

Probing Accretion in White Dwarf Binaries with IXO

D. de Martino *INAF- Capodimonte Observatory, Naples Italy*

M. Orio *INAF-Padova Observatory, Padua, Italy & Univ. Wisconsin, USA*

K. Mukai *NASA/GSFC/CRESST & Univ. Maryland, Baltimore USA*

G. Matt *Dept. Physics, University Roma Tre, Rome Italy*

Abstract:

Accreting white dwarf binaries (CVs, Symbiotics) are key systems to study accretion in non relativistic environments subject of strong gravitational forces. Many fundamental questions need to be addressed. We discuss the potential of IXO mission in this field to:

- 1) determine the mass of different types of systems to determine in which binaries the white dwarf may grow to the Chandrasekhar limit;**
- 2) map the accretion flow structure in magnetic and non-magnetic systems;**
- 3) probe the origin of iron fluorescent line;**
- 4) measure X-ray polarization in magnetized WDs**

Questions & Science Goals:

1) SN Ia Progenitors:

A long-standing problem is the identification of progenitors of **Type Ia SNe** that are an essential tool for cosmology. Single degenerate WD binaries represent the most viable progenitors between the two scenarios (single and double-degenerates) but there are still many questions to address. Two main parameters must be determined: the WD **Mass** and its **Mass Growth Rate**.

1a) Super Soft X-ray Sources:

Among **CVs** and **Symbiotics** those showing multiple thermonuclear outbursts, **Recurrent Novae (RN)**, have likely very massive WDs close to Chandrasekhar limit (Yaron et al. 2005). A large population of **RNs**, not been observed yet, has been predicted (Schaefer 2010). After the initial explosion, both **RN** and **Classical Novae (CN)** undergo **Super Soft X-ray Phase (SSS)** which may last months to years (see [Fig. 1](#)). **Quasi-steady Super-Soft Sources (SSS)** have WDs accreting at high rate ($\sim 10^7 M_{\text{sun}}/\text{yr}$) igniting H-burning non explosively that should allow mass growth. Hence, the **SSS** status is a strong indication the WD is massive and grows in mass.

IXO allows unprecedented characterization of **RN, CN, SSS** in the **Local Group** by measuring the WD temperature, composition, mass and size through high S/N high resolution spectra ([Fig. 1](#)). Large samples of **SSS** in **Local Group galaxies** (many will be selected through the IXO wide-field imager) will provide significant statistics.

1b) The hard X-ray bright non-magnetic WDs:

Massive WD binaries will also show up as hard X-ray sources. While most accreting WDs detected above 10keV are magnetic CVs (see [sect. 2](#)), a few **Symbiotics and one **RN** were detected in the **Swift/BAT** and **INTEGRAL/IBIS** surveys. It has been suggested that they are non-magnetic, massive WDs.**

A numerous population of non-magnetic accreting WDs is expected to be identified in forthcoming and future X-ray surveys, like **eROSITA; WEXT. The identification of massive WD binaries will be easily accomplished by the detection of hot unpulsed X ray component (10-50keV).**

Similarly to accreting NS binaries, a powerful tool is the detection of Gravitational Redshift (GR) in lines forming at the compact star surface. In **non-magnetic WD binaries a prominent **Fluorescent Fe line at 6.4keV** originates (see also [sect.3](#)) near the WD surface.**

For massive ($M > 1.2M_{\text{sun}}$) accreting WDs high resolution spectroscopy with **IXO allows to measure GR $>200\text{km/s}$, provided that the systemic velocity is determined from the ground (see [Fig.2](#)).**

2) Which is the accretion flow structure CVs?

The accretion structure strongly depends on fundamental parameters (WD B-field strength, specific mass accretion rate and WD mass). XMM-Newton and Chandra have provided unprecedented details on the accretion process but at the same time opened to new challenges.

2a) The Post-Shock Flow in MCVs:

Magnetic CVs (MCVs) host WDs with $B \sim 5\text{-}230\text{MG}$. Accretion is magnetically channelled onto WD polar caps where a stand-off shock forms below which matter cools via thermal Bremsstrahlung and cyclotron radiation. The relative proportion depends on B-field strength. The post-shock structure (Aizu 1973) can be substantially affected in high B-field CVs.

