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 $(v/c)^2 \ll 1$
- 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

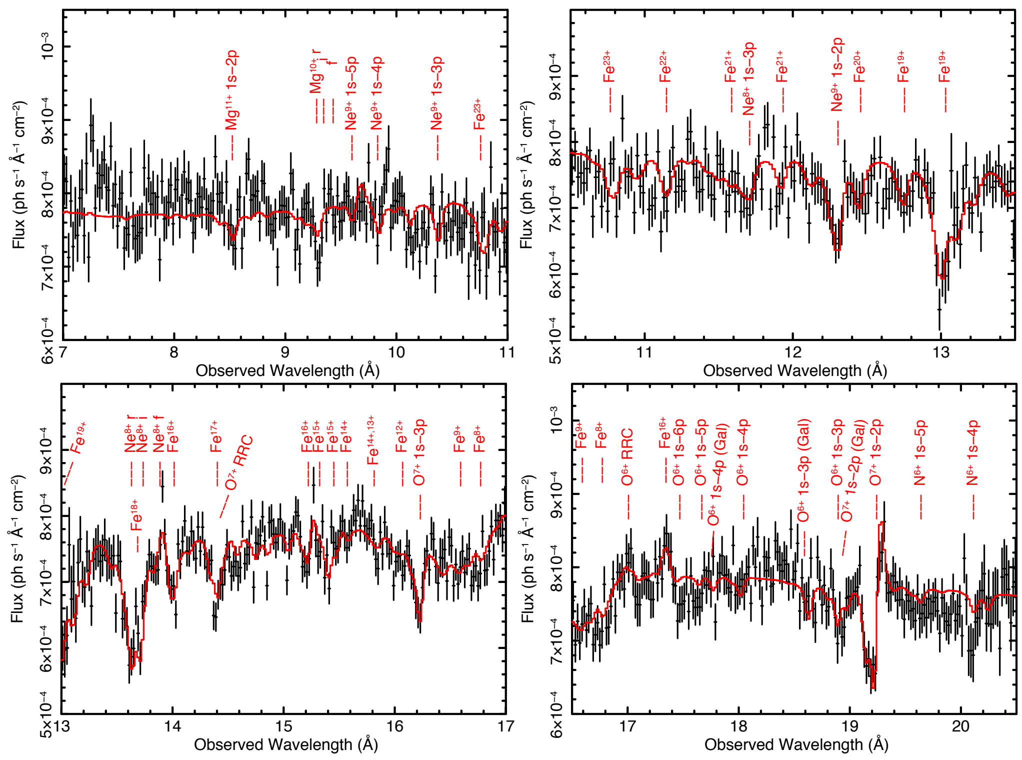
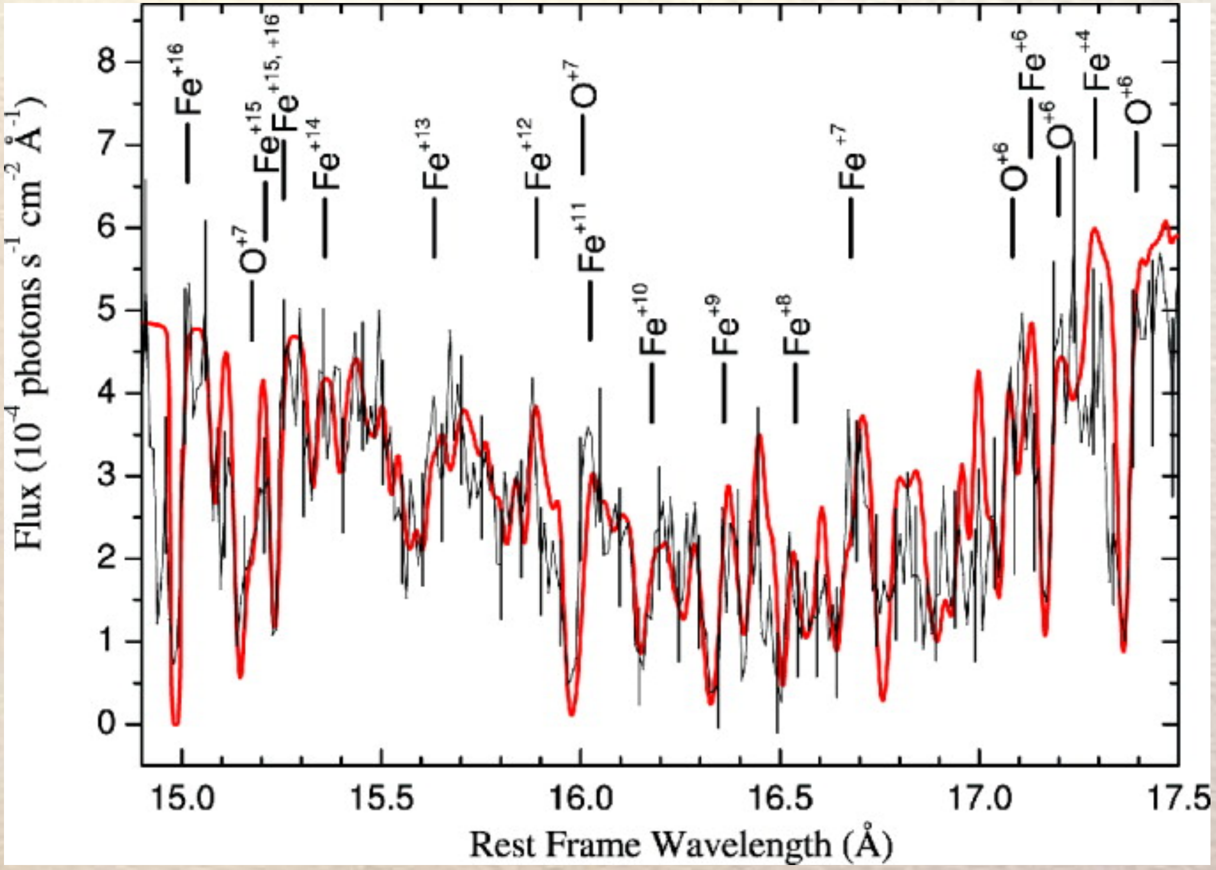
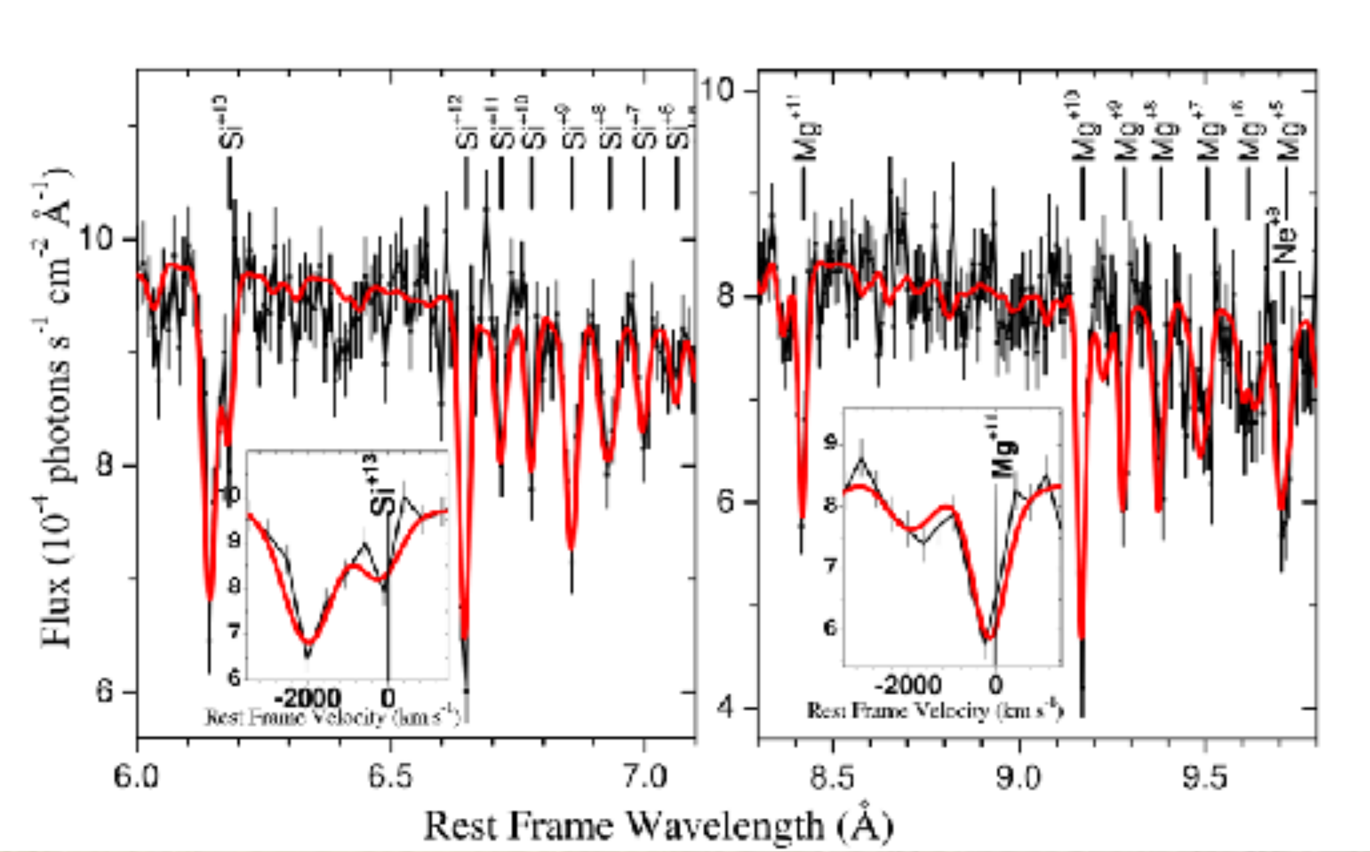


