Astron. Astrophys. 314, 275–280 (1996)

ASTRONOMY
AND
ASTROPHYSICS

Search for very high energy γ radiation from the radio bright region DR4 of the SNR G78.2+2.1

C. Prosch[1], E. Feigl[1], R. Plaga[1], F. Arqueros[2], J. Cortina[2], J. Fernandez[1,2], P. Fernandez[4], V. Fonseca[2], B. Funk[3], J.C. Gonzalez[2], V. Haustein[5], G. Heinzelmann[5], A. Karle[*][1], H. Krawczynski[5], F. Krennrich[**][1], M. Kühn[4], A. Lindner[5], E. Lorenz[1], N. Magnussen[3], S. Martinez[2], V. Matheis[6], M. Merck[***][1], H. Meyer[3], R. Mirzoyan[1,2], H. Möller[3], A. Moralejo[2], N. Müller[4], L. Padilla[2], J. Prahl[5], W. Rhode[3], M. Samorski[4], J.A. Sanchez[2], H. Sander[4], D. Schmele[5], W. Stamm[4], H. Wahl[†][1], S. Westerhoff[3], B. Wiebel-Sooth[3], and M. Willmer[4]

[1] Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany
[2] Facultad de Ciencias Fisicas, Universidad Complutense, E-28040 Madrid, Spain
[3] BUGH Wuppertal, Fachbereich Physik, Gaußstr.20, D-42119 Wuppertal, Germany
[4] Universität Kiel, Inst. für Kernphysik, Olshausenstr.40, D-24118 Kiel, Germany
[5] Universität Hamburg, II. Inst. für Experimentalphysik, Luruper Chaussee 149, D-22761 Hamburg, Germany
[6] Max-Planck-Institut für Kernphysik, P.O. Box 103980, D-69029 Heidelberg, Germany

Received 20 January 1996 / Accepted 24 February 1996

Abstract. Data from the HEGRA air shower array are used to set an upper limit on the emission of γ-radiation above 25 (18) TeV from the direction of the radio bright region DR4 within the SNR G78.2+2.1 of 2.5 (7.1)$\cdot$ 10^{-13} cm^{-2} sec^{-1}. The shock front of SNR G78.2+2.1 probably recently overtook the molecular cloud Cong 8 which then acts as a target for the cosmic rays produced within the SNR, thus leading to the expectation of enhanced γ-radiation. Using a model of Drury, Aharonian and Völk which assumes that SNRs are the sources of galactic cosmic rays via first order Fermi acceleration, we calculated a theoretical prediction for the γ-ray flux from the DR4 region and compared it with our experimental flux limit. Our 'best estimate' value for the predicted flux lies a factor of about 18 above the upper limit for γ-ray energies above 25 TeV. Possible reasons for this discrepancy are discussed.

Key words: gamma rays: observations – cosmic rays – ISM: supernova remnants – ISM: G 78.2+2.1

1. Introduction

More than 80 years after its discovery the origin of charged galactic cosmic radiation (GCR), which consists mainly of protons and heavier nuclei, is still not fully understood (Berezinsky et al. 1990). The main problem in identifying its sources is the fact that the Larmor radius of the charged cosmic rays in the weak galactic magnetic field seems to be smaller than the source distance (except perhaps for the component with super-high energies above 10^{19} eV). The arrival direction of GCR is thus randomised and gives no clue about the object in the sky from which it originated. It seems quite likely in a variety of models that high energy γ-radiation is produced as a secondary component in the cosmic ray sources (Aharonian 1995; Ormes et al. 1988). As this radiation is neutral its trajectory points back to its origin. An unambiguous identification of this secondary radiation is therefore considered to be a crucial step in the identification of cosmic ray sources.

