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THE SOLAR TWO GAMMA-RAY OBSERVATORY: Astronomy between 20-300 GeV

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Abstract

The Solar Two Gamma-Ray Observatory is a ground-based instrument designed to detect 20-300 GeV gamma rays by sampling the Cherenkov light generated as gamma rays and cosmic rays interact with the atmosphere. The observatory utilizes the facilities of the Solar Two Power Plant in Barstow, CA which has the largest heliostat mirror area in the world with over 2,000 heliostats. Thus, Solar Two has the potential to be the most sensitive ground-based gamma-ray detector between 20-300 GeV. A secondary mirror system capable of viewing 32 heliostats has been built and is being calibrated. We report on the design and testing of this secondary mirror system including the PMT camera, electronics, and heliostat field.

1 Introduction:

The field of gamma-ray astronomy exploded during the last decade largely due to the success of two instruments: the EGRET detector onboard the Compton Gamma-Ray Observatory (CGRO) satellite (100 MeV-20 GeV) and the Whipple 10 meter imaging atmospheric Cherenkov telescope (ACT) in southern Arizona (300 GeV-20 TeV). However, many of the questions in gamma-ray astronomy will only be answered by opening the unobserved 20-300 GeV energy window. Three different approaches are currently being pursued to narrow the energy gap between ground-based and space-borne gamma-ray instruments.

On the space side, GLAST is an instrument in development intended to observe between 20 MeV-300 GeV and is planned for flight in 2005. The ground-based VERITAS is an array of ACTs with an estimated energy threshold of $\sim$75 GeV and a planned completion in 2003. A third detector uses existing solar power plant facilities to observe 20-300 GeV gamma rays by collecting the light from individual heliostats with photomultiplier tubes (PMTs) placed on the central receiver (Figure 1). While all three types of detectors plan to observe the same energy region, the solar power plant detectors have two advantages over the ACT arrays and satellites: 1.) they will be ready for observations sooner and, more importantly, 2.) they can be built for 1/10th the cost of ACT arrays and 1/100th the cost of satellites.

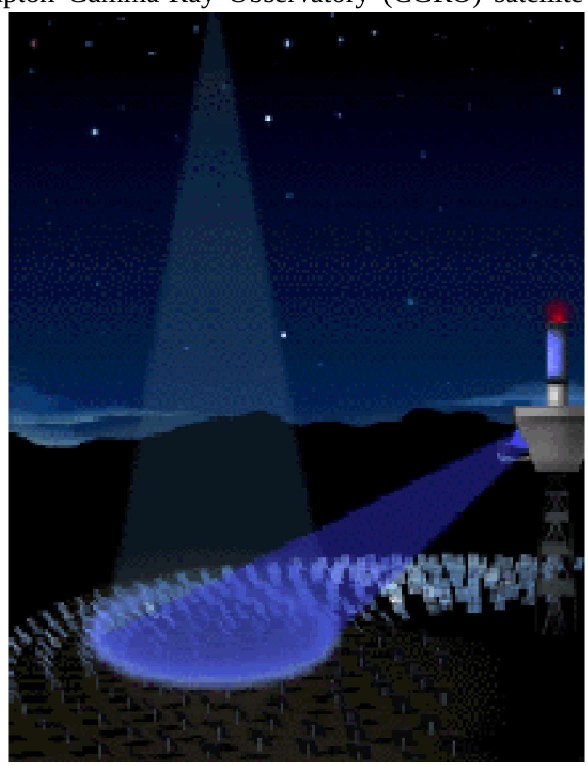

Figure 1: Cherenkov light from an extensive air shower is reflected from the heliostats on the ground to a secondary mirror on the tower. The light from each heliostat is then focused onto an individual PMT.

