Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 2 (OG part 1), pages 855–858

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Gamma-Ray Pulsar Candidates for GLAST

L. GUILLEMOT[1], ON BEHALF OF THE GLAST LAT COLLABORATION
PRESENTED BY M. LEMOINE-GOUMARD[1]
[1]*CENBG, Université Bordeaux 1 - CNRS - IN2P3, Chemin du Solarium, 33175 Gradignan, France*
guillemo@cenbg.in2p3.fr

Abstract: The Gamma-ray Large Area Space Telescope (GLAST) will be operating in early 2008, and its Large Area Telescope (LAT) is expected to discover scores to hundreds of γ-ray pulsars. This paper discusses which of the nearly 1800 known pulsars, mostly visible only at radio frequencies, are likely to emit γ-rays above 100 MeV with intensities detectable by the LAT. A figure of merit used to select γ-ray pulsar candidates is $\sqrt{\dot{E}}/d^2$, where $\dot{E}$ is the energy loss due to rotational spindown, and d is the distance to the pulsar. The figure of merit incorporates spin-down flux at earth (proportional to $\dot{E}/d^2$ times efficiency, assumed proportional to $1/\sqrt{\dot{E}}$). A few individual objects are cited to illustrate the issues. Since large $\dot{E}$ pulsars also tend to have large timing noise and occasional glitches, their ephemerides can become inaccurate in weeks to months. To detect and study the γ-ray emission the photons must be accurately tagged with the pulse phase. With hours to days between γ-ray photon arrival times from a pulsar and months to years of LAT exposure needed for good detections, GLAST will need timing measurements throughout the continuous γ-ray observations. The paper describes efforts to coordinate pulsar timing of the candidate γ-ray pulsars.

Introduction: which pulsars might emit gamma rays above 100 MeV ?

Nearly 1800 pulsars are currently listed in the ATNF Pulsar Catalog [1]. Seven of them were detected with high confidence as γ-ray pulsars with instruments on the Compton Gamma Ray Observatory, and three others were seen with lower confidence. The GLAST Large Area Telescope (LAT) is expected to increase the number of known γ-ray emitting pulsars with estimates ranging from dozens (see [2]) to hundreds (see [3]). Good knowledge of pulsar ephemerides (that is, of rotational periods and period derivatives) is needed to detect γ-ray pulsars efficiently. In order to focus on the best candidates and hence have high-precision ephemerides for them, a figure of merit has been chosen, motivated by theoretical considerations and empirical observations of γ-ray pulsars [4]:

$$\frac{\sqrt{\dot{E}}}{d^2} = \frac{\dot{E}}{d^2} \times \frac{1}{\sqrt{\dot{E}}} = \frac{1}{d^2}\sqrt{4\pi^2 I \frac{\dot{P}}{P^3}}$$

In this expression, $\dot{E}$ denotes the energy loss due to the pulsar spindown, d is the distance to the pulsar, and I is the moment of inertia of the neutron star. The factor $\dot{E}/d^2$ is the energy flux of the pulsar at Earth and $\dot{E}^{-1/2}$ is the γ-ray radiation efficiency. This efficiency for conversion of spindown energy into emission as a function of V, the open field line voltage, (proportional to $\sqrt{\dot{E}}$) is plotted for the high-confidence and low-confidence CGRO pulsars in Figure 1.

Pulsars may not be detectable as gamma-ray emitters when $\dot{E}$ falls below 3×10^{34} erg/s, the lowest value for the known γ-ray pulsars. **The following cut-off value has been chosen:**

$$\dot{E} > 10^{34} erg/s$$

This cut-off leads to a list of **224 candidates for γ-ray emission**. These candidates are then sorted

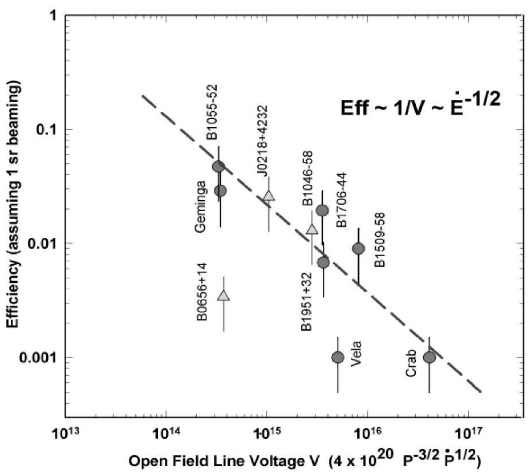

Figure 1: Efficiency for conversion of spindown energy into high-energy radiation, for the high-confidence (circles) and lower-confidence (triangles) γ-ray pulsars, as a function of the open field line voltage, $V \propto \sqrt{\dot{E}}$ [2].

by $\sqrt{\dot{E}}/d^2$. The values of this figure of merit for the γ-ray emitting pulsar candidates are plotted in Figure 2.

