Metallicity measurements in AGNs

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Abstract. Measuring metallicity in the nuclear regions of AGNs is difficult because only a few lines are observed and ionization correction becomes a major problem. Nitrogen to carbon ratio has been widely used as an indicator for metallicity, but precise measurements have been lacking. We made such measurements for the first time using a wide baseline of ionization states with observations from FUSE, HST and Chandra. O VI observations with FUSE were crucial in this effort. We measured super-solar metallicities in two AGNs and found that N/C does not scale with metallicity. This suggests that chemical enrichment scenario in nuclear regions of galaxies may be different from traditional models of metal enrichment.

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METALLICITY IN AGNS

Understanding chemical evolution of galaxies is one of the fundamental problems in astronomy and active galaxies are no exception. We now understand that most, if not all galaxies exhibit an active phase some times in their life. Thus knowing metallicity in AGNs allows us understand the chemical enrichment in galactic nuclei which may differ substantially from the enrichment on galactic scales. AGNs also show signs of outflow. The role of such outflows, especially those from powerful quasars, in enriching the intergalactic medium with metals is unclear. How does the kinematics, dynamics and metal content of AGN outflows compare with those from super-winds on galactic scales? While these are all important questions to answer, we have no knowledge of metallicity in the circumnuclear regions of AGNs.

This is because measuring AGN metallicity is difficult. In the optical, where most of the measurements are made, only a handful of broad emission lines are observed, mostly of hydrogen. At high redshift, the rest-frame UV spectrum is observed with several metal lines such as C IV, N V, Mg II. However, converting the emission line strengths to metallicity is not straight forward as it depends upon ionization balance, temperature, density and geometry. Nonetheless, attempts to estimate metallicities have been made, notably by Hamann & Ferland (1999 and references therein). They suggested the use of N V/C IV as a metallicity indicator. Because of the secondary C-N-O nucleosynthesis, N/C scales as metallicity Z, so N scales like Z^2. Using these method, Hamann & Ferland showed that high redshift quasars have super-solar metallicity.

The use of emission lines as metallicity indicators was questioned by Shemmer & Netzer (2002) who showed that N V/C IV ratio and N V/C IV ratio do not give consistent answers for N/C! Given the strong model dependence of emission line strengths, this
was not a surprise. Absorption line strengths, on the other hand, are geometry and density independent and so are potentially better tracers of metallicity. Converting the observed column densities of absorption lines to column densities of metals still involves ionization correction; once again this is a difficult quantity to measure because only a handful of lines of different metals are observed in a given band. A long base-line of ionization states is required to make the ionization correction. As discussed below, we performed multi-wavelength observations toward this goal and made the first precise measurement of metallicity in an AGN.

METALLICITY MEASUREMENT IN MRK 1044

Figure 1 shows the HST STIS spectrum of Mrk 1044. Multiple velocity components of C IV, N V, and Lyα are clearly seen. A FUSE spectrum of Mrk 1044 is shown in figure 2. Here we see absorption lines of O VI at the same velocities seen in the HST spectrum. Additionally we detect Lyβ absorption. We fit a “pseudo continuum” through the emission lines and the AGN continuum and measure the strengths of the absorption lines and determine their column densities (see Fields et al. 2005a,b for details).

The next step is to determine the ionization parameter of the absorption system. To this end we generated a grid of models of ionization parameter U and the total column density $N_H$ for solar metallicity and mixture using CLOUDY and looked for models consistent with observations. This is shown in figure 3; the hatched curves correspond to the locus on the log $N_H$ — log U plane corresponding to the observed column density of each ion. The intersection of all the curves, if present, defines the $N_H$ and U of the system. The curves of C IV, N V and O VI actually do intersect at log U = −1.29. What
is noteworthy, however, is that the curves for H I do not. For the inferred value of U, the H I column density is significantly lower. This implies that the metals are more abundant, or that the metallicity of the system is super-solar. We measure the metallicity to be about 5 times solar.

What is also interesting is that the metal mixture is consistent with solar. In particular, we do not find the locus of N V displaced from the intersection of C IV and O VI. Thus, we find no evidence for N scaling as Z^2.

