Modeling the Oxygen K-Shell Photoabsorption Spectrum of GX 339-4

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Introduction

- The X-ray band is a powerful tool to study the chemistry of the interstellar medium (ISM)
- X-ray telescopes can be used to determine the gas and dust content of the ISM by studying the photoabsorption spectra of low mass X-ray binaries
- In this examination we analyze absorption spectra of the black hole binary GX 339-4
- These absorption spectra can tell us the concentration of individual elements in the ISM and their depletion into dust
- By modeling the O K-edge we can determine the column densities of the oxygen species produced in each phase of the ISM

Methods I: Spectral fitting of the O K-edge

- Selected high signal-to-noise X-ray spectra of GX 339-4 from XMM-Newton, an X-ray space observatory. A sample spectrum is seen in Figure 1
- Fit X-ray spectrums of GX 339-4 from different XMM-Newton observations using pyXspec (Figure 2)
- Accounted for other elements in the fit such as carbon, nitrogen, iron, and neon
- Studied O K-shell ISM absorption using physical plasma models in SPEX (Figure 3)
- Fit gas and dust absorption features in SPEX
- Used SPEX to determine the column densities of oxygen species in different phases of the ISM (Figure 4)

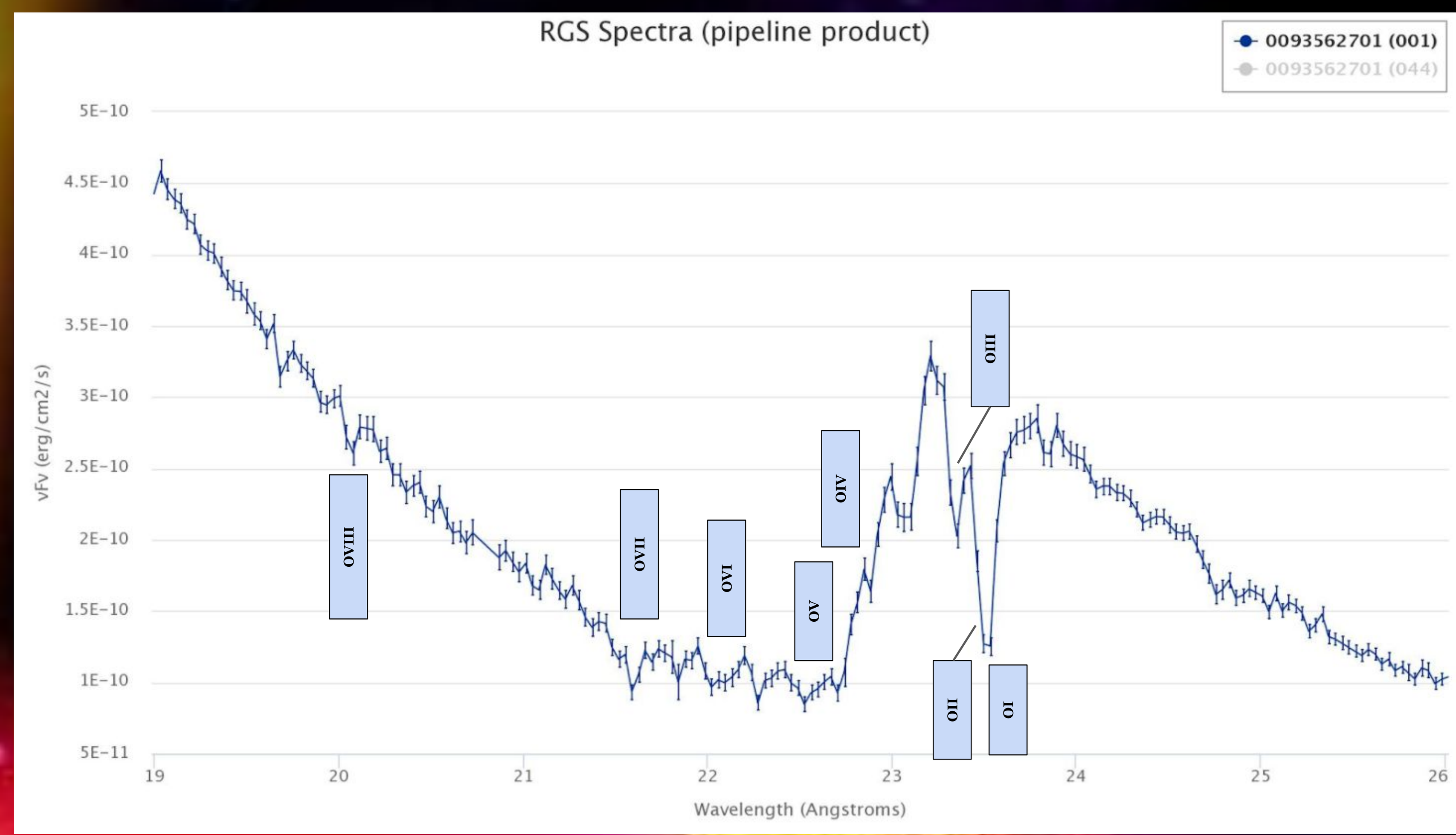

Figure 1: Example absorption spectrum of GX 339-4 (obsid 0093562701) from XMM-Newton archive zoomed in on the O K-edge with O species labeled. It fits our specifications for a strong candidate to study because the oxygen edge can be seen clearly and error bars are small. The difference between the flux near 22.5 A and 23.2 A is large compared to other spectra.

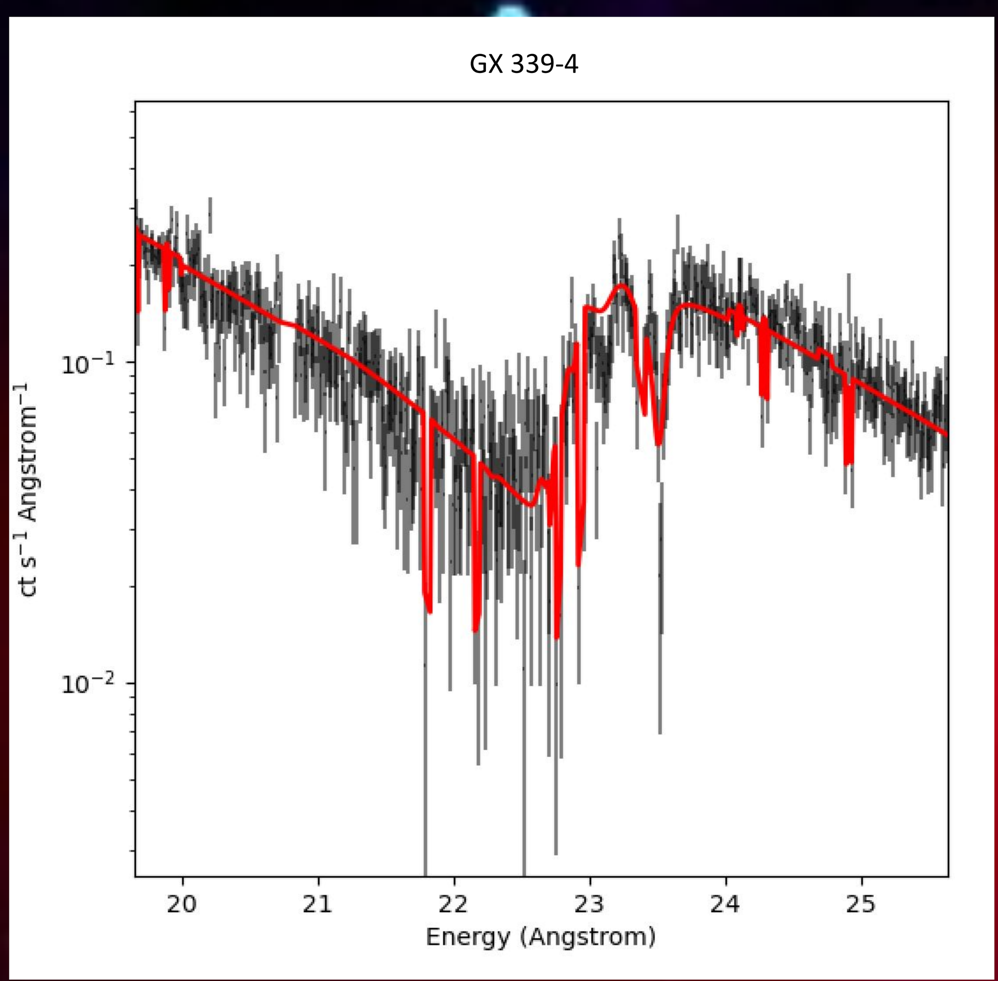

Figure 2: The absorption spectrum (black) and model (red) of GX 339-4 zoomed in on the O K-edge. Data was fit using power law with ISM extinction models in pyXspec. This model only assumes gas phase and provides each element as a separate fit parameter

