Spectroscopy of the photoionized wind and absorption dips in the Cyg X-1 system

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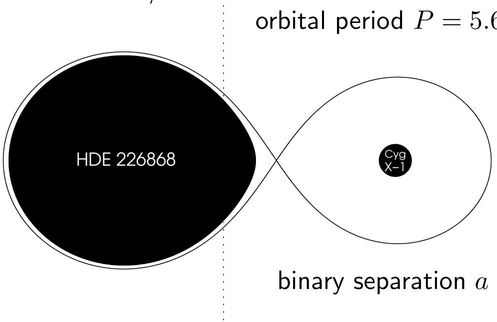
The high-mass X-ray binary system HDE 226868/Cygnus X-1

HDE 226868: O9.7 Iab supergiant
($M_\star = 18\,M_\odot$, $T_\text{eff} = 32\,000$ K,
$L_\star = 250\,000\,L_\odot$, $R_\star \approx 17\,R_\odot$,
fills ≈90 % of Roche lobe volume,
wind mass loss $\dot{M}_\star = 3{\times}10^{-6}\,M_\odot$/yr)

Cyg X-1: black hole
($M_\text{BH} = 10\,M_\odot$,
$L_X \approx 10\,000\,L_\odot$)

$v \sin i = 76$ km/s

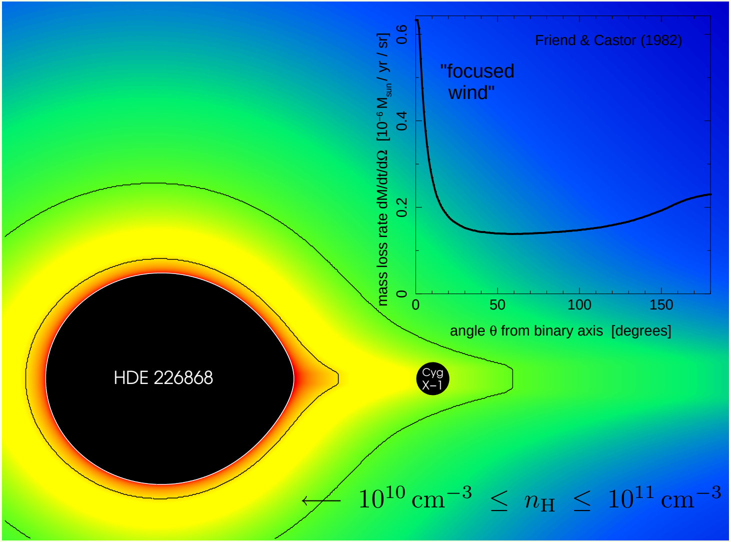
orbital period $P = 5.6$ d



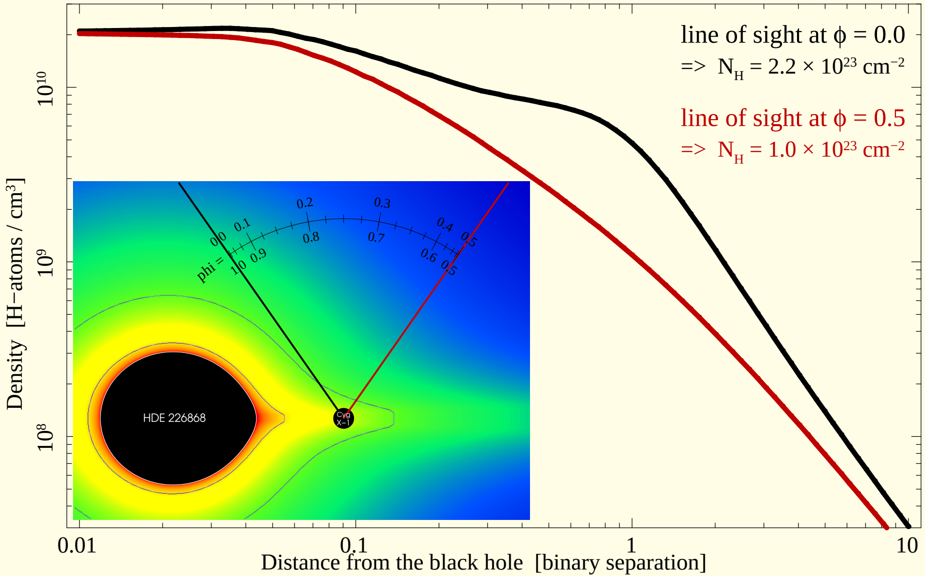
$d \approx 2.5$ kpc

binary separation $a = 41\,R_\odot$

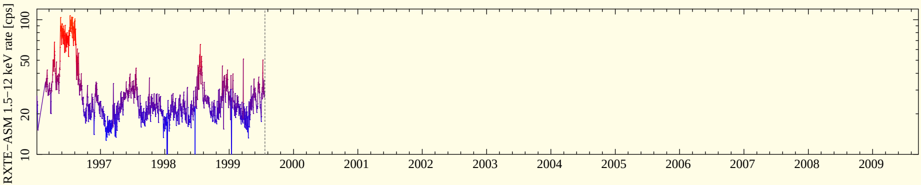
The focused wind in the HDE 226868/Cygnus X-1 system

