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Wind absorption in Cygnus X-1

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Abstract

Although Cygnus X-1 is the best studied BH X-ray binary, whose persistent brightness is powered by accretion of the focused stellar wind of the supergiant companion, the detailed accretion geometry is not yet understood. We present the spectroscopic analysis of the photoionized wind from a 50 ks observation obtained with the *Chandra* ACIS-S/HETGS on April 2003 during superior conjunction of the black hole, when the source was in its hard state. Detection of absorption lines from mostly H- and He-like ions allow us to study the ionization state and composition of the stellar wind in detail. We use a model that consistently describes the whole series of lines from each ion at once. Furthermore, the observation contains absorption dips, probably from clumps in the accretion flow, which are analyzed as well.

The observation and data reduction

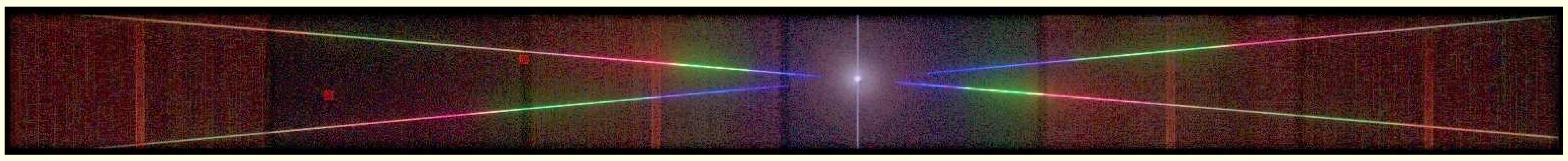

Figure 1: Dispersed image from *Chandra*'s HETGS, detected by ACIS-S. The source is surrounded by an X-ray scattering halo (Xiang et al., 2005).

We observed Cygnus X-1 on 2003 April 19–20 for 50 ks with *Chandra*'s spectroscopy array of the Advanced CCD Imaging Spectrometer (ACIS-S). The High Energy Transmission Grating Spectrometer (HETGS), containing High and Medium Energy Gratings (HEG/MEG), was used to produce X-ray spectra in the 1 Å . . . 20 Å range with highest resolution: $\Delta\lambda_{\mathrm{HEG}} = \Delta\lambda_{\mathrm{MEG}}/2 = 5.5\,\mathrm{m}\text{Å}$ (Fig. 1). The detector was operated in Timed Event (TE) mode with an exposure time of $t_{\mathrm{frame}} = 1.7\,\mathrm{s}$ per readout frame. We reduced the raw event lists with standard tools (CIAO 3.3) and analyzed the spectra with ISIS 1.4.7.

Pile-up in the CCD detector

Photons from the bright source Cyg X-1 may pile up in one detector pixel, even during the short frame time. In contrast to the zero order image, which is severely piled up, the dispersed spectra suffer only from moderate pile-up, which can be described very well by the `simple_gpile` model, developed at MIT/CXC and further improved for the needs in this work: the spectral count rate C [in units of $(\mathrm{s\,Å})^{-1}$] in a bin i is reduced in a nonlinear way:

$$C'(i) = \exp\left(-\beta\cdot C(i)\right)\cdot C(i), \quad \text{where} \quad \beta \approx 3\,\Delta\lambda\cdot t_{\mathrm{frame}}\,.$$