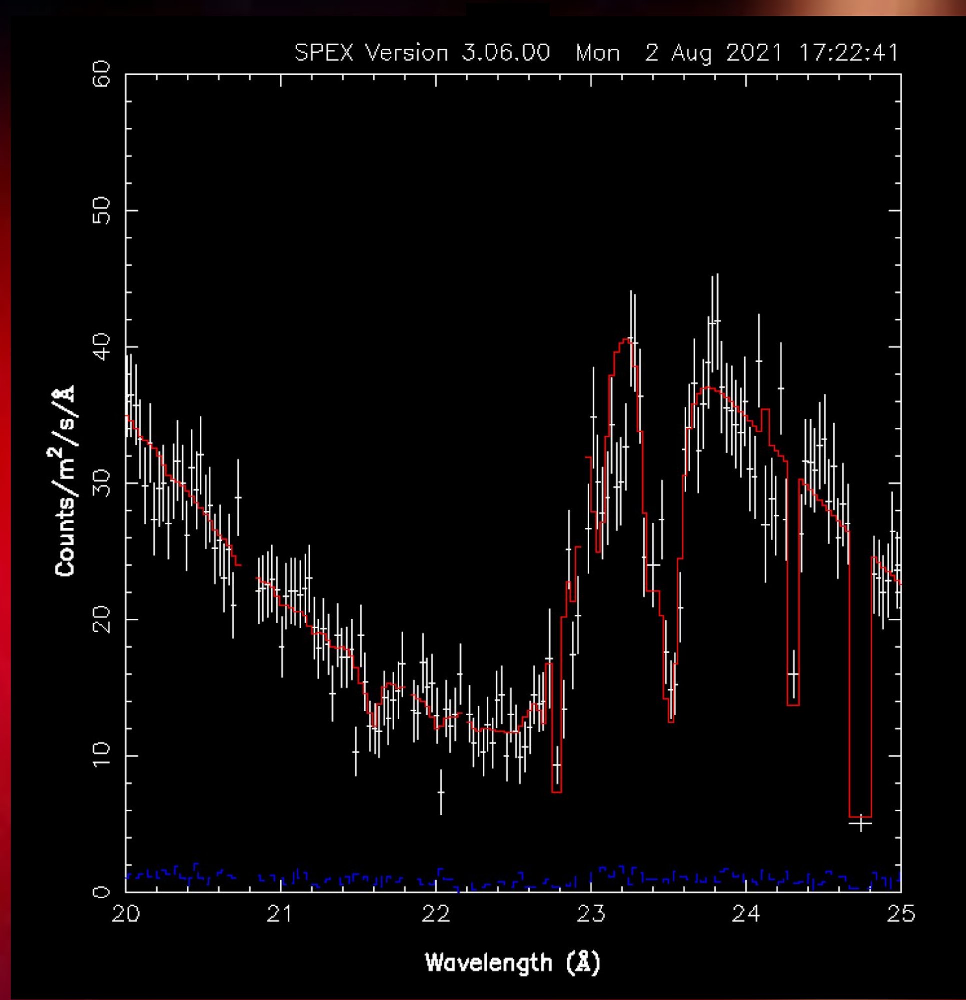

Figure 3: The absorption spectrum (white) and model (red) of GX 339-4 zoomed in on the O K-edge. Data was fit using physical plasma models in SPEX. These accounted for the cold, warm, and hot phases of the ISM as well as dust

Selecting photoabsorption spectra to study

- We searched for spectra in the XMM-Newton archive with clearly visible OI lines with small error bars
- Next we looked for the largest difference in flux between 22.5 A and 23.2 A. These wavelengths correspond with the lowest and highest point on the O K-edge
- Finally we looked for spectrums with the longest observation times

Model	Ion	Log Column Density (cm^{-2})
Cold	O I	18.599
Warm	O I	13.957
	O II	16.82
	OIII	16.748
	O IV	14.319
Hot	O I	12.109
	O II	15.229
	O III	16.573
	O IV	16.44
	O V	14.671
	O VI	10.569
Slab	O VI	15.843
	O VII	16.56
	O VIII	16.024

Figure 4: Table of the log column densities of each of the oxygen species present in the hot and slab models of the ISM. The hot and slab models were used to fit the O K-edge of the absorption spectrum of GX 339-4 in SPEX. The hot models represent different phases of the ISM such as cold, warm, and hot. The column densities and ions present are also recorded from SPEX. From this table we can see that the cold ISM contains the highest density of oxygen while the hot ISM contains the most species of oxygen.

Methods II: Calculating residuals

- Created a residual spectrum by subtracting the data from the model in pyXspec
- Set oxygen abundance to zero and extracted oxygen contributions from the residuals
- Replotted residuals displaying the O K-edge absorption features separated from the underlined continuum.
- This allows the modeling of the gas and dust absorption to be continuum independent.

