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The relation between GC systems and SMBH in spiral galaxies: The link to the $M_\bullet - M_*$ correlation

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Abstract. We explore the relationship between globular cluster total number, $N_{\rm GC}$, and central black hole mass, $M_\bullet$, in spiral galaxies. Including cosmic scatter, log $M_\bullet \propto (1.64 \pm 0.24)$ log $N_{\rm GC}$. Whereas in ellipticals the correlation is linear [log $M_\bullet \propto (1.02 \pm 0.10)$ log $N_{\rm GC}$], and hence could be due to statistical convergence through mergers, this mechanism cannot explain the much steeper correlation in spirals. Additionally, we derive total stellar galaxy mass, M_*, from its two-slope correlation with $N_{\rm GC}$ (Hudson et al. 2014).In the $M_\bullet$ versus M_* parameter space, *with* M_* *derived from* $N_{\rm GC}$, $M_\bullet \propto (1.48 \pm 0.18)$ log M_* for ellipticals, and $M_\bullet \propto (1.21 \pm 0.16)$ log M_* for spirals. The observed agreement between ellipticals and spirals may imply that black holes and galaxies co-evolve through "calm" accretion, AGN feedback and other secular processes.

Keywords. black hole physics, galaxies: spiral, galaxies: formation, galaxies: evolution, galaxies: star clusters: general, globular clusters: general

1. Introduction

It is widely accepted that all massive galaxies contain a supermassive black hole (SMBH). In spheroidal systems, the masses of the SMBH, $M_\bullet$, correlate with other properties of their host galaxies: the bulge luminosity (the $M_\bullet$–$L_{\rm bulge}$ relation, e.g., Kormendy 1993; Kormendy & Richstone 1995), the bulge mass (the $M_\bullet$–$M_{\rm bulge}$ relation, e.g., Dressler 1989; Magorrian et al. 1998), the bulge stellar velocity dispersion (the $M_\bullet$–σ_* relation, e.g., Ferrarese & Merrit 2000; Gebhardt et al. 2000), the dark matter halo mass (Spitler & Forbes 2009). Today, the $M_\bullet$–σ_* relation is known to have a ≈ 0.6 dex scatter and depend on the galaxy's merger history (Bogdán et al. 2018; Sahu et al. 2019b), and the $M_\bullet$–$M_{\rm bulge}$ relation depends on the morphology of the galaxy (Savorgnan et al. 2016; van den Bosch 2016; Sahu et al. 2019a).

An intriguing correlation, given the extremely disparate scales, is the one between $M_\bullet$ and the total number of globular clusters ($N_{\rm GC}$; Burkert & Tremaine 2010; Harris & Harris 2011; Harris et al. 2014). The correlation can be expressed as $N_{\rm GC} \propto M_\bullet^{1.02\pm0.10}$, and spans over 3 orders of magnitude. This somewhat surprising finding has been since intensely explored, as reviewed by Kormendy & Ho 2013. Possible causal links have been proposed, e.g., feedback by the jets of AGN (e.g., Silk & Rees 1998; Fabian 2012) and cannibalization of GCs by black holes (e.g., Capuzzo-Dolcetta & Donnarumma 2001; Gnedin et al. 2014). Since it is roughly linear for ellipticals, it has been argued that the $M_\bullet - N_{\rm GC}$ correlation could be due to statistical convergence through merging (Peng 2007; Jahnke & Macciò 2011).

