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TeV gamma-ray flux estimates from EGRET supernova remnant sources

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Abstract. The EGRET experiment, onboard the Compton Gamma-Ray Observatory (CGRO) satellite, has provided evidence of possible ≥ 100 MeV gamma-ray emission from ~ 22 supernova remnants through positional correlation alone. In view of the widely-held belief in the occurrence of cosmic-ray acceleration to energies of ~ 10^{14} eV in these remnants, we have estimated the TeV gamma-ray fluxes likely to result from these sources through the π^0 – decay and the inverse Compton processes, involving shock – accelerated relativistic protons and electrons.

1. Introduction

Supernova remnants (SNR's) are believed to be a major source of galactic cosmic rays with energies ≤ 10^{15}eV, both, on the basis of energy considerations as well as the strong possibility of charged particle acceleration to ~ 10^{15}eV through the diffusive shock acceleration process (Aharonian, 1995). This hypothesis is supported by the COS-B detection of ≥ 100 MeV gamma-rays from Loop I SNR (Bhat et al. 1985), EGRET detection of ≤ 10 GeV photons from several nearby SNR (Esposito et al, 1996) and non-thermal keV X-rays from Cas A, SN 1006 and IC443 (Koyama et al, 1995). Evidence for acceleration of charged particles to > 10 TeV energy in SNR is also provided by the recent TeV detections of Vela and SN1006. Romero et al. (1999) have recently identified 22 EGRET point sources which are positionally coincident with galactic SNR's. Here we study the possible detectability of these remnants at TeV energies by estimating the fluxes likely to be generated through the inverse Compton and the neutral pion decay mechanisms.

The 22 possible EGRET SNR sources have integral fluxes above 100 MeV energy ranging from a low of ~ 10^{-7} photons cm^{-2}s^{-1} (for 0631+0642, Monoceros) to a high of ~ 10^{-6} photons cm^{-2}s^{-1} (for 2020+4017; γ Cygni) and power law spectra with a differential index in the range of ~ 2.0-2.7 (Romero et al. 1999). Under the rather questionable assumption that the spectra continue unchanged into the TeV region, only four of these sources have fluxes above 1 TeV of ~ 10^{-11} photons cm^{-2}s^{-1}, the minimum detectable flux of a typical imaging Cerenkov telescope for a 5 σ detection in 100 h of source observations (Bhat, 1997). These four sources, namely, IC443, Sgr E, W44 and γ Cygni, are characterized by rather flat spectra with differential indices

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of ~ 1.90-2.0. The fact that none of these sources has been detected at TeV energies in a wide-ranging survey by the Whipple and HEGRA systems indicates a possible spectral steepening or cut off in the GeV-TeV region. (Buckley et al. 1997) It is, therefore, instructive to estimate the TeV fluxes expected from these sources on the basis of the two mechanisms referred to earlier in order to assess their detectability through the Cerenkov technique.

2. TeV gamma-rays from π^0 decay

When the ultra-high energy (~ 10^{15} eV) proton beam from a SNR interacts with the ambient interstellar medium, neutral pions are produced (alongwith other particles) which instantaneously decay into two gamma-rays. The TeV gamma-ray fluxes, expected from the π^0 decay process from SNR's which have entered the Sedov phase, have been calculated by several authors (Drury et al, 1994; Naito and Takahara, 1994). We have followed an essentially similar treatment in estimating the ≥ 1 TeV flux from the 22 EGRET SNR's, using appropriate values for the various parameters. Fig. 1 shows the typical π^0 – decay gamma-ray spectrum for a SNR with total energy output $E_{sn}=10^{51}$ ergs, and a 10% efficiency for conversion of SNR energy output to cosmic rays. The spectra are calculated for two representative values of ambient matter density (n_H = 1cm^{-3} and 10cm^{-3}), two distance values of 1kpc and 2.5 kpc and a power law accelerated proton spectrum with differential exponent $\gamma = 2.0$. While the estimated ≥ 1 TeV fluxes for most of these sources are found to be below 10^{-13} cm^{-2}s^{-1}, γ-Cygni alone has the highest flux of ~ 2 x 10^{-12} photons cm^{-2}s^{-1} above 1 TeV. This flux is, however, much lower than the typical flux sensitivity of an imaging atmospheric Cerenkov telescope, indicating that the detection of any of these sources at the currently available detection sensitivities is highly unlikely if the TeV gamma – rays result from neutral pion decay following p – p interactions between the shock – accelerated protons and the ambient matter. The chances of detecting a TeV signal are brighter if the SNR is embedded in a molecular cloud with a higher matter density of ~ 10 hydrogen atoms cm^{-3}.

