Ultra-Magnetized White Dwarfs and High-Energy Emission

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"Compact Stars in the QCD phase diagram V" and "Working Group 2 Meeting of COST Action MP1304"

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Outline

Motivation

- Why only few SGRs/AXPs emit in radio?
- Electromagnetic emission models in neutron stars and white dwarfs pulsars: the effect of the radius.
  - Polar Cap Model and Outer Gap Model
- Application to SGRs/AXPs.
- White Dwarfs Pulsars: Sources of ultra high energetic photons.

Models of electromagnetic emission

- **There are two basic standard models associate with pair $e^{\pm}$ production and emission of radiation in compact stars.**

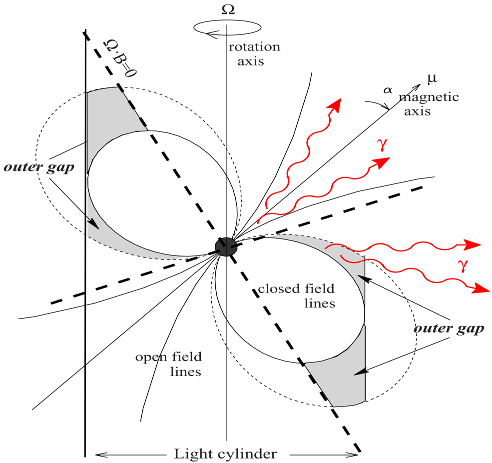

Figure: (REA; TORRES, 2011)

Polar Cap Model

- **The first process is the polar-cap model, where electrons are accelerated on the stellar surface emitting γ-rays by curvature radiation**

$$\hbar\omega \simeq \frac{3}{2}\frac{\hbar\gamma^3}{r_c}, \tag{1}$$

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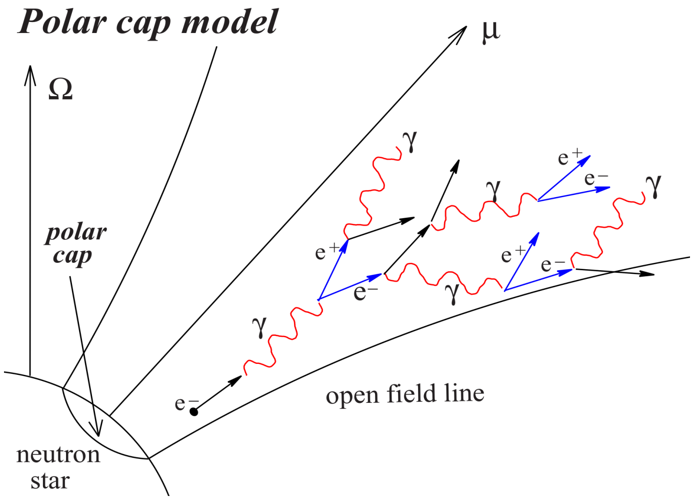
where r_c is the curvature radius

- **In this model the condition to pair production is given by**

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_\mathrm{c}} \geq \frac{1}{15}. \quad (2)$$

Polar Cap Model



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$$B(r) = B_{\mathrm{p}} R^3 / r^3 \tag{3}$$

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- **There is a minimum photon frequency given by the frequency of infrared photons IR**

$$\omega_c \approx \gamma_{\parallel}^{3} \frac{m^5 c^9}{e^7} \Omega^2 B^{-3}, \tag{4}$$

and a maximum frequency

$$\omega_{\rm max} \approx \frac{e^{15}}{\gamma_{\parallel} \hbar m^9 c^{15}} \Omega^{-4} B^7 \tag{5}$$

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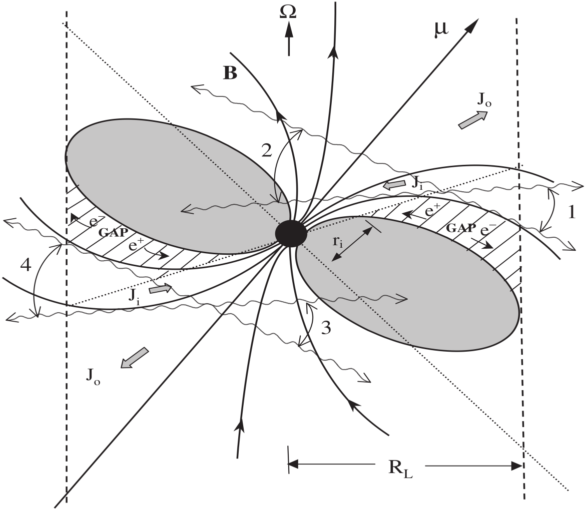

