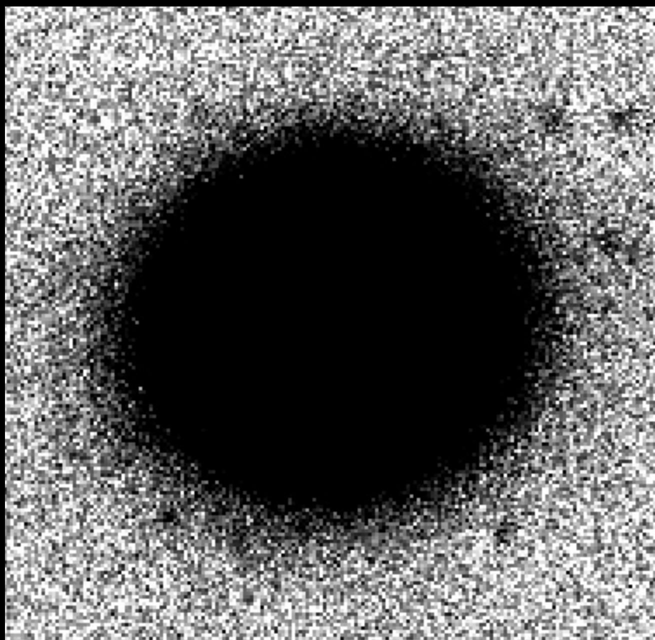
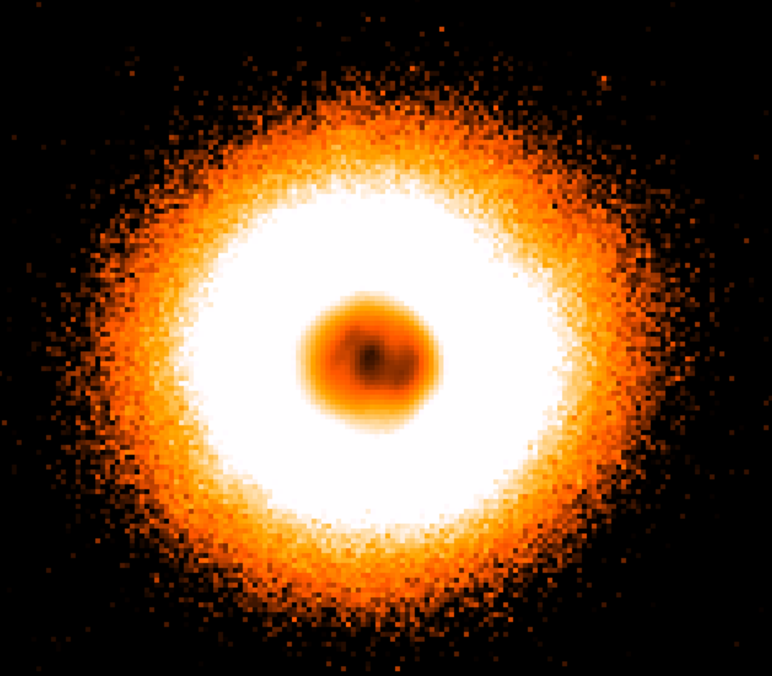
# Compact Massive Galaxy
## evolution through disk growth






Alister Graham
Centre for Astrophysics and Supercomputing

# Introduction

- Black hole scaling diagrams – “overmassive” black holes
- Intermediate-scale disks (disky ellipticals)
- Large-scale disks (lenticulars)
- Local (z~0) compact massive spheroids

# Black hole mass scaling relations

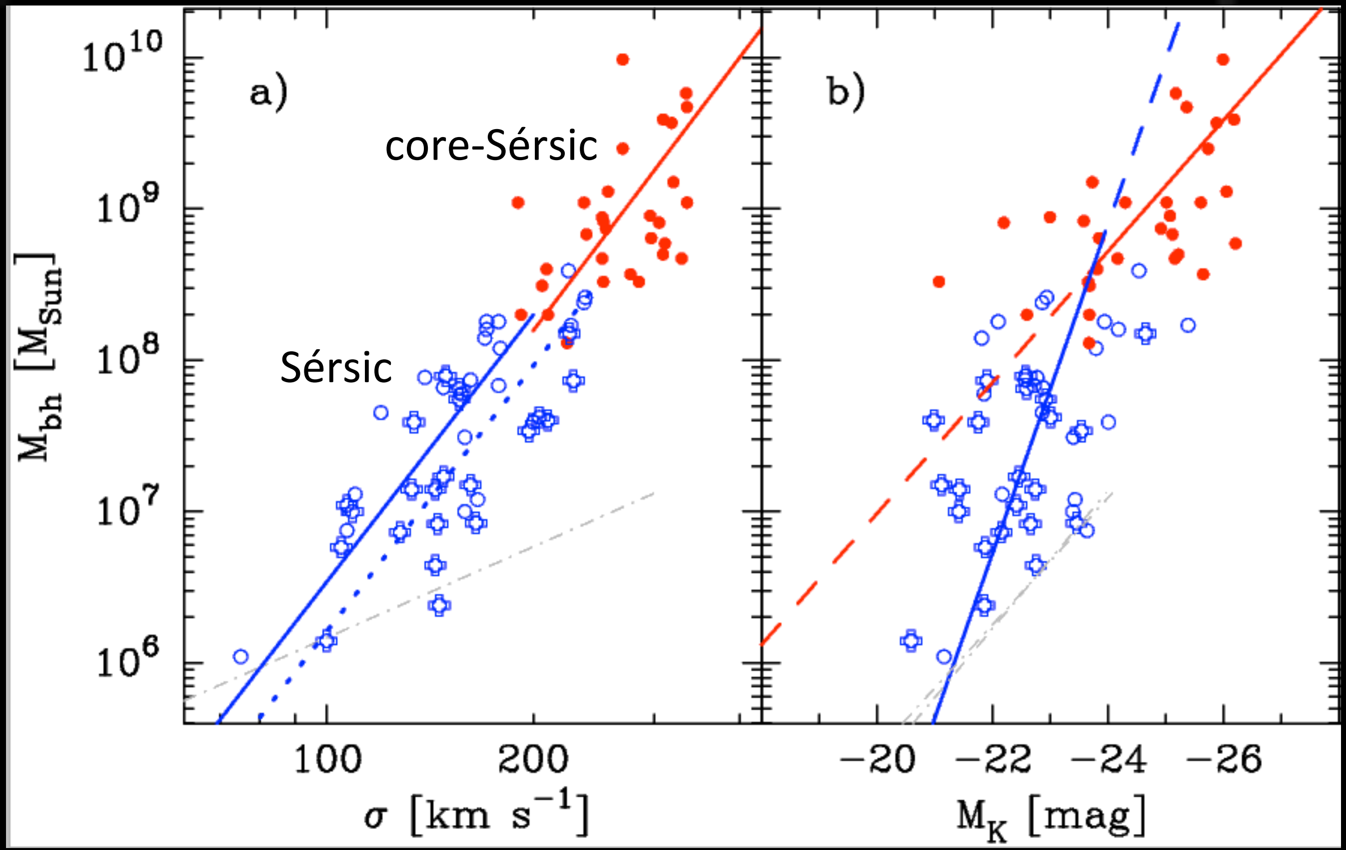
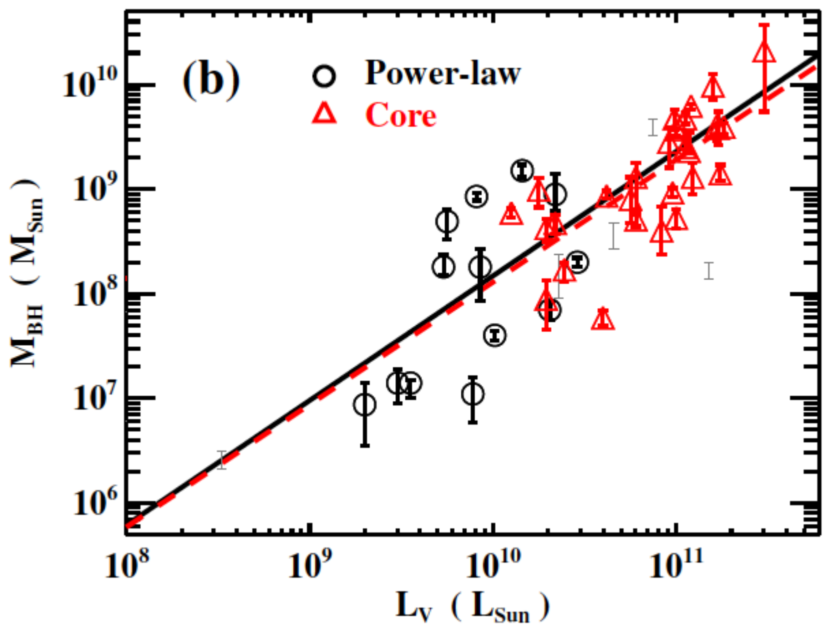
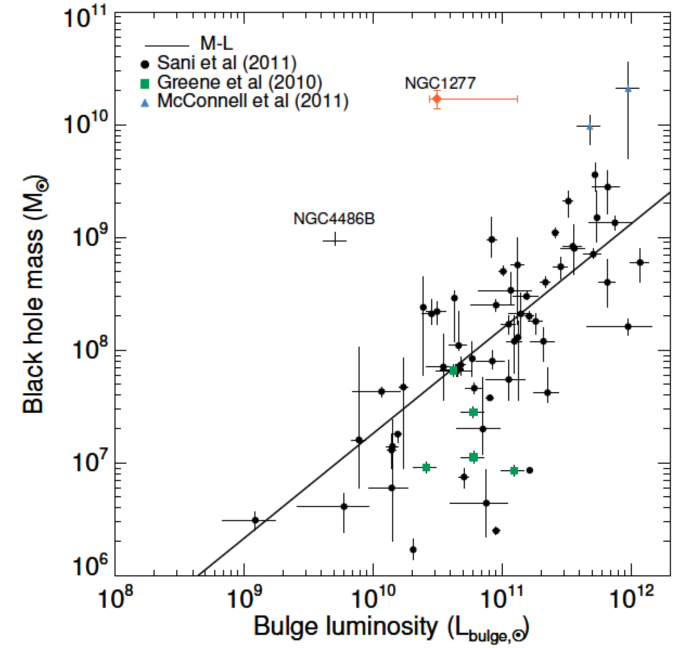