While evidence of a temperature gradient is found in **MCVs**, from $\sim 0.2\text{keV}$ to $40\text{-}50\text{keV}$, broad-band XMM-Newton spectra of many **MCVs** are not consistent with a power law model (see Fig. 3). Most **MCVs** are too faint to obtain grating spectra with XMM-Newton (Fig. 3) or Chandra to diagnose the post-shock flow through triplets of main emission lines of O, Mg, Si, Fe, Ne, etc...

Surprisingly in some bright systems the spectra reveal little Fe L-shell emission pointing to a photoionized spectrum instead of a cooling flow. **Two classes of X-ray spectra** are observed (see Fig.4). The local mass accretion rate was tentatively claimed to explain the difference (Mukai et al.2003). With **IXO** we can measure the post-shock temperature, density and velocity profiles in great details (see Fig. 3)

2b) The Pre-Shock Flow in MCVs:

Cool material in the **pre-shock flow** is revealed by a local absorbing dense gas column (up to 10^{23} cm⁻²) often partially covering the X-ray source. An increasing number of **MCVs** of the **Intermediate Polar (IPs)** type the absorber is complex (multiple columns).

Only recently it was recognized that pre-shock flow could also be ionized. XMM-Newton spectra have shown an absorption edge of OVII at 0.74keV in RXJ1730-0559 (de Martino et al. 2008) (see Fig. 5). The same edge was detected in a Chandra HETG spectrum of V1223 Sgr (Mukai et al. 2001). In a RXTE spectrum of V709 Cas an absorption edge of Fe XIX-XXII at 8.1keV was also detected (de Martino et al. 2001). This gives evidence that a **warm absorber** is also present in **MCVs** in addition to LMXBs.

Recently very deep Chandra HETG spectra of the bright MCV EX Hya revealed for the first time a broad component in addition to the narrow one in some X-ray lines and ascribed to **photoionized** matter in the pre-shock flow (Luna et al. 2010).

Such evidence is very promising to investigate ionization effects, like in LMXBs, but requires detailed investigation with high S/N and high resolution spectroscopy that only **IXO** can address.

2c) The X-ray Disk components in non-magnetic CVs:

*While the accretion disk in non-magnetic CVs is not dominant in the X-rays, its **Boundary Layer (BL)** is bright in the hard X-rays ($kT \sim 10\text{keV}$) during quiescence. A few bright CVs observed in quiescence with Chandra reveal X-ray spectra with wide range of temperature (see [Fig. 4](#)).*

*During Dwarf Nova (DN) outbursts the hard X-ray component disappears as the emission shifts to EUV range. However, Chandra spectra of WZ Sge in outburst reveal a distinct soft ($\sim 1\text{keV}$) X-ray component (Wheatley & Mauche 2005). A similar component was detected by XMM-Newton in the bright high Mdot nova-like (NL) system UX UMA during eclipse suggesting a large uneclipsed region. **High state CV disks** seem to have **MRI driven hot X-ray coroneae** similarly to those invoked for **AGNs** and **BHXRBs** (Wheatley 2006). To test this hypothesis eclipsing systems are the best examples.*

Interestingly a recent XMM-Newton study of X-ray flickering of CVs of different classes points to the presence of magnetically driven accretion (Anzolin et al. 2010).

*High resolution spectra of a large sample of non-magnetic CVs including eclipsing NL and DN in outburst will map in details the soft component to be compared with improved MRI models that will be available at the time of **IXO** launch.*

3) Probing the origin of the fluorescent iron line:

X-ray spectra of **MCVs** are characterized by a strong (E.W.~100-200eV) **fluorescent iron line at 6.4keV** that is also detected in a number of hard X-ray bright non-magnetic **CVs** (see [Sect. 1b](#)), indicative of a **Compton reflection** component from cool material. Its origin could be either the WD surface or the pre-shock flow above the polar regions in **MCVs** (Ezuka & Ishida 1999). Spin-phase resolved X-ray spectra obtained for a few bright **MCVs** E.W.s may prove that the origin is at the WD surface.

High resolution spectroscopy with **IXO** will allow one to:

1) test GR effects in massive WD systems (see [Sect. 1b](#));

2) identify the origin of the **fluorescent Fe line** through spin-phase resolved spectroscopy. This line would show spin dependant velocity shifts (up a hundreds km/s) if originating in the pre-shock flow.

3) Time-resolved spectroscopy will also link the **Fe line variability** with the changes in the **Compton reflection component** that would be detected with HXI. This latter in turn will better constrain the shock temperature, which at present is not well determined.

