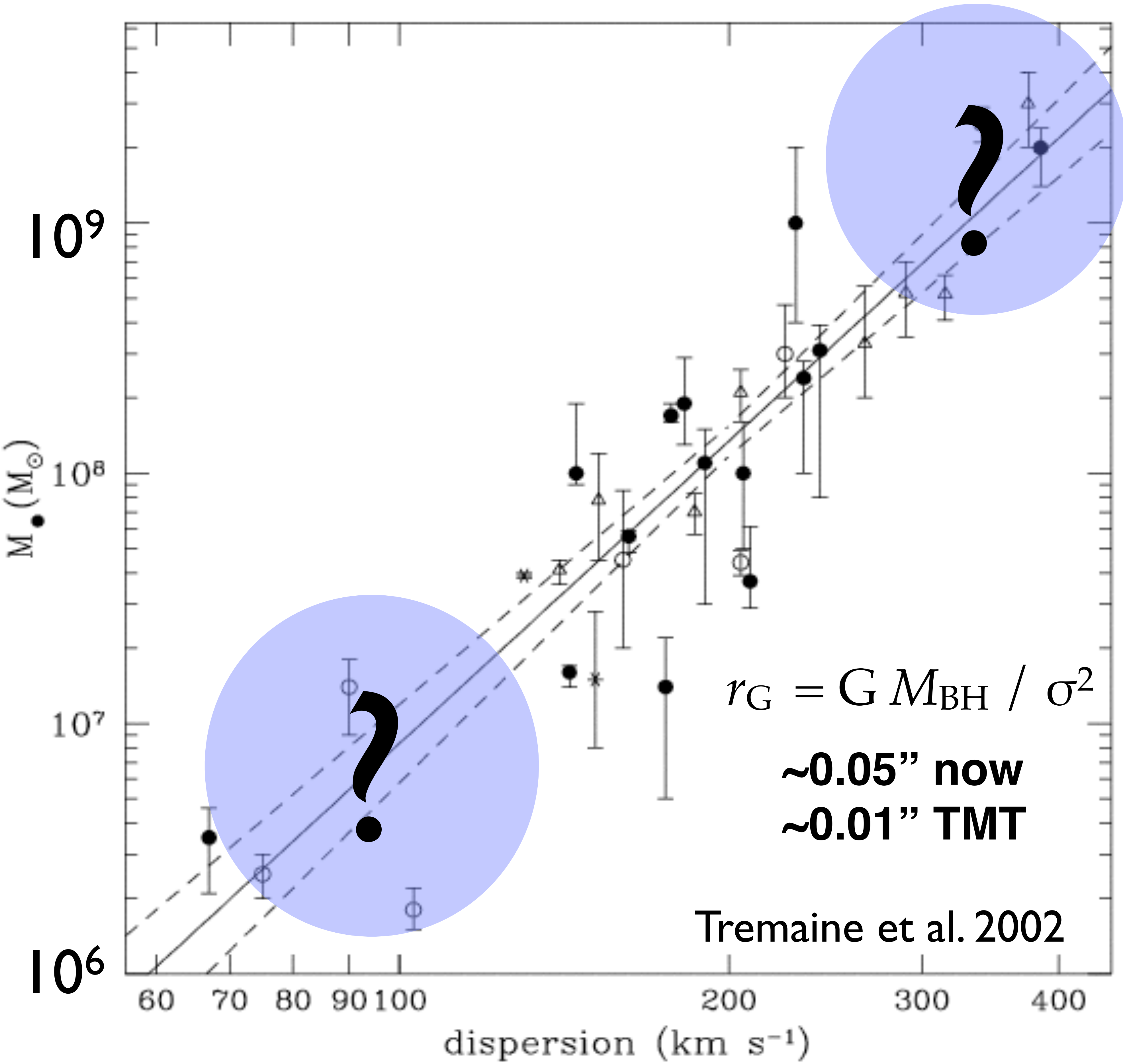
Black Hole Demographics Through The Ages (and the TMT)

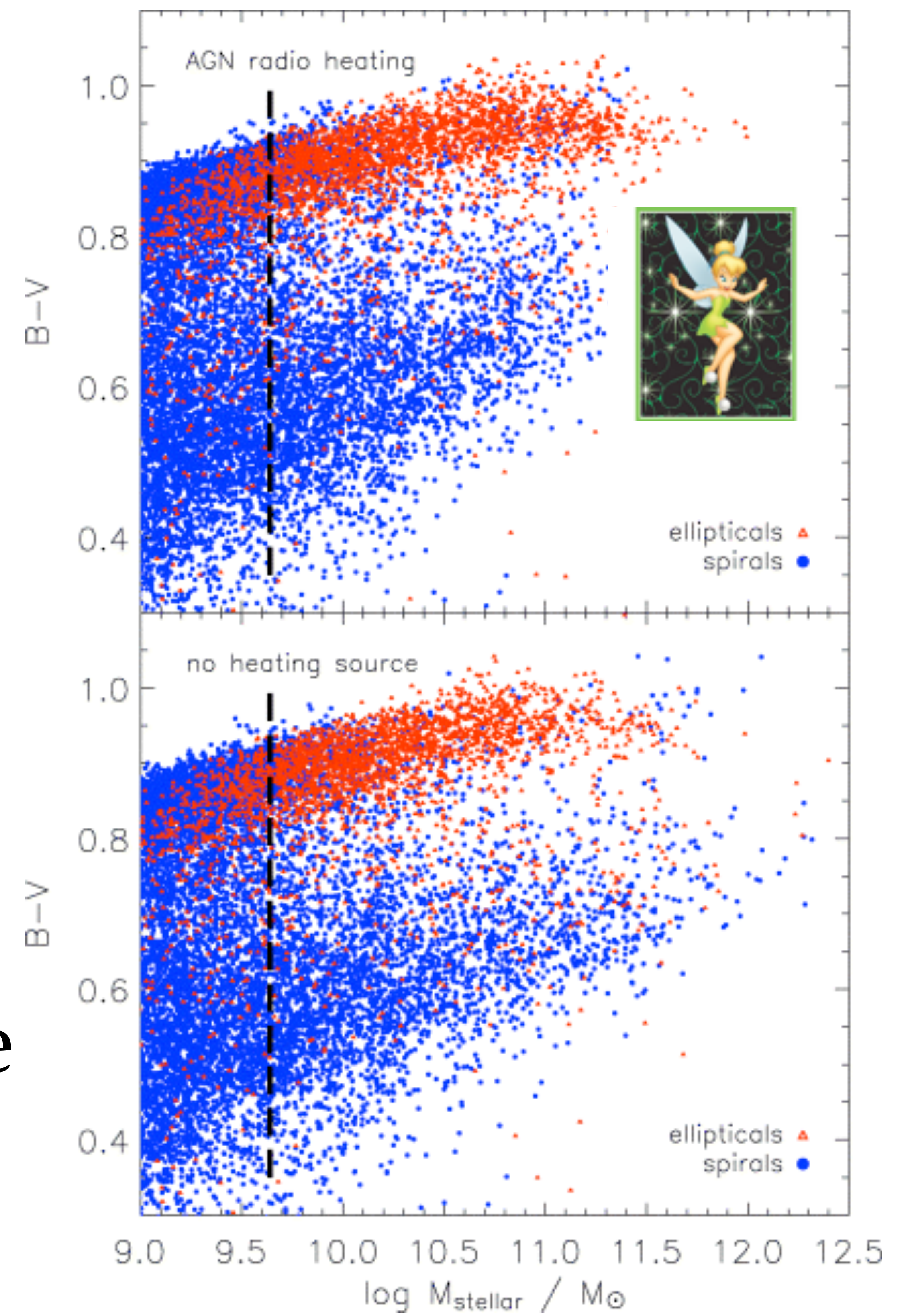
Jenny Greene
Ai-Lei Sun
Kristina Pardo & Andy Goulding
Amy Reines and Vivienne Baldassare



10^9
10^6
$M_\bullet (M_\odot)$
10^8
10^7
?
?
$r_G = G\, M_{BH} \;/\; \sigma^2$
~0.05" now
~0.01" TMT
Tremaine et al. 2002
60 70 80 90 100 200 300 400
dispersion (km s^{-1})

