SGRs/AXPs: source of energy and radio emission

Manuel Malheiro

Aeronautics Institute of Technology, ITA, Departament of Physics

"Supernovae, Hypernovae and Binary Driven Hypernovae"
An Adriatic workshop
June 20-30, 2016, Pescara, Italy

Tuesday, 28 June 2016

Outline

Motivation

- What is the nature of the SGRs/AXPs?
- Issues about the magnetar model.
- Issues about the highly magnetized, massive and fast white dwarfs.
- 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.

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- **Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.**

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.
- **Spin-Down rates ($dP/dt \sim (10^{-13}-10^{-10})$) s larger than normal pulsar** $(10^{-15}-10^{-14})$ **s.**

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.
- Spin-Down rates ($dP/dt \sim (10^{-13} - 10^{-10})$) s larger than normal pulsar ($10^{-15} - 10^{-14}$) s.
- **Isolated stars, 23 confirmed (11 SGRs and 12 AXPs) comparing with more than 2000 pulsars know.**

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.
- Spin-Down rates ($dP/dt \sim (10^{-13}-10^{-10})$) s larger than normal pulsar ($10^{-15}-10^{-14}$) s.
- Isolated stars, 23 confirmed (11 SGRs and 12 AXPs) comparing with more than 2000 pulsars know.
- **Strong outburst of energies $\sim (10^{41}-10^{43})$ erg. SGRs, giant flares of even large energies $\sim (10^{44}-10^{47})$ erg.**

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.
- Spin-Down rates ($dP/dt \sim (10^{-13} - 10^{-10})$) s larger than normal pulsar ($10^{-15} - 10^{-14}$) s.
- Isolated stars, 23 confirmed (11 SGRs and 12 AXPs) comparing with more than 2000 pulsars know.
- Strong outburst of energies $\sim (10^{41} - 10^{43})$ erg. SGRs, giant flares of even large energies $\sim (10^{44} - 10^{47})$ erg.
- **High X-ray luminosity** $L_x \sim (10^{32} - 10^{36}) \mathrm{erg/s}$

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.
- Spin-Down rates ($dP/dt \sim (10^{-13}-10^{-10})$) s larger than normal pulsar ($10^{-15}-10^{-14}$) s.
- Isolated stars, 23 confirmed (11 SGRs and 12 AXPs) comparing with more than 2000 pulsars know.
- Strong outburst of energies $\sim (10^{41}-10^{43})$ erg. SGRs, giant flares of even large energies $\sim (10^{44}-10^{47})$ erg.
- High X-ray luminosity $L_{\rm x} \sim (10^{32}-10^{36})\mathrm{erg/s}$
- **Hot stars -** $T \sim (0.4-0.6)$ **KeV, larger than** 10^6 **K.**

SGRs/AXPs phenomenology (OLAUSEN; KASPI, 2014)

- Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are very slow rotating pulsars: long periods ($P \sim (2-11)$) s. Periods in a narrow range comparing to ordinary pulsars ($P \sim (0.001-1)$ s.
- Spin-Down rates ($dP/dt \sim (10^{-13}-10^{-10})$) s larger than normal pulsar ($10^{-15}-10^{-14}$) s.
- Isolated stars, 23 confirmed (11 SGRs and 12 AXPs) comparing with more than 2000 pulsars know.
- Strong outburst of energies $\sim (10^{41}-10^{43})$ erg. SGRs, giant flares of even large energies $\sim (10^{44}-10^{47})$ erg.
- High X-ray luminosity $L_x \sim (10^{32}-10^{36})\mathrm{erg/s}$
- Hot stars - $T \sim (0.4-0.6)$ KeV, larger than 10^6 K.
- **Young stars - spin-down ages** (10^3-10^5) **yr; exception the new SGR 0418+5229 with 24 Myr.**

SGRs/AXPs - What are they?

Understood as:

- **Slowly rotating Neutron Stars -** $P \approx (2-12)$**s: (DUNCAN; THOMPSON, 1992)**
  Canonical Neutron Star
  $M = 1.4M_\odot$
  $R = 10\ km$
  $I \approx 10^{45} g\ cm^2$
  Their persistent X-ray luminosity, as well as the bursts and flares typical of these sources, are believed to be powered by the decay of their ultra strong magnetic fields $B > 10^{14}$**G.**

SGRs/AXPs - What are they?

Understood as:

- Slowly rotating Neutron Stars - $P \approx (2-12)$s: (DUNCAN; THOMPSON, 1992)
  Canonical Neutron Star
  $M = 1.4 M_{\odot}$
  $R = 10\ km$
  $I \approx 10^{45} g\ cm^2$
  Their persistent X-ray luminosity, as well as the bursts and flares typical of these sources, are believed to be powered by the decay of their ultra strong magnetic fields $B > 10^{14}$G.
- **It is important to note that the magnetic fields of magnetar also determine their energy activity. the energy stored in the magnetic field**

$$W_B = \int \frac{B^2}{8\pi} dV = 10^{45} \left(\frac{B_0}{10^{14}\mathrm{G}} \right)^2 \left(\frac{R}{10\mathrm{k}m} \right) \mathrm{erg} \tag{1}$$

  exceeds the neutron star rotation energy,

$$W_R = 2\pi I P^{-2}. \tag{2}$$

  This is not the case for radio pulsars: $W_R >> W_B$

Difficulties of magnetar model

- **The rotational energy of neutron stars is $E_{\rm rot} = \frac{1}{2}I\Omega^2$. This model is know as Rotation Powered Pulsars (RPPs)**

$$L_{\rm rot} = -\frac{dE_{\rm rot}}{dt} = -I\Omega\dot{\Omega} \sim 10^{30} - 10^{38} {\rm e}rg/s \tag{3}$$

$$L_{\rm rot} > L_{{\rm non}-th} \qquad \textbf{for all know pulsars} \tag{4}$$

However for SGRs/AXPs x-ray luminosity - $L_X >> \dot{E}_{rot}$:

Difficulties of magnetar model

- The rotational energy of neutron stars is $E_{\rm rot} = \frac{1}{2} I \Omega^2$. This model is know as Rotation Powered Pulsars (RPPs)

$$L_{\rm rot} = -\frac{dE_{\rm rot}}{dt} = -I\Omega\dot{\Omega} \sim 10^{30} - 10^{38} {\rm erg}/s \tag{3}$$

$$L_{\rm rot} > L_{\rm non-th} \qquad \text{for all know pulsars} \tag{4}$$

  However for SGRs/AXPs x-ray luminosity - $L_X >> \dot{E}_{rot}$:
- **RPPs are assumed born with a short period ~ 1 ms resulting in large magnetic fields by dynamo process, the SGRs/AXPs presents longs period, such that generation of high magnetic fields by this mechanisms is not well understood.**

