Relevant Environments for Analysis and Development (READy): Enabling Human Space Exploration Through Integrated Operational Testing

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READy Mission Management Team | EVA Lead

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Integrated Operational Testing for Space Exploration

Lead the development and execution of high-fidelity operational exploration missions that closely mimic the space environment of interest, thus developing and testing concepts that enable Exploration missions

Objectives

- *Establish a portfolio of relevant environment test facilities and approaches to support Human Exploration and Operations Mission Directorate (HEOMD) – including Gateway Utilization Phase 0-4 – as well as Science Mission Directorate (SMD) and Space Technology Mission Directorate (STMD) Exploration Research & Technology (ER&T) missions*
- *To establish an institutional resource for mission development integration, including for Gateway the Lunar Surface*
- *Fulfill key objectives of EISD Charter and Roadmap that enable the Journey to Cis-lunar space, the Moon, and Mars*
- *Provide synergy and ensure integration across a wide variety of on-going, active EISD work*
- *Provide a unique service to select and integrate objectives and testing locations across the Center and Agency; become the "go-to" resource for JSC and Agency operational development testing requirements and align existing dispersed capabilities within a strategic and tactical plan*

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

EXPLORATION INTEGRATION & SCIENCE DIRECTORATE

coordinated integration

- PLANNING
- EVA
- SCIENCE
- TECHNOLOGY

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 lead 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

Unique blend of capability and skill sets …

Leverage extensive knowledge and experience from …

MISSION CONCEPT DEVELOPERS

PLANETARY SCIENTISTS

EVA SYSTEM DEVELOPERS

eisd

HISTORICAL MISSIONS
Apollo Surface Operations

HUMAN SPACE FLIGHT
ISS, Shuttle

ROBOTIC MISSIONS
Mars Missions, OSIRIS-REx

MISSION SIMULATIONS
D-RATS, NEEMO & others

JSC ARC KSC JPL GSFC

esa CSA ASC JAXA

And a multitude of others…

XI XM XX

CB EC ER SK

FIU Florida International University

AQUARIUS REEF BASE

HONEYBEE ROBOTICS

NPS

NAVSEA NAVAL SEA SYSTEMS COMMAND

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

DRAPER

VEGA Telehealth

TELOREGEN

Micro Aerospace Solutions

IMaGeS Lab

SHARK MARINE TECHNOLOGIES INC.

AEXA

University of Houston Clear Lake

voxer

WHAT: Development & Integration Themes

TOOLS

EVA Systems
- **EVA tools and equipment**
- **Large equipment transport**
- **Small tool transport on suit**
- **Informatics**
- **Crew rescue**
- **EVA Support System & IV Workstation**
- **Science instruments and sample acquisition tools**

Instrumentation
- Sample identification / high-grading
- ISRU verification

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

TECHNIQUES

Exploration Operations
- Procedure development/refinement
- Signal latency (time delay) & blockage
- Bandwidth limitations

EVA Operations
- **EVA concepts of operations**
- **EVAs in undefined environments**
- **Advanced capabilities & informatics**

Science Operations
- **Flexecution methodology**
- **Decision making protocols**
- **Transverse planning**

Robotic Operations
- Autonomous
- Crew controlled
- Human-Robotic interface & integration

TECHNOLOGIES

Emerging Technologies
- Virtual/Hybrid reality opportunities
- **Relevant cutting-edge systems and capabilities for Exploration and EVA**
- **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
- **Enables development of engineers and scientists not normally exposed to operations**

AQUATIC

EXAMPLES

Neutral Buoyancy Laboratory (NBL)

Aquarius Reef Base (NEEMO)

ESA's Neutral Buoyancy Facility

Others …

TERRESTRIAL

EXAMPLES

Geo-Science Field Exercises & Sites

Field Training Areas

Extreme Environments (ex. Antarctica)

Others …

LABORATORY

EXAMPLES

Active Response Gravity Offload System (ARGOS)

Virtual Reality & Hybrid Reality Laboratories

International Space Station

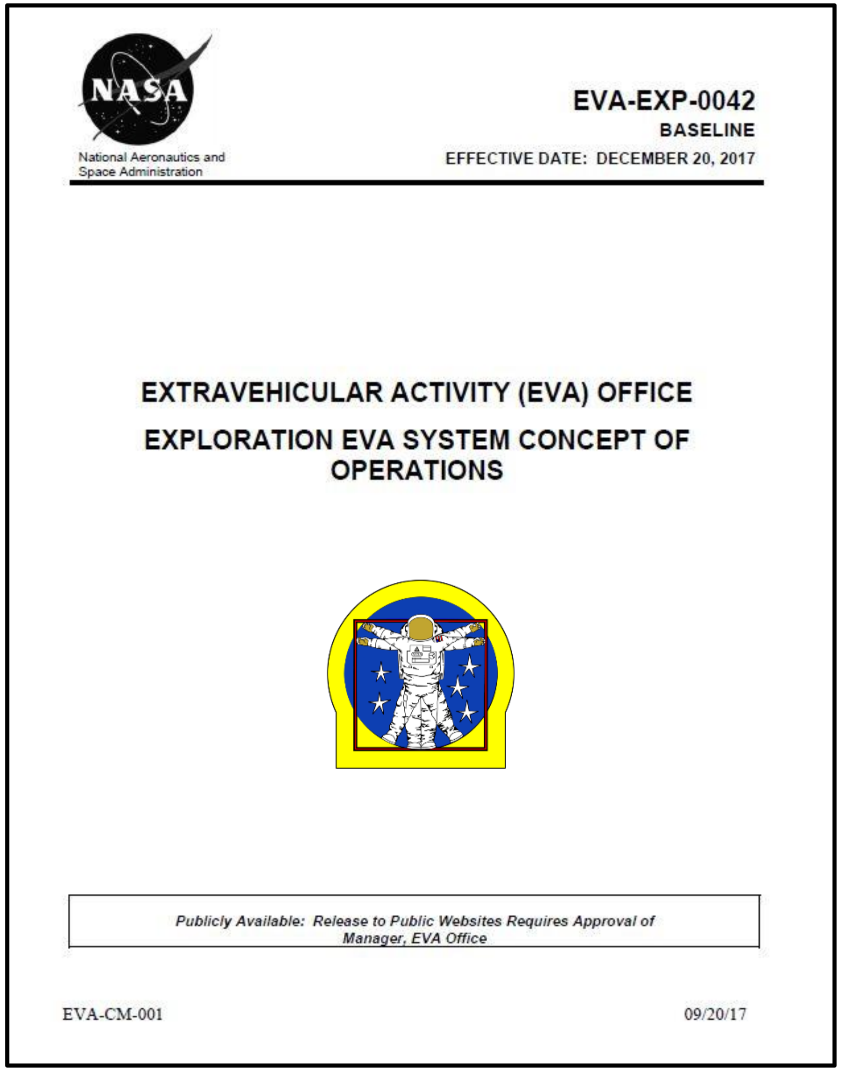
Others …

WHY: Exploration Capability Development via Integrated Operations

WHY: EVA Goals for Integrated Operational Testing

The primary goal for EVA is to inform the ***Exploration EVA System Concept of Operations*** by exploring the combination of **Operations** and **Engineering** with **Science** for Exploration destinations in a mission-like environment

- Advance the future of the Exploration EVA System and operations
- Understand EVA capability needs 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
- Develop and document concepts of operations for EVA at the Exploration destinations (**EVA-EXP-0042**)
- Realize the needs of EVA equipment and enable the development of concepts for design maturation on the road-to-flight



National Aeronautics and Space Administration

EVA-EXP-0042
BASELINE
EFFECTIVE DATE: DECEMBER 20, 2017

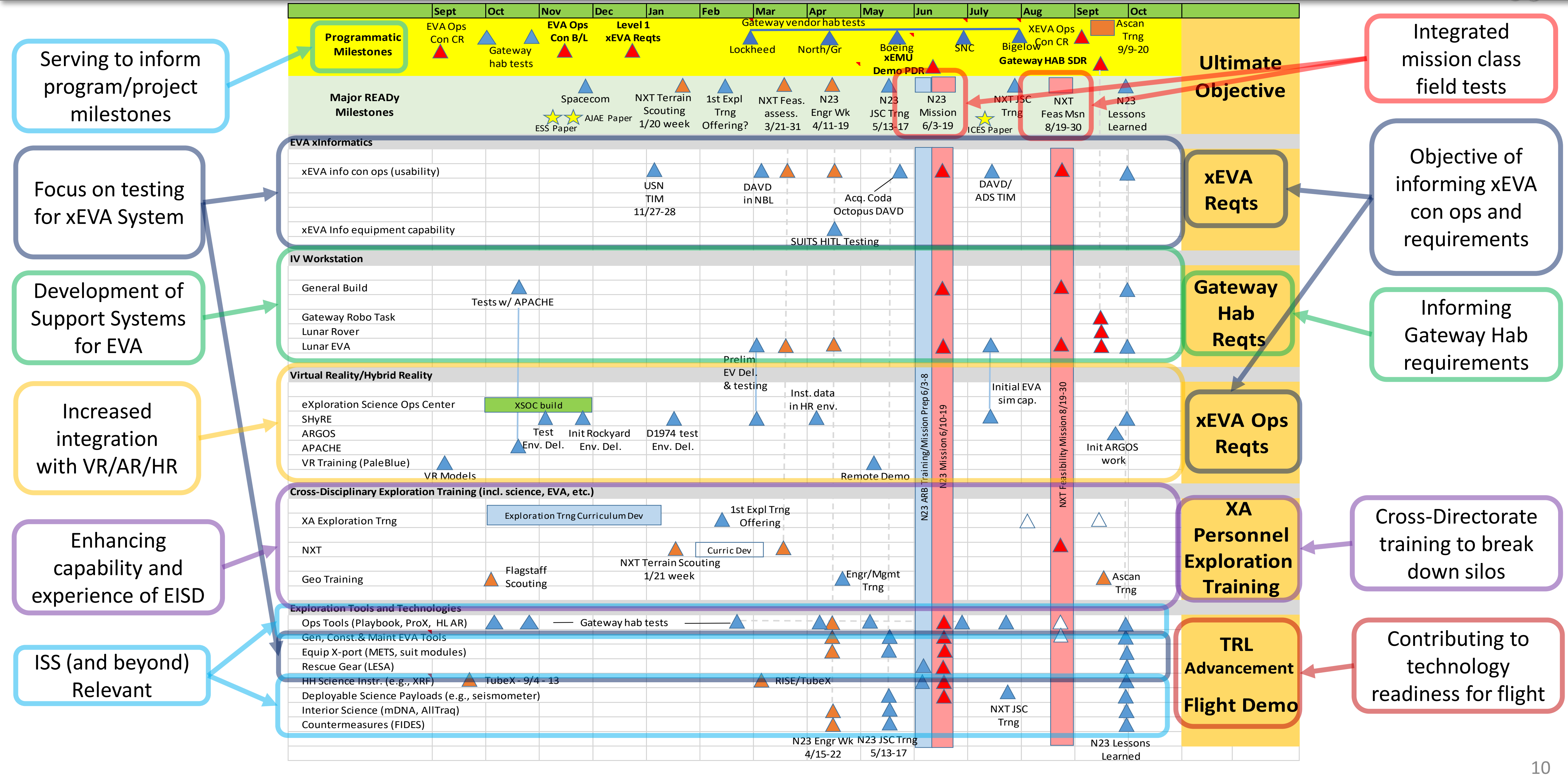
EXTRAVEHICULAR ACTIVITY (EVA) OFFICE

EXPLORATION EVA SYSTEM CONCEPT OF OPERATIONS

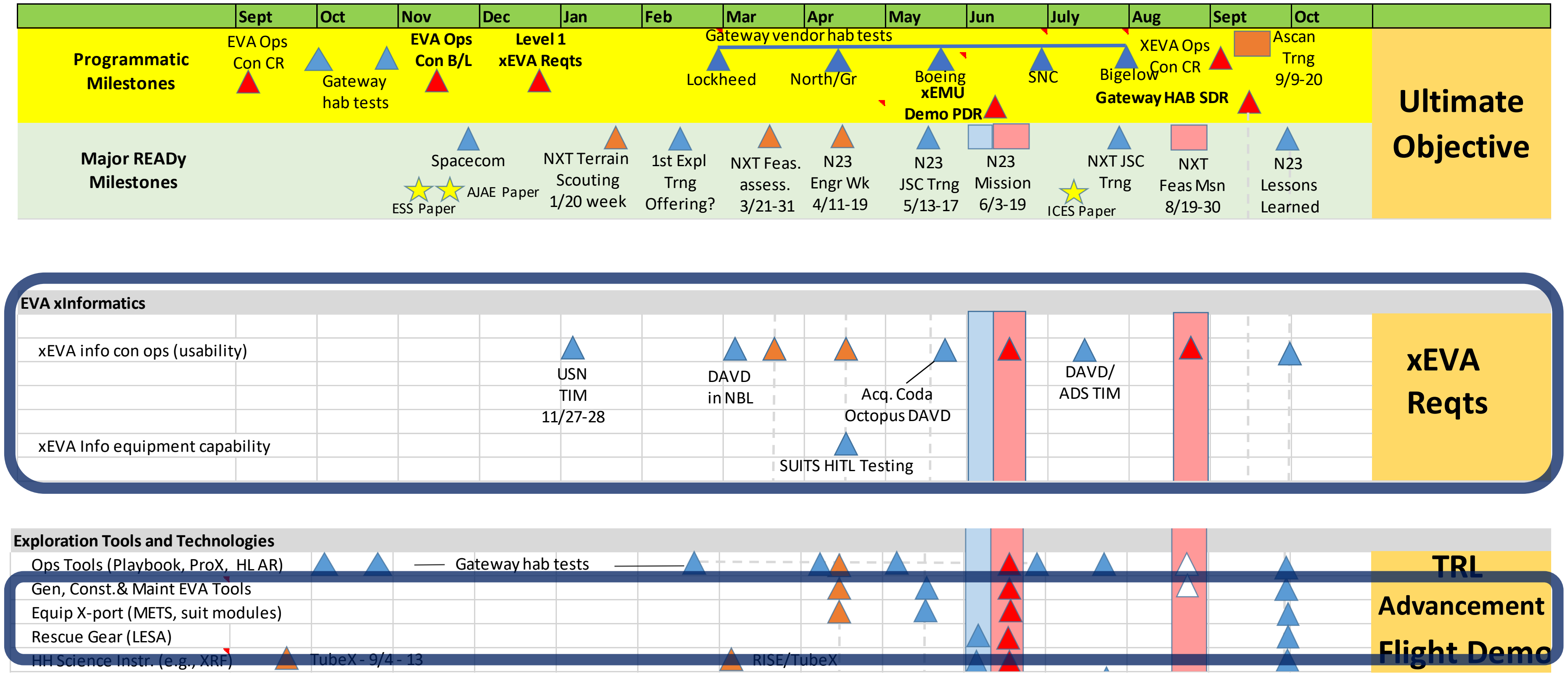
Publicly Available: Release to Public Websites Requires Approval of Manager, EVA Office

