



# Promoting Astronaut Autonomy in Human Spaceflight Missions

Jessica J. Marquez, Ph.D. | Human-Computer Interaction Group | NASA Ames Research Center

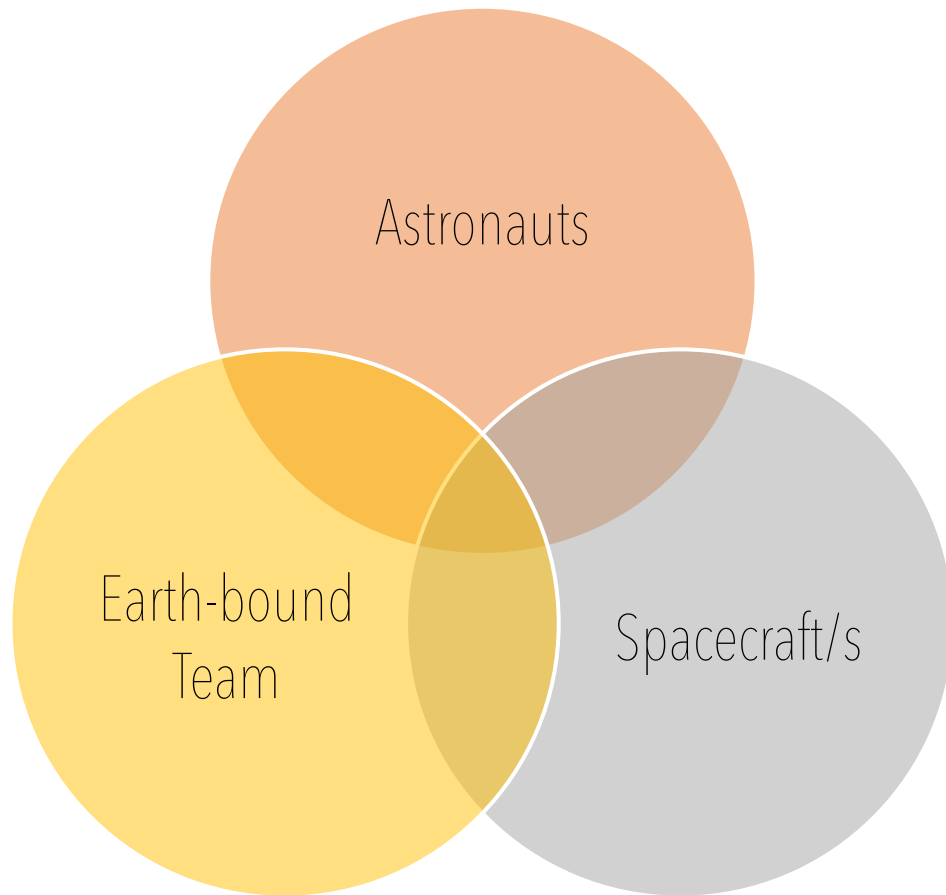
# Where are we headed?



A photograph of a Mars rover, likely Curiosity, on the surface of Mars. The rover is positioned in the center of the frame, facing away from the viewer. The terrain is a vast, flat, reddish-brown landscape with scattered rocks and small craters. The sky is a uniform, hazy orange color, suggesting a sunset or sunrise. The overall scene is desolate and barren.

*“We are going to the Moon to learn to live  
on other planets...”*

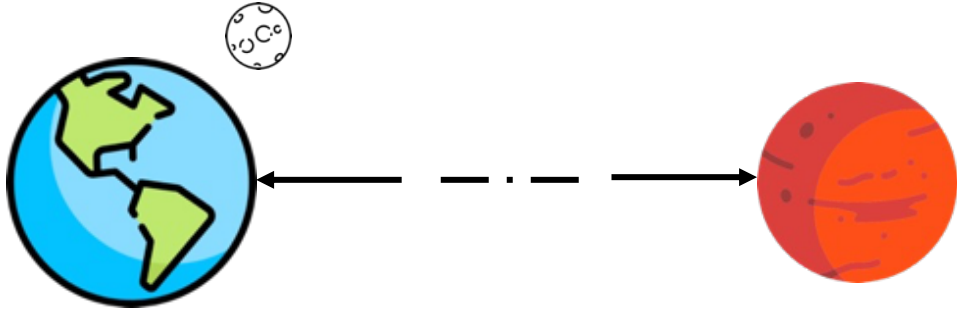
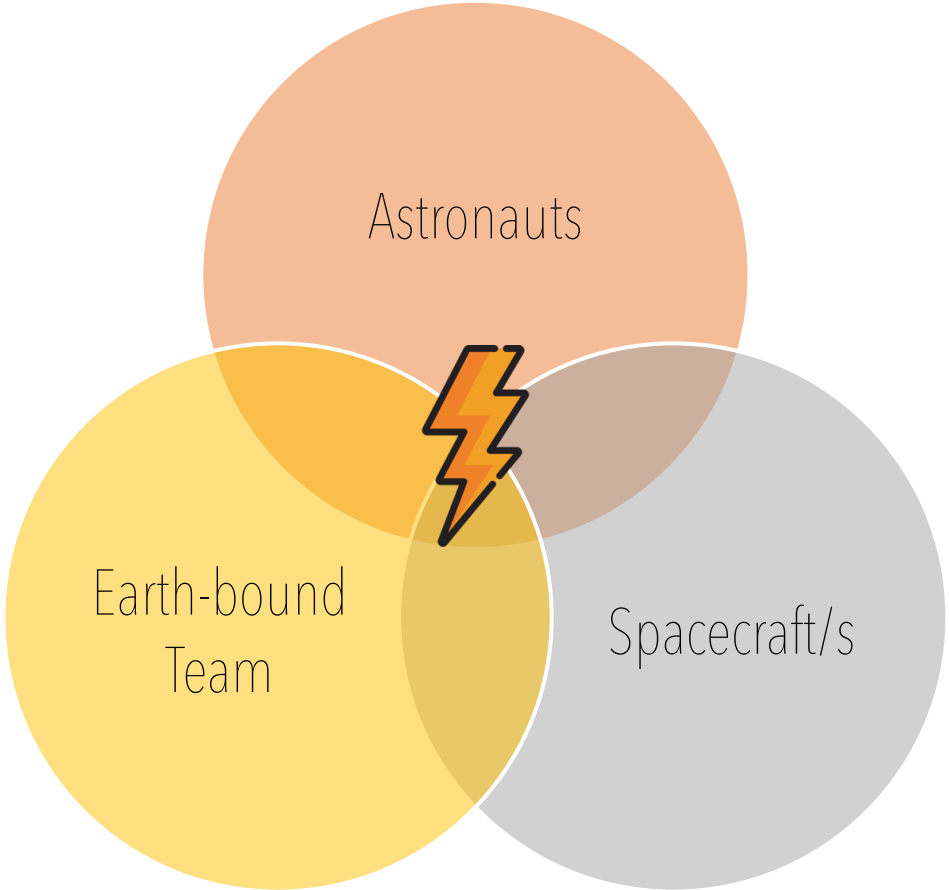
# Human Spaceflight



It isn't just about staying alive ...

but about exploring & working in space!

