

# X-raying stellar winds in high mass X-ray binaries

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\* part of X-wind collaboration



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## High mass X-ray binaries:

Material flows from O/B star onto neutron star or black hole

- ▶ accretion and ejection processes
- ▶ bulk of radiation in X-ray range
- ▶ emission region:  $\sim 10\text{--}100 R_G$

winds influence the accretion rate and thus X-ray production

- ▶ flares
- ▶ long-term variability?
- ▶ superfast X-ray transients



radiation from close to BH/NS effectively X-rays the wind

- ▶ in situ probes close to stellar surface
- ▶ different parts of the wind at different orbital phases

# Winds of O/B stars

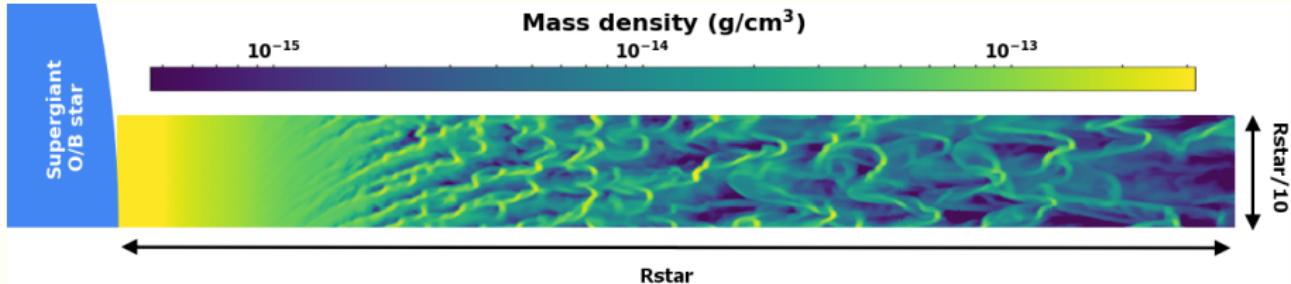


LH 72 in LMC; ESA/Hubble, NASA and  
D. A. Gouliermis

- line-driven (scattering of the star's UV radiation; CAK-winds after Castor, Abbott & Klein, 1975)
- mass loss:  
 $10^{-7}\text{--}10^{-4} M_{\odot}/\text{yr}$ 
  - ⇒ trigger/inhibit star formation
  - ⇒ chemical evolution of galaxies through enrichment
  - ⇒ impact the evolution of the star itself

