On the origin of the 'identified' and 'unidentified' gamma ray sources

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Abstract

A study is made of the 3EG Gamma Ray source catalogue [7] with particular regard to the nature of the so-called 'unidentified sources'. It is concluded that a case can be made for a significant number of them being pulsars, those at high latitudes being of the 'spun-up' variety.

1. Introduction

The present work examines gamma rays above 0.1 GeV, where the progenitor protons have a mean energy of about 2 GeV. The electron contribution is thought to be small (see [11] for details).

A very useful set of data has come from the EGRET detector on the Gamma Ray Observatory, both with regard to the diffuse continuum [12] and so-called 'gamma ray sources' [7]. It is with the latter that we are concerned here.

At these low energies, a number of possibilities arise. These include: The irradiation of molecular clouds by the ambient cosmic ray flux (e.g. [8], Supernova remnants, both in isolation and associated with molecular clouds (MC), Pulsars (e.g. the early SAS II results), and Extragalactic sources (starburst galaxies, active galactic nuclei (AGN), etc.).

2. The 3EG Source Catalogue

The catalogue lists the coordinates, the radius, in degrees (θ_{95}) of the circle containing the same solid angle as the 95% contour level, the flux (in fact, a series of fluxes from a series of viewing periods), the photon spectral index, γ, identifications—of varying degrees of certainty—and 'location maps' with contours of statistical probability that a single source lies within the given contour.

Also given are maps of the sky exposure and a full sky map distinguishing between AGN, Pulsars, the LMC, a Solar Flare (!) and the 'unidentified' sources (UIS). It is immediately apparent by inspection that the UIS are in the majority. It is also apparent that there may be serious selection effects associated with the variable exposure.

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An examination has been made of the shapes of the spatial probability maps and, therefore, the source shapes. It is found that there is a preponderance of near 'horizontal' shapes for near-Galactic Plane sources. Here 'horizontal' means an alignment along the Galactic Plane. This observation leads us to expect that many are genuine and extended, such as might be expected for either pulsars or SNR injecting accelerated particles into the ISM or the overlap of a few near circular contours from true discrete sources.

The exposure pattern over the Galaxy is a complicated one. There is rather a wide variation but it is interesting that the *shape* of the $\log N$, $\log F$ plot (N being the number of sources with flux greater than F) for the half of the map with more than the median exposure is similar to that for the other half; this is a good sign.

3. $\log N$, $\log F$ plots for $|b| < 10^\circ$

3.1. Identified pulsars and SNR

This latitude range is chosen so as to cover SNR and pulsars. We have included in the original list of pulsars and SNR those identified (as possible coincidences) in the list of Torres et al. [12] and the outcome is shown in Figure 1. Above about 50 f.u. (1 f.u.=10^{-8}cm^{-2}s^{-1}), the slope of $\log N$, $\log F$ is close to

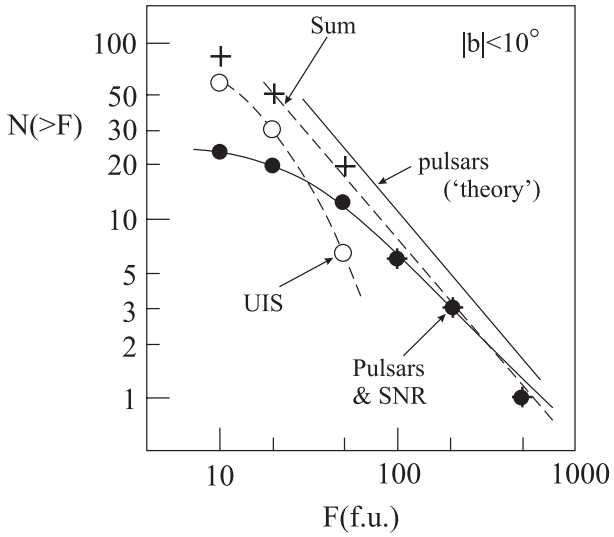

Fig. 1. $\log N$, $\log F$ distributions for EGRET sources at latitudes below 10°. The filled-in circles represent identified (both certain and probable) SNR and pulsars. The open circles are for the 'unidentified sources', UIS. The crosses represent their sum. 'Pulsars ('theory')' represents the result of a simple theory in which a fixed fraction of the energy loss of the pulsar (10^{-4}) goes into gamma rays above 0.1 GeV.

1, the form expected for a (uniform) distribution of sources in two dimensions.

Insofar as the distribution is for all longitudes, the known radial distribution of SNR and pulsars is sufficiently uniform over modest distances (to, say, $\sim$10 kpc) from the Sun for the simple form to be expected.

