OpenSpace Annual Progress Report – Year 2

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 2016–October 2017

II. Accomplishments

The American Museum of Natural History (AMNH) is pleased to submit this second 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 Informal Science Institutions (ISI), secondary school classrooms, and the 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 establishment of a network of ISI partners. During the project's second year, AMNH made significant progress toward these objectives through the accomplishment of ongoing work on code development, content visualization, and public programs and by bringing together all major stakeholders in a variety of meetings. These activities are described in greater detail below.

Software Development

The release date of January 1, 2018 has been announced for the beta version of OpenSpace. The project's advances in code development and creation of visualization content included the following:

Digital Universe Atlas (DU)

AMNH completed work on OpenSpace's dynamic scene graph functionality to support navigation of AMNH's multi-scale Digital Universe 3D Atlas and other astronomical atlases. The DU atlas has been integrated into OpenSpace, including the incorporation of data released from the European Space Agency's Gaia mission in mid-September.

Heliophysics

AMNH continued its collaboration with NASA Goddard's Community Coordinated Modeling Center (CCMC) to portray space weather through the visualization of Earth's magnetosphere as simulated by CCMC's Bats-R-US code, and the ENLIL real-time solar wind application. This marks the first **volumetric dynamic simulation visualization** for OpenSpace. NASA Goddard hosted two OpenSpace graduate interns from Linköping University for six months to work on this functionality and, in June 2017, project Co-I Carter Emmart presented a public program in the Hayden Planetarium at the AMNH using OpenSpace with CCMC's Science Director, Dr. Masha Kuznetsova and Deputy Director Dr. Leila Mays to an audience of 236. Admission to this event was free. 360 Video recording of the event received 1,435 views on YouTube. (This work will not be in the initial Beta release of the software to allow for fine-tuning of the code. We expect to release it in the following quarter of 2018, however.)

Planetary
OpenSpace's **Globe Browsing** functionality was completed for interfacing with Web Map Services (WMS) protocols to enable the use of multi-resolution map archives such as NASA Goddard's Global Imagery Browse Services (GIBS) and NASA's multi-center Lunar Mapping and Modeling Project (LMMP). AMNH hosted two graduate interns from Linköping University for five months to execute the latest phase of this work, which included improvements to the code to include Mars Rover 3-D panoramic models prepared by the Rover Operations Team and archived on NASA PDS.

The Globe Browsing functionality was then used in multiple Earth Day programs: an Earth Day program on April 21st with NASA Climate Scientist Dr. Benjamin Cook from NASA Goddard GISS that was in the Hayden Planetarium at the AMNH and networked with OpenSpace ISI Network Partner North Carolina Museum of Natural Sciences (total audience of 193); and Network Partner CalAcademy used assets from the program for their own event the evening prior (total audience of 120). An Earth Day Program was also offered at the AMNH for an audience of 164 NYC Educators on May 12.
Globe Browsing was also used for a Mars program on June 5th in the Hayden Planetarium presented by Co-I Carter Emmart and a group of high school interns from Bergen County Academy in NJ that engaged the audience in exploration of the surface of Mars utilizing ~400 terrain models (produced by the USGS/ASU) the interns prepared for OpenSpace. 380 people attended this event in the dome and 5,920 people have viewed the program online: https://www.youtube.com/watch?v=NWZAg6qpMlE&t=959s

The code for accurately visualizing **atmospheres**, including for Earth, Mars and other planets, was completed by OpenSpace project partner New York University.

Mechanism for accurately visualizing and explicating **eclipse** events was also completely by our NYU developers.

Additional functionality for OpenSpace were also added, including

- live streaming of 360 videos to YouTube. Watch an example here: https://www.youtube.com/watch?v=rDDjcxBP6ag
- a touch interface that has been prototyped on touch tables and that will be further developed as for a Web based GUI in the next quarter. View a demonstration of it here: https://www.youtube.com/watch?v=6joqAAco0O4

- Ability to overlay flat images from the Web or local source, which can be used to bring additional content into an OpenSpace presentation. For example, astronomical images can be shown from their proper location within the Digital Universe 3D Atlas as a strategy for communicating recent discoveries.