**Figure from Graham & Scott (2013, ApJ, 764, 151)**

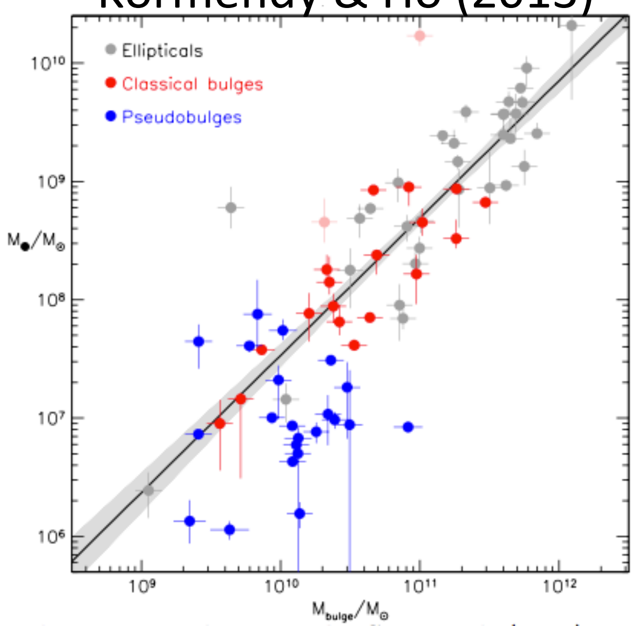
McConnell & Ma (2013)



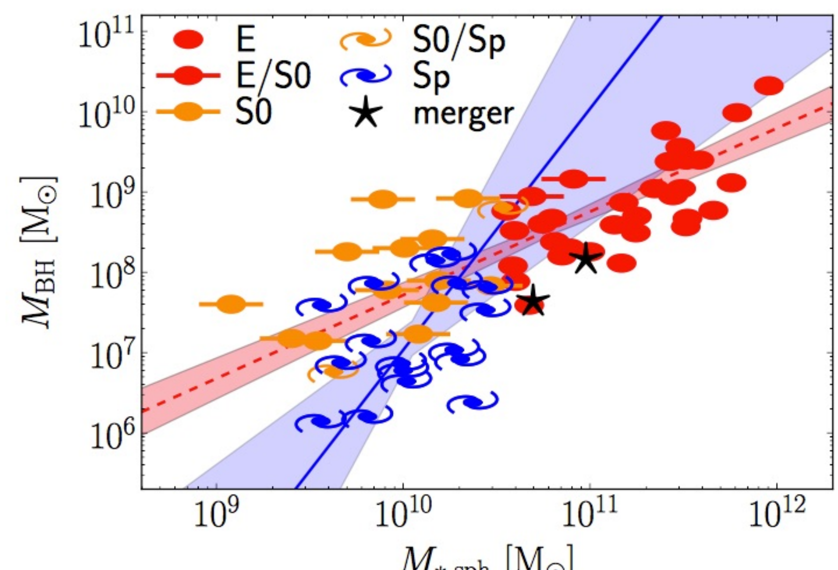

van den Bosch et al. (2012)



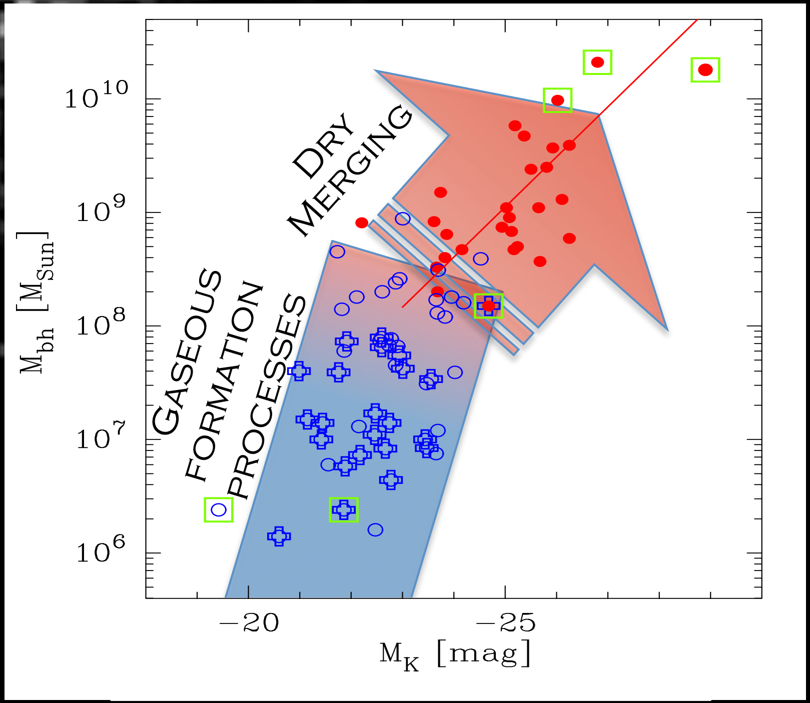

Kormendy & Ho (2013)

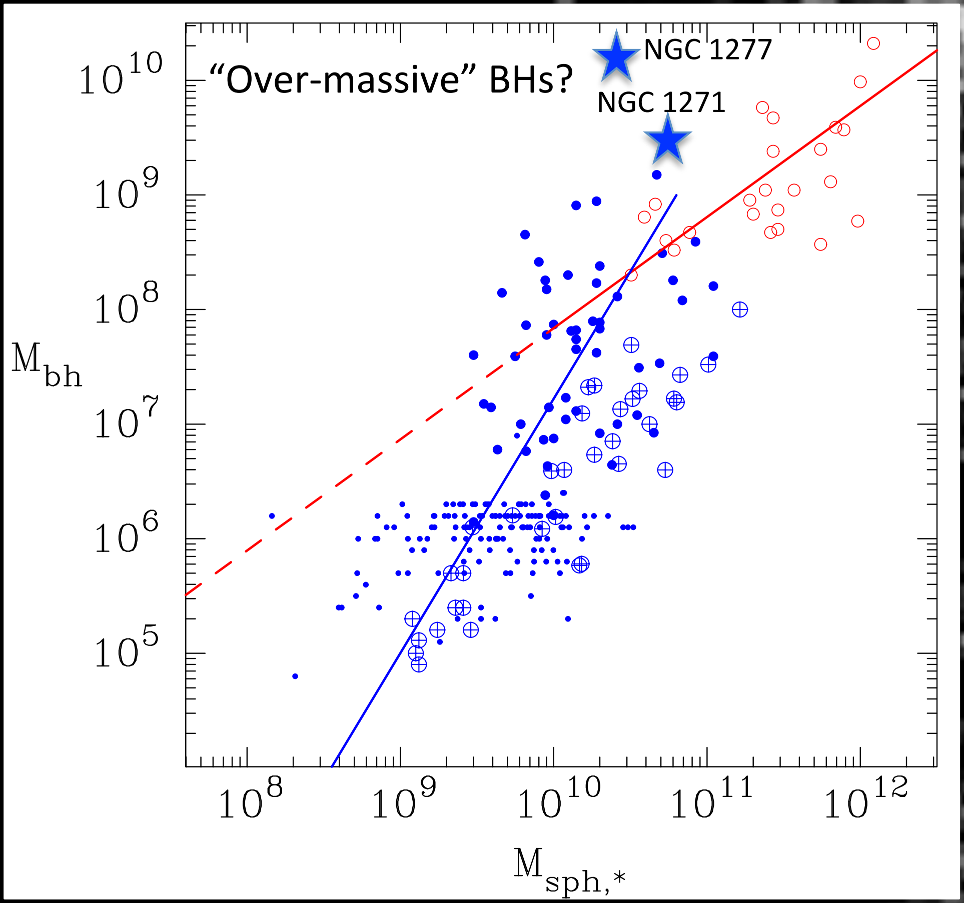



Savorgnan et al. (2016)