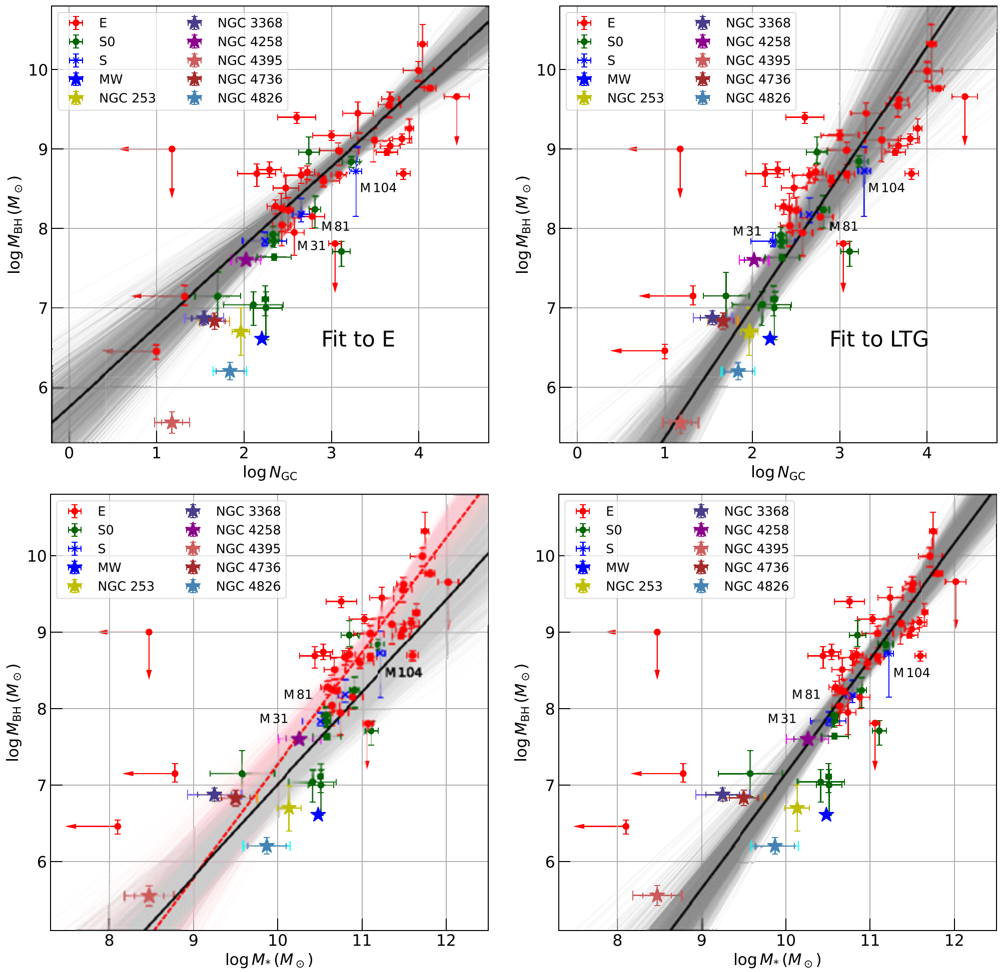

Figure 1. ***Top left:*** Bivariate Correlated Errors and Intrinsic Scatter (BCES; Akritas & Bershady 1996) fit to log $M_\bullet$ versus log N_{GC} of elliptical galaxies, with extra cosmic scatter in both variables. *Solid black lines:* best fits; *translucent gray lines:* range of possible solutions; 5% of the lines belong to fits separated by 2σ or more from the best values. Solid (*red*) and open (*green*) circles represent, respectively, elliptical and lenticular galaxies in the sample of Harris et al. 2014, reclassified as per Sahu et al. 2019b. ***Top right:*** BCES fit to log $M_\bullet$ versus log N_{GC} of LTG. Points and symbols as in left panel. The points in the left and right panels are the same, but only ellipticals are fit in the left, and only spirals in the right. ***Bottom left*** and ***bottom right:*** BCES fits to log $M_\bullet$ versus log M_* with extra cosmic scatter in both variables. *Bottom left, dashed red line:* best fit to elliptical galaxies; *translucent pink lines:* range of possible solutions for elliptical galaxies; *solid black line:* best fit to spiral galaxies; *translucent silver lines:* range of possible solutions for LTG. *Bottom right:* simultaneous fit to ellipticals and LTG. *Solid black lines:* best fit; *translucent gray lines:* range of possible solutions. Points in both panels are the same; ellipticals and LTG are fit separately in the left, simultaneously in the right.

2. The $M_\bullet$ versus N_{GC} correlation

Until relatively recently, there were only 5 spiral galaxies with precise measurements of both N_{GC} and $M_\bullet$: the Milky Way (MW, Sbc), M 104 (Sa), M 81 (Sab), M 31 (Sb), and NGC 253 (Sc). All of them, with the notable exception of the MW, fell right on the

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$N_{\rm GC} - M_\bullet$ correlation for ellipticals. Our Galaxy has a black hole that is about 1 order of magnitude lighter than expected from its $N_{\rm GC}$ and the correlation for ellipticals.

We have determined $N_{\rm GC}$ for five additional galaxies with precise black hole measurements (McConnell & Ma 2013): NGC 3368, NGC 4395, NGC 4258, NGC 4736, and NGC 4826. Hence, we have doubled the previous existing sample. Additionally, we have corrected the position of NGC 253, whose number of GC (92±21; Olsen et al. 2004) had been misread by Harris et al. 2014, on the $M_\bullet$ versus $N_{\rm GC}$ parameter space.

For most of these objects, there are strong arguments against major mergers (pseudobulges, low density environments, rotating GC systems). While log $M_\bullet \propto (1.02 \pm 0.10)$ log $N_{\rm GC}$ for ellipticals (Figure 1, *top left*), log $M_\bullet \propto (1.64 \pm 0.24)$ log $N_{\rm GC}$ for late type galaxies (LTG; Figure 1, *top right*), in both cases including cosmic scatter in both variables. Hence, the correlation for LTG is much steeper than and not consistent with the linear correlation for ellipticals, for which statistical convergence through mergers may be important.

3. The $M_\bullet$ versus M_* correlation: secular co-evolution

Finally, we have fitted $M_\bullet$ versus total galaxy stellar mass, M_*, for both ellipticals and LTG. **We derive M_* from $N_{\rm GC}$.** The relation between log $N_{\rm GC}$ and M_* is a broken power-law, with log $M_* = 2.11 \times$ log $N_{\rm GC}$ + 5.99, for lower galaxy masses, and log $M_* = 0.69 \times$ log $N_{\rm GC}$ + 8.96, for higher galaxy masses, with the inflection point at log $M_*/M_\odot \sim 10.4$, log $N_{\rm GC} \sim 2.1$ (Hudson et al. 2014). Far from mirroring the discrepant slopes of the $M_\bullet$ versus $N_{\rm GC}$ fits, the correlations between log $M_\bullet$ and log M_* for ellipticals and LTG are quite similar, and with a flatter slope for LTG. Once again including cosmic scatter, we obtain $M_\bullet \propto (1.48 \pm 0.18)$ log M_* for ellipticals (Figure 1 *bottom left, red-dashed* and *pink translucent lines*), and $M_\bullet \propto (1.21 \pm 0.16)$ log M_* for LTG (Figure 1, *bottom left, solid black* and *gray translucent lines*). The fits have a small offset of $\sim$ 0.2-0.3 dex at log $M_*/M_\odot = 10$. The simultaneous fit for ellipticals and LTG is shown in Figure 1, *bottom right*. These fits are in line with the results of Reines & Volonteri 2015 and Simmons et al. 2017, and argue for a mostly non-merger driven $M_\bullet$ growth, and galaxy-black hole co-evolution through secular processes, like "calm" accretion and feedback (Simmons et al. 2017; Martin et al. 2018).

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