A unified polar cap/striped wind model for pulsed radio and gamma-ray emission in pulsars

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Summary

1. The striped wind

2. Relation between geometry and light-curves

3. Gamma-ray luminosity

4. Conclusion & perspectives
1. The striped wind

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4. Conclusion & perspectives
The structure of the striped wind

Near the star:
- a magnetic dipole

At large distances:
- striped wind (Bogovalov 1999)

\[ \vec{\mu}, \vec{\Omega}, \zeta \]

- \( \vec{\Omega} \): rotation axis
- \( \chi \): magnetic axis inclination with respect to \( \vec{\Omega} \)
- \( \zeta \): line of sight inclination with respect to \( \vec{\Omega} \)

- hot and magnetized plasma in the sheet
- relativistic beaming \( \Gamma_{\text{vent}} \gg 1 \)

\[ \Rightarrow \] pulsed emission

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Multi-wavelength emission of pulsars

ESAC, Madrid, 22-24 may 2013
High-energy emission from gamma-ray pulsars

Objectives
- high-energy pulsed emission (MeV/GeV)
- spectral variability of several gamma-ray pulsars.

Processes
- synchrotron radiation from hot and magnetized plasma in the stripe
- inverse Compton with target photons
  - cosmic microwave background, CMB
  - synchrotron photons from the nebula, X-ray
- thermal emission from the neutron star surface, black body with $T_{bb} \approx 10^6$ K
- photons from companion star

Applications
- isolated pulsars => gamma ray pulsars
- binary pulsars => PSR B1259-63

Link to other wavelengths ?
- polar cap for radio emission : phenomenological
- striped wind for optical up to gamma rays
  \[ \Rightarrow \text{geometry could be defined (} \chi \text{ and } \zeta \). \]
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The striped wind

Relation between geometry and light-curves

Gamma-ray luminosity

Conclusion & perspectives
Relation between radio and gamma-ray pulses: phase-plot

Radio time lag and gamma-ray peak separation

From pure geometric considerations

**Gamma-ray peak separation $\Delta$**

$$\cos(\pi \Delta) = |\cot \zeta \cot \chi|$$

**Radio time lag $\delta$**

$$\delta \approx \frac{1 - \Delta}{2}$$

Main results

- **S-shape** around $\zeta = 90^\circ$ reflects emission from current sheets
- two symmetrical spots corresponding to emission from the two polar caps (north & south pole separated by half a period)
- several light-curve combinations possible depending on geometry $\chi, \zeta$

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- No radio/gamma pulse!

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![Graph showing gamma-ray pulse profile](image)

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![Graph](image)


**Only gamma**
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![Graph showing light-curve combinations](image)

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![Graph showing light-curve combinations](image)

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![Graph showing light curves with $\chi = 72^\circ, \zeta = 145^\circ$](image)

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1. no radio/gamma pulse !
2. only radio
3. only gamma
4. one radio + one/two gamma-ray pulse(s)
5. two radio pulse
   => perpendicular rotator, $\zeta \approx \chi \approx 90^\circ$

Radio and gamma-ray light-curve fitting

PSRJ0218+4232

PSRJ0437-4715

PSRJ2021+3651

PSRJ2229+6114

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Multi-wavelength emission of pulsars

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What about luminosities?

Assumptions

- synchrotron emission in the stripe
- radiative cooling compensated by reheating due to magnetic reconnection

Main results

- the predicted luminosity function

\[ L_\gamma \approx 2 \times 10^{26} \text{ W} \left( \frac{L_{sd}}{10^{28} \text{ W}} \right)^{1/2} \left( \frac{P}{1 \text{ s}} \right)^{-1/2} \]

- condition for pulsed emission

\[ \frac{L_{sd}}{P} \geq 10^{27} \text{ W/s} \]

**Force-free magnetosphere**

### Perpendicular rotator

Equatorial magnetic field lines for the orthogonal rotator

### Spin-down luminosity

Oblique rotator

\[ L_{sp} \approx \frac{3}{2} L_{\text{dip}} (1 + \sin^2 \chi) \]  

\[ \Rightarrow \text{more realistic formula than the magnetodipole in vacuum.} \]

\[ \Rightarrow B_\perp \text{ AND } B_\parallel \text{ constrained.} \]

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Conclusions & perspectives

Pulsed emission

- **high-energy pulsed emission** emanating from regions well outside the light cylinder, \( r \approx (\text{few} - 100) r_L \).
- **gamma-ray luminosities** from Fermi/LAT second source explained by **synchrotron emission in the stripe**.

Further investigations

- link between **asymptotic toroidal magnetic field** and magnetosphere \( \Rightarrow \) location where most of the high-energy pulsed emission is expected.
- phase-resolved polarisation properties in X-ray (Crab ?)
- possible explanation for gamma-ray binaries?
- deeper multi-wavelength study (anticorrelation in radio and X-rays flux, Hermsen et al., Science, 2013)