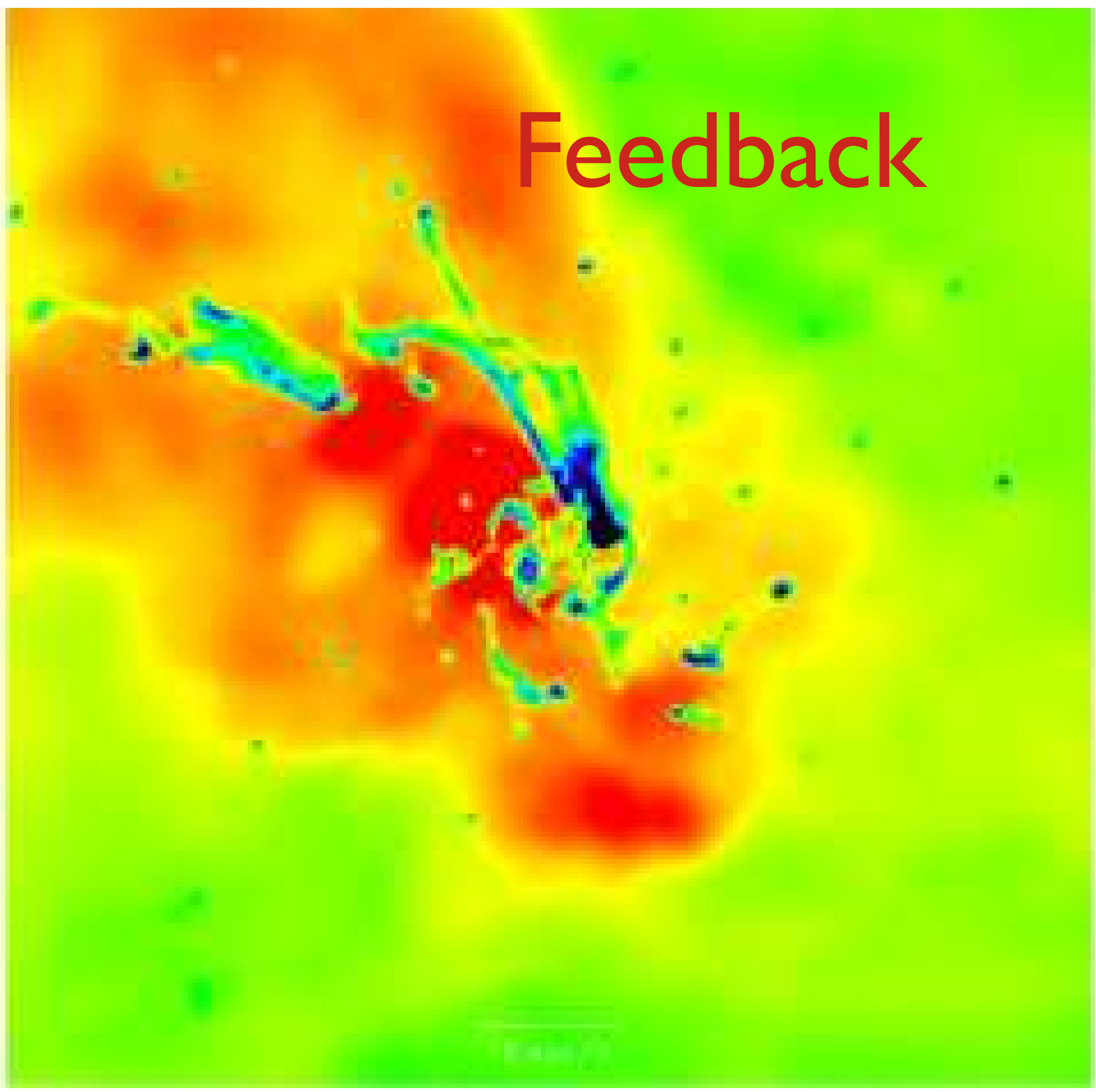
AGN save galaxy-formation theorists

Croton et al 2006

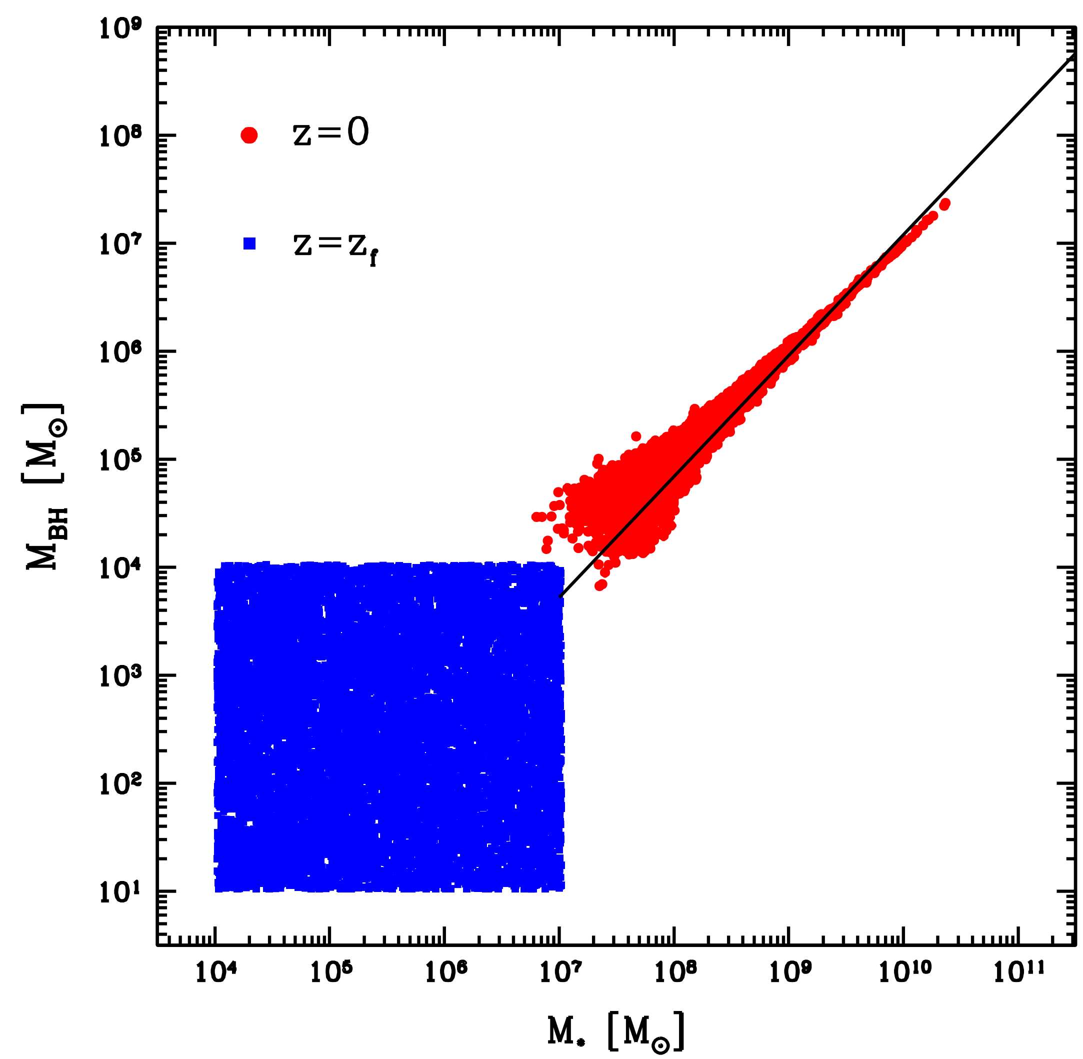


Only need a fraction of the grav. binding energy of the BH to unbind the galaxy

Origin of scaling relations

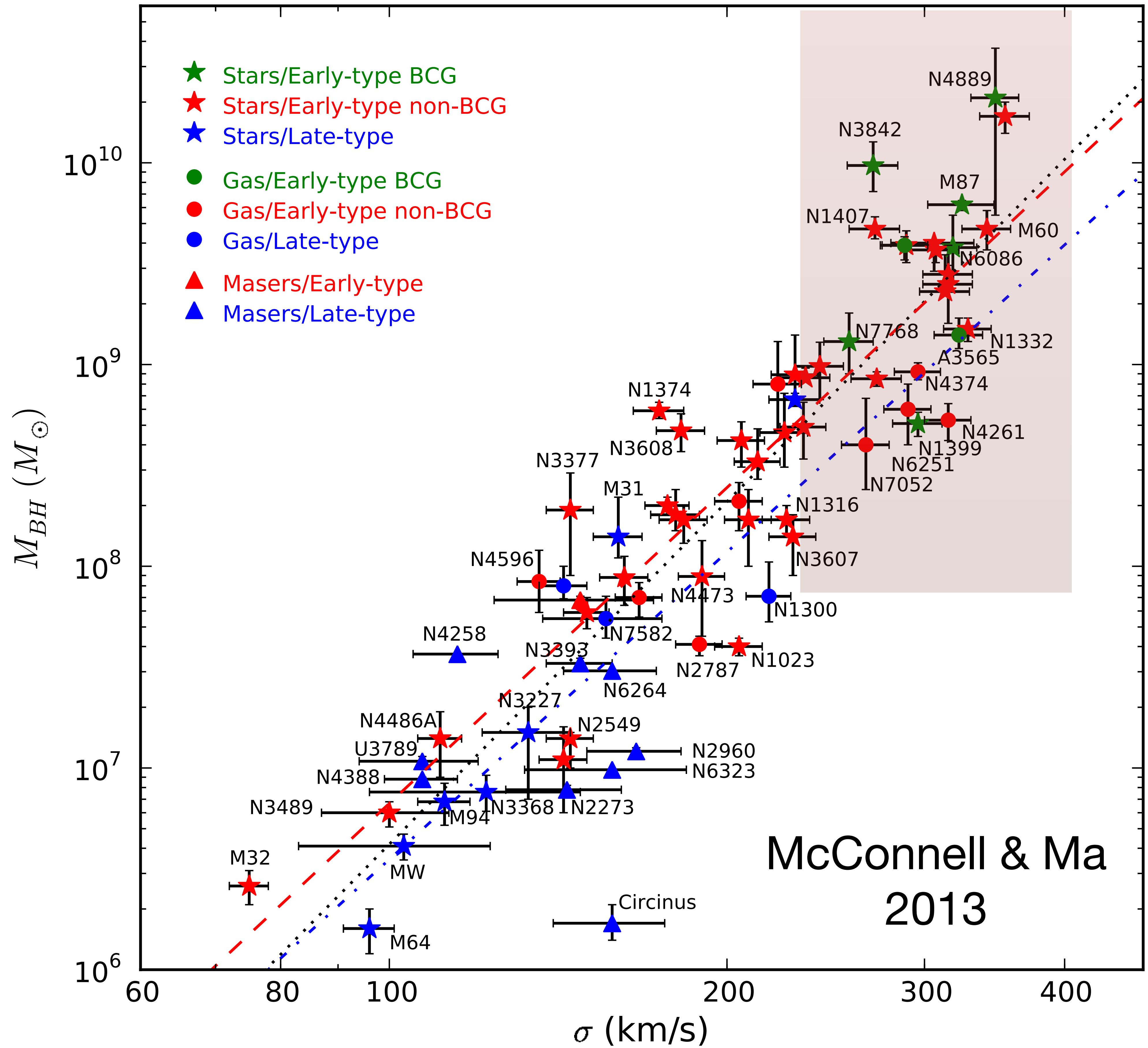


Choi et al. 2013



Jahnke & Maccio 2011

Peng 2007



Stars/Early-type BCG
Stars/Early-type non-BCG
Stars/Late-type
Gas/Early-type BCG
Gas/Early-type non-BCG
Gas/Late-type
Masers/Early-type
Masers/Late-type
N4889
N3842
M87
N1407
M60
N6086
N7768
N1332
A3565
N4374
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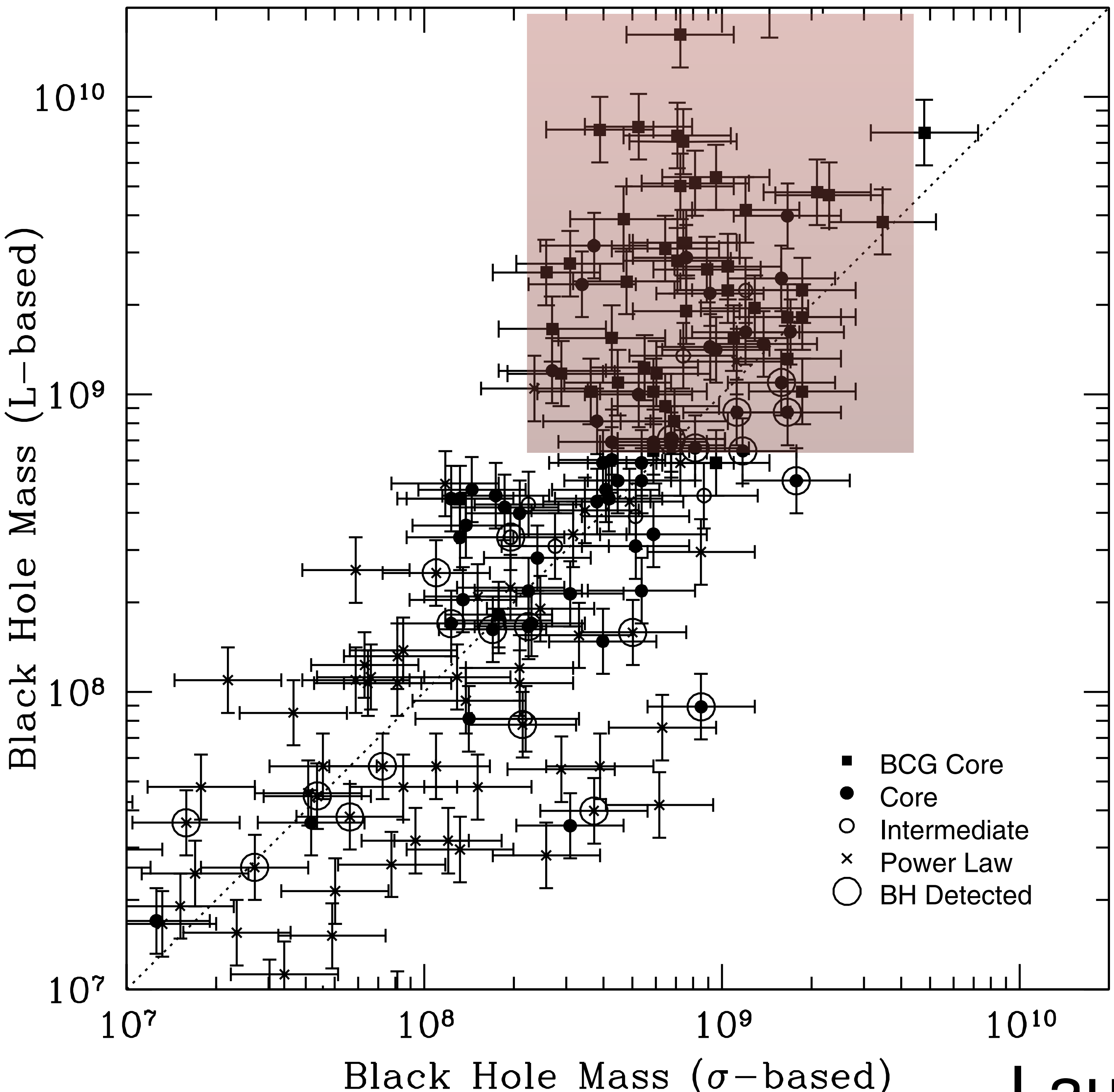
McConnell & Ma
2013
M_{BH} $(M_\odot)$
10^{10}
10^9
10^8
10^7
10^6
60
80
100
200
300
400
σ (km/s)

What correlations with BH mass at high mass?



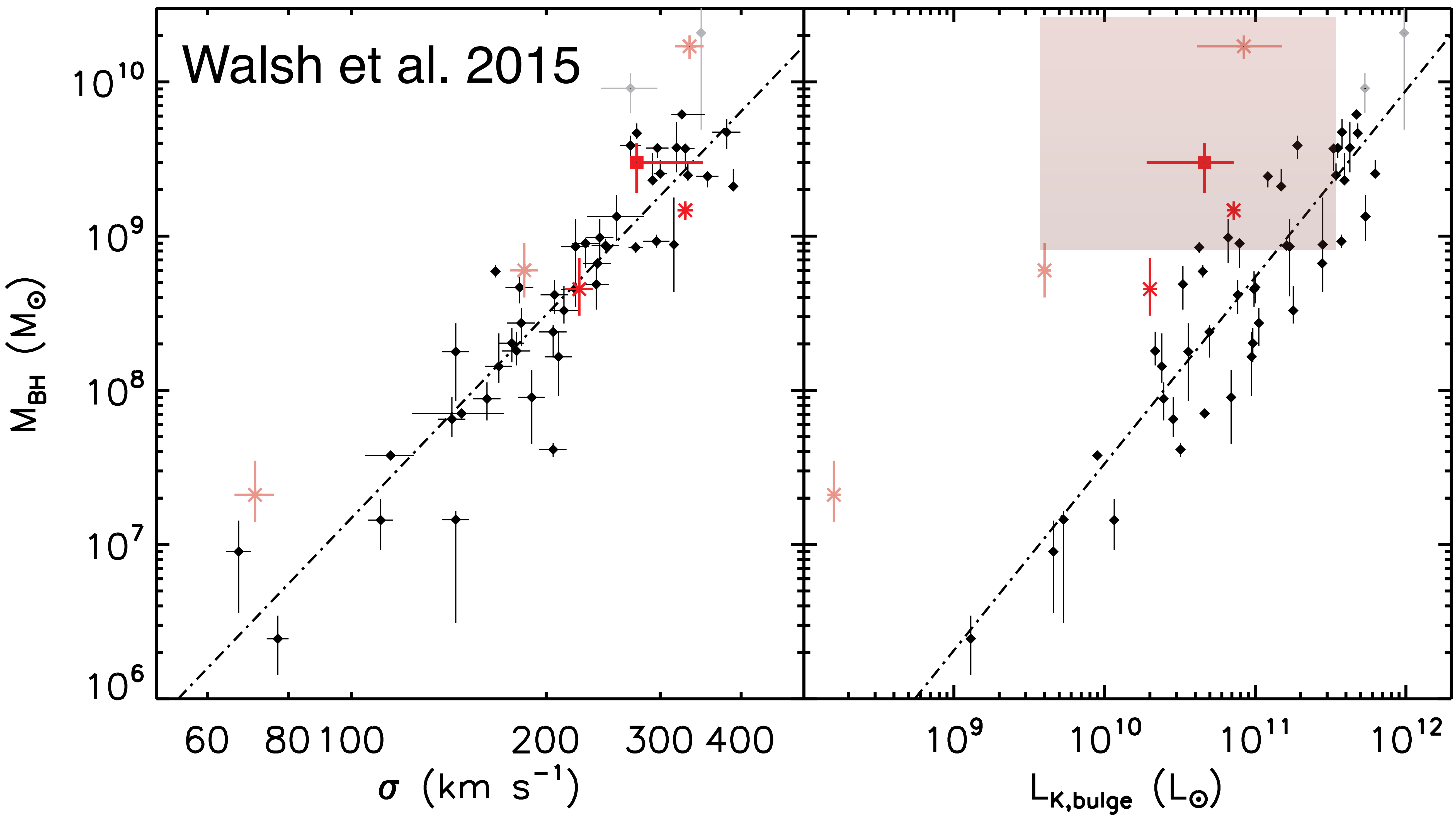
Is L or σ* the driving parameter?

Different for BCGs or any environmental dependance?

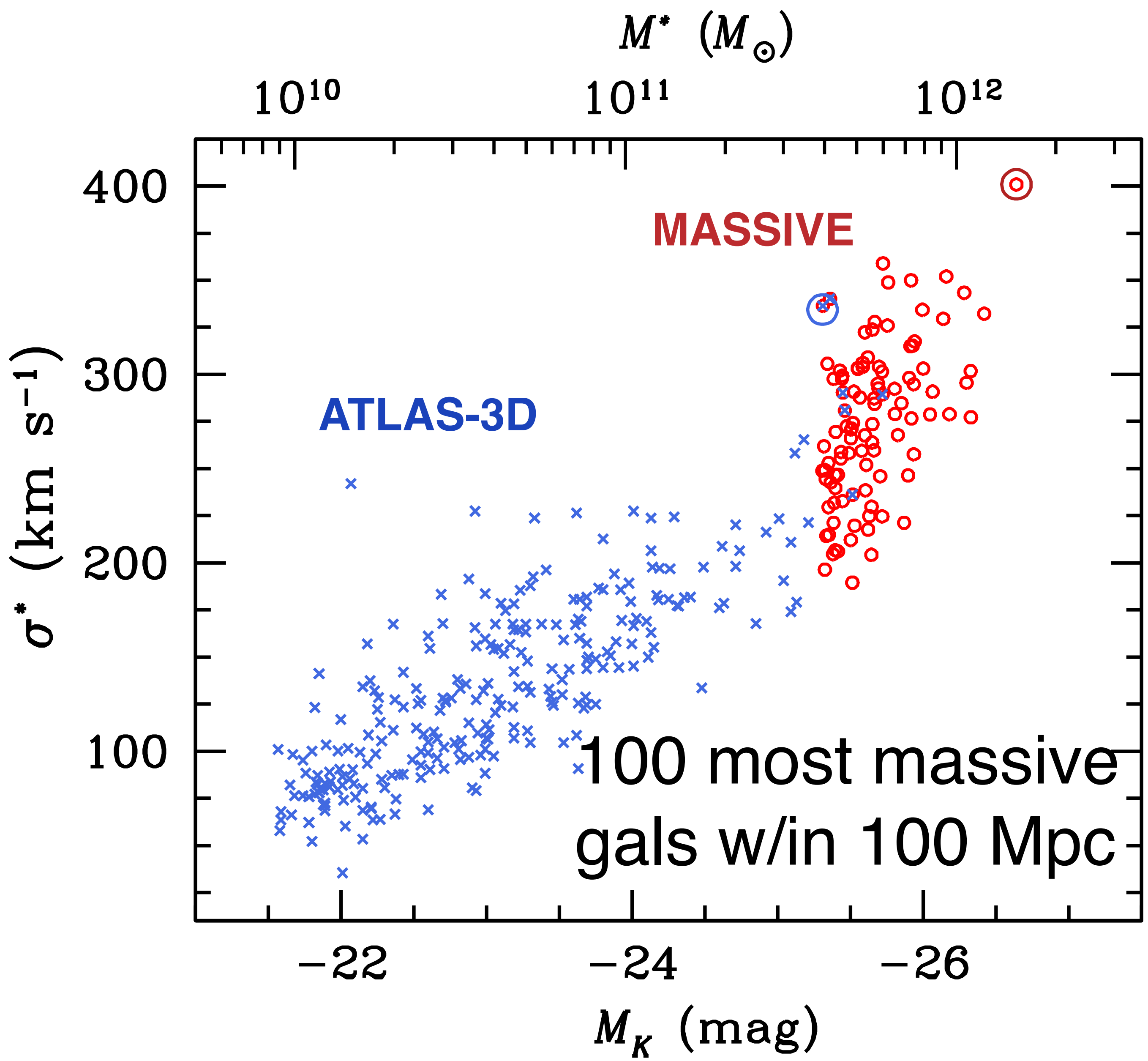
Implications for BH space density

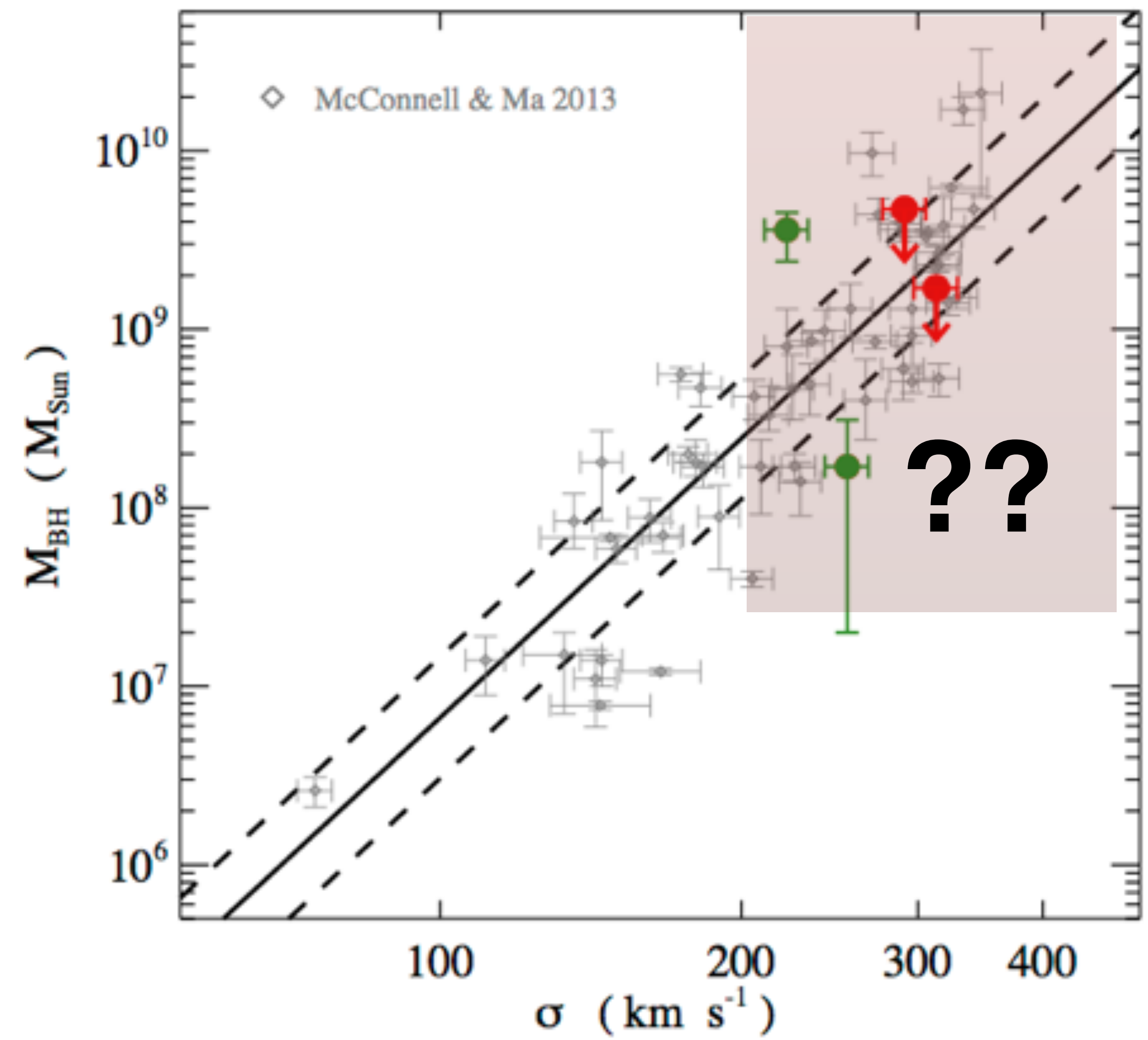
Lauer et al. 2007

Compact, high-dispersion galaxies



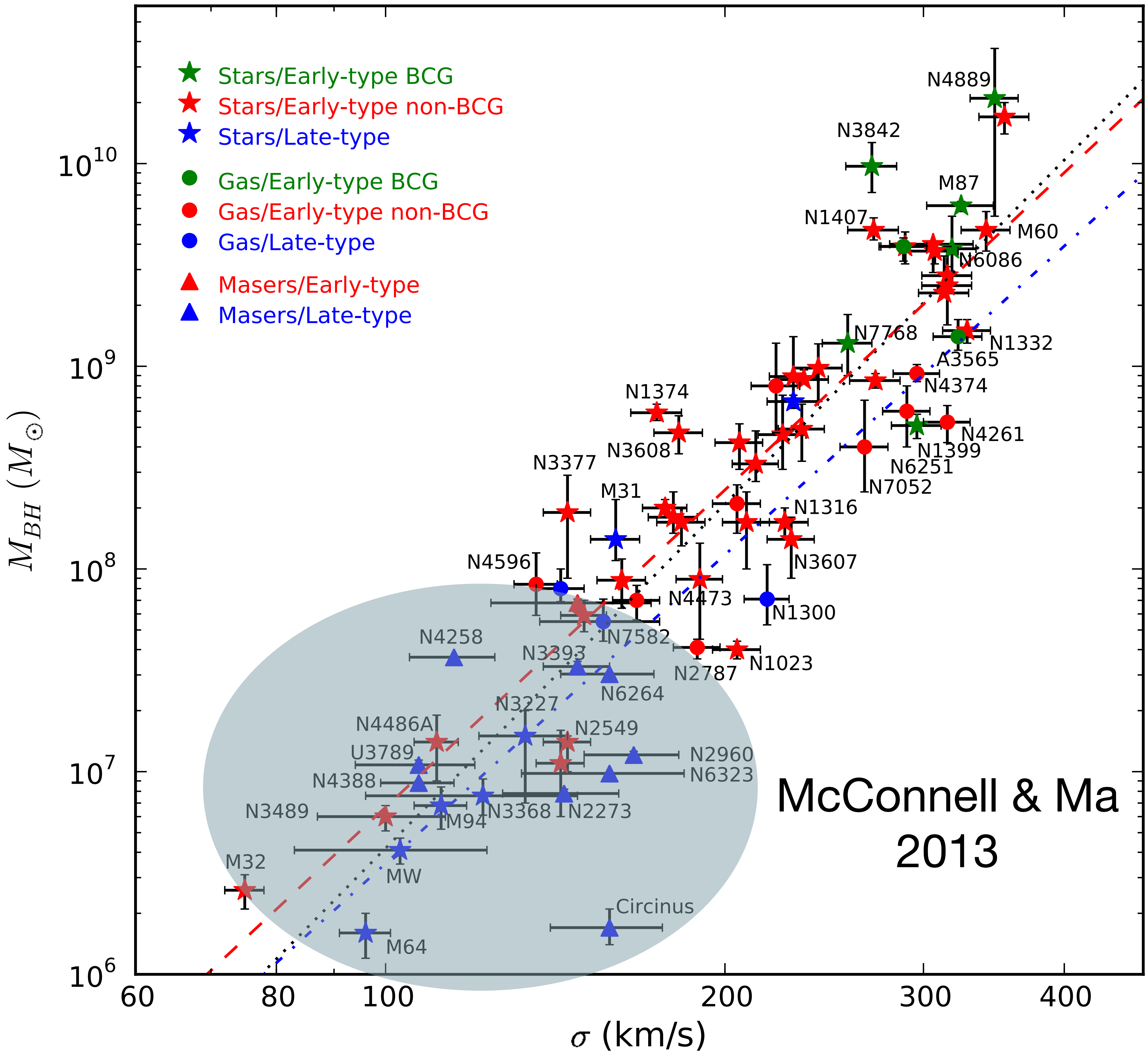
Complete Survey of MASSIVE Galaxies





Ma, Greene et al. 2015

McConnell et al. 2015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σ (km/s)
10^{10}
10^9
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200
300
400

