Astrophysics around 100 GeV with STACEE

David A. Williams
University of California, Santa Cruz

representing

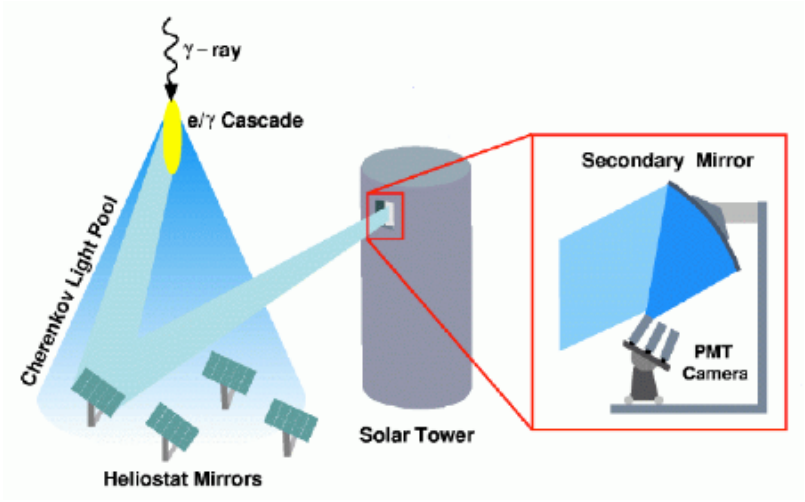
The STACEE Collaboration

L.M.Boone,[1] D.Bramel,[2] J.Carson,[3] C.E.Covault,[4] P.Fortin,[5] G.Gauthier,[5] D.Gingrich,[6] D.Hanna,[5] A.Jarvis,[3] J.Kildea,[5] C.Mueller,[5] R.Mukherjee,[2] R.A.Ong,[3] K.Ragan,[5] R.A.Scalzo,[7] D.A.Williams,[1] J.Zweerink[3]

[1]Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, USA
[2]Barnard College and Columbia University, New York, USA
[3]Division of Astronomy and Astrophysics, University of California, Los Angeles, USA
[4]Department of Physics, Case Western Reserve University, Cleveland, USA
[5]Department of Physics, McGill University, Montreal, Canada
[6]Centre for Subatomic Research, University of Alberta, Edmonton, Canada
[7]Department of Physics, University of Chicago, Chicago, USA

The STACEE Concept

- Adapt a solar power facility
- Sample the Cherenkov light pool at many locations on the ground
- Achieve a low energy threshold as a result of the large mirror collection area

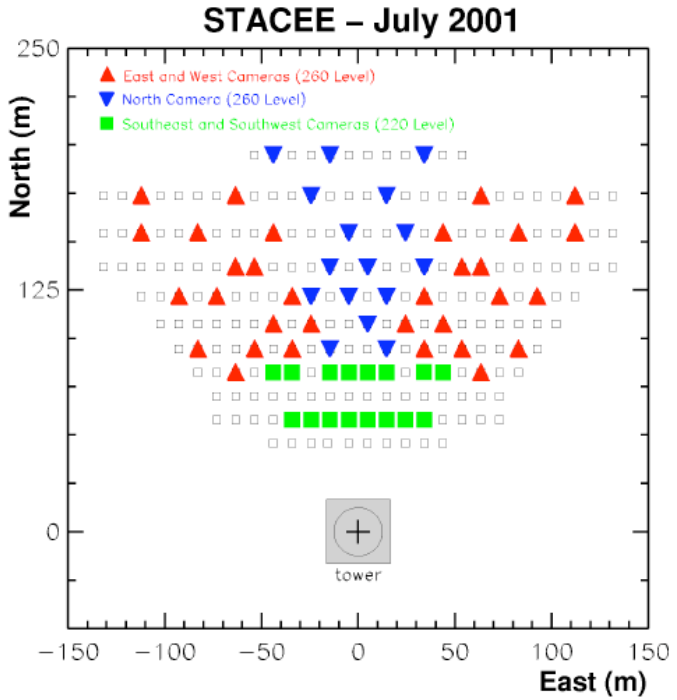


The NSTTF

- STACEE uses the National Solar Thermal Test Facility (NSTTF) at Sandia National Laboratories in Albuquerque, New Mexico, USA
- STACEE uses 64 heliostats, each with 37 m^2 area

34.96° N, 106.51° W, 1700 m a.s.l.

