STACEE Observations of Extra-galactic Sources

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Abstract

The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) is a ground-based gamma-ray telescope, which uses 64 large heliostats at a solar research facility near Albuquerque NM, USA, to achieve a gamma-ray energy threshold below that of traditional imaging telescopes. The full STACEE experiment started regular observations in October, 2001. Here we report the results from STACEE observations of extragalactic sources during the 2001-2002 observing season.

1. Introduction

STACEE is one of four 'solar farm' detectors that have been built to do gamma-ray astronomy. These detectors employ the large steerable mirrors (heliostats) found in central-tower solar power arrays to collect and focus Cherenkov light from gamma-induced air-showers. Their large mirror areas allow these detectors to operate at lower energies than traditional imaging detectors, such as the Whipple telescope [1], since they can make use of showers with lower photon densities. Due to the distributed nature of their light collectors they are also immune to backgrounds from single muons.

The goal of such detectors is to explore the gap between 10 GeV, where EGRET observations run out of statistics [2], and 200 GeV, the effective energy

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threshold of the present generation imaging detectors. In this region interesting things are known to happen. For example, pulsed emission of gamma-rays from pulsars such as the Crab is not observed at very high energy. Also, the number of observable blazars drops dramatically, perhaps due to interactions between their gamma-rays and extra-galactic infrared background photons which render the universe opaque above a certain energy.

2. The STACEE Detector

The STACEE detector is located in Albuquerque, New Mexico at the National Thermal Solar Test Facility (35° N, 107° W, 1700 m ASL). A plan view of the heliostat layout is shown in figure 1.; the shaded symbols denote the 64 heliostats used for STACEE. The light from each 37 m^2 heliostat is directed onto a PMT/light concentrator assembly by one of five secondary mirrors (figure 2.) such that each heliostat is viewed by its own PMT.

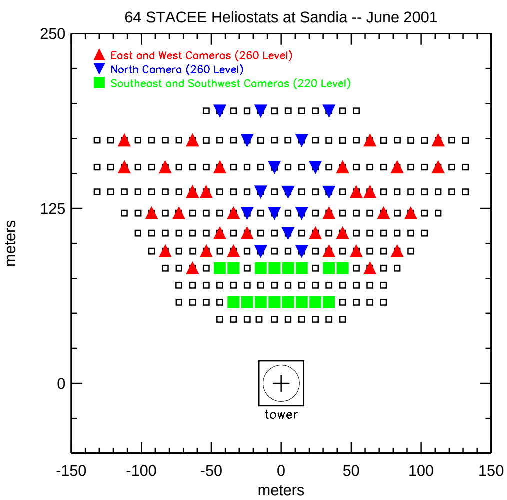

Fig. 1. Map of the National Solar Thermal Test Facility (NSTTF) showing the heliostats used by STACEE.

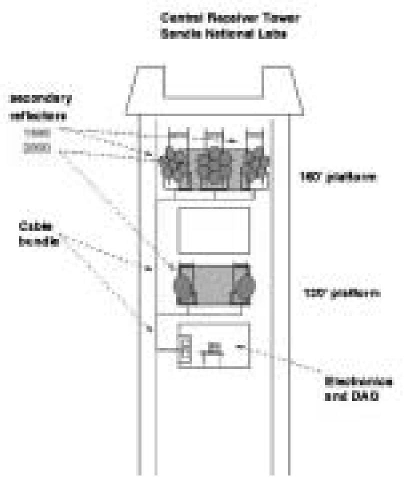

Fig. 2. Sketch of the tower at the NSTTF showing the positions of the STACEE secondary mirrors.

The PMT signals are amplified (by a factor of 100) 15 m from the PMTs and sent by low loss cable to a remote counting room. Here each signal is split, with one half being discriminated and used in digital logic to form a trigger. The other half is digitized using a 1 giga-sample/second flash analog to digital converter (FADC) system. The trigger system[3] uses custom field programmable gate array (FPGA) electronics to delay phototube pulses (to account for the changing photon arrival times as the source is tracked across the sky) and bring them into a coincidence. The 64 channels are grouped into 8 clusters of 8 channels each for triggering; a typical trigger topology requires 5 out of 8 clusters to have at least 5 PMTs with at least 4 photoelectrons. This trigger has the effect of requiring the Cherenkov light pool to be spread over the detector which enhances the detection ratio of gamma-generated showers to those coming from interactions of charged cosmic rays.

