OpenSpace Annual Progress Report — Year Four

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

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I. Administrative

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Principal Investigator	Dr. Ro Kinzler
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II. Accomplishments

The American Museum of Natural History (AMNH) is pleased to submit this fourth 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 (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 establishment of a network of ISI partners.

During the project's fourth year, AMNH made significant progress toward these objectives through ongoing work on code development, content visualization, and programs for the 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 open source code and related documentation, a

project management site, Slack channel, telecons, annual meetings, and close attention to project evaluation findings. These activities are described in greater detail below.

Software Development

The OpenSpace software has continued to grow in Year Four through cooperative development at AMNH, Linköping University and Norrköping Visualization Center C,[1] New York University Tandon School of Engineering, and the University of Utah Scientific Computing and Imaging Institute. As in previous years, software engineers and graduate research associates at each of these locations have collaboratively contributed to a workflow that fosters near real-time, memory-efficient algorithms to handle data intensive tasks, multi-modal rendering, integration of new data sets, and hardening the software code.

During this period, three significant updates of the OpenSpace software were published: Beta-3 (v0.13.0) was released on November 5, 2018; Beta-4 (v0.14.0) was released on May 20, 2019; and Beta-5 (v0.15.0) was released on September 17, 2019. Each of these updates improved the software stability and usability, particularly for older hardware. The releases also addressed priorities identified in Year Three by our ISI partners: an enhanced Graphical User Interface; the means to control OpenSpace on a handheld device for easier presentation; and increased documentation.

Major new features include:

OpenSpace Launcher: This new start-up option allows users to select their screen output and scene, negating the need to edit a text file to do so.

Session Recording: This feature enables the recording of camera movements, state changes, time, speed, and user interface interactions which can then be played back or shared between computers. This is done from a recording menu that allows users to create, play, and stop the recording.

Slides Menu: This menu allows users to show online and downloaded image files within OpenSpace. This can be used, for example, to show historic mission images within an OpenSpace visualization of that mission.

Anchor and Aim: The Anchor and Aim feature enhances the previous Focus Node concept. While it is still possible to focus the camera on a single object and have all camera movements occur relative to that object, it is now also possible to anchor on one object while aiming at another, which then stays fixed on the screen. This presents a view that shows the objects in relation to each other, affording cinematic results.

Search: Scene and settings menu search bar functionality were significantly improved, easing the usage of the system particularly for novices.

[1] The activities at Linköping University are not funded by this grant, but are supported by the Knut & Alice Wallenberg Foundation in Sweden, Swedish e-Science Research Centre, and Stena Foundation.

Content Development

Ongoing content development has brought the number of interactive scenes available in OpenSpace from 13 reported at the end of Year Three to 17 at the end of Year Four. The top-level metric for OpenSpace continues to be the number of interactive scenes of visualized NASA data available within OpenSpace, with the goal to reach 20 scenes by the end of Year Five.

In addition to introducing new content, we have concentrated on ways to support docents and other staff who may not have deep knowledge of subject matter or OpenSpace by introducing non-technical story guides and user-friendly presentation buttons that align with content points and can be accessed on a mobile device. This was one of the prioritized needs reported by our partners in Year Three.

The creation of new content continues to depend on collaboration with NASA agencies and infrastructure along with outside scientists and agencies, as detailed below.

New Scenes

Apollo 8: This scene contains models and trajectories for the Apollo 8 mission. Imagery of the Command Module interior was created from the Smithsonian National Air and Space Museum's scan of Apollo 11's Columbia Command Module. The trajectory was supplied by NASA GSFC SVSG Media Specialist Ernest T. Wright.

Apollo 11 and 17: This scene contains a model and trajectory for Apollo 11 and the landing sites of the Apollo 11 and 17 missions. The Apollo 11 orbit trajectories were supplied by NASA GSFC SVSG Media Specialist Ernest T. Wright. The three-dimensional Lunar Excursion Module model for Apollo 11 and 17 were created using photogrammetry of LM-2, on display at the Smithsonian Institution National Air and Space Museum. Boulders explored by the Apollo 17 astronauts were also created using photogrammetry, this from astronaut extravehicular activity photography. The Apollo 17 landing site map was created from the US Geological Survey in collaboration with the European Space Agency (ESA)/German Aerospace Center (DLR) and Lunar Reconnaissance Orbiter imagery.

Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) Lander: The new scene contains a model of the InSight lander, its trajectory during entry into the Martian atmosphere, and its eventual landing on November 26, 2018. The model changes throughout the different phases of the landing by showing, for example, the separation of the heat shield and the deployment of the parachute. This was created in collaboration with NASA Eyes, which provided data and models.

Gaia: ESA's Gaia mission data was added using a new and experimental multiscale renderer. The dataset that is automatically synchronized at startup contains over 7 million stars for which the radial velocity is available.

New Scene Content

Volumetric Milky Way Galaxy: Collaboration between the National Astronomical Observatory of Japan and the AMNH space show production team produced a constrained simulation of the Milky Way Galaxy that conforms to the Digital Universe dataset and new Gaia mission results and that was added to all scenes.

Space Debris: More efficient rendering methods for small objects have allowed us to visualize the trajectories and positions of all space debris objects as reported on the Celestrak webpage. This includes a number of debris-creating events as optional content that can be added to any scene.

Mars Surface Exploration: The Mars Surface Exploration scene developed in Years Two and Three was enhanced with two new maps layers: local High Resolution Imaging Experiment (HiRISE) data patches, and a blended CTX map from CalTech Bruce Murray Laboratory for Planetary Visualization's Manager and Research Scientist Jay Dickson. This content has been added to all scenes.

Saturnian Moons: Moons Hyperion and Mimas were added to the Saturnian system in all scenes.

Satellites: The trails of Pioneer 11 and 12 were added, and the Pioneer model itself was improved. Trajectories of the Swift-Tuttle comet, Tesla Roadster, and 'Oumuamua are optional content that can be added to any scene.

Stakeholder Meetings

Throughout the fourth year, key meetings were held among OpenSpace stakeholders.

Developer Meeting: Our grant-funded collaborators from Linköping University, New York University, and University of Utah joined us at AMNH for a meeting of project developers and managers, January 15-18. The meeting was devoted to reviewing work-to-date, identifying near-term and long-term development goals, with a special focus on extending partnerships beyond the core team and long-range strategies to support open source software. The agenda for this meeting is included in VII. Attached Information.

Informal Science Institution (ISI) Network and Advisory Board Meeting: In June, we convened representatives from the six grant-funded partners (listed below), unfunded users (Lower Eastside Girls Club and Franklin Institute), Advisory Board members (representing Jet Propulsion Laboratory (JPL), Esri, Denver Museum of Nature and Science, and E.R. Murrow High School), and project evaluators at AMNH to share the year's activities and discuss achievements and opportunities for growth to establish near-term and long-term network goals and inform software goals. The agenda for this meeting is included in VII. Attached Information.

