ISSRDC

Mapping the ISS with the Autonomous Free-Flying Astrobee Robots

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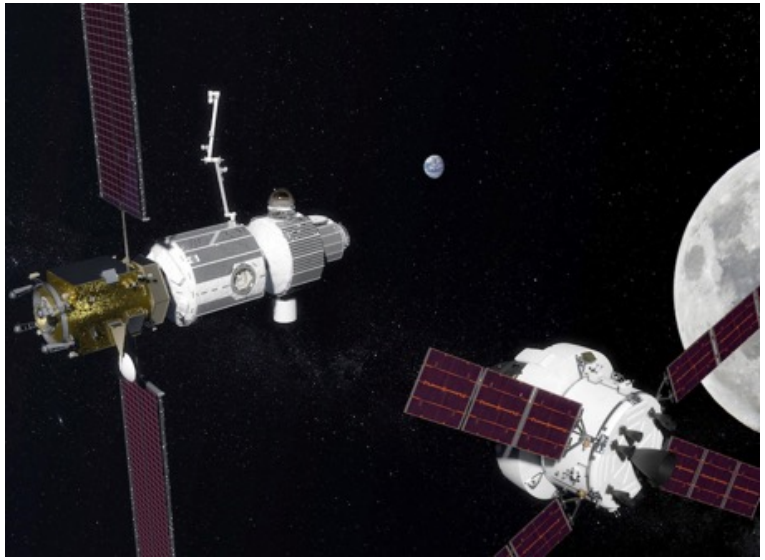
Presented by Maria Bualat

AIRBUS

Technical Session Sponsor

ISAAC Overview

- Integrated System for Autonomous and Adaptive Caretaking (ISAAC)
- Research project 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
- Do not:
  - Develop the IVR needed for Gateway
  - Develop Gateway flight software
  - (These tasks are vital but not part of ISAAC.)



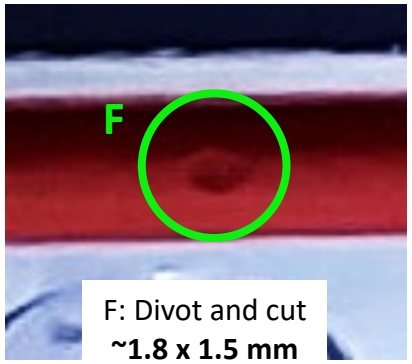
Why ISAAC?

- 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

Extended 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.