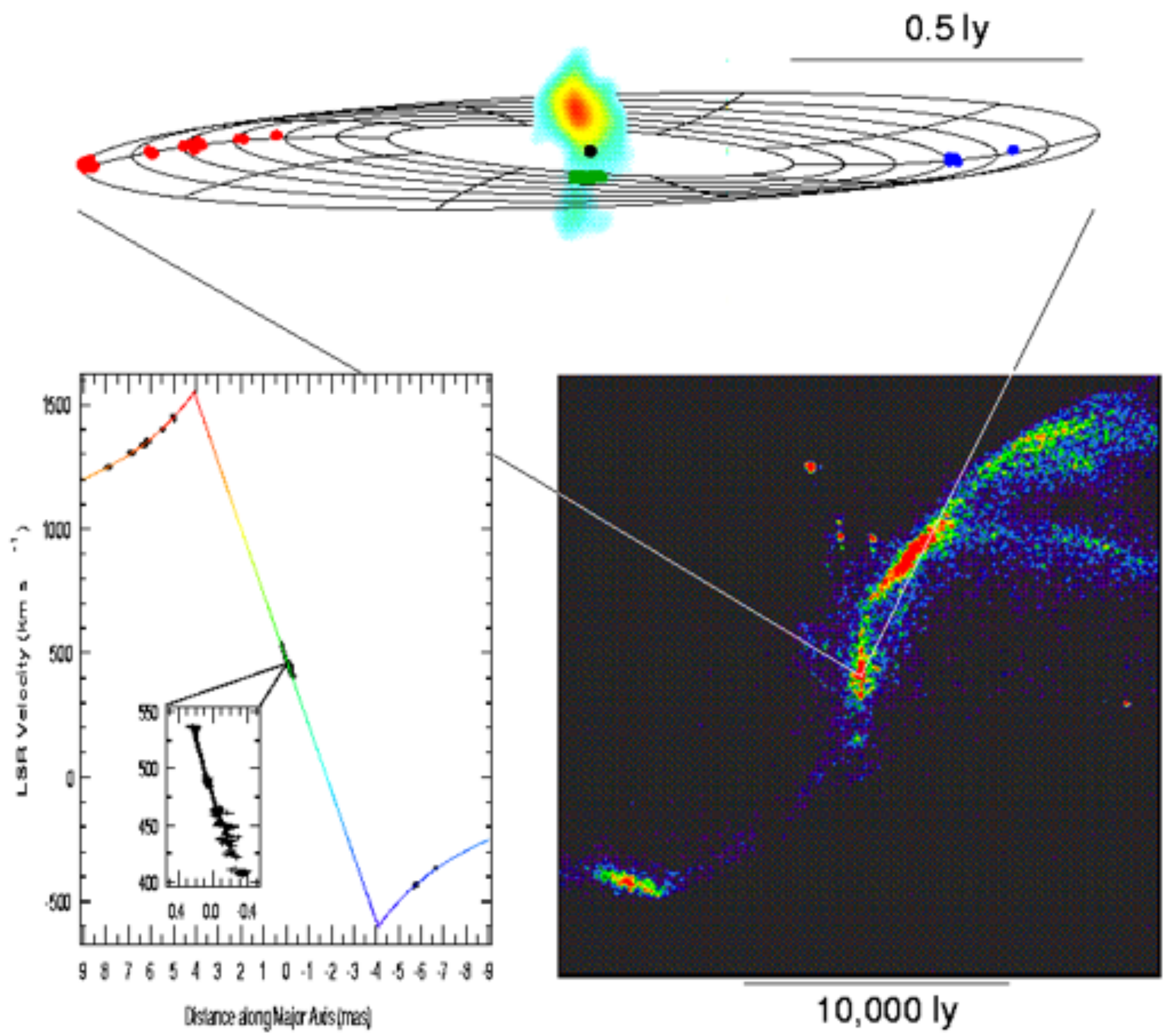
NGC 4258

$H_2$0 megamasers (microwave amplification by stimulated emission; 10^2-10^4 $L_\odot$) as dynamical tracers

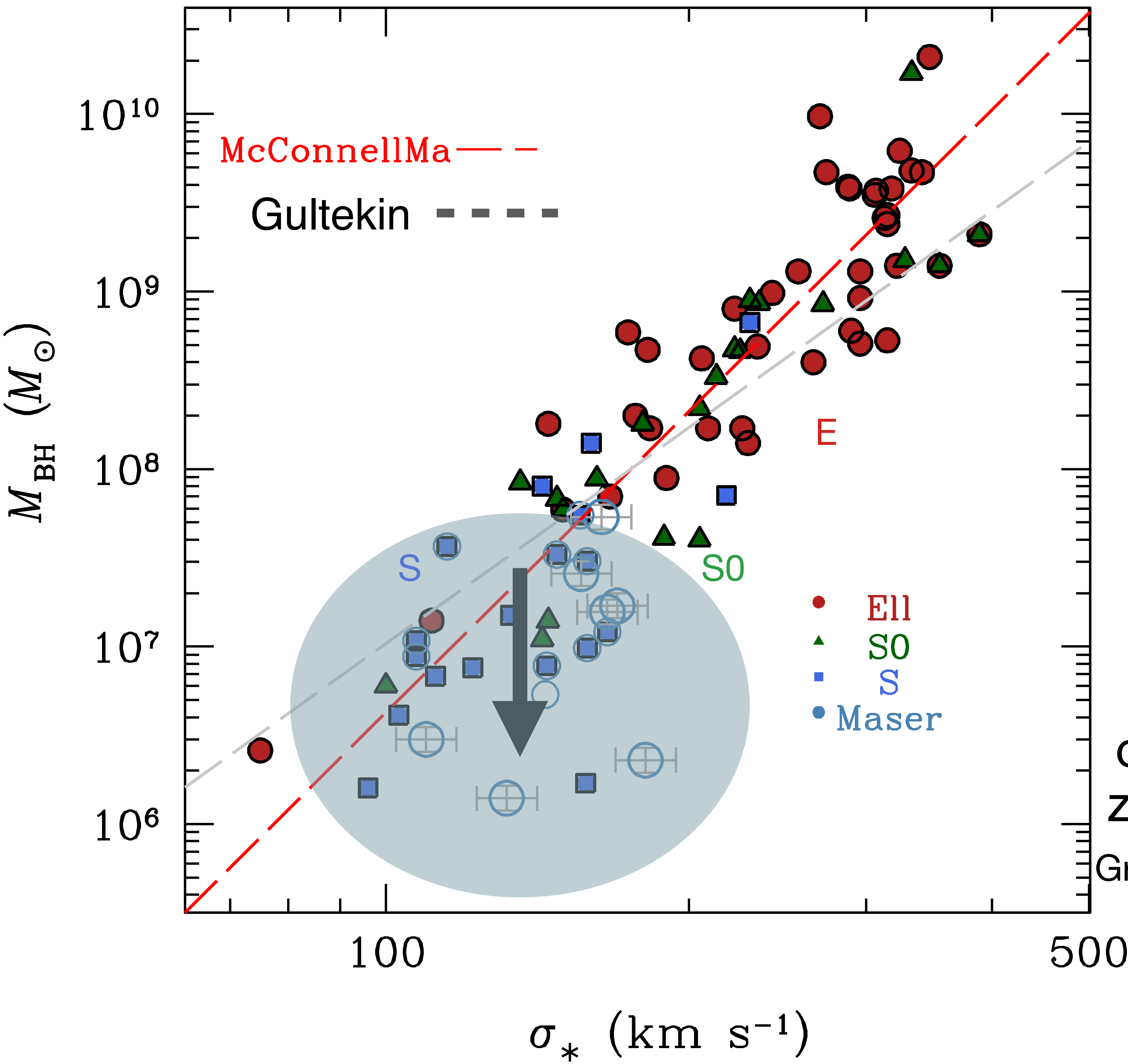
Very precise BH mass ($3.9\pm0.1 \times 10^7$ $M_\odot$), relatively free of systematic bias

With accelerations, also measure an independent distance

Along with MW, best case to rule out astrophysical alternatives to SMBH (e.g., Maoz et al. 1995, 1998)



Miyoshi et al., Herrnstein et al., Greenhill, Humphreys, Moran
galaxy is ~7 Mpc away



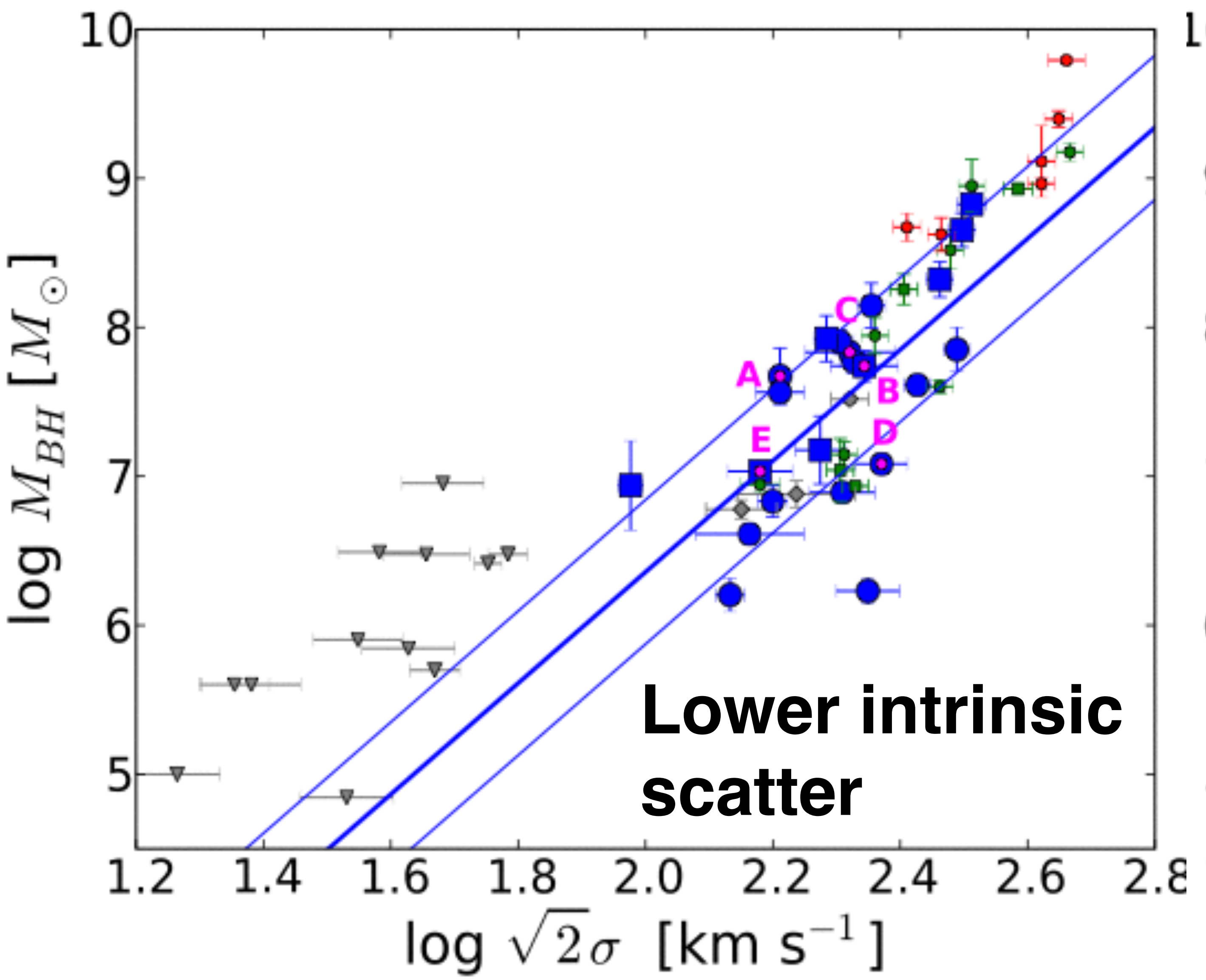
Gao et al. in prep

Zhao et al. in prep

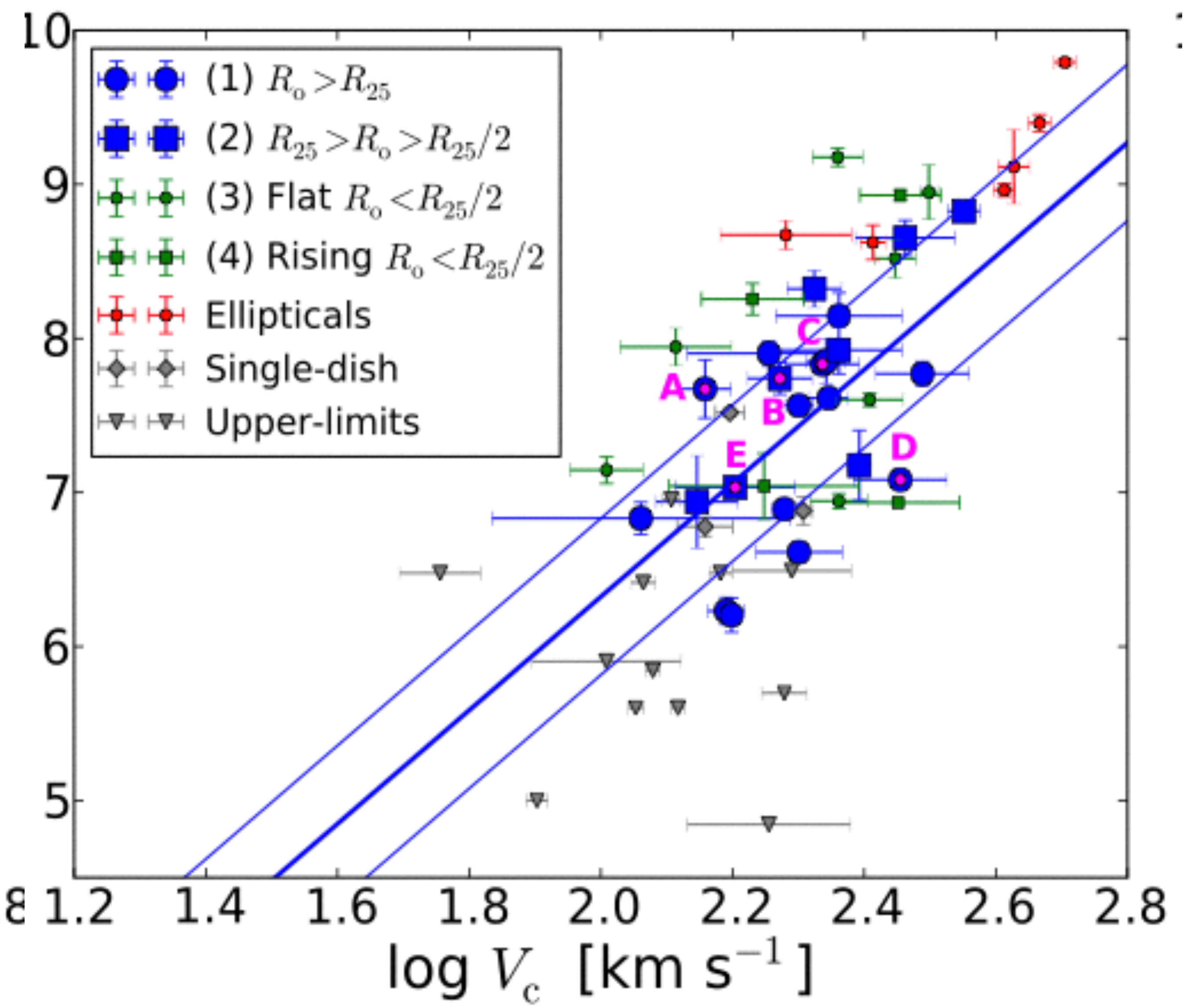
Greene et al. in prep

Or Circular Velocity (Halo Mass)

