A&A 390, L43–L46 (2002)
DOI: 10.1051/0004-6361:20020862

Astronomy & Astrophysics

Letter to the Editor

No evidence yet for hadronic TeV gamma-ray emission from SNR RX J1713.7−3946

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Received 7 May 2002 / Accepted 11 June 2002

Abstract. Recent TeV-scale γ-ray observations with the CANGAROO II telescope have led to the claim that the multi-band spectrum of RX J1713.7−3946 cannot be explained as the composite of a synchrotron and an inverse Compton component emitted by a population of relativistic electrons. It was argued that the spectrum of the high-energy emission is a good match to that predicted by pion decay, thus providing observational evidence that protons are accelerated in SNR to at least TeV energies.

In this Letter we discuss the multi-band spectrum of RX J1713.7−3946 under the constraint that the GeV-scale emission observed from the closely associated EGRET source 3EG J1714−3857 is either associated with the SNR or an upper limit to the gamma-ray emission of the SNR.

We find that the pion-decay model adopted by Enomoto et al. is in conflict with the existing GeV data. We have examined the possibility of a modified proton spectrum to explain the data, and find that we cannot do so within any existing theoretical framework of shock acceleration models.

Key words. ISM: cosmic rays – ISM: supernova remnants – gamma rays: observations

1. Evidence for particle acceleration in SNR

Supernova remnants (SNR) are considered the most likely sources of cosmic rays, either as individual accelerators or by their collective effect in superbubbles. Yet observational evidence in favor of this scenario has been found only for cosmic-ray electrons, not for the nucleons.

Three shell-type SNR have been detected at TeV γ-ray energies so far, all of which show non-thermal X-ray emission, which presumably is synchrotron radiation. It is known that the synchrotron radiating electrons would inverse-Compton scatter the microwave background and the ambient far-infrared photon field to TeV γ-ray energies with a flux depending mainly on the X-ray flux and the magnetic field strength within the remnant (Pohl 1996), provided both are measured at photon energies corresponding to the same electron energy and escape from the compression region at the SNR shock is inefficient. The X-ray and TeV spectra should then be similar, which would permit one to discriminate between a hadronic and a leptonic origin of the radiation.

Indeed, the observed TeV γ-ray spectrum of SN 1006 (Tanimori et al. 1998, 2001) is consistent with synchrotron/inverse Compton models (Mastichiadis & DeJager 1996; Aharonian & Atoyan 1999; Naito et al. 1999). A significant contribution of γ-rays from hadronic interactions appears unlikely on account of the low density environment in which the remnant resides.

Recently, TeV γ-rays have been detected from Cassiopeia A (Aharonian et al. 2001), if with 0.03 Crab above 1 TeV at a flux much lower that that reported for SN 1006. Estimates for the magnetic field strength at the shock and in the downstream region of Cas A suggest, that the leptonic TeV-scale γ-ray emission should be substantially weaker than in case of SN 1006 and should display a cut-off near 1 TeV. Because of the moderate statistical significance of the detection, the γ-ray spectral index is poorly constrained. Thus the present data can be interpreted as leptonic or hadronic γ-ray emission or as a mixture of both.

The SNR RX J1713.7−3946 is in many respects similar to SN 1006. Observations have revealed intense, apparently non-thermal X-ray emission from the north-west rim (Koyama et al. 1997), and TeV γ-ray emission from that region (Muraishi et al. 2000). Recent measurements with the CANGAROO II telescope have indicated that the TeV-scale γ-ray spectrum of RX J1713.7−3946 can be well represented by a single power-law with index $\alpha \simeq 2.8$ between 400 GeV and 8 TeV (Enomoto et al. 2002). The authors argue that the multi-band spectrum from radio frequencies to TeV γ-ray energies cannot be explained as the composite of a synchrotron and an inverse Compton component emitted by a population of relativistic electrons. It is then claimed that the spectrum of the high-energy emission is a good match to that predicted by pion

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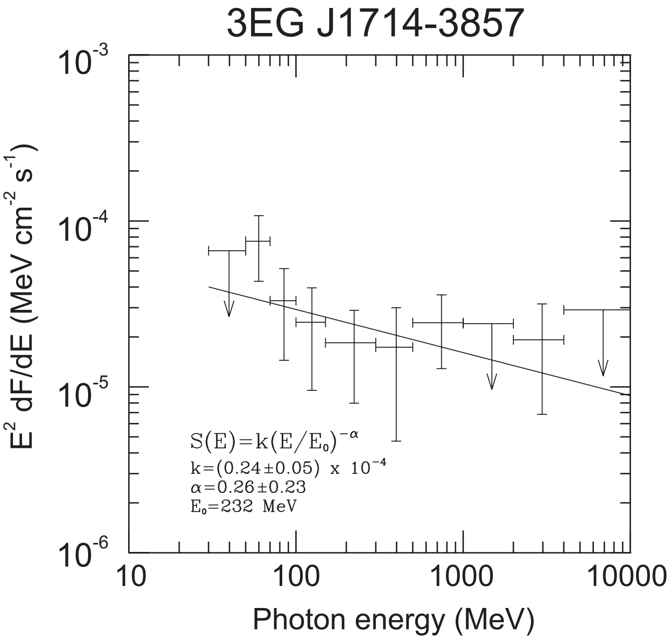

