Host Galaxies of Low-mass Black Holes

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Jenny E. Greene, Luis C. Ho, Aaron J. Barth, Ting Xiao

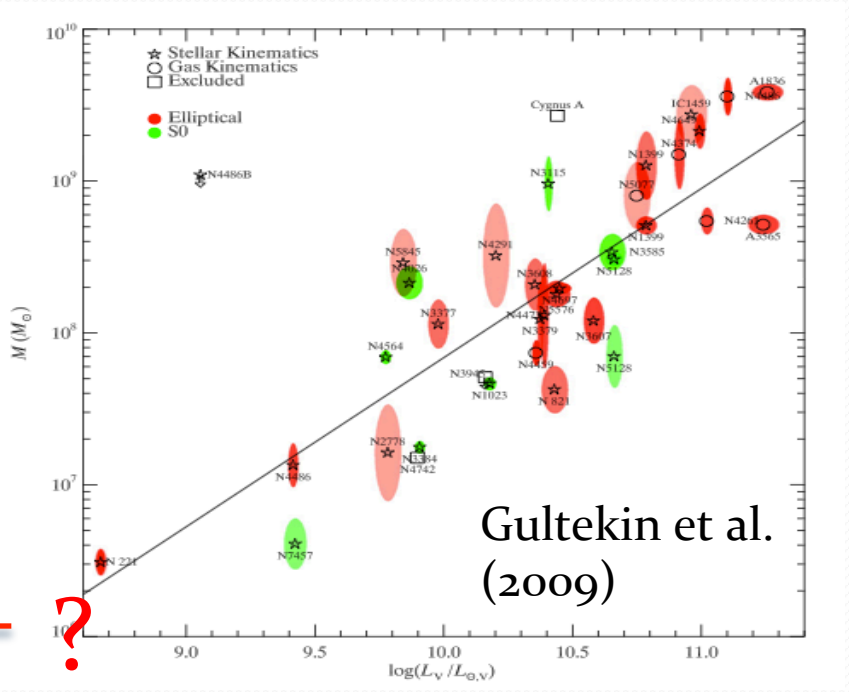
Jiang et al. 2011a, arXiv:1107.4105
Jiang et al. 2011b, ApJL, 737, L45

Outline

- Motivation: Low-mass BHs
- The Sample
- Image Decomposition
- Morphology Properties of the Sample
- Fundamental Plane Relation of Our Sample
  - Faber-Jackson Relation
- M – L Relation for Our Sample
  - Black Hole Mass and Bulge Dynamical Mass Relation
- Conclusion

Questions about Low-mass BHs

- Black holes with mass ≤ 10^6 solar mass.
- Relations between black hole mass and bulge properties for late-type spiral galaxies (Greene et al. 2008):
  - Are the scaling relations still the same for the low mass BHs?
  - What do the bulges of host galaxies look like for low-mass BHs?



?

Spiral galaxies with no SMBH:M33 & NGC205 (Gebhardt et al. 2001; Valluri et al. 2005)

M33

NGC 205

BHs with no bulge:
NGC4395 & POX52
(Filippenko & Ho 2003;
Barth et al. 2004)

NGC 4395

The Importance of Low-mass BHs

- Help us to understand the evolution of the BHs and host galaxies
- The origin of the good scaling relations between black hole mass and bulge properties
- Constrain the models of BH seed formation mechanism (e.g., Volonteri & Natarajan 2009)

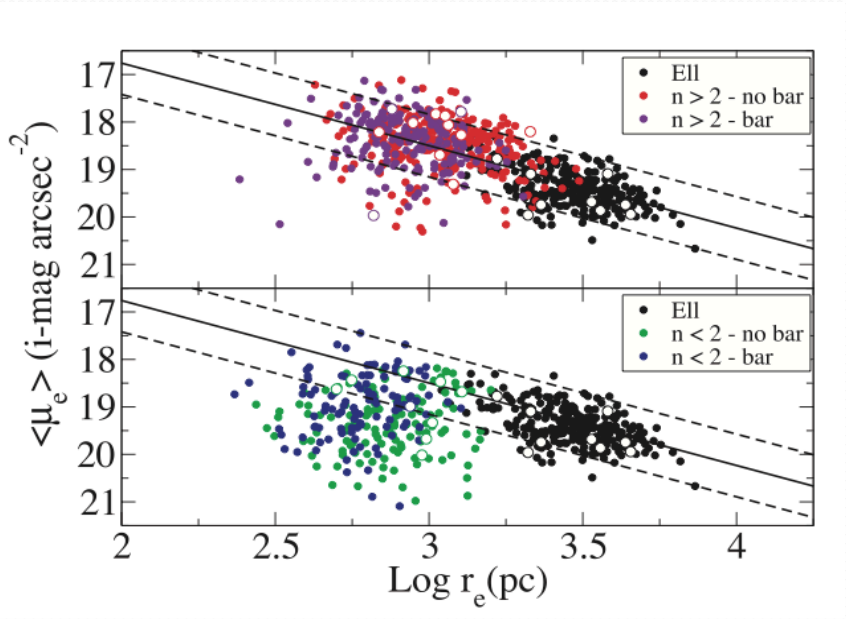
Host galaxies of low-mass BHs

- We focus on bulge properties of the host galaxies for low mass BHs.
  - Classical bulge vs. Pseudo-bulge (Kormendy & Kennicutt, 2004)
- Once we know the bulge properties, we can study the scaling relations between BH mass and bulge properties.

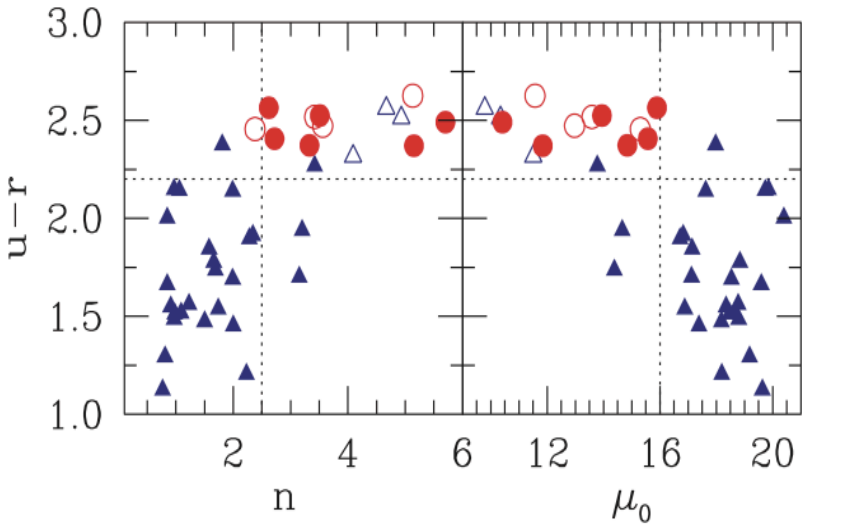
Pseudo-bulges Properties

Kormendy & Kennicutt 2004

- Flatter shape and Sérsic index n < 2
- Rotational support
- Have bar/spiral structure/ring
- Small B/T

