# Correlative Studies of Astrophysical Sources of Very High and Ultra High Energy Gamma-Rays

NASA Grant: NAG5-1591

Final Report

Carl W. Akerlof

January 20, 1993

## Overview

During the period of this contract, June 1, 1991 to November 14, 1992, the major results of our research effort have come from the Whipple air shower experiment in Tucson, AZ. The most notable development has been the discovery of TeV photons from the BL Lac object, Markarian 421. This result depended critically on the identification of Mrk 421 by the EGRET team as a source of GeV $\gamma$-rays.

## Very High Energy Astronomy

Following the announcements of numerous extragalactic sources of GeV radiation by the EGRET experiment onboard the CGRO, the Whipple Collaboration undertook searches at higher energies for all those objects visible from the latitude of Tucson, AZ. Six AGN's were targets for extensive observation, but only one of these yielded a detectable signal. The BL Lac object, Markarian 421 was monitored for 7.5 hours on-source and an identical time off-source. The data was analyzed using techniques developed in the course of numerous measurements of the Crab Nebula. The signal from Mrk 421 corresponded to a statistical significance of 6.3 $\sigma$. Numerous checks were made to ensure that this result was not some artifact of the measurement technique. We were particularly concerned that the two bright field stars within a few arc-minutes of Mrk 421 might bias the signal. Absence of such effects was demonstrated by removal of the central photomultipliers from the offline data analysis and by observing a bright field star similar in spectral class to the ones close to Mrk 421. The energy spectrum is shown in figure 1.

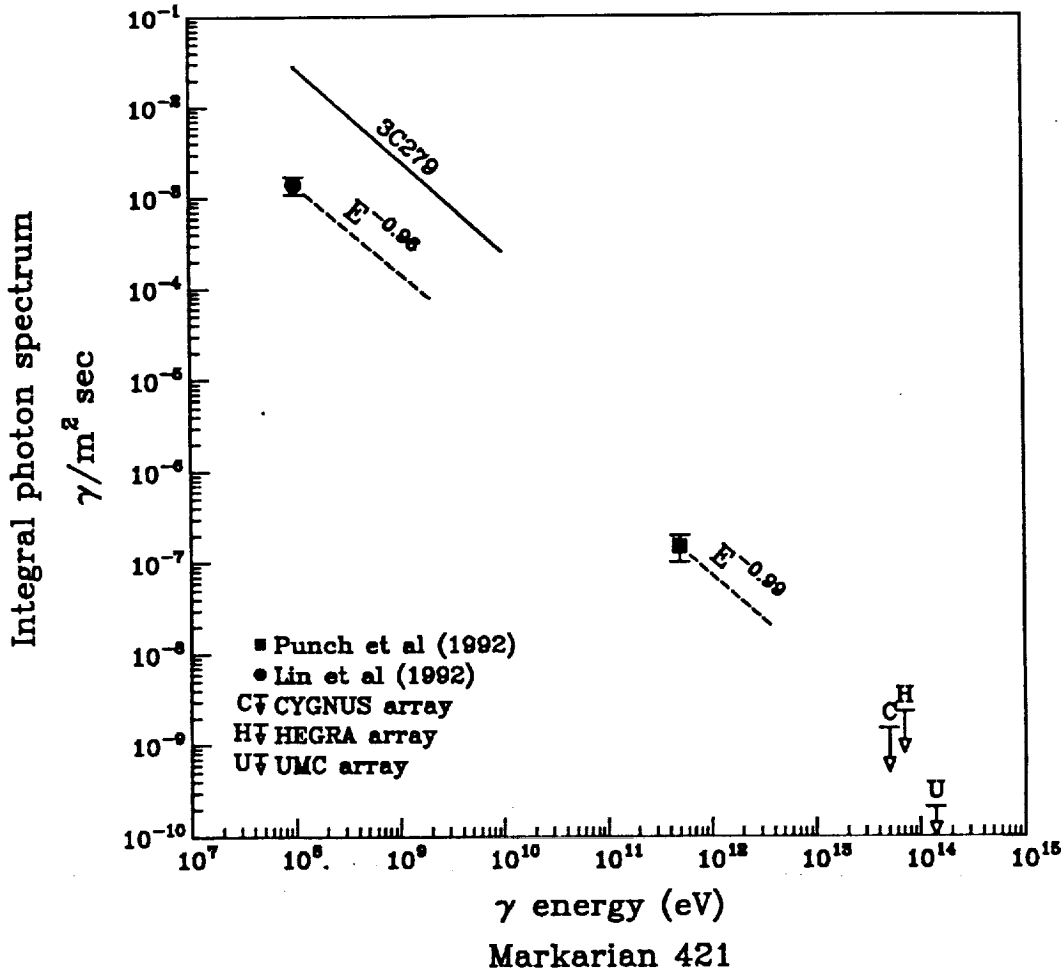


Figure 1. The integral energy spectrum for Markarian 421.

The fact that Markarian 421 is the nearest AGN detected by EGRET ($z = 0.031$) is probably not coincidental. Shortly before our discovery, Stecker et al. had published a paper demonstrating that TeV radiation would be difficult to detect from more distant objects such as 3C279 due to inverse annihilation with infrared photons in intergalactic space. If the detection threshold of our ground-based Cerenkov air shower telescopes could be reduced to 100 GeV, these absorption effects would diminish significantly, making it possible to view many more of the EGRET-identified AGN's. Such a detector development program has been a major aspect of our work at the University of Michigan during the period of this contract.

