The density of the boundary layer in non-magnetic cataclysmic variables

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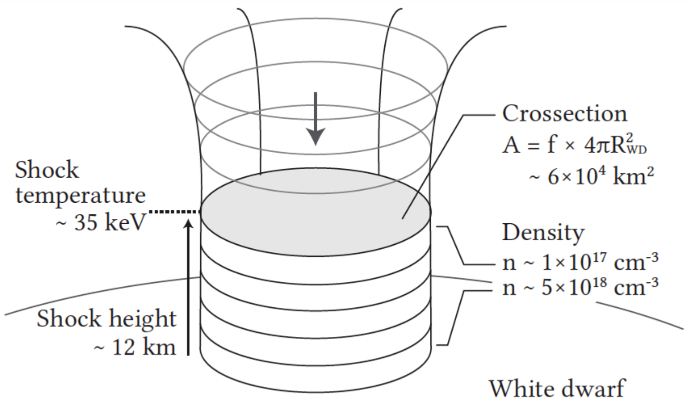
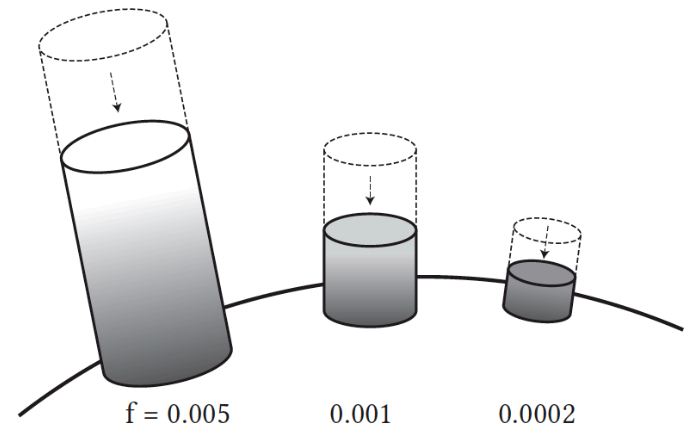
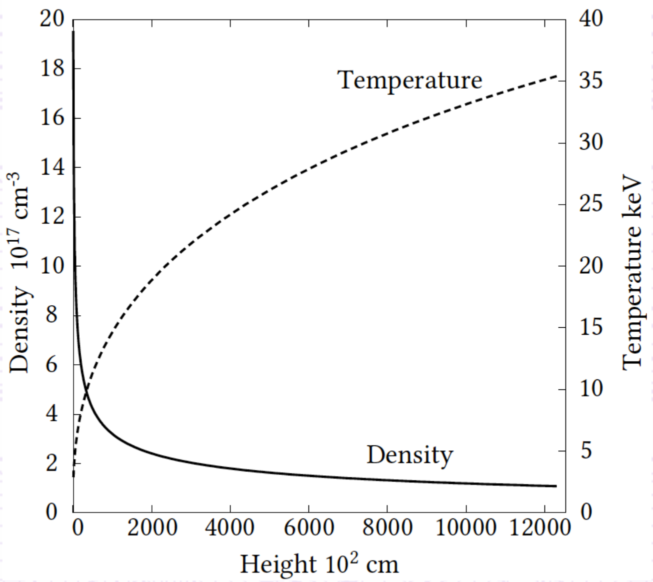
X-rays from Accreting White Dwarfs

