# Can gamma ray astronomy disprove the hypothesis that cosmic rays originate in Supernova remnants?

Erlykin, A.D.[1,2] and Wolfendale, A.W.[2]
*(1) P.N. Lebedev Physical Institute, Leninsky Prospekt, Moscow 117924, Russia.*
*(2) Department of Physics, University of Durham, DH1 3LE, U.K.*

## Abstract

Supernova remnants (SNR) appear to hold out the possibility of explaining the origin of cosmic rays, up to the 'knee' in the energy spectrum at least. However, it has been claimed that the non-observation of many SNR in high energy gamma rays makes the mechanism unlikely (e.g. [13, 14, 18]). Here, we make an examination of this problem, with particular reference to the question of the density of gas into which SNR expand and to the problem of the visibility of SNR gamma ray sources. We conclude that the lack of (some) gamma ray sources does not preclude most cosmic rays from originating in SNR.

## 1. Introduction

The lack of observation of many clear examples of SNR seen in gamma rays is often cited as a worry for the SNR origin of CR. This is not to say that gamma rays have not been seen from the direction of known SN — they have. There have been strong claims for the detection of gamma rays from Loop I ([4] and later papers) and a number of *likely* SNR signals [9,16,17]. It is at TeV energies, particularly, where difficulties arise (e.g. [13,14,18]) and, since this represents an important energy region where CR acceleration is needed, this is of concern. In the present work, a number of topics are examined

## 2. The experimental situation

A number of detections have been made, principally of CasA [15], SN1006 [9] and SNRG348.5 +00 [5]. In all the cases there is uncertainty in the extent to which nearby molecular clouds are irradiated by protons and other nuclei accelerated by the remnant. Indeed, molecular clouds irradiated by the ambient CR flux have been known to simulate genuine sources [11].

A standard problem in searching for SNR gamma rays is that the inverse square law dictates that nearby SNR will give the highest fluxes but that these will also have the biggest angular diameter and thus be difficult to detect against the rather irregular background. In our recent paper ([5c], to be referred to as I),

---

pp. 2353–2356

we have endeavoured to estimate the minimum detectable flux of gamma rays, for two threshold energies ($E_\gamma > 0.1$ GeV and $E_\gamma > 1$ TeV), as a function of angular size. The results, which relate to detectors that have been used so far, are as follows. The limiting fluxes for diameters 0.1°, 1° and 10° are, for energies above 0.1 GeV, 0.2, 0.3 and 1.5, all $\times 10^{-6}$ cm$^{-2}$ s$^{-1}$. For energies above 1 TeV, they are 0.5, 8 and 30, all $\times 10^{-12}$ cm$^{-2}$ s$^{-1}$.

## 3. The results of model calculations

### *3.1. The acceleration model*

Details are given in [5a,c], but briefly we have used the model of Axford [1], complemented by the numerical calculations of Berezhko et al. [2] and Berezhko [3]. An important feature concerns the manner in which the CR diffuse through the ISM after leaving the remnants. In I, anomalous diffusion ($\alpha = 1$, [10]) was adopted; evidence favouring this mode of transport is given elsewhere (e.g. [5b]).

The CR interact with gas both in the remnant and in the ISM in general and the ensuing gamma rays are the subject of interest here.

Figure 1 shows results from I. As an example of the rates and sizes, with an average SN rate of $10^{-2}$ y$^{-1}$ over the whole Galaxy, we expect an average of about 10 remnants of size below 5° and flux greater than $10^{-12}$ cm$^{-2}$ s$^{-1}$.

An interesting feature of Figure 1 is the slow rate at which the size of the 'residual' remnant grows after the 100 pc radius is reached, at which the CR are assumed to escape. The very slow transport of the bulk of CR is a very prominent feature of anomalous diffusion. This feature is particularly marked at low energies and is due to the fact that the characteristic diffusion distance $R_d$ is proportional to time $t$ as $R_d \propto t^{1/\alpha}$ and is, therefore, small at small $t$ when $\alpha = 1$.

## 4. SN and local ISM characteristics

It is in the nature of the formation of the massive stars responsible for SN that they form in groups. Thus SN themselves are often associated, both spatially and temporally. Parizot et al. [12] estimate that 90% of SN form in groups, although Wallace et al. [19] and Ferrière [7] quote 'about half'. A further point of relevance is that molecular clouds are, understandably, to be found in the vicinity of SN and SNR quite often. Both these features have, understandably, relevance to gamma ray production by SNR.

The question of the gas density in an SNR with which the CR interact is a matter of great complexity. The reasons are manifold, and include gas emitted by the precursor star, evacuation of the region by previous shocks, the presence of molecular clouds, and so on. Multiple SNR can have a collection of these situations but, importantly, there will be a class of SNR which are expanding into the hot ISM causes, in a restricted region, by previous SN. Loop I is thought to

