OpenSpace Annual Progress Report – Year 3

NASA Science Mission Directorate Science Education Cooperative Agreement Notice (CAN)

Solicitation: NNH15ZDA004C

I. ADMINISTRATIVE

Recipient Name and Address: American Museum of Natural History

Central Park West at 79th Street

New York, NY 10024

Recipient Cooperative Agreement Number: NNX16AB93A

Principal Investigator: Ro Kinzler

Cooperative Agreement Title: NASA Science Mission Directorate Science Education

Cooperative Agreement Notice (CAN) - 2015

Type of Report: Annual

Period Covered by the Report: November 2017–October 2018

II. ACCOMPLISHMENTS

The American Museum of Natural History (AMNH) is pleased to submit this third annual report on the achievements to date of *OpenSpace: An Engine for Dynamic Visualization of Earth and Space Science for Informal Education and Beyond*, referred to below as the OpenSpace project. The overarching goal of the OpenSpace project is to build a pipeline for transmitting visualized science content from across NASA SMD divisions to audiences at Informal Science Institutions (ISIs), and the general public. Central to achieving this goal is the development of open source software, known as OpenSpace, and the promotion of the software's use in informal settings through the growth of a network of ISI partners. During the project's third year, AMNH made significant progress toward these objectives through ongoing work on code development, content visualization, and programs for general public, youth and educator audiences. Key to these accomplishments has been ongoing engagement of all major stakeholders through a variety of channels including a publicly accessible website that provides access to the opensource code and related documentation, a project management site, Slack channel, telecons and annual meetings. These activities are described in greater detail below.

YEAR THREE ACTIVITIES

Software Development

As planned, the beta version of OpenSpace was released on January 1, 2018, with several new releases rolled out in the course of the ensuing months to introduce new features and content. The project's advances in code development and visualized content during Year 3 included the following:

- A Web based GUI (graphical user interface), which allows for more intuitive navigation of the software by a broader range of users with various levels of expertise. The Web GUI will also allow for customization and creation of new unfacilitated OpenSpace experiences across a range of interactive platforms.
- Content Delivery Network (CDN) for improved availability and updates of data sets
- Improved the performance of loading mission visualization scenes that deploy spacecraft models
- Field line and Volumetric rendering for dynamic simulations
- A High-dynamic-range (HDR) rendering applied to atmospheric rendering in order to preserve details lost due to limited visual contrast.
- An initial camera recording and playback feature to roll out to selected ISI partners to support users interested in limiting live navigation of the software during a facilitated program to focus on interaction with the audience and to promote sharing of curated content for public presentations across ISIs.
- Game controller compatibility
- Overall performance improvements targeted at supporting venues with less powerful hardware, especially in underserved communities

Content Development

Ongoing content development has brought the number of interactive Scenes available in OpenSpace from 7 reported at the end of Year 2 to 13 at the end of Year 3. New scenes include:

Scene Updates

Mars Surface Exploration

The Mars Surface Exploration Scene developed in Year 2 has been substantially enhanced to include global visible color or elevation coloration can be applied as a base layer to an array of monochromatic multiple resolution imaging campaigns. 100-meter, THEMIS infrared, six-meter CTX and 25 cm HiRISE data are available currently in OpenSpace.

New Scenes

Earth Observations

Currently two forms of Earth imagery are supported, NASA Global Imagery Browse Service (GIBS), and ESRI's high resolution global mosaic. NASA GIBS posts global, temporal / daily, multispectral and multi-platform satellite data gathered by NASA's Earth Observing System which OpenSpace Globe Browsing can access. The daily True Color, Soumi NPP VIIRS global mosaic is loaded by default, displayed under a physics based atmospheric rendering when OpenSpace is launched. This default layer cross-fades to the ESRI high resolution global mosaic when coming closer to the surface of Earth. ESRI global terrain is also the default height map used when close enough for fly-overs.

Lunar Exploration

Current lunar missions are mapping the Moon to reveal compelling levels of detail in resolution, surface composition, and gravity measurements. OpenSpace displays many of these exciting new data, acquired from mission sources and through collaboration with other NASA colleagues, including most obviously JPL's Moon Trek. All Apollo landing sites at 50 cm spatial resolution and one-meter height resolution can be viewed in OpenSpace. Historical reconstruction of the full Apollo 8 mission and orbital trajectory of Apollo 15 are included, along with Apollo 15 and 16 Metric Camera mosaics which cover terrain observed directly below orbital ground track. Global gravitational free-air anomaly mapping by the Japanese Kaguya mission is also included.

Mars 2020 Mission

Current deliberation over the best landing site for the Mars 2020 life science investigation and sample collection mission can be explored in OpenSpace with a combination of HiRISE and CTX imaging and derived stereo elevation modeling, with mineralogical coloration by the CRISM experiment onboard NASA's Mars Reconnaissance Orbiter (MRO). Landing ellipse identifications are also included.

Exoplanets

Natively part of Digital Universe, current 3D locations of exoplanets can be viewed in OpenSpace. Both dynamical and stellar occluding discoveries by the Kepler mission are included. Typically viewed within the context of the current extent of human-generated radio signals since the late 1930's (our "radio sphere"), these recent and ongoing findings indicate the ubiquity of planetary formation that we can extrapolate across the galaxy and across the universe of galaxies in OpenSpace. Development of closeup orbital inspection and data retrieval from the exoplanets.org website is ongoing work, which will allow for a rapid update cycle to include new exoplanets as they are discovered. We expect to release this feature in Year Four (see below).