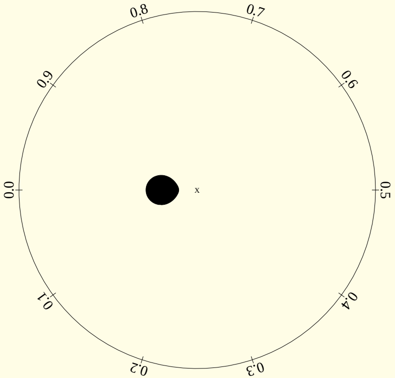


Density profile along our line of sight to Cyg X-1 at different phases

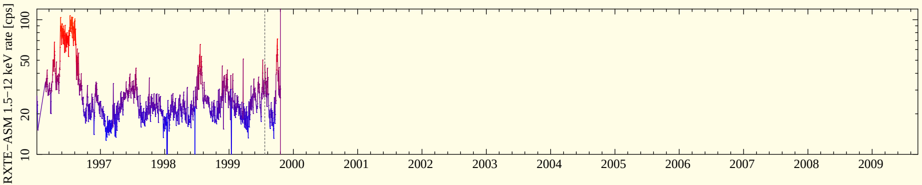


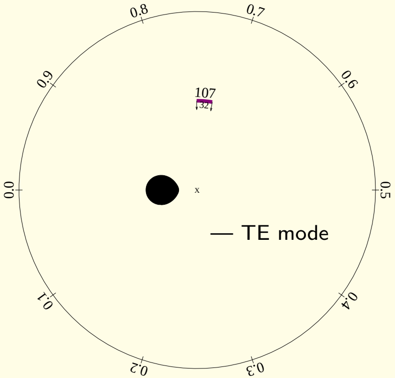
Cygnus X-1

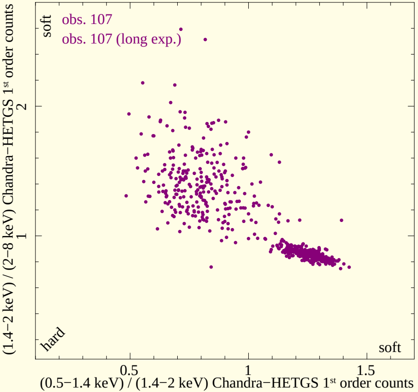

RXTE−ASM 1.5−12 keV rate [cps]
10
20
50
100
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009


0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x

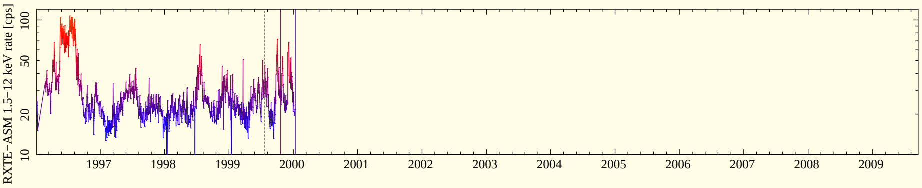
HETGS observations of Cygnus X-1 during *Chandra*'s First Decade