Hatch Seal Inspection



F: Divot and cut
~1.8 x 1.5 mm

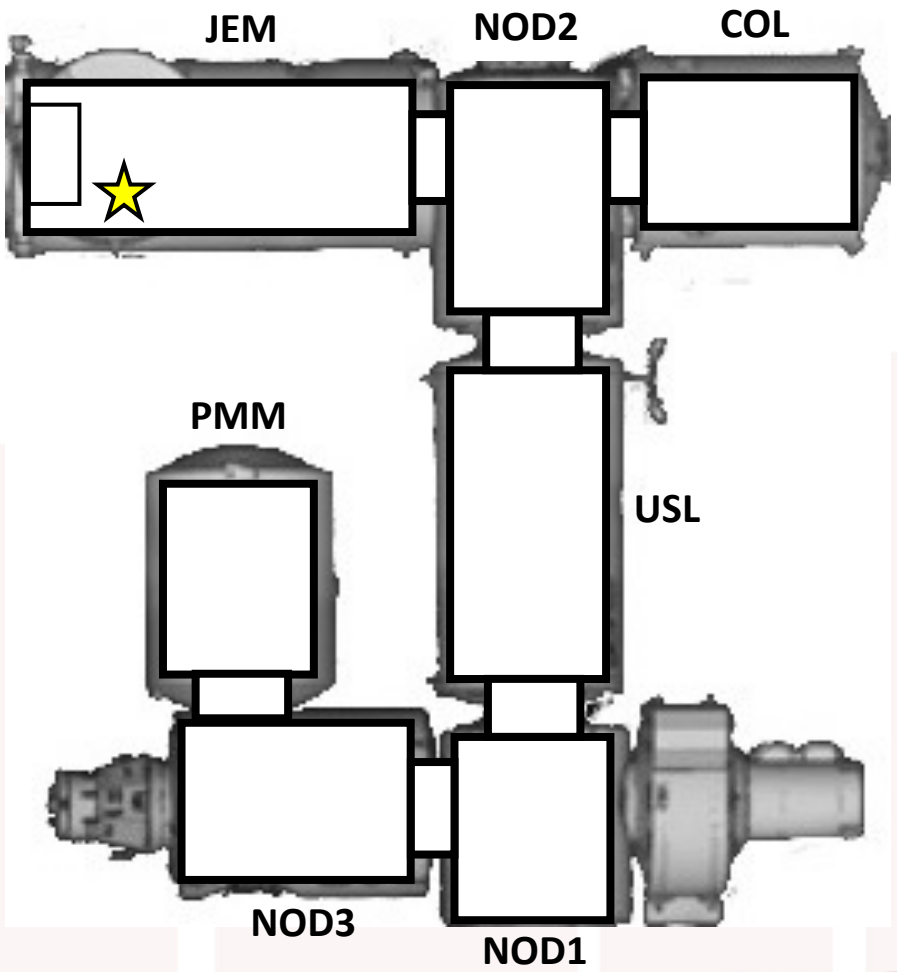
G: Divot
~0.7 x 0.3 mm

These Astrobee photos confirmed previously known hatch seal damage sites (ISAAC11, 2022/06/16). A new "focus stack" ops approach was used to get improved focus on the targets, yielding Astrobee's highest-resolution ISS images to date (~0.1-0.2 mm).

- The ISS OSO console team worked with the ISAAC and Astrobee teams to investigate the feasibility of using Astrobee to perform hatch seal inspections
  - The hatch seals are exposed to the crew cabin and could be damaged whenever the hatches are open (they usually are)
  - Since hatch closure would be used as an emergency hazard mitigation for some catastrophic hazards, hatch seal damage significant enough to cause a leak would be taken very seriously
  - Hatch seals are presently inspected by crew about twice a year
  - There are known locations of prior hatch seal damage that are specifically noted in the crew procedure for detailed inspection
    - None are presently considered a serious hazard
  - As a late-breaking change to ISAAC Phase 1X, secondary hatch seal inspection tasks were added to mapping activities ISAAC9, 10, and 11. ISAAC/Astrobee worked with OSO to iterate, improving targeting and image quality.
  - OSO's most recent evaluation is that the Astrobee hatch seal inspection demonstrated to date is not yet ready to be deployed for production use, but they are interested in further evaluation if the inspection process can be improved (potential improvements to image quality and analyst user interface for image review)

Astrobee ISS Campaign

Act #	Ph.	Objective	Module	Date
1	1	Calibration, risk reduction	JEM	2021/02/23
2	1	Baseline survey	JEM	2021/03/26
3	1	Repeat survey and fault detection	JEM	2021/04/19
4	1X	Crew sparse map new module	NOD2	2022/02/08
5	1X	Crew sparse map new module	USL	2022/03/31
6	1X	Validate nav, Queen calibration	NOD2, JEM	2022/04/07
7	1X	Validate nav, Queen risk reduction	USL, JEM	2022/05/16
8	1X	Multi-sensor map + SoundSee	JEM	2022/05/13
9	1X	Multi-sensor map	JEM	2022/06/08
10	1X	Multi-sensor map, validate nav	NOD2, USL	2022/06/17
11	1X	Multi-sensor map	USL	2022/07/11



