1407: New Results of the HEGRA Air Shower Detector Complex

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Abstract. Recent highlight results obtained with the air shower detector complex HEGRA at the Canary island La Palma are presented. Observations and searches for \( \gamma \) sources above an energy of 500 GeV are covered, where special emphasis is put on the recent flaring activities of the Blazar Mkn 501. A second main research topic of the experiment is the measurement of the energy spectrum and the elemental composition of the charged cosmic rays. Data covering the energy region of the "knee" around 3 PeV are presented.

1 The Setup

The HEGRA (High Energy Gamma Ray Astronomy) [1] experiment is located at the astronomical observatory of the Canary island La Palma at a height of 2200 m. It is operated by a collaboration of the German Max-Planck-Institutes für Kernphysik (Heidelberg) and für Physik (München), the univers. of Hamburg, Kiel, Wuppertal (Germany) and Madrid (Spain) and the Yerevan Physics Institute (Armenia). The experimental setup covers a square area of 40000 m\(^2\) (Figure 1).

The HEGRA experiment measures extensive air showers (EAS) initiated by high energetic cosmic photons and nuclei. It can roughly be divided into two parts: imaging air Cherenkov telescopes (IACTs) observe selected targets with an energy threshold of 500 GeV, while three arrays of detectors monitor the whole sky above the installation in the energy range beyond 15 TeV.

1.1 The HEGRA IACTs

Since the end of 1996 six IACTs are operational. Four identical telescopes and an upgraded prototype can operate as a system. This unique installation observes the air Cherenkov light images of EAS in a stereo mode. The segmented mirror area of each system telescope is 8.5 m\(^2\) large. Each camera consist of 271 pixels (photomultipliers each viewing 0.25\(^\circ\) of the sky) covering a field of view of 4.3\(^\circ\).
For photons above the energy threshold of 500 GeV the direction of the primary photon is deduced from the orientation of the air Cherenkov light image in the camera, where the stereo observations allow for an angular resolution of better than 0.1°. Photon induced EAS are separated from showers triggered by primary nuclei by the analysis of the image shapes. The excellent angular resolution and the efficient photon separation lead to a nearly background free observation of strong TeV point sources like the Crab nebula (the galactic standard candle of TeV astrophysics). The energy of primary photons can be determined with a resolution of better than 20%, thus detailed energy spectra can be measured [2]. The sensitivity of the telescope system can be summarized such, that within 100 h observation a detection on the $5\sigma$ level is possible for a point source with a flux of only 3% of the Crab.

1.2 The HEGRA Arrays

The HEGRA arrays sample the EAS showerfront. 243 scintillator huts on a grid with 15 m spacing and a more dense part around the center register charged particles. The so called AIROBICC array of 77 stations (consisting of 20 cm diameter open photomultipliers attached to a Winston cone) provides a non imaging measurement of the air Cherenkov light. A Geiger tower array of 17 stations is located in the central part of the array. They allow for the measurement of the electromagnetic energy of an air shower at detector level and the identification of muons. The energy threshold for vertical photon induced showers was around 20 TeV for scintillator triggered events, which has been lowered to 5 TeV after a DAQ upgrade in spring 1997. Air showers above 11 TeV trigger AIROBICC. The angular resolution for photon induced showers at threshold amounts to 0.3° for AIROBICC triggered events and 0.9° for scintillator data (above 20 TeV).

