# Studies of AGN Using the STACEE Detector

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### Abstract

We present a summary of current and future work to investigate the nature of AGN using the Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE). The spectral coverage of STACEE includes the 50 to 250 GeV energy range which is inaccessible by current space and ground-based experiments, and is largely unexplored. This is an important energy range where the spectra of most blazars are expected to cut off, either intrinsically, or owing to interactions of $\gamma$-rays from blazars with photons of the extragalactic infrared to UV background. STACEE is very well-suited for the study of several northern hemisphere AGN and is likely to measure spectral cutoffs in this energy range. We describe the current status of STACEE and our plans for continued observation of AGN using STACEE in the future.

## 1 Introduction:

The detection of a large number of active galactic nuclei of the blazar class by EGRET (Energetic Gamma-Ray Experiment Telescope) is one of the major discoveries of the Compton Gamma-Ray Observatory (CGRO). Blazars exhibit intense and hard power law spectra up to 5 GeV without spectral breaks. So far, EGRET has detected 68 blazars, of which 17 are BL Lacertae objects (Hartman et al. 1999). Of the 17 BL Lac objects (BLLs) seen by EGRET, three are X-ray selected BLLs (XBLs), namely, Mrk 421, Mrk 501, and PKS 2155-304. All of these XBLs have been detected by TeV telescopes, thereby reinvigorating the $\gamma$-ray studies of these objects. The detection of TeV emission from a handful of the EGRET blazars with ground based Cherenkov telescopes indicates that blazars can radiate photons up to TeV energies. Although a simple extrapolation of the power-law spectra of AGN observed by EGRET supports the possibility that blazars could be detected at TeV energies, only three EGRET blazars have been detected at energies $> 250$ GeV by Cherenkov telescopes. In particular, none of the FSRQs (flat-spectrum radio quasars) seen by EGRET have been detected at TeV energies, although most of them have been observed (Kerrick et al. 1995). These studies indicate that cutoffs exist in the blazar spectra between the energies of 10 GeV and 250 GeV. The measurement of the blazar spectra in the high energy $\gamma$-ray band, particularly in the 50 GeV to 250 GeV range, is therefore a complex and physically interesting subject. Until recently this has been a part of the electromagnetic spectrum that has not been systematically explored. However, the new generation Cherenkov Telescopes, STACEE and CELESTE, have started to bridge the gap between current space- and ground-based instruments (see Ong 1998 for a review). In this article we discuss the status of STACEE, its sensitivity to AGN spectra, and its plans for observing EGRET blazars.

## 2 The STACEE Detector:

STACEE is a ground-based instrument sensitive to the hitherto unexplored energy region between 50 and 250 GeV. It uses large heliostat mirrors to detect Cherenkov photons emitted in $\gamma$-ray air showers. STACEE is located at the Sandia National Laboratories in Albuquerque, New Mexico. It is currently operating with an array of 32 heliostats, which gives it a low energy threshold of $\sim 75$ GeV. The complete experiment of 64 heliostats will have sensitivity below 50 GeV. A detailed description of the design of the detector may be found in Chantell et al. (1998). The operation and performance of STACEE, based on preliminary observations, is described by Covault et al. (1999).

## 3 Scientific Goals of AGN Studies by STACEE:

The measurement of the spectra of AGN in the high energy $\gamma$-ray band, particularly between 50 and 250 GeV, is important for several reasons.

$\gamma$-rays above 10 GeV are expected to be attenuated by optical/infra-red (IR) photons through pair-production during their travel through intergalactic space, leading to a cutoff in the measured $\gamma$-ray spectrum (Gould & Schreder 1966). The optical depth ($\tau$) of the attenuation is a complex function of the $\gamma$-ray photon energy, the distance to the source (redshift), and the pair-production cross-section. In addition to intergalactic absorption, one must be able to distinguish between and separate out the effects of intrinsic absorption, as well as natural cutoff energies (Klein-Nishina effect) in the blazar emission spectra. The optical depth, and hence the cutoff in the blazar spectrum, is related to the density and spectrum of the cosmic IR background (CIB). The magnitude & shape of the CIB are fundamental to understanding the early evolution of galaxies and TeV $\gamma$-rays from blazars could be used as a probe of the CIB (Stecker, De Jager, & Salamon 1992). Various models for stellar production and evolution of the CIB have been studied under a variety of assumptions (e. g. Madau & Phinney 1996; MacMinn & Primack 1996).

In order to study spectral cutoffs in blazars it is important to measure the high energy $\gamma$-ray spectra of blazars spanning a range of redshift distances. Studies of the spectra of individual TeV blazars like Mrk 421 and Mrk 501 do not give definite conclusions about the CIB and the effect of intergalactic absorption (e. g. Aharonian et al. 1999; Biller et al. 1995). This is because the intrinsic spectra of sources is not known a priori, and the measurement of the spectrum of a single source can at best give only an upper limit on the CIB. All of the FSRQs seen by EGRET and most of the BLLs have not been detected at TeV energies, suggesting intergalactic absorption effects in the energy range between EGRET and TeV instruments. Measurement of the spectra of these blazars in the 50 to 250 GeV range by ground-based Cherenkov instruments could provide crucial information for studying the CIB.

