SPHERES/Astrobee Working Group (SAWG)

Quarterly Meeting

Nov. 6th, 2019

Agenda

Project Overview

Why Free Flyers on ISS? Provide a risk-tolerant testbed to:

- Enhance & Enable Human Exploration (e.g. Gateway)
  - Astrobee can potentially perform a range of Intra-Vehicluar Robotics (IVR) caretaking tasks to help maintain and protect the Gateway, particularly during uncrewed mission phases.
- Perform Fundamental Research

Objectives

- Ensures the facility readiness for ISS Astrobee test sessions
- Provides real-time ISS test session Ops support, and Increment Planning
- Supports a diverse user community of government, commercial, and academic investigators to enable Free-Flyer research

Current activities

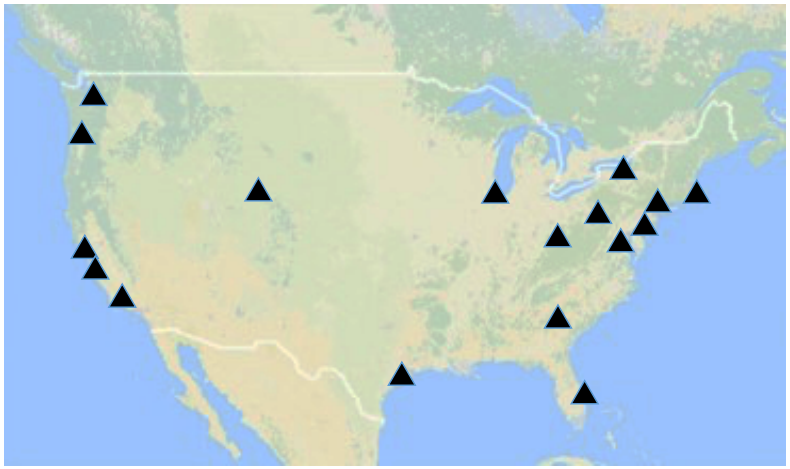
- Closing out SPHERES
- Completing Astrobee commissioning activities
- Maintaining & Operating Astrobee
- Facilitating Free Flyer user community
  - Quarterly SPHERES/Astrobee Working Group (SAWG)
  - International Partners: JAXA (Int-Ball) and DLR/Airbus (CIMON)

SAWG Community

- SPHERES/Astrobee Working Group (SAWG) Quarterly meeting
  - Face-to-Face, twice a year
  - Next will be scheduled in February 2020, location: TBD
- Purpose:
  - Information sharing across the SPHERES/Astrobee community
  - Astrobee Facility shares
    - National Lab Facility availability
    - Status of resources (batteries, CO2 tanks, etc.),
    - Overall Calendar (scheduled Test Sessions, upmass/return), and
    - Updates on “new” PD, Investigations, and ISS infrastructure.
  - Provide the SPHERES/Astrobee community (PD, investigators, etc.) with up-to-date information to determine opportunities to use the NL Facility
  - Discuss proposed changes/updates to Astrobee Nat Lab which may be required to support a specific activity or research.

Guest Scientists

- 8 Projects actively working towards ISS payloads
  - Astrobatics (Naval Postgraduate School)
  - SoundSee (Astrobotic/Bosch)
  - Gecko (Stanford)
  - RFID Recon (NASA REALM)
  - JAXA joint activity
  - Astroporter (Tethers Unlimited)
  - ISAAC
  - R2AL
- Ground Studies
  - FIT/RINGS
  - NMSU



Highlights

FY19 ISS utilization overview since (04/09/19)

- Number of ISS Activities:
  - SPHERES: 4 (159 total)
  - Astrobee: 15 (20 total)
- Number of active investigations:
  - SPHERES: 2
  - Astrobee: 5
- Console time:
  - SPHERES: 32 hours (962 total)
  - Astrobee: 37 (62 total)
- Crew members:
  - SPHERES: 2 (57 total)
  - Astrobee: 2 (5 total)

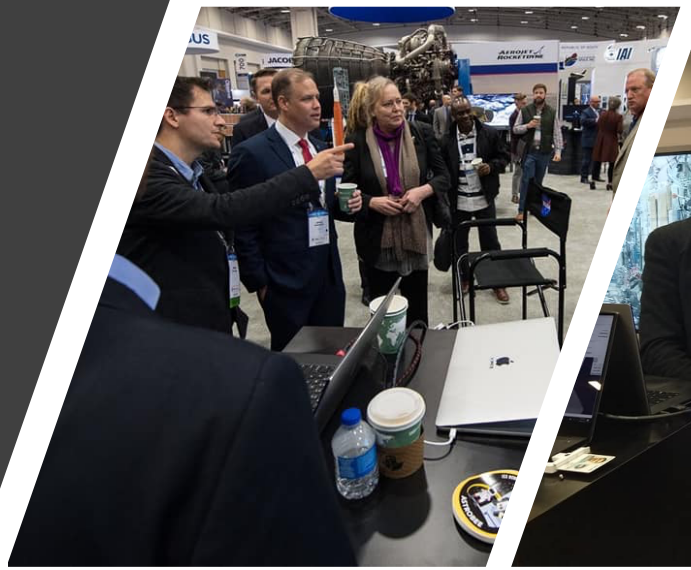
SPHERES

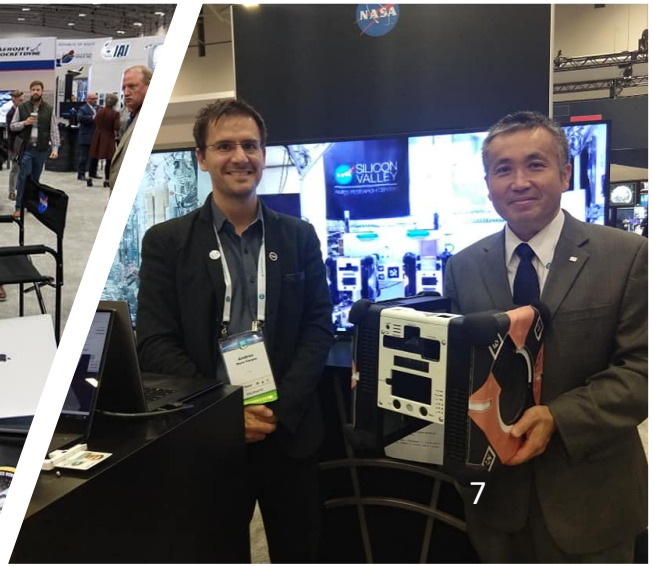
- Zero Robotics middle school competition completed (MIT/CASIS)
- ReSWARM Final Science activity (MIT/CASIS)
  - Partially successful, Attempting re-run before Dec. 31st

Highlights

- SPHERES/Astrobee Working Group, July 22nd, In-Person, NASA KSC
- ISS Research & Development Conference 2019 (Atlanta), two presentations
- IAC 2019, One Paper, NASA Booth Demo of Astrobee

- User integration testing and accomplishments
- Astrobee-Gecko launched on SpX-18
- Astrobee-SoundSee launched on NG-12
- RFID Recon launched NG-12





Completed Commissioning

Crew Activity	Robot	Date
Checkout	Bumble	4/30/19
Calibration & Mapping	Bumble	5/13/19
Additional Mapping	Bumble	5/23/19
Localization & Mobility 1	Bumble	6/14/19
Localization & Mobility 2	Bumble	7/12/19
Localization & Mobility 3a	Bumble	7/24/19
Localization & Mobility 3b	Bumble	8/28/19

What's next

- Extended Commissioning (Phase 1)

Crew Activity	Robot	Date
Checkout & Calibration	Honey	10/24/19
Localization & Mobility 4	Bumble	10/31/19
Ops Demo	Bumble	Nov
Localization & Mobility 1	Honey	Nov
Payload Installation	TBD	Nov
Payload Demo	TBD	Nov
SPHERES/Astrobee Hand-off	TBD	Dec

Completion of Phase 1 enables support of initial Guest Scientists

- RFID Recon, JSC
- SoundSee, Astrobotic / Bosch
- Gecko Gripper, Stanford
- Kibo-RPC, JAXA

What's next

- Plans for FY20
  - SPHERES commemoration & Astrobee ISS handoff
  - Complete Astrobee Commissioning (Phase 1)
  - SPHERES/Astrobee Working Groups
  - Astrobee User Integration Support (Testing, Verifications, Ops)
  - RFID Recon – Testing started (Potential Autonomous Logistics Demo)
  - SoundSee – Bosch tests
  - Gecko gripper – Stanford tests
  - Astrobee / IntBall - JAXA Kibo-RPC
  - ISAAC
  - Robonaut 2 Autonomous Logistics (R2AL)

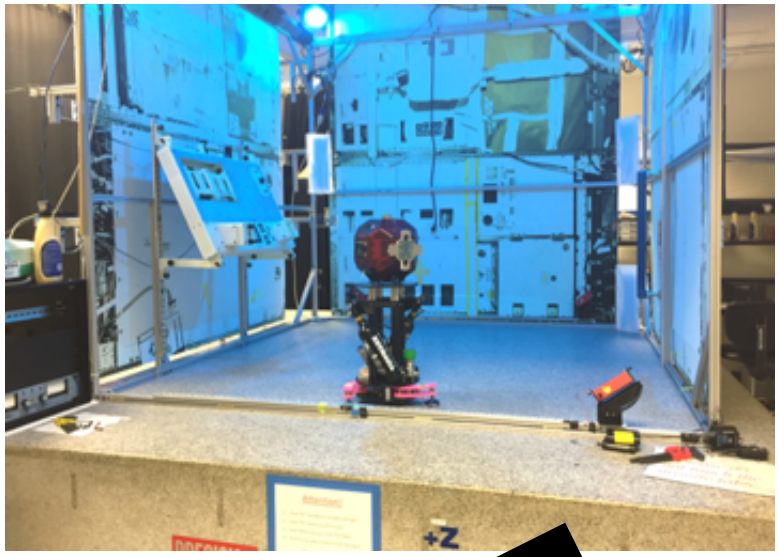
Challenges

- Degraded SPHERES hardware
- Aggressive Astrobee commissioning schedule through 2019
- Maturing and supporting Astrobee software to meet user expectations
- Getting ISS approval for untended operations and controlled imagery distribution to payload developers

