# Enabling Human Exploration Through Integrated Operational Testing

## NASA's Exploration & Science Analogs

EVA Technology Workshop 2017

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**Marc Reagan**
**Exploration Mission Planning**

**David Coan**
**Exploration EVA Systems & Operations**

# Agenda

- Describe Integrated Operational Testing
  - Who, What, Where, Why, How
- Discuss how participation in Integrated Operational Tests advances EVA Office goals (Who, What, Where, Why)
- Explain how EVA Office determines which analogs in which to participate
- Show some examples
- Provide historical context on other environmental and mission “analog” efforts across the agency

# ANALOGS: Who, What, Where, Why, & How

**High-fidelity integrated multi-disciplinary operational development missions that closely mimic the space environment of interest, and allow for end-to-end operations, thus developing and testing concepts that enable Exploration missions**

## WHO

### MULTI-ORGANIZATIONAL TEAMS

eisd
EXPLORATION INTEGRATION & SCIENCE DIRECTORATE

*coordinated integration*

- PLANNING
- EVA
- SCIENCE
- TECHNOLOGY

ETO
EXPLORATION TECHNOLOGY OFFICE

## WHAT

### INTEGRATION THEMES

- TOOLS
- TECHNIQUES
- TECHNOLOGIES
- TRAINING

## WHERE

### RELEVANT ENVIRONMENTS

- AQUATIC
- TERRESTRIAL
- LABORATORY

## WHY

To achieve mission readiness through integration and testing of technologies, systems, operations, and science in relevant environments

- Close technology, exploration, and science gaps
- Identify and develop the best systems, innovations, and operational approaches
- Drive out results not found in standalone testing, including things that do and do not work in a mission environment
- Inform strategic architectural and concept of operations development efforts
- Facilitate EVA concepts of operations development

**OUTCOME**: These efforts will ultimately led to mission readiness and success, reduce the risk, increase the scientific return, and improve the affordability of NASA programs and missions.

## HOW

### INTEGRATED OPERATIONAL TESTING

eisd READy
Relevant Environments for Analysis & Development

NEEMO

NASA Research and Technology Studies

RISE

SHyRE

# WHO: NASA, Academia, Industry, Military

JSC
ARC
KSC
JPL
GSFC

esa
CSA ASC
JAXA

And a multitude of others…

XI XM XX
CB EC ER SK
FIU
AQUARIUS
HONEYBEE ROBOTICS
NPS

CORAL RESTORATION FOUNDATION
JOHNS HOPKINS UNIVERSITY
ihmc FLORIDA INSTITUTE FOR HUMAN & MACHINE COGNITION
USF UNIVERSITY OF SOUTH FLORIDA
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
TELEDYNE TECHNOLOGIES INCORPORATED
GT
NMT
AllTraq
UNCW
TELOREGEN
VEGA Telehealth
IMaGeS Lab
SHARK MARINE TECHNOLOGIES INC.
AEXA
University of Houston Clear Lake
voxer

# WHAT: Development & Integration Themes

## TOOLS

### EVA Systems
- EVA Tools and transport
- Crew Rescue
- IV Workstation
- Informatics

### Instrumentation
- Sample identification / high-grading
- ISRU verification

### Sample Collection/Curation
- Collection
- Contamination Mitigation
- Preservation/Storage

## TECHNIQUES

### Exploration Operations
- Procedure development/refinement
- Time delay
- Bandwidth limitations
- EVAs in undefined environments

### Science Operations
- Flexicution Methodology
- Decision Making Protocols
- Transverse Planning

### Robotic Operations
- Autonomous
- Crew Controlled
- Human-Robotic Interface

## TECHNOLOGIES

### Emerging Technologies
- Virtual/Hybrid reality opportunities
- Rapid testing environment for development of emerging technologies

### Innovations Incubator
- Relevant environments and operational constraints are a breeding ground for innovation

### Partnerships
- Opportunities for external partners to demonstrate current capabilities
- Direct collaboration leading to proposal and other funding avenues
- Strengthens international partnerships

## TRAINING

### Cross-Disciplinary Training
- Learning each others language, requirements, and drivers in EISD
- Ex. Geo-Science Field Training for managers and engineers

### Astronaut Crew Training
- Additional expeditionary and leadership opportunities
- Enhances both operational and science training objectives

### Operational Training
- Provides ops training prior to payload flights for payload PIs and teams

# WHAT: Capability Development via Integrated Operations

# WHERE: Environments for Tests

## AQUATIC

EXAMPLES

Neutral Buoyancy Laboratory (NBL)

Aquarius Reef Base (NEEMO)

ESA's Neutral Buoyancy Facility

## TERRESTRIAL

EXAMPLES

Geo-Science Field Exercises & Sites

Field Training Areas

Extreme Environments (ex. Antarctica)

## LABORATORY

EXAMPLES

Active Response Gravity Offload System (ARGOS)

Virtual Reality & Hybrid Reality Laboratories

International Space Station

# **WHY**: EVA Utilization of Operational Field Tests

The primary utilization of operational field tests for EVA is to inform the *Exploration EVA Concepts of Operations* document and close knowledge/capability gaps by exploring the combination of **Operations** and **Engineering** with **Science** in a mission-like environment for future Exploration destinations

**Primary EVA Objectives**

| | | NEEMO 22 EVA Objectives | SMT EVA Knowledge/Capability Gaps |
|---|---|---|---|
| **EVA Tools** |  | ➢ Integrated Geoscience Sampling System<br>**Core sample acquisition (Honeybee Robotics)*<br>➢ Large tool/hardware transport & stowage<br>**EVA Modular Equipment Transportation System*<br>➢ Small tool transport on EVA suit | ➢ Tools for Science Sampling on a Surface EVA<br>➢ Subsurface samples (core)<br>➢ Tool Carrier Device<br>➢ Tool Attachment/Harness for Surface EVA |
| **Informatics** |  | ➢ IV Support System & Workstation<br>➢ EVA/Science task tracking<br>➢ EVA Digital Cue Cards<br>➢ EVA Navigation<br>➢ EVA Augmented Vision Heads-Up Display<br>**Navy Diver Augmented Vision Display demo* | ➢ IV Support System for EVA Operations<br>➢ EVA Graphical Display<br>➢ EVA Short Range Navigation<br>➢ Mixed / Augmented Reality Capability |
| **Concepts of Operations** |  | ➢ Integrated EVA Operations with Science Tasks<br>➢ Integrating Informatics<br>➢ IV support System & Workstation<br>➢ Flexecution<br>➢ Traverse Planning | ➢ Integrated EVA Flight Control Methodology<br>➢ Tools for Interacting with EVA Over a Comm Latency<br>➢ Flexible Execution Methodology for EVA Science Operations in Undefined Environments |

**Secondary Objectives**

| | | | |
|---|---|---|---|
| **Robotic-EVA Ops** |  | ➢ Situational Awareness for IVA & MCC<br>➢ Robotic Payload Transport for EVA | ➢ EVA-Robotic (Man-Machine) Work System |

# WHY: Relevant for Planetary Science Exploration

## SCIENCE

## NEEMO 22 PLANETARY SCIENCE RELEVANCY

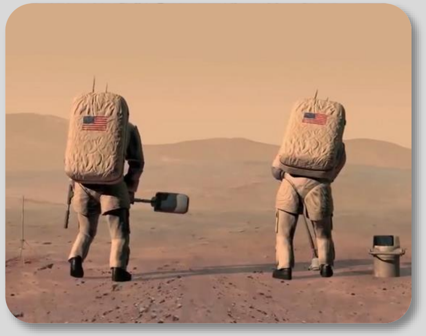
*Astromaterials Research & Exploration Science (ARES)*

- NEEMO EVA science activities included deployment of handheld instrumentation, context descriptions, imaging, and sampling
- The marine science activities and associated research objectives serve as an appropriate proxy for planetary surface exploration activities

- **Integration, coordination, and education from diverse disciplines and organizations**

**Astromaterials**

**Curation**

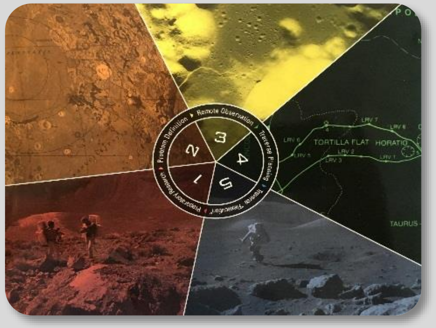


- Sampling Procedures
- Sampling Techniques
- Collection Tools
- Contamination
- Storage & Transport

**Research**

- Remote Sensing
- In-situ Instrumentation
- High-grading Samples
- Context Descriptions
- Documentation

**Exploration**



- Science Operations
- Traverse Planning
- Operational Flexibility
- Human-Robot Ops
- Crew Science Training

# **WHY**: EVA Goals for Integrated Operational Testing

**EVA Goals**

- Advance the future of the EVA System and operations
- Understand EVA capability, knowledge, and technology gaps and concepts of operations for a wide range of Exploration destinations being considered by NASA
- Assess the system and architectural interactions between Operations, Engineering, and Science
- Determine and document closures to gaps in EVA capabilities and knowledge for Exploration missions
- Develop and document concepts of operations for EVA at the Exploration destinations
- Realize the needs of EVA equipment and enable the development of concepts for design maturation on the road-to-flight

# HOW: Desired Elements for EVA Participation

There are many different types of operational field test activities. EVA is looking for the following qualities when determining which rise to the level of fidelity and return to warrant involvement:

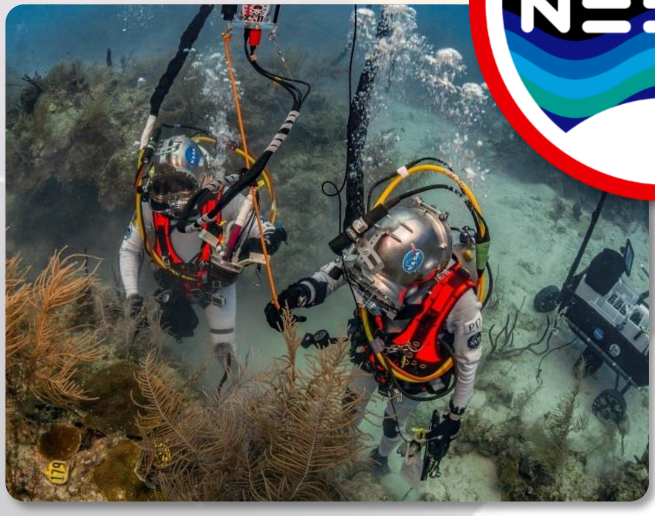
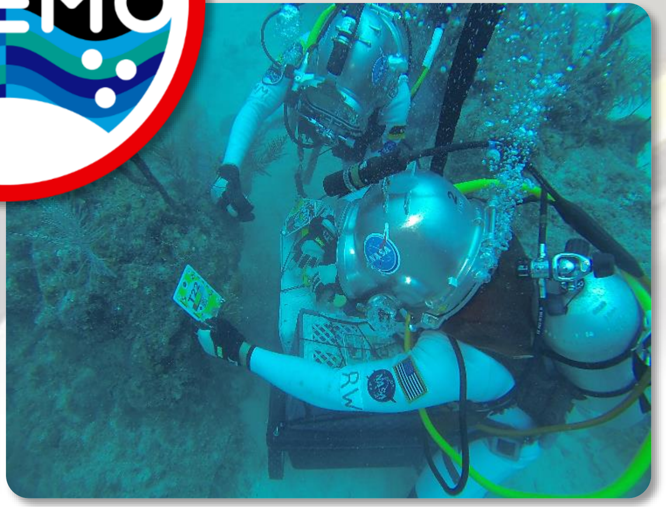
- Responsive to EVA Office input on mission and objective design
  (i.e., objectives mapped to specific <u>needs</u> and <u>capability, knowledge, and technology gaps</u>)
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Participation of experienced operators (crew and MCC)
- Participation of acknowledged stakeholders with expertise to evaluate concepts being worked on across the agency (e.g., science community (XI))
- MCC and Science Team components
- Incorporation of signal latency (time delay) and blockage
- Incorporation of partial gravity
- Availability of large area of un-engineered natural (planetary) surface
- Proxy science with high correlation to planetary science
- Participation of scientists invested in the proxy science outcome
- Inclusion of appropriate purpose-built prototype hardware for evaluation and maturation
- Full "mission" environment to drive out things that wouldn't be found in standalone testing
- Potential to benefit ISS as well as Exploration
- Enhances relationships with international partners, academia, industry, other government agencies, and other NASA orgs
- Highlights work in Exploration in a visible and tangible way (e.g. national media, social media, events like SpaceCom)
- Intersection of the 4Ts

