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Can the anomalous X-ray pulsar 4U 0142+61 be described as an accreting white dwarf?

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Abstract. The persistent emission of the anomalous X-ray pulsar 4U 0142+61 extends over a broad range of energy, from mid-infrared up to hard X-rays. In particular, this object is unique among soft gamma-ray repeaters and anomalous X-ray pulsars in presenting simultaneously mid-infrared emission and also pulsed optical emission. In spite of having many propositions to explain this wide range of emission, it is still lacking one that reproduces simultaneously all the observations. Filling this gap, we present a model that is able to reproduce the entire spectral energy distribution of 4U 0142+61 using plausible physical components and parameters. We propose that the persistent emission comes from an accreting white dwarf (WD) surrounded by a debris disk. This model assumes that: (i) the optical and infrared emission is mainly caused by the optically thick dusty disk, the WD photosphere; (ii) the hard X-rays are due to the post-shock region of the accretion column, and (iii) the soft X-rays are originated by the heating of the WD surface. In this scenario, 4U 0142+61 harbors a fast-rotator near-Chandrasekhar WD, which is highly magnetized. Such a WD can be formed by a merger of two less massive WDs. This WD merger event is also proposed as progenitor of the double-degenerated supernovae (SN) Ia scenario. In this case, 4U 0142+61 can be in a previous stage of a SN Ia and hence can give hints of the origin of these important astrophysical events.

Resumo. A emissão do pulsar anômalo de raios-X 4U 0142+61 estende-se em uma ampla faixa de energia, do infravermelho médio até os raios-X duros. Em particular, este objeto é único em sua classe, apresentando simultaneamente emissão de infravermelho médio e emissão ótica pulsada. Apesar de ter muitos modelos para explicar este amplo espectro de emissões, nenhum reproduz simultaneamente todas as observações. Preenchendo essa lacuna, apresentamos um modelo que é capaz de reproduzir toda a distribuição de energia espectral de 4U 0142+61 usando componentes e parâmetros físicos plausíveis. Nós propomos que a emissão persistente vem de uma anã branca circundada por um disco de detritos. Este modelo assume que: (i) a emissão ótica e infravermelha é causada pelo disco de poeira opticamente espesso e pela fotosfera da anã branca; (ii) os raios X duros são devidos à região pós-choque da coluna de acreção, e (iii) os raios-X moles são originados pelo aquecimento da superfície da anã branca. Neste cenário, 4U 0142+61 abriga uma anã branca rápida próxima ao limite de Chandrasekhar e altamente magnetizada. Tal anã branca pode ser formada pela coalescência de duas anãs brancas menos massivas. Este evento de coalescência também é proposto como um dos possíveis progenitores de supernovas Ia. Neste caso, 4U 0142+61 pode contribuir para o entendimento da origem desses importantes eventos astrofísicos.

Keywords. Accretion, accretion disks — Magnetic fields — Stars: rotation — White dwarfs

1. Introduction

The anomalous X-ray pulsars and soft gamma-ray repeaters (AXP/SGRs) are observationally characterized by a quiescent soft X-ray (2 – 10 keV) luminosity in the range 10^{29} – 10^{35} erg.s^{-1}, period of 2 – 12 s, and spin-down of 10^{-15} to 10^{-10} s.s^{-1}. In outburst, the luminosity can reach 10^{43} erg.s^{-1} (see, e.g., Olausen & Kaspi, 2014). Some AXP/SGRs also present emission in other energy ranges, such as radio, optical, infrared and hard X-rays, as well as soft gamma-ray flares events .

The emission nature of AXP/SGRs is still reason for debate and several scenarios have been proposed to explain their observed spectra and properties. The most accepted scenario is the magnetar model (Duncan & Thomson, 1992; Thomson & Duncan, 1995). In this model, the AXP/SGRs present a huge magnetic field (B), in the range of 10^{13} – 10^{15} G, and 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. However, some limitations of the model, such as the discovery of the low-B ($< 10^{13}$ G) source SGR 0418+5729 (Rea et al. 2010), have increased the interest for alternative scenarios in the past few years.

