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Astrobee: An International Research Platform On-board the ISS

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IISF, Science Beyond Borders
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Outline

- Background
- Astrobbee Platform
- Other Free-flying robots
- Astrobbee Guest Scientists
- Astrobbee's Impact
- Astrobbee's Future



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Background

- AERCamMini: Autonomous Extravehicular Robotic Camera
- PSA: Personal Satellite Assistant
- SPHERES: Synchronized Position Hold, Engage, Reorient, Experimental Satellites
- Astrobees



Background

Fundamental Research

- Free Flyers in the very unique microgravity environment enable a varied portfolio of basic research: Slosh, Formation flight, Docking, Close proximity operations
- Data has been shared and is being used by these companies internally: Orbital ATK, ULA, SpaceX NASA Glenn, NASA Goddard, Aerospace Corp
- History has shown that uncontrolled propellant slosh can lead to catastrophic failures
- Reference: "[The Value of Basic Research](#)" Jo Handelsman, Associate Director for Science at the White House Office of Science and Technology Policy

IVA

- **Crew spends a lot of IVA time on maintenance**
 - Increment 35/36 = 260 hr of maintenance work (44 hr/month average)
- **IVA Free-Flyer can off-load numerous tasks from crew**
 - Air sampling (5 hr/month), sound survey (3 hr/month), camera positioning (3 hr/month), video safety survey (1 hr/month)
 - **Crew time savings: 12+ hr/month (25%)**
- **Crew spends up to 1 hr/day looking for equipment, materials, etc..**
 - **Automated logistics can save > \$3M in lost crew-time per year**



Free Flyers on Docking Station, JEM 2024



SPHERES

- SPHERES: Synchronized Position Hold, Engage, Reorient, Experimental Satellites
- Installed on ISS in 2006, managed by ARC since Fall 2010
- Formation flight, Docking, Proximity Operations
- Required supervision, CO2 tanks



Scott Kelly working with SPHERES at the ISS' JEM.

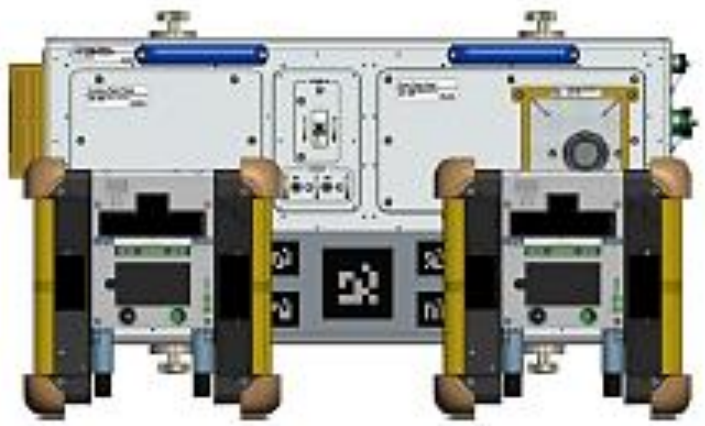


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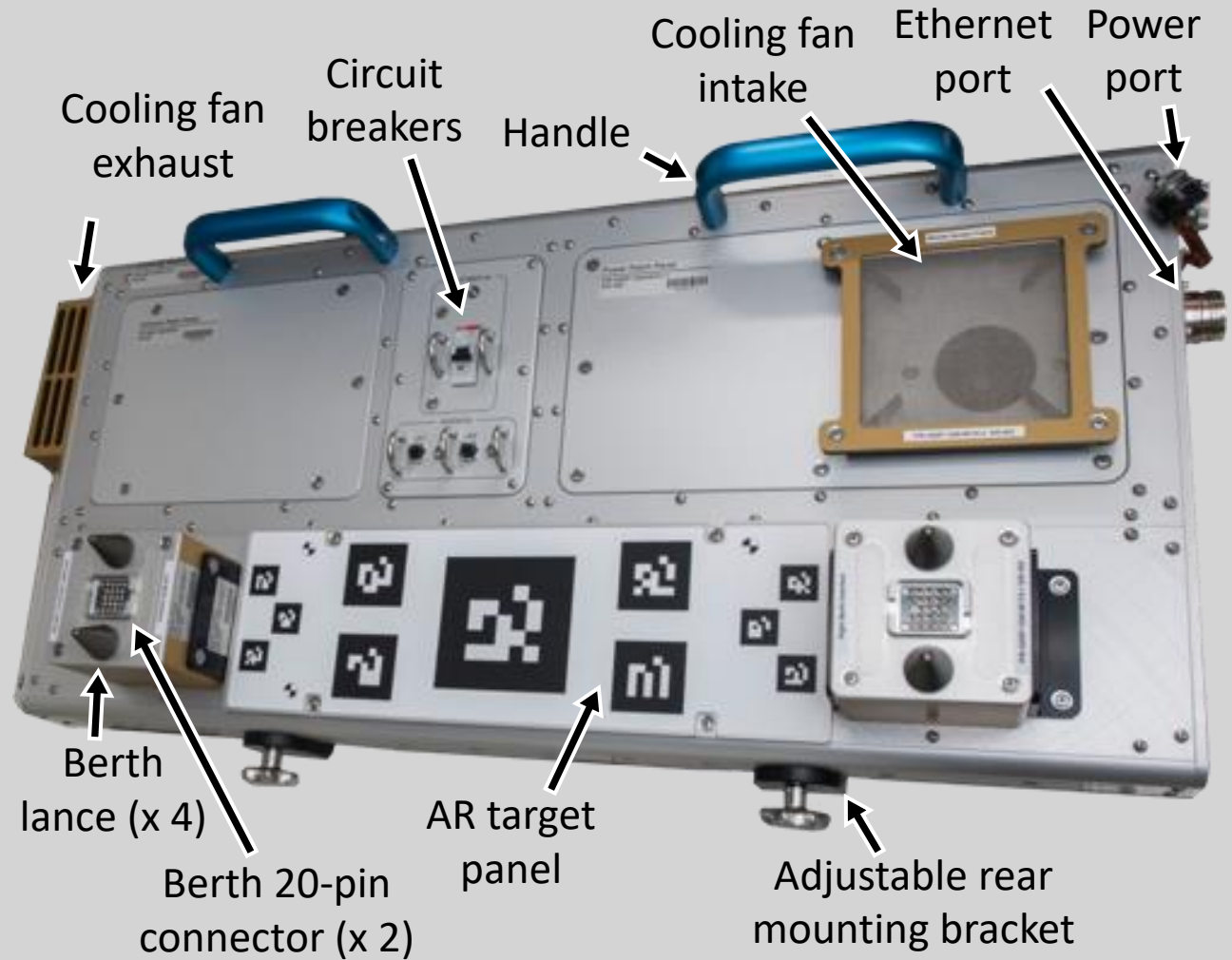