Difficulties of magnetar model

- The rotational energy of neutron stars is $E_{\mathrm{rot}} = \frac{1}{2} I \Omega^2$. This model is know as Rotation Powered Pulsars (RPPs)

$$L_{\mathrm{rot}} = -\frac{dE_{\mathrm{rot}}}{dt} = -I\Omega\dot{\Omega} \sim 10^{30} - 10^{38} \mathrm{e}rg/s \tag{3}$$

$$L_{\mathrm{rot}} > L_{\mathrm{non}-th} \qquad \text{for all know pulsars} \tag{4}$$

However for SGRs/AXPs x-ray luminosity - $L_X >> \dot{E}_{rot}$:

- RPPs are assumed born with a short period ~ 1 ms resulting in large magnetic fields by dynamo process, the SGRs/AXPs presents longs period, such that generation of high magnetic fields by this mechanisms is not well understood.
- **The large spin-down rates in comparison with the typical pulsars implies for example, that the source SGR 0418+5729 has a characteristic age** $\tau = P/2\dot{P} = 2.4 \times 10^7$ **years, Thus, it is difficult to understand, how being much older than ordinary pulsars, it still fits in the magnetar model, where the sources seen as young pulsars.**

SGRs/AXPs as fast rotating-powered magnetic white dwarf Pulsars

- Rapidly, massive white dwarfs and with observed high magnetic field $10^6 - 10^9$ G were detected in the recent years (CASTANHEIRA et al., 2013) and share some similarities with SGRs/AXPs.
- SGRs/AXPs as high density and fast rotating massive white dwarfs (MALHEIRO; RUEDA; RUFFINI, 2012)
  - $M = 1.4 M_\odot$ and radius $R = 1000$ km
  - Moment of inertia $I_{\mathrm{WD}} = 10^4 I_{\mathrm{NS}} = 10^{49} \mathrm{g.cm}^2$
- New scale of rotational energy losses

$$\frac{dE_{\mathrm{rot}}}{dt} = 4\pi^2 I \frac{\dot{P}}{P^3} = 3.95 \times 10^{50} \frac{\dot{P}}{P^3} \mathrm{erg/s} \tag{5}$$

- New scale of magnetic field

$$B = \left(\frac{3c^3}{8\pi^2} \frac{I}{R^6} P\dot{P} \right)^{1/2} \tag{6}$$

$$B = \underbrace{3.2 \times 10^{15} (P\dot{P})^{1/2} \mathrm{G}}_{\text{White dwarf}} \qquad B = \underbrace{3.2 \times 10^{19} (P\dot{P})^{1/2} \mathrm{G}}_{\text{Magnetar}} \tag{7}$$

Magnetic dipole moment $\mu \sim (10^{34} - 10^{36})$ emu (COELHO; MALHEIRO, 2014)

- Because of the small radius of the fast and massive white dwarf comparing to normal WD, the large magnetic field of the SGRs/AXPs as white dwarfs are generated by a magnetic dipole moment $\mu(10^{34} - 10^{36})$ emu, exactly in the range of μ for isolated and polar magnetic white dwarfs.
- The values for $\mu \sim (10^{33} - 10^{34})$ emu of the two SGRs with low B, are exactly at the same order of the three white dwarf pulsars observed, and in the lower values of the observed isolate and polar white dwarf magnetic dipole moment range.
- The large steady X-ray emission $L_{\rm X} \sim 10^{35}$ erg/s observed in the SGRs/AXPs is now well understood as a consequence of the fast white dwarf rotation ($P \sim 10$ s), since the magnetic dipole moment μ is at the same as the one observed for the very magnetic and not so fast WDs.
- This supports the description of SGRs/AXPs as belonging to a class of very fast and magnetic massive WDs perfect in line with recent astronomical observations of fast white dwarf pulsars.

Low L_X SGRs/AXPs

- Considering corrections to B from General Relativity and using realistic parameters (BELVEDERE et al., 2014) we can show that some SGRs/AXPs are RPPs.
- Almost 40% of the observed SGRs/AXPs can be rotation powered pulsars neutron stars: In the sense that their steady X-ray luminosity can be originated by the rotational energy (no need of magnetic field energy reservoir).

Algorithm

- **EOS** - Nuclear matter: Relativistic mean field-theory approach, nucleons interact via the exchange of mesons. Three parametrizations: GM1[1], TM1[2], NL3[3];
- **Global Neutrality** - Coulomb interactions are allowed, Einstein-Maxwell-Thomas-Fermi equations [4]
- **Structure** - Slowly Rotating Star: small dapartures from the TOV like solutions: Hartle Procedure[5];
- **Pulsar** - Observed periods and luminosities.

1 G. A. Lalazissis, J. König, and P. Ring, **Phys. Rev. C 55, 540 (1997)**.

2 K. Sumiyoshi, H. Kuwabara, and H. Toki, **Nuclear Physics A 581, 725 (1995)**.

3 N. K. Glendenning and S. A. Moszkowski, **Phys. Rev. Lett. 67, 2414 (1991)**.

4 R. Belvedere, D. Pugliese, J. A. Rueda, R. Ruffini, and S.-S. Xue, **Nucl. Phys. A 883, 1 (2012)**

5 Hartle, J. B., **ApJ 150, 1005 (1967)**.

EOS: Mass-Radius

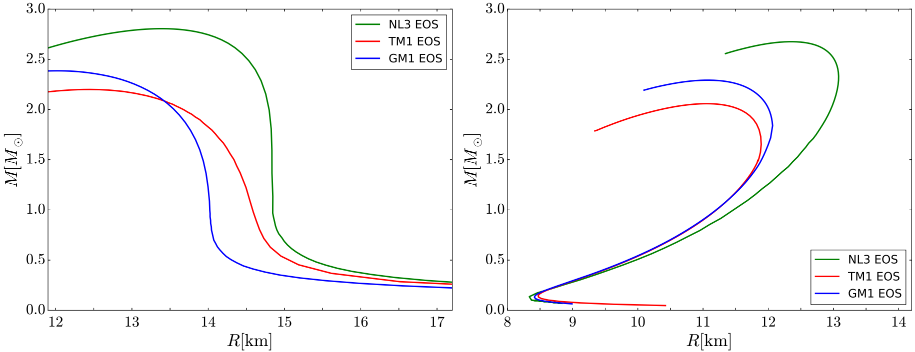


Figure: Mass-Radius relation for the NL3, TM1, and GM1 EOS in the cases of local (left panel) and global (right panel) charge neutrality.

