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ARTEMIS

An Early Career Initiative (ECI): Enabling Moon to Mars Crew Autonomy Using Informatics & Decision Support Technologies

Project: Joint Augmented Reality Visual Informatics System (Joint AR)

May 16, 2023

Presented by: Paromita Mitra, Joint AR Principal Investigator
Avionics Systems Division, NASA Johnson Space Center

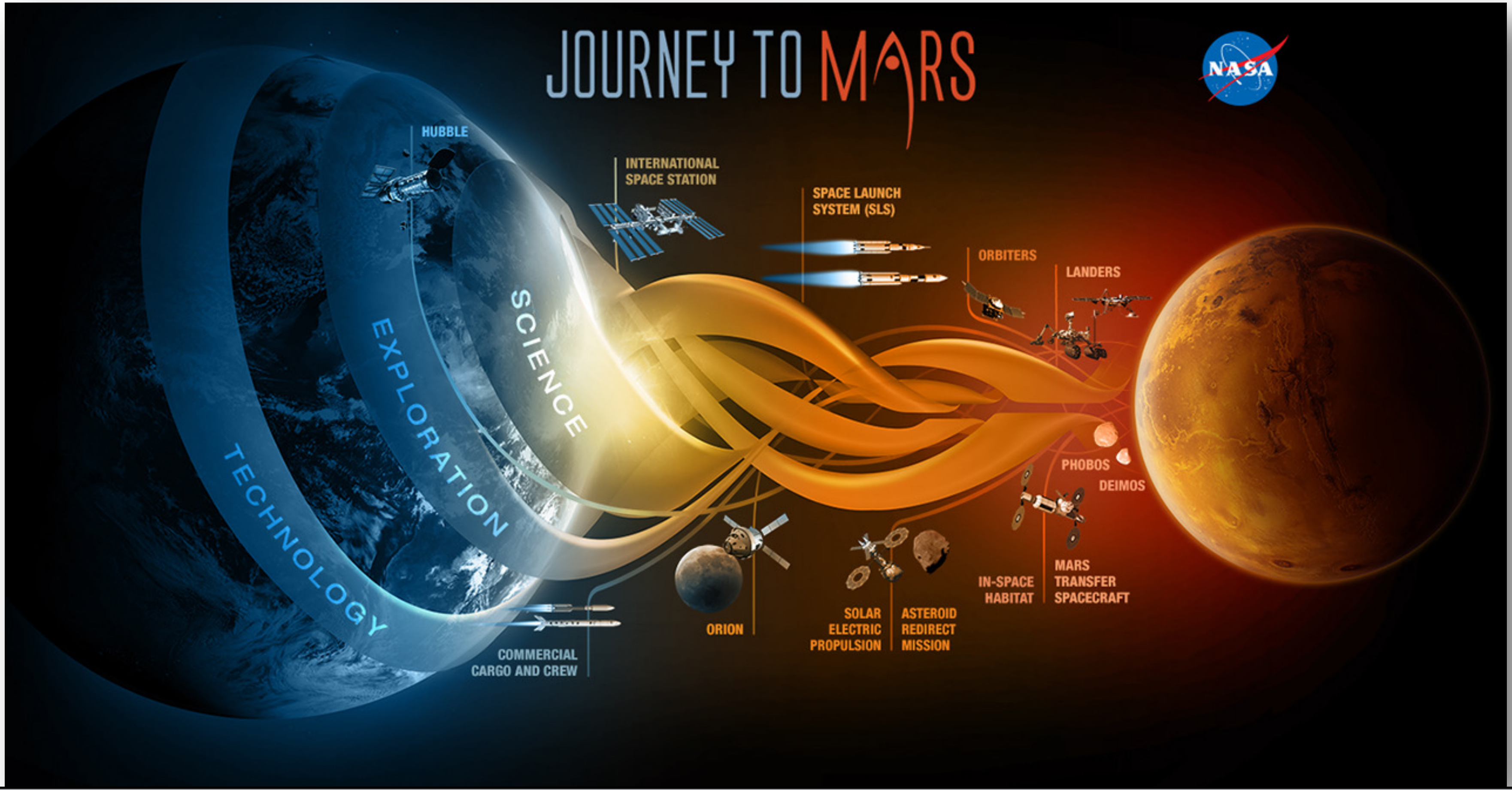
STMD ECI-funded: FY20-22
MCD Polaris-funded: FY22-23

Agenda

- Background
- Defining the Joint AR Product & Project
- Describing the Joint AR Team & Journey
- Exploring Agency Needs & Next Steps

Background

Goal: enable *crew autonomy* to more broadly enable Earth-independent missions



Proposition: Astronauts and flight teams need technologies to enable the crew to be self sufficient – suit-compatible augmented reality (Joint AR) is a proposed technology to meet this need.

The future of the NASA business model requires the Agency and Mission Control to have a close choreography of <u>multiple industry service providers to execute the mission</u>- from launch, surface exploration, to re-entry. With distributed assets, vehicles, data and payloads across EVA tasks, it is necessary to have <u>digital data be viewable</u> across assets.

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On Earth, we stay informed and connected via cell phones, computers, and their relative display and computer technology. These ubiquitous technologies generate useful information using common operating systems to drive the machine, graphics engines to render pixels on a screen, and software interfaces (APIs) to define rules for various apps like Google Maps. However, when exposed to radiation environments like the Lunar or Martian surface, traditional Earth displays would fail.

As a spaceflight community, we have not flown modern displays on the lunar surface. The extreme lunar environment (particularly radiation) will degrade displays over time. Joint AR has built a modular display system with potential safety critical, fault-tolerant graphics engine (STARK engine) flight certified software and relative display hardware for EVA assets.

