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THE BLACK HOLE MASS - GALAXY BULGE RELATIONSHIP FOR QSOs IN THE SDSS DR3

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We investigate the relationship between black hole mass, $M_{\rm BH}$, and host galaxy velocity dispersion, σ_*, for QSOs in Data Release 3 of the Sloan Digital Sky Survey. For redshifts $z < 0.5$, our results agree with the $M_{\rm BH} - \sigma_*$ relationship for nearby galaxies. For $0.5 < z < 1.19$, the measured $\sigma_{[\rm O\ III]}$ and $\sigma_{[\rm O\ II]}$ are narrower on average than what we expect from the $M_{\rm BH} - \sigma_*$ relationship by ~ 0.13 dex. Pending analysis of selection effects, we consider this an upper limit for evolution of the $M_{\rm BH} - \sigma_*$ relationship between redshift $z \simeq 1$ and the present. Within this limit, this suggests either that black holes and bulges grow concurrently or that both black holes and bulges have completed their growth by redshift $z \approx 1$. This material will be presented in more detail in Salviander et al. (2006).

Recent work has established that the mass of a supermassive black hole, $M_{\rm BH}$, correlates with properties of the host galaxy's bulge, especially the stellar velocity dispersion, σ_* (Gebhardt et al. 2000; Ferrarese & Merritt 2000; Kormendy & Gebhardt 2001). Tremaine et al.(2002) give this relationship as

$$M_{\rm BH} = (10^{8.13} M_\odot)(\sigma_*/200\ {\rm km\ s^{-1}})^{4.02}. \quad (1)$$

Studying the evolution of this relationship over cosmic time may yield clues as to its origin.

Shields et al. (2003, "S03") used QSO emission lines to study the $M_{\rm BH} - \sigma_*$ relationship for large lookback times. The black hole "photoionization mass" (based on Kaspi et al. 2000) was derived from

$$M_{\rm BH} = (10^{7.69}\ M_\odot) v_{3000}^2 L_{44}^{0.5}, \quad (2)$$

where $v_{3000} \equiv$ FWHM(Hβ)/3000 km s^{-1} and $L_{44} \equiv \nu L_\nu/(10^{44}$ erg s^{-1}), the continuum luminosity at 5100 Å. Following Nelson (2000), σ_* was estimated as $\sigma_{[\rm O\ III]}$ = FWHM([O III])/2.35. S03 found little change in the $M_{\rm BH} - \sigma_*$ relationship from redshifts $z \approx 2$ to today. However, they had only a small sample of high redshift objects and none in the range $0.3 < z < 1.1$. Here we use the Sloan Digital Sky Survey[2] Data Release 3 (SDSS DR3) (Abazajian et al. 2005) to study the $M_{\rm BH} - \sigma_*$ relationship at redshifts up to $z \simeq 1.2$.

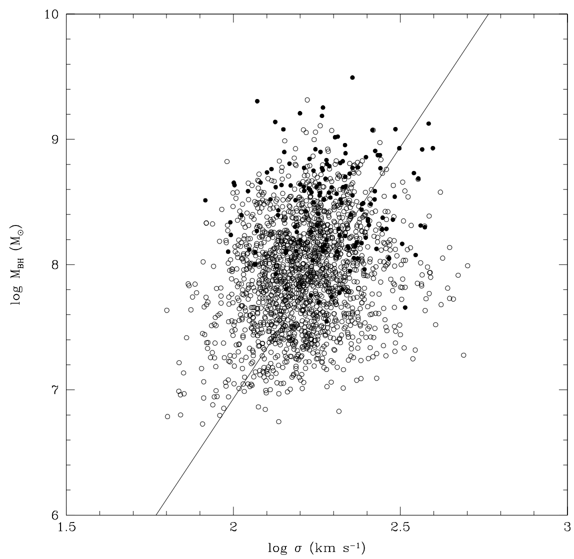

Fig. 1. The $M_{\rm BH} - \sigma_*$ relationship. $M_{\rm BH}$ is derived from FWHM of Hβ or Mg II and νL_ν(5100) or νL_ν(4000); σ_* is derived from FWHM of [O III] or [O II]. Open and closed circles show data for the HO3 and MO2 samples, respectively. The solid line is the Tremaine relationship for nearby galaxies (1) and is not a fit to the data.

