Mem. S.A.It. Vol. 83, 713

Memorie della

Precession of white dwarfs in CVs

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Abstract. Precession is observed routinely in solid bodies of Solar system and it has been invoked to explain number of phenomena observed in pulsars (i.e. Link 2003, Breton et al. 2008). White dwarfs also have been considered as possible candidates of precessing stellar objects. In slowly rotating compact stars, the precession period is extremely long and the amplitude of precession is small. However, in rapid rotating neutron stars and white dwarfs, the precession period is still within reasonable observational limits and can explain observed periodicities exceeding spin periods by several times.

Key words. Stars: cataclysmic variables – Stars: white dwarfs – X-rays: stars

1. Introduction

Precession as a tool to study internal structure of stars is not new. Monaghan (1968) considered the chance of detection of precession from a rotating magnetic star. About that time pulsars were discovered and soon thereafter Pines (1974) suggested that the observed 35 day period in Her X-1 may be attributed to a free precession of a neutron star. Later it was claimed that the precession of an isolated neutron star was viable and observational evidence has been found (Sedrakian et al. 1999; Jones & Andersson 2001). Neutron stars are considered to have a solid outer crust with a liquid interior and are expected to demonstrate free precession. Since pulsars emit highly collimated radio beams with highly predictable timing, the detection of precession is relatively easy. But in the case of white dwarfs, or ordinary magnetic stars which radiate isotropically, the observation of precession is practically impossible.

Binary stellar systems containing compact objects may offer the opportunity for the study of properties of matter under extreme conditions through measurements of interactions of the compact object with the orbital companion or through derivatives of the interaction, such as accretion disks, accretion flows, etc. The obvious candidates are magnetic Cataclysmic Variables (CVs), in which the accretion of matter from the Roche lobe filling secondary onto the white dwarf (WD) occurs via magnetic field lines to a relatively small spot on the surface of the WD. The shock created above that spot produces a beam of highly energetic radiation observed directly in X-rays. This beam or its reverberations from the components of the binary system can be used to detect possible precession of WD. The precession of a rapidly rotating, magnetic WD was proposed as a source of long periods detected in a few CVs, most notably FS Aur and V455 And (Tovmassian et al. 2007).

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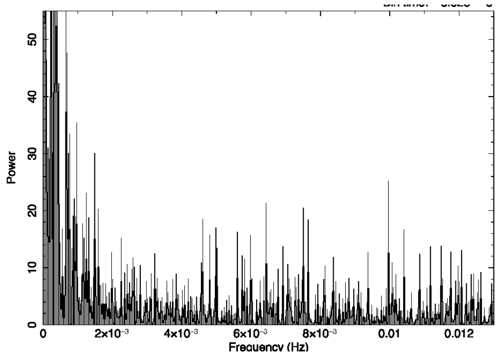

Fig. 1. The high frequency end of the power spectrum of the X-ray light curve of FS Aur (Tovmassian et al. 2012); the spin period is believed to be at 0.01 Hz, a marginal peak which nevertheless coincides with a similar result obtained from the rapid optical photometry (Neustroev et al. 2005).

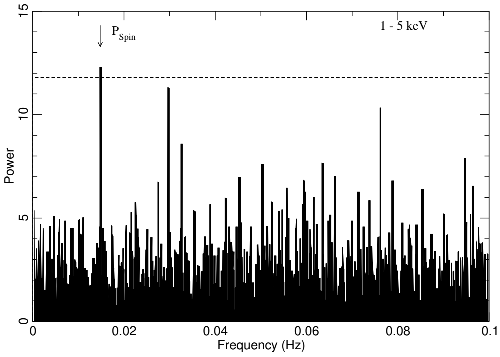

Fig. 2. The high frequency end of the power spectrum of the X-ray light curve of V455 And (Gänsicke et al. 2012); the spin period is known from the optical photometry (Gänsicke 2007).