BUT: uncertainties in mass loss estimates

# Clumpy winds

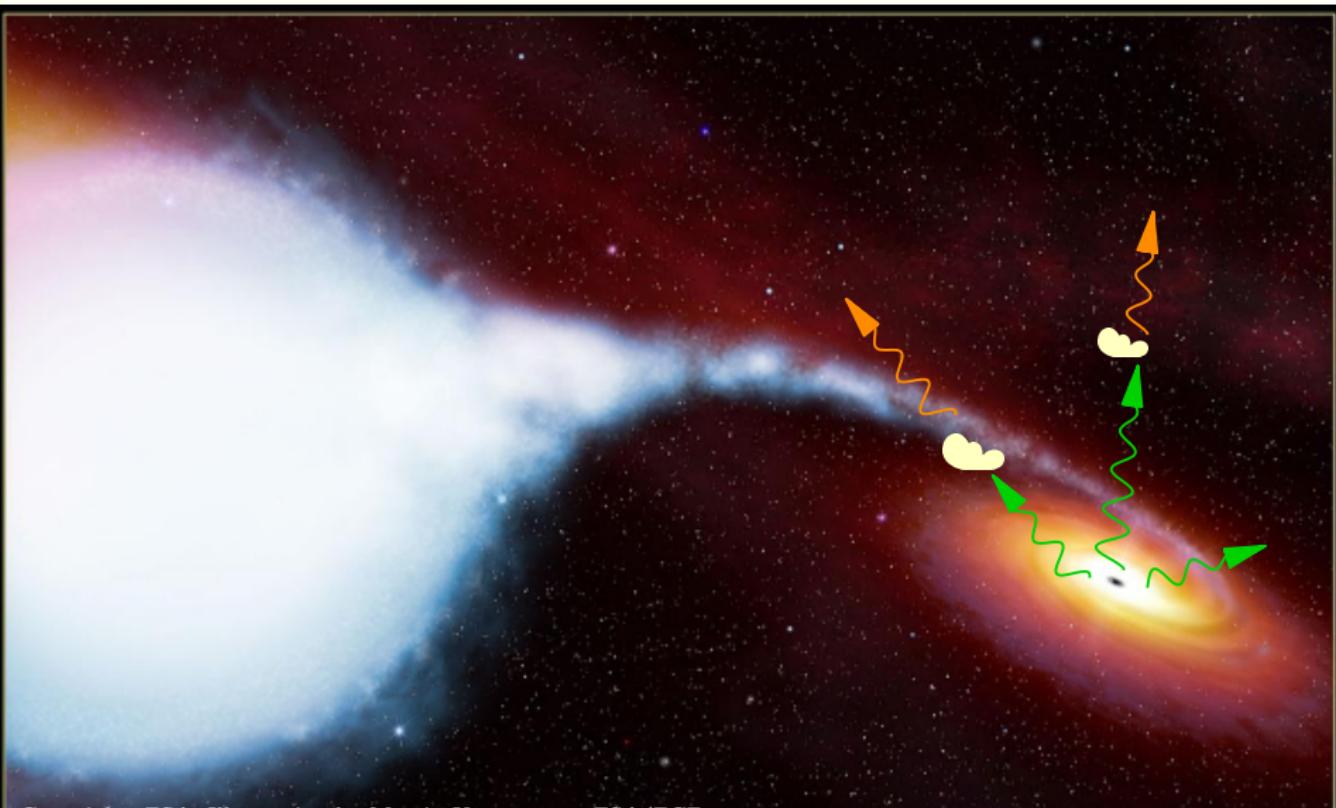


*El Mellah et al. 2018, after Sundqvist et al. 2017*

- line-driven winds **unstable to velocity perturbations**
- ⇒ perturbations grow rapidly
  - ⇒ strong shocks
  - ⇒ formation of dense gas-shells
  - ⇒ **wind clumping**

Multiple observational lines of evidence for clumping from single stars  
**BUT:** no way to probe individual clumps, except in X-rays!

# HMXBs: Probing the clumpy structure



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# Basic concept

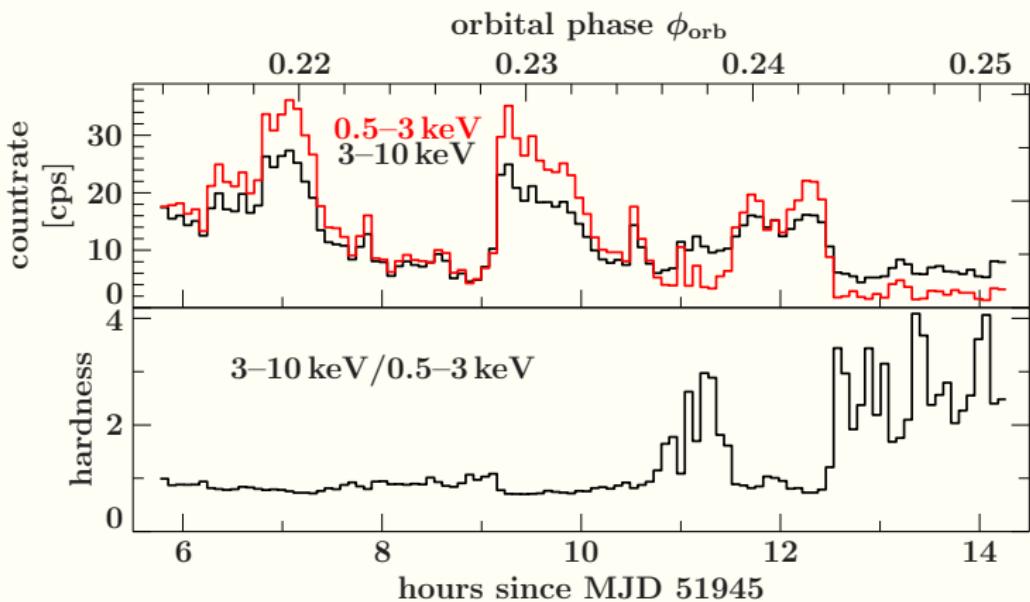
clumpy, disturbed winds & accretion streams imprint signatures onto continuum of compact object