Fig. 3: Segments of the RGS spectrum of NGC 7469 with the best-fit folded model overlaid. Spectra are presented in the observed (redshifted) frame. Prominent features are marked on the spectrum at their positions in the rest frame of NGC 7469. We note the varying vertical scale from one panel to the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

Fe M-shell UTAs



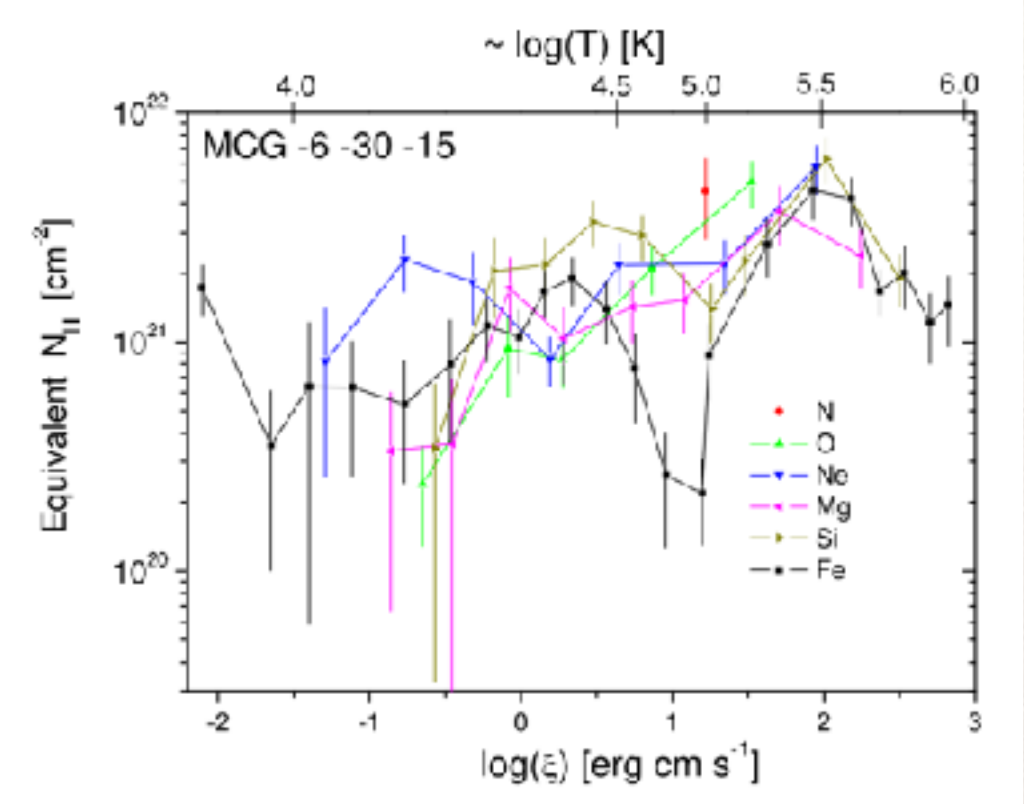
Kα in L-shell



Flux (10^{-4} photons s^{-1} cm^{-2} Å^{-1})
Rest Frame Wavelength (Å)
Rest Frame Velocity (km s^{-1})
Si^{+13}
Si^{+12}
Si^{+11}
Si^{+10}
Si^{+9}
Si^{+8}
Si^{+7}
Si^{+6}
Mg^{+11}
Mg^{+10}
Mg^{+9}
Mg^{+8}
Mg^{+7}
Mg^{+6}
Mg^{+5}
Ne^{+9}
6.0
6.5
7.0
8.5
9.0
9.5
-2000
0

N_H (logξ)
5 Orders of Magnitude in ξ

column density $N_H = \int n_H dr$



not "warm"

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

Standard Method: Keep Adding Components

Table 2: Outflow Absorption Components in NGC 7469

Comp. #	v_{out} [a] ($km\,s^{-1}$)	v_{turb} ($km\,s^{-1}$)	$\log\xi$ ($erg\,s^{-1}cm$)	N_H ($10^{20}\,cm^{-2}$)	ΔC
1	-650 ± 50	70 ± 10	-0.6 ± 0.2	0.2 ± 0.1	33
2	···	70 ± 10	1.4 ± 0.1	1.0 ± 0.3	221
3	···	70 ± 10	2.0 ± 0.1	5.5 ± 1.0	1027
4	-950^{+50}_{-100}	35 ± 20	2.7 ± 0.2	22 ± 10	383
5	-2050^{+50}_{-160}	60 ± 30	2.0 ± 0.3	1.1 ± 0.3	82
6	···	60 ± 30	0.3 ± 0.2	0.1 ± 0.1	48

[a] velocities and widths of Components 1-3 and those of 5-6 are tied

NGC 7469

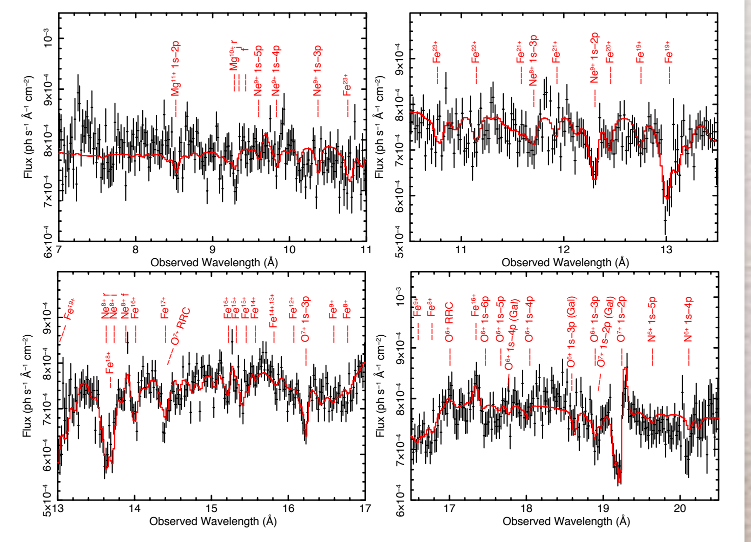


Fig. 3: Segments of the RGS spectrum of NGC 7469 with the best-fit folded model overlaid. Spectra are presented in the observed (redshifted) frame. Prominent features are marked on the spectrum at their positions in the rest frame of NGC 7469. We note the varying vertical scale from one panel to the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

