



Integrated System for Autonomous and Adaptive Caretaking (ISAAC) Astrobee Working Group Update

Trey Smith, Maria Bualat, and the ISAAC Team
11.10.2022

Agenda



- ISAAC update
- Localization experiments during Crew-Minimal S8 ISS activity (2022/11/01)
- Florida Atlantic University senior design projects

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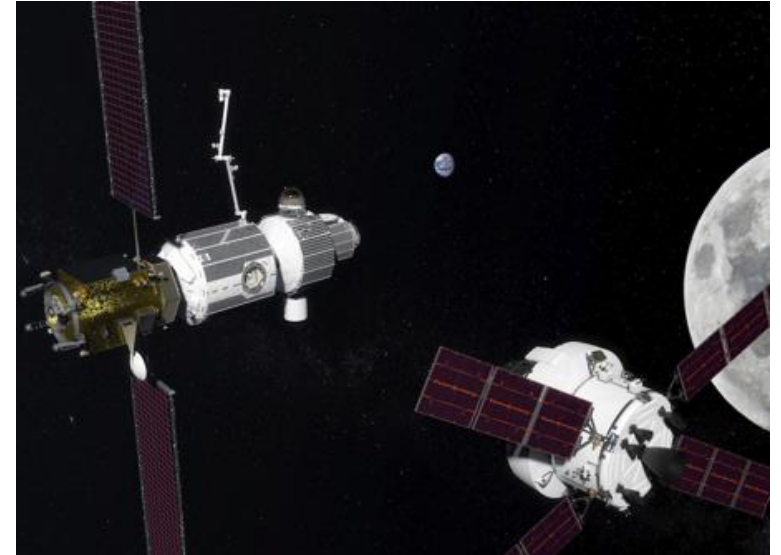


- **ISAAC update**
- Localization experiments during Crew-Minimal S8 ISS activity (2022/11/01)
- Florida Atlantic University senior design projects

ISAAC Overview



- 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.)



Phase 1X: Extended Multi-Sensor Mapping

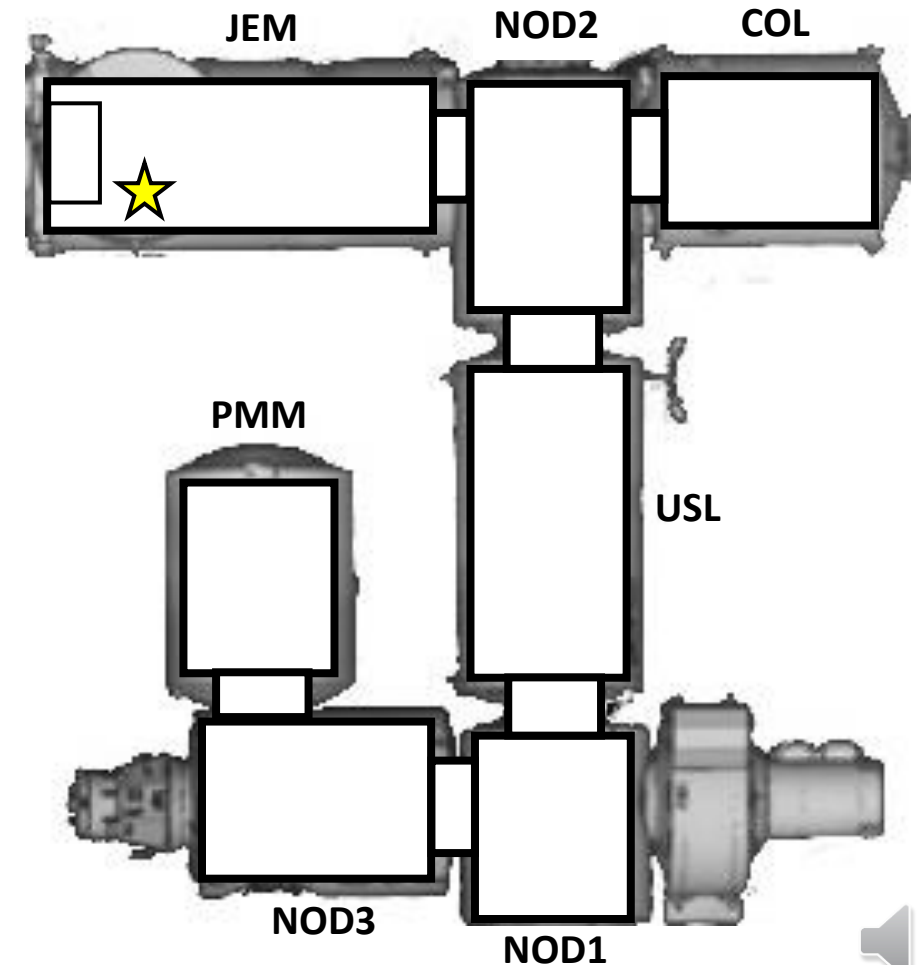


- Aim for near-term infusion of ISAAC multi-sensor mapping to **operational use with Astrobee on ISS** in addition to medium-term use on a future Gateway IVR platform
- Autonomous robotic multi-sensor mapping could provide several operational benefits to ISS:
 - **Save crew time.** Autonomous robotic 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.