ACTIVE

# HOW: NASA Extreme Environment Mission Operations

- Premiere analog that allows for evaluations of EVA end-to-end concepts of operations with crew that are in-situ in a true extreme environment and provides for flight-like interactions between the crew and an MCC/Science Team, including over comm latencies
- NASA analog mission that sends groups of astronauts, engineers and scientists to live, work and explore in a challenging environment
- Series of 22 space exploration simulations conducted since 2001



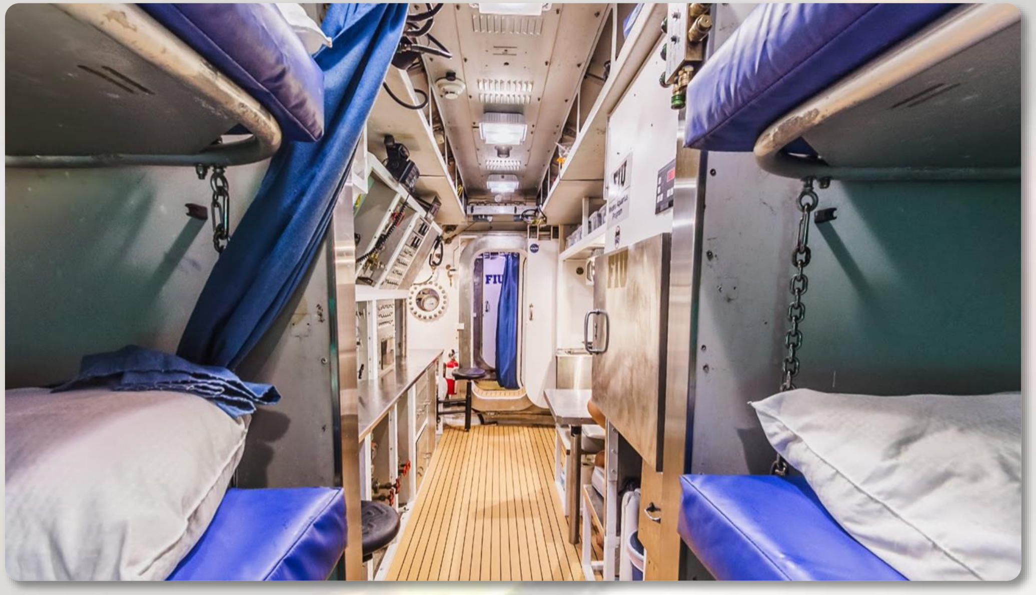

NEEMO

ACTIVE

# HOW: NEEMO Facilities

- Aquarius Reef Base, the world's only undersea research station
- Located 5.4 miles (9 kilometers) off Key Largo in the Florida Keys National Marine Sanctuary
- 62 feet (19 meters) below the surface next to a deep coral reef named Conch Reef
- Operated by Florida International University

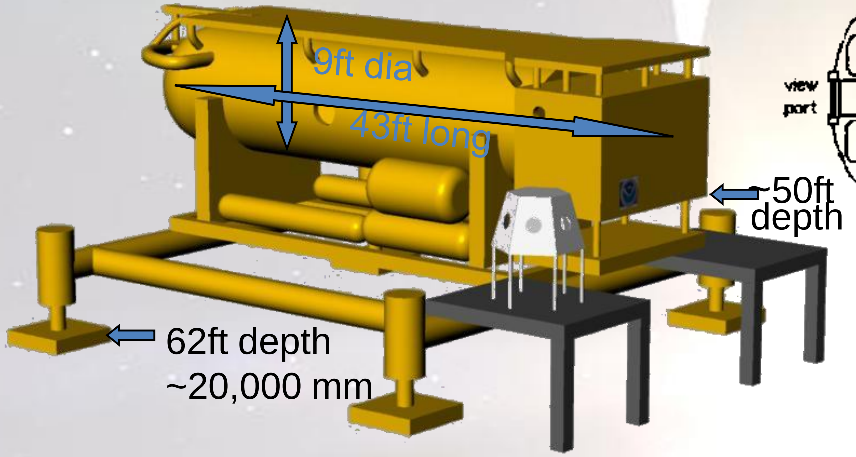


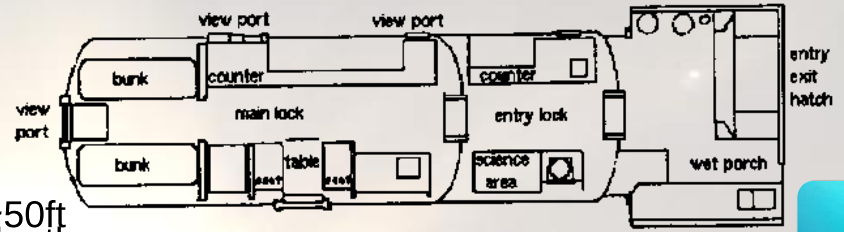


ACTIVE

# HOW: NEEMO “SPACECRAFT” AND “SPACESUIT”

## THE “SPACECRAFT”: AQUARIUS UNDERWATER HABITAT




## THE “SPACESUIT”: KM 37SS HELMET W/ WETSUIT & HARNESS FOR SURFACE SUPPLIED DIVING SYSTEM (SSDS)

KM 37SS

Dive helmet & system provide good analog to a spacesuit for concepts of operations evaluations

Both have different but comparable challenges for operations

37SS: Narrower FOV, Helmet movable
xEMU: Wider FOV, Helmet fixed

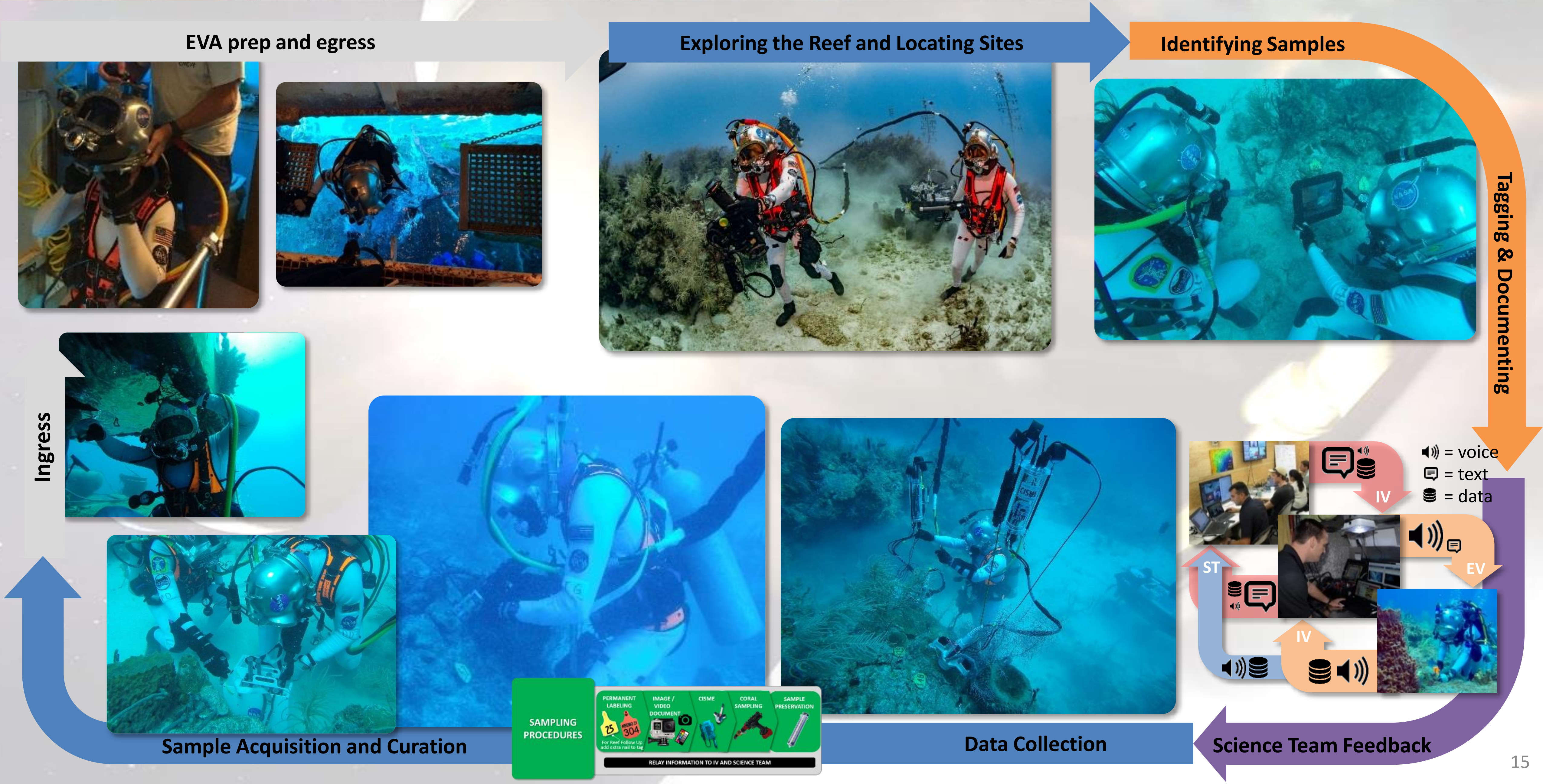
Wetsuit & harness: Flexible, but restrictive
xEMU: Pressurized, bulky

xEMU concept

**TBD mEMU concept**
(courtesy of *The Martian*)

ACTIVE

# HOW: A DAY IN THE LIFE OF NEEMO EVA OPERATIONS



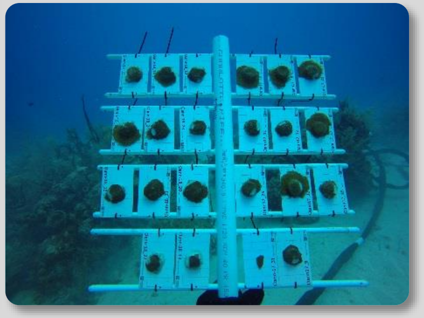
# WHY: Development of EVA Science Operations

## SCIENCE

NEEMO 22 EVA SCIENCE OVERVIEW

### NURSERY CONSTRUCTION & SCIENCE

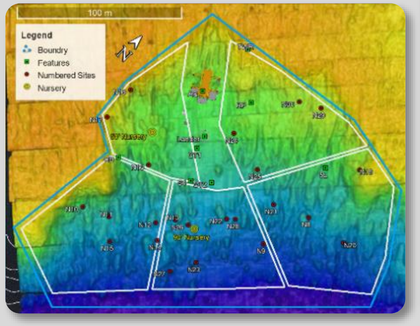
CORAL RESTORATION FOUNDATION™

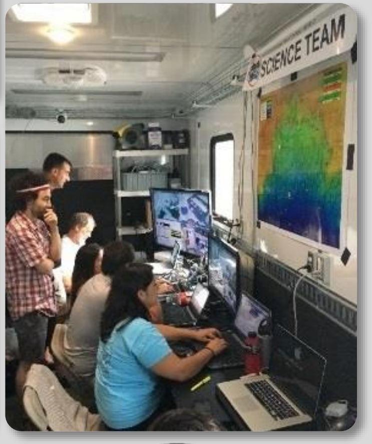


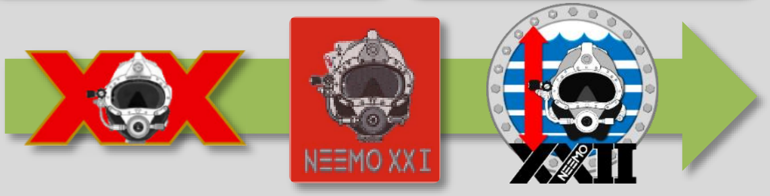
- Modified and conducted continued science investigation on two long-term coral nurseries near ARB
  - 50’ nursery
  - 90’ nursery (deepest in the world)