Engineering

Ground LabStatus

- Granite Lab: Online



- Flight Lab: Online

- Micro G[illegible]t Facility (MGTF) Lab: Under Renovations

- Engineering Evaluation Lab (EEL): Available upon request

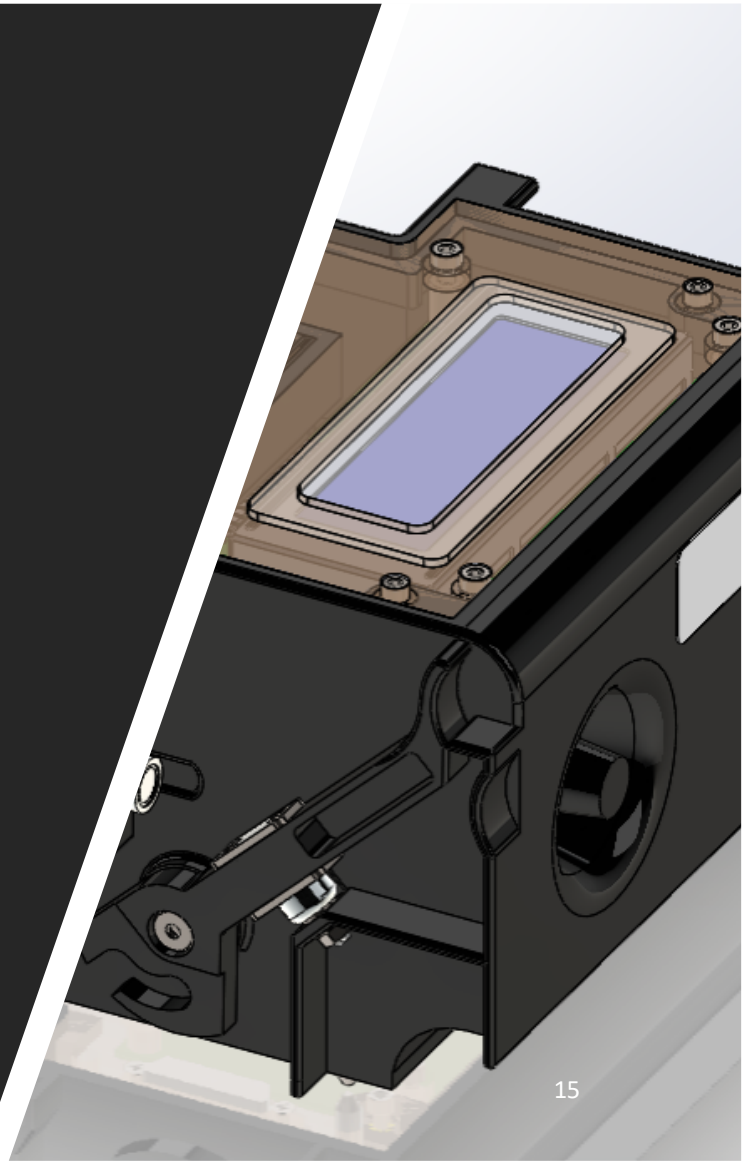
Hardware Status

Name	Status	Plans
P4E	Unsupported	Dev. Testing in MGTF
Flat Sat A	Operational	Hardware checkout
Flight 1,2	Complete	In Space, checked out
Flight 3	Complete	In Space, still in box
Flight Spare	Complete	At JSC for integrated testing (EMI, Acoustic)
Cert (B#)	Operational	In use by FSW team, available for testing
Ground (Wannabee)	Operational	In use by FSW team, available for testing

Port Tester

Astrobee Port Tester delivered for launch on SpX-19

- Objectives:
  - Facilitate diagnostics of the Astrobee Free Flyers' internal USB ports
  - Test safe electrical current and voltage operation limits
  - Connect with Astrobee through the High Level Processor (HLP) using Guest Science APK
  - Serves as a USB pass-through connection to the HLP
  - Serve as an internal ARC based payload to learn and better improve the guest science payload development process



Flight Testing

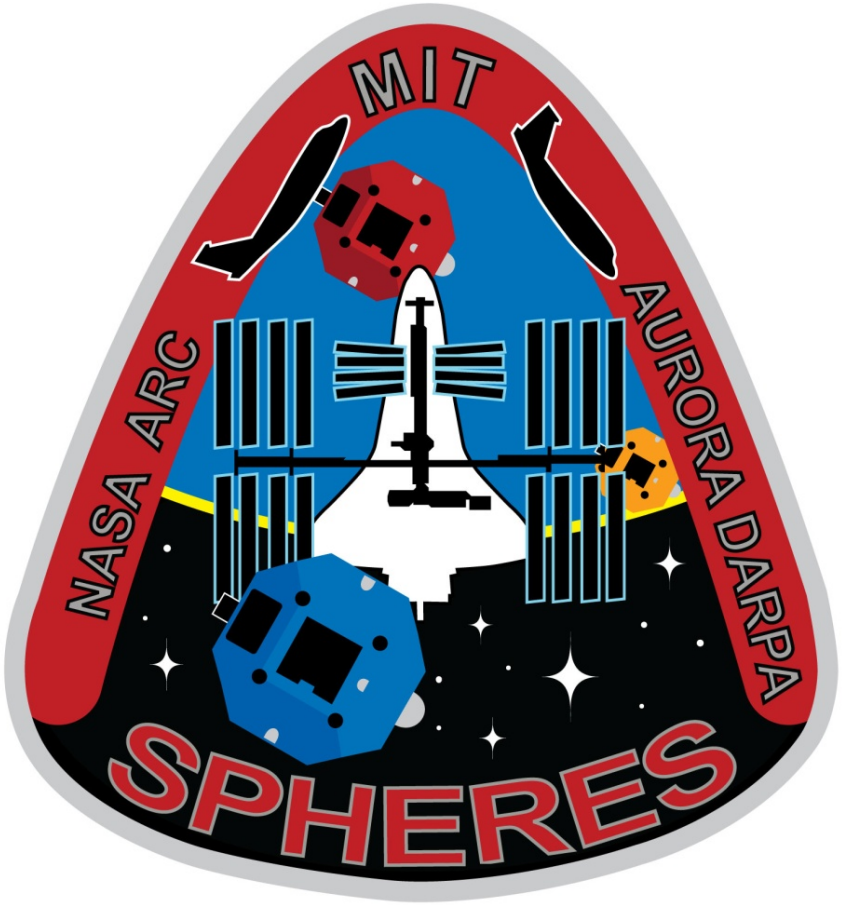
- Astrobee Robot Software release 0.10.2 is out on Github, it powered Bumble successfully during Lomo3b on ISS
- Last Wednesday: Honey Checkout
  - Performed Checkout and Calibration
  - Hardware functioning nominally
  - Data post-processing underway
- Last Friday: Lomo4a
  - Collected data autonomously to update the map after 2 months of no activity
  - Achieved “Mobile Camera” task which consists of teleoperating Astrobee to observe an Astronaut task
  - Performed motions in “difficult” (sporty) flight mode (0.4m/2 linear vel. / 30deg/s rot vel.) with good stability
  - Executed plans with good localization performance despite having multiple large CTB on the deck that were not in the previous map

Lab Testing - Highlights

- User Testing
  - End-to-end test with RFID Recon controlling lab Astrobee from their lab
- Imagery streaming to JSC Building 8
  - Demonstrated lab imagery streaming to Building 8
  - Procedure for coordinating with Building 8 in work
  - One step closer to operations without crew
- SciCam Streaming
  - Lab testing identified last firewall roadblocks to fully functioning streaming
  - Requests in work to fix issues.
  - Nearly ready for lab demonstration

Ames Lab Testing – Future Visitors

- JAXA 11/11-11/15
- Columbia 11/18-11/22
- Georgia Tech. TBD
- Purdue TBD
- Tethers Unlimited, Feb 2020



SPHERES & Astrobee Operations

Operations: Functions

Ensure Facility Readiness for ISS Test Sessions

- All crew training is handled via Onboard Training (OBT).
- Manage crew procedure and all planning products updates via OCR/ECR system
- Coordinate crew time with ISS Lead Increment Scientist and POIC Cadre
- Assist Astrobee team & PDs in acquiring proper access to ops systems as needed
- Coordinate with investigators for product development and delivery
- Help investigators set up remote communication capabilities as needed

Real-Time ISS Test Session support

- Coordinate with SpOC (Specialist OC) any deltas to real-time ops and products
- Support crew & POIC cadre real-time ops – conduct crew conferences as needed
- Coordinate Commanding Window requirements and planning
- Test session data and video management

Public Relations

- Maintain website, work with ARC PAO office to publish material on site

Operations: Functions

Increment Planning

- 2-pager development and submittal, updates as needed throughout increment
- Regular timeline planning with Lead PPM (Payload Planning Manager) and PPM planning team.

Safety and Verification Assessments

- Integrated Safety & Verification Assessments as needed (Guest Science etc.)
- Current SPHERES Safety & Verification focuses on return of hardware.
- Complete CoFR (Certification of Flight Readiness) for ground systems and on-orbit hardware and operations products.

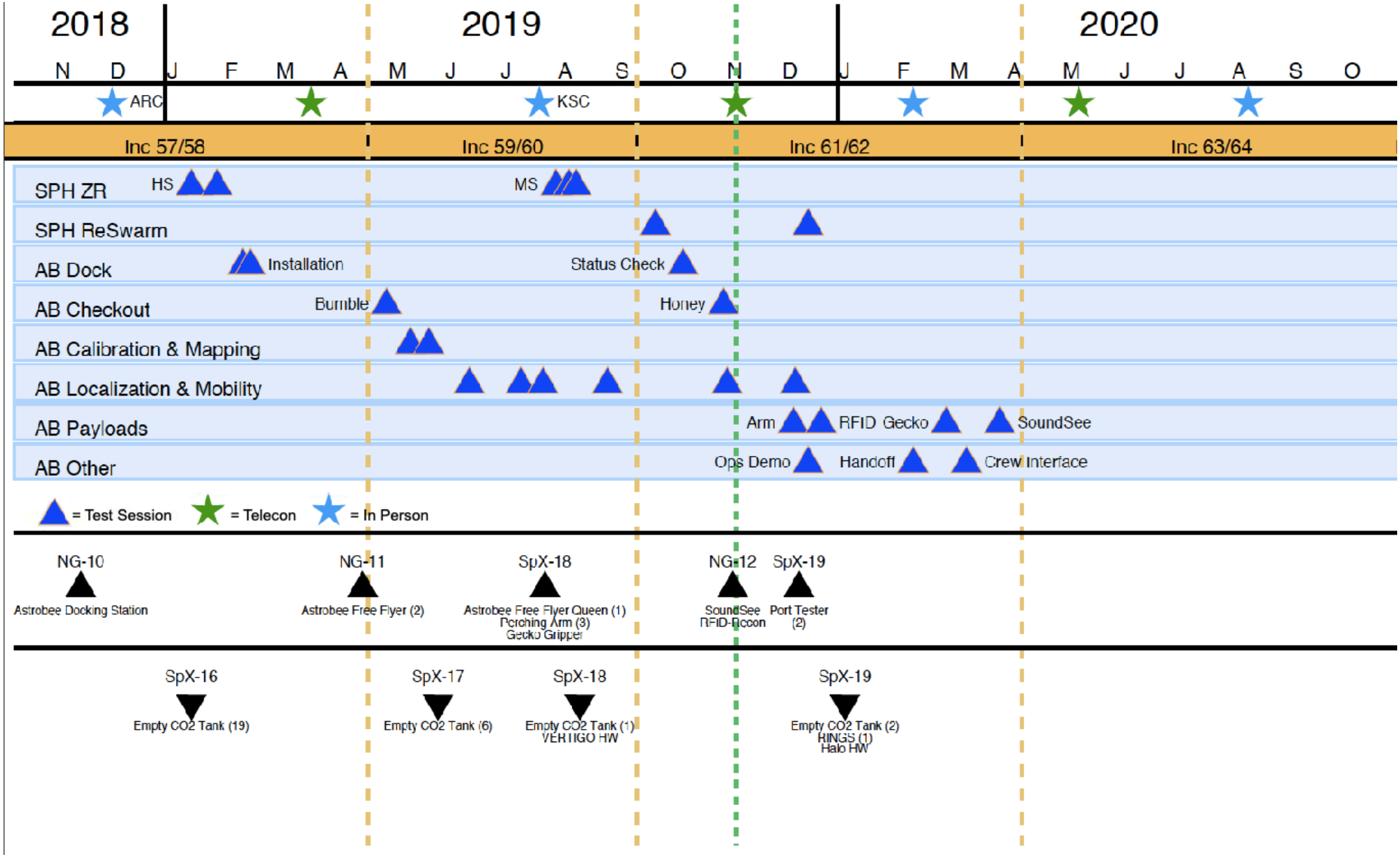
Astrobee Ground Ops Development

- Coordinate ground Engineering and Operations Readiness Tests (ERTs/ORTs) in preparation for real-time ops.
- Work with Astrobee team and PDs to develop flight procedures, coordinate reviews with MSFC for final delivery and formal ECR review.

