SGRs/AXPs DESCRIBED AS MASSIVE AND MAGNETIC WHITE DWARFS

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Abstract

The Anomalous X-ray Pulsars (AXPs) and Soft Gamma-ray Repeaters (SGRs) are some of the most interesting groups of pulsars that have been intensively studied in the recent years. They are seen usually as neutron stars with super strong magnetic fields, namely $B \gtrsim 10^{14}$ G. However, in the last two years two SGRs with low magnetic fields $B \sim (10^{12} - 10^{13})$ G have been detected. Moreover, fast and very magnetic WD pulsars have also been observed in the last years. Based on these new pulsar discoveries, white dwarf pulsars have been proposed as an alternative explanation to the observational features of SGRs and AXPs. The pulsar magnetic dipole moment depending only on the momentum of inertia I, and the observational properties as the period P and its first time derivative $\dot{P}$, can help to identify the scale of I for SGRs/AXPs. We discuss here the pulsar magnetic dipole moment m of SGRs and AXPs when a model based on a massive fast rotating highly magnetized white dwarf is considered. We show that the values for m obtained for almost all SGRs and AXPs are in agreement with the observed range $10^{34}\text{emu} \leq m \leq 10^{36}\text{emu}$ of isolated and polar magnetic white dwarfs. This supports the understanding of SGRs and AXPs as belonging to a class of very fast and magnetic massive white dwarfs, perfect in line to the recent astronomical observations of fast and massive white dwarfs.

Introduction

Recently, an alternative description of the Soft Gamma-ray Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) based on rotating highly magnetized and very massive white dwarfs (WD) has been proposed by Malheiro et al. 2012[1], following previous works of Morini et al. 1988 and Paczynski 1990. In this new description several observational features are easy understood and well explained as a consequence of the large radius of a massive white dwarf that manifests a new scale of mass density, moment of inertia, rotational energy, and magnetic dipole momentum in comparison with the case of neutron star. In this poster, we will discuss the magnetic dipole moment m of neutron stars and magnetic white dwarfs, to stress that the values obtained of m for SGRs and AXPs as white dwarfs are in agreement with the ones of polar and isolated magnetic WDs. The recent discoveries of SGR 0418+5729 (N. Rea et al. 2010) and Swift J1822.3-1606 (N. Rea et al. 2012 and Livingstone et al. 2012) with low magnetic field share some properties[2] with the recent detected fast WD pulsar AE Aquarii and RXJ 0648.0-4418, and the candidate EUVE J0317-855, to support the WD description of SGRs and AXPs as white dwarf pulsar.

The standard magnetic dipole model for rotation-powered pulsars

The magnetic dipole moment is related to the magnetic field strength at the magnetic pole of the star B_p by,

$$|\vec{m}| = \frac{B_p R^3}{2}, \tag{1}$$

where R is the star radius. If the star magnetic dipole moment is misaligned with the spin axis by an angle α, the energy per second emitted by the rotating magnetic dipole is (see, e.g., Shapiro & Teukolsky and references therein),

$$\dot{E}_{\rm dip} = -\frac{2}{3c^3}|\ddot{m}|^2 = -\frac{2|\vec{m}|^2}{3c^3}\Omega^4 \sin^2\alpha, \tag{2}$$

where $\ddot{m}$ is the second derivative of the magnetic dipole moment, $\Omega = 2\pi/P$ its rotational frequency and c is the speed of light. Thus, the physical quantity that dictates the scale of the electromagnetic radiated power emitted is, together with the angular rotational frequency, the magnetic dipole moment m of the star. The fundamental physical idea of the rotation-powered pulsar is that the X-ray luminosity - produced by the dipole field - can be expressed as originated from the loss of rotational energy of the pulsar,

$$\dot{E}_{\rm rot} = -4\pi^2 I \frac{\dot{P}}{P^3}, \tag{3}$$

associated to its spin-down rate $\dot{P}$, where P is the rotational period and I is the momentum of inertia. Assuming that all of the rotational energy lost by the the star is carried away by magnetic dipole radiation, equaling Eqs. (2) and (3) we deduce the expression of pulsar magnetic dipole moment,

$$m = \left(\frac{3c^3 I}{8\pi^2} P\dot{P}\right)^{1/2}. \tag{4}$$

Thus, from Eq. (1) we obtain the surface magnetic field at the equator B_e as:

$$B_e = B_p/2 = \left(\frac{3c^3 I}{8\pi^2 R^6} P\dot{P}\right)^{1/2}, \tag{5}$$

where P and $\dot{P}$ are observed properties and the moment of inertia I and the radius R of the object model dependent properties.

