Review of Advanced Informatics and Display Systems for Extravehicular Activity Operations

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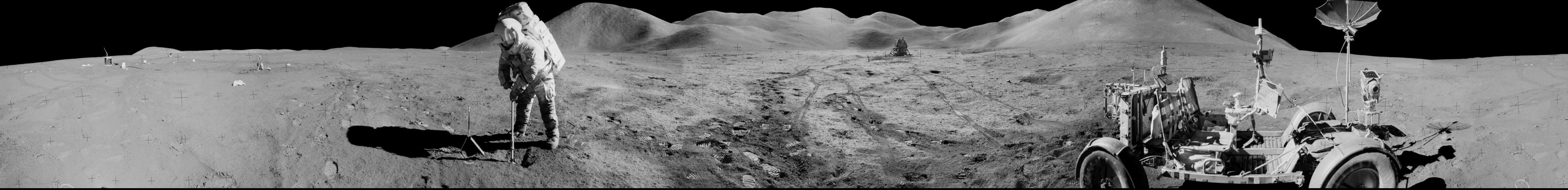
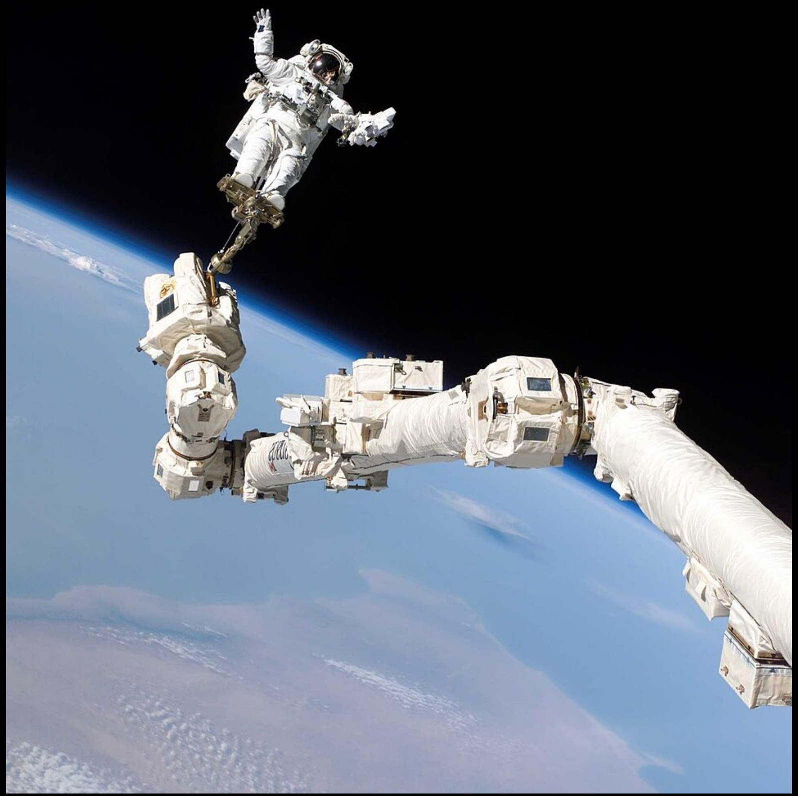


Extravehicular Activity (EVA): *Any activity performed by suited astronaut crew outside of a spacecraft*

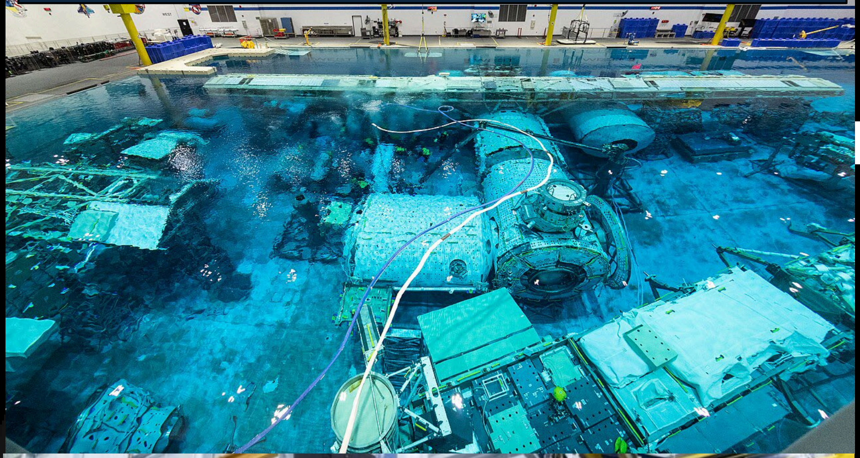


Caption here

- Often considered the most complex and risky element of human spaceflight
- Historically characterized by tight coordination with ground support teams [2]
- Successful EVA requires years of development, testing, and crew/flight team training

Approximation builds familiarity

Neutral Buoyancy Laboratory (NBL)