Increments 59/60

- SPHERES Test Sessions (since last SWG 7.22.19)
  - Zero Robotics Middle School Units Test – July 31
  - Zero Robotics Middle School Dry Run – August 7
  - Zero Robotics Middle School Finals – August 9
  - ReSwarm Science 2 – September 23
- Astrobee Commissioning Activities (since last SWG 7.22.19)
  - Astrobee A Localization & Mobility 3 – July 24
  - Astrobee A Localization & Mobility 3b – August 28
  - Astrobee Dock Troubleshooting - October 30
  - Astrobee B (Honey) Checkout & Calibration – October 30 [6 mo. To date]
  - Astrobee A Localization & Mobility 4 – November 1
  - Several Astrobee Commanding windows (now including weekly Mondays)
  - 18 ERT/ORTs (Engineering/Operational Readiness Test)
- Astrobee Ops Planning for Increment 61/62
  - Procedures/planning in work: Arm/REALM/Gecko/SoundSee/Port Tester
- Crew Debrief for David Saint-Jacques & Anne McClain

SPHERES & Astrobee Calendar



Safety-Verification & Consumables

Safety

- SPHERES CO2 Tanks (empty) and VERTIGO hardware Return on SpX-18 – Approved: 2019/08/15
- SPHERES CO2 Tanks (empty), RINGS, and Halo hardware Return on SpX-19 – Approved: 2019/010/31

Verification

- SPHERES Software Update – Approved: 2019/07/25

CO2 Tank Inventory

- **40 Tanks (1 gray, 39 pink) on orbit – one last SPHERES test session**

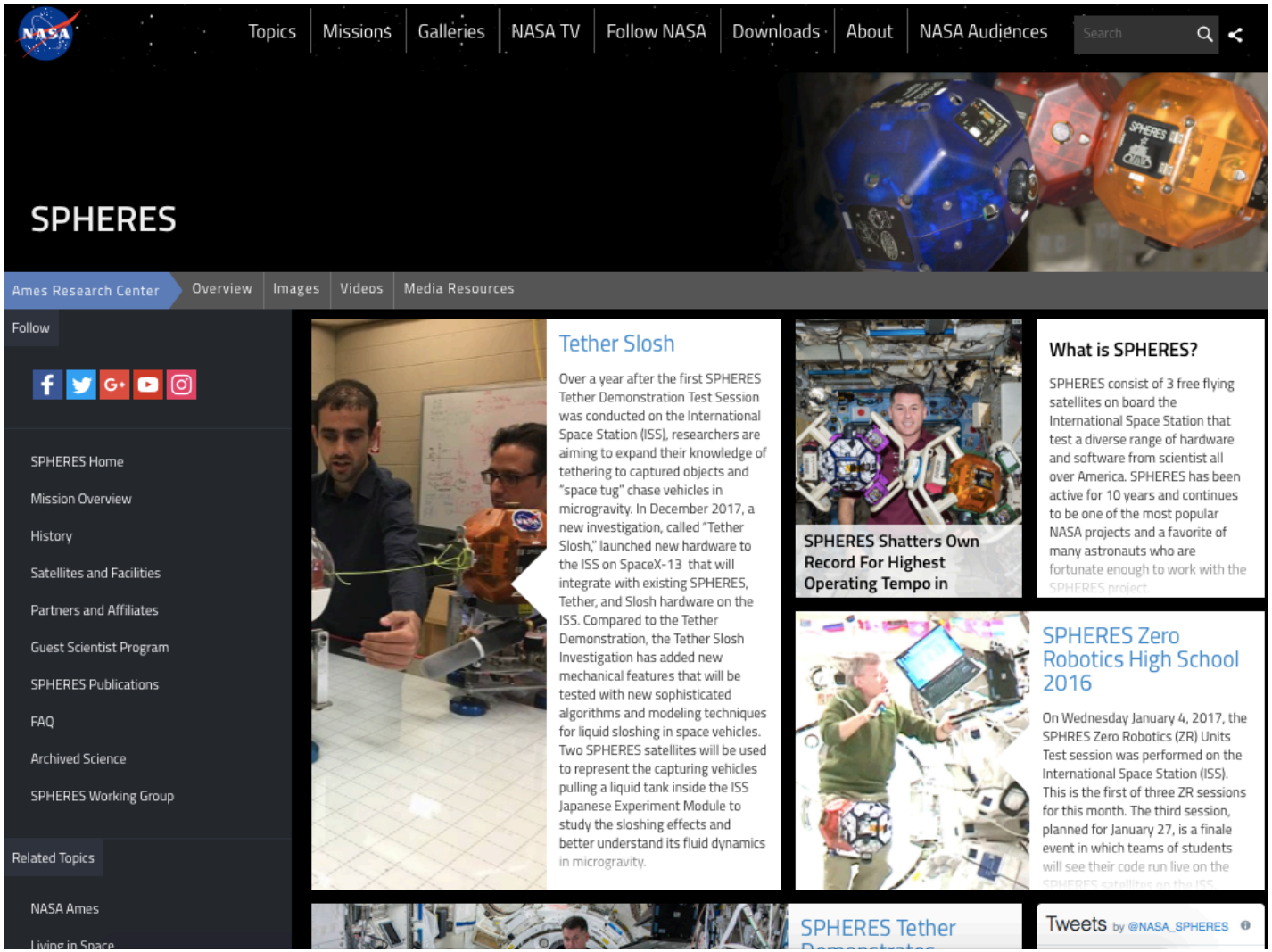
Battery Pack Inventory

- 10 SPHERES Rechargeable Batteries
- ~10+ disposable SPHERES Batteries (MIA), two were recently found

Consumables downmass

- 1 gray and 2 pink empty tanks returned on SpX-18 and SpX-19 respectively
- Planning to return empty gray and pink tanks

SPHERES & Astrobee on Social Media



Twitter

https://twitter.com/NASA_SPHERES

Website

http://www.nasa.gov/spheres

http://www.nasa.gov/astrobee

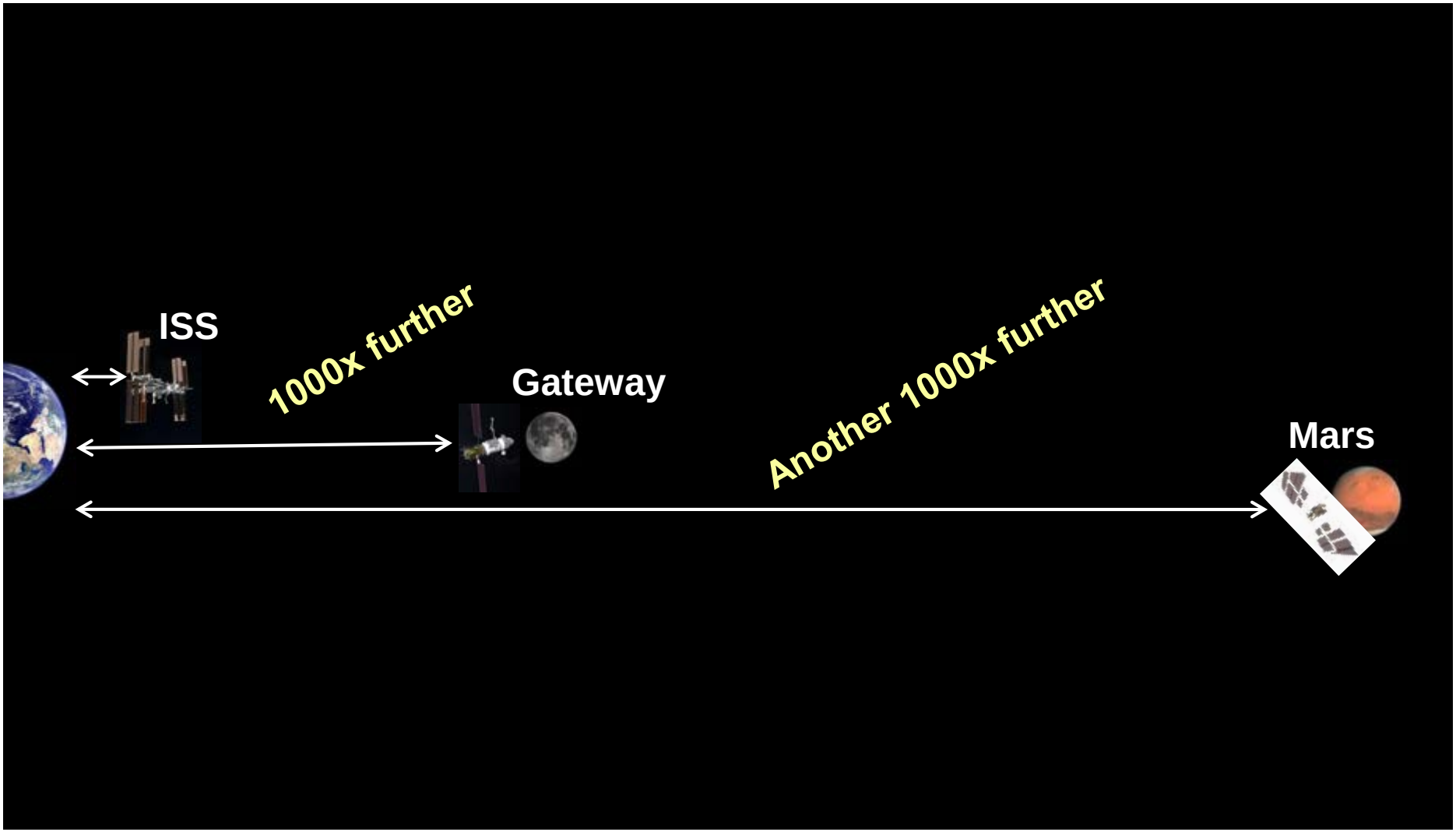
Integrated System for Autonomous and Adaptive Caretaking (ISAAC)

SPHERES/Astrobee Working Group Quarterly Meeting

Trey Smith
Julia Badger
Maria Bualat

06 Nov 2019

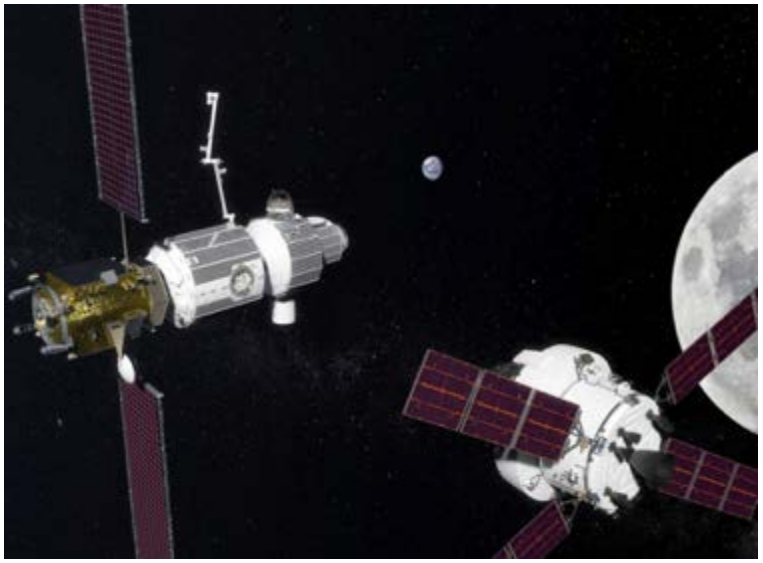
Deep Space Exploration



* ISS=0.40-0.41E+3 km; Moon=0.36-0.41E+6 km; Mars=0.06-0.40E+9 km

The ISAAC Concept

- Research project, 2020-2022, to develop technology for **autonomous caretaking** of spacecraft 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, Robonaut2) 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.)

