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THE GREAT AMERICAN ECLIPSE: TO TOTALITY AND BEYOND

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

&

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

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THE GREAT AMERICAN ECLIPSE: TO TOTALITY AND BEYOND

Thursday, September 28, 2017

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY AND
SUBCOMMITTEE ON SPACE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittees met, pursuant to other business, at 9:22 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Barbara Comstock [Chairwoman of the Subcommittee on Research and Technology] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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The Great American Eclipse: To Totality and Beyond

Thursday, September 28, 2017
9:30 a.m.
2318 Rayburn House Office Building

Witnesses

Dr. James Ulvestad, Assistant Director (Acting), Directorate for Mathematical & Physical Sciences, National Science Foundation

Dr. Thomas Zurbuchen, Associate Administrator, Science Mission Directorate, NASA

Dr. Heidi Hammel, Executive Vice President, Association of Universities for Research in Astronomy

Dr. Matthew Penn, Astronomer, National Solar Observatory

Ms. Michelle Nichols-Yehling, Director of Public Observing, Adler Planetarium

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

September 28, 2017

TO: Members, Subcommittee on Research and Technology & Subcommittee on Space

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Joint Research and Technology & Space Subcommittees Hearing: "The Great American Eclipse: To Totality and Beyond"

The Subcommittee on Research and Technology and the Subcommittee on Space of the Committee on Science, Space, and Technology will hold a hearing titled *The Great American Eclipse: To Totality and Beyond* on Thursday, September 28, 2017 at 9:30 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

On August 21, 2017, large portions of the continental United States experienced a total solar eclipse that stretched from Oregon to South Carolina. The purpose of the hearing is to review what scientific knowledge was gained from studying the eclipse, how U.S. telescopes and other scientific instruments were used to capture the eclipse, lessons learned from engaging the public and students in grades K-12 in STEM education and activities surrounding the event, and future preparations for eclipses in 2019 and 2024.

Witness List

- **Dr. James Ulvestad**, Assistant Director (Acting), Directorate for Mathematical & Physical Sciences, National Science Foundation
- **Dr. Thomas Zurbuchen**, Associate Administrator, Science Mission Directorate, NASA
- **Dr. Heidi Hammel,** Executive Vice President, Association of Universities for Research in Astronomy
- **Dr. Matthew Penn,** Astronomer, National Solar Observatory
- **Ms. Michelle Nichols-Yehling**, Director of Public Observing, Adler Planetarium

Staff Contact

For questions related to the hearing, please contact Jenn Wickre of the Majority Staff at 202-225-6371.

Chairwoman COMSTOCK. The Committee on Science, Space, and Technology will come to order.

Without objection, the Chair is authorized to declare recesses of the Committee at any time.

Good morning, and welcome to today's hearing titled "The Great American Eclipse: To Totality and Beyond." I recognize myself for an opening statement, but I am going to submit most of my prepared statement for the record. We need to finish the hearing before votes are called around 10:30 a.m., so our apologies for truncating things here.

We know we will be inspired by our witnesses today, and harnessing the enthusiasm for the eclipse that we saw when people really came together. I know my husband was with his cereal box doing that, and he's a math teacher, so he was very excited. So we're excited to see, you know, this whole generation of students who are interested in this and would like to now translate that into STEM careers. We're excited to hear from our witnesses today. I'm going to shorten up and submit my statement for the record.

[The prepared statement of Chairwoman Comstock follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
September 28, 2017

Media Contact: Thea McDonald
(202) 225-6371

Statement from Research and Technology Subcommittee Chairwoman Barbara Comstock (R-Va.)

The Great American Eclipse: To Totality and Beyond

Chairwoman Comstock: On August 21, the "Great American Eclipse" captured the imagination of a nation. For the first time in 99 years, a total solar eclipse could be seen coast-to-coast from Oregon to South Carolina.

Millions of Americans travelled to the 70-mile wide "path of totality" that stretched across 14 states. Millions more witnessed the partial eclipse from their home, school or office – using eclipse glasses, telescopes and even homemade cereal box viewers to watch the event. Hundreds of local museums, libraries and science centers hosted events that were packed.

NSF, NASA and their partners engaged in months of planning for the event.

The purpose of today's hearing is to review was scientific knowledge was gained from studying the eclipse, how U.S. telescopes and other scientific instruments were used to capture the eclipse, and lessons learned from engaging kids and the public in STEM education and citizen science.

I also want to learn how can we harness the enthusiasm for major events like the eclipse into inspiring a whole generation of students to go into STEM fields.
I am particularly happy to have two women on the witness panel today who are experts in their fields.

In order to fill the millions of open STEM jobs across the country, we must be able to harness the talent of our nation's young women.

It is estimated that only 3% of these jobs will be filled by a woman. That is why I introduced the INSPIRE Women Act, which was signed into law earlier this year.
The bill leverages NASA's talent pool of current and retired astronauts, and early career female scientists, engineers, and innovators to inform and inspire young women to pursue their dreams in STEM subjects.

I want to take a moment to recognize three students and their families in the audience today who have participated in my Young Women Leadership Program.

Reagan Williams – a junior from South County High School. She watched the Solar Eclipse in Fairfax County at home with one of her friends, dad and two young sisters. Kendall Pade and her mom, Genemarie Pade. Kendall is from McLean, Virginia and an 8th grader that attends the National Cathedral School located in Washington DC. They originally didn't have any eclipse glasses, however their neighbor called around 1PM saying they had two extra glasses and were able to watch the solar eclipse on their front lawn in McLean.

Christine Vuong and her mom, Linh. She is a junior from Centreville High School. She watched the eclipse in Ocean City.

I hope they will be inspired by our witnesses today, and that we can harness the enthusiasm for the eclipse into inspiring a whole generation of students to go into STEM careers.

We'll be sharing the videos and pictures from the hearing today with our constituents back home too.

I thank all of our witnesses and look forward to your testimony.

###

Chairwoman COMSTOCK. And Then I am going to now recognize the Ranking Member, the gentleman from California, Mr. Bera, for his opening statement.

Mr. BERA. Thank you, Madam Chairwoman.

You know, the eclipse was absolutely exciting, right? On August 21st, you know, I went to the Powerhouse Science Center in Sacramento, and what was great about it was the number of kids that were out there with their glasses, and the number of amateur astronomers that were out there. You know, that reminds me of the excitement, you know, growing up with the Apollo program and the excitement, and the generation of scientists that that spawned and, you know, encourage folks to go into science.

You know, we were out at Goddard, you know, with my staff visiting with one of the helio scientists out there, and they were talking about the Parker Solar Probe, and you know, she's probably—I can't remember the scientist's name but she was one of the most enthusiastic people that I've seen, so if we can have more of this enthusiasm, this excitement, it's going to generate a generation of kids wanting to go into science.

So I'm going to keep my comments short there, and I will yield back, and I'm excited to hear what you guys have to say.

[The prepared statement of Mr. Bera follows:]

OPENING STATEMENT
Ranking Member Ami Bera (D-CA)
of the Subcommittee on Space

House Committee on Science, Space, and Technology
Subcommittee on Research and Technology
Subcommittee on Space
"The Great American Eclipse: To Totality and Beyond"
September 28, 2017

Thank you to Chairwoman Comstock and Chairman Babin for holding this Joint Hearing on "*The Great American Eclipse: To Totality and Beyond*", and I want to welcome our witnesses for being here this morning. On August 21st, millions of Americans were treated to the rare sight of the Moon completely blocking the Sun—a total solar eclipse. Those Americans who were not in the path of totality saw a partial solar eclipse.

I had the opportunity to view the partial eclipse back in California at the Powerhouse Science Center in Sacramento. Surrounded by hundreds of enthusiastic adults and children, this experience reminded me of my childhood in Southern California watching the Apollo missions with the same amazement.

Preliminary estimates indicate that over 200 million Americans participated in a similar viewing event or watched live-streamed media coverage. It's critical that we learn from this experience and work to keep this level of public interest in space and science as future space activities can only benefit from an engaged and supportive American public. Children who experienced this eclipse may one day be part of the teams of scientists and engineers supporting missions that take us to cis-lunar space, Mars and beyond.

Although a total solar eclipse occurs somewhere on Earth every 18 months, the Great American Eclipse was extraordinary because, for the first time in a century, the path of totality passed across the United States eastward from Oregon and eastward to South Carolina. Those who experienced the total solar eclipse saw the Moon completely cover the bright disk of the Sun, revealing the much fainter corona and solar prominences. They also may have noticed changes in their environment—stars and planets in the mid-day sky, a decrease in air temperature, and changes in bird and animal behaviors.

Scientists used the occurrence to study the innermost region of the Sun's corona, which would otherwise not be visible even with dedicated solar probes and ground-based telescopes. Mr. Chairman, this level of participation from the American public would not have been possible without the planning of multiple Federal agencies and organizations, including the Department of Transportation, which helped ensure the safety of road travel for the many Americans that drove long distances to be in the path of totality.

While the total solar eclipse lasted only a few minutes at each point along its path, the amount of information we can learn about the public engagement in this event will have long-lasting value for science and science education.

To that end, I look forward to hearing from our witnesses on:

- What did we learn about the logistical, informational, and science planning of this event?
- What aspects of the preparations had the greatest impact in engaging the public?, and
- What lessons were learned from the Great American Eclipse that can be applied to encourage maximum public participation in other future science events?

Thank you, Mr. Chairman, and I yield back.

Chairwoman COMSTOCK. Great. And I now recognize the Chairman of the full Committee for a statement, Mr. Smith.

Chairman SMITH. Thank you, Madam Chairwoman.

In August, millions of Americans turned their eyes to the sky to witness a rare event: a solar eclipse. The Great American Eclipse was a profound experience for anyone fortunate enough to be in the path of totality, and exciting even for those of us who witnessed a partial eclipse.

An eclipse is a sight that has inspired previous generations, and one that I hope will inspire a whole new group of young people to study the universe and beyond. It was an 1878 American eclipse that inspired a young inventor named Thomas Edison. Edison took a trip to Wyoming to view the total eclipse and attempt an experiment to measure the sun's corona, or outer atmosphere. The experiment failed, but allegedly inspired him to think about the principles of light and transmission of power. The very next year he invented the incandescent electric light bulb.

Who knows what discoveries this year's eclipse will inspire, but we do know it has already rejuvenated an enthusiasm for astronomy, astrophysics and astrobiology. Thanks to the good work of NASA, NSF and their partners, that enthusiasm was converted into viewing parties, STEM education lessons, and citizen science that engaged millions of Americans.

We have the privilege today of hearing from a panel of witnesses who helped make the day a success for both science and education. I thank our witnesses, and look forward to seeing their incredible photos and videos, learning what scientific discoveries may come from experiments conducted during the eclipse, and hearing what's next for solar science.

It is human nature to seek out the unknown and to discover more about the universe around us. We have an extraordinary opportunity to turn enthusiasm for the Great American Eclipse into a renewal for American physics and astronomy that lasts far beyond the two minutes of totality.

Thank you, Madam Chairwoman. I yield back.

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
September 28, 2017

Media Contact: Thea McDonald
(202) 225-6371

Statement from Chairman Lamar Smith (R-Texas)

The Great American Eclipse: To Totality and Beyond

Chairman Smith: In August, millions of Americans turned their eyes to the sky to witness a rare event – a solar eclipse.

The "Great American Eclipse" was a profound experience for anyone fortunate enough to be in the path of totality, and exciting even for those of us who witnessed a partial eclipse. An eclipse is a sight that has inspired previous generations, and one that I hope will inspire a whole new group of young people to study the universe and beyond.

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I thank our witnesses, and look forward to seeing their incredible photos and videos, learning what scientific discoveries may come from experiments conducted during the eclipse, and hearing what's next for solar science.

It is human nature to seek out the unknown and to discover more about the universe around us. We have an extraordinary opportunity to turn enthusiasm for the "Great

American Eclipse" into a renewal for American physics and astronomy that lasts far beyond the two minutes of totality.

###

Chairwoman COMSTOCK. Thank you, and I now recognize the Chairman of the Space Subcommittee, Dr. Babin, for an opening statement.

Mr. BABIN. Thank you very much, Madam Chairwoman.

I want to start by thanking our colleagues and also our witnesses that have come forth on this very, very interesting hearing.

Something that struck me about this eclipse is the level of excitement that it generated all across the United States. The eclipse was something that that really brought us all together in our inspiration and awe.

I'd like to also add that NASA's web traffic during the eclipse skyrocketed. It peaked at seven times higher than its previous record. The eclipse's online viewing audience compared with the audience for the Super Bowl, and even Netflix lost ten percent of the day's viewership to the eclipse. And schools across the country incorporated the eclipse into teaching programs, and there's no telling how the eclipse sparked the imagination of our school kids and captured their fascination and I thoroughly enjoyed myself showing and explaining to our schoolchildren in some parts of my district during that time including my own grandchildren, the little cereal boxes that our Chairwoman had just talked about that we had made, their solar viewer projectors I think is what their real name is. But it was one of those rare wonderful events that was as exciting to the scientific community as it was the man the street. It was an inspiration to our youth and it brings to mind an interesting comparison. In a way, the 2017 solar eclipse was almost like a space mission that was brought into our own backyards.

I am excited about the upcoming 2024 eclipse, which, in my opinion, could even be more impressive and awe-inspiring, not the least because the path of totality for the eclipse travels right across my home State of Texas.

I want to thank you all for your testimony looking forward to it, and I yield back, Madam Chair.

[The prepared statement of Mr. Babin follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
September 28, 2017

Media Contact: Thea McDonald
(202) 225-6371

Statement from Space Subcommittee Chairman Brian Babin (R-Texas)

The Great American Eclipse: To Totality and Beyond

Chairman Babin: I want to start by thanking our colleagues on the research and technology subcommittee for hosting this joint hearing. The eclipse was an amazing and exciting event, and I look forward to our discussion.

Something that struck me about this eclipse is the level of excitement it generated all across the country. In a time when the country seems locked in controversy and division, the eclipse was something that brought all of us together in awe and wonder.

NASA's web traffic during the eclipse skyrocketed; it peaked at a level seven times higher than its previous record. The traffic set new records for overall government web traffic, according to the GSA's Digital Analytics Program. The eclipse's online viewing audience compared with the audience for the Superbowl. Even Netflix lost about 10 percent of the day's viewership to the eclipse.

Schools across the country incorporated the eclipse into teaching programs. There is no telling how the eclipse sparked the imagination of schoolchildren, or which school experiments might have captured critical scientific data.

The eclipse was also one of those rare, wonderful events that was as exciting to the scientific community as it was the person on the street.

Beyond the dozens of citizen science experiments — which I hope we can hear about today — scientists in government and academia were able to take advantage of this wonderful opportunity. Researchers carried out numerous of experiments and studies in fields from astronomy, to meteorology, to animal behavior during the eclipse.

This combination of public excitement, scientific benefit and, even more importantly, inspiration to our youth brings to mind an interesting comparison. In a way, the 2017 solar eclipse was almost like a space mission brought to our nation's backyard.

Instead of looking outward to see something amazing, something amazing came to us. This makes the public response a cause for optimism. The eclipse proved that wonder and awe can still bring us together. It proved that the public, particularly our

children, can get involved in science and be excited by new discoveries. That in a time of distraction and controversy, the majesty of nature can still outperform us all.

I am excited about the upcoming 2024 eclipse. Which, in my opinion, could even be more impressive and awe-inspiring. Not least, because the path of totality for the eclipse travels right through my home state, the great State of Texas.

I thank you all for your testimony and I look forward to the discussion.

###

Chairwoman COMSTOCK. Thank you.

And I will now introduce our witnesses.

Our first witness today is Dr. James Ulvestad, Acting Assistant Director of the Directorate for Mathematical and Physical Sciences at the National Science Foundation. Prior to the NSF, he was Assistant Director of the National Radio Astronomy Observatory, where he oversaw the Very Long Array and Very Long Baseline Array radio telescopes. He has also served in various capacities at the NASA Jet Propulsion Laboratory. He received his bachelor of arts degree in astronomy from the University of California at Los Angeles and his Ph.D. in astronomy from the University of Maryland.

Our second witness today is Dr. Thomas—I'm going to let you——

Dr. ZURBUCHEN. Zurbuchen.

Chairwoman COMSTOCK. Zurbuchen, Associate Administrator of the Science Mission Directorate at NASA. He previously served as a Professor of Space Science and Aerospace Engineering at the University of Michigan. He has worked on several NASA science missions including Ulysses, the MESSENGER spacecraft to Mercury, and the Advanced Composition Explorer. He earned both his master's of science degree and his Ph.D. in physics from the University of Bern in Switzerland.

Our third witness today is Dr. Heidi Hammel, Executive Vice President of the Association of Universities for Research in Astronomy, a group of 44 U.S. universities and institutions that operates world-class astronomical observatories including the Space Telescope Science Institute, the National Optical Astronomy Observatory, the National Solar Observatory, and the Gemini Observatory. Since 2003, she has served as one of six interdisciplinary scientists advising NASA on the science development of the James Webb Space Telescope. Dr. Hammel received her undergraduate degree from MIT and her Ph.D. in physics and astronomy from the University of Hawaii.

Our fourth witness today is Dr. Matthew Penn, Astronomer at the National Solar Observatory. He is a Principal Investigator on the Citizens Continental Telescope Eclipse Experiment, or Citizen CATE, and a Telescope Scientist for the McMath-Pierce Solar Facility at Kitt Peak. Specifically, he works on the DKIST Telescope Project under construction in Hawaii developing infrared science and instrumental requirements. He received his bachelor's of science degree in astronomy from Cal Tech as well as a Ph.D. in astronomy from the University of Hawaii.

And our fifth witness today is Ms. Michelle Nichols-Yehling, Director of Public Observing at the Adler Planetarium in Chicago. While at Adler, she has developed exhibits, shows, and programs and events for Adler guests. She also leads the Adler's various telescope observatory and sky-observing efforts. She earned her bachelor's of science degree in physics and astronomy from the University of Illinois at Urbana-Champaign and a master's of education degree in curriculum and instruction from National St. Louis University.

And I now recognize Dr. Ulvestad for his statement and testimony.

TESTIMONY OF DR. JAMES ULVESTAD, ASSISTANT DIRECTOR (ACTING), DIRECTORATE FOR MATHEMATICAL & PHYSICAL SCIENCES, NATIONAL SCIENCE FOUNDATION

Dr. ULVESTAD. Thank you, Chairwoman Comstock, Ranking Member Bera, Chairman Smith, Chairman Babin, Members of the Subcommittees. I'm James Ulvestad, Acting Assistant Director for the Mathematical and Physical Sciences Directorate at the National Science Foundation. Thanks for the opportunity to testify here today.

I want to focus my oral remarks on NSF's solar research efforts and the large-scale outreach associated with the eclipse. As you've all said, August 21st was an exciting day for our citizens and scientists alike as our nation was center stage for the 2017 total solar eclipse, the first in the continental United States since 1979.

Scientists and spectators from around the world, including Members of Congress from these Subcommittees—you can see yourselves up there possibly—gathered across the country to witness this extraordinary event. The eclipse was a total solar eclipse where direct sunlight was blocked for over two minutes while the moon covered the sun. It made its way from Oregon to South Carolina, illuminating a 70-mile-wide path across 14 states. The rest of the continental United States experienced some percentage of the partial solar eclipse during the eclipse's 90-minute traverse across the country.

The sun is the basis for life on Earth. Its magnetic fields and atmosphere, specifically its corona, fuel space weather that affects Earth's power grids and communications systems. The sun's power is also a source of renewable energy for our advanced civilization, and the fundamental importance of the sun leads the National Science Foundation to sponsor a broad array of research related to our local star.

NSF-supported scientists track the development of sun spots, flares, and coronal mass ejections. They work to better understand how these phenomena are associated with the sun's magnetic field, which influences the energetic space weather events that can wreak havoc on our technology.

During the eclipse, the high-altitude observatory of NSF's National Center for Atmospheric Research in partnership with the Harvard-Smithsonian Center for Astrophysics flew an airborne infrared spectrometer onboard NCAR's Gulfstream V research aircraft. This instrument collected infrared data to probe the complex magnetic environment of the sun's corona. Of course, there aren't results yet. As science goes, there will be results coming out over the next year or two.

Researchers in general continue to study the behavior of the sun to develop warnings of solar storms that may be coming toward Earth. So the Global Oscillations Network Group of NSF's National Solar Observatory, a network of six solar-monitoring telescopes sited worldwide, provides full-time monitoring of the sun and is a critical element of space weather forecasting models.

So now let me move to the eclipse and some of the outreach efforts. First I want to say here that any funding that the Federal Government put into this was leveraged by a factor of a thousand by the planetaria, the high school teachers, the college students, the random citizens and amateur astronomers who went out there and engaged with the public. So I really want to thank them for that.

So one of the activities that Chairwoman Comstock already mentioned was the citizen science project, Citizen CATE, the Continental America Telescope Eclipse, an experiment that included a network of 68 identical telescopes placed along the 2,500-mile path of totality operated by citizen scientists, high school groups, and universities. NSF Director Dr. France Córdova, who's shown on this slide, was pleased to be in Glendo, Wyoming, which I think had a 100- or 1,000-fold increase in population for one day, to experience the solar eclipse and participate firsthand in Citizen CATE outreach. You'll hear more about this from Dr. Matt Penn.

NSF also funded the American Astronomical Society program called Solar Eclipse Across America. This included a mini grants program that funded 31 projects in 21 states.

