High-Resolution Spectroscopy of the Stellar Wind in Cygnus X-1

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&

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Black Hole Universe

Outline

- Aim:

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

- Here:

  We present observations that provide strong constraints on clumpy models - support the presence of cold dense clumps in the stellar wind of Cyg X-1.

Stellar Wind

- very strong: mass loss rate $\sim 10^{-6}\ M_{\odot}/yr$
- line-driven winds (Castor, Abbot & Klein, 1975)
- hot, early type (O or B) stars, strongly radiating in UV

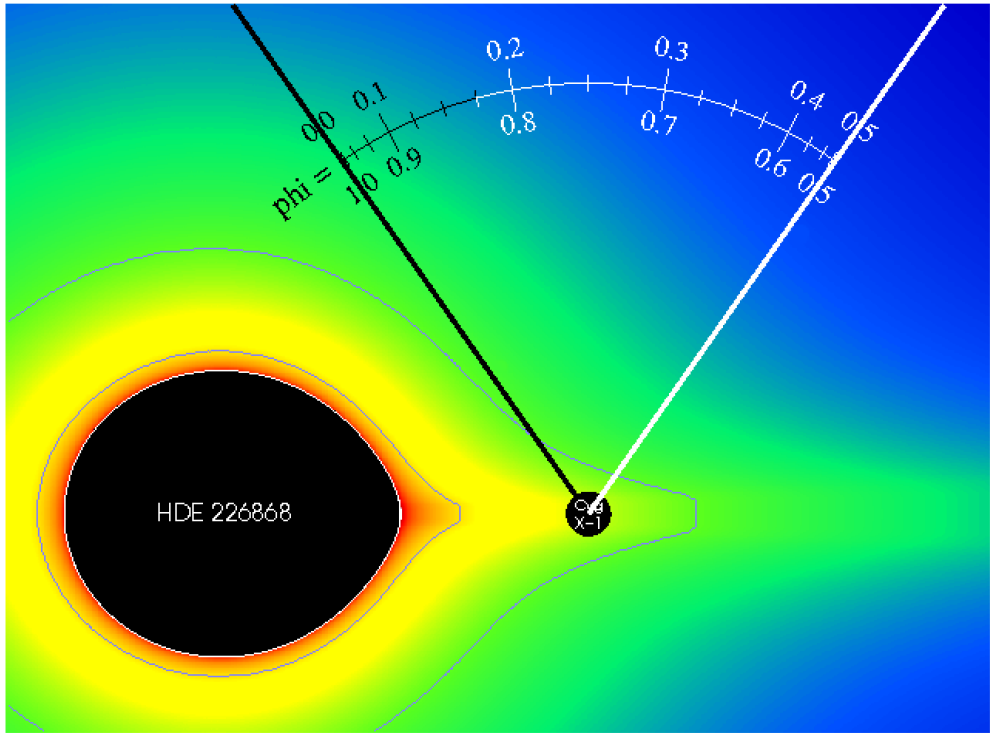
  - perturbations are present (Feldmeier et al. 1997, Oskinova et al.)
  - density, velocity & temperature variations
  - cold dense clumps embedded in hot photoionized gas

    - is focused in Cyg X-1 (Friend & Castor, 1982)

Lines of sight to Cyg X-1

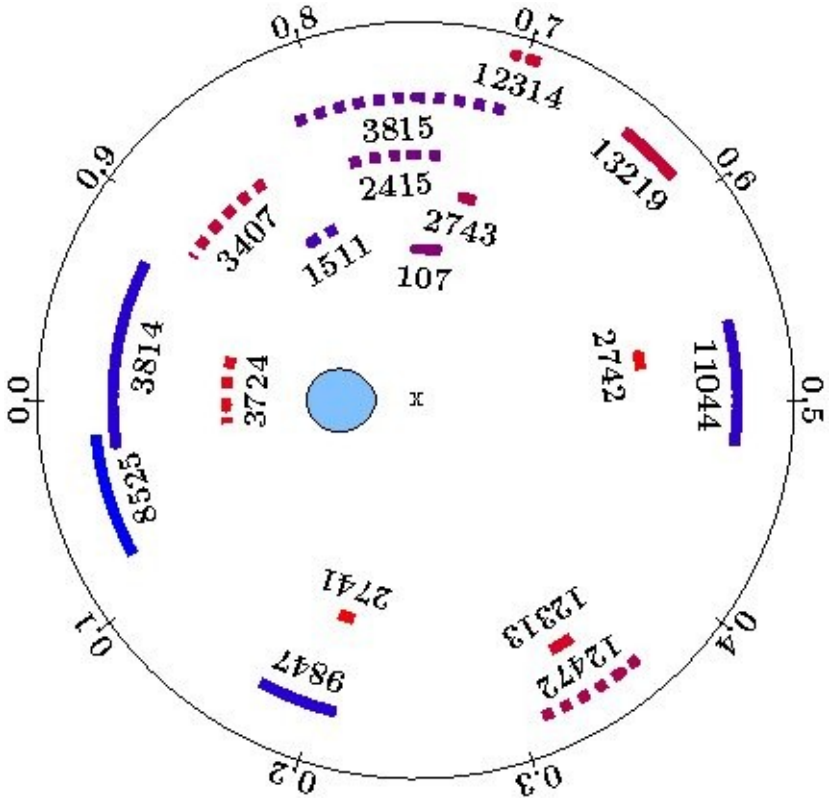
Assuming *i* ~ *35*°

(Gies & Bolton, 1986a)



(M.Hanke, 2009)

Chandra orbital coverage



- all observations by July 2011

- blue → red: hard → soft state
- dots / full line: CC/TE mode

Lines of sight to Cyg X-1

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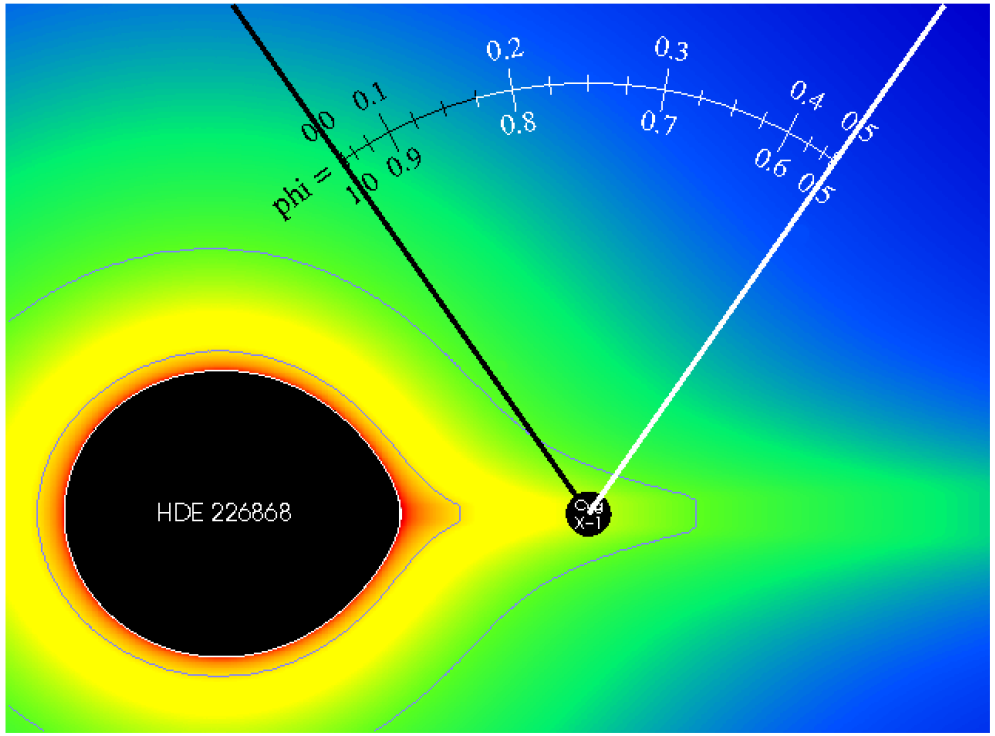
(Gies & Bolton, 1986a)



