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# ***Astrobee Facility***

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***Sponsoring Org/Office Code: ISS Program, OZ3  
Name of Forum: Astrobee Working Group  
Date: July 7<sup>th</sup>, 2021***



***Jose V. Benavides  
NASA Ames Research Center  
Intelligent Systems Division (Code TI)  
Henry Orosco  
ISS NASA Tech Demo Sphere Lead***



# Event Agenda



Draft, Subject to change			Location: Phone/ MS Teams			
Date:	Thursday, July 8th, 2021, 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	0:30
3	NASA ISS TDO		Astrobee PIM Status	Tyler Dorval/Melissa Boyer	8:45 AM	0:10
4	National Lab	Nat Lab	National Lab overview	Justin Doyle	8:55 AM	0:05
5	NASA Ames	NASA STMD	ISAAC	Trey Smith	9:00 AM	0:15
6	NASA JSC	NASA AES	RFID-Recon	Andrew Chu	9:15 AM	0:15
7	Break				9:30 AM	0:15
8	Astrobotic/Bosch	Nat Lab	Sound See	Sam Das	9:45 AM	0:15
9	NanoRacks/Braunschweig	Nat Lab	REGGAE	Jacob/Khalil	10:00 AM	0:15
10	MIT/DLR	Nat Lab	ReSwarm, Astrobee-ROAM	Keenan/Dr. Richard Linares	10:15 AM	0:20
11	Magnitude.io	Nat Lab/STMD	SMELS	Ted Tagami	10:35 AM	0:15
12	Zero G Horizons	Nat Lab/STMD	SOARS	Deepak Sathyanarayan	10:50 AM	0:15
13	Break/Lunch				11:05 AM	1:00
14	Stanford	NASA STMD	Gecko-Inspired Adhesive Appendages for Automated Logistics	Tony Chen	12:05 PM	0:15
15	Tethers Unlimited Inc.	NASA STMD	AstroPorter	Jim MacConnell	12:20 PM	0:15
16	FIT	NASA STMD	SVGS	Hector Gutierrez	12:35 PM	0:15
17	NPS	DOD	Astrobatix	Stephen/Jennifer/Marcello	12:50 PM	0:15
18	ILC Inc./MIT	Nat Lab	Zero Robotics	Kathleen Magrane/Danielle Wood	1:05 PM	0:15
19	Kibo-RPC	JAXA	Kibo-Robotic Programming Challenge 2	Arakane-san	1:20 PM	0:15
20	NASA Ames		Wrapup, Action Items	Jose Benavides & Henry Orosco	1:35 PM	0:10

ON LINE BREAK, RESTARTING AT 12:15 PM



## Purpose

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- **Purpose:** provide an Astrobe Facility overview and update
- **Select the appropriate box below:**
  - ☐ Request for Technical Concurrence
  - ☒ Information Only
  - ☐ Management Direction
  - ☐ Response to an Action Item
- **Agenda:**
  - Overview
  - Engineering
  - Operations



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# Overview





# Project Description

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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



# Overview



Why Free Flyers on ISS? Provide a risk-tolerant testbed to:

- Enhance & Enable Human Exploration (e.g. Gateway)
  - Astrobees can potentially perform a range of Intra-Vehicular Robotics (IVR) caretaking tasks to help maintain and protect the Gateway, particularly during uncrewed mission phases.
- Perform Fundamental Research

## Objectives

- Ensures the facility readiness for ISS Astrobees test sessions
- Provides real-time ISS test session Ops support, and Increment Planning
- Supports a diverse user community of government, commercial, and academic investigators to enable Free-Flyer research

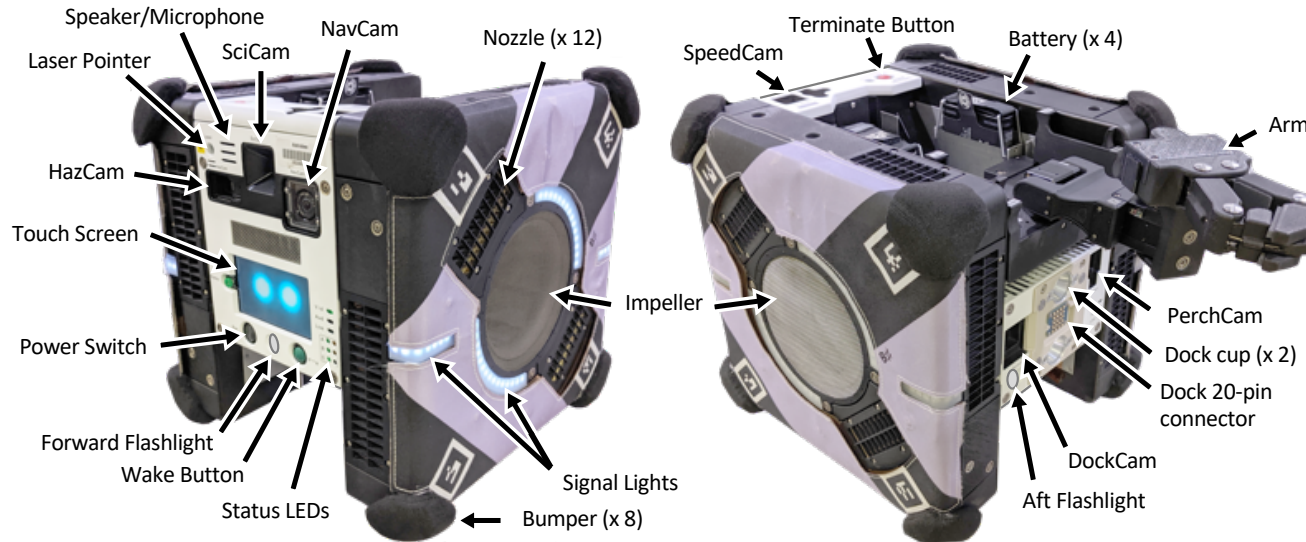
## Current activities

- Completing Astrobees commissioning activities
- Maintaining & Operating Astrobees
- Facilitating Free Flyer user community
  - Periodic Astrobees Working Group (AWG)
  - International Partners: JAXA (Int-Ball) and DLR/Airbus (CIMON)
- Supporting over 6 Astrobees users in various stages of integration





