



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



Aric Katterhagen^{1,2}, Jose Benavides¹, Maria Bualat¹, Trey Smith¹, Jonathan Barlow^{1,3}, M. Vargas^{1,4}, Roberto Carlino¹,
and the Astrobee Team

¹NASA Ames Research Center, Moffett Field, CA ² The Bionetics Corporation, Inc. ³ KBR, ⁴ MEI



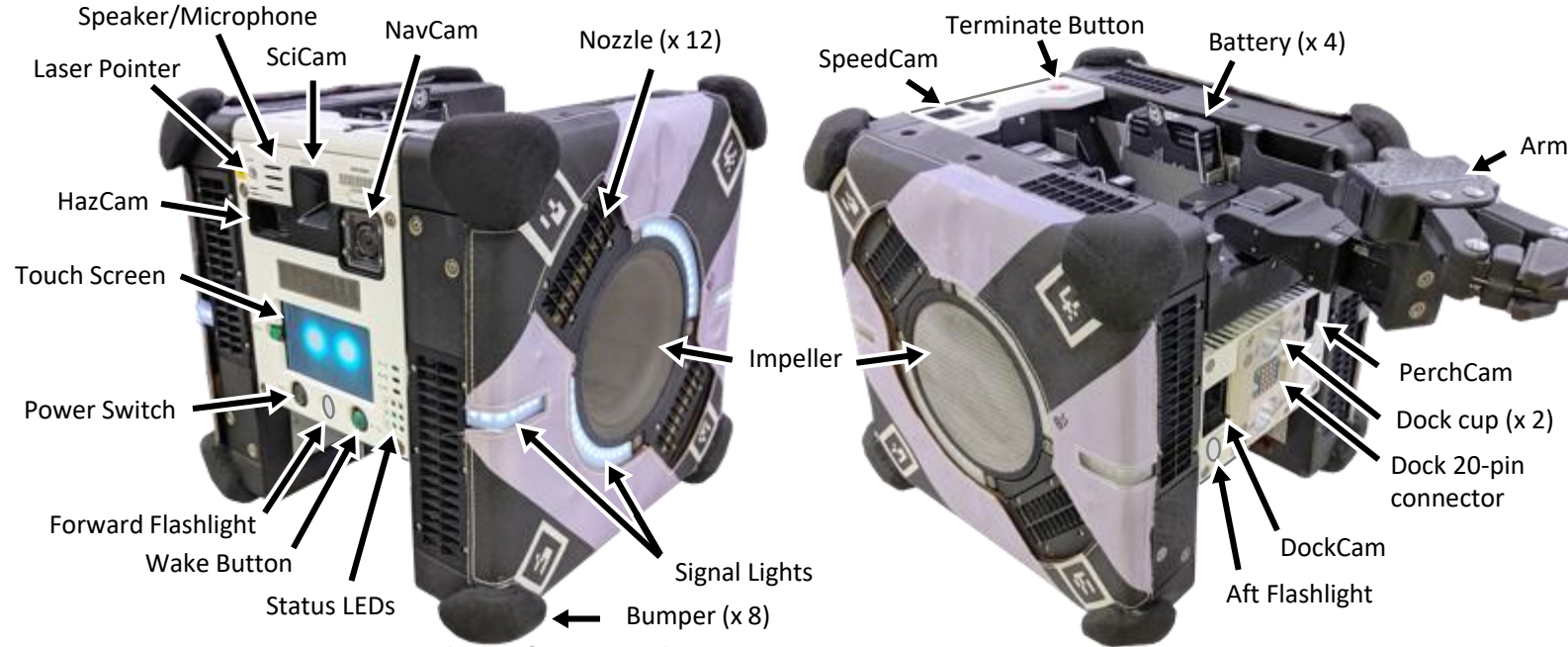
The Astrobee Family Bumble, Honey, Queen, & Crew



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



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





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:	25
Number of on-console hours:	900+
Crew hours	~200

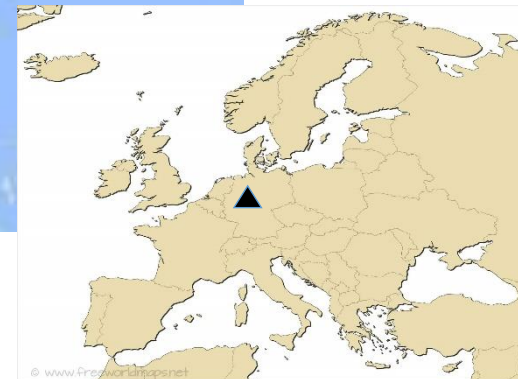




Astrobee Payload Developers



- Projects actively working towards ISS payloads
 - Astrobatix (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
- Complete:
 - Astoportor (Tethers Unlimited)
 - REGGAE (NanoRacks/Braunschweig)
 - ROAM (MIT/DLR)
 - ReSWARM (MIT)
 - Gecko (Stanford)





