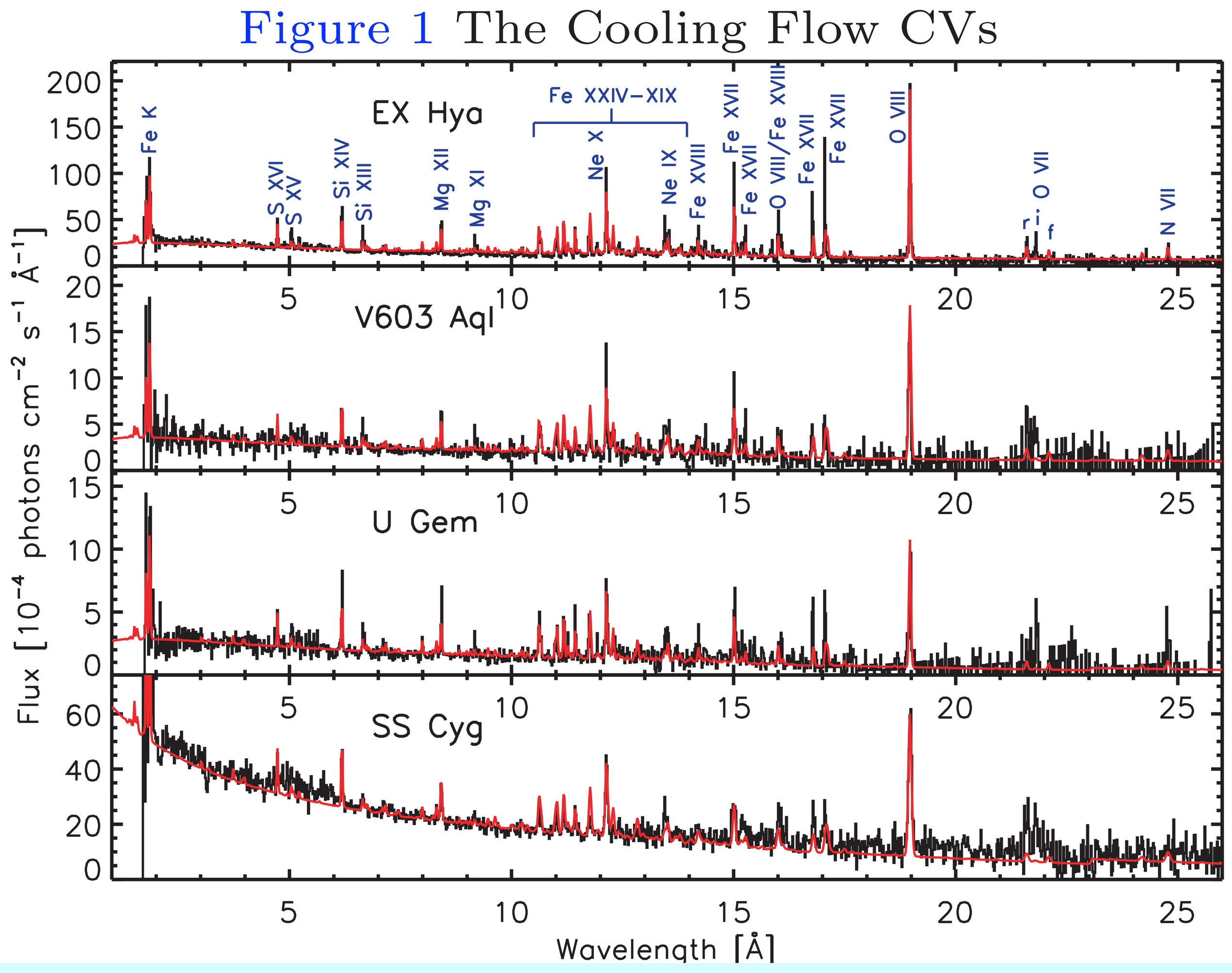
“Two Types of X-ray Spectra in Cataclysmic Variables” Revisited

