ENVISIONING AND SUPPORTING THE DEMANDS OF FUTURE SCIENTIFIC EXPLORATION OPERATIONS. M.J. Miller[1], T. Graff[1], K. Young[2], D. Coan[3], A. Abercromby[4]; [1]Jacobs, NASA JSC, Houston, TX 77058 (*matthew.j.miller-1@nasa.gov*), [2]UTEP-Jacobs JETS Contract, NASA JSC, [3]Aerospace Corp., NASA JSC, [4]NASA JSC.

Introduction: Envisioning a realistic and desirable future where human spaceflight missions successfully pursue scientific objectives necessitates a closer investigation of the inherent challenges facing extravehicular activity (EVA) operations. As it currently stands, a host of scientific knowledge gaps are under development in various analysis groups (e.g. MEPAG[1], LEAG[2], SBAG[3], etc) and have been instantiated in a number of operational concepts and design reference missions (DRMs) where crew would perform EVA to explore and study their environs [1-4]. A consistent theme among these envisioned operations is the expectation that astronauts will be productive and safe while also being less reliant on Earth-based support personnel. However, astronauts have not performed scientifically-driven EVA in five decades since Apollo J-class missions (15-17), and even those missions still adhered to scripted timelines, leaving little room for 'exploratory' behavior [5-6]. Furthermore, the entire history of NASA EVA experience to-date has had an intrinsic, real-time communication relationship between ground support and astronauts throughout EVA execution [7].

So how might the EVA work domain be extended to accommodate scientific objectives, in the absence of extensive ground support? One proposed solution is the development of decision support systems that will help future astronauts meet the demands they will face as they attempt to explore deep-space destinations. We contend that there are two overarching aspects to consider to realize this solution: 1) a more thorough understanding of work domain constraints that are likely to shape future EVA operations must be obtained, and 2) incremental technological development must be made alongside incremental development of the work expected of future crew.

This abstract briefly summarizes these perspectives by extending previous research on EVA as a formal work domain [8] and the implications this prior research has for promoting scientific exploration operations. Additionally, this abstract highlights relevant development of the *Scientific Hybrid Reality Environment (SHyRE)* program which will be used to design, prototype and test flight-like decision support system technologies for envisioned scientific EVA operations.

Capturing the Constraints that Shape EVA: The intrinsic balance between crew productivity and safety will persist in any future envisioned concept of operations, regardless of any potential scientifically-related demands (e.g. scientific data management, sample curation and processing, etc.). Previous research has already identified a comprehensive set of constraints that shape EVA execution and identified EVA timeline and life support system management as critical to mission success [9]. With the introduction of scientific objectives as part of future EVA timelines, there exists a need to provide crew with the means to critically assess their timeline progress as it relates to their scientific objectives all while maintaining crew and vehicle safety.

Building Support Systems to Meet Hypothesized EVA Demands: To help manage EVA constraints, next-generation support systems have been prototyped and tested to support future EVA operations [8], [10]. This development effort involved characterizing the underlying work domain constraints that shape EVA to arrive at a set of requirements that articulated the demands present during the execution of EVA, irrespective of any particular EVA objective [9]. These requirements were then prioritized and applied to the development and testing of decision support system software prototypes envisioned to be used in a future EVA context. Some key assumptions involved in this development effort were: 1) The intravehicular (IV) operator will be a critical component of future operations, serving as a communication relay and field marshal of EVA execution; 2) The IV operator will be responsible for synthesizing timeline progress (Timeline Management) as well as associate life support system constraints (e.g. consumables) with remaining timeline tasks (Life Support System Management); and 3) This research focuses specifically on the moment-by-moment execution of EVA, rather than aspects related to EVA planning or hardware development.

Two prototypes were developed, referred to as Baseline and Advanced configurations. The Baseline configuration consisted of a combination of existing NASA ISS paper-based and digital work artefacts necessary for simultaneous timeline and life support system management by an IV operator. While spacesuit telemetry variables exist in digital displays, all existing (and prior) NASA timeline products are paper-based. Furthermore, multiple ground support personnel manage these individual aspects. Therefore, the immediate challenge in the development of the Advanced configuration was to

[1] Mars Exploration Program Analysis Group: *https://mepag.jpl.nasa.gov/*
[2] Lunar Exploration Analysis Group: *https://www.lpi.usra.edu/leag/*
[3] Small Bodies Assessment Group: *https://www.lpi.usra.edu/sbag/findings/*

transition and synchronize timeline elements with life support variables in a digital tool for a single user.