The solar power plant concept was first proposed in 1982 (Danaher, 1982) but only recently built due to difficulties overcoming the large background caused by overlapping heliostat images. Tumer (1991) solved this background problem by using a secondary optic system on the central receiver to separate the individual heliostat images. Two such gamma-ray detectors under construction have already detected the Crab Nebula with thresholds below 100 GeV—STACEE (Chantell 1998; Oser 1999) at the National Solar Thermal Test Facility, Sandia National Laboratories and CELESTE (Pare 1997; Smith 1999) at the THEMIS site in France. We are currently building a similar detector at the Solar Two Power Plant in Barstow, CA which is the largest solar power plant in the world with over 2000 heliostats (the next largest solar facility has ∼200 heliostats). Thus, Solar Two has the potential to be the most sensitive gamma-ray detector of its kind.

2 The Solar Two Gamma-Ray Observatory:

Solar Two detects gamma rays by sampling the Cherenkov light generated as gamma rays interact with the atmosphere. Heliostats reflect the Cherenkov light to a secondary mirror on the central receiver which then focuses the light onto a PMT camera where the light from each heliostat is collected by a single PMT. To sample the full extent of the Cherenkov light pool on the ground, it is necessary to view a heliostat field that is larger than 300 meters in diameter.

Initial site tests (Ong 1994,1995) confirmed the feasibility of building a gamma-ray telescope at the Solar Two facility. The heliostats tracking accuracy was better than 0.05°, and the heliostat mirror spot size is between 3-5 meters at the secondary mirror. Recent heliostat reflectivity measurements from selected mirror samples were 90% above 350 nm. The night sky light for small zenith angles at the site was only 20-40% worse than at a good site like Dugway, UT.

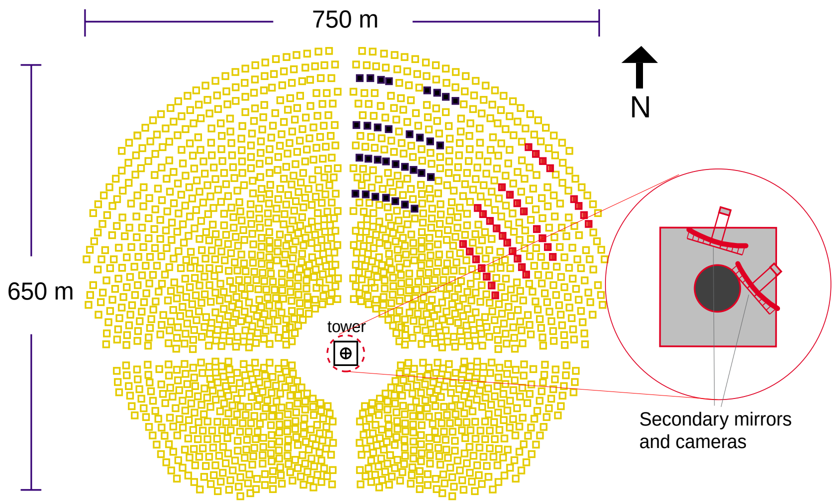

Figure 2: Schematic aerial view of the Solar Two heliostat field and tower. The 32 heliostats that will be viewed by the first secondary are the filled, blue squares in the upper left of the northeast quadrant. The filled, red squares on the east side of the northeast quadrant are the 32 heliostats to be viewed by the second secondary. We plan to build a third secondary to view an additional 32 heliostats closer to the central tower.

While the current 32 PMT detector at Solar Two views heliostats distributed over a 150 m x 175 m area, within the next year we will finish another secondary mirror system bringing the total to 64 heliostats covering a 350 m x 200 m area (see Figure 2). Over the next 3 years, we plan to expand to a three secondary, 96 PMT detector which will view a 350 m x 325 m area (the 64 heliostats in Figure 2 plus 32 closer to the central tower).

The construction of the first 32 PMT detector has been completed, and the detector is being calibrated. The filled blue squares in Figure 2 show the heliostats which will be viewed. Since each heliostat is ∼40 m^2, the effective mirror area (>1,300 m^2) is larger than the current STACEE and CELESTE detectors (Chantell 1998; Pare 1997). Construction of the next secondary will begin soon to bring the number of heliostats viewed to 64 (>2,600 m^2 of mirror area).