The STACEE detector has already been used in partially complete form to make measurements. A 32 channel prototype was used to detect the Crab at an effective threshold of 190 GeV [4], and more recently, a 48 channel version of the experiment detected the blazar Mrk 421 during its spring 2001 flare [5]. These results have already been published and are not presented here.

3. Observations in 2001-2002

We spent the first part of the observing season commissioning the final version of the STACEE detector. New for that season were 16 channels, corresponding to heliostats at the south end of the field, as well as FADC digitizers. At the start of the season we had only 32 FADCs and had to read out two PMTs with each digitizer. In April we were able to equip each PMT with its own FADC. We are currently developing analysis techniques based on having pulse height information for all channels. The preliminary results presented here are based only on trigger and timing information.

The standard data-taking procedure was the following: the source was tracked for 28 minutes, then a point in the sky at the same declination but 30 minutes behind in right ascension was tracked for 28 minutes. Between each run there was a two-minute pause to allow the heliostats to slew to the new direction. Given stable observing conditions, the difference in rate between on-source and off-source is assumed to be the gamma-ray rate.

Off-line, a simple counting analysis was carried out. Data were subjected to cuts on quality and stability. Runs or parts of runs where currents or rates from individual channels were unstable, usually due to the passage of clouds which affected night sky background and rates from cosmic-ray showers, were rejected. Only data where both the on-source and and corresponding off-source runs were acceptable were included in the final analysis. Data passing the quality cuts were subjected to an off-line trigger which was essentially a tighter version of that employed on-line.

Since pulse height information was not used in the results presented here it is difficult to produce differential energy spectra. To calculate an integral flux

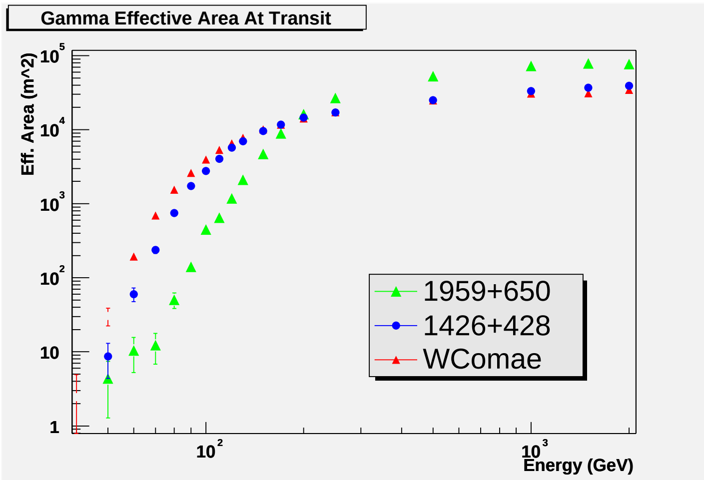

Fig. 3. Effective areas of the STACEE detector for gamma-rays as a function of energy for three sources observed by STACEE as calculated using a Monte Carlo.

we use simulations to estimate the effective area of the detector as a function of energy, then fold this response with a power law energy spectrum. The overall normalization of the resulting curve is constrained to match the number of detected gamma-rays or, in this case, the upper limit on the number of gamma-rays detected. The simulations use CORSIKA [6] to generate the showers; the optics and electronics, including trigger are modelled using STACEE-specific programs. Figure 3. shows the energy dependence of the effective area of the detector at the different transit elevations for three sources observed by STACEE. As can be seen, the effective areas plateau above 30000 m^2 at high energy and fall rapidly below 100 GeV although there is considerable effective area at 70 GeV for sources transiting close to zenith.

3.1. W-Comae

W-Comae is a BL Lac object which has been seen by EGRET but not by imaging telescopes operating above 250 GeV. This could be due to the infrared attenuation effect mentioned previously since the source is at a higher red-shift (z = 0.102) than Mrk 421 (z = 0.030) and Mrk 501 (z = 0.034) both of which have been detected at high energy. According to EGRET measurements, the energy spectrum above 100 MeV is described by a power law with index of 1.73 $\pm$ 0.18. If this hard spectrum continues to higher energies, the source could be detected by STACEE. Recently this source has been investigated by Boettcher *et al*[7] who have fit its X-ray spectrum (from 1998 Beppo-SAX data between 0.1 and 100 keV) to leading models of gamma-ray production. The authors conclude that all leptonic models (*eg* SSC) predict that the spectrum will be cut off near 100 GeV.

