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Comment on Kormendy et al. (2011, Nature, 469, 374)

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ABSTRACT

Comments on Kormendy, Bender & Cornell (2011, Nature, 469, 374; arXiv:1101.3781) are presented. A broader historical perspective is provided before a number of scientific concerns regarding their data and conclusions are discussed.

Key words: galaxies: elliptical and lenticular, cD; galaxies: evolution

1 HISTORICAL BACKGROUND

The non-compliant nature of certain disc galaxies in the (black hole mass)-(bulge velocity dispersion) diagram, known as the $M_{\rm bh}$-σ diagram (Figure 2 in Kormendy et al.'s Nature article), was first publicly announced three years ago, in January 2008 at the American Astronomical Society Meeting in Austin Texas. The associated journal paper (Graham 2008a), connected with the conference presentation (Graham 2007), revealed how barred galaxies can be offset from the $M_{\rm bh}$-σ relation defined by non-barred and elliptical galaxies. This discovery was simultaneously framed in terms of offset pseudobulges by Hu (2008), with Hu's pseudobulge sample effectively a barred galaxy sample[1]. Graham (2008a) reported that there was a 0.1 to 0.01 per cent probability of the galaxy sample being offset by chance. The deviant nature of these barred/pseudobulge galaxies, which has included the Milky Way, was again the focus in Graham (2008b), Graham & Li (2009), Gadotti & Kauffmann (2009), Greene et al. (2010), and discussed extensively in mid 2010 by Graham et al. (2010). This latter work expanded the sample of galaxies used in 2008-2009 from ∼50 to 64 (including 39 disc galaxies, 20 of which are barred galaxies) and constructed new relations after having identified and corrected an additional sample bias — an artificial black hole mass floor in the data set — affecting past studies.

The classical $M_{\rm bh}$-σ relation was constructed using galaxies of all morphological type (Ferrarese & Merritt 2000; Gebhardt et al. 2000; Merritt & Ferrarese 2001; Tremaine et al. 2002). To distinguish from this, Graham (2008a) introduced the barless $M_{\rm bh}$-σ relation and the elliptical-galaxy $M_{\rm bh}$-σ relation (see also Hu 2008 in regard to the latter), and reported that "Removal of the seven barred galaxies from the Tremaine et al. (2002) set of 31 galaxies gives a barless $M_{\rm bh}$-σ relation with an intrinsic scatter of 0.17 dex (cf. 0.27 dex for the 31 galaxies) and a total scatter of 0.25 dex (cf. 0.34 dex for the 31 galaxies)".

The $M_{\rm bh}$-σ relation was predicted (Silk & Rees 1998; Haehnelt, Natarajan & Rees 1998; Fabian 1999, 2010) before it was observed. The Silk & Rees (1998) $M_{\rm bh}$-σ relation with a slope of 5 is now observationally supported by both the barless $M_{\rm bh}$-σ relation and the elliptical-only $M_{\rm bh}$-σ relation (Graham et al. 2010; see also Ferrarese & Ford's 2005 classical $M_{\rm bh}$-σ relation).

As revealed by Novak, Faber & Dekel (2006), it is not yet established which physical property of the host bulge best correlates with the mass of the central black hole. What is known is that the scatter about the classical $M_{\rm bh}$-σ relation has increased as the number of barred, and likely pseudobulge, galaxies has increased (Hu 2008; Graham 2008b; Gültekin et al. 2009; Graham et al. 2010). Graham (2008a) wrote "Bar instabilities are believed to lead to the formation of pseudobulges. Such evolution may have resulted in (pseudo)bulges with an increased velocity dispersion and luminosity but a relatively anemic SMBH (unless it also grew during the formation of the pseudobulge). If the barred galaxies do indeed have discrepantly low SMBH masses rather than high σ-values, they should also appear as systematic outliers in the $M_{\rm bh}$-L diagram." The work by Graham and collaborators does not rule out this possibility which is what the Nature paper in question has attempted to answer.

2 CAUTIONARY REMARKS ON PSEUDOBULGE IDENTIFICATION AND LUMINOSITY

Pseudobulges are notoriously hard to identify, and there is not yet a consensus as to how to define them. For example, at odds with the Nature article, Peebles' (2011) review of the article reports that a pseudobulge "is a concentration of

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[1] Only one of Hu's (2008) nine "pseudobulge" galaxies was not barred.

starlight near the centre of [a] galaxy, but in the disk, not extending above it as do stars in a bulge".

While the detection of rotating bulges, pseudo or not, goes back a long time (e.g. Babcock 1939; Rubin, Ford & Kumar 1973; Pellet 1976; Bertola & Capaccioli 1977; Peterson 1978; Mebold et al. 1979; Rubin 1980), some classical bulges, just like low-luminosity elliptical galaxies, are expected to have significant rotation (Naab, Khochfar & Burkert 2006; Bekki 2010). Classical bulges can also appear to rotate due to the presence of a bar (e.g. Babusiaux et al. 2010). Furthermore, classical bulges can have Sérsic (1968) indices (a measure of how centrally concentrated their stellar light is, see Graham & Driver 2005 and references therein) less than 2, just as low-luminosity elliptical galaxies do (e.g. Caon et al. 1993; Young & Currie 1994; Scannapieco et al. 2010; Graham 2010 and references therein).

