Exploring Magnetic Cataclysmic Variables with XMM

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ABSTRACT

We discuss the implications of XMM observations in the study of temporal and spectral characteristics of magnetic Cataclysmic Variables. The long XMM orbit, the unique high temporal resolution of EPIC cameras together with a good energy resolution and a high sensitivity will allow a detailed investigation of periodic and aperiodic variabilities which are signatures of accretion modes and patterns. The unprecedented opportunity of a simultaneous UV/optical coverage offered by the OM will provide crucial constraints on the actual energy budgets of direct and reprocessed radiation.

1. Introduction

Magnetic Cataclysmic Variables (mCVs) are close X-ray binaries containing a magnetized white dwarf accreting material from a late type Roche lobe overflowing secondary star. These systems are subdivided in two classes: the Polars, or AM Her type stars and the Intermediate Polars (IPs), or DQ Her stars. In Polars, the magnetic field of the white dwarf is strong enough ($B \sim 10 - 230\,\mathrm{MG}$) to lock its rotation at the orbital period $P_{\mathrm{orb}} = P_{\mathrm{spin}} \sim$ few hrs. On the other hand, IPs are asynchronous systems ($P_{\mathrm{spin}} < P_{\mathrm{orb}}$) and are believed to possess much lower magnetic field white dwarfs.

The accretion geometry strongly depends on the mass accretion rate $\dot{M}$ and system parameters, such as the mass of the components, the orbital separation and the white dwarf magnetic field strength, the latter influencing the details of the flow down to the white dwarf polar regions where a stand-off shock is formed. The accretion pattern is then different in the two classes. In Polars the stream of material from the secondary star is directly channelled towards the magnetic poles (accretion column), whilst in IPs material is accreted via an eventual disc in an arc-shaped curtain (see Warner 1995 for a detailed review on both classes).

Differences in the accretion geometry reflect different emission properties which are discussed for both classes in Sect. 2 and 3 together with related open questions. The impact of future XMM observations are highlightened in Sect. 4.

2. Polars

In Polars, the post-shock plasma emits hard X-rays (5-30 keV) and optical/IR cyclotron emission. The relative proportion of bremsstrahlung to cyclotron radiation is sensitive to the magnetic field of the white dwarf and the local mass accretion rate, cyclotron cooling being generally more efficient in high field systems (Beuermann 1998). The post-shock region is expected to have a strong temperature gradient (Done et al. 1995; Matt et al. 1998). Additionally, absorption from the ionized gas and from cold neutral material in the accretion column adds to the complexity (Done et al. 1995).

Part of the downward emitted hard X-rays and cyclotron radiation is absorbed by the white dwarf surface and re-emitted in the soft X-rays, EUV (10-40 eV) and UV ranges. The thermalization can occur over a large fraction of the white dwarf area ($\sim 10\%$) (Gänsicke et al. 1995). An independent soft X-ray component can be produced by the infall of dense "blobs" penetrating deep into the white dwarf atmosphere. In a high mass flow rate regime a soft X-ray excess can be produced and for very high rates ($> 30\,\mathrm{g\,cm^{-2}\,s^{-1}}$) all energy appears in the soft X-rays (Woelk & Beuermann 1995). In addition, part of the bremsstrahlung radiation is Compton reflected from the white dwarf surface, producing a fluorescent 6.4 keV K_{α} iron line (Matt et al. 1991; Beardmore et al. 1995; Done et al. 1995; Matt et al. 1998).

The X-ray emission is modulated at $\mathrm{P_{spin}} = \mathrm{P_{orb}}$ and the study of phase resolved spectra as well as of the shapes of the rotational curves are crucial for a detailed simultaneous modelling of the different contributions arising from reflection and absorption. Currently these studies are limited to bright sources. It is known that at least some Polars display long term variability on unknown timescales in the shape of their rotational X-ray light curves, the soft X-rays being sometimes in anti-phase or double-peaked with respect to the hard X-rays. These changes appear to be related to the onset of accretion onto the secondary pole whose X-ray emission is mainly soft (e.g. Heise et al. 1985; Rosen et al. 1996). The nature of these changes, not necessarily related to variations of the mass accretion rate, is still far from being understood.