# A shift in Concept of Operations



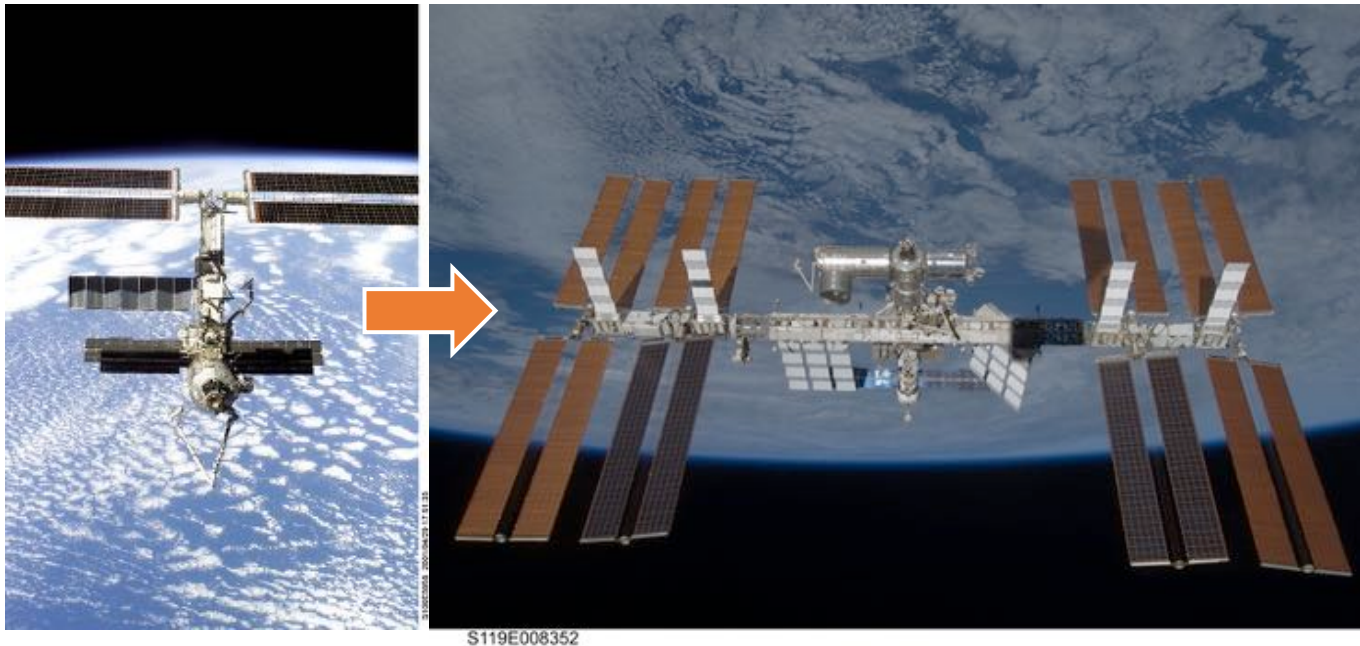
Communication transmission delays, limited bandwidth, and periods of no communication requires NASA to change mission operations.



**International Space Station (ISS)**

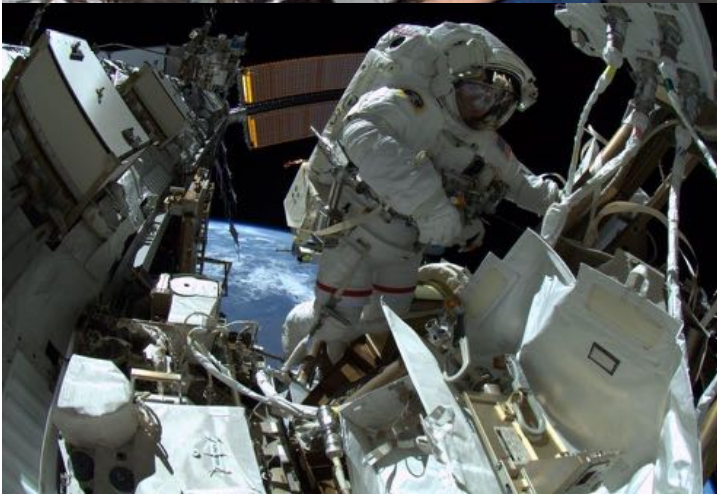
# Quick ISS Facts

- ~150 miles above
- Orbits Earth every 90 minutes
- 8 buses wide (1 football field)
- Existing for 20+ years
- National lab built in space by people
- International collaboration

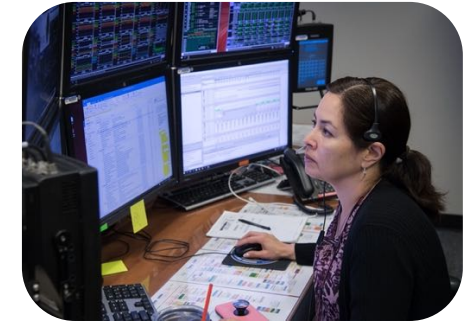




Daily life on ISS



# Mission Control Center Support



# Ground-Crew Daily Ops



S130E007813



# Ground-Crew Daily Ops



# Ground-Crew Daily Ops



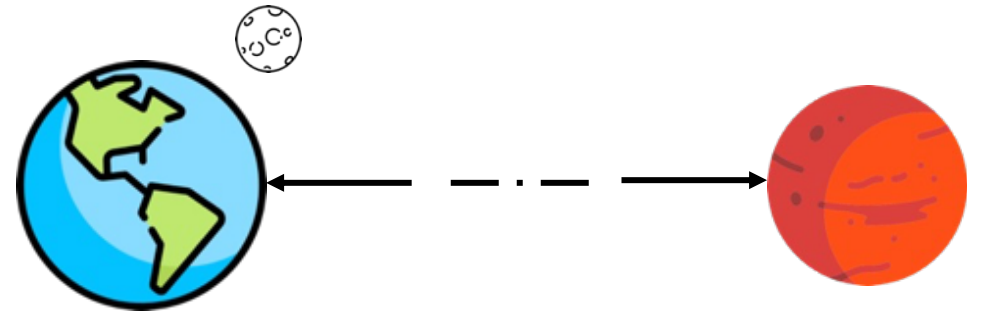
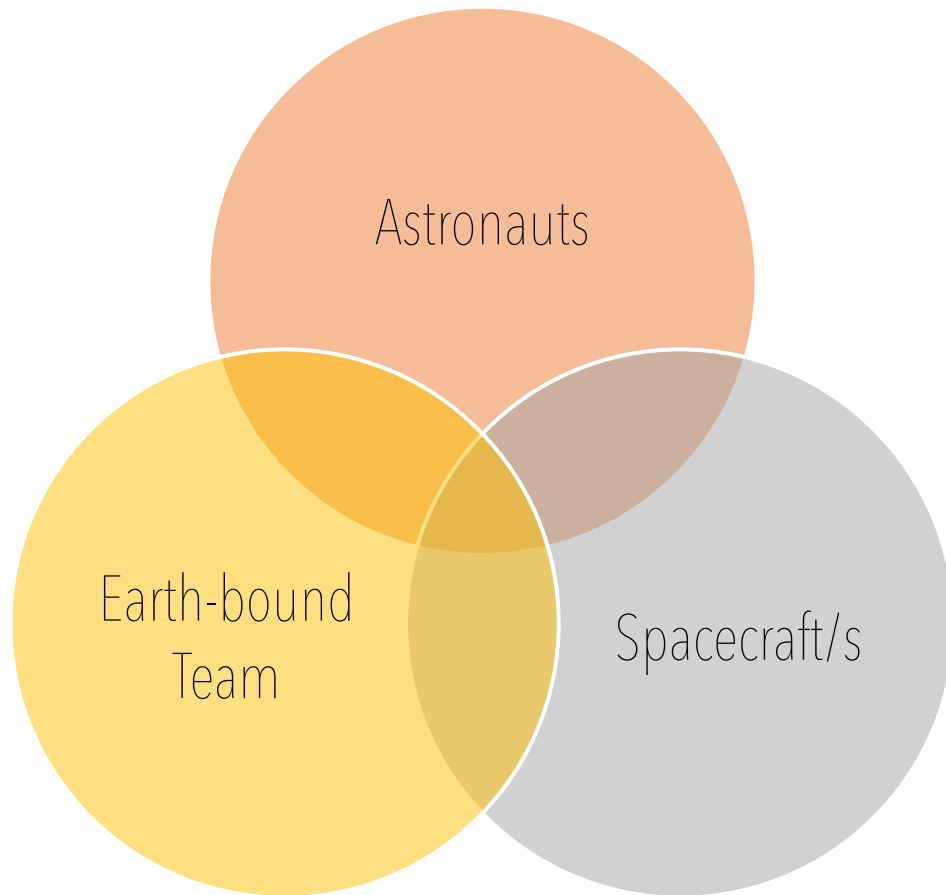
# Ground-Crew Daily Ops



