Multi-Satellite Observations of Cygnus X-1

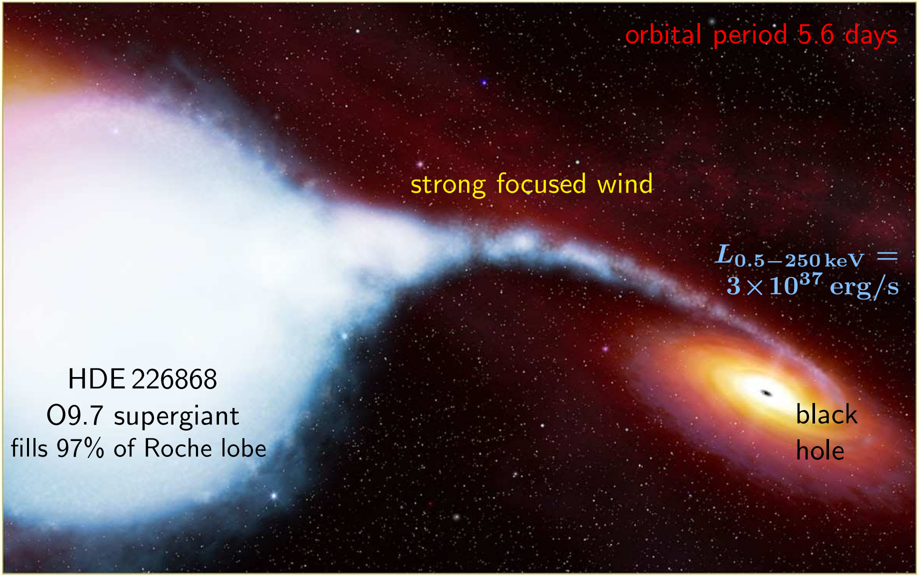
to Study the Focused Wind and Absorption Dips

Manfred Hanke* J. Wilms* M.A. Nowak K. Pottschmidt
F. Fürst* M. Böck* N.S. Schulz J.C. Lee

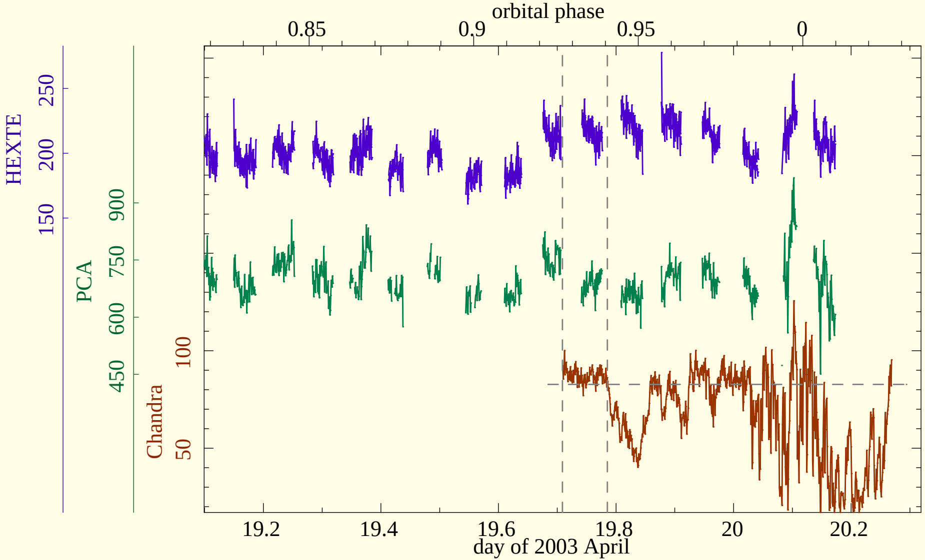
* Dr. Karl Remeis-Observatory
Bamberg, Germany

ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

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



Simultaneous *Chandra* + *RXTE* observation of Cyg X-1 (2003 April)



