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Cosmic rays from SNR, II: Anisotropies

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Abstract. The Monte Carlo analysis of Cosmic Rays from SNR has been used to predict the anisotropy of arrival directions of Cosmic Rays over a wide energy range. The measured energy dependence of anisotropy amplitude and phase are best fitted if there has been a recent, local SN.

1 Introduction

The Monte Carlo analysis described in detail by us elsewhere (Erlykin and Wolfendale, 2001) has been used to predict the dependence of the anisotropy of arrival directions on energy, and the extent to which the measurements lend weight, or otherwise, to our Single Source Model (Erlykin and Wolfendale, 1998).

Briefly, the Monte Carlo analysis involves Galactic SN at the rate of 10^{-2} y^{-1} distributed randomly in space and time from which cosmic rays are accelerated in the SNR and then diffuse through the ISM. The mean lifetime against diffusive loss from the Galaxy is given by $T(E) = 4 \times 10^7 E^{-0.5}$ y, with E in GeV. In fact, although the basic calculations relate to protons they are valid for all nuclei if E is replaced by rigidity, R.

The experimental data related to the anisotropy are those used by us previously (Erlykin et al., 1998) and are shown again in Figure 1.

2 The Predictions

For each configuration of SN the intensity is determined at 'the centre' (viz. the Sun) and at two points 100 pc away from it, viz. (X,Y) = (0,0), i.e. the centre, and (X,Y) = (+100,0) and (0,+100). The X and Y components of the anisotropy are then determined from the simple expression $A_X = \frac{\partial I}{I \partial X} \cdot \lambda$, $A_Y = \frac{\partial I}{I \partial Y} \cdot \lambda$, where λ is the mean free path for diffusion.

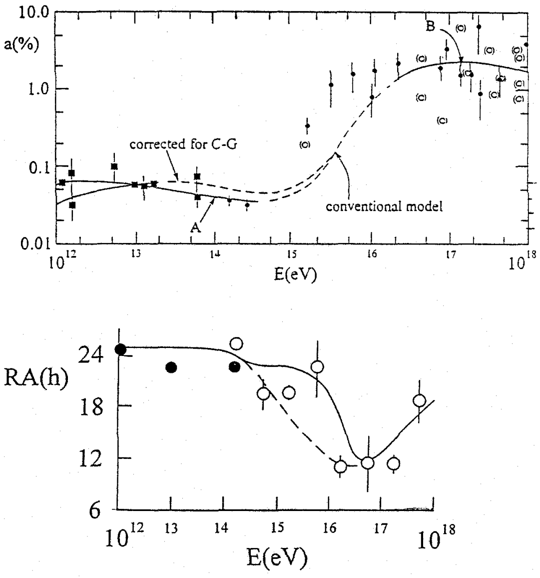

Fig. 1. Amplitude of the first harmonic, and phase, of the anisotropy versus energy from the summary by Erlykin et al. (1998). A and B were regarded by the authors as 'known'; the 'conventional model' is that for a smoothly varying direction of cosmic ray flow. We regarded the high experimental values just above 10^{15} eV as being due to the onset of a single source; the present work examines whether this view is supported by the Monte Carlo analysis.

Figure 2 shows the median amplitude of the anisotropy versus energy for both the adopted form of $T(E) = 4 \times 10^7 E^{-0.5}$ y and for a variant; $T(E) = 4 \times 10^7 E^{-0.33}$. The steady growth with increasing energy is a consequence of the form of $T(E)$.

The form of $\log A$ versus $\log E$ varies from one configuration to the next and Figure 3 shows the frequency distribution of the amplitude at the maximum energy of 4×10^5 GeV for protons (i.e. 4×10^5 GV rigidity). A number of corrections

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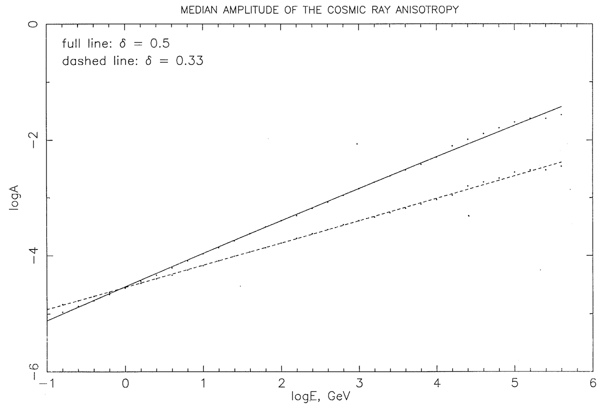

Fig. 2. Median amplitude of the spatial anisotropy for two values of the exponent in the lifetime equation.

are now necessary, to allow for conversion from spatial to projected anisotropy (the experimental data refer to results over a limited declination range) and to take into account the varying mass composition of the primaries. The (downward) correction is a factor of about 5.