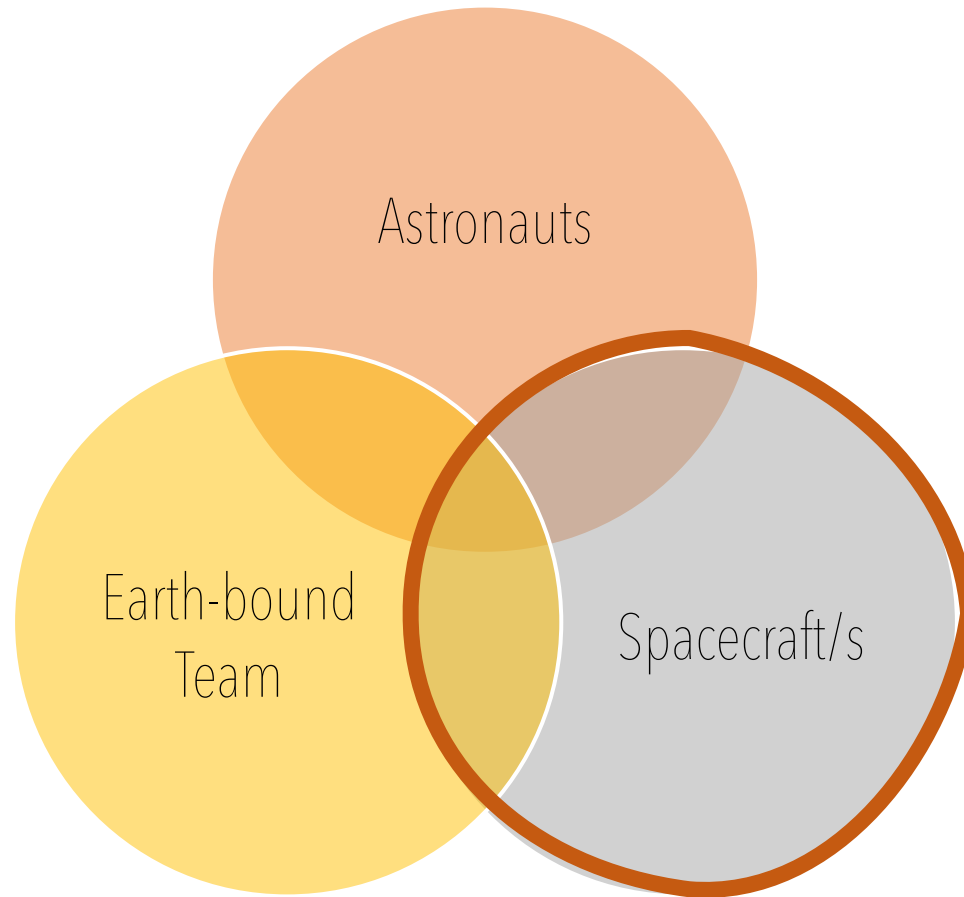
A satellite is shown in orbit above the Earth's horizon. The satellite is a complex structure with various components, including solar panels and antennas. The Earth's surface is visible at the bottom, showing a blue and white horizon line. The background is a dark, starry space.

**Safe crew and vehicle operations is highly dependent on communications infrastructure.**

# How will human spaceflight operations evolve?

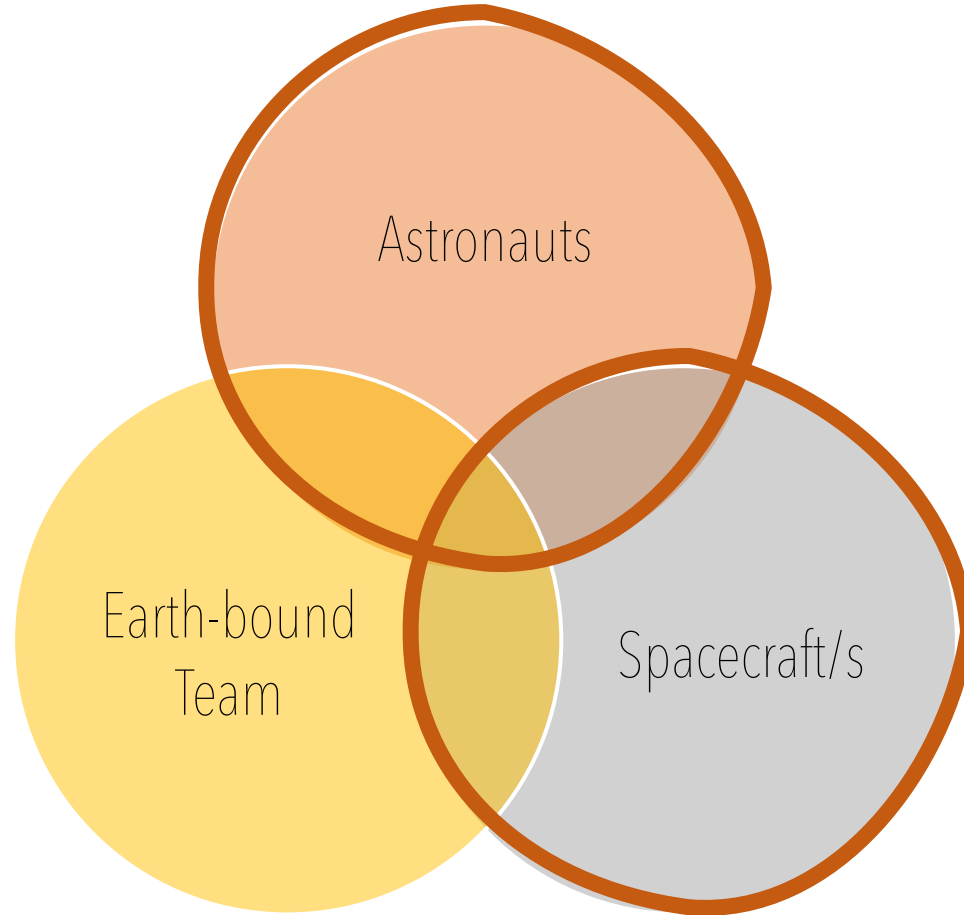


Moving from **Earth-reliant** to **Earth-independent** missions requires new technologies and concepts of operations.



Future missions require various, diverse space assets: landers, rovers, robotics, spacesuits, etc.

