Feeding the monster: Wind accretion in Cygnus X-1

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Black Hole Universe

Friedrich-Alexander-Universität Erlangen-Nürnberg

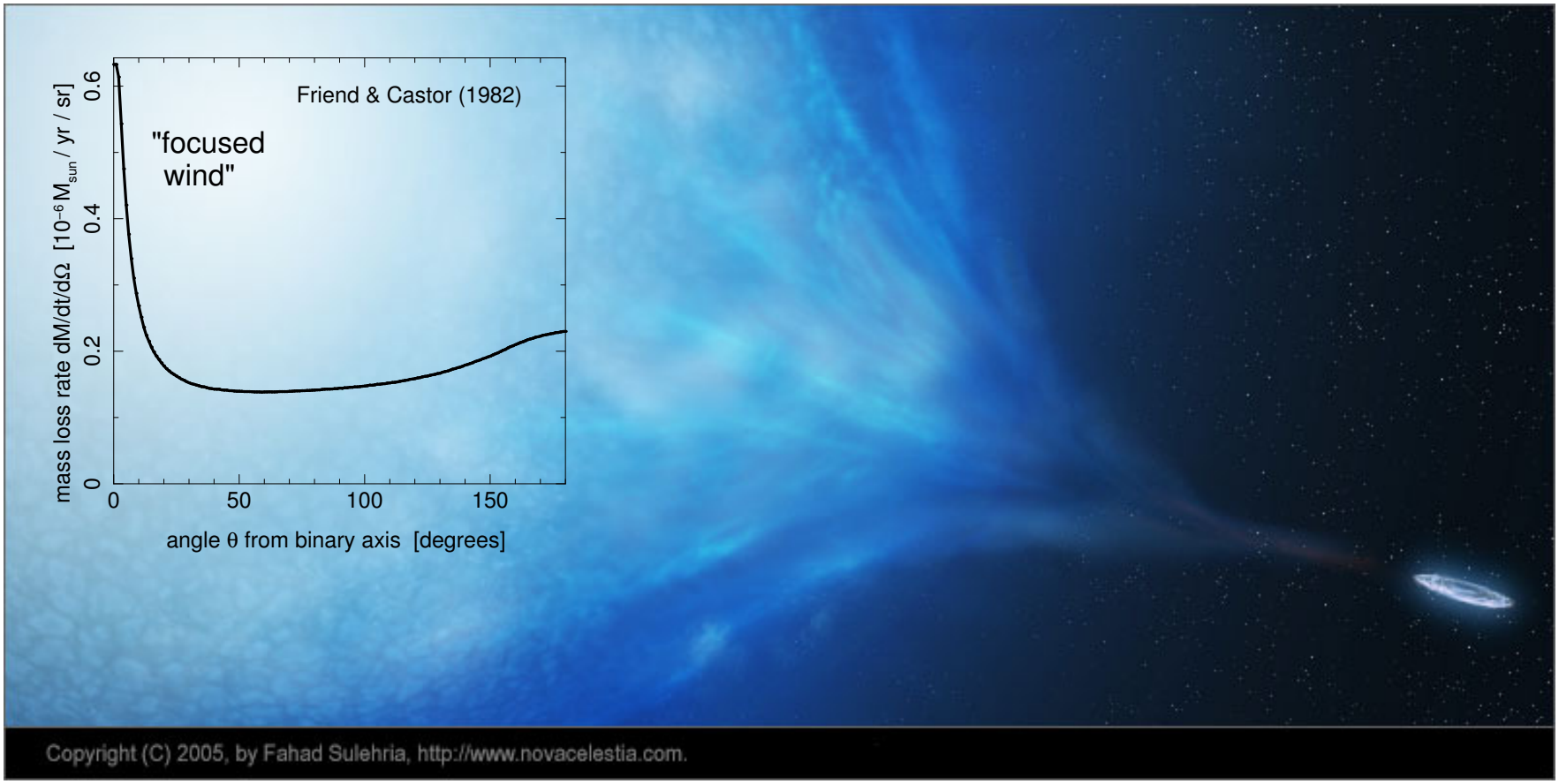
Stellar winds of O-stars

- line-driven wind (Castor, Abbot & Klein 1975)
- hot, early type (O- or B-) stars, strongly radiating in UV (like HMXBs)
  $\Rightarrow$ Cygnus X-1
- very strong: mass loss rate $\sim 10^{-6} M_{\odot}/\mathrm{year}$

- perturbations are present (Feldmeier et al. 1997, Oskinova et al.)
- density, velocity & temperature variations $\Rightarrow$
- two components of the wind:
  cool dense clumps embedded by hot photoionized gas
  (Castor, Abbot & Klein 1975; Sako et al. 2002)

- Cyg X-1 $\Rightarrow$ focused wind (Friend & Castor 1982)

Focused stellar wind in the system



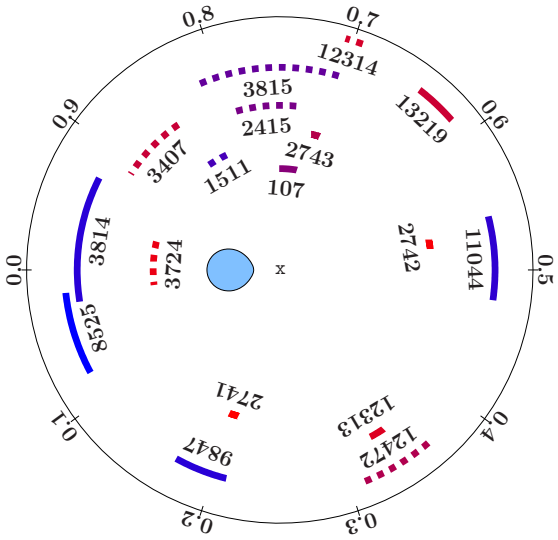
Aim:

- Better understanding of the structure and dynamics of stellar winds.

