Spectroscopy of the stellar wind in the Cygnus X-1 system

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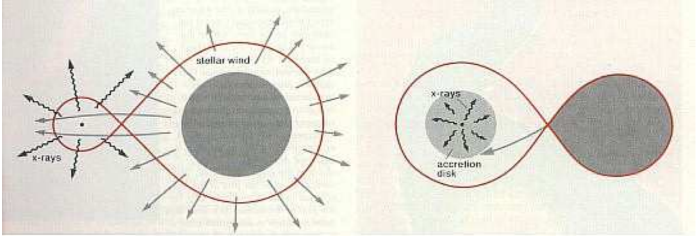
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Black Hole Universe

September 22, 2010

Outline of the talk

Accretion in X-ray Binaries



- stellar wind accretion in High Mass X-ray Binaries (HMXB)
- accretion disk accretion in Low Mass X-ray Binaries (LMXB)
- efficient energy release, X-ray luminosities $\sim 10^{38}$ erg/s

Stellar wind of HMXBs

- hot, O or early B stars: winds driven by absorption lines
- very strong: mass loss rate $\sim 10^{-6} M_{\odot}/\mathrm{year}$

- Theory: two components of the wind:
  cool dense clumps embedded by hot photoionized gas
  (Castor, Abbot, Klein, 1975; Sako et al. 2002)

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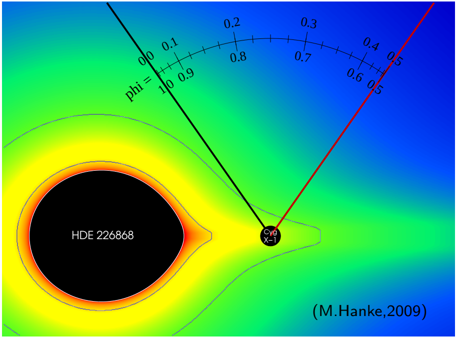
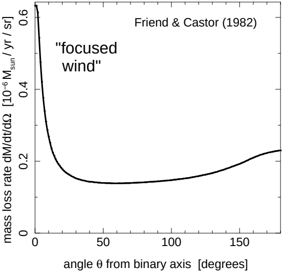
- wind structure can be probed directly by Chandra high-resolution spectroscopy
  (with bright sources like Cyg X-1)

The high-mass X-ray binary system Cygnus X-1

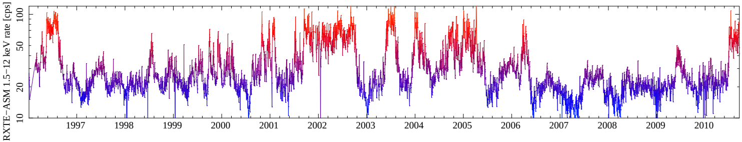
Focused stellar wind in the system

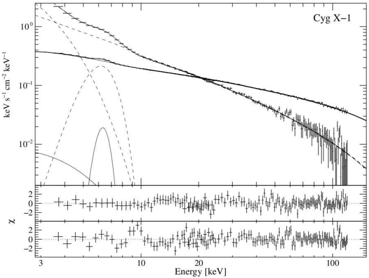




Hard and Soft State of the Cygnus X-1

- hard or soft





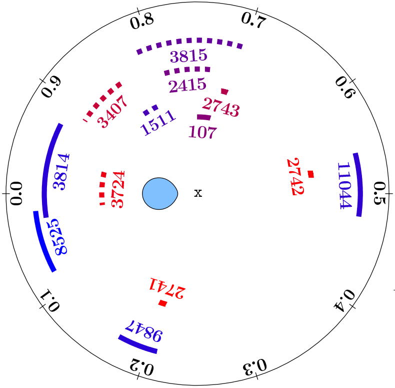
In the low/hard state:

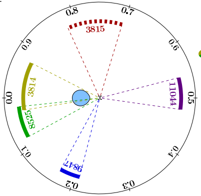
- hard powerlaw spectrum,
- low *soft X-ray luminosity,*
- high *radio flux*

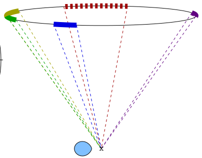
In the high/soft state:

- thermal spectral component
- high *soft X-ray luminosity*,
- low *radio emission*.

