Black Holes in Dwarf Galaxies and Star Clusters

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Collaborators:
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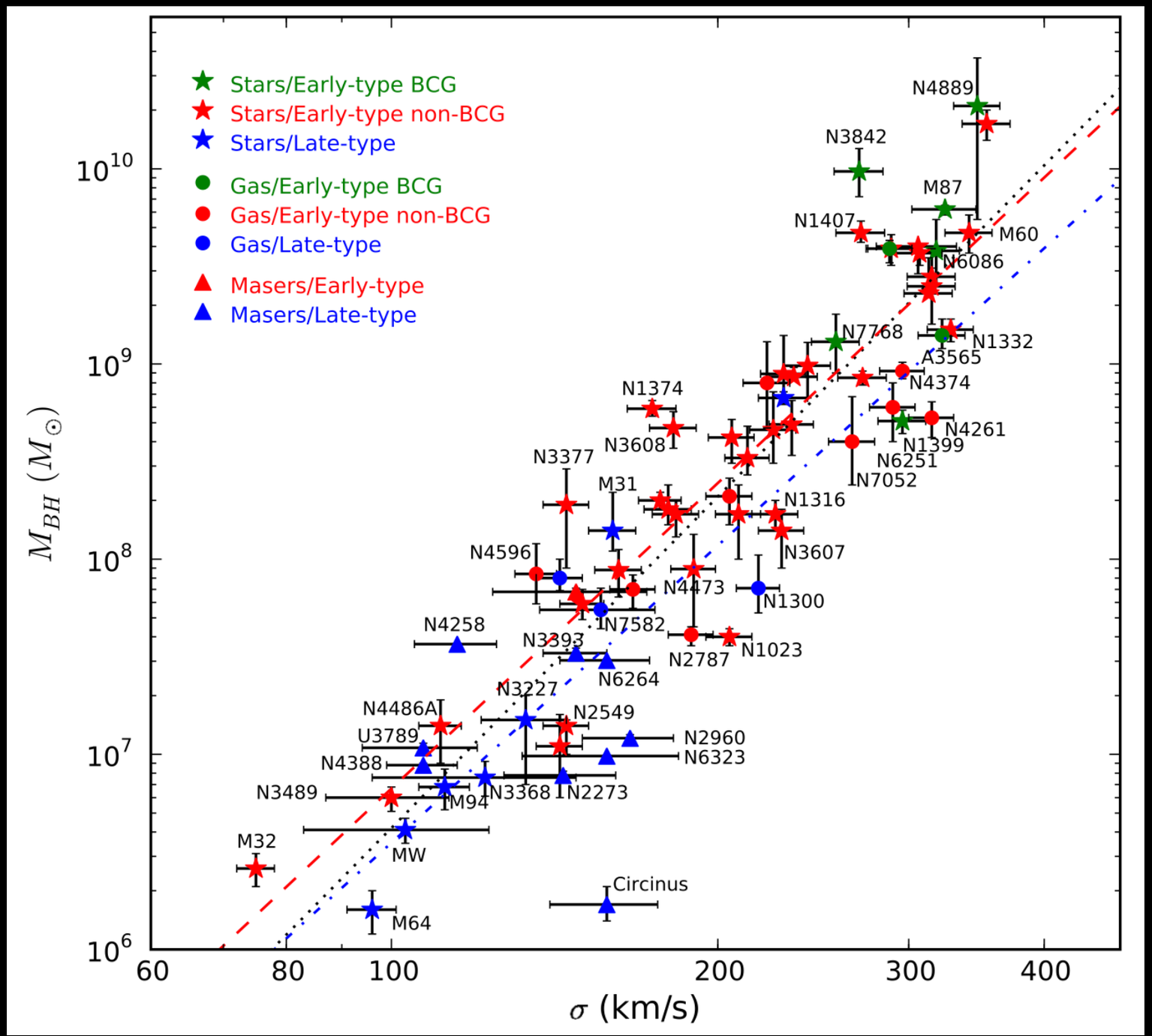
Mieske, Neumayer,
Strader, Chomiuk, van
den Bosch, Hilker,

Dynamical BH masses

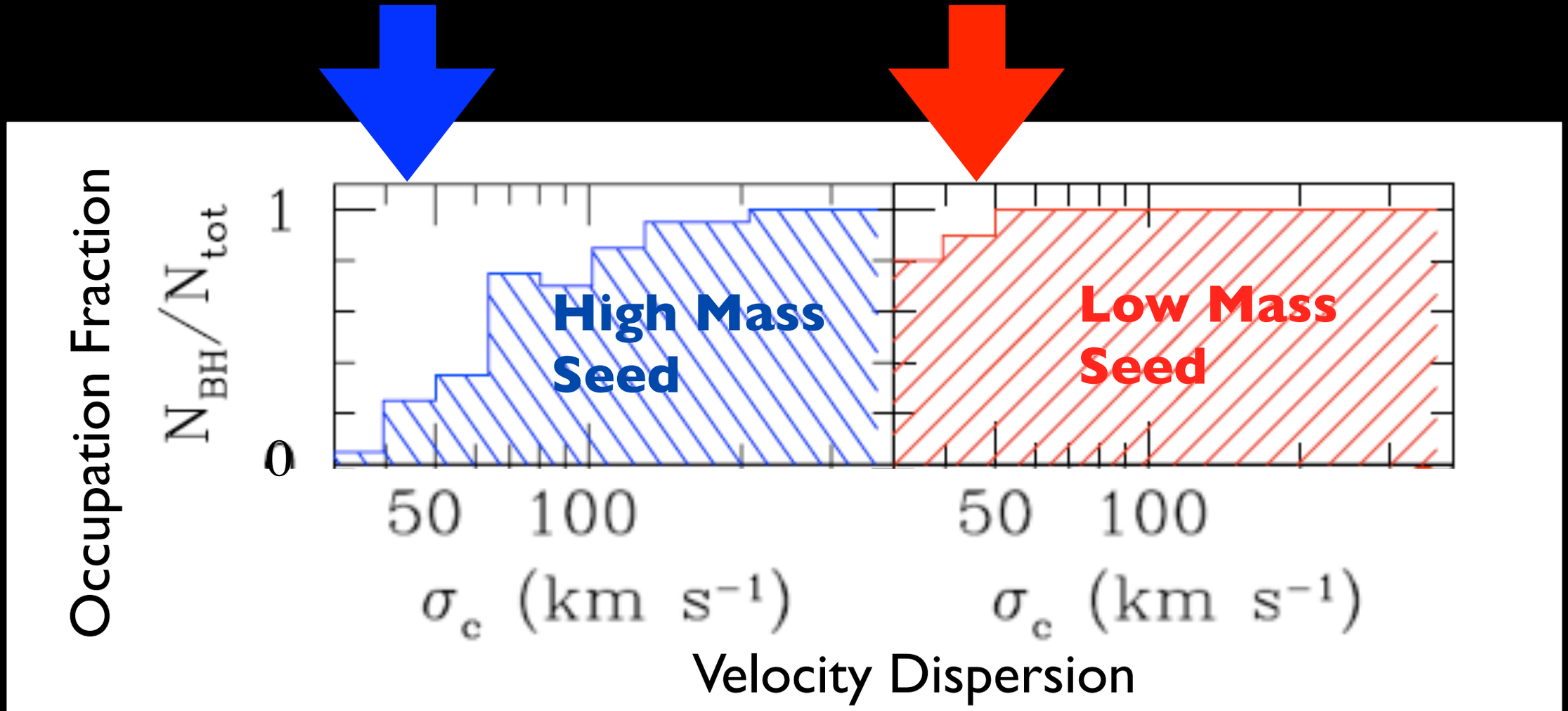


- Stellar kinematics
- Gas kinematics
- Masers

- No BHs under 1 million Msol: at 65 km/s sphere of influence is 1 pc; 0.05” at 4 Mpc.

