Recent AGN Observations by the Solar Tower Atmospheric Cherenkov Effect Experiment

Cite as: AIP Conference Proceedings **745**, 481 (2005); https://doi.org/10.1063/1.1878449
Published Online: 16 March 2005

J. Kildea, A. Alabiso, D. A. Bramel, J. Carson, C. E. Covault, D. Driscoll, P. Fortin, D. M. Gingrich, D. S. Hanna, A. Jarvis, T. Lindner, R. Mukherjee, C. Mueller, R. A. Ong, K. Ragan, R. A. Scalzo, D. A. Williams, and J. Zweerink

Recent AGN Observations by the Solar Tower Atmospheric Cherenkov Effect Experiment

J. Kildea*, A. Alabiso†, D.A. Bramel**, J. Carson‡, C.E. Covault†, D. Driscoll†, P. Fortin*, D.M. Gingrich§, D.S. Hanna*, A. Jarvis‡, T. Lindner*, R. Mukherjee**, C. Mueller*, R.A. Ong‡, K. Ragan*, R.A. Scalzo¶, D.A. Williams‖ and J. Zweerink‡

*Department of Physics, McGill University, 3600 University Street, Montreal, QC H3A 2T8, Canada.
†Department of Physics, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106.
**Department of Physics and Astronomy, Barnard College and Columbia University, New York, NY 10027.
‡Department of Physics and Astronomy, University of California at Los Angeles, 430 Portola Plaza, Box 951547, Los Angeles, CA 90095-1547.
§Centre for Subatomic Research, University of Alberta, Edmonton, AB T6G 2N5, Canada.
¶Lawrence Berkeley National Laboratory, MS 50R5008, 1 Cyclotron Road, Berkeley, CA 94720.
‖Santa Cruz Institute for Particle Physics, University of California at Santa Cruz, 1156 High Street, Santa Cruz, CA 95064.

Abstract. The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) is a ground-based atmospheric Cherenkov telescope for the detection of very high energy gamma rays from Galactic and extra-galactic sources. By utilizing the large collection area provided by the solar mirrors of the National Solar Thermal Test Facility in Albuquerque, New Mexico, STACEE achieves a low energy threshold, around 100 GeV, for the detection of gamma rays. We briefly describe the STACEE detector and detail recent observations of Active Galactic Nuclei.

INTRODUCTION

The Solar Tower Atmospheric Cherenkov Effect Experiment is an atmospheric Cherenkov telescope that uses the facilities of the National Solar Thermal Test Facility (NSTTF) in Albuquerque, New Mexico for the detection of astrophysical gamma rays with energies in the range 50 GeV to $\sim$1 TeV. The NSTTF is a solar power research facility incorporating a central receiver tower and an array of heliostats (solar mirrors). STACEE is one of four atmospheric Cherenkov telescopes which were built to employ the optical facilities of this type of solar energy installation; the others include CELESTE (the Cherenkov Low Energy Sampling and Timing Experiment) [1], GRAAL (Gamma-Ray Astronomy At ALmeria) [2], and Solar Two [3].

By utilizing the very large mirror area provided by the heliostats of the NSTTF (each heliostat has a surface area of $\sim$37 m^2) to collect the Cherenkov light emitted by atmospheric particle cascades, STACEE achieves an energy threshold of around 100 GeV for the detection of cosmic gamma rays; the energy threshold of an atmospheric Cherenkov

CP745, *High Energy Gamma-Ray Astronomy,* edited by F. A. Aharonian, H. J. Völk, and D. Horns

telescope scales approximately as $A^{-1/2}$ [4] (A is the mirror area). This relatively low energy threshold, compared to the second generation of imaging atmospheric Cherenkov telescopes, allows STACEE to detect gamma rays in a poorly sampled energy regime, until recently inaccessible to both satellite and ground-based instruments. Furthermore, since the gamma-ray horizon extends further for lower energy gamma rays than it does for higher energy gamma rays, which are attenuated by the Extragalactic Background Light (EBL) [5, 6], STACEE has a richer set of extra-galactic target sources than the more traditional imaging Cherenkov experiments. As such STACEE observations have the potential to address fundamental astrophysical issues, such as the unobserved cut-off in the pulsed emission spectra of gamma-ray pulsars and the EBL-induced cut-offs expected in AGN spectra.