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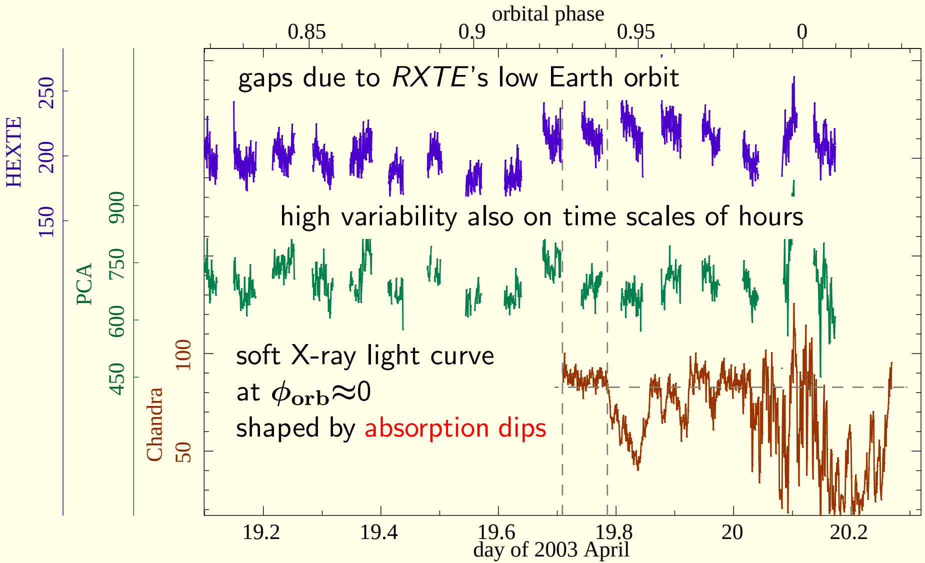
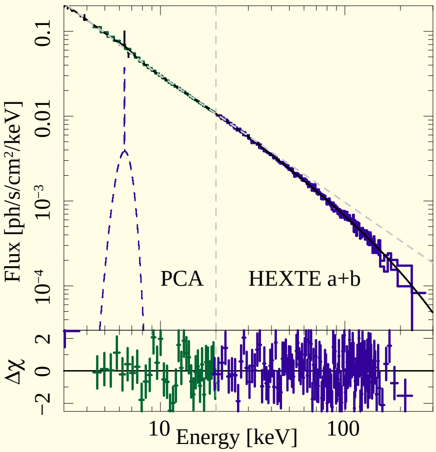


Joint spectral analysis of the non-dip continuum



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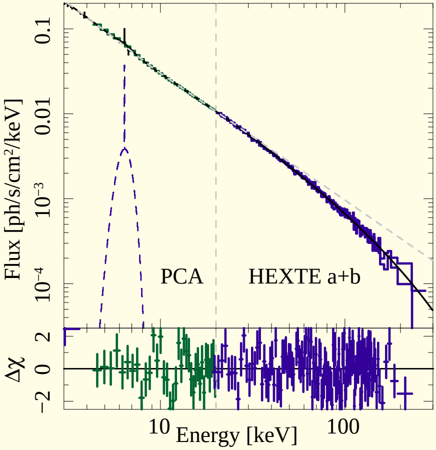
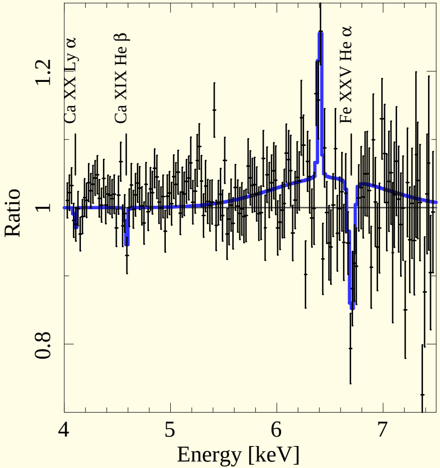
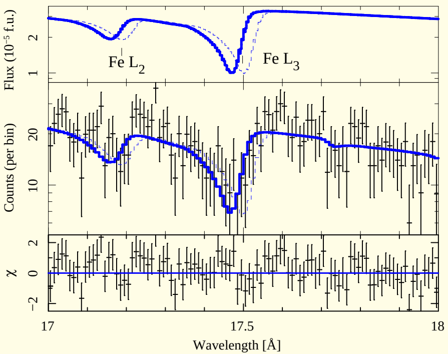
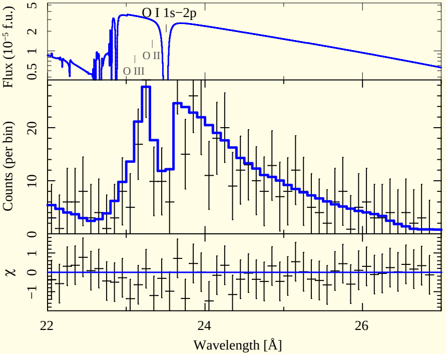




presence of both broad & narrow Fe Kα line
(More details on Iron lines will be given in the next talk by M. Nowak)

Neutral absorption by the interstellar medium (+ source environment)





- structured absorption edges
  - Fe $L_{2/3}$-edge at 17.2 Å / 17.5 Å
  - O K-edge at 22.8 Å with Kα resonance absorption line
  - Ne K-edge at 14.3 Å with Kβ resonance absorption line
- modeled with `tbnew`, an improved version of `tbvarabs`