4) X-ray polarimetry opening a new window for WD binaries:

*In **MCVs** significant polarization can arise as a result of the stratified flow structure in the shock-ionized column. Also the WD surface can be a source of polarized radiation. Therefore phase-dependent polarized flux is expected up to a few percent (Matt 2004).*

*Also, polarized emission from **ultra-compact double-degenerate** binaries is expected only in case of direct-impact accretor model but not in the case of unipolar-inductor model since in the former case the accretion geometry is very similar to **MCVs** (Wu et al. 2010).*

*An important challenge of **IXO** will be to probe Compton scattering through **X-ray polarimetry** not only in **MCVs** but also in **ultra-compact binaries**, solving the long debate on the mechanism generating X-rays in these systems.*

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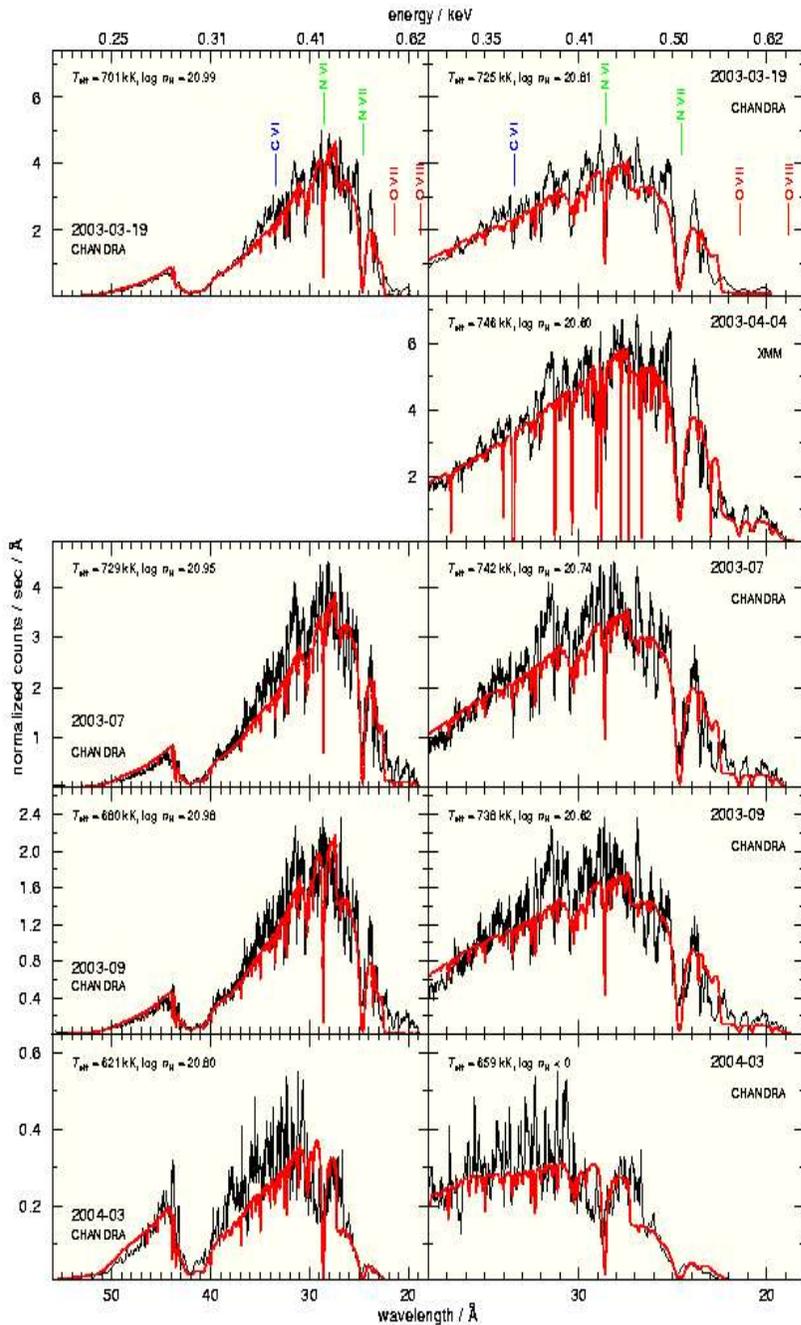


Fig. 1a: Chandra and XMM-Newton monitored the remarkable spectral evolution 6 months after the outburst of Nova V4743 Sgr. The spectra are fitted with the Tubigen NLTE model atmosphere package (Rauch et al 2010). To date a handful of novae have been observed. IXO will provide high resolution spectroscopy of hundreds of Novae tracing their spectral evolution.