GR Magnetic Field

$$f = -\frac{3}{8}\left(\frac{R}{M_0}\right)^3\left[\ln(N^2) + \frac{2M_0}{R}\left(1+\frac{M_0}{R}\right)\right], \tag{8}$$

$$N = \sqrt{1-\frac{2M_0}{R}}, \tag{9}$$

$$B\sin\chi = \frac{N^2}{f}\left(\frac{3c^3}{8\pi^2}\frac{I}{R^6}P\dot{P}\right)^{1/2}. \tag{10}$$

1 Rezzolla and Ahmedov, **MNRAS 352, 1161 (2004)**.

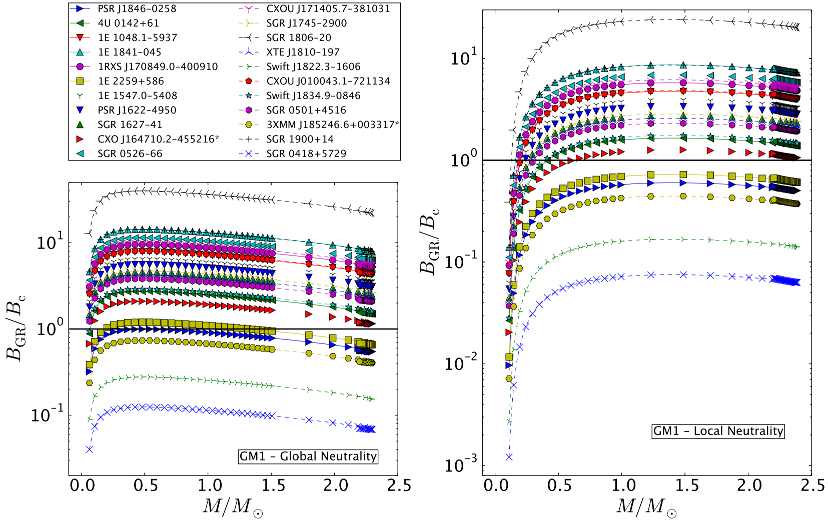


Figure: Magnetic field $B_{\rm GR}$ with a relativistic correction, in units of critical field B_c, as function of the mass (in solar masses) in the cases of global (left panel) and local (right panel) charge neutrality.

Efficiency

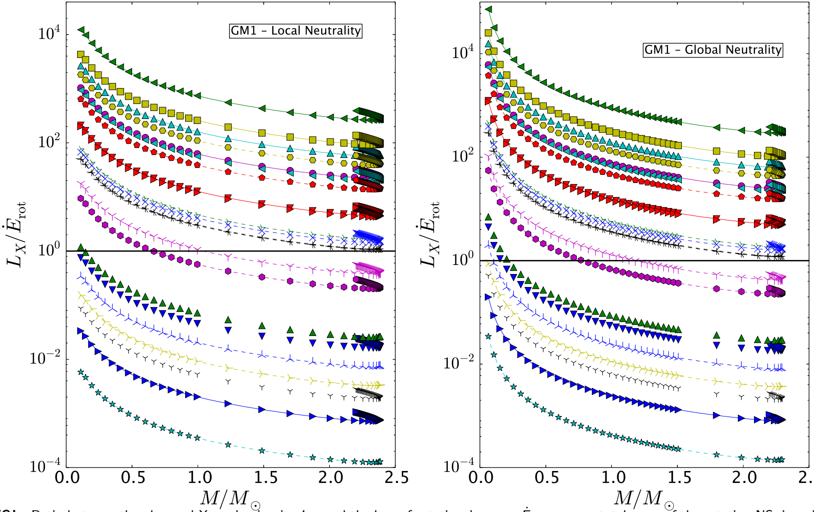


Figure: Ratio between the observed X-ray luminosity L_X and the loss of rotational energy $\dot{E}_{\rm rot}$ versus total mass of the rotating NS, in units of $M_\odot$, for the global neutrality case.

Canonical NS

Source	P (s)	$\dot{P}(\times 10^{-11}$ s/s)	$B_{NS}^{\rm fiducial}(\times 10^{14}$ G)	$L_X(\times 10^{33}$ erg/s)
SGR 0501+4516	5.8	0.59	1.9	0.81
1E 1547.0-5408	2.07	4.77	3.2	1.3
PSR J1622-4950	4.33	1.7	2.7	0.44
SGR 1627-41	2.59	1.9	2.2	3.6
CXOU J171405.7-381031	3.8	6.4	5.0	56
SGR J1745-2900	3.76	1.38	2.3	0.11
XTE J1810-197	5.54	0.77	2.1	0.043
Swift J1834.9-0846	2.48	0.79	1.4	0.0084
PSR J1846-0258	0.33	0.71	0.49	19

- It is interesting to notice that four of the above nine sources, namely 1E 1547.0–5408, SGR J1745–2900, XTE J1810–197, and PSR J1622–4950, are actually the only ones with detected radio emission, as expected from ordinary rotation-powered pulsars.

Low B SGRs/AXPs

- $L_X/\dot{E}_{\rm rot} < 1$: Swift J1834.9–0846, PSR J1846–0258, 1E 1547.0–5408, SGR J1745–2900, XTE J1810–197, PSR J1622–4950, SGR 1627–41, SGR 0501+4516, CXOU 171405.7–381031.
- $L_X/\dot{E}_{\rm rot} \sim 1$: SGR 1900+14, SGR 0418+5729, and Swift J1822.3–1606.
- among these nine sources, we can also find six sources with possible associations with supernova remnants (SNRs): Swift J1834.9–0846 associated with SNR W41, PSR J1846–0258 (with SNR Kes75),1E 1547.0–5408 with SNR G327.24–0.13, PSR J1622–4950 with SNR G333.9+0.0, SGR 1627–41 with SNR G337.0-0, CXOU J171405.7–381031 with SNR CTB37B

Predicted Glitches for the RPP SGRs/AXPs

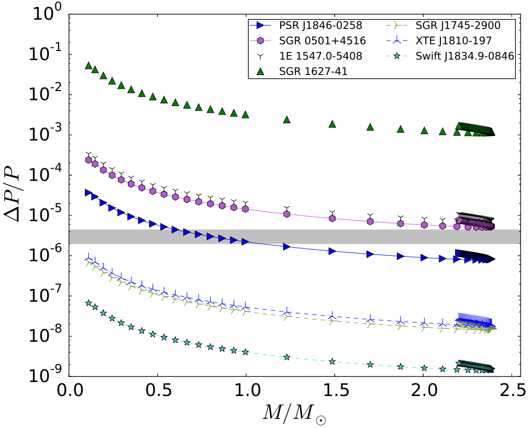


Figure: Inferred fractional change of rotation period during the glitch, $\Delta P/P$, obtained by equating the rotational energy gained during the glitch, $\Delta E_{\rm rot}$, to the energy of the burst. In this example the NS obeys the GM1 EOS and local charge neutrality is adopted. The gray-shaded area corresponds to the value of $|\Delta P|/P$ in the observed glitch of PSR J1846–0258 in June 2006.

