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TESTING COSMIC EVOLUTION OF SUPERMASSIVE BLACK HOLE-GALAXY SCALING RELATIONS IN THE SDSS

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ABSTRACT

Relations have been discovered between the masses of central supermassive black holes and the fundamental characteristics of their host galaxies. However, these relations have only been established in the local universe. This study attempts to determine if any of these relations have evolved with redshift, as this would have interesting implications for models of SMBH and galaxy evolution. Based upon the availability of suitable data in the Sloan Digitized Sky Survey, the stellar masses of galactic bulges (presented by the MPA/JHU collaboration) was compared to virially estimated central black hole masses. Over the redshift range 0.1 − 0.33, our results are consistent with no evolution between SMBH mass and stellar mass. However, large uncertainties in the stellar masses result in a large scatter in the SMBH - stellar mass relation, therefore it is difficult to draw any firm conclusions.

Subject headings: galaxies: evolution — galaxies: fundamental parameters

1. INTRODUCTION

Mass accretion onto supermassive black holes (SMBHs) is used to explain quasars and other classes of active galactic nuclei (AGN). Quasars put out so much luminosity from such compact region that SMBHs are the most probable objects to power them. SMBHs have also been discovered to be present in quiescent galaxies (see, for example, Ho 1999). The masses of central SMBHs ($M_\bullet$) have been found to relate to other characteristics of their host galaxy. Those found include the $M_\bullet - \sigma_*$ relation (mass of the SMBH to the velocity dispersion of the galactic bulge), the $M_\bullet - M_*$ relation (stellar masses), and the $M_\bullet$–B_T^0 relation (e.g., Ho 1999; Gebhardt et al. 2000; Ferrarese & Merritt 2000; Greene & Ho 2005; Woo et al. 2006; Treu et al. 2007). These relations have important implications for models of galaxy evolution. $M_\bullet$ can only be measured directly in the nearest galaxies, but can be estimated in AGN at larger distances. This makes it possible to research parameter relations of central black holes in AGN if the same empirical equations apply to both situations.

In the standard model for galactic nuclei frv^2/G gives the mass of the central SMBH, where v is the Doppler broadened velocity of the ionized clouds in the Broad-line Region (BLR), deduced from the FWHM of the broad emission lines (e.g., $H\beta$). Two techniques are used to substitute the radius r of the BLR, which cannot be directly observed in AGN: reverberation mapping and the photo-ionization method (Wandel et al. 1999; Denney et al. 2010). Reverberation mapping, assuming virial dynamics, gives an estimate of r. In brief, the light travel time across the BLR means the radius r is then $c\Delta\tau$, where $\Delta\tau$ is the time difference between the continuum-flux change and the broad emission line-flux change, found using cross-correlation techniques (Wandel et al. 1999). The factor f in this case is used to calibrate the masses calculated using the reverberation-mapping radius of AGN to the appropriate ones found in quiescent-galaxy conditions, and accounts for the unknown geometry of the BLR. Reverberation mapping, though, takes time-scales of months to years to get BLR radius estimates; previous studies of galactic parameter relations have included fewer than fifty objects. For studies of galactic relations on larger scales including many AGN and quasars, a different method is needed. The photo-ionization technique may be used in this case. A proportionality has been observed between the radius of the BLR and the luminosity of the continuum: the luminosity, with some exponent, multiplied by an adjusted calibration constant, gives an estimate of r.

The Sloan Digital Sky Survey has data for a large quantity of AGN. These data have been greatly supplemented by Shen et al. (2011), who have gone through the vast amount of AGN spectra to fit data points, including the continuum luminosity. These new resources allow for the relations found in galaxies to be studied over greater redshift, because these data have been used to virally estimate the masses of the central SMBHs. Galactic relations have been seen only for a small range of redshift (Woo et al. 2006; Treu et al. 2007); the interest of this study is to see if any of these relations evolves with redshift. A first-choice relation would the tight $M_\bullet - \sigma_*$, but it is very difficult to accurately determine σ_* in AGN host galaxies. However, the $M_\bullet - M_*$ relation can be investigated using the M_* estimates of Kauffmann et al. (2003). The exact value of the calibration factor f is still unknown, so relations that do and do not include it are considered.