ISI Network Telecons: We hosted four telecons with OpenSpace ISI partners to share the latest software developments and programming activities. This has been particularly crucial to familiarize our partners with the software updates that occurred this year, as well as to collaborate on milestone efforts such as the Apollo 11 and Earth Day anniversaries.

OpenSpace Telecon Training: In Year Four, we have expanded the use of telecons for training OpenSpace users. In addition to walking new users through installation, we were able to use telecons to hold OpenSpace trainings for our ISI Network and new users, including the Minnesota GeoDome Network. In addition, we've instituted "Micah Mondays," a weekly opportunity to have one-on-one time with AMNH Software Engineer Micah Acinapura.

Year Four ISI Network Activities

Each of our ISI Network partners has seen enormous growth in the use and impact of OpenSpace over the past year, with all seeing a three- to 13-time increase in reach. This is linked to the improved usability of the software, and also to the widening breadth of content and increased enthusiasm for, and increased adoption of the software by our institutional, vendor, and community partners. This positive development emerged with perfect timing for OpenSpace to be used across the network in a wide range of programs celebrating the 50th anniversary of the Apollo 11 Moon landing. In all, ISI Network programs reached 64,370 individuals in Year Four.

The Adler Planetarium: The Adler continues to use OpenSpace in its Space Visualization Laboratory and planetarium throughout Year 4. The Adler hosted a Research Computing Center Visualization Lab Open House, daily Apollo presentations during the summer, a Community Bash presentation, and an Apollo 11 Celebration with OpenSpace content. In all, OpenSpace reached 5,080 members of the public at the Adler, eight times its reach in Year Three.

The Adler's summer teen internship program included four OpenSpace summer interns. The high-schoolers used OpenSpace to learn astronomy content and programming, while also gaining professional development and public speaking experience.

The Adler's Mark SubbaRao joined the OpenSpace team at the Association of Science-Technology Centers annual meeting in September to present an OpenSpace workshop (see section IV).

American Museum of Natural History (AMNH): The use of OpenSpace continues to expand at AMNH. AMNH hosts popular live astronomy lectures throughout the year; in Year Four, OpenSpace was included in the content of nine of these well-attended events:

- "Probing Asteroids in Space," by Dr. Harold C. Connolly, Jr. (December 4);
- "Earthrise, Apollo 8," by Dr. Carter Emmart (December 19);
- "New Horizons Beyond Pluto," by Dr. David Grinspoon and Dr. Henry Throop (March 26);
- "Gaia and the Milky Way," by Dr. Jackie Faherty (April 23);
- "The Golden Age of Star Formation," by Dr. Mordecai-Mark Mac Low (May 8);
- "Under the Southern Cross," by Joe Rao and Irene Pease (May 18);
- "Manhattanhenge," by Dr. Jackie Faherty (July 11);

- "The Ancient Volcanoes of Mercury," by Dr. Brett Denenvi (October 7); and
- "Spooky Space," by Jackie Faherty (October 29).

The museum also used OpenSpace in three demonstrations, trainings for in-house youth educators, a 24-hour hackathon, and at the museum-wide SpaceFest marking the Apollo 11 Moon landing anniversary. In all, 10,357 people experienced OpenSpace this year through AMNH activities, over six times its Year Three reach.

The museum continued its relationship with the Bergen Academy for Technology and Computer Science with seven high school interns, plus one undergraduate intern, under the direction of co-I Dr. Carter Emmart throughout the year. These interns developed and deployed a method for utilizing the Ames Stereo Pipeline to import Mars HiRISE terrain models into OpenSpace. These models are now part of the Mars Surface Exploration scene being used in public programs, one of which included presentations by the interns themselves. In addition, the students are on the cusp of completing a catalogue of mission visualizations within OpenSpace that includes every NASA mission for which SPICE data is available.

PI Ro Kinzler, co-I Emmart, and other AMNH staff coordinated the OpenSpace workshop at the Association of Science-Technology Centers annual meeting in September. The team also boothed and presented on the exhibition floor (see section IV).

Emmart and Software Engineer Micah Acinapura hosted two livestreams in Year Four in collaboration with NASA @ My Library. In December 2018 and July 2019, Emmart and Acinapura guided YouTube viewers through the Apollo 8 Earthrise and Apollo 11 landing in OpenSpace. These videos peaked at 169 and 664 live viewers, respectively; this count includes a number of live watch parties at libraries across the United States, as organized by N@ML. The Apollo 8 video has since been viewed over 1,400 times on YouTube, and the Apollo 11 video over 4,600 times.

California Academy of Sciences (CAS): In Year Four, the public reach of OpenSpace at the California Academy of Sciences increased to 7,851, 13 times its previous annual reach. This is due largely to a daily OpenSpace solar system tour program that began in September after CAS developed customized, user-friendly presentation buttons for OpenSpace. These buttons allow the museum's educators, who may not have deep knowledge of subject matter or OpenSpace, to give these presentations. The show's content has been written into a guide that has been shared within our ISI Network and is currently under development for distribution on the OpenSpace project website.

Additionally, CAS held eight events, including four lectures; presentations on the museum floor for Asteroid Day; a Halloween-themed presentation for members; and interactive presentations in a portable planetarium at Splashdown 50, an event to mark the 50th anniversary of the recovery of the Apollo 11 capsule and crew on the USS Hornet.

Denver Museum of Nature and Science (DMNS): As with many of our ISIs, Denver Museum of Nature and Science had great success with Apollo-related OpenSpace programming, reaching 935 members of the public, about three times its Year Three reach. DMNS conducted seven "tours" of the Moon, focusing on Apollo mission landing sites.

DMNS hosted two high school interns working on OpenSpace. The internships centered on instructing the students in Linux in order to run shell commands to operate the NASA Ames Stereo Pipeline. They used this to create high-resolution digital elevation maps based on Mars Reconnaissance Orbiter CTX stereo image pairs, and inserted the imagery into OpenSpace. At the end of their internship, these Teen Science Scholars presented "Mars Colonist Story," a Mars colonization story in OpenSpace, twice to the public and at their end-of-internship showcase to a total of 175 people.

Houston Museum of Natural Sciences (HMNS): The Houston Museum of Natural Sciences has continued to employ OpenSpace in its inflatable dome, while expanding OpenSpace's use in its Burke Baker Planetarium and interactive Expedition Center. OpenSpace was used in much of the museum's Apollo anniversary programming which occurred throughout the summer, reaching over 15,504, or 13 times as many individuals as in Year Three.

The museum's six OpenSpace high school interns were essential to many of its Apollo events: Interns led daily Apollo 11 Moon tours for over a month, attracting 250 visitors, and also conducted a debate "Moon or Mars?" that was attended by 167 visitors and reached nearly 700 viewers through a Facebook Live video. Simulated expeditions to Mars and the Moon utilizing OpenSpace content were attended by a combined 2,498 visitors, including 1,008 Houston-area sixth graders.