Table: Predicted values of $|\Delta P|/P$ assuming rotation-powered NSs - Global Charge Neutrality

Source name	Total isotropic burst energy [erg]	Predicted $|\Delta P|/P$ for $M > 1\,M_\odot$
PSR J1846–0258	4.8×10^{41}	$(8.8 \times 10^{-7} - 2.6 \times 10^{-6})$
1E 1547.0–5408	1.1×10^{41}	$(8.1 \times 10^{-6} - 2.4 \times 10^{-5})$
XTE J1810–197	4.0×10^{37}	$(2.1 \times 10^{-8} - 6.3 \times 10^{-8})$
SGR 1627–41	1.0×10^{41}	$(1.0 \times 10^{-5} - 3.8 \times 10^{-5})$
SGR 0501+4516	1.0×10^{40}	$(5.7 \times 10^{-6} - 1.7 \times 10^{-5})$
Swift J1834.9–0846	1.5×10^{37}	$(1.6 \times 10^{-9} - 4.8 \times 10^{-9})$
SGR 1745–2900	6.7×10^{37}	$(1.61 \times 10^{-8} - 4.9 \times 10^{-8})$

Table: Predicted values of $|\Delta P|/P$ assuming rotation-powered NSs - Local Charge Neutrality

Source name	Total isotropic burst energy [erg]	Predicted $|\Delta P|/P$ for $M > 1\,M_\odot$
PSR J1846–0258	4.8×10^{41}	$(7.9 \times 10^{-7} - 2.2 \times 10^{-6})$
1E 1547.0–5408	1.1×10^{41}	$(7.2 \times 10^{-6} - 2.0 \times 10^{-5})$
XTE J1810–197	4.0×10^{37}	$(1.9 \times 10^{-8} - 5.3 \times 10^{-8})$
SGR 1627–41	1.0×10^{41}	$(1.1 \times 10^{-5} - 3.2 \times 10^{-5})$
SGR 0501+4516	1.0×10^{40}	$(5.0 \times 10^{-6} - 1.4 \times 10^{-5})$
Swift J1834.9–0846	1.5×10^{37}	$(1.4 \times 10^{-9} - 3.9 \times 10^{-9})$
SGR 1745–2900	6.7×10^{37}	$(1.4 \times 10^{-8} - 4.1 \times 10^{-8})$

Particle acceleration in pulsars and radio emission models

- The accelerating electric field ($E_{\parallel}$) parallel to magnetic field line arises in **gap** where

$$\rho = \rho_{\mathrm{GJ}} \tag{11}$$

$$\nabla^2 \Phi = -4\pi(\rho - \rho_{\mathrm{GJ}}) \tag{12}$$

$$E_{\parallel} = -\frac{\partial \Phi}{\partial s} \tag{13}$$

- There are two basic standard models associate with pair $e^{\pm}$ production and emission of radiation in compact stars.
  - Polar cap/Slot gap model: Strong acceleration region near the stellar surface above the polar cap.
  - Outer gap model: Strong acceleration between the null charge surface and the light cylinder.

Models of electromagnetic emission

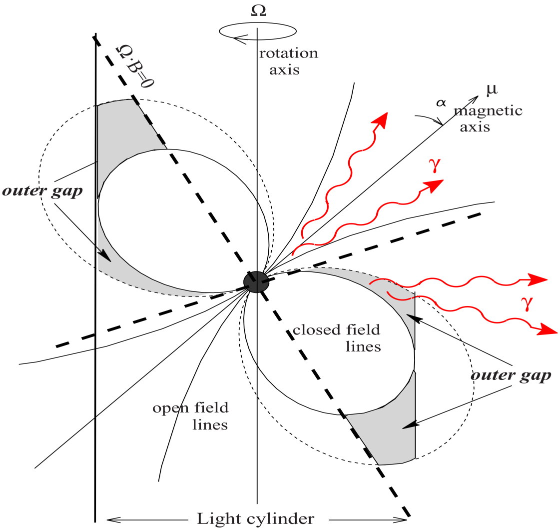


Figure: (REA; TORRES, 2011)

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**

$$\hbar\omega \simeq \frac{3}{2}\frac{\hbar\gamma^3}{r_c}, \tag{14}$$

where r_c is the curvature radius

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

$$\hbar\omega \simeq \frac{3}{2}\frac{\hbar\gamma^3}{r_c}, \tag{14}$$

where r_c is the curvature radius

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

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

where,

$$r_c \sim (Rc/\Omega)^{1/2}, \tag{16}$$

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

$$\hbar\omega \simeq \frac{3}{2}\frac{\hbar\gamma^3}{r_c}, \tag{14}$$

where r_c is the curvature radius

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

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

where,

$$r_c \sim (Rc/\Omega)^{1/2}, \tag{16}$$

- **only some photons of GeV escape to infinity.**

Polar Cap Model

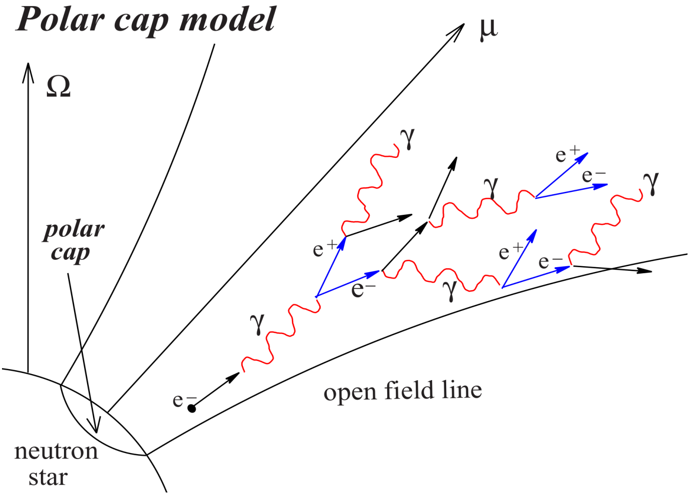


Figure: (REA; TORRES, 2011)