The discovery of TeV radiation from Mrk 421 raises many new questions. To the level of our measurement accuracy, the spectral index does not change

from the GeV to the TeV energy range. This implies that this object radiates as much energy in the TeV band as at all lower energies. The physical processes that can produce such efficient generation of high energy quanta are not understood, particularly given the propensity of such photons to degrade via the inverse annihilation processes mentioned above.

Observations of time variability give some hint to the physical size of the emitting region of the AGN. Our data was insufficient to resolve whether or not there was a significant variation of flux during the four month period when Mrk 421 was observed. We expect to improve the sensitivity of these observations in the next few months.

Some additional observations of the Crab Nebula were taken during the winter of '91-'92 with results similar to those reported in the past. Our group did attempt to search for time correlations in the TeV gamma-ray flux using an autocorrelation technique. No deviation from Poisson statistics was observed. We also began development of a method to optically detect the 30 Hz periodicity of the Crab pulsar using only the 11-meter diameter Cerenkov telescope. Normally, this would be impossible because of the poor focal properties (the point spread function is about 0.25° FWHM). However by integrating the photomultiplier current from the counter tube of the Cerenkov air shower imaging camera, it appears to be possible to obtain the requisite sensitivity using the FFT algorithm to filter the data. We have not yet detected the Crab optical modulation with this technique but hope to obtain better results in the next two months.

One of the major interests of our VHE program has been observations of Geminga. With the recent results reported by ROSAT, EGRET, and the reanalysis of older data by COS-B, we had hoped to extract a periodic signal from our TeV data. Although there are some questions regarding the phase-linking of observations that span from COS-B to EGRET, the bottom line is that we found no evidence for a signal in our data. The upper limit to the flux is about 10% of the Crab Nebula for energies above 400 GeV. A paper describing this search is now being completed.

## Ultra-High Energy Astronomy

During the period covered by this contract, the UMC experiment continued to amass extensive air shower data. This experiment has as a principle goal the observation of astrophysical sources of gamma-rays by selecting those showers with significantly fewer penetrating muons. No convincing evidence for gamma rays at these energies ($> 100$ TeV) has yet been found but the upper limits for the Crab Nebula are now beginning to approach the extrapolations of the flux from lower energies. Detection of Markarian 421 will probably be difficult due to the interaction of PeV photons with the cosmic

microwave background radiation in intergalactic space. The UMC experiment has also searched for diffuse sources of radiation caused by cosmic ray collisions with molecular clouds within our galaxy. No signal has yet been detected but current upper limits approach values suggested by theoretical estimates.

## Publications


"Locating very high energy gamma-ray sources with arcminute accuracy", C. Akerlof, M. Cawley, M. Chantell, D. Fegan, K. Harris, A. Hillas, D. Jennings, R. Lamb, M. Lawrence, M. Lang, D. Lewis, D. Meyer, G. Mohanty, K. O'Flaherty, M. Punch, P. Reynolds, M. Schubnell, T. Weekes, and T. Whitaker, *The Astrophysical Journal* **377**, L97-L100 (1991).

"Mirrors for an imaging gamma ray telescope", Curtis Weaverdyck, Donald Meyer, and Carl Akerlof, *Nuclear Instruments & Methods in Physics Research* **A310**, 690-692 (1991).

"Search for diffuse cosmic gamma rays above 200 TeV", D. Ciampa, et al., *Astrophys. J* **375**, 202 (1991).

"An inexpensive circuit for monitoring photomultiplier anode current", Dov Frishman and Carl Akerlof, *Nuclear Instruments & Methods in Physics Research* **A311**, 306-308 (1992).

"CAMAC modules for recording arbitrarily long time series", Steve Freeman and Carl Akerlof, *Nuclear Instruments & Methods in Physics Research* **A320**, 305-309 (1992).

"Markarian 421", Whipple Observatory Collaboration, *IAU Circular* **No. 5522**, May 16, 1992.

"Detection of TeV photons from the active galaxy Markarian 421", M. Punch, C. Akerlof, M. Cawley, M. Chantell, D. Fegan, S. Fennell, J. Gaidos, H. Hagan, A. Hillas, Y. Jian, A. Kerrick, R. Lamb, M. Lawrence, D. Lewis, D. Meyer, G. Mohanty, K. O'Flaherty, P. Reynolds, A. Rovero, M. Schubnell, G. Sembroski, T. Weekes, T. Whitaker, and C. Wilson, *Nature* **358**, 477-478 (1992).

"Search for discrete sources of 100 TeV gamma radiation", J.W. Cronin, et al., *Phys. Rev.* **D45**, 4385 (1992).

"Search for compact sources of cosmic photons above 200 TeV", D.P. Ciampa, et al, *Phys. Rev.* **D46**, 3248 (1992).

"A northern sky survey for astrophysical point sources of 100 TeV gamma radiation", T.A. McKay, et al., *submitted to Astrophys. J* (1993).

"A large air shower array to search for astrophysical sources emitting $\gamma$-rays with energies $\geq 10^{14}$ eV", C.E. Covault, et al., *submitted to Nucl. Instr. Meth.* (1993).

"Observations of the shadows of the Sun and the Moon using 100 TeV cosmic rays", A. Borione, et al., *submitted to Phys. Rev. D* (1993).

## Capital Expenditures

No equipment was purchased from funds supplied by this NASA contract.