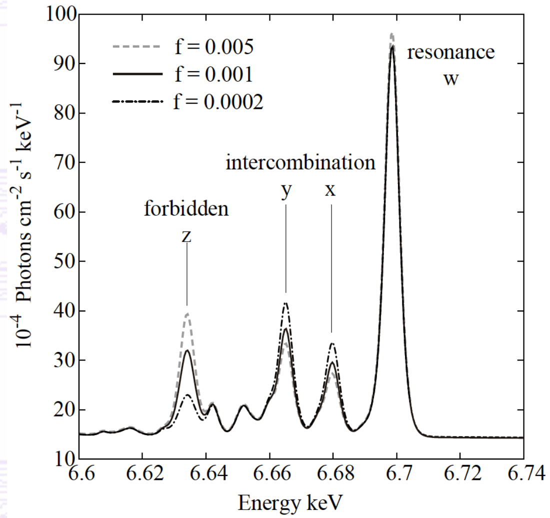
- Cataclysmic variables (CVs) and symbiotic stars often emit optically thin, thermal X-rays at moderate (10^{28}-10^{34} erg/s) range.
- They contain some of the hottest X-ray emitting plasma in the universe, with kT up to 50 keV and above.
  - Shock temperature is a good diagnostic for white dwarf (WD) mass; for strong shock from free-fall, kT_{shock} is 71 keV for 1.1 M_o.
- In many magnetic CVs, the density can be of order 10^{17} cm^{-3}, making the He-like Fe lines the triplet of choice for density diagnostic.
  - The case for the intermediate polar, V1223 Sgr, was described extensively in the ASTRO-H White Paper.

Digression: V1223 Sgr

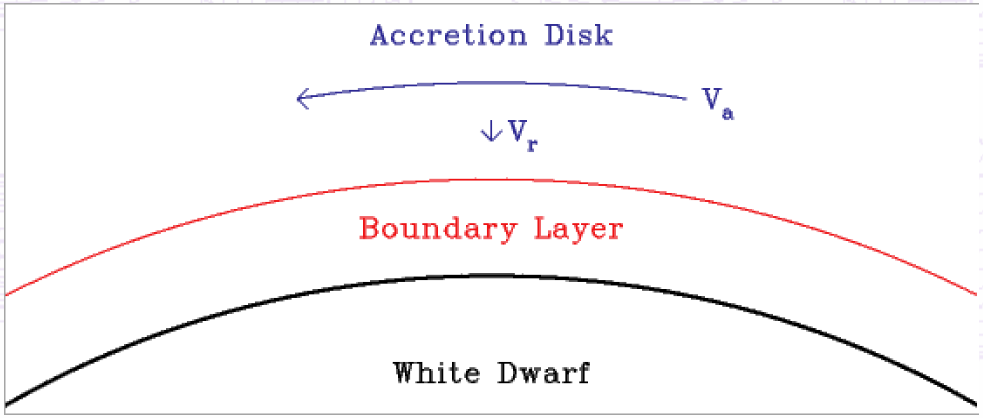








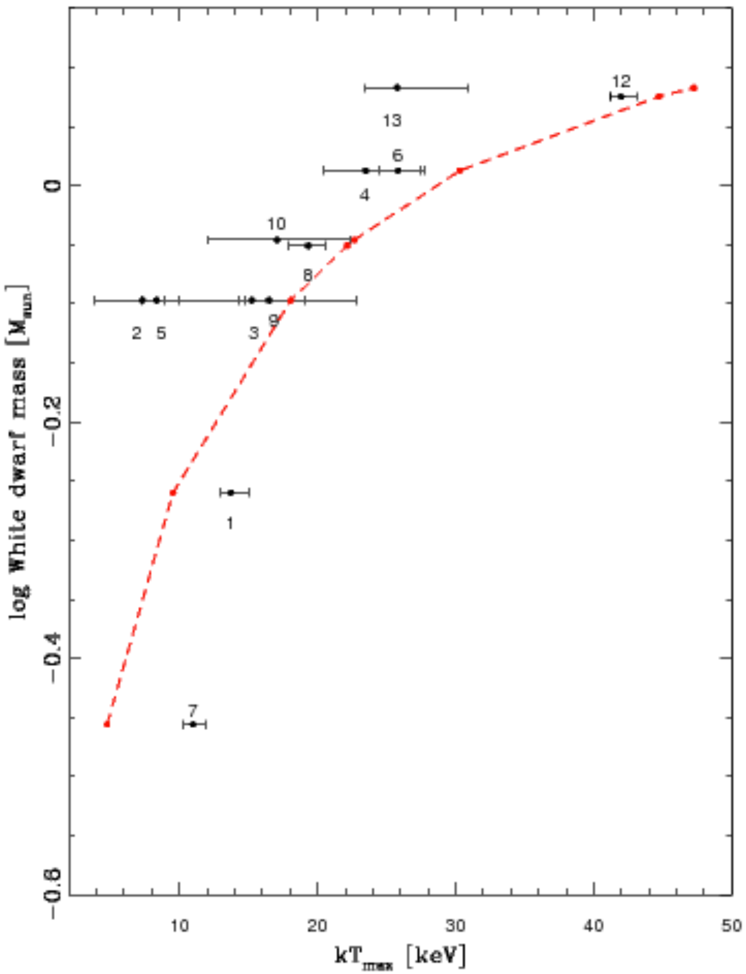
What about non-magnetic CVs?