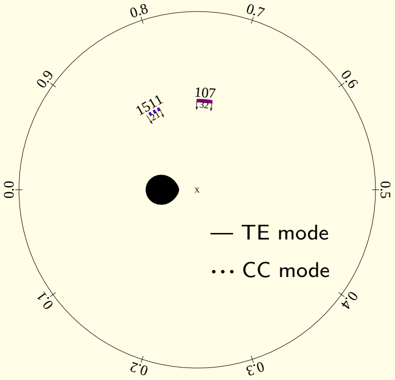


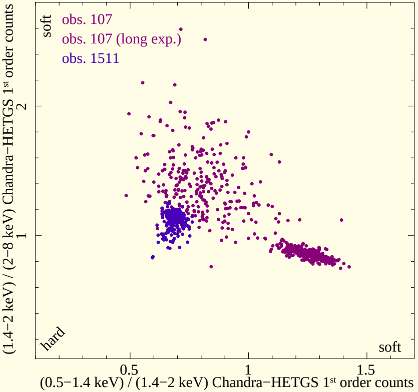




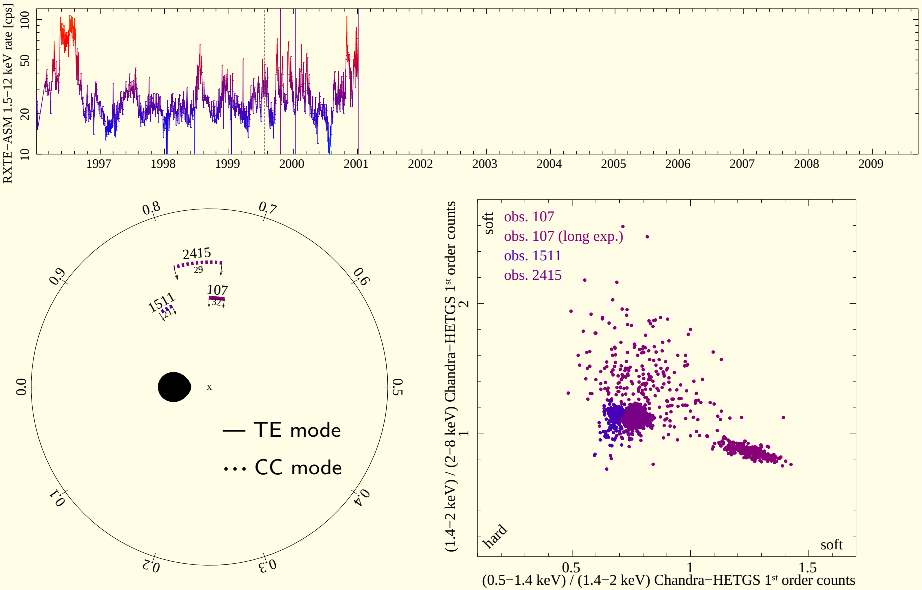
HETGS observations of Cygnus X-1



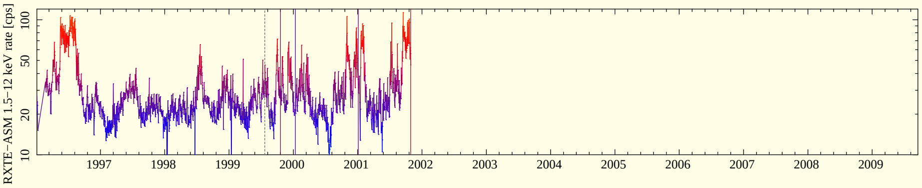


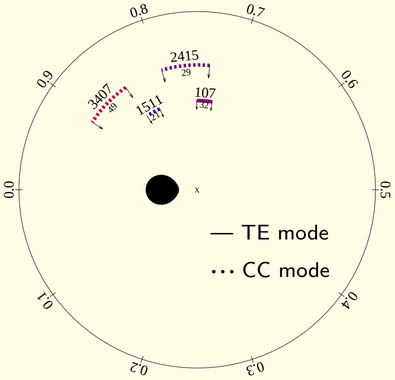


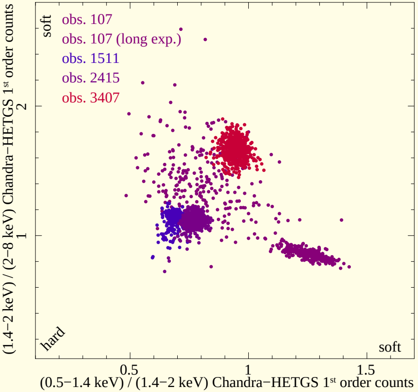
HETGS observations of Cygnus X-1



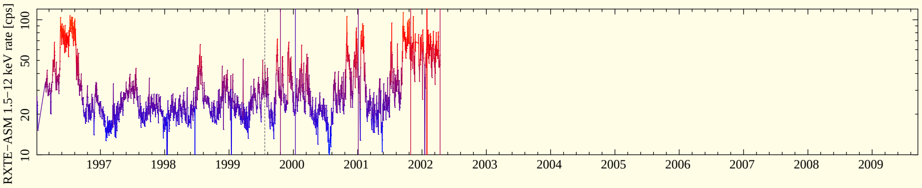
HETGS observations of Cygnus X-1

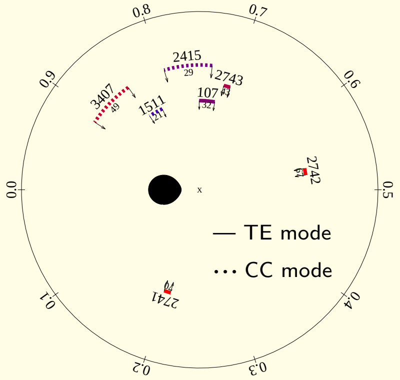


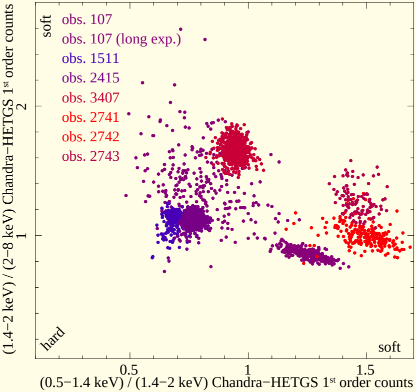




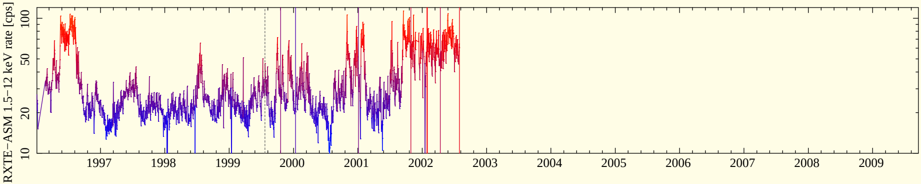
HETGS observations of Cygnus X-1