Active Response Gravity Offload System

ISS Expedition 66, EVA-4

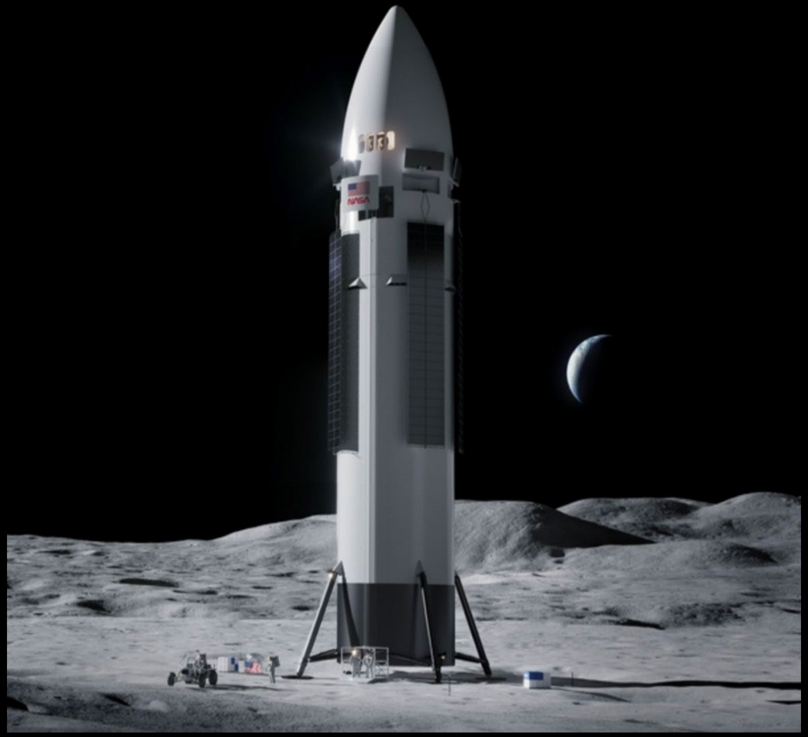
ESA Astronaut Matthias Mauer conducting his first EVA installing hoses on a Radiator Beam Valve Module.

EVA analog activities approximate unique/challenging conditions expected during the mission

- Not a monolith; can take various shapes/sizes
- Often exploratory, creating environment to replicate unique mission challenges
- Platform to explore & develop:
  - ConOps → OpsCon
    - Team configurations/roles
    - Tools/techniques/procedures

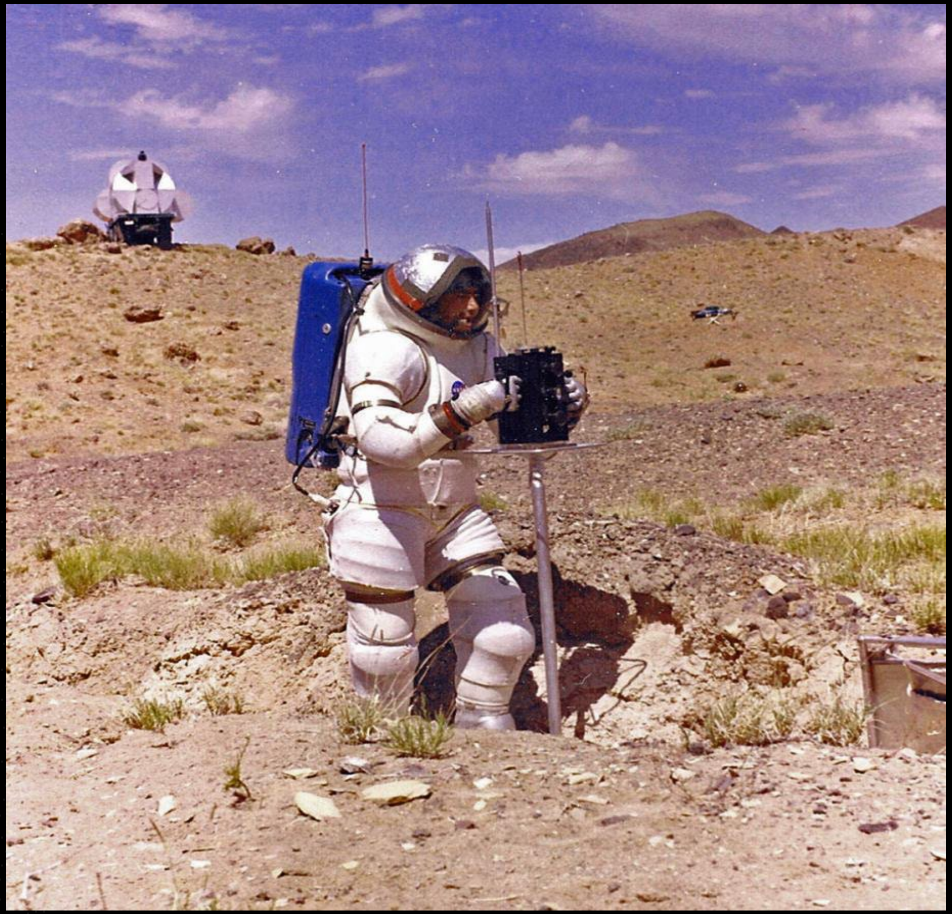
Beyond LEO: Planetary Surface EVA

- Artemis missions focused on science-based lunar surface EVAs [4]
- Communication delays will decrease assistive capabilities and influence of ground support [6]
- Flight control teams and astronaut crew need robust decision support tools to cope with additional coordination challenges and novel mission challenges



Historical EVA Analogs

- Planetary analogs began while preparing for Apollo missions, focusing on familiarization and testing of suits, tools, procedures, field geology



Joe O'Connor testing a spacesuit with a simulated lunar module in the background. Hopi Buttes volcanic field near Flagstaff, AZ, 1965.