Fig. 1. The γ-ray spectrum of 3EG J1714−3857 between 10 MeV and 10 GeV as obtained for the 3EG catalog (Hartman et al. 1999). The photon spectrum is publicly accessible at the Compton Science Support Center at GSFC. The solid line indicates a power-law fit to the observed spectrum, whose parameters are given in the figure.

decay. Hence RX J1713.7−3946 would provide observational evidence that protons are accelerated in SNR to at least TeV energies.

In this Letter we discuss the multi-band spectrum of RX J1713.7−3946 under the constraint that the GeV scale emission observed from the closely located EGRET source 3EG J1714−3857 is taken into account as either being associated with the SNR or an upper limit to the emission of the SNR. For both cases we find that a pion decay origin of the observed TeV-scale γ-ray emission of RX J1713.7−3946 is highly unlikely, and propose further observations which should help arrive at a solution.

2. The multi-band spectrum of RX J1713.7−3946 revisited

RX J1713.7−3946 is located in the vicinity of a molecular cloud complex (Slane et al. 1999), which itself coincides with the unidentified GeV-scale γ-ray source 3EG J1714−3857 (Hartman et al. 1999). The best-fit positions of 3EG J1714−3857 and the CANGAROO TeV γ-ray source are about 0.7° apart. The 2σ positional uncertainties toward each other are 0.4° for the EGRET source and >1° for the CANGAROO source. Nevertheless, the two experiments may have observed the same source, though that is not very likely on account of the spatial separation. In Fig. 1 we show the γ-ray spectrum of 3EG J1714−3857 as determined during the compilation of the Third EGRET catalog (Hartman et al. 1999) and since that time publicly available at the Compton Science Support Center.

If RX J1713.7−3946 and 3EG J1714−3857 indeed represent the same source seen at different wavelengths, the actual observed GeV-scale emission of 3EG J1714−3857 must be reproduced by any viable model for RX J1713.7−3946. If the two are different sources, the GeV-scale γ-ray radiation of RX J1713.7−3946 must be less than the emission observed from the EGRET source. In any event, the GeV-scale γ-ray radiation emitted by RX J1713.7−3946 cannot exceed that observed from 3EG J1714−3857.

In Fig. 2 we show the multi-band spectrum of RX J1713.7−3946, originally presented by Enomoto et al. (2002), here modified to include the γ-ray spectrum of 3EG J1714−3857. To be noted from the figure is that the predicted GeV-scale flux from π^0-decay significantly exceeds the observed flux, thus prohibiting a hadronic origin of the TeV-scale γ-ray emission from RX J1713.7−3946.

3. Discussion

Is it possible to modify the proton spectrum such that the resultant pion-decay γ-ray spectrum complies with the observed multiband spectrum that is shown in Fig. 2?

Enomoto et al. have used a power-law proton spectrum with high-energy cut-off ($s = 2.08, E_c \simeq 50$ TeV) to calculate the γ-ray spectrum. We have used a scaling model for the nucleon-nucleon interactions (Büsching et al. 2001) to realistically investigate what proton spectra would have a γ-ray yield in accord with that observed. As a result we find that a low-energy cut-off must be imposed on the proton spectrum with $E_1 \gtrsim 100$ GeV (for $s = 2$). We do not know a process that would cause such a low-energy cut-off in the spectrum of particles accelerated by a SNR.

Alternatively, a broken power-law ($s_1 \lesssim 1.6$, $s_2 \simeq 2.7$, $E_2 \simeq 20$ TeV) would fit the data, whereas a hard power-law with exponential cut-off gives a very bad fit. We note that such a broken power-law spectrum is not predicted by shock acceleration models and is also in conflict with the spectra observed from accelerated electrons in SNR. Additionally, the necessity to introduce many parameters to explain a few data points hardly qualifies as evidence for the underlying model, even more so if these parameters are far away from what can be expected based on observations and theoretical modelling. Therefore we conclude that a pion decay origin of the observed TeV-scale γ-ray emission of RX J1713.7−3946 is highly unlikely.

