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SEARCH FOR TEV GAMMA-RAY EMISSION FROM SUPERNOVA REMNANTS

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ABSTRACT

The supernova remnants (SNRs) G78.2+2.1 and IC443 have been observed for extended periods by the HEGRA IACT system (Daum, 1997a), which allows the reduction of trigger thresholds and the stereoscopic reconstruction of shower directions on an event-by-event basis. With its improved background rejection, with cameras with a large field of view (4.3°), and with the capability to unambiguously reconstruct events and to map extended sources, the HEGRA IACT system is optimized towards the investigation of SNRs with a typical angular size of 1°. Preliminary HEGRA results concerning the observations of the galactic SNRs G78.2+2.1 and IC443 are summarized.

SUPERNOVA REMNANTS

In the energy range up to 1 PeV, SNRs are the prime candidate for acceleration sites of cosmic rays. Therefore TeV gamma rays are expected to be generated by interactions of charged particles with ambient matter (Drury et al., 1994),(Naito, T., Takahara, F., 1994). In particular for SNRs interacting with clouds, the resulting gamma-ray flux is assumed to reach the detection thresholds of IACTs (Aharonian et al., 1994). For energies above a few hundred MeV COS-B (Pollock, 1985) found evidence for the identification of γ-ray sources with SNRs. Later on the EGRET instrument detected high confidence signals from the SNRs G78.2+2.1 and IC443 and measured their energy spectra in the range between 100 MeV and 10 GeV (Esposito et al., 1996). In addition there are strong hints that the SNR IC443 interacts with a molecular cloud (Claussen et al., 1997) while the same identification is not found for the SNR G78.2+2.1. To search for γ-rays in the TeV region extended observation periods were dedicated to these objects by the HEGRA IACT system.

OBSERVATION TIME AND OBSERVATION MODE

The SNR G78.2+2.1 was observed from August until November 1996. This period coincides with the build up phase of the HEGRA IACT system. Therefore the data was taken at the beginning of the period with 2 telescopes and later on with 3 telescopes which were not fully equipped with the final version of the readout electronics. The results summerized in this article are based on the data taken with 3 telescopes (from September until November 1996). Two third of the observation time was dedicated to ON runs and one third to OFF runs, both with a duration of 32 minutes. The object was tracked alternately on two slightly different coordinates: One on the center of the SNR and the other one on the foreground star Sadr which is near to the CO-cloud (Cong, 1977) which is assumed to be colliding with the SNR (Pollock, 1985).

Table 1: Summery of the observation time which is used in the analysis presented in this article.

Source	Period of data taking	No. of CTs	obs. time (hours)
G78.2+2.1	september-november '96	3	47h ON , 24h OFF
IC443	december '96 - april '97	4	11.3h ON , 11.3h OFF

The SNR IC443 was on the observation plan from December 1996 until April 1997. This object was observed with a system of 4 telescopes equipped with the final version of the readout electronics.

The data was taken in standard ON-OFF mode with 20 minutes duration each. The amount of observation time which is used for the analysis presented in this article is summerized in Table 1. During both observation periods the Crab Nebula, the standard candle of the TeV γ-ray astronomy, was also observed. The data taken on the Crab Nebula is used as a calibration data sample. Thus the results in this article are given in units of the flux of the Crab Nebula.

DATA ANALYSIS

For each recorded event the direction of the primary particle is stereoscopically reconstructed using the images in the cameras of the telescopes exceeding the trigger threshold. In order to supress background events of the charged primaries cuts on the shape of the images in the telescopes are applied.
For the case of the data taken on the SNR IC443 the shape cuts described in (Daum et al., 1997b) are used. These cuts on the *length* and the *width* of the images are a function of the image amplitude, of the distance to the shower core, and of the zenith angle under which the shower is observed. They reduce the background events by almost a factor of 100, while maintaining a 40% efficiency for γ-rays.
The data of the SNR G78.2+2.1 was taken with different hardware conditions during the build up phase of the IACT system leading to the use of higher two level tailcuts compared to IC443 (see Table 2). The two level tailcut is a criteria which pixels are selected to calculate the image parameters: The number of photoelectrons (p.e.) in a pixel must either exceed the high threshold or the lower threshold while having a neighbour pixel exceeding the higher threshold. In addition the night sky background

Table 2: Overview over the used values of the two level tail cuts for the analysis of the data taken on the SNRs and the corresponding Crab calibration data sample.

Source	Tailcuts CT3	Tailcuts CT4	Tailcuts CT5	Tailcuts CT6
G78.2+2.1	4/7 p.e.	8/10 p.e.	8/10 p.e.	—
IC443	3/6 p.e.	3/6 p.e.	3/6 p.e.	3/6 p.e.

light in the G78-ON region is much brighter than in the corresponding OFF region. Therefore the software padding method is introduced to add additional noise σ_{pad} to the pixel amplitude according to the difference of the pedestal variations in the ON σ_{on} and the OFF σ_{off} region.

$$\sigma_{pad,off} = \sqrt{\sigma_{on}^2 - \sigma_{off}^2} \quad \text{or} \quad \sigma_{pad,on} = \sqrt{\sigma_{off}^2 - \sigma_{on}^2} \tag{1}$$