Astrobee ISS Campaign

Not covered in this presentation

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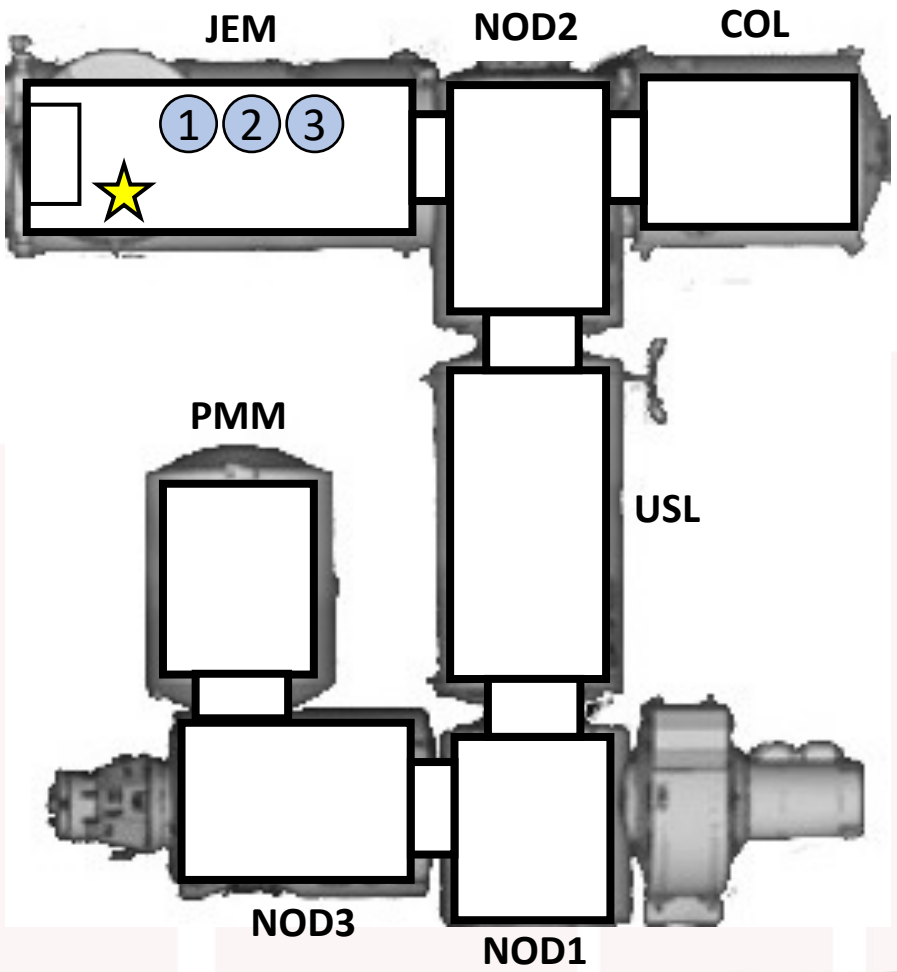

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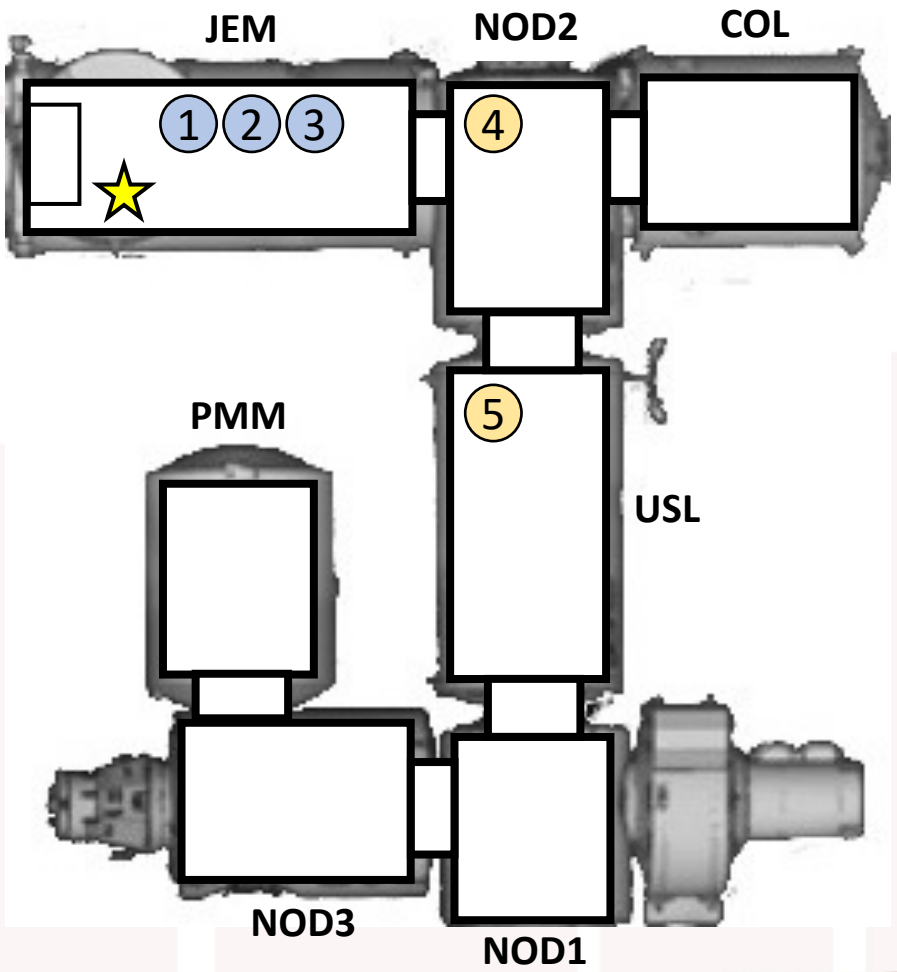

