Quasar Black Hole Masses from Velocity Dispersions

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Abstract.
Much progress has been made in measuring black hole (BH) masses in (non-active) galactic nuclei using the tight correlation between stellar velocity dispersions σ in galaxies and the mass of their central BH. The use of this correlation in quasars, however, is hampered by the difficulty in measuring sigma in host galaxies that tend to be overpowered by their very bright nuclei. We discuss results from a project that focuses on $z \sim 0.3$ quasars suffering from heavy extinction at shorter wavelengths. This makes it possible to obtain clean spectra of the hosts in the spectral regions of interest, while broad lines (like Hα) are still visible at longer wavelengths. We compare BH masses obtained from velocity dispersions to those obtained from the BLR and thus probe the evolution of this relation and BH growth with redshift and luminosity. Our preliminary results show an offset between the position of our objects and the local relation, in the sense that red quasars have, on average, lower velocity dispersions than local galaxies. We discuss possible biases and systematic errors that may affect our results.

Keywords: black hole physics — galaxies: active — quasars: general
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BACKGROUND

Black hole (BH) mass is believed to be one of the fundamental parameters that characterize quasar activity and much effort has been devoted to obtaining accurate BH masses for quasars and other AGN [*e.g.*, 1]. In recent years, much progress has been made in measuring BH masses in galactic nuclei, particularly with the remarkable discovery by Gebhardt et al. [2] and Ferrarese & Merritt [3] of a tight correlation between stellar velocity dispersion in galaxies and the mass of their central BH ($M_{BH} \propto \sigma^n$). The use of this correlation to derive BH masses in AGN, however, is hampered by the difficulty in measuring velocity dispersions in host galaxies that tend to be overpowered by their very bright nuclei. Nevertheless, the correlation has been shown to be present at low redshift ($z < 0.1$) in low luminosity AGN (*e.g.*, BL Lac objects: [4]; or Seyfert galaxies: [5]). Seyfert galaxies at higher redshift ($z \sim 0.36$ and $z \sim 0.57$), however, appear to show an offset from the local relation [9, and references therein].

It is not yet known whether the $M_{BH} - \sigma$ correlation holds for the highest luminosity AGN. A loose correlation has been found by using the width of [O III] lines in active nuclei [6, 7], but the width of these lines is dependent upon other parameters (outflows, radio luminosity, etc.) and therefore lead to a correlation with a large scatter. BH masses derived from [O III] emission line widths can only be accurate to within a factor of five at best [8]. More accurate determinations are necessary if we hope to use them to

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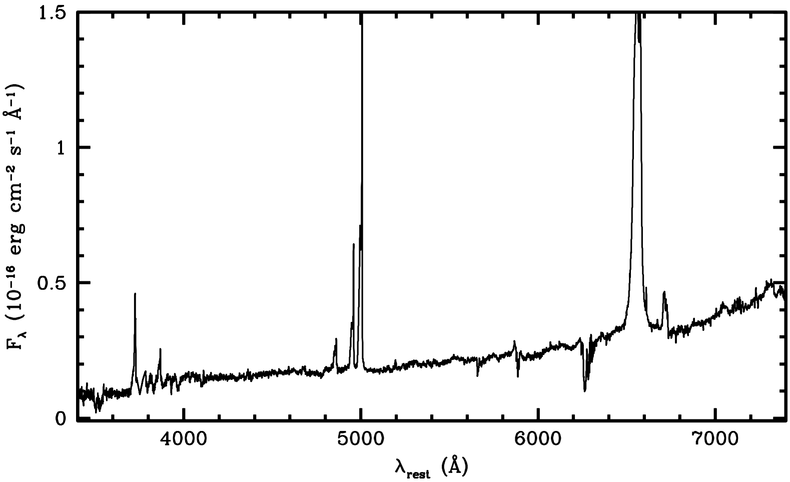

FIGURE 1. Keck ESI spectrum of a red 2MASS quasar. Although these objects show broad Hα emission characteristic of quasars, the spectra of the host galaxies suffer little contamination from the quasar at shorter wavelengths.

disentangle some of the other fundamental relationships among quasar parameters.

RED QUASARS

We are therefore carrying out a program to measure stellar velocity dispersions in quasar host galaxies. We have selected a sample of $z < 0.4$ *red* quasars from 2MASS. Red quasars are likely the dust obscured equivalent of the blue quasar population, and they have the advantage that the nucleus is highly extincted at optical wavelengths, so that the contrast between the stellar flux from the host galaxy and that of the nucleus is increased. Thus, the spectra of these objects show, at shorter wavelengths, stellar features that are useful to measure velocity dispersions and, at longer wavelengths, broad emission lines from which to obtain virial estimates of BH masses.