Two of the main attractions of the Apollo programming were "Destination: Moon" and a simulated Apollo 11 landing. The former was a six-minute 360-degree video of the Moon and Apollo 8 Earthrise produced in OpenSpace for Virtual Reality headsets. This was viewed by 11,730 visitors in over six months. The latter Apollo 11 Celebration invited 13 retired NASA staff to reprise their roles in the Mission Operations Control Room with their grandchildren to simulate an Apollo 11 landing. The event was broadcast live on Facebook, and has been viewed 2,400 times.

North Carolina Museum of Natural Science (NCMNS): The North Carolina Museum of Natural Science maintained another robust year of OpenSpace, reaching 24,339 members of the public through 13 varied programs in its Daily Planet Theater and Astronomy & Astrophysics Research Lab. The museum also livestreamed a preview of OpenSpace Apollo content prior to its event on July 20, which has since been viewed over 500 times. In addition to being used for specific programming, OpenSpace is constantly on display in the museum's Lab in the form of curated, looping visualizations, where 225,345 visitors had the opportunity to view them.

NCMNS hosted four interns focused on OpenSpace in Year Four. The undergraduate students were intensively involved with the OpenSpace programming at the museum, developing user and content guides, and leading many of the open lab tours.

These guides and an astrobiology content guide developed by Head of Astronomy & Astrophysics Research Lab Dr. Rachel Smith have been shared within our ISI Network for feedback before distribution on the OpenSpace website.

Additional Year Four Community, Academic, and ISI Activities[2]

Impact numbers at these locations, which are outside the OpenSpace grant, are not formally evaluated. Informal reports and conversations have shown the significance of OpenSpace at these locations, however, as science visualization and/or communication is often not otherwise possible because of financial or staff limitations.

For institutions that reported audience and visitor data, OpenSpace reached an additional 6,568 people in Year Four at these locations.

Amateur Astronomers Association of New York (New York, NY): Dr. Mordecai-Mark Mac Low used OpenSpace in his October lecture about star formation to 100 members of the Amateur Astronomer's Association. AAA was founded in the early part of the 19th century and helped found the premier amateur astronomy magazine, *Sky & Telescope*.

Appalachian State University (Boone, NC): NCMNS' Smith has continued to use OpenSpace in her Appalachian State University coursework, this spring in her undergraduate course, "Astrobiology: Searching for Life in the Universe." Her intern later brought OpenSpace to App State's Dark Sky Observatory (DSO) in a presentation to 37 people. A few months later, DSO used OpenSpace in their celebration of the Apollo 11 Moon landing anniversary and at a prospective student OpenHouse. In all, OpenSpace was experienced by 194 people at App State.

City College of New York Planetarium, City University of New York (New York, NY): CCNY has used OpenSpace for live shows and classroom instruction in its dome, and hopes to use OpenSpace exclusively as its main projection software in the future. CCNY students are also working on contributing new features to the software.

East Village Planetarium, Lower Eastside Girls Club (New York, NY): The AMNH has continued to support the Lower Eastside Girls Club's installation and use of OpenSpace in its 64-seat, 30-foot East Village Planetarium. The LESGC Director of Technology attended the annual partner meeting in June, contributing from the perspective of a community organization. AMNH Software Engineer Micah Acinapura and an OpenSpace intern were able to support the use of OpenSpace at the LESGC's all-female location of the 2019 Space Apps Challenge (see section IV).

[2] Activities are listed alphabetically by institution or organization.

Edward R. Murrow High School (New York, NY): Advisory Board member Marc Horowitz serves as the Planetarium Director and Astronomy Program Lead for Edward R. Murrow High School in Brooklyn. The high school is one of a select few in the area that has a planetarium, which is used in its Earth Science classes and astronomy electives. So far in the fall semester, Horowitz has used OpenSpace with all of his astronomy students and the Earth Science students, totaling 550 high schoolers. In the spring, students will work with OpenSpace to develop their own presentations.

Fiske Planetarium, University of Colorado, Boulder (Boulder, CO): OpenSpace was installed in the Fiske Planetarium in Year Four. With support from Astronomy faculty and AMNH staff, Fiske is aiming to begin using OpenSpace in public programming and coursework in Year Five.

Ho Tung Visualization Laboratory, Colgate University (Hamilton, NY): Colgate's Visualization Lab installed OpenSpace in its planetarium in October, receiving in-person training by Co-I Carter Emmart at the Data to Dome Workshop. Additional remote trainings are planned into Year Five to facilitate OpenSpace's use in college-level education and for visiting school groups.

Iziko Planetarium and Digital Dome, University of Cape Town (Cape Town, South Africa): OpenSpace has been installed in the Iziko Planetarium and Visualization Laboratory. Planetarium staff visited the AMNH in October of Year Four to further the possibilities of their use of OpenSpace.

Lamont-Doherty Earth Observatory, Columbia University (Palisades, NY): Columbia University Ph.D. Student Marina Gemma brought OpenSpace to Columbia University's Lamont-
Doherty Earth Observatory Open House in October. Around 3,500 attended the Open House, and an estimated 500, mostly children and families, stopped at the OpenSpace booth.

Norrköping Visualization Center C (Linköping, Sweden): A large number of events have been held over the last year at Linköping University's Visualization Center. Larger events included a public open-air showing at the Stockholm Culture Night festival and demo at Norrköping's Culture Night. About 50 VIP showings were held for university deans, ambassadors, the chairman of the Knut & Alice Wallenberg Foundation, and the board of the Swedish Foundation for Strategic Research (SSF). Additionally, about 25 presentations of 75 people each were offered for the general public, including mixed-media concerts and public-facing programming around the 50th anniversary of the Apollo 11 Moon landing. Organizers estimate over 3,500 individuals saw OpenSpace in some capacity at the Center in Year Four.

As the primary international contributor to OpenSpace, the Norrköping Visualization Center C and Linköping University provide two full-time developer positions through funding from the Swedish e-Science Research Centre and the Stena Foundation. In addition, the Visualization Center C is leading the WISDOME effort, funded by the Knut & Alice

Wallenberg Foundation, to increase outreach and improve scientific literacy, for which OpenSpace has been selected as one of the flagship projects.

Museum of Life and Science (Durham, NC): In collaboration with ISI Network partner NCMNS, OpenSpace visuals have been installed permanently in the Launch Window at the Museum of Life and Science. Initially installed for the Apollo 11 Moon landing anniversary, the videos have since been viewed by 121,501 museum visitors.

North Carolina State University (Raleigh, NC): NCMNS' Smith used OpenSpace in her 58-student Osher Lifelong Learning Institute (OLLI) series, "New Investigations of Forming Stars and Meteorites."

