AN INTEGRATED ENVIRONMENT FOR VISUALIZING IN-SITU AND ORBITAL PLANETARY DATA.

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Introduction: Planetary rovers and landers offer an opportunity to explore terrains from a vastly different perspective than from orbital data. In a rover operations context, orbital images are used for spatial referencing, to assess terrain hazards and for compositional context. However, despite extensive work to utilize these datasets together, to date an robust visualization environment does not exist to facilitate the co-analysis of orbital and ground-based data in a single platform.

Here we present an example application of a mixed orbital/ground-based visualization environment for the Mars Science Laboratory Curiosity rover. Analysis of orbital hyperspectral images from the visible and near-infrared instrument CRISM [1] was used in identification of the landing site at Gale Crater [e.g. 2] and has supported traverse planning before and after landing [e.g. 3]. Orbital spectroscopy remains the primary means of reconnoitering areas not yet visited by the rover. Meanwhile, Curiosity has collected a wealth of panoramic and multispectral imagery and chemical and mineralogical data along its traverse, but from a ground-based perspective and at much smaller spatial scales. We seek to create a tool that will allow us to more easily connect these two types of data.

Orbital Datasets: Targeted CRISM data cubes in FRT mode have a wavelength range of 0.36–3.92 μm and ~18 m/pixel spatial resolution [1]. This wavelength range is used to identify minerals of interest, e.g. clays, sulfates, and iron oxides, by their diagnostic absorption features. Surface reflectance as measured by CRISM is a function of mineralogy as well as physical parameters such as grain size and packing. CRISM is sensitive to the uppermost layers of the surface, and its spectra are affected by intimate and checkerboard mixing of different materials, dust cover, surface coatings, and topography at scales smaller than pixels. For this application, CRISM data are presented as single scattering albedo spectra (SSA), which have been atmospherically corrected and spatially and spectrally regularized [4] and manually registered to the existing HiRISE mosaic of Gale Crater [5] at 0.25 m/pixel.

Rover Datasets: Curiosity mosaics of its surroundings are composed of multi-frame Navcam [6] and Mastcam [7] imagery. These images reveal details such as rock textures and variable sand and dust cover. However, rover views of distant objects are often obscured by nearby topography and high-resolution views for interpretation are confined to small spatial areas. Mastcam captures multispectral information, but compared to CRISM has a smaller spectral range (~0.4–1.0 μm) that does not include diagnostic metal-OH vibrations in the near-infrared. ChemCam provides additional compositional information, but from very small spatial areas [8].

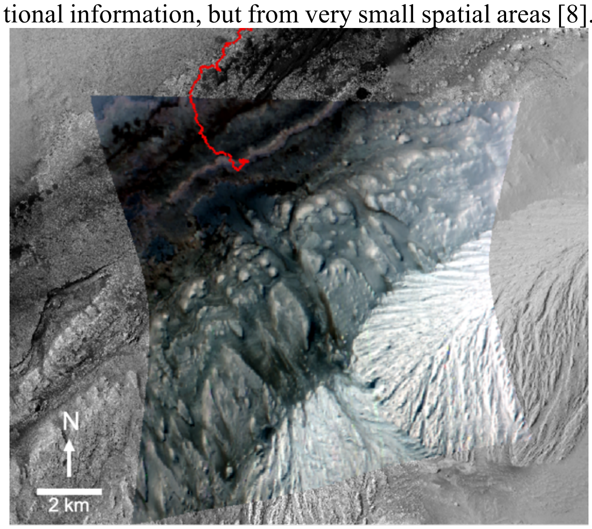

Figure 1: CRISM FRT0000B6F1, RGB = 2.53, 1.51, 1.06 μm, overlaid on HiRISE mosaic of lower Mt. Sharp. Red line shows Curiosity's traverse through its location on Vera Rubin Ridge on Sol 2137.

Interface: To visually unify the orbital and rover datasets, we develop an immersive interface with the Unity Game Engine, which can be viewed on any computer or mobile device. We have also implemented it in virtual reality using an HTC Vive headset. The primary view of the interface displays a "first person view" from the rover's perspective of stitched imagery from rover data. The user can rotate the presented view through keyboard arrow keys to change altitudinal and azimuthal viewpoint angles. The current view is static and shows a Mastcam mosaic from Curiosity's location on Vera Rubin Ridge on Sol 2137, with an artificially added sky at altitudes where data is lacking.

The CRISM spectral data is presented through two heads-up-display (HUD) panels. The right panel shows the map-projected CRISM image for context, with the location of the viewer indicated by a crosshair. The user can select a different highlighted pixel through keyboard commands or by selecting with a mouse or controller. The left panel shows a plot of the CRISM spectrum corresponding to the highlighted pixel. As the user selects different pixels on the area map, a 3-dimensional marker moves over the rover imagery to represent the location of the highlighted pixel from the orbital spectral area map. The marker represents the geometry of the covered area of the pixel from orbital data.

