Current and Future Science using Free Flying Robots on the ISS
The Astrobee Facility and Research Opportunities

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and the wider Astrobee Team
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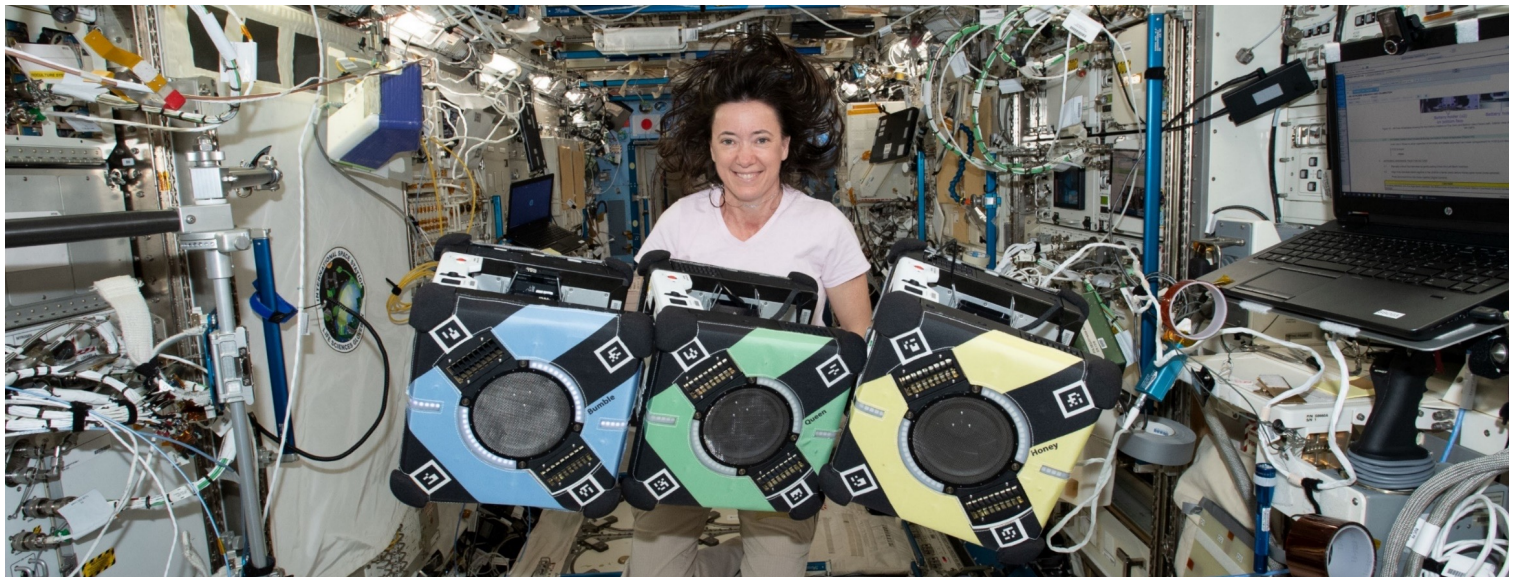
Meet The Astrobee Family
Bumble, Honey, Queen, & Crew

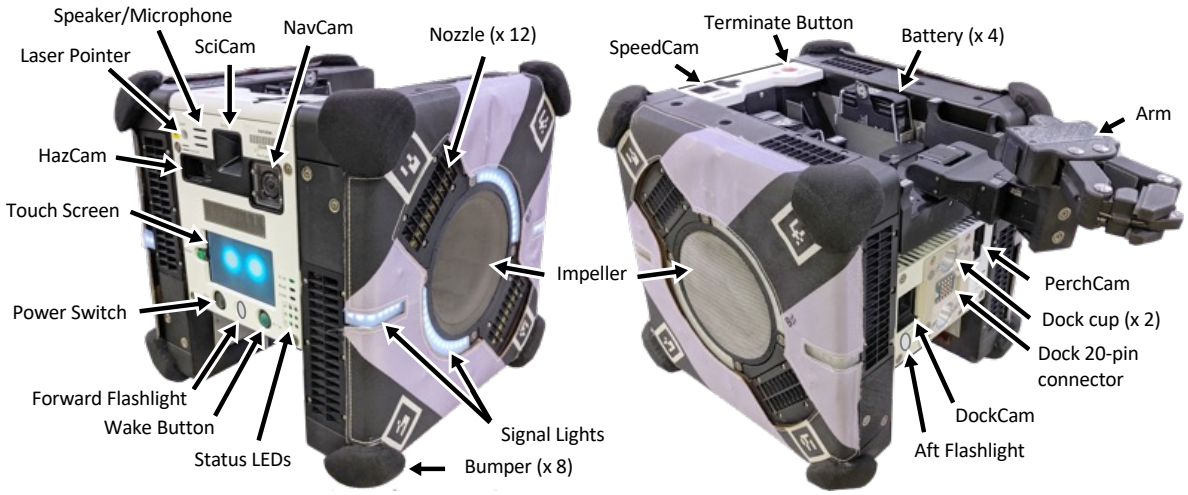


Megan McArthur, Queen unveiling, all three Astrobees, September 20th, 2021

Astrobee Objectives

- Provide a microgravity robotic research facility in the ISS US Orbital Segment (USOS), which will replace the existing SPHERES facility
- Provide remotely operated mobile camera views of the ISS USOS to enhance the situation awareness of mission control
- Perform mobile sensor tasks in the ISS USOS

Astrobee HW Overview



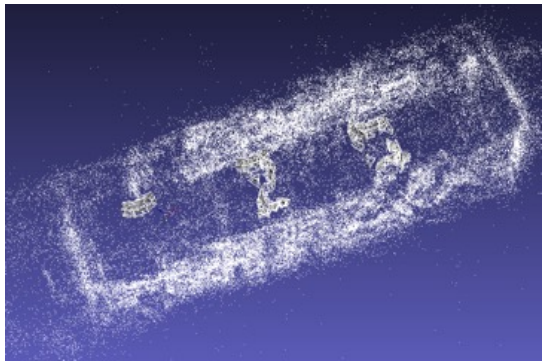
- Free flying robot inside the ISS
- 32 cm wide, ~9.1kg (2 batt., no arm)
- All electric + fan-based propulsion
- Robot arm for “perching”, ~1kg
- Three smartphone computers

- Three payload bays for expansion
- Microphone not currently enabled
- More: www.nasa.gov/astrobee

NOTE: The Astrobee shown above is a flight-like ground unit.