Phase 1X: Astrobees ISS Campaign



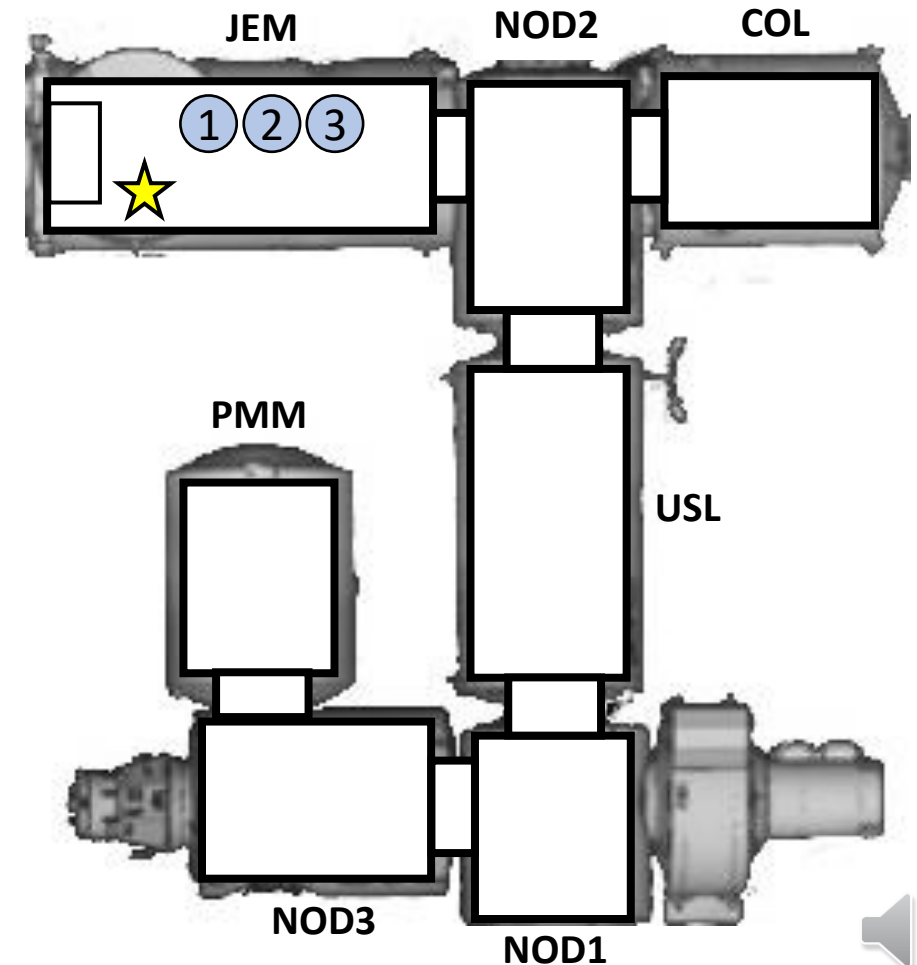
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1	1	Calibration, risk reduction	JEM	2021/02/23
2	1	Baseline survey	JEM	2021/03/26
3	1	Repeat survey and fault detection	JEM	2021/04/19
4	1X	Crew sparse map new module	NOD2	2022/02/08
5	1X	Crew sparse map new module	USL	2022/03/31
6	1X	Validate nav, 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
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Phase 1X: Astrobees ISS Campaign



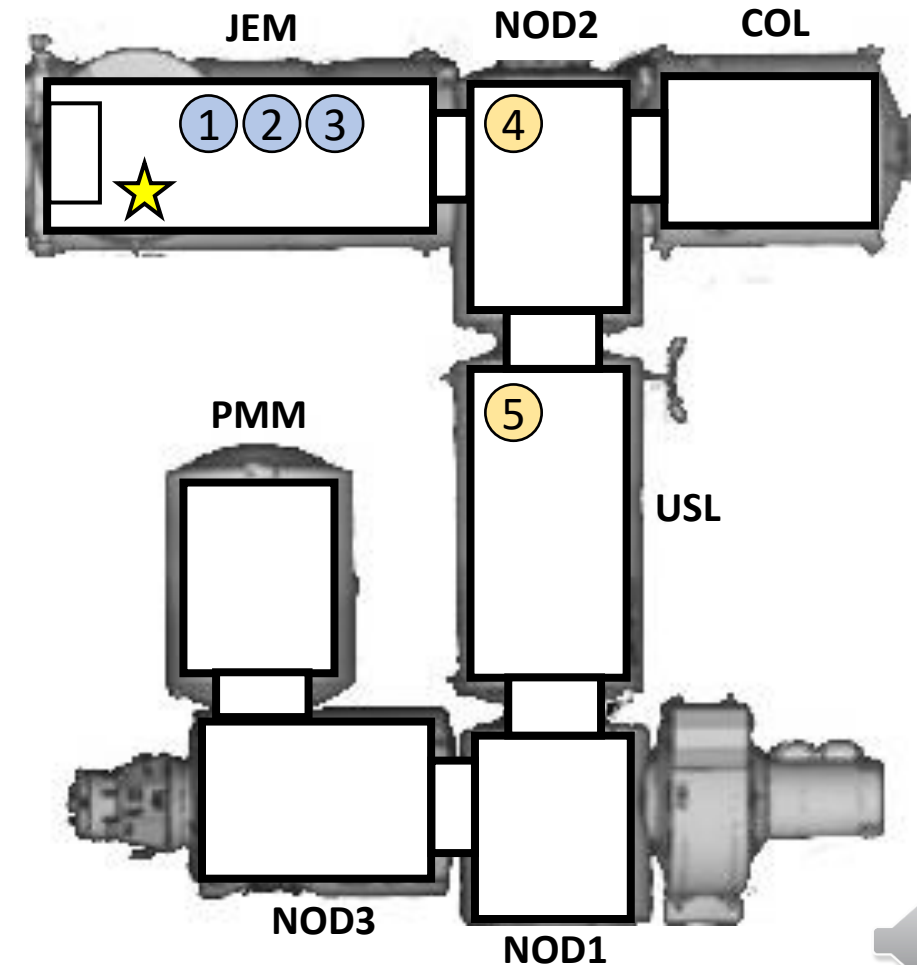
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Phase 1X: Astrobees ISS Campaign



