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

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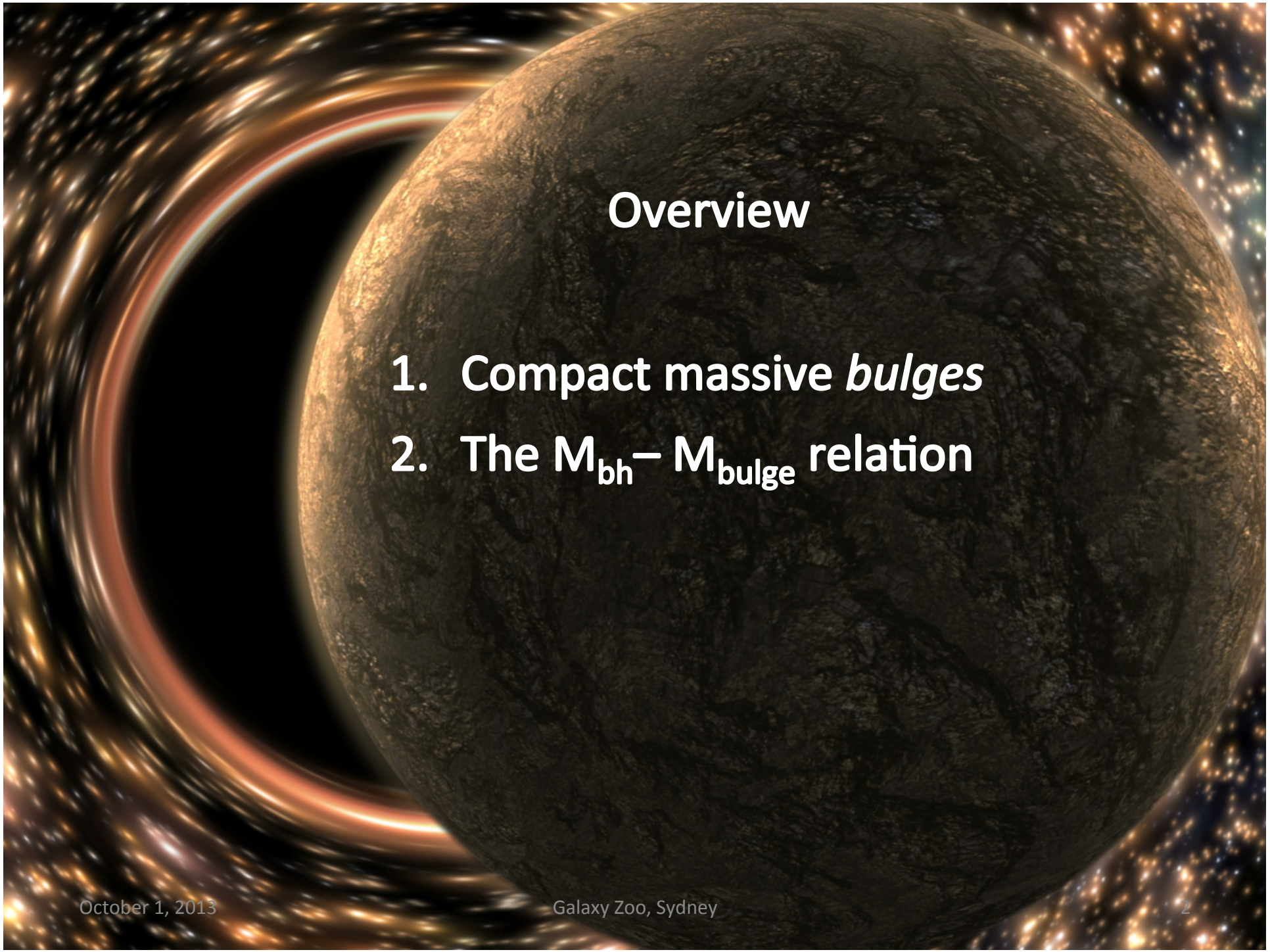
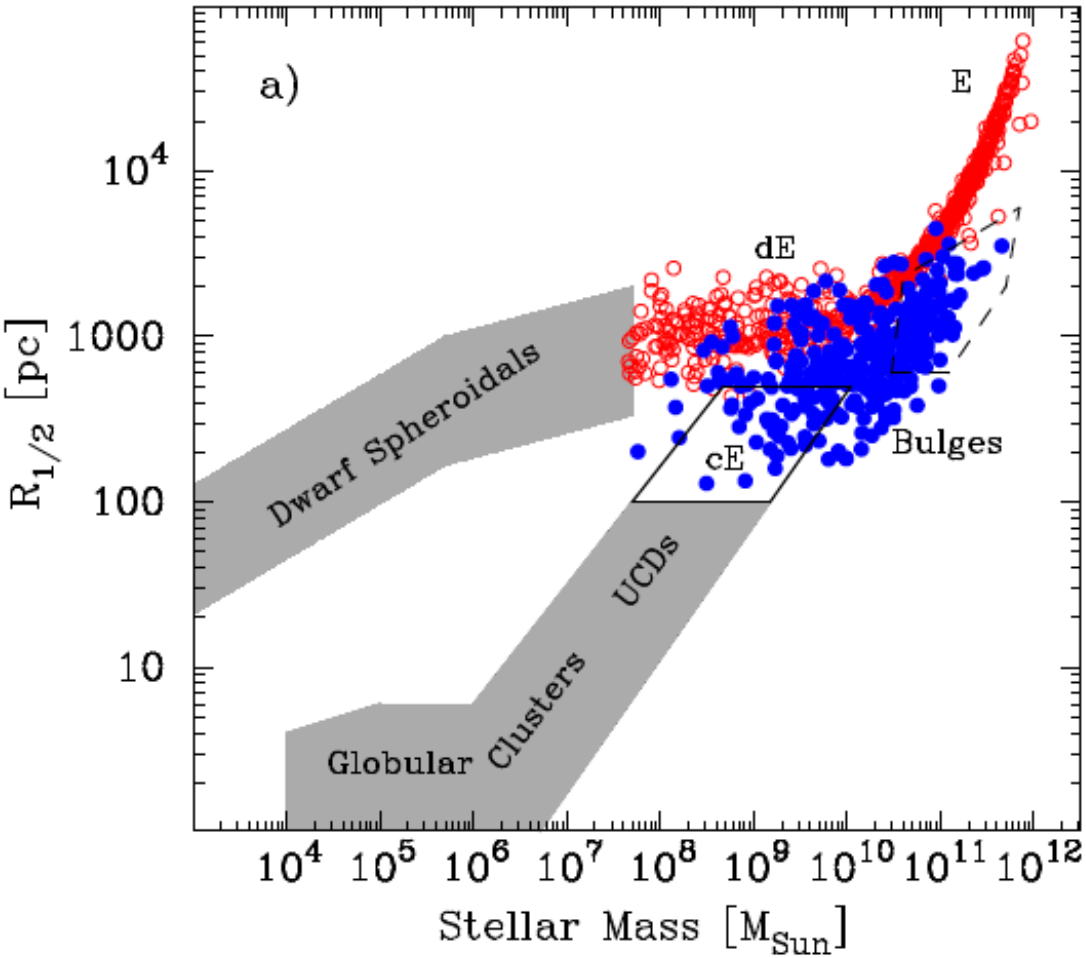
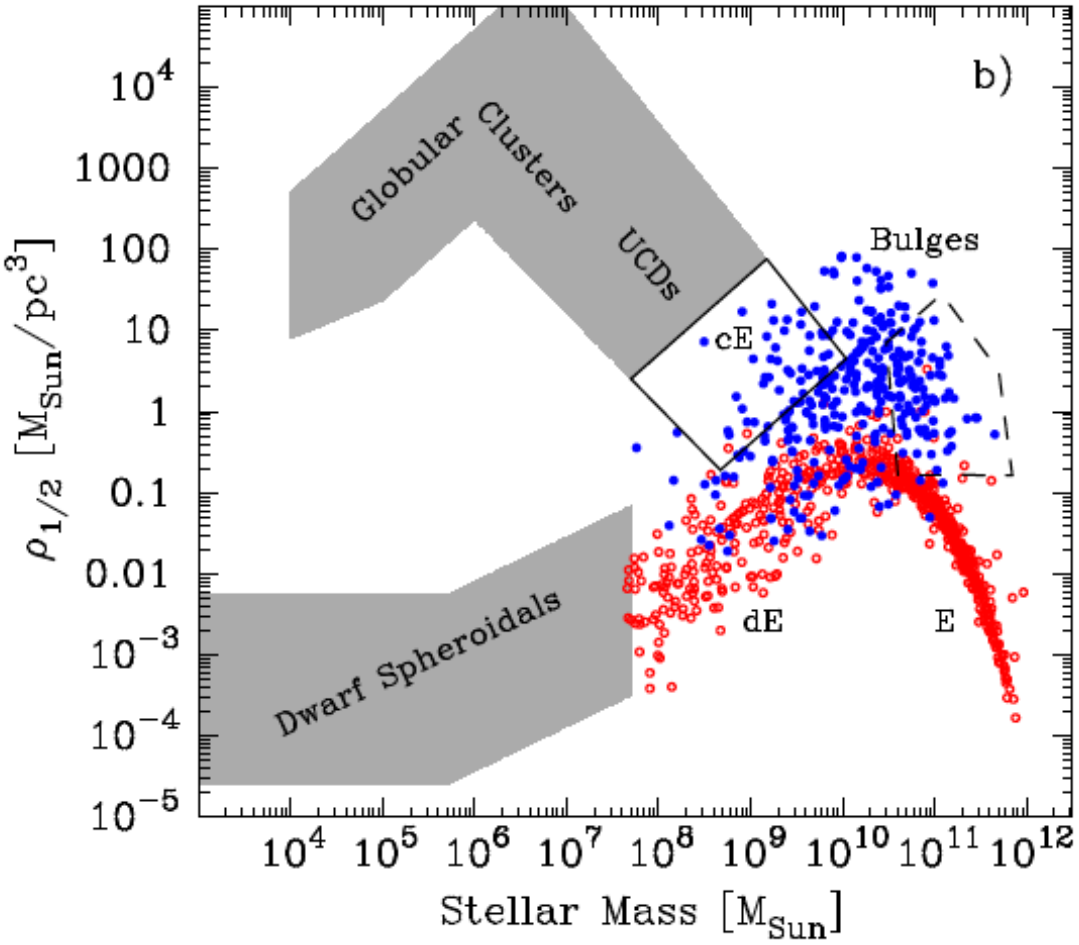