Koji Mukai
NASA/GSFC/CRESST and UMBC

ABSTRACT: In a 2003 paper, Mukai et al. presented the Chandra HETG spectra of 7 cataclysmic variables (CVs) then available in the public archive, and classified them into “cooling flow” and “photoionized” types. In this presentation, I will revisit this classification. It is clear that multi-temperature plasma exists in the post-shock region of accreting white dwarfs; I will discuss why the cooling flow model works well, and what its limitations are when applied to CVs. It is also clear that even the “photoionized” CVs are also powered by the same multi-temperature plasma. I will discuss how the appearance of a much harder continuum of these “photoionized” CVs is created by the complex intrinsic absorber. I will show that there is an additional soft emission in these systems that the multi-temperature plasma models cannot explain, and discuss what evidence there is for the photoionization origin of this component.

Figure 1 The Cooling Flow CVs



2. Why Cooling Flow?

The post-shock plasma in CVs loses energy by emitting X-rays and therefore must cool, and cannot remain at a single temperature. In the case of magnetic CVs, one can solve for the temperature-density structure of the postshock region assuming pure Bremsstrahlung cooling (Figure 3). The case of non-magnetic CVs accreting via a boundary layer is more complex, but a similar multi-temperature structure is expected. Due to the Keplerian motion of the disk, the maximum temperature possible in a non-magnetic CV (solid line) is lower by a factor of 2 than in a magnetic CV of the same mass (dashed line, Figure 4). We can use the cooling flow model (Mushotzky & Szymkowiak 1988) to fit the CV spectra, because it is unnecessary to know the post-shock structure to calculate the output spectrum. “Assuming that the same mass flow rate pertains throughout the cooling flow, the emission measure for each temperature is determined by the time it takes for the matter to radiate away sufficient energy to cool down to the next temperature shell. The differential emission measure is thus proportional to the reciprocal of the bolometric luminosity at that temperature.”