- ▶ broadband absorption traces accretion structure
- ▶ emission & absorption lines trace plasma properties

⇒ time-resolved high-resolution X-ray spectroscopy  
⇒ absorption-resolved high-resolution X-ray spectroscopy

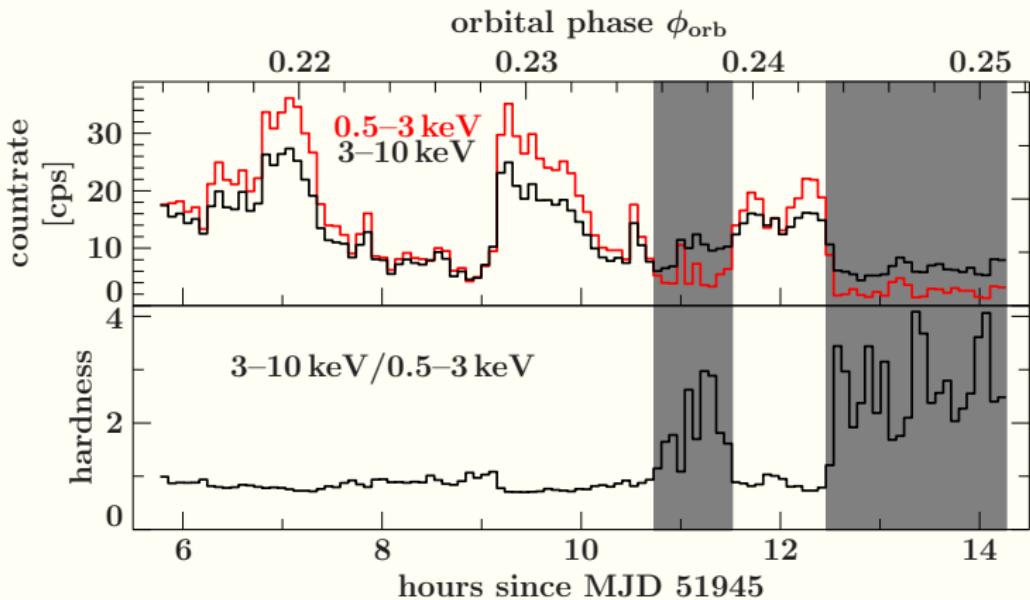