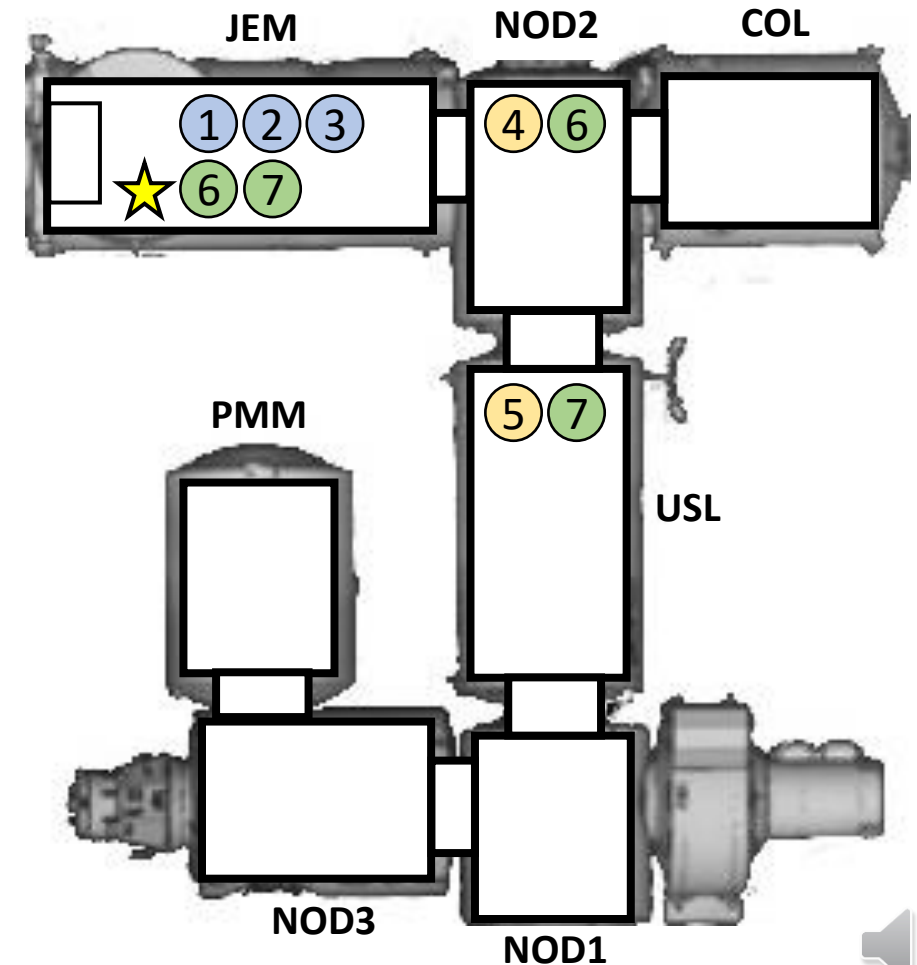
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Phase 1X: Astrobees ISS Campaign



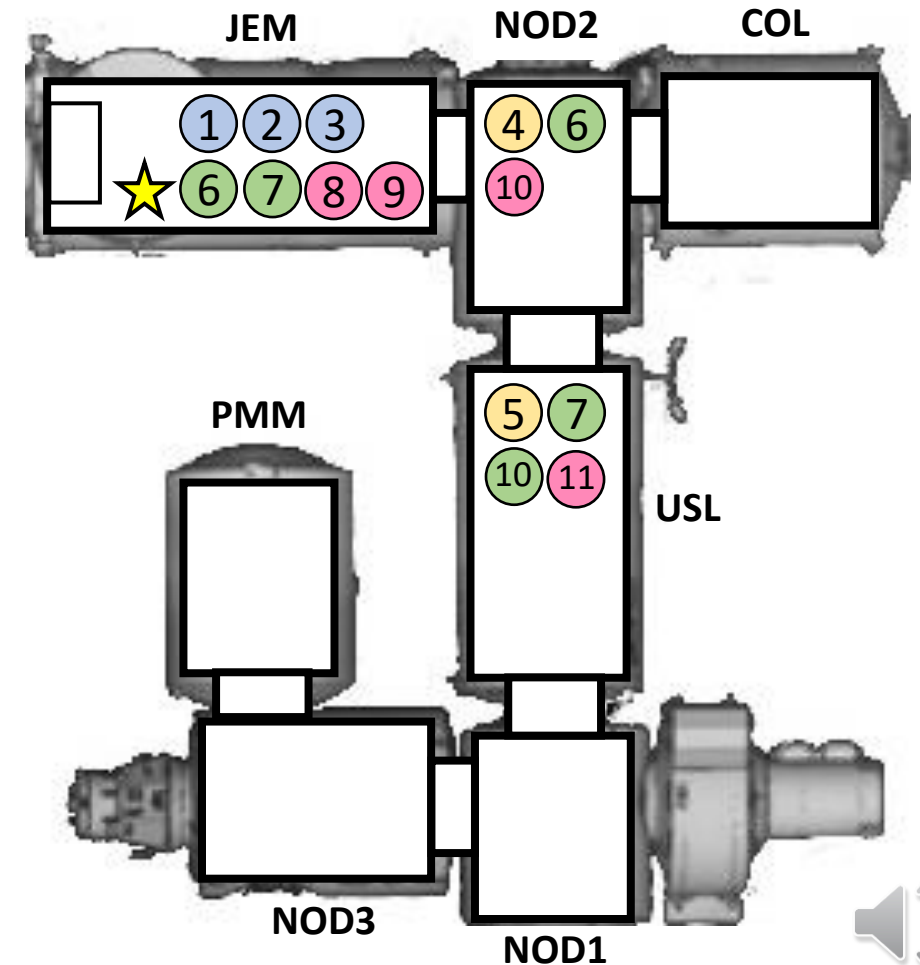
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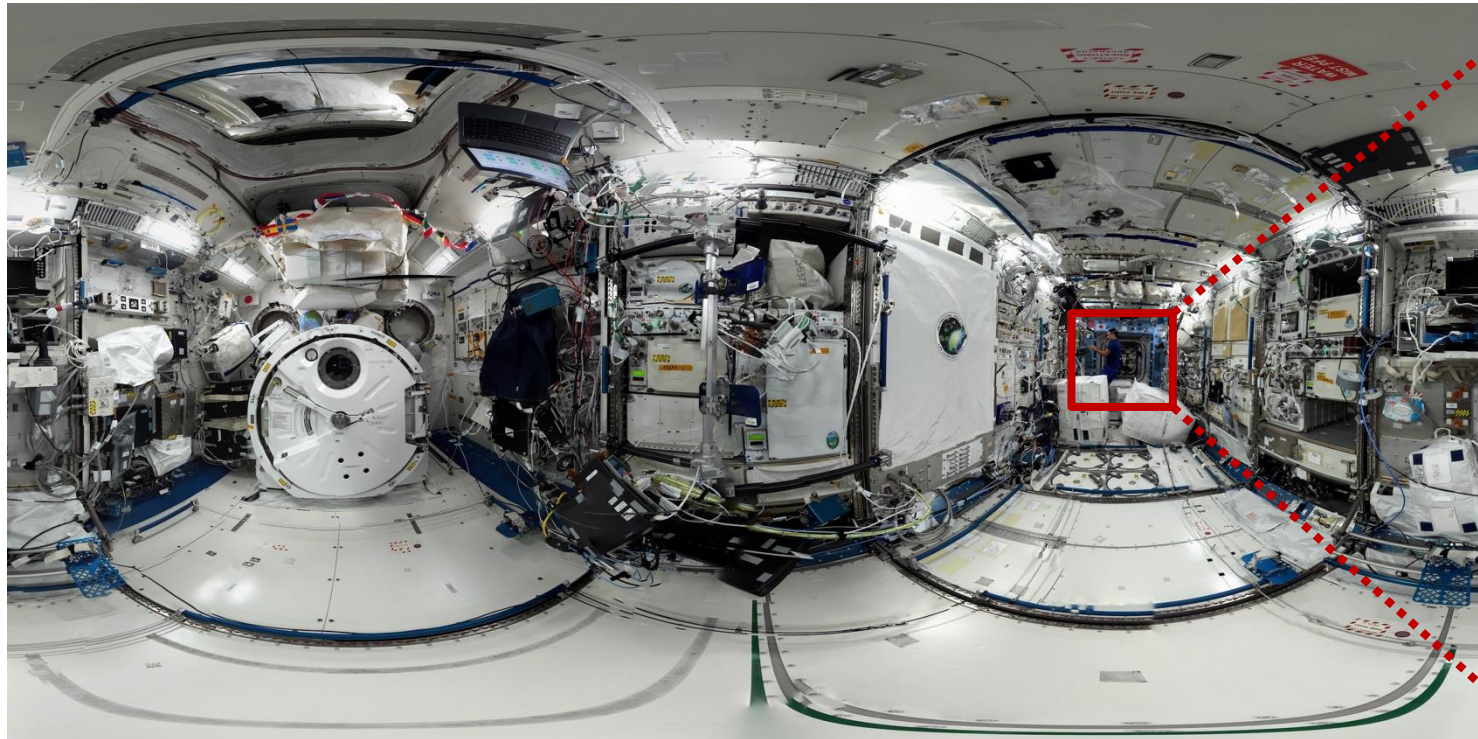
Phase 1X: Astrobees ISS Campaign



