Promoting Astronaut Autonomy in Human Spaceflight Missions

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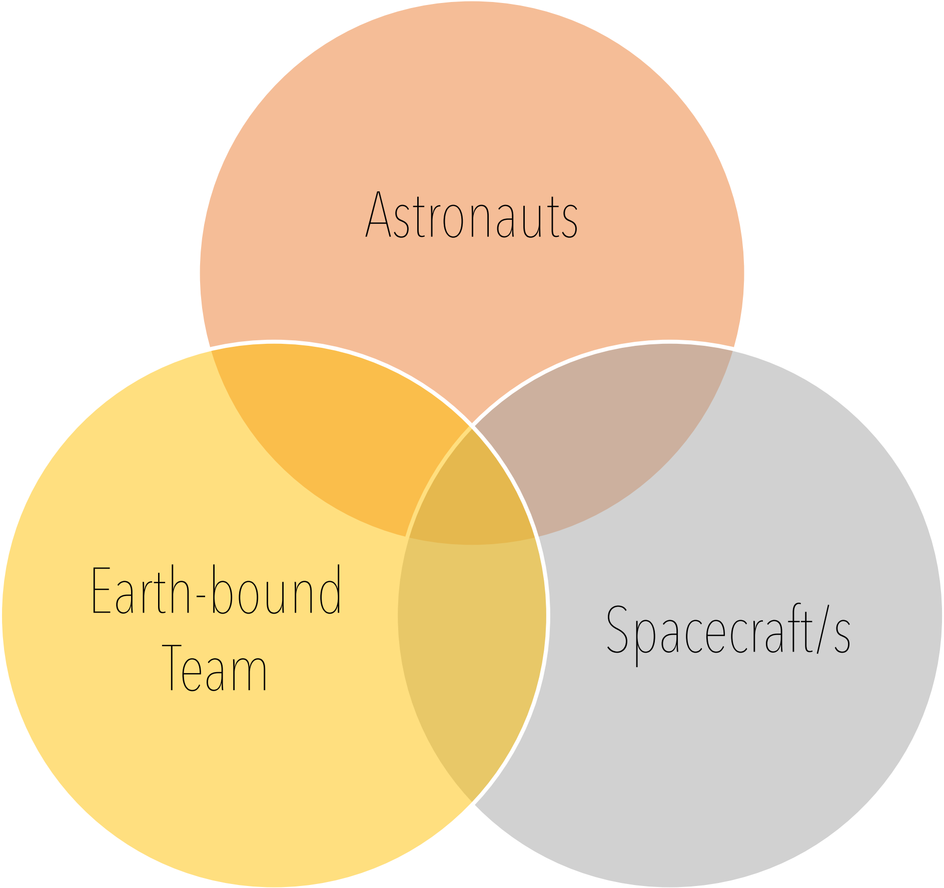
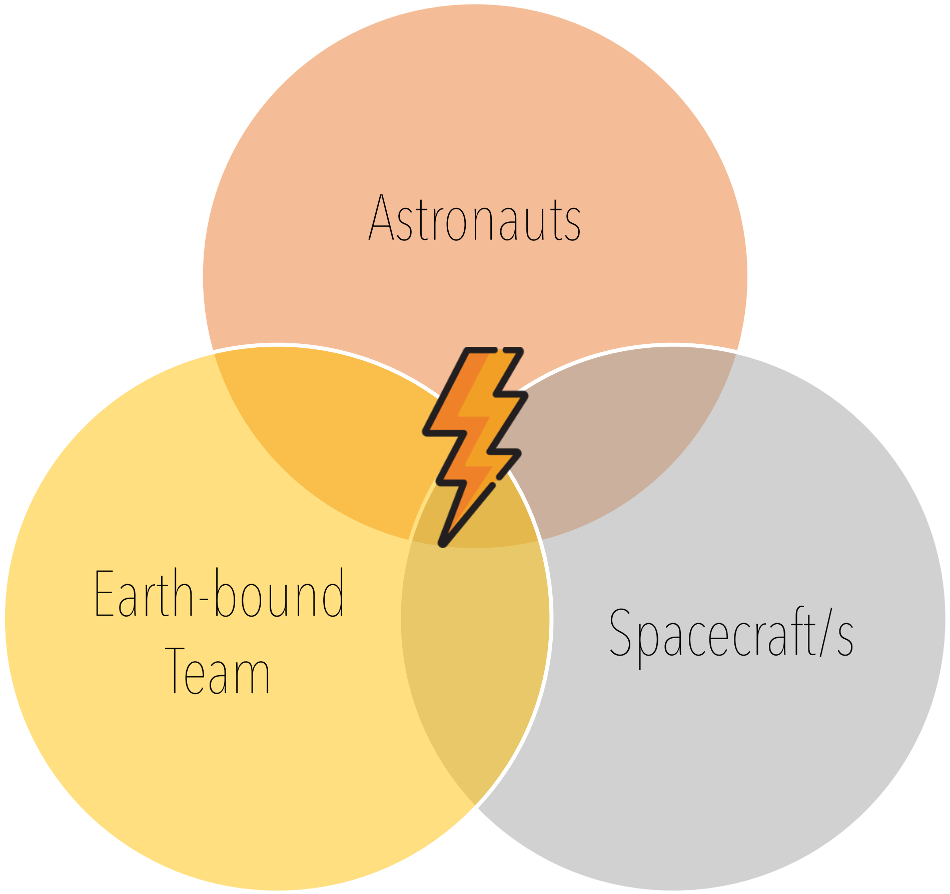
Where are we headed?

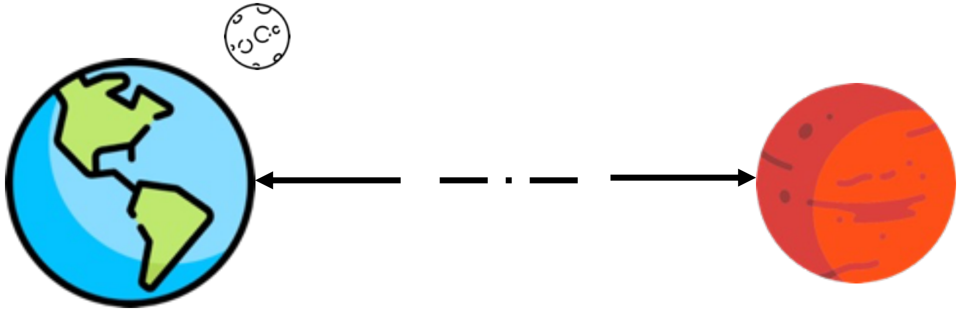
"We are going to the Moon to learn to live on other planets…"

