1.7 RECENT RESULTS ON THE SEARCH FOR 10^{11} eV GAMMA RAYS FROM THE CRAB NEBULA

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Abstract. The detection of Čerenkov light emitted by cosmic-ray air showers was used to search for cosmic gamma rays from the Crab Nebula. By use of the 10-m optical reflector at Mt. Hopkins, Arizona, the Crab Nebula was observed during the winter of 1969–1970 for approximately 112 hours, which was a significant increase in exposure time over previous experiments. Above a gamma-ray energy of 2.2×10^{11} eV, no significant flux was detected, resulting in an upper limit to the flux of 8.1×10^{-11} photon/cm² sec. In the synchrotron-Compton-scattering model of gamma-ray production in the Crab Nebula, this limit on the flux indicates the average magnetic field in the nebula must be greater than 3×10^{-4} G.

1. Introduction

At energies above 10^{11} eV, cosmic gamma rays interact with the atmosphere to generate a cascade of high-energy electrons and photons. This 'air shower' is highly directional and proceeds with relativistic velocity along the direction of the initial gamma-ray photon. Accompanying the shower is a cone of Čerenkov light about 2° wide and also directed along the shower axis. The duration of this light burst is about 10^{-8} sec, and its lateral spread at sea level is about 3×10^4 m². Cosmic-ray protons and nuclei of comparable energy also generate air showers and Čerenkov light, but primary gamma radiation from a discrete source can be distinguished by the presence of an anisotropy in the arrival directions of the Čerenkov light bursts.

2. Experimental Technique

The 10-m optical reflector at Mt. Hopkins, Arizona, was used to detect atmospheric Čerenkov light and to search for any anisotropy in the arrival direction of these bursts. The reflector was operated in a tracking mode, with two photomultiplier tubes (RCA 4522) in the focal plane. Each phototube had a full field of view of 1°, and the two phototubes were separated by 2.4°. One field of view was centered on the suspected source, in this case the Crab Nebula, while the other viewed a nearby region of sky to monitor the background shower rate. Every 10 min, the fields of view were interchanged by slewing the reflector. Every 1 min, the count rate from each phototube was recorded.

Before this experiment, the 'drift-scan' technique had been used to search for an anisotropy. This technique consisted of positioning the reflector at a point in the sky ahead in right ascension and allowing the earth's rotation to bring the source through

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the field of view. Such a scan required ~40 min with only 8 min on the suspected source. The tracking mode, however, allowed the source and background regions to be observed simultaneously and greatly increased the observing time over a given period.

3. Results

From October 1969 to February 1970, the Crab Nebula was observed for 6698 min. A net positive effect was detected from the Nebula; further observations are planned, but at present this effect is not interpreted to be due to a flux of gamma rays. The number of showers observed from the direction of the source divided by the number from nearby sections of the sky was 1.0026 ± 0.0011. This ratio corresponds to an upper limit (at 3 standard deviations) of 8.1×10^{-11} photon/cm^2 sec for the gamma-ray flux from the Crab Nebula for energies above 2.2×10^{11} eV.

The objects M87, M82, Sag A, 3C273, and Cyg A were also observed and analyzed to determine if any systematic errors that could produce a positive effect were introduced into the data. The data from these other observations are presented in Table I. No net effect comparable to that for the Crab Nebula was observed. The results obtained on the Crab Nebula during the winter of 1968–1969 (Fazio *et al.*, 1970) are also given in Table I.

A theoretical spectrum of the gamma-ray flux from the Crab Nebula can be calculated on the basis of Compton scattering in the Nebula between synchrotron electrons and the observed synchrotron-emitted photons, assuming a uniform value of the magnetic field (Gould, 1965; Rieke and Weekes, 1969). The gamma-ray flux

TABLE I

Summary of gamma-ray observations

Object	Date	Observation time (min)	Source on/ Source off ratio	Threshold energy (10^{11} eV)	Flux limit (10^{-11} photon/cm^2 sec)
Crab Nebula	1969–1970	6698	1.0026 ± 0.0014*	2.2	8.0
Crab Nebula	1968–1969	776	1.0010 ± 0.0038	1.7	20
M87 (Virgo A)	1969–1970	2126	1.0013 ± 0.0021	2.1	10
M82	1969–1970	1549	$1\,0010 \pm 0.0025$	3.2	7.1
Sag A	1969–1970	683	0.9886 ± 0.0073	22	0.46
3C273	1963–1970	1064	0.9947 ± 0.0033	2.8	3.6
Cyg A	1969–1970	518	0.9970 ± 0.0046	2.6	12

predicted is a sensitive function of the magnetic field. From these calculations and the upper limit to the flux set by this experiment, it is possible to place a lower limit of 3×10^{-4} G on the average strength of the magnetic field in the Crab Nebula.

* For the Crab Nebula (1969–1970), the standard deviation was based on experimental error; for all other sources, Poisson errors were used. The Poisson error for the Crab Nebula was ± 0.0011.

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