2.1 Optics:

The secondary mirror on the central receiver (Figure 3) is a 4.5 m x 2.7 m spherical mirror with a 6 meter radius of curvature assembled from 1 meter hexagonal facets (each facet also has a 6 meter radius of curvature). The mirror dimensions coupled with the heliostat field geometry insure that each heliostat is viewed with an off-axis angle less than 7°. In addition, this mirror serves to separate the heliostat images in the focal plane so that a given PMT only detects light from a single heliostat. However, the images of the heliostats are larger than the photocathodes of the our PMTs (LANCO XP2280) so a Winston cone is used to concentrate the light from the heliostat image onto the photocathode. The Winston cones are designed so that each PMT sees a 3 meter diameter circle on the secondary, thus the system has an *f*-number$\simeq$1.[1] This combination of *f*-number and off-axis angle minimizes Cherenkov light loss due to aberrations and camera occultation.

We have designed 4 different cones, corresponding to 4 different heliostat distances, to maximize the Cherenkov light collection from each heliostat while minimizing the amount of background light collected. As seen from Figure 4, the entrance aperature of the cones is smaller than the maximum size of the heliostat images. There are two reasons that we chose a smaller aperature. First, for a hollow Winston cone with an exit diameter no larger than 4.4 cm (the photocathode diameter of the PMTs) and an acceptance angle of 25.5° (necessary to view a 3 meter circle from a distance of 3 meters), the largest possible entrance diameter is 10 cm. For heliostat distances beyond 250 meters, the spot sizes of the heliostats at the tower are larger than 3 meters. Thus, the cone must have an acceptance angle of 25.5° to collect as much light from the heliostat image as possible. For heliostat distances around 200 meters, the spot sizes can be made smaller than 3 meters leading to a smaller allowable acceptance angle.

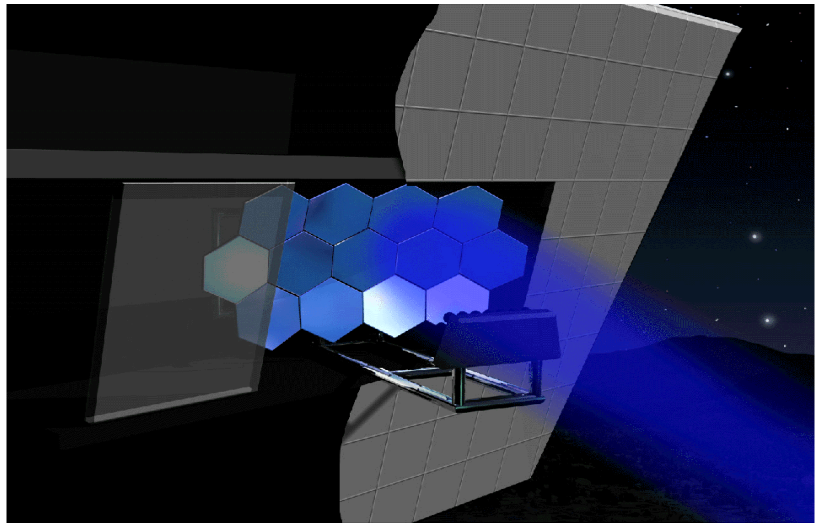

Figure 3: Illustration of the secondary mirror and camera mounted in the central tower at the Solar Two Power Plant. The secondary has a 6 meter radius of curvature is composed of 13 1 meter hexagonal facets, each with a 6 meter radius of curvature.

Second, albedo light can be as much or more than night sky background light as observed at STACEE. Since the heliostat images are rectangular and the cones are circular, there is some fraction of the Winston cone that is viewing the albedo from the ground. If we chose an entrance diameter equal to the maximum image size, 35% of the entrance aperature is viewing something other than the heliostat. By reducing the entrance diameter to collect 95% of the heliostat image, the fraction of the cone that is viewing the ground is reduced more than a factor of two.