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Defining the Joint AR Product & Project

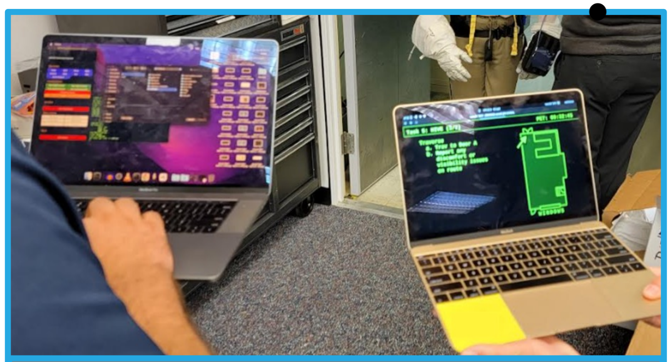
What is Joint AR?

The Joint Augmented Reality Visual Informatics System (Joint AR) product is suit compatible display for crew to access <u>centralized</u> mission data during EVA.

The Joint AR project integrates software (custom graphics engine & core flight software), physical hardware prototyping (suited AR platform), virtual prototyping platform (VR testbed), and operations (FOD + HSI con-ops definition) to address EVA mission needs of crew and flight teams.

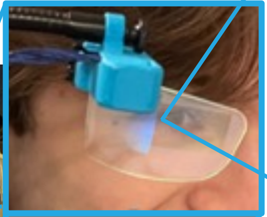
- Our name today is representative of what we learned is needed to make this EVA product succeed.
  - **Joint** = interdisciplinary people working **together** cross-agency on a **centralized** display system
    - **Together** - Johnson Space Center (Engineering divisions, Human Factors, Exploration directorate, Crew Office, and Flight Operations directorate), Ames Research Center, Glenn Research Center
    - **Centralized** - Common access point for crew for mission data
  - **AR** = discovering the advanced spaceflight display solution that is desired for Moon to Mars mission demands

Suited AR Platform

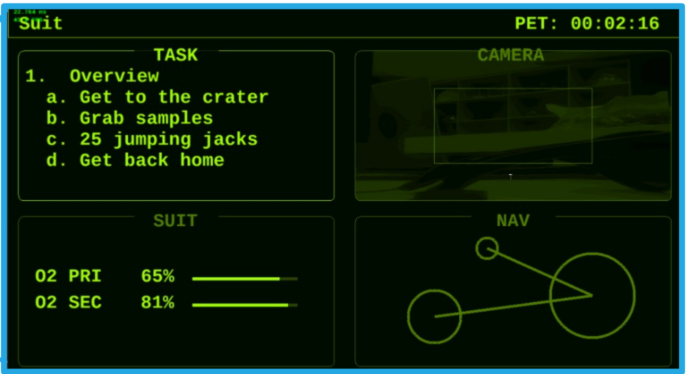


Remote control and remote viewer

Mobile Computing and Power

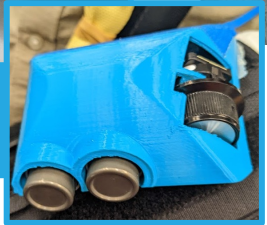


COTS waveguide prototype optics hardware



Prototype UI rendered in STARK

COTS 'Suit' Camera



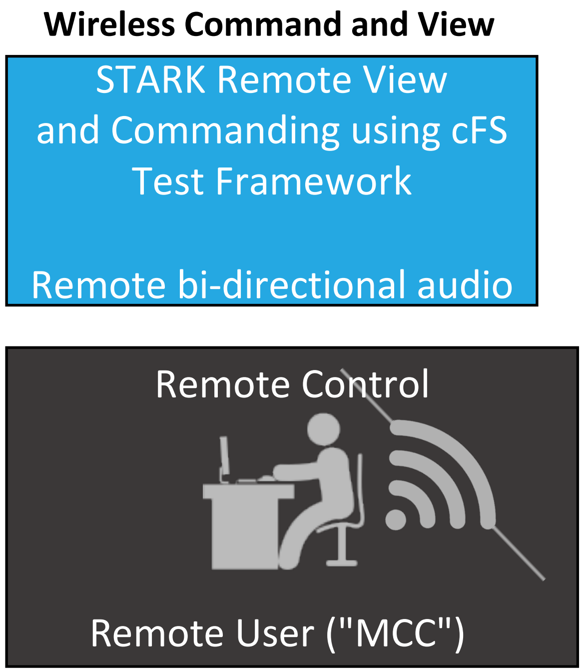
Custom glovebox tested "hands-on hardware" prototype controller

