High energy radiation of low energy neutron stars called electrospheres

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LUTH Observatoire de Paris | PSL cnrs

Outline

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Pulsars

- Compact objects:
  $R \sim 12$ km and
  $M \sim 1.4\mathrm{M}_{\odot}$.

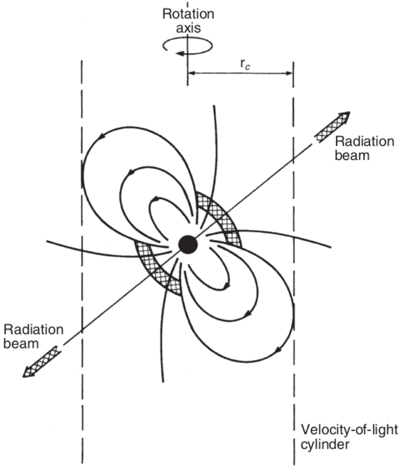

Figure 1: Pulsar magnetosphere. Credits: [Lyne, 2012].

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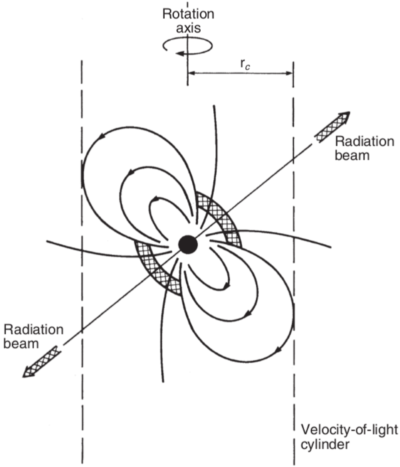

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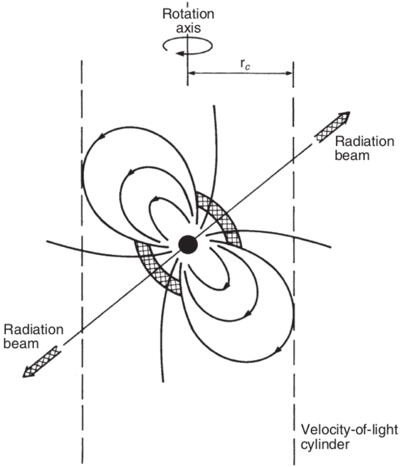

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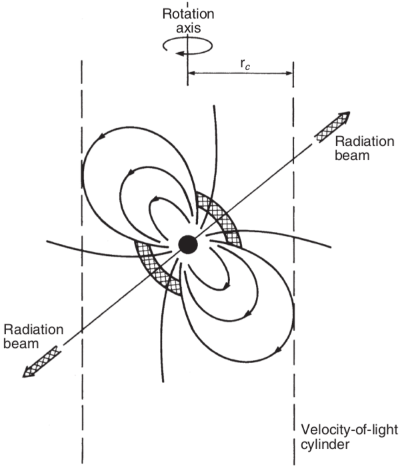
- Light cylinder radius:
  $\boxed{R_L = \frac{Pc}{2\pi}}$.



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Pulsar classification and electrospheres

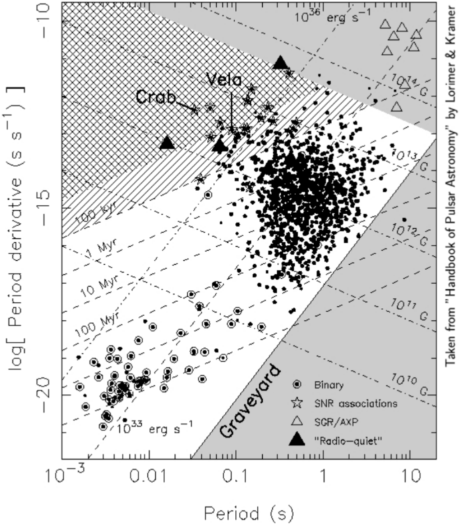

Figure 5: Credits: [Manchester et al., 2005]