To further complicate matters, classical and pseudobulges can exist within the same galaxy, such as the case of NGC 2787 (Erwin et al. 2003) used in the Nature article. The classical bulge in this galaxy has a magnitude roughly 1 mag fainter than the pseudobulge, yet no distinction is made in the Nature article's Figure 1 which would have revealed, at odds with the Nature article's premise, that the classical bulge, rather than the pseudobulge, is the outlying point.[2]

Figure 1 in the Nature article reveals that only 3 or 4 alleged pseudobulges appear to depart from the $M_{\rm bh}$-L relation defined by the other galaxies, while the remaining 7 or 8 alleged pseudobulges, i.e. the bulk of them, agree with the main relation. This would appear to support the notion of the coevolution of black holes and pseudobulges, at odds with the article's conclusion. This observation might instead reflect that the actual number of pseudobulges has been significantly over-estimated due to the use of questionable selection criteria and/or reveal a problem with the assigned bulge luminosities. One of the few offset galaxies is NGC 1068, an SB galaxy with a large 3 kpc bar oriented at a position angle of approximately 45 degrees (Scoville et al. 1988; Thronson et al. 1989). Given the connection between pseudobulges and the presence of large-scale bars (and nuclear bars), additionally modelling the bar light, along with the Sérsic-bulge plus the exponential-disc light, would be appropriate given that the galaxy samples now contain many barred galaxies. This, however, has not been done.

Figure 1 in the Nature article has used a bulge-to-total ratio of 0.11 for the barred (pseudobulge) galaxy NGC 3227, while not assigning the bar light to the bulge is known to give a ratio of 0.068 (Gadotti 2008), i.e. the bulge is actually half a magnitude fainter than assumed. Similarly, the barred galaxy NGC 4596 has been assigned a ratio of 0.3 in the article, where as Laurikainen et al. (2005) revealed that the bulge-to-total ratio is 0.13 when the bar light is excluded, this amounts to a difference of nearly 1 mag in Figure 1 of the Nature article, and explains much of the apparent offset nature of these galaxies in the $M_{\rm bh}$-$L_{\rm bulge}$ diagram.

A proper decomposition of the light is important to prevent over-estimating the bulge flux from not only large-scale bar light that is assigned to the bulge, but from unmodelled nuclear bars and star clusters which can increase the apparent Sérsic index of the bulge and consequently its derived luminosity (e.g. Balcells et al. 2003). Moreover, given the coexistence of massive black holes in dense nuclear star clusters at the low mass end of the $M_{\rm bh}$-σ diagram (Seth 2008, Gonzalez-Delgado 2008; Graham & Spitler 2009 and references therein), one is not looking at the full picture if one ignores these compact nuclei with masses up to $10^7 M_\odot$. Accounting for their mass may well partially explain the apparent offset nature of some (pseudobulge) galaxies at the low-mass end of the $M_{\rm bh}$-σ diagram.

Traditionally, all bulges were assumed to have the same concentration; the same Sérsic index with a value of 4 was used to describe their radial flux distribution. We now know this was wrong (e.g. Andredakis 1994; de Jong 1996; Balcells et al. 2003). Unfortunately the literature remains full of bulge-to-total (B/T) flux ratios which are too high. The average ratio for (classical bulges abundant among) the S0 galaxy population is ∼0.25 (e.g. Balcells et al. 2003; Laurikainen et al. 2005, 2007, 2010; Graham & Worley 2008). It is therefore somewhat concerning to find half of the classical bulges in Table 1 of the article with $B/T > 0.5$. At the other extreme is the unaccounted for excess central flux seen in the late-type spiral galaxy NGC 4395 (see Graham & Spitler 2009). That is, at least one of the two allegedly pure-disc galaxies with a black hole mass that is not consistent with a value of zero appears to have a bulge, pseudo or otherwise, of the size expected for its morphological type.

Only with reliable bulge luminosities will we know if pseudobulge and barred galaxies follow the same (black hole mass)-(bulge luminosity) relation as elliptical galaxies and non-barred galaxies. Importantly, if no clear offset of the former relative to the distribution of the latter in this diagram is found, it would suggest that these disc galaxies, or at least the majority of them, have bulges which coevolve with their black holes. The already established offset nature of (some of the) galaxies with bars and pseudobulges in the $M_{\rm bh}$ - σ diagram would then suggest an issue with the measured dynamics, i.e. the stellar "velocity dispersions" of the host bulges. This may arise due to differing levels of interference from the dynamics of the bars whose light signal is mixed with that of the bulge (an issue explore by Graham et al. 2010). Furthermore, if bar dynamics deviate significantly from the often assumed axisymmetric, rather than triaxial, stellar orbits used to constrain the black hole mass, then this could also contribute to potential offsets of barred galaxies in both the $M_{\rm bh}$ - σ and $M_{\rm bh}$ - L diagram.

[2] Curiously, it is of interest to note that the alleged pseudobulges in Greene, Ho & Barth (2008, their figure 7) are consistent with the $M_{\rm bh}$-$M_{\rm bulge}$ relation from Häring & Rix (2004), while their classical bulge data is inconsistent with this relation.

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