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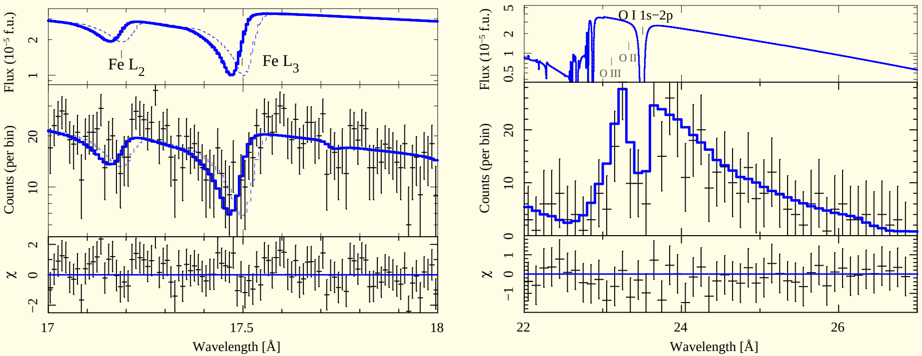

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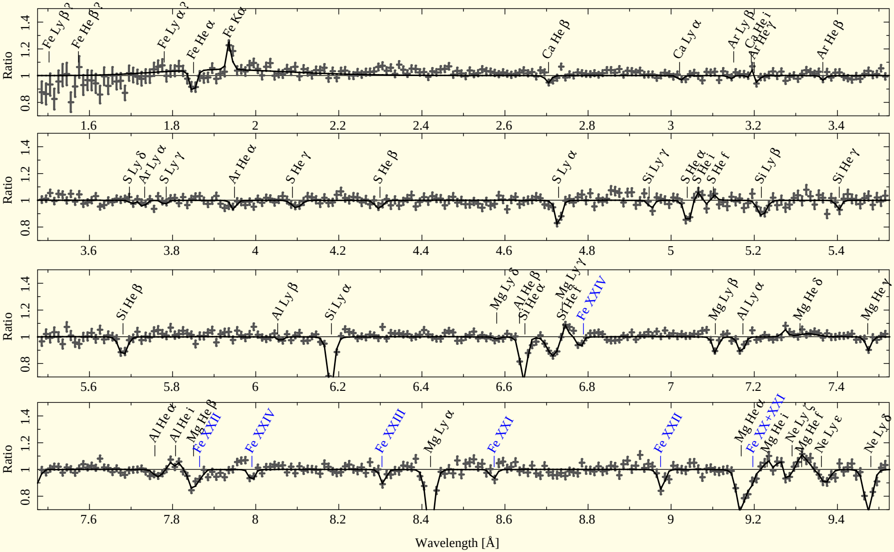
Non-dip *Chandra* HETGS spectrum: 1.5– 9.5 Å (8.3–1.3 keV)



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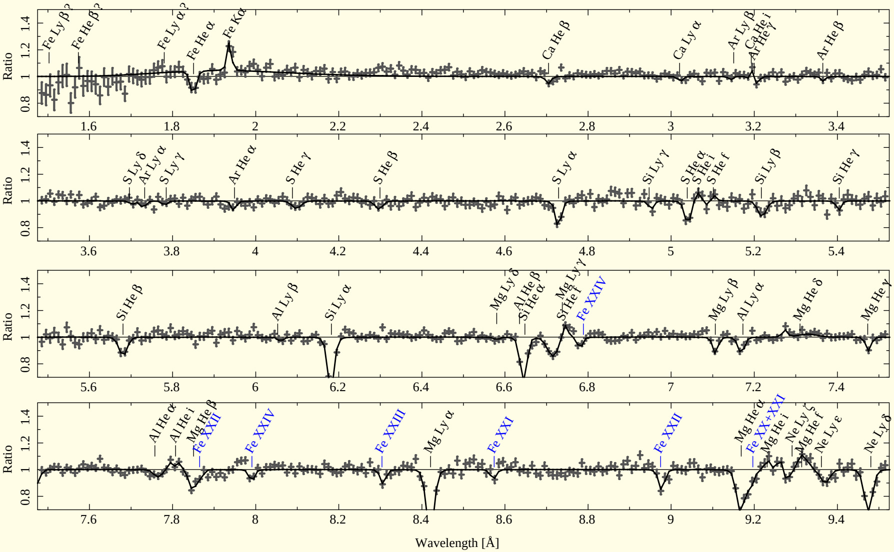
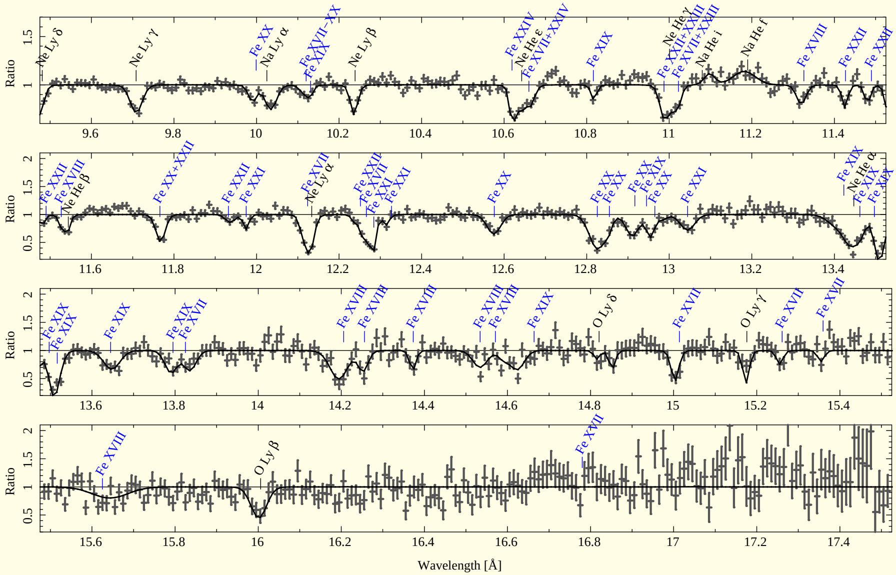