THE STACEE DETECTOR

STACEE is essentially a wavefront sampling atmospheric Cherenkov detector, using as its primary optic an array of 64 heliostats [7]. The heliostats are used to reflect Cherenkov light from extensive air showers onto 5 secondary mirrors located on the 200 ft solar tower adjacent to the heliostat field (see figure 1 for a map of the heliostat field currently used by STACEE). The secondary mirrors in turn focus the Cherenkov light onto a camera of 64 photomultiplier tubes. A one-to-one mapping between heliostats and PMTs allows the Cherenkov wavefront to be sampled independently at 64 different locations in the heliostat field.

Amplified and AC-coupled signals from the PMTs are fanned out to 8-bit FADCs (one per PMT) and to a three-level digital trigger and dynamic delay system. The first level of the trigger system provides fixed discrimination of the PMT pulses for input into a programmable delay pipeline. Dynamic delays are required to account for the combined effects of the sidereal motion of the source during observations and for the geometry of the Cherenkov wavefront, both of which result in time-of-flight differences for Cherenkov photons detected from different heliostats. The STACEE delay system is a custom built VME and FPGA based unit which provides programmable delays in 1 nanosecond steps over a one microsecond range [8]. The second and third levels of the trigger system demand sub-cluster and inter-cluster coincidences of the delayed pulses within a short time window, typically 16 nanoseconds. Trigger clusters are groups of eight heliostats which are located near each other on the heliostat field; STACEE-64 comprises eight such clusters (see figure 1). Cherenkov events which meet the trigger criteria are recorded for offline analysis, with a typical trigger rate of about 5 Hz.

The FADCs represent a major component of STACEE. Fully digitized waveforms from each PMT provide valuable timing and pulse shape information for use in the wavefront sampling technique. The STACEE FADCs are a commercial system produced by *Acqiris, Inc* and are operated using custom software running on a real-time Linux operating system. Each FADC samples at 1 GHz with a dynamic range of 1 V.

STACEE uses non-event information such as atmospheric monitoring data, heliostat tracking data, PMT anode current monitoring data, and laser flasher calibration data in offline calibration and detector stability monitoring.

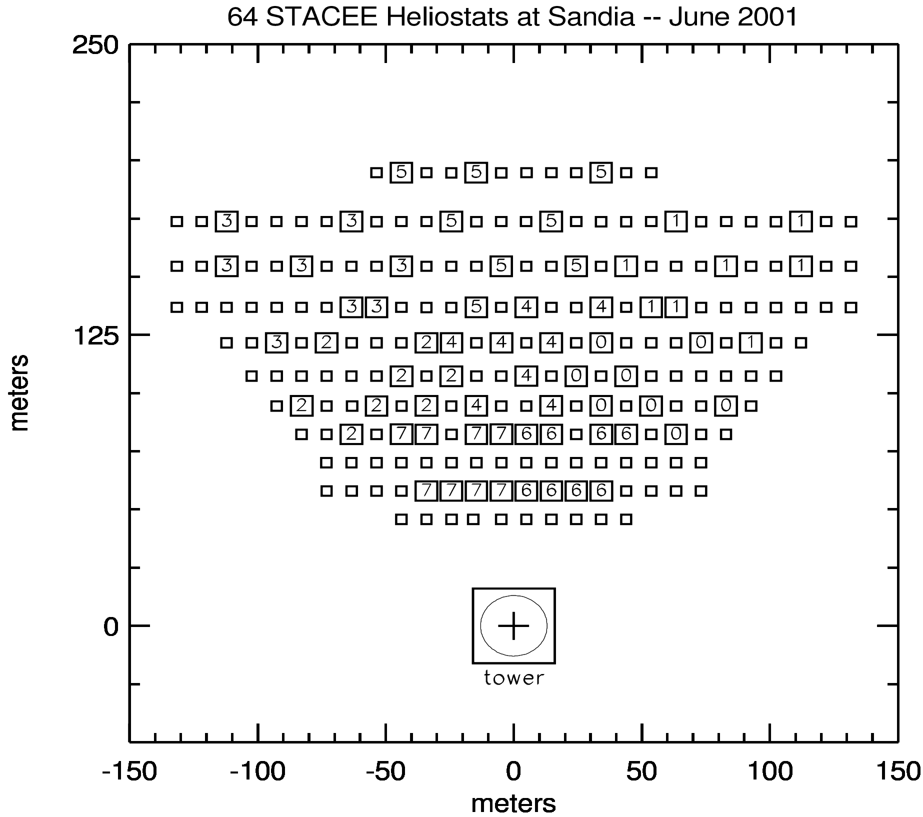

FIGURE 1. Map of the NSTTF heliostat field currently used by the STACEE experiment. Heliostats are numbered according to the trigger cluster (see text for explanation of trigger cluster) to which they belong. The base of the NSTTF solar tower, which houses the STACEE optics and electronics, marks the origin of the coordinate system.

DATA ACQUISITION AND ANALYSIS

STACEE observations are undertaken in an ON/OFF mode. In this mode coextensive observations of the source and a control region of sky, at the same azimuth and elevation as the source, are obtained. A gamma-ray signal from the source manifests itself as an excess of ON events. Any night-sky background brightness differences between the ON and OFF sky regions, which might otherwise introduce bias into the analysis, are accounted for through the use of software padding; the quieter ON or OFF FADC trace for a particular channel is padded up to the same noise level as its counterpart, through the use of a library of measured FADC noise traces.

As is the case for all atmospheric Cherenkov telescopes, the sensitivity of STACEE for the detection of gamma rays is limited by the abundant background flux of hadronic air showers. Unlike imaging Cherenkov telescopes, however, which reject hadronic events by exploiting pronounced differences between the focused images of gamma-ray and hadronic air showers, wavefront sampling experiments distinguish signal and background events on the basis of subtle differences in the lateral and temporal profiles of their Cherenkov light pools. Event reconstruction for STACEE involves the fitting of the shower front after the application of necessary timing corrections, the use of simulated optical efficiency values to account for photon losses between heliostat and PMT, and the location of the impact point of the shower core on the heliostat field. An accurate knowledge of the shower core position is vitally important in order to reconstruct the direction of origin of the instigating photon and to allow for an estimate of its energy.

RECENT OBSERVATIONS

During the 2003/2004 observing season STACEE undertook observations of AGN, plerions/pulsars, and Gamma Ray Bursts (GRBs). In total 184 hours of on-source data were recorded, of which 139 were spent observing blazars (namely W Comae, 3C 66A, H1426+428, OJ+287, and Markarian 421), 40 were dedicated to plerions/pulsars (the Crab nebula/pulsar) and 5 were GRB follow-up observations [9]. An equal amount of time was spent on off-source observations.

Markarian 421

The BL Lac object Markarian 421 (redshift z = 0.031) was detected by STACEE in a high state during the spring of 2004. The detection significance was at the level of 6σ in approximately 11 hours of clean data. Work is ongoing to increase the detection significance through improved background rejection, and to derive a spectrum from these data.

H1426+428

The high-frequency peaked BL Lac object H1426+428 is of interest to STACEE, due to its relatively large redshift of z = 0.129. Although only weakly detected by the imaging Cherenkov telescopes above $\sim$300 GeV [10, 11], its steep spectrum (α=3.5 [12]) favours a higher flux at STACEE energies. During the observing seasons 2002/03 and 2003/04 STACEE obtained a total exposure of 22.6 hours on this object. A preliminary on-source gamma-ray excess of 2.5σ was determined for the complete dataset. Further H1426+428 observations are planned for the season 2004/05.

3C66A

During the 2003/04 observing season, STACEE undertook extensive observations of the low-frequency peaked BL Lac object 3C66A. As is the case for H1426+428, STACEE's interest in this object is motivated by its large reported redshift (z = 0.444). An unconfirmed detection of 3C66A was reported by the Crimean Astrophysical Observatory in 1998 [14]. Given its high reported redshift, and the fact that it is a low-frequency peaked BL Lac, a confirmed detection of this object at TeV energies would have implications for the models of gamma-ray emission by AGN and the models of gamma-ray attenuation by the EBL. A total exposure of 16.9 hours was accumulated by STACEE from which an on-source gamma-ray excess significance of 2.2 σ was obtained [13]. Based on these data a STACEE upper limit on the TeV emission from 3C66A will be published in a forthcoming paper. Additional STACEE observations of this object are planned for the 2004/05 observing season.

W Comae

STACEE data on the BL Lac object W-Comae, detected by EGRET (spectral index $\alpha = 1.73$) but not by ground-based imaging telescopes operating above 250 GeV, have been used to produce upper limits on its gamma-ray flux [15]. Using 10.5 hours of STACEE W-Comae data, 95% CL upper limits on the integral flux above 100 GeV for leptonic emission models and above 150 GeV for hadronic emission models were obtained. Although the leptonic models predict fluxes below the STACEE limits, extrapolations of the best-fit EGRET power law, and some synchrotron-proton hadronic models, predict fluxes close to or above the STACEE upper limits.

CONCLUSIONS

STACEE observations of AGN are ongoing and are planned to continue regularly into the GLAST era, mid 2006 at least. Data accumulated thus far, on a variety of AGN with varying redshifts and predicted fluxes, have not produced evidence for any new gamma-ray sources. However, constraining upper limits have been derived and reported for the BL Lac object W Comae [15]. Work to increase STACEE's sensitivity, through improved gamma/hadron separation is in ongoing and a forthcoming publication will report STACEE upper limits for the LBL BL Lac object 3C66A.

ACKNOWLEDGMENTS

We are grateful to the staff at the National Solar Thermal Test Facility, who continue to support our science with enthusiasm and professionalism. This work is supported in part by the National Science Foundation, the Natural Sciences and Engineering Research

Council, FQRNT (Fonds Quebecois de la Recherche sur la Nature et les Technologies), the Research Corporation, and the California Space Institute.

REFERENCES

1. de Naurois, M., et al. 2002, Astrophysical Journal, 566, 343
2. Arqueros, F., et al. 2002, Astroparticle Physics 17 293
3. Tripathi, S. M., et al. 2002, BAAS, 34, 676
4. Weekes, T. C. 1988, Phys. Rep., 160, 1
5. J. R. Primack et al., 2001, "Probing Galaxy Formation with High Energy Gamma-Rays", in High Energy Gamma-Ray Astronomy, edited by F. A. Aharonian and H. J. Völk, AIP Conference Proceedings 558, American Institute of Physics, New York, pp. 463–478
6. J. R. Primack et al., 2004, "Observational Gamma-Ray Cosmology", in these proceedings
7. D. M Gingrich et al., 2004, "The STACEE Ground-Based Gamma-Ray Detector," in Proc. IEEE Nuclear Science Symposium
8. Martin, J.-P., & Ragan, K. 2000, Proc. IEEE, 12, 141
9. D.A. Williams et al., 2004, "Follow-up Observations of Gamma-ray Bursts with STACEE", in these proceeding
10. D. Horan et al., 2002, Astrophysical Journal, 571, 753
11. F. Aharonian et al., 2002, Astronomy and Astrophysics, 384, L23-L26
12. D. Petry et al., 2002, Astrophysical Journal, 580, 104
13. D. Bramel et al., 2004, "STACEE Observations of 3C66A", in preparation
14. Y.I. Neshpor et al., 1998, Astronomy Letters, 24, pp. 134-138
15. Scalzo, R. A., et al. 2004, Astrophysical Journal, 607, 778