Population Synthesis of unidentified EGRET Gamma-Ray Sources

G. Kanbach
Max-Planck-Institut fuer Extraterrestrische Physik, D-85748 Garching, Germany

Abstract

The third EGRET catalogue of gamma-ray sources above 100 MeV contains about 270 entries of which about 60% remain so far unidentified. Although intensive multiwavelength searches have revealed several tantalizing cases of likely counterparts and a general correlation of gamma-ray sources with population I objects is obvious, the gross of the high energy sources remains mysterious. We present, based on the observational constraints of the EGRET survey, a study on the distribution, luminosities, and variability of these sources and estimate their contribution to the overall galactic gamma-ray emission.

1 Introduction:

The 3rd EGRET (3EG) catalogue of high energy sources lists 271 entries (Hartman et al., 1999). Definite identifications with known astronomical objects have been achieved for six gamma-ray pulsars based on their unique timing signature. Early in the EGRET mission a popolous new class of extragalactic gamma-ray sources was discovered and identified with extremely luminous flat spectrum radio loud QSOs of the Blazar or other AGN types. The catalogue currently contains 67 gamma-ray blazar identifications with good positional coincidence (inside the 95% contour of the gamma-ray error box) and 27 sources with a possible blazar counterpart just outside this contour. Aside from two additional identified sources, a bright solar flare and the LMC, 3EG lists 170 'unidentified' high energy sources, roughly 60% of the complete catalogue. Identification of EGRET sources based alone on positional coincidence with known multiwavelength sources is of course very much dependent on the quality of the gamma-ray observation (source brightness and spectrum, exposure, surrounding background and neighbouring sources) and on the density and uniqueness of the potential counterparts. Many multiwavelength searches have been performed to link the unidentified EGRET sources with potential galactic and extragalctic source populations. For the low latitude galactic sources correlations with OB associations (Kaaret & Cottam, 1996), SNRs and HII regions (Yadigaroglu & Romani, 1997), radio bright SNRs (Esposito et al., 1996), general SNRs (Sturner & Dermer, 1995, Sturner et al., 1996) have been published. Although the individual cases are often disputable there is general consensus that at least a part of the high energy sources is related to the young population of galactic objects. The emission of these gamma sources could be either due to localized excesses of cosmic ray density possibly embedded in regions of dense ISM (π^o decay and bremsstrahlung) or from compact objects like so far unknown gamma ray pulsars or other relativistic sources. In a recent study Romero, Benaglia and Torres, 1999 come to similar conclusions from a correlation of 3EG sources with WR and Of stars, SNRs and OB associations.

The approach in this paper is to investigate the population properties of the 3EG sources in terms of their time variability, their distribution in brightness, galactic longitude and latitude. From a Monte Carlo model of a source population we can estimate typical luminosities, the number of sources and their contribution to the total galactic output at energies above 100 MeV.

2 Approach to Population Synthesis:

2.1 Variability: High energy gamma ray sources are known to show a wide variety of temporal behaviour. The range of sources extends from apparently stable emitters to sources that have marked variations although they remain detectable most of the time, to truly transient sources that have only been seen once. The six pulsars detected above 100 MeV in the EGRET data show a generally steady intensity whenever we had exposures of them. Blazars, a subset of active galactic nuclei, is the other population of gamma ray sources that are identified with a high degree of confidence. They are generally very time variable. Unidentified gamma ray sources also show variability, although generally to a lesser degree than the AGN sources. As we will show, the unidentified sources at low and medium galactic latitudes($<$ or $>$ $10°$) seem to be more variable than the strong pulsars but less than the AGN type sources

