Pulsar striped wind emission

A multi-wavelength and population synthesis perspective

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Summary

Outline

Objectives & Methods

Objectives

- constrain the geometry of the pulsar and observer line of sight.
- identify the γ-ray emission mechanisms.
- localize the associated photon production sites.

Methods

- good sample of young radio-loud γ-ray pulsar light-curves.
- some with additional radio polarization constraints from RVM model.
- but RVM not useable for millisecond pulsars (MSP) (use only γ-rays).
- γ-ray emission based on the striped wind.

Results

- γ-ray light-curves and radio polarization modelling to deduce the geometry.
- study of the whole γ-ray pulsar population in the striped wind framework.

Outline

2 Emission sites and model

Possible sites for pulsed emission

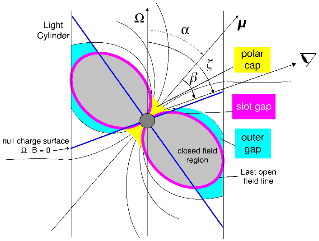


Fig.: *Emission models.*

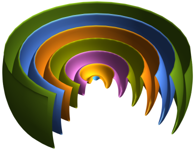


Fig.: *Pulsar striped wind.*

Basic picture

- magnetosphere filled with $e^{\pm}$ plasma corotating with the neutron star up to the light-cylinder.
- corotation charge $\rho_{\rm GJ} \approx -2\,\varepsilon_0\,\vec{\Omega} \cdot \vec{B}$.
- no acceleration in regions where $\rho = \rho_{\rm GJ}$ because $E_{||} = 0$.
- but acceleration in regions where $\rho \neq \rho_{\rm GJ}$ because $E_{||} \neq 0$.

Four important sites

- polar cap: star surface R.
- slot gap: from R to $r_{\rm L}$.
- outer gap: from null-line to $r_{\rm L}$.
- striped wind: outside $r_{\rm L}$.

Location of gaps tells you where emission comes from.

Emission model

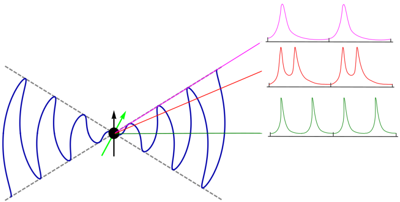


Fig.: *Striped wind emission model* ***(Mochol, 2017)****.*

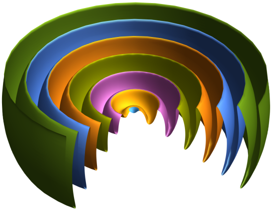


Fig.: *Pulsar striped wind current.*

Essentially two parameters to fit

1. magnetic dipole inclination α.
2. observer line of sight inclination ζ $(= \alpha + \beta)$.

Computation of γ-ray pulse profile depending on α and ζ.

γ-ray atlas (striped wind) depending on $\{\alpha, \zeta\}$

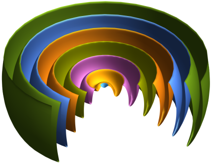
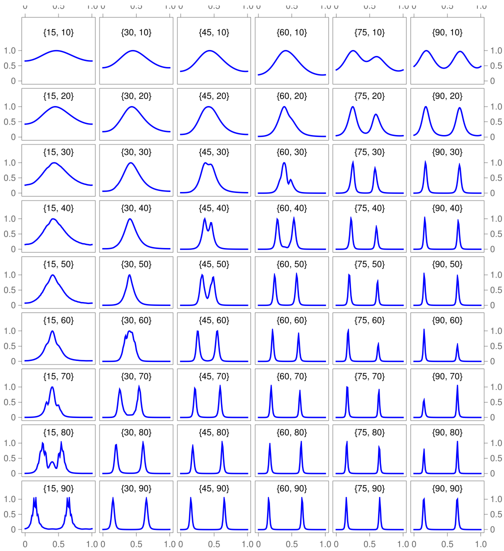


Fig.: *γ-ray photons coming from the striped wind (outside the magnetosphere).*

(Pétri, 2024)



Atlas of γ-ray light curves for $\alpha = \{15^\circ, 30^\circ, 45^\circ, 60^\circ, 75^\circ, 90^\circ\}$ from left to right column and $\zeta = \{0^\circ, ..., 90^\circ\}$ in steps of 10° in the format $\{\alpha, \zeta\}$.

