A New TeV Source in the Vicinity of Cygnus OB2

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Abstract

TeV Observations (during 1999, 2000 & 2001) of the Cygnus region using the HEGRA stereoscopic system of air Cherenkov telescopes have serendipitously revealed a signal positionally inside the core of the OB association Cygnus OB2, and $\sim 0.5^\circ$ north of Cyg X-3. The source appears steady, has a post-trial significance of $+4.6\sigma$, indication for extension with radius $5.6'$ at the $\sim 3\sigma$ level, and has a differential power-law flux with hard photon index of $-1.9 \pm 0.3_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}}$. The integral flux above 1 TeV amounts ∼3% that of the Crab. No counterpart for the TeV source at other wavelengths is presently identified. Preliminary analysis of follow-up 2002 observations reveal again the presence of this source.

1. Introduction

Ground-based γ-ray telescopes utilising the atmospheric imaging Cherenkov technique, with their arcminute-scale angular resolution and effective collection areas of order 10^5 m^2, are perfect instruments for follow-up γ-ray observations of EGRET unidentified sources. The stereoscopic method employed by the HEGRA CT-System of 5 idential telescopes at La Palma (Daum et al. [3]) offers highly accurate reconstruction of event directions at angles up to $\sim 3^\circ$ off-axis, permitting reasonably wide field of view (FOV) TeV surveys of the sky from a single tracking position. In early 2002, a search for TeV counterparts to the GeV sources GeV J2035+4214 and GeV J2026+4124 (Lamb & Macomb [6]), with archival data (1999-2001), resulted in the serendipitous discovery of a new TeV source (Aharonian et al. [1]). Here we summarise details of this new source and present preliminary results from 2002 observations.

2. Results from 1999 - 2001 Data

Analysis of HEGRA CT-System data is based on (1) a cut on the difference, θ, between reconstructed and the nominal arrival directions in the sky plane, and

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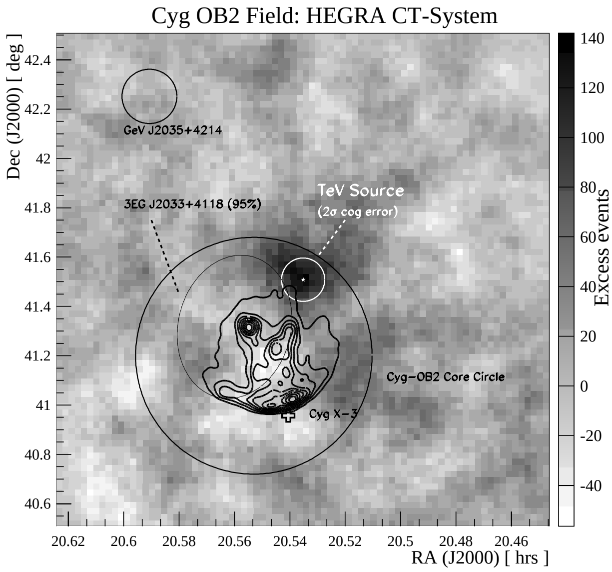

Fig. 1. Skymap ($2° \times 2°$ view at $0.05° \times 0.05°$ binning) of excess events using the template background model. At each bin, the excess is estimated from events within a radius $\theta = 0.12°$. Included are 95% error ellipses of various EGRET sources, the core of Cygnus OB2 (Knödlseder [4]), the TeV COG (star), its 2σ error circle, and the location of Cyg X-3. ASCA GIS contours (2-10 keV) are overlayed.

(2), a cut on the image shape parameter *mean-scaled-width* $\bar{w}$ (Konopelko [5]). For weak (background dominated) point-like and marginally extended sources, so-called tight cuts, *a-priori*-chosen, are considered optimal given the angular resolution of the CT-System under this analysis ($\sim 0.1°$): $\theta < 0.12°$ and $\bar{w} < 1.1$. The number of accepted images per event, $n_{\rm tel}$, used for calculating θ and $\bar{w}$ is also *a priori* chosen at $n_{\rm tel} \geq 3$. In searching for new TeV sources, *skymaps* of event direction excesses over the RA & Dec plane are generated after having estimated the background over the FOV. A new empirically-based *template* background model was developed with the goal of simple generation of such skymaps. An alternative, independent background estimation, the so called *ring* background model was also carried out in order to verify results obtained from the template model. See Aharonian et al. [2] and Rowell [14] for detailed descriptions of analysis techniques. Fig. 1. presents the event excess skymap obtained from our 1999-2001 observations of the Cygnus region (for a total of 112.9 hours), indicating clearly the new TeV source $\sim 0.5°$ north of Cyg X-3, and within the so-called core of the OB assocation Cygnus OB2. A pre-trial excess significance at the source centre of gravity (COG) amounts to $+5.9\sigma$ (both template and ring background models), which is reduced to $+4.6\sigma$ after accounting for statistical penalties accrued in constraining the COG calculation region. Our observations were taken at

Table 1. Summary of numerical results for the new TeV source, under two background models. Here, s and b are the resulting event numbers for the γ-ray-like and background $\bar{w}$ regimes respectively, and $s - \alpha b$ is the derived excess using a normalisation α. S denotes the excess significance using Eq. 17 of Li & Ma [7]. See text for definitions of θ and $\bar{w}$.

