THE SKY DISTRIBUTION OF EGRET SOURCES: HOW MANY RADIO QUIET PULSARS?

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ABSTRACT

We discuss the sky distribution of the EGRET γ-ray sources, taking into account the effects of non-uniform background and time exposure and avoiding the biases of binned distributions with small statistics. Simple considerations on the integral distributions in galactic latitude and longitude of all the sources, independent of their identification which might contain selection effects and observational biases, allows to constrain the properties of an anisotropic component of galactic origin.

We find that AGN constitute $\sim$50% of the EGRET sources and most of the remaining half are consistent in luminosity and sky distribution with (radio)/γ-ray pulsars. Contrary to other recent suggestions, we find no evidence for a population of low luminosity sources ($<10^{32}$ erg s^{-1}) in the presently observed sample.

Keywords: γ-ray sources; EGRET; pulsars.

1. INTRODUCTION

The population of celestial sources observed at γ-ray energies (>100 MeV) has substantially increased after the launch of the EGRET instrument on board the CGRO. The updated version of the Second EGRET catalogue (Thompson et al. 1995, 1996) contains 155 sources (excluding one solar flare and the LMC). Of these sources, 43 have identifications with AGN which are considered reliable, 11 have possible AGN counterparts and 5 are unambiguosly identified with radio pulsars. The possible nature of the 96 remaining unidentified sources has been discussed both in terms of objects already known as γ-ray emitters, as well as invoking new classes of high energy sources (see, e.g., Kaaret & Cottam 1996, Kanbach et al. 1996, Sturner & Dermer 1995, Yadigaroglu & Romani 1995).

Important information on the population of unidentified sources can be derived by the study of its sky distribution. Unfortunately, such investigations are complicated by the presence of selection biases and instrumental effects difficult to quantify. For instance, identifications with AGN are more easily obtained at high galactic latitudes, and many uncertainties are also introduced by the fact that the sensitivity limit achieved with EGRET in the different sky regions is far from uniform.

Contrary to the previous works, which treated separately the unidentified and identified sources, and/or considered only the sources below a given galactic latitude (see e.g., Kanbach et al. 1996, Mukherjee et al. 1995), we studied the EGRET source population as a whole. The use of integral distributions, instead of differential data histograms, allows us to fully exploit all the available information and to avoid the problems of fitting binned data with small number of counts. Our most reliable results are those described in section 2, where we consider only the sources (2/3 of the total) which constitute a complete flux limited sample. The results for the total population (section 3), for which we introduce a correction for the non uniform sensitivity limit, are consistent with those of the flux limited sample.

2. ANALYSIS OF A FLUX LIMITED SAMPLE

The flux limit of the EGRET catalogue varies significantly over the sky, as a result of different exposure factors and, mainly, of the presence of the diffuse galactic emission. The weaker sources can only be detected at high galactic latitudes (Figure 1). To reduce this selection effect, we restrict the analysis of the present section to the sources detected above a flux limit of 2 10^{-7} photons cm^{-2} s^{-1}. Though in a few small sky region the actual sensivity might be slightly worse than this, the adopted limit allows us to have a significant number of objects and, at the same time, to have a sample which is a very good approximation of a complete one. The resulting "flux limited sample" contains 99 sources (31 AGN, 5 pulsars, 63 unidentified). The galactic latitude distributions for all these sources and for the AGN only are shown in figure 2. The dotted lines indicate the cumulative distributions expected for isotropic populations with different number of sources. Since in this case the number of sources expected at a given latitude depends only on the sky solid angle element, these are linear in $\sin(b)$. From this figure, the following informations can be derived:

a) the total sample is clearly inconsistent with an isotropic population.

b) the 31 AGN identified so far have a $|b|$ distribution only marginally compatible with isotropy. Though some small selection effect might still be present, this most likely results from the fact that some of the unidentified sources are AGN.