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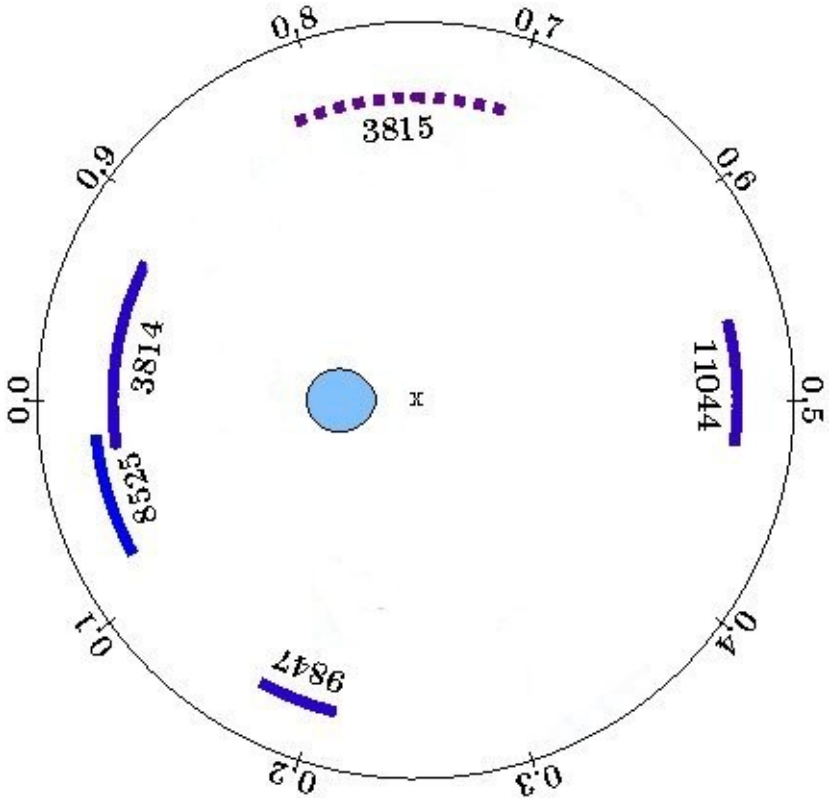

- concentrating on hard state

Lines of sight to Cyg X-1

Assuming *i* ~ *35*°

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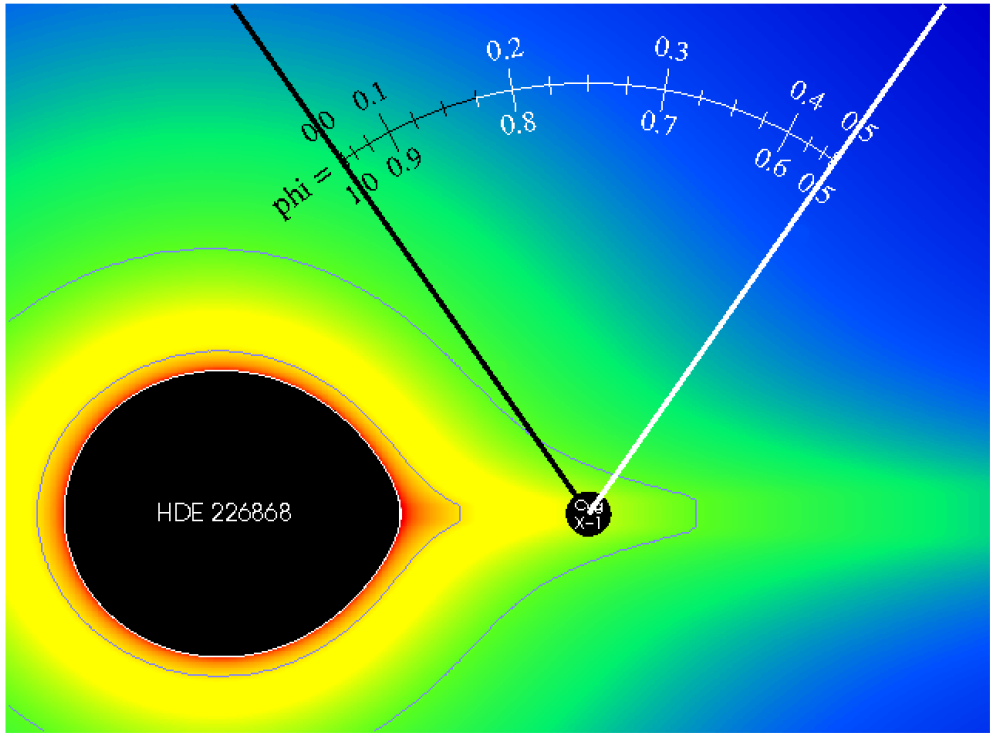

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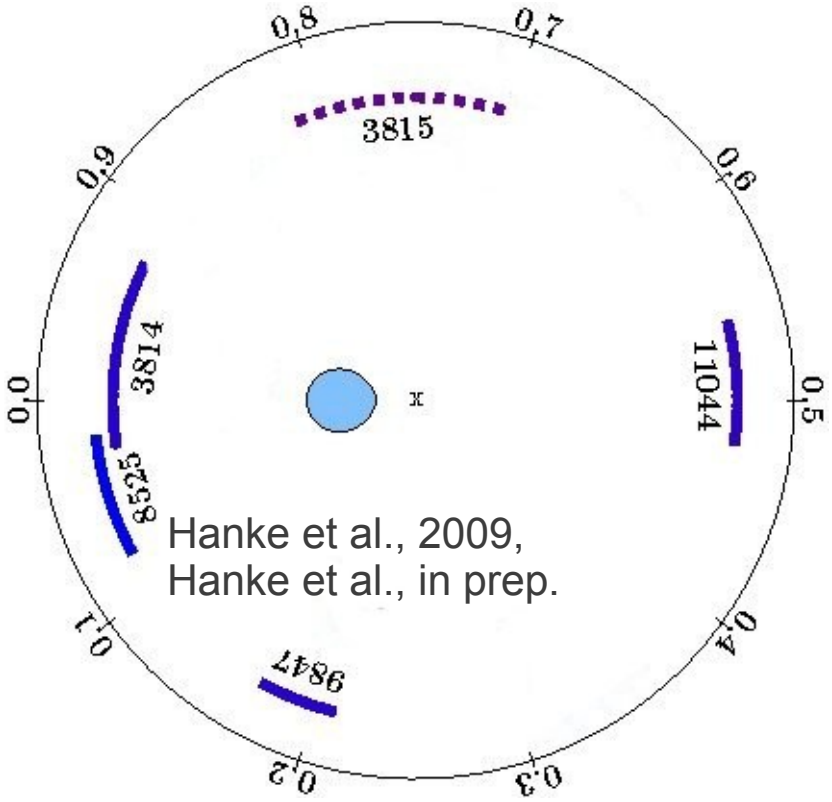


