Scaling relations between the SMBHs and their host galaxy

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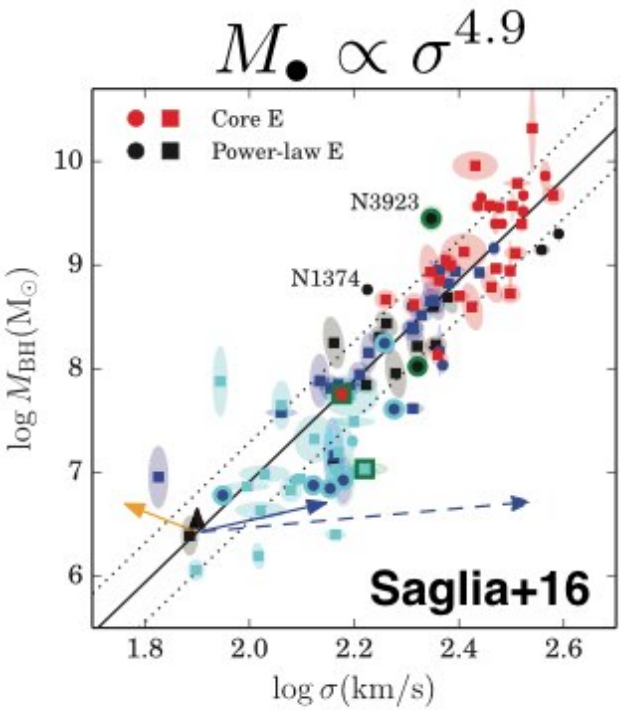
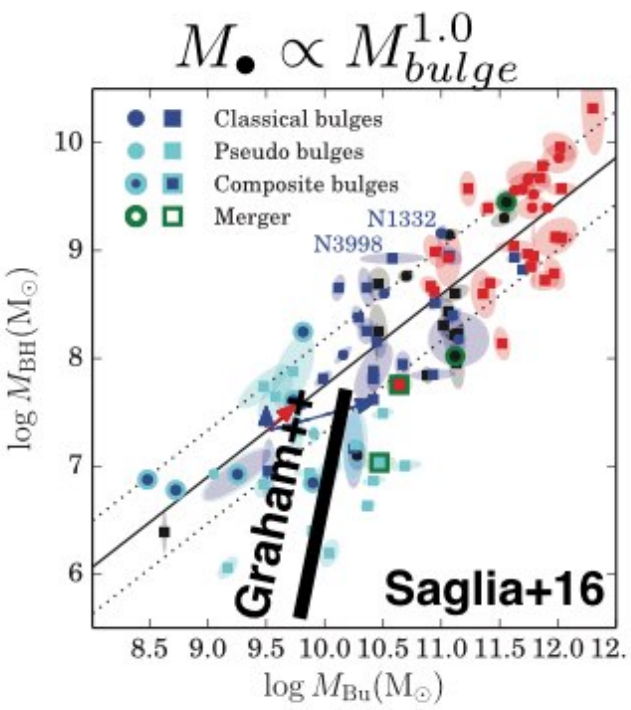
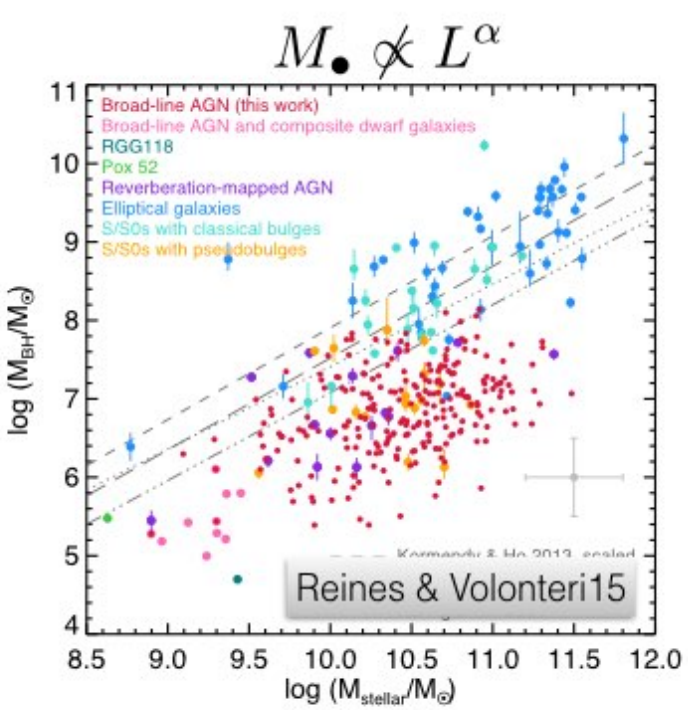
Black Hole Scaling relations

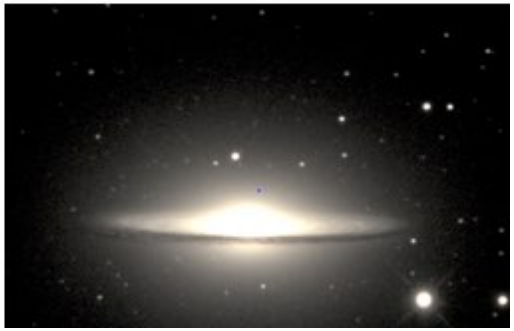
- Tight relations between the SMBH and its host. Very rich field of study.
- Which one is the best one?
  - M-sigma (Beifiori+09&12, Gultekin09, McConnell&Ma13, etc)
  - M-bulge (Kormendy&Ho13, Sani+11, Graham++, Savorgnon, etc)
- Are they set by local or global processes?
- Scaling relation should be consistent with each other.
- Correlation does in imply causation.

Black Hole Scaling relations





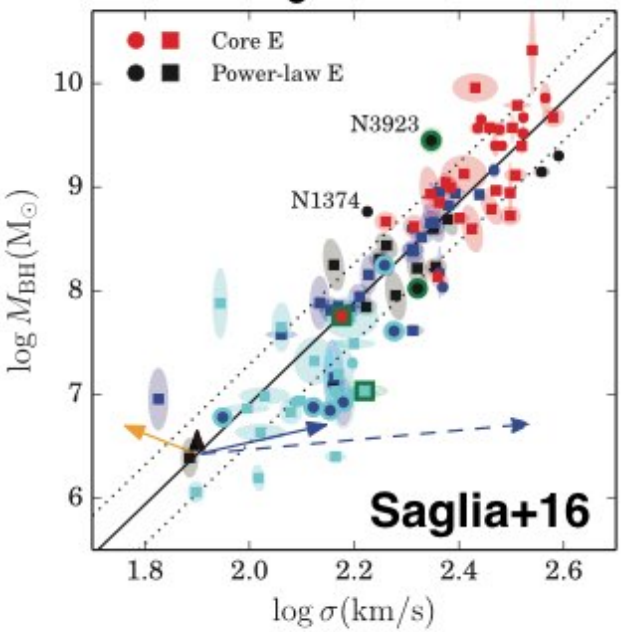




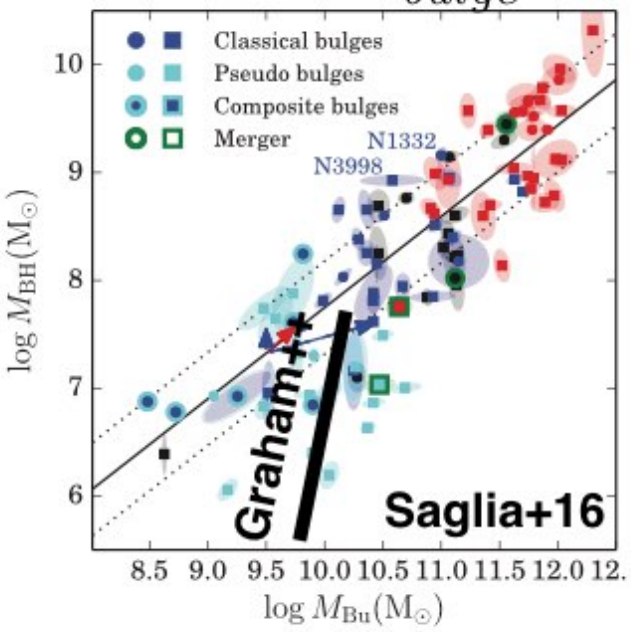
And Bulge-less galaxies?!?