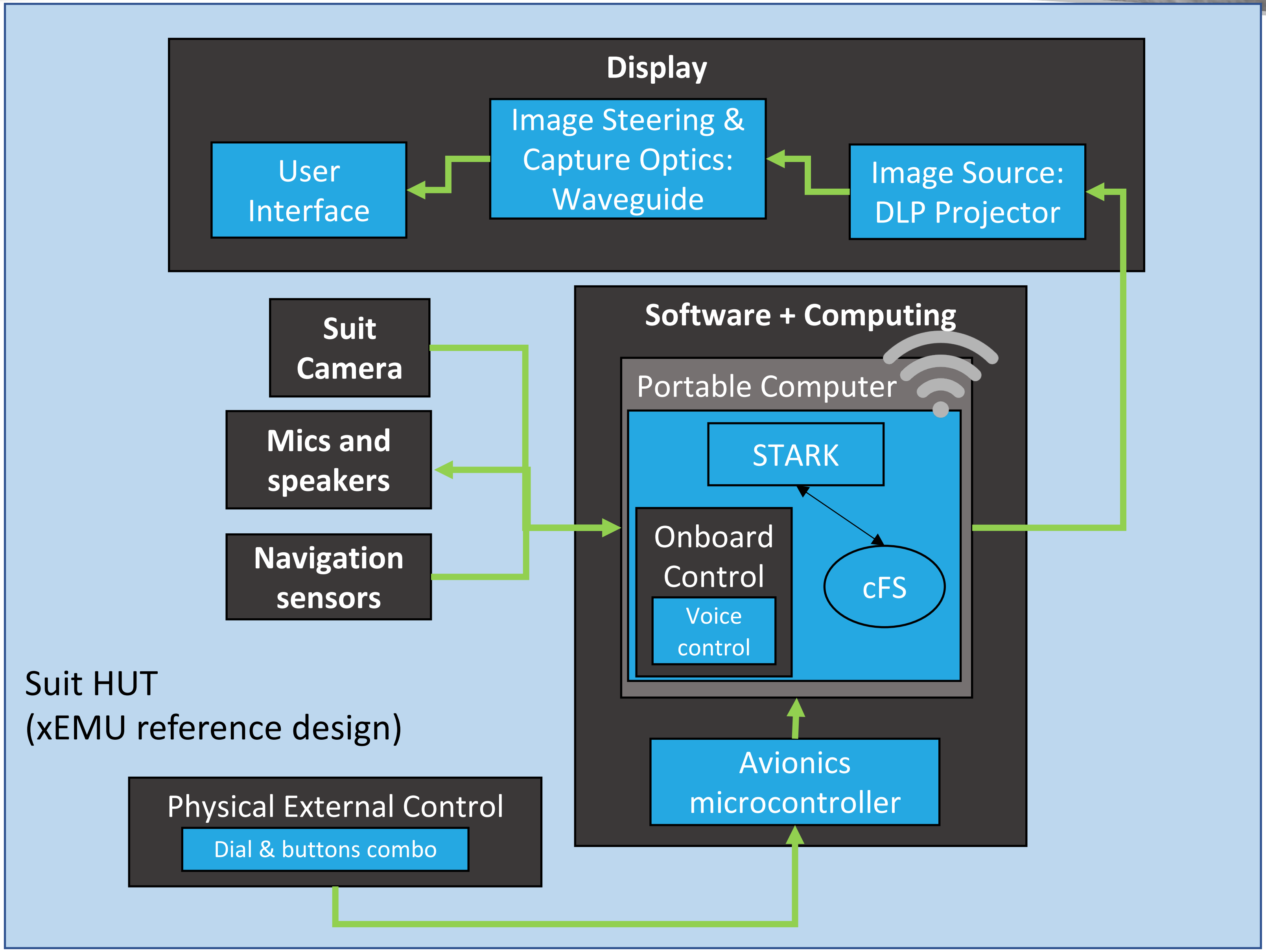
Crew/FOD/EA/Human Factors Human In The Loop Iterative Testing in Wearable Hard Upper Torso

Suited AR Platform System Diagram (as of May 2023)

Legend

DLP: Digital Light Processing
cFS: Core Flight Software
HUT: Hard Upper Torso
STARK: Space Technology Application Rendering Kit
MCC: Mission Control Center
xEMU: Exploration Extravehicular Mobility Unit





Display Functions & Apps

Table 1. EVA Concept of Operations and xEVAS Requirements Mapping

Exploration EVA System Concept of Operations (EVA-EXP-0042)	**xEVAS Contract Requirement: Information System (RQMT-065)** *The xEVA System shall provide an EVA information system and graphical display with the following key information to the suited crew member. Key information which enable efficient mission execution include:*
Suit systems monitoring and consumables displays	A. Consumable monitoring and display (Both)
Consumables calculation	B. Procedure viewer (Both)
Procedure and cue card viewing	C. Display of photo imagery and graphics (Artemis required, ISS goal)
Viewing of diagrams, photographs, annotated images, and videos	D. Timeline viewer (Artemis)
View timeline status, including time ahead/behind and consumables margin	E. Data storage (Artemis)
Navigation and tracking	F. Display for send/receive of text messaging (Artemis)
Augmented reality graphics and cues	G. Camera viewfinder (Artemis required, ISS goal)
Verifying helmet camera video framing and quality	H. Recording of crew audio/video/still image field notes (Artemis)
Interface with and transmission of scientific instrument, sensor, and camera	I. Map display, which includes EVA crewmember position and supports real-time navigation (Artemis Only)
Text communication from both MCC and an IV	J. Communication of relevant biomedical information. (Artemis required, ISS goal)
Ability to receive near real-time updates and content from MCC during the EVA	----

Matching Functions:

- Consumable monitoring
- Procedure viewing
- Imagery and photo viewing
- Timeline status
- Navigation
- Camera viewfinder
- Text communications

Un-matched Functions:

- xEVAS requests data storage & recording (assumed to be xINFO function not D&C component)
- xEVAS requests biomed information (not listed in original EVA con-ops; community debating on what relevant crew displays may show)
- AR form factor – NASA pursues this path due to reduced mass, studies which support reduced time on task, overall EVA cost reduced, usability, etc.
- NASA pursues a tool port (outlined in IRCD documents) to be compatible with science tools
- NASA pursues the ability to receive real-time updates from MCC