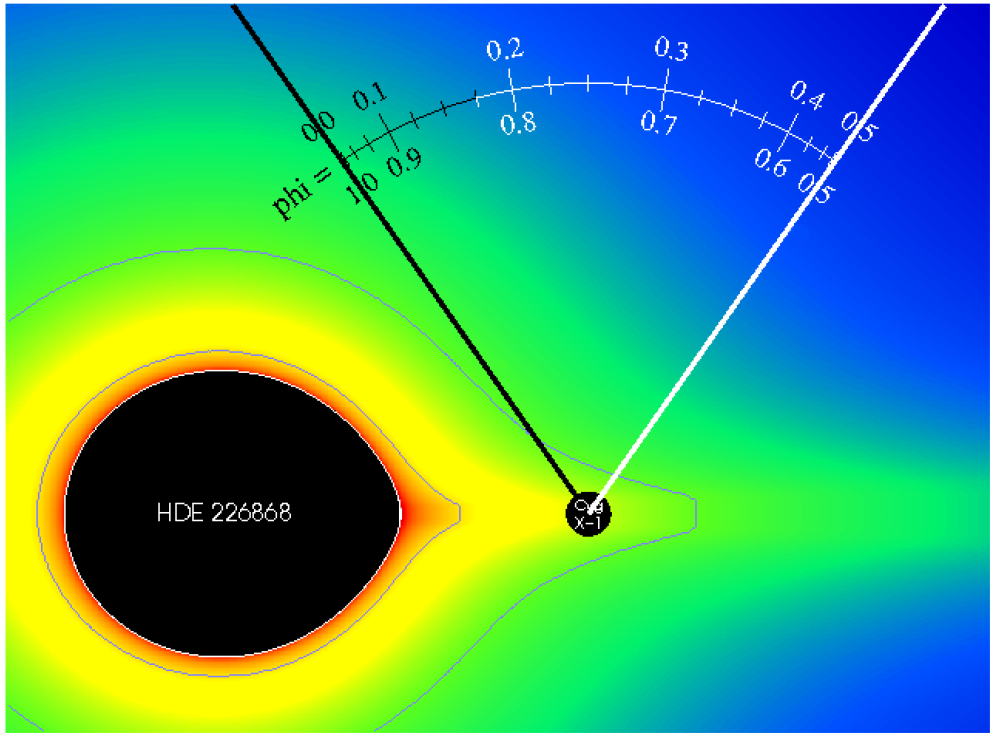
Hanke et al., 2009,
Hanke et al., in prep.

- concentrating on hard state

Lines of sight to Cyg X-1

Assuming *i* ~ *35°*

(Gies & Bolton, 1986a)



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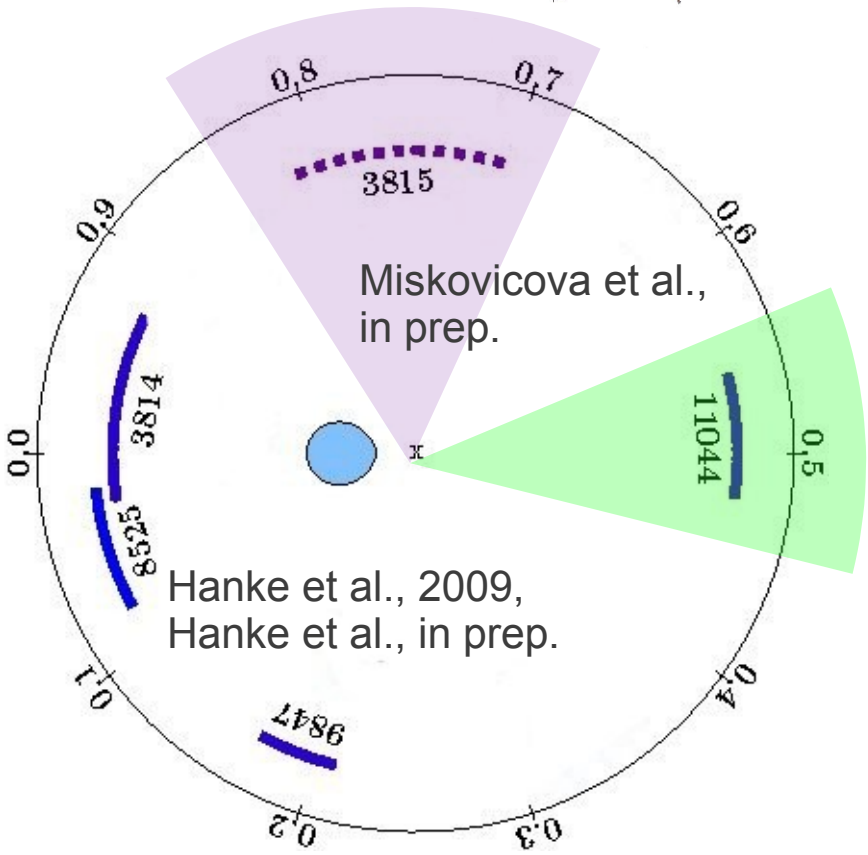
Chandra orbital coverage