Now, as far as the future goes, by early 2020, NSF's Daniel K. Inouye Solar Telescope, the new centerpiece of the National Solar Observatory, will be complete on the summit of Haleakala on Maui, Hawaii. It will provide researchers an unprecedented close-up view of the solar corona without having to wait for a solar eclipse. The enhanced understanding of the sun and the origin of solar storms will undoubtedly contribute to better predictions of space weather in the future.

The solar eclipse was a great opportunity for scientific research and citizen engagement in an event that brought a sense of wonder and curiosity to scientists and citizens alike. The basic research conducted with DKIST, which you see here, will revolutionize our understanding of the sun in the future. We're looking forward to the next eclipse in 2024. There will also be an annular eclipse in 2023 so you have a six-month-ahead rehearsal, and we're pleased to enjoy the support of the public in fulfilling our role.

We thank the Subcommittee members for their ongoing support of NSF and our efforts to serve the people of the United States.

[The prepared statement of Dr. Ulvestad follows:]

Testimony of

Dr. James S. Ulvestad, Ph.D.
Assistant Director (Acting)
Directorate for Mathematical and Physical Sciences
National Science Foundation

Before the
Subcommittee on Research and Technology
and
Subcommittee on Space

for the
U.S. House of Representatives
Committee on Science, Space and Technology

September 28, 2017

"The Great American Eclipse: To Totality and Beyond"

Chairwoman Comstock, Ranking Member Lipinski, Chairman Babin, Ranking Member Bera, and Members of the Subcommittees, I am Dr. James Ulvestad, Assistant Director (Acting) for the Mathematical and Physical Sciences Directorate at the National Science Foundation (NSF). Thank you for the opportunity to testify before you today to discuss the recent solar eclipse and NSF's solar research, education and outreach efforts. August 21st was indeed an exciting day for our citizens and scientists alike, as our nation was center stage for the 2017 solar eclipse. We welcomed scientists and spectators from around the world who gathered across the country to witness this extraordinary event.

Introduction

More than a million planets the size of Earth could fit inside the sun, yet our sun is only considered a "yellow dwarf." The Sun is larger than most stars, but considered a dwarf because it is nowhere near the size of many of the bright stars in the night sky, such as Rigel and Betelgeuse in the constellation Orion. Even though the sun appears to be a rather ordinary star, one cannot overstate the sun's significance to life on earth as we presently know it. Solar energy fuels life on Earth. Solar winds spark the Aurora Borealis and Aurora Australis in Earth's atmosphere. The sun's magnetic fields and atmosphere—specifically its corona—fuel space weather that affects Earth's power grids and communications systems. Moreover, the sun's undeniable power has increasingly become a source of renewable energy for our advanced

civilization. It's because of these connections and more that NSF sponsors a broad array of research related to the sun.

On August 21, 2017, the U.S. was treated to its own solar eclipse, a total solar eclipse that made its way from Oregon to South Carolina, illuminating a 70-mile-wide path across 14 states. While only those in that direct path could see the total eclipse—when daylight was extinguished for over two minutes while the moon completely covered the sun—the rest of the continental U.S. experienced some percentage of a partial solar eclipse. The eclipse traversed the continental U.S. in about 90 minutes.

Solar science

The total solar eclipse provided researchers a unique opportunity to study the sun's corona, the upper level of the sun's atmosphere. The corona is the launching point into space for the solar storms that create the space weather we experience on earth. This year's eclipse path, mostly over land, set up particularly good conditions for gathering data about this solar corona.

The recent total solar eclipse, the first in the continental U.S. since 1979, afforded extraordinary opportunities for scientific research. For example, the High Altitude Observatory (HAO) of NSF's National Center for Atmospheric Research (NCAR) in Boulder, Colorado, in partnership with the Harvard-Smithsonian Center for Astrophysics, designed, developed and flew an instrument called the Airborne Infrared Spectrometer (AIR-Spec) onboard NSF/NCAR's Gulfstream V research aircraft. AIR-Spec collected infrared data from the sun's corona during the eclipse, without needing to contend with clouds or compensate for the atmospheric distortion that affects ground-based telescopes. AIR-Spec was able to probe the complex magnetic environment of the sun's corona.

NSF also supports scientists who track the development of sunspots, flares and coronal mass ejections (giant clouds of solar plasma that are blown away from the sun during strong solar flares). These researchers, often using data from NSF's National Solar Observatory, are working to better understand how and when these phenomena are associated with the sun's magnetic field. That magnetic field is the apparent source of the energetic space weather events that can wreak havoc on Earth's power grids, satellites and communications systems. Space weather has the potential to interfere with everything from satellite communications to electrical power. Atmospheric scientists and geospace researchers are studying the behavior of the sun to develop warnings of solar storms that may be coming toward Earth. The National Solar Observatory's Global Oscillations Network Group (GONG) of six solar monitoring telescopes sited worldwide provides full-time monitoring of the sun and is a critical element of the models used to forecast solar storms and space weather.

Prior to the solar eclipse, a research team from Predictive Science Inc. (PSI) used the NSF-funded Stampede2 supercomputer at The University of Texas at Austin's Texas Advanced Computing Center (TACC) and Comet at the San Diego Supercomputer Center (SDSC) to forecast the corona of the sun during the upcoming eclipse. Similarly, the National Solar Observatory made a forecast of the magnetic field and the shape of the corona 25 days in advance of the eclipse, based on data from GONG and other sources. The findings shed light on

what the eclipse of the sun might look like. The opportunity provided researchers with a chance to compare projections with the actual event. This kind of predictive computer modeling improves the accuracy of space weather forecasting, which could have important practical ramifications. If a powerful solar storm such as the 1859 Carrington Event— which led to auroras being visible as far south as the Caribbean and caused telegraphs to short and catch fire—were to hit Earth today, it would cause more than $2 trillion in damages, according to a 2008 National Academy of Sciences workshop report.

Predicting the arrival of such a solar storm in advance would allow officials to take the most critical electronic infrastructure offline and limit the storm's impact. But doing so requires understanding how the visible surface of the sun (the photosphere) relates to the mass ejections of plasma from the corona, ultimately causing the space weather that we experience here on earth. The importance of this increased understanding was recognized by the 2013 National Academies decadal committee report in Solar and Space Physics. The first Key Science Goal in that report was to "Determine the origins of the Sun's activity and predict the variations in the space environment."

One of the sun's biggest mysteries is why its corona is so hot. The sun's core is a searing ~27 million degrees Fahrenheit (F), but by the time that heat reaches the sun's surface, it cools off to a mere ~10,000 degrees F, only to again heat up to several million degrees F in the corona, above the surface. This isn't just about understanding the sun, though. The corona is made of plasma, and many believe the answer has to do with the physics of how these plasmas work. NSF-funded researchers are investigating this issue and many other plasma physics issues that surround our sun.

Our sun emits trillions of times as much energy as the total electrical energy produced by all the Earth's power generators. Harnessing the power of the sun is a challenge that many scientists and engineers continue to work toward to solve more effectively. NSF-funded material scientists, engineers, physicists, mathematicians and computer scientists all play a role in moving this technology forward so that solar power can flourish and most effectively augment other energy sources in the future.

Outreach and education efforts

The NSF National Solar Observatory organized a citizen science project, Citizen CATE (Continental-America Telescopic Eclipse), an experiment that included a network of 68 identical telescopes, placed along the 2,500-mile path of totality and operated by citizen scientists, high school groups and universities. I'm sure you'll hear more about this project from Dr. Matt Penn of the National Solar Observatory. Citizen CATE was a joint project involving volunteers from more than 20 high schools, 20 universities, informal education groups, astronomy clubs across the country, 5 national science research labs and 5 corporate sponsors. The academic partners involved in the Citizen CATE project were drawn from a geographically and demographically varied set of institutions. These diverse partners connected with even broader audiences in different settings—from small, rural events to international broadcasts viewed by thousands.

The goal of Citizen CATE was to produce a scientifically unique data set of high-resolution, rapid-cadence images of the inner corona for 90 minutes. The full, high-resolution dataset captured consists of more than 4,000 highly processed images spanning the entire path of totality. The dataset continues to be assembled and will include the production of a continuous video of the eclipse as it passed over our country. NSF Director Dr. France Córdova was pleased to be in Glendo, Wyoming to experience the solar eclipse with scientists from the National Solar Observatory.

Another NSF-funded citizen outreach-focused project was the American Astronomical Society's program called, Solar Eclipse Across America. This project included an eclipse project manager, a centralized website of resources, and a mini-grants program to coordinate and facilitate local and national activities to educate the public about the science of the event. The program funded 31 projects in 21 states, leveraging curiosity about the eclipse to engage as many people as possible in the endeavor of science.

Lessons learned are now being collated in a publicly available formal report that will lay the groundwork for a strategic plan to fully capitalize on the next U.S.-based total solar eclipse in 2024. Because this project aligns well with the objectives of multiple NSF directorates, this award is co-funded by the Division of Undergraduate Education and the Division of Research on Learning in the Directorate for Education and Human Resources; the Division of Astronomical Sciences in the Directorate for Mathematical and Physical Sciences; and the Division of Atmospheric and Geospace Sciences in the Directorate for Geosciences.

Public participation in scientific research projects such as these are instrumental in educating K-12 learners and beyond because they provide hands-on experiences that can be followed through to results. These kinds of STEM (Science, Technology, Engineering, and Mathematics) education activities serve to inspire and train the next generation of scientists and engineers.

Future

Two more major solar eclipses are coming to the U.S. in the not-too-distant future. On Saturday, October 14, 2023, an annular ("ring of fire") eclipse sweeps from Oregon to Texas in a 125-mile-wide path. Just six months later, on Monday, April 8, 2024, a total solar eclipse darkens a 115-mile-wide swath from Texas to Maine. In both cases, all of North America will have at least a partial solar eclipse.

By early 2020, NSF won't need to wait for an eclipse to study the sun's corona in great detail. NSF's Daniel K. Inouye Solar Telescope (DKIST), which will be the new centerpiece of the National Solar Observatory, is now nearing completion on the summit of Haleakalā on Maui, Hawaii. DKIST, at a total project cost of $344 million, will be the largest, most powerful solar telescope in the world, located at an optimal site for solar research. Research conducted with DKIST is expected to lead to a better understanding of the sun. Such understanding has the potential to reduce significantly the impact from a Carrington event by enabling an increased warning time for such an event.

The primary mirror for DKIST—the heart of this sophisticated instrument—was successfully delivered to its destination atop Haleakalā on August 2. The safe delivery marks a major milestone for the DKIST project. The 4-meter (13-foot) mirror is an engineering marvel, polished to a surface roughness of only 2 nanometers (2 billionths of a meter), the scale of single molecules. The mirror will be supported by 142 electromechanical actuators that will adjust the structure, compensating for the pull of gravity as it tilts throughout the day, from sunrise to sunset. A fast, adaptive optics system also will compensate for atmospheric distortions to provide views of solar phenomena on scales as small as 20 kilometers (roughly 10 miles) on the sun.

DKIST will be the most sensitive instrument available for studying the various layers of the sun, including the corona. Specifically, DKIST will include a coronagraph, which allows researchers to create an artificial eclipse blocking the bright light of the sun. This will permit researchers an unprecedented, close-up view of the solar corona, which is nearly 1 million times dimmer than the light from the sun itself. The summit of Haleakalā is one of the few places on Earth with "coronal skies," meaning solar astronomers can view the sun's corona relatively free from the hazy scattering of light caused by the Earth's atmosphere.

Summary

The recent solar eclipse was a great opportunity for scientific research and for citizen engagement in an event that brought a sense of wonder, curiosity, and awe to scientists and citizens alike. It helped highlight all that we still have to learn about the sun and its impacts on earth. The basic research to be conducted with NSF's Daniel K. Inouye Solar Telescope will revolutionize our understanding of the sun, and our ability to mitigate future extreme space weather events. The combination of grass-roots citizen engagement and leading-edge scientific research exemplify the role of the National Science Foundation for our society, and we are pleased to enjoy the support of the committee and the public in fulfilling this role.

Biography
Dr. James S. Ulvestad



Dr. James S. Ulvestad is the Acting Assistant Director in charge of the Directorate for Mathematical and Physical Sciences at the National Science Foundation (NSF), a position he has held since January 2017. Previously, he was the NSF Division Director for Astronomical Sciences from 2010 to 2017. Prior to coming to NSF, Dr. Ulvestad was an Assistant Director of the National Radio Astronomy Observatory (NRAO), where he was in charge of the Very Large Array and Very Long Baseline Array radio telescopes, and later was the head of the NRAO New Initiatives Office. Before going to NRAO, Dr. Ulvestad served in various capacities at the NASA Jet Propulsion Laboratory, where he played important roles in several interagency and international programs. Among his community service activities, Dr. Ulvestad chaired the Demographics Study Group of the 2010 National Academy of Sciences decadal survey in astronomy and astrophysics, was an elected member of the American Astronomical Society Council, and has been a member of NASA's Structure and Evolution of the Universe Subcommittee. Dr. Ulvestad is an author or co-author of more than 80 refereed papers in the scientific literature, as well as numerous technical reports.

Chairwoman COMSTOCK. I now recognize Dr. Zurbuchen.

TESTIMONY OF DR. THOMAS ZURBUCHEN,
ASSOCIATE ADMINISTRATOR,
SCIENCE MISSION DIRECTORATE, NASA

Dr. ZURBUCHEN. Madam Chair, Members of the Subcommittee, as the head of NASA's Science Mission Directorate, I represent the thousands of volunteers, partners and NASA employees who made the 2017 eclipse the biggest media event in modern history of NASA. I would like to describe NASA's experience with the eclipse, highlight some of the results of our science and STEM efforts, and discuss how important heliophysics is for NASA's mission.

Monday, August 21st, a total solar eclipse across the continental United States occurred for the first time in almost a century, and I'll share with you my own vantage point, which was at 45,000 feet over the Pacific Ocean in an aircraft outfitted with science experiments to capture views, before, during and after the event. It was truly breathtaking. Watch.

[Video playback]

So I was excited. You may be able to tell. I was so excited that I mixed up the colors. It's called the diamond ring, not the solar ring, if you want to quote that.

Well, anyway, our NASA team and scientists around the country have been planning for this eclipse for many years, and with me at the hearing is Dr. Alex Young right behind me, our Project Manager, who has been a champion for the eclipse and working with a broad NASA team for over three years. The team focused key priorities: safety, science and citizen science education, and public engagement. To accomplish these priorities, we knew we couldn't do it alone. The entire agency rallied, and each of our 10 centers led major functions and events partnering really broadly. The eclipse was the biggest science outreach event in modern NASA history. Working with our partners, we engaged with citizens across 14 states, nearly 7,000 libraries, 200 museums, planetaria and science centers, 40 Challenger centers, and 20 national parks, zoos, and even baseball stadiums. More than 50 million unique viewers watched the TV broadcast across multiple NASA and social media platforms, and we had 90 million page views of the NASA website on eclipse day alone. These numbers exceed previous records by many times over.

I talked to many people after the eclipse, and it was really clear that not only professionals were deeply moved by it but amateurs alike. This is truly moving. That's what NASA science does for us every day.

Showing now our views of the solar eclipse from various NASA assets. Eleven of them were focused on this unique event as well as three aircrafts. In fact, when looking at the eclipse, I could not help myself, just like the Congressman, thinking of the Parker Solar Probe launching next year, which will travel closer to the sun than any time we've been there before, really making these unique observations of the extended corona and revolutionizing our understanding of the sun, which is really the Rosetta Stone of understanding of all stars in the universe.

Additionally, NASA solicited experiments to take advantage of the unique opportunities provided by the eclipse to do science. Eleven grantees were selected, three of which are studying the ionosphere, measuring how the sun's energy affects this reach in this region of the outer atmosphere. ICON and GOLD will continue to improve after the launching later on our understanding and capability for what is happening to that region and the edge of space.

We also want to stress citizen science, and I'm going to let Matt talk about this. It's really valuable to have science done, valuable science done by citizens, not just professionals, and there's true value with this, not just here but elsewhere.

With safety a top priority, we published protocols on our websites and partnered with the American Astronomical Society, NSF, and others to spread the world about eye safety. This provided critical—proved critical when it was discovered that uncertified solar glasses were making it into the markets. We owe a debt of gratitude to our partners that helped us identify and communicate which glasses were safe, and in the end, NASA, Google and the Moore Foundation distributed over 4.3 million glasses.

In closing, let me talk about heliophysics, or solar and space physics, as others referred to it, that really protects and improve life on Earth. This total solar eclipse provided a unique opportunity of seeing the source of space weather with our naked eye, the atmosphere of our magnetic star. This corona impacts the Earth through the solar wind explosions on the sun, flares and energetic particles affecting our space assets and our technological infrastructure, and so we want to really make these improvements better for operational use for NOAA and the DOD.

So I too suggest that we start making plans for the next solar eclipse in the United States on April 8, 2024. It's going to be another great opportunity for all of us to learn about the solar system we live in, and I really suggest you get started with these hotel reservations. They got really expensive for those who were latecomers.

Thank you so much.

[The prepared statement of Dr. Zurbuchen follows:]

Statement before the House Science Committee's Subcommittees on Research & Technology, and Space
Thomas H. Zurbuchen
NASA Science Associate Administrator
September 28, 2017

Members of the Subcommittees:

I am honored to appear before you to share both NASA's experience and also my personal experience related to the recent 2017 Total Solar Eclipse. As NASA's Associate Administrator for the Science Mission Directorate (SMD), I represent the thousands of volunteers, partners, grantees, and NASA employees who made this the biggest media event in the modern history of NASA.

I would also like to highlight some of the results of our STEM Activation efforts, and discuss how important Heliophysics is to NASA's overall mission.

On Monday, August 21, 2017, a total solar eclipse across the continental United States occurred for the first time in almost a century. My vantage point was unique in that I was fortunate to welcome the shadow from 45,000 feet over the Pacific Ocean in an aircraft specially outfitted with scientific instruments to capture views before, during, and after the event. After doing research on the Sun for well over 25 years, I saw the solar atmosphere – the corona for the first time: it was breathtaking. NASA had many other vantage points to observe this cosmic event, from space, from high altitude balloons, from airplanes and from the ground.

We look at the Sun everyday using NASA's Heliophysics System Observatory, with 18 active missions comprised of 28 spacecraft. However, nothing can compare to the awe-inspiring experience of witnessing a total solar eclipse for the first time.

I have devoted many years to studying the Sun and its corona, but through the lens of telescopes and NASA's missions like the Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) probe, Advanced Composition Explorer (ACE), and Solar and Heliospheric Observatory (SOHO). Seeing the spectrum change as the Moon transited the Sun, creating a natural coronagraph, uncovering the inner corona -- the part of the Sun's inner atmosphere that we can only see during total eclipses. When looking at the Sun, I was reminded that the Parker Solar Probe, launching next year, will travel closer to the Sun than any spacecraft, and will dive into the corona to provide the closest-ever observations,

and will revolutionize our understanding of the Sun, our Rosetta Stone for the understanding of stars throughout the Universe.

So how did we successfully engage the Nation's citizens to witness this event, to pause their busy lives, and observe this celestial wonder?

Our NASA team and scientists around the country have been planning for this eclipse for many years. Also supporting this hearing is Dr. Alex Young, our Project Manager. Three years ago, NASA established the priorities for our program as: Safety, Science, Education, Citizen Science, and Public Engagement. To accomplish these priorities, we knew we could not do it alone. Internal to NASA, there was recognition that this was an opportunity to widely engage and disseminate information on our missions and activities. The entire Agency rallied and each of our 10 Centers led major functions and events.

Additionally, last year, the Heliophysics Division solicited experiments to take advantage of the unique opportunities provided by the eclipse to do science. Eleven grantees were selected, three of which are studying the ionosphere – measuring how the Sun's energy effects this region of the Earth's outer atmosphere. Ultimately, these data will improve models and our understanding of the ionosphere and help us understand the relative importance of various inputs of the Solar radiation. Measurements collected through upcoming missions Ionospheric Connection (ICON) and Global-scale Observations of the Limb and Disk (GOLD) will continue to improve our understanding and predictive capabilities for what is happening in this atmospheric region at the edge of space that affects us all.

Safety

Consistent with NASA's number one core value, from the beginning, we required every event or activity to include a Safety Plan. This became increasingly important as more and more locations were contacting NASA for materials and experts to engage with their guests. On the day of the eclipse, there were 120 officially designated events, and I believe by getting the message out early, NASA helped communities to plan out transportation routes, provide community services, and to really think through what it would take to accommodate the anticipated influx of visitors to their communities – up to ten times the normal rates! In addition to NASA, there were almost 400 volunteer experts through our Solar System Ambassador network deployed all with a safety focus.

With Safety a top priority, we published protocols on our website and partnered with the American Astronomical Society, National Science Foundation, and others,

to spread the word about eye safety. This partnering proved critical when it was discovered that uncertified solar glasses were making their way into our markets. We all owe a debt of gratitude to our partners for helping us identify and communicate which glasses were safe. In the end, NASA, Google, and the Moore Foundation distributed over 4.3 million glasses.

Public Engagement

The eclipse was the biggest science outreach event in modern NASA history. Working with our partners, we engaged with citizens across 14 states, in 6,900 libraries, over 200 museums, planetaria and science centers, 40 Challenger Centers, NASA Visitor Centers, 20 national parks, zoos, and even baseball stadiums. More than 50 million unique viewers watched our TV broadcasts across multiple NASA and social media platforms. We had 90 million page views on NASA websites on eclipse day. These numbers exceed previous records many times over, including some pretty major events like landing on Mars and flying past Pluto. I talked to many strangers and friends after the eclipse – the experience touched them whether or not they are scientific experts! That is what nature does – we just have to take time to watch! It is these kinds of moments that help us relate and learn about nature in life-changing ways. That is what NASA Science does each and every day.