The STACEE Heliostats



160-foot platform:

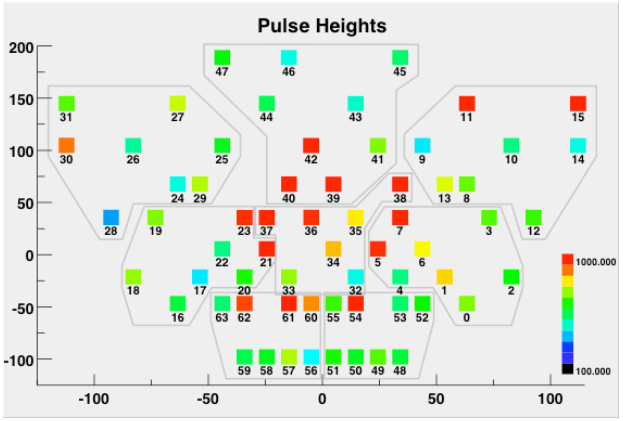
- 2-meter secondaries (3)
- 16 channels each
- West, North, East

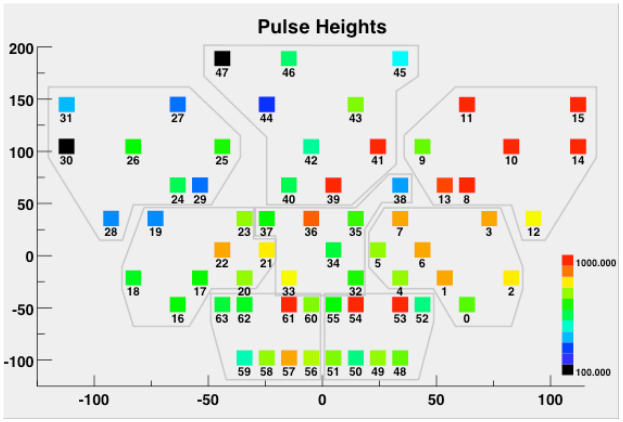
120-foot platform:

- 1-meter secondaries (2)
- 8 channels each
- Southeast, Southwest

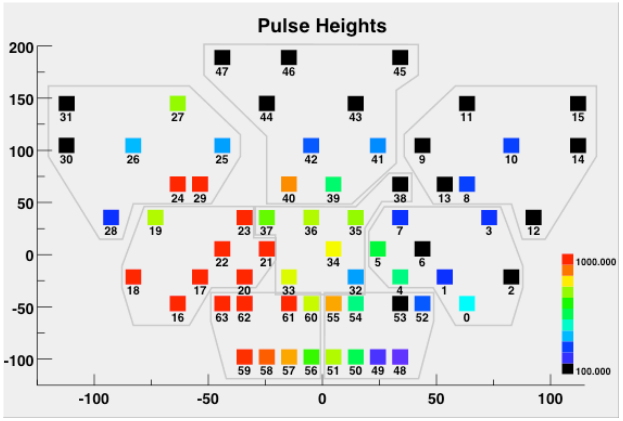
FADCs Added in Fall 2001

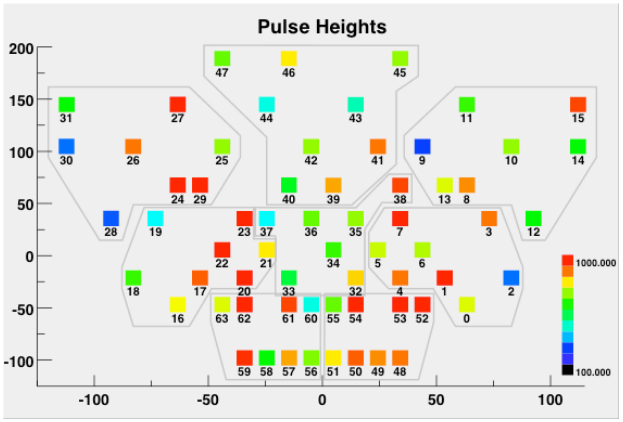
Monte Carlo 100 GeV gammas



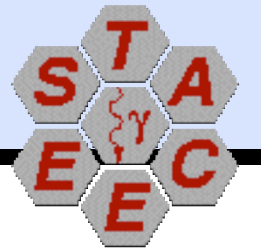


Zenith data showers



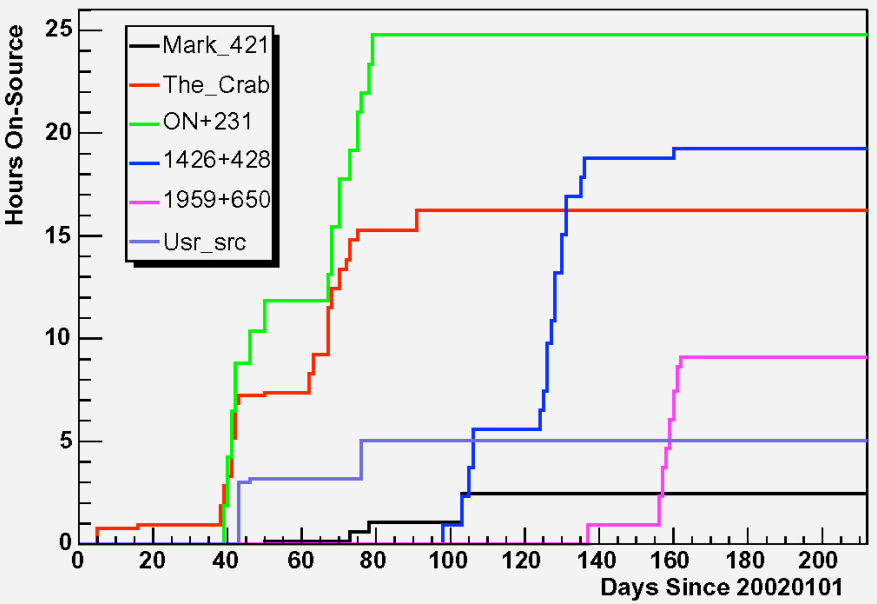


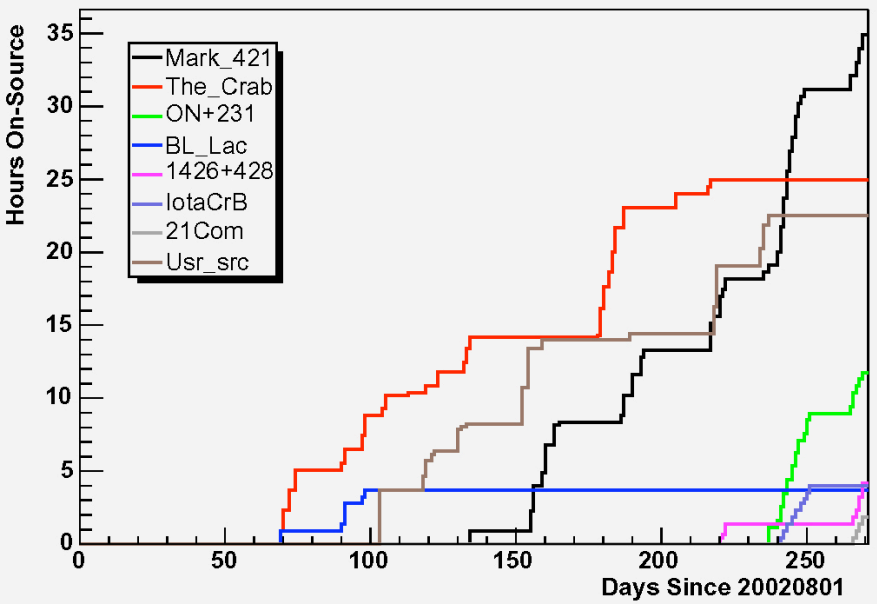
Recent STACEE Observing



- Crab
  - Search for pulsed emission
  - Benchmark instrument performance
- AGN (Mrk 421, W Comae, 1426+428, …)
  - Elucidate emission mechanism(s)
  - Participate in multiwavelength campaigns
  - Seek evidence of IR absorption
- GRB
  - Follow up satellite alerts

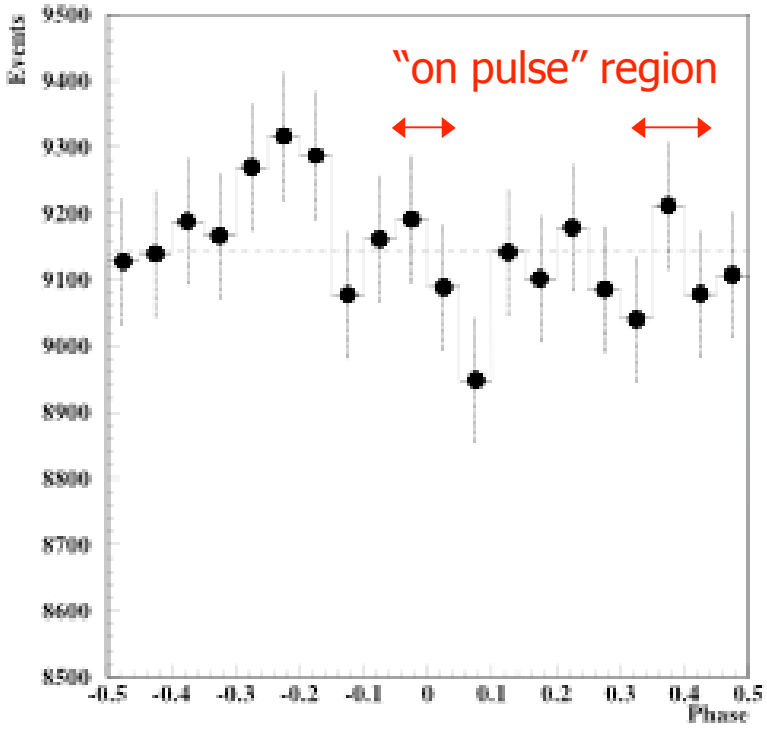
Recent Data Acquired





Data acquired in the first half 2002 and so far during the 2002-2003 observing season

