Ionization structure of the warm wind in NGC 5548

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Abstract

The velocity structure of the X-ray absorber is consistent with the velocity structure measured simultaneously in the UV spectra. We find that the highest velocity outflow component, at -1040 km s^{-1}, becomes increasingly important for higher ionization parameters. This velocity component spans at least three orders of magnitude in ionization parameter, producing both highly ionized X-ray absorption lines (Mg XII, Si XIV) as well as UV absorption lines. A similar conclusion is very probable for the other four velocity components.

Based upon our observations, we argue that the warm absorber probably does not manifest itself in the form of photoionized clumps in pressure equilibrium with a surrounding wind. Instead, a model with a continuous distribution of column density versus ionization parameter gives an excellent fit to our data.

Observations

The exposure time and the observation details for the XMM-*Newton*, *Chandra* and HST observations of NGC 5548. The E140M grating covers the wavelength range between $1150 - 1730$ Å, the E230M grating between $1607 - 3119$ Å.

Instrument	detector	start date	exposure
RGS		2001 Jul. 09	137 ks
HETGS	ACIS-S	2002 Jan. 16	154 ks
LETGS	HRC-S	2002 Jan. 18	170 ks
LETGS	HRC-S	2002 Jan. 21	170 ks
HST STIS	E140M	2002 Jan. 22	7.6 ks
HST STIS	E230M	2002 Jan. 22	2.7 ks
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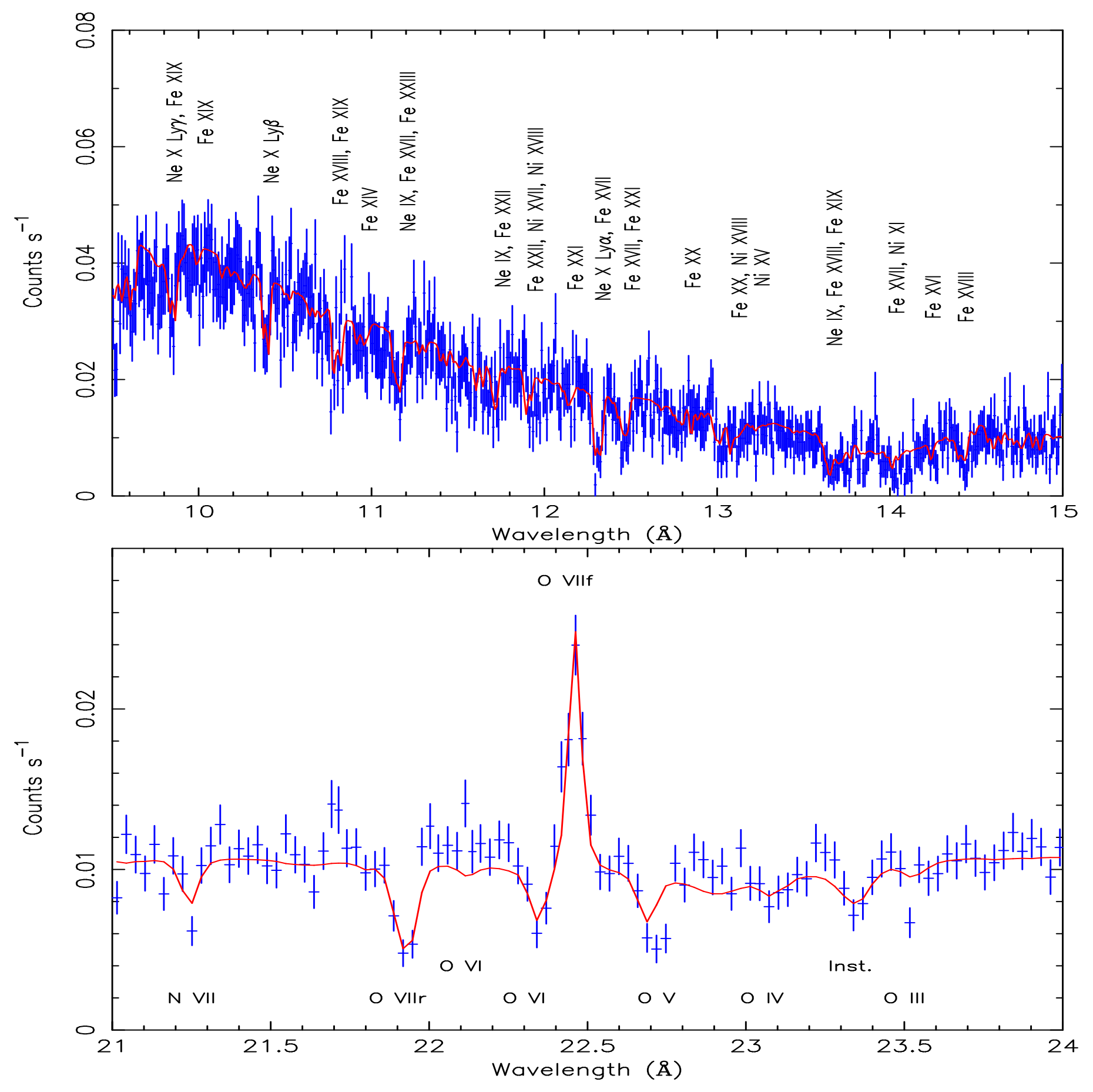
Spectra

