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NASA Ames capabilities in IVA Robotics

Jose V. Benavides, Tech Area Lead, Autonomous Systems and Robotics

CLDP Utilization Forum

Outline

- History of Intra-Vehicular Activity Robotics (IVR) at Ames
  - PSA, SPHERES, Astrobee, ISAAC
- Astrobee's future (RFI)
- NASA's future in IVR, A vision for IVR on a CLD
  - NASA STMD Shortfalls ranking
  - NASA's Low Earth Orbit Microgravity Strategy [Aug 2024]
  - CLD IVR leading to Moon/Mars

Microgravity Free-Flyer Technologies
past, present, & future

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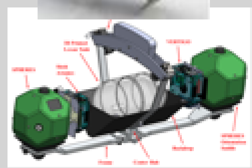
- RINGS
- SLOSH
- Tether
- Vertigo



- UDP/HALO
- SmartSPHERES
- Interact
- Zero Robotics

PSA — 2000 - 2008

SPHERES — 2006 - 2019

Astrobee — 2019 - Now

- TA02 In-Space Propulsion
- TA05 Communication & Navigation
- STEM Education
- TA04 Robotics, Tele-Robotics & Autonomous
- Avionics & Software Risk mitigation

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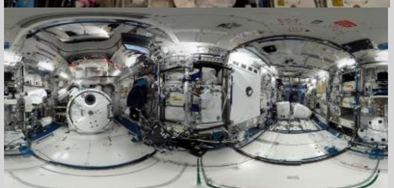
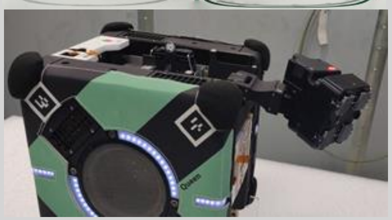

SoundSee
Astrobatics
RFID Recon
ISAAC
Gecko
SVGS



ROAM/ReSWARM
Clingers
MRS
REACCH
AstroSee
Zero Robotics Kibo-RPC



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TA02 In-Space Propulsion
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Why Free Flyers in LEO?

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

Astrobee Overview

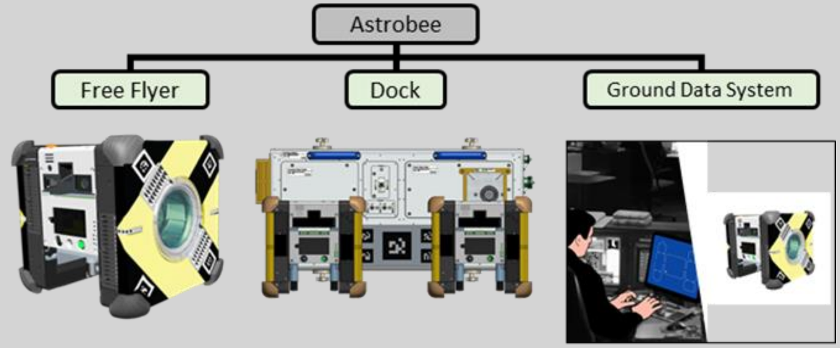
- An ISS Astrobee Facility provides a free-flying robotic system for ISS research and ISS STEM outreach. The Astrobee free-flying robotic system consists of three cubed-shaped robots, software, and a docking station used for recharging.

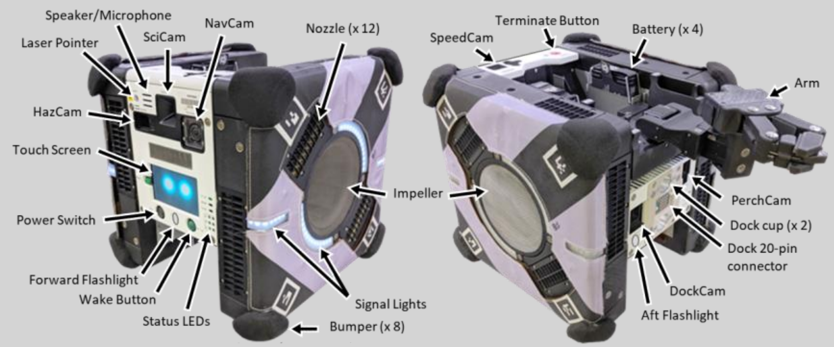
Chris Cassidy, GMT 248 2020

Free Flyers on Docking Station, JEM 2024

ISS 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!
- Concept of ops summary
  - Dock battery recharging when idle
  - Autonomously undock, survey multiple modules, return to dock, and no crew supervision
- Overview Video: https://youtu.be/IEuAVK1nNp0
- Project Website: www.nasa.gov/astrobee

