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New Astronomy Reviews 48 (2004) 489–492
New Astronomy Reviews
www.elsevier.com/locate/newastrev

HEGRA discovery of the first unidentified TeV source

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Abstract

The first unidentified TeV source in the Cygnus region is confirmed by follow-up observations carried out in 2002 with the HEGRA stereoscopic system of air Cherenkov telescopes. Using the combined ~279 h of data, this new source TeV J2032+4130, appears to be steady in flux over the four years of data taking, it shows an extension with radius 6.2′, and has a hard spectrum with photon index −1.9 between 1 and 10 TeV. Its location places it at the edge of the core of the extremely dense stellar OB association, Cygnus OB2. Its integral flux above energies $E > 1$ TeV amounts to ~3% of the Crab nebula flux. No counterpart at radio, optical, nor X-ray energies is as-yet seen, leaving TeV J2032+4130 presently unidentified. Summarized here are observational parameters of this source and brief astrophysical interpretation.

Keywords: Unidentified TeV source; HEGRA; Imaging air Cherenkov; Stereoscopic observations; Cosmic rays; Multiwavelength observations; γ-ray; X-ray; Radio

1. Introduction and data analysis

Analysis of archival data (~121 h) taken with the HEGRA system of imaging atmospheric Cherenkov telescopes (HEGRA IACT-system see for, e.g., Pühlhofer et al., 2003) devoted to the Cygnus region revealed the presence of a new TeV source (Aharonian et al., 2002). This serendipitous discovery is now confirmed in follow-up observations carried out in 2002 (~158 h) by the same telescopes. Given the lack of a counterpart at other energies, TeV J2032+4130 may represent a new class of particle accelerator. The data-analysis here follows closely (Aharonian et al., 2002) with the sole exception of applying a cut on the error on the reconstructed arrival direction ($\varepsilon \leqslant 0.12°$, see also Hofmann et al., 2000b) for the calculation of the position of the source (defined as the centre of gravity (CoG) of the excess event directions) and the angular size of the object (defined as the size of a 2-D Gaussian shaped brightness profile of the source convolved with the Gaussian point-spread function of the telescopes (Hofmann et al., 2000a). At the CoG, the excess significance exceeds 7σ for the combined data set encompassing 278.2 h of good data. The source extension is confirmed as non point-like.

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1387-6473/$ - see front matter
doi:10.1016/j.newar.2003.12.028

Table 1
Summary for TeV J2032+4130 (preliminary)

(a) Tight cuts: $\theta < 0.12°$, $\bar{w} < 1.1$, $n_{\mathrm{tel}} \geqslant 3$					
Background	s	b	α	$s - \alpha b$	S
Template	1245	5926	0.168	252	+7.1
Displaced	1245	15492	0.065	243	+7.1
(b) Spectral cuts: tight cuts + core $\leqslant$ 200 m					
Displaced	974	5122	0.143	242	+7.9
(c) CoG and extension ($\varepsilon \leqslant 0.12°$)					
α_{2000}:	$20^{\mathrm{h}}31^{\mathrm{m}}\ 57.0^{\mathrm{s}}\ \pm 6.2^{\mathrm{s}}_{\mathrm{stat}}\ \pm 13.7^{\mathrm{s}}_{\mathrm{sys}}$				
δ_{2000}:	$41°29'56.8''\ \pm 1.1'_{\mathrm{stat}}\ \pm 1.0'_{\mathrm{sys}}$				
σ_{src}:	$6.2' \pm 1.2'_{\mathrm{stat}}\ \pm 0.9'_{\mathrm{sys}}$				
(d) Fitted spectrum: pure power-law					
$\mathrm{d}N/\mathrm{d}E$	$= N(E/1\ \mathrm{TeV})^{-\gamma}(\mathrm{cm}^2\ \mathrm{s\ TeV})^{-1}$				
N	$= 5.3(\pm 2.2_{\mathrm{stat}} \pm 1.3_{\mathrm{sys}}) \times 10^{-13}$				
γ	$= 1.9(\pm 0.3_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}})$				

(a) Event summary. The values s and b are event numbers for the γ-ray-like and background (from the Template and Displaced models, see Rowell, 2003), respectively, and $s - \alpha b$ is the excess using a normalization α. S denotes the excess significance using Eq. (17) of Mukherjee et al. (2003); (b) Events after spectral cuts; (c) Centre of Gravity (CoG) and extension σ_{src} (standard deviation of a 2D Gaussian); (d) Fitted power law.

In order to extract the energy spectrum of the source, an improved energy reconstruction algorithm has been applied (Hofmann et al., 2000b) with a relative energy resolution of $\Delta E/E <$ 15%. The event-selection follows the same conditions as for the signal search with additional cuts on the distance of the core to be within 200 m of the central telescope. The resulting energy spectrum is well described ($\chi^2/\mathrm{d.o.f.} < 1$) by a pure power-law with a photon index of -1.9. A lower (95% confidence) limit to the cut-off energy $E_{\mathrm{c}} \sim$ 3.6, 4.2, and 4.6 TeV for a power-law with exponential cut-off is estimated depending on the power-law index chosen (-1.7, -1.9, and -2.1). The integral flux above 1 TeV is $(5.9 \pm 3.1) \times 10^{-13}$ photons/(cm^2 s) or about 3% of the Crab nebula flux. Results are summarized in Table 1 and Fig. 1(a).