System Description - Navigation

- Vision-based navigation
  - Compares features with on-board a priori map
  - Incorporates inertial measurements
- Fiducials used for autonomous docking
  - Requires approximately 1 cm position accuracy



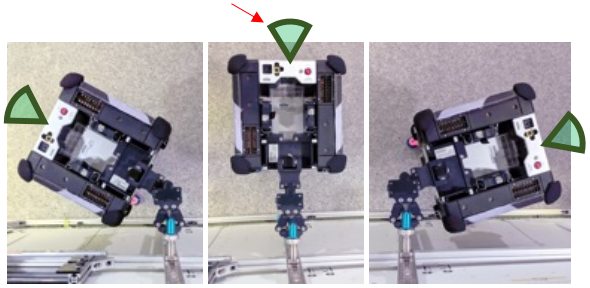
Feature map of the JEM-PM

- Visual odometry
  - Robot can continue to navigate where no map features are recognized

System Description - Perching Arm

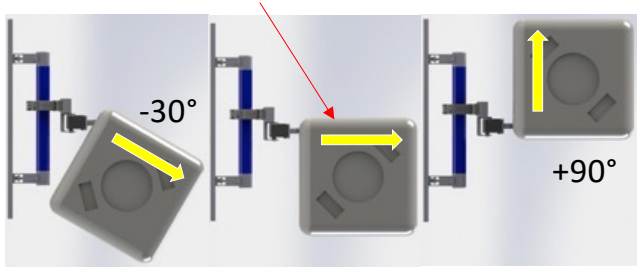
- Designed to grasp handrails
- Stows completely in payload bay
- Acts as a pan-tilt unit while perched
- Flexible and back-drivable
- May be perched manually

Camera View Direction



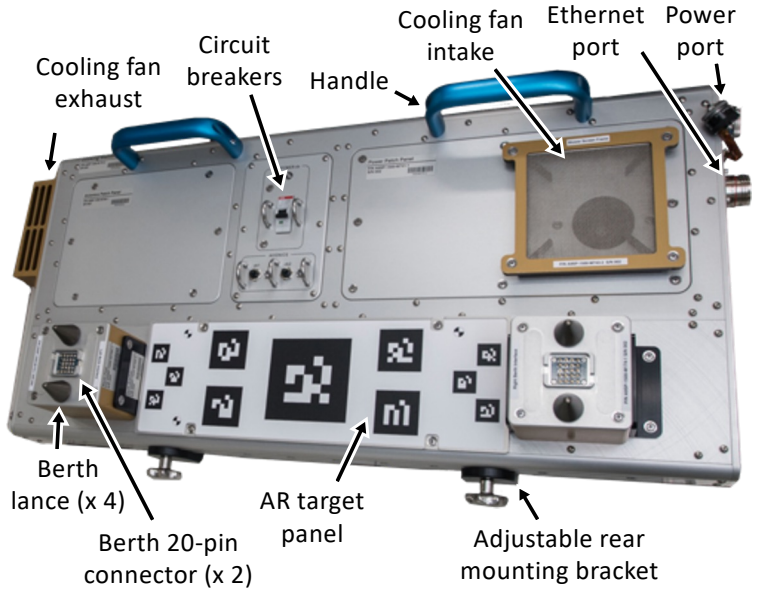
Astrobee Perching Arm pan motion

Camera View Direction



Astrobee Perching Arm tilt motion

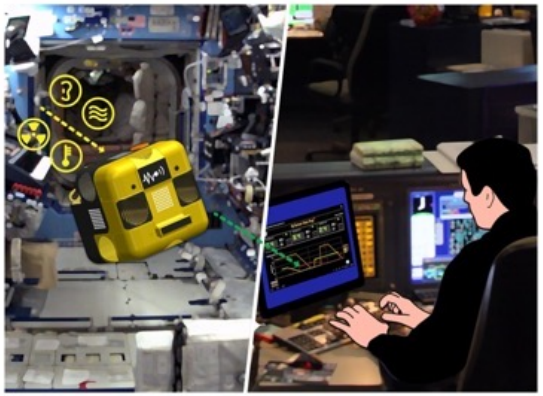
System Description - Docking Station



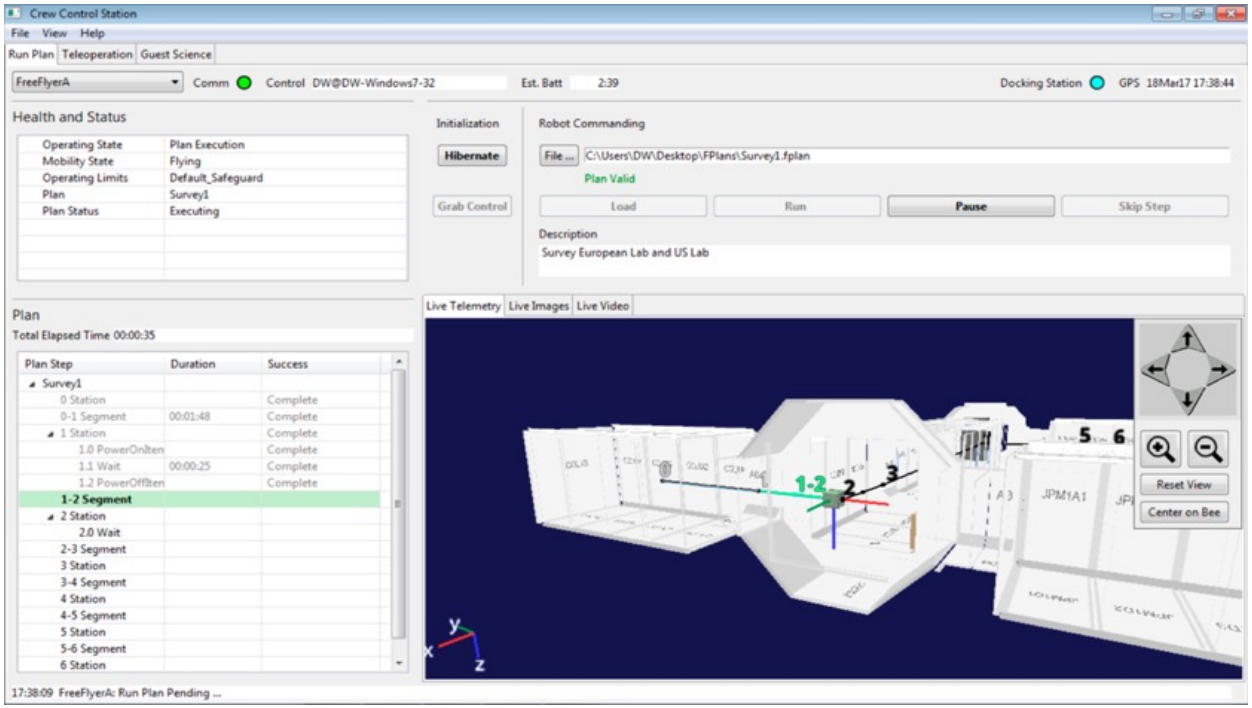
- 85 cm x 38 cm x 28 cm
- Berths for 2 free flyers
- Provides power and Ethernet
- Fiducials used for visual servoing to autonomously dock
- Magnets provide retention force