In the ASTRO-H White Paper, we did not discuss the density of the X-ray emitting region in non-magnetic CVs, which tend to have lower X-ray luminosity. However, the density depends on:

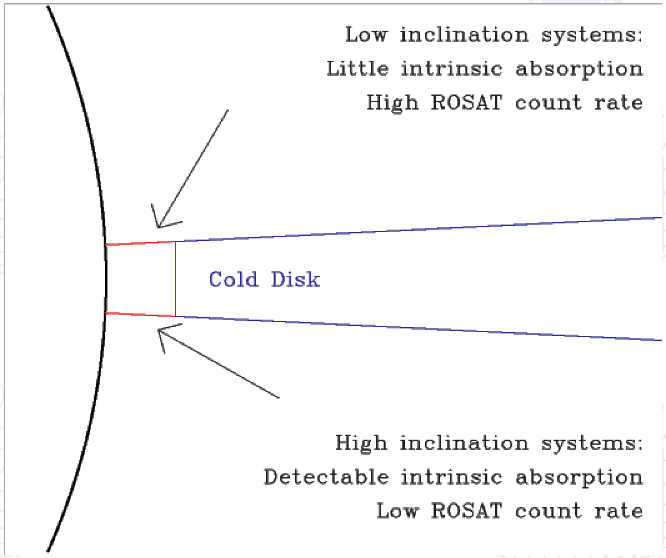
- ✓ Total accretion rate (perhaps ~100 higher in typical IPs, such as V1223 Sgr, than in most non-magnetic CVs)
- ✓ Fraction of the white dwarf surface over which accretion takes place: <0.002 in the IP, XY Ari; equatorial belt whose width is determined by the accretion disk scale height, H, in non-magnetic CVs.
- ✓ The radial component of the velocity of the accreting matter, V_r: free-fall velocity (~5,000 km/s) in magnetic CVs, $<c_s$ (the sound speed), or ~10 km/s, in non-magnetic CVs.

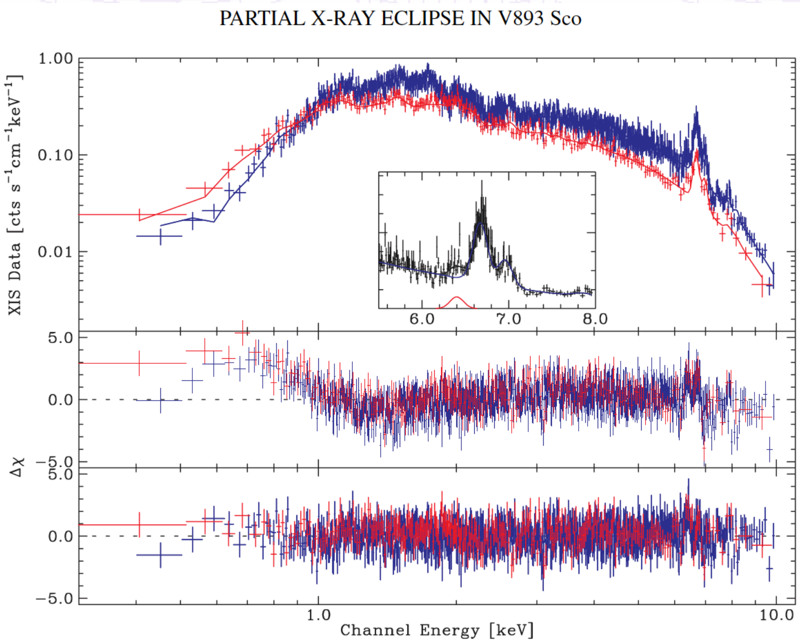
Strong Shock – how?