Southwest Minnesota State University Planetarium (Marshall, MN): OpenSpace was installed in SMSU's planetarium in Year Four, and has been used to deliver content to the public. Planetarium staff reports great success with their Apollo 11 anniversary show series, which relied heavily on OpenSpace.

University of Chicago (Chicago, IL): The Adler Planetarium facilitated the installation of OpenSpace at the University of Chicago on a large touch-enabled tiled display.

University of Utah (Salt Lake City, UT): The Scientific Computing and Imaging Institute presented nine demonstrations of OpenSpace to visitors, students, and dignitaries visiting the research institute throughout Year Four.

WaterFire Providence (Providence, RI): As part of the nonprofit arts' organization's month-long celebration of the Apollo 11 Moon landing anniversary, Emmart was invited to speak and demo OpenSpace at an evening Space Chat lecture to an estimated 500 people. Emmart also produced OpenSpace videos of the Apollo 8, 11, and 17 missions that were shown on 13- and 23-foot screens at the WaterFire's all-day July 20 festival, "To the Moon and Beyond," which was sponsored by NASA/RI Space Grant Program, Brown University, Providence College, University of Rhode Island, and NASA/RI EPSCoR Program.

In addition to the above, OpenSpace has had new or reignited installation conversations, including site visits, with 12 institutions in Year Four, that we will continue in Year Five:

- Bell Museum, University of Minnesota (St. Paul, MN)
- Connecticut Science Center (Hartford, CT)
- Fels Planetarium, Franklin Institute (Philadelphia, PA)
- Kitt Peak National Observatory (Tucson, AZ)
- Naturhistorisches Museum Wien (Vienna, Austria)
- Ontario Science Centre (Toronto, Ontario, Canada)
- Ralph Mueller Planetarium, University of Nebraska — Lincoln (Lincoln, NE)
- South Florida Science Center and Aquarium (West Palm Beach, FL)
- Science North (Sudbury, Ontario, Canada)
- Sir Thomas Brisbane Planetarium (Brisbane, Australia)
- Smithsonian National Air and Space Museum (Washington, D.C.)

- Suffolk County Vanderbilt Museum & Planetarium (Centerport, NY)

Planetarium vendors
We have continued productive conversations with and demonstrations for the major planetarium vendors in Year Four. We have worked directly with The Elumenati, ePlanetarium, Evans & Sutherland, Front Pictures, Fulldome Pro, Seiler Instruments, Sky-Skan, Vioso (newly added in Year Four), and ZEISS to optimize OpenSpace's use in their planetarium systems, including portable domes and half-domes, panorama screens, and permanent dome and screen installations. Through these vendors, OpenSpace was installed, or is presently being installed, in 10 additional planetariums in Year Four, listed below. Expanding on our grant focus on ISIs, nine of the 10 institutions are formal education settings, from elementary to college education. These locations are still in the process of either installing or learning the software.

K-12 schools
- Anoka-Hennepin Schools Planetarium (Anoka, MN)
- Como Planetarium, St. Paul Public Schools (Saint Paul, MN)
- Mankato East High School Planetarium, Mankato Area Public Schools (Mankato, MN)
- Mayo High School Planetarium (Rochester, MN)

Colleges and universities
- Marshall W. Alworth Planetarium, University of Minnesota Duluth (Duluth, MN)
- Minnesota State University Moorhead Planetarium (Moorhead, MN)
- Southwest Minnesota State University Planetarium (Marshall, MN)
- University of North Dakota Planetarium (Grand Forks, ND)
- University of Wisconsin River Falls Planetarium (River Halls, WI)

ISI: Journey Museum (Rapid City, SD)

III. Status, Changes, Issues

As mentioned above, we have seen OpenSpace adopted in more formal education environments in Year Four, which was not a target audience within this grant. The interest in and use of OpenSpace at these institutions demonstrates the range of its value as an educational tool, and has identified a potential audience for future focus.

The two greatest common obstacles delaying or preventing OpenSpace's installation and use in Year Four were:

Hardware / vendor compatibility: OpenSpace is a robust software that runs best on high-end computer graphics cards and processors. These features are not ubiquitously found at ISIs. Further, to install OpenSpace at many locations requires the cooperation of their planetarium

vendors, which is not always forthcoming. The project team is continuing to develop productive relationships with industry vendors, offering to actively partner with them to optimize the software for their unique hardware and software configurations. As an open source product, OpenSpace is freely available to vendors and provides added value to their products — a fact that is becoming clear as customer ISIs are beginning to make specific requests for installation of the software on their systems.

Complexity of the software: Due to the advanced nature of the software, there is a steep learning curve for users. This has been and will continue to be reduced by a simplified Graphical User Interface (GUI), software tutorials, and content guides.

These challenges are at the forefront of our plans for upcoming software and content development (see section VI).

For personnel changes, Jason Craig, Manager of Visualization Technology Applications and Development at NASA JPL, has joined our Advisory Board in place of Kevin Hussey, who shifted roles at JPL.

IV. Dissemination Activities[3]

Conferences

NISE Network Partner Meeting (February 13-15): PI Dr. Ro Kinzler and Co-I Dr. Carter Emmart attended the NISE Net Earth & Space Partner Meeting in Tempe, AZ. The OpenSpace demonstration garnered considerable interest from attendees.

Middle Atlantic Planetarium Society and Southeastern Planetarium Association Annual Meeting (June 4-8): Emmart attended the MAPS-SEPA annual meeting held in Columbia, SC. Emmart gave a conference-wide demonstration of OpenSpace in South Carolina State Museum Planetarium, receiving interest in the software from a number of attendees.

Brilliant Minds (June 13-15): Co-I Dr. Anders Ynnerman and Linköping University Software Engineer Dr. Alex Bock presented OpenSpace at the annual Brilliant Minds festival in Stockholm to an audience of about 500 people. This presentation sparked great interest in the audience and was the source for in-depth discussions throughout the conference. Other speakers at the conference included President Barack Obama, former Secretary of State John Kerry, and activist Greta Thunberg.

4th Planetary Data Workshop (June 18-20): Emmart and AMNH Software Engineer Micah Acinapura attended the Planetary Data Workshop in Flagstaff, AZ. Organized by the Lunar and Planetary Institute, Universities Space Research Association, US Geological Survey, NASA Planetary Data System, and NASA Regional Planetary Image Facility Network, this

[3] Activities are listed chronologically within each subsection.

workshop connected the OpenSpace team with scientists and their data that could then be incorporated into the software.

Gordon Research Conference: Origins of the Solar System, Meteoritical, Spacecraft and Astrophysical Perspectives on the Assembly and Composition of Planets (June 23-28): Dr. Denton Ebel and Columbia University Ph.D. student Marina Gemma had a demo of and poster about OpenSpace at the Gordon Research Conference held at Mount Holyoke College in South Hadley, MA.