# Vela X-1: variable hardness



*Chandra*-HETG; ObsID 1928, Feb 11 2001

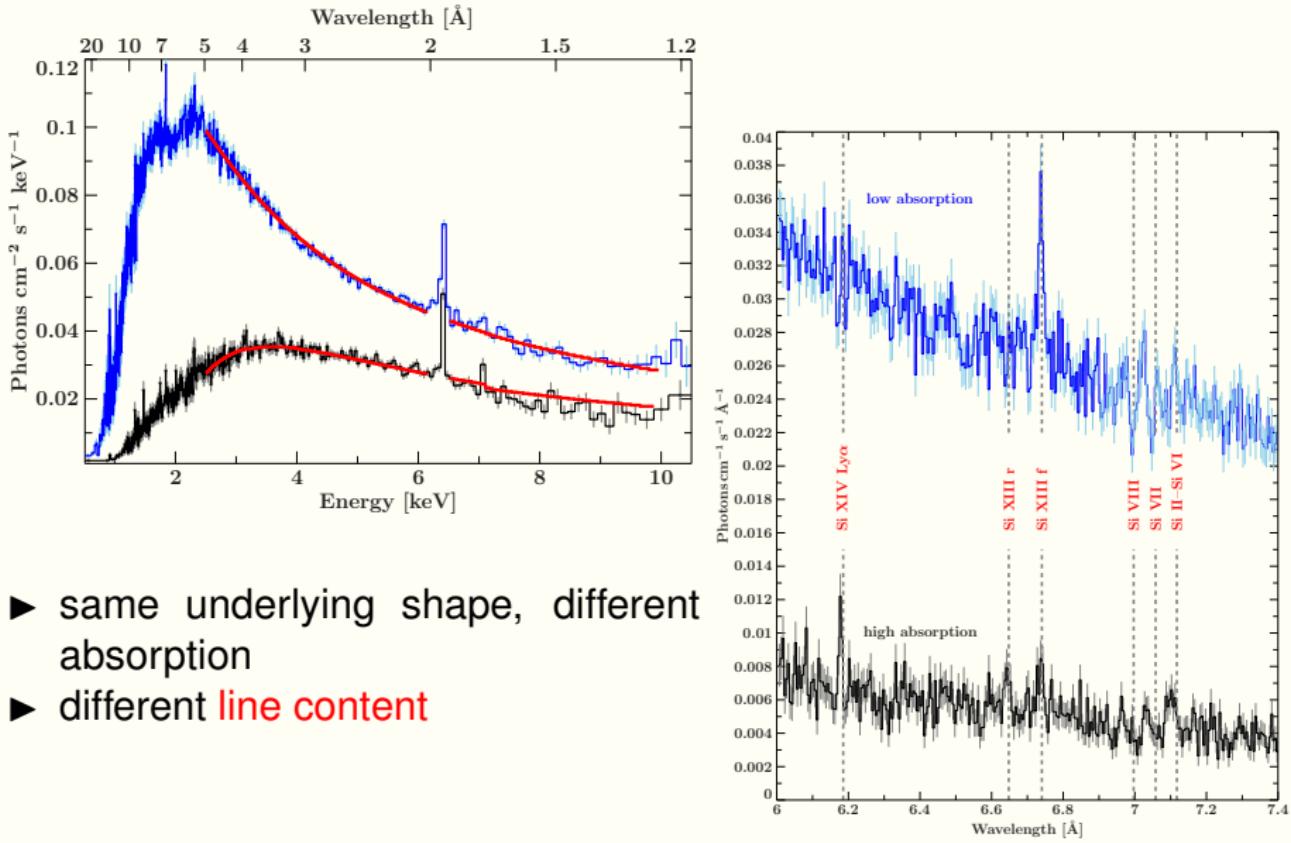
*Grinberg et al. 2017*

# Vela X-1: variable hardness



*Chandra*-HETG; ObsID 1928, Feb 11 2001  
⇒ clearly defined periods of enhanced hardness  
*Grinberg et al. 2017*