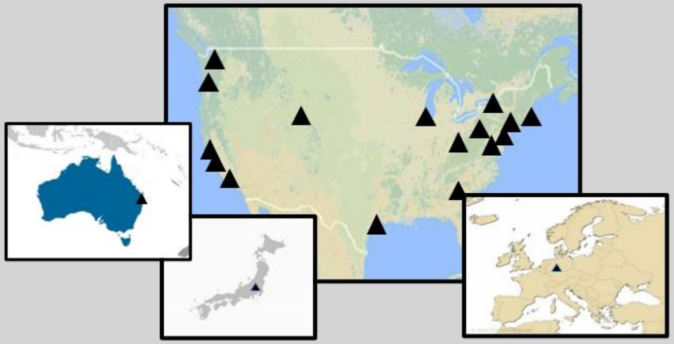




- Free flying robot inside the ISS
- 32 cm wide, ~9.1kg
- All electric + fan-based propulsion
- Robot arm for “perching”, ~1kg
- Three smartphone computers
- Three payload bays for expansion
- Microphone not currently enabled

Astrobee Guest Scientists

- Astrobatics (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 Programing 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/Astrobotic-Bosch) TX04
  - 3D Acoustic Monitoring

Astrobee Utilization

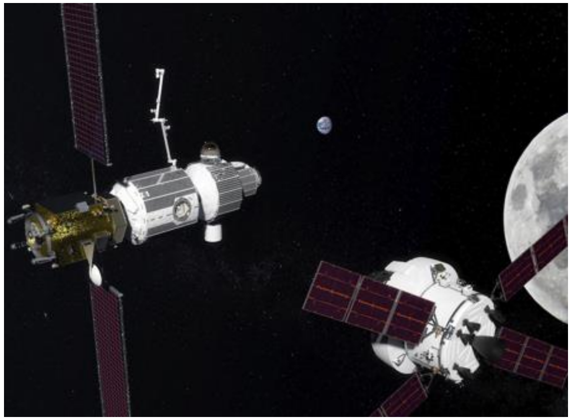
Utilization Stats to date (9/3/2024)	
Number of on orbit operations:	179
Number of on orbit remote Test Sessions	137
Unique Crew Members trained and who have operated Astrobee on the ISS:	36
Number of on-console hours:	1350
Crew hours	333

Impacts of past work

- 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 $40 mil.

ISAAC Overview

- Research project FY20-24 to develop technology for **autonomous caretaking** of spacecraft primarily during **uncrewed** mission phases
- Led by NASA Ames Research Center with collaboration from Johnson Space Center
- Integrate **autonomous intra-vehicular robots** (IVR) with **spacecraft infrastructure** (power, life support, etc.) and **ground control**
- Focus on capabilities required for the **Gateway** that also apply to human missions to Mars and beyond
- Test with **existing IVR on the ISS** (Astrobee, Robonaut) as an analog for **future IVR on Gateway**
- As ISAAC progressed, the project pivoted to focus more on Astrobee as the main demonstration platform (because Robonaut didn't return to station) and more on infusion into ISS operations (because Gateway IVR development has been delayed)



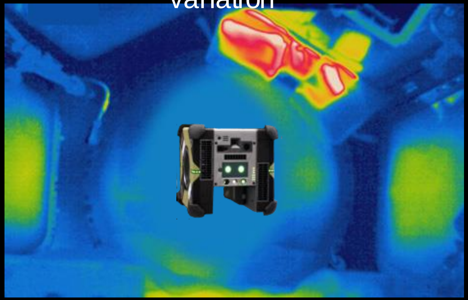
Why ISAAC?

