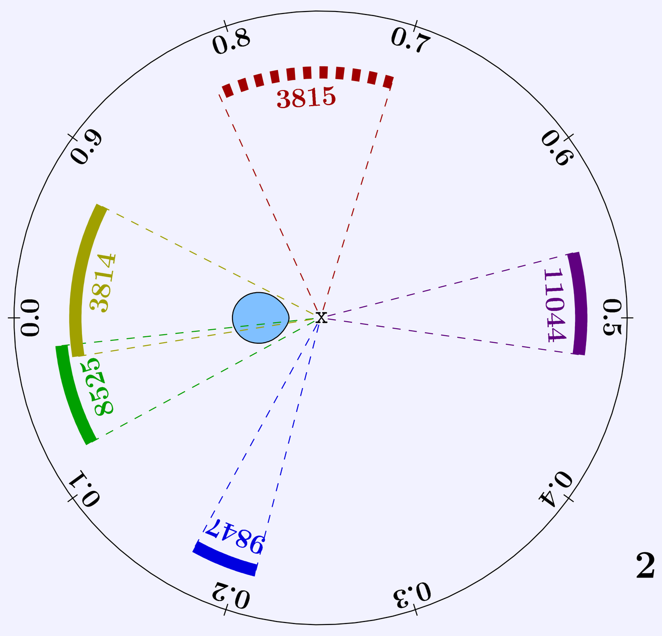
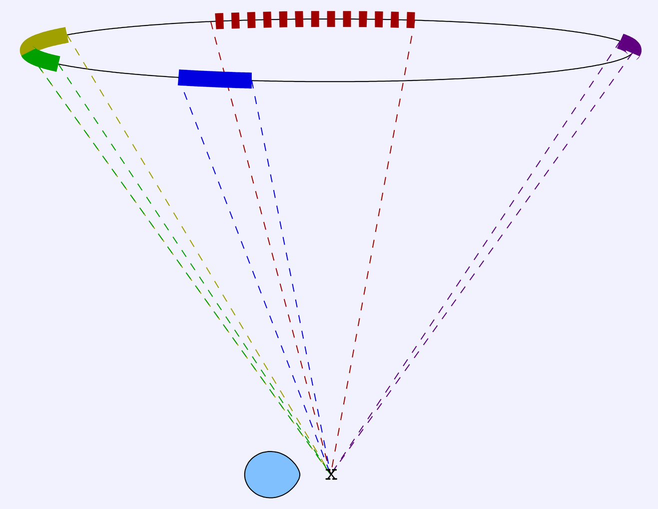


