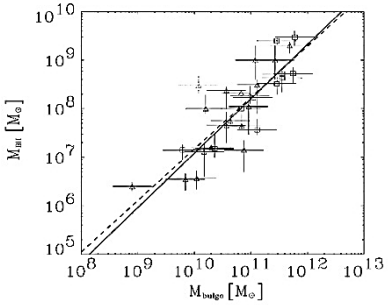
Local Scaling Relations of Super-Massive Black Holes: *Origin, Evolution, Consequences*

FRANCESCO SHANKAR

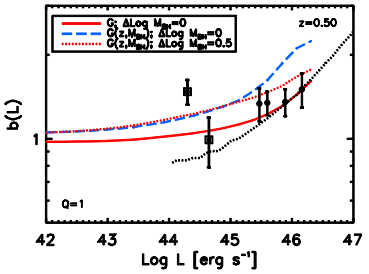
With: D. H. Weinberg, J. Miralda-Escudé, M. Bernardi, L. Ferrarese, J. Moreno, R. K. Sheth, Y. Shen, R. Läsker

WHAT I WILL DISCUSS:

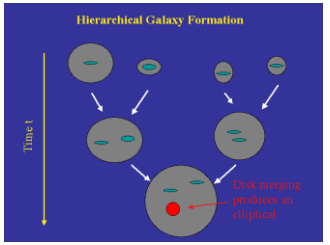
Local Scaling Relations:
Slopes, Breaks, Scatters, BHMF



Semi-empirical Models:
Accretion, Clustering, z-Evol.