Outer Gap Model

- **The second model of emission consider the production of the photons far away from the stellar surface, where the magnetic field lines are open. In this model, the energy is limited by a combination of curvature radiation and inverse Compton scattering.**

Outer Gap Model

- The second model of emission consider the production of the photons far away from the stellar surface, where the magnetic field lines are open. In this model, the energy is limited by a combination of curvature radiation and inverse Compton scattering.
- **The magnetic field responsible for the pair production is given by their dipole expression**

$$B(r) = B_{\mathrm{p}} R^3 / r^3 \tag{17}$$

Outer Gap Model

- The second model of emission consider the production of the photons far away from the stellar surface, where the magnetic field lines are open. In this model, the energy is limited by a combination of curvature radiation and inverse Compton scattering.
- The magnetic field responsible for the pair production is given by their dipole expression

$$B(r) = B_{\mathrm{p}} R^3 / r^3 \tag{17}$$

- **The difference of potential in the the gap using the same previous expression is**

$$\Delta V \approx \frac{\Omega^2 R^3 B(r)}{2c^2} \tag{18}$$

Outer Gap Model

- The second model of emission consider the production of the photons far away from the stellar surface, where the magnetic field lines are open. In this model, the energy is limited by a combination of curvature radiation and inverse Compton scattering.
- The magnetic field responsible for the pair production is given by their dipole expression

$$B(r) = B_{\mathrm{p}} R^3 / r^3 \tag{17}$$

- The difference of potential in the the gap using the same previous expression is

$$\Delta V \approx \frac{\Omega^2 R^3 B(r)}{2c^2} \tag{18}$$

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

$$\omega_c \approx \gamma_{\|}^3 \frac{m^5 c^9}{e^7} \Omega^2 B^{-3}, \tag{19}$$

and a maximum frequency

$$\omega_{\max} \approx \frac{e^{15}}{\gamma_{\|} \hbar m^9 c^{15}} \Omega^{-4} B^7 \tag{20}$$

Outer Gap Model

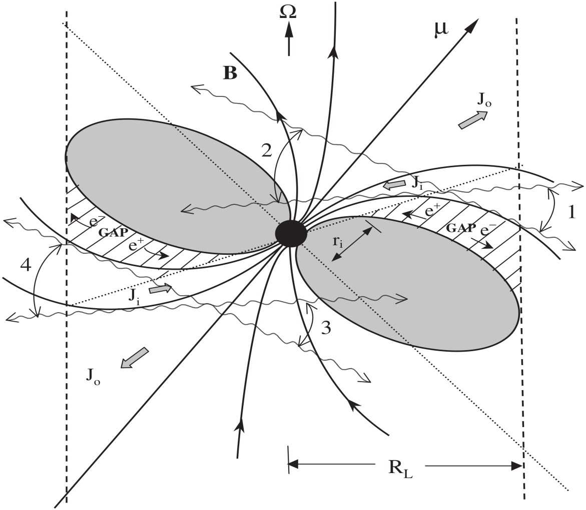


Figure: (BECKER, 2009)

Results

- **In our work we applied this two models of emission for the group of 23 SGRs/AXPs using the data from McGill catalog:**
  periods $P\,(2.48 - 11.78\,s)$**,**
  spin-down $\dot{P}$ $(\sim 10^{-11}\ \mathrm{s/s})$**,**
  luminosity $(L_{\mathrm{X}} \sim 10^{33}\ \mathrm{erg/s})$**,**

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

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

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\rm p}^{\rm NS} \sim 10^{14}\ {\rm G}. \tag{21}$$

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

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\rm p}^{\rm NS} \sim 10^{14}\ {\rm G}. \tag{21}$$

- **We calculate the rotational energy**

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\rm NS} \sim 10^{33}\ {\rm erg/s}. \tag{22}$$

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

- The value of magnetic field is calculate using the expression

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P} \right)^{1/2} = B_{\rm p}^{\rm NS} \sim 10^{14} \text{ G.} \tag{21}$$

- We calculate the rotational energy

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\rm NS} \sim 10^{33} \text{ erg/s.} \tag{22}$$

- **The value of *gap* $h_{\rm max}$ and the curvature radius are given in terms of period and the radius of the star**

$$h_{\rm max} = R_{\rm p} \approx \left(\frac{R^3 \Omega}{c} \right)^{1/2} \sim 1 \text{ cm}; \qquad r_c \sim (Rc/\Omega)^{1/2} \sim 10^8 \text{ cm.} \tag{23}$$

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

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\rm p}^{\rm NS} \sim 10^{14}\ {\rm G.} \tag{21}$$

- We calculate the rotational energy

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\rm NS} \sim 10^{33}\ {\rm erg/s.} \tag{22}$$

- The value of *gap* $h_{\rm max}$ and the curvature radius are given in terms of period and the radius of the star

$$h_{\rm max} = R_{\rm p} \approx \left(\frac{R^3\Omega}{c}\right)^{1/2} \sim 1\ {\rm cm;} \qquad r_c \sim (Rc/\Omega)^{1/2} \sim 10^8\ {\rm cm.} \tag{23}$$

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

$$R_{\rm L} \equiv c/\Omega \simeq 5 \times 10^9 P \sim 10^{10}\ {\rm cm} \tag{24}$$

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

- **The difference of potential is**

$$\Delta V = \frac{B_{\rm p} \Omega h^2}{2c} \sim 10^{13}\ \mathrm{V}, \tag{25}$$

and the associate Lorentz factor

$$\gamma = \frac{e \Delta V}{m c^2} \sim 10^{7}. \tag{26}$$

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

- **Using the condition**

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_c} \geq \frac{1}{15}. \tag{27}$$

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

- Using the condition

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_\mathrm{c}} \geq \frac{1}{15}. \tag{27}$$

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

$$\begin{aligned} 4\log B_p - 7.5\log P + 9.5\log R &= 106.37 \\ 4\log B_p - 7.5\log P &= 49.37, \end{aligned} \tag{28}$$

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

- Using the condition

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_c} \geq \frac{1}{15}. \tag{27}$$

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

$$\begin{aligned} 4\log B_p - 7.5\log P + 9.5\log R &= 106.37 \\ 4\log B_p - 7.5\log P &= 49.37, \end{aligned} \tag{28}$$