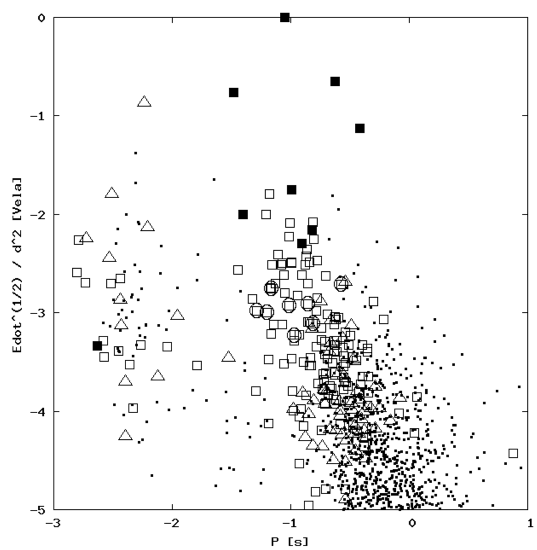

Figure 2: Gamma-ray pulsar candidates for GLAST LAT. Squares: $\dot{E} > 3 \times 10^{34}$ erg/s (main candidates). Triangles: $\dot{E} > 10^{34}$ erg/s (secondary candidates). Dots: other pulsars. Full squares: EGRET pulsed detections and candidates. Circled squares: EGRET un-pulsed sources.

Timing campaigns for GLAST

A study of J2229+6114, only known at the end of the CGRO mission, through the EGRET data archives, could not find any significant evidence of a possible pulsation, for EGRET photon dates were too old compared to the ephemerides [5]. This is a concrete example of GLAST's need for contemporaneous timing measurements. Good ephemerides will enhance the number of detectable pulsars substancially.

Pulsar ephemeris collaboration

Three radio telescopes will routinely time (that is to say, calculate ephemerides) for the bulk of the 224 γ-ray candidates: the Parkes observatory in the southern sky, the Jodrell and Nançay telescopes in the north. The most sensitive but less available instruments such as Green Bank Telescope or Arecibo will be involved in timing pulsars which are difficult to detect in radio, or in performing deep searches for radio counterparts to γ-ray sources, pulsed or un-pulsed, that the LAT will detect. In addition to radio observations, very interesting radio-faint pulsars will be timed in X-rays by the RXTE telescope. In this case only sparse long term monitoring can be considered though. The monitoring must be sustained for 5 to 10 years, a strain for any observatory, so other contributions are welcome.

Gamma-ray candidates

Table 1 and Table 2 are two samples of the list of 224 γ-ray emitting candidate pulsars, sorted by $\sqrt{\dot{E}}/d^2$. Table 1 lists the 7 high-confidence CGRO detections. CGRO pulsars are highly ranked in our list of 224 candidates. In a search for EGRET events with $E > 10$ GeV within 1 degree around the pulsar's position, 5 of these 7 EGRET pulsars can be correlated with these very high energy events (this study is based on [6]). These 7 objects are often associated with supernova remnants (SNR) or pulsar wind nebulae (PWN) as well as with possible HESS counterparts, which reinforces the interest of their study. These pulsars will obviously be prime targets for the upcoming LAT.

On the other hand, Table 2 gathers some other examples of very interesting γ-ray candidates for GLAST. First of all, PSR B0656+14, B1046-58 and J0218+4232 are the three EGRET lower-confidence detections. Apart from the latter, these objects are once again ranked highly in our list. However, the fact that PSR J0218+4232 has a quite medium rank even though it was the first millisecond pulsar (MSP) to be detected in γ-rays seems to indicate a flaw in the figure of merit. Indeed, some parameters are not taken into account, such as the γ-ray beaming solid angle $\Delta\Omega_\gamma$ which affects both flux and luminosity calculations (see e.g. [7]). J0437-4715 and J0537-6910 are millisecond pulsars (MSP) or near millisecond pulsars too (their rotational periods are 5.8 ms and 16 ms respectively). PSR J0437-4715 is ranked fourth but it has no obvious 3EG counterpart and no EGRET photon above 10 GeV can be attributed to this pulsar. The latter has the largest spindown energy loss ($\dot{E}$) in our list. Both the "outer gap" and the "polar cap" models predict detectable γ-ray emission from millisecond pulsars (see [8], [9] and [10]). The other pulsars in this list can be associated to EGRET photons above 10 GeV within one degree, as well as with third EGRET catalog possible counterparts, PWN, SNR or HESS sources (the energy range covered by HESS often enables detections of Pulsar Wind Nebulae. High-energy emission from PWN are supposed to be powered by the high-energy emission from a pulsar in its core so it might be a good indicator of a possible γ-ray detection of a pulsar), making these objects other prime γ-ray emitting candidates for the LAT.