A very plausible theory for the origin of GCR below about 10^{15} eV invokes its first order Fermi acceleration in the shock fronts of supernova remnants (SNR) (Axford 1981; Bogdan & Völk 1983; Blandford & Eichler 1987). This theory naturally explains the observed power-law dependence of the cosmic-ray flux on primary energy and can account for the total galactic power requirement for the acceleration of GCR. Several authors have given a quantitative estimate of the expected secondary γ-ray flux from these GCR accelerators (Bhat et al. 1986; Dorfi 1990, 1991; Drury et al. 1994; Naito & Takahara 1994). Aharonian et al. (1994) suggest that the SNR G78.2+2.1 is of particular interest because in this object a molecular cloud is being overtaken by the supernova shell (Pollock 1985). The molecular cloud acts as a 'target' for the GCR produced in the SNR and an enhanced production of secondary γ-radiation is expected. Aharonian et al. (1994) point out that this mechanism could account for the γ-radiation above 300 MeV from the direction of G78.2+2.1 de-

---

Send offprint requests to: R. Plaga

[*] *Present address:* IfH DESY-Zeuthen, D-15735 Zeuthen, Germany

[**] *Present address:* Iowa State University, Ames, USA

[***] *Present address:* MPI für Extraterrestrische Physik, D-85748 Garching, Germany

[†] *Present address:* CERN, Ch-1211 Geneve 23, Switzerland

tected by the COS-B satellite. The part of the molecular cloud overtaken by the SNR shock can be seen as the radio bright region 'DR4' in the south-east of the radio map of Higgs et al. (1977) (solid contour lines in Fig. 1). The cause of this enhanced brightness is believed to be increased synchrotron radiation from the shock compressed molecular cloud's magnetic field[1]. The shock compressed matter of the cloud acts as the 'target'.

Sturner and Dermer (1995) also proposed the association of 13 unidentified low galactic latitude EGRET γ-ray sources ($E > 100$ MeV) with SNRs and suggest that this radiation is due to the mechanism described by Drury et al. (1994). These identifications are not definitive however because low energy γ-radiation can also be produced by radio-quiet pulsars, for example. However at much higher energies the secondary radiation from GCR production is expected to dominate because of its predicted hard spectral index over a very wide energy range. The CYGNUS collaboration recently searched for this predicted radiation from five of the SNRs on the list of Sturner and Dermer (1995) above $\sim$ 100 TeV γ-ray energy (Allen et al. 1995). They attribute their failure to find emission from any of these candidates on a level expected from an extrapolation in energy of the EGRET fluxes to any one of the following causes: (1) the γ-ray spectra soften above $\sim$ 100 TeV γ-ray energy or (2) the GCR spectra produced in SNRs are steeper than the most simple expectation from shock-wave acceleration or (3) the γ-rays detected by EGRET are not due to the SNR shock.

We examined the radio bright region of SNR G78.2+2.1 from which most of the SNR's γ-radiation is expected (Aharonian et al. 1994) with the HEGRA detector above a γ-ray energy of 18 TeV. The γ-ray flux expected from this object is calculated here following the theoretical model of Drury et al. (1994). A comparison of our upper flux limit with this expectation allows us to constrain possibility (1) above and is independent of the EGRET flux normalisation (possibility (3)). Point (2) remains as a viable possibility.

2. The HEGRA experiment

The data were taken with the HEGRA air-shower array at the Observatorio de Roque de los Muchachos on the Canary Island La Palma (17.7 ° W, 28.8 ° N, 2200m a.s.l.) (Aharonian et al. 1993). The array covers an area of ground of roughly 35000 m^2. The main components relevant to this measurement were:

1. an array of 219 plastic-scintillator detector stations with an active area of typically 0.9 m^2 each (167 stations are on a square grid with 15 m grid spacing and 52 further stations increase the station density in the central region of the array). Each station consists of a 4 cm thick plastic scintillator sheet covered with 5 mm of lead, viewed from below by photomultiplier tubes.
2. the AIROBICC array (Karle et al. 1995a) of 49 open photomultiplier detector stations on a square grid of 30 m spacing with a photomultiplier tube (diameter 20 cm) viewing directly the night sky to detect atmospheric Čerenkov light from the air shower.

3. Data analysis

The dataset used for the present analysis was recorded from March 1992 to April 1993 and consists of a total of 40 million showers recorded with both the scintillator array and AIROBICC. The techniques for the cuts on the data, shower reconstruction and background estimation were described in previous publications (Karle et al. 1995a; Karle et al. 1995b). They result in an energy threshold (50 % trigger probability) averaged over the altitude range of G78.2+2.1 of 25 TeV. As the detection of low energy γ-rays is of great importance in the present analysis, we also analysed the data with a less stringent cut on the number of triggered AIROBICC stations (more than 6 instead of more than 11). This leads to a slightly lower energy threshold of about 18 TeV and a reduced data quality. The angular resolution[2] of the data with the high (low) threshold was $\sigma_{63} = 0.29°(0.45°)$ (Karle et al. 1995a); 14 (24) million showers survive the high (low) threshold cuts.