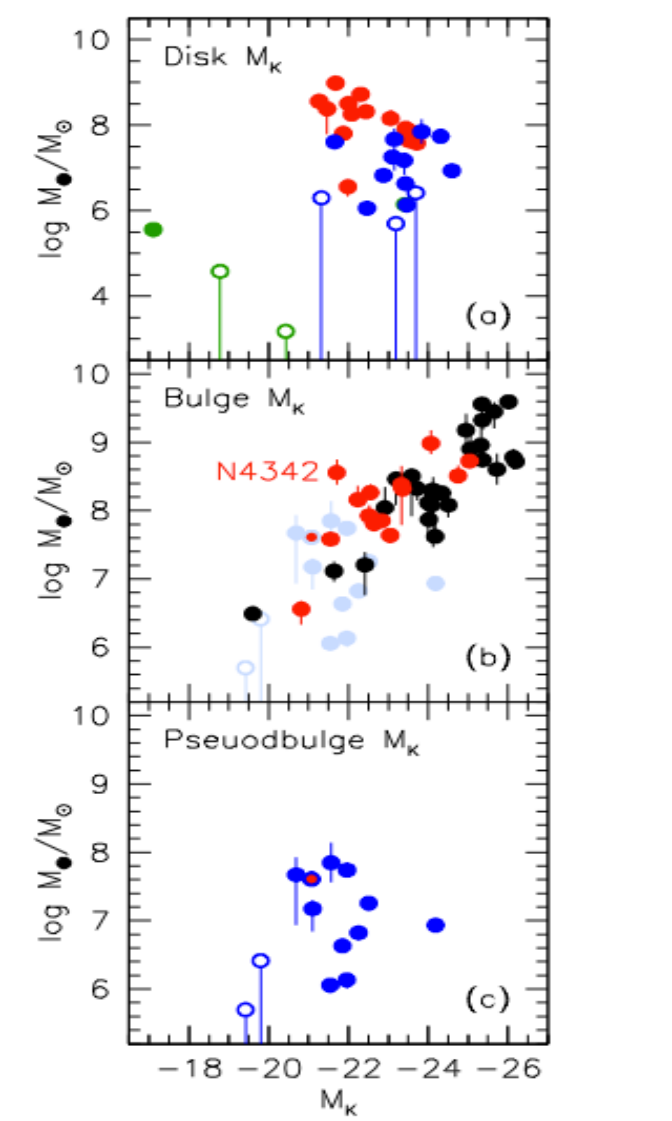


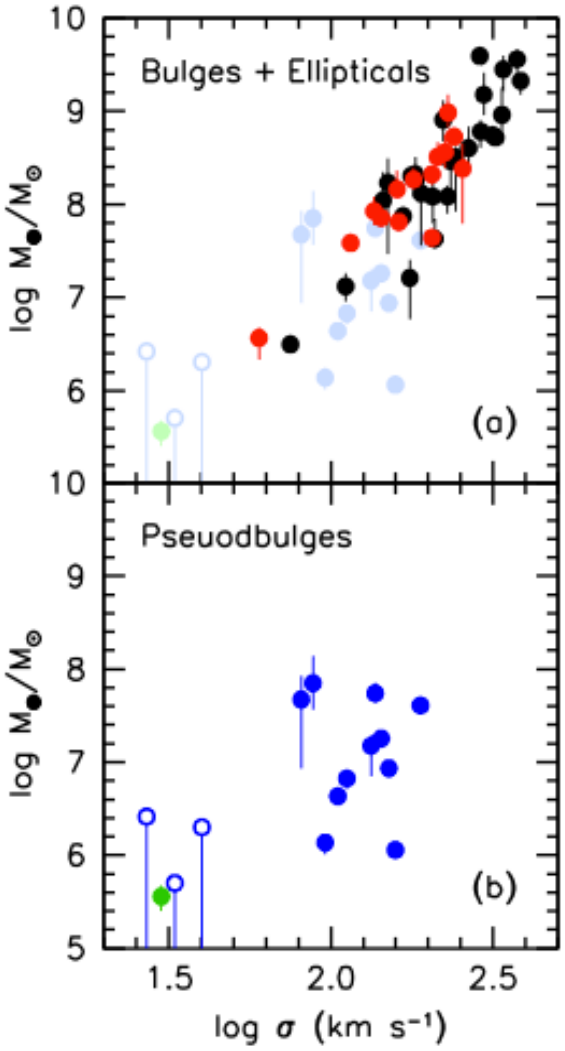
Gadotti 2009



Drory & Fisher 2007

The scaling relations





Kormendy et al. (2011)

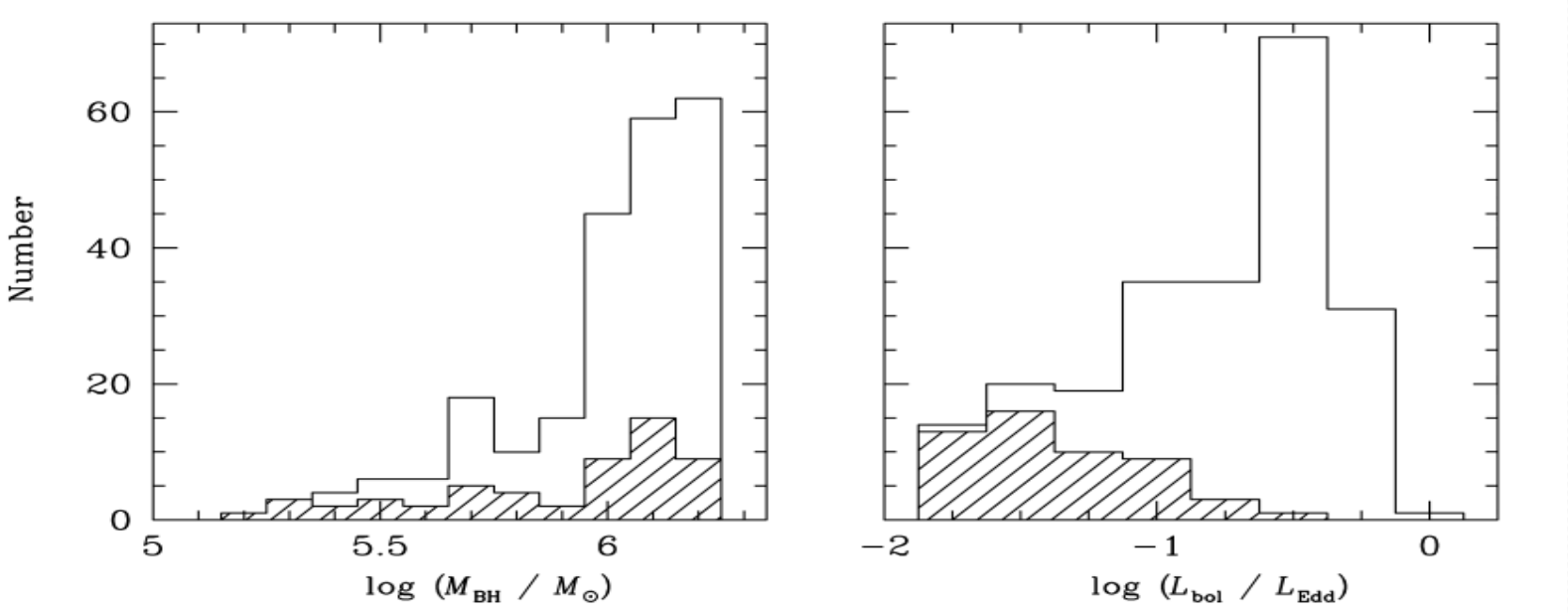
- What kind of bulges do low mass BHs have
- What do the scaling relations for low-mass BHs look like
- We need a larger sample.