The most accepted alternative model invokes accreting NSs and was proposed by van Paradijs, Taam & van den Heuvel (1995). In this model, the X-ray emission is consequence of infalling gas reaching a isolated NS. Moreover, there are models considering quark stars (Ouyed, Leahy & Niebergal 2011), in which the object would have magnetic fields of the order of 10^{15} G, or WD pulsars (Malheiro, Rueda & Ruffini 2012), in which the emission comes from a very massive, rapid and magnetic WD pulsar.

4U 0142+61 is an AXP that presents quiescent emission in a broad range of energy, from mid-infrared up to hard X-rays. In particular, this object is unique among SGR/AXPs in presenting simultaneously mid-infrared emission and pulsed optical emission, which are rare features for the class. Its period is 8.68 s, the spin-down is around 2.0×10^{-12} s.s^{-1} and the soft X-rays luminosity is about 10^{35} erg.s^{-1} (Olausen & Kaspi 2014).

All the current models fail to explain the entire spectral range of 4U 0142+61. That problem is not exclusive of 4U 0142+61, since no scenario presents a complete model for the SGR/AXPs class. In this context, we propose that the persistent emission comes from an accreting isolated WD surrounded by a debris disk, having gas and dusty regions. This scenario is inspired by the periodic flux modulation and by the presence of mid-infrared emission, which is rare for NSs. In fact, apart from the SGR/AXP class (in which only 1E 2259+586 and 4U 0142+61 have mid-infrared; Kaplan et al. 2009; Wang, Chakrabarty & Kaplan 2006), only three isolated NSs have detected mid-infrared: the radio pulsars Crab, Vela, and Geminga (Sandberg & Sollerman 2009; Danilenko el al. 2011). Thus, mid-infrared appears in about 0.3% of all isolated NSs. On the other hand, the presence of mid-infrared in WDs is quite common. Debes et al. (2011) found that about 7% of all isolated WDs presents an excess of mid-infrared detected by *WISE*, which reinforces the WD origin for 4U 0142+61.

This proceedings presents a study of 4U 0142+61 emission in the context of a WD nature. It is organized as follows. In section 2, we show the spectral fit of 4U 0142+61 and discuss the derived parameters. In Section 3, we derive the magnetic field of 4U 0142+61 from the spin-down. In Section 4, we discuss the probable origin and evolution of the object in our scenario. Finally, in section 5, we summarize our findings.

2. An accreting WD model for 4U 0142+61

We propose that the persistent emission components are the WD photosphere, a disk, and an accretion column. The disk is formed by a dusty external region and a gaseous internal region. The dusty disk is optically thick and emits such as a multi-temperature blackbody. The temperature of its inner radius is the grain sublimation temperature, which is about 1500 K for silicates. Conversely, the internal gaseous disk is optically thin and its emission can be neglected. The inner radius of the gaseous disk is equal to the magnetosphere radius. From that point on, the matter flows into the WD surface following the magnetic field lines and the debris disk ceases to exist.

Close to the WD photosphere, the in-falling flow of matter produces a shock, forming an extremely hot region, the so called post-shock region that emits bremsstrahlung. About half of that energy reaches the WD surface, where it is reprocessed, forming a hot spot. Once the high-energy emission for 4U 0142+61 is pulsed, with two peaks per phase, the most plausible option is that we see the emission from two different accreting regions. Thus, we can express the total flux by:

$$F_{total} = F_{disk} + F_{wd} + F_{spot} + F_{brem}. \qquad (1)$$

The WD photosphere (F_{wd}) and the hot spots (F_{spot}) emit such as blackbody whereas the post-shock region emits by thermal bremsstrahlung (F_{brem}). According to Mewe, Lemen & van der Oord (1986), the bremsstrahlung emitted power is:

$$P(\lambda, T_{brem}) = 2.051 \times 10^{-22} g_{ff} n_e^2 \lambda^{-1} T_{brem}^{-1/2} exp\left(\frac{-143.9}{\lambda T_{brem}}\right). \qquad (2)$$

The parameters n_e, T_{brem}, λ, and g_{ff} are the electrons number density, the temperature of the bremsstrahlung emission, the wavelength, and the Gaunt factor, respectively. Equation 3 gives the flux of the bremsstrahlung emission.

$$F_{brem}(n_e, R_{brem}, H, T_{brem}, d) = \frac{hP_{\lambda,T_{brem}}}{4}\left(\frac{R_{brem}}{d}\right)^2, \qquad (3)$$

in which we assume that the region is optically thin and cylindrical, with a height h and radius R_{brem}.