STACEE-32 Crab Results



S. Oser *et al.*, ApJ **547**, p. 949 (2001)

Integral Flux

$(2.2 \pm 0.6 \pm 0.2) \times 10^{-10}$ cm^{-2}s^{-1}

Above 190 GeV

Consistent with $E^{-2.4}$ IACT results

Pulsed fraction

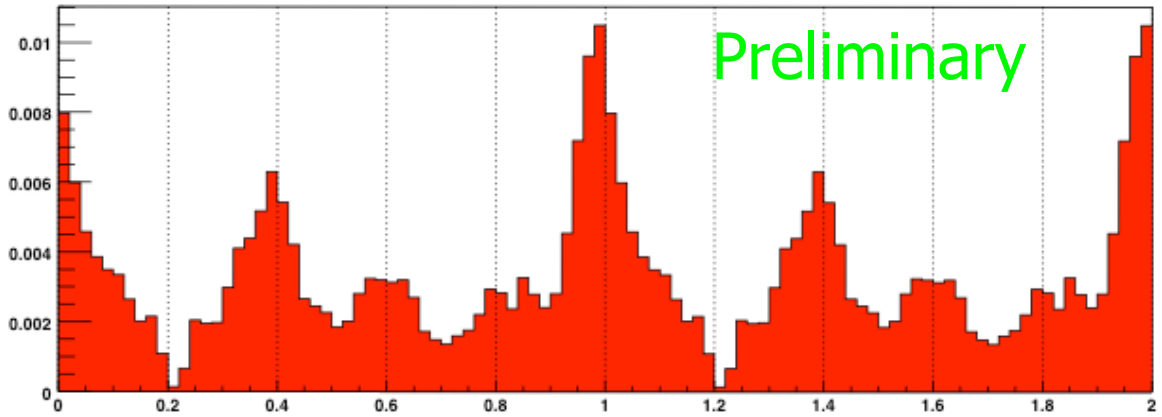
<5.5%

Gamma-ray rate

1.6 min^{-1}

STACEE Crab Observations

Optical Pulsar Phase Histogram



Saturn limited observations this season

Data on optical pulsar—test barycentering code

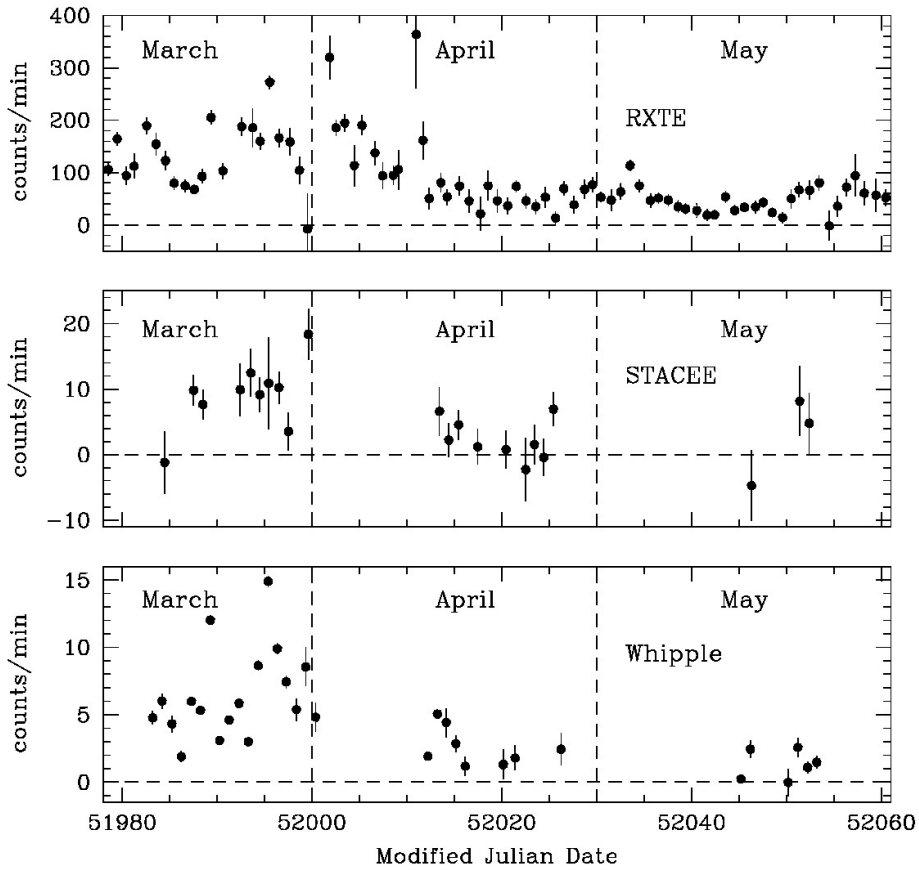
Gamma-ray rate ~5 min^{-1}

Markarian 421

- First AGN detected at TeV energies
  - Punch *et al.*, 1992
- First AGN detected by STACEE
  - Boone *et al.*, 2002
- High energy peak of SED apparently near STACEE energies