They have AGN. (e.g. Greene++,Reines+13)

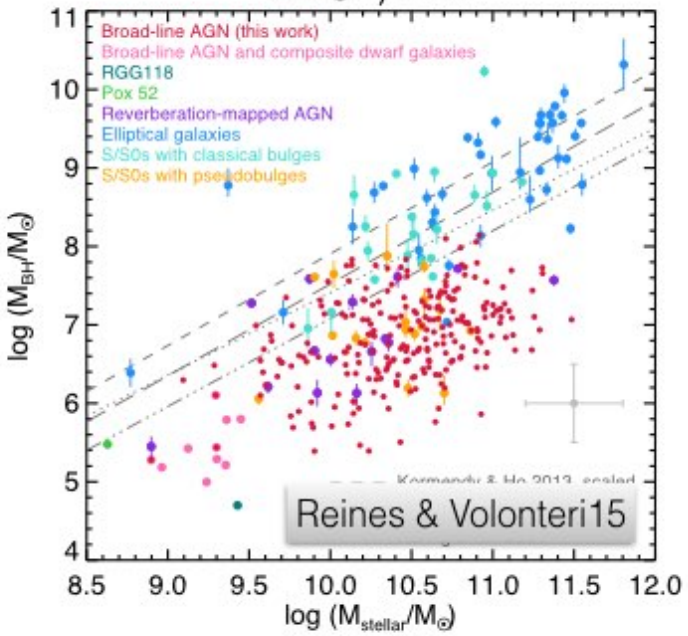
$M_\bullet \propto \sigma^{4.9}$

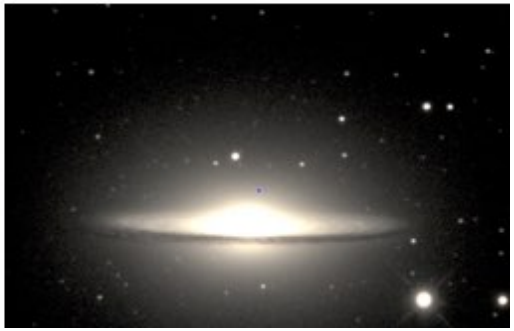


$M_\bullet \propto M_{bulge}^{1.0}$



$M_\bullet \not\propto L^\alpha$



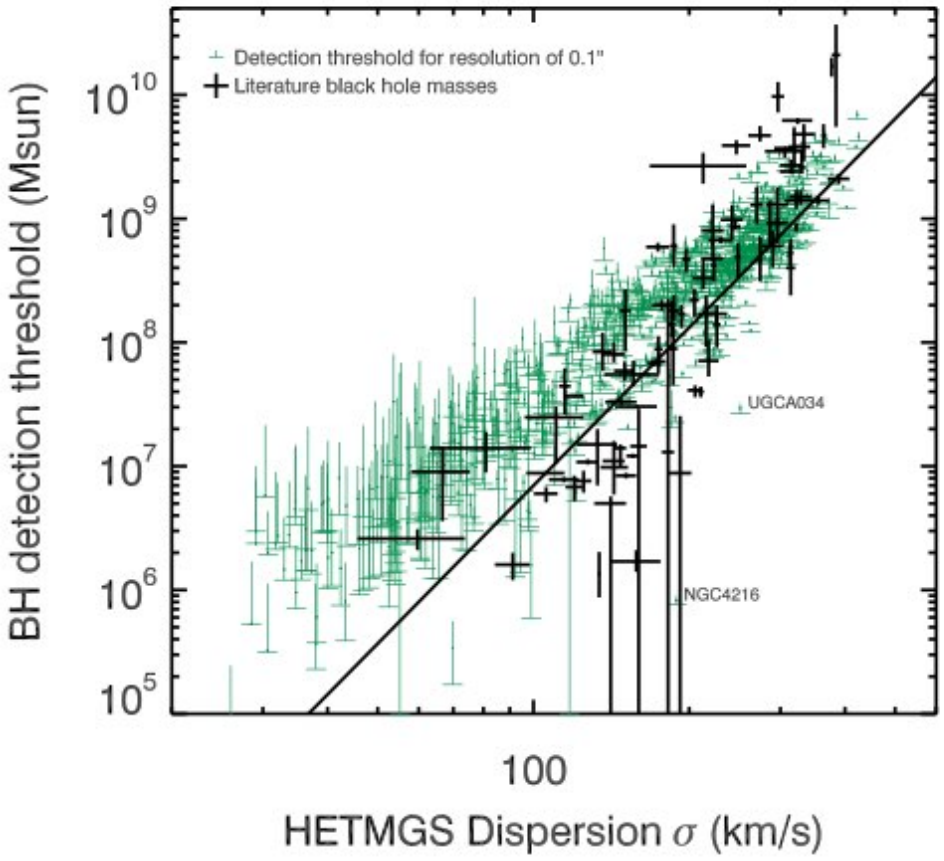


WHAT CAN WE EXPECT?

- HETMGS: 1022 galaxies to find possible targets for BH mass measurements. (Data publicly available online.)
- Given resolution of AO and HST it is possible to predict the discovery space. Assume BH sphere-of-influence (R_soi) is 0.1”

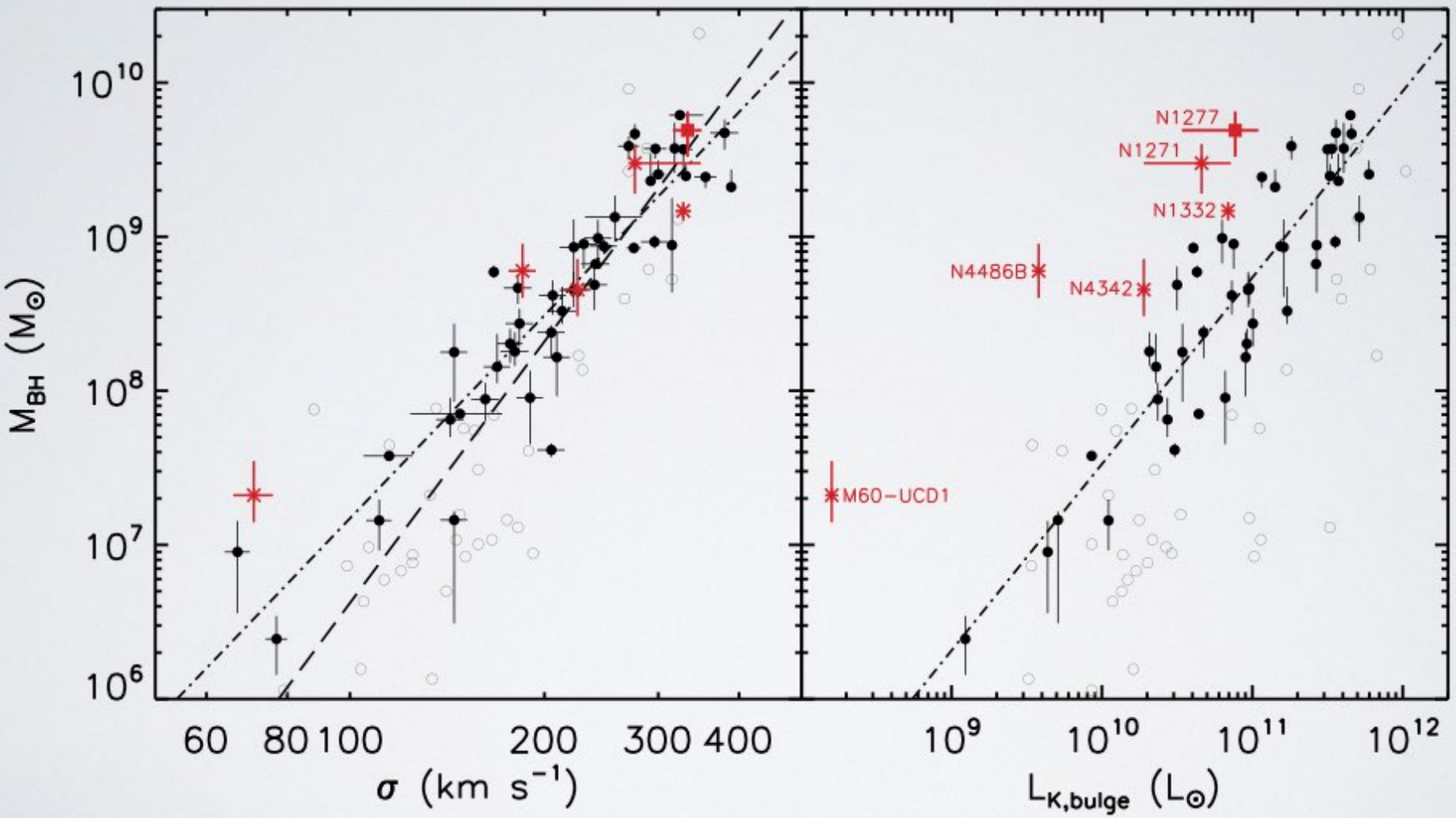
$$R_{soi} = \frac{GM_\bullet}{D\sigma^2}$$

- The only extreme we can find is over-massive black holes.