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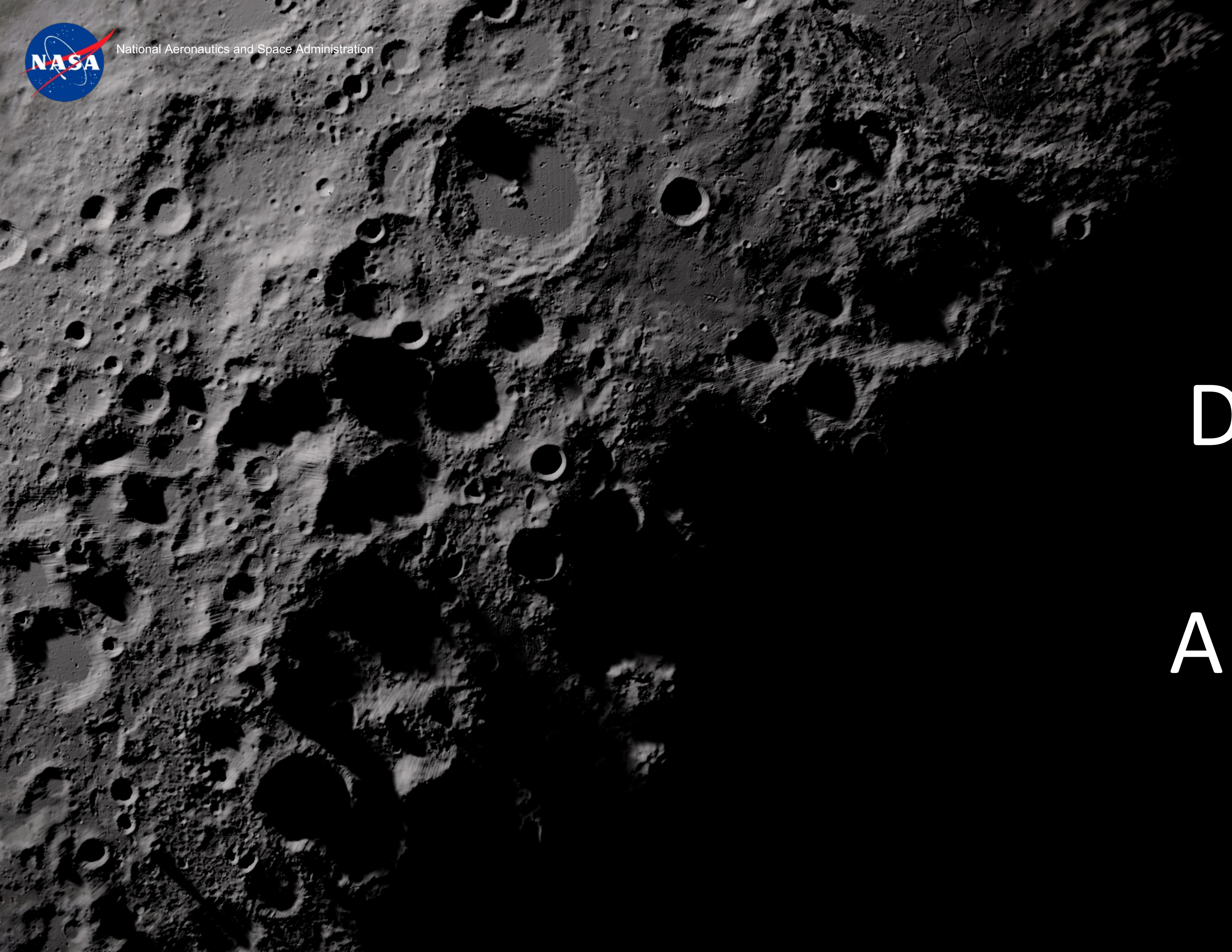

Describing the Joint AR Team & Journey

The Team

Legend:
Full Time
*Part-time

Stakeholders
Polaris/MCD
JSC Engineering
Crew Office
Flight Operations
EHP/xEVAS

Avionics
Morgan Novak (JSC/EV)*
Arjun Sethi (JSC/EV)*
Tyler Garrett (JSC/AH/SHREC)*

Software
Matthew Noyes (ER/JSC)*
Robin Onsay (ER/JSC)*
Jonathan Hoffstadt (EV/METECS)
Geraldo Cisneros (EV/JSC)*
Forrest Porter (ER/METECS)*

Project Leadership
Paromita Mitra (EV/JSC)
Matthew Miller, PhD (XI/JETS)*
Briana Krygier (EV/JSC)
Advisor: Mike Lewis (GRC)*

Mechanical
Kelly Mann (EC/JSC)
Kevin Lee (EC/JSC)*
Advisor: Kristine Davis (EC/JSC)*

FOD/HSI & SE&I
Daren Welsh (CX/KBR)*
Skye Ray (EC/JETS)*
Sarosh Nandwani (SF/JSC)*
Amanda Smith, PhD (SF/KBR)*
Mingyue Lanssie Ma, PhD (ARC/KBR)*

Partnerships
MIT.nano (via SAT)
NASA SUITS Design Challenge
-> Microsoft (via SAA)

Management Approach

Take-away: Over the last 4 years, this early career team has evolved its approach to meet product design and integrated work needs. The new Challenge Team structure allows for cross disciplinary collaboration and numerous iterations of the Joint AR product.

ECI emphasized unique management approaches than traditional NASA waterfall. At the time, we chose a *loose* framework of Rational Unified Process (RUP) = Waterfall + Agile.

Team Structure: Skill-oriented sub-teams

Dev Cycles: 3-month sprints to demos

SE&I: meeting xEMU waterfall products

Location: Remote due to COVID

Early Career Initiative
FY20-FY21

Today we are iteration based with a user testing focus to respond to the most pressing improvement desires.