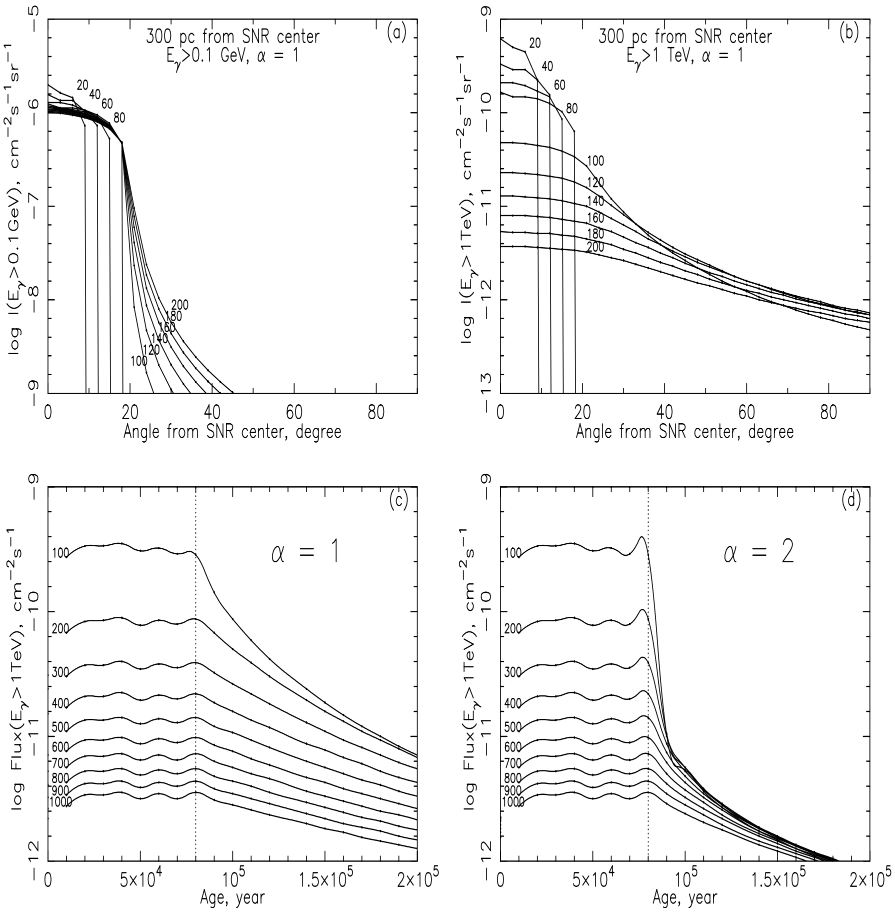

**Fig. 1.** (a,b) Angular profile of SNR in gamma rays observed from the distance of 300 pc at the energy thresholds shown. Anomalous diffusion, with $\alpha = 1$, is adopted. The numbers on the curves are ages in ky.
(c,d) Total flux of gamma rays with $E_\gamma > 1$ TeV from SNR as the function of their age for both normal ($\alpha = 2$) and anomalous ($\alpha = 1$) diffusion. The numbers on the curves are distances in pc.

be an example, and is relevant to our 'Single Source Model', [5]. but the number of such SNR is thought to be rather small.

## 5. Comparison of observations (or lack of them) with our estimates

Inspection of Figure 1 and the rates given in Section 3.1 shows that, for the gas density $n = 1\mathrm{cm}^{-3}$, we expect no more than a few remnants of size below 5° with fluxes above $\sim 10^{-12}$ cm$^{-2}$ s$^{-1}$ ($E_\gamma > 1$ TeV). The flux of $10^{-12}$ cm$^{-2}$ s$^{-1}$ is about a factor 20 below the presently detectable flux for a 5° source. Dramatically high gas densities would need to be seen by virtually *all* the accelerated CR so that, immediately, we see that the number of TeV sources from the SNR mechanism is going to be very small. Smaller sources would be seen for nearer, younger SNR but the numbers go down very rapidly.

## 6. Conclusions

It is not surprising that so few SNR have been definitely observed, in view of the special conditions needed. The claimed gamma ray source–SNR associations could be pulsars associated with SNR, but not recognized in radio as such. An interesting feature is that there may be small halos round the sources arising from the slow diffusion of CR particles accelerated by the pulsars themselves. Elsewhere (EW, these Proceedings) we discuss the analysis of the preliminary results from the Cherenkov array MILAGRO [8] and conclude that there may be such evidence for TeV gamma rays from GEMINGA.

The final conclusion is that gamma ray astronomy does not sound the death-knell of CR origin in SNR (yet).

## References

1. Axford, W.I., 1981, *Proc. 17th ICRC (Paris)*, **12**, 155.
2. Berezhko, E.G. et al., 1996, *J. Exp. Theor. Phys.* **82**, 1.
3. Berezhko, E.G., 1999 (private communication).
4. Bhat, C.L. et al., 1985, *Nature*, **314**, 515.
5. Erlykin, A.D., Wolfendale, E.W., (a) 2001, *J. Phys. G*, **27**, 941; (b) 2002, *J. Phys. G*, **28**, 2329; (c) 2003, *J. Phys. G* (in press), `astro-ph/0301653`.
6. Enomoto R. et al., 2002, *Nature*, **416**, 823
7. Ferriére, K.M., 2001, `astro-ph/0106359`.
8. Fleysher, R., 2003, `astro-ph/0302520`.
9. Hara, S. et al., 2001, *Proc. 27th ICRC (Hamburg)*, **6**, 2455.
10. Lagutin, A.A. et. al., 2001, *Nucl. Phys. B ( Proc. Supl.)*, **97**, 267.
11. Li, T.P., Wolfendale, A.W., 1981, *Astron. Astrophys. Lett*, **100**, L26.
12. Parizot, E. et al., 2001, *Proc. 27th ICRC (Hamburg)*, **6**, 2070.
13. Plaga, R., 2001, `astro-ph/0111555`.
14. Pohl, M., 2001, *Proc. 27th ICRC (Hamburg)*, Inv., Rapp., High. Papers, 147
15. Puhlhofer, G. et al., 2001, *Proc. 27th ICRC (Hamburg)*, **6**, 2451.
16. Sturner, S.J., Dermer, C.D., 1995, *Astron. Astrophys.*, **293**, L17.
17. Sturner, S.J. et al., 1996, *Astron. Astrophys. Suppl. Ser.*, **120**, 445.
18. Völk, H., 2002, `astro-ph/0210297`.
19. Wallace, B.J. et al., 1994, *Astron. Astrophys.*, **286**, 565.