Search for γ radiation from the SNR G78.2+2.1: A test of the SNR theory of cosmic ray origin

HEGRA collaboration

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Abstract

The SNR G78.2+2.1 is a prime candidate for VHE, UHE gamma emission because of its shock wave expanding into a molecular cloud thus forming the configuration of an accelerator and nearby target [1]. The HEGRA collaboration has made a detailed study of possible gamma emission using the wide angle air Cerenkov detector AIROBICC. The excellent angular resolution of AIROBICC allows for a scan for any structure in the vicinity of G78.2+2.1. Our upper γ flux limit remains a factor of 27 below a theoretical flux value, assuming certain plausible parameter values.

1 Introduction

Supernova remnants (SNRs) are widely believed to be the origin of the bulk of cosmic radiation below 10^{14} TeV because they release enough energy to produce the observed cosmic rays and the assumed acceleration mechanism (diffusive shock acceleration) is plausible. An experimental proof of this idea would be the observation of cosmic γ radiation from some SNRs up to some TeV γ energy [1].

The remnant G78.2+2.1 (distance $\sim$ 1.5 kpc, age $\sim$ 5000 a [2]) has a good chance of being detected as γ ray source. While most of the SNRs expand into the interstellar medium which has a low particle density, a part of the shock front of G78.2+2.1 moves currently through a dense molecular cloud [3]. Thus the charged cosmic rays produced by G78.2+2.1 have a higher chance to interact with nuclei of the ambient medium and produce π^0s and through them γ rays. The expected γ flux > 1 TeV from G78.2+2.1 has been calculated by Aharonian et al. [1].

In the following we present an analysis of measurements with the AIROBICC detector for G78.2+2.1 and a comparison of the results with the model of Aharonian et al. [1].

AIROBICC is a wide angle Cerenkov detector located at the HEGRA site on the Canary island la Palma. Each of the 49 detector stations of AIROBICC is equipped with a winston cone mirror for light collection and a big (20 cm diameter) photomultiplier tube which can detect Cerenkov light from a solid angle of 1 sr. Due to the possibility of exact timing measurement of the Cerenkov light pulses the angular resolution of AIROBICC is superior to that of scintillator arrays and therefore very well suited for looking for γ sources.

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The design and performance of AIROBICC is described in detail in [4]. An overview of the HEGRA experiment is given in another contribution to this conference [5].

2 Data and Analysis

The dataset used for this analysis was recorded from March 1992 to April 1993 (as in Karle et al. [6]) and consists of a total of 40 million showers. Some quality cuts were applied on the data, namely:

- reduced χ^2 of the fit for the shower direction (cone fit to the Cerenkov light arrival time distribution) ≤ 2
- shower core position at least 5 m inside the array
- number of triggered AIROBICC huts ≥ 12 (≥ 7)

These cuts lead to an angular resolution of $\sigma_{63} = 0.29°(0.45°)$ and an energy threshold of $E_\gamma = 25$ TeV (18 TeV) [4](number in brackets for low trigger threshold).

G78.2+2.1 has a radio bright region 'DR4' in the south-east of the radio map of Higgs et al. [2] (solid contour lines in Fig. 1). The reason for this enhanced brightness is believed to be due to increased synchrotron radiation from the shock compressed molecular cloud's B-field [3]. The shock compressed matter of the cloud should in turn lead to enhanced γ emission. The size of DR4 is of the same order as the angular resolution of AIROBICC. Therefore this object cannot be treated as a point source candidate of γ radiation.

Because DR4 has an irregular shape, a rectangle ($0.44° \times 0.16°$) has been chosen as nominal source region. This shape fits the region > 30 K brightness temperature in Fig. 1 quite well. The value of 30 K has been taken because there are no brighter regions in the SNR except near DR4.

