THE METAVERSE IS HERE – SO LET'S USE IT TO EXPLORE MARS C. D. Tate[1*], A. M. Annex[2], M, Wolff, A. H. Hayes[1], N. Randazzo[3], K. E. Powell[4]. [1]Cornell University, Department of Astronomy, Ithaca, USA; [2]California Institute of Technology Division of Geological and Planetary Sciences, Pasadena, USA., [3]Dept. of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada [4]School of Earth & Space Exploration, Arizona State University, Tempe, USA. [*]corresponding author cdt59@cornell.edu.

Introduction: The metaverse is a new frontier that can bring scientists together on the surface of Mars, the Moon, or anywhere else we have the imagery required to construct semi-realistic virtual environments of real places. Our understanding of the metaverse is a collection of 3D virtual spaces where people can interact with each other and with data. We use photogrammetry [1,2] and panoramas [3] to construct virtual spaces of Jezero Crater, Mars landscapes, where the Perseverance Rover is capturing an astonishing collection of high-resolution imagery [4]. Our work shows the initial progress towards actualizing the scientific benefits of the metaverse leveraging the data collected from a planetary surface.

However, challenges remain in using both virtual reality (VR) and augmented reality (AR), abbreviated as XR. The primary difficulty has been the software powering XR virtual environments, often requiring advanced programming experience to code from scratch. Secondly, costs for both the software and hardware must be economical for the purposes of broad accessibility. Finally, the potential longevity of the solution was considered, as a solution should remain usable for years to come. Therefore, we desire a metaverse solution based on free, potentially open-source software that users can run on commodity hardware.

We are exploring applications of several commodity hardware and software platforms for XR. We provide an overview of these tools, browser-based examples we have created, and several use cases that we are pursuing.

Software Solutions: We require a metaverse platform that can host a multi-user, collaborative, virtual workspace in which we can easily upload, view, and annotate high-quality reconstructions of Martian outcrops. Mozilla Hubs [5] and Spatial.io [6] provide the best solutions, although no ready-made platform fully realizes our vision. Hubs (hereafter Hubs), supported by the Mozilla Foundation and Corporation, is our preferred metaverse platform because it is free to use and user-friendly. Hubs works across web browsers and VR headsets including Google Cardboard and Meta Quest headsets by using the WebXR API. Mozilla Hubs hosts virtual spaces called rooms that can support more than a dozen users within a shared virtual environment. Rooms are constructed using software like Blender or within a web browser using the Mozilla Spoke tool. Spoke provides a convenient environment to construct rooms for Hubs within a web browser. Rooms are published as permanent URLs that can be opened like public Zoom or Webex meetings. On entry, the user chooses a name and avatar representing them as they travel around the room and interact with other users.

Browser-based tools eliminate much of the user's burden of installing specific software. This greatly improves the accessibility and viability of our application, which can be experienced in the "Getting Started" instructions below.

Mozilla Hubs rooms are accessible from any PC, smartphone, or head-mounted display that can run a supported browser such as Chrome, Firefox, or Oculus Browser. Hubs serves the virtual environment with a level of detail appropriate for its memory and processing capabilities.

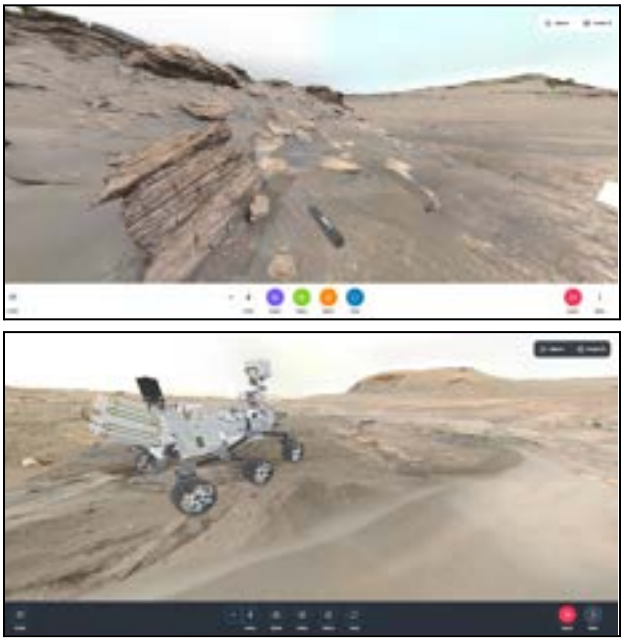

Figure 1: Screenshots from PC viewer of Mozilla Hubs. The location of the top room is unofficially called "Hogwallow Flats," and the bottom is called "Enchanted Lake."

