High Energy Astrophysics and NSB Noise Analysis with C.A.C.T.U.S.

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The *Converted Atmospheric Cherenkov Telescope Using Solar II,* also known as C.A.C.T.U.S., is a gamma ray detector used by UC Davis to understand various things about the radiation and its emitting sources. Radiation from other sources, such as starlight, nearby towns, airports and military bases is detected by the telescope, causing problems in data analysis. It is seen that the fields of views of the channels and mirrors that make up the observatory are very complicated, affecting the amount of radiation that is understood to enter the detector. Monte Carlo simulations created by the team are used for night sky background (NSB) noise analysis. This enables better understanding of the noise such that the team can focus on the important data, the gamma rays.

Introduction:

C.A.C.T.U.S. is an acronym for the gamma ray detector called the *Converted Atmospheric Cherenkov Telescope Using Solar II* used by a high energy physics group at University of California at Davis. The group led by Professor Mani Tripathi began their experiments with C.A.C.T.U.S. in 2004 only after the once solar test plant was given up by UC Riverside.

Gamma rays are not the only type of radiation detected; there are other hadronic showers as well as starlight from stars surrounding the gamma ray emitting astrophysical sources. Thus there is a necessity to understand the NSB.

Apparatus:


(left to right/West to East) is 1.0 kilometer

The C.A.C.T.U.S. observatory consists of approximately 2000 mirrors, also known as heliostats or helios, set up in an array with a tower in the center. There is a spherical mirror located approximately 60 meters high on the tower as well as a camera with 80 photomultiplier tubes (PMTs) located directly in front of the mirror. Generally there are 140-160 helios on-line during data acquisition.

The purpose of C.A.C.T.U.S. is to detect gamma rays from astrophysical sources. Ground based detectors do not detect gamma rays directly; instead they detect the products of gamma ray and atmospheric nuclei interactions, called Cherenkov radiation. Cherenkov radiation is a coherent effect that occurs when a charged particle travels faster than the speed of light in a medium. As a charged particle passes through a dielectric medium, it induces dipoles in surrounding nuclei [1]. As the nuclei try to return to equilibrium positions, they oscillate and produce electromagnetic radiation. The radiation ranges from blue through ultraviolet light.

The C.A.C.T.U.S. group is interested in high energy gamma rays from 50 GeV and up coming from sources such as Active Galactic Nuclei (AGNs), massive black holes at the center of galaxies, and Supernova Remnants (SNR), remains of cataclysmic star deaths where pulsars are found [2].

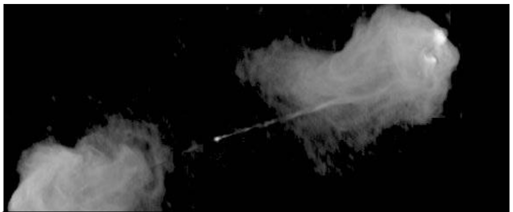


Fig 2. An AGN named Cygnus A (NASA).

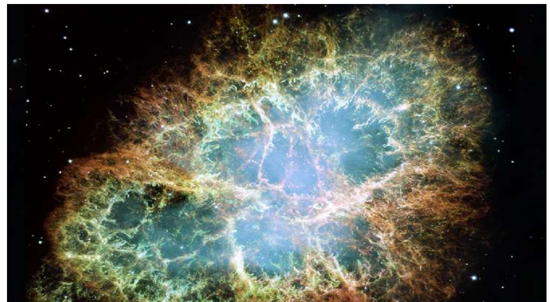


Fig 3. An SNR named the Crab Nebula (NASA).

Methods:

Monte Carlo simulation programs are used for data analysis created by the UC Davis C.A.C.T.U.S. team. One particular program used, called S2optics, creates radiation air showers from any angle in the sky and ray traces the radiation through the apparatus to the camera.