3.2. Our predictions for SNR

A comparison can now be made with the absolute numbers expected. Concerning SNR, we have made detailed studies of CR from these objects using a Monte Carlo analysis (see [4] for details). It is found that, for the gas density $n = 1\text{cm}^{-3}$, $N(> F)$ equals unity for diameter less than 2° at $F \simeq 0.1$ f.u. and for 10° at $F \simeq 1$ f.u. It is apparent that the flux is inadequate, particularly for the necessary small angular sizes. The increase in flux needed, a factor of about 1000, may be achieved only very occasionally for a few remnants very close to molecular clouds of high density, but this would still not give a $\log N$, $\log F$ curve of appropriated slope for the necessary small sources – necessary because the efficiency of detection falls rapidly as the size increases.

It is concluded that our model of SNR acceleration of CR is not able to explain many of the low energy gamma ray sources. (This does not preclude most low energy cosmic ray particles coming from SNR, however.)

3.3. A pulsar model

Our pulsar model, based on information from [2,9,10] gives the result shown in Figure 1. In the model the total rate of energy loss, $\dot{E}$, is related to age, τ, by the approximate expression $\dot{E} \propto \tau^{-1.8}$ and a fraction of 10^{-4} goes into gamma rays above 0.1 GeV. It is evident that this model is 'in with a chance', particularly when it is borne in mind that some or all of the unidentified sources could be pulsars, as could those classed as 'SNR'. The sum of identified and UIS is seen to be of very similar shape to the predictions of the pulsar model.

4. Sources with $|b| > 10°$

Here, for UIS, we have $N(> 20$ f.u.$) = 2$ to be compared with 30 for $|b| < 10°$. Concerning their origin, a number of possibilities spring to mind: high latitude molecular clouds and spun-up pulsars. With the MC masses from [1] the fluxes will be too low but following the work of [3] very cold molecular gas at high latitudes might just give big enough fluxes.

Spun-up pulsars are old pulsars which have been spun-up by accretion from a binary companion. They have been put forward by us, as perhaps being responsible for some of the ultra-high energy CR ($E \geq 10^{19}$ eV) [5]. There is an *a priori* likelihood of their having an association with gamma ray sources. The high velocity of pulsars at birth means that old ones have a wide latitude distribution, the median latitude being about 40°.

Inspection of the map shows only one associated with an UIS but many with AGN, of which several are 'possible', i.e., they *could*, in fact, be UIS. The lack of coincidences is not too worrying because the polar diagram of the pulsars for radio and gamma rays could be quite different [6], although this feature makes a proof of this hypothesis impossible.

5. Conclusions

It is likely that many of the 3EG gamma ray sources within 10° of the Galactic Plane are pulsars; the apparent association of sources with SNR could, in reality, be genuine in some cases but be with pulsars, themselves associated with SNR, in other cases. Those UIS at higher latitudes, right up to $|b| = 60°$ and beyond, appear to be associated with the Galaxy. Spun-up pulsars are a possibility.

6. References

1. Blitz, L. and Shu, F.H., 1980, *Astrophys. J.*, **238**, 148.
2. Buccheri, R., 1980, 'Advances in Space Exploration', **7**, 17, Pergamon Press, Oxford.
3. Combes, F., Pfenniger, D., 1997, *Astron. Astrophys.*, **327**, 453.
4. Erlykin, A.D., Wolfendale, E.W., 2001, *J. Phys. G*, **27**, 941;
5. Erlykin, A.D., Mikhailov, A.A., Wolfendale, A.W., 2002, *J. Phys. G*, **28**, 2225.
6. Harding, A.K., 2000, 'High Energy Gamma Ray Astronomy', *AIP Conf. Proc.*, **558**, Ed. F.A. Aharonian and H.J. Völk, 115.
7. Hartman, R.C. et al., 1999, *Astron. Astrophys. Suppl. Ser.*, **123**, 179.
8. Li, T.P., Wolfendale, A.W., 1981, *Astron. Astrophys. Lett*, **100**, L26.
9. Lichti, G.G. et al., 1980, 'Advances in Space Exploration', **7**, 49, Pergamon Press, Oxford.
10. Lipski, M. and Giller, M., 2000, private communication.
10. Ramana Murthy, P.V., Wolfendale, A.W., 1993, 'Gamma Ray Astronomy', C.U.P.
11. Thompson, D.J. et al., 1993, *Astrophys. J. Suppl.*, **86**, 629.
12. Torres, D.F. et al., 2003, `astro-ph/0301424`