- **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

Capability Areas

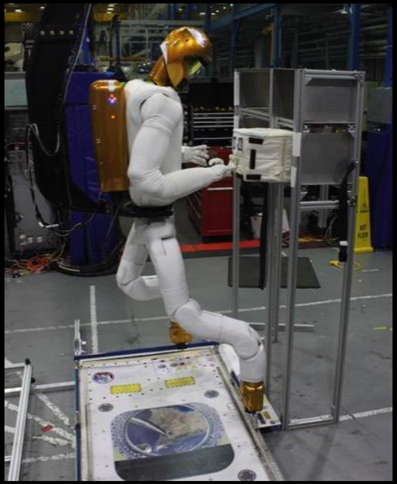
Autonomous State Assessment

Localizing signal sources by analyzing signal strength variation



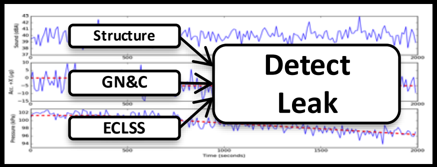
Habitat thermal mapping

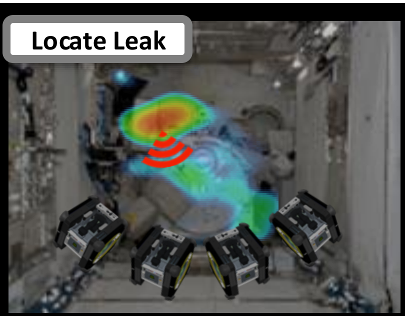
Autonomous Logistics Management



Robotic cargo transfer

Integrated Fault Management

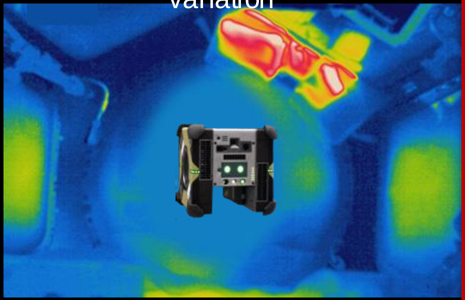




Capability Areas

Autonomous State Assessment

Localizing signal sources by analyzing signal strength variation



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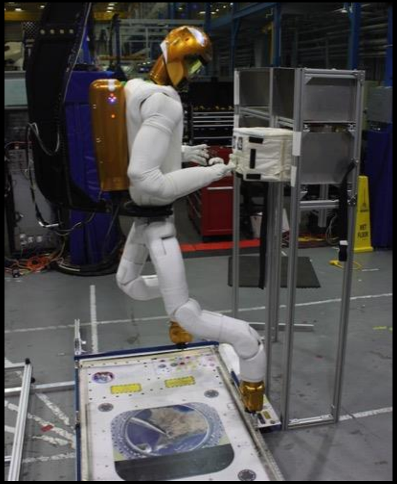
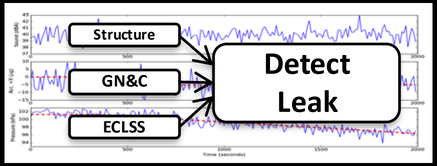
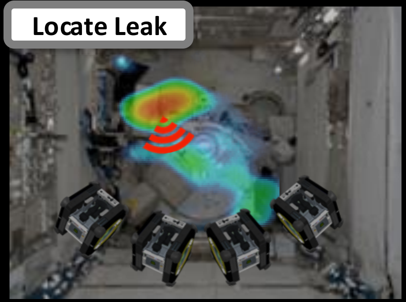