At last, we have the multi-temperature disk component (F_{disk}):

$$F_{disk}(\nu, T_{in}, T_{out}, T_{wd}, R_{wd}, d) = 12\pi^{1/3}\cos(i)\left(\frac{R_{wd}}{d}\right)^2 \times \left(\frac{2kT_{wd}}{3h\nu}\right)^{8/3}\left(\frac{h\nu^3}{c^2}\right)\int_{x_{in}}^{x_{out}} \frac{x^{5/3}}{e^x - 1}dx. \qquad (4)$$

In this equation, $x = h\nu/kT$, where T is the debris disk temperature which ranges from T_{out} to T_{in} and T_{wd} is the WD effective temperature. The model, as well as the parameters for each flux component, are described thoroughly in Borges (2018).

2.1. Fitting 4U 0142+61 SED

As the model parameters for each spectral region are not the same, we opted to fit spectral regions separately. To fit the SED of 4U 0142+61 we use the data presented in Figure 1. All the fitted data are dereddened and deabsorbed. We have used Markov Chain Monte Carlo (MCMC Goodman & Weare 2010) to estimate the parameters and their uncertainties. The parameters of the fit and the resulting SED are shown in Table 4 and Figure 1. We consider the distance of 2.57 kpc (Borges 2018) and $N_H = 6.4 \times 10^{21}$ cm^{-2}(Durant & van Kerkwijk 2006a).

The fit quality of the hard X-rays increases for high bremsstrahlung temperatures, which we can only achieve for near-Chandrasekhar white dwarfs. The highest temperature we can reach for the limiting mass of 1.41 $M_\odot$ and radius of 1021 km (Carvalho, Marinho & Malheiro 2018) is 670.3 keV. Thus, we fixed the temperature in 670.3 keV in order to guarantee the best fit for a WD scenario.

After modelling the hard X-rays, we find the best fit for soft X-rays. The bremsstrahlung component is also included in the fit of the soft X-ray SED. To be consistent with the double peak in the soft X-rays light curve and to increase the quality of the fit, we use two black bodies components, which can have different temperatures and radii. The flux for each hot spot is a blackbody component.

To fit the optical and infrared emission, we use the WD photosphere blackbody and the debris disk. The tail of bremsstrahlung component from the post-shock region also contributes to the optical emission as shown in Figure 1. The WD photosphere emits such as a blackbody and the flux of the disk is given by eq. 4. We use same values of R_{wd} derived from the bremsstrahlung fit.

2.2. Post-shock region

To fit the data, we need a high value of temperature for the accretion structure, around 670 keV. Such a high temperature is not observed for any known cataclysmic variable (accreting WD in a binary system). However, those high values are theoretically possible for a massive WD composed by carbon. Furthermore, D. Belloni (private communication) has implemented a shock solution for accreting WDs. Their results show that shock temperature as high as 1000 keV can be found for massive WDs accreting C-O material, which corroborates the temperature of our fitting.