Prior Analog Environments: EVA Operational Elements

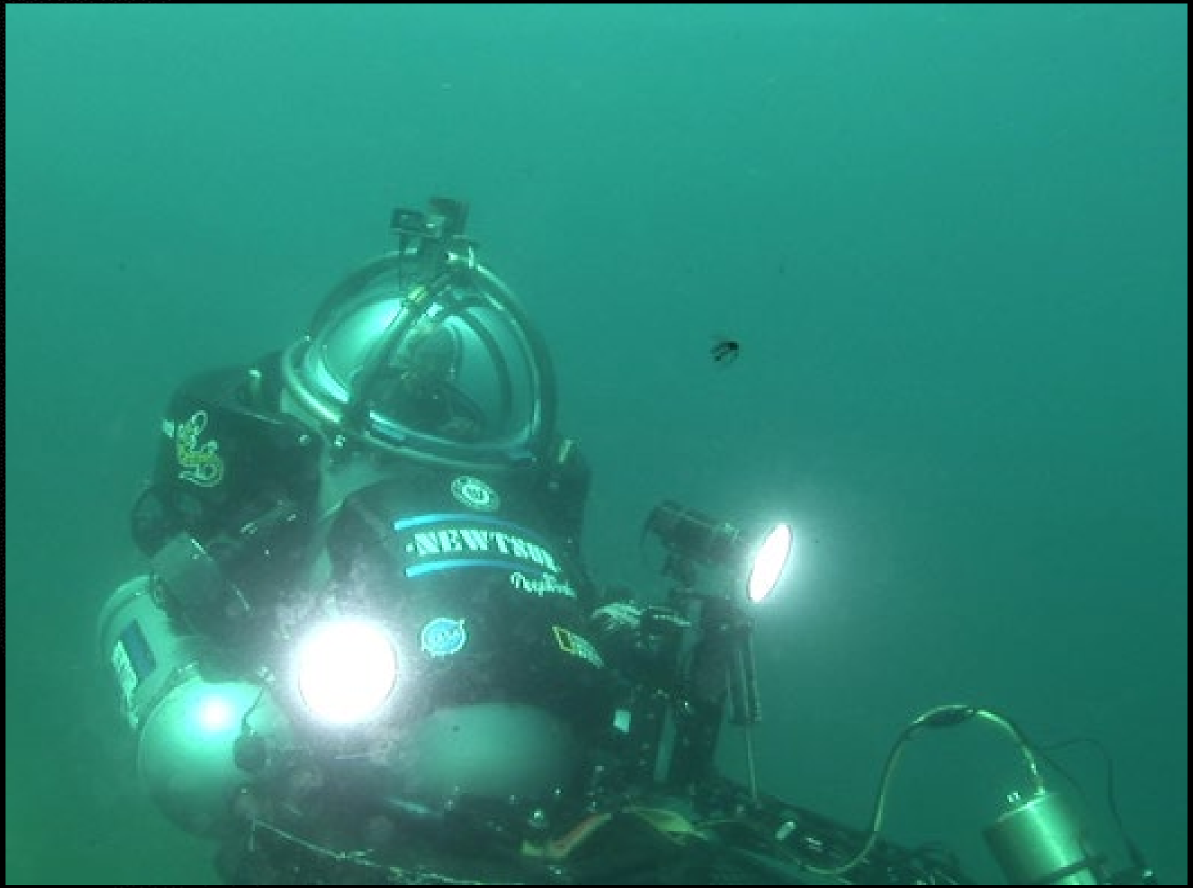
Surface Mobility EVA – DRATS

Exploration Geology – CAVES (ESA)

[8] "Desert RATS - NASA" ; [9] Young et al. (2013); [10] Gruener et al. (2013); [11] Ross et al. (2013); [12] Yingst et al. (2019); [13] "What is CAVES?" – ESA

Prior Analogs : Aquatic Environments

Environmental Constraints [14] – NEEMO (left), PLRP (right)



[14] Miller et al. (2016); [15] “About NEEMO (NASA Extreme Environment Mission Operations) - NASA”; [16] Kelly (2014)

Prior Analog Environments: Simulated Mission Conditions

Martian Operational Conditions [17-19] – BASALT

[20]

- **Mars-relevant field science** within planetary EVA operations
- Ground-based support structure to *influence operations under latency*

Artemis EVA Schedule and ConOps [21,22] – JETT

[23]