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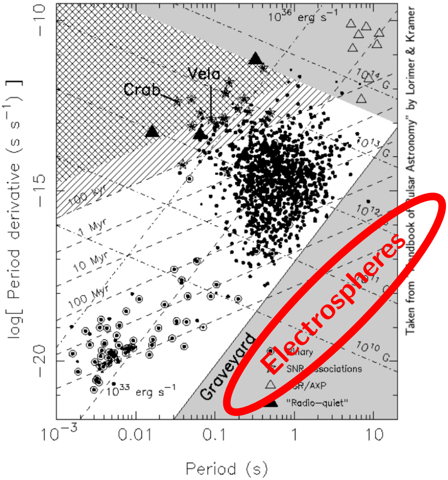

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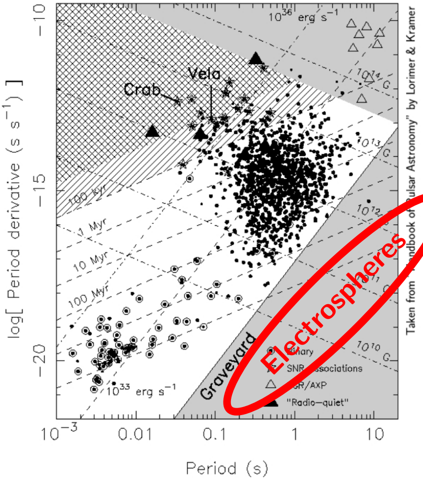

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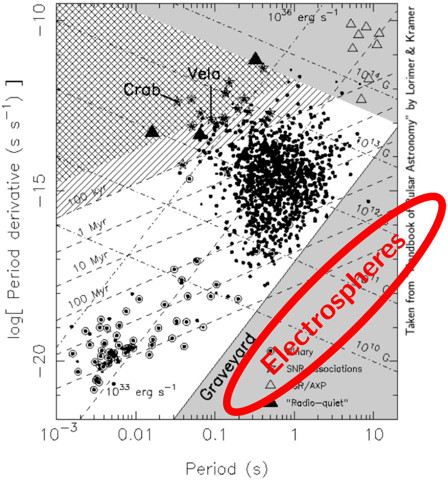

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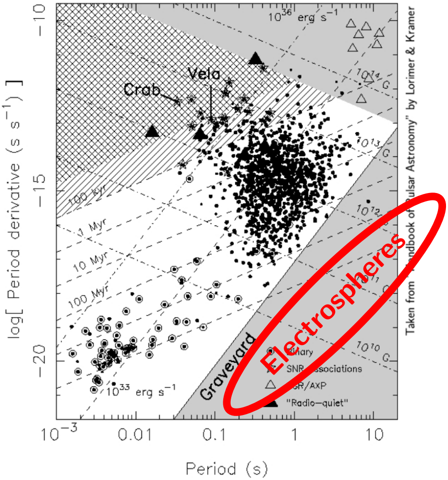

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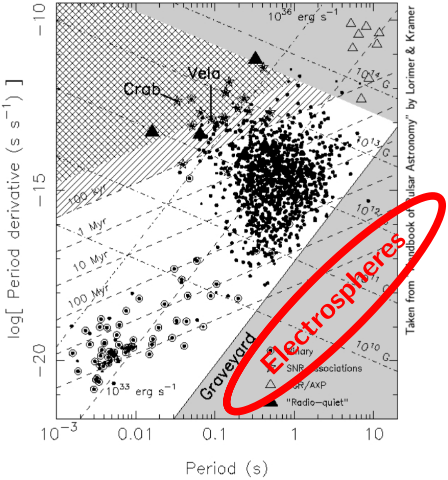

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$\Rightarrow$ Gamma-ray transparent.

Outline

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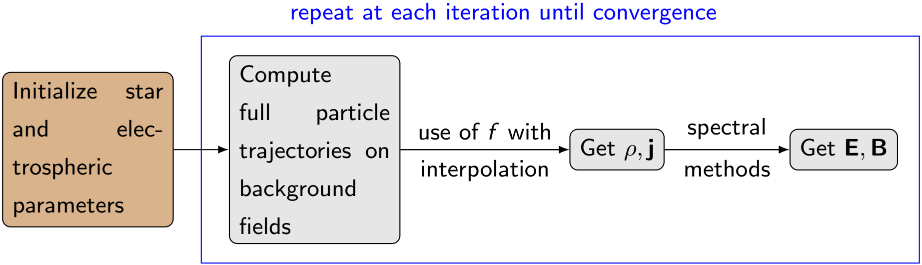
Pulsar Aroma [Mottez, 2024] computes self-consistent stationary solutions of electrospheres.