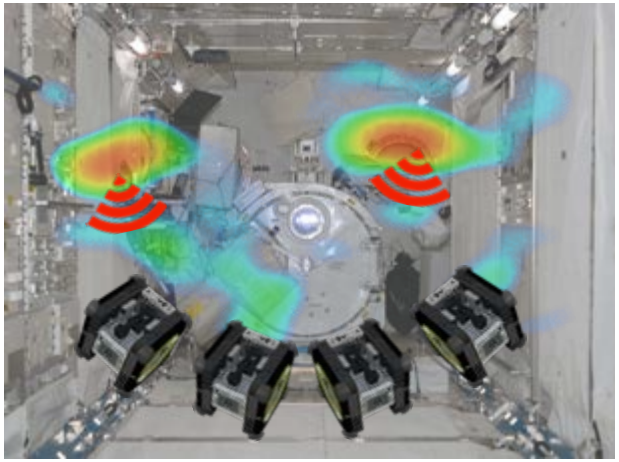


Objectives for Mission Impact

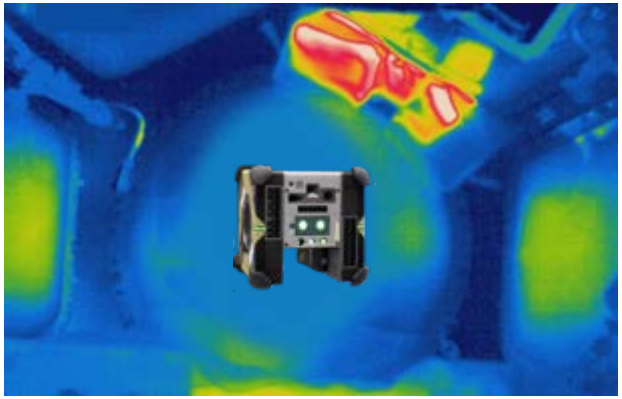
- **Reduce risk** through improved fault recovery during uncrewed phases
- **Reduce cost** by enabling new design options (e.g. one mobile sensor vs. many fixed sensors)
- **Free up crew time** spent on maintenance and logistics
- **Enhance utilization** during uncrewed phases (e.g. enabling sample transfer for experiments that need it)

ISAAC Capability Areas

Autonomous State Assessment



Localizing signal sources by analyzing signal strength variation

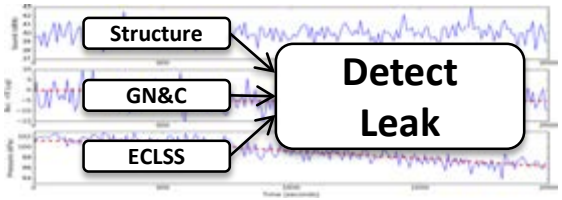


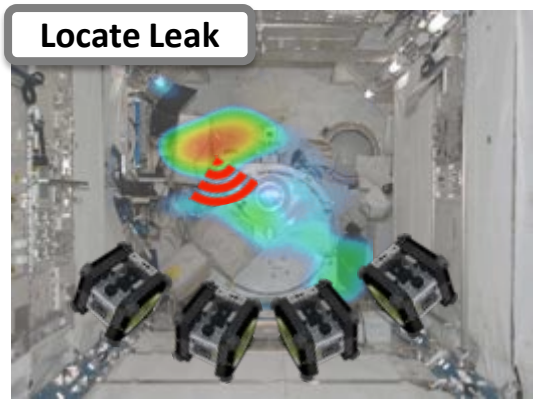
Habitat thermal mapping

Autonomous Logistics Management

Robotic cargo transfer

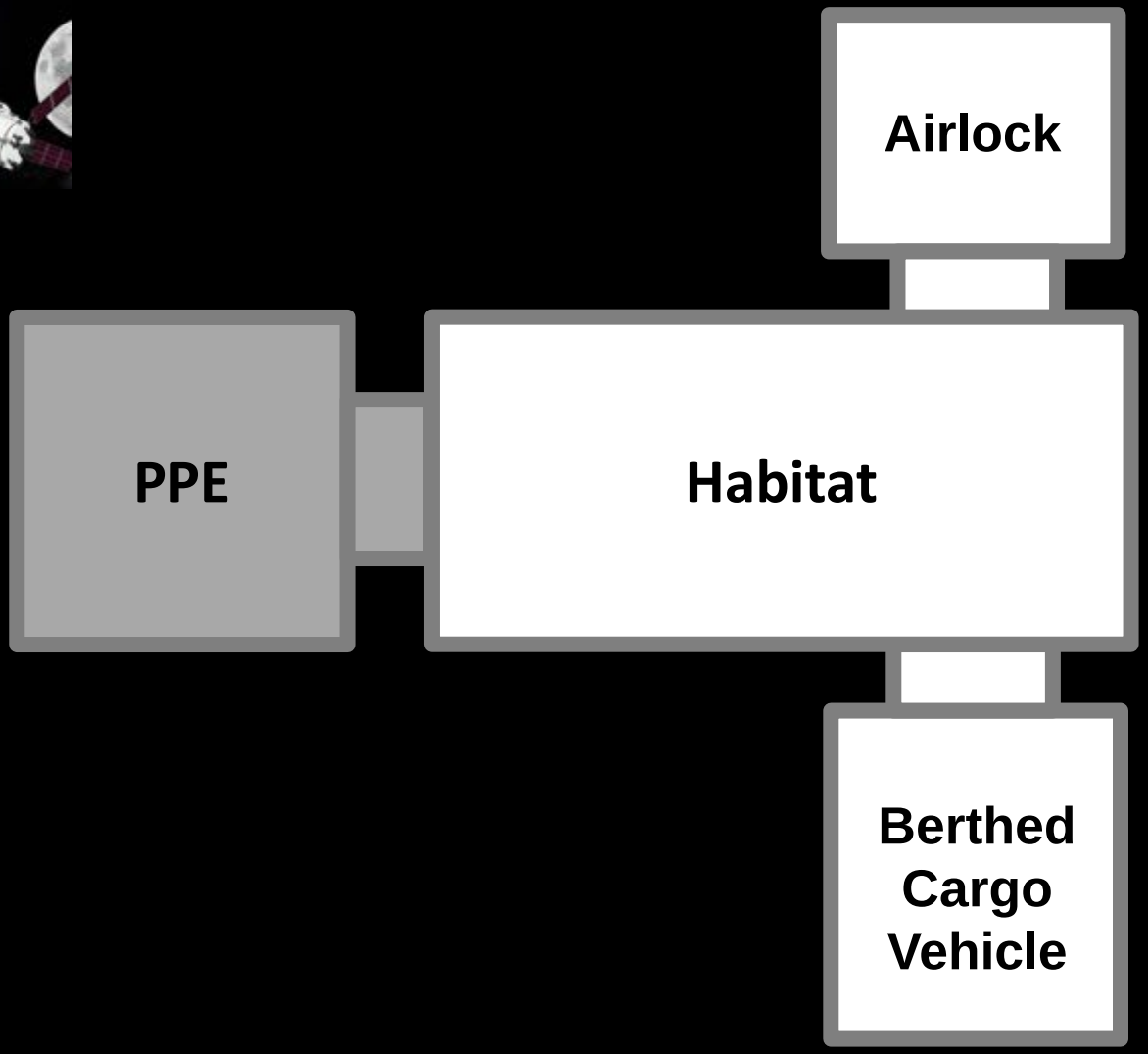
Integrated Fault Management





Leak Scenario

Gateway



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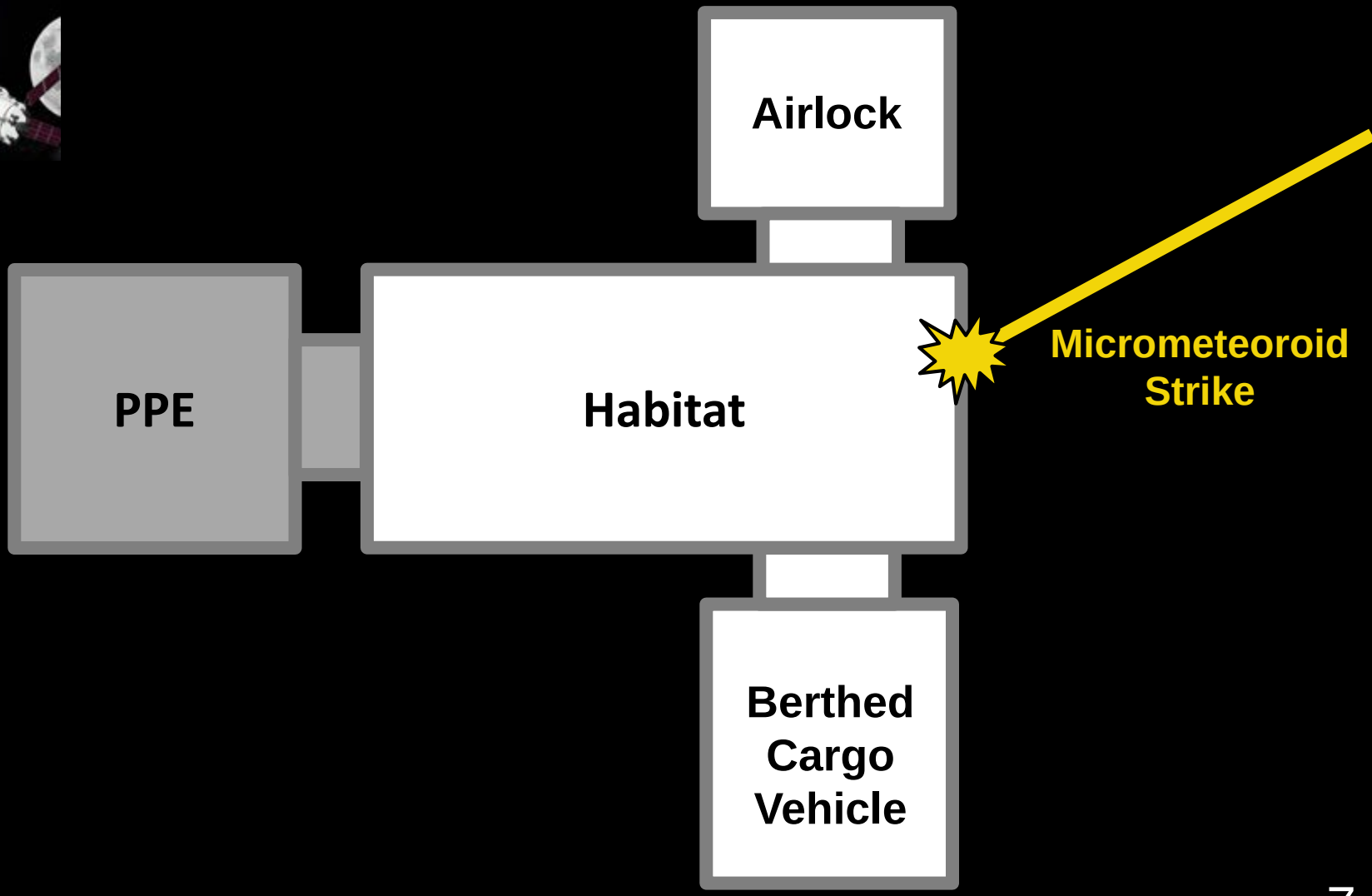