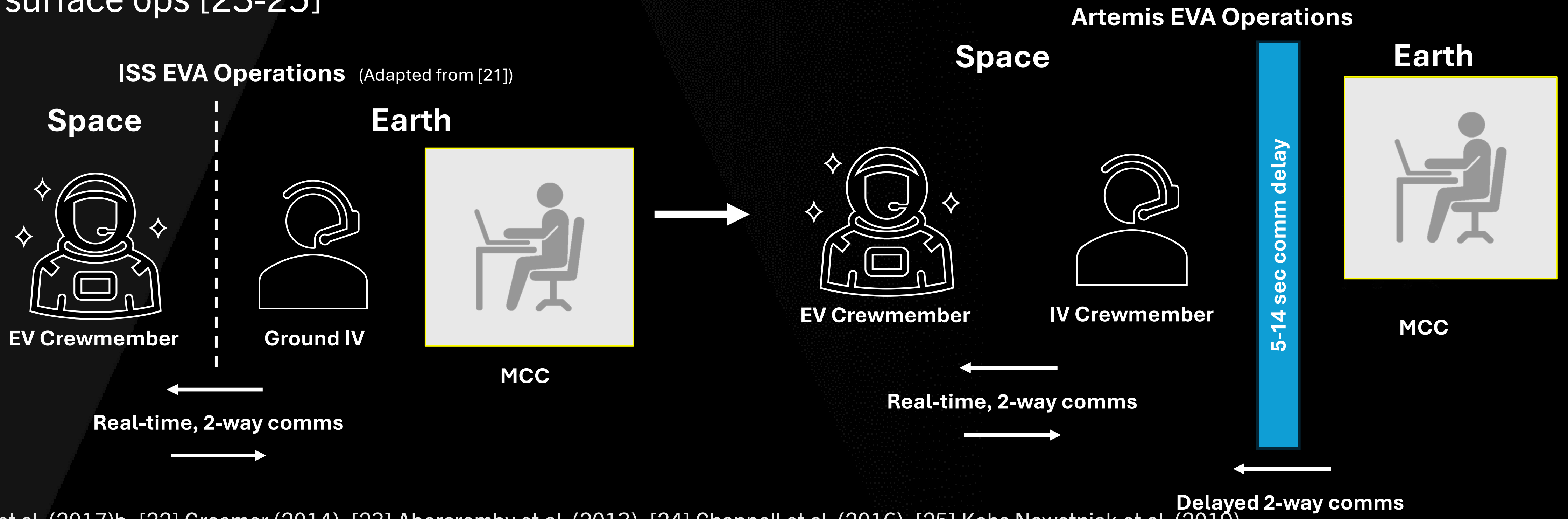
- Most complete **Artemis flight team surface EVA planning and execution activities** performed to date

[17] Beaton et al. (2019)a; [18] Beaton et al. (2019)b; [19] Lim et al. (2019); [20] "BASALT Home Page - NASA"; [21] Caswell et al. (2023); [22] Young et al. (2023); [23] "Practicing Our Moonwalk - NASA"

Shifting Crew Roles

- Intravehicular (IV) crewmembers will assume greater responsibilities, akin to traditional MCC [21]
  - Ground-based mission control will shift to role of **mission support** [22]

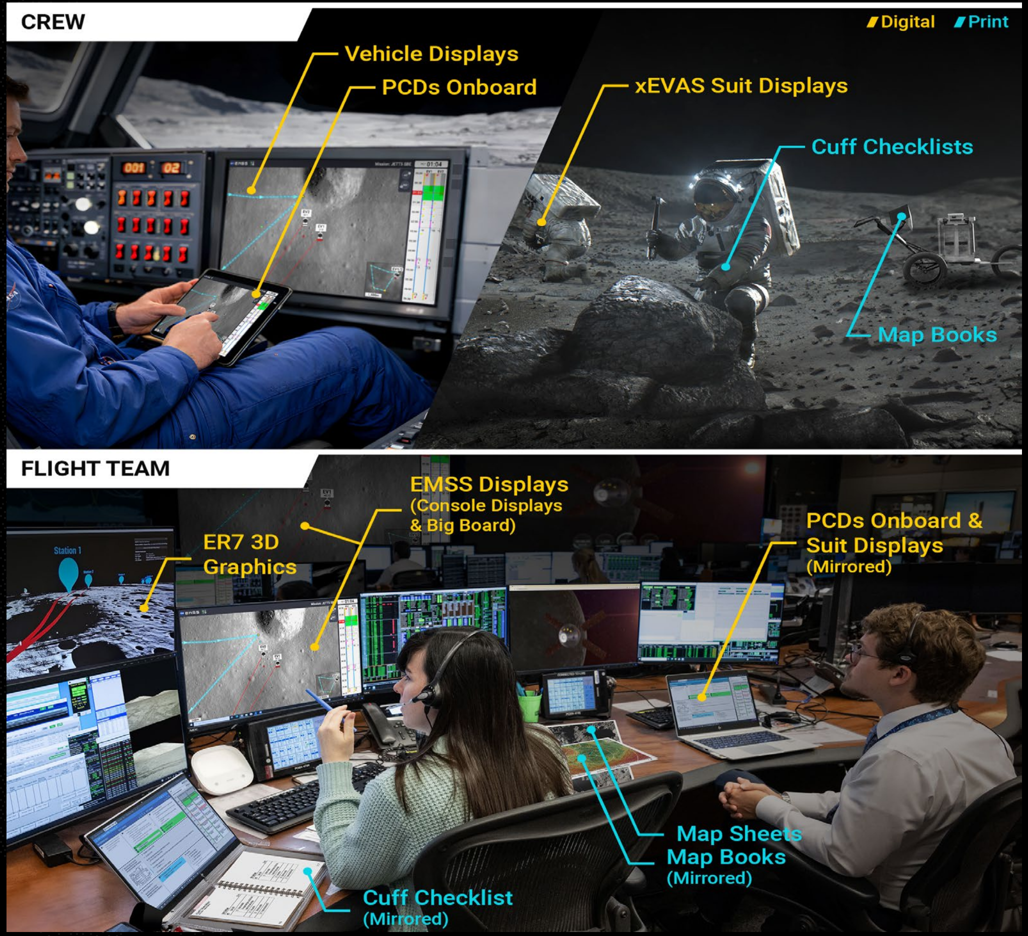
- IV crewmembers found critical to successful analog EVA operations simulating Earth-independent surface ops [23-25]