### REEF FOLLOW-UP SCIENCE

FIU FLORIDA INTERNATIONAL UNIVERSITY




- Continued research and sampling conducted during NEEMO 20 and 21
- Crew successfully navigated to, located, documented and re-sampled colonies
- Science team developed the overall sampling strategy and traverse plans

### REEF EXPLORATION SCIENCE

FIU FLORIDA INTERNATIONAL UNIVERSITY

UNCW

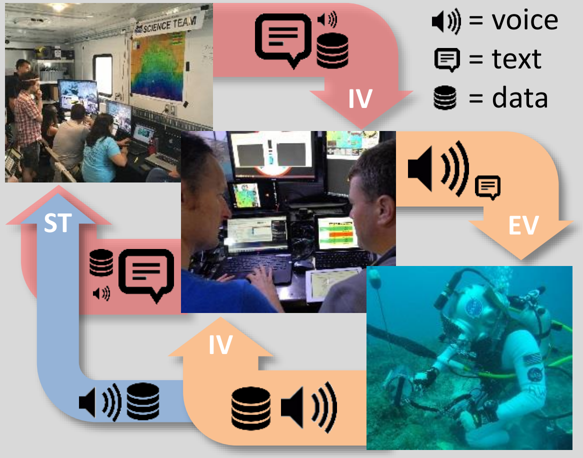
- Explored and expanded into new sites; coral science was correlated to nurseries as a natural baseline
- Described, documented, and sampled additional samples for long term research

# WHY: Development of Exploration EVA Operations Concepts

## OPERATIONS

NEEMO 22 EVA OPS CON OVERVIEW

### INTEGRATED EVA & SCIENCE OPERATIONS

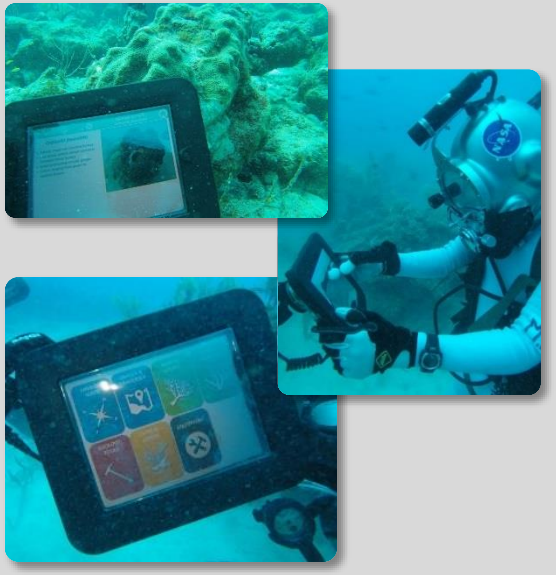



- Evaluated Exploration EVA operations that predominately include science tasks
- Examined con ops that enable interaction between the MCC & the crew over a long comm latency and blockage including:
  - Interaction with an integrated Science Team
  - Authentic scientific objectives and hypothesis
  - Flexecution methodology

### EVA/IV SUPPORT SYSTEM & PLANNING FOR EVA

- Evaluated a Support System that utilizes an open-source digital timeline execution and life support system management tool designed to support Intravehicular Activity during EVA
- Examined ways to minimize number of computers and monitors required for operations, hence reducing space and launch mass needed
- Looked at using a projector for crew planning and briefing

### EVA DIGITAL CUE CARDS



- Evaluated digital cue cards for EVA crew that allowed crew to operate more effectively and offload IV tasks
- Additional crew autonomy requires further access to information in their hands
- Tested concept for a potential “one-device” for cue cards/procedures, images/video, instrument control, etc.

### UTILIZATION OF SCIENTIFIC INSTRUMENTS

- Assessed the effects of incorporating scientific instruments into EVA ops

### NAVIGATION & TRAVERSE PLANNING

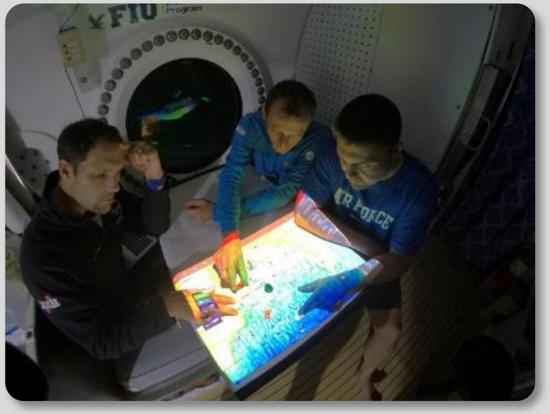

- Evaluated procedures for navigating both to previously-sampled regions and new exploration zones

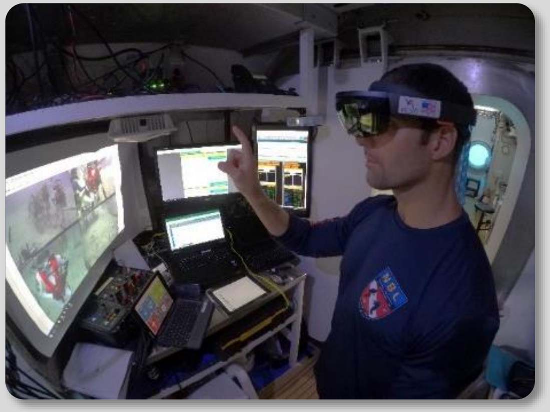
WITH LUNAR AND MARS COMMUNICATION LATENCY & BLOCKAGE CON OPS

EXAMPLE

# WHY: EVA SUPPORT SYSTEM & IV WORKSTATION

- Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the large amount of information and tasking that they must contend with while actively directing an EVA
- Examine potential EVA task/timeline tracking systems (Marvin & Playbook), along with tracking of EV suit data and consumables
- Assess hardware needs for a workstation, including ways to minimize what's required for operations to reduce space and launch mass
- Look at potential ways to incorporate augmented reality into workstation (HoloLens)





***Evolution of EVA Support System for IV Operator***


NEEMO 20


NEEMO 21

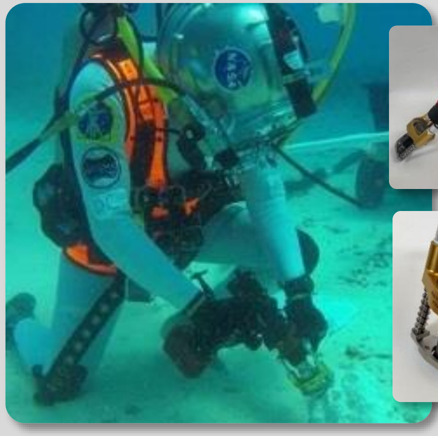

NEEMO 22

# WHY: Development of EVA Systems & Equipment

## ENGINEERING

NEEMO 22 EVA EQUIPMENT OVERVIEW

### CORE SAMPLE AQUISITION



- Evaluated EVA tools and hardware for science core sample acquisition
- Leveraged breakaway core bit technology developed by Honeybee Robotics and implemented on Mars rovers to develop a drill bit for an EVA tool

### EVA EQUIPMENT TRANSPORTATION

- Tested the Modular Equipment Transport System (METS), a concept for manually transporting & stowing larger tools and samples on exploration traverses
- Evaluated potential concepts for transporting small tools on an EVA suite from a rover/caddy to a worksite

### LUNAR EVACUATION SYSTEM ASSEMBLY (LESA)

- Evaluated a new crew rescue concept developed by ESA at the European Astronaut Centre
- This technique is aimed to ease the lifting-up and securing of an incapacitated EVA crewmember on a Moon EVA Litter

### EVA AUGMENTED VISION HEADS-UP DISPLAY

- Based on Navy's Divers Augmented Vision Display, which incorporates real-time data input and allows for augmented reality input in a heads-up display
- EVA Office and astronauts evaluated lab version topside for potential incorporation on future missions and spacesuit design

EXAMPLE

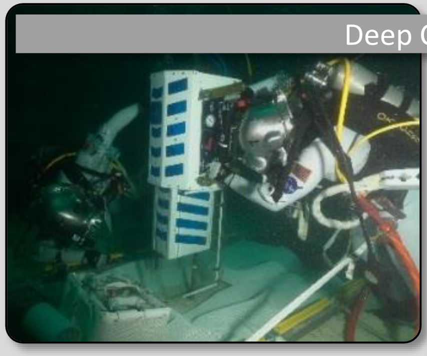
# WHY: CORE SAMPLE ACQUISITION SYSTEM

- Evaluate EVA hardware and operations for subsurface (core) science sampling in a surface/partial-g environment
- Applied a breakaway core bit technology developed by Honeybee Robotics with an underwater battery powered drill to acquire core samples
- Used small tools, such as forceps, to stow samples for curation

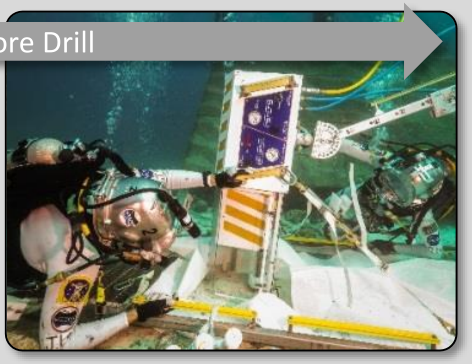

***Core Sample Acquisition Tool Evolution***

Deep Core Drill

**SEATEST 2**



**NEEMO 18**



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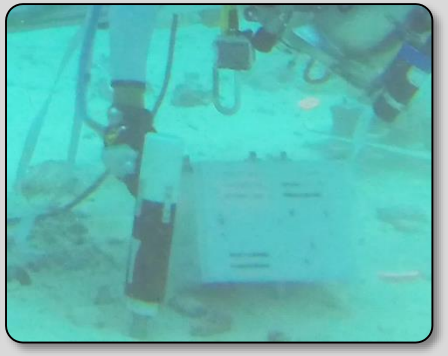


