Multi-platform Immersive Visualization of Planetary, Asteroid, and Terrestrial Analog Terrain. S.P. Abercrombie, A. Menzies, H.E. Abarca, V.X. Luo, S. Samochina, M. Trautman, L.A. Klyne, S.A. Fernandez, A.H. Lidawer, J.R. Pamer, A.B. Winter, R. Crocco, M.A. Vona, A.J. Byon, NASA Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, parker.abercrombie@jpl.caltech.edu

Introduction: A primary challenge of planetary, lunar, and small-body geology is understanding a remote environment from the limited data returned by spacecraft. Visual images are a key data source for learning about these remote environments. However, looking at two-dimensional pictures is dramatically different than how geologists (and humans in general) explore the Earth.

To address this challenge, we have developed a set of tools, called OnSight [1], to enable three-dimensional (3D) visualization of planetary and small-body surfaces both in mixed reality (using the HoloLens head-mounted display developed by Microsoft) and using web-based interfaces. OnSight was developed initially for the Mars Science Laboratory mission to provide immersive visualization of the surface of Mars (Figure 1) and we are extending the system to support target selection for the Mars 2020 rover mission. We have also applied this technology to visualizing asteroid data and to field analog environments on Earth. Here we present the core components of the system and how it has been used to support Mars rover missions, asteroid missions, and analysis of terrestrial analog sites.

Core capabilities: The OnSight framework consists of the following components:

Terrain reconstruction: The OnSight team developed a custom photogrammetry pipeline [2] to take images returned by the Curiosity rover and create 3D terrain reconstructions. We are working to generalize this pipeline to support other datasets, and have already applied it to asteroids and terrestrial analogs.

Immersive terrain view: The OnSight HoloLens application runs on the Microsoft HoloLens headset and provides an immersive visualization of Mars terrain. This application renders terrain at full scale and allows the user to explore by walking and looking around.

Web terrain view: Like the OnSight HoloLens application, Web OnSight provides an interactive 3D model of the terrain around the Curiosity rover but runs as a WebGL application that works in any modern web browser. In addition to viewing the 3D terrain, Web OnSight allows the user to browse and search the raw rover images in a novel 2D/3D interface.

Multi-user collaboration service: OnSight includes a "Discussion" feature, which allows users to collaborate in a shared, virtual space. Any OnSight user can create a discussion that is then available for other users to join. Users in a discussion can see each other as digital avatars. OnSight synchronizes the position of the avatars, as well as the point on the terrain that each user is observing, which is visualized as a "gaze ray" emanating from the avatar's eyeline. The discussion feature is powered by a centralized collaboration server. Both HoloLens users and web users can collaborate in the same discussions.

Mars Science Laboratory: The HoloLens version of OnSight was deployed in August 2016 to members of the MSL science team. Since then it has received consistent usage (measured through application telemetry) and has become a widely accepted tool on the mission. OnSight is used both for scientific understanding (e.g. [3]) and for vehicle operations (e.g. is this a safe path to drive?). The majority of use is by solo users for short duration sessions.

Collaborative science: Using the collaboration features of OnSight, the team facilitates a "Meet on Mars" meeting series, which allows members of the science team to meet together in the virtual environment and discuss Martian geology in a shared spatial context. The science team has held more than 25 of these sessions, and any OnSight user can also arrange ad-hoc sessions. Meet on Mars sessions tend to be longer than solo sessions, typically lasting about one hour.

Mars 2020: The Mars 2020 science targeting tool ASTTRO, the Advanced Science Targeting Toolkit for Robotic Operations, provides increased functionality to meet the new visualization needs of the next generation rover by building off of the core OnSight codebase. ASTTRO provides a web-based interface for the M2020 science team to see the 3D terrain around the rover and to identify targets of scientific interest in the terrain (Figure 2). The tool includes modeling specific to each of the instruments on the rover. ASTTRO integrates closely with other parts of the rover planning system, providing the science team with much greater context and greatly enhanced robotic simulation capabilities compared to previous missions. We expect this capability to enable more efficient selection of achievable science targets.

