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

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• 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.
- very strong: mass loss rate $\sim 10^{-6} \ M_\odot/\text{yr}$
- 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)
Assuming $i \sim 35^\circ$  
(Gies & Bolton, 1986a)

(M.Hanke, 2009)

- all observations by July 2011
  - blue $\rightarrow$ red: hard $\rightarrow$ soft state
  - dots / full line: CC/TE mode

**Chandra** orbital coverage

Lines of sight to Cyg X-1
Assuming $i \sim 35^\circ$  
(Gies & Bolton, 1986a)

(M.Hanke, 2009)

- concentrating on hard state
Assuming $i \sim 35^\circ$
(Gies & Bolton, 1986a)

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-Chandra orbital coverage

- concentrating on hard state

Hanke et al., 2009,
Hanke et al., in prep.
Assuming $i \sim 35^\circ$  
(Gies & Bolton, 1986a)

- concentrating on hard state

(M.Hanke, 2009)
Define:
- Non-dip level
- Dip level
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$\phi \sim 0.76$

- Non-dip and dip spectrum treated separately!
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- Non-dip level
- Dip level

$\varphi \sim 0.76$

- Non-dip and dip spectrum treated separately!

$\varphi \sim 0.5$

- Unique, undisturbed $\sim 30$ks non-dip spectrum
High-resolution Spectrum

\[ \phi \approx 0.76 \]

**non-dip spectrum**

**dip spectrum**
H-like and He-like absorption lines

\[ \varphi \sim 0.76 \]

- Si XIV
- Mg XII
- Mg XI
- Na XI
- Na X
- Ne X
- Ne IX
- Non-dip spectrum
H-like absorption lines profiles

\[ \phi \approx 0.76 \]

- redshift \( \approx 100 - 400 \text{ km/s} \)

\[ \phi \approx 0.0 \]

- \( v_{\text{rad}} \approx 0 \text{ km/s} \) (Hanke et al., 2009)

\[ \phi \approx 0.5 \]

- P-Cygni profiles (Miskovicova et al., 2011)
  - emission at \( v_{\text{rad}} \approx 0 \text{ km/s} \)
  - absorption blueshifted by \( \approx 500 - 1000 \text{ km/s} \)
H-like and He-like absorption lines

\[ \phi \sim 0.76 \]

- Si XIV
- Mg XII
- Mg XI
- Na XI
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Dip spectrum

Non-dip spectrum
H-like and He-like absorption lines

\[ \phi \sim 0.76 \]

Si XIV  Mg XII  Mg XI  Na XI  Na X  non-dip spectrum  Ne X  Ne IX

dip spectrum

Chandra-HETGS Flux [photons/s/cm²/Å]

Wavelength [Å]
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