- Very active source in the last several years
  - Gaidos *et al.*, 1996 …
- Spectrum varies as flux changes
  - Krennrich *et al.*, 2002
- Target of many multiwavelength efforts

STACEE-48 Mrk 421 Results

Spring 2001 Markarian 421 Light Curves



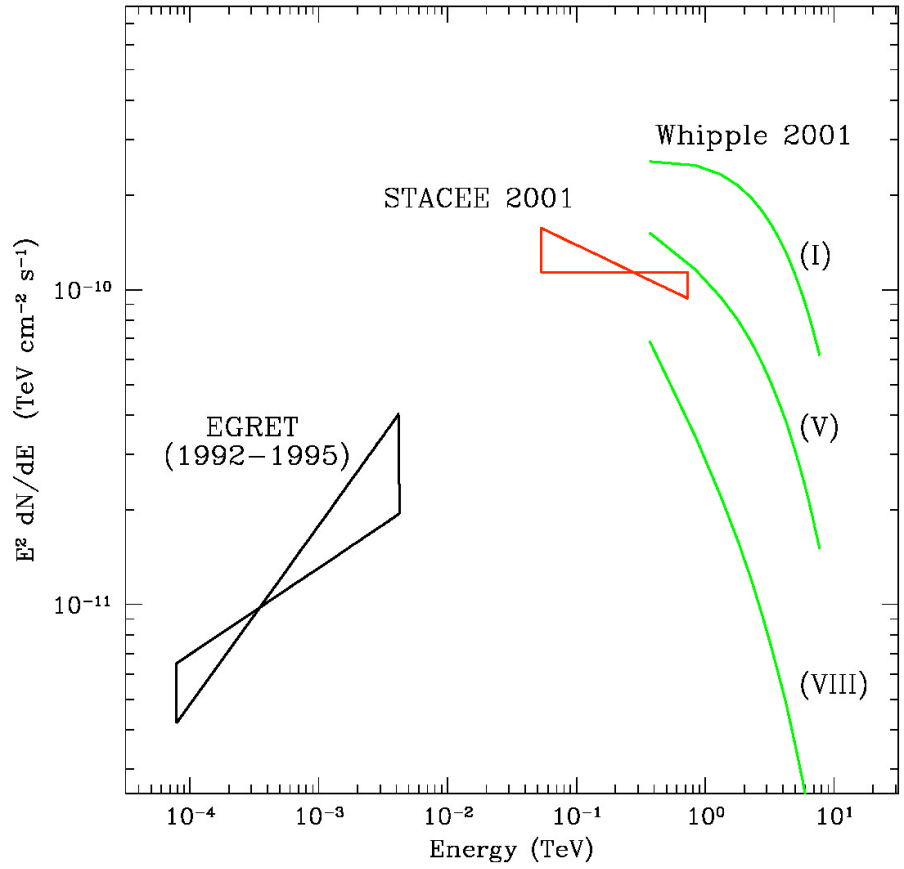
RXTE ASM 2–10 keV
RXTE All-Sky Monitor Team

STACEE 50–300 GeV
Boone *et al.*, 2002 ApJLett **579**, L5

Whipple 0.25–8 TeV
Holder *et al.*, 2001 ICRC **1**, 2613

STACEE-48 Mrk 421 Results

Integral Flux (8.0±0.7±1.5) x 10^{-10} $cm^{-2}s^{-1}$ above 140 GeV



Red butterfly reflects spectral indices from 2.0 to 2.2

Whipple curves (Krennrich *et al.*, 2002 ApJ **560**, L9) represent high, medium, and low flux levels