Terrestrial analogs: OnSight provides visualization of a remote environment that is difficult to visit, and this capability has many applications beyond planetary and solar system exploration. An interesting use of OnSight related to human space flight is to use immersive visualization prior to Extravehicular Activity (EVA) for operators to pre-plan activities in the virtual environment. In this case, the terrain model would be generated using precursor data from robotic scouts or a prior EVA. The team tested this use case as part of the Biologic Analog Science Associated with Lava Terrains (BASALT) [4, 5] project in November 2017. BASALT is a multi-year project which evaluates concepts of operations for human scientific exploration of Mars using field analog sites on Earth. Using data collected by the BASALT team, we produced a 3D reconstruction of a field site in Volcanoes National Park, Hawaii, and loaded it into the OnSight software running on a HoloLens. Participants in the BASALT study used OnSight to view the field site prior to performing simulated EVA's in the analog terrain.

JAXA Hayabusa2 asteroid mission: In collaboration with the Hayabusa2 Optical Navigation Camera team the OnSight team produced a 3D model of the Hayabusa2 landing site on the Ryugu asteroid. In preparation for this work, the OnSight team also used Web OnSight to visualize data from the Hayabusa mission to the asteroid Itokawa (Figure 3). The 3D model of asteroid Ryugu was loaded into the OnSight HoloLens application to aid the Hayabusa2 team in their analysis of mission and science objectives, primarily related to rover/spacecraft trajectories and landing site selection. This system was demonstrated at the Hayabusa2 joint science team meeting in December 2018. Similar opportunities have been discussed with the NASA OSIRIS-REx and Psyche missions.

Future work: OnSight was developed in the context of Mars rover science and operations. However, the technology has applications to many areas of study, some of which we are already pursuing through our work with the BASALT and Hayabusa2 teams. Our future work will include making the technology more easily adaptable to different datasets and improving integration between immersive and web-based views of the environment. We have found that both platforms offer distinct advantages (e.g. the immersive view provides an inherent sense of scale and easily learned navigation, while the web view provides familiar text input and a high resolution display suitable for zooming into images to the pixel level). We expect immersive visualization to become an increasingly important complement to traditional analysis tools as head mounted displays become more commonly available.

References: [1] Abercrombie et. al. (2017), "OnSight: Multi-platform Visualization of the Surface of Mars", *AGU Fall Meeting*, [2] Abercrombie et. al. (2017) "Building Virtual Mars", *AGU Fall Meeting*, [3] Adair et. al. (2018) *LPS XLVII* Abstract #1799, [4] Beaton et. al. (2019) *Astrobiology,* [5] Nawotniak et. al. (2017), *LPS XLVIII*, Abstract #2793, [6] Gaskell et. al. (2016) *AAS/AIAA Astrodynamics Specialists Conf.*

Figure 1: OnSight HoloLens interface shows full-scale view of terrain model. Other users in collaborative discussions are represented by virtual avatars.

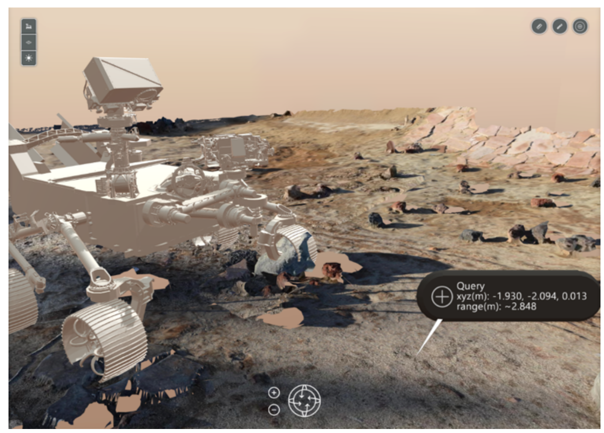

Figure 2: ASTTRO web 3D user interface displaying the Mars 2020 Rover in the JPL Testbed

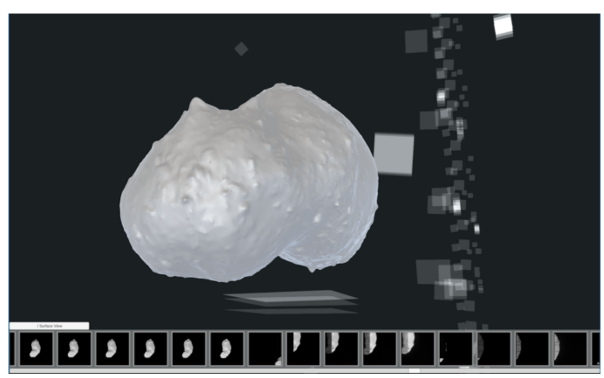

Figure 3: Web OnSight applied to Hayabusa 1 data to visualize Itokawa asteroid and associated images. (Itokawa shape model produced by Gaskell et. al. [6])