The sample

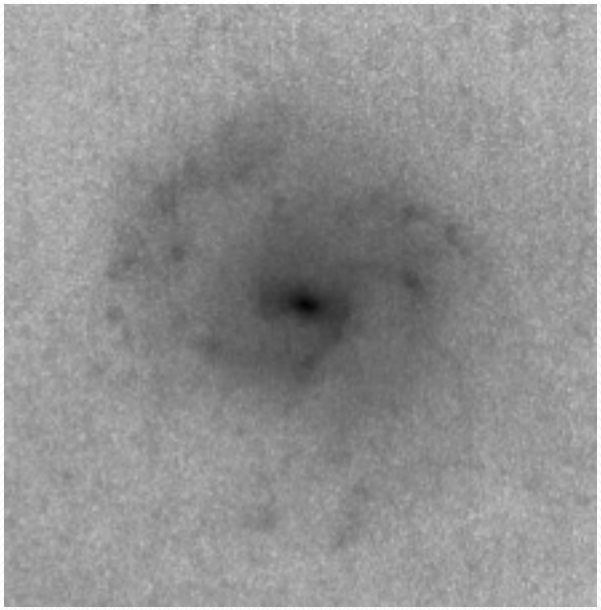
- Selected from SDSS4 with <z>=0.085 and maximum Z=0.35 (Greene & Ho 2007)
- BH mass is estimated based on empirical relation from reverberation mapping (e.g., Bentz et al. 2009)

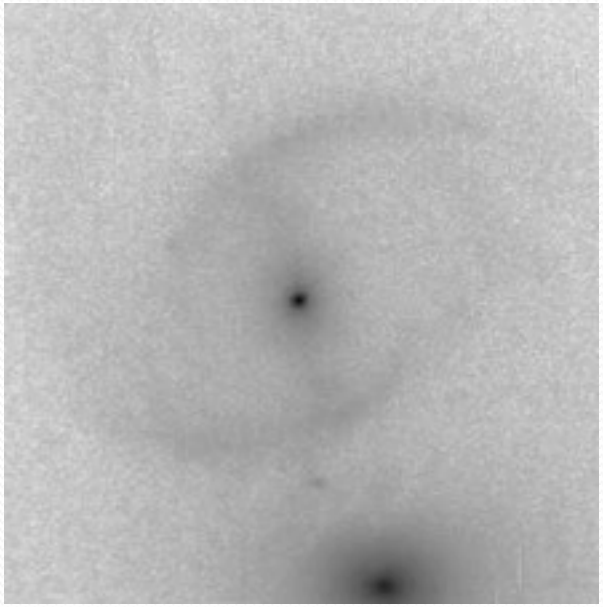
$$M_{BH} \quad 6\times10^{4} \sim 3\times10^{7}\ M_{\odot}.$$

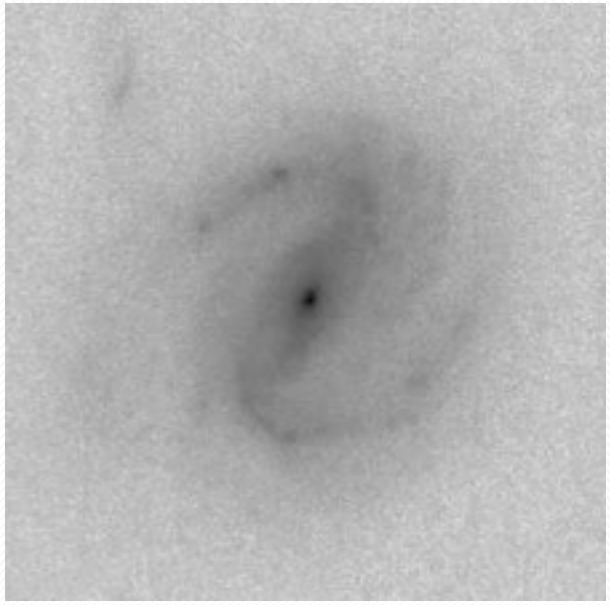
- We have HST I band (F814W) observations of 147 galaxies with WFPC2.

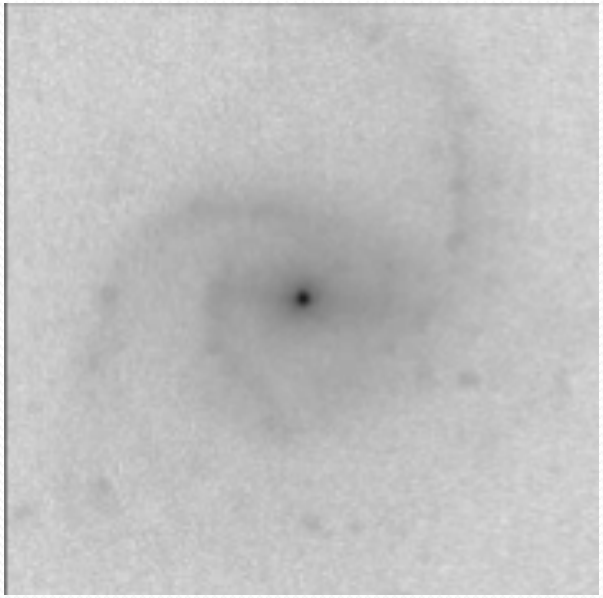


Examples:









GALFIT: Image decomposition

- 2D fitting with GALFIT (Peng et al. 2010) to decompose the galaxies to different components:

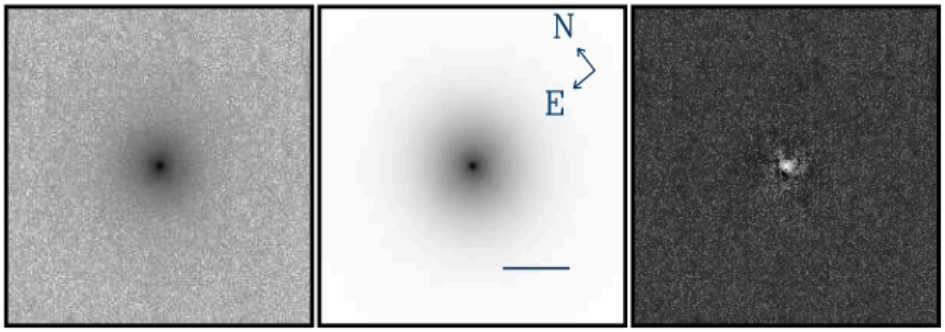
  AGN + bulge? + disk? + bar?