Astrographics: Interactive Data-Driven Journeys Through Space, Schloss Dagstuhl (June 23-26): Emmart; Board Member Dr. Lucian Plesea; Ynnerman; Bock; LiU Software Engineer Emil Axelsson; ISI partners Dr. Mark SubbaRao and Ryan Wyatt; and University of Utah Co-I Dr. Chuck Hansen joined a host of the leading astrovisualization experts at a Schloss Dagstuhl seminar in Wadern, Germany. Intensive workshopping resulted in an Astro2020 white paper submission (included in Academic Publications below).

Annual Meeting of the Meteoritical Society (July 7-12): Ebel and NCMNS' Dr. Rachel Smith attended the 2019 Annual Meeting of the Meteoritical Society in Sapporo, Japan. Ebel gave two informal OpenSpace demos at the meeting.

Gordon Research Conference: Visualization in Science and Education (July 14-19): Kinzler and Emmart attended and brought a poster of OpenSpace to the Gordon Research Conference held in Lewiston, ME. Kinzler also led a discussion during the conference, "Visualization in Informal Education."

Spacefest X (August 8-11): Emmart gave multiple OpenSpace demonstrations throughout this annual gathering of astronauts, scientists, historians, and space enthusiasts in Tucson, AZ, making connections for potential future collaborative projects.

Association of Science-Technology Centers Annual Conference (September 20-23): The OpenSpace team was well-represented at the annual ASTC conference by Kinzler, Emmart, Bock, Acinapura, SubbaRao, Smith, and Project Coordinator Corrie Roe. The team presented an intensive half-day pre-conference workshop, "How to Present a Universe of Data with OpenSpace." This workshop was attended by six new institutions which all are enthusiastic about installing OpenSpace. OpenSpace was also used in The Elumenati and Seiler Instruments exhibition booths, and Emmart presented twice on the NASA Hyperwall. The OpenSpace and collective SciAct presence at ASTC expanded our contact list for interested institutions as well as data sources.

Future in Review Conference (October 8-11): Hansen and University of Utah Software Engineer Gene Payne demonstrated OpenSpace at the FiRe Conference, a global conference on the intersection of technology and the economy.

Data to Dome Workshop (October 18-19): Emmart presented the capabilities of OpenSpace at this hands-on conference focused on creating data visualizations, held at Colgate University in Hamilton, NY. SubbaRao also attended.

Institute of Electrical and Electronics Engineers Scientific Visualization Conference (October 20-25): Bock presented a published journal article describing the architecture of OpenSpace at the premier visualization conference to an audience of world-leading visualization researchers. The publication is included in Academic Publications below.

Great Lakes Planetarium Association Annual Conference (October 23-26): Dan Tell and Mary Holt, of ISI Network partner CAS, presented a paper, "Implementing the open source astronomy software OpenSpace for planetarium and floor programs," that was attended by about 50 conference participants and livestreamed on Facebook and YouTube.

Rensselaer Polytechnic Institute Space Imaging Workshop (October 28-30): Emmart gave a keynote presentation, "OpenSpace: a Tool for Immersive Interactive Data Context Visualization," at RPI's second Space Imaging Workshop, held in Saratoga Springs, NY.

Hackathons

Hack the Solar System (February 9-10): For 24 hours at the AMNH, 145 hackers worked on two projects related to OpenSpace. The overnight February event included students, teachers, technologists, and museum scientists who used MARCI imagery to visualize the daily weather on Mars, and developed solar browsing, allowing STO imagery to be downloaded.

NASA International Space Apps Challenge (October 18-20): OpenSpace was again included as a resource in the NASA International Space Apps Challenge in October, this time at the Lower Eastside Girls Club's all-female location. AMNH Software Engineer Acinapura and an AMNH OpenSpace high school intern supported a team of six high school girls to engage with the software, attending the weekend-long event and acting as group mentors.

Academic Publications

Faherty, J.K. et al. (2019). *IDEAS: Immersive Dome Experiences for Accelerating Science* (ASTRO 2020 decadal white paper). Retrieved from arXiv, Cornell University: https://arxiv.org/abs/1907.05383.

Bock, A., Axelsson, E., Costa, J., Payne, G., Acinapura, M., Trakinski, V., Emmart, C., Silva, C., Hansen, C., and Ynnerman, A. (2019) *OpenSpace: A System for Astrographics*. IEEE Transactions on Visualization and Computer Graphics. Retrieved from IEEE: https://ieeexplore.ieee.org/document/8805462.

Graduate Theses

OpenSpace has continued to be a focus of Master student work at Linköping University; NASA Community Coordinated Modeling Center, Goddard Space Flight Center; New York University; and University of Utah. The following theses were submitted in Year Four:

Reidarman, K. (2018). *Exoplanets: Interactive Visualization of Data and Discovery Method* (Master's Thesis, Linköping University, Linköping, Sweden). Retrieved from: http://liu.diva-portal.org/smash/get/diva2:1315169/FULLTEXT01.pdf.

Berg, M. & Grangien, J. (2019). *Implementing an Interactive Simulation Data Pipeline for Space Weather Visualization* (Master's Thesis, Linköping University, Linköping, Sweden).

Hassler, L. & Heppich, A. (2019) *Interactive 3D Visualization of the NASA Deep Space Network Activity* (Master's Thesis, Linköping University, Linköping, Sweden). Retrieved from: http://liu.diva-portal.org/smash/get/diva2:1322083/FULLTEXT01.pdf.

Olsson, E. and Fransson, J. (2019). *Visualization of Space Debris using Orbital Representation and Volume Rendering* (Master's Thesis, Scientific Computing and Imaging Institute, University of Utah, Salt Lake City, UT).

Huy, S. and Kollberg, A. (2019). *Interactive streaming of Space Weather Observation and Simulation data for Visualization* (Master's Thesis, NASA Community Coordinated Modeling Center, Goddard Space Flight Center, Greenbelt, MD).

Press

Powell, C.S. (2018, December 24). 50 years later, still processing Apollo 8's message of hope and desolation. *Discover Magazine*. Retrieved from: http://blogs.discovermagazine.com/outthere/2018/12/24/apollo-8s-message.

A fantastic voyage: Hayden Planetarium's instruments offer incredible views of stars, planets, and more. *Rotunda* (American Museum of Natural History), Spring 2019.

Jonsson, H. (2019, February 14). En världsunik upplevelse [A unique experience]. *Folkbladet.* Retrieved from: https://www.folkbladet.se/nyheter/norrkoping/en-varldsunik-upplevelse-om5778275.aspx

Linköping University (2019, February 15). 'Världens bästa dom' visar nästan verkligheten ['World's most advanced dome' almost shows reality]. Retrieved from: https://liu.se/nyhet/uppgradering-av-domen-pa-visualiseringscenter-campus-norrkoping---itn

New York University Tandon School of Engineering (2019, July 15). With NYU Tandon's help, the American Museum of Natural History relaunches Apollo 11. Retrieved from: https://engineering.nyu.edu/news/nyu-tandons-help-american-museum-natural-history-relaunches-apollo-11.

