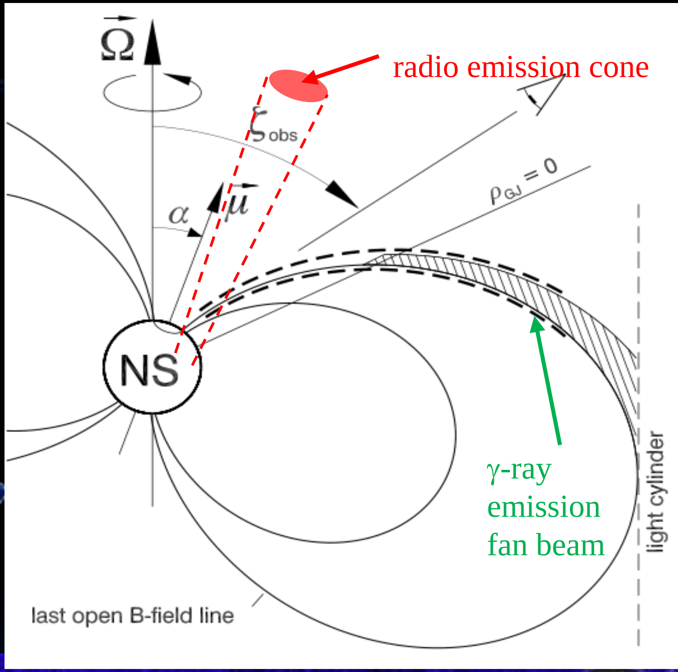
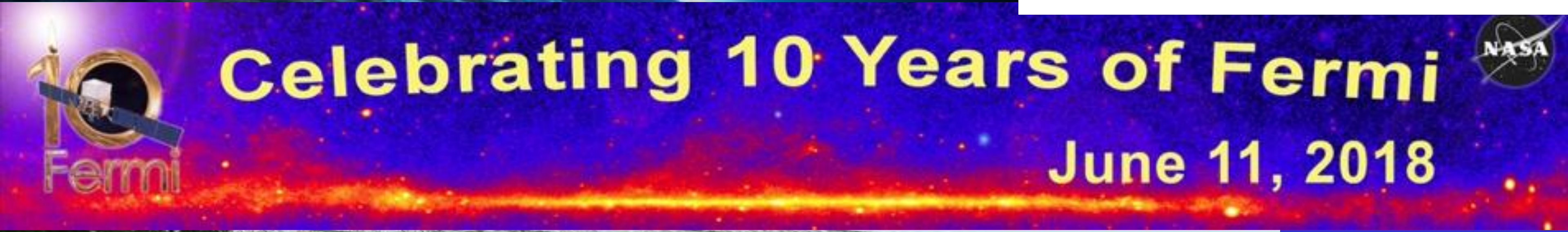
Faint gamma-ray pulsars

