



ISS Astrobee Facility

***Sponsoring Org/Office Code: ISS Program, OZ3
Name of Forum: Astrobee Working Group Nov. 2022
Date: November 10th, 2022***



***Jose V. Benavides
NASA Ames Research Center
Intelligent Systems Division (Code TI)
Henry Orosco
ISS Research Portfolio Manager***



Purpose



- **Purpose:** Provide Astrobeer Facility overview, status and near-term plan

- **Select the appropriate box below:**
 - Request for Technical Concurrence
 - Information Only
 - Management Direction
 - Response to an Action Item

- **Agenda:**
 - Overview
 - Facility Status
 - Engineering
 - Operations
 - ROS upgrade



Agenda



Astrobee Working Group		Join by Teams Link:				
Draft, Subject to change		Location: Phone, MS Teams, and NASA Ames Research Center in-person				
Date: Thursday, November 10th, 2022, 8am PST						
Agenda	Group	Sponsor	Project	Name	Time	duration (min)
0	NASA ISS		Introductions/Welcome	Henry Orosco	8:00 AM	0:05
1	NASA Astrobee	NASA TDO	NASA ISS Program TDO overview	Henry Orosco	8:05 AM	0:10
2	NASA ISS		Astrobee Facility Status	Jose Benavides	8:15 AM	0:40
3	NASA ISS TDO		Astrobee PIM Status	Cristian Garcia/Melissa Boyer	8:55 AM	0:10
4	National Lab	Nat Lab	National Lab overview	Robbie Hampton	9:05 AM	0:05
5	NASA Ames	NASA STMD	ISAAC (+ Semantic Localization + FAU Capstone)	Trey Smith	9:10 AM	0:20
6	NASA JSC	NASA AES	RFID-Recon	Andrew Chu	9:30 AM	0:15
7	Break				9:45 AM	0:20
8	Astrobotic/Bosch	Nat Lab	Sound See	Sam/Charles	10:05 AM	0:15
9	JPL/USC	Nat Lab	Clingers	Adarsh Rajguru	10:20 AM	0:15
10	Zero G Horizons	Nat Lab	SOARS	Deepak	10:35 AM	0:15
11	Kall Morris Inc. (KMI)	Nat Lab	REACCH	Austin Morris	10:50 AM	0:15
12	ILC Inc./MIT	Nat Lab	Zero Robotics	Kathleen Magrane/Danielle Wood	11:05 AM	0:15
13	Stanford	NASA STMD	Gecko	Somrita Banerjee	11:20 AM	0:15
14	DLR/Airbus	DLR	CIMON	Christian/Till Eisenberg	11:35 AM	0:15
15	Break/Lunch				11:50 AM	1:30
16	FIT	NASA STMD	SVGS	Hector Gutierrez	1:20 PM	0:15
17	NPS	DOD	Astrobotics	Jonathan/Jennifer/Marcello	1:35 PM	0:15
18	Metis	NASA SBIR	CoSLAM	Tom Zurales	1:50 PM	0:15
19	Picknik	NASA SBIR	Perception Framework	Mark Moll	2:05 PM	0:15
20	Makel Engineering	NASA SBIR	EMMA	Darby Makel	2:20 PM	0:15
21	TRAC Labs, Inc.	NASA SBIR	PLUMMRS: A collection of Plan Ledgers and Unified Maps for Multi-Robot Safe	Ana Quispe	2:35 PM	0:15
22	Orbit Fab	N/A	Docking-Refueling	Connor Geiman	2:50 PM	0:15
23	JAXA	JAXA	Kibo-RPC (Robotic Programming Challenge) / IntBall-2	Arakane-san	3:05 PM	0:15
24	CSIRO/Boeing	Nat Lab	Multi-resolution Scanning	Marc Elmouttie	3:20 PM	0:15
25	STEMX365	N/A	STEMX365	Mizan Chowdhury	3:35 PM	0:15
26	NASA Ames		Wrapup, Action Items	Jose Benavides & Henry Orosco	3:50 PM	1:00
27	NASA Ames		Astrobee Granite Lab Tour	Jonathan Barlow	4:50 PM	



Overview



Project Description



Based at Nasa Ames Research Center, the ISS Astrobee Facility provides a free-flying robotic system for ISS research and ISS STEM outreach. The Astrobee free-flying robotic system consists of three cubed-shaped robots, software, and a docking station used for recharging. The project provides sustaining engineering tasks for ensuring the facility operational readiness on ISS. The project provides payload support to users from academia, private industry, NASA, and other government agencies in the execution of ISS approved research and STEM objectives.



Chris Cassidy, GMT 248 2020

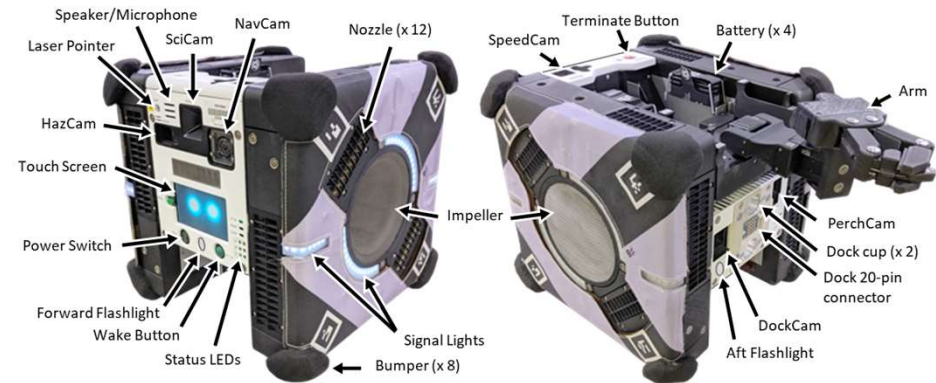
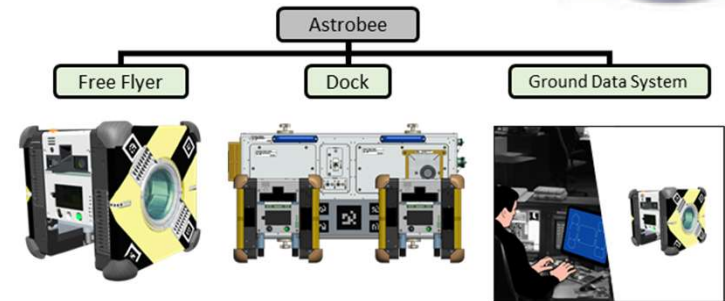


Astrobee Facility Overview



- Astrobee research platform ecosystem
 - Astrobee hardware: Ground and flight units
 - Ames Research Center Experimental Facilities
 - Astrobee Robot Software
 - Access to the International Space Station

- Support different research: Artificial Intelligence, manipulation, computer vision, Human Robotic Interactions, many, many other fields!