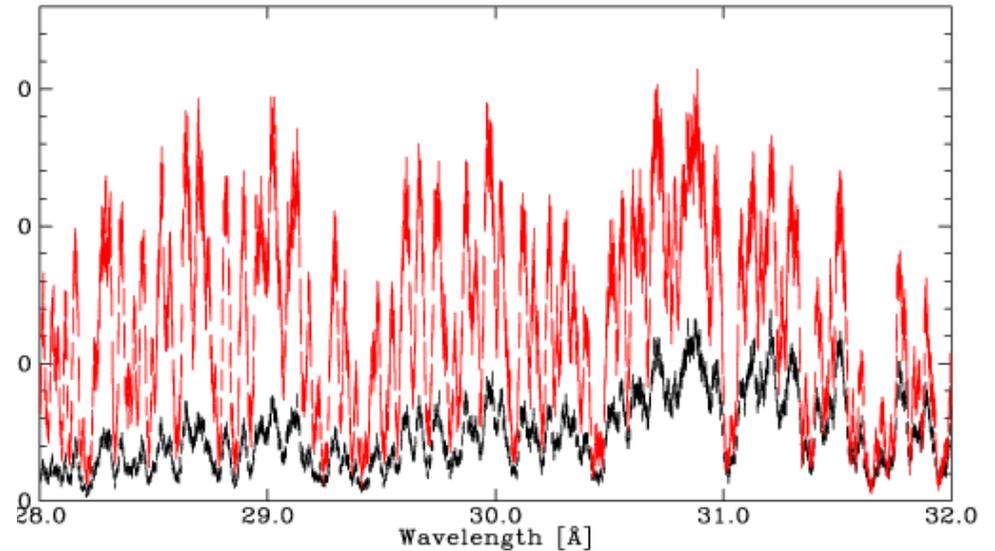


Fig. 1b: A section of simulated IXO/CAT spectra of the SSS CAL 83 for a 100ks exposure and 300cm² response. Both first order (black) and the second order (red) spectra are shown based on spectral model of Lanz et al. (2005). From Mukai et al. (Astro 2010,S215)