2. DATA

Acquiring the desired data was a task of extracting it from online catalogs, originally only from the Sloan Digital Sky Survey Data Release 8 (SDSS DR-8) catalog. The desired data were a few things: 1) A representative portion of continuum luminosity flux emitted by the bright central AGN, 2) the FWHM of any broad emission line representative of the broad-line region's orbital velocity, and 3) the σ_* measure of the velocity dispersion

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TABLE 1
Results of Linear Fits to the Data

Relation	All Points		0.1z bins		N = 100 bins	
	α	β	α	β	α	β
$\log(L_{5100})$	43.90 ± 0.01	1.08 ± 0.07	44.04 ± 0.02	0.92 ± 0.07	43.99 ± 0.02	1.07 ± 0.09
$\log(Lv^2/M_\bullet)$	0.60 ± 0.02	-0.81 ± 0.09	0.64 ± 0.02	-1.0 ± 0.1	0.60 ± 0.03	-0.8 ± 0.1
$\log(M_*/M_\bullet)$	2.89 ± 0.04	-0.6 ± 0.02	3.05 ± 0.05	-1.4 ± 0.2	2.89 ± 0.04	-0.6 ± 0.2
$\log(M_*/Lv^2)$	2.29 ± 0.04	0.2 ± 0.1	2.44 ± 0.04	0.4 ± 0.2	2.29 ± 0.04	0.2 ± 0.2

Note. — Results of the linear fits presented in Figures 1, 2, 3, and 4. All linear fits are of the form *relation* = $\alpha + \beta(z)$.

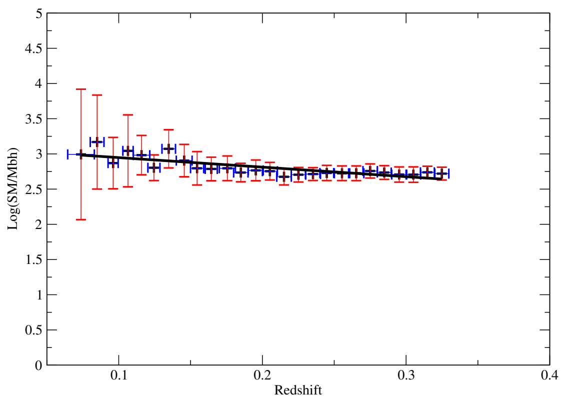

Fig. 1.— The relationship between redshift and $\log(M_*/M_\bullet)$ (stellar mass to black hole mass) in 0.01 wide redshift bins.

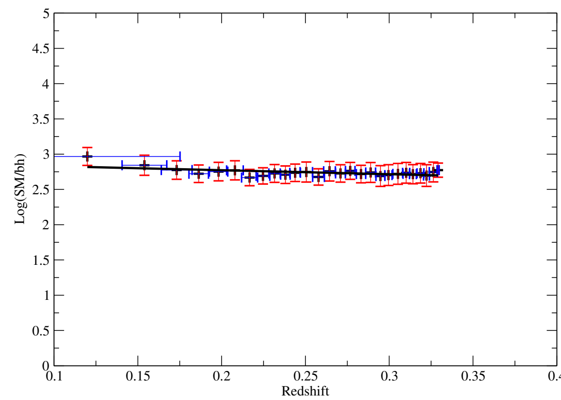

Fig. 2.— Same as Figure 1 but for N = 100 bins.

of bulge stars. These data were obtained by querying the database using Structured Query Language (SQL).

