Human Scientific Field Exploration – Lessons from Earth, for Mars

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Museum Alliance Talk, November 2, 2015

Topics for Today

Science-driven, human exploration analogs

2004-2016
Pavilion Lake Research Project

2015-2019+
Biologic Analog Science Associated with Lava Terrains

Humans conducting science in hostile environments

<u>Human Needs:</u>

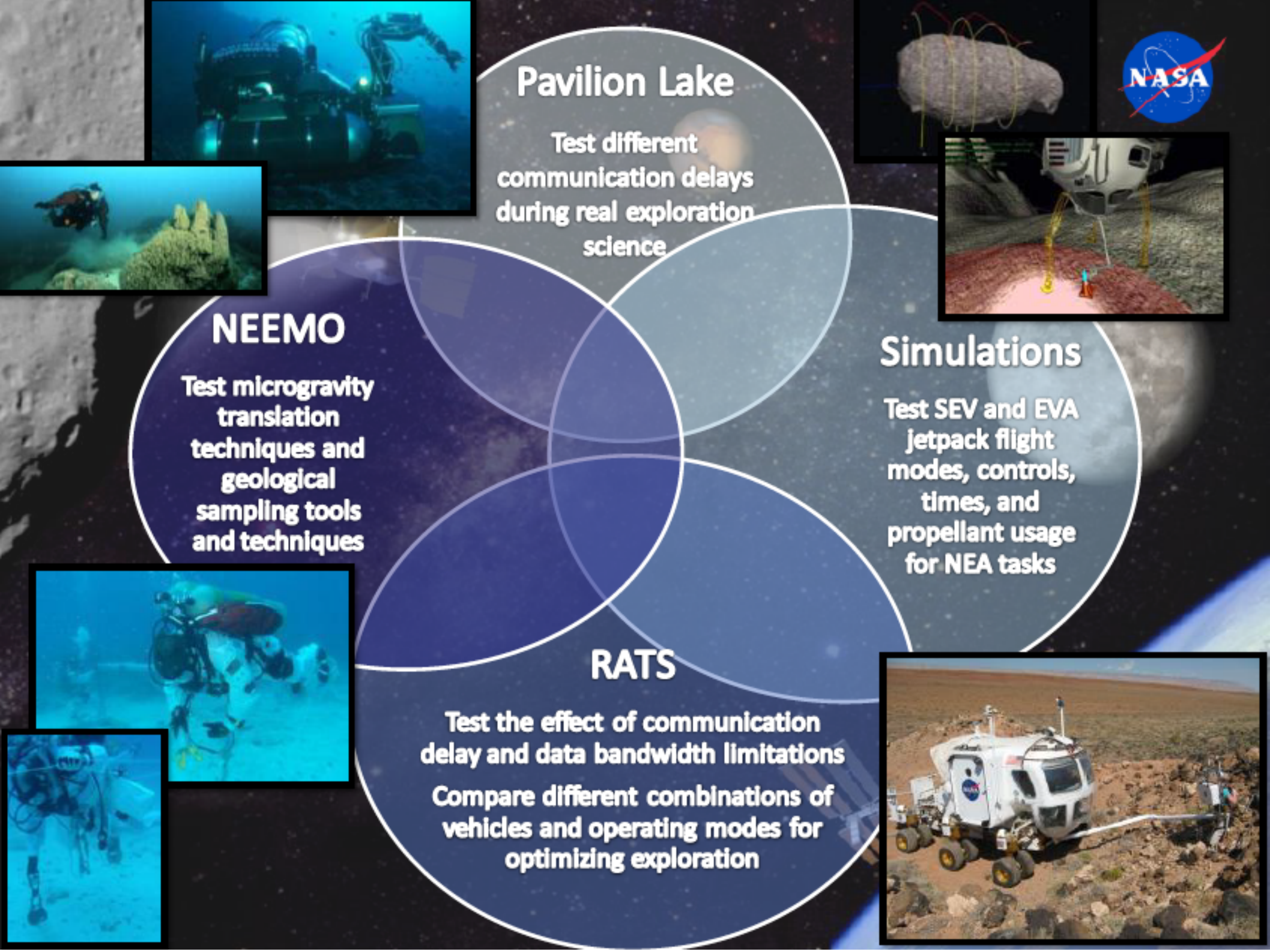
Stay Alive

Protect the Environment

Productively conduct your science

Explore to make discoveries

Which Concepts of Operations (ConOps) and Capabilities enable and enhance science return?


Pavilion Lake
Test different communication delays during real exploration science
NEEMO
Test microgravity translation techniques and geological sampling tools and techniques
Simulations
Test SEV and EVA jetpack flight modes, controls, times, and propellant usage for NEA tasks
RATS
Test the effect of communication delay and data bandwidth limitations
Compare different combinations of vehicles and operating modes for optimizing exploration

Communications

How do communications latencies and bandwidth constraints affect science return during human exploration of the Moon, NEAs and Phobos & Deimos?

COMMUNICATION DELAYS BETWEEN EARTH AND HUMAN DESTINATIONS[1]
DELAY SHOWN FOR EACH DIRECTION (x2 FOR ROUND-TRIP)

	CLOSEST	FURTHEST
ISS (DIRECT UPLINK)	0.0011 s	0.0012 s
EARTH GEOSYNCHRONOUS	0.12 s[2]	
ISS (VIA TDRS RELAY)	0.25 s	0.28 s
EARTH-MOON L1	1.01 s	1.15 s
LUNAR SURFACE[3]	1.21 s	1.35 s
EARTH-MOON L2 (aka "WAYPOINT")	1.30 s	1.45 s
EARTH-SUN L1	4.91 s	5.07 s
NEAR-EARTH ASTEROIDS[4]	50 s[5]	648.71 s[6]
PHOBOS/DEIMOS (MARS)	~186 s	~1340 s

[1] INFRASTRUCTURE SYSTEM DELAYS NOT SHOWN, WILL ADD 1-2%
[2] ASSUMES AN AVERAGE GEOSYNCHRONOUS ORBIT OF 35,000 KM
[3] ASSUMES NEAR-SIDE LUNAR SURFACE, FAR SIDE ADDS ORBITING RELAY DELAY
[4] NEAR EARTH ASTEROIDS OF INTEREST BETWEEN THE MOON AND JUPITER
[5] THIS REPRESENTS THE CLOSEST NEO CONSIDERED FOR A HUMAN MISSION (0.1 AU)(NASA/HEFT2)
[6] FOR ASTEROIDS LOCATED AS FAR FROM EARTH AS 1.3 AU

Capability Driven Framework

- "Concepts of Operations" (ConOps) are defined as operational design elements that guide the organization and flow of hardware, personnel, communications, and data products through the course of a mission implementation
- The term "Capabilities" is defined as specific functional mission aspects that can take the form of hardware or software. Additionally, capabilities may be high-level ("architecture level") such as high-bandwidth communications or can be lower-level such as pan-tilt-zoom capability on a camera.

By learning which ConOps and Capabilities are enabling or enhancing (and which are not) early on in the development process, NASA's limited resources are better managed towards value-add systems and support technologies.

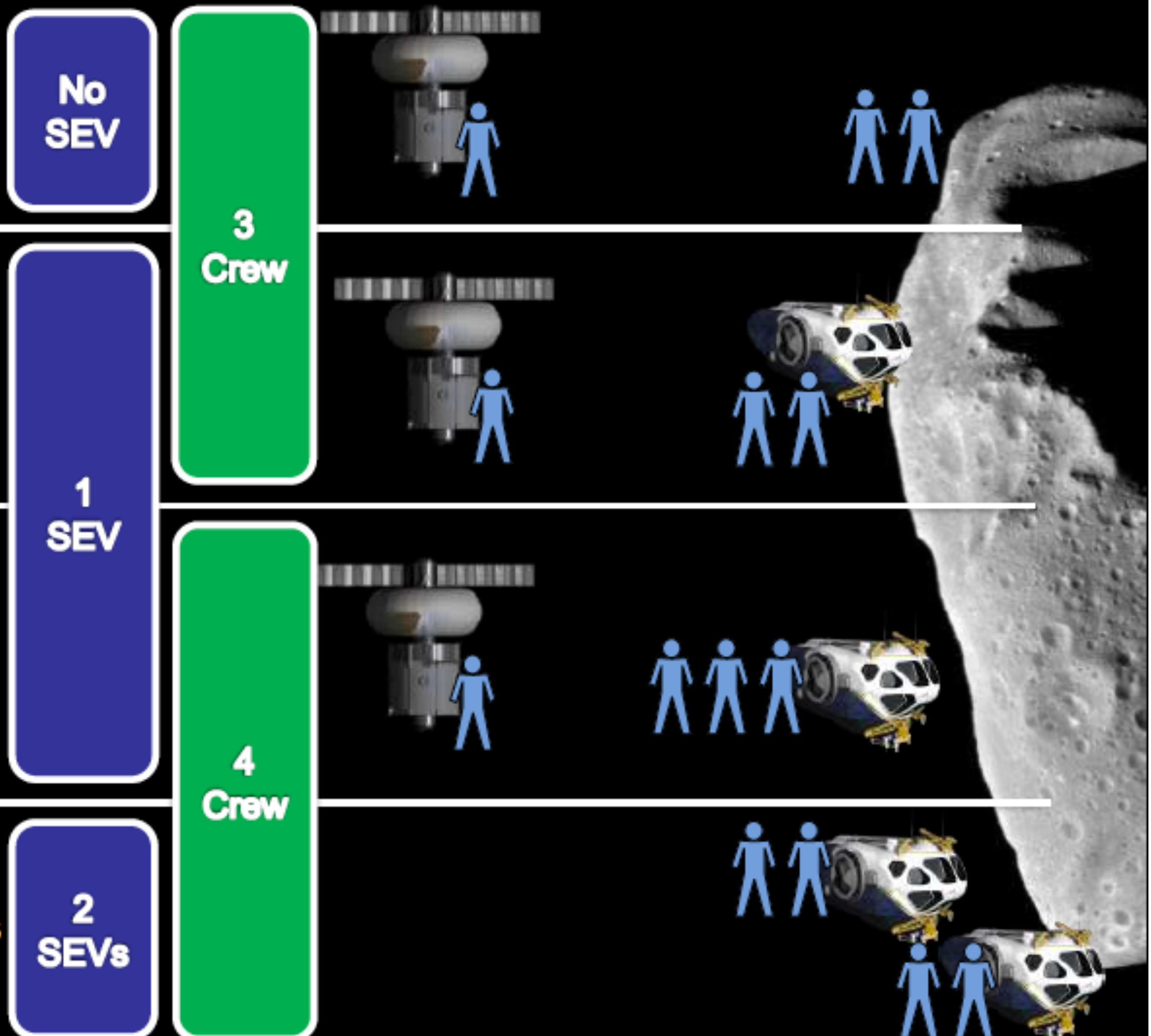
Fundamental Issue: A dearth of relevant data

Testable ConOps Conditions

Free-Flying Mode with Astronaut Positioning System (APS)

Four Integrated Scenario Conditions

- Condition 4
  - 2 EVA (no SEV)
  - 1 in Hab
- Condition 5
  - 2 in SEV
  - 1 in Hab
- Condition 6
  - 3 in SEV
  - 1 in Hab
- Condition 7
  - 2 in each of 2 SEVs
  - 0 in Hab



Rating Scales

Simulation Quality

Scale Rating	Criteria
1	Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data.
2	Some simulation limitations or anomalies encountered, but minimal impact to the validity of test data.
3	Simulation quality was adequate to provide a meaningful evaluation of most of the test objectives; simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe).
4	Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe).
5	Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe).

Acceptability

Categorical Difference

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable		No Rating
No improvements necessary		Minor improvements desired		Improvements warranted		Improvements required		Major improvements required		Unable to assess capability
1	2	3	4	5	6	7	8	9	10	NR

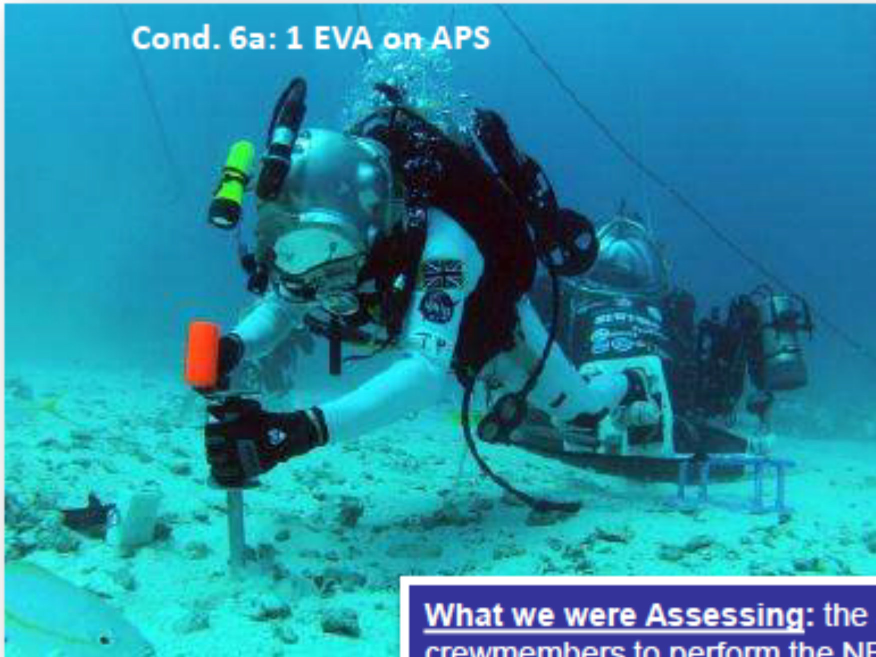
No Categorical Difference

Capability Assessment

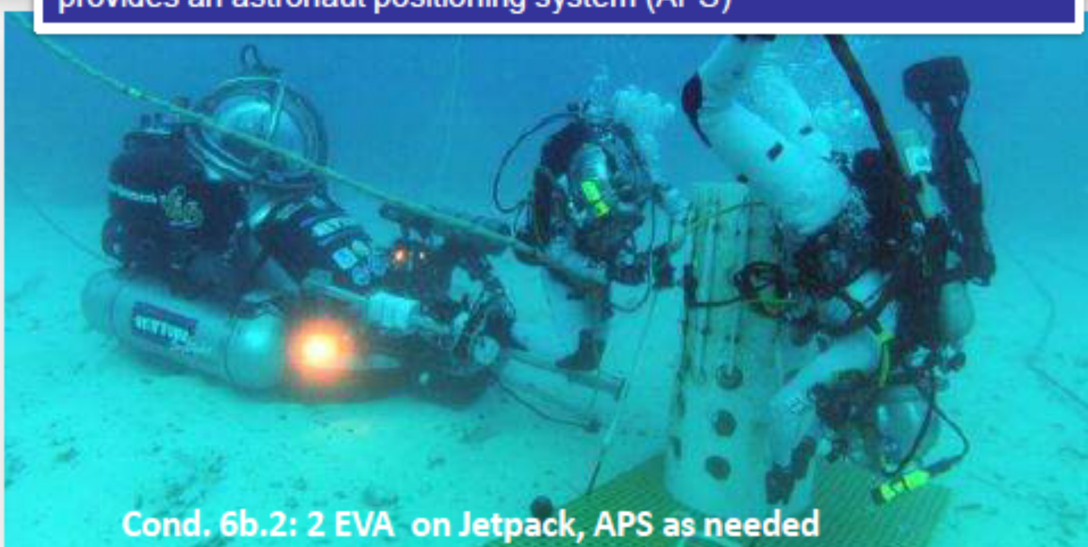
Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement		No Rating
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.		Unable to assess capability
1	2	3	4	5	6	7	8	9	10	NR