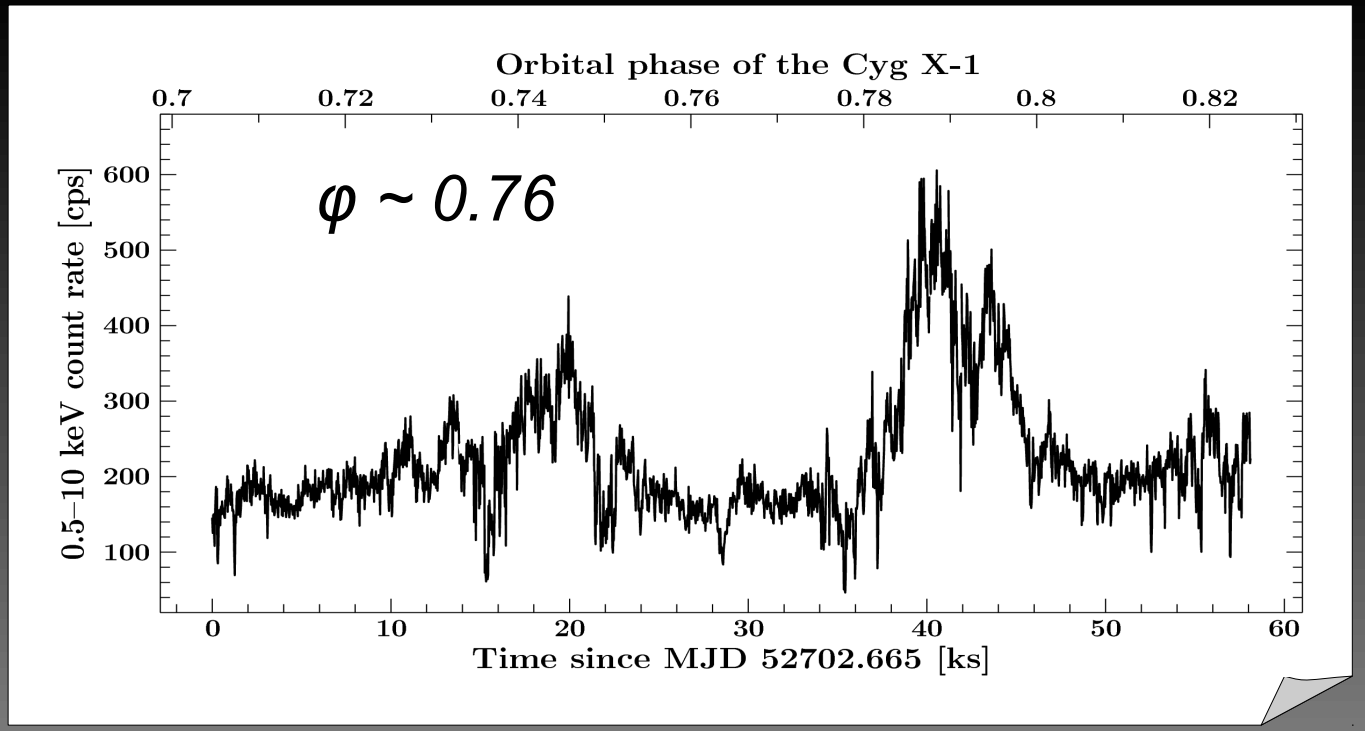


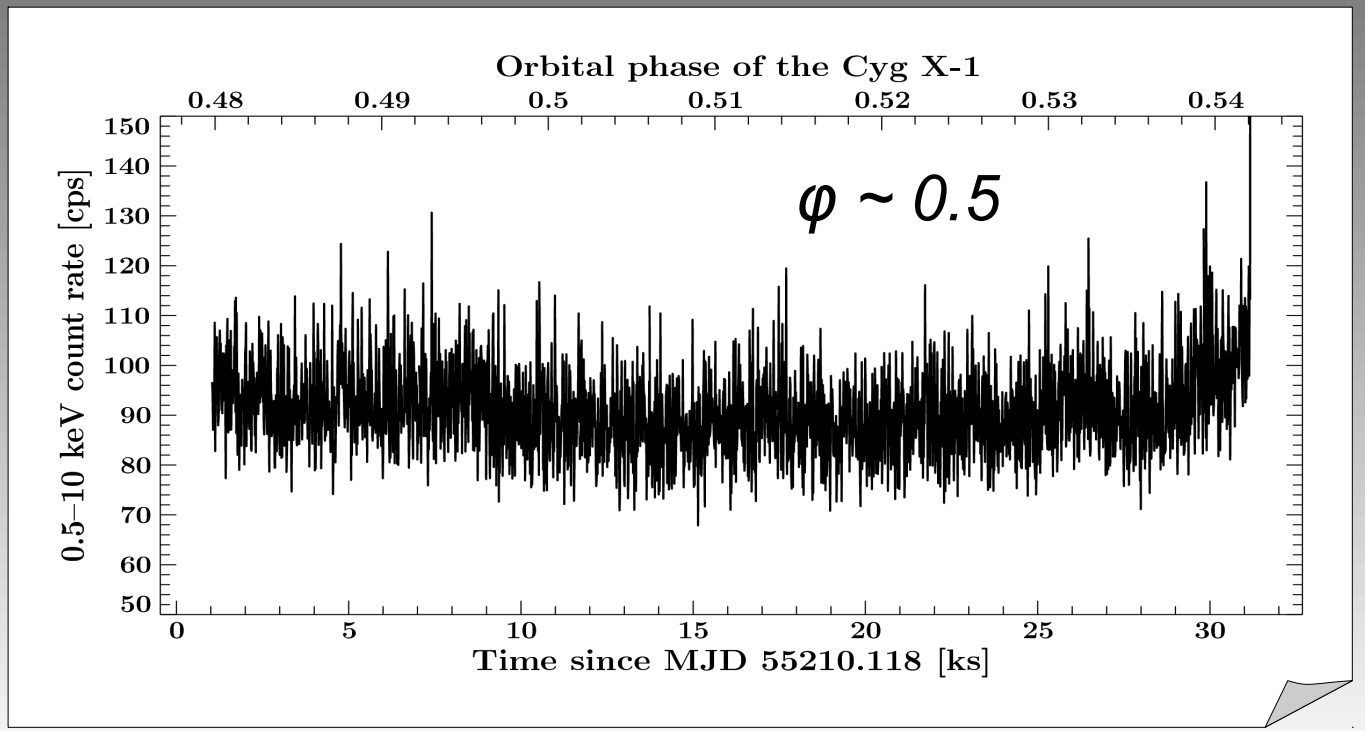
- concentrating on hard state

Light Curves

Define:

- Non-dip level
- Dip level





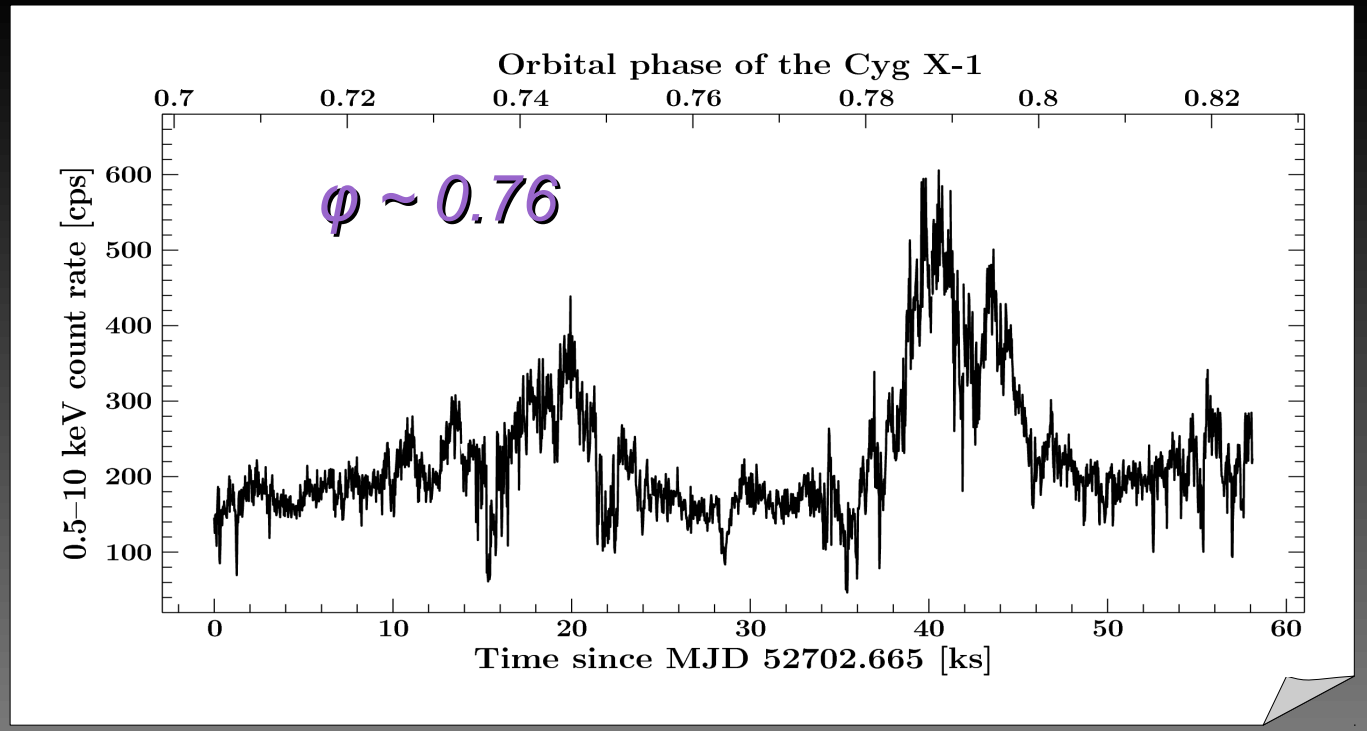
Light Curves

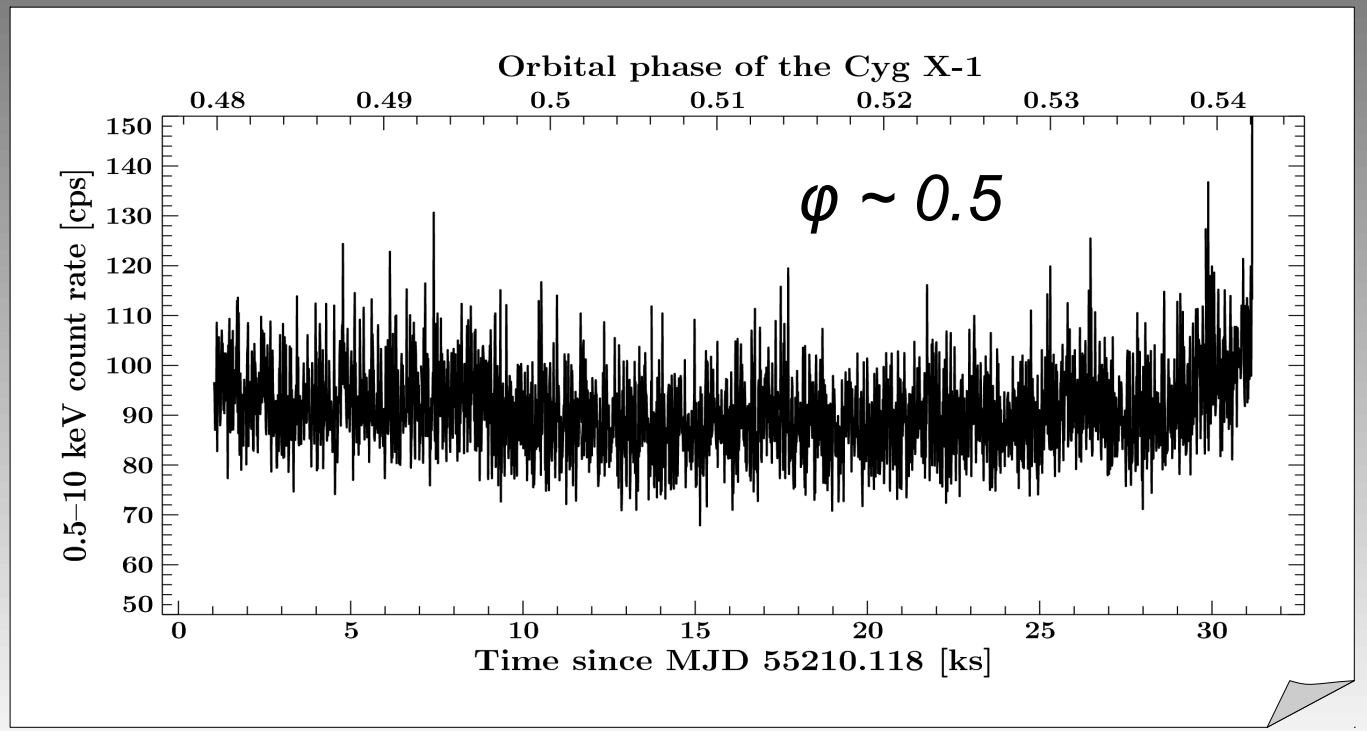
Define:

- Non-dip level
- Dip level

φ ~ 0.76

- Non-dip and dip spectrum treated separately!





Light Curves

Define:

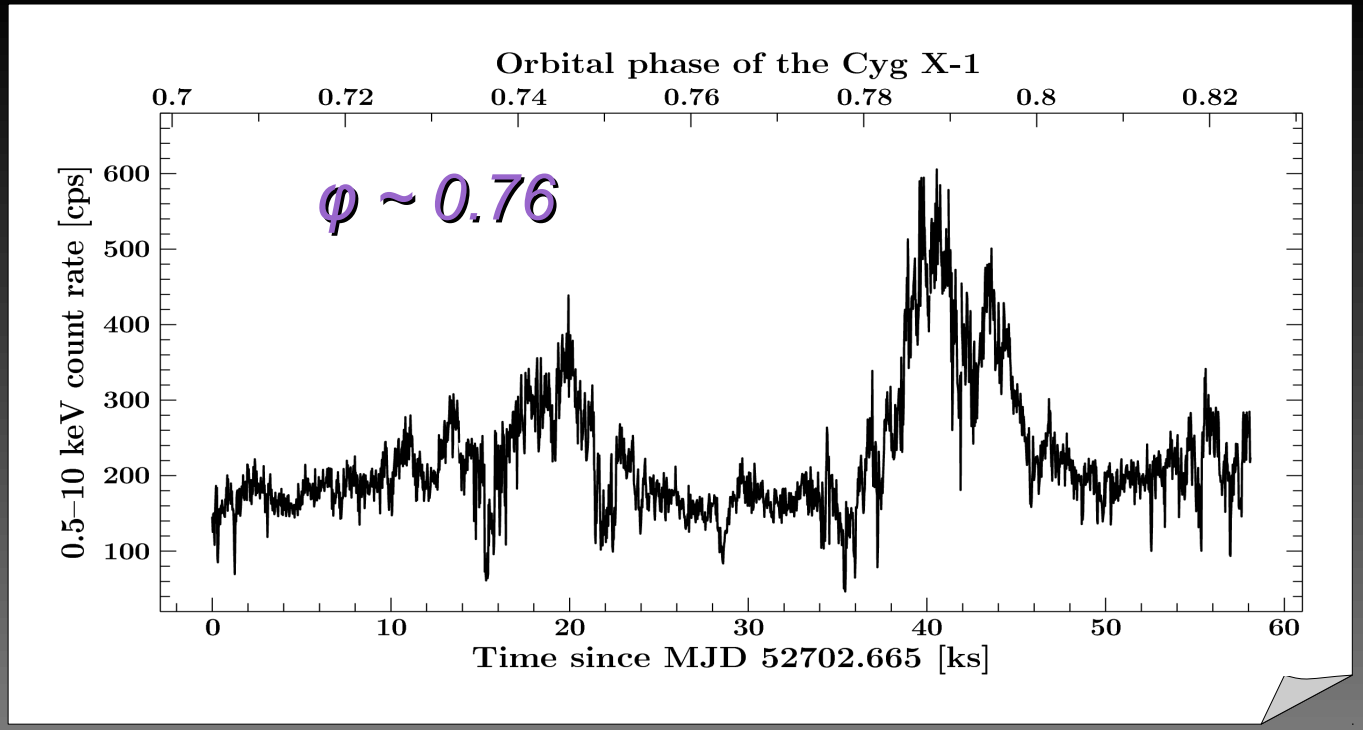
- Non-dip level
- Dip level

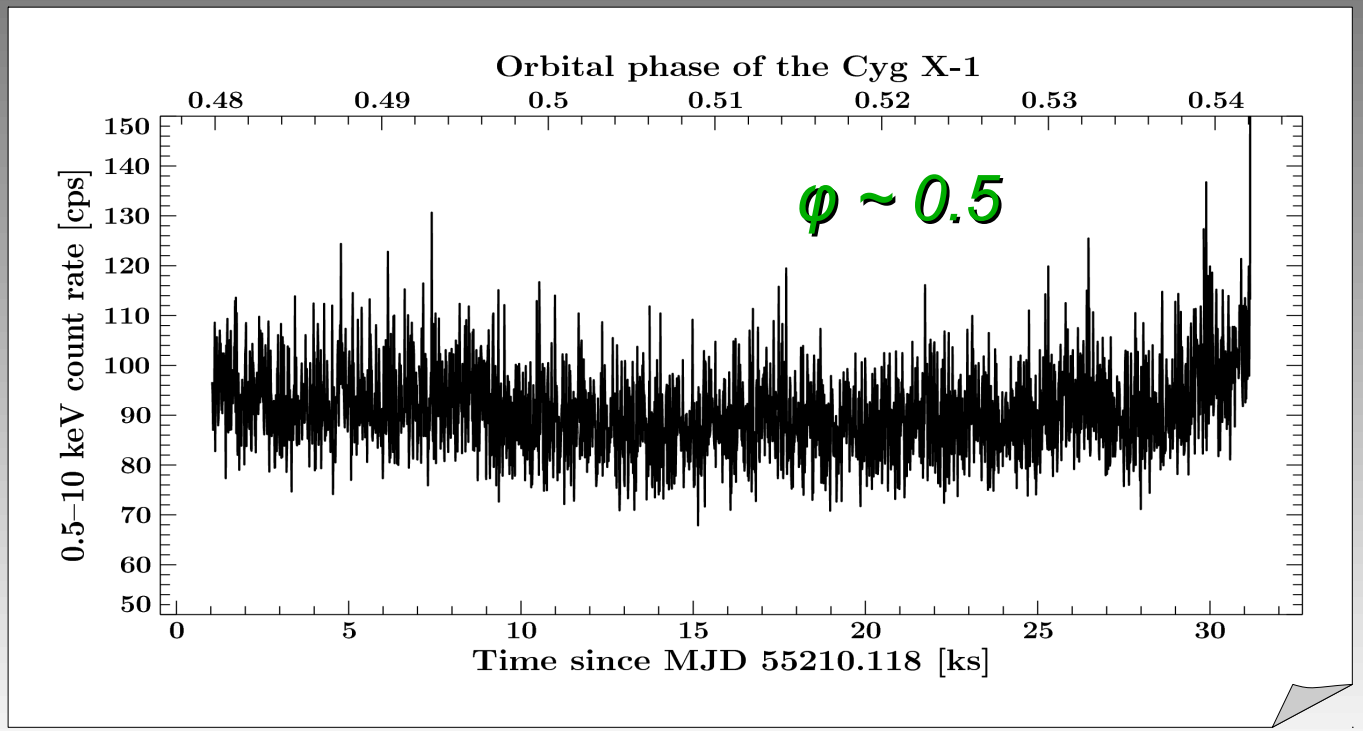
φ ~ 0.76

- Non-dip and dip spectrum treated separately!