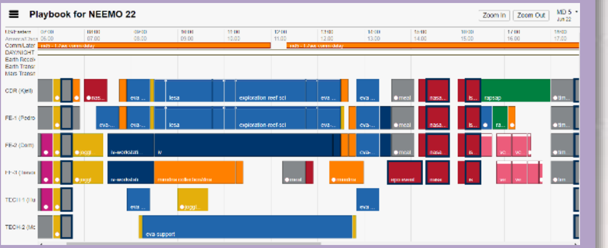
**NEEMO 20**

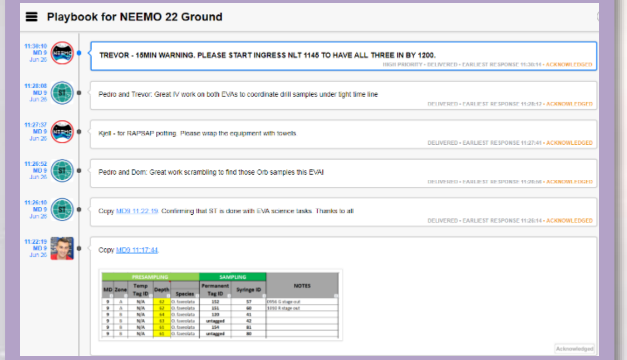
**NEEMO 21**

**NEEMO 22**

# WHY: Evaluation of Experiments for ISS & Exploration

## Playbook – Planning, Procedure Viewing, and Comm Tool




## AR Assisted Procedures

## VETTS

## DNA Sequencer

## IHMC & USF Studies:

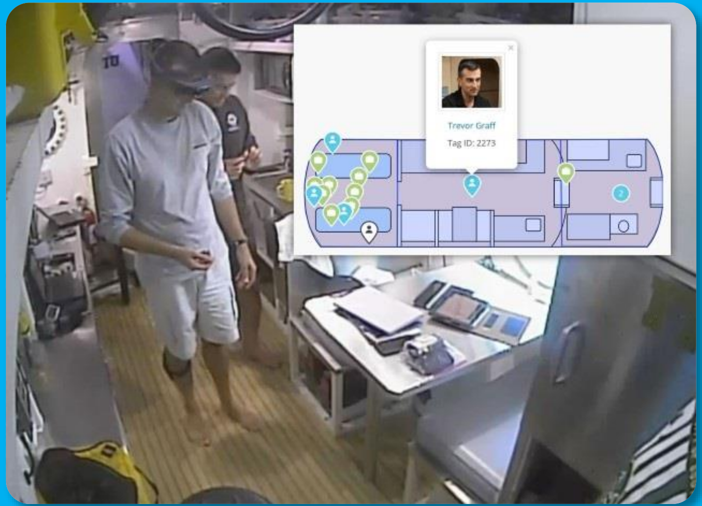
USF UNIVERSITY OF SOUTH FLORIDA

ihmc FLORIDA INSTITUTE FOR HUMAN & MACHINE COGNITION

Sleep
Metabalomics
Body Composition
Psych

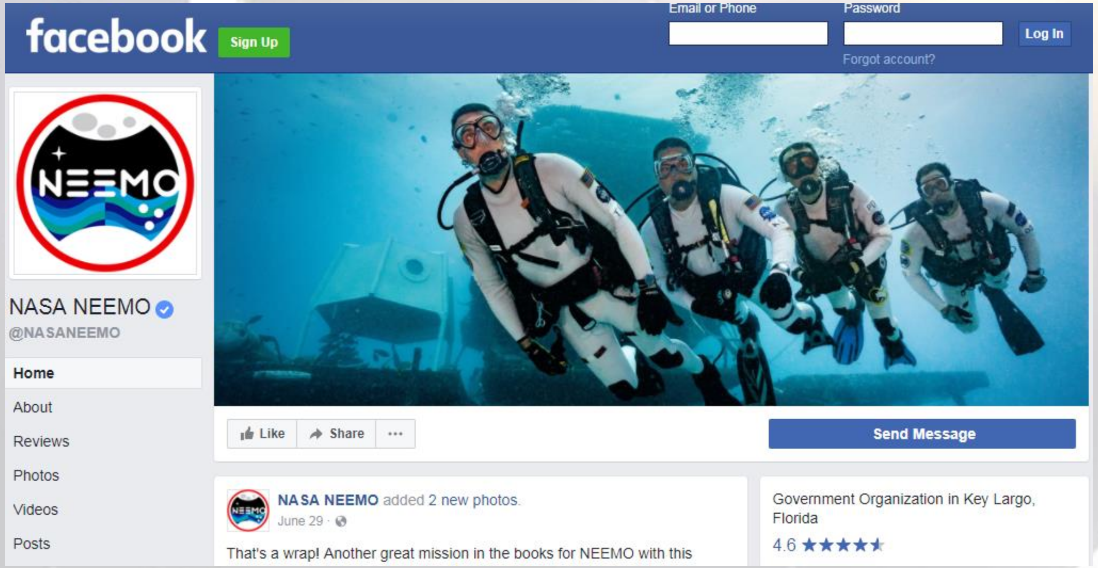
## RAPSAP

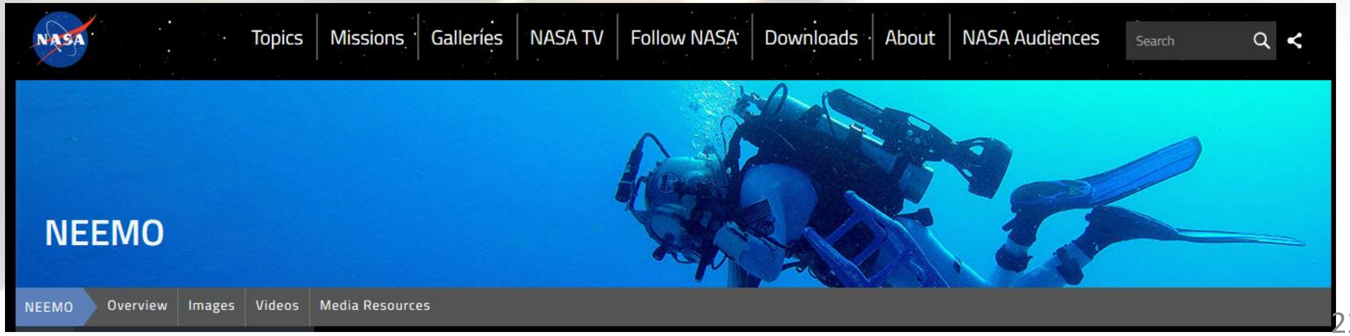
## AllTraq



# WHY: Public Outreach & Education



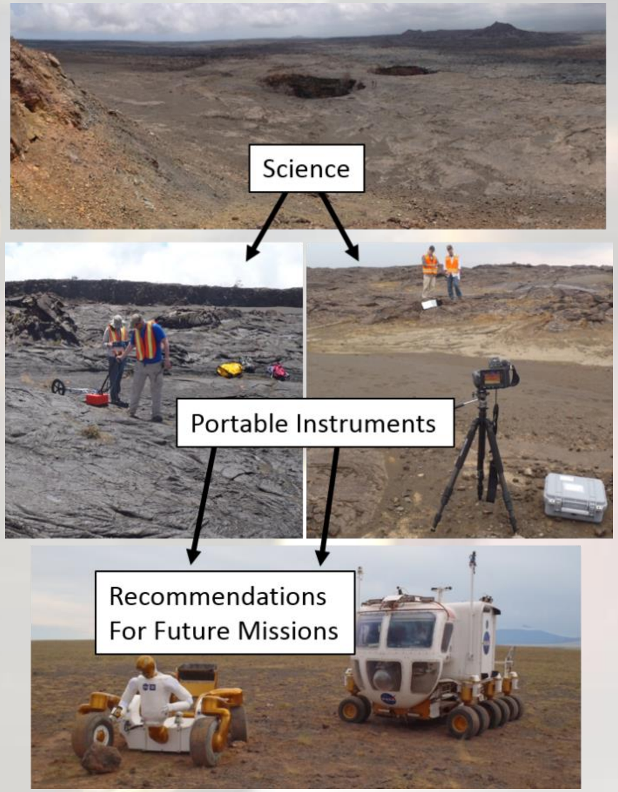



ACTIVE

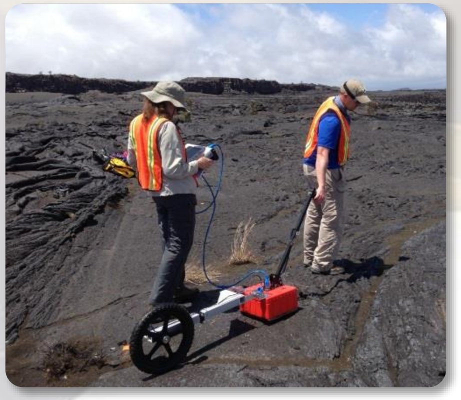
# HOW: SSERVI RIS$^4$E Science Field Campaign

- RIS$^4$E: Remote, In Situ and Synchrotron Studies for Science and Exploration
- Solar System Exploration Research Virtual Institute (SSERVI)-funded project that investigates the effects of incorporating field portable instrumentation into scientific EVA timelines
- Objectives:
  - Fundamental science questions serve as basis for understanding how to operate on planetary surfaces
  - Evaluate role of portable instruments for *in situ* analysis
  - Recommendations to HEOMD for science instrument operations and technology development
- Led by Stony Brook University with participation from across academia and multiple NASA centers
- Field locations
  - December 1974 flow, Kilauea Volcano, HI
  - Potrillo Volcanic Field, NM





**Multispectral Imaging & LiDAR for broad FOV**



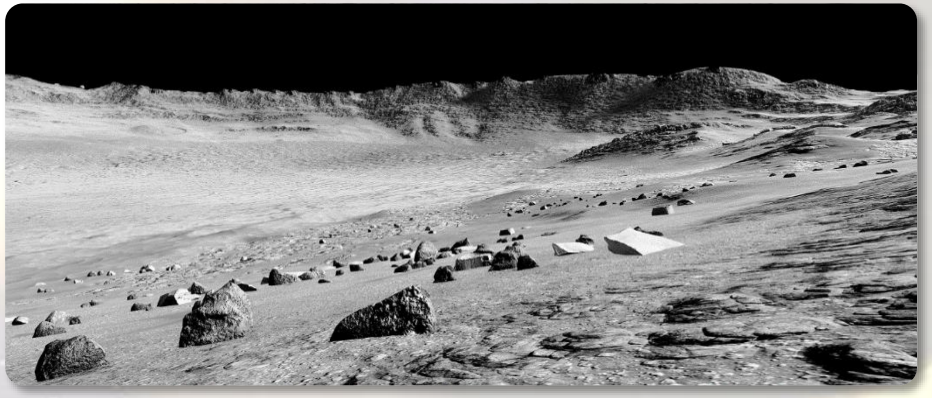
**GPR for subsurface structure**


**hXRF & XRD for in situ chemistry and mineralogy**

ACTIVE

# HOW: Scientific Hybrid Reality Environment (SHyRE)

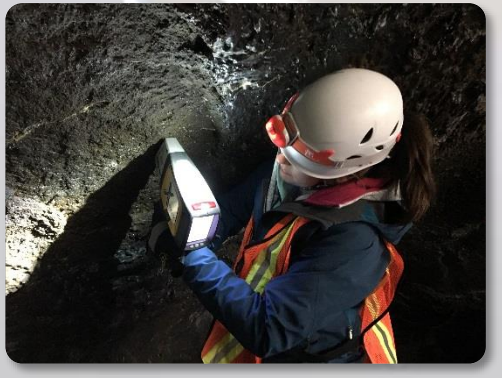
- Developing a high scientific fidelity hybrid reality (HR) model of real-world geological sites of interest, including embedded data and applicable tool usage
- Creates a testing environment onsite at JSC that will be a go-to Exploration facility
- Builds off of several years of RIS$^4$E *in situ* data collection
- Will be utilized for:
  - Ops con development for science-driven EVAs
  - Instrument deployment procedures
  - EVA Support System and IV Workstation capabilities for science
  - Crew training platform
- 3 years of Science Mission Directorate (SMD) Planetary Science and Technology from Analog Research (PSTAR) funding



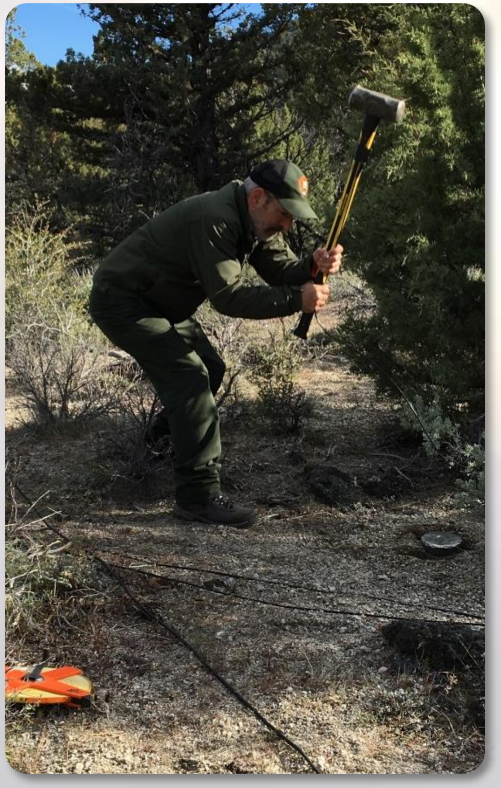
ACTIVE

# HOW: TubeX PSTAR Science Field Campaign

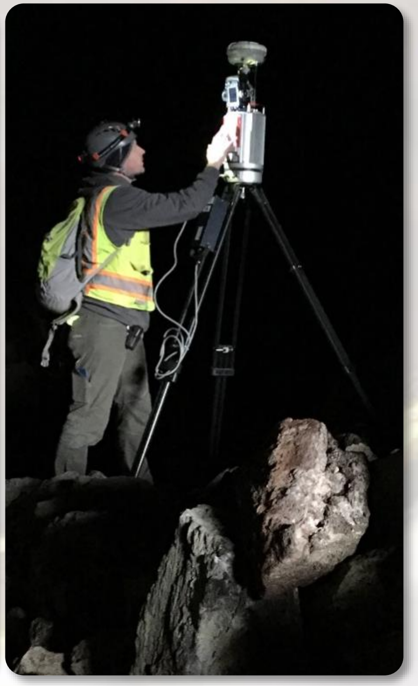
- Lava tubes are compelling exploration targets as they provide radiation shielding for astronauts and support systems
- TubeX develops exploration strategy for how to select and establish a tube for habitation
- Combines GPR, LiDAR, magnetometry, and hXRF, as potential EVA instruments, to explore varying lava tube exploration strategies
- Field location: Lava Beds National Monument, CA
- Participants: JSC, Goddard Space Flight Center, University of South Florida, University of Maryland