Human Spaceflight



A shift in Concept of Operations



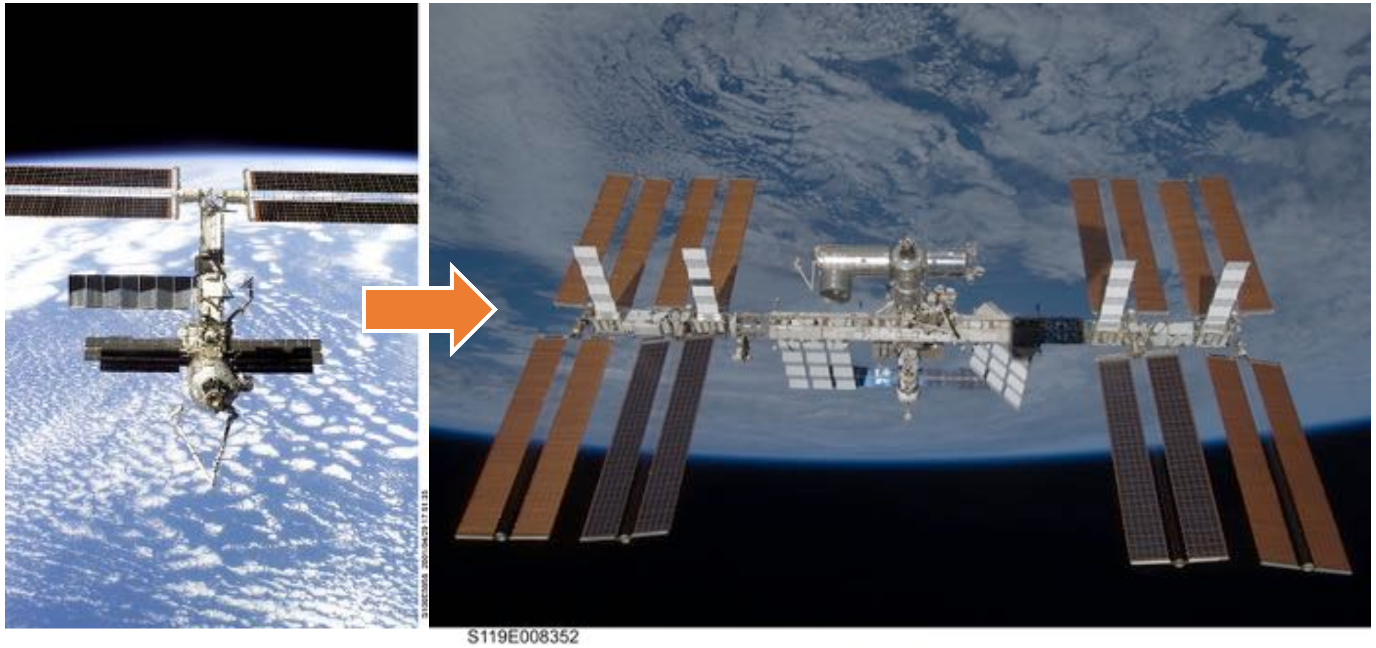


Communication transmission delays, limited bandwidth, and periods of no communication requires NASA to change mission operations.

International Space Station (ISS)

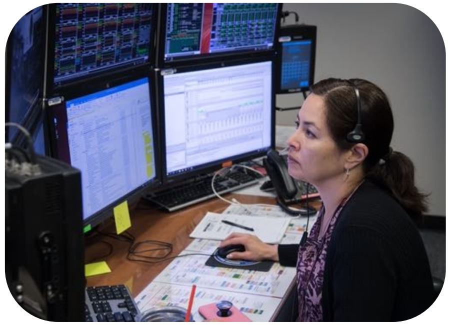
Quick ISS Facts

- ~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

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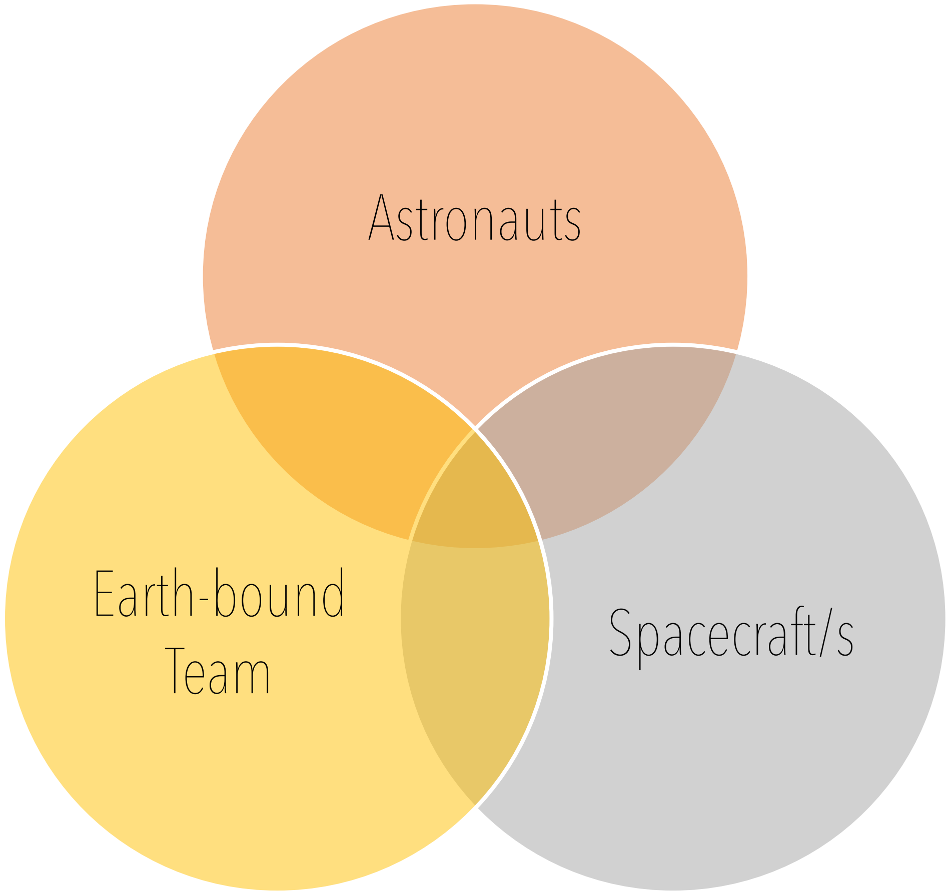
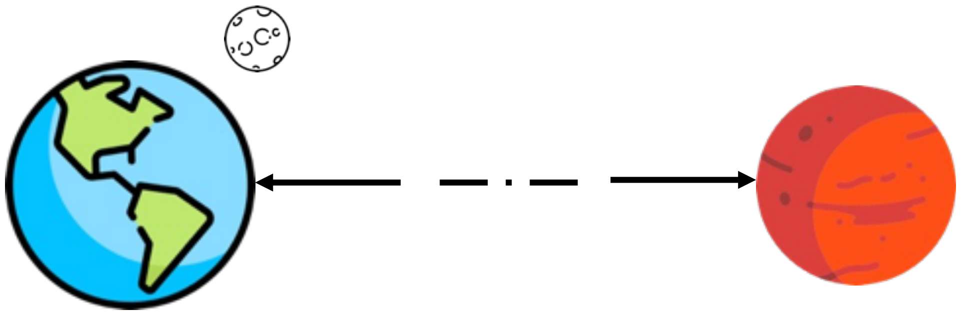
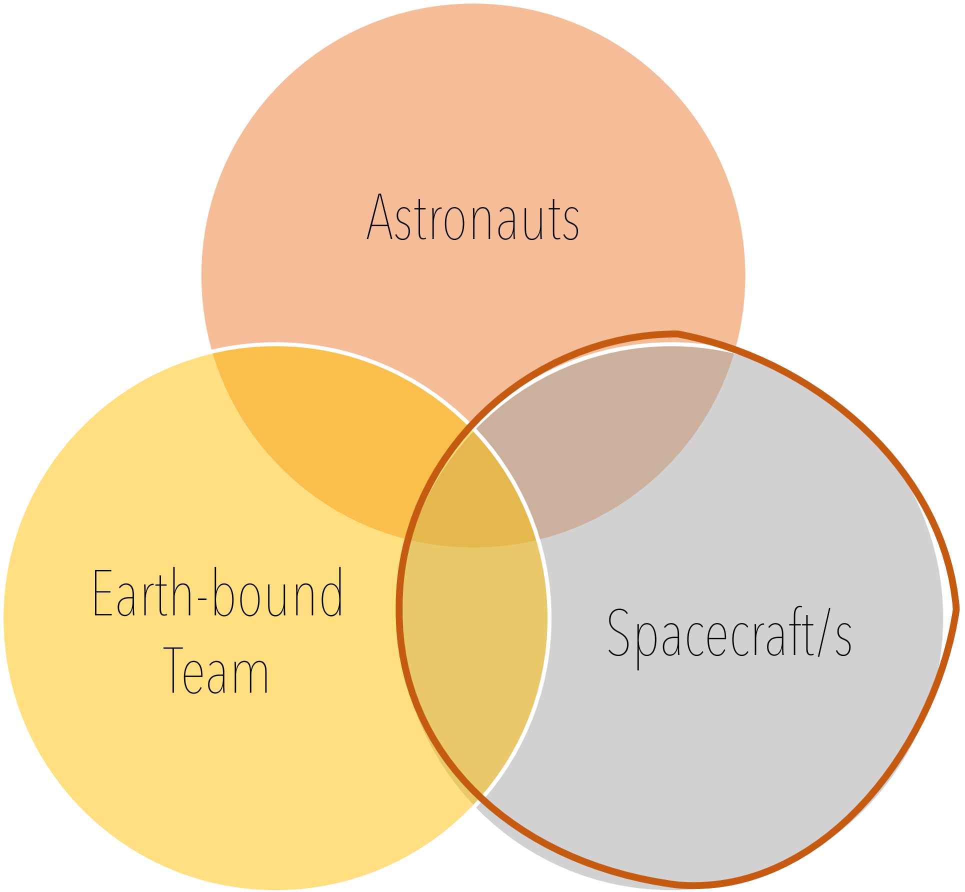
Safe crew and vehicle operations is highly
dependent on communications infrastructure.

