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A PHOTOMETRIC METHOD TO DETERMINE SUPERMASSIVE BLACK HOLE MASSES

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We report the discovery of a strong correlation between the shape of a bulge's light-profile and the mass of its central supermassive black hole ($M_{\rm bh}$). We find that $\log(M_{\rm bh}/M_\odot) = 2.91(\pm0.38)\log(n) + 6.37(\pm0.21)$, where n is the Sérsic $r^{1/n}$ shape index. This correlation is shown to be at least as strong as the relationship between the logarithm of the stellar velocity dispersion and $\log M_{\rm bh}$ and has comparable scatter.

Our galaxy sample has come from the updated list of galaxies with supermassive black hole (SMBH) mass estimates given in the first two sections of Merritt & Ferrarese's (2001) Table 1 (see also Kormendy & Gebhardt 2001 and Gebhardt et al. 2000). This initial sample of 30 galaxies was reduced to 22 because we were unable to find reliable, and publicly available, images for all 30 galaxies — excluded galaxies were usually too large for a single CCD image to have sufficient sky background.

The data, and reduction procedures, will be described in Erwin et al. (2002). The extracted galaxy light profiles were modelled with either a seeing-convolved Sérsic $r^{1/n}$ profile or, in cases when a disk was also present, with a seeing-convolved combination of Sérsic bulge and exponential disk. The values of the bulge Sérsic index n were converted into the 'central concentration index' $C_{r_e}(1/3)$ (Trujillo, Graham, & Caon 2001; Graham, Trujillo, & Caon 2001b) and plotted against the SMBH mass in Graham et al. (2001a). This current presentation is based on this work, except here we show the results from plotting n directly against the SMBH mass (Figure 1a).

The orthogonal regression routine we have used in Figure 1 treats both variables equally, and allows for intrinsic scatter as well as measurement errors in the data; as Merritt & Ferrarese (2001) point out, it is generally the best method to use when there are errors in both variables. A 20% error has been assumed for the value of n. The errors for the SMBH mass and central velocity dispersion $\sigma_{\rm c}$ come from the above mentioned tables.

A word of caution may be in order when comparing the different measures of significance for the relations shown in Figure 1a and 1b. The strength of a correlation itself — regardless of which function fits it — is best measured by the Spearman rank-order coefficient r_s. The χ^2 merit function for a *linear fit* to the data, the Pearson coefficient r, and the vertical scatter in $\log M_{\rm bh}$ all measure how well a straight line fits the data (or the logarithm of the data, as the case may be).

The χ^2 value depends on the size of the measurement errors: overestimating the errors will decrease the resulting χ^2, even though the correlation is unchanged; underestimating the errors can produce a misleadingly large χ^2. Thus, even though the χ^2 values for the $\log M_{\rm bh}$–$\log n$ relation are smaller than those for the $\log M_{\rm bh}$–σ_c relation, we do not take that as strong evidence that the $\log M_{\rm bh}$–$\log n$ relation is better. Ferrarese & Merritt (2000) argued that their optimal $\log M_{\rm bh} - \log\sigma_c$ relation had negligible intrinsic scatter ($\chi^2 < 1$); this led them to posit that, "Our results suggest that the stellar velocity dispersion may be the fundamental parameter regulating the evolution of supermassive BHs in galaxies." All twelve of their 'Sample A' galaxies, on which this conclusion was based, had an uncertainty of ±13% on their central velocity dispersions, except for the Milky Way which had an uncertainty of ±20%. If these uncertainties have been overestimated, it will result in an underestimate to the χ^2 value of the fit which may then lead one to wrongly conclude that there is no intrinsic scatter in the relation. The situation is identical if the 20% errors we assigned to the Sérsic indices are too large. However, irrespective of the errors one assigns, the strengths of both correlations shown in Figure 1 appear to be equal. *This suggests that one can use (relatively inexpensive) photometric images, instead of velocity dispersion measurements, for determining SMBH masses.*

It is well established that more luminous bulges have larger values of n. They also have greater central concentrations, deeper gravitational poten-