Stakeholder Meetings

Throughout the second year, key meetings among OpenSpace stakeholders took place:

- **Developer meeting**, in which our grant-funded collaborators from New York University and the University of Utah joined us and our developers from Linköping University and two representatives from Evans and Sutherland, one of the field's largest planetarium vendors, for a two-day meeting in Utah on February 2nd and 3rd. The meeting was devoted to reviewing work to-date, identifying near-term and long-term development goals, with special focus on the Beta release of the software planned for the end of the calendar year.

- **Informal Science Institution (ISI) User Network meeting**, at ASTC on October 22nd, in which our grant-funded partners from, California Academy of Science, the Denver Museum of Nature and Science (DMNS), the Franklin Institute, the Houston Museum of Natural Science (HMNS), and the North Carolina Museum of Natural Sciences (NCMNS), (our partner from Adler Planetarium was unfortunately unable to attend) convened to discuss the past year's programming, near-term goals for programming, desired feature development, and opportunities for collaboration. Also present at the meeting were the project's evaluator and and its lead developer from NYU.

Year Two Programmatic Offerings at OpenSpace ISI Network Partners

- **The Adler Planetarium**

Adler continues to use OpenSpace in its Space Visualization Laboratory (SVL). The software is utilized in the Astronomy Conversations program. In this program Adler staff scientists and volunteers from the local Chicago scientific community make informal presentations to the visiting public. We are in the process of training more presenters to use OpenSpace in their presentations. In addition, Co-I SubbaRao worked with the OpenSpace team to plan for the inclusion of OpenSpace in the 'Data to Dome' workshop in Tokyo (March 2nd -3rd 2017), a workshop that Dr. SubbaRao chaired. This workshop focused on extending the state of the art in data visualization in the Planetarium and included OpenSpace Co-I Carter Emmart giving a keynote talk on OpenSpace and an afternoon practicum session on developing OpenSpace content. and is jointly sponsored by the International Planetarium Society and the National Astronomical Observatory of Japan.

Six OpenSpace Summer interns, rising Juniors and Seniors, (all representing underserved audiences) were recruited. The students gained familiarity with Mars and Mars exploration and learned to work with ISIS and the NASA Ames Stereo pipeline as well as OpenSpace, and developed and made their own public presentations.

In addition to the six OpenSpace Summer interns, all underserved, Adler reached 1400 members of the general public, with 200 of these underserved, as well as 40 Informal Science Institution professionals with OpenSpace programming.

- **Denver Museum of Nature and Science**

Dan Neafus from DMNS attended the OpenSpace ISI Users Network at ASTC where ongoing technical issues delaying installation of OpenSpace in their dome were discussed. Plans to work directly with their vendor, SCISS, to resolve the situation were devised, as were strategies for training staff and volunteers on the software.

- **Houston Museum of Natural Sciences (HMNS)**

The Astronomy Department of the Houston Museum of Natural Science (HMNS) created an Open Space Theater in the rotunda of the Astronomy Department to showcase Open Space simulations and to show how the data collected help us determine what it would be like to visit different places in the solar system. This theater offered three shows a day (12:00, 1:00, and 2:00) Monday through Friday for visitors to the Museum's exhibit halls. The program was prepared, programmed, and presented by high school interns from June 12 to August 16, 2017.

The HMNS reached an audience of 1429 with OpenSpace programming.

- **North Carolina Museum of Natural Science (NCMNS)**

Four 65-inch screens in the Astronomy & Astrophysics Research Lab run continuously during opening hours at NCMNS are now looping *OpenSpace* movie clips of "zoom-ins" and "tours" of the Sun, planets, and the Moon.

In late April, special members only tours of the Astronomy Lab at NCMNS during which OpenSpace was featured as part of the introduction to the science and outreach of the lab Many visitors were very interested in the visuals and how they were rendered, and showed interest in using the software themselves. *OpenSpace* was also showcased at two special events during the summer, the annual "International SunDay" and "Superhero Science Night". The lab was open for visitors during these events, and much of the visitor interaction included discussions on *OpenSpace*, with visuals shown on the large wall tiles. Further, interested visitors could "drive" with *OpenSpace*, an activity led by Michael Tucker, last year's *OpenSpace* intern. An *OpenSpace* public program, "Astrobiology and the Giant Planets" was presented by OpenSpace Project Co-I Dr. Rachel Smith and showcased some of *OpenSpace*'s best visuals available to the project partners; *OpenSpace* intern, Chris Allen, flew. Audience members were diverse in age, including adults and school groups, as well as small children, and overall they were attentive and had questions about the software, as well as many general inquiries about space and the planets. OpenSpace Project Evaluator Kate Haley Goldman observed Astrobilogy programs, taking note of the visual spaces and visitor interactions, as well as how the implementation of *OpenSpace* fits into the goals of NCMNS and of the project.