Cision. (2019, July 15). Återupplev den första månlandningen i specialvisning på Visualiseringscenter C 20/7 [Revisit the first Moon landing at the Visualization Center C on July 20]. Retrieved from: https://news.cision.com/se/visualiseringscenter-c/r/aterupplev-den-forsta-manlandningen-i-specialvisning-pa-visualiseringscenter-c-20-7,c2853243

Bruffy, M. (2019, July 16). App State's Kara Snow excels in internship at North Carolina Museum of Natural Sciences. *Appalachian Today* (Boone, NC). Retrieved from: https://today.appstate.edu/2019/07/16/snow.

Levere, J. (2019, July 16). Carnegie Hall, top New York art and natural history museums celebrate 50th anniversary of Apollo 11. *Forbes*. Retrieved from: https://www.forbes.com/sites/janelevere/2019/07/16/carnegie-hall-top-new-york-art-and-natural-history-museums-celebrate-50th-anniversary-of-apollo-11/.

Pruznick, M. (2019, July 18). Christie helps AMNH celebrate the Moon landing with a giant leap in projection technology. *AVNetwork.* Retrieved from: https://www.avnetwork.com/news/christie-helps-amnh-celebrate-the-moon-landing-with-a-giant-leap-in-projection-technology.

Online Presence

In Year Four, we established a digital strategy that was designed to increase the visibility of the software and its capabilities, thereby leading to greater awareness and support while expanding the potential user group. Another goal of these efforts was to build a community between developers, users, and interested audiences for wider interaction and communication.

Website (openspaceproject.com)

The OpenSpace website remains the entry point for potential new users, with an overview of the project, team, and opportunities, and the place to download the software. This year, we have made efforts to maintain our public events calendar and increase the resources available for the interested public and users.

Since January of 2019, openspaceproject.com has received over 25,000 unique visitors (275% compared to the last calendar year) and 19,000 visits (184% compared to the last calendar year). Half of these visits are initiated on a search engine (Google, DuckDuckGo, and Bing). Of the visits, 12,000 used IP addresses in the United States, followed by 1,300 in Sweden, 1,100 in the Netherlands, and 1,000 in Germany; an additional 25 countries had at least 100 visitors each.

From the website, visitors can connect with our support and social media platforms.

Support and Community Channels

Wiki (wiki.openspaceproject.com): We have continued to populate this public wiki-style website for users, content creators, and developers. This space currently has the most detailed instructions for each of these audiences.

GitHub (github.com/OpenSpace/): GitHub is the public source code repository for OpenSpace. Users and developers can also report technical problems with the software and contribute to the code in a community effort.

Slack (openspacesupport.slack.com; team-openspace.slack.com): These messaging and file sharing spaces also act as community spaces for collaboration. In Year Four, we continued to create private channels for institutions to connect directly with software developers, and have also reorganized several of the channels, such as "events" and "presenting," to foster community sharing.

Newsletter (example: https://bit.ly/368W0o3): In May, we began sending monthly newsletters targeted at contacts we had met at conferences who indicated their interest to learn more about OpenSpace. The newsletter is opened by an average of 57% of our 250 subscribers; we have been finding it to be effective at keeping our potential and current users informed about new developments and use of OpenSpace.

Social Media Accounts

YouTube (https://bit.ly/35ZH8IN): OpenSpace's YouTube channel generates the largest reach of its social media accounts, in Year Four, making 1.6 million impressions — the number of times a video thumbnail is shown to viewers on YouTube.[4] The channel has grown enormously in Year Four: Of the channel's 142,840 cumulative views, 125,000 occurred this year. Similarly, 1,100 of the channel's 1,300 subscribers followed the channel in Year Four.

The OpenSpace team published four new videos in Year Four, two of which were the recordings of the livestreams hosted in collaboration with NASA @ My Library. We have also begun to share OpenSpace updates as well as OpenSpace coverage that is posted on other channels, such as a presentation at the Great Lakes Planetarium Conference.

Twitter (@openspaceproj): Our Twitter account has also seen great growth in Year Four. We started sharing OpenSpace events and posting more content — especially tied into historic NASA "On This Day / OTD" events, such as mission anniversaries — and saw a positive impact on our reach and engagement numbers.

In Year Four, we doubled our number of followers from 188 to 374, 80% of which happened in the last six months. The number of times OpenSpace was mentioned by other users also doubled. The greatest expansion can be seen in the total number of impressions — that is, the number of times users saw our content[5]: Our impressions totalled over 48,000 for Year Four, compared to over 18,000 in Year Three, or a 250% increase.

Facebook (@OpenSpaceVisualization): Our Facebook page has maintained a steady audience of over 300 followers. In Year Four, we primarily used Facebook for its events page and reached over 1,500 users with this content.

[4] This frequency is determined by an algorithm based on a number of user behaviors, including what users chose to watch, how much time users spend watching a video, how quickly a video's popularity grows, how new a video is, how frequently a channel uploads a video, and the rate of viewer engagement on a video.

[5] Twitter also uses an algorithm that determines which tweets are shown to its users. Twitter's 'Top Tweets' are chosen based on recency, engagement by other users, the use of media, and account audience and location.

Instagram (@openspaceproj): The popularity of astronomy and official NASA Instagram accounts inspired our team to start our own account in April. This is the most emergent of our social media accounts, with 78 followers gained over the first six months of its existence. We see a high engagement rate for these followers, but would like to expand this reach by posting more OpenSpace visualizations.

Other Online Media

TED Talk (https://bit.ly/32KITaM): Dr. Juna Kollmeier used OpenSpace in her April 2019 TED Conference Talk to visualize the number of galaxies in the universe. The video on ted.com has been viewed over 1.8 million times.

Space by the California Academy of Sciences Podcast (https://apple.co/32JijP8): CAS posted a free downloadable recordings of Brian Day's and Dr. Jackie Faherty's OpenSpace lectures on Apple Podcasts.

PBS Space Time Episode (https://youtu.be/E8rel2-kLJA)*:* OpenSpace was used to explore the size and scale of the universe in a YouTube episode of the PBS Digital Studios' series Space Time, hosted by Dr. Matt O'Dowd. Since being posted on July 25, the video has been viewed over 610,000 times.

V. Evaluation, Collaborators, and Cross-Collaboration Agreements Activities

Evaluation and Assessment by HG&Co

The OpenSpace project's external evaluator is HG&Co (507 Dartmouth Ave, Silver Spring MD; 301-655-1925; kate@hgandco.com). In Year Four, HG&Co worked with the AMNH team to develop a survey instrument to collect data from audiences across the six ISI partner sites following OpenSpace-based public programs held on or near the 50th anniversary of the Apollo 11 lunar landing. By developing a simple close-ended survey to measure the impact of the programming, the evaluators were able to see how audiences were impacted by OpenSpace content across seven factors, as well as age and education level attainment.