Spectroscopy of the stellar wind in the Cygnus X-1 system

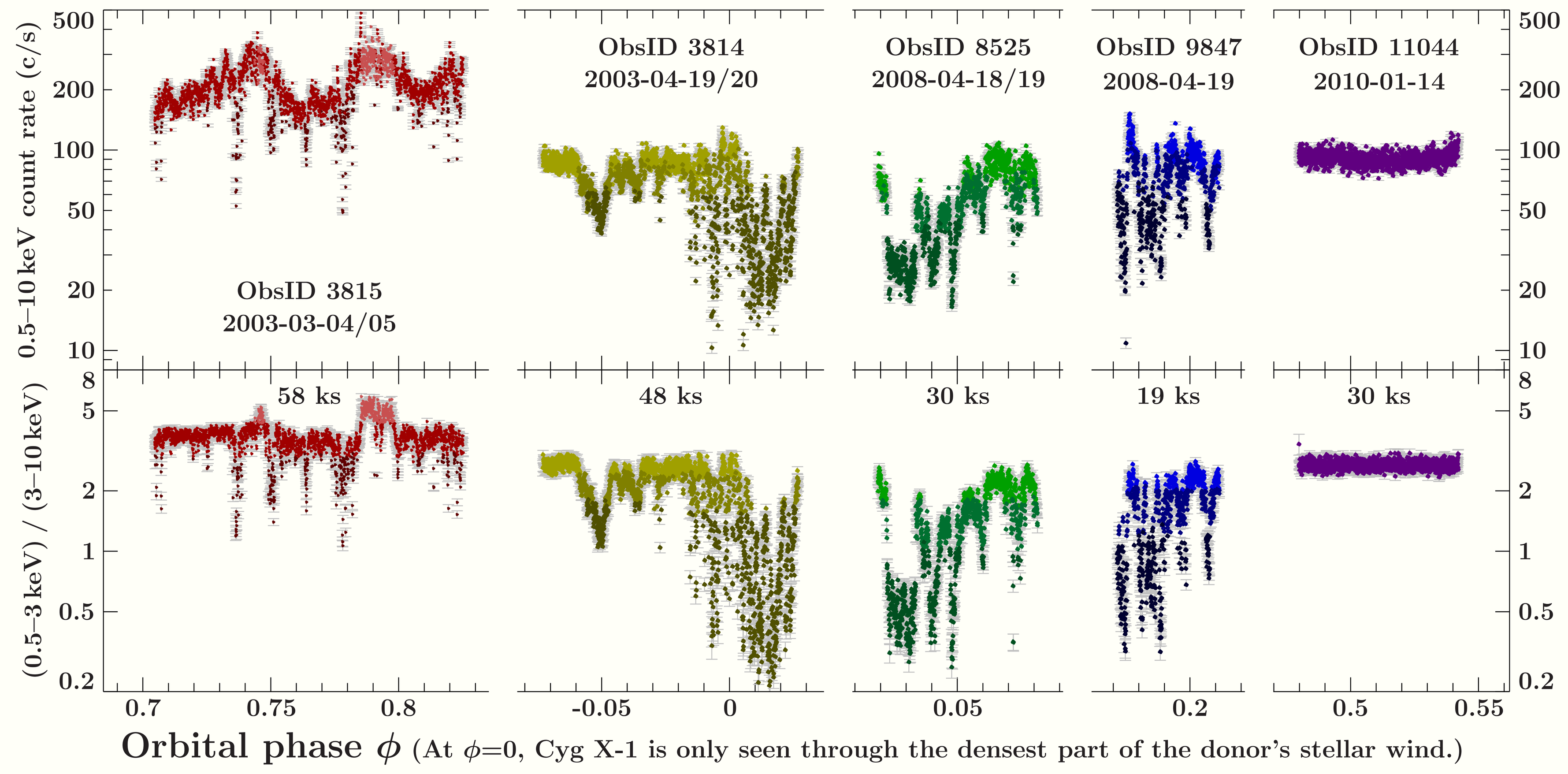
Ivica Miskovicova[1], Manfred Hanke[1]
{Ivica.Miskovicova, Manfred.Hanke}@sternwarte.uni-erlangen.de
Jörn Wilms[1], Michael A. Nowak[2], Katja Pottschmidt[3], Norbert S. Schulz[2]
[1] Remeis-Observatory / ECAP, University of Erlangen-Nuremberg, Germany
[2] MIT/*Chandra* X-ray Center, Cambridge (MA), USA [3] CRESST-UMBC/NASA-GSFC, Greenbelt (MD), USA