# 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](http://www.nasa.gov/astrobee)





# AWG Community

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- Astrobee Working Group (AWG) meeting
  - Meet twice a year (ideally in-person)
  - Timed similarly to the POIWG conference
  - Next: October 2021
- Purpose:
  - Information sharing across the Astrobee community
  - Astrobee Facility shares status, updates, overall calendar
  - Discuss proposed changes/updates



# Astrobee Users

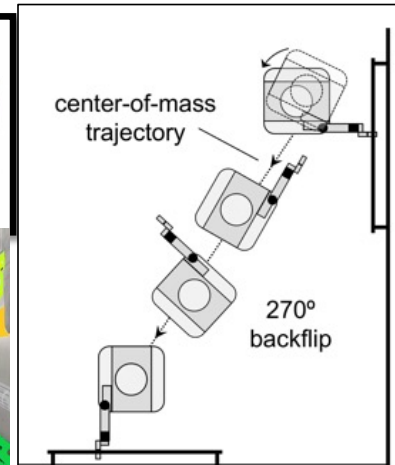
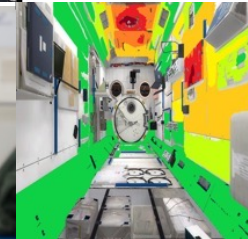
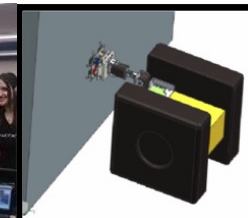
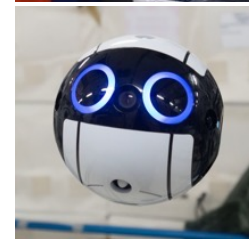


## • 11 Projects actively working towards ISS payloads

- Astrobotics (Naval Postgraduate School)
- SoundSee (Astrobotic/Bosch)
- Gecko (Stanford)
- RFID Recon (NASA AES/REALM-2)
- JAXA Kibo-RPC
- Astroporter (Tethers Unlimited)
- ISAAC (NASA STMD/GCD)
- ROAM (MIT/DLR)
- ReSWARM
- SVGS (FIT)
- SOARS (Zero-g Horizons)

## • Complete:

- REGGAE (NanoRacks/Braunschweig)

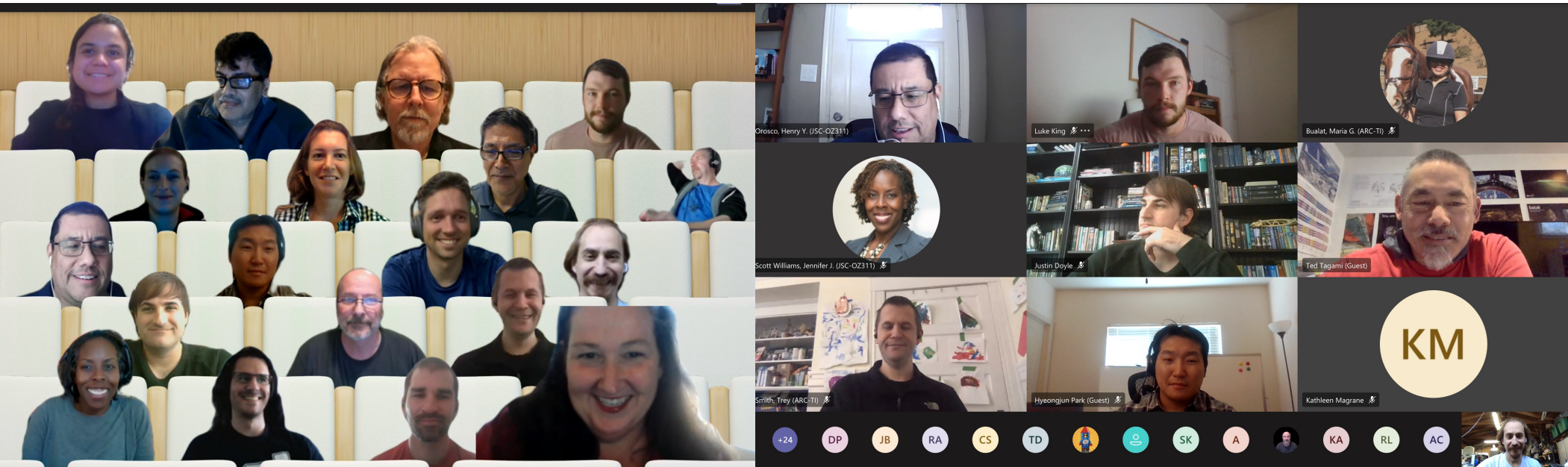




# Astrobee ops from home



Day 500 of WFH



October 29<sup>th</sup>, 2020, Astrobee Working Group



# Highlights

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- Localization now works, and Astrobees continues to mature free-flyer Intra-Vehicular Robotic (IVR) capabilities for research and future NASA missions
  - robot operations without crew
  - autonomous image acquisition
  - heterogeneous free-flying robots from 2 different space agencies working together (Int-Ball & Astrobees)
  - Astrobees remotely controlled from multiple ground locations
  - Multi-robot coordination and rendezvous
  - Inventory management
- Dozens of successful research activities executed successfully and looking forward to dozens more in 2021 and beyond





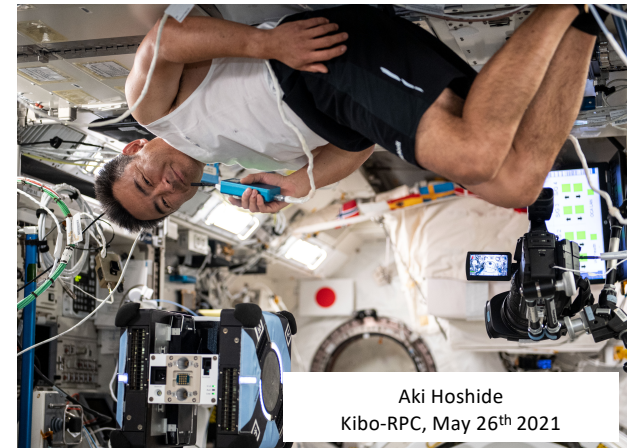
# Highlights



- Continued lab and integration testing activities at NASA Ames Astrobees Lab under Covid-19 restrictions
- Initial SoundSee and REGGAE activities in December 2020
- REGGAE completed in January
- Initial RFID-Recon Checkout in January
- Astrobees Dock repaired in February
- Perching Arm Checkout in February
- Mapping and new localization algorithm improvements
  - First tested in February 2021 (Crew-Minimal 10)
  - Demonstrated successful in March 2021 (Crew-Minimal 11)
  - Mapping update (LoMo) in April



