

M- σ Relation

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• Main References

- Gebhardt, K., Bender, R., Bower, G., et al. 2000, ApJ, 539, L13
- Ferrarese, L., & Merritt, D., 2000, ApJ, 539, L9
- Kormendy, J., & Ho, L. C., 2013, ARAA, 51, 511

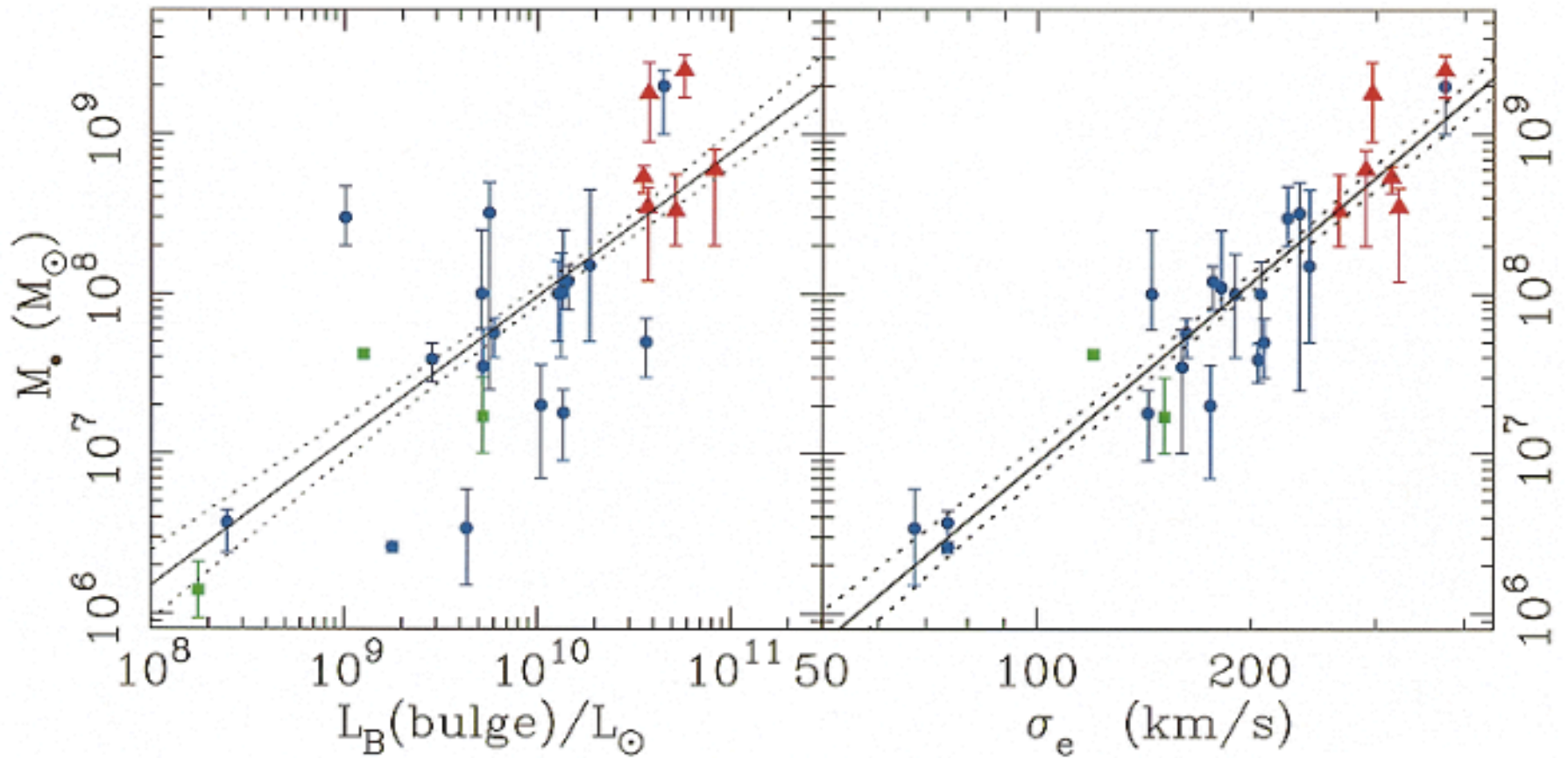
Mass of Supermassive Black Hole

Velocity Dispersion of Elliptical/Bulge

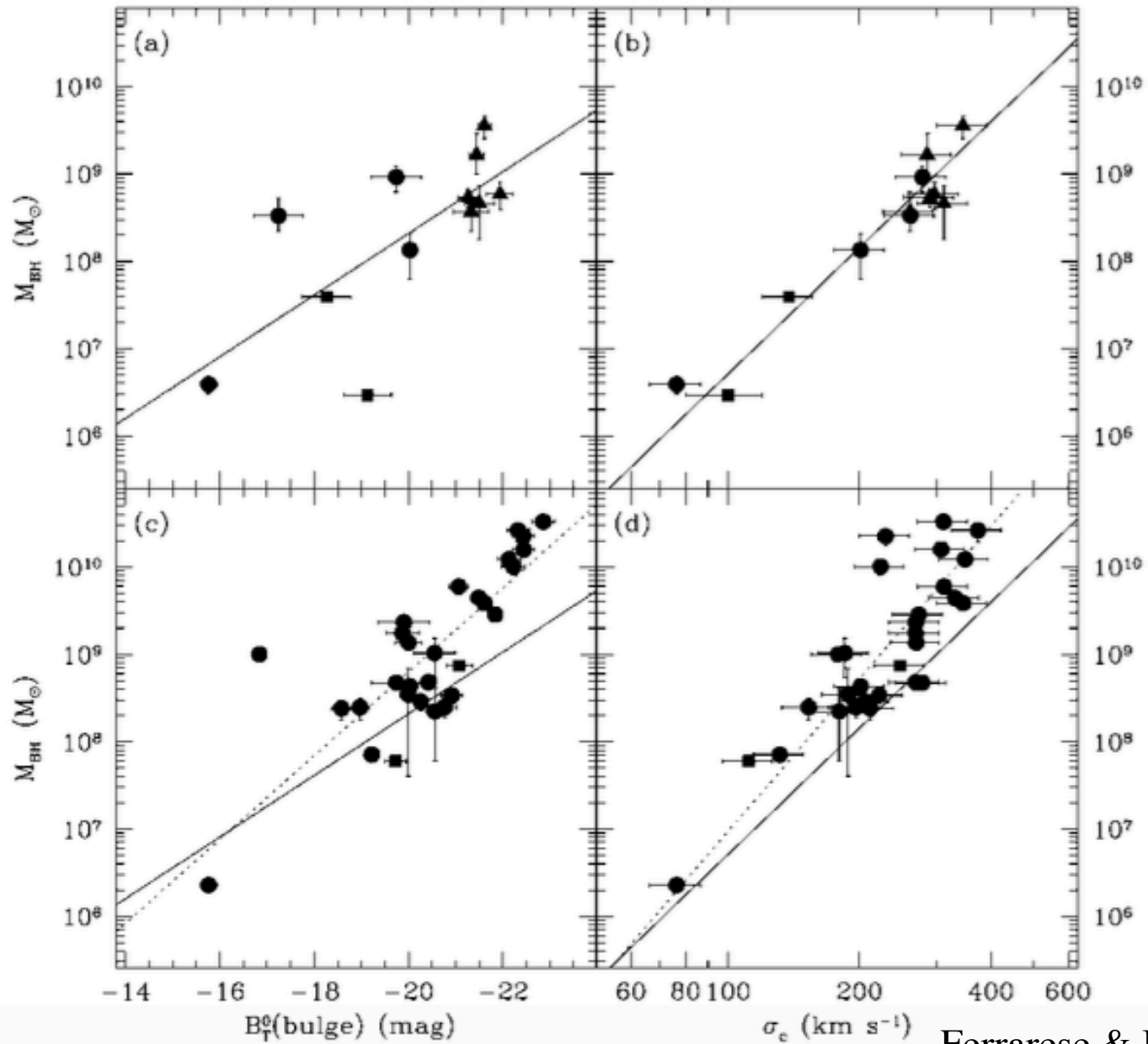
$M - \sigma$

- Other correlations: $M - L_{\text{bulge}}$, $M - M_{\text{bulge}}$
- Conditions/Extensions
- Interpretations (Coevolution / BH Feedback mechanisms?)

