AGN Physics with the Sloan Digital Sky Survey
ASP Conference Series, Vol. 311, 2004
G.T. Richards and P.B. Hall, eds.

Using MgII to Investigate Quasars and Their Black-hole Masses

Matt J. Jarvis

Astrophysics, Department of Physics, University of Oxford, Keble Road, Oxford, OX1 3RH, UK

Ross J. McLure

Institute for Astronomy, University of Edinburgh, Royal Observatory, Edinburgh EH9 3HJ

Abstract. We highlight the importance of the Mg II λ2800 emission-line doublet in probing high-redshift quasars and their supermassive black holes. In the SDSS era, where large scale investigations of quasars across the age of the Universe are possible, this emission-line has the ability to provide accurate systemic redshifts which are important for a variety of follow-up studies, as well as probe the masses of the supermassive black holes that power these phenomena.

1. Introduction

The Sloan Digital Sky Survey will provide us with the largest database of quasars in existence, over all cosmic epochs. Therefore, we now need to find useful diagnostic tools in order to study these highly energetic phenomena at all redshifts.

Various properties of quasars can now be investigated with their optical spectra alone. As discussed in this meeting, these include orientation, dust composition, the accretion disk, the broad-line region, the narrow-line region and the black-hole masses. In this contribution we highlight the usefulness of the Mg II emission-line doublet as a diagnostic of black-hole masses in quasars at $z > 0.3$ and also as a means to determining an accurate systemic redshift for follow-up studies at other wavelengths.

2. Estimating Black-hole Masses in Quasars with Mg II

2.1. The Virial Estimator

In recent years estimating black-hole masses has become somewhat easier than in the past. This is due to the large amount of work carried out on reverberation mapping of Seyfert galaxies and quasars (Wandel, Peterson & Malkan 1999; Kaspi et al. 2000; and see Peterson & Onken 2004, this volume) and the correlation discovered by Kaspi et al. between the radius of the broad-line region and the monochromatic luminosity at 5100Å. If the velocity of the broad-line region gas can be measured along with the luminosity then the mass of the dominant gravitational mass can be estimated, assuming that the motion is virialised via,

$M_{bh} = G^{-1} R_{BLR} V_{BLR}^2$, where the velocity of the broad line region is usually derived from the FWHM of the broad-emission lines, traditionally Hβ.

However, using this technique to estimate the masses of black holes in quasars at high redshift ($z > 0.9$) is difficult because Hβ is redshifted out of the optical passbands and into the near-infrared where observations are much more difficult. Therefore, to probe the high-redshift regime we need a proxy for Hβ and λL_{5100} in the ultraviolet region of the spectrum. An obvious choice for this proxy is Mg II λ2800.

2.2. Mg II as a Proxy for Hβ

Mg II λ2800 has a similar ionisation potential to that of Hβ and thus we would expect that the line emission arises from a similar distance from the central ionising source. Mg II is far enough in the ultraviolet part of the spectrum that it can be seen in optical spectra up to redshift $z \sim 2.3$. Thus, calibrating the use of this line with Hβ allows us to estimate black-hole masses over the majority of the age of the Universe.

A detailed account of calibrating Mg II with Hβ to estimate black-hole masses in quasars is given in McLure & Jarvis (2002). We will only summarize this work here. The correlation between the radius of the broad-line region, $R_{\rm BLR}$, and the monochromatic luminosity at 3000Å is given by,

$$R_{\rm BLR} = (26.1 \pm 3.6) \left[\lambda L_{3000}/10^{37} W\right]^{(0.50\pm0.02)} . \quad (1)$$

This leads to[1],

$$\frac{M_{\rm bh}}{\rm M_{\odot}} = 3.21 \left(\frac{\lambda L_{3000}}{10^{37}\rm W}\right)^{0.5} \left(\frac{\rm FWHM(Mg\ II)}{\rm kms^{-1}}\right)^2 . \quad (2)$$

By compiling spectra covering both Hβ and Mg II of the reverberation mapped samples of Wandel et al. (1999) and Kaspi et al. (2000) we are able to directly compare the UV virial black-hole mass estimate (using Mg II and monochromatic luminosity at 3000Å) and the traditional method using Hβ. Figure 1a shows that the FWHM(Mg II) closely follows the FWHM(Hβ) in these spectra, as expected if the lines are emitted from the same region.

3. The Dependence of Radio Power on Black-hole Mass

We can now use the virial estimator to calculate $M_{\rm bh}$ in quasars over all cosmic epochs using optical or near-infrared spectroscopy alone. This gives us sufficient numbers of objects to probe the black-hole masses in different populations of quasars, i.e., the radio-loud quasars and the radio-quiet quasars. In Fig. 2a we plot the black-hole masses derived from spectra of the Large Bright Quasar Survey (LBQS; Hewett, Foltz, & Chaffee 1995), predominantly comprised of radio-quiet quasars and the Molonglo quasar sample (Kapahi et al. 1998), which

[1]This relation has now been updated for genuinely powerful, high-redshift quasars only (see McLure & Dunlop 2003)

