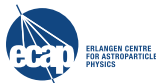


# Spectroscopy of the photoionized wind and absorption dips in the Cyg X-1 system

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- 1 *Introduction: Cygnus X-1 and Chandra's First Decade of Discovery*
- 2 *The second-recent Chandra obs. of Cyg X-1, i.e., the first hard state one*
- 3 *The recent Chandra observation of Cyg X-1, aka the monster campaign*
- 4 *Physics: High-resolution spectroscopy with Chandra*
- 5 *Summary & Conclusions*

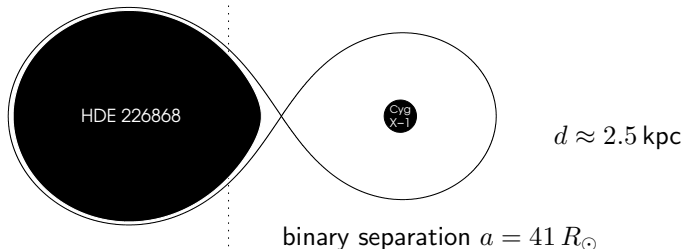
## The high-mass X-ray binary system HDE 226868/Cygnus X-1

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

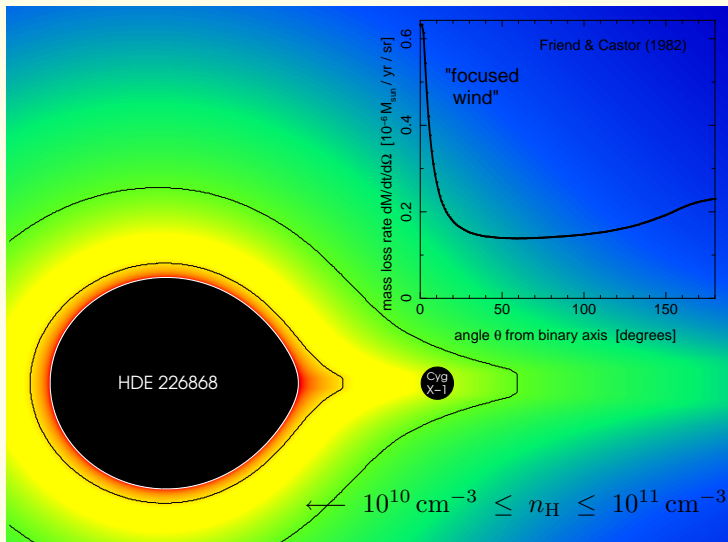
**Cyg X-1:** black hole  
 ( $M_{\text{BH}} = 10 M_{\odot}$ ,  
 $L_X \approx 10\,000 L_{\odot}$ )

$$v \sin i = 76 \text{ km/s}$$

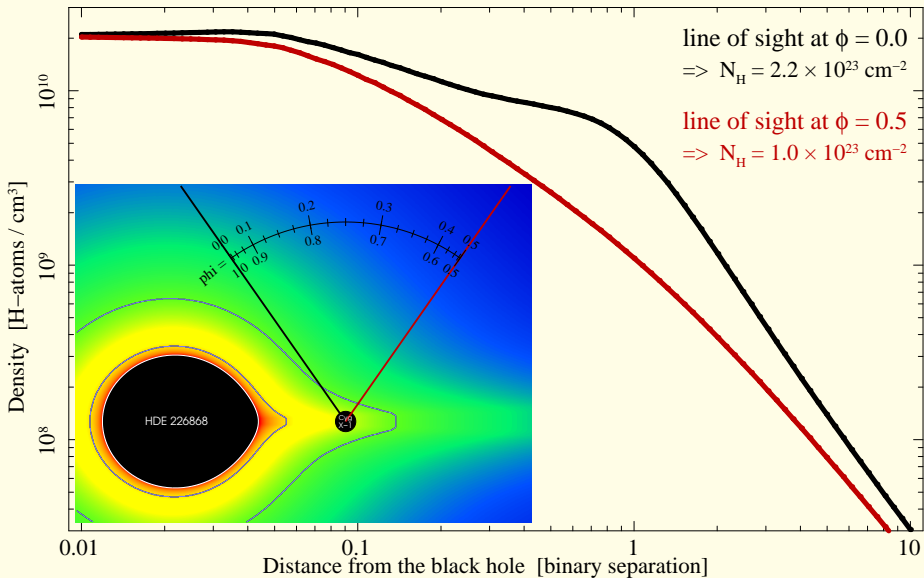
orbital period  $P = 5.6 \text{ d}$



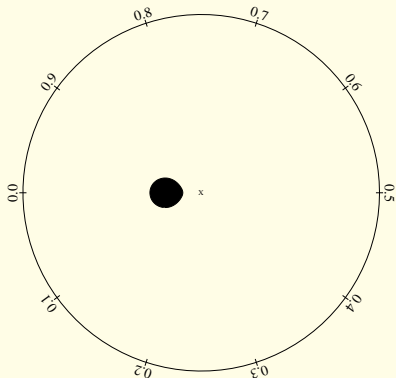
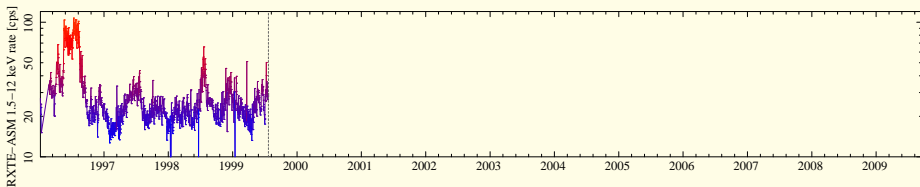
# The focused wind in the HDE 226868/Cygnus X-1 system