Conclusion

We have used a figure of merit to discriminate between pulsars and guess which pulsars might be good γ-ray emitting candidates. It seems to be a good indicator for known γ-ray pulsars are often ranked highly but the case of PSR J0218+4232 is an exception, so we will hedge our bets. Indeed, we will search for pulsed γ-ray emission from a sampling of all types of pulsars for which we have accurate ephemerides.

References

[1] http://www.atnf.csiro.au/research/pulsar/psrcat
[2] D. J. Thompson, arXiv:astro-ph/0312272v1 (2003)
[3] M. A. McLaughlin, J. M. Cordes, *ApJ* **538**, 818 (2000)
[4] J. Arons, *A & A Suppl.* **120**, 49 (1996)
[5] D. J. Thompson, arXiv:astro-ph/0112518 (2002)
[6] D. J. Thompson, D. L. Bertsch, R. H. O'Neal, *ApJSS*, **157**, 324 (2005)
[7] Z. J. Jiang, L. Zhang, *ApJ* **643**, 1130 (2006)
[8] T. Bulik, B. Rudak, J. Dyks, *MNRAS* **317**, 97 (2000)
[9] L. Zhang, K. S. Cheng, *A & A* **398**, 639 (2003)
[10] A. K. Harding, V. V. Usov, A. G. Muslimov, *ApJ* **622**, 531 (2005)
[11] R. C. Hartman, et al., *ApJSS*, **123**, 79 (1999)
[12] http://www.mpi-hd.mpg.de/hfm/HESS/

Rank $\sqrt{\dot{E}}/d^2$	Name	$\dot{E}$ (erg/s)	$>$ 10 GeV EGRET events	3EG association	PWN/SNR association	HESS association
1	B0833-45	6.92e+36	5	3EG J0834-4511	SNR:Vela	HESSJ0835-456
2	J0633+1746	3.25e+34	10	3EG J0633+1751	GRS:Geminga	
3	B0531+21	4.61e+38	10	3EG J0534+2200	SNR:Crab	
6	B1706-44	3.41e+36	8	3EG J1710-4439	SNR:G343.1-2.3	
10	B1951+32	3.74e+36	2		PWN:CTB 80	
14	B1509-58*	1.77e+37			SNR:G320.4-1.2	HESS J1514-591
39	B1055-52	3.01e+34		3EG J1058-5234		

Table 1: Pulsars detected by CGRO with high-confidence, sorted by $\sqrt{\dot{E}}/d^2$. $> 10GeV$ *EGRET events*: γ rays with measured energy above 10 GeV within 1 degree and associated with only one pulsar. *3EG association*: possible counterpart in the third EGRET catalog. *PWN/SNR association*: possible association with a Pulsar Wind Nebula or a SuperNova Remnant. *HESS association*: possible HESS counterpart. (*): PSR B1509-58 was only seen by COMPTEL below 10 MeV. Above 100 MeV, EGRET failed to detect this object. References: [6], [11], [12]

Rank $\sqrt{\dot{E}}/d^2$	Name	$\dot{E}$ (erg/s)	$>$ 10 GeV EGRET events	3EG association	PWN/SNR association	HESS association
4	J0437-4715	1.19e+34				
5	B0656+14	3.81e+34			SNR:Monogem Ring	
12	J1747-2958	2.51e+36	5	3EG J1744-3011	PWN:Mouse	HESS J1745-303
20	B1046-58	2.01e+36		3EG J1048-5840	PWN:puppy	
22	J1811-1925	6.42e+36	3		SNR/PWN:G11.2-0.3	
45	B1727-33	1.23e+36	9			
59	J2229+6114	2.25e+37		3EG J2227+6122	PWN	HESS J1813-178
73	B1830-08	5.84e+35	6			
94	J0218+4232	2.44e+35		3EG J0222+4253		
121	J0537-6910	4.88e+38			SNR:N157B	

Table 2: Same as Table 1 for other pulsars of interest for GLAST, sorted by $\sqrt{\dot{E}}/d^2$.