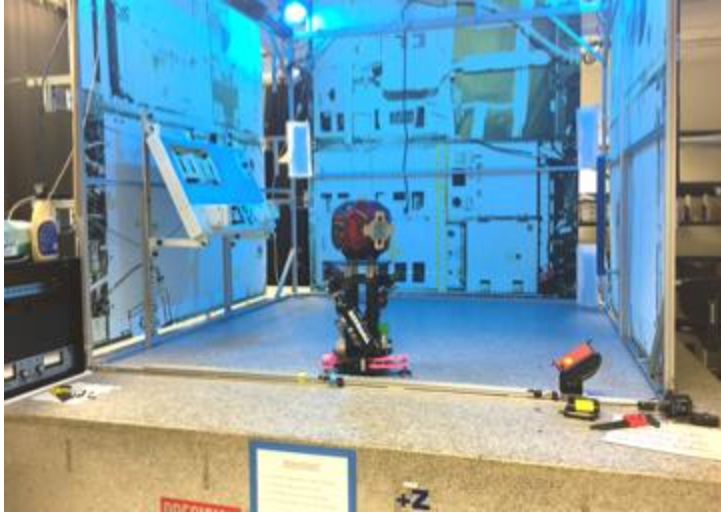
- Red: 100%
- Blue: 100%
- Black: 25%
- Orange: @ MIT
- Stack: 100%
- Battery recharger: 4 of 4
- New air carriage: 3 of 4
  - ✓ Tall 3-puck: 2 of 3
  - ✓ Single puck: 1 of 1
  - ✓ More in work





# 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

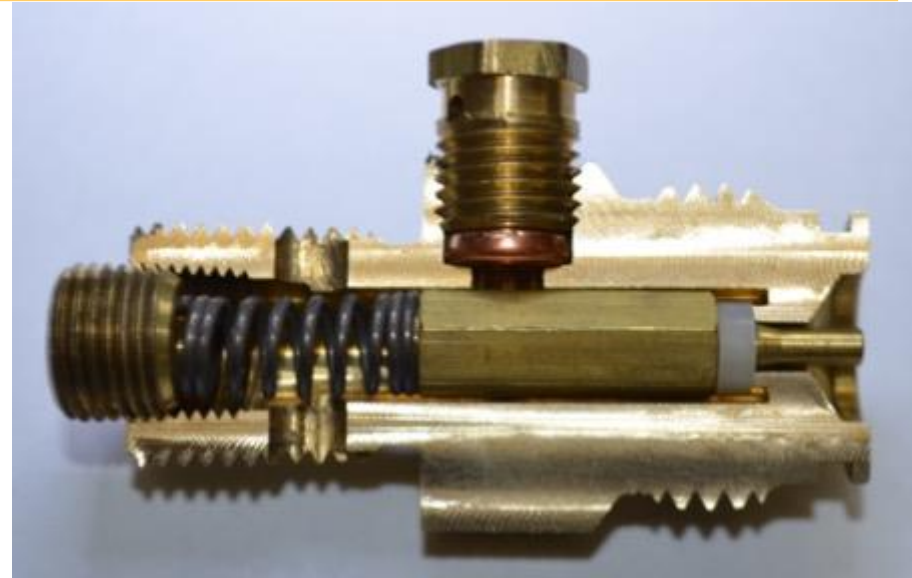
- ~60 Tanks Ready for Filling
- Decals Arrived ( IMS Barcode / Hazzard waste / Fill Status )