Fermi-LAT *collaboration, and Pulsar Timing Consortium*





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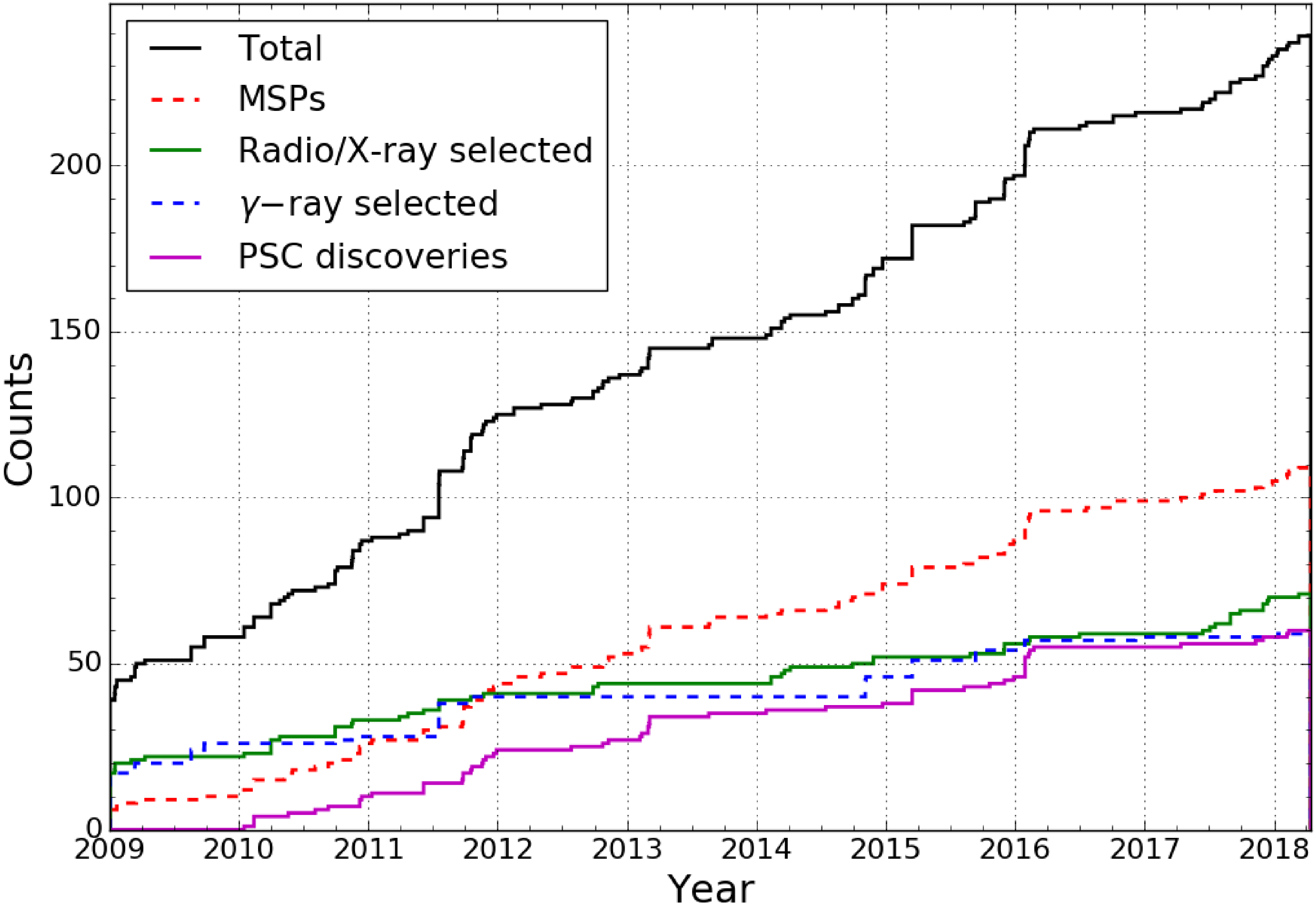
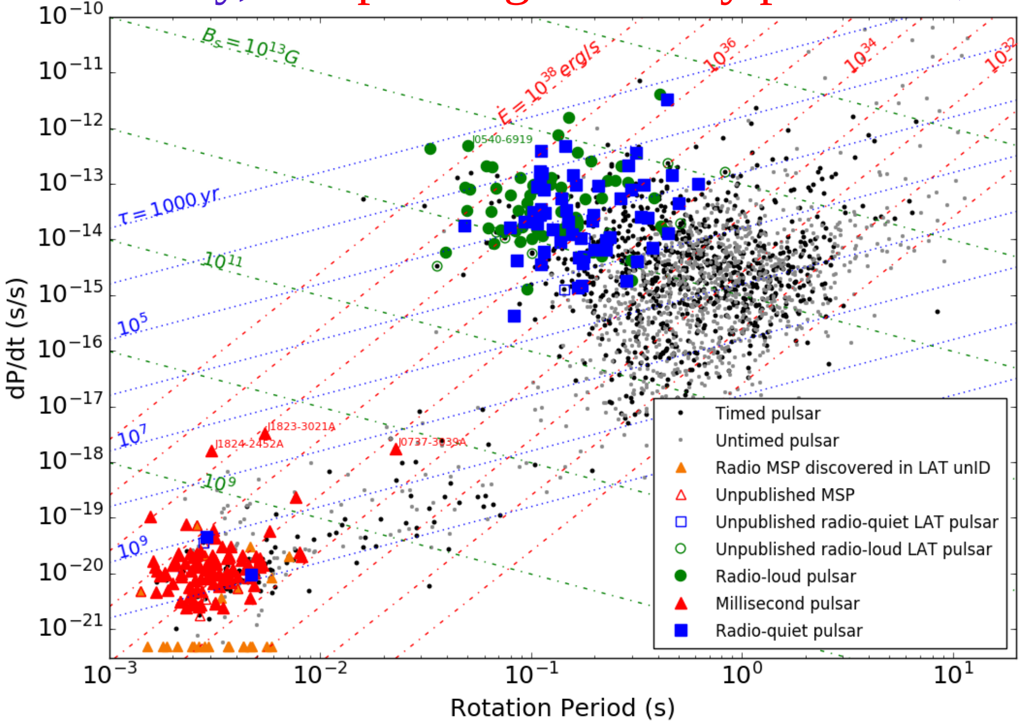
Radio télescope de Nançay