vdB+15

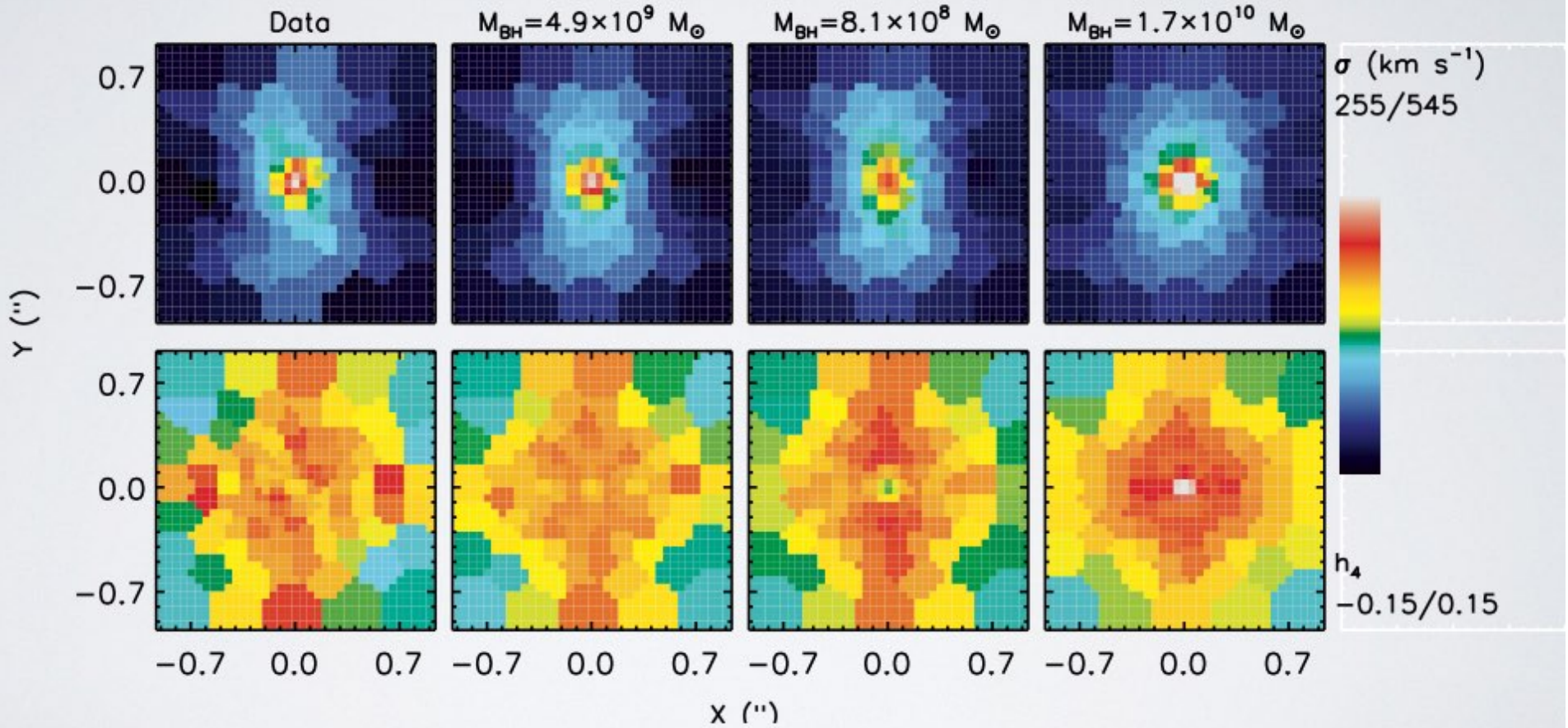
OUR PROGRESS: OVER-MASSIVE BLACK HOLES



Seth+14, Yildirim+15, Walsh+15, +16

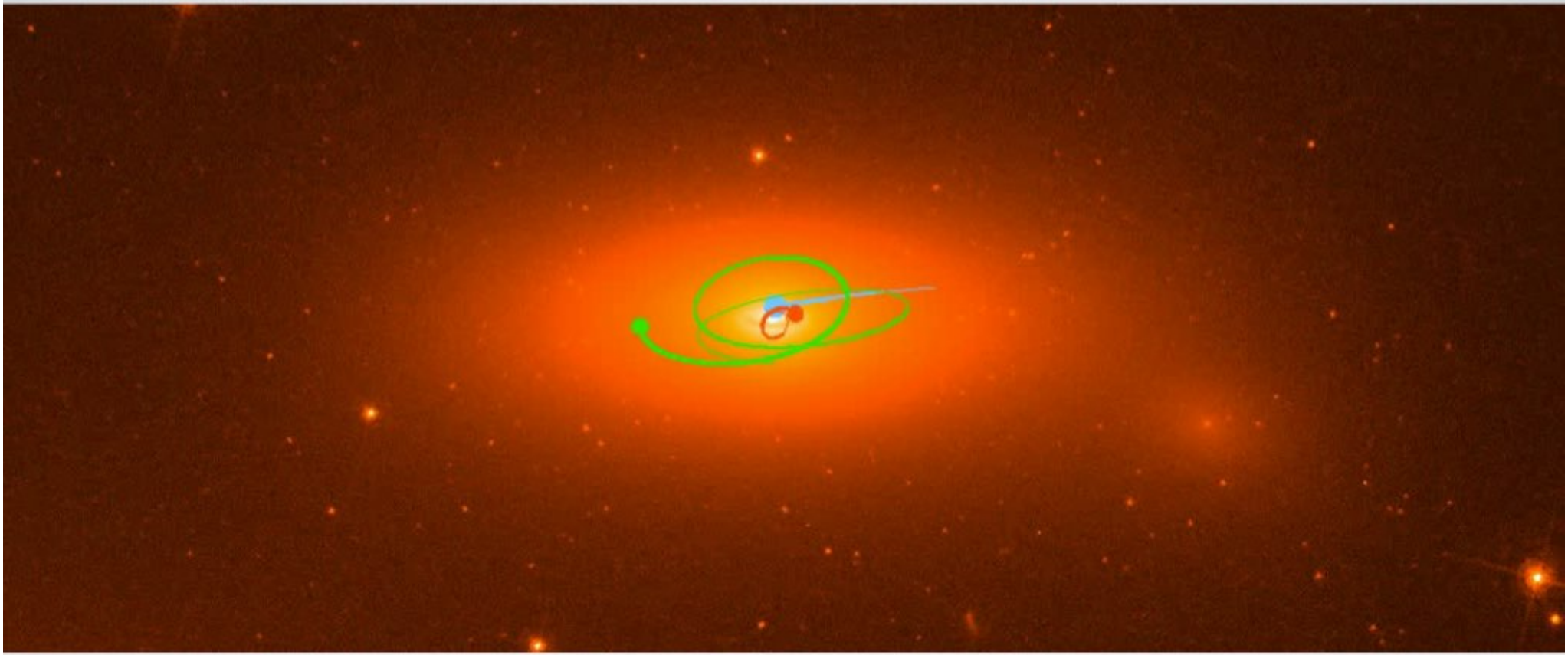
NGC1277

WITH NIFS ADAPTIVE OPTICS

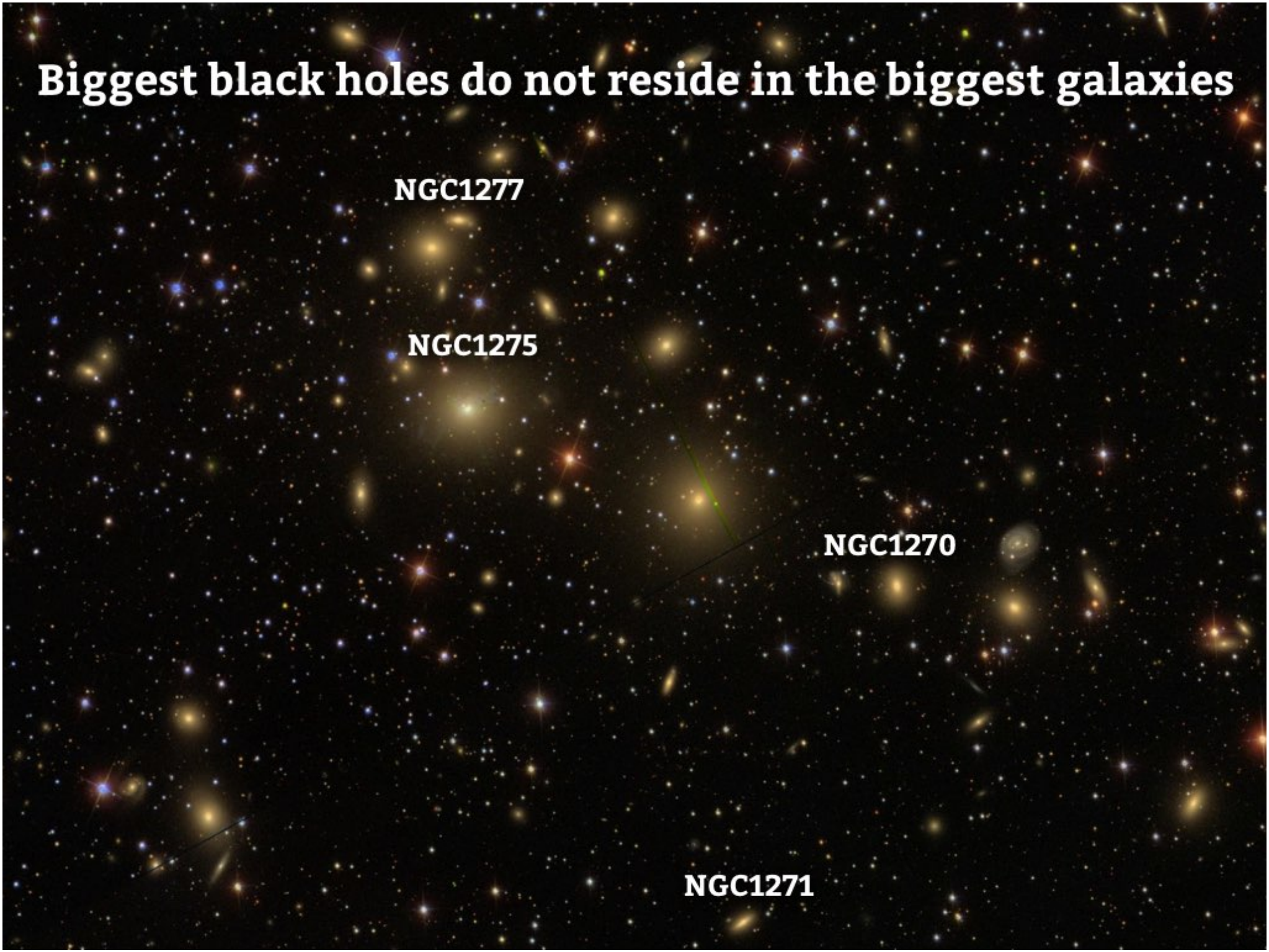


vdB12,Yildirim+15a,Walsh+16
Emsellem13,Scharwächter+15,Graham+16

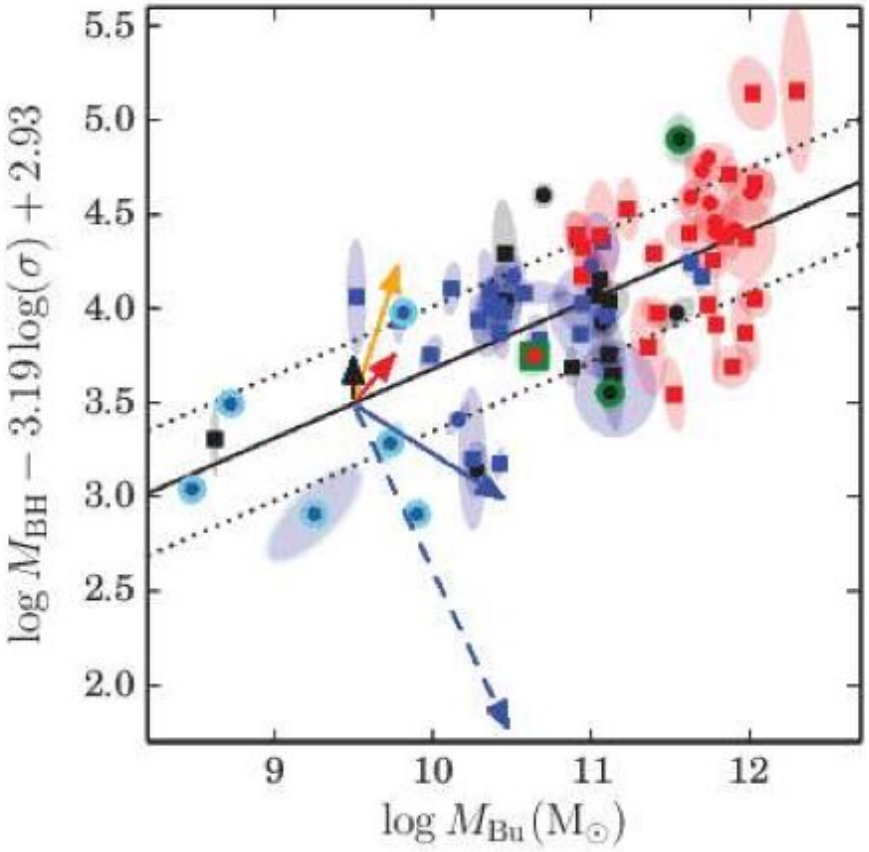
OLD DISK GALAXIES. BIG BHS.

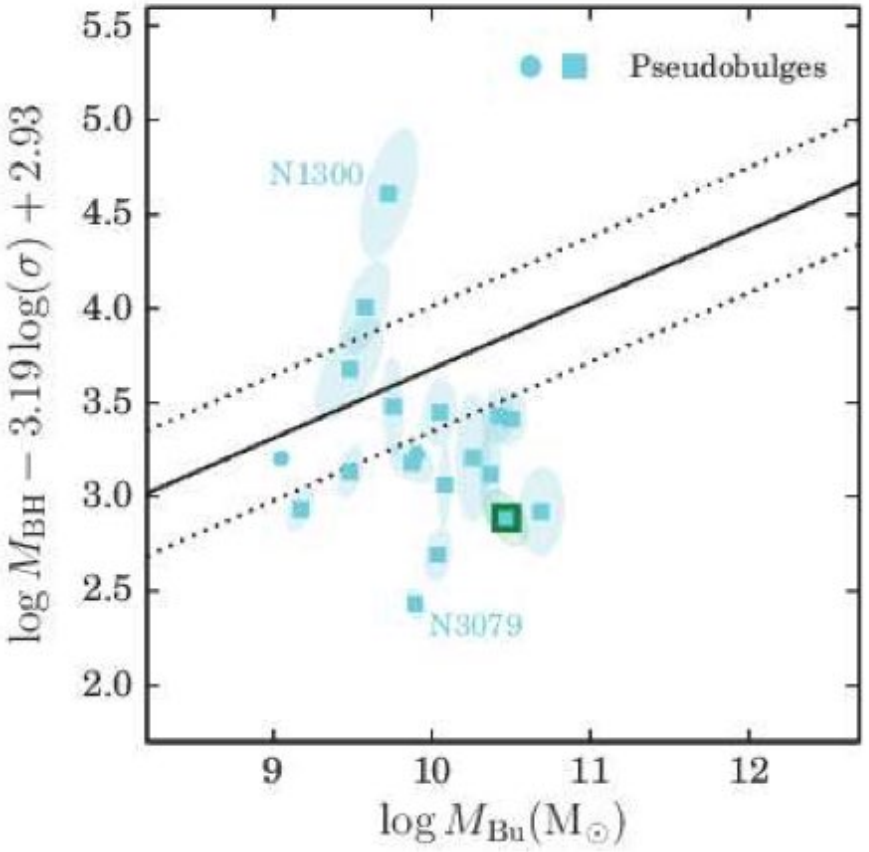


- No Classical Bulge, which implies no coevolution with a bulge. (Yildirim15a)
- Stellar ages >10 Gyr. Passively evolved relics from earlier times (Ferre-Mateu+15, Yildirim+15b)
- High stellar mass-to-light ratios (bottom heavy IMF?, Emsellem+13)
- Number densities are about 100 times lower than at z=2 (Saulder+15, Lasker+13)
- One with a particularly large amount of DM (NGC1281, Yildirim15b)
- **7 of these objects are included in the extension sample of the CALIFA DR3**