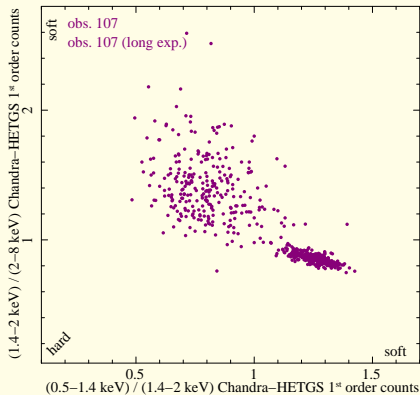
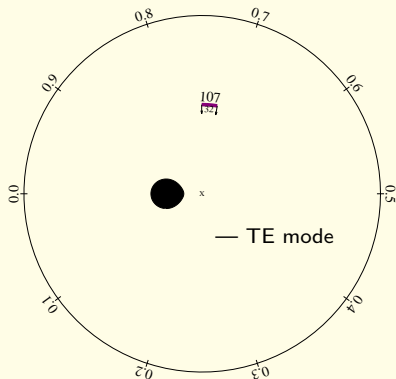
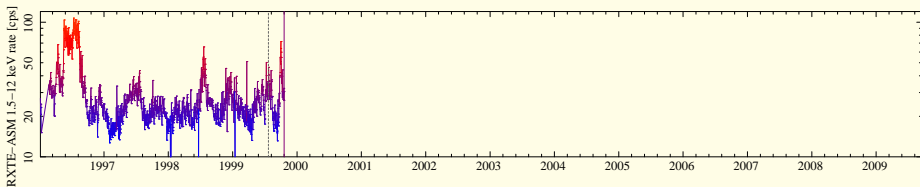
# Density profile along our line of sight to Cyg X-1 at different phases



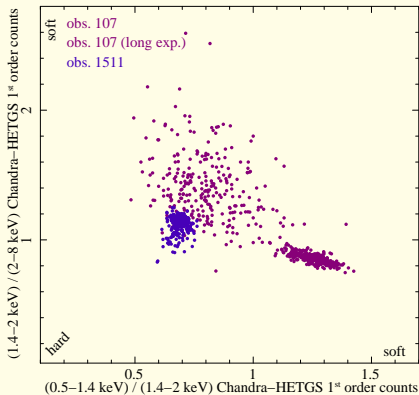
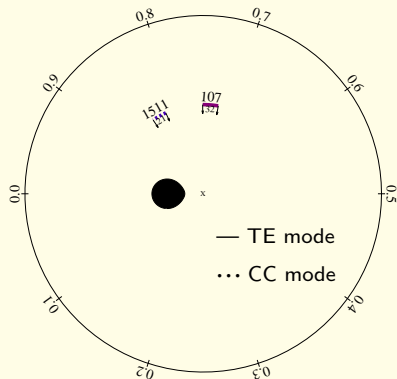
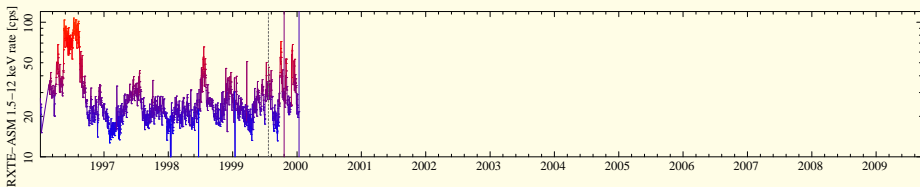
# Cygnus X-1



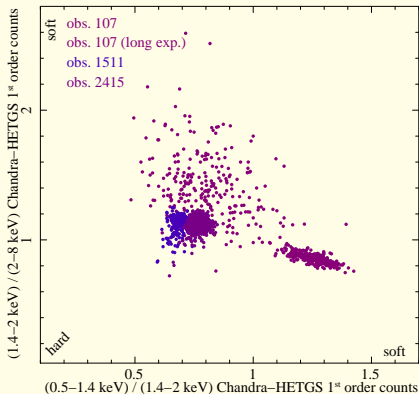
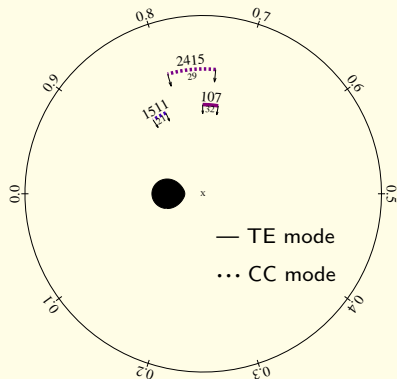
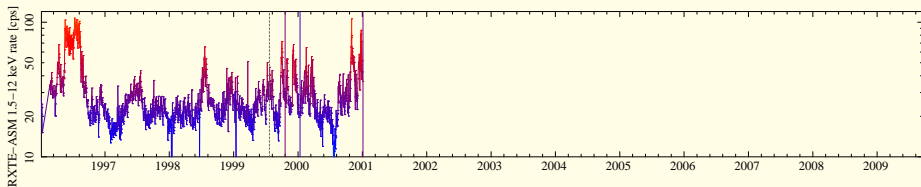
# HETGS observations of Cygnus X-1 during *Chandra's* First Decade



# HETGS observations of Cygnus X-1

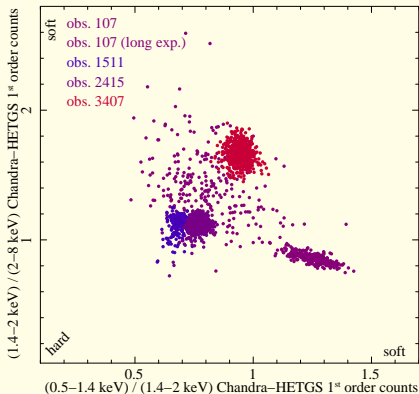
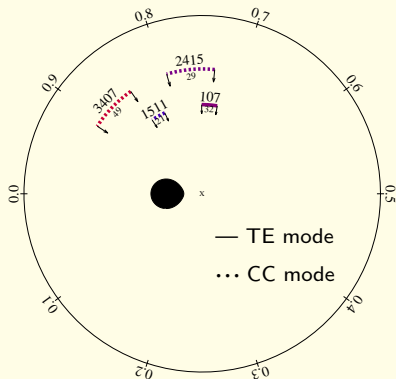
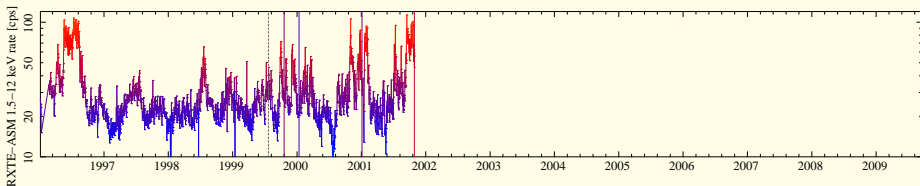