NCMNS reached 101,411 members of the general public, 15,651 K-12 students, 3,188 educators and 41 graduate students with OpenSpace programming, 30,039 of these were

representative of underserved audiences.

- **California Academy of Sciences**

The California Academy of Sciences hosted two events in Morrison Planetarium that leveraged OpenSpace as a real-time full-dome interactive presentation tool.

OpenSpace at AGU
For the third year in a row, attendees of the annual American Geophysical Union (AGU) Fall Meeting, held in San Francisco, were invited to attend an informal presentation in Morrison Planetarium. For 2016, CalAcademy featured a presentation by Carter Emmart speaking to both real-time and pre-recorded OpenSpace full-dome content.

Earth Day at NightLife
As part of CalAcademy's weekly "cocktails and science" event at the Academy, a live 6:30 p.m. program is hosted in Morrison Planetarium. For Earth Day on April 20th, a program was created that leveraged OpenSpace assets from the program that would be presented the following day in New York City. The attendance was lower than anticipated (a third to a quarter of our typical attendance) because of an annual 4/20 event that takes place in Golden Gate Park, which prevented or delayed many NightLife attendees' participation.

The California Academy of Sciences reached 128 members of the general public with OpenSpace programming.

Planetarium vendors

We have continued to have productive conversations and demonstrations with all the major planetarium vendors this year. University of Utah engineer Gene Payne worked directly with Evans and Sutherland (E&S) to achieve alignment between OpenSpace cameras and the configuration of their Digistar 6 program. OpenSpace is functioning with SCISS systems at several locations. Proper configuration for mirror projection in the ePlanetarium's Discovery dome and other travelling domes was achieved. OpenSpace is now fully integrated into Eluminati's software for their wide variety of traveling domes and also functions on Fulldome Pro systems.9

III. Status/Changes/ Issues

In Year Two of the OpenSpace project, we continued the development of the software with our focus on achieving the core functionality features we had specified for the beta release. In addition we developed 7 Scenes – each built from the visualization of several different data sets to support interactive programming focusing on a variety of NASA SMD activities.

As we had discovered in Year 1 we continued to find that more time and resources was required to develop the features specified for the beta version of OpenSpace, thus, some of our program goals have been shifted into Year Three.

The web presence for OpenSpace for educators and the general public has been deferred to Year Three as well as the use of OpenSpace at the AMNH and by OpenSpace ISI Network Partners in afterschool, weekend and summer programming for children and youth.

The Year Two Advisory Board meeting has been deferred due to the extended time frame required to meet the development milestones required to produce the beta version of the software. We look forward to convening the board in Year Three to discuss work to date and long-range OpenSpace planning and strategic initiatives. Members of the board include: Marc Horowitz, Edward R. Murrow High School; Lucian Plesea, ESRI; Kevin Hussey, NASA JPL; Julie Edmonds, Carnegie Academy for Science Education; and Ka Chun Yu of the Denver Museum of Nature and Science. Also present at the meeting will be Kate Haley Goldman, our external evaluator.

We have made important discoveries with regards to building community and efficiency through networked OpenSpace events. Because of different time zones and programming needs, networking across institutions in real time is not always feasible or even desirable and several additional models for shared programming have evolved this year, including: 1) Sharing assets such as script outlines, data sets, and SMEs to reproduce an event at other insitutions. 2) Sharing rendered movies of a live event for direct playback or as a template for reproduction. 3) Inviting other institutions as well as home audiences to join via live streaming on YouTube 360.

Networking in real time remains an exciting prospect for many, however, especially when it is scheduled to coincide an important scientific or cultural milestone (e.g. New Horizon's close encounter with Pluto) or naturally occurring event (e.g. seasonal equinox or eclipse); or leverages a unique scientific or engineering resource. We are planning a Sun-Earth Day event in March, 2018 that features continued work from the CCMC at Goodard, as well as a visualization of the Total Solar Eclipse of 2017 produced from the Citizen CATE data that has generated great enthusiasm across our ISI network. Greater lead time and common interest in the Sun-Earth Connection and the total eclipse make it an excellent candidate for a networked event. In addition, it showcases work that has been central to the development activities undertaken in Years One and Two: globe browsing and Earth-Sun interactions. We plan to hold this event in the Museum's giant screen 3D theater, launching the premier of OpenSpace 3D, with our networked partners joining from a variety of settings including 3D theaters, domes, and other large screen venues.