Voyager

The grand Voyager twin mission, launched in August 1977 has been reconstructed into NASA's current digital mission description of SPICE (see above), so that we can view the journeys of both spacecraft to the outer planets within OpenSpace. Like Juno, this mission visualization has yet to develop image projection.

Messenger

NASA MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission to the planet Mercury can be investigated in OpenSpace complete with spacecraft model, trajectories, global maps (image and elevation), regional closeups, and a static volumetric magnetosphere model. Image projection of specific observation sequences has yet to be developed.

Website

New materials and resources have been added to the website for OpenSpace (openspaceproject.com) including images that can be used for marketing, directions for download, links to the OpenSpace YouTube channel and more.

New videos have been added to the OpenSpace YouTube channel, including additional tutorial videos featuring co-I Emmart providing step-by-step instructions for using various aspects of OpenSpace.

New ISI Partners

The OpenSpace ISI User Network consisted initially of 6 funded partners (AMNH, DMNS, HMNS, NCMNS, Cal Academy and Adler). Four new US-based, and six international ISI partners have joined the OpenSpace ISI user network during Year 3 bringing the total number to 16. New U.S. partners include:

- Exploratorium, San Francisco
- Fisk Planetarium, University of Colorado, Boulder
- Lower East Side Girls' Club planetarium, NYC
- CUNY CCNY Planetarium, NYC

International partners include:

- Norrköping Visualization Center C
- Ghana Planetarium
- Planetarium Südtirol
- Hamburg Planetarium
- Singapore Science Center
- Natural History Museum Vienna.

Stakeholder Meetings

In Year Three, key meetings among OpenSpace stakeholders took place:

- April 3 - 4, 2018, AMNH. This year we decided to bring together our Informal **Science Institution (ISI) User Network and Advisory Board for a joint meeting to** discuss the past year's activities, near-term goals for programming, desired feature development, and opportunities for collaboration. **Bringing the two groups together gave board members the opportunity to hear directly from our expanding cadre of OpenSpace users, and for our ISI partners to benefit from board members' feedback.** In attendance were representatives from California Academy of Science, Denver Museum of Nature and Science (DMNS), Houston Museum of Natural Science (HMNS), North Carolina Museum of Natural Sciences (NCMNS), Adler Planetarium, and the Exploratorium, as well as our advisory board members Marc Horowitz, Edward R. Murrow High School; Lucian Plesea, ESRI; Kevin Hussey, NASA JPL; and Ka Chun Yu of the Denver Museum of Nature and Science; project evaluator Kate Haley Goldman, lead software developer Alex Bock.

- **April 23 – 28, 2018, Linköping University, Sweden. Our annual Developer meeting** brought AMNH's project management team together with our grant-funded collaborators from New York University and the University of Utah as well as OpenSpace developers from Linköping University to review work to-date, identifying near-term and long-term development goals.

Programmatic Offerings at OpenSpace ISI Network Partners

American Museum of Natural History (AMNH)

OpenSpace is used primarily in the Museum's Hayden Planetarium and Giant Screen 3-D theater. In addition, it is used within the Museum's youth internship programs.

Youth Internships

Seven high school interns from Bergen Academy worked under the direction of project co-I Emmart to further develop OpenSpace's Mars Exploration scene. The students converted Mars HiRISE terrain models to OpenSpace-ready VRT format; Documented descriptive summaries of each target; and used the Ames Stereo Pipeline photogrammetry process on Mars CTX 6m stereo coverage surrounding to identified high priority HiRISE targets.

Programs

November 28, 2017, *Astronomy Live: Voyagers*

In celebration of the 40th anniversary of the Voyager mission, OpenSpace was used to visualize the spacecrafts' trajectory through the solar system while an ensemble performed *Voyagers*, an original piece for clarinet and string quartet composed by Gerald Cohen. Timothy Ferris, producer of Voyager's Golden Record, gave opening remarks.

March 24, 2018, *Sun-Earth Day*

AMNH highlighted its continued collaboration with NASA Goddard's Community Coordinated Modeling Center (CCMC) by visualizing the beautiful interactions between our Sun and the Earth in the Museum's giant screen 3D theater. Co-I Carter Emmart, NASA solar scientists Masha Kuznetsova and Leila Mays, and Jon Linker from Predictive Science Inc., presented and OpenSpace's lead developer, Alex Bock, flew live. This program included visualizations of the Sun and Earth's entwined magnetic fields, NASA observations from the August 2017 total solar eclipse, and a screening of Aurora Borealis, a 3D film directed by Ikuo Nakamura. 496 people attended this event and California Academy of Science offered a live feed of the program to visitors in their 3D Theater.

March 27, 2018, *Astronomy Live: Mars in Focus*

OpenSpace Project Co-I Carter Emmart and Irene Pease led a tour of Mars and examined multiple iconic locations in exquisite detail including the latest high-resolution imagery of rocky terrain assembled from NASA and the European Space Agency.