NASA

NEEMO 16 Astronaut Positioning System Modes



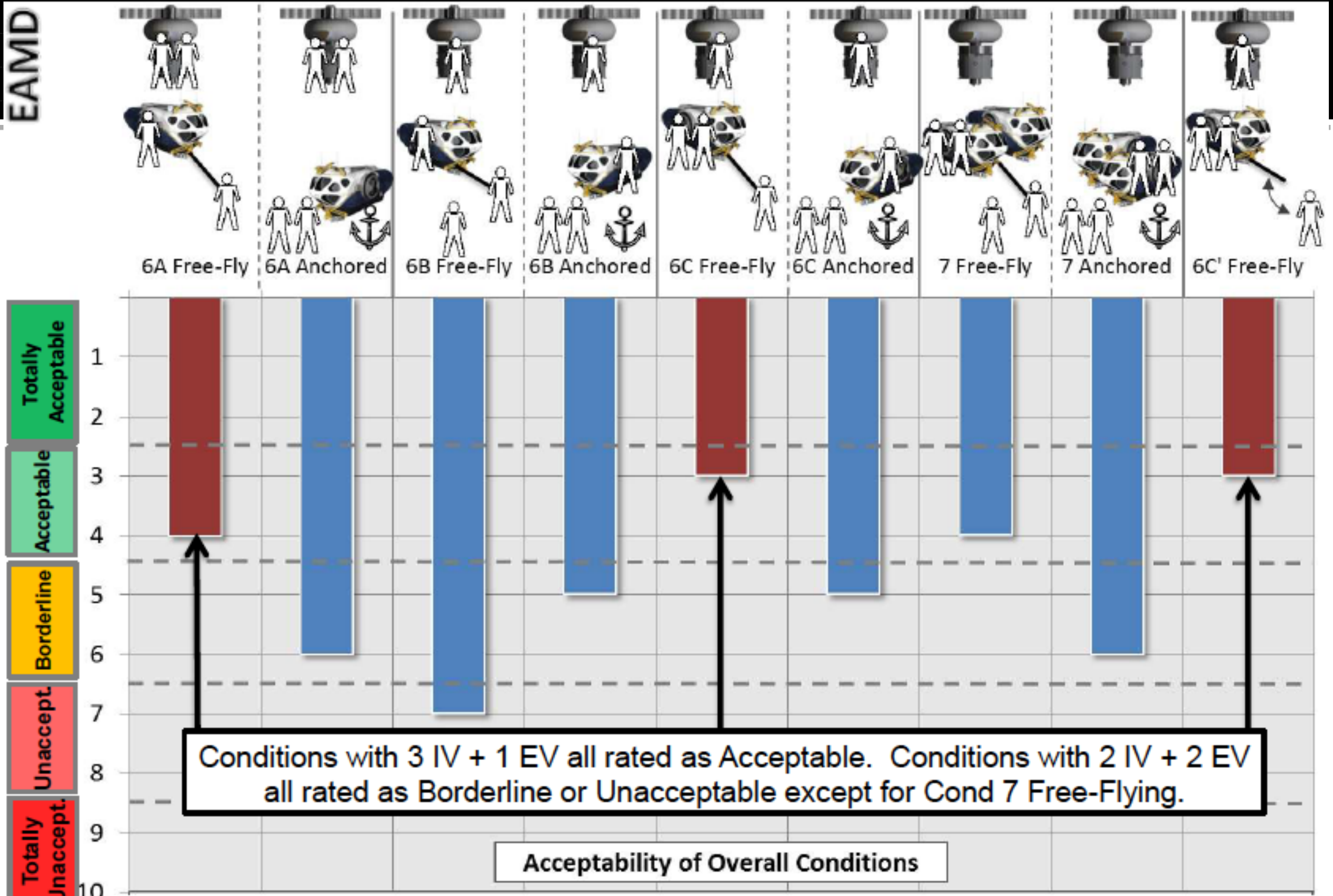
What we were Assessing: the acceptability of techniques for EVA crewmembers to perform the NEA circuit tasks assuming a vehicle provides an astronaut positioning system (APS)



Cross-over comparison of the NEA EVA tools and techniques tested at NEEMO 15 and 16 completed using the Active Response Gravity Offload System (ARGOS)

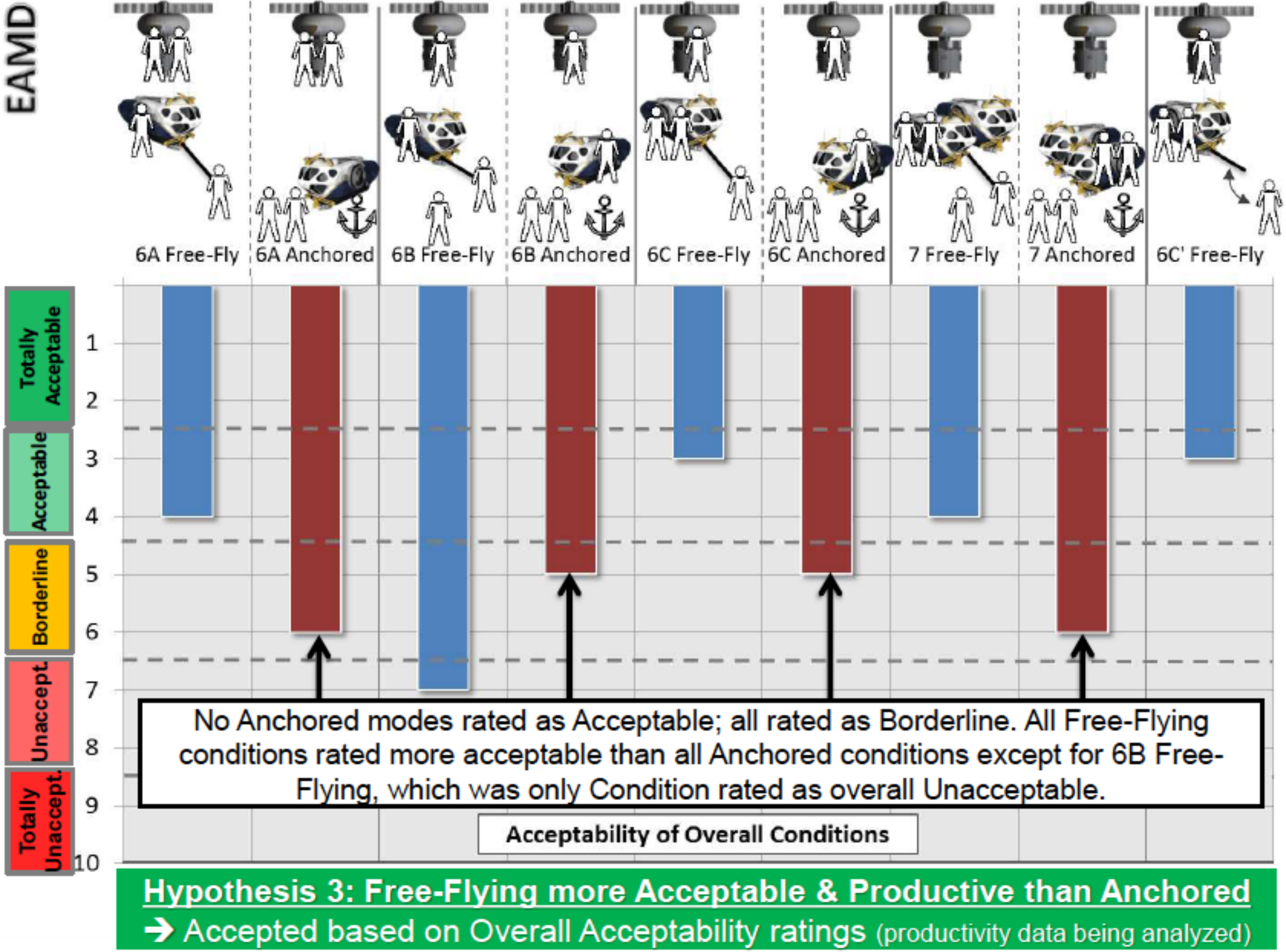
- Data collected from 6 astronaut crewmembers.
- Performed preliminary evaluation of EVA Jetpack constant-thrust mode.

Hypothesis 9: Ratings for Prototype NEA EVA Tools & Techniques will be Consistent with NEEMO



Hypothesis 1: 2 IV + 2 EV better than 3 IV + 1 EV

➔Rejected based on Overall Acceptability Ratings


EAMD
6A Free-Fly
6A Anchored
6B Free-Fly
6B Anchored
6C Free-Fly
6C Anchored
7 Free-Fly
7 Anchored
6C' Free-Fly
Totally Acceptable
Acceptable
Borderline
Unaccept.
Totally Unaccept.
1
2
3
4
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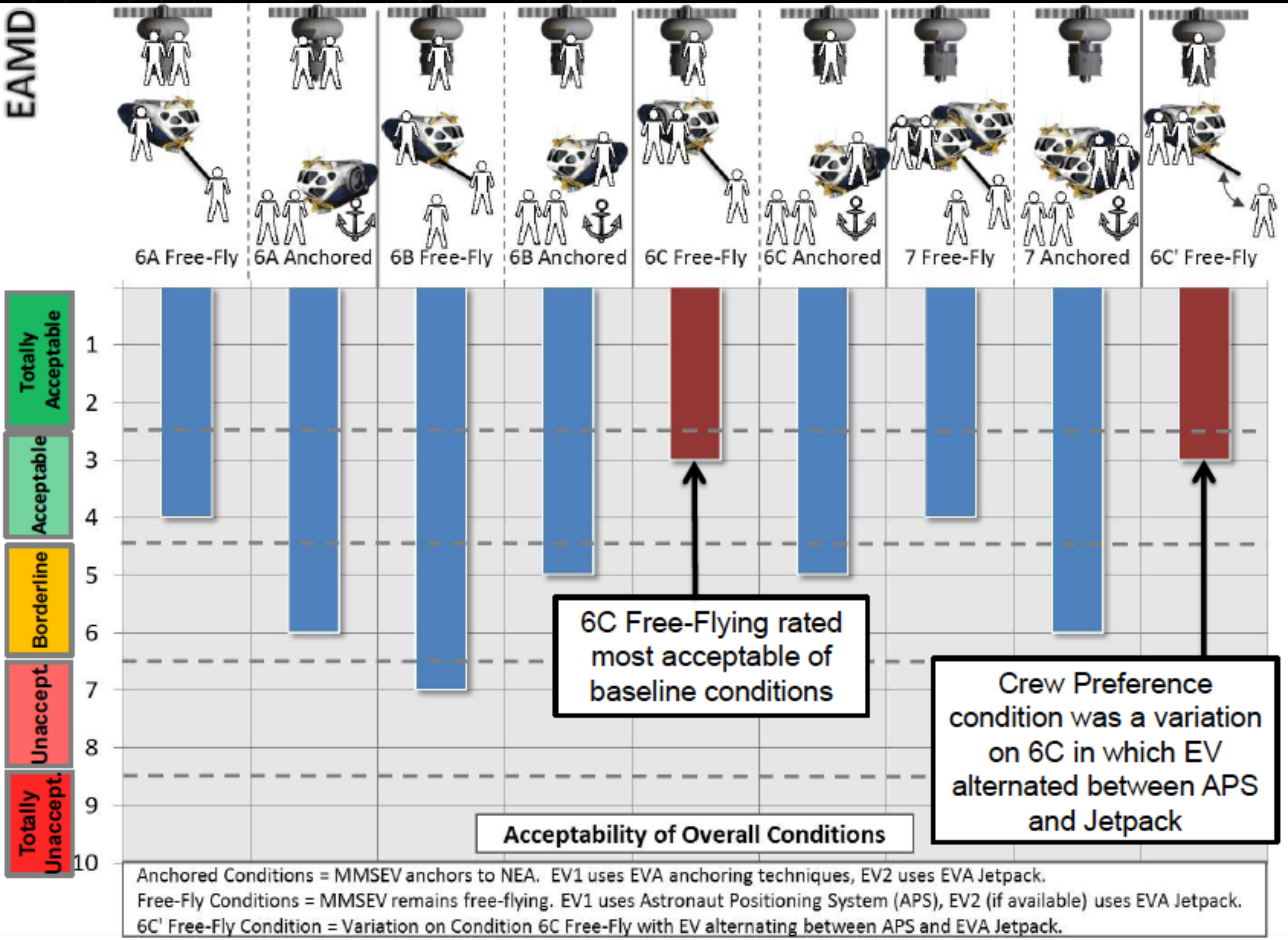
7
8
9
10
No Anchored modes rated as Acceptable; all rated as Borderline. All Free-Flying conditions rated more acceptable than all Anchored conditions except for 6B Free-Flying, which was only Condition rated as overall Unacceptable.
Acceptability of Overall Conditions
Hypothesis 3: Free-Flying more Acceptable & Productive than Anchored
→ Accepted based on Overall Acceptability ratings (productivity data being analyzed)