Team Structure: Interdisciplinary Challenge Teams with product focus

Dev Cycles: 1-month sprints to meet Challenges

SE&I: Testing-driven use-case definition for con-ops and ultimately, requirements

Location: Co-located lab space with hybrid workspaces

Polaris Project
FY22-FY23

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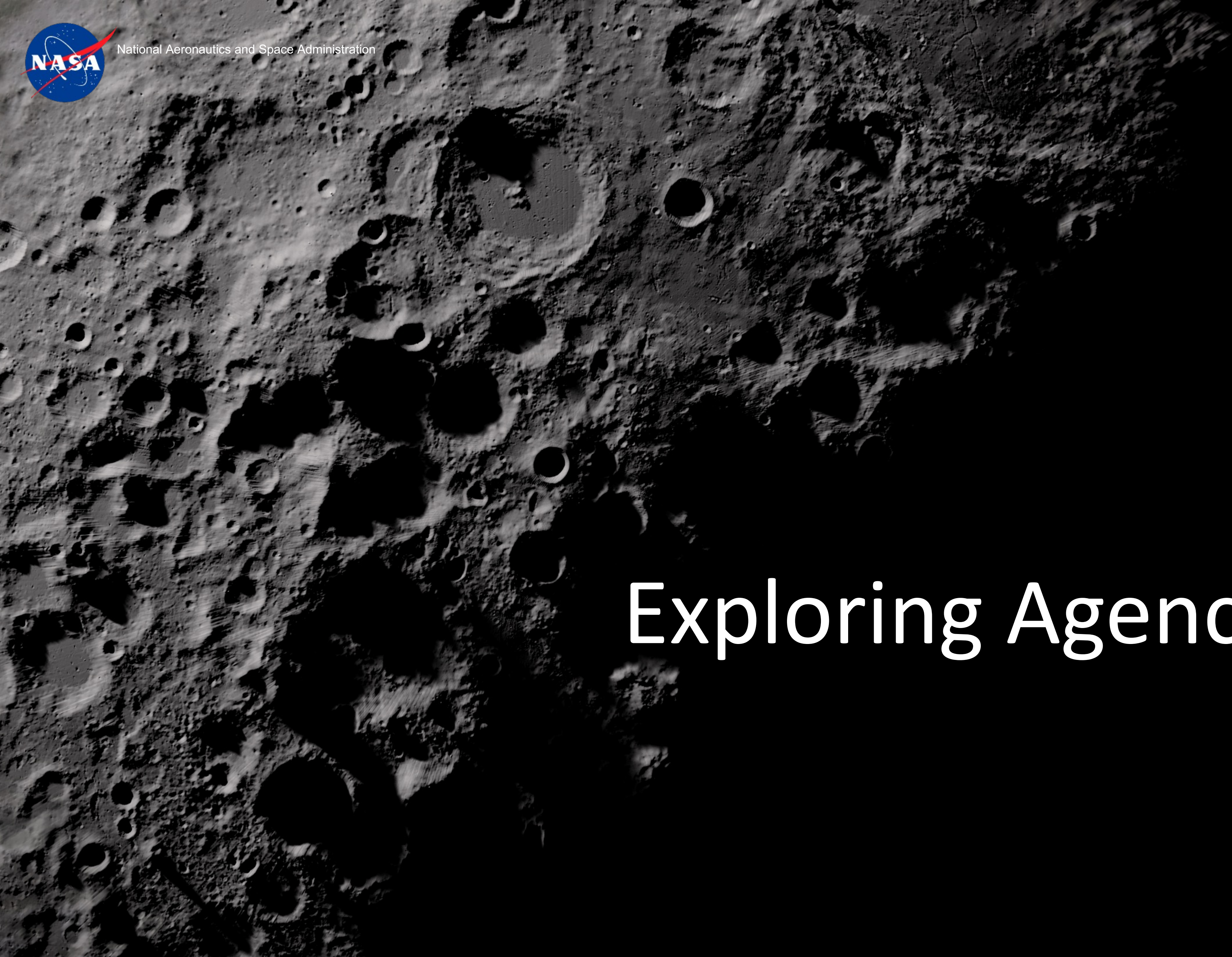
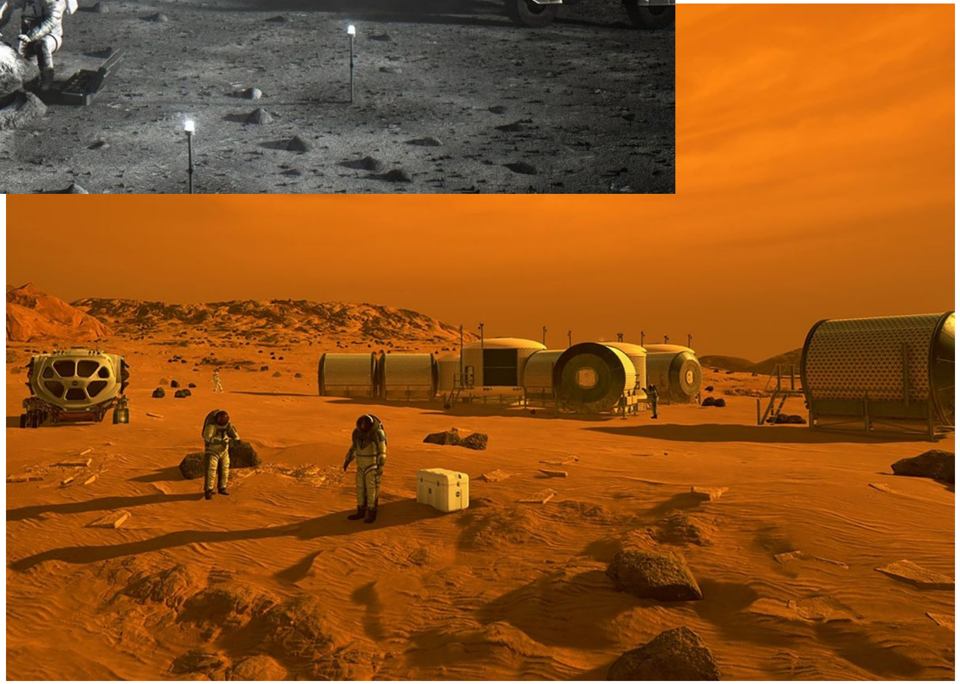