c) the total number of AGN in the sample cannot be

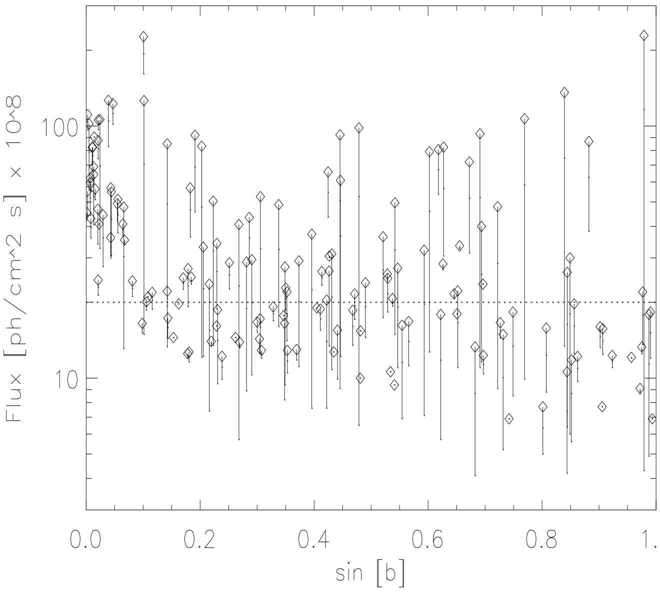

Figure 1: *The flux of all the 2EG sources plotted as a function of $|b|$ clearly shows the incompleteness of the sample at low galactic latitudes. For each source the diamond marks the flux corresponding to the EGRET detection with the highest statistical significance, while the lower end of the bar represents the smallest observed flux (or upper limit). The sources above the dotted line constitute the "flux limited sample" considered in section 2. (The two brightest sources, Vela and Geminga are not shown in the plot).*

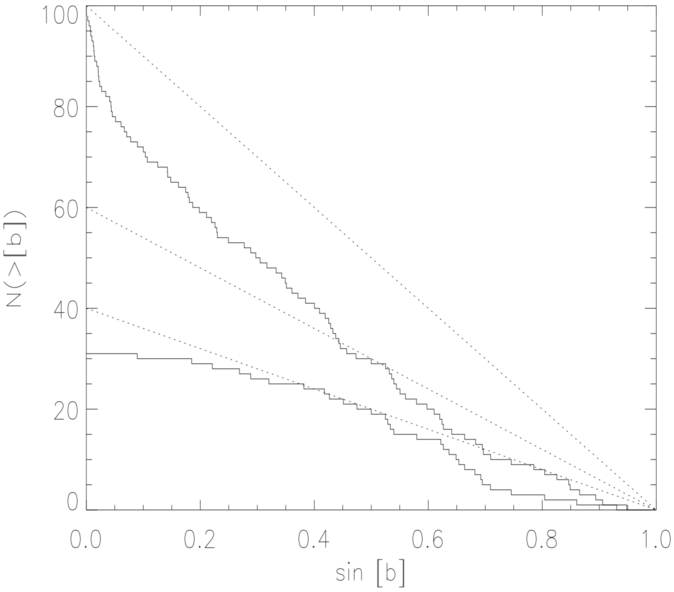

Figure 2: *Galactic latitude distribution of the flux limited sample. Upper curve: total sample, lower curve AGN only. The expected distributions for AGN (isotropic distribution) are linear in sin(b). Three examples, corresponding to 99, 60 and 40 isotropically distributed sources, are shown by the dotted lines.*

greater than ∼45. In fact a larger number would cause an inconsistency with the high latitude tail of the total distribution (see fig.2). Thus among the unidentified sources there are only ∼14 AGN.

d) contrary to expectations, the majority of these ∼14 AGNs cannot be at low galactic latitude ($|b|<20$). Otherwise the resulting AGN latitude distribution would be inconsistent with isotropy at high latitudes.

The above arguments shows that the possible fraction of AGN in the total flux limited sample is quite strictly constrained to ∼45%. This allows us to keep fixed the isotropic contribution in the following modelling of the total source distribution.

Our model consists of the sum of two distributions: an isotropic component, entirely attributed to the AGN, and an anisotropic galactic component. For the latter we used a disk distribution with exponential profiles both in galactocentric radius and scale height:

$$n(R,z) = \text{constant} \cdot \exp\left(-\frac{z}{z_0} - \frac{R}{R_0}\right)$$

where R and z are cylindrical coordinates with origin at the Galactic Center. They are related to l and b by:

$$d \cdot \sin(b) = z$$

$$R = (R_s^2 + d^2 \cdot \cos^2 b - 2 \cdot R_s \cdot d \cdot \cos b \cdot \cos l)^{1/2}$$

where d is the distance from the Sun. We fixed R_0=5 kpc and R_s=8.5 kpc.

For simplicity, all the sources in the galactic component have been assumed of the same luminosity L_γ. The expected $|b|$ distributions have been computed numerically, as a function of z_0 and L_γ, and compared to the observed ones with a Kolmogorov-Smirnov test.