Figure: (BECKER, 2009)

SGRs/AXPs as pulsars of neutron stars, $M = 1.4M_{\odot}$ e radius $R = 10^6$ cm

- **The value of magnetic field is calculate using the expression**

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\mathrm{p}}^{\mathrm{NS}} \sim 10^{14}\ \mathrm{G}. \tag{6}$$

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$$h_{\rm max} = R_{\rm p} \approx \left(\frac{R^3\Omega}{c}\right)^{1/2} \sim 1\ {\rm cm}; \qquad r_c \sim (Rc/\Omega)^{1/2} \sim 10^8\ {\rm cm}. \quad (8)$$

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- **We highlight the importance of the light cylinder comparing to neutron star radius.**

$$R_{\rm L} \equiv c/\Omega \simeq 5 \times 10^9 P \sim 10^{10}\ {\rm cm} \tag{9}$$

SGRs/AXPs as pulsars of neutron stars, $M = 1.4M_\odot$ e radius $R = 10^6$ cm

- **The difference of potential is**

$$\Delta V = \frac{B_{\mathrm{p}}\Omega h^2}{2c} \sim 10^{13}\ \mathrm{V}, \tag{10}$$

and the associate Lorentz factor

$$\gamma = \frac{e\Delta V}{mc^2} \sim 10^7. \tag{11}$$

Polar Cap Model for SGRs/AXPs as pulsars of neutrons stars

- **Using the condition**

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_{\rm c}} \geq \frac{1}{15}. \tag{12}$$

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- **M1 - Pure Dipole,** $B_s = B_p$ **e** $r_c = (Rc/\Omega)^{1/2}$ **e** $h \approx R(R\Omega/c)^{1/2}$

$$\begin{aligned} 4\log B_p - 7.5\log P + 9.5\log R &= 106.37 \\ 4\log B_p - 7.5\log P &= 49.37, \end{aligned} \qquad (13)$$

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- **M2 - Lines of magnetic field B very curved, such that $r_c \sim R = 10^6$ cm, and polar cap area similar to the anterior case and $B_s = B_\mathrm{p}$**

$$\begin{aligned} 4\log B_p - 6.5\log P + 10.5\log R &= 108.70 \\ 4\log B_p - 6.5\log P &= 45.70 \quad (14) \end{aligned}$$

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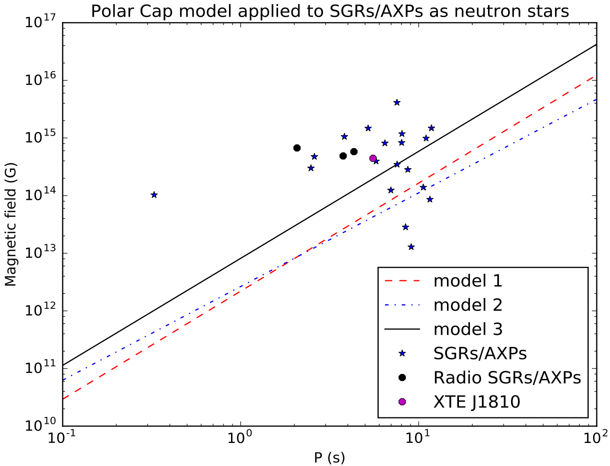
- **M3 - Lines of magnetic field B very curved on the Polar Cap $r_c \sim R$, but now we consider the value of h with magnetic field dependence, $h \sim (B_{\mathrm{p}}/B_s)^{1/2} R(R\Omega/c)^{1/2}$, where $B_s = 2\times 10^{13}$ G is a fix value**

$$\begin{aligned} 7\log B_p - 13\log P + 21\log R &= 204.08 \\ 7\log B_p - 13\log P &= 78.08 \end{aligned} \tag{15}$$

Polar Cap Model for SGRs/AXPs as pulsars of neutrons stars

- **The three curves and the SGRs/AXPs with their respective magnetic field inferred for neutron stars and their periods**



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- **SGRs/AXPs are within the GZK limit ($\approx$ 10 Mpc for photons with a energy of 10^{19} eV)**