- First proposed by Gebhardt et al. (2000) and Ferrarese & Merritt (2000)



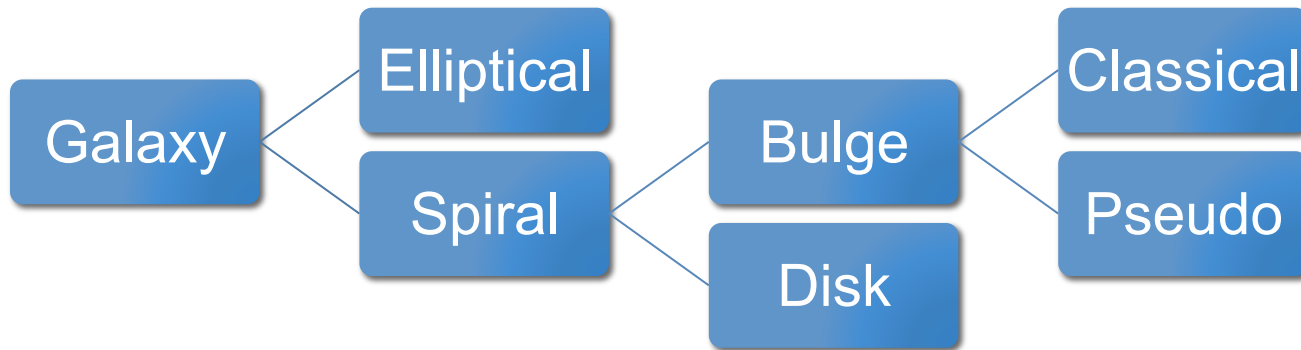
Gebhardt et al. (2000)



Implications:

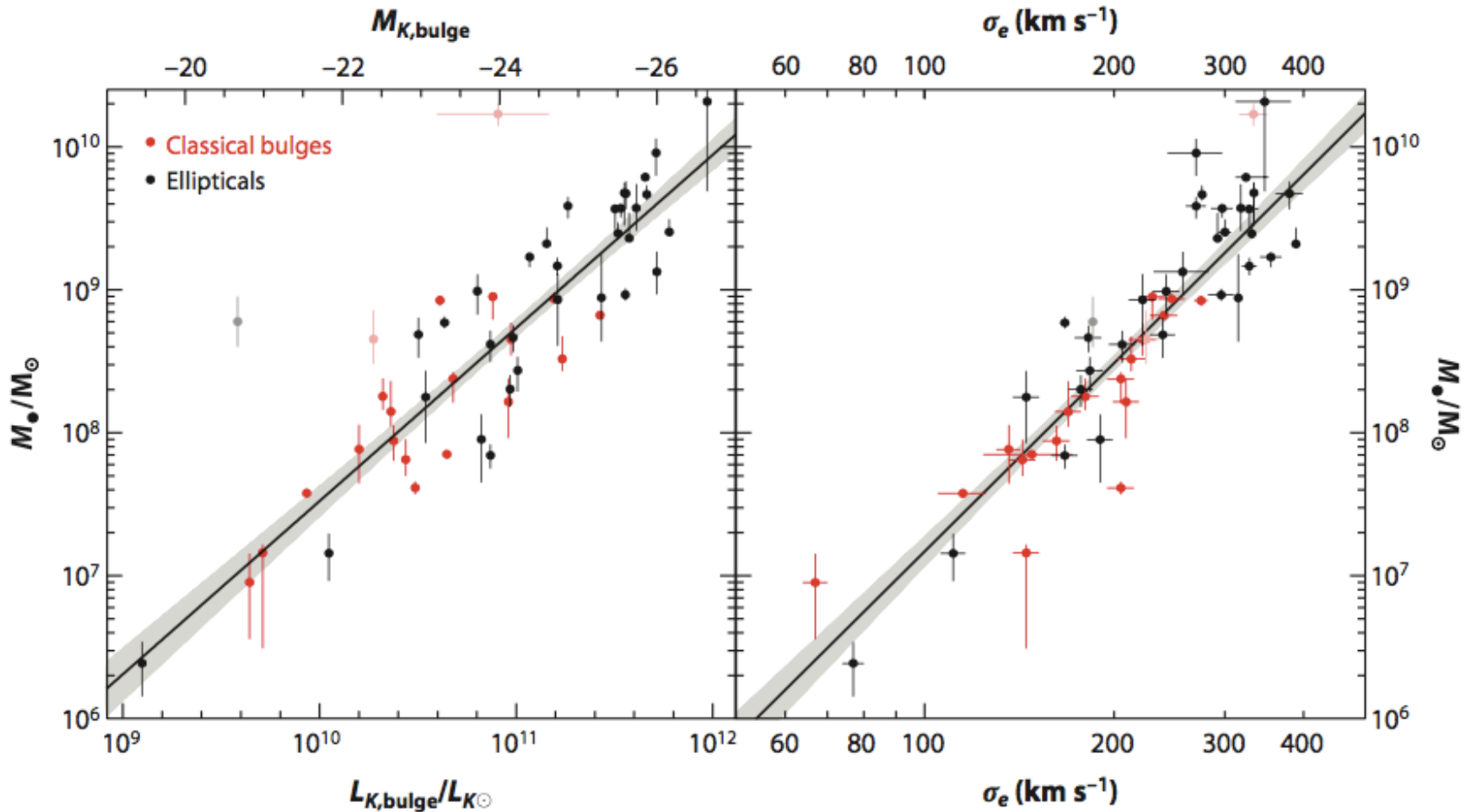
- Tight correlation between MBH and σ over 3 orders of magnitude
- Approach to BH mass measurement
- Link between different scales
- Fundamentality: Correlation \rightarrow Close BH-host coevolution?

• Galaxy Classification



• Ellipticals / Classical Bulges

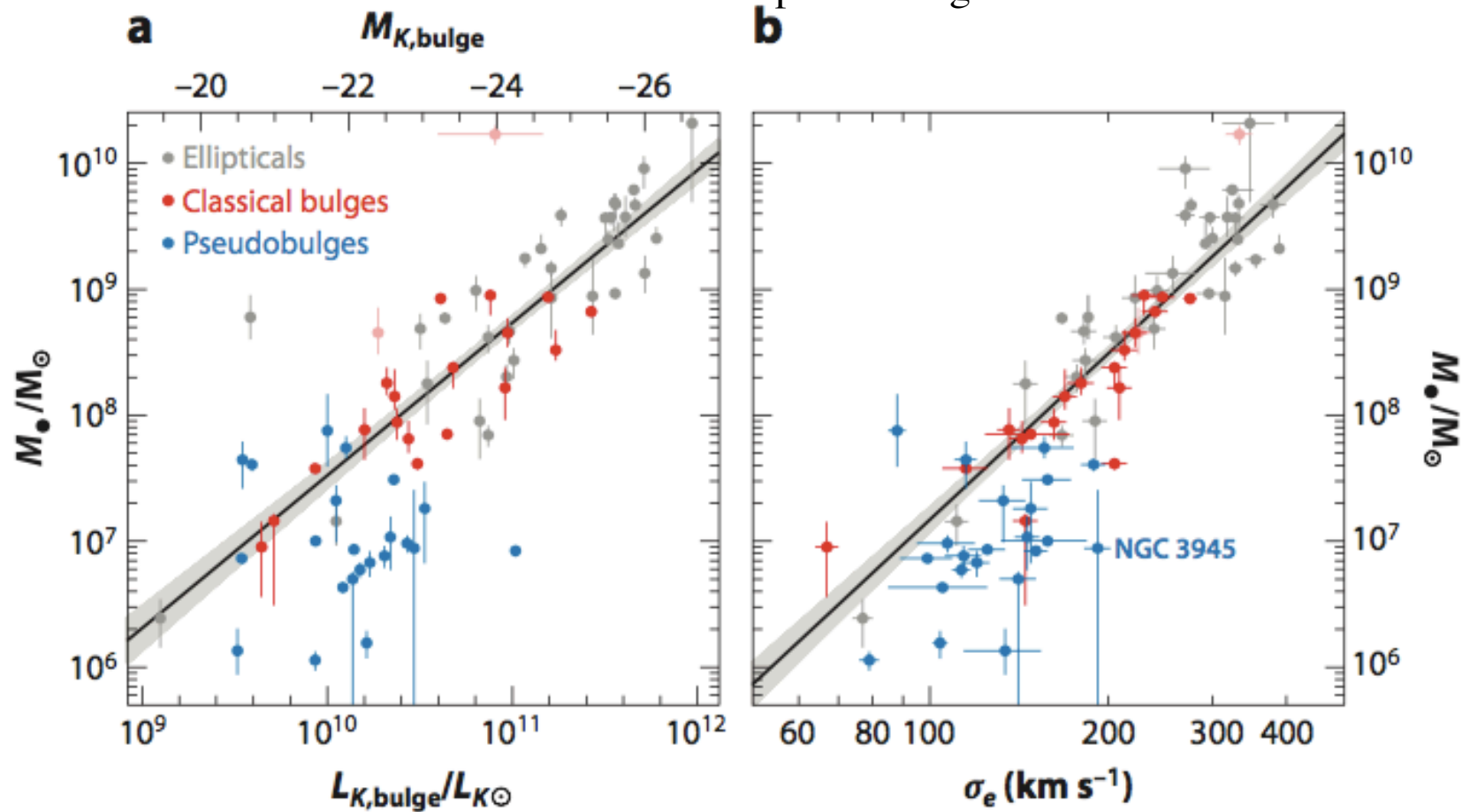
- Ellipticals = Classical Bulges <- Major Mergers
- Tight Correlation between BHs and ellipticals / classical bulges