Fermi LAT still detecting ~25 gamma pulsars per year.



Currently, 216 public gamma-ray pulsars* (241 total)

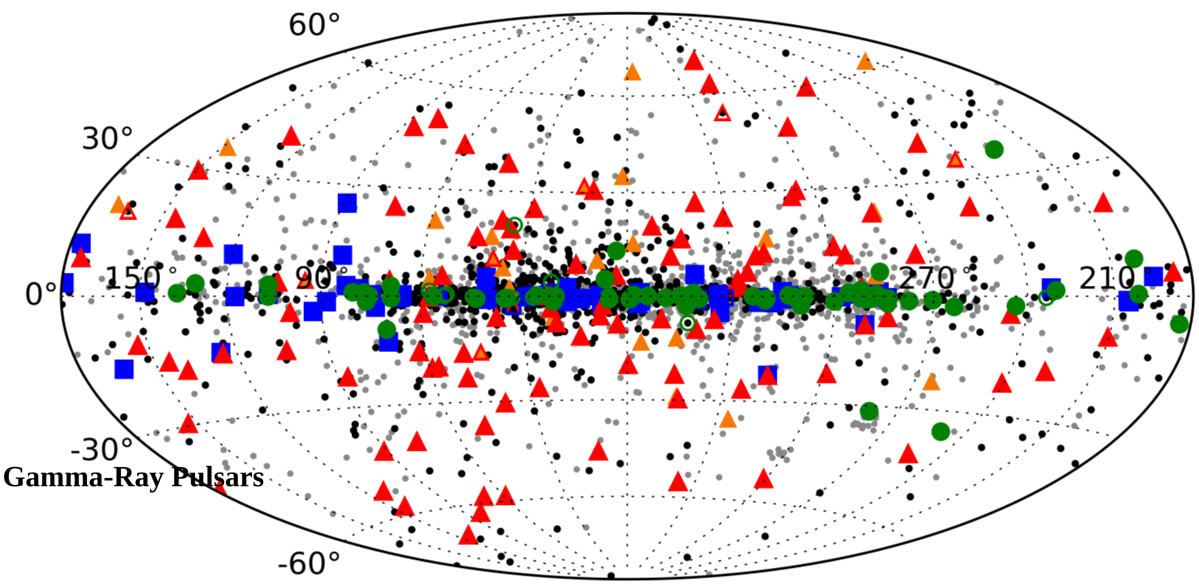


½ are young, ½ are MSPs.

Of the young: ½ radio loud, ½ radio quiet

⅓ already known.
⅔ found from *Fermi* data
(½ radio MSPs, ½ young gamma).