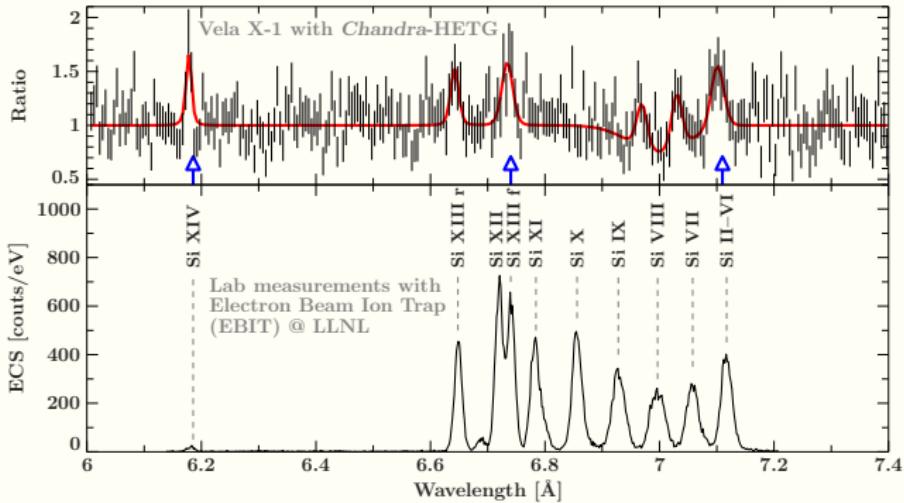
# Vela X-1: Hardness-resolved spectra



- ▶ same underlying shape, different absorption
- ▶ different **line content**

# Vela X-1: multiphase medium

- ▶ use newest lab reference values for line energies
- ▶ high and low ionization ions present  $\Rightarrow$  hot and cold gas present

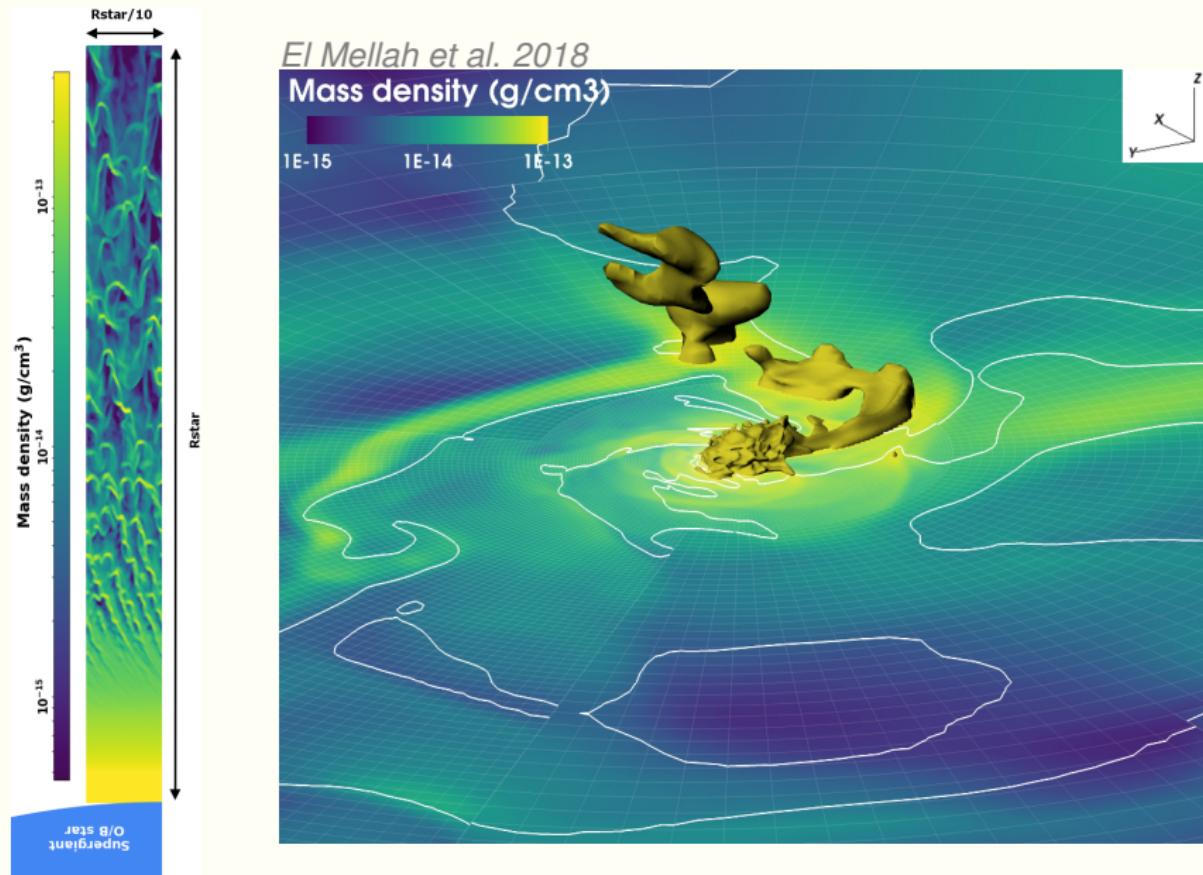


hints of different  
velocities?  
↳ data limited!