We decided to participate in the National Planetarium Conference (Pliedies) in Saint Louis in October in lieu of attending regional planetarium conferences in Year Two. We do plan to attend two regional planetarium conferences in Year Three: The Great Lakes Planetarium Association conference in June 2018 and the Southeastern Planetarium Association conference in October 2018.

IV. Dissemination Activities

Conferences Attended and Organizations Visited on Behalf of the OpenSpace Project

- **Space Apps NYC**
  Co-I Carter Emmart and Lead Developer Alex Bock (NYU) presented OpenSpace

- **Pleiades National Planetarium Conference, Saint Louis, MO**
  Co-I Carter Emmart presented remotely in the Eluminati Dome, networked with North Carolina Museum of Natural Science
- **Association for Science and Technology Centers conference (ASTC), San Jose, CA**
  The OpenSpace project shared a both with ePlanetarium to showcase our content in their Discovery Dome. In additon Co-Is Emmart and Lead Developer Bock demonstrated OpenSpace in domes from Eluminati and Full Dome Pro. In addition, Co-I Vivian Trakinski moderated a panel in which Co-I Emmart, and collaborators Ryan Wyatt, Cal Academy, and Brian Day, NASA Ames, discussed "Immersive Visualizations using NASA Data: Resources, Tools, and Techniques."
- **American Geophysical Union conference, San Francisco, CA**
  OpenSpace presented a variety of Earth and Mars data sets in the Morrison Planetarium dome at California Academy of Sciences
- **IPS Data-to-Dome Workshop, Mitaka Japan**
  Co-I Emmart ran a hands-on workshop with OpenSpace at this two-day even dedicated to bringing together member of the astronomy and planetarium community to solve problems related to visualizing big data in the planetarium.
- **Flatiron-AMNH Visualization Conference, NYC**
  OpenSpace was presented at this 2-day meeting in several sessions, including by Co-I Anders Ynnerman, Chris Johnson for University of Utah SCI Institute, and by Co-I Emmart in the Hayden planetarium during a plenary session open to the public.

In addition, five academic papers were submitted, including "Globe Browsing: Contextualized Spatio-Temporal Planetary Surface Visualization," which was awarded Best Paper at IEEE Vis conference in October.

OpenSpace Web Presence

- www.openspaceproject.com. For developers and the open source community.
- Our OpenSpace YouTube channel: https://www.youtube.com/channel/UCHZpv-5zARkWibw1Z-g6ptQ -- has received 33K views.

V. Evaluation, and Cross-Collaboration Agreements Activities

Evaluation and Assessment by Kate Haley Goldman

The OpenSpace project's external evaluator is Kate Haley Goldman of Haley Goldman Consulting Inc. (507 Dartmouth Ave, Silver Spring MD; 301-655-1925; kate@haleygoldman.com). In Year Two, Kate has worked with project PIs to refine the Project Logic Model and Evaluation Plan and conducted telephone interviews and site visits to survey the ISI Network Partners to inform the development of use cases of OpenSpace. Please see the Evaluator Update Template submitted separately for the OpenSpace project