2. The concept of precession and conditions to detect it

The idea of precession of WDs was suggested by Leins et al. (1992), who explicitly mention a possible application of their models to the Intermediate Polars, i.e. Cataclysmic Variables in which the magnetic WD rotation is not synchronized with the orbital period of the binary system. In this model free precession is expected to occur in a WD containing elastic matter. Two different free precession modes are considered: that of a rigid and axially symmetric body precessing with the Euler frequency, and the Chandler frequency of an elastic body in which the instantaneous rotation axes slightly deviate from the figure axes. It is worth mentioning here the fact that the elasticity effects necessary to sustain the free precession are achieved in a carbon WDs of relatively large mass and low temperatures in which the crystallization of the core has taken place (van Horn & Savedoff 1976). In the context of CVs it means that mostly the old, evolved systems with WDs cooled to 10 000 K and mass $\sim 1M_{\odot}$ are candidates to contain a precessing WD.

One of the important conclusions stemming from the calculations is that only a fast rotating WDs will have precession rates possible to detect. Leins et al. (1992, see Table 3) and Tovmassian et al. (2007, see Figure 7) illustrate the ratio of spin period to the precession period. The number of known systems with spin periods of order of $10^1 - 10^2$ s is not very large. The spin periods of IPs predominantly cluster around $P_{spin} \sim 0.1\,P_{orb}$ (Norton et al. 2004). In 2004 only four had $P_{spin} < 150$ s. Among them, only WZ Sge is a short period, evolved system with possibly massive and cool WD. Since this list was published, a few discoveries have been made of short orbital period systems which show in addition long periods either photometrically (Tovmassian et al. 2003; Vican et al. 2011) or spectroscopically (Araujo-Betancor et al. 2005; Tovmassian et al. 2007). These periods are not directly associated with the orbital or any other periods found usually in CVs. One such object, V455 And, has been proven to possess a rapidly rotating and hence a magnetic WD (Gänsicke 2007). For GW Lib the 97 ± 12 s spin period estimate (van Spaandonk et al. 2010) is indirect, and no evidence of magnetic WD has been reported. In the case of FS Aur there is only weak evidence for the presence of the spin period in the light curves (Neustroev et al. 2005). One way to detect the spin period of the magnetic WD in a CV is by X-ray observations. FS Aur and V455 And were both observed by X-ray telescopes and in both cases the signal at the presumed spin frequency is marginal. The power spectrum of FS Aur X-ray light curve is presented in Figure 1. Although the spin period of

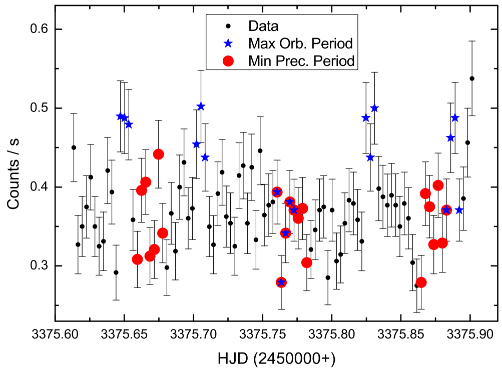

Fig. 3. The X-ray light curve of FS Aur obtained with *Chandra* is presented as small dots with error bars. The stars indicate moments of X-ray pulses separated by modulo the orbital period. The large dots mark the moments of minima in the hardness ratio modulated with the precession period. The pulse is missing when the its occurrence coincides with the hardness ratio minimum, i.e. when the pole is occulted.