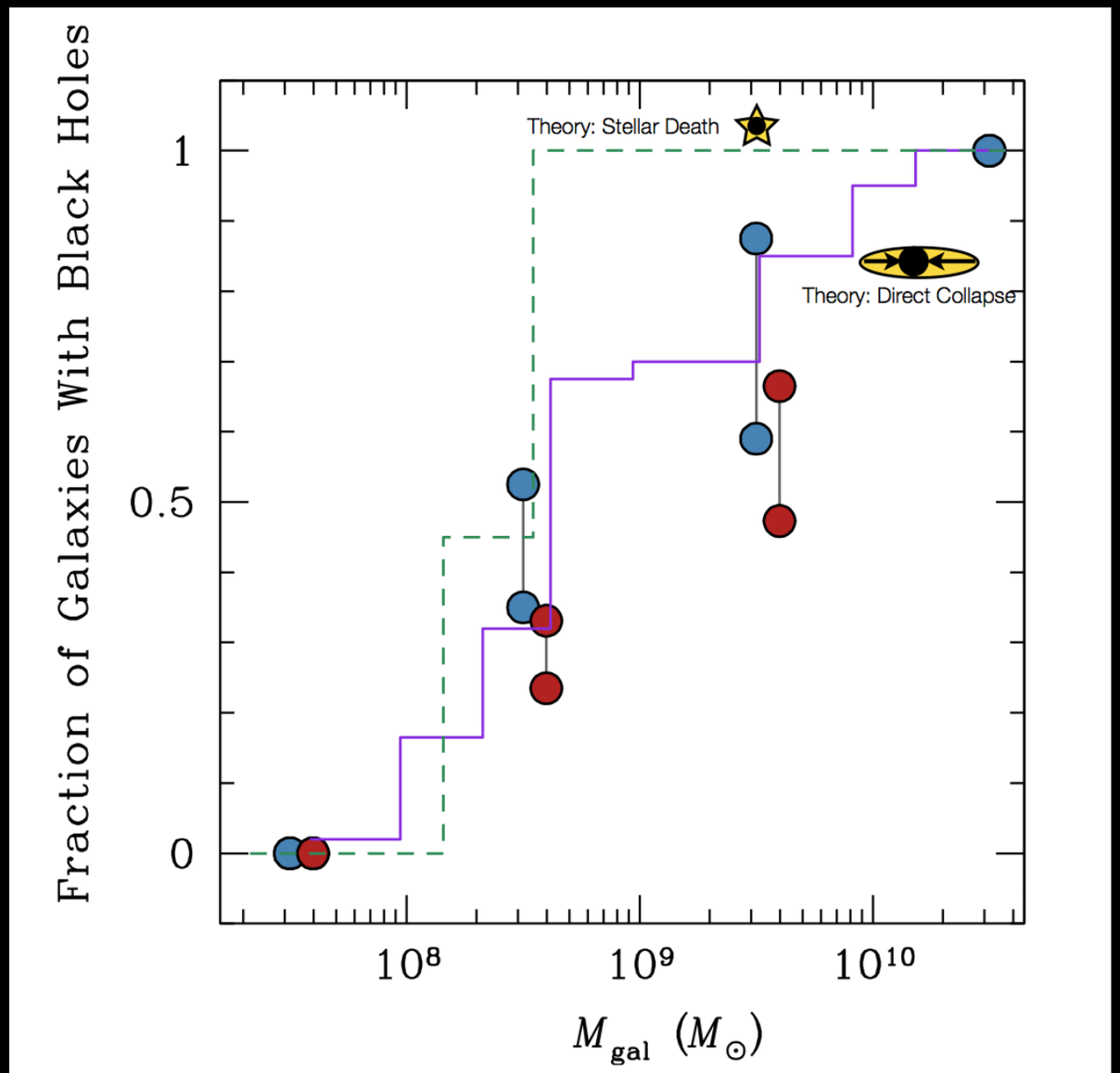
McConnell & Ma 2013

Black Holes in Low Mass Galaxies



Volonteri+ 2008

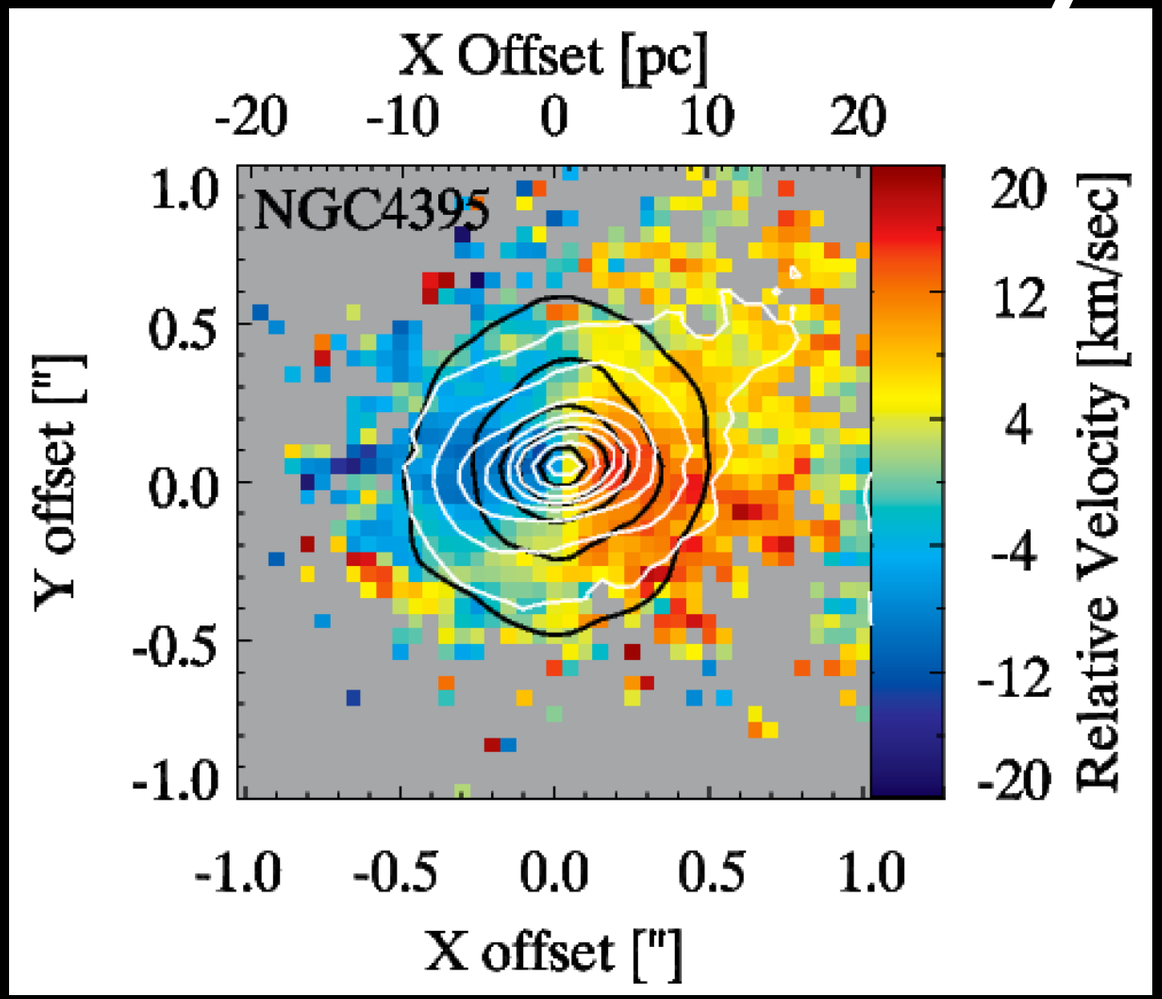
Do they exist? Accretion

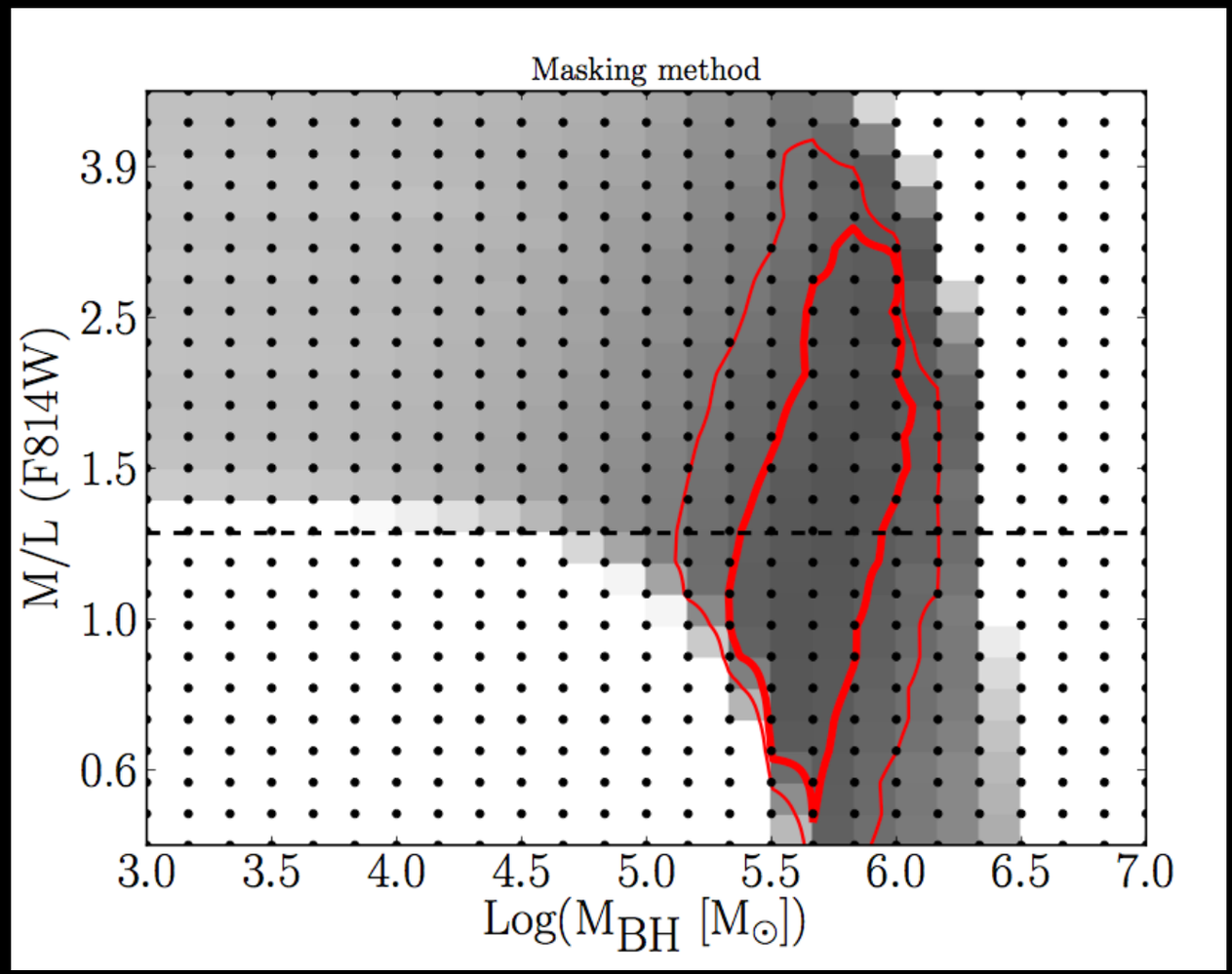


Greene 2012

- Best constraints: X-ray observations (Gallo+ 2010, Miller+ 2014)
- Galaxy type variation?
- Lowest mass galaxy with black hole ~3×10^8 $M_\odot$ (Maksym+ 2014, Moran+ 2014, Reines+ 2014)

What do they weigh?
Dynamics



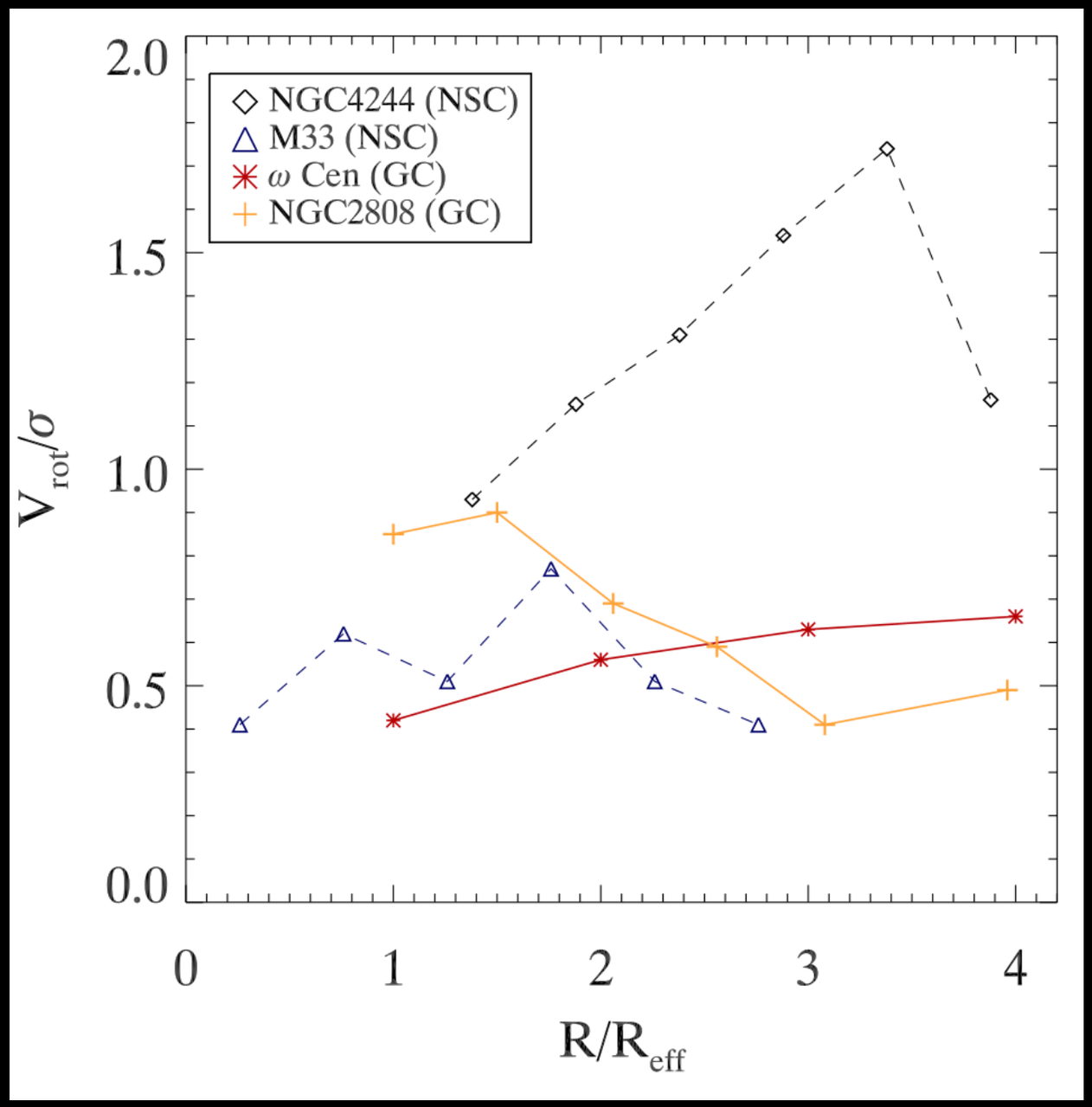


Dynamical Mass Measurement in NGC4395
postdoc Mark den Brok, *submitted*

Globular Clusters & UCDs as stripped galaxy nuclei

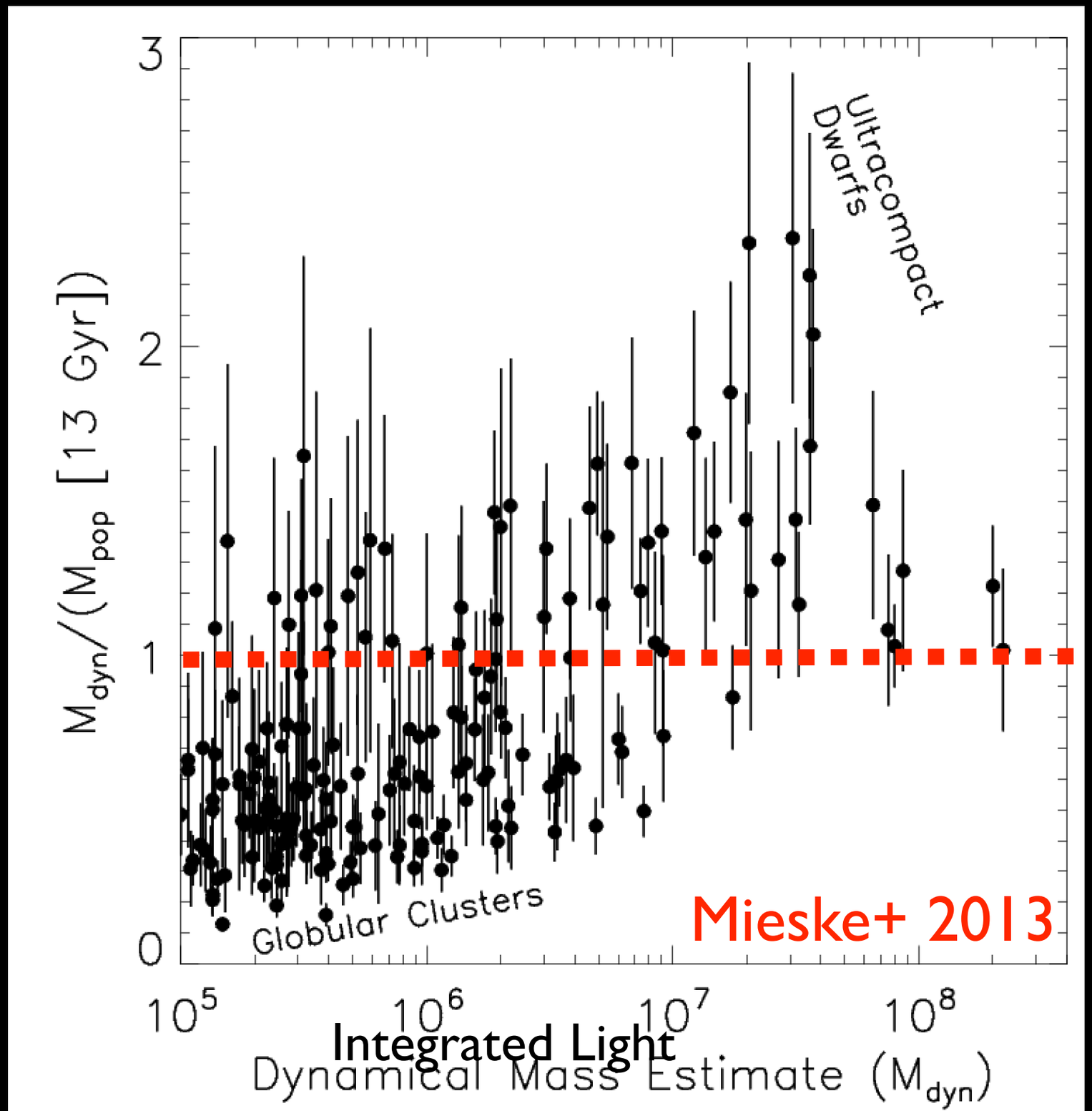
- Black Holes provide evidence for this
- Opportunity to study low mass central black holes
- Comparable number of present day nuclei vs. massive UCDs in Fornax (Hilker+ 2010, Mieske+ 2011)
- Local Group Nuclear Star Clusters (6 nuclei > $1.4 \times 10^6 M_\odot$) vs. globular clusters (19 above this mass)

What might indicate a stripped nuclear star cluster?
Helps to know how NSCs form.



- Multiple populations with large age spread or spatial separation (Walcher+, Rossa+, Seth+ 2006; Chilingarian+ 2008, Janz+ 2015, Carson+ 2015)
- Rotation? (Seth+ 2008, Feldmeier+2014, Seth+ *in prep*)
- Abudance Spreads, High Metallicity?
- A Black Hole (Frank+ 2011)

Black Holes in UCDs?



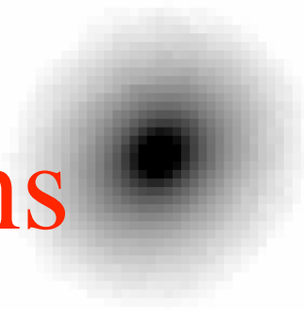
- Integrated spectra mass estimates assume mass traces light.
- ~10% mass black holes required (Mieske+ 2013)
- IMF variations (Dabringhausen) and tidal effects (Forbes+ 2014)?