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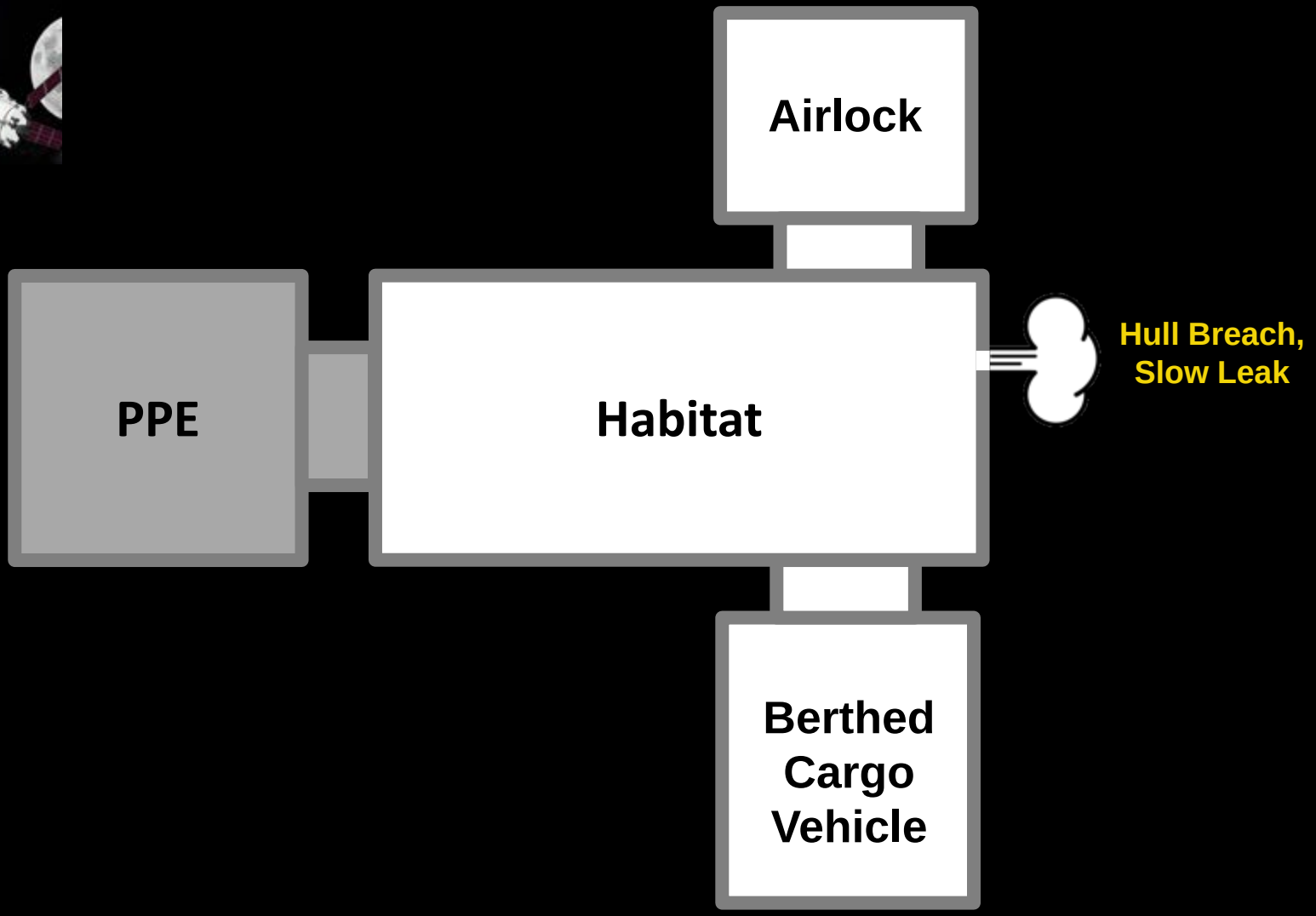
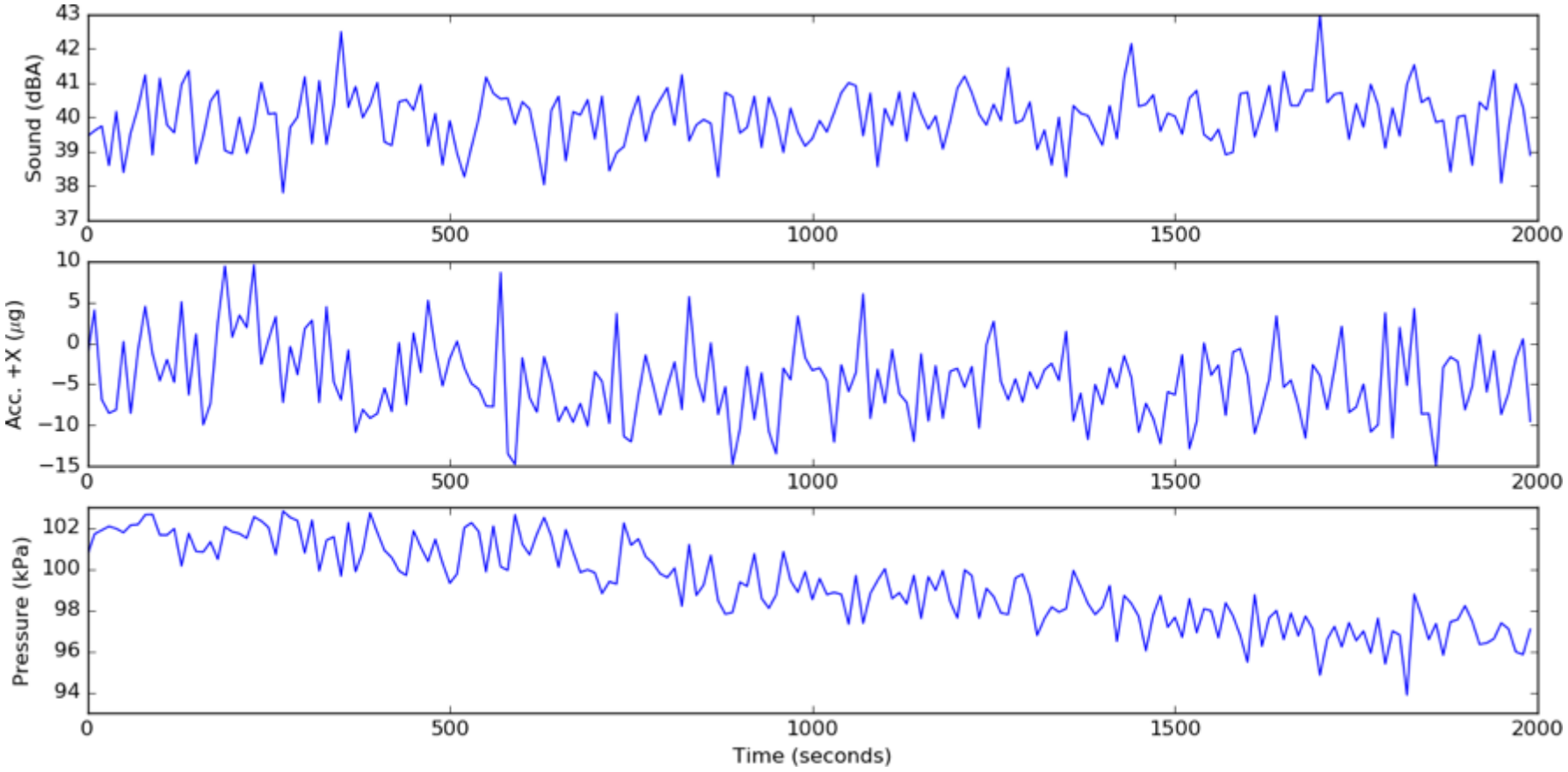


Leak Detection



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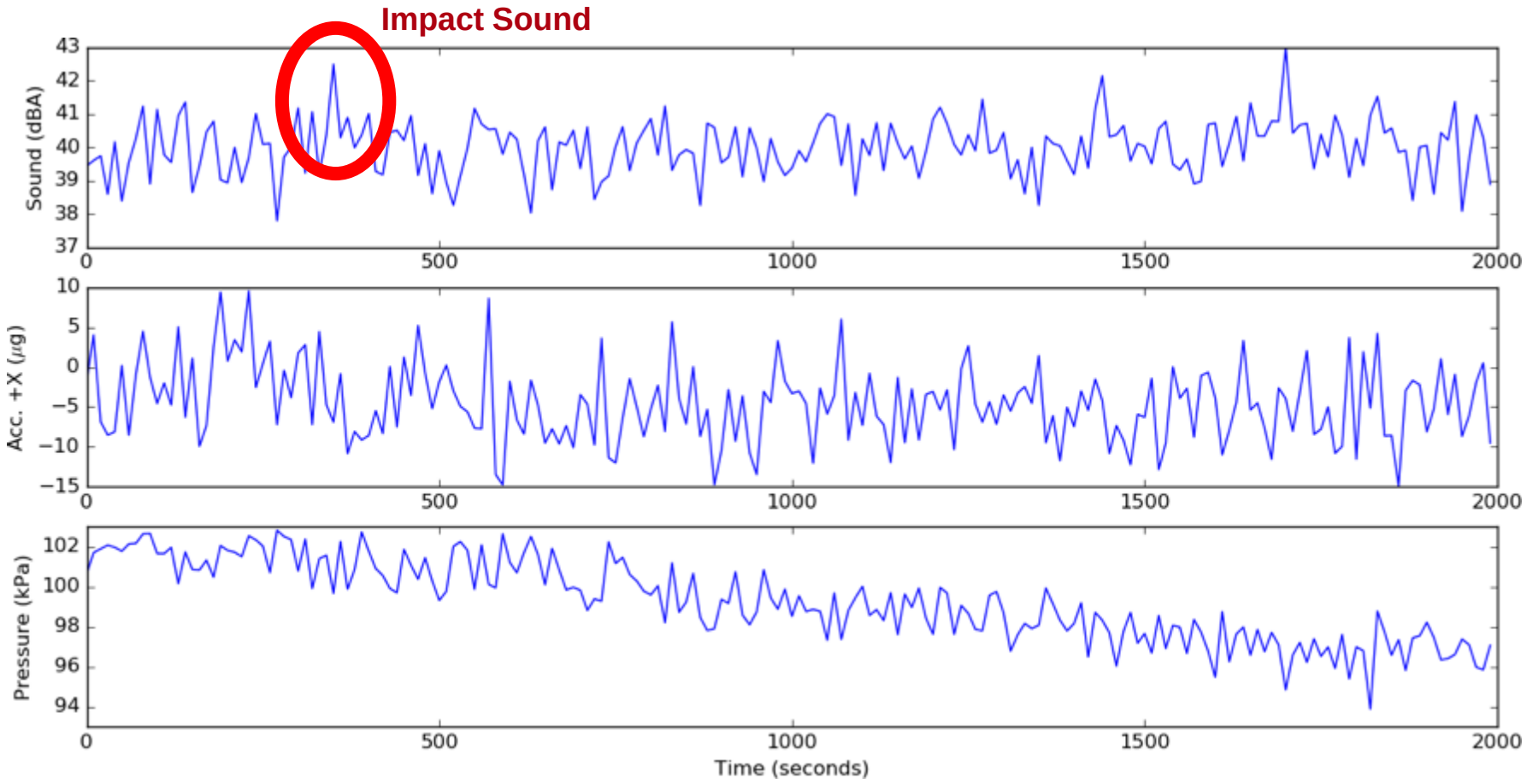