Thus, smaller entrance diameters permit a hollow Winston cone to be used and reduce background light with a minimal reduction in signal. Simulations show that a hollow Winston cone transmits roughly 10% less light than a solid cone like those currently used at STACEE and CELESTE, however, the solid cones strongly absorb light below 350 nm where the Cherenkov light intensity is the greatest. The UV absorbtion of the solid cones has not been an issue to this point because the heliostats at Solar Two, STACEE and CELESTE are back-silvered and absorb most of the UV light before it ever gets to the cone. However, we are investigating ways to front-coat the heliostats at Solar Two, so we want a cone that will take full advantage of the UV light reflected by front-coated heliostats.

2.2 Hardware: The signal from each fast PMT will be first filtered and amplified, then fanned-out to a trigger system and to 1 GS/s digitizers. In the trigger electronics, the PMT signal will be discriminated and digitally delayed. Then, the delayed signals of heliostats within a cluster will be summed and discriminated to form a pre-trigger. The pretriggers from each cluster are delayed again and summed to form a final trigger. For each trigger, the digitizers will be read out with a time stamp. Initially, the pre-trigger will require five

[1]The *f*-number is actually less than 1 in the horizontal direction since the height of the mirror is less than 3 meters.

of eight discriminators in a cluster to fire within a 12 ns window and three of four cluster pre-triggers will form a final trigger. With the exception of a custom analog summer used to form the pre-trigger, all of the trigger electronics are commercially available. Only recently have affordable, fast (1 GS/s) digitizers been available. We plan to equip each PMT with a digitizer to provide precise pulse timing and detailed pulse shape information.

Although the combined collection area of the heliostats is large, it is not well utilized because each PMT is discriminated independently. We are working on building an ASIC chip that will analog delay and then sum each of the PMT signals. The summed signal will then be discriminated to form a trigger. Because the photon statistics in each PMT are Poissonian and scale as Sqrt(N), this will reduce the trigger threshold by a factor of 8 when all 64 heliostats are used. Consequently, the energy threshold of the 64 heliostat detector should be less than 20 GeV. An added benefit of the ASIC chip will be a reduction of the background events because the trigger electronics can be more precisely tuned to trigger only on gamma rays.

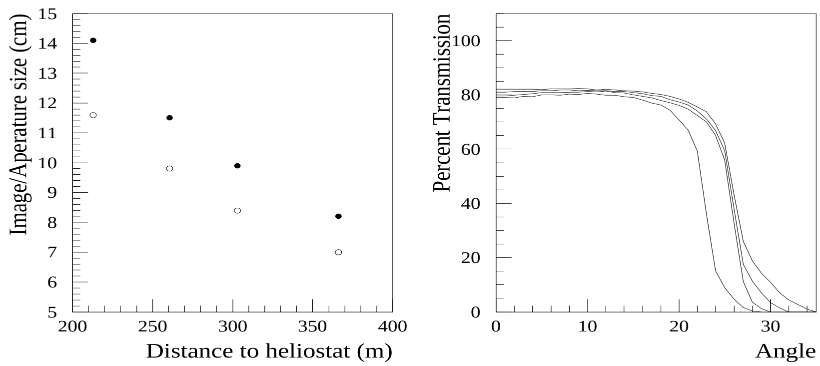

Figure 4: On the left, the maximum heliostat image size in the focal plane (filled circles) and the entrance aperature diameter (open circles) are plotted as a function of the distance from the heliostat to the secondary mirror. On the right, the transmission of the cones as a function of angle is plotted.

3 Summary:

A 64 heliostat gamma-ray detector is under construction at the Solar Two Power Plant in Barstow, CA. The first secondary mirror capable of viewing 32 heliostats is completed and being calibrated so that observations of the Crab Nebula can begin in September 1999. Construction on the second mirror to raise the number of heliostats viewed to 64 will begin soon. We also plan to finalize the design of the ASIC chip for the trigger electronics in order to begin fabrication and testing.

4 Acknowledgements:

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