System Description - Ground Data System

- Astrobee Control Station
  - Sortie planning tool
  - Execution monitoring
    - Live telemetry
    - Image and video streams
    - 3D virtual display
  - Supervisory control (run plans or single commands)
  - Typically used by ground operators
- Crew Control Station runs on an EXPRESS Laptop Computer (ELC)
- Server for archiving and distributing Astrobee data
- Suite of engineering tools to support maintenance and software upgrades



Astrobee Control Station

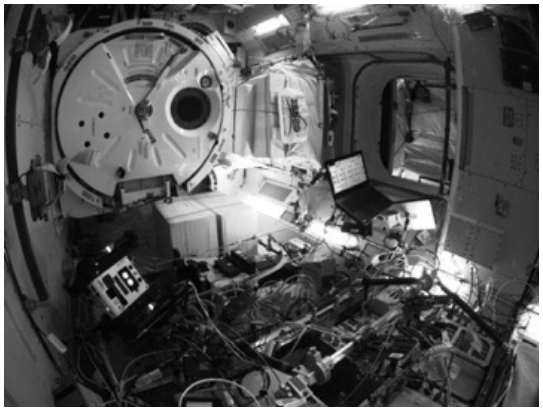


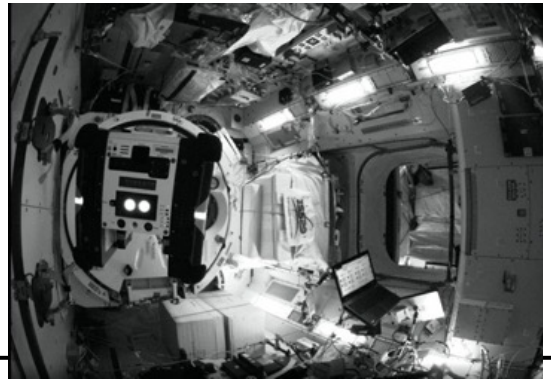
Basic Conops

- When an Astrobee is idle, it charges in its dock
- Astrobees can execute complex plans with full autonomy and no astronauts present
  - Including undock, traverse multiple modules, return to dock
- However, Astrobees run with ground operator oversight
  - When an anomaly occurs, an Astrobee generally stops and waits for operator intervention
  - It can continue operating during communication outages until it encounters an anomaly
- The operator can always take over and teleoperate
- Astronauts can also be operators, but this is will likely be a rare occurance (minimize crew time)

Perching Demonstration

- Honey perched autonomously on 07/26/2021
- Perch location was also useful to see how Bumble had become entangled.
- Operator was able to use the view from Honey to free Bumble.





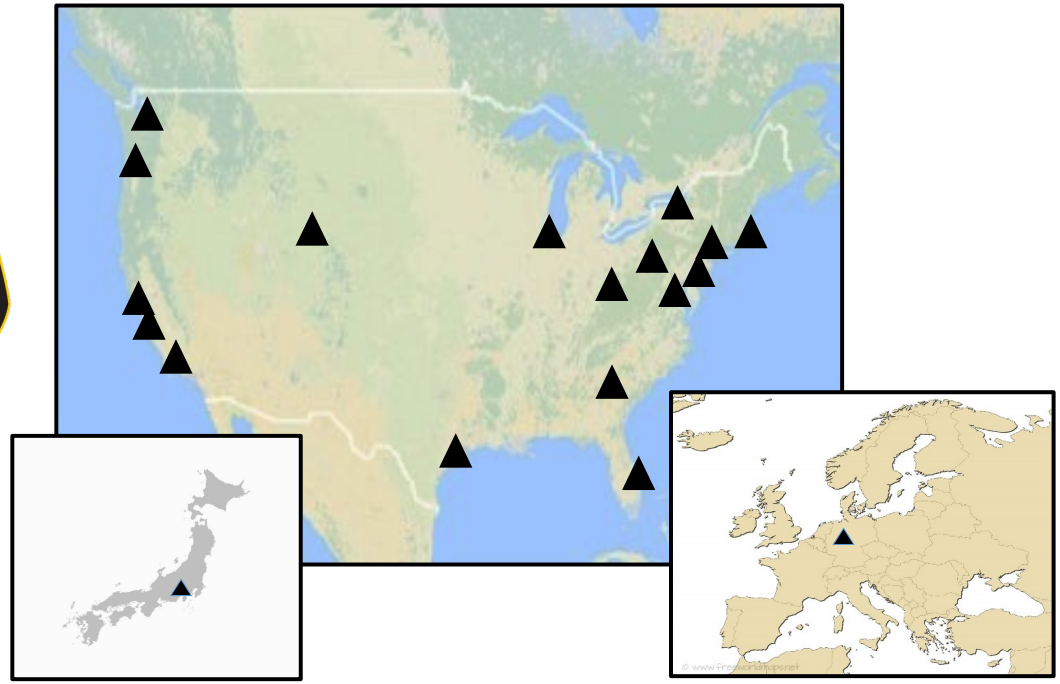
Astrobee Utilization Stats

Utilization Stats to date	
Number of on orbit operations:	123
Number of on orbit REMOTE* Test Sessions	82 (66% of total operations)
Unique Crew Members trained and who have operated Astrobee on the ISS:	25
Number of on-console hours:	900+
Crew hours	~200

* REMOTE ops are ISS Ops that were run offsite from Ames Research Center (ARC) from April 2020 to present. All other ops were run onsite at ARC.

Astrobee Payload Developers

- Payloads in ISS Integration (currently on the ISS or in development)
  - Astrobatics (Naval Postgraduate School)
  - SoundSee (Astrobotic/Bosch)
  - RFID Recon (NASA AES/REALM-2)
  - JAXA Kibo-RPC (Third Annual)
  - ISAAC (NASA STMD/GCD)
  - SVGS (FIT)
  - SOARS (Zero-g Horizons)
  - Cubee/CLING
  - Zero Robotics
- Completed Investigations:
  - Astoporter (Tethers Unlimited)
  - REGGAE (NanoRacks/Braunschweig)
  - ROAM (MIT/DLR)
  - ReSWARM (MIT)
  - Gecko (Stanford)



