Effects of clumpy stellar wind in the microquasar Cyg X-1

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Observational campaigns: RXTE monitoring

Grinberg et al. 2013, 2014
Observational campaigns: Chandra

Miskovicova et al. 2016
Observational campaigns: CHOCBOX

INTEGRAL (3-1e4 keV) (Grinberg)
NuSTAR (3-79 keV) (Uttley)
XMM (0.1-15 keV) (Uttley)
NOEMA (145 GHz) (Tetarenko)
KVN/KaVa (22,43 GHz) (Miller-Jones)
VLA (1-50 GHz) (Miller-Jones)
AMI-LA (15 GHz) (Pooley)
VLBA (8.4 GHz) (Miller-Jones)
EVN (5 GHz) (Tudose)
eMERLIN (5 GHz) (Rushton)
LOFAR (200 MHz) (Marcote)

**Uttley et al. in prep., Miller-Jones et al. in prep.**
Why Cygnus X-1?

- bright
- persistent
- constantly crosses the jet line

Figure: Nowak et al., 2012
Fast state transitions

state transitions can happen on timescale of $\sim$ hours

(see also NICER observation; talks by Ron & Jack)

Boeck et al. 2011
Why not Cygnus X-1?
How strongly does absorption change?

Grinberg et al. 2015

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

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

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

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

\[ N_H \approx 0.62 \times 10^{22} \text{ cm}^{-2}, \ \phi \approx 0.37 \]
Cyg X-1 / HDE 226868 system

Hanke 2011

black hole + O-type supergiant

\[ \dot{M} \sim 2 \times 10^{-6} M_\odot \text{ yr}^{-1} \]

orbital period: 5.6 days

inclination: \( i \approx 27^\circ \) (Orosz et al., 2011)
Variable absorption in hard state

Grinberg et al., 2015
Variable absorption in hard state

homogeneous, focussed wind cannot explain the variability

Grinberg et al., 2015
Clumpy winds

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

Dessart & Owocki, 2005; 2D simulations

Multiple observational lines of evidence for clumping from single stars
Absorption variability: a clumpy wind model

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

(Fig. from Sundqvist et al. 2012)

- discrete, spherical clumps
- $\beta$ velocity law: $v = v_\infty (1 - \frac{R_*}{r})^\beta$
- no focussed wind component (yet)

- known: stellar parameters, terminal velocity, mass loss rate
- variable: number of clumps $N$ and terminal porosity length $h_\infty$
  
  ($h_\infty = 3 \frac{R_*}{L_*^2 N}$ with $L_*$ initial radial size of the clump)
Absorption variability: a clumpy wind model

Grinberg et al. 2015

$h_\infty = 0.1 R_*$

Grinberg et al. 2015

fractional number of observations

cumulative fractional number of observations

$N_H - N_{H,\text{ISM}} \times 10^{22} \text{ cm}^{-2}$

observations

model

$\phi_{orb} = 0.0 - 0.1$
$n = 58$

$\phi_{orb} = 0.1 - 0.2$
$n = 30$

$\phi_{orb} = 0.2 - 0.3$
$n = 34$

$\phi_{orb} = 0.3 - 0.4$
$n = 41$

$\phi_{orb} = 0.4 - 0.5$
$n = 34$

$\phi_{orb} = 0.7 - 0.8$
$n = 38$

$\phi_{orb} = 0.8 - 0.9$
$n = 41$

$\phi_{orb} = 0.9 - 1.0$
$n = 32$

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Absorption variability: a clumpy wind model

Grinberg et al. 2015

model

\( h_\infty = 10 R_* \)

Grinberg et al. 2015
Absorption variability: a clumpy wind model

Grinberg et al. 2015

\[ h_\infty = R_* \]
Wind effects & reflection

Cyg X-1: NuSTAR soft state observations

similar relativistically broadened iron line
⇒ high spin, $i \approx 40^\circ$

variable ionized absorption at $\sim 6.7$ keV
⇒ focussed wind
⇒ needs to be taken into account when modelling reflection

Walton et al. 2016
CHOCBOX Timing: wind effects

Cyg X-1:

- wind strongly affects spectro-timing at low energies
- possibility of wind reverberation studies?

P. Uttley et al., in prep.
Clump structure

Hirsch et al., in prep.; see also Miskovicova et al. 2016
Clump structure

Cyg X-1

same Dopplershift ⇒ origin in the same medium

lower ionization lines when absorption higher

⇒ onion-like clump structure

Hirsch et al., in prep.; see also Miskovicova et al. 2016
Clump structure

Cyg X-1
same Dopplershift $\Rightarrow$ origin in the same medium
lower ionization lines when absorption higher

$\Rightarrow$ onion-like clump structure

Hirsch et al., in prep.; see also Miskovicova et al. 2016
variable absorption makes analysis even more complex

constraints on clumpy wind structure

Variable absorption affects:

- broadband spectral shape
- iron line
- (some) variability properties
One astronomers’s noise is another astronomer’s data.

Variable absorption makes analysis even more complex

\[ \uparrow \]

constraints on clumpy wind structure

Variable absorption affects:

- broadband spectral shape
- iron line
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Other possible wind effects:

- disk outer boundary
- jet shape (S. Heinz’s talk)
- $\gamma$-rays from jet-wind interaction