ICRC'07 Mérida, México

Observations of the first unidentified TeV γ-ray source (TeV J2032+4130) with the MAGIC telescope

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Abstract: The TeV source J2032+4130 is the first ever detected unidentified VHE gamma-ray source. There have been contradictory claims regarding its extension, flux level and variability in γ-rays, although the longest and most sensitive observation up to now favor a steady, extended source. MAGIC has devoted more than 80 hours on J2032+4130 during 2005 and 2006. We present the most recent results with the MAGIC telescope on this source.

Introduction

The TeV source J2032+4130 [20], [2] is one the most enigmatic detection in high energy astrophysics. As discussed below, there have been various claims on its spatial extension, flux level, and time variability in γ-rays as observed with different facilities, although the longest and most sensitive observation up to now favors a steady, extended source. Its counterpart at lower energies is yet unknown. It was the first unidentified γ-ray source found at very high γ-ray energies, and also the first-discovered, likely galactic TeV source which appeared to be extended. These properties were to be shared by other detections made more recently with the HESS telescopes. Intensive observational campaigns at different wavelengths have been carried out on TeV J2032+4130.

It was first reported by the HEGRA collaboration. They claimed the serendipitous discovery of a TeV source in the Cygnus region [3], when analyzing data originally taken during Cyg X-3 and the EGRET source GeV J2035+4214 observations. About 113 hours of data recorded during 3 years of regular observations (from 1999 to 2001) were analyzed. The detection was confirmed [2] by follow-up observations (about 158 hours) carried out during the final season of operation of the HEGRA array (2002). Using all data (1999 to 2002) this source was determined to be steady in flux over the four years of data taking, extended, with radius $6.2 \pm 1.2_{\rm stat} \pm 0.9_{\rm sys}$ arcmin, and exhibiting a hard spectrum with a photon index $-1.9 \pm 0.1_{\rm stat} \pm 0.3_{\rm sys}$. Its integral flux above $E > 1$ TeV was found to be $\sim 5\%$ of the Crab, assuming a Gaussian profile for the intrinsic source morphology. The center of the source position was determined at $\alpha_{2000} = 20^h31^m57^s$, $\delta_{2000} = 41°29'56.8''$.

Previously, the Crimean group reported a significant excess ($\sim 6.0\sigma$ pre-trial) and the flux of this source above 1 TeV was reported to be 3×10^{-11} cm^{-2} s^{-1}, or about 1.7 times the flux of the Crab Nebula [18]. This flux claim was never followed up in subsequent journal publications of the same collaboration, or confirmed by other experiments.

After the HEGRA discovery claim was made public, the Whipple collaboration also reported an excess at the position of the HEGRA unidentified source (3.3σ) in their archival data of 1989 and 1990 [17]. These results are at face value in conflict with the HEGRA estimates of flux level and steady nature of the TeV source, assuming they all

ICRC 2007 Proceedings - Pre-Conference Edition

have the same origin. The average flux detected in 1989-1990 by Whipple ($\sim$ 12% of the Crab for E>600 GeV) is above the average steady flux reported by HEGRA over the four year observation period, although yet substantially below that reported by the Crimean group in 1993. Notably, neither the Whipple nor the HEGRA experiments find any evidence for variability within their individual datasets. The large differences between the detected flux levels, if real, might suggest episodic emission (with low duty cycle) or slow variability in γ-ray emission from TeV J2032+4130. Nevertheless, the existence of γ-ray variability is difficult to reconcile with an extended nature of the source.

Recently, the Whipple collaboration reported new observations of this field with its 10-m telescope for 65.5 hours during 2003 and 2005 [16]. They find a pre-trial excess with a significance of 6.1σ. Given the $\sigma = 7.6'$ width of the PSF of their telescope, their data is consistent with both, a point-like or an extended source with less than $6'$ angular size. Regarding the observed source position, HEGRA and recent Whipple data are barely in agreement: their centers being $\sim 9'$ apart. The flux levels seems also barely consistent: Recent Whipple claims do not provide a spectrum for this source, but just give a 8% Crab-level flux (although with no energy threshold provided) under the assumption of an steep (Crab-like) spectrum and 1.7 kpc distance (the one to Cyg OB2 association).

Finally, the MILAGRO scan [1], shows an excess in the Cygnus region, although it comes from a more extended region and is possibly a superposition of individual objects plus diffuse emissions. The MILAGRO flux in a 3x3 square degree region centered on the HEGRA source at 12 TeV is $(2.41 \pm 0.48_{\rm stat} \pm 0.72_{\rm sys}) \times 10^{-12}$ cm^{-2} s^{-1} assuming a differential photon source spectrum of $E^{-2.6}$. The MILAGRO flux would thus exceed the HEGRA one. This may be expected if additional contribution of the diffuse emission and/or additional sources are considered.

Several attempts has been done to identify the source in different wavelenghts, i.e. [10], [11], [12], [21], [19]. No clear counterpart has been found (a more detailed discussion can be found in [4]).

We report here recent MAGIC telescope results. More details will be given during the conference and in the follow up proceeding.

Analysis and Results

MAGIC is a new generation single dish Imaging Air Cherenkov Telescope (see e.g., [6], [13] for a detailed description). Located on the Canary Island La Palma (28.8°N, 17.8°W, 2200 m a.s.l.), the telescope has a 17-m diameter mirror, and it is equipped with a 576-pixel 3.5° field-of-view photomultiplier (PMT) camera. The analogue PMT signals are transported via optical fibers to the trigger electronics and are read out by a 300 MSamples/s FADC system. MAGIC's angular resolution is approximately $0.1°$, its energy resolution is about 20%, and the trigger (analysis) threshold is 55 (90) GeV. The data analysis was carried out using the standard MAGIC analysis and reconstruction software [9], the first step of which involves the calibration of the raw data [14]. After calibration, image cleaning tail cuts of 10 photoelectrons (pe) for image core pixels and 5 pe (boundary pixels) have been applied. These tail cuts are accordingly scaled for the larger size of the outer pixels of the MAGIC camera. The images are parameterized by image parameters [15]. In this analysis, the Random Forest method (see [7], [8] for a detailed description) was applied for the γ/hadron separation.

The source position-independent image parameters SIZE, WIDTH, LENGTH, CONC and the third moment of the pe distribution along the major image axis were selected to parameterize the shower images. After the training, the Random Forest method allows to calculate for every event a parameter, the HADRONNESS, which is a measure of the probability that the event is not γ-like. The γ-sample is defined by selecting showers with a HADRONNESS below a specified value, which is optimized using a sample of Crab data which has been processed with the same analysis stream. An independent sample of Monte Carlo γ-showers was used to determine the cut efficiency.

Since part of our observations were carried out in the presence of partial Moon shine, we have corrected the efficiency loss due to the increase of ambient light. The correction factor and other details for moon-shine observations with MAGIC is discussed by [5].

A total of 87 h were devoted to TeV J2032+4130, spammed during 2005 and 2006. The observation zenith angle ranges from 12 to 43^o. The results of the analysis of this long expose observation will be given in the conference and the follow up proceeding.

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