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ISAAC6 Panorama

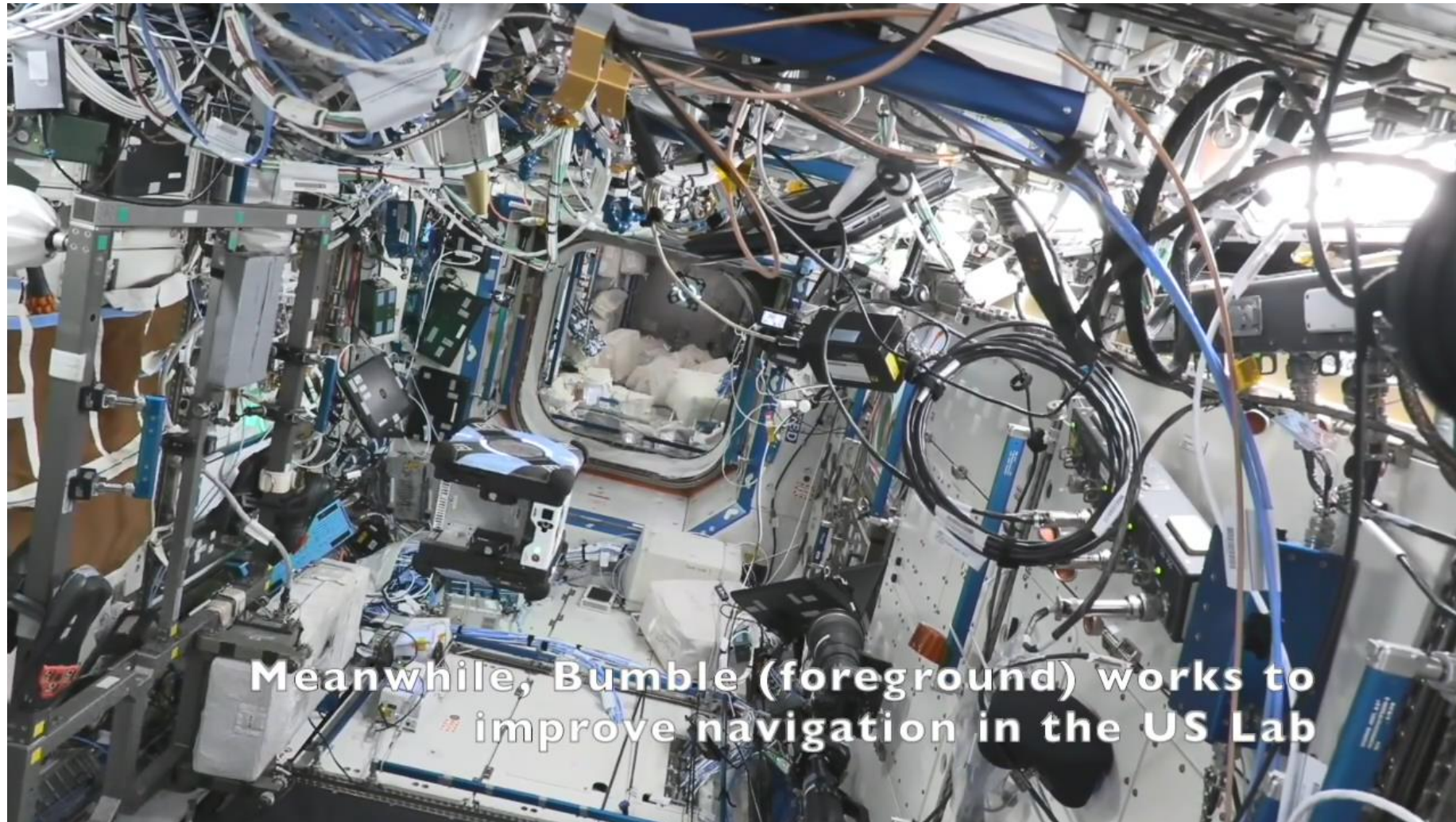


First full 360-degree spherical panorama captured with an autonomous free flyer in space (stitched from 56 SciCam images)