EVA-CM-001 09/20/17

EXAMPLE READY IMPLEMENTATION PLAN FOR FY19



BACKUP



- Divers Augmented Vision Display (DAVD) and Digital Cue Cards
- HoloLens (SUITS)

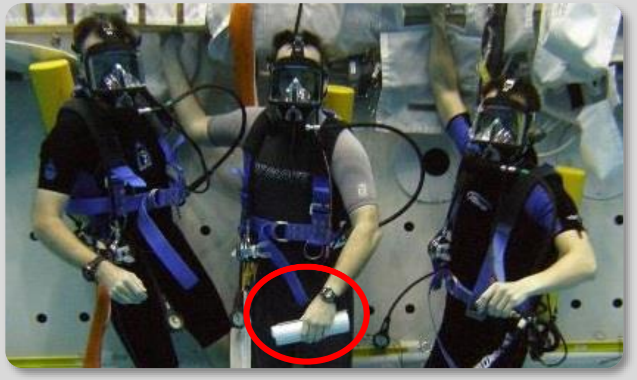
- Science Sample Acquisition Tools
- xEVA Equipment Transport
- Lunar Evacuation System Assembly

NASA Exploration EVA Spacesuit and Operations

- An EVA Augmented Vision Heads-Up Display (HUD) would allow for real-time data update, augmented cue input, procedure viewing, enhanced task direction, and self-navigation capability
  - Enables Exploration mission concepts of operations baselined by the EVA Office, especially those on natural planetary surfaces
  - Relevant for current spacesuit (xEMU) development efforts and the xINFO system
- DAVD system abilities translate into capabilities needed by NASA for the Exploration EVA Suit and planetary operations

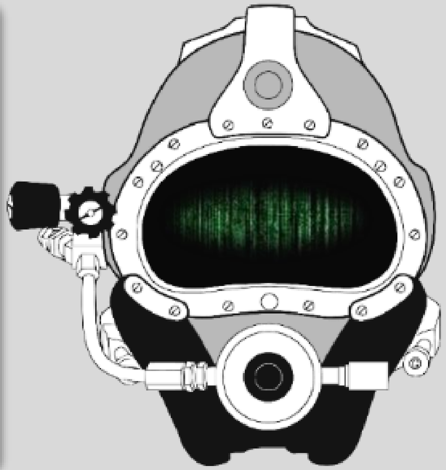
Enhanced ISS EVA Training

Utilize MK20 FFM version of DAVD to view procedures and graphics sent by Test Conductor

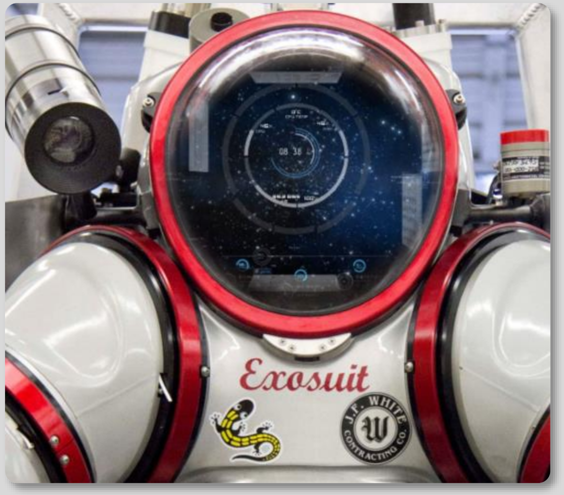


Potential Spacesuit (xEMU) Development

DAVD Mounted Lenses



DAVD Projection System



DAVD System in Suit

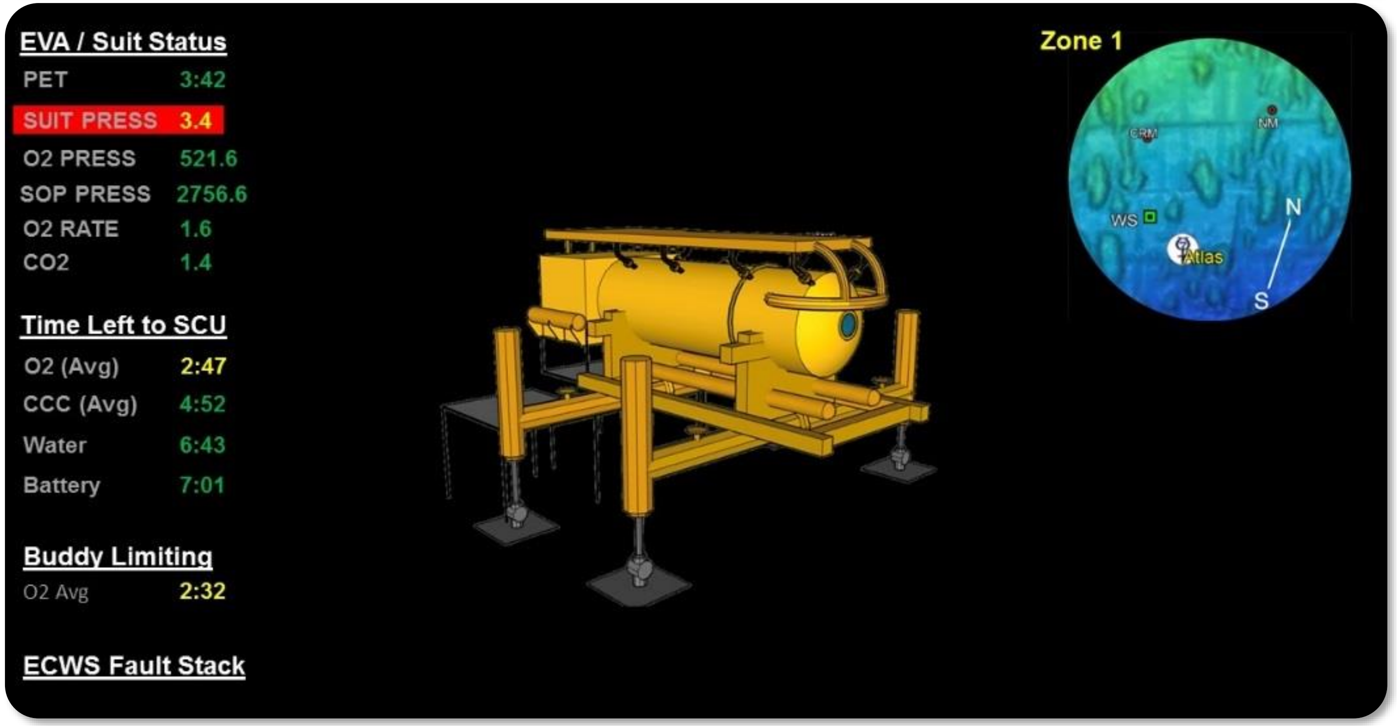
xEMU HUD

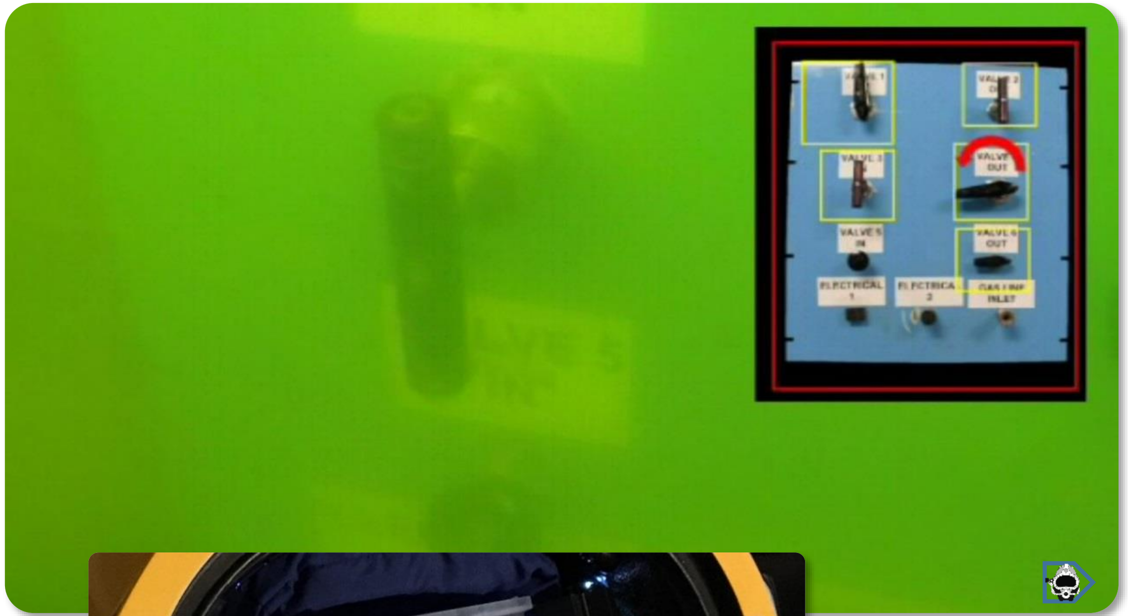
Objective

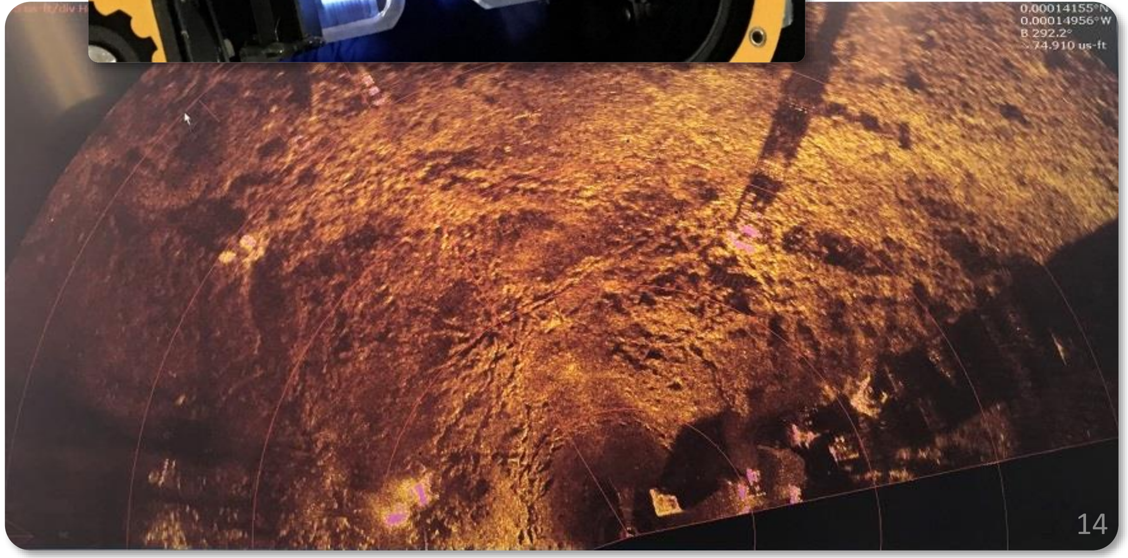
- Evaluate DAVD as a potential capability concept for an EVA Augmented Vision Heads-Up Display – allowing for real-time data update, augmented cue input, procedure viewing, task direction capability, and navigation – for spacesuit (xEMU) development

Implementation

- Utilize DAVD mounted inside a KM37 dive helmet
- Send real-time data to the EVA crewmember from the IV workstation via DAVD for task direction





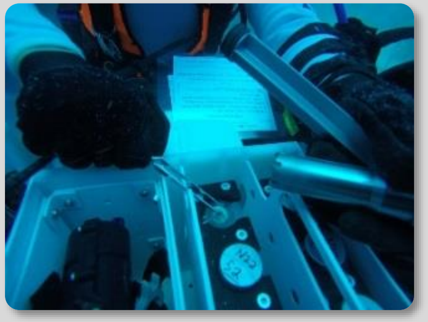


Objective

- Evaluate EVA hardware and operations for subsurface (core) and regolith science sampling in a surface/partial-g environment

Implementation

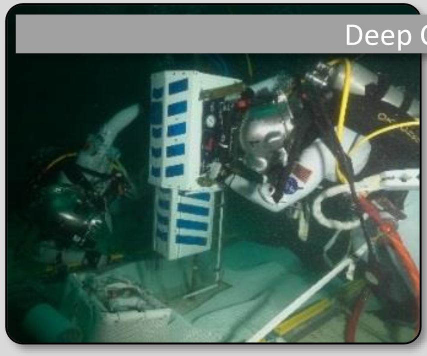
- Apply a breakaway core bit technology developed by Honeybee Robotics with an underwater battery powered drill to acquire core samples
- Use small tools, such as forceps, to stow samples for curation

