EXCESS GAMMA RAYS FROM THE LOOP I SUPERNOVA REMNANT

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ABSTRACT

Evidence is presented for an excess of cosmic ray intensity within the Loop I supernova remnant, based on an interpretation of the observed distribution of γ-rays across the remnant and the column densities of the associated gas. A strong case can thus be made for the bulk of the cosmic radiation ($E < 10^{11}$eV) being produced in the Galactic supernova remnants.

1. Introduction. The search for the origin of the cosmic radiation has been a long one but we believe that a recent study in γ-ray astronomy has now provided definitive information on this question.

The principle of the method adopted in this recent investigation is to examine the profile of γ-ray intensity across the nearby 'Loop I' supernova remnant (SNR), a remnant clearly identified in radio synchrotron radiation, and to determine the magnitude of the cosmic ray intensity present therein based on current estimates of the associated gas. Full details of this work are given in a paper by Bhat et al. (1985) and only a summary is given here, together with some more recent results.

The characteristics of the Loop I SNR have been given by Berkhuijsen et al. (1971): it is centred on a point ∿ 130 pc away and its radius is ∿ 115 pc. The loop is prominent at latitudes between -30° to +80° and at longitudes between 260° to 60°.

The γ-ray data used by us come from the SAS II and the COS B satellite observations (Fichtel et al., 1978 and Strong et al., 1982). The gas data are derived from the 21cm Berkeley survey (Weaver and Williams, 1973 and later papers) for HI and 2.6mm CO observations by Lebrun and Huang (1984) together with the galaxy count results (Strong et al., 1982) for molecular hydrogen. The H_2 column densities are found to be small (∿ 25% of HI).

2. Results and Conclusion. Figures 1 and 2 summarise the results, which are:

(a) An excess of γ-rays of energy $E_\gamma > 300$ MeV, correlated with the longitude-averaged, latitudinal radio profile (408 MHz) of Loop I, is apparent. In so far as protons are the main parents of γ-rays at these energies, this suggests that protons have been efficiently accelerated in the remnant.

(b) A similar excess at lower γ-ray energies argues strongly in favour of electrons also having been accelerated in this remnant. This suggestion is consistent with the interpretation of the radio synchrotron data by Heiles et al. (1980).

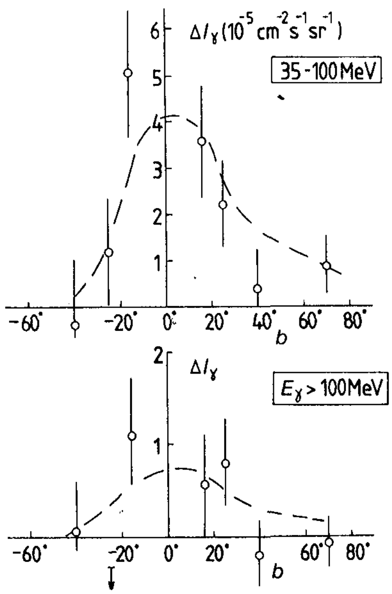

Fig. 1. The excess γ-ray intensity associated with Loop I as a function of galactic latitude. The basic γ-ray data are from the SAS II experiment. ΔI_γ is the difference between observed and expected γ-ray intensity for the Loop region minus the same quantity outside the Loop. The smooth curve is the corresponding T_{408}, averaged in the same way, normalized in height to observation. The particles generating the γ rays are almost entirely electrons in the lower energy band. At higher energies protons generate about 60% of the γ rays.

(c) The observed average γ-ray luminosity for the Loop I is close to that predicted by Blandford and Cowie (1982) for a model in which the initial SN energy is 10^{51}ergs and the cosmic rays (CR) are accelerated by shocks in the remnant.

The following main conclusions of a general nature can be drawn:

(i) Adopting Blandford & Cowie's model for the CR acceleration, and allowing the accelerated particles to leak out of a remnant into the general ISM, when the SNR radius is ∿ 150 pc, gives an acceptable model for the origin of low energy (< 10^{11}eV) Galactic CR. Thus, the CR energy flux input to the Galaxy turns out to be ∿ 10^{41} erg s^{-1} for a supernova explosion rate in the range ∿ 1 per 30 to 1 per 100 years.

(ii) An interesting feature of the Blandford and Cowie model, and indeed any model involving shock acceleration in the SNR, is that the efficiency of acceleration is higher in low density regions of the ISM. Thus, the shocks propagating out into the Galactic halo are likely to be highly efficient, with important consequences on various propagation features e.g., the total grammage traversed and the CR lifetime. Analogously, in the Galactic disc, the volume density of the gas is known to fall with increasing Galactocentric distance as one proceeds away from the sun. It would, therefore, be expected that the cosmic ray intensity would not fall off as rapidly as does the 'density' of the SNR, as the remnants in the outer Galaxy should be more efficient at accelerating cosmic rays than their more numerous inner Galaxy counterparts. This feature may explain the comparatively flat radial distribution of CR (protons) reported by Bloemen et al. (1984) (although it should be remarked that we consider that there is actually evidence for a small residual 'cosmic ray gradient' for protons). A contributory factor here is the likely longer lifetime of CR in the outer Galaxy, before escape.

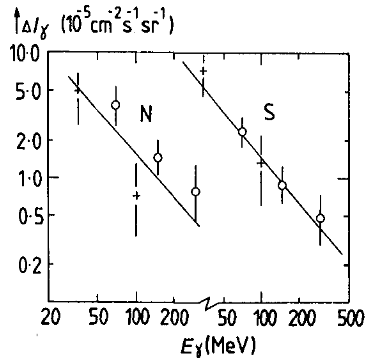

Fig. 2. The excess γ-ray intensity defined in Fig. 1 as a function of threshold energy. The latitude ranges are: 11° → 19°, -11°→-19°. The circles refer to COS B data and the crosses to SAS II. There appears to be a significant excess for the highest energy γ rays, these quanta being generated very largely by cosmic-ray protons.

(iii) Concerning the γ-ray production, only about 5% of the Galactic γ-rays above 100 MeV can be shown to come from the composite of the Galactic SNR of various ages. The detection of the corresponding small contributions from the individual remnants, farther than Loop I, should therefore, prove quite difficult in the presence of comparatively intense backgrounds resulting from the interactions between the CR and the general ISM.

(iv) The consequences of adopting the shock-acceleration models for the cosmic ray anisotropy and the time-variations in pre-history, are considered by us in another paper in these Proceedings.

References

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