Citizen Science

My sincere hope is this eclipse inspires our fellow Americans to become new citizen scientists. For the eclipse, Dr. Matt Penn of the National Science Foundation's National Solar Observatory led the Citizen CATE effort, with 68 teams of citizen scientists, high schoolers, and universities to take the exact same observations using the exact same solar telescopes across the "path of totality." Of the 68 teams, 60 captured the inner corona and polar plumes. The Citizen CATE effort itself was a very successful partnership effort with the National Science Foundation and several corporate sponsors. NASA's role in the Citizen CATE effort was providing support for pre-eclipse training.

In addition, the Global Learning and Observations to benefit the Environment (GLOBE) program created a mobile device application that anyone could download to measure temperature and light changes. Over 107,000 measurements were taken on that day.

Science and Societal Impact

A total solar eclipse provides the unique opportunity of seeing the Sun's gases – called solar wind - streaming from the Sun with your naked eye. This solar wind is the very origin of space weather. We used this event to test our models of space weather, so we can continually improve them.

NASA has the unique capability to monitor the Sun from more than a dozen different locations throughout the solar system and beyond. We work with the National Science Foundation on expanding our scientific understanding of the Sun and space weather, and working together, we help the operational space weather arms of NOAA and DoD, to incorporate that understanding into operational models and space weather predictions that better prepare us for potential impacts on Earth, such as power outages or interruptions of communications.

I am excited about the contributions of upcoming missions, and especially those Parker Solar Probe will make, toward improving our understanding of this challenging phenomena. Better understanding space weather will help protect our electrical grid on the Earth, airline passengers in the air, and astronauts and spacecraft in deep space – providing national security and economic benefits for all. Research continues to develop and improve predictive models through enhanced understanding of the science of space weather; and NASA is at the forefront of that research.

Summary

My hope is that this eclipse creates a new appreciation for and relationship with our nearest star that allows us to learn more about nature. Learning about nature is not only inspiring, it is eminently useful in our daily lives. Our investments in space science/Heliophysics will pay dividends for generations to come. They will result in improved forecasts that affect our lives on all time-scales, they are at the heart of new companies, and they support our economic and national security.

My only suggestion: Start making plans for the next total solar eclipse in the US on April 8, 2024. It is going to be another great opportunity for all of us to learn more about the solar system we live in.

Thank you for the invitation to be here with you today.



Dr. Thomas Zurbuchen is the Associate Administrator for the Science Mission Directorate at the Agency's Headquarters in Washington, D.C.

Previously, Zurbuchen was a professor of space science and aerospace engineering at the University of Michigan in Ann Arbor. He was also was the university's founding director of the Center for Entrepreneurship in the College of Engineering. Zurbuchen's experience includes research in solar and heliospheric physics, experimental space research, space systems, and innovation and entrepreneurship.

During his career, Zurbuchen has authored or coauthored more than 200 articles in refereed journals on solar and heliospheric phenomena. He has been involved with several NASA science missions -- Ulysses, the MESSENGER spacecraft to Mercury, and the Advanced Composition Explorer (ACE). He also has been part of two National Academy standing committees, as well as various science and technology definition teams for new NASA missions.

Zurbuchen earned his Ph.D. in physics and master of science degree in physics from the University of Bern in Switzerland.

His honors include receiving the National Science and Technology Council Presidential Early Career for Scientists and Engineers (PECASE) Award in 2004, a NASA Group Achievement Award for the agency's Ulysses mission in 2006, and the Swiss National Science Foundation's Young Researcher Award in 1996-1997.

Chairwoman COMSTOCK. Thank you, and I now recognize Dr. Hammel.

TESTIMONY OF DR. HEIDI HAMMEL,
EXECUTIVE VICE PRESIDENT,
ASSOCIATION OF UNIVERSITIES
FOR RESEARCH IN ASTRONOMY

Dr. HAMMEL. Madam Chair and Members, thank you for the opportunity to testify about the total solar eclipse.

On August 21, 2017, millions of Americans including me witnessed the total solar eclipse, watching in wonder as our star disappeared from the sky. At the same time, scientists scrambled to collect as much data as possible about the sun's faint corona.

The sun's corona is the source of solar storms. The term "space weather" refers to the effects of these storms on the Earth and other planets in our solar system. We live inside the atmosphere of an active star.

In 1859, a monster solar storm, the Carrington Event, stunned the world. Telegraphic systems worldwide went haywire, emitting sparks that not only shocked the telegraph operators but actually set telegraph paper on fire. It's sobering to imagine the catastrophic social and economic disruption of a Carrington-like storm on today's infrastructure including GPS satellites, electricity grids, and communications satellites, and that is why understanding the sun and space weather are critical national imperatives.

Eclipses offer one of the best opportunities to study the sun's active corona but eclipses are rare. To study the corona without an eclipse, the National Solar Observatory, or NSO, is building the Daniel K. Inouye Solar Telescope, DKIST, for the NSF. When completed in 2020, DKIST will be the world's most powerful solar telescope. Its 4-meter mirror will yield exquisite spectropolarimetric observations of the sun's corona and magnetic field.

But let me return to the 2017 total solar eclipse because it too was a unique opportunity to advance solar science and public engagement. NSO began preparing more than five years ago, focusing their efforts on science and safety. Claire Raftery, who is here with us today, and her team developed a social media campaign with a variety of content including monthly webcasts that focused both on science and on educational engagement, and on eclipse day, NSO participated in two major solar outreach events. The first, that you heard about, was in Glendo, Wyoming. It culminated years of effort to prepare this tiny community of 200 people for this event, and the local sheriff's office estimated that 180,000 people descended on tiny Glendo, Wyoming, including, as you saw, the Director of NSF, Dr. France Cordova. The second event, in Salem, Oregon, focused on high school students. NSO, in partnership with other groups, trained a dozen students, all of whom are minorities that are under-represented in the STEM fields, to be ambassadors for science, and on eclipse day, the students led the programs for the community.

Looking to the future, as you heard, another total solar eclipse will sweep the country from Texas to Maine, and we are already preparing. We plan to engage with students in under-represented demographic groups well in advance of the 2024 eclipse to prepare

a new set of students to be community leaders and science ambassadors.

And finally, my colleague here, Matt Penn, developed an ambitious eclipse program to combine public engagement with science, and I'd like to share a video about several young people in Dr. Penn's Citizen CATE program.

[Video playback]

This eclipse changed their lives, and their citizen CATE observations may improve our lives. These young people helped us gather the largest volume of science quality eclipse data ever recorded, and I will now turn the microphone over to Dr. Penn to describe his program.

On behalf of AURA and NSO, I appreciate your attention, and I'd be happy to answer any questions. Thank you.

[The prepared statement of Dr. Hammel follows:]

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Heidi B. Hammel

Executive Vice President

Association of Universities for Research in Astronomy

Joint Subcommittee on Research and Technology and Subcommittee on Space Hearing - The Great American Eclipse: To Totality and Beyond

September 28, 2017

Sincere thanks to the Chair and Members of the Subcommittees, for the opportunity to share our experiences with the 2017 Great American Total Solar Eclipse.

My name is Heidi Hammel, and I am the Executive Vice President of AURA. AURA is the "Association of Universities for Research in Astronomy." We are a consortium of 44 US institutions and 5 international affiliates that operates world-class astronomical observatories, including the National Solar Observatory, which AURA runs on behalf of the National Science Foundation. I am a planetary astronomer with degrees from MIT and the University of Hawaii, and I am a card-carrying "Hubble Hugger" because of my years using the Hubble Space Telescope. And, I have personally experienced three total solar eclipses.

August 21, 2017 was an exceptional day across the United States. On that day, millions of Americans, including me, witnessed a total solar eclipse, an event that has intrigued humans since the dawn of recorded history.

From a mountaintop in Idaho, I watched the sky darken, I felt the air cool, and I saw flocks of birds swarm as they sensed the environmental changes. I, and the other Americans in the path of totality, felt a deep emotional response as our life-giving star disappeared from the sky.

At that same moment, my fellow scientists were scrambling to collect as much data as possible in the fleetingly short window of time that the Sun was entirely blocked by the Moon. This was our ephemeral opportunity to study a faint outer zone of the Sun called the "corona," which usually hidden by the Sun's brighter surface. This zone holds a key to understanding our local star, the Sun.

The Sun is our major source of light, warmth and energy on Earth. Yet the Sun, sometimes, can be dangerous. Driven by magnetic fields and million-degree plasmas, the Sun is in a state of constant dynamism. Flows, bursts, flares, eruptions, and ejections are the norm, with some solar phenomena reaching through space to impact the Earth. Just this month we observed the

eighth largest solar flare in a decade (it was the eighth largest in half a century). This event had the potential to trigger large-scale geomagnetic effects, not just lovely aurorae, but far more concerning power-grid fluctuations and communications disruptions.

Our exploration of the Sun began centuries ago, long before the technological revolution of the modern age. The unique alignment of the Sun, Earth, and Moon during a total solar eclipse was studied by the ancient Chinese, Greeks, and Babylonians. Today, that same alignment presents an opportunity to conduct science experiments like no other. Under normal circumstances, the sun's bright surface overwhelms all other light being emitted in the vicinity of the Sun. During a total solar eclipse, the Moon completely blocks out all of this surface light, allowing fainter objects to be analyzed.

Scientific experiments conducted during past eclipses have resulted in amazing discoveries. The element Helium was first discovered during a total solar eclipse in 1868 – that was just 150 years ago (our great-grandparent's time). Helium was detected by splitting the Sun's light during the solar eclipse into its component parts, much like a prism spreads sunlight into a rainbow. Elements and molecules absorb specific colors of light, leaving a fingerprint in the rainbow that reveals the element's presence. This technique, known as spectroscopy, is regularly used by astronomers today to reveal the extreme temperature of the solar atmosphere to the composition of objects ranging from our nearest Solar System neighbors to the most distant galaxies in the Universe.

Coronium, an element so unusual that scientists believed it could only be found in the Sun's corona, was discovered in a similar fashion the following year. Coronium is actually a form of iron with half of its electrons stripped off, which can only happen when it is exposed to temperatures of a million degrees or more. This discovery led astronomers to realize that parts of the Sun's atmosphere are significantly (ridiculously!) hotter than its surface. This counterintuitive observation continues to perplex the solar physics community today.

In fact, the very existence of the solar corona—the mystical, ethereal white glow that appeared around the Sun during totality on August 21st—is puzzling. Although we know that it exists (many of us have just seen it with our own eyes!), we are not sure *why* it exists. In order to better understand this mysterious solar structure, AURA and the National Solar Observatory are building the Daniel K. Inouye Solar Telescope, or DKIST, for the United States' National Science Foundation (NSF). When DKIST is completed in 2020, it will provide us with continuous high-spatial resolution observations of the solar corona with sophisticated instrumentation.

Equipped with a 4-meter mirror, and more than 2 and a half times larger than the world's current largest solar telescope, DKIST will be the most powerful solar telescope in the world. Currently under construction on Haleakala in Maui Hawaii, it will provide us the opportunity to investigate the Sun's magnetic field at exquisitely high resolution. Two of the five facility

instruments are especially designed to closely replicate a solar eclipse by blocking out surface light from the Sun, enabling us to view and analyze the solar corona in greater detail than ever before. When we combine the light-collecting power of the DKIST, with the support and intellectual talent at NSO's headquarters, located on the University of Colorado Boulder's campus, we will usher in a new age of solar physics discovery.

Given our dependence today on technology, GPS, satellite communication, and readily available and stable electricity grids, our understanding our Sun and its magnetic eruptions is thus essential. The Sun is the source of earth-effects known as space weather. A major space weather event, such as the so-called "Carrington Event", could cause catastrophic social and economic disruption if it were to happen today. That event stunned the world. As NASA describes the consequences: telegraph systems worldwide went haywire; spark discharges shocked telegraph operators and set telegraph paper on fire; and even when telegraphers disconnected the batteries powering the lines, aurora-induced electric currents still flowed in the wires. (https://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare).

In order to be best prepared for these hugely impactful events it is essential to effectively predict them, however we must first understand why they occur. DKIST will explore the magnetic fields that are at the root of solar flares and coronal mass ejections. Its cutting-edge optical design, advanced instrumentation, and world-class scientists and engineers combine into a state-of-the-art system that will help us understand what drives the Sun's dynamic behavior.

But let me return to the 2017 total solar eclipse, because it too provided a unique opportunity to advance solar science and, just as importantly, yielded an opportunity for science engagement with our country's citizens.

The 2017 eclipse path cut right across the continental United States, meaning that this eclipse was an opportunity for millions of Americans to directly participate in scientific discovery. Through the efforts of NSF, NASA, NSO, and many other groups, millions of citizens were engaged, and more importantly, educated about the Sun and its effects as they witnessed the grandeur and spectacle that is a total solar eclipse. Many American children will remember this eclipse for the rest of their lives. For many of them, their experience will inspire them to become involved in science, engineering, technology, and math (STEM) fields.

Those of you who were fortunate to witness the eclipse for yourself will know that no photograph or video can ever do it justice. The difference between a total solar eclipse and a partial one is literally the difference between night and day. The sky becomes dark, but not completely night-like: it is more like the weird twilight of a moon-lit but moon-less night, with silvery light diffused all around. You see the stars and planets in the middle of the day and 360

degrees of sunset in every direction. The temperature plummets, sending shivers down your spine and making goosebumps on your arms. As the temperature drops, air pressure changes, causing sound to change. The wild life – both flora and fauna – react to these environmental cues changes, and sometimes react strangely – birds take flight, some start vocalizing as if it were sunrise.

And, perhaps most surprising to me, even my teenagers are impressed by this event. Two of my children (ages 16 and 20) were only grudgingly accepting of the "honor" to join me in Idaho to see this. Pre-eclipse, I heard: "Oh maaahhmmm, not another one of your spaaaace things" more than once (accompanied by eyerolls as only a teenager can do). But afterwards, this changed to: "Wow. That was really interesting!" From my teenagers, that is high praise indeed.

My organization, AURA, through the National Solar Observatory, began preparing for the 2017 eclipse more than five years ago. As a federal facility dedicated exclusively to solar research, the National Solar Observatory brought a unique and detailed understanding to outreach about the eclipse. For the National Solar Observatory, our goal was to leverage this teachable moment, to make sure that as many people as possible understood -- as well as witnessed -- this great event, and did so safely.

The Observatory's Outreach and Communications head, Claire Raftery, and her team developed a social media campaign, online content, and a monthly webcast to focus on science and safety. We hoped that everyone along the path of totality who looked at the sky on August 21st would see the Sun's corona. Thus, we disseminated information about the corona, what gives it its structure, what it represents, and how it might have been formed. Following the lead of the American Astronomical Society, who had an NSF-funded eclipse task force, NSO created infographics about how to safely view the eclipse, and distributed them on Facebook, Instagram and Twitter.

Each month, the National Solar Observatory released a webcast covering an overview of one aspect of solar science related to the eclipse, followed by a demonstration of an activity that could be used in a classroom, informal setting, or on the day of the eclipse itself. Each webcast ended with a presentation from a solar science expert. As the eclipse approached, these became increasingly popular and were shared extensively via social media. All are available here: https://www.youtube.com/watch?v=5Yz-ZWmsC6g&list=PLo2YDpGbMTNBK4zzk-EKPdtYmPMADxtOM.

On the day of the eclipse, the National Solar Observatory ran two major public outreach events.

The first was in Glendo, Wyoming, the closest point of totality to the Denver metro area. The Glendo total solar eclipse event culminated five years of effort to prepare this tiny community of 200 for the thousands expected for the eclipse. In the end, the Platte County Sheriff's office

estimated 185,000 people viewed the eclipse from Glendo! This included the NSF Director, Dr. France Cordova, who attended the Glendo event as a private citizen and enjoyed clear skies and excellent viewing.

A part of the National Solar Observatory's emphasis on safety, every car entering Glendo State Park received a Solar Safety visor hangars, and we organized numerous "pop-up" style solar viewing safety seminars to explain how visitors should safeguard their eyes. Current and retired Emeritus NSO staff brought solar science to the public by giving talks throughout the eclipse weekend.

Media reports attributing the NSO's efforts to support Glendo appeared in many outlets and media formats, including on ABC News, Nightline, the *Washington Post*, the China Global Television Network (CGTN), KTWO-TV (the ABC Casper, WY affiliate), KCWY-TV (the NBC Casper, WY affiliate), *Air and Space Magazine*, the American Geophysical Union's "EOS" magazine, FiveThirtyEight, a digital publication of Nielsen Digital media and *Sky and Telescope* magazine. Additionally, approximately 54,000 "hits" were recorded on the 2017 Glendo Total Solar Eclipse website built and managed by former Observatory employee Jackie Diehl, who assisted the Town of Glendo in raising about $25,000 for expenses related to the eclipse.

The second event was in Salem, Oregon, the first major urban center along the path of totality. The National Solar Observatory, in partnership with the American Astronomical Society's Solar Physics Division, worked with a local high school group to provide science-related activities for children and families in Salem on eclipse day. The high-school students, all of whom are minority and underrepresented in STEM fields, had attended a training session led by staff from the National Solar Observatory. On the day of the eclipse, the students led a dozen different eclipse-related activities, supported by solar experts including the Director of the National Solar Observatory, Dr. Valentin Pillet.

Daniel and Crystal, two first generation Hispanic students who participated in the NSO program in Salem, Oregon, told their stories in an NPR interview (start at 51 minutes) :http://www.opb.org/radio/programs/thinkoutloud/segment/special-coverage-the-great-american-eclipse/] For them, and the other students in the program, this event was truly transformative and opened their eyes to the possibility of a career in STEM. Crystal explained what the event meant to her, "This is absolutely fascinating, I love anything that has to do with science, so to be here and to participate in this is a huge deal for me." She continued, "it's like a little sizzle, like when you are lighting a fire, that's me right now, a hunger for knowledge and to learn more."

Although the 2017 solar eclipse spanning the country was a rare opportunity to engage millions of people, it is *not* a once in a lifetime opportunity. It is not even once-in-a-decade opportunity! We in the United States are incredibly fortunate, because this extremely rare alignment of the

Sun, Moon, and Earth will cross our country again in just seven years! In 2024, another total solar eclipse will sweep north to south across the nation, this time from Texas up to Maine.

At AURA and NSO, we are already processing the lessons learned from our 2017 experience in order to prepare for 2024. The 2024 eclipse takes place in April when most schools are in session. A key focus for us will be to make sure teachers are prepared, educated, and excited. Advance preparation will include assistance to teachers to build the eclipse into their curriculum, and to ensure they are prepared to be outside on the day of the eclipse.

Engaging with more students well in advance of the eclipse day in 2024 will prepare those students to be community leaders for science. Also, outreach to parents and families can provide support for students who may not have the support in pursuing a science career, especially in underrepresented communities where science research may not be seen as a valuable career choice.

I have mostly been describing public engagement activities, but my colleagues at the National Solar Observatory, led by Dr. Matt Penn, developed an ambitious citizen science project. With the help of hundreds of civilian and non-expert volunteers, Dr. Penn's "Citizen CATE" project gathered the largest volume of science-quality eclipse data ever recorded. I will now turn the microphone over to Dr. Penn, to tell us about this incredibly successful endeavor.

Thank you for your support, and that of the Subcommittees. On behalf of the National Solar Observatory and AURA, I appreciate your time and attention. I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.

Brief Narrative Biography: Heidi B. Hammel

Dr. Heidi B. Hammel received her undergraduate degree from MIT in 1982 and her Ph.D. in physics and astronomy from the University of Hawaii in 1988. After a post-doctoral position at the Jet Propulsion Laboratory, she returned to MIT, where she spent nearly nine years as a Principal Research Scientist. She then worked as a Senior Research Scientist and co-Director of Research at the Space Science Institute until 2011.

Dr. Hammel is now the Executive Vice President of the Association of Universities for Research in Astronomy (AURA). AURA -- a consortium of 44 U.S. universities and institutions, as well as five international affiliates -- operates world-class astronomical observatories including Hubble, the National Optical Astronomy Observatory, the National Solar Observatory, and the Gemini Observatory. AURA is also building the Daniel K. Inouye Solar Telescope on Maui, and the Large Synoptic Survey Telescope in Chile.

Dr. Hammel primarily studies planets. Her current research involves studies of Uranus and Neptune with Hubble, the Keck 10-m telescope, and other Earth-based observatories. In 1994 when comet Shoemaker-Levy 9 crashed into Jupiter, Dr. Hammel was the leader of the Hubble Space Telescope team that analyzed images of the event. She was also a member of the team that first spotted Neptune's Great Dark Spot with the Voyager 2 spacecraft, and led the Hubble team that later documented that Great Dark Spot's disappearance. Since 2003, she has served as one of six Interdisciplinary Scientists advising NASA on the science development of the James Webb Space Telescope, the space observatory that will succeed Hubble.

Dr. Hammel has been widely recognized for her science. She was profiled by the New York Times in 2008[1], Newsweek Magazine in 2007[2], and was identified as one of the 50 most important women in science by Discover Magazine in 2002[3]. She was elected a Fellow of the American Association for the Advancement of Science in 2000. In 1996, she received the Urey Prize from the American Astronomical Society's Division for Planetary Sciences.