Astrobee Working Group Community



- Astrobee Working Group (AWG) meeting
 - Meet twice a year (ideally in-person)
 - Timed similarly to the POIWG conference
 - Next: Spring 2023
- Purpose:
 - Information sharing across the Astrobee community
 - Astrobee Facility shares status, updates, overall calendar
 - Discuss proposed changes/updates



Pictures from last AWG



April 28th, 2022, Astrobee Working Group



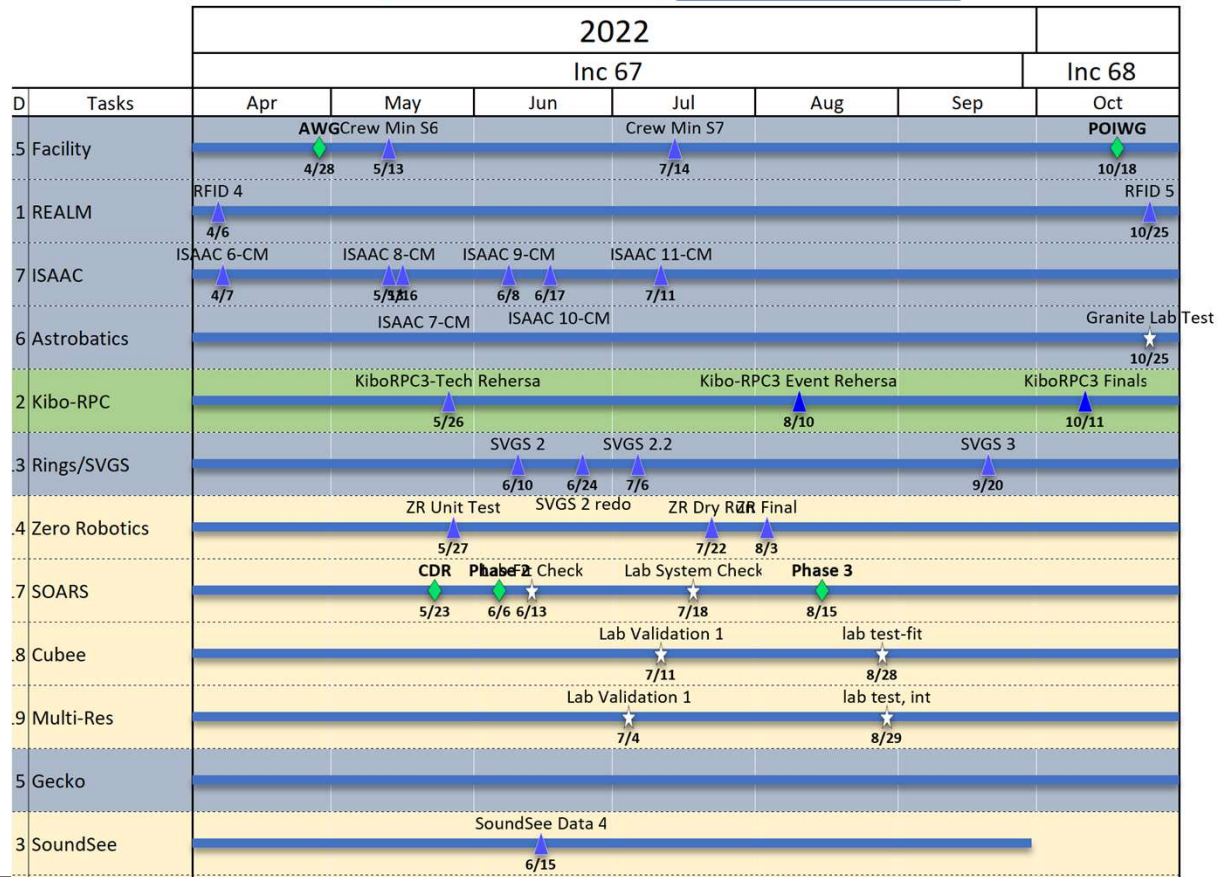
Astrobee Summary since last AWG



4/1/2022
7

- Start Date
- Number of Months

▲ Ops	☆ Lab Visit	🚀 Launch	▲ B	▲ H	▲ B+H	▲ H+Q
◆ Milestone	👤 EVA		▲ Q	▲ B+Q		





On-Orbit Activities (since 4.28.22)



AB111: ISAAC 8	May 13	AB121: SVGS 2 Redo Continuation	July 6
AB112: ISAAC 7	May 16	AB122: ISAAC 11	July 11
AB113: JAXA KIBO RPC3 Tech Rehearsal	May 26	AB123: Crew Minimal S7	July 14
AB114: Zero Robotics Unit Test	May 27	AB124: Zero Robotics Dry Run	July 22
AB115: ISAAC 9	June 8	AB125: Zero Robotics Finals	Aug. 3
AB116: SVGS 2	Jun 10	AB126: Kibo RPC3 Dry Run	Aug. 10
AB117: SoundSee Data 4	June 15	AB127: SVGS Science 3	Sept. 20
AB118: ISAAC 10	June 17	AB128: KIBO RPC3 Finals	Oct. 11
AB119: SVGS 2 Redo	June 24	AB129: REALM 2 Science 5	Oct. 25
AB120: Vacuum Activity	June 28	AB130: Crew Minimal S8	Nov. 1
		AB131: SVGS Science 4	Nov. 7

- 131 Ops Sessions since Dock Install and Checkout (February 11, 2019)
 - = 3+ Test Session/month
- 21 Ops Sessions since last Astrobeer Working Group Meeting
 - = 3+ Test Sessions/month