[21] Miller et al. (2017)b; [22] Groemer (2014); [23] Abercromby et al. (2013); [24] Chappell et al. (2016); [25] Kobs Nawotniak et al. (2019)

Distributed Multiteam Systems

- As spatial and temporal distances of the team increase, so do coordination challenges [29, 31, 32]
- Tools designed to enhance coordination and shared awareness have been found to improve communication and coordination [33]
- For future missions with communications latency, we need capabilities that explicitly support coordination needs

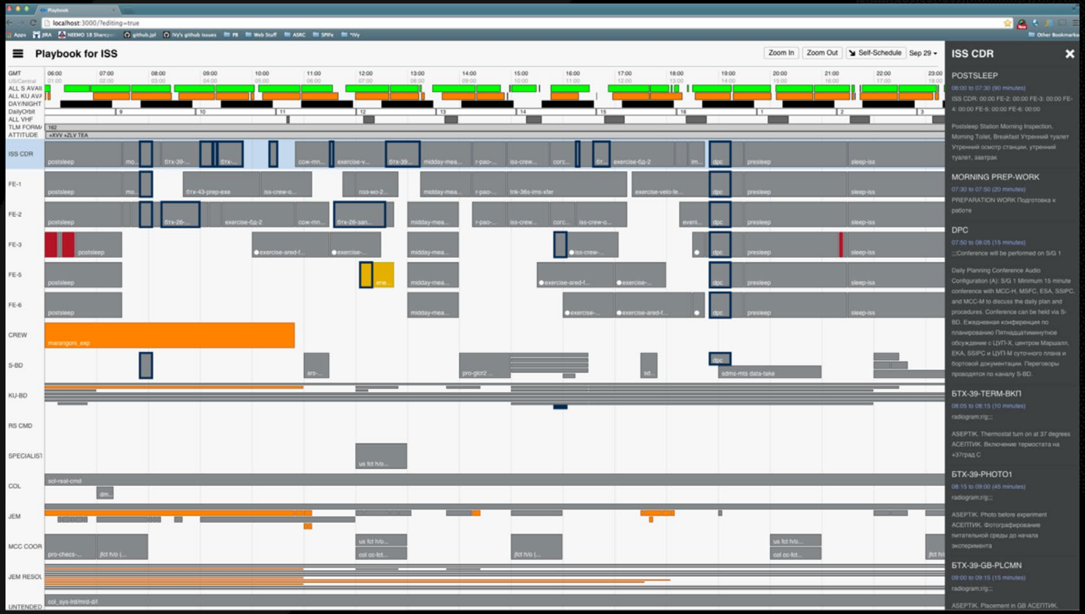


Categories of existing EVA Decision Support

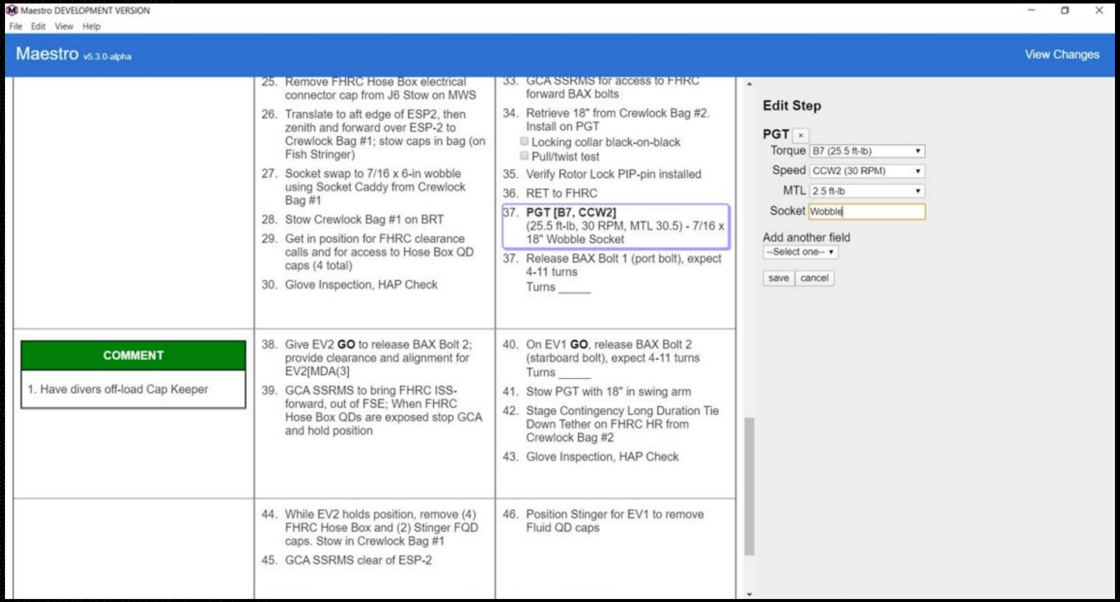
- Non-exhaustively, with overlap:
  - Spatial Planning and Execution
  - Activity Scheduling and Procedures
  - Post Hoc Mission Analysis
  - Advanced Informatics Displays