EAMD
6A Free-Fly
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6B Free-Fly
6B Anchored
6C Free-Fly
6C Anchored
7 Free-Fly
7 Anchored
6C' Free-Fly
Totally Acceptable
Acceptable
Borderline
Unaccept.
Totally Unaccept.
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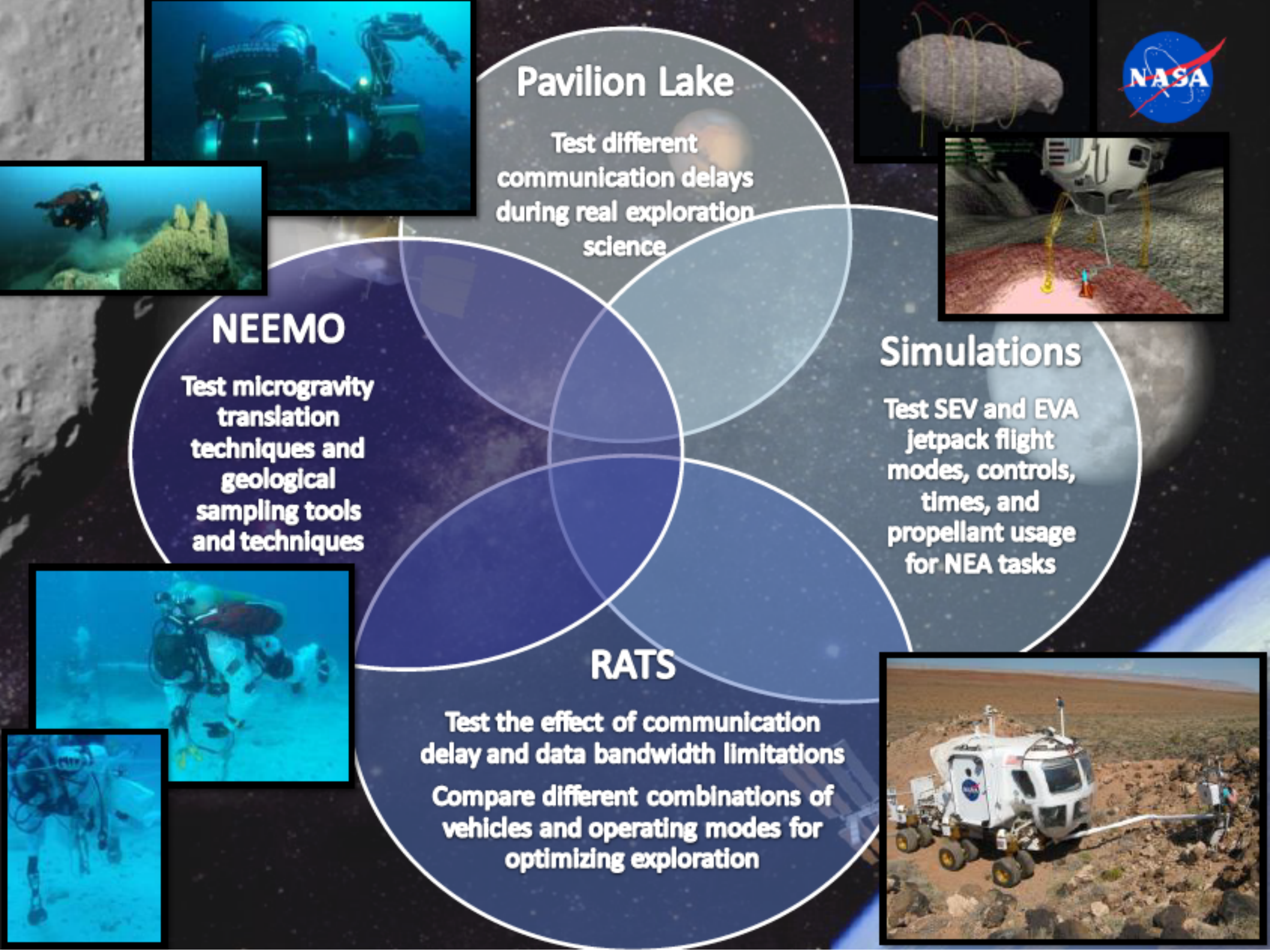
6C Free-Flying rated most acceptable of baseline conditions
Crew Preference condition was a variation on 6C in which EV alternated between APS and Jetpack
Acceptability of Overall Conditions
Anchored Conditions = MMSEV anchors to NEA. EV1 uses EVA anchoring techniques, EV2 uses EVA Jetpack.
Free-Fly Conditions = MMSEV remains free-flying. EV1 uses Astronaut Positioning System (APS), EV2 (if available) uses EVA Jetpack.
6C' Free-Fly Condition = Variation on Condition 6C Free-Fly with EV alternating between APS and EVA Jetpack.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NASA

Conducting non-simulated scientific field investigations under simulated exploration conditions

- Our focus is on <u>non-simulated</u> scientific field investigations

- Non-simulated = graduate students' (research) lives are truly on the line

- Within these field science activities certain planetary exploration conditions can be simulated, tested and assessed against the priority to generate scientific data return. For example,
  - » Human ConOps
  - » Human and robotic ConOps
  - » Communication latencies (e.g. NEA)

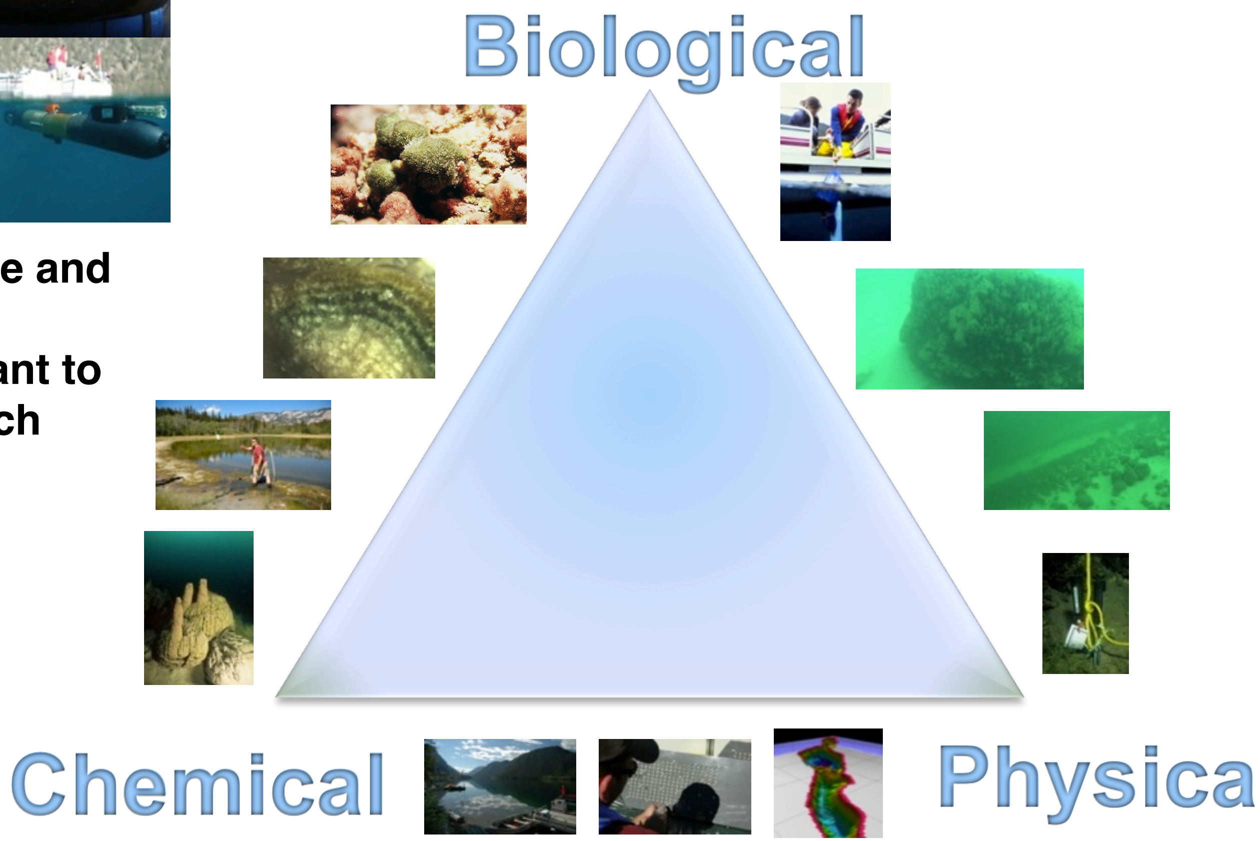
- Allows us a "keeps you honest" science environment to check our assumptions

An Example

Drum roll please…

Pavilion Lake Research Project (PLRP)

What Mechanisms and Associated Interactions Control Microbialite Morphogenesis in Pavilion and Kelly Lakes, British Columbia, Canada?



- Multi-disciplinary Science and Exploration Initiative
- Program goals are relevant to SMD and HEOMD research ojectives

PAVILION LAKE RESEARCH PROJECT

PLRP Overview

A few key points about PLRP

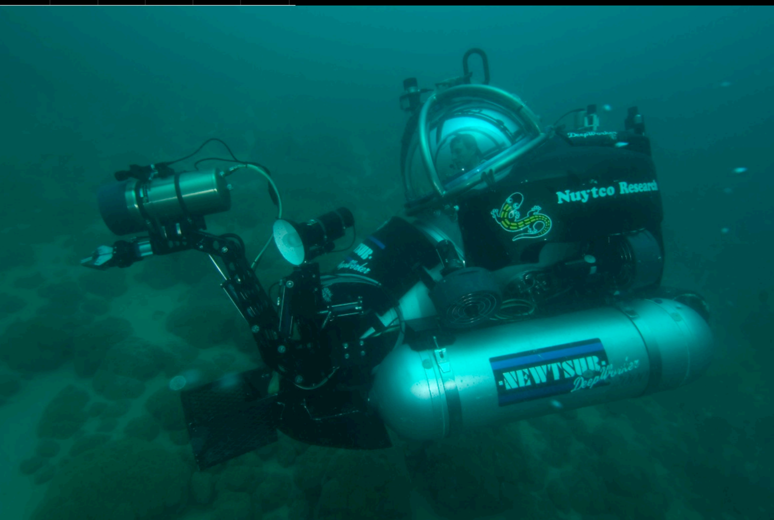
- Science drives PLRP, but the science and exploration research objectives are part on one cohesive program. They do not run in parallel with each other.

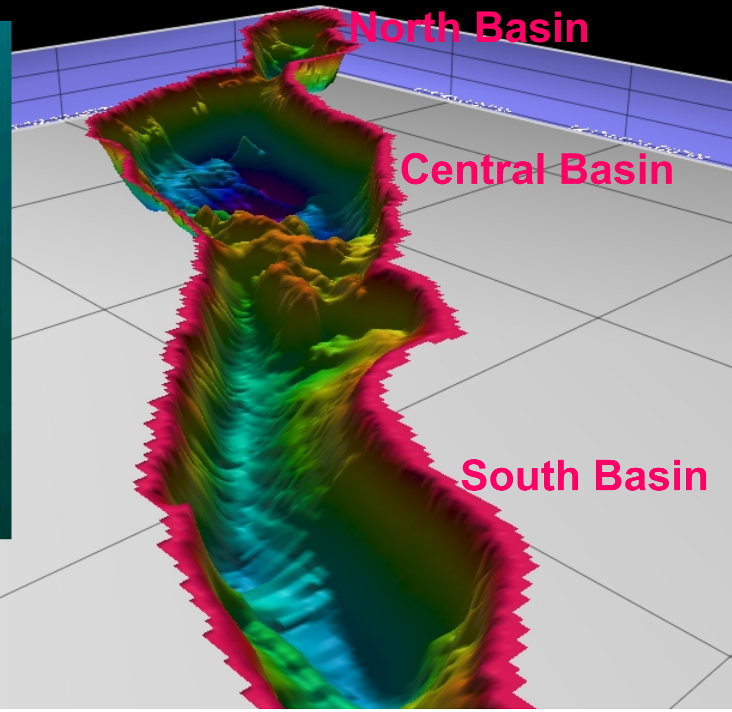
- Humans are fully in the loop at both ends of the field work plan.

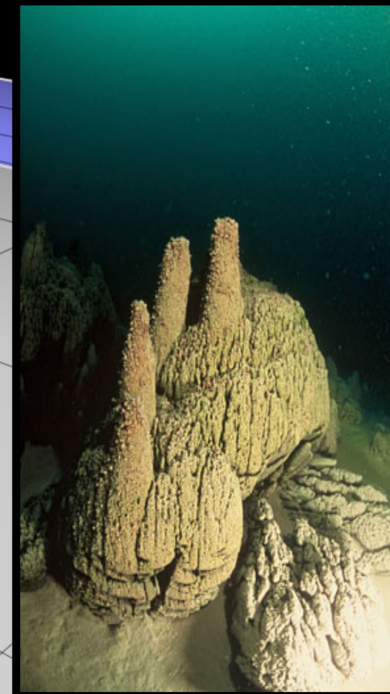
- Underwater-based project, which lends a higher degree of fidelity to our human science and exploration activities. Underwater, humans are in a life support limited environment. This puts constraints on our operational designs and execution tempo that are comparable to space.