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



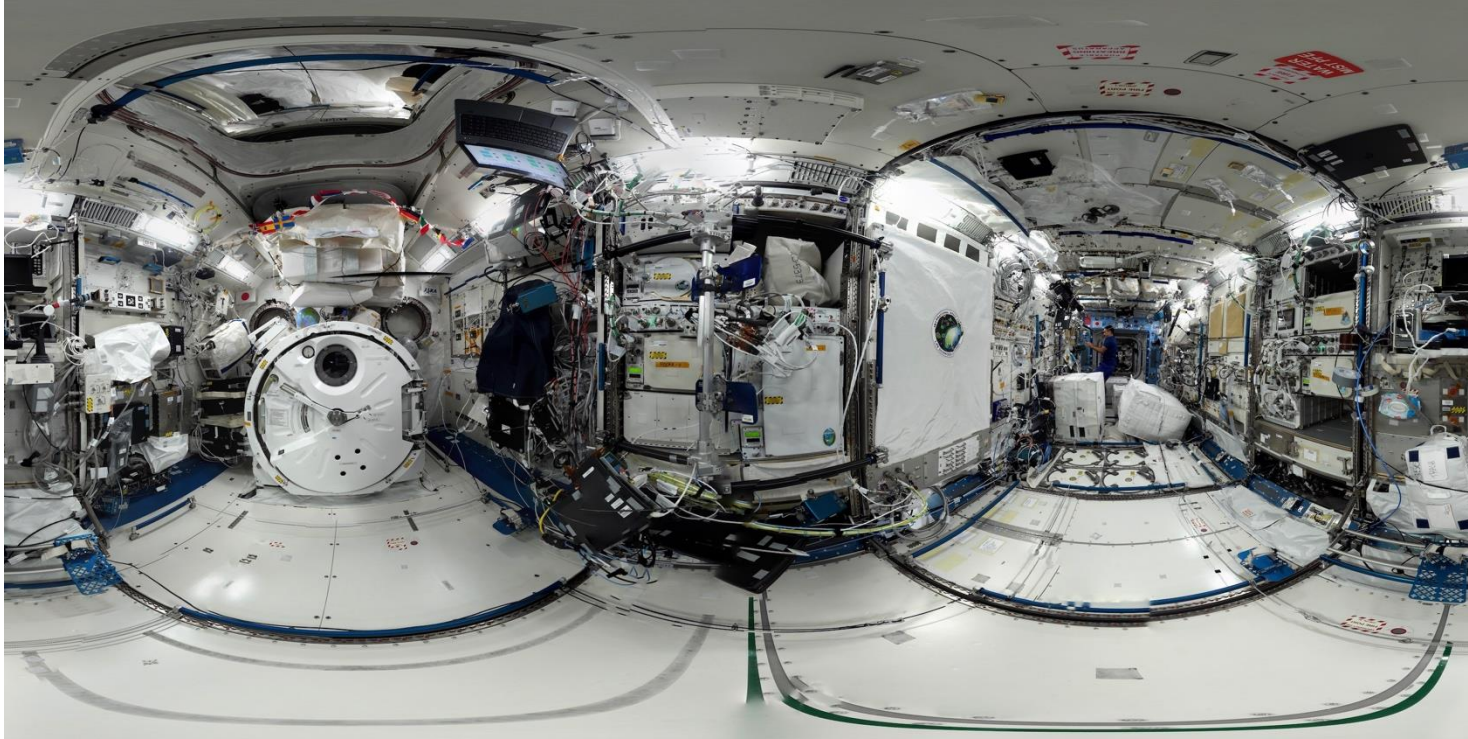
ISAAC-6 Video

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



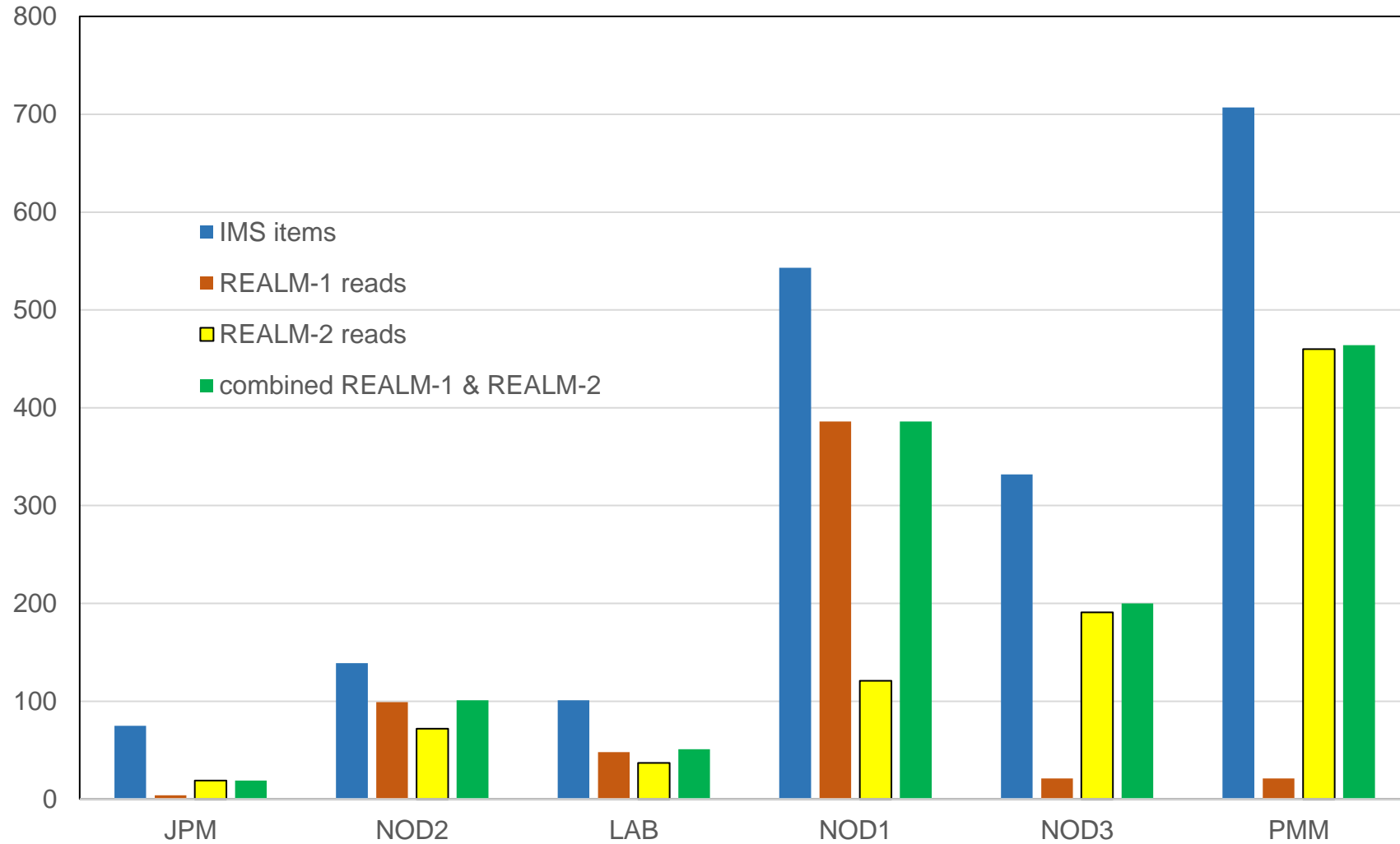
RFID reader with
2 antennas

Propulsion
Module
Antenna