How will human spaceflight operations evolve?



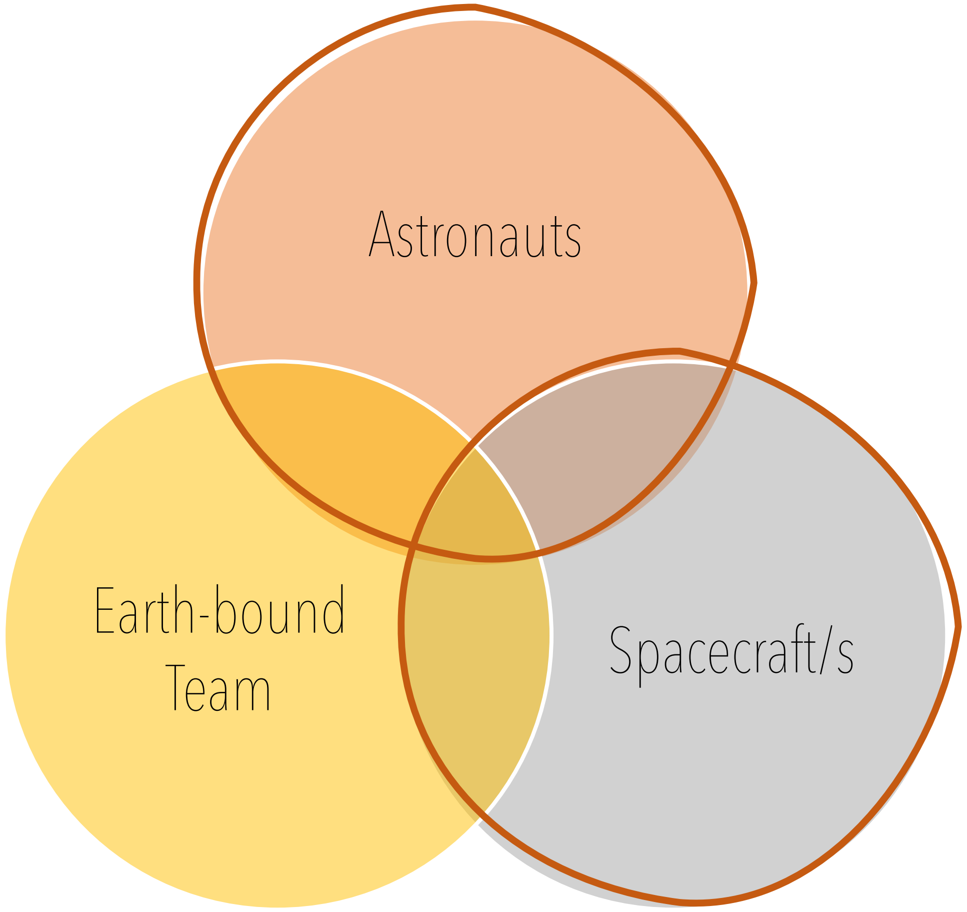


Moving from **Earth-reliant** to **Earth-independent** missions requires new technologies and concepts of operations.



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

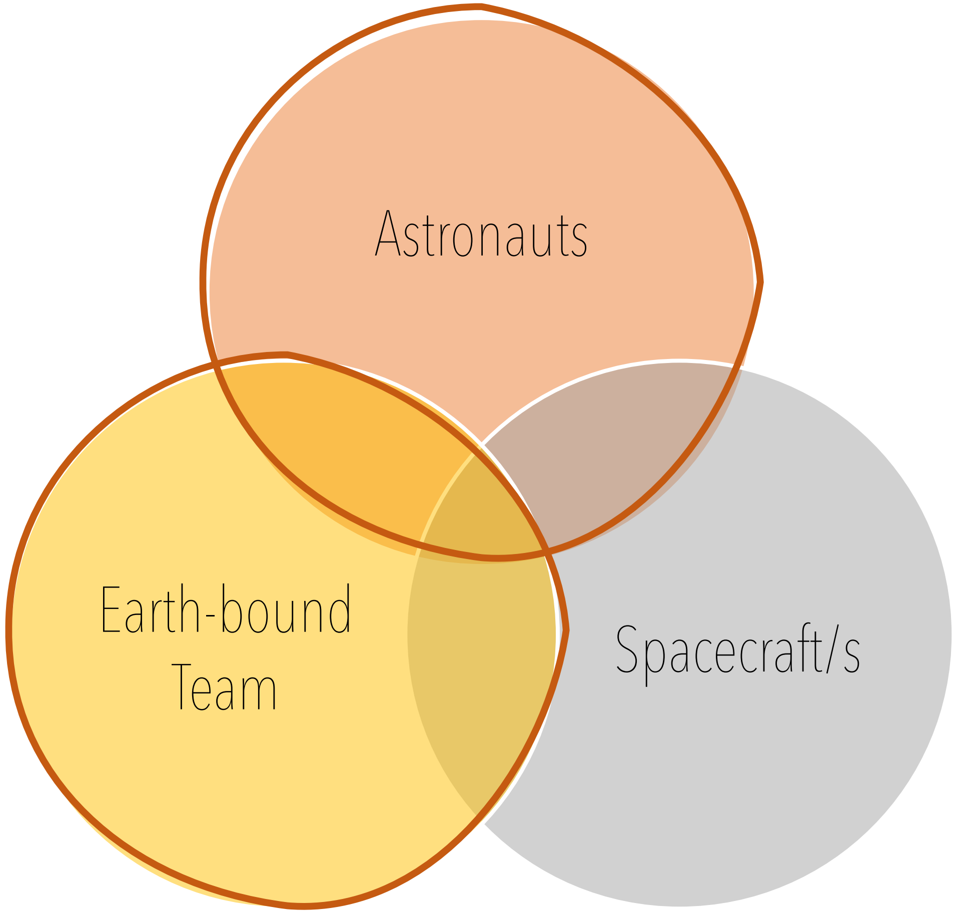
Develop more capable vehicles by increasing the use of automated & autonomous systems.