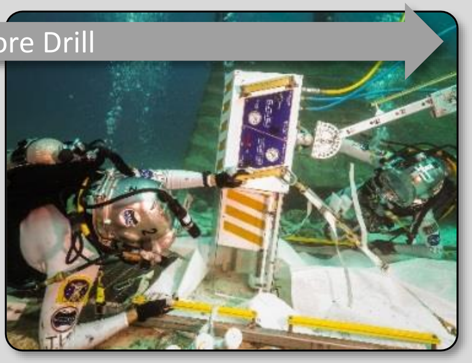


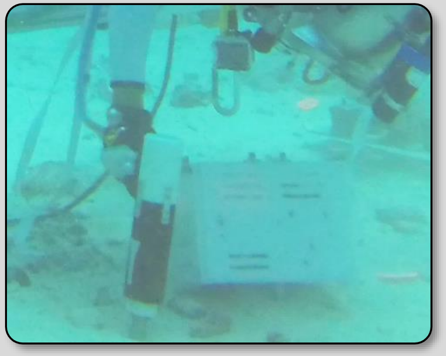
Core Sample Acquisition Tool Evolution

Deep Core Drill


SEATEST 2


NEEMO 18


NEEMO 19


NEEMO 20


NEEMO 21

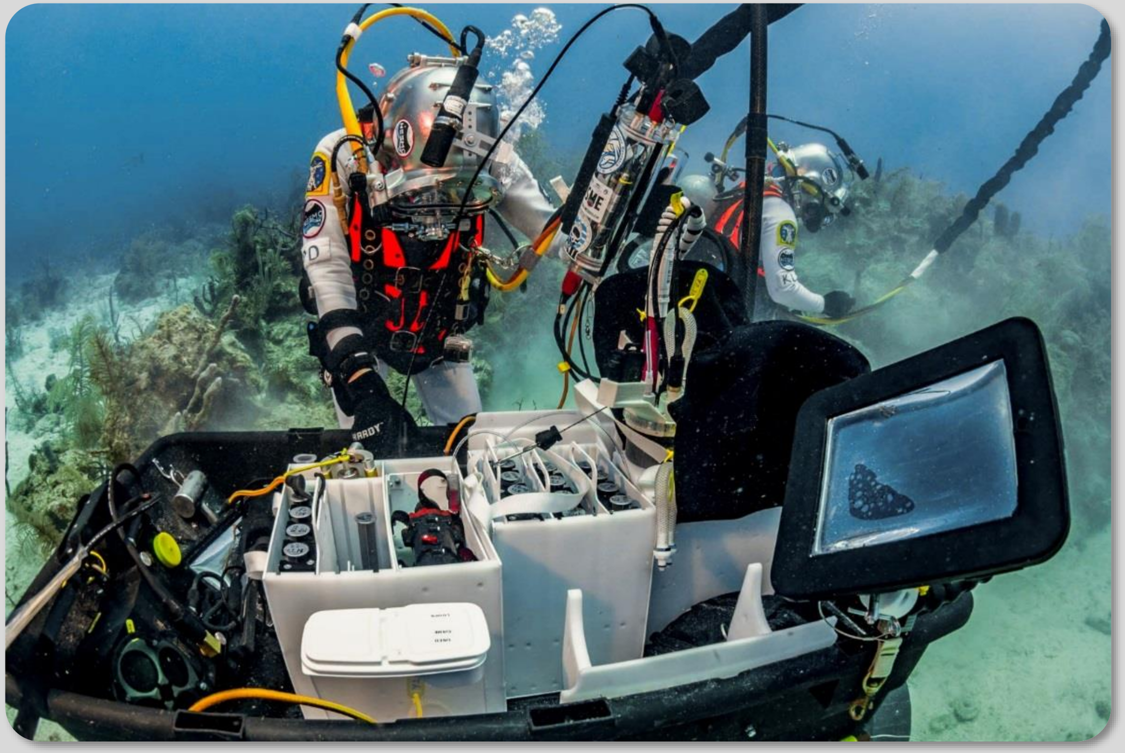

NEEMO 22

Objective

- Evaluate Modular Equipment Transport System (METS) for manually transporting/stowing tools and samples on exploration traverses
  - Evaluate the Wheeled Equipment Transport (WET) for transport of large equipment in a mobile carrier
  - Evaluate the Suit-mounted Equipment Carrying System (SECS) for 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
  - WET – Configurable wheeled carrier, with attachments for modules and science instruments
  - SECS – a forearm stowage device and thigh module attached to the suit after egress



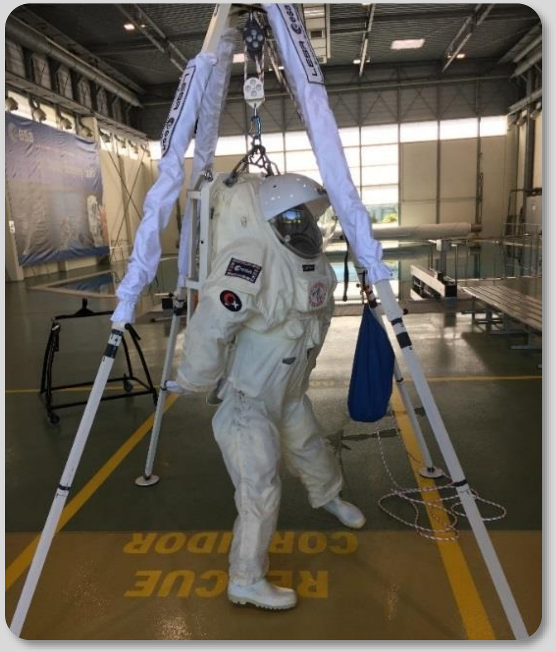
Incapacitated EVA Crew Rescue – Lunar Evacuation System Assembly (LESA)

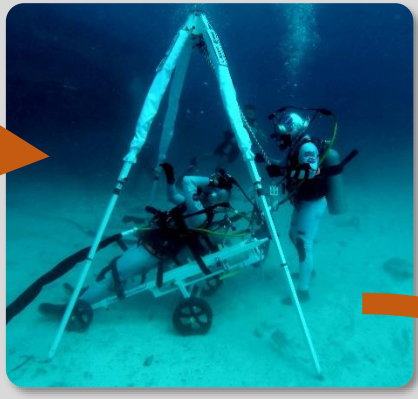
Objective

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

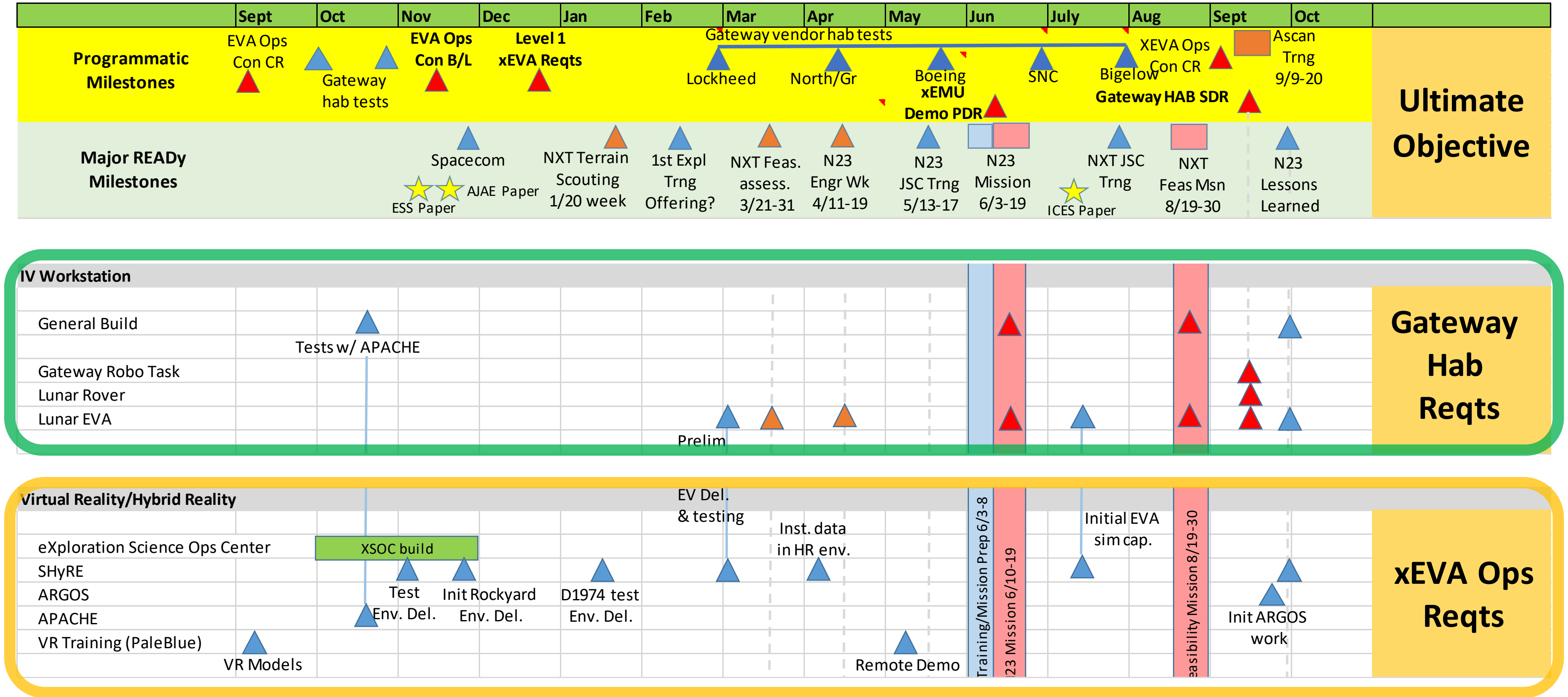
Implementation

- 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



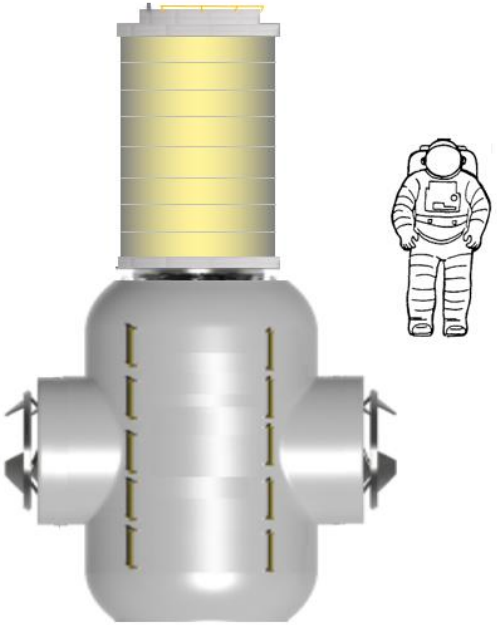


IV Workstation for EVA Support and VR/Hybrid Reality



- Gateway Hab Testing
- IV Workstation Requirements
- SHyRE

- **READy team ops contribution to Gateway Hab testing**
  - Have participated in tests to date as
    - Test Director
    - Sim Sup
    - Capcom
  - Plan to similarly support at least the first 3 tests next CY
  - Numerous components also being developed in other READy activities (e.g., Playbook, ProX, AllTraq, IV Workstation)



EVA Support System & IV Workstation @ NEEMO

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 they must contend with while actively directing an EVA
- Examine potential EVA task/timeline tracking systems (Playbook), along with tracking of EVA 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

Implementation

- Open MCT for consolidating input data
- Life support system tracking tool with simulated spacesuit data
- Playbook Tactical EVA Execution Feature
- Integrated with DAVD

