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Search for TeV gamma ray emission from young open star clusters with the HEGRA Cherenkov Telescopes

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Abstract.

Observations of the nearby young open star clusters Berkeley 87 and IC 1805 as well as the COS B source CG135+1 have been carried out in the TeV energy range with the system of Imaging Cherenkov Telescopes of the HEGRA Collaboration.

Both clusters contain members with strong stellar winds (up to 5200 km/s for Berkeley 87 and 3800 km/s for IC 1805), favouring shockfront acceleration of cosmic rays. The association of the EGRET source 2EG J2019+3719 with Berkeley 87 and COS B and EGRET sources in the neighbourhood of IC 1805 give a further motivation for VHE observations of these objects and their neighbourhood.

No evidence for the emission of TeV gamma rays has been found. The derived upper limits on the integral flux make a significant contribution of young open star clusters to the acceleration of charged Galactic cosmic rays seem unlikely.

1 Introduction

1.1 Young Open Star Clusters

The questions for the origin and acceleration mechanisms of charged Galactic cosmic rays are still not resolved. A promising alternative to the acceleration in shell type super nova remnants (Drury, Aharonian and Völk, 1994) could be the acceleration in strong stellar winds of young massive stars. It has been shown that the maximum energy that a particle can reach through the acceleration in the shockfront of stellar winds under similar local conditions is higher than the maximum energy reached in super nova shock acceleration (Cesarsky and Montmerle, 1983). Galactic young open star clusters contain many young massive stars and could thus contribute to the observed flux of charged Galactic cosmic rays (Manchanda et al., 1996), (Polcaro et al., 1991). Two of

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the most promising candidates among the known young open star clusters are Berkeley 87 and IC 1805.
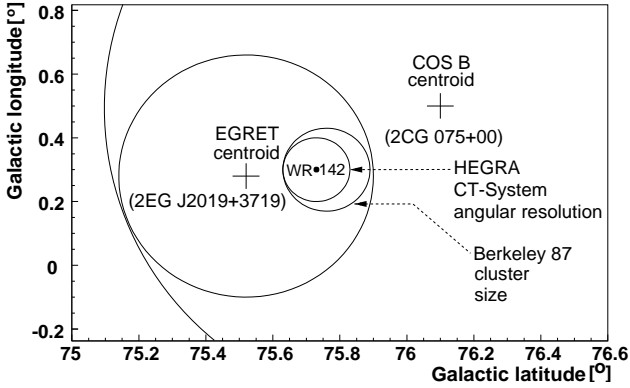
1.2 Berkeley 87

At a distance of 0.9 kpc Berkeley 87 is probably part of the Cygnus star forming region ON2. It contains approximately 100 young massive stars of the OB spectral class with strong stellar winds embedded in a very dense interstellar medium and molecular clouds. The most prominent of these stars is the Wolf–Rayet star WR–142, located at the centre of the cluster. With a mass of approx. 60 $M_\odot$ and a mass loss rate of $1.68 \cdot 10^{-5} M_\odot \mathrm{yr}^{-1}$ (Barlow, 1990), WR–142 produces stellar winds of approx. 5200 km/s propagating into the ambient interstellar medium with an estimated Mach number of 26 and thus producing a system of shock fronts. The EGRET source 2EG J2019+3719 (= 3EG J2021+3716) has been associated with Berkeley 87 (Polcaro et al., 1991). In Figure 1 the position and error centroid (95%) of 2EG J2019+3719 is drawn together with the position and size of Berkeley 87, the position and error centroid of 2CG 075+00 and the angular resolution of the HEGRA Cherenkov telescopes. Expecting the size of the production region of γ–rays to be centered around WR–142 and confined to the cluster size, one can assume the emission to be point like regarding the angular resolution of the HEGRA Cherenkov telescopes.

The observed γ–ray flux above 100 MeV could be explained by a cosmic ray energy density in the open cluster of a factor 100 higher than the average local density (Giovanelli et al., 1996). Extrapolations of the hard EGRET spectrum ($dN/dE \sim 1.91$) to higher energies are shown in Figure 2 (Giovanelli et al., 1996). The predicted fluxes are in the detection range of the HEGRA telescopes.

1.3 IC 1805 and 2CG 135+01

The young open cluster IC 1805 shows features very similar to Berkeley 87. It is the central cluster of the star association CAS OB6, embedded in the H II region W4. It is located at 2.4 kpc distance to the sun (Guetter et al., 1989),

Fig. 1. Positions and error centroids of 2EG J2019+3719, 2CG 075+00 and Berkeley 87 as well as the position of WR–142 in galactic coordinates. Superimposed is the angular resolution of the HEGRA Cherenkov telescope system.

and contains several members with hypersonic winds among which the two peculiar stars HD 15570 and HD 15578 both have estimated wind velocities of 3800 km/s (Burki et al., 1979). The hard X–ray source 4U 0241+61 (Forman et al., 1978), the EGRET gamma–ray sources 3EG J0241+6103 and 3EG J0229+6151 (Hartmann et al., 1999) as well as the COS B source 2CG 135+01 (Schwanenburg et al., 1981) were detected in the neighbourhood of IC 1805. IC 1805 was suggested to be associated with 4U 0241+61 and with 2CG 135+01 (Montmerle, 1979), (Perotti et al., 1980), (Bignami and Hermsen, 1983).