This MEG spectrum clearly shows the multitude of absorption lines detected in the warm absorber. Most of the lines are due to iron and neon. For Ne X note the Lyα, Lyβ and Lyγ lines. Strong inner shell oxygen lines (O V and O VI) are observed in the LETGS spectrum. O VI is also observed in the near simultaneously UV spectra, thus allowing for a direct comparison of the ion column density measured in the UV band and X-rays. Furthermore, this proves that the UV and X-ray absorber are different manifestations of the same outflow.



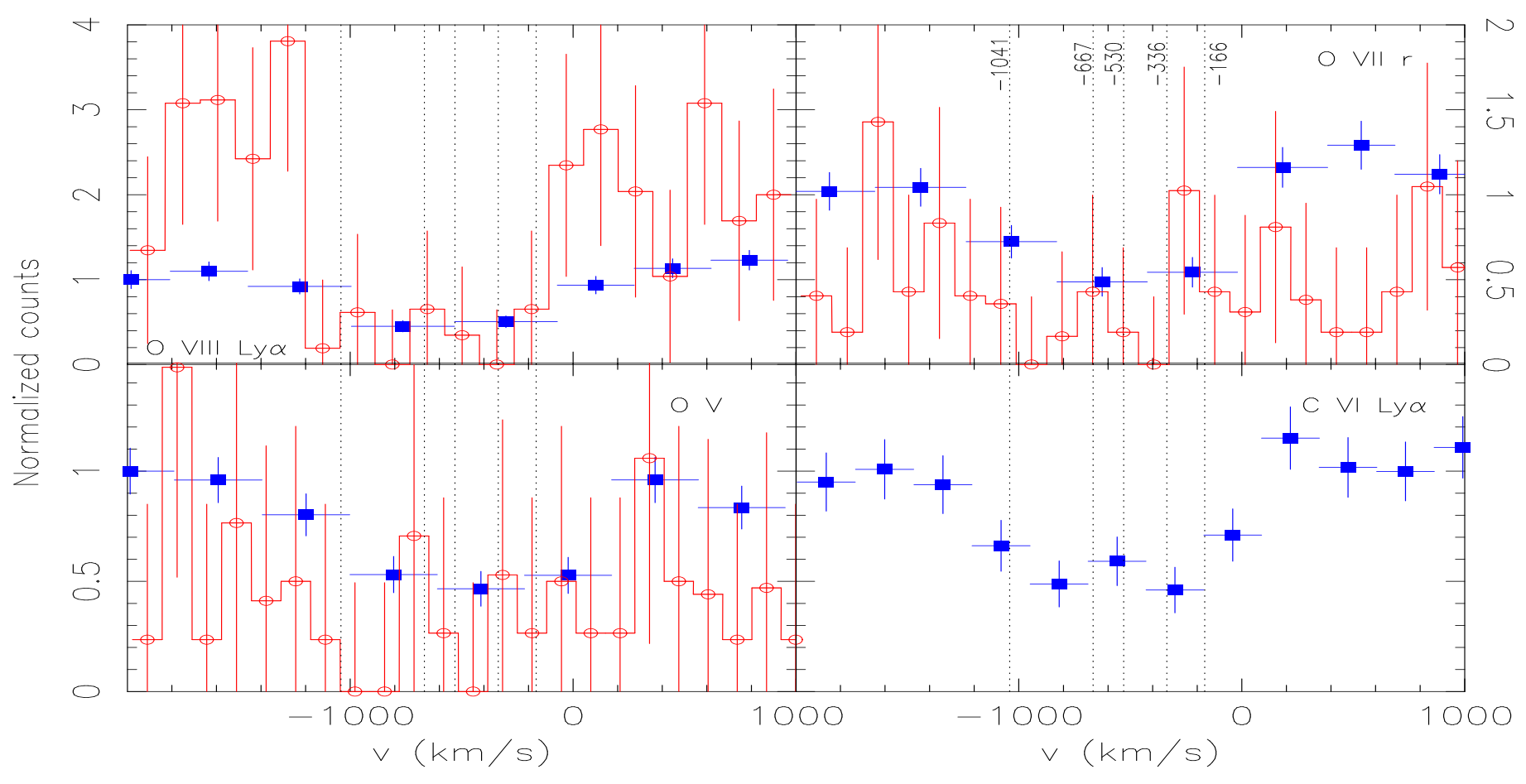
UV velocity structure

From the UV data (Crenshaw et al. 2003) we know that there are five distinct outflow velocities. Each velocity component can have a different ionization parameter and hydrogen column density. Also the variability detected in the ionization parameter is different for the five outflow velocities.

Outflow km s^{-1}	broadening km s^{-1}	U	N_H log m^{-2}
-1040	94	0.03	22.8
-667	18	0.03	22.6
-530	68	0.24	24.3
-336	62	0.03	23.3
-160	90	0.03	22.6