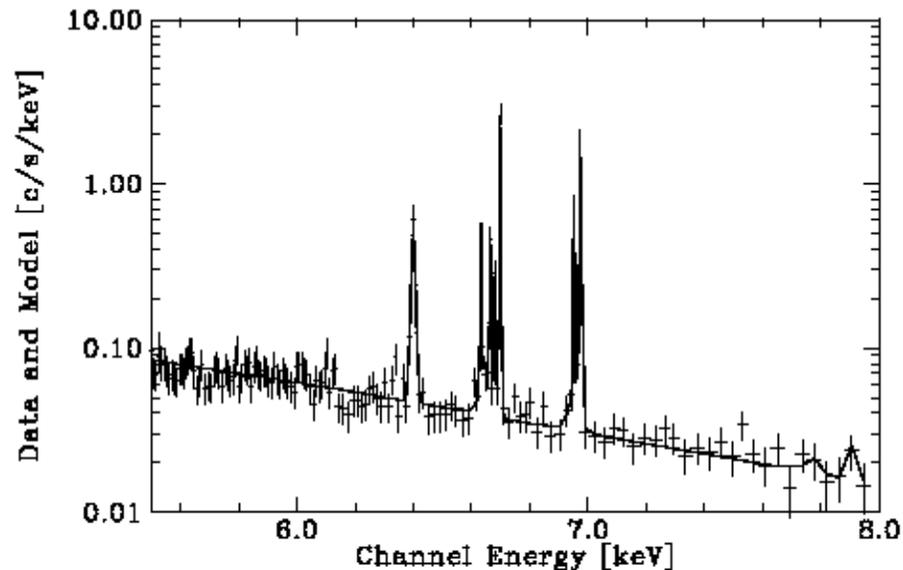
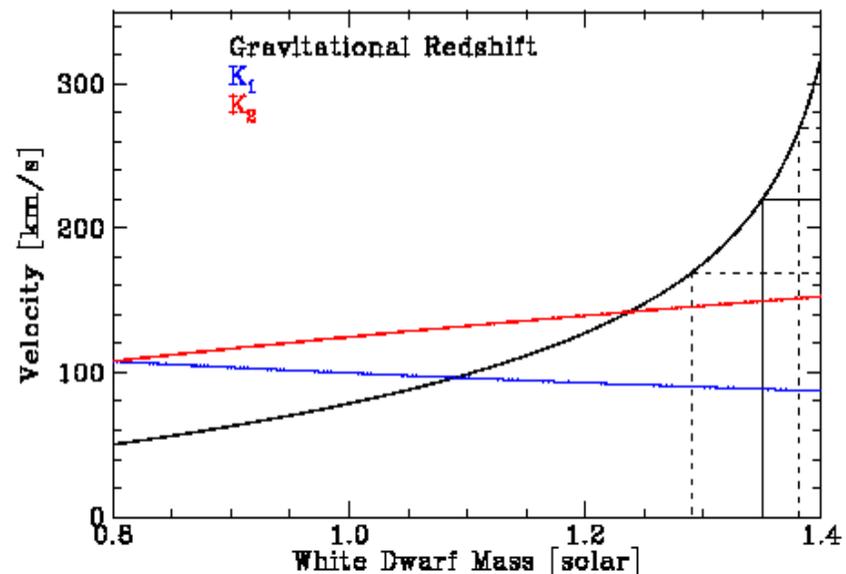
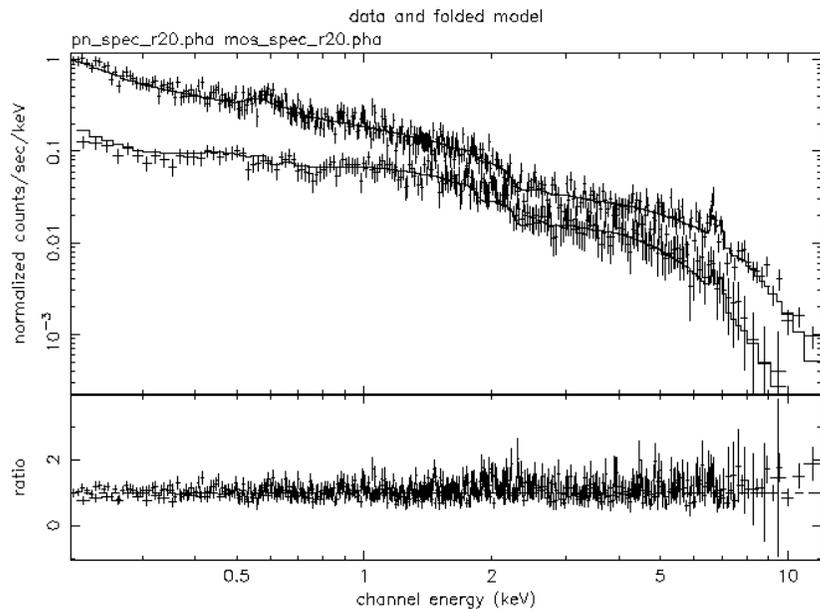


Fig. 2: Left: Gravitational Redshift expected for WDs in the 0.8-1.4 M_{sun} range (black) together with radial velocities of semi-amplitudes of WD and donor mass for a 1-d binary and 0.8 M_{sun} donor and inclination of 60deg.

Right: A simulated calorimeter spectrum for a WD with a 2-10keV luminosity of 10^{32} erg/s at 1kpc and for 50ks exposure adopting a multi-temperature thermal emission and a reflection line (E.W.=130eV) at 6.4keV. The line centroid can be determined at an accuracy of +/- 50km/s. From Mukai et al. (Astro 2010,S215)