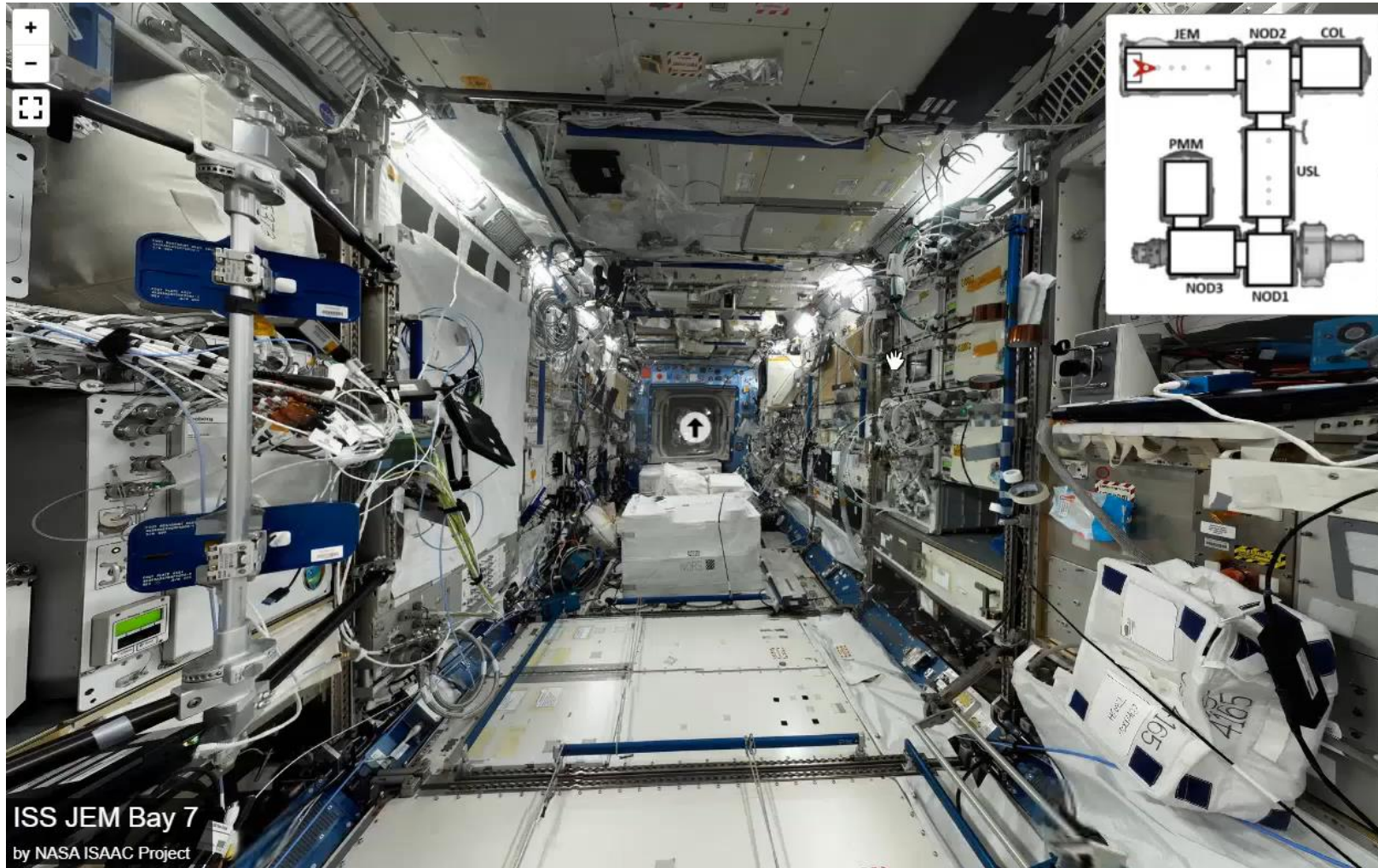
Detail: In a happy accident, Queen also captured NASA astronaut Raja Chari and Bumble together in the panorama

ISAAC9-11: Multi-Sensor Mapping of Three Modules



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

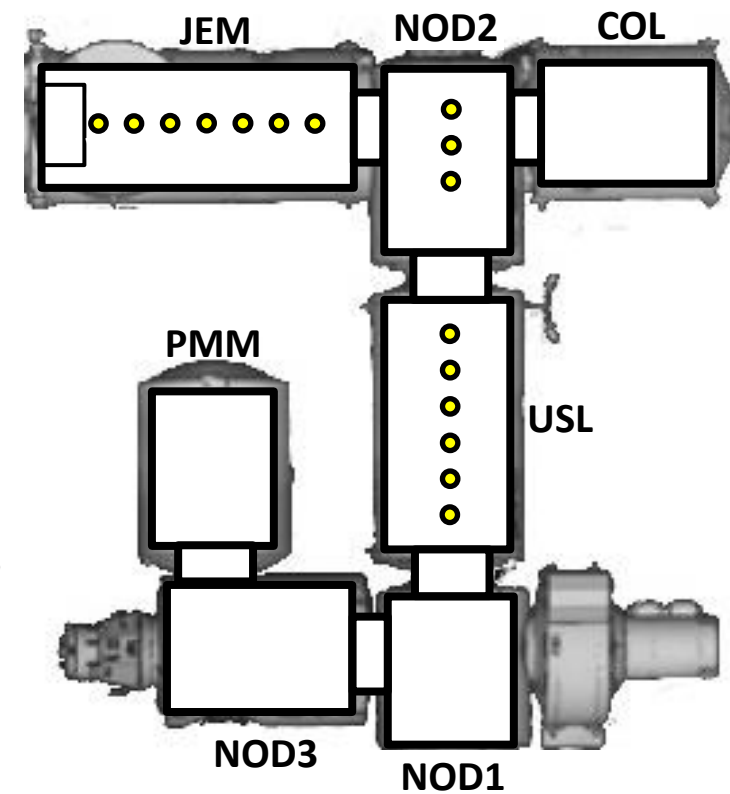
ISS Tour Using Preliminary 2D Panorama Interface