Overview
1. Compact massive *bulges*
2. The M_{bh}– M_{bulge} relation

The size-mass diagram for spheroidal stellar systems

Graham (2011-13,
arXiv:1108.0997
Springer Pub. 2013)

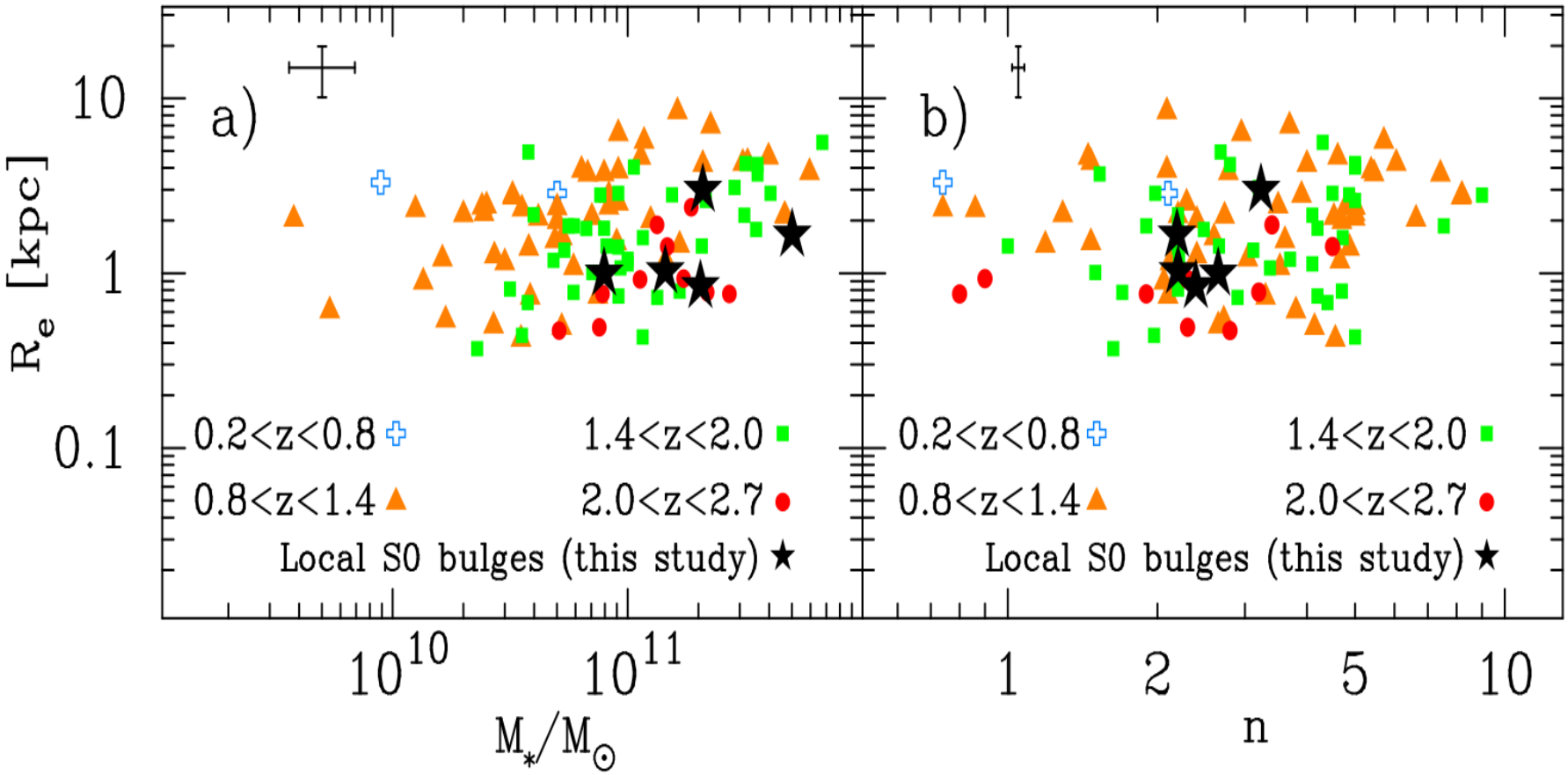


The density-mass diagram: Compactness



Graham (2011-13, arXiv:1108.0997 Springer Pub. 2013)

Compact galaxies & bulges of modern disk galaxies (★)