On the other hand, luminosity variations (high and low states) occurring on long term (months to years) timescales are related to changes in $\dot{M}$ from the secondary star (de Martino et al. 1998a; King & Cannizzo 1998). Such changes affect not only the energetics of the accretion process but also the accretion pattern. The response of the white dwarf to these variations (cooling timescale) is still unknown.

Variability in Polars also occurs on very short timescales. So far, rapid fluctuations from a few seconds to minutes have been detected in a few bright systems. While few seconds QPOs are observed in the optical range, only upper limits have been derived in the hard X-rays (Larsson 1995; Bonnet-Bidaud et al. 1996; Beardmore & Osborne 1997a). QPOs are believed to arise from shock instabilities but the driving mechanism remains debated (Langer et al. 1982; Wu et al. 1992), until their X-ray properties will be known. On the other hand, low frequency (order of minutes) oscillations in the optical (e.g. Bonnet-Bidaud et al. 1991) and X-rays (see Chanmugan 1995) recently triggered searches in other energy domains as in the UV (de Martino et al. 1998b). These can arise from instabilities at the Lagrangian point (King 1989) or by Alfen wave excitation in the accretion column (Chanmugan 1995). Further X-ray and UV/optical observations are needed to characterize their true nature. Also, flickering or flaring type variability (tens of seconds to minutes) have been observed in some systems in soft and/or hard X-rays (Ramsay et al. 1996; Beardmore & Osborne 1997a; de Martino et al. 1998c) which reveal inhomogeneous accretion, in the form of filaments or blobs, onto the white dwarf. Their study is extremely promising to infer the details of accretion modes.

3. Intermediate Polars

Differently from Polars, IPs are generally hard X-ray emitters, with the exception of two "true-interpolars" which also show optical/near-IR polarized radiation. Their X-ray spectra are highly absorbed (up to $10^{23}\,\mathrm{cm}^{-2}$) with multiple absorption components, accounted for by a simple partial covering model (Mukai et al. 1994). Mg and Fe emission lines, from He- and H-like ions have been observed in the bright system EX Hya, but their ratios cannot be accounted for by a simple isothermal plasma (Ishida 1994). This indicates that temperature gradients are also present in these asynchronous systems. Furthermore, like the Polars, the 6.4 keV fluorescence Fe line from cold matter is also present suggesting that reflection is also important. X-ray irradiation in the accretion curtain and at azimuthal structures in the accretion disc manifests itself in the UV and optical ranges (de Martino et al. 1994; 1995; 1998d). The energy balance of the primary and secondary radiations cannot be derived until X-ray and UV/optical simultaneous observations will be gathered (see below).

Due to the asynchronous rotation of the white dwarf, IPs show a wide variety of periodicities, mainly at the spin (tens of minutes), orbital (hours) and sideband frequencies. The dominant X-ray periodicity is signature of the actual accretion mode. In disc-fed systems the rotational variability dominates, while the relative proportion of orbital and sideband modulations are indicative of stream or disc-overflow accretion (Hellier 1995). Furthermore, long term (years) variability in the relative amplitudes of these periodicities not only in the X-rays but also in the UV/optical range has been recently recognized as a signature of changes in the accretion mode (Beardmore et al. 1998; de Martino et al. 1995; 1998d). Such changes affect the determination of the energy budgets making strong the need of simultaneous observations in the high and low energy domains.

4. The role of XMM

A large amount of information on the physics of accretion in mCVs can be gathered with the unique capabilities of XMM. The high temporal resolution together with the good spectral resolution and high sensitivity of the EPIC cameras will provide an unprecedented opportunity to study both variable and spectral characteristics of these systems. Also, the relatively wide energy domain encompassing soft and hard ranges is crucial to derive the relative proportions of energy release by different processes. It will be possible to apply more reliable models to the observed spectra such as reflection from the white dwarf. The inclusion of this component is now recognized to be important, since a lower post-shock plasma temperature than previous estimates is derived and it predicts the 6.4 keV fluorescence Fe component in addition to the thermal Fe complex. To illustrate this, a simulation with the EPIC/pn camera is shown in Fig. 1, for the prototype Polar system AM Her. Furthermore, unlike AXAF, RGS spectroscopy will be gathered together. For bright sources high resolution spectra of the 0.4-2.5 keV region will allow the detection of the Fe L complex, thus providing further details on the ionization states.