Three-fingered Hand Integration, Columbia University



Aki Hoshida  
Kibo-RPC, May 26<sup>th</sup> 2021



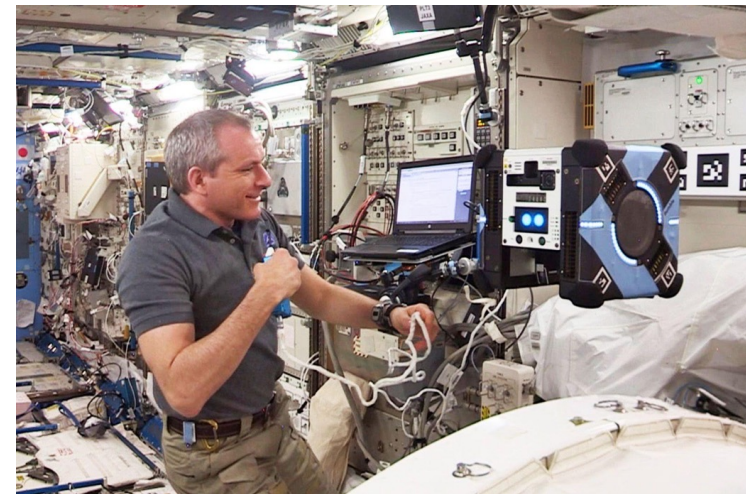


# Highlights

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- ISAAC Phase 1 (three on-orbit activities) completed
  - ISAAC-1 February, ISAAC-2 March, ISAAC-3 in April
- Astrobatcis-1 Completed in March
- Gecko 1 & 2 in March
- ROAM (Relative Operations for Autonomous Maneuvers) initial activity in May
- Crew Minimal S1 & Kibo-RPC2 Tech Rehearsal in May



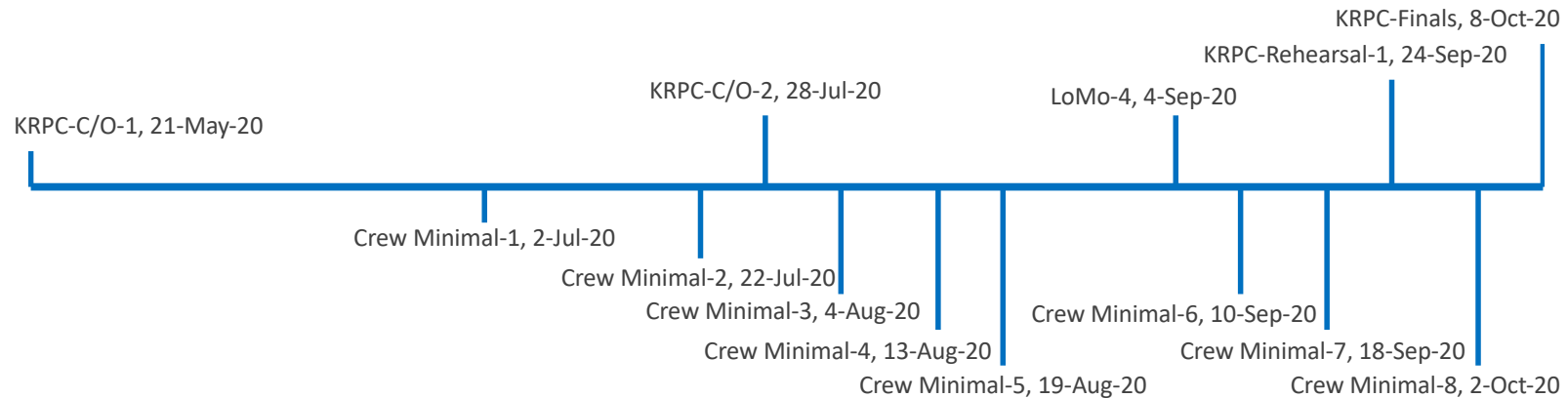
CSA astronaut David Saint-Jacques supporting Astrobee commissioning



# 2020 (Kibo-RPC) Astrobee Summary



## Kibo RPC Activity Timeline



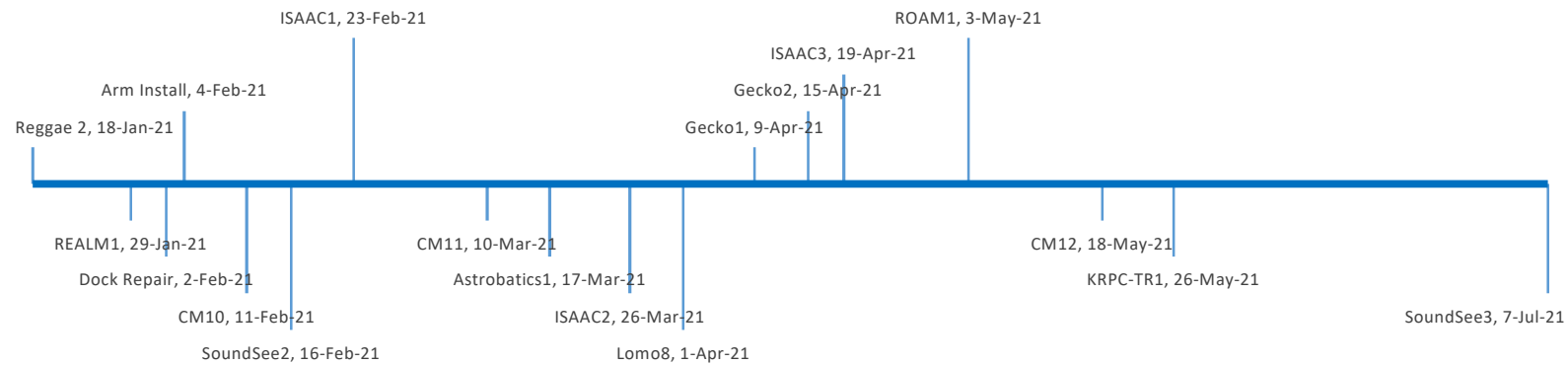
- Activities both crewed and not-crew tended started on 2020-04-30 and ended with the final round on 2020-10-08
  - Number of Crew-tended Kibo-RPC activities: 4
  - Number of Crew-tended LoMo's: 3
  - Number of Not-crew tended (Crew Minimal) activities: 8
  - **All 15 done within 23 weeks and done with Ames' personnel working from home**
  - Note: Many activities considered part of Astrobee's commissioning



