PLANETARY SCIENCE IN OPENSPACE: ALL-IN-ONE VISUALIZATION. M. E. Gemma[1,2,*], M. Villa[1], C. Emmart[1], V. Trakinski[1], R. L. Smith[3,4,5], M. Acinapura[1], B. Abbott[1], J. Faherty[1], D. S. Ebel[1,6,7], and R. Kinzler[1]. [1]American Museum of Natural History (AMNH), New York, NY 10024, [2]Dept. Of Geosciences, Stony Brook U., Stony Brook, NY 11794, [3]North Carolina Museum of Natural Sciences (NCMNS), Raleigh, NC 27601, [4]Appalachian State U., Boone, NC 28608, [5]UNC Chapel Hill, NC 27599, [6]Dept. of Earth and Environmental Sciences, Columbia U., New York, NY, 10027, [7]Graduate Center of CUNY, New York, NY. *mgemma@amnh.org.

Introduction: OpenSpace [1] is an open-source interactive data visualization software designed to visualize planetary science data, the known universe, and our investigation of the cosmos. It supports dynamic presentation of data from space mission planning & operations, to observations & simulations. It allows visualization at the outcrop level on extraterrestrial bodies.

Development continues as a collaboration between software engineers and graduate students at AMNH, Linköping University, New York University (NYU) Tandon School of Engineering, and the University of Utah Scientific Computing and Imaging Institute.

OpenSpace can be used on a variety of platforms, from laptops to multi-channel immersive displays (e.g., planetarium domes). Expert users can integrate their own datasets for sharing with the OpenSpace community. The software streams data from dedicated servers in Utah, New York, and Sweden to power live presentation and interactive exploration. OpenSpace thus enables engaging public and professional audiences through livestreamed and recorded videos produced by Informal Science Institution (ISI) professionals, astronomy groups, science communicators, educators, and researchers. Public programs using OpenSpace at the AMNH and partner ISIs and universities may be found on our website [1] and YouTube [2].

Public Outreach: The flexibility of OpenSpace allows its use for onsite and online programming. In 2022, over 203 programs and 4 exhibits utilized OpenSpace to communicate science and engineering concepts, reaching 513,329 people onsite. Virtual programs reached 348,611 people online and received over 38.5 million views on social media platforms.

OpenSpace is particularly effective as a science communication tool, as it can be used to explore questions about celestial phenomena at all scales with compelling visuals. It enables virtual exploration of the Moon, Mars and Earth using the most recent, highest resolution data (e.g., lunar LROC WAC 100m and Kaguya 7m) and NASA TREKs layers. This allows in-classroom or virtual guided exploration of cratering and crustal processes, planetary morphology, and landscape evolution by students and instructors alike. Examples of the variety and breadth of programming include:

Landscapes of the Solar System: This 15-minute daily presentation at California Academy of Sciences' Morrison Planetarium compares landscapes on Earth (e.g., Himalayas, Grand Canyon) to other planetary surfaces, introducing comparative planetology to audiences of all ages.

Exhibits: Four touch-screen kiosks at the NC Museum of Natural Sciences feature a selection of on-demand OpenSpace videos that highlight various planetary, solar system, galactic and extragalactic themes.

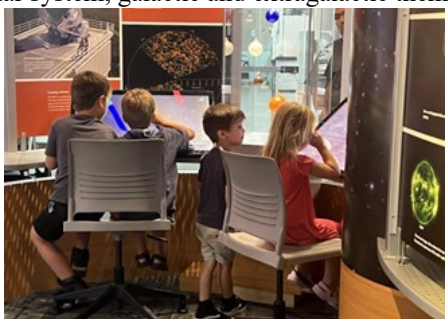

Fig. 1: NCMNS kiosks**.**

Astronomy Live: AMNH's family-friendly programs returned to the Hayden Planetarium to explore astronomy topics, guided by AMNH's Jackie Faherty. The programs "Our Dynamic Universe" and "Insights from the James Webb Space Telescope" were attended by 1,157 onsite visitors (Fig. 2).

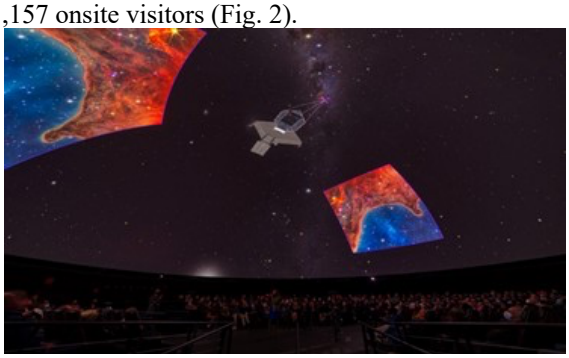

Fig. 2: JWST model pointing into space with JWST images of the Cosmic Cliffs, inset on the Hayden dome.