As shown in figure 3, the best description of the observed latitude distribution is obtained for the values $L_\gamma \sim 10^{35}$ erg s^{-1} and z_0 in the range 300–600 pc. Values of $L_\gamma > 10^{36}$ erg s^{-1} are clearly excluded. Combinations of lower z_0 and L_γ, though consistent with the latitude distribution, can be rejected when also the distribution in galactic longitude is considered.

3. ANALYSIS OF THE WHOLE 2EG SAMPLE

An analysis similar to that described above can be done on the whole population of EGRET sources containing 155 objects (54 AGN, 5 PSR, 96 unidentified). In this case we have to properly take into account the non uniform sensitivity when comparing the observed and expected $|b|$ distributions. For an isotropic source population, the expected latitude distribution is given by

$$N(>|b|) = \text{norm} \cdot \int_b^{90} \cos(b') \cdot [F_{lim}(|b'|)]^{-1.5} \, db'$$

where $F_{lim}(|b|)$ is the average limiting flux as a function of $|b|$. We have derived $F_{lim}(|b|)$ from the map of upper limits provided with the 2EG catalog (Thompson et al. 1995). As an example, the resulting curves $N(>|b|)$ for the cases of 75 and 90 sources are shown in figure 4. The deviation from a straight line clearly reflects the reduced average sensitivity in the galactic plane.

We can now proceed as we did for the flux limited sample: First we derive the constraints on the allowed number of AGN. By comparing the expected curves for different

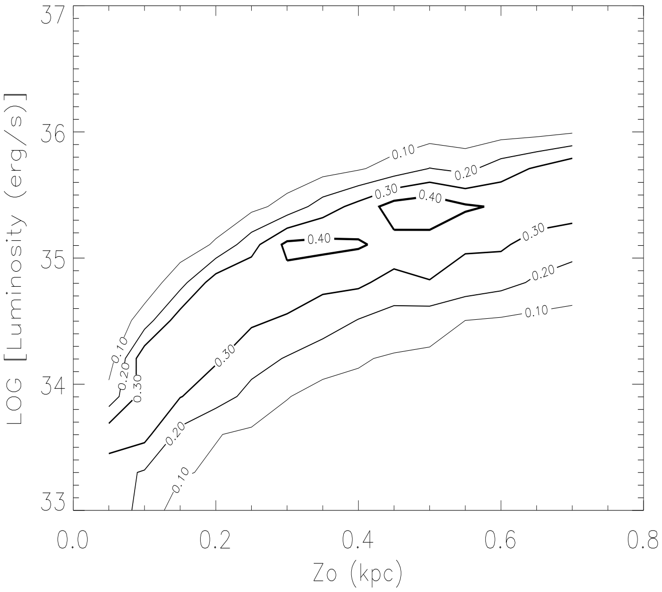

Figure 3: Probability contours for disk models of the galactic source population. The probabilities were computed by comparing with a KS test the $|b|$ distribution of the 99 sources with those expected from the sum of 45 isotropically distributed sources and 54 with a disk distribution (see text).

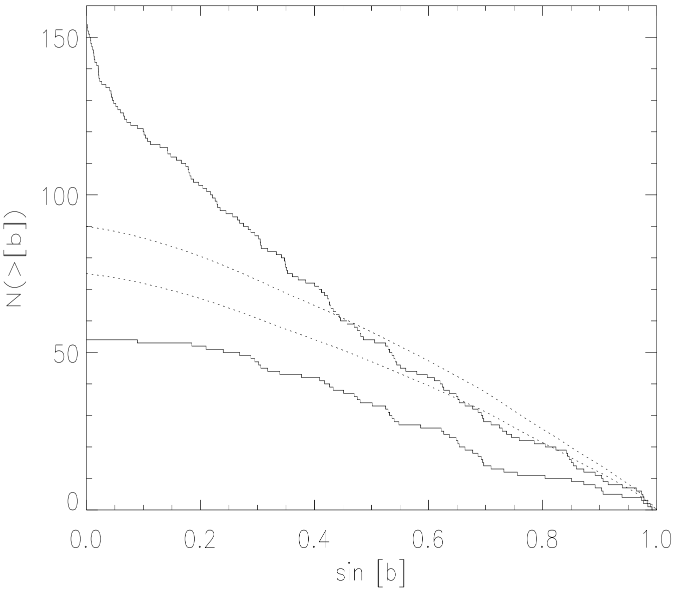

Figure 4: Galactic latitude distribution of the whole sample. Upper curve: total sample, lower curve AGN only. The dotted curves correspond to the expected distributions for 75 and 90 isotropically distributed sources. The figure shows that the total number of isotropic sources in the sample cannot be greater than ~50%.