Dr. Hammel has also been lauded for her work in public outreach, including the 2002 Sagan Medal for outstanding communication by an active planetary scientist to the general public, the 1996 "Spirit of American Women" National Award for encouraging young women to follow non-traditional career paths, and the San Francisco Exploratorium's 1998 Public Understanding of Science Award. Asteroid "1981 EC20" has been renamed *3530 Hammel* in her honor.



[1] http://www.nytimes.com/2008/09/02/science/02conv.html
[2] http://www.newsweek.com/id/70975
[3] http://discovermagazine.com/2002/nov/feat50

Chairwoman COMSTOCK. Thank you.
I now recognize Dr. Penn.

TESTIMONY OF DR. MATTHEW PENN,
ASTRONOMER, NATIONAL SOLAR OBSERVATORY

Dr. PENN. Madam Chair and Members of the Subcommittees, thank you for the invitation to speak to you about the Citizen CATE experiment.

While Reva Dusette was crying tears of joy in Wyoming, Jack Erickson and his students from Cienega High School in Vail, Arizona, were close to tears but for a completely different reason. If I could have my first slide?

[Slide]

It was raining at their city in Pawnee City, Nebraska. Jack and his students were really eager to collect data. They had practiced for months, and along the way they had spoken with many newspaper and radio and TV reporters about the program. This media coverage followed many of our CATE teams across the Nation. Local TV affiliates would find their CATE students from our 27 university and 22 high school partners and do stories on them, and these students would get recognized not for scoring a touchdown in a football game but for doing a STEM project and observing the sun.

My colleagues at NASA do an excellent job of observing the solar corona, but even their advanced instrumentation has a gap in our understanding. If I could have the next slide?

[Slide]

A total solar eclipse opens up a window that allows us to study the inner corona, and the Citizen CATE experiment was designed to take advantage of that opportunity. You can see in the flashing rectangle the Citizen CATE data fills the gap that we currently have in our understanding of the corona.

Specifically, we're designed—we're trying to measure the solar wind above the north and the south poles of the sun as it moves through thin magnetic structures that we call polar plumes. Now, just like sitting across the table from your daughter and watching her drink a milkshake through a transparent straw, you can measure the velocity of the milkshake by tracking features. We can use the CATE data to track features in the fast solar wind and measure the velocity of the solar wind that way.

But unlike a milkshake, the fast solar wind has important implications for space weather, and therefore it's really critical that we understand it. So on the day of the eclipse, the CATE teams had enormous success. Sixty-two of our 68 sites collected images of the corona, and today I'm happy to be joined by Miles McKay from the Space Telescope Science Institute. On the day of the eclipse, Miles returned to his alma mater at South Carolina State University and took data on the 50-yard line with a CATE instrument in a stadium filled with 5,000 cheering fans.

[Slide]

We can see in the third slide that the skies cleared for Jack Erickson and his team. They were able to capture imagines with their telescope. On the left you can see the corona that's been filtered slightly to show you as—to show it as you might see with

your eye, and then on the right we see a more highly enhanced version of that image that brings out details that you can't see with your eye. Each of the CATE images shows the solar atmosphere across a region that's more than a million miles across on each side, and so from any one location where you just have two minutes to view the corona, you don't see a lot of changes during that short period of time, but the CATE data set when it's combined allows us to see changes across 93 minutes of time.

[Slide]

So on the next slide, I've put together a very rough-cut movie of the CATE data set. We collected over 45,000 imagines of the corona on that day but in the 4 weeks, I've only been able to process about 300 of them to show you here today. If you imagine that the moon is a clock face, at about the seven o'clock position, you can see a system of outflows moving away from the sun. These are traveling at about 20,000 miles per hour. It's pretty slow for the solar wind. And then if you look closely at five o'clock, you can see a quicker outflow. This is, we think, a signature of the fast solar wind in the south pole of the sun, and that's traveling at something like 200,000 miles per hour, or perhaps faster. So even with just one percent of the CATE data analyzed so far, we're getting a new view of the solar corona that we haven't seen before. A lot of science will follow.

I'd like to close by saying that a total solar eclipse is both an uplifting and a humbling experience at the same time. It's uplifting because it teaches us that we're smart enough to predict when these will occur.

[Slide]

In my next slide, we can see, as my colleagues have mentioned, that the next eclipse visible across the country, across the United States, will occur on April 8, 2024, but if we go further and try to figure out when is the next solar eclipse, total solar eclipse, visible from Dallas, Texas, we can predict that it will occur at 1:57 p.m. on Saturday, June 30th in the year 2345. So mark your calendars, please.

A total solar eclipse is also a humbling experience because it teaches us that we have no control over the huge planetary bodies that cause eclipses. It reminds us that we're just little people sitting on a big rock watching the show, and it doesn't matter what your nationality is or what your age or your gender, a total solar eclipse is a really moving and human experience.

So I'm looking forward to enjoying the next experience—experiencing the next eclipse with all of you in April of 2024, and I'm looking forward to answering any questions that you might have as well.

[The prepared statement of Dr. Penn follows:]

Chairwoman COMSTOCK. And now we'll hear from Ms. Nichols-Yehling.

Testimony for the House Committee on Science, Space and Technology,
Subcommittee on Research and Technology and Subcommittee on Space

Matt Penn, Astronomer, National Solar Observatory / AURA

28 Sep 2017

Mr. Chairman and Members of the Subcommittees, thank-you for the invitation to testify about the Citizen CATE Experiment.

Mr. Jack Erickson, the astronomy teacher at Cienega High School, and his team of students were frustrated and close to tears. They had trained with their Citizen CATE Experiment telescope over and over for 6 weeks: they practiced the telescope set up and alignment, they took calibration data, and they simulated observing the solar corona during totality. The board of the Vail Unified School District supported Jack and his group with funding, enabling 11 students and two chaperones to travel from Tucson, Arizona to the total eclipse. But only one hour before totality, his students were huddled over their telescope protecting it from the rain as a thunderstorm drenched them at the public library in the little town of Pawnee City, Nebraska.

In 2012, a white paper by Hudson et al. pointed out that the August 21 2017 total solar eclipse would present a remarkable opportunity. These authors discussed the fact that tens of millions of Americans lived in the path of totality, that tens of millions more were likely to travel to the path, and that the infrastructure available along the path of totality made access very easy at nearly any location. This was indeed an unusual circumstance, since most total eclipses pass over the ocean or through remote places on the globe. The accessibility to the path of totality, from which one can view the corona (the hot atmosphere of the Sun) offered unique scientific opportunities, as the shadow of the moon traveled for 93 minutes from Oregon to South Carolina.

It is from these initial ideas that the Citizen Continental-America Telescopic Eclipse experiment, or the Citizen CATE Experiment for short, developed. While some citizen science programs like the Megamovie project proposed using a variety of equipment to observe the eclipse (equipment that the volunteers already owned), my understanding of the Global Oscillations Network Group (GONG) project at the National Solar Observatory convinced me that CATE should use identical equipment to collect data across the path of totality. The GONG network combines data from six identical telescopes around the world, and this is a difficult task. Combining data from 60 identical telescopes across the continent would be even more challenging, and perhaps at the limit of what could be done to produce research-quality data.

The Citizen CATE Experiment planned to place about 60 identical telescopes in the path of totality. At any one location in the path, one telescope could image the solar corona for about two minutes; but this isn't enough time to measure changes in the

gas in the solar atmosphere. But if a network of telescopes were positioned in the path so that the shadow of the moon covered one telescope before it uncovered the previous telescope, then continuous observations of the corona could be made for the entire 93-minute duration of the event. This continent-wide network of telescopes could then measure changes in the inner solar corona never seen before.

I wanted CATE to be different from past eclipse experiments: I didn't want to collect all of the CATE equipment after the eclipse and store it in a warehouse. I wanted to make sure that the universities, high schools, and even the individuals involved in the project kept their equipment after the eclipse. After getting excited by the eclipse, I wanted our volunteers to be empowered to continue to engage in citizen science projects in astronomy.

This introduced some complexity into raising funds for CATE. In the end, nearly 75% of the equipment funds were raised from private or corporate sources. Our main corporate sponsors, Daystar Filters, Mathworks, Celestron and colorMaker donated equipment, cash and time to make the CATE experiment a success. Jen Winters from Daystar donated 60 free telescopes to CATE. Mathworks donated cash, software, and several enthusiastic volunteers who wrote new software and helped with hardware. Cory Lee from Celestron donated 60 telescope mounts to CATE. But my favorite story is that Stephen Lauro, the CEO of colorMaker donated funds to support five CATE sites. colorMaker manufactures food-dye in Anaheim, California; but Lauro is an avid amateur astronomer, and wanted to help teams observe the eclipse hundreds of miles from Anaheim. This gives you a small glimpse of the economic impact of the events surrounding the eclipse.

Could we train citizen scientists to operate the CATE telescopes under the unforgiving deadline imposed by a solar eclipse? Our first attempt was made by Dr. Fred Isberner, a retired faculty member from Southern Illinois University Carbondale. In 2015 Isberner traveled on vacation to the Faroe Islands in the northern Atlantic. We shipped a prototype telescope to his hotel, and he set it up in the rain the in the parking lot on the morning of the eclipse. He collected 30 seconds of data as the clouds momentarily gave him a glimpse of the eclipse, and from his data we were able to measure the calibrated intensity of the solar corona. Fred proved that even under dire conditions, a citizen scientist could use the CATE equipment to collect science quality data.

The CATE plan was to take Isberner's experience and multiply it. With help from a 2-year grant from NASA, we sent a team of 8 faculty and students to the 2016 eclipse in Indonesia. My colleagues Mr. Robert Baer, Dr. Michael Pierce, Dr. Richard Gelderman and Dr. Don Walter traveled with their students Sarah Kovac, Logan Jensen, Honor Hare and Myles McKay to various locations in Indonesia. Fred Isberner and I trained these students in a workshop in Tucson and they traveled to the path of totality with their telescopes and collected data! Their work resulted in our first Citizen CATE Experiment publication.

Now with a team of experts who had on-the-job training at an eclipse, we developed a set of state coordinators across the United States who could identify sites for the 2017 event and the volunteers to work at those sites. In addition to my four colleagues who traveled to Indonesia, we recruited Mike Conley from Oregon, Lynn Powers from Montana, Dr. Mariana Lazarova from Nebraska, Joseph Wright and David Young from Missouri, and Dr. Mary Kidd and Dr. Jim Dickens from Tennessee. This team of CATE state coordinators refined the locations for our observing sites, and identified and interfaced with all of our CATE volunteers.

In early 2017 our group was still lacking funding for the equipment costs for the full CATE network. This is when the National Science Foundation stepped in and provided a grant for our university and high school partners, bringing our network from 28 sites to 58 sites. In addition, 10 groups and individuals across the country purchased CATE equipment by themselves, bringing the total number of sites to 68. On the day of the eclipse, we had about 270 volunteers including 117 students at our 68 sites, the list of names appears at the end of this testimony.

The CATE team now included volunteers from 27 universities, 22 high schools, 8 informal science education centers and 5 national research labs. They received their equipment and initial training in workshops held along the path of totality near the end of May, and then they practiced taking solar data with their equipment for several weeks during the summer. The CATE students who observed in Indonesia traveled to these workshops and discussed their experience with the 2017 volunteers.

Jack Erickson and his students practiced often, and were interviewed by local TV and radio stations, and by a group doing a show for the Discovery Channel. In small towns all across the path of totality, as the media became more aware of the eclipse, CATE high school teams were interviewed by their local TV stations and newspapers. These students became local heroes, not because they scored a touchdown in a football game, but because they were involved in a STEM program engaged in scientific research about the Sun. I'm extremely proud of all of these students and their teachers for the level of professionalism with which they represented themselves and the CATE project.

What exactly will be the scientific contribution of the CATE observations? The inner regions of the hot solar corona are difficult to observe. From the ground, we are currently limited to relatively small telescopes that view this region, and those telescopes have to contend with light scattered from the Earth's atmosphere into the telescope. From space, this region is seldom viewed because of the difficulty in blocking the Sun's surface within the size constraints that limit satellite instruments. The result is that the solar corona is poorly understood from near the solar surface up to about 2.5 solar radii. But a solar eclipse opens a brief window that allows us to study this region of the solar corona in detail.

The physical processes occurring in this region of the corona are mysterious. In parts of the inner corona above the north and south poles of the Sun, the solar wind is accelerated from nearly a standstill at the solar surface to over 200,000mph at the height of 2.5 solar radii. The best observations of the solar wind in these polar plumes so far is from Poletto in 2015; and in that work we see that the outflow speed can disagree by a factor of 10 or 100. With this uncertainty, very little can be said about how the speed changes with height. This lack of observational evidence means that we cannot evaluate the several models that describe the physics of the acceleration process and so we don't know which physical process is actually operating in the Sun's atmosphere.

It is important to understand the processes controlling the solar wind. The fast solar wind can cause space weather effects here at the Earth, and the same processes involved in the solar wind acceleration may interact with coronal mass ejections – solar storms that are the most destructive parts of space weather.

The CATE experiment was designed to measure the fast solar wind in the polar plumes. The telescope and camera were selected to resolve the polar plumes, and the data collection program was designed to provide the velocity sensitivity needed to observe the expected outflows. CATE data will provide a new view of the inner corona where these processes dominate and control the gas, and will produce the tightest constraints on current theories of the gas acceleration that have ever been made. Observations from the CATE experiment have the potential to revolutionize our understanding of the fast solar wind acceleration.

The new NSO Daniel K Inouye Solar Telescope (DKIST) facility coming on-line soon will directly measure the strength and direction of the magnetic field that sculpts the gas in the inner corona and directs the flow of the solar wind. The evolution of the magnetic field observed by DKIST will also provide clues about how the Sun produces coronal mass ejections and solar storms. DKIST may also directly observe the solar wind in smaller regions of the solar corona, and here the CATE data will instruct us about how best to make these measurements with DKIST.

As the rain continued to fall on the Cienega students, and as the clock counted down to the start of the eclipse, Jack Erickson began to wonder if they would be able to observe the eclipse from their site. But as the Moon's shadow cooled the Earth's atmosphere, cloud-cover reduced across the path of the eclipse. The rain stopped and the sky cleared. It was uncomfortably close to the eclipse time, but the Cienega students sped through their calibration tasks faster than they had ever been able to before. When the Moon completely blocked the solar surface, Jack and his students were ready and they successfully recorded images of the solar corona.

Across the path of totality, the CATE volunteers had amazingly good fortune. Data was collected from 62 sites, with only 6 sites being completely clouded out. More than 45,000 images of the solar corona are now compiled into the CATE data set,

and the associated 50,000 calibration images elevate the coronal images from pretty pictures to research quality science observations.

At this date I am just beginning to process the CATE science data, and I only have a "first cut" movie sequence made from about 300 images. In this sequence, we see changes of the coronal structures, including fast solar wind outflow in the polar regions of the Sun where our primary science interest lies. We are also seeing solar atmospheric gas change temperature and get ejected from the Sun in a process that we have never directly measured before.

I am thrilled to work with this data and build even more detailed movies; many scientific papers will come from our team's work. Another important aspect of the work is that high school science fair season is about to occur, and we are planning to develop a data set for our CATE high school teams to use as they produce their own science fair projects from the observations.

Apart from the scientific and educational impacts of the Citizen CATE experiment, CATE reached the general public in many different ways. Several of our sites acted as a nucleus for small towns to plan larger eclipse events: in Weiser Idaho, the CATE group at the Weiser High School spurred interest in the local community. The town of 5,000 residents estimates that it hosted 20,000 visitors on the day of the eclipse. The CATE experiment was set up on the 50 yard line in several stadiums along the path of totality, and the stadium was filled with people from the local community. At Southern Illinois University Carbondale (SIUC) it's estimated that 14,000 people filled the stadium during the eclipse. SIUC also estimates that the eclipse activities produced advertising and other economic gains totaling $8M. And finally through newspaper, radio, on-line and TV, the CATE team reached many people across the country: by appearing on the NASA-TV coverage, information about CATE and the solar corona was delivered to an estimated 600 million viewers.

The CATE team has learned many lessons to apply to the next eclipse in the USA, on 8 April 2024. We distributed nearly one hundred thousand eclipse glasses, but could have easily distributed three or five times that number. We engaged volunteers at 68 sites, but again could have easily supported three times that many. For the large crowds gathered at CATE locations, we could have enabled them to directly reach out to their local, state and federal government representatives to express their interest and enthusiasm for the eclipse events, thus closing the loop by providing feedback about their opinions regarding how these events were organized. With some effort and time, these and several other lessons that we learned can be applied to communities under the path of totality for the 2024 total solar eclipse. I am already getting emails from people interested in volunteering for a second Citizen CATE Experiment to be run seven years from now!

The Citizen CATE Experiment has achieved its eclipse goals: we have captured new research-quality science data, we have engaged hundreds of volunteers to observe the eclipse and impacted hundreds of millions of Americans with our media

presence, and we have enabled follow-up research programs by educating our volunteers about the use of their equipment and transferring ownership or making a long-term loan of the equipment to them. CATE now has a working group that will identify follow-up astronomy projects for the eclipse volunteers, so that they can use their equipment for additional citizen science programs and make even more contributions. The goal is to turn the excitement and enthusiasm that was engendered by the eclipse into long-term salience in astronomy and STEM. Sample projects include high-cadence observations of the Sun, long-term observations of comets, new measurements of linear polarization of bright objects, and stereoscopic measurements of asteroids, including near-Earth objects. The sky is literally the limit for these enthusiastic volunteers.

The Citizen CATE Experiment is just one small citizen science project. Our group had many inquiries for participation, many more requests than our $260k equipment funds could support. With more funding before the eclipse we could have easily staffed 200 CATE sites with volunteer observers. Across the country there is a very high level of interest in citizen science programs. Such programs provide incredible opportunities for young students to carve out science careers, and also to connect citizens to the latest research topics in all fields of science. Citizen science programs provide a natural pathway for strengthening education and STEM activities in the USA.

A total eclipse is both an uplifting and a humbling experience. It's uplifting because it reaffirms that we're smart enough to use science to predict exactly when these will occur. We know that the next total eclipse visible in Dallas TX on Monday 8 April 2024, and that the next total eclipse after that will begin at exactly 1:57:04pm on Saturday 30 June 2345. But even though we can precisely predict eclipses for hundreds of years into the future, we cannot change the orbits of the huge planetary bodies that are involved. We have no control over eclipses; they remind us that we are little people sitting on a big rock, and all we can do is to enjoy the view. It doesn't matter what nationality, ethnicity, gender, or age you are: watching an eclipse is a moving and unique human experience. I'm looking forward to sharing that experience with all of you in April of 2024.