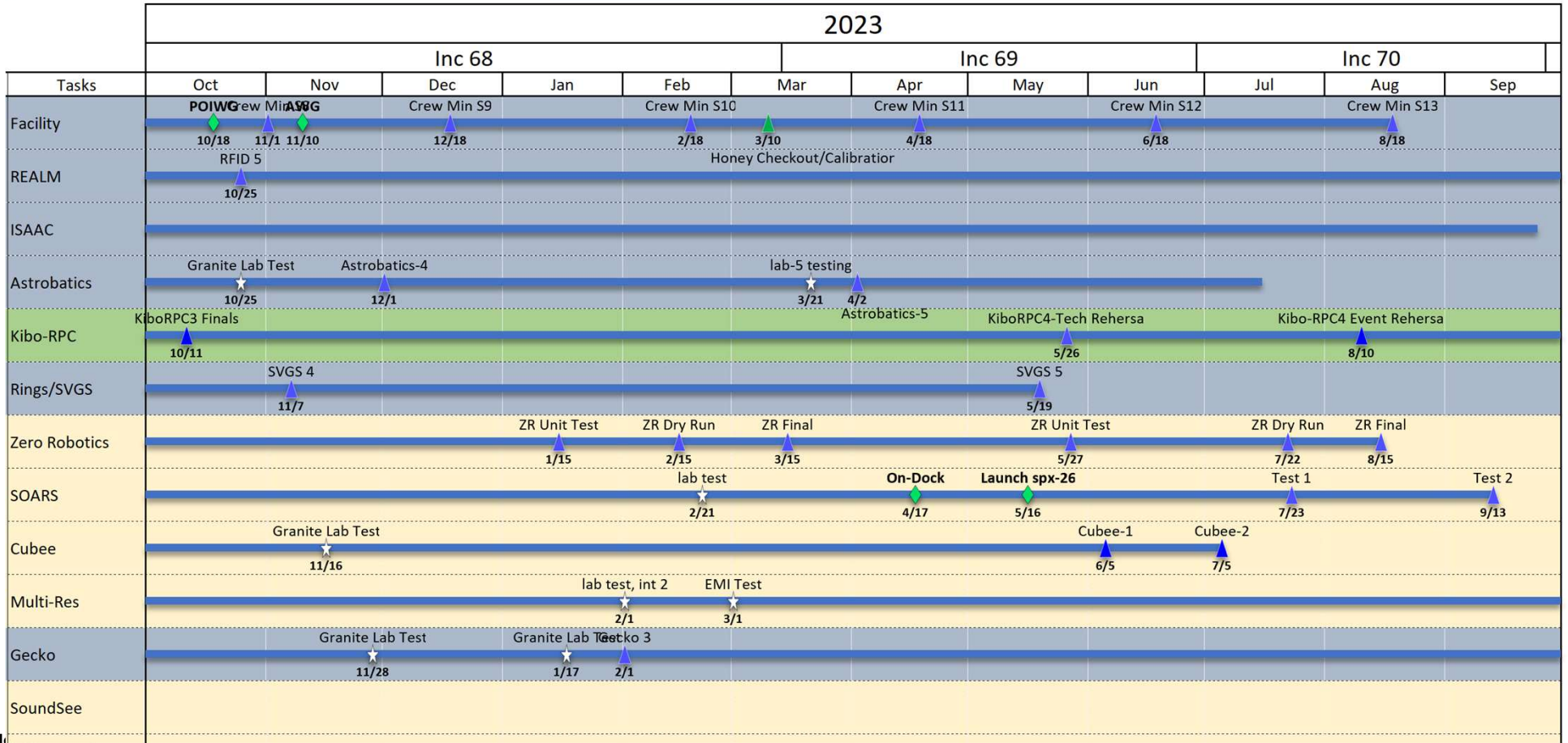
Astrobee 12-month forward plan



10/1/2022
12

- Start Date
- Number of Months

▲ Ops	☆ Lab Visit	🚀 Launch	▲ B	▲ H	▲ B+H	▲ H+Q
◆ Milestone	👤 EVA		▲ Q	▲ B+Q		





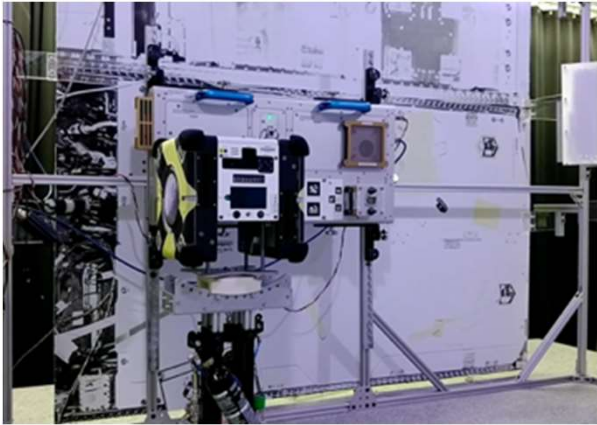
Facility Status



Hardware and Lab Status



- Granite Lab: Online



- Flight Lab: Online



- Engineering Evaluation Lab (EEL): Available upon request

Name	Status
Flat Sat A	Operational
Flight 1 (Bumble), 3 (Queen)	In Space, Operational
Flight 2 (Honey)	On Ground, In Repair
Flight Spare	Operational
Cert (B#)	Operational
Ground (Wannabee)	Operational



Honey Repair



- Confirmed SD card as root cause
- New/more robust SD cards formatted and ready to be installed on Honey
- Honey repair rehearsal with Wannabee
- Next Steps:
 - Installation of the SD cards on Honey
 - SW update for Honey
 - Functional test
 - Packing and shipping





Current Status



- Inspected Honey for any physical damage or missing parts
 - None was found only dust, hair, and minor stains
- Honey was booted but failed to boot nominally
 - Placed on granite table and mated to dock
 - Through serial umbilical cable, verified LLP SD card corrupted and not able to boot
 - Attempts to repair card failed
- Ordered new SD card
 - Supply chain issues took longer then expected for it to arrive
- Practiced with Wannabee
 - Removal of LLP SD card, reformatting, setting correct images, configuration is setup correctly
 - Removed MLP and HLP SD cards and performed same steps as LLP SD card removal
- Ready for Honey repair pending ARB discussion



Mapping More ISS Modules



- ISAAC 6-11 activities included operations in JEM, Node 2 and US Lab
- Good performance with all maps
- On-going discussions for commissioning more modules

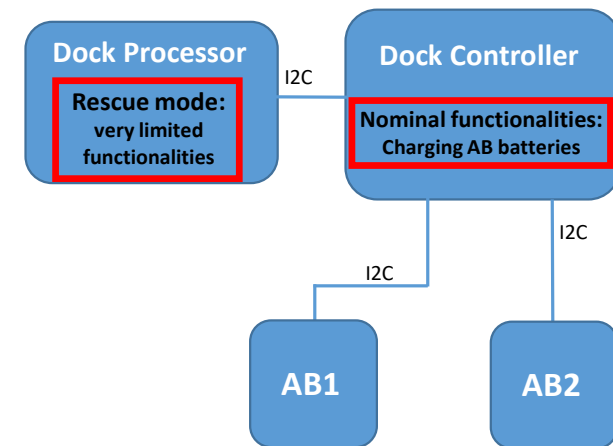




ISS Dock Station: status



- On 10-11-22, during the prep activity for the Kibo RPC Finals 3, the dock processor presented multiple read-only errors.
- After crew performed a power cycle, the Dock Processor restarted into rescue mode.
- The Dock controller is unaffected – still able to charge Astrobee's batteries.
- Investigation is underway to possibly recover the Dock Processor remotely.





Ubuntu 20.04 Transition



- Current status
 - New Debian repo with multiple distribution support deployed
 - Image generation scripts updated to create Ubuntu 20 images
 - File system Ubuntu 20 images generated and deployed to ground unit.
 - FSW compiles for armhf and deployed on Wannabee
 - Initial tests of FSW on new images show no issues.
- Next Steps
 - More extensive FSW testing.
 - Updated custom images.
 - Update Astrobeek Debian generation.
 - Cleanup of scripts and documentation.
 - Transition plan for ground/ISS units and software products.



Operations: Functions



- Ensure Facility Readiness for ISS Test Sessions
 - All crew training is handled via Onboard Training (OBT).
 - Manage crew procedure and all planning products updates via OCR/ECR system
 - Coordinate crew time with ISS Lead Increment Scientist and POIC Cadre
 - Assist Astrobeer team & PDs in acquiring proper access to ops systems as required for real-time ops support
 - Coordinate with investigators for product development and delivery
 - Help investigators set up remote communication capabilities as needed
- Real-Time ISS Test Session support
 - Coordinate with MSFC and POIS (POIC Specialist) all deltas to real-time ops and products
 - Support crew & POIC cadre with real-time ops – plan and conduct crew conferences as needed
 - Coordinate commanding and data download window requirements and planning
 - Test session data and video management
 - Real-time commanding support
- Public Relations
 - Maintain website, work with ARC PAO office to publish material on site



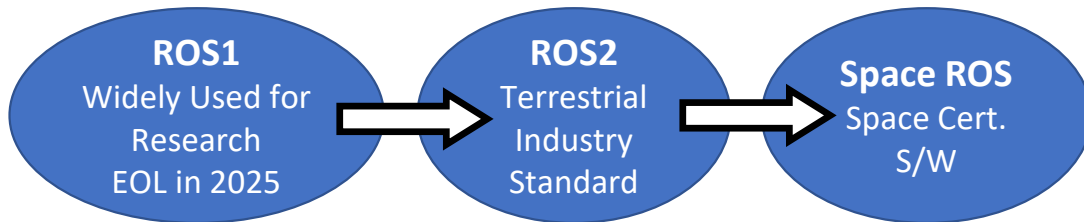
Operations: Functions



- Increment Planning
 - 2-pager development and submittal, updates as needed throughout increment
 - Assist PIM (Payload Integration Manager) with CEF inputs as needed
 - Regular timeline planning with Lead PPM (Payload Planning Manager), PPM planning team and MSFC POIS/PARC team
- Safety and Verification Assessments
 - Integrated Safety & Verification Assessments as needed for Astrobees Facility and Guest Science Payload Developers (PDs)
 - Continued SPHERES Safety & Verification focuses on return of hardware.
 - Complete CoFR (Certification of Flight Readiness) for ground systems and on-orbit hardware and operations products
- Astrobees Ground Ops Development
 - Coordinate ground Engineering and Operations Readiness Tests (ERTs/ORTs) in preparation for real-time ops
 - Work with Astrobees team and PDs to develop flight procedures, coordinate reviews with MSFC for final delivery and formal ECR review



Why move Astrobbee from ROS1 to ROS2?