embedded in
left and right
skins





Accomplishments - continued





SoundSee – Bosch Research Pittsburgh



SoundSee Mission – Acoustic Monitoring of the International Space Station



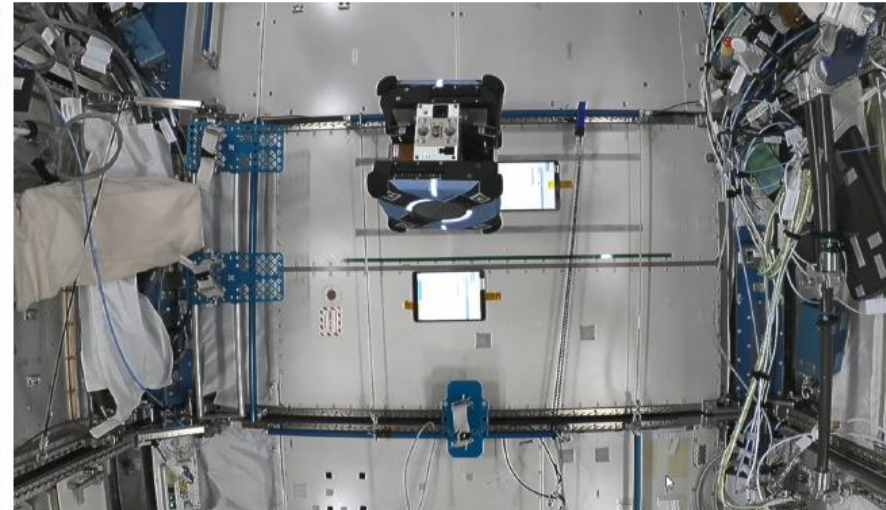
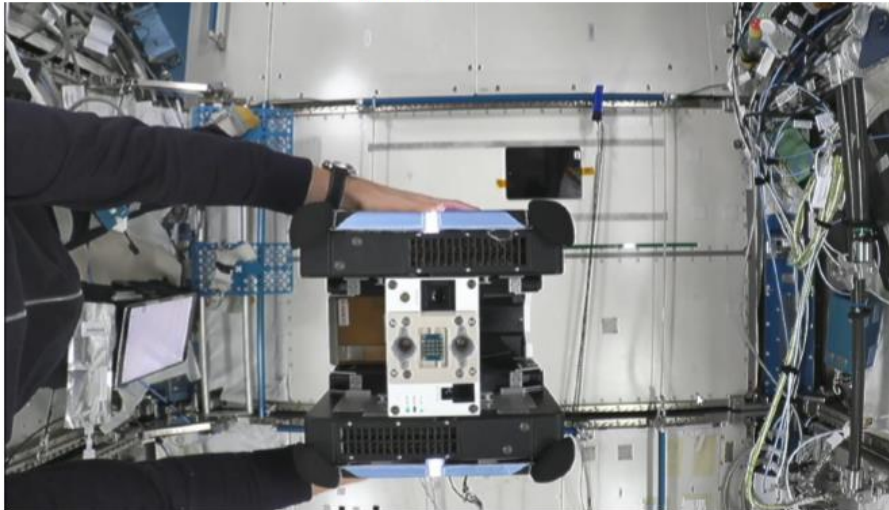