- **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 $B_s = B_{\rm p}$**

$$\begin{aligned} 4\log B_p - 6.5\log P + 10.5\log R &= 108.70 \\ 4\log B_p - 6.5\log P &= 45.70 \end{aligned} \tag{29}$$

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

- Using the condition

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_c} \geq \frac{1}{15}. \tag{27}$$

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

$$\begin{aligned} 4\log B_p - 7.5\log P + 9.5\log R &= 106.37 \\ 4\log B_p - 7.5\log P &= 49.37, \end{aligned} \tag{28}$$

- 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 $B_s = B_\mathrm{p}$

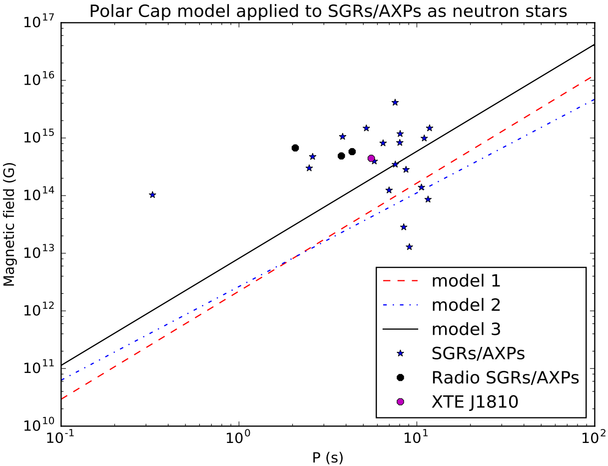
$$\begin{aligned} 4\log B_p - 6.5\log P + 10.5\log R &= 108.70 \\ 4\log B_p - 6.5\log P &= 45.70 \end{aligned} \tag{29}$$

- **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**

$$\begin{aligned} 7\log B_p - 13\log P + 21\log R = 204.08 \\ 7\log B_p - 13\log P = 78.08 \end{aligned} \tag{30}$$

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**



SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^8$ cm

- **Considering the SGRs/AXPs as white dwarfs, we inferred the news values for the quantities: item The new value for the magnetic field is calculate using the dipole expression,**

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\rm p}^{\rm WD} \sim 10^9 \ {\rm G}. \tag{31}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^{8}$ cm

- Considering the SGRs/AXPs as white dwarfs, we inferred the news values for the quantities: item The new value for the magnetic field is calculate using the dipole expression,

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\mathrm{p}}^{\mathrm{WD}} \sim 10^{9}\ \mathrm{G}. \tag{31}$$

- **We calculate the rotational energy**

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\mathrm{WD}} \sim 10^{38}\ \mathrm{erg/s}. \tag{32}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^8$ cm

- Considering the SGRs/AXPs as white dwarfs, we inferred the news values for the quantities: item The new value for the magnetic field is calculate using the dipole expression,

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\rm p}^{\rm WD} \sim 10^9 \text{ G.} \tag{31}$$

- We calculate the rotational energy

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\rm WD} \sim 10^{38} \text{ erg/s.} \tag{32}$$

- **The size of $h_{\rm max}$ and the curvature radius**

$$h_{\rm max} = R_{\rm p} \approx \left(\frac{R^3\Omega}{c}\right)^{1/2} \sim 10^3 \text{cm}; \qquad r_c \sim (Rc/\Omega)^{1/2} \sim 10^9 \text{ cm.} \tag{33}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^8$ cm

- Considering the SGRs/AXPs as white dwarfs, we inferred the news values for the quantities: item The new value for the magnetic field is calculate using the dipole expression,

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\rm p}^{\rm WD} \sim 10^9 \text{ G}. \tag{31}$$

- We calculate the rotational energy

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\rm WD} \sim 10^{38} \text{ erg/s}. \tag{32}$$

- The size of $h_{\rm max}$ and the curvature radius

$$h_{\rm max} = R_{\rm p} \approx \left(\frac{R^3\Omega}{c}\right)^{1/2} \sim 10^3 \text{cm}; \qquad r_c \sim (Rc/\Omega)^{1/2} \sim 10^9 \text{ cm}. \tag{33}$$

- **The difference of potential is given by**

$$\Delta V = \frac{B_{\rm p}\Omega h^2}{2c} \sim 10^{16} \text{ V}, \tag{34}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^{8}$ cm

- Considering the SGRs/AXPs as white dwarfs, we inferred the news values for the quantities: item The new value for the magnetic field is calculate using the dipole expression,

$$B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2} = B_{\mathrm{p}}^{\mathrm{WD}} \sim 10^{9}\ \mathrm{G}. \tag{31}$$

- We calculate the rotational energy

$$\dot{E} = I\Omega\dot{\Omega} = \dot{E}_{\mathrm{WD}} \sim 10^{38}\ \mathrm{erg/s}. \tag{32}$$

- The size of h_{max} and the curvature radius

$$h_{\mathrm{max}} = R_{\mathrm{p}} \approx \left(\frac{R^3\Omega}{c}\right)^{1/2} \sim 10^{3}\mathrm{cm}; \qquad r_c \sim (Rc/\Omega)^{1/2} \sim 10^{9}\ \mathrm{cm}. \tag{33}$$

- The difference of potential is given by

$$\Delta V = \frac{B_{\mathrm{p}}\Omega h^2}{2c} \sim 10^{16}\ \mathrm{V}, \tag{34}$$

- **and the associate Lorentz factor,**

$$\gamma = \frac{e\Delta V}{mc^2} \sim 10^{10}. \tag{35}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^8$ cm

- **The difference of potential is given by**

$$\Delta V = \frac{B_{\mathrm{p}} \Omega h^2}{2c} \sim 10^{16}\ \mathrm{V}, \tag{36}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^{8}$ cm

- The difference of potential is given by

$$\Delta V = \frac{B_{\mathrm{p}}\Omega h^{2}}{2c} \sim 10^{16}\ \mathrm{V}, \tag{36}$$

- **and the associate Lorentz factor,**

$$\gamma = \frac{e\Delta V}{mc^{2}} \sim 10^{10}. \tag{37}$$

SGRs/AXPs as white dwarfs pulsars, $M = 1.4 M_\odot$ e radius $R = 3 \times 10^8$ cm

- The difference of potential is given by

$$\Delta V = \frac{B_\mathrm{p} \Omega h^2}{2c} \sim 10^{16} \ \mathrm{V}, \tag{36}$$