We have analyzed the DR3 QSO spectra with the aid of an automated spectrum fitting program. A lower-redshift sample ($0.10 < z < 0.80$) was used for study of the $M_{\rm BH} - \sigma_*$ relationship using Hβ and [O III] (the "HO3" sample). A higher redshift sample ($0.46 < z < 1.19$) was chosen to study the $M_{\rm BH} - \sigma_*$ relationship using Mg II and [O II] in place of Hβ and [O III], and the continuum luminosity at 4000 Å scaled to 5100 Å by assuming a power law function fitted by Vanden Berk et al. (2001) for SDSS quasar composite spectra, $F_\nu \propto \nu^{-0.44}$ (the "MO2" sample). The algorithm fit the selected lines and continuum wavelengths, and the line FWHM was determined from the fits. Data with poor error bars were discarded, and the remaining fits were inspected vi-

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[2]The SDSS Web site is http://www.sdss.org/

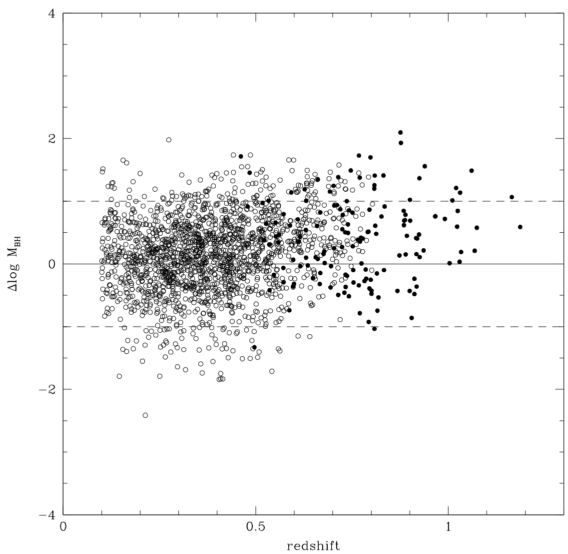

Fig. 2. Redshift dependence of Δ log $M_{\rm BH}$ for the HO3 and MO2 samples. Open circles are the HO3 data; closed circles are the MO2 data.

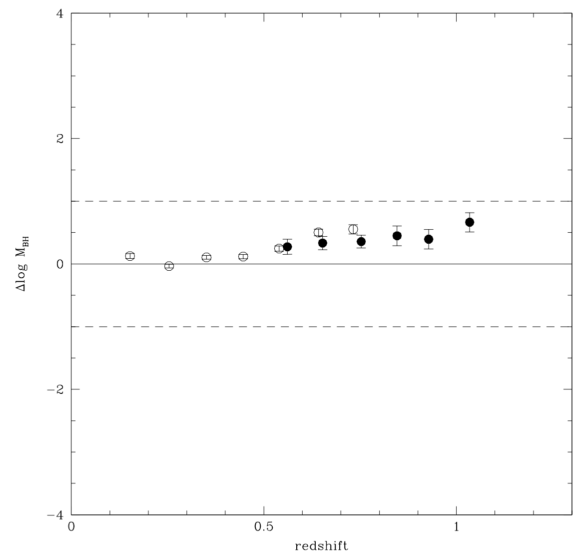

Fig. 3. Mean Δ log $M_{\rm BH}$ as a function of redshift. Large open and closed circles show the average Δ log $M_{\rm BH}$ in redshift bins $\Delta z = 0.1$ for the HO3 and MO2 samples, respectively. The error bars show the standard error of the mean.

sually for reliability. The widths of Mg II and Hβ agree closely in the mean, as do those of [O II] and [O III], supporting the use of Mg II and [O II] at higher redshifts (see also McLure & Jarvis 2002).

The $M_{\rm BH} - \sigma_*$ relationship for both the HO3 and MO2 samples is shown in Figure 1. For low redshifts, the results are consistent with the findings of S03 based on Hβ and [O III]. For higher redshifts, the mean $\sigma_{\rm [O\ III]}$ and $\sigma_{\rm [O\ II]}$ depart from the σ_* expected from the $M_{\rm BH} - \sigma_*$ relationship for nearby galaxies, in the sense that $\sigma_{\rm [O\ III]}$ and $\sigma_{\rm [O\ II]}$ are too small.

A measure of the evolution of the $M_{\rm BH} - \sigma_*$ relationship with lookback time is shown in Figures 2 and 3. We compare $M_{\rm BH}$ calculated with Equation 2 to the "[O III] mass" of S03—that is, $M_{\rm BH}$ calculated with Equation 1 using $\sigma_{\rm [O\ III]}$ in place of σ_*. The mean Δ log $M_{\rm BH} \equiv$ log M(Hβ) - log M([O III] is +0.14 for the HO3 sample, but this offset is comparable to the calibration uncertainties of Equation 2. The MO2 sample shows a mean Δ log $M_{\rm BH}$ of +0.40 dex.

At face value, Figures 2 and 3 indicate that Δ log $M_{\rm BH}$ evolves slightly for $z > 0.5$, both for the MO2 sample and the higher redshift objects in the HO3 sample. It is possible that the ~ 0.5 dex rise in Δ log $M_{\rm BH}$ with redshift is due the effect of the limiting magnitude of the sample survey or to inadvertent exclusion of objects with large $\sigma_{\rm [O\ III]}$ or $\sigma_{\rm [O\ II]}$ for $z > 0.5$, with wider lines being more difficult to measure in noisy spectra. A study of the possible biases is currently under way.

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