M_{BH} - σ

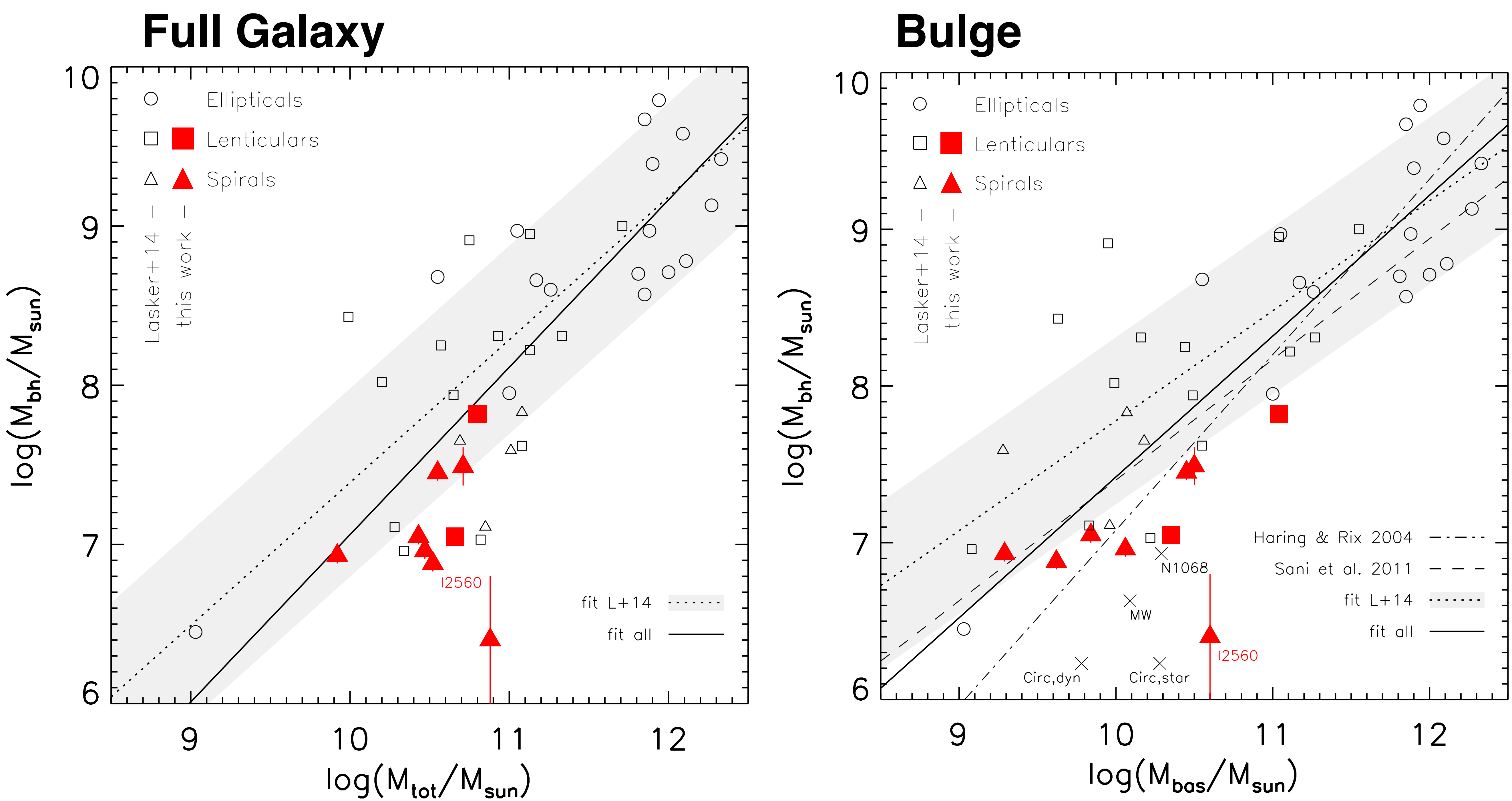


M_{BH} - Vc

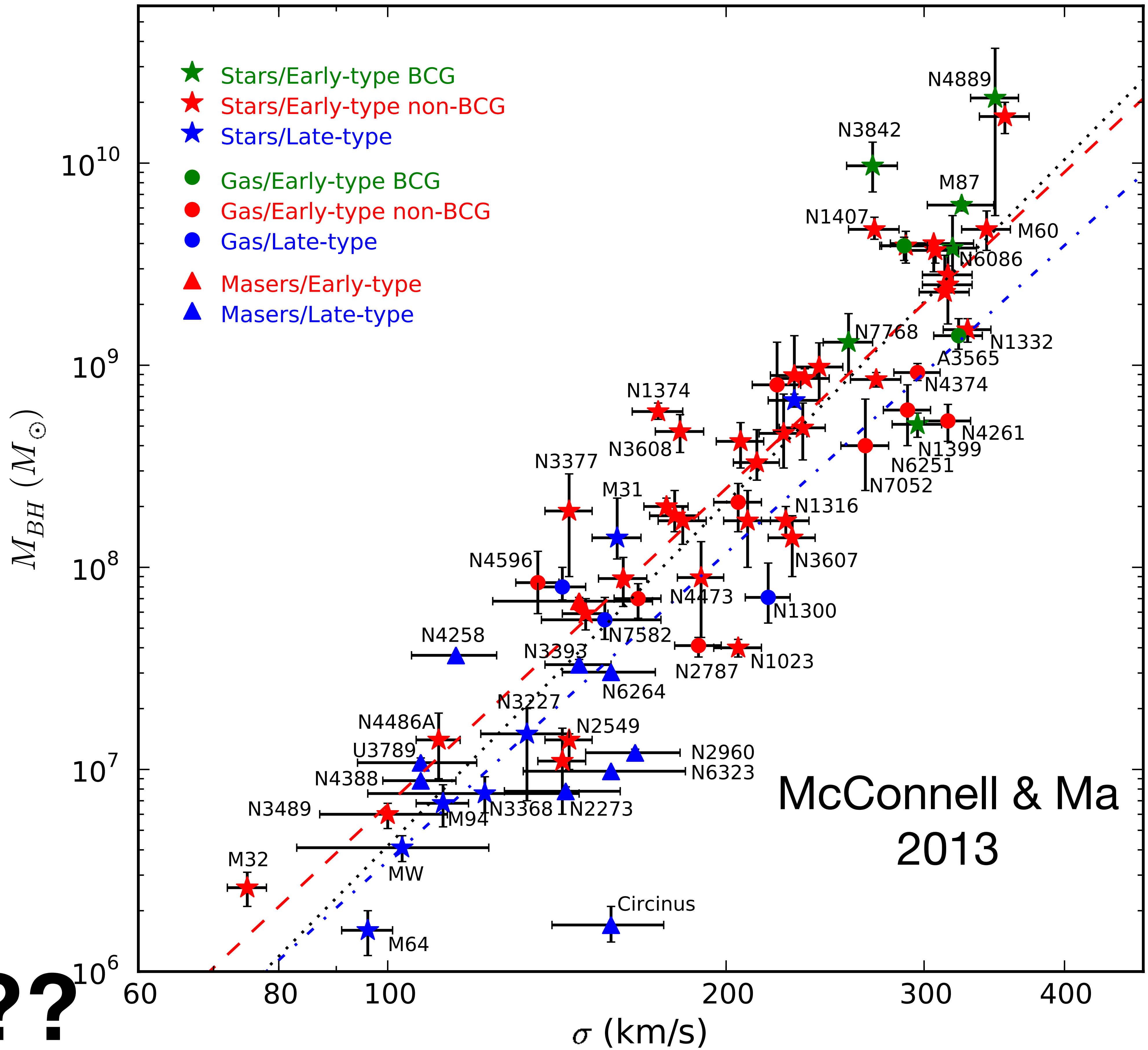


Sun, Greene+ 2013 — Talk to Ai-Lei, she is here!

Or bulge mass…



Laesker, Greene+ in prep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10^6
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300
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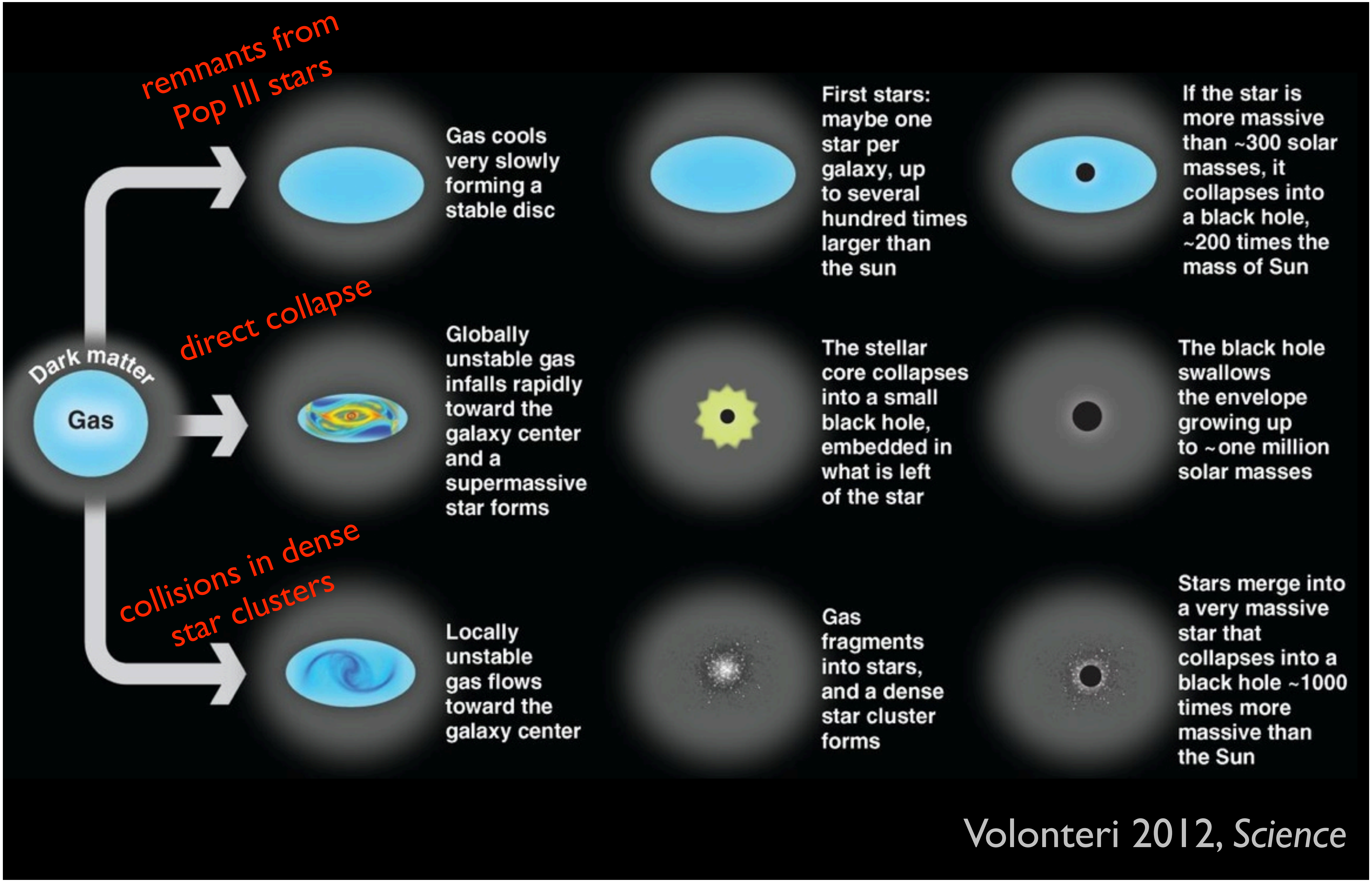
McConnell & Ma
2013

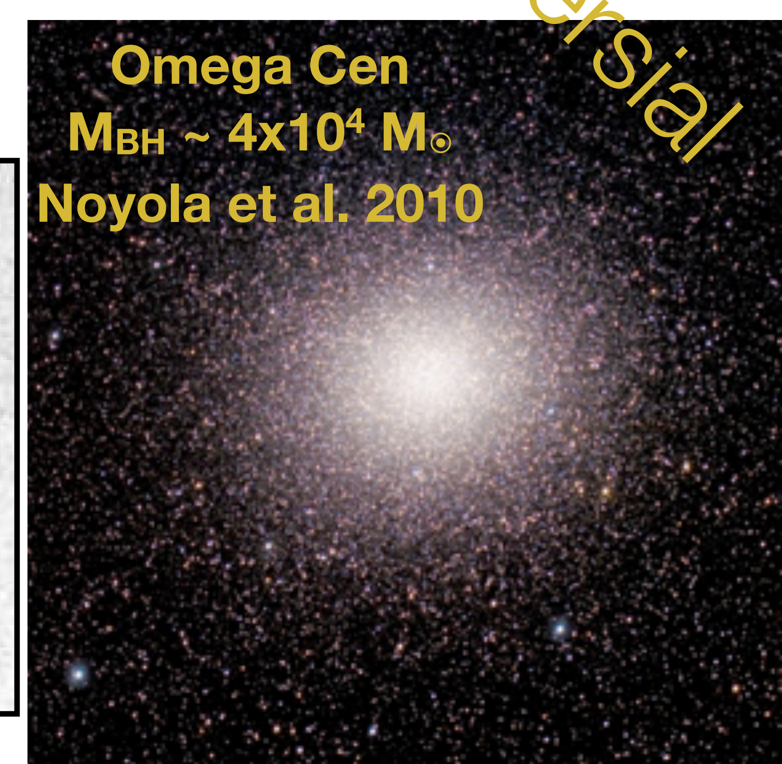
???

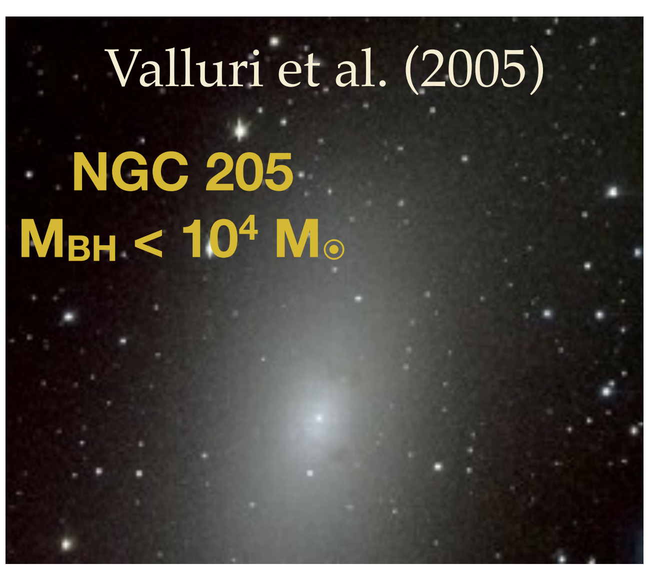

remnants from Pop III stars
direct collapse
collisions in dense star clusters
Dark matter
Gas
Gas cools very slowly forming a stable disc
First stars: maybe one star per galaxy, up to several hundred times larger than the sun
If the star is more massive than ~300 solar masses, it collapses into a black hole, ~200 times the mass of Sun
Globally unstable gas infalls rapidly toward the galaxy center and a supermassive star forms
The stellar core collapses into a small black hole, embedded in what is left of the star
The black hole swallows the envelope growing up to ~one million solar masses
Locally unstable gas flows toward the galaxy center
Gas fragments into stars, and a dense star cluster forms
Stars merge into a very massive star that collapses into a black hole ~1000 times more massive than the Sun
Volonteri 2012, *Science*

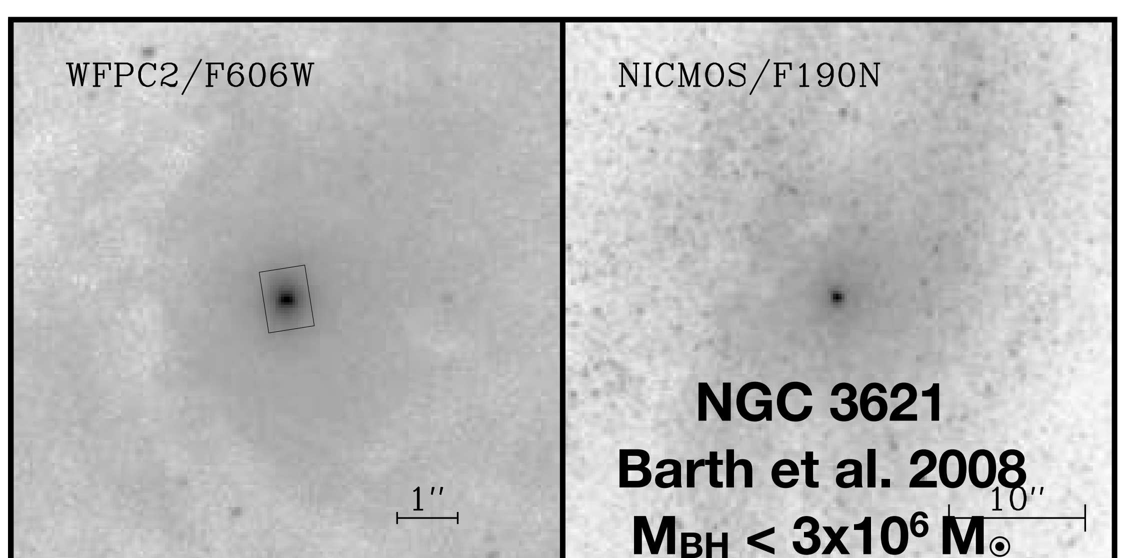
Dynamical BH masses for <10^6 M☉ BHs only possible within a few Mpc

Controversial

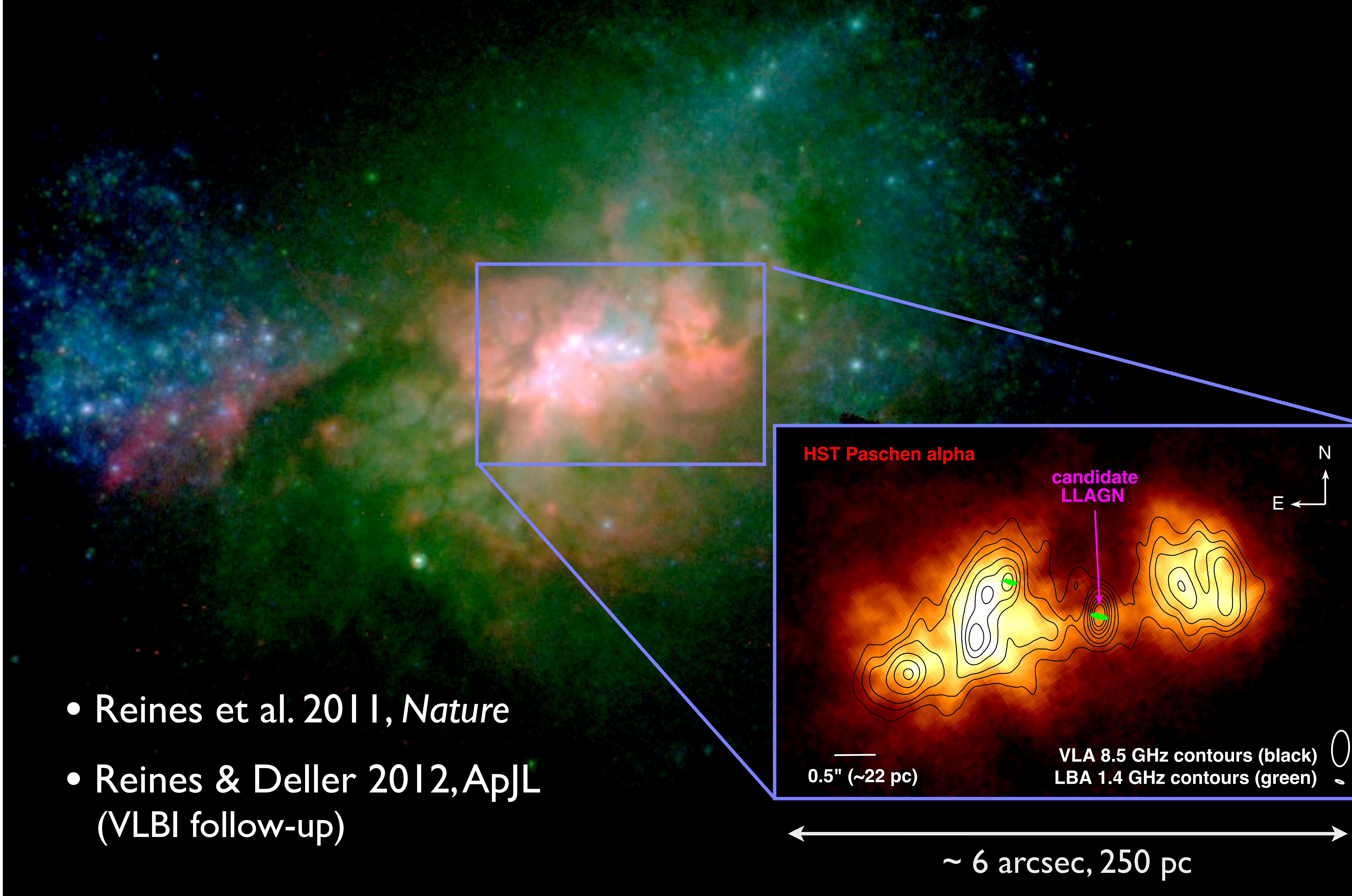
see also Lora et al. 2009,
Jardel & Gebhardt 2012