¼ of all known MSPs are gamma MSPs.
For spindown power Ė>5E33 erg/s is >¾ (!)



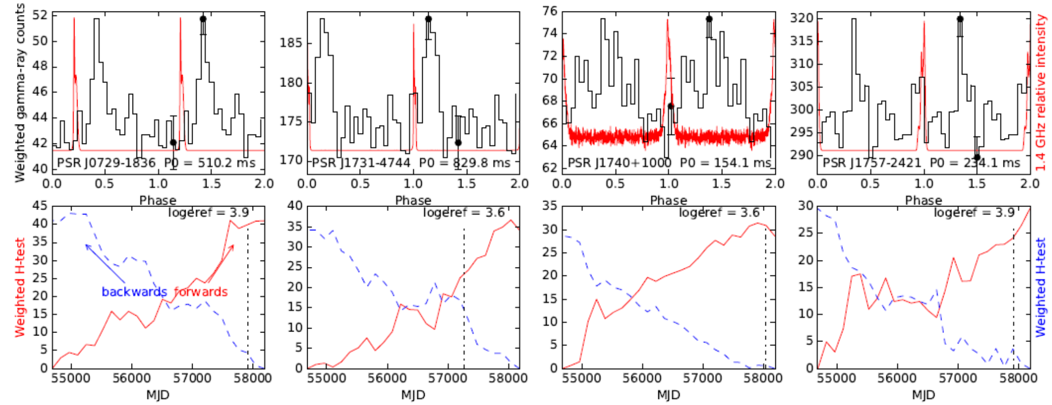
Figures updated from:
The Second Fermi Large Area Telescope Catalog of Gamma-Ray Pulsars
A. A. Abdo et al. 2013, ApJS, 208, 17

*https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

Faint gamma-ray pulsars

• Other groups discover previously unknown pulsars through deep searches of pulsar-like unassociated catalog sources.

• Candidate sources must be relatively γ-bright.

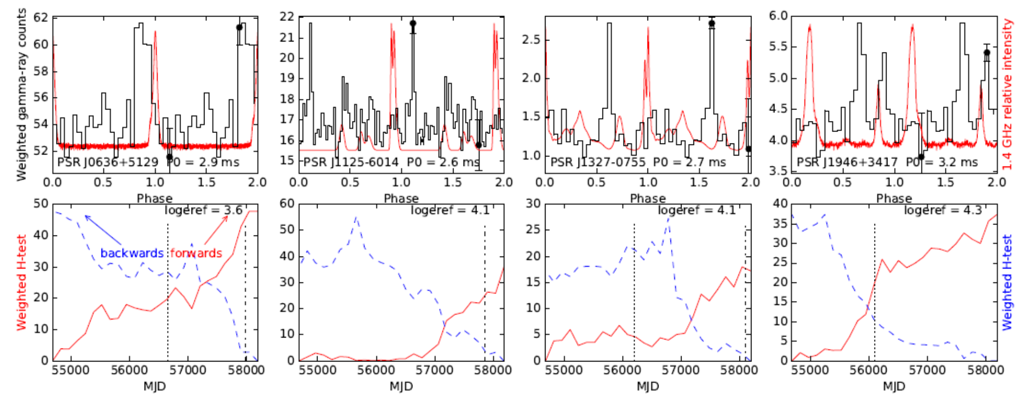


Four recently discovered young gamma-ray pulsars.

• We use timing ephemerides provided by radio (and X-ray) astronomers to calculate the rotational phase of each gamma photon.

• Pulsations show up as a non-flat histogram of the phases.

• For Test Significance > 25 (‘*H-test*’),
<1 false positive detection in this sample.



Four recently discovered gamma-ray millisecond pulsars.

• Bruel (2018) developed a simple but effective way to *weight* the photons. It is as good as Kerr’s method (2011), yet can be applied to pulsars poorly characterized in a phase-integrated analysis.