Kormendy & Ho (2013)

• Pseudobulges

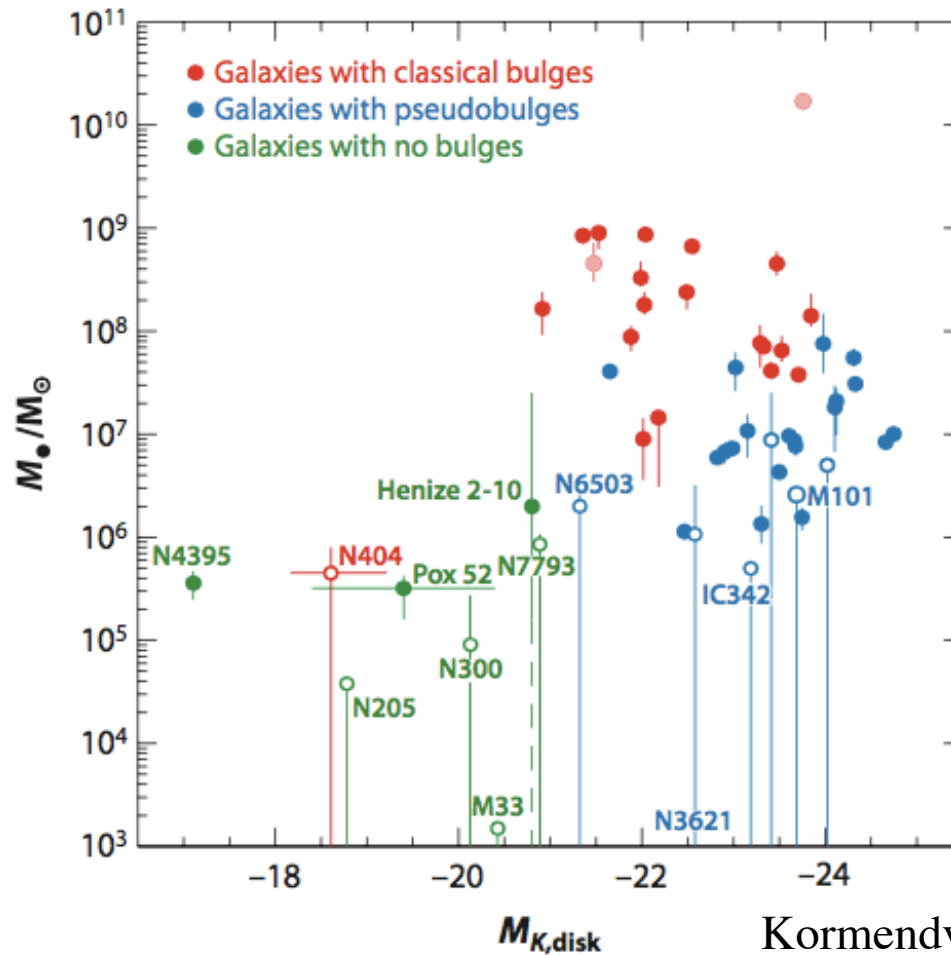
- Undermassive BHs
- Secular, episodic, stochastic BH feeding
- Weak/No Correlation between BHs and pseudobulges



Hu (2008); Kormendy & Ho (2013)

• Disks

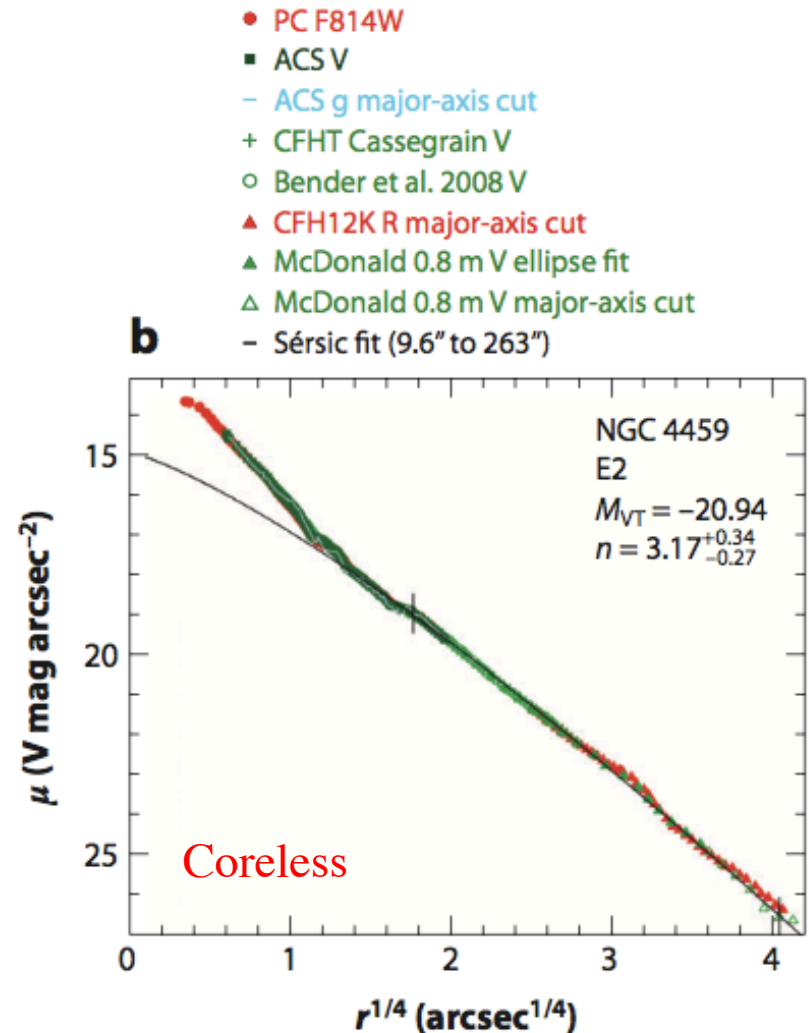
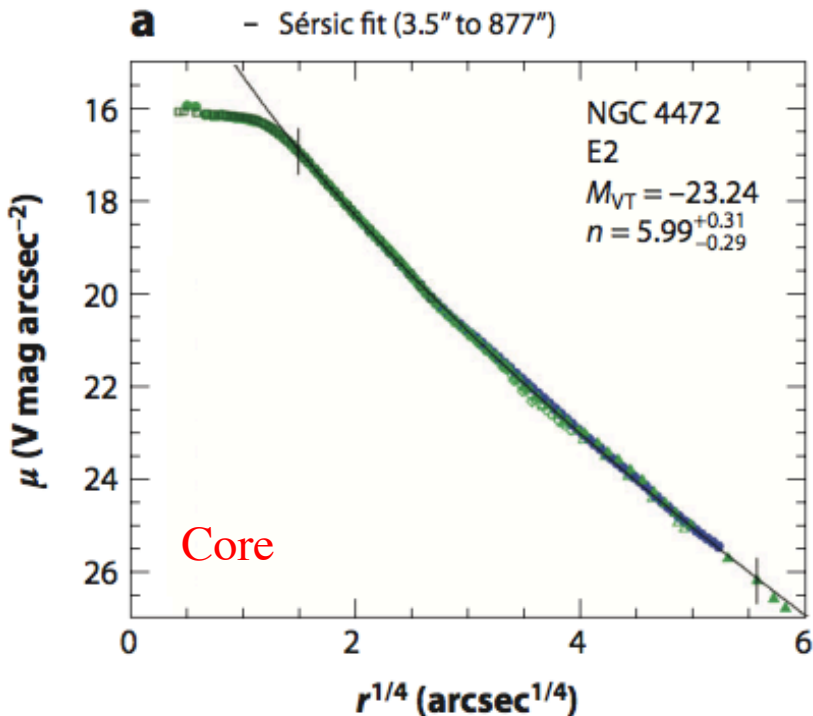
- Weak/No Correlation between BHs and disks



