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Observation of the giant radio galaxy M87 with the HEGRA Cherenkov telescopes

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Abstract

The giant radio galaxy M87, well studied from radio to X-ray energies, is located in the Virgo cluster of galaxies at a distance of $\sim$16 Mpc (redshift $z = 0.00436$). M87 has been observed with the HEGRA stereoscopic system of five Cherenkov telescopes in the years 1998 and 1999 for more than 80 h. An excess of TeV γ-rays on the 4σ level has been found in the data corresponding to an integral flux ($E > 730$ GeV) of 3.3% of the Crab nebula flux. The HEGRA detection – if confirmed – would make M87 the first TeV γ-ray emitting AGN observed with the imaging atmospheric Cherenkov technique not belonging to the BL Lac class.

Keywords: γ-rays: observations; TeV emission; Galaxies: individual: M87

1. Introduction

The HEGRA collaboration has operated until September 2002 six imaging atmospheric Cherenkov telescopes (IACTs) on the Canary island of La Palma (28°45′N, 17°53′W) at 2200 m a.s.l., five of them being used for the stereoscopic observation mode (Daum et al., 1997) allowing for an improved direction reconstruction and γ-hadron-separation. All TeV γ-ray emitting Active Galactic Nuclei (AGN) detected with IACTs so far are of the blazar type, i.e., objects with their plasma jets pointing very close to the observer's line of sight. The TeV γ-emission can be described either by leptonic models, e.g., the Synchrotron Self Compton model (SSC) or hadronic ones (photo-pion production as well as proton synchrotron radiation), e.g., the SPB model (Reimer, 2003). The giant radio galaxy M87 is located at a distance of only $\sim$16 Mpc ($z = 0.00436$) in the Virgo cluster of galaxies. The angle between the pc scale plasma jet – well studied at radio, optical and X-ray wavelengths – and the observer's line of sight has been estimated to be 30–35°, the mass of the black hole in the center of M87 is of the order of $2\text{–}3 \times 10^9$ $M_{\odot}$. M87 is discussed to be a powerful accelerator of high energy particles, possibly even up to the highest energies. M87 has been observed with the HEGRA IACT system in the years 1998/1999 for a total of 83.4 h. An analysis of a subset thereof has

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been published in Götting et al. (2001), a detailed description of the analysis and results of the whole data set presented here can be found in Aharonian et al. (2003).

2. Observations and analysis results

M87 has been observed by HEGRA for 83.4 h in the years 1998 and 1999 (most of it with a 4-telescope setup) in the so-called *Wobble* mode allowing for simultaneous background measurements by shifting the tracking-position by $\pm 0.5°$ in declination with respect to the position of M87. The mean zenith angle of 21.6° of the whole data set corresponds to a mean energy threshold of 730 GeV for the observations. Roughly 5% of the data have been rejected from the analysis due to weather and technical status cuts.

2.1. Excess of γ-events

The background has been estimated using a ring segment region (260° opening angle) at the same radial distance as the ON-source position to the center of the camera. A tight image shape cut (mscw < 1.1) and an angular cut (optimized on nearly contemporaneous Crab data at similar zenith angles) of $\theta^2 < 0.016$ deg^2 have been applied to the data. For detailed information about the analysis, see Aharonian et al. (2003). The resulting distributions of ON-source events and the background expectation plotted as a function of the squared angular distance θ^2 between the reconstructed shower direction and the nominal source position is shown in Fig. 1(a). The excess of 107.4 ± 26.8 events corresponds to a statistical significance of 4.1σ calculated using formula (17) of Li and Ma (1983). Statistical tests for burst-like behaviour and variability indicate a steady TeV emission from M87 (confirmed by the number of accumulated excess events as a function of accumulated background events, see Fig. 1(b)). A possibly spatially extended emission can neither be confirmed nor be rejected due to the low event excess statistics.

2.2. Flux and spectrum

The observed excess can be converted into an integral flux of (3.3 ± 0.8)% of the Crab nebula corresponding to an integral photon flux of $\Phi_\gamma(E > 730\ \text{GeV}) = (0.96 \pm 0.23) \times 10^{-12}$ photons cm^{-2} s^{-1}. The resulting differential energy spectrum can be fitted with a power law $\mathrm{d}N/\mathrm{d}E \sim E^{-\alpha}$ with a spectral index of $\alpha = 2.9 \pm 0.8_{\text{stat}} \pm 0.08_{\text{syst}}$.