EGRET data from Hartman *et al.*, 1999, ApJS **123**, 79

Recent STACEE Mrk 421 Data

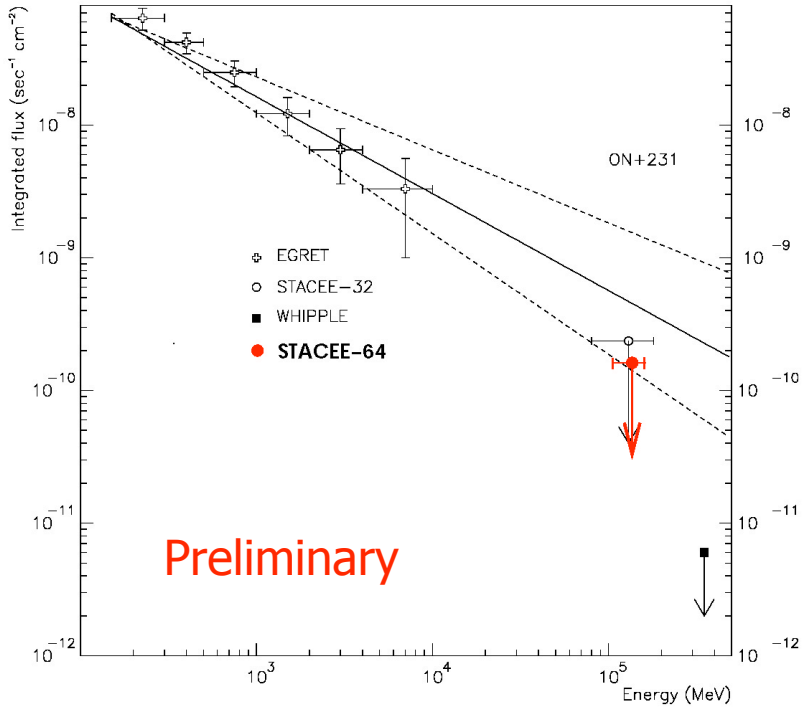
- STACEE participated in two MW campaigns including RXTE data
  - 2002 Dec 2 - Dec 16 & 2003 Jan 10 - Jan 14 (PI: H. Krawczynski)
    - ~4 hours on source (horrible weather)
  - 2003 Feb 26 - Mar 5 (PI: R. Edelson)
    - <1 hour on source (more bad weather)
- Continue to record 0.5-1 hour each night as weather and moon allow

W Comae (ON+231)

- BL Lac object at moderate redshift (z=0.1)
- Hard EGRET spectral index (-1.73)
  - One of few detected above 1 GeV
  - 27 GeV photon was detected (Dingus & Bertsch 2001)
- Predicted to be a strong TeV source
  - Mannheim *et al.* (1995) astro-ph/9502085
- Not yet detected above EGRET energies
- Signal could be a smoking gun for hadronic processes
  - X-ray data constrain SEDs for leptonic models to cut off sharply above 100 GeV (Boettcher, Mukherjee & Reimer(2002), ApJ **581**, p. 143)

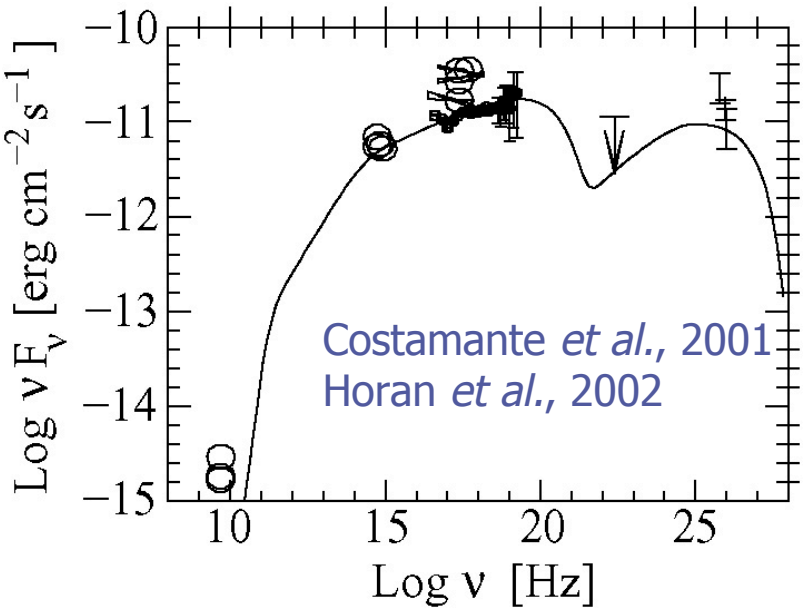
W Comae Results

- Preliminary upper limit integral flux–2002 data
  - $<1.41 \times 10^{-10}$ cm^{-2}s^{-1}
  - (above 140 GeV)
- Earlier limit–1999 data
  - C. Théoret, Ph.D thesis
- Observations continue this season



