SGRs and AXPs: White Dwarf Pulsars versus Magnetares

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SUMMARY

The recent observations of SGR 0418+5729 with a rotational period of $P = 9.04$ s, an upper limit of the first time derivative of the rotational period $\dot{P} < 6.0 \times 10^{-15}$, and an X-ray luminosity of $L_X = 6.2 \times 10^{31}$ erg/s [1] offer an authentic Rosetta Stone for deciphering the energy source of SGRs and AXPs. The "magnetar" model, appeals to a yet untested new energy source in astrophysical systems: a primary energy source due to bulk magnetic energy. It leads for SGR 0418+5729 to results in contradiction with observations. Our aim is to show how a consistent model for SGRs and AXPs can be expressed in terms of canonical physics and astrophysics within massive, fast rotating, and highly magnetized white dwarfs [2].

The energetics of SGRs and AXPs, including their outburst activities can be well explained through the change of rotational energy of the white dwarf, associated to the observed glitches, the sudden changes of the rotational period. In addition, we evidence that the sources PSR J1846-0258 with $P = 0.3$ s, SGR 1627-41 with $P = 2.59$ s, 1E 1547.0-5408 with $P = 2.07$ s as well as PSR J1622-4950 with $P = 4.33$ s, traditionally indicated as magnetar candidates, can be indeed interpreted as ordinary neutron stars. Their rotational periods are below the limit of stability $P \sim 5$ s for uniformly rotating carbon white dwarfs; their steady X-ray luminosity can be well explained within the neutron star model, and their magnetic fields are close to the ones of some known radio pulsars. Excluding these sources, we find for all the other sources traditionally indicated as magnetar candidates, a consistent model based on rotating white dwarfs. Their surface dipole magnetic fields are comprised in the range $7.5 \times 10^8\mathrm{G} \lesssim B \lesssim 2.1 \times 10^{11}\mathrm{G}$, well below the critical field $B_c = m_e^2 c^3/(e\hbar) = 4.42 \times 10^{13}$ G.

SGRs AND AXPs WITHIN THE WHITE DWARF MODEL

The pioneering works of M. Morini et al. (1988) and of B. Paczynski (1990) on 1E 2259+586 are extended and further developed to describe the observed properties of all known SGRS and AXPs by assuming spin-down powered massive, fast rotating, and highly magnetized white dwarfs. We adopt the white dwarf parameters: mass $M = 1.4 M_\odot$, radius $R = 10^3$ km, and moment of inertia $I \approx 10^{49}$ g cm^2. Such a configuration leads for SGR 0418+5729 to a magnetic field $B < 7.45 \times 10^8$ G. *The X-ray luminosity can then be expressed as originating from the loss of rotational energy of the white dwarf* leading to a theoretical prediction for the first time derivative of the rotational period:

$$\frac{L_X P^3}{4\pi^2 I} \leq \dot{P}_{\mathrm{SGR0418+5729}} < 6.0 \times 10^{-15}\,, \tag{1}$$

where the lower limit is established by assuming that the observed X-ray luminosity of SGR 0418+5729 coincides with the rotational energy loss of the white dwarf. For this specific source, the lower limit of $\dot{P}$ given by Eq. (1) is $\dot{P}_{\mathrm{SGR0418+5729}} \geq 1.18 \times 10^{-16}$. The upper limit on the magnetic field obtained by requesting that the rotational energy loss due to the dipole field be smaller than the electromagnetic emission of the dipole, is given by

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

where P and $\dot{P}$ are commonly observed properties and the moment of inertia I and the radius R of the object are model dependent properties. For the above mentioned parameters of a fast rotating magnetized white dwarf, Eq. (2) becomes

$$B = 3.2 \times 10^{15}\,(P\dot{P})^{1/2}\,\mathrm{G}\,. \tag{3}$$

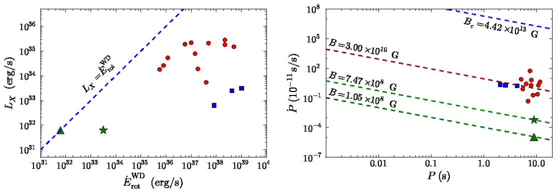

Figure 1: **(Left panel:)** *X-ray luminosity L_X versus the loss of rotational energy $\dot{E}_{\mathrm{rot}}$ describing SGRs and AXPs by fast rotating magnetized white dwarfs. The green star and the green triangle correspond to SGR 0418+5729 using respectively the upper and the lower limit of $\dot{P}$ given by Eq. (1). The blue squares are the only three sources with $L_x < \dot{E}_{\mathrm{rot}}$ within the magnetar model.* **(Right panel:)** *$\dot{P}$-P diagram for all known SGRs and AXPs. The curves of constant magnetic field for white dwarfs given by Eq. (3) are shown. The blue dashed line corresponds to the critical magnetic field $B_c = m_e^2 c^3/(e\hbar)$.*

MASSIVE ROTATING HIGHLY MAGNETIZED WHITE DWARFS OBSERVATIONS

A specific example is the highly magnetized white dwarf in AE Aquarii, where spiky pulsations in hard X-ray are observed [3]. Although it is a binary system with orbital period ~ 9.88 hr, there is evidence that the power due to accretion of matter is inhibited by the fast rotation of the white dwarf. Many of the observed physical properties of this white dwarf are very similar to the recently discovered SGR 0418+5729, as we explicitly show in Table 1.

