Draft version March 20, 2015
Preprint typeset using LATEX style emulateapj v. 01/23/15

M-M PAPER, MORPHOLOGICAL BIAS

G. A. D. Savorgnan[1] and A. W. Graham[1]
Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Hawthorn, Victoria 3122, Australia.
Draft version March 20, 2015

ABSTRACT

abstract
Subject headings: keywords

1. INTRODUCTION

More than two and a half decades ago, Dressler (1989) foresaw a "rough scaling of black hole mass with the mass of the spheroidal component", as suggested by the sequence of five galaxies (M87, M104, M31, M32 and the Milky Way). His "rough scaling" was a premature version of the nowadays popular correlation between black hole mass, $M_{\rm BH}$, and host spheroid luminosity, $L_{\rm sph}$, and also host spheroid mass, $M_{\rm sph}$ (Yee 1992; Kormendy & Richstone 1995; Magorrian et al. 1998; Marconi & Hunt 2003; Häring & Rix 2004). These early studies were dominated by high-mass, early-type galaxies, for which they reported a quasi-linear $M_{\rm BH} - M_{\rm sph}$ relation, consistent with a dry-merging formation scenario. Subsequent studies of the $M_{\rm BH} - L_{\rm sph}$ and $M_{\rm BH} - M_{\rm sph}$ diagrams (Ferrarese & Ford 2005; Lauer et al. 2007a; Graham 2007, 2008; Gültekin et al. 2009; Sani et al. 2011; Beifiori et al. 2012; Erwin & Gadotti 2012; Vika et al. 2012; van den Bosch et al. 2012; McConnell & Ma 2013; Kormendy & Ho 2013; Rusli et al. 2013; see Graham 2015 for an extensive review about the early discovery and successive improvements of these correlations) used similar galaxy samples, which remained dominated by high-mass, early-type objects having $M_{\rm BH} \gtrsim 0.5 \times 10^8$ M$_\odot$, and recovered a near-linear relation. However, the consensus about a linear $M_{\rm BH} - M_{\rm sph}$ correlation was not unanimous. Some studies reported a slope steeper than 1, or noticed that low-mass spheroids were downwards offset from the relation traced by their high-mass counterparts (Laor 1998; Wandel 1999; Laor 2001; Ryan et al. 2007). Recently, Läsker et al. (2014a,b) derived 2.2 μm bulge luminosities for 35 galaxies (among which only 4 were classified as spiral galaxies), and reported a slope of 0.75 ± 0.10 for their $M_{\rm BH} - L_{\rm sph}$ relation. They also claimed that the black hole mass correlates equally well with the total galaxy luminosity as it does with the bulge luminosity.

The $M_{\rm BH} - L_{\rm sph}$ relation can be predicted from other two correlations involving the bulge velocity dispersion, σ. The first of these two is the $M_{\rm BH} - \sigma$ relation (Ferrarese & Merritt 2000; Gebhardt et al. 2000), which can be described by a single power-law $M_{\rm BH} \propto \sigma^5$ over the range in velocity dispersion $70 - 350$ km s^{-1} (e.g. Graham et al. 2011; McConnell et al. 2011; Graham & Scott 2013). The second is the $L_{\rm sph} - \sigma$ relation, which has long been known to be a "double power-law", being $L_{\rm sph} \propto \sigma^5$ at the luminous end (Schechter 1980; Malumuth & Kirshner 1981; von der Linden et al. 2007; Liu et al. 2008), and $L_{\rm sph} \propto \sigma^2$ at intermediate and faint luminosities (Davies et al. 1983; Held et al. 1992; Matković & Guzmán 2005; de Rijcke et al. 2005; Balcells et al. 2007; Chilingarian et al. 2008; Forbes et al. 2008; Cody et al. 2009; Tortora et al. 2009; Kourkchi et al. 2012). The change in slope of the $L_{\rm sph} - \sigma$ relation occurs at $M_B \approx -20.5$ mag, corresponding to $\sigma \approx 200$ km s^{-1}. That is, the $M_{\rm BH} - L_{\rm sph}$ relation should be better described by a "broken", rather than single, power-law, having $M_{\rm BH} \propto L_{\rm sph}^{2.5}$ at the low-luminosity end, and $M_{\rm BH} \propto L_{\rm sph}^{1}$ at the high-luminosity end. Due to the scatter in the $M_{\rm BH} - L_{\rm sph}$ (or $M_{\rm BH} - M_{\rm sph}$) diagram, studies that have not sufficiently probed below $M_{\rm BH} \approx 10^7$ M$_\odot$ miss the change in slope occuring at $M_{\rm BH} \approx 10^{(8\pm1)}$ M$_\odot$, and erroneously recover a single log-linear relation,