Evolution of EVA Support System for IV Operator

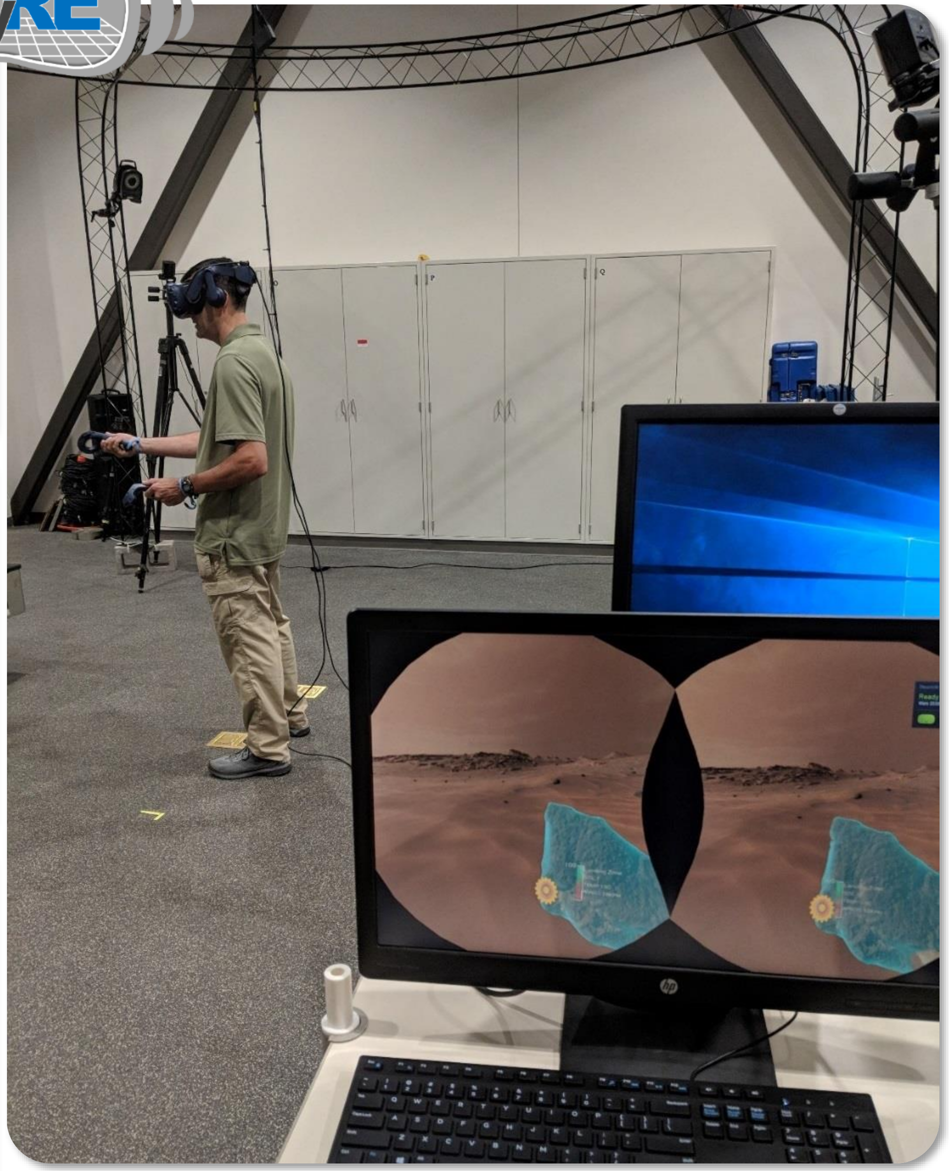
NEEMO 20

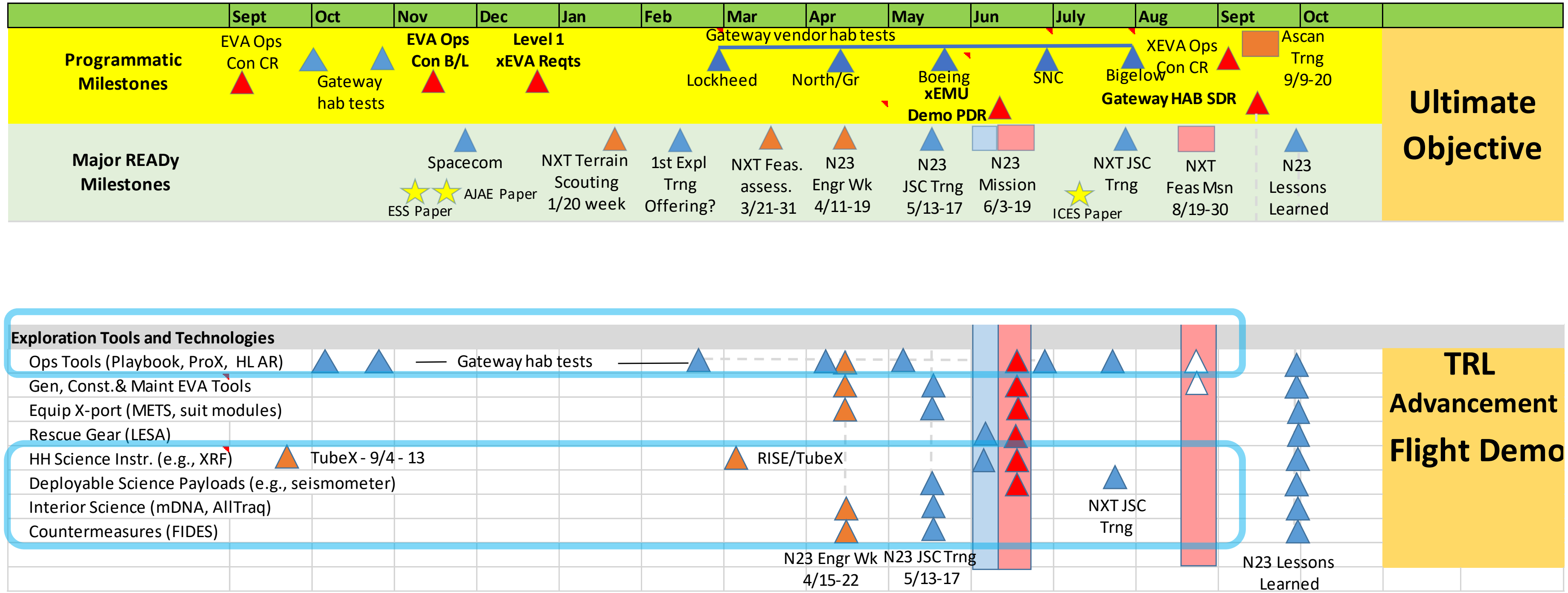
NEEMO 21

NEEMO 22

Scientific Hybrid Reality Environment (SHyRE)

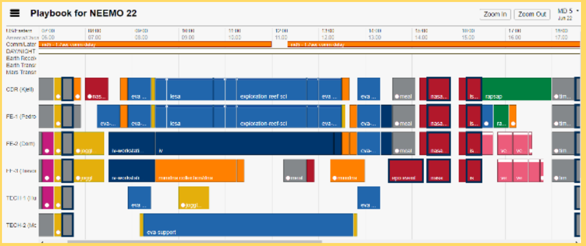
- Developing a high scientific fidelity hybrid reality (HR) model of real-world geological sites of interest, including embedded data and applicable tool usage
- Creates a testing environment onsite at JSC that will be a go-to Exploration facility
- Builds off of several years of RIS^4E *in situ* data collection in addition to data collected at the December 1974 flow, Kilauea Volcano, HI
- 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

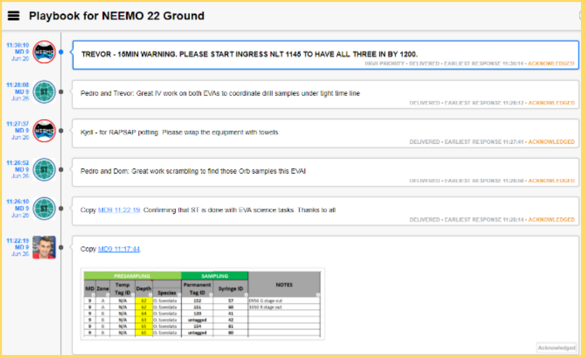




- Ops Tools
- Science Instruments/Payloads
- Interior experiments
- Published Results

Playbook – Planning, Procedure Viewing, and Comm Tool





Telementored Medical Scenario

Countermeasures

Electron Microscope

AR Assisted Procedures

Location Tracking

1-2 years (ISS)

3-4 years (Gateway)

5+ years (Lunar Surface)

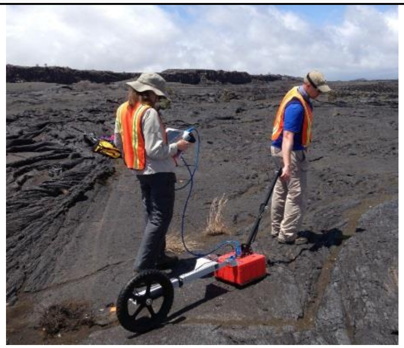
RIS^{4}E and TubeX

Multispectral Imaging & LiDAR for broad FOV

Airborne data for site context

hXRF & XRD for in situ chemistry and mineralogy

GPR for subsurface structure



AGU100 ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

RESEARCH ARTICLE

10.1029/2018EA000378

Special Section:
Science and Exploration of the Moon, Near-Earth Asteroids, and the Moons of Mars

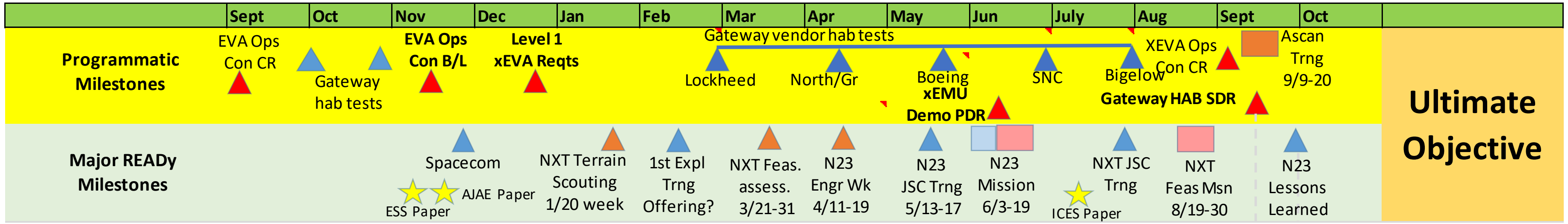
This article is a companion to Ito et al. (2018), https://doi.org/10.1029/2018EA000375.

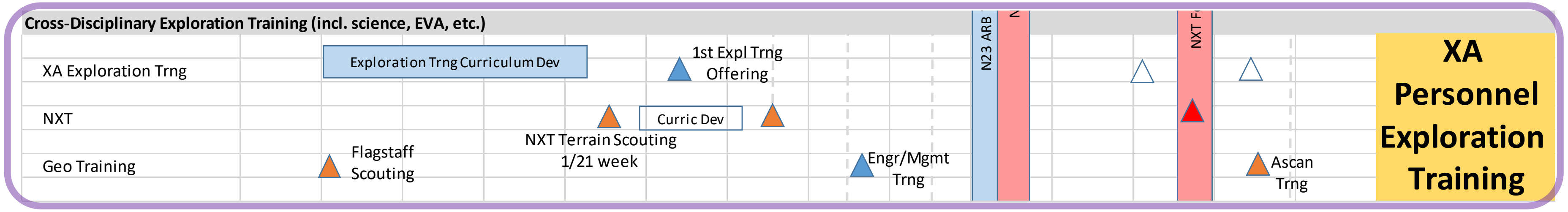
The Incorporation of Field Portable Instrumentation Into Human Planetary Surface Exploration

K. E. Young[1], J. E. Bleacher[1], A. D. Rogers[2], H. H. Schmitt[3], A. C. McAdam[1], W. B. Garry[1], P. L. Whelley[4], S. P. Scheidt[5], G. Ito[2], C. A. Knudson[4], T. G. Graff[6], L. V. Bleacher[1], N. Whelley[4], C. A. Evans[7], J. M. Hurtado Jr.[8], and T. D. Glotch[2]

[1]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [2]Department of Geosciences, Stony Brook University, Stony Brook, NY, USA, [3]Department of Engineering Physics, University of Wisconsin-Madison, Albuquerque, NM, USA, [4]College Park/CRESST Cooperative Agreement at NASA Goddard Space Flight Center, University of Maryland, Greenbelt, MD, USA, [5]University of Arizona, Tucson, AZ, USA, [6]Jacobs JETS Contract, NASA Johnson Space Center, Houston, TX, USA, [7]NASA Johnson Space Center, Houston, TX, USA, [8]University of Texas at El Paso, El Paso, TX, USA

CROSS-DISCIPLINARY EXPLORATION TRAINING

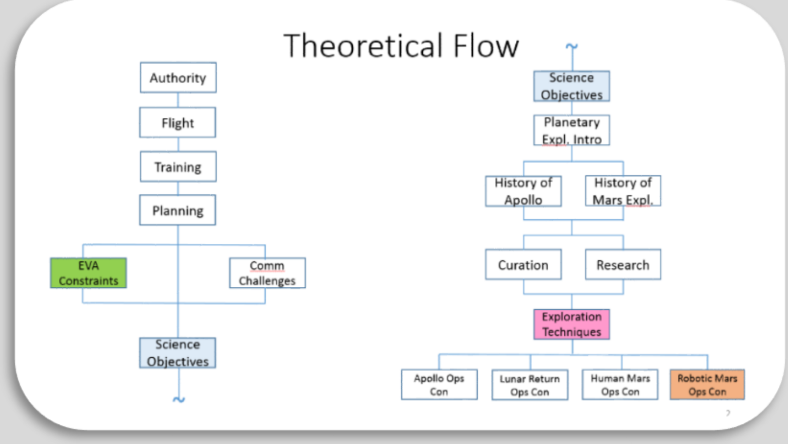


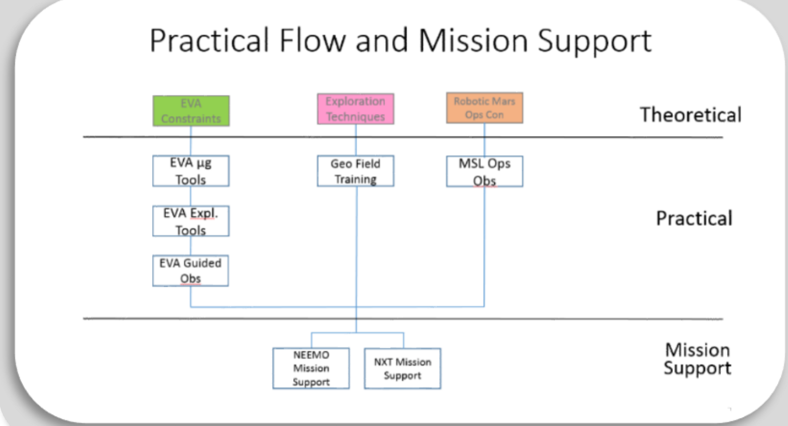


- XA Exploration Training
- Geological Field Training
- Participation in an Integrated Operational Mission

1 Exploration Ops Class Training

- Seminar and/or classroom-based curriculum focused on training Exploration personnel on operations and flight control, EVA constraints, and science techniques and considerations Priority given to EISD personnel.