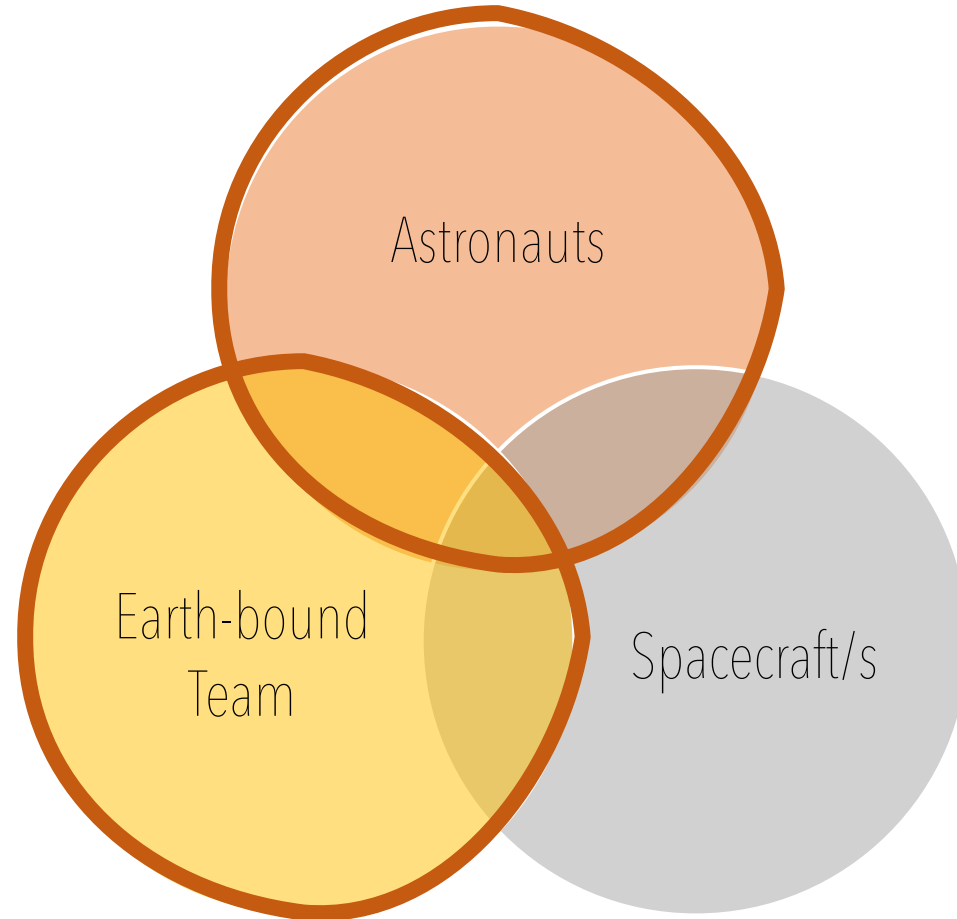
Develop more capable vehicles by increasing the use of automated & autonomous systems.



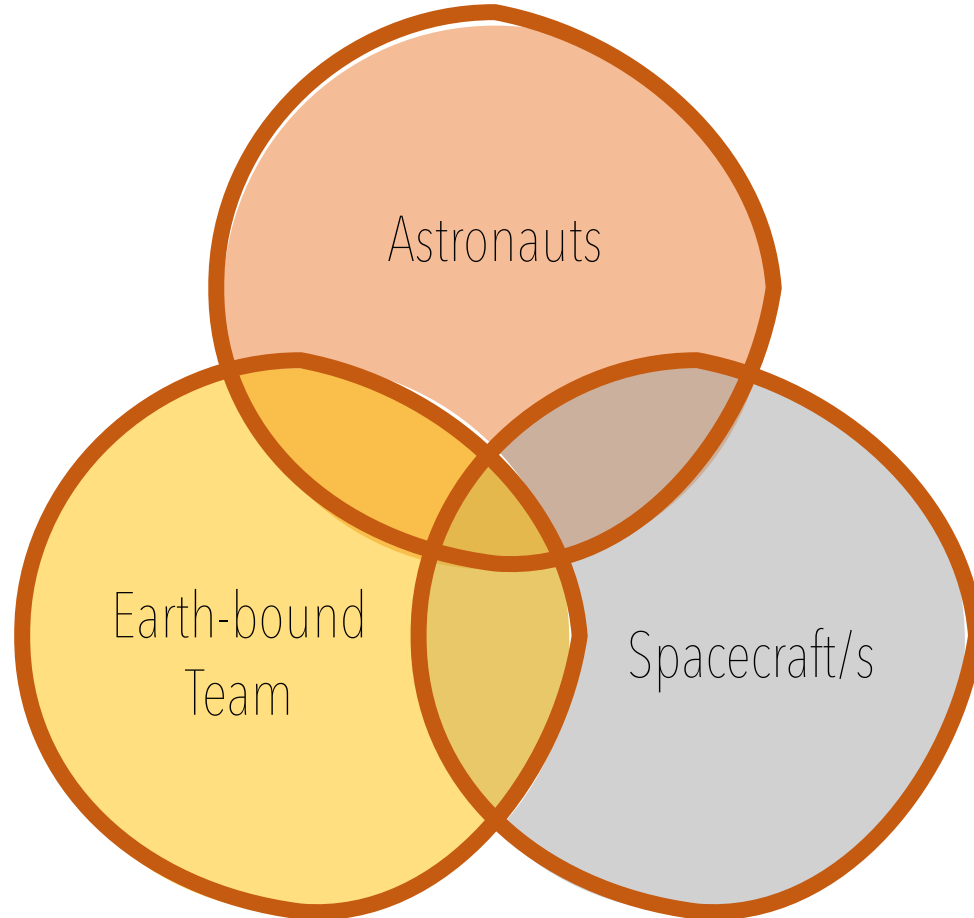
Develop better human-systems integration that includes more advanced systems.

New systems will help astronauts managed vehicle operations as well as fault detection, isolation, and resolution of anomalies.

Develop better tools to communicate, coordinate, and collaborate across a diverse set of tasks.



New systems will help **astronauts perform more autonomously** from ground support teams.



**Astronaut autonomy**  
astronauts' ability to work more independently from mission control.

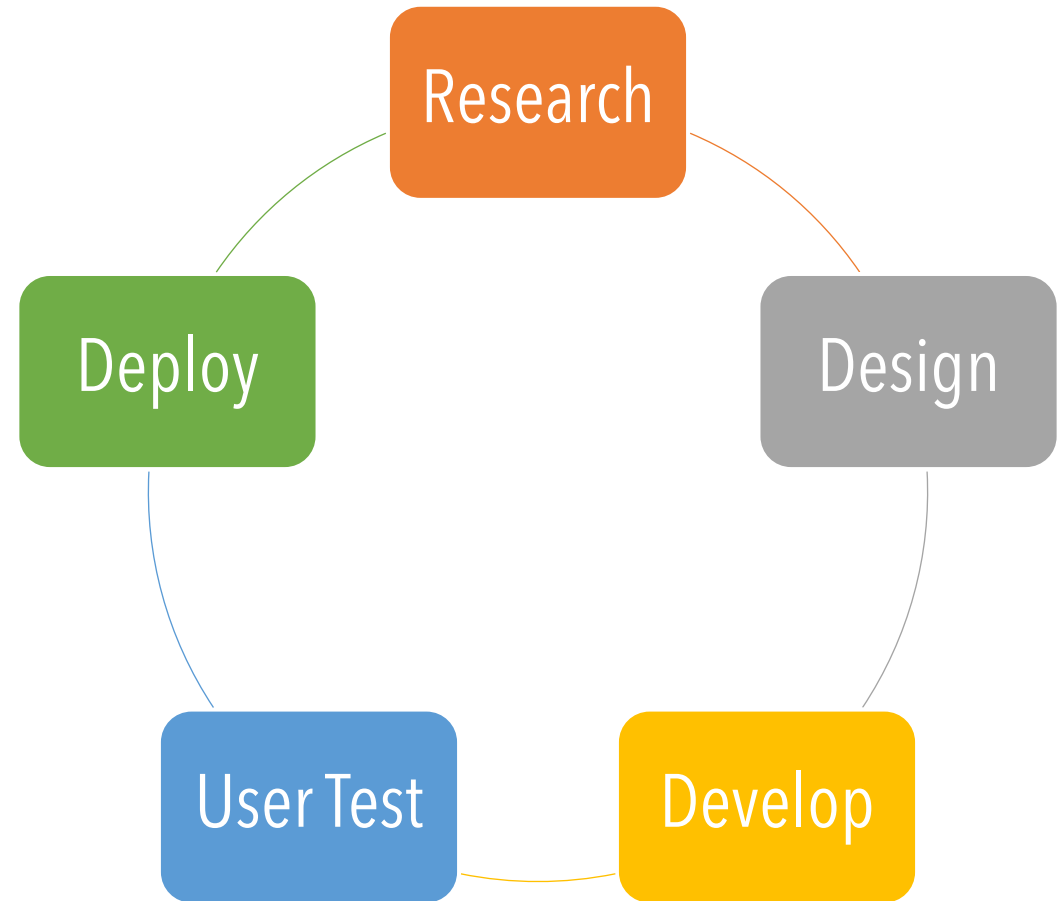
# Promoting Astronaut Autonomy

- Improving procedure execution tools
- Improving communication tools across transmission delays
- Enabling crew self-scheduling



