Can one see gamma rays from the Single Source responsible for the knee?

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Abstract

Some 6 years ago, we proposed the 'single source model' in which a local, recent supernova remnant (SNR) was responsible for the 'knee' in the cosmic ray (CR) energy spectrum at ~ 3 PeV [3]. In this paper we study the possibility of observing that SNR in gamma rays and conclude that its non-observation is due to the SNR being local and in a low density region. Furthermore, being nearby it is an extended source, occupying up to 40° region of the sky, and indistinguishable from the background.

1. Introduction

It is commonly asserted that the 'knee', a rather sharp steepening in the primary cosmic ray (CR) spectrum at about 3 PeV, is due to an increasing failure of 'Galactic containment' of the CR generated by sources within the Galaxy. However, it is our firmly-held view that the 'knee' is too sharp for this explanation and we claim that it is due to the truncation that occurs at 3 PeV for oxygen nuclei from a single, recent, nearby SNR.

Recently, Bhadra has argued that the single source should be visible in TeV gamma rays, and, since it is not seen, it cannot be a SNR [2]. He made, however, necessary reservations, vis. *detection could be crucial, depending on the angular size of the object* and *unless the source is in a lower density environment* and these are the points addressed here.

2. Estimates of the age and the distance of the Single Source

In our paper [5] we predicted proton spectra for alternative assumptions about the propagation of the particles from the source characterized by the parameter α. $\alpha = 1$ corresponds to anomalous diffusion, viz. making allowance for the non-uniform fractal-like nature of the ISM, $\alpha = 2$ corresponds to normal, gaussian diffusion. The case for $\alpha = 1$ is shown in Figure 1. Also indicated is the rigidity spectrum 'required' by the SS model.

This figure shows that $\alpha = 1$ can give a reasonable fit, at least for energies

pp. 2349–2352

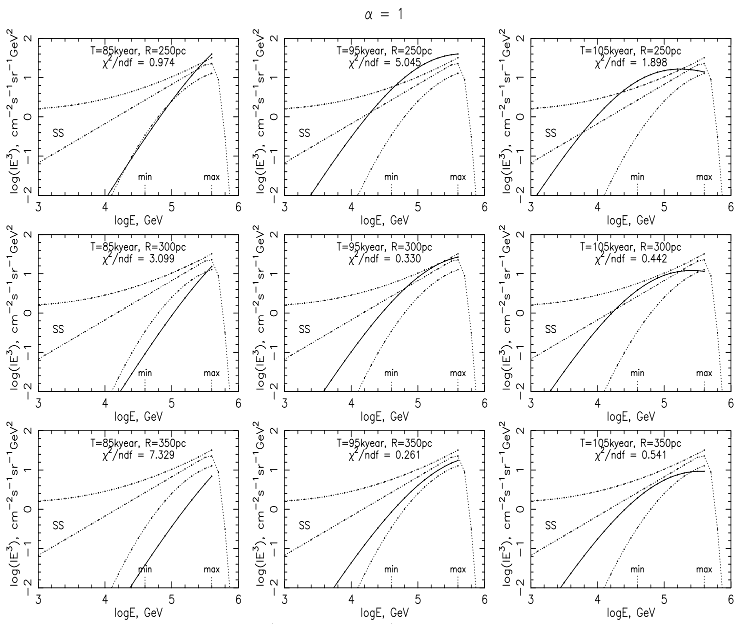

Fig. 1. Energy spectra of protons (full lines) expected from SNR of different ages (T) and at different distances (R) from the Sun, indicated inside the graphs, compared with the rigidity spectrum of CR according to our Single Source Model (the line denoted by SS). SNR protons propagate through the ISM by means of anomalous diffusion with $\alpha = 1$.

above 10^4 GeV, up to the cut-off at $4{\cdot}10^5$ GeV, for a range of age (T) and distance (R) values. The case of $\alpha = 2$ presented in [5] is not shown here because it always gives a bad fit. Calculations made for a wide range of T and R allow us to estimate the range over which there is satisfactory agreement between calculations and the SS model; it is $84 < T < 100$ kyear and $230 < R < 350$ pc for the adopted set of input parameters. The lack of fit at lower energies has no significance because the SS contribution is a small fraction of the total there.

The shape and the absolute intensity of the CR energy spectrum give the most stringent constraints on the age and distance. The T-R region of SNR which could give an acceptable spectrum is shown in Figure 2 by the full line. Following Bhadra's approach we have also used such an integrated characteristic of the spectrum as the energy density contained in it. Again, we used for the comparison just the high energy part of the spectrum. The energy density contained in the spectrum of our single source between 10^3 GeV and $4 \cdot 10^5$ GeV is $2.24{\cdot}10^{-4}$eVcm^{-3}. Comparison of this value, allowing for a 40% error, with those expected for SNR of different ages and distances gives an acceptable T-R region indicated by a dashed line in Figure 2. It overlaps with the region deduced from the comparison of the spectral shape and indicates that our single source should be located at about 300 pc from the Sun and should be about 90 kyears old.