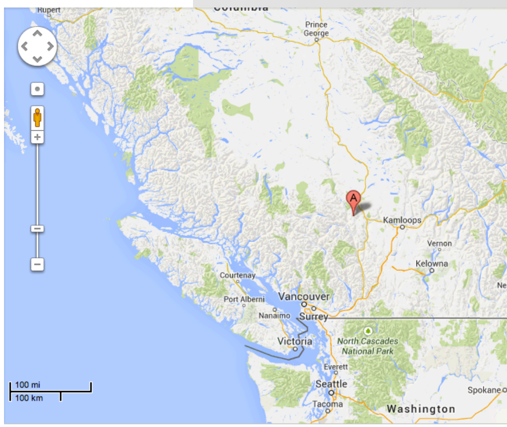
- PLRP Phase 2 – DeepWorker Science and Exploration Program - completed
- PLRP Phase 3 – Integrated human and robotic field science investigations – underway!

PLRP Phase 2 – DeepWorker Science and Exploration Program (2008-2011)



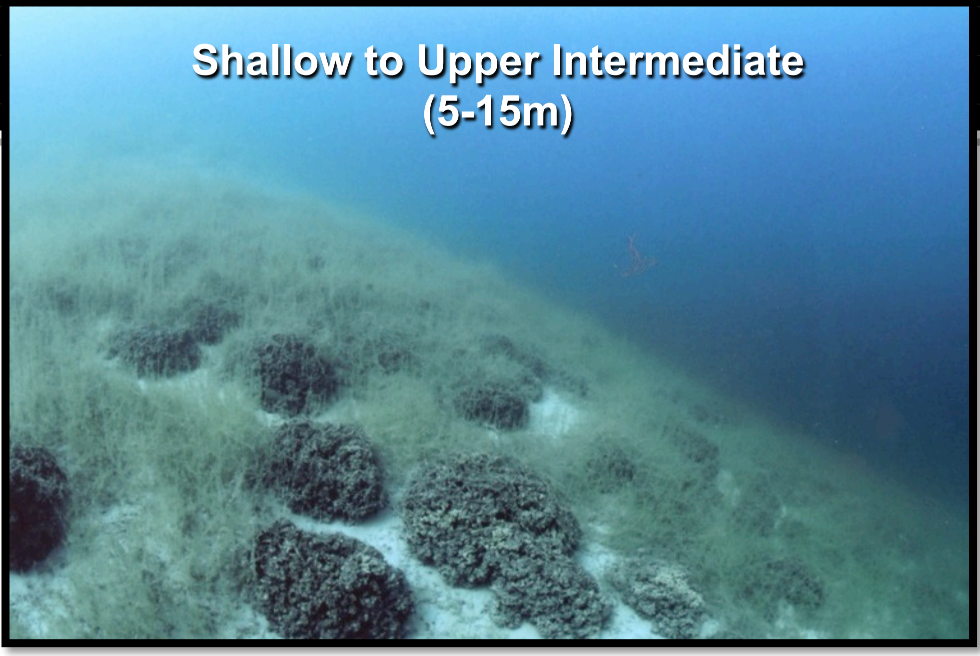




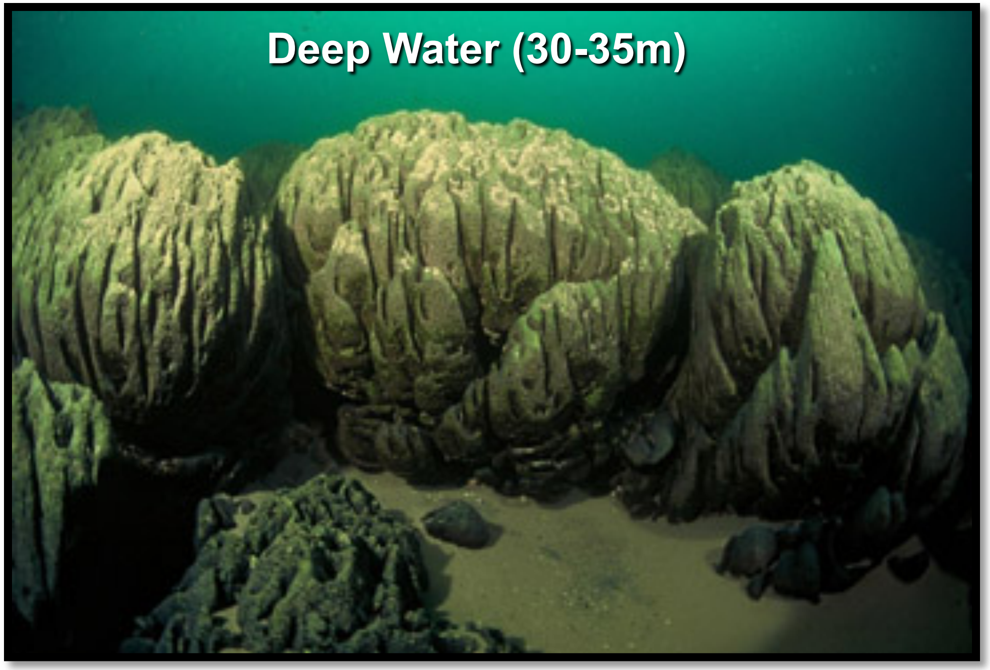


<u>PAVILION LAKE</u>
(50° 52′ 0.37″ N, 121° 44′ 30.88″ W)
Brady et al 2010, 2009; Lim et al 2009; Forrest et al 2008; Laval et al 2000
Elevation: 823 m/2697 FT
Zmax: ~65 m/210 FT
Lake length: 5582 m
Lake width (widest): 847 m
pH_{mean} = 8.4

Ultra-oligotrophic, $TP_{mean} = 3.3\ \mu g\ L^{-1}$
Low sedimentation rates with negligible carbonate content
- highest mean COND (388 $\mu S\ cm^{-1}$)
- highest mean [Na+] (7.7 $mg\ L^{-1}$)
- highest mean [DIC] (35.5 $mg\ L^{-1}$)
- lowest mean [Ca^{2+}] (39.5 $mg\ L^{-1}$)

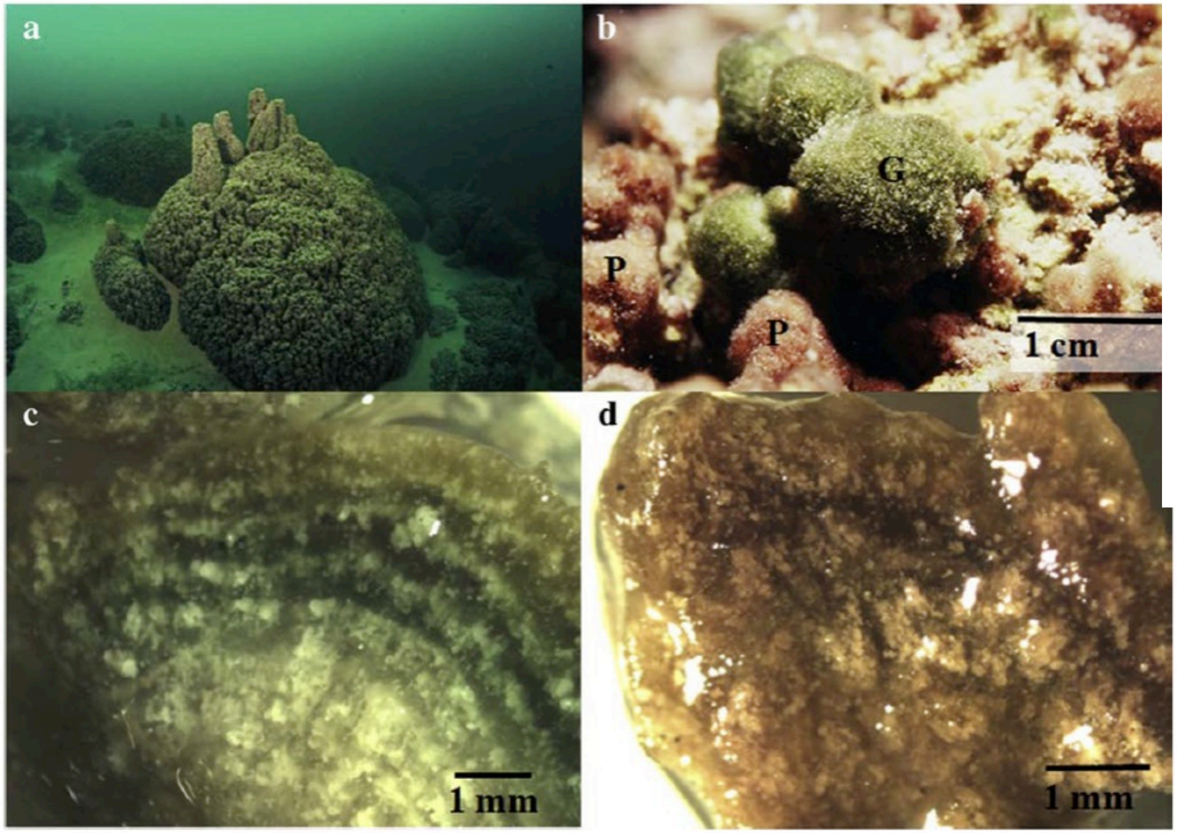

Shallow to Upper Intermediate
(5-15m)

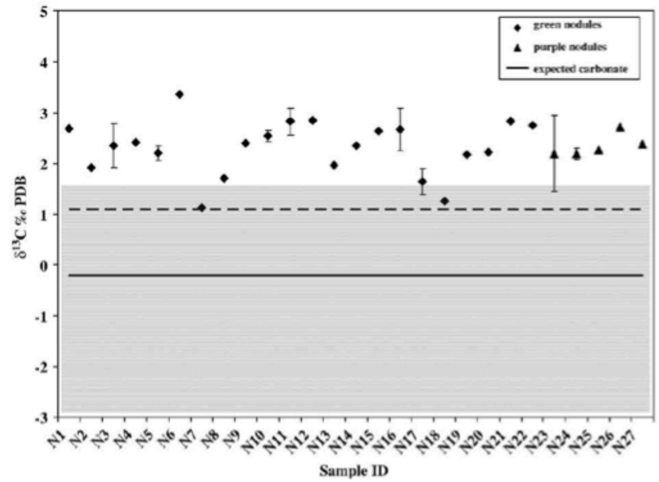

Intermediate to Lower Intermediate
(20-30m)


Deep Water (30-35m)

Evidence for photosynthetic influences on microenvironmental geochemistry and isotopic composition of Pavilion Lake microbialites:

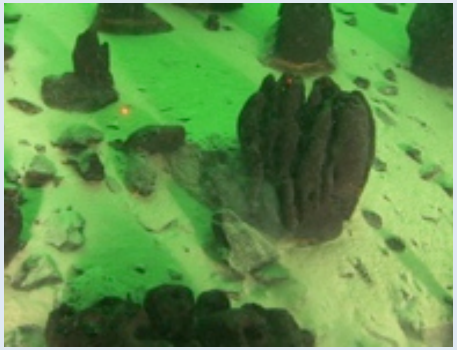
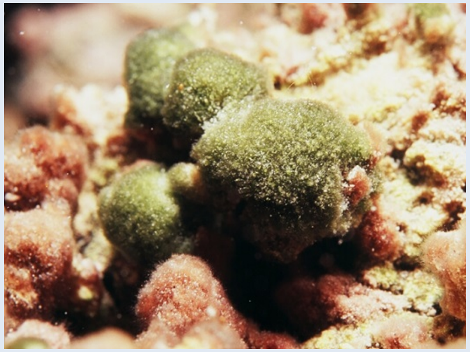
Brady et al. 2009, Brady et al 2010, Brady et al in prep, Lim et al. in prep





Predicted carbonate d13C values precipitated under abiotic conditions with no biological influence from the mean DIC d13C value in PL. Shaded area illustrates total range in predicted abiotic precipitation d13C values based on all measured DIC values. Solid line represents mean predicted carbonate d13C values while the dashed line represents one standard deviation of the mean DIC values. Green and purple nodules carbonate d13C are elevated above the range for abiotic precipitation.

- ^{13}C enrichment in nodule carbonate
- Depleted $\delta^{13}C$ values of organic matter
- $\delta^{18}O$ estimated formation temperatures present evidence for summer precipitation when photosynthesis rates are highest
- Observation within nodules of elevated oxygen (up to 275% saturation) and pH levels increased by 0.7 pH units compared to ambient water (pH 8.3)

OPERATING DOMAIN	AUV 	Deepworker 	SCUBA diver 
Range (km)	25	7	1
Speed (m/s)	2	0.5	< 0.25
Dive Time (hours)	3-5	4-6 +	1
Depth (m)	500	600	40
Spatial Scale	km- 100s m	km-10s m	10s - < 1m
Real Time Intellectual Resolution	*Low – Medium*	*Medium - High*	*Medium - High*
Example Image			

Pavilion Lake Research Project (PLRP) Background

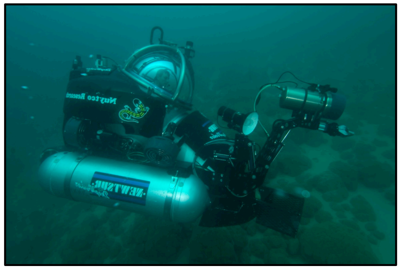
- The physical, mental and operational rigors associated with the SCUBA diving and DeepWorker operations at Pavilion Lake are analogous to astronaut EVA scenarios using spacesuits and pressurized rovers, respectively.
- Divers and submersible pilots contend with life support systems, communication and navigation systems, limited connection to colleagues, protection/isolation from the environment, intense operator workloads, and fatigue, all while exploring and conducting science in variable and unfamiliar terrains.
- These working constraints are not simulated, but real and inextricable from the PLRP activities.

- In the same way that EVA will be used on future NEA exploration missions, SCUBA divers are used at Pavilion Lake to perform delicate or complicated Microbialite sampling or instrument deployment tasks that cannot easily be performed from inside the DeepWorker submersibles.