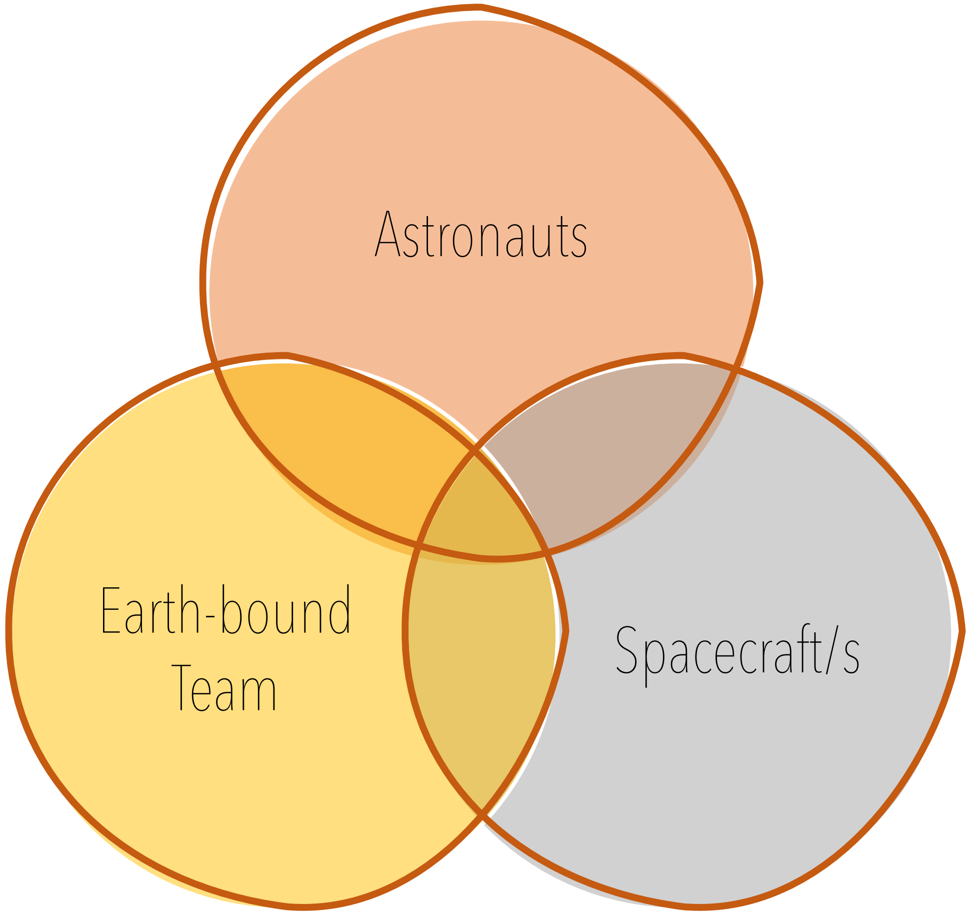
Develop better human-systems integration that includes more advanced systems.

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

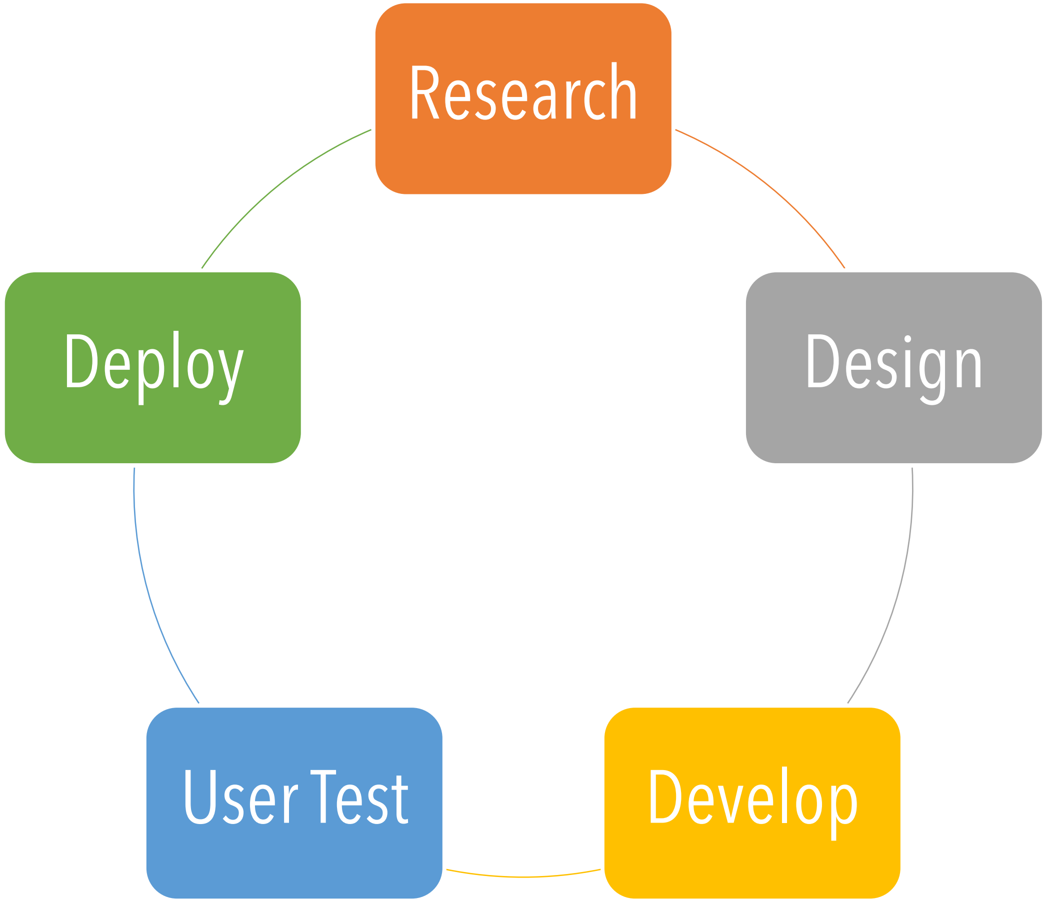
astronauts' ability to work more independently from mission control.

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

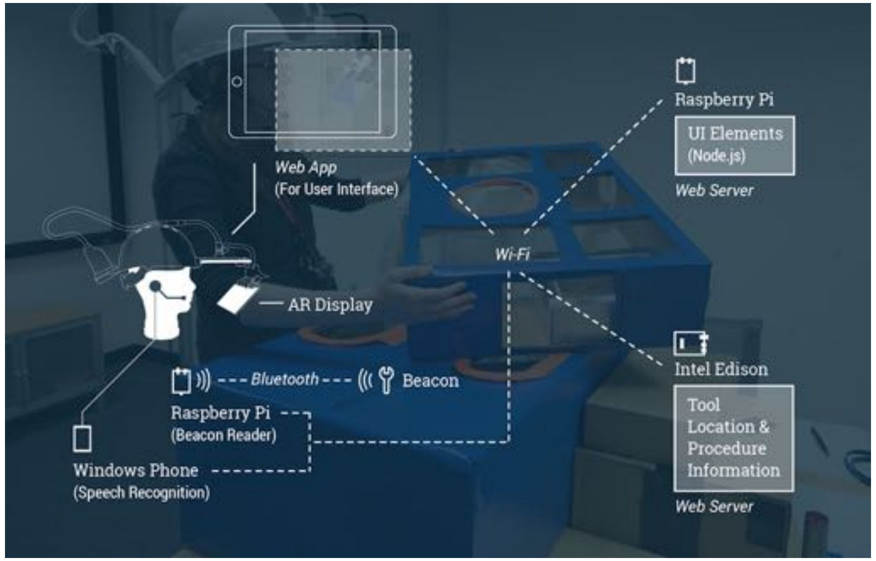


Improving Procedure Execution Tools

- 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

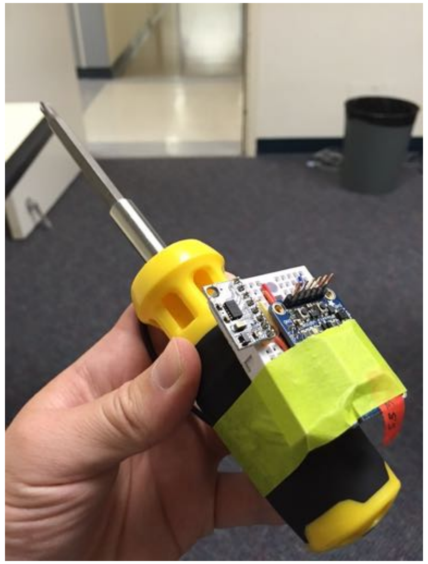
- Four research efforts that included low- to medium-fidelity technology demos, usability studies with prototype procedure tools implementing emerging technologies:
  - Task completion management
  - Crew training
  - Habitat feedback integration
  - Analogous procedure testing
- High school, undergraduate,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