April 13-14, 2018, *Mickey Hart Presents Musica Universalis*

Mickey Hart, legendary Grateful Dead drummer, presented Musica Universalis in the Hayden Planetarium. The program included a live performance of music created and performed in collaboration with the co-I Emmart who directed the immersive visuals, including some generated with OpenSpace.

June 7, 2018, *Gaia Sky*

During the week of June 4th, 100 researchers from around the world came to NYC for a "sprint" at the Center for Computational Astrophysics (CCA) to hack the Gaia dataset. On June 7th, the scientists were joined by members of the public in the Hayden dome for live presentation and interactive exploration of more than 900 million stars from the Gaia visualized in OpenSpace.

June 11, 2018, *Mercury Rising*

Co-I Denton Ebel showed newly integrated data from NASA's MESSENGER mission to an audience of 280. The new data gave context to Mercury's dynamic geological surface.

July 24, 2018, *Astronomy Live: To the Moon and Back*

Project Co-I Carter Emmart showed 402 event attendees the historic landing sites of the Lunar Mission Program, including Apollo 11, which was aided by high resolution lunar surface imagery combined with Apollo astronauts' photos and documented accounts.

September 25, 2018, *Mars 2020,*

Co-I Carter Emmart and Brown University's Christopher Kremer led 336 event attendees through a tour of Mars' surface from the perspective of NASA's Curiosity Rover using the latest high-resolution imagery of rocky terrain assembled from NASA. This program also explored the potential landing sites for the Mars 2020 rover mission.

The Adler Planetarium

Adler continues to use OpenSpace in its Space Visualization Laboratory (SVL). They have purchased a new computer for the laboratory that will enable OpenSpace to run on a 3D display.

Youth Internships

Two teen interns were recruited as part of Adler's Summer Teen Program which was partially facilitated by two undergraduate students. The students learned to create speck and asset files from the Galaxy Zoo dataset that could be used in OpenSpace. From this, they were able to use OpenSpace for their visualizations and final presentations. The students made the tools developed for this publicly available as Jupyter notebooks.

Programs

Adler Planetarium reached 600 members of the general public, 2 K-12 students and 2 graduate students with OpenSpace Programming; 110 of these were representative of underserved audiences.

Denver Museum of Nature and Science

With the help of Alex Bock and Micah Acinapura from the development team, OpenSpace was installed in DMNS' Gates Planetarium at the end of the summer 2018. DMNS also uses OpenSpace in in its permanent exhibits on a mobile Space Screen.

Programs

September 28 & October 1, 2018, *Our Active Sun*

Two OpenSpace pop-up events featured a 12-foot diameter Space Screen in the Museum's permanent Space Odyssey exhibit. 36 museum attendees were served across the two days and 18 were from underserved groups. On October 18, a pop-up event on the same screen presented DMNS's long-running "Digital Earth" program via OpenSpace. Approximately 50 museum attendees experienced this event.

October 2, 2018, *Earth-Sun Connection*

DMNS had its first public OpenSpace programs this past year. Research associate and solar physicist Mark Miesch presented, and Ka Chun Yu flew OpenSpace live. The event, which was marketed to Museum Members and the general public, used datasets from the *Sun-Earth Day* presentation at AMNH.

DMNS reached 153 members of the general public and 43 K-12 students with OpenSpace Programming, 30 of these were representative of underserved audiences.

Houston Museum of Natural Sciences (HMNS)

OpenSpace is primarily used at HMNS in a 7-meter inflatable dome.

Youth Internships

This year the Houston Museum of Natural Science hosted 13 interns, 4 of which were funded by the OpenSpace grant, to learn programming skills and planetarium operations through their Discovery Dome program, which utilizes a 7-meter inflatable dome. Over the course of the program, the interns created their own sequences in OpenSpace, some of which focus on the Moon in preparation for the Apollo 50th Anniversary celebrations and learned to pilot OpenSpace in real-time.

Programs

July 6 – August 10, 2018, *OpenSpace Intern Presentations*

Interns presented public programming Mondays through Fridays resulting in 69 OpenSpace presentations reaching 1132 visitors. Three interns also worked on a 29-page programming manual for OpenSpace which has become critical for sharing programming strategies among other interns. HMNS plans to use this manual to expand OpenSpace programming and presentation opportunities.

Discussion is underway with Evans and Sutherland to develop the capability to install OpenSpace in the main planetarium venue at HMNS.

HMNS reached 1132 members of the general public and 13 K-12 students with OpenSpace Programming.

North Carolina Museum of Natural Science (NCMNS)

OpenSpace is used on large screens in the Astronomy & Astrophysics Research Lab which routinely hosts public audiences at NCMNS, as well as in the Daily Planet theater.

Youth Internships

Three interns worked with OpenSpace at NCMNS during Year 3, post-baccalaureate, a college junior and recent high school graduate. The interns make many of the presentations described below.

Programs

This year at NCMNS, four 65-inch screens in the Astronomy & Astrophysics Research Lab grew to six screens, where OpenSpace continues to run looping movie clips of "zoom-ins" and "tours" of the Sun, planets, and the Moon during operating hours.

December 2017 & April 2018, *Members Only Tours*

NCMNS hosted special members-only tours of their Astronomy Lab, during which visitors learned about OpenSpace. Members had the opportunity to discuss how real data is being used in astrophysics research, mission planning, and planetary explorations, and how data visualization creates an easy path to communicate complex scientific research data.