Phase 2: Foundation building activities for human science ops during time delayed communications conditions

Hi-Bandwidth Scenario: Nominal Science Operations

Voice/Video 50 second OWLT delay



<u>Key Characteristics</u>

•Wi-Fi operational

•Tether operational

•CapCom & SBT in MMCC

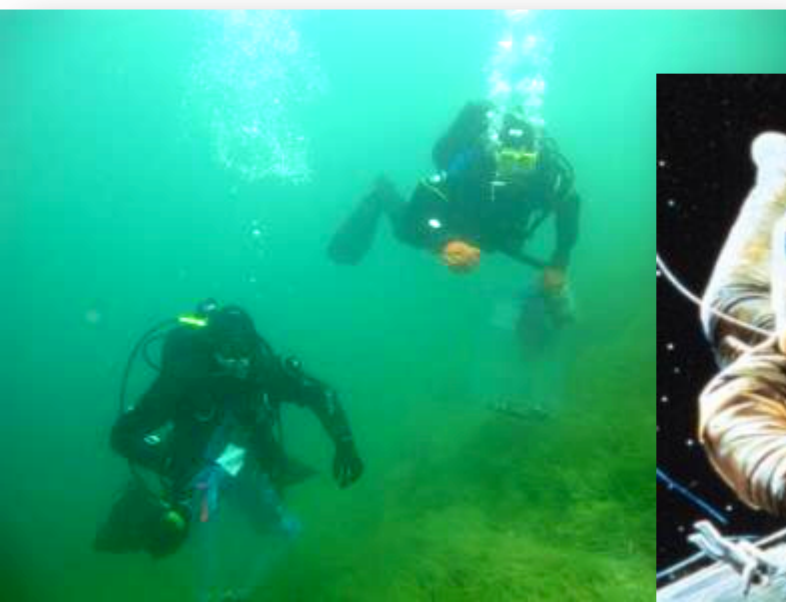
•Voice, Video, Telemetry from DW (through Surface Support) to CapCom (in MMCC)

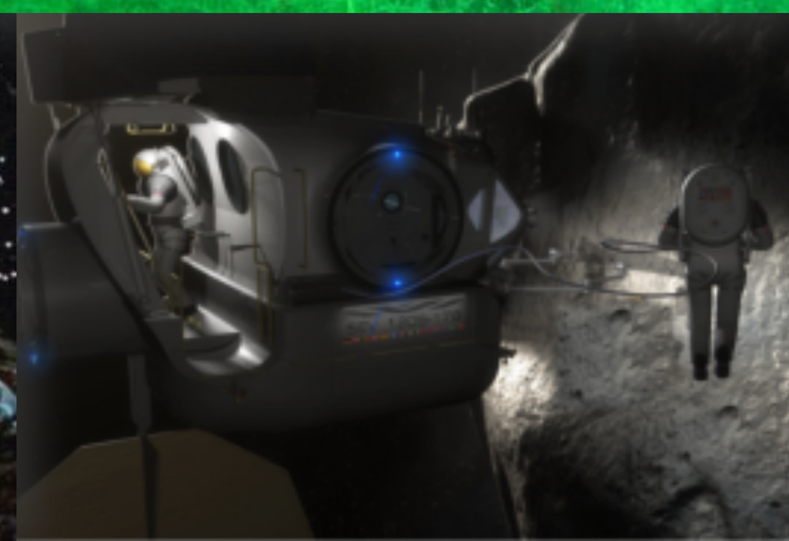
•Voice from CapCom (in MMCC) (through Surface Support) to DW Pilot via tether

•Telemetry from Surface Support to DW Pilot via tether

PLRP Phase 3, 2014 & 2015: Follow-Up Hi-resolution Imaging and Sample Collection

- Sample locations identified by DeepWorkers
- SCUBA divers used to collect samples to simplify sample collection and minimize damage to samples and environment
- Analogous to using EVA crew from SEV to take advantage of human dexterity, improving sampling and reducing SEV complexity and mass





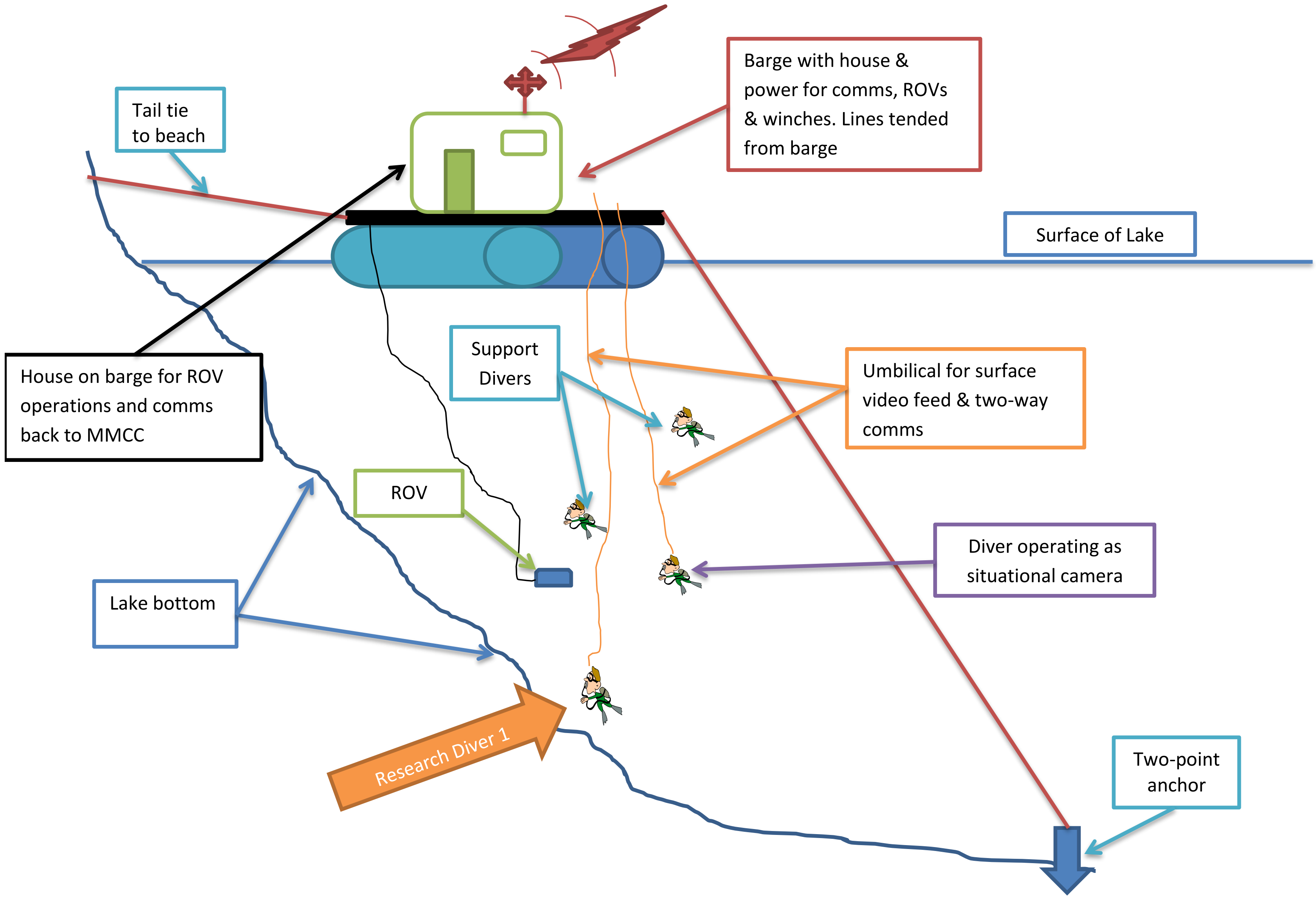
PLRP 2014 Exploration Research Questions

- ***Research Question 1.*** Do the NEA and Mars moons mission operations concepts, communications protocols, and exploration data systems developed and tested during previous NASA analog tests work acceptably during real scientific field exploration?
  - What improvements are desired, warranted, or required?

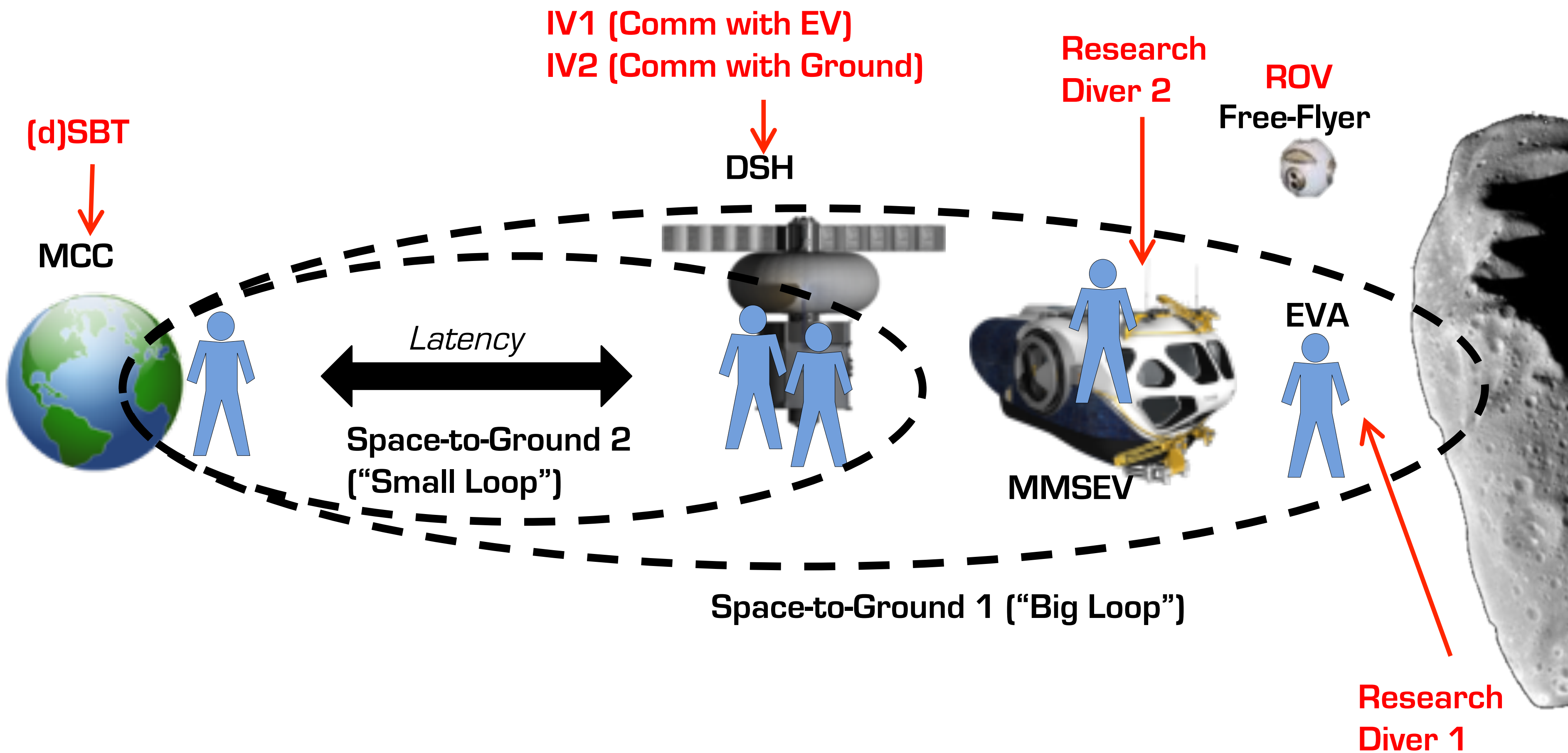
- ***Research Question 2.*** Do these operations concepts, communications protocols, and exploration data systems remain acceptable as communications latency increases from 50 seconds to 5 minutes one-way light time (OWLT)?
  - What improvements are desired, warranted, or required?

The ops con, comm protocols, and exploration data systems have been developed and tested during PLRP 11, DRATS11, RATS12, NEEMO 15-16, and SEATEST2.