SoundSee



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 Astrobees being moved manually by astronaut, and with Astrobees navigating autonomously
- ▶ Data Analysis in progress





MIT-DLR ROAM/TumbleDock



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

IEEE Spectrum FOR THE TECHNOLOGY INSIDER

Q Type to search

NEWS AEROSPACE

To Catch a Falling Satellite > NASA's Astrobes used to test feasibility of satellites capturing tumbling space junk

MIT News
ON CAMPUS AND AROUND THE WORLD

SUBSCRIBE

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.

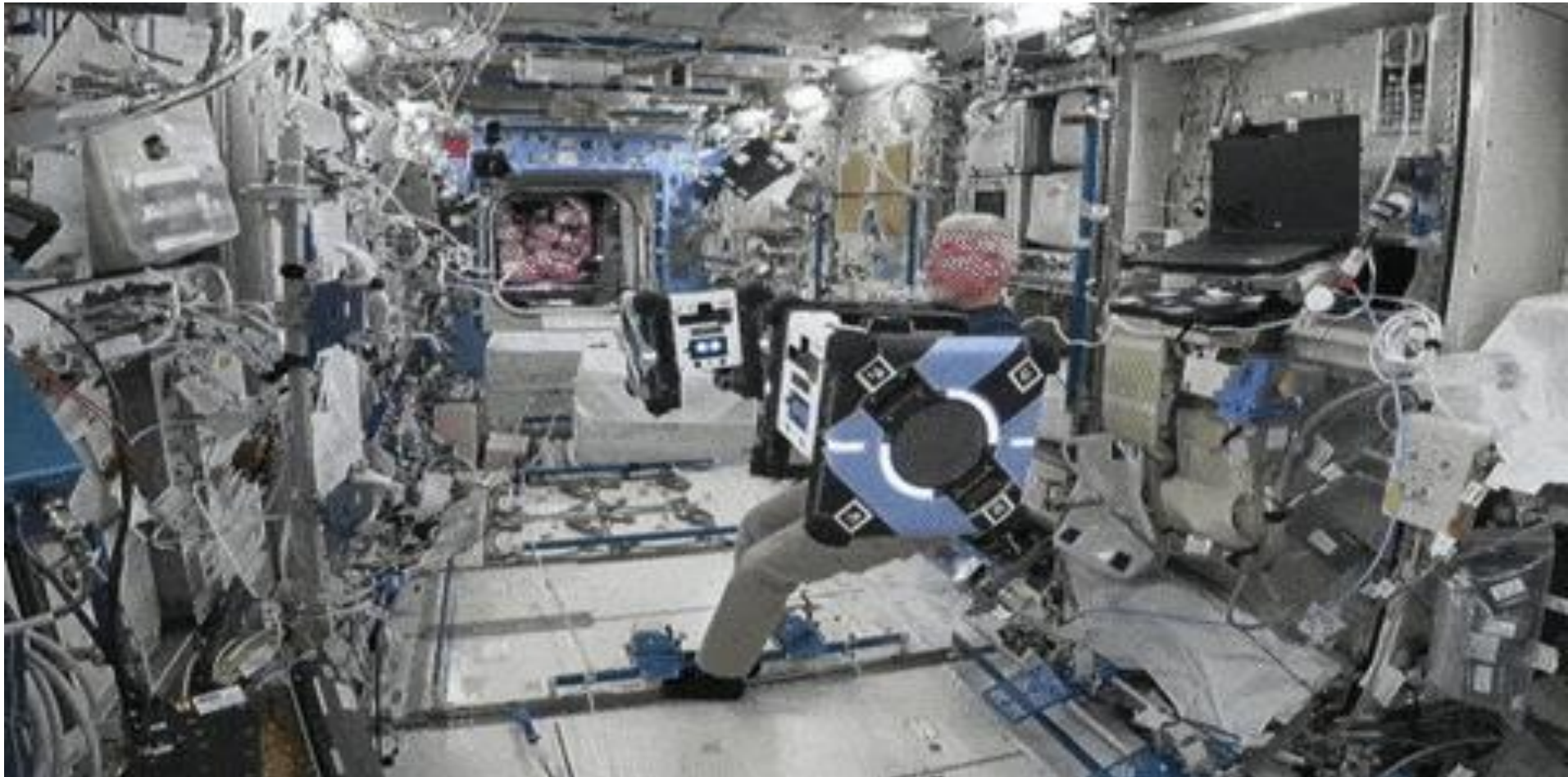




ROAM-2

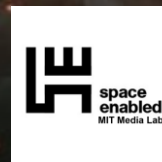
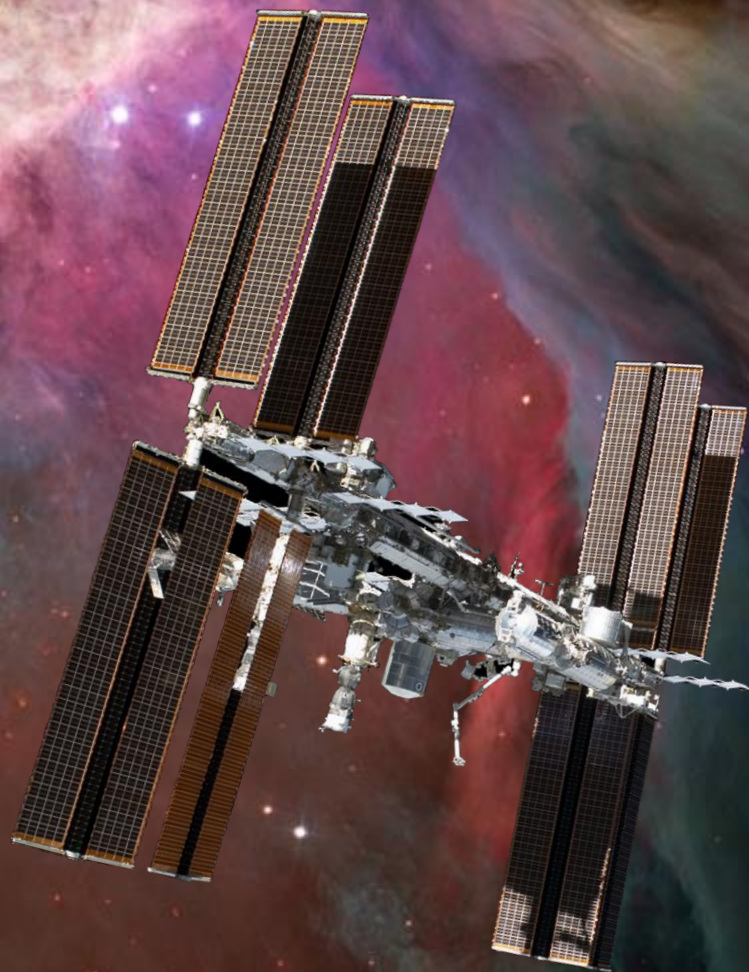


- Best “full pipeline” run yet
- 2-3 additional “close” full pipeline runs
- Localization updates, first full verification of all pipeline components



ZERO ROBOTICS

ISS PROGRAMING CHALLENGE





Zero Robotics: Our Impact

10 Years of ZR on the International Space Station!

20,000 Students writing code for satellites in space

- 15,000 HS students;
- 5,000 MS students
- 1M student/hrs

16 states; **16** countries

- 14,000 US students;
- 6,000 International students





In 2021, Zero Robotics hosted a transitional version of Zero Robotics that used the simulation based on SPHERES while preparing to set up the Astrobee-based system.



- **30** Participating Teams registered from across the US
- **~200** Middle School students participated
- **85** In/Formal Educators trained in ZR Coding
- **2** MIT Students supported the ZR/Astrobee transition
- **30 College Interns** provided by The Aerospace Corporation to virtually support ZR's Summer 2021 Space Coders Camp

We are applying for a second year of funding from Aerospace Corporation to support 2022!





The Zero Robotics Team



- Danielle Wood, MIT, Principal Investigator
- Katie Magrane & Team, Victoria Nguyen, Ryan Thompson, John Scharff, Innovation Learning Center
- Alvar Saenz-Otero, MIT ZR Co-Founder and Technical Expert
- Wendy Feenstra, Aurora Flight Sciences
- Mizanul Chowdury, Varset Engineering, Technical Expert
- Gladys Ngetich, MIT PostDoc; Scott Dorrington (Incoming MIT Postdoc)
- Yiyun Zhang, Kristen Ammons, M. Regina A. Moreno, MIT Grad Students
- Darius Nguepi, MIT Undergrad Student
- + Many collaborators, educators and supporters around the world!