# HETGS observations of Cygnus X-1

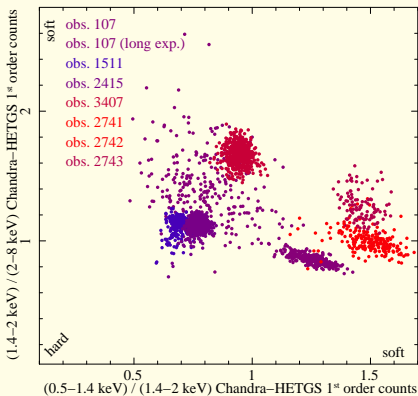
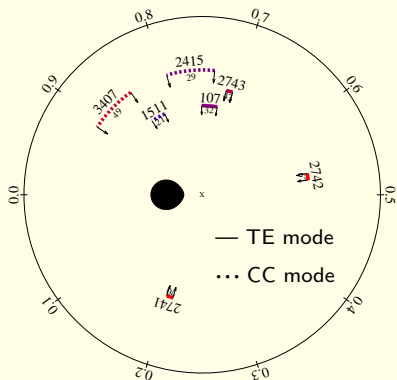
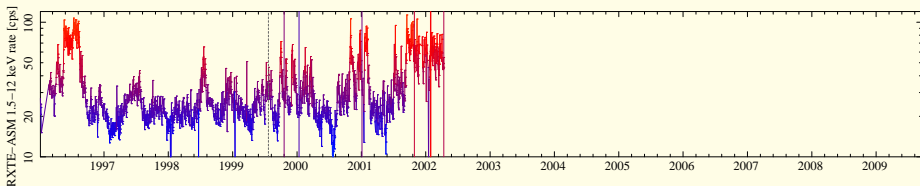




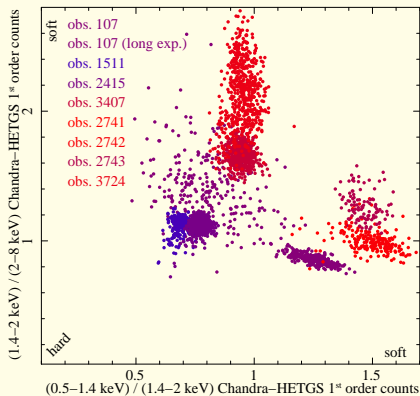
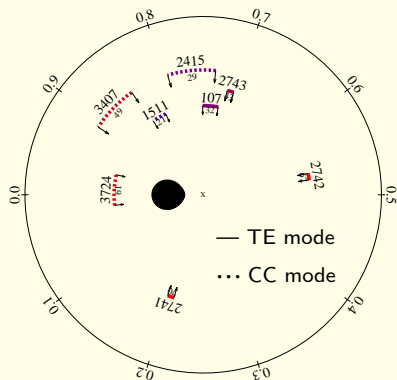
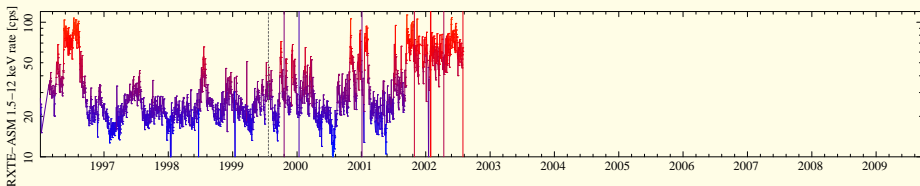
# HETGS observations of Cygnus X-1



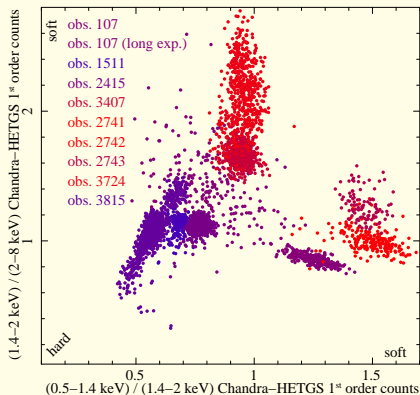
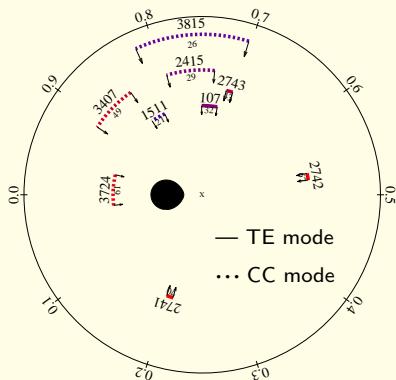
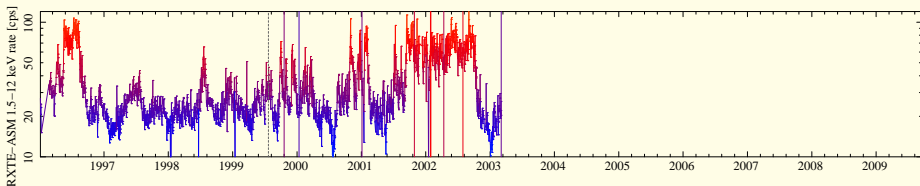
# HETGS observations of Cygnus X-1



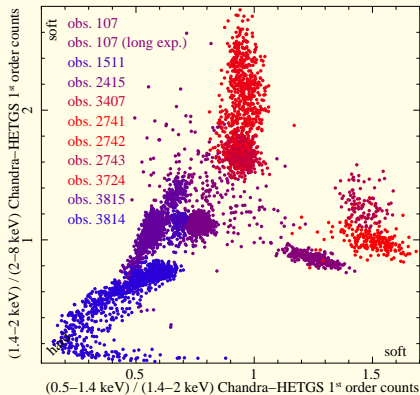
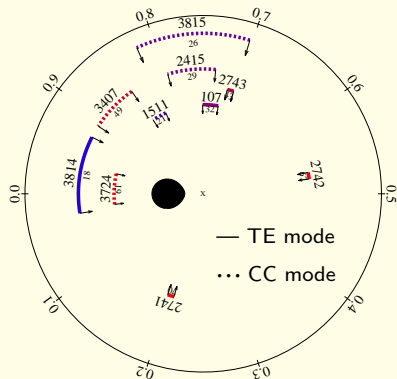
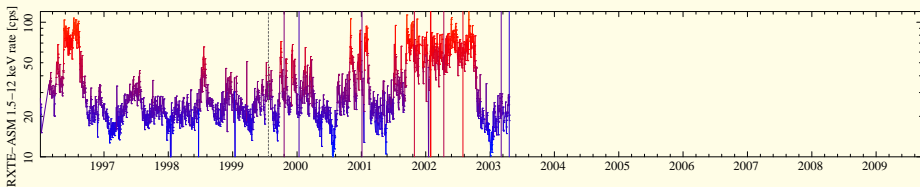
# HETGS observations of Cygnus X-1



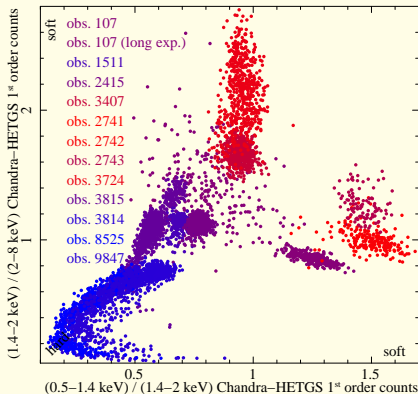
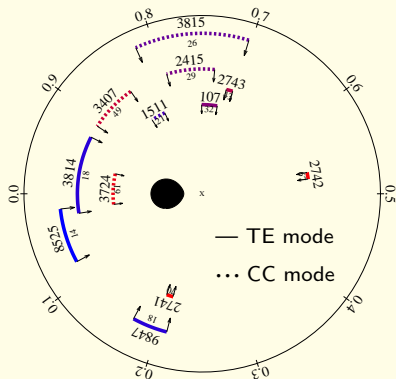
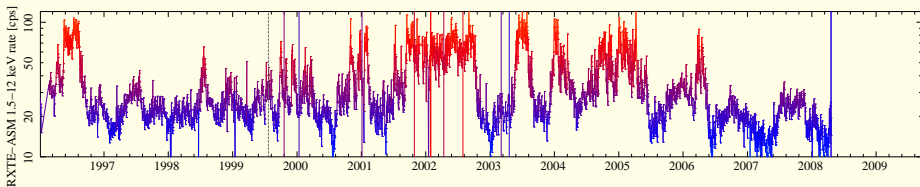
# HETGS observations of Cygnus X-1



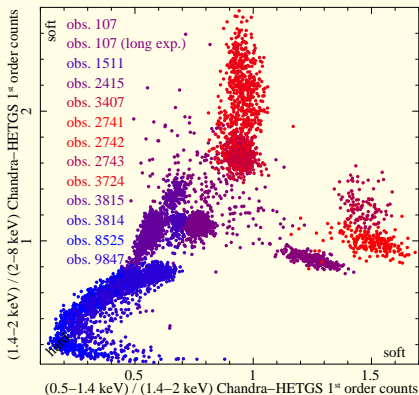
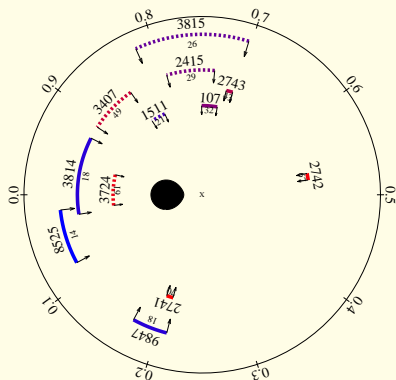
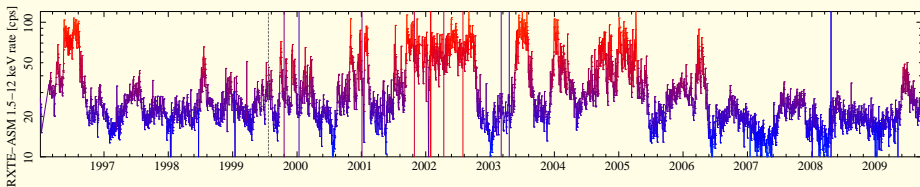
# HETGS observations of Cygnus X-1

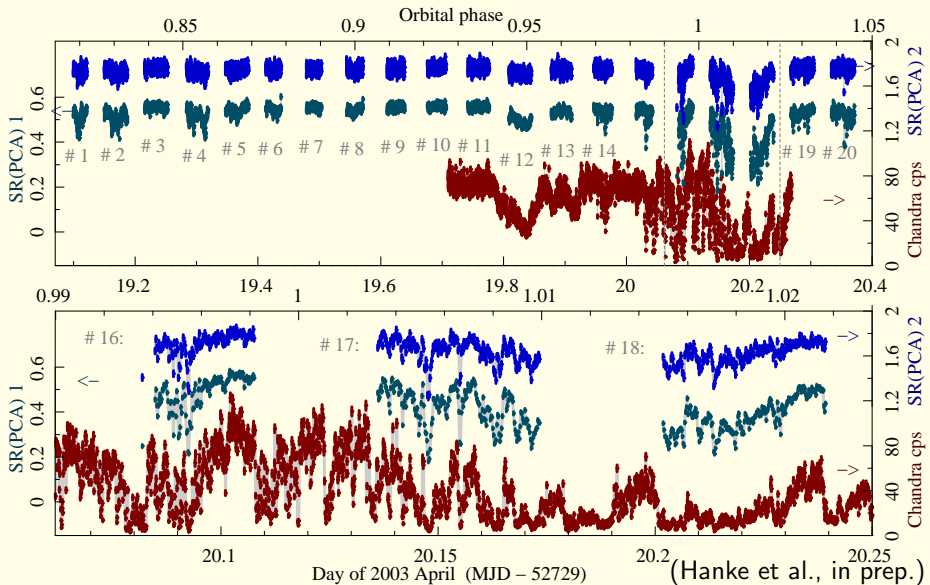


# HETGS observations of Cygnus X-1



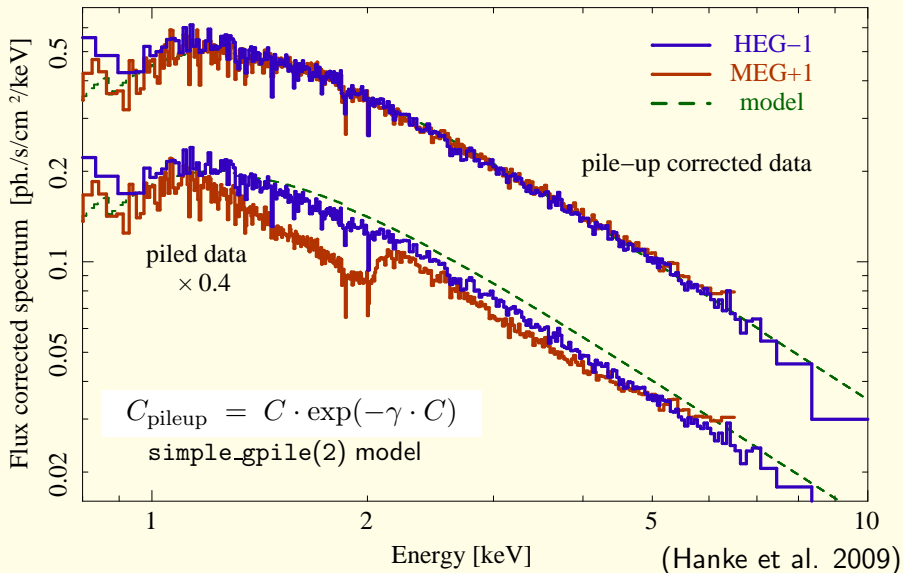
# HETGS observations of Cygnus X-1



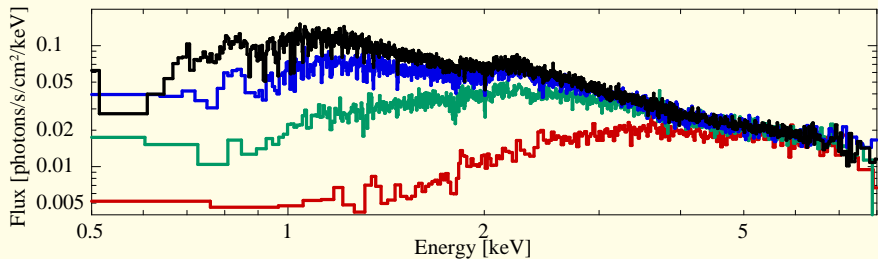
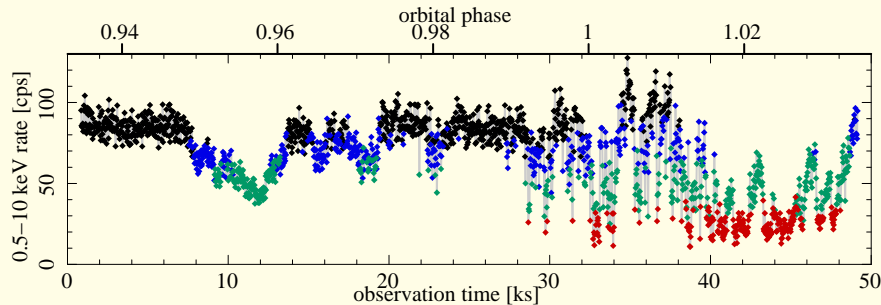
First *Chandra* obs. at  $\phi_{\text{orb}}=0$  in the hard state, simult. with *RXTE*



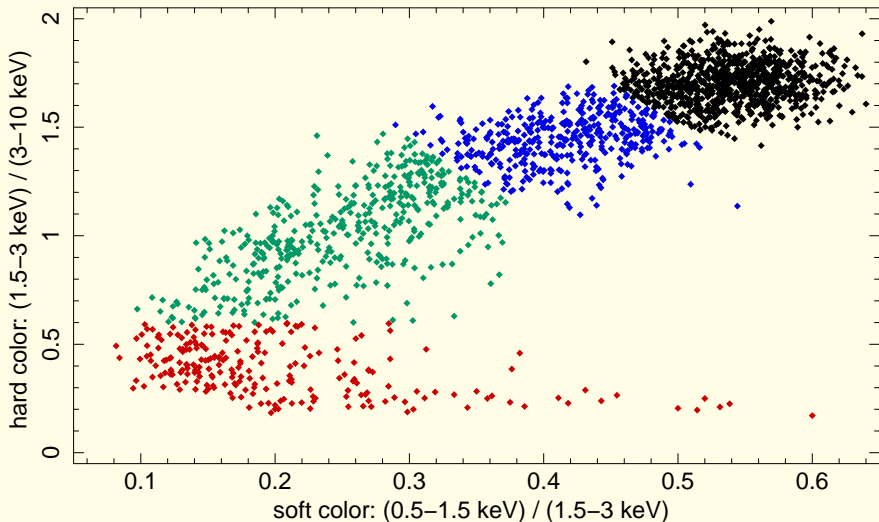
# HETGS (TE mode) observation of Cyg X-1 / hard state @ 0.25 Crab



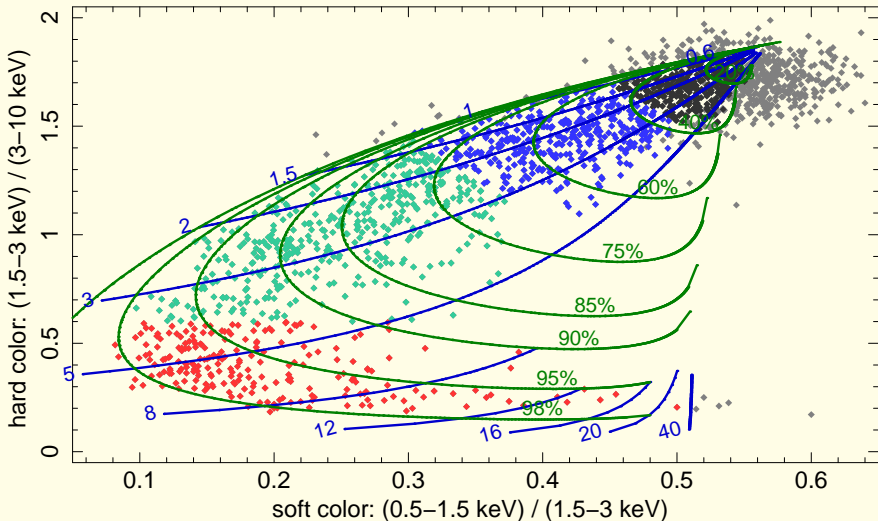
# Analysis of the absorption dips: the light curve and some spectra



## The dips in a color-color diagram

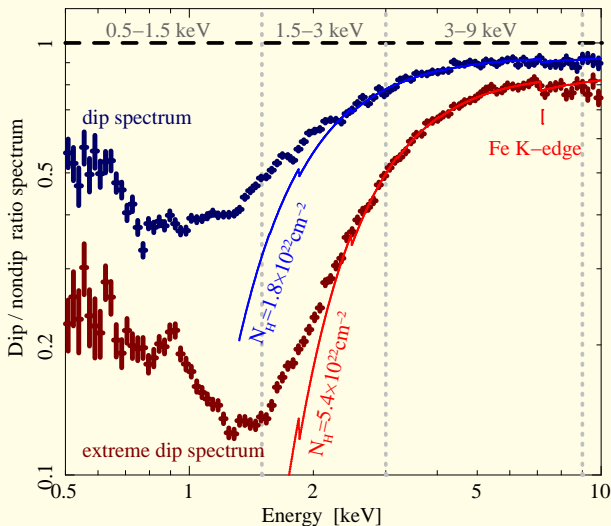
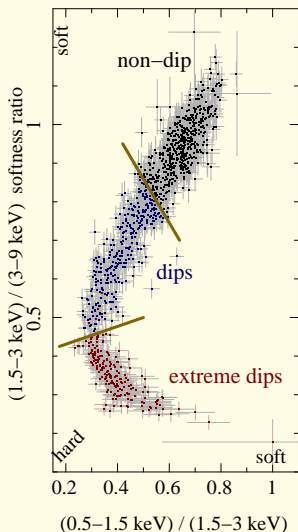


The dips in a color-color diagram require a partial covering model:  
 $(1 - f_c) \cdot \exp(-5.4 \cdot 10^{21} / \text{cm}^2 \cdot \sigma(E)) + f_c \cdot \exp(-N_{\text{H},2} \cdot \sigma(E))$

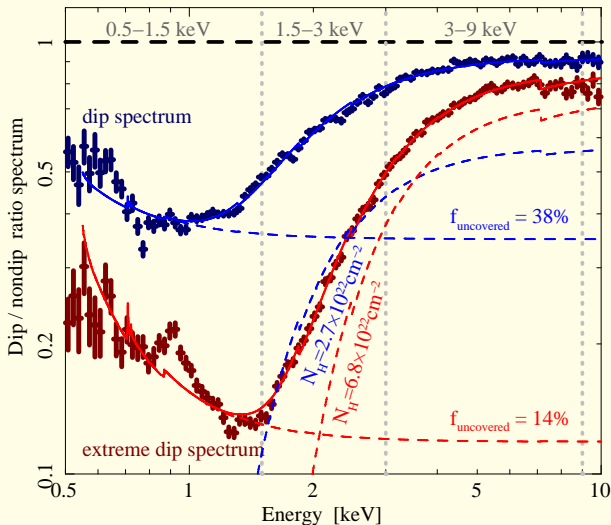
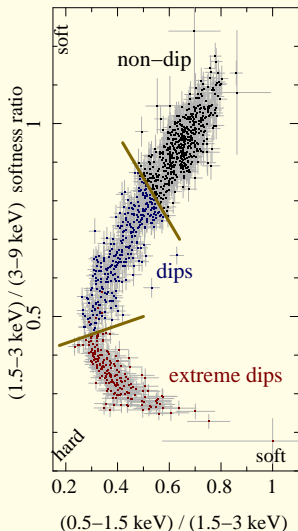


## Suzaku XIS:

## absorption AND electron scattering

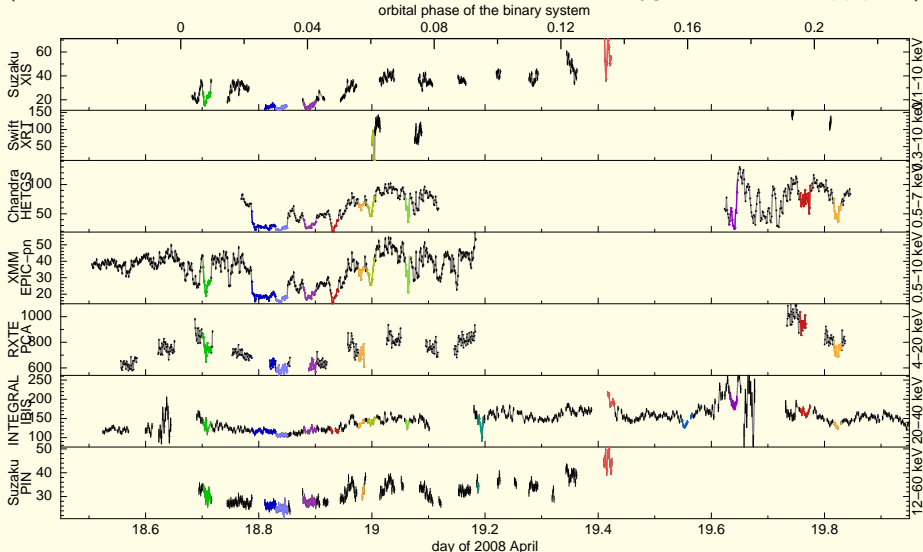


# Suzaku XIS: Partially covering absorption AND electron scattering

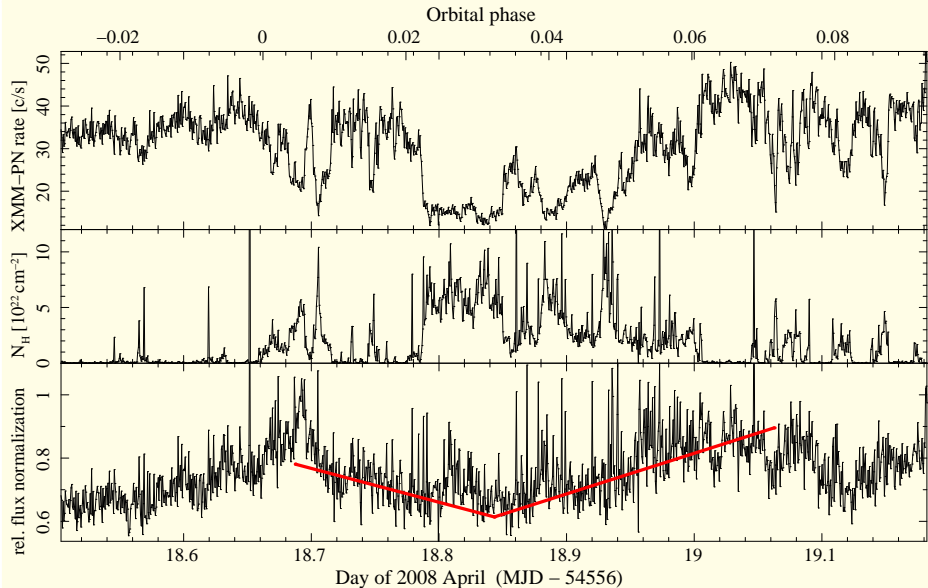


# The multi-satellite observation (*the monster campaign*) of 2008 April

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

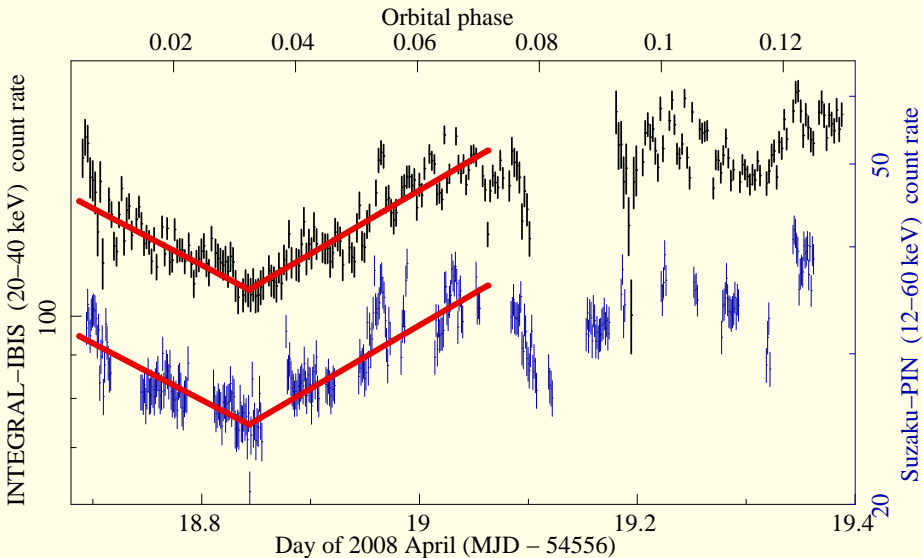


# XMM EPIC-pn: Time resolved absorption and electron scattering

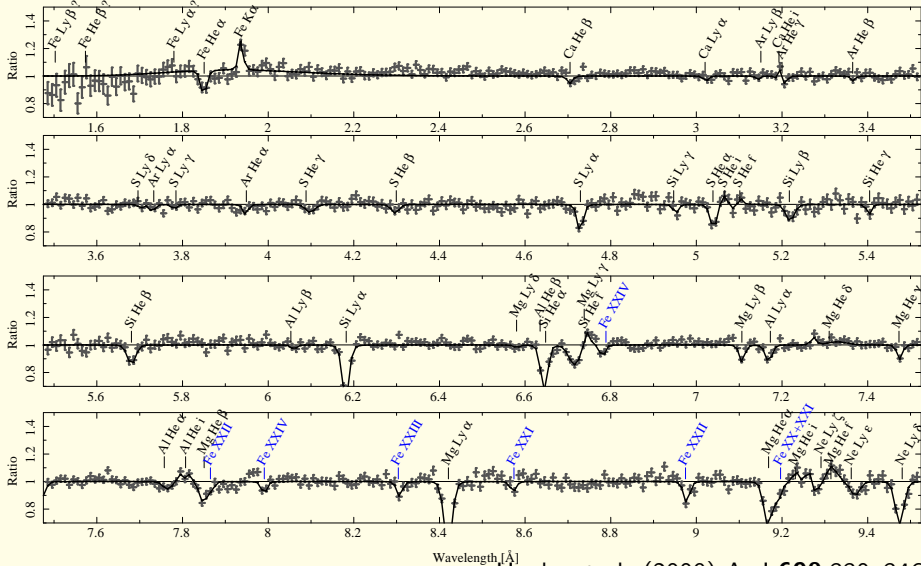




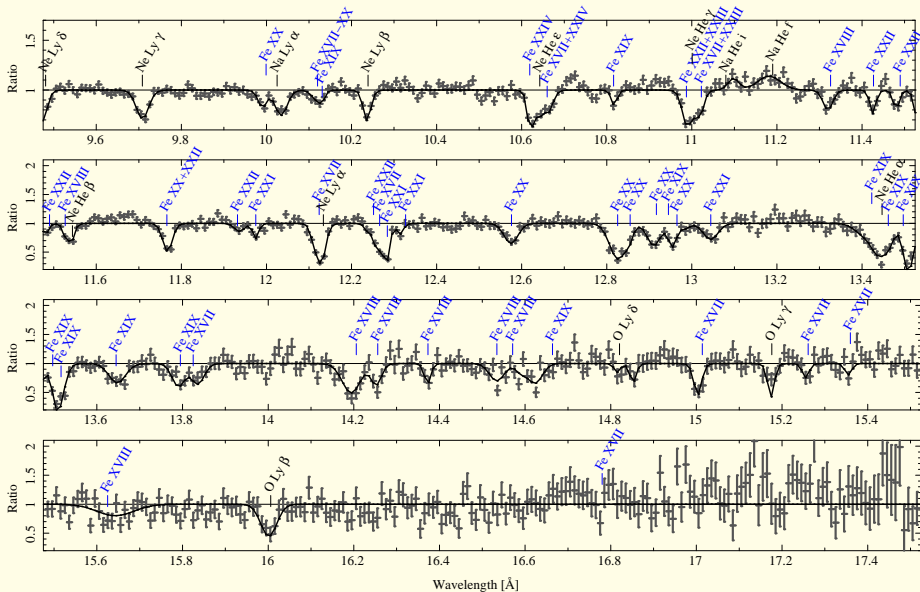
## Scattering of X-rays above 12 keV = beyond photoelectric absorption



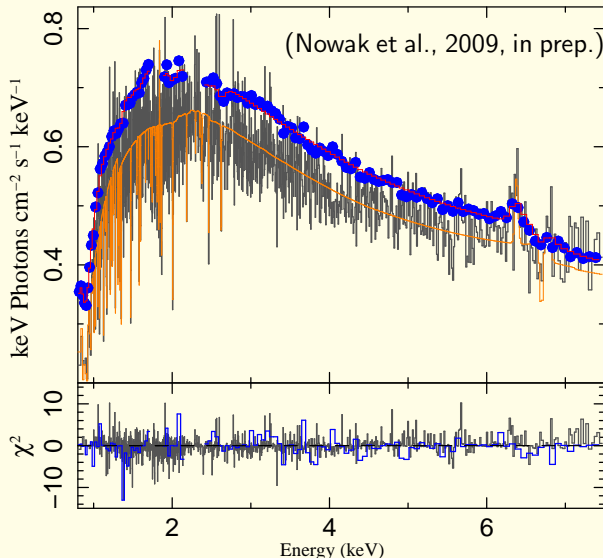
## Non-dip analysis: absorption lines from a highly photoionized wind

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.

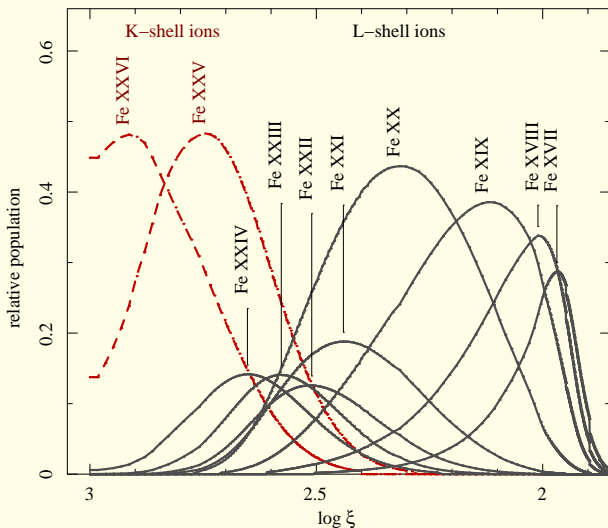
Ion column densities in  $10^{16} \text{ cm}^{-2}$ :

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

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  $N_{\text{H}} \gtrsim 10^{21-22} \text{ cm}^{-2}$
- → understanding the **photoionization structure of the wind**

## XSTAR simulation of the wind's photoionization structure



$$\xi = \frac{L}{n_{\text{H}} r^2}$$

$$= 100 \frac{\text{erg cm}}{\text{s}} \cdot \frac{L_{37}}{n_{11} r_{12}^2}$$

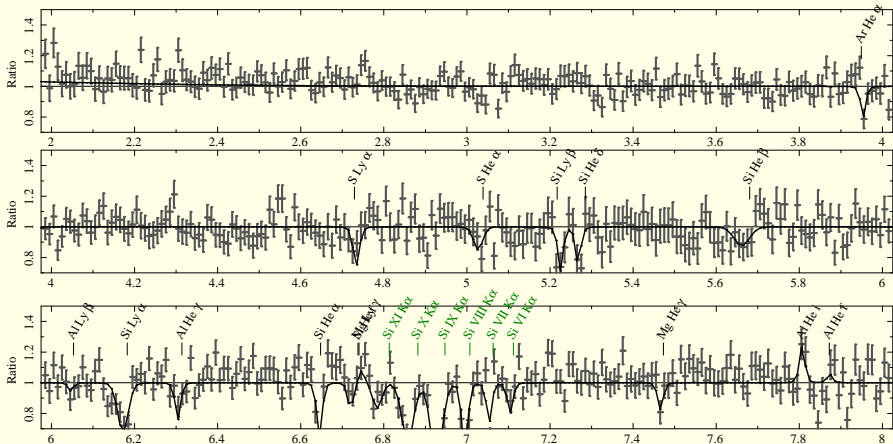
$$L \approx 3 \times 10^{37} \text{ erg s}^{-1}$$

$$n_{\text{H}} \approx 10^{11} \text{ cm}^{-3}$$

$$a = 2.9 \times 10^{12} \text{ cm}$$

(Hanke et al., 2009)

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



resonance K $\alpha$  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  $\phi_{\text{orb}} \approx 0$  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