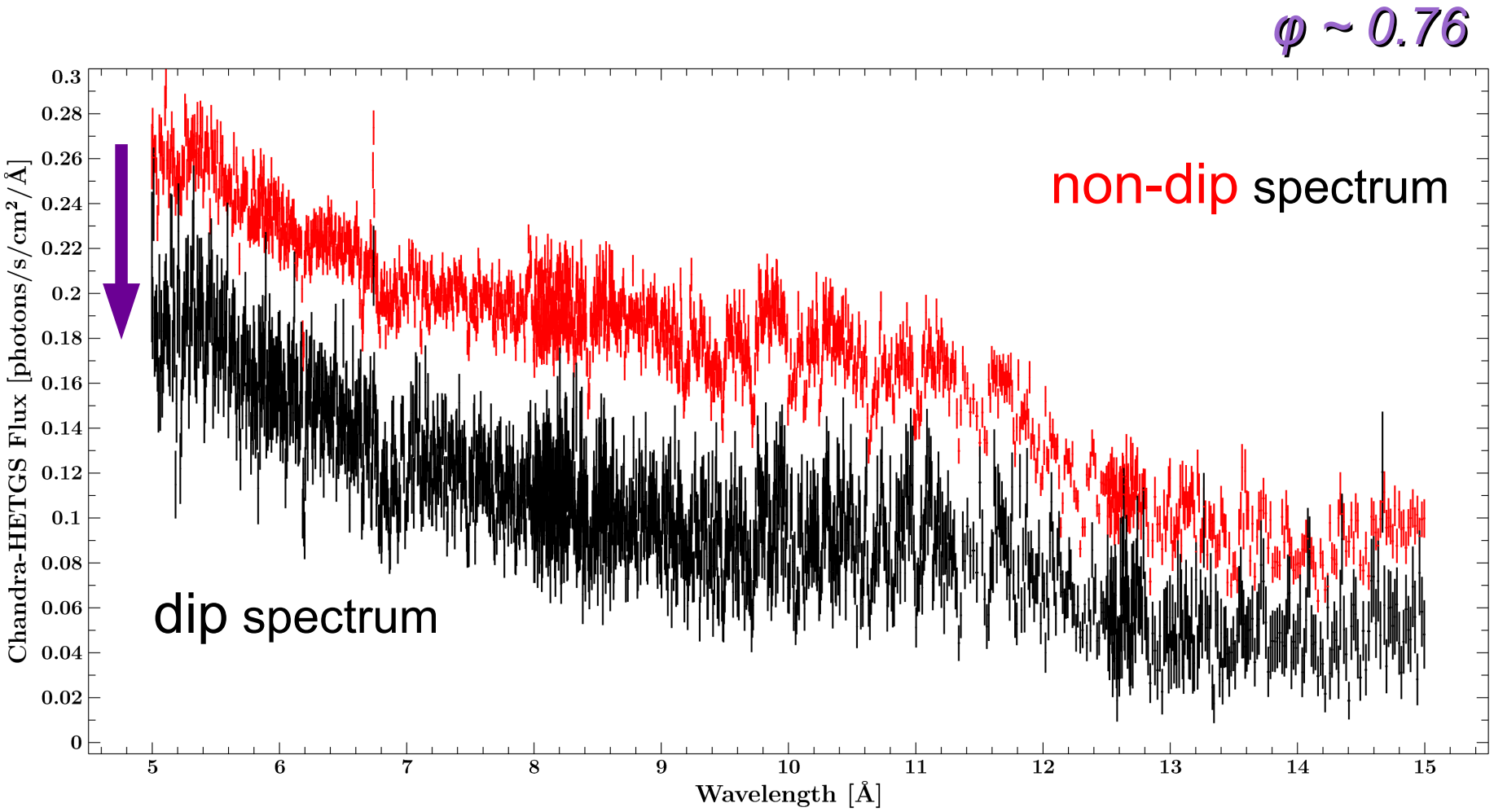
φ ~ 0.5

- Unique, undisturbed ~30ks non-dip spectrum

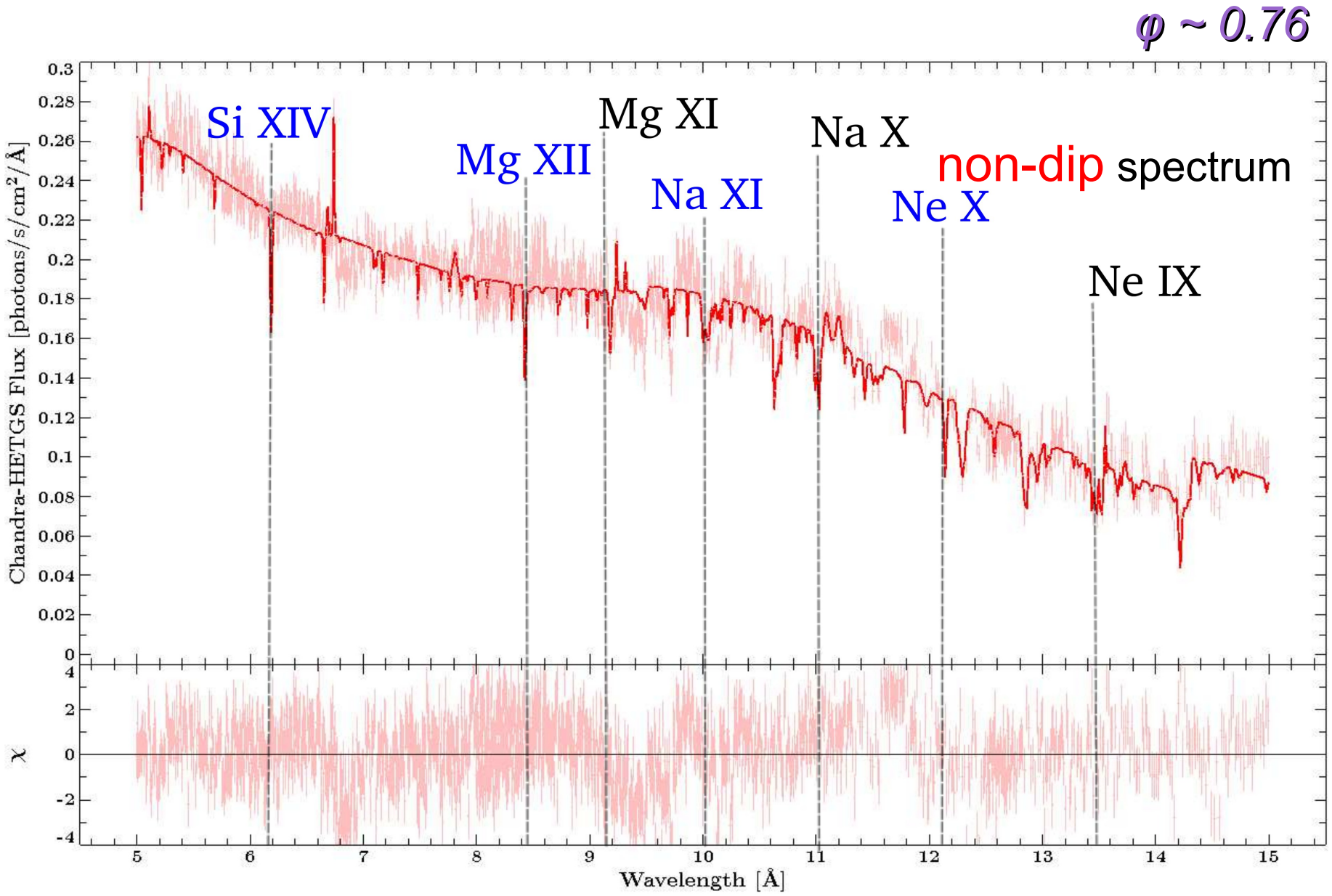




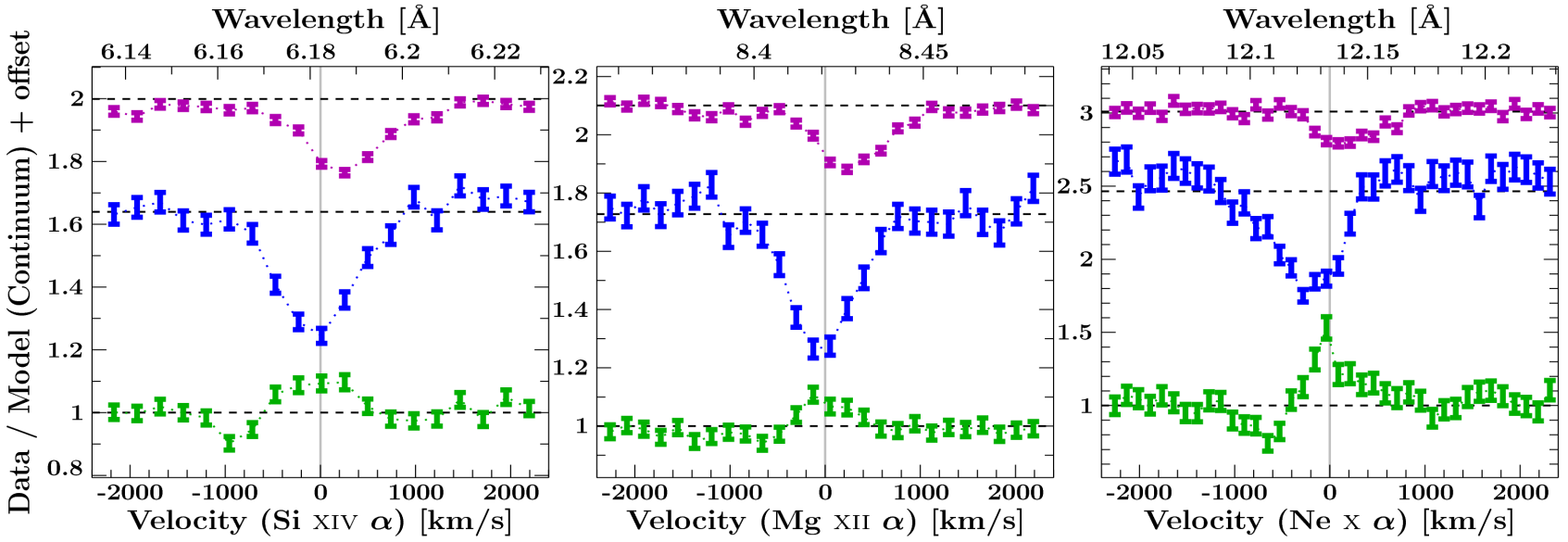
High-resolution Spectrum