plenty of absorption lines from the stellar wind
of H- and He-like O, Ne, Na, Mg, Al, Si, S, Ar, Ca, Fe

Non-dip *Chandra* HETGS spectrum: 9.5–17.5 Å (1.3–0.7 keV)



plenty of absorption lines from the stellar wind of Fe L-shell ions

Doppler shift in absorption lines: $|v| < 200\,\mathrm{km\,s^{-1}}$

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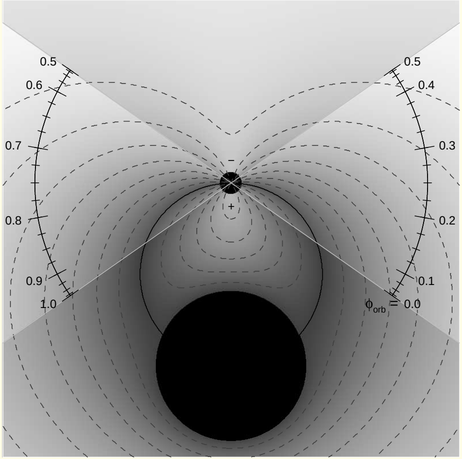
- can be understood within a simple (spher. symmetric) CAK-model for the wind:

$$v(r) \;\sim\; v_\infty \cdot \left(1 - \frac{R_\star}{r}\right)^\beta$$

projected velocity against the black hole



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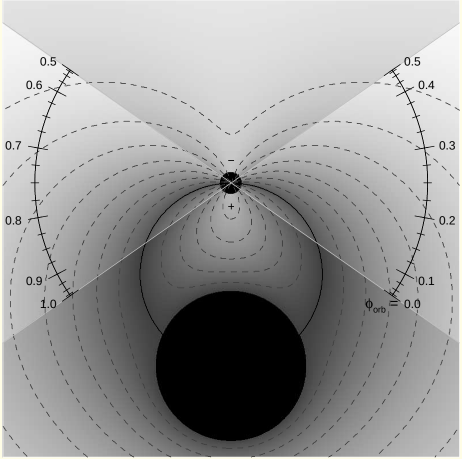

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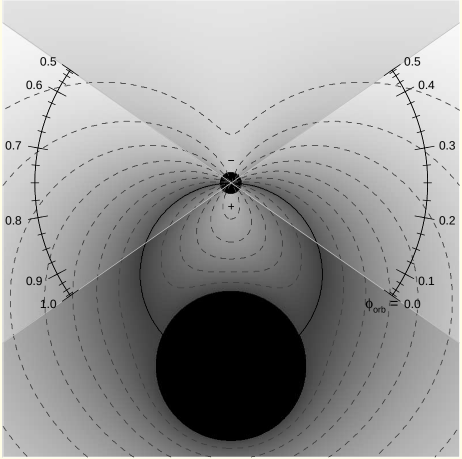
  $\Rightarrow$ observations constrain the location of the absorber

- distances agree with XSTAR simulation of the photoionization structure

projected velocity against the black hole



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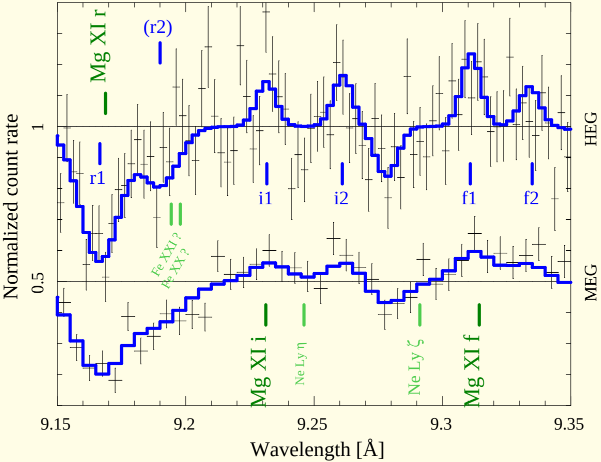
He-like Mg XI i and f emission lines



- 2 pairs of i and f emission lines
- i1 & f1 ≈ at rest
- i2 & f2 at $v =$ 500–900 km s^{-1}

