DATA EXPLORATION USING OPENSPACE. M. E. Gemma[1,2], C. Emmart[1], V. Trakinski[1], R. L. Smith[4,5,6], M. Acinapura[1], B. Abbott1[1], D. S. Ebel[1,2,3] and R. Kinzler[1]. [1]American Museum of Natural History, New York, NY 10024, USA, [2]Dept. of Earth & Environmental Sci., Columbia University, New York, [3]Graduate Center of CUNY, New York, NY, [4]NC Museum of Natural Sciences, Raleigh, NC 27601, [5]Appalachian State U., Boone, NC 28608, [6]UNC Chapel Hill, NC 27599.

Introduction: OpenSpace [1] is an open source interactive data visualization software designed to visualize the entire known universe and portray our ongoing efforts to investigate the cosmos. OpenSpace supports interactive presentation of dynamic data from observations, simulations, and space mission planning and operations. Recent developments of OpenSpace allow visualization at the outcrop level on extraterrestrial bodies. The software works on multiple operating systems (Windows, Mac, Linux) with an extensible architecture powering high-resolution tiled displays and planetarium domes, making use of the latest graphic card technologies for rapid data throughput. In addition, OpenSpace enables simultaneous connections across the globe creating opportunity for shared presentations among audiences worldwide.

Invitation: Several participants in the OpenSpace project are present at the 2019 LPSC. Interested attendees are invited to:

1) Visit the OpenSpace booth any time this week.

2) Let us know what you want from the project.

3) See Carter Emmart's demonstration of OpenSpace in the exhibitions area, through Thursday.

Planetary scientists are welcome to team with programmers at their home institutions to develop modules for OpenSpace. A module could include, e.g., a visualization of part or all of an individual mission, including spacecraft model and 'spice' navigation kernels and visualization of science results. The OpenSpace project can offer targeted assistance.

Recent Developments: Work within OpenSpace has been shared via public programs at the AMNH and partner informal science institutions (ISI's). These advances include visualization of Mercury's hollows at high resolution using the Ames Stereo Pipeline and Isis3, as well as implementation of spice kernel reconstructions of the Apollo 8 mission based on DSN telemetry (by Ernie Wright, GFSC, SVS) to visualize the Earthrise moment from the interior of the crew module (interior 3D by Smithsonian). Photogrammetry of boulders from Apollo 17 Haselblad photography has also been implemented, along with USGS/DLR visualizations of Apollo 17 rover traverses (**Fig. 1**). CRISM, CTX, and HiRise data have been used to visualize NASA's Mars 2020 and InSight missions (**Fig. 2**). Guided visualizations of Curiosity rover surface operations apply multi-scale terrain maps combined with navcam terrain models and rover telemetry (**Fig. 3**).

Technical improvements in the last year include an improved user interface, with the option to build custom user interfaces using WebGUI in html5. This comes at some cost of graphics card rendering performance (10-20%) but allows simplification of menus.

OpenSpace now includes the ability to record and play back an interactive session, together with audio recording and streaming live to YouTube and YouTube360 with automatic recording/archiving.

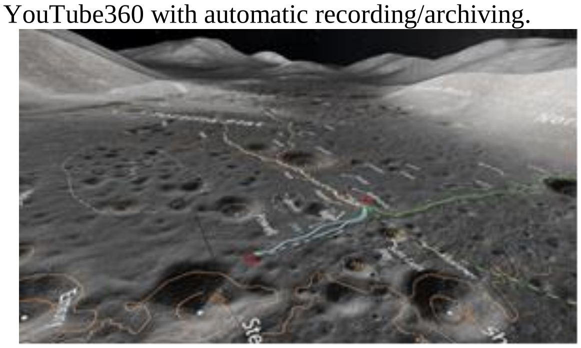

Fig. 1: Taurus-Littrow valley with USGS/DLR plotted rover traverses, labels and elevation contours. Kaguya global imagery over LOLA elevation background.

Fig. 2: Mars, light-toned sulfate mounds in Ganges Chasma. The crest of the mountain is similar in form and scale to Yosemite's Half Dome. HiRise over CTX.