Messier 60

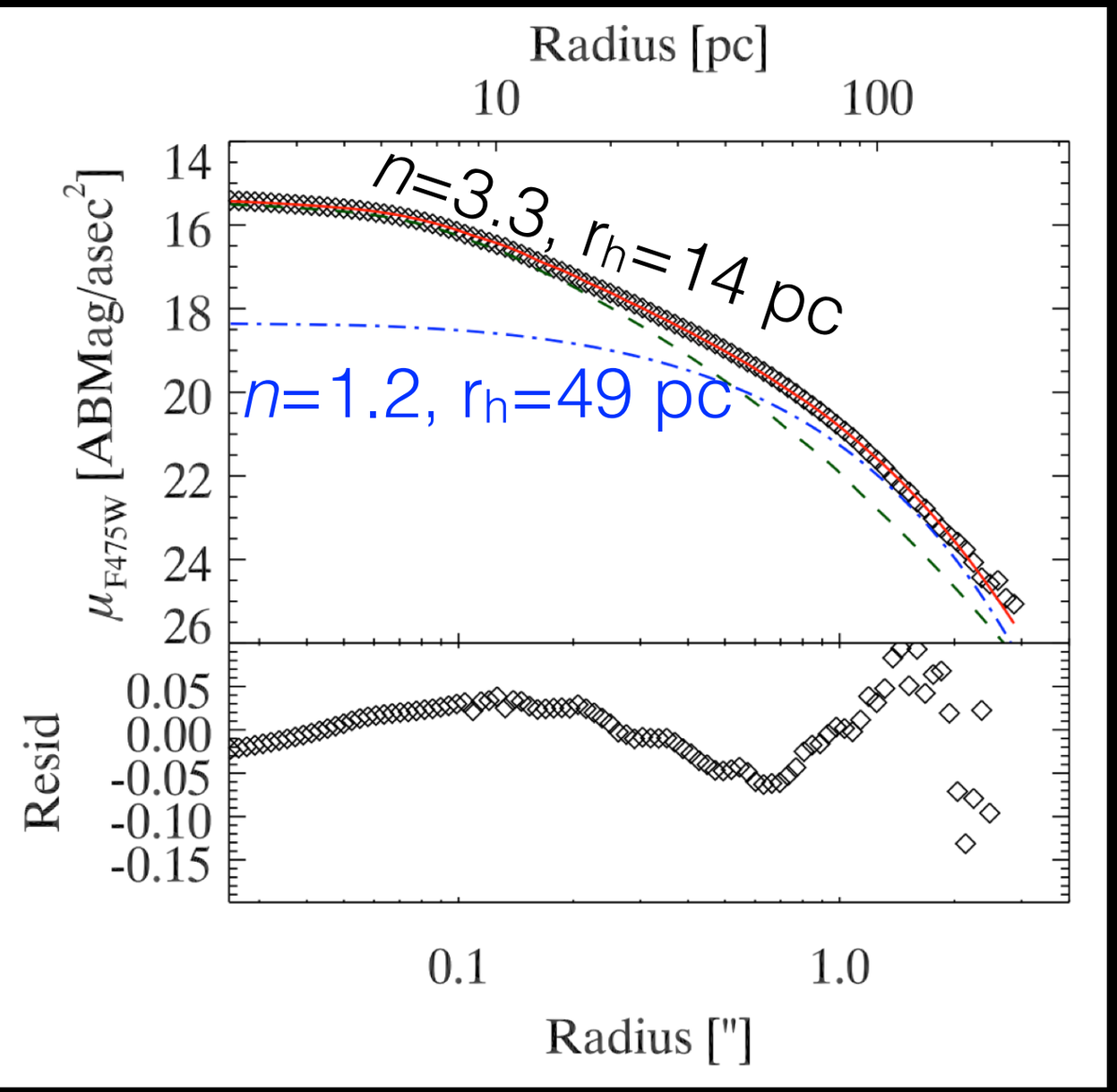
1) 4.5 billion suns

3) 21 million suns

M60-UCD1

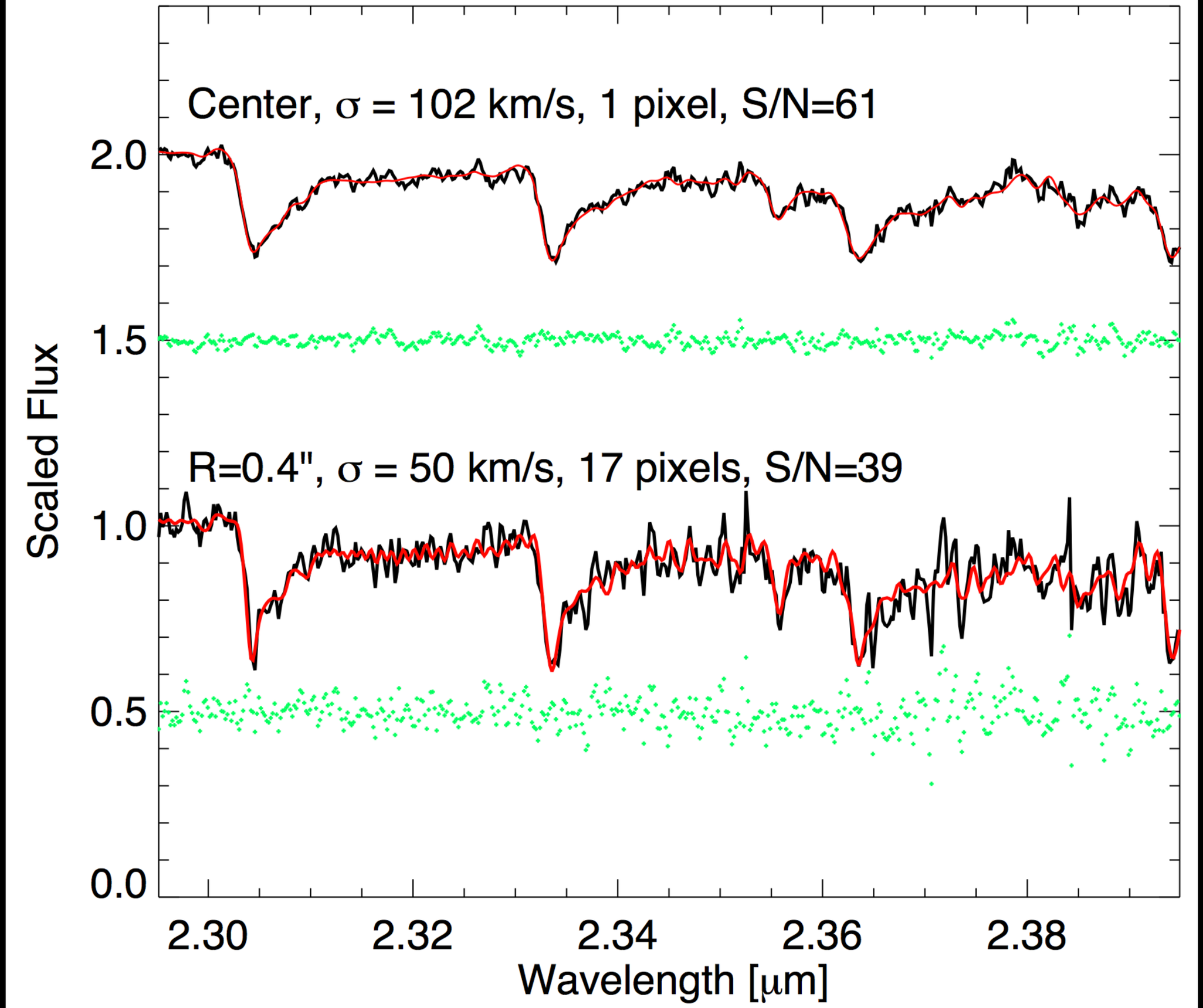


M60-UCD1 the "densest galaxy"

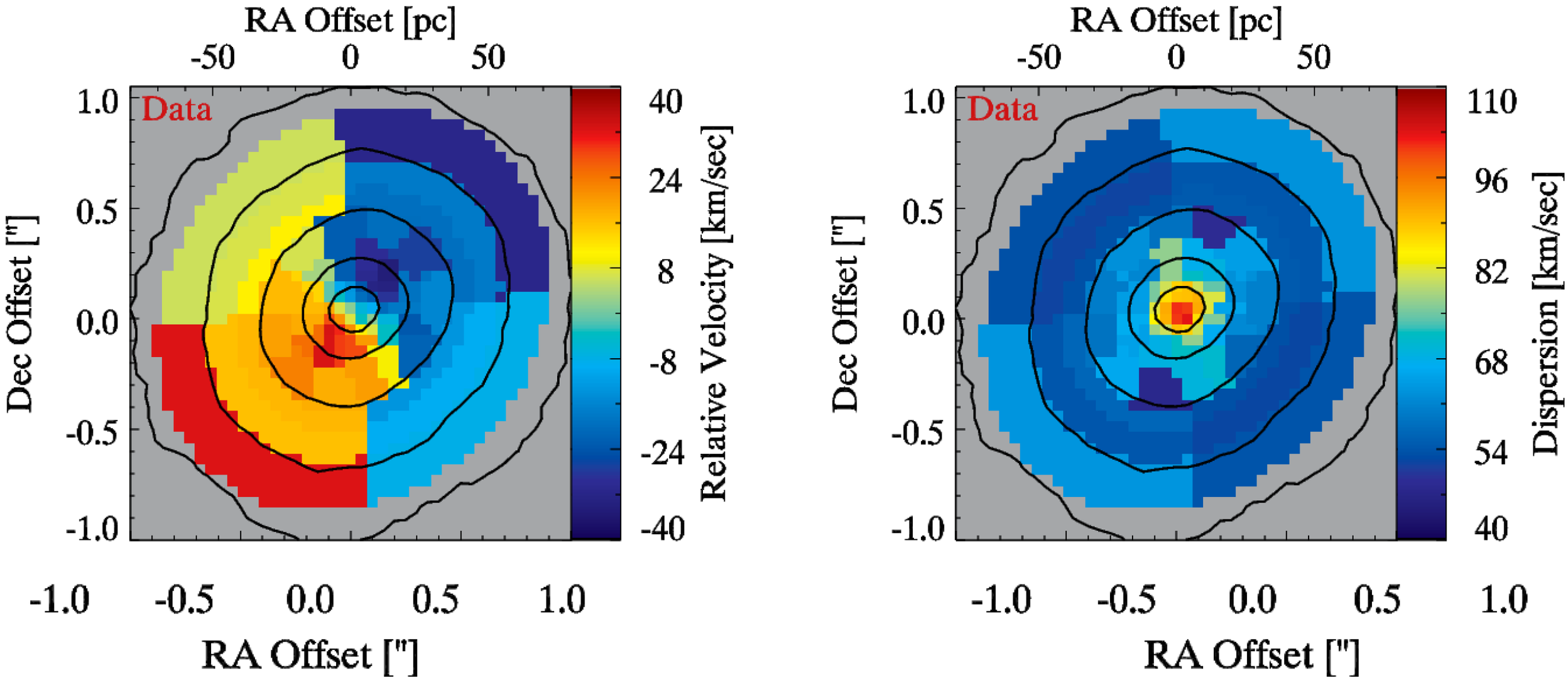


Strader, Seth+ 2013

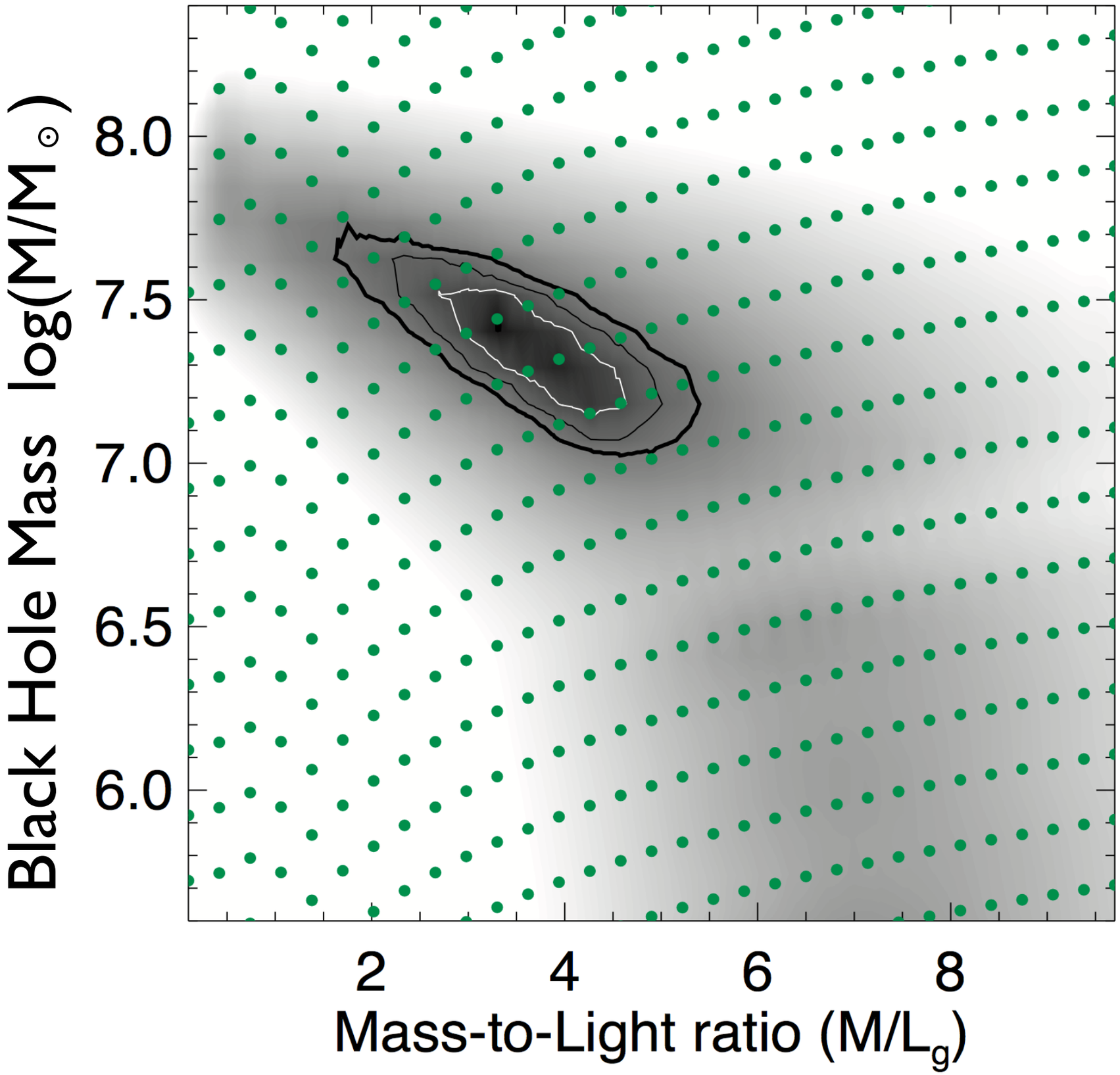
- R_h = 24 pc, LV=4.1x10^7 L$_\odot$
- Integrated σ=68±5 km/s suggests 2x10^8 M$_\odot$
- Solar metallicity, α-enhanced ([N/Fe]=+0.6)
- Variable X-ray source, LX=1.3x10^{38} erg/s
- Two Sérsic best fit