PLRP 2014 Dive Configuration



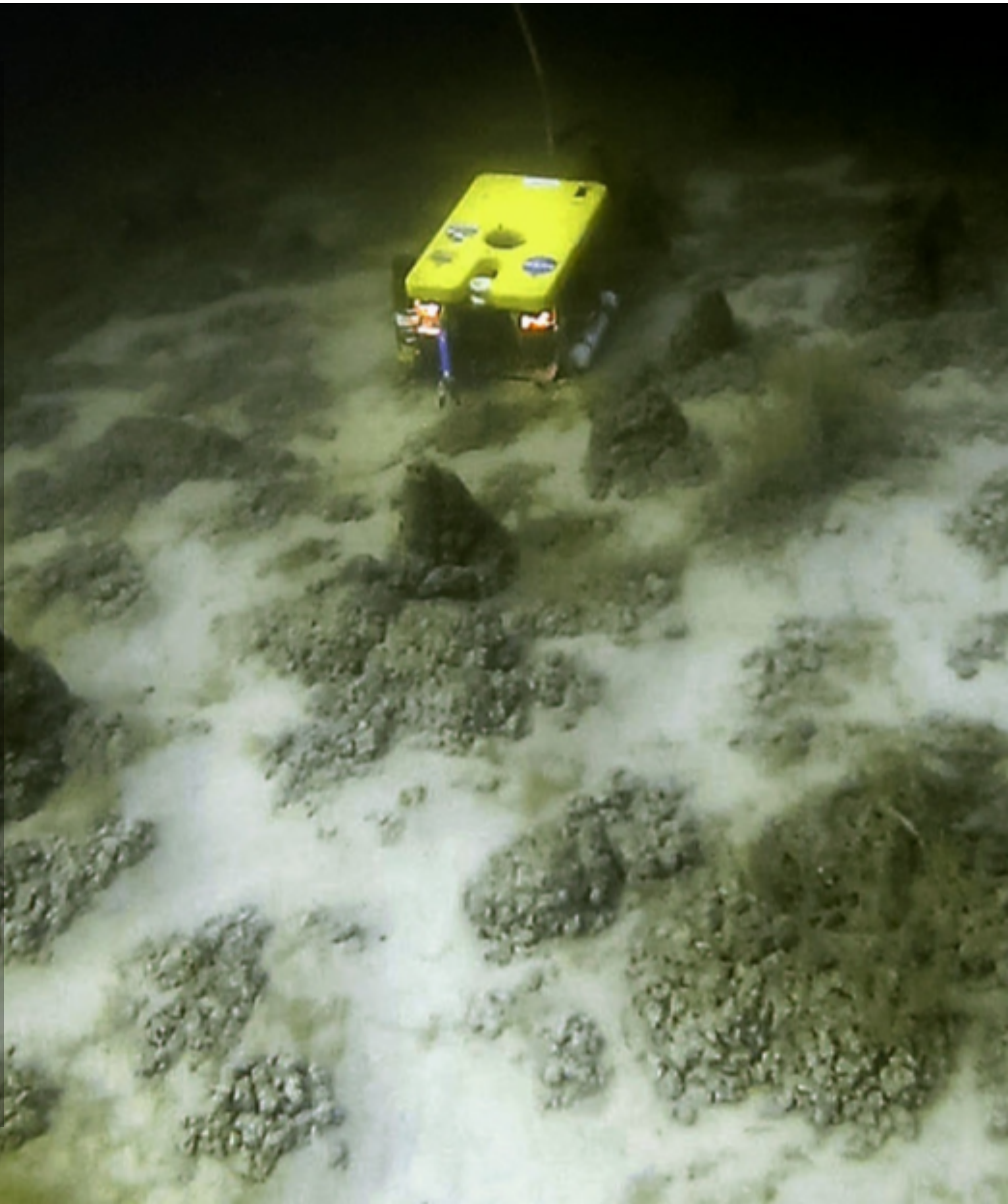
PLRP 3.0 Con Ops



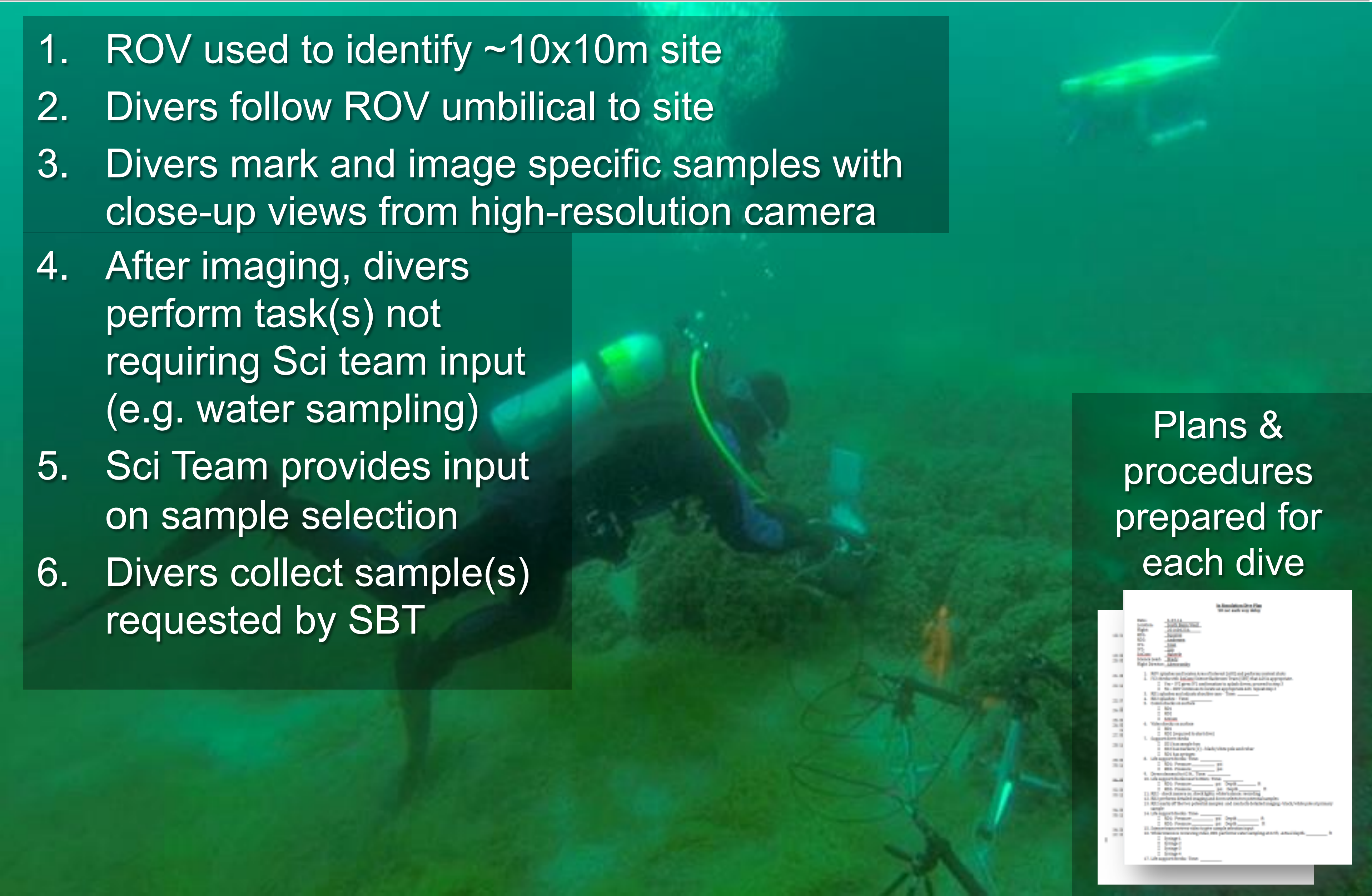
- **Ground nominally does not talk on Big Loop**
- **Crew talk with each other on Big Loop (ground hears, does not talk)**
- **Ground and crew IV(s) use Voice and/or Text with each other on small loop**
  - **When ground talks to crew, use verbal pre-alerts e.g. *"Incoming message in 10 seconds"***

ROV Flights

- DeepWorker imagery from previous field deployments used to identify regions of interest (~1000m^2)
- ROV used to explore regions of interest and identify specific sites for divers to explore (< 100m^2)
  - Resolution of DeepWorker imagery inadequate for identifying ~1cm nodule features
- ROV also used to guide divers to specific sites & provide tracking



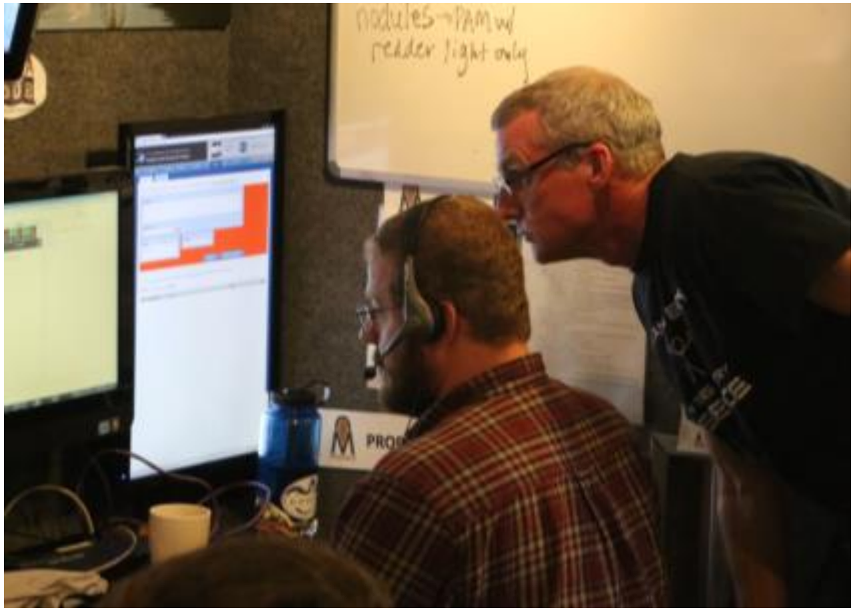
ROV + Diver Operations



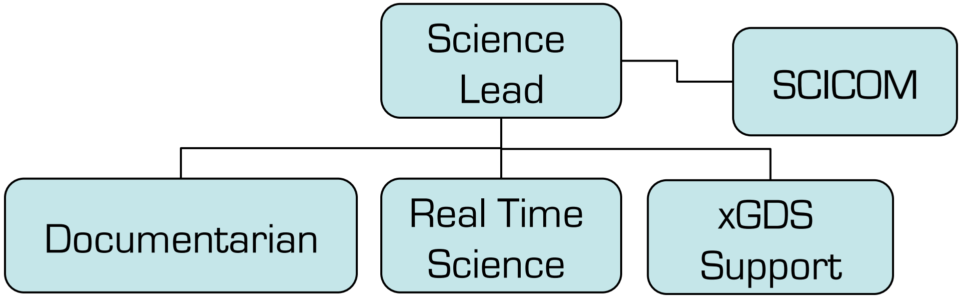
1. ROV used to identify ~10x10m site
2. Divers follow ROV umbilical to site
3. Divers mark and image specific samples with close-up views from high-resolution camera
4. After imaging, divers perform task(s) not requiring Sci team input (e.g. water sampling)
5. Sci Team provides input on sample selection
6. Divers collect sample(s) requested by SBT

Plans & procedures prepared for each dive

Science Backroom Team (SBT)

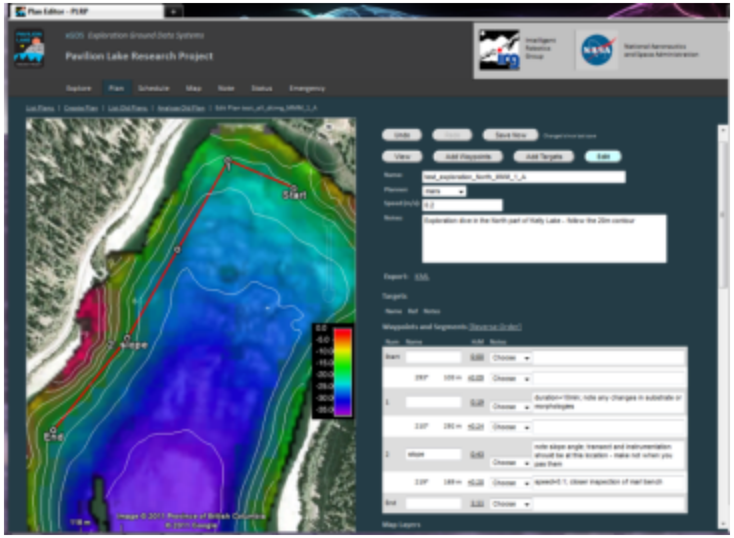


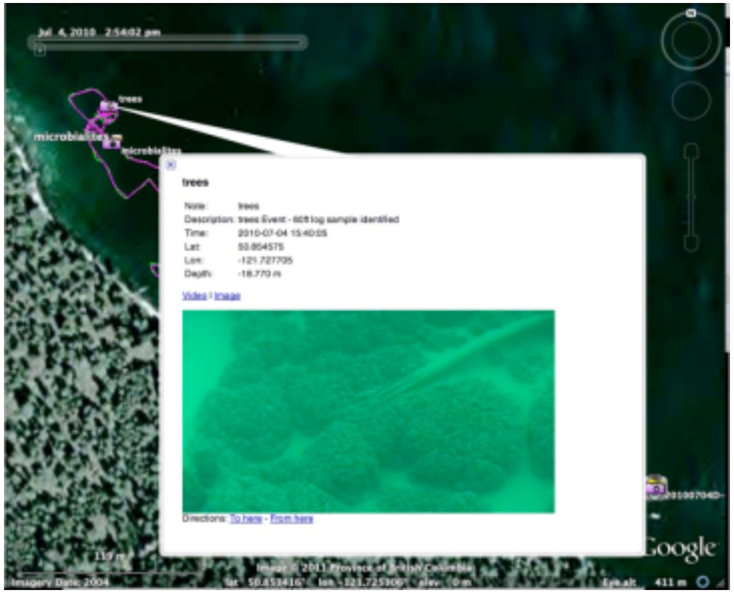
- Voice, video & data transmitted to Science Backroom Team in MMCC (on lake shore)
- During 40 minute dives, the SBT is in an advisory role
- Backroom led by Dr. Steve Squyres (Mars Exploration Rovers PI)
- Exploration Ground Data Systems (xGDS) utilized for dive planning, execution & analysis
- Organization:



Exploration Ground Data Systems (xGDS)

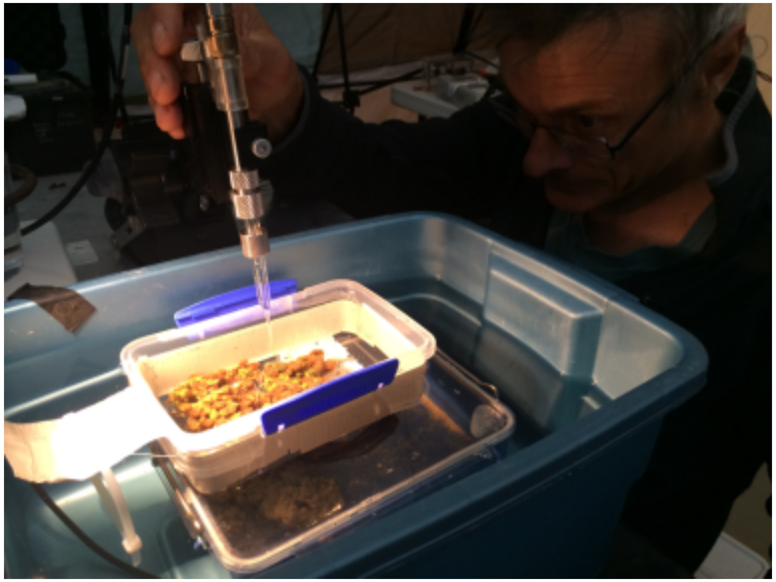
- Software developed & implemented by Intelligent Robotics Group at NASA Ames since PLRP 2008
  - Also used at NEEMO and RESOLVE field tests.
  - Initial purpose was to facilitate in-field distillation & review of large quantities of DeepWorker data
- Tools for planning, execution, and analysis of scientific exploration activities incl. flight plan generation, geo-referenced data visualization, video compression, field documentation, & sample archiving
- Enabling capability for PLRP 2014:
  - Provided real-time & delayed audio-video streams to boat and MMCC during dives & ROV flights
  - Enabled note-taking in MMCC during dives/flights
  - Video available for DVR-style review almost immediately post-dive
- Included in post-test assessment for evaluation of existing features and identification and prioritization of capabilities for future development

