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GRB Observations around 100 GeV with STACEE

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STACEE is an atmospheric Cherenkov detector that uses the large mirror area of a solar research facility to detect gamma rays above approximately 100 GeV. The low energy threshold of STACEE allows for the detection of gamma rays from higher redshifts than most other ground-based experiments. During the summer of 2004, the primary mirrors of the STACEE detector were outfitted with new motors that allow the detector to re-target to most observable GRB positions within one minute. To date, follow-up observations have been made of 14 bursts, some within minutes of the burst. We discuss the sensitivity of STACEE to high-energy gamma-ray emission from gamma-ray bursts and preliminary results of observations.

1. The STACEE Detector

The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) is a wavefront-sampling Cherenkov telescope sensitive to gamma-rays above approximately 100 GeV. It is located at the National Solar Thermal Test Facility (NSTTF) at Sandia National Laboratories outside Albuquerque, New Mexico, USA. The NSTTF is located at 34.96°N, 106.51°W and is 1700 m above sea level. The facility has 220 heliostat mirrors designed to track the sun across the sky, each with 37 m^2 area. STACEE uses 64 of these heliostats to collect Cherenkov light produced by cascades in the atmosphere.

STACEE employs five secondary mirrors on the solar tower to focus the Cherenkov light onto photomultiplier tube (PMT) cameras, as shown in Figure 1. The light from each heliostat is detected by a separate PMT and the waveform of the PMT signal is recorded by a flash ADC. A programmable digital delay and trigger system[1] selects showers for acquisition while eliminating most random coincidences of night sky background photons. STACEE operates with a cosmic-ray trigger rate of about 6 Hz and a trigger threshold around 5 photoelectrons per heliostat. A detailed description of the instrument can be found in D.M. Gingrich et al.[2].

The large mirror area of the STACEE detector leads to an energy threshold lower than those attainable by most single-dish imaging telescopes or water-tank telescopes. The exact energy threshold - defined as the energy at which the trigger rate peaks - is determined by the spectrum of the source and the effective area of the detector at the target position. For targets above 60° in elevation with power-law spectral indices between 2 and 3, energy threshold is typically between 150 and 200 GeV. For targets near zenith, STACEE can be triggered by gamma rays with energies as low as 50 GeV.

A low energy threshold opens up the possibility of detecting more distant sources[3]. Collisions of gamma rays with starlight photons produce electron-positron pairs, attenuating the gamma-ray flux from distant sources,

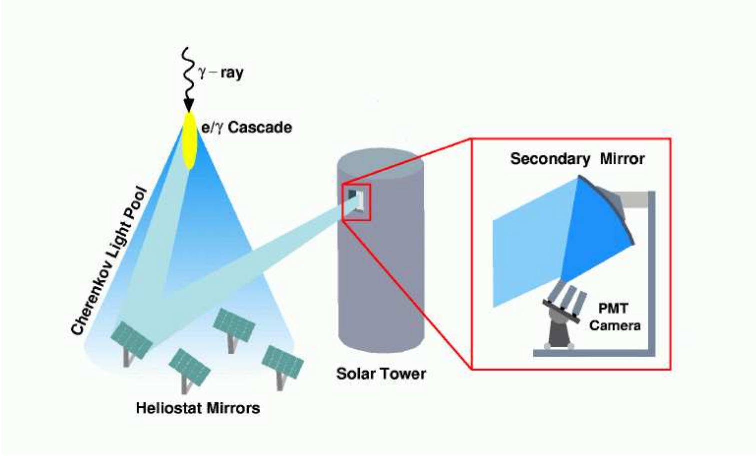

Figure 1. The STACEE technique. Cherenkov light produced in the atmosphere is reflected by the heliostat mirrors, which track the candidate source, to stationary secondary mirrors on the solar tower. The secondary mirrors focus the light from each heliostat onto a distinct PMT in the PMT camera.

as shown in Figure 2. The extinction becomes more severe with increasing energy, producing an energy-dependent horizon for gamma-ray observations.

The construction of the STACEE experiment is complete. However, analysis methods, including background rejection techniques, are still under development. During the 2003-04 observing season STACEE acquired approximately 14.3 hours of on-source live time for the Crab, yielding a detection at the 5 sigma level with the background rejection cuts currently available[4, 5]. Based on this result, sensitivity of STACEE to a gamma-ray burst with a Crab-like spectrum would be $4\times10^{-9}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ above 100 GeV (5σ in a 30 minute observation). STACEE would easily detect the flux estimated by power-law extrapolations of the EGRET data.

2. GRB Observing Strategy

Observing gamma-ray bursts is a high priority for STACEE. The GRB Coordinates Network (GCN) distributes burst alerts in a variety of formats. STACEE uses email alerts sent by the GCN to alert observers in two ways. One set of email notices is processed by a computer on site that updates a web page and initiates an audio alert. A second set of emails is sent directly to a cellular phone and a pager that are carried by the observers. We are currently exploring ways to improve our response time, such as setting up a socket connection for GCN burst alerts and automating the repositioning of our heliostats.

In the summer of 2004, the 64 heliostats used by STACEE were outfitted with new motors. The new motors have performed very well, allowing the detector to be re-targeted from any of the sources we typically observe to most observable GRB positions within 1 minute. This corresponds to nearly four-fold improvement in the slewing speed. With the launch of the Swift GRB observatory[7] in November 2004, fast, accurate burst localizations have become a reality, allowing STACEE to make follow-up observations within minutes of the arrival of the first emission from a GRB. In addition to doing immediate GRB follow-up observations, we search for afterglow emission from bursts that have occurred within the previous 12 hours. EGRET detected GeV emission, including an 18 GeV photon, from GRB940217 up to ninety minutes after the start of the burst[6].