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 Astrobees 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

ASTROBATICS

Simulation of a hopping maneuver
March 2018

PI: Prof. Marcello Romano
Co-I: Dr. Josep Virgili-Llop

Naval Postgraduate School
Spacecraft Robotics Laboratory
Prof. Marcello Romano – mromano@nps.edu

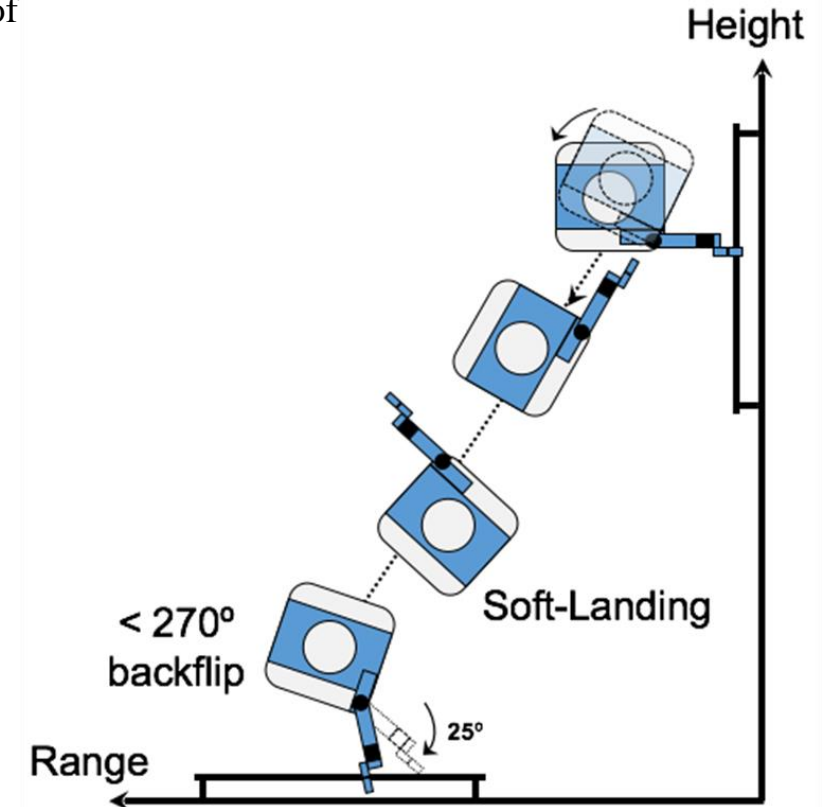
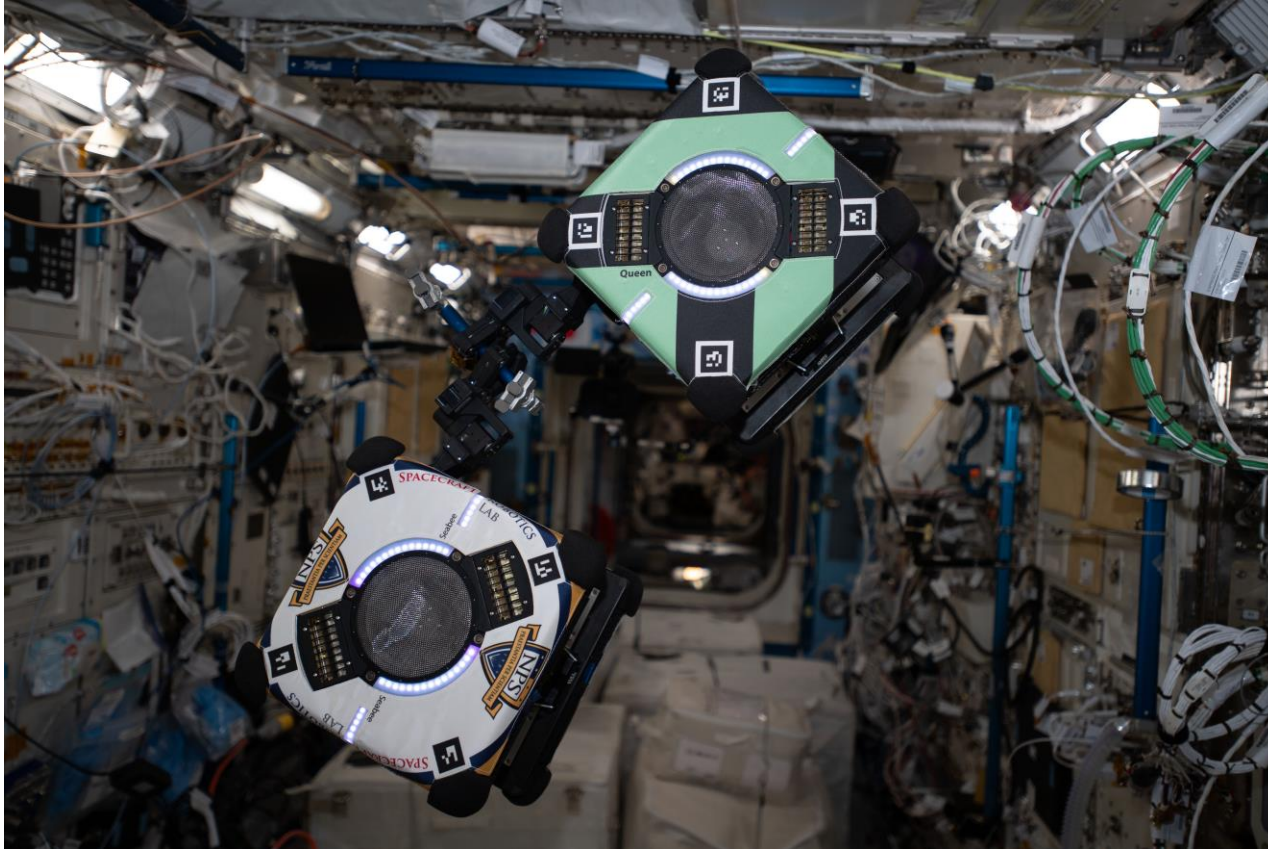