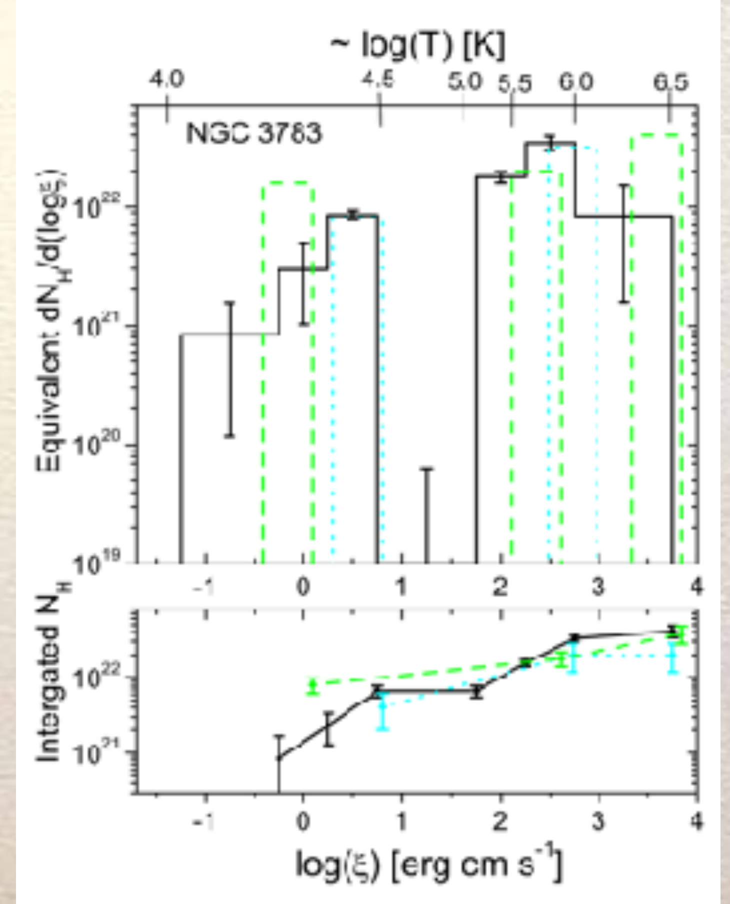
Or Assume a Distribution

Absorption Measure Distribution

$AMD(\xi) = dN_H/d\log\xi$

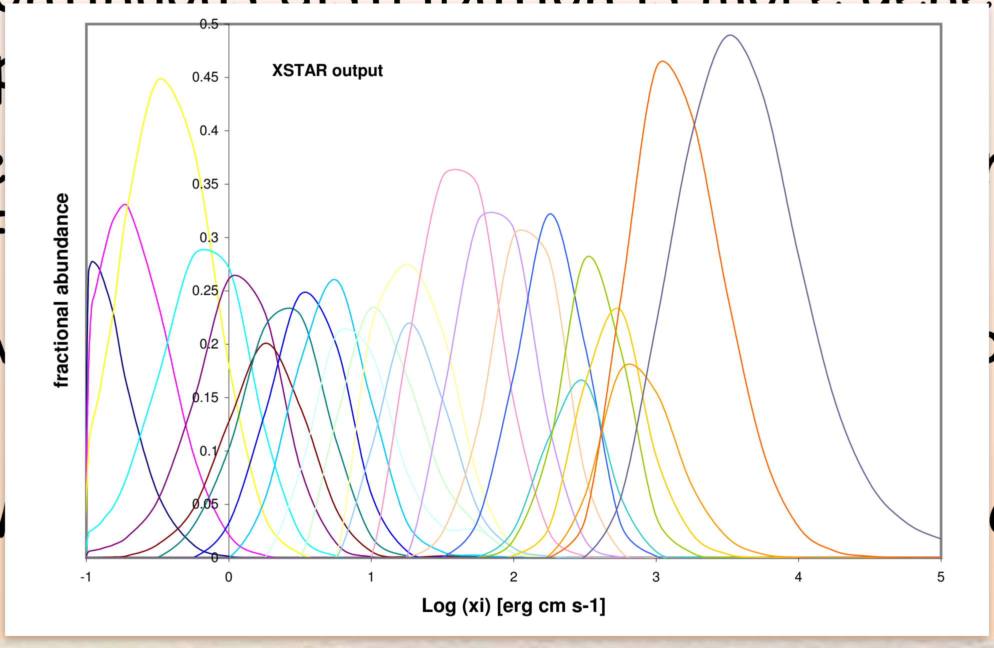
N_{ion} (measured) =

$A_Z \int AMD(\xi)\, f_{ion}(\xi)\, d\log\xi$



What's the Difference?

- A continuous distribution is more general, simp
- The … nce of f
- Prov … ins, and … ions
- A… CAL



But …

- More degrees of freedom (1 per ion), not necessarily better fit
- There is a limit to the "resolution" in ξ (AMD binning)
  - motivation for physical models
- Structure depends on separately computed $f_{ion}(\xi)$, in turn affecting the cooling (T) and determining (in)stability.

