Metallicity Evolution of Active Galactic Nuclei

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Abstract. In this contribution we report our recent investigation of the gas metallicity in active galactic nuclei and its dependence on luminosity and redshift. We compile large spectroscopic datasets of broad-line and narrow-line AGNs, and compare them with the results of our photoionization models. Through the analysis of both the broad and the narrow emission-line regions, we find that: (1) for a given luminosity, there is no redshift dependence of the gas metallicity; (2) for a given redshift, there is a significant correlation between gas metallicity and luminosity; (3) the luminosity-metallicity relation does not show any evolution in the redshift range $2 \lesssim z \lesssim 4$.

1. Introduction

Understanding the galaxy evolution is one of the key astrophysical topics of this decade. The gas metallicity in galaxies provides important information because it is a tracer of their star formation history. However, the observation of faint emission lines (most of which are in the rest-frame optical range and therefore shifted into the near infrared at high-z), associated with H II regions in star forming galaxies, is very difficult and time consuming. Instead, AGNs exhibit bright emission lines at rest-frame UV wavelengths, which can be used to investigate the gas metallicity even in high-z objects. In this contribution, we report our recent studies on the gas metallicity of high-z AGNs for both the broad-line region (BLR) and the narrow-line region (NLR). Details are given in Nagao et al. (2006a), Nagao et al. (2006b), and Maiolino et al. (2006).

2. The BLR Metallicity

The BLR metallicity in quasars is generally higher than solar (e.g., Hamann & Ferland 1992; Dietrich et al. 2003). Some observations suggest that quasars at higher-z quasars show higher metallicity than lower-z quasars (e.g., Hamann
It is also recognized that the BLR metallicity tends to be higher in more luminous quasars (e.g., Hamann & Ferland 1993). However, since higher luminosity quasars tend to be selectively observed at higher-\(z\), the above relations are degenerate. More specifically, it was not clear whether the BLR metallicity depends primarily on the luminosity or on the redshift.

To tackle this issue we focused on SDSS quasars. We retrieved 5344 spectra of quasars at \(2.0 \leq z \leq 4.5\) from the SDSS Data Release 2. The quasars were divided into redshift and luminosity bins with intervals \(\Delta z = 0.5\) and \(\Delta M_B = 1\) mag. Then we made a composite spectrum for each \((z, M_B)\) bin, after correcting for the Galactic reddening, removing BAL quasars, and by applying an appropriate normalization.

The composite spectra show that there are significant correlations between the quasars luminosity and various metallicity-sensitive emission-line flux ratios, such as N\(v/\)C\(iv\) and N\(v/Heii\), while there are almost no correlations between the quasars redshift and such emission-line flux ratios (Figure 1). The correlation of line ratios with luminosity is interpreted in terms of higher gas metallicity in more luminous quasars. For a given quasar luminosity, there is no significant metallicity evolution within the redshift range \(2.0 \leq z \leq 4.5\). The absence of the metallicity evolution up to \(z \sim 4.5\) may suggest that the active star-formation epoch of quasar host galaxies occurred at \(z \gtrsim 7\), inferred by timescale required for the enrichment of some elements such as C and Si (produced mainly by low- or intermediate-mass evolved stars).
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3. The NLR Metallicity

The NLR metallicity offers information complementary to the BLR metallicity since it traces spatial scales comparable with the host galaxies, although the measurements are much more tough with respect to the BLR. By using the Nv/Civ flux ratio, De Breuck (2000) claimed a NLR metallicity evolution of radio galaxies, in their spectroscopic sample, from $z > 3$ to $z < 3$. However, since the Nv emission becomes very weak at low metallicities, only upper-limit fluxes on Nv are available for the majority of high-$z$ radio galaxies, which makes the studies on the evolution of the NLR metallicity difficult. Alternative diagnostics of the NLR metallicity are required to make further progresses in the understanding of the NLR metallicity at high-$z$.

We focused on CIV, HeII and CIII], which are the most strong NLR emission lines seen in the rest-frame UV spectra. The CIV/HeII ratio is expected to be sensitive to the NLR gas metallicity. This is because the gas temperature decreases when the metallicity increases and thus the collisional excitation of CIV is gradually suppressed, while the HeII luminosity is basically proportional to the number of He$^{++}$ ionizing photons and thus rather insensitive to the metallicity. The CIII]/CIV ratio is instead sensitive to the ionization degree and therefore it is used to check any dependence of CIV/HeII on the ionization state of the gas. As a result, a diagnostic diagram that consists of these two flux ratios is quite useful to estimate the NLR metallicity, without the need to rely on weak emission lines such as Nv (see also Groves et al. 2004).
We investigated the spectroscopic data of radio galaxies at $1.2 \leq z \leq 3.8$ given by De Breuck et al. (2000), and found that most of the flux ratios are inconsistent with shock models, suggesting that the NLRs of radio galaxies are mainly photoionized. We then compared the observed flux ratios with the results of our photoionization model calculations obtained by using Cloudy (Ferland et al. 1998) assuming one-zone, dust-free clouds. Note that NLR clouds emitting relatively high ionization lines are expected to be dust-free (see, e.g., Marconi et al. 1994; Nagao et al. 2003). The photoionization dust-free models provide two possible scenarios which are consistent with the observed data: low-density gas clouds ($n_H \lesssim 10^3 \text{ cm}^{-3}$) with a sub-solar metallicity ($0.2 \lesssim Z_{\text{gas}}/Z_\odot \lesssim 1.0$), or high-density gas clouds ($n_H \sim 10^5 \text{ cm}^{-3}$) with a wide range of gas metallicity ($0.2 \lesssim Z_{\text{gas}}/Z_\odot \lesssim 5.0$). Regardless of the specific interpretation, the observational data do not show any evidence for a significant evolution of the gas metallicity in the NLRs within the redshift range $1.2 \leq z \leq 3.8$ (Figure 2). Instead, we found a trend for more luminous radio galaxies to have more metal-rich gas clouds, which is in agreement with the same finding in the studies of the broad-line regions including ours (§2).

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