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

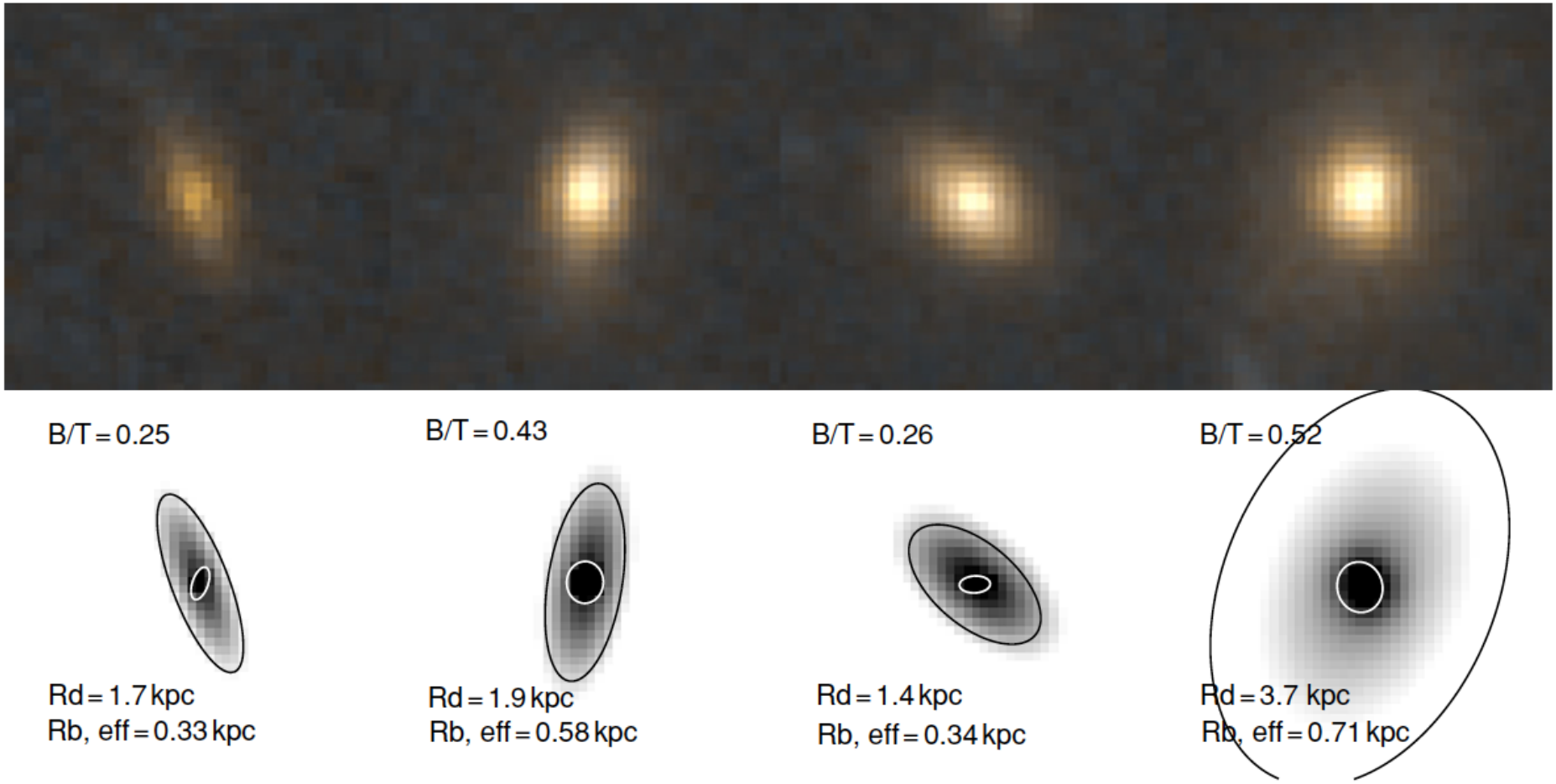
Compact Spheroids

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.
- The feeding is ultimately coplanar rather than random:
  Pichon et al. (2011,MNRAS, 418, 2493);
  Danovich et al. (2012, MNRAS, 422, 1732)
  Stewart et al. (2013, ApJ, 769, 74);
  Prieto, Jimenez & Haiman (arXiv:1301.5567).

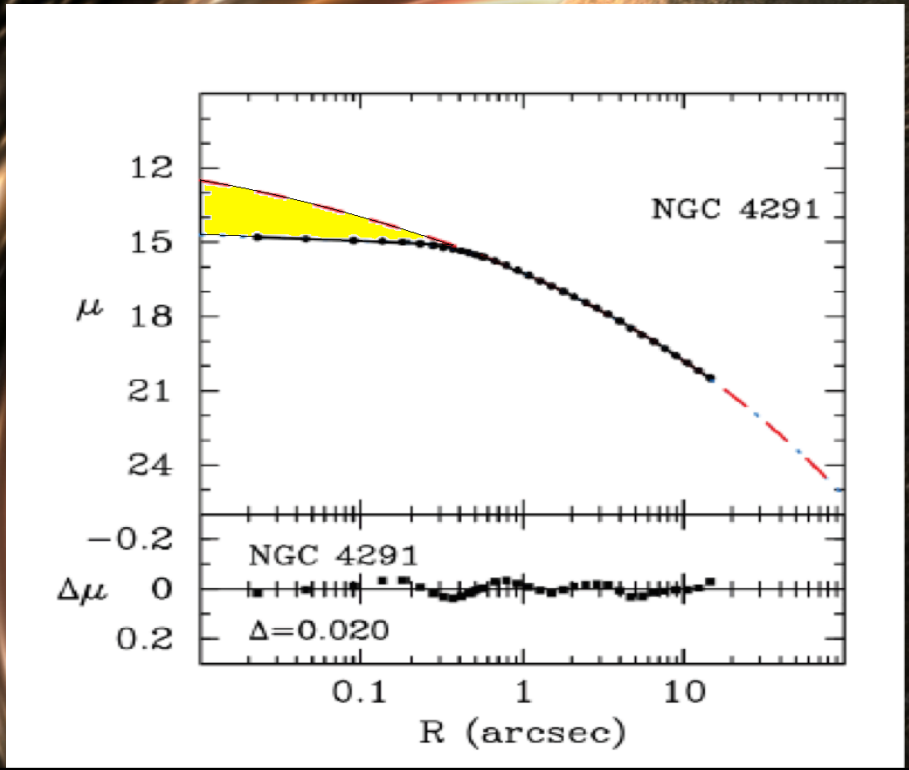
Local, compact elliptical galaxies may be the bulges of stripped disc galaxies, or, they were too small to ever acquire a substantial disc.

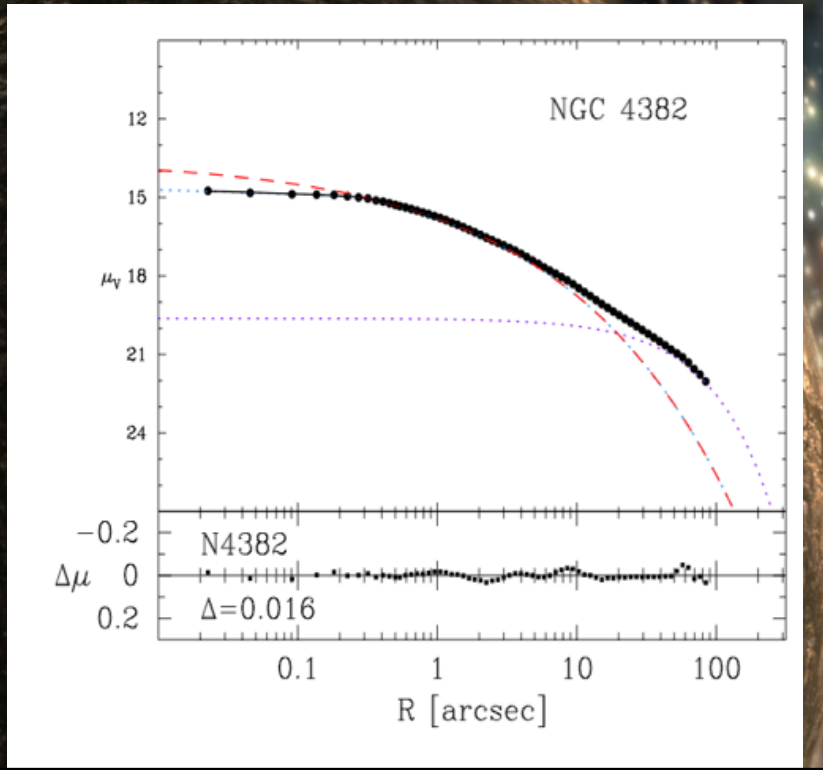
Compact Spheroids, cont.