(a) Centre of Gravity

RA α_{2000}:	$20^{\mathrm{hr}}\ 32^{\mathrm{m}}\ 07^{\mathrm{s}}$	$\pm 9.3^{\mathrm{s}}_{\mathrm{stat}}$	$\pm 2.2^{\mathrm{s}}_{\mathrm{sys}}$
Dec δ_{2000}:	$41^{\circ}\ 30'\ 30''$	$\pm 2.0'_{\mathrm{stat}}$	$\pm 0.4'_{\mathrm{sys}}$

(b) Tight cuts: $\theta < 0.12^{\circ}$, $\bar{w} < 1.1$, $n_{\mathrm{tel}} \geq 3$

Background	s	b	α	$s - \alpha\, b$	S
Template	523	2327	0.167	134	**+5.9**
Ring	523	4452	0.089	128	**+5.9**

three different tracking positions. Splitting data accordingly reveals commensurate contributions to the TeV excess, suggesting consistency with a steady source during the three years of data collection. To determine the source extension, we fitted a radial Gaussian convolved with the point spread function (determined from Crab data) to the excess events as a function of θ^2, using a subset of events with the best angular resolution (accepted images in all 5 telescopes, $n_{\mathrm{tel}} = 5$) for which errors are minimised. The intrinsic size of the TeV source was then estimated at $\sigma_{\mathrm{src}} = 5.6' \pm 1.7'$. Correlations between the fit parameters suggest that the significance for a non-zero source size is at the $\sim 3.0\sigma$ level rather than the 3.5σ level indicated above. A breakdown of the excess with n_{tel} also shows that the n_{tel}=5 exclusive subset contributes strongly to the excess, pointing to a rather hard energy spectrum. Indeed the resulting energy spectrum (Fig. 2.) appears well-fit by a pure power law with hard photon index:

$$\begin{aligned} dN/dE &= N\ (E/1\,\mathrm{TeV})^{\gamma}\ \ \mathrm{ph\,cm^{-2}\,s^{-1}\,TeV^{-1}} \\ N &= 4.7\,(\pm 2.1_{\mathrm{stat}} \pm 1.3_{\mathrm{sys}})\ \times 10^{-13} \\ \gamma &= -1.9\,(\pm 0.3_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}}) \end{aligned} \tag{1}$$

The integral flux at $F(E > 1\ \mathrm{TeV}) = 4.5\,(\pm 1.3_{\mathrm{stat}}) \times 10^{-13}$ ph cm^{-2} s^{-1} amounts to 2.6% that of the Crab.

3. Results from 2002 Data

To confirm our results, over 130 hours of observation were taken during 2002. The skymap (Fig. 3.) obtained from these data, using an identical analysis as applied to 1999-2001 data, shows clearly the presence of the TeV source at the expected position within errors. The excess significance at the previous COG is

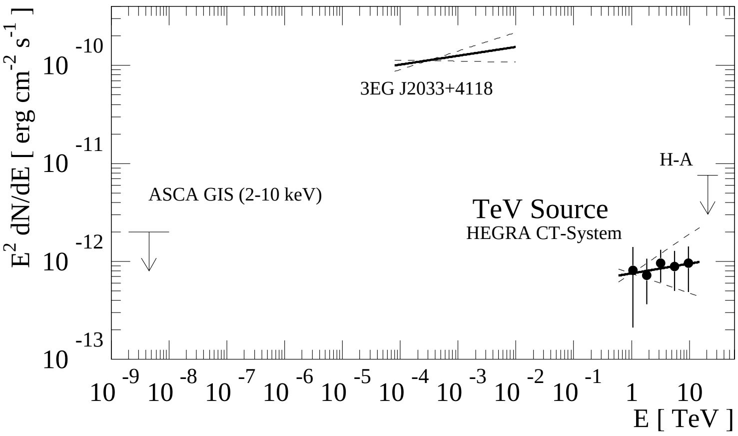

Fig. 2. Differential energy fluxes of the TeV source and other results. 'H-A' is the AIROBICC 90% confidence level upper limit (Prahl [12]) at the TeV COG converted to differential form at 20.8 TeV assuming a spectral photon index of -2.0. We interpret the 3EG J2033+4118 flux as an upper limit. The ASCA GIS 99% upper limit assumes a photon index of 2, and $N_H = 10^{22}$ cm^{-2}. Data fits (solid lines) and their 1σ statistical errors in photon index (dashed lines) are shown.