Illustration of Astrobees Self-Toss Maneuver



Astrobotics S3 session: ISS November 2021 / February 2022



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

Contact:

Dr. Jennifer Hudson

Research Associate Professor

jennifer.hudson@nps.edu

Dr. Marcello Romano

Professor (Tenured)

mromano@nps.edu

Dr. Stephen Kwok-Choon

NRC Postdoctoral Research Associate

stephen.kwokchoon.mp@nps.edu

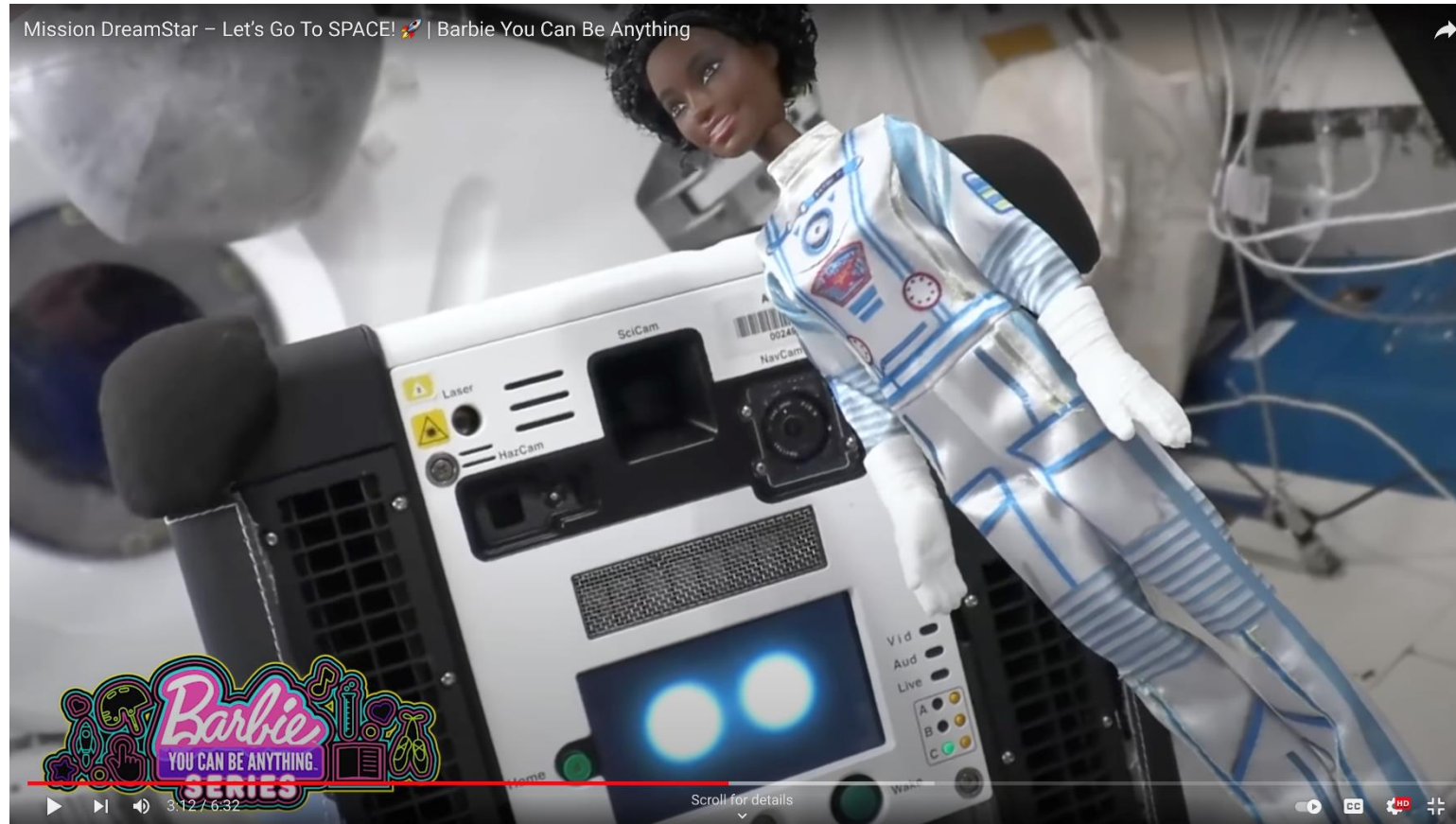
11/2021 Two of the space station's free-flying Astrobee robots perform operations for Astrobotics, which demonstrates a hopping or self-toss maneuver that could serve as a means of robotic propulsion that uses very little propellant or fuel. **Credit: NASA**