Title: The Majority of (14) Compact Massive Galaxies at z ~ 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).

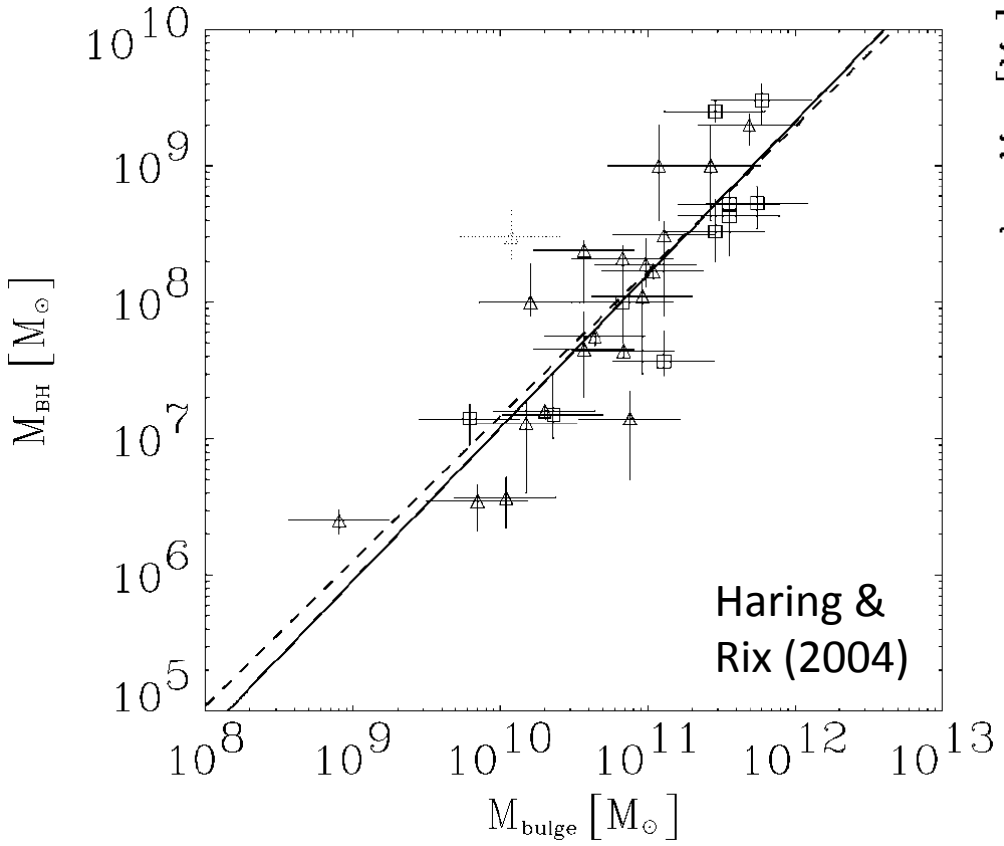
Cores span 10 pc to a few hundred parsec

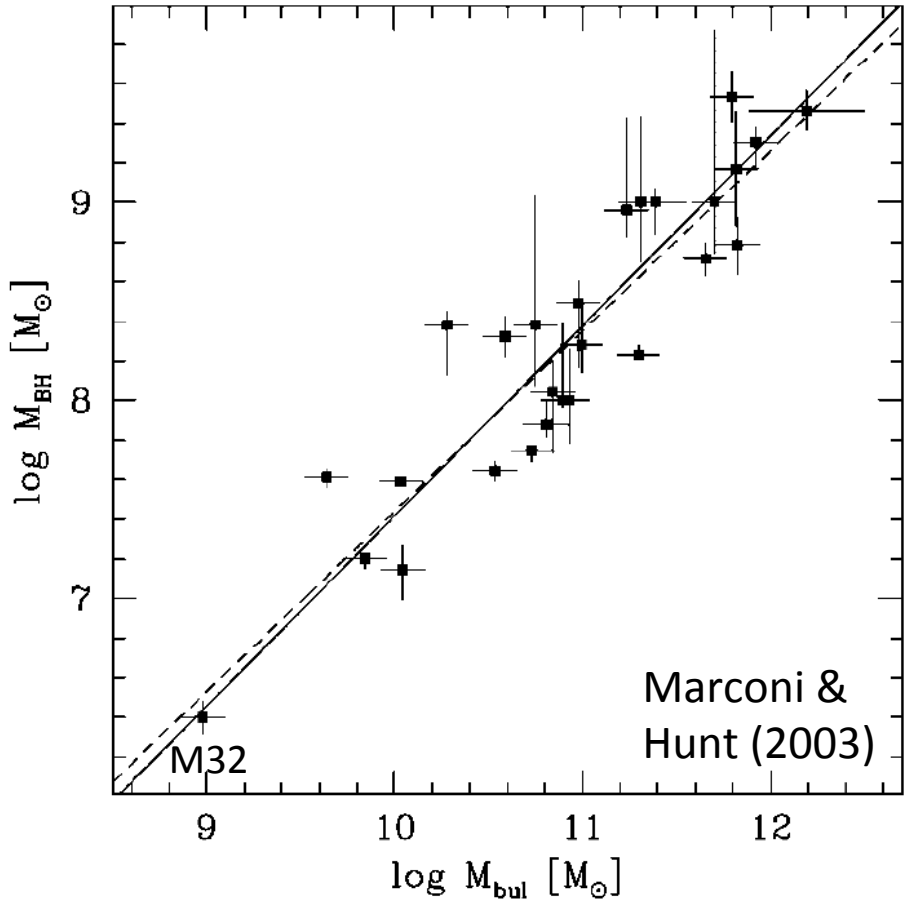
Signature of binary/multiple supermassive black hole coalescence.

(Dullo & Graham 2012, 2013)

The Black hole mass – Bulge mass scaling relation: M_{bh} – M_{bulge}

The black hole mass was thought to scale linearly with the host bulge mass (0.15 to 0.2%).