Analogous to the procedure in Ref. [6] a rectangular on-source region ($0.68° \times 0.58°$, rectangle in Fig. 1) has been determined which has for a potential detection the highest significance [4]. This was done by first calculating the event distribution from the source region seen with an angular resolution of $\sigma_{63} = 0.29°$ (numerical folding of a rectangular step function as source function and a two dimensional gaussian, $\sigma = 0.2°$ [6], as angular resolution function) and then maximizing the significance by varying the size of the on-source region. [5]

To take the systematic pointing error (0.10°) of the AIROBICC detector [6] into account the region around the position of G78.2+2.1 has been scanned with the γ search rectangle in a 3×3 grid ($\pm$ 0.18° angular distance in right ascention and declination). For the calculation of an upper γ flux limit the highest value of source events from this scan has been used.

The number of background events expected in the source region has been calculated from the number of events in a ring around the source position (opening angle $0.7° - 2.5°$).

3 Results and Discussion

With the cut of ≥ 12 triggered AIROBICC huts the highest value of number of events in the on-source region in the 3×3 scan is 205. The mean background at the source position

[3] CO emission from the cloud [7] is indicated as dashed line in Fig. 1

[4] The on-source region contains 72% of all source events

[5] For the case of ≥ 7 triggered AIROBICC huts the on-source rectangle has the size $0.98° \times 0.94°$

Table 1: Comparison of upper γ flux limits and theoretical predictions

E_γ [TeV]	γ flux limit $[10^{-13}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$ (90% CL)	theory prediction $[10^{-13}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$		prediction/upper limit	
		sharp cutoff	Drury cutoff	sharp cutoff	Drury cutoff
18	7.1	29	110	4.1	15
25	2.5	14	67	5.6	27

is 206.2 events. For the cut ≥ 7 triggered AIROBICC huts the values are 814 on-source and 798.5 mean bachground events. There is thus no evidence for a γ signal at an energy threshold of 25 TeV or 18 TeV.

In Fig. 1 the number of events seen by AIROBICC for the case of ≥ 12 triggered huts are displayed as greyscale boxes with a size slightly smaller than the angular resolution.

From the measured cosmic ray flux from the direction of G78.2+2.1 and the above numbers upper γ flux limits (90% confidence level) have been calculated (see Table 1).

We compare our upper limits with the theoretical prediction according to the model of Aharonian et al [1]. While it would be best to determine some 'minimum expected' flux from DR4, this is not really possible at present (one could e.g. still call into question the physical correlation of the molecular cloud and the SNR). Following largely Aharonian et al.[1] we assumed 'most plausible' parameters for an estimate of the γ flux, namely a source spectrum with differential spectral index $\alpha = -2.1$, acceleration efficieny $\theta = 0.1 \cdot E_{SN}$ (kinetic energy released by the SN $E_{SN} = 10^{51}$ erg), distance to SNR = 1.5 kpc and a filling factor $\Delta V/V = 0.05$. Standard SNR theory predicts particles to be accelerated up to $100 - 1000$ TeV. We therefore assumed conservatively a spectral cutoff at 100 TeV with the shape given in Drury [8] (the extreme case of a sharp cutoff is also given). The expected γ-ray flux was determined using the γ-ray yield in proton-proton collisions as given by the SIBYLL code [9]. For the density of the target we assumed following Ref. [3] the pre-shock cloud particle density (300 cm^{-3} mostly in the form of molecular H_2[7]) as being compressed by the passing shock front by a factor of 9 [3] (a factor of 4 is the usual strong shock compression, and some additional compression is expected due to cooling [3]). Our results are summarized in Table 1. The discrepancy is seen to be a factor of 5.6 even under the extreme assumption of a sharp cutoff at 100 TeV. It will be interesting to see how the above parameters have to be changed to bring theory and experminental results into agreement.

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Figure 1: Number of events from the direction of G78.2+2.1 measured with AIROBICC at energy threshold E_γ = 25 TeV as greyscale boxes. The solid lines are contour lines of the radio map of Higgs et al.[2]. The dashed line indicates the 0.5°K-MHz ^{13}CO emission of the molecular cloud [7]. (The region of the CO emission is not expected to completely coincide with the radio bright region because the CO molecules are destroyed at the high temperatures (10^4 K) in the post-shock region.) Also plotted is the rectangular on-source region for the derivation of the flux limit.