• *Weighting* : the probability that a photon from a given direction, with a given energy, comes from the pulsar direction (as opposed to background).

(LAT’s point-spread-function has a strong energy dependence.)

The optimal weighting parameter *logeref* depends on the pulsar’s spectral hardness as well as the local background intensity.

We try a small (here: three) number of *logeref* values, and then correct for the number of trials.

Vertical dashed lines show end of ephemeris validity.
9.5 years of LAT data, >50 MeV, within 5° of pulsar position.

Phase-aligned radio pulse superposed on gamma histogram.

Probing the dark corners of parameter space

- *Faint* can simply mean the pulsar is distant.
- Or has high background.

- But it can also mean
  - ➢ it is less luminous than similar pulsars,
  - ➢ or has a softer spectrum,
  - ➢ or that broad peaks make it hard to see.

We search for faint pulsars so that our final sample will reflect the true population.

- Applications include:
  - ➢ Emission modeling.
  - ➢ Population modeling.

Example: how much do unresolved pulsars contribute to the diffuse Galactic emission?

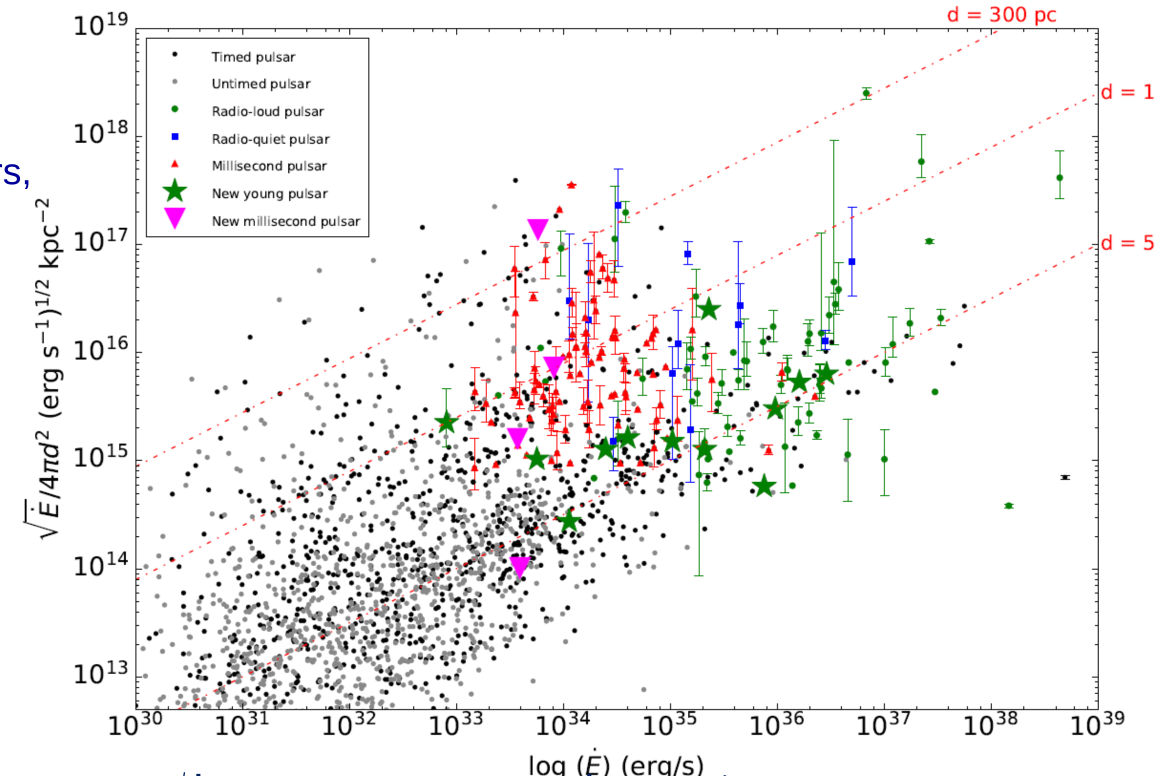


Figure: Gamma-ray luminosity scales roughly as $L_\gamma = \sqrt{\dot{E}}$ for spin-down power $\dot{E} = 4\pi^2 I \dot{P} / P^3$ and moment of inertia $I = kMR^2$. k = 2/5 for a uniform sphere, a bit less for a neutron star. $\sqrt{\dot{E}}/4\pi d^2$ is a useful L_γ forecaster.