EVA Support Domain	EVA Execution Phase	Tool	Tool Capabilities	Maturity Level	Intended End User
Activity Scheduling and Procedures	Pre-mission	SPIFe [38, 52]	Planning and scheduling of crew activities	Actively Supporting ISS Operational Scheduling	Flight control team
	Pre-mission + real-time execution	Playbook [21, 53-55]	Schedule viewer for crew activities	Flown on ISS, Actively Supporting Variety of Analogs	Flight control team & crew
	Pre-mission + real-time execution + post mission	Maestro [50, 56]	Digital EVA procedure authoring; real-time procedure tracking	Actively Supporting ISS EVA, Ongoing Artemis EVA development	IV crew, MCC personnel
EVA Traverse Planning and Execution	Pre-mission + real-time execution + post mission	xGDS [21, 24]	Traverse plan editor; map sharing, authoring, and visualization; EV location tracking	Supported Analog Testing Only	MCC personnel, IV crews, EV astronauts
	Pre-mission	PATH [57-60]	Pre- and intra-EVA traverse planning optimization with lighting conditions, precursor to SEXTANT	Research Platform	MCC personnel
	Pre-mission + real-time execution	SEXTANT [21, 84]	Path planning optimization considering traverse length/time or metabolic rate; EV crew traverse monitoring; estimated traverse time; path feasibility	Supported Analog Testing Only	MCC personnel, IV crews
	Pre-mission + real-time execution	Electronic Field Book [87]	Traverse planning; EV traverse monitoring overlayed on aggregate maps	Supported Analog Testing Only	IV crew, MCC personnel
	Pre-mission + real-time execution + post mission	AEGIS [50, 56]	Estimated EVA times; traverse coverage of scientific goals; comparing path plans	Supports Ongoing Artemis EVA Development	Flight control team
	Pre-mission + real-time execution + post mission	xGDS [21, 24]	Data archive for analysis, browsing, and searching	Supported Analog Testing Only	IV crew, MCC personnel
Post-Hoc Data Analysis	N/A	AiRT [61]	Horizontally consolidating data products from Apollo 17 EVAs	Available for Public Use	General public
	Execution + post mission	Electronic Field Book [87]	Data aggregation, embedded machine learning, and archiving	Supported Analog Testing Only	MCC personnel
	Real-time execution + post mission	CODA [56, 62]	Tagging/association of geospatial data to imagery/video and audio	Actively Supporting ISS EVA, Artemis EVA Development	MCC personnel
	Pre-mission + real-time execution	VR Training [63]	Simulate EVAs for training procedures	Supported Shuttle and ISS EVA Operations	EV astronauts
Advanced Display Informatics	Real-time execution	Wrist-mounted displays [21, 64, 89, 102, 104]	Display crewmember vitals or condensed information from other support tools	Flown for Shuttle EVA and Supported Analog Testing	EV astronauts
	Real-time execution	Tablet display [89]	Display cuff checklist procedures	Supported Analog Testing Only	EV astronauts
	Real-time execution	EVA Information System [89]	Digital tablet display for cuff checklist	Supported Analog Testing Only	EV astronauts
	Pre-mission + real-time execution	Joint AR [36, 65]	Heads-up display containing information from local onboard data sources, local lunar data sources, and remote data assets	Supported Analog Testing Only	EV astronauts
	Real-time execution	Electronic Field Book [87]	Display providing scientific and operational guidance to the astronauts, integrating data from ground teams and instruments	Supported Analog Testing Only	IV crews, EV astronauts

Activity Scheduling and Procedure Tools



Playbook tool for scheduling crew activities [43]



EVA procedure editing in Maestro [46]