# HCI Process

- Human-Computer Interaction (HCI) Group follows HCI principles.
- Since 2002, HCI group has deployed software tools that enable spaceflight operations.
- Emphasize human-centered design process that includes:
  - Observation work of operations
  - Usability testing
  - Iterative deployment software processes



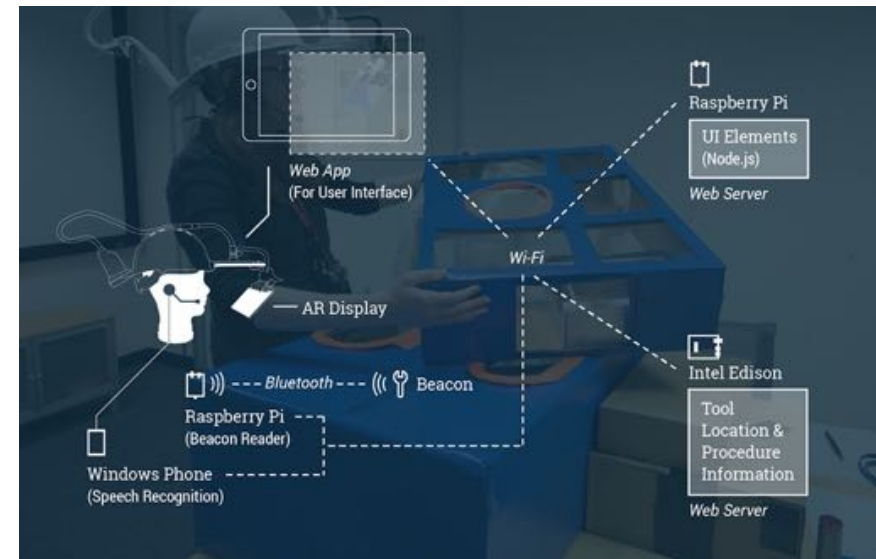
# Improving Procedure Execution Tools

- Beyond making procedures steps easier to understand.
- Leveraging new technologies to provide information about procedure step execution and correctness.
  - Internet of Things: integrated suite of sensors (e.g., proximity, accelerators);
  - Augmented Reality displays;
  - Haptic and aural feedback.



# Improving Procedure Execution Tools

- Four research efforts that included low- to medium-fidelity technology demos, usability studies with prototype procedure tools implementing emerging technologies:
  - Task completion management
  - Crew training
  - Habitat feedback integration
  - Analogous procedure testing
- High school, undergraduate, and graduate student work.



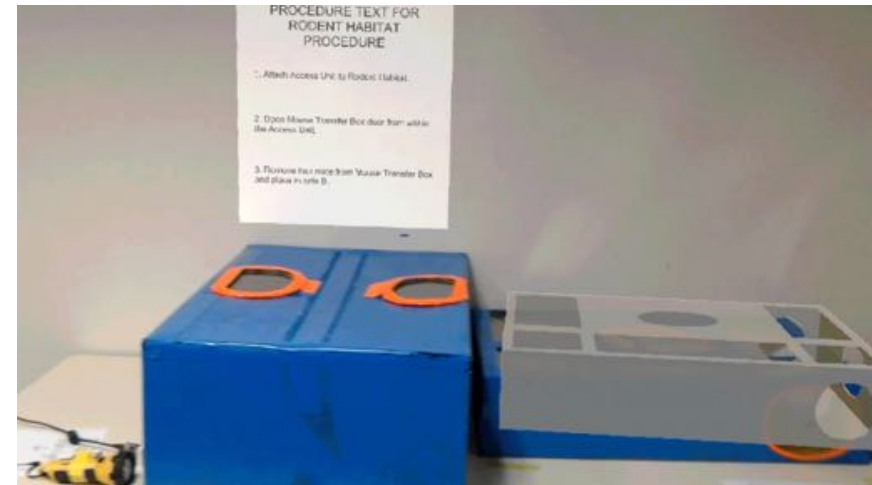
Marquez, Karasinski, & Zheng. How the Internet of "Space" Things will Disrupt and Transform Astronaut Work-Life. SpaceCHI. 2021.

Karasinski et al. Designing Procedure Execution Tools with Emerging Technologies for Future Astronauts. Applied Sciences. 2021; 11(4):1607. <https://doi.org/10.3390/app11041607>

Karasinski et al. Integrating Mission Timelines and Procedures to Enhance Situational Awareness in Human Spaceflight Operations. SpaceCHI. 2022.

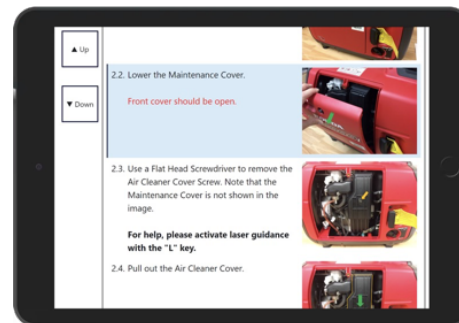
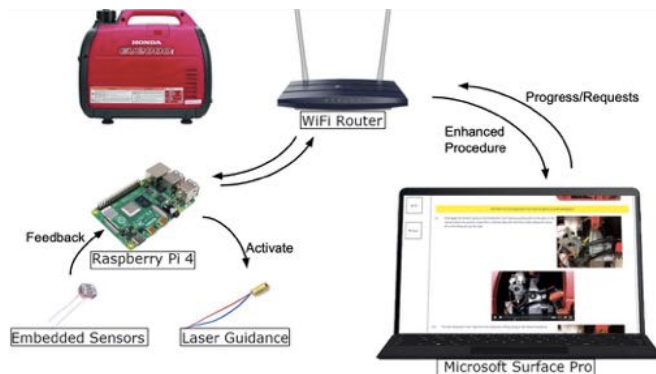
# Improving Procedure Execution Tools

- IoT technology can help identify and confirm correct selection of tools
- AR can help visually explain spatially complex procedural steps.



# Improving Procedure Execution Tools

- Integrating complex procedural task with embedded sensors: enhanced procedure viewer with integrated sensor information, videos, and laser guidance.
- Evaluating aspects of these concepts in spaceflight analog: assessing crew performance in HERA as they perform a mechanical repair task on generator.



# Improving Communication Tools



- Multiple analogs that have simulated communication transmission delays have shown that text is easier to manage than voice communications (Rader et al., 2013; Love & Reagan, 2013).
- Space-to-ground texting is uncommon, and enhancement to ordinary chat interfaces are necessary to support transmission delays.

# Improving Communication Tools

## Mission Log

The screenshot displays a mission log interface. At the top, there are navigation icons for EV1, EV2, IV1, IV2, ST, and MCC. Below this is a text input field with the placeholder "In a few words, describe what happened." and a "Send" button. The log shows a list of messages with timestamps and status icons (ST or IV2). A detailed view of a message is shown in the foreground, titled "Playbook for BASALT - Ground". The message content includes: "Priority 1: Relict", "BB (1)", "AD (3)", and "Priority 2: Syn-empl". It also shows delivery status: "HIGH PRIORITY - 04:00 UNTIL DELIVERY - EARLIEST RESPONSE 13:02:35".

- Common chat interface features:
  - Multimedia messages (text, images, video, and files)
  - Sender's time-stamps
  - Embedded text search
- Unique features that support transmission delay:
  - Counters for received and earliest response times
  - User-driven acknowledgement of messages
  - Prioritization of messages

# Improving Communication Tools

- Evaluated in NEEMO analog for interior science & dive support.



- Evaluated in **BASALT** analog for planetary EVA & science support.