- ROS = Robot Operating System
- ROS1 will be deprecated in [2025](#)
- New tech developments from industry players moving to ROS2
- [Space ROS](#) (kicked off via Blue Origin ACO) is an open-source extension of ROS2 designed to support robot flight software

Table 1. Summary of ROS 2 features compared with ROS 1.

Category	ROS 1	ROS 2
Network transport	Bespoke protocol built on TCP/UDP	Existing standard (DDS), with abstraction supporting addition of others
Network architecture	Central name server (roscore)	Peer-to-peer discovery
Platform support	Linux	Linux, Windows, and macOS
Client libraries	Written independently in each language	Sharing a common underlying C library (rcl)
Node versus process	Single node per process	Multiple nodes per process
Threading model	Callback queues and handlers	Swappable executor



Features	ROS1	ROS2	Space ROS
Swappable middleware		✓	✓
Multi-platform		✓	✓
Built-in network security, authentication, quality of service		✓	✓
Additional aerospace-focused V&V			✓
Artifacts for NPR 7150.2 certification / analysis			✓

S. Macenski, T. Foote, B. Gerkey, C. Lalancette, W. Woodall, "Robot Operating System 2: Design, architecture, and uses in the wild," Science Robotics vol. 7, May 2022.

ROS2 Migration Approach 1/2



➤ Status:

- We're confident that ROS2 migration is a good long-term choice
- We're currently estimating effort required for ROS2 migration and evaluating different migration approaches
- We don't yet have a timeline for when a ROS2 version of the Astrobeer Robot Software (FSW + sim) will be available

➤ Notional approach (these details could change):

- Astrobeer FSW on MLP and LLP would change to ROS2 but initially retain the same Astrobeer API (Command Dictionary) and telemetry topics, and replicate almost exactly the same behavior as the ROS1 version
- We may be able to make the migration entirely transparent in terms of the interfaces used by guest science software running on the HLP (this is still TBD). On the other hand, software running on the MLP and LLP will have to choose whether to target ROS1 or ROS2.

ROS2 Migration Approach 2/2



➤ Notional approach [continued]:

- During early phases of the migration, we will develop using the ROS2 Rolling release rather than freezing a particular distro such as ROS2 Humble.
 - This is because ROS2 quality is still improving rapidly, and we want to benefit from its ongoing improvements.
 - As the ROS2 version of FSW matures toward flight, we may eventually freeze to use a particular ROS2 distro, based on assessing the choices available at that time.
- When ROS2 FSW matures enough for flight, the initial deployment configuration on MLP and LLP might look like:
 - Ubuntu 20.04 Linux – this is the last Ubuntu version with standard ROS1 support, migration to 20.04 already in work
 - ROS1 Noetic available – stable platform for legacy users, will eventually end-of-life
 - ROS2 (TBD distro) available – initially used on an experimental basis for facility activities, guest science gradually migrates to new platform
- This combination of older Ubuntu 20.04 with a recent ROS2 version running on the robot (ARM architecture) will be sufficiently non-standard that we will probably need to custom compile the ROS2 core packages for use on the robot. However, we'll also try to support a more standard combination of versions to enable guest scientists developing in software sim to work with ordinary pre-compiled ROS2 packages for convenience.
- We think ROS1 and ROS2 installations of FSW can co-exist side-by-side on the robot, but we intend to avoid running a mix of ROS1 and ROS2 nodes at the same time (this complicates launch files, requires a communication bridge, etc.)



ROS2 Stakeholder Involvement



- The Astrobeer Facility exists to serve our stakeholders, including guest scientists, ISS operational users, and others. We'd love to hear what you think about this migration:
 - If you are a fan of ROS2, are there specific ROS2 features you care about Astrobeer supporting? Is the transition an important enabler for your work? Is there a particular timeline you care about us hitting with the migration process?
 - Do you have concerns about the ROS2 migration impacting your work? Have any feedback about our approach or timeline? (An example impact: potentially requiring your custom MLP software to be migrated to target ROS2, depending on your activity schedule and when we end-of-life the ROS1 version.)
- We hope to keep the lines of communication open, in part using our open-source GitHub repo at <https://www.github.com/nasa/astrobee>
 - The first related issue used for discussion is <https://github.com/nasa/astrobee/issues/542>
 - Watch that issue and tune into future Astrobeer Working Group meetings to get updates
- Are you interested in contributing to the migration as a developer?
 - Let's talk! With external help, we may be able to complete the migration faster, and you can help make sure the migrated version serves your needs.
 - Many thanks to Pedro Roque and his colleagues at KTH for raising this migration question again and already starting to help with investigating the approach



QUESTIONS?



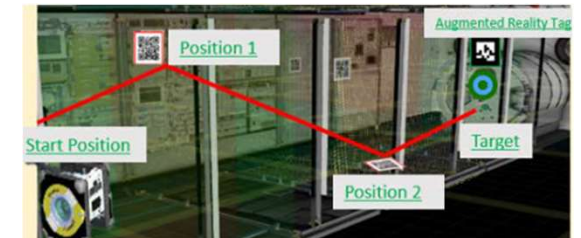
KIBO-RPC Competition



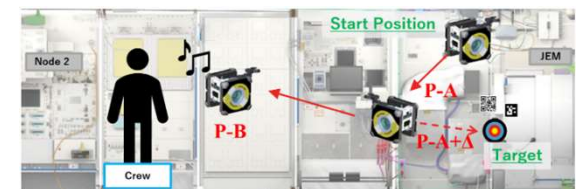
- NASA/JAXA collaboration 2018
- Educational outreach using NASA' Astrobees & JAXA's Int- Ball
- Kibo Robot Programming Challenge (Kibo-RPC): students solve various problems by programming Astrobees.
- For 1st Kibo-RPC (2020):
 - 1,168 students participated
 - 313 teams
 - 7 countries
- For 2nd Kibo-RPC (2021):
 - 905 students participated
 - 286 teams
 - 11 countries



Snapshot of 1st Kibo-RPC Final event (JAXA)



