Citizen CATE Experiment: Prototype Testing and Plans

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Abstract

An off-the-shelf small refracting telescope and digital imaging system was purchased and tested for application to a citizen science experiment to be run during the 2017 total solar eclipse. Ease of set-up, imaging ability, and sensitivity tests were done, and then the telescope was shipped to take data at the 2015 total solar eclipse from the Faroe Islands. Details of the equipment, results from the tests, and plans for future eclipses are discussed.

1. Introduction

The path of the total solar eclipse of 21 August 2017 passes over about 10 million homes in the USA. Tens of millions more people will travel to the path of totality to view the eclipse first-hand. Using TV and the internet broadcasts, hundreds of millions of people will watch the eclipse, making the event the most viewed astronomical event in the history of mankind.

A number of citizen science projects for the eclipse have been proposed, including combining images from smartphones taken by people across the continent into a movie sequence (Hudson et al., 2012). The Citizen Continental-America Telescopic Eclipse (CATE) Experiment for 2017 is being developed at the National Solar Observatory in partnership with universities, amateur astronomy clubs, and corporations. If the 2017 total eclipse is viewed at one location along the path of totality, for instance at the town park in Rosebud, Missouri, people will see the solar corona during totality for only two and one-half minutes. But, from the time the shadow of the moon touches the coast of Oregon until it leaves the coast of South Carolina, 90 minutes of time will have elapsed. The Citizen CATE experiment will use more than 60 identical telescopes equipped with digital cameras positioned from Oregon to South Carolina to image the solar corona. The project will then splice these images together to show the corona during a 90 minute period, revealing for the first time the plasma dynamics of the inner solar corona.

The goals for the highly leveraged CATE experiment are diverse and range from providing an authentic STEM research experience for students and lifelong learners, to making state-of-the-art solar coronal observations of the plasma dynamics of coronal polar plumes, to increasing the US scientific literacy. The data collected for the 2017 eclipse will be freely available to the scientific, education and amateur astronomy communities. Moreover, the eclipse ends at about 3pm on the South Carolina coast, about 3 hours before the start of the evening news; as the total eclipse progresses across the country the CATE team will begin assembling a first-cut movie sequence, and will aim to deliver it to TV media to show on the evening news that night. A live webcast from the path of totality is also planned.

One aim of the Citizen CATE experiment is to boost the Citizen Science participation in astronomy in the United States, and an effective way to do that is to ensure that after the total eclipse, the eclipse instrument goes home with the volunteer citizen scientists. These volunteers will be taking time off from work on Monday (or more days), they will be traveling to a location along the eclipse path at their own expense, and they will be taking part in training programs before the event. It is exactly these people who are motivated the most to continue to engage in citizen science with this equipment after the eclipse, and so it is imperative that the equipment becomes their personal property. Because of this, no public funding for the Citizen CATE equipment is being requested. Private and corporate support is being developed for all of the equipment expenses for the project. Currently the CATE project has a letter of agreement with DayStar Filters, LLC, to donate 60-100 telescopes for the 2017 eclipse. We expect to develop several more corporate partnerships, making the Citizen CATE project highly leveraged.

2. The CATE Instrument

The ideal eclipse imaging equipment will track the Sun throughout the event, will have a field-of-view of about 1 degree square, will use a B&W CCD camera with about 2000x2000 pixels, the camera will be sensitive enough to allow for short exposures and the data storage rate for the camera will allow for several frames per second (exposure time limited). The start time for each exposure should be recorded and saved in each image. Developing more detailed requirements can be done as follows (see Figure 1 for a graphical representation of these constraints):

1. CATE camera will be at prime focus: Having the CATE camera at prime focus means fewer optics required (i.e. just primary lens) and so this reduces the overall cost. It also means that the telescope is easier to use for follow-up observations by the volunteers, and will remain flexible.

2. 2" resolution at 600nm or better: D>=60mm: Using lambda/D at 600nm wavelength gives us a diameter of the primary lens greater than or equal to 60mm for 2 arcsecond resolution.

3. large FOV of 4000x4000 arcseconds, in focus: f/ >=5: Having a FOV larger than 1 degree across with a flat focal plane becomes much more difficult as the f/ of the primary lens decreases. This is an estimate, but a good guess is that the f/ of the primary should be f/5 or greater to make this lens easy to manufacture with a flat focal plane and minimal chromatic aberration.