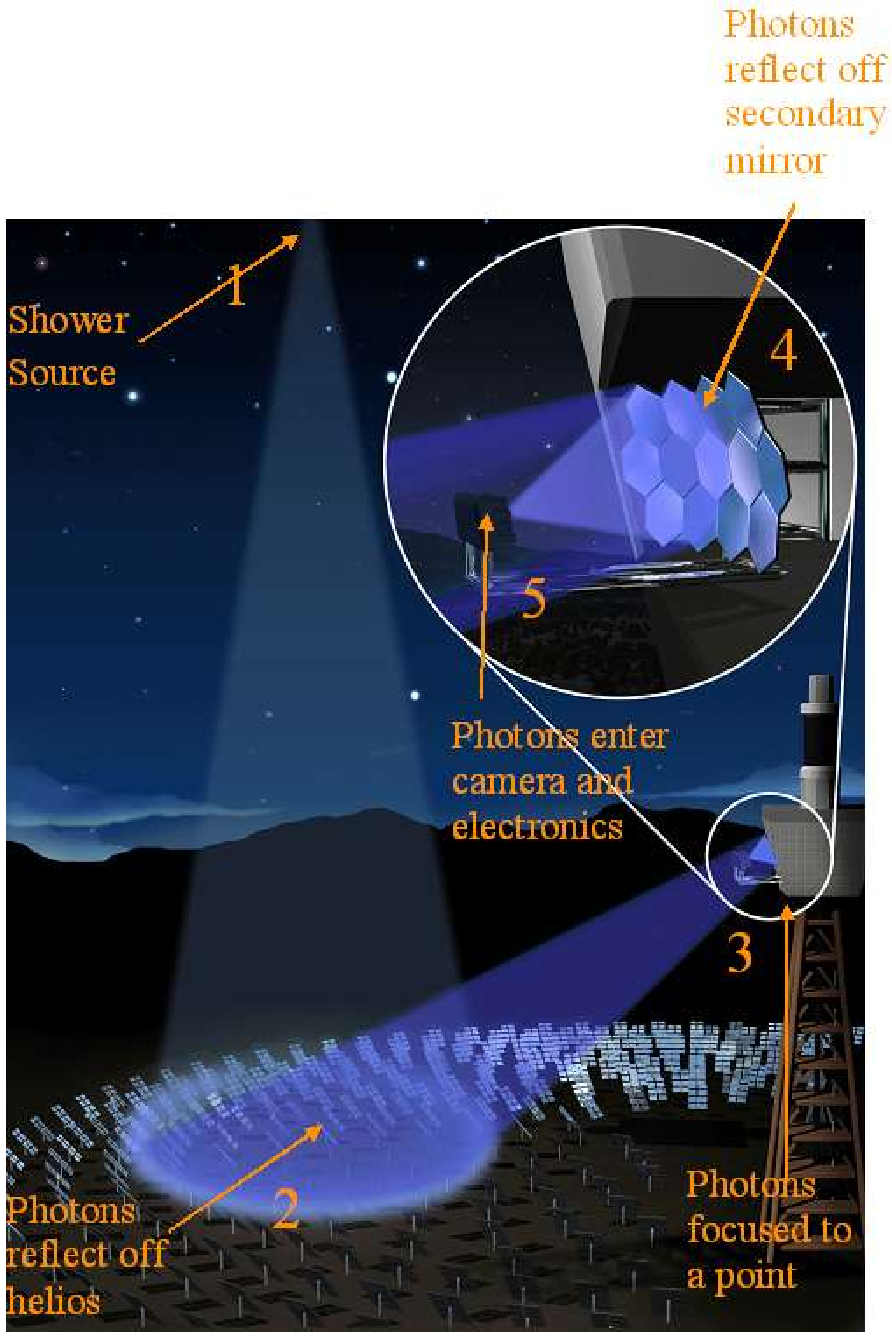


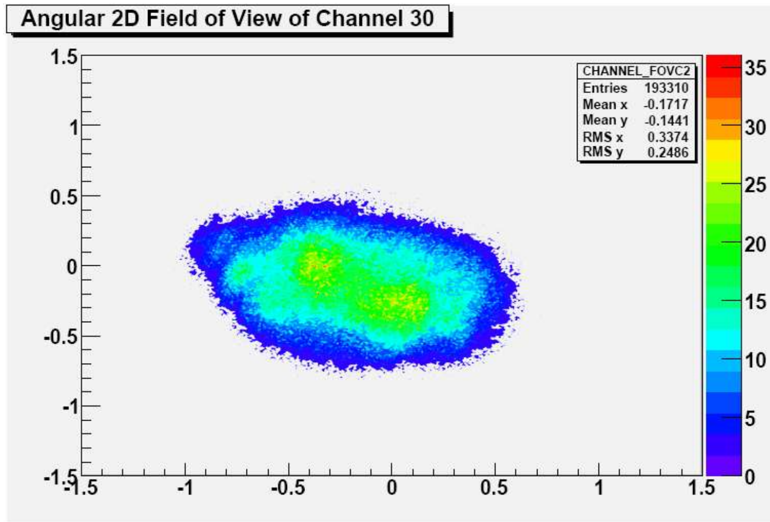
Fig 4. A schematic representation of the C.A.C.T.U.S. set up.