Robotic cargo transfer

Integrated Fault Management



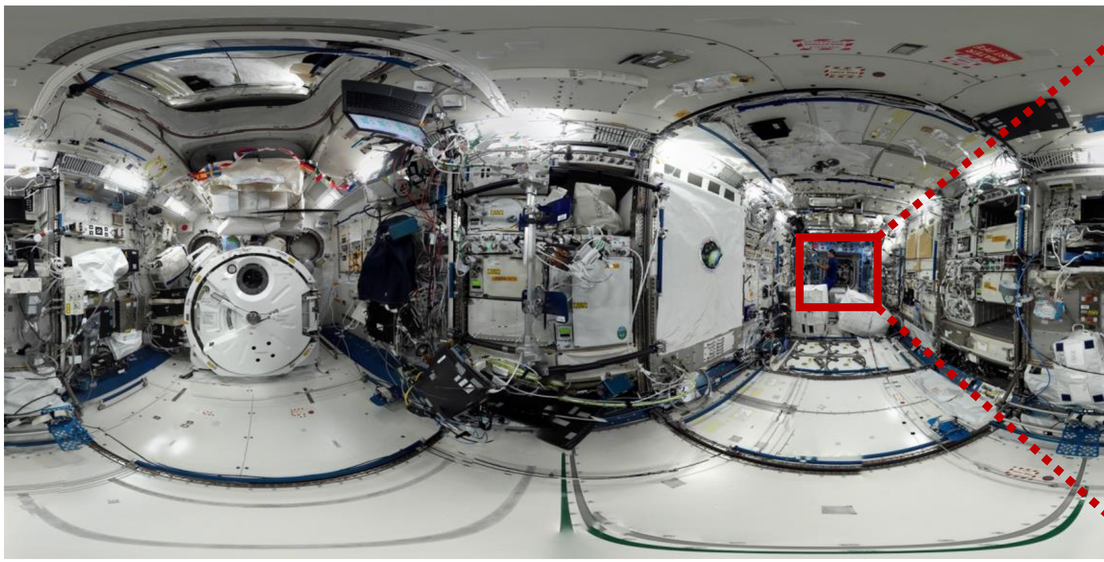


ISAAC Multi-Sensor Mapping

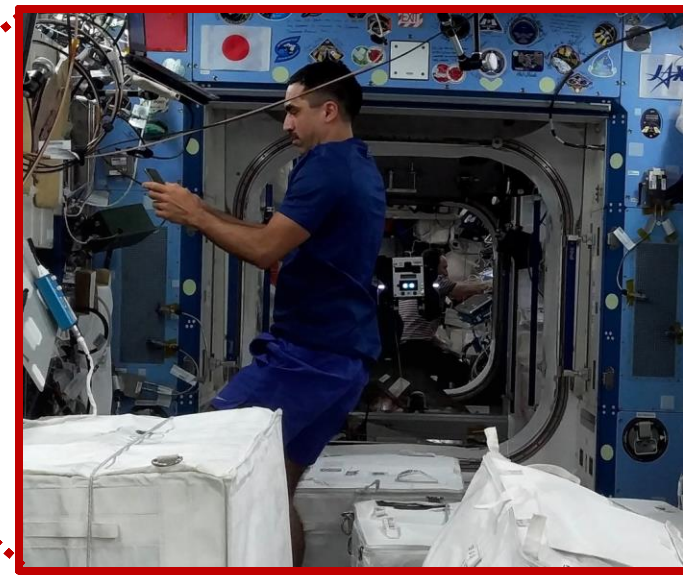
- Aim for near-term infusion of ISAAC multi-sensor mapping to **operational use with Astrobee on ISS** in addition to medium-term use on a future Gateway IVR platform
- Autonomous robotic multi-sensor mapping could provide several operational benefits to ISS:
  - **Save crew time.** Autonomous robotic data collection could partially replace the need for crew safety videos (although Astrobee can't cover all parts of the ISS)
  - **Provide more accurate and timely information**. The ISS interior is a very dynamic environment, and the robot could collect map updates more frequently than the current tempo of crew safety videos (once every few months).
  - **Enhance usability.** Enable users to navigate directly to the area of interest in a 3D model of the ISS, rather than downloading a massive video file and scrubbing through it to find the area of interest
  - **Provide new "superpower" senses**. In the near term, we propose to enhance ISAAC maps with sound source information from the SoundSee microphone array payload for Astrobee. Going forward, the ISAAC mapping framework can easily accommodate new sensor payloads added to Astrobee.
  - **Enable automated change and anomaly detection.** Automated detection of many types of anomaly (e.g., hardware intruding into a keepout zone) requires understanding the scene geometry and naturally builds on ISAAC's 3D map building. Without automation, labor-intensive manual review of safety videos is presently slow enough that by the time the review is done, its recommendations are often obsolete.
- Initial candidate ISS use cases for map data:
  - **Safety:** Check keepout zone violations, hatch seals, Emergency Egress Guidance System visibility, translation paths, and other items.
  - **Logistics:** Spot check the locations of cargo. Review available capacity of stowage locations. Correlate data from RFID Recon payload and update Inventory Management System database.


