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THE BLACK HOLE–BULGE RELATIONSHIP IN QSOS

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Masses of black holes in nearby galactic nuclei are closely related to the velocity dispersion of the host galaxy bulge. QSO emission-line widths indicate a similar relationship in the early universe.

Recent studies show that black hole masses in galactic nuclei increase with stellar velocity dispersion as $M_{BH} = (10^{8.13}\ \mathrm{M}_{\odot})(\sigma_*/200\ \mathrm{km\ s}^{-1})^{4.02}$ (Tremaine et al. 2002, and references therein). The origin of this M_{BH}–σ_* relationship is unknown, and measurements of this relationship as a function of cosmic time would provide a valuable clue. QSO emission-lines afford an opportunity (Shields et al. 2002).

Black hole masses can be derived from the widths of the broad Hβ line, assuming virial motions of the emitting gas (Kaspi et al. 2000; McLure & Jarvis 2002; and references therein). We use $M_{BH} = (10^{7.69}\ \mathrm{M}_{\odot})v_{3000}^2 L_{44}^{0.5}$, where $v_{3000} \equiv \mathrm{FWHM(H}\beta)/3000\ \mathrm{km\ s}^{-1}$ and $L_{44} \equiv \lambda L_\lambda(5100\ \text{Å})/(10^{44}\ \mathrm{erg\ s}^{-1})$. Following Nelson (2000), we take $\sigma_* = \mathrm{FWHM([O\ III])}/2.35$, involving the narrow [O III] $\lambda\lambda 5007, 4959$ lines.

We take observations of QSOs and Seyfert galaxies from several sources, including infrared spectra of high redshift QSOs by Dietrich et al. (2002), McIntosh et al. (1999), and Brotherton (1996); our unpublished spectra of PG QSOs at McDonald Observatory; and spectra of low redshift AGN by Grupe et al. (1999). Objects were selected on the basis of signal-to-noise and quoted uncertainties. We also include measurements of a small sample of QSOs from the Early Data Release of the Sloan Digital Sky Survey (SDSS) (Stoughton et al. 2002), selected for good signal-to-noise. The results show considerable scatter but center on the M_{BH}–σ_* relationship above, including both high and low redshift objects (Shields et al. 2002).

In order to display any redshift dependence in the M_{BH}–σ_* trend, we define an offset $\Delta\log M = \log M_{\mathrm{BH}} - \log M_{\mathrm{[OIII]}}$ Here M_{BH} is the actual mass derived from the Hβ line width, and $M_{\mathrm{[OIII]}}$ is the mass expected on the basis of the [O III] line width if the object obeyed perfectly the $M_{\mathrm{BH}} - \sigma_*$ relationship quoted above. Positive $\Delta\log M$ signifes a black hole larger than expected for its host galaxy velocity dispersion. Figure 1 shows that the redshift 1 to 3 objects, as a group, agree within ~ 0.3 dex with the mean $\Delta\log M$ of the lower redshift objects. These results are consistent with the idea that the growth of black holes and bulges was approximately contemporaneous as the universe evolved.

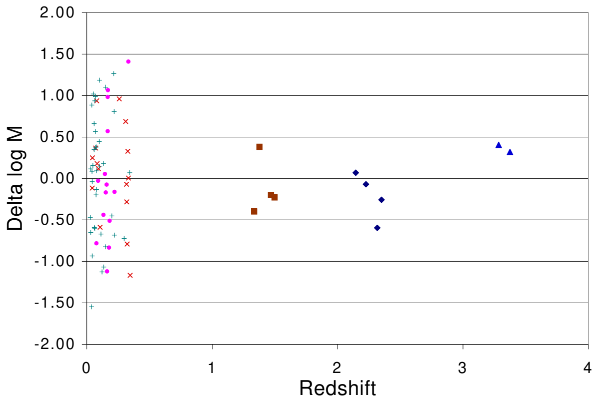

Fig. 1. Black hole masses of QSOs relative to expected mass from $M_{\mathrm{BH}} - \sigma_*$ relation. Abcissa gives redshift and ordinate gives $\Delta\log M$ defined in the text. See references for key to sources: triangles–D02; diamonds–M99; squares–B96; crosses–SDSS; dots–PG; pluses–G99.

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