SGRs/AXPs within the white dwarf model

Let's described all SGRs and AXPs as white dwarfs of radius $R = 3000$ km and a mass $M = 1.4M_{\odot}$, as recent studies of fast and very massive white dwarfs obtained (see K. Boshkayev et al. 2012). Thus, these values of mass and radius generating the momentum of inertia $I \sim 1.26 \times 10^{50}\text{g cm}^2$, will be adopt hereafter in this work as the fiducial white dwarf model parameters. Using that parameters we obtain the magnetic dipole moment and the magnetic field of the white dwarf pulsar,

$$m_{\rm WD} = 1.14 \times 10^{40}(P\dot{P})^{1/2}\text{emu}, \tag{6}$$

and

$$B_{\rm WD} = 4.21 \times 10^{14}(P\dot{P})^{1/2}\text{G}. \tag{7}$$

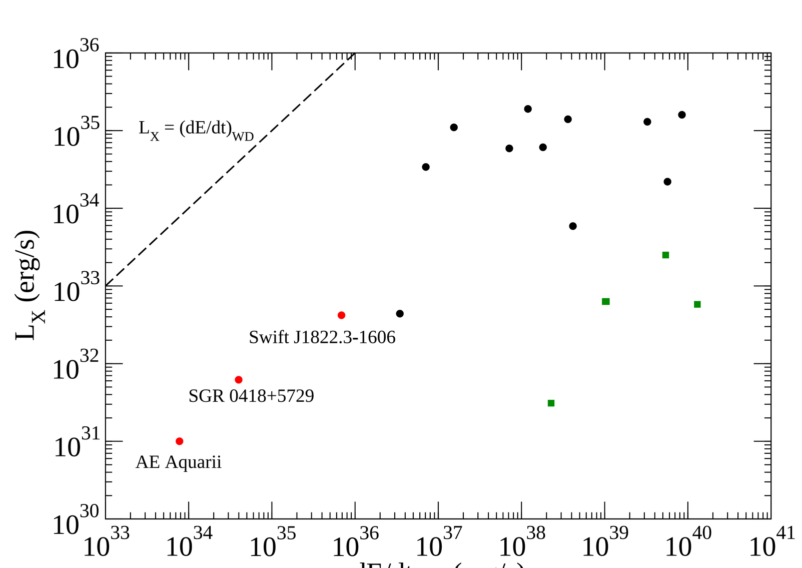

Figure 1: X-ray luminosity L_X versus spin-down luminosity $\dot{E}_{\rm rot}$ describing SGRs/AXPs as rotation-powered white dwarfs. The red points correspond to recent discoveries of SGR 0418+5729 and Swift J1822.3-1606 with low magnetic field and AEAquarii, and the green squares are the AXPs transients.

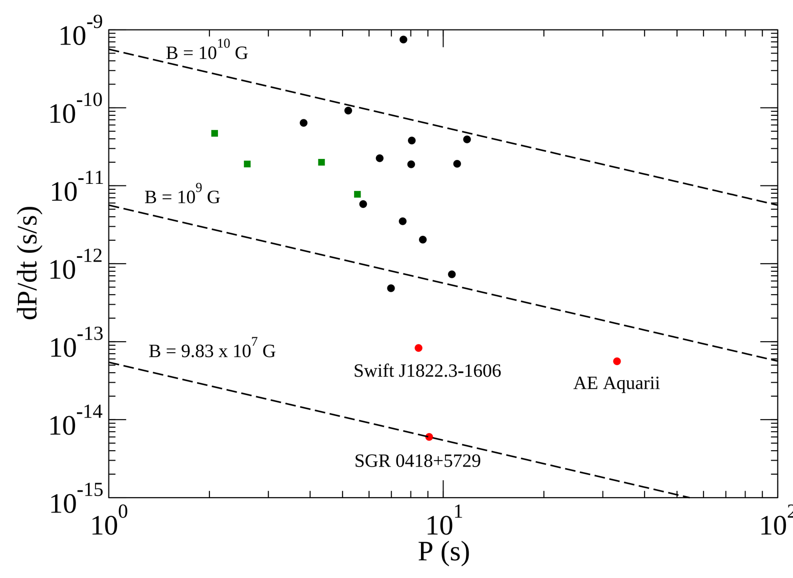

Figure 2: $\dot{P} - P$ diagram for all known SGRs/AXPs. The curves of constant magnetic field for white dwarfs given by Eq. (7) are shown.