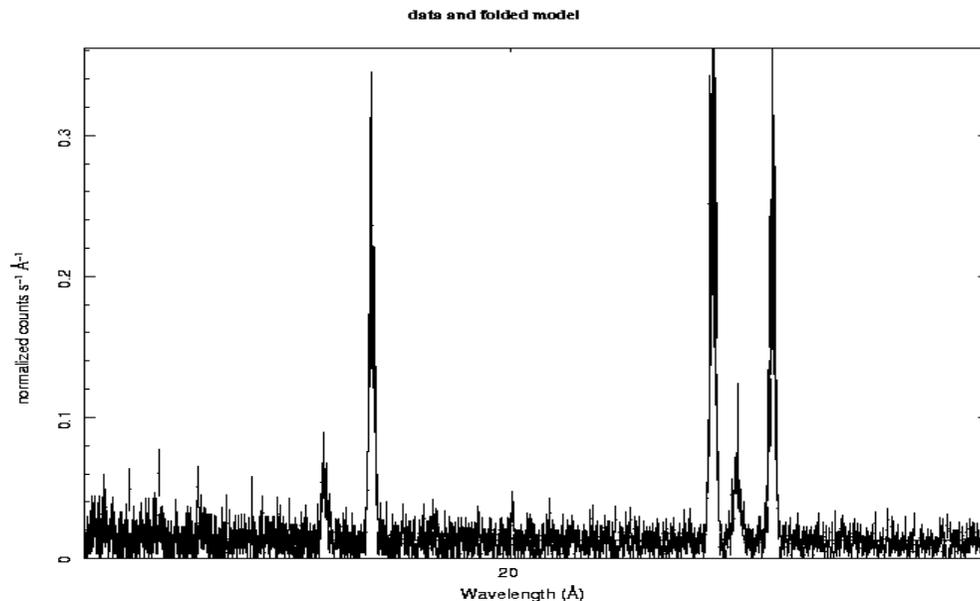
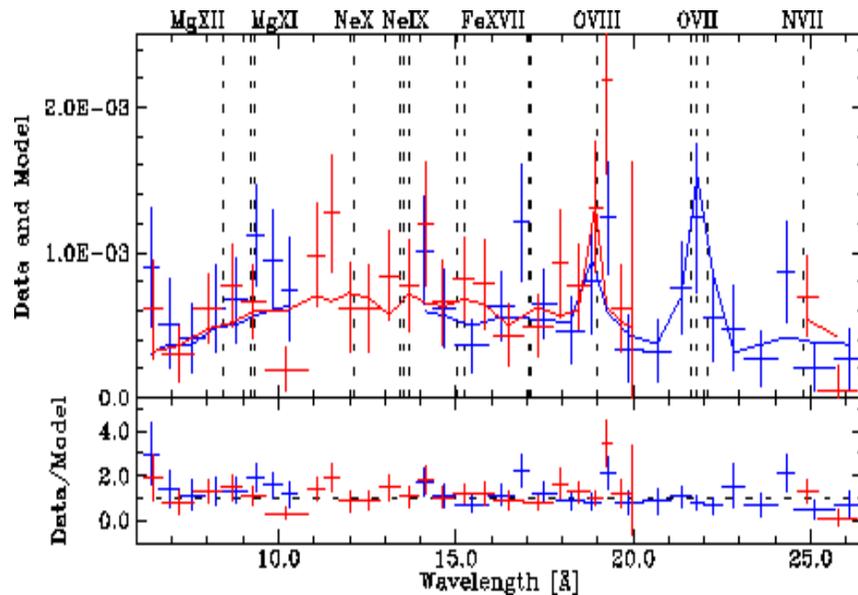


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Fig. 3: Top Left: Broad-band XMM-Newton spectrum of the faint MCV UU Col consistent with a composite model using a 50eV black-body plus a two-temperature optically thin plasma with 0.18keV and 11keV with $A_z=0.4$ absorbed by a partially covering dense ($N_h=10^{23} \text{ cm}^{-2}$) material.

Top Right: XMM-Newton RGS spectra of UU Col showing OVII and OVIII lines with intensity ratio indicating a temperature of $\sim 0.2\text{keV}$ (From de Martino et al. 2006).

Bottom Right: A 50ks simulated IXO/XGS spectrum around Oxygen lines for UU Col using spectral parameters derived from XMM-Newton.