# AGN Feedback produces a quadratic relation




Graham (2012, ApJ, 746, 113)
Graham & Scott (2013; 2015)
Scott, Graham, Schombert (2013, ApJ, 768, 76)

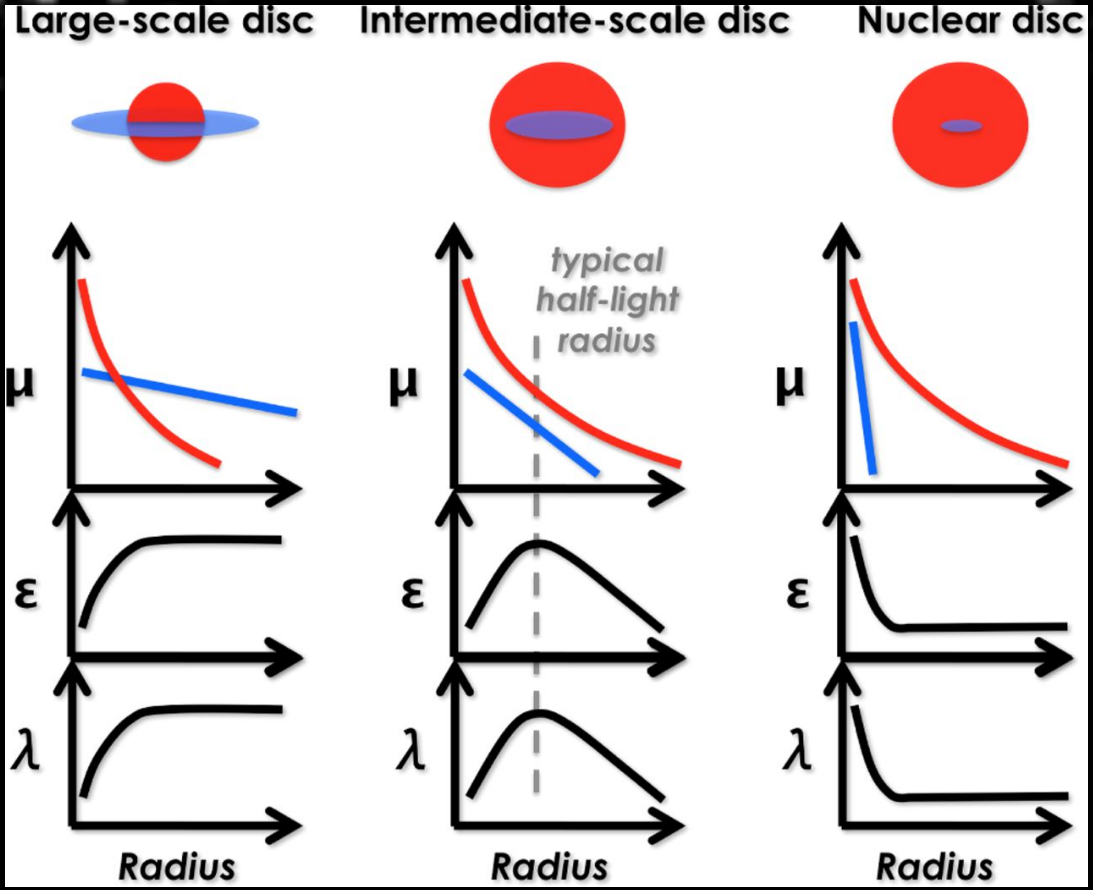
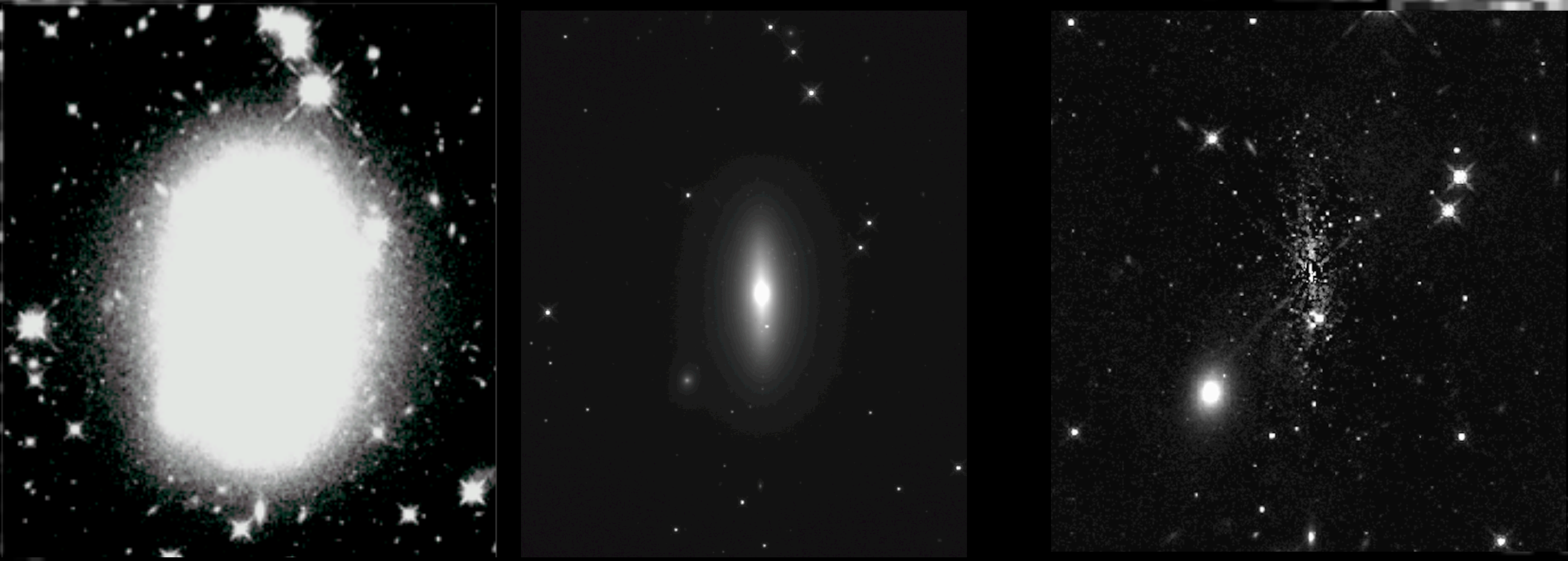


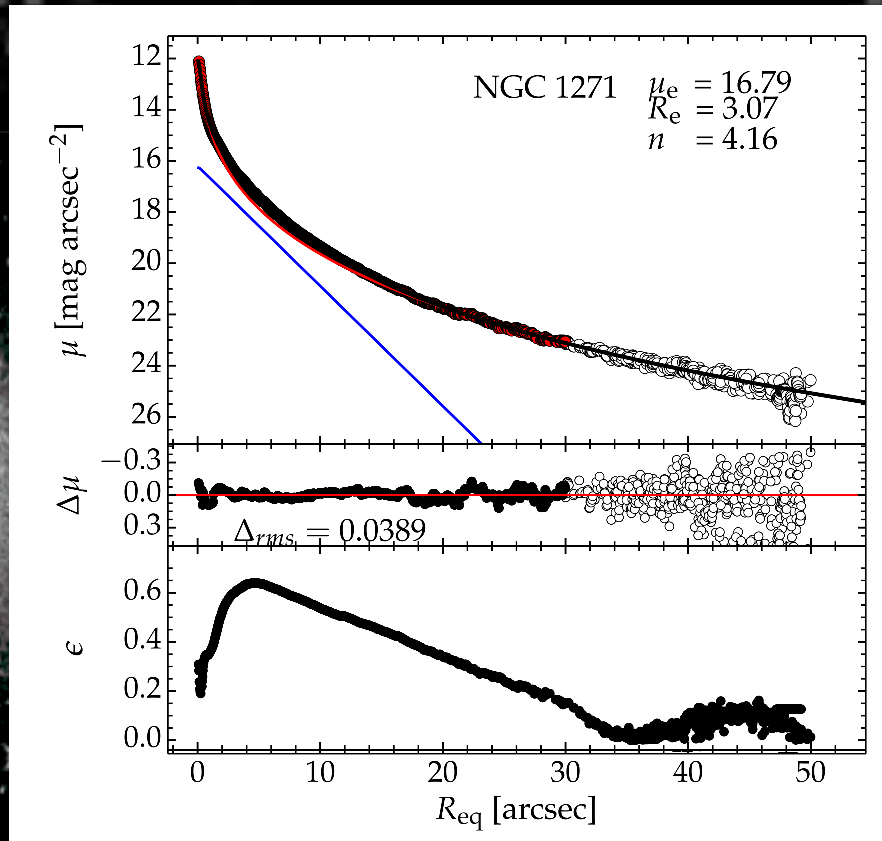

Figure from Savorgnan & Graham (2016, MNRAS)