Polar Cap Model for SGRs/AXPs as white dwarfs pulsars

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$$\begin{aligned} 4\log B_p - 7.5\log P + 9.5\log R &= 106.37 \\ 4\log B_p - 7.5\log P &= 25.84, \end{aligned} \tag{22}$$

m2 -

$$4\log B_p - 6.5\log P = 23.68 \tag{23}$$

m3 -

$$7\log B_p - 13\log P = 34.06 \tag{24}$$

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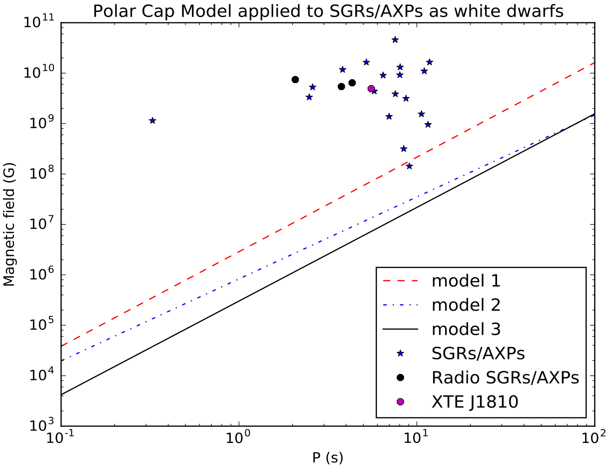
- **m1, m2 e m3 and SGRs/AXPs with its respective magnetic fields like WD and their periods**



Outer Gap Model para SGRs/AXPs like neutron star

- **In this model the magnetic field is given by its dipolar expression**

$$B = B_{\rm p} R^3/r^3 = B_{\rm p}(\Omega R/c)^3, \tag{25}$$

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- **O1 combining $\omega_c \approx \omega_{\rm max}$, we have the next death-line**

$$\begin{aligned} 5\log B_{\rm p} - 12\log P + 15\log R &= 161.54 \\ 5\log B_{\rm p} - 12\log P &= 71.53 \end{aligned} \tag{26}$$

where $\gamma_{\|} \sim 10$ fitting by Vela pulsar.

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- **O2 - If the tertiary photons has a synchrotron frequency $\omega_s \approx \omega_B$ we have the next curve**

$$\begin{aligned} 2\log B_p - 5\log P + 6\log R &= 67.41 \\ 2\log B_p - 5\log P &= 31.40 \end{aligned} \tag{27}$$

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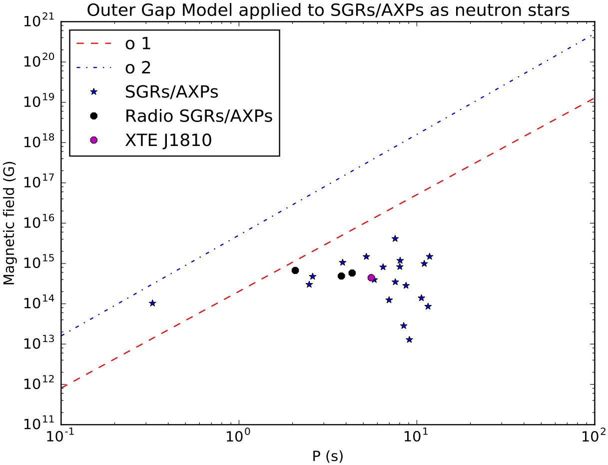
- **The two curves of the Outer Gap Model and the SGRs/AXPs**



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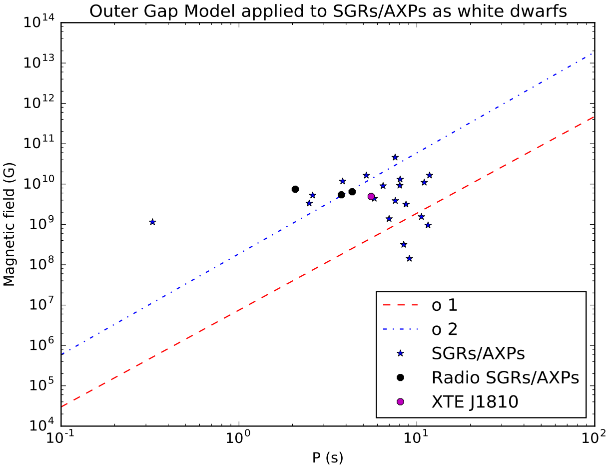

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- **The four SGRs/AXPs that emit in radio seems to be neutron stars pulsars with emission explained by the Polar Cap Model.**

Acknowledgments

- Organizing Committee of "Compact Stars in the QCD phase diagram V" and "Working Group 2 Meeting of COST Action MP1304"
- Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)
- Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)
- FAPESP thematic project 2015/26258-4

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Grazie!

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