SUPERNOVA EXPLOSION IN DENSE CLOUDS IN THE GALAXY AND THE COS-B GAMMA RAY SOURCES

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ABSTRACT

Supernova (SN) exploding in dense cloudlets produce large flux of γ-rays. They would shine on γ-ray sources, but their life time is small. We calculate the flux distribution of these sources in the Galaxy and compare with the Cos-B catalogue of sources.

1. Introduction. It has been pointed out recently that large flux of secondary antiprotons ($\bar{p}$) is produced in envelopes of SN which explode in dense cloudlets in the Galaxy [1]. Taking into account all energy loss processes, including adiabatic cooling, it is shown that the resultant spectral shape of these $\bar{p}$ match the observations [2]. These SN should also be an intense source of γ-rays [3], but their life time in the cloud is small. The absolute brightness and time evolution of these sources depend upon the density of the cloudlets [4]. Because of these reasons, the number of such sources in the Galaxy at a given time, is small and its brightness depends upon its age and the distance from the Sun. We have calculated the flux (>100 MeV) distribution of these γ-ray sources, by folding in the surface density of molecular hydrogen in the Galaxy and the density distribution of cloudlets. These estimates are compared with the observed distribution of Cos-B sources [5].

2. γ-ray Production in Sources. During the evolution of SN in dense clouds, cosmic ray nucleons interact with matter to produce π° decay γ-rays. As the matter traversal increases, the spectral shape of nucleons, which is initially assumed to be a simple power law in rigidity, flattens due to ionization loss, and the γ-ray spectrum near 70 MeV peak is also altered [4]. Electrons interact with matter to produce bremsstrahlung γ-rays. Electron spectrum evolves rapidly with the age of SN. The initially accelerated electrons are depleted by synchrotron energy loss process at high energies, and the spectrum is dominated by secondary electrons during the late stages of evolution. At low energies, the spectrum is flattened due to ionization loss. As a result of these, the relative contribution of bremsstrahlung γ-rays decreases with time. We have calculated the γ-ray spectrum from these sources as described elsewhere [4].

From the study of $\bar{p}$ produced from these sources, it is shown that about 30% of the observed nucleons in cosmic rays come from such sources [1,2]. The remaining cosmic ray nucleons come from SN exploding in ordinary clouds with $n_H = 10$ atom.cm^{-3} in the Galaxy. If the rate of SN explosion in the clouds is about once in 30 years in the Galaxy, the energy release in the form of cosmic rays soon after acceleration, about 200 yrs, is $\sim 10^{62}$ eV [4]; it is assumed that adiabatic cooling takes place only upto the end of the adiabatic phase when remnant fragements. We consider that the total energy release in the form of cosmic rays is the same for all sources. With this information, the brightness evolution of SN with time is calculated. Observations show that cloudlets have H_2 densities varying from about a few times 10^3 molecules/cm^3 to about 10^5/cm^3 [6]. In Fig. 1, we have shown the brightness above 100 MeV as a function of time for SN exploding in cloudlets for different n_H values. The adiabatic loss is higher for SN exploding in rarer medium, and it is seen that the brightness decreases rapidly with time for sources in rarer medium.

3. Luminosity Distribution of γ-ray Sources. We consider in this analysis that cosmic rays are accelerated in dense source by the beginning of the adiabatic phase; the remnant leaves the cloudlet when cosmic rays traverse about 50 g.cm^{-2} of matter. One can estimate from the observed p the relative number of SN, which explodes in dense clouds to that in ordinary clouds. Our calculation show that the ratio is 1.34:1.0, 0.82:1.0, 0.6:1.0 and 0.44:1.0 respectively for $n_H = 10^4$, 4×10^4, 10^5 and 2.5×10^5 atom.cm^{-3}. We make use of this to calculate SN rate in the Galaxy. The flux distribution is evaluated by the integral

$$N(>L) = \iiint N(R,n_H)\, R\, dR.\, d\Phi\, .\, \{B(n_H,t)/4\pi d^2\}\, dt \qquad \ldots \qquad (1)$$

In this equation $L = B/4\pi d^2$, where $d^2 = R_o^2 + R^2 - 2\, R_o R \cos\Phi$; here $R_o = 10$ kpc the abundance of galactic centre and, R the radius and Φ the azimuthal angle between radius R and the Sun-Centre line. The restriction in this integral is that the integrant becomes zero when $\{B(n_H,t)/4\pi d^2\} < L$. In this equation $N(R,n_H)$ is the number of SN per unit area, weighted according to the molecular hydrogen density [7] and is normalized to the number of SN produced per unit time in the entire galaxy for a given cloud of density n_H.