Applications and Ongoing Development: This approach removes the guesswork from orbital image localization and allows rapid comparison of multiple orbital and rover-based datasets. Integrating precise spacecraft pointing with high-resolution local topography to precisely place rover footprints on 3D surfaces. With this framework we will be able to display single-band layers, e.g. CRISM-derived mineral parameter maps, in their proper spatial locations from the rover's perspective. Future work may integrate existing MSL datasets by precisely locating targets and simultaneously displaying MSL instrument data, e.g. Mastcam multispectral plots. Additionally, this framework is scalable to other rover-based datasets, such as the upcoming Mars 2020 mission to Jezero Crater or other future rover and human exploration sites.

References: [1] Murchie, S.L. et al. (2007), *JGR*, 112, E05S03. [2] Milliken, R.E. et al. (2010), *GRL*, 37, L04201. [3] Fraeman, A.A. et al. (2016), *JGR*, 121, 1713-1736. [4] Kreisch C.D. et al. (2017), *Icarus*, 282, 136-151. [5] Calef III, F.J. and Parker, T., 2016, MSL Gale Merged Orthophoto Mosaic, U.S. Geological Survey, http://bit.ly/MSL_Basemap. [6] Maki, J.N., et al. (2011), *Space Sci. Rev.*, 170, 77-93. [7] Malin, M.C. et al. (2017), *Earth & Space Sci.*, 4, 506. [8] Wiens et al., (2012) *SSR*, 170, 167– 227.

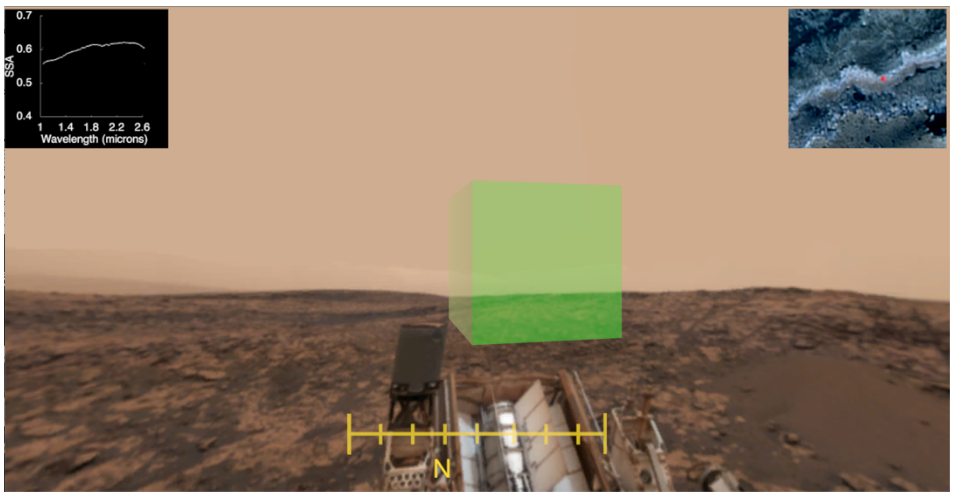

Figure 2: Sample view in browser mode from atop Vera Rubin Ridge (Sol 2137). The green box represents a CRISM pixel (~18x18 m). The upper left box shows the corresponding CRISM spectrum. The upper right box (~2.4 km across) shows CRISM image FRT0000B6F1 with the current pixel indicated in red.

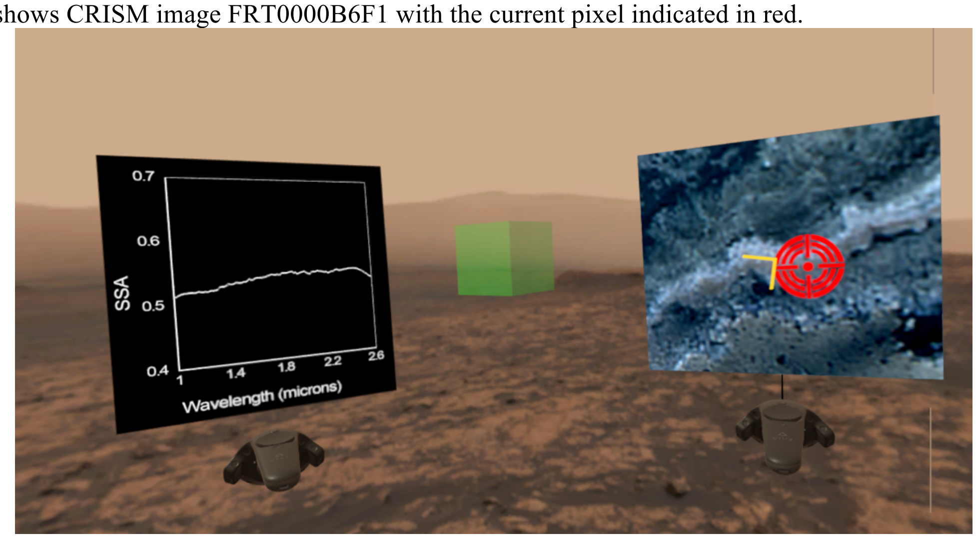

Figure 3: Sample view in VR using HTC Vive headset and controllers. The user can move the plot and map as desired. The pixel location can be chosen by pointing with the controllers at the desired area of the landscape.