Perseus in Sicily: From Black Hole to Cluster Outskirts
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A Photoionization Method for Estimating Black Hole Masses in Quasars

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Abstract. We present a method that uses photoionization codes (CLOUDY) to estimate the supermassive black hole masses ($M_{\rm BH}$) for quasars at low and high redshift. This method is based on the determination of the physical conditions of the broad line region (BLR) using observational diagnostic diagrams from line ratios in the UV. We also considered that the density and metallicity of the BLR in quasars at high z could be different from those at the nearby Universe. The computed black hole masses obtained using this method are in agreement with those derived from the method of reverberation mapping.

Keywords. galaxies: active, quasars: general, quasars: emission lines

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Our "photoionization method" (ϕ) estimates the size of the BLR ($r_{\rm BLR}$) based on the ionization parameter (U) definition. Solving for $r_{\rm BLR}$ we obtain:

$$r_{BLR} = \left[\frac{\int_{\nu_0}^{+\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi n_{\rm H} U c} \right]^{1/2} \tag{1}$$

Where the integral represents the number of ionizing photons, and $n_{\rm H}$ is the hydrogen density.

Using diagnostic line ratios of the broad components (BC) in the UV spectra, we can estimate the product $n_{\rm H}$U (Negrete *et al.* 2012): Al IIIλ1860/Si III]λ1892, sensitive to $n_{\rm H}$; C IVλ1549/Si III]λ1892, a marker of ionization level; Si IVλ1397/Si III]λ1892, sensitive to ionization, roughly independent of metallicity.

CLOUDY simulations (Ferland *et al.* 2013) were performed at fixed $n_{\rm H}$ and U values spanning in the ranges 7.00 $\leqslant \log n_{\rm H} \leqslant$ 14.00 and -4.50 $\leqslant \log$ U $\leqslant$ 00.00. We assumed plane-parallel geometry, column density $N_c = 10^{23} cm^{-2}$, a "standard" quasar continuum (Mathews & Ferland 1987), and three metallicities: 1$Z_\odot$, 5$Z_\odot$ and 5$Z_\odot$SiAl (an overabundance of Si and Al due to type II supernovae; Sani *et al.* 2010, Negrete *et al.* 2014).

To obtain the line fluxes; and then the line ratios, we used the IRAF task Specfit (Kriss 1994) to fit the spectral components and isolate the BCs. These line ratios allow us to draw isopleths i. e., curves representing measured values of these ratios in the $n_{\rm H}$ vs. U plane (Fig. 1).

Having the $r_{\rm BLR}$ we can compute the $M_{\rm BH} = \left(\frac{3}{4G}\right) f_{0.75} FWHM^2 r_{\rm BLR}$; where $f_{0.75} = 1.4$ is the geometry factor and G is the gravitational constant. Figure 2 shows that the $M_{\rm BH}$ computed following this method is in agreement with the ones derived from the reverberation mapping directly (RM; Bentz *et al.* 2009) and by the luminosity-$M_{\rm BH}$

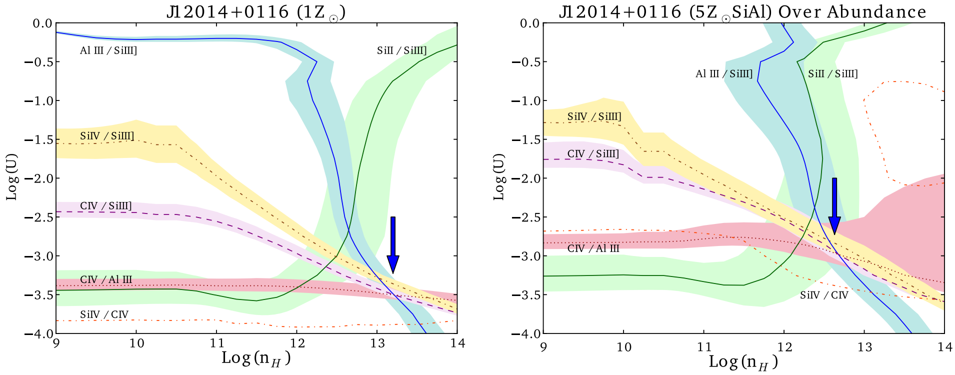

Figure 1. Isocontour maps considering 1Z$_\odot$ and 5Z$_\odot$SiAl metallicities. The intersection points give us the best estimates of $n_{\rm H}$ and U. Shaded areas are the uncertainties.

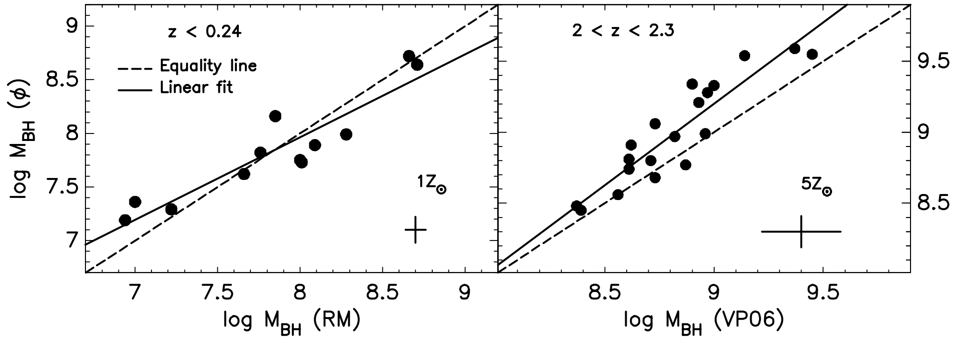

Figure 2. Left – $M_{\rm BH}$ comparison derived with our method and RM results for a low-z sample described in Negrete *et al.* (2013). Right – Preliminar results for a high-z sample of high accreting quasars (Martnez-Aldama *et al.* in prep).

relation (Vestergaard & Peterson 2006). It is worth to mention that VP06 computations are based on CIVλ1549 measurements, a line that systematically shows blue asymmetries (Sulentic *et al.* 2017).

Conclusion

We are able to estimate BLR distances and black hole masses using an independent photoionization method that yields results consistent with reverberation values and previous works in the UV. We suggest that the derived $r_{\rm BLR}$ values can significantly improve $M_{\rm BH}$ estimation especially at z $\geqslant$ 2 when the intermediate ionization lines are shifted into the wavelength range accessible to optical spectrometers.

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