X-raying the *Global* Hot Interstellar and Circum-galactic Media

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In collaboration with T. Tripp (Umass), et al.
X-ray absorption line spectroscopy: adding depth into the map

ROSAT all-sky survey in the $0.5\text{-keV}$ band

Futamoto et al. 2004, Wang et al. 05, Yao & Wang 05/06, Yao et al. 06/07/08
X-ray absorption line spectroscopy is powerful!

- Tracing all K transitions of metals → all three phases of the ISM.
- Not affected by photo-electric absorption → unbiased measurements of the global ISM.

Yao & Wang 2006, Yao et al. 2006, Futamoto et al. 2004
Spectroscopic diagnostics

• One line (e.g., OVII Kα) → velocity centroid and EW → constraints on the column density, assuming b and T
• Two lines of different ionization states (OVII and OVIII Kα) → T
• Two lines of the same state (Kα and Kβ) → b
• Lines from different species → relative abundance \( f_a \)
• Multiple sightlines --> differential hot gas properties
• Joint-fit of absorption and emission data --> pathlength and density
LMC X-3: absorption lines

- BH X-ray binary undergoing Roche lobe accretion
- Away from the LMC main body
- 50 kpc away
- $V_s = +310 \text{ km/s}$
- The line centroids of the OVI and OVII lines are consistent with their Galactic origin.
- $N_{\text{OVII}} \sim 1.9 \times 10^{16} \text{ atoms/cm}^2$, similar to those seen in AGN spectra!
- $T \sim 1.3 \times 10^6 \text{ K}$
- $b \sim 79 \text{ km/s}$

Wang et al. 2005
Joint-fit to the Suzaku XIS diffuse emission spectrum

- Single temperature fit $\rightarrow T = 2.4 \times 10^6$ K, significantly higher than that inferred from the X-ray absorption lines.

- Joint-fit to the absorption and emission data gives
  - $n_e = (3.6 \times 10^{-3}$ K $) e^{-|z|/2.8 \text{ kpc}}$;
  - $T = (2.4 \times 10^6$ K $) e^{-|z|/1.4 \text{ kpc}}$

$\rightarrow P/k \sim 1.1 \times 10^4 \text{ cm}^{-3} \text{ K}$, assuming filling factor = 1.

$\rightarrow$ This thick hot disk can explain all the OVI absorption, except for $\sim$10% of high-$\nu$ OVI emission.

100 ks Suzaku observations of LMC X-3 off-fields
(Yao, Wang, et al. 2008)
Galactic global hot gas properties

- **Thermal property:**
  - mean $T \sim 10^{6.3}$ K toward the inner region
  - $\sim 10^{6.1}$ K at solar neighborhood

- **Velocity dispersion** from $\sim 200$ km/s to 80 km/s

- **Abundance ratios** $\sim$ solar

- **Structure:**
  - A thick Galactic disk with a scale height of $\sim 2$ kpc,
    $\sim$ the values of OVI absorbers and free electrons
  - Enhanced hot gas around the Galactic bulge
  - 95% upper limit: $N_{\text{OVII}} \sim 3 \times 10^{15}$ cm$^{-2}$ for $r > 10$ kpc
    $\sim 1 \times 10^{15}$ cm$^{-2}$ for $r > 50$ kpc

No evidence for a large-scale X-ray-emitting/absorbing halo!
No evidence for X-ray line absorption by hot gas in intervening groups of galaxies

- Sightline: PKS 2115-304
- Total exposure: 1 Ms
- Selected galaxies: < 500 kpc projected distance.

### Background AGNs, Chandra observations, and the number of intervening galaxies

<table>
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<th>Src. Name</th>
<th>$z_{\text{AGN}}$</th>
<th>No. of Obs.</th>
<th>Exp. (ks)</th>
<th>No. of gal.</th>
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<td>80</td>
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<td><strong>3076</strong></td>
<td><strong>154(143)</strong></td>
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</table>

Blue lines: Galactic absorption

Vertical red bars: expected group absorption line positions

Yao, Y., QDW, T. Tripp, et al. (2010)
Stacking of absorption line spectra according to intervening galaxy/group redshifts

With an effective exposure: ~ 10 Ms, no absorption is detected!

- \( N_{\text{OVII}} < 10^{15} \text{ cm}^{-2} \), or < 1/10 of the column density observed around the Milky Way.
- Groups typically contain little gas at \( T \sim 10^{5.3}-10^{6.3} \text{ K} \), unless the Oxygen abundance is \(< 1/10 \) solar.
The intergalactic warm-hot gas: Stacking according to OVI absorbers

Y. Yao, T. Tripp, QDW, et al. (2009)
Stacked Chandra grating spectrum

- 16 absorbers along 6 sight lines.
- \( N_{\text{OVII}} < 10 N_{\text{OVI}} \) at the 95% confidence; similar constraints on the complex and strong OVI absorbers, separately.
- Implications: 1) \( T < 10^{5.7} \) K for the OVI-bearing gas (assuming CIE); 2) the OVI gas may be mostly photo-ionized or at interfaces between cool and hot (\( T > 10^{6.4} \) K) phases.