In summary, the majority of those surveyed:

- experienced a high degree of awe
- increased knowledge of, appreciation of, and interest for NASA missions
- appreciated the complexity of NASA missions
- understood that visualizations are constructed from a wide variety of datasets
- believed OpenSpace supports science and education

HG&Co also interviewed OpenSpace interns at each of these ISI sites. These interviews are detailed with the above in the Evaluator Report.

Top-Level Metric Projections

The top-level metric for OpenSpace continues to be the number of interactive scenes of NASA data available within the software. A scene consists of the full astrophysical context plus multiple visualized assets required to support rich narrative programming about NASA missions and science results.

The OpenSpace target goal is to increase the number of scenes within OpenSpace from 0 in 2015 to 20 by the end of Year Five. In Year Four, we increased from last year's 13 scenes to 17 scenes. The project is projected to reach 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, 2, and 4:

1. Enabling STEM Education in 50 States

OpenSpace enables STEM education in 50 states through our ISI Network. Each of the six institutional partner, located across the United States, promote science learning through public programming, and support STEM-focused internships and mentored experiences.

Our Network hosted 22 interns ranging from high school to graduate level in a variety of multi-week, semester, and year-long internships and mentored experiences with data visualization and code development. Cumulatively, OpenSpace has been the focus of 118 internships.

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

As noted elsewhere in this report, OpenSpace focuses on increasing public engagement in STEM via ISI programs for public audiences of all ages.

In Year Four, 120 programs held by our ISI Network utilized OpenSpace to impart science and engineering learning to 64,370 people. These programs continue to represent a variety of activities, from permanent exhibitions and daily presentations to special lectures and festivals. These activities bring the total number of OpenSpace ISI programs to 177, fast approaching our projected 225 programs projected by the end of Year Five.

In addition to this, 346,846 visitors saw OpenSpace in a museum exhibit, and ISI and formal education users hosted 16 programs and demonstrations, reaching another 6,568 people. In total, this brings OpenSpace's reach to over 415,000 in Year Four, and the total impact of OpenSpace to 915,000 over the grant period.

While these metrics do not represent the full reach of OpenSpace, as it does not include such activities as dissemination online and at conferences, it demonstrates OpenSpace's strength in engaging learners in a variety of live presentations.

4. Leverage through partnerships

We strive to increase the number of users and commercial vendors who are key to the broad distribution and adoption of OpenSpace. During Year Four, we had 18 OpenSpace users, two of which are international. Our team also has productive relationships with nine planetarium vendors, one new in Year Four.

SMD Collaborators, Cross-CAN Awardee, and NASA Infrastructure Collaboration Activities in Year Four

We have had ongoing conversations, development activities, and public programming in collaboration with NASA Subject Matter Experts and other awardees.

Cross-Collaboration with Science Activation Awards

Projects preceded by an *asterisk had not previously collaborated with OpenSpace.

GSFC/NSSEC: Dr. Masha Kuznetsova co-supervises Master's students' development of new features and functions of OpenSpace. Additionally, NSSEC representatives attended and presented at AMNH SpaceFest (July 2019).

Gulf of Maine Research Institute: We have continued to regularly share educational best practices with the Gulf of Maine team.

**NASA @ My Library:* This emergent collaboration resulted in two successful livestreamed events that have reached over 6,000 viewers on YouTube. This includes over 800 live viewers, many of whom were at watch parties hosted at libraries across the country.

NISE Net: Members of the OpenSpace team participated in NISE Net's February showcase, demoing OpenSpace to attendees. As our ISI Network develops content and user guides, we have discussed contributing to a NISE Net kit that could be distributed to NISE Net's user group.

STSci/Universe of Learning: STSci has shared Hubble Ultra-Deep Field data that OpenSpace developers have incorporated into the software dataset. In addition, a shared galaxy collision simulation has led to plans for future OpenSpace development that will enable visualization of point cloud data, a format that will allow for visualization of many new scientific models and simulations.

University of Colorado, Boulder: OpenSpace was installed in Fiske Planetarium in Year Four, and our team will continue to support its implementation in Year Five. AMNH is very interested in utilizing Colorado's 360-degree videos in pop-up showcases in our Hall of the Universe. While this has been delayed thus far, we will continue to explore the logistics of this in Year Five.

WGBH: Dr. Rachel Connolly planned to participate in our OpenSpace educator evening; unfortunately due to illness, she was unable to attend. We look forward to hosting WGBH at this event in Year Five as we continue to collaborate on leveraging resources.

NASA Infrastructure Resources

Resources preceded by an *asterisk had not previously been used with OpenSpace.

JPL/Eyes: Working with Eyes' data and models, we produced a video of the InSight landing in OpenSpace that was shown at JPL on the day of the event. Additionally, Jason Craig, Manager of Visualization, Technology, and Development, is a member of our Advisory Board.

Treks: Our software engineers continue to use data that was shared by Treks in OpenSpace.

**Museum Alliance:* This year, OpenSpace utilized the Museum Alliance calendar and Ryver chat forum to share upcoming events with the public and STEM educators. Looking ahead, we have discussed the opportunity to hold a Museum Alliance webinar that introduces OpenSpace and its capabilities to the Alliance's wide audience, which is now possible due to the software's improved stability and usability. Given enough interest, we would also hold a series of workshops that would provide live tutorials that would then be archived as a resource.

**Solar System Ambassadors:* Solar System Ambassador Tony Rice presented at NCMNS' Mars InSight landing event, utilizing OpenSpace to visualize the descent and landing.

NASA-Funded SMEs in Year Four

Fifteen NASA-Funded Subject Matter Experts contributed to and/or used OpenSpace in Year Four, eight of whom are new to the project (indicated with an *asterisk). This brings the total number of unique SMEs to 36.[6]

Dr. Harold C. Connolly, Jr. (Mission Sample Scientist, GSFC): Utilized OpenSpace visualizations of OSIRIS-REx during Frontiers Lecture at AMNH.

Brian Day (SSERVI; Ames): Presented "Journeys to the Moon with NASA" at CAS, which utilized OpenSpace visualizations of the Apollo missions.

**Dr. Brett Denenvi* (Planetary Geologist, GSFC): Used OpenSpace visualizations of Mercury and MESSENGER in presentation at AMNH.

[6] In previous reports, the total number of NASA-funded SMEs was generated by adding the cumulative number by year. This meant some individuals were counted more than once if involved with OpenSpace across multiple years. We feel this new metric of unique SMEs better reflects the diversity of relationships across NASA.