Out of ~2800 known pulsars (all dots), we gamma-folded 1260.
Colored (black) symbols: gamma-pulsations (un-)detected. (Distances unknown for most radio-quiet pulsars.)

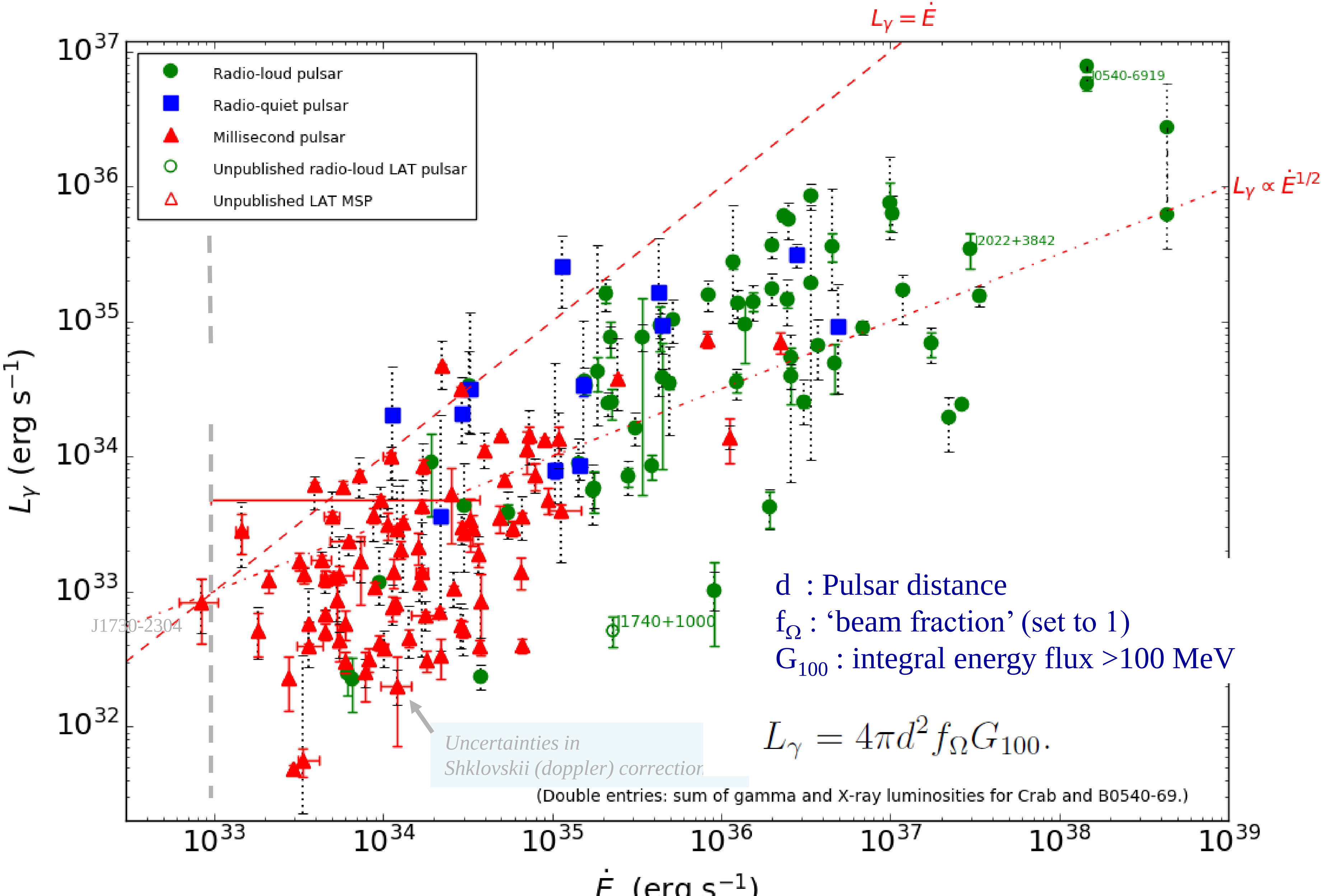
Gamma-ray emission mainly ceases below $\dot{E} \sim 10^{33}$ erg/s, but most pulsars in that range are far.