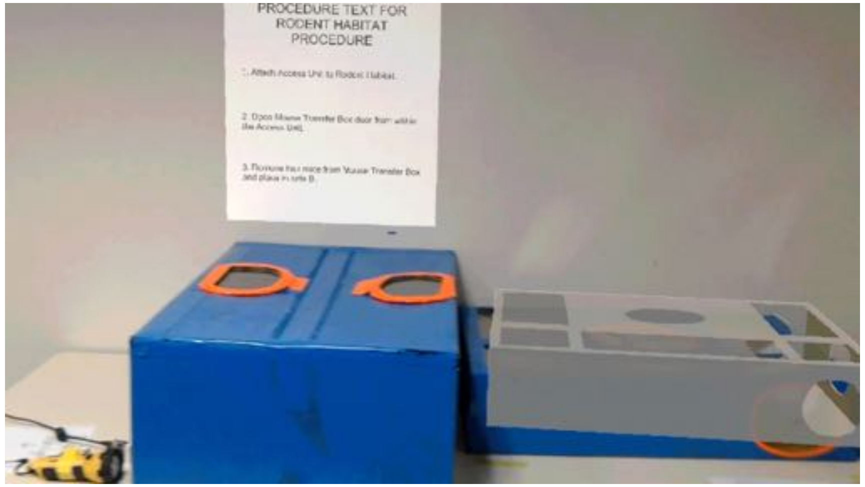
Marquez, Karasinski, & Zheng. How the Internet of "Space" Things will Disrupt and Transform Astronaut Work-Life. SpaceCHI. 2021.
Karasinski et al. Designing Procedure Execution Tools with Emerging Technologies for Future Astronauts. Applied Sciences. 2021; 11(4):1607. https://doi.org/10.3390/app11041607
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

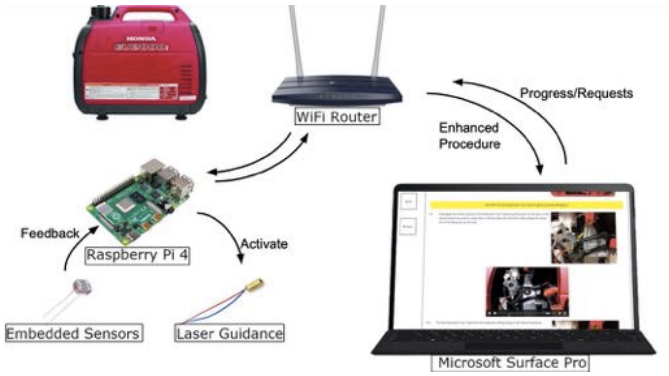


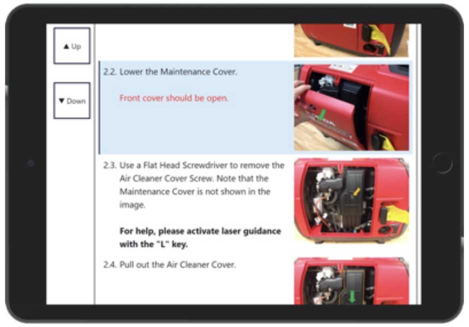
- AR can help visually explain spatially complex procedural steps.



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.



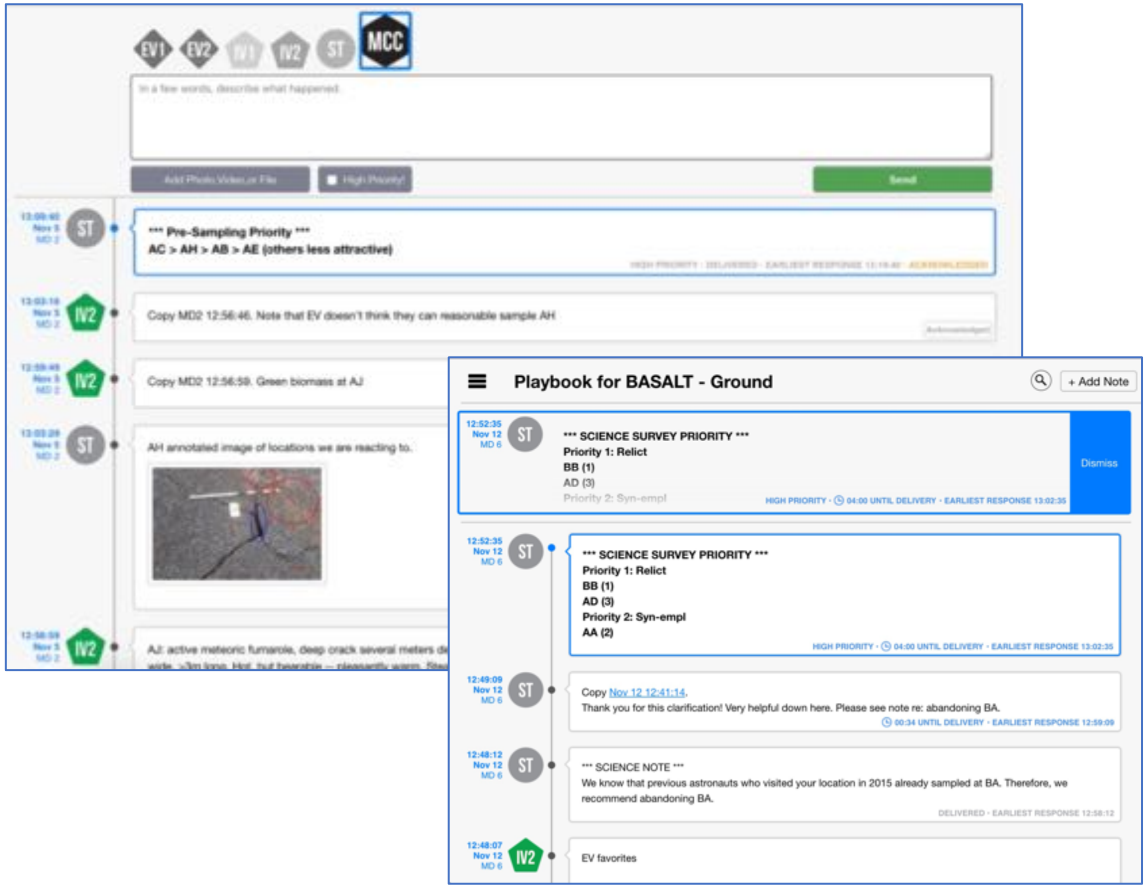


Improving Communication Tools

- 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



- 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.

Lim et al. The BASALT Research Program: Designing and Developing Mission Elements in Support of Human Scientific Exploration of Mars. Astrobiology. Mar 2019.245-259. http://doi.org/10.1089/ast.2018.1869