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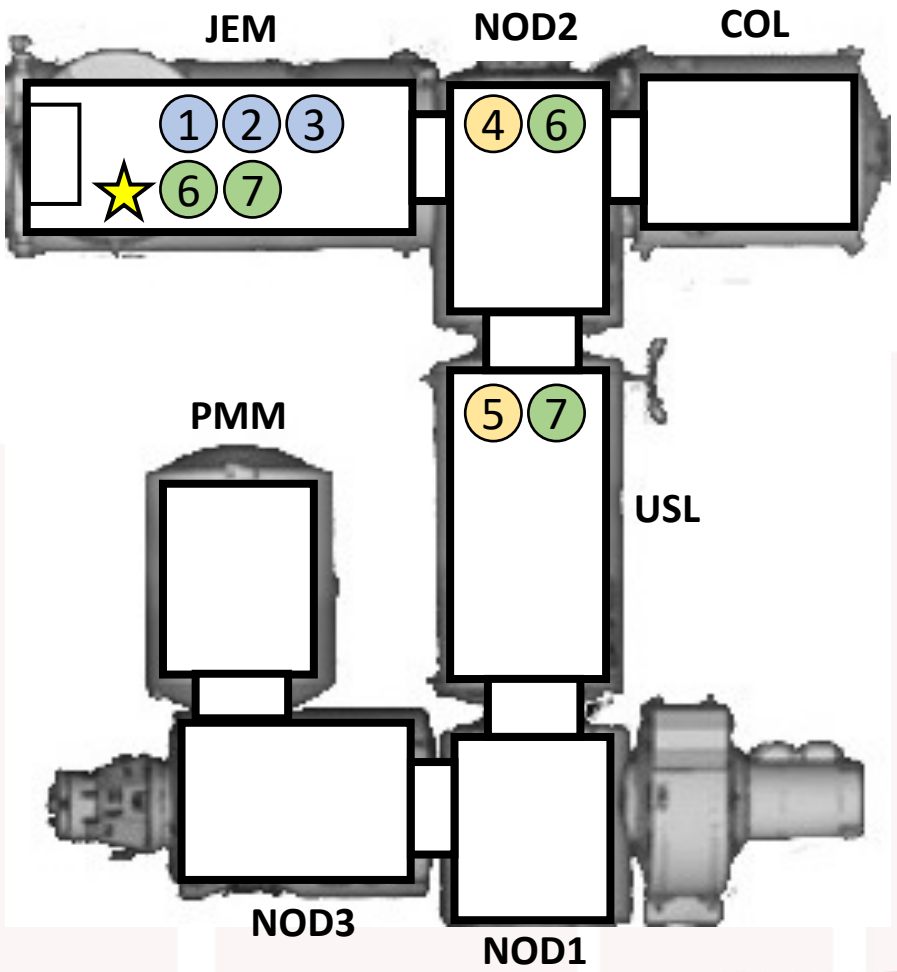

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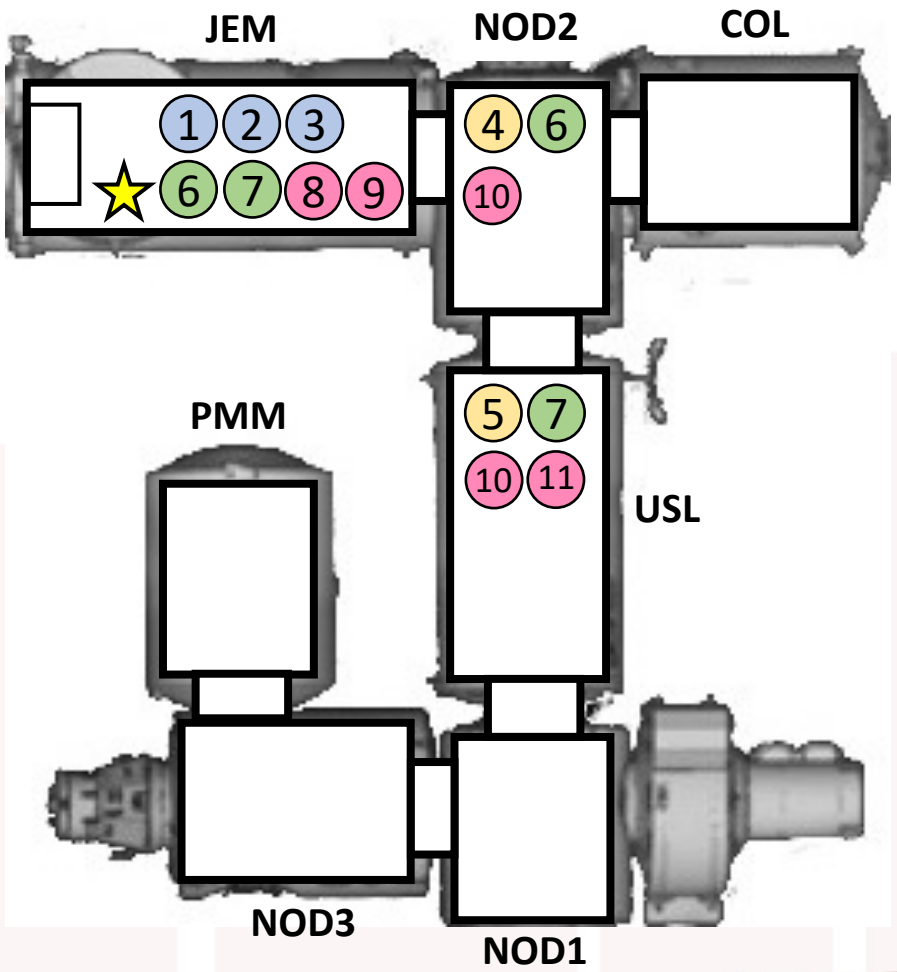