Biggest black holes do not reside in the biggest galaxies
NGC1277
NGC1275
NGC1270
NGC1271

MULTI-VARIATE RELATIONS DO NOT IMPROVE ANYTHING





I couldn't find any. And neither could anyone else (e.g. **Beifiori**+12,Saglia+16, vdB16b)

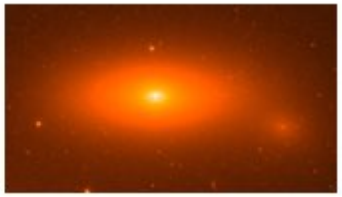
NEW BH COMPILATION

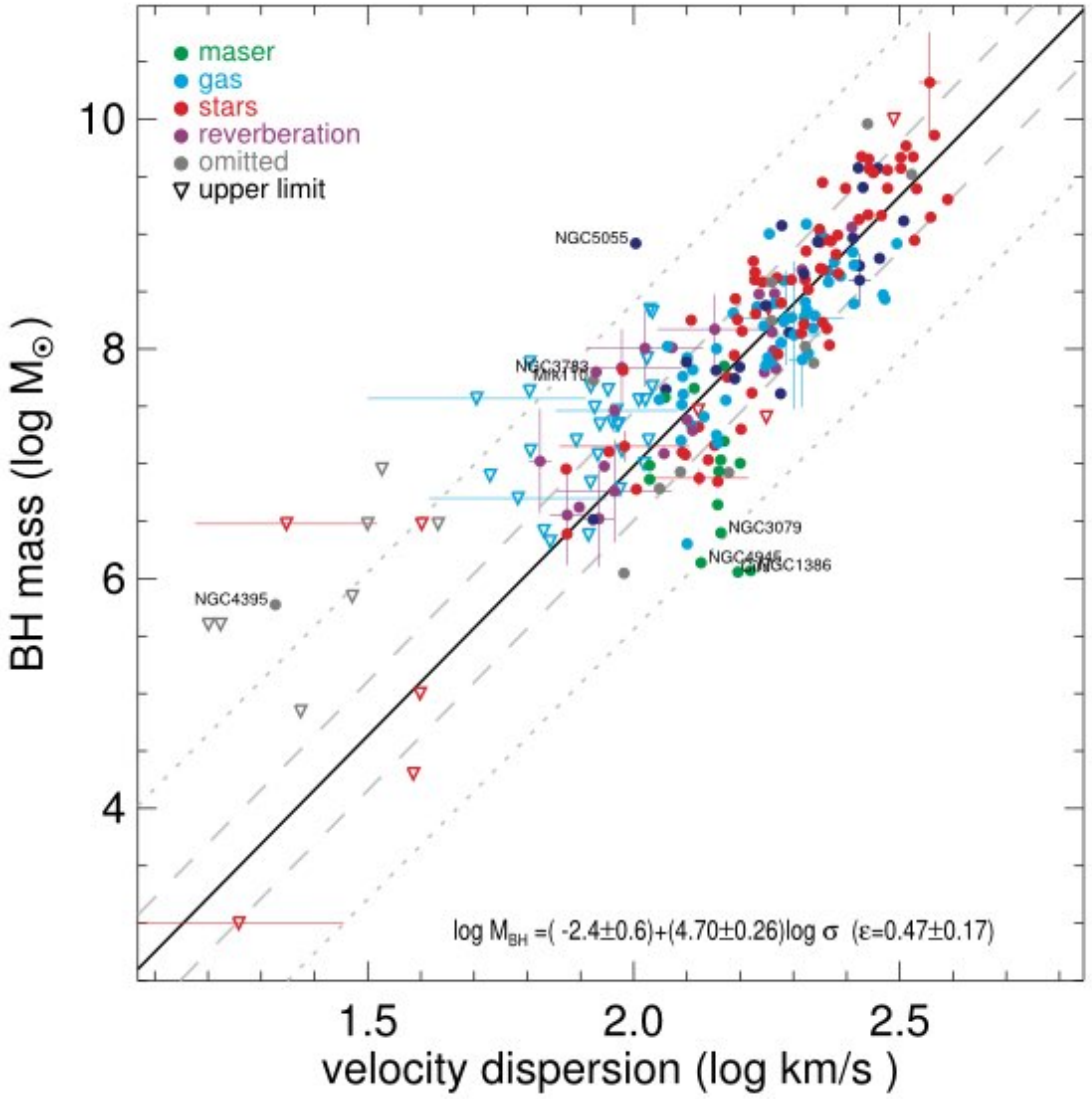
- Many more (local, resolved) BH estimates exist.
  - 20 `weird' masses that are excluded in previous compilations
  - 30 new or updated BH masses in the literature.
    - e.g. NGC1428 (Lyubenova+13), NGC4151 (Onken+15), NGC1097 (Onishi+15), nearby NSCs (Neumayer&Walcher12)
    - e.g. local group dwarfs M33, M110 w/o BHs (Merrit+01,Valluri02)
  - 80 (spirals) from HST/STIS spectroscopy (Beifiori+09&12)
  - 24 reverberation mapped AGN (Bentz&Katz15)
- Uniform photometric measurement from MC growth-curve fits to 2MASS images.

