CTCV J2056-3014 and other fast-spinning white dwarfs

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This contribution summarises our recent determination of the spin period of the magnetic white dwarf in CTCV J2056-3014, a cataclysmic variable binary system. Its X-ray and optical emission comes from its magnetic accretion column and is modulated with a 29.6 s period, due to the WD rotation. We briefly discuss this object in the context of other fast-spinning white dwarfs.

Keywords: White dwarfs; Cataclysmic variable stars; X-rays: stars.

1. Introduction

White dwarfs (WDs) are the evolutionary fate of most stars. WDs are composed of degenerated matter and, together with neutrons stars and stellar black holes, constitute the group of compact stellar objects with strong gravitational fields in their neighborhood. The maximum mass that a WD can reach is around 1.4 $M_{\odot}$, the Chandrasekhar limit. The exact limit depends on many assumptions as the rotation, the magnetic field strength, and the adopted equation of state, which is related to the physical conditions and processes taking place in the stellar interior. Due to the compactness of their degenerated interior, WDs can rotate very rapidly, reaching spin periods as small as a few tens of seconds. WDs also show the largest values of magnetic moments among stellar objects. As stars in general, they are found isolated or in binary systems.

In isolated WDs, high values of mass, spin, and magnetic field seem to appear together. WD 0316-849 is one example of such an extreme WD. It has a magnetic field (B) of around 500 MG, a spin (P_{spin}) of 725 s, and a mass (M_{WD}) equal to 0.86 $M_{\odot}$(see Ref. 1 and references therein). ZTF J190132.9+145808.7 has been recently associated with a very massive WD, $M_{WD} > 1.3$ $M_{\odot}$. Its P_{spin} is 416.4 s and its surface magnetic field is estimated to be in the range $600 - 900$ MG.[2] Those WDs are probably originated by mergers - see, for instance, the discussion in Ref. 3. In particular, mergers can produce remnants with high angular momenta.

CVs are binary systems in which a WD accretes matter from the secondary star, a low-mass on the main sequence or slightly evolved that loses material by Roche lobe overflow. The magnetic CVs are those systems in which the WD magnetic field is strong enough to play a role in the dynamics of the accretion flow. If the WD magnetic field is not strong enough to synchronize the WD spin with the orbital period, the system is classified as an intermediate polar.

The optical and X-ray emission of intermediate polars is caused by mass accretion onto the magnetic WD and modulates with the WD spin. It is caused by accretion onto a magnetic WD. This process produces a stand-off shock near the WD surface where gravitational energy is converted to thermal energy. This enhances the gas density and heats it to keV temperatures producing the X-ray emission and the high excitation optical spectrum. The footprint of the accretion structure covers a small area of the WD surface. Therefore, the WD rotation causes a modulation of the emission as seen by the observer.

In this contribution, we outline our recent finding that CTCV J2056-3014, an intermediate polar, harbors a very fast-spinning WD. We also discuss this result in the context of similar objects.

2. CTCV J2056-3014

The optical spectrum of CTCV J2056-3014[4,5] is characterized by a very blue continuum and strong emission lines, including the Bowen complex, indicative of high excitation temperatures. The radial velocity variation of the emission lines indicates an orbital period of 1.76 h.[4] The first indications that CTCV J2056-3014 could be an intermediate polar were the possible association with the X-ray source 1RXS J205652.1−301433 and a photometric modulation of around 15 min.[4] However, this periodic variability was not confirmed by further observations.[6]

Recently, XMM-Newton X-ray observations of CTCV J2056-3014 have revealed a coherent modulation at 29.6098 ± 0.0014 s, also present in the optical emission.[7] This modulation and the X-ray spectrum of CTCV J2056-3014 confirm that the object is an intermediate polar, i.e., an accreting magnetic WD in an asynchronous CV. The fit of its X-ray spectrum provides an accretion mass rate, $\dot{M}$, of about 6×10^{-12} $M_{\odot}yr^{-1}$ (Ref. 7).