ISAAC Phase 1X On-Orbit Activities

ISAAC-4
2022/02/08

NASA Astronaut Kayla Barron manually flew Bumble

- Crew collect imagery to build the first Astrobee sparse map of NOD2

ISAAC-5
2022/03/31

DLR astronaut Matthias Maurer manually flew Bumble

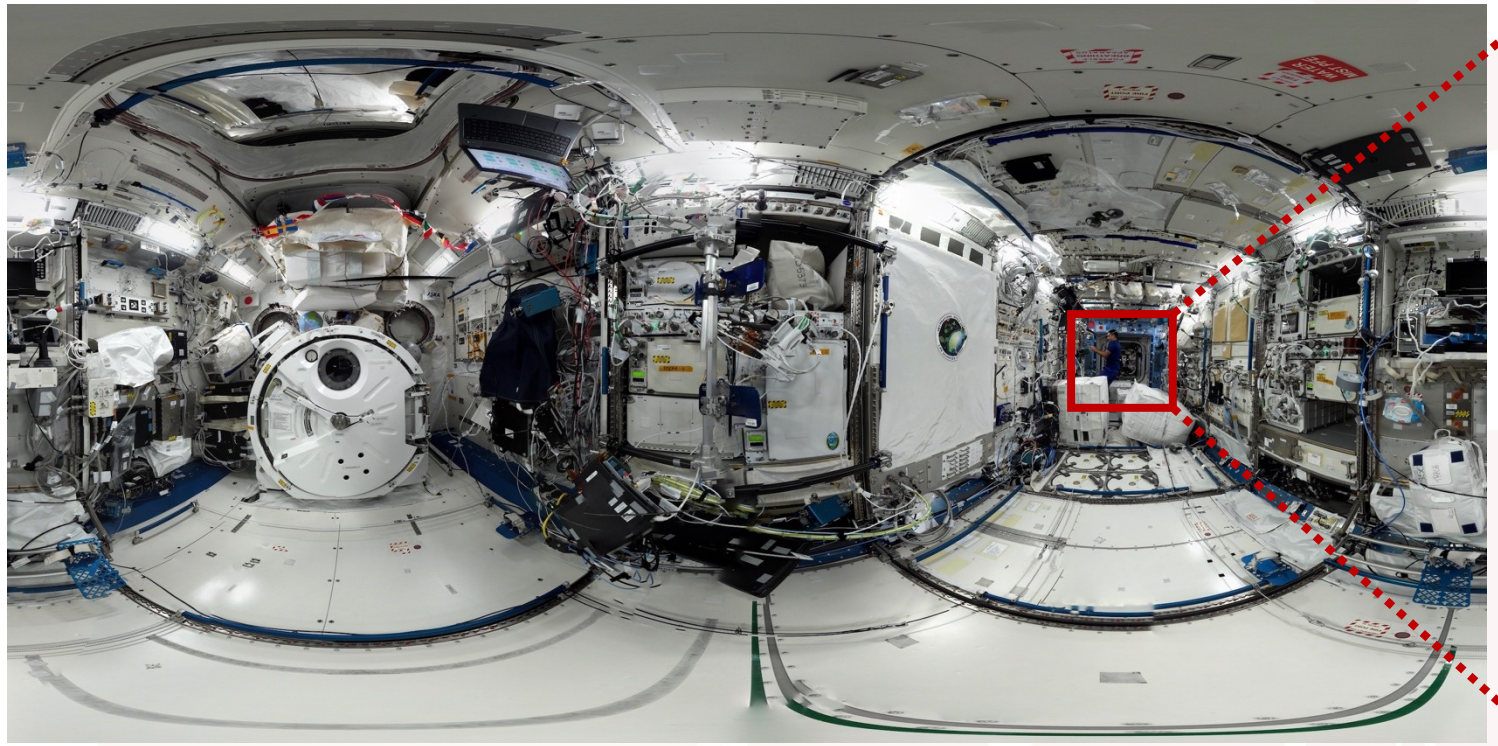
- Crew collect imagery to build the first Astrobee sparse map of USL