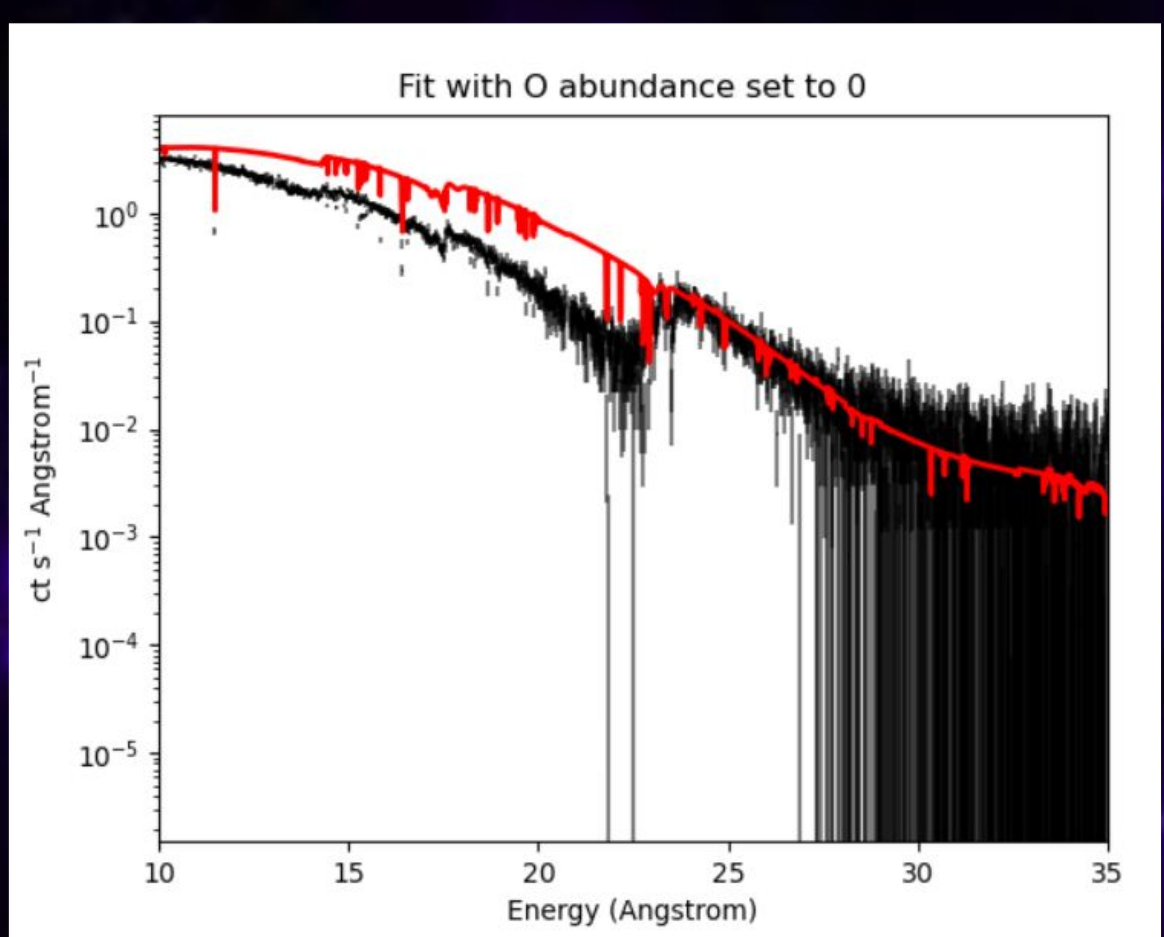

Figure 5: The absorption spectrum and model (red) of GX 339-4 after setting the oxygen abundance to zero. When reading the plot from right to left we can see that the model does not have an O K-edge and veers from the spectrum at approximately 23 Angstroms. This value corresponds with the peak of the O K-edge. When plotting the difference between the model and the data, we would see that the residuals have a non-zero value after the O K-edge.

Results and next steps

- The process for fitting the O K-edge in the absorption spectrum of GX 399-4 can be scripted
- The fitted O K-edge can be used to determine the column densities of oxygen species in the ISM as seen in Figure 4
- Absorption features from the O K-edge can be separated form the continuum by setting oxygen contributions to zero
- Stacking residuals allows us to better interpret oxygen contributions in the spectrum
- This process can be automated with pyXspec scripts, allowing us to interpret oxygen contributions in multiple photoabsorption spectra at once

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