OPENSPACE: SETTING THE UNIVERSE FREE. E. J. Crapster-Pregont[1], M. E. Gemma[1,2], C. Emmart[1], V. Trakinski[1], R. L. Smith[4,5,6], 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. Bringing the latest techniques from data visualization research to the general public, OpenSpace supports interactive presentation of dynamic data from observations, simulations, and space mission planning and operations. The software works on multiple operating systems 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 experiences among audiences worldwide.

Digital Universe: The American Museum of Natural History's (AMNH) Digital Universe (DU) atlas is a three-dimensional atlas of the cosmos, first launched with funding from NASA in 1998. Over the years, 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. DU is a critical component of OpenSpace, significantly strengthening the ability to convey complex science phenomena across a vast range of scales 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, continuously extending from the Earth's surface to the cosmic microwave background.

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

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. Multiple informal science institutions (ISI's) across the US are actively engaged in the emerging OpenSpace ISI Network. For example, an extensive high-resolution digital library of solar system and star field media clips, created from OpenSpace using open-source rendering software (such as Open Broadcast Studio), is now being used in public exhibit spaces at ISI partner The NC Museum of Natural Sciences on an ongoing basis. These visuals provide compelling starting points to discuss current astrophysics research with visitors, including a variety of current NASA missions and solar system exploration projects. OpenSpace lends itself particularly well to student involvement in visual renderings, as well as interactive "tours" as part of public programs. International vendors of planetarium display systems are on board to facilitate the use of OpenSpace in public displays with various projection systems. 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 mission activities and data into the common OpenSpace platform for public education and engagement.

Invitation: Several participants in the OpenSpace project are present at the 2018 LPSC. Interested attendees are invited to:

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

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

Planetary mission scientists are welcome to team with programmers at their home institutions to develop modules for OpenSpace. A module could be a visualization of part or all of an individual mission, including spacecraft model(s) and navigation kernels. The OpenSpace project can offer targeted assistance.

Features: OpenSpace currently has the following visualization features:

- A scale graph approach to handle coordinate systems of all magnitudes in the cosmos, allowing for the display of micrometer as well as billion-light-year resolutions in a unified framework
- Volume visualization techniques to inspect, verify, and make simulation output available to the public. This includes the capability to fuse different kinds of media, such as volumes, geometries, and images
- Interface to NAIF's SPICE navigation and spacecraft pointing kernels to provide accurate ephemeris and pointing information for all planetary objects and spacecraft in the solar system

- Capability to display the fields-of-view of various instruments and missions to visualize mission engineering and science operations by applying acquired (or future) images onto objects through projective texturing
- Capabilities to seamlessly switch between single-user single-machine operation to display on a planetarium dome or other immersive media
- Synchronization features between different, geographically separated, instances of the application for networked remote education. This includes control of visualizations, as well as the capability to include the video stream of a presenter to an arbitrary number of connected instances
- Ability to record and playback an interactive session, together with audio recording
- Globe browsing techniques across spatial and temporal scales to examine scientific campaigns on multiple planets, including close up surface exploration.

Current areas of focus within OpenSpace include:

- Visualization of dynamic simulations via interactive volumetric rendering, as a priority for communicating research in astrophysics
- Utilization of NASA's SPICE observational geometry system with its Planetary Data System (PDS) to enable space mission visualization that reveal how missions are designed to gather science

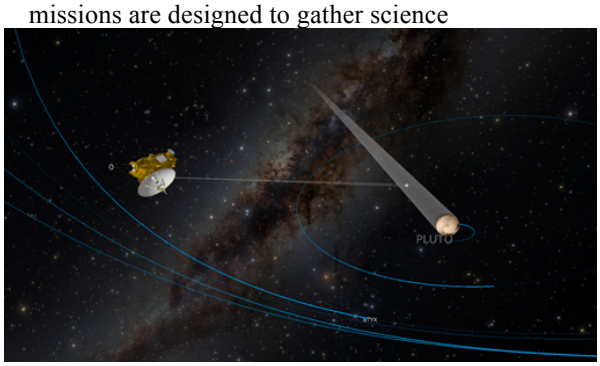

Figure 1. New Horizons encounter with the Pluto system, with spacecraft model, moon paths and accurate background stars from DU, and accurate instrument pointing and imaging frustum from SPICE kernels [2].

Discussion: OpenSpace allows visualization of scientifically important data, as well as the technology, engineering, and math required to gather that data. A goal of the project is to enable scientists and presenters of science to engage learners in 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., MESSENGER), and beyond (e.g., Voyager 1).

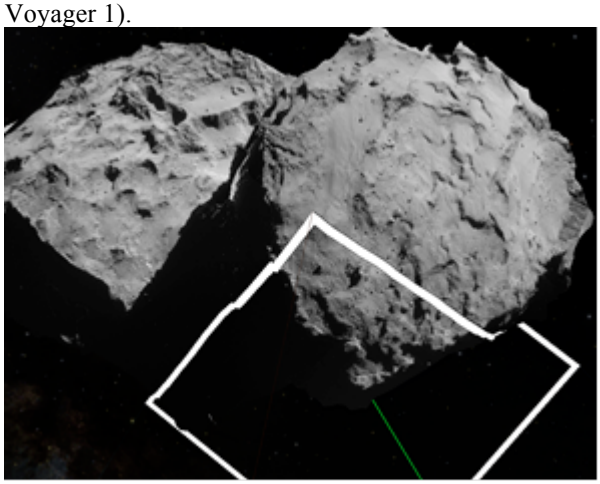

Figure 2. Projecting Rosetta's NAVCAM images onto 67P/Churyumov–Gerasimenko using OpenSpace [3].

Globe browsing in OpenSpace allows visualization of images on observed topography, for example sculpted terrains on Mars [4]. 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 [5]. 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 [6].

The open source nature of the OpenSpace software encourages module development by collaborators beyond the original and existing team (see "Invitation", above).

References: [1] http://openspaceproject.com/ Home
[2] https://www.youtube.com/watch?v=26BEYD2XYzs OpenSpace video showing two New Horizons image campaigns on Pluto and representing the increase in image resolution that was achieved on July 14th, 2015
[3] https://www.youtube.com/watch?v=gqWBgL4wSjo Rosetta comet 67P imaging campaign visualization
[4] https://www.youtube.com/watch?v=NWZAg6qpMlE Mars terrain from HiRISE orbiter data in OpenSpace
[5] https://www.youtube.com/watch?v=3exuifro1aM VIIRS satellite Earth data renderings in OpenSpace
[6] P. Schultz, pers. comm. 3-Nov-2017

Acknowledgments: OpenSpace is supported by the NASA Science Mission Directorate in response to NASA Cooperative Agreement Number (CAN) NNH15ZDA004C, Amendment 1.