Astrobee Platform



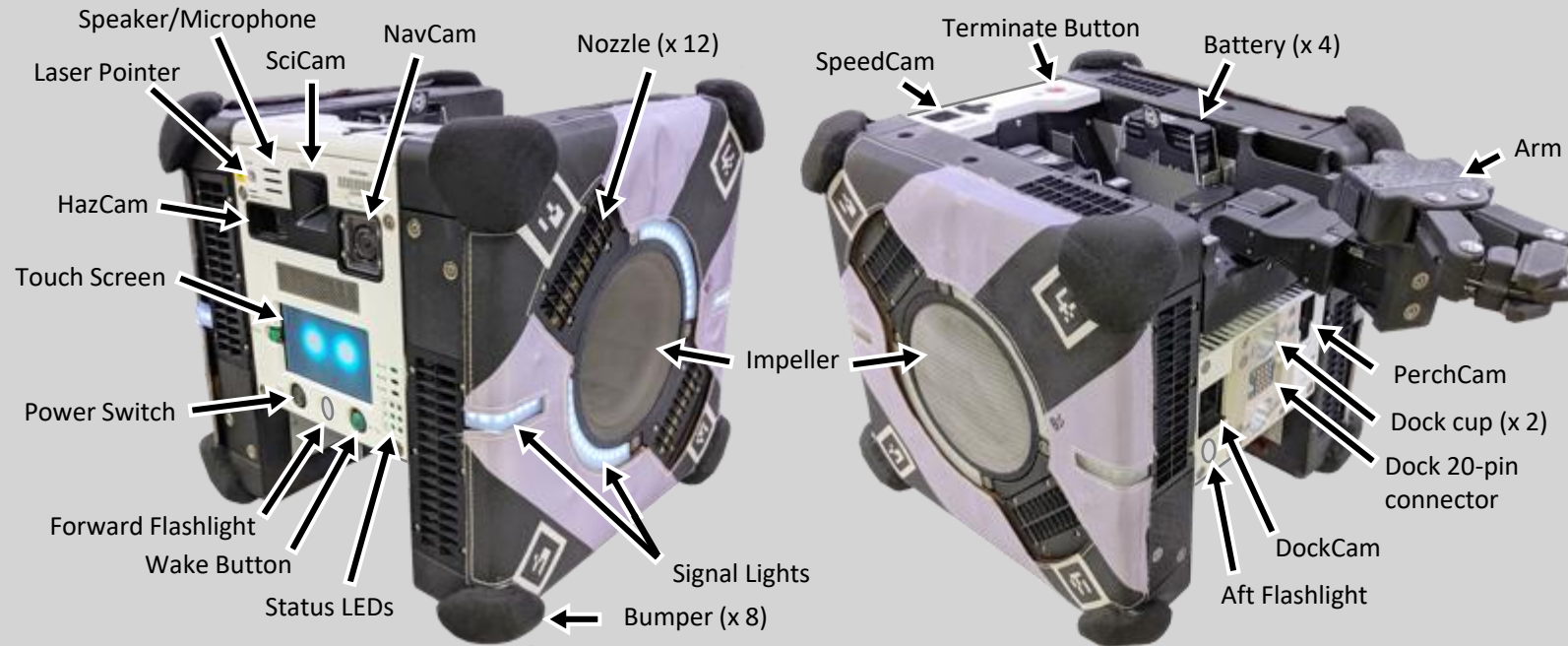
Docking Station

- 85 cm x 38 cm x 28 cm
- Berths for 2 free flyers
- Provides power and Ethernet
- Fiducials used for visual servoing to autonomously dock
- Magnets provide retention force