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

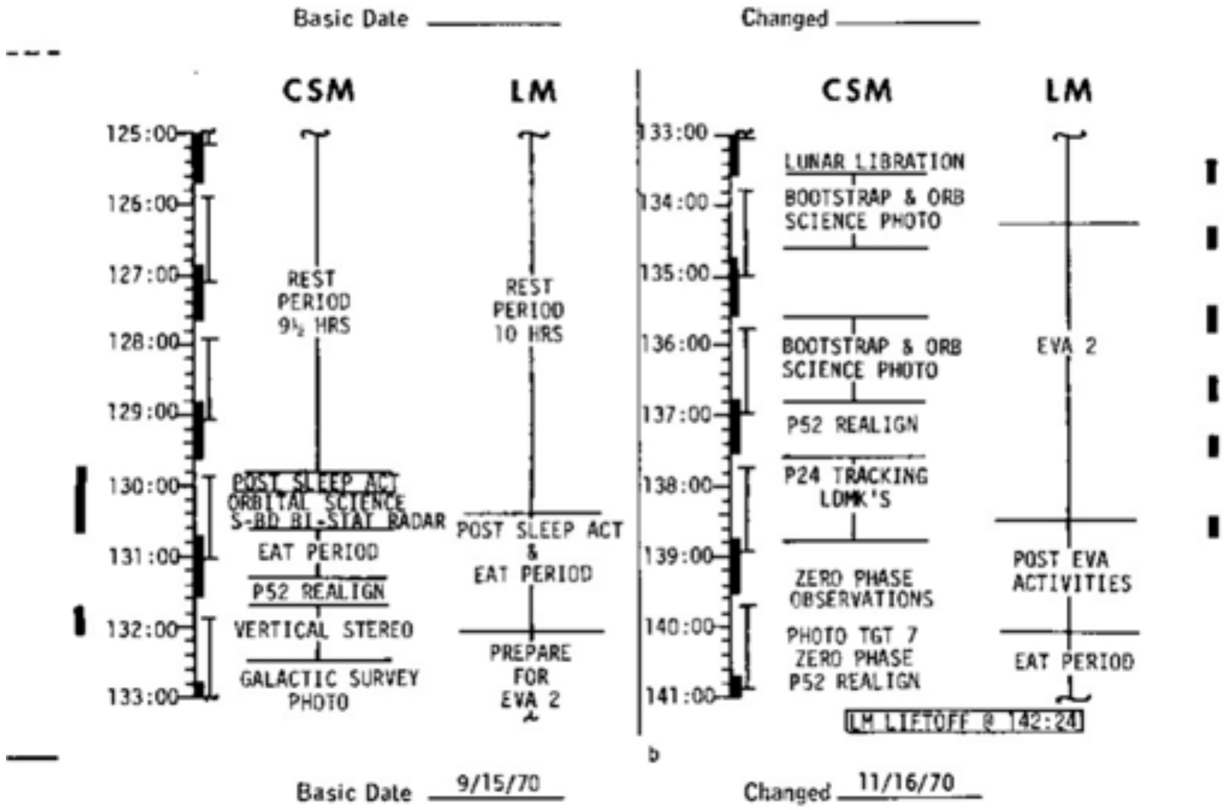
- Mitigates effects of communication latency, intermittent communication, and limited bandwidth.
- Enables crew to contribute their insight how to best manage schedule.
- Minimizes idle time waiting for Mission Control responses.

