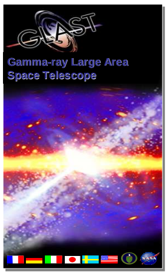

Gamma-Ray Pulsar Candidates for GLAST

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Abstract

The Gamma-ray Large Area Space Telescope (GLAST) will be launched less than a year from now, and its Large Area Telescope (LAT) is expected to discover scores to hundreds of gamma-ray pulsars. This poster discusses which of the nearly 1700 known pulsars, mostly visible only at radio frequencies, are likely to emit >100 MeV gamma rays with intensities detectable by the LAT. The main figure of merit used to select gamma-ray pulsar candidates is $\dot{E}^{1/2}/d^2$, where $\dot{E} = dE/dt$ 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 $\dot{E}^{1/2}/d^2$) times efficiency, assumed proportional to $1/\dot{E}^{1/2}$. A few individual objects are cited to illustrate the issues. Since large dE/dt 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 gamma-ray emission the photons must be accurately tagged with the pulse phase. With hours to days between gamma-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 gamma-ray observations.

Which pulsars might emit gamma rays above 100 MeV ?

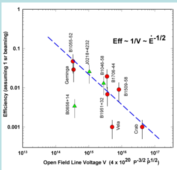

Figure 1: Efficiency for conversion of spindown energy into high-energy radiation, for the high-confidence (red dots) and lower-confidence (green triangles) gamma-ray pulsars, as a function of open field line voltage V. This trend cannot extend much below 10^{14} V without violating the total available energy.

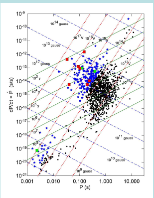

Figure 2: Candidate pulsars in the Period vs. period derivative diagram from the ATNF catalog, showing some derived parameters. Red: high-confidence gamma-ray pulsars; Green: lower-confidence gamma-ray pulsars; **Blue: best candidates for GLAST LAT.**

Of the 1627 pulsars currently listed in the ANTF Pulsar Catalog, seven were detected with high confidence as gamma-ray pulsars with instruments on the Compton Gamma Ray Observatory, and three others were seen with lower confidence. The GLAST Large Area Telescope (LAT), with its unprecedented sensitivity, is expected to increase the number of known gamma ray emitting pulsars substantially (with estimates ranging from dozens, Thompson, 2003, up to hundreds, McLaughlin and Cordes, 2000).

In order to succeed in discovering gamma-ray emission from known pulsars, it will be essential to have high-precision ephemerides: that is, for a typical pulsar, an uncertainty on its period ΔP < 2% of P, maintained over a long period of observation. Hence, it is important to determine which of the 1627 pulsars may be potential gamma-ray sources.

Motivated by theoretical considerations and empirical observations of gamma-ray pulsars (Arons, 1996), we have chosen as a measure of gamma-ray detectability a quantity :

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

In this expression, $\dot{E}$ denotes the energy loss due to the pulsar spindown, d the distance to the pulsar, I the moment of inertia of the neutron star, and V the open field line voltage. The factor $\dot{E}/d^2$ is the available energy of the pulsar at Earth and $\dot{E}^{-1/2}$ is the gamma-ray radiation efficiency (see Figure 1). Pulsars are expected to stop being gamma ray emitters when $\dot{E}$ falls to a « death-line » which is somewhere below 3×10^{34} erg/s, the lowest value for any of the known gamma-ray pulsars. The following cut-off has been chosen :

$$\dot{E} > 1 \times 10^{34} \text{ erg/s}$$

This choice leads to a list of 215 candidates for gamma-ray emission, shown in the pulsar period vs period derivative diagram in Figure 2. These candidates are then sorted by $\dot{E}^{1/2}/d^2$ (Fig. 3). A few examples are cited below.

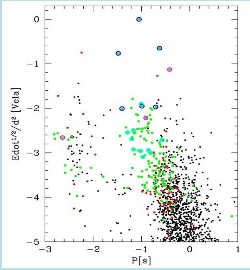

Figure 3: Gamma-ray pulsar candidates for GLAST LAT. The figure of merit is scaled to the value for the Vela pulsar.

- The green dots have $\dot{E} > 3 \times 10^{34}$ ergs/s -- Primary GLAST LAT candidates.
- The red dots have $3 \times 10^{34} > \dot{E} > 1 \times 10^{34}$ ergs/s -- Possible GLAST LAT candidates
- Black dots are lower $\dot{E}$ pulsars -- probably not of interest, even when close.