vdB16b, submitted

M-SIGMA IS UNIVERSAL

(INCLUDING SPIRALS, BULGE-LESS, *PSEUDO*-, ETC)

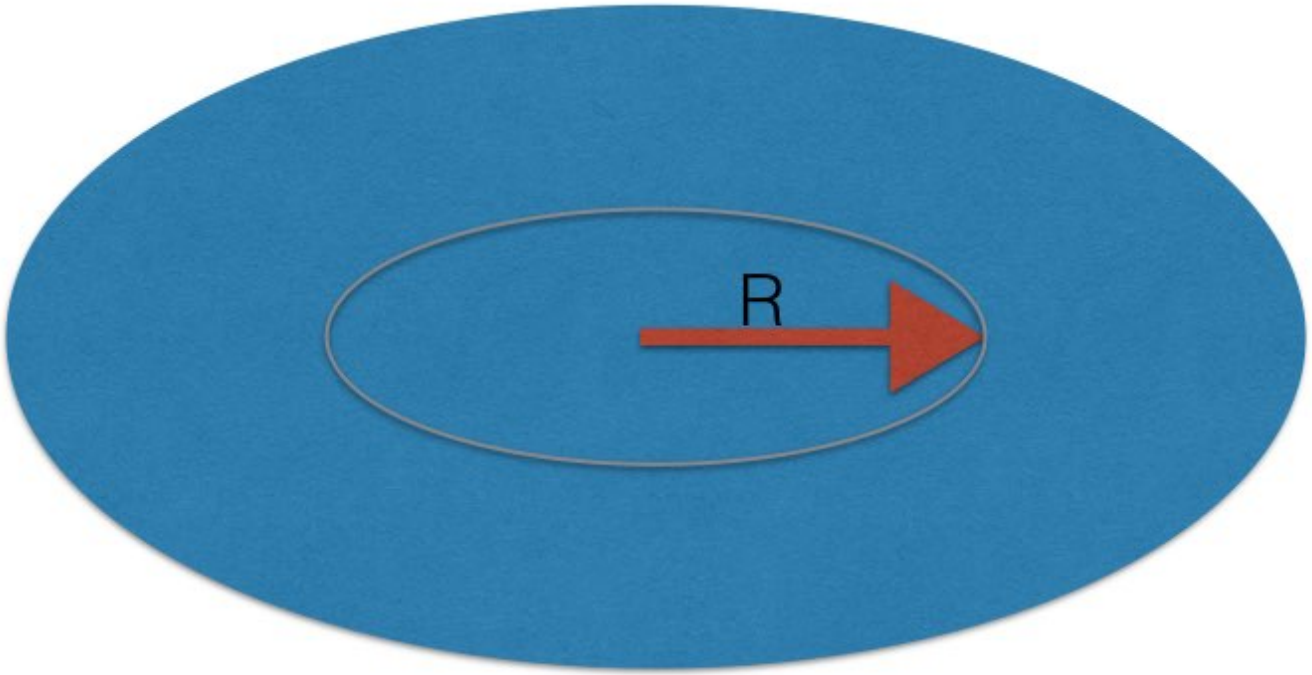




vdB16b, submitted

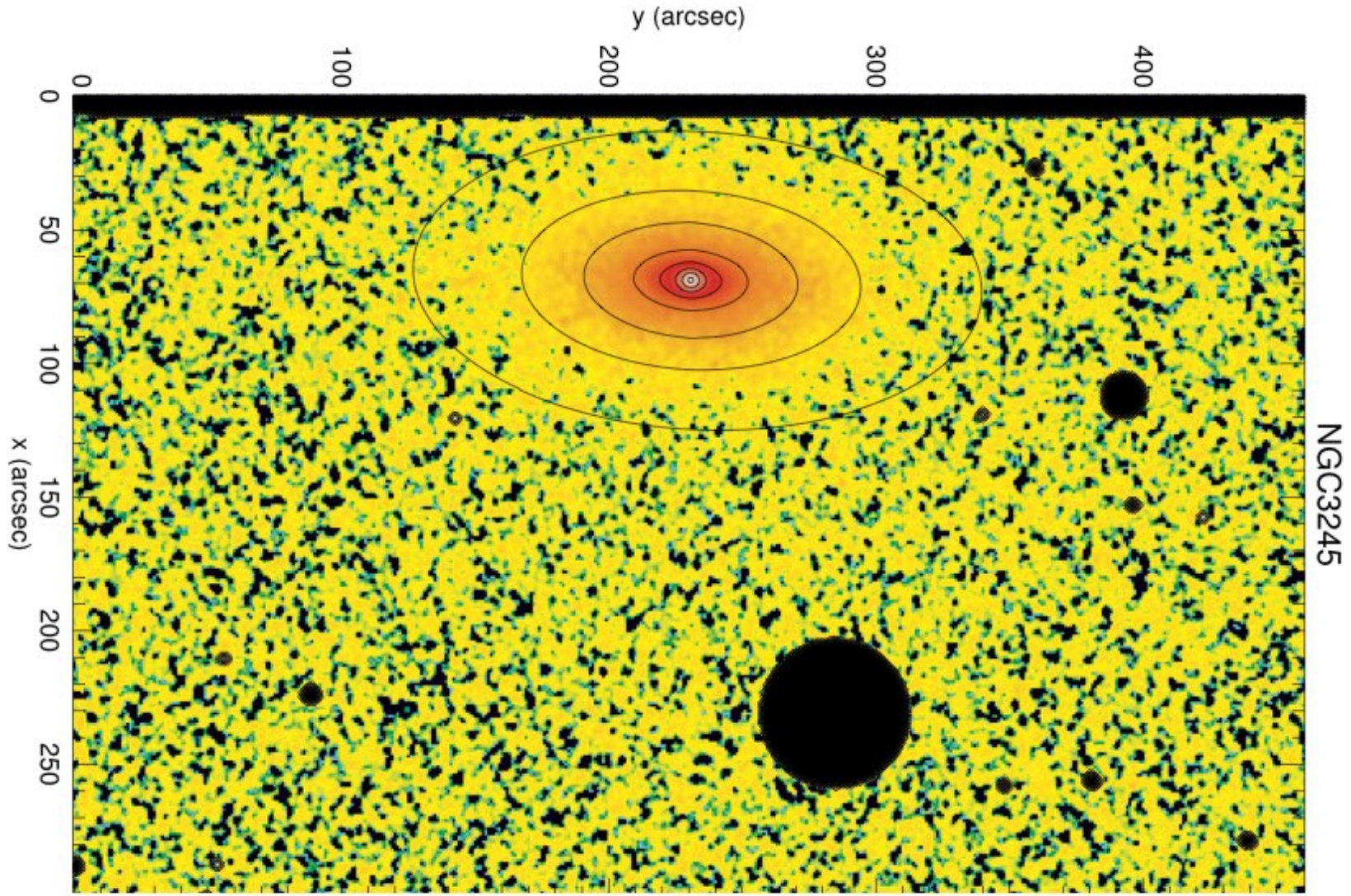
$$GM_{\frac{1}{2}} = R_{\frac{1}{2}} \left\langle V^2 + \sigma^2 \right\rangle_{\frac{1}{2}}$$

All kinetic energy in 3D



VIRIAL THEOREM

$$GM_{\frac{1}{2}} = R_{\frac{1}{2}} \left\langle V^2 + \sigma^2 \right\rangle_{\frac{1}{2}} \Rightarrow \sigma_e^2 = \frac{L_k}{R_e}$$



FUNDAMENTAL PLANE

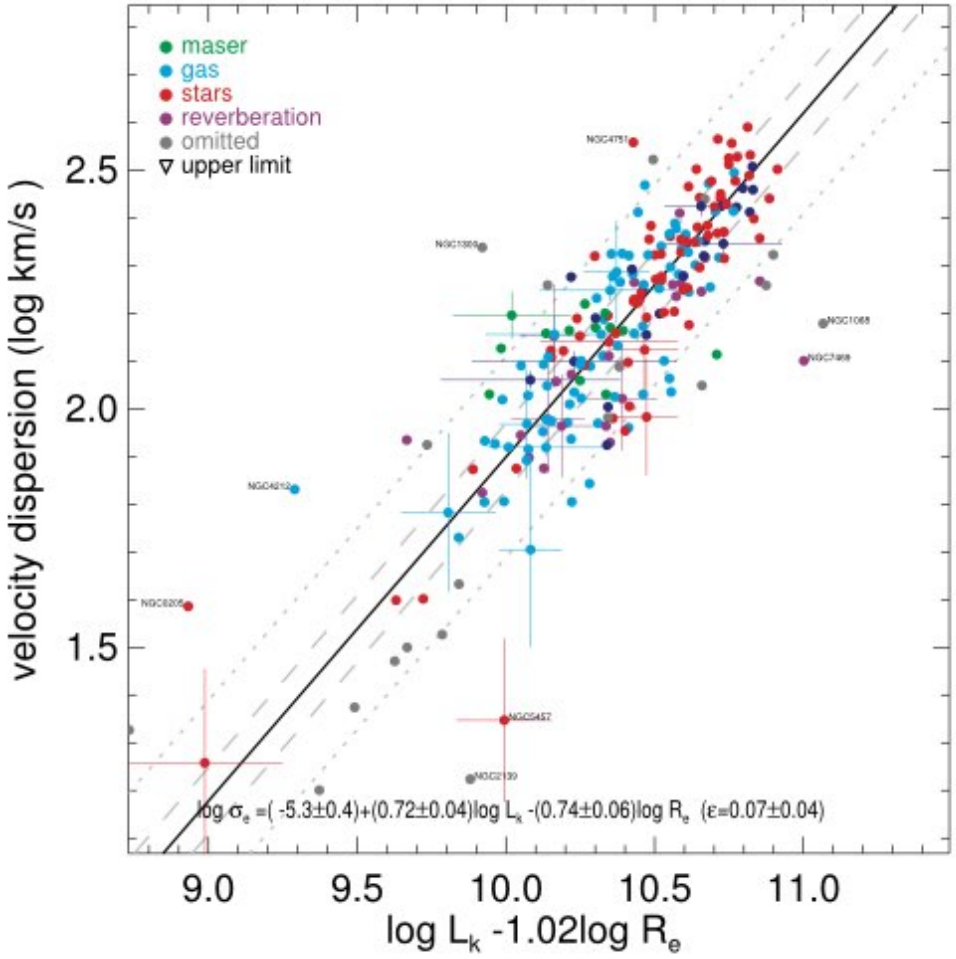
$$\sigma_e^2 = \frac{L_k}{R_e} \Leftrightarrow \sigma_e^{1.46} \propto \frac{L_k}{R_e}$$