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



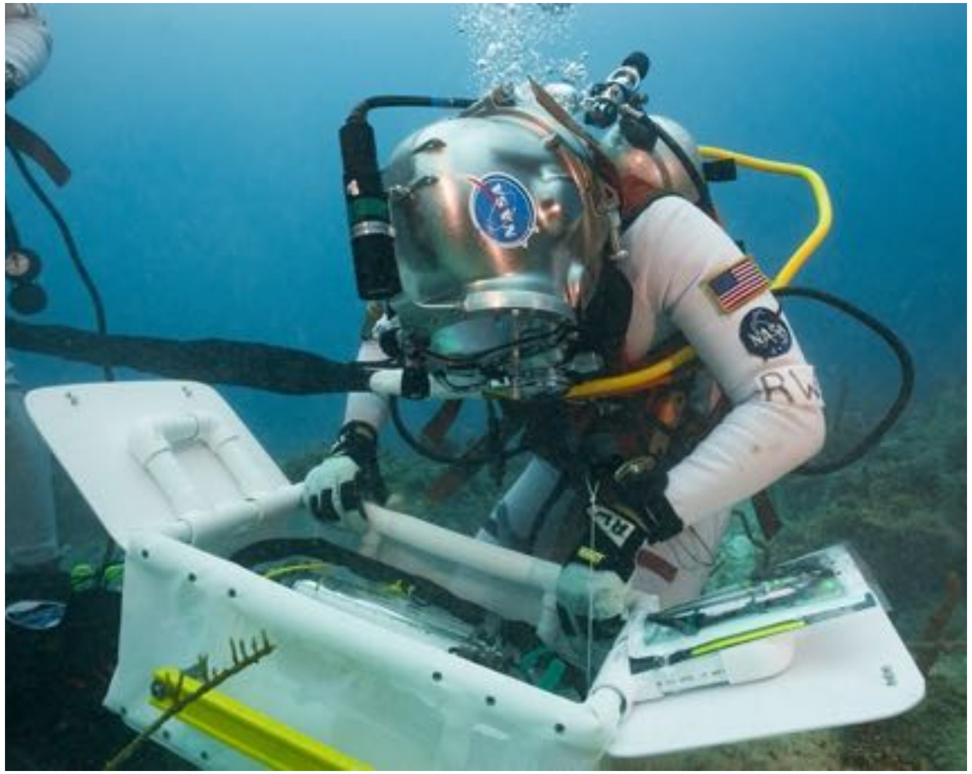
Snippet of Apollo 14 Timeline

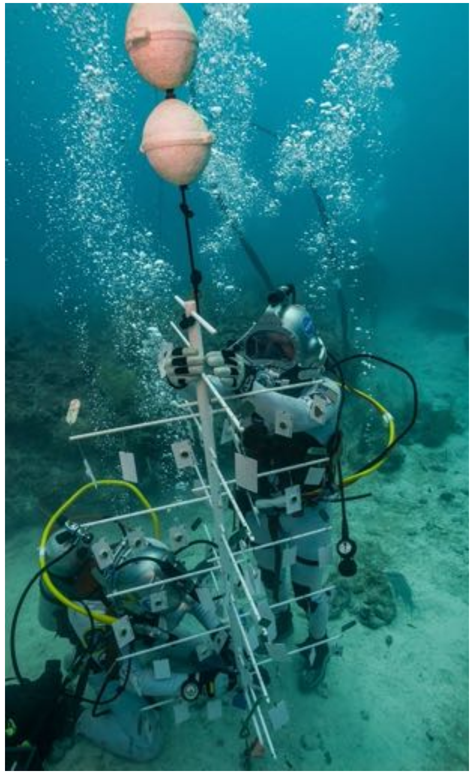
Playbook

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

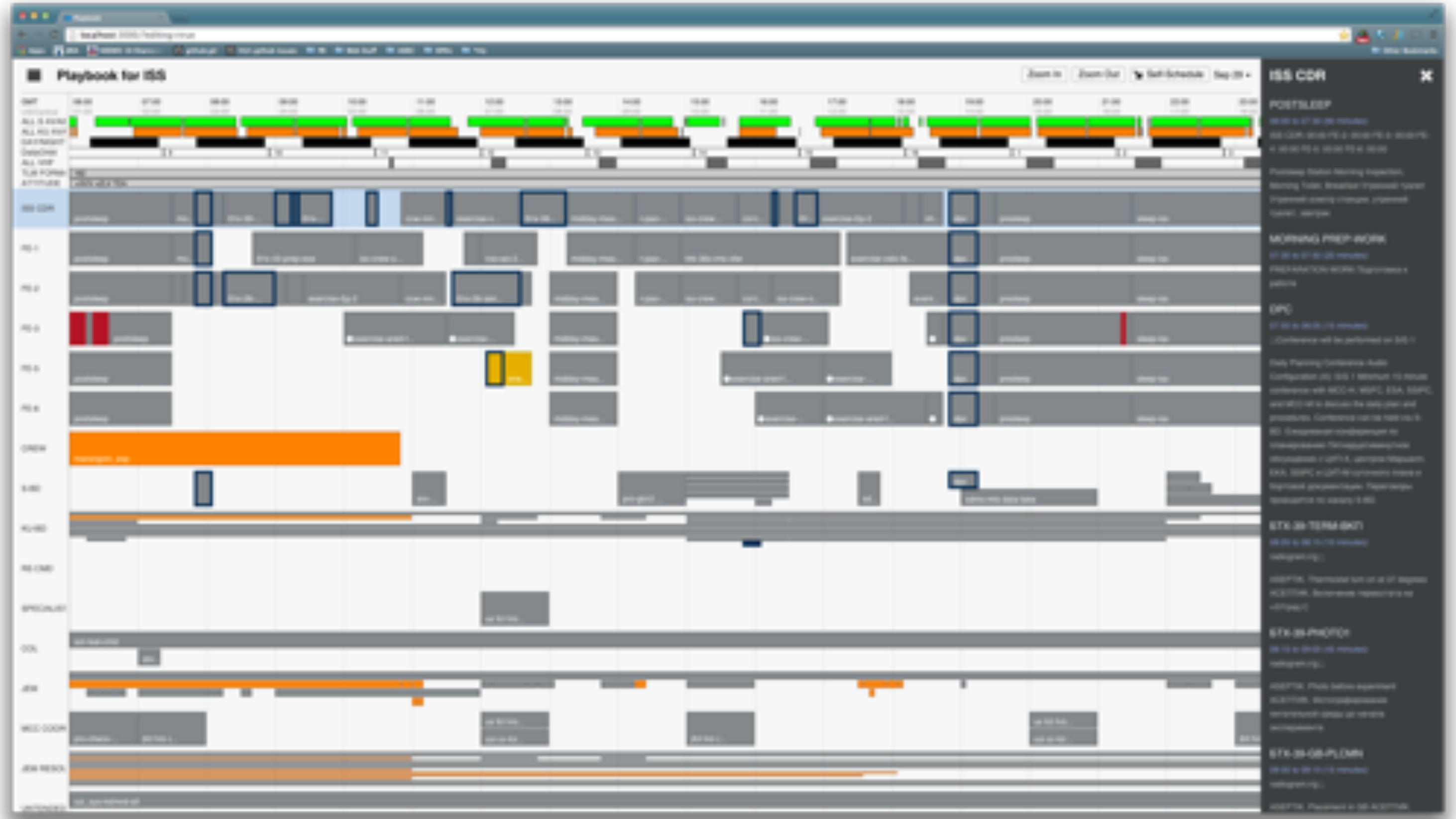
Crew Autonomous Scheduling Test (CAST)

- 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.

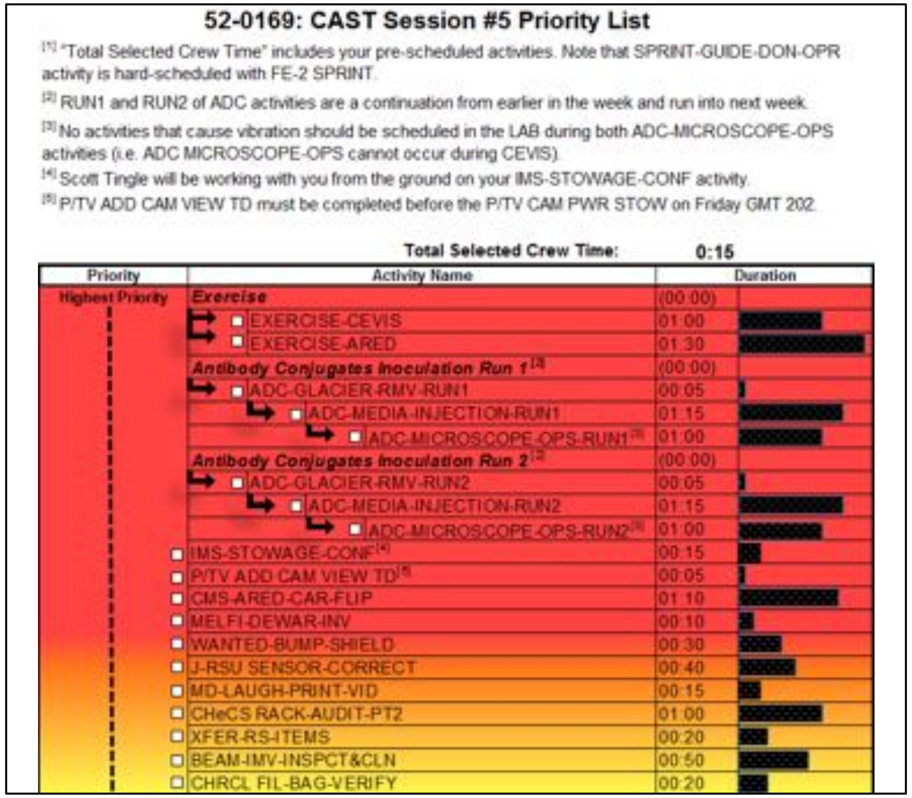
Familiarization & Training		**Practice**	**Self-Schedule**			
Exercise #1	Exercise #2	Exercise #3	Exercise #4	+2 days	Exercise #5	+2 days
Planning Familiarization (Fake day)	Execution Familiarization (Prepared Plan)	Schedule Afternoon (Limited Planning)	Self-Schedule	Execute Self-Schedule	Self-Schedule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

Increasing Crew Autonomy →

Self-Scheduling Exercise



Astronaut moved activities from **Playbook** Task List to their own timeline band two days ahead of execution



52-0169: CAST Session #5 Priority List

[1] "Total Selected Crew Time" includes your pre-scheduled activities. Note that SPRINT-GUIDE-DON-OPR activity is hard-scheduled with FE-2 SPRINT.

[2] RUN1 and RUN2 of ADC activities are a continuation from earlier in the week and run into next week.

[3] No activities that cause vibration should be scheduled in the LAB during both ADC-MICROSCOPE-OPS activities (i.e. ADC MICROSCOPE-OPS cannot occur during CEVIS).

[4] Scott Tingle will be working with you from the ground on your IMS-STOWAGE-CONF activity.

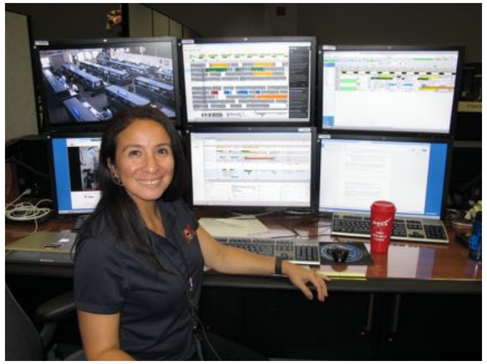
[5] P/TV ADD CAM VIEW TD must be completed before the P/TV CAM PWR STOW on Friday GMT 202.

Total Selected Crew Time: 0:15

Priority	Activity Name	Duration
Highest Priority	*Exercise*	(00:00)
	EXERCISE-CEVIS	01:00
	EXERCISE-ARED	01:30
	Antibody Conjugates Inoculation Run 1 [2]	(00:00)
	ADC-GLACIER-RMV-RUN1	00:05
	ADC-MEDIA-INJECTION-RUN1	01:15
	ADC-MICROSCOPE-OPS-RUN1 [3]	01:00
	Antibody Conjugates Inoculation Run 2 [2]	(00:00)
	ADC-GLACIER-RMV-RUN2	00:05
	ADC-MEDIA-INJECTION-RUN2	01:15
	ADC-MICROSCOPE-OPS-RUN2 [3]	01:00
	IMS-STOWAGE-CONF [4]	00:15
	P/TV ADD CAM VIEW TD [5]	00:05
	CMS-ARED-CAR-FLIP	01:10
	MELFI-DEWAR-INV	00:10
	WANTED-BUMP-SHIELD	00:30
	J-RSU SENSOR-CORRECT	00:40
	MD-LAUGH-PRINT-VID	00:15
	CHeCS RACK-AUDIT-PT2	01:00
	XFER-RS-ITEMS	00:20
	BEAM-IMV-INSPCT&CLN	00:50
	CHRCL FIL-BAG-VERIFY	00:20

Astronaut's list of prioritized activities to schedule

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.