# NASA BASALT

- Biologic Analog Science Associated with Lava Terrains (BASALT) Research Program focused on *"how do we support and enable scientific exploration during human Mars missions?"*
- Earth to Mars communication latencies included 5 and 15 minutes.
- Mission Log was used in all three deployments.



# Benefits of Multimedia Chat

- Enables communication across communication transmission delay.
  - Can read and respond when ready.
  - Allows for traceability of recommendations.
  - A picture is (sometimes) worth a thousand words.
  - Provides insight as to transmission delays.
- Supports operational work as well as fosters team camaraderie despite transmission delay.

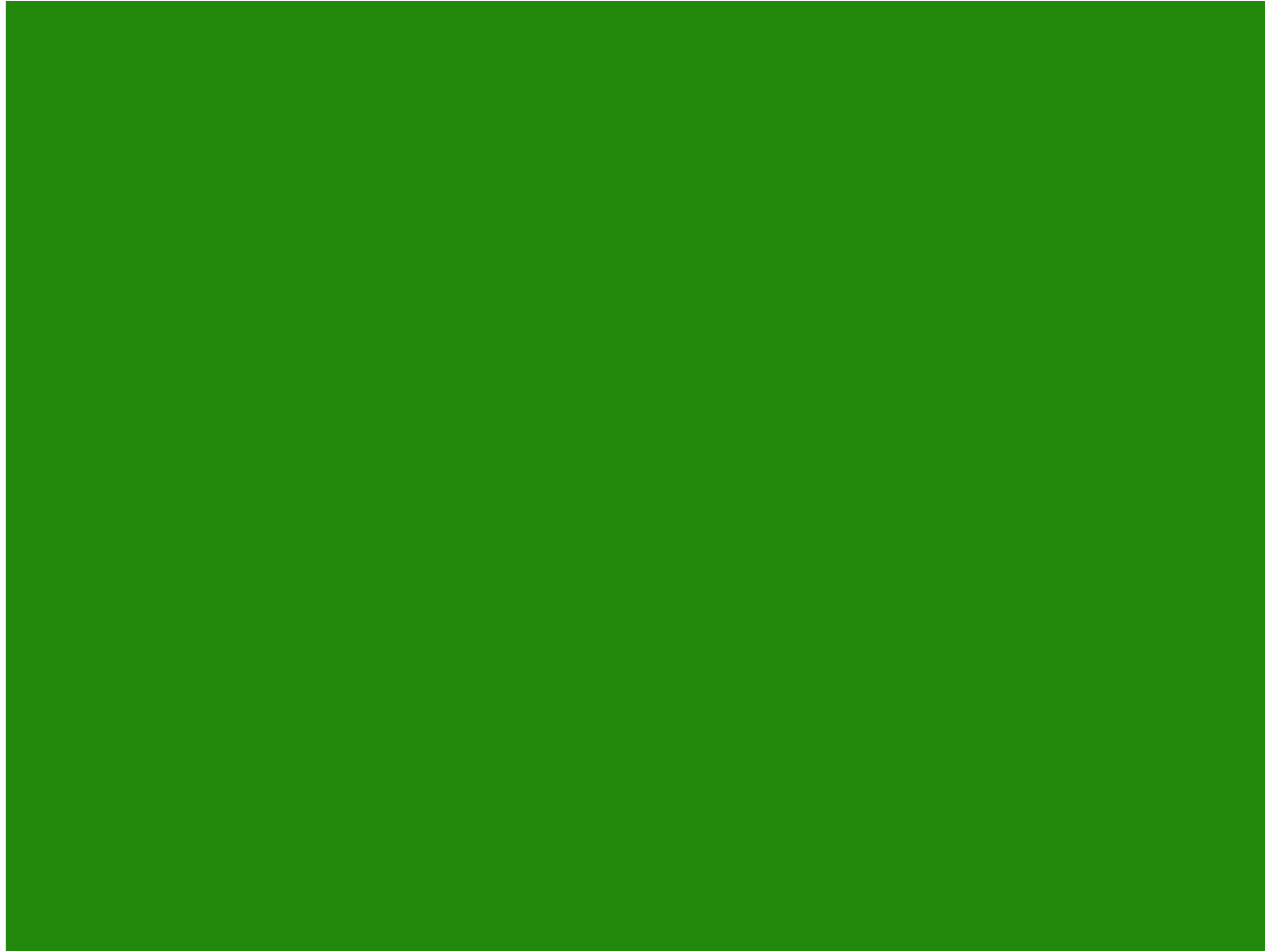


Marquez et al. Enabling Communication Between Astronauts and Ground Teams for Space Exploration Missions. 2019. IEEE Aerospace Conference. Big Sky, MT.

Marquez et al. Future Needs for Science-Driven Geospatial and Temporal Extravehicular Activity Planning and Execution. 2019. Astrobiology. <https://doi.org/10.1089/ast.2018.1838>

Kobs Nawotniak et al. Opportunities and Challenges of Promoting Scientific Dialog through Execution of Future Science-Driven Extravehicular Activity. 2019. Astrobiology. <https://doi.org/10.1089/ast.2018.1901>

# Enabling Self-Scheduling



# Crew Self-Scheduling

## Benefits

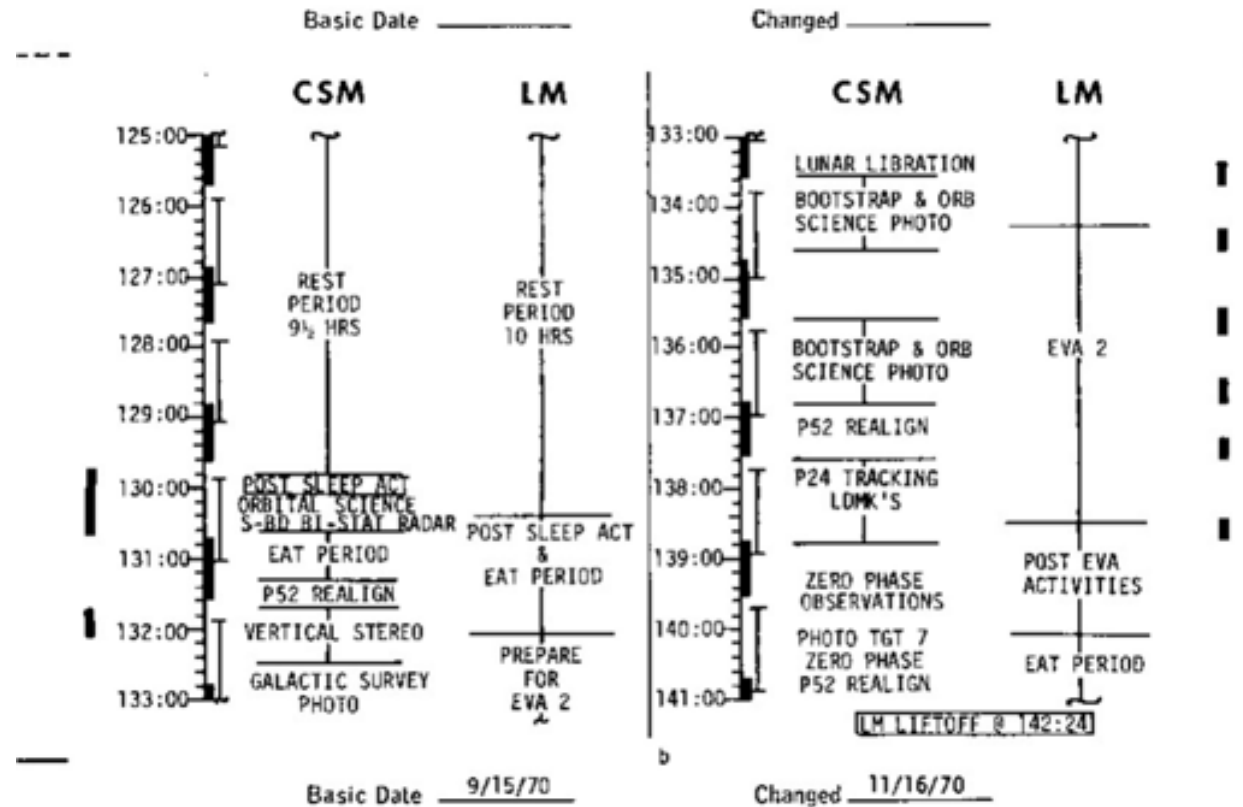
- Mitigates effects of communication latency, intermittent communication, and limited bandwidth.
- Enables crew to contribute their insight how to best manage schedule.
- Minimizes idle time waiting for Mission Control responses.