ISS Integration Astrobee Free flyer Highlights*

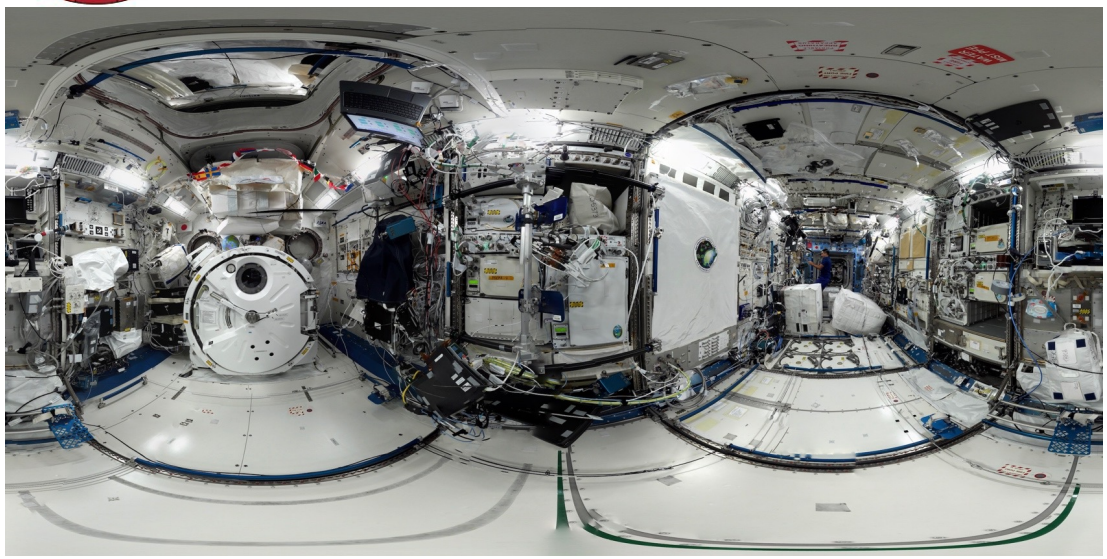
* For research objectives of each of the following Guest Science Payloads see the Astrobee Working Group presentations located at www.nasa.gov/Astrobee

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

ISAAC-6 Video

4 crew members working independently

ISAAC-6 Panorama



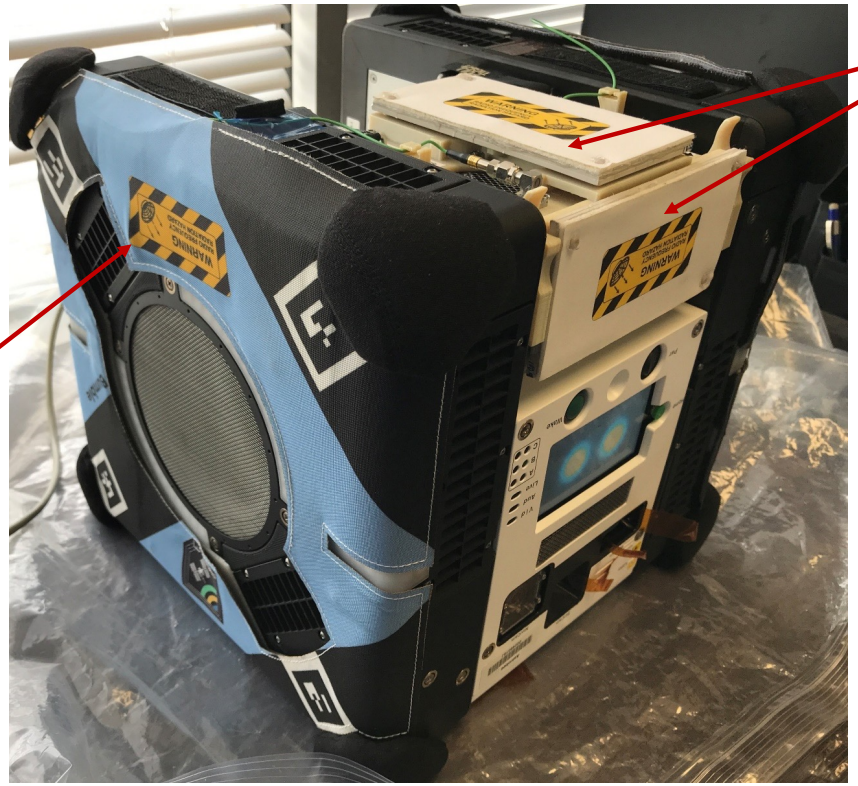
First full 360-degree spherical panorama captured with an autonomous free flyer in space (stitched from 56 SciCam images)

Queen captured NASA astronaut Raja Chari and Bumble together in the panorama.