January 27 & 28, 2018, *Astronomy Days*

OpenSpace was prominently featured due to the enhancement in the capabilities of the Astronomy lab. The Astronomy Days event included an interactive live program with OpenSpace Co-I Carter Emmart titled "Journey to Space!" which featured a tour from Earth to Mars and beyond.

May 4, 2018, *May the 4th*

An adults-only Star Wars themed event that brought 1035 space enthusiasts to the lab and highlighted OpenSpace. June 24th was International SunDay, an annual event in the lab held on a Sunday to feature Sun-related talks and solar observing. During International SunDay, three OpenSpace interns rotated as presenters, engaging museum visitors with OpenSpace, resulting in approximately 1093 interactions.

September 21, 2018, *Daily Planet: Virtual Tour of Space*

This program focused on astrobiology, visiting extreme environments on Earth, Mars, and other locations throughout the solar system. NASA space missions were also highlighted.

October 5, 2018, *Daily Planet: Earth to the Universe*

This program focused on exploring Exoplanets and deep space using OpenSpace.

October 19, 2018, *Penn State Seminar*

Rachel gave a seminar for the Exoplanets & Habitable Worlds group of the Dept. of Astronomy & Astrophysics at Penn State. As part of this she showed a few slides that included OpenSpace videos, as part of the intro to the research lab at the museum. This led to a meeting with one of their astronomy media people (Nahks Tr'Ehnl) and a follow-up discussion on his video work for the department.

October 26, 2018, *Upside-down Halloween*

The Astronomy Lab was open for visitors for a themed event around Upside-Down/Stranger Things/Halloween, and the lab angle to this was "Stranger Things in the Universe". OpenSpace intern Tierra showed visitors live tours with OpenSpace for the 3 hours of the event, which seemed very successful in terms of visitor interest. OpenSpace certainly looks nice - the high-resolution terrain of Mars – this was highlighted as were extra-solar visuals. The interactive program was shown on the large wall tile, as well as mirrored on the 48-inch desktop screen.

NCMNS reached 218,775 members of the general public, 17,982 K-12 students, 62 educators and 34 graduate students with OpenSpace Programming, 59,121 of these were representative of underserved audiences.

California Academy of Sciences

OpenSpace is used in the Morrison Planetarium at the Academy and on the floor of the Museum.

Programs

March 24th, *Sun-Earth Day, 3-D Theater*

The Academy joined AMNH for Sun-Earth Day, feeding the program described above live into their 3D theater.

June 25th, *Piecing Together Mars: From Discovery and Surprise Toward Understanding a Sister World, 3-D Theater*

The Academy used OpenSpace in during one of its prestigious Benjamin Dean lectures, which bring leading experts in astronomy, astrophysics, and other areas of science to the Academy's Morrison Planetarium. The lecture featured OpenSpace Project Co-I Carter Emmart and Dr. Jeff Moore, Planetary Geologist at NASA-Ames Research Center exploring the surface of Mars using OpenSpace.

October 7th, 14th, 21st, 28th, *Mars Member Program, Floor of the Museum*

The Academy has hosted four members-only OpenSpace demonstrations on the floor of the museum, flying around known areas of Mars. Approximately 55 members attended these events.

California Academy of Sciences reached 424 members of the general public with OpenSpace Programming.

Planetarium vendors

Partnering with vendors who support domes and immersive theaters in planeteria and other ISIs is a key strategy for disseminating OpenSpace. OpenSpace currently has an active distribution and development partnership with Eluminati, which support OpenSpace across their wide variety of Geodomes and with Evans and Sutherland (E&S), which supports OpenSpace within their Digistar 6 software. We also made progress collaborating with SkySkan to integrate OpenSpace within their systems. In addition, we have received support for specific installations from SCISS, ePlanetarium, Front Pictures, and Full Dome Pro since Year 2, and have started new conversations in Year 3 with Zeiss and Digitalis.

III. Status/Changes/ Issues

The use of OpenSpace at the AMNH in afterschool, weekend and summer programming for children and youth has been delayed to Year Four to take advantage of the simplified Graphical User Interface (GUI).

IV. Dissemination Activities

Conferences & Events

Astroviz
In June 2018 the Spitzer Science Center at Caltech hosted Astroviz, a gathering of professionals involved in the fields of astronomical and astrophysical data visualization. OpenSpace presented both a talk and an hour-long workshop. OpenSpace Mac and Windows versions were made available on flash drive to cut the data downloading time for general handout as well as during the how-to demonstration, which was well attended. This meeting helped to improve the knowledge and hand-on working ability to fellow professionals in the field, (including vendors) and network about possible future collaborations. Co-I Emmart presented and led the workshop. AMNH Astronomer Jackie Faherty presented about the use of OpenSpace to visualize the results of the Gaia Mission.

IPS

The 2018 meeting of the International Planetarium Society took place in Toulouse, France at the Cite de L'espace, at the beginning of July. OpenSpace presented a workshop on the second to last day and was well attended by both planetarium directors and leaders of the industry. Anders Ynnerman from Linköping University

introduced the session. Carter Emmart presented recent visualization scope of OpenSpace, and Micah Acinapura gave a technical introduction to the downloading and organizational structure of the software. Several vendors were interested in knowing more about how to team up with OpenSpace, including Zeiss, the company which invented planetarium projection in the 1920's.