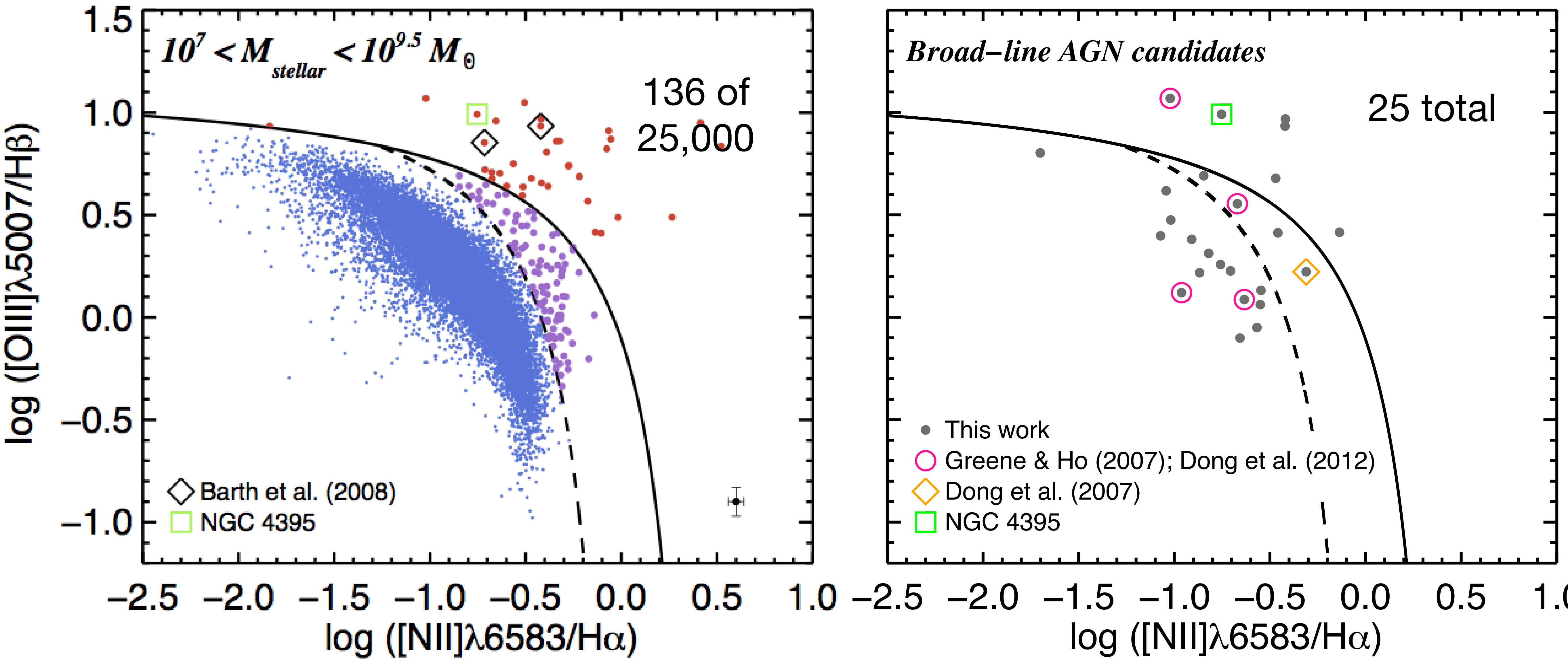
A massive BH in the dwarf starburst galaxy Henize 2-10



- Reines et al. 2011, *Nature*
- Reines & Deller 2012, ApJL (VLBI follow-up)

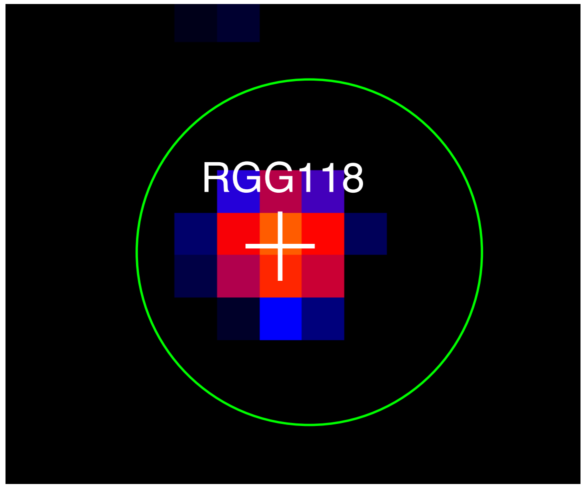
Reines, Greene, & Geha 2013

DWARF (~LMC) GALAXIES IN SDSS

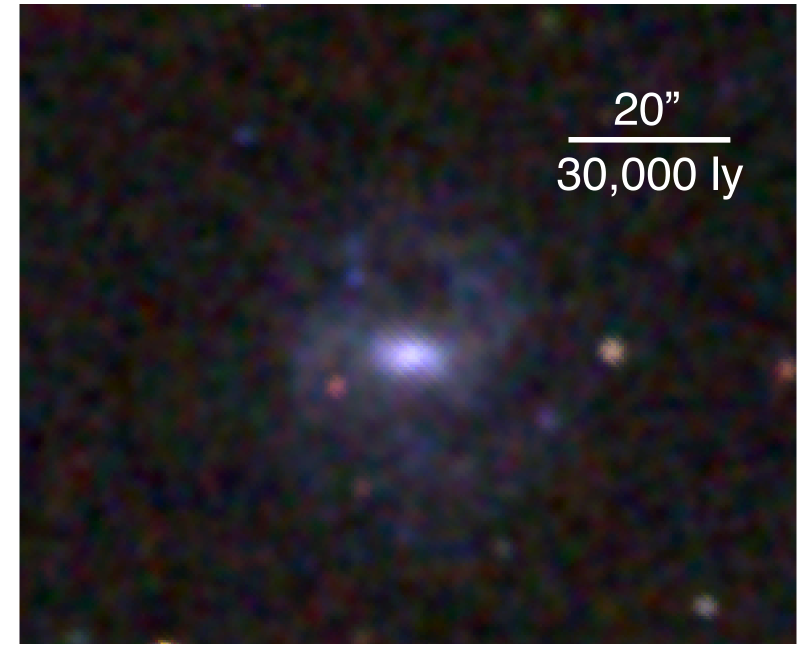


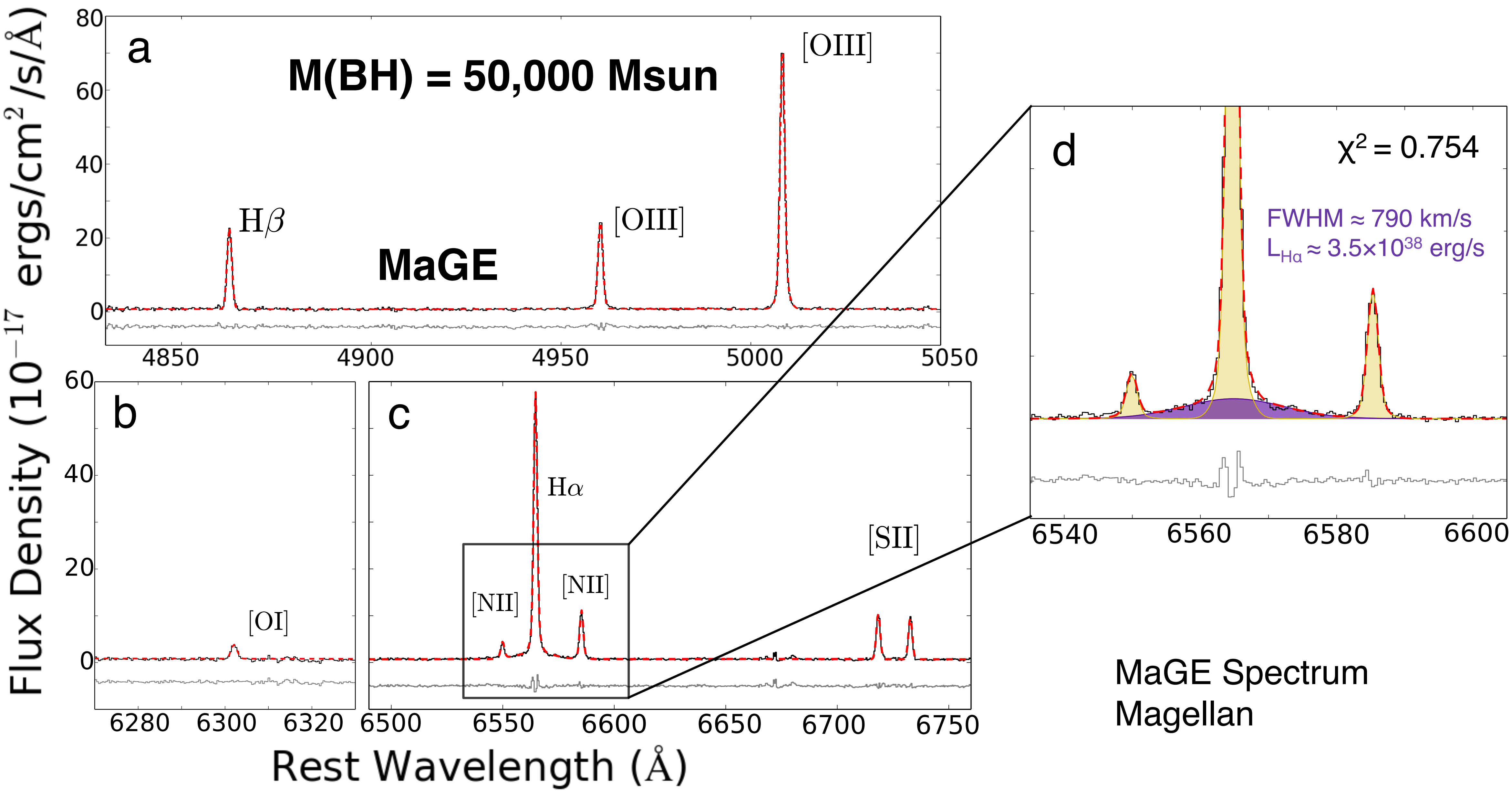
Started with the SDSS-NASA/Sloan Atlas; Select LMC-mass or lower galaxies; Search for signs of nuclear activity from optical emission lines

Vivienne Baldassare, Reines et al. 2015



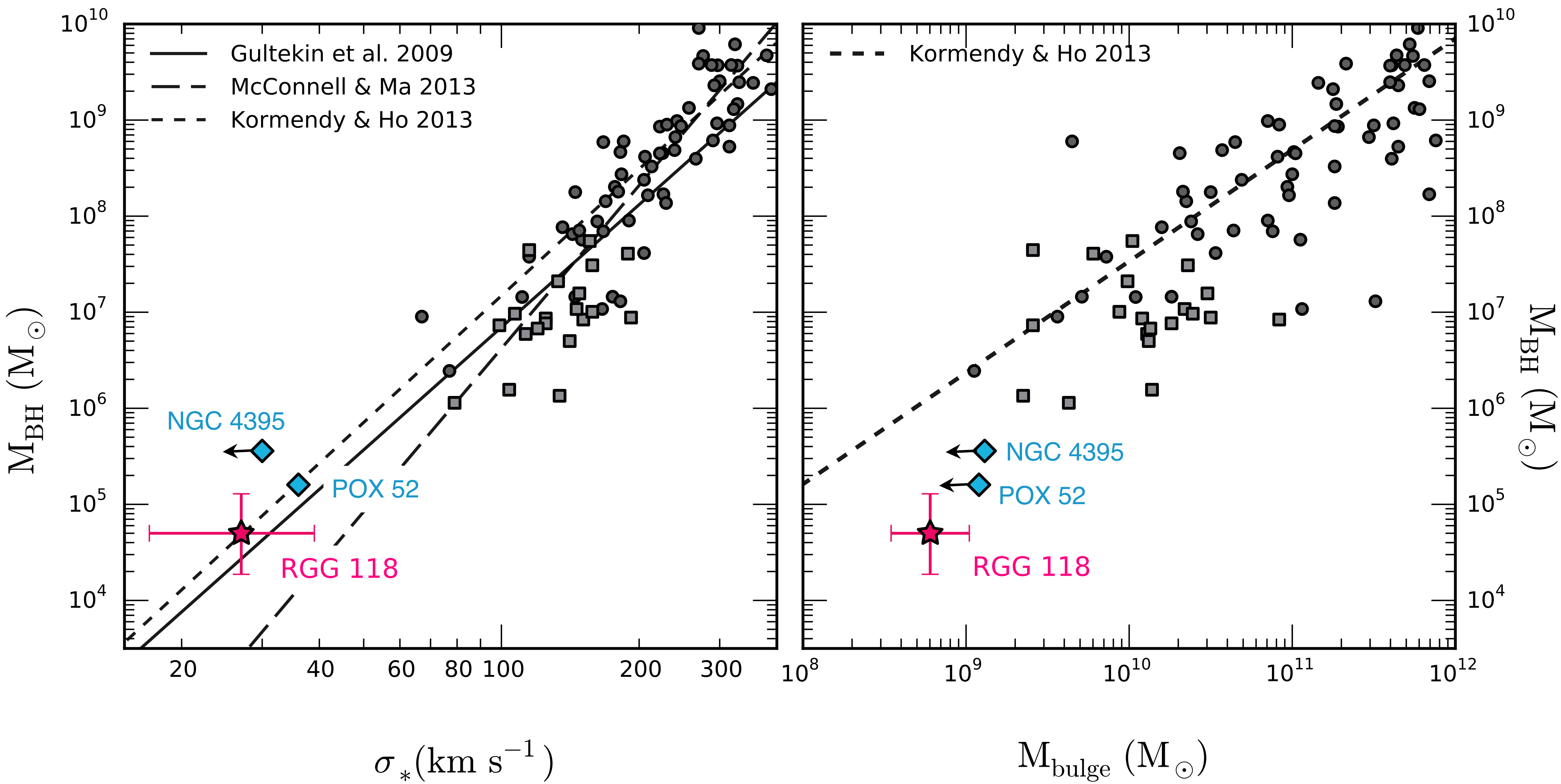
4 x 10^{39} erg/s
Chandra





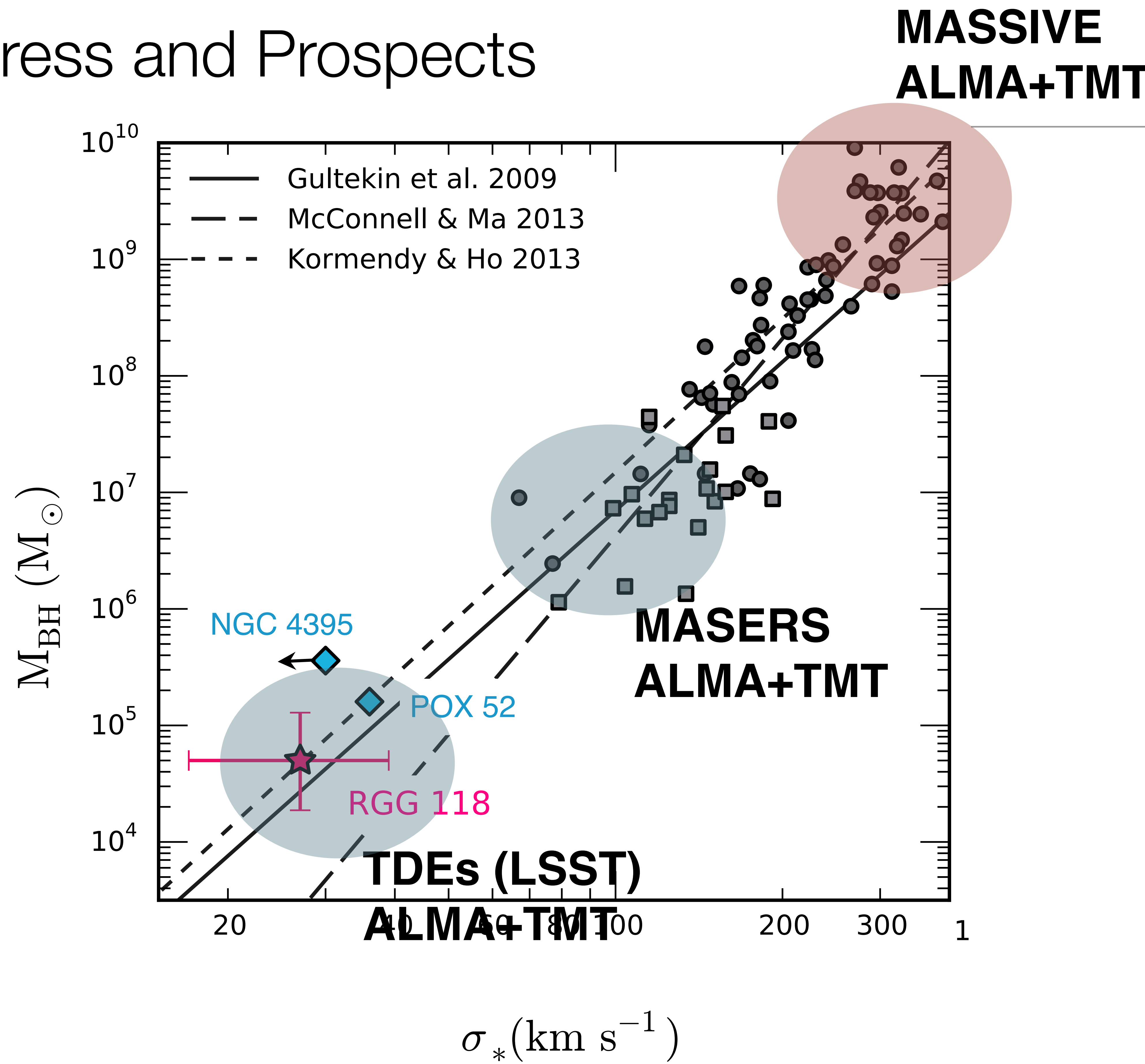
MaGE Spectrum
Magellan

Lowest Mass Found in Galaxy Centers?