The angular extent of DR4 is of the same order as the angular resolution of AIROBICC. Therefore this object cannot be treated as a candidate point source of γ-radiation. We decided to search for γ-ray emission from the radio bright region DR4 rather than from the molecular cloud as defined by the CO radio emission (Cong 1977), because this corresponds to the region overtaken by the SNR shock where GCR-hadron collisions with cloud matter are expected to lead to secondary γ-ray production. Because DR4 has an irregular shape, a rectangle ($0.44° \times 0.16°$) has been chosen as the 'nominal source region'. This shape fits the region > 30 K brightness temperature in Fig. 1 quite well. The value of 30 K was chosen because there are no brighter regions in the SNR except near DR4. Analogous to procedures in Karle et al. (1995b) a rectangular on-source region which allows a potential detection to have the highest predicted significance was determined as follows. First the expected event distribution (f_{event}) from the source region seen with the angular resolution of AIROBICC was determined (see Fig. 2). This was done with a numerical two dimensional folding of the source function f_{source} and the angular resolution function f_{angres}:

$$f_{\mathrm{event}} = f_{\mathrm{source}} \otimes f_{\mathrm{angres}} \tag{1}$$

with

$$f_{\mathrm{source}} = \begin{cases} 1 & : \quad |x| \leq L/2 \quad \text{and} \quad |\mathrm{y}| \leq \mathrm{W}/2 \\ 0 & : \quad \text{else} \end{cases} \tag{2}$$

(a step function; it is assumed that the emission from the source region is spatially uniform)
and

$$f_{\mathrm{angres}} = \frac{1}{2\pi\sigma^2} \cdot \mathrm{e}^{-\frac{\mathrm{x}^2 + \mathrm{y}^2}{2\sigma^2}} \tag{3}$$

---

[1] CO emission from the cloud (Cong 1977) is indicated by a dashed line in Fig. 1

[2] The angular resolution is defined as σ_{63}, the angular distance from a point source which encloses 63% of all source events.