Seth+ 2014, Gemini/NIFS LGSAO spectra



- Dispersion peak is >100 km/s (integrated=68 km/s)
- Rotation of ~40 km/s



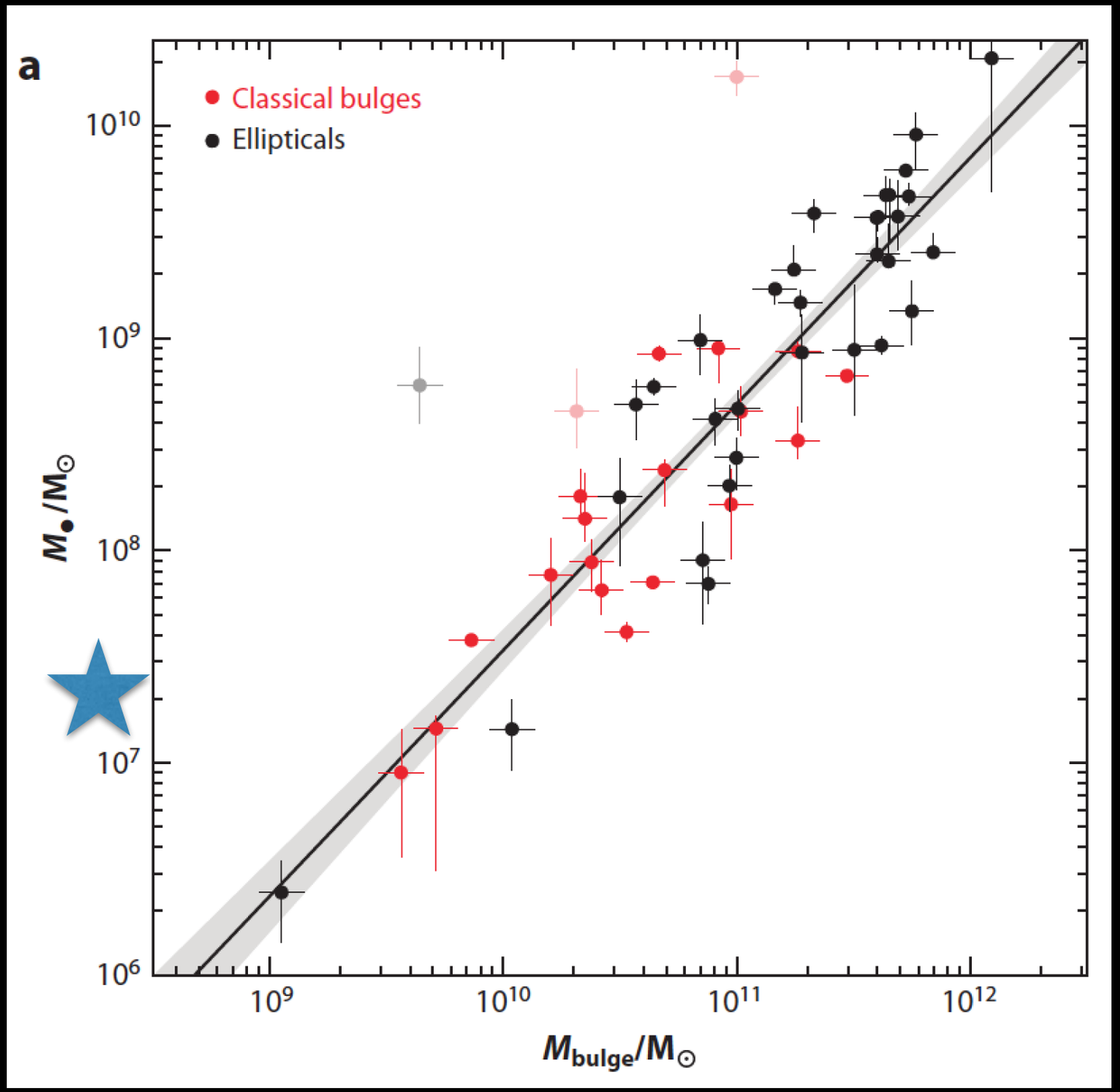
Constant M/L Schwazschild models (van den Bosch+ 2008,2010)

Best fit BH mass

$2.1^{+1.4}_{-0.7} \times 10^7\ \mathrm{M}_\odot$

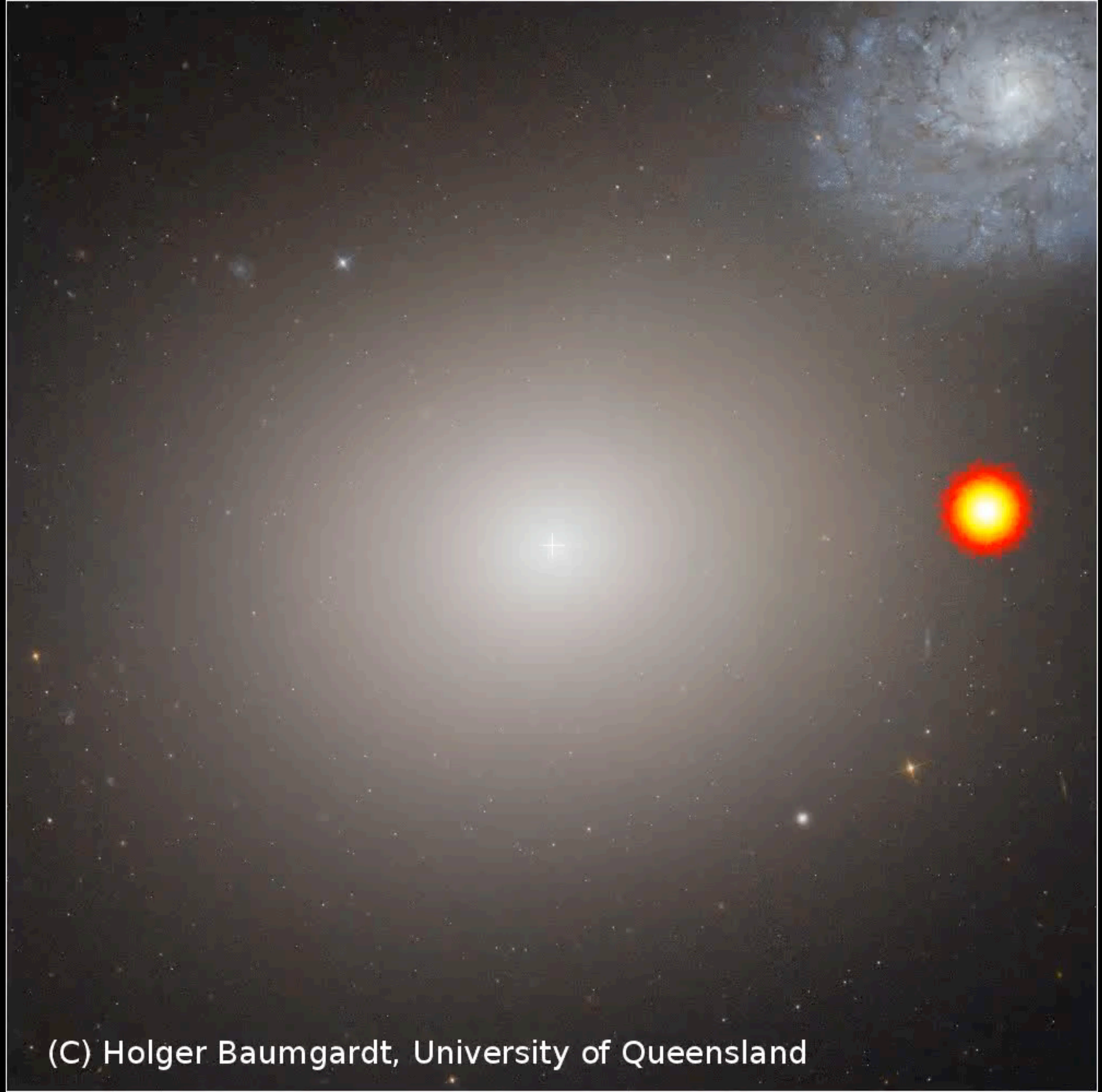
Best fit no BH model $\Delta\chi^2 = 20$ (>4σ)

M60-UCD1 in context



- Lowest mass system ($1.2 \times 10^8\ M_\odot$) known with a supermassive black hole (dynamical or accretion evidence)
- 15% BH mass fraction comparable to NGC 4486B

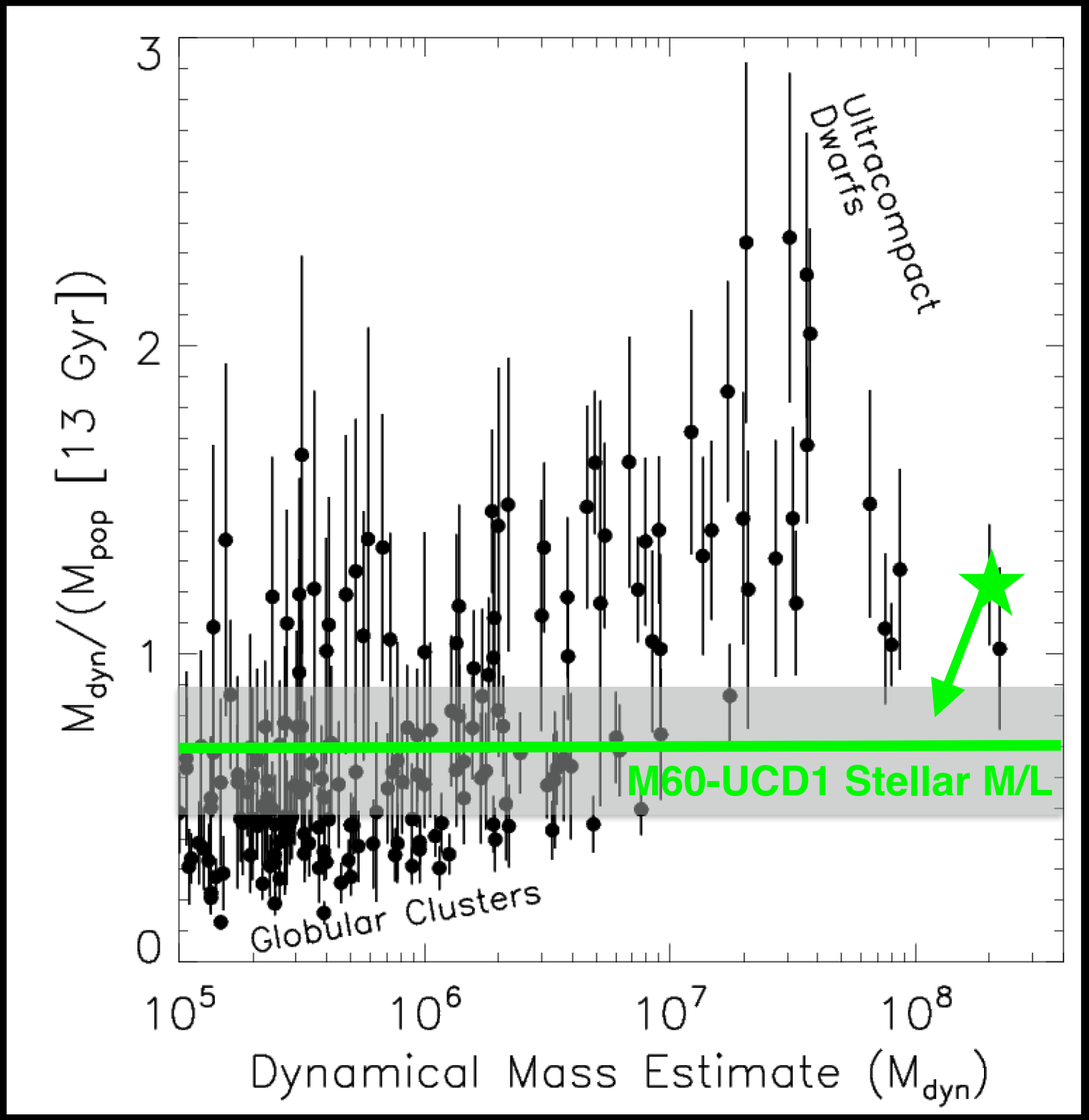
Kormendy & Ho 2013



Consistent with nuclear clusters (and black holes?) in $\sim 10^{10}\,M_\odot$ progenitor.

Many more black holes?