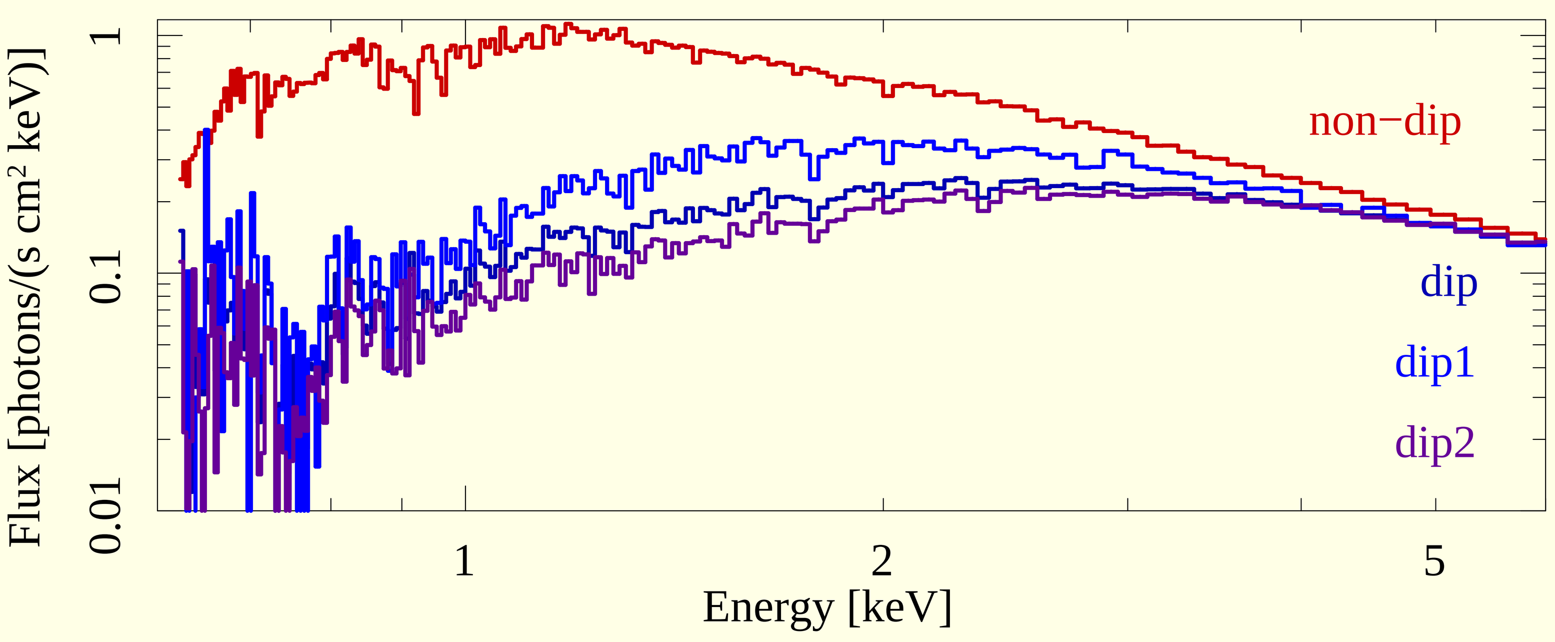

Figure 3: Spectral photon flux for 'non-dip' and 'dip' spectra (cf. Fig. 2).

