ISMABS: A NEW X-RAY ABSORPTION MODEL FOR THE ISM

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INTRODUCTION

The study of the physical and chemical properties of the interstellar medium (ISM) provides important information about the formation and evolution of galaxies. The stars are formed in the ISM and there are several mechanisms by which heavier elements are deposited back to it. X-rays interact with the ISM via scattering (by dust and grains) and absorption (by the excitation and ionization of inner K-shell electrons, mainly); thus X-ray observations of the ISM give us the opportunity to study the column densities and ionization fractions for a large number of chemical elements.

We present a new ISM X-ray absorption model that includes most of the up-to-date atomic data available, and through it, an ISM analysis along eight X-ray binary lines of sight.

OBSERVATIONS AND DATA REDUCTION

Observations were obtained with the Medium Energy Gratings (MEG) of the High Energy Transmission Grating Spectrometer (HETGS) on board Chandra satellite-borne X-Ray Observatory. We have determined the zeroth-order source position in order to fix the wavelength scale following standard procedures*.

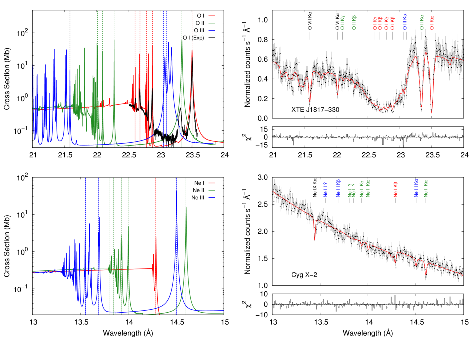
We have analyzed the following observations:

Source	Observations	Total time (ks)
4U 1636-53	4	105
4U 1735-44	3	72
4U 1820-30	5	118
GX 9+9	2	115
Cygnus X-1	2	26
Cygnus X-2	4	221
Sco X-1	1	16
XTE J1817-330	4	145

ATOMIC DATA

The detailed understanding of atomic processes and the accuracy of the atomic data in models are crucial to avoid incorrect interpretations of absorption structures detected in X-ray high resolution spectra. We include in our model the following cross sections:

- Neutral states of Si, S, Ar and Ca from Verner et al. (1995)
- Singly and doubly ionized states of Si, S, Ar and Ca from Witthoeft et al. (2009) and Witthoeft et al. (2011)
- Neutral, singly and doubly ionized states of N from Garcia et al. (2009)
- Neutral states of O from Gorczyca et al. (2013)
- Singly and doubly ionized states of O from Garcia et al. (2005), including corrections applied by Gatuzz et al. (2013)
- Neutral state of Ne from Gorczyca et al. (2000)
- Singly and doubly ionized states of Ne from Gorczyca et al. (2005)
- For the Fe-L edge region we use the measurement of metallic iron by Kortright & Kim (2000)
- Neutral, singly and doubly ionized states of Mg from Hasoglu et al. (2014).



In this figure we show an example of the atomic data benchmarking performed in our work using X-ray binary spectra. The wavelength scale of the cross sections was calibrated according to astronomical line positions in order to get the best spectral fit with the model.

*http://cxc.cfa.harvard.edu/ciao

ISMABS MODEL

The ISMabs model considers the absorption effects of the ISM in observed spectra in the following way

$$I_{obs}(E) = e^{-\tau} I_{source}(E)$$

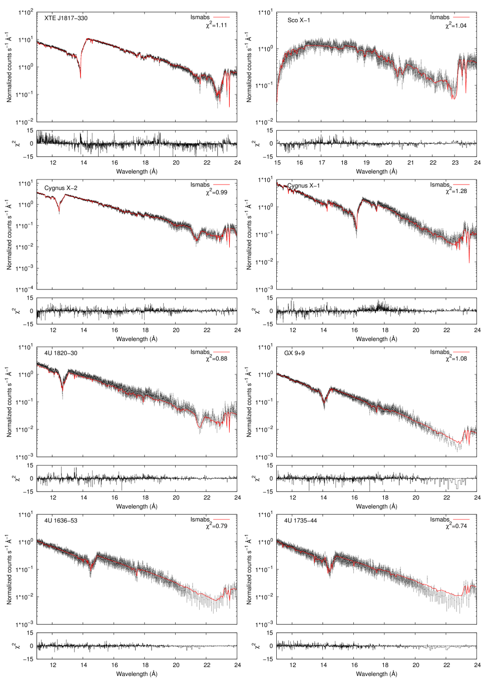
where $I_{obs}(E)$ is the observed X-ray intensity, $I_{source}(E)$ is the X-ray emitted intensity by the X-ray source and $e^{-\tau}$ is the absorption coefficient. The optical depth is defined as

$$\tau = \sum \sigma_i(E) N_i$$

where $\sigma_i(E)$ and N_i are the cross sections and the ionic column densities, respectively. The ionic column densities are the model free parameters. All the cross sections are loaded and cached to reduce computational overhead while data fitting. Redshift is also included as a model parameter.

