The Active Galaxy 3C 66A:  
A Variable Source of Very High-Energy Gamma-Rays  

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Abstract—Observations of the very-high-energy gamma-ray flux of the blazar 3C 66A ($z = 0.444$) carried out at the Crimean Astrophysical Observatory with the GT-48 atmospheric Cerenkov detector are reported. The gamma-ray fluxes in 1997 and 1998 were lower than in 1996. The optical luminosity of the object in 1997–1998 also decreased in comparison with its value in 1996. If the emission is isotropic, the very-high-energy gamma-ray power is $10^{46}$ erg/s.

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1. INTRODUCTION

Blazars—active galactic nuclei whose prototype is BL Lac—are probable extragalactic sources of gamma rays with very high energies ($VHE, E > 10^{11}$ eV). These objects are very interesting astrophysically, because they are characterized by substantial flux variations at all wavelengths from radio to X-rays. In some cases, large-amplitude X-ray variations coincide with optical variations [1]. The timescales of the variations are from minutes to about one year. Blazars are distinguished by a strong tendency for flaring (with timescales of several days) and outburst activity (with durations of several months). This suggests that these objects contain a large number of high-energy particles, which can generate VHE gamma rays when they interact with matter or electromagnetic fields.

The first such objects from which VHE gamma rays were detected were the BL Lac objects Mrk 421 and Mrk 501 [2, 3]. The related active galaxy 3C 66A was detected optically [4] as a 15th magnitude pointlike blue source. Its optical emission is strongly polarized, with the degree of polarization varying widely with time, sometimes reaching 30%. The brightness of the object also varies appreciably with time; for instance, it exceeded $14^{m}$ in 1996.

High-energy gamma rays were detected toward 3C 66A at energies $> 100$ MeV by EGRET, and the gamma-ray source was given the name 2EG J0220+4228. The position error of the EGRET measurement was $1^\circ$ [6]. Additional measurements of the gamma-ray flux from this direction allowed the source position to be determined to higher accuracy. In the third EGRET catalog [7], this object was listed as the gamma-ray source 3EG J0222+4253 with coordinates $\alpha = 35^\circ 7$ and $\delta = 42^\circ 9$, which differ from the coordinates of 3C 66A by $0^\circ 15$.

We detected VHE gamma rays from the blazar 3C 66A in 1996 in our observations on the GT-48 Cerenkov detector [8]. The observations were continued in 1997 and 1998. The results of the three-year flux measurements are presented below.

2. BRIEF DESCRIPTION  
OF THE GT-48 GAMMA-RAY TELESCOPE

Gamma rays with energies $E > 10^{11}$ eV can be detected using ground-based equipment, using the fact that VHE gamma rays interact with the nuclei of atoms in the air, generating so-called electron–photon showers. These are made up of high-energy electrons and positrons, which emit optical Čerenkov radiation, primarily at small angles ($0^\circ 5$—$1^\circ$) to the direction of motion of the primary photon. This makes it possible to determine the direction from which the flux of gamma rays arrives.

The effective area in which Čerenkov events from electron–photon showers can be detected is rather large. The region on the Earth covered by an event with vertical incidence of the primary particle is approximately $4 \times 10^8$ cm$^2$; i.e., it forms a circle with a diameter of 250 m. This makes it possible to detect small (approximately $10^{-11}$ photons cm$^{-2}$ s$^{-1}$) gamma-ray fluxes.

The main obstacle to detecting and studying VHE gamma-ray sources is the presence of an appreciable cosmic-ray background, whose particles cause Čerenkov events in the Earth’s atmosphere that are difficult to distinguish from those due to discrete gamma-ray sources. Nevertheless, there are some differences between these two types of events. Currently, multielement receiving cameras are used to make images of Čerenkov events. Differences in the parameters of the images of Čerenkov events resulting from gamma rays and from cosmic-ray particles enable us to eliminate most of the latter events.
The first telescope with a multichannel camera began operation at the Whipple Observatory (USA) in 1982 [9]. A similar telescope, GT-48, started working at the Crimean Astrophysical Observatory in 1989. We have described the GT-48 telescope in a number of papers (see, for example, [10]). The facility consists of two identical northern (1) and southern (2) altitude–azimuth mounts (sections) separated by 20 m in the north–south direction at a height of 600 m above sea level. We showed in [11] that, in contrast to single telescopes, a double telescope operating in a coincidence regime can almost completely eliminate events due to individual charged particles hitting the light detectors.

Six aligned telescopes are mounted on each section. The optics of each telescope consist of four 1.2-meter mirrors with a common focal point. The mirrors of three telescopes have a focal length of 5 m. Light detectors (cameras) consisting of 37 photomultipliers (37 cells) that can image Čerenkov events at visual wavelengths (300–600 nm) are located in their focal plane. Events are recorded only when the amplitudes of time-coincident signals in any two of the 37 cells exceed a preset threshold. The time resolution of the coincidence circuit is 15 ns.

There is a conical hexagon-shaped light-guide in front of each photomultiplier. The mean diameter of the entrance window corresponds to the linear angle of the field of view of one cell, 0.4° (Fig. 1). The field of view of the entire light detector is 256.

The other three telescopes have focal lengths of 3.2 m and are intended for detection of the ultraviolet radiation of Čerenkov events at 200–300 nm. The detectors are sun-blind photomultipliers.

The total area of the mirrors on both mountings (sections) is 54 m². The installation can be moved by a control system with a drive accuracy of ±1°. Observations can be carried out both in a coincidence regime using the two sections and independently by each section. The effective threshold energy for detection of gamma rays is 1.0 TeV.

3. OBSERVATIONS AND DATA PROCESSING

Observations of 3C 66A (α = 2°22'40", δ = 43°02'08") were carried out in 1996, 1997, and 1998 using the two sections in a coincidence regime with a time resolution of 100 ns. We tracked the object and an area of sky (background) at the same azimuth and zenith angles with a 30-min time shift between trackings (the duration of a single observation was 25 min). The observations of the background preceded those of the source.

In total, we processed the data for 12 sessions in 1996, 30 in 1997, and 17 in 1998, corresponding to a total duration for the observations of 3C 66A of 1175 min (24 h 35 min). We performed a preliminary reduction of the data, necessary for correct calculation of the first and second moments of the brightness distribution, from which we derived the parameters of the Čerenkov events: effective length A, effective width B, angle φ describing the direction of maximum elongation of the image (i.e., its orientation), and the coordinates X_c and Y_c of the center of “gravity” of the brightness distributions (Fig. 1). We calculated the moments for cells whose signal exceeded a certain threshold value [12]. All other parameters of a Čerenkov event can be derived from these parameters [10].

As a result of our preliminary reduction, there remained over the three years of observations 34695 source events and 34770 background events for further analysis. Thus, the difference of the number of source (N_s) and background (N_b) events \( N_s = N_s - N_b = -75 \pm 264 \), where 264 is the statistical error. This includes a contri-