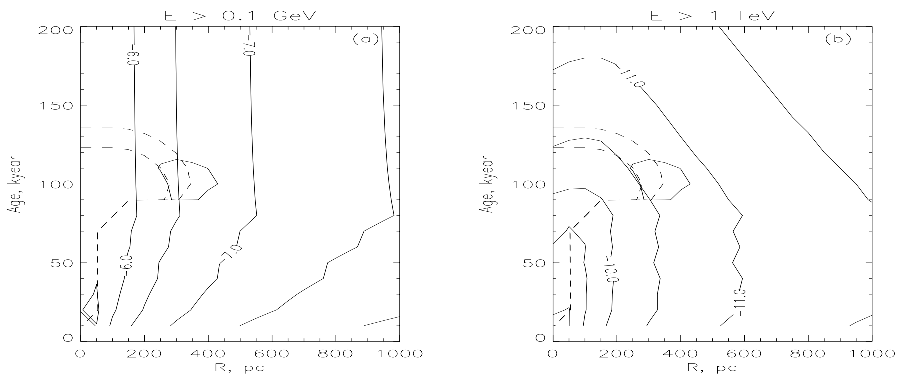

Fig. 2. Age - Distance diagram for a SNR which is responsible for the formation of the knee - i.e. for our 'Single Source'. The inside full line indicates the allowed region deduced from the analysis of the shape and the intensity of the CR particle spectra, dashed lines show limits based on the comparison of the energy density, contained in the Single Source. Full-line contours show the expected total gamma ray fluxes with the energy of gamma quanta above 0.1 GeV (a) and 1 TeV (b) expected for PP-interactions. Labels on the contours indicate values of log(Flux), the flux being in units of $cm^{-2}s^{-1}$.

3. The predicted gamma ray flux

Fluxes of gamma rays from SNR of different ages and at different distances from the Sun have been calculated in [4] for threshold energies of 0.1 GeV and 1 TeV. In Figure 2 we show contours of the fluxes calculated for P-P interactions of primary protons with ISM. The density of the ISM for these calculations has been taken to be standard $n = 1\text{cm}^{-3}$. It is seen that the expected fluxes are about $3{\cdot}10^{-7}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 0.1$ GeV and about $3{\cdot}10^{-11}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 1$ TeV. For the mixed mass composition of cosmic rays from the Single Source the expected fluxes should be increased by a factor of 10.5 [5]. This gives $\sim 3 \cdot 10^{-6}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 0.1$ GeV and $\sim 3{\cdot}10^{-10}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 1$ TeV. However, since the distance to our Single Source was estimated as ~300 pc it is very likely situated within our Local Superbubble with its matter density of $n \approx 3 \cdot 10^{-3}\text{cm}^{-3}$. This reduces the predicted fluxes to $\sim 10^{-8}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 0.1$ GeV and $\sim 10^{-12}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 1$ TeV. If, surprisingly, the source is not in the Local Superbubble, but is isolated, then as it was discussed in [4], $n \sim 0.1\text{cm}^{-3}$ and the predicted fluxes are $\sim 3 \cdot 10^{-7}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 0.1$ GeV and $\sim 3 \cdot 10^{-11}\text{cm}^{-2}\text{s}^{-1}$ for $E_\gamma > 1$ TeV. All predicted fluxes are shown in Figure 3.

The sources must be detected against a background. This background can be allowed for for 'point' sources, where a subtraction can be made of the signal on either side of the source, but for extended sources the problem is much more severe. The angular radius of a SNR, which is 90 kyear old, seen from the distance of 300 pc is about 20°. For such a large size the determination of the background

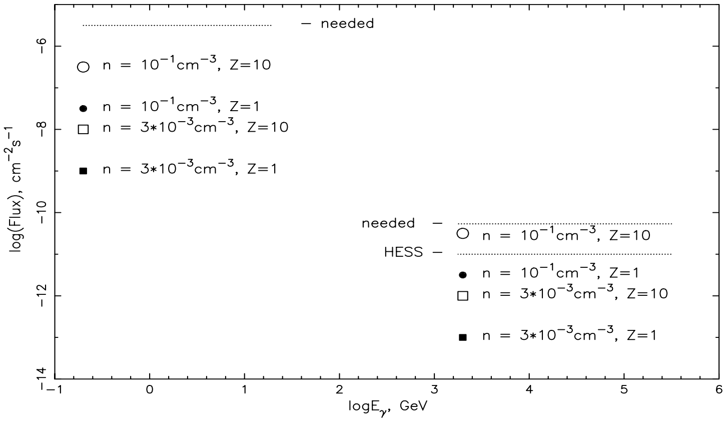

Fig. 3. Schematic representation of the gamma ray fluxes from the claimed 'Single Source' at energies $E_\gamma > 0.1$ GeV and > 1 TeV for a variety of scenarios. The dotted lines marked 'needed' are the minimum fluxes required for the source to have been detected so far by the arrays in use up to now. As an indication of the future we also give the estimated minimum detectable flux for $E_\gamma > 1$ TeV for a source of 20° radius from [1] denoted 'HESS'.

by a linear interpolation of the intensity between the adjacent regions is not at all accurate. Estimates of the background based on the known column density of the target gas, although more appropriate, are again not sufficiently accurate because the intensity of the initiating cosmic rays along the line of sight cannot be assumed to be strictly constant.

Estimates of the limiting fluxes were made from the available data and they are given in [4]. For a source of radius 20° the average limits are $3 \cdot 10^{-6}$cm^{-2}s^{-1} for $E_\gamma > 0.1$ GeV and $5 \cdot 10^{-11}$cm^{-2}s^{-1} for $E_\gamma > 1$ TeV. These limiting sensitivities, which relate to observations made so far, are indicated in Figure 3.

4. Conclusions

Only if the single source is in a 'high' density region ($n \sim 0.1$ cm^{-3}) and the primaries are 'heavy' nuclei (Z = 10) it will be possible to detect the Single Source at high energies. Insofar as we consider it very likely that the source is in the Local Superbubble and it occupies about 40° region of the sky the chance of detecting it with contemporary instruments is considered, by us, to be very low.

5. References

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