In addition, the spectral shape and variability of TeV blazars can place constraints on $\gamma$-ray emission mechanisms in blazars, which is thought to originate in relativistic jets. The emission in the high energy range is believed to be due to the inverse Compton scattering of low-energy photons by relativistic electrons in the jet. However, the source of the soft photons that are inverse Compton scattered remains questionable. The soft photons can originate as synchrotron emission either from within the jet (Synchrotron Self Compton or SSC model) or external to the jet (External Radiation Compton or ERC model) (see Urry 1998 for a review).

Recently, Tavecchio et al. (1998) derived constraints for a homogeneous SSC model from the broadband spectra of a few TeV blazars. Using the simplest model proposed for TeV blazars, Tavecchio et al. (1998) assume a single zone and a single population of relativistic electrons emitting synchrotron radiation from radio to X-rays and inverse Compton (IC) emission from X-rays to $\gamma$-rays. The seed photons for the high energy emission are assumed to be the synchrotron photons themselves. Measuring the peak location of the IC spectrum would be crucial to testing SSC models. Currently, a major source of uncertainty in SSC model calculations is the location of the IC peak, and its change with different spectral states of the source. Measurement of the spectra of AGN with STACEE as well as at lower energy and TeV bands might enable us to constrain the peak of the IC spectrum better.

The nature of the relativistic particles in the jet, whether leptonic or hadronic, as well as the source of the soft photons that are inverse Compton scattered, is still a subject of debate. Although recent measurements of the spectra of these sources do not contradict SSC models (e. g. Aharonian et al. 1999; Kataoka et al. 1999), other models of $\gamma$-ray emission cannot be completely ruled out. Further measurements of the spectra energy distribution (SED) of AGN with as few gaps in the spectra as possible could help in resolving some of the current uncertainties.

## 4 STACEE Observations - Status and Future Plans:

In the past year observations were carried out with the partially-completed STACEE detector on clear, moonless nights between 1998 October and 1999 May. During this time most of the observations conducted by STACEE were of the Crab Nebula and pulsar. The results of these observations and the analysis techniques are described by Oser et al. (1999). In addition, STACEE also carried out observations of Mrk 421, Mrk 501 and PKS 1219+285 during February to April, 1999. A typical STACEE observation consists of a 28 minute "on-source" run, followed by an "off-source" run of the same length, with the detector tracking a point $\pm 7.5^{\circ}$ away. A total of $\sim 24$ on-off pairs were collected during this period. These data sets are currently being analysed.

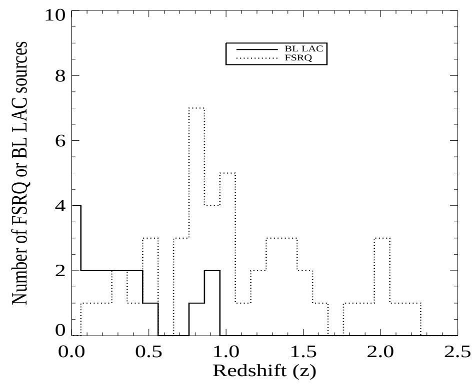


**Figure 1:** Redshift distributions of flat-spectrum radio quasars (FSRQs) and BL Lac objects (BLLs) detected by EGRET.

STACEE plans to observe several of the FSRQs and BLLs observed by EGRET, particularly the ones not detected at $> 250$ GeV. Figure 1 (Mukherjee et al. 1999) shows the redshift distribution of BLLs and FSRQs in the 3EG catalog. In general, the BLLs tend to have smaller redshifts than FSRQs. Recently, Salamon & Stecker (1998) have calculated the absorption of 10-500 GeV $\gamma$-rays for different redshifts by taking into account the evolution of both the SED and of the emissivity of galaxies with redshift, and also including the effects of metallicity evolution on galactic stellar population spectra. Using these values Stecker (1999) has calculated the critical energy for absorption, $E_{\rm crit}$ (GeV), corresponding to $\tau = 1$, as a function of redshift. $\tau \gg 1$ for energies much larger than $E_{\rm crit}$, leading to a predicted cutoff in the spectrum of a blazar. $\gamma$-rays above an energy of $\sim$ 50 GeV will be attenuated if they are emitted at a redshift of $\sim 0.9$. Sources with redshifts in the range $\sim$ 0.2 to 0.9 are found to have $E_{\rm crit}$ in the range $\sim$ 50 to 250 GeV. These numbers change somewhat if a different model without metallicity evolution is used for the CIB; this is an indicator of the uncertainty in extinction for high redshift sources.