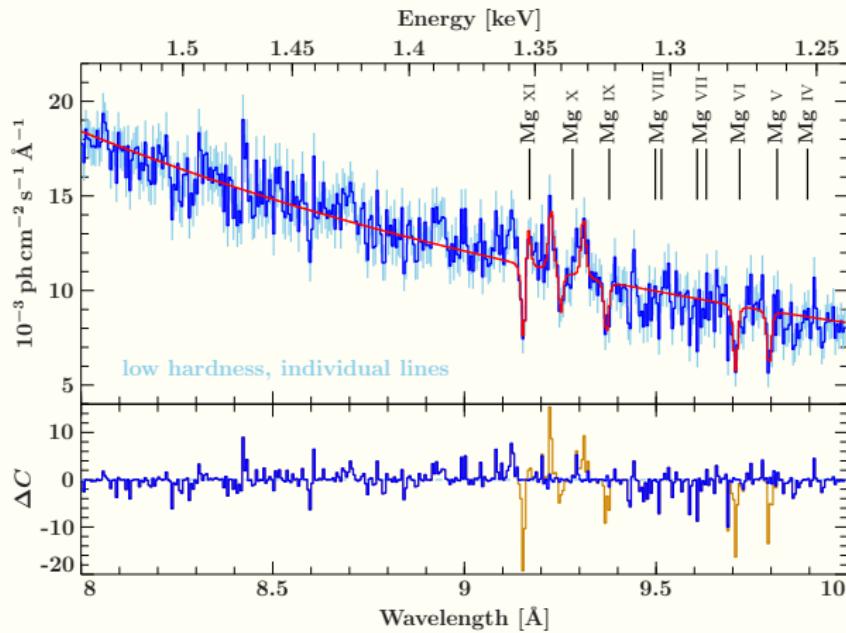
Si-region during dips;  
Grinberg et al. 2017

ionized part of the winds vs. reflection from clumps  
 $\Rightarrow$  shocks? clump interaction with compact object?

# Vela X-1: multiphase medium



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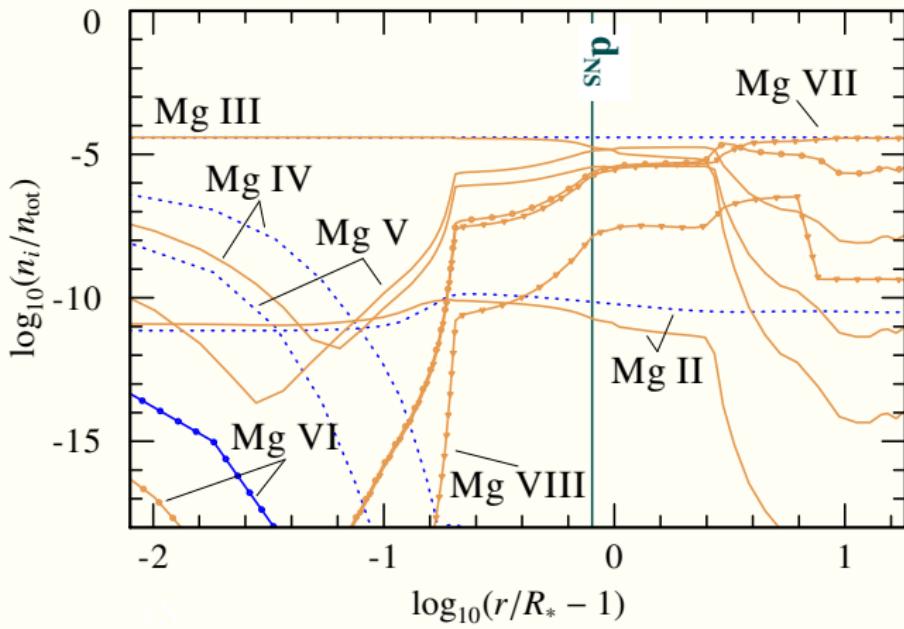