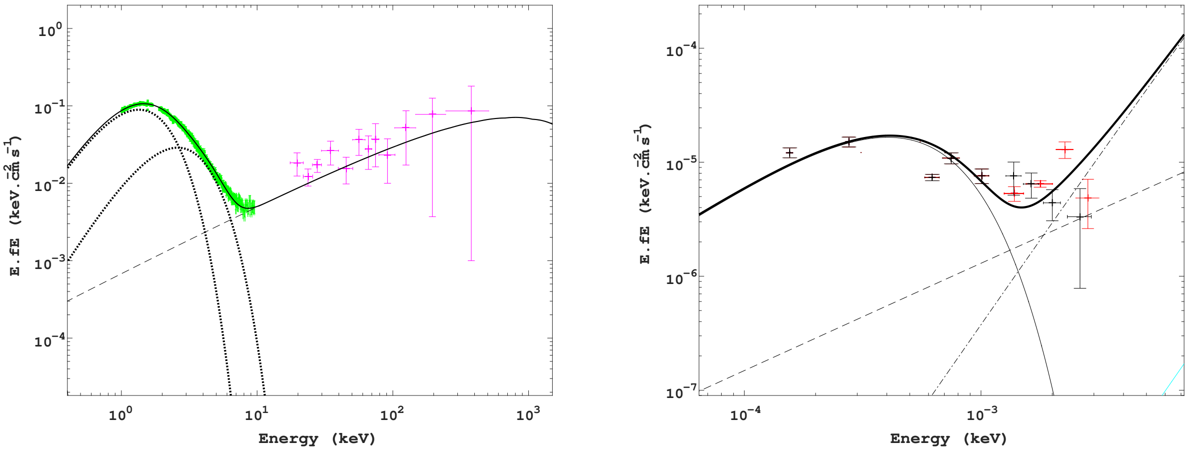

Figure 1. *Left panel:* X-rays fit of 4U 0142+61. The dotted lines are the blackbody components, the dashed line is the bremsstrahlung component and the bold black line is the total emission The data of 4U 10142+61 are deabsorved. The green crosses are soft X-rays from Enoto et al. (2010, Suzaku); and magenta crosses are the 2003.12 data from Wang, Tong & Guo (2014, INTEGRAL). *Right panel:* Optical/infrared fit of 4U 0142+61. The filled line is the disk component, the dot-dashed line is the blackbody emitted by the WD photosphere, the dashed line is the hard X-rays bremsstrahlung tail and the bold black line is the total emission. The black crosses are from Wang, Chakrabarty & Kaplan (2006, mid-infrared), Durant & van Kerkwijk (2006b, near-infrared) and Muñoz-Darias, de Ugarte Postigo & Casares (2016, optical); and the red crosses are from Hulleman, van Kerkwijk & Kulkarni (2000, 2004).

2.3. WD cooling age

From the effective WD temperature, we can estimate the WD age. Hurley & Shara (2003) present an improved version of the Mestel cooling law, which for t < 9,000 Myr is:

$$L = \frac{300MZ^{0.4}}{\left[A(t+0.1)\right]^{1.18}}. \tag{5}$$

In this equation, L is the luminosity of the WD photosphere in solar units, M is the WD mass in solar units, A is the average atomic number, t is the age in Myr, and Z is the photosphere metallicity. We consider a core composition of 60% carbon and 40% oxygen, and Z = 0.001 (Althaus et al. 2010; Rueda et al. 2013), which results in a cooling age of 31 kyr.

2.4. Debris Disk

The inner temperature of the debris disk is 1937 K (see Table 4), larger than the silicate sublimation temperature (T_s) of about 1,300 – 1,500 K (Lodders 2003). However, this T_s is based on the solar abundance and is mainly used to model protoplanetary disk of young stars. Rafikov & Garmilla (2012) argue that those values of T_s provide underestimated values of T_{in} for disk around WDs once the composition and evolution of these disks are distinct from those around young stars. In fact, some WDs have T_{in} larger than 1500 K, such as He 1349−2305 (Girven et al. 2012), with T_{in} = 1700 K. Moreover, according to Rafikov & Garmilla (2012), T_{in} is larger for WD with higher accretion rates and T_{WD}, in line with the larger T_{in} of 4U 0142+61 compared to T_{in} of other isolated WDs.

3. Spin-down, propeller regime, and the magnetic field

4U 0142+61 is slowing down. Thus, in this section, we estimate the possible magnitude of the magnetic field of 4U 0142+61 to reproduce the spin-down for an accreting regime.