National Aeronautics and Space Administration
Integrated System for Autonomous and Adaptive Caretaking (ISAAC)
Survey Demo
Abiola Akanni, Oleg Alexandrov, Laura Barron, J Benton, Maria Bualat, Brian Coltin, Janette Garcia, Kathryn Hamilton, Lewis Hill, Marina Moreira, Robert Morris, Nicole Ortega, Joseph Pea, Misha Savchenko, Khaled Sharif, Trey Smith, Ryan Soussan
June 2021

ISAAC-6 Panorama

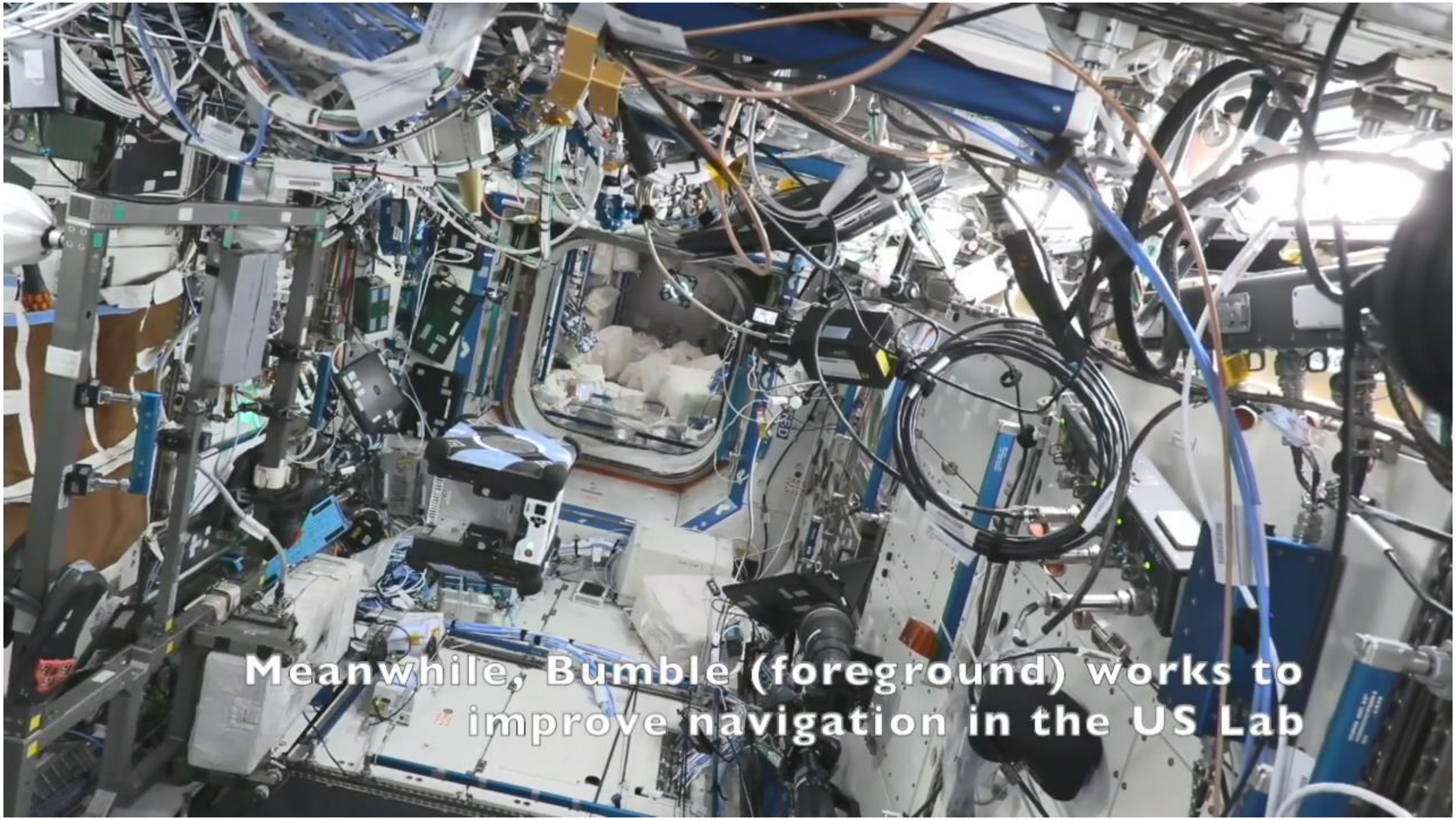


First full 360-degree spherical panorama captured with an autonomous free flyer in space (stitched from 56 SciCam images)