ISAAC-6
2022/04/07

NASA astronaut Raja Chari worked alongside Bumble (in NOD2) and Queen (in the JEM)

- First autonomous flight outside JEM!
- Calibrate Queen's HazCam/SciCam
- Collect first full-360 spherical panorama with Astrobee
- First activity with Astrobees operating simultaneously in different modules

ISAAC6 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

ISAAC Phase 1X On-Orbit Activities

ISAAC-8
2022/05/13

Queen acquires a SoundSee acoustic survey

- Queen and Bumble independently collected full-spherical panoramas at the same time
- Collected an acoustic survey of the JPM1A5 EXPRESS rack with the SoundSee microphone array to enable SoundSee to demonstrate localizing equipment noise sources within the context of an ISAAC 3D map.

ISAAC-7
2022/05/16

Bumble flies in the USL for the first time

- Bumble
  - Tested ability to navigate in the USL
  - Autonomously flew back to the dock in the JEM
- Queen collected a makeup panorama to complete the survey of the JEM started in ISAAC-8.

ISAAC-9
2022/06/08

2 Astrobees simultaneously mapping the JEM

- Queen and Bumble split up the task of completely surveying the interior of the Japanese Exploration Module.
- Collected SciCam imagery of the hatch seal between the JEM and Node 2 modules.

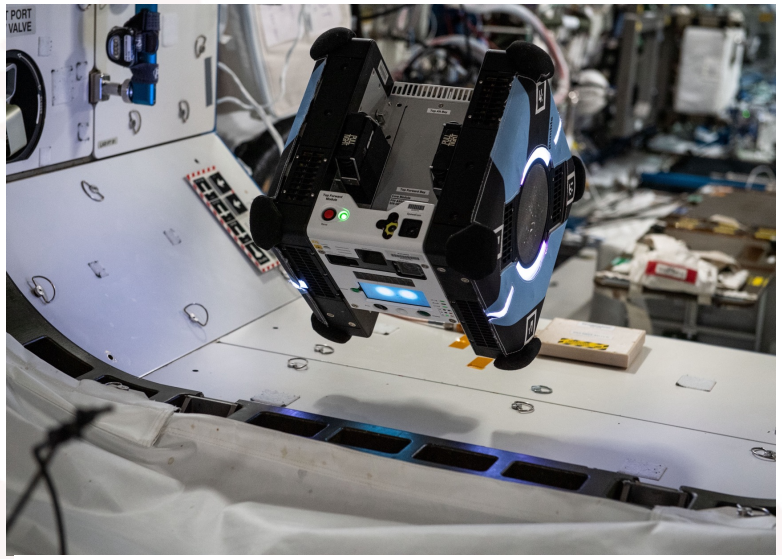
ISAAC Phase 1X On-Orbit Activities

ISAAC-10
2022/06/17

Bumble (foreground) works in USL, while Queen operates in Node 2

- Queen performed multi-sensor 3D mapping Node 2
- Bumble collected additional NavCam imagery in the USL to improve Astrobee's sparse map in that area
- Bumble performed inspection of USL/Node 1 hatch seal