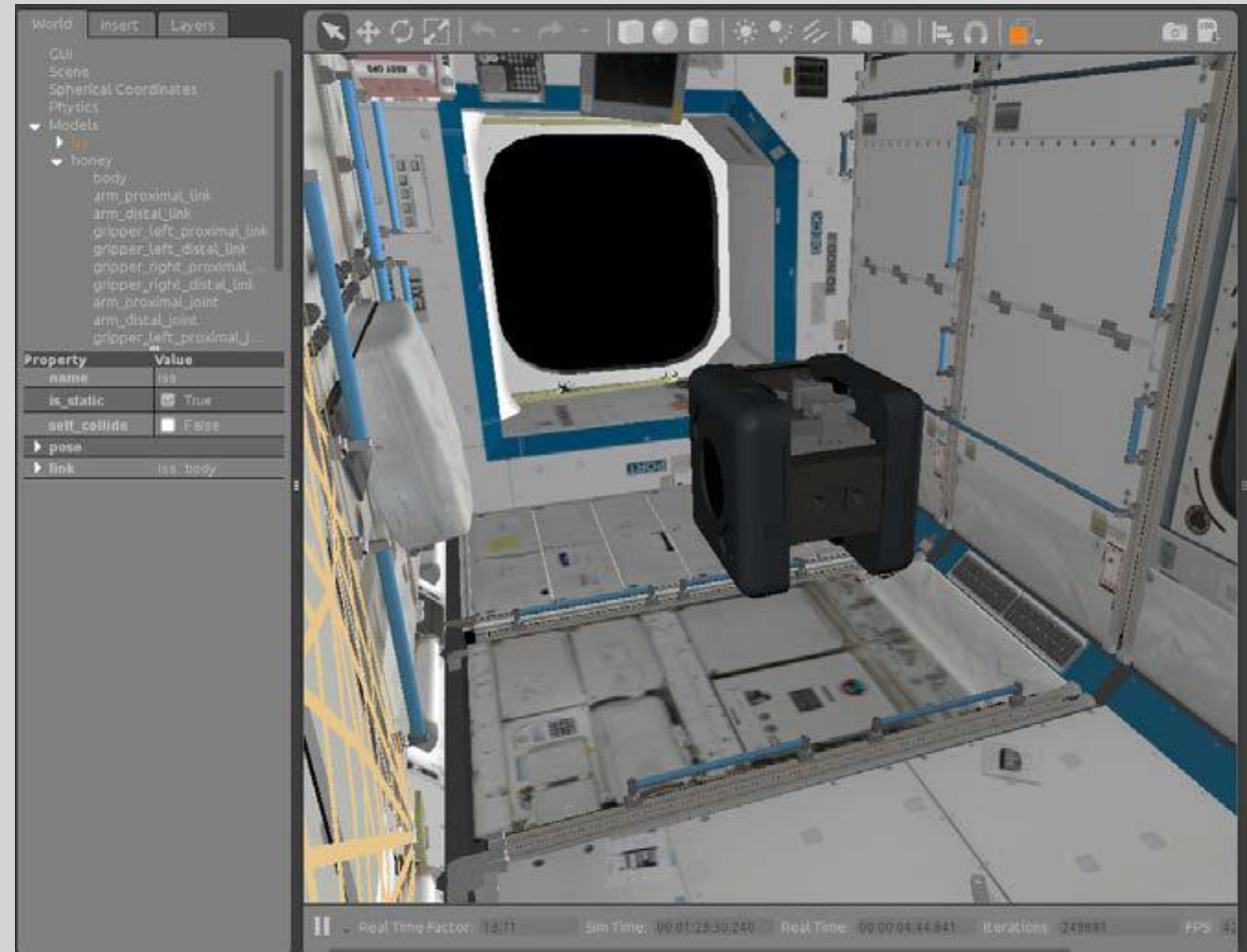
Hardware

- 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



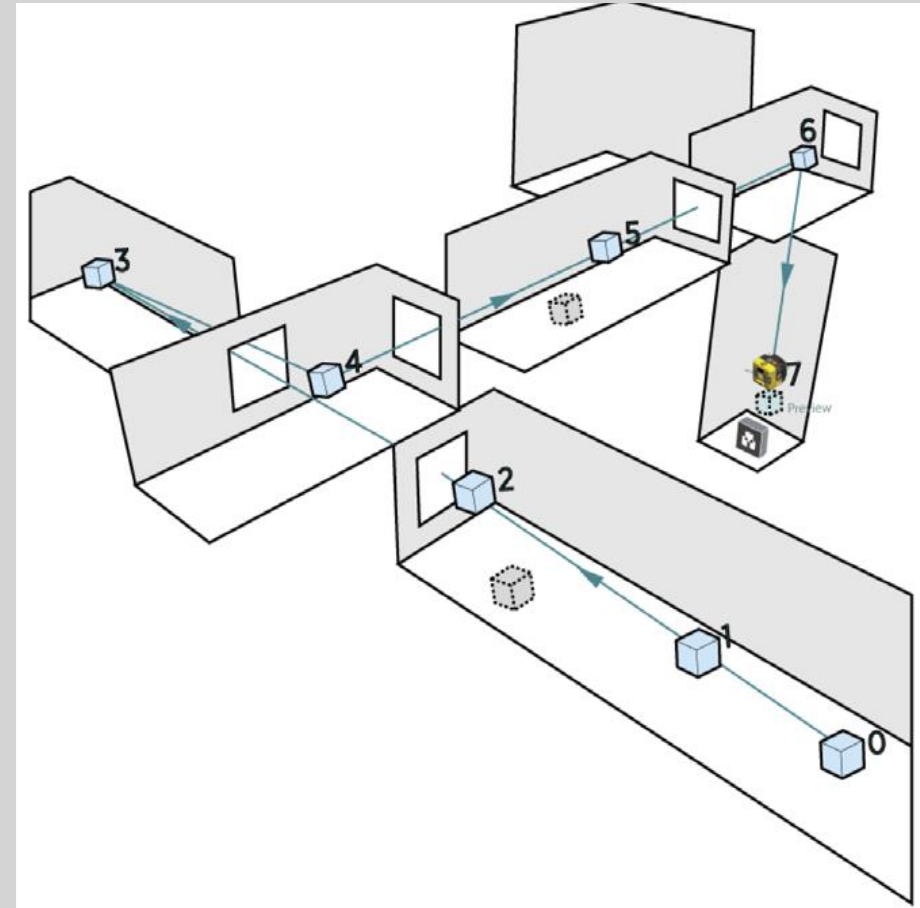
Astrobee Platform & Simulator

- Astrobee Robot Software (A.R.S.) 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



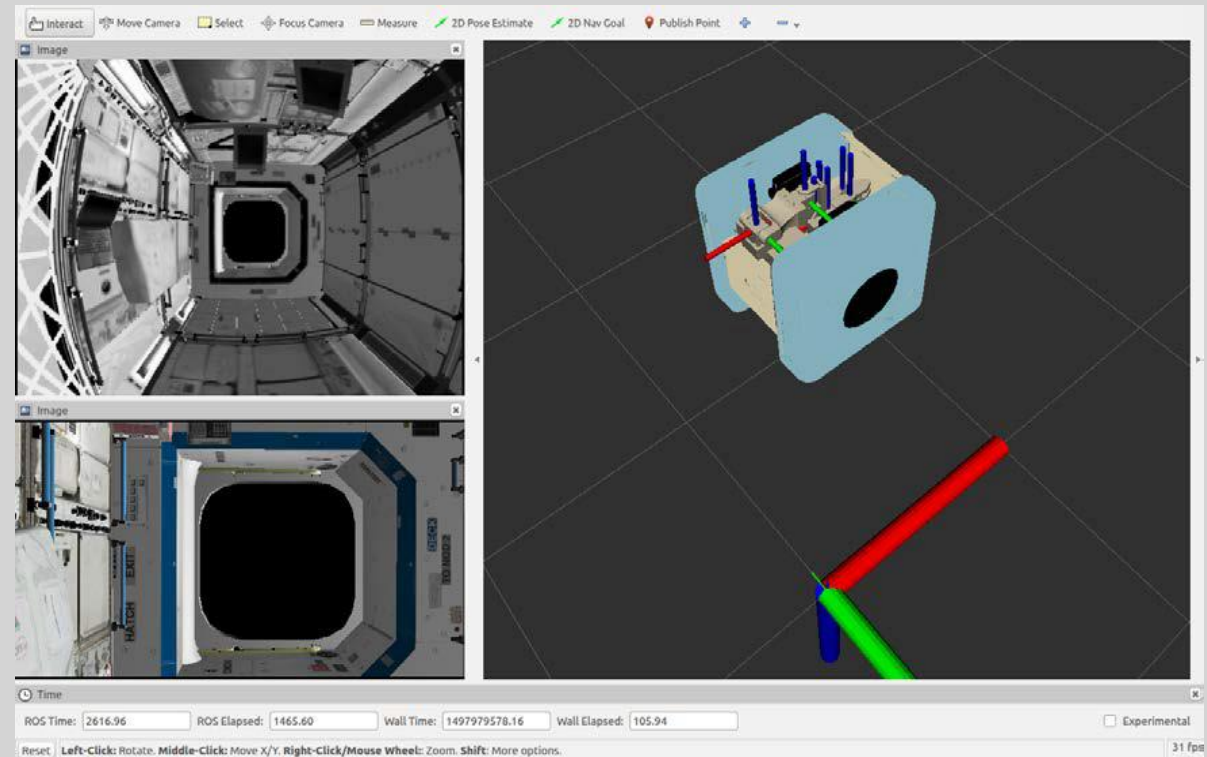
Astrobee Platform & Simulator

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



Astrobee Platform & Simulator

- Astrobee 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





ISS Crew helpers



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Other Free-flyers

JAXA's JEM Internal Ball Camera (Int-Ball) I & II

- Int-Ball I developed during 2016 and launched in 2017
- Autonomous, fan-propelled
- 1kg, 15 cm in diameter



JAXA's INT-BALL I



Other Free-flyers

DLR, Airbus, IBM's
Crew Interactive
Mobile Companion
(CIMON)