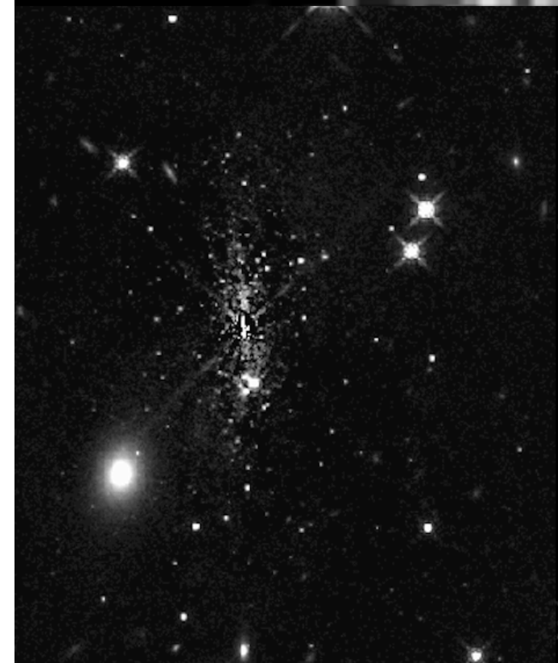
# The massive early-type galaxy NGC 1271



Graham, Ciambur, Savorgnan (2016, ApJ) for NGC 1271

Ciambur (2015, ApJ) for
https://github.com/BogdanCiambur/ISOFIT

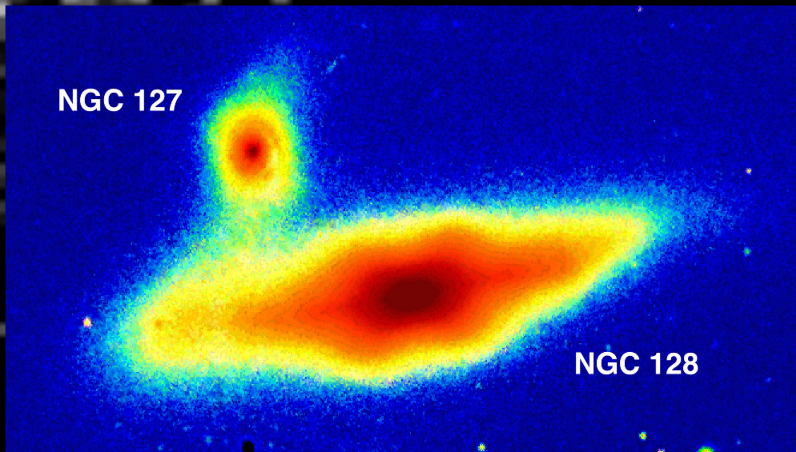


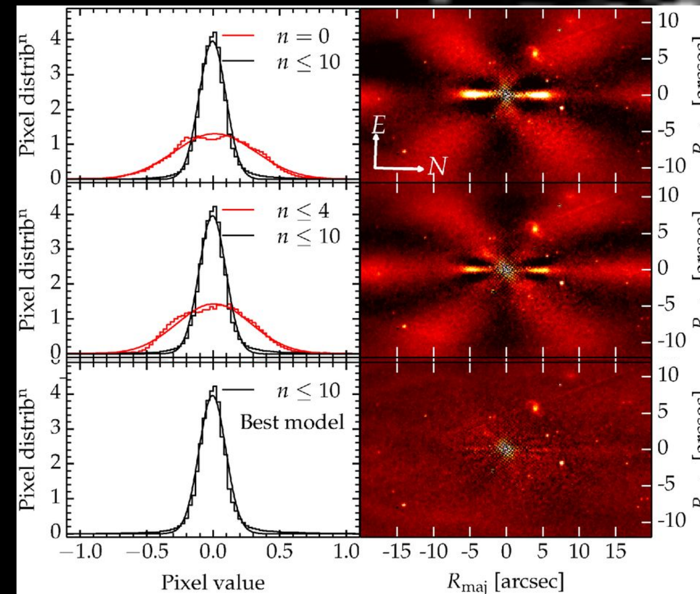



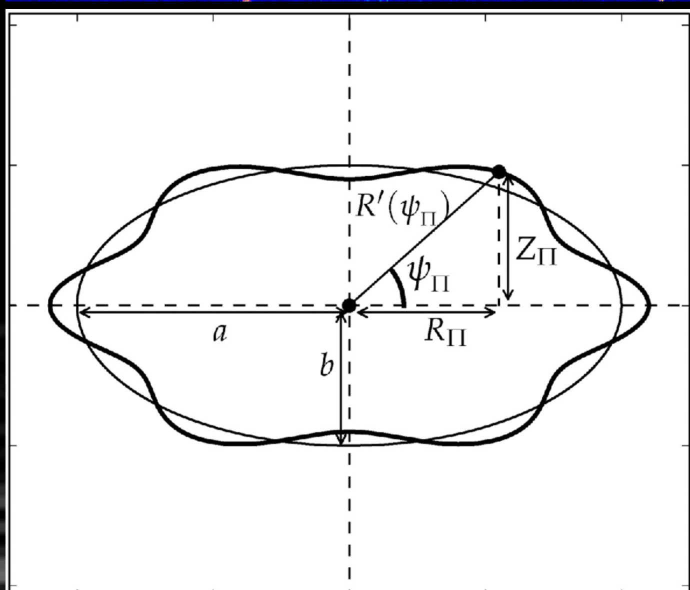
Graham, Ciambur, Savorgnan (2016, ApJ) for NGC 1271

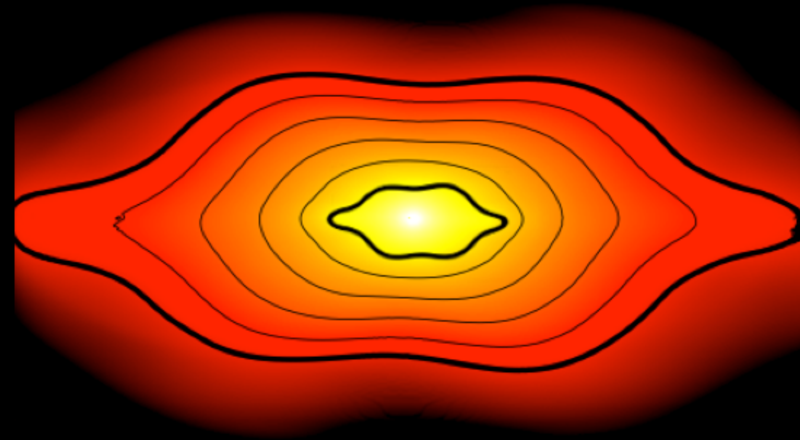
Ciambur (2016, arXiv:1607.08620)
https://github.com/BogdanCiambur/PROFILER