The Hβ-broad emission line was chosen for the BLR radial velocities as the Hα-line may be shifted out of the observable bands in high redshift galaxies. The SDSS DR-8 catalog does not explicitly give the FWHM of emission lines, but the Shen et al. (2011) quasar catalog does so their data were used for this parameter. This made the central-emitter continuum luminosity at 5100Å a natural choice for the luminosity data, as it corresponds with Hβ, as well as being the common selection in the literature. The continuum-luminosity data points were also taken from the Shen et al. (2011) quasar catalog.

The idea of using the velocity dispersion σ_* had to be abandoned. It was quickly found that stellar absorption lines, were swamped by the continuum luminosity of the central AGN. This made the lines almost completely lost; the result being that the SDSS DR-8 was unable to perform fits on the majority of these lines. A substitute was needed, so the stellar masses calculated by (Kauffmann et al. 2003) were chosen. This is for objects with a redshift less than 0.33.

Once the desired data were identified, they had to be extracted and analyzed in a multi-step process. Both of these catalogs were downloaded in FITS format, and read with IRAF[2]. They were then dumped using IRAF into ASCII files. These were imported into Excel and put together to construct the table as a whole. This was necessary because the Shen quasar catalog was composed of more than 100,000 rows, and could not all be dumped and imported at once. The two catalogs were combined for matching stellar objects using an IDL script; the new table was a windows formatted text document. This was again imported to Excel, to be manipulated and analyzed.

The exact columns extracted and used are as follows. From the SDSS catalog only the logarithm of the stellar mass with a 50% confidence range was used. From the Shen quasar catalog: SDSS name, redshift, luminosity at 5100Å, Hβ FWHM, and the log of the black hole mass as calculated by Shen et al. (2011). It should be noted that the log of the black hole mass from the Shen quasar catalog contains a calibration factor.

The tables were combined by matching the Plate ID, Fiber ID, and the modified Julian date. These values were defined in the SDSS and were restated in the Shen quasar catalog. To take out unnecessary data, the table was ordered by redshift and those with zero-values were taken out, and all objects above a redshift of 0.33 were taken out. Using the extracted columns, some others were defined, and these were used to plot the data and analyze trends. These newly calculated columns are: $\log(L_{5100}\mathrm{FWHM}^2)$, $\log(M_*/M_\bullet)$, $\log(M_*/L_{5100}(FWHM)^2)$, and $\log(M_\bullet/L_{5100}(FWHM)^2)$.

The plotting was done in the program Grace. This program reads windows formatted text documents, so this was the format exported from Excel. All the newly calculated data were plotted against redshift. Linear fits were made to the data. To analyze trends in the data for each plot, the data were binned in two ways. The first way was binning by 0.01 wide ranges in redshift; the second way was binning by every 100 counts of objects. The

[2] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

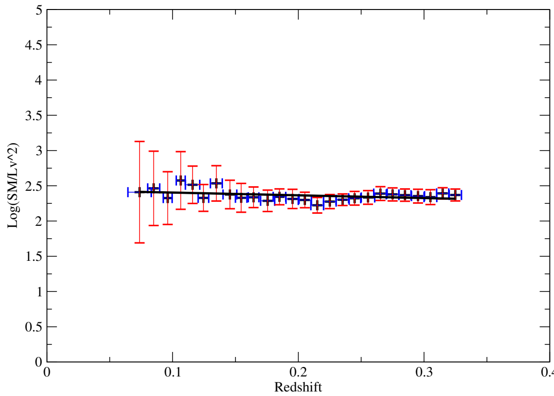

FIG. 3.— The relationship between redshift and $\log{(M_*/Lv^2)}$ in 0.01 wide redshift bins.

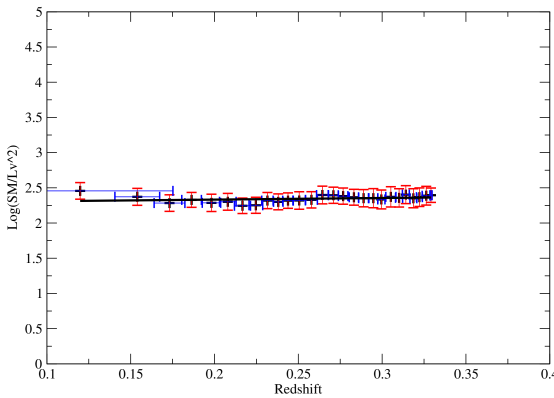

FIG. 4.— Same as Figure 3 but for N = 100 bins.

data and fitted relations for the $0.01z$ bins are plotted in Figures 1, 2, 3, and 4, with 3σ uncertainties.