*Mg-region outside  
of dips; Grinberg+  
2017*

absorption lines  
detected:

- Mg XI, X, IX
- Mg VI, V

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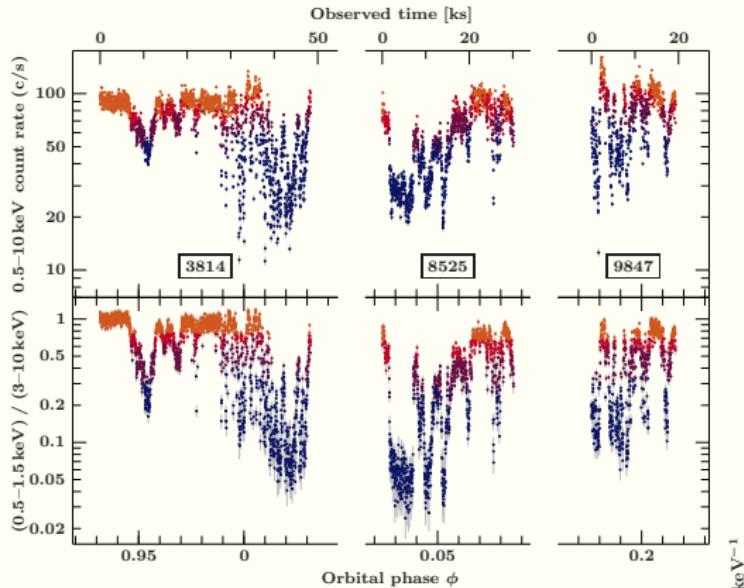
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newest stellar  
atmosphere  
models, includ-  
ing X-ray irradia-  
tion

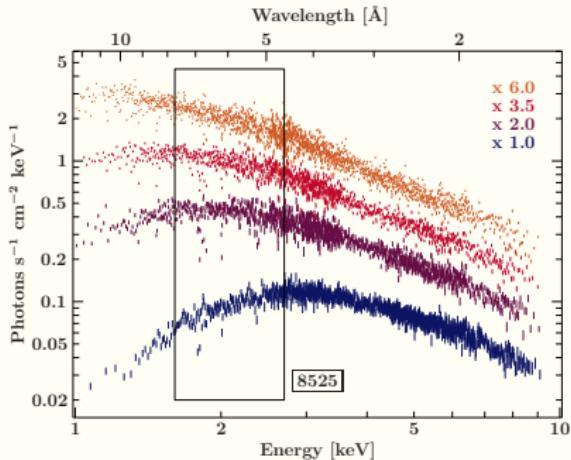
⇒ observed Mg-ions not present in high enough abundance in  
undisturbed wind