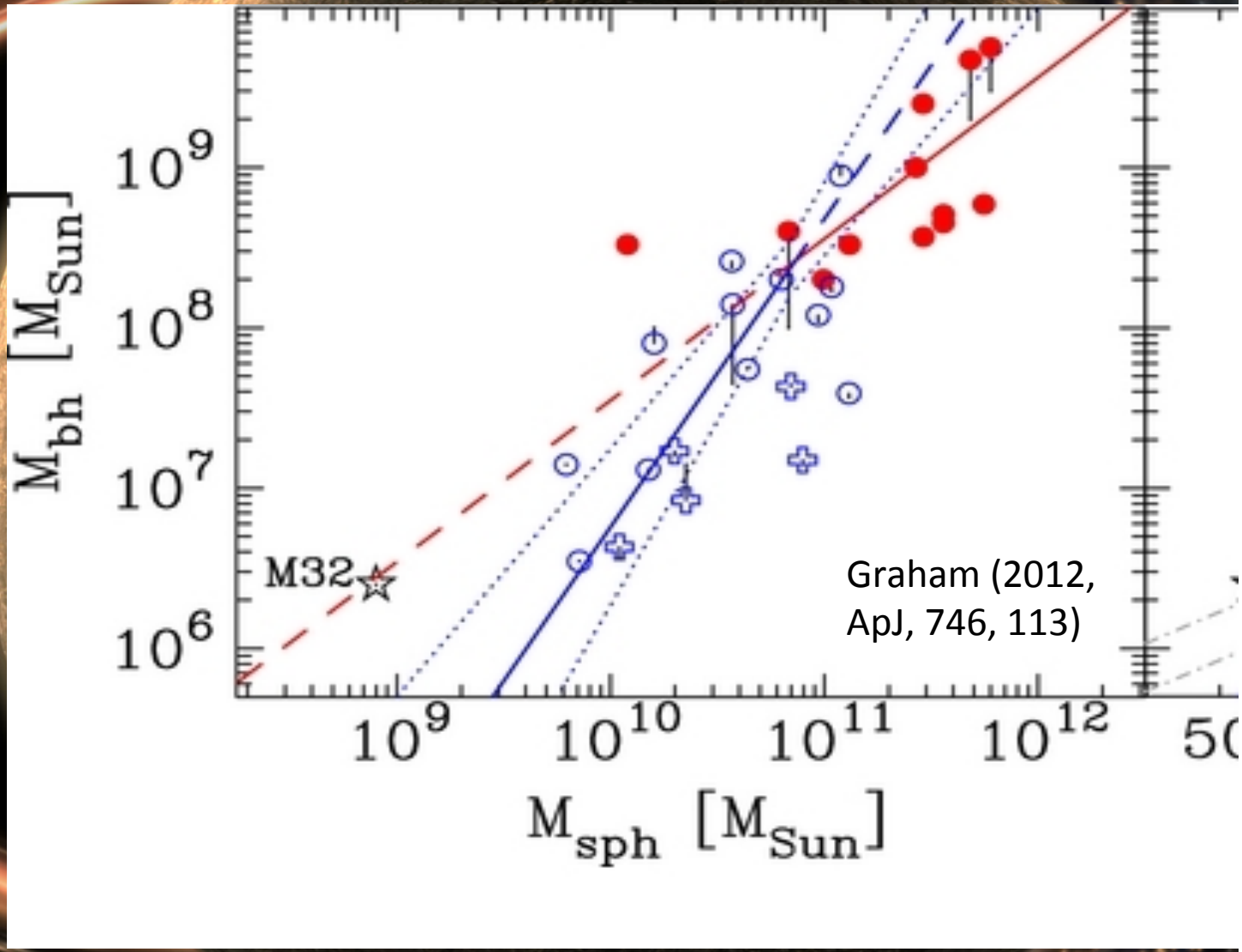




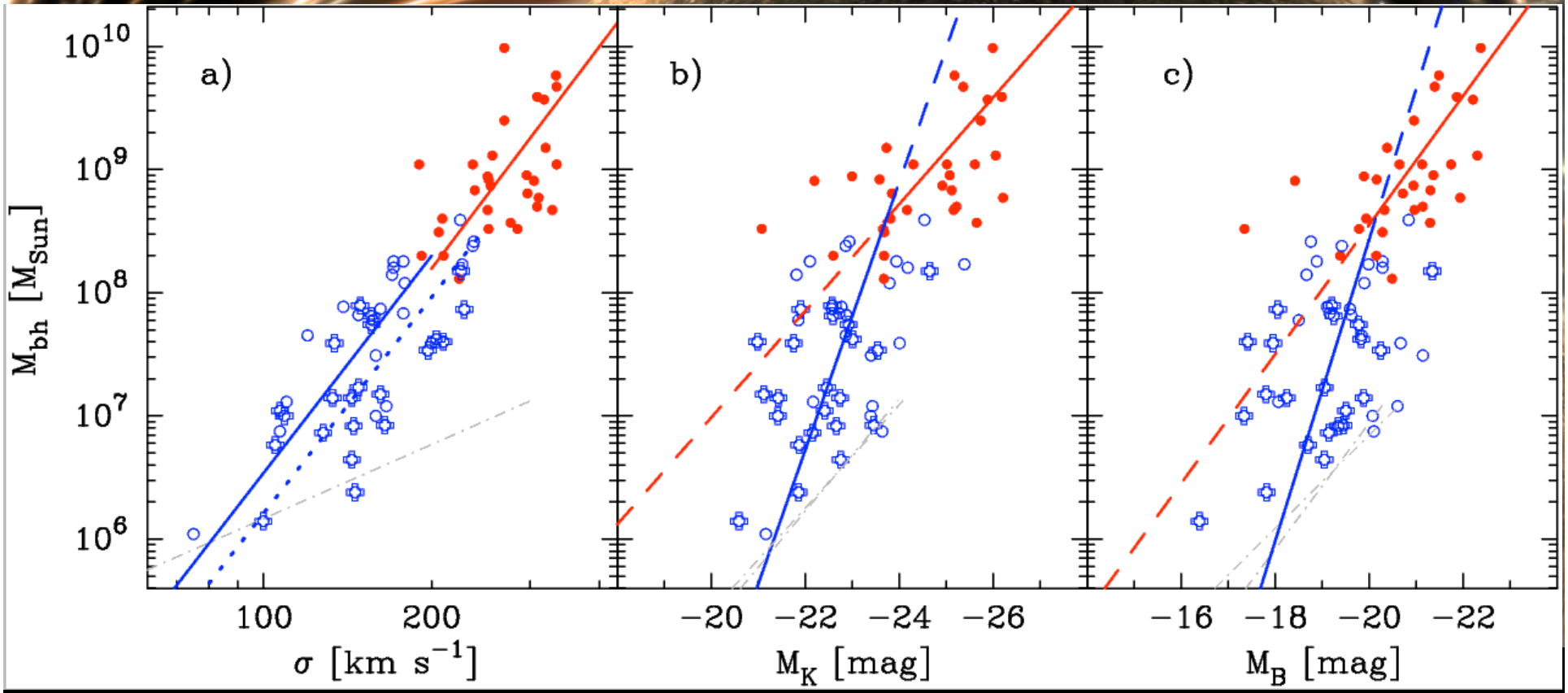
Re-analysis of the Haring & Rix (2004) data