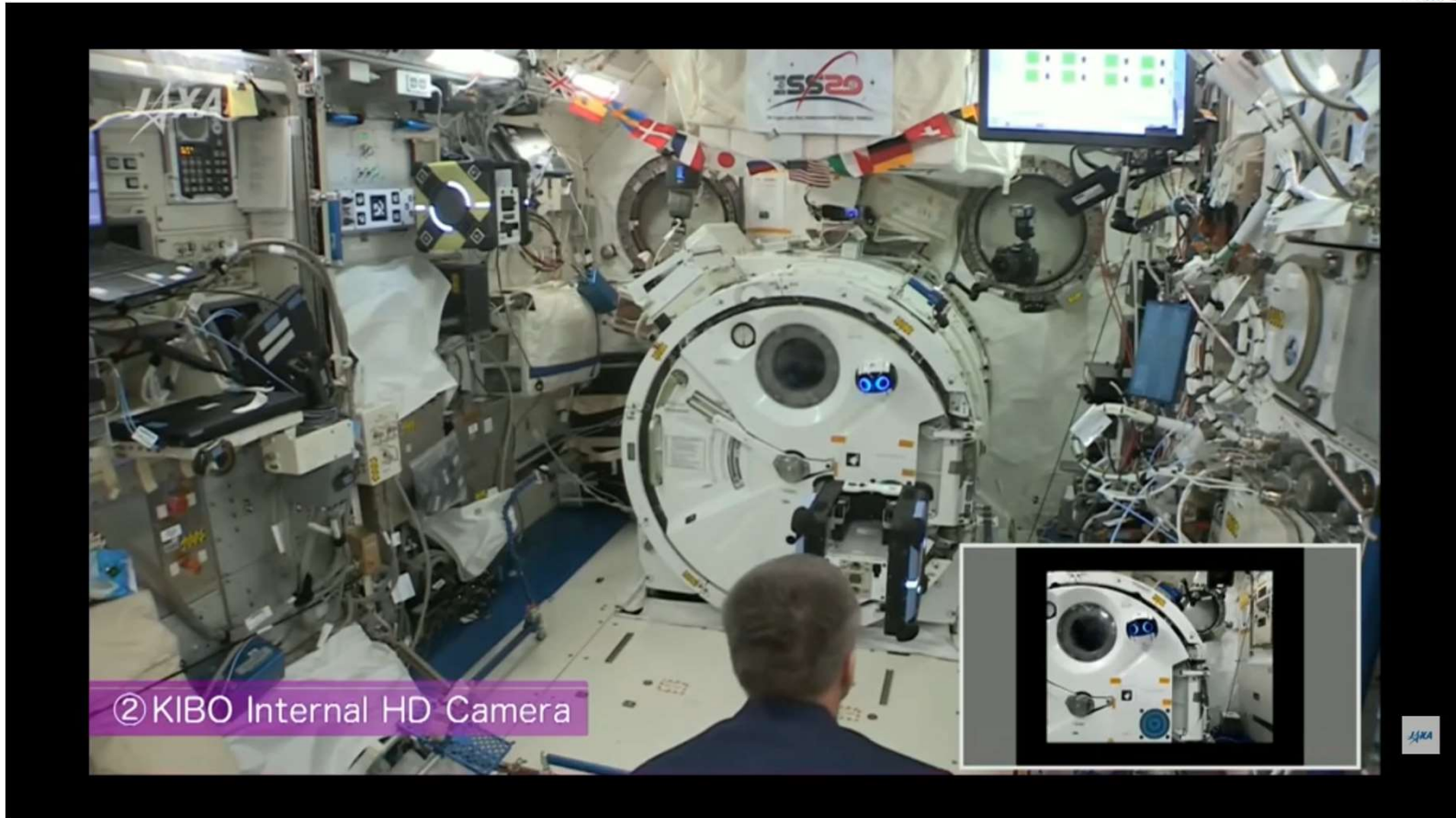
1st Kibo-RPC (JAXA)



2nd Kibo-RPC (JAXA)



KIBO-RPC Competition





Outline



- What's Astrobees?
- KIBO-RPC competition
- Mapping & Localization
- ISS Ops Summary
- Conclusions

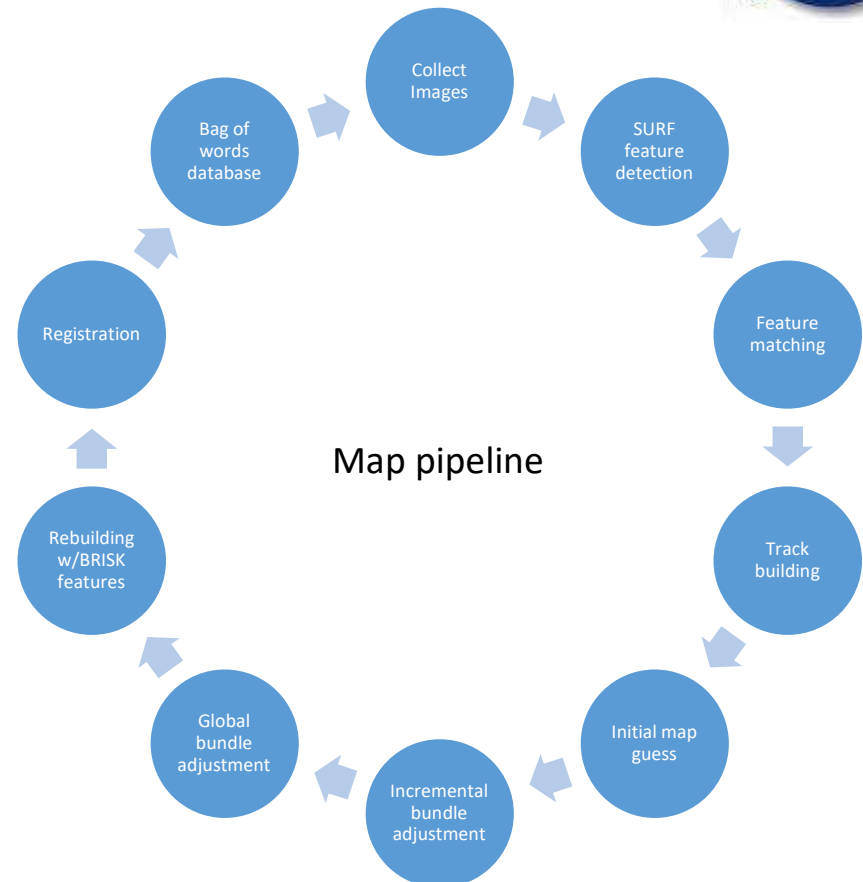


Mapping and Localization



Mapping

- Astrobbee uses natural landmarks to generate an off-line map for use in localization
- Astrobbee needs to detect landmarks to get a position estimate, the more the better
- Once map is build, its performance only verifiable at during ISS ops
- Needed pre-assessment tool





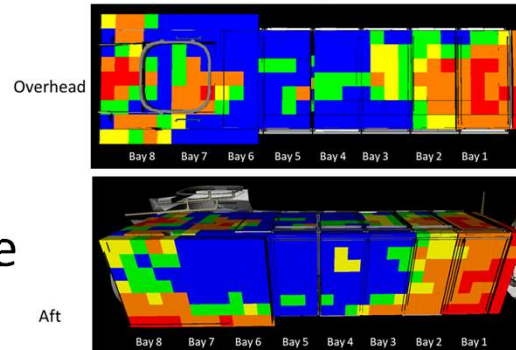
Mapping and Localization



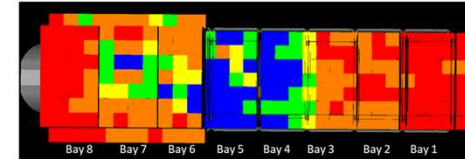
Coverage Analysis

- Visualizes coverage of a given map or Astrobeer trajectory
- Map pre-assessment for Astrobeer team and Guest scientists
- Trajectory post-assessment
- Analysis produces:
 - 3D JEM heat map
 - 3D Astrobeer trajectory heat map
 - PDF report