Abstract

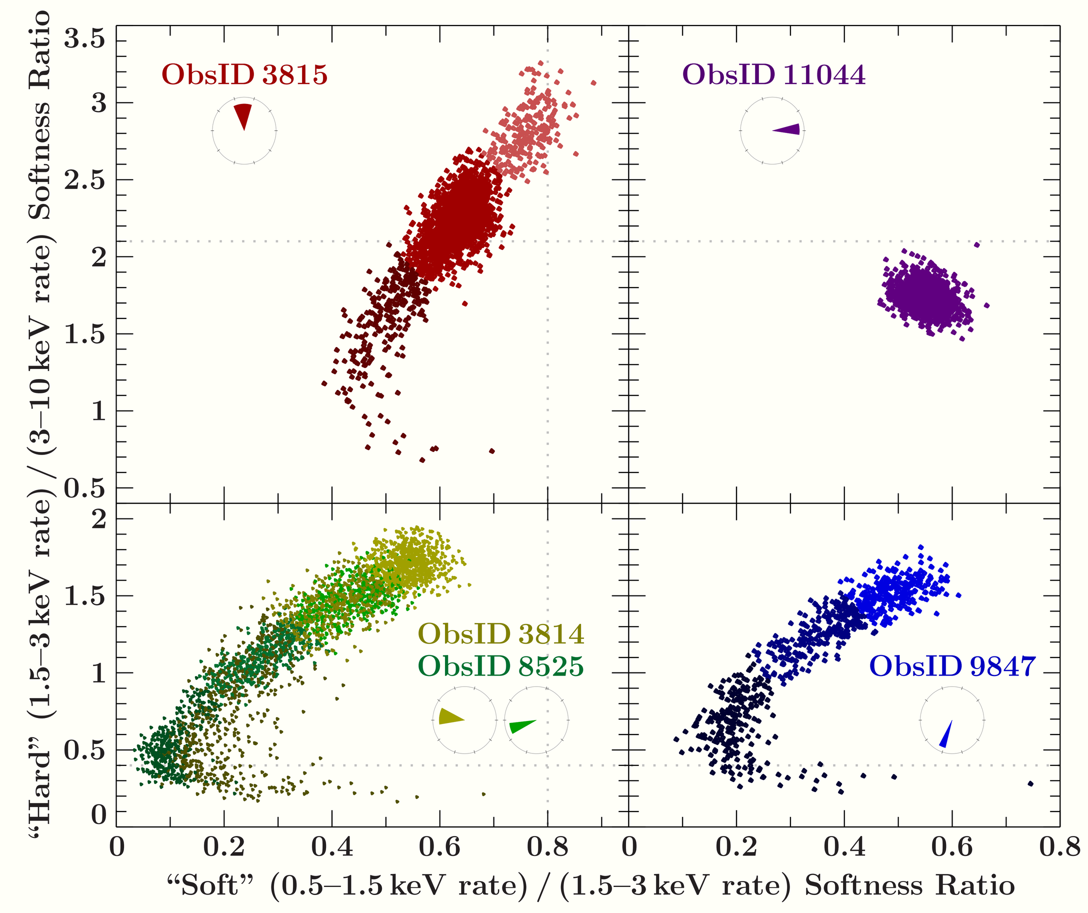
The black hole high-mass X-ray binary Cygnus X-1 is powered by accretion of the stellar wind of its supergiant companion star HDE 226868. As the donor is close to filling its Roche lobe, its wind is therefore not symmetric, but strongly focused towards the black hole. *Chandra*-HETGS observations allow for an investigation of this wind's properties. In the hard state, absorption lines of H- and He-like atoms reveal a highly photoionized wind. As different parts of the wind can be probed at different orbital phases of the binary system, we investigate the structure and dynamics of the wind by comparing observations at the prominent orbital phases ϕ=0, 0.2, 0.5, and 0.75.
In addition, we study transient dips. During these absorption events, caused by density inhomogeneities in the wind, lower ionization stages are detected.

Chandra observations around $\phi \approx$ 0.76, -0.02, 0.05, 0.19, and 0.51



While all recent *Chandra* observations caught **Cyg X-1 in the hard state** at $\lesssim$ 100 c/s, comparable to ObsID 3814, the spectrum was more than twice as high during ObsID 3815. The light curves at $\phi\approx0$ are shaped by violent **absorption dips**, but dipping occurs already at $\phi\approx0.7$ and has not ceased at $\phi\approx0.2$, though the dip events seem to become shorter with distance from ϕ=0. ObsID 11044 at $\phi\approx0.5$ is totally free of dips, yielding 30 ks of remarkably constant flux.

Color-color diagrams reveal dips with partial covering



All of these diagrams show a "*soft* softness ratio" on the x-and a "*hard* softness ratio" on the y-axis.