Here:

- Observations providing support for clumpy wind models.
- Modulations of the wind with orbital phase.

Chandra's view of Cygnus X-1: Orbital coverage



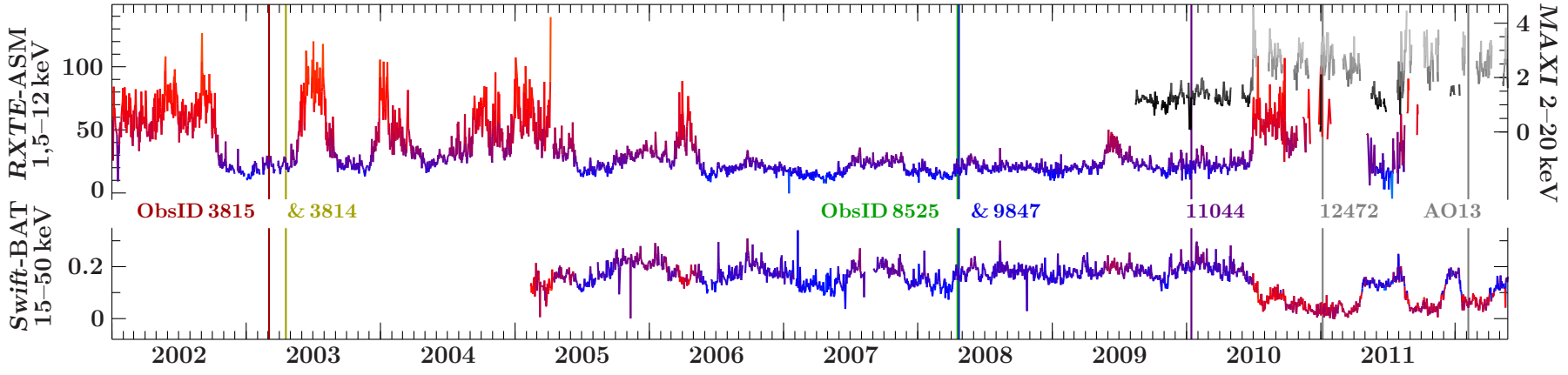
Good orbital coverage in the hard state of the source is essential.