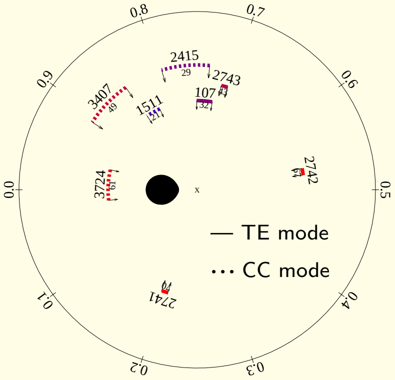


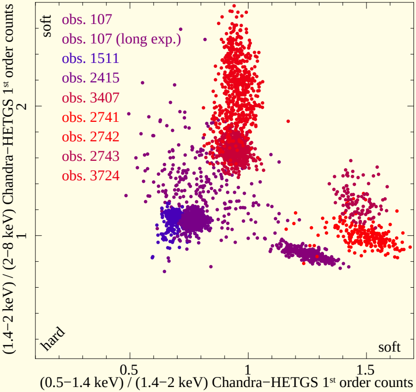




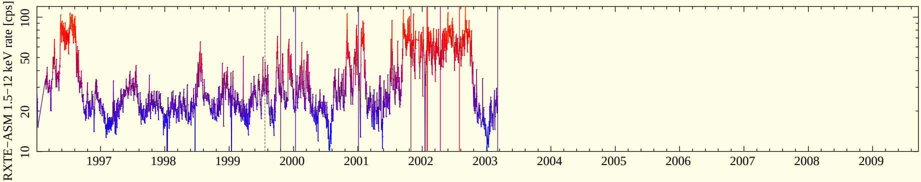
HETGS observations of Cygnus X-1

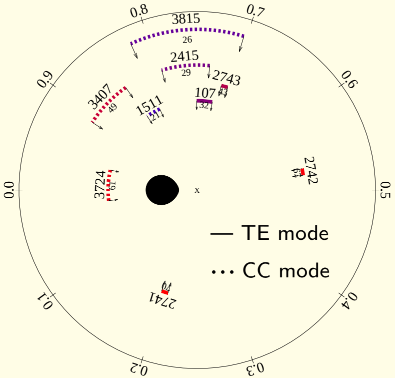


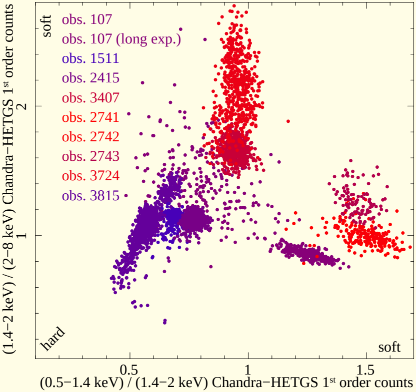




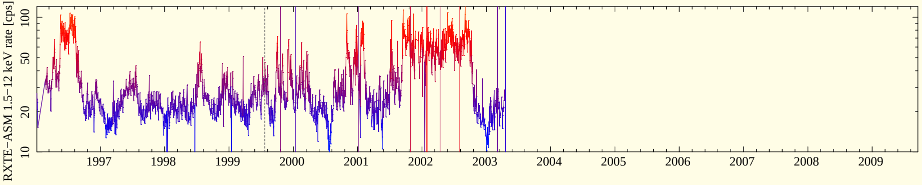
HETGS observations of Cygnus X-1

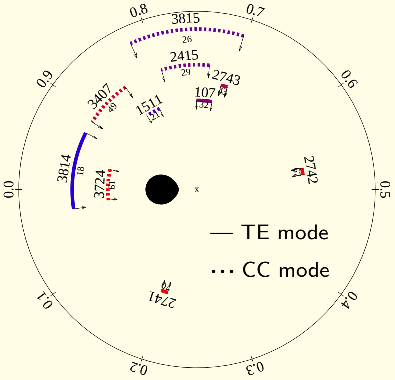


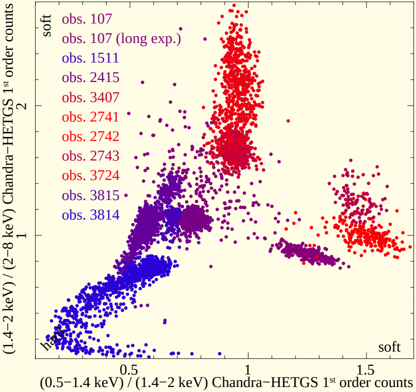




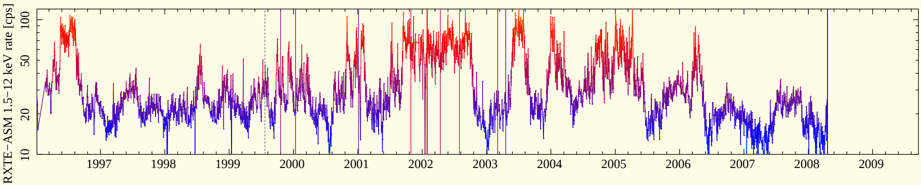
HETGS observations of Cygnus X-1

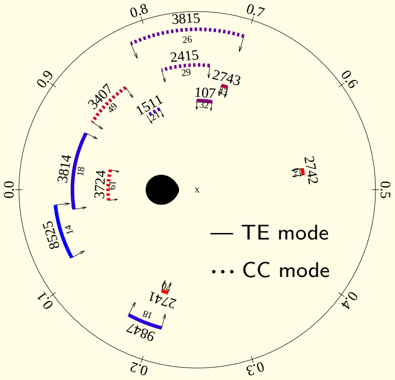


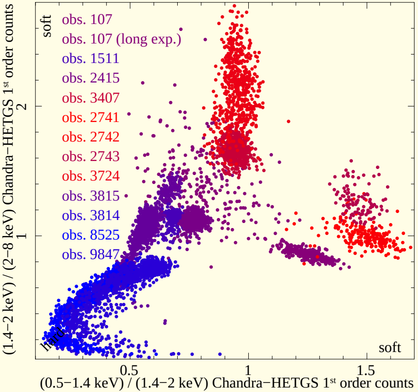




