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Gamma Ray Pulsar Luminosities

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Abstract. We apply a likelihood analysis to pulsar detections, pulsar upper limits, and diffuse background measurements from the OSSE and EGRET instruments to constrain the γ-ray pulsar luminosity law. We find a steeper dependence on period and magnetic field at OSSE than at EGRET energies. We also find that pulsars may be an important component of the OSSE diffuse flux, but are most likely not important for EGRET. We estimate that as many as half of the unidentified EGRET sources may be γ-ray pulsars. Furthermore, we predict that GLAST will detect roughly 1000 γ-ray pulsars, only 100 of which are currently known.

1. Introduction

Because pulsed γ-rays have been detected from only 8 spin-driven pulsars, many questions in pulsar γ-ray astronomy remain unanswered. The γ-ray pulsar (GRP) emission mechanism and the relationship between γ-ray and radio pulsar emission are not well-understood. The number of unidentified EGRET sources which are actually GRPs and the GRP contribution to the diffuse background are uncertain. Furthermore, it is important and timely to predict the pulsar population that next generation γ-ray telescopes will see.

We therefore have developed an analysis which makes use of all the available data about GRPs to constrain their luminosity law and population parameters. We describe the data used, the model for pulsar luminosity and population evolution, the method of likelihood analysis, and our results.

2. Data

We include 3 OSSE pulsar detections (B0531+21, B0833−45, B1509-58), 27 upper limits to the pulsed OSSE flux for known pulsars (Schroeder et al. 1995; Ulmer et al. 1999), and 3 measurements of the diffuse Galactic OSSE flux. We include 6 EGRET detections (B0531+21, J0633+1746, B0833−45, B1055−52, B1706−44, B1951+32), 354 upper limits (Nel et al. 1996; Fierro et al. 1995; Arzoumanian et al. 1999), and 3 diffuse Galactic background measurements.

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3. Luminosity and Population Model

We model a pulsar's γ-ray luminosity L as

$$L = \gamma P^{-\alpha} {B_{12}}^{\beta}, \tag{1}$$

where P is the spin period in seconds and B_{12} is the surface dipole magnetic field in units of 10^{12} Gauss. Given this luminosity law and assuming a spindown law $\dot{\Omega} \propto \Omega^n$, we may calculate a population-averaged γ-ray luminosity

$$\langle L_\gamma \rangle = \frac{10^{15} \gamma {B_{12}}^{\beta-2} P_0^{2-\alpha}}{T_g(\alpha-2)} \left[1 - \left(1 + \frac{T_g}{\tau_0}\right)^{\left(\frac{2-\alpha}{n-1}\right)} \right], \tag{2}$$

which depends upon initial spin period P_0, magnetic field B_{12}, age of the Galaxy T_g, initial spindown time τ_0, braking index n, and the parameters α, β, and γ. Assuming a constant pulsar birthrate and a pulsar spatial distribution, we may calculate the total diffuse flux due to GRPs in any direction of the Galaxy.

4. Likelihood Analysis

We calculate the total likelihood for one set of model parameters as $\mathcal{L}_{\rm tot} = \mathcal{L}_{\rm det} \mathcal{L}_{\rm up} \mathcal{L}_{\rm dif}$, where $\mathcal{L}_{\rm det}$, the total likelihoods for the detections, will be the product of the likelihoods of the individual detections. We do a grid search over a range of parameters to find the combination of parameters which maximizes the total likelihood. For each parameter, we calculate marginalized PDFs and confidence intervals by integrating over all other parameters.

We assume that pulsars are distributed in a disk with Gaussian radial scale, exponential vertical scale, and a molecular ring. We take the age of the Galaxy to be 10^{10} years and allow pulsars to contribute a maximum of 1/2 of the total measured diffuse flux. The parameters α, β, γ, P_0, B_{12}, and n are varied to find best-fit values.

5. Results

OSSE (50-200 keV): We calculate the likelihood across a range of parameter values and find a well-defined maximum at values of α, β, and log γ of 8.3, 7.6, and 19.4, respectively, leading to a best luminosity law of

$$L = 10^{19.4} P^{-8.3} {B_{12}}^{7.6} \text{ ergs/s}. \tag{3}$$

This law is quite different from the often used $L \propto \dot{E}$ and hence produces a new ranking of γ-ray detectable pulsars. Figure 1 illustrates that undetected pulsars may be quite important in contributing to the OSSE diffuse background. In fact, measurements of the diffuse background can be used to constrain P_0, B_{12}, and n for the γ-ray pulsar population. Figure 2 shows the histogram of predicted pulsar OSSE fluxes for the best-fit model. The pulsar with the fourth highest predicted flux is B0540−69, illustrating the capability of a more sensitive low-energy γ-ray instrument for detecting young, distant pulsars.