Other indicators of detected or possible gamma-ray activity:

- Blue ring = EGRET pulsed detection
- Purple RIng = EGRET pulsed candidate
- Cyan Ring = EGRET unpulsed source

GLAST needs contemporaneous timing measurements

With a large effective area (~10000 cm² at 1 GeV), a narrow point spread function, and a large field of view (>2.4 sr), GLAST will record enough photons for gamma-ray pulsation searches far more sensitive (for 1 year, 4×10^{-9} ph/cm²/s (E>100 MeV)) than EGRET's and should detect scores to hundreds of large $\dot{E}$ radio pulsars. Figure 4 illustrates GLAST's superior source localization. However, timing noise also scales with Pdot and timing ephemerides become inaccurate within weeks to months for many of the best gamma pulsar candidates (Arzoumanian et al 1994). With GLAST operating in scanning mode, data from pulsars will be accumulated over long time intervals.

The high $\dot{E}$ radio pulsar J2229+6114 discovered at the end of the CGRO mission is a concrete example. A search in EGRET data archives using different methods failed to find significant evidence of pulsation (Figure 5) since the EGRET photons were too few, and too old compared to the ephemerides (Thompson et al., 2002).

Good ephemerides will dramatically enhance the number of detectable pulsars, as well as phase-resolved and multiwavelength studies. GLAST needs timing measurements contemporaneous to the continuous gamma ray observations.

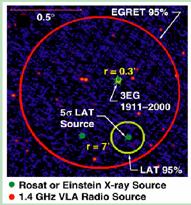

Figure 4 : Comparison of EGRET observations with simulated GLAST LAT error boxes (credit S. Digel).

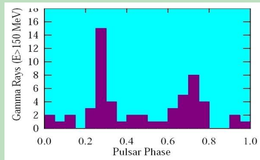

Figure 5: Best EGRET light curve for PSR J2229+6114. After taking N trials into account, the statistical significance of a positive detection is low, and no detection is claimed (Thompson et al., 2002).

Vela Pulsar, #1 Test Case

The Vela pulsar, PSR B0833-45, is the brightest known gamma-ray pulsar (Kanbach et al., 1994). It is surrounded by a pulsar wind nebula (Fig. 6). The variation of the light curve with energy (Fig. 7) suggests multiple components contribute to the pulsed emission. The phase-resolved spectrum (Fig. 8) is a powerful diagnostic measurement for testing pulsar models. The LAT will point at Vela for two weeks during the 60 days of GLAST checkout operations, providing a « standard candle » to test LAT performance.

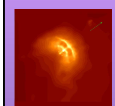

Figure 6: X-ray image of the Vela pulsar surrounded by its pulsar wind nebula, taken with the *Chandra* ACIS. The arrow indicates the proper motion of the pulsar (Pavlov et al., 2000).

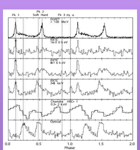

Figure 7: Example of lightcurves in multiple energy bands: gamma rays (EGRET), X-rays (RXTE and *Chandra*) and optical (Harding et al., 2002).

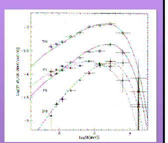

Figure 8: Phase-resolved spectrum of the Vela pulsar (Romani, 1996), showing the total, peak 1, peak 2 and one interpulse region spectra. The EGRET data are from Fierro (1995).

PSR J0218+4232, first of many gamma MSP's ?

PSR J0218+4232 is a millisecond pulsar (MSP) orbiting a low mass white dwarf companion. J0218+4232 is the only MSP with evidence of gamma-ray emission (Fig. 9), using EGRET (Kuiper et al., 2000, 2002). J0218+4232 is close to the blazar 3C66A, which made detection by EGRET difficult. The superior LAT localization will be very helpful to separate the two sources.
Many authors predict gamma ray emission by MSPs (Fig. 10 is an example), because the open field line potential for these is similar to those of the known gamma-ray pulsars.

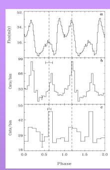

Figure 9: Multiwavelength pulse profiles of PSR J0218+4232. Figure a shows the radio pulse profile at 610 MHz. Figure b shows the X-ray pulse profile, in the 0.8-10 keV band, taken with *Chandra* HRS-C. Figure c shows the EGRET gamma ray pulse profile, in the 0.1-1 GeV band (Kuiper et al., 2002).

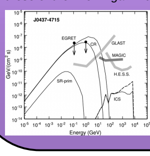

Figure 10: Model of emission from the nearby MSP PSR J0437-4715, compared with EGRET upper limits and GLAST LAT sensitivity (Harding et al. 2005)

Gamma-ray Candidates

An extract of the list of 215 gamma-ray candidate pulsars sorted by normalized expected flux, defined by $(\dot{E}^{1/2}/d^2) / (\dot{E}_{Vela}^{1/2}/d_{Vela}^2)$. Normalizing to Vela is conservative, because Vela has a relatively low efficiency (see Fig. 1). High-confidence gamma-ray detections are in red, and lower-significance ones in green. B1509-58 (*) is seen up to 10 MeV by COMPTEL, but not above 100 MeV by EGRET. Pulsars shown in *italics* have $\dot{E} < 3 \times 10^{34}$ ergs/s and are considered secondary candidates.