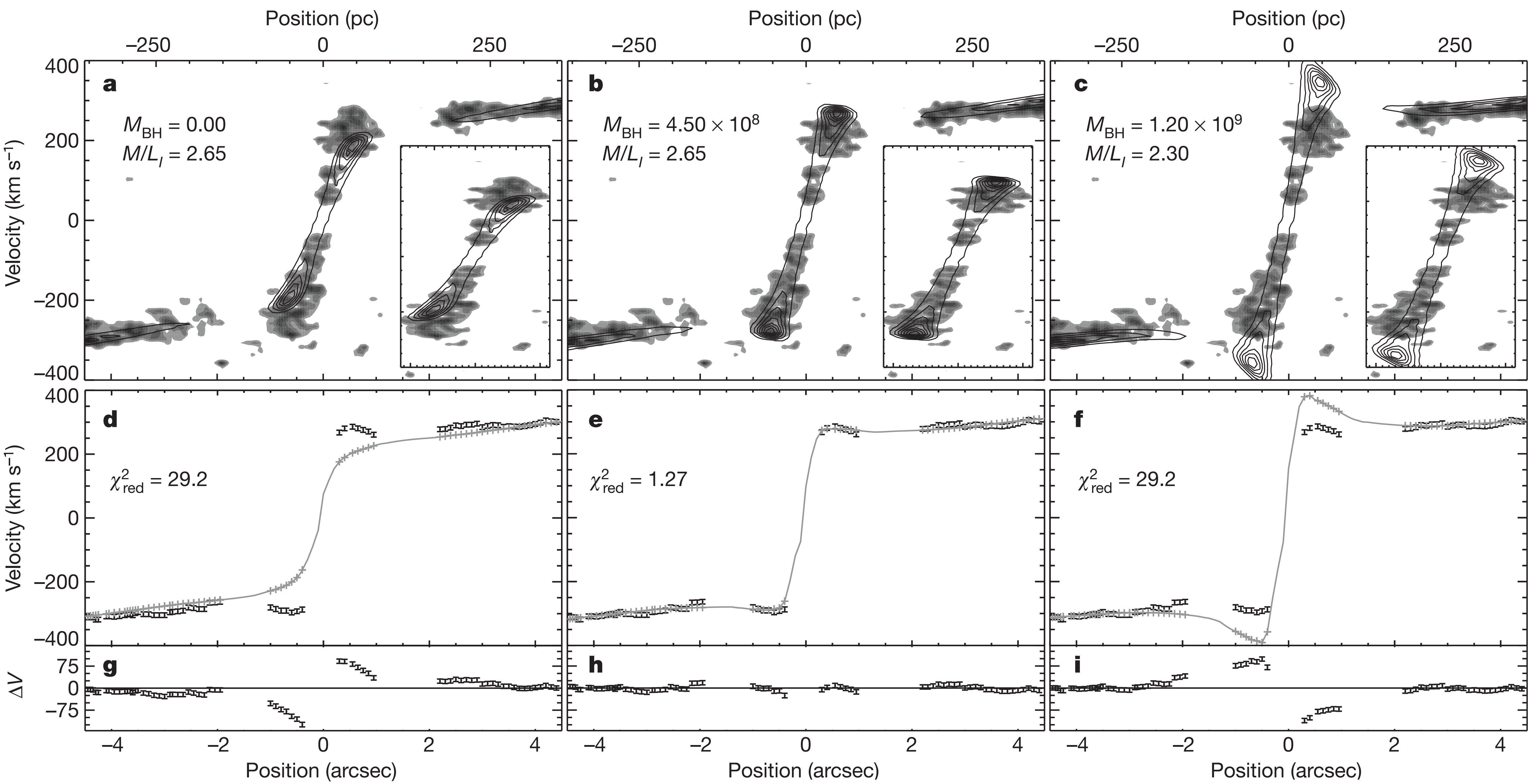


Baldassere, Reines+ 2015

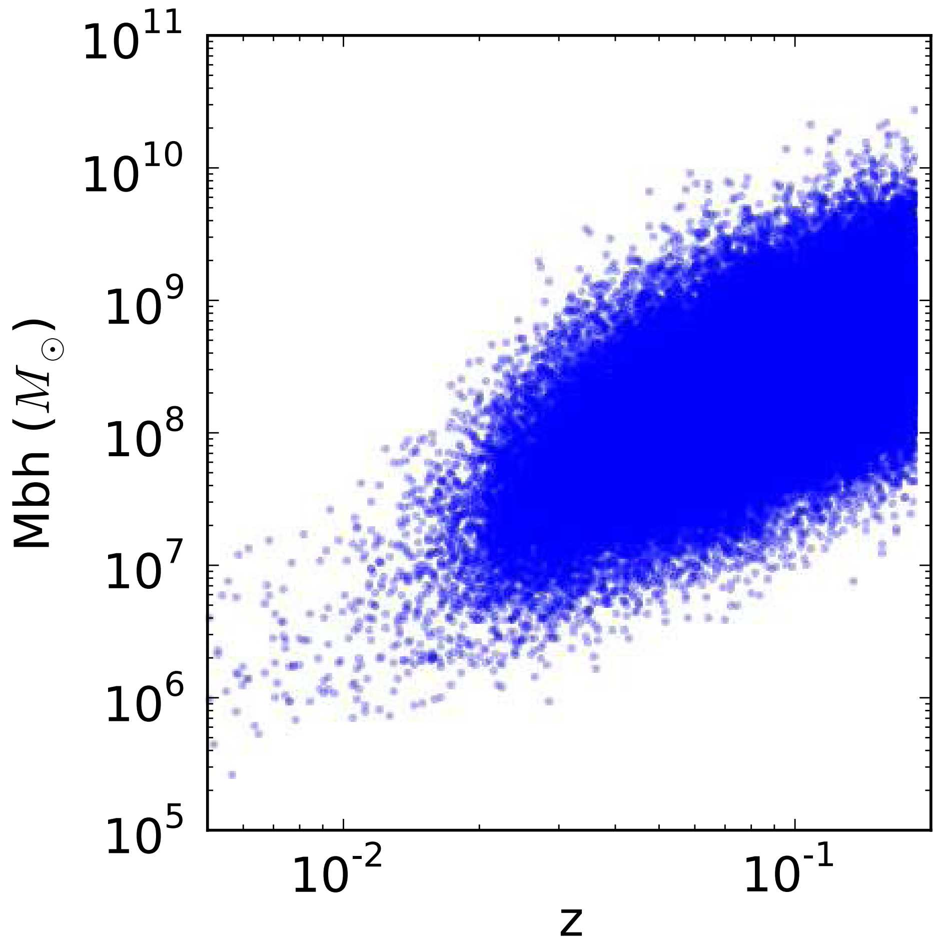
Progress and Prospects

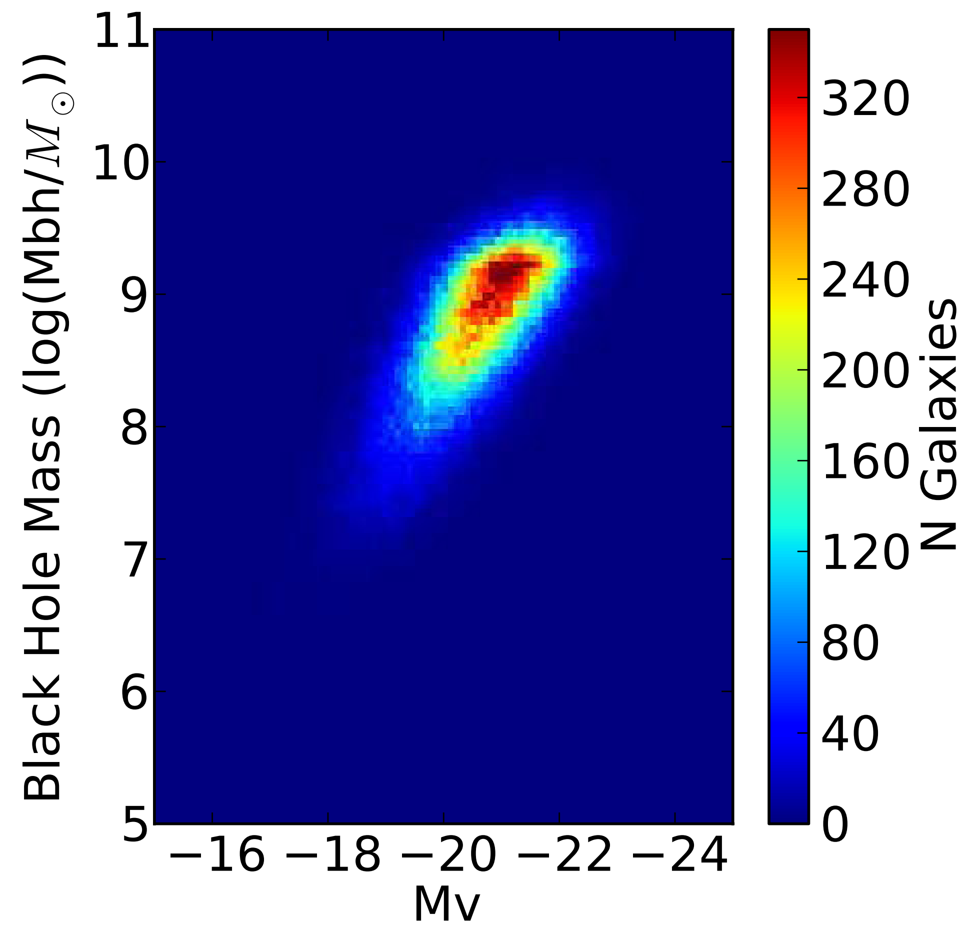


Prospects: Molecular Gas Dynamics



Davis et al. 2013, see also Onishi+ 2015 (ALMA!)



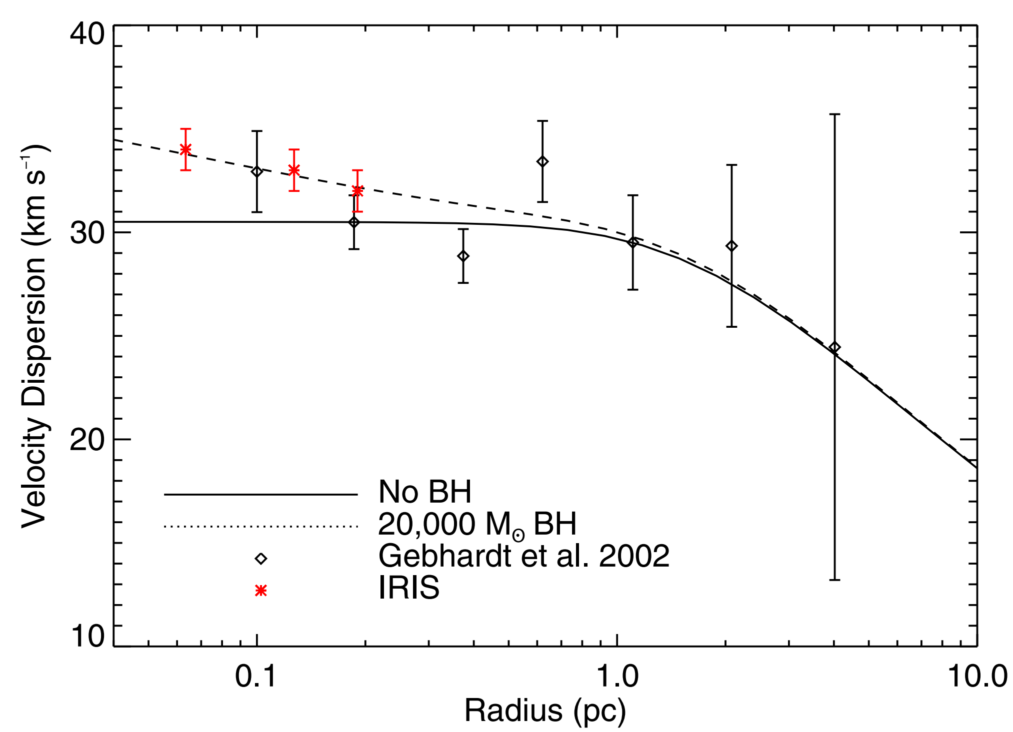


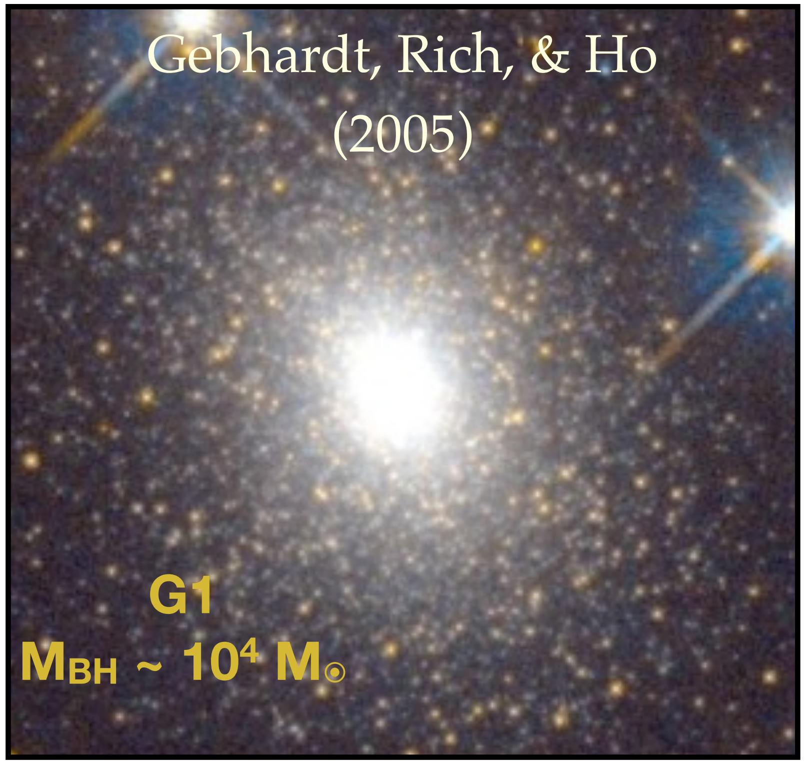
New insights into M_{BH} from dynamical masses