4. FOV is 4000 arcsec on a side on the camera 177 <= focal length <= 770mm: The largest CCD detector today is the Canon APS-C sensor, which has a width of 14.9mm, and the smallest common detector is an iPhone5 with a width of 3.42mm. The fact that the 4000 arcsecond FOV must fit on this detector then constrains the focal length of the system to be less than 770mm and greater than 177mm. Note that at D=60mm, and f/5 or greater, the iPhone5 detector will not show 4000 arcseconds.

5. Telescope is portable: focal length <= 1000mm: These telescopes must be shipped and then transported to remote locations in order to view the eclipse. Having a focal length of less than 1m will help make these more portable. Note that the largest CCD detector size already constrains the focal length to be 770mm or shorter.

We can also develop derived requirements as follows:

1. Since we f/5 or greater at 60mm implies that the detector must be larger than 5.81mm width (larger than 1/1.6" size).

2. Cost constraints likely imply that D <=120mm

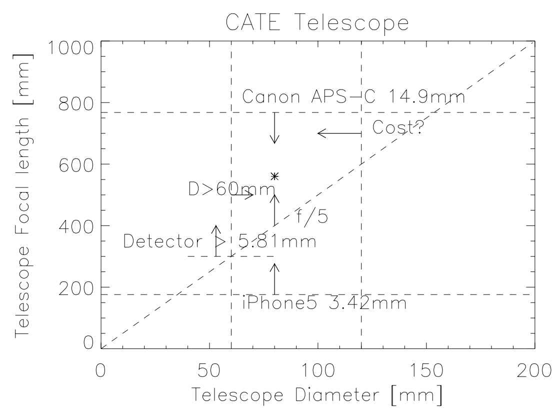

Figure 1 – The parameter space of telescope diameter vs. telescope focal length, and the constraints for the optimal CATE telescope, as discussed in the text. The prototype telescope is shown by the asterisk.

The proto-type for the Citizen CATE Experiment has been defined. The test instrument will be an 80mm f/7 refractor and a 2048x2048 CMOS detector with 5.5 micron pixels. The pixel scale will thus be 2.03 arcseconds per pixel, and the FOV on the array will be 4157 x 4157 arcseconds. The telescope will be mounted on a German Equatorial mount with a RA drive powered by two "D" batteries. The data collection computer will be a Windows laptop and the detector will communicate with the laptop over a USB3 cable. Extra power for the camera will be provided by a rechargeable battery pack. Finally, a full aperture neutral density filter will allow drift calibration data to be taken during the partial phases of the eclipse. The control laptop will be a 1.7GHz, 4Gbyte DDR3, 1TByte disk, USB3, 15-inch display running Windows. The system as of January 2015 is shown in Figure 2.

Figure 2 – The prototype instrument for the Citizen CATE experiment.

3. CATE Science Goals

As 2017 will be near the expected minimum between sunspot cycles 24 and 25, there may not be a CME event occurring during the 90 minutes of the eclipse. However, we are certain that during this eclipse, the solar corona will have a bi-polar structure associated with sunspot minimum, and the solar poles will be very pronounced. For this reason, the science target for the CATE experiment will be a study of the dynamics of polar plume events.

The polar plumes, which are dramatically visible in the corona seen at solar minimum, show very dynamic changes. DeForest and Gurman (1998) found upwardly moving density enhancements of 5-10%, traveling at 75-150 km/s velocity and displaying periodicity at 10-15 minute periods using the SOHO EIT 171A observations. Cranmer (2004) estimated 3-15% variations in the electron density in these events. Using UVCS observations at two alternating heights in the corona (R=1.9 and 2.1 Rsun), Ofman et al (2000) found quasi-periodic variations of 5-10% in polarized brightness traveling radially at 210 km/s with periods between 6.5 -10.5 minutes. Morgan et al (2004) used Lyman alpha data to find oscillations with 7-8 minute periods persisting out to 2.2 Rsun. Gupta et al (2012) used Sumer observations of Ne VIII emission on the solar disk to find 5-10% intensity oscillations traveling at 60 km/s with a period of 14.5 minutes. While changes in the corona above the southern solar pole are visible in the two images taken 19 minutes apart during a solar eclipse by Pasachoff (2009), it is difficult to find systematic radial motion using the two images. The CATE data will profoundly impact the study of these events. With 540 images taken at 10 second cadence across 90 minutes, the motions of these density enhancements will be measured. Periodicities at the 15 minute time scale will be fully sampled, and the velocities and accelerations of these events will be measured from R=1.05 Rsun out to at least 2Rsun. The CATE data will be sensitive to transverse velocities of roughly 0.8 to 145 km/sec (3pix/90 min to 1 pix/10 sec) and will easily measure these events.