Our sample of 11 objects is drawn from Marble et al. [10]. We obtained deep, medium resolution spectroscopic observations with the Echelle Spectrograph and Imager (ESI) on the Keck II telescope. We placed the slit through the center of the host galaxies in order to measure velocity dispersions of the bulges of the hosts. Figure 1 shows the spectrum of one of the objects in the sample demonstrating that they suffer little contamination from the nucleus at wavelengths shorter than Hα.

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Velocity Dispersions

We first estimated the size of the stellar bulges by inspecting archival *HST*/WFPC2 images (proposal ID 9057; PI D. Hines) and extracted spectra from these regions. We measured velocity dispersions (σ_c) by fitting the spectra in the rest frame region between 5220 and 5550 Å for each of the targets. We used templates formed from the combination of spectra of stars of different spectral types observed also with ESI. To these templates we added a small fraction of a continuum to simulate any potential contamination from the active nucleus. We were able to obtain a reliable σ_c for eight of the targets, with typical errors at the 95% confidence level of $\sim \pm$ 20 km s^{-1}.

Black Hole Masses

We estimated virial masses for the BHs in the sample by first fitting the FWHM of the broad component of Hα, and then using the scaling relation given by Kaspi et al. [11]. In this relation, the size of the broad line region is a function of the continuum luminosity at rest frame 5100 Å. However, as mentioned before, the quasar continuum suffers from heavy extinction in this spectral region. To obtain the unobscured flux at 5100 Å, we used the following procedure: (1) We measured the flux of the quasar at F814W in the HST images by fitting an empirical PSF to the nucleus. In this way, we also determined the relative flux contribution from the host galaxy and the quasar in the region covered by the slit. (2) We scaled the Keck ESI spectrum to match the flux obtained from the HST images. (3) We fitted a reddened version of the SDSS composite quasar spectrum plus a reddened stellar population, using the relative contributions determined in (1), and varying the amount of reddening, guided by the measured ratios of Hα/Hβ. The E(B-V) that we measured in the sample varied from 0.5 to 2. Measuring the extinction accurately is currently our main source of uncertainty and, until we perform more detailed fitting of the spectra, our results are only tentative.

The M$_{BH}$–σ_c relation.

Preliminary results for the eight objects we measured are plotted as solid circles in Fig. 2, along with results from local objects taken from Gebhardt et al. [2] and Ferrarese & Merritt [3], and Seyfert galaxies at $z = 0.37$ taken from Treu et al. [12]. While half of the objects have positions consistent with the local relation, the other half seem to have an offset in the sense that σ has lower values for a given BH mass. The positions of these objects in the plot are more consistent with those of Seyfert galaxies at higher z published by Treu et al. [12], who have found evidence for evolution in the relation from $z = 0.57$ to the present [9]. The two objects that fall beneath the relation in Fig. 2 are indeed the ones with the lowest z in our sample. However, until we perform more careful modeling to determine the nuclear extinction, we can only speculate about this potential evidence pointing to evolution.

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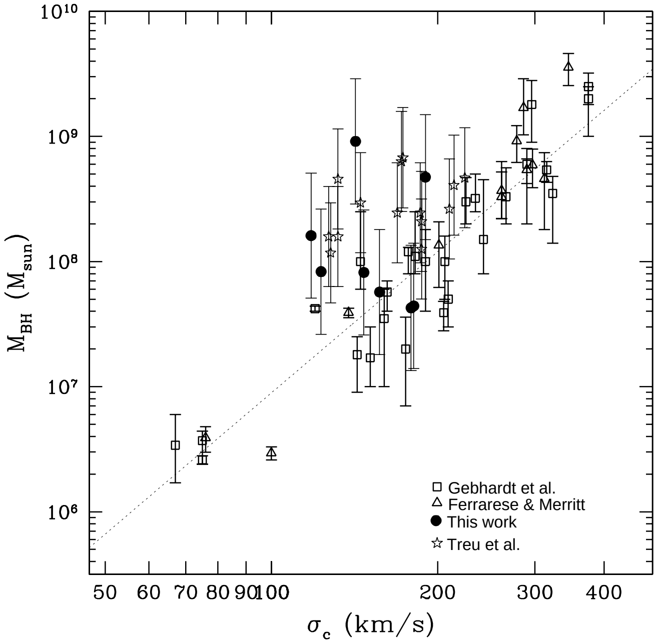

FIGURE 2. M_{BH}–σ_c relation for red quasars. The objects in our sample are plotted as solid circles, along with local objects (open squares and triangles) and Seyfert galaxies at $z = 0.37$ (open stars). The dotted line marks the empirical relation derived for local objects.

ACKNOWLEDGMENTS

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