Most intermediate polars have X-ray luminosities, L_X, of $\sim 10^{33}$ erg s^{-1}. The luminosity of CTCV J2056-3014 is around 100 times smaller (10^{31} erg s^{-1}); a property shared with a very small group of CVs named low-luminosity intermediate polars (LLIPs).[8] It is not clear if the number of LLIPs is small because they are rare objects or because their X-ray faintness hampers their discovery in X-ray surveys. If the true number of LLIPs is high and we are missing them because of observational biases, this class of objects is probably a relevant contributor to the Galactic X-ray background.[8]

3. The fastest spinning WDs

In this section, we enumerate the bona fide fastest spinning WDs, which are all located in compact binary systems. However, for completeness, we also mention some objects that could be WDs with a rapid spin. A summary of selected characteristics of individual objects is shown in Table 1.

There is a debate in the literature if some soft gamma-ray repeaters (SGR) and anomalous X-ray pulsars (AXP), the so-called magnetars, could contain a WD instead of a neutron star.[9,10] For example, the spectral energy distribution from the infrared to the gamma-rays of 4U 0142+61 (P_{spin}= 8.62 s) can be fitted in a scenario of a fast, massive, and magnetic WD.[3] If some magnetars were indeed WDs, they would put strong constraints on the physics of the WD interiors, to cite only one consequence of this hypothesis. In spite of the importance of this subject, those objects are not considered here.

WZ Sge is a short orbital period cataclysmic variable that shows dwarf-nova outbursts with a very long recurrence time (a few decades). The system has intermittent periodical signals at 28.87 s and 28.96 s. One of these periods could be the WD spin period, but it is not a settled question (see Ref. 11 and references therein). We do not consider this system as a confirmed fast-spinning WD, but we list its properties in Table 1.

Another fast-spinning compact object is RX J0648.0-4418, with a P_{spin} of 13.2 s. This object is in a relatively wide binary system, with an orbital period of 1.55 d. However, it is debated if the compact object is a WD or a neutron star.[7,12] In some sense, this object is a link between fast-spinning WDs and magnetars. As for WZ Sge, we do not include it in the list of bona fide fast-spinning WDs, but its properties can be found in Table 1.

AE Aqr was the first discovered fast and magnetic WD, and its peculiar properties prompted many studies.[13] Its WD spins at a 33 s rate. The system is the prototype of a propeller: a system in which the centrifugal force of a magnetic fast-rotating object prevents the accretion from a mass reservoir to reach the object's surface. This is one of the possible accretion-flow configurations in cataclysmic variables. It depends on the WD magnetic field, WD spin, and accretion rate.[14] However, even if part of the material is propelled out of the WD magnetosphere, some material can reach the WD surface. This is probably the case for AE Aqr,[15,16] since its X-ray luminosity is small but not null: $\dot{M} \approx 10^{31}$ erg s^{-1}.[15] The radius of the companion star is twice as large as is expected for its mass, indicating a very inflated object.

V1460 Her is an intermediate polar with a WD that spins at 38.9 s.[17] The companion star is less massive than that of AE Aqr, but it is also significantly inflated. Contrary to AE Aqr, there is an accretion disk in V1460 Her, clearly seen in optical spectra.

At the time of this conference, CTCV J2056-3014 was known as the fastest-spinning WD. However, a faster WD has been recently discovered: LAMOST J024048.51+195226.9, with a spin period of 24.9328 ± 0.0038 s.[18] The system shows strong evidence of an outflow with properties consistent with those expected for a propeller.[19]

4. Discussion and conclusions

Two possible mechanisms for spinning up WDs are mergers and accretion.

