What can XMM-Newton tell us about the spin periods of Intermediate Polars?

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Abstract. XMM-Newton’s unprecedented combination of spectral resolution and high throughput allows us to perform the best phase-resolved X-ray analysis of intermediate polars to date. The Optical Monitor gives optical/UV photometry simultaneously with the X-ray data. We present a comprehensive study of X-ray spin pulses in IPs, giving spin-pulses and hardness ratios for every IP looked at with XMM-Newton to date.

1. Introduction

In an intermediate polar (IP) the white dwarf has a magnetic field strong enough to affect the accretion flow, but not strong enough to synchronise the white dwarf rotation with the binary period; the magnetic dipole is also inclined to the spin axis of the star. Generally accretion occurs from a magnetically truncated accretion disc; at some radius the disc material threads to the white dwarf’s field lines and is channeled towards the gravitationally preferable pole in large accretion curtains. Stand-off shocks form above each pole, resulting in hard X-ray emission. As the white dwarf rotates, our view of these regions changes and the position of the accretion curtains relative to our line of sight also varies, giving rise to spin-period modulations (e.g. Hellier, Cropper, & Mason 1991).

To date eleven IPs have been observed with XMM-Newton. In this paper we present a compilation of X-ray spin-pulse profiles, hardness ratios, and UV data from XMM’s Optical Monitor (OM) for these systems.

2. AO Piscium and V1223 Sagittarii

AO Psc and V1223 Sgr show sinusoidal X-ray and UV modulations (Fig. 1). The fact that their spectra get harder at pulse minimum suggests that the modulation is caused by absorption. These are thus good examples of the accretion curtain model for X-ray modulation in IPs (e.g. Hellier et al. 1991).

3. HT Camelopardalis

HT Cam’s X-ray spin-pulse (Fig. 2) appears sinusoidal with a flattened maximum, and, judged from the softness ratio, appears to be energy independent. No pulse is detected in the UV, although the B-band shows sinusoidal variation. For more information, see de Martino et al. (2004b).
4. RX J1548.2−4528

The recently discovered IP RX J1548.2−4528 shows a sinusoidal X-ray spin-pulse (Fig. 2). Haberl, Motch & Zickgraf (2002) analysed this observation, and suggested that while there may be a small change in absorption with spin phase, the predominant source of modulation is a change in the visibility of the emission.

5. EX Hydrae

EX Hya’s softness ratio has the same shape and phasing as the lightcurve (Fig. 3), making it tempting to interpret this modulation as changing absorption in the accretion curtains (indeed, it was for this system that accretion curtains were first proposed as the cause of X-ray modulation; Rosen, Mason, & Córdova 1988). However, various X-ray studies (e.g. Allan, Hellier, & Beardmore 1998) have suggested that the upper emitting pole is periodically occulted by the white dwarf, giving rise to the modulation. Since such occultation will affect the lower, cooler parts of the accretion column more than the higher, hotter ones, we see a deeper modulation at lower energies.

6. AE Aquarii

AE Aqr differs from many IPs as it is a rapid rotator ($P_{\text{spin}} \sim 33$ s), and thus its magnetic field might be expelling material from the system like a propeller (e.g., Eracleous & Horne 1996). It is unclear whether the X-ray emission arises from
Figure 2. As for Fig. 1, but for HT Cam (left) and RX J1548.2−4528 (right). The UV band for HT Cam is 1800–2250 Å, and the B band (3900–4900 Å) is also shown.

Figure 3. As Fig. 1, but for EX Hya (left) and AE Aqr (right).
accretion, as is usual in IPs, or further out in the magnetosphere, as suggested by Ikhsanov (2001). However, the XMM-Newton data shows that the pulse profile is sinusoidal and largely independent of energy.

7. GK Perseii (in outburst)

Watson, King, & Osborne (1985) suggested that the X-ray spin-pulse of GK Per in outburst was caused by increased absorption at spin minimum. Ishida et al. (1992) blamed changing absorption for the profile in quiescence as well, but suggested that the outburst profile may show evidence for occultation of the upper pole. Fig. 4 shows that the outburst softness ratio follows the lightcurve, making it more likely that absorption changes are responsible for this pulse, as Watson et al. (1985) claimed. Hellier, Harmer, & Beardmore (2004) agree with this, in analysis of an RXTE observation.

8. V405 Aurigae

V405 Aur differs from IPs such as AO Psc, first because it shows a soft blackbody component to its X-ray emission (Haberl et al. 1994), and second because the blackbody is double-peaked on the spin period, while the harder emission is single-peaked but sawtoothed (Fig. 4). Furthermore, de Martino et al. (2004a) and Evans & Hellier (2004) have shown that the absorption does not change with spin phase. Evans & Hellier (2004) suggest that if the angle between the magnetic and spin axes in this system is very high, then the double-peaked profile of the blackbody emission is explained.
9. FO Aquarii

The X-ray pulse profile of FO Aqr (Fig. 5) shows X-ray minimum to occur after UV minimum. Many authors (e.g. Hellier 1993; Beardmore et al. 1998) have identified the ‘notch’ at phase 0.7 as the result of occultation of the upper accretion column, and the dip around phase 0.5 as arising from the accretion curtains intercepting our line of sight. Evans et al. (2004) note that, if this is the case, the upper pole will be pointed towards the observer nearly a quarter of a cycle before the accretion curtain dip. They thus suggest that the accretion curtains are twisted, explaining the lightcurve and softness ratio.

10. PQ Geminorum

PQ Gem shows a soft blackbody component as well as the hard, optically thin emission characteristic of IPs (Mason et al. 1992). The spin-pulse profile (Fig. 5) differs greatly from that of AO Psc, with UV maximum coinciding with X-ray minimum. Potter et al. (1997) and Mason (1997) have suggested that the blackbody modulation is caused by changing views of the accretion region as the white dwarf rotates. Maximum (phase 0) occurs when the upper pole is towards us. Since this occurs after the dip around phase 0.8, interpreted as absorption by the accretion curtains, Potter et al. (1997) and Mason (1997) suggest that PQ Gem accretes preferentially along field lines preceding the magnetic pole.
11. V2400 Ophiuchi

V2400 Oph is thought to be the only discless IP, since it shows a dominant X-ray modulation on the spin-orbit beat period (Buckley et al. 1995; Hellier & Beardmore 2002). We have recently discovered evidence for a spin pulse during an XMM-Newton observation (Fig. 6), the first in the X-ray band.

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