Do+ 2014

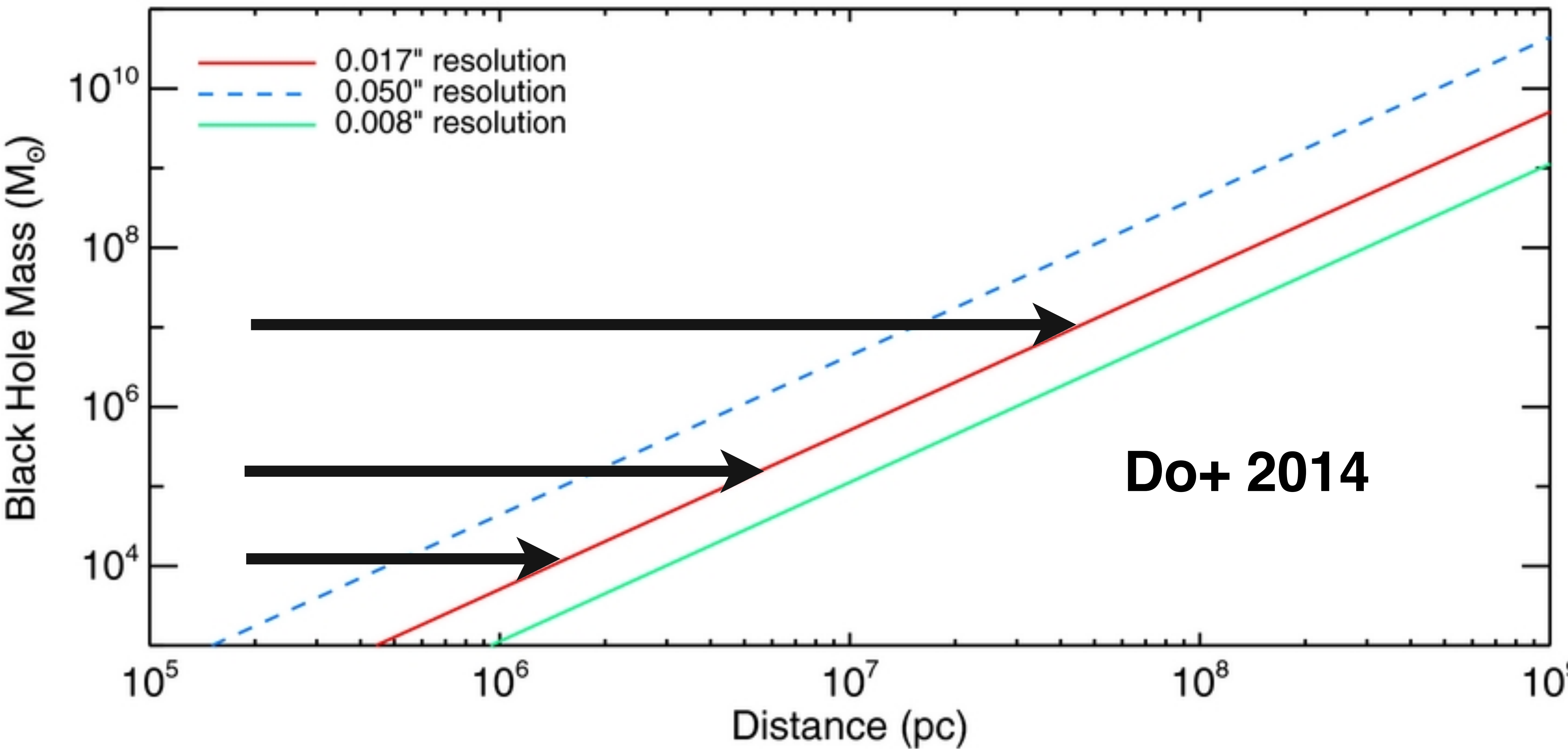
Prospects: TMT

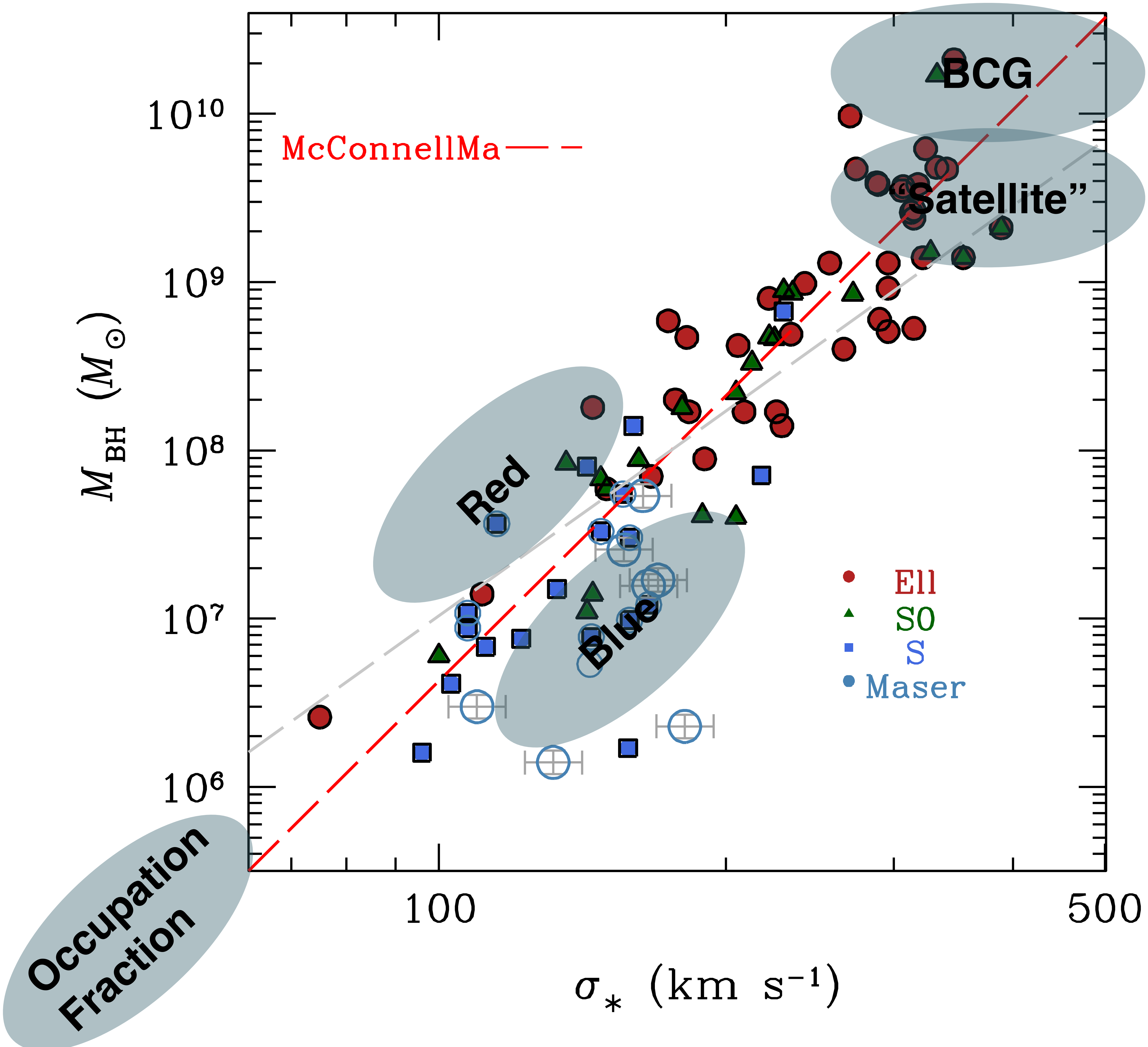
Small stellar systems in LG





Prospects: TMT

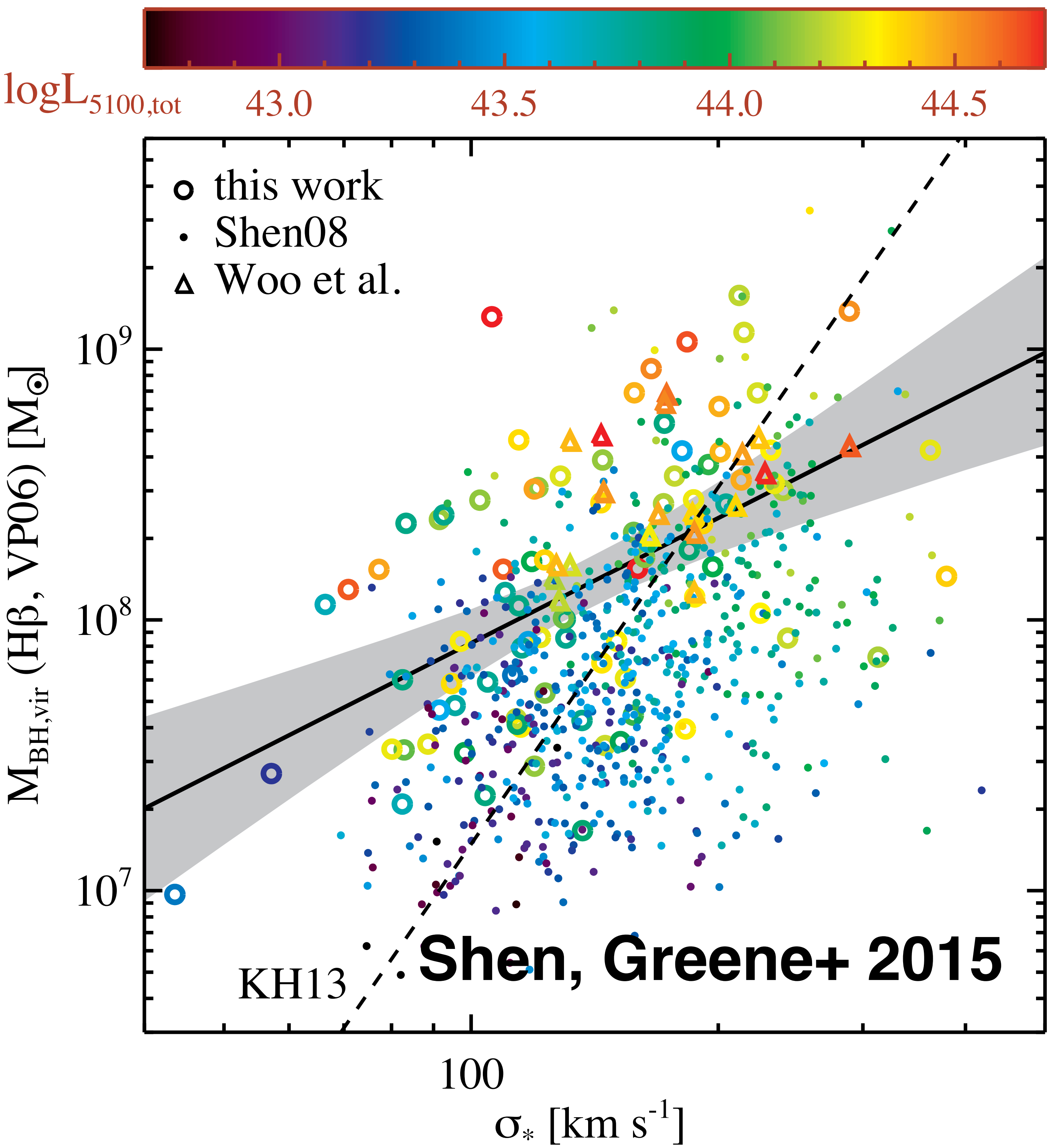




BCG
"Satellite"
Red
Blue
Occupation Fraction
McConnellMa
Ell
S0
S
Maser
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
100
500
$M_{\rm BH}$ $(M_\odot)$
σ_* (km s^{-1})

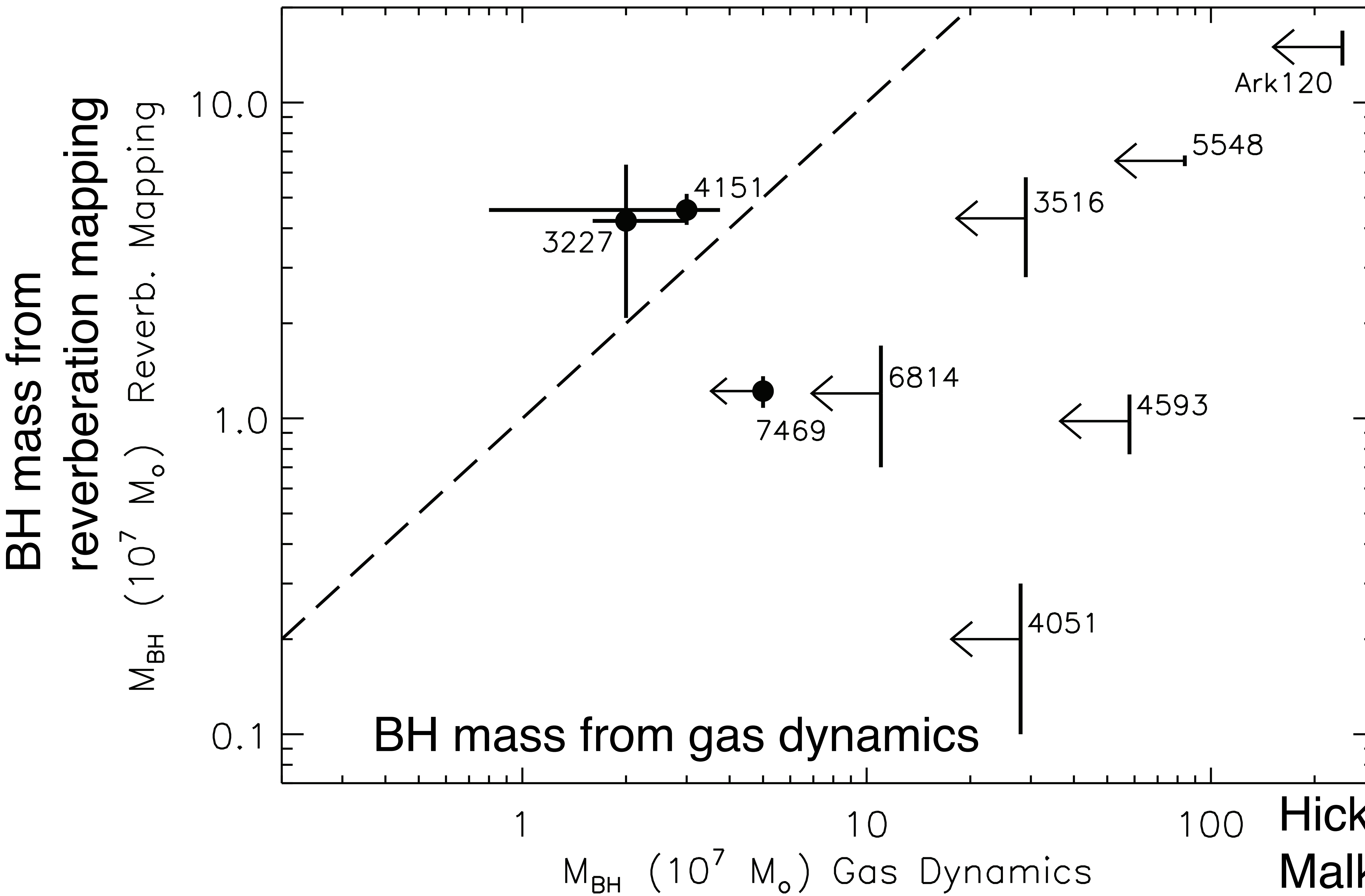
But does it matter for galaxy evolution? Let’s try to look back in time…

Evolution in Scaling Relations?



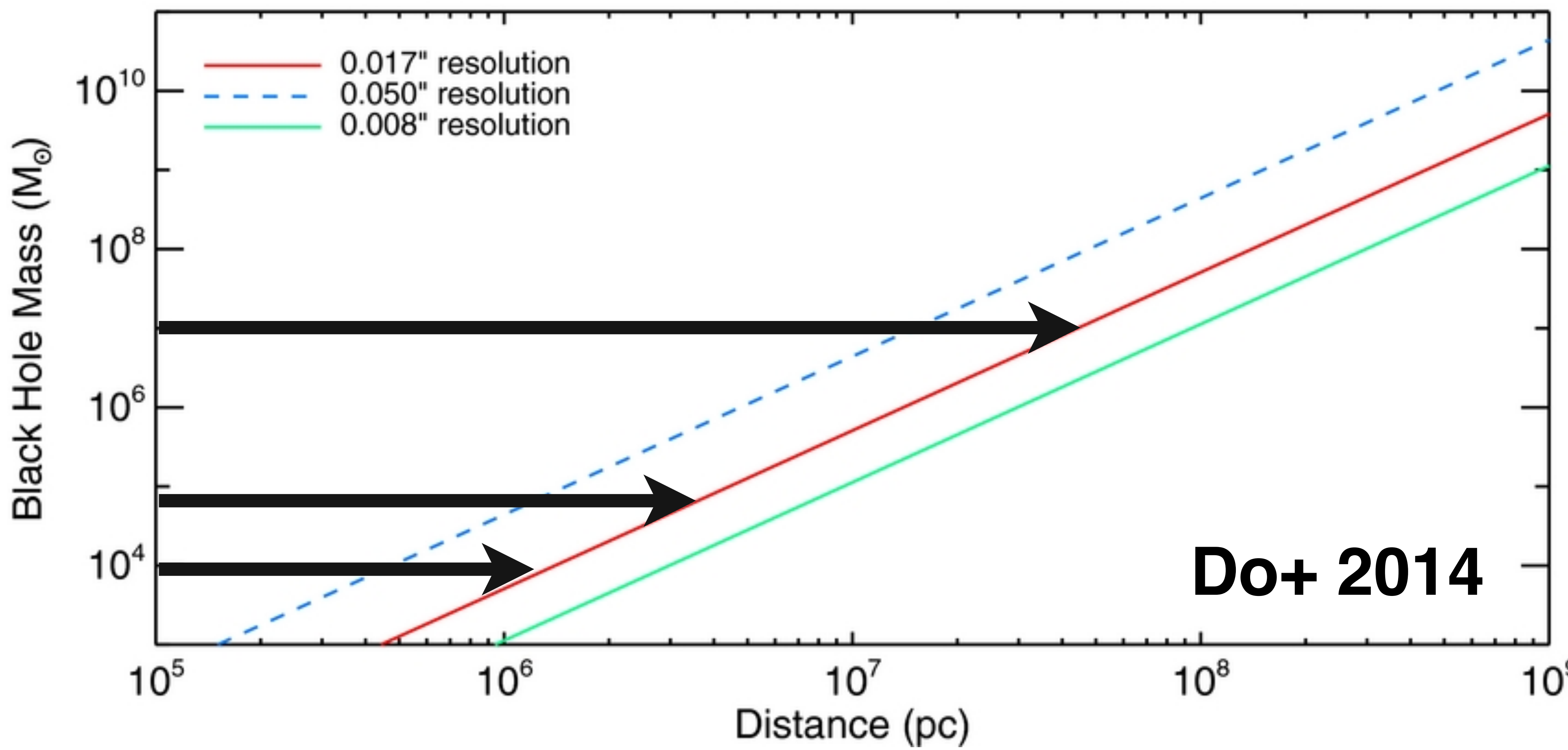
- Observations show higher M_{BH} at fixed galaxy property at higher redshift
- But, these offsets likely can be explained by selection bias
- What is the way forward?

Need to understand BH masses from Reverberation Mapping



Hicks & Malkan 2008

Prospects: TMT



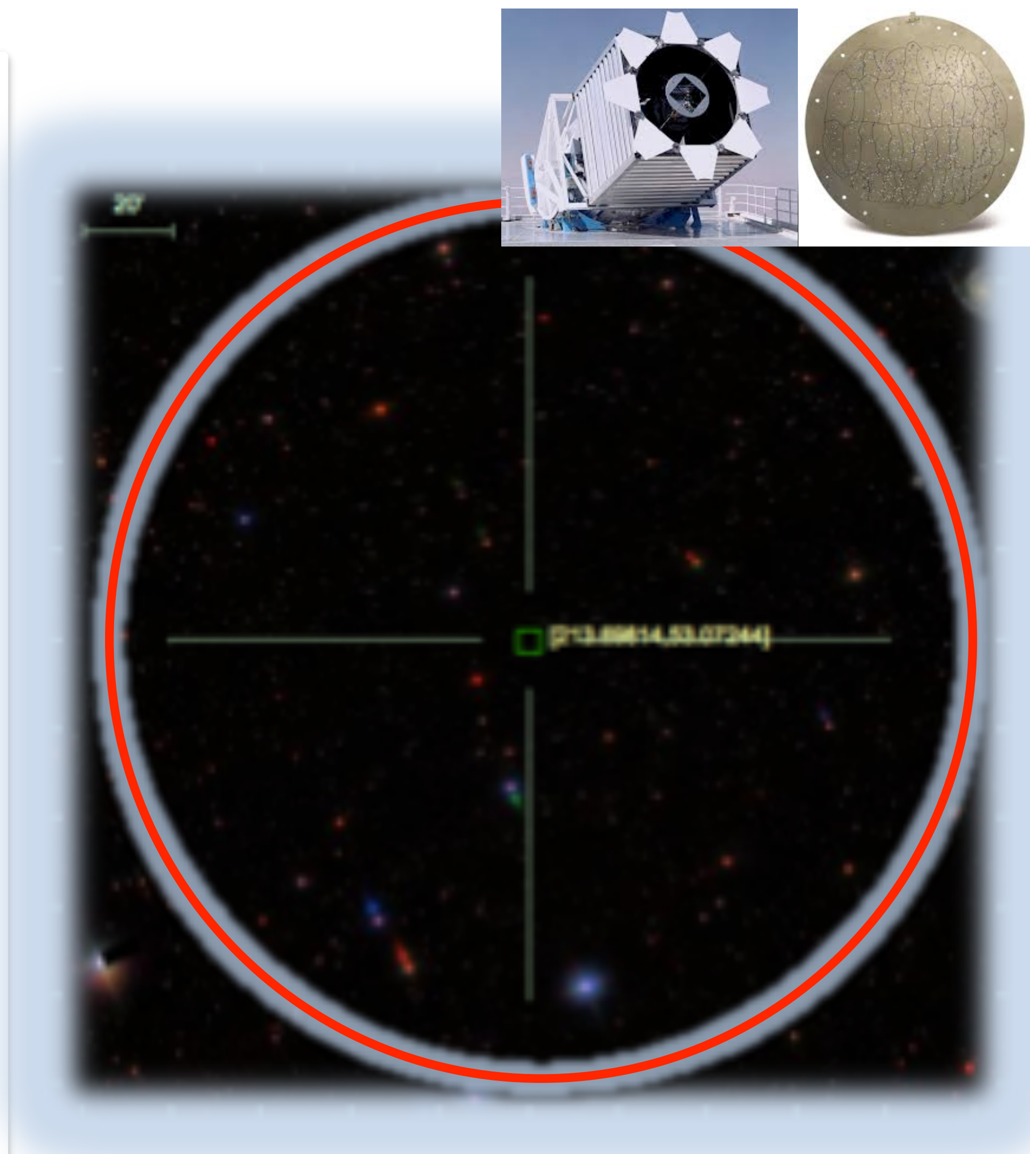
- Calibrate AGN BH masses out to 100 Mpc at least
- Get dynamical BH masses for the entire megamaser sample