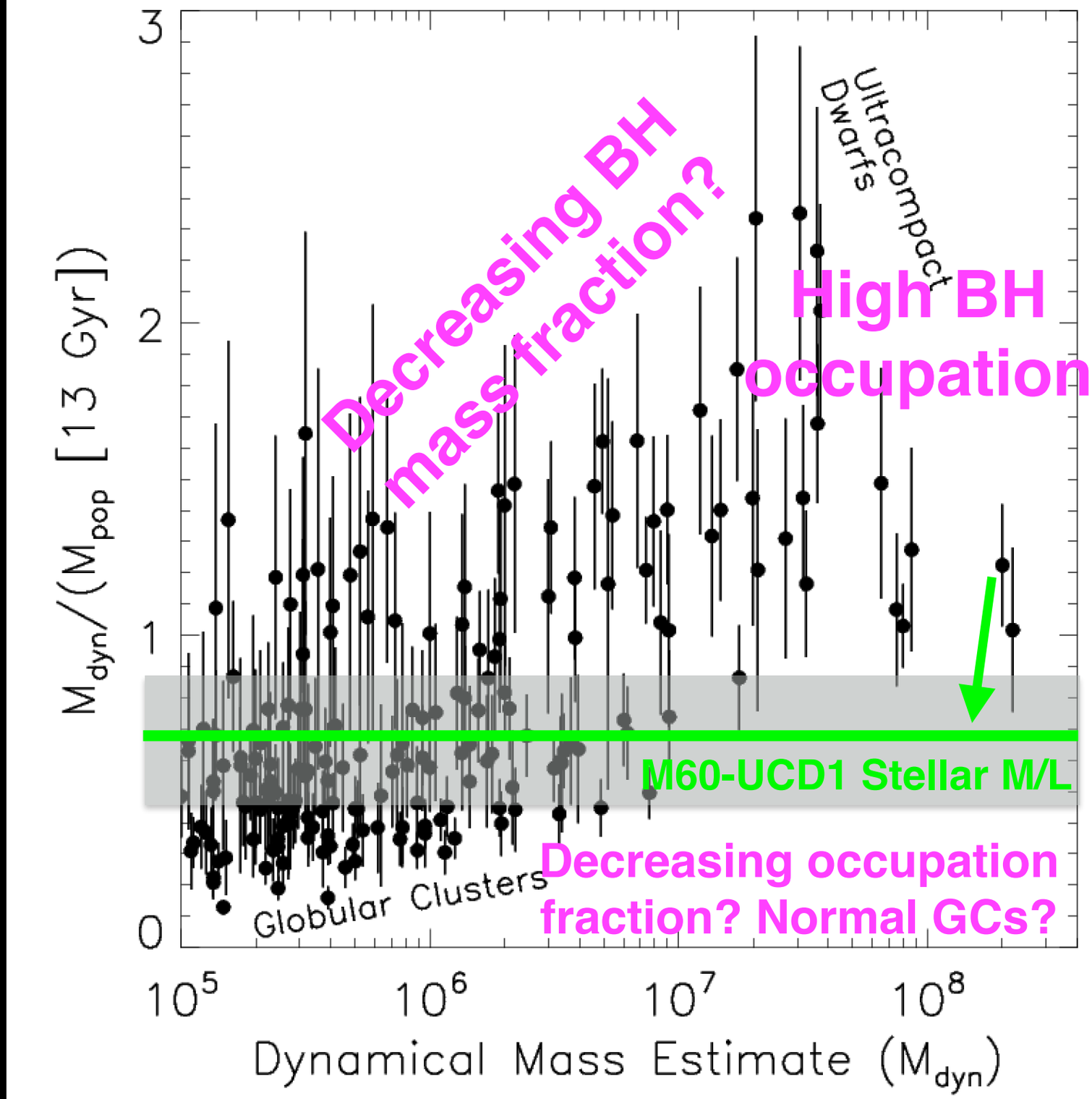
Adopted from Mieske+ 2013



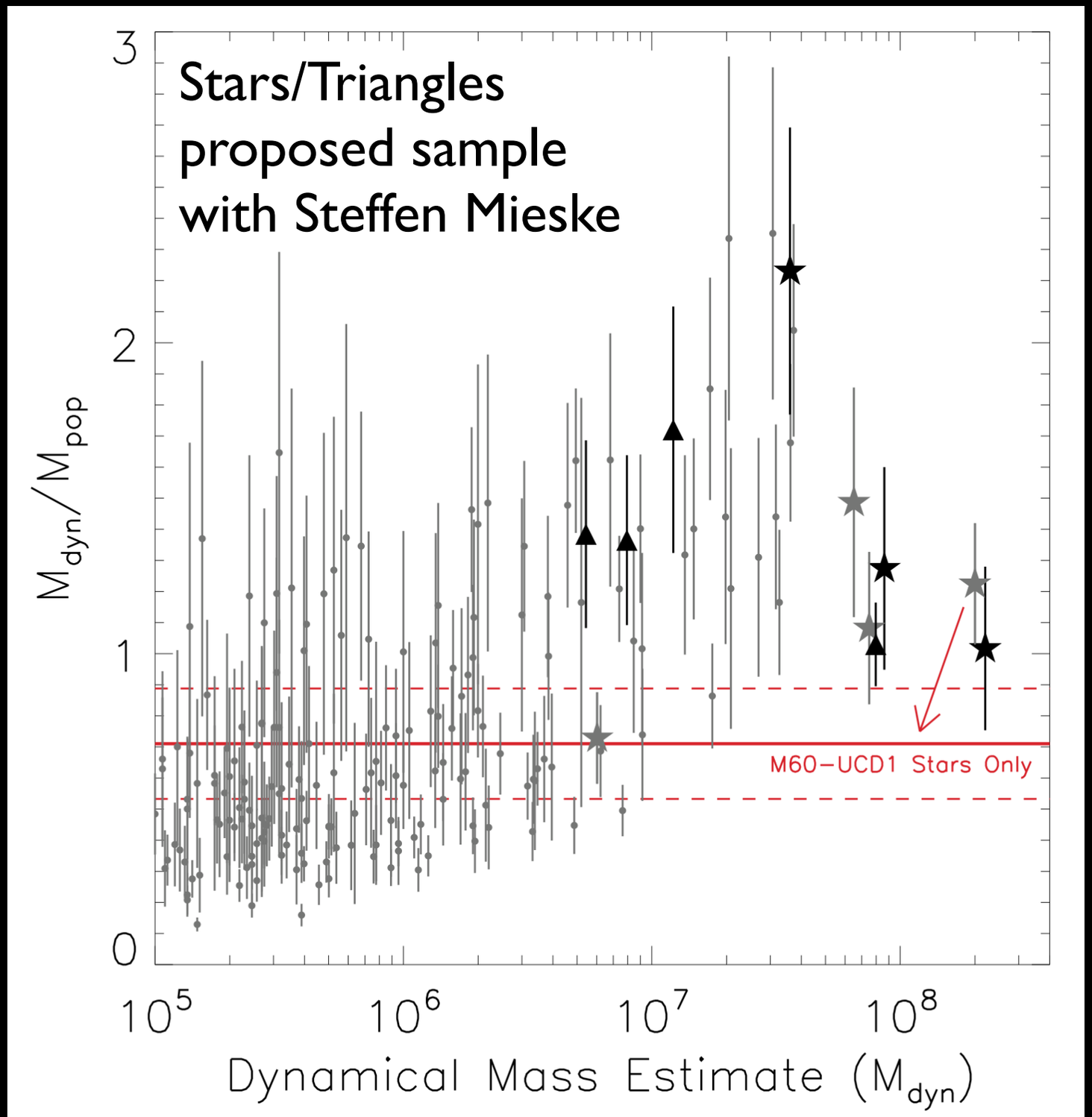
Stellar mass estimate drops from 2×10^8 $M_\odot$ to 1.2×10^8 $M_\odot$

consistent with globular cluster M/Ls (Strader+ 2011)

log(Host galaxy M_{star})
~8.5 9.5 10.5

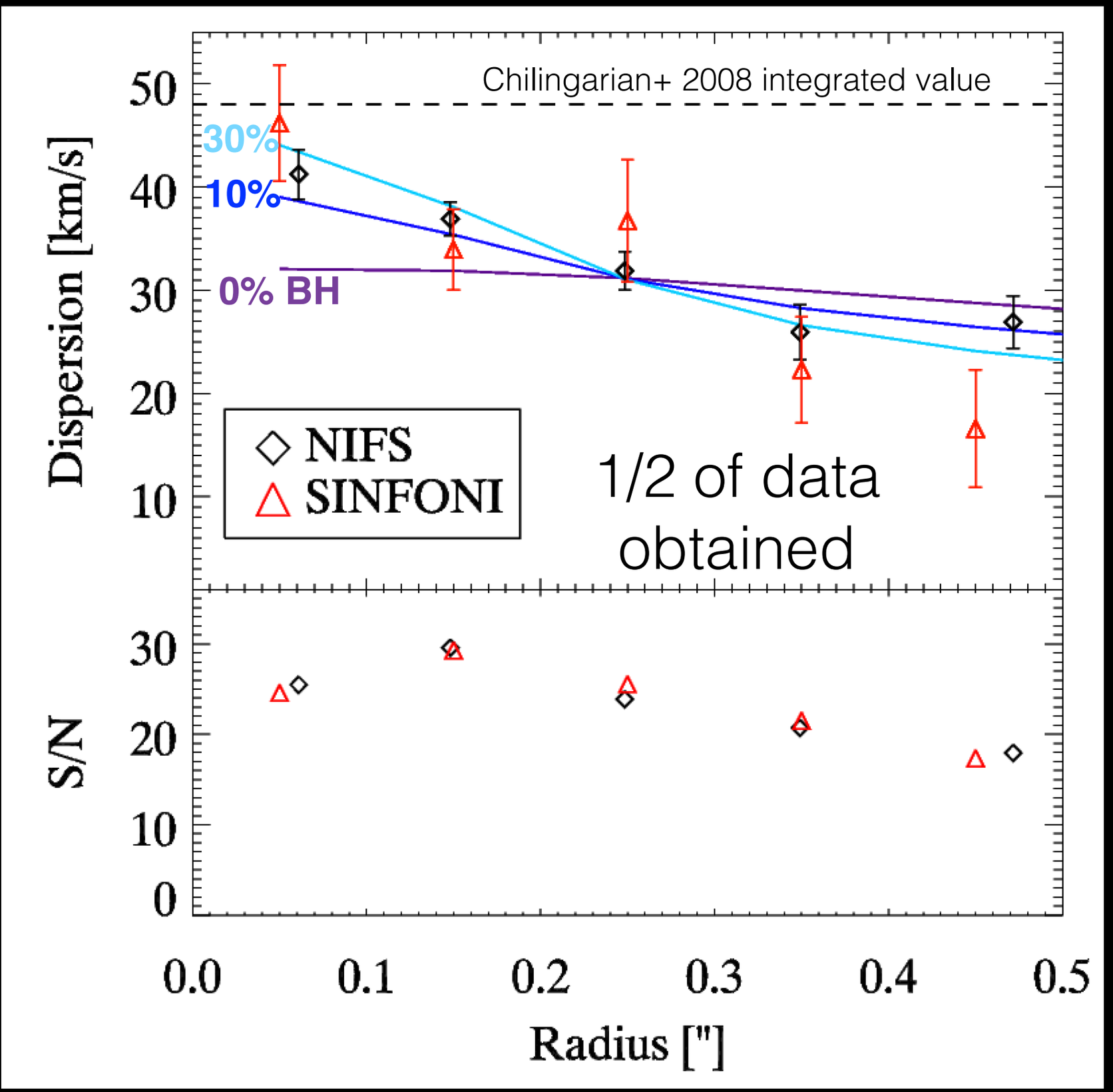


Are BHs common in UCDs?

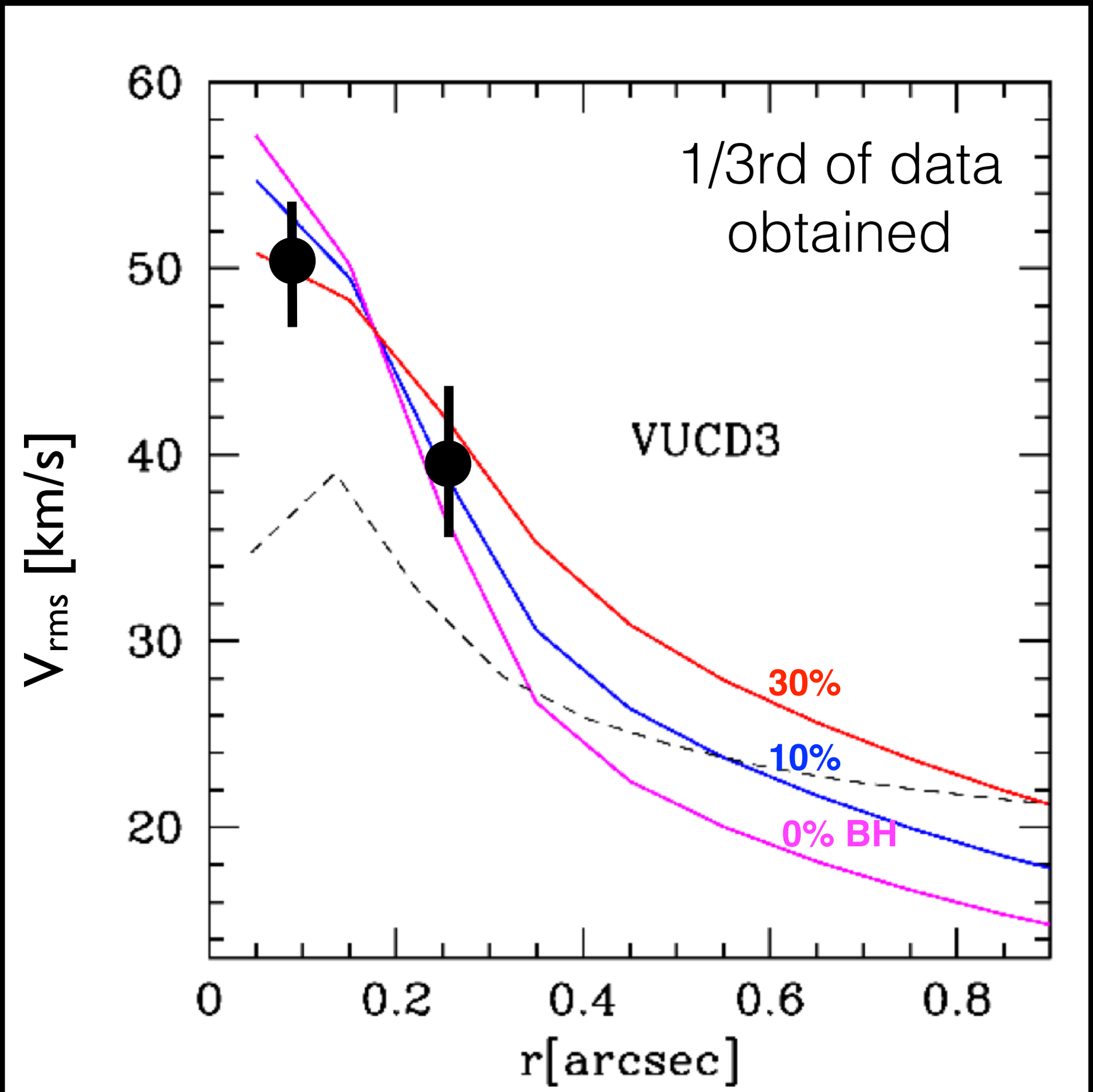


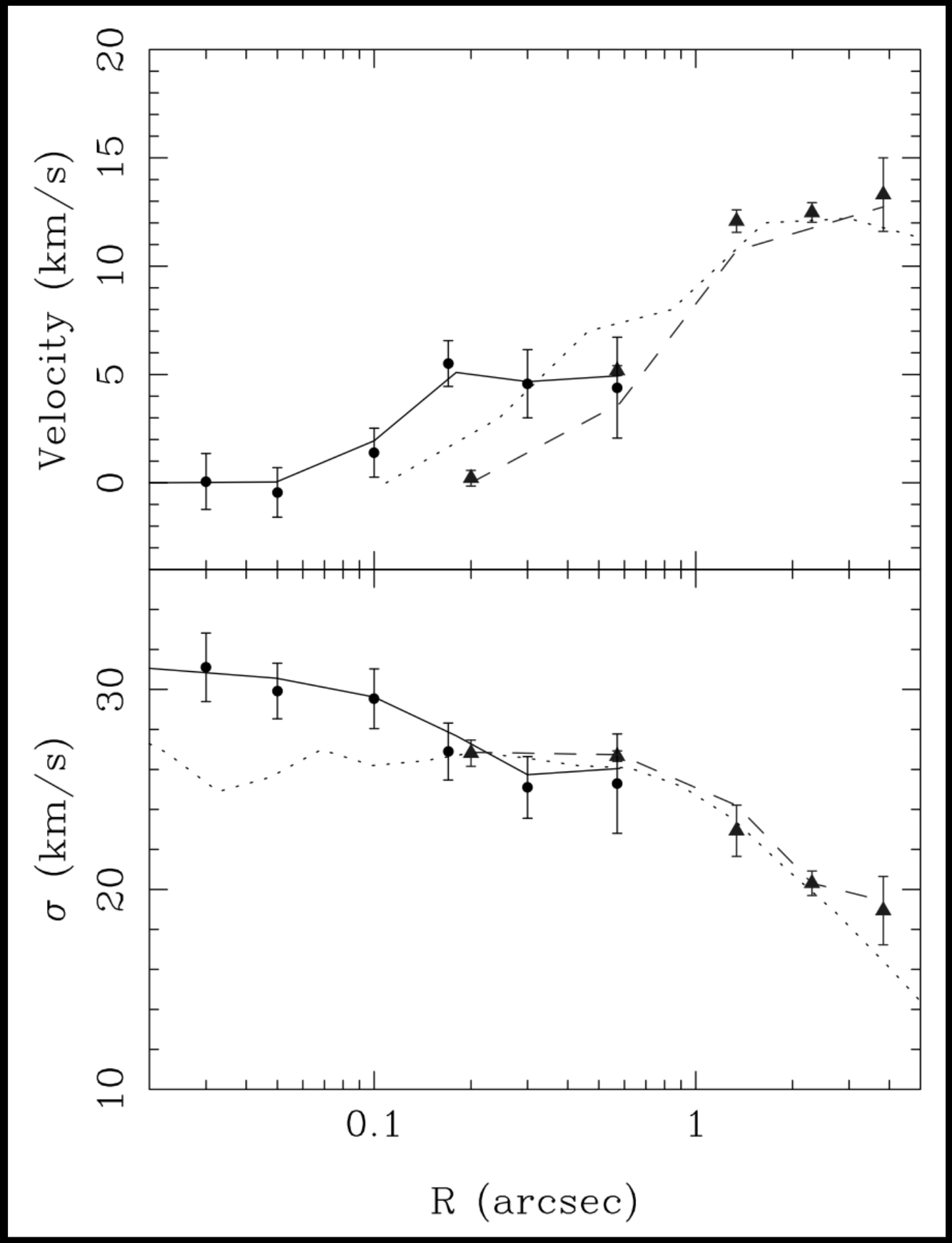
- Simulations: only half of high mass UCDs can be produced by tidal stripping Pfeffer+ 2014
- Massive UCDs are diverse; some metal-poor
- Total number of UCD BHs depends critically on what happens at low mass.