Figure 4 is a schematic representation of the C.A.C.T.U.S. observatory. The showers are created and reflect off the heliostats, which are positioned such that they point the radiation at the tower door, where a secondary spherical mirror is located. The camera with PMTs collects the particles. The particles are then sent through the electronics that are set up and everything is recorded for later analysis.

There are many advantages of ground based detectors opposed to using satellites but despite these, there are still many problems with this method of detecting gamma ray showers. One particular problem that has been of interest is the night sky background (NSB) from stars. This is executed in order to understand the fields of views of the heliostats and channels and thus the amount of noise detected by the apparatus. The NSB is hypothesized to consist of photons or noise that lands on the heliostats, as well as gamma rays. Working with Monte Carlo simulations to simulate showers of any kind onto the heliostats and ray trace them to the camera. I am ray tracing simple photon showers onto the heliostats, through to the secondary mirror and into the camera. I create photon showers with 10^9 particles, about 10 billion per heliostat with around 160 helios on-line for each angle chosen. Using a Linux OS with C, C++ and ROOT, an object oriented data analysis framework for large scale data analysis, I simulated the showers and creating histograms of photon efficiency (how many photons are detected). Photon efficiency is executed and analyzed for all helios used, each particular helio and also on each particular channel, where the channels correspond to the PMTs. I also created histograms of stars drifting across the sky, to understand the field of view of particular channels.

Results and Discussion:

The histograms of the fields of views of channels and stars drifting across the heliostats have been created via ROOT to show that the fields of views are very difficult



compared to five years ago, when the same simulations were executed. Figure 5 is an angular two-dimensional field of view of one particular channel, 30. It is important to note here that in 2002 there were only 32 heliostats and 32 PMTs in use during the data recording process, thus each channel had only one heliostat in its field of view. This made it easy for the team to understand the amount of radiation per channel. Presently, the numbers of heliostats has increased to ~160 used during data acquisition as the PMT number count has increased to 80 causing more than one heliostat to be mapped to each channel. This makes the fields of views of each channel much harder to understand. Figure 6 is a strip of the field of view from figure 5 simulating a star drifting across the heliostats and reflecting into channel 30. This shows that the field of view is complicated. It is believed that the three peaks are due to radiation reflecting off three heliostats into this channel.

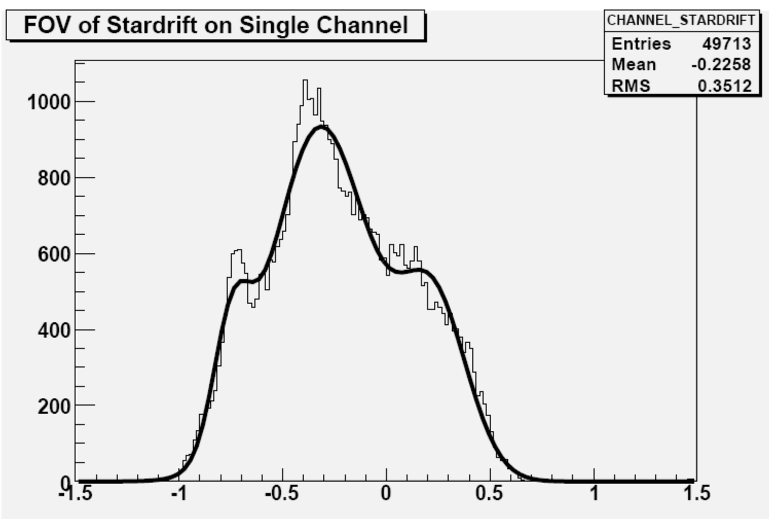


Fig 6. Simulation of a star drifting across the field of view of one channel. This was created by taking a strip of less than 0.1 degree out of figure 5.

One expects that the simulated acceptance for the channels (how many photons hit the channels) should be very close to the data recorded in March and July for the astrophysical sources Crab and Draco, respectively. Via ROOT, histograms have been plotted to see how they differ and/or compare. Figure 7 represents the relative number of *simulated* photons detected per channel for Crab and Draco. The downward shape of the histogram is due to higher channels being mapped to heliostats that are farther away from the tower, thus less radiation being focused to a smaller point on the side of the tower and less radiation entering the camera. Figure 8 represents the real data that was recorded in 2005 for Crab and Draco. It is important to note here that between March and July data acquisitions the first 32 mirrors were cleaned. From figure 8, it can be seen that cleaning the heliostats affected the data. There is a big decrease in noise for