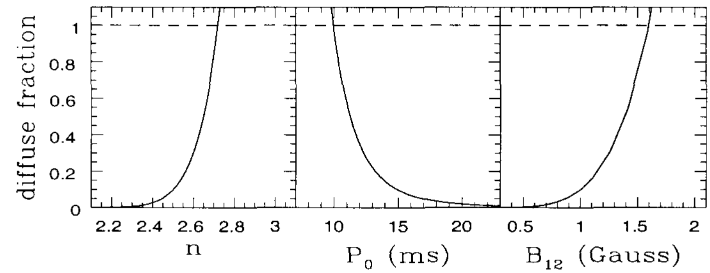

Figure 1. The fraction of OSSE diffuse flux attributable to undetected pulsars as a function of n, P_0, and B_{12}.

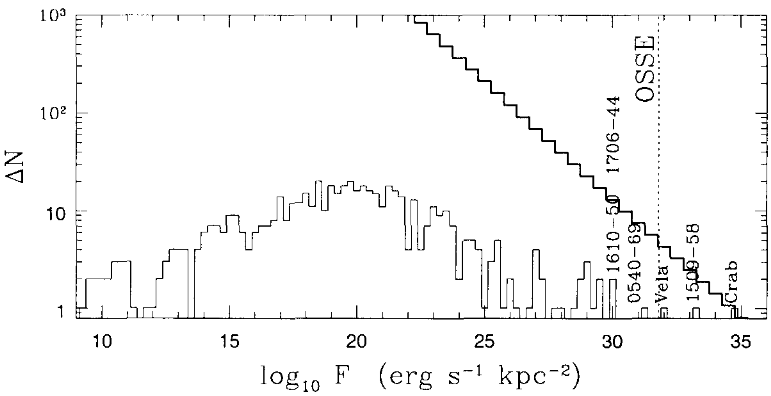

Figure 2. The thin solid line shows predicted OSSE fluxes for known pulsars. The thick solid line shows predicted OSSE pulsar fluxes for our model. The dotted line shows OSSE's sensitivity.

EGRET (10 MeV - 1 GeV): We again find a well-defined maximum in the log likelihood, leading to a best luminosity law of

$$L = 10^{32.0} P^{-1.9} {B_{12}}^{1.5} \text{ ergs/s}. \tag{4}$$

The EGRET law varies much more slowly in P and B_{12} than the OSSE law, suggesting that different mechanisms are responsible for pulsar low- and high-energy γ-ray emission. Figure 3 shows that undetected pulsars are likely not an important contributor to the EGRET diffuse background. Figure 4 shows that EGRET should have detected roughly 80 pulsars as steady sources. This number is tantalizing, as 74 of the 169 unidentified EGRET sources are within 10 degrees of the Galactic plane, and pulsars are the only known Galactic γ-ray emitting point source population. We therefore suggest that as many as half of the unidentified EGRET sources may be GRPs. As searches for pulsars of unknown period are not possible with the sparse EGRET data, detecting these unidentified sources as pulsars will likely have to wait for GLAST, a more sensitive EGRET-energy instrument with a predicted launch date of 2005. According to our model, GLAST should detect roughly 1000 GRPs as steady sources, al-

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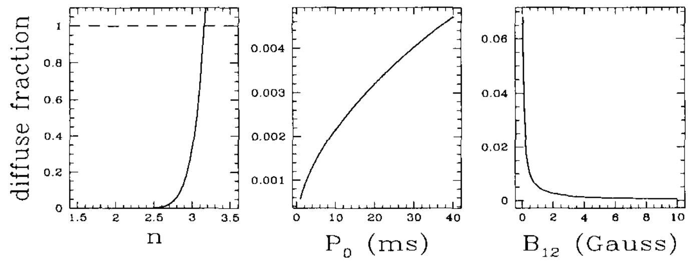

Figure 3. The fraction of EGRET diffuse flux attributable to undetected pulsars as a function of n, P_0, and B_{12}.

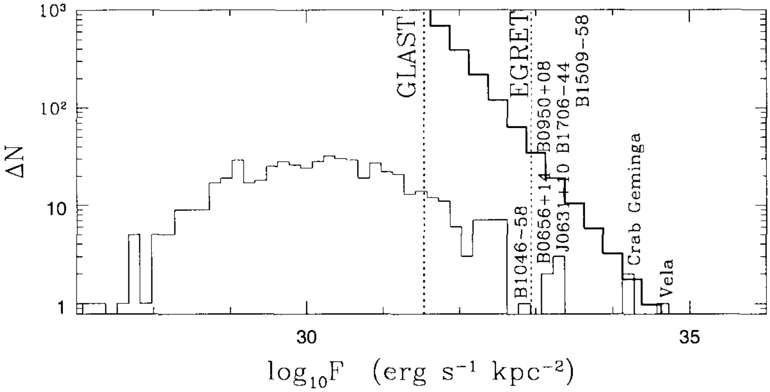

Figure 4. The thin solid line shows the predicted EGRET fluxes for known pulsars. The thick solid line shows the predicted pulsar flux distribution of our model. EGRET's sensitivity and the predicted sensitivity of GLAST are shown.

lowing us to form a complete picture of the pulsar population. About 100 of these pulsars are currently known radio pulsars. Comparing their radio and γ-ray pulse profiles will enable us to determine the GRP emission mechanism and the relationship between radio and high-energy pulsar beams. An detailed article on GRP luminosities is being prepared (Mclaughlin & Cordes 1999).

References

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