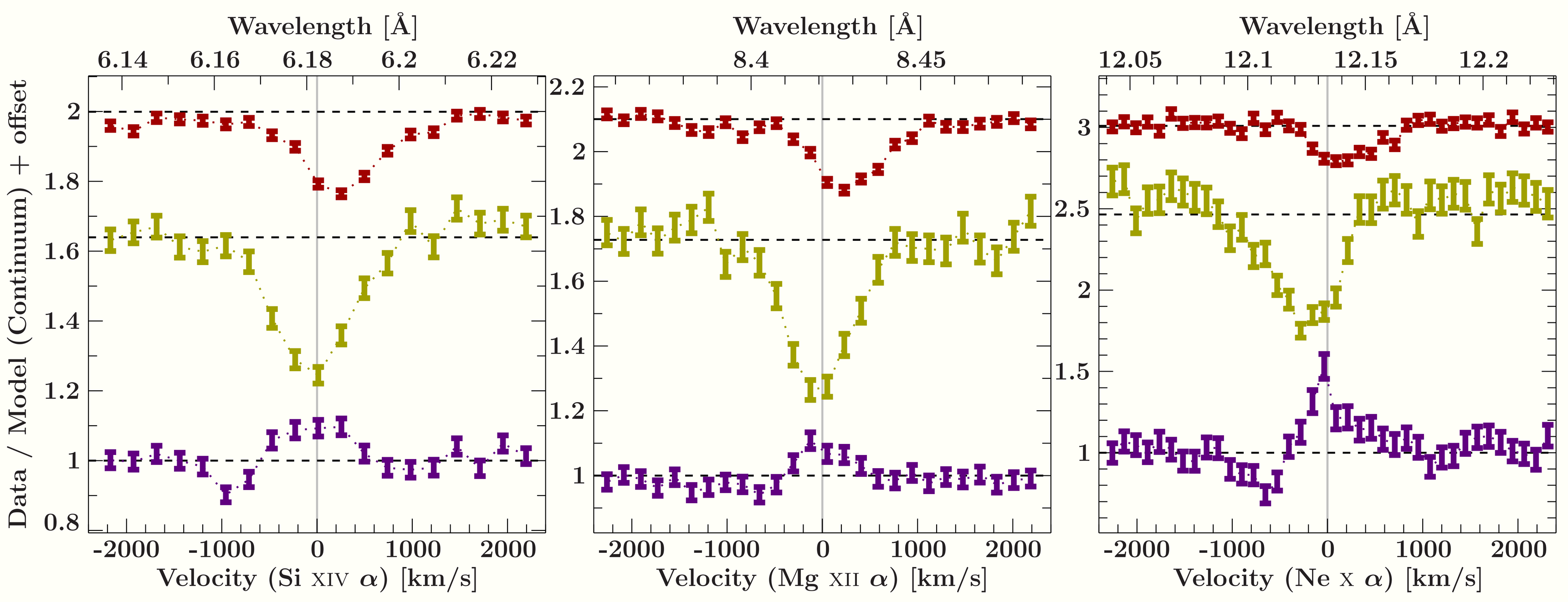
Dipping produces a clear **track** in the color-color diagrams: At first, both colors harden towards the lower left corner, due to increased absorption. Then, during extreme dips, the soft color becomes softer again, indicating that the absorber causing the dips only **partially covers** the source of X-rays.

The apparent extraordinary softening after a flare in the CC-mode ObsID 3815 might be an instrumental artifact.

preliminary!

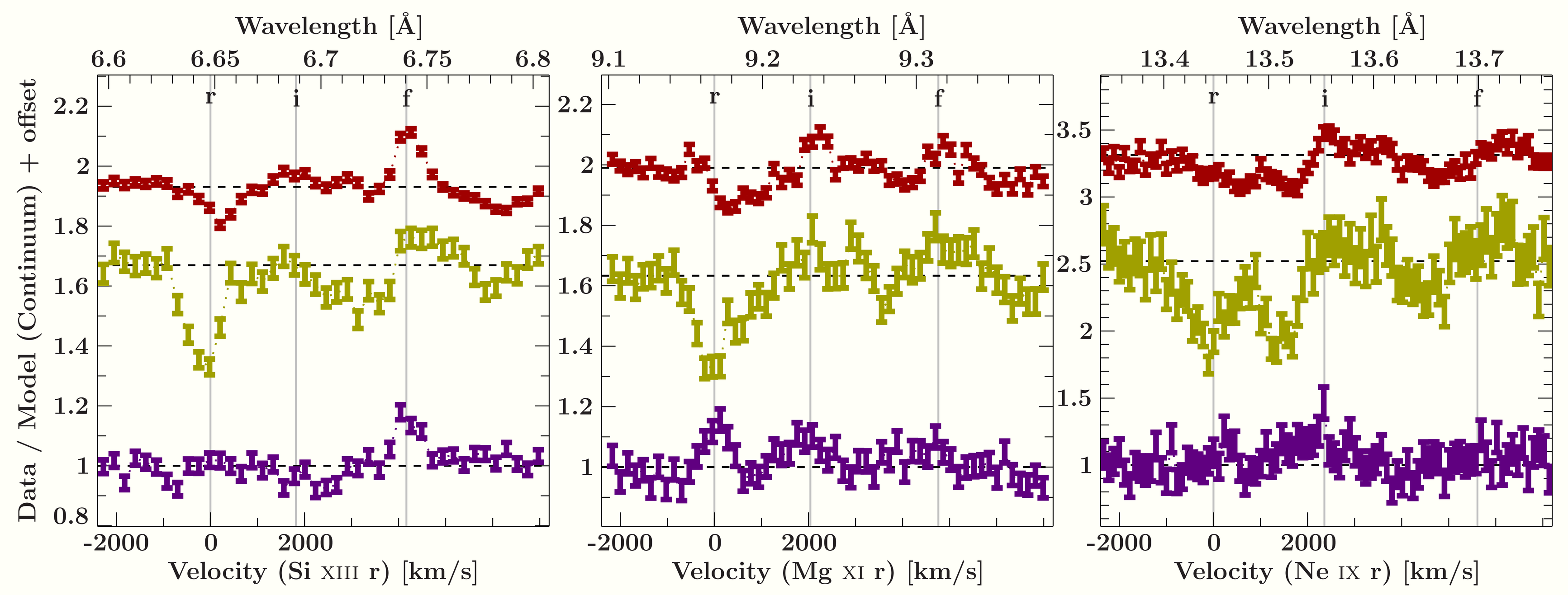
Different stages of dipping can be classified according to these softness ratios. In particular, we extract a "non-dip" spectrum from the least absorbed phases at the upper right corner (except for ObsID 3815). The following spectroscopic results refer to these **non-dip** phases.