M59co



- R_h = 32 pc, LV=1.7x10^7 L$_\odot$ Chilingarian+ 2008
- Two component structure
- Previous M/L significantly overestimated (2-3x)


1/3rd of data
obtained
VUCD3
30%
10%
0% BH
60
50
40
30
20
0
0.2
0.4
0.6
0.8
r[arcsec]
V rms [km/s]



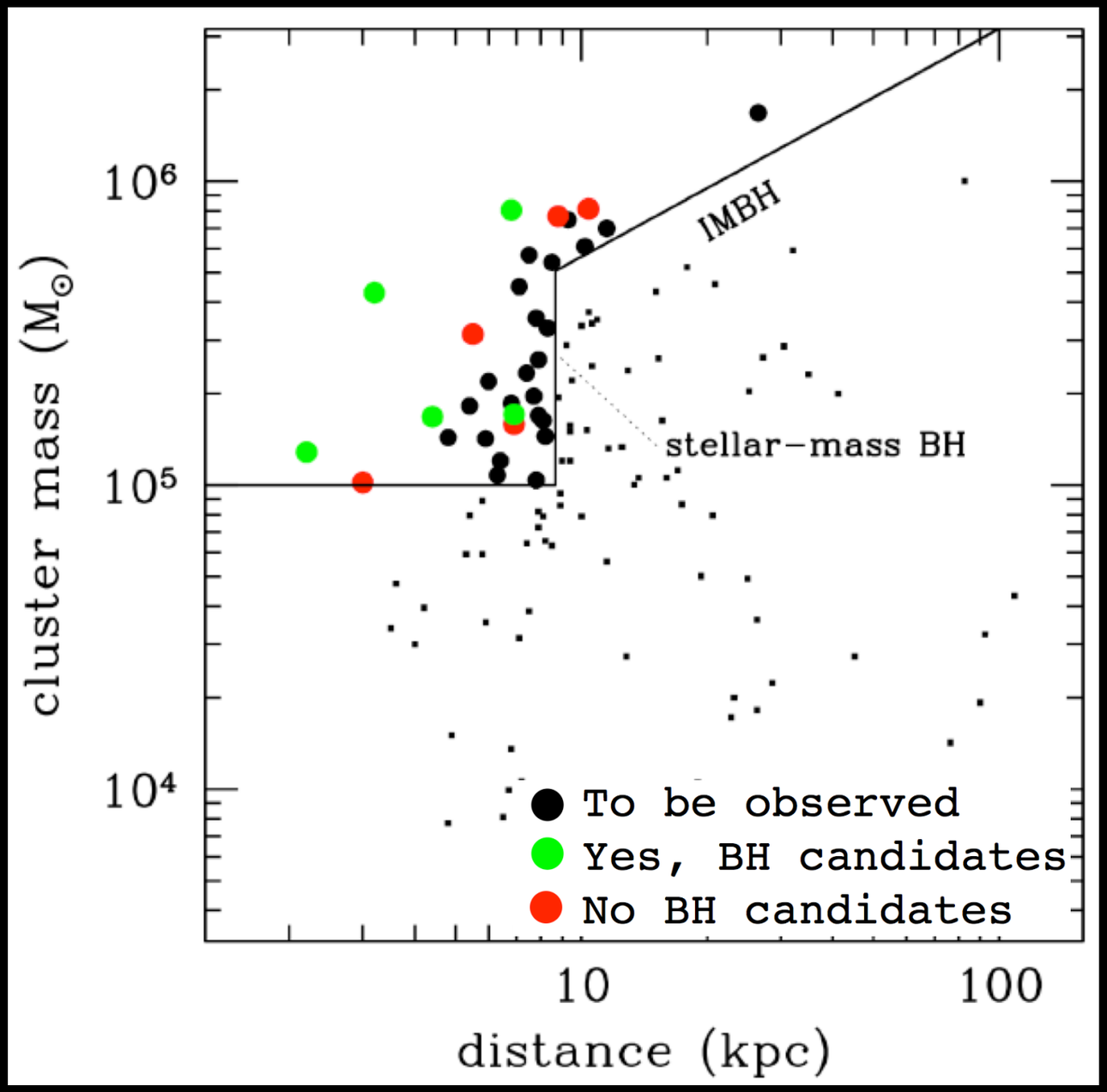
Globular Cluster BHs?

Gebhardt, Rich & Ho 2005, G1 globular cluster
97% likelihood (2.xσ)
constant M/L assumed

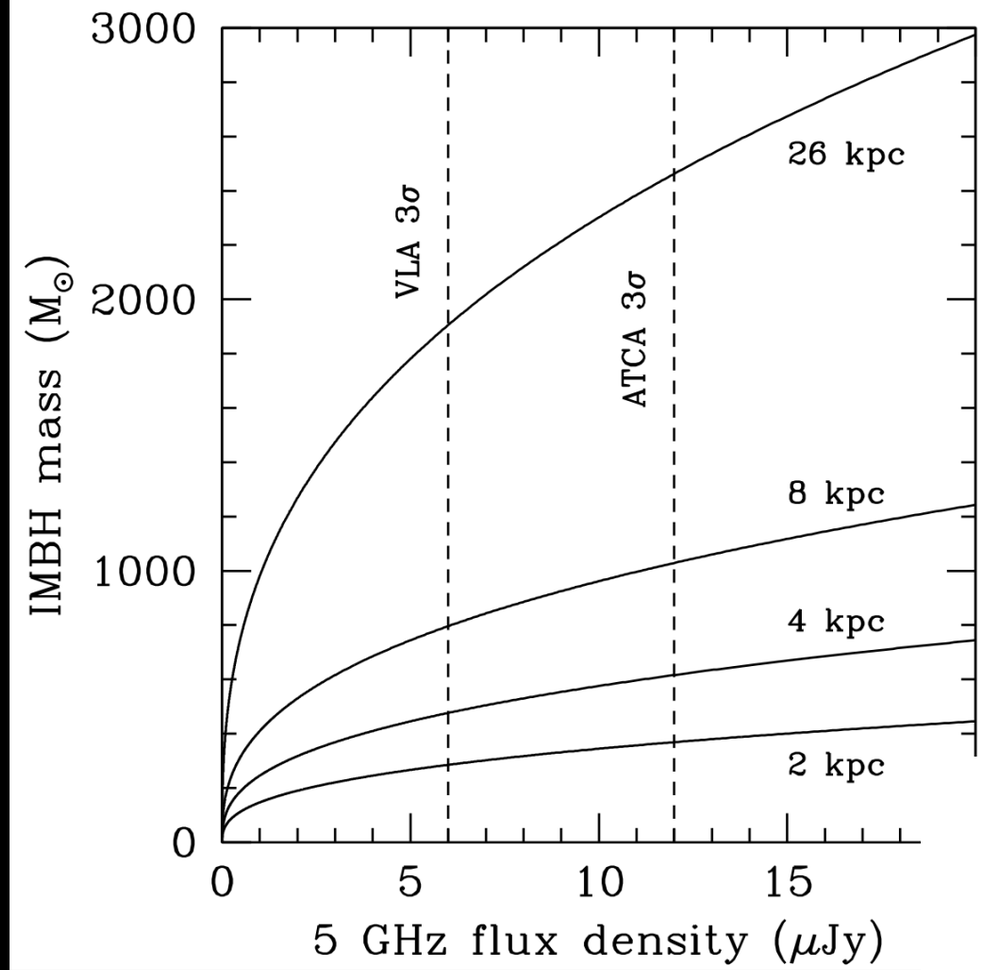
No strong or uncontroversial dynamical detections (e.g. Noyola+ 2010, van der Marel & Anderson 2010, Lutzgendorf+ 2011, 2013)

Accretion evidence

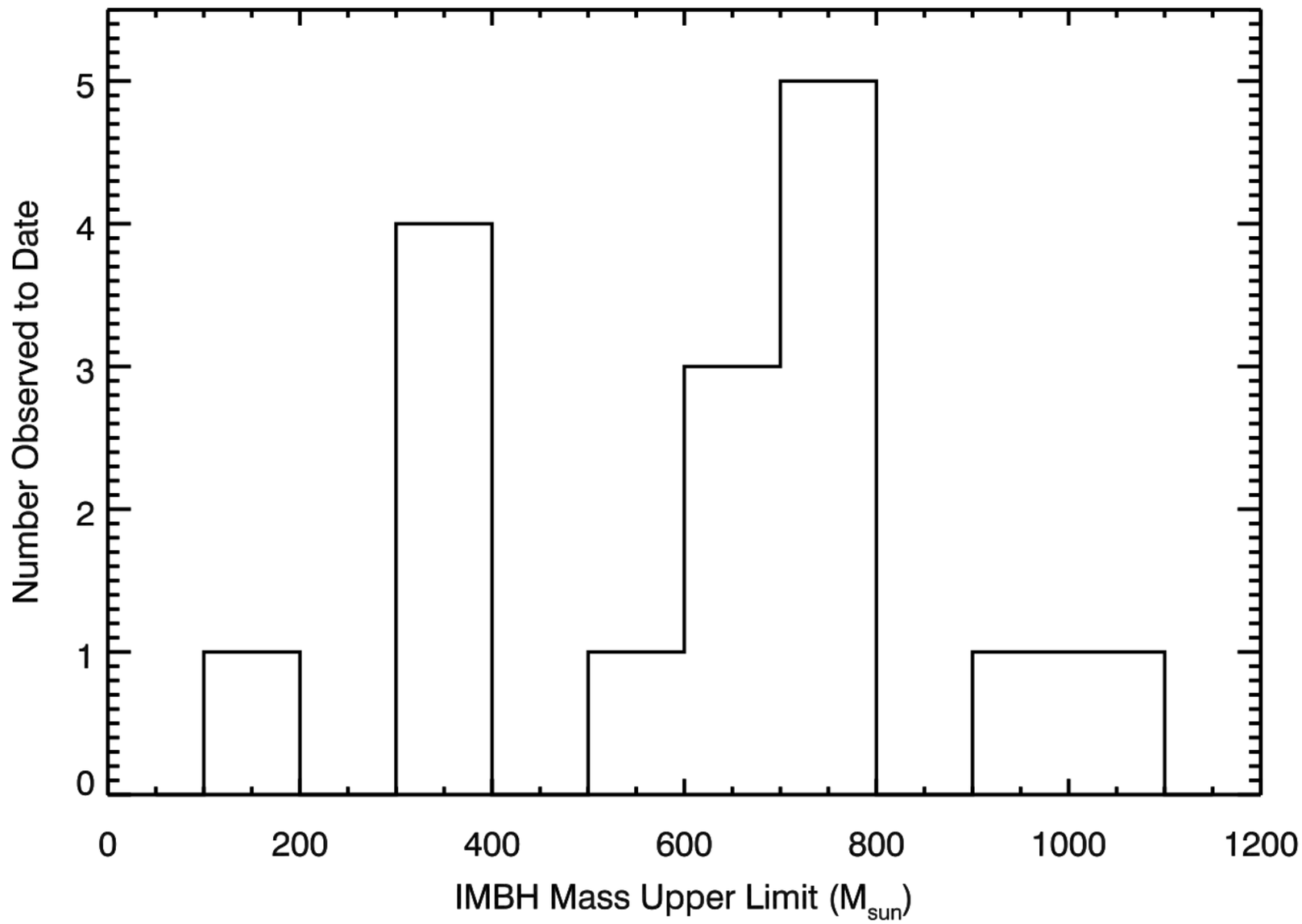
Globular Cluster VLA survey (Laura Chomiuk, Jay Strader, James Miller-Jones, Tom Maccarone)