LPSC

A poster entitled *OpenSpace: Setting the Universe Free (authors, E. J. Crapster-Pregont, M. E. Gemma, C. Emmart, V. Trakinski, R. L. Smith, D. S. Ebel, and R. Kinzler)* was presented at Lunar and Planetary Science Conference (LPSC) in Woodland, Texas.

ASTC

Association of Science and Technology Centers (ASTC), Hartford, CT - Co-I Carter Emmart and lead developer Alex Bock gave 3 presentations using OpenSpace on the NASA Hyperwall at ASTC this year. The presentations were well attended and sparked new awareness of and interest in the project.

Space Apps

The OpenSpace was included as a resource in NASA's international Space Apps challenge this year, with five teams hacking the software, including one that incorporated voice commands. The OpenSpace team spent the weekend at the local NYC chapter of Space Apps, engaging local hackers the software.

Press

Open Space was featured in the New York Times article "*At the Hayden Planetarium, A Joy Ride Across the Cosmos."* https://www.nytimes.com/2018/03/09/arts/mars-hayden-planetarium-solar-system.html

Academic Papers

OpenSpace: Bringing NASA Missions to the Public

Bock, A., Hansen, C., and Ynnerman, A.

IEE Computer Graphics & Applications, Issue No. 05 - Sep/Oct. (2018 vol. 38)

OpenSpace: Changing the Narrative of Public Dissemination in Astronomical Visualization from What to How

Bock, A., Axelsson, E., Emmart, C., Kuznatsova, M., Hansen, C., and Ynnerman, A.

IEEE Computer Graphics & Applications, Volume 38 Issue 3 • May/Jun. 2018

Graduate Theses

Alexander Bock, lead developer for the OpenSpace Project, completed his doctorate degree from Linköping University this summer with the successful defense of a thesis entitled *Tailoring Visualizations Applications for Tasks and Users,* which is based on his work creating OpenSpace. In addition, Michal Marcinkowski defended a thesis entitled *Contextualization of Autonomous Spaceflight Operations for deep space planetary encounters*, which also reflects OpenSpace research and development, Adam Alsegård defended his thesis working on the real-time rendering of a billion stars contained in the Gaia dataset, Sofie Khullar and Hanna Johansson defended their thesis on the development of a new user interface design used on touch-table interfaces, and Caroline Gard and Kristin Bäck defended their thesis on the accurate visualization of the movements of the Curiosity Mars rover.

OpenSpace Web Presence

- Main Website - www.openspaceproject.com -- For developers, the open source community, and general public.
- Public wiki-style information for users, content creators, and developers at wiki.openspaceproject.com
- YouTube channel - https://www.youtube.com/channel/UCHZpv-5zARkWibw1Z-g6ptQ -- has received 33K views.
- Twitter - https://twitter.com/OpenSpaceProj -- currently has 188 followers.

V. Evaluation, and Cross-Collaboration Agreements Activities

Evaluation and Assessment by Kate Haley Goldman

The OpenSpace project evaluator Kate Haley Goldman worked with the team to align project goals with the SciAct Crosswalk, facilitate development of summative indicators, pilot summative data collection tools for public programs, conduct implementation evaluation with partners, and impact evaluation with youth interns. In addition, the evaluator worked to coordinate data collection and program reporting across the network.

OpenSpace Top Level Metric Projections through the end of Year 5

The top-level roll-up metric for OpenSpace continues to be the number of interactive scenes of visualized NASA data available within OpenSpace. The OpenSpace target goal is to increase the number of Scenes within OpenSpace from 0 in 2015 to 20 by 2020 (end of year 5). A scene consists of the full astrophysical context plus multiple visualized assets required to support rich narrative programming about NASA missions and science results.

In Year 3 of the OpenSpace project we went from 7 scenes to 13 scenes. The project is projected to be at 20 scenes by the end of 2020.

SciAct Alignment

The OpenSpace PIs and evaluator worked together to ensure the project is aligned with the SciAct goals and determine which specific program indicators track back to those goals.

OpenSpace is currently aligned with SciAct goals 1, Enabling STEM Education in all 50 states; and 3, CoSTEM goals, specifically #2, Increasing and Sustaining Public and Youth Engagement in STEM focusing on increasing public engagement in STEM via ISI programs for public audiences of all ages (including youth).

SciAct Goal 1: Enabling STEM Education in 50 States

OpenSpace focuses on enabling STEM education in 50 states in through OpenSpace Network ISI Partners in different locations across the country offer a variety of multi-week, semester, and year-long internships and mentored experiences with data visualization and code development to youth from high school through graduate school. OpenSpace accomplishes this in two ways:

1. Years 1 -5: OpenSpace Network ISI Partners in different locations across the country offer a variety of multi-week, semester, and year-long internships and mentored experiences with data visualization and code development to youth from high school through graduate school; and
2. Years 4 – 5: OpenSpace Network ISI Partners in different locations across the country offer the Digital Universe Flight School – a 40-hour program that engages middle and high school students at informal science institutions in the use of OpenSpace to explore our solar system, stellar neighborhood, and Digital Universe Atlas, with an emphasis on NASA mission activities. The Digital Universe Flight School curriculum will be piloted and refined at the AMNH in year 4, and then distributed to network partners for implementation in Year 5.