1996A&A...314..275P

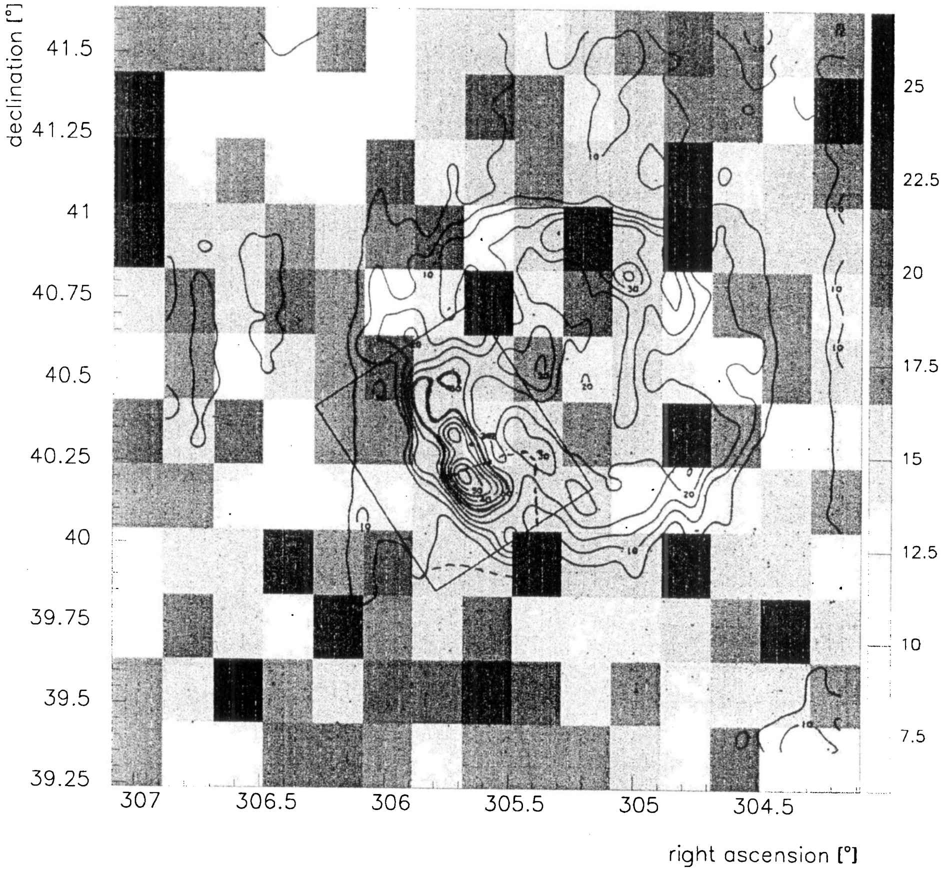

Fig. 1. Number of events from the direction of G78.2+2.1, measured with AIROBICC at an energy threshold E_γ = 25 TeV, as grey-scale boxes. The solid lines are contour lines from the radio map of Higgs et al. (1977). The dashed line indicates the 0.5°K-MHz ^{13}CO emission of the molecular cloud (Cong 1977). The CO emission region is not expected to completely coincide with the radio bright region because molecular CO cannot exist at the high temperatures (10^4 K) in the post-shock region. Also plotted is the rectangular on-source region used in the derivation of the flux limit.

(a two dimensional Gaussian distribution).
Here x and y are the angular distances from the centre of the on-source region in the directions of right ascension and declination, L and W are the length and width of the source rectangle and σ is the angular resolution σ_{63} divided by $\sqrt{2}$.

In the second step the significance

$$S = N_{\text{source}} / \sqrt{N_{\text{background}}} \tag{4}$$

of an assumed signal was maximised by choosing appropriate parameters L_{on} and W_{on}. N_{source} is the number of source events in a 'nominal search region' defined as a rectangle with a length L_{on} and a width W_{on}:

$$N_{\text{source}} = \int_{-W_{\text{on}}/2}^{+W_{\text{on}}/2} \int_{-L_{\text{on}}/2}^{+L_{\text{on}}/2} f_{\text{event}} \, \mathrm{d}x \, \mathrm{d}y. \tag{5}$$

$N_{\text{background}}$ is the expected number of background events in this region (determined in a similar way as in Karle et al. (1995b) as the number of events in a ring around the source position with an inner radius of 0.7° and an outer radius of 2.5°). N_{source} can be determined experimentally by subtracting $N_{\text{background}}$ from the number of measured events in the nominal search region. For $>$ 11(6) triggered AIROBICC huts the maximum significance is obtained with a nominal search region of size L_{on}= 0.68(0.98)° and W_{on}= 0.58(0.94)° (see Fig. 2), which contains 72(73)% of all source events.
To take the systematic pointing error (0.10°) of the AIROBICC detector (Karle et al. 1995a) into account the region around the position of G78.2+2.1 has been scanned by shifting the nominal search window over a 3 × 3 grid (± 0.18° angular distance in right ascension and declination). For the calculation of an upper limit to the γ-ray flux the highest value of N_{source} obtained during this scan has been used. With the cut of $>$ 11(6) triggered AIROBICC huts the highest number of events in the on-source region in the 3 × 3 scan is 205(814). The mean background at the source position is 206.2(798.5) events. There is thus no evidence for a γ-signal at energy thresholds of 25 TeV or 18 TeV. In Fig. 1 the number of events seen by AIROBICC in the case of $>$ 11 triggered huts are displayed as grey-scale 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 limits to the γ-ray flux (90% confidence level) have been calculated (see Table 1).

4. Discussion

In the case of SNR G78.2+2.1 it seems very doubtful that the low energy γ-radiation detected by COS-B and EGRET is due to shock acceleration because DR4, from which most of the radiation would be expected (Aharonian et al. 1994), lies far outside the 90 % error limits of the EGRET position (Fichtel et al. 1994). We therefore compare the AIROBICC upper limits with our theoretical prediction made following largely the procedure of Aharonian et al. (1994). The predicted integral γ-ray

Table 1. Comparison of AIROBICC upper limits to the γ-ray flux from DR4 with our theoretical predictions. 'Sharp cut-off' is the value calculated under the assumption of a sharp cut-off in the source spectrum at a proton energy of 100 TeV, 'Drury cut-off' is our 'best estimate' with a more realistic, gradual energy cut-off somewhat above 100 TeV and 'no cut-off' is the (somewhat unrealistic) value calculated without taking into account any cut-off. The values are given for differential spectral indices α of the cosmic rays accelerated in the SNR of 2.1 and 2.3.