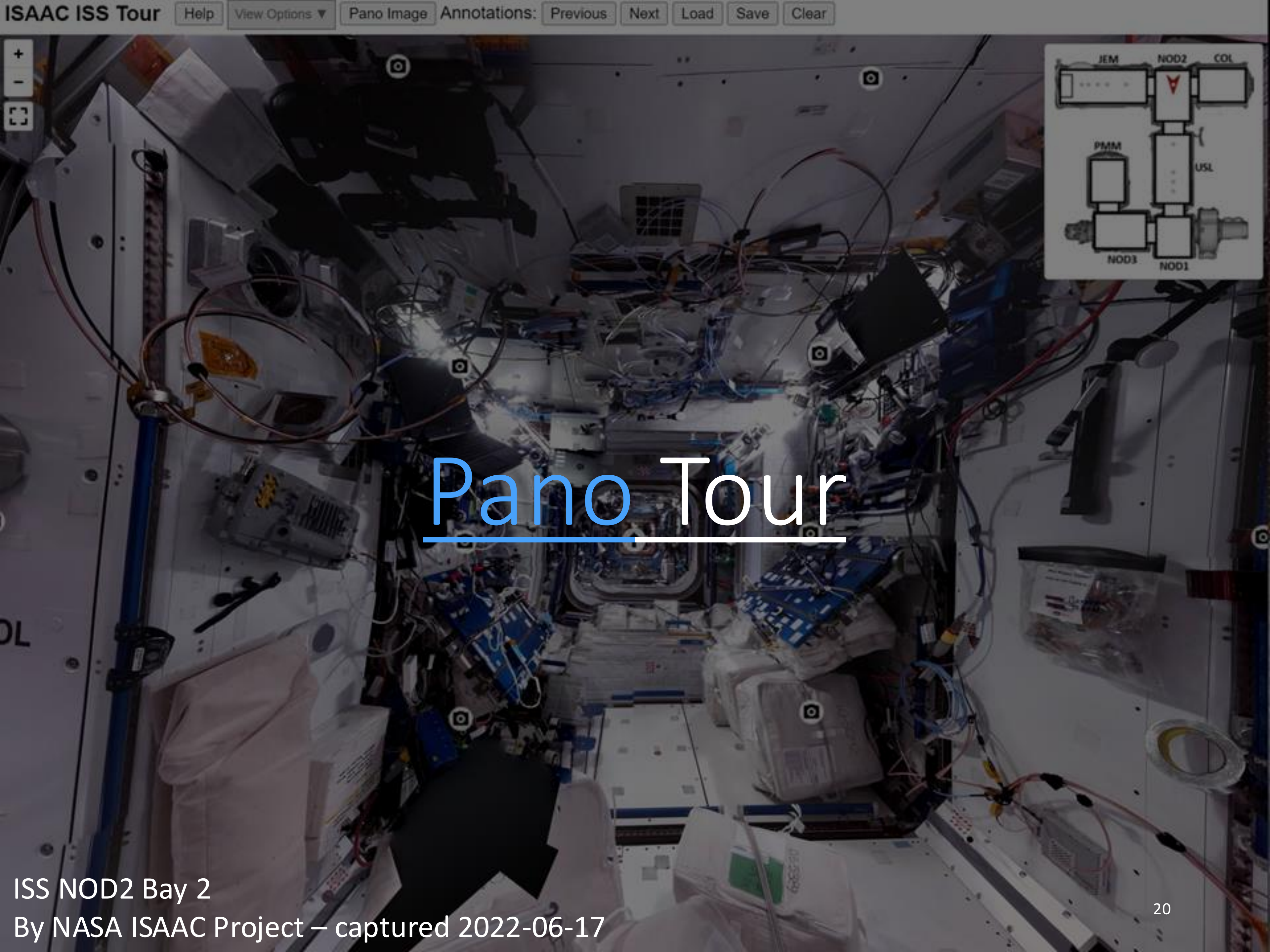


Detail: In a happy accident, Queen also captured NASA astronaut Raja Chari and Bumble together in the panorama