The corotational radius is the disk position in which the particles rotational velocity is equal to stellar rotation. According to Ekşi, Hernquist & Narayan (2005), the corotational radius (R_c - eq. 6) must be larger than both R_{wd} and R_m (which is the magnetosphere radius, defined by equation 7) for the system to be in the accretor region. Moreover, R_m must be higher than R_{wd} for magnetic accretion.

$$R_c = \left(\frac{GM_{wd}}{\omega^2}\right)^{1/3}. \tag{6}$$

$$\frac{R_m}{R_{wd}} \simeq 13.4\left[\frac{B(1+3\sin^2\beta)^{1/2}}{3\times10^7}\right]^{4/7}\left(\frac{f}{10^{-3}}\right)^{2/7}\times \\ \times\left(\frac{M_{wd}}{M_\odot}\right)^{-8/21}\left(\frac{\dot{M}}{10^{16}}\right)^{-2/7} \tag{7}$$

On the other hand, the total spin-down is given by eq. 8.

$$\dot{P} = -\frac{P^2}{2\pi}\left[\frac{2\pi\dot{M}R_c^2}{PI}n(\omega_s) - \frac{2\Omega^3\mu^2}{3Ic^3}\sin^2\beta\right]. \tag{8}$$

The parameters μ (G.cm^3) and I (g.cm^2) are the magnetic moment and the moment of inertia, respectively. $n(\omega_s)$ can be obtained in Wang (1987), where $\omega_s = R_m/R_c$. The second term is always positive (spin-down) whereas the first term must have the relation between the magnetosphere radius and the corotational radius in the range of 0.971 to 1.0 (Wang 1987) to be in a spin-down behavior.

For $\beta = 90°$, we must have $B = 3.91\times10^7$ G to reach 2×10^{-12} s.s^{-1}. Conversely, if we consider $\beta = 0°$, we must have $B = 7.82\times10^7$ G. Thus, the magnetic field range in the WD accreting model is $3.91\times10^7 < B < 7.82\times10^7$ G. This spin-down requires $R_m/R_c = 0.995$, which is extremely close to 1 but still consistent with the criteria to be in the accreting regime.

Table 1. Parameters of the fitting of 4U 0142+61 in the accreting WD model

Parameter	Description	Value
X-rays		
FIXED PARAMETERS		
d (kpc)	distance of 4U 0142+61	2.57
N_H (10^{21} cm^{-2})	columnar density of hydrogen	6.4
T_{brem} (keV)	temperature of the emission for the accretion column	670.3
FITTED PARAMETERS		
M_{wd} ($M_\odot$)	mass of the white dwarf	1.41
R_{wd} (10^5 cm)	radius of the white dwarf	1.021
$\dot{M}$ (10^{17}g.s^{-1})	accretion rate	2.66
R_{brem} (10^5 cm)	radius of the hard X-ray emission	9.62
H (10^4 cm)	height of the accretion column	4.47
n_e (10^{19} cm^{-3})	electrons number density	3.38
χ^2_{brem}/dof	reduced chi square for the hard X-rays	0.86
T_{spot1} (keV)	temperature of the spot 1	0.336 (11)
R_{spot1} (10^5 cm)	radius of the spot 1	9.49 (48)
T_{spot2} (keV)	temperature of the spot 2	0.632(32)
R_{spot2} (10^5 cm)	radius of the spot 2	1.62 (28)
χ^2/dof	reduced chi square for the soft X-rays	1.05
Optical/Infrared		
FITTED PARAMETERS		
T_{wd} (10^5 K)	effective temperature of the white dwarf	2.87(28)
T_{in} (K)	inner temperature of the debris disk	1937(170)
T_{out} (K)	outer temperature of the debris disk	120(109)
R_{in} ($R_\odot$)	inner radius of the debris disk	1.14
R_{out} ($R_\odot$)	outer radius of the debris disk	47

Note. The fixed parameters were derived before the fit by independent methods. For the infrared/optical fit all the X-rays parameters are considered fixed, therefore, R_{wd} is not a fitted parameter for this range of energy. The 1σ uncertainties for the last digit for the fitted parameters are in parenthesis.