Exploring Agency Needs & Next Steps

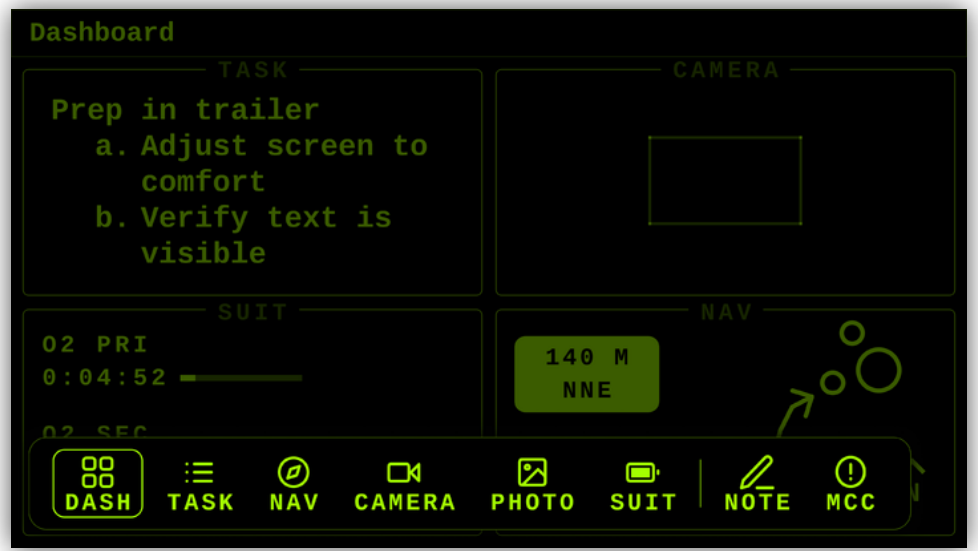
Envisioning an Integrated Moon to Mars Architecture: EVA Informatics

- ***Imagine a world in which crew transitions to the rover and their display maintains all the relevant data for the changed mission context and work demands (e.g. – crew sees data relevant to the lunar asset of interest).***
- **Informatics – Spacesuit avionics and display subsystem responsible for crew autonomy technology**
- **Extensible safety critical, radiation tolerant software is a necessity**
  - The STARK graphics engine and flight software development exists in an extensible development path
  - Space Technology Application Rendering Kit (STARK) is a platform-agnostic high performance graphics engine optimized for an embedded environment
  - Integrate with mission operations personnel (MCC)
  - Conduct design iterations based on hundreds of hours of relevant user testing (between flight controllers, EVA stakeholders, and crew members)
  - STARK can be leveraged as an integration point across the mission profile
    - Integrate NASA ground software products – EMSS (EVA Mission Support Software), AEGIS, Maestro, CODA
- **Core architecture of the Joint AR display avionics and optics can be leveraged in many form factors to meet additional mission contexts beyond the suit (SW is not limited to AR)**



Space Technology Application Rendering Kit (STARK) Graphics Engine

- The Space Technology Application Rendering Kit (STARK) is a low-power, high-performance, radiation-tolerant, zero-dependency graphics engine developed by NASA for next-generation human exploration missions.
- The problem motivating the STARK's development was the need for a an extremely lightweight, high-performance, platform-agnostic, low-power spacesuit graphics augmented reality engine capable of servicing Class A Safety Critical display needs.
- A STARK application consists of 3 primary components:
  - **The STARK Runtime** -- the executable which contains all engine-level software
  - **The Application Library** -- a dynamic library which "plugs in" to the running engine like a cartridge to an old game console
  - **The STARK Plugins** -- both engine and application-level plugins which provide additional functionality to the main application



Progress Toward Gaps

- **Enabling NASA to field an AR system for Mars xEVA, using Lunar xEVA as a proving ground. Prototyping and testing in analog environments today.**
- (Gap #2820) **Graphics Processing for Deep Space Missions** - STARK development – custom graphics engine optimized for spaceflight that can be leveraged across the mission profile
  - Leverage NASA integration – EMSS (EVA Mission Support Software)
- (Gap #2815 and 2821) **Displays (Two-Dimensional Visual Electronic) for Deep Space Missions** & **Heads Up Display (HUD) Optics for Exploration EVA** - Commercial AR market studies and evaluation to determine spacesuit compatible display and optics technologies, university research funded custom optics development
  - Leverage the agency and commercial AR efforts
    - XR community of practice, SUITS, technical conference attendance
- (Gap #2941) **EVA Bioinformatics & Decision Support** - Instead of worrying about displaying all the things a 'system has to offer' we rather focus on the <u>decisions that a crew member might need to make </u>with that information to build the right product
  - Building Crew earth-independent tendencies by testing in analog environments, fielding the system for Lunar xEVA, and then for Mars xEVA
  - Collaborate with FOD/MCC who will play an important role in Earth independent modes of operation
- Publishing knowledge
  - "Realizing a Spacesuit Compatible Augmented Reality System to Meet the Work Needs of Future Human Spaceflight Exploration" – M. Miller, D. Welsh, B. Krygier, M. Noyes, K. Mann, P. Mitra
  - "Trades, Architecture, and Design of the Joint Augmented Reality Visual Informatics System(Joint AR) Product" – P. Mitra, et al.
  - "Using Virtual Reality to Envision Deployment of Spacesuit-Compatible Augmented Reality Displays for Lunar Surface Operations" – J. Keller, et al.

Call to Action – What's next?