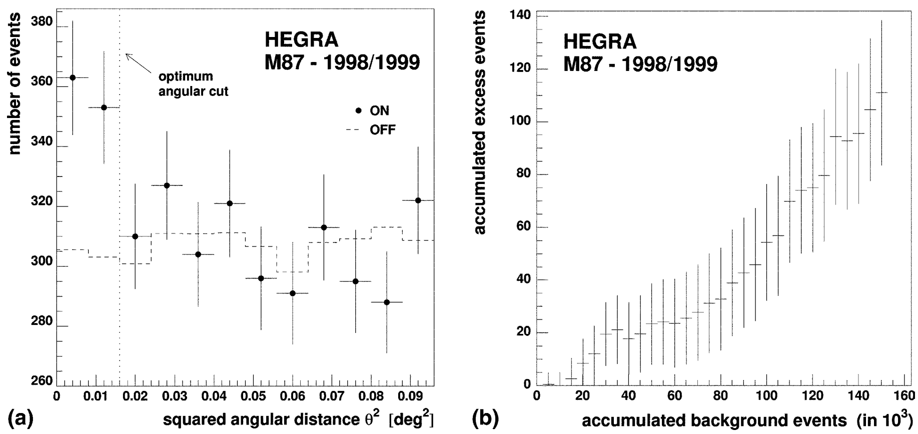

Fig. 1. (a) Distribution of ON-source events (dots) and the background expectation (histogram) as measured with the HEGRA IACT system plotted as a function of the squared angular distance θ^2 between the reconstructed shower direction and the nominal source/background position. The vertical dotted line indicates the optimal cut obtained from nearly contemporaneous Crab observations at similar zenith angles. (b) The number of accumulated excess events plotted as a function of accumulated number of background events, indicating a steady emission.

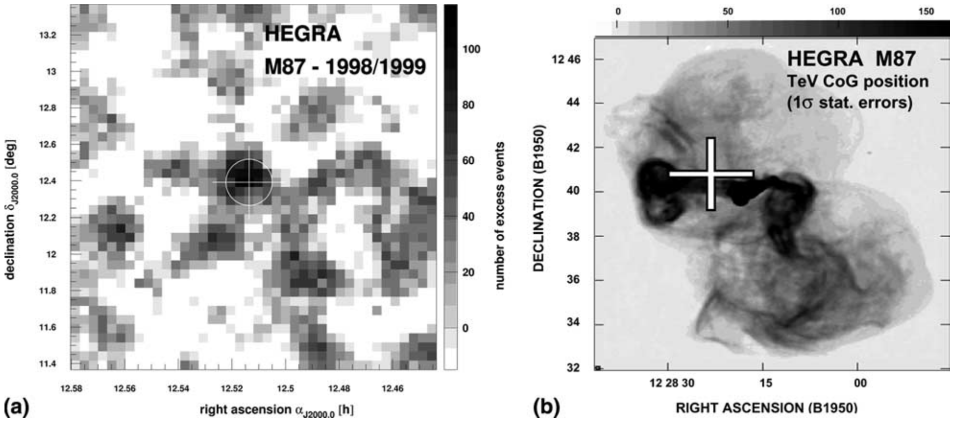

Fig. 2. (a) $2° \times 2°$ TeV excess skymap ($0.02° \times 0.02°$ binning) of the M87 HEGRA data set using the *template background model* for the background estimation. The nominal M87 position is indicated by the circle. (b) The TeV center of gravity (with stat. 1σ errors) plotted into a M87 radio skymap at 90 cm (taken from Owen et al., 2000).

A 3σ upper limit on the M87 γ-ray flux of $\Phi_\gamma(E > 250\ \text{GeV}) < 2.2 \times 10^{-11}$ photons cm^{-2} s^{-1} has been reported by the VERITAS collaboration (Lebohec et al., 2001) obtained from a 14 h observation campaign in 2000/2001 not ruling out the HEGRA results.

2.3. Skymap and center of gravity

A TeV skymap has been created from the whole M87 data set using an alternative background estimation with the so called *template background model* (Aharonian et al., 2002) as shown in Fig. 2(a). The TeV center of gravity (CoG) has been calculated to be $\alpha_{J2000.0} = 12°30'54.4'' \pm 6.9'_{\text{stat}} \pm 1.7'_{\text{syst}}$, $\delta_{J2000.0} = +12°24'17'' \pm 1.7'_{\text{stat}} \pm 0.4'_{\text{syst}}$, see Fig. 2(b). Due to the large statistical position errors it is not possible to conclude about the position of the TeV emission region within the M87 structure.

3. Summary and conclusion

The giant radio galaxy M87 has been observed with the HEGRA IACT system. For the first time an excess of 4.1σ has been found in IACT data corresponding to an integral flux of 3.3% of the Crab nebula flux. The spectrum can be fitted with a power law with a spectral index of $\alpha = 2.9 \pm 0.8_{\text{stat}} \pm 0.08_{\text{syst}}$. Due to the low event statistics of the HEGRA data it is not possible to draw detailed conclusions about the TeV γ-production mechanism and the emission region within the M87 structure. Both, leptonic as well as hadronic models can accommodate the HEGRA data; the hadronic Synchrotron Proton Blazar model has recently been adjusted to the HEGRA M87 measurement, see Reimer (2003). Along with the confirmation of the HEGRA signal, the exact location of the TeV emission region, the search for extended emission and the determination of an accurate energy spectrum allowing to draw conclusions for the TeV production mechanism will be of special interest for the next generation Cherenkov telescope projects like CANGAROO, HESS, MAGIC and VERITAS.

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