Chandra observations of Cygnus X-1







hard → soft state — TE mode, ⋯ CC mode $i \approx 35^\circ$

Goals and aims of the research

We focus on

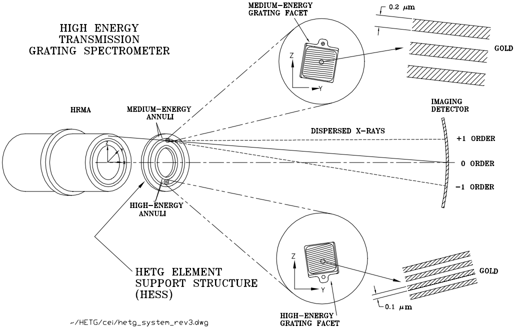
- High Mass X-ray Binaries, especially Cyg X-1
- strong and focused stellar wind and its properties
- source states transitions
- understanding of the accretion process

by detailed

- study of photoionization of material (high X-ray luminosity)
- spectral analysis of absorption lines

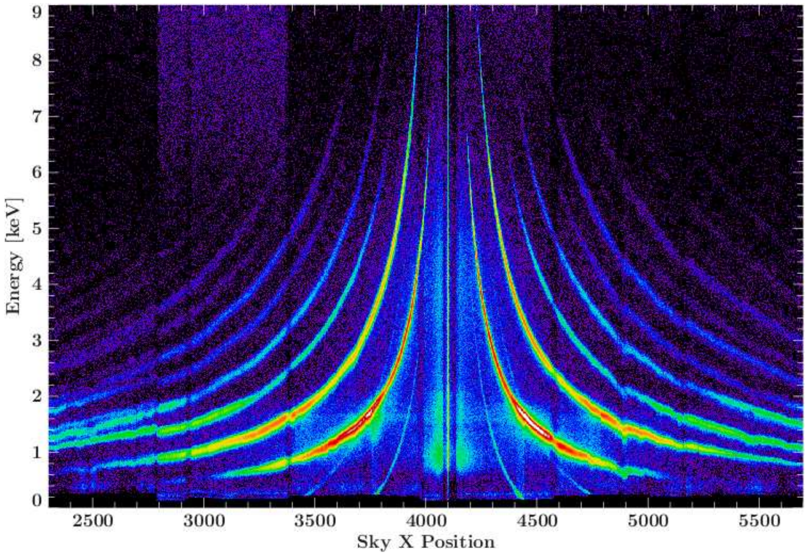
Chandra High Energy Transmission Grating (HETG)

- two sets of gratings: the High and the Medium Energy Grating (HEG and MEG)