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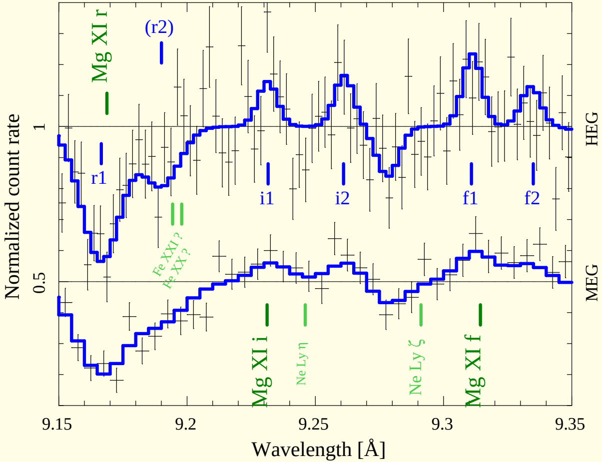

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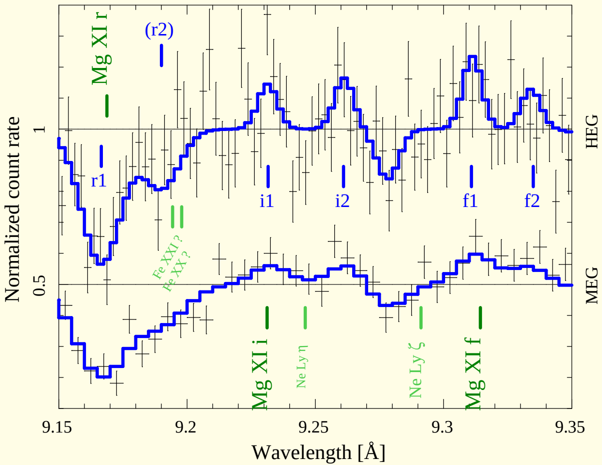
(absolute) density diagnostics not applicable due to UV-radiation

He-like Mg XI i and f emission lines → spherical + focused wind



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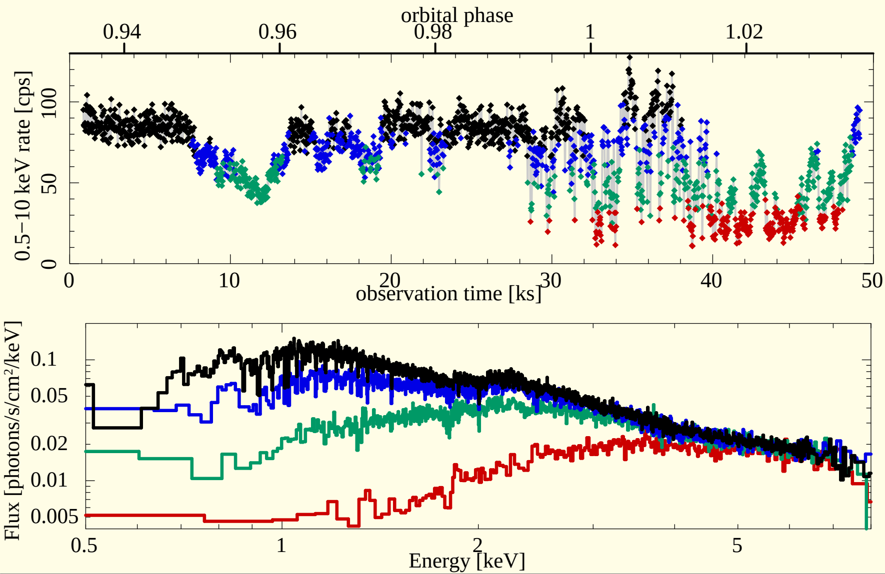
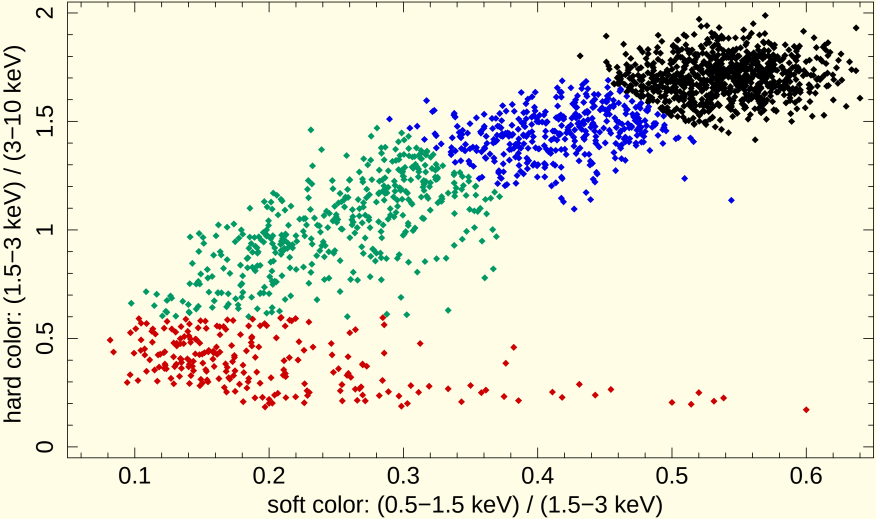
Analysis of the dip spectra