Young pulsar sample: Best fit from polarization and γ-rays

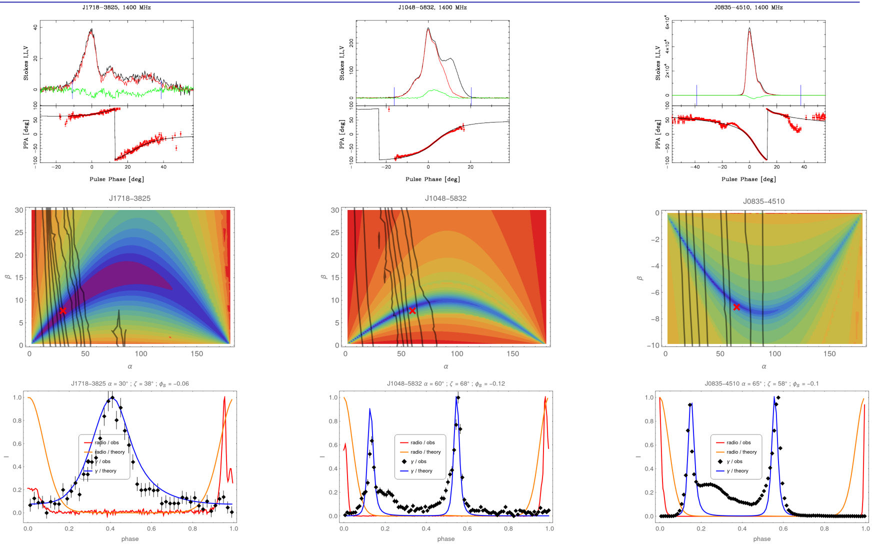


Fig.: *Best fit from polarization and γ-rays.*

(Pétri & Mitra, 2021)

Young pulsar sample: Best fit from γ-rays only

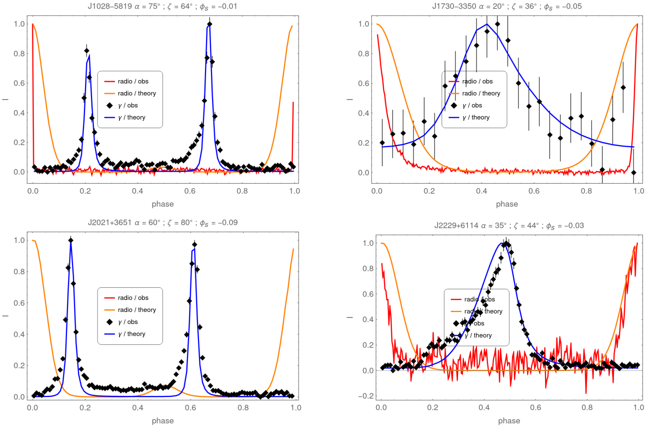
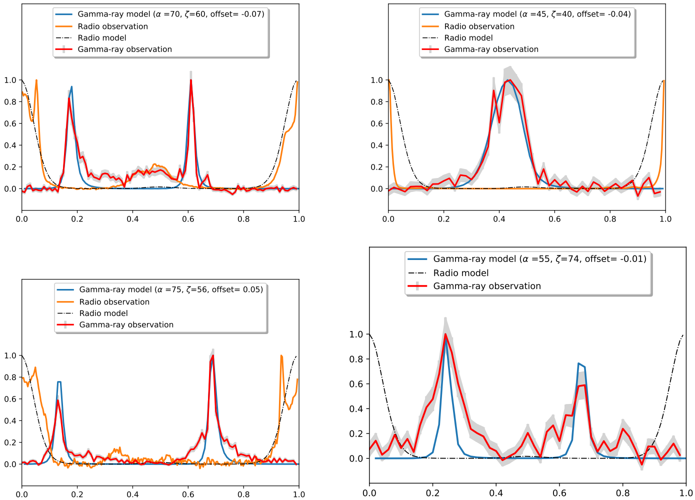


Fig.: *Best fit parameters and γ-ray light-curves for the second part of the young radio loud γ-ray pulsar sample not having usable RVM fits.*

(Pétri & Mitra, 2021)

MSP pulsar sample: Best fit from γ-rays only



(Benli et al., 2021)

Outline

Radio and γ-ray pulsar populations

- evolve isolated pulsars according to state-of-the-art modelling (force-free magnetosphere, magnetic obliquity evolution, magnetic field decay).
- $P(t), \chi(t), B(t), \vec{r}(t)$.
- compute radio and γ-ray fluxes.
- use telescope sensitivities for detectability.

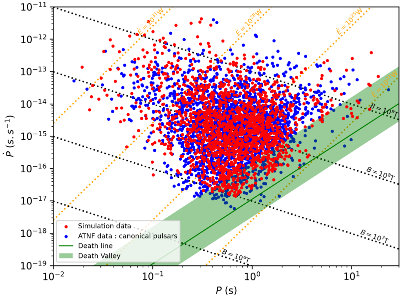


Fig.: *$P - \dot{P}$ diagram of the radio pulsars, observations in blue & simulations in red.*

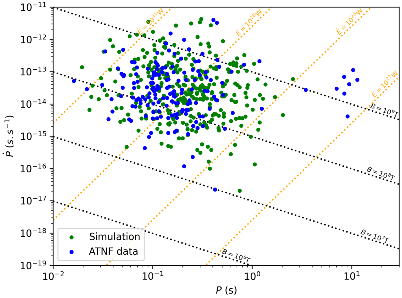


Fig.: *$P - \dot{P}$ diagram of the γ-ray pulsars, observation in blue & simulations in green.*

(Sautron et al., 2024)

Radio and γ-ray pulsar population

- radio and γ-ray pulsars well reproduced by the model.
- γ-ray light curve peak separation Δ statistics similar to observations.
- increasing Fermi/LAT sensitivity by $\times 10$ leads to $7\times$ more γ-ray pulsars detected.

