

High-Resolution Photoelectric Absorption Spectroscopy of Interstellar Oxygen

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September 16, 2003

Motivation

Study the properties of the ISM absorption.

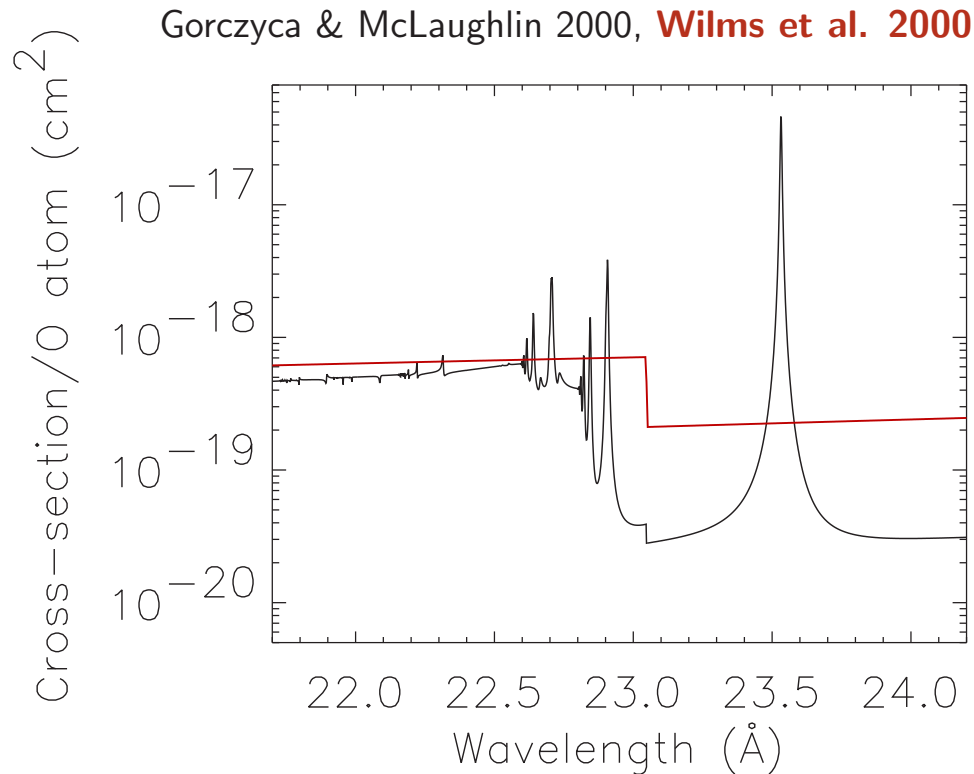
- X-rays provide unique opportunity to study ISM.
- Can probe ionization structure of ISM over large scales.

Four studies of O edge have found different results (Paerels et al. 2001, Schulz et al. 2002, Takei et al. 2002, de Vries et al. 2003).

- Found 1–3 edges with positions from 22.58–23.13 Å.
- Found 1–2 absorption lines.
- All identified O I 1s-2p absorption line.

Standard absorption models (tbabs, phabs, wabs) do not have resolution comparable to the gratings on *Chandra* and *XMM*.