Listing of 21 Aug 2017 CATE sites and volunteers

CATE-000, CATE-000b (from Tucson AZ, observing in Weiser ID)
Kate Allen-Penn, Debbie Penn, Matt Penn

CATE-001 (observing in Siletz, OR)
Bruce Alder, Ryan Alder

CATE-002 (from Salem, OR, observing in Salem, OR)
Mike Conley, Geri Hall-Conley

CATE-002b (from various locations, observing in Scio, OR)
David Gerdes, Katherine Weber, Jeffrey Johnson, Gerald Matzek, Steven Somes, Rob Sobnosky

CATE-003 (observing in Detroit, OR)
Robert McGowen, Michael Meo, Damani Proctor, Charlie Wessinger, Jeannine Schilling, Jay Kerr

CATE-004 (from San Diego, CA, observing in Madras, OR)
Alexander Beltzer-Sweeney, Alex Falatoun, David Higgins, Grady Boyce, Jared Hettick, Philip Blanco, Scott Dixon, Sepehr Ardebilianfard, Pat Boyce

CATE-005 (observing in Richmond, OR)
Richard Lighthill, Denese Lighthill

CATE-006 (observing in Mt. Vernon, OR)
David Anderson, Mine Anderson

CATE-006b (from various locations, observing in Canyon City, OR)
Thomas Schad, Sonna Smith, Declan Jensen, Anthony Allen, Donavan Smith, Gage Brandon

CATE-007 (observing in Dixie Butte, OR)
Joe Earp, Jane Earp, Bob Blair

CATE-008 (from Tucson AZ, observing in Rye Valley, OR)
Chuck F. Claver, Jennifer A. Claver, Ryan H. Claver

CATE-009 (from Weiser, ID, observing in Weiser ID)
Danielle Hoops, Esteban Rivera, Llanee Gibson, Martin Hiner, Rein Lann, Shaedyn Miller, Weiser High School

CATE-010 (observing in Crouch, ID)
Burton Briggs, Karan Davis, Brian Jackson, Kaleb Kautzsch, Wesley Sandidge,

CATE-011 (observing in Stanley, ID)
Russell Lucas

CATE-012 (from Bozeman, MT, observing in MacKay, ID)
Lynn Powers, Duane Gregg

CATE-012b (from Salt Lake City, UT, observing in Rexburg, ID)
Julia Kamenetzky, Tiffany Rivera

CATE-013 (from Bozeman MT observing in Howe, ID)
Joe Shaw, Bryan Scherrer, Dylan Sandbak, Richard McFate, Wilson Harris

CATE-014 (observing in Rexburg ID)
Zachery Brasier, Stephen McNeil

CATE-015 (observing in Tetonia, ID)
Jack Jensen, Makai Jensen, Mason Moore, Alexandria Temple, Thomas Vanderhorst

CATE-Pol-001 (from Boulder, CO, observing in Driggs, ID)
Dr. Richard Kautz, David Elmore

CATE-016 (observing in Kelly, WY)
Orion Bellorado, LaVor R Jenkins, Corey Pantuso, Marley Carey, Josh Byrnes, Kyle Scholtens, Julian Web, Brain Baker

CATE-017 (from Dubois WY, observing in Dubois WY)
Katie Barngrover, Drew Hathaway, Kallen Smith, Kellyn Chandler, Lydia Hinkle, Ione Chandler

CATE-018 (from Los Alamos, New Mexico, observing in Kinnear, WY)
Galen Gisler, Jack Benner, Madison Mas, Maya Rogers, Prescott Moore, Elijah Pelofske, Stephen Gulley, Beth Short, Isabel Crooker

CATE-018b (observing in Riverton, WY)
Jennifer Hammock, Katsina Cardenas, Kateri Cardenas, Jennifer Wellman

CATE-019
Mark Roy, Joe Meyer, Jalynne Brough, Kameron Brough, Tim Nelson, Zack Nelson, Caleb Russell, Theresa Bautz

CATE-021 (observing in Casper WY)
Michele Wistisen, Shae Aagard, Zachary Whipps, Logan Neuroth, Dawson Poste, Connor Worthen

CATE-022 (from Boulder, CO, observing in Casper, WY)
Sanjay Gosain, Mark Steward, Vanshita Gosain, Ruchi Gosain

CATE-022b (from Harlem, MT, observing in Jay Em, WY)
Janet Jorgensen, Eleanor Doucette, Reba Doucette, Elliott Iwen, Alexus Cochran

CATE-023 (Observing in Guernsey, WY)
James Stith, Doug Scribner, Austen Kenney, Kolby Pisciotti

CATE-023b (from Brooklyn, NY, observing in Glendo, WY)
Irene Pease

CATE-024 (from Mount Airy, MD observing at Agate Fossil Beds, Nebraska)
Samuel Cynamon, Charles Cynamon, Dawn Cynamon

CATE-025 (observing in Alliance, NE)
Bart Tolbert, Jean A. Dupree

CATE-026 (from Chadron, NE, observing in Hyannis, NE)
Jeremy Weremeichik, Nathan Pindell, Kristen Stives

CATE-027 (from Phoenix, AZ, observing in Ringgold, NE)
Thomas K Simacek, Yolanta G Simacek, Anne L. Simacek

CATE-028 (observing in Broken Bow, NE)
Wayne Boeck, Andrea Boeck

CATE-029 (from Kearney, NE, observing in Revenna, NE)
Mariana Lazarova, Austin Ryan, Gabriel Wierzorec

CATE-030 (from Denver, CO, observing in Sutton, NE)
Dimitri Klebe, Bryan Costanza

CATE-031 (from Beatrice, NE, observing in Beatrice, NE)
Arnie Cerny, Trevor Schmale, Tessa Hoffman, Sam Streeter

CATE-032 (from Tucson AZ, observing in Pawnee City, NE)
Jack Erickson, Michele McClellan, Ella Erickson, Brynn Brettell, Savannah Shoffner, Emilie McClellan, Julie VanVoorhis, Cole Bramhall, Daniel Stelly, Bentley Bee, Bruno Acevedo, Madison Kroeger, Ben Trumpenski.

CATE-033 (from Hiawatha KS, observing in Hiawatha KS)
Nolan Sump, Liam Brook, Jagert Ernzen, Jessica Lewis

CATE-034 (from Atchison, KS, observing in Atchison KS)
Ryan Maderak

CATE-035 (from Lawson, MO, observing in Lawson, MO)
Joseph Wright, David Young, Charles Kennedy, David Dembinski

CATE-036 (from Warrensburg MO, observing in Marshall MO)
Michael Foster, Mohammad Ahmadbasir, Monty Laycox, James Foster, Ethan Orr, Ashley Staab

CATE-037 (from Columbia MO, observing in Columbia, MO)
Sean Baldridge, Lucy Kegley, Jordan Bavlnka, Thomas Ballew

CATE-038 (from Springfield, MO observing from Hermann, MO)
Bruce Callen, Gregory Ojakangas

CATE-039 (from Hillsboro MO, observing in Hillsboro MO)
Mark Bremer, Maryanne Angliongto, Mark Redecker, Chris Bremer

CATE-040 (from Cape Girardeau, MO, observing in Perryville, MO)
Peggy Hill, Michael Rodgers, Jordan Duncan, Sam Fincher, Ben Nielsen, Samantha Hasler, Taylor Shivelbine, Tyler Howard

CATE-040b (from Carbondale IL, observing at Alto Pass, IL)
Chris Midden, Sean Patrick, Kerry Glenn

CATE-041 (from Carbondale, IL, observing at Carbondale, IL)
Chris Mandrell, Kyle Dawson, Margaret Cortez, Alyssa Levsky, Gallaba Dinuka

CATE-POL-02 (from various, observing at Carbondale, IL)
Padma A. Yanamandra-Fisher, Adriana M Mitchell, Tavi Anne Griener

CATE-041b (from Carbondale, IL, observing at Carbondale, IL)
Bob Baer, Sarah Kovac, student, Mason Perrone

CATE-042 (from Carbondale, IL, observing in Makanda, IL)
Fred Isberner, Howard Harper, Jasmyn Taylor

CATE-042b (from Gallatin County, observing in Galconda, IL)
Lindsay Adams, Michaela Springer, BillyJoe Menard, Dylan Boggs, Caitlin Lynch, Jacob Watson, Andi York, David Matthews, Kiley Brown, Dylan Garrison

CATE-043 (observing in Burna KY)
Jonathan Mangin, Isaac Mangin

CATE-044 (from Morehead, KY, observing in Hopkinsville, KY)
Jennifer Birriel, Ignacio Birriel, Capp Yess, Jesse Anderson, Ethan Caudill

CATE-044b (from Clarksville TN, observing in Hopkinsville, KY)
Allyn Smith, Spencer Buckner, Russ Longhurst, Ben Fagan
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CATE-044c (from Hopkinsville KY, observing in Hopkinsville, KY)
Christian Nations, Jeffrey DiMatties

CATE-045 (observing in Adairville, KY)
Honor Hare, Tricia Thompson

CATE-046 (from Natick MA, observing in Hartsville, TN)
David Garrison, Thomas Garrison, William Garrison

CATE-047 (from Cookeville, TN, observing in Cookeville, TN)
Mary Kidd, Maria Baker, Mary-Beth Ledford, Amy Winebarger

CATE-047b (observing in Nashville TN)
Michael Freed, Morgyn Church, Jim Dickens

CATE-048 (observing in Spring City, TN)
Bob Anderson

CATE-049 (observing in Madisonville, TN)
Ned Smith, Lynne Dorsey, Doug Justice, Daniel Zavala

CATE-050 (from Murphy, NC, observing in Andrews, NC)
Zach Stockbridge

CATE - 051 (from Clemson SC, observing at Clemson, SC)
Sean Brittain, Stanley Jensen, Harrison Leiendecker, Erin Thompson

CATE - 052 (from Greenwood SC, observing at Greenwood, SC)
Michelle Deady, Kelly Quinn-Hughes , David Slimmer

CATE - 053 (from Hartsville SC, observing at Lexington, SC)
Valerie Granger, Michael LaRoche, Serena Hill LaRoche, Rachel Manspeaker, Peter Nguyen

CATE - 054 (from Orangeburg SC, observing at Orangeburg, SC)
Myles McKay, Daniel Smith, Donald Walter

CATE - 055 (from Orangeburg SC, observing at Cross, SC)
Jim Payne, Jerry Zissett

CATE - 055b (from Natick, MA, observing at Isle of Palms, SC)
Arianna M. Roberts, Gabrielle W. Roberts, Harrison Roberts

CATE - 056 (from Natick, MA, observing at Awendaw, SC)
Amy Riddle, Corina Ursache, Elena Ursache, Andrei Ursache

Penn 28 Sep 2017 Short Biography

Dr. Matt Penn is an astronomer with the National Solar Observatory in Tucson Arizona. He is the principal investigator on the Citizen Continental-Telescopic Eclipse Experiment (Citizen CATE Experiment) and telescope scientists for the McMath-Pierce solar facility on Kitt Peak. Penn works on the DKIST telescope project developing coronal and infrared science and instrument requirements. Penn has a BS degree in astronomy from Caltech and a PhD in astronomy from the University of Hawaii.

**TESTIMONY OF MS. MICHELLE NICHOLS-YEHLING,
DIRECTOR OF PUBLIC OBSERVING,
ADLER PLANETARIUM**

Ms. NICHOLS-YEHLING. Madam Chairwoman and Members of the Subcommittees, thank you for this opportunity to testify.

On August 21st, 2017, millions of people across the United States gathered. Friends, families and strangers gathered by the hundreds, thousands, or tens of thousands in public spaces. They gathered in small groups or they found places to be alone. No matter the size of the group, the goal was the same: look up at the sky at an astronomical spectacle that hadn't been seen to this degree in our country for several decades: a solar eclipse.

Coordination and planning of efforts for public engagement around the eclipse started several years ago. Organizations such as the American Astronomical Society and the Astronomical Society of the Pacific helped institutions and groups talk to each other to see where efforts could be shared. The American Astronomical Society and NASA served as clearinghouses of reliable scientific content to help the media, the public, and educators engage with the eclipse phenomenon. Universities such as Southern Illinois University at Carbondale and the University of Missouri in Columbia planned extensive public opportunities at many audience engagement levels. Institutions such as the Adler Planetarium in Chicago organized events for those who could not travel to the path of totality but who still wanted to enjoy the sight of the partial eclipse. These were massive efforts that reached millions of people across the country.

The Adler Planetarium started planning for this eclipse three years ago. We had several goals for our programs: increase the capacity of organizations around the Chicago area to host their own eclipse-observing events, make residents of Chicago, the surrounding suburbs, and those in the region aware of what was happening and empower them with the skills and tools to observe the eclipse themselves, serve as a trusted source of information for the public and the media, provide eclipse resources for those who might not otherwise have access to them, reach traditionally underserved audiences, engage a variety of communities and get them interested in our universe, even if they had not been interested previously, and bring Chicago together because this was Chicago's eclipse to share. Our events were free and open to everyone.

In addition to our programs in Chicago and the surrounding suburbs, we brought our Galaxy Ride outreach program to over 2,300 people in several rural communities in southern Illinois. We were also honored to be asked by Southern Illinois University to assist them with planning and facilitating several of their eclipse events that garnered national and international attention.

And what were the results these efforts? We distributed, free of charge, over 250,000 safe eclipse viewing glasses, including 10,000 given to schools to help students and teachers in the Chicago area watch the eclipse during the school day. The Chicago Public Library System and libraries throughout the region held eclipse viewing activities at dozens of library branches. Chicago Park District parks held eclipse viewing events. Our partners such as the Chi-

cago Botanic Garden, the Morton Arboretum, Naper Settlement, and WonderWorks Children's Museum held viewing opportunities that welcomed thousands more participants. We empowered people who did not have solar viewing glasses to find safe and easy ways to view the eclipse via other means.

The Eclipse Fest block party held at the Adler Planetarium attracted 60,000 people, which is ten times the highest number we ever previously recorded for a sky observing event, and ten percent of our annual attendance. The audience at that event was a cross-section of the diverse population of Chicago, including participants who had never interacted with the Adler Planetarium previously. We estimate the number of people directly impacted by all of our activities to be over a half million.

The next logical step to ask is, "What's next?" How do we leverage the momentum and excitement from this eclipse to carry us forward? This kind of effort is what out-of-school-time institutions like the Adler Planetarium already do. The Adler Planetarium exists to help people become better connected with the universe. The public interest in the eclipse allowed us to scale our efforts upward to welcome more people. Illinois responded to us with an enthusiasm that was staggering.

In addition to the collective inspiration provided by the eclipse, the Adler Planetarium hopes this incredible experience will also lead to, one, financial and programmatic support for out-of-school-time institutions to continue providing science activities to the public; two, support for institutions and organizations to communicate with each other and jointly plan and sustain small and large science programs that have a variety of impacts; and three, support for institutions to bring high-quality science and engaging science activities, at low or no cost, to underserved populations in urban, suburban, and rural locations.

We hold fast to our core belief that making science welcoming, engaging and accessible to all helps strengthen communities socially, culturally and economically. After all, we share a sky above our heads, and everyone deserves the opportunity to engage with it.

Thank you.

[The prepared statement of Ms. Nichols-Yehling follows:]

Oral Testimony: Michelle Nichols-Yehling, Adler Planetarium
September 28, 2017

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Thank you.

Biography: Michelle Nichols-Yehling, Adler Planetarium, Chicago, Illinois

Michelle Nichols-Yehling is Director of Public Observing at the Adler Planetarium in Chicago, Illinois. She earned her Bachelor of Science degree in Physics and Astronomy from the University of Illinois at Urbana-Champaign in 1995 and a Master of Education degree in Curriculum and Instruction from National-Louis University in 2002. Michelle has been employed by the Adler since 1995 and has served on many staff teams to develop exhibits, planetarium shows, and programs and events for Adler guests. As Director of Public Observing, Michelle leads the Adler's various telescope, observatory, and sky observing efforts, including the *'Scopes in the City* telescope outreach program, free nighttime observing in the Doane Observatory via *Doane at Dusk*, Adler's telescope volunteer program, the Adler's *Galaxy Ride* outreach program, and more.

Chairwoman COMSTOCK. Thank you. And I now recognize myself for questions for a five minute round.

First of all, I'd like to thank all of you for your role in what was just an incredible sort of universal experience that we all had. I loved watching the plane, Dr. Zurbuchen. While my husband was with his cereal box, I really enjoyed having that birds-eye view, and it just was fascinating how, you know, all of the communication beforehand to get everyone participating, to get the glasses, to do the cereal boxes, to have those large group events. I know in my district we had the Udvar-Hazy Center, so we were very—and there was—my daughter lived near it. I was trying to tell her to get over there, and the backup was—the traffic was incredible, so it was worse than the normal traffic that we might have, but I take that as a great sign of the engagement.

So how do we now capture this in terms of directing this into STEM science? Because it was such a wonderful thing that you made in a real teaching moment and how going forward can we get people more engaged in these fields and in STEM careers?

Dr. ZURBUCHEN. At NASA we're committed to continuing the discussion and continuing the engagement about science of various types. We have really made a focus on telling the story. Whether it's the discovery of planets elsewhere, whether it's about science of the sun, the Earth or everything in between, I really want to focus on that. Our STEM activities are through a series of collaborations out of the Science Mission Directorate that are supporting activities across the country in a variety of centers that are focused on both population, you know, certain groups but also on schools and museums to carry the message forward. We do so in partnerships with so many such as the NSF or organizations that are represented here.

Chairwoman COMSTOCK. And I really appreciate the comments on the children from the Indian reservation and how you're engaging them and the diversity of folks that you were able to engage in this. I did want to recognize, since three of my students—I guess two of my students from my district who were active in doing this also. They're also two young women who are active in my Young Women's Leadership program where we tried to focus a lot on science, and we have Kendall and Reagan and then Kendall's mom, Jane Marie, so thank you for bringing them here. But maybe address a little bit about how you were able to engage everybody in that, and so how can we make—with this particular interest in mind, we had the Inspire Women Act that passed earlier this year. We were trying to get more women engaged in these fields. So maybe to our female witnesses how we might do a little bit more of that.

Dr. HAMMEL. Thank you. We're fortunate in that the universe has granted us a second go-round on this eclipse and so the lessons that we learned from this eclipse about engaging the young people as being the ambassadors themselves to their communities is a fabulous way to engage young people in science and also get them into leadership roles, and that's what will keep young women and other people engaged in this kind of activity. So we're going to continue the kinds of programs that we started and I hope we can—try to expand those things as well. As you know from your experience,

having the young people engaged, involved and being the leaders themselves, is a great way to capture them intellectually and emotionally.

Ms. NICHOLS-YEHLING. One of our projects that the Adler Planetarium had was to give telescopes to some libraries and teach teens, young people at those libraries how to use those telescopes. One of our goals is increasing the capacity of communities to provide their own observing opportunities, and so this was a great test of that, but in the future, we hope to do more of it and also work with other partners, other museums and folks, especially those we haven't worked with before, because this gave us an opportunity to reach other audiences. So reaching teens, reaching young folks, reaching other partners will be important to us, especially going into 2024.

Chairwoman COMSTOCK. Thank you, and thank all of you again. It really was an incredible, all the work that you did, and we can't thank you enough, and I think we've harnessed a lot of that enthusiasm going forward for STEM. Thanks.

And I now recognize Mr. Lipinski for five minutes.

Mr. LIPINSKI. Thank you. I hate to admit it, but unfortunately, I was not in the country the day of the eclipse, and I had a neighbor who was telling me his plans about driving down from Chicago to close to St. Louis, and they were going to—waiting for the morning, the weather forecast. They knew where they could go, where they could see it, and when he came back, it was just something that raised that excitement, and I remember from my own childhood, and it wasn't even anything like this, a total eclipse. I remember that. So it's a great opportunity and it's especially great to know that it's not too long we're going to have that opportunity again.

So I wanted to sort of ask Ms. Nichols-Yehling about ways that you're going to use this, the Adler Planetarium is going to sort of try to use this to leverage interest in other of your outreach activities and longer-term public engagement in science because you captured a lot of attention here, a lot of people's interest, and how do you sort of keep that going and also give the—make sure people are aware of and draw people into other opportunities and other things that they can learn.

Ms. NICHOLS-YEHLING. Exactly. This is basically what the Adler Planetarium does and what we're really proud to do. The goal in the future, we want to not only reach people broadly but we want to reach them in depth, and so we have several programs, especially those in our teen programs area, that really try to hook teens but get them involved in real science, and that's one of the goals is not just have people come out and enjoy the eclipse for one day, give them other opportunities to come back to the planetarium and also explore other resources in their community to be able to go in more depth.

And so one example is our High Altitude Ballooning program called Far Horizons, and so we have ways for kids to be involved in that, taking real science data, and have teens involved in potentially recovering pieces of meteorite from the floors of Lake Michigan. And so these are ways that we can really reach people, not

just broadly but try to really focus on the fact that science is best engaged when it's real.

Mr. LIPINSKI. Thank you. And anyone else on—any they're working on in that regard?

Dr. PENN. If I could just interrupt, we designed the funding for the CATE instrument so that the groups keep their telescopes the day after the eclipse, and so now we have a small network of 68 groups that have their telescopes, and we have a working group that's looking at following up with nighttime projects so the students who were really excited by the eclipse and are now really excited as well about STEM can continue observing with their CATE instrumentation.

Mr. LIPINSKI. Very good. Anyone else have anything to add?

So what have we—anything that we've learned, you expect to learn getting more sort of beyond the public engagement about the—potentially about solar storms, threat of space weather? What are the expectations from the data that was collected from the eclipse?

Dr. ZURBUCHEN. So one of the most important elements—you know, there's many but one of the most important elements for NASA is that we were able to use this unique view to test space weather models. So what we actually did is, we tested models that were supported both by NSF and NASA and we ran them on the fast computers, the fastest computers at NASA with days to spare, and were making predictions that are now tested and analyzed. And so it's really became a benchmark type of test of these models that are so critical for space weather applications.

Mr. LIPINSKI. Thank you.

Dr. ULVESTAD. If I could add to that, we, NSF, used our Stampede 2 supercomputer for one of those activities that Dr. Zurbuchen mentioned, but also our network of solar telescopes around the world. We used that to help make predictions, and those are used operationally by NOAA and the Air Force for space weather prediction. So this gave us a chance to test the models that we're using from those observing telescopes and see if what they predicted was close to the truth or not, and that will enable us then to refine the models and do better in the future.

Mr. LIPINSKI. Thank you. My time is up, and I yield back.

Mr. BABIN. [Presiding] Yes, sir. I now recognize myself. I'm Brian Babin from the State of Texas, and I'm sitting in for our Subcommittee Chairman, Mrs. Comstock.

I'd like to ask you, Dr. Zurbuchen, NASA is launching the Parker Solar Probe next year to dive into the corona closer than we've ever been to the sun before. What technological advancements will allow that to work, and what do we hope to learn?

Dr. ZURBUCHEN. So this is one of those missions that the community wanted to do since the 1960s when it was clear that there's a solar wind and we were trying to figure out how it arose, right? It's now clear that that solar wind and its storms are really affecting our technological society, and so the technologies that are enabling the Solar Probe are really an advanced heat shield, first of all. This thing gets really hot at the front end and the back, you could easily sit. It's room temperature, I mean, so in the middle is high-tech heat shield, so that's technology number one. The second

one is high-temperature solar panels, so if you took a regular solar panel to make solar energy out there from here it would of course not work because it gets too hot and kind of the panel shorts so that the panels that were developed for that particular mission were panels that can sustain the temperature to be down there at close solar distance and work. So those are the enabling technologies, certainly the ones that stand out in my mind.

What we hope to get from it is really measurements that are focused on answering the pivotal question here, which is, how does the sun accelerate the solar wind. We actually don't really know the extent how—what heats the extended corona, understanding that underlying physics not only will tell us about space weather but about magnetic stars and channel because we know that these effects are everywhere. So this pivotal measurement we wanted to do for a long time. It's finally in reach.

Mr. BABIN. Thank you. Very fascinating.