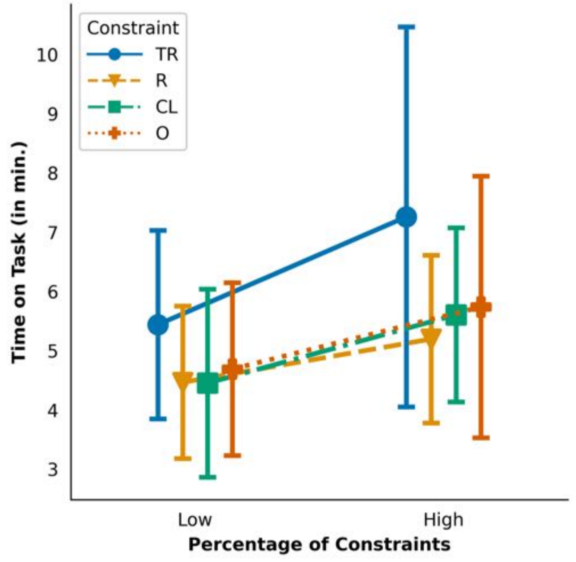
Marquez et al. Lessons Learned from International Space Station Crew Autonomous Scheduling Test. 2019. International Workshop on Planning and Scheduling for Space. Berkeley, CA.
Marquez, Hillenius, & Healy. Increasing Human Spaceflight Capabilities: Demonstration of Crew Autonomy through Self-Scheduling Onboard International Space Station. 2018. ISS R&D Conference. San Francisco, CA.

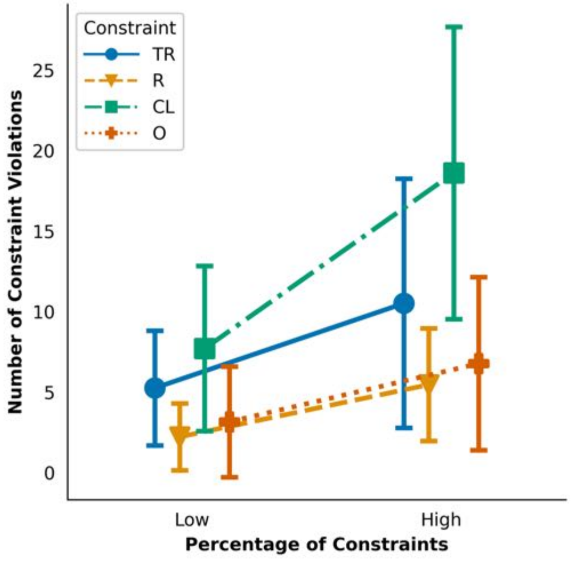
What makes self-scheduling challenging?

- 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.

Publications in AIAA SciTech, HCII, AHFE, IAC, AIAA ASCEND, and IWS

Quantifying Performance on Novice Schedulers



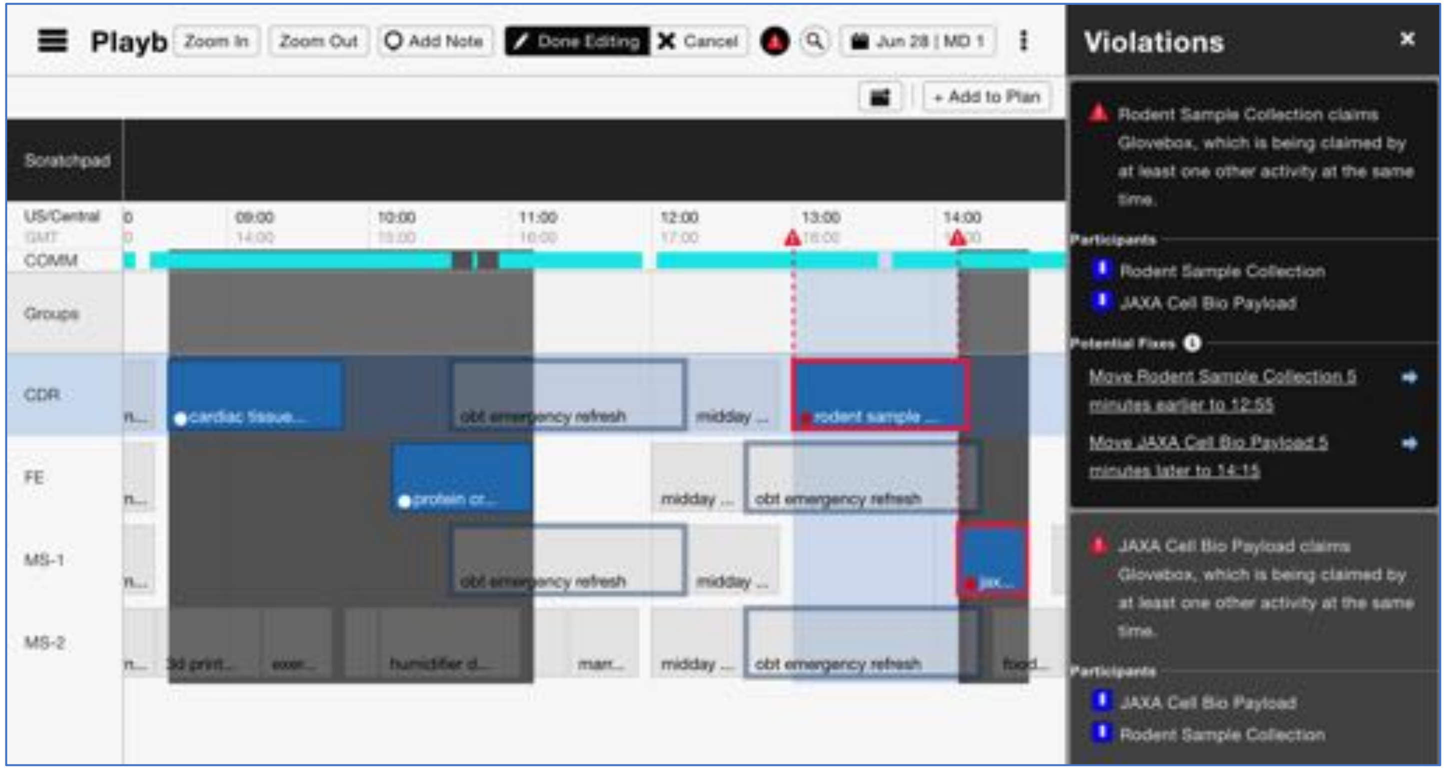


- **Big Take Aways**:
  - More workload, less efficient and effective when more activities had constraints.
  - Reduced situation awareness when constraint involved more than one activity.
  - Differences in workload, efficiency, and effectiveness based on type of constraint.

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. 72nd International Astronautical Congress. Dubai, United Arab Emirates.

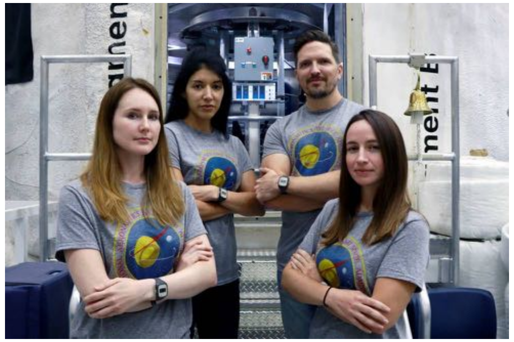
Visualizations and Aids

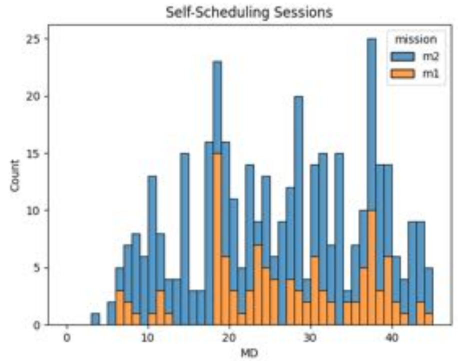
- Integration of three visualizations and aids, hypothesizing they will improve performance:
  - No-Go Zones
  - Suggested Violations Fixes
  - Network Move



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.






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?

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Images Credit: NASA and/or NASA publications

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