Figure 3 The Post-Shock Region

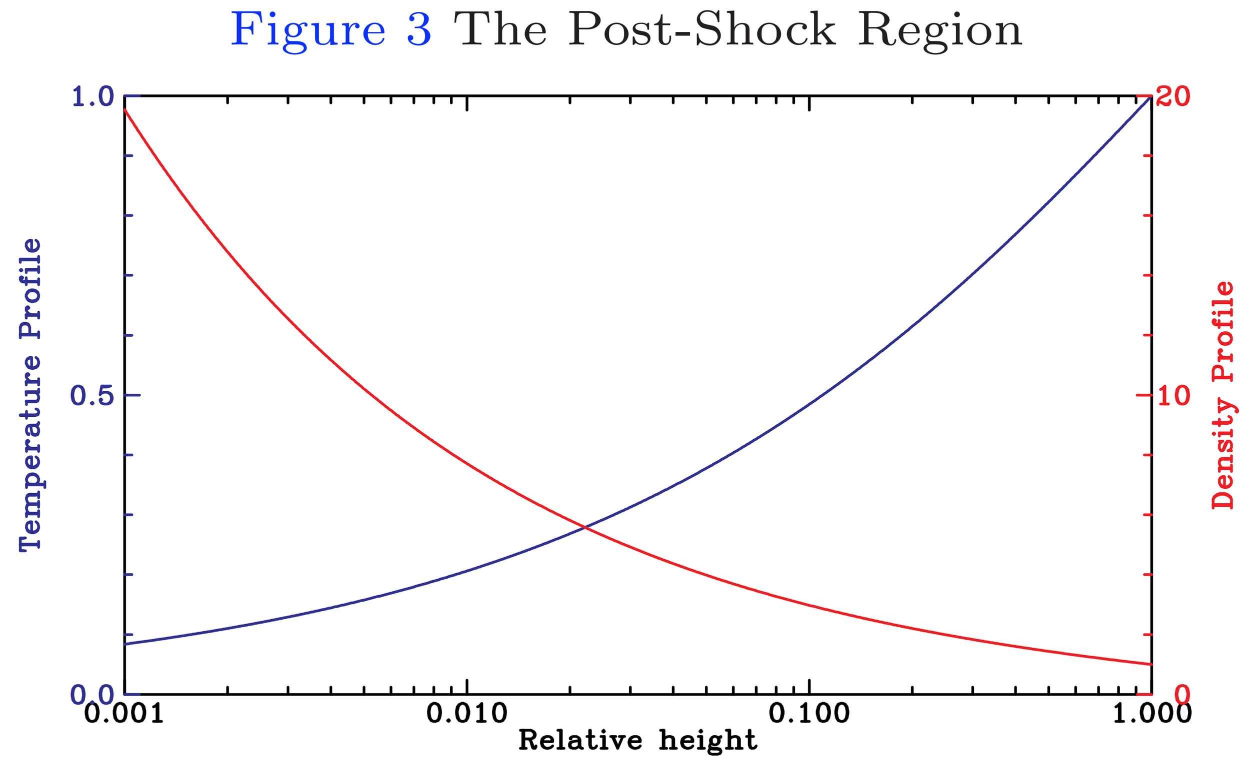
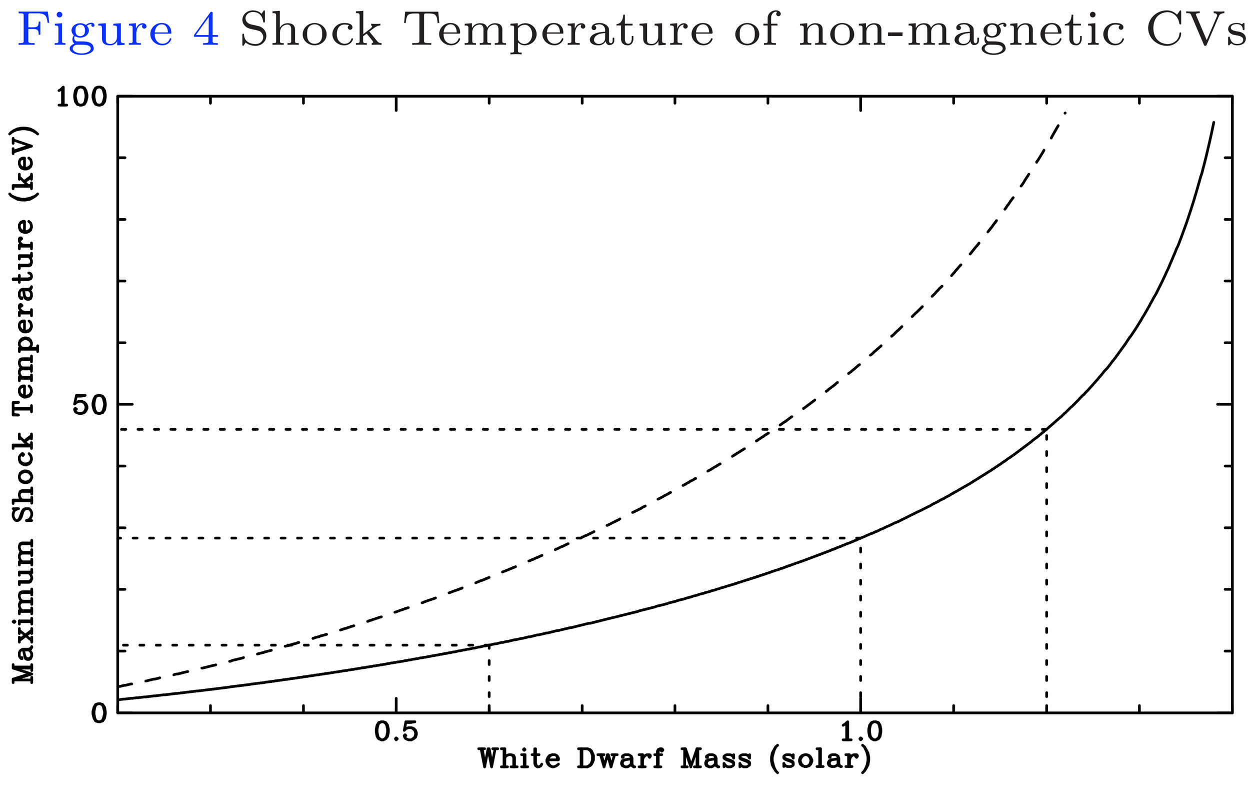