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. 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. The recent discoveries of SGR 0418+5729 and Swift J1822.3-1606 with low magnetic field share some properties with the recent detected fast WD pulsar AE Aquarii and RXJ 0648.0-4418, and the candidate EUVE J0317-855, as we explicitly show in table below, to support the description of SGRs/AXPs as white dwarf pulsar.

	SGR 0418+5729	Swift J1822.3-1606	AE Aquarii	RXJ 0648.0-4418	EUVE J0317-855
P(s)	9.08	8.44	33.08	13.2	725
$\dot{P}$ (10^{-14})	< 0.6	8.3	5.64	< 90	-
Age (Myr)	24	1.6	9.3	0.23	-
L_X (erg/s)	$\sim 6.2 \times 10^{31}$	$\sim 4.2 \times 10^{32}$	$\sim 10^{31}$	$\sim 10^{32}$	-
$B_{\rm WD}$(G)	$< 9.83 \times 10^7$	3.52×10^8	$\sim 5 \times 10^7$	$< 1.45 \times 10^9$	$\sim 4.5 \times 10^8$
$B_{\rm NS}$(G)	$< 7.47 \times 10^{12}$	2.70×10^{13}	-	-	-
$m_{\rm WD}$(emu)	2.65×10^{33}	0.95×10^{34}	$\sim 1.35 \times 10^{33}$	3.48×10^{34}	1.22×10^{34}
$m_{\rm NS}$(emu)	7.47×10^{30}	2.70×10^{31}	-	-	-

Figure 3: Comparison of the observational properties of five sources: SGR 0418+5729, Swift J1822.3-1606, and three observed WD pulsar candidates.

SGRs/AXPs within the magnetar model

Within the model commonly addressed as magnetar, based on a canonical neutron star of $M = 1.4M_{\odot}$ and $R = 10$ km and then $I \sim 10^{45}\text{g cm}^2$ as the source of SGRs/AXPs and from Eqs. (4) and (5), we obtain the magnetic dipole moment and the magnetic field of the neutron star pulsar,

$$m_{\rm NS} = 3.2 \times 10^{37}(P\dot{P})^{1/2}\text{emu}, \tag{8}$$

and

$$B_{\rm NS} = 3.2 \times 10^{19}(P\dot{P})^{1/2}\text{G}. \tag{9}$$

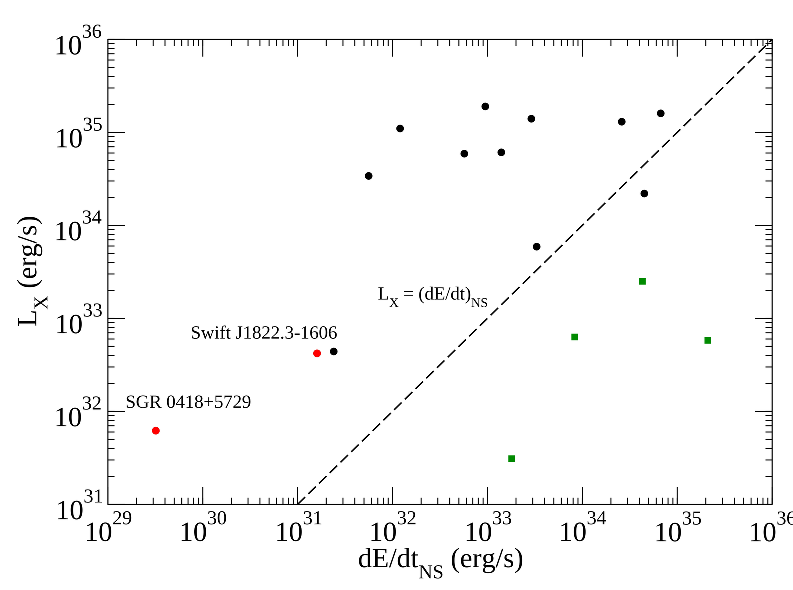

Figure 4: X-ray luminosity L_X versus spin-down luminosity $\dot{E}_{\rm rot}$ describing SGRs/AXPs as neutron stars. The red points corresponds to recent discoveries of SGR 0418+5729 and Swift J1822.3-1606 with low magnetic field, and the green squares are the AXPs transients.