- Not the first FP. Not the last.
- Scatter is 7 times smaller than M-sigma.
- Works for the all the galaxies, including spirals, bulge-less, etc.
  - The baryons dominate inside 1 Re.
  - Total luminosities and global half-light radius.
- The tilt is consistent with earlier works. (Cappellari+06, Bolton+08, Falcon-Barroso +08) Mass-to-light ratio scales with sigma:

$$M_\star/\bar{L}_K = \bar{0}.13\sigma_e^{0.40}.$$

$$GM_\star = \hat{9}.1\sigma_e^{1.86}R_e^{1.01}$$

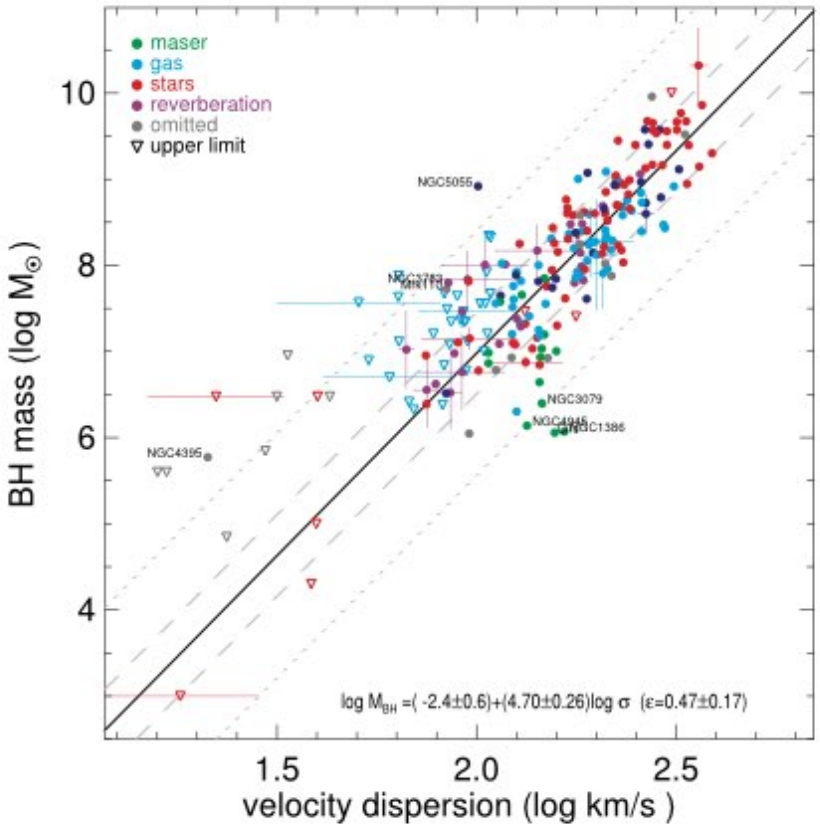
- Sigma is set by all the baryons. Not just by the *bulge*.

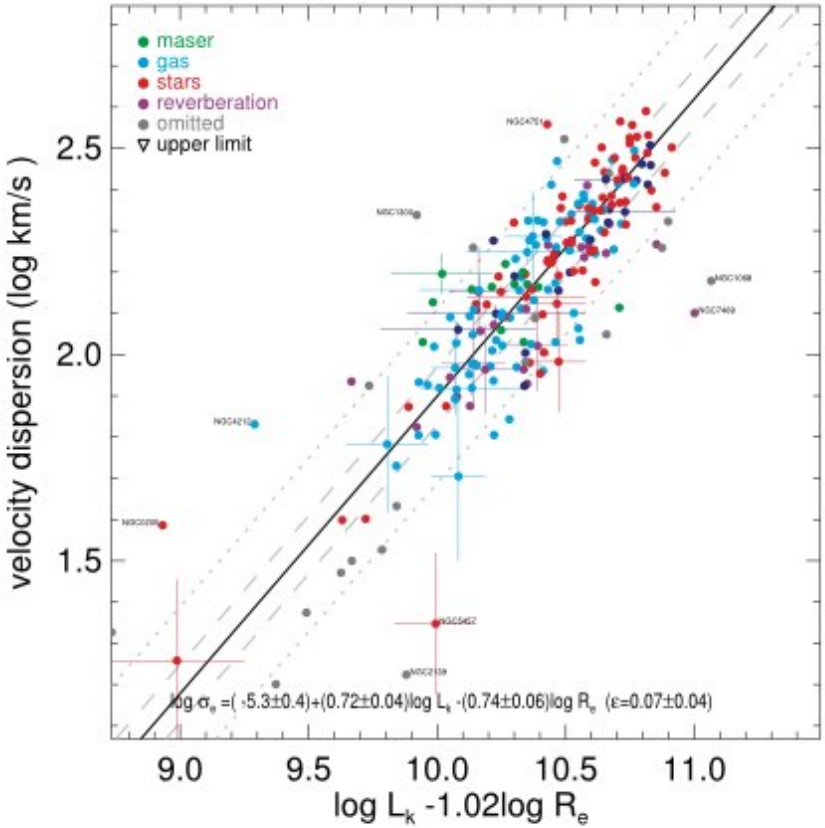


M-sigma + FP ?

$$M_\bullet \propto \sigma_e^{4.7}$$

$$\sigma_e^{1.46} \propto \frac{L_k}{R_e}$$



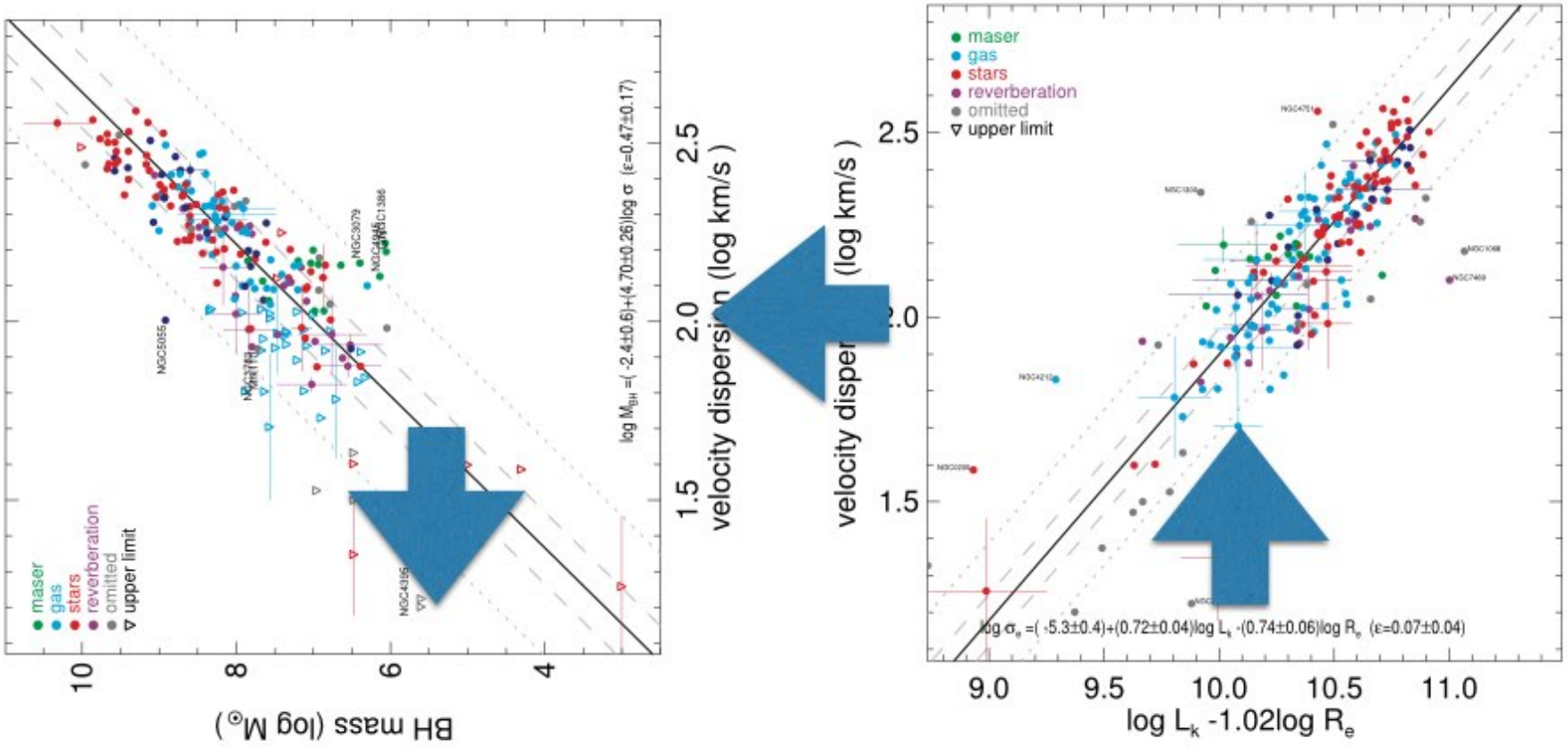


M-sigma + FP ?