- We've built a TRL 5 display platform that lets us discover an AR solution to meet mission autonomy, safety criticality, and radiation tolerant demands
  - Leverage NASA/JSC connections to build STARK with relevant connections to multi-vehicle display products as an extensible graphics engine across mission profiles
- Seeking infusion into EVA HSM program
  - Support test bed and EVA analog development activities
  - Seeking infusion into xEVAS space suit vendors; meeting regularly with Collins and Axiom for vendor infusion
- Open issue: there's currently no foreseeable efforts to ensure vendor services' data and EVA displays are interoperable, radiation tolerant, and useful for mission operations. Yet, crew autonomy gaps are being defined by display and informatics.
  - We exemplify the needs of the broader EVA data ecosystem to enable the distributed displays and informatics vision
  - Seeking support for FY24 and beyond
- Open questions: What does FY24 and beyond look like for enabling suited crew autonomy?
  - When and how do the missions start to shift toward 'Earth independent' operations and rely on crew autonomy?

In-Room Demo System

Hardware

DLP Projector/Waveguide Evaluation Kit

Joint AR hand controller – dials and buttons

Software

Joint AR Custom Graphics Engine - STARK Rendered User Interface Application: procedures, navigation (2D AEGIS Maps), camera view finder, photos, suit consumables, notes, and MCC messages

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"I had the opportunity to test the integrated [Joint AR] system. It is a potentially extremely valuable tool for lunar navigation and heads-up, real-time display of procedures, science data viewing, and for enhancing crew situational awareness. I hope we can continue to develop this system and integrate it with spacesuit and lunar EVA surface ops development."

Kate Rubins, PhD
Astronaut ISS Expedition 48/49 and 63/64
EVA/Robotics Technical Assistant to the CB Chief
August 24, 2022

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Distributed Displays & Informatics

HARDWARE

Real-time Sensing
- Environment sensing – computer vision needs (IR, orientation states/IMU, gray scale cameras for compute)
- User sensing – user interaction needs (facial recognition)

Compute System
- Vulkan Safety critical compatible avionics
- Deploy fault mitigation techniques

Display
- Radiation-hardened display & optical components
- Form factor is a heads-up display for spacesuit

SOFTWARE

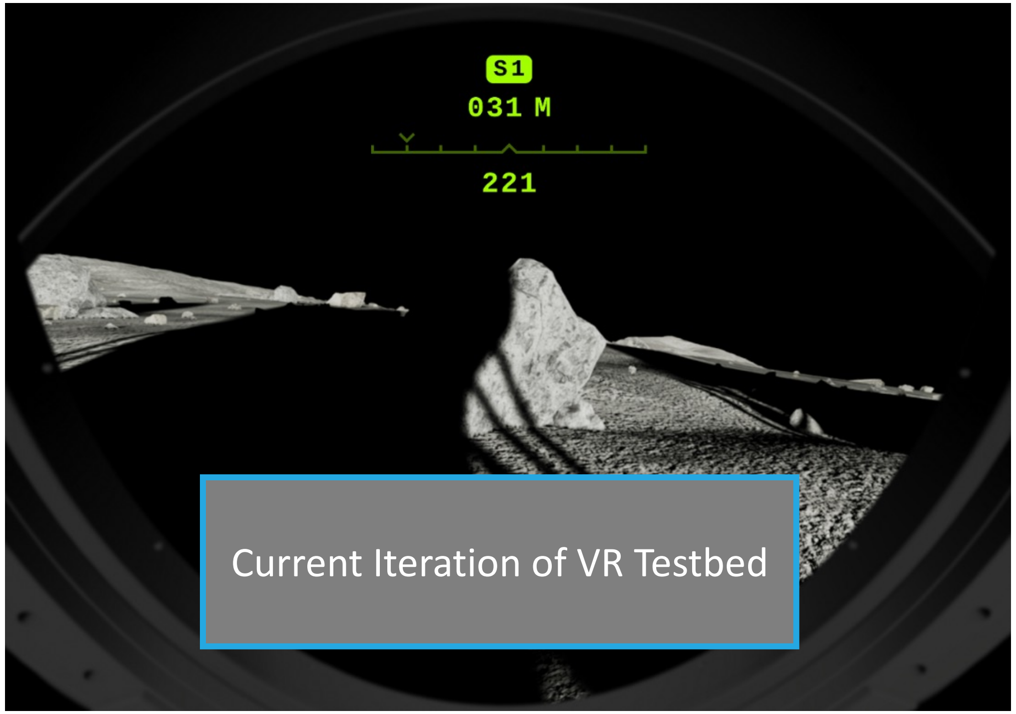
Any Display SW
- Flight software with safety critical Vulkan SC
- STARK graphics engine (low power, cross platform, high performance, low compute graphics rendering capability)

Vendor Interface
- Software interface (API) to enable vendors to build a safety critical visualization and display ecosystem

