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

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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.