Having established that pion decay is not a viable model for the TeV γ-ray emission from RX J1713.7−3946, contrary to the proposal by Enomoto et al. (2002), one has to reconsider the possible association of the EGRET and the CANGAROO source as well as the origin of the multi-band emission.

The low intensity of the thermal component determined in thermal emission plus power-law spectral fits to X-ray data of SNR RX J1713.7−3946 (Slane et al. 1999; Pannuti & Allen 2002) suggests that the remnant is still expanding into the wind bubble of the progenitor (Ellison et al. 2001). No analysis of X-ray data of the possible interaction region between the molecular clouds and either the progenitor's stellar wind or the supernova blast wave has been published so far. It has

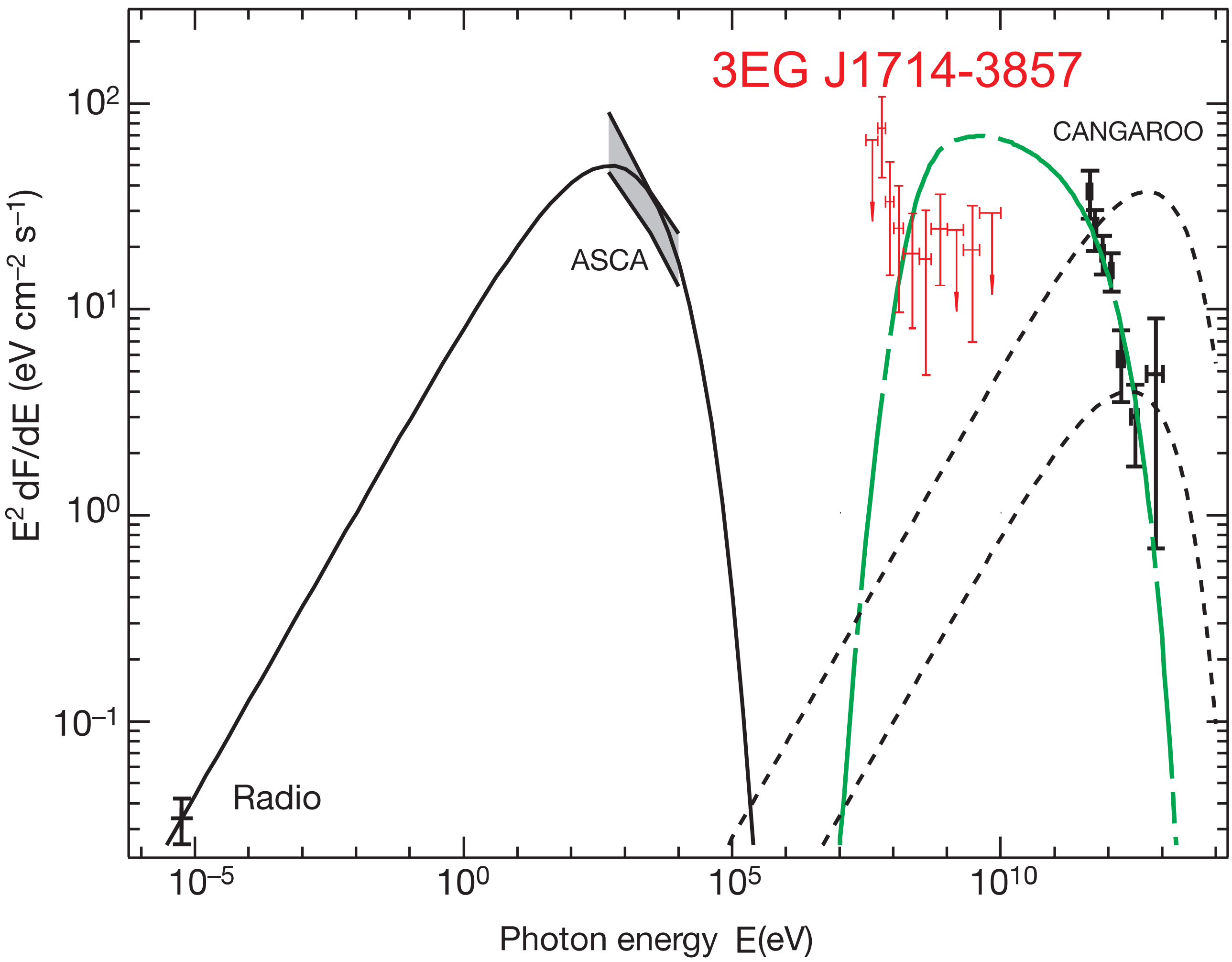

Fig. 2. The multi-band spectrum of RX J1713.7−3946 from Enomoto et al. (2002) revised to include the γ-ray spectrum of 3EG J1714−3857, shown in comparison with emission models presented in the same publication. The solid line indicates the synchrotron emission of relativistic electrons, and the dashed lines are the corresponding inverse Compton spectra based on the microwave background and the ambient far-infrared photon field for two sets of parameters. As Enomoto et al. have pointed out, both IC model spectra violate the observed TeV γ-ray spectrum. The green (grey) long-short-dashed line shows the pion decay spectrum, which was supposed to reproduce the γ-ray emission of RX J1713.7−3946. The modelled GeV-scale pion decay flux would significantly exceed the observed emission by a factor of three.

been proposed that the radio, X-ray, and TeV γ-ray emission of RX J1713.7−3946 is produced by synchrotron radiation and inverse Compton scattering by relativistic electrons, similar to the case of SN 1006, but that the EGRET source should be identified with the nearby molecular cloud, which provides dense target material for relativistic protons having escaped from the SNR (Slane et al. 1999; Butt et al. 2001).

While the spatial association of the EGRET and the CANGAROO source can be observationally tested with forthcoming γ-ray missions such as GLAST, the expected absolute flux level of π^0-decay γ-rays is not well determined in the context of general acceleration models (for a detailed discussion see Pohl 2002). One of the crucial but poorly known parameters is the injection efficiency, with which suprathermal protons are injected at the shock front. In contrast to the electrons, for which the non-thermal X-ray flux can be used as a primer for the electron flux, whatever the micro-physics at the acceleration site, the high energy cosmic ray nucleons do not reveal themselves in any presently observable channel other than γ-ray emission from π^0-decay and radiation from secondary electrons. The overprediction of the hadronic TeV γ-ray flux from Cas A and the Tycho SNR (Atoyan et al. 2000; Völk et al. 2001) also compromises corresponding model predictions for hadronic γ-ray emission from SN 1006 (Berezhko et al. 2002).