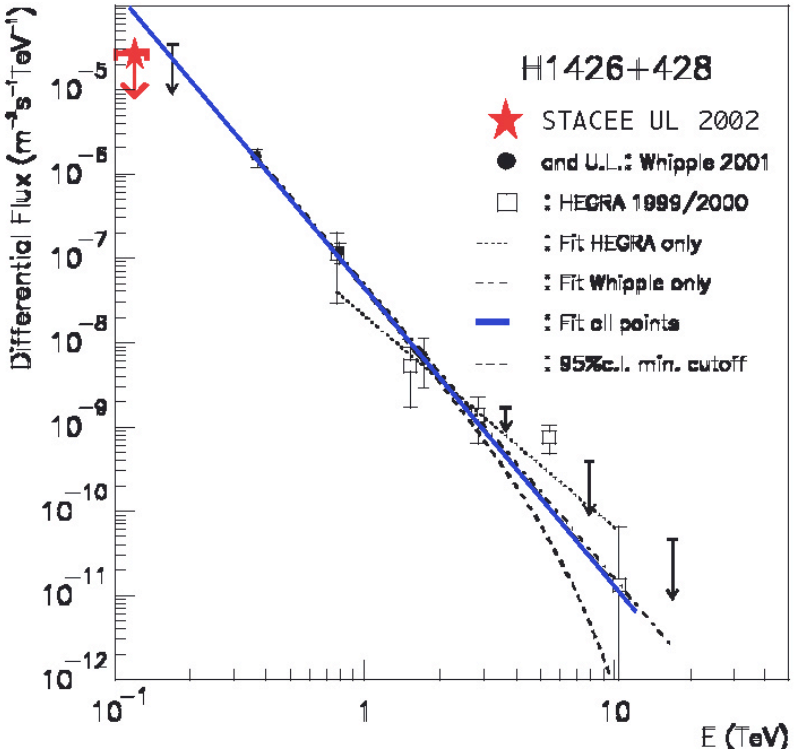
H 1426+428

- "Extreme" X-ray BL Lac
  - Synchrotron peak at ~100 keV
  - One of the best TeV candidates in SSC models
- Weak TeV source
  - Whipple, HEGRA, & CAT
  - ~3% of Crab
  - Very soft spectrum, $E^{-3.5}$
- Not detected by EGRET
- Highest redshift TeV blazar (z=0.129)



H 1426+428 Results

- Data taken in 2002 in conjunction with multiwavelength campaign
- Preliminary flux upper limit
  - $<2.0 \times 10^{-5}$ $m^{-2}s^{-1}TeV^{-1}$
  - at 120 GeV
- Starting to collect more data this month



Adapted from A. Aharonian *et al.*, A&A **384**, p. L23 (2002)

3C 66A (0219+428)

- Relatively high redshift (z=0.44) BL Lac object, intermediate between the sub-classes of high- and low-frequency-peaked (HBL and LBL)
- Good candidate for IR absorption features
- One of the most promising candidates for future ACT detections above 100 GeV
- Detected by EGRET several times
- X-ray observations indicate that its synchrotron component extends into the X-ray regime

3C 66A … continued

- Detection at > 100 GeV would open the door for VHE astronomy towards a new class of objects
- Participate in recently-awarded RXTE campaign in winter 2003-2004 (PI: Boettcher)
- STACEE Multiwavelength page has details:

  http://www.astro.columbia.edu/~stacee/multi.html

Multiwavelength Campaigns

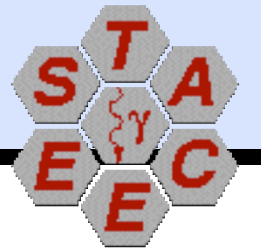
STACEE participation in multiwavelength campaigns is posted on the web:

http://www.astro.columbia.edu/~stacee/multi.html

X-Ray and GeV-TeV Gamma-Ray Multiwavelength Observations Following the Detection of New TeV Blazars

- RXTE AO8 (PI: H. Krawczynski)
- STACEE will join the ToO follow-up observations upon notification by the PI about the detection of new TeV blazars

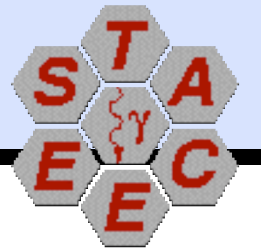
Multiwavelength Campaigns



X-Ray TeV Multiwavelength Observations of Markarian 501 and 1ES 1959+650

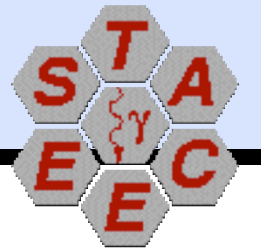
- RXTE AO8 (PI: H. Krawczynski)
- STACEE will observe Markarian 501 during the RXTE observations in 2003, upon ToO notification
- Decision to observe 1ES 1959+650 is pending, based on recommendations of the STACEE source committee

Gamma-Ray Bursts



- Little is known about >1 GeV emission from GRB
  - EGRET has seen 18 GeV photon from GRB940217
  - Milagrito observation of GRB970417a, …
- Cosmological Distances Limit Horizon
  - STACEE can see to z~1
- STACEE subscribes to e-mail GCN notices