2.1.1 Statistics of source variability: We selected from the 3EG catalog 77 sources that were detected with a significance of more than 6σ in the combined exposures of phase 1 through 4. Among them are 36 identified blazars and 5 pulsars. The remaining highly significant sources lack identification. They are grouped in sources at low galactic latitudes of $|b| < 10°$ (30 objects) and those at $|b| > 10°$ (6 objects). Each source was observed in multiple single viewing periods (VPN) of typically two weeks duration. We test for variability by comparing the longterm average flux F_{AVG} with the flux detected in individual VPNs F_{VPN}. The statistic of variations is then expressed as the frequency of occurence of the ratio $r = F_{VPN}/F_{AVG}$. We account for the errors inherent in the flux measurements (ΔF_{VPN} and ΔF_{AVG}) by distributing the occurence of a certain ratio over a range of ratios r_- to r_+:

$$r_\pm = F_{VPN}/F_{AVG} \times (1 \pm \sqrt{(\Delta F_{VPN}/F_{VPN})^2 + (\Delta F_{AVG}/F_{AVG})^2})$$

with a value of $1/(r_+ - r_-)$ for the frequency of occurence. Upper limits in individual observation periods are of course only meaningful for this statistic if they are significantly below the average flux. We have chosen to accept an upper limit only if it is less than 75% of the average value. In this case we increment the statistic between $r_- = 0$ and $r_+ = F_{U.L.}/F_{AVG} \times (1 + \Delta F_{AVG}/F_{AVG})$.

Figure 1 shows the statistics of variation for the sources, classified according to their identification. The measured data points are connected by a solid line. The dashed gaussian curves indicate the level of variability expected from counting statistics if the sources were of constant flux (flux ratio = 1). It is obvious that the identified source classes, blazars and pulsars, are markedly different. The blazars exhibit the well known large variations, while the pulsars show a narrow distribution, indicative of a rather constant emission. For the unidentified sources at high and low galactic latitudes we obtain a measure of the variability that is intermediate between the behaviour of blazars and pulsars. Occasionally their brightness can increase (factors 2-3) beyond what is expected only on statistical grounds. However one rarely finds, that these sources disappear (i.e. are observed with a significant upper limit much below their average intensity)

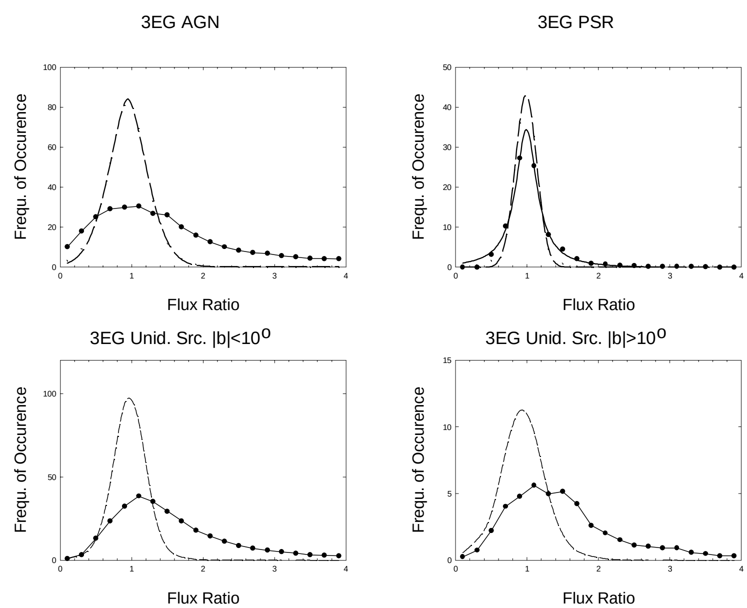

Figure 1: Variability statistics for the selected classes of $> 6\sigma$ sources from the 3EG catalog

2.2 Modelling of galactic sources: A model for the unidentified galactic sources has to account for the spatial distributions as well as for the distribution of the observed fluxes.

Monte Carlo models for assumed source populations were performed and compared to the observed distribution of resolved sources. The procedure has been described in more detail by Kanbach et al., 1996. We assume that the source population is distributed in height (z) above the galactic plane following a Gaussian with standard width of 130 pc. This approximates the height of the HI gas or more general the typical distribution of young stellar populations. The density of sources versus galactocentric distance is assumed to be proportional to the gamma-ray emissivity of the 'diffuse' interstellar medium. This radial distribution has been derived in an unfolding procedure under the assumption of a spiral geometry for the Galaxy by Siebenlist, 1997 and is shown in figure 2. We further assume sources of constant luminosity (standard candles) and test for a range of luminosities.