Absorption and P Cygni line profiles of Lyman α transitions



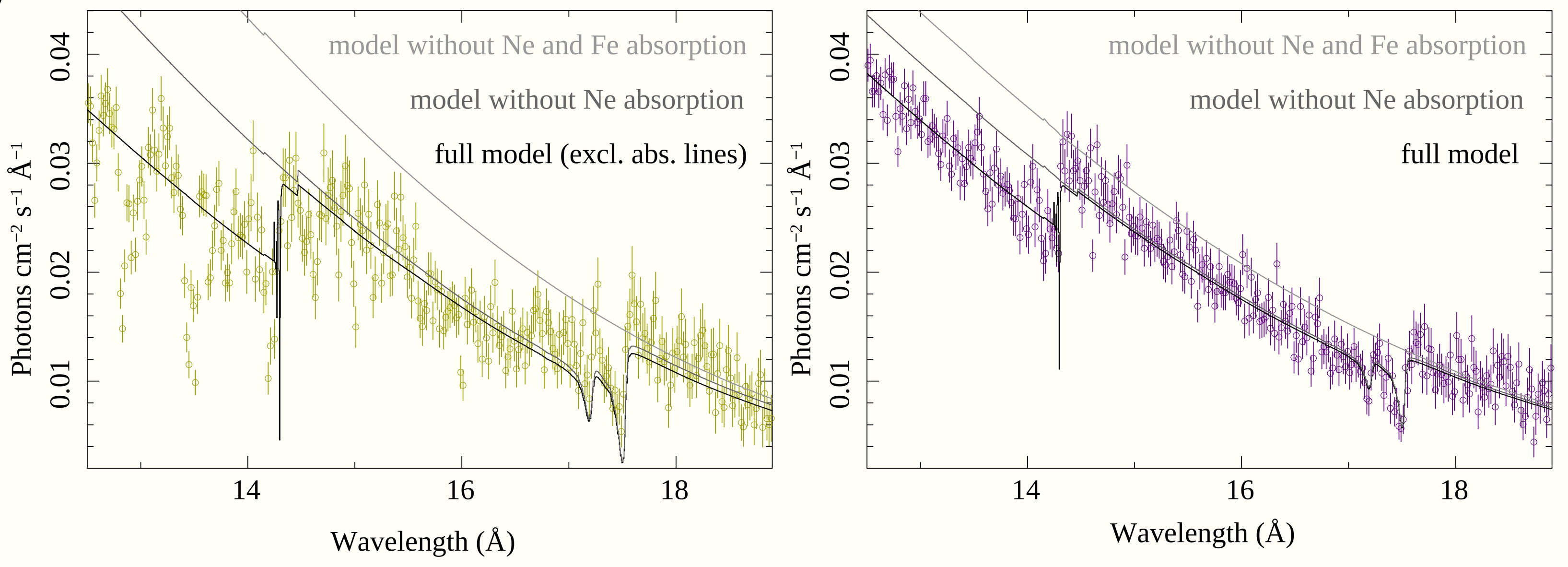
The **highly photoionized wind** is detected at $\phi\approx0$ via numerous strong **absorption lines** at $v_\mathrm{rad}\approx0$. Lacking Doppler shifts *can* be explained by the wind flow being orthogonal to the line of sight (Hanke et al., 2008, 2009). However, the recent observation at $\phi\approx0.5$ reveals (for the first time for Cyg X-1) clear **P Cygni profiles** with a strong emission component at a projected velocity $v_\mathrm{rad}\approx0$. If, despite the rotated line of sight by $2i\approx70°$, the emission at $\phi=0.5$ is caused by the same plasma as the absorption at $\phi=0$, its full space velocity must be quite small, i.e., we are probing a **dense, low-velocity wind** near the stellar surface. In contrast, the (relatively weak) absorption components at $\phi\approx0.5$, occuring at a blueshift of $\approx$500–1 000 km/s, demonstrate the downstream **acceleration of the wind**. The fact that the absorption line profiles measured at $\phi\approx0.76$ are redshifted by $\approx$200–300 km/s proves that the **wind flow** is **not radial** from the star.