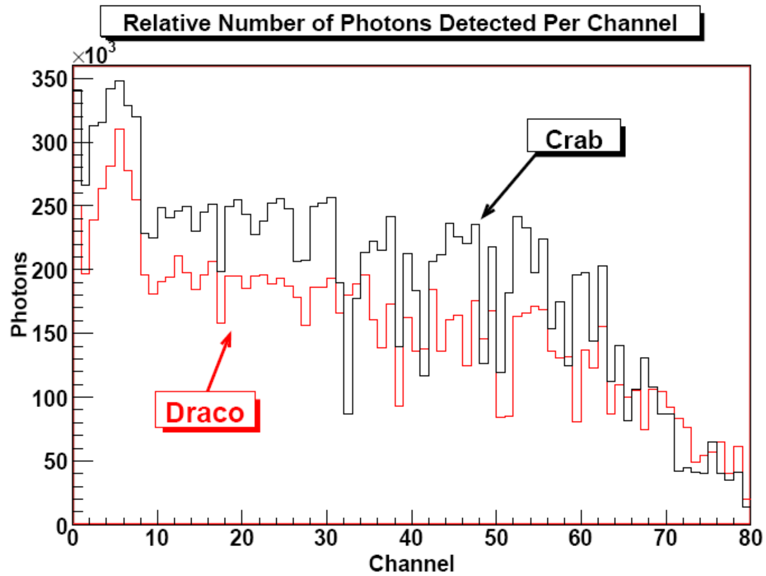


Fig 7. Simulated photons detected per channel for Crab and Draco sources in March and July of 2005.

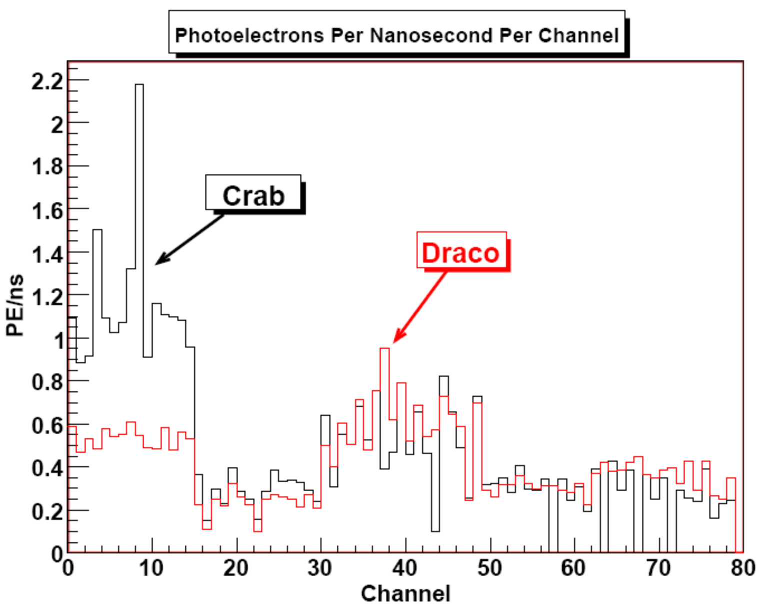


Fig 8. Real data taken in March and July of 2005 for Crab and Draco sources, respectively.

the first 16 channels between March and July. It is evident that the cleaning matters a great deal in the amount radiation that hits the mirrors. The Crab happens to have higher statistics in the lower channels (first 32), which correlate to the mirrors that were later cleaned in before data acquisition in July 2005. This is a direct result of diffuse light coming from areas other than the source as well as the source itself and reflecting off the heliostats and into the PMTs. The important outcome here is that the night sky background not only consists of starlight but also light from around the observatory, such as the military base, the airport and the lights from the town of Barstow, CA. This is obviously a problem and should be dealt with but unfortunately lack of funding and man power puts constraints on what can be done.

Conclusion:

Using Monte Carlo simulations to ray trace photons showers onto the heliostats and through the C.A.C.T.U.S. set up proves to be useful in the analysis of real data. This is important because the night sky is always changing, making it hard to understand data. The fields of views of the channels and heliostats are very complicated but via these simulations they will be understood better, aiding in better data analysis. Most importantly (and intuitively), clean mirrors will detect and produce better data leading to better results and possibilities.

References

[1] P. Marleau, Search *for a Dark Matter Gamma-Ray Signal from Dwarf Spheroidal Galaxies with CACTUS* (2006), in preparation.

[2] F.A. Aharonian. *Very High Energy Cosmic Gamma Radiation: A Crucial Window on the Extreme Universe.* World Scientific Publishing Co. Pte. Ltd., New Jersey (2004).