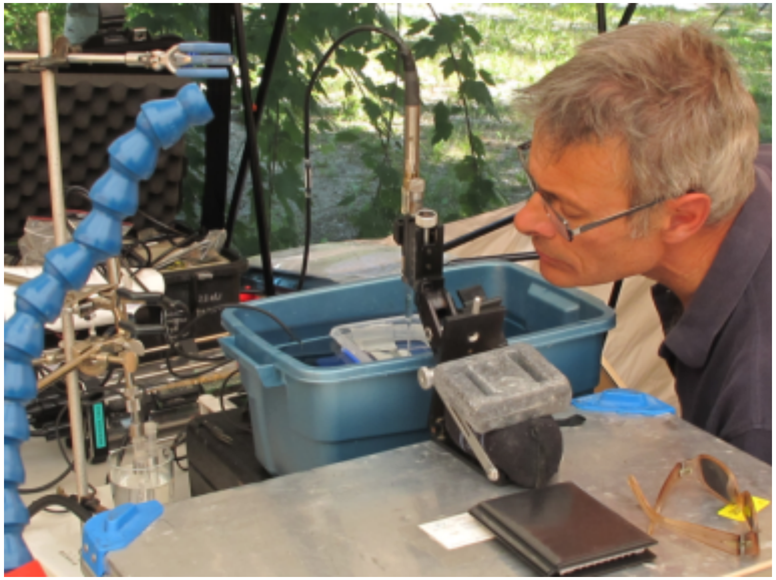




Sample Processing & Analysis

- Samples were processed and analyzed on-site, which helped inform subsequent sample collection decisions





SBT Consensus Review Meetings

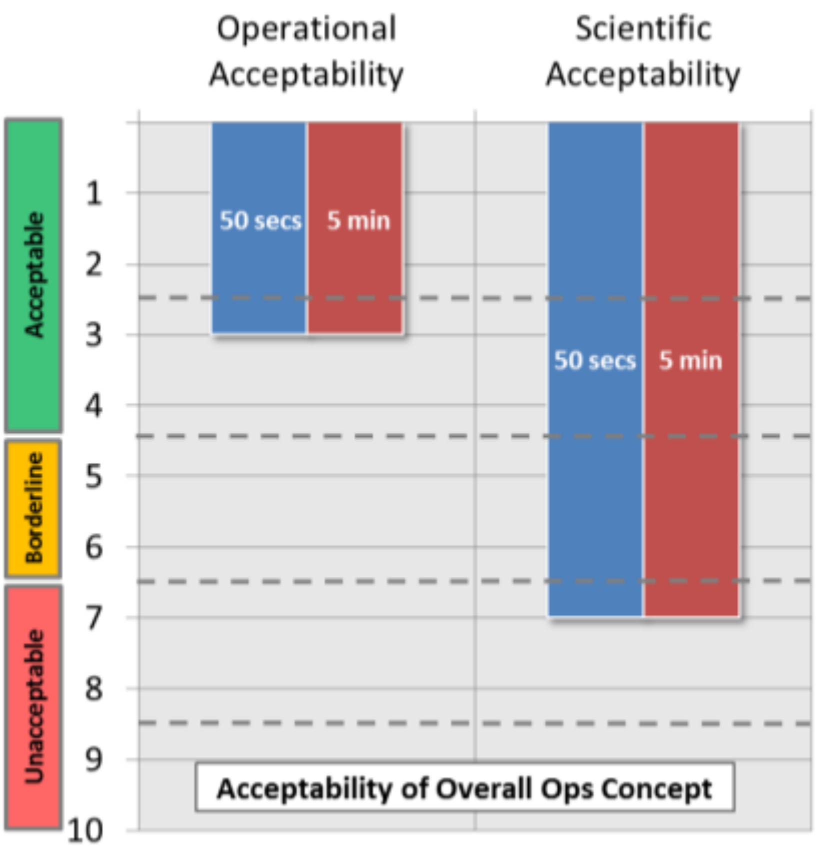
Approach:

- No *individual* ratings or data were collected; data were provided by consensus of the science team
- Minimum of six team members (excluding exploration team) were required to provide consensus ratings including divers, IV, and MMCC crewmembers.

- Science Team feedback: *Exploration discussion was "most engaging and interesting we have ever had"*

Results: Acceptability Ratings (50 s OWLT Delay)

- **Ops Acceptability: 3** (Minor Improvements Desired):
  - Better definition of science backroom roles / organization desired
  - Expected that organization of SBT will depend on specific science objectives, instruments, etc



- **Scientific Acceptability: 7** (Improvements Required)
  - Low-resolution imagery in SBT was inadequate for SBT to provide good input; Still images [vs. video] with higher resolution scale bar required
    - Hi-res imagery was collected but not transmitted to MMCC during dives
  - Suggested that ops con "would work great" with hi-res stills + scale bar

Results: Ops Con Capability Assessments

Capability Assessment Ratings:

- Used to assess the anticipated importance or usefulness of different exploration capabilities e.g. technologies, systems, design features, data products, etc

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement		No Rating
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.		Unable to assess capability
1	2	3	4	5	6	7	8	9	10	NR

IV Support for EVAs *(RATS 12)*

Realtime (with latency) Ground Support for EVAs *(PLRP14)*

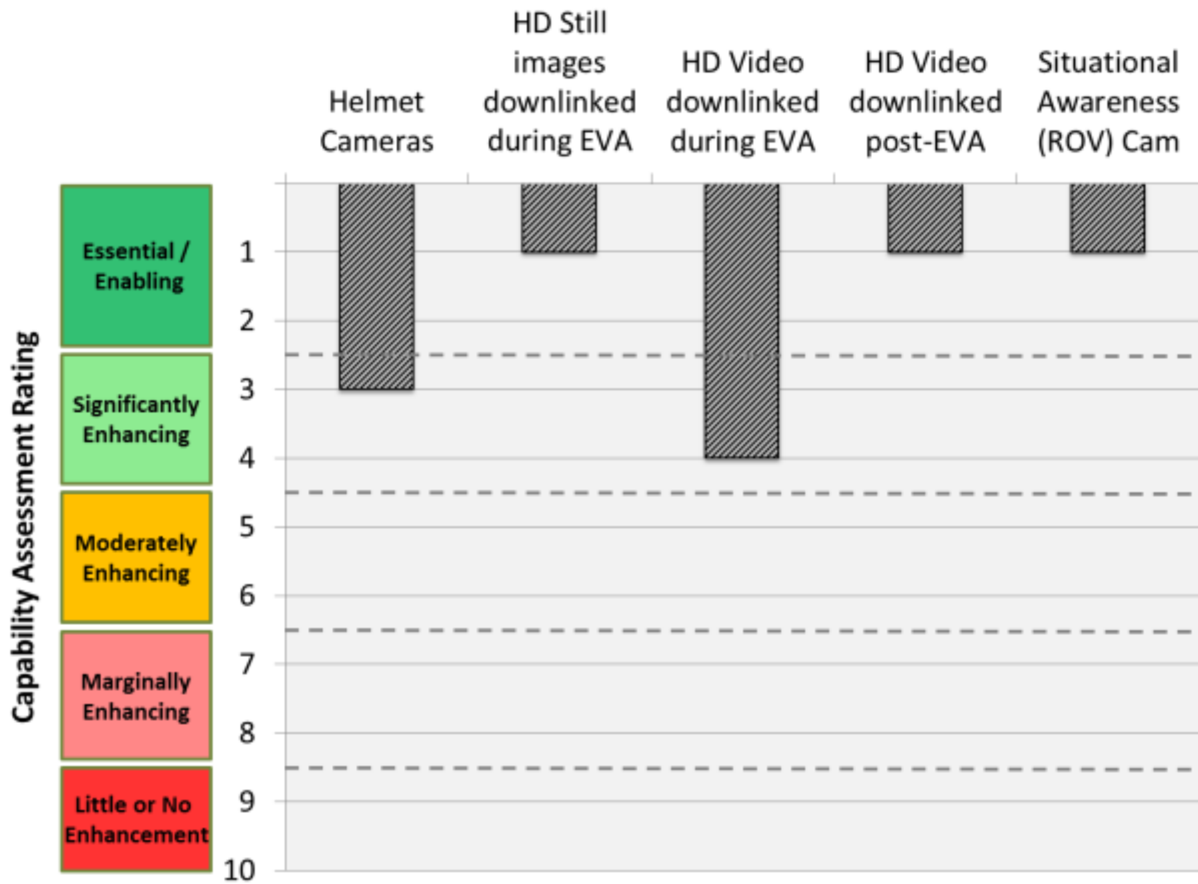
IV Support for EVAs *(PLRP14)*

- Utility of Ground Support for EVAs depends on training and expertise of crew vs. SBT and availability and quality of data available prior to vs. during EVAs

- PLRP 14 consensus that IV support for EVAs is essential and that two IV crewmembers supporting is probably required

Results: Camera / Imagery Capabilities

- Helmet / shoulder cameras were of inadequate resolution for science purposes but important for operational SA
- Video streaming to Science Team less useful than stills – need to be able to capture stills and compare them with other stills to allow for prioritization
  - Rapid screenshot compilation capability within xGDS rated as essential if only shooting video
- Situational Awareness (ROV) camera rated as essential to provide context for diver / sample locations within site and relative to each other
  - Higher resolution grayscale/BW may be more useful than lower resolution color.



Results: Communications Capabilities

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement		No Rating
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.		Unable to assess capability
1	2	3	4	5	6	7	8	9	10	NR

Rapid Screenshot / HD Still Compilations *(PLRP14)*

Voice messaging/ playback (e.g. Voxer) *(PLRP14)*

Integrated timers within text client *(PLRP14)*

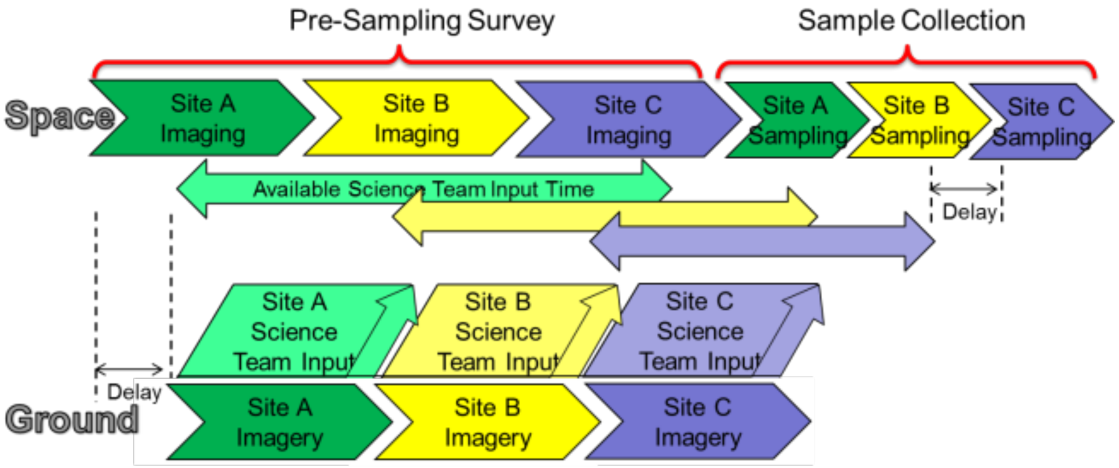
- Timers to indicate when messages will have been received and earliest time at which response can be expected

- Assessment and comparison of potential samples requires HD still frames
  - Stills also more bandwidth efficient vs. HD Video

- Ability to replay voice messages and choose when they are listened to could improve utility and convenience of voice comms

5-minute OWLT Delay

- Dive & Science Details:
  - ROV data was used to identify area of interest for sampling
  - Multiple samples were to be collected by divers, but dive was time constrained to 40 minutes.
  - Science Backroom Team (SBT) wanted to provide input to sample prioritization process
- Circuit Sampling Strategy
  - Sampling options were selected by divers and identified with physical markers.
  - Samples were marked off sequentially and divers moved through a circuit
  - While SBT reviewed selections, divers filled wait time with other science tasks (water sampling, inclinometer measurements, detailed imaging)
  - Through this process, SBT was provided with adequate time to receive, review, and respond to imaging prior to sample collection
  - EVA crew not required to wait idly for SBT input
- EVA/dive must be of adequate duration to enable Pre-Sampling Survey plus round-trip light-time plus Sci Team discussion prior to sample collection



Dynamic Prioritization of Science Targets (aka "Leaderboard")

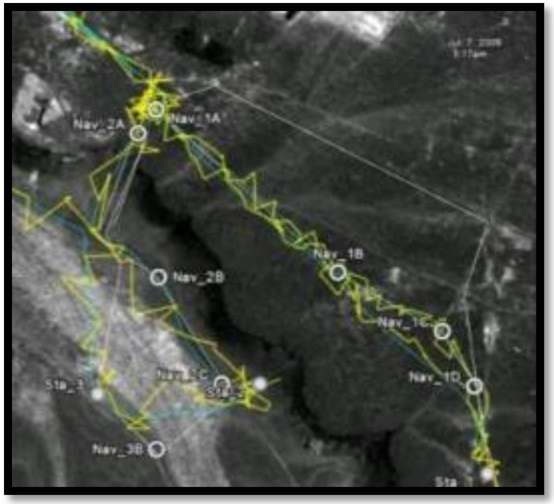
The concept of dynamic prioritization of science targets, or a "scientific leaderboard" was developed and employed