Comparison of He-like triplets



The 1s2s/1s2p $\to$ 1s^2 transitions of an He-like ion form the **triplet** of resonance, **i**ntercombination and **f**orbidden lines, which can provide density and temperature diagnostics of an *emitting* plasma. In the observations at $\phi\approx0.76$ and $\phi\approx0$, the dipole-allowed **r transition** is, however, seen in **absorption**. (Note that the strong absorption $\approx$1 500 km/s redward of Ne IX r is caused by Fe XIX.) Hanke et al. (2009) investigate the Mg XI i and f lines in the non-dip spectrum of ObsID 3814, which apparently consist of *two* pairs: one unshifted (consistent with other absorption lines), and one redshifted, from a denser plasma (with lower $R=f/i$ ratio), attributed to the **focused wind**. However, such a double pair is not clearly seen in the other spectra. While ObsID 11044 at $\phi\approx0.5$ displays P Cygni-shaped Ly α lines, only the (weak) blueshifted absorption component from the Si XIII r transition, and only the (strong) unshifted emission component from Mg XI r are detected.

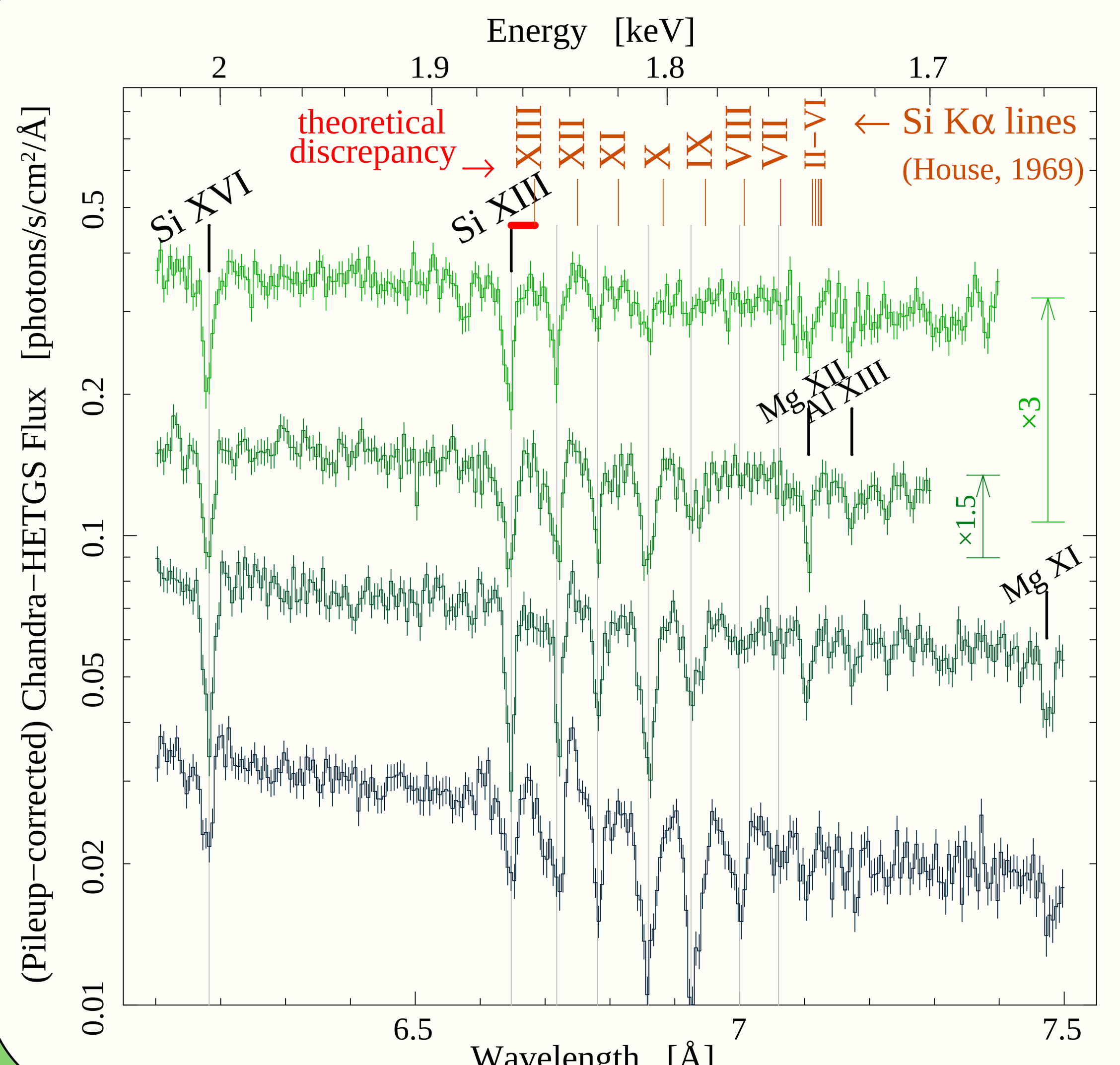
Neutral absorption: more indications for the wind?