numbers of isotropic sources with the observed distributions (figure 4) we find that no more than ~75 AGN can be present in the whole 2EG sample. Fixing to this value the contribution of the isotropic population, we can look for the best values of L_γ and z_0 to reproduce the b and l distributions of the total sample. To properly take into account the different sensitivities as a function of l and b, the expected distributions have been computed by means of a Montecarlo program, rather than by a numerical integration as we did in the flux limited case. We assign random source positions in the Galaxy according to the chosen distribution, and then we count only the sources whose flux is above the sensitivity threshold at the corresponding sky coordinates. Fixing the isotropic contribution to ~50% (figure 4), the values of z_0 and L_γ derived for the galactic component are in agreement with those of the flux limited sample.

4. DISCUSSION

We have shown that the AGN population accounts for ~ half of the 2EG sources. Can low luminosity ($L_\gamma < 10^{32}$–10^{33} erg s^{-1}) galactic sources significantly contribute to this sample? We know that the isotropic component must include the 31 AGN of the flux limited sample. We can expect of the order of $2^{1.5}$ more sources, i.e. about 87 AGN in the total sample, if its average flux limit is a factor 2 lower. This number might be an overestimate if the average flux limit is actually worse than assumed, or if some of the 31 AGN are wrong identifications. On the other hand, we have neglected in the above extrapolation the 14 still unidentified AGN in the flux limited sample. It thus appears that not much room is left for isotropically distributed sources different from the AGN. Nearby, low luminosity sources, (e.g. massive early type stars or RS CVn systems, as proposed by Özel & Thompson 1996) can account for a few of the 2EG sources only if a significant number of the present AGN identifications is wrong.

Having estimated the extragalactic fraction of sources, we have attempted a very simple modelling of the remaining anisotropic component of the 2EG catalogue. We found that, within the limited context of our exponential disk model and "standard candle" luminosities, a good agreement with the observed distributions can be obtained with scale height ~ 400 pc and average luminosity of the order of 10^{35} erg s^{-1}. This value is well within the range of observed luminosities of gamma-ray pulsars, which goes from ~10^{34} erg s^{-1} for Geminga, to ~10^{36} erg s^{-1} for the Crab (4π beaming) (Nolan et al. 1996). Also the allowed values of z_0 are compatible with those of radio pulsars, suggesting that most of the unidentified sources be isolated neutron stars.

A similar conclusion was also reached, with a different statistical analysis of the 2EG sources, by Kanbach et al. (1996). Yadigaroglu & Romani (1995) computed the expected number of pulsars visible by EGRET, based on the efficiency and beaming evolution predicted by the outer gap model for pulsar γ-ray emission. They found that most of the sources in the galactic plane can be accounted for by relatively young pulsars. This is also supported by a spatial correlation between unidentified sources and regions of massive star formations (Yadigaroglu & Romani 1996). It is still unclear if similar γ-ray pulsars can also account for the unidentified sources at intermediate galactic latitudes (see, e.g., Grenier 1997). It is beyond the scope of our simple analysis to assess the possible presence of a further galactic population.

5. CONCLUSIONS

By means of very simple and robust considerations, we have shown that the AGN population accounts for $\sim$ half of the 2EG sources. A larger number of AGN (or in general a larger number of isotropically distributed sources) would require more objects at high latitude than observed.

Contrary to other recent suggestions (see e.g. Özel & Thompson 1996), we find no evidence for a population of low luminosity sources ($<10^{32}$–10^{33} erg s^{-1}) in the presently observed sample.

The population properties of the anisotropic component suggest that most of the unidentified sources might be isolated neutron stars. However, more detailed modellings are necessary to establish if they are similar to the few already known γ-ray pulsars, and to determine whether other populations of galactic high-energy emitters are required. Unfortunately, such investigations suffer from our limited knowledge of the γ-ray properties of the candidate source populations. Only with more accurate localizations, as will be obtained with INTEGRAL, and subsequent identifications at longer wavelengths it will be possible to solve the mistery of the unidentified EGRET sources.

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