The question whether or not inverse Compton scattering can be responsible for the observed TeV-scale γ-ray emission of RX J1713.7−3946, whatever the origin of the EGRET source 3EG J1714−3857, will be easier to answer once a better defined synchrotron spectrum is available. It is important to know at what frequency the peak of the synchrotron intensity is located in a νF_ν spectrum, for that determines the location of the peak of the inverse Compton component. For the inverse Compton model to work, the peak of the synchrotron spectrum should be located at about an order of magnitude lower frequency than in the best fit of Enomoto et al., implying the power-law index $s \leq 2.0$, which is not excluded by the sparse radio data available to date. The analysis is complicated and clearly beyond the scope of this Letter, for the radio image of SNR RX J1713.7−3946 displays small-scale structure with the high magnetic field regions producing the bulk of the synchrotron radiation and the low field regions presumably being responsible for most of the inverse Compton emission. Nevertheless, CHANDRA and NEWTON observations in conjunction with radio measurements at different frequencies may be sufficient to prove or disprove the assertion that inverse Compton models are not viable for RX J1713.7−3946.

4. Summary

In this Letter we have discussed the most recent TeV γ-ray measurements of RX J1713.7−3946 (Enomoto et al. 2002) under the constraint that the GeV scale emission observed from the closely associated EGRET source 3EG J1714−3857 is either associated with the SNR or an upper limit to the gamma-ray emission of the SNR.

Our conclusions are the following:

- The nearby EGRET source 3EG J1714−3857 may or may not be related to RX J1713.7−3946. In any event, the GeV-scale γ-ray radiation emitted by RX J1713.7−3946 cannot exceed that observed from 3EG J1714−3857.
- A pion decay origin of the observed TeV-scale γ-ray emission of RX J1713.7−3946 is highly unlikely, contrary to a previous claim.
- Answering the question whether or not inverse Compton scattering can be responsible for the observed TeV-scale γ-ray emission of RX J1713.7−3946, whatever the origin of the EGRET source 3EG J1714−3857, requires a better knowledge of the synchrotron spectrum of the SNR than available to date.

Acknowledgements. Financial support for OR and MP by the Bundesministerium für Bildung und Forschung through DESY, grant *05 CH1 PCA/6*, and DLR, grant *50 QV 0002*, is gratefully acknowledged. We are indebted to Yousaf M. Butt, Diego F. Torres, and Gustavo E. Romero, who went along with this manuscript in frequent and extensive discussions. Due to an editorial request by Nature concerning overlapping authorlists between a brief communication to Nature by Butt et al. 2002 and this letter they decided to obey and withdraw from coauthorship at a time when this letter has already been accepted for publication.

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