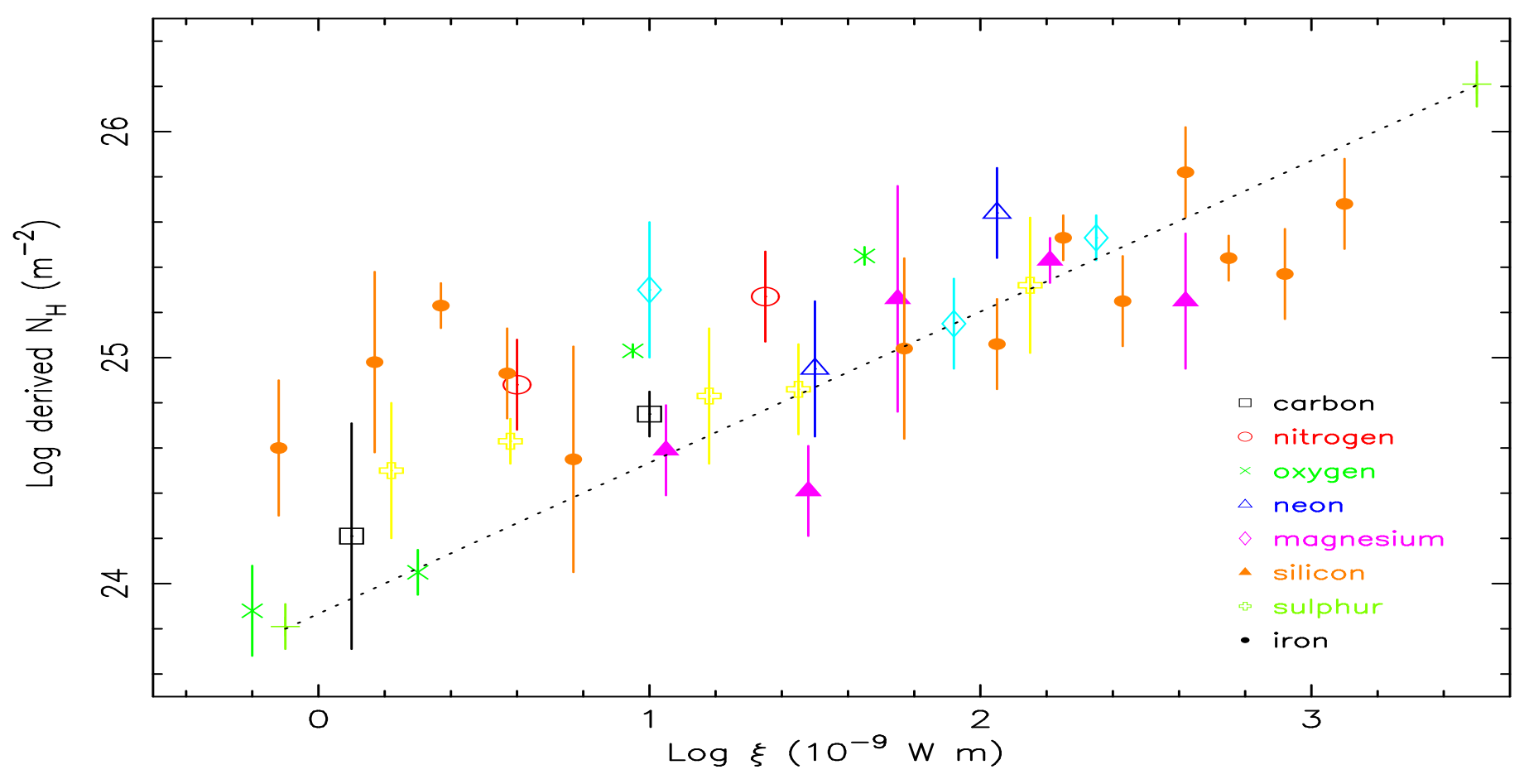
X-ray velocity structure

Using the MEG (open circles), HEG and LETGS (filled squares) data we were able to resolve the -1040 km s^{-1} component from the 4 other velocity components in the 6 strongest lines. This clearly indicates that this velocity component spans an ionization range of at least 3 orders of magnitude, from lowly ionized UV lines to Si XIV. Dotted lines indicate the measured velocity from the UV spectra.