More Advanced Models:
Mergers vs secular models

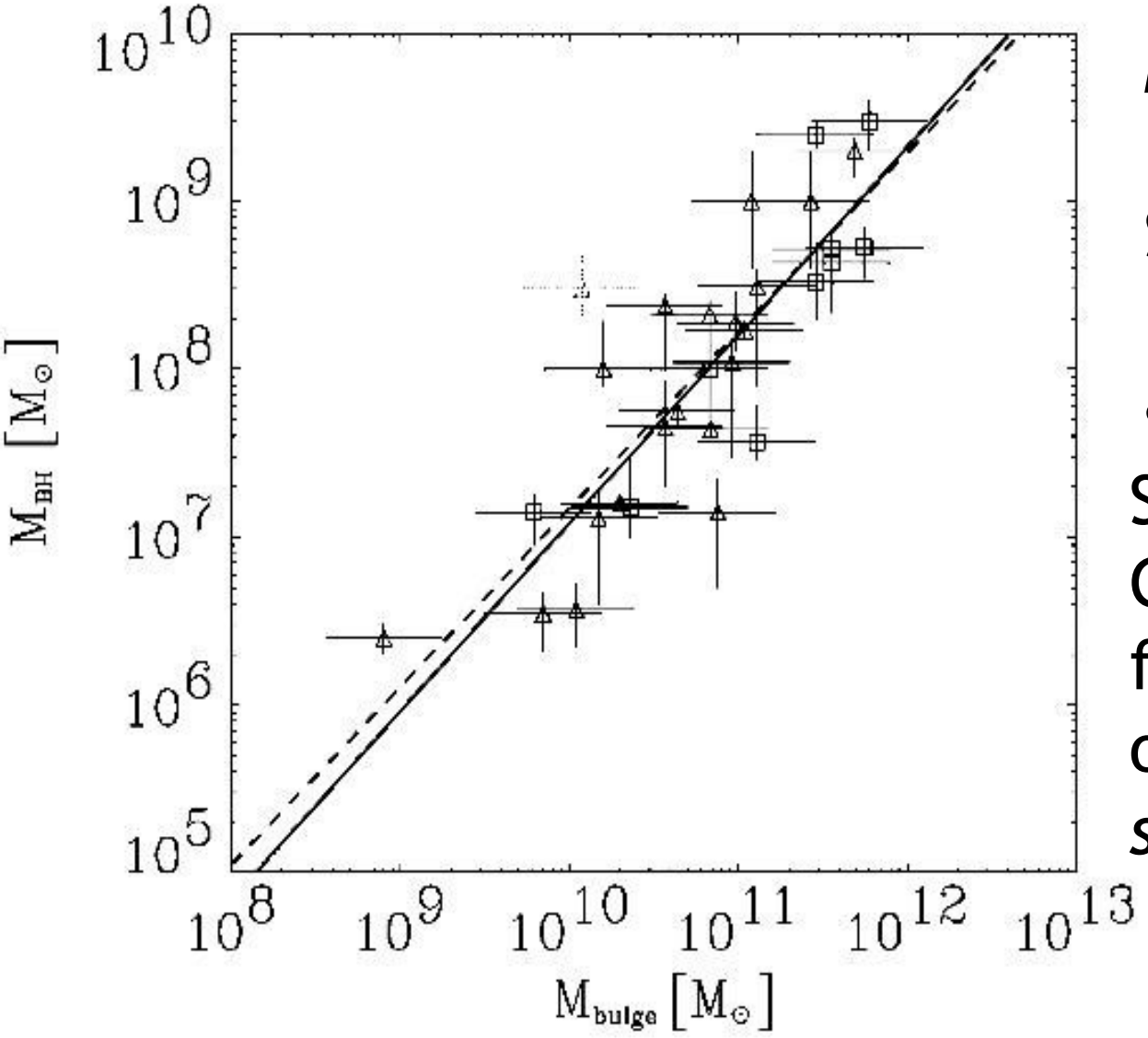


See talk by Michaela Hirschmann for further insights into models!!

Reviews available: Shankar 09; Shankar 13

Local Scaling Relations:
Slopes, Breaks, Scatters, BHMF

The «Magorrian» relation: M_{BH}-Mbulge

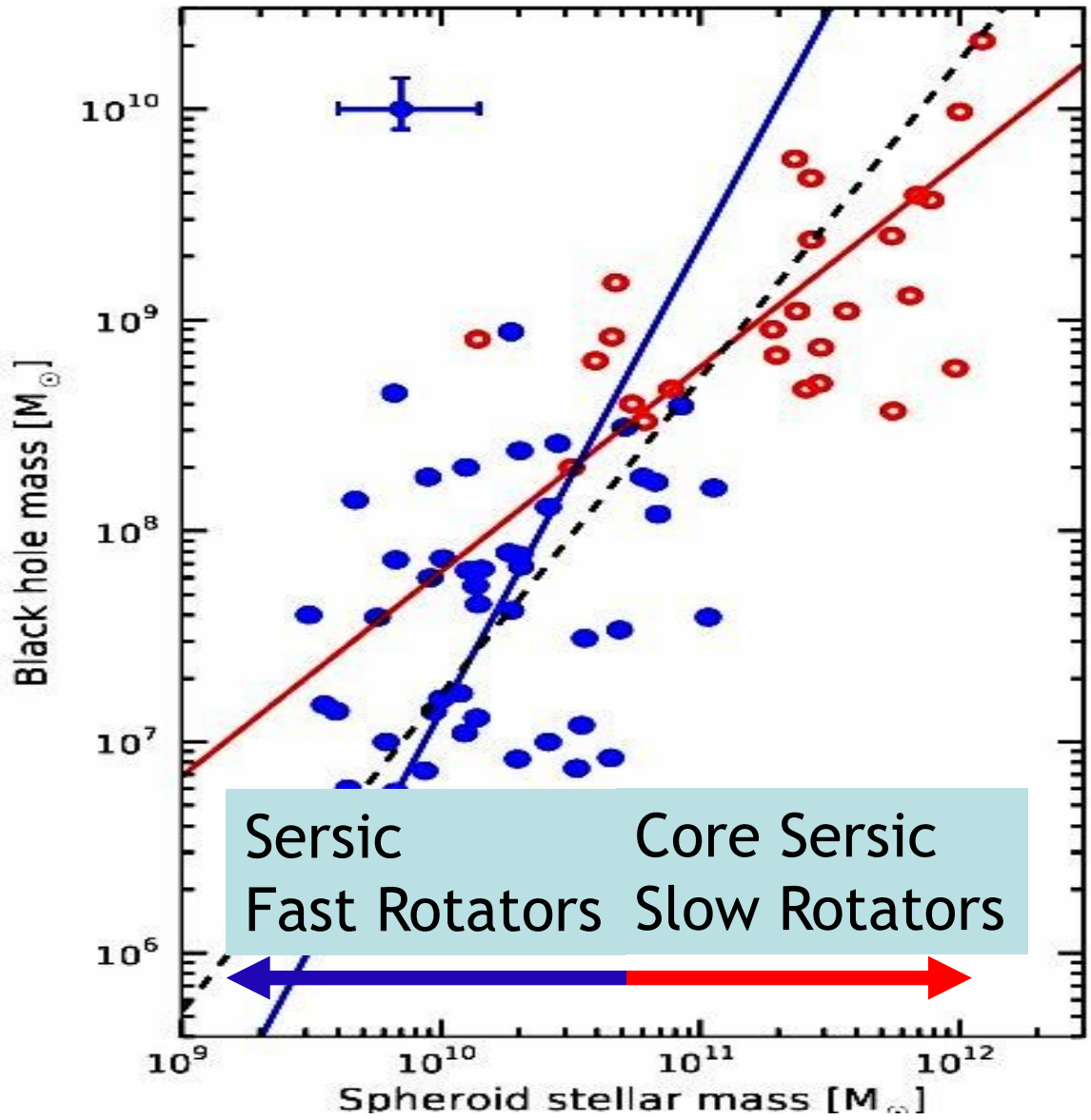


Marconi-Hunt 03
Haering-Rix 04:
Slope about unity, normalization about 10^{-3}

Sample of about 30 Galx, bulge masses from NIR (MH) or <u>dynamical</u> (HR)
scatter < 0.3 dex!!