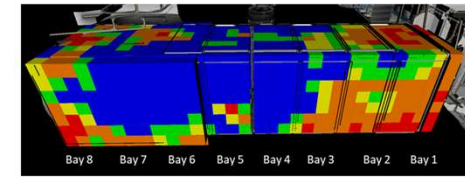
3D JEM Heat Map



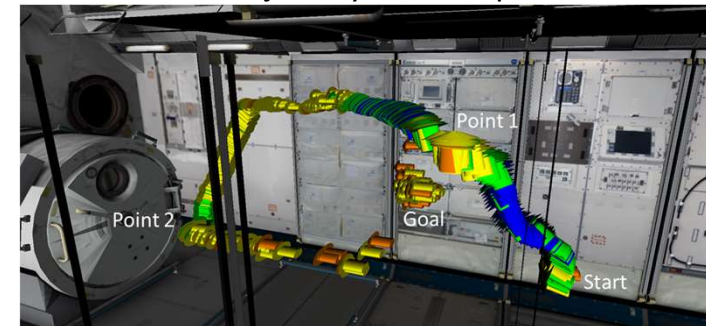
Deck



Forward



3D Astrobeer Trajectory Heat Map



Color	# Features
Red	0
Orange	1-10
Yellow	11-20
Green	21-40
Blue	40+

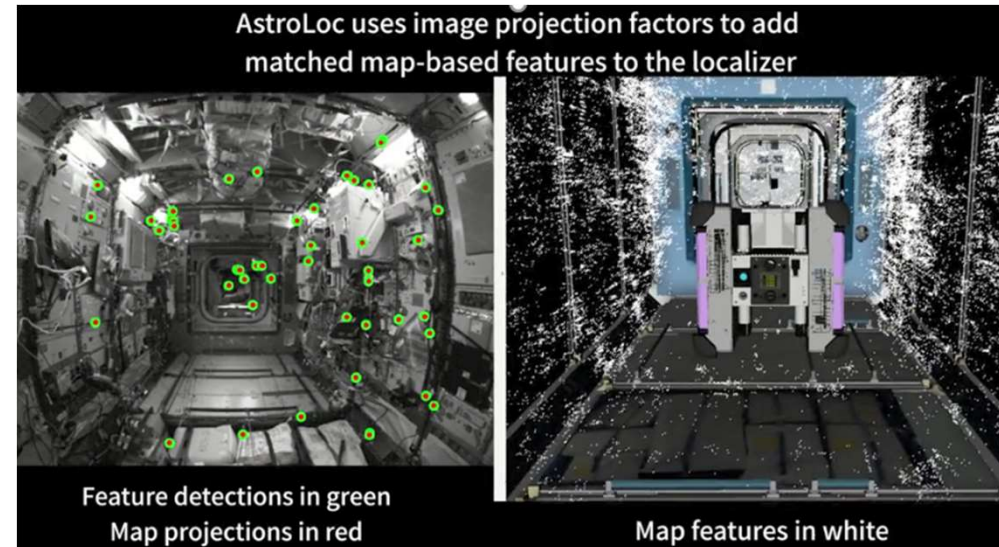


Mapping and Localization



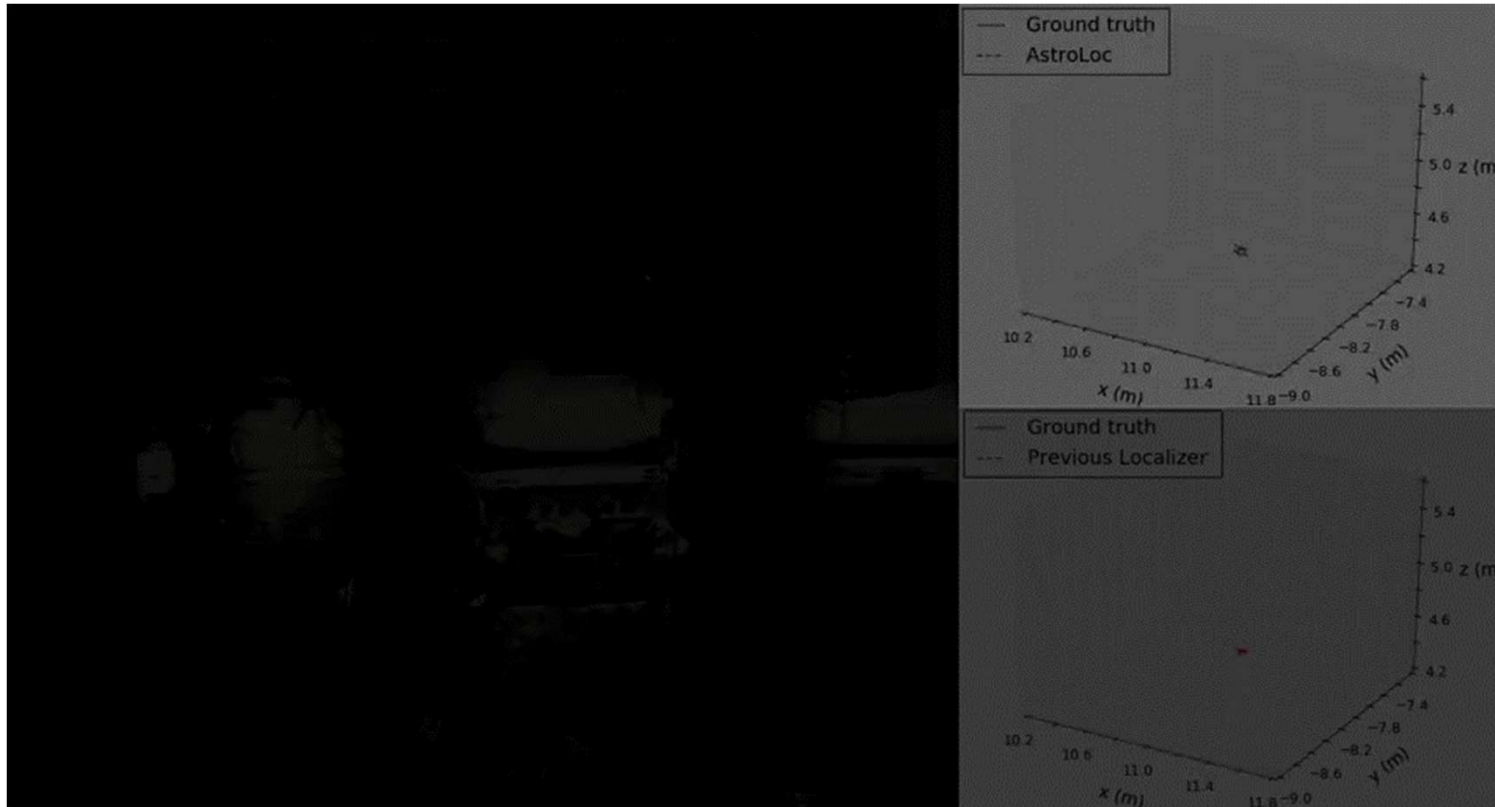
Localization

- Extended Kalman Filter (EKF) upgraded to graph-based localizer
 - Reduced number of “lost robot” events
 - Graph localizer had 54% smaller position error on average
 - Since deployment, multiple Astrobees ISS activities have logged hours of free flying with no crew intervention





Mapping and Localization



R. Soussan, V. Kumar, B. Coltin y T. Smith, «AstroLoc: An Efficient and Robust Localizer for a Free-flying Robot,»
IEEE International Conference on Robotics and Automation (ICRA), Philadelphia, USA, 2022.