Then Dr. Hammel, I'm very interested in the Carrington Event, which I've read about, and you mentioned—I think it was you that mentioned it earlier. How likely do you think another catastrophic event like this will happen in the next, say, decade? Do we have any good predictive models for this? And then what are we currently doing? I think one big topic today is our infrastructure, our electric grid, whether it be manmade or some natural disastrous event like this. If you can answer some of those questions and elaborate, I would appreciate it.

Dr. HAMMEL. Sure. As you heard from Dr. Zurbuchen, one of the activities that took place during this total solar eclipse was exercising our models, and it's our models that we rely on to determine whether or not an event like the Carrington Event is likely to happen in the future.

Yesterday when we were preparing for this, we had some discussions about how likely is it because we are curious too, and there have been some studies that have predicted that the probability of something like this happening is something like ten percent per decade. Not everybody agrees with that. That's just one of the models. But when you do the math and you think about when the Carrington Event took place and where we are now, how many decades is that? A 10 percent probability? So we're pretty close to maybe having another one. And in fact, there have been in recent months some very large-scale solar flares that have taken place. Fortunately, they have not been directed at the Earth, and so we have escaped for now. There are, though, of course, on record—there's evidence that solar storms have affected things like airplane navigation systems, other kinds of—lower-level-scale effects. So it's real. It's going to happen sooner or later. So it's important that we are prepared for that.

So what are we doing to prepare for that? A lot of people are thinking about that. Every year there's meetings of people that get together that include a lot of people who are interested in trying to mitigate, prepare, how to set up our infrastructure so that it is more robust, how to prepare our satellites so that if we know an event is going to happen, what can we do to power then down so they are not quite as severely damaged, and I know that there are many groups in the government who are working collaborative to-

gether, not only are NASA and NSF representatives but NOAA, FEMA, the Air Force, all of these groups have been talking actively about this, so it's a subject that is on people's minds.

Do any of my colleagues want to add——

Mr. BABIN. Yes, I'd like to hear anyone else has——

Dr. ULVESTAD. I'll just add to the last point Heidi was making, which is for the last three years under the National Science and Technology Council, there's been a group called the Space Weather Operations Research and Mitigation Task Force, and they produced the National Space Weather Action Plan back in late 2015. That involves, as Dr. Hammel said, NASA and NSF but also FEMA is involved, and the Department of Energy, so understanding how to predict solar storms and then understanding okay, what is your response, how do the public utilities respond, and given a certain probability of a solar storm of a certain magnitude, what should they do. That's the kind of question that this interagency task force is wrestling with.

One of the things that we've been doing recently is sort of working on establishing benchmarks for the level of solar activity that would cause us to recommend certain actions as a government, so I think that's ongoing. It's good to see a lot of different agencies working together. In the course of my normal daily life, I wouldn't interact with FEMA so I think it's really good that we have that opportunity through this task force.

Mr. BABIN. Thank you very much.

My time is expired, but I want to say that I've been very active with FEMA here lately too because we had Hurricane Harvey down there, and I appreciate your testimony.

Now I'd like to recognize Ms. Bonamici.

Ms. BONAMICI. Thank you very much, Mr. Chairman.

Thank you to all of our witnesses. I'm from Oregon, so this was a very big deal in our state. The estimates were about a million people came into the state. We only have 4 million people living in Oregon so it was significant, really, really important to our state, and really, it was awe-inspiring. We had astronomers and hobbyists and families from all over the world actually traveling to my home state. OMSI, our Oregon Museum of Science and Industry, hosted a big event. Oregon State University in Corvallis had thousands of people for a viewing. They hosted exhibits, educational lectures. The university also had research projects that they initiated on the coast. A team of students from Lynn Benton Community College, for example, and OSU launched a balloon from the research vessel, the Pacific Storm, to capture live video of the eclipse. This balloon investigated the high-altitude temperature and pressure variations, so that was exciting. The Ocean Observatories Initiative used in-water instruments to study how oceanic zoo planktons responded to the darkness caused by the eclipse an hour before the sky went dark. They started their nighttime feeding procedure, and scientists found actually that the ocean temperature barely moved even at totality. Really, really amazing experience from what I personally felt, and I was at 99 percent just in my own neighborhood. The temperature dropped significantly, and that was the first thing everybody could feel, a significant drop in the temperature, and as the sky began to turn dark, we saw the

wavy lines. It was a really, really amazing, awe-inspiring experience.

I wanted to ask you, Dr. Penn, about Citizen CATE because I saw how many sites you had across the State of Oregon, and what a great way to really capture so much as the eclipse moved across the country. Can you talk about—and I read a little bit and heard a little bit about your funding challenges along the way. Can you talk about the importance of the federal funding from NASA and NSF? And I know that that was a big part, but as we set budget priorities here, it's really helpful to have yet another example of where federal funding made a difference.

Dr. PENN. Yes. So we started out in 2016 by getting a grant from NASA to do some student training. So Miles McKay was one of the students. We shipped up a bunch of—or packed up—a bunch of students with telescopes and sent them to Indonesia to get on-the-job training during the 2016 eclipse. When they returned we had some summer programs where they did some research with their data, but most importantly, they ran the workshops, the training workshops, for 2017 volunteers across the country. So that was really critical. It not only took the burden off of me to try to train 68 teams, they spread out and did the training, but it empowered them to learn about solar physics and to have the experience of the eclipse to start with.

And then building the instrumentation funding for 2017 was a challenge but actually looking back, I'm just amazed at the cooperation from corporate sponsors. We had Daystar Filters donating 60 free telescopes to us and Celestron donated 60 free mounts. Mathworks and Color Maker were our other corporate sponsors, major corporate sponsors. And then the National Science Foundation was able to bring us from a site—it looked like we were going to get about 30 sites, bring us up to the full 68-site total. So it was a challenge but it was just a great honor to be involved with that.

My favorite story is that Color Maker—you may not have heard of them but they make food dye in Anaheim, California, but the CEO is an avid amateur astronomer and he read about our program and sponsored five sites.

Ms. BONAMICI. That's a wonderful example of public-private partnerships.

Ms. Nichols-Yehling, I know from your background at the planetarium, you had a really important role in bringing the experience to the public, and talk a little bit about sort of outreach and the level of participation. How did you reach audiences and groups of young people not typically engaged in sort of out-of-school science activities?

Ms. NICHOLS-YEHLING. So about three years ago, we started, as I mentioned before, working with libraries to bring telescopes to them, and teach folks there how to use those telescopes, and then they were able to use them on the day of the eclipse, and we intend to keep that program going forward and even reach more libraries, other institutions, schools and that sort of thing. We worked with other institutions including a botanic garden, an arboretum, to teach their staff about science-related to the eclipse but try to connect the eclipse to things that would connect with their audiences

such as seeing the eclipse shadows through the leaves on trees and look at them on the ground. So ——

Ms. BONAMICI. I'm on the Education Committee as well as the Science Committee, and I'd heard a concern that some of the schools were planning to close because they were concerned that they wouldn't be able to protect students' eyes. It seems like sort of a lost opportunity. So we need to prepare ahead for the next eclipse to make sure that this is a great and wonderful learning opportunity for students. We'll get those glasses and make sure that everybody knows. Because that was a real serious concern in Oregon.

And in my remaining few seconds, I'd like to—and there won't be enough time but to follow up on what are some of the leading theories about, you know, one of the big outstanding questions about the sun is why the corona is so much hotter than the surface and what are we hoping to learn, and what are these experiments during 2017, how are they going to advance our understanding of the heating of the coronal area. Anybody want to——

Dr. PENN. Yes. So the heating issue is being addressed by several of my colleagues looking at images at different temperatures, and they've had a short network of a few sites, so we hope to get a handle on that. And then the acceleration of the solar winds, another coronal problem, and the Citizen CATE data should address that.

Ms. BONAMICI. And thank you. And as I yield back, Madam Chairman, I want to say, Chairwoman, that in 1979, February 1979, at the time of the eclipse then, an ABC news report at that time said about the world on August 21st, 2017, "May the shadow of the moon fall on a world at peace," and may we say that about 2024, and I yield back. Thank you, Madam Chairwoman.

Chairwoman COMSTOCK. Thank you.

And I now recognize Mr. Beyer for five minutes.

Mr. BEYER. Thank you, Madam Chair, very much.

I just have a series of short questions.

Dr. Zurbuchen, so we call this the Great American Eclipse. What are we going to call the next one?

Dr. ZURBUCHEN. That's a good question. Do you have a suggestion?

Mr. BEYER. No. It's just you have to be careful. You know, it's like saying this is my favorite child.

Dr. ZURBUCHEN. Yeah, I know, I know. I worried about it too, you know. I don't know. I mean, I don't have a good idea at this moment.

Mr. BEYER. We can have a contest.

Dr. ZURBUCHEN. Yes, we should. We should.

Mr. BEYER. Dr. Ulvestad, I've always been concerned—you know, is it just accidental—we look in the sky and the disc of the moon looks about the same size to us as the disc of the sun, and if you look at the nice picture we have on our things, you figure that if the moon were bigger or smaller, that eclipse wouldn't look the way it does. Is this accidental or is there something bigger that's driving this like——

Dr. ULVESTAD. So we live in a fortunate time in that sense, okay? The Earth is slowing down in its rotation due to the tidal forces from the moon, and as the Earth slows down, the moon moves far-

ther away. So I was actually curious about your question myself because the moon moves away at some centimeters per year, or something like that, and I was thinking, well, when is the moon going to be too far away to not ever have a total solar eclipse again, and it's hundreds of millions of years, so we've got some time yet.

Mr. BEYER. But other than that, it's just accidental?

Dr. ULVESTAD. Other than that, if you go into the theories of anthropomorphism and why humans appeared on Earth at a certain time, you could probably come up with something but I don't think there's any scientific reason that the moon and the sun happen to be the same angular size right now.

Mr. BEYER. I think we'll recommend to our Chairman and Chairwoman that we have a hearing on the anthropomorphism coming up. We'll invite you back.

Dr. Penn, on the Parker Solar Probe, how long will it survive? Is this a—is it going to be going there for 2 minutes and 48 seconds or——

Dr. PENN. No, I think it'll make several passes. I must admit, I'm not an expert on this but I think it'll make several orbits through the corona and gather on both.

Dr. ZURBUCHEN. I think it's a seven-year mission duration but hopefully it will survive even longer. So it's cranking down, so the first time it flies by it's closer to, you know, Venus and then Mercury distance and then really taking the periapsis, the close part of the ellipse, closer and closer until it's at 9.8 solar radii. We live at 215 solar radii, just for scale.

Mr. BEYER. Great. Thank you.

Dr. Hammel, I noticed when Dr. Zurbuchen was on the airplane looking at the eclipse, he didn't have those classes on. Do you not need the glasses when it's at totality or——

Dr. HAMMEL. I brought my glasses for this very purpose. Actually, once totality has been achieved, you can take off the glasses and then you have a fantastic view. You need these glasses when any little piece of the sun is exposed. So I'm so sorry that you only saw a 99 percent eclipse.

Ms. BONAMICI. It was awesome.

Dr. HAMMEL. Yes, but it's even awesomer if you can get into the path of totality. The difference between 99 percent and 100 is literally the difference between day and night. Even that tiny little piece of the sun is a million times brighter than the corona. So once you have that last bit disappear behind the moon, everything changes. Everything changes. So I hope for 2024 you make that trek to the totality line. It's worth it.

Mr. BEYER. As Mark Twain said, the difference between lightning and a lightning bug.

Dr. HAMMEL. Yeah. There you go.

Mr. BEYER. Dr. Hammel, though, I'm struck with the notion that I think the testimony was, we gave our 4.3 million glasses, but 51 percent of Americans intended to look, which gives you 165 million. Does that mean we have 161 million people who can expect some eye damage?

Dr. HAMMEL. No, not at all. We can share glasses. The amount of the totality—the amount that leads up to totality when you must have these glasses takes over an hour. It takes quite a long time.

And so you put the glasses on and you see the sun sort of being chipped away by the moon but then you take your glasses off and you hang out with your family and your friends, and a few minutes later you put them back on again, so there's a great deal of sharing that can go on. And there are many other ways to experience the eclipse. As we heard, you know, the cereal box is a fabulous way to do it as well, and that has the advantage of teaching kids a little bit about optics too and how a pinhole can act somewhat like a telescope, and there's a lot of other things that—and all of us who were involved in outreach shared many of those other ways of enjoying the eclipse in addition to the glasses.

I think that one of the lessons that we all learned from this eclipse is that we have to be even more rigorous about ensuring that there are many, many millions of glasses available in the 2024 event. I'll share my own experience. I worked closely with a teacher in Virginia, and she was training 500 of her fellow teachers that day, the day of the eclipse, and they had ordered their glasses from Amazon, and then when this came about that they couldn't be sure that their glasses were safe, she and I brainstormed on all the other ways that the teachers could experience the eclipse. I think that we will take the lesson to heart because in 2024, the eclipse is in April and the schools will be in session and so we want to be sure that everybody has the opportunity to experience the eclipse and can experience it safety.

Chairwoman COMSTOCK. I now recognize Mr. Veasey.

Mr. VEASEY. Thank you, Madam Chair.

I wanted to ask just about the days leading up to the eclipse. I know that like you were talking about, there was a lot of confusion about the glasses, and Amazon actually issued a recall on some of the glasses that were out there in the marketplace, and I just wanted to know, from you, can you talk about the efforts that your agencies made to help spread information about the glasses? Because I think when we get ready to have the next one, as far as the general public is concerned, you know, we're here having this Committee hearing today and going into, you know, great detail about the eclipse and what it means, but in 2024 they're going to want to know about what glasses to use again. So is there any lessons, anything like that that you can talk about?

Dr. ULVESTAD. So I'll say a couple words about that. We funded the American Astronomical Society to create a web page of resources, and that web page of resources had instructions on what you should do and what you shouldn't do, and that's fine if you know where to go to look for that web page, but I think the lesson for that is that we need to be more aggressive about marketing that kind of web page and that kind of information and do more pushing out to the public rather than waiting for people to stumble across it because it showed up on their browser.

Ms. NICHOLS-YEHLING. And we also as a public institution directed people to that American Astronomical Society web page as a very trusted source of information. We also allayed people's fears because we got our glasses directly from one of the trusted manufacturers. But then for those folks who were still concerned, definitely pushing those other ways to be able to safety view the eclipse because it wasn't necessary to actually have a pair of glass-

es. There were many, many other ways to do it that were still perfectly safe. So getting all those messages across through our social media, through the regular traditional media was really important in the days and weeks leading up.

Mr. VEASEY. All right. What do you think just about lessons, you know, learned? I mean, you talked about the steps that you guys took to make sure that you were getting them correctly and trying to get that information out into the public. Do you think there's something else that we can do when the next one comes around to maybe even prepare even better?

Ms. NICHOLS-YEHLING. I'd say get the word out even sooner because it was really hectic right at the end, maybe the last two or three weeks. We were just getting phone calls and emails of people concerned every single day, but definitely working with our partners, working with the media several months ahead of time, that's one of the lessons we took from it.

Dr. ZURBUCHEN. And I just want to add, I think it's absolutely important to recognize that not everybody is getting their news the same way, right? Some URLs may or may not be used. I mean, my children, if they ever see me, it's on Instagram, which I don't know, I don't hang out there, but you know—so basically really looking at all the communication channels, and I think what really helped with the glasses, frankly, is people practicing up front, you know, basically really looking at the glasses and measuring what they blocked, and then it was clear, hey, days ahead, right, that these particular set of glasses were not safe and then, you know, thank God for the companies really replacing them. So again, really using all communication channels that are relevant and going ahead and practicing, making sure we don't take it for granted.

Mr. VEASEY. Thank you. Thank you, Madam Chair.

Chairwoman COMSTOCK. I now recognize Mr. Foster for five minutes.

Mr. FOSTER. Thank you, Madam Chairman.

And I'm—well, first of all, I myself had the pleasure of watching the eclipse with students and their families at the Joliet Library's solar eclipse viewing party in my district, and like our panelists and the members here, I was really encouraged to see people from every walk of life taking an interest in science just because of the eclipse.

But, you know, I'm a scientist so I tend to like numbers about things, and a few weeks ago I became aware of a NASA-funded research project led by Dr. John Miller of the University of Michigan to actually quantify who viewed the eclipse, how people prepared for it, gathered information for it ahead of time, when and how they viewed it, and in the months and weeks following how—you know, the effects that it had on their scientific engagement and literacy. So this seemed like it was precisely the sort of, you know, fact-based public engagement that NASA should be engaged in, so I was thrilled to see this report.

And I would like at this point to ask unanimous consent to enter into the record a preliminary version of the report——

Chairwoman COMSTOCK. Without objection.

[The information appears in Appendix II]

Mr. FOSTER. Thank you. By Dr. John Miller titled "Americans and Their 2017 Solar Eclipse."

With that out of the way, one of the things I just want to mention about this is that one of the—just to capture one sentence from his report, it said "During the two months prior to the eclipse, millions of American adults engaged in a wide array of information-seeking and acquisition activities to improve their understanding of the forthcoming event," and trying to really understand that, and you know, I understand that Dr. Miller has, you know, a very aggressive program of expanding this. He's looking at things like social media and so forth to actually quantify this, and I think I just want to—if any of you have any specific familiarity with that, I'd be happy to hear comments on it.

Dr. ZURBUCHEN. So this study was funded out of the STEM activation parts of our Science Mission Directorate. We're really excited about it. Of course, both coverage that, you know, we managed to get all together, right? It's not just one source. What I wanted to point out also is of course that a lot of the studies are still ongoing, so I'm really glad you're looking at this initial report but we'll make sure that we draw your attention to the final report once it's been completed. I really want to make sure that we look at it just like you said. We feel it's absolutely crucial to use the tools of social sciences, you know, to really make sure that our outreach efforts are targeted and are also up-to-date as things are changing as we go forward.

Mr. FOSTER. Well, thank you. It's always nice to see government doing its job well.

Now, to get to a little bit of scientific things here, how much overlap is there between preparation and mitigation for coronal mass injection events and EMP events caused by potential nuclear attacks? Is this now a completely separate set of preparation and mitigation or are there enough similarities about what you have to protect even though obviously the time structure and intensity of the pulses are very different?

Dr. ULVESTAD. I can say a few words about that, which I've fortunately learned from listening to my FEMA colleagues at the Space Weather Task Force. They have lots of plans on the shelf, and when they start thinking about what's going to be the result of a space weather event then they go to their shelf and they say here's the kind of thing we have that looks a lot like a space weather event. So an EMP pulse that you just mentioned, I imagine, is one of the things that they would say it looks kind of like a space weather event. So within at least my organization, within NSF, we don't engage in that activity but I think what they do is, they take as a starting point what they already have, rather than starting from scratch. They say okay, what's different about a solar event from another event that we've studied, and that means they're not starting from square zero.

Dr. ZURBUCHEN. So one of the major differences between the two events is the geographic extent of the event, and so basically the real worry about a solar event of the type Dr. Hammel outlined earlier is that it would be regional in nature, and so basically what would happen in an electrical system, it would overload as a regional type of thing so far less it's a local thing like lightning or

even a pulse of the type that you're outlining. There are similarities relative to the physics locally with the electrical fields going up and so forth, how the systems react. But there's real differences relative to the geographic event and therefore the overall extent of the damage that could occur from it.

Mr. FOSTER. Of course, all nuclear EMP events are not created equal, depending on altitude and related things.

Well, you know, it's nice—I just want to encourage you to actually, you know, share your planning on that because, you know, neither of the two events unfortunately are low-probability events, and often dealing with low-probability, high-damage events is something that in our democracy does not do that well, and so I'm encouraged to see that you're at least thinking about part of that problem.

Thank you, and at that point I'll yield back.

Chairwoman COMSTOCK. Thank you. And again, I thank our witnesses for the great experience that you provided for our students and for people across the country, watching on the plane, seeing all the web activity and having that all captured, and now all the information that you have for research going forward. It was really exciting to see this all in action.

I believe we only have about nine minutes left to vote, so I do thank the witnesses, and the record will remain open for two weeks for additional written comments and written questions from members, and the hearing is now adjourned.

[Whereupon, at 10:36 a.m., the Subcommittees were adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. James Ulvestad

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Great American Eclipse: To Totality and Beyond"

Dr. James Ulvestad, Assistant Director (Acting), Mathematical and Physical Sciences Directorate, National Science Foundation

Questions submitted by Representative Ed Perlmutter, House Committee on Science, Space, and Technology

1. How specifically will this eclipse contribute to our understanding of the Sun and more specifically space weather?

   Answer: The science that comes out of the August 21, 2017 Great American Eclipse will contribute to our understanding of the Sun and space weather primarily through our increased knowledge of the inner solar corona. The inner corona is the region of the solar atmosphere where phenomena like flares, coronal mass ejections and the fast and slow solar wind originate. This inner solar corona, from the chromosphere out to about 1.5 solar radii, is inaccessible to current ground- and space-based assets. This is because the coronal emission is about a factor of a million times fainter than the light from the solar photosphere. The only way to block this light is with an occulting disk known as a coronagraph. Coronagraphs, however, can suffer light leakage and edge effects that limit how close to the solar surface we can view the corona.