- AI-based assistant,
fan-propelled
- 5kg, 32 cm diameter



DLR, Airbus, IBM's CIMON



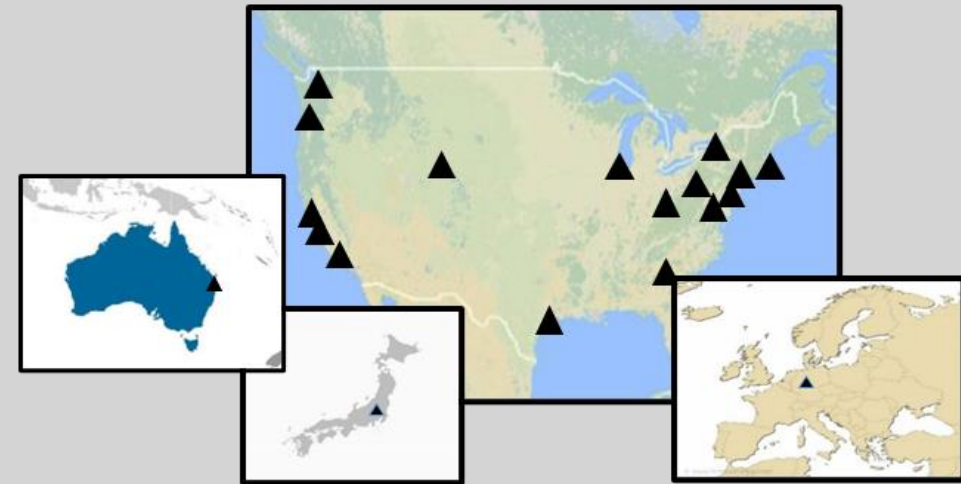
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Astrobee Guest Scientists

- Astrobotics (NASA-DoD/Naval Postgraduate School) TX04.2
 - Advanced Free-Flyer maneuvers for self-toss and cargo retrieval
- RFID Recon (NASA AES/REALM-2) TX07.2
 - Autonomous Logistics Management with Radio Frequency Identification (RFID) Reconnaissance (Recon)
- ISAAC (NASA STMD-GCD/ARC) TX04.6
 - Technology for autonomous caretaking of spacecraft
- Gecko (NASA STMD-STRG/Stanford) TX04.5
 - Gecko material grasping and safe trajectory optimization
- JAXA Kibo-RPC (JAXA) N/A
 - Kibo Robot Programming Challenge for STEM Education
- SOARS (ISS NL/Zero-g Horizons) TX03.2
 - Spacecraft On-Orbit Refueling and Storage
- CLINGERS (ISS NL/JPL-USC) TX04.5
 - Docking for Rendezvous Proximity Operations
- Zero Robotics (ISS NL/MIT) N/A
 - ISS Programming Challenge for students using Astrobee
- Multi-Resolution Scanner (MRS) (ISS NL/CSIRO) TX04.1
 - Sensor payload to support multi-resolution 3D scanning and mapping
- AstroSee (ISS NL/TBD) TX04
 - Rendezvous Proximity Operations (RPO)
- REACCH (ISS NL/TBD) TX04
 - Gecko adhesion for orbital debris removal



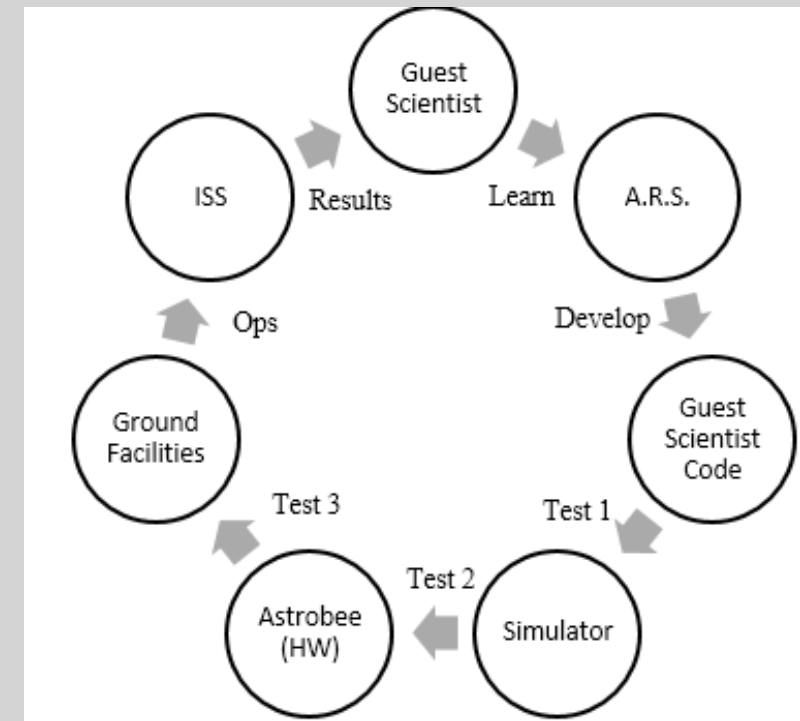
- Astroporter (NASA-STMD/Tethers Unlimited) TX04
 - Algorithms for collaborative behavior between multiple robots in space including cargo transfer
- SVGS (NASA STMD/FIT) TX04
 - Beacon-assisted vision-based navigation for formation flight
- REGGAE (ISS NL/NanoRacks-Braunschweig) TX04
 - Gecko material grasping
- ROAM (ISS NL/MIT-DLR) TX04
 - Autonomous rendezvous with non-cooperative tumbling targets
- ReSWARM (ISS NL/MIT) TX04
 - Algorithms for safe on-orbit assembly, logistics, and cooperative control
- SoundSee (ISS NL/Astrobotics-Bosch) TX04
 - 3D Acoustic Monitoring



Astrobee Guest Scientists

Guest Science Program

- Guest scientists (GS) can become part of this program following the Guest Science Lifecycle (GSL).
- Steps:
 1. GS contacts the Astrobee Facility
 2. Strategic phase: defines high-level who, what, where, and how the GS research will be done
 3. Tactical phase: technical planning, development, and evaluations.
 4. Operations phase: GS science using the HW/SW developed during Tactical phase is run on the ground (at the MGTf or at the Granite laboratory) or on the ISS.
 5. Post-Operations phase: GS receives experimental data and reports from Operations phase