- f: distribution function of the particles
- ρ: charge density; $\mathbf{j}$: current density
- $\mathbf{E}$: electric field; $\mathbf{B}$: magnetic field

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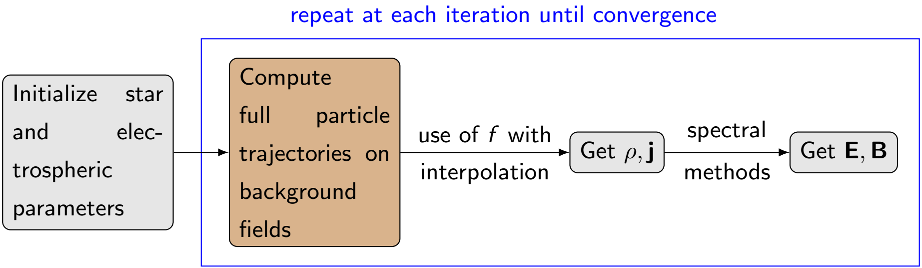

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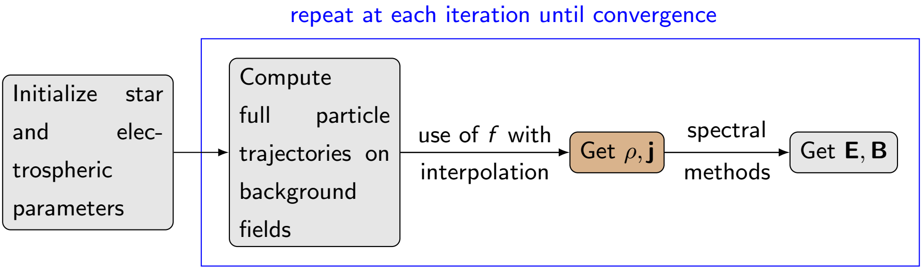

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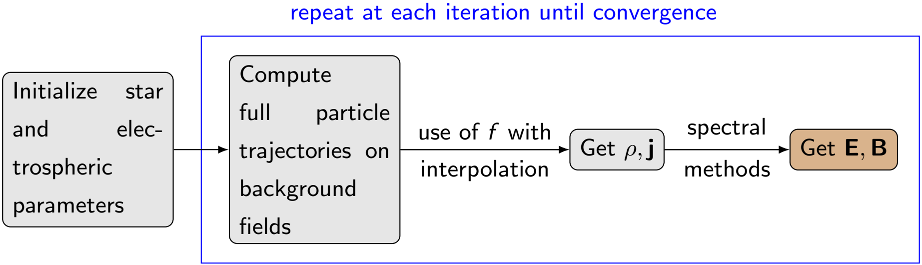

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Example of numerical solution

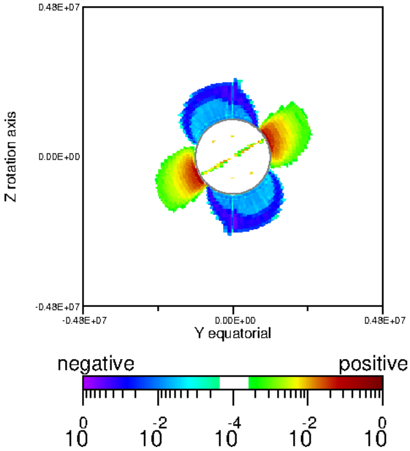

Figure 6: Charge density (left), parallel electric field (right). $B = 10^{11}$ G, $P = 5$ s and $i = 30^{\circ}$.