   During a total solar eclipse, the moon provides a nearly perfect natural occulting disk allowing scientists unprecedented access to the inner solar corona. In addition, because the Great American Eclipse passed across the entire continental United States, this inner coronal region was accessible for more than 90 minutes when viewed from multiple sites spread along the path of totality. NSF-funded scientists took this opportunity to study new spectral lines and magnetic fields in the inner corona. These magnetic fields provide the immense energy necessary to drive the space weather that impacts our Earth through mechanisms that are currently unknown. One project, Citizen CATE, observed the eclipse from 68 sites along the path with identical telescopes and instrumentation supported, in part, by funding from NSF. From their data, Citizen CATE scientists will generate a 90-minute movie of the inner workings of the solar corona. This, in turn, will allow them to study the dynamics of the inner solar corona and gain new insights into this region where space weather originates.

2. How will current and future facilities, including the Daniel K. Inouye Solar Telescope and the National Solar Observatory's Integrated Synoptic Program, work together with other facilities and agencies to enhance our knowledge of and future prediction of space weather?

   Answer: NSF's Daniel K. Inouye Solar Telescope (DKIST) will be the world's most powerful ground-based solar observatory poised to answer fundamental questions regarding the Sun and its magnetic fields. DKIST will make the highest-resolution images of the Sun and its magnetic fields ever made, down to a scale of 20-30 km on the Sun. It will have a suite of instruments capable of observing the Sun and its corona from the near-ultraviolet, to the visible, all the way into the infrared. DKIST will be used by scientists to explore the fundamental physics behind the solar magnetic fields that drive phenomena like solar flares, coronal mass ejections, and the solar wind, all of which constitute the space weather that impacts the Earth.

   While DKIST will provide the detailed views of the Sun necessary to understand the fundamental physics that drive space weather, accurate predictions of space weather require long-term, full-disk monitoring of the Sun on a continuous basis. The National Solar Observatory's Integrated Synoptic Program (NISP) is well suited to provide the high-cadence, large field-of-view capabilities required for space weather prediction. NISP consists of the Global Oscillations Network Group (GONG) and the Synoptic Optical Long-term Investigations of the Sun (SOLIS) facilities. GONG observes the entire disk of the Sun 24/7, 365 days per year from six stations spread around the globe. It is this continuous, full-disk data that is vital to the space weather prediction models of NOAA, NASA, and the DoD.

   Both DKIST and NISP will be able to exploit synergies with upcoming space missions like NASA's Parker Solar Probe and the European Space Agency's Solar Orbiter, expected to launch in 2018 and 2019, respectively. These missions will make in-situ measurements of the inner heliosphere and the solar corona that will complement the high-resolution imaging capability of NSF's DKIST and the full-disk, synoptic capabilities of NISP. NSF and NSO have been reaching out to the space-based solar community through a series of topic-based workshops designed to introduce the community to the science capabilities of DKIST. One of these workshops, to be held at the Johns Hopkins University's Applied Physics Lab, is specifically targeted at exploring the ways in which DKIST, Parker Solar Probe, and Solar Orbiter can be combined to enhance our understanding of the Sun and the space weather it drives.

Responses by Dr. Thomas Zurbuchen

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Great American Eclipse: To Totality and Beyond"

Dr. Thomas Zurbuchen, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration

Questions submitted by Representative Ed Perlmutter, House Committee on Science, Space, and Technology

1. How specifically will this eclipse contribute to our understanding of the Sun and more specifically space weather?

   Answer: To understand the origins of space weather, its impact upon our technological society and ultimately predict it much like we do for terrestrial weather, requires detailed understanding of the Sun's outer atmosphere, the corona. This dynamic region -- especially the lowest part of the corona -- is the origination point for the giant eruptions such as solar flares, coronal mass ejections and bursts of solar energetic particles which can cause space weather events at Earth. We can observe this special region in many different wavelengths of light from missions in space -- but visible light, the light we see with our own eyes, is not one of these wavelengths. We can see this lower part of the corona only when its dim light is revealed during a total solar eclipse.

   Consequently, a total solar eclipse is a golden opportunity for solar science, dependent wholly on using telescopes on the ground and in aircraft to capitalize on the singular eclipse geometry visible only from Earth's perspective. The August 2017 total solar eclipse was especially important for NASA and its science partners because the eclipse covered thousands of miles of accessible land. This allowed for observations of the relatively short period of totality (roughly 2 minutes) at different locations and with different instruments amounting to more than an hour of consecutive coronal observations. NASA funded 11 ground-based and aircraft studies, including six designed to make critical measurements of the corona. These different studies are helping to piece together puzzles of our dynamic Sun. All the experiments provide important information. Two notable ones include telescope measurements of the temperature and motions of material in the corona and high-speed images of the corona taking by high altitude research aircraft. This information will help to provide an understanding of the triggers of energy release driving space weather eruptions and the overall flow of energy through the corona respectively.

2. How will current and future facilities, including the Daniel K. Inouye Solar Telescope and the National Solar Observatory's Integrated Synoptic Program, work together with other facilities and agencies to enhance our knowledge of and future prediction of space weather?

Answer: NSF's Daniel K. Inouye Solar Telescope (DKIST) will be the world's most powerful ground-based solar observatory poised to answer fundamental questions regarding the Sun and especially its magnetic field. DKIST will make unprecedented high-resolution images of the Sun and its magnetic fields, down to a scale of 20-30 km on the Sun. It will have a suite of instruments capable of observing the Sun and its corona in specific lines ranging from the near-ultraviolet, to the visible, all the way into the infrared. DKIST will be used by scientists to explore the fundamental physics behind the solar magnetic fields that drive phenomena like solar flares, coronal mass ejections, and the solar wind, all of which constitute the space weather that impacts the Earth.

While DKIST will provide the detailed views of the Sun necessary to understand the fundamental physics that drive space weather, accurate predictions of space weather require long-term, full-disk monitoring of the Sun on a continuous basis. The National Solar Observatory's Integrated Synoptic Program (NISP) is well suited to provide the high-cadence, large field-of-view capabilities required for space weather prediction. NISP consists of the Global Oscillations Network Group (GONG) and the Synoptic Optical Long-term Investigations of the Sun (SOLIS) facilities. GONG observes the entire disk of the Sun 24/7, 365 days per year from six stations spread around the globe. It is this continuous, full-disk data that is vital to the space weather prediction models of NOAA, NASA, and the DoD.

Both DKIST and NISP will be able to exploit synergies with the current suite of NASA Heliophysics spacecraft observing the Sun remotely as well as upcoming space missions like the NASA's Parker Solar Probe and the joint European Space Agency/NASA Solar Orbiter; expected to launch in 2018 and 2019, respectively. These missions will make in-situ measurements of the inner heliosphere and the solar corona that will complement the high-resolution imaging capability of NSF's DKIST and the full-disk, synoptic capabilities of NISP. NSF and NSO have been reaching out to the space-based solar community through a series of topic-based workshops designed to introduce the community to the science capabilities of DKIST. At the same time, the Parker Solar Probe and Solar Orbiter science teams have stood up a working group to plan for collaborative science. One upcoming workshop, to be held at the Johns Hopkins University's Applied Physics Lab, is specifically targeted at exploring the ways in which DKIST, Parker Solar Probe, and Solar Orbiter can be combined to enhance our understanding of the Sun and the space weather it drives.

Responses by Dr. Heidi Hammel

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Great American Eclipse: To Totality and Beyond"

Dr. Heidi Hammel, Executive Vice President, Association of Universities for Research in Astronomy, Inc.

Questions submitted by Representative Ed Perlmutter, House Committee on Science, Space, and Technology

1. How specifically will this eclipse contribute to our understanding of the Sun and more specifically space weather?

   Answer: A total solar eclipse offers a rare opportunity to study the innermost layers of the Sun's atmosphere, called the corona. Under normal circumstances, this region is completely overwhelmed by light from the Sun's surface scattered by the Earth's atmosphere. Space missions can artificially eclipse the Sun using coronagraphs, but they must always "over-occult" the disk to ensure they do not damage instrumentation. Thus, we cannot routinely observe this lowest layer of the corona. Yet this layer is the source of many phenomena that result in space weather effects on Earth, such as the solar wind and coronal mass ejections. Although we see these eruptions occurring, we rarely observe their onset. This lack of knowledge limits our understanding of *why and how* they happen. In order to better predict these events, we must understand the fundamental physics driving them.

   The 2017 solar eclipse allowed us the opportunity to observe the innermost layer of the solar corona. The "Citizen Continental America Telescope Eclipse" (Citizen CATE, or CATE) experiment, led by the National Solar Observatory (NSO) obtained 90 continuous minutes of coronal imaging. This is the longest that this region has ever been studied in one sitting. And, even more importantly, this unique data set was collected by hundreds of STEM students from a diverse pool of high-schools and colleges across the country. The combined results of the CATE project with the plethora of science experiments run by other collaborations all over the United States will push forward our understanding of the complex and dynamic corona, and thus advance our knowledge of space weather.

2. How will current and future facilities, including the Daniel K. Inouye Solar Telescope and the National Solar Observatory's Integrated Synoptic Program, work together with other facilities and agencies to enhance our knowledge of and future prediction of space weather?

   Answer: Unlike space-based assets, the Daniel K. Inouye Solar Telescope (DKIST) will have the ability to observe the corona close to the solar surface. This is a result of its new technology, specifically its off-axis telescope configuration and its complex system of occulting disks that block the light scattered from the solar disk. These advances will enable DKIST to produce significant leaps in our understanding of the Sun's magnetic field and the processes that drive space weather.

The processes driving space weather remain largely a mystery due to the small physical scales in which they occur. It is impossible to significantly enhance our forecasts of space weather without understanding the fundamental physical processes that create it in the first place. The images with DKIST's extremely high resolution will form the basis for future space weather predictions.

DKIST, while exquisitely tuned to study fine details on the Sun, will admittedly lack a global view. We simply do not have the technology to produce a telescope that has the spatial resolution and sensitivity of DKIST yet at the same time can observe the entire Sun. However, we address this by combining DKIST data with output from the Global Oscillation Network Group (GONG).

GONG is a network of six solar telescopes placed at strategic points around the world. Run by NSO's Integrated Synoptic Program, GONG observes the entire Sun all the time, albeit at reduced resolutions and sensitivities compared with DKIST, and is the only one of its kind in the world. GONG already plays a critical role in daily space weather operations. The GONG network was recently upgraded to include observations of the Sun's magnetic field. NOAA's Space Weather Prediction Center currently uses the GONG global magnetic field observations to refine their daily space weather predictions.

The GONG network has been declared critical for the national interest, and is in the process of being integrated directly into the Space Weather Prediction Center pipeline. Current GONG refurbishment will keep the network operational for the next 10 years. NSO is also starting to work on the future "SPRING" network that will replace GONG in the future.

Responses by Dr. Matthew Penn

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Great American Eclipse: To Totality and Beyond"

Dr. Matthew Penn, Astronomer, National Solar Observatory

Questions submitted by Representative Ed Perlmutter, House Committee on Science, Space, and Technology

1. How specifically will this eclipse contribute to our understanding of the Sun and more specifically space weather?

   Answer: Space weather events are caused when high-energy particles or regions of intense magnetic fields from the Sun cause changes in the magnetized plasma in space near the Earth (or near other locations of interest in the solar system). Eruptions from the Sun called coronal mass ejections are the main space weather instigators, and these can be predicted with some success by observing flares on the Sun. But additional space weather is caused by less violent events, particularly when the fast solar wind from the Sun changes and interacts with a region of slower solar wind. These areas of wind interactions can trigger changes in the geomagnetic field and result in high-frequency radio blackouts and other space weather events.

   The acceleration mechanism for the fast solar wind is not understood in detail, and the 2017 total eclipse provided a chance for the Citizen CATE Experiment teams to measure it in a new way. The teams measured the fast solar wind speed in the inner corona above the solar poles for 90 minutes, and thus have a unique opportunity to determine how the fast wind speed changes. Knowing the change in the speed – the acceleration – of the fast solar wind gives a direct path to determine the forces on the particles, and this new information provides critical tests to determine exactly which physical process is accelerating the fast solar wind.

   Understanding how the fast solar wind is accelerated will be an extremely valuable piece of our future space weather forecasts. After the eclipse is over, we will observe the Sun and use our new fast solar wind model to predict the speed of the solar wind. With our fast solar wind forecast we will then predict the occurrence and strength of these solar wind interaction regions, and then we can more accurately predict the space weather effects these regions will produce.

2. How will current and future facilities, including the Daniel K. Inouye Solar Telescope and the National Solar Observatory's Integrated Synoptic Program, work together with other facilities and agencies to enhance our knowledge of and future prediction of space weather?

   Answer: The future facilities of the National Solar Observatory will work in complementary ways to improve the accuracy of space weather forecasts. The NSO synoptic program provides nearly real-time data that enhances real-time space weather forecasts. The NSO maps of the magnetic field at the solar surface and the images of the solar atmospheric structures provide valuable inputs into the likelihood of coronal mass ejection (CME) events, and will provide indirect information about the magnetic field structures embedded within those CME events.

   The DKI Solar Telescope will be ground breaking by providing a new ability to routinely measure the magnetic fields in the solar corona near the Sun, in regions just like the erupting regions that cause space weather at the Earth. While modern solar physics proposes that the magnetic field controls the structure and changes that we observe in the solar corona, there are no consistent measurements of the strength of this critical magnetic field! With new precise measurements of the coronal magnetic field, we will develop more accurate models of the structure in the corona and how that structure will change. And most importantly, for the first time we will quantitatively understand the magnetic field that is embedded within coronal mass ejections. With this measurement of the magnetic fields, we will understand how the CME plasma will interact with the Earth's magnetic field and what space weather events this solar plasma can precipitate

Responses by Ms. Michelle Nichols-Yehling

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Great American Eclipse: To Totality and Beyond"

Ms. Nichols-Yehling, Director of Public Observing, Adler Planetarium

Questions submitted by Representative Elizabeth Esty, House Committee on Science, Space, and Technology

1. Ms. Nichols-Yehling, how do we use an event like the Great American eclipse to build momentum in engaging public interest in science?

   Answer: The Great American Eclipse provided an opportunity for the public to engage with a real, and rare, astronomical phenomenon that they could see with their own eyes. No expensive or hard-to-obtain equipment was required. The eclipse passed over the entire United States, and every American in all 50 states had the opportunity to see it in partial or full form. Preliminary estimates are that over 200 million people engaged with this eclipse. This is twice the number that normally watch the largest cultural or sporting events in our country.

   This event showcased that the public *is* interested in science, and we can build upon this monumental show of interest. A key factor in this experience is that the public were directly connected to the sky. This was not science presented on the pages of a textbook. It was not science as seen through the eyes of figureheads from long ago. This was science that could be enjoyed by everyone and which reached everyone where they were, regardless of prior knowledge, experience, or socio-economic background. Additionally, this event involved all of the senses—touch, sight, sound, smell, and hearing, and it was an event with many entry points, including direct observation, scientific study, historical highlights, and cultural connections.This was science at its most real, and how science should be presented.

   With this landscape of multiple points of engagement, the eclipse provided a template for small-scale and large-scale science programs and events to meet people where their interests lie. Support for programs that address science in this multifaceted manner will allow institutions to leverage the opportunity this eclipse provided to meet people where they are and take them where only science can lead.

2. Why is public interest such an important measureable for universities and institutions to use to scale efforts for engaging even more people in science?

   Answer: Public interest is a strong marker of what is important to our country, important to our society, and important to communities. To take part in eclipse events and programs, people had to expend time, money, effort, and energy. Sixty thousand people made the effort to go to the Adler Planetarium to watch the sky together. Hundreds of thousands of people made the effort to obtain Adler's solar viewing glasses. And across the country, millions made the effort to travel to the path of totality of the eclipse. This

investment of effort is a direct measure of the level of interest—and clearly people are interested in science. Science may not be at the forefront of everyone's mind on a daily basis, but they *are* interested. As evidence of public interest grows, universities and institutions will be able to defend expending time, money, effort, and energy to scale their programs accordingly, for interest is only where it begins. From interest grows engagement, from engagement grows progress, and progress in all forms is the purpose of society.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Great American Eclipse: To Totality and Beyond"

Ms. Nichols-Yehling, Director of Public Observing, Adler Planetarium

Questions submitted by Representative Ed Perlmutter, House Committee on Science, Space, and Technology

1. How specifically will this eclipse contribute to our understanding of the Sun and more specifically space weather?

2. How will current and future facilities, including the Daniel K. Inouye Solar Telescope and the National Solar Observatory's Integrated Synoptic Program, work together with other facilities and agencies to enhance our knowledge of and future prediction of space weather?

Answer (for both Questions 1 and 2): My area of expertise is public engagement and outreach. These two questions are best answered by the other panelists who appeared at the hearing, and I respectfully defer to them

Appendix II

Additional Material for the Record

STATEMENT SUBMITTED BY REPRESENTATIVE DANIEL LIPINSKI

OPENING STATEMENT
Ranking Member Daniel Lipinski (D-IL)
of the Subcommittee on Research and Technology

House Committee on Science, Space, and Technology
Subcommittee on Research and Technology
Subcommittee on Space
"The Great American Eclipse: To Totality and Beyond"
September 28, 2017

Thank you, Chairwoman Comstock, Chairman Babin, and all of the witnesses for sharing your insights and experience with us today.

The Great American Eclipse offered up a chance for scientists to obtain one-of-a-kind measurements of the Sun's outer atmosphere, or corona. The 2017 solar eclipse was unique because it traversed a path across a large, continuous land mass. By gathering data along the path of totality, researchers were able to take measurements of the Sun's corona over a time span of 90 minutes, rather than the 2 minutes one would experience from a single site. I look forward to hearing from our witnesses today about how scientists are stitching these observations together to study the structure, temperature, and evolution of the corona.

The key benefit of this dataset is that it informs computer simulations of solar activity. These models help scientists predict and mitigate disruptive solar storms that threaten critical infrastructure like GPS and communications satellites and electric grids. Experiments conducted during the eclipse also enlisted the help of members of the public as data collectors. This was the first total solar eclipse visible across the United States since the advent of the smart phone, and many observers were able to collect data right from their personal devices. For instance, NASA's GLOBE Observer app relied on volunteers to measure cloud and temperature data before and after the eclipse. Other projects involving public participation included the Citizen CATE experiment, in which volunteers across the country used identical telescopes to capture high-resolution images of the eclipse, and the NSF-funded EclipseMob experiment, in which enthusiasts operated radio receivers to study the effects of sunlight on radio and telecommunications signals that travel through the ionosphere.

The 2017 total solar eclipse was also an event that reached beyond the bounds of science. It captured the imagination of millions of Americans, whether they were only able to see the partial eclipse, or they found themselves in the path of totality. Preliminary estimates tell us that about a third of eclipse watchers took photos or recorded video and about one fifth of eclipse watchers posted their recordings to social media. The 2017 solar eclipse was likely the most watched, studied, photographed, and shared solar eclipse in history.

I look forward to learning about the research that was enabled by the eclipse and to hearing the panelists' thoughts on how we can best capitalize on the widespread excitement generated by the eclipse to keep the public engaged with science going forward.

Thank you, again to the witnesses for being here today. I yield back the balance of my time.

STATEMENT SUBMITTED OF COMMITTEE RANKING MEMBER EDDIE BERNICE JOHNSON

OPENING STATEMENT
Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Subcommittee on Research and Technology
Subcommittee on Space
"The Great American Eclipse: To Totality and Beyond"
September 28, 2017

Thank you, Chairwoman Comstock and Chairman Babin for holding this hearing, and thank you to all of the witnesses for being here today.

Before I start my formal remarks, I just want to say that our thoughts are with our fellow citizens in Puerto Rico and the Virgin Islands as they attempt to deal with devastating damage caused by hurricane Maria. We all hope for a swift recovery effort. As Ranking Member of the Science Committee, the Arecibo observatory and the safety of its staff are also on my mind and I hope it will soon be back online.

This morning we are here to talk about something much more lighthearted. Last month the entire country was treated to the sight of a solar eclipse. While most Americans experienced a partial eclipse, millions were fortunate enough to live in or travel to the path of totality to see the Moon completely block out the light from the Sun. The eclipse affected people in different ways depending on their worldview, their background, and their stage in life. For some, the eclipse was a thing of beauty, a once-in-a-lifetime chance to see the faint, feathery corona with their own eyes. For others, the eclipse was a chance to make some extra money. States in the path of totality saw a boost to their economies through tourism; many residents in the path of totality rented out their homes to eclipse watchers; and small businesses held eclipse-themed promotions. Many teachers and parents saw the eclipse as an educational opportunity to teach children about the solar system, and scientists used the eclipse to get data that are otherwise out of reach.

Perhaps the most important impact of the eclipse was the chance it gave us to come together for a shared experience. Some people viewed the eclipse with family and friends, some went outside in the middle of the workday with their co-workers, and others gathered with strangers for an organized viewing event. In a time when Americans are deeply divided on a host of issues, the eclipse brought us together and helped us rise above our differences to experience the beauty of nature and the wonder of science together. The value of that cannot be overstated.

I look forward to hearing from our panel about the value the eclipse has for science, for public engagement with science, for education, and for bringing people together. I yield balance of my time.

REPORT SUBMITTED BY REPRESENTATIVE BILL FOSTER

Americans and the 2017 Eclipse

An initial report on public viewing of the August total solar eclipse

Jon D. Miller
University of Michigan

September 21, 2017

Americans and the 2017 Eclipse:

An initial report on public viewing of the August total solar eclipse

On August 21, 2017, a total solar eclipse crossed the United States from the west coast to the east coast, providing millions of Americans with the first opportunity to see a total solar eclipse in their life time. This experience represents an important stimulus to interest in our solar system and in cosmology broadly. It is important to understand how many American adults viewed the eclipse – in totality or partially – and what impact this experience has had on them.