Figure 4 shows the resulting median (projected) anisotropy amplitude. Results are given there for our adopted lifetime versus energy (rigidity) expression and also for one with an $E^{-0.3}$ dependence, instead. The experimental values clearly favour the $E^{-0.5}$ dependence.

Confining attention to the upper curve, the excess for the last point is about a factor 5. Moving to Figure 3, we note that such a displacement from the median is not uncommon (i.e. from $\log A = -1.4$ to $\log A = -0.7$). The probability of such a displacement or more is, in fact, about 5%. Bearing in mind the fact that the density of SN locally, over the past 1 My, has been four times higher than the Galactic average (Grenier and Perrot, 1999) the percentage will increase somewhat.

3 Conclusions

The consistency of the derived amplitude with the experimental data lets us conclude that the anisotropy results are not inconsistent with the Single Source Model; indeed, including the fact that change of phase at the 'correct' energy there is support for it.

References

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Grenier, I.A. and Perrot, C., 1999, *Proc. Int. Cosmic Ray Conf., Salt Lake City*, **3**, 476.

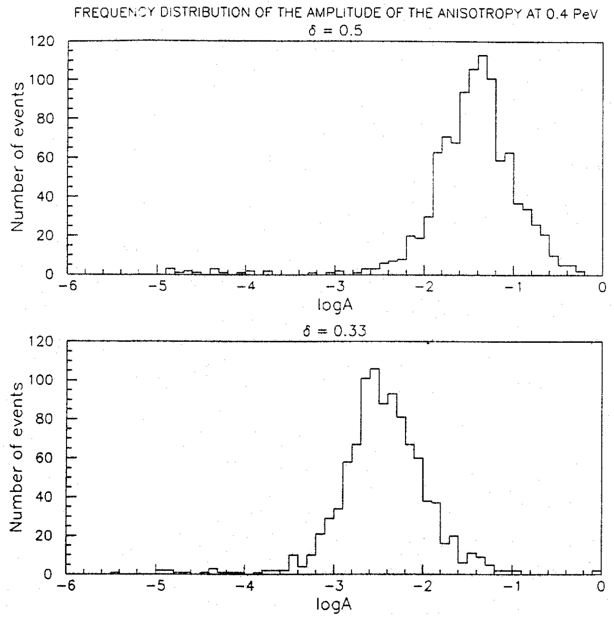

Fig. 3. Frequency distribution of the amplitude of the anisotropy at 0.4 PeV for two values of the exponent δ in the expression for mean lifetime, $T = 4 \times 10^7 E^{-\delta}$ y.

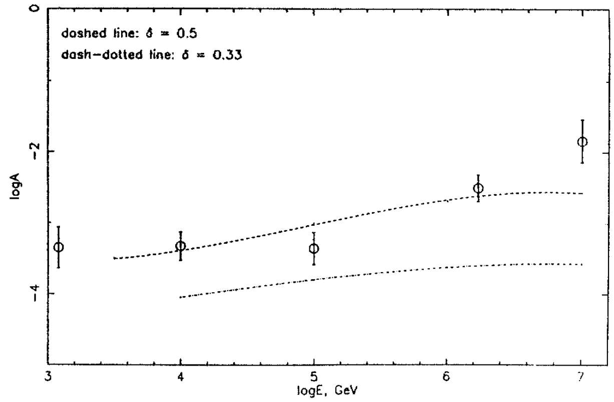

Fig. 4. Predicted amplitude of the projected anisotropy for the mass composition adopted by us (e.g. in Erlykin and Wolfendale, 1998). The points are from the experimental data (Figure 1). The lines are median values for many trials. It is evident that the final point is high — this is just where we predict that the nearby single source could cause a rise (of this magnitude) in the anisotropy amplitude. The lower line, which has the energy coefficient of $\delta = 0.33$, is clearly too low.