Try out this interface at: https://ivr.ndc.nasa.gov/isaac_panos/
Let us know if you have trouble accessing it! (only NASA network or VPN)

Recent Updates: Complement to Crew Safety Video

- The ISS OSO team viewed the ISAAC6 panorama and immediately expressed interest in using ISAAC Astrobees panoramic surveys as a complement to crew safety videos for improving OSO situation awareness
- The ISS Imagery Working Group has requested as many ISAAC panoramas as possible to present for evaluation by the XF-705 Safety Video team
 - The ISAAC team is working to prepare high-quality stitched versions of the 16 ISS panoramas collected during our Phase 1X activities
 - Due to reliability issues with our stitching solution and lack of staff time to debug, we were unable to provide all the panoramas for evaluation, and some panoramas had to be delivered with stitching artifacts we believe to be correctable
- **If XF-705 indicates interest, the ISS program will likely request further Astrobees panoramas (both updates in previously surveyed modules, and expanding the coverage to more modules)**
 - Further ISAAC effort would likely be needed to support tech transition to the Astrobees Facility. The Astrobees Facility team has requested specific FY23 funding from the ISS program to support their side of the effort.

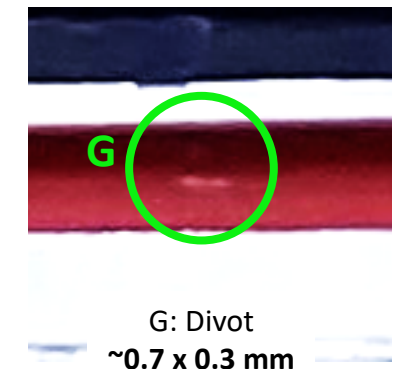
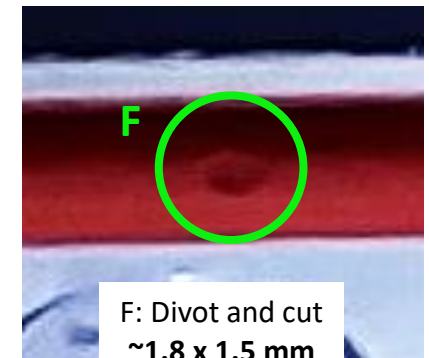


Approximate locations of panoramas collected during ISAAC Phase 1X mapping activities

Recent Updates: Hatch Seal Inspection



- **The ISS OSO console team worked with the ISAAC and Astrobees teams to investigate the feasibility of using Astrobees 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/Astrobees worked with OSO to iterate, improving targeting and image quality.
 - OSO's most recent evaluation is that the Astrobees 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)



These Astrobees 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 Astrobees’ highest-resolution ISS images to date (~0.1-0.2 mm).

ISAAC Phases 1 & 1X: 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



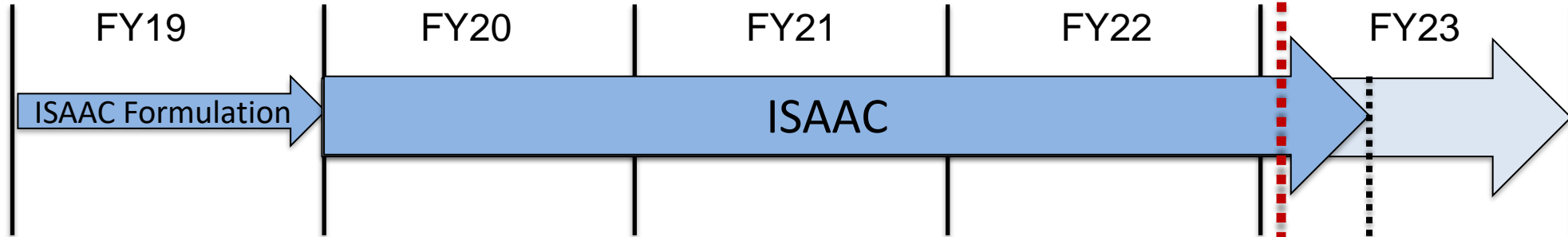
ISAAC10: Bumble operates in USL while Queen operates in NOD2