# 2021 Astrobees Summary



## 2021 Activity Timeline



- Activities both crewed and not-crew tended started on 2021-01-18 and ended with 2021-07-07



# Astrobee Calendar (planning)



By Months  
7/1/2021  
3

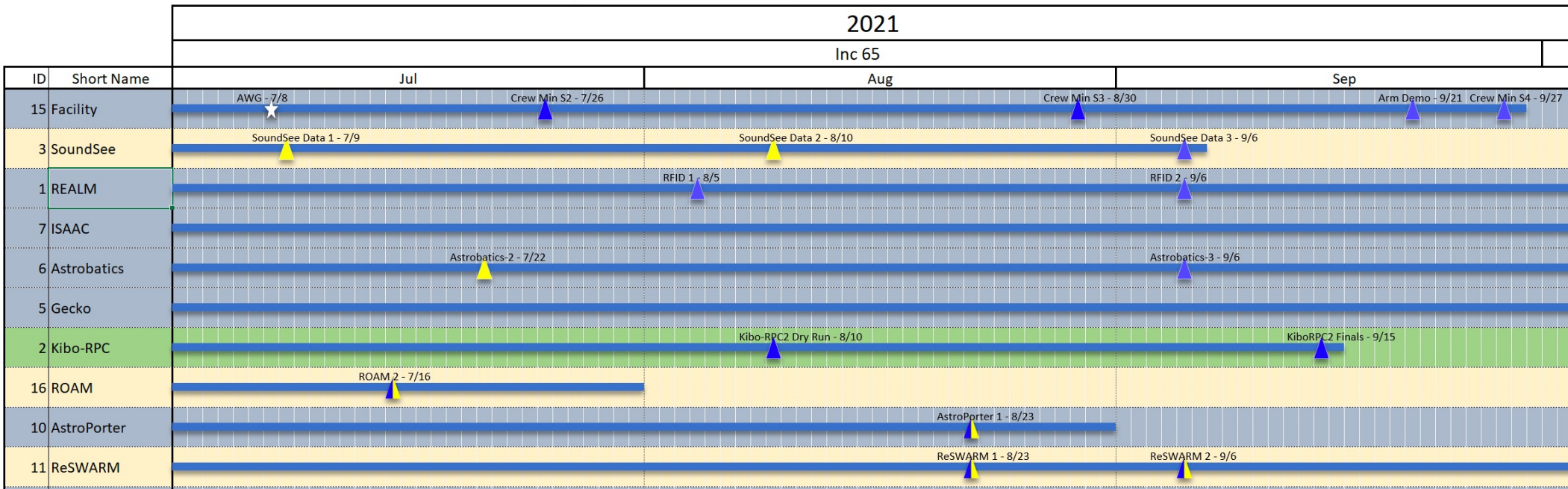
- Start Date  
- Number of Months

Legend

- Ops
- Lab Visit
- Launch
- Milestone
- EVA

Astrobee

- H
- B+H
- H+Q
- B
- Q
- B+Q





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# Engineering

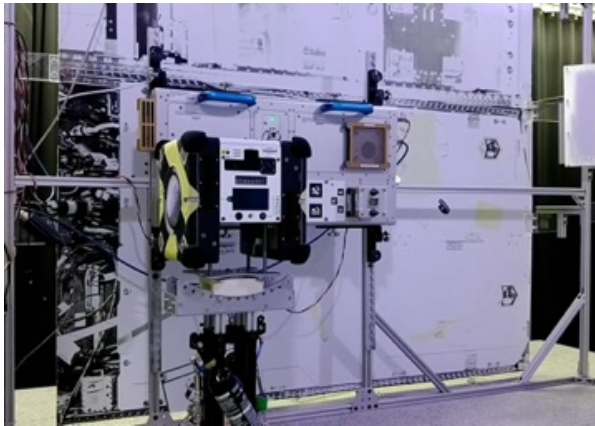




# Hardware and Lab Status



- Granite Lab: Online



- Flight Lab: Online



- Engineering Evaluation Lab (EEL): Available upon request

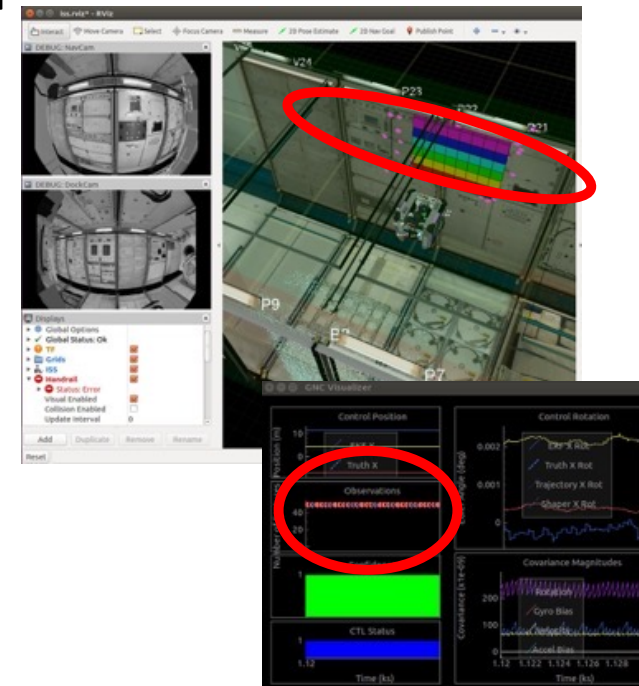
Name	Status
Flat Sat A	Operational
Flight 1,2	In Space, Operational
Flight 3	In Space, still in box
Flight Spare	Complete
Cert (B#)	Operational
Ground (Wannabee)	Operational