The left-most star, discovered during this work, lowered the known deathline.

Smith, Bruel, Cognard et al, ApJ in preparation.

End.

Gamma-ray luminosity versus spindown power



d : Pulsar distance

f_Ω : 'beam fraction' (set to 1)

G_{100} : integral energy flux >100 MeV

$$L_\gamma = 4\pi d^2 f_\Omega G_{100}.$$

Update of 2PC Fig 9 [1].

The observable timing parameters of pulsars are:

The spin period **P** $= 1/\nu = 2\pi/\Omega$

Slowdown rate, $\dot{P} = dP/dt$

A magnetic dipole with the size/mass of a neutron star, loses energy by electromagnetic braking.

> Spin-down power: $\dot{E} = 4\pi^2 I \dot{P} / P^3$
>
> $I = kMR^2$ is the moment of inertia. $k = 2/5$ for a uniform sphere, but…

Physical parameters can be approximated:

Characteristic age : $\tau = \frac{1}{2} P / \dot{P}$

Surface B field: $B = 3.2 \times 10^{19} (P \dot{P})^{1/2}$ **Gauss**

Open field line voltage $V = 4 \times 10^{20} \dot{P}^{1/2} P^{3/2}$ **Volts** $\propto \sqrt{\dot{E}}$

Size of "speed of light" cylinder $R_L = 5 \times 10^9 P$ **cm**

Extrapolate log N-log S

Estimate the contribution of unresolved pulsars.

Search hard for faint γ sources in the G.C. region, then confirm via deep radio searches.

Future (meerkat, SKA) sensitivity required.