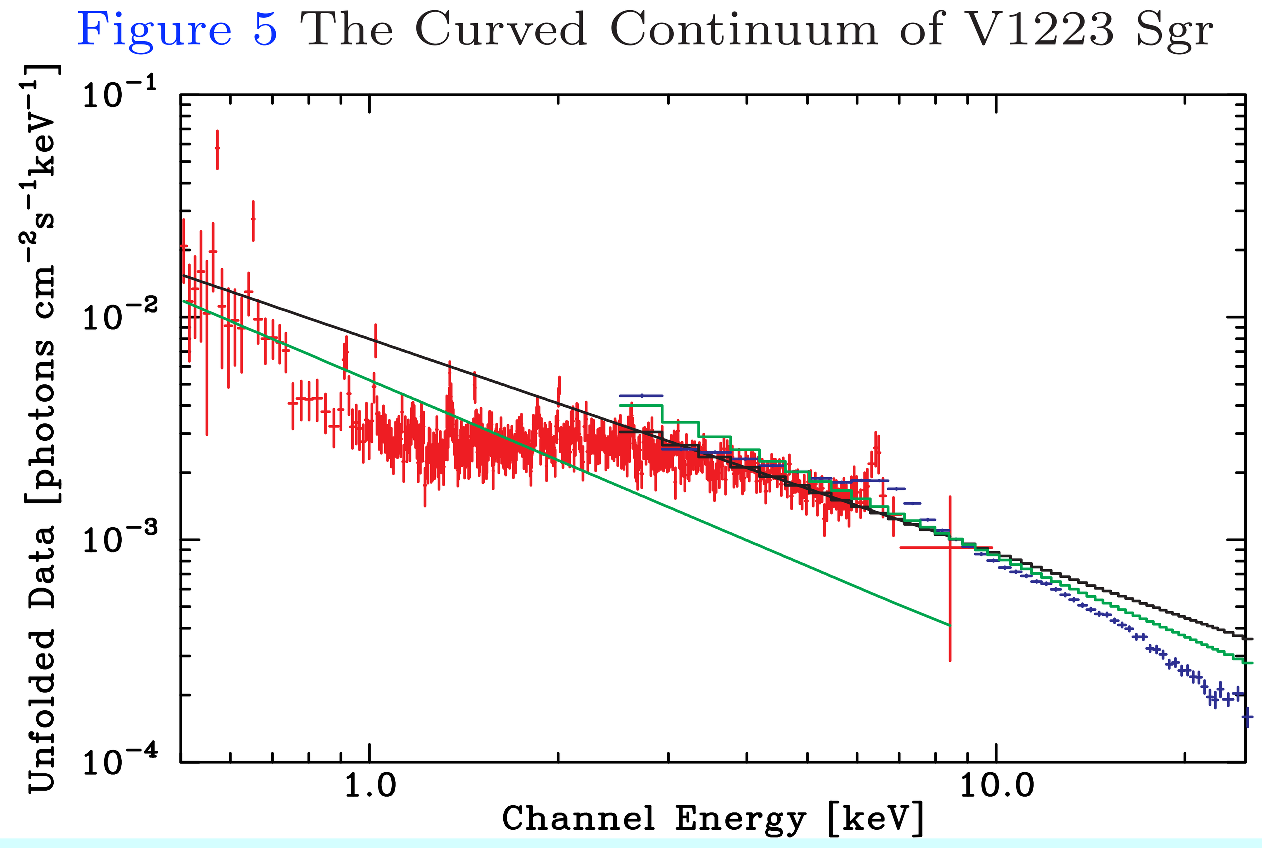
Figure 4 Shock Temperature of non-magnetic CVs



1. Introduction

Cataclysmic variables (CVs) are interacting binaries in which the accreting object (the primary) is a white dwarf (see Warner 1995 for a review). X-ray emission in CVs is powered by the accretion of material onto the white dwarf, which is shock-heated to high temperatures ($kT_{\rm max} \sim$ 10–50 keV) and must cool before settling onto the surface of the primary. The emergent X-ray spectrum is expected to be the sum of emission from plasmas over a continuous temperature distribution, from the shock temperature to the white dwarf photospheric temperature. However, Mukai et al. (2003) presented *Chandra* HETG spectra of 7 CVs then available in the archive, and showed that they can be divided into two types, “cooling-flow” (Figure 1) and “photoionized” (Figure 2).