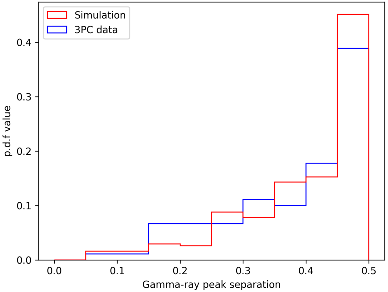


Fig.: *γ-ray peak separation, observations in blue vs simulations in red.*

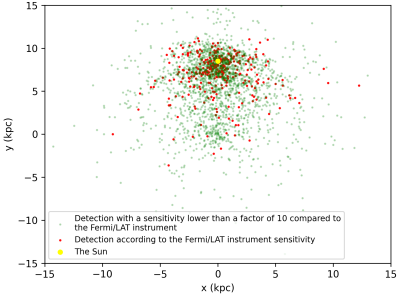


Fig.: *γ-ray pulsars position in the Milky Way, in red for Fermi sensitivity and in green for a 10 times higher sensitivity instrument.*

(Sautron et al., 2024)

Statistics of radio and γ-ray pulsars: a simple model

- simulate a sample of 10 millions pulsars with an isotropic or uniform distribution of obliquity χ but an isotropic distribution in viewing angle ζ.
- no spin evolution, no spatial velocity, no spatial distribution.
- population not evolved from birth to present time.

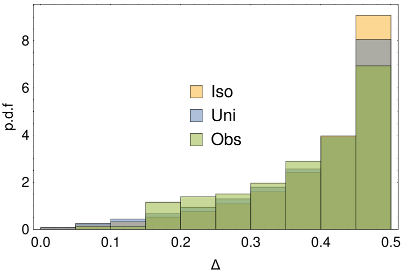


Fig.: *γ-ray peak separation from the 3PC observations (Obs) in green vs. model prediction for isotropic (Iso) obliquity distribution in orange and uniform (Uni) distribution in blue.*

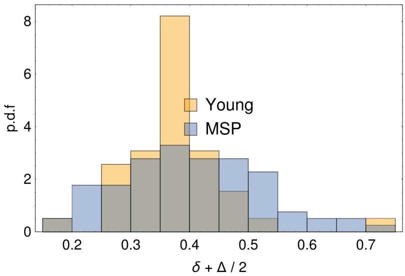


Fig.: *Relation between time lag δ and peak separation Δ from 3PC.*

The simplest striped wind model predicts

$$\delta + \Delta/2 \approx 0.5 \,.$$

(Pétri, 2024)

Fraction of radio and γ-ray pulsars vs radio beam opening

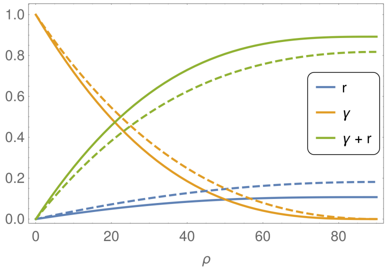


Fig.: *Fraction of radio-only pulsars (r), γ-only pulsars (γ), and radio-loud γ-ray pulsars (r+γ) vs radio beam cone half-opening angle, ρ. Solid/dashed line for isotropic/uniform χ distribution.*

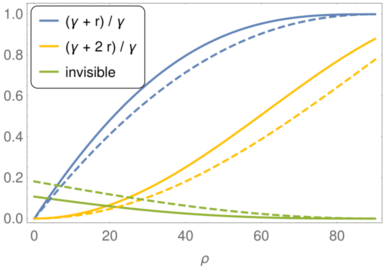


Fig.: *Fraction of radio-loud γ-ray pulsars with one peak $(\gamma + r)/\gamma$ and two peaks $(\gamma + 2r)/\gamma$ and a fraction of invisible pulsars (not detected in either r or γ).*

- radio beam opening angle ρ controls the fraction of radio pulsars detected.
- a lot more γ-ray pulsars detected than radio pulsars.

(Pétri, 2024)

Outline

Conclusions & Perspectives

Results of time-aligned radio and γ-ray pulse profiles

- very efficient to constrain the geometry of the magnetic dipole.
- radio polarization reduces even more the uncertainties.
- striped wind model for γ-ray consistent with multi-wavelength modelling.
- γ-ray pulsar population from 3PC reproduced with the striped wind.

Perspectives

- extension to VHE in the TeV range.
- compute the phase-resolved spectra in GeV/TeV.
- 4FGL catalogue contains hundredth of unknown sources: how many γ-ay pulsars?

Thank you

Outline

References

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