Kormendy & Gebhardt (2001);
Kormendy, Bender & Cornell (2011);
Kormendy & Ho (2013)

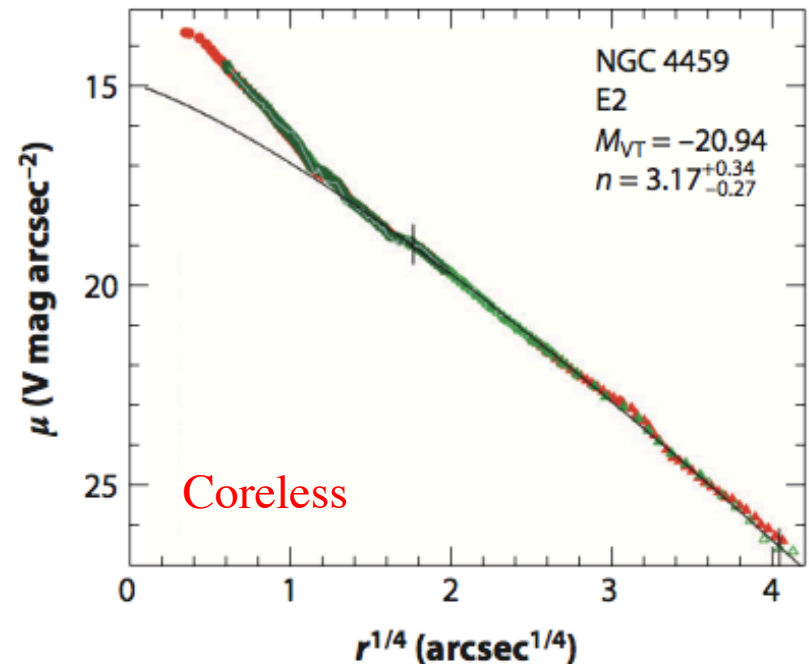
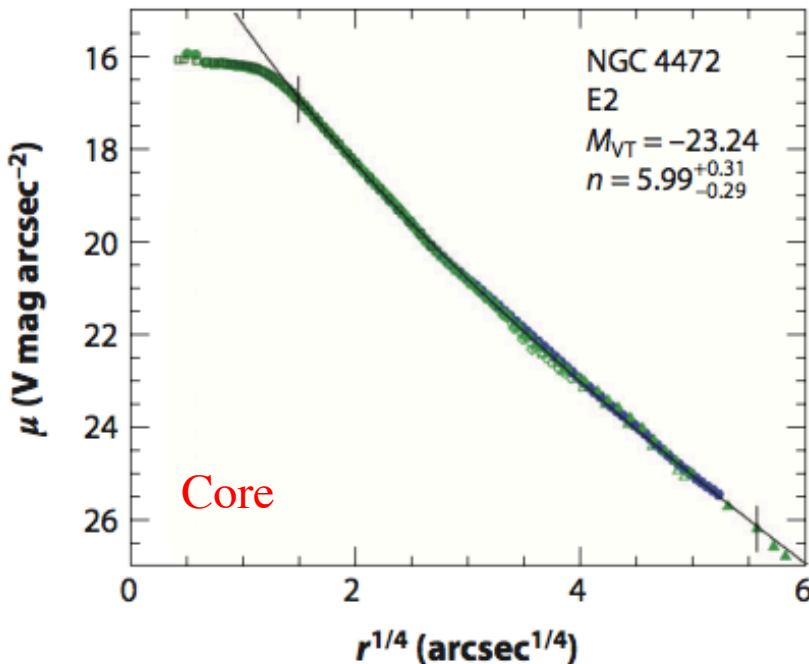
• Core / Coreless Ellipticals

- Lauer et al. 2005 V
- ACS V
- + CFHT Cassegrain V
- SDSS V
- Bender et al. 2008 V
- ◇ Peletier et al. 1990 V
- △ Kim, Lee & Geisler 2000 V
- Caon, Capaccioli & D'Onofrio 1994 B
- ▲ McDonald 0.8 m V
- Sérsic fit (3.5" to 877")