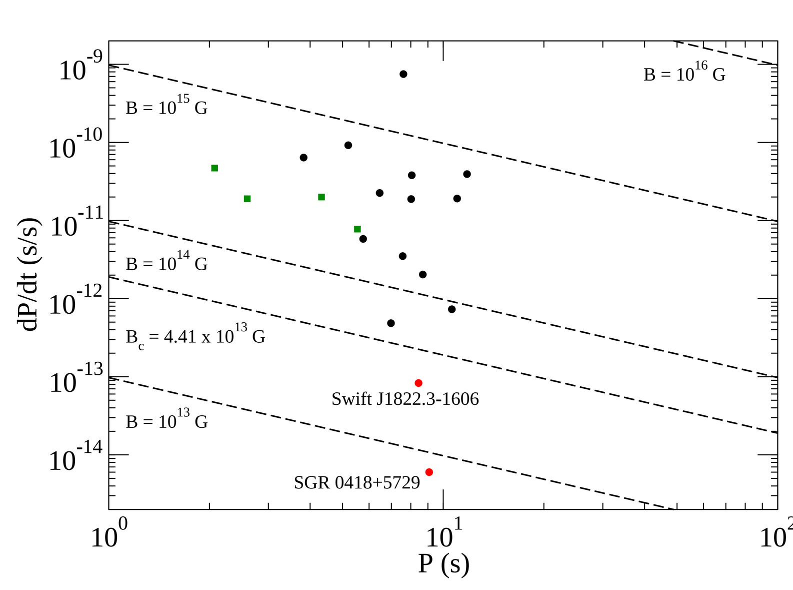

Figure 5: $\dot{P} - P$ diagram for all known SGRs/AXPs. The curves of constant magnetic field for neutron stars given by Eq. (9) are shown. The line B_c corresponds to the critical magnetic field. The red points corresponds to recent discoveries of SGR 0418+5729 and Swift J1822.3-1606 with low magnetic field, and the green squares are the AXPs transients.

Magnetic dipole moment of NSs and WDs

The possibility that strongly magnetized white dwarfs, could behave as neutron star pulsars with a pulse emission of high-energy photons in the X-ray to γ-ray band, originate interesting and very suggestive plots done for the first time by Terada et al.: plots of the magnetic field strength and the dipole magnetic field as a function of the period of neutron stars and white dwarfs. In this work, we reproduce these plots including the SGRs and AXPs as neutron stars (magnetars) and white dwarfs, using for them the fiducial parameters presented before, and including the fast WD recently discovered.