Table 1 shows a list of candidate blazars that could be observed by STACEE. All of these sources have been detected at $> 100$ MeV by EGRET. In order to be detectable by STACEE during the September to May period, a source must lie in the declination range $0^{\circ} < \delta < 50^{\circ}$, and a right ascension range of 0h to 17h. In addition, Table 1 shows only those EGRET blazars that have redshifts below 2.0. Also listed in the table are the photon spectral indices of the blazars, $\Gamma$, measured by EGRET (Hartman et al. 1999).

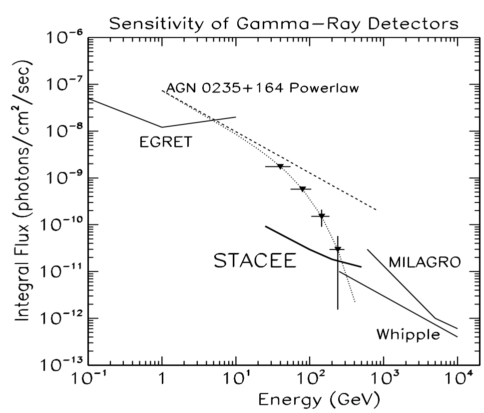


**Figure 2:** Projected sensitivity of STACEE and other contemporary experiments.

The expected sensitivity of STACEE to sources can be calculated using the instrument performance model and the known energy spectrum of the sources. Extrapolations for the EGRET spectra of a few AGN indicate that a source with intensity 1/20 of the Crab should be detected at about $5\sigma$ by STACEE in 50 hours of observation. Figure 2 illustrates the projected sensitivity of STACEE and other contemporary experiments. The figure shows an example of an AGN detected by EGRET and the expected spectral detection by STACEE, assuming that the spectrum is cut off at 80 GeV. This figure demonstrates that STACEE will be

**Table 1: Possible AGN targets for STACEE.**

| Source | RA | Dec | $\Gamma$ | Type | Redshift ($z$) | Other Name |
|---|---|---|---|---|---|---|
| 0202+149 | 31.11 | 14.97 | $2.23 \pm 0.28$ | FSRQ | 0.405 | 4C+15.05 |
| 0219+428 | 35.70 | 42.90 | $2.01 \pm 0.14$ | BLL | 0.444 | 3C66A |
| 0235+164 | 39.36 | 16.59 | $1.85 \pm 0.12$ | BLL | 0.940 | |
| 0446+112 | 72.61 | 11.09 | $2.27 \pm 0.16$ | FSRQ | 1.207 | |
| 0459+060 | 74.93 | 5.75 | $2.36 \pm 0.40$ | FSRQ | 1.106 | |
| 0735+178 | 114.47 | 17.35 | $2.60 \pm 0.28$ | BLL | 0.424 | |
| 0738+545 | 115.83 | 54.80 | $2.03 \pm 0.20$ | FSRS | 0.723 | |
| 0829+046 | 127.04 | 5.14 | $2.47 \pm 0.40$ | BLL | 0.180 | |
| 0851+202 | 133.42 | 19.68 | $2.35 \pm 0.35$ | BLL | 0.306 | OJ+287 |
| 1101+384 | 166.10 | 38.15 | $1.57 \pm 0.15$ | BLL | 0.031 | Mrk421 |
| 1156+295 | 180.12 | 28.80 | $1.98 \pm 0.22$ | FSRQ | 0.729 | 4C+29.45 |
| 1219+285 | 185.75 | 28.70 | $1.73 \pm 0.18$ | BLL | 0.102 | ON+231 |
| 1222+216 | 186.11 | 21.31 | $2.28 \pm 0.13$ | FSRQ | 0.435 | |
| 1226+023 | 187.25 | 2.17 | $2.58 \pm 0.09$ | FSRQ | 0.158 | 3C273 |
| 1604+159 | 241.30 | 15.89 | $2.06 \pm 0.41$ | BLL | 0.357 | 4C+15.54 |
| 1606+106 | 242.12 | 10.93 | $2.63 \pm 0.24$ | FSRQ | 1.226 | 4C+10.45 |
| 1611+343 | 243.54 | 34.40 | $2.42 \pm 0.15$ | FSRQ | 1.401 | |
| 1633+382 | 248.92 | 38.22 | $2.15 \pm 0.09$ | FSRQ | 1.814 | 4C+38.41 |
| 1652+398 | 253.47 | 39.76 | $1.20 \pm 1.0$ | BLL | 0.033 | Mrk 501 |

quite capable of detecting EGRET AGN with high significance and measuring their spectral cutoffs.

# 5 Summary

To summarize, because of its sensitivity to a part of the $\gamma$-ray spectrum that is inaccessible to current space- and ground-based instruments, STACEE will be able to study the spectra of AGN in a unique way. Some of the topics that STACEE will address are: CIB cutoff and intrinsic absorption in the AGN spectra, the peak of the IC component of the SED of AGN, and distinction between models of $\gamma$-ray emission. Further observations of AGN by STACEE will resume in the fall of 1999, when the completion of the STACEE detector is anticipated.

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