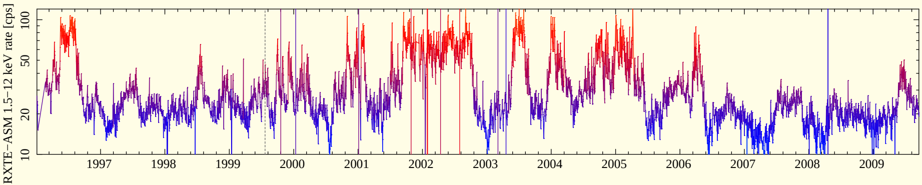
HETGS observations of Cygnus X-1

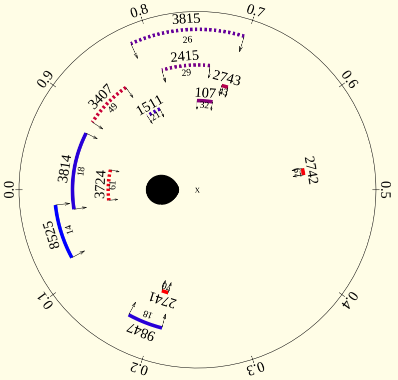


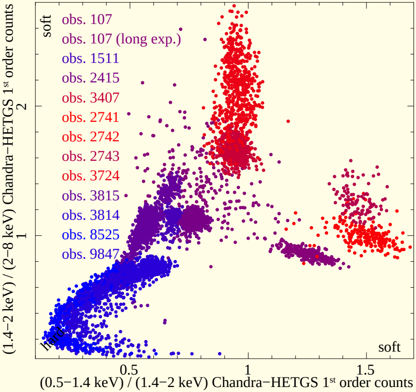




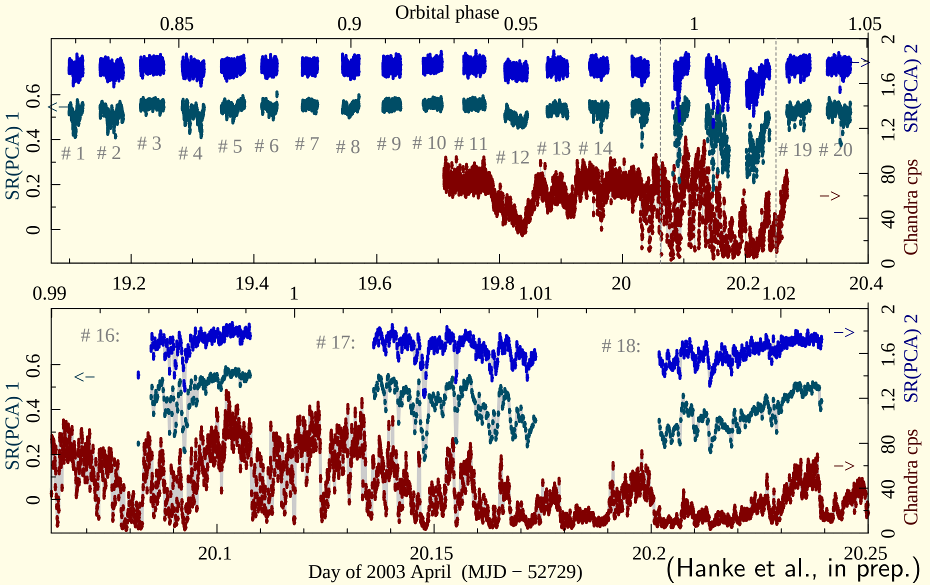
HETGS observations of Cygnus X-1





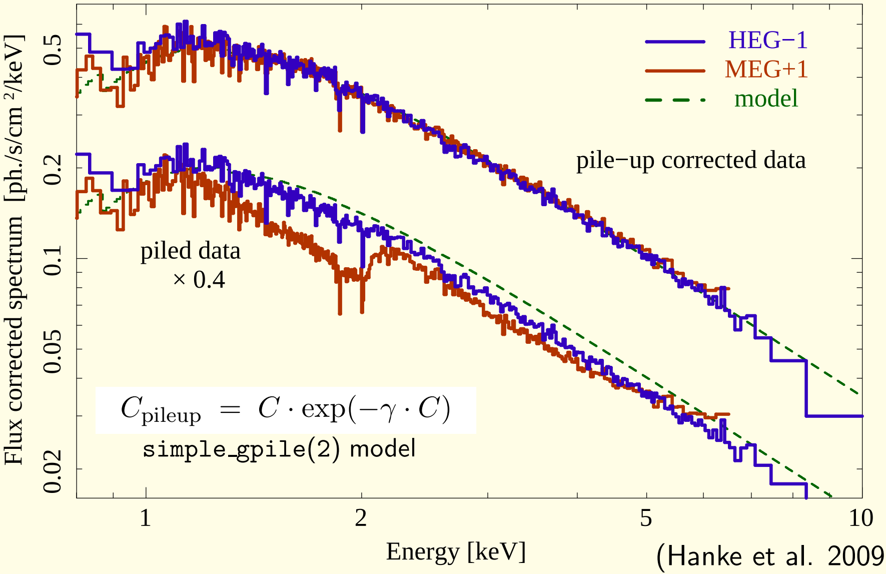


First *Chandra* obs. at $\phi_{\mathrm{orb}}=0$ in the hard state, simult. with *RXTE*



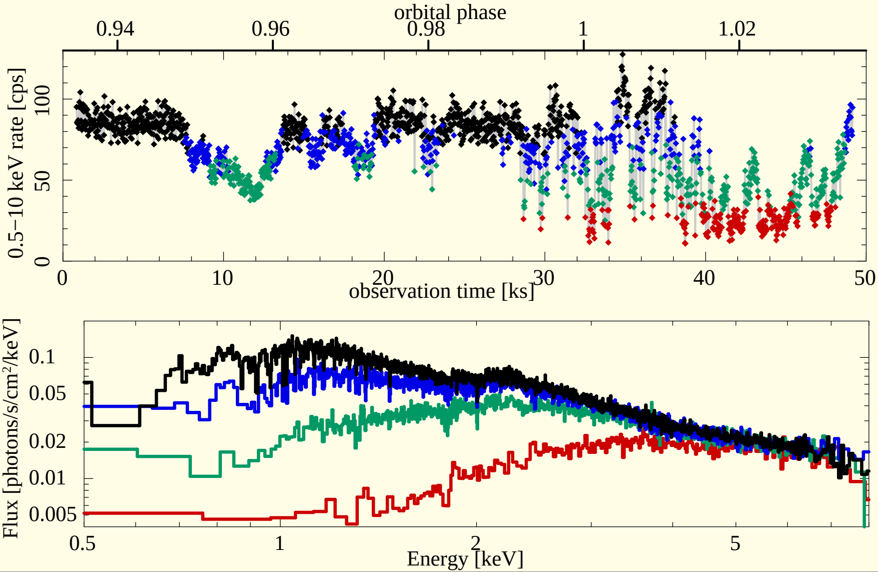
(Hanke et al., in prep.)

HETGS (TE mode) observation of Cyg X-1 / hard state @ 0.25 Crab

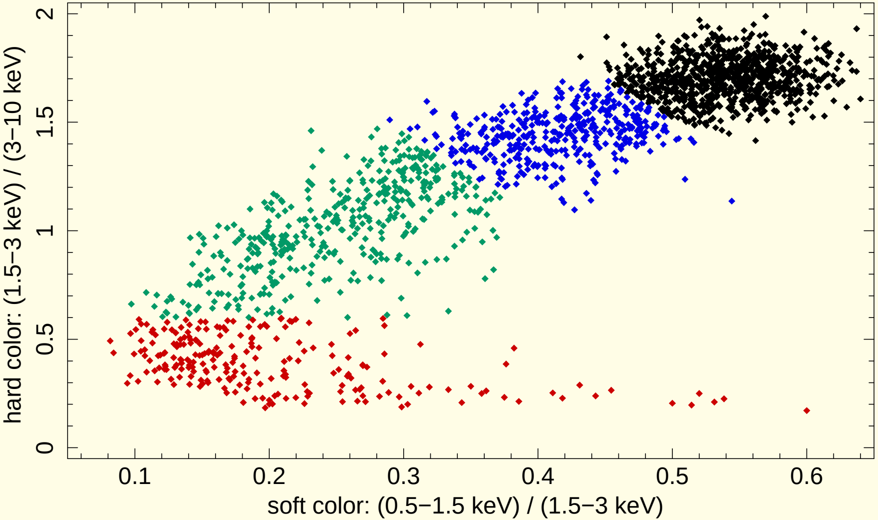


(Hanke et al. 2009)