When Graham (2012) pointed out this overlooked inconsistency, he identified two different populations of galaxies, namely the core-Sérsic (Graham et al. 2003; Trujillo et al. 2004) and Sérsic spheroids[1], and attributed the change in slope (from log-quadratic to log-linear) to their different formation mechanisms. In this scenario, core-Sérsic spheroids are built in additive dry merger events, where the black hole and the bulge grow in lock steps ($M_{\rm BH} \propto L_{\rm sph}^{1}$), whereas Sérsic spheroids originate from gas-rich processes, in which the mass of the black hole increases more rapidly than the mass of its host spheroid ($M_{\rm BH} \propto L_{\rm sph}^{2.5}$). Graham & Scott (2013) and Scott et al. (2013) presented double power-law linear regressions for the Sérsic/core-Sérsic spheroids in the $M_{\rm BH} - L_{\rm sph}$ and $M_{\rm BH} - M_{*,{\rm sph}}$ (spheroid stellar mass) diagrams, respectively. To obtain their dust-corrected *bulge* magnitudes, they did not perform bulge/disc decompositions, but instead they converted $B-$band and K_S-band observed, total *galaxy* magnitudes using a mean statistical correction based on each object's morphological type and disc

[1] Core-Sérsic spheroids have partially depleted cores relative to their outer Sérsic light profile, whereas Sérsic spheroids have no central deficit of stars. While core-Sérsic spheroids are also "core galaxies", as given by the Nuker definition (Lauer et al. 2007b), it should be noted that $\sim 20\%$ of "core galaxies" are not core-Sérsic spheroids (Dullo & Graham 2014, their Appendix A.2), i.e. do not have depleted cores. The change in slope of the $L_{\rm sph} - \sigma$ relation corresponds to the division between core-Sérsic and Sérsic spheroids (e.g. Graham & Guzmán 2003).

gsavorgn@astro.swin.edu.au

inclination[2]. It should be noted that ∼80% of their core-Sérsic spheroids were morphologically classified as elliptical galaxies, and ∼80% of their Sérsic spheroids were morphologically classified as bulges of disk galaxies.

range mbh not to miss the bend

2. DATA

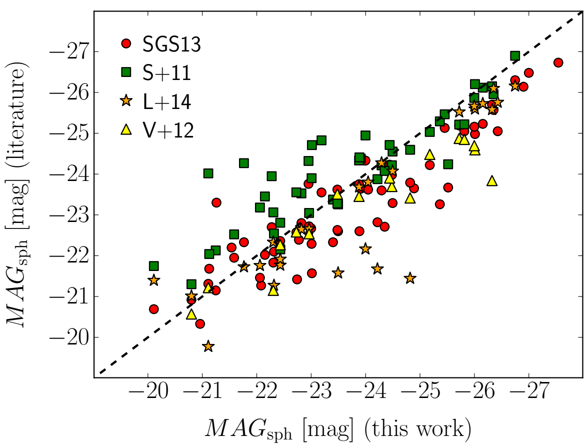

FIG. 1.—

3. ANALYSIS

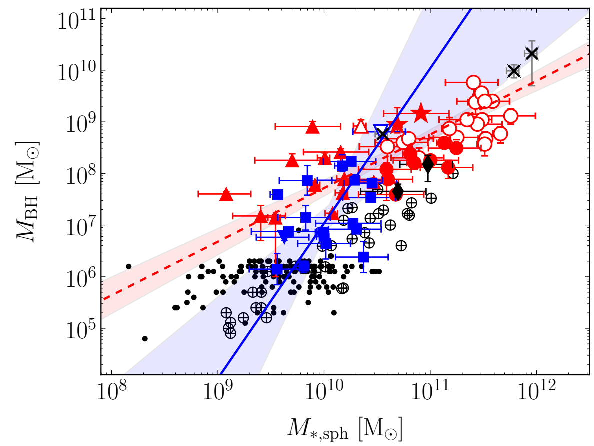

FIG. 2.—

4. RESULTS

5. CONCLUSIONS

This research was supported by Australian Research Council funding through grants DP110103509 and FT110100263. This work is based on observations made with the IRAC instrument (Fazio et al. 2004) on-board the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. This research has made use of the GOLDMine database (Gavazzi et al. 2003) and the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