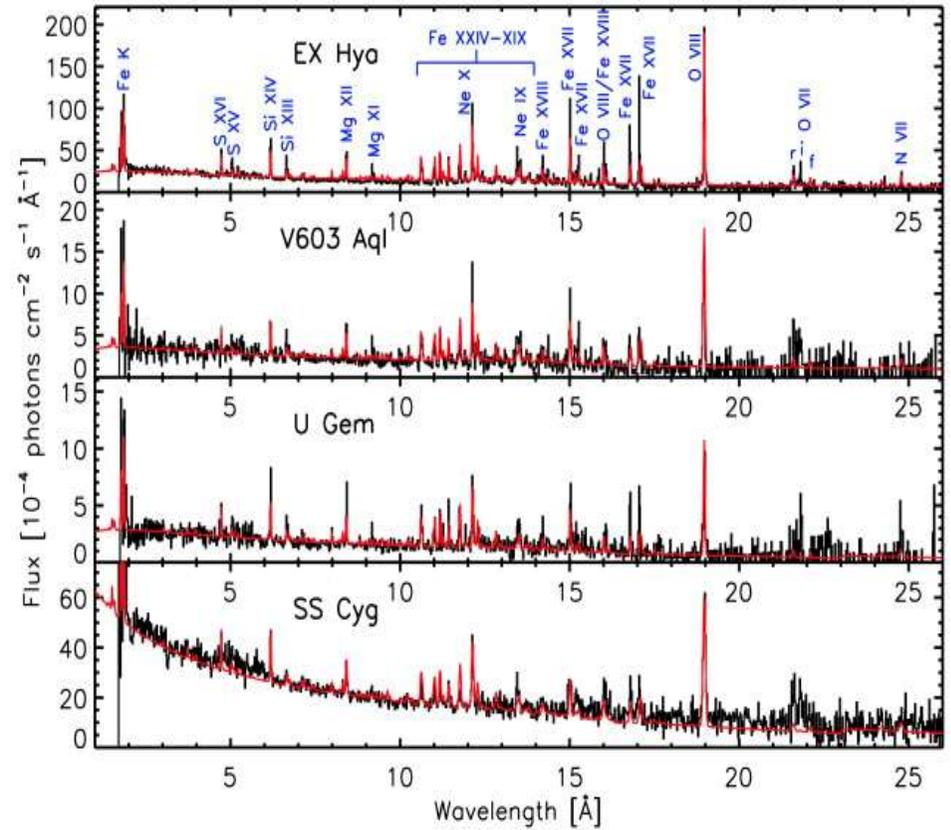
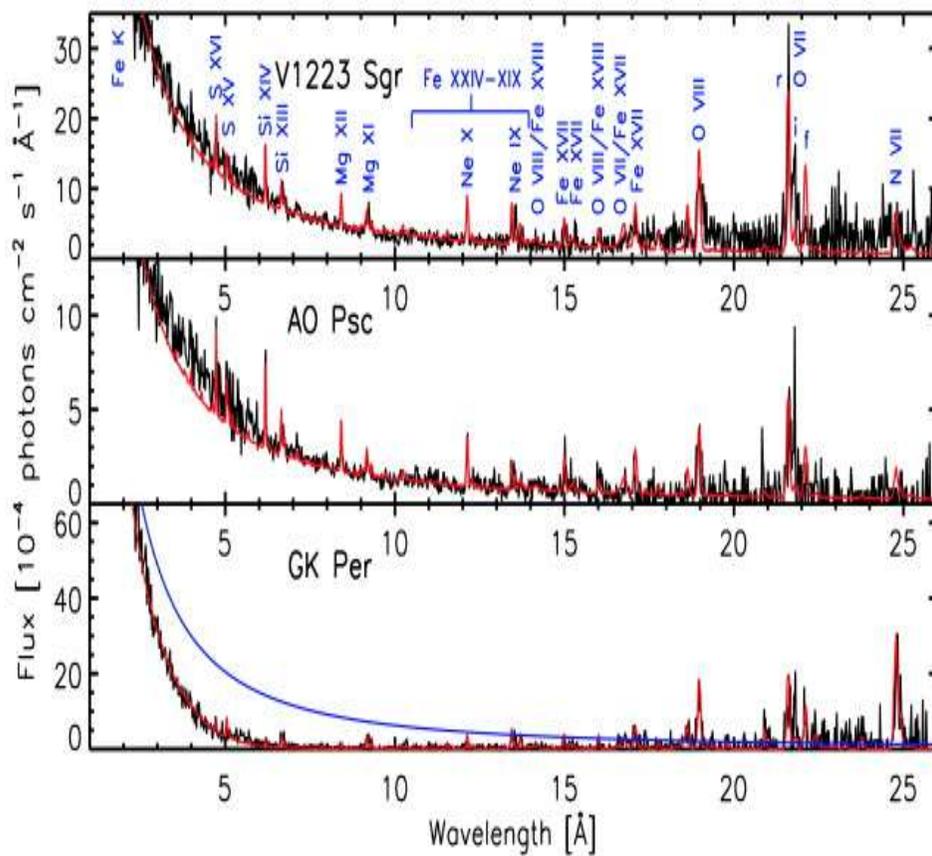


Fig. 4: Left: Chandra HETG spectra of three MCVs that are consistent with photoionized models. Data are in black and model in red. The blue line represent the inferred intrinsic continuum in GK Per. Right and from bottom to top: Chandra HETG spectra of three non-magnetic CVs and of the MCV EX Hya (top) consistent with cooling flow model. The two figures clearly show different type of X-ray spectra exist in CVs. (From Mukai et al. 2003).

