Clues to galaxy evolution from galaxy structure and the $M_{bh} - M_{bulge}$ relation

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Overview

1. Compact massive bulges
2. The $M_{bh} - M_{bulge}$ relation
The size-mass diagram for spheroidal stellar systems

The density-mass diagram: Compactness

Compact galaxies & bulges of modern disk galaxies (★)

Dullo & Graham (2013. ApJ. 768. 36)
Damjanov et al. (2011)
Compact Spheroids

High-z, compact galaxies may be today’s massive bulges

- **Cold streams**, gas accretion (Khochfar & Silk 2006; Combes arXiv: 1309.1603) builds discs around the compact galaxies / bulges.


Local, compact elliptical galaxies may be the bulges of stripped disc galaxies, or, they were too small to ever acquire a substantial disc.
Compact Spheroids, cont.

**Title:** The Majority of (14) Compact Massive Galaxies at $z \sim 2$ are Disk Dominated: van der Wel et al. (2011, ApJ, 730, 38)
Partially depleted cores in luminous `bulges’

Core-Sersic model fit to an E (NGC 4291) and an S0 (NGC 4382).

Cores span 10 pc to a few hundred parsec

Signature of binary/multiple supermassive black hole coalescence.

(Dullo & Graham 2012, 2013)
The black hole mass was thought to scale linearly with the host bulge mass (0.15 to 0.2%).

Haring & Rix (2004)

Re-analysis of the Haring & Rix (2004) data

Slope = 1 for core-Sérsic spheroids.

Slope = 2 for Sérsic spheroids.

Black hole mass scaling relations


The luminosity (L) / velocity dispersion (σ) relation for elliptical galaxies

For luminous spheroids ($M_B < -20.5\text{ mag}$): Luminosity $\sim \sigma^5$
(e.g. Schechter 1980; Malumuth & Kirshner 1981; Von Der Linden et al. 2007; Liu et al. 2008)

For the less luminous spheroids ($M_B > -20.5\text{ mag}$): Luminosity $\sim \sigma^2$
(Davies et al. 1983; Held et al. 1992; de Rijcke et al. 2005; Matkovic & Guzman 2005; Kourkchi et al. 2007)

Given $M_{bh} \sim \sigma^5$ (e.g., Graham et al. 2011; McConnell & Ma 2012):

\[ M_{bh} \sim L^1 \quad \text{(for luminous core-Sérsic spheroids)} \]
\[ M_{bh} \sim L^{2.5} \quad \text{(for faint Sérsic spheroids)} \]

The division is associated with the core-Sérsic / Sérsic division of spheroids (as reviewed in Graham arXiv:1108.0997)

Remco van den Bosch et al. (2012, Nature, 491, 729)
AGN Feedback produces a quadratic relation


Black hole/spheroid mass ratio should increase (e.g. Seymour et al. 2012, ApJ, 755, 146)
Consequences... I.

- New relations / predictions for BH masses in other galaxies.

- In luminous spheroids the $M_{bh}/M_{sph}$ mass ratio is $\sim 0.5\%$ (more than double the old, assumed constant, value).

- The expected BH mass at $M_B = -19$ mag is now $10x$ smaller.

- Expect that intermediate mass black holes have already been discovered (see Graham & Scott 2013).

- Need to revise BH mass function derived from $M_{bh}$-L relation (and need to re-compute the associated BH mass density).
Consequences... II.

✓ Reinvestigate observational claims of $M_{bh}/M_{sph}$ evolution with $z$.


✓ Rethink BH / galaxy formation theories that predicted $M_{bh} \sim L$.

✓ Modify semi-analytic models which programmed in `quasar mode’ / `cold-gas mode’ BH growth assuming $M_{bh} \sim L$. 
Stellar capture by a supermassive black hole

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