Digital Earth: The Denver Museum of Nature & Science's longstanding Digital Earth program used sub-orbital flights with OpenSpace over regions around the Nile River to show the landscape and geophysical context of ancient civilizations while dozens of 360° panoramic images of archeological sites immersed audiences in on-the-ground exploration.

Academic and conference presentations: OpenSpace was used for: public presentations at Columbia University; lectures by Southwest MN State U, City College of NY, Towson U, and Appalachian State

astrobiology professors; and presentations at the Astrobiology Science Conference (AbSciCon), 240th American Astronomical Society, Meteoritical Society, Geological Society of America, and American Geophysical Union 2022 meetings, among others.

In addition to experts from OpenSpace university and ISI partners [3] and other ISI users, programs featured professionals from:

NASA Centers: Goddard Space Flight Center's Community Coordinated Modeling Center (CCMC), Ames Research Center, Jet Propulsion Laboratory, and Goddard Institute for Space Studies.

Scientific and research institutions: Virtual Planetary Lab, Space Telescope Science Institute.

Universities and colleges: Appalachian State University, Columbia University, City College of NY, Southwest MN State University, and Northwestern University.

Education: OpenSpace has supported 100s of interns at partnering institutions, who learn STEM skills and content [1], enabling student involvement in developing visual renderings and producing interactive tours of the universe. In 2022, the software was utilized in 29 internships hosted by: Adler Planetarium, AMNH, Houston Museum of Natural Science, Linköping University, NASA CCMC, NYU, NCMNS, and University of Utah. Interns ranged from the high school to graduate level and were focused on supporting, producing, and giving public presentations, adding new content into OpenSpace, and developing major new software features.

Feature Development: In 2022, one significant software update and two patch updates were released: Beta-11 (v0.18.0 to 0.18.2). These updates improved performance and stability and made adoption easier for new users. Updates through 2020 were summarized by [4]. Major new features introduced since include [5]:

SkyBrowser: Through collaboration with the American Astronomical Society's WorldWide Telescope, this new integration allows users to view high-resolution astronomical images in OpenSpace in the context of the Digital Universe. SkyBrowser can be used in combination with mission visualizations (e.g., JWST, Chandra, Hubble, Spitzer) to display their observations.

Fly-To: Users can automatically fly between different objects by clicking an airplane icon in the navigation menu, simplifying piloting for live presentations.

Actions: Users can customize and activate complex tasks with one button click, supporting complex content.

Event System: To enhance production values of programs, specific events are auto-triggered depending on the state in OpenSpace, such as automatically fading an object's trail (e.g., a planet's) upon approach.

Additional interface improvements include: Updated Launcher panels for Simple Graphics Custom Toolkit (SGCT) configurations; added Launcher panels for the JPL Horizons interface, which simplifies the process of bringing in data from NASA JPL; added ability to enable and disable the Exoplanet and SkyBrowser components for individual profiles; inclusion of links to tutorial pages in the menu.

Work continues to connect OpenSpace more seamlessly to Glue [6], an innovative software package for visualizing multiple linked datasets.

Content Development: OpenSpace includes 17 prepackaged profiles found on the installation page. Two new profiles and one update were incorporated in 2022:

Bastille Day 2000 and Solar Storm 2012: One of the most violent solar storms in recorded history occurred on July 14-16, 2000. This profile traces the flight path of the magnetized plasma particles ejected from the Sun and their impact on Earth's magnetic field. The massive CME of July 23, 2012 is similarly visualized. These profiles were created through a collaboration with CCMC.

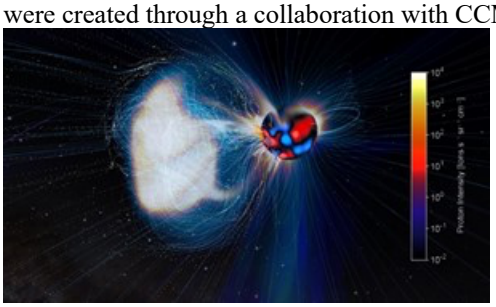

Fig. 3: Bastille Day 2000 CME visualization.

JWST: This updated profile includes two visualizations of the Webb trail: One plotted with respect to the Earth-Sun Lagrange Point 2, where the telescope is stationed; and another with respect to the Sun, as we plot the orbits of the planets. The profile includes a dynamic model of JWST and a time-lapse of its deployment, with the capability to point the telescope with an associated view frustrum to any celestial coordinates.

Additional new content includes: Image sequences available from NOAA's Science On a Sphere; NASA Treks Moon, Mars, and Mercury layers; Starlink satellites and other active satellites; model-based representations of Mars moons Phobos and Deimos; and notable landmark models for use as scale references.

References: [1] http://openspaceproject.com/
[2] www.youtube.com/c/openspacesoftware
[3] https://www.openspaceproject.com/partners.
[4] Gemma et al. (2021). LPSC LII, Abstract 2206.
[5] http://wiki.openspaceproject.com/ [6] https://glueviz.org/

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