REALM-2 Project

Radio Frequency Identification (RFID) Reconnaissance (Recon) Payload

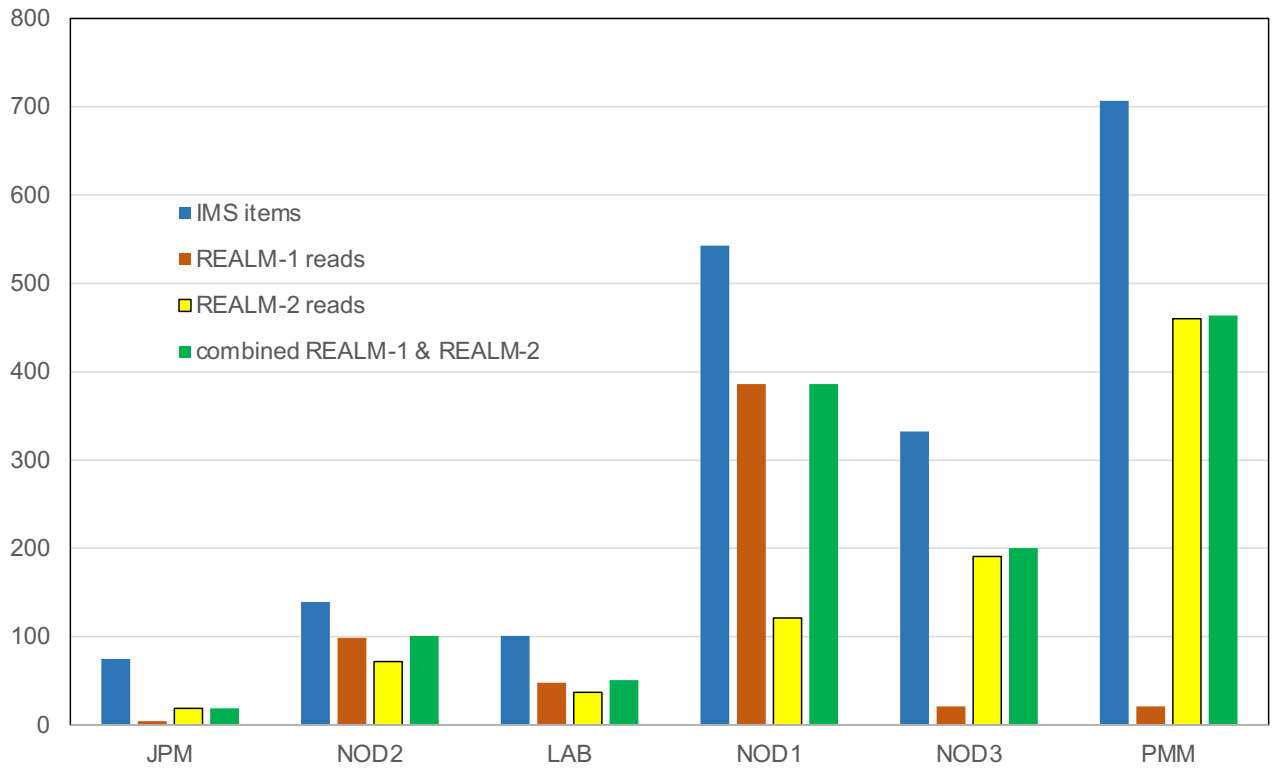
RFID Recon Installed on Astrobee



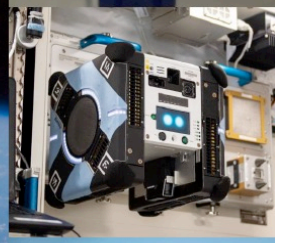
RFID reader with 2 antennas

Propulsion Module Antenna embedded in left and right skins

Accomplishments - continued



SoundSee – Bosch Research Pittsburgh



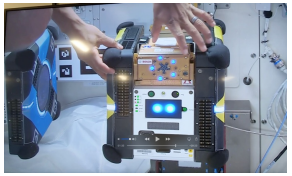
Current Status and On-orbit Ops Timeline

Dec 21st, 2020 — **Checkout**

Ops 1: Check basic recording, data handling features

Feb 16th, 2021 — **Experiment 1**

Ops 2: Check out/verified high quality data collection)

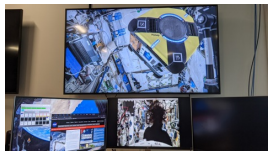


April. 2021

ISAAC collaboration

July 7th, 2021 — **Experiment 2**

Data Ops 1: Data with Astrobee in flight (acoustic imaging with ISAAC)



July 22nd, 2021

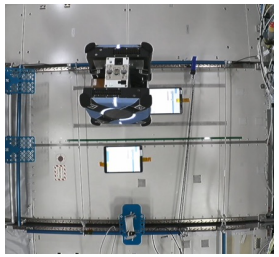
Data Ops 2: ISAAC + SoundSee Recording of JEM Plant Habitat

Sept 17th, 2021 — **Trouble shooting**

Debug Ops: Test & fix SoundSee & Astrobee time sync issue

Jan 3rd, 2022 — **Experiment 3**

Data Ops 3: ISAAC + SoundSee Machine Monitoring Simulation Experiment



Jun 2022 — **Experiment 4**

Data Ops 4: SoundSee + Acoustic Monitor Evaluation

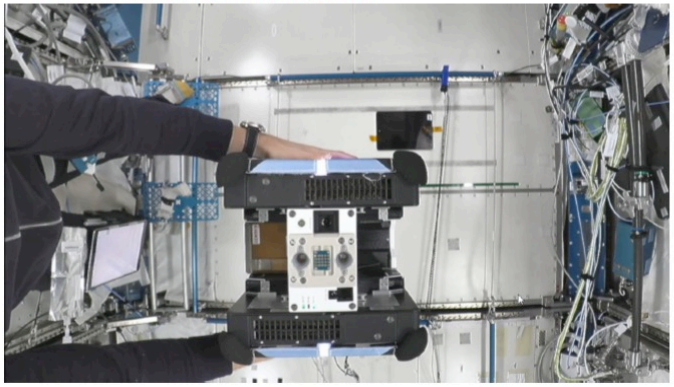
ISS U.S. NATIONAL LABORATORY

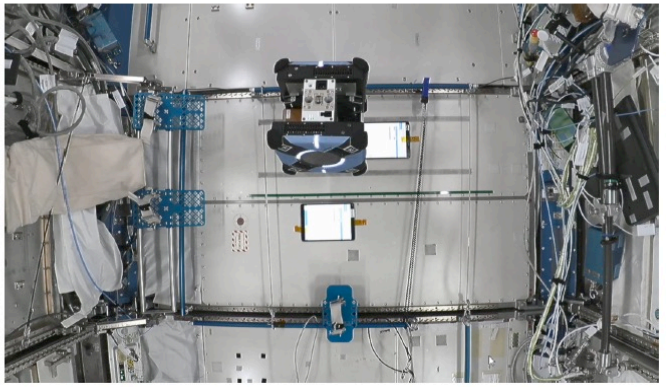
SoundSee

SoundSee (Data Ops 3): Simulated Leak Audio Data Collection

Create Simulated Audio Signals Using iPads on ISS for Evaluation

- Two iPads play audio files to simulate noise and leak audio signals
- Record audio with SoundSee with Astrobee being moved manually by astronaut, and with Astrobee navigating autonomously
- Data Analysis in progress

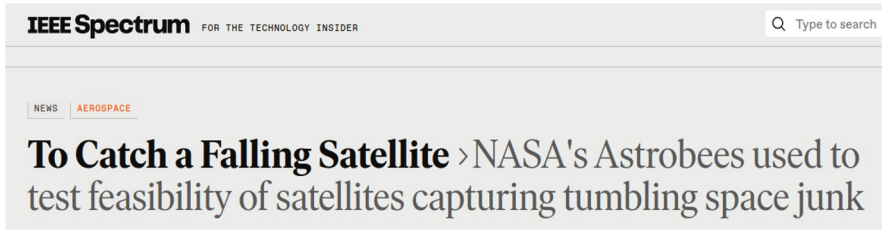


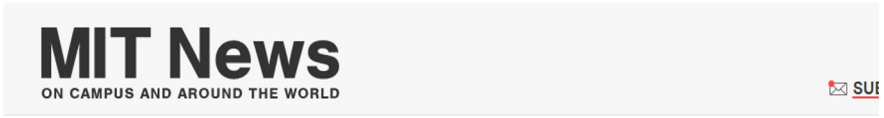


BOSCH

ROAM/TumbleDock

- ROAM/TumbleDock
  - ROAM: **R**elative **O**perations for **A**utonomous **M**aneuvers
  - **Autonomous** rendezvous with non-cooperative tumbling targets