Rank	Pulsar Name	Expected Flux (Vela = 1)			
1	**B0833-45**	**1**	25	J1124-5916	0.003804
2	**J0633+1746**	**0.2237**	26	B1259-63	0.003725
3	*J0437-4715*	*0.179*	27	J0834-4159	0.003656
4	**B0531+21**	**0.1717**	*28*	*J1909-3744*	*0.003655*
5	**B0656+14**	**0.07422**	29	B0906-49	0.003502
6	*B0743-53*	*0.05373*	30	J1509-5850	0.003489
7	*J0034-0534*	*0.01902*	31	B1823-13	0.003469
8	J0205+6449	0.01625	32	J1809-1917	0.003409
9	J1747-2958	0.01253	33	J1420-6048	0.003195
10	**B1706-44**	**0.01116**	34	B1800-21	0.003155
11	**B1055-52**	**0.0107**	35	B0114+58	0.00302
12	J1833-1034	0.0101	*36*	*J1046+0304*	*0.00302*
13	J1740+1000	0.009987	37	J2229+6114	0.002857
14	**B1951+32**	**0.009855**	38	J1718-3825	0.002817
15	J1357-6429	0.009241	39	B1727-33	0.002799
16	*B1257+12*	*0.007444*	40	B0740-28	0.002796
17	J1524-5625	0.007306	41	J1617-5055	0.002754
18	**B1509-58***	**0.007017**	42	J1843-1113	0.002746
19	J1531-5610	0.006993	43	B1937+21	0.002591
20	**B1046-58**	**0.006076**	44	J1913+1011	0.002407
21	B0355+54	0.005614	*45*	*J1911-1114*	*0.002357*
22	J0940-5428	0.005072	46	J2043+2740	0.002339
23	J0538+2817	0.004762	47	J1740-5340	0.002265
24	J1930+1852	0.004437	48	J0855-4644	0.002231
			49	**J0218+4232**	**0.0022**
			50	*J2129-5721*	*0.00219*

Cooperative pulsar timing campaigns for GLAST

As for the Compton Observatory (Taylor, 1990), we have an *a priori* list of radio pulsars most likely to be detectable with the GLAST LAT (https://confluence.slac.stanford.edu/display/GLAMCOG/GLAST+LAT+Multiwavelength+Coordinating+Group). Also as before (see e.g. Arzoumanian et al 1994), timing campaigns have begun. However, GLAST's timing needs are substantially greater than EGRET's were:

- The number of known radio pulsars has more than tripled since the CGRO launch.
- The LAT's gamma ray sensitivity will be 25x better than EGRET's.
- GLAST will scan the whole sky continuously during the first year, and generally thereafter: ***All pulsars will be observed all the time***.

Three observatories are currently cooperating with the LAT team for routine timing of most of the gamma ray candidates: Parkes for the southern sky (contact: dick.manchester@ciro.au or simon.johnston@csiro.au), and Jodrell (contact: mkramer@jb.man.ac.uk) and Nançay (contact: icognard@cnrs-orleans.fr) in the north. The most sensitive but less available instruments, Green Bank and Arecibo, will be used for pulsars particularly interesting in gamma rays but difficult to detect in radio, and to perform deep searches for radio counterparts to gamma ray sources that the LAT will detect, pulsed or unpulsed.

We need help from other radio telescopes: the *a priori* list reflects current theoretical prejudices, heavily influenced by the very small number of currently known gamma ray pulsars, yet the LAT will observe *all* radio pulsars so we want valid ephemerides for as many as possible. Some radio-bright, glitch-prone pulsars require more frequent observations. **The monitoring must be sustained for 5 to 10 years, a strain for any observatory.**

A database (http://glast.gsfc.nasa.gov/ssc/dev/psr_tools/) readable by the Science Tools package (http://glast-ground.slac.stanford.edu/workbook/sciTools_Home.htm) will allow analysis of data as they becomes available on the servers (http://glast.gsfc.nasa.gov/cgi-bin/ssc/LAT/DC2DataQuery.cgi) For pulsars more easily detectable in X-rays than in radio, we welcome any help in providing the GLAST LAT with accurate ephemerides.

Those who provide ephemerides used to obtain gamma-ray results will co-author publications. While true that GLAST data become public after the first year, GLAST data analysis is complex, especially for weaker sources not seen during the first year: radio, X-ray and gamma-ray astronomers are all likely to benefit from cooperation.

If you would like to contribute to LAT pulsar timing, please contact the GLAST pulsar IDS (InterDisciplinary Scientist), Stephen Thorsett (thorsett@ucolick.org), the LAT multiwavelength coordinator David Thompson (djt@egret.gsfc.nasa.gov), and/or the "Pulsar, Supernova, and Pulsar Wind Nebula Science Working Group" leaders, Alice Harding (harding@twinkie.gsfc.nasa.gov) and Roger Romani (rwr@astro.stanford.edu).

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