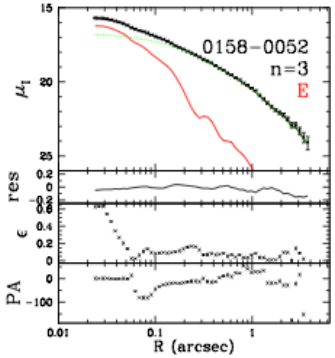
- Sérsic model:

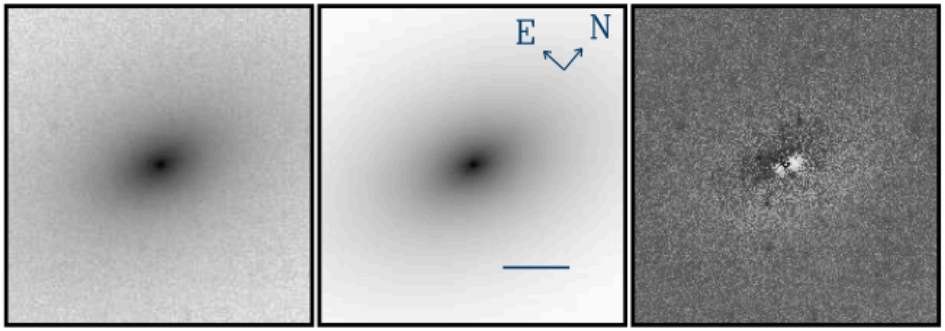
$$\Sigma(r) = \Sigma_e \exp\left\{-b_n\left[\left(\frac{r}{r_e}\right)^{1/n} - 1\right]\right\}$$

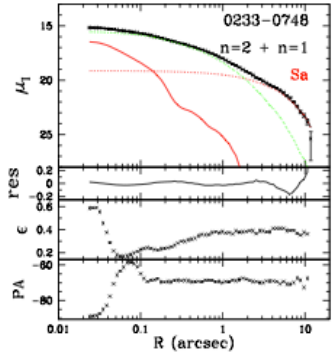
- Spiral arms or knots of star formation and other non-axisymmetric features are not fitted.

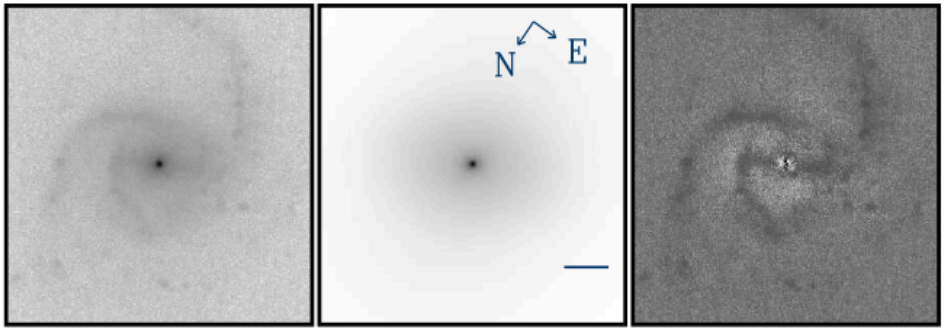
Fitting Examples:

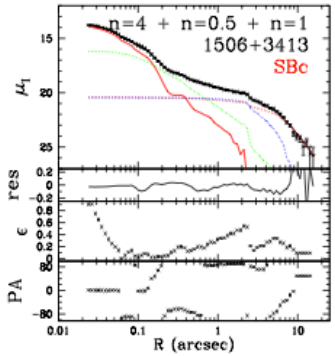




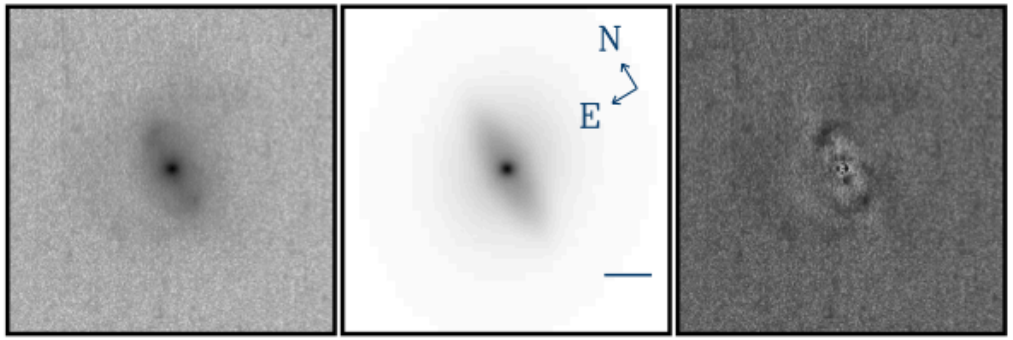


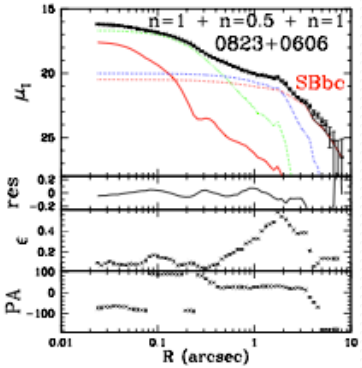


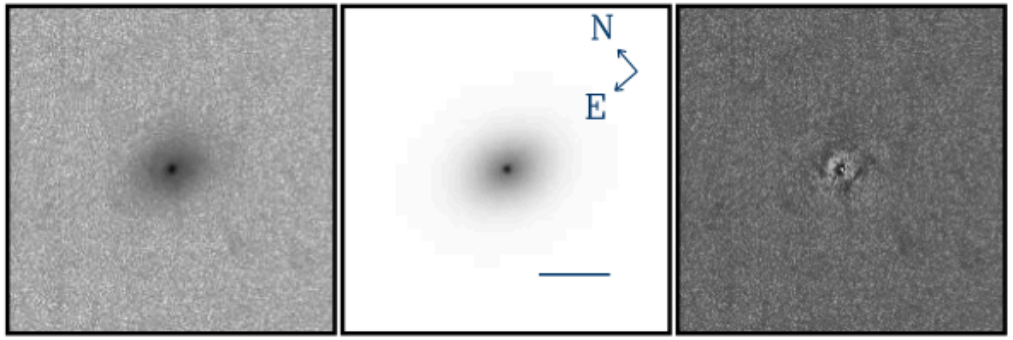


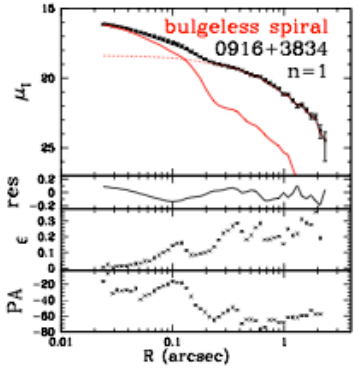


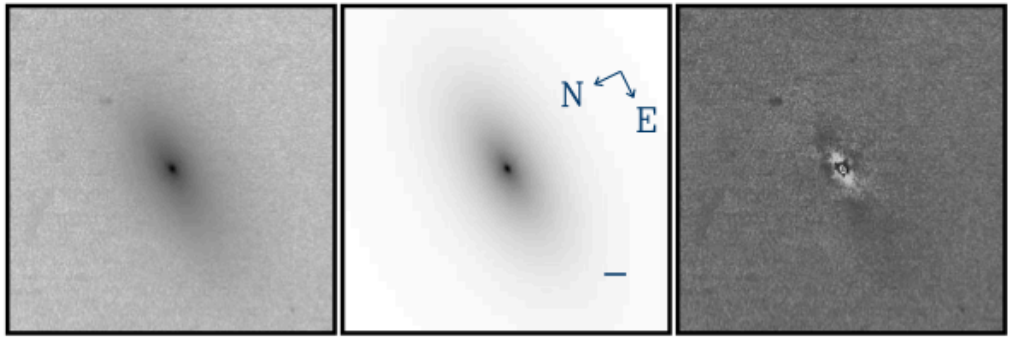
Fitting examples (II)

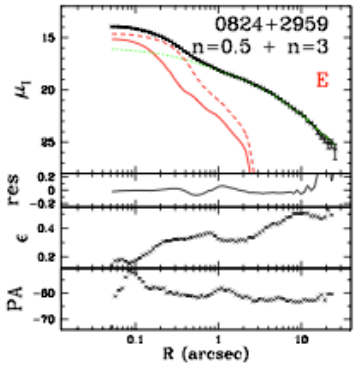










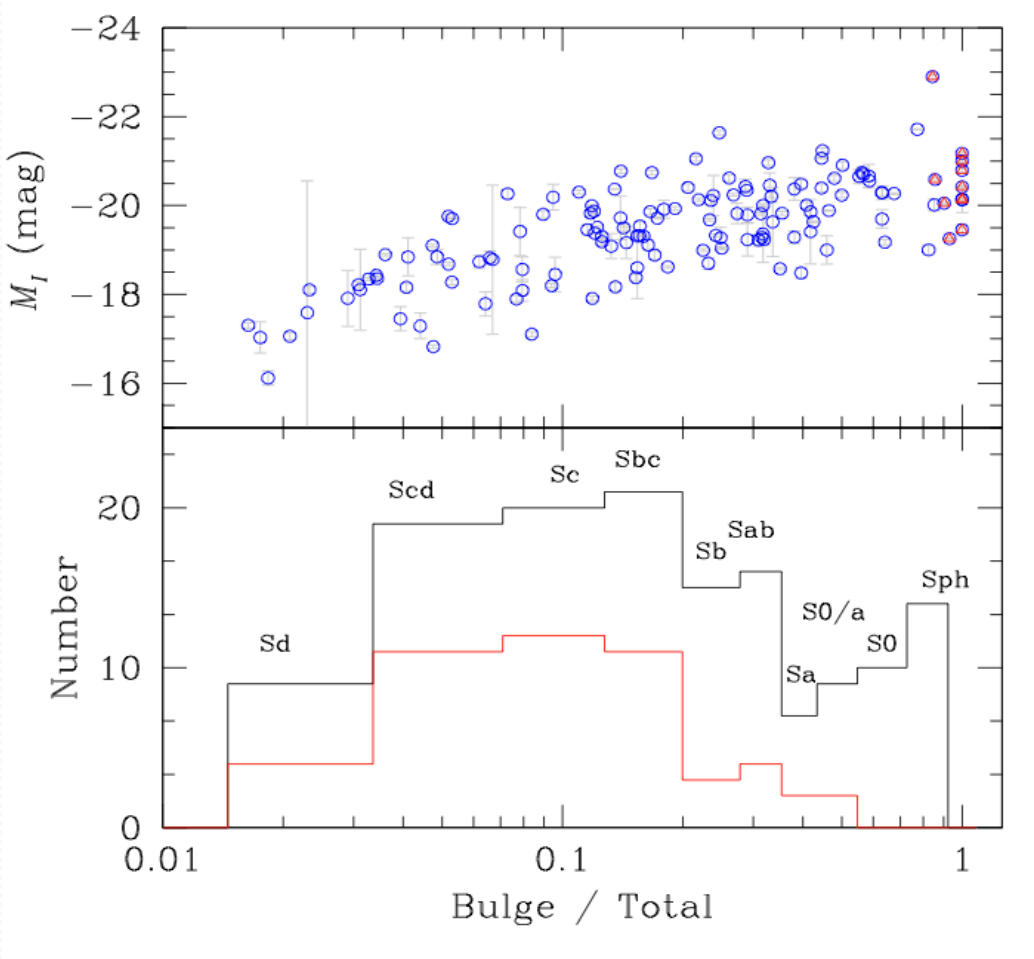


Morphology Properties

- 5% are consistent to be bulgeless galaxies.
- 93% of the galaxies have extended disks.
- 39% of disky galaxies have bars
- 75% have Sérsic index $n < 2$
- All galaxies satisfy the criterion for pseudobulge given by Gadotti (2009).