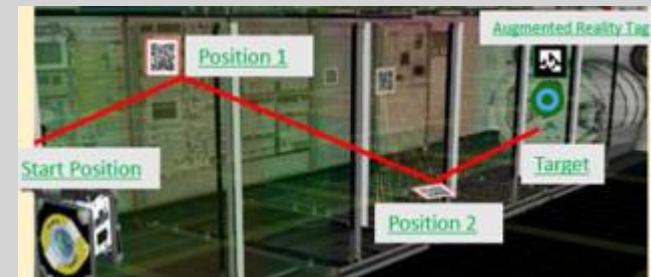


JAXA's KIBO-Robotic Programming Challenge

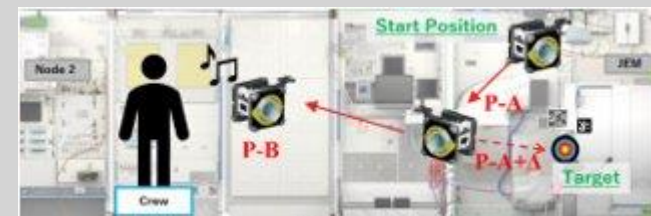
- NASA/JAXA collaboration 2018
- Educational outreach using NASA' Astrobbee & JAXA's Int-Ball
- Kibo Robot Programming Challenge (Kibo-RPC): students solve various problems by programming Astrobbee.
- For 1st Kibo-RPC (2020):
 - 1,168 students participated
 - 313 teams
 - 7 countries
- For 2nd Kibo-RPC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



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



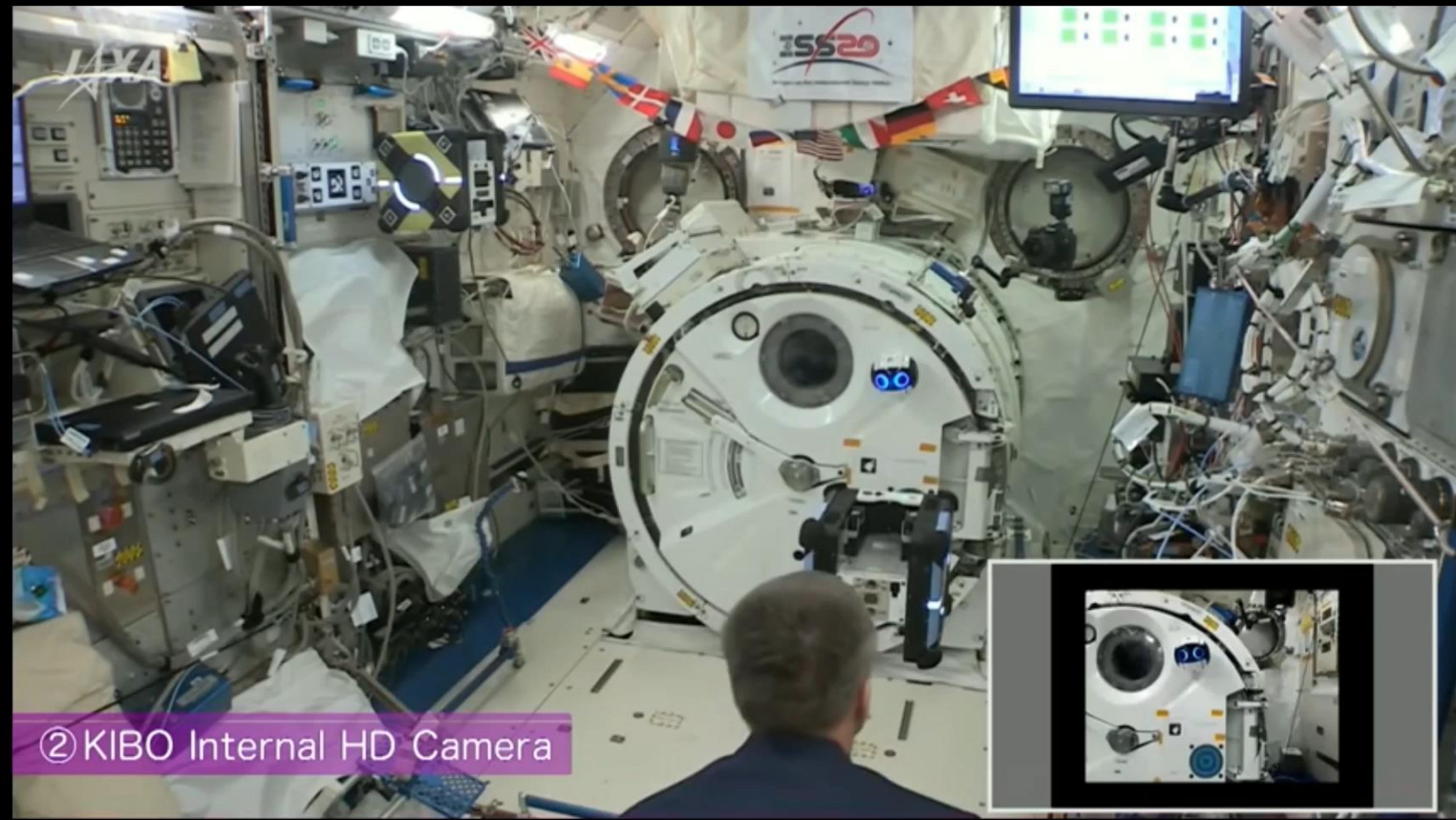
1st Kibo-RPC (JAXA)



2nd Kibo-RPC (JAXA)

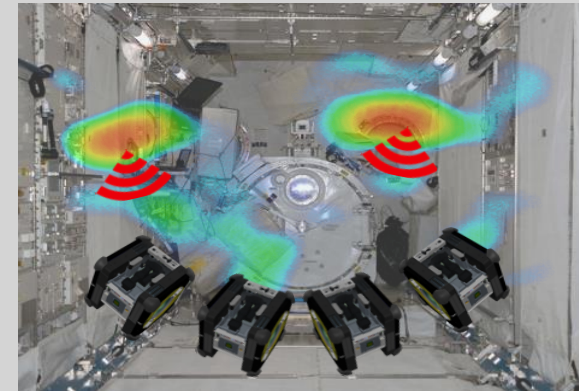


JAXA's KIBO-Robotic Programming Challenge

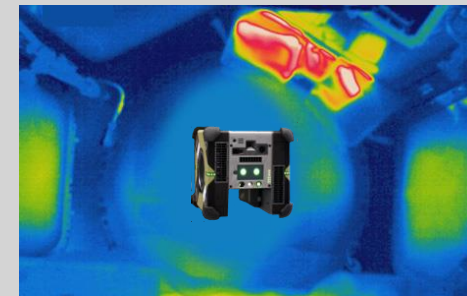


ISAAC Overview

- **Gateway will be uncrewed for extended periods. During these periods NASA needs autonomous systems that can perform:**
 - Fault Detection, Isolation, and Recovery (FDIR)
 - Routine maintenance
 - Logistics operations
 - All through high latency communication to ground controllers
- **Autonomous systems can free crew from routine maintenance and logistics tasks**
 - Gateway Ground Rules & Assumptions has crew spending 3.5 hours/day working non-utilization/non-exercise tasks
- **ISAAC provides the glue between Intra-Vehicular Robotics (IVR) and vehicle systems (power, life support, etc.) through**
 - Integrated data
 - Coordinated execution
 - Integrated control interface
- **Infusion into Gateway:**
 - Interaction with IVR Working Group
 - ISAAC MOU with Gateway



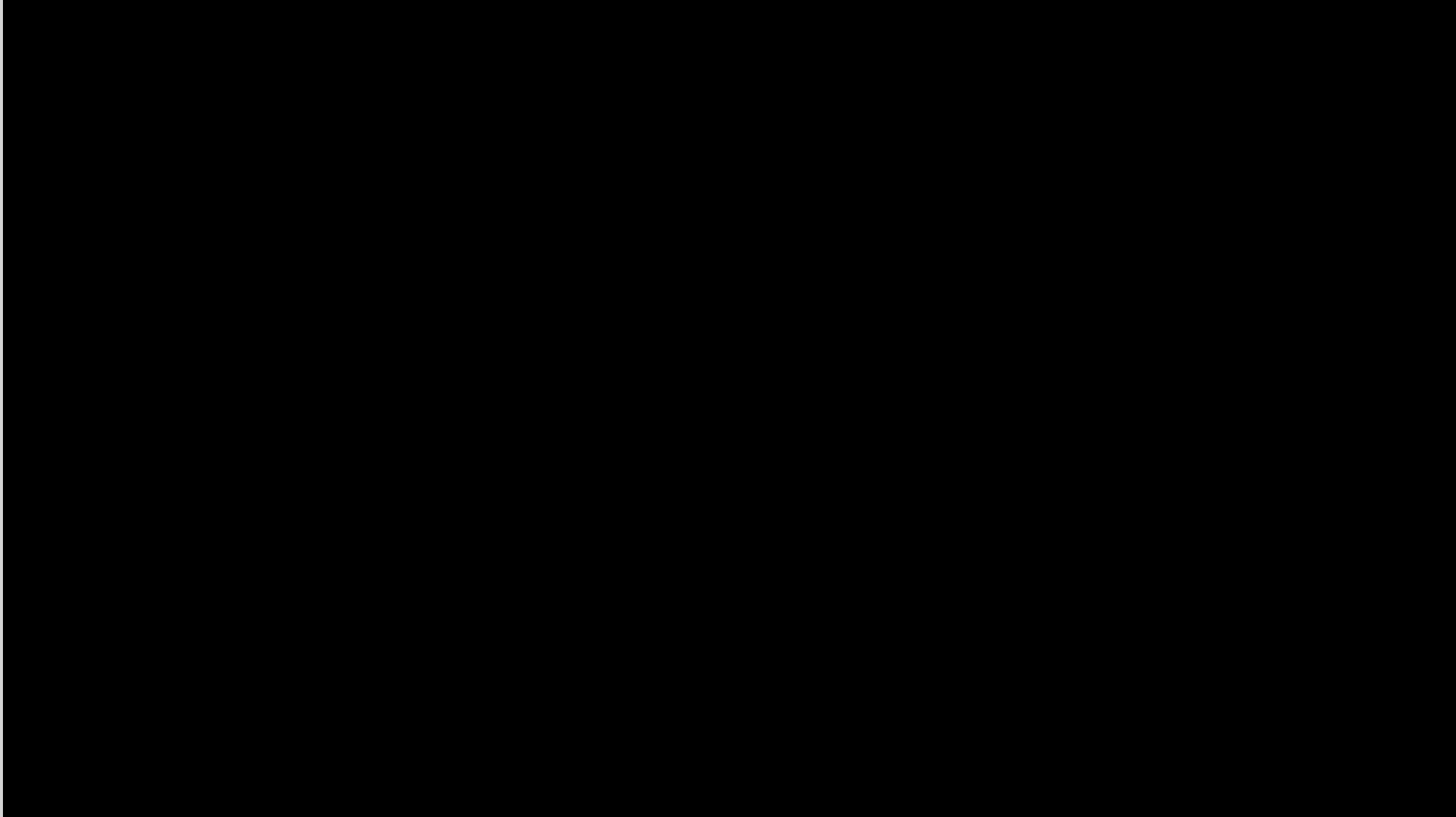
Localizing signal sources by analyzing signal strength variation