- The maximum temperature of X-ray emitting plasma in quiescent dwarf novae are close to that expected for a strong shock from Keplerian velocity (left figure, from Byckling et al. 2010).
- Quiescent dwarf novae have high X-ray to optical luminosity: most of the kinetic energy of the disk material is radiated as X-rays.
- But how can there be a strong shock, if the boundary layer geometry is exactly as sketched on the previous page – i.e., grazing?
- If the Keplerian flow suddenly decelerates, what happens to the angular momentum?

Accretion Disk as X-ray Absorbers





- Multiple lines of evidence suggest that, in high inclination systems, the inner disk acts as a partial covering absorber of the boundary layer X-ray emission.
- In the case of V893 Sco (above), partial covering absorber has N_H~2x10^{22} cm^{-2}
- Given the X-ray luminosity of 10^{32} erg/s, a standard disk with V_r~10 km/s should have a surface density of ~0.1 g/cm^2 – so perhaps the disk actually has a supersonic radial infall velocity of V_r~50 km/s?
- The inner disk could be somehow truncated – however, the inflow has to retain K shell electrons to be seen as X-ray absorbers

Density Diagnostics with Chandra

- Accretion rate and V_r determines the surface density of the disk (cf. absorber)
- The density of the X-ray emitting boundary layer also depends on the disk thickness

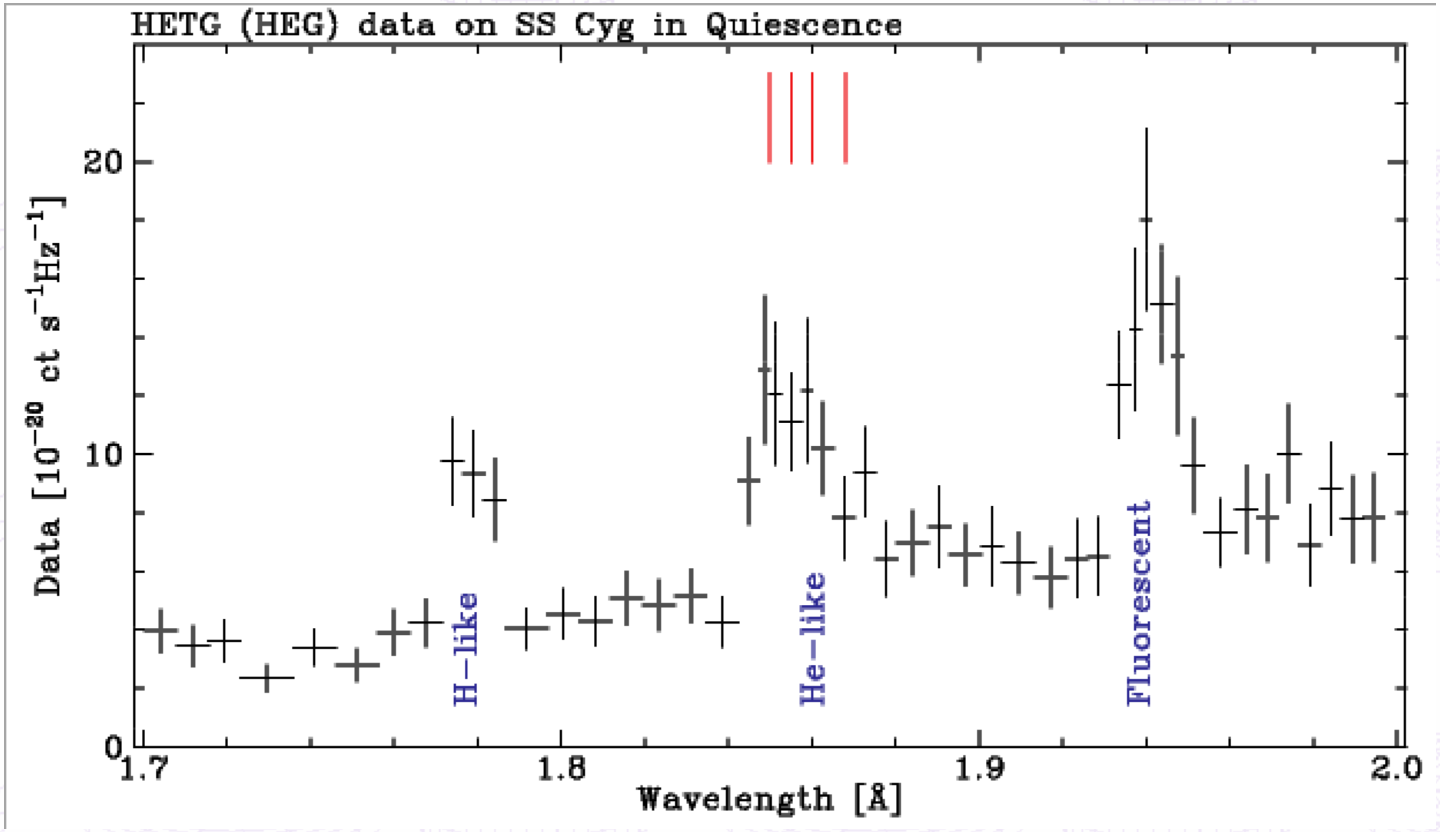
What do the existing X-ray spectra say about the latter? Not much, as it turns out