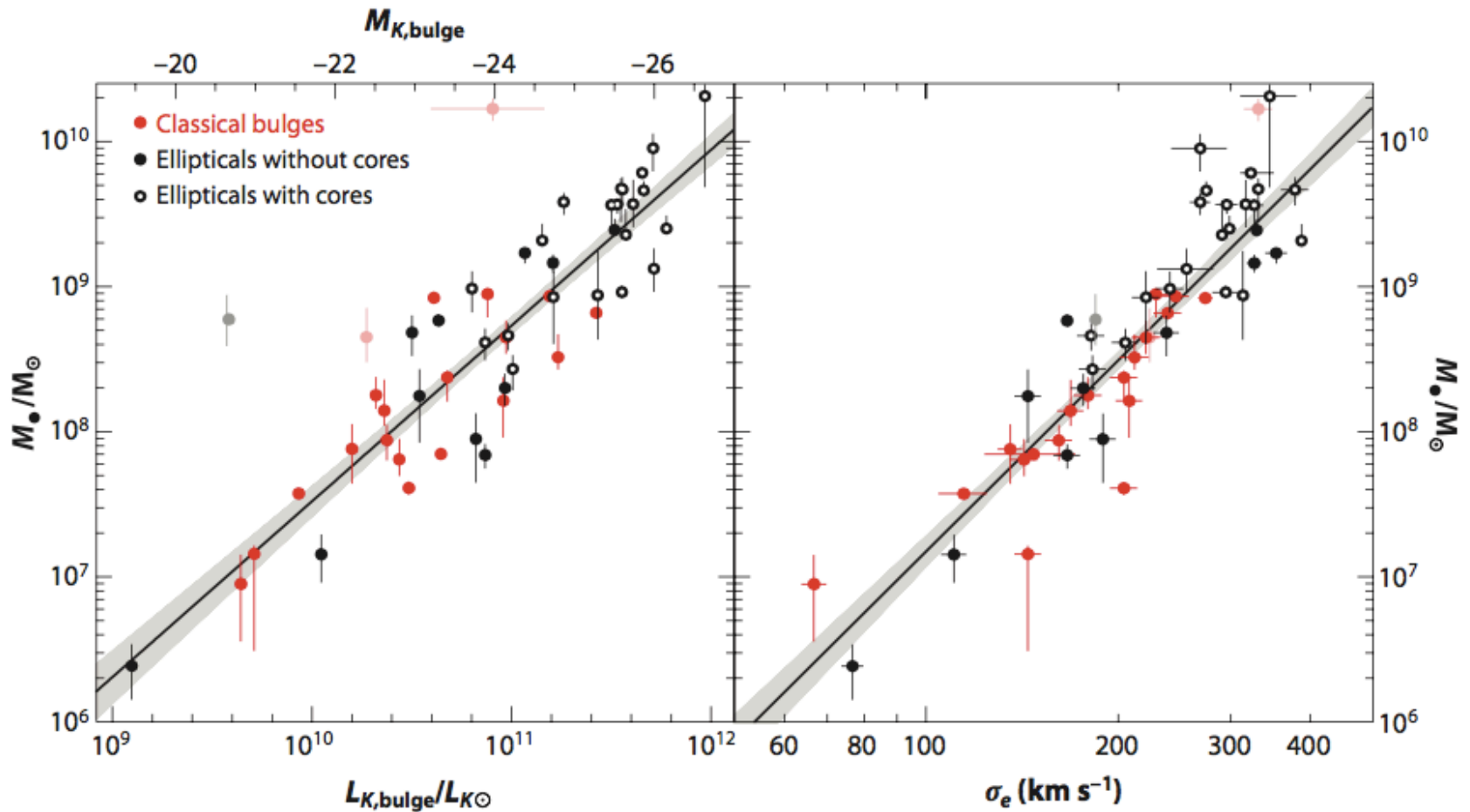
• Core / Coreless Ellipticals

- Core ellipticals -> light deficit at center
 - Produced by dry (gas-poor, dissipationless) mergers
 - BH scouring: BH binary decays by flinging stars away
 - M_{crit} quenching: When $M_{\text{BH}} > M_{\text{crit}}$, X-ray and radio sources keep gas in hot phase
- Coreless ellipticals -> light excess at center
 - Produced by wet (gas-rich, dissipative) mergers
 - Sufficient cold gas to fuel starbursts



• Core / Coreless Ellipticals

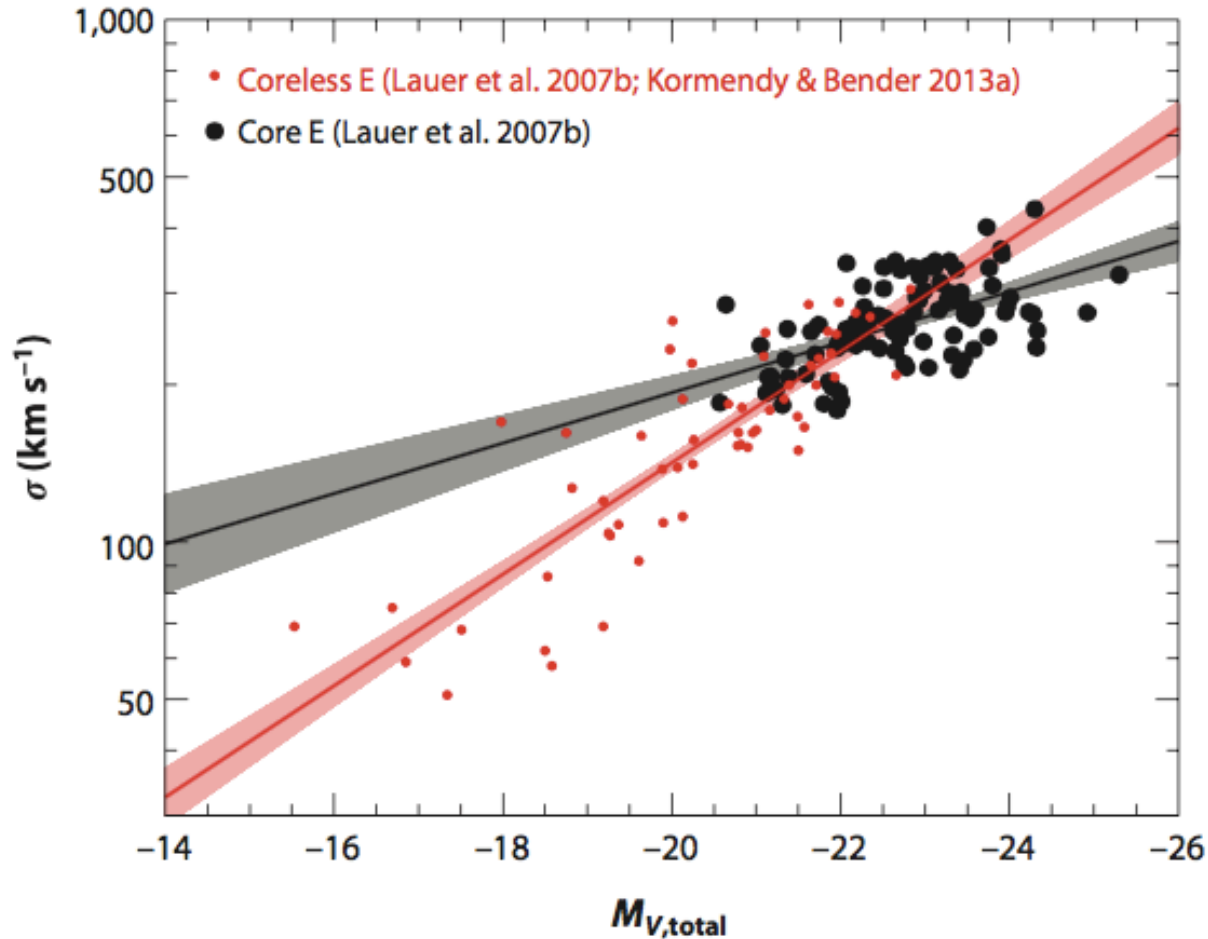
- Core ellipticals: Large, High-mass BHs
- Core ellipticals: Correlation holds for luminosity, but it is “saturated” for σ



Kormendy & Ho (2013)

• Core / Coreless Ellipticals

- Core ellipticals: Small variations in σ

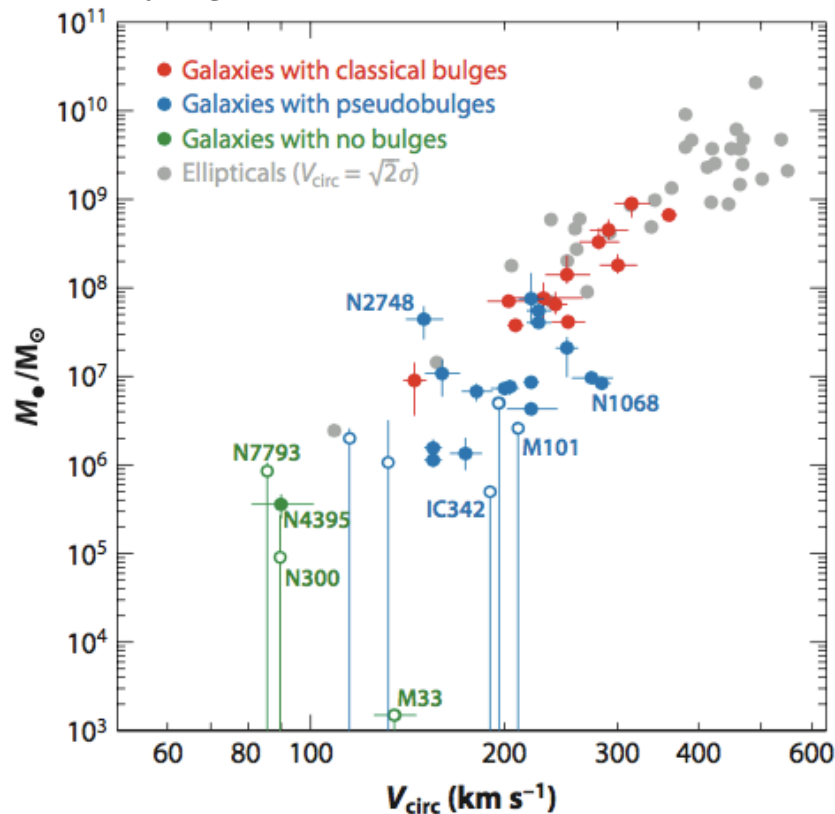


• Take-away Points

- Pseudobulges / bulgeless galaxies
 - Small BHs
 - Secular, episodic, stochastic BH feeding
 - Weak/No $M - \sigma$ relation or other BH-host correlations
- Coreless Ellipticals / Classical Bulges
 - Large BHs
 - Wet major mergers
 - Strong $M - \sigma$ relation and other BH-host correlations
- Core Ellipticals
 - Largest BHs
 - Dry major mergers
 - Strong $M - \sigma$ relation and other BH-host correlations, but deviation is present
- $M - \sigma$ Relation: suggestive of BH feedback, but less compelling than expected

- Extended Picture:
Is Dark Matter More Fundamental?