Grating equation: $m.\lambda = p.\sin\beta$

Data reduction with CIAO 4.2 and order-sorting problem



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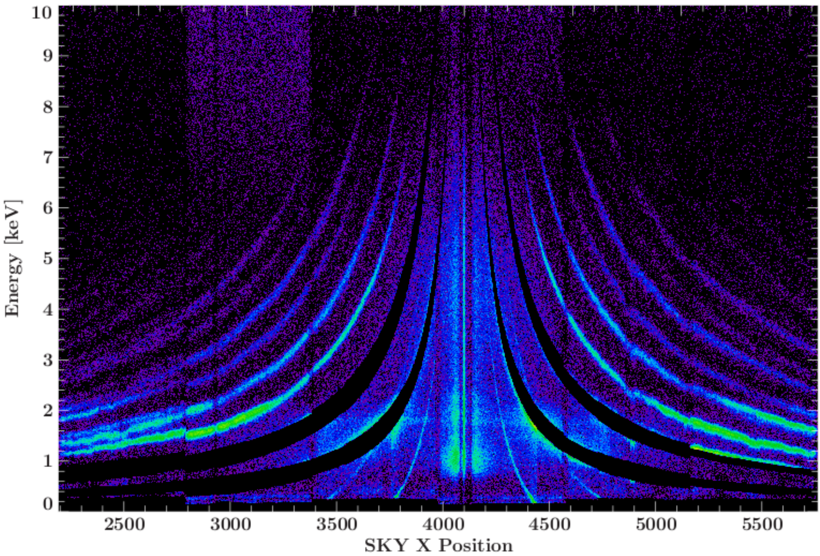
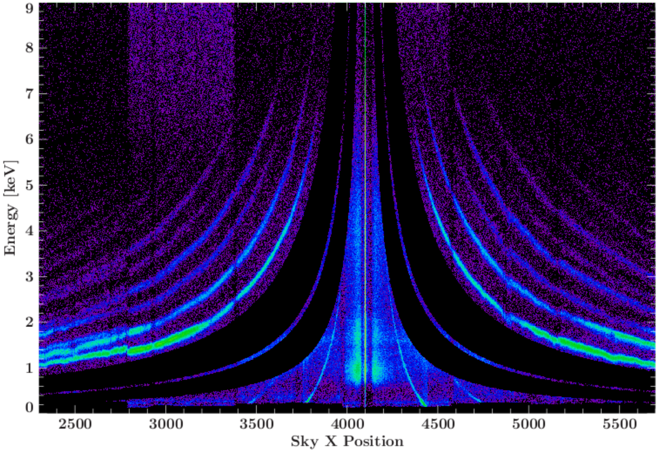
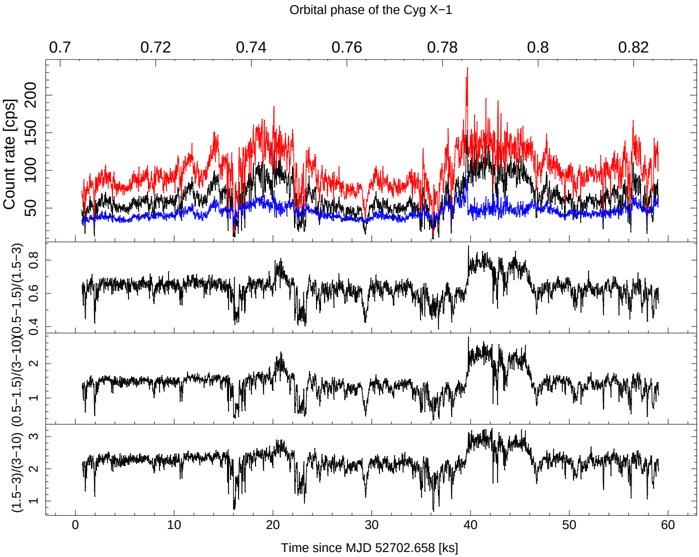


Data reduction with CIAO 4.2 and order-sorting problem

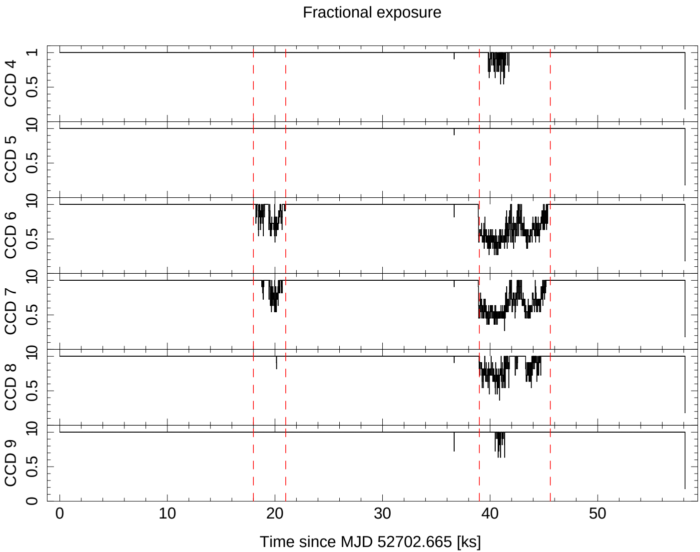
Solution: tg_resolve_events ⇒ *osipfile*="none", *osip_lo* and *osip_hi*



