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

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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