# ISOFIT (Ciambur 2015)
# In action quantifying peanuts (Ciambur & Graham 2016)

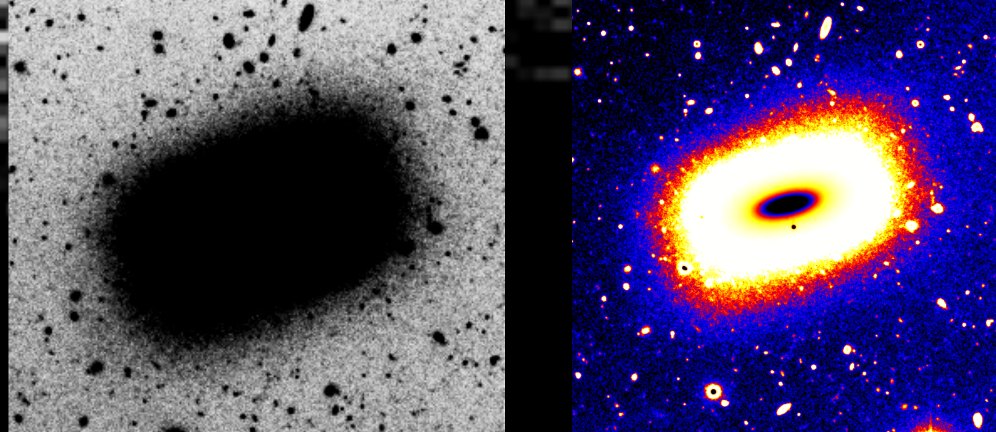


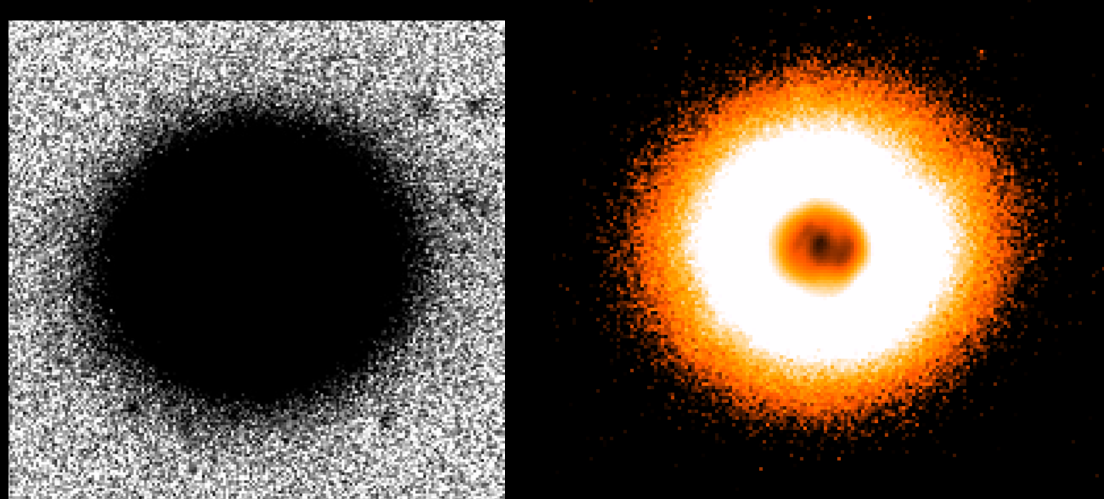



NGC 128: Nested double peanut-shaped bulge structure

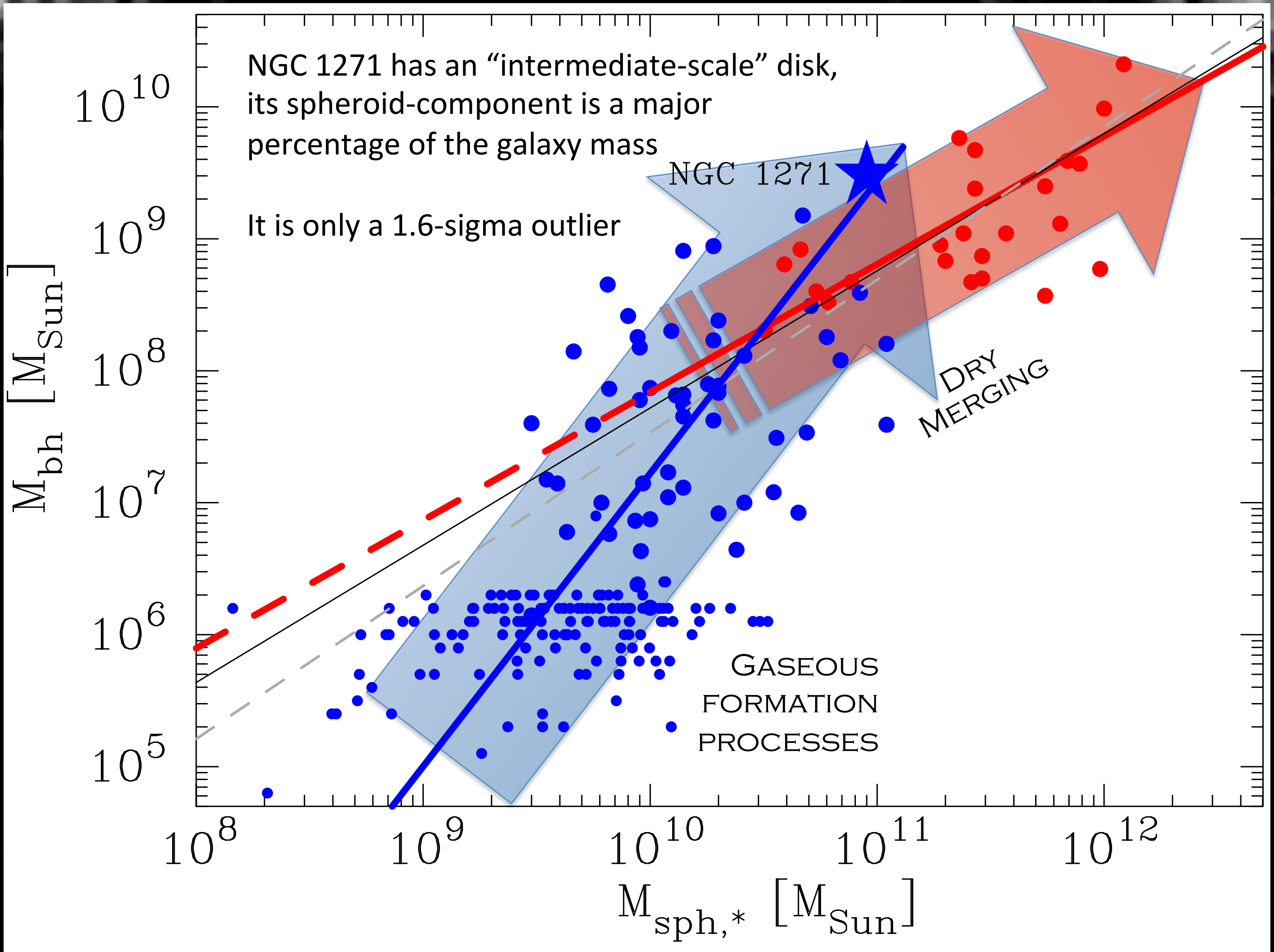


Dwarf early-type galaxies can also have intermediate-scale discs



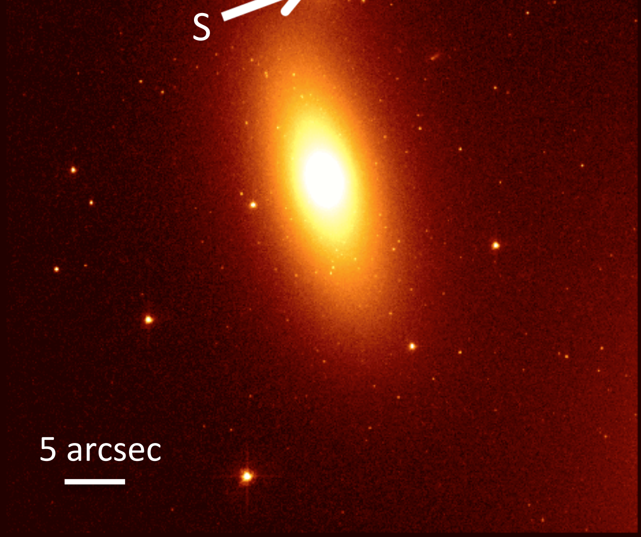
An extremely isolated dwarf ETG with inner disk. Watch for paper with A.Graham, S.Penny, J.Janz et al.

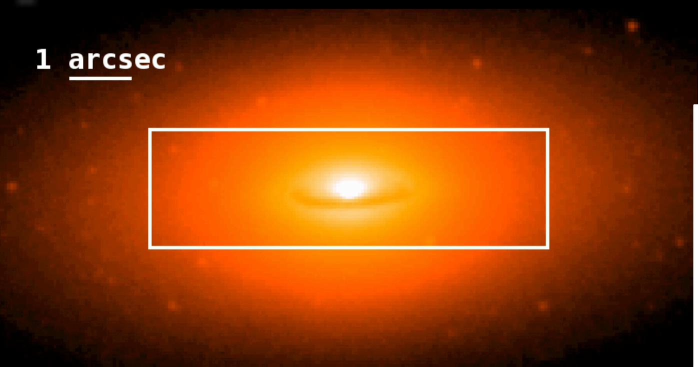
Disk structure not (always) a signature of a harassed spiral gal.