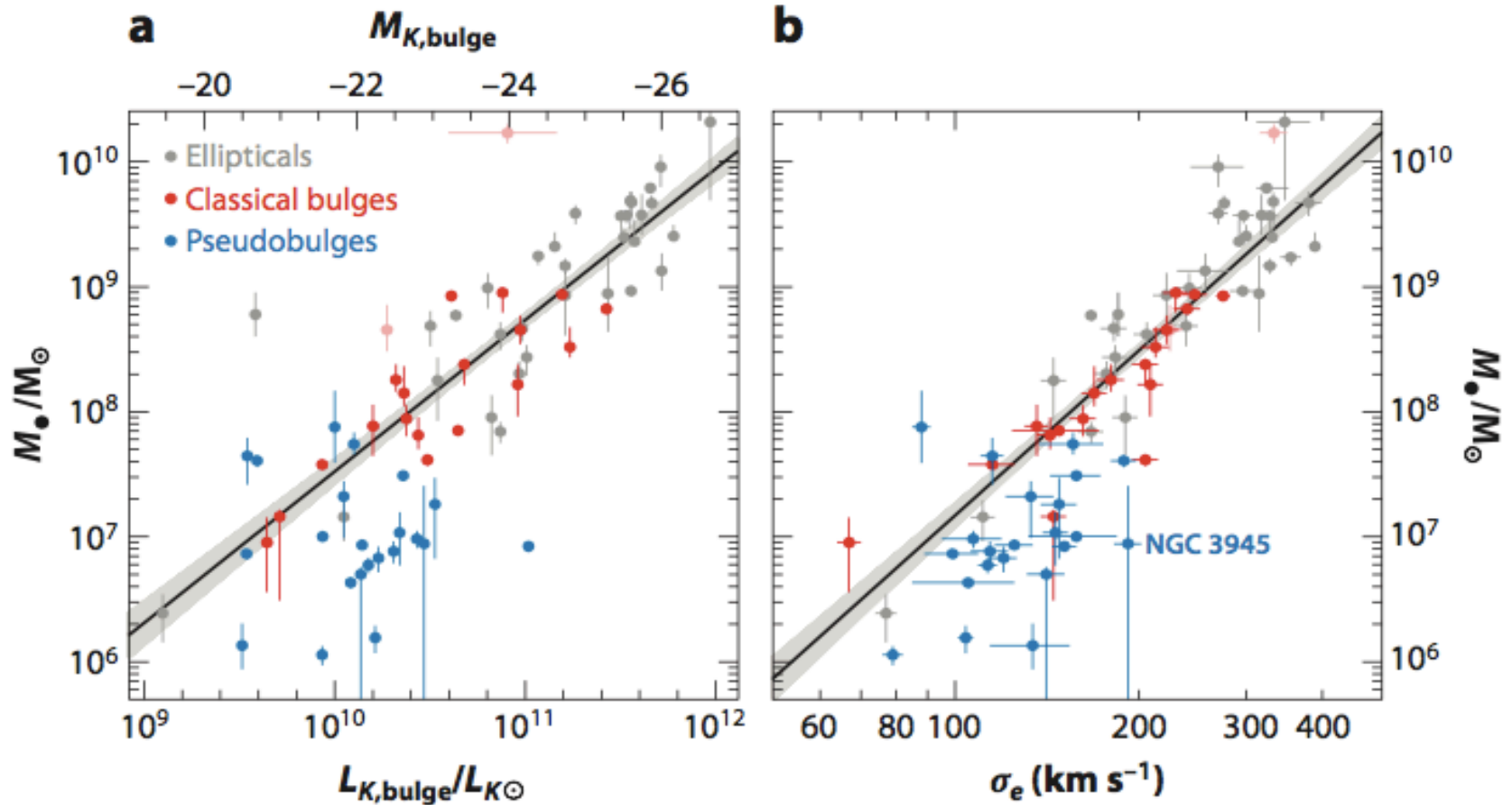
- Correlation between BHs and DM **only** for ellipticals / classical bulges
- DM is not the underlying **determinant** of the relation



Kormendy & Bender (2011); Kormendy & Ho (2013)

- Extended Picture:
Besides BH feedback, is there another mechanism?

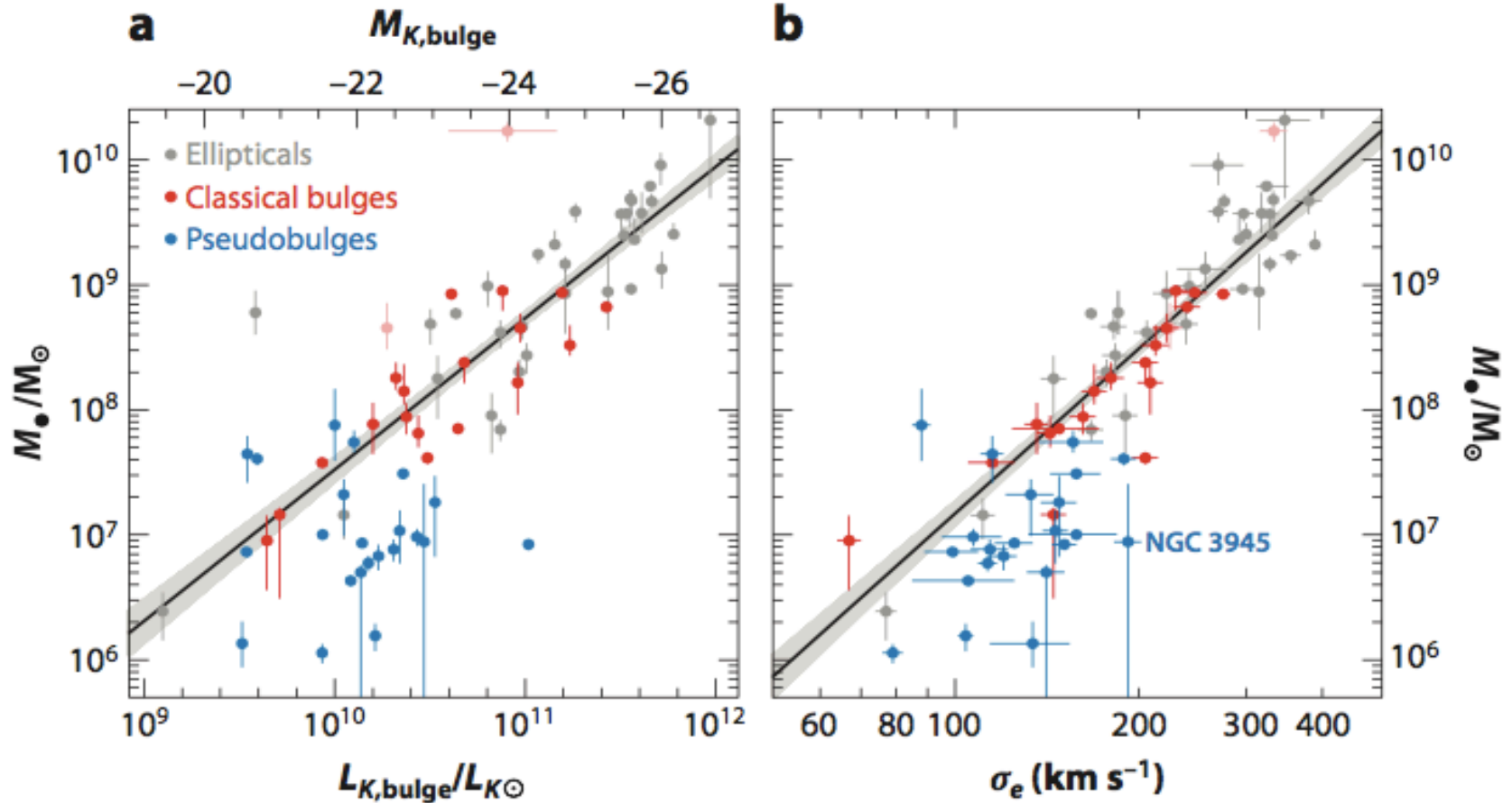
- Weak/No Correlation between BHs and pseudobulges