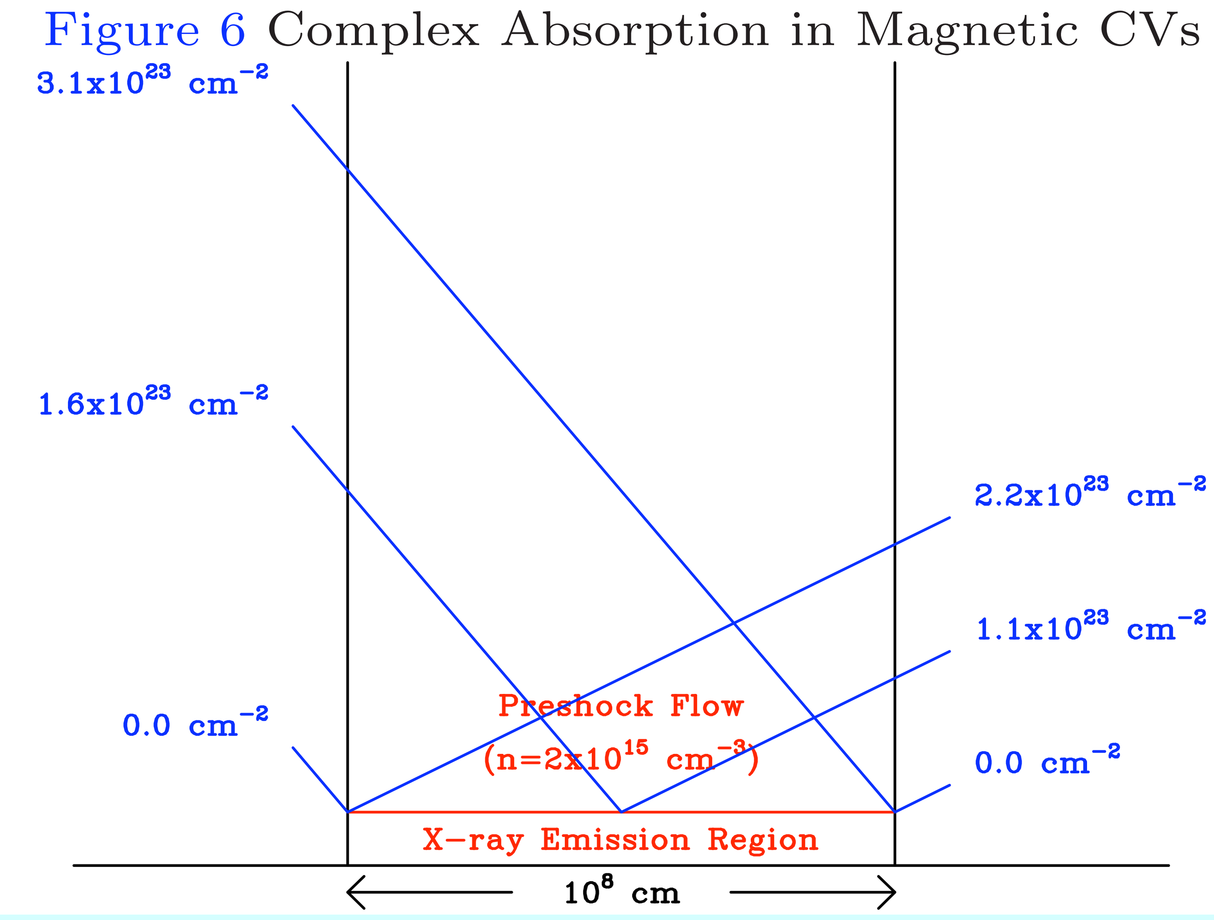
Figure 5 The Curved Continuum of V1223 Sgr