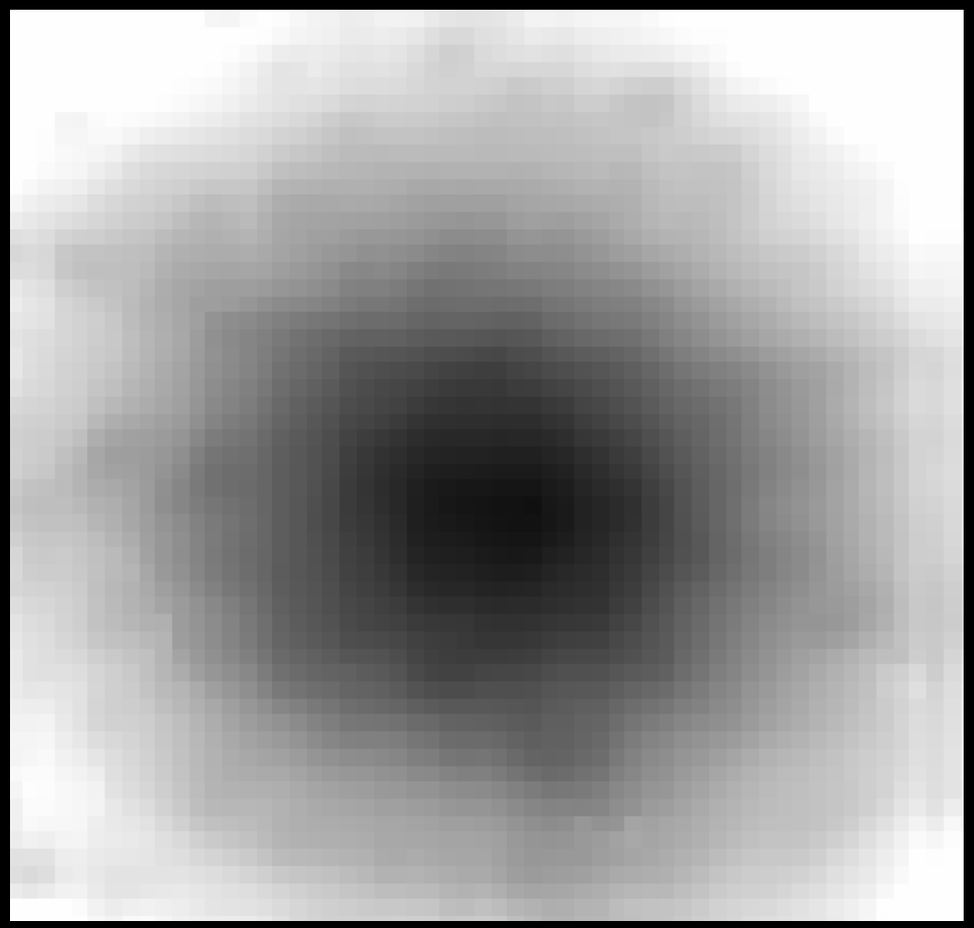
- First upper limits in Strader+ 2012, conservative assumptions
- Lots of stellar mass BH candidates (Strader, Chomiuk Miller-Jones)



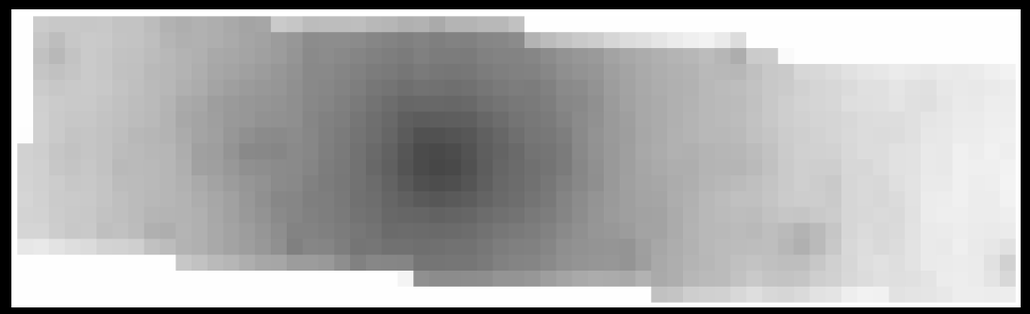
16 observations
No IMBHs 😢



Do it Dynamically?
Local Group: 7 most massive clusters all in M31!



B023-G078, 6×10^6 $M_\odot$



B225-G280, 3.2×10^6 $M_\odot$

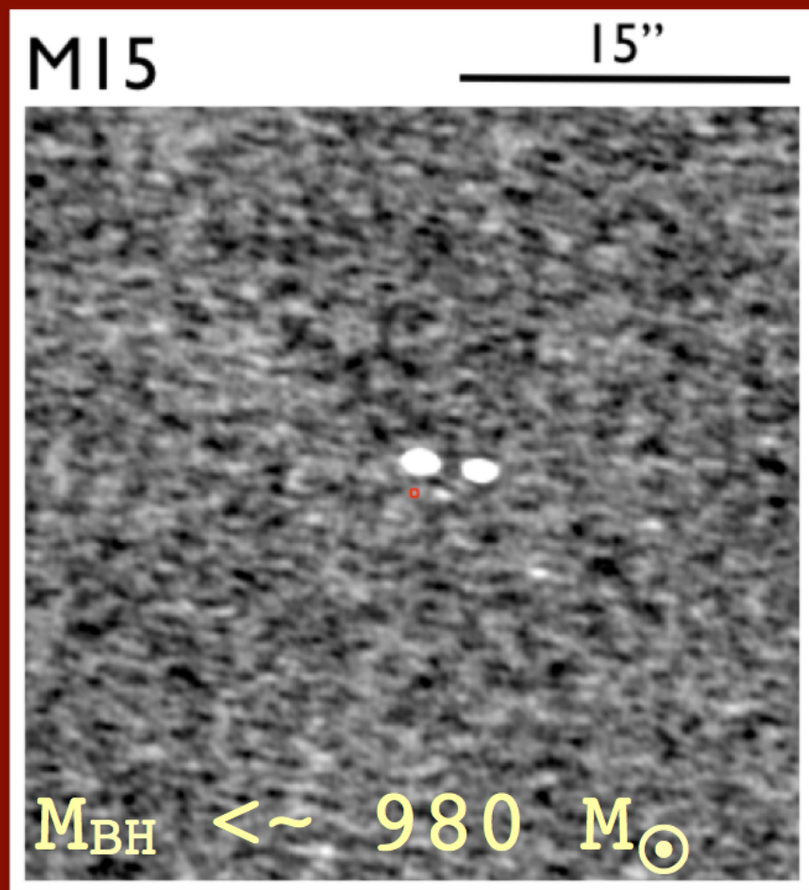
Work of graduate student Chris Ahn

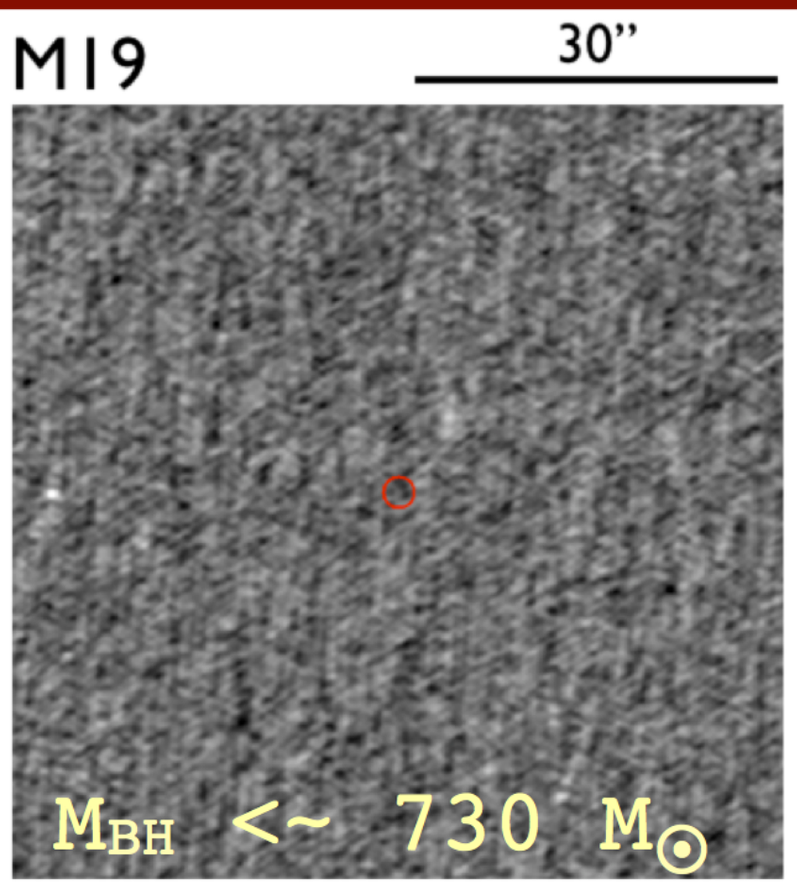
1) BHs may be common in UCDs; confirmation underway

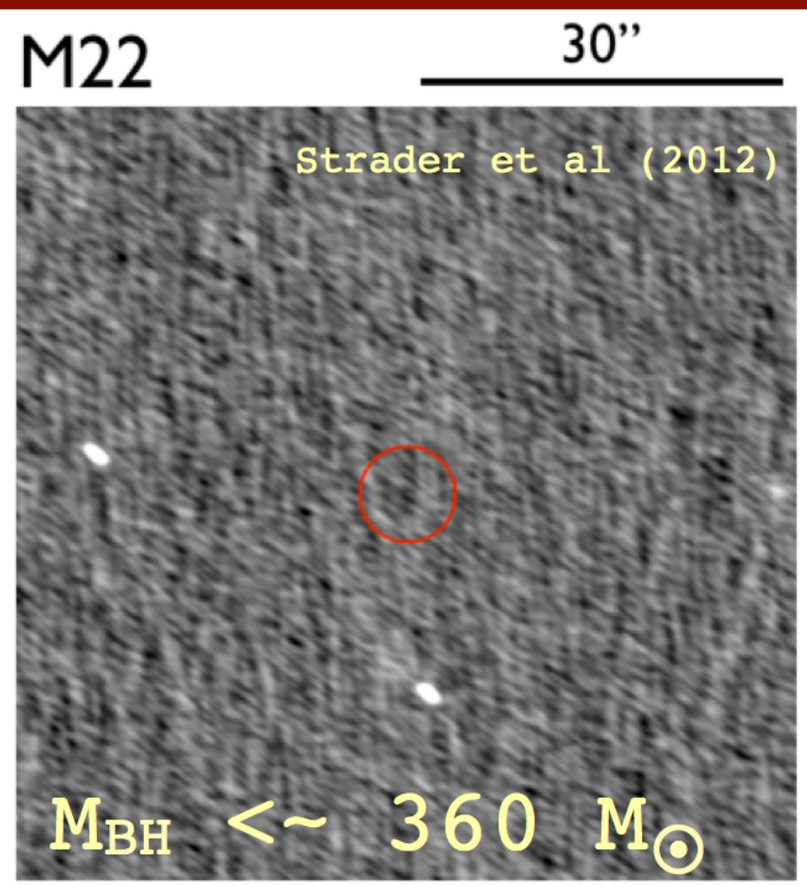
2) May be a good tool for studying low mass central BHs

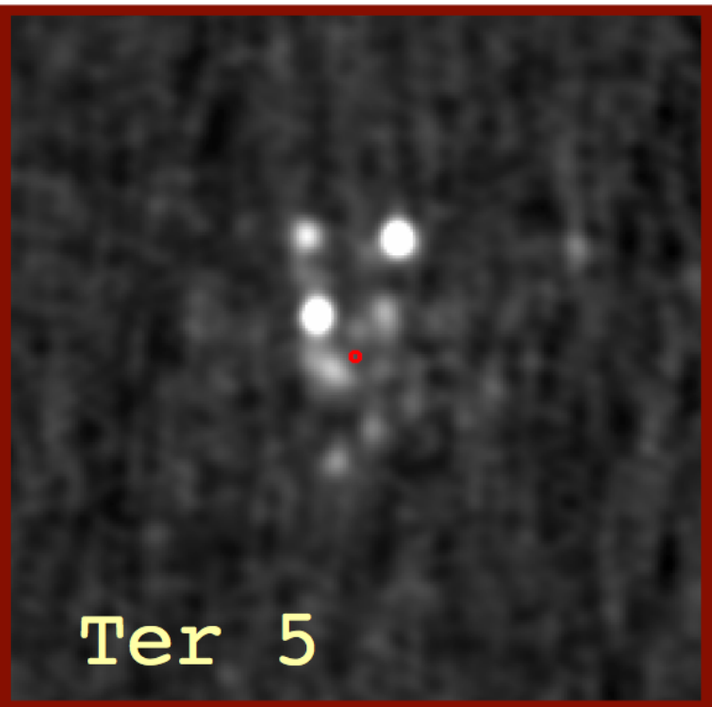
3) No good globular cluster (lower mass UCD?) BH candidates

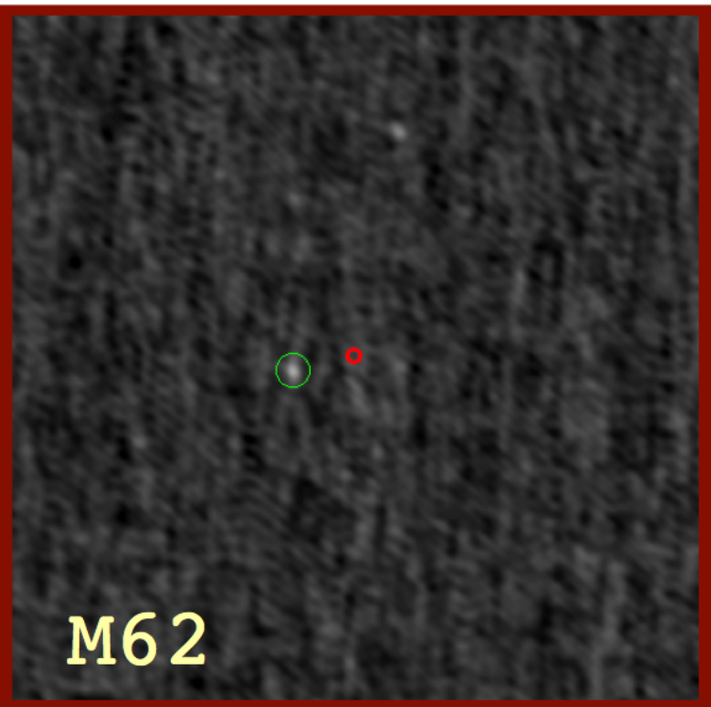
IMBH Non-detections in all GCs (16, to date)











Predicting radio emission from IMBHs: Typical Numbers (using Fundamental Plane)

$$\dot{m}/\dot{m}_{\rm edd} \approx 5 \times 10^{-7}$$

Accretion rate is 0.1% of wind from a single red giant.