Prospects: TMT + LSST

SDSS-RM in a nutshell

Shen+

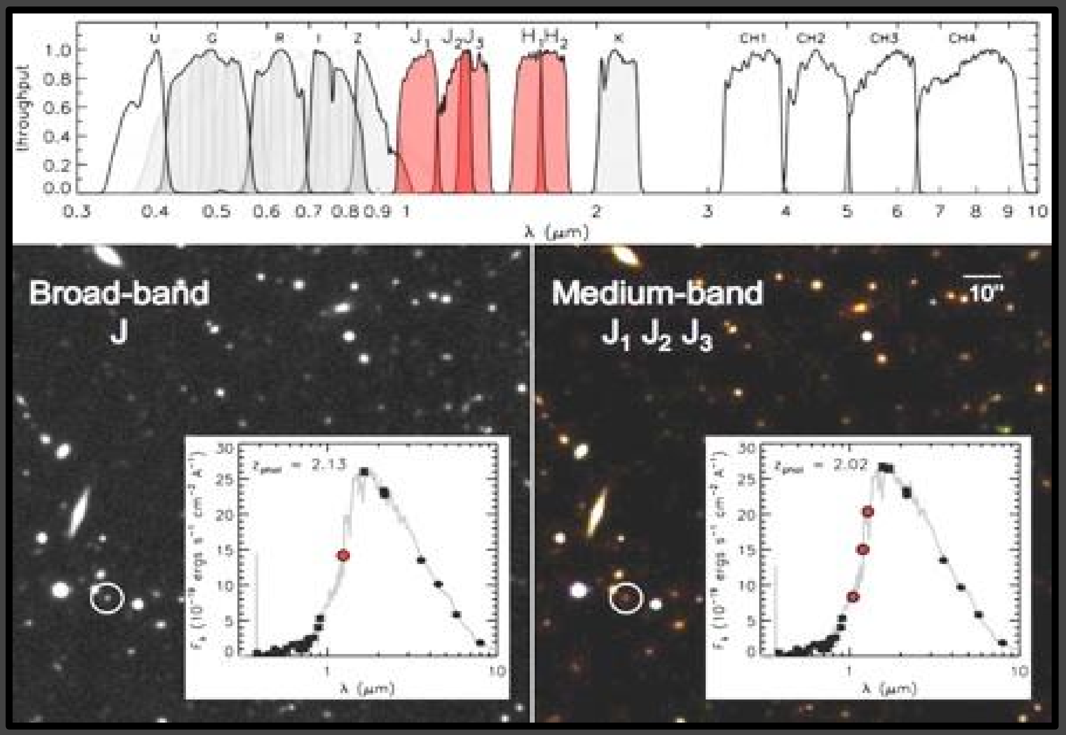
- Motivation: expand the RM AGN sample in both size and luminosity-redshift range
- Simultaneous monitoring a uniform sample of 849 quasars at $0.1<z<4.5$ in a single 7 deg^2 field with the SDSS-BOSS spectrograph; 32 epochs completed in 2014A; continue through 2017 at reduced cadence
- Dense photometric light curves (~2-4 day cadence) since 2010 (PanSTARRS 1 + SDSS-RM imaging)



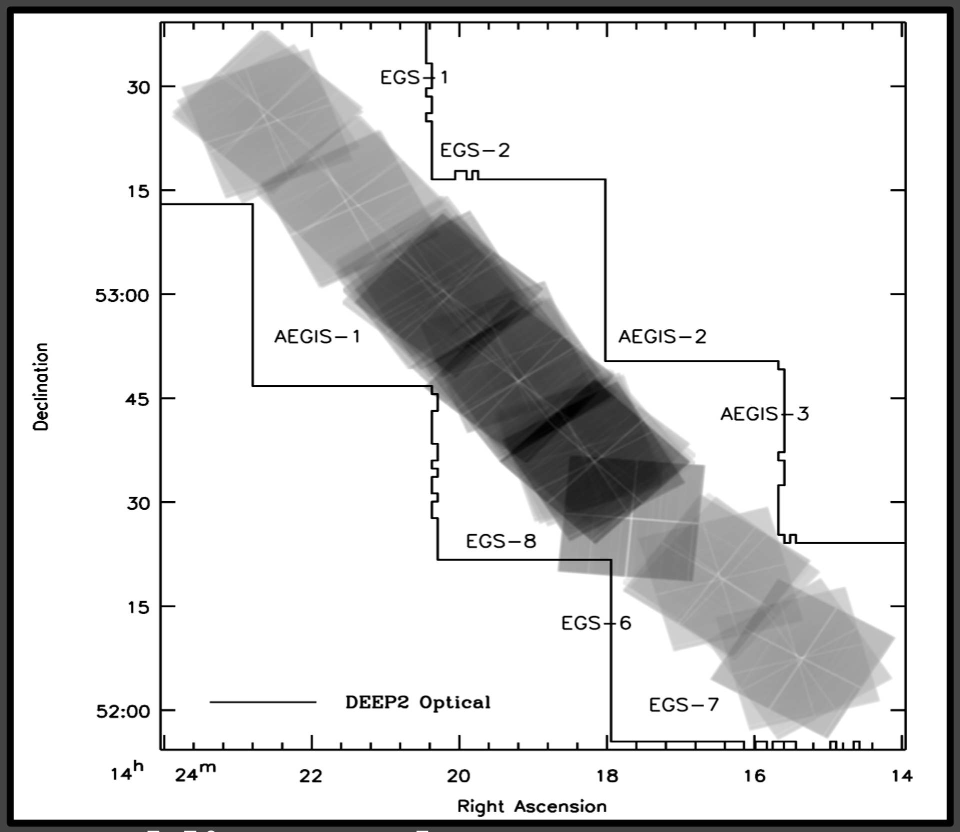
SDSS-RM Project: http://www.sdssrm.org

See also Martini+

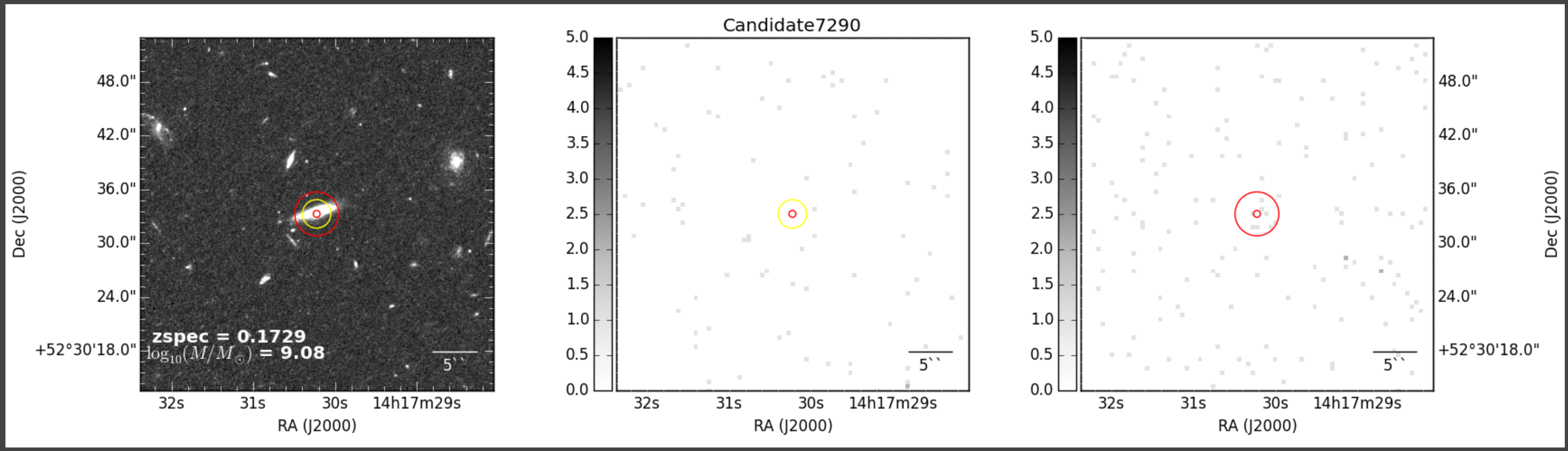
NEWFIRM, AEGIS, and Chandra



astro.yale.edu



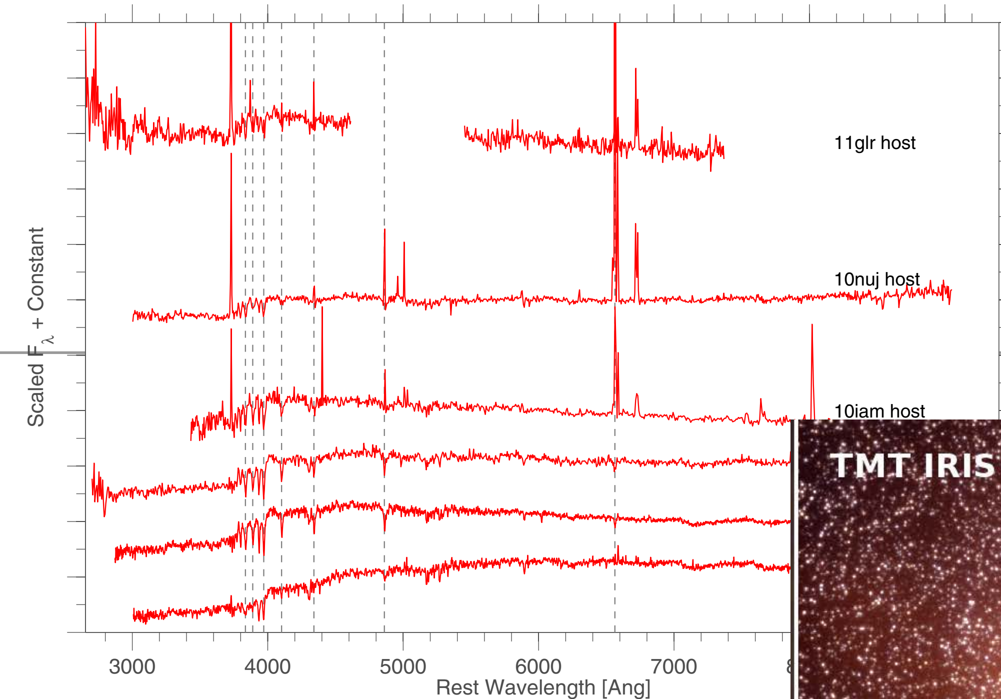
Goulding et al. 2012



Pardo, Goulding et al. in prep

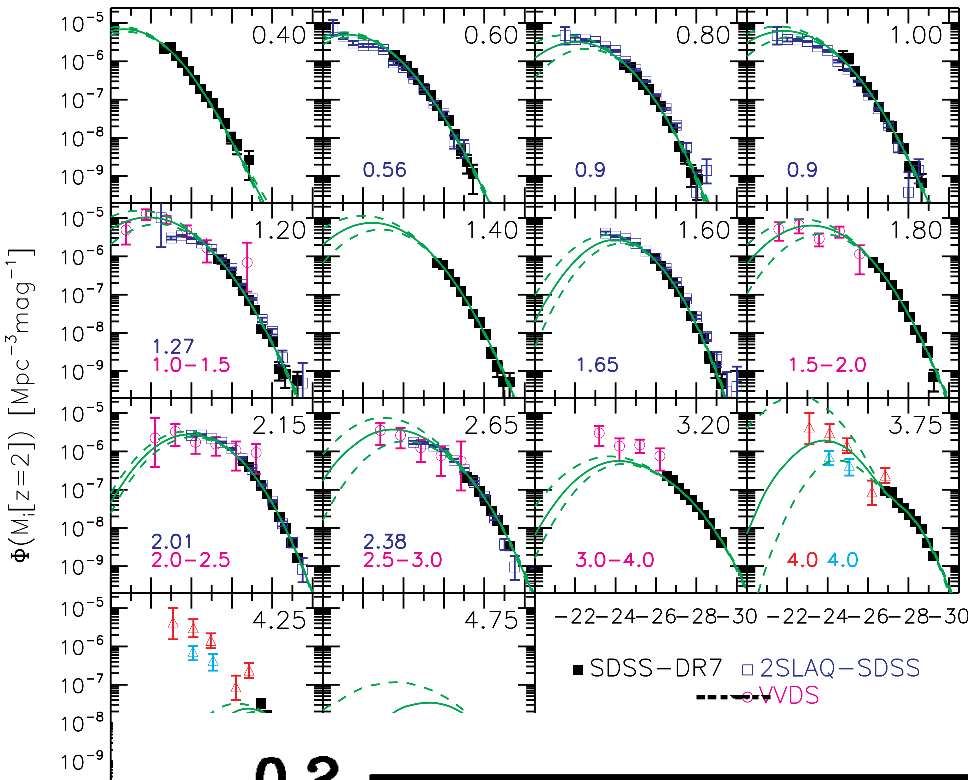
Other things

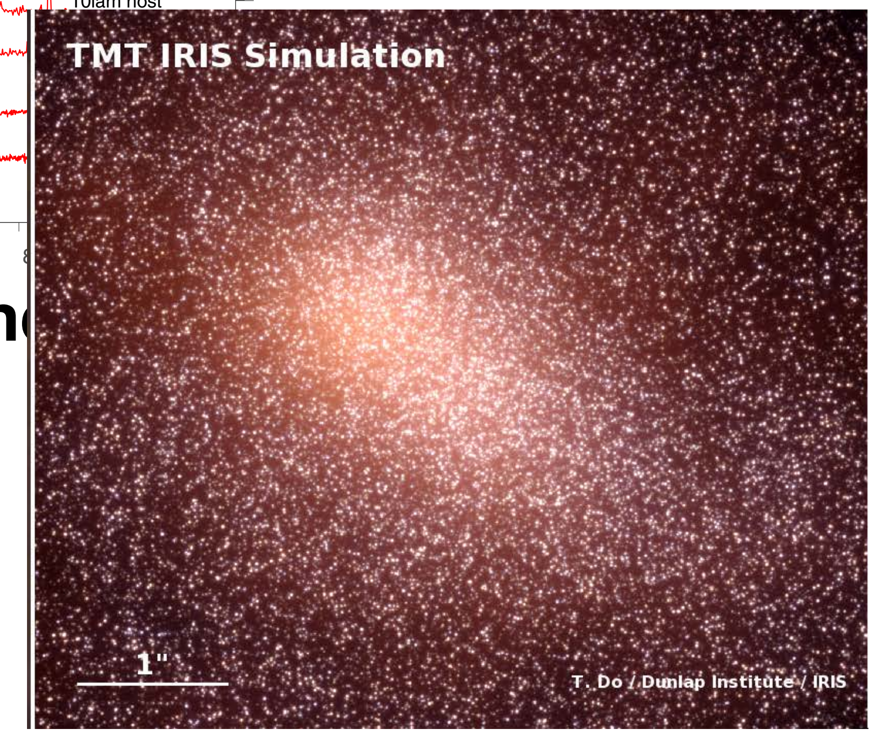
Arcavi+ 2015



Follow-up of TDE can

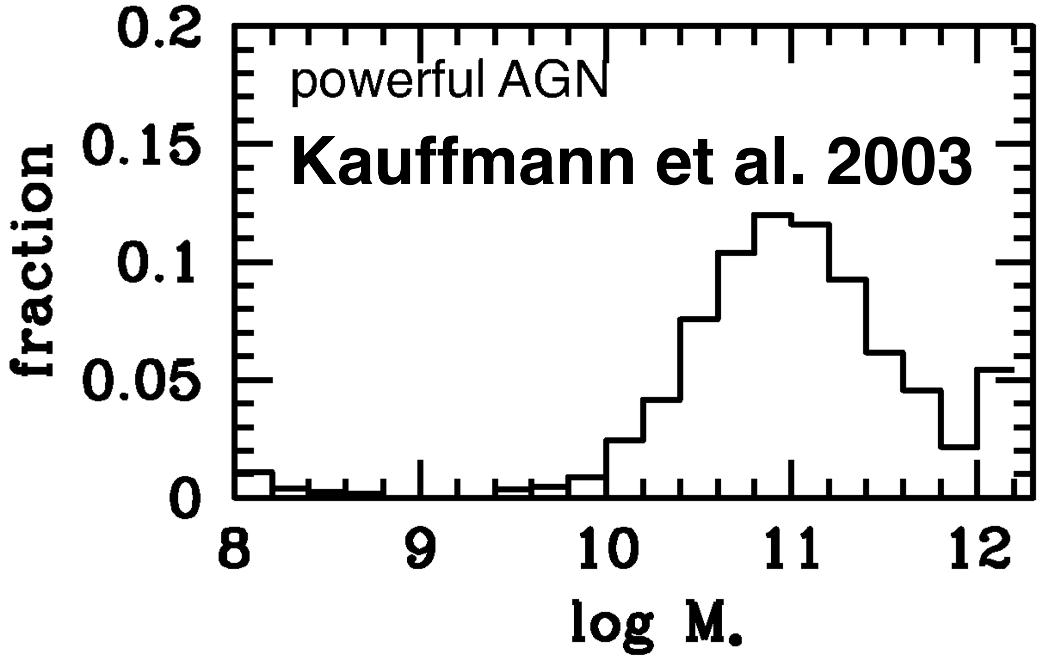
Shen & Kelly 2014





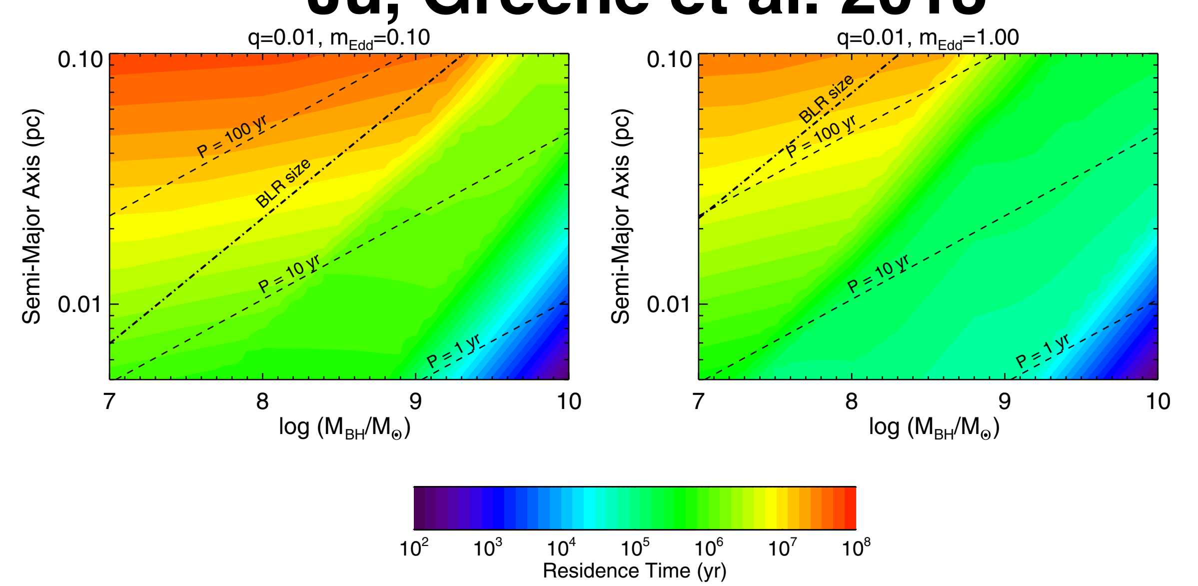
Stellar dynamics in nearby nucle

Kauffmann et al. 2003



AGN-Galaxy Surveys

Ju, Greene et al. 2013



Binary Black Hole Lifetimes