Comparing Cross-Sections

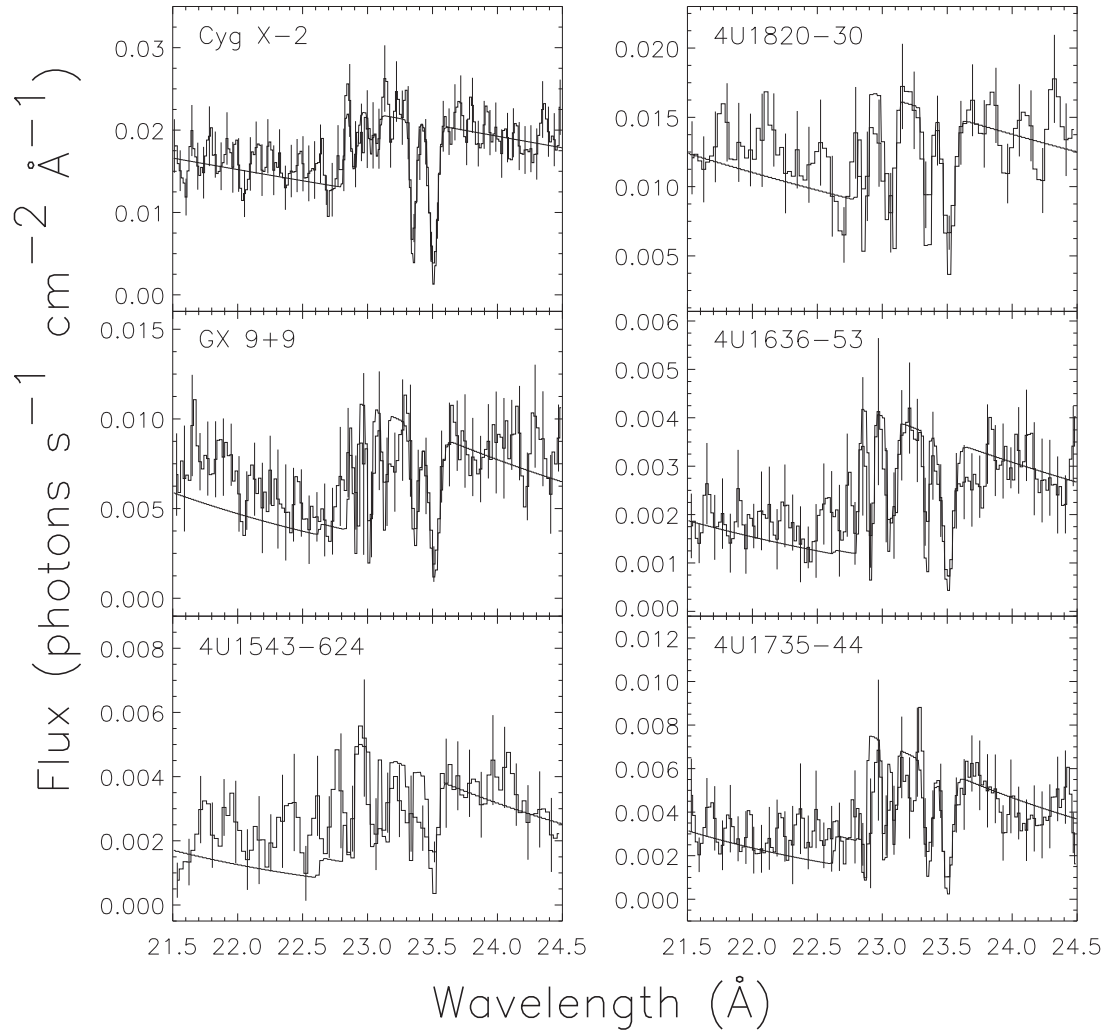


- Old models no longer appropriate.
- New instruments can resolve structure in neutral O absorption.
- Expect features from ionized O as well.

Compared data with theoretical predictions from neutral and ionized O (Gorczyca & McLaughlin 2000, Pradhan et al. 2003).