Analysis of the absorption dips: the light curve and some spectra

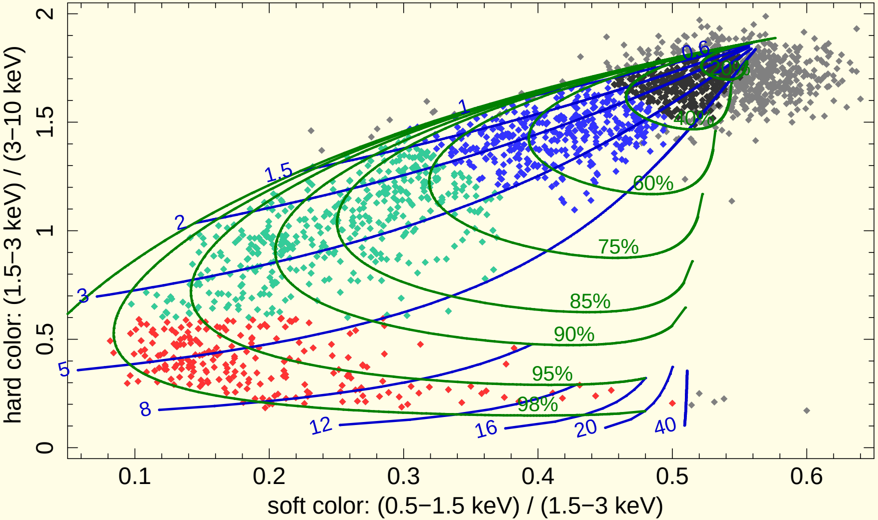


The dips in a color-color diagram

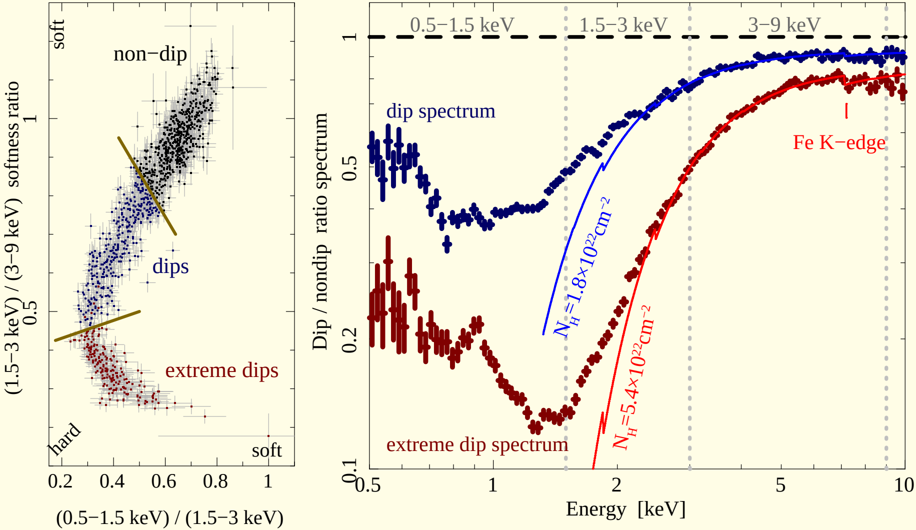


The dips in a color-color diagram require a partial covering model:

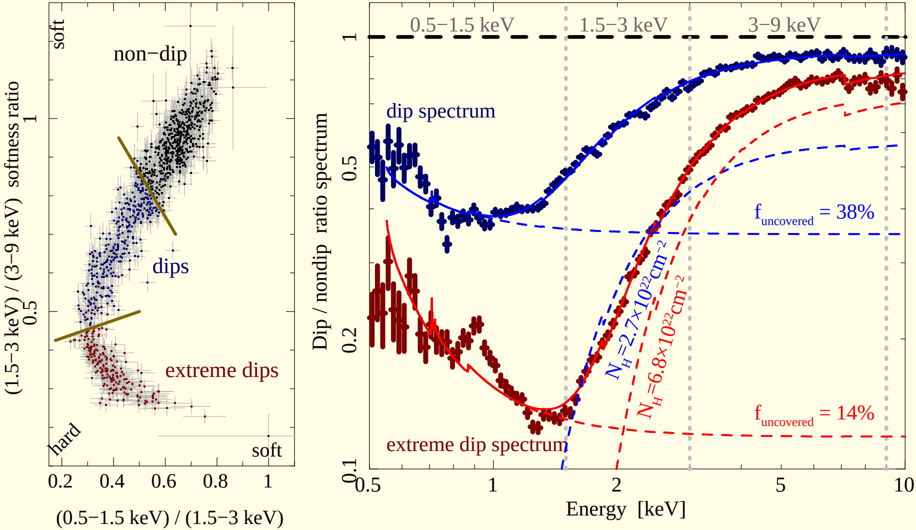
$$(1 - f_c) \cdot \exp\left(-5.4\cdot10^{21}/\mathrm{cm}^2 \cdot \sigma(E)\right) + f_c \cdot \exp\left(-N_{\mathrm{H},2} \cdot \sigma(E)\right)$$