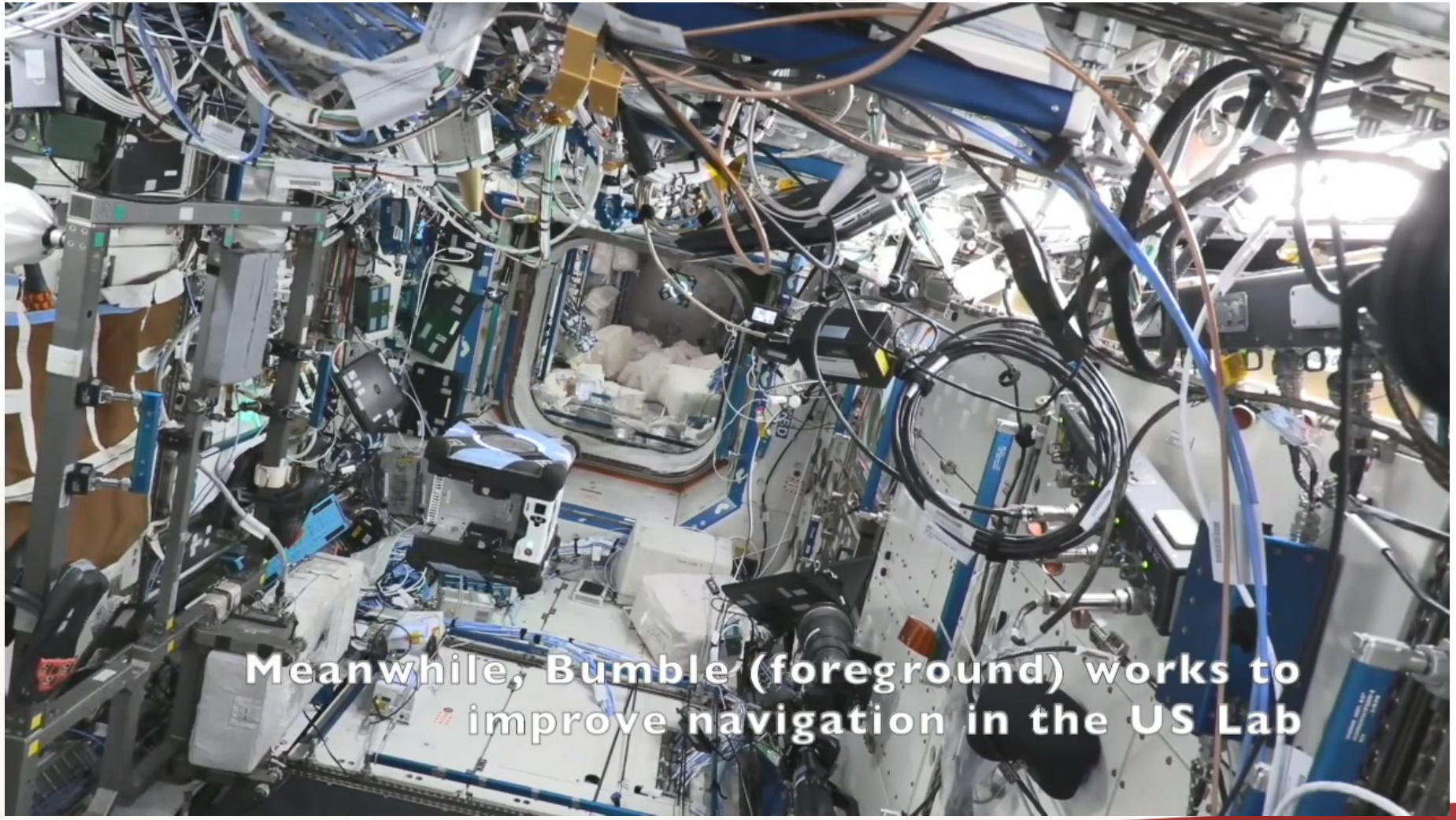
ISAAC-11
2022/07/11



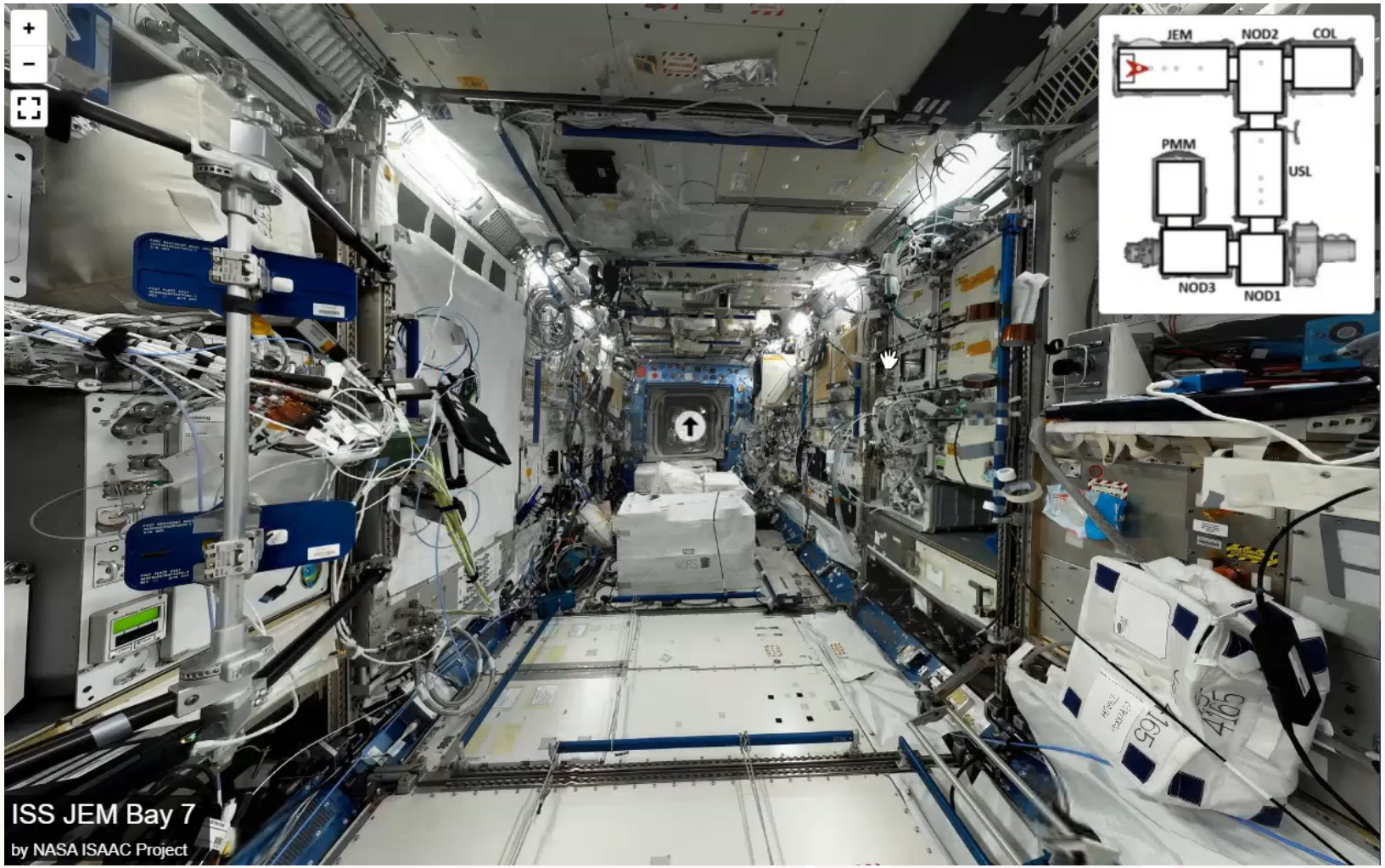
Bumble inspects the USL aft hatch seal

- Bumble and Queen Astrobees operated together to collect a multi-sensor 3D map of the US Lab module.
- Inspected the US Lab forward and aft hatch seals.
- Inspected life support intake vents, both in USL and JEM

ISAAC9-11: Multi-Sensor Mapping of Three Modules



ISS Tour Using Preliminary 2D Panorama Interface



ISAAC Space Robotics Firsts

- ISAAC Phases 1 & 1X included the first time
  - … a robot autonomously navigated between modules inside a spacecraft
  - … multiple robots operated together in different modules of a spacecraft
  - … a robot located a sound source inside a spacecraft
    - (ISAAC helped to operate the SoundSee Astrobee payload developed by Bosch USA)
  - … a robot surveyed a spacecraft interior to map it for human viewing

ISAAC10: Bumble operates in USL while Queen operates in NOD2

NASA astronaut Kayla Barron supporting SoundSee/ISAAC activity

Future Work in ISAAC's Last Year

- Close-up inspection: Improving on the prior result. Making accurate targeting and focus more repeatable, improving user interface for target selection and review of resulting imagery
- Multi-robot coordination: Integrating an onboard task manager to coordinate multi-robot activities with Astrobees, improving robot productivity and reducing the effort level for operator oversight
- Change and anomaly detection: A flexible "analyst notebook" to automatically extract interesting features in Astrobee ISS imagery, potentially including 3D objects intruding into user-defined keepout zones and warning labels that were previously visible but are now obscured.
- Recent/ongoing intern projects:
  - Search for text on decals imaged in Astrobee panoramas of the ISS! (Uses OCR to extract label text and index it for search.)
  - Significant improvements to Astrobee localization
  - Enabling Astrobee to use a form of affordance template for detecting and inspecting arbitrary object types defined by a user

We would like to thank:

The ISS Astrobee Facility

The ISS Program

The SoundSee team at Bosch North America and Astrobotics Technology

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