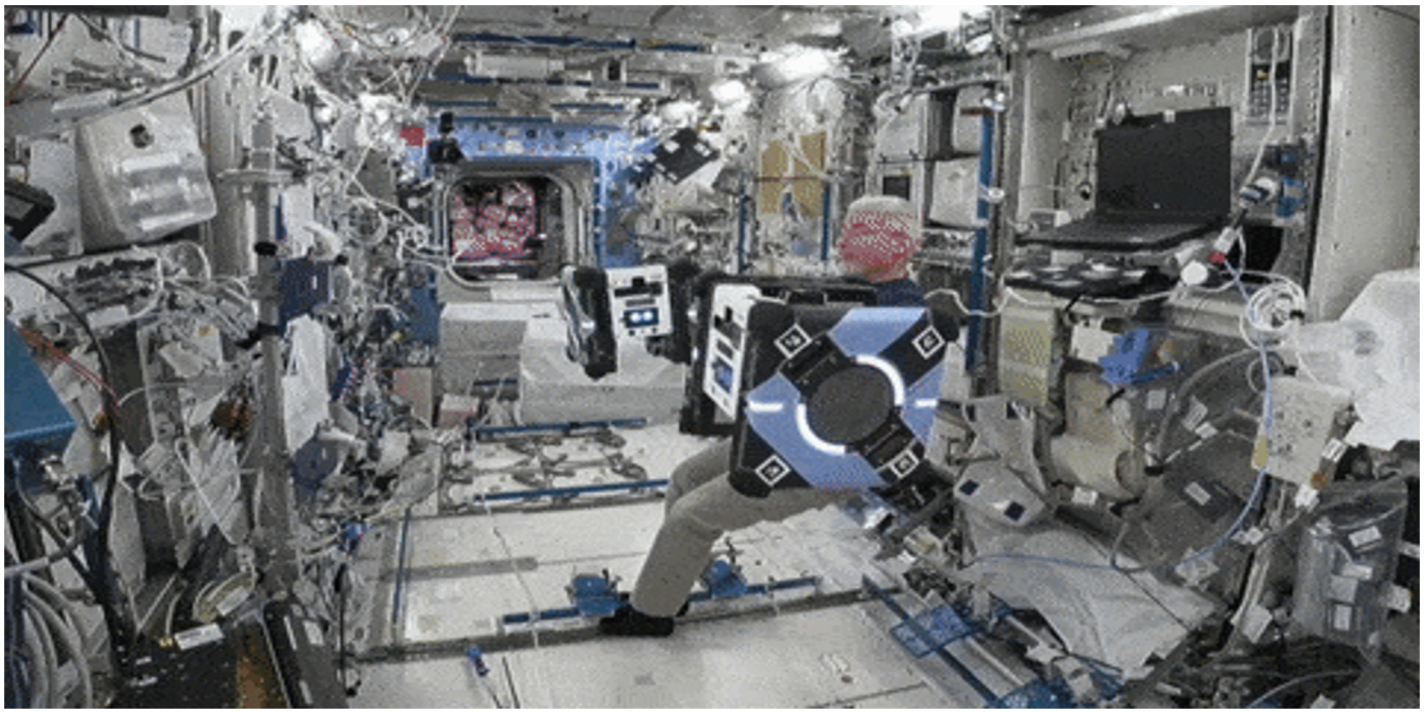


How to reach a tumbling target in space

Experiments aboard International Space Station demonstrate a potential solution for cleaning up orbital debris and repairing damaged satellites.

ROAM Science 2

- Best “full pipeline” run
- 2-3 additional “close” full pipeline runs completed
- Localization updates, first full verification of all pipeline components



Astrobatics

NASA Ames Research Center,
Intelligent Robotics Group (IRG),
Moffett Field, California

Naval Postgraduate School,
Spacecraft Robotics Laboratory (SRL),
Monterey, California

Investigate self-toss maneuvers with the Astrobee free-flyer vehicle and its 3 Degree-Of-Freedom robotic arm in simulation, ground testing, as well as aboard the International Space Station. Composed of five planned ISS sessions, of

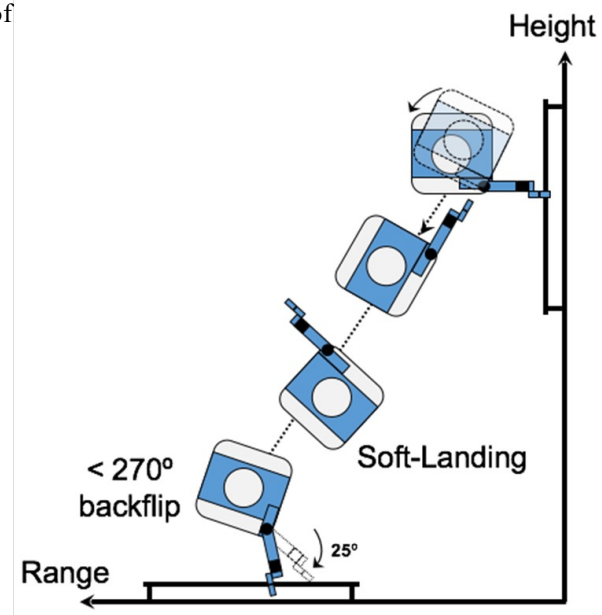
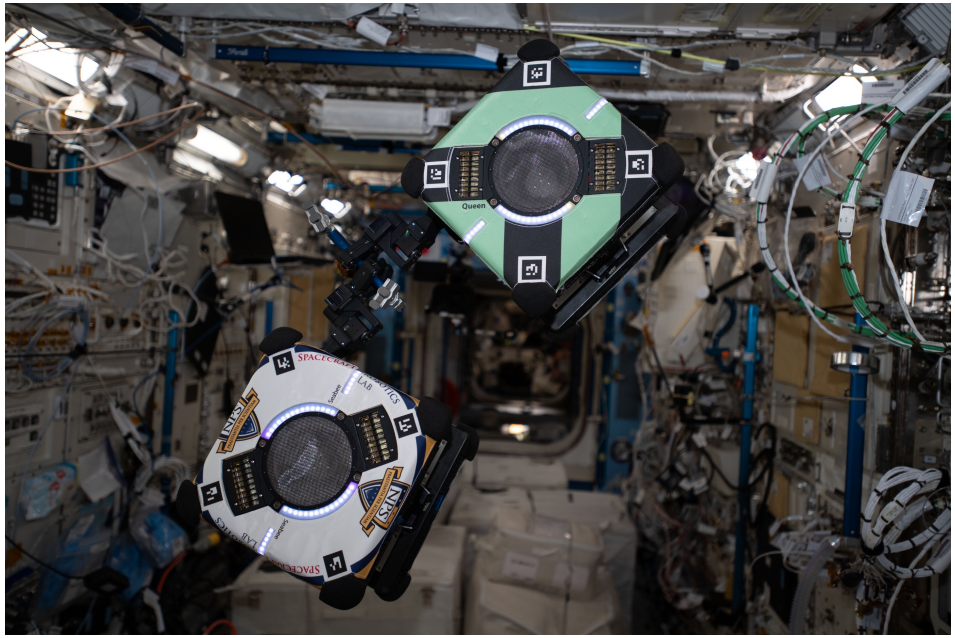


Illustration of Astrobee Self-Toss Maneuver

Astrobatics S3 session:
ISS November 2021 / February 2022



11/2021 Two of the space station's free-flying Astrobee robots perform operations for Astrobatics, which demonstrates a hopping or self-toss maneuver that could serve as a means of robotic propulsion that uses very little propellant or fuel. **Credit: NASA**

https://www.nasa.gov/mission_pages/station/research/news/space-station-science-highlights-22nov21

Exploring dynamic maneuvers with Astrobee/s aboard the International Space Station.