Goosmann et al. 2016 using TITAN

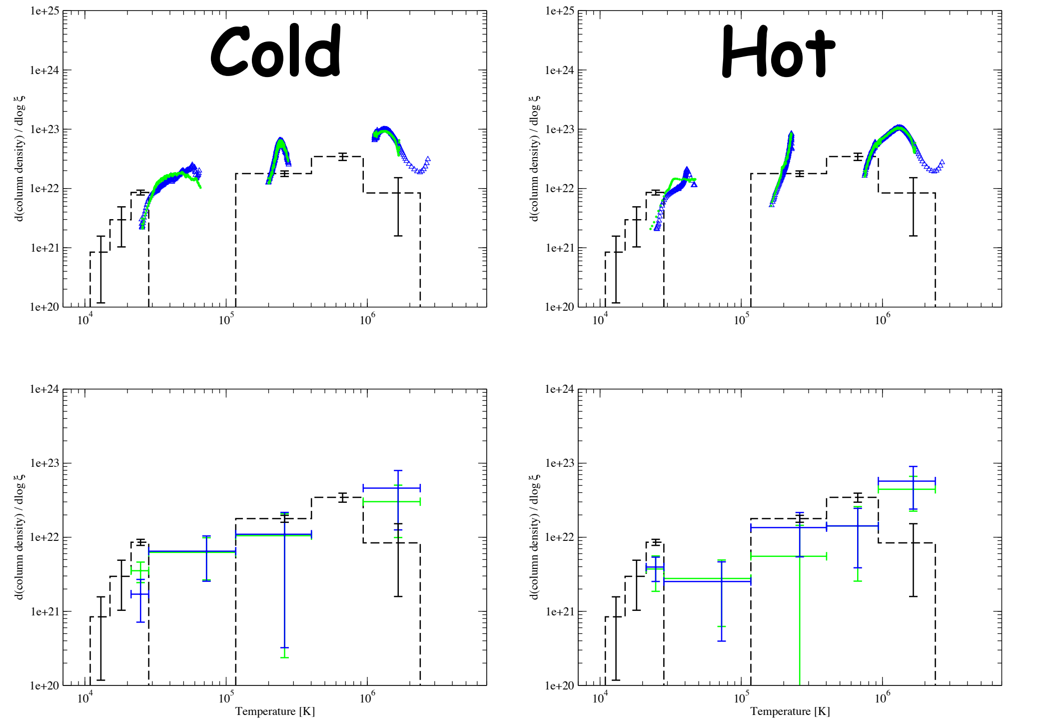
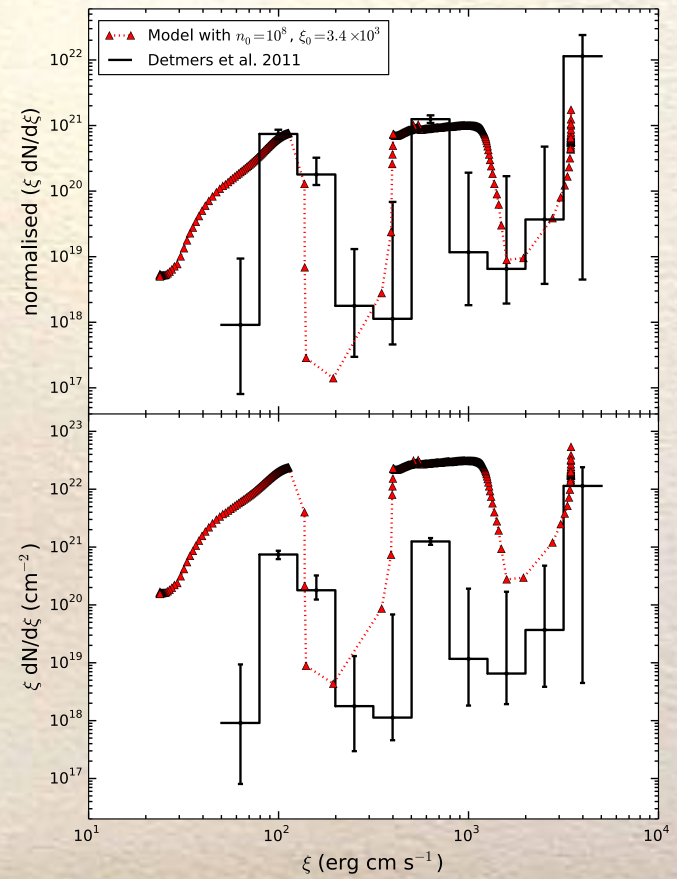


Fig. 7. Comparison between the observed and the modeled AMD as a function of temperature inside the medium (see Sect. 3). We construct theoretical AMD curves for the cold (left) and hot (right) solutions of the cases $\xi_{\rm tot} = 4000$ (green) and $\xi_{\rm tot} = 8000$ (blue). The observational AMD is denoted by the dashed line. The botom panels show the same theoretical AMDs as above but degraded to the resolution of the observed AMD and plotted on a larger vertical scale.

AMD or Discrete Components?