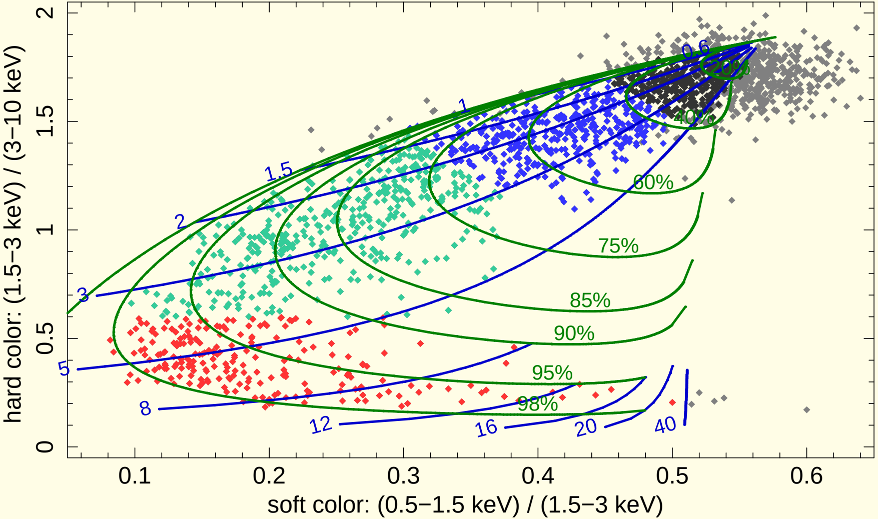


The dips in a color-color diagram



The dips in a color-color diagram require a partial covering model:

$$(1 - f_c) \cdot \exp\left(-5.4\cdot 10^{21}/\mathrm{cm}^2 \cdot \sigma(E)\right) + f_c \cdot \exp\left(-N_{\mathrm{H},2} \cdot \sigma(E)\right)$$



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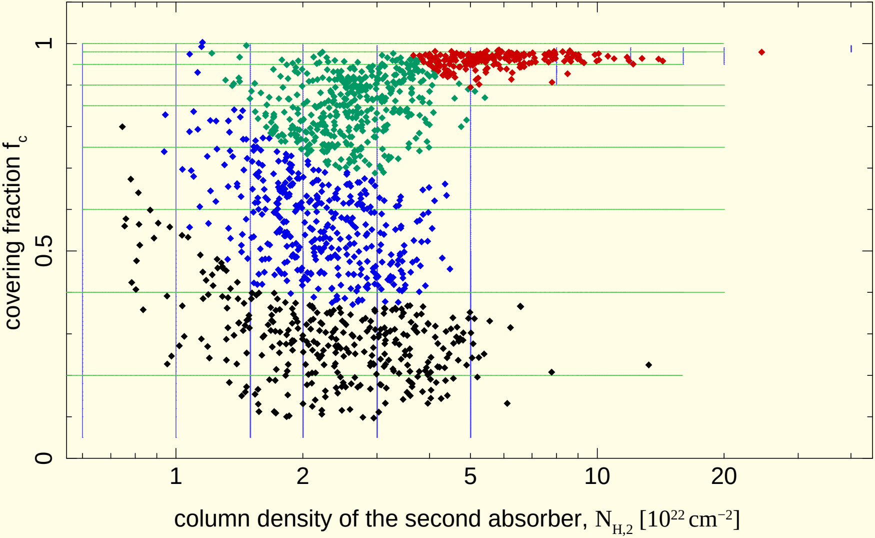
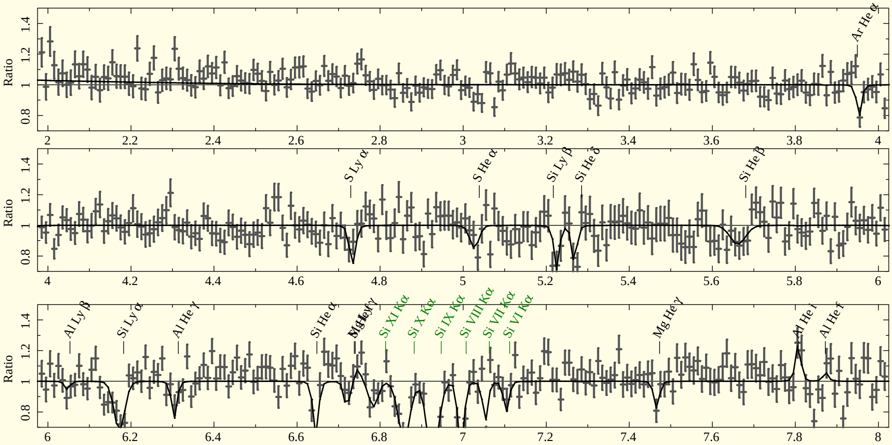