## Challenges

- Different concept of operations that requires new protocols.
- Do not want to overwhelm astronauts who are not expert mission planners.
- Still need to ensure and retain constraint-abiding plans and schedules.

# Enabling Self-Scheduling

1. Easy-to-use tool for astronauts
2. Feasibility assessment
3. Performance & aids
4. Mission-level impact assessment



Snippet of Apollo 14 Timeline

# Playbook

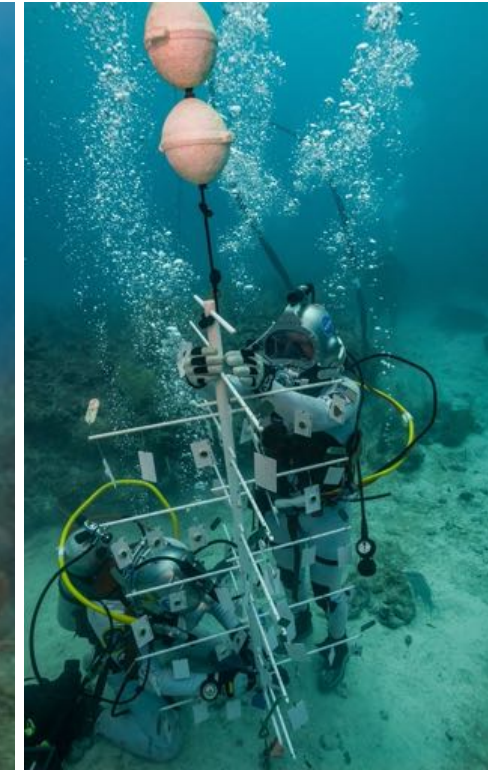
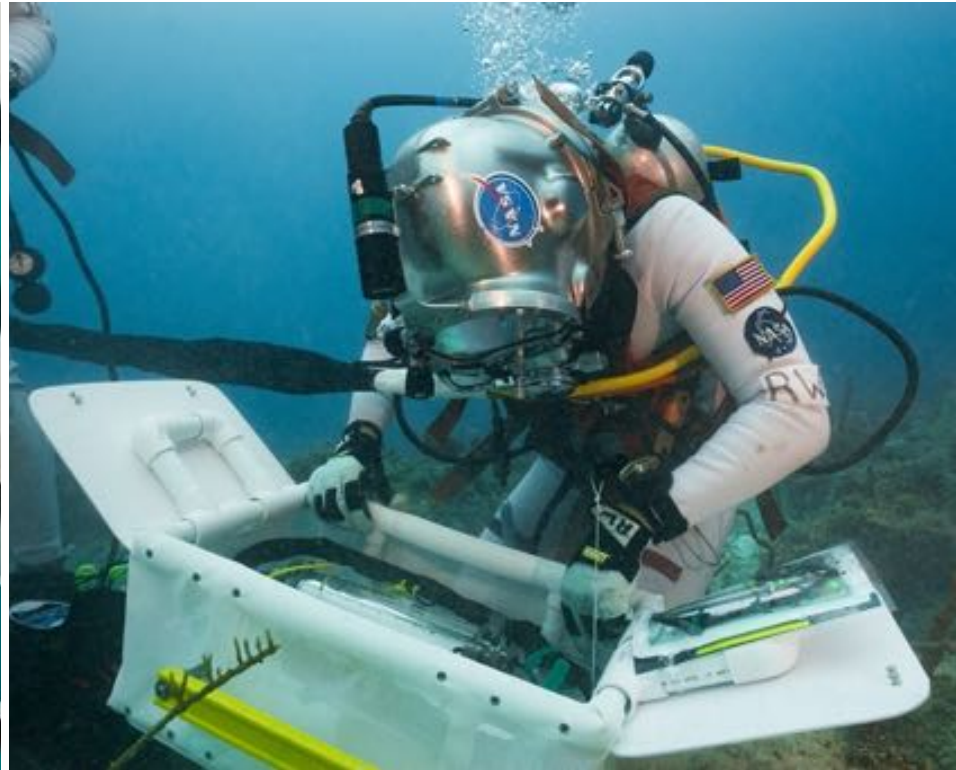


Marquez et al. Supporting Real-Time Operations and Execution through Timeline and Scheduling Aids. 2013. International Conference on Environmental Systems, Vail, CO.

Marquez et al. Increasing Crew Autonomy for Long Duration Exploration Missions: Self-Scheduling. 2017. IEEE Aerospace Conference. Big Sky, MT.

- Ten years ago, our team started developing a web-based, mobile timeline tool.
- Field testing crew self-scheduling over the course of multiple analog missions has resulted in an easy-to-use, next generation scheduling and timeline tool.

# NEEMO: Variety of Science Tasks



# Self-Scheduling in NEEMO



# Self-Scheduling in Playbook


---



# Crew Autonomous Scheduling Test (CAST)

- ISS Tech Demo in collaboration with Flight Operations Directorate (FOD) to evaluate feasibility of self-scheduling in spaceflight environment.
- Deployed Playbook (v5) onboard ISS, gave astronaut five exercises, incrementally increasing crew autonomy.

Familiarization & Training		Practice	Self-Schedule			
Exercise #1	Exercise #2	Exercise #3	Exercise #4	+2 days	Exercise #5	+2 days
Planning Familiarization (Fake day)	Execution Familiarization (Prepared Plan)	Schedule Afternoon (Limited Planning)	Self-Schedule	Execute Self-Schedule	Self-Schedule	Execute Self-Schedule

Increasing Crew Autonomy 



# CAST Lessons Learned



- Playbook provided a low-entry barrier for crew to self-schedule an ISS timeline.
  - First time astronaut self-scheduled in space!
- New constraints visualizations are required for the type of constraint complexity that exists in human spaceflight operations.
- Crew timeline flexibility resulted in significant overhead to ISS ground support personnel.

Marquez et al. Lessons Learned from International Space Station Crew Autonomous Scheduling Test. 2019. International Workshop on Planning and Scheduling for Space. Berkeley, CA.

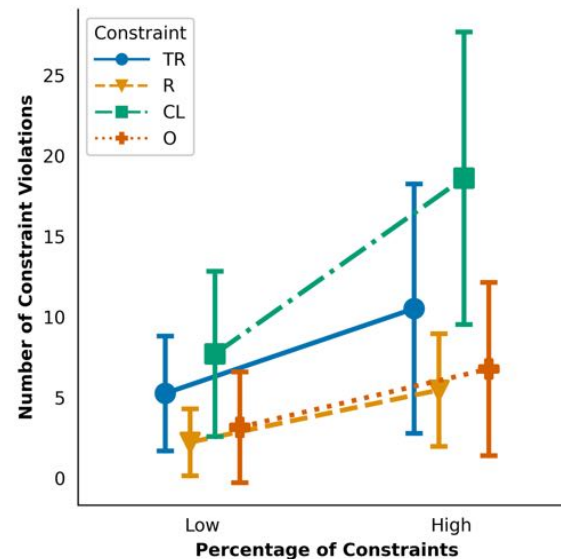
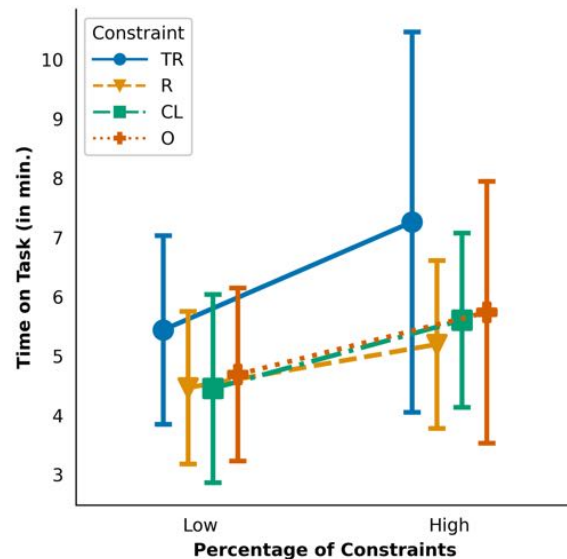
Marquez, Hillenius, & Healy. Increasing Human Spaceflight Capabilities: Demonstration of Crew Autonomy through Self-Scheduling Onboard International Space Station. 2018. ISS R&D Conference. San Francisco, CA.