Handheld geochemical analyses for composition



Seismology for subsurface structure



LiDAR for precise tube geometry

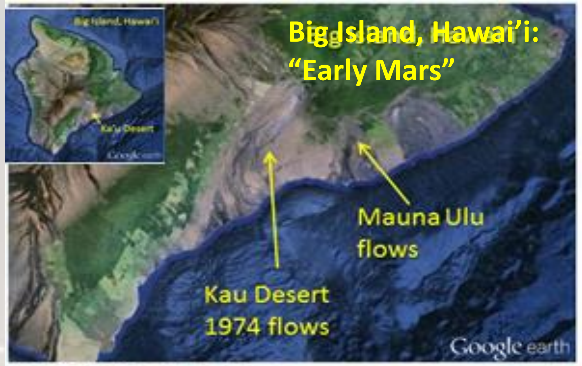
Ground Penetrating Radar for subsurface structure

Magnetometry for subsurface structure

ACTIVE

# HOW: Biologic Analog Science Associated with Lava Terrains (BASALT)

- Objectives: Investigate terrestrial volcanic terrains and their habitability as analog environments for early and present-day Mars
- Science: Seek, identify, and characterize life and life-related chemistry in basaltic environments representing these two epochs of Martian history.
- Science Operations: Conduct the science within simulated Mars exploration conditions based on current architectural assumptions. Identify which human-robotic ConOps and supporting capabilities enable scientific return and discovery.
- Technology: Incorporate and evaluate technologies directly relevant to conducting the science, including mobile science platforms, extravehicular informatics, display technologies, communication and navigation packages, remote sensing, advanced science mission planning tools, and scientifically-relevant instrument package
- Funded by NASA SMD ROSES-2014 Program Element C.14 (PSTAR)
- Field locations
  - Craters of the Moon, Idaho
  - Hawai'i





# HOW: Desert Research and Technology Studies (D-RATS)

- Desert RATS missions were a planetary analog
  - Took place at the Black Point Lava Flow near Flagstaff, AZ
  - Provided environment analogous to Moon and/or Mars, with crew conducting geoscience operations
  - Allowed immersion of whole team, both flight crew and flight controllers
  - Geoscience data still utilized for research
- Final Desert RATS mission took place in 2011

# HOW: Research and Technology Studies (RATS) 2012

- Research & Technology Studies
  - Mission tested techniques, tools, planning, and communication protocols
  - Matured operational concepts and technologies through integrated demonstrations
  - Exercised overall ‘MCC style’ coordination between hardware, procedures, crew operations, mission control operations, science team operations, and engineering team
- RATS 2012 was an asteroid analog mission
  - Took place at NASA JSC
  - EVAs conducted in VR Lab and on ARGOS
  - Vehicle/asteroid sim was tied to VR lab/EVA sim to allow vehicle and EV interaction
  - Reliable and cost-efficient test, with validation of potential NASA next-generation human exploration mission concepts
- Mission took place in 2012

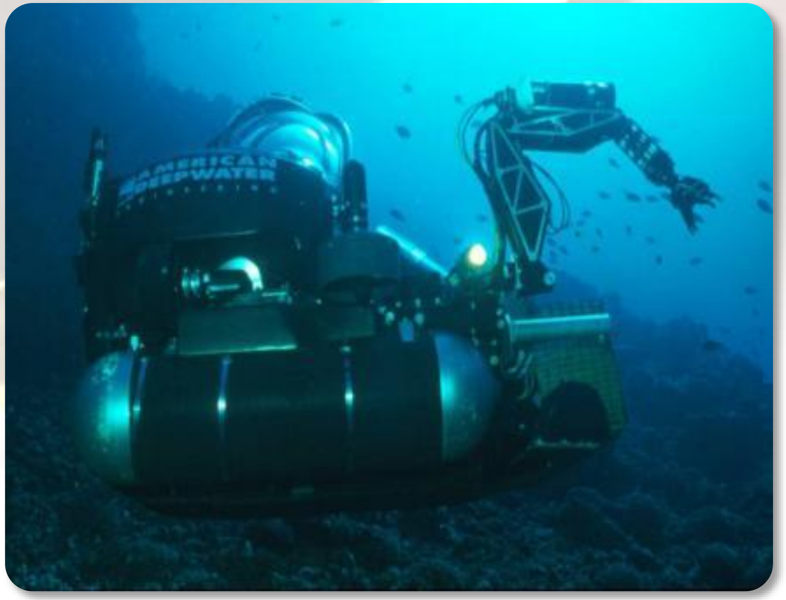





PAST

# HOW: Pavilion Lake Research Project (PLRP)

- Summary:
  - An international, multi-disciplinary, science and exploration effort to explain the origin of freshwater microbialites in Pavilion Lake, British Columbia, Canada
- Objectives
  - Used DeepWorker submersibles as analogs to the MMSEV
  - Evaluated comm delays and the effects on doing effective science
  - Evaluated pilot workload and effects on doing effective science
- Final mission took place in 2015

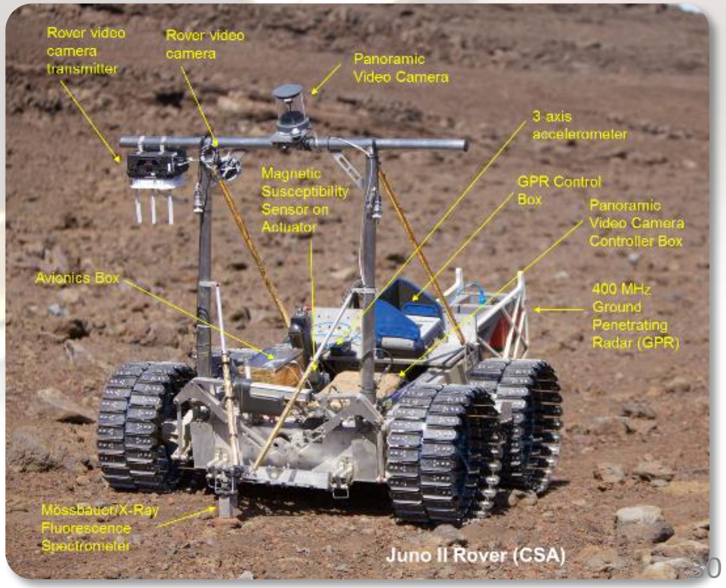


# HOW: In-Situ Resource Utilization (ISRU)

- Summary
  - Planetary analog mission
  - Hardware tested under stressful environmental conditions
- Objectives
  - Expand scope of international involvement and mission criticality for hardware and remote test operations
  - Expand integration of science and technology
  - Streamline path to flight
- Hawai'i deployment in July 2012

**Analog Site for 3rd International Hawaii Field Testing: "Apollo Valley" in Mauna Kea Hawaii**

**Pu'u haiwahini in Hawaii**




Juno II Rover (CSA)

# Collaborating with NASA Operational Field Tests

- NASA is always looking for collaboration with external groups to help facilitate development of the next generation spaceflight systems for EVA
  - https://www.nasa.gov/suitup
  - Primary EVA POCs: Brian Johnson (EVA/NASA JSC) and Jesse Buffington (EVA/NASA JSC)
- Current NASA operational testing programs
  - EVA will continue to evaluate concepts for closing knowledge gaps
  - Link to list of existing NASA analog projects: https://www.nasa.gov/analogs
  - Testing will be integrated by the **READy team**
    - Marc Reagan (NASA JSC)
    - David Coan (EVA/Aerospace/NASA JSC)
    - Trevor Graff & Kelsey Young (ARES/Jacobs/NASA JSC)
    - Bill Todd (USRA/NASA JSC)
- Solar System Exploration Research Virtual Institute (SSERVI)
  - Addresses basic and applied scientific questions fundamental to understanding the Moon, Near Earth Asteroids, the Martian moons Phobos and Deimos, and the near space environments of these target bodies
  - Funds investigators at a broad range of domestic institutions, bringing them together along with international partners via virtual technology to enable new scientific efforts
  - http://sservi.nasa.gov/
  - Continuing EVA relevant testing through RIS$^4$E
- Planetary Science and Technology Through Analog Research (PSTAR)
  - Exploring objectives to further development in science, technology, and operations
  - https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={B0EE1F61-F9A7-AB2B-1695-ACD354C484E0}&path=open
- Human Exploration Research Opportunities (HERO)
  - Examining objectives related to human factors and physiology
  - https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={9927D6DC-C2F9-5D3E-8BF1-EA4EE3EE0A37}&path=open

- NEEMO POC
  - Project Manager & Mission Management: Bill Todd (USRA/NASA JSC)
  - Mission Director & Mission Management: Marc Reagan (NASA JSC)
  - EVA Lead & Mission Management: David Coan (EVA/Aerospace/NASA JSC)
  - Science Lead & Mission Management: Trevor Graff (ARES/Jacobs/NASA JSC)
  - https://www.nasa.gov/mission_pages/NEEMO/index.html
- RIS$^4$E POC
  - Timothy Glotch (Stony Brook University)
  - Jacob Bleacher (NASA GSFC)
  - Kelsey Young (ARES/UTEP/NASA JSC)
  - ris4e.labs.stonybrook.edu/
- RATS POC
  - Mission Manager: Barbara Janoiko (NASA JSC)
  - Exploration EVA Testing: David Coan (EVA/SGT/NASA JSC)
  - Science Operations: Trevor Graff (ARES/Jacobs/NASA JSC) & Kelsey Young (ARES/UTEP/NASA JSC)
  - https://www.nasa.gov/exploration/analogs/desertrats/
- Desert RATS POC
  - Mission Manager: Barbara Janoiko (NASA JSC)
  - Exploration EVA Testing: David Coan (EVA/SGT/NASA JSC)
  - Science Operations: Trevor Graff (ARES/Jacobs/NASA JSC) & Kelsey Young (ARES/UTEP/NASA JSC)
  - https://www.nasa.gov/exploration/analogs/desertrats
  - https://www.nasa.gov/analogs/desert-rats
- ISRU POC
  - www.nasa.gov/exploration/analogs/isru/
- BASALT POC
  - PI: Darlene Lim (NASA ARC)
  - Deputy PI: Andrew Abercromby (NASA JSC)
  - Leads: Steve Chappell (Wyle/NASA JSC) & Kara Beaton (Wyle/NASA JSC)
- PLRP POC
  - PI: Darlene Lim (NASA ARC)

# BACK UP

# HOW: Heritage & Background

*Leveraging experience and lessons learned from …*

## Apollo Surface Operations
- Exploration traverses were planned in advance using imagery gathered from precursor satellites
- Crews had significant training in geology and science tasks
- An Earth-based science team (ST) supported EVAs (Precursor plans, Feedback during EVA, and changes between EVAs)

## Mars Robotic Missions
- Remote science operations
- Instrumentation / sample selection

MER A - Spirit
MER B - Opportunity
MSL - Curiosity

1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

## NASA Extreme Environment Mission Operations
- Utilizes unique facility & environment; rapid prototyping; Evaluations of both IVA and EVA objectives

Science

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

## Research and Technology Studies
- Utilizes terrain appropriate for geo-science tasks; Suit and robotic tested-bed

Science

1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

## Other NASA Analog Programs
- Each exploring various aspects of exploration
- Funded though grant programs
- Science focused

# NASA & EVA Goals for Integrated Operational Testing

**An analog mission is an integrated multi-disciplinary operational field development test that allows for early end-to-end testing of concepts of operations and equipment in a true operational scenario**