**METALLICITY IN MRK 279**

Encouraged by the success in measuring metallicity in Mrk 1044, we attempted to apply our technique to another AGN for which multi-wavelength observations existed. Mrk 279 was observed with Chandra, HST and FUSE. In contrast to UV/FUV bands, the X-ray region contains hundreds of lines spanning a range of ionization states and so potentially provides powerful diagnostics. We found that the Chandra spectrum of Mrk 279 did not have sufficiently high quality to make robust metallicity measurements. However, the data were better fit with a model containing super-solar metallicity.

A consistent picture is now emerging with high resolution grating spectroscopy of X-ray absorbing outflows. The absorber seems to be made up of two or more components in pressure balance with each other. Costantini et al. (2007) had reported that the two components in Mrk 279, the one with low ionization parameter (LIP) and the one with high ionization parameter (HIP) are not in pressure equilibrium. In fact the pressure–
FIGURE 3. CLOUDY models assuming solar metallicity. Shaded regions correspond to observed column densities at the 1σ level for several ions. Note that all the metal lines agree in a small region of parameter space around \( \log U = -1.29 \) and \( \log N_H = 18.85 \). The distance in \( \log N_H \) between this point and the HI curve is at least +0.7.

temperature curve in Costantini et al. did not have an equilibrium zone. We had shown previously that super-solar metallicity can restore an equilibrium zone in the pressure–temperature curve (Komossa & Mathur 2000). So we re-made a pressure–temperature plot for the absorbers in Mrk 279 with super-solar metallicity as suggested by the fit to the Chandra data. As shown in figure 5, this not only restored a equilibrium zone, but now the LIP and the HIP components were found to be in pressure balance. While not conclusive, this make the case for super-solar metallicity in Mrk 279 stronger.

We then compared our X-ray results with the UV data from Gabel et al. (2005). Only when we invoke the model with super-solar metallicity, could we match the X-ray and UV data. Given that the LIP X-ray component is generally found to be consistent with the UV absorber, this gives an additional supporting evidence for super-solar metallicity in Mrk 297 (Fields et al. 2007). Arav et al (2007) independently arrived at the same conclusion.

CONCLUSIONS

Studies of Mrk 1044 and Mrk 279 have given strong evidence for super-solar metallicity in these AGNs. The Mrk 1044 result with five times solar metallicity is robust; first such precise measurement for an AGN. While we find metallicity to be overall super-solar, the abundance mixture is consistent with solar. Notably, we do not find any evidence for N/C scaling with metallicity. These studies imply that the chemical enrichment process in galactic nuclei is likely to be very different from traditional models. The Cosmic Origins Spectrograph (COS) to be installed on HST will prove to be invaluable in generalizing
FIGURE 4. The $\chi^2$ surface for models for bulk metallicity of 5 times solar, with a solar mixture of metals and helium enhanced by $\Delta Y/\Delta z = 2$ (see Fields et al. 2005b for details).

these results for a large number of AGNs.

REFERENCES

1. N. Arav, et al. ApJ, 658, 829 (2007).
2. E. Costantini, et al. A&A 461, 121 (2007).
3. D. Fields, S. Mathur, R. Pogge, F. Nicastro, and St. Komossa, ApJ, 620, 183 (2005a)
4. D. Fields, S. Mathur, R. Pogge, F. Nicastro, St. Komossa, and Y. Krongold ApJ, 634, 928 (2005b)
5. D. Fields, S. Mathur, Y. Krongold, Rik Williams, and F. Nicastro, ApJ, 666, 828 (2007)
6. F. Hamann & G. Ferland, ARA&A, 37, 487 (1999)
7. St. Komossa and S. Mathur, A&A, 374, 914 (2001)

FIGURE 5. The pressure–temperature plot for Mrk 279. The dotted curve is for solar metallicity while the solid curve is for super-solar C,N,O as observed. The LIP and the HIP components do not correspond to the same pressure (plotted as $\log U/T$) on the dotted curve, but are consistent with the same pressure on the solid curve. Note also that there is no equilibrium zone in the dotted curve, but there is one in the solid curve.
8. O. Shemmer, and H. Netzer, *ApJ*, **567**, L19 (2002)