3. TeV gamma-rays from inverse Compton process

In plerions, or filled centre SNR's, the relativistic wind from the central pulsar, which carries the bulk of its spindown power, is confined by a more slowly expanding shell of the SNR. The spin-down energy of the pulsar is then dissipated in a shock which accelerates charged particles to energies ~ 10^{14} eV and randomizes their pitch angles. While the high energy protons can generate TeV gamma-rays through the above mentioned π^0 decay process (if sufficient target material is available), the accelerated electrons radiate synchrotron emission in the radio, optical and/or X-ray bands. The observation of non – thermal keV energy X-rays from several SNR's, including SN 1006 and Cas A (Koyama et al, 1995) indicates the presence of ~ 100 TeV electrons in these systems. These ultra-relativistic electrons can, in turn, generate inverse Compton gamma-rays at TeV energies by upscattering the soft photon background (MWBR, synchrotron radiation from plerion, IR radiation from dust, galactic starlight and far IR radiation). Figure 2 shows a typical inverse Compton gamma-ray spectrum for a SNR with $E_{sn} = 10^{51}$ ergs, two representative values of nebular magnetic field (3μG and 20μG) and 1 keV X-ray flux of 10 mJy. It is not possible to estimate the IC component of TeV gamma-rays for most of the 22 sources in consideration due to inadequate information about the nebular magnetic field intensity