Figure 1: Marvin interface excerpt with action abstraction levels.

The Advanced configuration utilized a prototype system known as Marvin (Figure 1) that integrated key features of an EVA timeline directly to life support telemetry variables. Central to the design of Marvin is its internal timeline structure that is built to handle four levels of abstracted task detail currently found in ISS EVA timelines. The IV operator simply 'checks-off' each incremental action as they are completed by EV crew. Marvin then instantaneously relates timeline progress with life support system status. Rather than expect the crew to perform mental math, as demanded by the Baseline configuration, to assess timeline progress and limiting consumable estimates, Marvin provides a continuous combined assessment of these constraints in the form of *Timeline Margin* and *Minutes Behind* in the header of the interface. This design solution represents the first step towards making the highest priority EVA constraints transparent to the operators to afford crew decision making capability.

Synchronizing EVA Work and Technology Development: Across all primary measures of performance in simulated operations, the Marvin prototype design exhibited statistically significant benefits in promoting IV operator timeline tracking, life support system monitoring as well as overall perceived ease of use [8]. However, this work represents just a first step towards securing operational support. Open areas of research exist in extending Marvin's timeline structure to incorporate a wider variety of other timeline details that relate more directly to exploratory scientific actions. As summarized in [11], planetary field geologists prefer an emergent approach to exploration where each incremental observation informs and guides subsequent actions. How might this emergent approach to timeline execution impact the content and structure of action abstraction currently exhibited in existing EVA timelines? Furthermore, how might we enable crew to actively create, rearrange, and forecast new potential timelines during execution? We anticipate the EVA work domain will need to expand to accommodate objectives with a wider variety of success criteria that are potentially also amenable to alteration. Marvin provides a platform to explore these concepts because its underlying design promotes maintaining an appropriate state of crew safety, agnostic to any given timeline objective. Key to the success of this development will be successfully envisioning how future crew access, analyze and utilize this information *in situ* all while executing EVA timelines.

To examine and develop these concepts for scientific EVA execution, the SHyRE program is a Planetary Science and Technology from Analog Research (PSTAR) funded, multi-year campaign aimed at developing a scientifically-robust analog environment using a new and innovative hybrid reality (HR) setting. As shown in Figure 2, the SHyRE program seeks to develop a simulated EVA environment where EV crew in HR execute scientific timelines while in collaboration with an IV operator. This simulated EVA environment affords an unprecedented level of controlled, repeatable simulation data acquisition regarding operationally relevant metrics (e.g. what the crews see, tool utilization, information transfer and interaction, etc.) to objectively measure the execution of scientific operations. In doing so, we overcome the limited sample sizes and high programmatic costs typically associated with analog research studies.

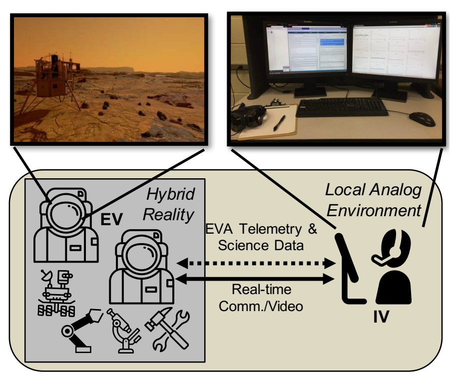

Figure 2: Envisioned SHyRE concept of operations.

References: [1] B. G. Drake, (2009) NASA/SP–2009–566. [2] B. G. Drake, (2009) NASA/SP–2009–566-ADD. [3] B. G. Drake, et al., (2010) IEEE Aero Con. [4] A. F. J. Abercromby et al., (2013) *Acta Astro, 91*. [5] M. M. Connors, et al., (1994) TM-108846. [6] M. J. Miller, et al., (2017) NASA/TP–2017–219457. [7] M. J. Miller, et al., (2015) IEEE Aero Conf. [8] M. J. Miller, (2017) PhD Thesis. [9] M. J. Miller, et al., (2017) JCEDM 11(2). [10] M. J. Miller, et al., (2017) 68th IAC. [11] W. B. Garry, et al., (2011) *Analogs for Planetary Exploration*, 483.