Focused winds in high mass X-ray binaries: the case of Cyg X-1/HDE 226868

Victoria Grinberg

MIT Kavli Institute for Astrophysics and Space Research

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June 9, 2015
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Cyg X-1 / HDE 226868 system

- high mass X-ray binary
- bright, persistent source
- companion: O-type supergiant
- line-driven winds (CAK-mechanism)
- mass loss: \( \sim 2 \times 10^{-6} \, M_\odot \, yr^{-1} \)
- ISM equivalent hydrogen density: \( \sim 0.5 \times 10^{22} \, \text{cm}^{-2} \) \((Xiang \ et \ al., \ 2011)\)
Orbital variability

Orbital period: 5.6 days
Inclination: 27° (Orosz et al., 2011)

- Orbital variability of overall absorption
  ⇒ focussed wind

- Orbital variability of ‘dip’-occurrence
  ⇒ individual clumps in the wind

Hanke 2011
Grinberg et al., 2013, 2014
RXTE campaign

Grinberg et al., 2013, 2014

typical exposure: $\sim 2$ ks
RXTE campaign

Grinberg et al., 2013, 2014

typical exposure: $\sim 2$ ks
Orbital variability of absorption

hard state

intermediate state

soft state

no disk component
disk component
disk component

Grinberg et al., 2015
Orbital variability of absorption: soft and intermediate states

disk component ⇒ large uncertainties in $N_H$

wind strongly ionized ⇒ mainly transparent to X-rays
Orbital variability of absorption: soft and intermediate states

ionized material $\Rightarrow$ line-driving mechanism breaks down $\Rightarrow$ changes in the geometry of the system

Čechura & Hadrava, 2015
Orbital variability of absorption: hard state

all hard state data

\[ N_{\text{H}}[10^{22}\text{cm}^{-2}] \]

orbital phase \( \phi_{\text{orb}} \)

\[ \sigma\{N_{\text{H,22}}\} \]

\[ N_{\text{H}}[10^{22}\text{cm}^{-2}] \]

orbital phase \( \phi_{\text{orb}} \)

\[ \sigma\{N_{\text{H,22}}\} \]

Grinberg et al., 2015

one long, stable hard state
Orbital variability of absorption: hard state

Grinberg et al., 2015
How important is absorption?

\[ N_H \approx 2.5 \times 10^{22} \text{ cm}^{-2}, \ \phi \approx 0.09 \]

\[ N_H \approx 3.6 \times 10^{22} \text{ cm}^{-2}, \ \phi \approx 0.12 \]

\[ N_H \approx 1.5 \times 10^{22} \text{ cm}^{-2}, \ \phi \approx 0.93 \]

\[ N_H \approx 0.62 \times 10^{22} \text{ cm}^{-2}, \ \phi \approx 0.37 \]

\[ N_H \approx 5.5 \times 10^{22} \text{ cm}^{-2}, \ \phi \approx 0.99 \]

\[ \sim 9.4–14.8 \text{ keV} \]

\[ \sim 4.5–5.7 \text{ keV} \]

\[ \Rightarrow \]

\[ \Gamma_1 \]

\[ \text{RMS [\%]} \]

\[ \text{time lag [ms]} \]

\[ \text{F}_\nu \text{ [erg cm}^{-2} \text{s}^{-1} \text{keV}^{-1}] \]

\[ \text{Energy [keV]} \]

Grinberg et al., 2013, 2015
Hard state: a focussed wind model

- toy model for a focussed CAK wind (Gies & Bolton, 1986; Friend & Castor, 1982)

\[ \phi_{\text{orb}} = 0 \quad \phi_{\text{orb}} = 0.5 \]

Grinberg et al., 2015

- fails to describe the variability due to lack of clumps
Hard state: a clumpy wind model

(Owocki & Cohen 2006, Sundqvist et al. 2012, but see also Oskinova et al. 2012)

- discrete, spherical clumps
- $\beta$ velocity law
- no focussed wind component (yet)

- known: stellar parameters, terminal velocity, mass loss rate
- variable: number of clumps $N$ and terminal porosity length $h_\infty$

(Fig. from Sundqvist et al. 2012)
Hard state: a clumpy wind model

terminal porosity length $h_\infty = 0.1 \, R_\ast$ stellar radii

Grinberg et al., 2015
Hard state: a clumpy wind model

terminal porosity length $h_\infty = 10 R_*$ stellar radii

$Grinberg$ $et$ $al.$, $2015$
Hard state: a clumpy wind model

terminal porosity length \( h_\infty = R_\star \) stellar radius

Grinberg et al., 2015
Hard state: a clumpy wind model

\[ h_\infty = R_* \]

**model**

**observations**

\[ N_H - N_{H,ISM} [10^{22} \text{ cm}^{-2}] \]
Hard state: a clumpy wind model

Grinberg et al., 2015

agreement between data (black) and model (red)

\( h_\infty \approx R_* \) agrees with values for single O stars

non-Gaussian tail for \( \phi_{\text{orb}} \approx 0 \) in data

\( \Rightarrow \) structure in wind \( \Rightarrow \) focussed wind? non-spherical clumps?

average values (circles) and standard deviations (error bars on the average values)
absorption changes highly significant
proof of principle for applicability of clumpy wind models to HMXBs
absorption variability can be used to constrain porosity and study clump distribution and shape

clumpy wind models with focussed wind component and/or more complex clump-shapes
variability on shorter time scales with Suzaku, Chandra & Astro-H
diagnosis of individual clumps with high resolution spectroscopy