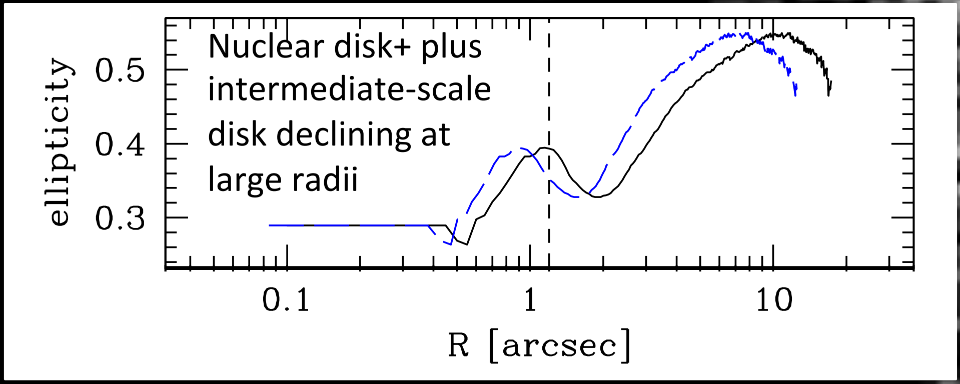


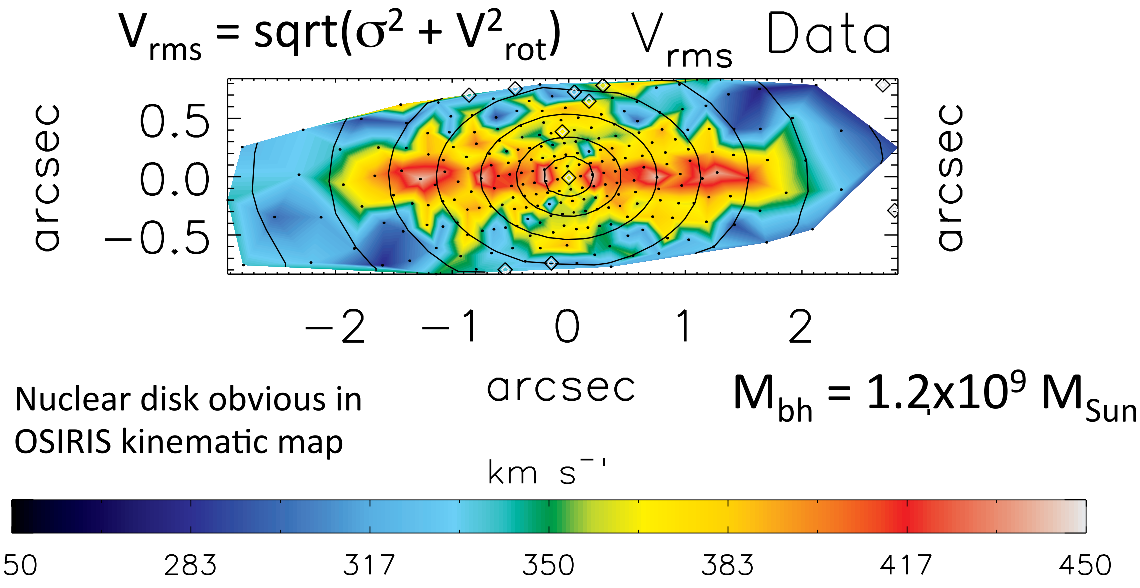
NGC 1271 has an "intermediate-scale" disk,
its spheroid-component is a major
percentage of the galaxy mass
It is only a 1.6-sigma outlier
NGC 1271
Dry
Merging
Gaseous
formation
processes
$M_{bh}$ [$M_{Sun}$]
$10^{10}$
$10^9$
$10^8$
$10^7$
$10^6$
$10^5$
$10^8$
$10^9$
$10^{10}$
$10^{11}$
$10^{12}$
$M_{sph,*}$ [$M_{Sun}$]

# The massive galaxy NGC 1277



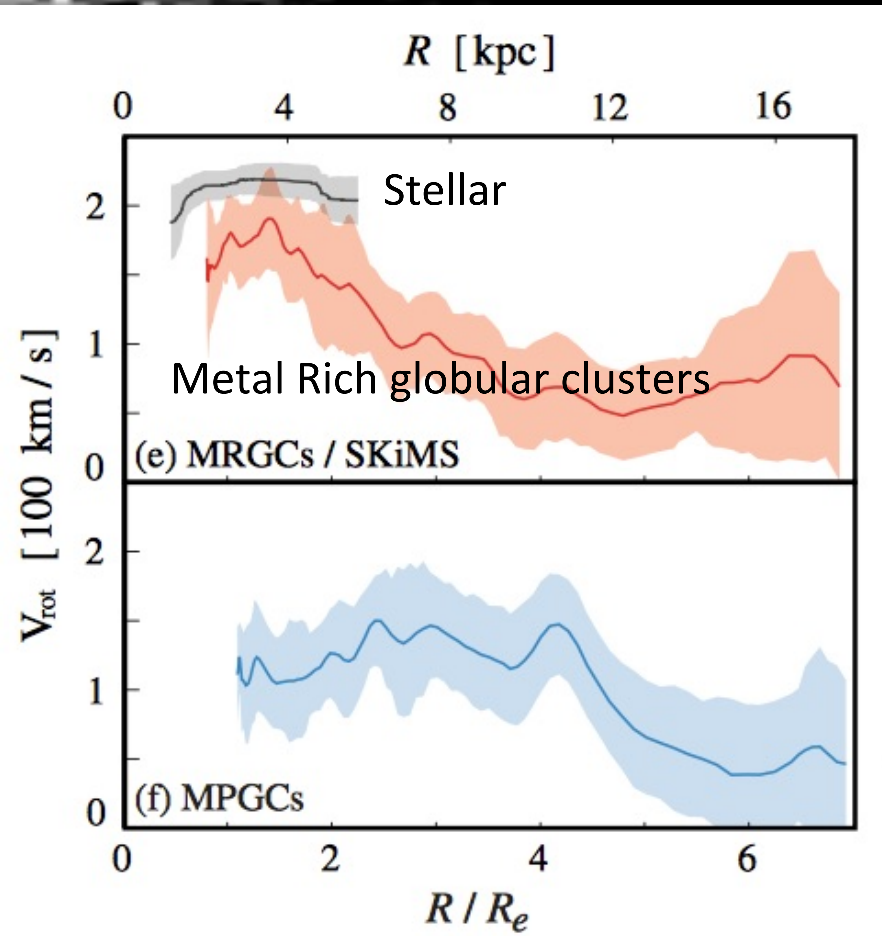



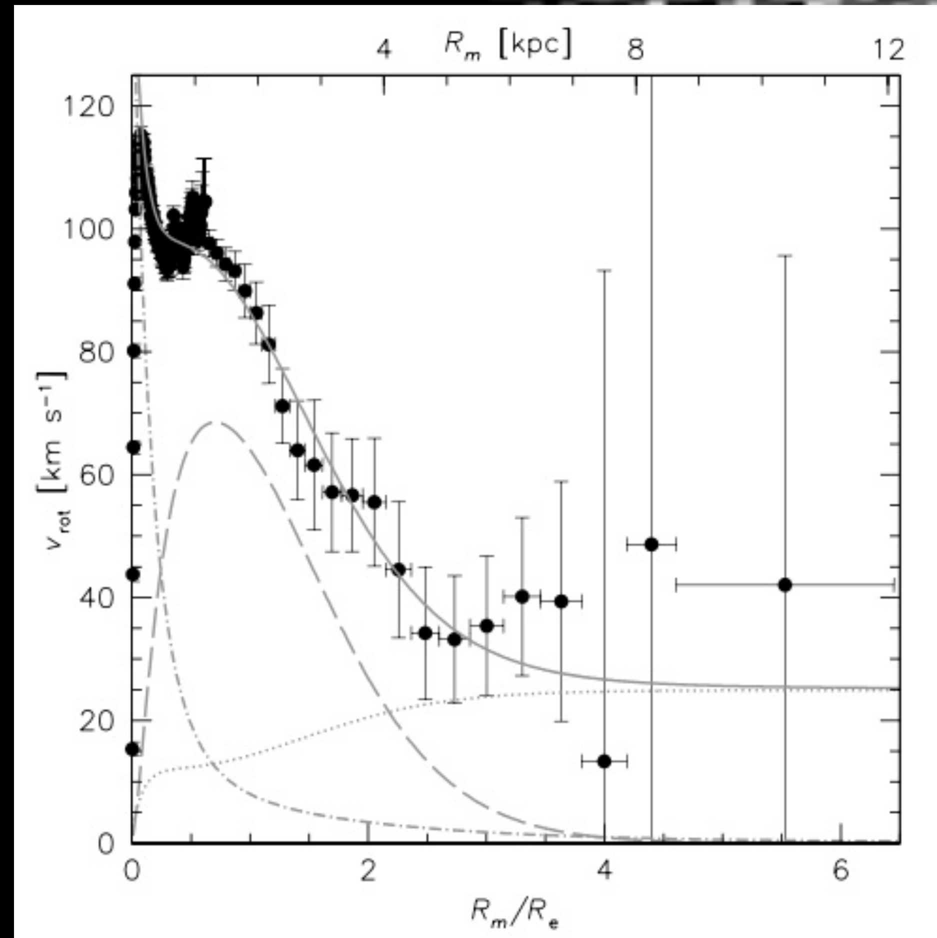

Nuclear disk obvious in OSIRIS kinematic map

$M_{bh} = 1.2\mathrm{x}10^9 M_{Sun}$

Graham et al. (2016, incl. Nic Scott)

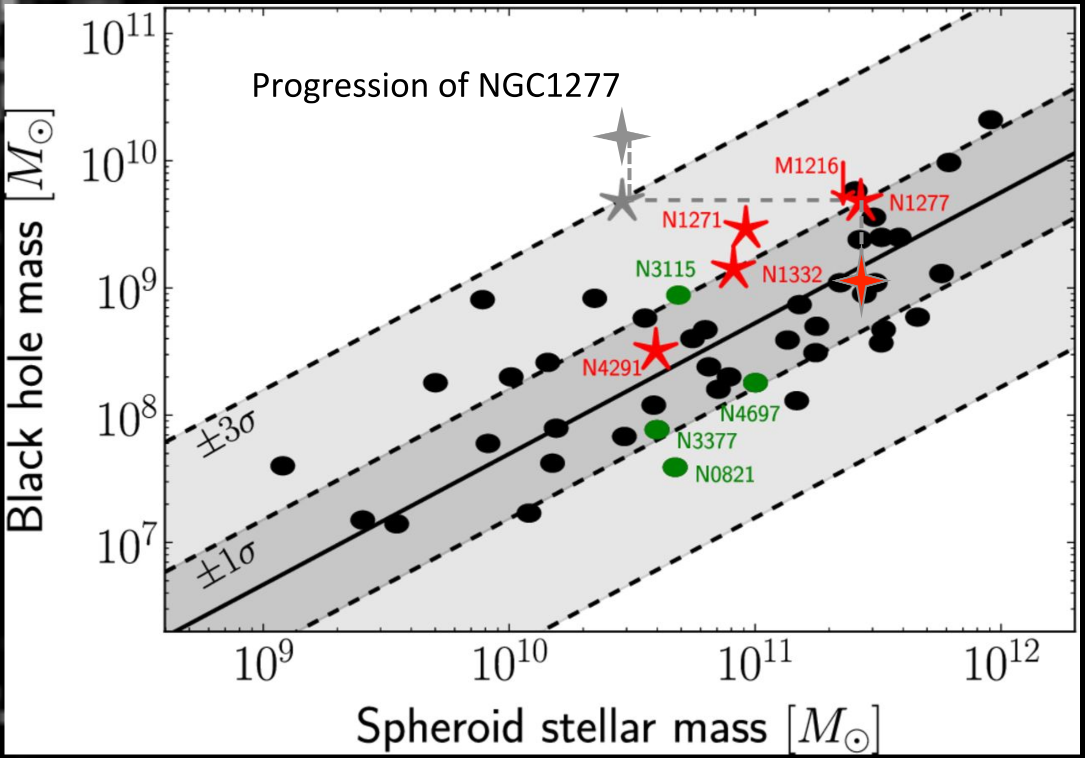
# Intermediate-scale disks
# Fast rotating inner, slow rotating outer