- and the associate Lorentz factor,

$$\gamma = \frac{e \Delta V}{m c^2} \sim 10^{10}. \tag{37}$$

- **this potential can produce curvature photons with a energy up to $\sim 10^{21}$ eV.**

SGRs/AXPs as white dwarfs pulsars, $M = 1.4M_{\odot}$ e radius $R = 3 \times 10^8$ cm

- The difference of potential is given by

$$\Delta V = \frac{B_{\rm p}\Omega h^2}{2c} \sim 10^{16}\ {\rm V}, \tag{36}$$

- and the associate Lorentz factor,

$$\gamma = \frac{e\Delta V}{mc^2} \sim 10^{10}. \tag{37}$$

- this potential can produce curvature photons with a energy up to $\sim 10^{21}$ eV.
- **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

- **Using the condition**

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_c} \geq \frac{1}{15}. \tag{38}$$

we achieved the next curves:

Polar Cap Model for SGRs/AXPs as white dwarfs pulsars

- Using the condition

$$\left(\frac{e\Delta V}{mc^2}\right)^3 \frac{\hbar}{2mcr_c}\frac{h}{r_c}\frac{B_s}{B_c} \geq \frac{1}{15}. \tag{38}$$

we achieved the next curves:

- **m1** -

$$\begin{aligned} 4\log B_p - 7.5\log P + 9.5\log R &= 106.37 \\ 4\log B_p - 7.5\log P &= 25.84, \end{aligned} \tag{39}$$

m2 -

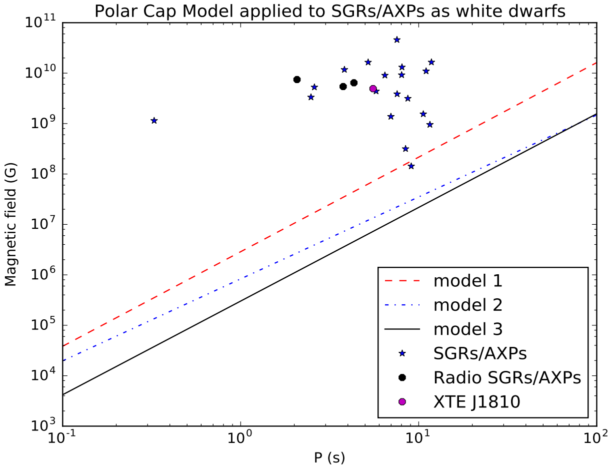
$$4\log B_p - 6.5\log P = 23.68 \tag{40}$$

m3 -

$$7\log B_p - 13\log P = 34.06 \tag{41}$$

Polar Cap Model for SGRs/AXPs as white dwarfs pulsars

- **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**

$$B = B_{\mathrm{p}} R^3 / r^3 = B_{\mathrm{p}} (\Omega R / c)^3, \tag{42}$$

at light cylinder radius $r_c = c/\Omega$.

Outer Gap Model para SGRs/AXPs like neutron star

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

$$B = B_{\rm p} R^3/r^3 = B_{\rm p}(\Omega R/c)^3, \tag{42}$$

at light cylinder radius $r_c = c/\Omega$.

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

$$\begin{aligned} 5\log B_{\rm p} - 12\log P + 15\log R &= 161.54 \\ 5\log B_{\rm p} - 12\log P &= 71.53 \end{aligned} \tag{43}$$

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

Outer Gap Model para SGRs/AXPs like neutron star

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

$$B = B_{\rm p} R^3/r^3 = B_{\rm p}(\Omega R/c)^3, \tag{42}$$

at light cylinder radius $r_c = c/\Omega$.

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

$$\begin{aligned} 5\log B_{\rm p} - 12\log P + 15\log R &= 161.54 \\ 5\log B_{\rm p} - 12\log P &= 71.53 \end{aligned} \tag{43}$$

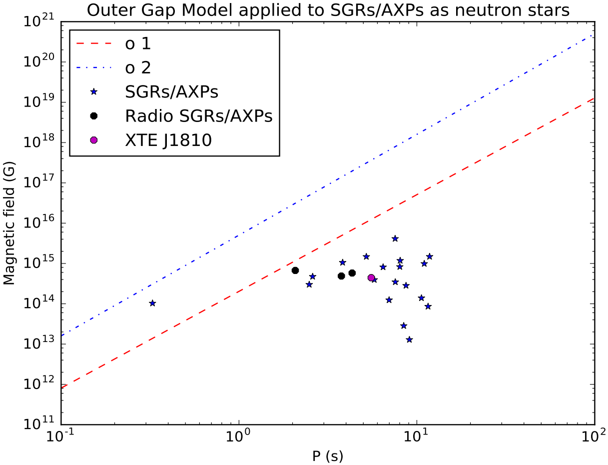
where $\gamma_{||} \sim 10$ fitting by Vela pulsar.

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

$$\begin{aligned} 2\log B_p - 5\log P + 6\log R &= 67.41 \\ 2\log B_p - 5\log P &= 31.40 \end{aligned} \tag{44}$$

Outer Gap Model para SGRs/AXPs like neutron star

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



Outer Gap Model for SGRs/AXPs as white dwarfs pulsars

- **Considering the Outer Gap Model we have the anterior conditions ω_s, ω_c e $\omega_{\max}$ used to WD, we have,**

Outer Gap Model for SGRs/AXPs as white dwarfs pulsars

- Considering the Outer Gap Model we have the anterior conditions ω_s, ω_c e $\omega_{\max}$ used to WD, we have,
- **o1** -

$$\begin{aligned} 5\log B_{\rm p} - 12\log P + 15\log R &= 161.54 \\ 5\log B_{\rm p} - 12\log P &= 34.38 \end{aligned} \tag{45}$$

Outer Gap Model for SGRs/AXPs as white dwarfs pulsars

- Considering the Outer Gap Model we have the anterior conditions ω_s, ω_c e $\omega_{\max}$ used to WD, we have,
- o1 -

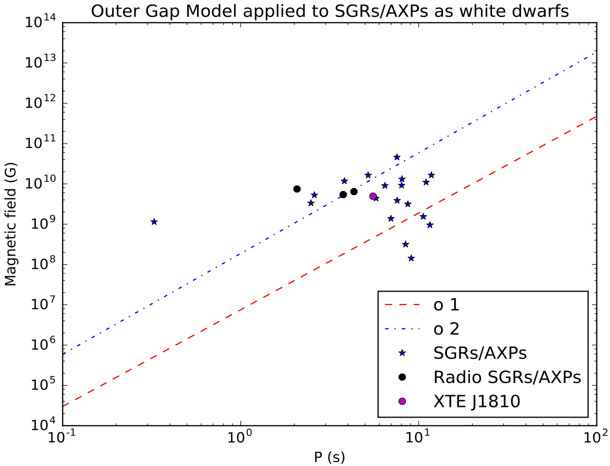
$$\begin{aligned} 5\log B_{\rm p} - 12\log P + 15\log R &= 161.54 \\ 5\log B_{\rm p} - 12\log P &= 34.38 \end{aligned} \tag{45}$$