3. RESULTS

The results to the linear fits of the data are presented in Table 1. Here α is the zero-point and β the gradient of the fits. It can be seen from the fits presented in Table 1 that the $\log{(M_*/M_\bullet)}$ results are consistent with the findings of Magorrian et al. (1998), where the bulge to SMBH mass ratio is 1000:1. The relationships for $\log{(Lv^2/M_\bullet)}$ do not reveal anything significant, it is simply a comparison of the two mass estimates, but the $\log{(M_*/M_\bullet)}$ and $\log{(M_*/Lv^2)}$ reveal if there is any evolution between $M_\bullet$ and M_*. The only difference between them is how the Shen catalog's calculation of $M_\bullet$ is different from the basic virial mass of Lv^2 (through calibration factors). The increased scatter in the data at lower redshift reflects the volumetric bias in redshift samples (higher redshift corresponds to a larger volume and therefore more galaxies). The linear fits have not weighted the results by the uncertainties derived from the binned data. If weighted fits were performed the slopes could flatten out and give rise to a relations even more consistent with zero evolution.

4. DISCUSSION

The most interesting data to consider are the ones presented in Figures 1, 2, 3, and 4 - the relationships between stellar mass and SMBH mass proxies. There is no evidence for an evolution of these relations within a redshift of 0.33. To illustrate this point further, we present in Figure 5 all of the $\log{(M_*/Lv^2)}$ without binning. Here the

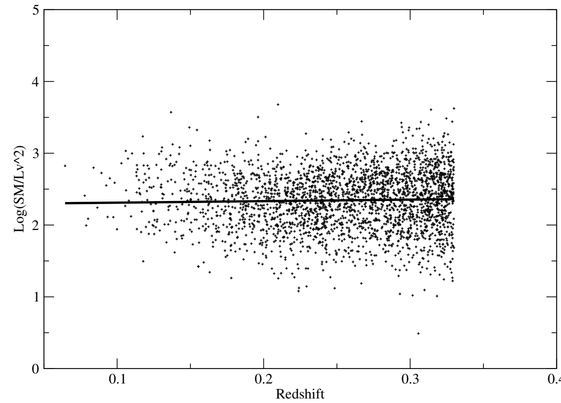

FIG. 5.— All data points (unbinned) for the $\log{(M_*/Lv^2)}$ relation. The fit to the data is consistent with zero evolution.

volumetric sample effects can more easily be seen. One likely cause of the scatter in the data are uncertainties in the stellar mass estimates

In order to calculate more accurate stellar masses for use in this method, good galaxy spectra are required. Unfortunately, the 4000Å break, which this technique relies on, is swamped by the light emission from the nucleus, making it very hard to measure. For stellar masses to be accurately calculated, there must be two spectra taken for each studied galaxy. One spectrum of the nucleus, and another of the whole galaxy, allowing for the AGN to be subtracted from the overall spectrum. While the SDSS is a very great resource, the spectra taken of the galaxies is not sufficient for the purpose of this study. The scope of objects studied in this paper should be evaluated further, but it seems necessary that for accurate relationships to be claimed, better observations much be done on individual objects.

5. CONCLUSIONS

Based on these data, there is no significant evidence of evolution in the ratio of $M_\bullet$ to $M_{stellar}$, as there is too much scatter in the data. The data could may simply not be good enough. These data need to be analyzed more fully. This includes plotting every parameter separately, out of ratio, to see how they develop by themselves over redshift. For all plots, linear regression lines that take errors into account must be fitted, for a more accurate representation of any possible trends.

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