The first dip's *Chandra* HETGS spectrum: 2–8 Å (6.2–1.5 keV)



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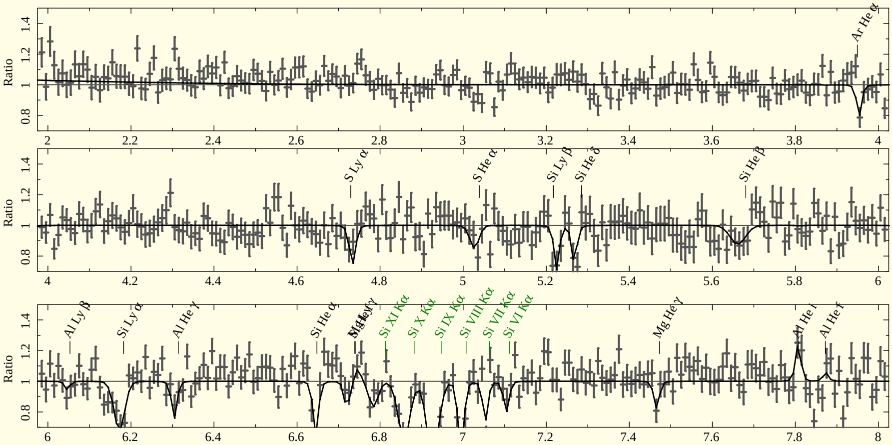


resonance Kα absorption lines of lower ionization stages of silicon

Summary

Wind

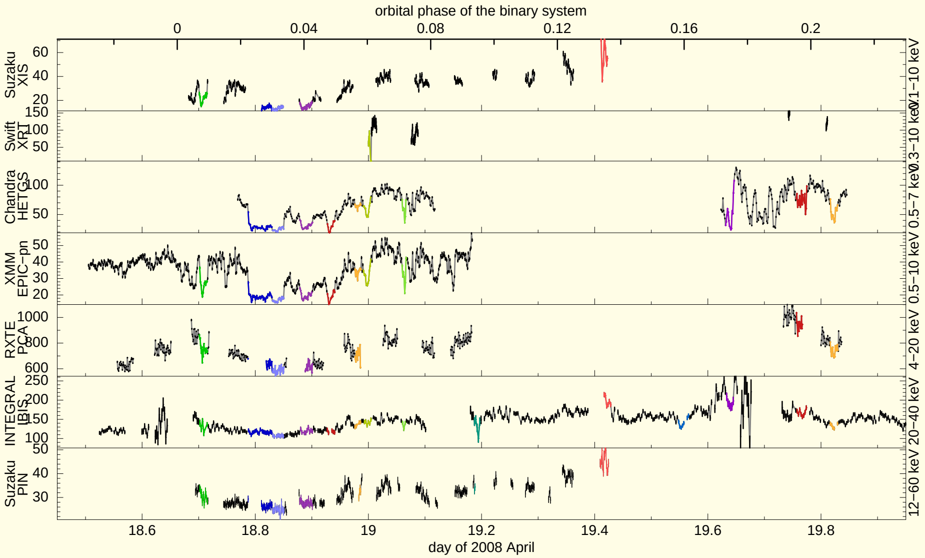
- The photoionized spherical wind can be detected in absorption lines.
- There is also evidence for a dense focused wind.

⇒ The wind has a complex structure (photoionization, velocity, density).
(Changes in the wind properties *could* trigger state transitions.)
All details are given by Hanke et al. (2008; just accepted by ApJ).

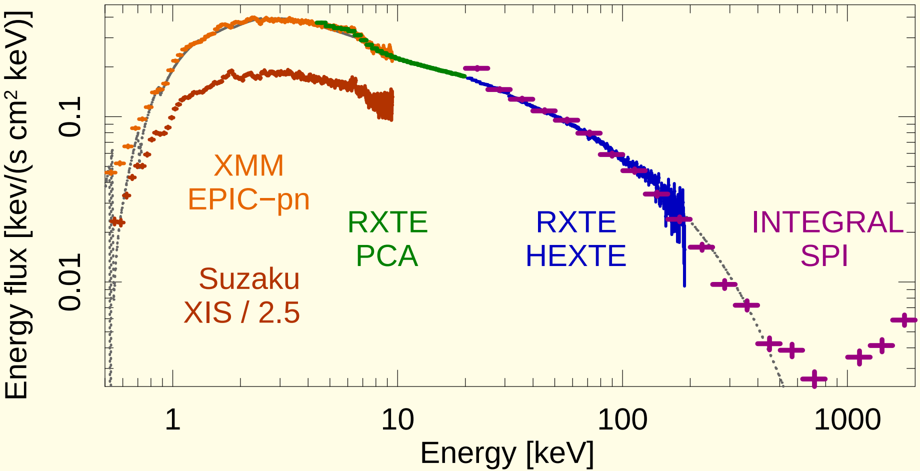
Dips

- Cyg X-1 experiences soft X-ray absorption dips close to $\phi_{\mathbf{orb}} = \mathbf{0}$.
- During dips, an additional absorber covers up to 98 % of the source.
  Lower ionization stages indicate colder / denser (shielded) material.