NASA astronaut Kayla Barron supporting SoundSee/ISAAC activity



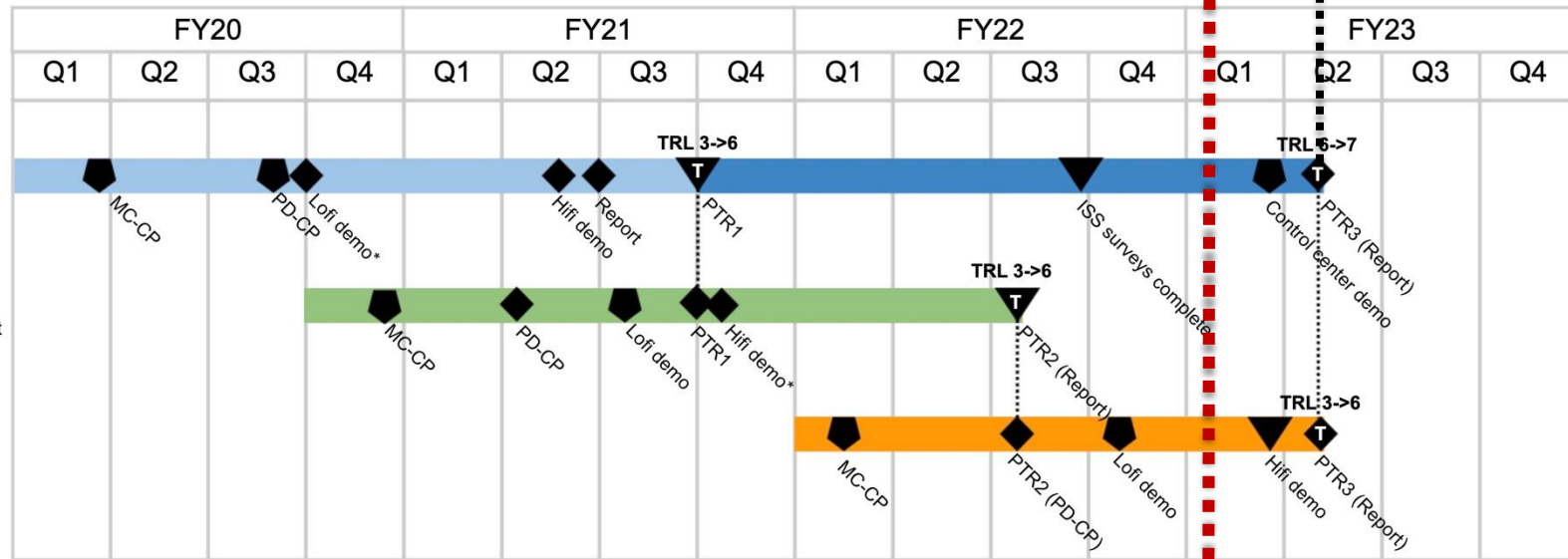
ISAAC Schedule



Phase 1 / 1X
 - Integrated data
 - Autonomous state assessment

Phase 2
 - Integrated control interface
 - Autonomous logistics management

Phase 3
 - Coordinated execution
 - Integrated fault management



▲ Project milestone ◆ Key milestone (GCD) ▼ Controlled milestone (STMD) * Dates set in §A-7.1 Gateway-ISAAC MOU
 ▼ With TAPR

We are here

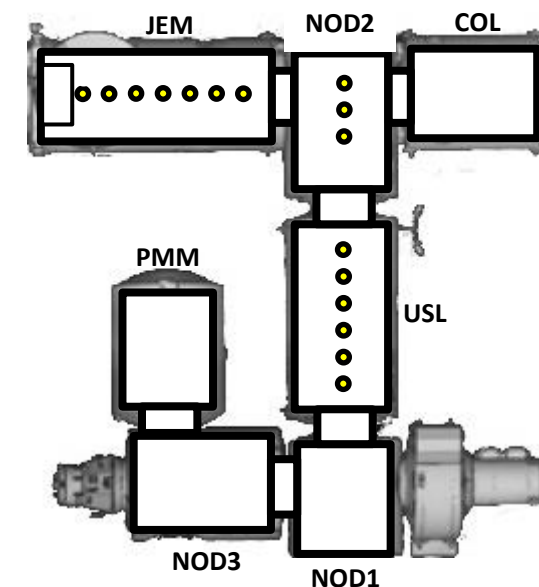
Phase 1X: Plans Forward and Infusion Plan



- **Objectives from FY22, completion rephased to FY23**
 - 3D map building
 - User interface
 - Anomaly detection
- **Possible scope change to reflect feedback from ISS program:**
 - **Targeted close-up inspection capability:** Add ISS activities to improve and streamline this capability for Astrobees, inspired by late-breaking OSO hatch seal use case
 - **ISAAC multi-sensor mapping tech transition to ISS production use:** Streamline ops and data analysis, support further ISS data collection, tech transition to production use with XF-705 Safety Video team customer



Targeted close-up inspection: Details of Astrobees photos from ISAAC11



ISAAC multi-sensor mapping: Approximate locations of panoramas collected to date

Agenda

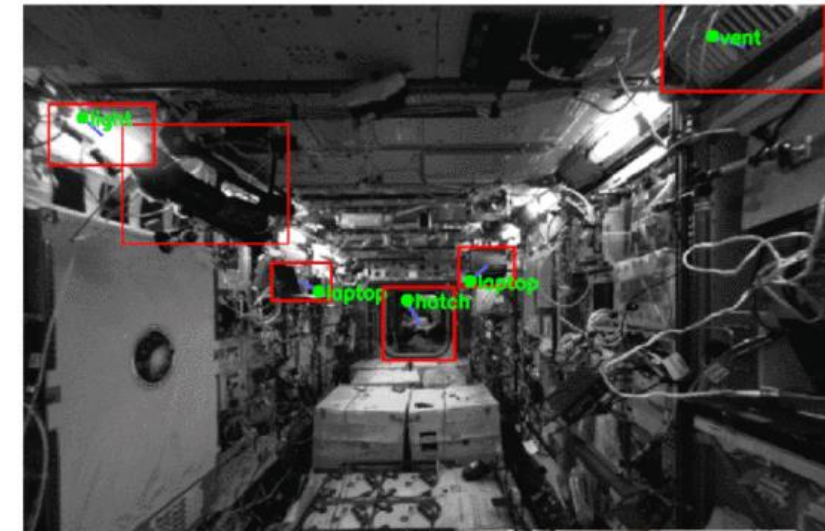


- ISAAC update
- **Localization experiments during Crew-Minimal S8 ISS activity (2022/11/01)**
- Florida Atlantic University senior design projects

