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Can Soft Gamma-Ray Repeaters and Anomalous X-Ray Pulsars be described as white dwarfs?

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Abstract. The Soft Gamma Repeaters (SGR) and Anomalous X-Ray Pulsars (AXP) are widely interpreted as magnetars, neutron stars having a huge magnetic field in the range 10^{13} to 10^{15} G, greater than the critical limit imposed by quantum mechanics. Because of that, other interpretations are also studied, among them is the massive white-dwarf model. We present a study of the three SGR/AXP that have detected optical counterparts to verify whether that emission is consistent with a white-dwarf origin. Adopting a hot spot at the surface to explain the optical variability observed, the required dimension of this hot spot is around 1 to 5 % of the white dwarf radius, which supports the white dwarf model for those SGR/AXPs. Besides, the white-dwarf temperatures estimated for 4U 0142+61 and SGR 0501+4516 are also consistent with the white-dwarf hypothesis.

Resumo. As fontes *Soft Gamma Repeaters* (SGR) e *Anomalous X-Ray Pulsars* (AXP) são interpretadas pela maioria da comunidade científica como magnetares, estrelas de nêutron com um alto campo magnético da ordem de 10^{13} até 10^{15} G, acima do limite crítico imposto pela mecânica quântica. Dessa forma, outras interpretações são sugeridas, entre elas o modelo de anãs brancas massivas. Nós apresentamos um estudo de três fontes SGR/AXP que possuem contrapartida óptica, de forma a verificar se tal contrapartida é consistente com a emissão de uma anã branca. Adotando uma mancha quente para explicar a variabilidade observada no óptico, a dimensão encontrada para tal mancha é de 1 a 5 % do raio da anã branca, o que suporta um modelo de anãs brancas para tais SGR/AXPs. Além disso, as temperaturas estimada para 4U 0142+61 e SGR 0501+4516 também são consistentes com a hipótese de anãs brancas.

Keywords. Accretion, accretion disks – Stars: magnetars – white dwarfs

1. Introduction

Supposing that the SGR/AXPs can be interpreted as rotation-powered neutron pulsars, the inferred magnetic field is in the range of 10^{13} G to 10^{15} G. On the other hand, because of the larger inertia moment, the magnetic field needed to explain the observational properties of the SGR/AXPs as white dwarfs (WD) is in the range of 10^7 G to 10^9 G, within the observed range of values for magnetic field in isolated WD (Ferrario, 2015). A further explanation of the WD model can be found in Malheiro et al. (2012) and Coelho & Malheiro (2014) .

Besides that, three sources have pulsed optical counterparts, which is unexpected for isolated neutron stars. For that reason, we tried to explain the observed optical counterpart in a WD context. We verify if a hot spot model could simulate the variability observed and we also estimate the WD temperature.

2. Methodology

We focus on verify how plausible is the interpretation of SGR/AXP as WD. To explain the pulsed optical emission, we suppose that the flux in the phase of minimum brightness is caused by the WD photosphere, with no contribution from the hot spot, it is possible to estimate the WD temperature value by knowing the WD radius. In addition, to explain the pulsed optical emission, we consider a hot spot in the WD surface. The relation between the temperature of the hot spot and the WD mass is calculated assuming an accretion scenario using Aizu (1973). We adopt the mass and radius for massive WDs from Coelho (2017). The distance and the hydrogen column density N(H) for the two AXP's are from Durant & van Kerkwijk (2006) and for the SGR these values are from Camero et al. (2014).

Table 1. Limiting values of temperature for 1E 1048.1-5937

WD radius (km)	4250	1050
WD mass ($M_\odot$)	1.27	1.39
Spot's temperature (keV)	58.5	420.5
WD temperature (K)	3.2×10^5	5.9×10^6

We apply the above methodology for the three SGR/AXP that have pulsed optical emission. They are SGR 0501+4516, 4U 0142+61 and 1E 1048.1-5937.

3. Results

According to Dhillon et al. (2009), the mean magnitude for 1E 1048.1-5937 in the i' band is 25.3 mag and the pulsed fraction is 52 ± 15%. For SGR 0501+4516, these values are respectively 24.4 mag and approximately 80% (Dhillon et al., 2011). And for 4U 0142+61, 27.3 mag and 58 ± 16% (Dhillon et al., 2005). The values of the white dwarf temperature obtained for the two limiting values of radii for each one of the three SGR/AXP can be seen in tables 1, 2 and 3.