2 Field Geology Ops Training

- Geology training in the field geared towards Engineers and managers to provide an understanding and appreciation of science tasks and methodology
- Modeled on the Earth & Planetary Science Training taken by the ASCANs (https://wiki.jsc.nasa.gov/fod/index.php/Earth_and_Planetary_Science_Training)

3 Integrated Operational Mission

- Support a Mission-class integrated operational field test (e.g., NEEMO or NEEMO NXT)
- Take a responsible role (e.g., science team member) engaging in
  - Timeline development
  - Priorities discussions
  - Ops product development
  - Planning and plan reviews

NEEMO NXT: Neoteric eXploration Technologies

- NEEMO NXT
  - Addresses the gaps of:
    - Representative planetary geology environment with unrestricted real estate to explore
    - Human/machine work systems
    - Restrictive EVA suit
  - Utilizes both terrestrial and subsea environments
  - Adds <u>exploration</u> ops training appropriate for ARES scientists and other select EISD personnel
  - Maintains astronaut end-user involvement
  - Furthers technology and capability development for exploration EVA
    - Tasks
    - Tools
    - Science
    - Robotics
    - Informatics
  - Proactively postures for possible loss of access to Aquarius in the not-too-distant future
  - Smaller operation than NEEMO, with a lighter footprint

NEEMO NEOTERIC EXPLORATION TECHNOLOGIES (NXT)

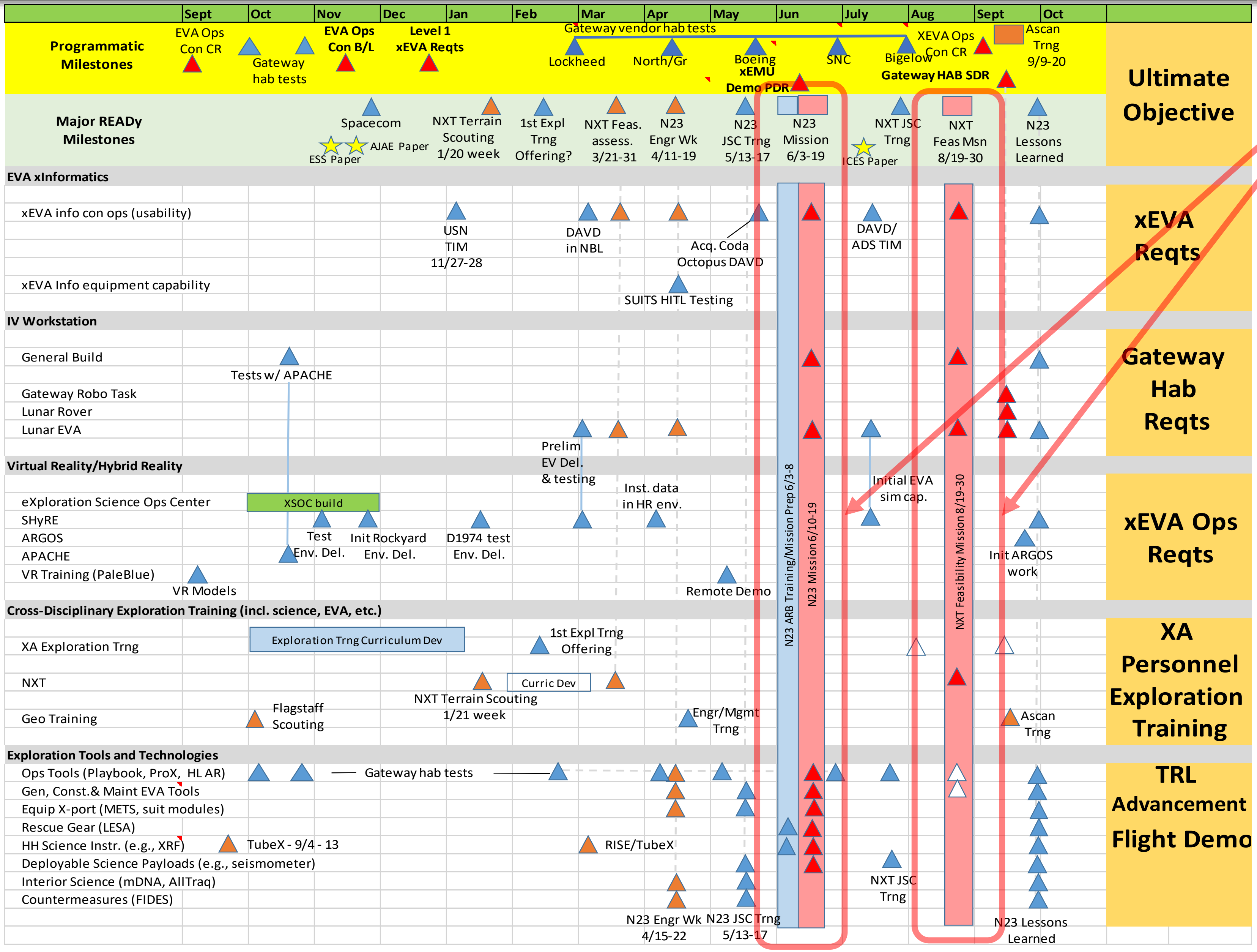
NEEMO NXT

- Concept currently in development for an add-on and eventual follow-on for NEEMO
- Focuses on Exploration operations development and training, xEVA informatics, xEVA con ops, and integration of science operations
- Offers a high intensity operationally challenging environment, with high workload, elevated stress, high bandwidth, time pressure, and unexpected external perturbations
- Utilizes Nuytco Research Exosuit and DeepWorker submersibles
  - Potential partner for spacesuit development, especially for joints
- Exosuit provides an analogous restrictive suit that requires similar effort for positioning and working in an EVA suit, along with a relatively large helmet volume at 1 ATM to evaluate off the shelf informatics hardware (e.g., DAVD, HoloLens, etc.)
- Provides operations training and experience for XA/EISD personnel (managers, engineers, scientists) without extensive ops experience
- Expands partnership with Navy for development of xEVA informatics
- READy FY19 plans include
  - Terrain scouting and feasibility mission planning
  - Feasibility assessment of assets and core team training
  - Feasibility mission as a 'test flight' of the concept

xEVA SYSTEM CON OPS & CAPABILITIES DEVELOPMENT

- **Tools**
  - Development of a heads-up display (HUD) concept (e.g., HoloLens and DAVD) in an encumbered suit (Exosuit) for potential expansion into the xEMU
  - Development of an IV Workstation and Support System needed for EVA and Science operations, especially at destinations with long signal/comm latencies
- **Techniques**
  - Evaluation of planetary pioneering and science operations while conducting tasks with a restrictive suit in an extreme environment
  - Development of integrated operations and capabilities between EVA and Science, with operations being directed by an MCC Science Team
- **Technologies**
  - Evaluation of concepts for hands-free advanced informatics with real-time data that could be applied to future Exploration spacesuit systems (e.g., DAVD)
- **Training**
  - Exploration operations training for personnel that don't have extensive direct operational experience

INTEGRATED OPERATIONAL FIELD TESTS



Integrated mission class field tests

- NEEMO 23
- NEEMO NXT Feasibility Mission
- Integrated MCC Ops

Integrated Mission Control Operations for Exploration

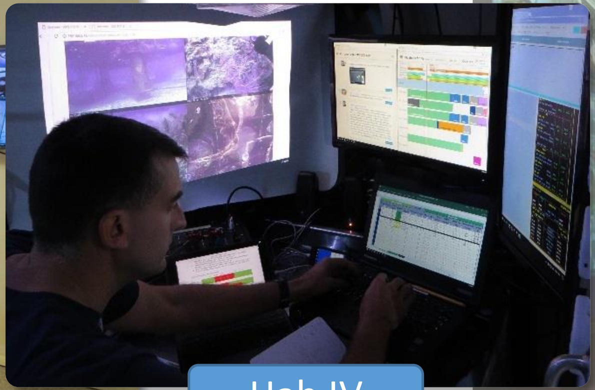
Objective

- Analyze integrated EVA/science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) and integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a lunar signal (comm & data) 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

Mission Control


Hab IV

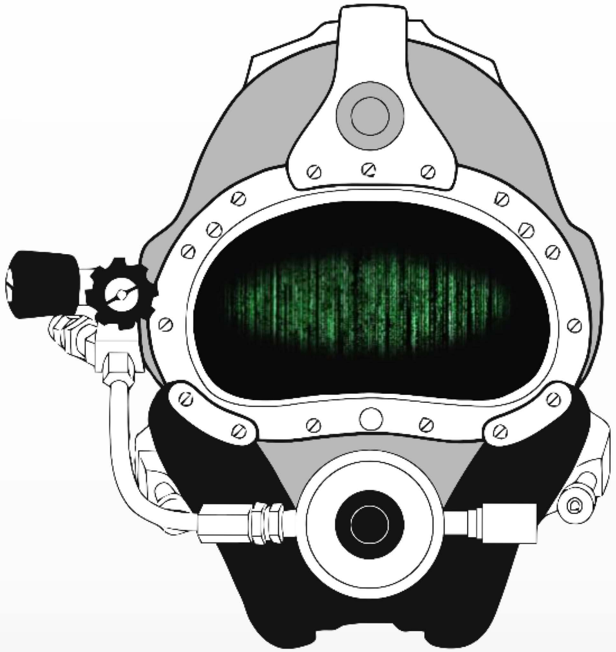

Science Team

- **READy provides integration across Training, Tools, Techniques and Technology that is**
  - Positioned to inform and influence Surface Systems, xEVA, and Gateway designs and requirements
  - A collaboration between multiple NASA Centers
  - A collaboration between multiple divisions within EISD
  - A means to start building the planetary exploration knowledge and experience our workforce needs to enable Agency goals

- **READy is rolling**
  - Integrated plan is coming together and we're executing per the plan

- **New Initiatives are in work**
  - Exploration Training curriculum
  - Geology Field Training for Engineers and Managers
  - NEEMO NXT feasibility assessment
  - Opportunity to cross-train select people through mission operations responsibilities

- **Previous work on track**
  - NEEMO 23
  - SHyRE
  - RIS^4E
  - TubeX
  - EVA IV Workstation development
  - EVA Informatics development



Exploration EVA Testing at NEEMO 23

And candidates for further testing in the NBL

Exploration EVA Objectives for NEEMO 23

The primary goal for EVA is to inform the ***Exploration EVA System Concept of Operations*** by exploring the combination of **Operations** and **Engineering** with **Science** for Exploration destinations in a mission-like environment

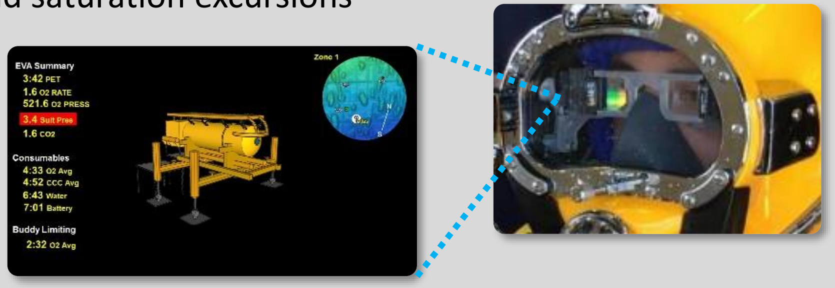
Primary EVA Objectives

	EVA Objectives	EVA Knowledge/Capability Gaps
Informatics	➢ **Navy Diver Augmented Vision Display (DAVD)** ***"EVA Augmented Vision Heads-Up Display"*** ▪ **Spacesuit HUD concept development for NASA** ▪ **Operational assessment of DAVD for NAVSEA** ➢ **Surface navigation for EVA** ➢ **EVA Support System and IV Workstation** ➢ **EVA digital cue cards**	➢ **EVA Suit Heads-Up Display** ➢ **Mixed / Augmented Reality Capability** ➢ **EVA Graphical Display** ➢ **EVA Short Range Navigation** ➢ **IV Support System for EVA Operations**
Tools & Equipment	➢ **Core Sample Acquisition System** *(Honeybee Robotics)* ➢ **Modular Equipment Transportation System (METS)** ▪ Wheeled Equipment Transport (WET) ▪ Suit-mounted Equipment Carrying System (SECS) ➢ **Pioneering construction** ➢ **ESA's Lunar Evacuation System Assembly (LESA 2.0)**	➢ **Tools for Science Sampling on a Surface EVA** ▪ **Subsurface samples (core)** ➢ **Tool Carrier Device** ➢ **Tool Attachment/Harness for Surface EVA** ➢ **Surface EVA Incapacitated Crewmember Rescue**
Concepts of Operations	➢ **Integrated EVA operations with science tasks** ▪ Lunar-focused with signal blockages ▪ Comparison of crew IV vs ground IV ➢ **Integrating informatics during EVA** ▪ Use of advanced informatics concepts during EVA ➢ **Flexible Execution Methodology (Flexecution)**	➢ **Integrated EVA Flight Control Methodology** ➢ **Tools for Interacting with EVA Over a Comm Latency (Blockage)** ➢ **Flexible Execution Methodology for EVA Science Operations in Undefined Environments**

U.S. NAVY DIVER AUGMENTED VISION DISPLAY (DAVD)




- Evaluate a potential concept for an EVA Augmented Vision Heads-Up Display that allows for real-time data update, augmented cue input, procedure viewing, and task direction capability, which is relevant for spacesuit (xEMU) development
  - "…this would be invaluable for EVA." – Shuttle/ISS 7-EVA experienced astronaut
- Assess the concept of using an area scanning system (side-scan sonar) for EVA crewmember self-navigation, and IV and MCC situational awareness
- Utilize the DAVD system during topside dives and saturation excursions
- Testing plan
  - Topside test dives (EVA & ARES)
  - Saturation test dives (EVA & ARES)
  - Saturation mission evals (NEEMO crew)
  - TBD follow-on testing in the NBL



IV SUPPORT SYSTEM FOR EVA


- Evolve and evaluate a Support System that utilizes a digital timeline execution and life support system management tool to support the IV crewmember during an EVA
- Examine use of OpenMCT and Playbook
- Incorporate DAVD
- Continue looking into developing an efficient IV workstation

EVA DIGITAL CUE CARDS



- Refine and evaluate digital cue cards to capture data on what information set is ideal to enable additional EVA crew autonomy

Ironman Modernizes Aquaman

By Jacqui Barker, Public Affairs Officer, NSWC Panama City Division

U.S. Navy photo by Anthony Powers

DAVD Proves Successful HVL Event, Surpasses Phase II Testing

PANAMA CITY, Florida - Ironman is one step closer to modernizing Aquaman, at least for the U.S. Navy's Fleet.

Naval Surface Warfare Center Panama City Division's Diver Augmented Vision Display (DAVD) project team successfully surpassed all expectations at the first in-water testing Oct. 10-13, 2017.