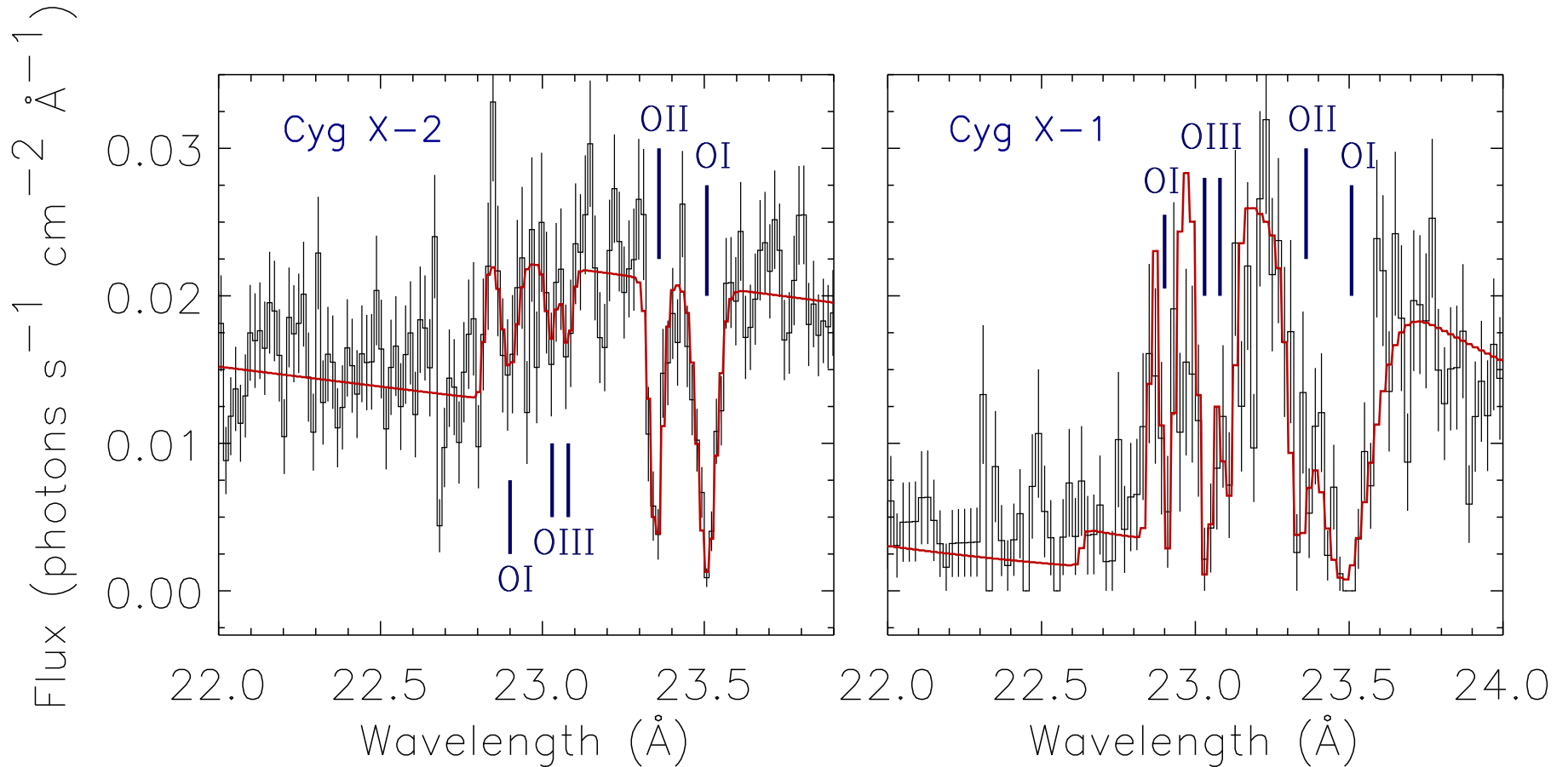
Used O I 1s-2p absorption line as benchmark.

Modeling HETGS Spectra



- HETG: $\Delta\lambda = 0.023 \text{ \AA}$, highest resolution.
- Fit spectra of 7 X-ray sources.
- Used high-S/N data as template.
- Model includes 2 absorption edges and 5 Gaussian absorption lines.