Mrk 509

Adhikari et al. '15

NGC 1068: Broad AMD in Emission

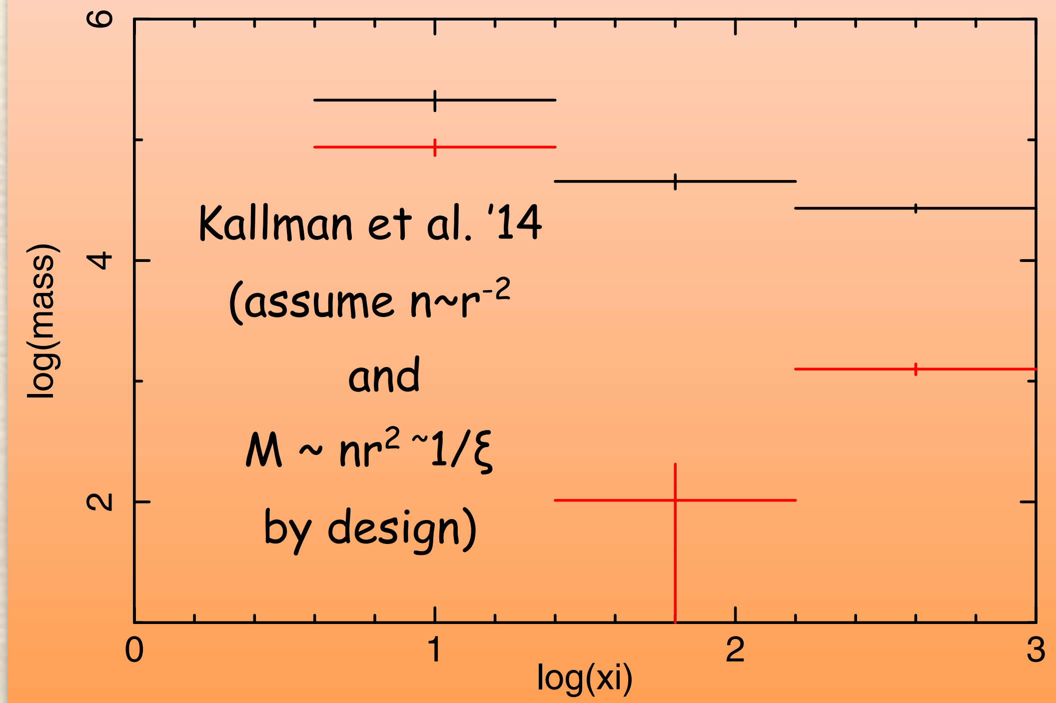


Figure 11. Distribution of mass among the emission components used to model the spectrum. Black points correspond to the component with column 3×10^{23} cm^{-2}, and red corresponds to the component with column 3×10^{22} cm^{-2}.

AMD Slopes & Density Profiles

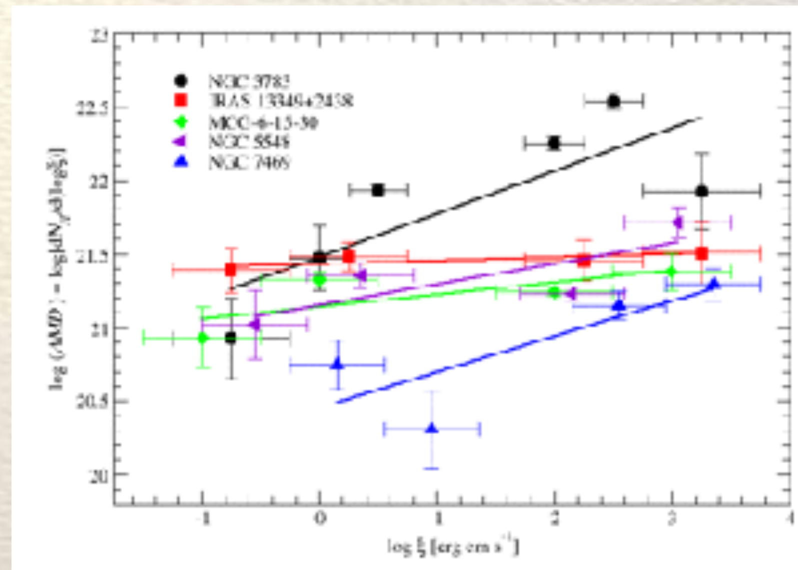
- Since the AMD and ξ both depend on n and on r (or dr), an analytic expression for AMD(ξ) could hint to what n(r) is doing
- Example: approximate $AMD \sim \xi^{a}$
- Assume global wind density profile $n(r) \sim r^{-\alpha}$

  $\Rightarrow \xi \sim n^{-1} r^{-2} \sim r^{\alpha-2}$
- $dN_H \sim n(r)dr = n(r)(dr/d\xi)d\xi \sim \xi^{(3-2\alpha)/(\alpha-2)}$
- $AMD = |dN_H/d\log\xi| = \xi|dN_H/d\xi| \sim \xi^{-(\alpha-1)/(\alpha-2)}$

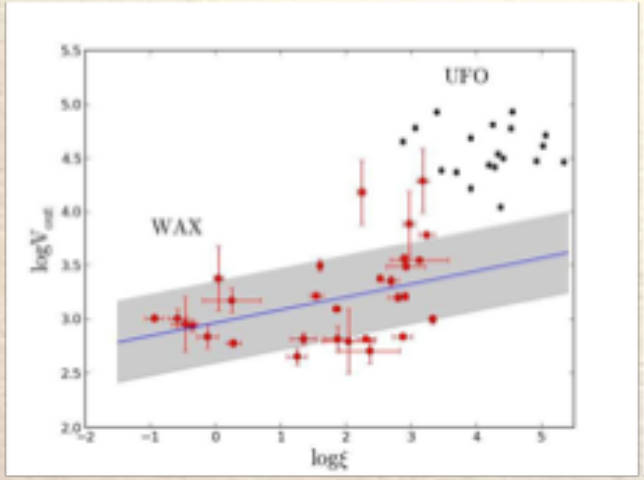
  $\Rightarrow a = -(\alpha-1)/(\alpha-2) \Rightarrow \alpha = (1+2a)/(1+a)$