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





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 Astrobes 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 Astrobes Buzzing on Space Station



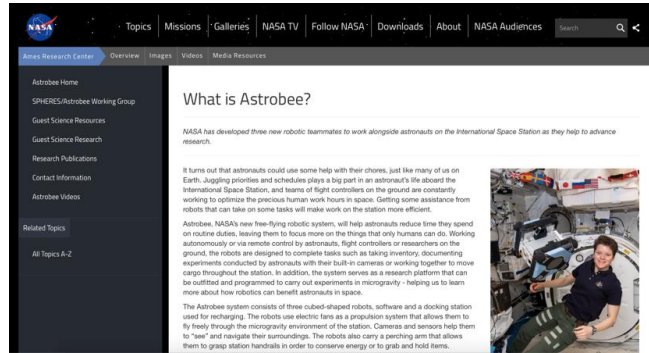
NASA astronaut Shane Kimbrough poses aboard the International Space Station with all three Astrobee robotic free-flyers.

Credits: NASA/Shane Kimbrough





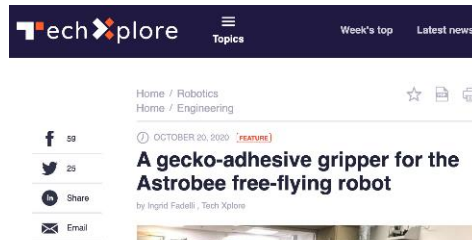
Web Features



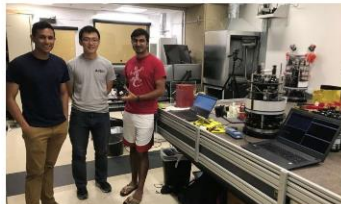
www.nasa.gov/Astrobbee

Hi Honey! NASA's Second Astrobbee Wakes Up in Space

Hi Honey! NASA's Second Astrobbee Wakes Up in Space

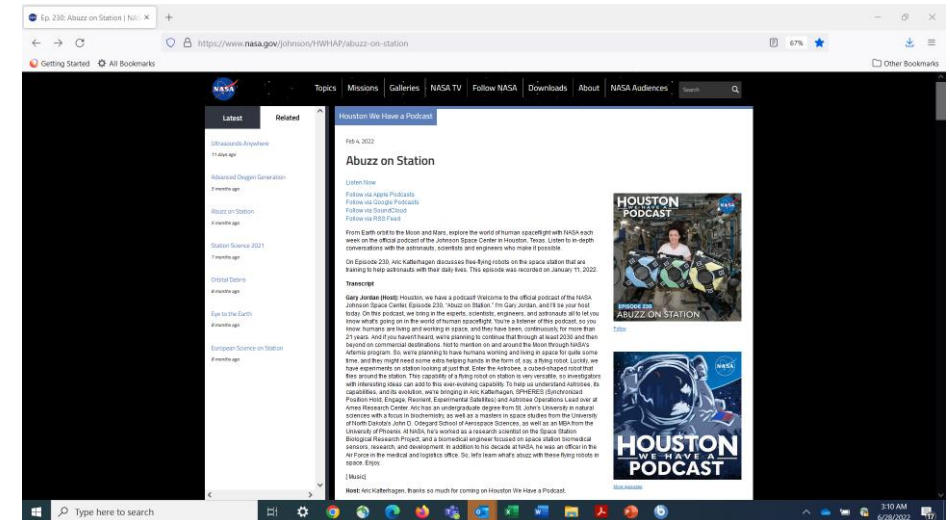


A gecko-adhesive gripper for the Astrobbee free-flying robot



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





QUESTIONS?