Density Profiles of Seyfert Outflows

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Outline

• Wide Range of charge states observed in X-ray spectra of Seyfert outflows
• How does one model such spectra
• What is the distribution of $N_H (\log \xi)$
• What can it tell us about the density gradients in the outflow
Seyfert Outflows - Basics

• Why not study them
  - Slow $v < 1000$ km/s
  - Insignificant energy feedback $(v/c)^2 << 1$

• On the other hand,
  - Best high resolution X-ray spectra
  - Simultaneous UV observations
  - Best chance for capturing detailed physics

• Basic properties still TBD
  - Location - disk, torus, galaxy?
  - Launch mechanism - radiation, magnetic, thermal?

• (please) do not call them “warm absorbers”
Rich in elements, ions, & lines

Fig. 3: Segments of the RGS spectrum of NGC 7469 with the best-fit folded model overlaid. Spectra are presented in the observed (redshifted) frame. Prominent features are marked on the spectrum at their positions in the rest frame of NGC 7469. We note the varying vertical scale from one panel to the next, none of which reach zero. Longer wavelengths are presented in Fig. 4 below.
Fe M-shell UTAs
Kα in L-shell
$N_H \ (\log \xi)$

5 Orders of Magnitude in $\xi$

Column density $N_H = \int n_H \, dr$

Ionization parameter $\xi = L / n_H r^2$

Not "warm"
relative to K-shell lines (Kallman et al. 1996; Kinkhabwala et al.) plasmas, where they form by means of recombination, are weak which are shown in Fig. 6. The L-shell lines in photo-ionized line at 15.25 Å and the 17.38 Å doublet (both observed frame),

After Fig. 3: Segments of the spectrum of NGC 7469 (redshifted) frame. Prominent features are marked on the spectrum at their positions in the rest frame of NGC 7469. We note the varying vertical scale from one panel to the next, none of which reach zero. Longer wavelengths are presented in Fig. 4 below.

Table 2: Outflow Absorption Components in NGC 7469

<table>
<thead>
<tr>
<th>Comp. #</th>
<th>$v_{out}^a$ (km s$^{-1}$)</th>
<th>$v_{turb}$ (km s$^{-1}$)</th>
<th>log $\xi$ (erg s$^{-1}$ cm)</th>
<th>$N_H$ (10$^{20}$ cm$^{-2}$)</th>
<th>$\Delta C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$-650 \pm 50$</td>
<td>70±10</td>
<td>$-0.6 \pm 0.2$</td>
<td>$0.2 \pm 0.1$</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>...</td>
<td>70±10</td>
<td>$1.4 \pm 0.1$</td>
<td>$1.0 \pm 0.3$</td>
<td>221</td>
</tr>
<tr>
<td>3</td>
<td>...</td>
<td>70±10</td>
<td>$2.0 \pm 0.1$</td>
<td>$5.5 \pm 1.0$</td>
<td>1027</td>
</tr>
<tr>
<td>4</td>
<td>$-950^{+50}_{-100}$</td>
<td>35±20</td>
<td>$2.7 \pm 0.2$</td>
<td>$22 \pm 10$</td>
<td>383</td>
</tr>
<tr>
<td>5</td>
<td>$-2050^{+50}_{-160}$</td>
<td>60±30</td>
<td>$2.0 \pm 0.3$</td>
<td>$1.1 \pm 0.3$</td>
<td>82</td>
</tr>
<tr>
<td>6</td>
<td>...</td>
<td>60±30</td>
<td>$0.3 \pm 0.2$</td>
<td>$0.1 \pm 0.1$</td>
<td>48</td>
</tr>
</tbody>
</table>

$a$ velocities and widths of Components 1-3 and those of 5-6 are tied.
Absorption Measure Distribution

\[
AMD(\xi) = \frac{dN_H}{d\log \xi}
\]

\[
N_{\text{ion (measured)}} = A_Z \int AMD(\xi) f_{\text{ion}}(\xi) \, d\log \xi
\]
What's the Difference?

- A continuous distribution is more general, simple, and perhaps physical.
- The AMD includes the actual dependence of fractional abundances on bins, and potentially highlights unstable regions.
- AMDs can be related to physical models.

XSTAR output
But ...