It is likely that during the eclipse there will be prominences visible at the solar limb. Using data from the Hinode SOT instrument, Berger et al (2007) show upwardly moving hot gas parcels, presumed to be Rayleigh-Taylor instabilities, rising in prominences. Typical sizes were 2250 km, with upward speeds of roughly 20 km/s. Lower resolution white-light eclipse images from Druckmuller et al (2014) point to a new type of static structure observed near a prominence called a "smoke ring", and the authors speculate that these structures may be related to the RT instabilities seen in prominences. The CATE data will show the motions of these new coronal structures during the 90 minutes of the eclipse, with a transverse velocity sensitivity which easily covers the expected 20km/s motion. For the first time, these observations will reveal how the instabilities seen in prominences interact with the corona and produce density enhancements or depletions as shown by white-light observations.

4. Prototype Sensitivity Tests

Intensities in the outer corona at Rsun=2.0 may be 300 to 1000 times fainter than the inner corona; however the coronal intensity in this region is brighter than the Earthshine seen on the moon during the eclipse. In turn, the Earthshine intensity during an eclipse is brighter than the Earthshine during the crescent phase of the moon (Rodriguez, Palle & Goode, 2007). Figure 3 shows a single 538 msec exposure with the prototype telescope with the Earthshine from the crescent moon clearly visible; stars are also visible near the dark limb of the moon. From this image and subsequent images of planets, we conclude that we will measure the coronal intensity features at Rsun=2.0 with a signal to noise level of about 100 by coadding about 16 frames with this exposure value.

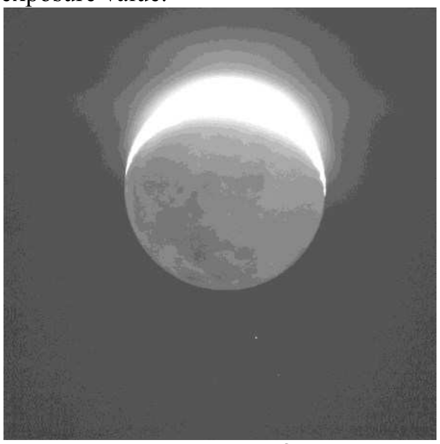

Figure 3 – Earthshine image of the crescent moon as seen with the CATE prototype instrument.

5. CATE at the 2015 Eclipse: Results

During August 2014, the AAS held an eclipse planning meeting, organized by Shadia Habbal and Penn, at the University of Missouri, Columbia. There, Penn spoke about the CATE experiment and developed ties with Baer and Isberner. After NSO purchased a proto-type telescope, Penn tested the telescope in Tucson. In discussions with Baer and Isberner, a plan to ship the telescope to join Isberner during the 20 March 2015 solar eclipse in Torshavn, Faroe Islands. First, the prototype was shipped to SIU Carbondale, and during only two clear days, Isberner was trained by Baer about the telescope and camera use. The prototype used a Pt. Grey Grasshopper 3 CMOS camera, and at that point only the test software (FlyCapture) was working on the instrument laptop. A set of two exposure times was planned for totality, but Isberner would have to make this adjustment with the non-user-friendly FlyCapture package.

The telescope was then shipped by NSO from SIU-Carbondale to Torshavn, and Isberner met the packages at his hotel. Weather during the day of the eclipse in the Faroe islands was not good, but Isberner set up the telescope mount in the hotel parking lot in the rain. A few minutes before totality, the sky became partly-cloudy, and Isberner successfully captured images of the partial phase, and ran the drift-test calibration procedure planned for the CATE experiment. The weather stayed partly cloudy, and Isberner then captured about 30 seconds of data at one exposure value during the total solar eclipse (see Figure 4). This was the shortest exposure value, and captured the intensity only in the inner solar corona. While Isberner was switching to the other exposure value, the clouds returned, and no more images of the solar corona were captured.

The solar corona image in Figure 4 is a successful test of the idea for the CATE experiment. A citizen scientist who had never captured a digital image through any type of telescope was successfully trained, set-up the telescope at the site, took calibration data and took data during the totality phase of the solar eclipse. In many ways, Isberner's task was much more complicated than the task imagined for the CATE volunteers: he was trained for only two days, he traveled half-way around the world, he used only proto-type software, and he encountered very poor weather. His work provides an excellent validation of the process (and the training skill from Baer) and provides the model for which the undergraduate students in this program will be trained.