In Year 2 of the OpenSpace project we had 46 interns across partner sites, in Year 3 we increased by another 50 interns, for a cumulative total of 96 interns. By the by end of 5 years the project is anticipated to have offered mentored experiences to 266 interns.

SciAct Goal 3, CoSTEM goal #2: Increasing public engagement in STEM via **ISI programs for public audiences** of all ages (including youth and educators).

OpenSpace focuses on increasing public engagement in STEM via ISI programs for public audiences of all ages (including youth). As noted elsewhere in this report OpenSpace focuses on increasing public engagement in STEM via ISI programs for public audiences of all ages (including youth). During Year 3 of the project, we held 32 programs across 6 sites, serving a total of 363,854 individuals.

The cumulative number of OpenSpace ISI programs to date is 57. By the end of Year 5 the project had projected offering 227 or more ISI programs. The project has recognized that the range of offerings currently included in the program count across the ISI network is broad, including installation in permanent exhibitions, scheduled presentations on exhibit floors multiple times a day throughout the week, and one-time offerings in domes and theaters. Thus, the count of 33 programs in Year 3 spans programs of all these types. We will develop new strategies to refine reporting these activities in Year 4 to accurately reflect this variety. We also anticipate reporting programmatic offerings and audiences reached at new members of the expanding OpenSpace ISI User Network.

SciAct Goal 4, Leverage through partnerships

OpenSpace has the specific goal to increase the number of ISI users and commercial vendors who are key to the broad distribution of the software and integration into planetarium systems and a variety of large-screen and 3D theater environments. During Year 3 the number of US-based ISIs using OpenSpace has increased from 5 to 10, and the project is actively working with 9 vendors. By the end of Year 5 the project is anticipated to have 20 US-based ISI users and to have established productive partnerships with as many of the 9 vendors as possible.

Summative (Impact-level) Other Indicators

Our pilot evaluations have shown that audience members recognize the quality, sense of immersion, and enormous consolidation of NASA data within the OpenSpace visualizations. Members of the public, space enthusiasts, or staff and scientists have all expressed amazement at the quality and detail of the visualizations, and an eagerness to see more content areas. In interviews, several audience members have noted that when the software has glitches or stalls, those moments reinforce the fact that the OpenSpace system is based on data, and that what they are seeing is the result of many different missions and data streams, rather than artistic models of the universe. These moments underscore both the complexity and level of effort of the work of NASA and partnering scientists.

Summative Methodologies Pilot

Over the course of multiple programs at multiple project sites, we have experimented with the optimal methods of collecting data about the impact of the programs on audiences. Notwithstanding the variety of content communicated and types of locations where OpenSpace is used, the majority of uses are in the form of a public program. Some are held in theater spaces and involve lecture-style presentations with multiple types of visualizations and a question and answer period. Others are held in planetariums, or on large flat-screens on a museum floor. One common element is that attendees do not tend to linger after a presentation. After daytime programs, they are often eager to move on to see as much of the institution as possible while it is still open, or, after evening programs, to head home after a long day. Post-program individual interviews have thus proven difficult, as attendees all leave at the same time, and one evaluator can get only 8-10 interviews out of a program of 300 attendees.

To combat the low response rate, we have experimented with SMS-based surveys. In this format, there is a phone number that individuals can text with a response to a question. The benefit of the texting method is that program attendees do not have to download an app or enter a URL to answer a survey. As you can see in the picture attached, attendees simply text their responses to a particular phone number. We have had variable response rates to this method, at times having almost no answers submitted, at other times receiving a slow trickle of responses. The response rate has never exceeded 10% of attendees.

Picture 1:

We have also tried more traditional paper-and-pencil surveys, using best practices such as handing out surveys at the beginning of a program, providing a pencil, and personally soliciting the return of the surveys at the end of the program with a smiling individual holding a large basket and asking for surveys. Some partner ISIs report this technique gives them response rates of 40% or more, however we have not achieved those levels in our programming. The institutions who have reported these higher rates have generally had fairly desirable incentives for survey returns.

Moving forward we will continue experimenting with SMS-based surveying on a limited basis, and more extensive work with paper-and-pencil surveys. We will be strongly incentivizing survey return in the coming year in an effort to improve response rate. In order to get deeper responses than surveys allow, we will be conducting focus groups with key audience segments at a number of ISI partner sites in the coming months.

Partner Implementation Needs

Over the course of Year 3, we have had in-person meetings, conference calls, and individual telephone interviews to track partner programmatic implementation and to identify specific OpenSpace innovations that partners think would lead to enhanced programming at their ISI sites. As we build towards full implementation, these innovations would allow partners to implement OpenSpace in new or extended formats. High on the priority list of potential innovations identified by OpenSpace ISI partners are:

1) an enhanced graphical user interface (initial version available in the latest release, but still under development for improved user experience and to create novice and expert modes of operability)

2) means to control OpenSpace on an iPad or similar handheld device, so that presenters on the museum floor or within a theater can use the software more easily. (With the Web based GUI now implemented, we will prioritize this functionality early in Year 4.)

3) gaining easier methods for locating specific sites, like a coordinate system that could be typed into OpenSpace (this feature will be discussed as a priority at the OpenSpace Year 4 developer meeting in January, 2019.