Slope = 1 for core-Sérsic spheroids.

Slope = 2 for Sérsic spheroids.



Black hole mass scaling relations



Graham & Scott (2013, ApJ, 764, 151), see also Scott et al. (2013, ApJ, 768, 76), to be superceded by Gilua Savorgnan (2014…)

Panel a) builds on Graham, Onken, et al. (2011, MNRAS, 412, 2211);
The offset barred galaxies are explained in Hartmann et al. (arXiv:1309.2634).

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

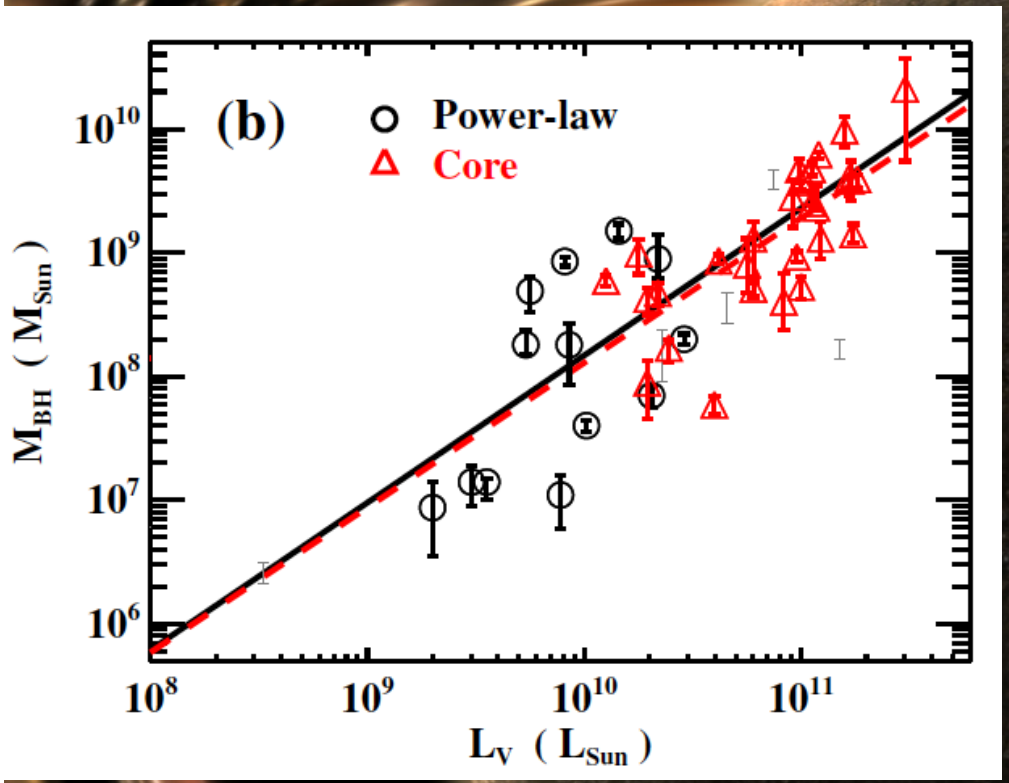
For luminous spheroids ($M_B < -20.5$ mag): Luminosity ~ σ^5
(e.g. Schechter 1980; Malumuth & Kirshner 1981; Von Der Linden et al. 2007; Liu et al. 2008)

For the less luminous spheroids ($M_B > -20.5$ mag): Luminosity ~ σ^2
(Davies et al. 1983; Held et al. 1992; de Rijcke et al. 2005; Matkovic & Guzman 2005; Kourkchi et a