The isolated WDs with large values of M_{WD}, B, and P_{spin} are probably produced by mergers. The majority of the most massive WDs have high values of magnetic fields,[1,2,24–26] which indicates that these two properties may have a common origin. Simulations show that double-degenerated mergers can produce WDs with high and stable magnetic fields.[27] From an observational perspective, there is also evidence for mergers. The color-magnitude distribution of a *Gaia* sample of nearby WDs ($d \lesssim 100$ pc) indicates the presence of two populations of WDs, which can be explained if some objects are formed by a merger.[28] Considering objects within 20 pc, the fraction of WDs in binary systems is considerably smaller than the fraction of binary systems composed of two main-sequence objects. This can be explained if a portion of the isolated WDs is formed via mergers.[29] Although mergers can play an important role in producing extreme WDs, the bona fide fastest-rotating WDs are all located in binary systems, specifically cataclysmic variables.

In cataclysmic variables, the rapid WD spin may be the result of the mass transfer. Specifically, the accretion transforms the orbital angular momentum into the rotational angular momentum of the WD. To reach the observed high P_{spin}, high values of $\dot{M}$ are necessary. However, a high mass-transfer rate should produce a high X-ray luminosity, which is not observed in the fast-spinning WDs (see Table 1). Therefore, the current high spin is explained by a previous phase of high mass transfer rate from a secondary star in a thermal time-scale phase. In fact, the

Table 1. Selected properties of the confirmed fastest spinning WDs and related objects.

Object	P_{spin} (s)	Orbital period (h)	M_{sec} ($M_{\odot}$)	M_{WD} ($M_{\odot}$)	L_X (erg s^{-1})	Confirmed	Comments	References
LAMOST J024048.51+195226.9	24.9328	7.33	-	-	-	Yes	Propeller	18, 19
CTCV J2056-3014	29.6098	1.76	-	0.56 – 1.38	10^{-31}	Yes	Below the period gap	4, 7, 20
AE Aqr	33	9.88	0.37 ± 0.04	0.63 ± 0.05	10^{-31}	Yes	Inflated secondary; Propeller	21, 21
V1460 Her	38.9	4.99	0.295 ± 0.004	0.869 ± 0.006	-	Yes	Inflated secondary	17
RX J0648.0-4418	13.2	37.2	1.50 ± 0.05	1.28 ± 0.05	10^{-32}	No	WD or neutron star?	22
WZ Sge	28.87 or 28.96	1.36	0.078 – 0.13	0.88 – 1.53	10^{-30}	No	Period is not firmly associated with spin	11, 23

secondary stars in AE Aqr[13] and V1460 Her[17] are twice as large as is expected for their masses, which reinforces the idea of a star slightly out of equilibrium. If the same is true for CTCV J2056-3014 and LAMOST J024048.51+195226.9 cannot be said, because their secondary stars have not yet been directed observed. Along its evolution, a CV evolves to shorter orbital periods. Consequently, the component separation as well as the radius of the secondary star shrink. In particular, the mass of the secondary, M_{sec}, is expected to decrease together with the orbital period. Moreover, above the observed period gap in the orbital period distribution of CVs, the angular-momentum transfer occurs by magnetic braking and produces larger $\dot{M}$ in comparison with objects below the period gap, which should have the angular momentum transfer sustained by gravitational radiation. Interestingly, CTCV J2056-3014 is the only object among the fast-spinning WD below the period gap.

The WDs in CTCV J2056-3014 and AE Aqr are certainly magnetic.[7] The understanding of the origin of the modulation in V1460 Her and LAMOST J024048.51+195226.9 would benefit from X-ray observations, which could reveal the presence of a magnetic WD.

Until recently, AE Aqr occupied an isolated position as the fastest-spinning confirmed WD. In the last years, other fast-spinning WDs have been discovered, all of them in CVs. Although most of them are similar to AE Aqr in the context of CV evolution, CTCV J2056-3014 - the only system with an orbital period below the CV period gap - seems to be a more evolved object. Those new results can help us understanding the physics behind the rapid spin of WDs in CVs and how the WD spin evolves along the CV evolution.

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