Back-up Slides



Topic	Slide



Lessons Learned

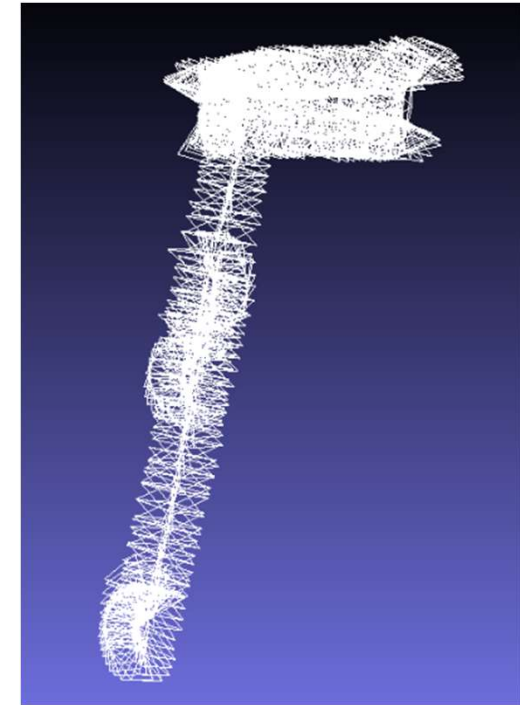


Lessons Learned



- Mapping & Localization

- The ISS is a dynamically changing environment.
- Localization algorithms need to be able to function stably for a time without mapped landmarks, the longer the better.
- Until a map has good features over the entire area, maneuvers will always need to point periodically to areas with good features.
- Generating a map takes time and effort.
- Data gathering for mapping needs to reduce reliance on crew.
- Built tools quantify and improve map coverage quality and minimize need to frequently create them
- More detail can be found in the Astrobees IAC paper ([here](#))



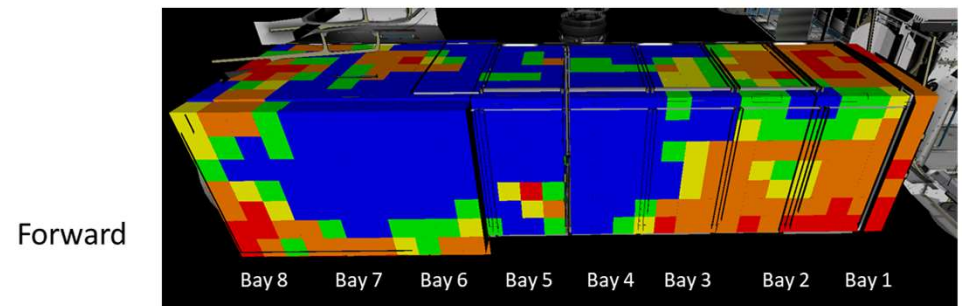
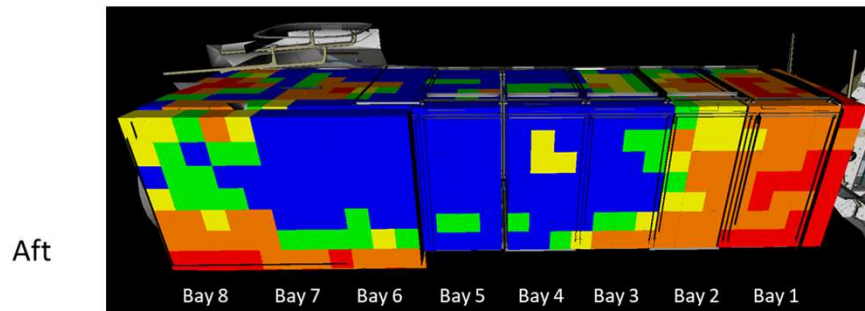
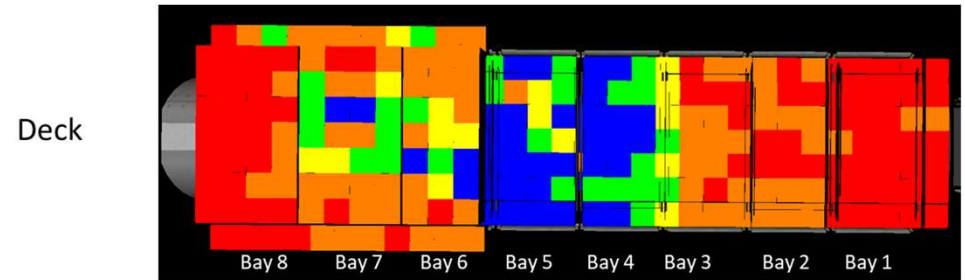
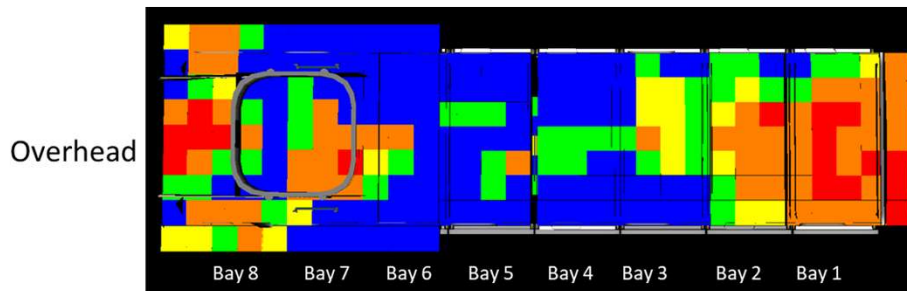
3D view of JEM, NOD2, USL camera poses



Coverage Analysis



3D JEM Heat Map



Color	ML features
Red	0
Orange	1-10
Yellow	11-20
Green	21-40
Blue	40+



Lessons Learned



Science Camera Imagery

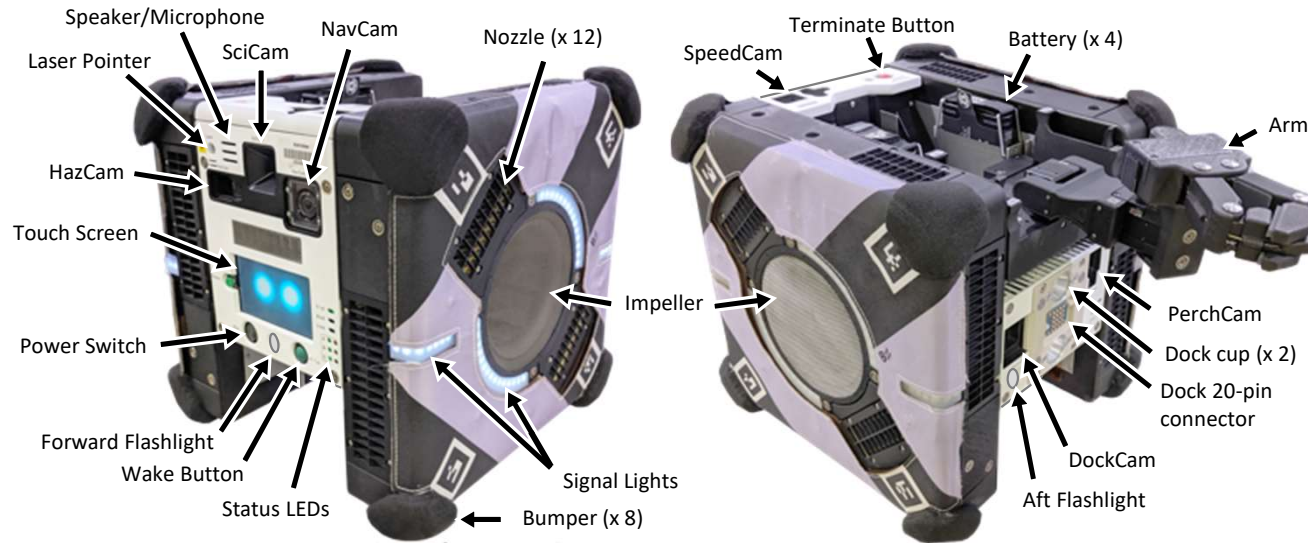
- Users need both streaming and still imagery from the Science Camera
- Recording still images from the SciCam can be unstable
 - The instability was corrected for ISAAC surveys
- Users continue to have interest in running Linux on the HLP.