- Provides a means of advancing Human Spaceflight and future EVA Systems by evaluating Exploration EVA concepts of operations and hardware/tool prototypes
- Enables authentic science objectives by directly conducting geoscience operations or utilizing proxy science to test relevant operations concepts, with both an Earth-based Science Team and in-situ EVA crew
- Allows for end-to-end testing of operations concepts, techniques, and hardware in an operational scenario
    - Concepts of operations can be accurately tested to determine their viability and changes
    - Has the crew in-situ and a ground control team separated from them in a mission-like manner
    - Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
    - Drives out results not found in standalone testing, including things that do and do not work in a mission environment
- Evaluates objectives mapped to specific <u>needs</u> and <u>capability/knowledge/technology gaps</u>
    - Informs updates to the **NASA Exploration EVA Concepts of Operations** document by having crewmembers test relevant concepts in mission environments
    - Facilitates **EVA gap closures** by tying all EVA-relevant objectives to specific gaps and testing potential concepts
    - Addresses **Science gaps** by assessing tools and techniques for science sample collection
    - Provides data for hardware design maturation to assist in road-to-flight, especially the **EVA geo-science sample collection tools**
    - Assesses concepts of operations associated with science EVAs that require input from an MCC Science Team over a comm latency
- Realizes the needs of EVA equipment and enables the development of designs by evaluating purpose-built prototype hardware in a field test to provide data for design maturation on the road-to-flight
- Ties in the right expertise to evaluate concepts being worked on across the agency
- Benefits programs from ISS to Exploration
- Enhances relationships with international partners, academia, and other NASA orgs

# HOW: Future for Integrated Operational Testing

- Currently looking at next round of integrated testing
- Continued focus on objectives that facilitate closure of SMT gaps and updates to the Exploration EVA Concepts of Operations document
- Will further evaluation of different types of EVA tasks – Science operations and Pioneering
- Examining other potential testing opportunities

## NEEMO

- Plan and execute NEEMO 23
    - Focus on EVA concepts of operations that involve science tasks
    - Evolve concepts for EVA tools and techniques
    - Mature near term (ISS) flight hardware and ops concepts

## SHyRE

- Collect field data for incorporation into the HR sim
- Develop EVA procedures for use of science instruments and EVA Support System
- Begin testing
- Evolve system to incorporate ARGOS

## SCIENCE FIELD CAMPAIGNS

- Upcoming deployments in 2017 and 2018
- EVA will be looking at possible collaboration

## POTENTIAL ANALOGS

?

Continued integration across all operational tests and field campaigns

# WHY: Training for Crew and New Flight Control Methods

## Astronaut-Aquanauts

Numbers after names refer to NEEMO mission

1. Carpenter (SEALAB II, 8/29/65)
2. Gernhardt (NEEMO 1&8, 10/22/01)
3. Lopez-Alegria (NEEMO 1)
4. D. Williams (NEEMO 1&9, 10/22/01)
5. Tani (NEEMO 2, 5/14/02)
6. J. Williams (NEEMO 3, 7/16/02)
7. S. Kelly (NEEMO 4&8, 9/24/02)
8. Walheim (NEEMO 4, 9/24/02)
9. Whitson (NEEMO 5, 6/17/03)
10. Fincke (NEEMO 2, 4/18/04)
11. Herrington (NEEMO 6, 7/13/04)
12. Thirsk (NEEMO 7, 10/12/04)
13. Coleman (NEEMO 7, 10/12/04)
14. Wakata (NEEMO 10, 7/23/06)
15. Magnus (NEEMO 11, 9/17/06)
16. Patrick (NEEMO 6&13, 12/9/06)
17. S. Williams (NEEMO 2, 12/9/06)
18. Stefanyshin-Piper (NEEMO 12, 5/8/07)
19. Anderson (NEEMO 5, 6/8/07)
20. Olivas (NEEMO 3&8, 6/8/07)
21. Wheelock (NEEMO 6, 10/23/07)
22. Behnken (NEEMO 11, 3/11/08)
23. Reisman (NEEMO 5, 3/11/08)
24. Chamitoff (NEEMO 3, 5/31/08)
25. Garan (NEEMO 9, 5/31/08)
26. Nyberg (NEEMO 10, 5/31/08)
27. Arnold (NEEMO 13, 3/15/09)
28. Barratt (NEEMO 7, 3/26/09)
29. Feustel (NEEMO 10, 5/11/09)
30. Kopra (NEEMO 11, 7/15/09)
31. Hernandez (NEEMO 12, 8/28/09)
32. Stott (NEEMO 9, 8/28/09)
33. Creamer (NEEMO 11, 12/20/09)
34. Hadfield (NEEMO 14, 5/10/10)
35. Marshburn (NEEMO , 5/10/10)
36. Furukawa (NEEMO 13, 6/7/11)
37. Walker (NEEMO 15, 10/21/11)
38. Metcalf-Lindenburger (NEEMO 16, 6/12/12)
39. Acaba (NEEMO 17, 9/10/13)
40. Noguchi (NEEMO 17, 9/10/13)
41. Hoshide (NEEMO 18, 7/22/14)
42. Bresnik (NEEMO 19, 9/8/14)
43. Parmitano (NEEMO 20, 7/21/15)
44. Yui (NEEMO 16, 7/22/15)
45. Mogensen (NEEMO 17&19, 9/2/15)
46. Peake (NEEMO 16, 12/15/15)
47. Onishi (NEEMO 15, 7/7/16)
48. Rubins (NEEMO 17, 7/7/16)
49. M. Behnken (NEEMO 21, 7/22/16)
50. Wiseman (NEEMO 21, 7/22/16)
51. Pesquet (NEEMO 18, 11/17/16)
52. Lindgren (NEEMO 22, 6/19/17)
53. Duque (NEEMO 22, 6/19/17)
54. Vande Hei (NEEMO 18, 9/12/17)

**Scott Carpenter (Sealab II, 1965)**
first Astronaut-Aquanaut

U.S.NAVY SEALAB

# EVA: INTEGRATED EVA OPERATIONS WITH SCIENCE-FOCUSED TASKS

## Objective

- Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a signal (comm & data) latency and blockage
- Determine what functions/capabilities and techniques are needed to enable the EVA crew to effectively operate more autonomously and communicate information to MCC over a signal latency and blockage
- Evaluate flexible execution methodology and decision making protocols for science tasks during EVA operations

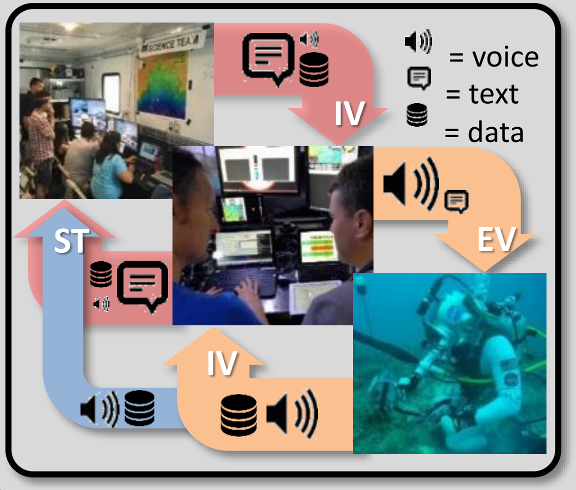
## Implementation

- An onshore MCC Flight Control Team (FCT) that includes a Mission Director, EVA Officer, CAPCOM, and other system/subject matter experts
- An onshore Science Team that includes a Science Lead, subject matter experts, and Science Communicator (SCICOM)
- Mission (flight) rules volume and mission priorities
- Heightened mission tempo and pressure with additional flight control rigor, spacesuit telemetry, FCT GO/NO GO calls, and IVA task/experiment timeline


MCC Flight Control Team

MCC Science Team

## Key Take-Always




- EVA crew demonstrated the capability to operate more autonomously while simultaneously communicating with and incorporating input from an Earth-based MCC and ST
- With science` instruments that take time to acquire data, it is possible to plan the EVA such that the crew can successfully receive input from the ST to execute science sampling operations during an EVA
- An EVA support system for the IV crewmember directly ops will be critical for management of the large volume of data
- Additional complexity of airlock and spacesuit EVA operations will impact the way operations and science tasks will be planned and directed
- Daily Planning Reviews will be critical for relaying pertinent information to the crew before any EVA
- A flight control operations paradigm and decision making protocols will need to be developed in order to integrate science tasks and subject matter experts within the context of an EVA while executing in dynamically changing situations in a natural environment – including how decisions are made between a Mission Director, EVA Officer, and SCICOM/Science Lead

# EVA: EVA SUPPORT SYSTEM & IV WORKSTATION

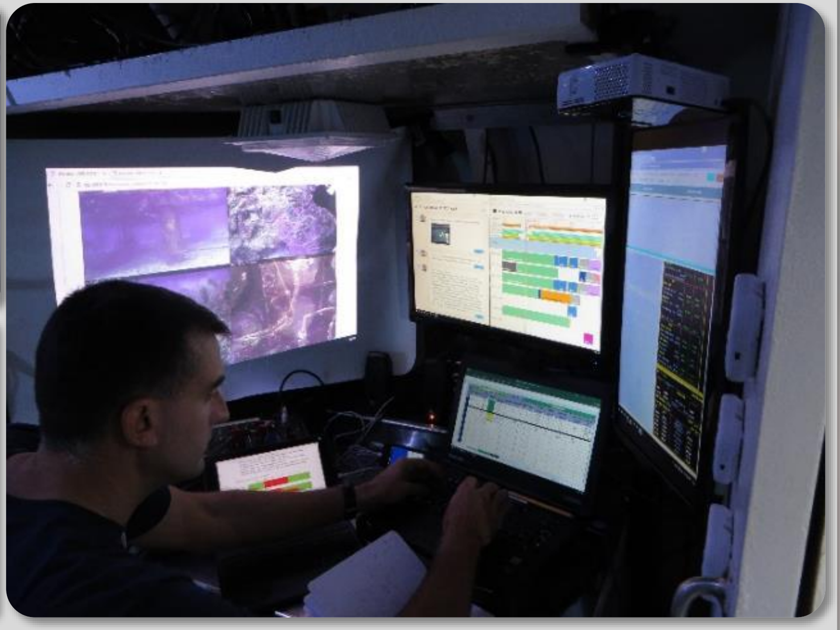
## Objective

- Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the large amount of information and tasking that must contended with while actively directing an EVA
- Examine potential EVA task/timeline tracking systems (Marvin & Playbook), along with tracking of EV suit data and consumables
- Assess hardware needs for a workstation, including ways to minimize what's required for operations to reduce space and launch mass
- Look at potential ways to incorporate augmented reality into workstation (HoloLens)

## Implementation

- Utilized Marvin, an open-source digital timeline execution and life support system management tool that implements extensive details contained within a timeline (activities, tasks, and procedures), along with accommodating suit telemetry data and consumable limitations, and provides synthesized timeline status in the form of timeline margin which adjusts throughout the execution of the EVA
- Utilized Playbook Tactical EVA Execution Feature

Evolution of EVA Support System for IV Operator



## Key Take-Always

- An EVA support system for an IV to direct EVA operations will be key for Exploration missions
- A system that utilizes a single computer with multiple ways to display abundant information would enable to single IV crewmember to direct EV ops while incorporating input from an MCC science team
- Augmented Reality systems (such as HoloLens) may hold some promise as a possibility, though were not useful at this stage
- Key lessons learned were recorded that will be incorporated into the concept that is continuing to evolve into a future capability

# EVA: INTEGRATED INFORMATICS – DIGITAL CUE CARDS & TRAVERSE MAPS

## Objective

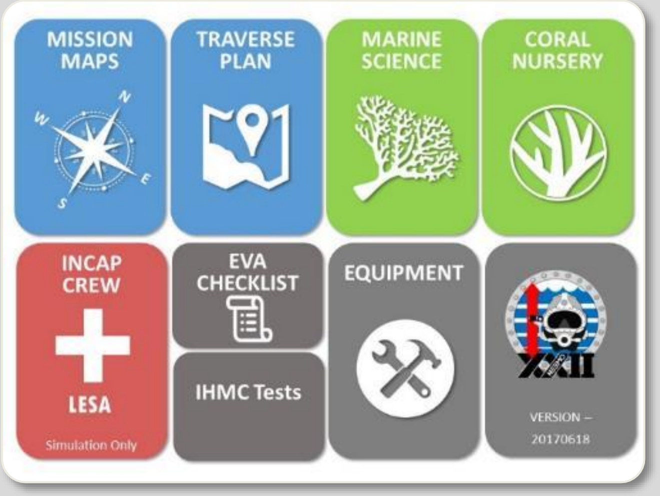
- Evaluate digital cue cards for EVA crew that allowed crew to operate more effectively and autonomously while offloading IV tasking
- Assess tool needs (hardware and software) for short distance navigation data to support EVA geology/science