- **o2** -

$$\begin{aligned} 2\log B_p - 5\log P + 6\log R &= 67.41 \\ 2\log B_p - 5\log P &= 16.54 \end{aligned} \tag{46}$$

Outer Gap Model for SGRs/AXPs as white dwarfs pulsars

- **The curves o1, o2 and the all SGRs/AXPs**



Conclusion

- **We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- **The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).
- $L_X/\dot{E}_{rot}$ **is overestimated for fiducial parameters.**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).
- $L_X/\dot{E}_{rot}$ is **overestimated** for fiducial parameters.
- B **is overestimated for fiducial parameters.**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).
- $L_X/\dot{E}_{rot}$ is **overestimated** for fiducial parameters.
- B is **overestimated** for fiducial parameters.
- **The dependency of the death-lines with the radius of the star.**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).
- $L_X/\dot{E}_{rot}$ is **overestimated** for fiducial parameters.
- B is **overestimated** for fiducial parameters.
- The dependency of the death-lines with the radius of the star.
- **The radius of SGRs/AXPs seems to be out of scale in the comparison with the light cylinder radius** $R_{\rm NS}/R_{\rm L} \sim 10^6/10^{10}$**, for white dwarfs** $R_{\rm WD}/R_{\rm L} \sim 10^8/10^{10} \sim 10^{-2}$**, the same value of ordinary pulsars.**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).
- $L_X/\dot{E}_{rot}$ is **overestimated** for fiducial parameters.
- B is **overestimated** for fiducial parameters.
- The dependency of the death-lines with the radius of the star.
- The radius of SGRs/AXPs seems to be out of scale in the comparison with the light cylinder radius $R_{\rm NS}/R_{\rm L} \sim 10^6/10^{10}$, for white dwarfs $R_{\rm WD}/R_{\rm L} \sim 10^8/10^{10} \sim 10^{-2}$, the same value of ordinary pulsars.
- **In the polar Cap Model without corrections in B, all stars should emit, i.e., both neutron and white dwarf stars, however, only in four of them was observed radio emission.**

Conclusion

- We explored the consequences of a realistic calculations for neutron stars to the observables of SGRs/AXPs.
- The X-ray luminosity of nine SGRs/AXPs (40%) can be explained by rotational energy losses (RPPs).
- $L_X/\dot{E}_{rot}$ is **overestimated** for fiducial parameters.
- B is **overestimated** for fiducial parameters.
- The dependency of the death-lines with the radius of the star.
- The radius of SGRs/AXPs seems to be out of scale in the comparison with the light cylinder radius $R_{\rm NS}/R_{\rm L} \sim 10^6/10^{10}$, for white dwarfs $R_{\rm WD}/R_{\rm L} \sim 10^8/10^{10} \sim 10^{-2}$, the same value of ordinary pulsars.
- In the polar Cap Model without corrections in B, all stars should emit, i.e., both neutron and white dwarf stars, however, only in four of them was observed radio emission.
- **We have shown that the magnetic field is too small at light cylinder for neutrons stars. It explain why the Outer Gap Model does not work to explain radio emission in Magnetars, but could explain in white dwarfs.**

Conclusion

- **We have explored for the nine sources with $L_X < \dot{E}_{\rm rot}$ the possibility that the energetics of their bursting activity, $E_{\rm burst}$ be explained from the rotational energy gained in an associated glitch, $\Delta E_{\rm rot}$. We thus computed a lower limit to the fractional change of rotation period of the NS caused by the glitch, $|\Delta P|/P$, by requesting $\Delta E_{\rm rot} = E_{\rm burst}$. The fact that exist solutions for $|\Delta P|/P$ reinforces the possible rotation-powered nature for these sources (e.g., the case of PSR J1846–0258).**

Acknowledgments

- Organizing Committee of “Supernovae, Hypernovae and Binary Driven Hypernovae”
- Coordenaçãxo de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)
- Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)
- FAPESP thematic project 2015/26258-4

Contact: malheiro@ita.br

Grazie!

BECKER, W. *Neutron Stars and Pulsars*. [S.l.]: Springer Science & Business Media, 2009. 702 p. ISBN 9783540769651.

BELVEDERE, R. et al. Uniformly rotating neutron stars in the global and local charge neutrality cases. *Nuclear Physics A*, v. 921, p. 33–59, 2014.

CASTANHEIRA, B. G. et al. Discovery of five new massive pulsating white dwarf stars. *Monthly Notices of the Royal Astronomical Society*, v. 430, n. 1, p. 50–59, mar 2013. ISSN 0035-8711, 1365-2966.

COELHO, J. G.; MALHEIRO, M. Magnetic Dipole Moment of SGRs and AXPs Described as Massive and Magnetic White Dwarfs. *Publications of the Astronomical Society of Japan*, v. 66, n. 1, p. 14–14, feb 2014. ISSN 0004-6264, 2053-051X.

DUNCAN, R. C.; THOMPSON, C. Formation of very strongly magnetized neutron stars - Implications for gamma-ray bursts. *The Astrophysical Journal*, v. 392, p. L9, jun 1992. ISSN 0004-637X. Disponível em: ⟨http://adsabs.harvard.edu/doi/10.1086/186413⟩.

MALHEIRO, M.; RUEDA, J. A.; RUFFINI, R. {SGRs} and {AXPs} as Rotation-Powered Massive White Dwarfs. *Publications of the Astronomical Society of Japan*, v. 64, n. 3, p. 56, jun 2012. ISSN 0004-6264, 2053-051X.

References II

OLAUSEN, S. A.; KASPI, V. M. THE McGILL MAGNETAR CATALOG. *The Astrophysical Journal Supplement Series*, v. 212, n. 1, p. 6, may 2014. ISSN 0067-0049, 1538-4365.

REA, N.; TORRES, D. F. *High-Energy Emission from Pulsars and their Systems: Proceedings of the First Session of the Sant Cugat Forum on Astrophysics*. [S.l.]: Springer Science & Business Media, 2011. 656 p. ISBN 9783642172519.