Hu (2008); Kormendy & Ho (2013)

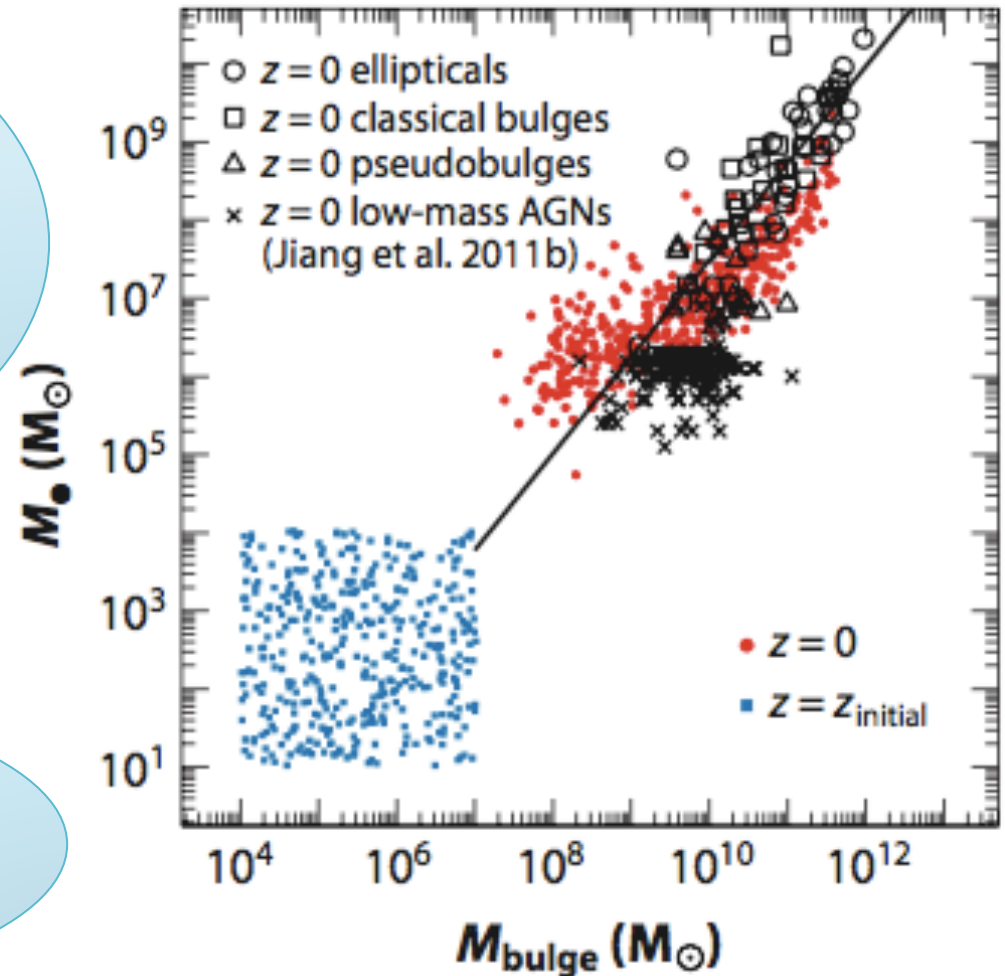
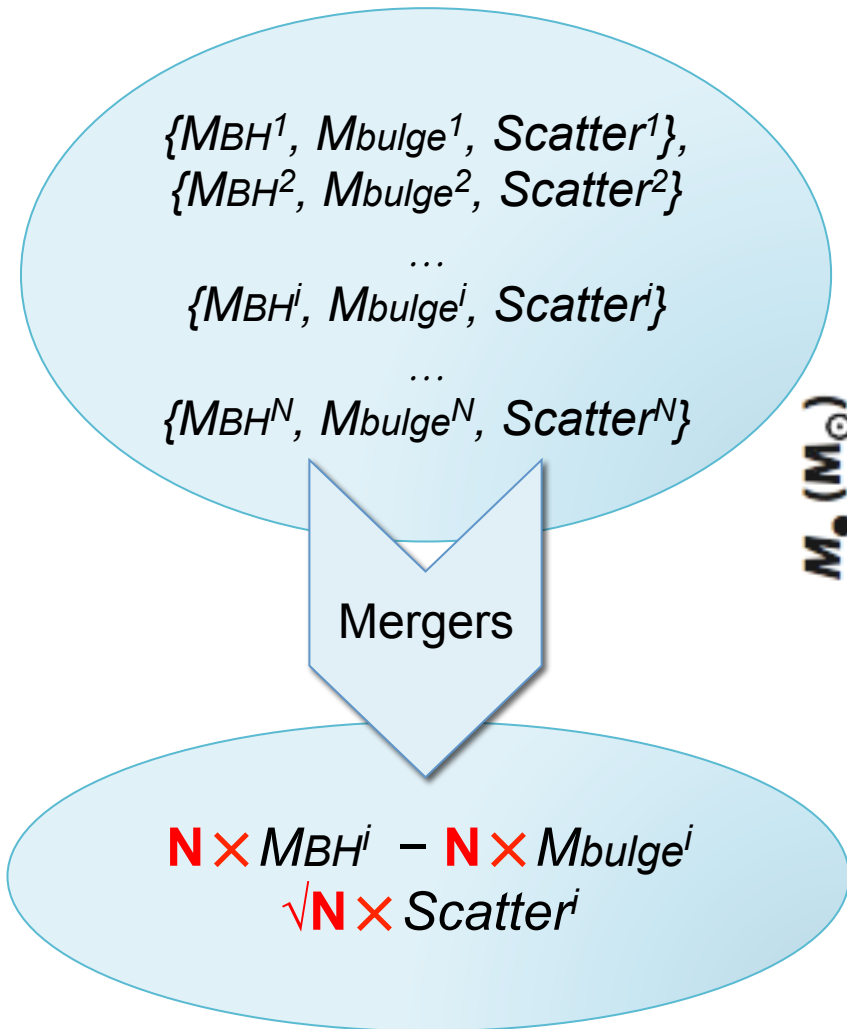
- Extended Picture:
Besides BH feedback, is there another mechanism?