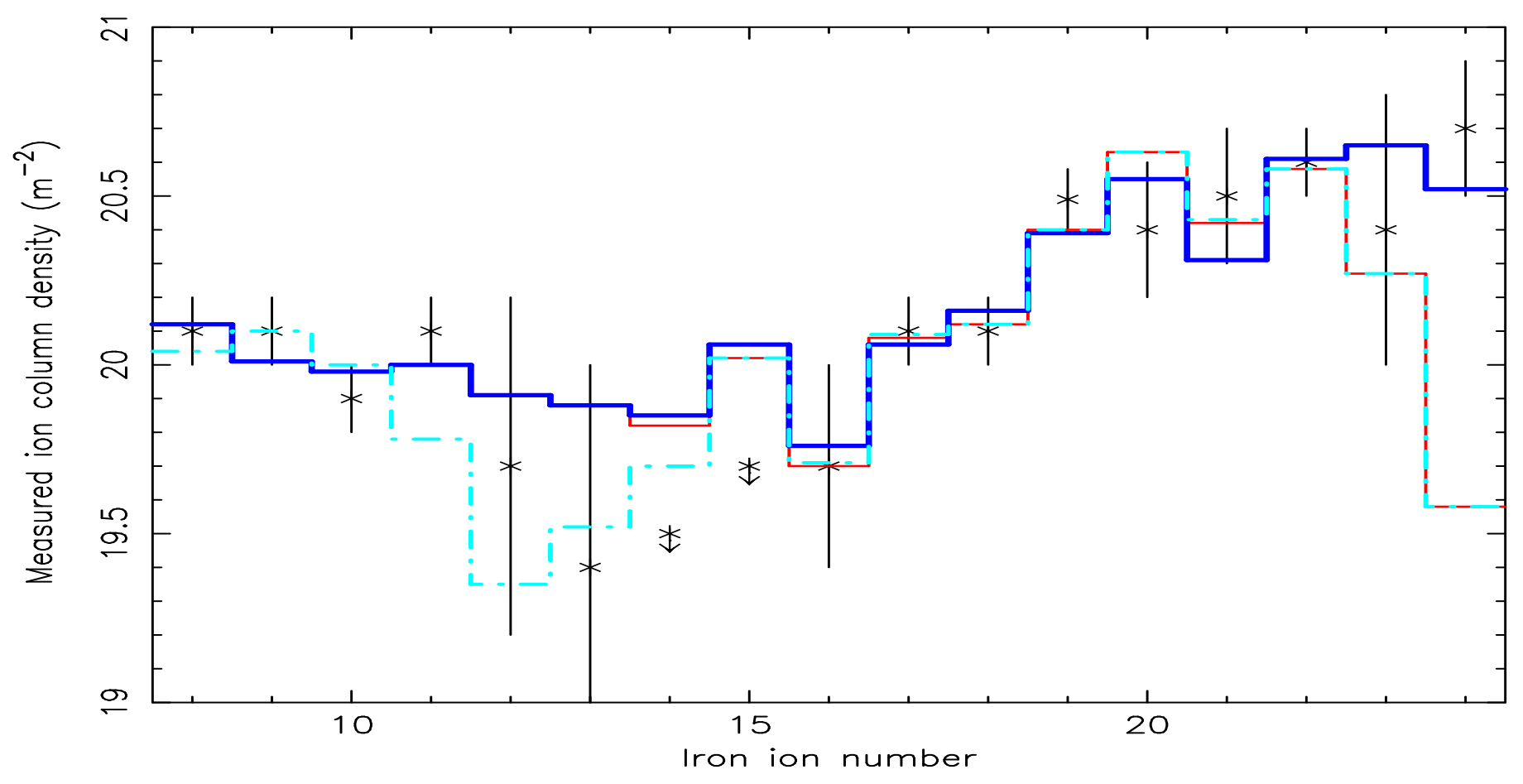


Ionization structure

Assuming solar abundances (Anders & Grevesse 1989) we can derive the hydrogen column density taking into account that each ion is formed over a range in ionization parameters. The dotted line in the figure bounded by light green crosses indicate the slope of the power-law if we fit the LETGS spectrum with a continuous ionization parameter model, i.e. fitting for the hydrogen column density at those two points.