Habitat thermal mapping



ISAAC9-11: Multi-Sensor Mapping of Three Modules



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Astrobee's Impact

- The bi-annual Astrobee Technical Interchange meeting has shown over the last four years, a proven capacity for enabling key research, science, and technology for dozens of ISS payloads spanning NASA-Exploration, NASA-STMD, ISS International Partners (JAXA), and the National Lab in commercial utilization.
- The Astrobee Facility continues to provide a key ISS science utilization capability with minimal additional costs to launch mass, stowage, and crew time.
- The JAXA sponsored Kibo-RPC payload has successfully completed its fourth annual Kibo-RPC Finals STEM activity in support of thousands of students. Further, the JAXA Kibo-RPC team has already begun utilizing Astrobee for a fifth annual STEM competition spanning into early FY25.
- The NASA STMD SBIR/STTR program regularly references the Astrobee Facility capability in it's SBIR/STTR solicitations that focus on key NASA technology needs in the future such as Gateway, Lunar, and other deep space capabilities.

NASA's TechPort show's the total downstream NASA funding impact is on the order of over \$40M.



Chris Cassidy, GMT 248 2020



Astrobee's Impact

Utilization Stats to date (9/3/2024)	
Number of on orbit operations:	180
Number of on orbit remote Test Sessions	137
Unique Crew Members trained and who have operated Astrobee on the ISS:	36
Number of on-console hours:	1350
Crew hours	340
Number of past/present users	15



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Astrobee's Future

- ISS funding for the Astrobee Facility was cut beginning in October 2025
- Astrobee was classified as a candidate to be converted to a commercial provider
- RFI Web Feature:
 - <https://www.nasa.gov/technology/robotics/nasa-seeks-input-for-astrobee-free-flying-space-robots/>



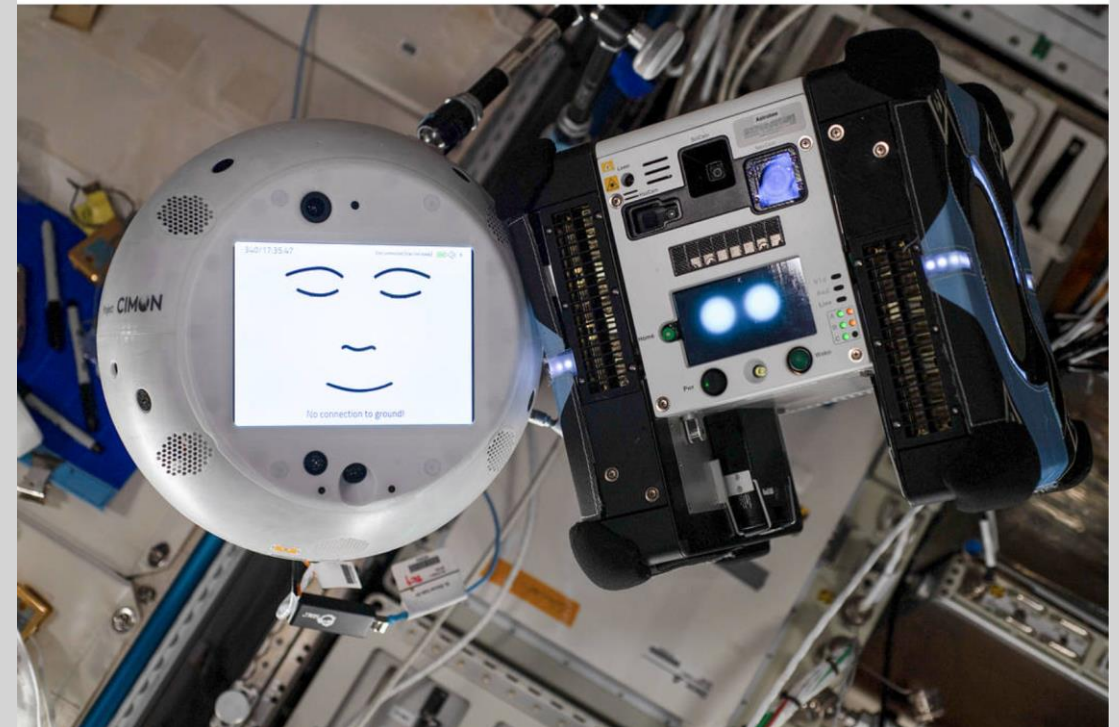
Robot Colleagues

JAXA's Int-Ball, DLR/Airbus/IBM CIMON, NASA's Astrobees at IAC2019



Mar 22, 2022

Robot Colleagues Meet Aboard the International Space Station





QUESTIONS?