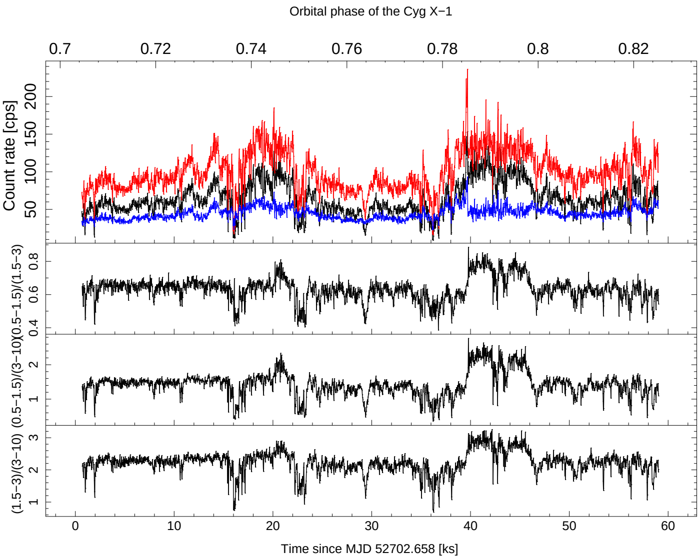
ObsID 3815 - light curve



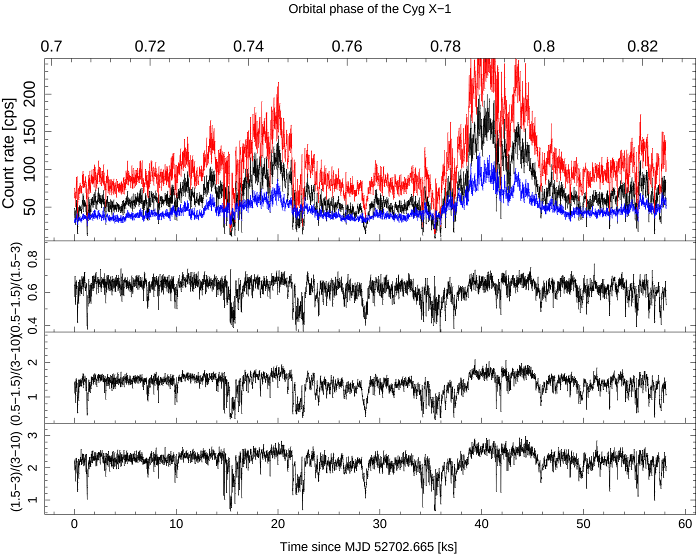
Telemetry saturation



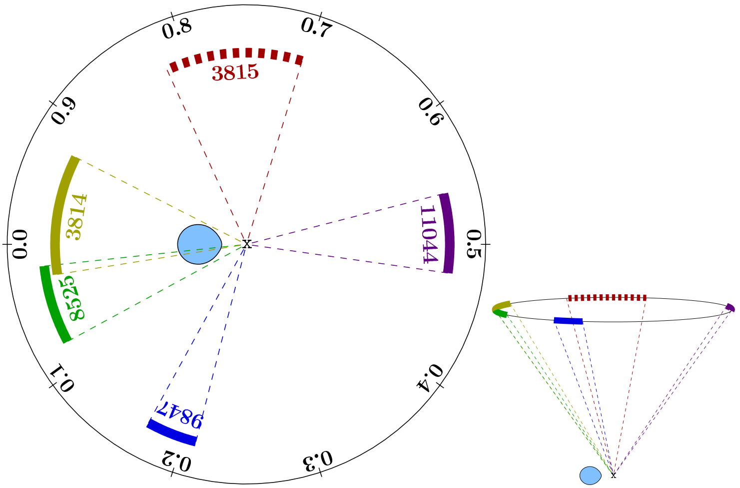
ObsID 3815 - corrected light curve



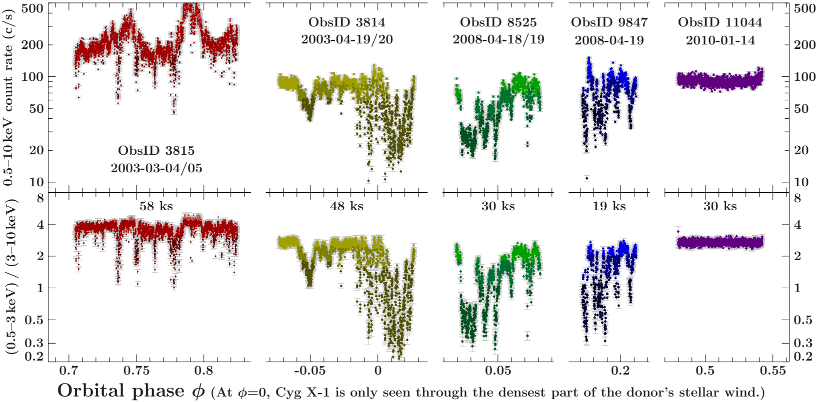
ObsID 3815 - corrected light curve



Compared *Chandra* observations of Cygnus X-1