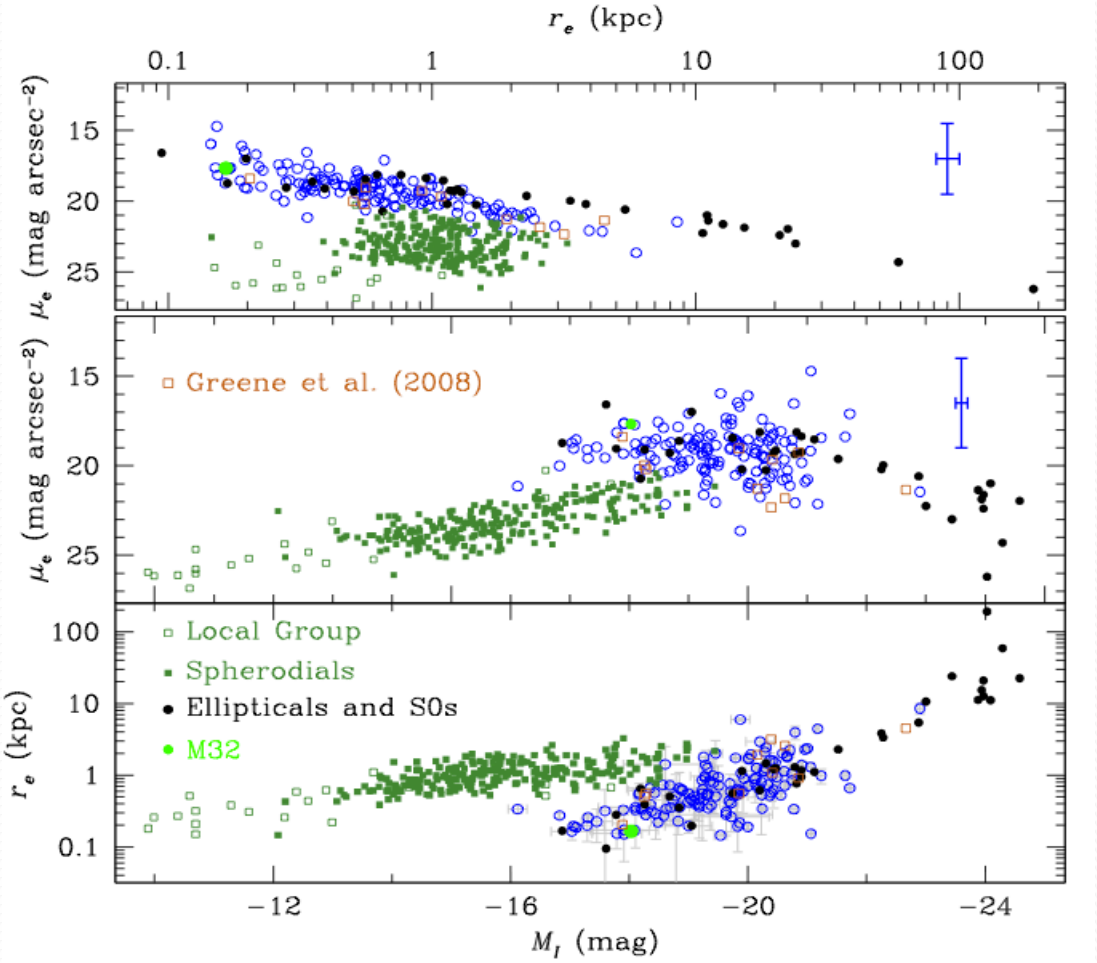
- For disky galaxies, median value of B/T is 0.16

Conclusion: most of the bulges in the host galaxies
of low-mass BHs have properties consistent with pseudobulges.



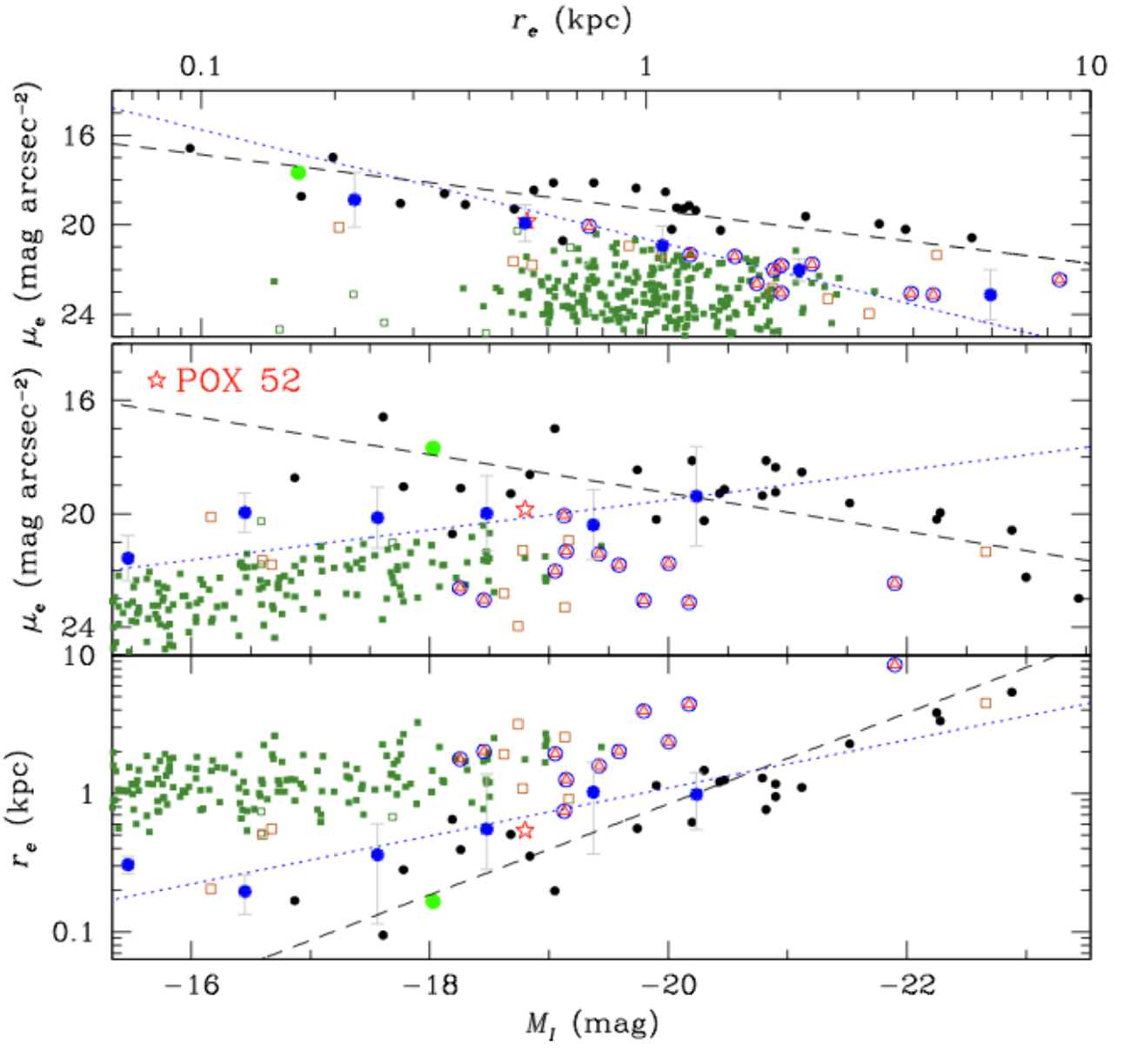
Fundamental Plane relations

- For our pseudobulges, we want to know where they are located in the Fundamental Plane compared with classical bulges.



Blue circles are our sample.

Fundamental Plane relations



Blue circles are our sample.

Location of our sample in the Fundamental Plane is also consistent with pseudo-bulges studied by others (e.g., Fisher & Drory 2010, Gadotti 2009).