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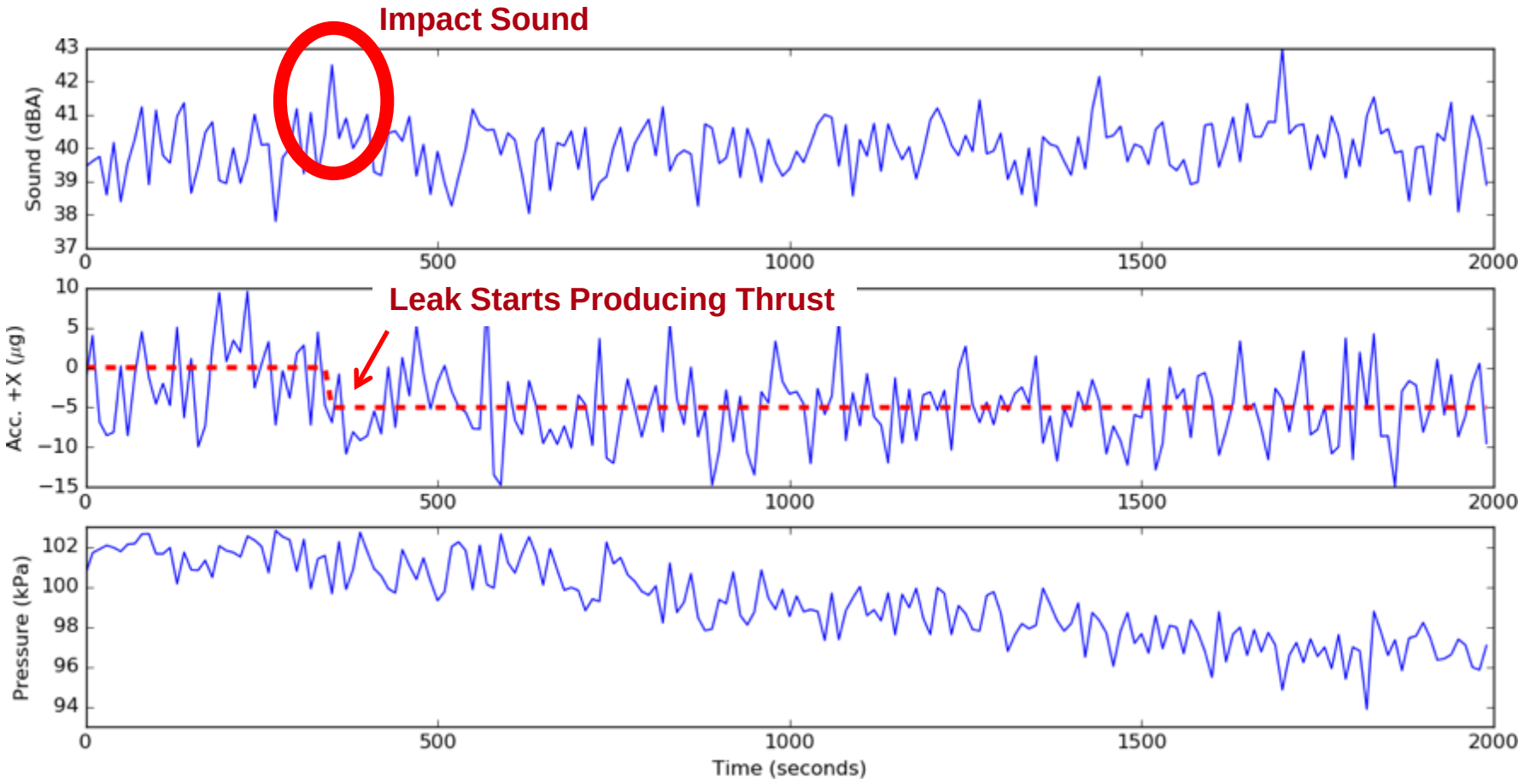

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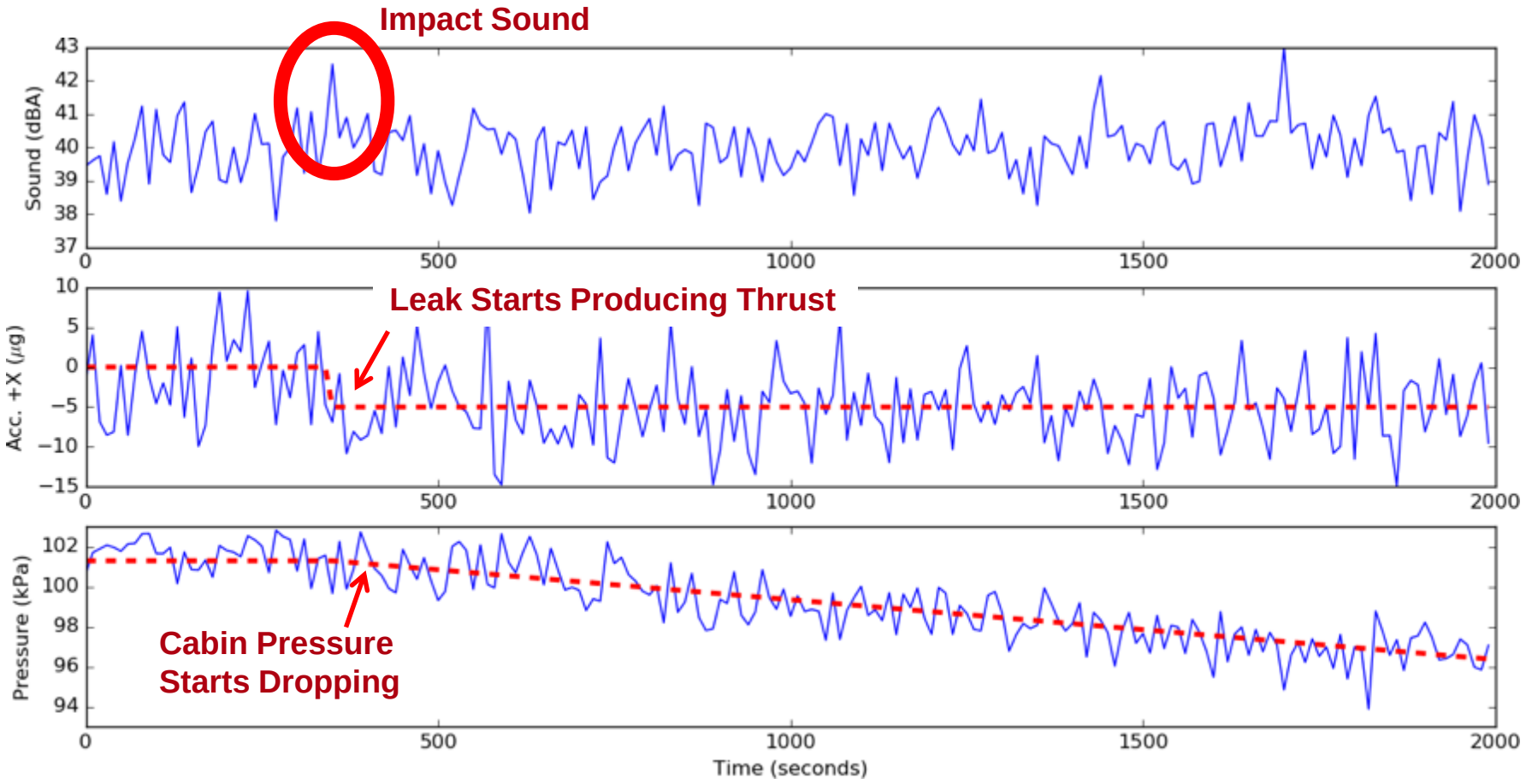

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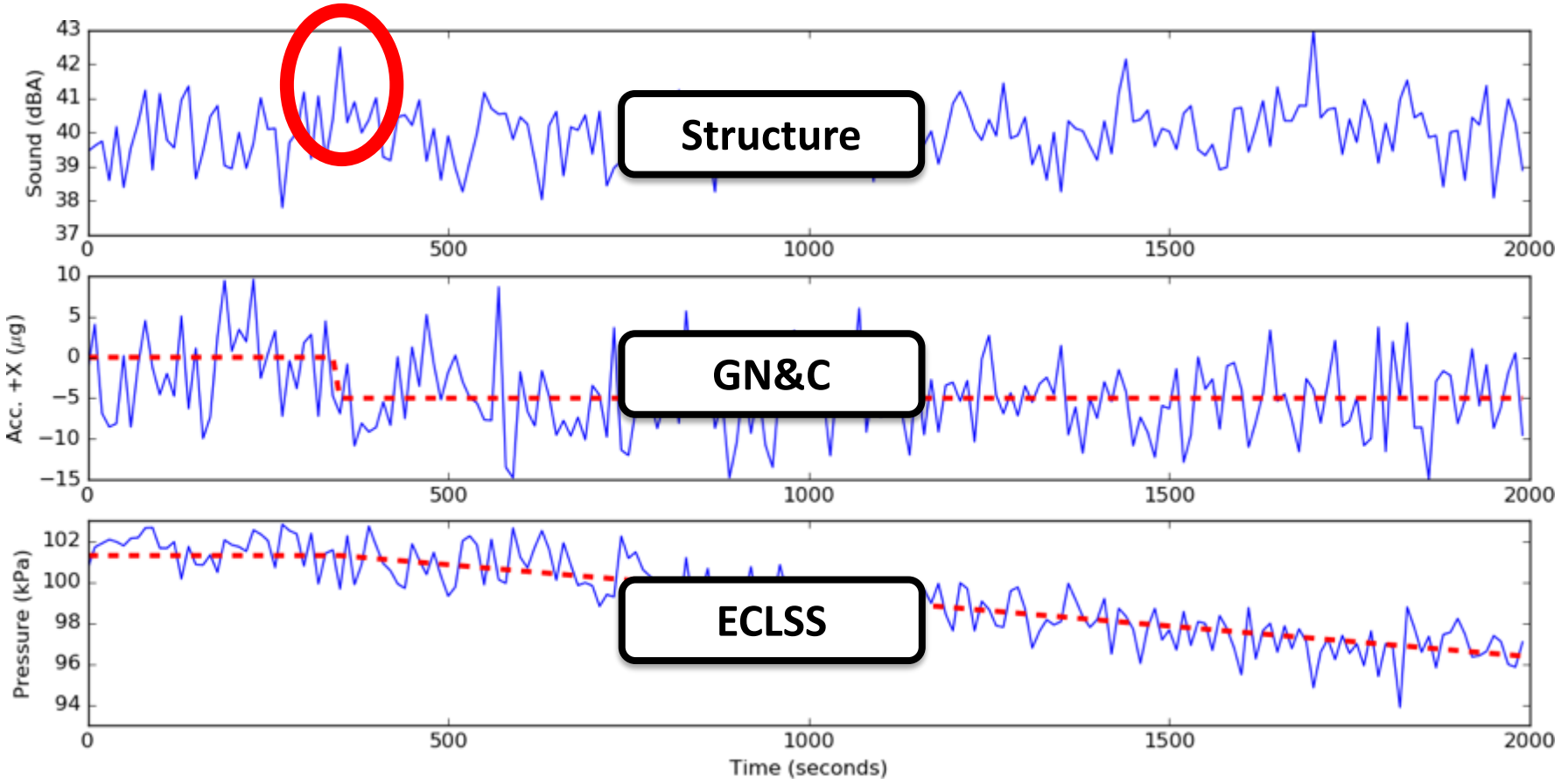
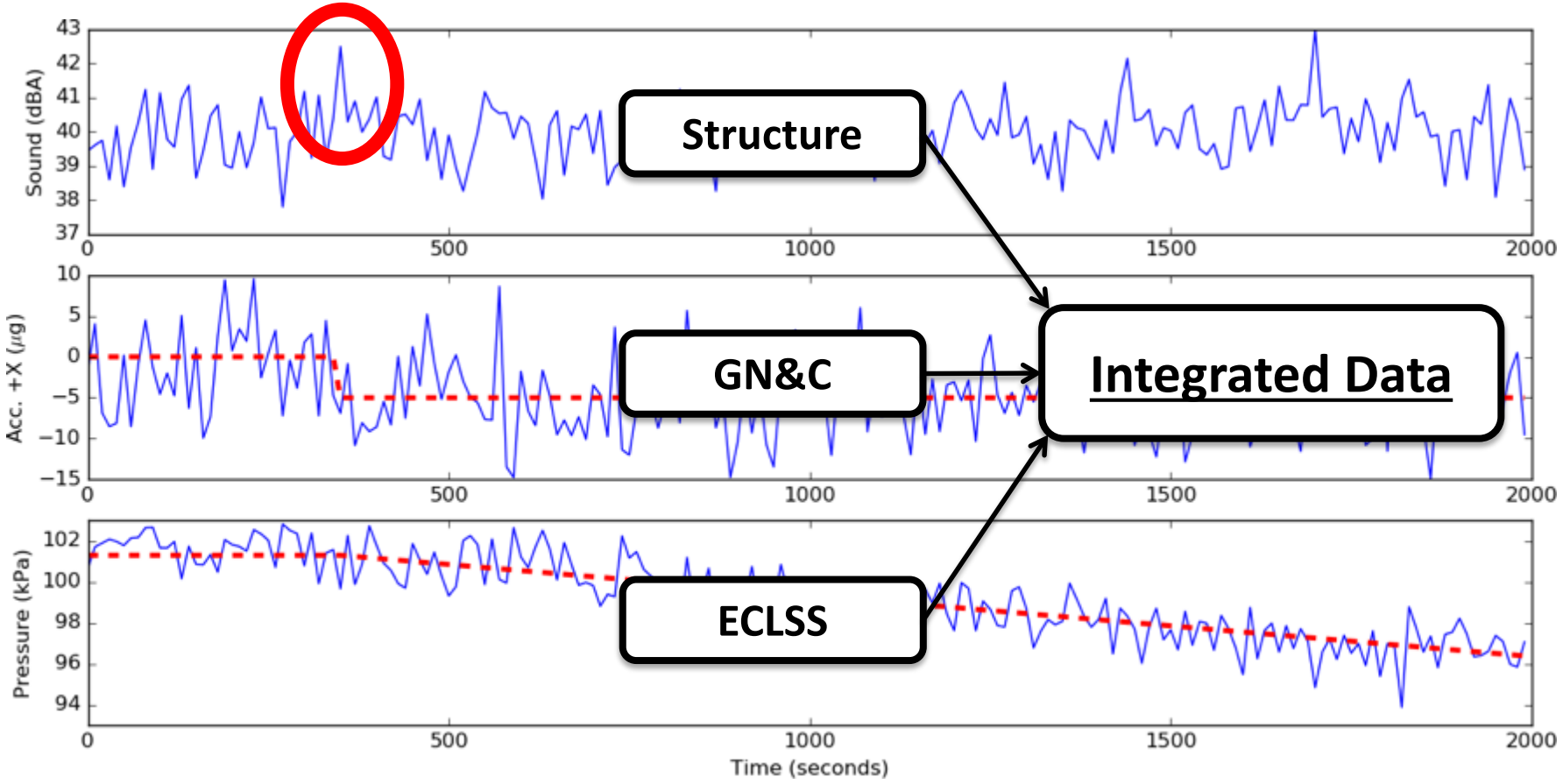
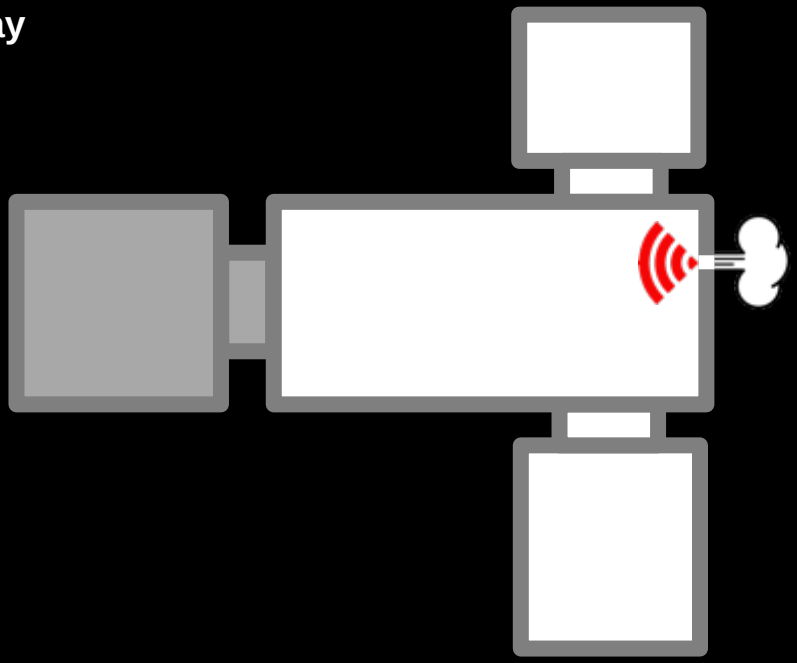