Table 4. *R* Ratios for He-like Triplets

(From Schelegel et al. 2014)

CV	Fe XXV	S XV	Si XIII	Mg XI	Ne IX	O VII
V603 Aql	0.84 ± 0.69	<0.94	0.90 ± 0.74	0.64 ± 0.61	0.21 ± 0.14	<0.97
AE Aqr	<0.08	<3.66	1.12 ± 0.98	<4.94	4.40 ± 3.78	<1.14
TT Ari	0.10 ± 0.08	<0.71	0.95 ± 0.50	0.34 ± 0.29	0.27 ± 0.25	<0.29
V834 Cen	0.23 ± 0.20	0.46 ± 0.39	0.40 ± 0.29	0.56 ± 0.42	1.05 ± 0.92	<0.95
SS Cyg-Q	<0.48	0.86 ± 0.45	<1.36	<1.17	1.24 ± 1.00	0.25 ± 0.22
SS Cyg-O1	0.43 ± 0.28	2.20 ± 1.89	0.45 ± 0.40	1.09 ± 0.91	0.27 ± 0.17	0.21 ± 0.15
SS Cyg-O2	3.81 ± 2.93	0.42 ± 0.21	0.94 ± 0.84	0.17 ± 0.10	0.23 ± 0.09	0.04 ± 0.02
YY Dra	0.51 ± 0.43	0.83 ± 0.39	1.29 ± 0.66	0.50 ± 0.38	0.41 ± 0.29	<0.74
UG Gem-Q	0.18 ± 0.14	<1.12	<0.19	<0.91	<0.63	<0.62
UG Gem-O	0.07 ± 0.05	0.79 ± 0.59	0.26 ± 0.07	1.20 ± 1.13	0.25 ± 0.21	<0.08

Limitations of HETG



- ❖ At Fe K, the resolution of HETG/HEG is barely adequate for density measurements.
- ❖ The effective area is also very low.
- ❖ In some best cases, we might be able to constrain the density of lower kT regions but O, Ne and Mg lines are sensitive only to lower densities.

Summary and Prospects

- X-ray emitting plasma in CVs and symbiotic stars can reach very high temperatures and very high densities.
- We have previously advocated the use of high resolution spectroscopy in the Fe K region to determine the density of X-ray emitting plasma in magnetic CVs.
- We now believe the same should be done for non-magnetic CVs.
  - Accretion probably occur over a larger area of the white dwarf surface; however, the low expected radial infall velocity means the density may be as high as in magnetic CVs.
  - The apparent presence of strong shocks in a grazing geometry of the boundary layer remains a puzzle.
  - Complex absorbers in high-inclination non-magnetic CVs suggest the disk surface density may be lower than the standard model predicts.
  - The density of the X-ray emitting plasma depends also on the disk thickness, another parameter with potential uncertainty (if the standard disk model is not applicable).
- Upcoming missions XRISM and Athena can provide the data necessary to measure the density of the X-ray emitting plasma.