Time variable absorption dips

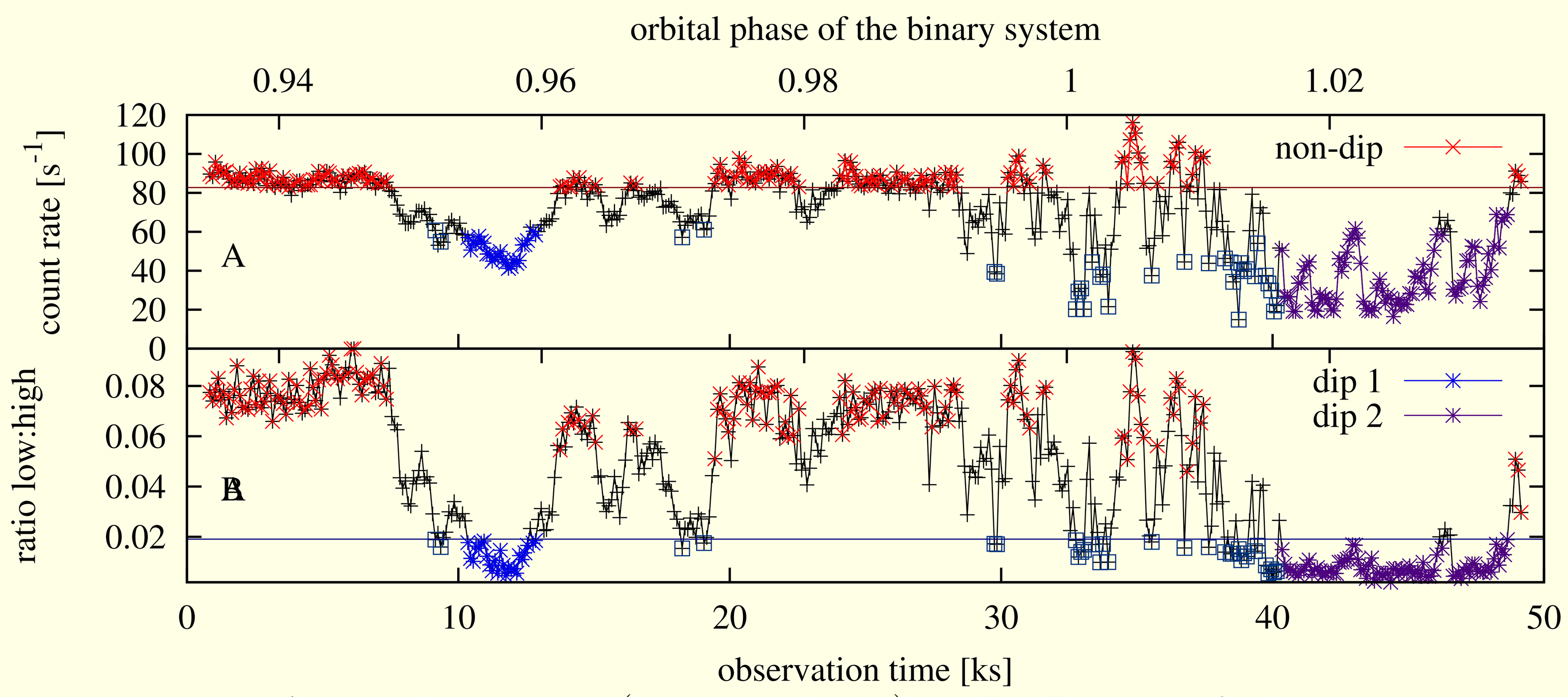

Figure 2: A: Light curve (0.5–7.2 keV). B: Ratio of the count rates in a low energy (0.7–1.0 keV) and a high energy (2.1–7.2 keV) band.

The observation covers orbital phase 0.93–0.03 of the binary system (P = 5.6 d). We chose this time to study the absorption dips preferentially seen at superior conjunction of the black hole. The light curve (Fig. 2 A) shows two major dips with complex substructures. Low energies are more strongly affected by the dips than high energies (Fig. 2 B). The curves of Fig. 2 define extraction times for 'non-dip' and 'dip' spectra.

Spectral analysis: identification of the continuum and high-resolution spectroscopy

Consistent with the broad band spectra simultaneously obtained with *RXTE*/PCA and HEXTE (Wilms et al., 2006), the 'non-dip' continuum spectrum in the 0.5–7.2 keV range can be described by a $\Gamma = 1.5$ power law, photoabsorbed by $N_{\mathrm{H}} = 4\cdot 10^{21}\,\mathrm{cm}^{-2}$ (Fig. 3). The 'dip' spectra require higher absorption, but also another model: The available data predict a lower Γ even if only partial covering of the source by clumps during the dips is considered.

The high-resolution spectra show many absorption lines from H- and He-like ions of O, Ne, Mg, Al, Si, S, Ar and Ca. He-like (r, i, f)-triplets are mostly observed as well, with the forbidden i- and f-line seen in emission. Furthermore, lots of iron L-shell transitions in the 10 Å . . . 15 Å range are detected. All absorption lines from a specific ion's common ground state are fitted simultaneously with a line series model which directly gives the ion's column density.

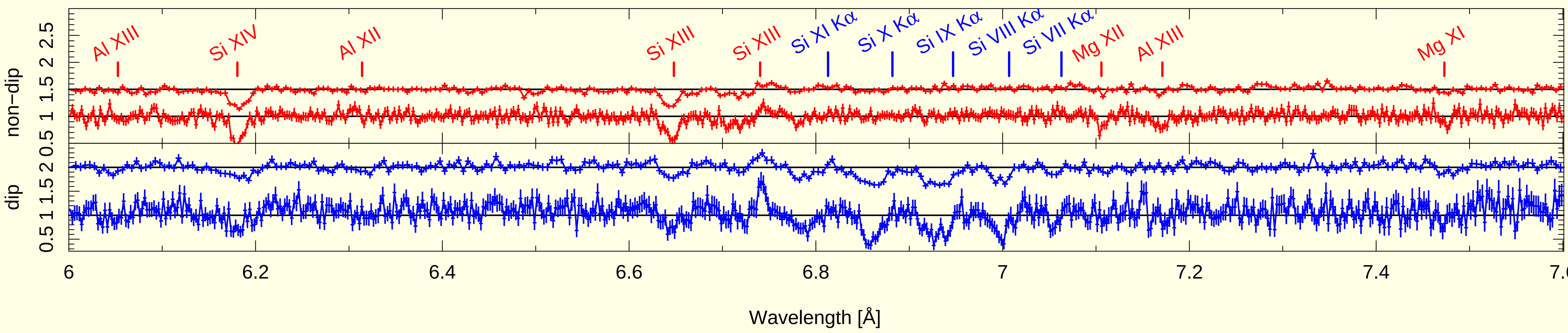

Figure 4: Ratio data/continuum for the 'non-dip' (red) and the 'dip' (blue) spectrum. The MEG-spectra are shown on top of the HEG spectra.

The stronger absorbed 'dip' spectrum has a worse signal-to-noise ratio and shows less lines than the 'non-dip' spectrum. In the 6.8 Å . . . 15 Å range, however, new lines emerge which can be identified with K α lines of lower ionized silicon (Fig. 4). This confirms that the dips are caused by cold, dense clumps.

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Conclusions

A high-resolution X-ray spectrum of Cygnus X-1 during superior conjunction can reveal many properties of the focused stellar wind.

References

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Xiang J., Zhang S.N., Yao Y., 2005, ApJ 628, 769