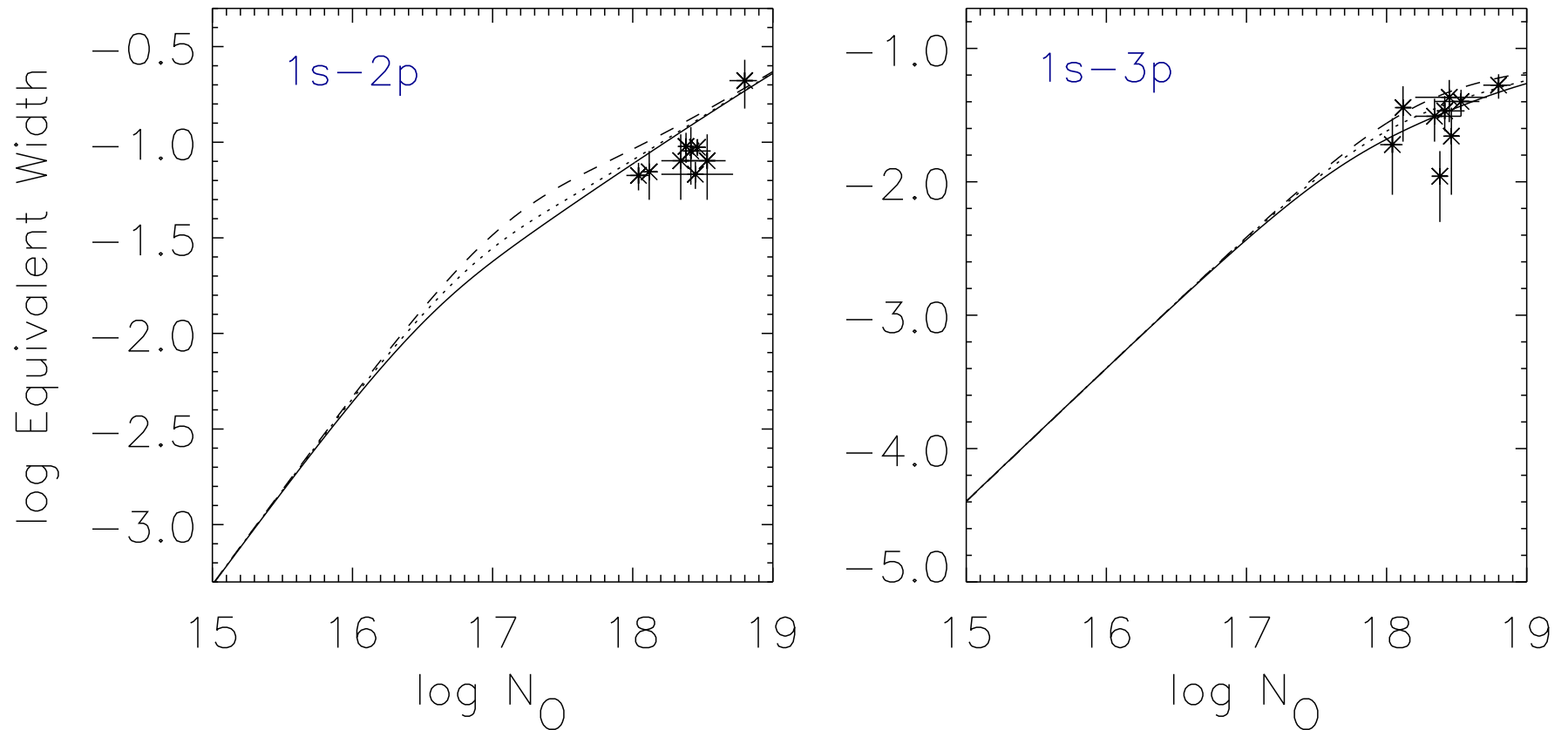
Identified Lines



Identified only neutral and ionized O features.