3. “Photoionized” CVs

In Mukai et al. (2003), an underlying power-law continuum was assumed. Such a continuum, however, is unphysical in CVs, and does not fit the data, as clearly demonstrated in the simultaneous *Chandra* HETG/*RXTE* PCA observation of V1223 Sgr (Figure 5, where the unfolded data are shown with “best fit” power law, with or without allowing the normalization to be different between the two instruments). Also in Mukai et al. (2003), all emission lines (except the 6.4 keV fluorescent Fe Kα) were assumed to be due to photoionization: this requires a degree of ionization unlikely in CVs.

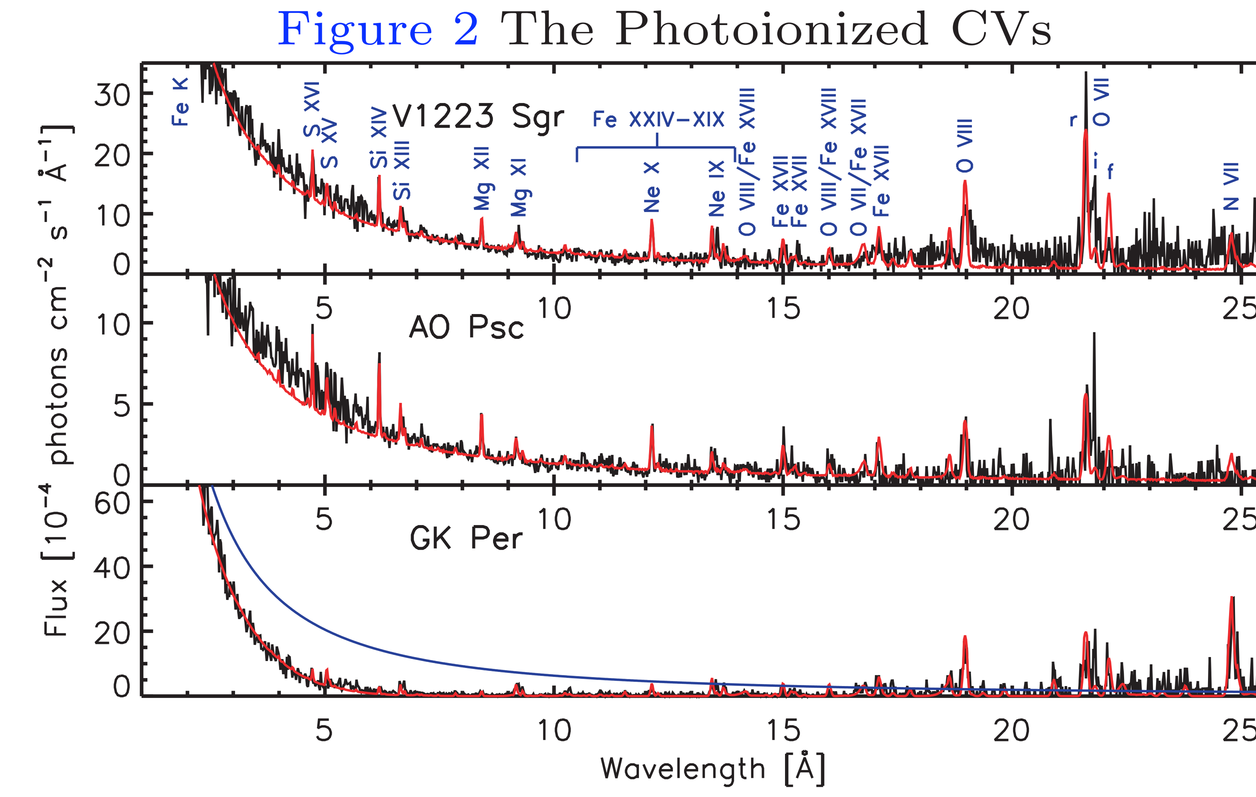
Figure 6 Complex Absorption in Magnetic CVs



4. Complex Absorber Model

The hard continuum in “photoionized” CVs are in fact the cooling flow spectrum modified by a complex absorber. The main absorbers in magnetic CVs are located in the immediate pre-shock flow (see Figure 6), which Done & Magdziarz (1998) approximated as a power law distribution in N_H. This (`pwab` model in `xspec`) results in a power law-like (rather than exponential) absorber (Figure 7).