To be able to compare the results obtained from the G78.2+2.1 analysis with the Crab Nebula, the Crab data is padded by software to the level of the G78.2+2.1 data. The cuts (in this case on the *width* and the *concentration* parameters of the images) are optimized at the padded Crab data sample leading to a background rejection of a factor of 23 while maintaining a 40% efficiency for γ-rays.
For both sources the events surviving the shape cuts are grouped into zenith angle bins of 10° width. For each zenith angle bin the two-dimensional distributions of shower directions of the ON- and the OFF-data are subtracted resulting in the two-dimensional distribution of the excess events. In case of the SNR G78.2+2.1 the OFF distribution is multiplied by a weighting factor according to the different number of ON and OFF events in the zenith angle bin due to the different amount of ON and OFF runs. In order to compare the results with the Crab data the expected number of excess events $N_{crab,exp.}$ from a Crab like source observed for the same effective observation time and under the same zenith angles like the corresponding SNR data are calculated using the number of excess events $S_{crab,z}$ after the shape cuts in the Crab data sample and a normalization factor n_z for all zenith angle bins z.

$$N_{crab,exp.} = \sum_z n_z \cdot S_{crab,z} \quad \text{with} \quad n_z = \frac{B_{snr,z}}{B_{crab,z}} \tag{2}$$

Instead of the different observation times as a normalization factor n_z the background rates $B_{crab,z}$ and $B_{snr,z}$ after a soft cut on the amplitude averaged over the telescopes are used to take into account different atmospheric conditions between the Crab and the SNR observations.

PRELIMINARY RESULTS

The number of ON-events $n_{snr,on}$ and OFF-events $n_{snr,off}$ are calculated under different assumption of the source position and size of the source. Under the assumption of a point source the events within a circle of radius r_0 arround the source position are summed up to calculate $n_{snr,on}$ and $n_{snr,off}$. In case of the IC443 data the best value of r_0 is 0.13° (Daum et el., 1997) while for the G78.2+2.1 data $r_0 = 0.32^\circ$ gives the best signal to noise ratio. It is important to note that r_0 is larger than the angular resolution of the IACT system. Under the assumption of an extended source with radius r_{source} the events within a circle of radius r_* are used.

$$r_* = r_{source} + r_0 \tag{3}$$

For none of the points within the observed SNRs a significant excess could be detected. Therefore for some special regions and points of interest within the SNRs the upper limit on the number of γ-ray events $N_{\gamma,u.l.}$ is determined using the method described by Helene (1983). All results are preliminary and are calculated using the 3σ confidence level. The upper limit on the number of γ-rays $N_{\gamma,u.l.}$ is converted into a flux limit $F_{\gamma,u.l.}$ in units of the flux of the Crab Nebula.

$$F_{\gamma,u.l.} = \frac{N_{\gamma,u.l.}}{N_{crab,exp.}} \tag{4}$$

The statistical error on the number of expected events $N_{crab,exp.}$ is for both sources about 10%. The energy threshold related to the upper limits is about 500 GeV. Table 3 and 4 summarize the results of the upper limits under the assumption of various source positions and sizes.

Table 3: Summery of the upper limits in units of the flux of the Crab Nebula on the SNR G78.2+2.1 under the assumption of several source locations and sizes.

Assumed source	RA(2000)	DEC(2000)	$F_{\gamma,u.l.}$
Point source at the EGRET position	20 20.6	40 26	0.08
CO cloud as a point source	20 22.2	40 01	0.11
CO cloud as an extended source with a radius of 0.2°	20 22.2	40 01	0.15
SNR with radius of 0.5°	20 20.6	40 26	0.19

Table 4: Summery of the upper limits in units of the flux of the Crab Nebula on the SNR IC443 under the assumption of several source locations and sizes.

Assumed source	RA(2000)	DEC(2000)	$F_{\gamma,u.l.}$
Point source at the EGRET position	06 18.0	22 35	0.11
Point source at the detected maser position (Claussen et al., 1997)	06 16.7	22 33	0.08
Point source at a X-ray feature in the south	06 17.1	22 21	0.14
SNR with a radius of 0.375°	06 17.0	22 35	0.32

Using the knowledge of the flux of the Crab Nebula from other measurements all given upper limits are well below the EGRET results extrapolated to the TeV region. Further investigations using Monte Carlo data are planned to end up the analysis with final results.

CONCLUSIONS

Since the analysis is not yet finished only preliminary conclusions can be drawn. In our search for TeV γ-rays from the SNRs G78.2+2.1 and IC443 no compact sources with an angular size $\leq 0.2^{\circ}$ at the level of more than ≈ 0.2 Crab have been detected. In particular, the flux upper limits above 500 GeV from the direction of the GeV γ-ray source positions reported by EGRET (Esposito et al., 1996) are below the extrapolation of the EGRET fluxes to the TeV energy region.

Also of much interest are the upper limits from the extended regions of the SNRs: Approximately 20% and 30% of the Crab flux for G78.2+2.1 and IC443, respectively. The estimates of the absolute fluxes are in progress, but it is obvious that these upper limits will provide a rather tight constraint on the content of cosmic rays in those SNRs.

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