Thrust: Integrated Data

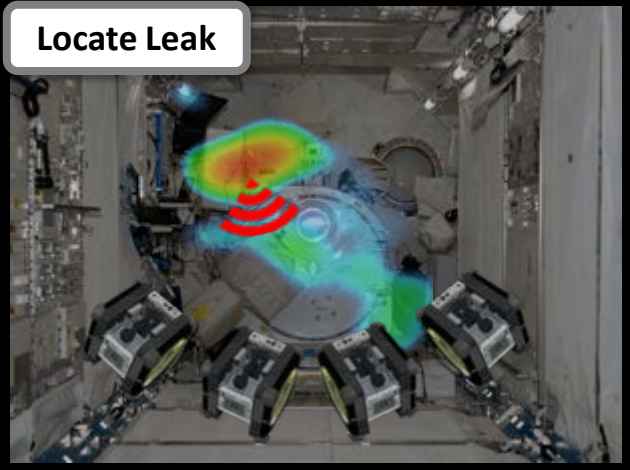


Leak Isolation

Gateway

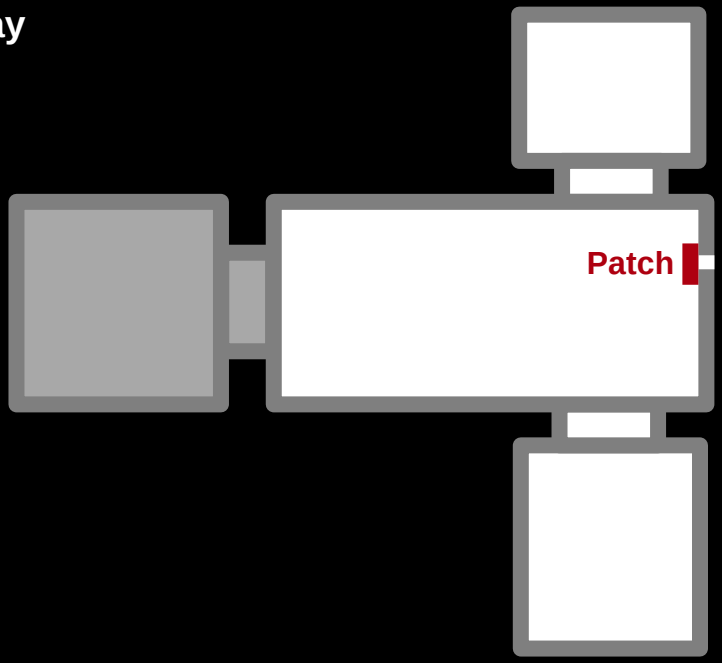


Locate Leak



Leak Recovery

Gateway



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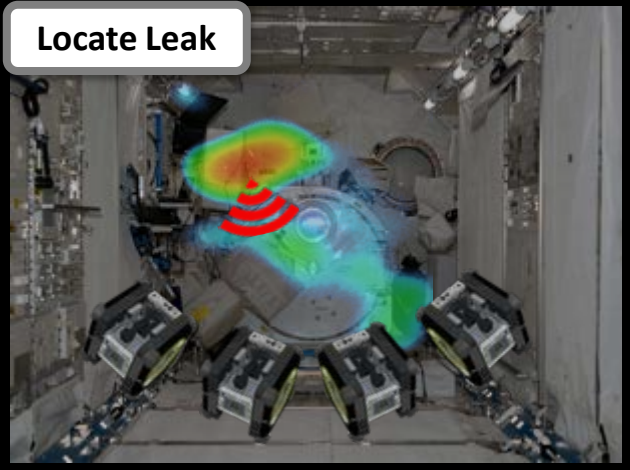
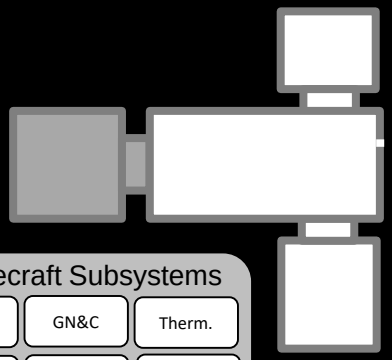
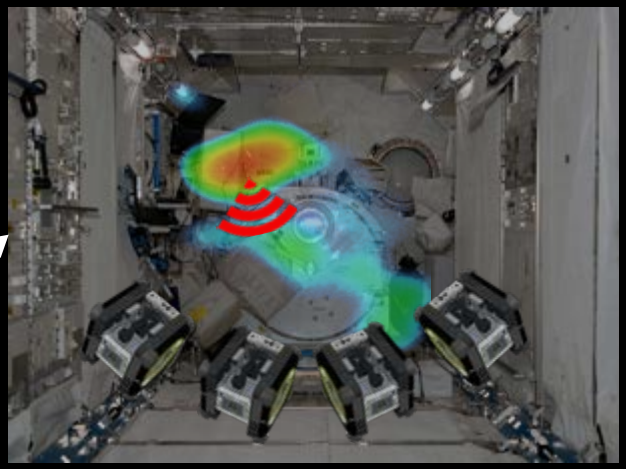


Patch Leak

Architecture

Gateway



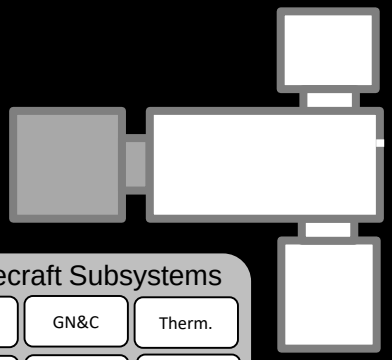


Integrated System Manager

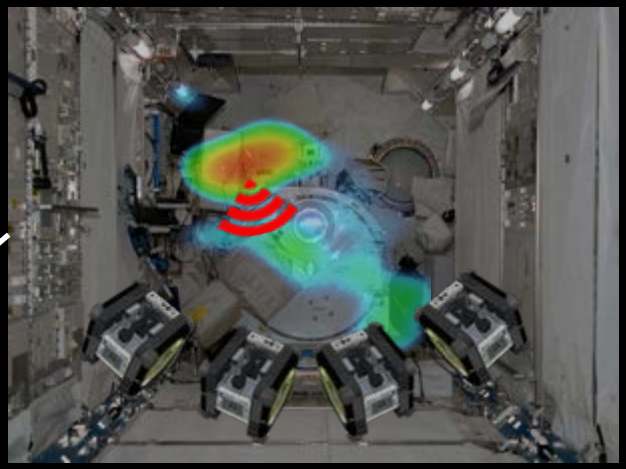
Mission Control

Thrust: Integrated Data

Gateway



Integrated Data

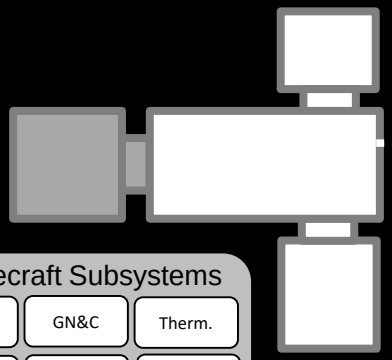


Integrated System Manager

Mission Control

Thrust: Coordinated Execution

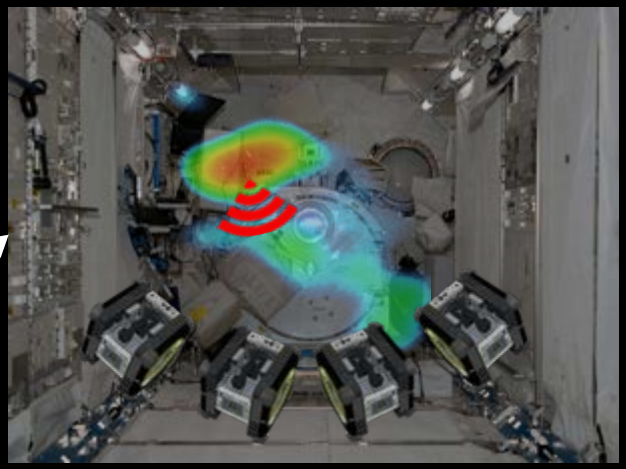
Gateway



Spacecraft Subsystems

ECLSS	GN&C	Therm.
EPS	Comm	Struct.