Dr. Jackie Faherty (Co-PI, ROSES ADAP): Utilizes OpenSpace in public and youth programs at ISIs, particularly AMNH. Uses OpenSpace to visualize Gaia data for research on brown dwarfs.

**Dr. David Grinspoon* (Co-I, MSL): Utilized OpenSpace visualizations of New Horizons during Astronomy Live lecture at AMNH.

**Eddie Gonzales* (Education, JPL): Presented at AMNH SpaceFest.

**Abbey Interrante* (Science Writer, NSSEC): Presented at AMNH SpaceFest.

Dr. Masha M. Kuznetsova (Director, CCMC, GSFC): Co-supervised Master's students' development of new features and functions of OpenSpace.

**Dr. Steven W. Lee* (Co-I, MARCI, CTX, MRO; PI, MDAP): Utilized OpenSpace visualizations in multiple presentations at DMNS.

Dr. Mordecai-Mark Mac Low (ROSES ATP): Used OpenSpace for live visualizations during his lecture about star formation to the Amateur Astronomer's Association.

Dr. Rachel Smith (PI, NASA Emerging Worlds Research Program, Astrobiology): Utilizes OpenSpace in undergraduate coursework, and NCMNS public programming and internships.

**Dr. Henry Throop* (Senior Scientist, CDAP): Utilized OpenSpace visualizations of New Horizons during Astronomy Live lecture at AMNH.

**Ernest T. Wright* (Media Specialist, SVSG, GSFC): Provided data for Apollo 8, 11, and 17 trajectories that were incorporated into the new Apollo scenes.

Dr. C. Alex Young (Associate Director for Science, Heliophysics, GSFC): Presented at AMNH SpaceFest.

**Dr. Edward Young* (Researcher, NAI): Presented at NCMNS about his Moon research, which was contextualized with OpenSpace presentations.

Additionally, Lucas Smith and Robert Lewis, Appalachian State University undergraduate students who interned at JPL on the project "Investigating Carbon Inheritance in the Early Solar Nebula: An Interdisciplinary Approach" (PI: Dr. Rachel Smith), presented at NCMNS using OpenSpace.

<u>Other SMEs in Year Four</u>

Collaborations beyond NASA have expanded the use of OpenSpace as a tool for exploring and communicating space science data for a broad audience. New relationships are indicated with an *asterisk.

Dr. Dan Canton (Dark Sky Observatory, Appalachian State University): Began to use OpenSpace at public events, including a student open house.

**Jay Dickson* (CalTech Bruce Murray Laboratory for Planetary Visualization): Provided blended CTX map for new Mars map layer.

Dr. Denton Ebel (AMNH): Supports AMNH OpenSpace internships and demonstrates OpenSpace in poster and workshop sessions at conferences such as the Annual Meeting of the Meteoritical Society and Gordon Research Conference.

**Dr. Jana Grcevich* (Columbia University): Worked with developers to create an OpenSpace recording of Mars that was shown at the World Science Festival in June.

**Dr. Juna Kollmeier* (Carnegie Institution for Science): Worked with developers to develop an OpenSpace recording for use in her TED Talk on the Sloan Digital Sky Survey and creating a map of the universe.

**Dr. Matt O'Dowd* (Lehman College of the City University of New York): OpenSpace developers worked with O'Dowd to develop a recording for his PBS Digital YouTube show, Space Time, which has 1.8 million subscribers.

**Divya Persaud* (Ph.D. Student, University College London): Integrating Mars Rover and Gale Crater data into OpenSpace for visualization supporting her ongoing research and youth outreach.

Dr. Mark SubbaRao (Adler Planetarium, University of Chicago, IPS): Uses OpenSpace to map data from Zooniverse, a citizen science project.

VI. Year Five Plans

In Year Five, we plan to focus on reducing the challenges that prevent or delay the adoption of OpenSpace. This will include continuing to improve the software's Graphical User Interface with feedback from our users, and providing better documentation, program guides, and video-rich training resources.

Further fostering its capabilities and expanding its use, OpenSpace was included in two accepted SSERVI proposals — "RESOURCE" by Dr. Jennifer Heldmann (Ames) and "RIS^{4}E" by Dr. Timothy Glotch (Stony Brook University) — that will begin in Year Five. OpenSpace is also receiving $125,000 of funding from the National Science Foundation to visualize solar activity and produce associated public programs through a grant awarded to Dr. Jon Linker (Predictive Science Inc.).

Software and Content Development Goals

The Year Five Developers Meeting will be held at NYU Tandon School of Engineering in New York, NY, January 27-31, 2020.

Software and content development activities planned for Year Five include:

- Provide ongoing technical support of OpenSpace across our ISI Network and expanding user group
- Create additional online resources for users, developers, and scientists
- Develop and distribute program guides and training resources, including tutorial videos
- New features, including:
    - Programmatic flight path controls
    - A streamlined method for rapid testing of code changes across multiple systems to ensure high quality use experiences for ISI partners and the general public
- New scenes being considered include:
    - Astrophysical volumetric simulation of galaxy collision
    - Jovian magnetic field
    - Earth-based climate model simulation, to be produced collaboratively with NASA scientists at NASA Goddard GISS in NYC
    - Exoplanets
    - Surface activity visualization of rovers, i.e. Curiosity
- Updates to current scenes will include:
    - New map layers for solar system worlds
    - Improvements to Saturn and ring-based systems
    - Additional atmospheres for solar system worlds
    - Updated imagery for OSIRIS-REx and New Horizons missions
    - Additional NASA mission visualizations (LRO, Cassini, etc.)

ISI Network Goals

An annual ISI Network Partner and Advisory Board Meeting will be scheduled in spring 2020.

ISI Network programs planned for Year Five include:

- *Astronomy Days* (January 2020): OpenSpace will be utilized in NCMNS' annual Astronomy Days weekend in its Research Lab and Daily Planet Theater.
- *Frontiers Lecture* (March 2020): Brown University professor and researcher John F. Mustard will utilize OpenSpace visualizations in his AMNH Frontiers Lecture in the Hayden Planetarium.
- *Earth Day* (April 2020): A simultaneous livestream across multiple ISIs is being planned to mark the 50th anniversary of Earth Day. Current topic ideas leverage NASA Earth data and SMEs.
- *Educator Professional Learning* (Spring 2020): The AMNH Education Department is planning a two-day teacher Professional Learning event during New York City public schools' spring break. This event will highlight OpenSpace as a resource available for educators.

Additional ISI Network activities planned for Year Five include the documentation of programming to enable reproduction by other ISIs. This includes:

- Content guides for public programs,
- Agendas for educator events,
- Curricula for youth programs, and
- Guidelines and activities for internship programs.

VII. Attached Information

OpenSpace Developer Meeting Agenda
OpenSpace ISI Network and Advisory Board Meeting Agenda
OpenSpace Year Four Triangle