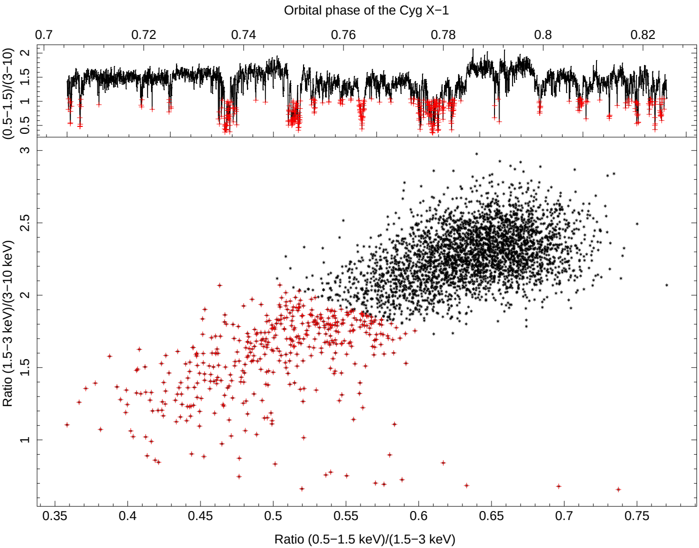


Light curves of Cyg X-1 at prominent phases

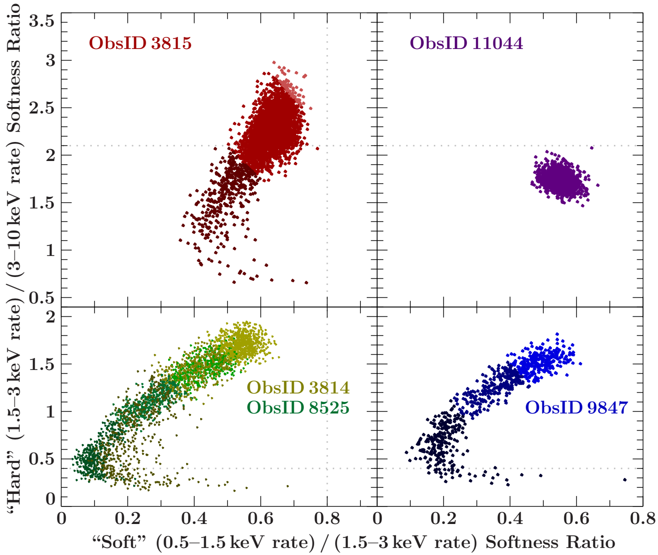


- $\phi \approx 0$: violent absorption dips
- dipping occurs already at $\phi \approx 0.7$ and has not ceased at $\phi \approx 0.2$
- $\phi \approx 0.5$: totally free of dips!