$+5.3\sigma$. Furthermore, the energy spectrum (Fig. 4.) also appears consistent with 1999-2001 results. Results from 2002 should be considered preliminary since these have utilised data not fully reduced, in terms of a number of calibration issues. We do not expect however significant change in results when analysing final data products.

4. Discussion & Conclusion

The new TeV source lies positionally within the core of Cygnus OB2, a remarkably dense concentration of hot OB and O stars (eg. Knödlseder [4]). Assuming the TeV source is as distant as Cygnus OB2 (1.7 kpc), a luminosity $\sim 10^{32}$ erg s^{-1} above 1 TeV is implied, well within the kinetic energy (KE) budget of Cygnus OB2 estimated ([8]) at a few$\times10^{39}$ erg s^{-1}, and also within the KE budget of a number of notable member stars. So far, no counterparts at other wavelengths are identified and analysis of archival ASCA GIS data yields a 99% upper limit (2–10 keV) of 2.0×10^{-12} erg cm^{-2} s^{-1} (ASCA contours are included on Fig. 2.). Presently we qualitatively invoke two scenarios to explain the TeV emission: (1) Acceleration of hadrons in a shock arising from the winds of Cyg OB2 member star(s), with the hadrons interacting with a local dense cloud leading to π°-decay TeV emission; or (2) A jet-driven termination shock is able to accelerate electrons giving rise to X-ray synchrotron and TeV inverse-Compton emission. Such a jet could emanate from a nearby microquasar. In

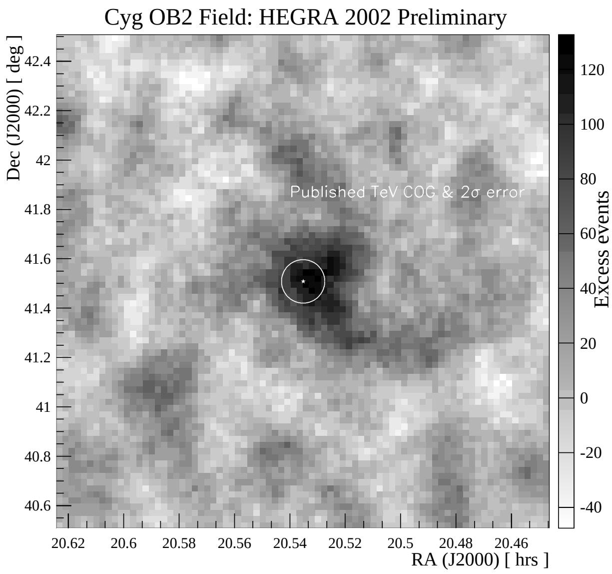

Fig. 3. Preliminary skymap ($2° \times 2°$ view at $0.05° \times 0.05°$ binning) of excess events using the template background model for 2002 data. The excess significance at the previously published COG (white star, from 1999 - 2001 data) is $+5.3\sigma$.

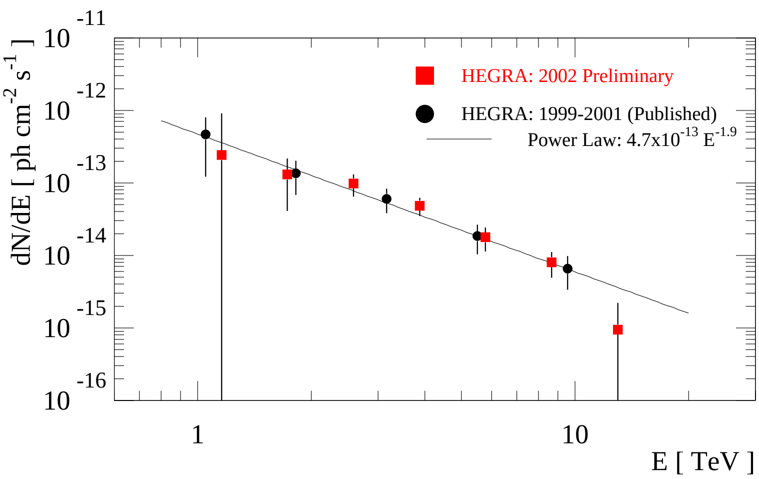

Fig. 4. Comparison of energy spectra for the new TeV source from the 1999-2001 (filled circles), and 2002 (filled squares) datasets. The power law fit of eq. 1 is included.

fact two nearby sources, 3EG J2033+4118 and also the EGRET source possibly associated with Cyg X-3 (Mori et al. [11]) could be GeV indicators of such a microquasar. Remarkably, Cyg X-3 appears to have a bi-lobal jet (Martí et al. [9][10]) well-aligned with the TeV source, the latter which would be $\sim$ 70pc from Cyg X-3 in absolute terms if it is at the same distance (>8.5 kpc). Future X-ray observations will be a crucial constraint on the IC emission in this context.

Final analysis of our 2002 HEGRA observations will soon be underway, including a combined analysis of all data. The latter is motivated by important questions such as the extension of the excess, and to what energy the spectrum is well-explained by an unbroken power law.

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