- More degrees of freedom (1 per ion), not necessarily better fit
- There is a limit to the "resolution" in $\xi$ (AMD binning)
  - motivation for physical models
- Structure depends on separately computed $f_{\text{ion}}(\xi)$, in turn affecting the cooling ($T$) and determining (in)stability.
We construct theoretical AMD curves for the cold (left) and hot (right) solutions of the cases $\xi_{\text{tot}} = 4000$ (green) and $\xi_{\text{tot}} = 8000$ (blue). The observational AMD is denoted by the dashed line. The bottom panels show the same theoretical AMDs as above but degraded to the resolution of the observed AMD and plotted on a larger vertical scale.

Fig. 7. Comparison between the observed and the modeled AMD as a function of temperature inside the medium (see Sect. 3).
AMD or Discrete Components?

Mrk 509
Adhikari et al. '15
**NGC 1068: Broad AMD in Emission**

**Figure 11.** Distribution of mass among the emission components used to model the spectrum. Black points correspond to the component with column $3 \times 10^{23}$ cm$^{-2}$, and red corresponds to the component with column $3 \times 10^{22}$ cm$^{-2}$.
AMD Slopes & Density Profiles

• Since the AMD and $\xi$ both depend on $n$ and on $r$ (or $dr$), an analytic expression for $\text{AMD}(\xi)$ could hint to what $n(r)$ is doing

• Example: approximate $\text{AMD} \sim \xi^a$

• Assume global wind density profile $n(r) \sim r^{-\alpha}$
  $\Rightarrow \xi \sim n^{-1} r^{-2} \sim r^{\alpha-2}$

• $dN_H \sim n(r)dr = n(r)(dr/d\xi)d\xi \sim \xi^{(3-2\alpha)/(\alpha-2)}$

• $\text{AMD} = |dN_H/d\log\xi| = \xi |dN_H/d\xi| \sim \xi^{-(\alpha-1)/(\alpha-2)}$
  $\Rightarrow a = -(\alpha-1)/(\alpha-2) \Rightarrow \alpha = (1+2a)/(1+a)$
AMD Slopes & Density Profiles

- Measured values:
  \[ a = 0.0 - 0.4 \Rightarrow \alpha = 1.0 - 1.3 \]
- \[ n(r) \sim r^{-1} \]
Extended to 26 Seyferts
Laha et al. '14, '16

\[ \text{AMD} \sim \xi^{0.3} \text{ or } \]
\[ n \sim r^{-\alpha} \text{ with } \alpha = 1.236 \pm 0.034 \]
Conclusively rule out
- simple radial flow
  \( n \sim r^{-2}, \text{constant } \xi \)
- constant density clouds
  \( \alpha = 0, a = -0.5 \)
- Blandford & Payne Jets
  \( n \sim r^{-3/2} (a = 1) \)
Large-Scale MHD Winds
See talks by Keigo and Demos

Fukumura+’10
Another Possibility:
Local Gradients in Remote Absorber

• Well localized $r_0$ absorber
• Density gradients on short scales $\delta r \ll r_0$
  $n(\delta r) \sim \delta r^{-\alpha}$ (with uniform $v_{out}$)
• Ionization then depends solely on density
  $\xi = L/nr_0^2 \sim 1/n$ (requires 4-5 dex)
• AMD slope $a = -(\alpha-1)/\alpha$ or $\alpha = 1/(1+a)$
• $a = 0.0 - 0.4 \Rightarrow \alpha = 0.7 - 1.0$
• What can produce $n(\delta r) \sim \delta r^{-1}$?
• Density fluctuations in ISM (Kolmogorov turbulence) produces
  $n(\delta r) \sim \delta r^{0.4}$ ($\alpha = -0.4$)
Radiation Pressure Confinement
(Dopita '02, Rozanska+’06, Stern+’14)

- Hydrostatic plane-parallel geometry
- See talks by Agata, Ari, Jonathan

![Graph showing density and temperature profiles](image)
THANK YOU
FOR YOUR ATTENTION
Points for Discussion

• Are AGN outflows discrete ionization-components (i.e. random clouds) or a meaningful distribution?
• Are we able to identify unstable regions through the AMD, namely are the ionization balance calculations reliable?
• Are the outflows on galactic scales? or are they a distribution within a single entity (cloud)?
  • Is there a velocity trend with $\xi$, or are we seeing all charge state moving together?
• Can we learn from the ionization distribution about the launching mechanism?
Absorption Measure Distribution of Radiation Pressure Confinement

$$\text{AMD (calc. RPC)} = \frac{dN}{d \log \xi} = 7.6 \times 10^{21} \xi^{0.03} \text{ cm}^{-2}$$

$$\text{AMD (obs. mean)} = \frac{dN}{d \log \xi} = 3 \times 10^{21} \xi^{0.05} \text{ cm}^{-2}$$
More Features of RPC