# Cygnus X-1: dips



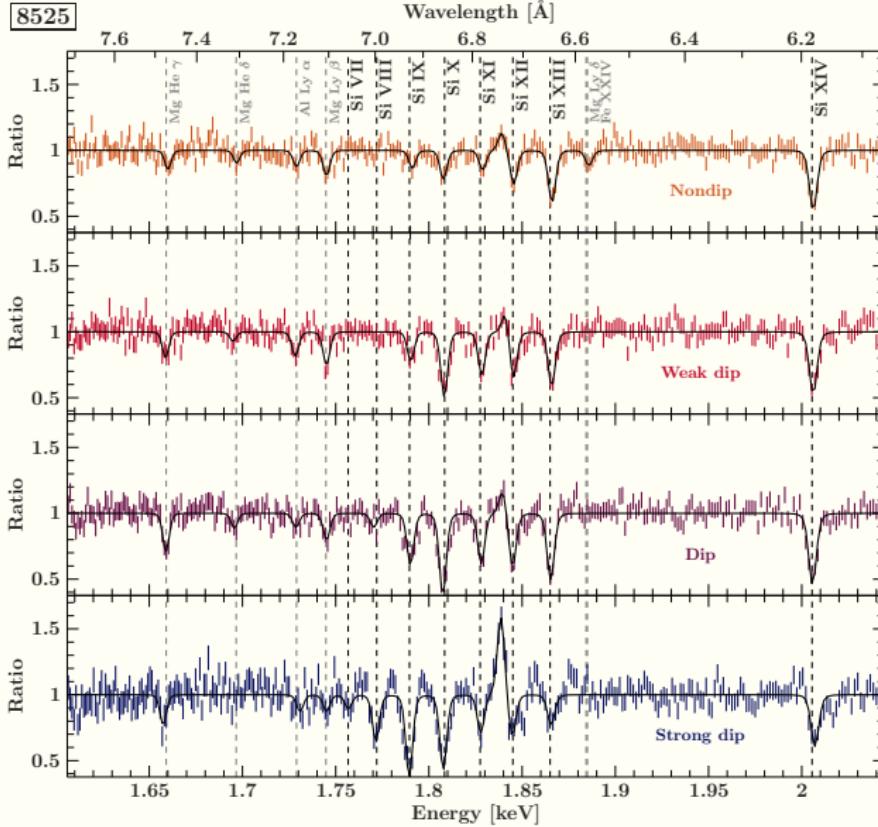
*Chandra-HETG*

four absorption stages with  
similar SNR  
(using color-color diagrams;  
*Grinberg et al., in prep.*)



*Hirsch et al., in prep.*

# Cygnus X-1: Clump structure



lower ionization stages of Si and S appear when absorption stronger

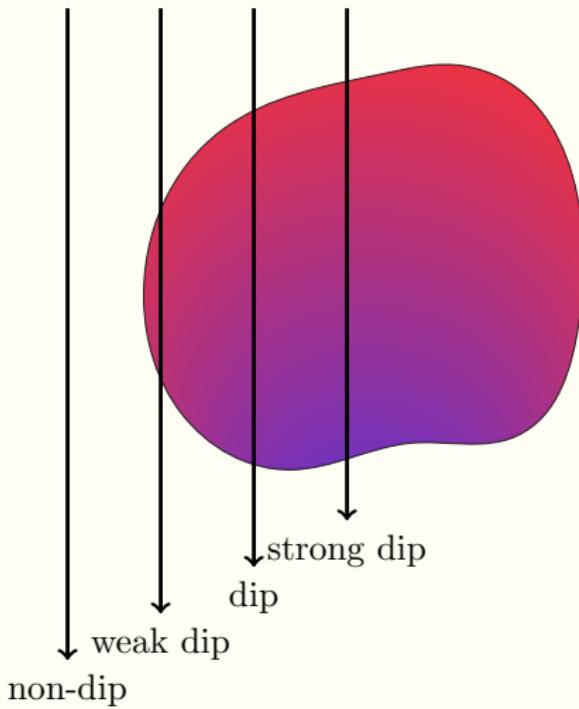
same Doppler-shift for lines in the same ObsID

⇒ structured  
clumps with cold  
cores

Hirsch et al., in prep.

↳ no probes of individual clumps yet!

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## Summary & Outlook

1. high mass X-ray binaries are excellent probes for stellar winds
  2. winds are structured
  3. variable absorption is really important!
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### **current limitations:**

- ▶ limited to especially bright sources
  - ▶ short term variability, studies of individual clumps
  - ▶ clump dynamics

⇒ ... come back tomorrow morning  
for the *Athena* view!