2 The HEGRA Cherenkov Telescope System

The system of imaging Air Cherenkov telescopes (IACT) of the HEGRA collaboration consists of five Cherenkov telescopes (CT). Four telescopes are placed on the corners of a square and one telescope is placed in the centre. Each CT is equipped with a tessallated reflector of 30 mirrors of 60 cm diameter each resulting in a total reflector area of ≈ 8.5 m^2. In the focus of each telescope reflector a camera of 271 photo multiplier tubes is mounted. The total field of view is 4.3° in diameter. The energy threshold of the telescope system is 0.5 TeV for photon showers of vertical incidence. The telescopes allow a reconstruction of energy and direction of the primary particle with an energy resolution of $\Delta E/E \leq 20\%$ and an angular resolution of ≤ 0.1 degrees. The telescopes are used in the stereoscopic observation mode, allowing the observation of an air shower from different viewing angles, thus making a complete geometrical reconstruction of the shower parameters possible. The image of a shower is reconstructed for each telescope and overlayed in a common plane. The intersection of the main axes of the elliptical images in the observation plane corresponds to the shower core position and the intersection in the camera plane corresponds to the direction θ relative to the optical axis of the telescopes of the primary particle. For each event, the width of the elliptical shower

image in each triggered telescope is scaled with a simulated expected width depending on shower core position, image size (in photoelectrons) and zenith angle of the shower. The mean value of this scaled width is the mean scaled width (*mscw*) parameter, which allows a very good γ–hadron separation. For further details see Daum et al. (1997).

3 Data analysis and results

For the analyses presented here, the mean scaled width cut was chosen as *mscw* < 1.2 and only data within an angular distance θ of the reconstructed event to the source direction of $\Delta\theta^2 < 0.05°^2$ were taken into account.

Crab Nebula data samples from the data periods October 1999 and October/November 2000 were used for upper limit calculations (Helene et al., 1983), (Aharonian et al., 1999) of the Berkeley 87 and the IC 1805 data respectively, giving γ- and hadron–efficiencies of $\epsilon_\gamma = 0.68$ and $\epsilon_{hadron} = 0.12$ for October 1999 and $\epsilon_\gamma = 0.71$ and $\epsilon_{hadron} = 0.10$ for October/November 2000.

3.1 Berkeley 87

In total 6.4 h observation time on Berkeley 87 have been accumulated in August 1999. 5.6 h of the observation were performed with the complete 5 telescope system, while 0.8 h were performed with a 4 telescope system due to technical reasons. The average zenith angle of 15° translates into an energy threshold of the data sample of 700 GeV.

In Figure 3 the difference between the number of reconstructed γ–ray events in the ON–source and the OFF–source regions is plotted versus the squared angular distance $\Delta\theta^2$.

The 90% confidence level upper limit on the integral flux has been calculated to be: $\Phi_{90\%}(E>0.7\text{TeV}) = 0.12$ in units of the Crab Flux (Konopelko and Pühlhofer, 1999) corresponding to $\Phi_{90\%}(E>0.7\text{TeV}) = 3 \times 10^{-12}\text{cm}^{-2}\text{s}^{-1}$, assuming a differential source energy spectrum $\sim E^{-1.9}$. This upper limit is indicated in Figure 2 as a bar with an arrow.

Assuming the EGRET source 2EG J2019+3719 to be associated to Berkeley 87, one can constrain the proposed models. However, this result makes a significant contribution of young open star clusters to the acceleration of charged Galactic cosmic rays seem unlikely.

In order to find a possible TeV counterpart of the EGRET source 2EG J2019+3719, a search for γ–ray emission in the total effective field of view of the HEGRA cameras is underway. Results of this analysis will be presented.