Radiative processes: modelling emission

The single particle spectrum (e.g. [Rybicki, 1979]) is multiplied by the number of emitters $N(\mathbf{r})$,

$$\mathscr{P}_\nu(\mathbf{r}) = \int_0^{+\infty} \frac{\sqrt{3}q^2\gamma}{cT} \mathrm{F}(x) \frac{\partial N(\mathbf{r},\gamma)}{\partial\gamma} \mathrm{d}\gamma \quad . \tag{1}$$

- $\mathrm{F}(x) = x \int_x^{+\infty} \mathrm{K}_{\frac{5}{3}}(\xi)\mathrm{d}\xi$, Westfold function
- $x = \frac{\nu}{\nu_c}$ with ν_c the critical frequency
- $T = \frac{2\pi a}{c}$, the period associated to the motion along the circle of radius a

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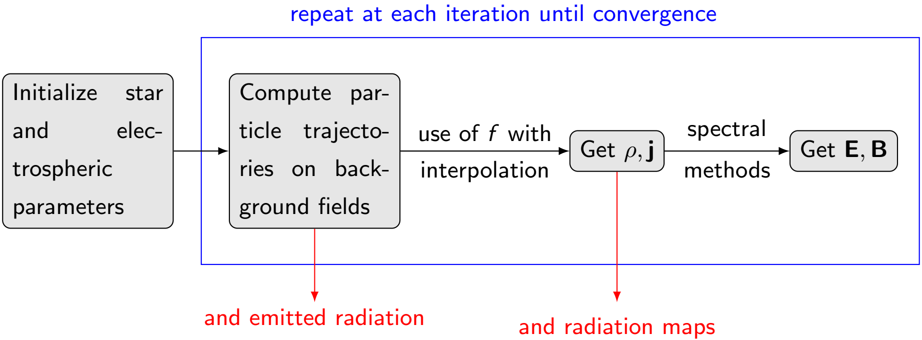

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Spectra

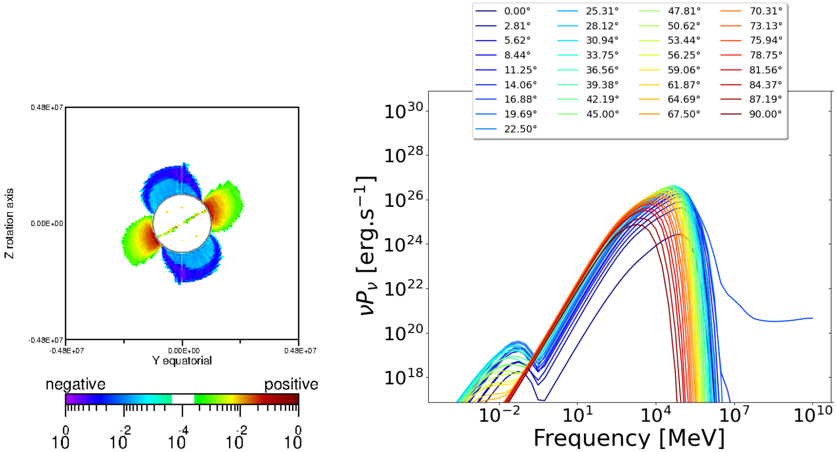
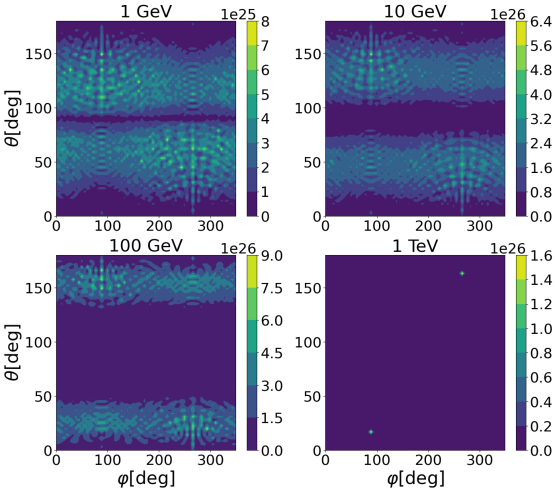


Figure 7: Charge density (left) and spectral energy density at different line of sight average over one period (right). $B = 10^{11}$ G, $P = 5$ s and $i = 30^\circ$.