E_γ [TeV]	measured flux limit $[10^{-13}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$ (90% CL)	our theoretical prediction for α=2.1 (2.3) $[10^{-13}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$		
		sharp cut-off	Drury cut-off	no cut-off
18	7.1	37 (6.5)	85 (13)	213 (25)
25	2.5	17 (2.9)	46 (6.8)	148 (16)

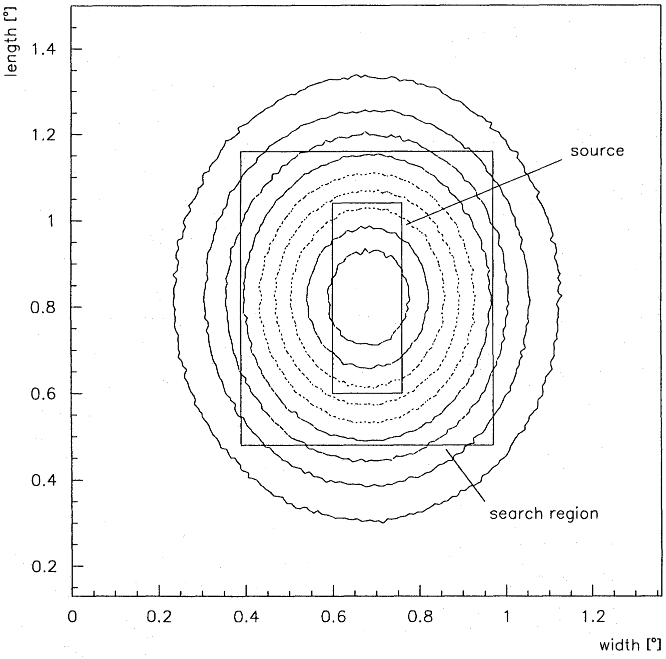

Fig. 2. Event distribution (contour lines) from a rectangular source (inner rectangle) seen with an angular resolution of σ_{63} = 0.29°. Also drawn is the optimum rectangular on-source region (outer rectangle).

flux above an energy E_γ from the region of DR4 is given by:

$$\phi_\gamma = q_\gamma(\alpha, 1\mathrm{TeV})\ (\mathrm{E}_\gamma/\mathrm{TeV})^{-\alpha+1}\ \mathrm{E}_{\mathrm{SN}}\ \theta\ (\Delta\mathrm{V}/\mathrm{V}) \cdot (f_\gamma^{\mathrm{cut}}/f_\gamma^{\infty})\ \rho\ (4\pi d^2)^{-1} \qquad (6)$$

Below we explain the meaning of the variables and our choice of their 'most plausible' values in DR4. While it would be best to determine some 'minimum expected' γ-flux from DR4, this is not really possible at present (one could for example still call into question the physical connection between the molecular cloud and the SNR).
We assume as a best estimate:

1. the source spectrum has a differential spectral index α = 2.1. (a value very near two is predicted by most modern computer simulations of the acceleration process (Berezhko et al. 1994));
2. q_γ is the production rate for γ-rays per unit time, energy density and per atom, taken for the appropriate α and energy from Table 1 of Drury et al. (1994);
3. the kinetic energy E_{SN} released by the Supernova is 10^{51} erg, and a fraction θ = 0.1 of that is used for the acceleration of cosmic rays;
4. the filling factor $\Delta V/V$ = 0.05 is the ratio of the volume of DR4 to that of the SNR as a whole and is estimated from the radio image (Aharonian et al. 1994);
5. for the density ρ of the target we assumed (following Pollock 1985) a pre-shock cloud particle density of 300 cm^{-3}, mostly in the form of molecular hydrogen (Cong 1977). This gas is compressed by the passing shock front by a factor of 9 (a factor of 4 is the usual strong shock compression ratio, and some additional compression is expected due to cooling (Pollock 1985)); so we assumed a total density of nuclei of 2700/cm^3 within DR4;
6. d = 1.5 kpc, the distance to the SNR (Landecker et al. 1980);
7. f_γ is a factor introduced to take into account the effect of a high energy spectral cut-off.