# Localization & Mapping Improvements



- A set of tools to speed up map creation and evaluation is under continuous improvement





# Localization & Mapping Improvements



- Major Astrobees Facility challenge: localization
  - Robot would get lost, could not turn quickly
  - (Gentle) collisions common
  - Crew intervention needed to recover
  - Frequent ISS data collection activities required to update prior map, map very sensitive to new objects and lighting changes
  - Especially concerning given ISAAC conops:
    - Multiple-hour ISAAC survey sorties demand reliability
    - ISAAC activities are designated “crew-minimal” – if crew rescue is needed, activity is likely to be aborted
- The baseline localization algorithm was based on an Extended Kalman Filter (EKF)
- A new Graph-based localizer algorithm was implemented
  - Reference “Astrobee Updated Localizer” talk at October 2020 Astrobee Working Group by Ryan Soussan



NASA astronaut Christina Koch supporting Astrobee commissioning



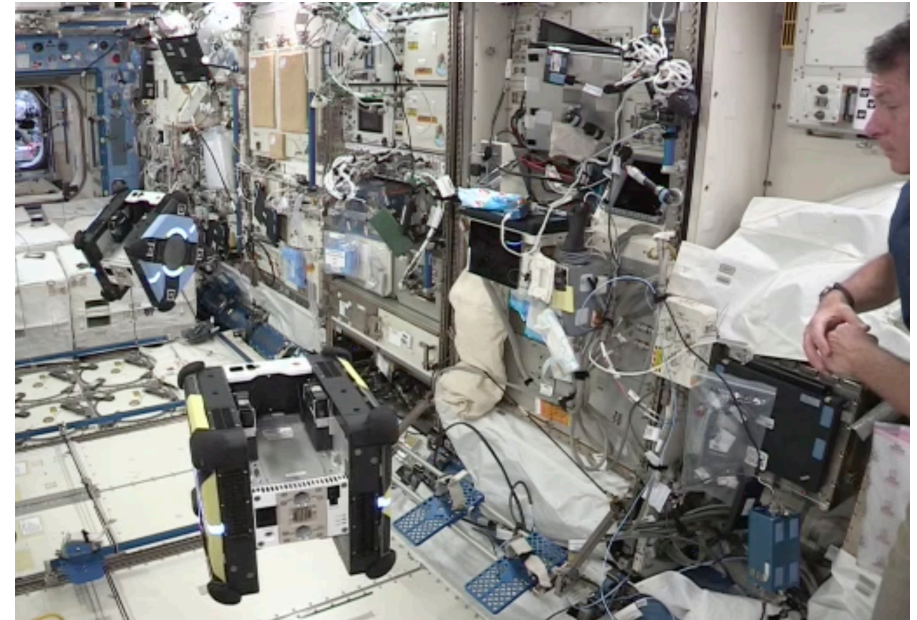


# Localization Results

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- Astrobee has completed multiple **2+ hour** sessions **without requiring astronaut intervention**
- Reduces need for frequent activities to collect updated imagery to rebuild prior map



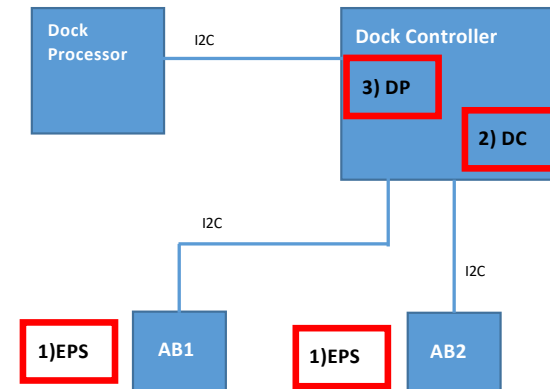
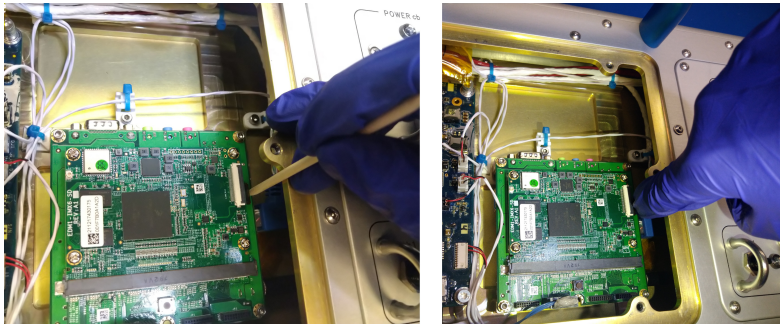
NASA astronaut Robert Kimbrough watches Honey approach Bumble for rendezvous during MIT ROAM activity



# Dock Repair



- Dock Repair Completed Successfully
- Dock in use, no issues so far
- Software update
  - Includes watchdog timers and recovery mode ssh
  - Pending verification completion





# Building-8 Imagery Integration

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- Milestone 1: Astrobeer Control Station running in Bldg8
  - Completed: August 2019
- Milestone 2: Astrobeer Sci-Camera streaming to Bldg8 decoder via G2G VPN
  - Completed: March 2020
- Milestone 3: JAXA distribution method tested and available
  - Completed: September 2020
- Milestone 4: General PD/PI distribution method tested and available
  - Target: as needed by users



# Completed Commissioning 2019



Crew Activity	Robot	Date
Checkout	Bumble	4/30/19
Calibration & Mapping	Bumble	5/13/19
Additional Mapping	Bumble	5/23/19
Localization & Mobility 1	Bumble	6/14/19
Localization & Mobility 2	Bumble	7/12/19
Localization & Mobility 3a	Bumble	7/24/19
Localization & Mobility 3b	Bumble	8/28/19
Checkout & Calibration	Honey	10/30/19
Localization & Mobility 4	Bumble	11/01/19