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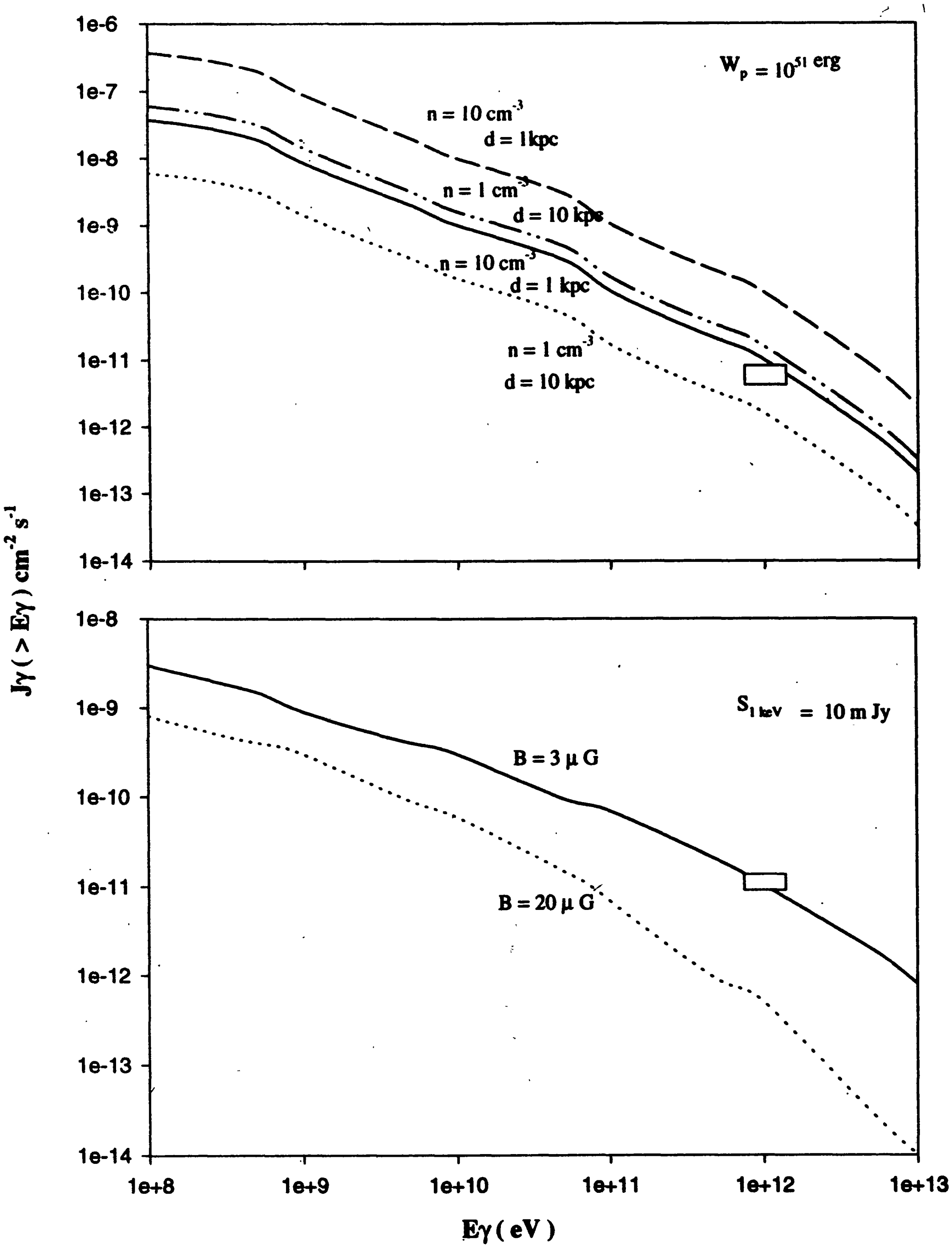

Figure 1. (Top) π^0 decay gamma-ray fluxes for a SNR with total explosion energy $E_{SN} = 10^{51}$ erg, for two representative distance values of 1 kpc and 2.5 kpc and two typical values of interstellar matter density, 1 cm^{-3} (normal ISM) and 10 cm^{-3} (SNR embedded in molecular cloud). 10% of the total SNR energy is assumed to be carried away by the relativistic protons (differential exponent = 2.0). (Bottom) Inverse Compton gamma-ray fluxes for a SNR with $E_{SN} = 10^{51}$ erg, for two representative values of nebular magnetic field (3μG and 20μG). The primary electron spectrum is taken to be of the form ~ $E^{-2} \exp(-^{E}/_{100}$ TeV) such that the X-ray flux at 1 keV is 10 mJy. The rectangles in both the diagrams represent the typical flux sensitivity of an atmospheric Cerenkov telescope at ~ 1 TeV energy, for a 5σ source detection in 100 h of observations.

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and the non – thermal X-ray and accelerated eleectron spectrum. In the few cases where this estimate has become possible (SN 1006, Vela and CAS A etc.), the ≥ 1 TeV gamma-ray fluxes turn out to be $\leq 10^{-12}$ photons $cm^{-2}s^{-1}$, under the best conditions, again making their detection difficult at the present levels of experimental sensitivity.

4. Results

Our calculations show that in case of a continuous power law spectrum extending from the MeV-GeV to the TeV region, four galactic SNR's (IC 443, SgrE, W44 and γ Cygni) may be detectable with the presently operational imaging Cerenkov telescopes. However, if the TeV gamma-rays are assumed to result from either the π^0 decay process involving shock – accelerated protons or the inverse Compton process involving relativistic electrons (responsible for the non – thermal keV X-ray emission), none of these SNR sources would be detectable at the present sensitivity levels for the most representative source characteristics.

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