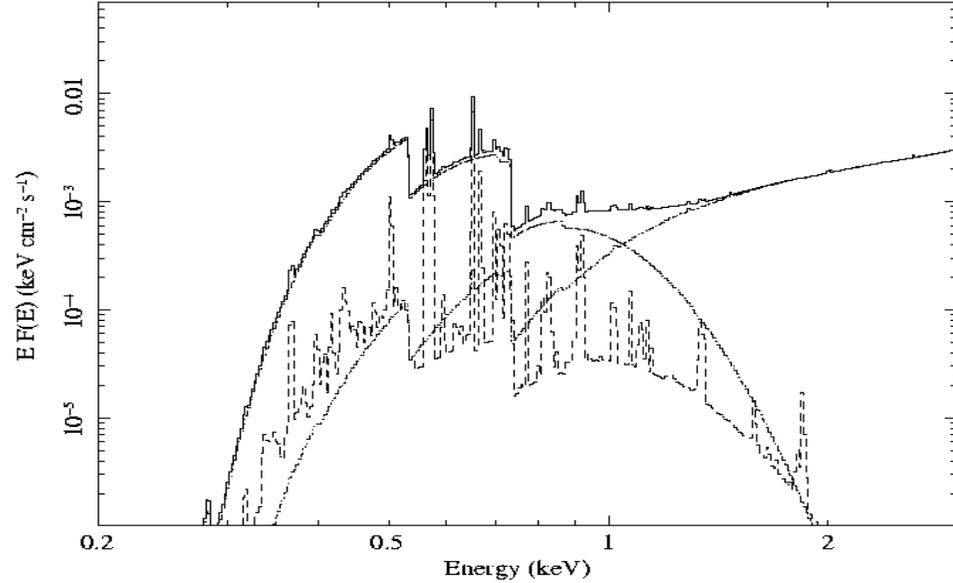
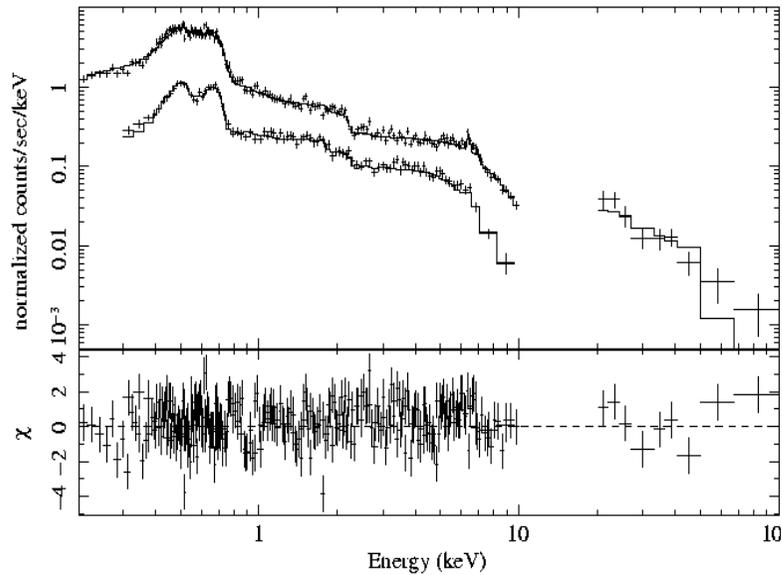


Fig. 5: Top left: The combined XMM-Newton EPIC-pn and INTEGRAL IBIS/ISGRI spectrum of RXJ1730-0559 fitted with a composite model consisting of a blackbody at 90eV plus two optically thin components at 0.17keV and >60keV $A_z=0.4$ absorbed by a total ($3.6 \times 10^{21} \text{cm}^{-2}$) and a partial (56% and $1.4 \times 10^{23} \text{cm}^{-2}$) absorbers plus an absorption edge at 0.74keV and an iron fluorescent line at 6.4keV (E.W.=110eV).

Top right: a section of the unfolded model in the soft portion showing the spectral complexities.

Right: The XMM-Newton RGS spectra showing the edge at 17Ang. The OVIII emission could be present (From de Martino et al. 2008)