the WD in V455 And is observed in the optical domain, the power in X-rays at the spin frequency is similarly low (Figure 2). This may sound discouraging, but in fact it is a good argument in favor of the WD precession hypothesis, because it was shown that if the magnetic axes and the rotational axes of a WD are closely aligned, then there might be no X-ray signal at the spin frequency or it will be very weak (Ramsay et al. 2008). The long periods corresponding to the precession period (or the beat period between the precession and orbital periods) observed in the optical originate not on the WD itself, but in the coupling region of the accretion disk with the magnetosphere of the WD. The coupling region in magnetic CVs is known to be highly ionized and contribute to the optical emission. It also may emit soft, reprocessed by photo-electric absorption X-rays, and curtain the hard X-ray emission from the magnetic pole. We assume that the coupling region is not stationary but revolves around the inner edge of truncated accretion disk, following the magnetic pole with the precession period. And that would only happen if the magnetic pole is located at the rotational axes of the WD or very close to it. Excess emission from that coupling region revolving with the precession period gives rise to the wings of emission lines in V455 And and FS Aur as detailed in Tovmassian et al. (2007). Meanwhile, if the magnetic pole is near the equator, then regardless of whether the WD is precessing or not, the X-ray beam sweeping around with the spin period will create an emission modulated with the spin, not precession period. The excellent example of that is demonstrated by high speed spectroscopy of DQ Her (Bloemen et al. 2010; Saito et al. 2010).

Thus, in order to detect precession of a WD one needs:

– an asynchronous magnetic Cataclysmic variable, i.e. an Intermediate Polar.
– the spin period of the WD in such IP must be of order of 150 s or less.
– the magnetic and rotation axes of the WD must be closely aligned.
– the WD must be cool and and heavy, i.e. probable candidates should have short orbital periods.

This long list of requirement makes the detection of precession in many systems very unlikely. Also the viewing angle may weight into the probability to observe effects associated with the precession of the WD. V455 And is a high inclination system with grazing eclipses, and the modulation in the wings of the emission lines is always clearly seen. The FS Aur orbital plane has a smaller viewing angle and the modulation in emission lines was barely detected. In contrast, FS Aur shows prominent photometric variability at the beat period between precession and orbital periods, something which was never observed in V455 And. In contrast, GW Lib is a very open system, where the observer looks perpendicular to the orbital plane and only a 4.2 h photometric period has been detected.

3. The modulation of the X-ray light curve with the orbital period and its relation to the precession of WD in FS Aur

The strongest periodic signal in the X-ray light curve of FS Aur is the orbital. It gives a unique chance to explore the precession hypothesis. According to our model (Tovmassian et al. 2007) most of the X-rays, and certainly the hard emission originate from the magnetic polar region overlapping with the rotational axes. The optical emission and some of the soft X-rays arise from the inner part of the disk. Both emitting regions revolve with the WD with the binary period, but also independently with the precession period. The precession may cause an occultation of X-ray emitting region by the WD itself with the precession period.

After our *Chandra* observations of FS Aur we performed two follow-up observations on this object with the *Swift/XRT* (Tovmassian et al. 2012). First, the analysis of *Chandra* X-ray light curve of FS Aur, showed that the orbital period modulation of its light curve was pulsed, i.e. it was not some sinusoidal variability but rather a series of short pulses on the otherwise flat curve. We observed 5 orbital periods, in where we see 4 increases in flux, repeated by the orbital period if one assumes a pulse was masked between the 2nd and 3rd pulses (Figure 3). If one considers separately the soft and hard X-ray light curves, there is a dip in the hard X-ray flux at the time of the missing pulse, as might be expected if the magnetic pole partially disappears behind the WD because of precession. We believe the disappearance of the pulse supports the hypothesis of 147 m precession period of the WD in a 85.7 m orbital period FS Aur. In the Figure 3 the orbital period phase at which the X-ray pulses appear is shown with starlike symbols and the minimums of hardness ratio modulated with the precession period are shown by large dots. The X-ray pulse is missing when its orbital phase coincides with the minimum of the precession phase.