f_γ^{cut} is f_γ calculated with an appropriate high energy cut-off and taking into account chemical composition, f_γ^{∞} is f_γ calculated without such a cut-off (factor f_{c} below equal to 1) and for protons only. The quotient $f_\gamma^{\mathrm{cut}}/f_\gamma^{\infty}$ corrects the production rate q_γ for the effects of high energy cut-offs. q_γ as given in Drury et al. (1994) already contains the effect of a realistic chemical composition of the accelerated particle and target matter, but in our case it is necessary in addition to take into account the fact that for elements heavier than hydrogen the upper nucleon energy cut-off will be a factor Z/A smaller than the proton energy cut-off. f_γ is then given by:

$$f_\gamma = \sum_A r_{\mathrm{c}}(A) \left[\frac{\int_{E_{\min}}^{\infty} E_A^{-\alpha} \cdot f_{\mathrm{c}}(E_A, Z/A) \cdot Y(A) \mathrm{dE_A}}{\int_{E_{\min}}^{\infty} E_A^{-\alpha} \cdot f_{\mathrm{c}}(E_A, Z/A) \mathrm{dE_A}} \right] \qquad (7)$$

with

$$Y(A) = \int_{E_{\min}}^{E_A} \frac{\mathrm{dN}(\mathrm{E}_\gamma, \mathrm{E_A})}{\mathrm{dE}_\gamma} \mathrm{dE}_\gamma . \qquad (8)$$

Here the sum extends over all elements and r_{c} is the respective contribution to the γ-ray production of each element calculated according to abundances measured near earth and the appropriate cross sections. We followed the calculation by Dermer (1986) which was also used by Drury et al. (1994) and assumed r_c(proton)=0.92 and r_c(helium)=0.08 (elements heavier than helium have r_c-values < 0.02 and are negligible in γ-ray production). $E_{\rm min}$ is the γ-ray detection threshold. The cut-off function f_c parameterises the upper energy limit of the acceleration process. It is defined as the ratio of the accelerated cosmic-ray flux calculated under the assumption of a cut-off in the source spectrum to the flux calculated under the assumption that the spectrum continues with no limit to higher energies following the power law determined at low energies. Two different cases were investigated. In the first case we took a sharp cut-off at a nucleus energy of 100 TeV. In the second case a theoretical cut-off function calculated for the case of shock-wave acceleration in SNRs and published by Drury (1991) was assumed. This function also cuts off around 100 TeV but it causes a sharp downturn in the energy spectrum rather than a step function. In both cases it was assumed that a nucleus with charge Z is accelerated to a Z times higher energy than a proton (Gaisser 1990) and so the upper cut-off for heavier elements is a factor Z/A lower than for protons. $\frac{\rm dN}{{\rm dE}_\gamma}$ is a parameterisation of the yield of γ-rays of energy E_γ in proton-proton collisions at a specified proton energy ($E_{\rm p} = \frac{1}{A}E_A$). This parameterisation is based on a Monte Carlo simulation with the SIBYLL code and was read off a plot (Fig. 1) of Berezinsky et al. (1993). The calculation neglects cooperative nuclear effects. Our parameterisation leads to spectrum weighted moments which are about a factor of 1.3 - 2.0 smaller than the ones quoted by Drury et al. (1994) and Gaisser (1990); the ratio of the spectrum weighted moments for $\alpha = 2.8$ and for $\alpha = 2.0$ lies between the ratios quoted by Drury et al. (1994) and Gaisser (1990). A calculation of $q_\gamma(\alpha{=}2.1)$ with the γ-ray yield function used gives a value a factor of 2.1 lower than that of Drury et al. (1994); clearly the precise calculation of γ-ray yields at very high energies remains an important problem.

Our results are summarised in Table 1, our prediction for the 'best estimate value' of the γ-ray flux above 25 TeV is a factor of 18.4 above the measured upper flux limit and even under the somewhat unrealistic assumption of a sharp cut-off of the accelerated proton spectrum at 100 TeV there remains a discrepancy of a factor of 6.8. In principle these theoretical estimates should be raised by an additional factor of 1.5 in our case to account for the change in normalisation of q_γ if one assumes a cut-off around 100 TeV with a power law spectrum with a spectral index α=2.1 (there is more energy in the remnant available for the acceleration at lower energies if particles are not accelerated to energies above the cut-off). Our estimate of the discrepancy is conservative in this sense. For comparison with other calculations we show in Table 1 also the values of our theoretical predictions without a high energy cut-off.