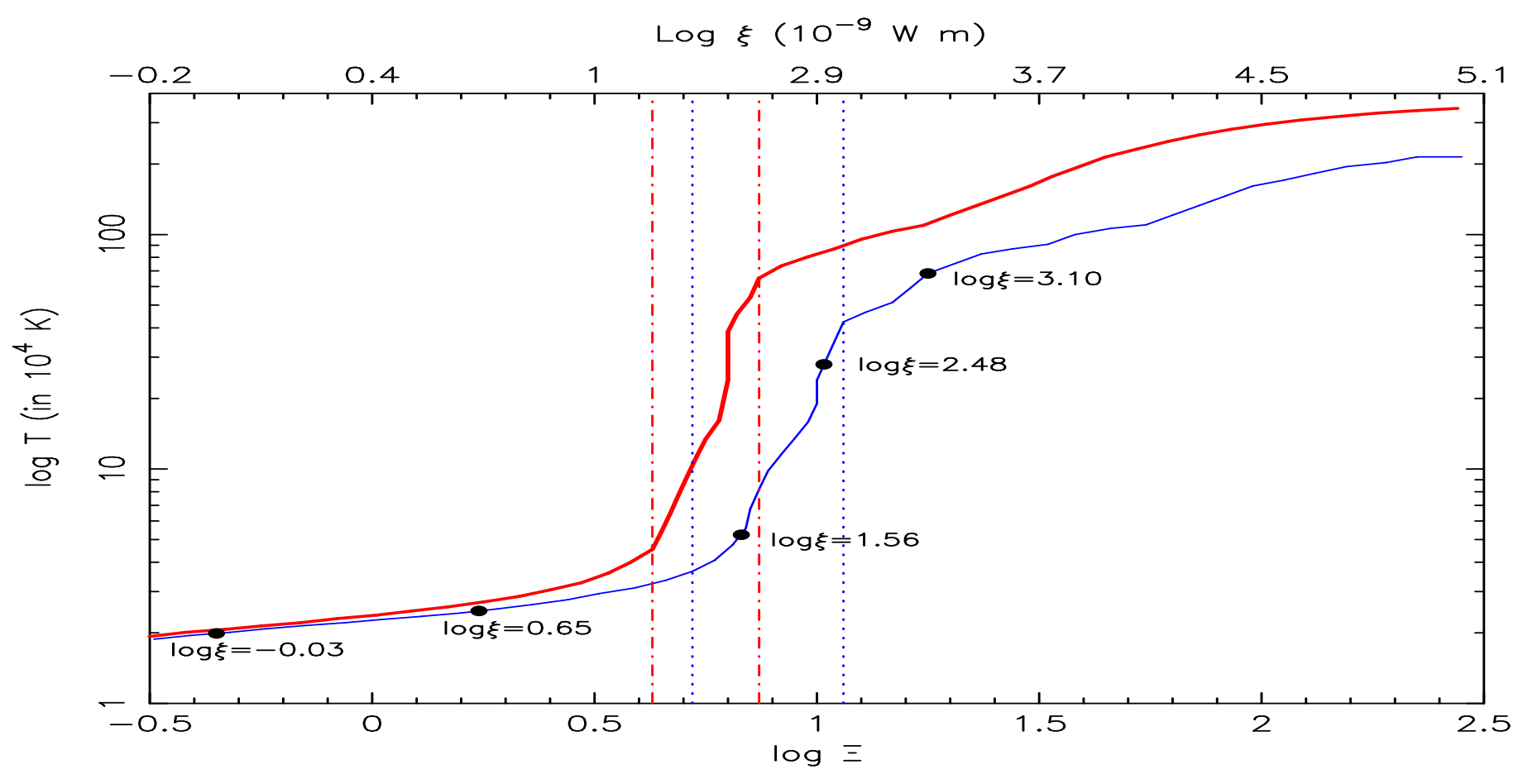


Using the high effective area of the RGS at the UTA wavelengths, we detect lowly ionized iron (Fe VIII) to highly ionized iron (Fe XXIV). We thus sample a large range in ionization parameter, without abundance effects. Fitting only iron, we find that we need five ionization parameters. The dot-dashed light blue line is a model with 3 ionization parameters, the red thin line with four, and the thick dark blue line with five ionization parameters.



Pressure equilibrium?

The temperature versus ionization parameter for constant pressure Ξ for the two different spectral energy distributions (SED's). Red for the HEG/LETGS observation, blue for the RGS observation. The ionization parameter ξ for the HEG/LETGS observations is indicated on the top x-axis. The five ionization parameters determined from the iron in the RGS spectra are indicated. The dotted and dashed lines indicate the boundaries for the marginally stable branch for both SEDs.



Density stratified wind

From the five different ionization components certainly the two lowest ionized absorbers can not be in pressure equilibrium with the remaining absorbers. Possibly, also the highest ionized absorber can not be in pressure equilibrium with the lower ionized absorbers. Therefore, we prefer a density stratified wind as proposed by Arav (2004). In the wind there is a continuous ionization distribution, compared with several discrete components in pressure equilibrium. To test this hypothesis we fit the spectra assuming a continuous ionization parameter, fitting just the hydrogen column density at two ionization extremes detectable in the spectra. We find an excellent fit, with a power-law slope of 0.25.

Conclusions

The velocity structure observed in the X-rays is consistent with the velocity structure measured from UV spectra.
Using only iron ions we need five ionization parameters to describe the ion distribution, independent of abundance effects.
These five ionization parameters can not be in pressure equilibrium.
We prefer a density stratified wind as outflow model.