Sponsored by Naval Sea Systems Command Supervisor, Diving and Salvage (NAVSEA 00C), Panama City's project team was elated to see how well the DAVD prototype performed in the intended environment.

The DAVD is a binocular head-up display (HUD) that is mounted inside the Kirby Morgan 37 (KM-37) dive helmet and the MK-20 Full Face Mask (MK-20 FFM). The prototype uses commercial see-through lenses and custom 3D printed frame systems for the helmet and facemask versions.

Dive supervisors relay high-resolution visual mission data to the HUD via an Ethernet cable married to the diver's primary umbilical. Divers can clearly view text messages, video, photographs, instructions, and augmented reality images even in murky, zero visibility conditions. They can also see their real-time location during the dive mission via scanning sonar imagery, just like a virtual reality video game.

> "The break-through head-up display technology can be used for other types of work conducted in low or zero visibility conditions... even in outer space."
>
> *- Dennis Gallagher, DAVD Project Manager*

"We learned a lot about how the system can be used effectively by our divers conducting real missions. Overall, our test objectives were met, and now were are focused on Phase III development," said DAVD Project Manager Dennis Gallagher.

DAVD is one of NSWC Panama City's most recent rapid prototyping and high-velocity learning initiatives. Total concept to test time has been less than two years.

"This is my first life-cycle project," said DAVD mechanical engineer Allie Pilcher. "It feels really good to see our team come so far so fast and for all the right reasons."

The DAVD project and tests were made possible by innovation and collaborative efforts between NSWC PCD and local commands. NSWC PCD welcomed Fleet divers and commanding officers from the Naval Experimental Diving Unit, Naval Diving and Salvage Training Center, and the Center for Explosive Ordnance and Diving to participate in the tests.

"DAVD has multiple applications - military diving, public safety/first responders, science diving, as well as for commercial use," said Gallagher. "The break-through head-up display technology can be used for other types of work conducted in low or zero visibility conditions…even in outer space."

Outer space?

Representatives from the National Aeronautics And Space Administration's (NASA's) Johnson Space Center were on hand to observe the DAVD tests, and are in discussions with NSWC PCD to explore a possible collaborative development for the next-generation Extra Vehicular Activity (EVA) space suit's informatics head-up display capability.

Ironman and Aquaman.
Aquanauts and Astronauts.

The saga continues…

NSWC PCD Commanding Officer Capt. Aaron Peters, USN, dives the DAVD system October 12, 2017.

U.S. Navy photos by Ronnie Newsome

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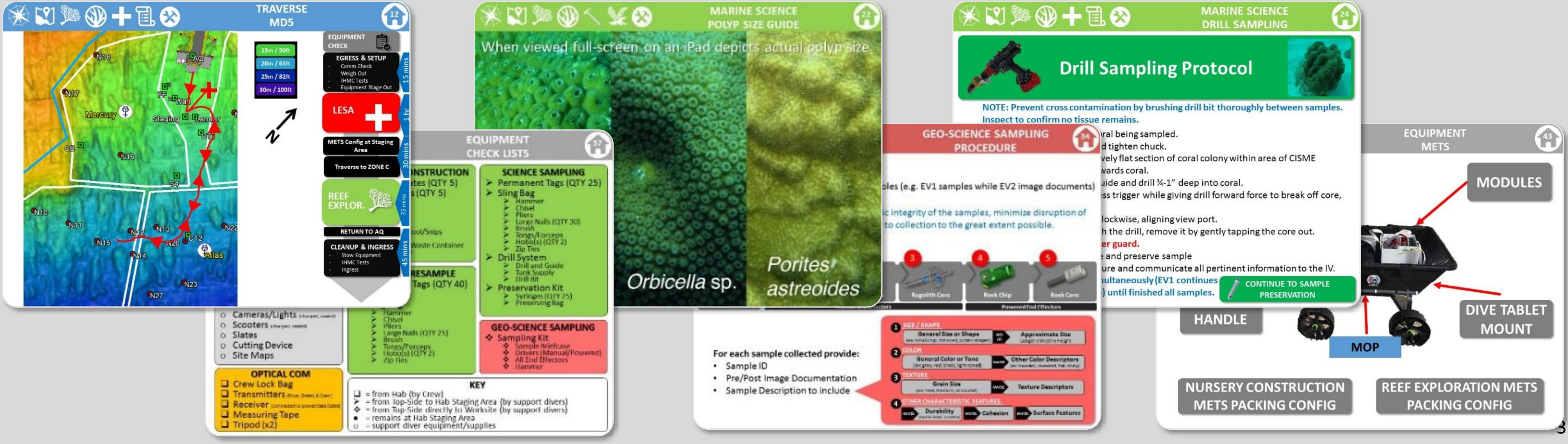
Objective

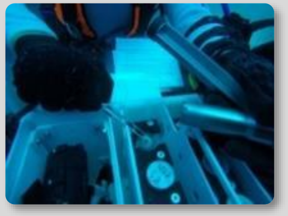
- Evaluate digital cue cards for EVA crew that allow crew to operate more effectively and autonomously while offloading IV tasking

Implementation

- Utilize 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 will be put into a digital cue card set that's loaded on the iPad



CORE SAMPLE AQUISITION

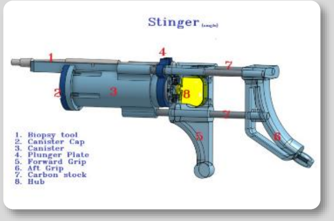


- Evaluate EVA tools and hardware for end-to-end science core sample acquisition
- Iterate core bit technology developed by Honeybee Robotics
- Evaluate curation system capabilities
- Look for ways to compensate for the limited down-force that crew is able to put into a sampling operation due to lower gravity levels
- Answer what efficiencies are gained/lost with having 2 crew work together to sample compared to 1 crewmember separately.

MODULAR EQUIPMENT TRANSPORTATION SYSTEM (METS)

- Evolve and test the Modular Equipment Transport System (METS), a concept for manually transporting & stowing equipment and samples on exploration traverses
- Examine improvements to the Wheeled Equipment Transport (WET; i.e. cart)
- Refine the Suit-Mounted Equipment Carrying System (SECSy) to more effectively transport smaller tools

ASTROBIOLOGY SAMPLE AQUISITION



- IHMC and Harbor Branch Oceanographic Institute objective to evaluate sampling tool
- Include in EVA ops con to evaluate tools and techniques for collecting astrobiology samples during an EVA

ESA EAC EQUIPMENT

- Integrate and evaluate Lunar Evacuation System Assembly (LESA 2.0), ESA's next version of their crew rescue concept
- Integrate and evaluate various ESA geological sampling tools, including scoops and sample markers

INTEGRATED EVA SCIENCE OPS

- Evaluate Exploration EVA operations that predominately include science tasks
- Assess lunar-focused science-driven EVA operations with an MCC-based ST providing direction
- Examine con ops with interaction between the MCC ST & the crew over lunar (real-time) comm and with signal outages (scheduled LOS and terrain shadows)
- Assess con ops with MCC/ST generating data (graphics) real-time and sending to IV, and IV sending that data to EV crew's HUD
- Compare a crew IV vs ground IV for science operations

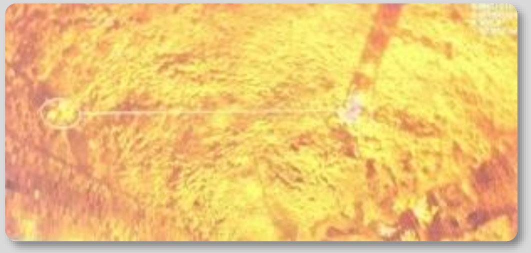
FLEXECUTION DURING EVA

- Appraise a flexecution methodology while utilizing a Science Team and authentic proxy science
- Assess capability for real-time alteration of science-driven EVA timeline

EVA OPS W/ SCIENCE INSTRUMENTS

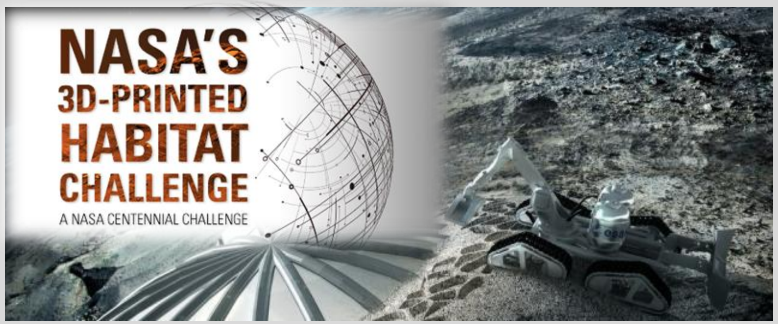
- Evaluation scenarios for operating on the lunar surface utilizing science instruments and tools

INTEGRATING INFORMATICS FOR EVA



- Evaluate use of advanced informatics concepts during an EVA
- Assess utilizing an area scanning system with data sent to EVA crew for self-navigation

PIONEERING



- Investigate the feasibility of a Critical Contingency EVA Habitat Tile Remove & Replace of a 3D-Printed ISRU Lunar Habitat

INTEGRATED MISSION CONTROL OPERATIONS @ NEEMO 23

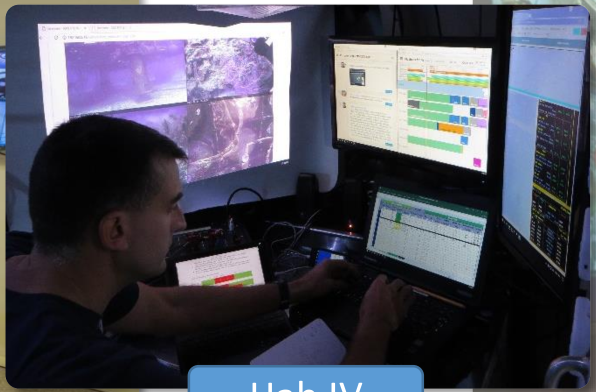
Objective

- Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) and integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a lunar signal (comm & data) 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

Mission Control


Hab IV

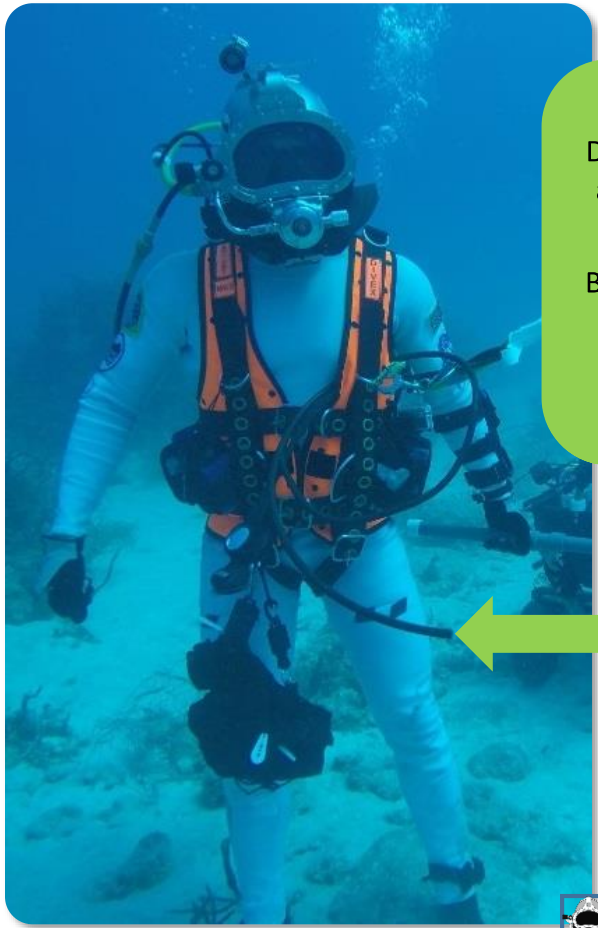

Science Team

The "Spacesuit": KM 37SS Helmet w/ Wetsuit & Harness


KM 37SS

37SS: Narrower FOV, Helmet movable

xEMU: Wider FOV, Helmet fixed



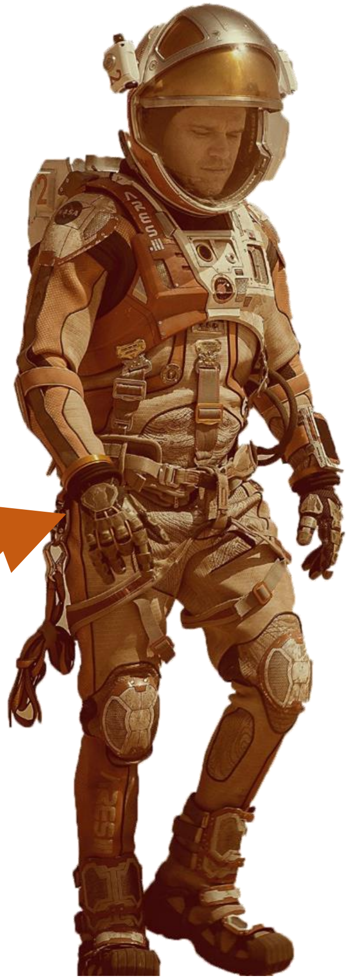
Dive helmet & system provide good analog to a spacesuit for concepts of operations evaluations

Both have different but comparable challenges for operations

Will utilize EMU TMG

Wetsuit: Very flexible
xEMU: Pressurized, bulky

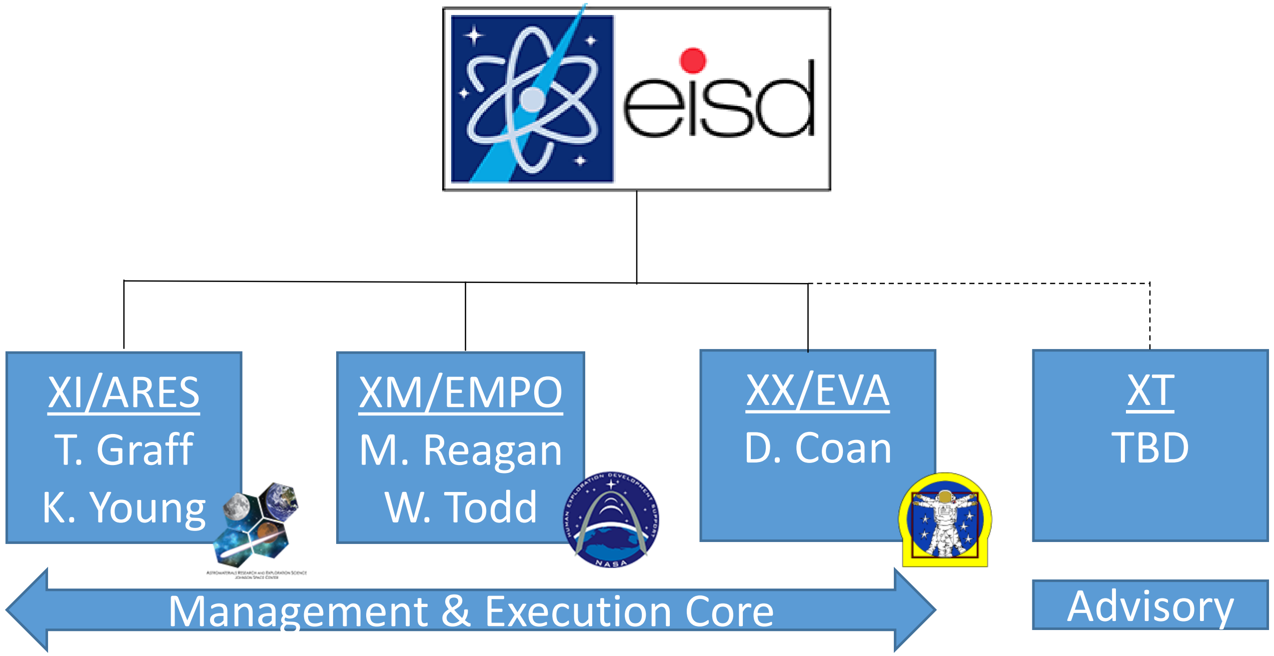

xEMU concept


TBD mEMU concept
(courtesy of *The Martian*)

Other

READy Core Team Concept

- **XI/ARES, XM/EMPO, XX/EVA team members are the core management and execution team**
- **Skills include**
  - Identifying applicable mission objectives
  - Establishing contributing partnerships
  - Developing mission timelines and supporting products (e.g., procedures, mission rules, crew training, etc.)
  - Mission operations & execution
  - Capturing post mission lessons learned and briefing appropriate audiences
  - Leverage and expand existing proposals/grants

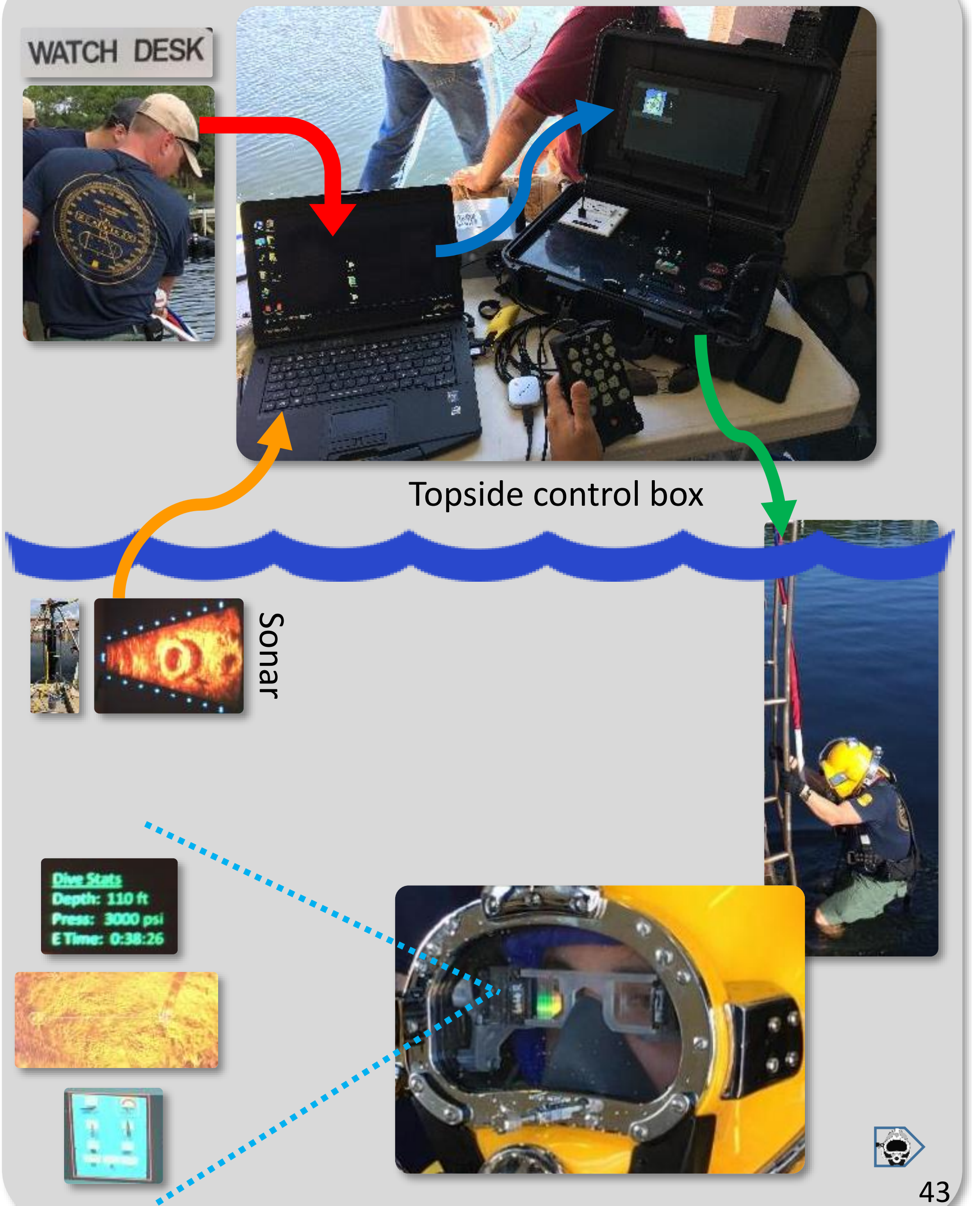


- **Non-READy duties include staying plugged in to HSF ops and architectural activities and feeding READy lessons learned back into them as appropriate:**
  - ISS Ops
  - EVA Ops
  - Mars Science Ops (e.g., MSL)
  - Gateway (DSG)
  - BAA NextStep Hab
  - EVA Strategic Planning and Architecture Integration
  - xEVA System Development
  - Mars Study Capability
  - Lunar Science objectives
  - Emerging…

KM37

MK20 FFM

- Sponsored by Naval Sea Systems Command Supervisor, Diving and Salvage (NAVSEA 00C), and developed by the Naval Surface Warfare Center Panama City Division
- The DAVD system
  - Binocular heads-up display (HUD) mounted inside a Kirby Morgan 37 (KM37) dive helmet and a MK-20 Full Face Mask (MK20 FFM)
  - Prototype uses commercial lenses (Lumus) and custom 3D printed frame/mounting systems
- DAVD capabilities
  - Allows a topside dive supervisor to relay visual mission data to the HUD via an Ethernet cable
  - Divers can view text messages, video, photographs, instructions, and augmented reality images
  - Divers can also utilize real-time sector scanning sonar imagery for navigation
  - Allows for operations even in murky, zero visibility conditions
- During diver testing, DAVD operated as advertised, with Navy divers able to utilize it for navigation, identification of objects, and for receiving task instructions real-time



DAVD Equipment: Diver-worn, Control Box, and Sonar

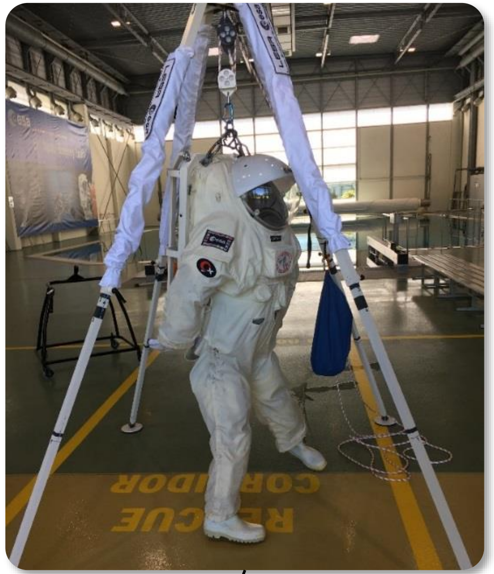
- DAVD Generation 1 Prototype
  - Lens mounted into KM37 Diver-worn canister for data
- 300’ data umbilical from canister (on diver) to control box (inside hab)

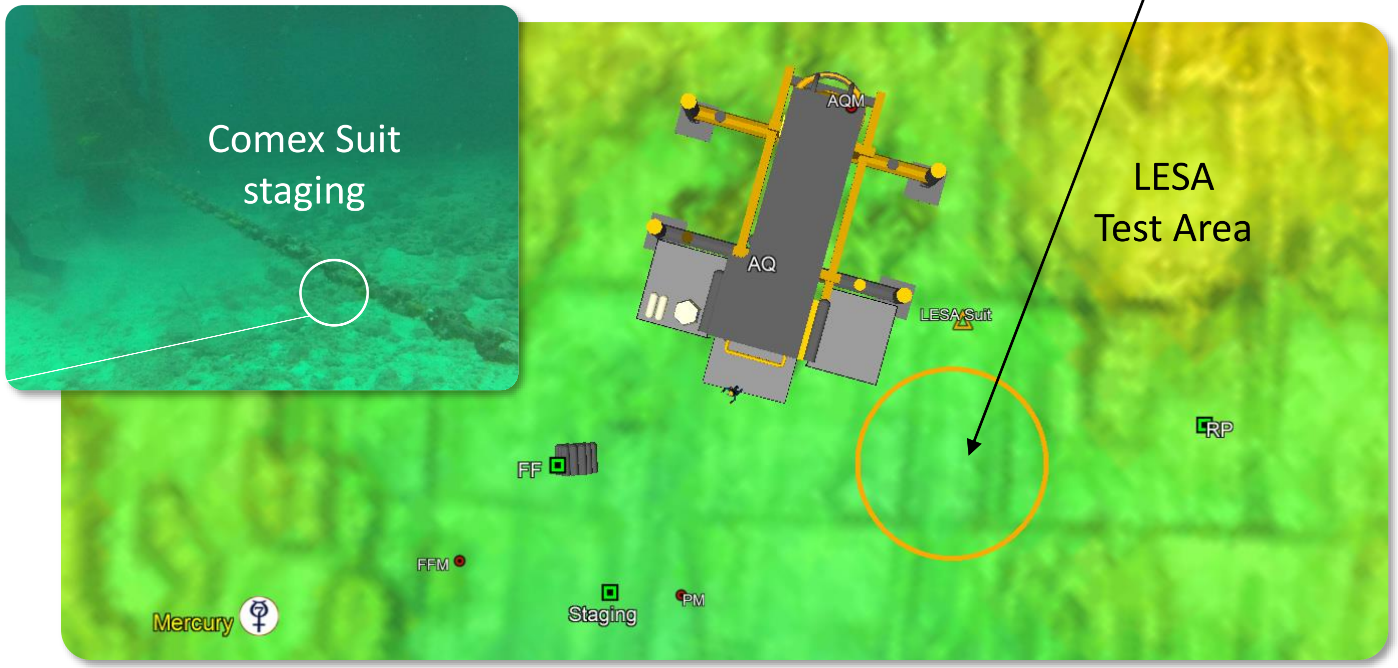
- Control box that takes data from laptop and pushed into lenses
- Display for IV to see what diver sees
- Box will be inside the hab and connected to the IV workstation

- Kongsberg MS1000 Sonar
  - Sonar head on stand
- Interface box (connects to laptop)
- Handheld controller for directing sonar
- 300’ cable from sonar head to interface box (in hab)

LESA 2.0

- New feature will of test will have crew utilize an empty spacesuit simulator (Comex suit) as the incapacitated crewmember
- Test area will be near the stbd-aft side of the hab
- Comex suit will need to be restrained overnight, possibly on chain running from stbd side of hab

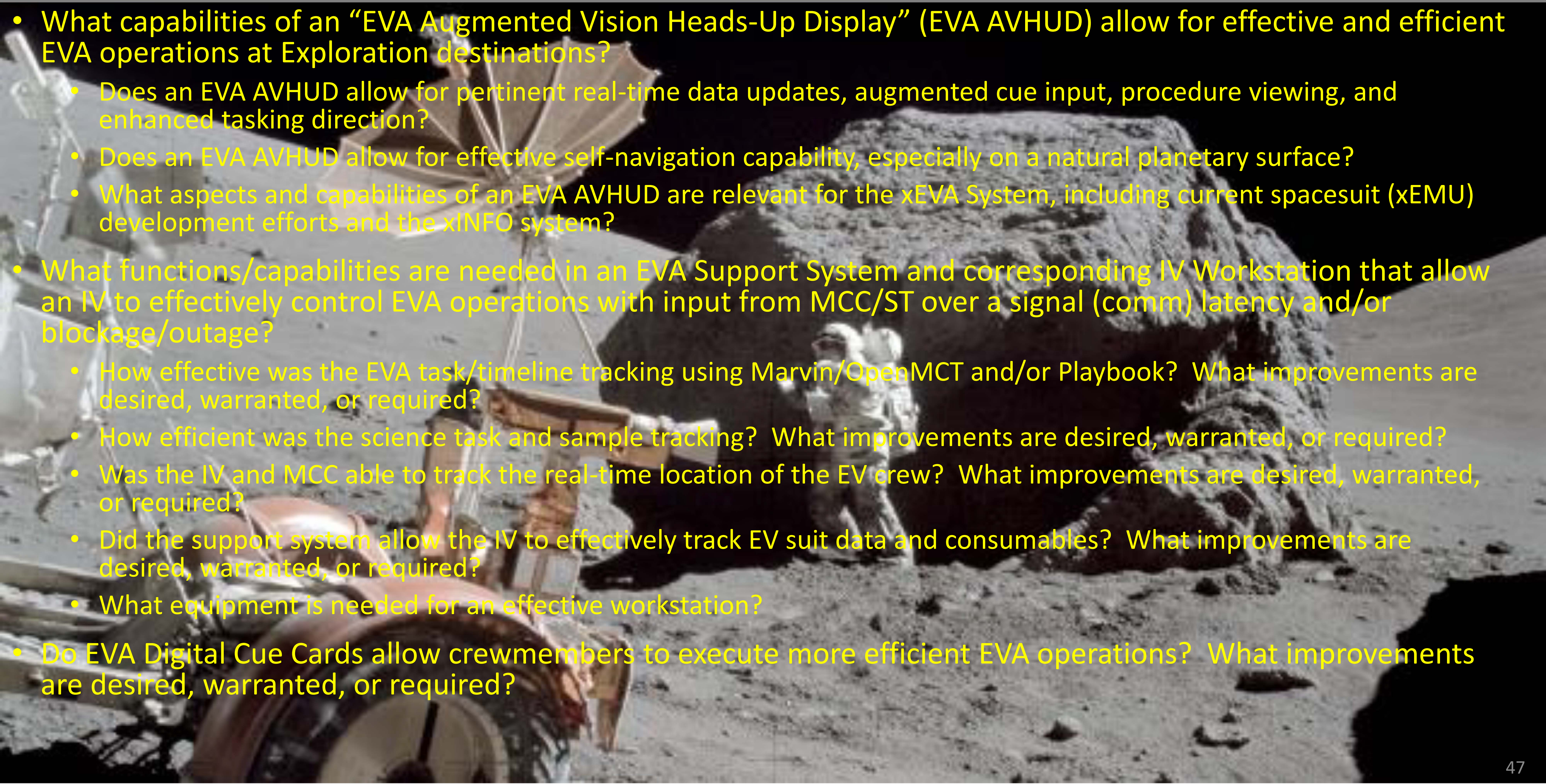




PaleBlue VR Trainer

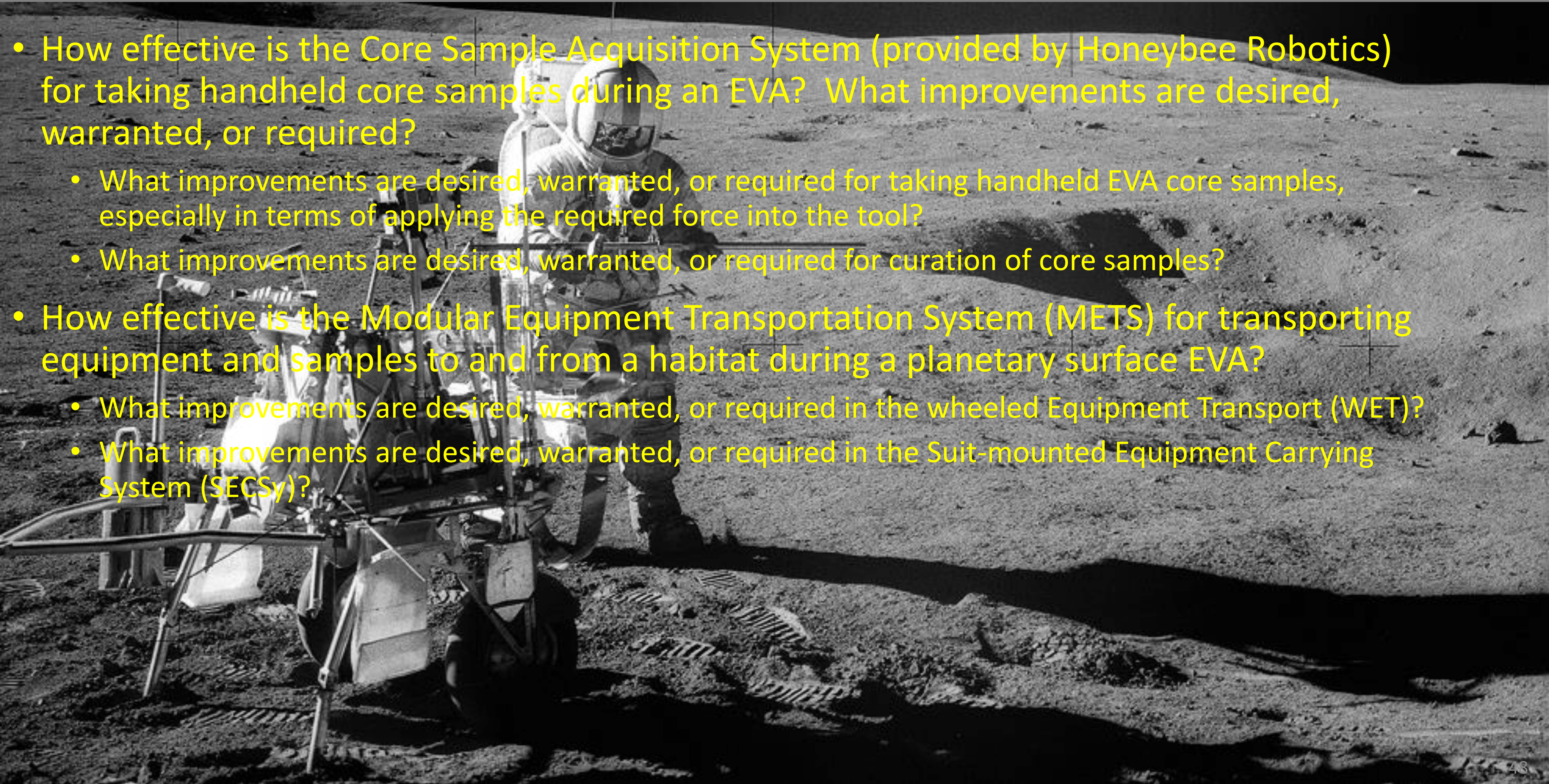
- PaleBlue is a company that specializes in providing VR, AR, and 3D simulators for the real world applications
- Developed a VR trainer for commercial diving using hard hats from a saturation bell – similar diving as NEEMO and analogous to real EVAs
- Models dynamics of things such as diver umbilicals – may translate to modeling of other flexible objects such as MLI, safety tethers, etc.
- Models of virtual consoles and panels
- Virtual demonstration on 5/16/2018 showed promise for NEEMO training and potential application for EVA training
- Currently planning an in-person demo during the NEEMO 23 ESAT (or crew training week) at ARB

Test Objective Questions for xEVA Informatics Concepts



- What capabilities of an "EVA Augmented Vision Heads-Up Display" (EVA AVHUD) allow for effective and efficient EVA operations at Exploration destinations?
  - Does an EVA AVHUD allow for pertinent real-time data updates, augmented cue input, procedure viewing, and enhanced tasking direction?
  - Does an EVA AVHUD allow for effective self-navigation capability, especially on a natural planetary surface?
  - What aspects and capabilities of an EVA AVHUD are relevant for the xEVA System, including current spacesuit (xEMU) development efforts and the xINFO system?
- What functions/capabilities are needed in an EVA Support System and corresponding IV Workstation that allow an IV to effectively control EVA operations with input from MCC/ST over a signal (comm) latency and/or blockage/outage?
  - How effective was the EVA task/timeline tracking using Marvin/OpenMCT and/or Playbook? What improvements are desired, warranted, or required?
  - How efficient was the science task and sample tracking? What improvements are desired, warranted, or required?
  - Was the IV and MCC able to track the real-time location of the EV crew? What improvements are desired, warranted, or required?
  - Did the support system allow the IV to effectively track EV suit data and consumables? What improvements are desired, warranted, or required?
  - What equipment is needed for an effective workstation?
- Do EVA Digital Cue Cards allow crewmembers to execute more efficient EVA operations? What improvements are desired, warranted, or required?

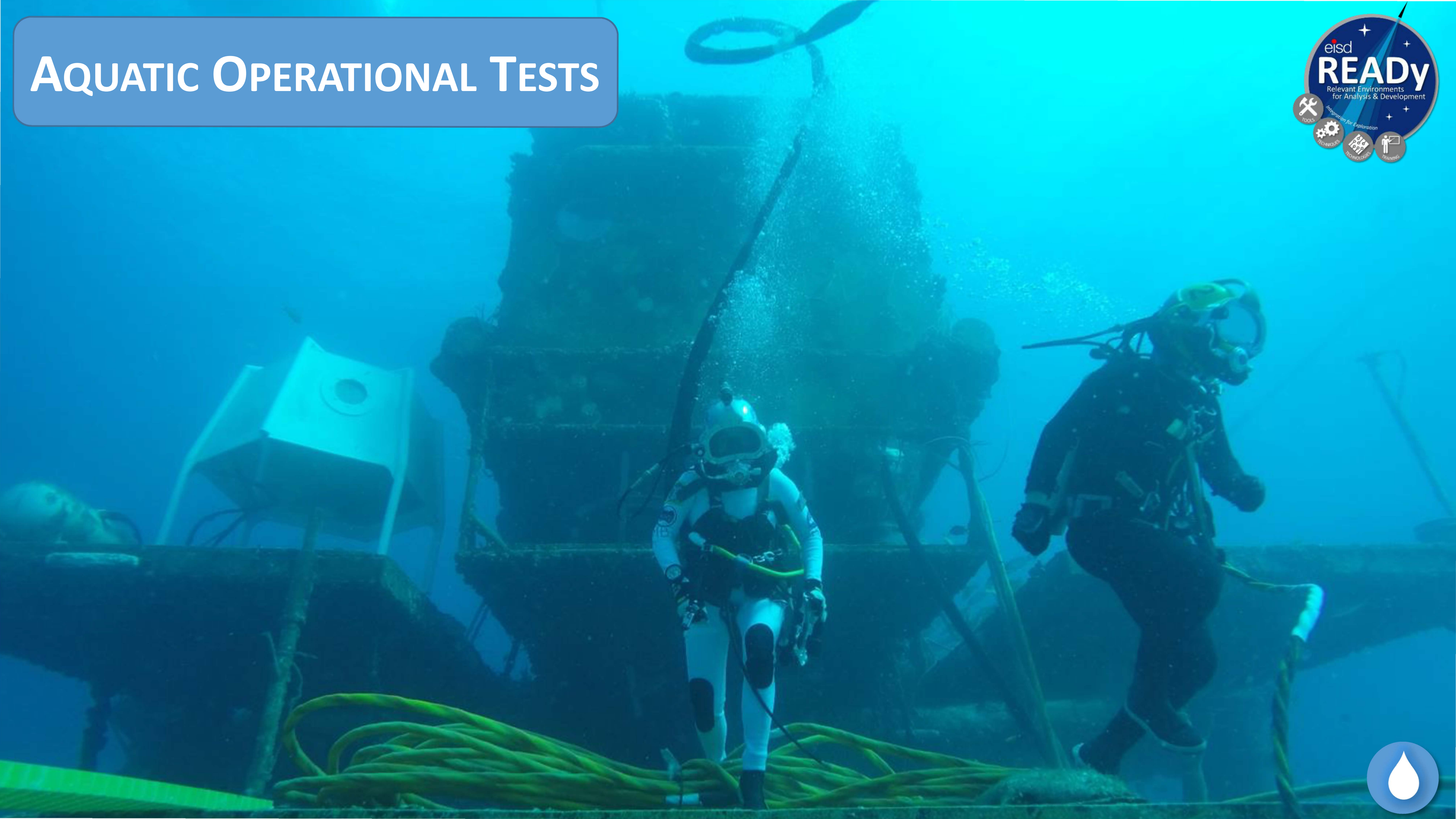
- How effective is the Core Sample Acquisition System (provided by Honeybee Robotics) for taking handheld core samples during an EVA? What improvements are desired, warranted, or required?
  - What improvements are desired, warranted, or required for taking handheld EVA core samples, especially in terms of applying the required force into the tool?
  - What improvements are desired, warranted, or required for curation of core samples?
- How effective is the Modular Equipment Transportation System (METS) for transporting equipment and samples to and from a habitat during a planetary surface EVA?
  - What improvements are desired, warranted, or required in the wheeled Equipment Transport (WET)?
  - What improvements are desired, warranted, or required in the Suit-mounted Equipment Carrying System (SECSy)?



Test Objective Questions – Concepts of Operations

- Is it Acceptable for an MCC Science Team to provide input and direction to the crew during planetary surface integrated EVA science operations with signal (comm) blockage/outages?
  - How doe lunar-relevant signal blockage/outages effect EVA operations?
  - How does utilizing a crew IV compare to using a ground IV
  - What improvements are desired, warranted, or required for decision making protocols?
  - What functions/capabilities are needed (software, hardware, techniques) to enable an MCC Science Team to effectively direct EVA science operations when limited with signal (comm) blockage/outages?
- What functions/capabilities in terms of integrated informatics are needed to enable the EVA crew to effectively operate and communicate information to an MCC Science Team during planetary surface operations with signal (comm) blockage/outages?
  - What advanced informatics concepts are effective for EVA operations?
  - What improvements are desired, warranted, or required for EVA crew self-navigation?
  - What improvements are desired, warranted, or required for IV/MCC tracking of EVA crew?
- What improvements are desired, warranted, or required for decision making protocols that enable effective flexible execution methodology (flexecution) for planetary surface EVA science operations?
- Which capabilities and techniques are enabling and significantly enhancing for the lunar surface mission operations concepts tested?

Aquatic Operational Tests



Terrestrial Operational Tests

Other Science Field Campaigns and Geology Training

Laboratory Operational Tests