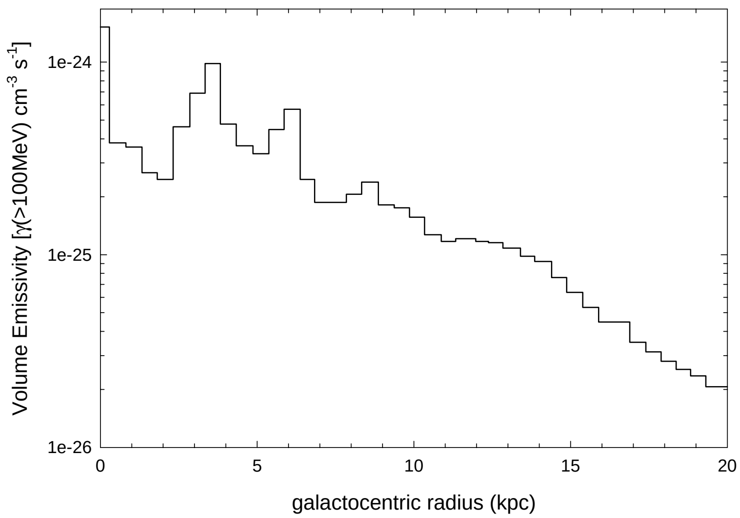

Figure 2: Volume emissivity (units: $\gamma(>100MeV)\ cm^{-2}\ s^{-1}$) of the diffuse galactic gamma ray emission versus galactocentric radius, The sun is assumed at r=8.5 kpc.

After the Monte Carlo generation of a source the observability of the source at the given location in the Galaxy with at least the required significance of 5σ is judged from the published upper limits map (Hartman et al., 1999). The M.C. procedure generates 1000 sources for every one observed and subsequently renormalises the distributions. The resulting distributions in longitude, latitude and flux for each model are compared to the data in a likelihood test.

3 Results and Conclusions:

From the analysis of the time variability of unidentified sources it was found that their population is probably not as uniform as the population of blazars or pulsars respectively. Although the brightest unidentified sources are always detected by EGRET (no significant upper limits indicating that these sources are in an off state are found) some of them can be detected also with an increase in flux of a factor 2-3. A further proof of the constant nature of many galactic gamma ray sources can be derived by comparing the new 3EG catalog with the COS-B catalog derived about 20 years ago (Swanenburg et al., 1981, Mayer-Hasselwander & Simpson, 1990): of a total of 21 COS-B sources EGRET finds corresponding sources in 13 to 16 cases (about 75% long term stable sources). The spectra derived for the low latitude unidentified EGRET sources by Merck et al., 1996 indicate also that these objects are probably not a homogeneous population.

We have further modelled the spatial and flux distributions of unidentified galactic gamma-ray sources under the assumption of cylindrical symmetry in the Galaxy and of a z-distribution that corresponds to population I objects. The radial distribution of the model sources follows the function for the volume density of the diffuse galactic emission. The acceptable source luminosities to satisfy the distribution in longitude, latitude and flux simultaneously are in the range from about 10^{34} to 10^{36} erg/s; the luminosity range depends only weakly on the large scale distribution of the gamma-ray sources because the typical distance (visibility limit) of the sources is 1-4 kpc. The typical source luminosity (4π emission assumed) matches rather closely the emission from the identified pulsars. The weakest pulsar, Geminga, emits 1.5×10^{34} erg/s and the strongest, Crab, 7.0×10^{35} erg/s under the 4π assumption. The total number of high energy sources in the Galaxy is found to be typically 1000. The luminosity of these sources would account for about 10-20% of the total luminosity of the Galaxy, which is at E>100 MeV ($\sim 1.3 \times 10^{39}$ erg/s).

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