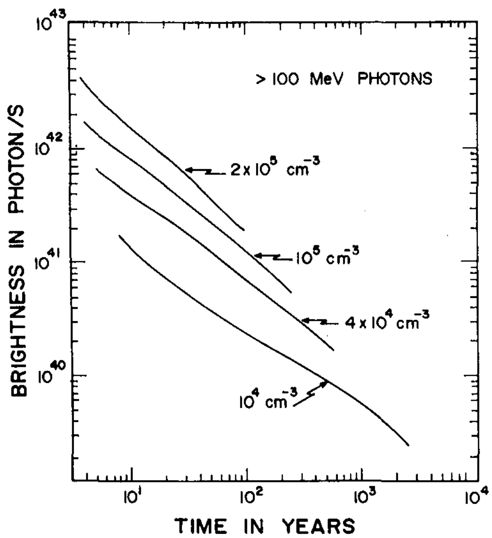

Fig. 1 Brightness of γ-ray sources > 100 MeV is shown as a function of time for different n_H values

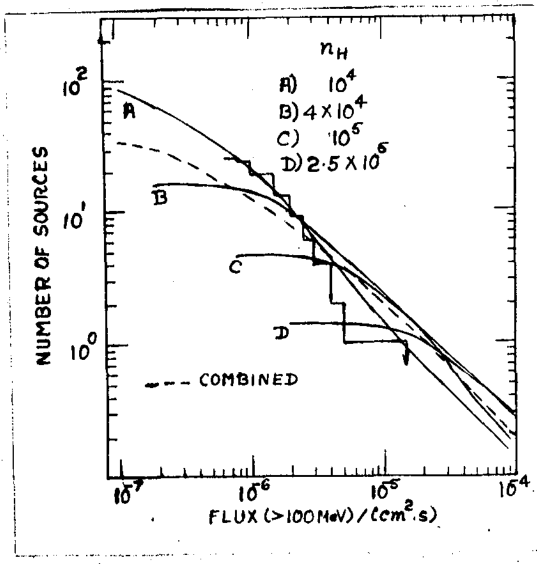

Fig. 2 Integral source distribution is plotted as a function of observable flux; for comparison Cos-B data is shown.

We have plotted in Fig. 2, the number of expected γ-ray sources in the Galaxy with flux > L as a function of L. We have considered a range of L values from 10^{-7} to 10^{-4} photon/(cm^2.s). Curves B, C and D correspond to n_H values $4x10^4$, 10^5 and $2.5x10^5$ atom. cm^{-3} respectively. The observed Cos-B source distribution is shown by the step function. It is clear from this figure that anti-protons are produced in dense cloudlets do not contradict the γ-ray observations. The good agreement Curve A has, with the observed data, suggests that indeed Cos-B sources could have this origin.

The observation of dense cloudlets show that the density peaks around $n_H = 10^5$ atom cm^{-3}. We have evaluated $N(n_H,R)$ distribution using the available information on the density distribution of clouds [6]. Making use of the weighted distribution of $N(n_H,R)$ we have integrated Eqn. 1 over n_H and the result is shown as dashed curve in Fig. 2. The agreement with data is not as good as that for $n_H = 10^4$ atom cm^{-2}.

4. Discussion. We have shown that if antiprotons are produced in envelopes of SN, which explodes in dense cloudlets in the Galaxy, the γ-ray produced in these sources do not contradict the observed Cos-B data.

It is also seen from Fig. 2 that the source distribution calculated for $n_H = 10^4$ atom.cm^{-3} is in good agreement with the observed data. However, the calculated distribution after folding the distribution of observed mean densities in cloudlets predicts too small a number of γ-ray sources at low flux values. This may perhaps be due to the following reason. We have assumed a uniform density of matter in the cloud during the entire evolution of SN. Observations show [8] that the radial gradiant in density varies between $r^{-1.5}$ and r^{-2}, with densities $\lesssim 10^4$ atom. cm^{-3} beyond 0.1 pc. Therefore, when SN explodes in these clouds, the remnant would spend most of its time in regions of low densities $\lesssim 10^4$ atom. cm^{-3}.

On the basis of Curve A in Fig. 2, one expects about 100 γ-ray sources in the Galaxy with flux densities $> 10^{-7}$ photon/(cm^2.s) at energies > 100 MeV. This can be checked by GRO. We can predict the hardness of spectrum in such sources, which can also be measured accurately by GRO. Our calculations show that the variation of $F(>300 \text{ MeV})/F(>100)$ is from 0.26 to 0.34 over the life of SN and this is consistent with the observations [5]. The high energy γ-ray spectrum is dominated by $\pi°$-decay and the spectral shape will be indicative of the accelerated spectrum of nucleons in these sources.

We have shown elsewhere [9] that the observed positron data can be well explained by secondary production of e^+ in these sources. It is important at this stage to calculate the radio spectrum emitted by electrons in these sources.

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