4. Possible origin and evolution of the object

If this accreting WD model is correct, 4U 0142+61 is a fast-spinning, isolated, magnetic, hot, and extremely massive WD. Even though those characteristics are very uncommon for an WD, sources with similar characteristics have already been observed. Re J0317-853, for example, is in an binary system without any interaction with the secondary. This object has a period of 725.4 s, a estimated mass of 1.35 $M_\odot$, an effective temperature of ~ 50.000 K, and magnetic field of ~ 340 MG (Barstow et al. 1995). The most plausible origin for that source is the merger of two less massive CO WDs (Ferrario et al. 1997). This merger can occur between WDs with different cores compositions and lead to several final results (Dan et al. 2014). However our interest is in two CO WD progenitors, which results in a near-Chandrasekhar mass product. The remnant consists in a cold core formed by the primary, a hot envelope made by a fraction of the secondary mass and a disk containing the remaining of the secondary. Just a small fraction of mass (about $10^{-3}M_\odot$) is ejected and leaves the system (Lorén-Aguilar, Isern & García-Berro 2009). The exact percentage of the secondary in the disk varies according to the mass of the progenitors. According to previous simulations, a good estimate for this percentage is ~ 50% of the less massive progenitor (Becerra et al. 2018), which gives a initial mass of the disk in the order of 10^{-1} $M_\odot$.

This newborn WD is also expected to have a short period right after the coalescence. Becerra et al. (2018) state that the remnant (cold core+envelope) spins as a rigid body. In contrast, Yoon, Podsiadlowski & Rosswog (2007) argue that the cold core rotates as a rigid body whereas the envelope spins deferentially leading the photosphere to present almost a Keplerian angular velocity. This differential rotation, however, vanishes quickly and the remnant eventually starts to rotate uniformly. It is also expected the growth of a magnetic field during the coalescence (Ji et al. 2013; Zhu et al. 2015) and in the early years after the merger (García-Berro et al. 2012). All those properties - presence of the disk, small spin period, and huge magnetic field - are consistent with the observations of 4U 0142+61 . Thus, if the accreting WD model for 4U 0142+61 is correct, this object probably is a young product of a merger of two less massive CO WDs.

In addition, the remnant is expected to accrete matter from the disk during its early years, which is also consistent with the proposed model. Yoon, Podsiadlowski & Rosswog (2007) argue that the disk is more likely to be thermal-pressure supported and the initial accretion rate is of the order of $10^{-7}M_\odot$.yr^{-1} (Becerra et al. 2018). Considering the initial spin period of about 2.5 s (Becerra et al. 2018) and an accretion rate smaller than the Eddington limit, we have $R_m > R_c$ in the early years. Thus, the remnant would initially pass trough a propeller phase. This propeller phase spun-down the remnant, preventing it from break. As a consequence of the spin-down, the period and, hence, the corotational radius increases thus enabling the WD to accrete matter from the disk.

To predict how this very massive WD would evolve after accretion starts is a hard task, once neither the evolution for the post-merger product nor the fate of very massive accreting WDs are well understood. In either case, 4U 0142+61 would be a great candidate to become a NS, by collapse or SN Ia. It is also possible for 4U 0142+61 to become an extremely massive WD, such as Re J0317-853.

For the accreting WD model, both the spin-down and infalling matter can also disturb its stability. Saio & Nomoto (2004) argues that a WD with the same origin of 4U 0142+61 probably would not explode as a SN Ia because it would inevitably become a O-Ne-Mg WD. In this case, the accretion could lead 4U 0142+61 to exceed the limiting mass and become a NS by carbon deflagration collapse (Nomoto & Kondo 1991). However, they consider a $10^{-5} - 10^{-6}\ M_{\odot}.\mathrm{yr}^{-1}$ and do not take into account the effect of the magnetic field nor the spin period, which are essential parameters to predict the evolution of WD merger products.