# Commissioning Status 2021



Crew Activity	Robot	Date
Localization & Mobility 5	Honey	4/30/20
Localization & Mobility 6	Bumble	5/13/20
Crew-Minimal 1-5	Bumble	7/2-8/19/20
Localization & Mobility 7	Bumble	9/4/20
Crew-Minimal 6-8	Bumble	9/10-10/01/20
Crew-Minimal 9-11	Bumble + Honey	12/07-3/10/21
Dock Repair	N/A	02/02/21
Arm Installation	Bumble + Honey	02/04/21
Arm Demo	TBD	Ready



# User Integration Status

overall assessment



## User Support: (by user, percent complete)

- User community support (Comm)
  - System documentation, working group meetings, conferences, public outreach
- Assessment and technology demonstration (Assess)
  - initial payload assessments,
  - ground-only/non-IPL technology demonstration support (e.g. NASA-STMD funded SBIR's and Grants)
- Integration, safety, and verification (Integration)
- Interface and user training (Interface)
- Lab testing (Lab)
  - Hardware/Software/Network interface testing
  - Operational Readiness Testing (ORT)
- Ops planning (Planning)
  - procedures, crew training, increment scheduling
- Ops activates (Ops)
- Data distribution

User	Percent Complete
Astrobatix (Naval Postgraduate School)	100
SoundSee (Astrobotic/Bosch)	100
Gecko (Stanford) – Phase 2	20
JAXA Kibo-RPC - Year 2	80
Astroporter (Tethers Unlimited)	50
RFID Recon (NASA AES/REALM-2)	100
ISAAC (NASA AES)	100
SVGS (FIT)	40
SOARS	10
ROAM (MIT)	100
ReSWARM (MIT)	70
<b>Finished Investigations</b>	
Gecko (Stanford) – Phase 1	
JAXA Kibo-RPC - Year 1	
REGGAE (NanoRacks/Braunschweig)	





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# Operations



# Operations: Functions

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- 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 needed
  - 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 SpOC (Specialist OC) any deltas to real-time ops and products
  - Support crew & POIC cadre real-time ops – conduct crew conferences as needed
  - Coordinate Commanding Window requirements and planning
  - 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
  - 2-pager development and submittal, updates as needed throughout increment
  - Regular timeline planning with Lead PPM (Payload Planning Manager) and PPM planning team.
- Safety and Verification Assessments
  - Integrated Safety & Verification Assessments as needed (Guest Science etc.)
  - Current 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.



# Astrobee Utilization Stats to date

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Utilization Stats to date	
Number of on orbit test sessions:	59 (27 science, 31 commanding, 1 other)
Number of crew hours:	48
Unique Crew Members trained:	6
Number of on-console hours:	316
Number of Astrobee Users:	12



## Increment 65-66 (2021) Forward Plan

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• Astrobatix 2	July
• ROAM 2	July
• Crew Minimal S2	July
• RFID 1	August
• Kibo-RPC Dry Run	August
• SoundSee Data 2	August
• Astroporter 1	August/September
• ReSwarm 1	August/September
• Crew Minimal S3	September
• SoundSee Data 3	September
• RFID 2	September
• Astrobatix 3	September
• Kibo-RPC Finals	September
• ReSwarm 2	September
• Arm Demo	October
• Crew Minimal S4	October



# Software Integrated Safety

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- IHS Records:
  - Astrobee
    - ROAM – Under Review
    - SVGS – Under Review
    - ReSWARM – Approved: 2021/04/22
    - Astrobotics – Approved: 2021/03/04
    - Astroporter – Approved: TBD
    - JAXA Kibo-RPC (April 2020) – TBD
  - SPHERES
    - SPHERES Hardware Return on SpX-22 – Approved: 2021/05/12



# Crew Procedures (1 of 2)

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- Baselined
  - Astrobee Perching Arm Demo
  - ReSWARM Science 1
  - Astrobatix Science 2
  - RFID Recon Science 1
  - SoundSee Data Collection 1
  - ROAM Setup and Checkout
  - ISAAC Follow-Up Survey and Fault Management (ISAAC 2)
  - Astrobatix Science 1
  - SciCam Calibration and Mapping Checkout (ISAAC 1)
  - REGGAE Installation and Checkout
  - REGGAE Assemblies Inspection
  - Astrobee Dock Repair





# Crew Procedures (2 of 2)

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- Upcoming
  - Astrobeer Perching Arm Demo
  - RFID Recon Science 2
  - Astrobaties Science 3
  - SVGS
  - Astroporter
- Updated (Baselined)
  - Astrobeer PREP
  - RFID Recon Installation
  - RFID Recon Removal
- JAXA
  - Kibo RPC-2 Rehearsal



## Astrobee Outreach



**What is Astrobee?**

*NASA has developed three new robotic teammates to work alongside astronauts on the International Space Station as they help to advance research.*

It turns out that astronauts could use some help with their chores, just like many of us on Earth. Juggling priorities and schedules plays a big part in an astronaut's life aboard the International Space Station, and teams of flight controllers on the ground are constantly working to optimize the precious human work hours in space. Getting some assistance from robots that can take on some tasks will make work on the station more efficient.

Astrobee, NASA's new free-flying robotic system, will help astronauts reduce time they spend on routine duties, leaving them to focus more on the things that only humans can do. Working autonomously or via remote control by astronauts, flight controllers or researchers on the ground, the robots are designed to complete tasks such as taking inventory, documenting experiments conducted by astronauts with their built-in cameras or working together to move cargo throughout the station. In addition, the system serves as a research platform that can be outfitted and programmed to carry out experiments in microgravity - helping us to learn more about how robotics can benefit astronauts in space.

The Astrobee system consists of three cubed-shaped robots, software and a docking station used for recharging. The robots use electric fans as a propulsion system that allows them to fly freely through the microgravity environment of the station. Cameras and sensors help them to "see" and navigate their surroundings. The robots also carry a perching arm that allows them to grasp station handrails in order to conserve energy or to grab and hold items.