XMM will be an ideal satellite to investigate in details both aperiodic and periodic variabilities in mCVs. Actually, the high temporal resolution capabilities provided by the EPIC/pn camera operated in timing mode (down to a $30\,\mu$ resolution) are ideal to disentangle rapid flickering and QPOs of a few percent amplitude. Furthermore, differently from low Earth orbit satellites, precluding detailed studies of orbital variabilities in systems with $\mathrm{P_{orb}} \propto \mathrm{P_{S/C}}$, the long XMM orbit will provide uninterrupted observations. The study of phase resolved spectra at $\mathrm{P_{spin}}$ and for IPs also at different orbital phases is fundamental to derive the correct proportion, location and parameters of the different components.

Finally, XMM will also provide for the first time simultaneous coverage in the UV and optical ranges. The variety of filters – especially the UVW1 and UVW2 and the V one – and grisms – especially that covering the 160-290 nm range – and observing modes offered by the Optical Monitor will allow the simultaneous study of the effects of the reprocessed radiation thus extablishing univocally the link with the high energy domain emission.

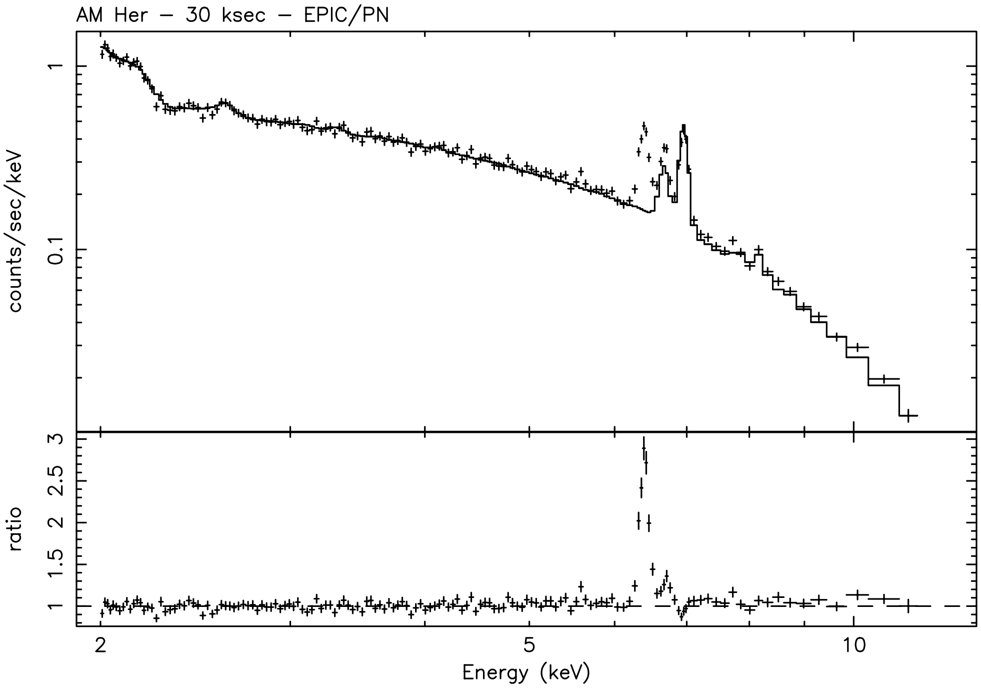

Fig. 1.— A 30 ksec simulation with the EPIC/pn camera of the 2-15 keV spectrum of AM Her. The source spectrum was derived from a multi-component fit to a BeppoSAX observation during an intermediate state (Matt et al., in prep). The simulated spectrum is obtained using an isothermal plasma at 13 keV together with a partial covering with $C_F = 0.39$ and $N_H = 5 \times 10^{21}\,\mathrm{cm}^{-2}$ and a reflection component with the cold line at 6.4 keV; $W_{6.4} = 176$ eV. In the simulated spectrum the K_α 6.7 keV (FeXXV) and 6.97 keV (FeXXVI) lines are clearly separated. The omission in the fit of the reflection component results, apart from the 6.4 keV line, in an excess of counts above ∼ 7-8 keV and residuals at the 6.7 keV He-like iron line due to the consequent overestimate of the temperature. This is depicted in the lower panel where the ratio with the above model without reflection is shown.

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