Conversely, Yoon, Podsiadlowski & Rosswog (2007) considered an accretion rates smaller than $10^{-6}\ M_{\odot}.\mathrm{yr}^{-1}$ and taken into account the spin period. They found that the remnant of two CO WD can lead to a SN Ia after $\sim 10^{5}$ yr. Moreover, Becerra et al. (2018) simulate the evolution of a 1.45 $M_{\odot}$ WD remnant for a thermal pressure supported disk. For a 10^{7} G magnetic field (see sec. 3), the object would suffer a carbon ignition after a few 10^{4} yr. Therefore, the age to explode as a SN 1a is higher than the derived cooling age but extremely closer. Thus, if the accreting WD model were correct, 4U 0142+61 is a good candidate to explode as a SN Ia in a small amount of time. Conversely, if the fate of 4U 0142+61 were the collapse into a NS or a very massive WD, it is still a priceless object, since it provides clues of how the merger of two CO WDs evolves.

5. Conclusions

We obtained a good fit for the entire SED of 4U 0142+61 . The optical/infrared emission of 4U 0142+61 comes from the WD itself and from the debris disk with a non-negligible contribution from the low-energy tail of the post-shock region. The hard X-rays is emitted by the accretion column and the soft X-rays by two hot spots in the WD photosphere.

The hard X-rays bremsstrahlung implies a near-Chandrasekhar WD, assumed to have a mass of 1.41 $M_{\odot}$ and a radius of 1 021 km. Moreover, from the optical/infrared emission, we obtain an WD effective temperature of 287,000 K. Those radius and temperature point out to an young WD, with an estimate age of 31 kyr. The inner and outer disk temperatures are 1937 and 120 K, which leads to a minimum mass of about 10^{26} g. From the spin-down, we can estimate a magnetic field of $\sim 10^{7}$ G, which is consistent with several magnetic WDs.

In short, we were able to present a model that explains all the quiescent emission of 4U 0142+61, as well as the observed spin-down. Such a WD can be understood as the result of a recent merger of two less massive WDs. In this scenario, 4U 0142+61 is a good candidate to becoming a SN Ia.

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References

Althaus, L. G., Córsico, A. H., Isern, J., & García-Berro, E. 2010,A&A Rev., 18, 471

Barstow, M. A., Jordan, S., O'Donoghue, D., et al. 1995,MNRAS, 277, 97

Becerra, L., Rueda, J. A., Loréen-Aguilar, P., & Garcıa-Berro, E.2018, ApJ, 857, 134

Borges, S. V. 2018, 'Emission models of Soft Gamma-Ray Repeaters/Anomalous X-Ray Pulsars described as White Dwarfs', Master thesis, Instituto Tecnológico de Aeronáutica.

Carvalho, G. A., Marinho, R. M., & Malheiro, M. 2018, GeneralRelativity and Gravitation, 50, 38

Dan, M., Rosswog, S., Brüggen M.,& Podsiadlowski, P. 2014,MNRAS, 438, 14

Danilenko, A. A., Zyuzin, D. A., Shibanov, Y. A., & Zharikov,S. V. 2011, MNRAS, 415, 867

Debes, J. H., Hoard, D. W., Wachter, S., Leisawitz, D. T., & Cohen, M. 2011, ApJS, 197, 38

Duncan, R. C., & Thompson, C. 1992, ApJ Lett., 392, L9

Durant, M., & van Kerkwijk, M. H. 2006 ApJ, 650, 1082

Durant, M., & van Kerkwijk, M. H. 2006 ApJ, 652, 576

Ekşi, K. Y., Hernquist, L., & Narayan, R. 2005, ApJ Lett., 623,L41

Enoto, T., Nakazawa, K., Makishima, K., et al. 2010, ApJ Lett.,722, L162

Ferrario, L., Vennes, S., Wickramasinghe, D. T., Bailey, J. A., &Christian, D. J. 1997, MNRAS, 292, 205

Ferrario, L., Wickramasinghe, D. T., & Tuohy, I. R. 1989, ApJ,341, 327

Frank, J., King, A., & Raine, D. J. 2002, Accretion Power in Astrophysics: Third Edition, 398

García-Berro, E., Lorén-Aguilar, P., Aznar-Siguán, G., et al.2012, ApJ, 749, 25

Girven, J., Brinkworth, C. S., Farihi, J., et al. 2012, ApJ, 749, 154

Goodman, J., & Weare, J. 2010, Communications in Applied Mathematics and Computational Science, Vol. 5, No. 1,p. 65-80, 2010, 5, 65

Hulleman, F., van Kerkwijk, M. H., & Kulkarni, S. R. 2000,Nature, 408, 689

Hulleman, F., van Kerkwijk, M. H., & Kulkarni, S. R. 2004, A&A, 416, 1037

Hurley, J. R., & Shara, M. M. 2003, ApJ, 589, 179

Ji, S., Fisher, R. T., García-Berro, E., et al. 2013, ApJ, 773, 136

Kaplan, D. L., Chakrabarty, D., Wang, Z., & Wachter, S. 2009,ApJ, 700, 149

Kaspi, V. M., & Beloborodov, A. M. 2017, ARA&A, 55, 261

Kilic, M., Hambly, N. C., Bergeron, P., Genest-Beaulieu, C., & Rowell, N. 2018, MNRAS, 479, L113

Külebi, B., Ekşi, K. Y., Lorén-Aguilar, P., Isern, J., & García-Berro, E. 2013, MNRAS, 431, 2778

Lodders, K. 2003, ApJ, 591, 1220

Lorén-Aguilar, P., Isern, J., & García-Berro, E. 2009, A&A, 500,1193

Malheiro, M., Rueda, J. A., & Ruffini, R. 2012, PASJ, 64, 56

Maoz, D., Mannucci, F., & Nelemans, G. 2014, ARA&A, 52, 107

Mewe, R., Lemen, J. R., & van den Oord, G. H. J. 1986, A&AS,65, 511

Muñoz-Darias, T., de Ugarte Postigo, A., & Casares, J. 2016,MNRAS, 458, L114

Naleźyty, M., & Madej, J. 2004, A&A, 420, 507

Nomoto, K., & Kondo, Y. 1991, ApJ Lett., 367, L19

Nozawa, S., Itoh, N., & Kohyama, Y. 1998, ApJ, 507, 530

Olausen, S. A., & Kaspi, V. M. 2014, ApJS, 212, 6

Ouyed, R., Leahy, D.,& Niebergal, B. 2011, MNRAS, 415, 1590

Rafikov, R. R., & Garmilla, J. A. 2012, ApJ, 760, 123

Rueda, J. A., Boshkayev, K., Izzo, L., et al. 2013, ApJ Lett., 772,L24

Rybicki, G., & Lightman, A. 1979, Radiative Processes in Astrophysics, A Wiley-Interscience publication (Wiley)

Saio, H., & Nomoto, K. 2004, ApJ, 615, 444

Sandberg, A., & Sollerman, J. 2009, A&A, 504, 525

Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337

Suleimanov, V., Doroshenko, V., Ducci, L., Zhukov, G. V., & Werner, K. 2016, A&A, 591, A35

Thompson, C., & Duncan, R. C. 1995, MNRAS, 275, 255

Rea, N., Esposito, P., Turolla, R., et al. 2010, Science, 330, 944

Toonen, S., Hollands, M., Gänsicke, B. T., & Boekholt, T. 2017,A&A, 602, A16

van Hoof, P. A. M., Ferland, G. J., Williams, R. J. R., et al. 2015,MNRAS, 449, 2112

van Paradijs, J., Taam, R. E., & van den Heuvel, E. P. J. 1995,A&A, 299, L41

Wang, W., Tong, H., & Guo, Y.-J. 2014, Research in Astronomy and Astrophysics, 14, 673

Wang, Y.-M. 1987, A&A, 183, 257

Wang, Z., Chakrabarty, D., & Kaplan, D. L. 2006, Nature, 440,772

Warner, B. 2003, Cataclysmic Variable Stars, 592

Yoon, S.-C., Podsiadlowski, P., & Rosswog, S. 2007, MNRAS,380, 933

Zhu, C., Pakmor, R., van Kerkwijk, M. H., & Chang, P. 2015,ApJ Lett., 806, L1