Partners have also noted that at times they were rendering video of OpenSpace, and then sharing that during presentations, so they didn't have to "fly live". As one partner said "Us rendering out a video from OpenSpace also allowed me to carefully tweak the sequence to show what we wanted to see. It would have been much more haphazard, if I was "flying" live during the talk." Other ISI partners have discussed ways to support docents and other staff who may not be as knowledgeable or confident in navigating OpenSpace, so they can use portions of OpenSpace for their talks. Video capture

capability is currently in the final stages of implementation and will be rolled out early in Year 4.

Partners have also identified the need for increased documentation. Now that several more content scenes have been developed, the team is developing reference and training materials to support staff at the ISI sites in their use of OpenSpace. These materials will be launched in Year 4.

ISI Partner Excitement and Investment

As part of the evaluation, we have been speaking with the ISI partners about where they feel OpenSpace extends and supports their work as well as their hopes for how it will further their work in the future.

Dr. Ka Chun Yu at Denver Museum of Nature and Science asserted “OpenSpace has been a game changer in opening the planetarium community’s eyes as to what types of data sets and visualizations are possible.” He gave the examples of animations of the Sun and computer simulations of solar wind field lines as datasets that most people have not been exposed to before OpenSpace. He believes that visualizing these massive datasets could be a very important element of how OpenSpace can be important for scientific research as well as public outreach and education.

Ryan Wyatt, Director of the Morrison Planetarium at California Academy of Science, notes he is especially excited about the opportunities for future collaborations. “There’s great potential in expanding dome casting without needing to have the same proprietary software. Additionally, open source software gives researchers and data providers an added incentive to collaborate, as they can then use it themselves and/or share it with others.”

Ryan believes that incentive, combined with NASA’s involvement, will help engage astronomy and space science researchers in general. OpenSpace combines the interactivity of platforms that researchers are already engaged with, such as NASA Trex, with the immersive environment of the planetarium. In that way, it helps to bridge these worlds.

Professor Rachel Smith at North Carolina Museum of Natural Sciences said that OpenSpace is so visually stunning, it has an immediate impact on audiences. It has made depictions of their lab’s research more interesting, and thus is a great gateway to talk about research with audiences. She feels it has been an important addition to the museum.

Dr. Mark SubbaRao at Adler Planetarium is especially excited about OpenSpace as a tool in the planetarium for accurate visualization of mission data and interesting visualizations. While the accuracy of visualizing missions existed previously, they did

not have the capacity to do it in the planetarium. He's very interested in future possibilities of real-time volumetric rendering of dynamic data sets.

Mark thinks that OpenSpace's real power will be seen when it can be installed in a majority of planetariums, allowing greater collaborations on content development. To parcel out the work would increase the quality of visuals being shown around the world.

In the future, Adler would like to increase the number of networked dome cast events for professional scientists, as an open source software means that the potential audience is the entire scientific community. Additionally, because OpenSpace is such a wonderful visualization tool, not just for the public but for researchers as well, Mark imagines that being able to see increasingly large and complex datasets in an immersive environment will allow researchers to understand patterns more quickly.

Dr. Carolyn Sumners at Houston Museum of Natural Science, said that not only has she really enjoyed working with OpenSpace but that they see more potential in it now than they had even imagined at the inception of the project. With the anticipated ability to prerecord paths, she plans to expand OpenSource programming to her other venues, serving an additional approximate 200,000 visitors annually.

- **SMD Collaborators and Cross CAN Awardee and NASA Infrastructure collaboration Activities in Year Three**

  We have had ongoing conversations, development activities, and public programming in collaboration with NASA personnel and other awardees, as the chart below shows:

SMD Personnel	NASA Infrastructure	Cross-collaboration with Science Activation Awards
Alfred Wardon, Apollo 15 CMP	Kevin Hussey, Visualization, Technology, and Development, JPL	U Colorado Boulder - Installation of OpenSpace at Fiske Planetarium
Asher Pembroke, NASA CCMC	NASA Eyes	GSFC/NSSEC - Collaborated for Sun Earth Day events at AMNH
Ben Cook, NASA GISS	NASA Trek	STSci – Universe of Learning - exploring sharing visualization assets
Bob Pappalardo, NASA JPL		WGBH - Exploring sharing educational assets

Carl Hostetter, NASA GSFC		Exploratorium - Installing OpenSpace for public exhibition (San Francisco, CA)
Charles Duke, Apollo 16 LMP		Gulf of Maine Research Institute – ongoing sharing of educational best practices
Chris McKay, NASA Ames		ASU NISENet - ongoing discussion about mutually beneficial dissemination activities
Darren DeZeeuw, NASA GSFC, CCMC		Astronomical Society of the Pacific
Jeff Moore, NASA Ames		
Jeffrey E. Schmaltz, NASA GSFC		
Lelia Mays, NASA CCMC		
Lika Guhathakurta, NASA Heliophysics Science Division		
Masha Kuznesova, NASA CCMC		
Ross Beyer NASA Ames		
Ryan Boller NASA GSFC		
Thomas Grubb NASA GSFC		
Tim Parker, NASA JPL		
Troy James NASA GSFC		

In addition, **new collaborations** with scientists and educators within and beyond NASA are being proposed been established that will expand the use of OpenSpace as a tool for exploration of Earth and space science data across broad audiences. These partnerships include:

- Brown University & the University of Minnesota are porting OpenSpace to their virtual reality caves using the MinVR framework that was developed at these locations.