Lightcurves (*Suzaku*, *Swift*, *Chandra*, *XMM*, *RXTE*, *INTEGRAL*, *Suzaku*)



The 0.5 keV – 2 MeV **broad** band spectrum



Appendix

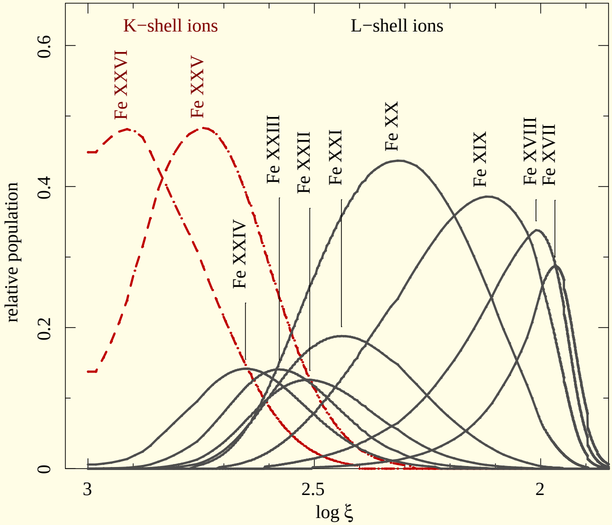
Thales of Miletus


7. MICROQUASAR WORKSHOP
September 1-5 2008
Foça,İzmir Turkey
TÜBİTAK
Sabancı Üniversitesi
FOÇA BELEDİYESİ
EUXINUS
Galatia
CAPPADOCIA
LYCAONIA
PISIDIA
CARIA
LYCIA
CILICIA
SYRIA
CYPRUS
Lesbos
Phocaea
Chios
Smyrna
Ephesus
Samos
Miletus
Rhodes
Crete
Sardis
Pergamum
Ancyra
Tarsus
ANTIOCH
Salamis
Strait of Cilicia

Thales of Miletus Foça Ephesus

Thales of Miletus lived ≈120 km south-southeast of Foça, 2.5 kyr ago

XSTAR simulation of the wind's photoionization structrue



$$\xi = \frac{L}{n_\mathrm{H}\, r^2} = 100\,\frac{\mathrm{erg\,cm}}{\mathrm{s}} \cdot \frac{L_{37}}{n_{11}\, r_{12}^2}$$

$$L \approx 3\times10^{37}\,\mathrm{erg}$$
$$n_\mathrm{H} \approx 10^{11}\,\mathrm{cm}^{-3}$$
$$a = 2.9\times10^{12}\,\mathrm{cm}$$

Goals of a multi-satellite observation of Cyg X-1

- spectroscopic analysis of further absorption dips

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  - requires high-resolution grating spectra $\longrightarrow$ *Chandra*

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  - requires good signal-to-noise at high resolution $\longrightarrow$ *XMM*

Goals of a multi-satellite observation of Cyg X-1

joint *XMM-Chandra* observation at $\phi_{\mathrm{orb}} = 0$

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  - requires high-resolution grating spectra $\rightarrow$ *Chandra*
  - requires well constrained continuum $\rightarrow$ *RXTE*
- analysis of the Iron Kα line
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Goals of a multi-satellite observation of Cyg X-1

extended joint *XMM-Chandra* observation at $\phi_{\rm orb} = 0$

- spectroscopic analysis of further absorption dips
  - requires high-resolution grating spectra $\rightarrow$ *Chandra*
  - requires well constrained continuum $\rightarrow$ *RXTE*
- analysis of the Iron Kα line
  - requires good signal-to-noise at high resolution $\rightarrow$ *XMM*
- studying the wind at very hard X-rays
  - requires γ-ray instruments $\rightarrow$ *INTEGRAL*

Goals of a multi-satellite observation of Cyg X-1

extended joint *XMM-Chandra* observation at $\phi_{\rm orb} = 0$ + good luck...

- spectroscopic analysis of further absorption dips
  - requires high-resolution grating spectra $\longrightarrow$ *Chandra*
  - requires well constrained continuum $\longrightarrow$ *RXTE*
- analysis of the Iron Kα line
  - requires good signal-to-noise at high resolution $\longrightarrow$ *XMM*, Suzaku
- studying the wind at very hard X-rays
  - requires γ-ray instruments $\longrightarrow$ *INTEGRAL*, *Swift*, *Agile*
- studying the jet (Cyg X-1 is a microquasar!)
  - requires radio monitoring $\longrightarrow$ *VLA*