Faber-Jackson Relation

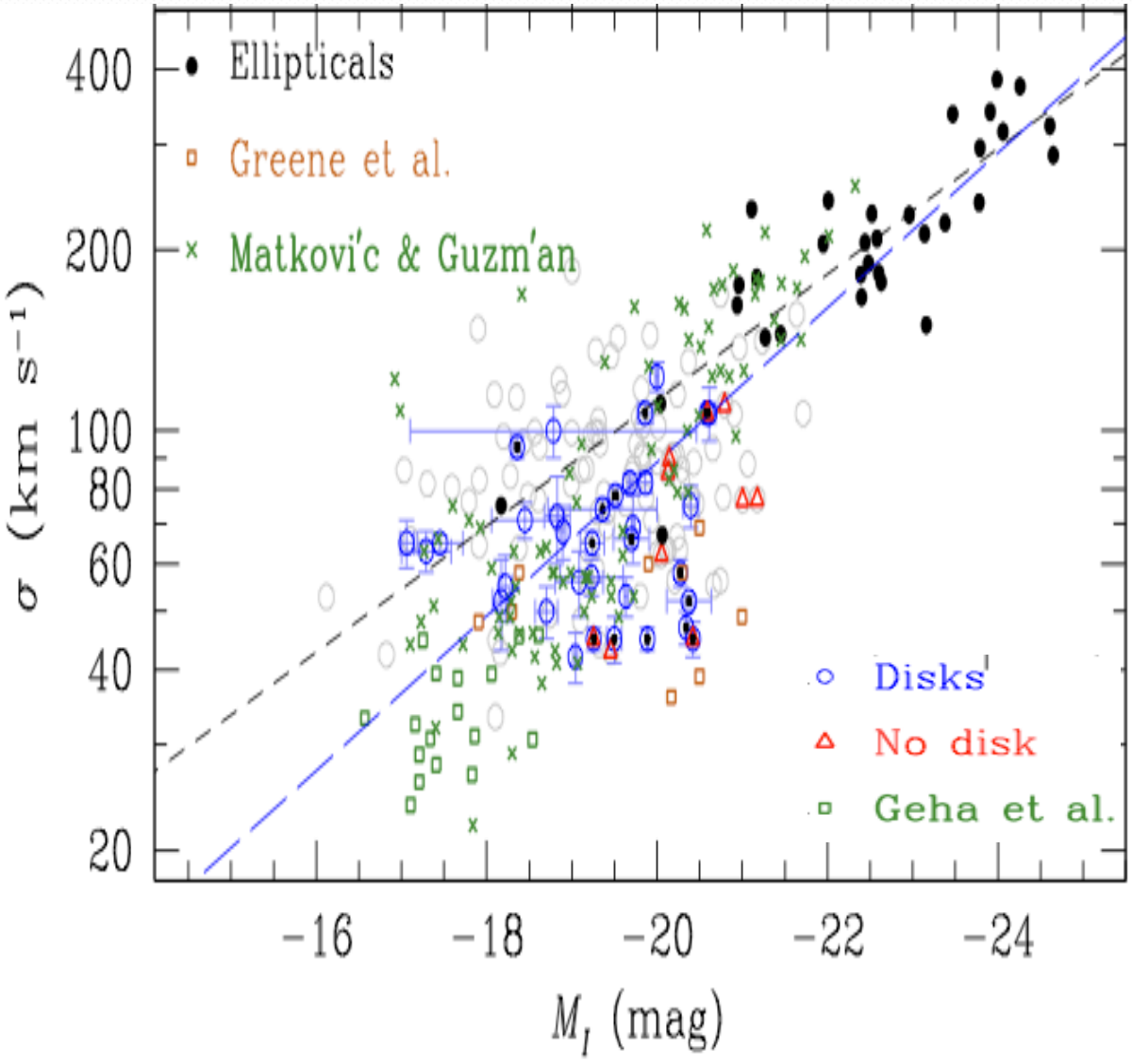
- σ is based on either ESI/MagE spectrum

(Xiao et al. 2011)

or [SII].

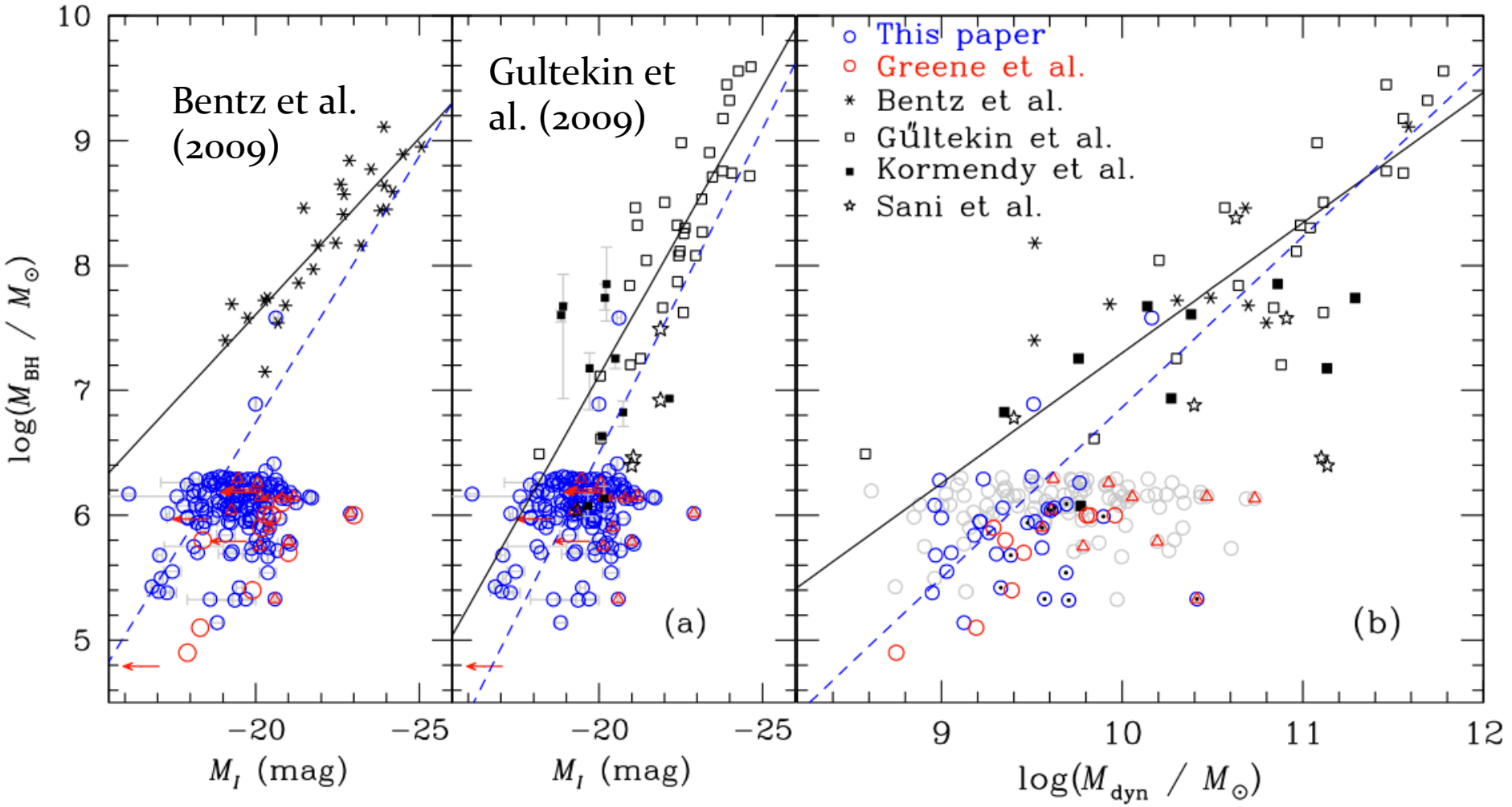
- Our galaxies have smaller velocity dispersion for a fixed bulge magnitude.
- Combine our sample and classical bulges,