2 TeV Photon Sources

The most exciting result in 1997 were the measurements with the imaging air Cherenkov telescopes (IACT) of the emission of TeV photons with a very high and variable flux from the extragalactic source Mkn 501 [3, 4]. This object in a distance of 500 million lightyears belongs to the Blazar class of active galactic nuclei (AGN) and is thought to contain probably a black hole of $10^8$ solar masses. Blazars are AGNs which emit relativistic jets pointed towards the observer. Under certain conditions they can also be detected in the TeV energy regime. TeV $\gamma$'s from Mkn 501 were first measured in 1995 [5] with a flux corresponding to 8% of the galactic Crab nebula (the strongest known TeV emitter before). The activity rose to 0.3 Crab in 1996 [6]. In 1997 the mean flux lies around 2.0 Crab, but flares with intensities of up to 10 times the Crab flux have been registered approx. once a month (Fig. 2). The energy spectrum in comparison to the spectrum of the Crab nebula is shown in Figure 3. The Mkn 501 spectrum follows a power law up to 10 TeV. At higher energies the study of systematic detector effects is not finished yet so that the data points are not included in the plot.

Due to the absorption of high energy
HEGRA

Date [Mjd-50000]

Rate [mHz]

0
50
100
150
200
250
525 550 575 600 625

Crab

Fig. 2. The HEGRA IACT system trigger rate of photons from Mkn 501 in a part of 1997. April 1st corresponds to 539 on the horizontal axis, July 1st to 630.

HEGRA

Flux \(10^{-11}\) TeV cm\(^{-2}\) s\(^{-1}\)

Crab

(x 0.1)

10

10

10

1

10

E [TeV]

Fig. 3. The energy spectra of Mkn 501 (averaged over all measurements in 1997) and of the Crab nebula. Data beyond 10 TeV are not shown.

HEGRA

Mkn 501

an object very similar to Mkn 501 at nearly the same distance, but not as spectacular as Mkn 501 in 1997, and the Crab nebula. No evidence for TeV photon emission could be found from other AGNs. Also no TeV photons could be detected from the supernova remnants (SNR) IC443 and G78+2. The upper limits provide significant constraints on models which try to explain the acceleration of the bulk of charged cosmic rays in the shells of SNRs.

Source searches with the HEGRA arrays (with a higher energy threshold and less flux sensitivity compared to the IACTs) have not been successful up to now. Only small excesses have been found from the Crab nebula, Hercules X-1 and a sample of near Blazars, but all need further confirmation.

3 Charged Cosmic Rays

The energy spectrum of charged cosmic rays (CR) follows a power law up to roughly 3 PeV, where the CR spectrum becomes steeper and follows another power law. The understanding of this so called “knee” feature may provide a clue to understand the origin of CR. HEGRA developed new methods to measure the energy spectrum and the coarse composition in the energy region around the knee. One method is described in more detail: the air Cherenkov light measurements of AIROBICC allow to reconstruct the distance between the detector and the air shower maximum. Together with the registered number of charged particles at detector level or the total amount of Cherenkov light the energy contained in the electromagnetic shower component can be...
determined. This is combined with the energy per nucleon of the primary nucleus estimated from the depth of the shower maximum to calculate the primary energy and the nucleon number. While the primary energy can be determined for cosmic ray nuclei with an accuracy of 30%, the determination of the nucleon number is possible only in a coarse manner due to natural fluctuations in the shower developments. Figure 4 shows the reconstructed (preliminary) fraction of light nuclei (H and He) in the CR. The results below 1 PeV are in good agreement to data obtained by balloon and satellite measurements. The decrease near the knee is in agreement with models describing the CR acceleration in supernova remnants, but also a constant composition is not excluded.

4 Other HEGRA Results

No Gamma Ray Burst (GRB) counterparts have been found for energies above 5 TeV, neither coincident with the GRBs or for long time measurements. This is in accordance with an extragalactic origin of GRBs, where no TeV emission is expected due to intergalactic absorption of these photons.

A small evidence for TeV photons related to the direction of the highest energetic (320 EeV) CR event registered so far [9] was detected, which may hint at an intergalactic cascade initiated by extremely energetic particles. Currently IACT measurements in this region are under way.

5 Summary

The last years have established air shower measurements as a new branch of high energy astrophysics. Both TeV γ observations of extragalactic and galactic sources as well as analyses of charged cosmic rays have been performed successfully and will enhance our understanding of the nonthermal universe even more in the near future.

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