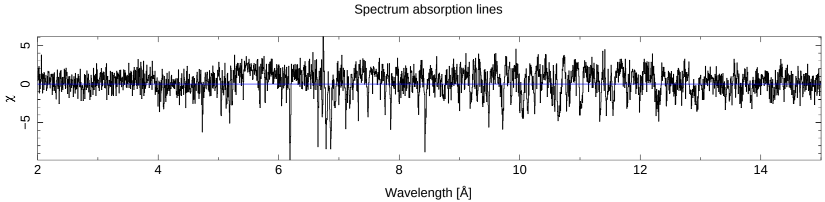
ObsID 3815 - Color-color diagram



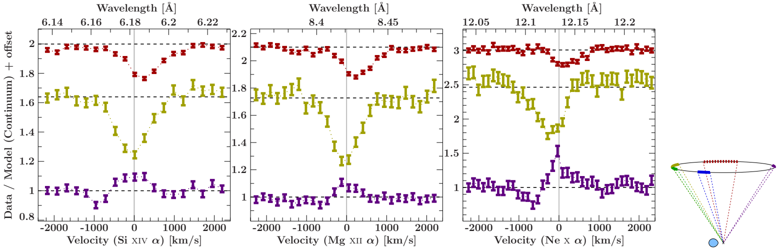
Color-color diagrams - comparison



Absorption lines



Absorption and P Cygni profiles of Si XIV, Mg XII, Ne X

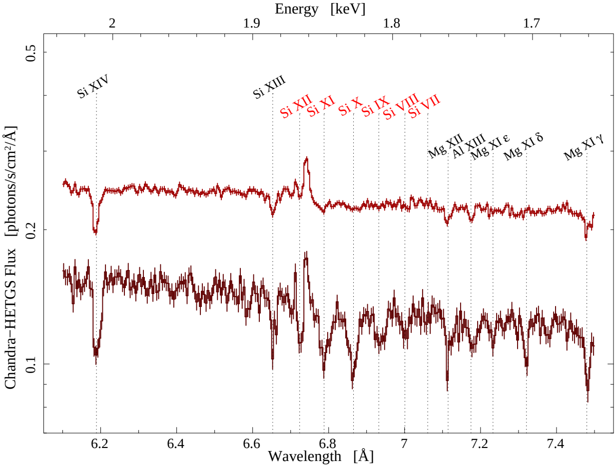


- $\phi\approx0$: strong absorption lines, $v_{\rm rad}\approx0$
- $\phi\approx0.5$: P Cygni profiles:
  strong emission at $v_{\rm rad}\approx0$ and weak absorption tail blueshifted by $\sim 500-1\,000\,km/s$

$\Rightarrow$ if the same plasma is observed in both cases $\Rightarrow$ the real velocity has to be small $\Rightarrow$ we see a dense wind close to the stellar surface

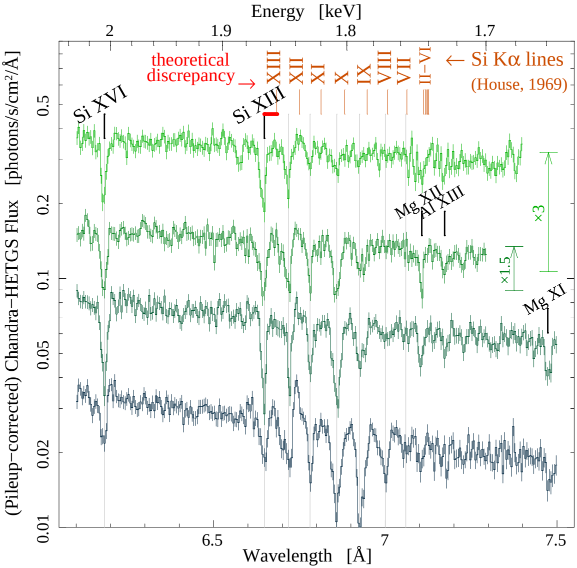
- $\phi\approx0.7$: absorption lines, but redshifted by $\sim 200-300 km/s$

Si absorption lines



- non-dip spectrum: Si XIV and Si XIII
- dip spectrum: additional absorption lines of Si XII–VII

Si absorption lines



Summary

- Comparison of $\phi \approx 0$, $\phi \approx 0.2$, $\phi \approx 0.5$, $\phi \approx 0.7$
- Strong absorption dips around $\phi \approx 0$, while NO dips at $\phi \approx 0.5$
- P Cygni profiles observed for the first time in Cyg X-1! at $\phi \approx 0.5$ in contrast to strong pure absorption at $\phi \approx 0 \Rightarrow$ environment close to stellar surface
- Si absorption lines of lower ionization stages present only in dip spectra$\Rightarrow$ inhomogeneities of lower temperature in the wind

Outlook

- Photoionization modeling
- Wind structure modeling

The high-mass X-ray binary HDE 226868/Cygnus X-1

HDE 226868 parameters:

- O9.7 Iab supergiant
- $M_\star = 18\,M_\odot$
- $T_{\rm eff} = 32\,000\,$K
- $L_\star = 250\,000\,L_\odot$
- $R_\star \approx 17\,R_\odot$
- $v\ \sin\ i = 76\,$km/s
- fills $\approx$90 % of Roche lobe volume
- $\dot{M}_\star = 3{\times}10^{-6}\,M_\odot$/yr

Binary system parameters:

- orbital period $P = 5.6\,$d
- distance $d \approx 2.5\,$kpc
- binary separation $a = 41\,R_\odot$

Cyg X-1 parameters:

- $M_{\rm BH} = 10\,M_\odot$
- $L_X \approx 10\,000\,L_\odot$

Advanced CCD Imaging Spectrometer (ACIS) focal plane