## Implementation

- Utilized an iPad in an iDive underwater housing to demonstrate the potential for a single device for cue cards/procedures, images/video, instrument control, etc.
- All EVA-accessed and required information was put into a digital cue card set that was loaded on the iPad

## Key Take-Always

- EVA digital cue cards permit increasing crew autonomy by enabling EV crew to efficiently understand exploration areas, conduct general site navigation, identify specimens for measurement and potential sampling, and guide themselves through task procedures
- Information layout will need to be modified for different display methods, such as a heads-up display or electronic cuff
- Information should be limited to only what is pertinent to the current operation
- Ways to navigate through the cue cards will need to be easy and intuitive




# EVA: MODULAR EQUIPMENT TRANSPORT SYSTEM (METS) & SMALL TOOLS ON SUIT

**Objective**

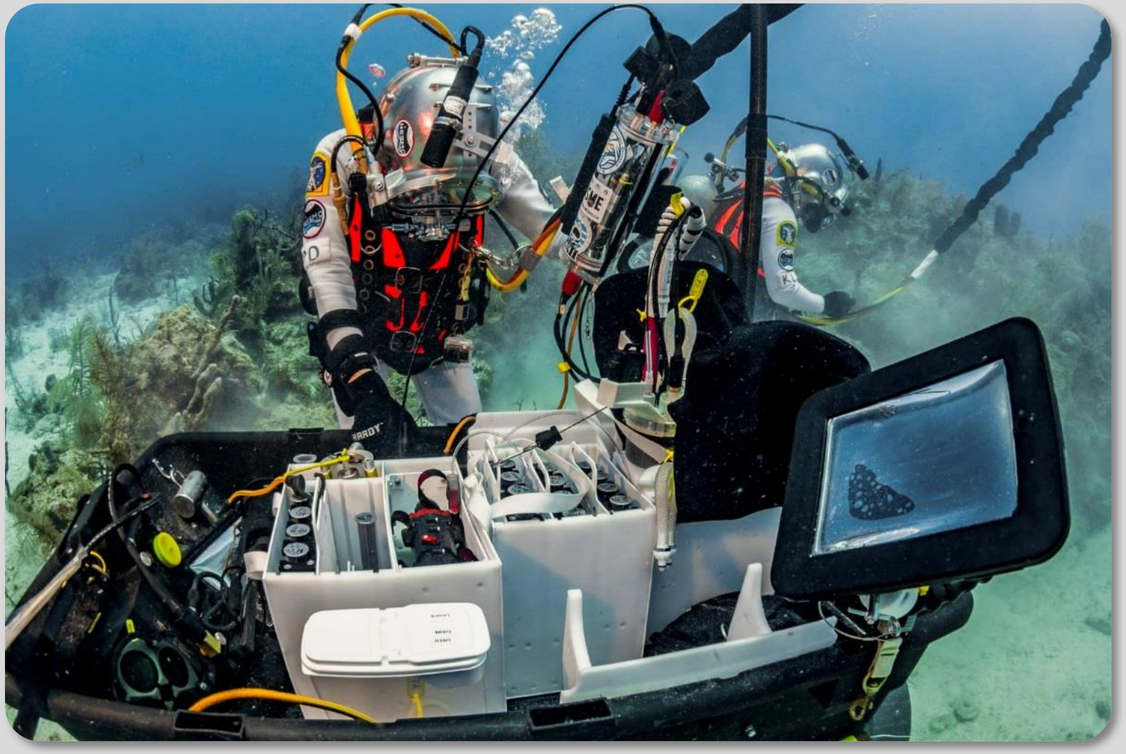
- Evaluate transport of large equipment in a mobile carrier
- Evaluate transport of small tools on an EVA spacesuit

**Implementation**

- The Modular Equipment Transport System (METS) is a method for transporting equipment from one location to another, grouping hardware into Modules for the appropriate planned activities
- For small tools transport on the spacesuit, crew utilized a forearm stowage device and thigh module

**Key Take-Always**

- METS concept of putting tools into modules has the potential to provide efficiencies during EVAs
  - However, it requires close integration for planning to ensure all pieces of equipment are accounted for when populating/arranging the modules
  - Concept could become over-constraining, so it's important to think through potential contingencies and ensure operational flexibility
  - A wheeled carrier works well, however future concepts may consider larger wheels or ways to get over/around obstacles
  - Efficiencies for working with a METS at a worksite were recorded
- Small, lightweight, generic tools could be carried on the forearm, torso, and other locations to provide easy access and should be considered for surface operations
  - Small tools carried on the suit forearm work well
  - Methods of carrying tools on the thigh (or other areas not easily visible) still need careful consideration – ways to move those modules into view helped



# EVA: INCAPACITATED EVA CREW RESCUE – LUNAR EVACUATION SYSTEM ASSEMBLY (LESA)

## Objective

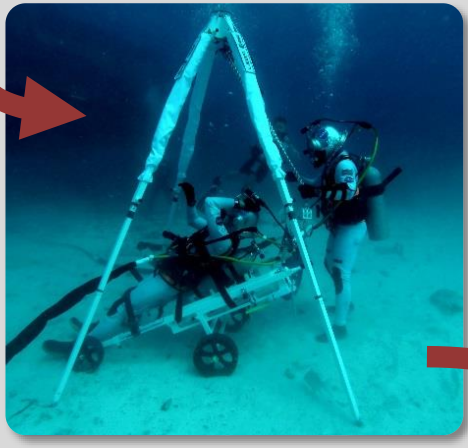
- Evaluated a new EVA incapacitated crewmember rescue concept developed by ESA at the European Astronaut Centre

## Implementation

- Utilized the new concept Lunar Evacuation Systems Assembly (LESA)
- LESA allows an incapacitated crewmember to be lifted up and secured to a Moon EVA Litter for transport back to a habitat/rover

## Key Take-Always

- Concept of hoisting an incapacitated EVA crewmember onto a litter for transport back to a habitat holds promise
- Need to look into making LESA a smaller and more portable package



# Example of Progression Across Missions

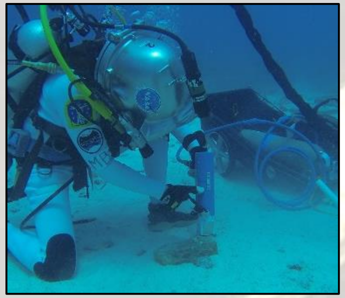
- Objective:
  - Evaluate EVA hardware and operations for science sampling (EVA Integrated Geology Sampling System)
- Gaps addressed
  - EVA SMT: Tools for Science Sampling on a Surface EVA
  - EVA SMT: Micro-g tool for chip samples
  - CAPTEM: Collection of 1000 g from two sites
- Summary Take-Away for EVA
  - Concept proved feasible for EVA collection of geology and astrobiology samples
  - Provides a viable method for minimizing sample contamination
  - Tool improvements will be incorporated into designs for the next generation of hardware on the road-to-flight


Pneumatic chip hammer - NEEMO 17 (SEATEST 2)


Pneumatic chip hammer - NBL/MACES


Pneumatic chip hammer - NEEMO 18/19


Pneumatic chip hammer - NEEMO 20


Pneumatic chip hammer - NEEMO 21





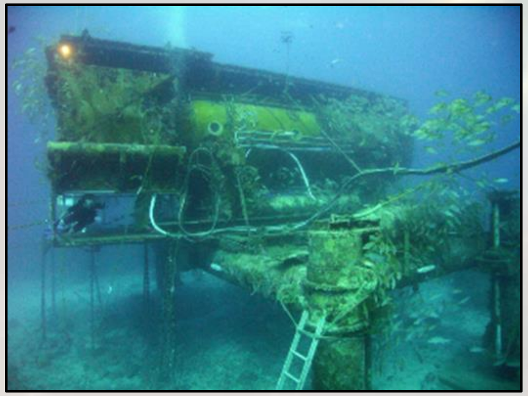
Powered rock chip hammer/core drill concepts (ARM DRM animation)

ACTIVE

# HOW: NEEMO

NEEMO is a project that utilizes Aquarius, the only operational undersea research facility in the world, as a setting for accomplishing a host of NASA and synergistic partner objectives

- Funded by partners and collaborators from across NASA centers, DoD, universities, and industry
- 1-2 missions/year, 10 – 20 days in length
- Shore side Mission Control, staffed by experienced operators
- Crew largely consists of astronauts from CB and IPs, along with PIs and engineers
- Missions have high operational rigor by design (timelines, procedures, etc.)
- Enables evaluation of both IVA and EVA objectives
- Allows for evaluations of end-to-end concepts of operations with crew that are in-situ in a true extreme environment
- Provides for flight-like interactions between the crew and an MCC Science Team, including over comm latencies
- Enables a testing ground for hardware and tool concepts on the start of the road to flight
- Analog Testing Details:
  - Previous mission: July 21- Aug 5, 2016
  - Next mission: TBD (July 2017)
- Points of Contact:
  - Project Manager & Mission Management: Bill Todd (USRA/NASA JSC)
  - Mission Director & Mission Management: Marc Reagan (NASA JSC)
  - EVA Lead & Mission Management: David Coan (EVA/SGT/NASA JSC)
  - Science Lead & Mission Management: Trevor Graff (ARES/Jacobs/NASA JSC)
  - [https://www.nasa.gov/mission_pages/NEEMO/index.html](https://www.nasa.gov/mission_pages/NEEMO/index.html)



# NEEMO 21 EVA Gap Closure Updates and Recommendations

| EVA SMT GAP | GAP CLOSURE UPDATES | RECOMMENDATIONS |
|---|---|---|
| Integrated EVA Flight Control | Formalize gap and update closure with demonstrated capabilities and methods for enabling a Science Team to provide input to EVA operations | Evolve the systems needed for directing operations and evaluate at a future NEEMO/operational field test |
| Flexible Execution Methodology for EVA Science Operations in Undefined Environments | Formalize gap and update closure with need for data systems and flight rules to govern decision making process during flexible science operations | Evaluate a mission utilizing a true flexecution methodology over multiple days/EVAs with more complicated science operations at a future NEEMO mission |
| Tools for Interacting with EVA Over a Comm Latency | Update gap closure with results for the MCC/ST systems, IV support system, and EVA digital cue cards | Evolve the systems (MCC console, IV support, EVA digital cue cards) needed and evaluate at a NEEMO mission/operational field test utilizing true flexecution over multiple days/EVAs |
| IV Support System for EVA Operations | Formalize gap and update closure with results of computer assets and applications needed | Iterate the workstation configuration and applications to enable more efficient science operations, and evaluate at a future NEEMO mission |