3.2 IC 1805

The young open star cluster IC 1805 has been observed to a total of 12 h in October/November 2000. The average zenith angle of 34° translates into an energy threshold of 1.15 TeV for the IC 1805 data sample. No evidence for the emission of TeV γ–rays has been found. Assuming a point like emission, a preliminary upper limit $\Phi_{90\%}(E>1.15\text{TeV})$ on the integral flux has been calculated to $\Phi_{90\%}(E>1.15\text{TeV}) = 0.11$
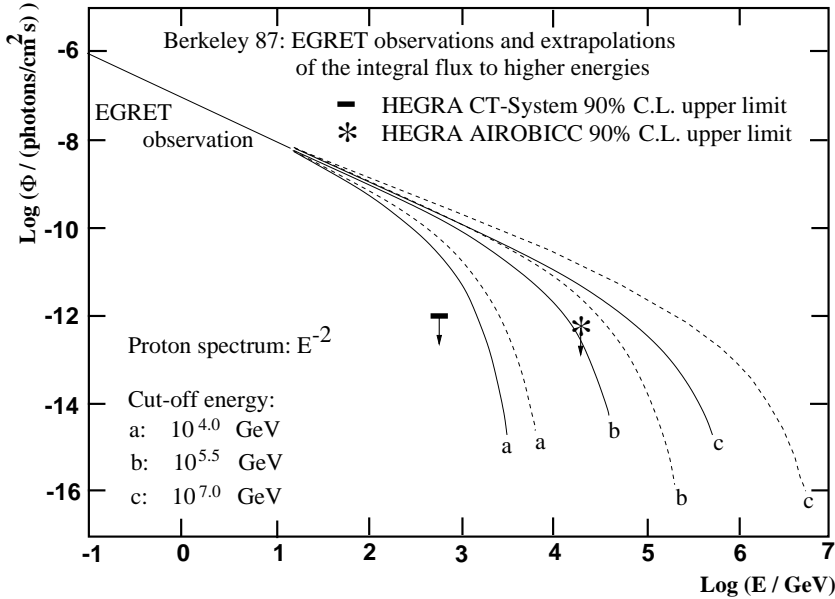
Fig. 2. EGRET flux (Φ) spectrum and predicted flux spectra, extrapolated from the spectrum of the EGRET observation (E>100 MeV) to higher energies, assuming an input proton spectrum $\approx E^{-2}$ with different cutoff Energies at 10^4, $10^{5.5}$ and 10^7 GeV and γ–ray production from π^0–decay (Giovanelli et al., 1996). The solid Line was computed using the scaling model (Stephens and Badhwar, 1981) while the dotted line represents the predictions from the scaling break model (Wdowczyk and Wolfendale, 1987). The upper limit calculated in this work is indicated as a bar. An earlier upper limit calculated with the HEGRA AIROBICC detector is also shown (asterisk) (Prahl, 1999).
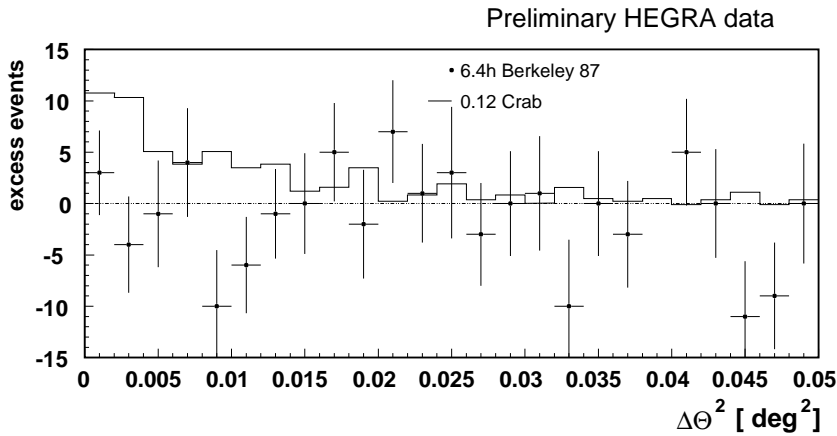
Fig. 3. Number of reconstructed excess events vs. angular distance $\Delta\theta^2$ for Berkeley 87 (dots). Also shown is a histogram of a 6.4h Crab data sample scaled down to the value of the upper limit (0.12 Crab units) obtained for Berkeley 87. The data were taken in the so called *wobble mode*, allowing simultaneous ON and OFF source observations.

in units of the Crab Nebula flux, corresponding to $\Phi_{90\%}(E>1.15\text{TeV}) = 2\cdot10^{-12}\text{ph.cm}^{-2}\text{s}^{-1}$ in absolute flux units. These results were obtained through the analysis of uncalibrated data and should thus be considered as preliminary. The results of the analysis of calibrated data as well as a search for TeV γ–rays in the total effective field of view of the HEGRA cameras will be presented.

3.3 2CG 135+01

Observations of 2CG 135+01 have also been carried out with the HEGRA IACT System in October and November 1999. The observation was centered on a point in the sky between 2CG 135+01 and QSO 0241, including both nominal positions of these objects inside the field of view. In total 30h of data were accumulated with an average zenith angle of 35° corresponding to an energy threshold of 1.2 TeV. The results

of a search for TeV γ–ray emission will be presented.

4 Conclusion

The derived upper limits on the integral flux of Berkeley 87 and IC 1805 constrain the possible contribution of young open star clusters to the observed flux of charged Galactic cosmic rays. In the case of Berkeley 87 the upper limit rules out the models proposed by Giovanelli et al. (1996). These results make a significant contribution of young open star clusters seem unlikely. The results of a search for TeV γ–rays from the neighbourhood of the two objects will be presented. In addition to the results from direct observations of IC 1805 the data from observations of 2CG 135+01 will be included in the analysis.

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