Balcells, M., Graham, A. W., & Peletier, R. F. 2007, ApJ, 665, 1104
Beifiori, A., Courteau, S., Corsini, E. M., & Zhu, Y. 2012, MNRAS, 419, 2497
Chilingarian, I. V., Cayatte, V., Durret, F., et al. 2008, A&A, 486, 85
Cody, A. M., Carter, D., Bridges, T. J., Mobasher, B., & Poggianti, B. M. 2009, MNRAS, 396, 1647
Davies, R. L., Efstathiou, G., Fall, S. M., Illingworth, G., & Schechter, P. L. 1983, ApJ, 266, 41
de Rijcke, S., Michielsen, D., Dejonghe, H., Zeilinger, W. W., & Hau, G. K. T. 2005, A&A, 438, 491
Dressler, A. 1989, in IAU Symposium, Vol. 134, Active Galactic Nuclei, ed. D. E. Osterbrock & J. S. Miller, 217
Dullo, B. T., & Graham, A. W. 2014, MNRAS, 444, 2700
Erwin, P., & Gadotti, D. A. 2012, Advances in Astronomy, 2012, 4
Fazio, G. G., Hora, J. L., Allen, L. E., et al. 2004, ApJS, 154, 10
Ferrarese, L., & Ford, H. 2005, Space Sci. Rev., 116, 523
Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9
Forbes, D. A., Lasky, P., Graham, A. W., & Spitler, L. 2008, MNRAS, 389, 1924
Gavazzi, G., Boselli, A., Donati, A., Franzetti, P., & Scodeggio, M. 2003, A&A, 400, 451
Gebhardt, K., Bender, R., Bower, G., et al. 2000, ApJ, 539, L13
Graham, A. W. 2007, MNRAS, 379, 711
—. 2008, PASA, 25, 167
—. 2012, ApJ, 746, 113
—. 2015, ArXiv e-prints, arXiv:1501.02937
Graham, A. W., Erwin, P., Trujillo, I., & Asensio Ramos, A. 2003, AJ, 125, 2951
Graham, A. W., & Guzmán, R. 2003, AJ, 125, 2936
Graham, A. W., Onken, C. A., Athanassoula, E., & Combes, F. 2011, MNRAS, 412, 2211
Graham, A. W., & Scott, N. 2013, ApJ, 764, 151
Gültekin, K., Richstone, D. O., Gebhardt, K., et al. 2009, ApJ, 698, 198
Häring, N., & Rix, H.-W. 2004, ApJ, 604, L89
Held, E. V., de Zeeuw, T., Mould, J., & Picard, A. 1992, in IAU Symposium, Vol. 149, The Stellar Populations of Galaxies, ed. B. Barbuy & A. Renzini, 429
Kormendy, J., & Ho, L. C. 2013, ARA&A, 51, 511
Kormendy, J., & Richstone, D. 1995, ARA&A, 33, 581
Kourkchi, E., Khosroshahi, H. G., Carter, D., et al. 2012, MNRAS, 420, 2819
Laor, A. 1998, ApJ, 505, L83
—. 2001, ApJ, 553, 677
Läsker, R., Ferrarese, L., & van de Ven, G. 2014a, ApJ, 780, 69
Läsker, R., Ferrarese, L., van de Ven, G., & Shankar, F. 2014b, ApJ, 780, 70
Lauer, T. R., Faber, S. M., Richstone, D., et al. 2007a, ApJ, 662, 808
—. 2007b, ApJ, 662, 808

[2] While this resulted in individual bulge magnitudes not being exactly correct, their large sample size allowed them to obtain a reasonably ensemble average correction.

Liu, F. S., Xia, X. Y., Mao, S., Wu, H., & Deng, Z. G. 2008, MNRAS, 385, 23
Magorrian, J., Tremaine, S., Richstone, D., et al. 1998, AJ, 115, 2285
Malumuth, E. M., & Kirshner, R. P. 1981, ApJ, 251, 508
Marconi, A., & Hunt, L. K. 2003, ApJ, 589, L21
Matković, A., & Guzmán, R. 2005, MNRAS, 362, 289
McConnell, N. J., & Ma, C.-P. 2013, ApJ, 764, 184
McConnell, N. J., Ma, C.-P., Gebhardt, K., et al. 2011, Nature, 480, 215
Rusli, S. P., Erwin, P., Saglia, R. P., et al. 2013, AJ, 146, 160
Ryan, C. J., De Robertis, M. M., Virani, S., Laor, A., & Dawson, P. C. 2007, ApJ, 654, 799
Sani, E., Marconi, A., Hunt, L. K., & Risaliti, G. 2011, MNRAS, 413, 1479
Schechter, P. L. 1980, AJ, 85, 801
Scott, N., Graham, A. W., & Schombert, J. 2013, ApJ, 768, 76
Tortora, C., Napolitano, N. R., Romanowsky, A. J., Capaccioli, M., & Covone, G. 2009, MNRAS, 396, 1132
Trujillo, I., Erwin, P., Asensio Ramos, A., & Graham, A. W. 2004, AJ, 127, 1917
van den Bosch, R. C. E., Gebhardt, K., Gültekin, K., et al. 2012, Nature, 491, 729
Vika, M., Driver, S. P., Cameron, E., Kelvin, L., & Robotham, A. 2012, MNRAS, 419, 2264
von der Linden, A., Best, P. N., Kauffmann, G., & White, S. D. M. 2007, MNRAS, 379, 867
Wandel, A. 1999, ApJ, 519, L39
Yee, H. K. C. 1992, in Astronomical Society of the Pacific Conference Series, Vol. 31, Relationships Between Active Galactic Nuclei and Starburst Galaxies, ed. A. V. Filippenko, 417