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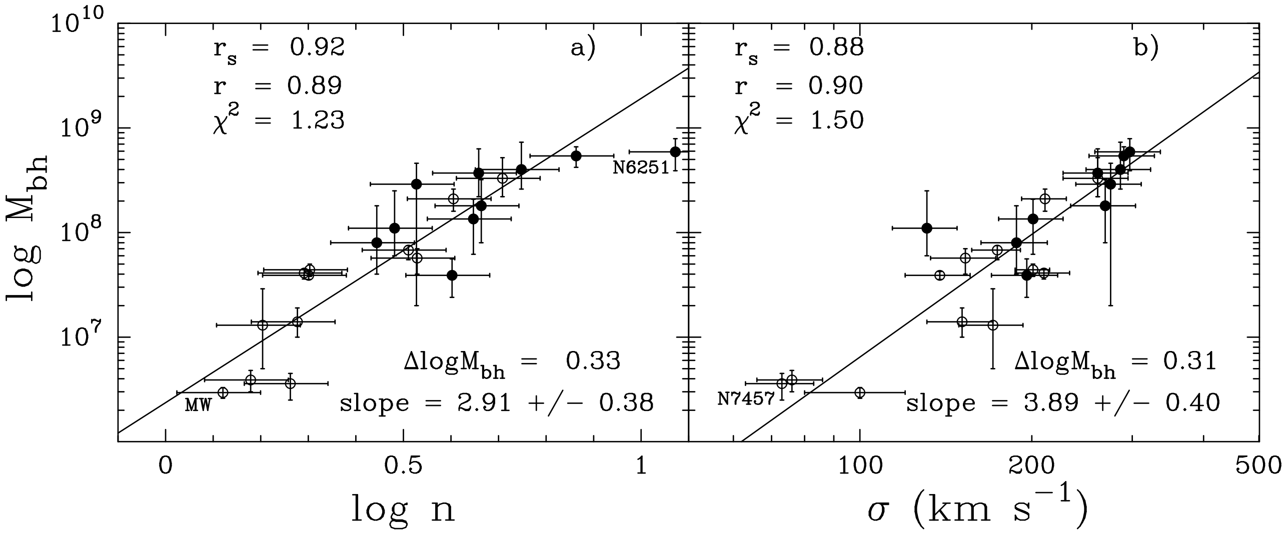

Fig. 1. Correlations between the logarithm of a bulge's supermassive black hole mass and its a) bulge shape parameter (i.e. Sérsic index n) and b) stellar velocity dispersion within $r_e/8$. The orthogonal linear-regression routine from Akritas & Bershady (1996) has been used. The Spearman rank-order correlation coefficient r_s is given, as is the Pearson linear correlation coefficient r. The χ^2 merit function for a linear fit and the absolute vertical scatter $\Delta \log M_{\rm bh}$ about the linear fit are also given. Elliptical galaxies are denoted by filled circles, lenticulars and spirals by open circles. The $M_{\rm bh}$ and σ_c data have been taken from Kormendy & Gebhardt (2001) and Merritt & Ferrarese (2001). Values of n are from Erwin et al. (2002) and supersede those given in Graham et al. (2001a).

tial wells, higher central gravitational potential gradients (Ciotti 1991, Trujillo et al. 2002), and house more massive SMBHs. One might expect these characteristics to result in bulges which are better able to fuel and build their central black holes.

To date, most models incorporating SMBHs have addressed their formation from the standpoint of the older $\log M_{\rm bh}$–$M_{\rm bulge}$ relation (Haiman & Loeb 1998; Richstone et al. 1998; Silk & Rees 1998; Blandford 1999; Kauffmann & Haehnelt 2000; Archibald et al. 2001; Umemura 2001; Caon, Erwin & Graham 2002). A few recent papers have offered possible explanations for the $\log M_{\rm bh}$–$\log\sigma$ correlation (Haehnelt & Kauffmann 2000; Adams, Graff, & Richstone 2001; Burkert & Silk 2001). It is hoped that a more complete understanding will be achieved when the correlation between SMBH mass and bulge light-profile shape is additionally explained.

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