– all observations up to end of 2011

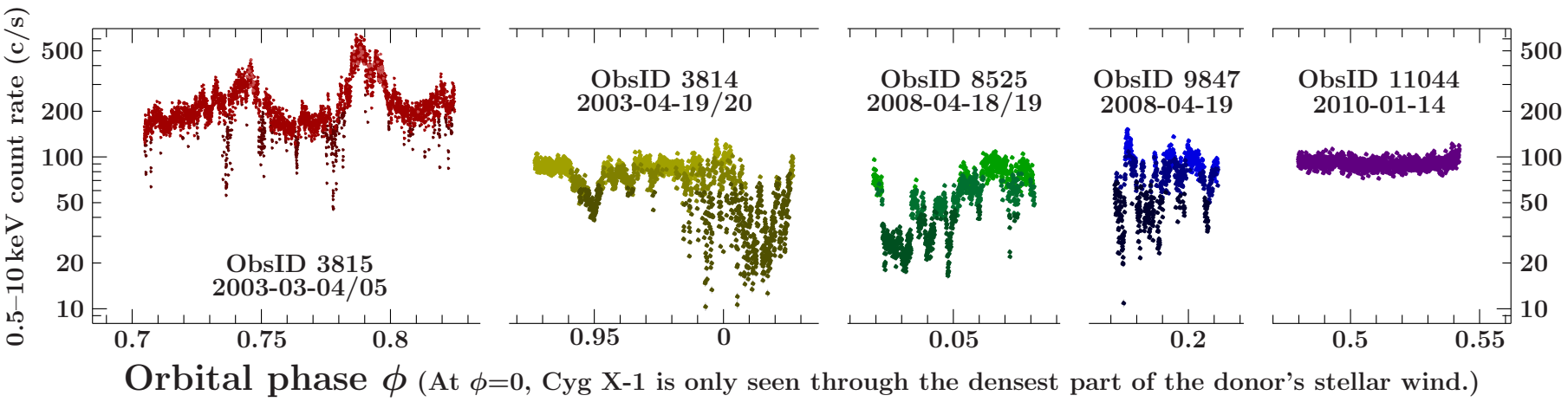
— TE mode, ••• CC mode

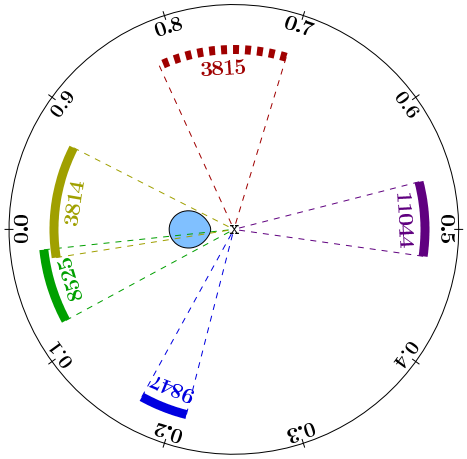
hard → soft state

Chandra's view of Cygnus X-1: Hard vs. soft state



Chandra light curves



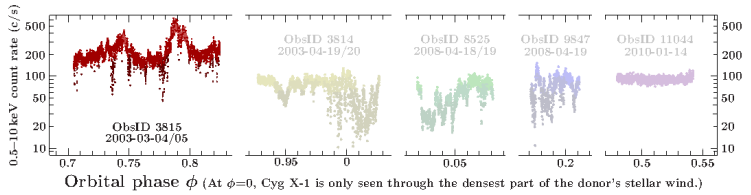


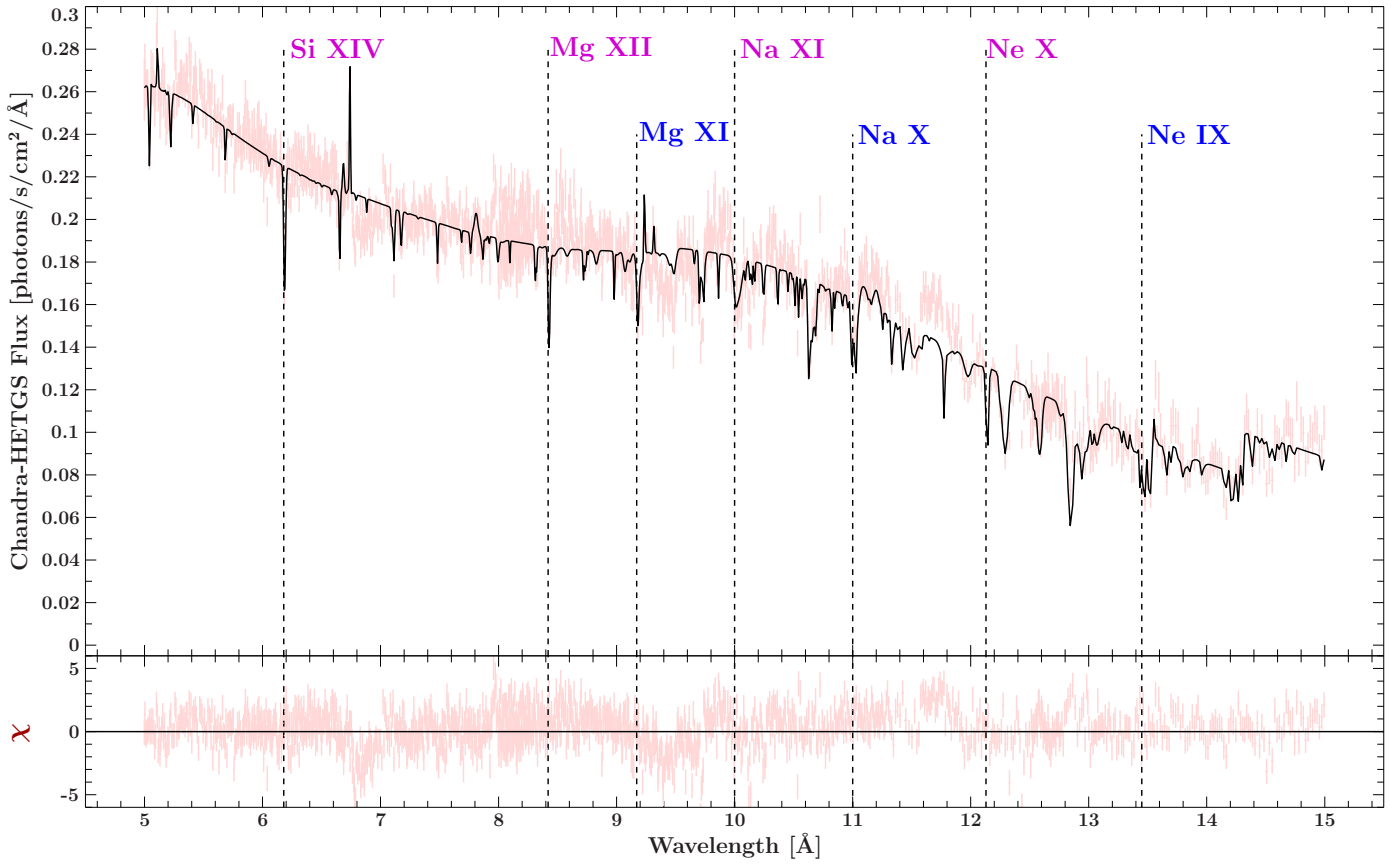
Stellar wind varies over orbital phase.

Dips caused by clumps in the wind are the strongest in the focused stream at $\phi \sim 0$ and $\phi \sim 0.05$, but not present on the other side at $\phi \sim 0.5$.

Non-dip and Dip Spectra:

$\phi \sim 0.75$ (ObsID 3815)

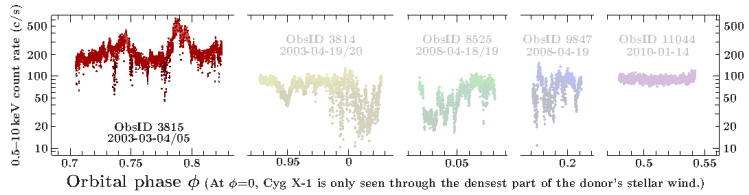


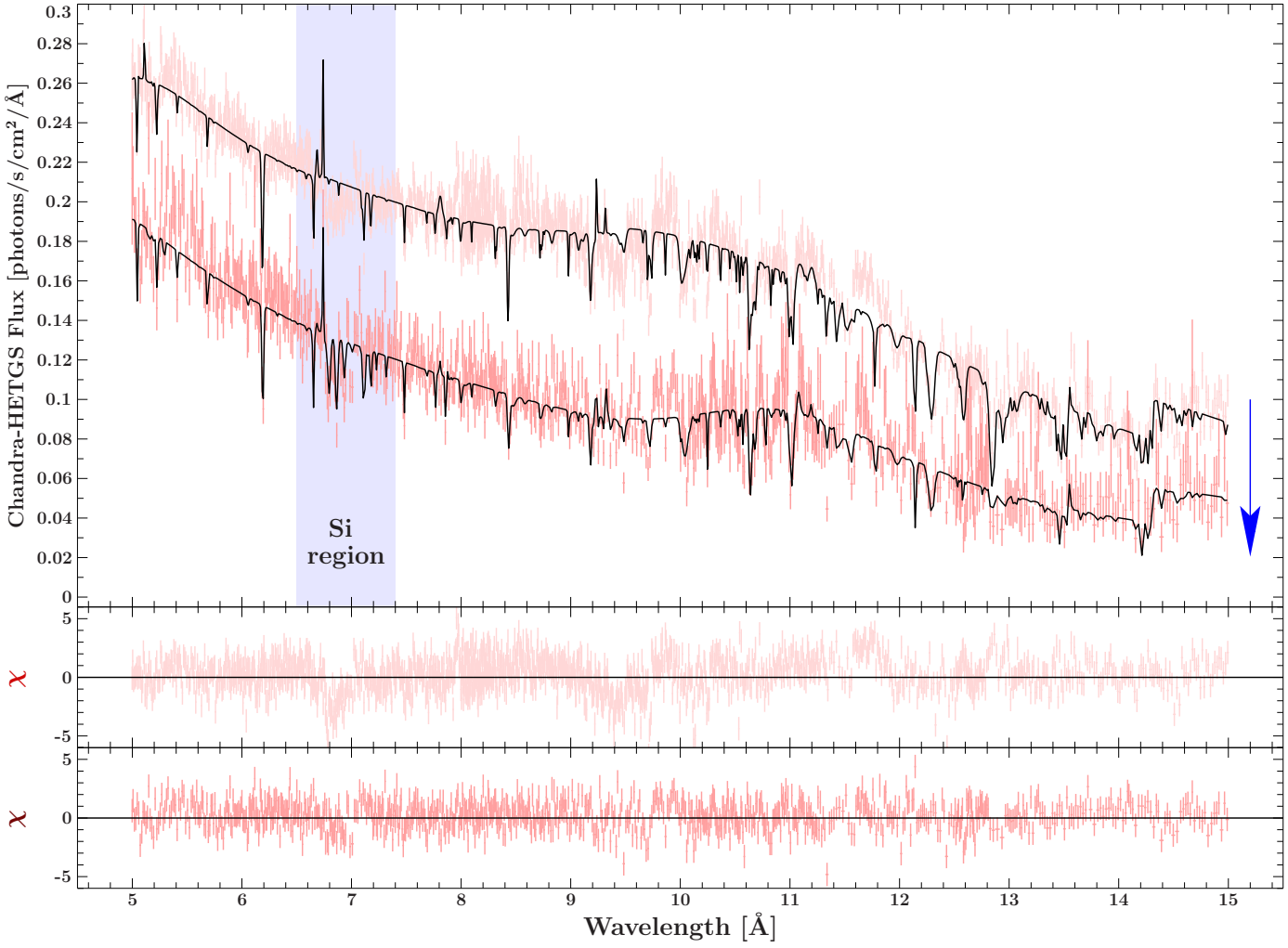


H-like, He-like and Fe absorption lines.

Non-dip and Dip Spectra:

$\phi \sim 0.75$ (ObsID 3815)



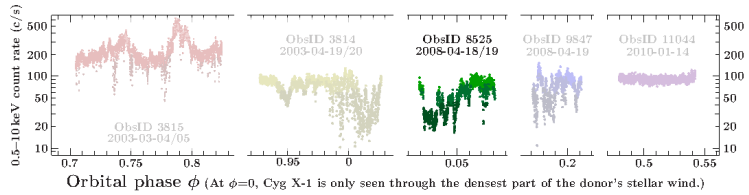


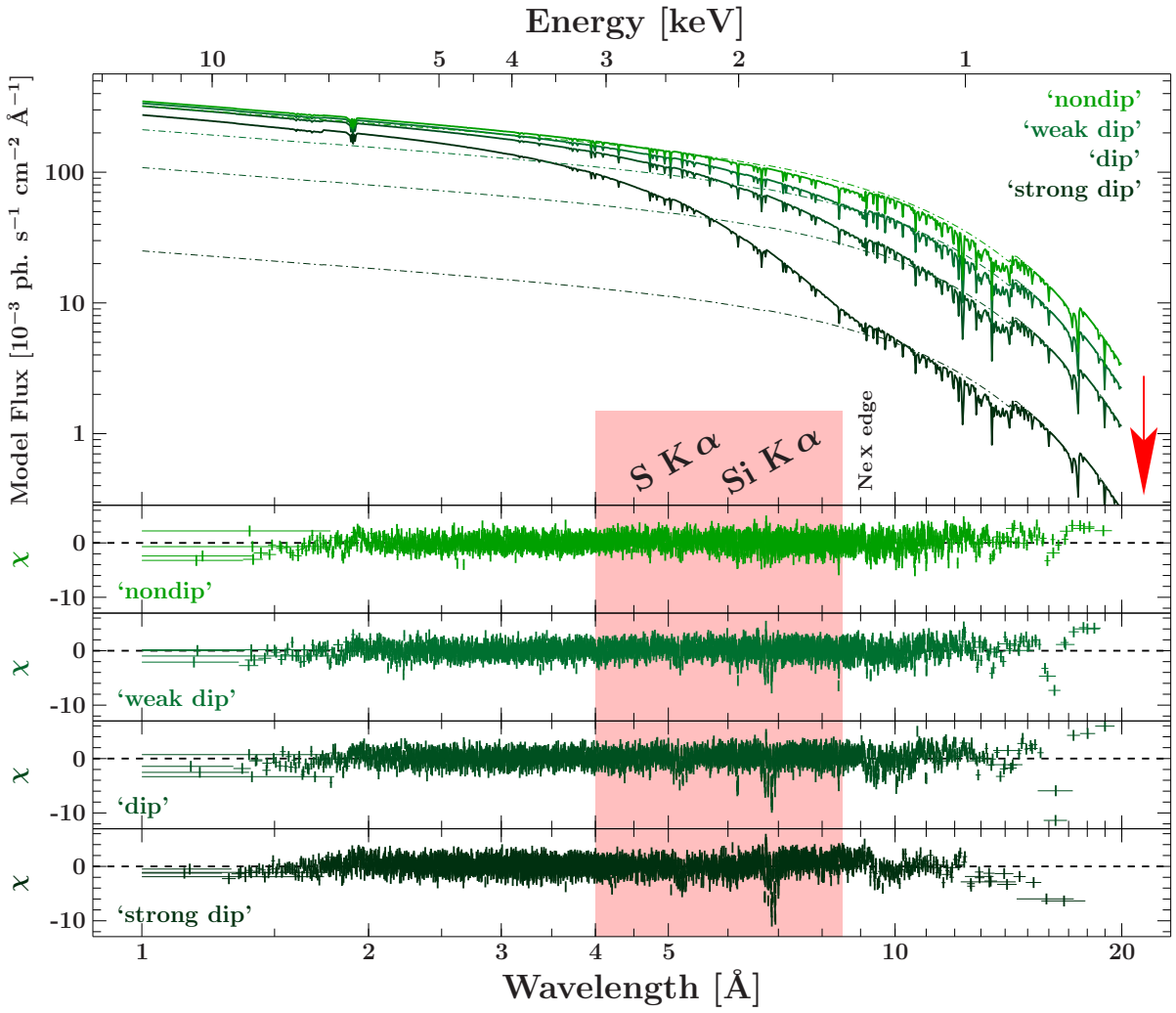
Real reduction in flux due to dips.

Dip spectrum: lower ionized Si abs. lines.

Non-dip and Dip Spectra:

$\phi \sim 0.05$ (ObsID 8525)





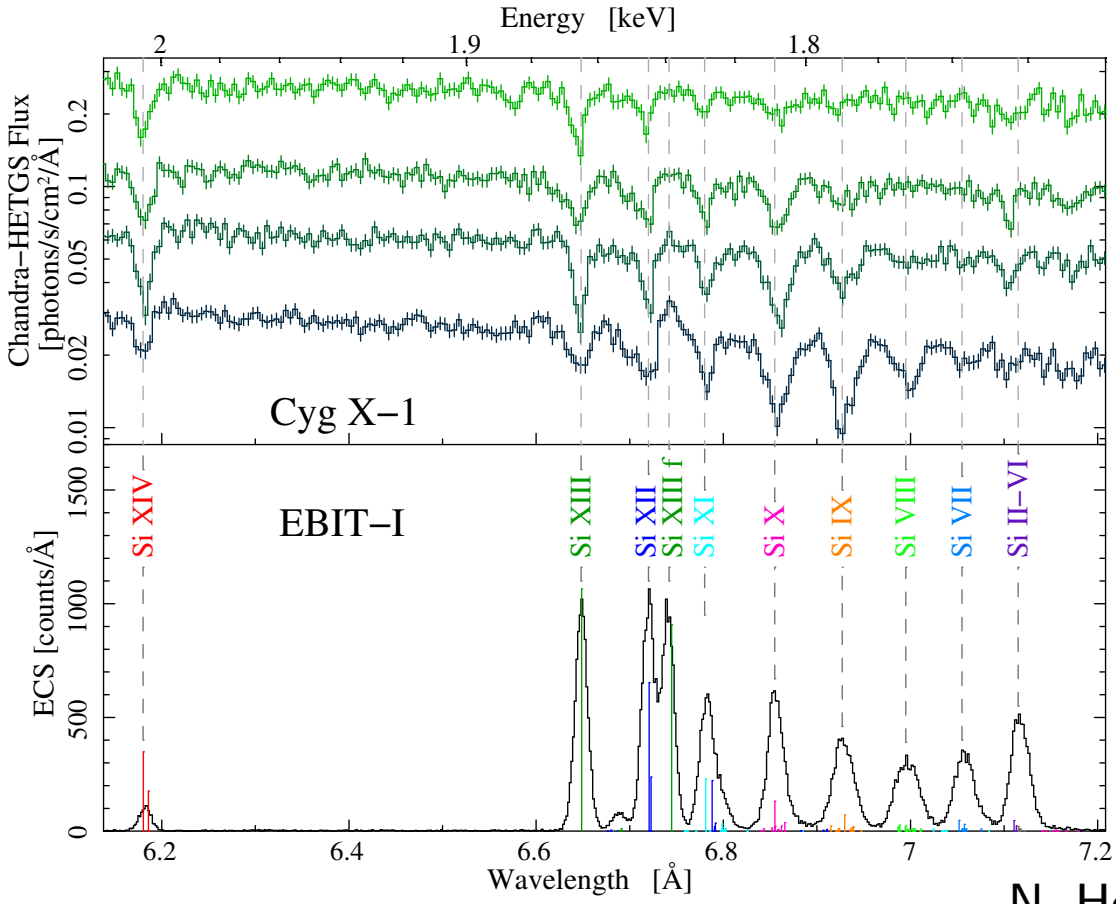
Spectrum with strongest dips.

Real reduction in flux due to dips.

Dip spectra: lower ionized Si and S abs. lines.

The strength of lines increases with the degree of dipping.

Si Region + Electron Beam Ion Trap (EBIT) measurements

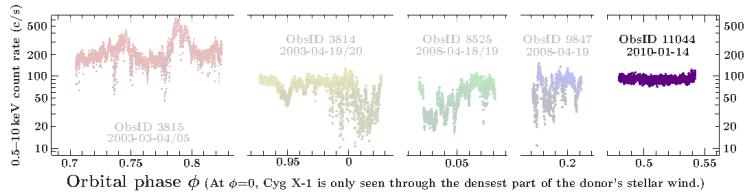


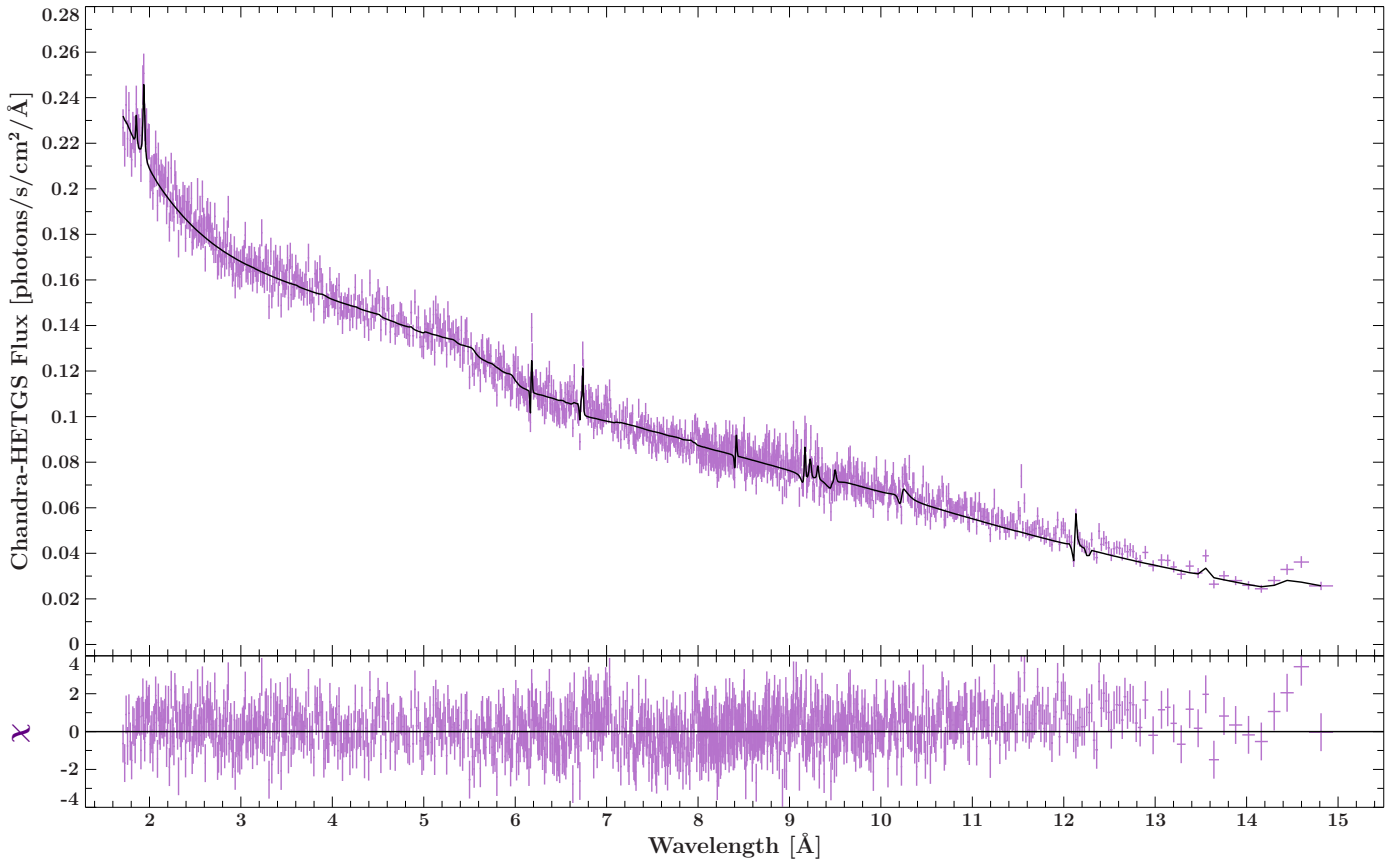
N. Hell, priv.com.

Doppler shifts are consistent with zero velocity ⇒ matter close to BH.
Doppler shifts are consistent for all lines in all dipping stages
⇒ material from clumps.

Non-dip and Dip Spectra:

$\phi \sim 0.5$ (ObsID 11044)





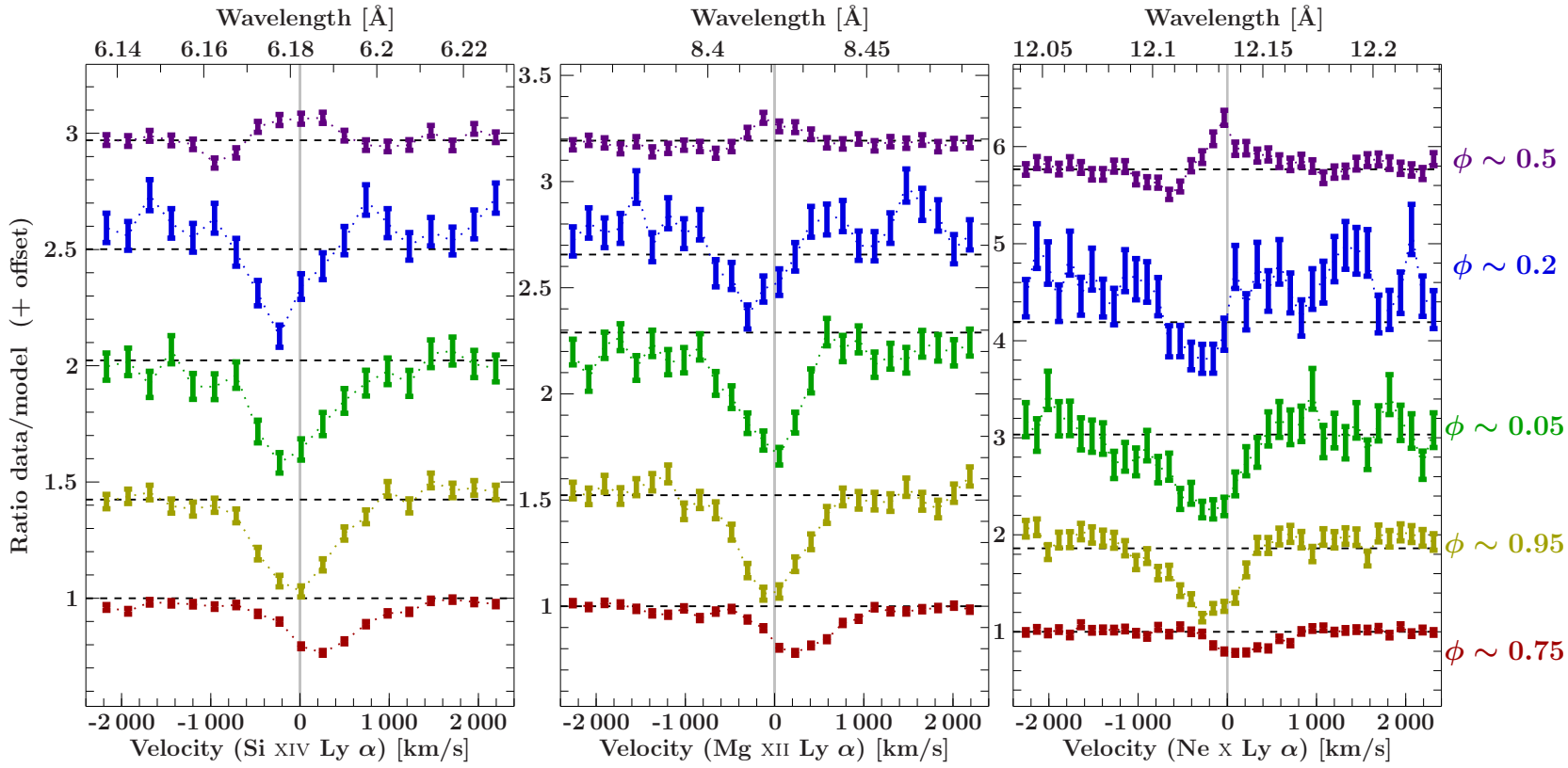
Undisturbed 30 ks non-dip spectrum.

Only a few strongest lines.

P-Cygni profiles.

Profiles of chosen lines: Si XIV, Mg XII, Ne X

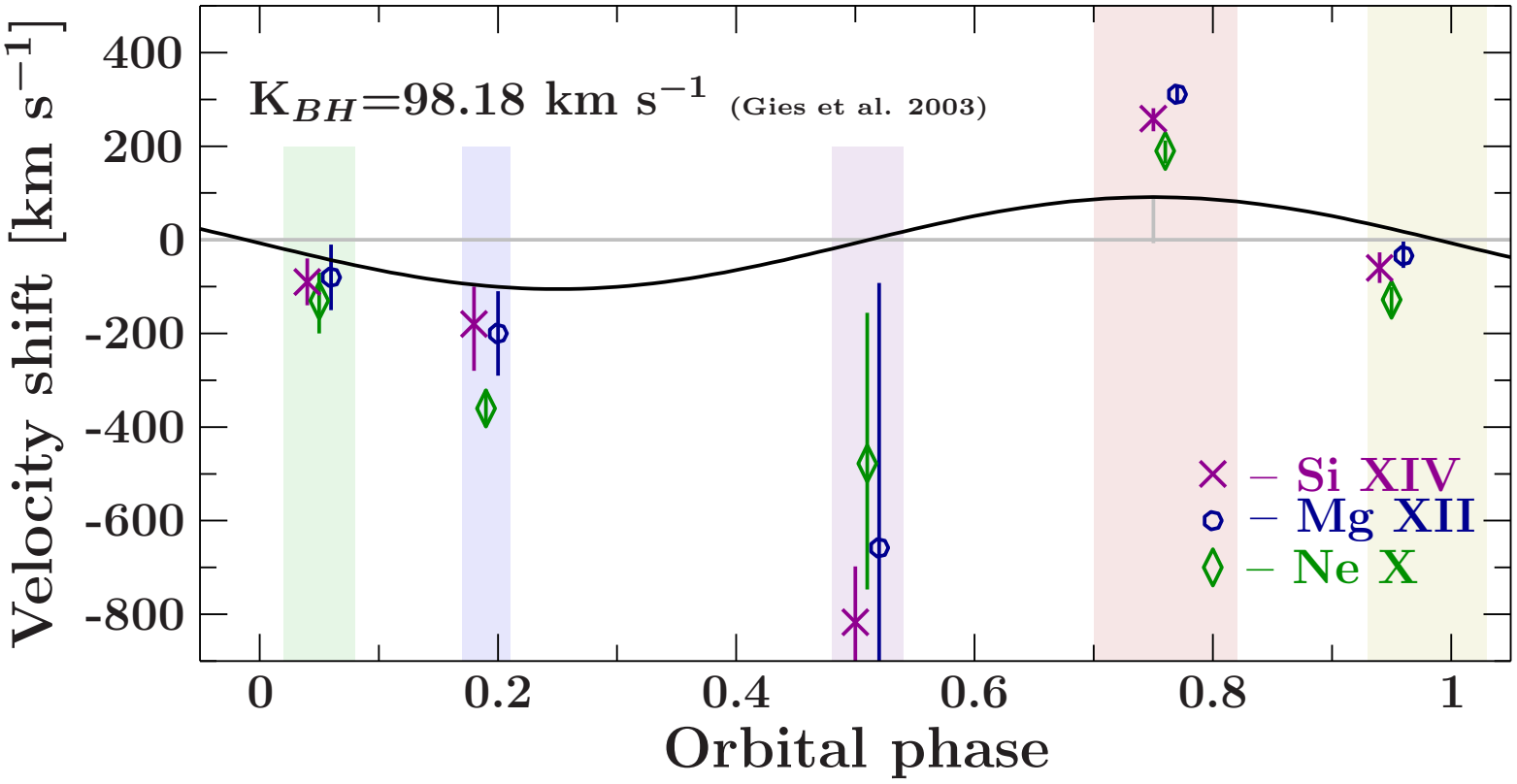
(– non-dip spectrum)



From P-Cygni at $\phi \approx 0.5$, through strong absorption of low blueshift at $\phi \approx 0 - 0.2$, to redshifted absorption at $\phi \approx 0.75$.

Modulation of Velocity Shift over Orbital Phase

(– non-dip spectrum, chosen lines)

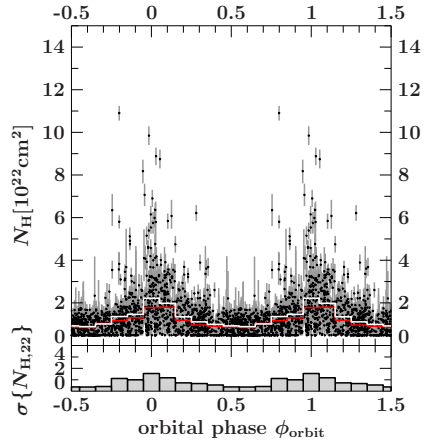


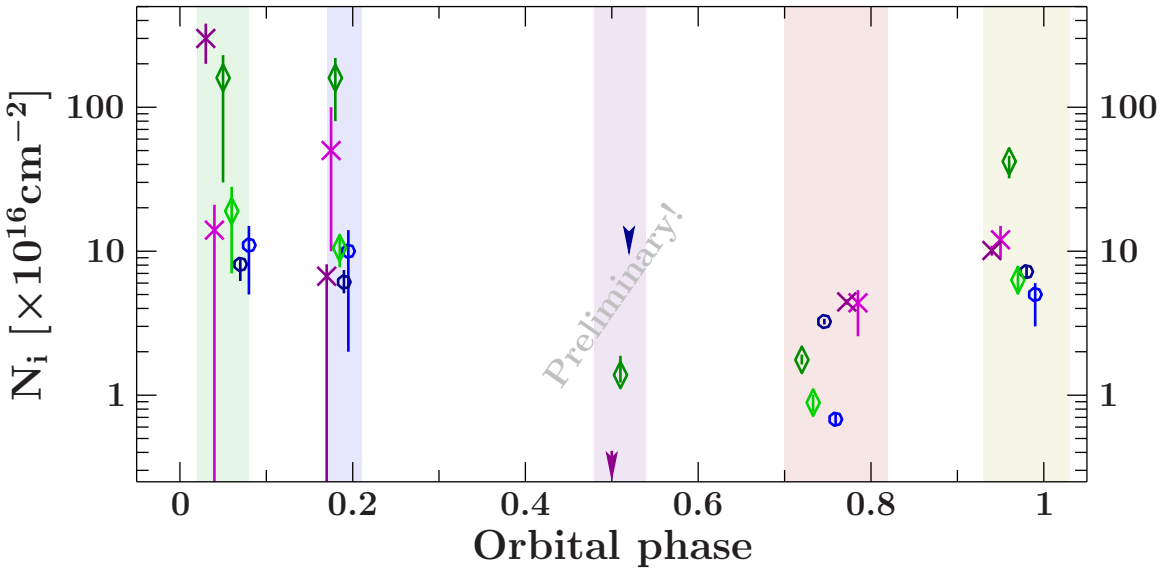
Velocity shifts follow the trend of the radial velocity of the BH. ⇒ Lines originating from infall onto BH.

Modulation of Column Densities over the Orbital Phase

(– non-dip spectrum, chosen lines)

Grinberg et al. 2012: (in prep.)





Variation of column densities of individual elements corresponds to the observed N_H orbital variation in Cyg X-1.

Summary

Better understanding of the structure and dynamics of stellar winds:

- High-res spectra + bright source = ideal tool to study stellar wind
- Good orbital coverage = a complex structure and dynamics of a wind

Wind = cool dense clumps embedded by hot photoionized gas

- Non-dip spectra of persistent flux represents photoionized gas.
- Dips are caused by clumps.
- Si and S absorption lines of lower ionization stage have origin in colder medium then highly ionized lines.

Modulations of the wind with orbital phase:

- Lines originate from infall onto black hole.
- Column densities show similar trend as the N_H.