While the 0.66–1 keV (non-dip) spectrum at $\phi\approx0$ is dominated by complex Fe L-shell absorption (left: ObsID 3814), the most prominent features at $\phi\approx0.5$ are neutral absorption edges, specifically the Ne K-edge at 14.3 Å and the Fe L_2 and L_3 edges at 17.2 Å and 17.5 Å. The fine structures at these edges are taken into account by the `tbnew` model†. An accurate measurement of the neutral column density requires a good modelling of the continuum, which is complicated at $\phi\approx0$ due to the large number of (probably unresolved) absorption lines. The preliminary fits shown above imply $N_\mathrm{Ne}=1.1\times10^{18}\,\mathrm{cm}^{-2}$ and $N_\mathrm{Fe}=2.8\times10^{17}\,\mathrm{cm}^{-2}$ at $\phi\approx0$, but only $N_\mathrm{Ne}=5.6\times10^{17}\,\mathrm{cm}^{-2}$ and $N_\mathrm{Fe}=1.3\times10^{17}\,\mathrm{cm}^{-2}$ at $\phi\approx0.5$.

† `tbnew` is an improved version of `tb[var]abs` (Wilms et al., in prep.). It uses internal caching of cross-sections and therefore performs much faster than many previous absorption models. One can fit relative abundances or total atomic column densities. The code is available at `http://pulsar.sternwarte.uni-erlangen.de/wilms/research/tbabs/`.

Low ionization stages from a cool(er) absorber during dips



ObsID 8525 was split into four parts according to the stage of dipping.

The first two spectra, corresponding to almost no and to weak dipping only, have been shifted by a factor ×3 and ×1.5 in flux (arrows) for visual clarity. Further **reduction in flux** in the last two spectra is real and due to dips.

While absorption lines of Si XIV and Si XIII are already present in the non-dip spectrum, the dip spectra contain **additional strong absorption lines** that can be identified with Kα transitions of **lower ionized Si** XII–VII. (Note the systematic discrepancy of "adjusted line positions" reported by House (1969).) The **strength** of the low-ionization lines **increases** with the **degree of dipping**, suggesting that the latter is related to **high-density clumps at lower temperature**.

Friedrich-Alexander-Universität Erlangen-Nürnberg

References

Hanke, M., Wilms, J., Nowak, M. A., Pottschmidt, K., Schulz, N. S., & Lee, J. C. 2009, ApJ, 690, 330
Hanke, M., Wilms, J., Nowak, M. A., Schulz, N. S., Pottschmidt, K., Lee, J., & Böck, M. 2008, in Proc. VII Microquasar Workshop, 29

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS