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RX J0648.0–4418: THE FASTEST-SPINNING WHITE DWARF

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HD 49798/RX J0648.0–4418 is a post common-envelope X-ray binary composed of a hot subdwarf and one of the most massive white dwarfs with a dynamical mass measurement (1.28±0.05 $M_\odot$). This white dwarf, with a spin period of 13.2 s, rotates more than twice faster than the white dwarf in the cataclysmic variable AE Aqr. The current properties of these two binaries, as well as their future evolution, are quite different, despite both contain a fast-spinning white dwarf. HD 49798/RX J0648.0–4418 could be the progenitor of either a Type Ia supernova or of a non-recycled millisecond pulsars.

Keywords: Stars: white dwarfs, subdwarfs, rotation

1. Introduction

The soft X-ray source RX J0648.0–4418 is optically identified with the bright star HD 49798(V=8), well known to optical astronomers since the sixties as the brightest member of the small class of hot subdwarf stars. HD 49798 attracted much interest due to its peculiar composition: the overabundance of nitrogen and helium, and the low abundance of carbon and oxygen, indicate that its surface layers once belonged to the outer part of the hydrogen-burning core of a massive star.[1,2] HD 49798 is the stripped core of an initially much more massive and larger star that lost most of the outer hydrogen envelope, most likely as a consequence of non conservative mass transfer in a close binary.

Indeed, early radial velocity measurement showed that HD 49798 is in a binary system with orbital period of 1.55 days,[3] but the nature of the companion star could not be determined due to its faintness compared to the much brighter subdwarf. Only in 1996, with the discovery[4] of X-ray pulsations at 13.2 s, it became clear the the "invisible" companion of HD 49798 is a compact object: either a neutron star or a white dwarf.

More recently, thanks to *XMM–Newton* X-ray timing of its regular pulsations, which make this system equivalent to a *double-lined* spectroscopic binary, and the discovery of the eclipse, which constrains the orbital inclination, we could get a dynamical measure of the masses of the two stars. These are 1.50±0.05 $M_\odot$ for the subdwarf and 1.28±0.05 $M_\odot$ for its compact companion.[5]

The high-quality *XMM–Newton* spectra also showed that the compact object is most likely a white dwarf.[6] In fact, the measured X-ray bolometric luminosity of $\sim 10^{32}$ erg s^{-1} (for the well known distance[1] of 650 pc) is exactly what one would expect for a white dwarf accreting in the stellar wind of HD 49798. This hot subdwarf shows evidence of mass loss[7] at a rate of $\dot{M}_{\rm W} \sim 3 \times 10^{-9}$ M$_\odot$ yr^{-1} and with a wind terminal velocity of 1350 km s^{-1}. Despite this wind is much weaker that that of massive O type stars, its accretion onto a neutron star would produce a luminosity much higher than the observed one. The large pulsed fraction of ∼55% rules out the possibility that the low luminosity be due to a neutron star in the propeller stage. The X-ray spectrum of RX J0648.0–4418 is dominated by a very soft blackbody component with temperature kT∼40 eV and emitting radius larger than ∼20 km. The size of the emitting region is too large compared to the dimensions of a hot spot on the surface of a neutron star required to account for the high pulsed fraction. Thus RX J0648.0–4418 is most likely one of the most massive white dwarfs and the one with the shortest spin period.

Table 1. Comparison of RX J0648.0–4418 and AE Aqr

	RX J0648.0–4418	AE Aqr
Period	13.18 s	33.08 s
Period derivative	$< 6 \times 10^{-15}$ s s^{-1}	6×10^{-14} s s^{-1}
White dwarf mass	1.28±0.05 $M_\odot$	0.7–1.2 $M_\odot$
Companion mass	1.50±0.05 $M_\odot$	0.5–0.9 $M_\odot$
Companion	sdO subdwarf, V=8	K3-5 main sequence, V∼12
Orbital period	1.55 days	0.41 days
Mass transfer	Stellar wind	Roche-lobe overflow
X-ray luminosity	$\sim 10^{32}$ erg s^{-1}	$\sim 10^{31}$ erg s^{-1}
Rotational energy loss rate	$< 10^{34}$ erg s^{-1}	6×10^{33} erg s^{-1}
Distance	650 pc	100 pc

2. Comparison with AE Aqr

It is interesting to compare the properties of RX J0648.0–4418 with those of another fast-spinning white dwarf: the intermediate polar AE Aqr[8] (see Table 1). Cataclysmic variables of the intermediate polar class have magnetic fields of ∼5–20 MG, which can influence the accretion flow and disrupt an eventual accretion disk, but lower than those found in polars, where the white dwarf rotation is synchronized with the orbital period.

AE Aqr exhibits a hard X–spectrum and strong rapid variability at all wavelengths, contrary to RX J0648.0–4418 which shows a nearly constant X-ray flux, dominated by a thermal-like component. The spin-period of AE Aqr increases at a rate of 5.6×10^{-14} s s^{-1}, most likely as a result of the magnetic propeller effect. This means that the accretion stream from its companion is disrupted by the magnetic field of the white dwarf and most of the mass is ejected.[9] The fast rotation and high magnetic field of AE Aqr imply that, in principle, particle acceleration in the white dwarf magnetosphere might occur,[10] similar to what happens in rotation-powered neutron stars. The possible detection of pulsed hard X-rays (10–30 keV) in AE Aqr[11] indicates that non-thermal emission powered by rotational energy might be present. The implied efficiency of ∼0.1% is similar to that of radio pulsars.

While RX J0648.0–4418 is rotating more than twice faster than AE Aqr, there is no evidence for rotation-powered activity. Indeed there is evidence that its magnetic field is rather small[6] and the observed luminosity is naturally explained by accretion from the wind of HD 49798.

3. Conclusions and open questions

The origin of the rapid rotation of the white dwarf in RX J0648.0–4418 is unclear. This system is necessarily the result of evolution involving a common-envelope phase.[12] If the fast rotation was not imparted at birth, significant spin-up must have occurred either before or during the common envelope phase, since the transfer of angular momentum is very small at the currently observed low accretion rate. It seems more likely that spin-up occurred before the common-envelope phase, considering its short duration and complicated dynamics. A possibility is that the white dwarf was spun-up when the expanding HD 49798 was close to fill its Roche-lobe just before the ensuing of the common-envelope phase.

The high rotational velocity has important consequences for the future evolution of the system. If RX J0648.0–4418 hosts a CO white dwarf, it could be the progenitor of an over-luminous type Ia supernova, since the fast rotation can increase the mass stability limit above the value for non-rotating stars. Descending from relatively massive stars ($\sim$8–9 $M_\odot$), the delay time for such a supernova could be relatively short, unless the explosion is delayed by the centrifugal effect.[13]

If instead the white dwarf has an ONe composition, an accretion induced collapse might occur, leading to the formation of a neutron star. The high spin rate and low magnetic field make this white dwarf an ideal progenitor of a millisecond pulsar. This could be a promising scenario for the direct formation of millisecond pulsars, i.e. one not involving the recycling of old pulsars in accreting low mass X-ray binaries.

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