$$\dot{m} \approx 5 \times 10^{-12}\ {\rm M}_\odot\ {\rm yr}^{-1}$$

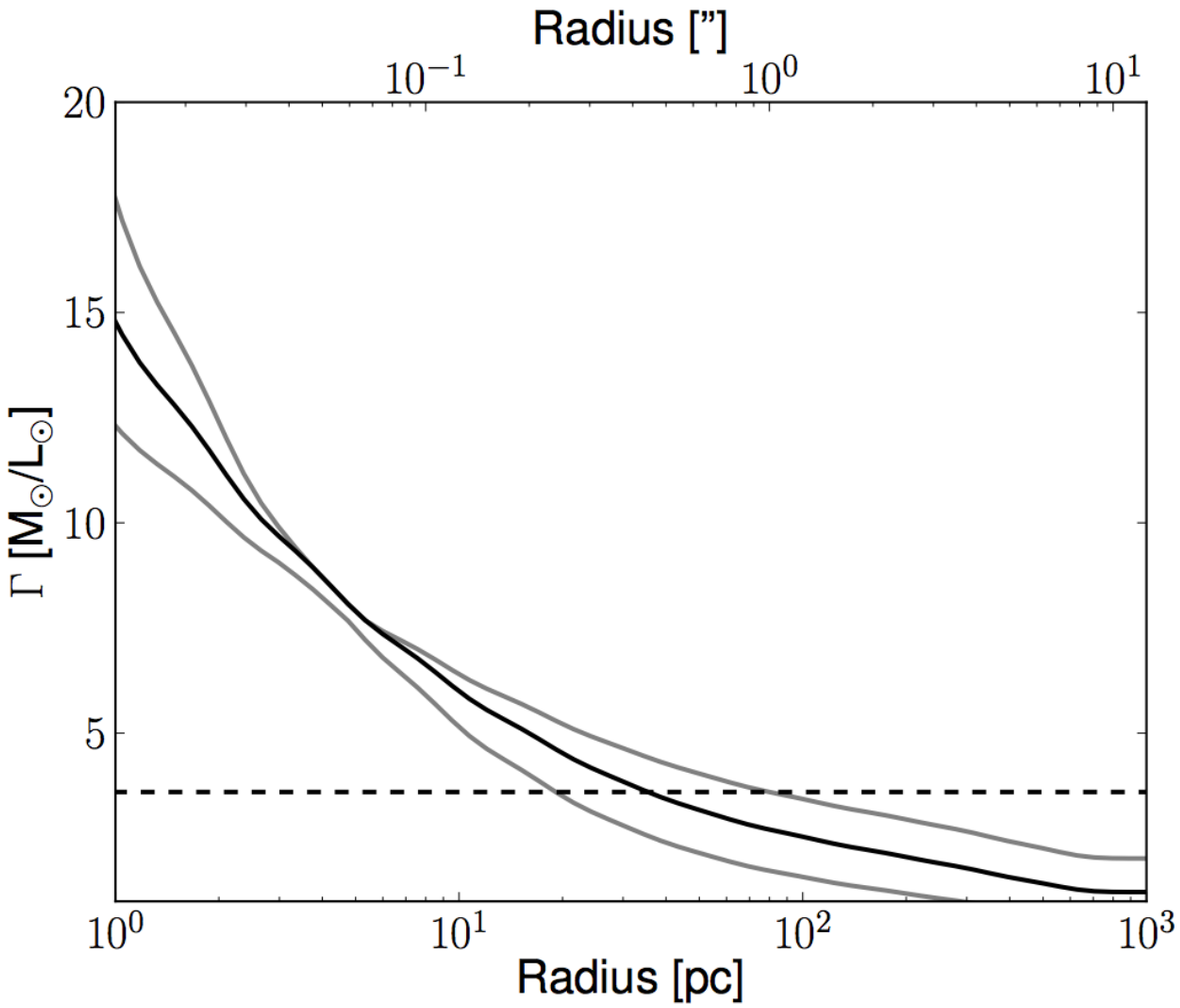
$$\epsilon \approx 10^{-6}$$

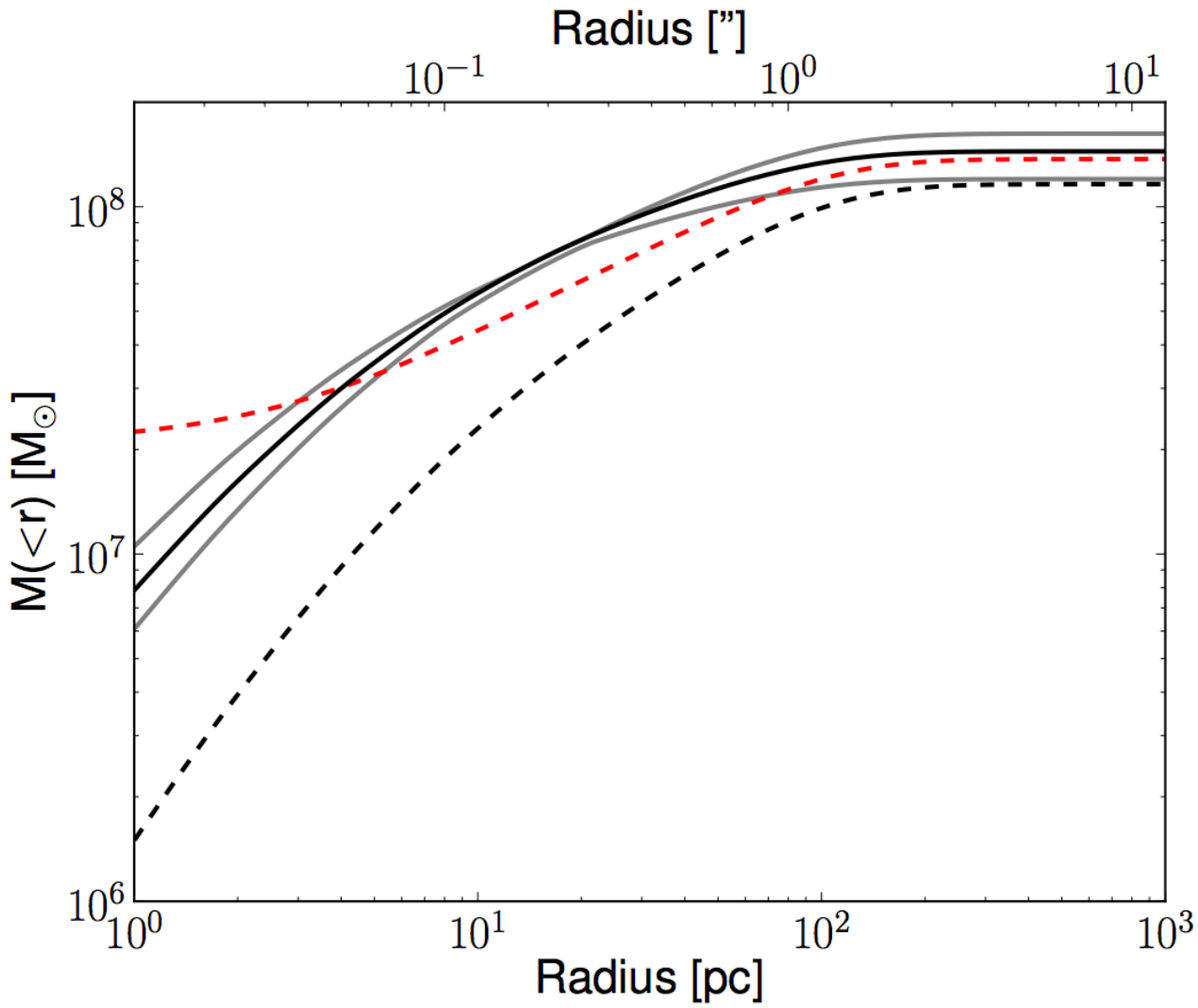
Radiative efficiency comparable to Sgr A*.

$$L_X \approx 10^{30}\ {\rm erg/s}$$

Maccarone & Servillat 2008

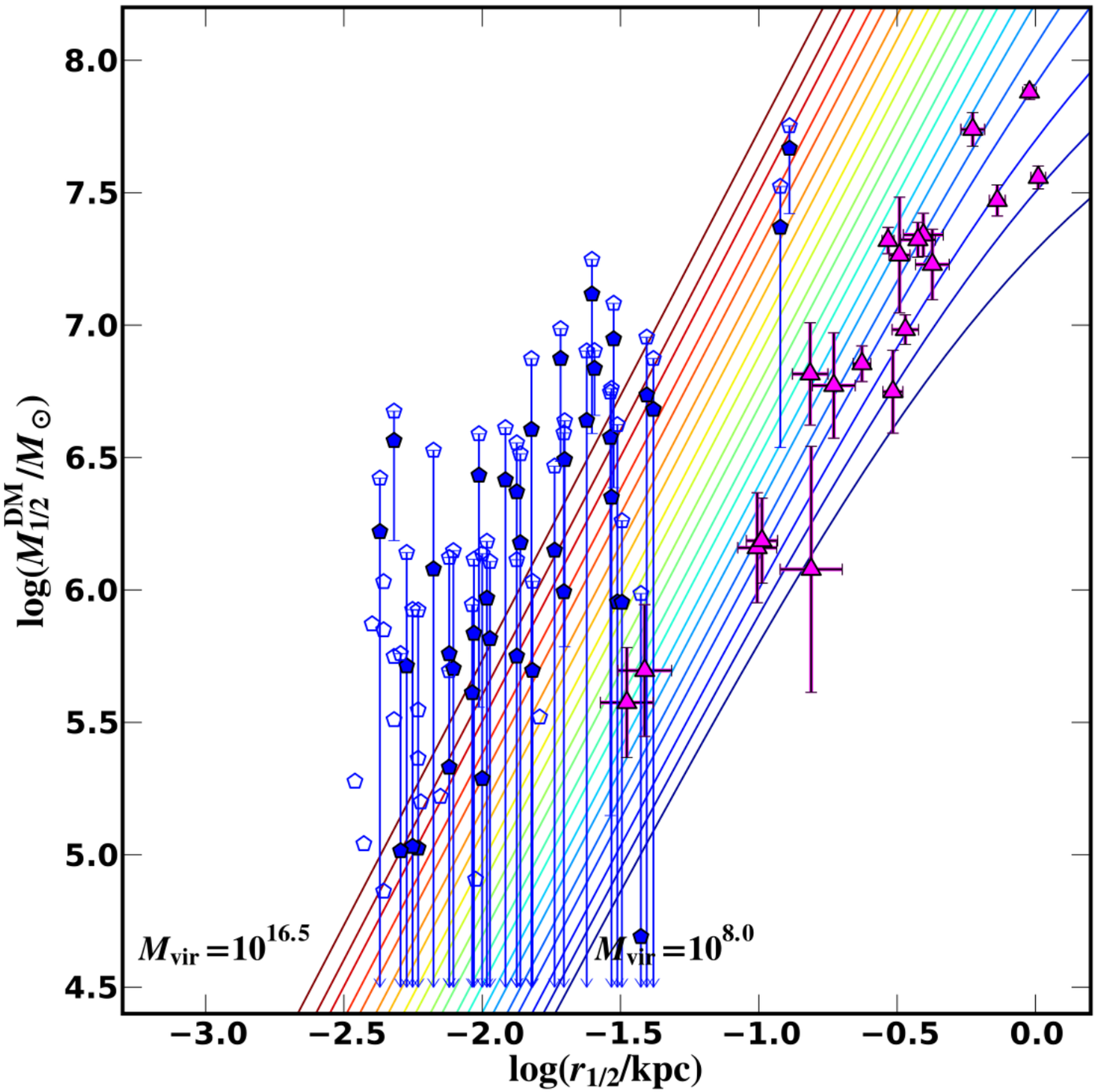
M/L gradient fits





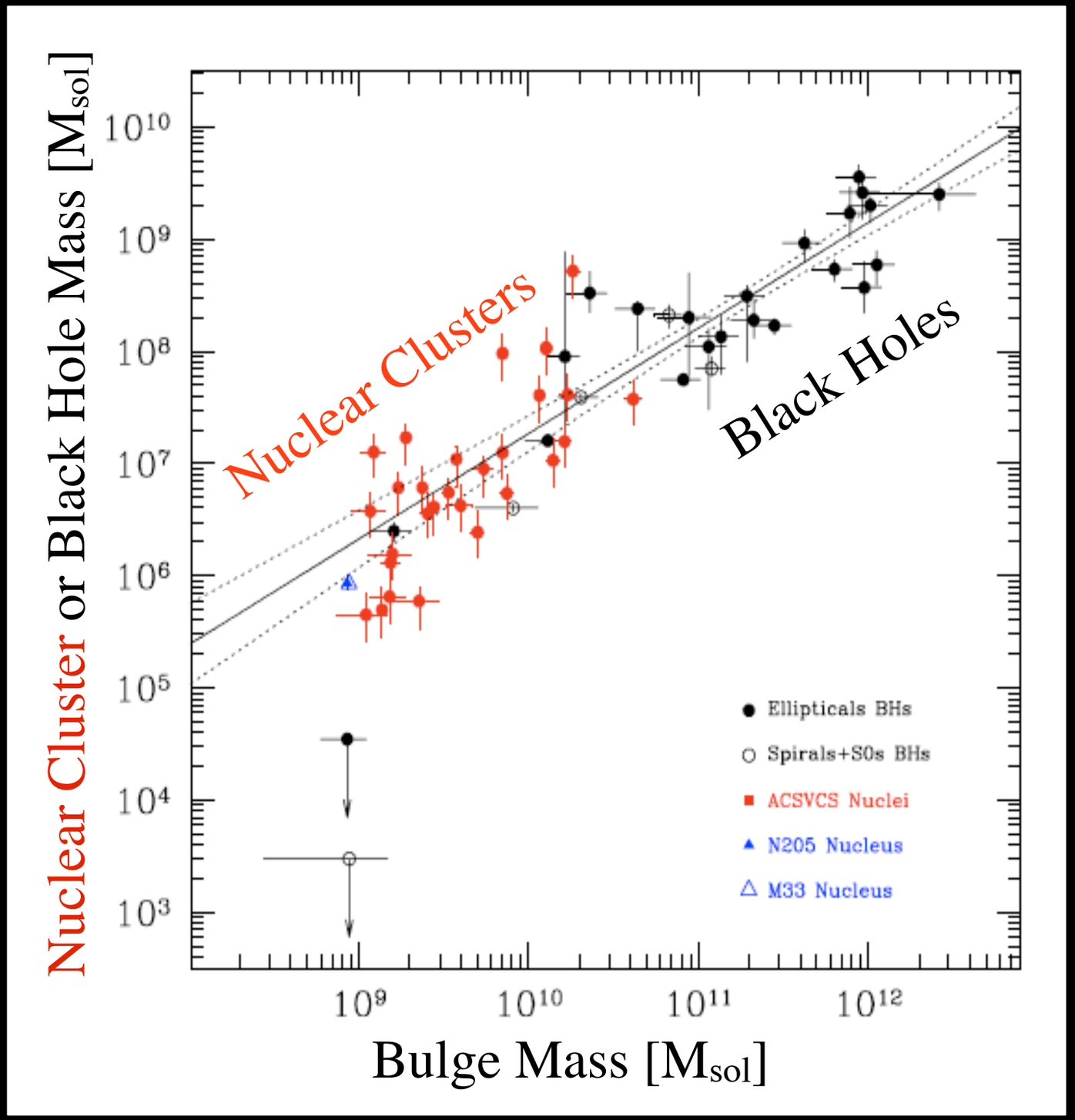
Half mass relaxation time ~350 Gyr

Dark Matter Not Expected



- Very massive galaxy halos required to have any detectable amount of dark matter (Tollerud+ 2011)

Nuclear Star Cluster Scaling Relations



Ferrarese + 2006 (for early type galaxies)
also Wehner & Harris 2006, Rossa+ 2006, Balcells+ 2003