Suzaku XIS: absorption AND electron scattering

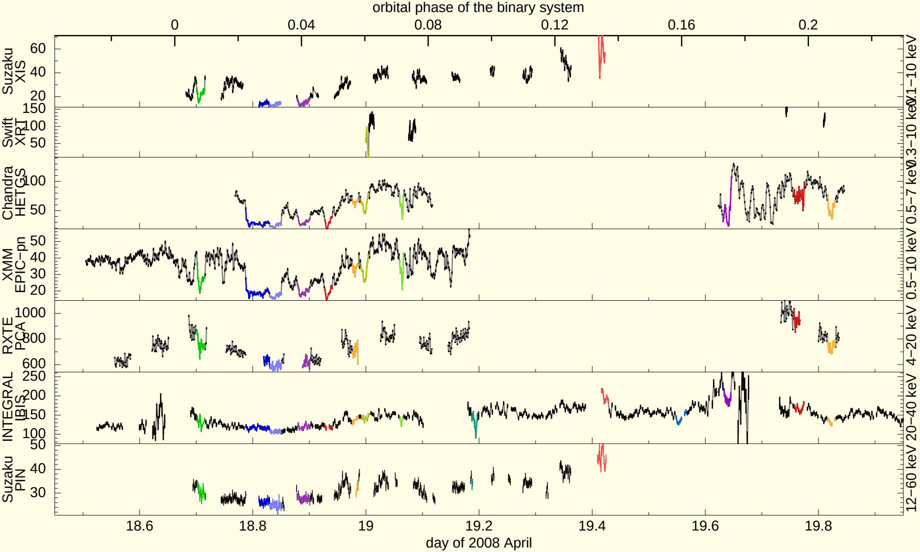


Suzaku XIS: Partially covering absorption AND electron scattering

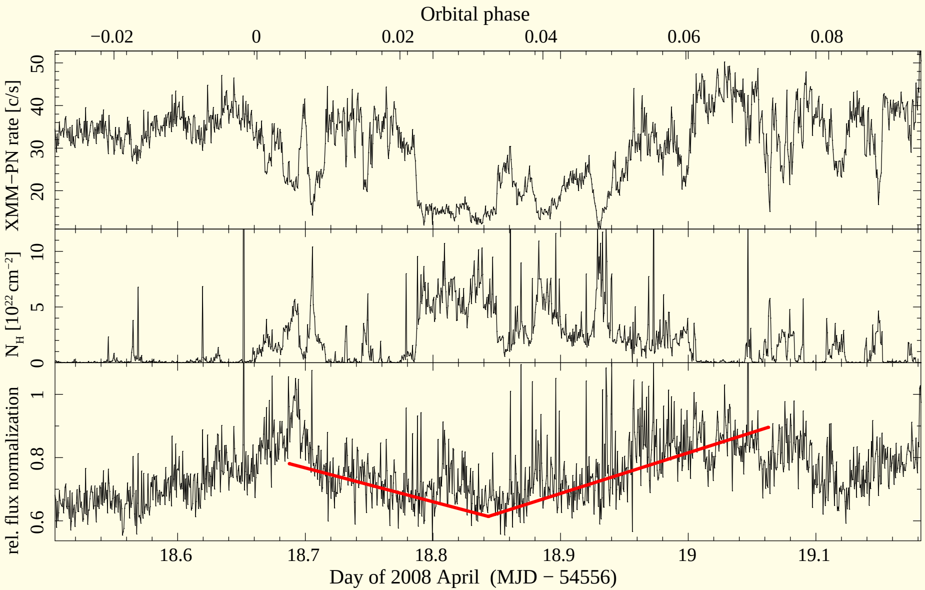


The multi-satellite observation (*the monster campaign*) of 2008 April

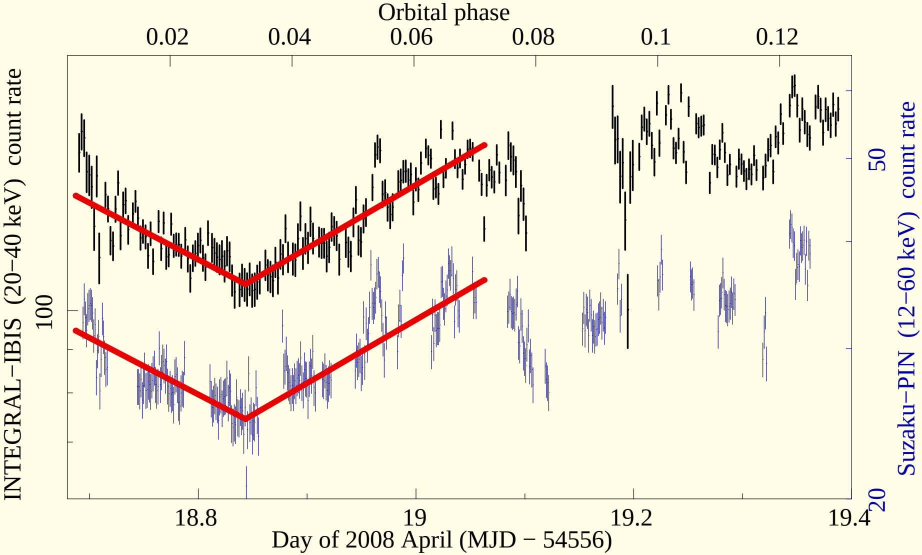
(*Chandra*, *XMM*, *RXTE*, *INTEGRAL*, *Suzaku*, & *Swift* observed Cyg X-1 simultan. at $\phi_{\text{orb}} \approx 0$)



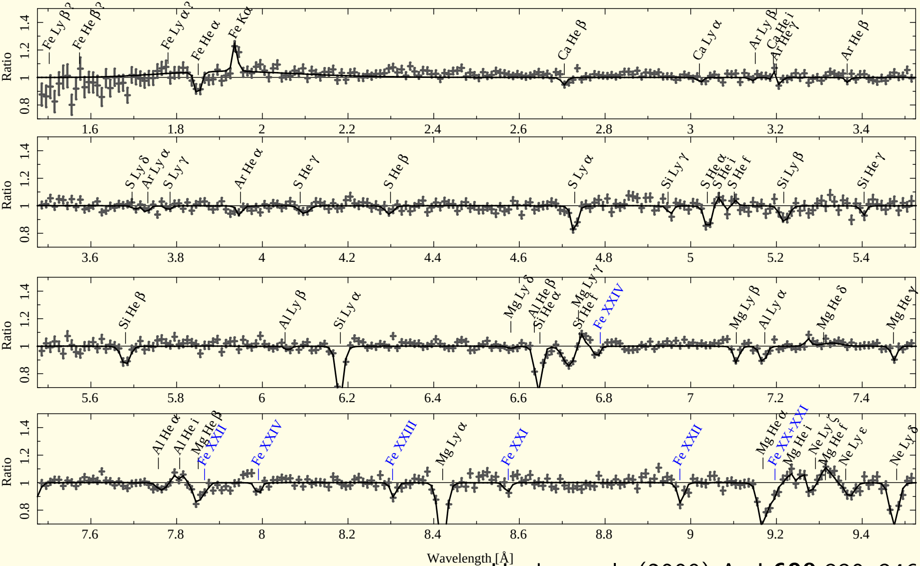
XMM EPIC-pn: Time resolved absorption and electron scattering