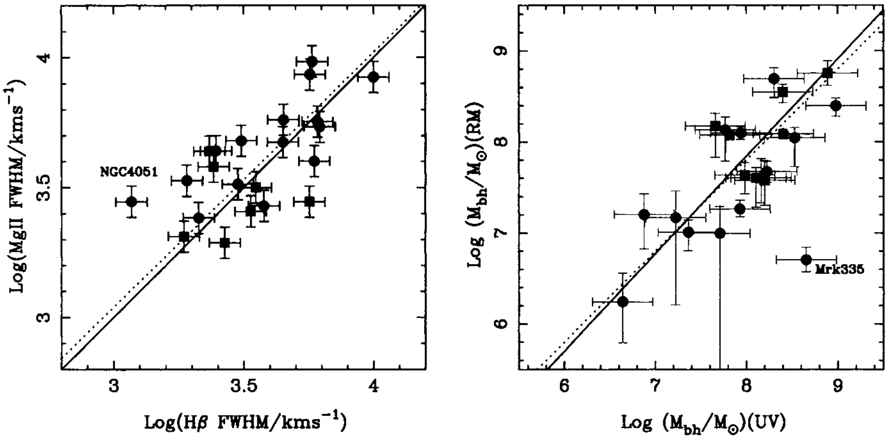

Figure 1. *Left:* FWHM(Hβ) versus FWHM(Mg II) for a sub-set of the reverberation mapped (RM) samples of Wandel et al. (2000) and Kaspi et al. (2000). *Right:* Black-hole masses measured directly from reverberation mapping versus the black-hole mass estimate using the virial technique with Mg II and λL_{3000} from McLure & Jarvis (2002).

is a low-frequency radio selected sample. One can easily see how the radio-loud quasars almost exclusively lie to the top right of the plot, whereas the radio-quiet quasars from the LBQS stretch out across the full range of black-hole mass.

Therefore, there does seem to be evidence for the genuinely powerful radio-loud quasars ($L_{5\mathrm{GHz}} > 10^{24}$ W Hz^{-1} sr^{-1}) to have black-holes confined to upper mass range of $M_{\mathrm{bh}} \gtrsim 10^8\,\mathrm{M}_\odot$, in agreement with Dunlop et al. (2003). Flat-spectrum radio-loud quasars do not necessarily conform to this suggestion (e.g., Oshlack, Webster, & Whiting 2002), but this may be explained by the consideration of source geometry and Doppler boosting of the radio-flux in these sources (Jarvis & McLure 2002; Fig. 2b).

4. Accurate Redshifts using Mg II

In addition to using Mg II as a black-hole mass estimator in quasars, it can also be used to provide accurate quasar redshifts, which are important in various follow-up studies of the quasar host galaxies and the neutral gas within the epoch of reionization.

Recently Walter et al. (2003) have detected the presence of molecular gas in the quasar SDSS J1148+5251 at $z \sim 6.42$. This kind of search is only efficient when relatively accurate redshifts are known due to the limited bandwidth of molecular line searches in the radio regime.

Accurate redshifts are also required to determine the fraction of neutral hydrogen to the foreground of the high-redshift $z > 6$ quasars which exhibit the Gunn-Peterson trough (Becker et al. 2001). This is extremely difficult with

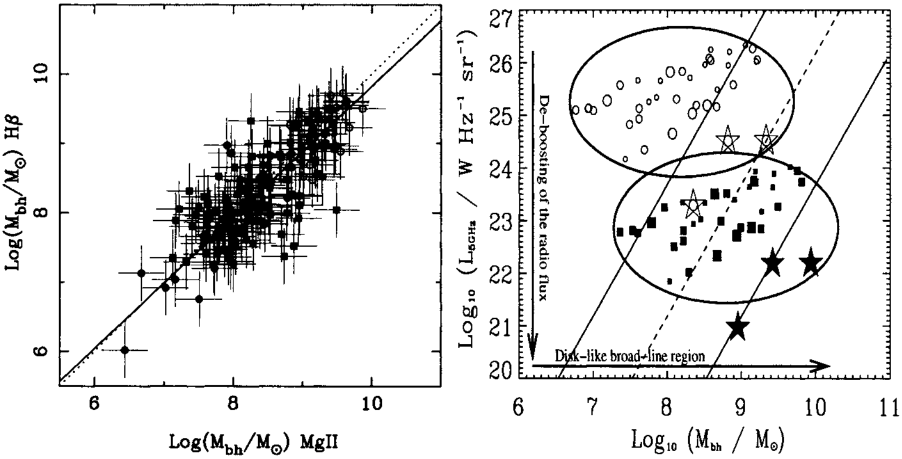

Figure 2. *Left:* The Hβ versus MgII virial black-hole estimators for 150 objects from the RM (filled circles), LBQS (filled squares) and MQS (open circles) samples. The dotted line is an exact 1:1 relation. The solid line is the BCES bisector fit which has a slope of 0.95 ± 0.06 (McLure & Jarvis 2002). *Right:* The $M_{\rm bh}$ – $L_{\rm rad}$ plane adapted from Jarvis & McLure (2002). Open symbols are from the study of Oshlack et al. (2002), the filled symbols represent where these points would lie after corrections for Doppler boosting and a disk-like geometry for the broad-line region. The large stars are anomalous steep-spectrum objects and are probably not dominated by the core emission.

Lyman-α alone due to the significant absorption blueward of the Lyman-α emission line. The accurate redshifts derived from Mg II are relatively easy to obtain and thus, may be very important in future studies.

References

Becker, R. L., et al. 2001, AJ, 122, 2850

Dunlop, J. S., et al. 2003, MNRAS, 340, 1095

Hewett, P. C., Foltz, C. B., Chaffee, F. H. 1995, AJ, 109, 1498

Jarvis, M. J., & McLure, R.J. 2002, MNRAS, 336, L38

Kapahi, V. K., et al. 1998, ApJS, 118, 327

Kaspi, S., et al. 2000, ApJ, 533, 631

McLure, R. J., & Jarvis, M. J. 2002, MNRAS, 337, 109

McLure, R. J., & Dunlop, J. S. 2003, MNRAS, submitted (astro-ph/0310267)

Oshlack A., Webster R., & Whiting M. 2002, ApJ, 576, 810

Walter, F., et al. 2003, Nature, 424, 406

Wandel, A., Peterson B. M., & Malkan M. A. 1999, ApJ, 526, 57