Assuming the basic paradigm of the stochastic GCR acceleration in SNRs to be correct, the following could be reasons for our failure to detect γ-radiation:

1. one or more of our 'best estimate' parameters as listed above could be inappropriate. All of them have large and often difficult to estimate errors. For example, Biermann (in contrast to most other researchers) advocated α=2.3 as the typical spectral index for shock wave acceleration in SNRs (Biermann 1993). In this case the 'best estimate' discrepancy would be reduced to a factor of 2.7. At energies near the upper energy cut-off there could also be uncertainties in the model of Drury et al. (1994) not accounted for by our parameters. As an example one could call into question whether cosmic rays with tens of TeV are still magnetically trapped in the SNR as assumed by Drury et al. (1994). While a simple estimate assuming Bohm diffusion with plausible parameters shows that the condition for trapping as given in Drury et al. (1994) is fulfilled up to the highest energies for the SNR G78.2+2.1, less efficient diffusion might lead to a large loss of cosmic radiation from the SNR at very high energies. Another example is a possible reduction of the upper energy cut-off by damping of the shock wave in dense regions (Drury et al. 1996).
2. despite much evidence to the contrary (Pollock 1985) the molecular cloud Cong 8 might in reality not be physically coupled to DR4; further radio and infrared observations are urgently required to settle this issue.

In summary we set a limit to high energy γ-radiation above 25 TeV from the region of DR4. This limit seems stringent enough to allow constraints on models of cosmic ray origin in SNRs. In particular a cut-off in the region around 100 TeV as discussed to explain other experimental results (Allen et al. 1995) cannot account alone for the discrepancy of our data to theoretical expectations.

Acknowledgements. The support by the Deutsche Forschungsgemeinschaft DFG, the German Ministry for Education and Research BMBF and the Spanish Research Council CYCIT is gratefully acknowledged. We further thank the Instituto de Astrofisica de Canarias IAC for supplying excellent working conditions at La Palma. The many useful comments from S.M. Bradbury are gratefully acknowledged.

References

Aharonian F.A. et al. 1993, Proc. 23rd ICRC Calgary 4, 291
Aharonian F.A. et al. 1994, A&A 285, 645
Aharonian F.A. 1995, Nucl.Phys.B (Proc.Suppl.) 39A, 193
Allen G.E. et al. 1995, ApJ 448, L25
Axford W.I. 1981, Proc. 17th ICRC Paris 12, 155
Berezhko E.G. et al. 1994, Astropart. Phys. 2, 215
Berezinsky V.S. et al. 1990, Astrophysics of Cosmic Rays, North Holland, Amsterdam
Berezinsky V.S. et al. 1993, Astropart. Phys. 1, 281
Bhat C.L. et al. 1986, J. Phys. G 12, 1067
Biermann P.L. 1993, A&A 271, 649
Blandford R.D., Eichler D. 1987, Phys. Rept. 154, 1
Bogdan T., Völk H.J. 1983, A&A 122, 129
Cong H.I. 1977, PhD thesis, Columbia University, p.136
Dermer C.D. 1986, A&A 157, 223
Dorfi E.A. 1990, A&A 234, 419

Dorfi E.A. 1991, A&A 251, 179
Drury L.O'C. 1991, Shock Acceleration of Cosmic Rays. In: M.M. Shapiro et al.(eds.) Proc. Conf. 'Cosmic Rays, Supernovae and the Interstellar Medium', Kluwer Academic Publishers, Dordrecht/Boston/London
Drury L.O'C et al. 1994, A&A 287, 959
Drury L.O'C et al. 1996, A&A in press
Fichtel C.E. et al. 1994, ApJS 94, 551
Gaisser T.K. 1990, Cosmic Rays and Particle Physics, Cambridge University Press, Cambridge, p.158
Higgs L.A. et al. 1977, AJ 82, 718
Karle A. et al. 1995a, Astropart. Phys. 3, 321
Karle A. et al. 1995b, Astropart. Phys. 4, 1
Landecker T.L. et al. 1980, A&AS 39, 133
Naito T., Takahara F. 1994, J Phys G 20, 477
Ormes J.J. et al. 1988, ApJ 334, 722
Pollock A.M.T. 1985, A&A 150, 339
Sturner S.J., Dermer C. 1995, A&A 293, L17

This article was processed by the author using Springer-Verlag LaTeX A&A style file version 3.