Scattering of X-rays above 12 keV = beyond photoelectric absorption

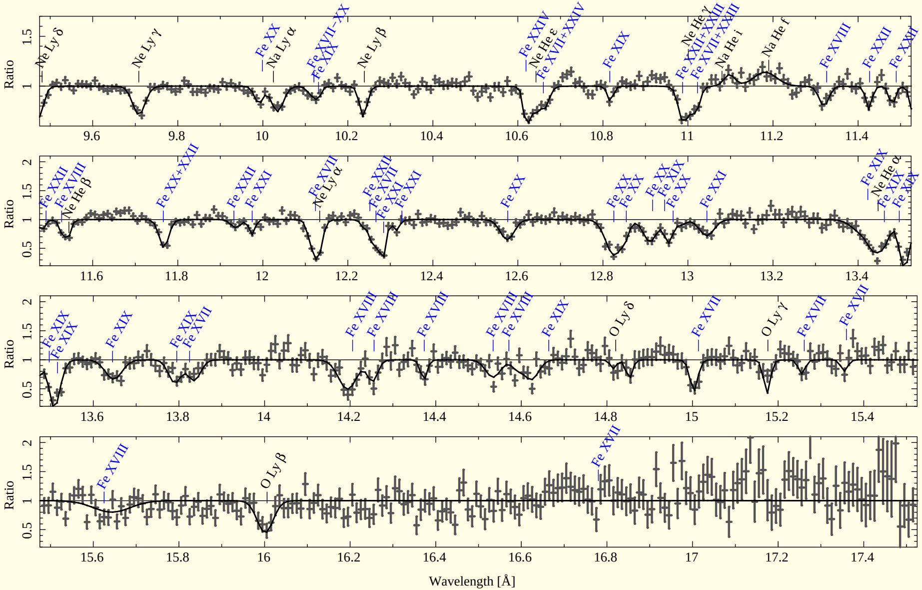


Non-dip analysis: absorption lines from a highly photoionized wind

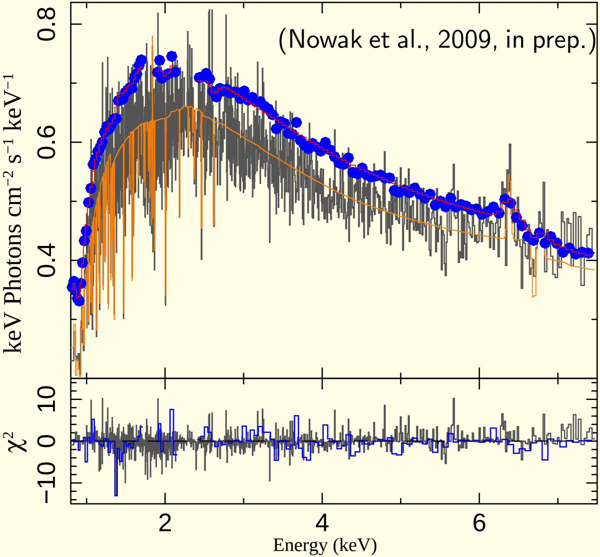


Hanke et al. (2009) ApJ **690**:330–346

Non-dip analysis: absorption lines from a highly photoionized wind



Importance of the highly ionized absorption for soft X-ray modelling



The narrow absorption lines are *not resolved* by, e.g., *Suzaku*-XIS,

but they still have to be taken into account when modelling the soft X-ray continuum.

⇒ One has to know the wind absorption very well!

Results from the non-dip analysis

If Cygnus X-1 is observed in the low/hard state at an orbital phase $\phi \approx 0$, the X-ray source is seen through a highly ionized wind.

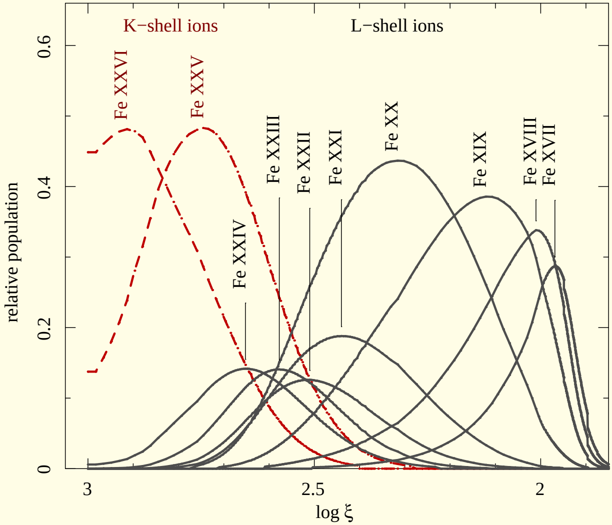
Ion column densities in $10^{16}\,\mathrm{cm}^{-2}$:

	O	Ne	Mg	Al	Si	S	Ar
H-like	36^{+18}_{-12}	42^{+10}_{-4}	7.2 ± 0.6	1.4 ± 0.5	10.1 ± 0.8	15^{+12}_{-5}	11^{+1}_{-6}
He-like	0^{+4}_{-0}	$6.3^{+1.3}_{-1.6}$	5^{+2}_{-1}	$0.8^{+0.2}_{-0.4}$	12 ± 3	15^{+2}_{-3}	8^{+1}_{-4}

Hanke et al. (2009) ApJ **690**:330–346

- Ionization balance: low-Z elements mostly H-like (or *fully* ionized?), higher-Z elements: K-shell ions, Fe: L-shell ions (as well)
- equivalent H column densities of $N_\mathrm{H} \gtrsim 10^{21-22}\,\mathrm{cm}^{-2}$
- $\rightarrow$ understanding the photoionization structure of the wind

XSTAR simulation of the wind's photoionization structrue

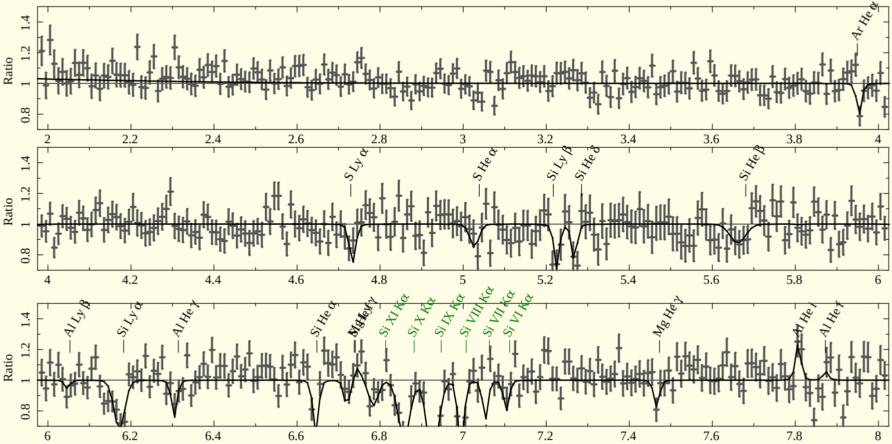


$$\xi = \frac{L}{n_{\rm H}\, r^2} = 100\, \frac{\rm erg\, cm}{\rm s} \cdot \frac{L_{37}}{n_{11}\, r_{12}^2}$$

$$L \approx 3\times10^{37}\,{\rm erg}$$
$$n_{\rm H} \approx 10^{11}\,{\rm cm}^{-3}$$
$$a = 2.9\times10^{12}\,{\rm cm}$$

(Hanke et al., 2009)

The first dip's *Chandra* HETGS spectrum: 2–8 Å (6.2–1.5 keV)



resonance Kα absorption lines of lower ionization stages of silicon

Summary and conclusions – *messages to take home to your family*

- In the hard state, soft X-ray observations of Cygnus X-1 at $\phi_{\mathrm{orb}} \approx 0$ are shaped by transient absorption dips.
  (In the near future, we're going to investigate other phases in detail, too.)
- Outside of dips, we see highly photoionized wind absorption – which needs to be taken into account when modelling soft X-ray spectra!
- These measurements constrain the wind's photoionization structure and will improve our understanding of the (hard state) accretion flow.
- Absorption dips are caused by partially covering absorption from (nearly) neutral clumps, which are embedded in a fully ionized blob.
- The spectroscopy of the dips confirms the lower ionization state.

More details are given by Hanke et al. (2009) ApJ **690**:330–346.
The results on the dips will be reported by Hanke et al. ApJ (in prep.).

Appendix: A 2d histogram of the Cyg X-1 ASM count rate