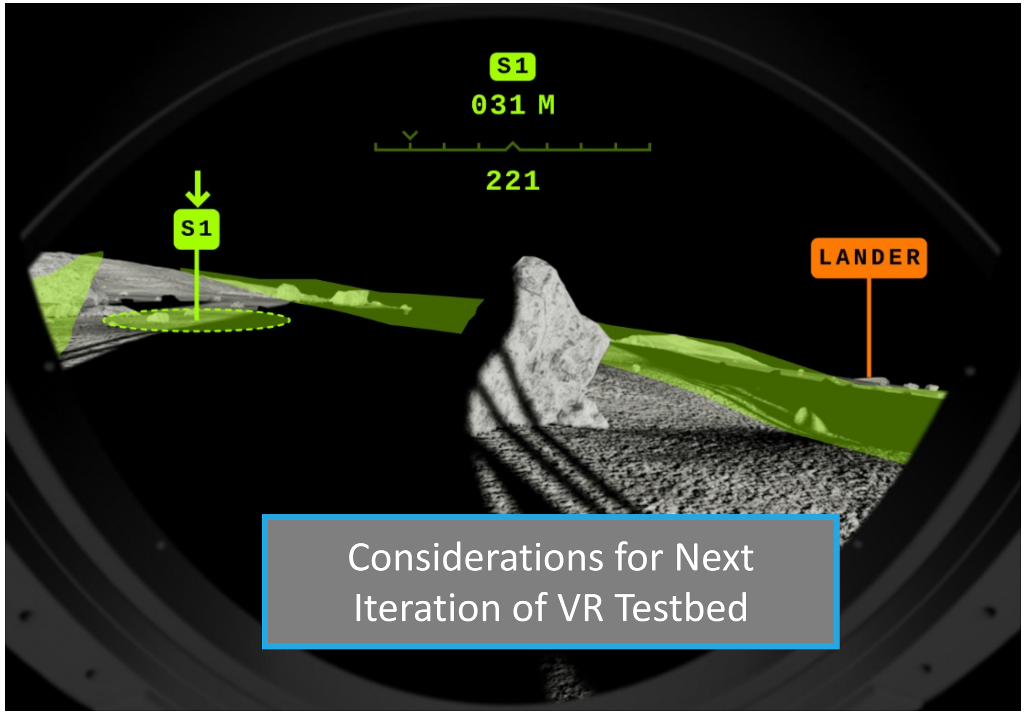
Ground/ MCC
- Immersive displays for MCC (CX tool used during EVA)

Virtual Reality Environment

- Proving ground for future forward features while stressing relevant EVA environment states. We are creating the building blocks for future states of this technology.
    - Rapid iteration before implementing in suited AR platform
    - Sensor integration and registered AR



Current Iteration of VR Testbed



Considerations for Next Iteration of VR Testbed

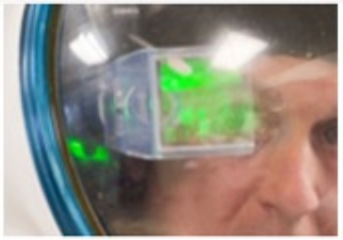
Historical NASA AR Investigations vs Now

- The displays market has transformed since Joint AR began as a project. AR is forecasted to grow from a $4.16B in 2020 to $97.76B in 2028; a CAGR of 48.6% [source]
  - Waveguide optics has emerged as a lead optics architecture for AR (Display Week 2022) which meets medium eye relief needs.
- Safety critical frameworks (Vulkan) to support new capabilities (static memory allocation in GPU) that previously did not exist are now available (March 2022)[source]

Take-away: commercial market boom is a critical piece enabling Joint AR's meaningful discovery process towards spaceflight AR features/expectations

1990 — JSC

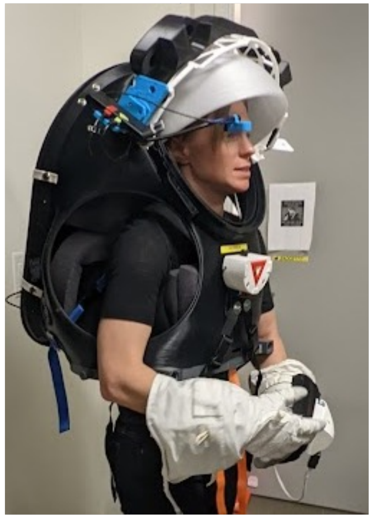
2011 — GRC



2013 — GRC

2017 — GRC-JSC-MSU

Today — JSC



Joint AR Journey (*COVID)

Pre-ECI (2017-2019)

- Unfunded Displays and Controls req'ts existed for xEMU Informatics subsystem
- Market study to identify optics gap
- GRC-MSU research to define performance impacts of EVA HUD

ECI Year 1 (FY20)

- Goal to meet xEMU interface for 2023 flight and sustained lunar/deferred +140 req'ts
- Explore partnership w/Collins, encountered legal complications
- Shifted to pursuing a university research partnership with MIT

- Project chose to stay in xEMU design space and work toward implementing a novel technology/capability within an existing project/architecture
  - E.g. Crit 3 functionality
- Deliver requirements and design review SE&I products to mirror xEMU milestones

ECI Year 2 (FY21)

- Engineering development for three demo iteration goals

- STARK creation
- Avionics cable harness and design
- Publicly released Joint AR optical requirements

- End of ECI saw the creation of EHP (EVA & Human Surface Mobility Program) and the shift of xEMU to xEVAS

Polaris Year 1 (FY22)

- Joint AR chose to pursue two parallel paths
  - xEMU reference ECI baseline – MIT
  - Commercial AR industry re-exploration
- ECI MIT Contract commenced
- New Commercial AR Market Study

- Developed the <u>integrated</u> 'Joint AR Experience'
- Leverage Joint cross-agency network and stakeholders
- xEVAS selection announced – Axiom and Collins

- Developed the <u>integrated</u> 'Joint AR Experience'

Project Axioms & Risks

Project Axioms and Assumptions

- Crew at the broadest level need contextually relevant information to make informed decisions to cope with mission demands.
- Data across platforms in the mission must be accessible. Data access and control must be appropriate for the work context of the crew member.
- Autonomy enabling technology cannot be created independent of the full team of stakeholders. The imagination and conceptualizing of future missions will require iterative discovery and consensus.
- Joint AR needs to field a solution, assess, iterate, redeploy in an appropriate mission context. We can do this via analog testing and Moon deployment in order to achieve autonomy on Mars.

Acknowledged Risks

- Any data that cannot be locally accessed poses a risk to Earth independent operations because we cannot presuppose what data is and is not useful for all the possible scenarios crew might one day face.
- Community adoption of AR to be the desired medium to interact with data to make informed decisions.

Take-away: Joint AR believes these axioms must be true for success of the product. The Joint AR project is actively working to mitigate these risks and unifying cross-agency stakeholders. Joint AR seeks agency support and feedback.