Team: OpenSpace builds on over a decade of collaboration between Sweden's Linköping University and the AMNH by including computer science experts at University of Utah's Scientific Computing and Imaging Institute and New York University's Tandon School of Engineering as well as several NASA Science Mission Director collaborators. The AMNH team has worked with scientists from OSIRIS-REx, New Horizons, MESSENGER, the Community Coordinated Modeling Center (solar fields, and others to incorporate their missions and data into the common OpenSpace platform for public STEM education and data exploration. Multiple ISI's across the US are also partnering with the OpenSpace project.

OpenSpace lends itself well to student involvement in the development of visual renderings, as well as the production of interactive "tours" for various audiences. International vendors of planetarium display systems are collaborating to facilitate the use of OpenSpace in public displays with various projection systems.

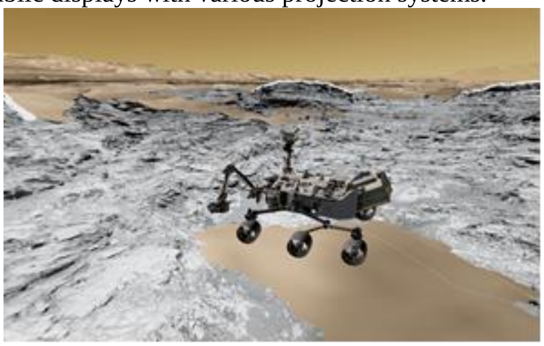

Fig. 3: Curiosity at Gale Crater. Navcam terrain models arrayed along the rover transect over USGS HiRISE terrain mosaic with rover articulation from telemetry history.

Digital Universe: The American Museum of Natural History's (AMNH) Digital Universe (DU) atlas is an interactive, three-dimensional atlas of the cosmos, first launched with funding from NASA in 1998. Since then, the DU has grown to include a diverse collection of data from ground-based and space-based astronomical missions. Within the atlas are such varied data types and accompanying metadata as planet topographical data, stars, exoplanets, spacecraft, galaxies, and multi-wavelength surveys. Recently, the Gaia star catalog has been incorporated into the DU and presented in the Hayden Planetarium. DU is a critical component of OpenSpace, significantly strengthening the ability to convey complex science content to the public.

Missions: With OpenSpace, one can dynamically visualize spacecraft and their imaging viewpoints, as well as numerical simulations, and place them within the larger evolving universe using the Digital Universe database, continuously extending from the Earth's surface (**Fig. 4**) to the cosmic microwave background.

Platforms: OpenSpace is scalable from full size planetarium domes to large format display walls to classroom projection to laptop screens, with broad compatibility with multiple software platforms and graphics hardware.

Future: Anticipated versions of OpenSpace will, among other improvements, seek to include a way to show the Milky Way with a volumetric model, and an embedded web browser to allow exploration of another object while still preserving the local scene.

Discussion: OpenSpace allows visualization of scientifically important data, as well as the technology, engineering, and math of space missions. A goal of the project is to enable scientists and presenters of science to visually explain how we engage in discovery across the solar system and beyond. This is accomplished in part by accurate rendering of image pointing and regions of acquisition projected from instruments as view frustums in OpenSpace (Figures). Navigation kernels and the DU allow time- and space-accurate rendering of spacecraft paths throughout the solar system (e.g., OSIRIS-REx), and beyond (e.g., Voyager 1).

Globe browsing in OpenSpace allows visualization of images on measured topography, for example sculpted terrains on Mars [2]. Earth observing data such as the Suomi weather satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) spectra and sea surface temperatures can be rendered on the globe as time series using OpenSpace (**Fig. 4**) [3]. Our recent experience is that this kind of visualization actively 'wows' even the most expert planetary scientists and stimulates new ideas through dynamic, interactive engagement with rich data overlaid on digital elevation maps [4].

The open source nature of the OpenSpace software encourages module development by collaborators beyond the original and existing team (see "Invitation", above). Academic publications about OpenSpace are at [5].

Fig. 4: Earth temporal data streamed from NASA GIBS, surrounded by accurate astronomical data from 3D catalogs of the AMNH Digital Universe.

References: [1] http://openspaceproject.com/ ,
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[3] https://www.youtube.com/watch?v=3exuifro1aM VIIRS satellite Earth data renderings in OpenSpace
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