Control Station (Guest Science Expansion, Guest Scientist Operators)

- Frequent anomalies during ISS operations drove most users to rely on the Astrobeer team for command and control.



Astrobee HW Overview



- Free flying robot inside the ISS
- 32 cm wide, ~9.1kg (2 batt., no arm)
- All electric + fan-based propulsion
- Robot arm for “perching”, ~1kg
- Three smartphone computers
- Three payload bays for expansion
- Microphone not currently enabled
- More: www.nasa.gov/astrobee



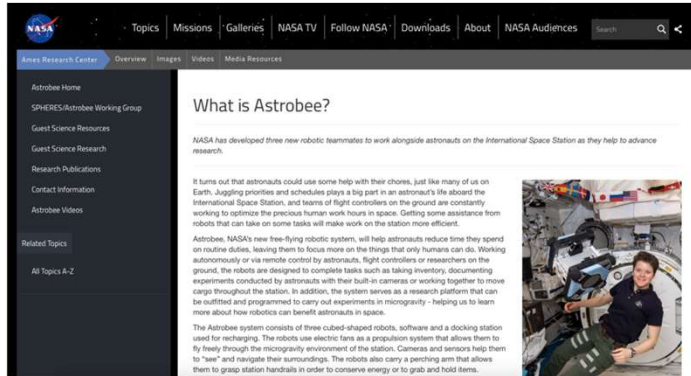
EPO Activities



- Summary of Education and Public Outreach
- Significant Media Coverage



Web Features

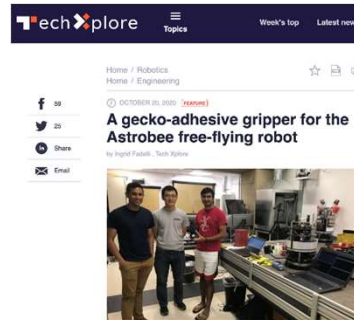


www.nasa.gov/Astrobee

Hi Honey! NASA's Second Astrobee Wakes Up in Space



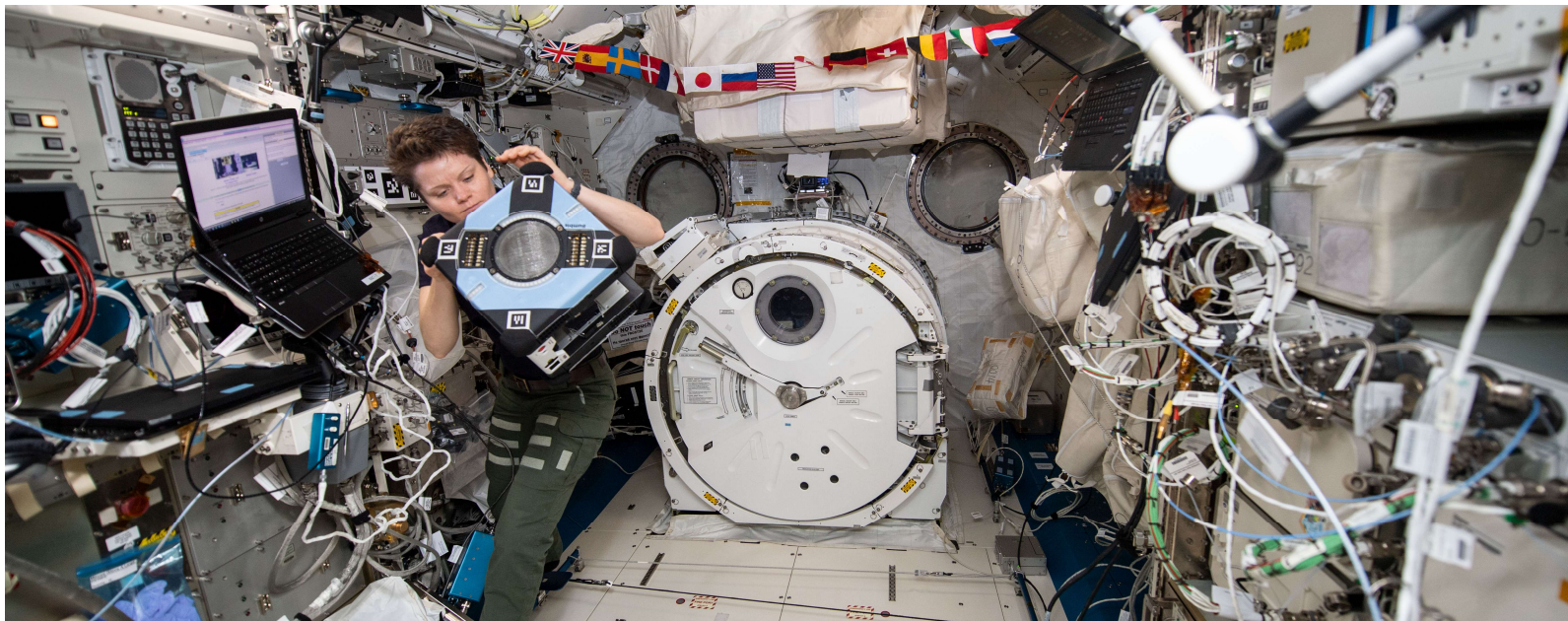
[Hi Honey! NASA's Second Astrobee Wakes Up in Space](#)



[A gecko-adhesive gripper for the Astrobee free-flying robot](#)



www.nasa.gov/astrobee





Stats



- **From the last AWG (7.8.21) to date**
 - 15 Test Sessions over 16 weeks (highlighted on slide 5 of the ops deck)
 - 4 unique crew
 - ~113 real-time console ops hours (not including data downloading)
 - 40 crew hours
- **Fiscal year (Oct 2020 through September 2021)**
 - 40 Test Sessions
 - 9 unique crew
 - ~330 real-time console ops hours (not including data downloading)
 - 101 crew hours
- **From 4/30/20 (our first remote ops Test Session) to date**
 - 55 total remote Test Sessions (1.4 weeks/session)
 - 10 unique crew (Chris Cassidy was our sole crew member for months.)
 - ~440 real-time console ops hours (not including data downloading)
 - 122 crew hours



Agenda



On Lunch, back at 01:05pm PST



On Break, back at 01:05pm PST