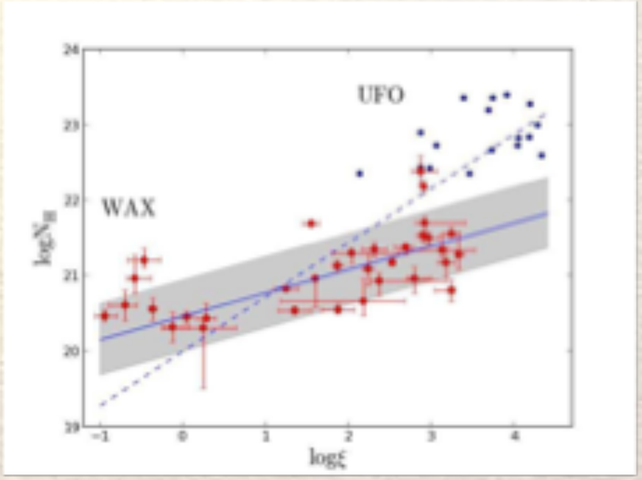
AMD Slopes & Density Profiles

- Measured values:
  a = 0.0 - 0.4 => α = 1.0 - 1.3
- $n(r) \sim r^{-1}$



Extended to 26 Seyferts Laha et al. '14, '16



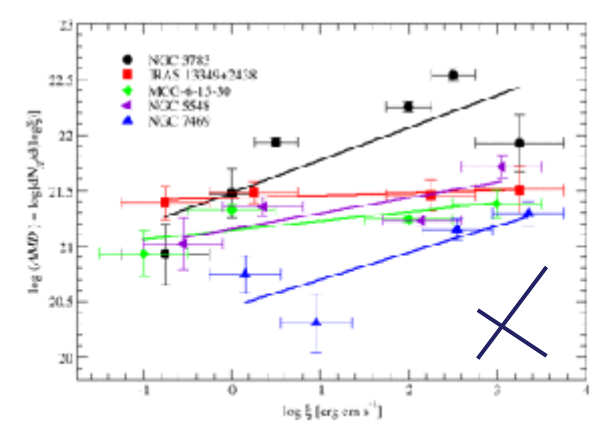


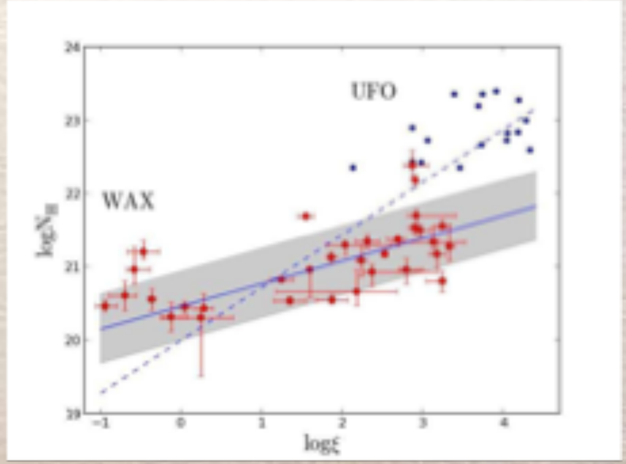
AMD ~ $\xi^{0.3}$ or

$n \sim r^{-\alpha}$ with $\alpha = 1.236 \pm 0.034$

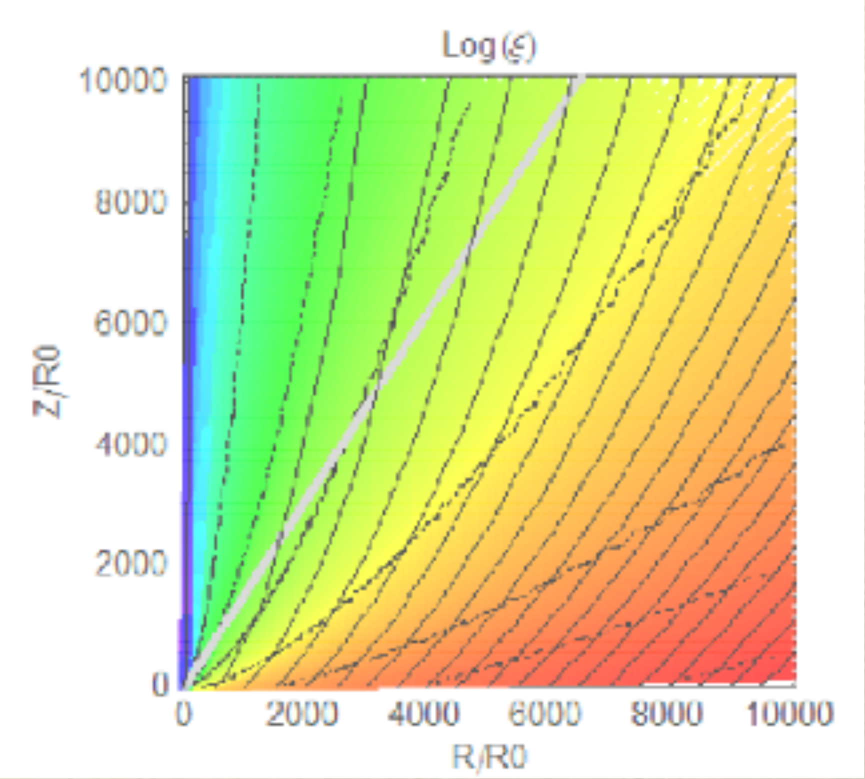
AMD Slopes & Density Profiles (cont.)