- Scatter decreases as MBH increases



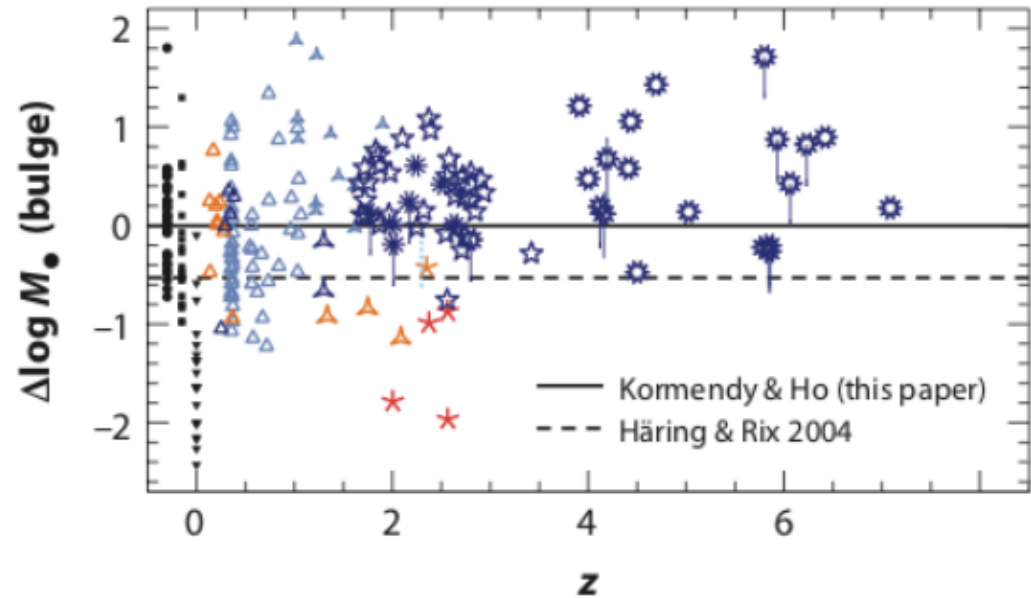
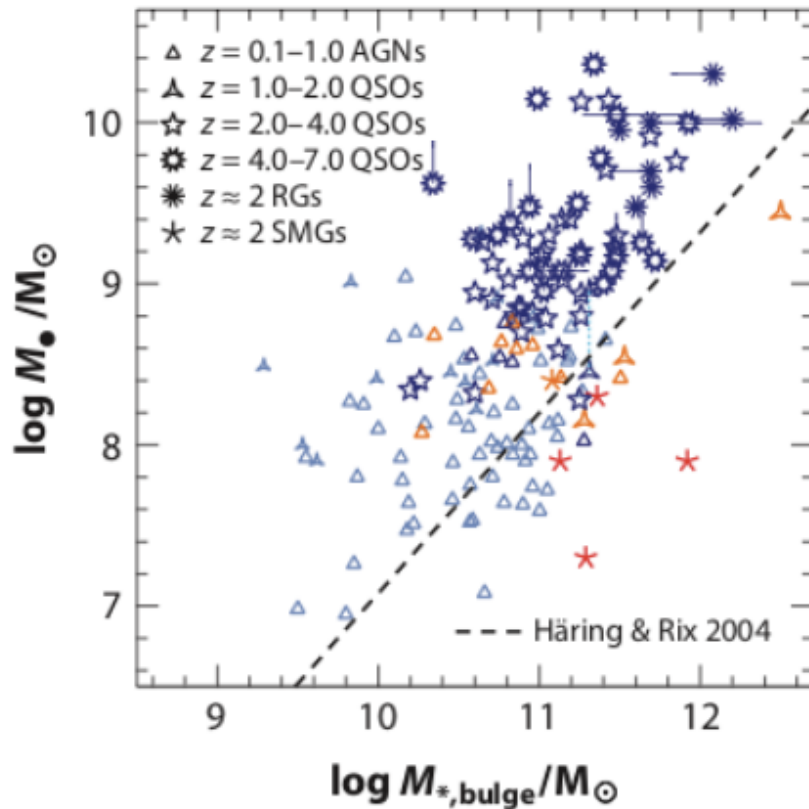
Hu (2008); Kormendy & Ho (2013)

- Extended Picture: Mass Averaging



• Extended Picture: Downsizing

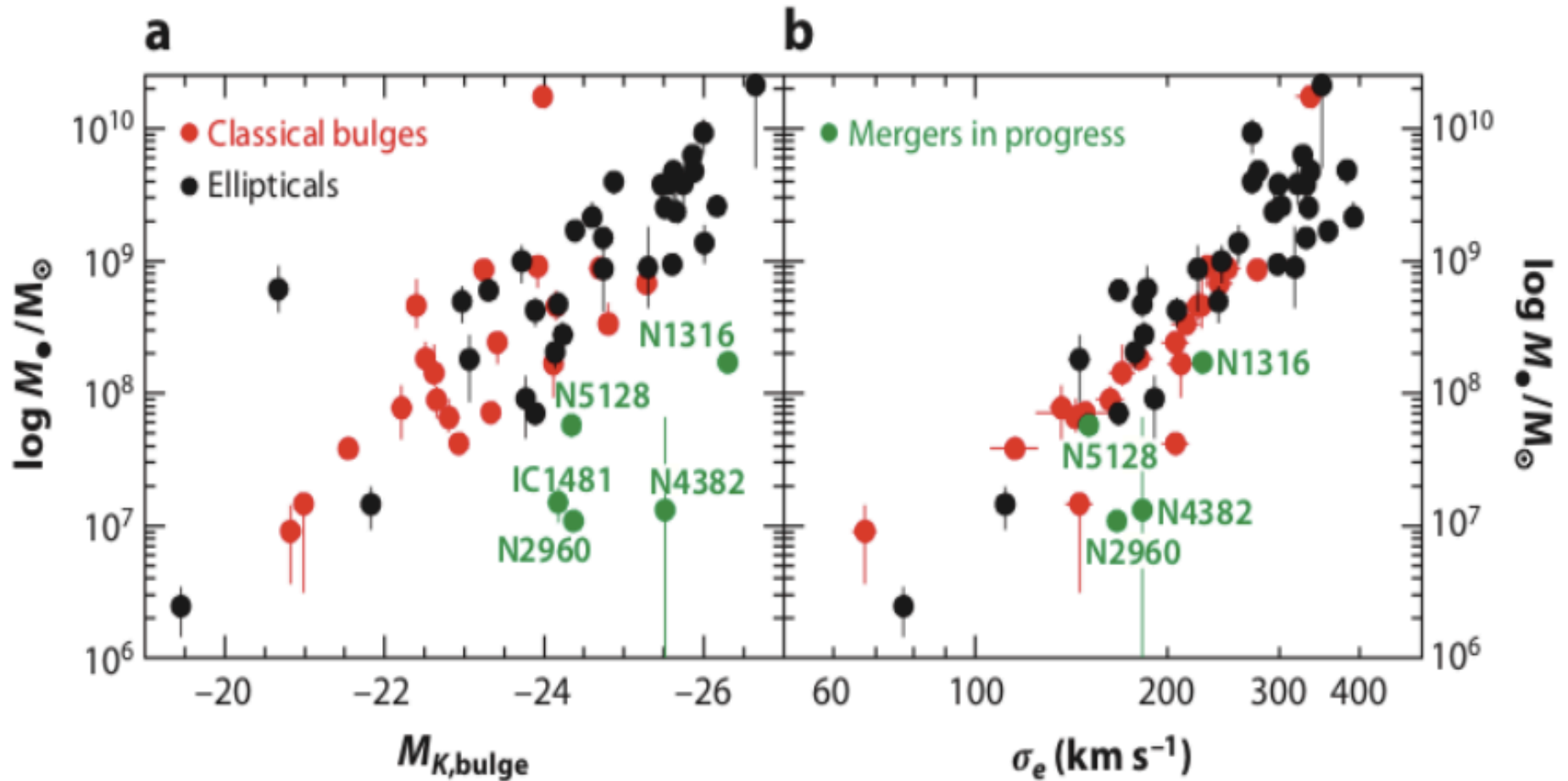
- Massive BHs outpaced bulge growth
 - Primarily with high- z ellipticals / classical bulges
- Low-mass BHs with large variations
 - Primarily with low- z bulgeless galaxies / pseudobulges



Ho (2013); Kormendy & Ho (2013)

Extended Picture: Outliers

- Mergers in progress ($z \sim 0$): Low-mass BHs



• Interpretations

Ingredients:

- Observational facts: correlations (or not), outliers, deviations
- Two mechanisms: BH feedback & mass averaging

Regimes of BH-host coevolution (or not):

- Coreless Ellipticals / Classical Bulges
 - Large BHs; Mainly $z \sim 2-4$
 - Wet major mergers: concurrent BH feeding and star formation
 - Global BH feedback: BH-host coevolution engineers $M - \sigma$ relation
- Core Ellipticals
 - Largest BHs
 - Dry major mergers: BH feedback plays a negative role
 - Inherit feedback effects from progenitor galaxies, but deviate from $M - \sigma$ relation

• Interpretations

Regimes of BH-host coevolution (or not):

- Pseudobulges / bulgeless galaxies
 - Small BHs; Mainly $z \sim 0$
 - Too little energy to affect the host
 - Local BH feedback: No coevolution
- Coevolution era has largely ended at $z \sim 0$
 - Gas fractions become small
 - Most mergers only involve modest star formation and BH growth
 - BH-host correlations dilute
- Mass Averaging
 - Help regulate BH-host correlations for all BH masses
 - Reduce scatters in BH-host correlations

• Summary

- BHs correlate differently with different galaxy component
 - ✓: Ellipticals / Classical bulges
 - ✗ : Disks / Pseudobulges / DM halos
- Buildup of BH-host correlations
 - BH feedback / BH-host coevolution
 - Mass averaging through merger processes
- Evidence of coevolution is not as compelling as expected
 - Relative importance of BH feedback and mass averaging is unknown
 - The picture has been further extended and enriched