2. Modeling TeV J2032+4130

Possible origins of TeV J2032+4130 have been discussed in literature (Aharonian et al., 2002; Butt et al., 2003; Hartman et al., 1999; Mukherjee et al., 2003). One interpretation involves association with the stellar winds of member stars in Cygnus OB2, individually or collectively, which provide conditions conducive to strong and stable shock formation for diffusive particle acceleration. Certainly the existence of TeV emission suggests particles accelerated to multi-TeV energies. We have therefore matched the spectral energy distribution of TeV J2032+4130 with coarse leptonic and hadronic γ-ray emission models (Fig. 1(b)). Another scenario involves particle acceleration at a termination shock, which is expected to form where the ram pressure of a relativistic jet balances the pressure of the interstellar medium. TeV J2032+4130 actually aligns well within the northern error cone of the bi-lobal radio jet of the famous binary system Cygnus X-3 (Martí et al., 2000, 2001).

For simplicity we assume the TeV emission arises exclusively from either a sample of non-thermal hadronic or leptonic parent particles. Within the hadronic scenario the $\pi°$-decay prediction explains well the TeV flux when using a parent proton power law spectrum of index of ≈ -2.0 with a sharp limit up to energies >100 TeV. The neighbouring EGRET source 3EG J2033+4118

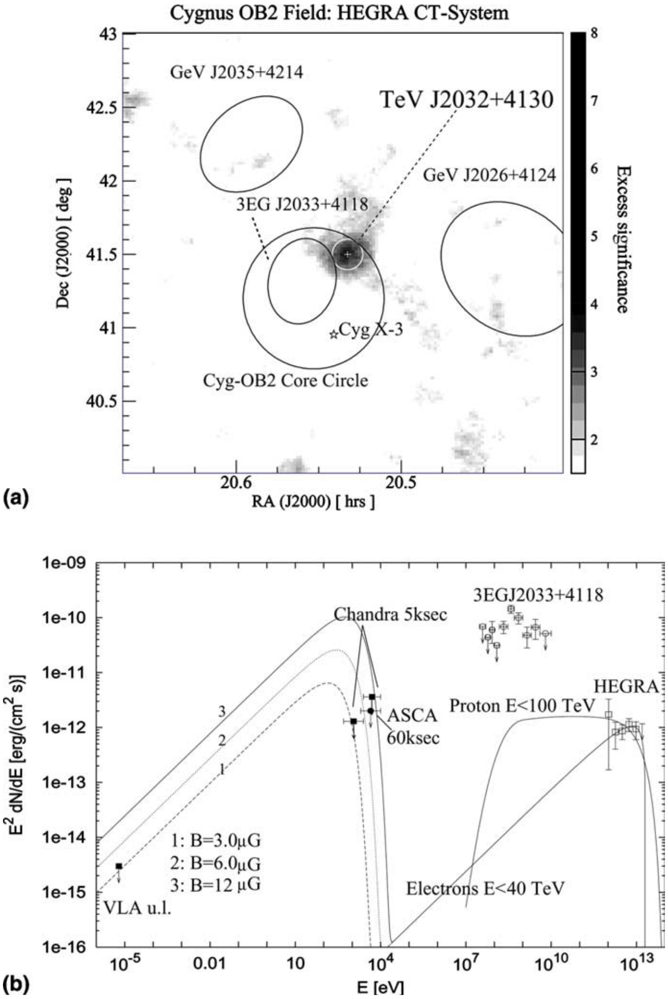

Fig. 1. (a) Skymap of event excess significance (σ) from all HEGRA CT-system data ($3.0° \times 3.0°$ FoV) centred on TeV J2032+4130. Some nearby objects are indicated (GeV sources with 95% contours). The TeV source CoG with statistical errors, and error circle (65% confidence) for the extension (standard deviation of a 2D Gaussian, σ_{src}) are indicated by the white cross and white circle, respectively. (b) Spectrum of TeV J2032+4130 (labelled HEGRA) compared with purely hadronic (Protons $E < 100$ TeV) and leptonic (Electrons $E < 40$ TeV) models. Upper limits, constraining the synchrotron emission, are from the VLA and Chandra (Butt et al., 2003) and ASCA (Aharonian et al., 2002) satellites. EGRET data points are from the 3rd EGRET catalogue (Hartman et al., 1999).

(likely not related to TeV J2032+4130) provides no constraint on this model. Associated synchrotron X-ray emission would also be expected from tertiary electrons ($\pi^{\pm} \ldots \rightarrow \mu^{\pm} \ldots \rightarrow e^{\pm} \ldots$). We have not yet modeled this component which essentially represents an absolute lower limit on any synchrotron emission visible. Assuming a pure leptonic scenario, TeV data are matched well by an inverse-Compton spectrum (up-scattering the cosmic microwave background) arising from an uncooled electron spectrum with power law index ~ -2.0 and hard cutoff at 40 TeV. This allows us to predict the synchrotron emission as a function of local magnetic field, constrained by the available upper limits at radio and X-ray energies. The most conservative synchrotron prediction arises from the $B_0 = 3$ μG choice, which is realistically the lowest such field expected in the Galactic disk. But in fact, much higher fields ($B_0 > 10$ μG) are generally expected in such regions containing young/

massive stars with high mass losses and colliding winds (Eichler and Usov, 1993). Deep observations by XMM and Chandra will provide strong constraints on the leptonic component.

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