- Conclusively rule out
  - simple radial flow ($n \sim r^{-2}$, constant ξ)
  - 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

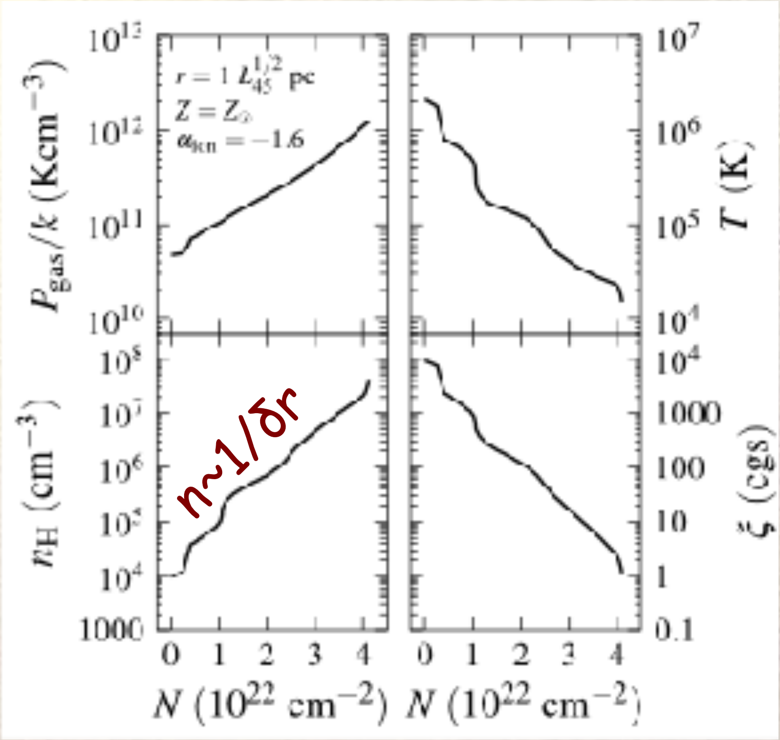
  $\xi = L/nr_0^2 \sim 1/n$ (requires 4-5 dex)
- AMD slope $a = -(\alpha-1)/\alpha$ or $\alpha = 1/(1+a)$
- $a = 0.0 - 0.4 \Rightarrow \alpha = 0.7 - 1.0$
- What can produce $n(\delta r) \sim \delta r^{-1}$?
- Density fluctuations in ISM (Kolmogorov turbulence) produces

  $n(\delta r) \sim \delta r^{0.4}$ ($\alpha = -0.4$)

Radiation Pressure Confinement

(Dopita '02, Rozanska+'06, Stern+'14)

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

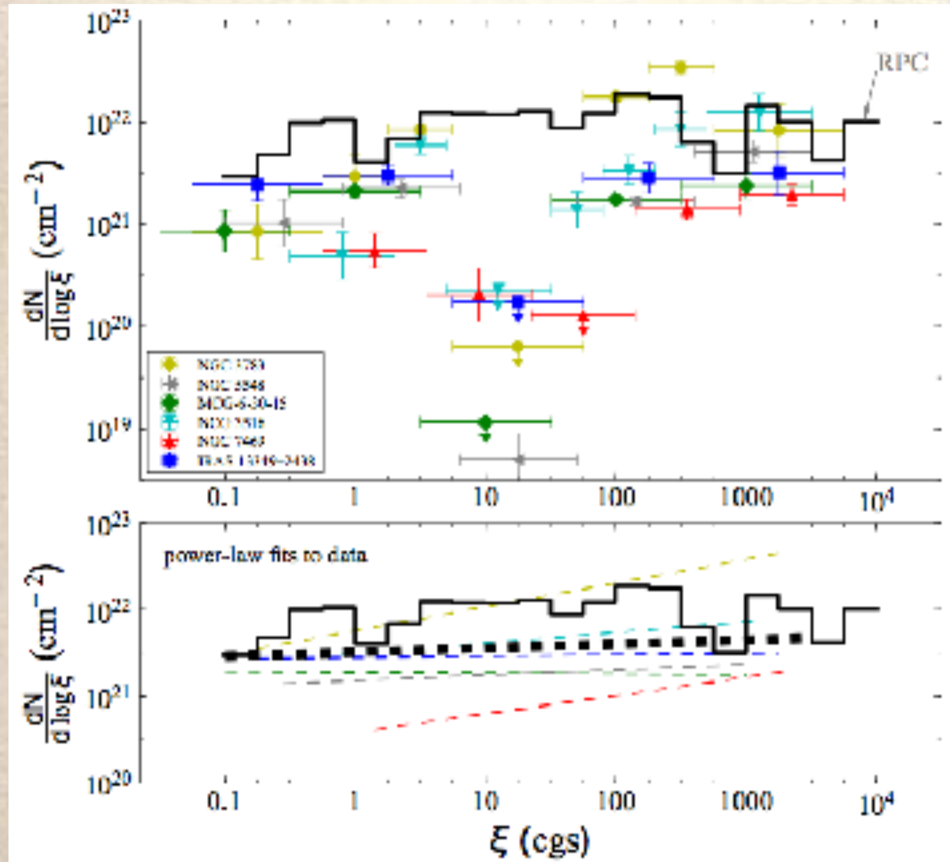


THANK YOU
FOR YOUR ATTENTION

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 ξ, 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



AMD (calc. RPC) = dN/dlogξ = $7.6 \times 10^{21}\ \xi^{0.03}\ \mathrm{cm}^{-2}$

AMD (obs. mean) = dN/dlogξ = $3 \times 10^{21}\ \xi^{0.05}\ \mathrm{cm}^{-2}$

More Features of RPC