GeV Gamma-ray Observations of Blazars with STACEE

Jennifer Carson (UCLA) for the STACEE Collaboration:

L.M. Boone (Wooster U.), D. Bramel (Columbia U.), J. Carson (UCLA), C.E. Covault (CWRU), P. Fortin, G. Gauthier (McGill U.), D. Gingrich (U. Alberta), D. Hanna (McGill U.), A. Jarvis (UCLA), J. Kildea, T. Lindner, C. Mueller (McGill U.), R. Mukherjee (Barnard College), R.A. Ong (UCLA), K. Ragan (McGill U.), R.A. Scalzo (U. Chicago), D.A. Williams (UCSC), and J. Zweerink (UCLA)

Abstract

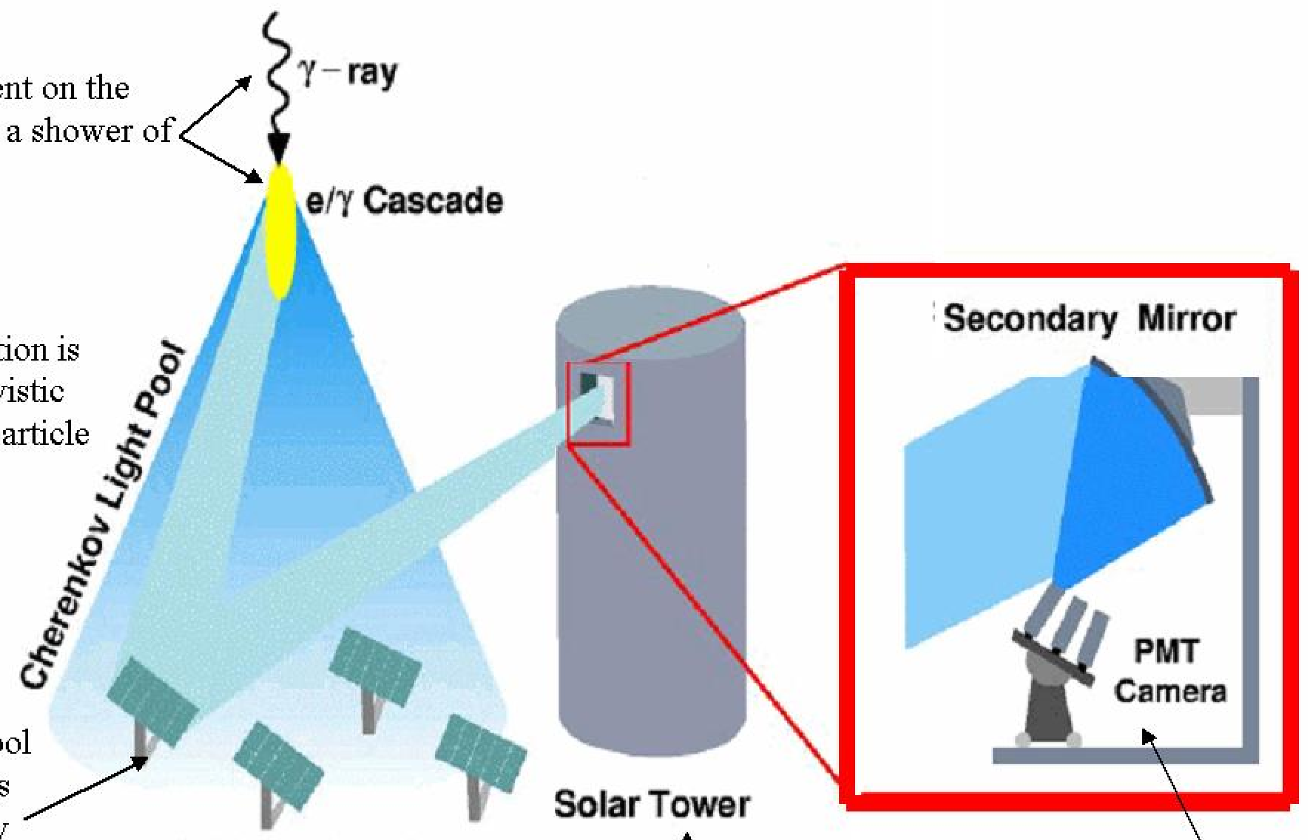
The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) is a ground-based experiment sensitive to GeV gamma rays. STACEE is in a unique position to measure gamma rays from blazars at lower energies than those probed by other ground-based instruments, ultimately providing new information about the particle acceleration mechanisms in these powerful objects. We explain the STACEE experiment itself, review recent results and discuss future plans.

Atmospheric Cherenkov Arrays

Gamma rays incident on the atmosphere induce a shower of particle reactions.

Cherenkov radiation is emitted by relativistic electrons in the particle cascade.

On the ground, the ~200-m-diameter pool of Cherenkov light is collected by an array of heliostats, mirrors used for solar energy research.



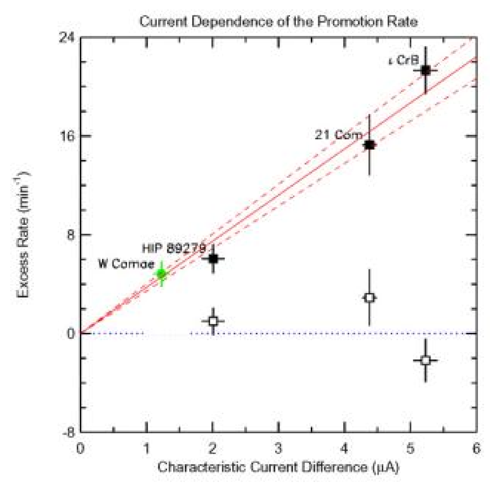
The optical Cherenkov light is reflected onto secondary mirrors located in a tower with the camera and data acquisition electronics.

The light is focused onto a camera of photomultiplier tubes, one per heliostat.

Analysis

1) **Data Quality Cuts**: Eliminate data taken during instrument malfunction or questionable weather conditions.

2) **Field Brightness Corrections**: The background light levels between the on- and off-source observations are equalized (see Scalzo *et al.* 2003 for details). The figure shows the difference in event rate between on- and off-source observations vs. the difference in average PMT current. The excess rate is caused by extra starlight in the off-source observation promoting sub-threshold cosmic ray showers, which then trigger the system. For fields with bright stars, a clear linear trend is seen (filled black points). After correcting for light level differences, the excess rate is eliminated (open points). The blazar W Comae's excess is consistent with the linear promotion trend.



3) **Calculation of excess**: $\sigma_{excess} = \frac{(N/T)_{ON} - (N/T)_{OFF}}{\sqrt{(N/T)_{ON} + (N/T)_{OFF}}}$ where T = live time, N = number of events

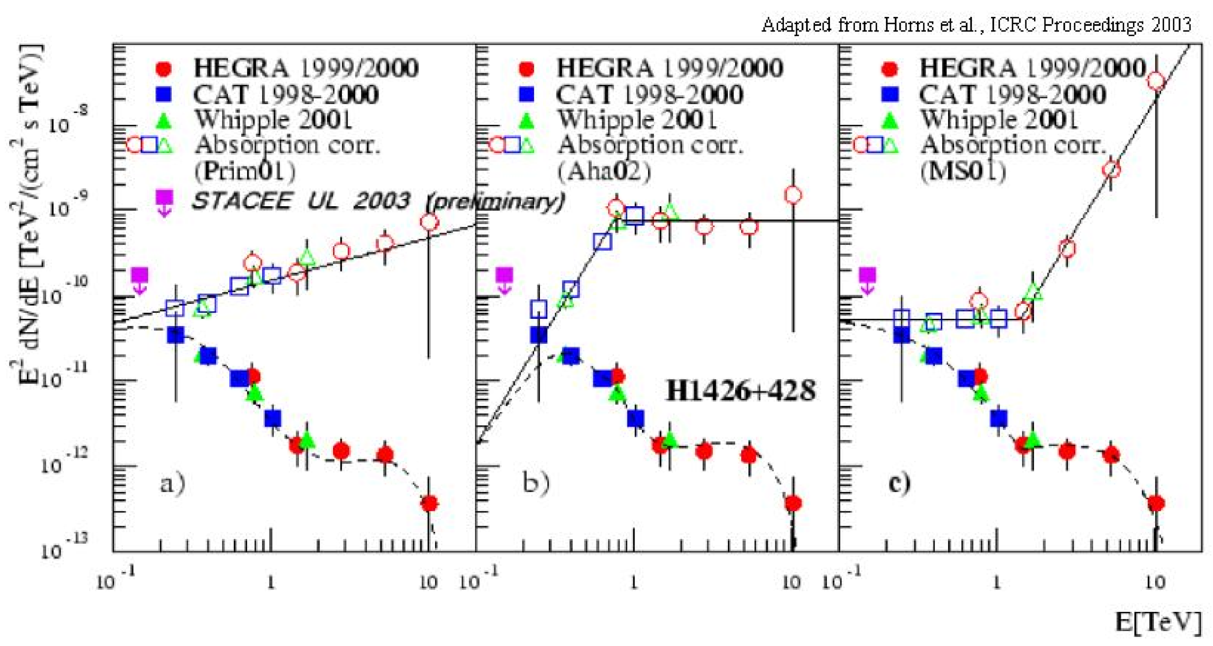
4) **Calculation of integral flux or flux limit:** Simulate the efficiency of the detector as a function of energy and pointing direction. From this information and an assumed form for the source spectrum, estimate the integrated flux or flux limit above a determined energy threshold.

5) **Cherenkov wavefront reconstruction (*work in progress*)**: Use the PMT charge and timing information along with detailed simulations to reconstruct: 1) the location of the air shower on the ground, 2) the arrival direction of the shower, and 3) the energy of the originating gamma ray. This information will be used to reject showers initiated by cosmic rays and to deduce gamma-ray spectra.

Results: 1426+428

The **95% confidence level upper limit on the GeV flux, 1.8×10^{-10} TeV cm^{-2} s^{-1} above 140 GeV,** is shown (purple square) along with other higher-energy gamma-ray measurements (filled points). The open points represent the data after making EBL absorption corrections based on the predictions of three different models (see references).

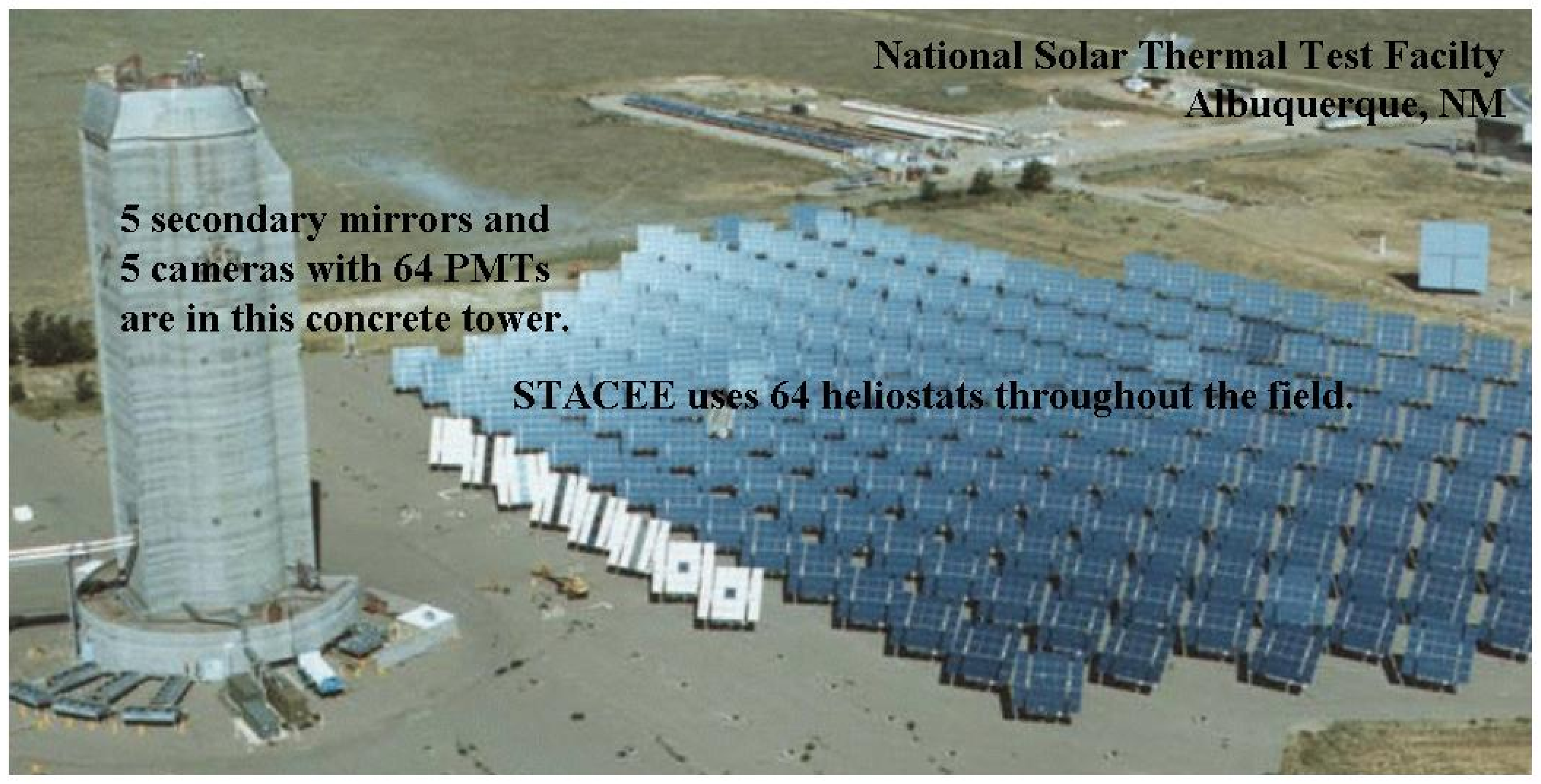
Adapted from Horns et al., ICRC Proceedings 2003



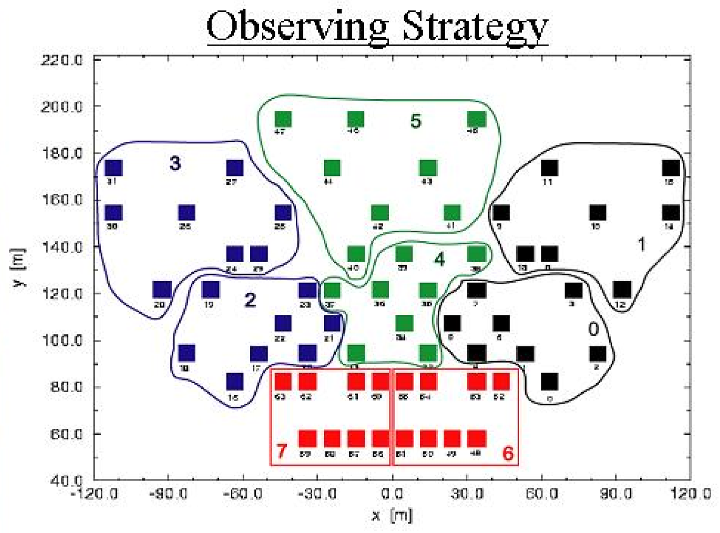
References

Aharonian, *et al.* 2002, *A&A*, 384:L23 (Aha02)
Horns, D. *et al.* 2003, ICRC Proceedings
Malkan, M.A. & Stecker, F.W. 2001, *ApJ*, 555:641 (MS01)
Primack, J.R. *et al.* 2001, *AIPC*, 558:463 (Prim01)
Scalzo, R.A., et al. *High-Energy Gamma-Ray Observations of W Comae with STACEE*, *ApJ*, submitted

STACEE: The Solar Tower Atmospheric Cherenkov Effect Experiment

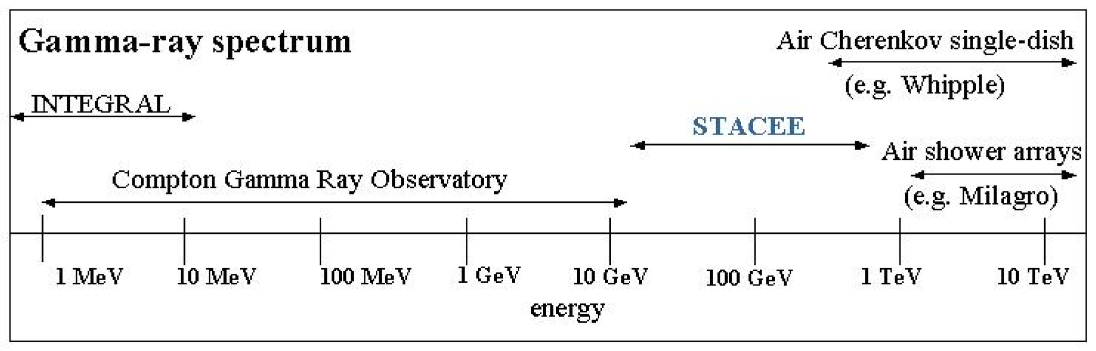


Observing Strategy



STACEE's 2-level **trigger system** significantly reduces the formidable background from cosmic-ray-induced Cherenkov light. It requires 5 heliostats out of each cluster and 5 out of 8 clusters to detect >~5 photoelectrons within a 24-ns time window before data are recorded. This condition also eliminates triggers from night sky background.
To further reduce the contamination from cosmic-ray showers, a background "off-source" observation is taken for each on-source one.

STACEE observations close the gap between low- and very-high-energy gamma-ray observations, **opening a previously unobserved band of the EM spectrum.**

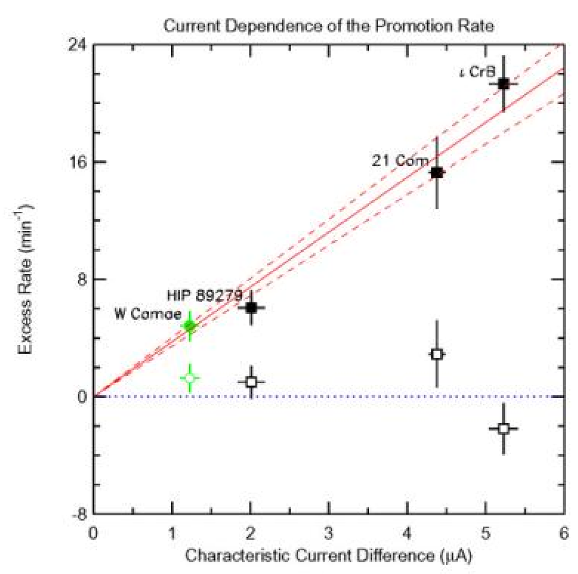


Data Acquired: **Timing information ⇒ Arrival direction of gamma ray**
Intensity of light pool ⇒ Gamma-ray energy

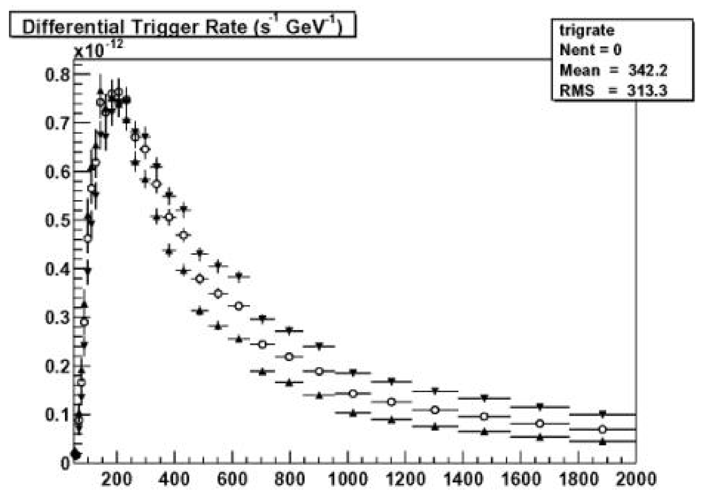
Summary of STACEE Observations and Results

Source	Redshift	Dates of observations	Time on-source before cuts	Time on-source after cuts	Sky brightness correction?	Results/Status of analysis
Mkn 421	0.030	Dec 2002 – May 2003	23.7 hours	20.9 hours	Yes	No signal detected
W Comae	0.102	March – May 2003	14.9 hours	10.5 hours	Yes	Flux upper limit (see below)
1426+428	0.129	March – June 2003	10.7 hours	8.7 hours	No	Flux upper limit (see below, left)
3C 66A	0.444	Sept – Dec 2003	33.5 hours	18.9 hours	Yes	Slight signal seen in *preliminary* analysis

Results: W Comae (Scalzo et al. 2003)

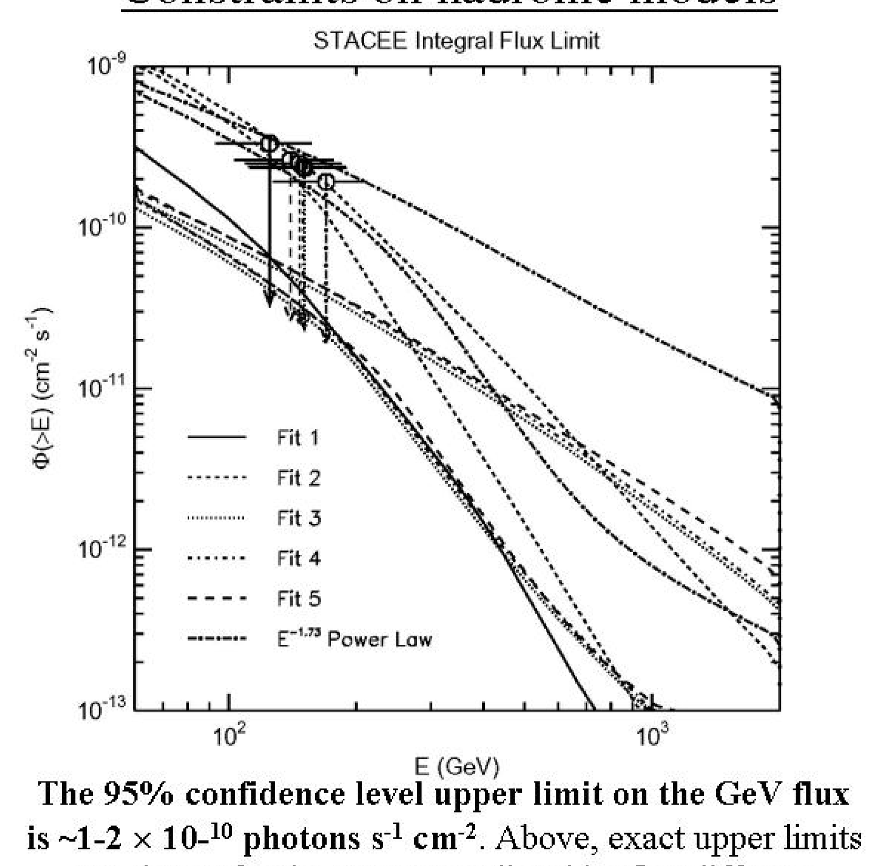


Sky brightness corrections reduced the excess from 4.6σ to 0.7σ, consistent with no signal. Left, the dynamic threshold padding technique (Scalzo et al. 2003) is applied to the W Comae observations and to the observations of three bright stars. Filled and open points represent the excess rate before and after corrections, respectively.



The simulated trigger rate, which depends on source elevation, azimuth, and spectral index, is plotted as a function of gamma-ray energy. The three curves assume three different spectral indices. The **energy threshold** is defined as the peak of this curve. For the W Comae observations, it is **165 ± 40 GeV**.

Constraints on hadronic models



The 95% confidence level upper limit on the GeV flux is ~1-2 × 10-^{10} photons s^{-1} cm^{-2}. Above, exact upper limits are shown for the spectra predicted by five different hadronic models of gamma-ray production. The STACEE limit rules out the most extreme of these models, "Fit 2", which has a cutoff Lorentz factor in the proton energy distribution of 3×10^9. The STACEE limits come within a factor of 10 of placing significant constraints on the other models. Observations in the Spring of 2004 and analysis advances may allow STACEE to further constrain these models. See Scalzo *et al.* (2003) for details.