Playbook [40, 42]: mobile schedule viewer and real-time execution software aid

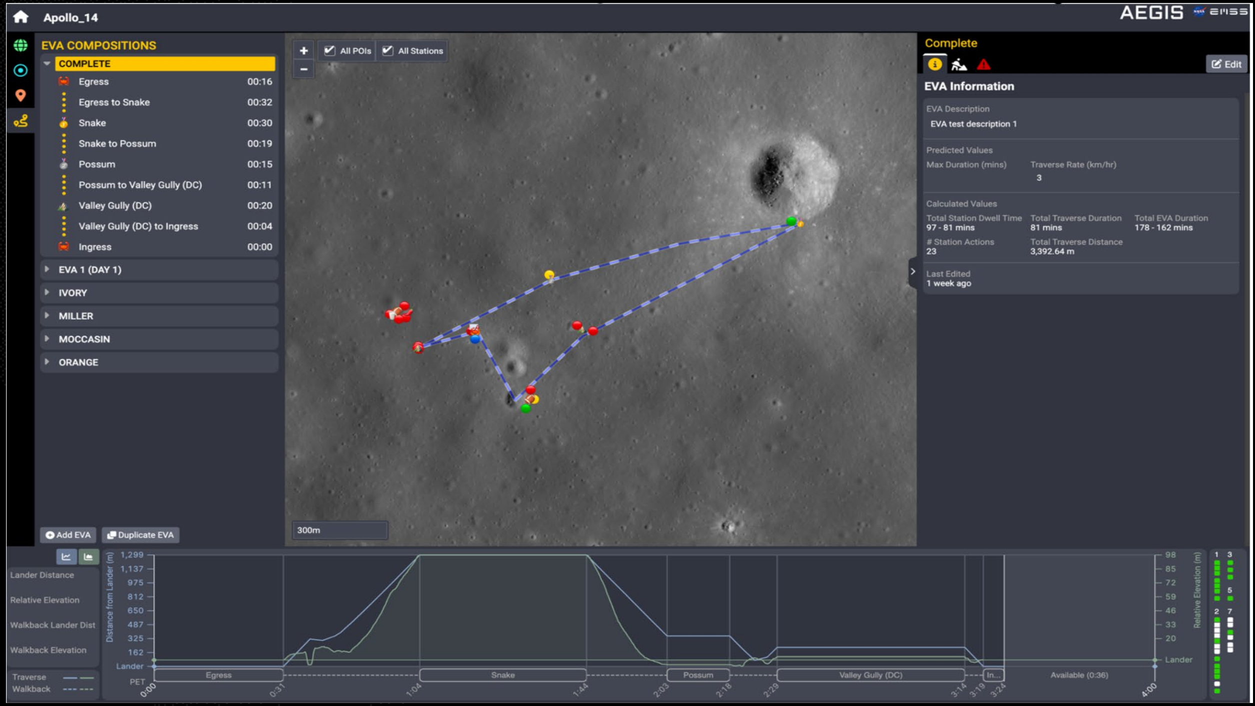
Capabilities iterated over NEEMO, PLRP, BASALT, and ISS deployments [43,44]

Maestro [45]: enables dynamic digital procedure alteration to accommodate real-time changes

Utilized in JETT tests, ISS EVA, and Artemis III EVA development events. [ref]

Spatial Planning and Execution Tools

- Extensive tool development to support path optimization and traverse replanning [49,50]
  - xGDS, SEXTANT deployed in BASALT [51]; EFB deployed in CAVES [52]
- Future work may integrate real-time EV data (e.g., suit consumables, physiological performance) with traverse planning

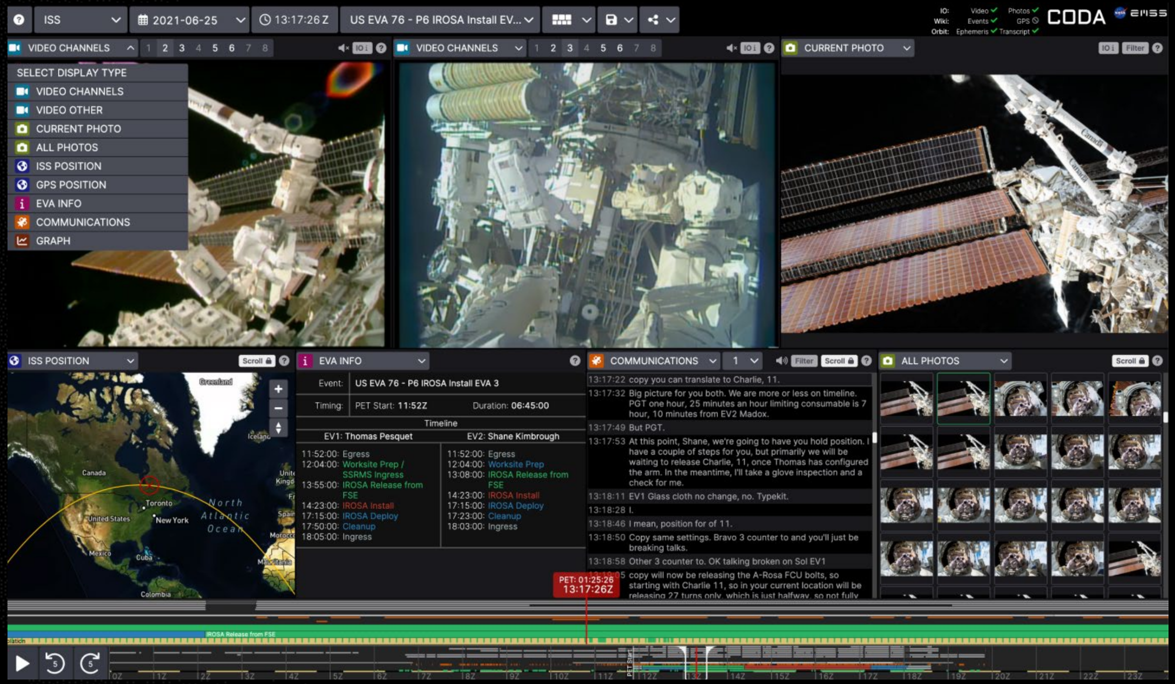


Artemis EVA Geographic Information System (AEGIS) [53]: supports flight controllers tasked with supporting Artemis planetary surface exploration Can spatially correlate lunar map data with EVA mission data.