- **SMD Collaborators and Cross CAN Awardee and NASA Infrastructure collaboration Activities**
  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 Activity
Masha Kuznetsova, Director CCMC, GSFC Dr. Leila May, Deputy Director, CCMC, GSFC Darren De Zeeuw, CCMC, GSFC Jeffrey E. Schmaltz,Earth Data LANCE Rapid Response Team, GSFC Ryan Boller, Data Visualization Lead, Earth Science Data and Information System Project, GSFC Bob Pappalardo, Senior Research Scientist, JPL Jeff Moore, New Horizons Imaging Team Leader, Geology & Geophysics, NASA AMES Research Center Chris McKay, Space Science and Astrobiology, NASA AMES Research Center Paul Schenk, Staff Scientist, Lunar and Planetary Institute Mark Powell, Mobility Systems Concept Development, JPL Ross Beyer, Research Scientist, SETI Institute Carl Hostetter, Thomas Grubb, Matthew Brandt, Troy James Software Engineering Division 587, NASA GSFC - Developing VR support of OpenSpace	Dr. Emily Law and Dr. Brian Day, Mars Trek; OpenSpace provided CTX data. Kevin Hussey, Visualization, Technology, and Development, JPL invited co-I Carter Emmart to present during the total solar eclipse along with NASA engineer Randii Wessen Dr. Jim Green (SMD Division Director for Planetary Science) in Idaho Falls, Idaho; conversation ongoing re complimentary development of Eyes and OpenSpace. Daniella Scalice, NASA Astrobiology program; conversation is ongoing re public program utilizing Mars and Earth data; met with Chris McKay, NASA AMES Research Center to begin planning for OpenSpace Program featuring Mars/Earth analog research	Leigh Peak, Gulf of Maine Research Institute; ongoing sharing of expertise re data literacy and visualization and educational programming. Denise Smith, Universe of Learning; building on conversations with Dr. Brandon Lawton at ASTC and Dr. Frank Summers at the FlatIron-AMNH Science Visualization Conference in NYC, OpenSpace will work with Denise Smith and her colleagues to identify visualizations of simulations and observed data sets of astrophysics phenomena to integrate into OpenSpace; and to identify astrophysics SMEs interested in communicating their science to various public audiences using the software. Matthew Penn, National Solar Observatory; re: ingestion of the images captured by the Citizen CATE project into OpenSpace for a networked public program on Sun-Earth day in March 2018

In addition, **new collaborations** beyond NASA have 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:

Michael Blanton, Center for Cosmology and Particle Physics, NYU
- Providing OpenSpace as a research tool to Sloan Dataset scientists

João Alvés, University of Vienna
- Providing OpenSpace as a research tool to Sloan Dataset scientists

Doug Roberts, Fort Worth Museum of Science and History
- Developing an application aimed at mid- to high-school students for virtual spacecraft design (NSF grant application)

David Holland, Center for Atmosphere Ocean Science
- Providing a visualization tool for the research of glacial movements

VI. Year Three Plans

We are already engaged in planning with our Development and ISI partners for Year Three. The Year Three Developers meeting will be held in late winter or early spring of 2018 at Linkoping University in Sweden and the ISI Network Partner Meeting is being scheduled for April, 2018. Development goals include

- Ongoing technical integration of OpenSpace across our ISI partner venues and beyond.
- Online resources included instructional videos and simplified documentation
- New features, including:
    - Web based user interface design
    - Content Delivery Network (CDN) for improved data streaming
    - Improved model loading
    - Fieldline and Volumetric rendering
    - High-dynamic-range (HDR) rendering to preserve details lost due to limited visual contrast.
    - Camera recording and Playback to support users interested in limiting live interaction with the software during a facilitated program (in order to focus on interaction with the audience).
    - Kiosk mode, to broaden distribution beyond immersive theaters
- New Content, including
    - Model-based Milky Way Galaxy
    - Mars Rover surface reconstruction

Educational Program and Resource Development activities for Year Three include:

- Sun-Earth Day networked program event (tentatively scheduled for March 17, 2018) that will feature new work from the CCMC at Goddard, as well as a visualization of the Total Solar Eclipse of 2017 produced from the Citizen CATE data, presented in 3D.
- A program for NYC educators at AMNH (scheduled for June 7, 2017) that will also feature elements of the Sun-Earth Day program.
- Develop Educator content for the 2018 Educator's evening and post online at www.amnh.org/openspace.
- The launch of AMNH's OpenSpace Digital Flight School.
- A range of programs at OpenSpace ISI Network Partners including:
    - OpenSpace Interactive programs during Astronomy Days event at North Carolina Museum of Natural Sciences the end of January, which annually attracts nearly 15,000 visitors over a weekend, that will integrate undergraduate students from Appalachian State University to help with interaction and interpretation among visitors.
    - Mars event at California Academy of Sciences featuring Co-I Emmart and Dr. Jeff Moore, NASA Ames; in addition, over the next twelve months, the Academy team plans to support several additional programs utilizing OpenSpace, including popular talks in our Benjamin Dean Astronomy Lecture Series and special members events.

Two additional programs being considered for AMNH and networking and/or sharing assets across our ISI Network are:

- Pluto Update, hosted by Alan Stern and David Grinspoon
- Mars Exploration Rovers, led by Jim Bell

VII. Attached Information

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