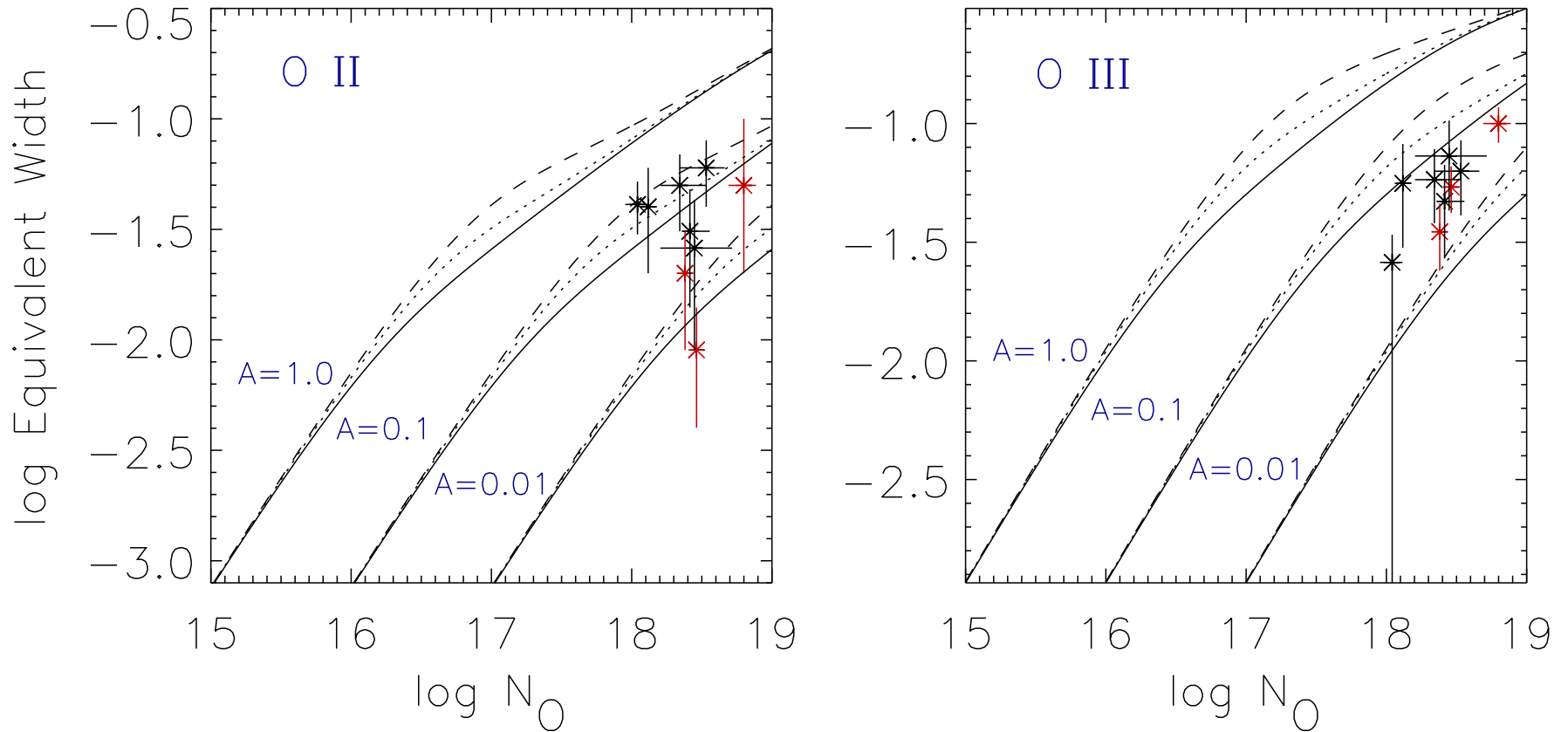
Column density measurements calculated at wavelength away from edge structure.

Curve of Growth — Neutral O



Data consistent with the low velocity dispersions found in other studies.

Curve of Growth — Ionized O



$$A = N_{\text{ionized}}/N_{\text{neutral}}$$

First measurement of large-scale ionization fraction in ISM.

Other Issues

- Instrumental Contribution
 - Instrumental absorption feature at 23.33 Å included in model of contaminant.
- Oxygen in Molecules/Dust
 - Place limits on amount of O in other forms: 10–40%.
 - Consistent with other determinations (Andrè et al. 2003).
- Local vs. ISM
 - Correlation between neutral column density and ionized EW suggests that to first order ionized lines are from ISM.
 - But some evidence for material local to the binary in Cyg X-1.

Conclusions

Oxygen edges of X-ray binaries are well described by a model that includes neutral and ionized O features.

Velocity dispersions consistent with other measurements: $\lesssim 200 \text{ km s}^{-1}$.

Made the first measurements of the large-scale O II and O III abundance, relative to O I.

- $\text{O II/O I} \approx 0.1$, $\text{O III/O I} \lesssim 0.1$.
- Roughly consistent with expectations given $\text{H II/H I} \approx 1/3$.