H-like and He-like absorption lines



H-like absorption lines profiles



φ ~ 0.76

φ ~ 0.0

φ ~ 0.5

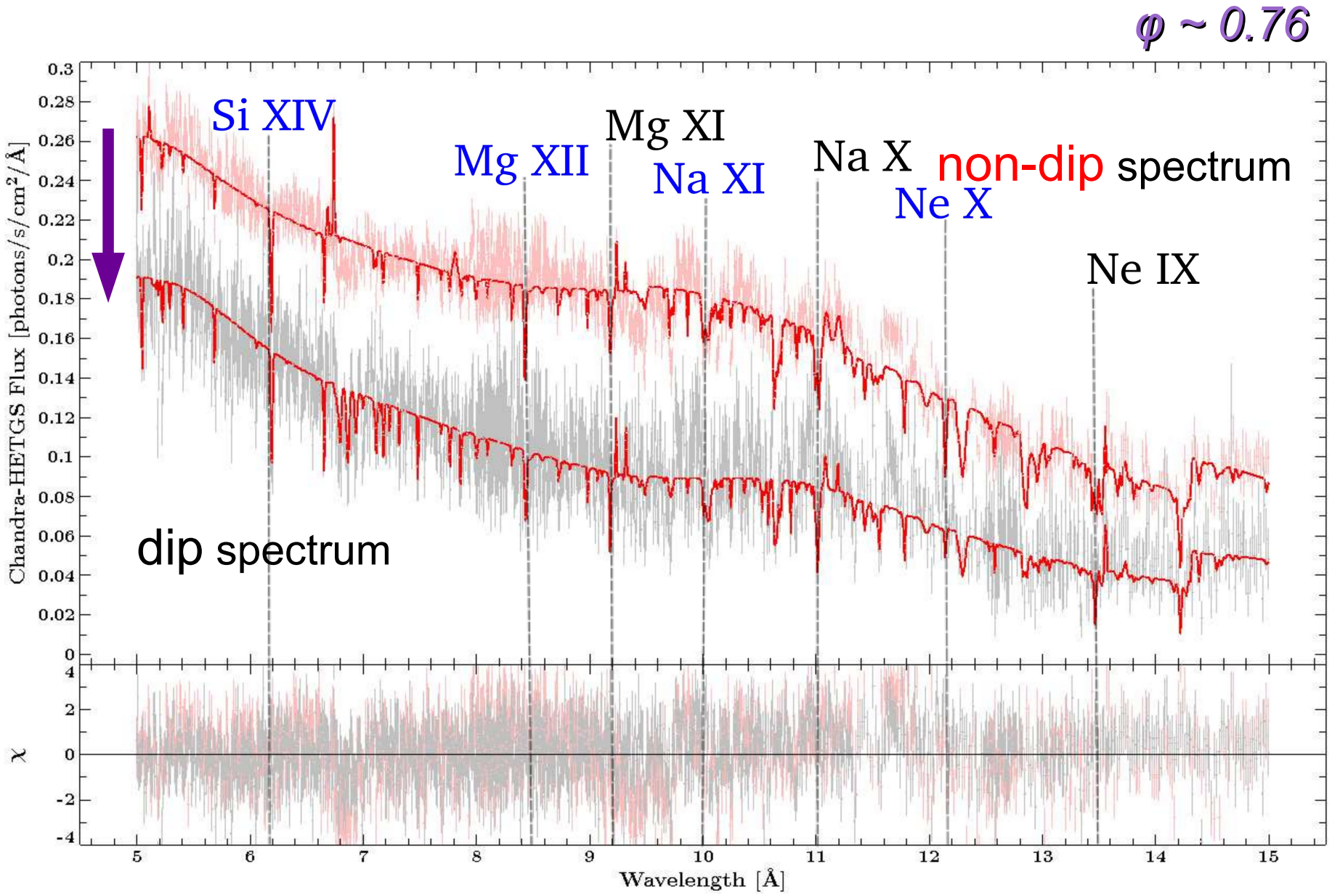
φ ~ 0.76 redshift ~ *100 – 400 km/s*

φ ~ 0.0 v_{rad} ~ *0 km/s* (Hanke et al., 2009)