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Dr. Marcello Romano
Professor (Tenured)
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Dr. Stephen Kwok-Choon
NRC Postdoctoral Research Associate
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SVGS

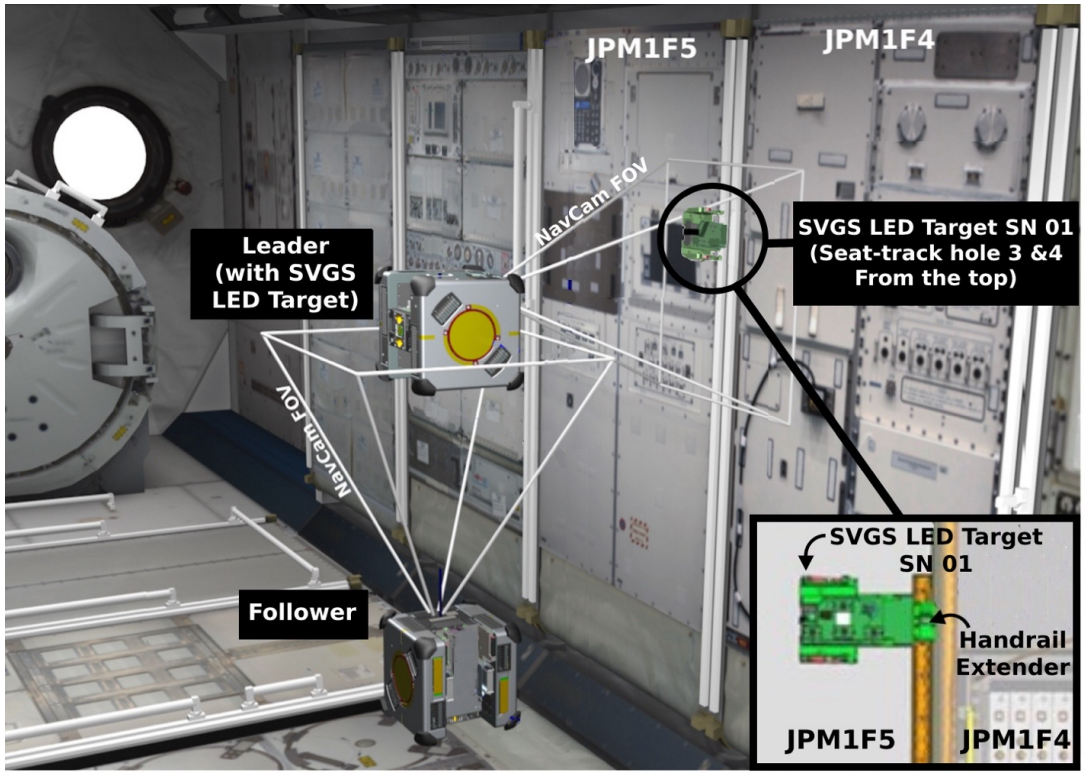
Smartphone Video Guidance Sensor
Vision-Based Navigation for Formation Flight on ISS

HECTOR GUTIERREZ
FLORIDA INSTITUTE OF TECHNOLOGY - AEROSPACE SYSTEMS AND PROPULSION LAB

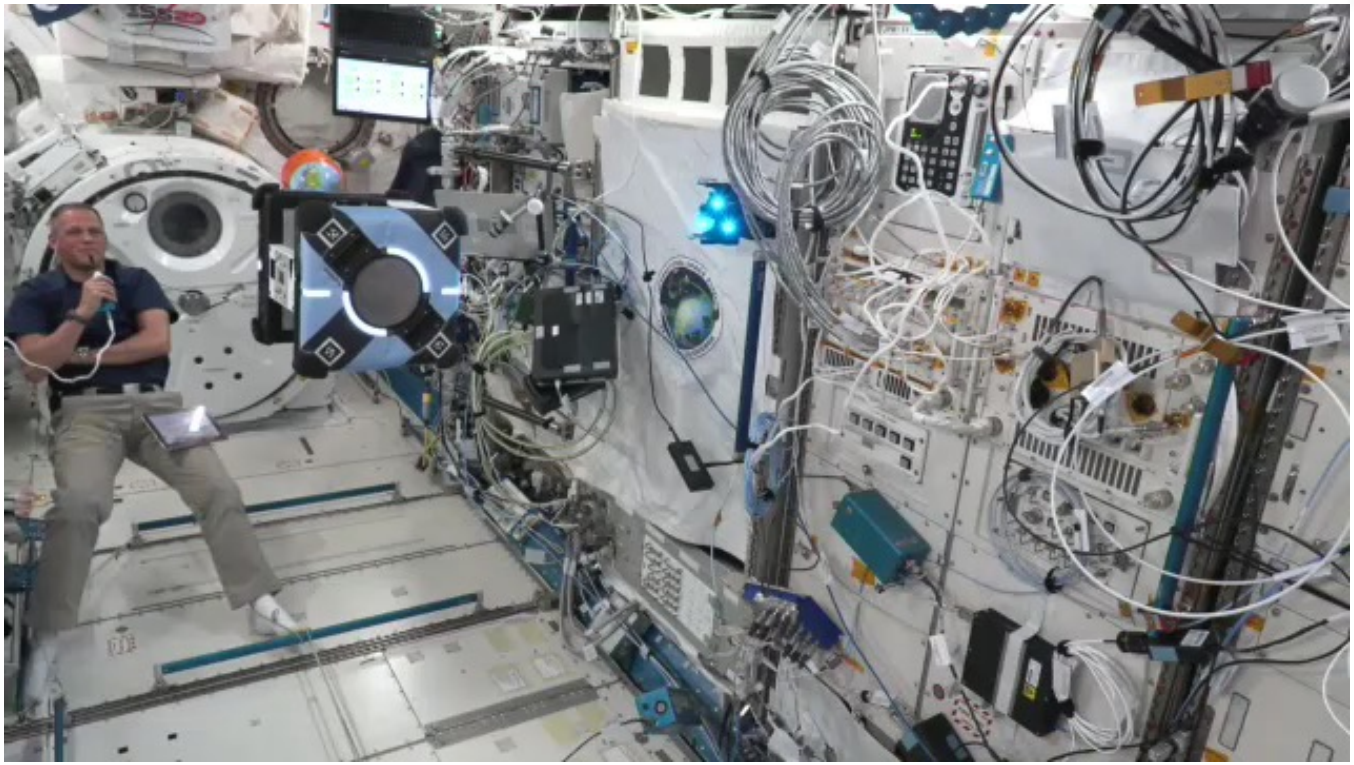
Follower Maneuver

"Leader" Astrobee performs square maneuver in horizontal plane w.r.t. SVGS beacon