	SGR 0418+5729	White Dwarf in AE Aquarii
P (s)	9.08	33.08
$\dot{P}$	$< 0.6 \times 10^{-14}$	5.64×10^{-14}
Age (Myr)	24	9.4
L_X (erg/s)	6.2×10^{31}	$\sim 10^{31}$
kT (keV)	0.67	0.5
B_{WD} (G)	$< 7.45 \times 10^8$	$\sim 10^8$
Pulsed Fraction	0.3	$\sim$ 0.2–0.3

Table 1: Comparison of the observational properties of SGR 0418+5729 and the white dwarf in AE Aquarii.

SGRs AND AXPs WITHIN THE MAGNETAR MODEL

Within the magnetar model [4], [5], a neutron star of $M = 1.4 M_\odot$ and $R = 10$ km and then $I \approx 10^{45}$ g cm^2 as the source of SGRs and AXPs, the limit of the magnetic field obtained from Eq. (2) becomes

$$B = 3.2 \times 10^{19}\,(P\dot{P})^{1/2}\,\mathrm{G}\,, \tag{4}$$

which is four orders of magnitude larger than the surface magnetic field within the fast rotating magnetized white dwarf model (see Fig. 2).

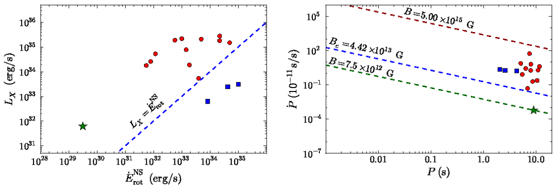

Figure 2: **(Left panel:)** *X-ray luminosity L_X versus the loss of rotational energy $\dot{E}_{\mathrm{rot}}$ describing SGRs and AXPs as neutron stars. The green star corresponds to SGR 0418+5729 using the upper limit of $\dot{P}$ given by Eq. (1). The blue squares are the only three sources with $L_x < \dot{E}_{\mathrm{rot}}$ within the magnetar model.* **(Right panel:)** *$\dot{P}$-P diagram for all known SGRs and AXPs. The curves of constant magnetic field for neutron stars given by Eq. (4) are shown. The blue dashed line corresponds to the critical magnetic field $B_c = m_e^2 c^3/(e\hbar)$.*

GLITCHES

In this magnetar model there is no role of the rotational energy of the source [6]: the X-ray luminosity is much bigger than the loss of rotational energy of the neutron star (see Fig. 2 - left panel). Paradoxically, although the bursts appear to be correlated to the presence of glitches in the rotational period of the neutron star, the corresponding increase of change of rotational energy of the neutron star cannot explain the burst energetic $\sim (10^{44}$–$10^{47})$ erg. This is a clear major difference between the two models based respectively on neutron stars and white dwarfs (see Fig. 3).

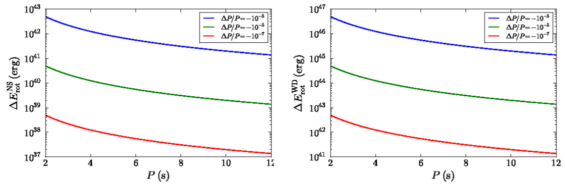

Figure 3: *Change in the rotational energy ΔE_{rot} as a function of the rotational period P of the object for different fractional changes of period $\Delta P/P$.*

	SGR 0526-66	1E 2259+586	1E 1048.1-5937	SGR 1806-20
Date	March 1979	June 2002	March 2007	December 2004
Observed Energy (erg)	3.6×10^{44}	3×10^{41}	4.2×10^{42}	$\sim 10^{46}$
$\lvert\Delta P\rvert/P$	1.2×10^{-4} (predicted)	4.24×10^{-6} (observed)	1.63×10^{-5} (observed)	3×10^{-3} (predicted)
Predicted Energy (erg)	3.6×10^{44}	1.7×10^{43}	7.7×10^{43}	$\sim 10^{46}$

Table 2: Glitches and Outbursts of some SGRs and AXPs within the white dwarf model.

CONCLUSIONS

The recent observations of the source SGR 0418+5729 cast a firm separatrix in comparing and contrasting the two models for SGRs and AXPs based respectively on a neutron star and a white dwarf. The limit on the magnetic field derived in the case of neutron star $B = 7.5 \times 10^{12}$ G makes it not viable as an explanation based on the magnetar model both from a global energetic point of view and from the undercritical value of the magnetic field. In the white dwarf model, the picture is fully consistent.

Our theory predicts the value of the first derivative of $\dot{P}$ given by Eq. (1), the surface magnetic field is, accordingly to Eq. (3), constrained by $1.05 \times 10^8\ \mathrm{G} < B_{\mathrm{SGR0418+5729}} < 7.47 \times 10^8\ \mathrm{G}$ (see Fig. 1).

From the above considerations it is evident that the characteristic changes of period $\Delta P/P \sim -(10^{-7}$–$10^{-3})$ and the relating bursting activity $\sim (10^{41}$–$10^{46})$ erg in SGRs and AXPs can be explained in term of the rotational energy loss of white dwarfs. It is also appropriate to recall that similar changes, on smaller scale, are also observed in pulsars and routinely expressed in terms of the rotational energy loss of neutron stars, without appealing to any magnetars phenomena.

References

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Acknowledgments:

Manuel Malheiro acknowledges the hospitality and support of ICRANet, and the Brazilian agency FAPESP (fellowship BPE 2010/0558-1 in the thematic project 2007/03633-3) by the financial support.