Figure 2 The Photoionized CVs



5. Test Case: V1223 Sgr

I obtain a good fit to the HETG and PCA data on V1223 Sgr above 1 keV by applying `pwab` and `reflect` to `mkcflow` and adding a 6.4 keV Gaussian (Figure 8). The spectral curvature and most of the emission lines are fit well. Below 1 keV, the absorber is more transparent because it is ionized (as evidenced by the OVII edge). The observed He-like lines of O VII, Ne IX, and Mg XI are much stronger than this model: they are indeed likely to be produced via photoionization. Addition of lower temperature plasma does not work because the hypothetical component necessary to explain the Ne IX triplet will also produce additional OVIII lines. Thus, I confirm that photoionization plays a role in V1223 Sgr, creating ionized absorbers and He-like emission lines. Underneath, there is a cooling flow CV modified by the complex absorber.

Figure 7 Resulting Power Law-Like Absorption

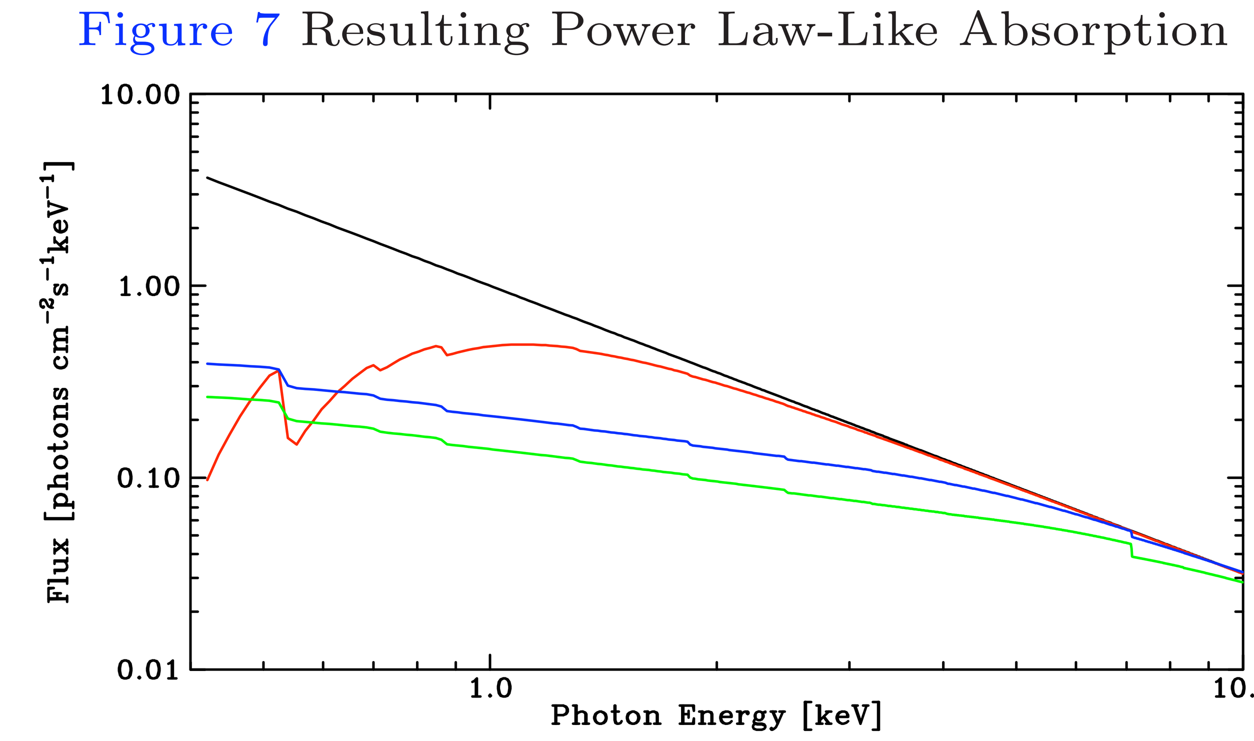
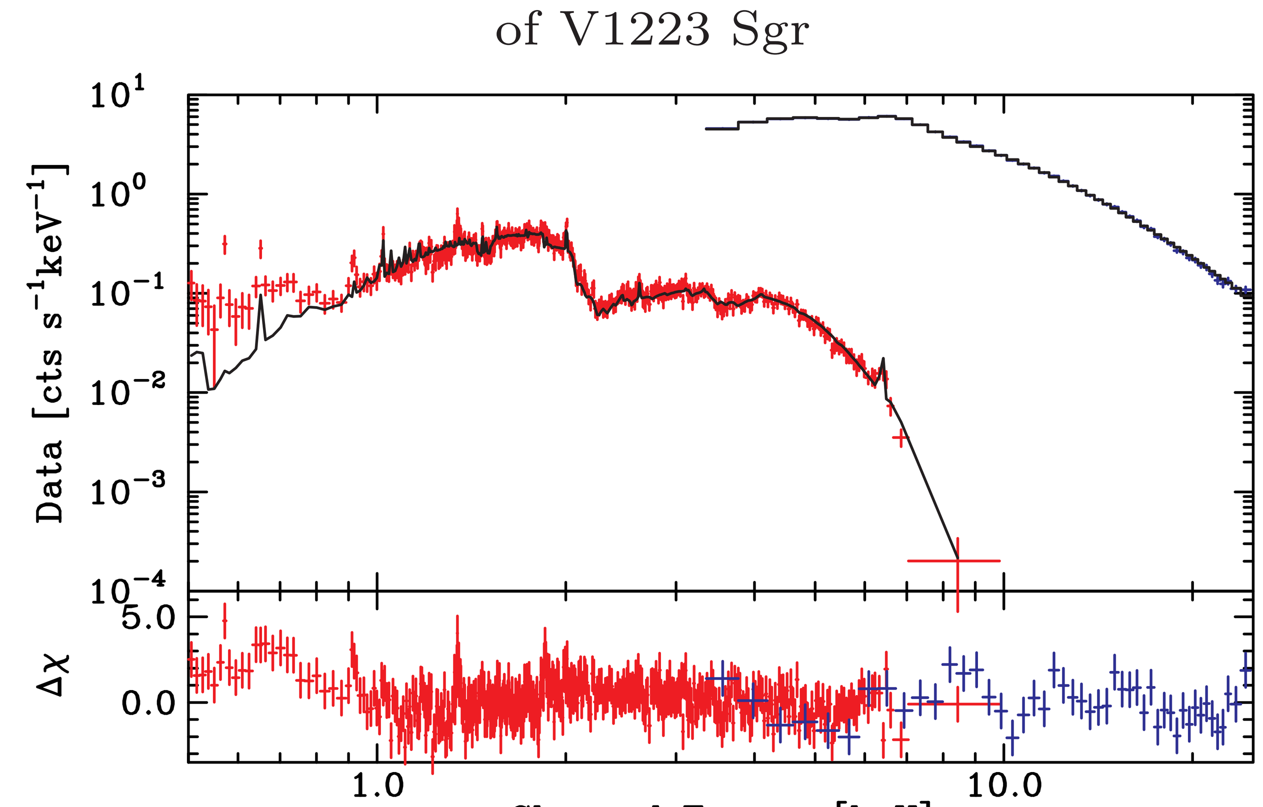


Figure 8 Best-fit model for MEG & PCA spectra of V1223 Sgr



References

Done, C. & Magdziarz, P. 1998, MNRAS, 298, 737

Mukai, K., Kinkhabwala, A., Peterson, J.R., Kahn, S.M. & Paerels, F. 2003, ApJLett, 486, L77.

Mushotzky, R.F. & Szymkowiak, A.E. 1988, in “Cooling flows in clusters and galaxies,”Kluwer, p53.