$$M_\bullet \propto \sigma_e^{4.7}$$

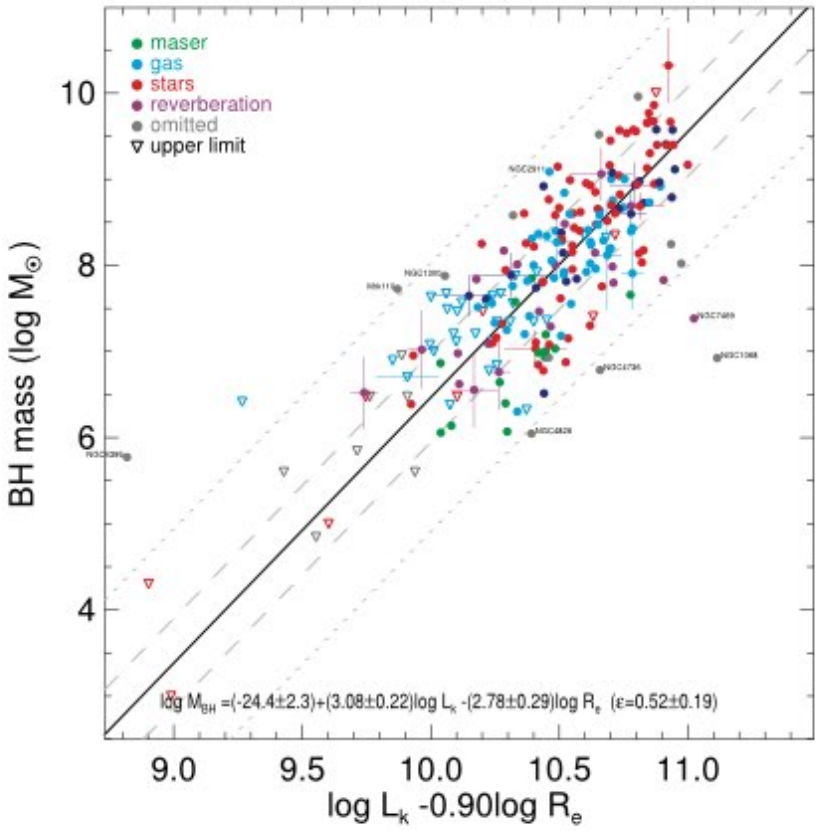
$$\sigma_e^{1.46} \propto \frac{L_k}{R_e}$$

$$M_\bullet \propto \left(L_k/R_e\right)^{?}$$

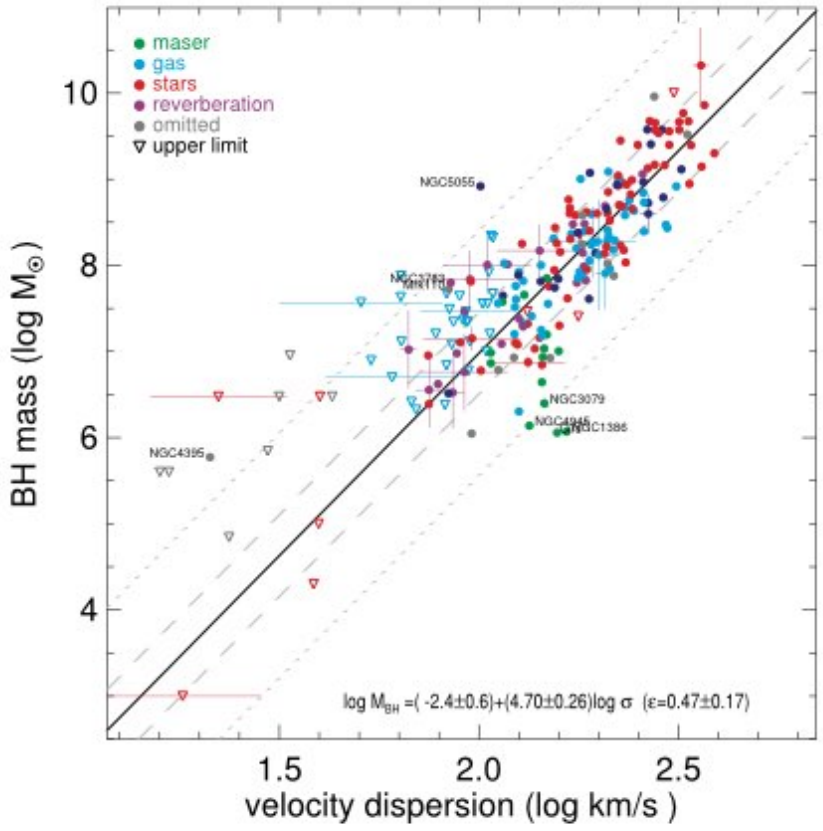


M-sigma is consistent with the FP!

$$M_\bullet \propto \left(L_k/R_e\right)^{3.2}$$



$$M_\bullet \propto \sigma_e^{4.7}$$

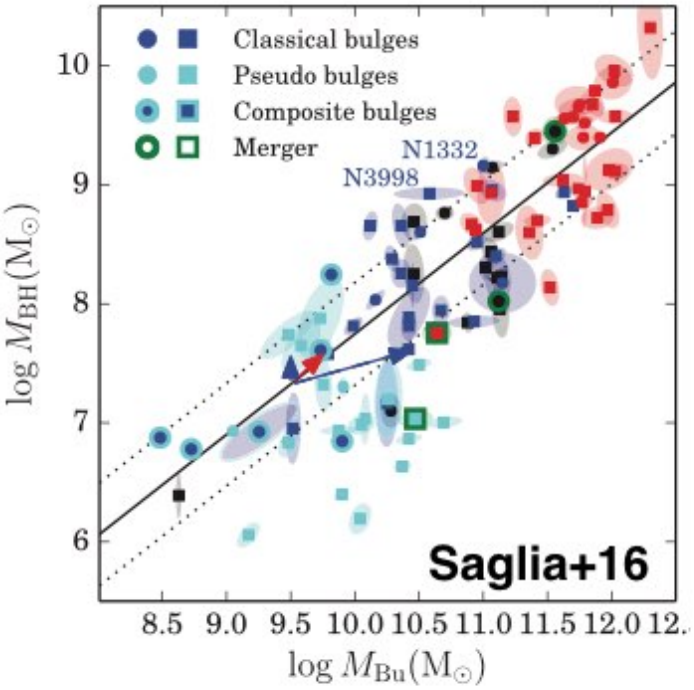


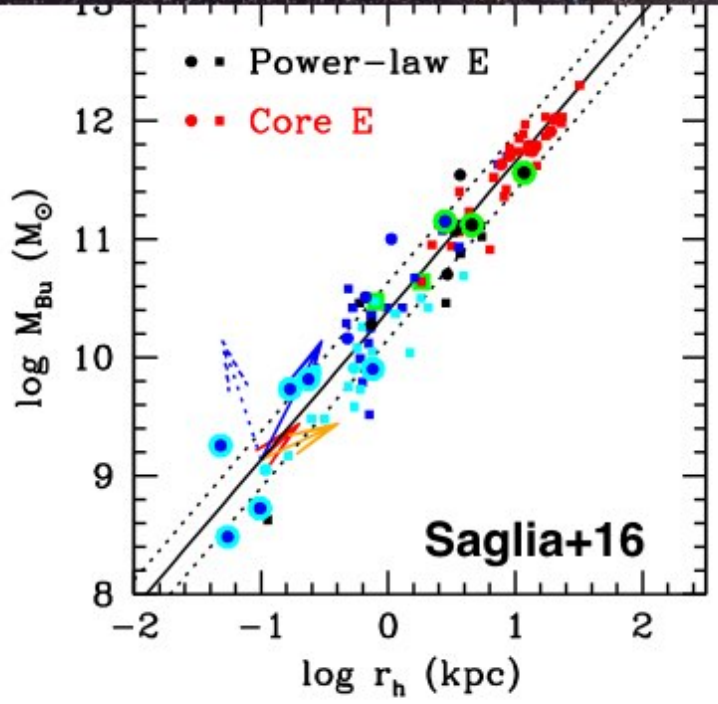
Bulges?