Left: NGC 3115, Arnold et al. (2011, ApJ, 736, L26)
Right: NGC 3377, Arnold et al. (2014, ApJ, 791, 80)

# Early-type galaxies
# No strong evidence for over-massive BHs

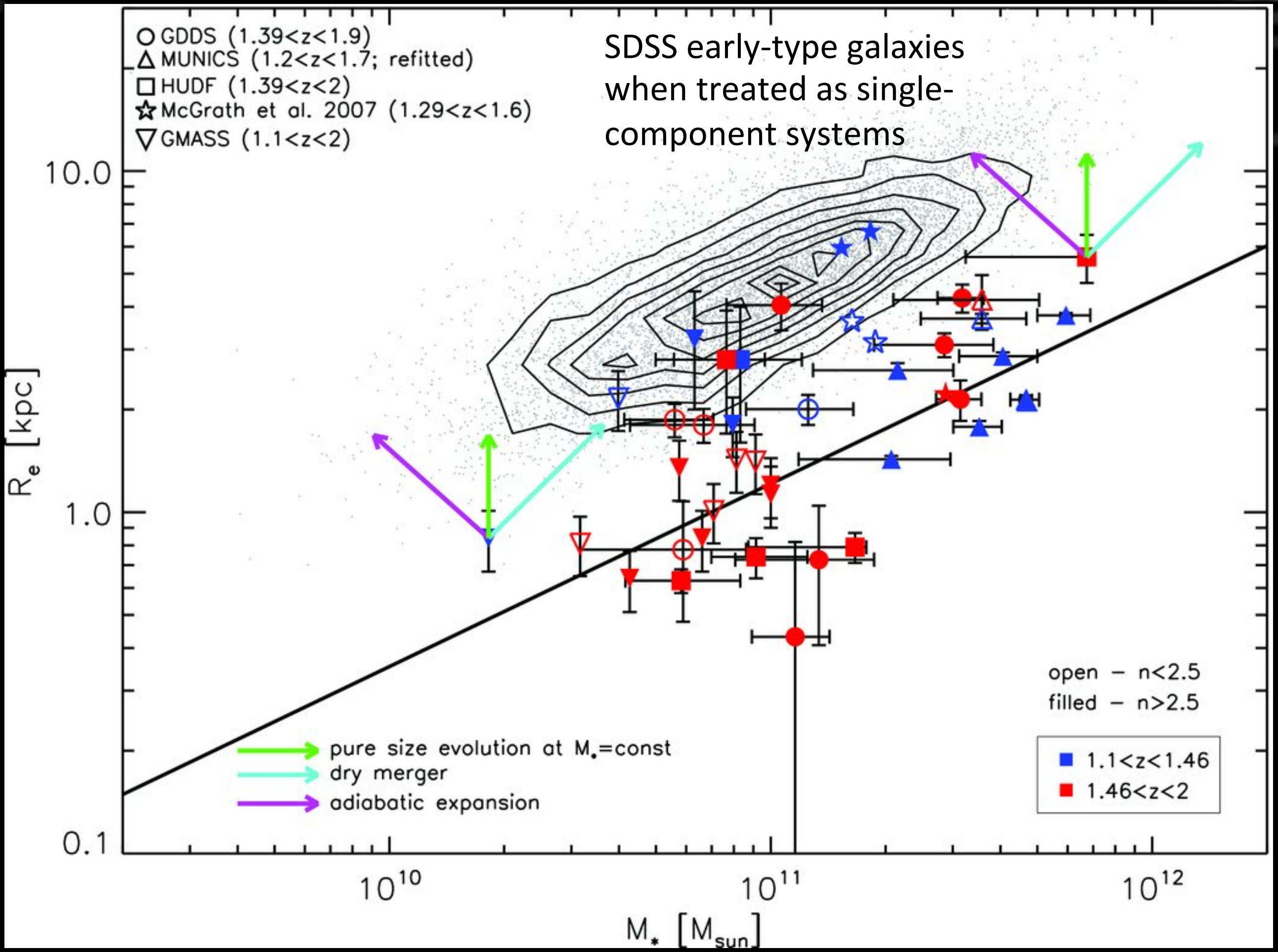



Savorgnan & Graham (2016, MNRAS)

For NGC 1277
See Graham et al. (2016) for a detailed galaxy decomposition and a BH mass derivation via AO-assisted Keck/OSIRIS data.

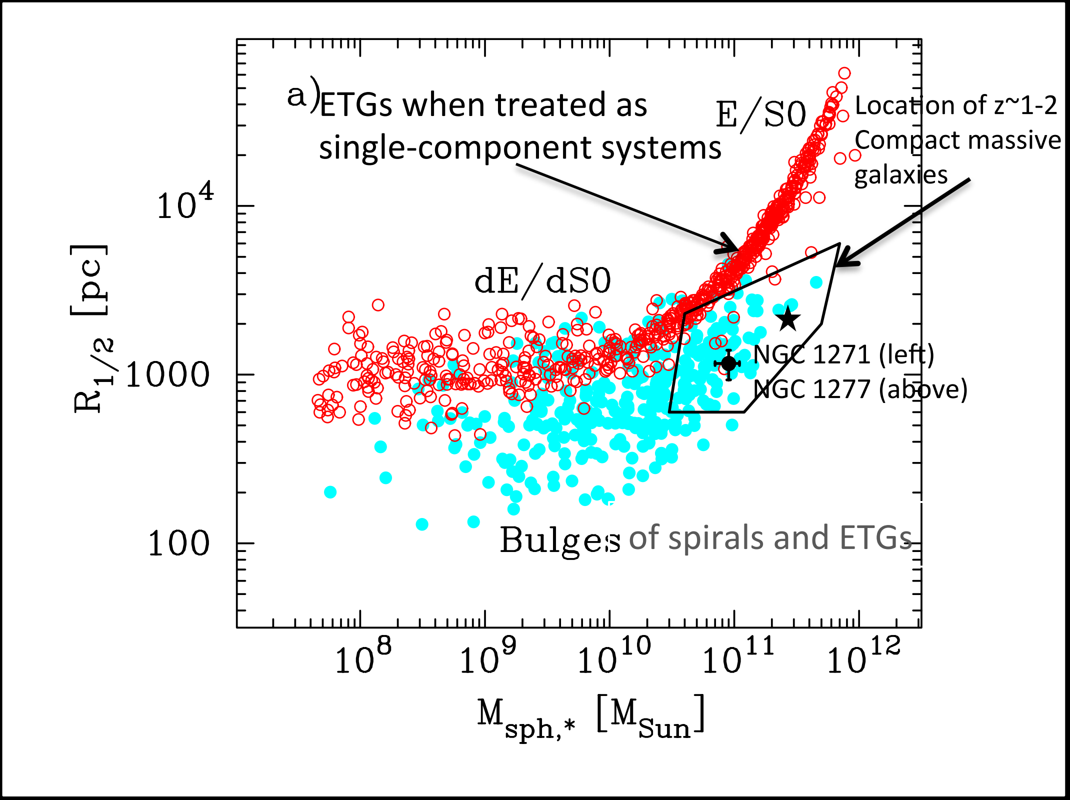
See also Emsellem et al. (2013), and Walsh et al. (2016) for BH mass derivation via AO-assisted Gemini/NIFS data.