$$L \propto \sigma^3$$



M-L relation for our sample

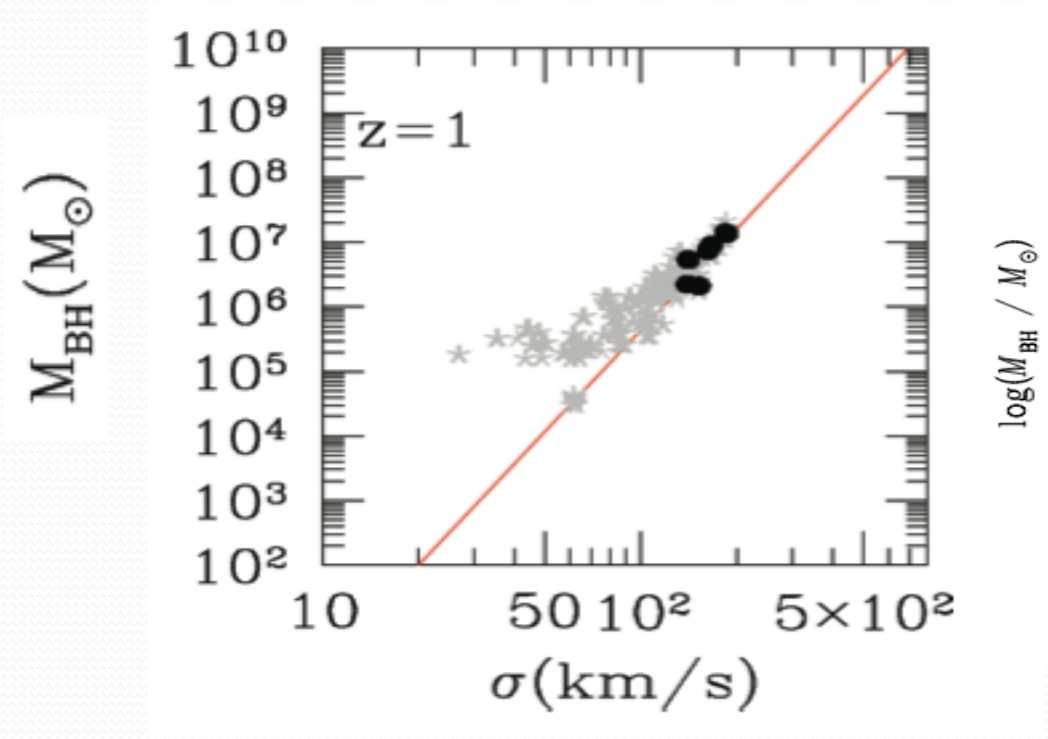
- Dynamical mass $M_{dyn} = 5 r_e \sigma^2 / G$ Cappellari et al. (2006)
- No significant correlation found for our sample alone

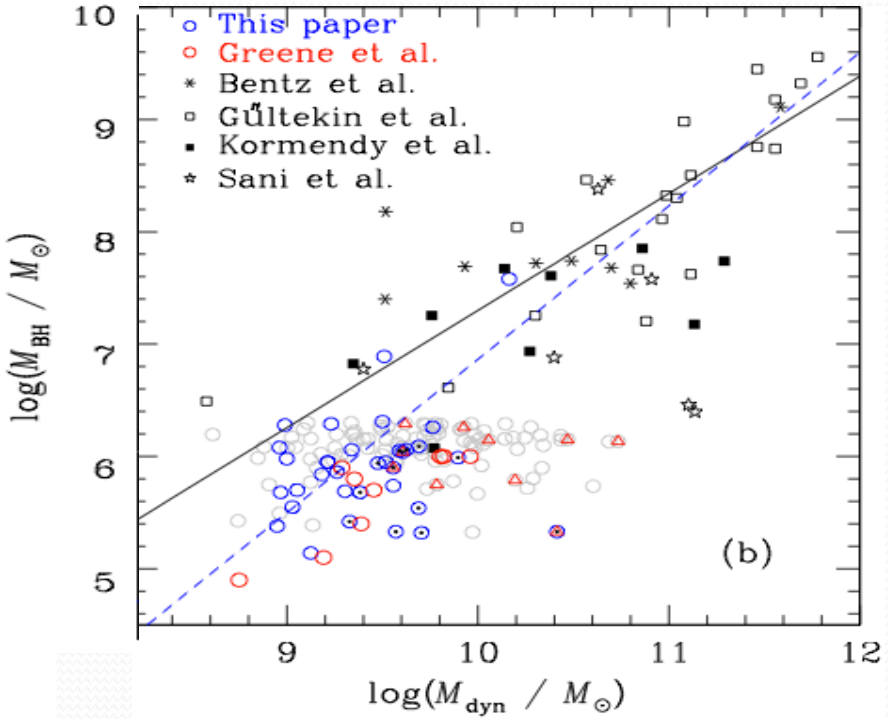


BH seed formation mechanism

Volonteri & Natarajan (2009)

- Two BH seeding models:
  - Light model: Population III remanant.
  - Heavy model: Direct gas collapse





Conclusions

- Low mass BHs in the disk galaxies have pseudo-bulges.
- Galaxies without a disk component are consistent with spheroidal galaxies.
- Those pseudo-bulges are located at a quite different position in the fundamental plane compared with classical bulges.
- A classical bulge is not a prerequisite to host a supermassive BH.
- The host galaxies of active sample are not that different from inactive sample in similar luminosity range.
- The M-L relation for classical bulges does not exist for pseudo-bulges.

Open questions

- Are there more bulgeless host galaxies of BHs?
- How are the first generation black hole seeds formed?
- How do BH-galaxy scaling relations evolve as BHs grow?