$$M_\bullet \propto M_{bulge}^{1.0}$$

$$M_\bullet \propto \left(\frac{M_\star}{R_e}\right)^{2.6}$$

van der Wel+14



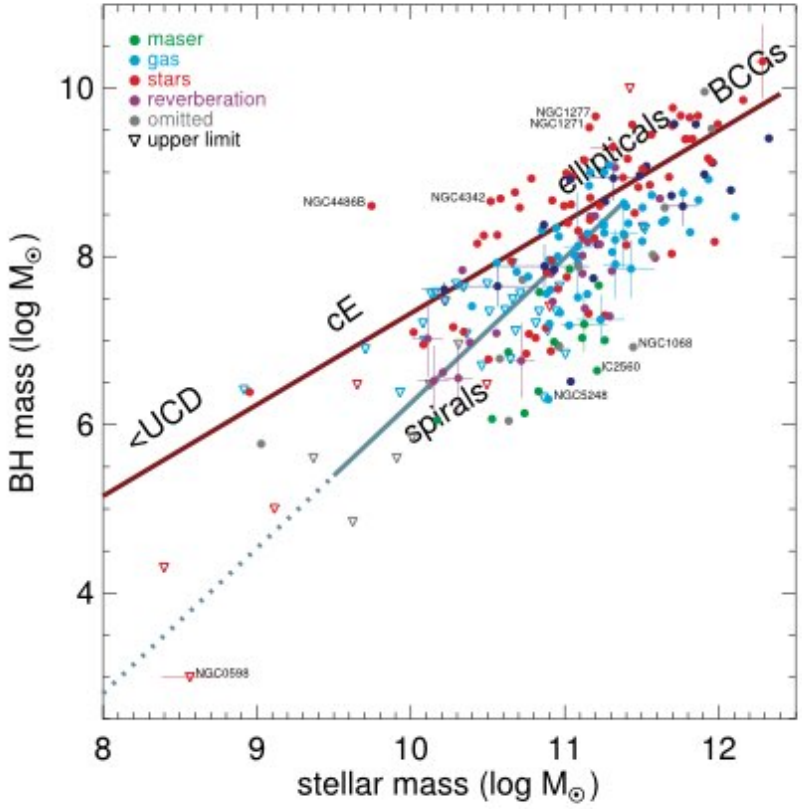


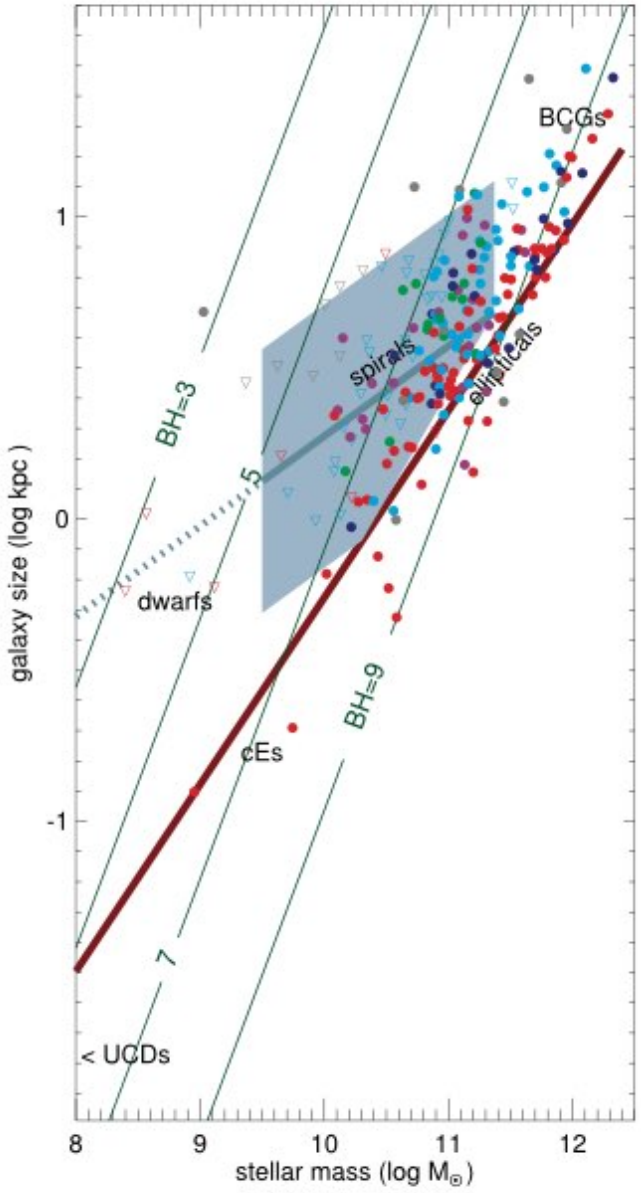
Turns out the bulge relation is just a projection

$$M_\bullet \propto M_{bulge}^{1.0}$$

$$M_\bullet \propto \left(\frac{M_\star}{R_e}\right)^{2.6}$$

$$R_e \propto M_\star^{0.6}$$





THEORIES...

Several explanations have been proposed for the existence of these empirical relationships

Prediction:

- direct **energy** or momentum feedback between the black hole and its host galaxy (Silk & Rees, Fabian, King & Pringle)

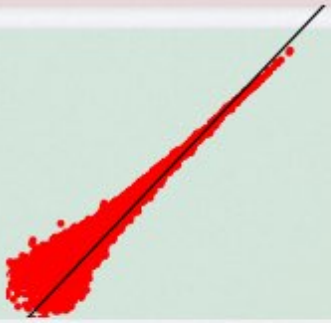
$$M_\bullet \propto \sigma^5$$

No scatter

- galaxy-galaxy merging and the subsequent violent relaxation and dissipation (e.g. Kormendy, Hopkins)

BH linked to galaxy bulge

- non-causal, statistical process of galaxy-galaxy merging (Peng 2007, Jahnke & Maccio 2010)



Scatter decreases with # mergers

Conclusions

- HET Massive Galaxy survey provides the necessary groundwork for future systematic black hole mass measurement campaigns.
- Compact galaxies have big BHs
  - appear very similar to high-redshift passive galaxies
- Galaxies obey tight network of dynamical scaling relations
  - The fundamental plane for the baryons
  - The M-sigma for the black holes or its other identity: $M_\bullet \propto \left(\frac{M\star}{R_e}\right)^{2.6}$
- The M-sigma is universal and works for all galaxies.
  - Bulges are certainly not the best BH mass predictor.

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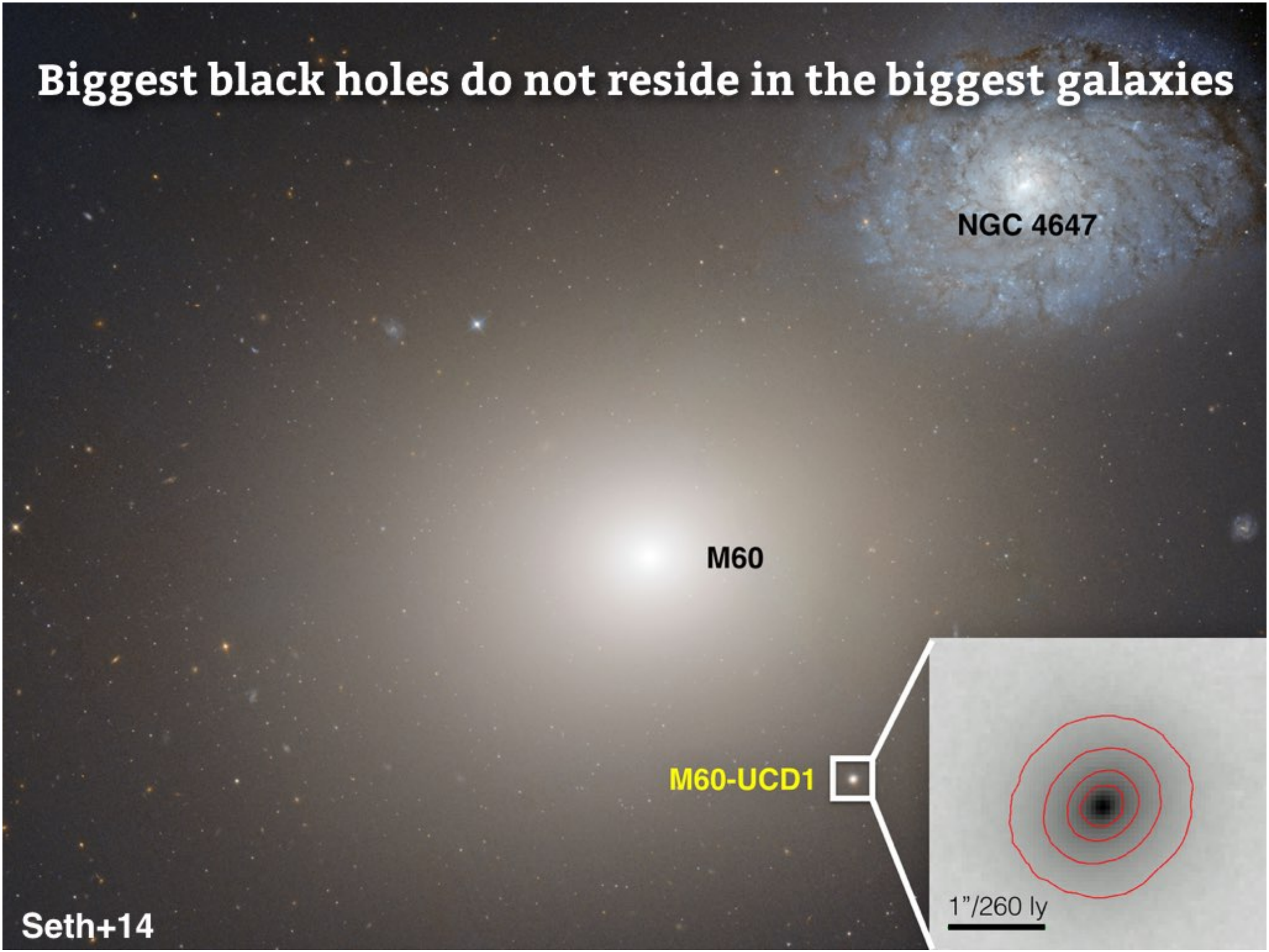
Biggest black holes do not reside in the biggest galaxies
NGC 4647
M60
M60-UCD1
1"/260 ly
Seth+14