# Compact massive galaxies



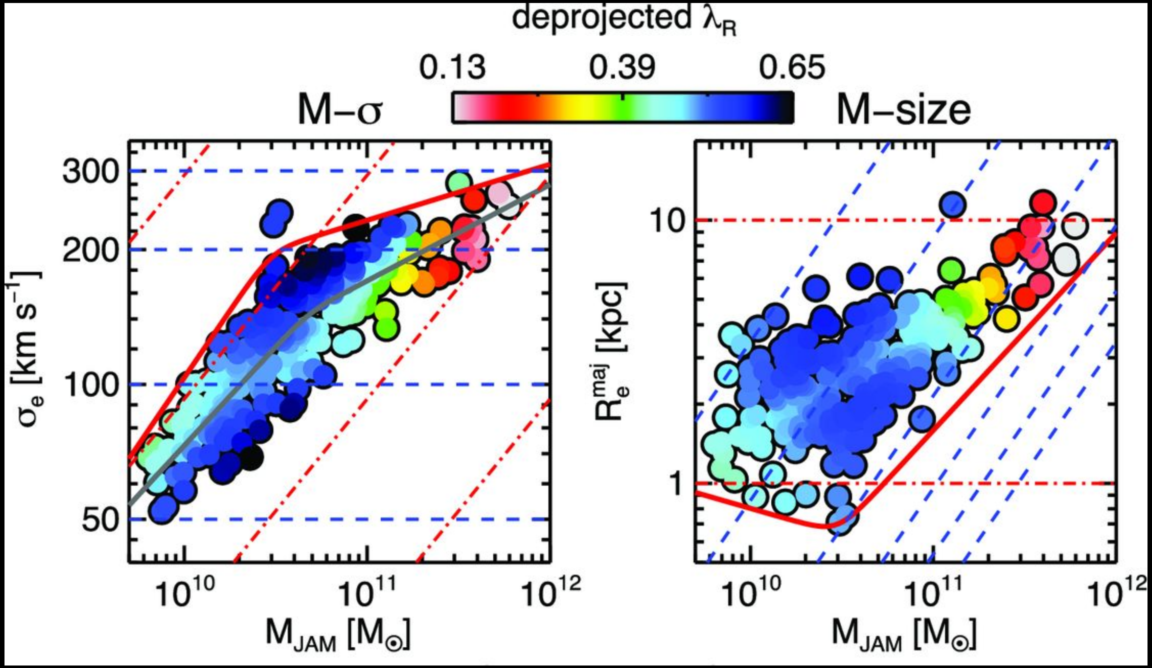

Damjanov et al. (2009)

# Size-mass and density-mass diagram (Graham arXiv:1108.0997)




400+ disk galaxy bulges (in cyan) from K-band bulge/disk decompositions (see Graham & Worley 2008)

Most early-type galaxies are "fast rotators" containing disks. They require a b/d/etc. decomposition of their light.

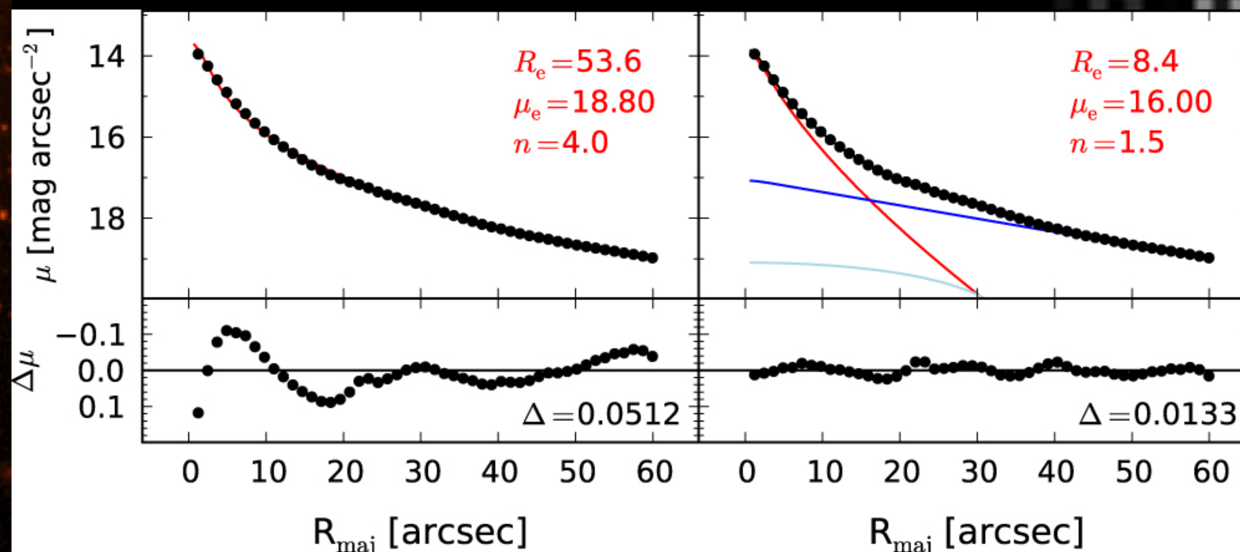



Cappellari et al. (2013, MNRAS, 432, 1862)
See also Krajnovic et al. (2013, 432, 1768)
and Nic Scott et al. (2014, MNRAS, 441, 274).

# Example face-on S0 galaxy

Sandage & Tammann (1981)
Laurikainen et al. (2010). Bulge much smaller than galaxy…


NGC 5419 (Spitzer 3.6 μm)




Radial surface brightness profile

Images from Graham, Dullo & Savorgnan (2015)

# Compact massive galaxies

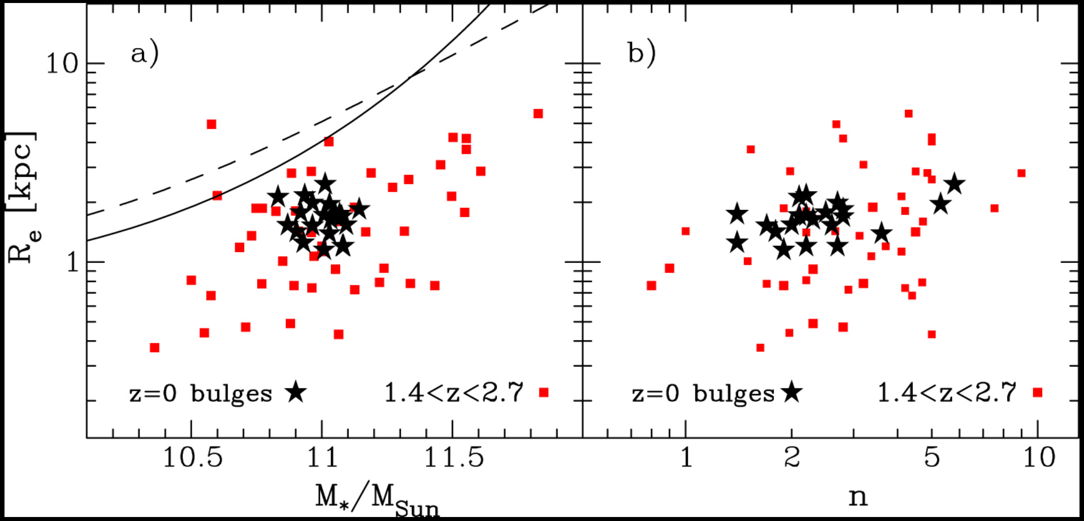



Figure and black points from Graham, Dullo & Savorgnan (2015). Local early-type galaxies now modelled as bulge/disc/ etc. systems.
Red points from Damjanov et al. (2011).

Disk growth may explain their transformation from z~1-2 to z=0.

Abundance of z=0 compact massive spheroids (in ETGs) since confirmed by de la Rosa et al. (2016).

# Conclusions

- Galaxies are not single-component systems.
- It is important to model the galaxy light carefully and perform reliable bulge/disk/bar/etc. decompositions, especially for certain "scaling relations".
- Little evidence for spheroids with over-massive black holes at z=0.
- The compact massive spheroids observed at high-z are not rare at z=0, they simply have large-scale disks around them.
- Weak disk structure and rotation need not be evidence of disk stripping and galaxy harassment, but rather past gas accretion and disk building.

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SUPPLEMENT SERIES

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# Extended stellar kinematics of elli cluster*,**

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**Abstract.** We present extended stellar kinematics for a sample of elliptical galaxies in the Fornax cluster. Out of the 13 galaxies presented here, five (FCC 119, FCC 136, NGC 1373, NGC 1428, FCC 335) have no previously published kinematical data. Major-axis velocity dispersion profiles (VDPs) and rotation curves (RCs) are given for 12 of the galaxies. A major feature of this data is the spatial extension: for 8 galaxies the data extends beyond 1 $R_e$, and for 5 it extends beyond 2 $R_e$. Compared to the previously available data, this corresponds to an increase in spatial coverage by a factor from 1 to 5. The present sample represents 86% of the ellipticals in Fornax brighter than $B_T = 15$ mag.

Five of the ellipticals in the sample turn out to be rotationally-supported systems, having positive rotation parameter $\log(\frac{V}{\sigma})^*$. One of these five, and another 3 galaxies from the remaining sample, display evidence for bar-like kinematics.

The data indicate that the true number of "dynamically hot" stellar systems, is much lower than previously thought: of the Es in the present sample only 1/4 are confirmed as "pressure-supported" systems.

The data reveal a host of individual peculiarities, like: wiggles, strong gradients, and asymmetries in the rotation curve and/or in the velocity dispersion profile, thus showing that the presence of kinematically distinct components and/or triaxiality is a common characteristic of this class of object.

Graham, Colless, Busarello, Zaggia & Longo (1998)