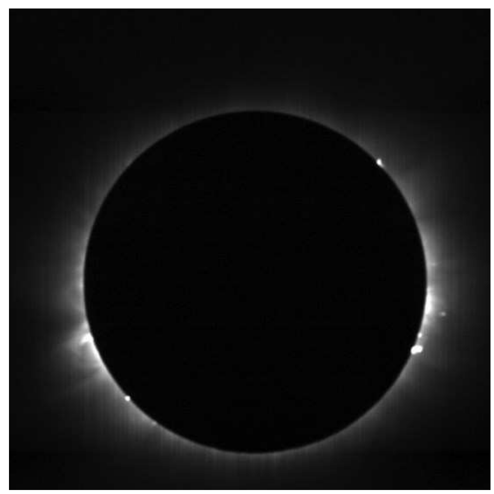

Figure 4 – Image of the inner corona, taken by Fred Isberner from the Faroe Islands using the CATE prototype instrument. Only one exposure value was used in the test since clouds covered the corona after about 40 seconds of time.

6. Application to other Citizen Science

The telescope and imaging camera in the CATE prototype telescope are fully functional for wide FOV night time studies as well. Some sample images taken during the testing period of the Orion Nebula and the Double Cluster in Perseus are shown in Figure 5 and 6. Several follow-up citizen science campagins will be developed, for the volunteers, and in particular, they will be encouraged to participate in comet observing programs as coordinated by Padma Yanamandra-Fisher for the ISON, Sliding Springs and Churyumov-Gerasimenko comets. The FOV and the sensitivity of the CATE instruments will allow observations of cometary structures and evolution, and (with additional equipment) could facilitate the collection of low-resolution cometary spectra..

Another popular citizen science project that will benefit from participation by the Citizen CATE volunteers is the AAVSO Citizen Sky program. Penn has an ongoing conversation with the ex-President of the AAVSO Arne Henden concerning the CATE instrumentation, and how it can be used for variable star observations. While no formal collaboration has been established at this point, we hope to have the eclipse volunteers participate in the Citizen Sky program. This will provide another avenue for sustaining the interest of the Citizen CATE volunteers, and providing an exceptional opportunity for leveraging even more scientific output from these motivated participants.

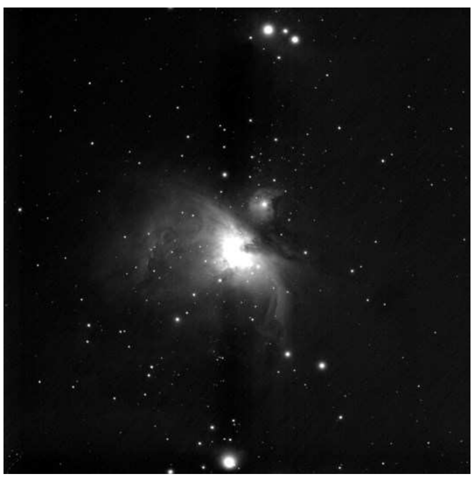

Figure 5 – Image of the Orion nebula taken with the CATE prototype telescope, constructed from 1500 images and representing 1050 seconds of exposure time.

7. Conclusion

The CATE project is seeking collaborations with interested individuals or organizations in order to implement this advanced citizen science project for the 2017 total solar eclipse, and to instigate follow-up citizen science projects after the 2017 eclipse.

The project has a Google site page which describes many more details here: https://sites.google.com/site/citizencateexperiment/home

People interested in participating in the project, or companies or private parties interested in sponsoring the CATE equipment costs, are encouraged to contact one of the authors at the emails provided above.

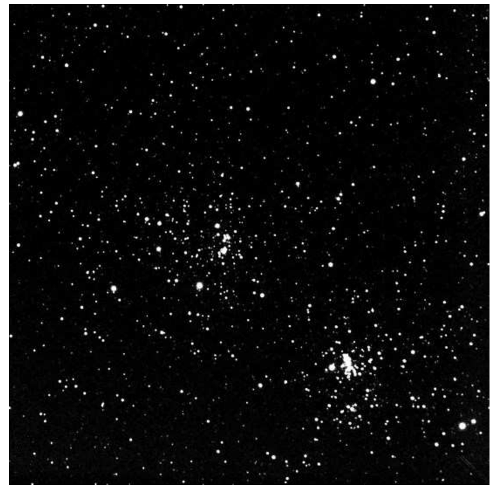

Figure 6 – Image of the double cluster in Perseus, taken with the CATE prototype instrument.

8. Acknowledgements

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