As a part of an ongoing national study of the development of scientific literacy at the University of Michigan, NASA asked Jon Miller and his team to assess the impact of the August total solar eclipse in terms of the number of adults who viewed the event directly or on some form of electronic media and to estimate the impact of that experience on subsequent interest in and understanding of the solar system and related cosmology.

The University of Michigan/NASA cooperative study[1] of the development of civic scientific literacy is a three-wave study. In February and March of 2017 a national probability sample of 2,915 adults was selected[2] and asked a set of baseline questions designed to estimate their level of civic scientific literacy and their interest in and engagement with science and space-related matters. To assess the preparation for and viewing of the total solar eclipse on August 21, the same sample of adults were asked to complete a short questionnaire – online or by phone – describing their actual viewing experience and their activities in the months prior to the eclipse. This report will describe the initial findings from the baseline and immediate post-eclipse surveys.

A third survey will be conducted with the same individuals in October and November of 2017 to measure the science and eclipse-related activities that eclipse viewers engaged in during the months following the eclipse. The full impact of engagement in an event like the total solar eclipse is a combination of (1) the actual viewing experience, the preparation for eclipse viewing, and short-term discussion and engagement activities directly related to the viewing experience, and (2) subsequent science information seeking activities and the increased learning that comes from additional information acquisition and discussion with friends, family, and colleagues. A final report will be issued in January, 2018, summarizing the full impact of the viewing of the 2017 total solar eclipse.

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[1] The 2017 Michigan Scientific Literacy Study is supported by a collaborative agreement between the University of Michigan and the National Aeronautics and Space Administration (award NNX16AC66A). The author gratefully acknowledges this support, but any errors or omissions are the responsibility of the author and not of NASA or any of its staff or officers.

[2] The data collection for the Michigan Study is conducted by AmeriSpeak, an address-based national probability sample of U.S. households operated by the National Opinion Research Center at the University of Chicago. AmeriSpeak uses a combination of online questionnaires and telephone surveys, reflecting the preference of each respondent. A complete description of the AmeriSpeak Panel and its sample can be found at: http://d3qi0qp55mx5f5.cloudfront.net/amerispeak/i/research/AmeriSpeak_Technical_Overview_2017_05_09.pdf?mtime=1494625611.

How many American adults viewed the total solar eclipse?

To obtain an accurate estimate of the viewership of the total solar eclipse, all of the adults that were surveyed in February and March were asked to complete a short follow-up survey about their experiences on August 21st. The online survey and telephone interviewing began on the evening of August 21st hours after the eclipse and continued through the end of Labor Day. This short window was used to assure more accurate recall by respondents. Of the original 2,925 baseline respondents, a total of 2,175 participants were reached and persuaded to participate in the immediate follow up – a response rate of 74% of the baseline sample.

A total of 154 million American adults – 62.8% of all adults age 18 or older – viewed the eclipse directly (see Table 1). An additional 61 million adults who did not see the eclipse directly viewed the eclipse electronically on a television, computer, tablet, or smart phone screen. Twelve percent of American adults – about 29 million – reported that they did not see the eclipse in person or electronically. A total 215 million American adults viewed the eclipse directly or electronically, or 88% of American adults.[3]

Table 1: Viewing of the total solar eclipse, 2017.

	Percent	Number*	N
Did not view the eclipse directly or electronically	12.0	29,425,000	261
Viewed the eclipse electronically, not directly	25.2	61,575,000	547
Viewed the eclipse directly in home town	54.7	134,025,000	1,191
Traveled to another city to view the eclipse	8.1	19,782,000	176
Total	100.0	244,807,000	2,175
* Population estimates are rounded to the nearest whole thousand.			

Although the total level of viewing directly and electronically is very high, it is important to ask whether some groups were significantly more likely to experience the eclipse than others. An analysis of some of the major demographic groups shows that there is no difference in the frequency of eclipse viewing by men and by women, but that there are small, but statistically significant, differences by age, education, and the degree of totality in an individual's home area (see Table 2).

Younger adults were slightly more likely to view the 2017 total solar eclipse directly than were older adults, but older adults were more likely to watch the event electronically than were young adults (see Table 2). When direct viewing and electronic viewing are combined, young adults were slightly more like to have seen the eclipse than older adults. The gamma[4] for this relationship is -0.17.

American adults with higher levels of formal education were more likely to have viewed the eclipse directly than were adults with less formal education. The differences were moderate – 11% of college graduates did not see the eclipse at all compared to 19% of adults who did not finish high school. Less well educated adults were more likely to have viewed the eclipse electronically than better educated adults (see Table 2).

[3] Comparatively, Nielsen reported that 111 million Americans watched the 2017 Super Bowl.

[4] Gamma is an ordinal proportional reduction of error statistic and can be interpreted the same as a Pearson's r^2. For a discussion of gamma and other PRE statistics, see Costner (1965).

It is not clear whether this differential reflects a higher level of interest by better educated adults or a lack of job and time flexibility by less-well-educated adults. The gamma for this relationship is 0.19.

It is possible to compute the degree of totality for each respondent's city or area and the results indicate that adults who live closer to the path of totality were more likely to have viewed the eclipse directly (see Table 2). Slightly more than three-quarters of adults living in areas of 90% to 100% totality reported viewing the eclipse directly, compared to 54% of adults living in areas with less than 70% totality. Surprisingly, adults who live in areas of higher totality were more likely to reporting traveling to another

Table 2: Frequency of eclipse viewing, by selected demographic group, 2017.

	Did not view	Viewed electronically only	Viewed in-person in home area	Traveled to view in another area	N
All U.S. Adults	12%	25%	55%	8%	2,175
Gender					
Female	11	27	54	8	1,122
Male	13	23	55	9	1,052
Age					
18 to 29 years	10	22	58	10	464
30 to 39 years	12	18	62	8	371
40 to 49 years	10	20	60	10	358
50 to 59 years	14	26	52	8	388
60 to 69 years	13	32	49	6	350
70 or more years	15	39	41	5	242
Education					
Less than high school	19	28	40	13	155
High school graduate/GED	12	31	51	6	1,081
Associate degree	10	29	54	7	204
Baccalaureate	11	18	59	12	408
Graduate/professional degree	11	12	67	10	322
Degree of Totality					
Less than 70%	14	32	50	4	411
70% to 79%	16	30	46	8	562
80% to 89%	12	25	54	8	566
90% to 100%	7	16	67	10	634

area to improve their viewing experience. While this may seem counter intuitive, it suggests that individuals who live close to totality were willing to make the shorter trip than individuals living much farther away. In future analyses, we expect to use the available GIS information about each individual's address and the location from which they viewed the eclipse to quantify the travel distances involved.

The nature of the viewing experience

Seventy-five percent of the 154 million America adults who viewed the solar eclipse directly watched the event with other friends, family, or co-workers (see Table 3). Adults who viewed the eclipse in their home area were slightly more likely to have viewed it alone than those who traveled to another site. A third of Americans who viewed the eclipse directly reported that they watched along with co-workers, suggesting that the mid-day viewing occurred on a break from normal work activities. Thirty percent of viewers indicated that they viewed the eclipse with their spouse or partner, and 23% said that they watched the eclipse with their children or grandchildren. Only three percent of all viewers reported that they watched the eclipse as a part of group activity organized by a local astronomy group, planetarium, science center, or similar organization.

Seventy-four percent of adult viewers indicated that they used special solar glasses to observe the eclipse. Eighty-three percent of adults who traveled to another location to get a better view indicated that they used solar glasses (see Table 3).

A third of adult viewers reported that they photographed the eclipse or made a video recording of the event. About one in five adults who viewed the eclipse indicated that they posted a picture or commentary on social media to share the experience. Twenty-seven percent of adults who traveled to another location to view the eclipse reported posting their pictures or experiences on social media (see Table 3).

Most adult viewers of the eclipse characterized it as enjoyable and educational. When asked to agree or disagree with the statement "watching the eclipse was an enjoyable experience," American adult viewers of the eclipse gave the experience a mean rating of 7.6 using a zero-to-10 scale. When asked to agree or disagree with the statement that "watching the eclipse was an educational experience," the same adults gave a mean rating of 7.0 using a zero-to-10 scale (see Table 4).

When asked more specifically about learning more about "the Sun and the solar system" from watching the eclipse, the mean level of agreement dropped to 4.9 – just below the mid-point on a zero-to-10 scale (see Table 4). For a statement that they planned to "learn more about the Sun and the solar system in the near future," the mean level of agreement dropped to 4.5 on the same zero-to-10 scale. These results suggest that many adults found the eclipse viewing experience to be enjoyable, but only a smaller proportion were stimulated to plan additional solar learning activities in the coming months.

Table 3: The August solar eclipse viewing experience, 2017.

	Used solar glasses	Made photo or video recording	Posted on social media	Viewed .... *						N
				Alone	With spouse or partner	With children or grandchild	With co-workers	With friends	At organized event	
All direct viewers	74%	34%	18%	24%	30%	23%	33%	29%	3%	1,366
Viewers in home area	73	34	17	27	29	23	32	29	3	1,191
Viewers in other area	83	38	27	9	37	22	37	30	5	175

* Note: The percentages will exceed 100% because a respondent may have viewed the eclipse with various combinations of viewers (i.e., spouse, children, and friends).

Table 4: Mean viewer assessment of the 2017 viewing experience.

	All viewers	Viewed in home area	Traveled to view in another area
Watching the eclipse was an enjoyable experience.	$7.6_{(0.07)}$	$7.5_{(0.08)}$	$8.1_{(0.19)}$
Watching the eclipse was an educational experience.	$7.0_{(0.08)}$	$6.9_{(0.09)}$	$7.5_{(0.21)}$
I learned about the Sun and the solar system by watching the eclipse.	$4.9_{(0.09)}$	$4.9_{(0.10)}$	$5.0_{(0.23)}$
I plan to learn more about the Sun and the solar system in the near future.	$4.5_{(0.09)}$	$4.5_{(0.10)}$	$4.6_{(0.24)}$
Note: Cell entries are the mean score on a zero-to-10 scale, with zero representing complete disagreement with the statement and 10 meaning complete agreement with the statement. The standard error of the mean is shown in the subscript parentheses.			

What was the impact of prior understanding of an eclipse on actual viewing?

Half of American adults understood the meaning of a total solar eclipse six months prior to the August event. In the February-March baseline survey, each respondent was asked to provide an explanation of a total solar eclipse in an open-ended question and 49% of American adults were able to provide a scientifically correct answer. Were those adults who understood the idea of a total solar eclipse prior to the event more likely to view the eclipse than adults who did not have a prior understanding of an eclipse? The results of the 2017 Michigan study indicate that American adults who had a prior understanding of a total solar eclipse were slightly more likely to view the eclipse directly than were adults who did not have this understanding six months prior to the event (see Table 5).

A second measure of prior understanding uses a question about the relative position of the Earth and the Sun. This question has been asked of national probability samples of Americans since 1988 and is a component of Miller's Index of Civic Scientific Literacy (Miller, 1983, 1987, 1995, 1998, 2000, 2004, 2010a, 2010b, 2012; Miller, Pardo, & Niwa, 1997), but it is a useful stand-alone question because it demonstrates an understanding of the rotation of the Earth and the Sun. The first part of this question asks whether the Earth rotates[5] around the Sun or the Sun rotates around the Earth. Those respondents who indicated that the Earth rotates around the Sun were then asked if the Earth rotates around the Sun once a day, once of month, or once a year. Individuals who were able to report that the Earth rotates around the Sun once a year are classified as having provided a correct response and all other responses are coded as incorrect. In early 2017, 62% of American adults were able to describe the relationship of the Earth and the Sun correctly.

American adults who understand the relationship of the Earth and the Sun were slightly more likely to view the August total solar eclipse directly than adults who did not understand this relationship. Sixty-nine

[5] Some astrophysicists have observed that this statement implies that the Sun is stationary and that the Earth rotates around it. The authors of this question understand that our heliosphere is rotating around the center of a large spiral galaxy at a substantial speed and that none of these objects are stationary. Given the limits inherent in questionnaire wording, nearly 30 years of experience with this question leads us to conclude that most respondents do not think that it implies a stationary Sun and that those that might be confused often have a more fundamental misunderstanding of the solar system and the universe.

percent of adults who understand this relationship viewed the eclipse directly (at home or elsewhere) compared to 53% of adults who did understand this relationship. The gamma for this relationship is 0.25, meaning that 25% of the variance in viewing can be attributed to this form of prior understanding.

Table 5: The impact of prior understanding on the likelihood of viewing the 2017 eclipse.

	Did not view	Viewed electronically only	Viewed in-person in home area	Traveled to view in another area	N
All U.S. Adults	12%	25%	55%	8%	2,175
Understanding of total solar eclipse [G = 0.18]					
Incorrect	14	27	52	7	1,113
Correct	10	23	58	10	1,063
Understanding of Earth and Sun [G = 0.25]					
Incorrect	16	31	45	8	822
Correct	10	22	61	8	1,354
Civic Scientific Literacy [G = 0.29]					
Not scientifically literate	12	30	51	6	1,501
Scientifically literate	11	14	63	12	673

A third – and more comprehensive measure – of prior understanding is Miller's Index of Civic Scientific Literacy (Miller, 1983, 1987, 1995, 1998, 2000, 2004, 2010a, 2010b, 2012; Miller, Pardo, & Niwa, 1997). The CSL Index is a measure of an individual's understanding of a core set of scientific constructs – the nature of matter, energy, and life – and should be thought of as an indicator of an individual's cognitive toolbox for reading and understanding quality science journalism. Approximately 30% of American adults age 18 and older qualify as civic scientific literate. American adults who are scientifically literate were more likely to view the eclipse directly (at home or elsewhere) than adults who are not scientifically literate (see Table 5). The gamma for this relationship is 0.29.

The strength of association between these three measures of prior understanding and subsequent viewing behavior was consistently positive and ranged from 0.18 to 0.29, indicating that some level of prior understanding serves as a foundation for thinking about a forthcoming event and enables an individual to know where and how to obtain additional information about an event – the total solar eclipse in this case – prior to the event or experience. This relationship has been documented in the informal science learning literature for several decades, but it has been observed more often in regard to an exhibit or staged event rather than a major natural event like the 2017 eclipse.

How did individuals prepare for viewing the 2017 solar eclipse?

The preceding analyses have outlined the magnitude of the public viewing experience on August 21 but it is useful to inquire about the level of information seeking and preparation in the months prior to the event. For several months prior to the August eclipse, NASA and a national coalition of informal science learning organizations worked to raise public awareness about the August eclipse and to improve public understanding of some of the safety issues involved in direct observation of the Sun. For future

programming efforts for similar natural and planned events, it is important to examine the kinds and frequency of information acquisition activities that interested adults used to improve their understanding of the forthcoming eclipse and related solar system questions.

Respondents to the post-eclipse survey were asked to identify the kinds of eclipse relevant information acquisition activities they engaged in and report how many times they engaged in each activity in the two months prior to the eclipse (see Table 6). The two most common activities – talking to one's co-workers and family – involved interpersonal communication rather than broadcast or electronic media. Using

Table 6: Information acquisition activities in the months prior to the 2017 eclipse.

Information Acquisition Activity	All Viewers	Did not View	Viewed electronically only	Viewed in-person in home area	Traveled to view in another area
Talked to your friends or co-workers about the solar eclipse?	4.0	2.0	3.0	4.6	5.6
Talked to other members of my family about the solar eclipse?	2.7	1.2	2.1	3.1	3.9
Read a story about the solar eclipse in a newspaper or magazine (printed or online)?	2.3	0.9	1.8	2.6	3.5
Looked for information about solar eclipses on the Internet?	1.9	0.4	1.2	2.3	4.0
Talked to my children about solar eclipses?	1.4	0.5	0.8	1.7	2.2
Look for information about the solar eclipse at a public library (in person or online)	1.0	0.3	0.7	1.3	1.5
Watched a television show about solar eclipses?	0.7	0.2	0.7	0.8	0.7
Listened to a podcast about solar eclipses?	0.3	0.1	0.2	0.3	0.5
Printed or saved an Internet article or report about the solar eclipse?	0.2	0.1	0.1	0.3	0.6
Read a book (print or electronic) about solar eclipses?	0.1	0.1	0.1	0.2	0.2
Attended or streamed a lecture about solar eclipses?	0.1	0.0	0.1	0.1	0.2
Visited a planetarium or science center/museum to learn about solar eclipses?	0.1	0.0	0.0	0.1	0.1
Read or contributed to a blog about solar eclipses?	0.0	0.0	0.1	0.2	0.1
Mean number of eclipse information acquisition activities	$15.0_{(0.38)}$	$5.9_{(0.59)}$	$10.9_{(0.58)}$	$17.6_{(0.54)}$	$23.6_{(1.77)}$

Note: Cell entries are the mean number of times survey respondents reported doing an eclipse-related information acquisition activity during the two months prior to the eclipse. The number of reported information acquisition activities ranged from zero to 132 for the two-month reporting period. The standard error of the mean is reported for only the total number of information acquisition activities and is shown in subscript parentheses.

this two-month window, American adults reported an average of four conversations with friends and co-workers during the two months prior to the eclipse. More than 60 years ago, Katz and Lazarsfeld (1955) outlined the power of personal influence in a landmark study and these data confirm the continuing importance of interpersonal conversation in the development of interest and the sharing of information. The same adults reported an average of 2.7 conversations with other family members during the two months prior to the eclipse and 1.4 conversations or discussions with their children or grandchildren.

Newspaper and magazine stories (printed or online) were the third most frequent source of information about the forthcoming solar eclipse, with adults reporting that they read an average of 2.3 stories relevant to the eclipse during the two months prior to the event. During the same period, adults reported an average of 1.9 internet searches about the solar eclipse (see Table 6). These adults also reported using a public library (in-person or online) at least once during the two months prior to the eclipse. It is possible that some newspapers or magazines were consulted during library visits, but the granularity of the survey does not allow us to discern what kinds of materials were consulted or used.

In contrast, the adults in the 2017 eclipse follow-up study reported watching a television show about the solar eclipse slightly less than one time during the two months prior to the event. The use of podcasts, books (printed or electronic), lectures (attended or streamed), and reading or contributing to a blog was cited less often that once every two months (see Table 6). Few adults reported visiting a planetarium, science center/museum, or similar facility as a means to obtain information about the forthcoming solar eclipse.

When these information acquisition activities are combined, America adults engaged in an average of 15 information seeking activities in the two months prior to the eclipse. Those adults who eventually viewed the solar eclipse directly were more likely to have engaged in a larger number of information seeking activities than adults who saw the eclipse only on television or a computer or phone screen or who did not see it at all (see Table 6). Adults who traveled to see the eclipse in an area of higher totality reported an average of 23.6 information seeking activities prior to the eclipse, and individuals who watched the eclipse in their home city or area reported an average of 17.6 information seeking activities in the two months before the eclipse. In contrast, adults who did not see the eclipse at all reported only 5.9 information acquisition activities in the months prior to the event.

Conclusions and Implications

The first two waves of the 2017 Michigan Scientific Literacy Study finds that approximately 154 million American adults watched the total solar eclipse on August 21, 2017. An additional 61 million adults viewed the total solar eclipse on a television, computer, tablet, or smartphone screen (but not directly). This is a level of exposure that dwarfs the viewership of Super Bowl games and ranks among the most viewed events in American history.

Most of the adults who viewed the eclipse found it to be enjoyable and educational. Three-quarters of eclipse viewers obtained and used special solar viewing glasses. Most adults viewed the eclipse with friends, family, children, or co-workers. Nearly 20 million American adults traveled to a place other than their home city to improve their view of the eclipse and to increase the level of totality observed.

During the two months prior to the eclipse, millions of American adults engaged in a wide array of information seeking and acquisition activities to improve their understanding of the forthcoming event. The average American adult reported 15 information seeking activities in the months prior to the eclipse, and those adults who viewed it directly or who traveled to another location to improve their view reported even higher levels of eclipse-related information seeking prior to the event itself. In the October-November follow-up survey of these same individuals, we will explore in greater depth their post-eclipse information seeking activities and any longer-term changes in their interest in science or space. We expect that the

largest amount of information seeking activity will occur subsequent to the viewing of the eclipse, but it is important to examine and understand both pre-eclipse and post-eclipse information acquisition activities.

We hope that this baseline work and future measurements and analysis will be helpful to NASA and the informal science learning community in advancing our understanding of the development and maintenance of civic scientific literacy in the United States.

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Statement for the Record
Hearing of the House Committee on Science, Space, and Technology
Subcommittee on Research and Technology,
"The Great American Eclipse: To Totality and Beyond"
September 28, 2017

- One of our shared goals as members of this committee is to inspire young people to pursue fields in science, technology, engineering, and math (STEM).

- Leading up to and in wake of the Great American Eclipse, we learned some important lessons about inspiring young people to get excited about science: sometimes, all it takes is a most amazing natural phenomenon.

- That was certainly the case for folks back home in central and northwest Connecticut.
    - John J. McCarthy Observatory in New Milford hosted an eclipse event, where volunteers provided telescopes, binoculars, and solar eclipse glasses to attendees. Volunteers raffled off a child's space pod playhouse, which they described as "big enough for small, future astronauts to enter."
    - Central Connecticut State University's Copernican Observatory and Planetarium offered easy-to-follow instructions online on how to make pinhole projections to view the partial eclipse in Connecticut.

- As awe-inspiring as it was, we can't rely on a natural phenomenon to engage tens of millions of people.

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