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

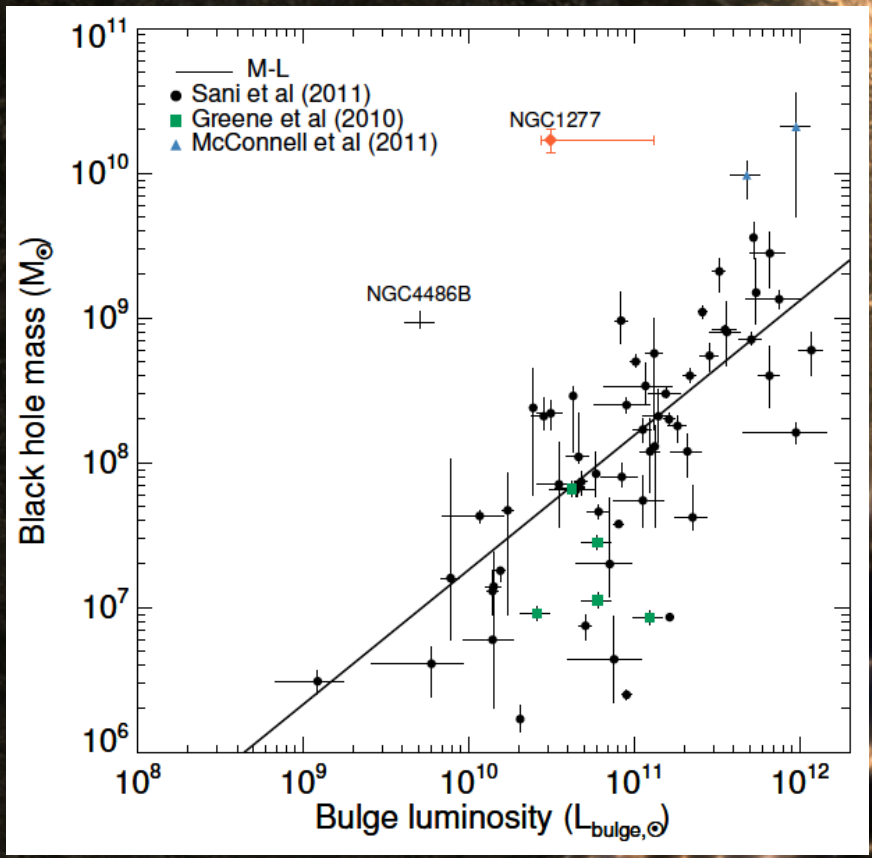
$M_{bh} \sim L^1$ (for luminous core-Sérsic spheroids)
$M_{bh} \sim L^{2.5}$ (for faint Sérsic spheroids)

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

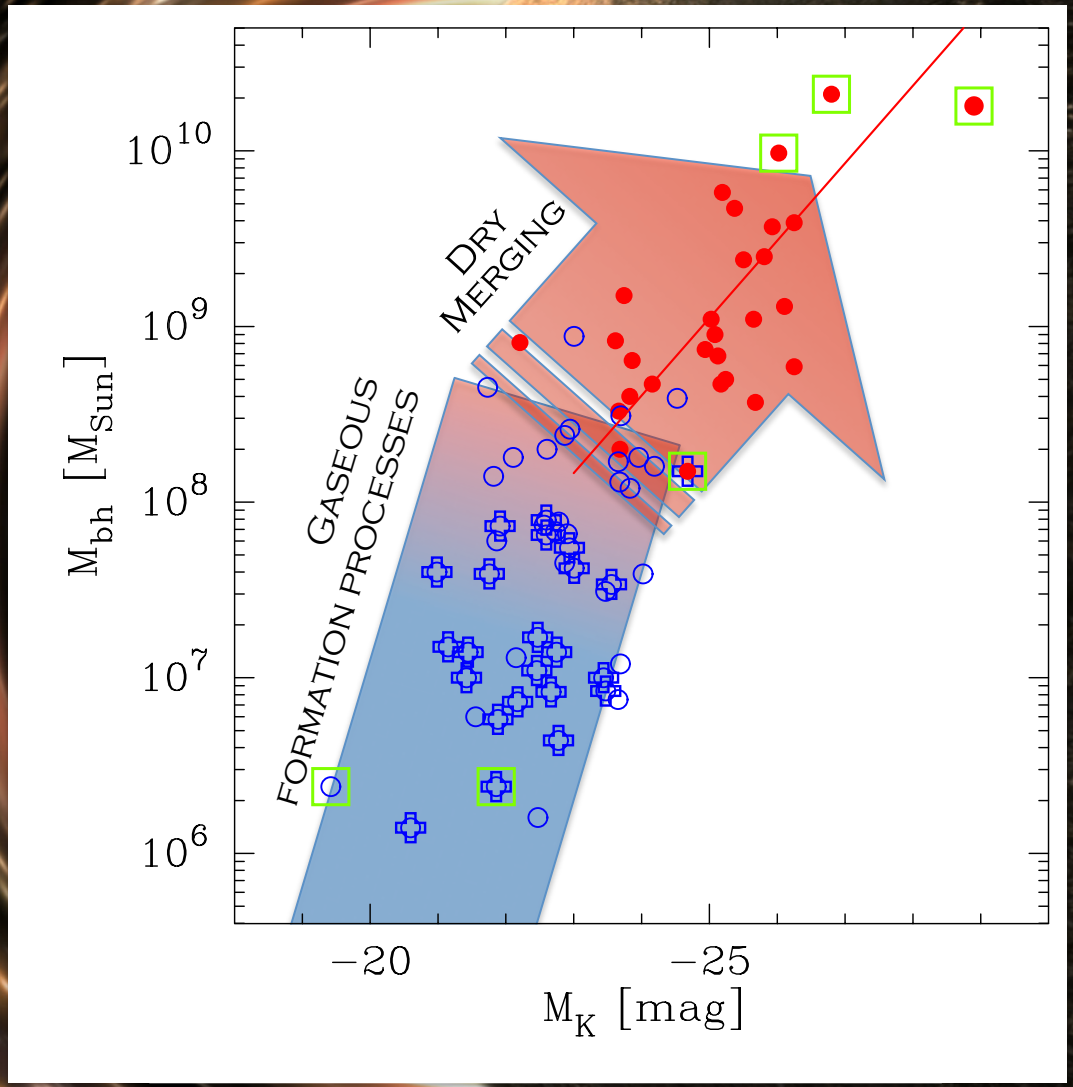


McConnell & Ma
(2013, ApJ, 764, 184)

Remco van den Bosch et al.
(2012, Nature, 491, 729)



AGN Feedback produces a quadratic relation



Graham (2012, ApJ, 746, 113)

Graham & Scott (2013, ApJ, 764, 151)

Scott, Graham & Schombert (2013, ApJ, 768, 76)

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 ~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.
- ✓ Strong impact on expected gravitational radiation signal (Mapelli et al. 2012, A&A, 542, A102).
- ✓ 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 $M_{bh} \sim L$.

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Stellar capture by a supermassive black hole

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