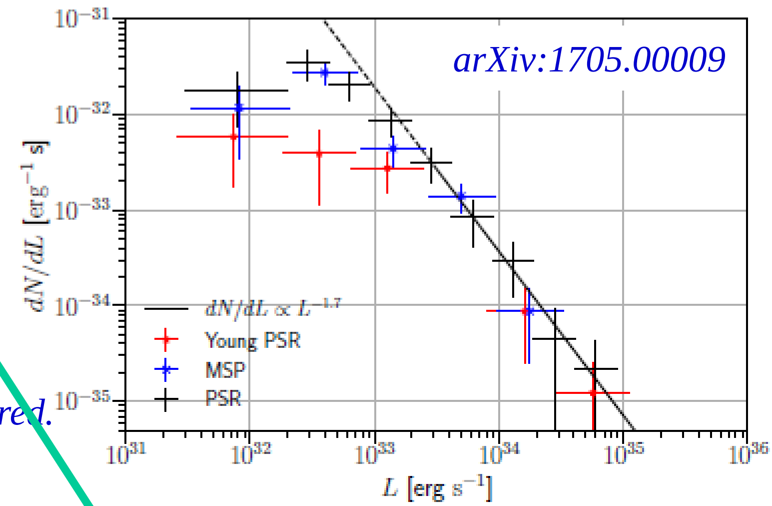
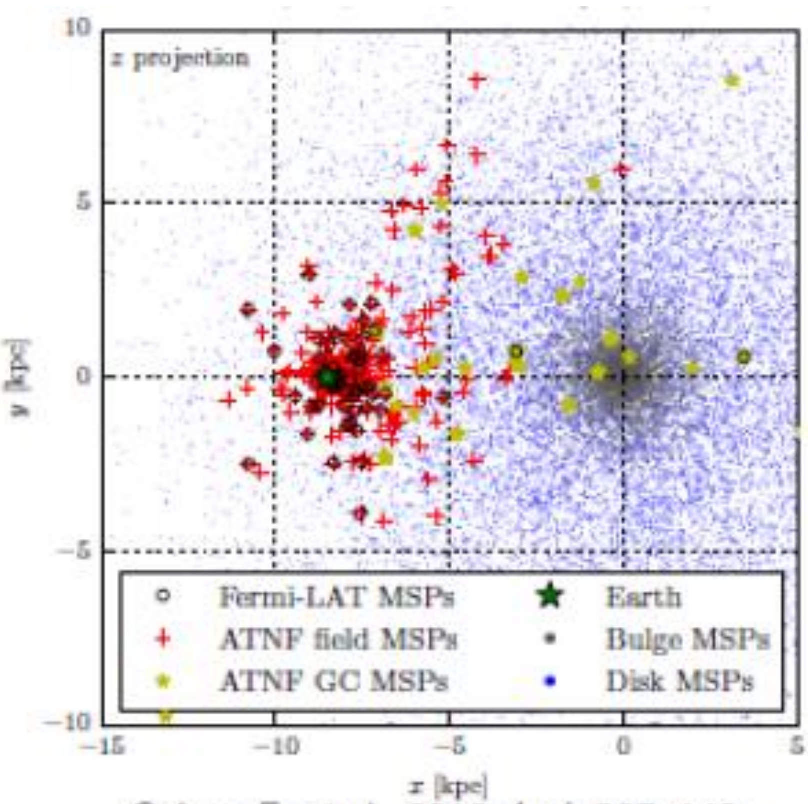


Figure 9. Observed luminosities for young PSRs (red data), MSPs (blue data) and the whole population of PSRs with $d < 1.5$ kpc (black data). The best fit to the luminosity distribution for $L > 3 \times 10^{33}$ erg s^{-1} is also reported (black line). The luminosity is integrated over the energy range [0.3, 500] GeV.

Model a putative MSP bulge population.



Calore, F., et al., 2016, ApJ, 827, 143

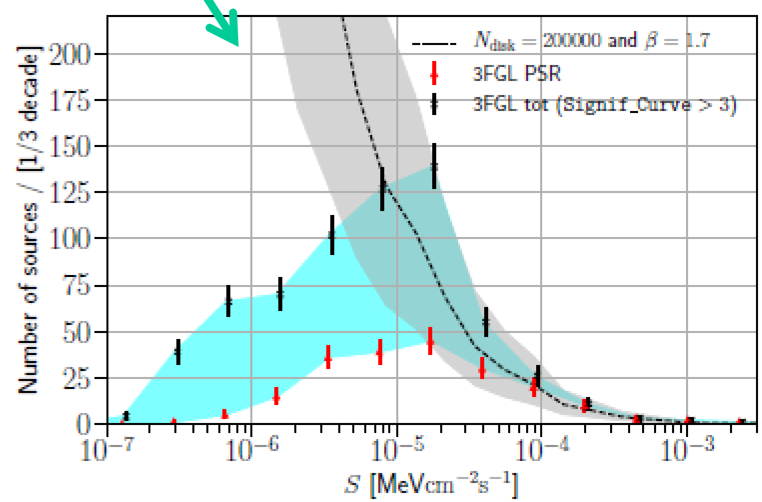


Figure 10. Flux histogram of 3FGL PSRs alone (red triangles) or added to the flux distribution of unassociated 3FGL sources with curvature Signif_Curve > 3 (black points). The cyan band represents the region between the lower limit (already detected PSRs) and upper limit (3FGL PSRs plus unassociated 3FGL sources with detected spectral curvature). Finally the black curve (gray band) represents the benchmark (band between the minimum and maximum) number of disk PSRs. The flux is integrated over the energy range [0.3, 500] GeV.