Maps at various energies



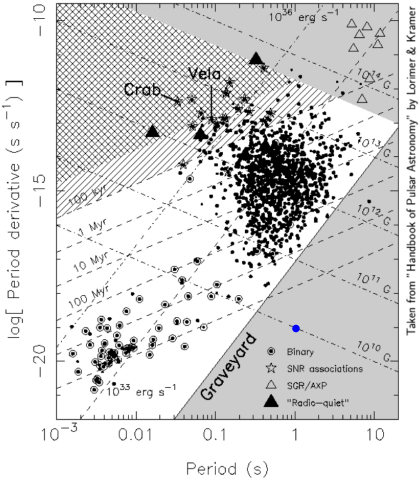
$\longrightarrow$ shallow structures reminiscent of pulses

Figure 8: Spectral energy, νP_ν $\left[\mathrm{erg\,s^{-1}}\right]$ density maps at infinity

Can we observe electrospheres collectively ?

B (G)	P (s)	L_γ (erg s^{-1})
10^{10}	1	8.927×10^{27}
10^{11}	5	3.589×10^{28}
10^{12}	10	8.935×10^{29}

Table 1: Luminosities of various electrospheres in the 0.1-100 GeV band averaged over one period. $i = 30^\circ$ and $R = 12$ km.



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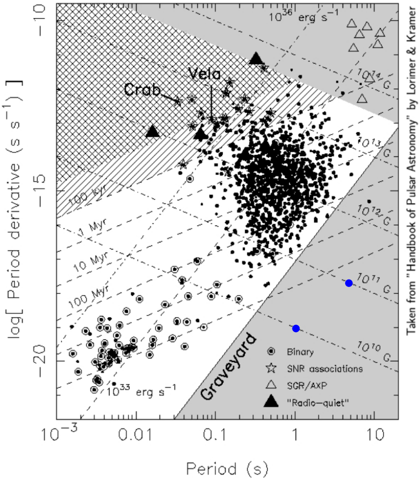

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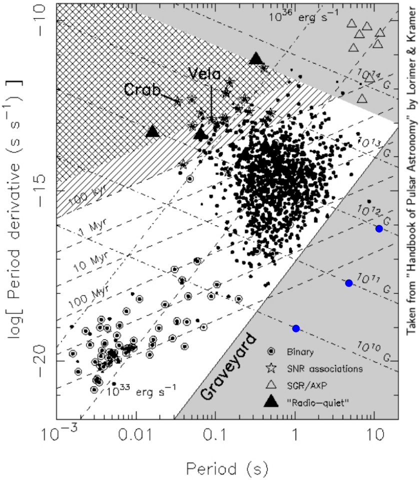

Can we observe electrospheres as a whole group ?

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- Much lower than pulsar luminosties ($L_\gamma \gtrsim 10^{33}$ $\mathrm{erg\,s^{-1}}$).
- The typical FERMI-LAT sensitivity threshold for gamma-ray pulsar detection in the 0.1-100 GeV band is $\sigma \sim 10^{-12}$ $\mathrm{erg\,s^{-1}\,cm^{-2}\,sr^{-1}}$.

Can we observe electrospheres collectively ?

- Estimated flux of an electrosphere with an average gamma-ray luminosity $L_\gamma \sim 10^{28}$ erg s^{-1}, located at an average distance of 8.5 kpc:

$$F \sim 1 \times 10^{-18}\,\mathrm{erg\,s^{-1}\,cm^{-2}\,sr^{-1}} \approx 6 \times 10^{-16}\,\mathrm{GeV\,s^{-1}\,cm^{-2}\,sr^{-1}} \quad .$$

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$\Longrightarrow$ **Consequences**:

1. diffuse gamma-ray background;
2. contribution to the high energy tail (10-50 GeV) of the Galactic Center Excess (e.g. [Linden et al., 2016]) ?

Conclusion and discussion

- Spectra peak at or above 10 GeV.
- Faint pulse-like structures.
- Possibly detectable as a diffuse gamma-ray flux but population dependent and the number of electrospheres in the Galaxy is very uncertain.
- Very preliminary study, should be refined with low pair creation regime, synchro-curvature radiation for example.

Thank you for your attention !

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