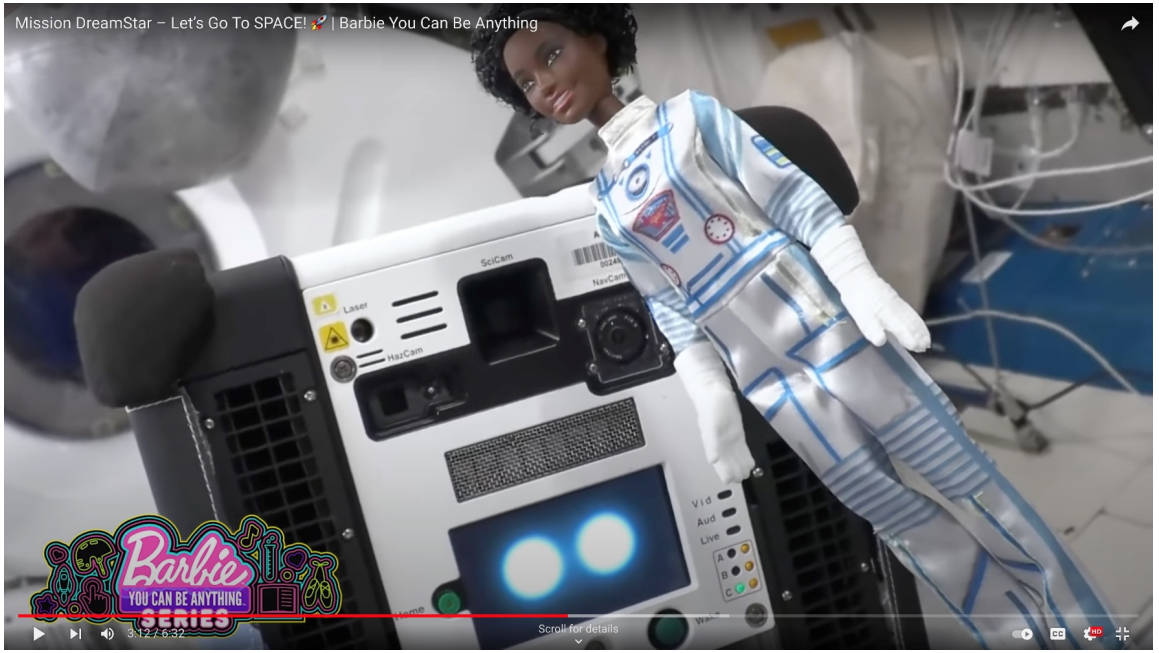
"Follower" Astrobee follows leader at set distance



SVGS-Maneuver 1A



Mission DreamStar



https://youtu.be/8zFdrgl8XpQ

3-years!

ISS Research
@ISS_Research

Happy 3-year @Space_Station-iversary to this trio of buzzing bots!
In that time, the Astrobees have participated in student STEM challenges, tested out robotic technologies, and helped researchers try out new adhesive techniques. go.nasa.gov/3kkWkbE

NASA Ames and 2 others

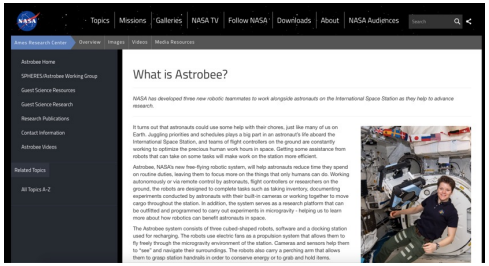
9:57 AM · Apr 27, 2022 · Twitter Web App

Apr 27, 2022

NASA Celebrates Three Years of Astrobees Buzzing on Space Station

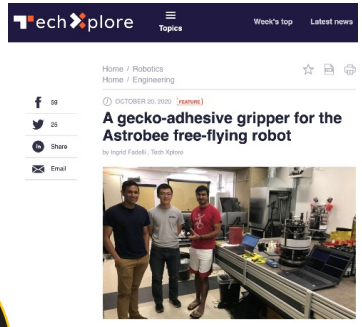
NASA astronaut Shane Kimbrough poses aboard the International Space Station with all three Astrobee robotic free-flyers.
Credits: NASA/Shane Kimbrough

Web Features & Astrobee Contact Info

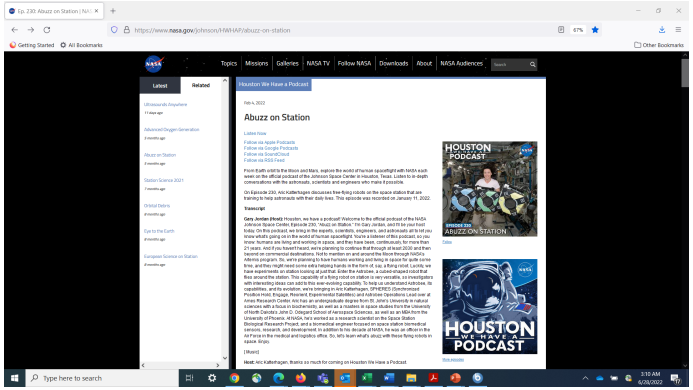


www.nasa.gov/Astrobee

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



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



Houston, we have a podcast!
Episode 230 - January 11, 2022
https://www.nasa.gov/sites/default/files/atoms/audio/ep230_a_buzz_on_station.mp3

Process to place payloads onto the Astrobee Facility PIA User List

- Sponsor submits request to OZ3/Astrobee Facility Tech Monitor, Henry Orosco, email address henry.y.Orosco@nasa.gov
  - Sponsors can be NASA or NL
  - Submission should include overview of the Payload and its objectives. Overview should include:
    - Payload Name
    - Hardware or Software Availability Date
    - Sponsor
    - Research Objectives
    - Unique Business considerations
    - Points of Contact and Additional information deemed important
- Submission assessed for feasibility and OZ3/
- Accepted submission are brought forth to OZ management final approval to place on Astrobee Facility PIA Users List
- Sponsors will be notified if the submission was accepted and final disposition


QUESTIONS?