Besides, Figures 1, 2 and 3 show the size of the accretion region as a percentage of the WD radius for different values of WD mass for these three SGR/AXPs.

4. Discussion and conclusions

We estimate WD temperatures around 100,000 K for 4U 0142+61 and SGR 0501+4516. This is in agreement with the WD hypothesis, since WD can be as hot as 200,000 K, as,

Table 2. Limiting values of temperature for SGR 0501+4516

WD radius (km)	4550	1040
WD mass ($M_\odot$)	1.17	1.39
Spot's temperature (KeV)	76.9	415.5
WD temperature (K)	2.1×10^4	2.5×10^5

Table 3. Limiting values of temperature for 4U 0142+61

WD radius (km)	4250	1040
WD mass ($M_\odot$)	1.30	1.39
Spot's temperature (KeV)	84.5	415.5
WD temperature (K)	8.0×10^4	1.9×10^6

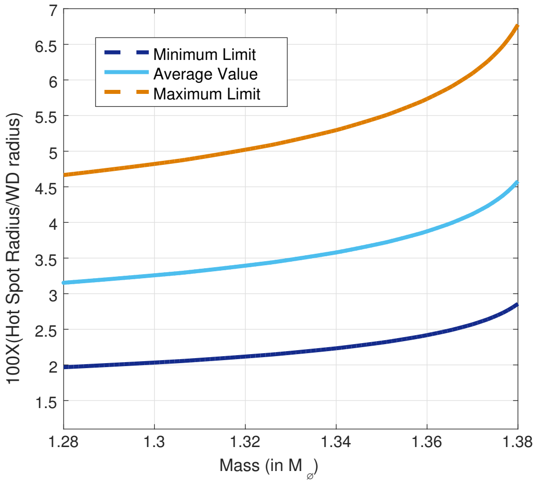

Figure 1. Size of the accretion region for 1E 1048.1-5937 as a percentage of the WD radius for different values of WD mass

for instance, H1505+65 (Werner & Ranch,2015). On the other hand, the white dwarf model for 1E 1048.1-5937 results in a temperature in the range 300,000 to 6,000,000 K, discarding this model for this source. The required dimension of the hot spot is around 1 to 5 % of the white dwarf radius to 4U 0142+61 and SGR 0501+4516. These results support the white dwarf model for some SGR/AXP.

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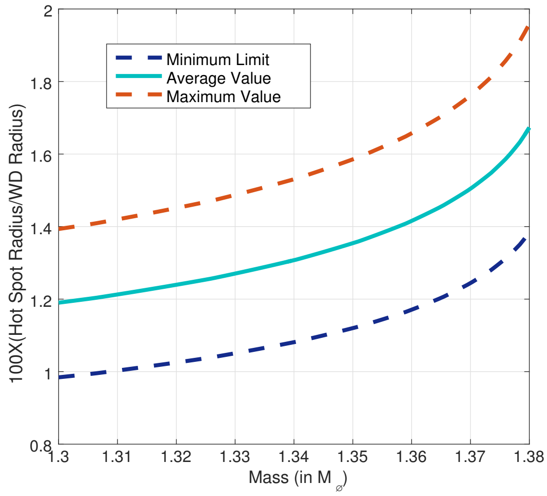

Figure 2. Size of the accretion region for SGR 0501+4516 as a percentage of the WD radius for different values of WD mass

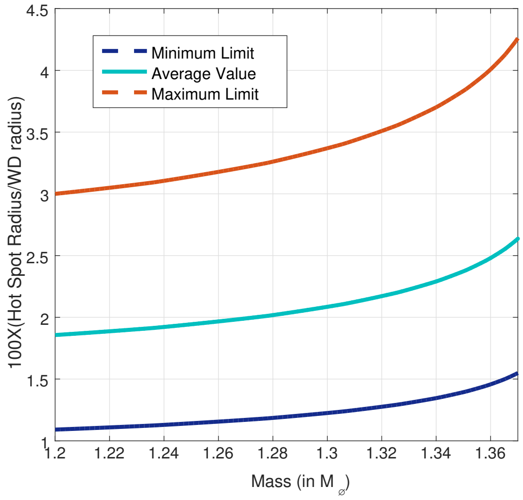

Figure 3. Size of the accretion region for 4U 0142+61 as a percentage of the WD radius for different values of WD mass