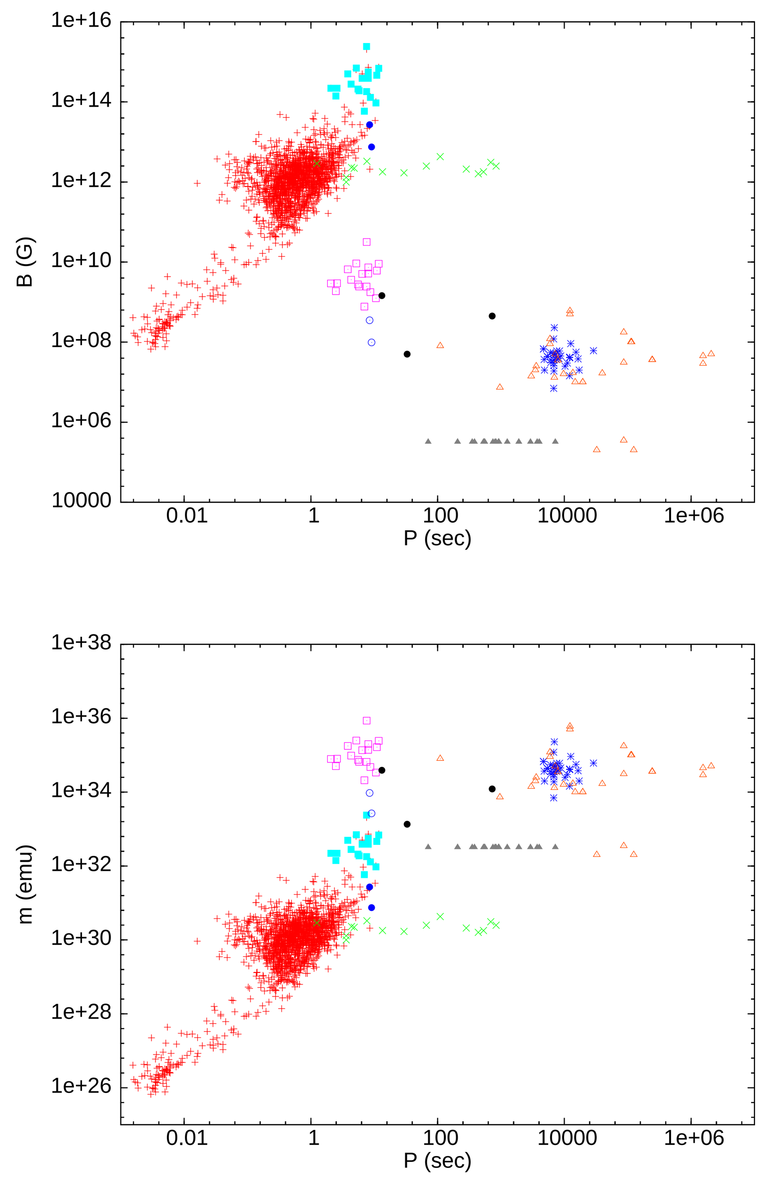

Figure 6: The figure shows as a function of the rotational period and the magnetic field strength (upper) and magnetic dipole moment (under) of neutrons stars and white dwarfs. The red plus sign points are the known pulsars from the ATNF online pulsar database. The green cross points are X-ray pulsars. The blue full square and the pink square correspond to SGRs and AXPs as neutron stars and white dwarfs, respectively. The two blue full and open circle points are the recent observed SGR 0418+5729 and Swift J1822.3-1606 considering neutron stars and white dwarfs parameters, respectively. The black full point are the three observed white dwarf pulsar candidates: the X-ray pulsator RX J0648.0-4418, AE Aquarii and EUVE J0317-855. The gray triangles are the intermediate polar and the other points are polar and isolated white dwarfs (see Terada et al. 2008d, for details of these points).

In Fig. 6 (upper panel), we present the magnetic field as a function of the period. Here we see that the magnetic field B of the SGRs and AXPs as NSs or WDs are quite different ($\sim 10^5$ order of difference) as pointed out before and also in Malheiro et al. 2012[1]. The magnetic field B of the two recent SGRs discovered (blue full circle) are comparable with the ones observed for the fast white dwarfs also ploted (black full circles). The magnetic fast white dwarfs are separated in two classes: isolated (orange triangles) and polars (blue asterisks), very magnetic with $B \sim (10^7 - 10^8)$ G, and the intermediate polars (gray triangle) with weaker field $B \sim 10^5$ G (few isolated magnetic WDs also belong to that class).
In Fig. 6 (under panel), the magnetic dipole moment m is presented as a function of the rotational period. To calculate from Eq. (6) the values of m for SGRs/AXPs (as white dwarfs), and also for the three fast white dwarfs of Table 1, we used the radius $R = 3000$ km in agreement with Boshkayev et al. 2012, whereas for the others white dwarfs we adopted $R = 10^4$ km following Terada et al. 2010 (for NSs the radius used is $R = 10$ km). This figure clearly shows that because of the small WD radius of the fast and massive white dwarf comparing to normal WD, the large magnetic field of the SGRs/AXPs as white dwarfs generated a magnetic dipole moment $10^{34} \leq m \leq 10^{36}$ emu, exactly in the range of isolated and polar magnetic white dwarfs .
This plot also shows that the property of white dwarf magnetic dipole moment range to be almost independent of the rotational period, is also reproduced by the SGRs and AXPs in the white dwarf model. This is not true for neutron stars where m increases with period P. This increase (slope) of m with P is in fact much larger for SGRs/AXPs as NSs comparing to normal X-ray pulsars, and the magnitude of m is quite large $10^{32} \leq m \leq 10^{33}$ emu a manifestation of the overcritical magnetic fields deduced in the magnetar model.
The values for $m \sim (10^{33} - 10^{34})$ emu of the two SGRs with low B, are exactly at the same order of the three white dwarf pulsars observed (see Table 1, and in the lower values of the observed isolated and polar white dwarf magnetic dipole moment range.
The large steady X-ray emission $L_X \sim 10^{35}$ 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 m is at the same scale as the one observed for the very magnetic and not so fast white dwarfs. These evidences supports the description of SGRs and AXPs as belonging to a class of very fast and magnetic massive white dwarfs perfect in line with recent astronomical observations of fast white dwarf pulsars.

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