- Dr. Jon Linker, Predictive Science Inc., AMNH OpenSpace has joined a proposal to and NSF PREEVENTs to visualize solar and space physics phenomena using the models they are proposing.

- In addition we are in conversation with Dr. Timothy Glotch, SUNY Stonybrook and Dr. John Christian, RPI about proposing use of OpenSpace in their upcoming NASA SSERVI CAN proposals.

VI. Year Four Plans

Year Four plans will focus on responding to evaluation feedback by stabilizing the code, improving graphical user interface design, providing flexible control options, improving recorded playback, and generating documentation and new video tutorials.

In addition, we plan to continue ongoing work to support use of OpenSpace in VR headsets and on interactive touch tables.

Plans for new scenes and expand content for existing scenes in Year Four include:

Scene Expansions:

Exoplanets

Masters thesis work related to OpenSpace in spring 2018 focused on visualizing known quantities of orbital parameters, object sizes and mass, and uncertainty measurements. This work will be integrated into the Exoplanet scene currently available in OpenSpace to provide the opportunity to interact with exoplanets close up.

Mars Surface Exploration

Two dual thesis projects (2017 and 2018) have successfully visualized the imaged surface terrain and telemetry recorded actions of the Mars Surface Laboratory / Curiosity rover. Stereo imaging by the wide field navigation cameras is used to generate terrain models which are published on NASA's Planetary Data Service (PDS). OpenSpace uses these, positioned along the rover transect atop the official HiRISE, 25 cm base map mosaic to see a browsable context of surface site observation. Recorded telemetry, also available on the PDS is played back to watch the rover's actions across the mission. Again, a delivery strategy is currently being evaluated for delivering this very large data set.

Mars 2020 Mission

Mars Mission surface investigation (MER) and Like the MSL / Curiosity rover visualization, the precursor MER rovers, Spirit and Opportunity are planned to be visualized. Curiosity visualization provides a template which can be emulated by future thesis students or Columbia University Engineering undergraduates. More similar to

Curiosity, the planned Mars 2020 rover can benefit from this same template for visualization once anticipated surface operations commence.

New Scenes

Gaia Mission

Masters thesis project (spring, 2018) successfully visualized the Gaia second data release of effectively one billion stars and was presented in the Hayden Planetarium as part of a collaboration with the Center of Computation Astrophysics (described above). The enormous size of this data set poses a challenge for delivery in live programming. A strategy is currently being evaluated and we hope to implement it next year in OpenSpace.

Volumetric Milky Way Galaxy

Core OpenSpace developer time is currently being evaluated to visualize data sets derived from a constrained simulation of our galaxy by researchers at Japan's National Observatory and refined at AMNH for space show production. This state-of-the-art simulation was based on radial velocity studies across the Milky Way, with a level of detail hat is a challenge to visualize for interactivity. We hope to implement this work next year providing new and improved context for a subset of the Digital Universe atlas.

Deep Space Network:

Central to operating the world's fleet of spacecraft beyond Earth orbit is the triple system of geographically dispersed communication stations of the Deep Space Network (DSN). Located in California's Mojave Desert, Canberra, Australia, and Madrid, Spain, these three stations maintain continuous command and data gathering of active missions. A dual thesis project is currently underway in collaboration with NASA Eyes and DSN staff to visualize in OpenSpace the uplink and downlink history and current operations.

Programs planned for Year Four include:

- Apollo Anniversary Program at AMNH (scheduled for December 28th, 2018)
- Educator's Evening at AMNH (scheduled for January 3rd, 2019) that will focus on the Apollo Anniversary, educator resources from WGBH.
- Collaboration with Eyes on the Solar System to create a feed for NASA TV visualizing the Insight Landing in real time.
- The launch of AMNH's OpenSpace Digital Flight School
- A range of programs at OpenSpace ISI Network Partners including:
    - Apollo/Moon
    - Mars
    - GAIA
    - Exoplanets

VII. International Partnerships

University and ISI Partnership with Norrköping Visualization Center C

The visualization center, hosted by Linköping University, is the main international contributor to OpenSpace and contributes by:

- Selection, supervision and examination of master's students from the Media Technology program at Linköping University
- Development of core functionality with support from the Swedish eScience Research Center (SeRC) corresponding to 1 FTE.
- Deployment of OpenSpace in the public program of the center

A highlight from use of OpenSpace was "Space fever" a full day program based on OpenSpace on July 7th 2018. The program was hosted by Swedish astronaut Christer Fuglesang and project Co-I Anders Ynnerman. OpenSpace was also shown at the MIRAI meeting in Japan to an audience including the Swedish ambassador to Japan and presidents of the most prominent Swedish and Japanese universities.

OpenSpace has also been selected as one of five themes for the Swedish national science center program "WISDOME" with support from the Knut and Alice Wallenberg foundation. The program will develop content for five dome theaters in Sweden with the Norrköping Visualization Center as the coordinator.

Additional science partners include Nanyang Technological University and Lunar and Planetary Science Institute.

VIII. Attached Information

- OpenSpace Developer Meeting agenda
- OpenSpace ISI Network and Advisors Meeting agenda