Website

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

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





**QUESTIONS?**



# Back-up Slides

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Topic	Slide







**Astrobee ISS SoundSee-Data-1**  
**Astronaut Megan McArthur, 32x speed**



# ISAAC Survey Demo Video







# ISAAC Phase 1 ISS Activities

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## ISAAC-1

2021/02/23



NASA astronaut Shannon Walker manually moving Honey near target to collect calibration imagery

## ISAAC-2

2021/03/26



JAXA astronaut Soichi Noguchi pauses to watch Bumble conducting a multi-sensor map survey

## ISAAC-3

2021/04/19



NASA astronaut Victor J. Glover configuring the JEM module for Astrobee ops



# EPO Activities

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- Summary of Education and Public Outreach
- Significant Media Coverage



# Software of the year Award, Runner up



The screenshot shows the 'InsideAmes' website interface. On the left is a dark sidebar with the NASA logo and the text 'InsideAmes'. Below this are three menu items: 'Directories', 'Web Tools', and 'Safety & Reporting', each with a downward arrow. On the right is the main content area with a dark header containing 'InsideAmes Search'. The main headline reads 'Ames' Astrobeerobot & Ground Software Selected as a Runner-up for the NASA SoY Award'. Below the headline is a sub-header that says 'MESSAGE FROM THE CENTER DIRECTOR'.

[insideames.arc.nasa.gov/tag\\_posts/ames-astrobeerobot-ground-software-selected-as-a-runner-up-for-the-nasa-soy-award](https://insideames.arc.nasa.gov/tag_posts/ames-astrobeerobot-ground-software-selected-as-a-runner-up-for-the-nasa-soy-award)





# NASA Group Achievement Award

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Dear Ms. Bualat:

I am extremely pleased to tell you that the Astrobe Development And Facility Team has been selected to receive the NASA Group Achievement Award. This is one of the most prestigious awards a group can receive, and is presented to selected groups who have distinguished themselves by making outstanding contributions to the NASA mission.

The award will be presented to you, on behalf of the team, at Ames' annual NASA Honor Awards Ceremony to be held virtually this year recognizing the group and the other NASA Honor Award recipients. Ceremony details will be provided as soon as they are finalized. If you have any questions, you may contact Ms. Lynette Forsman at [Lynette.I.Forsman@nasa.gov](mailto:Lynette.I.Forsman@nasa.gov).

Please accept my personal congratulations on your selection.

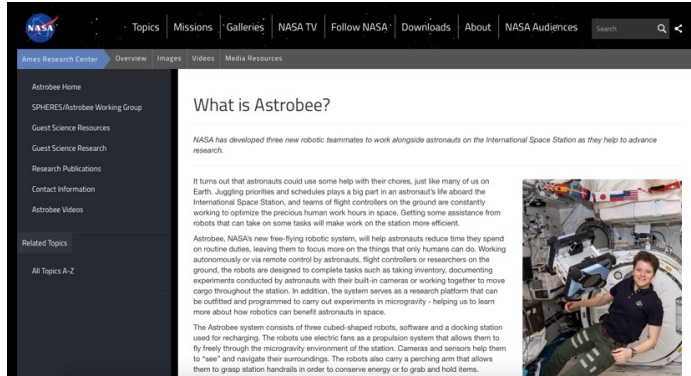
Sincerely,

*Eugene L. Tu*

Eugene L. Tu  
Center Director

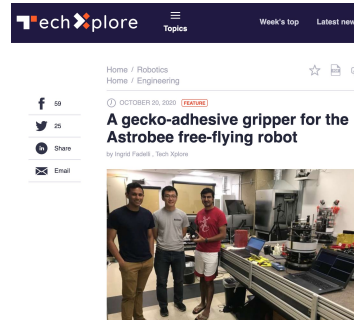


# Web Features



[www.nasa.gov/Astrobee](http://www.nasa.gov/Astrobee)

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



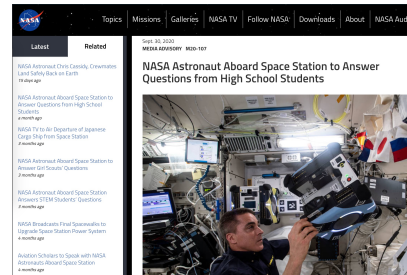
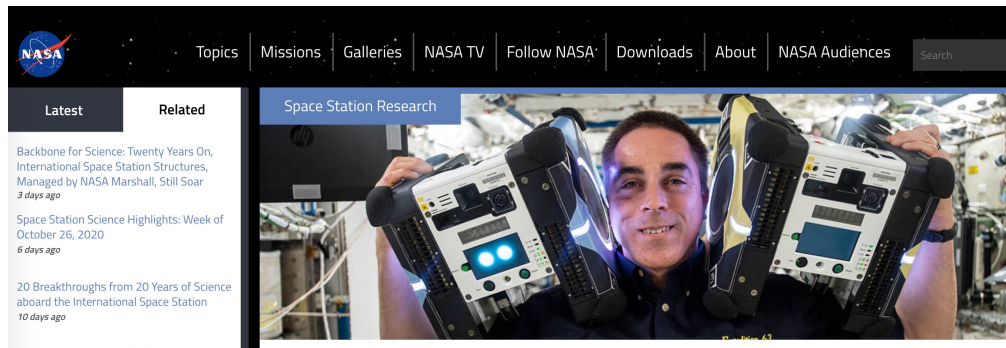
[A gecko-adhesive gripper for the Astrobee free-flying robot](#)