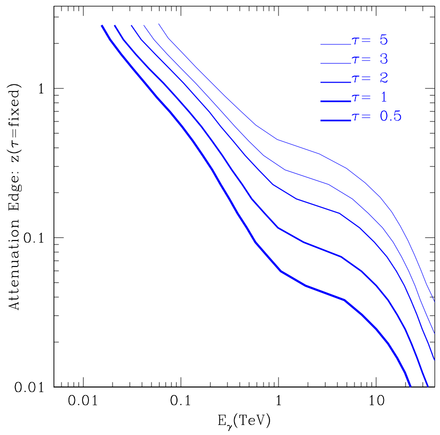

Figure 2. Gamma-ray Attenuation Edge. Redshift, as a function of gamma-ray energy, at which the predicted attenuation is $e^{-1/2}$, e^{-1}, e^{-2}, e^{-3}, and e^{-5} (Figure from Ref. [3])

3. Past and Future Observations

During the 2002-03 and 2003-04 observing seasons, STACEE made afterglow observations of 5 bursts. Due to weather and delays in accurate burst localizations, the fastest of these follow-ups was 95 minutes after the burst. In the 2004-05 observing season, despite having a significantly lower duty cycle due to weather, STACEE has made afterglow observations for 9 additional bursts. Table 1 summarizes the GRB afterglow observations obtained by STACEE.

Our observation of GRB 050607 is of particular interest, as it began quickly and at relatively high elevation. Emission from GRB 050607 triggered Swift at 09:11:23 UT. The GCN distributed the alert 19 seconds later. After another 36 seconds, the email alert was received by a computer at the STACEE site, which updated our burst alert page and initiated an audio alarm. The observers quickly checked the coordinates and validity of the alert and re-targeted the heliostats. The heliostats slewed to the target in approximately 30 seconds. Due to an operator error, there was an additional delay of approximately 1 minute. Data acquisition began 3 minutes and 11 seconds after the initial emission was detected by Swift. This has been our most rapid follow-up observation to date, but there is still room for improvement. Now that the slewing of the heliostats is no longer the rate limiting step, there is much to be gained by using a socket connection, rather than email, to receive alerts from the GCN. Operator error can also be removed from the equation if we are able to automate the response of the detector to burst alerts.

When observations of GRB 050607 began, the target was at an elevation of 61.88° and rising. After data quality cuts, the live-times on and off source are each approximately 1150 seconds. There were 8858 events in the on-source run and 8972 events in the off-source run. If we assume the target was a source of high energy gamma rays with a differential power-law photon index of -2.8, and we fold this into the effective area as a function of energy for these observations, then we can place an upper limit on the time-averaged flux above 100 GeV of approximately $4.4\times10^{-9}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with a 95% confidence level. For photon indices of -2.6 and -3.0, the upper limits on the flux above 100 GeV would be $4.1\times10^{-9}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $4.8\times10^{-9}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, respectively. Temporal analysis of the on-source run showed no significant spikes in the rate. Once background rejection techniques are fully developed, and their effects on the detector's effective area are fully understood, these data will be re-analyzed.

STACEE is still collecting data for the 2004-05 observing season and will continue to run at least through the summer of 2006. With the current rate of burst alerts from the Swift satellite, we can expect to obtain around a dozen more GRB afterglow observations, some of those being rapid follow-ups within minutes of

Burst ID	Time to Target (min)	Initial Elevation	Approx. Live-time On Source (min)	Preliminary Significance
021112	217	73°	66	0.2
030324	123	31°	0[a]	na
030501	369	47°	0[b]	na
031220	310	59°	0[c]	na
040422	95	35°	20	-0.7
040916	104	46°	na[d]	na
041016	142	51°	16	-1.8
050209	146	56°	22	1.1
050402	3.8	49°	0[e]	na
050408	640	43°	20	-1.0
050412	5.7	54°	na[f]	na
050509B	20	83°	25	0.45
050509A	480	53°	15	0.1
050607	3.2	62°	19	-0.9

Table 1. GRB Afterglow Observations with STACEE. Live-times account for data quality cuts. *Notes:* [a] 030324: Analysis complicated by bright star at edge of field of view. [b] 030501: Unstable rates due to instrumental problem. [c] 031220: Unstable rates due to weather. [d] 040916: Partial data corruption has delayed analysis. [e] 050402: Partial heliostat malfunction has delayed analysis. [f] 050412: Partial data corruption has delayed analysis.

the bursts. Further improvements to our GRB observation strategy may even yield observations during the prompt emission phase of some long bursts. Additional work on analysis techniques to discriminate gamma rays from background hadronic events should improve the sensitivity of the detector in future observations and in re-analysis of past observations. Finally, the rapid, multi-wavelength observations made possible by the Swift satellite should provide redshifts for many bursts, allowing us to set interesting limits on the intrinsic high-energy spectra of gamma-ray bursts.

4. Acknowledgments

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References

[1] J.-P. Martin and K. Ragan, Proc. IEEE Nuclear Science Symposium, 2000, vol. 8, pp 12-141-12-144.
[2] D.M. Gingrich et al., Presented at the 2004 IEEE Nuclear Science Symposium; astro-ph/0506613.
[3] J. R. Primack et al., Proc. AIP Conf. 745, 23 (2005); astro-ph/0502177.
[4] J. Kildea et al., “Shower Reconstruction Techniques for STACEE”, these proceedings (2005).
[5] J. Kildea et al., “Observations of the Crab Nebula and Pulsar with STACEE”, these proceedings (2005).
[6] K. Hurley et al., Nature, 372, 652-654 (1994).
[7] N. Gehrels et al., ApJ 611, 1005 (2004).