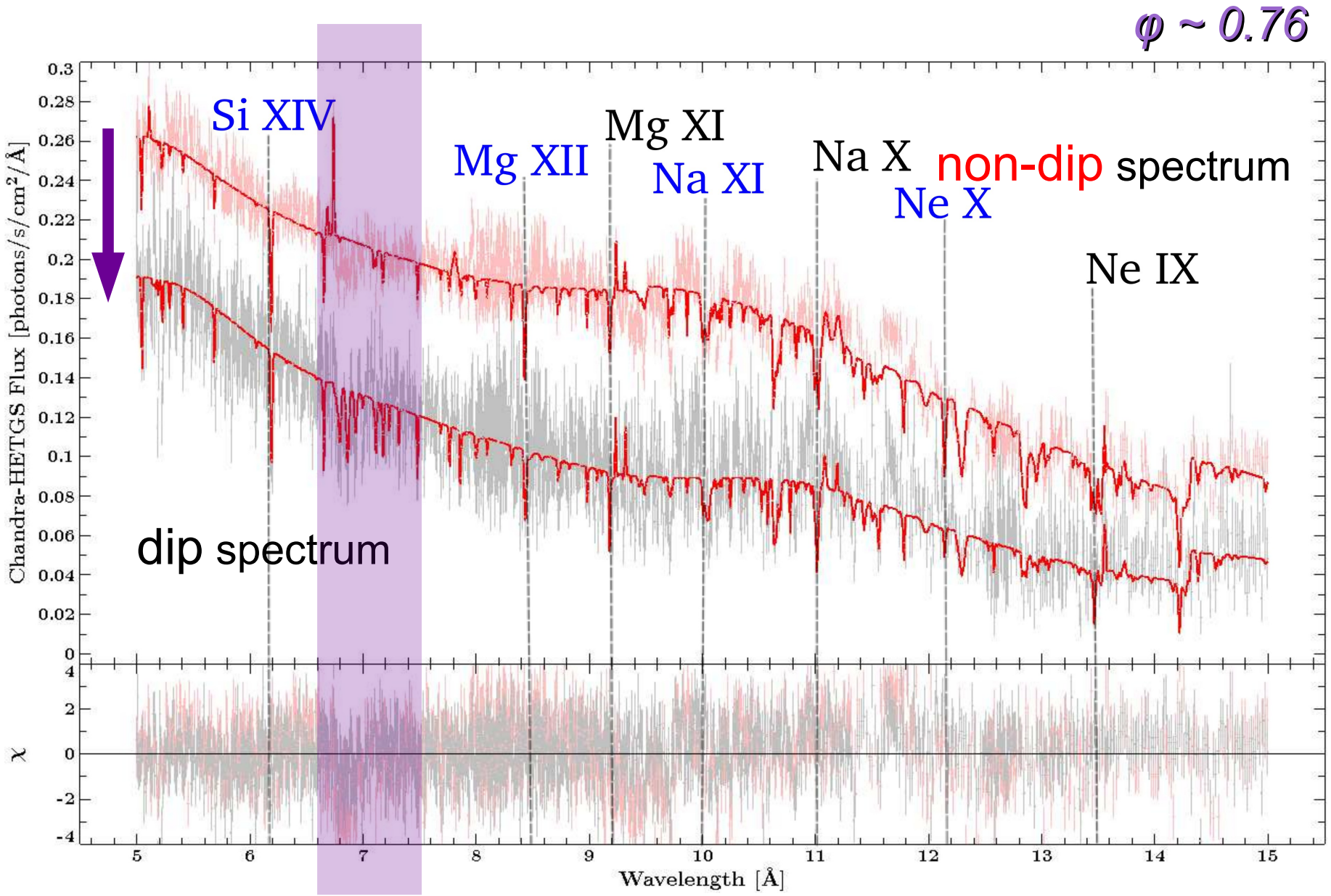
φ ~ 0.5 P-Cygni profiles (Miskovicova et al., 2011)

- emission at v_{rad} ~ *0 km/s*
- absorption blueshifted by ~ *500 – 1000 km/s*

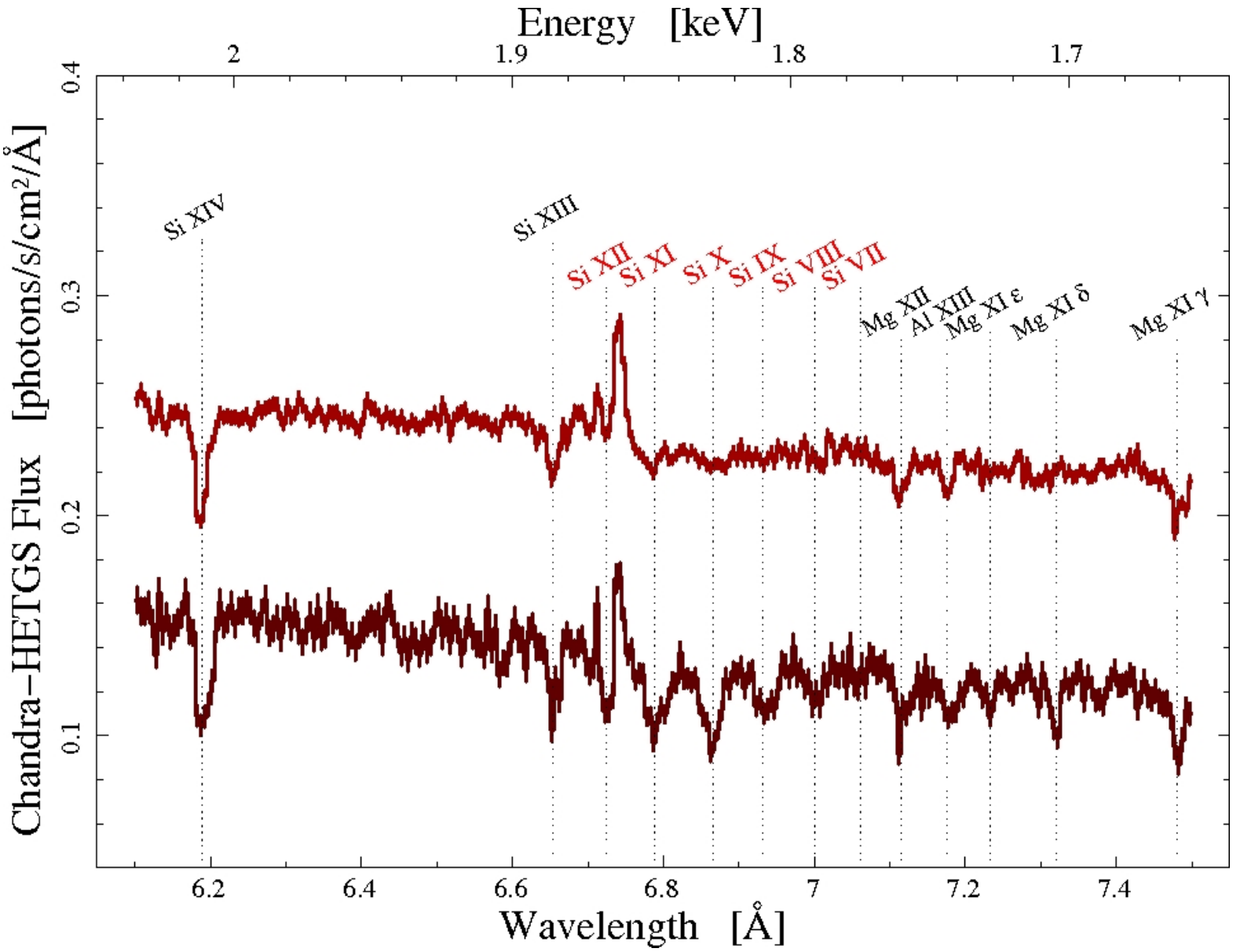
H-like and He-like absorption lines



H-like and He-like absorption lines



Si XI – VII absorption lines in Dip spectrum



Summary

• Better general understanding of the structure and dynamics of stellar winds.

- high-resolution spectra (*Chandra, XMM-Newton*)
- detailed analysis of individual H-like and He-like absorption lines

- very good orbital coverage
  current proposals: *XMM-Newton* - Uttley et al., 2010

• We present observations that provide strong constraints on clumpy models - support the presence of cold dense clumps in the stellar wind of Cyg X-1.

- Si absorption lines of lower ionization stage
- origin in colder medium then highly ionized lines

- non-dip spectrum represents highly ionized gas of the wind
- dips are caused by cold dense clumps