Coordinated Execution

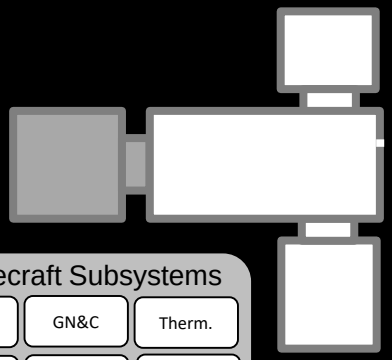


Integrated System Manager

Mission Control

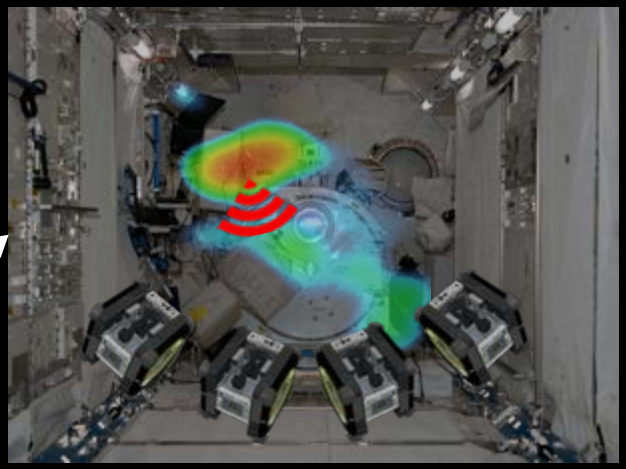
Thrust: Integrated Control Interface

Gateway



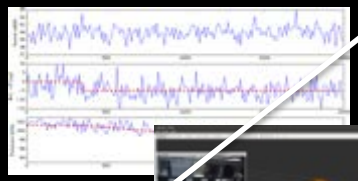
Spacecraft Subsystems

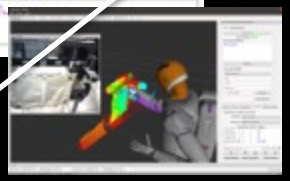
ECLSS	GN&C	Therm.
EPS	Comm	Struct.



Integrated System Manager

Integrated Control Interface





Mission Control

Demo from ISAAC Formulation

ISAAC in 2020

- **ISAAC will focus on integrated data**
  - Fly Astrobee with multiple sensors and integrate the data into a common 3D model in real time
  - Spatially link robot data with other data sources, possible examples:
    - CAD models
    - Schematics
    - Telemetry from vehicle sensors
  - Visualize all spatial data in a common 3D view that links out to other kinds of information
  - Perform automated analysis and change and anomaly detection, possible examples:
    - Detect new thermal hot spot (possible fire)
    - Detect new hissing sound source (possible leak)
    - Perform optical character recognition on labels to enable answering, “Where is that label?”
- **Testing**
  - Start with simulation and ground testing
  - On-orbit testing with Astrobee around late 2020
  - First use of Robonaut2 not until 2021

QUESTIONS?

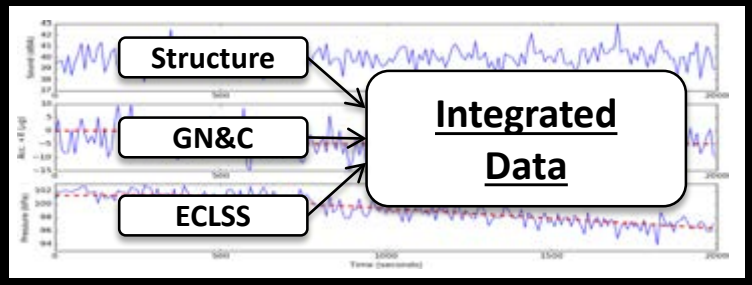
BACKUP SLIDES

Integrated System for Autonomous and Adaptive Caretaking (ISAAC)

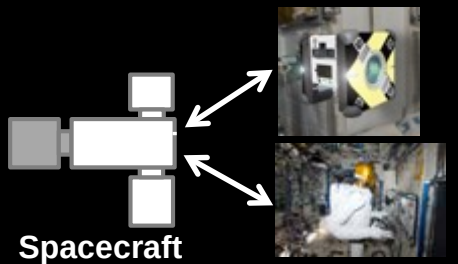
PT: Terry Fong (Autonomous Systems)
Thrust Area: ST5
PM: Trey Smith (ARC)
Deputy PM: Julia Badger (JSC)
Centers: ARC + JSC

Description and Objectives

- Develop a **critical capability to support autonomous caretaking of exploration spacecraft while uncrewed**
- Integrate autonomous robots, spacecraft infrastructure (avionics, sensors, network), and ground control
- Enhance **autonomous state assessment**, **autonomous logistics management**, and **integrated fault management**
- Focus on **capabilities required for the Gateway** (Human Exploration Requirements HEOMD-004: GTW-L2-0044, 0047, 0050, 0142, 0143, 0145) and applicable beyond the Earth-Moon system.
- Enable **important assessments of feasibility and relevance** for the design of future deep space spacecraft.
- Extend **autonomous system manager architecture** to enhance integrated analysis of data, operator productivity, and reliable coordinated execution of system-level tasks.




Gateway



Customers

- **Gateway.** ISAAC-developed capabilities directly relevant to HEOMD-004 and other requirements for Gateway.

Partners

- **AES Autonomous Systems and Operations**. Support fault diagnosis and planning+execution technologies used by ISAAC architecture.
- **AES Astrobee Facility.** Support Astrobee testbeds and ops.
- **AES Logistics Reduction**. Support Robonaut2 testbeds and operations. Collaborate on logistics demonstration.
- **Gateway Intra-Vehicular Robotics (IVR) and Vehicle System Manager (VSM) Working Groups.** Provide Gateway guidance.

Leverage

- **GCD/HET2.** Developed analog robot platforms for Gateway IVR.
- **MAST.** Developed system architecture that ISAAC will extend.

Technical Approach

- Focus on three technical thrusts:
  - Integrated Data: Link models and telemetry across multiple spacecraft subsystems and robots
  - Coordinated Execution: Enable higher-level commanding and effective collaboration
  - Integrated Control Interface: Enable mission control to understand and control integrated autonomous systems
- Perform tests with the iPAS facility (JSC) and on ISS
  - Leverage existing testbeds and robots developed with STMD support
  - Capstone demo on ISS: Link embedded sensors and multiple robots to detect, isolate, and patch a simulated leak
- Proposing ISAAC development in **FY20-22**
  - Deliverables staged to respond to relevant Gateway milestones
- **Investment is needed now in order to meet Gateway needs**

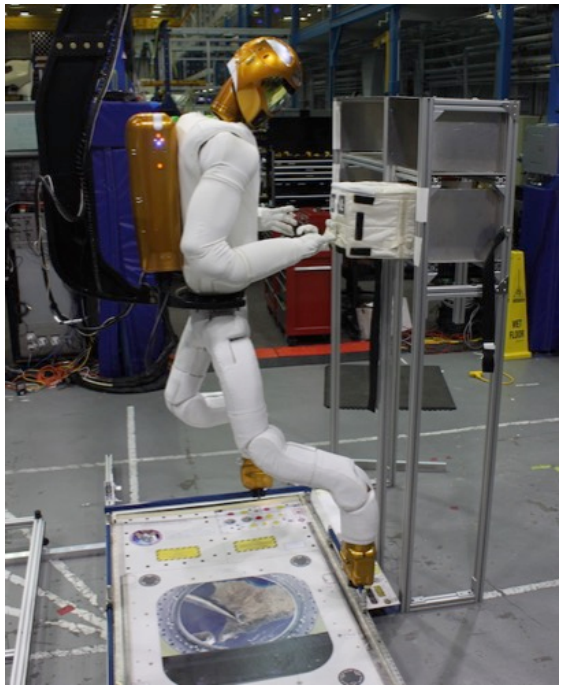
Robonaut2 Autonomous Logistics: Astrobee Integration

SPHERES/Astrobee Working Group
Quarterly Meeting

Trey Smith
Phil Strawser
06 Nov 2019

R2 Returns!

- **Robonaut 2 originally launched to the ISS in 2011**
- **Its initial configuration was a torso only, mounted to a stanchion**
- **A pair of legs were later developed to enable handrail-to-handrail walking mobility**
  - Ground testing in the Active Reduced Gravity Offload System (ARGOS) facility at JSC was successful
- **The legs were launched in 2014, but never functioned on-orbit**
  - The problem was likely due to subtle differences between the R2 torso flight unit and the ground units used for integrated torso + leg ground testing
  - There were probably electrical problems that damaged the avionics after integration
  - Significant astronaut debugging didn't lead to a clear diagnosis and fix
- **Further development with R2 ground units never stopped**
- **Recently, the R2 flight unit was returned to the ground, repaired, and verified for reflight**
- **Most likely relaunch date either 12/2019 or 2/2020**
- **The R2 team plans to eventually make R2 into an ISS facility for guest science, similar to Astrobee**



R2AL Context

- **NASA's Advanced Exploration Systems program has a project called Logistics Reduction (LR) that focuses on improving how cargo is managed for future human missions**
- **A long-standing task within the larger LR project is Robonaut2 Autonomous Logistics (R2AL)**
  - Study how to use an autonomous mobile manipulator intra-vehicular robot (IVR) to off-load cargo tasks from crew
  - Test with **R2 on ISS** as an analog for **future IVR on Gateway** and other human missions
  - LR and R2AL are led by NASA Johnson Space Center, with collaboration from Ames Research Center
  - LR provided the funding for repair and reflight of R2 to ISS
- **Another part of LR is the RFID Recon payload for Astrobee**
  - RFID Recon is a mobile RFID tag reader that works together with fixed readers (for example, in hatches and "smart drawers") to update location of RFID-tagged objects in an inventory management system
  - Astrobee with RFID Recon can be used to confirm an item's location or search for lost items

R2AL Astrobee Conops

- **R2AL/Astrobee integrated conops:**
  - Astrobee uses RFID Recon to find an RFID-tagged item in a cargo bag
  - R2 moves to retrieve the cargo bag
- **In 2018, R2AL conducted ground testing:**
  - Testing was conducted with an R2 ground unit in the ARGOS facility
  - A TurtleBot rover carrying RFID Recon stood in for an Astrobee free flyer
    - Astrobee was still under development, and in any case unable to fly in ARGOS
- **In 2019, R2AL focused on improving R2 mobility:**
  - R2 can now walk from handrail to handrail, while avoiding unexpected clutter
  - Mobility tested in ARGOS
- **In 2020, R2AL will repeat the 2018 test, but this time with real robots on the ISS**

R2AL Astrobee Integration Challenges

- **On-orbit operational testing of RFID Recon**
  - RFID Recon will be tested in various operating modes as soon as possible after Astrobee commissioning wraps up
  - This is a prerequisite for the joint activity with R2
- **Commissioning Astrobee in US Lab**
  - R2 is tethered (for power and data) in the US Lab
    - Astrobee must operate in the US Lab for any joint activities
  - Astrobee was always designed to operate throughout the ISS US Orbital Segment
    - Including JEM, N2, COL, USL, N1, N3
  - However, we still need to commission Astrobee for use in each new module
    - Collect map data, validate navigation, understand any special constraints
- **Coordination of two ISS robots across three operating centers:**
  - Robonaut Control Center at JSC
  - RFID Recon control center at JSC
  - Multi-Mission Operating Center at ARC (Astrobee)
- **Data connectivity between R2 and Astrobee**
  - Ironically, although R2 and Astrobee will operate side by side, they will connect to different ISS networks (Ops LAN vs. Payload LAN) that are isolated for security and reliability reasons
  - It may be easiest for them to communicate through a network bridge on the ground

QUESTIONS?