ISAAC9-11: Multi-Sensor Mapping of Three Modules



ISAAC multi-sensor mapping video from ISAAC9-11 ISS activities

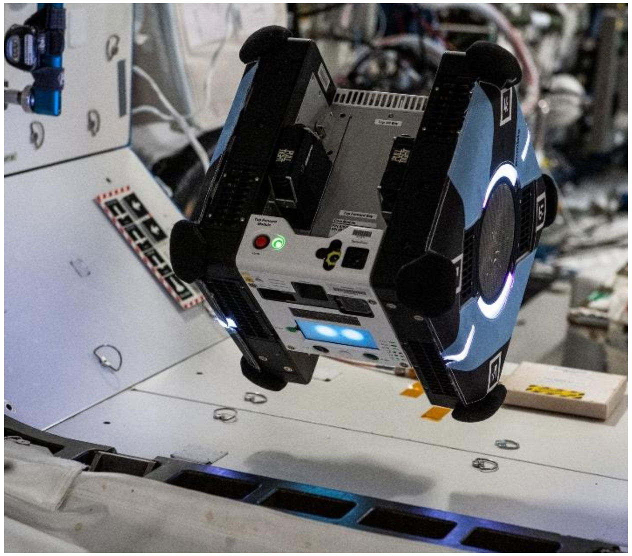


Pano Tour

ISS NOD2 Bay 2
By NASA ISAAC Project – captured 2022-06-17

Other ISAAC Highlights

- **Targeted robotic inspection:** For example, inspecting sub-millimeter scuffs on ISS hatch seals. Targets were selected using survey imagery.
- The first time a **robot located a sound source in space** (collaboration with the Bosch USA SoundSee payload team)
- Used **onboard planning and execution** to manage multi-robot survey operations (deconflicting survey locations to avoid collisions). Survey was executed fully autonomously including through loss-of-signal periods, with operators watching and managing fault recovery.
- ISAAC contributed many improvements to the open-source release of Astrobee's flight software for the benefit of future Astrobee users:
  - Navigation reliability improvements
  - Improved inter-robot communications
  - Began long-term effort to port Astrobee flight software to run using the next-generation "Space ROS" framework designed to enable advanced robotic capabilities in a safety-critical mission computing environment.
- ISAAC's own open-source software release includes many reusable capabilities including:
  - The multi-robot planning and execution framework.
  - Processing pipelines for stitching panoramas and doing 3D reconstruction of spacecraft module interiors from depth sensors and stereo imagery.
  - Web interfaces for exploring 3D data and panoramic tours.
  - A flexible "analyst notebook" framework for automated analysis of robotic survey data.



Bumble performing a close-up inspection of a hatch seal in USL during ISAAC-11 (2022/07/11)

NASA astronaut Kayla Barron supporting SoundSee/ISAAC activity

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
- Request For Information (RFI) due 9/27/2024:
  - https://sam.gov/opp/7893fe01e7bf4ae69029b5d8915e62c5/view
  - Interested offerors will submit papers outlining their interest, capabilities, history, and proposed plans for operating and sustaining Astrobee assets
- RFI Web Feature:
  - https://www.nasa.gov/technology/robotics/nasa-seeks-input-for-astrobee-free-flying-space-robots/

Future IVR

- NASA's future in IVR, A vision for IVR on a CLD
  - NASA STMD Shortfalls (Ranking)
    - 10 IVR relivant shortfalls are ranked (see backup slide)
  - NASA's Low Earth Orbit Microgravity Strategy [Aug 2024]
    - Exploration Technology (ET-1): Demonstrate and validate robotic and autonomous systems that maximize crew time available for science and engineering activities.
  - CLD IVR leading to Moon/Mars
    - LEO provides a high-fidelity, yet risk-tolerant environment for IVR technology maturation

QUESTIONS?

STMD Shortfalls

- 1545: Robotic Actuation, Subsystem Components, and System Architectures for Long-Duration and Extreme Environment Operation, (#5)
- 1304: Robust, High-Progress-Rate, and Long-Distance Autonomous Surface Mobility, (#9)
- 1531: Autonomous Guidance and Navigation for Deep Space Missions (#11)
- 1548: Sensing for Autonomous Robotic Operations in Challenging Environmental Conditions, (#18)
- 1546: Robotic Mobile Manipulation for Autonomous Large-Scale Logistics, Payload Handling, and Surface Transport, (#31)
- 1542: Metrics and Processes for Establishing Trust and Certifying the Trustworthiness of Autonomous Systems, (#33)
- 498: Broad and dependable supply chain for space-qualified robotic hardware, electronics, and associated software, (#40)
- 1538: General-Purpose Robotic Manipulation to Perform Human-Scale Logistics, Maintenance, Outfitting, and Utilization, (#65)
- 1535: Autonomous Vehicle, System, Habitat, and Infrastructure Health Monitoring and Management, (#72)
- 680: Robust Robotic Intelligence for High-Tempo Autonomous Operations in Dynamic Mission Conditions, (#85)