## ❑ 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





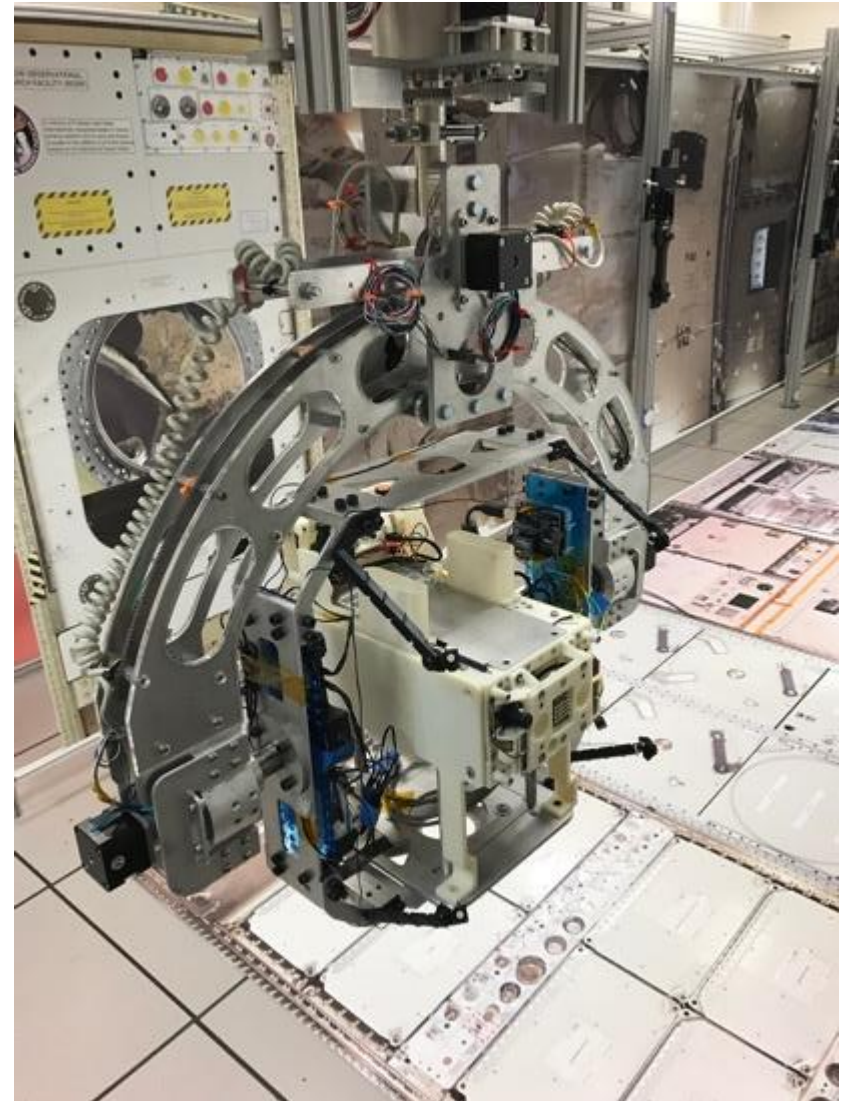
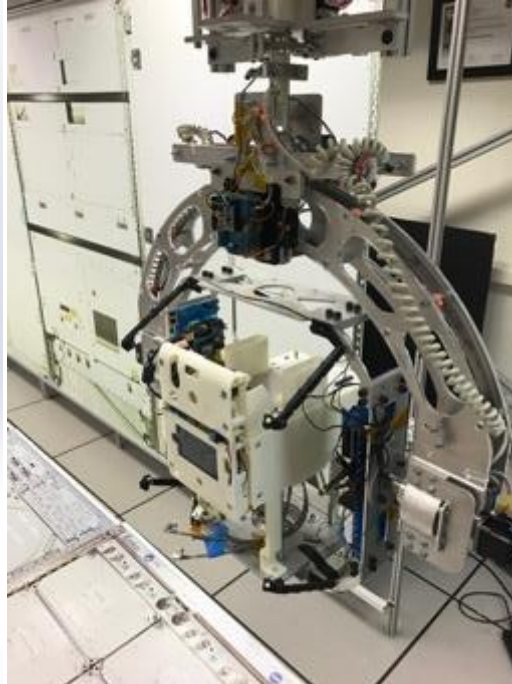
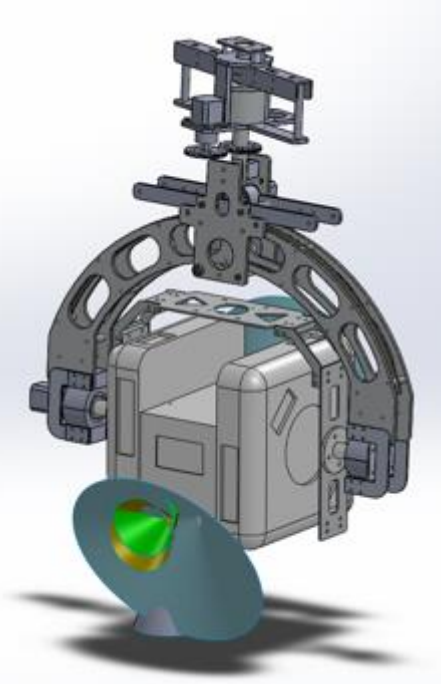
# MGTF Gimbal

## □ 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.
- Visualeyex for ground truth
- Real time commands from simulation or from the payload over Xbee.



## Status:

- 6-DOF operational.
- Testing in progress