# Web Features Cont.



## NASA Astronaut Aboard Space Station to Answer Questions from High School Students



## NASA Astronaut Chris Cassidy's Scientific Journey aboard the Space Station

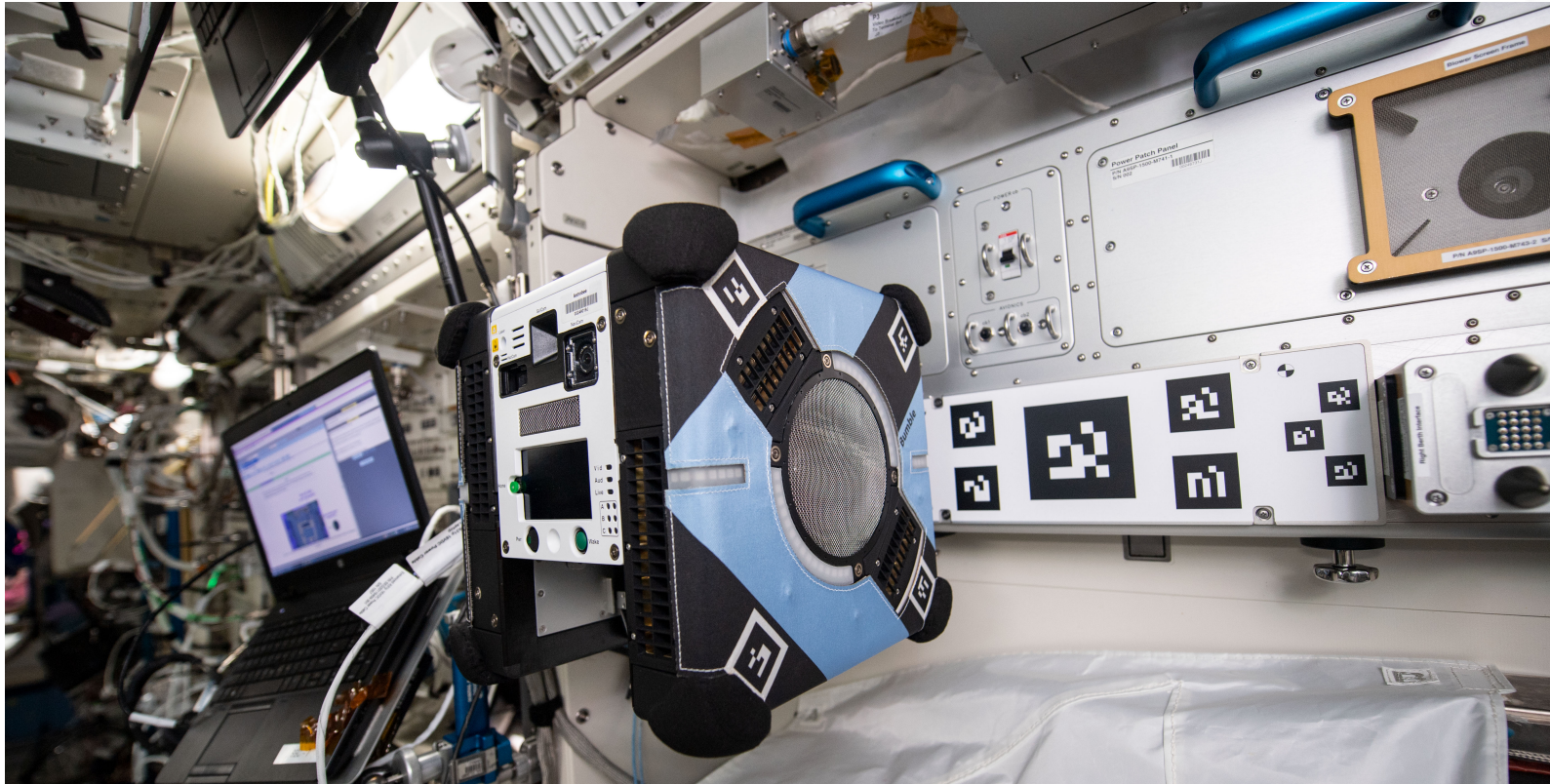
## Kibo-RPC News: Announce the results of the 1<sup>st</sup> Kibo Robot Programming Challenge!







# Bumble



A view of the free-flying Astrobees robot named Bumble and the docking station onboard the International Space Station (ISS).



[www.nasa.gov/astrobee](http://www.nasa.gov/astrobee)

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# Flight Software

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- Astrobbee Robot Software release 0.14.3 is out on Github, it is being used on-orbit





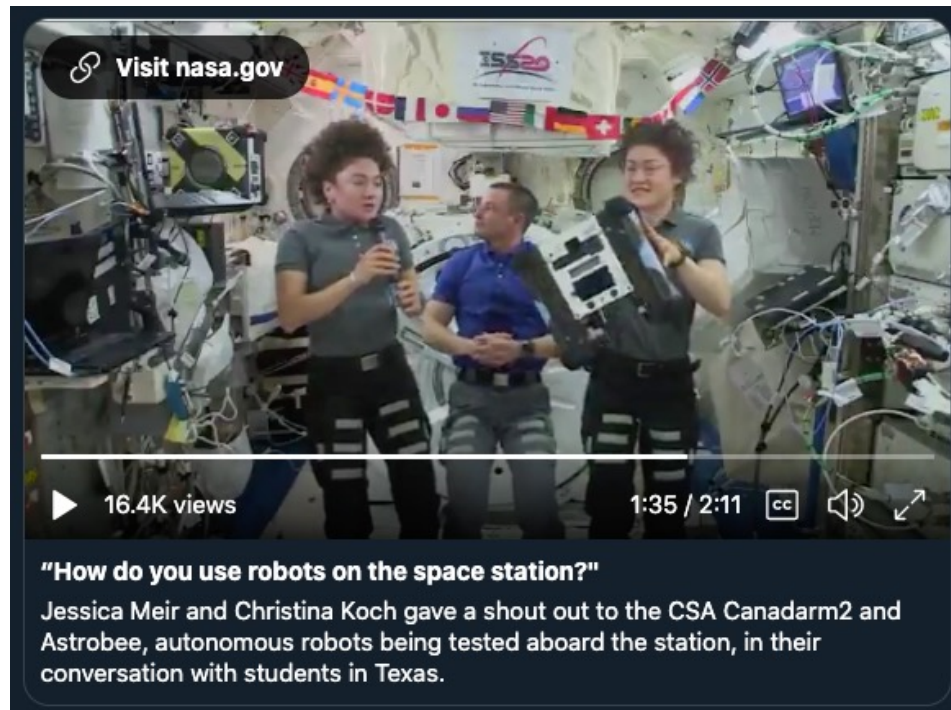
# Astrobee Backdrop



- <https://youtu.be/-UZB0RcNbG4>
- April 16<sup>th</sup> 2020



# How do you use robots on ISS?



- [https://twitter.com/ISS\\_Research/status/1218567473605169152](https://twitter.com/ISS_Research/status/1218567473605169152)
- January 18<sup>th</sup> 2019