Comparison of the X-ray light curve obtained by *Chandra* in 2005 with the *Swift* light curves in 2007 and 2011, all folded with the precise orbital period, shows that the minima in the light curves occur at different phases from year to year (see the presentation of Neustroev in this volume for the hardness ratio graph). The data from *Swift* is not of high sensitivity and the pulses and dips are not as discernible as in *Chandra* observations to determine phases

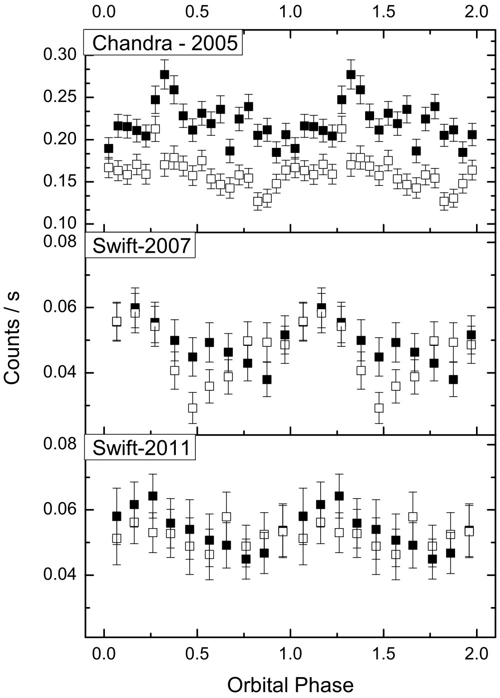

Fig. 4. The X-ray light curves of FS Aur from three separate observations folded with the orbital period. The filled symbols are soft (< 1.5keV), the open symbols are hard photons (> 1.5keV). The minima, more pronounced in hard energies are occurring at different orbital phases.

of observed minima and prove that they are clocked with the precession period, but the phenomenon we have predicted is there. The X-ray light curves folded with the orbital period are presented in Figure 4.

4. Additional considerations

The sample of objects which demonstrate the phenomena related to the precession of the WD is very small. In addition each system is different, which in some cases provides additional support to the hypothesis, in other cases is a detriment. Tovmassian et al. (2010) show that FS Aur is probably a triple system. A presence of precession might be more easily explainable in a triple system than in a simple binary. On the other hand, the long spectroscopic period of V455 And, while present since its discovery in

2004, is not very stable. Its value varies around the averageof 3.5 hours by as much as 10%. This is be very difficult to explain in terms of precession model, but it must be noted, that the WD in V455 And, as well as in GW Lib, is pulsating. The period of pulsations itself is not very stable. It is beyond the scope of this presentation to discuss how pulsations would affect the precession of a WD.

5. Conclusions

The show here what conditions are necessary to detect the precession of a WD in a CV. A few very strict conditions must coincide in order for us to be able to detect precession. We also demonstrate on the examples, that the idea of precession put forward to explain a longer than orbital optical periodicities in a number of CVs may find additional support from X-ray observations of these objects.

6. Discussion

PAULA SZKODY: As there are now several (5-6) systems that show this longer period (all of which have short orbital periods), are you proposing that all, or many, systems are precessing and would have the right geometry to show this effect? Generally, enough data do not exist to show whether there are long periods (several hours) for many of the faint short orbital period CVs.

GAGIK TOVMASSIAN: The long periods are well studied only for FS Aur and V455 And with several years of monitoring. New systems are being reported lately, but they need verification. So on the sample of two systems it is difficult to predict if all or many will be precessing systems. If the precession is a result of purely internal structure of certain white dwarfs, then it might be common phenomena, but if the precession in FS Aur is consequence of triplicity of this system, then it might be a unique situation.

ABDIEL RAMIREZ-TORRES: What could be the explanation of losing the long spectroscopic period in V455 And not only during outburst but until two years later.

GAGIK TOVMASSIAN: V455 And underwent a spectacular super-outburst in 2007. During the outburst and immediately after, the long spectroscopic was not visible on the first inspection. First, during outburst the disk suffers drastic changes, and the coupling region at the inner edge of the disk obviously has been affected. Secondly, a careful measurements of the wings conducted lately shows that the long spectroscopic period is always present, although is not so apparent as it is during quiescence before and 2 years after the outburst.

Acknowledgements. We are grateful to B. Gänsicke and E. Breedt for providing data from papers in preparation on objects discussed in this presentation. The research on FS Aur and similar objects was supported financially by CONACyT grant 34521. Our research was based on X-ray observations by NASA missions *Chandra* and *Swift* which we acknowledge.

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