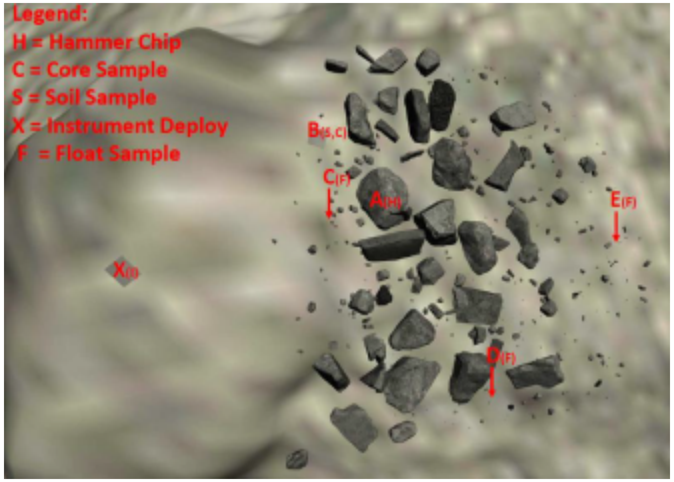
As imagery of potential samples is viewed in the MMCC, the Science Team continually provide the in-space IV with their list of prioritized samples (via text)

- **Supporting Capabilities:**
  - HD stills / screenshots of each sample option; Rapid picture board generation to compare options side by side.
  - Location / sample marking & communication

Location/Sample Marking & Communication

- **Communication across latency regarding sample collection requires unambiguous identification / marking of locations and features at the scale of the samples to be collected**
  - Physical markers used at PLRP allowed divers to communicate to IV and ground.
  - Virtual location marking would allow IV and ground to communicate locations to crew and vice-versa
    - Could combine regional navigation with annotated imagery to achieve necessary accuracy (DRATS 2009)





Abercromby, A. F. J., Gernhardt, M. L., & Litaker, H. (2012). Desert Research and Technology Studies (DRATS) 2009: A 14-Day Evaluation of the Space Exploration Vehicle Prototype in a Lunar Analog Environment *NASA/TP-2012-217360*.

Other Science Team Lessons Learned

- **Design EVAs so that: Roundtrip Comm Latency < Time Available Between Sample Imaging & Sample Collection**

- List of prepared text responses can expedite communications
- Where possible, crew should include need-by times in requests to SBT
- Predefine times/locations/situations for SBT to provide specific informational and/or decisional inputs
- Verbal and/or text “hashtags” for specific types of comms might help with prioritization of comms
- If SBT has inadequate information, either ask for more imaging or go with diver/IV preference
- Probably not good practice to use text and voice in case of ambiguities / inconsistencies. Voice is usually unnecessary. Sometimes unreadable. Possibly detrimental.
- Define Pixels-on-Target requirement for science objectives
  - Camera resolution; proximity to target; target size/scale


What’s Next?
NASA

BASALT Program Objectives

- The BASALT (Biologic Analog Science Associated with Lava Terrains) program will investigate terrestrial volcanic terrains and their habitability as analog environments for early and present-day Mars.

- We will conduct our scientific fieldwork under simulated Mars mission constraints to evaluate strategically selected concepts of operations (ConOps) and capabilities with respect to their anticipated value for the joint human and robotic exploration of Mars.

- Funded March 2015 for four years (FY15-19) by NASA SMD PSTAR (Planetary Science & Technology Through Analog Research) Program

BASALT Team

NASA

Ames Research Center

Goddard Space Flight Center

The First 50 Years
Johnson Space Center

NASA Kennedy Space Center

CSA ASC

Purdue University

Idaho State University 1901 Veritas Vos Liberabit

Massachusetts Institute of Technology

Cornell University Founded A.D. 1865

ASU

wyle

Strength Through Support

UMASS

University of Hawai'i
Mālamalama
1907
Ua Mau Ke Ea O Ka ʻĀina I Ka Pono

The University of Edinburgh

PISCES
Pacific International Space Center for Exploration Systems

LMT

Bay Area Environmental Research Institute

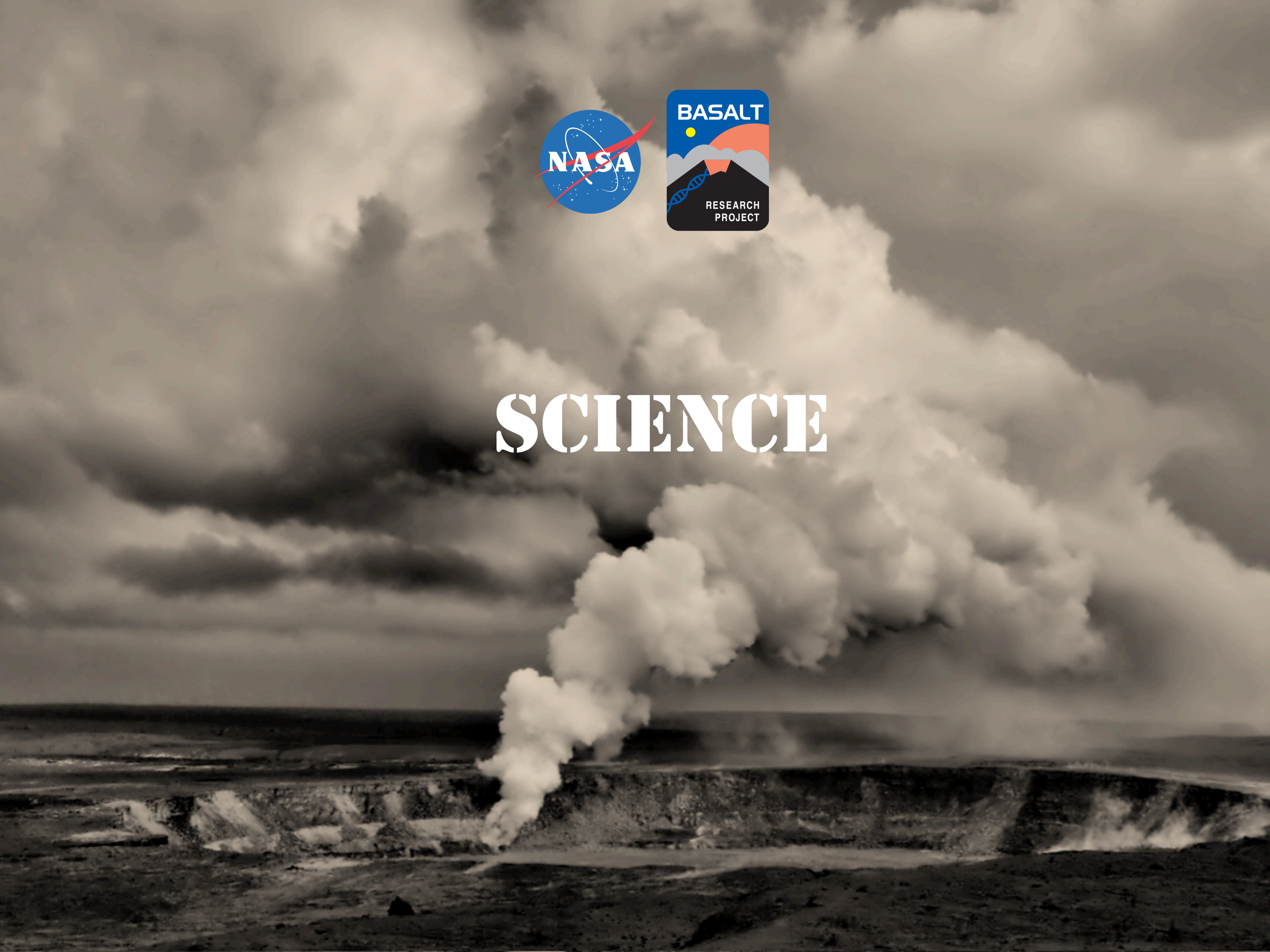
Pavilion Lake Research Project

BASALT Program Elements

- **<u>Science</u>:** The BASALT science program is focused on understanding habitability conditions of early and present-day Mars in two relevant Mars-analog locations (the Southwest Rift Zone (SWRZ) and the East Rift Zone (ERZ) flows on the Big Island of Hawai'i and the eastern Snake River Plain (ESRP) in Idaho) to characterize and compare the physical and geochemical conditions of life in these environments and to learn how to seek, identify, and characterize life and life-related chemistry in basaltic environments representing these two epochs of Martian history.

- **<u>Science Operations</u>:** The BASALT team will conduct real (non-simulated) biological and geological science at two high-fidelity Mars analogs, all within simulated Mars mission conditions (including communication latencies and bandwidth constraints) that are based on current architectural assumptions for Mars exploration missions. We will identify which human-robotic ConOps and supporting capabilities enable science return and discovery.

- **<u>Technology</u>:** BASALT will incorporate and evaluate technologies in to our field operations that are directly relevant to conducting the scientific investigations regarding life and life-related chemistry in Mars-analogous terrestrial environments. BASALT technologies include the use of mobile science platforms, extravehicular informatics, display technologies, communication & navigation packages, remote sensing, advanced science mission planning tools, and scientifically-relevant instrument packages to achieve the project goals.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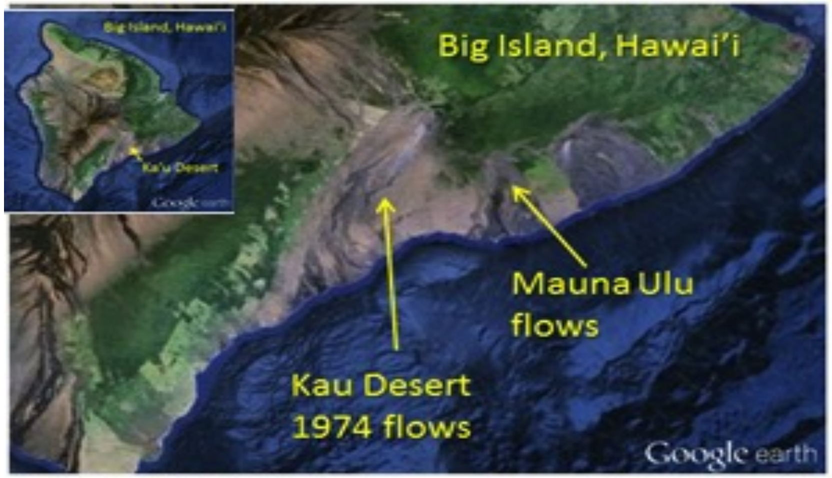
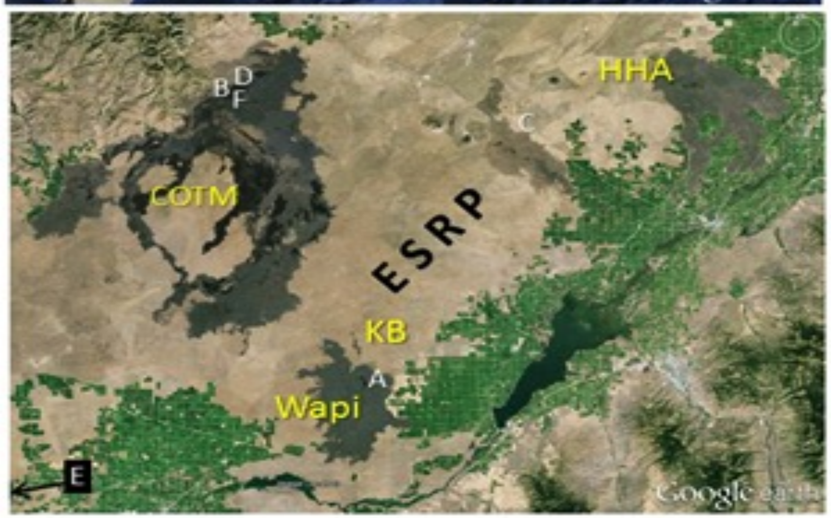
BASALT
RESEARCH PROJECT
SCIENCE

Map of BASALT Field Locations



Mauna Ulu flows and East Rift Zone 1969-1974 flows, Kilauea volcano on the Big Island of Hawai'i, USA.



Holocene basaltic lavas on the eastern Snake River Plain (ESRP) of Idaho, USA. Regions labeled in yellow are Craters of the Moon (COTM), Wapi lava field, and King's Bowl (KB) lava field.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BASALT
RESEARCH PROJECT
EXPLORATION

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By learning which ConOps and Capabilities are enabling or enhancing (and which are not) early on in the development process, NASA's limited resources are better managed towards value-add systems and support technologies.

Minerva – Integrated Mission Planning, Monitoring and Data Archiving

- ***1) xGDS (Exploration Ground Data Systems)*** is a set of tools to support science and mission operations and post-operation data analysis.
- ***2) SEXTANT*** is a resource-based path planning tool that optimizes traverses based on distance, time, or energy consumption.
- ***3) Playbook*** will be used during BASALT field campaigns primarily for scheduling and timelining support, and will be fully integrated with xGDS.

Year 1 Schedule for BASALT

- August 2015: First Idaho field deployment
- October 2015: Hawaii Reconnaissance trip
- December 2015: BASALT AGU F2F
- June 2016: BASALT-FINESSE Idaho Deployment
- November 2016: BASALT Hawai'i Deployment

Thanks for coming to the talk!

PLRP Website:

www.pavilionlake.com

PLRP is currently funded by the NASA SMD MMAMA and LASER programs. Previous support for the program has also been received from the CSA CARN program, NASA AES Analogs, ESMD Analogs, NASA ASTEP, Nuytco Research, NASA Spaceward Bound Program, the National Geographic Society, University of British Columbia and McMaster University.

BASALT Website :

http://spacescience.arc.nasa.gov/basalt/

Twitter:

@BASALT_research

BASALT is currently funded by the NASA SMD PSTAR program.