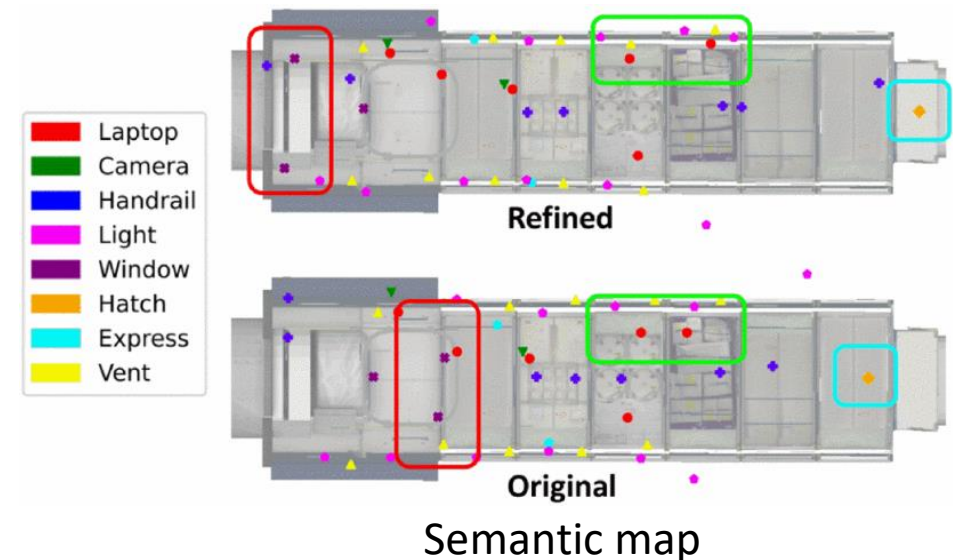
Semantic Localization Experiment



- The primary credit for this work goes to Ian Miller, a Ph.D. student at the Penn GRASP Lab, advised by Vijay Kumar, funded by a NASA NSTRF fellowship
- Semantic localization refers to using semantic object detection as a source of landmarks to use for localization
 - Semantic objects come in classes that a person might use, like “laptop”, “handrail”, etc.
 - This contrasts with the “point features” used by Astrobbee’s baseline localization. Semantic objects have the potential to be more consistently recognizable across large changes in viewpoint, illumination, etc.
- Ian’s approach:
 - Starts with a prior data set of Astrobbee NavCam images. A subset of the images are used to train a deep learning semantic object detector, then build a semantic map analogous to Astrobbee’s baseline sparse map.
 - On a later activity, the semantic localizer runs onboard the robot, performing real-time semantic object detection to extract landmarks and compare them to the prior map, providing a new input for localization. Object detection is computationally expensive and runs on the HLP.
 - The semantic localizer does not replace the existing localization inputs (visual/inertial odometry and the sparse map localizer). Instead, all three input sources are merged. The objective is to improve localization reliability, especially when point features are not being recognized, for example due to environment changes since mapping.
- Status:
 - Last year, Ian ran his system using post-activity playback of Astrobbee ISS telemetry bags and showed it improved overall accuracy, leading to a publication in ICRA this year:
 - Ian D. Miller, Ryan Soussan, Brian Coltin, Trey Smith, Vijay Kumar. Robust Semantic Mapping and Localization on a Free-Flying Robot in Microgravity. ICRA, May 2022.
 - The first experimental use in closed-loop control of Astrobbee on ISS was conducted during the Astrobbee Facility Crew-Minimal S8 activity 2022/11/01.
 - The data has yet to be analyzed. Unfortunately, the results are likely to be inconclusive because Astrobbee motion that day was observed to be somewhat erratic for unknown reasons, both with and without the semantic localizer active.



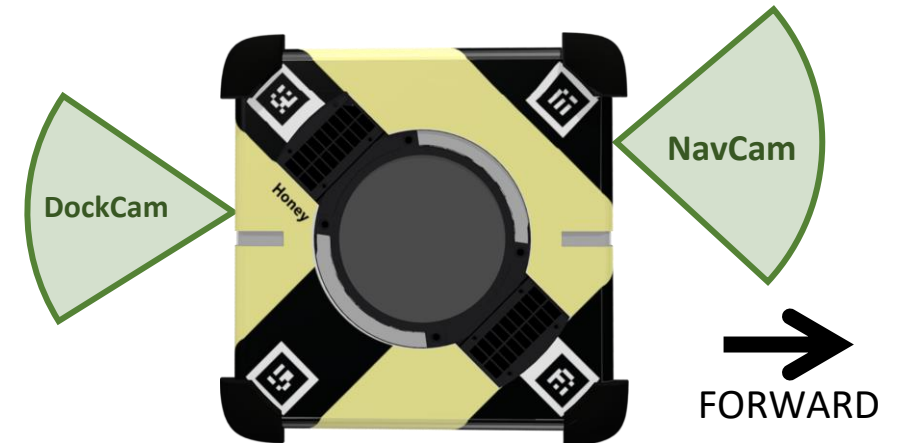
NavCam semantic object detections



NavCam+DockCam Data Collection



- **Baseline:**
 - The visual component of Astrobees general-purpose navigation relies solely on its forward-facing NavCam
 - Its rear-facing DockCam (same sensor model, similar lens) is only used to localize during docking approach, using fiducials on the dock
- However, the DockCam images could theoretically be fed into the same localization algorithms as the NavCam
- **Pros:**
 - DockCam localization might be available when NavCam is not. For example:
 - While performing a close-up inspection with the SciCam, the NavCam might be too close to the wall to see sparse map features previously mapped from further away.
 - When the task is to track a moving object with the SciCam (e.g., some SVGS experiments), the moving object in the NavCam field of view can throw off visual odometry.
 - We could localize with one camera, whichever one we expect to be more useful based on the situation, or try to use both simultaneously (about twice as much area viewed, so twice as many features)
- **Cons:**
 - Must take care not to overwhelm Astrobees processors (e.g., process alternate frames from each camera when using them together)
 - Using both cameras simultaneously tricky to integrate into baseline graph optimizer
- **Status:** Starting to collect some ISS data sets during facility CM activities, recording both NavCam+DockCam. Will enable initial feasibility testing (using post-activity telemetry playback).



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FAU Design Course



- **NASA's Astrobees/ISAAC projects are acting as a "client" for a year-long senior design course at Florida Atlantic University**
 - Brian Coltin is the lead POC from the NASA side, with support from Marina Moreira and Trey Smith
 - Prof. Zhen Ni at FAU is the course instructor
- **The course covers two academic terms (Fall 2022 + Spring 2023)**
 - The baseline expectation is that each multi-disciplinary student design team of 4-5 undergrad seniors will produce a design during the first semester and some prototype hardware during the second semester
- **As the NASA/Astrobees topic was popular with the students, two student teams were assigned to work with us. The selected project objectives are:**
 - Team 1: Design a **thermal infrared camera payload** for Astrobees.
 - Because the Astrobees robots can autonomously survey the ISS interior without requiring significant astronaut time, deploying an Astrobees thermal camera could potentially enable regular thermal mapping of much of the ISS, as well as targeted thermal inspection on demand.
 - Team 2: Design a **cargo berth fixture** for temporarily parking cargo bags during transfer ops
 - Astrobees can transfer cargo bags, but doesn't have the dexterity to manage typical restraint harnesses, bungees, etc. The cargo berth fixture would mount to a wall and provide a place for Astrobees to temporarily stow and retrieve bags using visual guidance for mating and a bag retention system that Astrobees can release remotely.
- **Future:**
 - At present, this is an exploratory side-project
 - There is no funded effort to mature and launch these payloads
 - If the prototyping effort goes well, it might be worth performing integrated payload testing with an Astrobees ground unit and seeking funding for further work.



QUESTIONS?