Hardware Solutions: Although conventional computers can access Mozilla Hubs rooms, many VR headsets are also able to be used with Hubs for a richer experience. After researching the available hardware, we found that the Meta Quest 2 headset had the best balance of hardware capability and price as of late

2022. The internal hardware of the Meta Quest 2 is powerful enough for most of the functionality that Hubs provides and can be tethered to a desktop or laptop with more powerful hardware to access more resource-intensive rooms.

Science Collaboration: The goal of this work is to improve the scientific accessibility and interpretability of the Mars 2020 digital terrain models by experiencing them in 3D space with other scientists [7,8,9,10]. As a 3D data-viewer and a teleconference platform, these metaverse tools could supplement the ubiquitous 2D, screen-based teleconferencing that scientists use.

We created a collection of rooms for key locations throughout the Mars 2020 Crater Floor and Delta Front campaigns. The 3D models come from the same photogrammetry reconstructions regularly posted on Mastcam-Z's official account on the Sketchfab platform at https://sketchfab.com/Mastcam-Z/models.

Our room design starts with a base model to form the ground and a 360-degree panorama to form the sky, both created with Agisoft Metashape. The base model is an 8-16 meter square on which user avatars can walk to explore the landscape. The panorama is projected on a sphere about a 100-meter diameter and gives the illusion of a horizon beyond the base model. Smaller models superimposed on the base model can increase the resolution of important features like workspace abrasion/sampling sites or 1-2 meter scale outcrops. We also add a rover model, 1-meter scale bars, and compasses to aid scientific interpretation.

This room format is easy to assemble in Mozilla Spoke and render on the user's device, but it also has major imitations. Firstly, the room is limited to about 100 square meters which prevent long walkabouts that geologists often need to "read" the landscape. Portals between rooms help with this by letting users switch between adjacent rooms. Secondly, headsets like the Meta Quest 2 have hardware constraints that limit the allowed complexity of the models. Thirdly, the discontinuity between the base model and the panorama is distracting when the user is near the edge of the model and can even cause vertigo. Preventing the user from coming within several meters of the model's edge can ameliorate this along with extending the boundary with a low-resolution mesh. Finally, the only annotation tool in Hubs is a marker, which erases itself after the user logs off. Add-ons that enable permanent cross-platform annotations with text, audio, and scribbles are much desired. Additional specific tools such as measuring on the surfaces or adding planes in 3D space for strike and dip measurements would greatly enhance the scientific value.

The solutions to these limitations of Mozilla Hubs might require migration to more sophisticated purpose-built metaverse platforms developed in engines like Unity or Unreal Engine 5.

Future Work: The use of video game engines such as Unity or Unreal have the potential to overcome limitations in the browser-based tools used here. These engines provide advanced graphical realism and programmable functions to enhance user intractability (e.g. measurements, annotations, and integrations with conventional tools).

Getting started: From a computer or headset internet browser, the virtual lobby here (https://hubs.mozilla.com/PamE5DX/mature-buttery-plane) from which several sites on Mars are connected. After clicking the link, users follow the prompts to choose a name and an avatar before selecting "Join Room." Once loaded, the user should see an indoor space with a model rover in the center of the room.

A desktop user can move around the room with the arrow or WASD keys and look around by clicking on the window and dragging the mouse. Users on a Meta Quest should select "View in VR" if the browser window is still visible. Once immersed in the virtual environment, the user moves with the left controller joystick and looks around with the right joystick or simply turns the head. The toolbar is visible by looking up.

The inner walls of the lobby have several images of other rooms that link to our reconstructed sites on Mars. Hover the pointer over one and select "visit room." Users can return to the lobby by using the back button in the browser.

Conclusions: Mozilla Hubs and other metaverse platforms show great promise for collaborative planetary exploration. We examine this potential by creating virtual rooms in Hubs for several rover locations. Despite current limitations in functionality, the rapid development of these technologies could revolutionize how scientists engage with large, rich, image-based datasets like those produced by planetary surface missions.

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