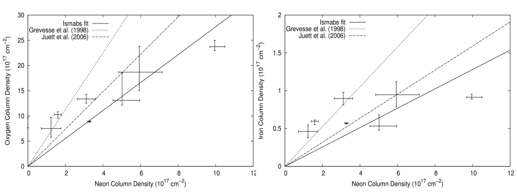
SPECTRAL FITTING

For all the sources, we fit the available spectra in the 11-24 Å wavelength range using a simple power law plus the ISMabs model, including the O-, Ne- and Fe-edge regions. In cases where we have more than one observation, the fit was carried out simultaneously with the column density linked between the observations. In the figure below we show the best fits for 8 different X-ray binaries. In all the cases, the upper panel shows the data and the model, while the lower panel shows residuals in sigma units. The resulting χ^2 are indicated in the figures.



COLUMN DENSITIES

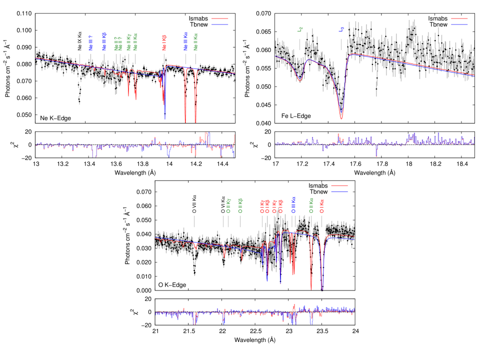
Figures below show the O/Ne (left panel) and Fe/Ne (right panel) abundance ratios in the X-ray domain using the column densities derived from the continuum fit using the ISMabs model. Neon is chosen as a reference due to the fact that it should not be depleted as it is a noble gas. The O/Ne ratio derived by ISMabs is in good agreement with the solar value from Grevesse et al. (1998) for low-column neon densities. Saturation of the lines may lead to differences at high column densities. Iron depletion or Ne overabundance may lead to the discrepancies observed between ISMabs and the Grevesse et al. (1998) solar values in the Fe/Ne ratio plot.

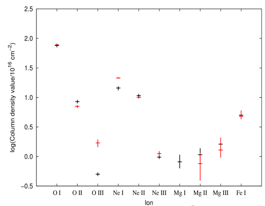


X-RAY ABSORPTION MODEL COMPARISON

	ISMabs	warmabs	TBNew
Ionization Balance	No	Yes	No
Parameter (Abundances)	No	Yes	Yes
Parameter (Column densities)	Yes	No	Yes
Singly and double ionized elements	Yes	Yes	No

The figure below shows an example of the continuum fit for XTE J1817-330 using two different absorption models: TBNew (blue line), which only includes neutral species, and ISMabs (red), which takes into account neutral, singly and doubly ionized species. For each plot, the upper panel shows the observation and the best fit of the spectra (in flux units), while the lower panel shows the corresponding standard deviations. The figure depicts the Ne K-, Fe L- and O K-edge regions. Although the neutral component dominates the spectral features, the inclusion of ions in ISMabs leads to a better fit than that with TBNew, as we can see in the residual reduction. We obtain χ^2=2.07 using TBNew and χ^2=1.78 with ISMabs.





The left figure shows a comparison of ion column densities obtained from ISMabs (red lines) and warmabs (black lines) using observations of XTE J1817-330 taken by the Chandra X-ray observatory.

For most ions the figure shows that both fits agree, considering the errors.

CONCLUSIONS

In order to perform reliable modeling of the ISM X-ray absorption, we have developed a new model (ISMabs) that includes neutral, singly and doubly ionized column densities for H, He, N, O, Ne, Mg, Si, S, Ar, Ca and Fe. This model enables the direct determination of ionic column densities. Although the predominant component in the ISM is the neutral gas, the inclusion of singly and doubly ionized column densities leads to improvements in spectral modeling.

Finally, the new model ISMabs is available** for use in familiar X-ray analysis packages such as XSPEC and ISIS.

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**http://hea-www.cfa.harvard.edu/~javier/ismabs/