STACEE GRB Response



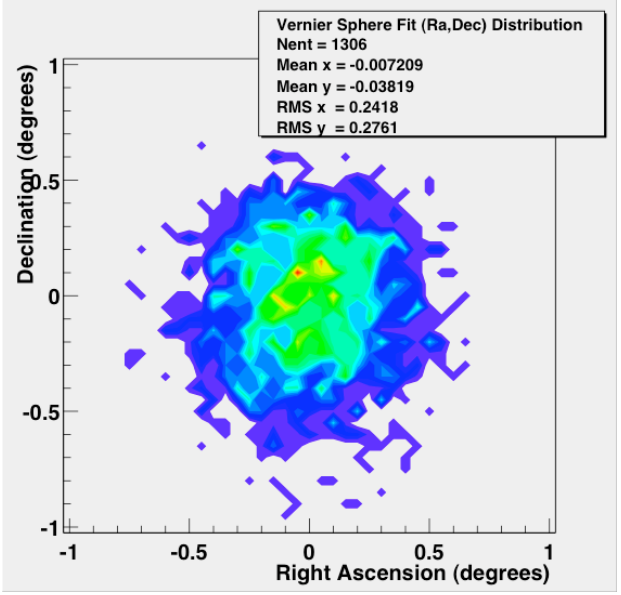
- Bursts <12 hours old within STACEE f.o.v. receive top priority
- Can retarget to burst location in a couple minutes
- Several per year now
- SWIFT era ~7 prompt, ~45 afterglow per year
- Sensitivity ~2 x 10^{-9} $cm^{-2}s^{-1}$ above 70 GeV
  - 5□ in a 30 minute observation
  - Extrapolated GRB940217 flux ~50 times higher

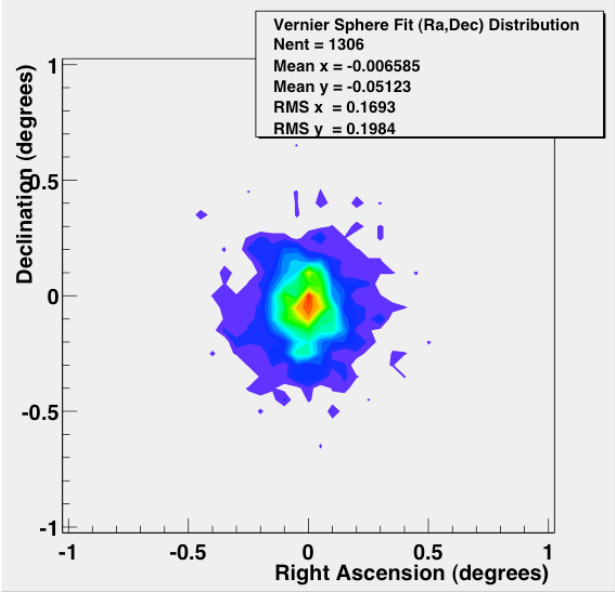
Using FADC Information

- STACEE observations in On – Off mode
- Stars in On or Off fields can change background rate
- STACEE-48 Markarian 421 detection corrected using On – Off star pairs
- FADC data can be padded to equalize NSB rates (*cf.* CELESTE work)
- Taking data on stars to test various methods

Reconstruction Using FADCs

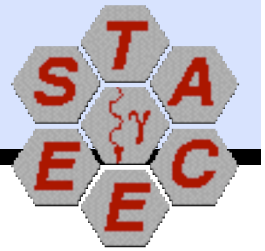
Simulated Vertical Gamma Rays





- Core finding with pulse height info (right) improves energy and angular resolution
- Using maximum likelihood fit to template showers
- Background rejection quality factor of 2.5 to 3.5

STACEE Performance

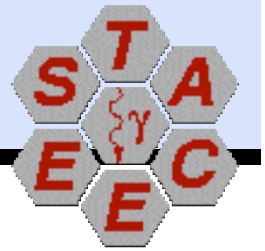


- ~8 Hz trigger rate
- 4 p.e. discriminator threshold (~50 GeV)
- 10□ sensitivity to Crab flux
  - 25 hours—without hadron rejection
  - 6 hours—with hadron rejection

75 GeV
- 0.18^{o} Angular Resolution
- 30% Energy Resolution
- 1100 m^2 Effective Area

250 GeV
- 0.15^{o} Angular Resolution
- 25% Energy Resolution
- 15000 m^2 Effective Area

Summary



- STACEE is complete
- Analysis being developed to take full advantage of FADC information
- Results illustrate role STACEE plays understanding "low energy" part of spectrum
- Science has concentrated on AGN and Crab so far
- STACEE plans include the full range of other potential sources (SNR, pulsars, unidentified, …)