Observations of VHE gamma-rays with the HEGRA system of IACTs

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I.THE HEGRA STEREOSCOPIC SYSTEM

The study of astrophysical sources of very high-energy photons in the range 0.1-30 TeV, the *VHE gamma-ray astronomy*, is a relative new field of research. The HEGRA collaboration has built one of the most powerful instruments to detect these photons from astrophysical sources. The detector was placed at the "Roque de los Muchachos" Observatory, on the Canarian Islands of La Palma.

The atmosphere is opaque to photons of such energy. Nevertheless, the cascades of secondary particles created in the interaction of a VHE photon in the upper atmosphere emit electromagnetic radiation by *Cherenkov effect* when travelling with a speed $v>c/n$ through the medium. The emitted Cherenkov photons reach the ground in very short flashes, with typical duration of few ns, and are collected by means of large reflectors, which focus them to a camera formed by an array of small photo-multipliers. Such detectors are known as *imaging air Cherenkov telescope (IACT)* (see Fig.1)[1]. A *Cherenkov* telescope permits to form an image of the shower in its focal plane, which maps its longitudinal and lateral development.

Figure 1. One of the HEGRA Cerenkov telescope.

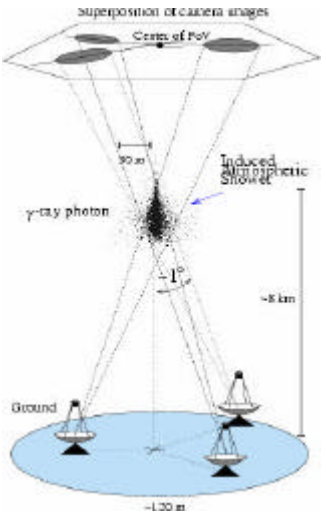

Figure 2. Stereo reconstruction of an air shower induced by a VHE gamma ray.

The HEGRA collaboration has been the first one to apply the stereoscopic technique to the observation of VHE gamma-ray-induced air showers. The idea is to observe the atmospheric showers from different viewing angles, in a *stereoscopic mode*, using more than one *IACT*[2] (see Fig.2). That permits to reconstruct with high accuracy the shower arrival direction and the shower impact point as well as the energy of the shower. In what follows, we will review the main results achieved by the system of IACTs HEGRA.

II.THE CRAB NEBULA

The Crab nebula is commonly accepted as the standard candle in gamma-ray astronomy. It can be classified as a *plerion*, a pulsar embedded within the nebula originating from the supernova explosion. TeV emission comes from high-energy electrons interacting with ambient photons within the nebula scattering them to higher energies by Inverse Compton effect[3]. The steady integral flux measured by the HEGRA system is F(E>1 TeV)=1.6x10^(-11) ph cm^-2 s^-1[4]. A measure below the standard energy threshold (500

[1] Weekes, T.C., *Spac. Sci. Rev.*, **1996**, *75*, 1.
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[3] de Jager O.C., et al., *ApJ*, **1996**, *457*, 253
[4] Aharonian F.A., et al. (HEGRA coll.). *ApJ*, **2000,** *539*, 317

GeV) is also available[5]. The differential energy spectrum measured by the HEGRA IACTs array is well described by a pure power law with a spectral index 2.6 in the energy range 1-20~TeV. No pulsed emission has been detected at TeV energies.

III. DETECTION OF AGNS

The HEGRA system of IACTs has detected 4 AGNs at TeV energies: Mrk 421[6] and 501[7], H1426+428[8] and 1ES1959[9]. All of four belong to the class of *blazars* AGN, with a jet of plasma ejecting from the central engine and pointing to the observer. The TeV emission comes from a population of particles accelerated at the base of the jet which emit TeV photons for IC effect or photo-production of neutral pions on the ambient photon field. Mkn 501 and 421 have shown strong variability at TeV energies in different period of observations, sometimes reaching values of flux as high as 7 times the Crab flux in less than 1 hr. These observations permit to constrain the size of the emitting region and the Lorentz factor of the plasma bulk motion inside the jet. A strong correlation between X-ray and TeV emission has also been observed during several multiwavelength campaigns[10]. Very recently, the collaboration has also reported hints of TeV photon emission from the giant radio-galaxy M87[11], that is considered as one of the main extragalactic cosmic rays accelerators.

IV. SUPERNOVA REMNANTS

The origin of cosmic rays is a long-standing problem, which still has not found a definitive solution. Supernova remnants (SNRs) are widely believed to be one of the sites of cosmic rays acceleration. If cosmic rays are indeed accelerated there, TeV photons are expected from the decay of neutral pions produced in the interaction between the accelerated protons and the ambient matter. Most of the HEGRA system observation time has been spent on the observation of SNRs. Despite the theoretical previsions, only the SNR Cassiopeia A has been detected after a very deep observation (around 200 hours)[12], with a flux F (E>1 TeV) of 3.3% of the Crab flux. A nearby giant molecular cloud could enhance the gamma-ray emission due to the higher density of the target matter. The expanding shell of the Monoceros Loop SNR seems to collide with the nearby Rosette Nebula molecular cloud. Hints of TeV emission from this sky region (where an unidentified EGRET source is also present[13]) have been detected by the HEGRA system of IACTs[14] (see Fig.3).

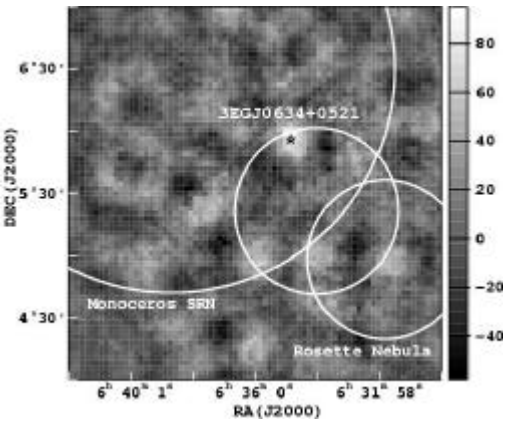

Figure 3. Number of excess events detected with the HEGRA IACTs system from the interaction region between the Monoceros Loop SNR and the Rosette Nebula molecular cloud. Also the EGRET error circle of the unidentified 3EGJ0634+0521 is shown. The white star indicates the position of the TeV photon excess.

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The HEGRA system of IACTs was shutdown on Sept. 2002.