Hadronic jet models, in contrast, predict detectable fluxes above 100 GeV.

After cuts on data quality and detector perfomance, we were left with 6.1 hours of on-source data (and a matching amount of off-source data). No signal was seen and an upper limit on the flux was calculated using standard methods. The limit and the corresponding energy point at which to plot the point were determined by folding a spectrum with a power of 1.7 with the effective energy curve of STACEE. The elevation dependence of the effective area curve was taken into account by weighting according to the time spent at each elevation. The peak of the acceptance-modified power law spectrum is at 140 GeV; we quote our threshold for this measurement as 140 $^{+20}_{-30}$ GeV where the uncertainties come from changing the power indices within the errors quoted by the EGRET group. The 90% confidence level upper limit on the integrated flux above 140 GeV is $1.41 \times 10^{-10} cm^{-2} s^{-1}$. This is not inconsistent with a simple extrapolation of EGRET data.

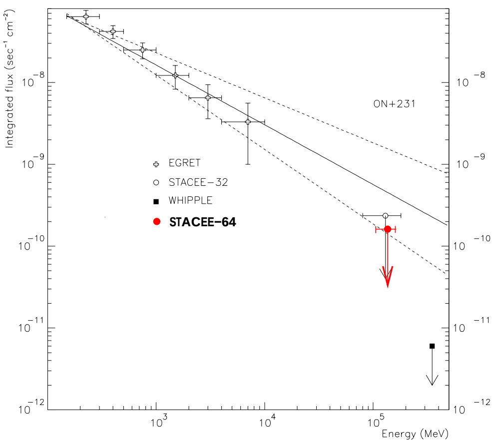

Fig. 4. Upper limit point as measured by STACEE for W-Comae. Also plotted are data points from EGRET and an upper limit from the Whipple collaboration as well as an upper limit obtained in 1998 data using the STACEE-32 detector [8].

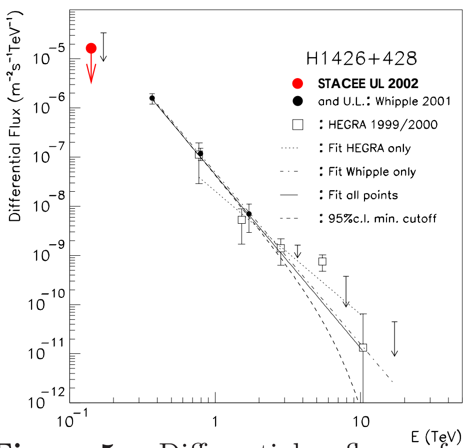

Fig. 5. Differential flux from H1426+428 as measured by the Whipple and HEGRA collaborations along with an upper limit determined by STACEE. The STACEE limit is calculated from an integral measurement assuming a spectral index of -3.5. Adapted from [9]

3.2. H1426+428

H1426+428 is a weak source which has been detected by the Whipple [9] and HEGRA [10] collaborations; it has a flux about 3% that of the Crab. Normally one would not expect to detect a source of this strength with a few hours of data from a detector like STACEE. However, H1426+428 has a rather soft energy spectrum; observations are consistent with a spectral index of 3.5. Thus its flux at STACEE energies could be high enough for a detection. Using 7.2 hours of on-source data taken under good conditions and following an analyis procedure similar to that described for W-Comae we obtain a 90% confidence level upper limit of $1.96 \times 10^{-5}\ m^{-2}\ s^{-1}\ TeV^{-1}$ at 120 GeV. This is a differential point obtained from an integral measurment using the assumption of a power law spectrum with index 3.5. This point is plotted in figure 5. along with the published results from Whipple and HEGRA. The STACEE point is consistent with the lowest energy Whipple point and slightly lower in energy.

4. Conclusions

Construction of the STACEE experiment is essentially complete. During the 2001-2002 observing season we commissioned the final components and took a limited amount of data on extra-galactic sources. Simple analysis of some of these data indicate that STACEE's energy threshold is approaching 100 GeV and its sensitivity is such that it is already able to produce competitive limits on source fluxes. During the 2002-2003 season we will install pre-amplifiers on the the PMTs and will tighten the on-line trigger to allow us to run at lower threshold. Off-line strategies exploiting the full power of the FADC data are being developed to improve background rejection and therefore the sensitivity.

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5. Title of the Paper

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