# What makes self-scheduling challenging?

- Quantifying self-scheduling performance as a function of scheduling task complexity.
  - Controlled lab experiment to measure task effectiveness, efficiency, workload, situation awareness, trust, and usability.
- Scheduling complexity: different type and amount of spaceflight ops constraints
  - Pilot study evaluated number of activities.



# Quantifying Performance on Novice Schedulers



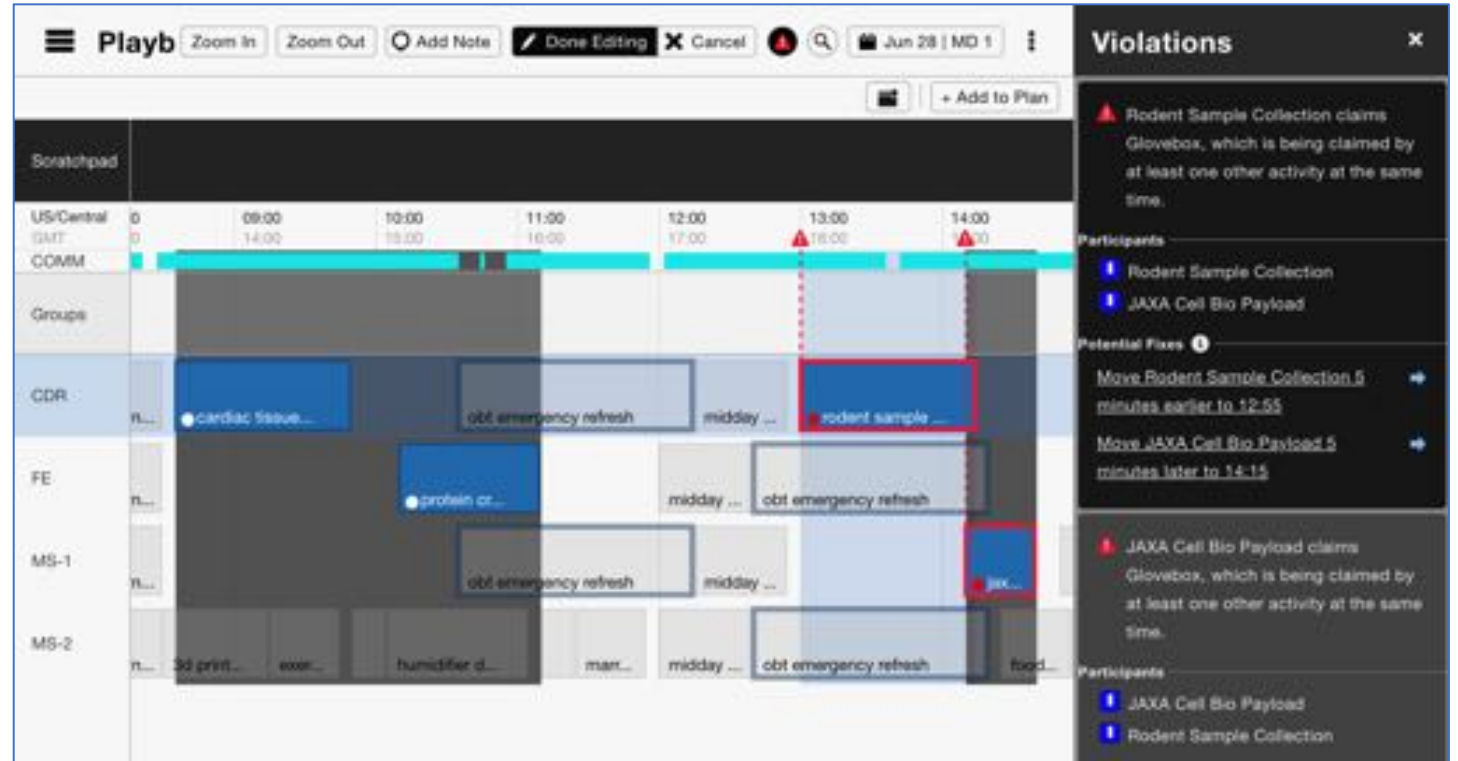
- **Big Take Aways:**

- More workload, less efficient and effective when more activities had constraints.
- Reduced situation awareness when constraint involved more than one activity.
- Differences in workload, efficiency, and effectiveness based on type of constraint.

Marquez et al. Human Performance of Novice Schedulers for Complex Spaceflight Operations Timelines. 2021. Human Factors. <https://doi.org/10.1177/00187208211058913>  
Lee, Marquez, & Edwards. Crew autonomy through self-scheduling: Scheduling performance pilot study. 2021. AIAA SciTech. <https://doi.org/10.2514/6.2021-1578>  
Shyr et al. The Path to Crew Autonomy – Situational Awareness in Scheduling and Rescheduling Tasks for Novice Schedulers. 2021. 72<sup>nd</sup> International Astronautical Congress. Dubai, United Arab Emirates.

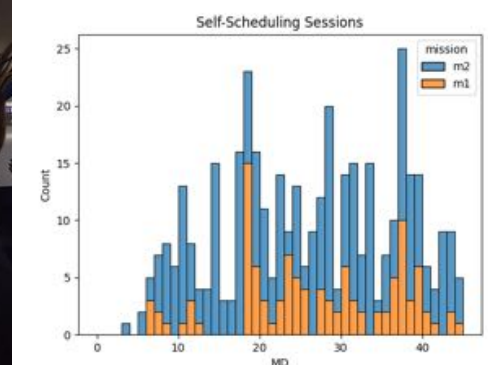
# Visualizations and Aids


- Integration of three visualizations and aids, hypothesizing they will improve performance:
  - No-Go Zones
  - Suggested Violations Fixes
  - Network Move



# Playbook and HERA

- Human Exploration Research Analog (HERA) Campaign 6 emphasizes **crew autonomy**.
  - Four crew, four missions, 45-day long missions.
  - Crew use Playbook operationally.
- Research part of a suite of experiments. Aids integrated into Playbook.
  - Comparing effect of aids between missions.
- Crew required to self-schedule four days, but then are allowed to conduct self-initiated self-scheduling throughout mission.
  - Assessing mission-level impact.



A composite image featuring a view of Earth from space. The Earth's horizon is visible, with a thin layer of atmosphere and city lights glowing from below. A bright sun or star is in the upper left, creating a lens flare. A vibrant green aurora-like glow stretches across the horizon. The text 'Astronaut autonomy is a key component to moving from Earth-reliant to Earth-independent missions.' is overlaid in the upper right quadrant.

*Astronaut autonomy is a key component to moving from Earth-reliant to Earth-independent missions.*

*"We are going to the Moon to learn to live on other planets..."*



*So we can allow astronauts to truly explore!*



# Questions?

Jessica.J.Marquez@nasa.gov

Images Credit: NASA and/or NASA publications

Imbedded graphics used resources from Flaticon.com