# NEEMO 21 EVA Gap Closure Updates and Recommendations

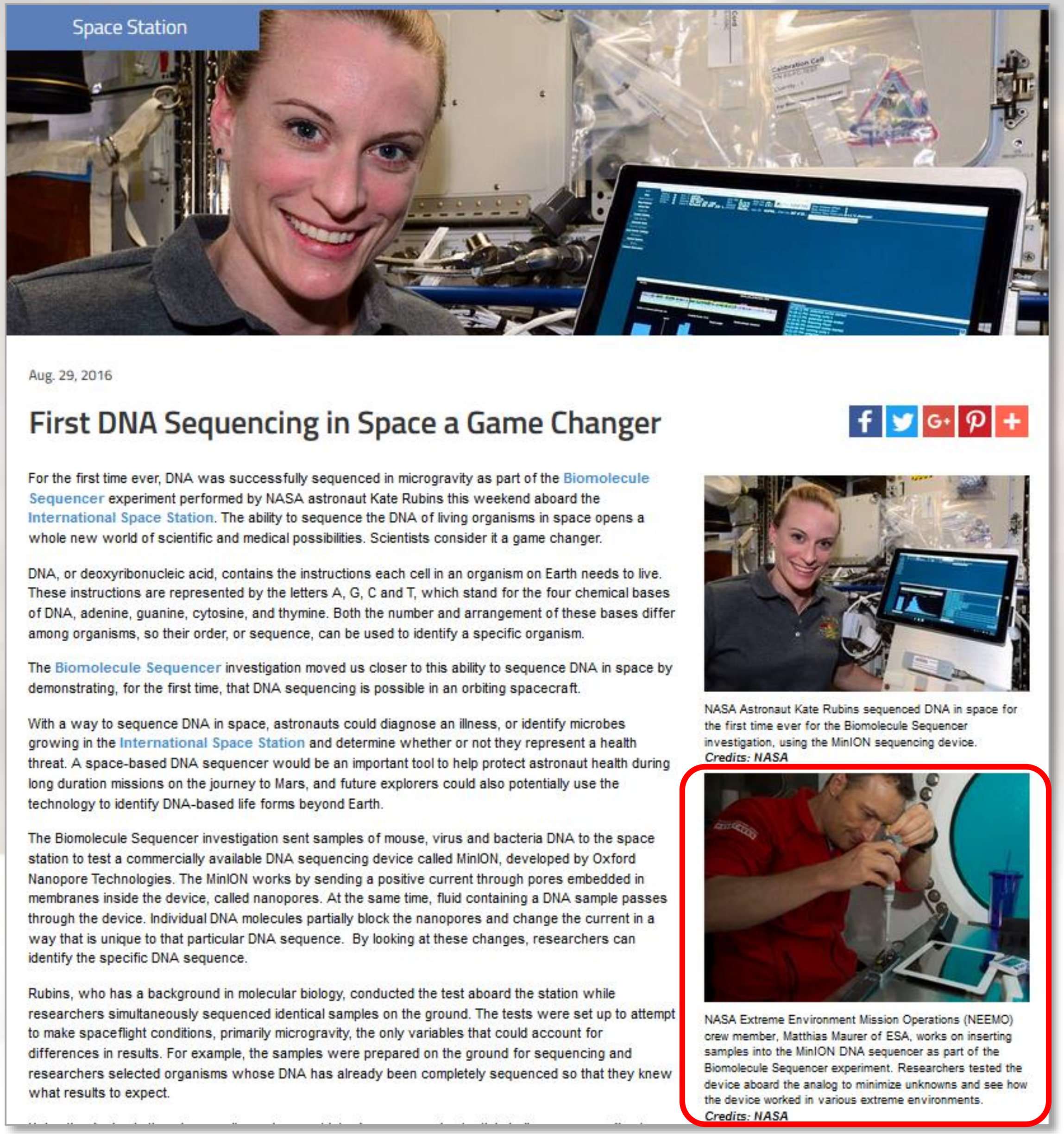
| EVA SMT GAP | GAP CLOSURE UPDATES | RECOMMENDATIONS |
| --- | --- | --- |
| Display (EVA Integrated Camera) | Update gap closure with results and need for a way to stream high-resolution photos along with video | Test a camera system that is capable of streaming high-res imagery at an operational field test |
| Navigation (EVA Short Distance Navigation) | Update gap closure with results and need for EVA digital maps, a relative nav system for EV crew, and a way for IV and ST to track and guide EV crew | Assess a method for EVA and IV crew to track EV relative location, and use that data to locate sampling regions and previously marked specimens at a future NEEMO |
| Tools for Science Sampling on a Surface EVA | Update gap closure with the surface version of the Integrated Geology Sampling System, “stamper” mechanism, IRIS tool, and lessons from marine science tools | Evaluate tools while wearing pressurized EVA suits, possibly on ARGOS<br>Iterate tools and evaluate at a future NEEMO/operational field test |
| Tool Caddy Device on a Surface EVA | Update gap closure with lessons learned for a tool caddy to carry larger items and sling bag/harness for smaller tools | Test a purpose-built tool caddy at NEEMO<br>Develop a vest/bag/harness system to carry smaller tools and evaluate at NEEMO |
| EVA-Robotic (Man-Machine) Work System | Gap closure unchanged | Assess a robotic system to give better SA of EV crew and also provide high-res imagery for the ST at a NEEMO mission |


## Miniaturized Exercise Device MED 2.0

- **Potential Safety issues raised by the crew caused changes to upcoming ISS eval:**
  - New Caution Block added to flight procedures
  - Ground training modified
  - Shoulder presses will be eliminated from in-flight eval
- **Other ISS ops changes that will result from this eval:**
  - "How to" videos will be easy to find and can be updated without changing flight software
  - Identified shortcoming of the MED 2 heart rate monitor Bluetooth pairing with the Microsoft Surface Pro 3 => all MCC operators will be familiar with troubleshooting steps required, and step-by-step procedures will be available for the crew
  - Accomplished extensive procedure verification which closed numerous holes in the procedures
  - Additional training/simulation opportunity for MED 2 ISS ops and engineering support teams
  - Add flexibility to change ops parameters remotely

# Intra-Vehicular Activities: Miniaturized DNA Sequencer

- **Validated a usable swab-to-sequencer protocol (procedure) in which environmental samples are collected**
  - Currently applying numerous suggestions from crew feedback to streamline procedure execution on ISS
    - Developing "just in time" training videos
    - Improving packaging
    - Targeted improvements to crew training
    - Assessing alternate enzymes that are all stable at a common temperature
    - Simplifying labeling and increased use of color coding
- **Demonstrated that a crew member, regardless of background, can collect an environmental sample, extract DNA from that sample, amplify the DNA, prepare the amplified DNA to be sequenced, and, finally, sequence DNA in an extreme environment.**
  - Normally requires trained molecular biologists with a complete suite of sophisticated equipment

Space Station

Aug. 29, 2016

## First DNA Sequencing in Space a Game Changer

For the first time ever, DNA was successfully sequenced in microgravity as part of the Biomolecule Sequencer experiment performed by NASA astronaut Kate Rubins this weekend aboard the International Space Station. The ability to sequence the DNA of living organisms in space opens a whole new world of scientific and medical possibilities. Scientists consider it a game changer.

DNA, or deoxyribonucleic acid, contains the instructions each cell in an organism on Earth needs to live. These instructions are represented by the letters A, G, C and T, which stand for the four chemical bases of DNA, adenine, guanine, cytosine, and thymine. Both the number and arrangement of these bases differ among organisms, so their order, or sequence, can be used to identify a specific organism.

The Biomolecule Sequencer investigation moved us closer to this ability to sequence DNA in space by demonstrating, for the first time, that DNA sequencing is possible in an orbiting spacecraft.

With a way to sequence DNA in space, astronauts could diagnose an illness, or identify microbes growing in the International Space Station and determine whether or not they represent a health threat. A space-based DNA sequencer would be an important tool to help protect astronaut health during long duration missions on the journey to Mars, and future explorers could also potentially use the technology to identify DNA-based life forms beyond Earth.

The Biomolecule Sequencer investigation sent samples of mouse, virus and bacteria DNA to the space station to test a commercially available DNA sequencing device called MinION, developed by Oxford Nanopore Technologies. The MinION works by sending a positive current through pores embedded in membranes inside the device, called nanopores. At the same time, fluid containing a DNA sample passes through the device. Individual DNA molecules partially block the nanopores and change the current in a way that is unique to that particular DNA sequence. By looking at these changes, researchers can identify the specific DNA sequence.

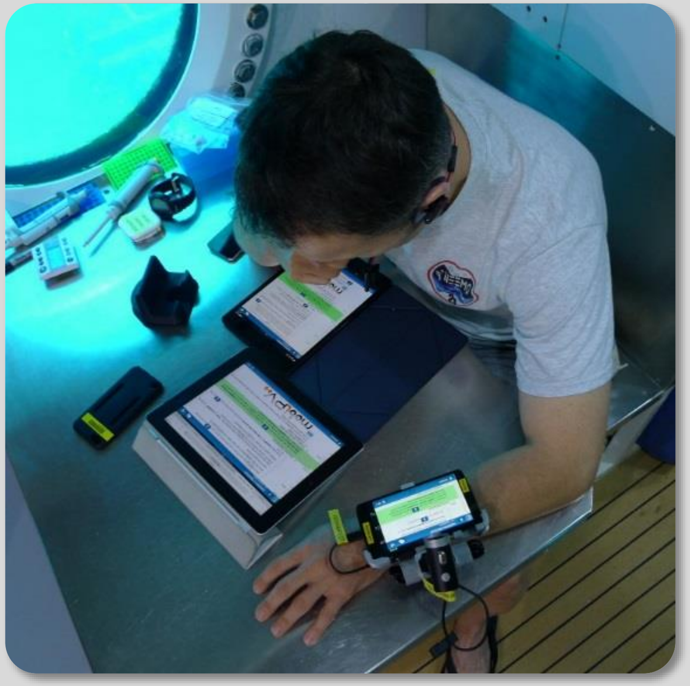
Rubins, who has a background in molecular biology, conducted the test aboard the station while researchers simultaneously sequenced identical samples on the ground. The tests were set up to attempt to make spaceflight conditions, primarily microgravity, the only variables that could account for differences in results. For example, the samples were prepared on the ground for sequencing and researchers selected organisms whose DNA has already been completely sequenced so that they knew what results to expect.

NASA Astronaut Kate Rubins sequenced DNA in space for the first time ever for the Biomolecule Sequencer investigation, using the MinION sequencing device.
*Credits: NASA*

NASA Extreme Environment Mission Operations (NEEMO) crew member, Matthias Maurer of ESA, works on inserting samples into the MinION DNA sequencer as part of the Biomolecule Sequencer experiment. Researchers tested the device aboard the analog to minimize unknowns and see how the device worked in various extreme environments.
*Credits: NASA*

# Intra-Vehicular Activities: ESA Evaluations

## MobiPV Evaluation

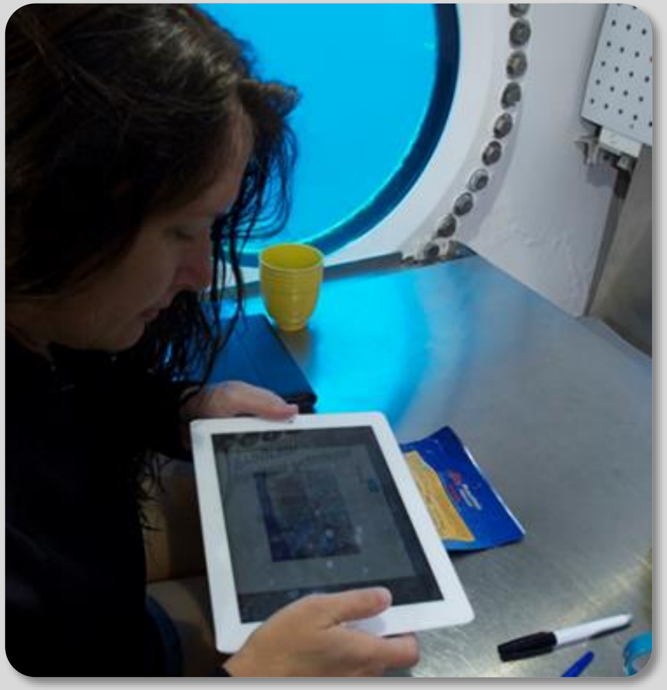


- ➢ Procedure viewer tool for ISS use (CY 17)
- ➢ Concept has operational value and holds the potential to greatly simplify and speed up the execution of intensive, hands-busy activities
- ➢ Validated multiple concurrent ground mobiPV systems (e.g. Capcom on the top side, engineering support in Europe)
- ➢ Ops environment provided extensive feedback that is being incorporated into FSW

## Aquapad Evaluation

- ➢ Water sampling protocol for ISS (Inc. 50)
- ➢ Validated Aquapad is faster and simpler to use than current ISS method
- ➢ Trash reduction of > 50% realized from crew feedback

## ESA Nutritional Assessment Tool Evaluation



- ➢ Nutrition tracking tool for ISS use (Inc. 50)
- ➢ Validated approach and received concrete feedback for improvements
- ➢ Maintaining food database was difficult with mid-mission resupplies
- ➢ Database on Ground (vice Onboard) server improved software updates, data transfer without sacrificing reliability

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