[47] Bleacher et al. (2013); [48] Hörz et al. (2013); [49] Marquez et al. (2005); [50] Marquez and Newman (2007); [51] Deans et al. (2017); [52] Turchi et al. (2021); [53] Miller et al. (2023)

Post Hoc Mission Analysis

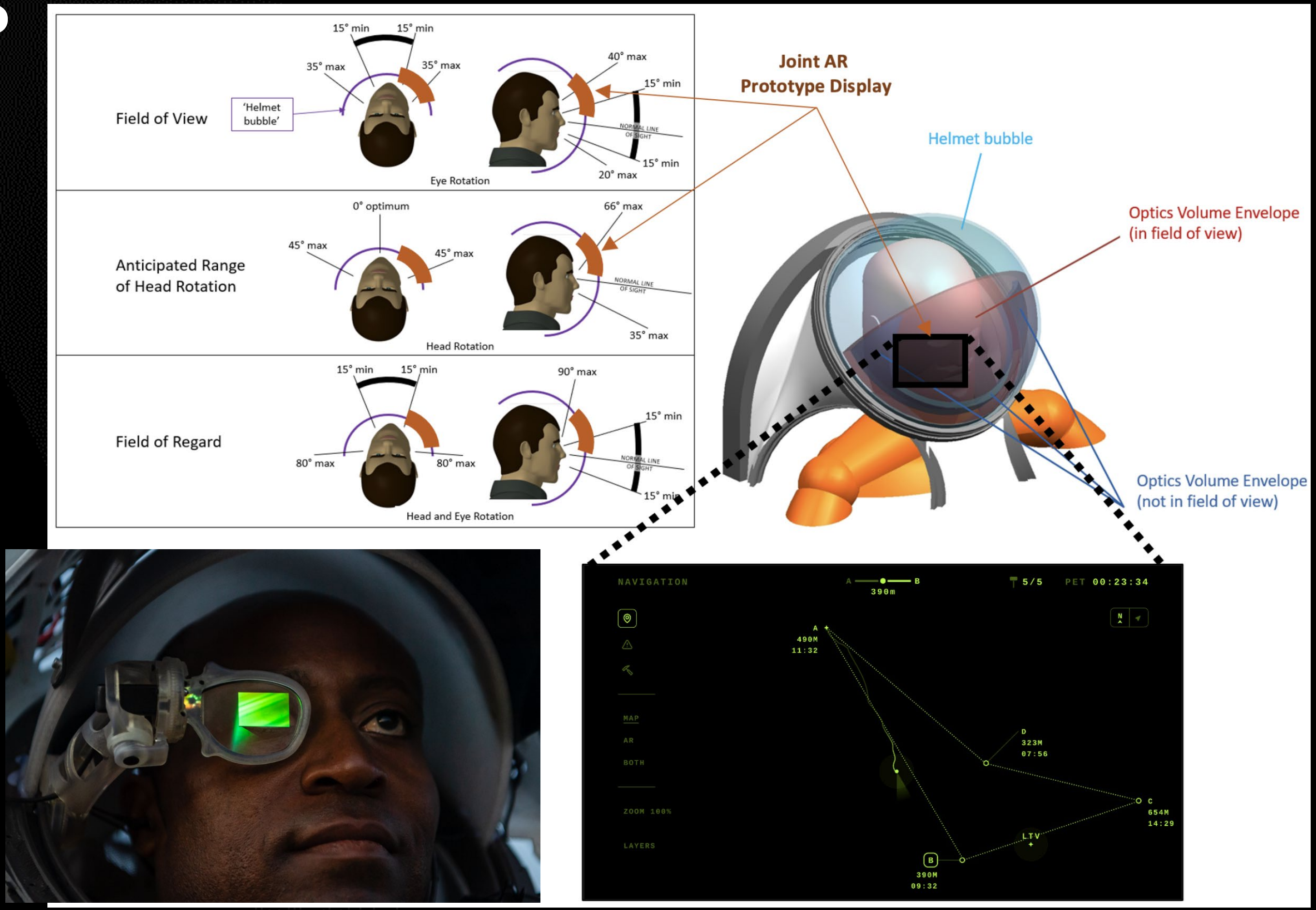
- Contextualize disparate data sources and streamline access to data from surface operations
- Allows exploration of mission data, enhancing scientific outcomes and generational impacts [55]



Collaborative Operations Data Activation (CODA) [53, 55]: horizontally integrates mission context (Maestro EVA timeline data; AEGIS map products; ground audio, video, and telemetry feeds

EVA Decision Support Tools: Advanced Informatics Displays

- Wrist-mounted displays used in field tests [56] and Shuttle flights [57]; enhancements stalled
- Promising helmet-mounted optics capabilities have been prototyped, but significant technical challenges exist [61]



Joint Augmented Reality Visual Informatics System [60]

Takeaways for Future Tool Development

- Despite over five decades of EVA experience, operational focus has remained almost exclusively on microgravity rather than planetary surface operations
- Shifting from lunar ‘proving ground’ to heavy communication latency on Mars, tool development must align with specific jobs to be done
- Leveraging analogs and user-centered design approaches emphasizing distributed teamwork is the best approach to meet challenges associated with shifting team dynamics anticipated in future missions

Questions