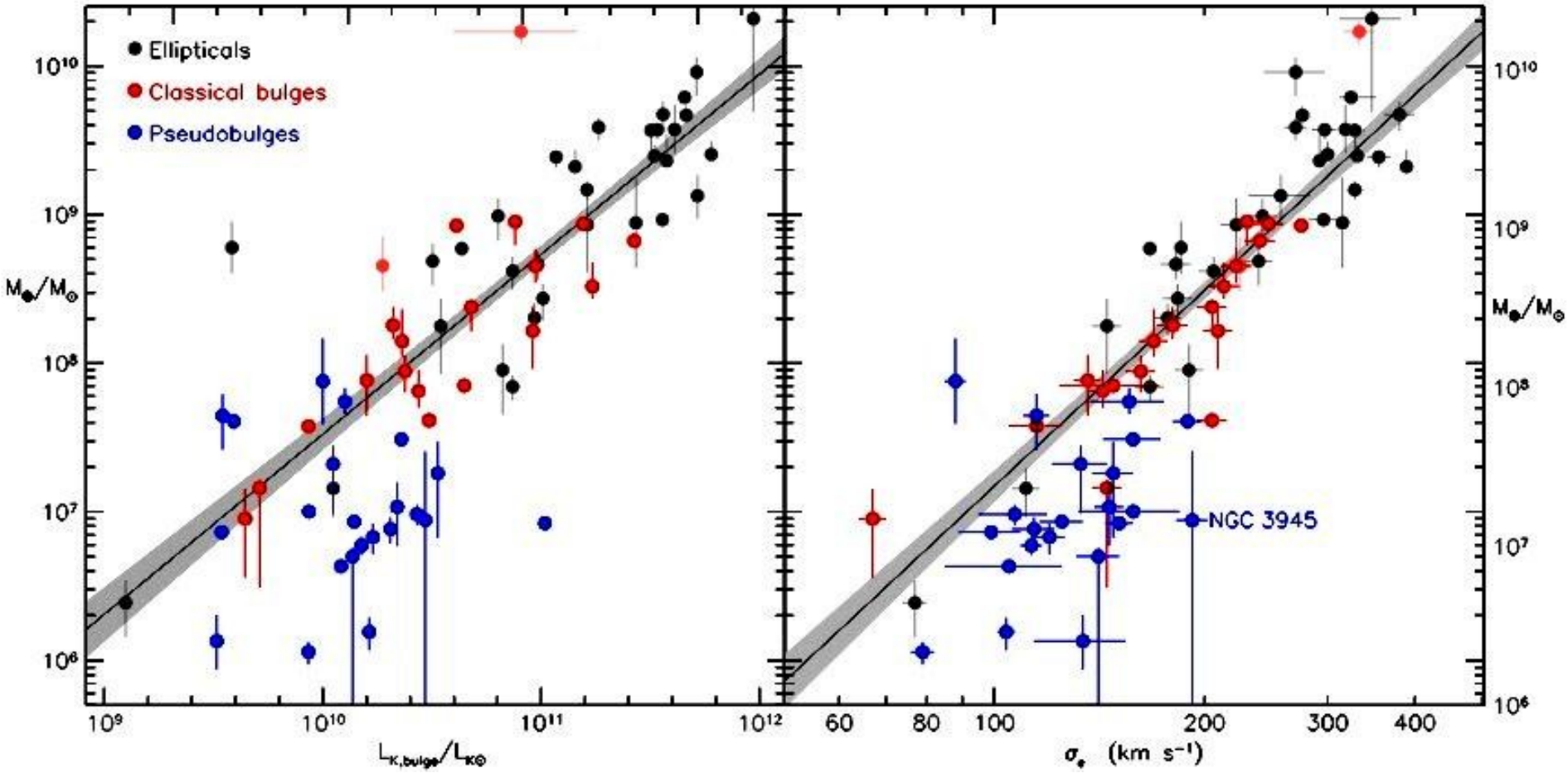
See also Sani+11, Beifiori+12,and many, many others

The «Magorrian» relation today ?



Scott et al. 2013
Graham 2012
sample of 75 galx;
bulge masses from
K-band corr.;
slope from 2.2 to 1,
scatter from 0.9
to 0.47!!

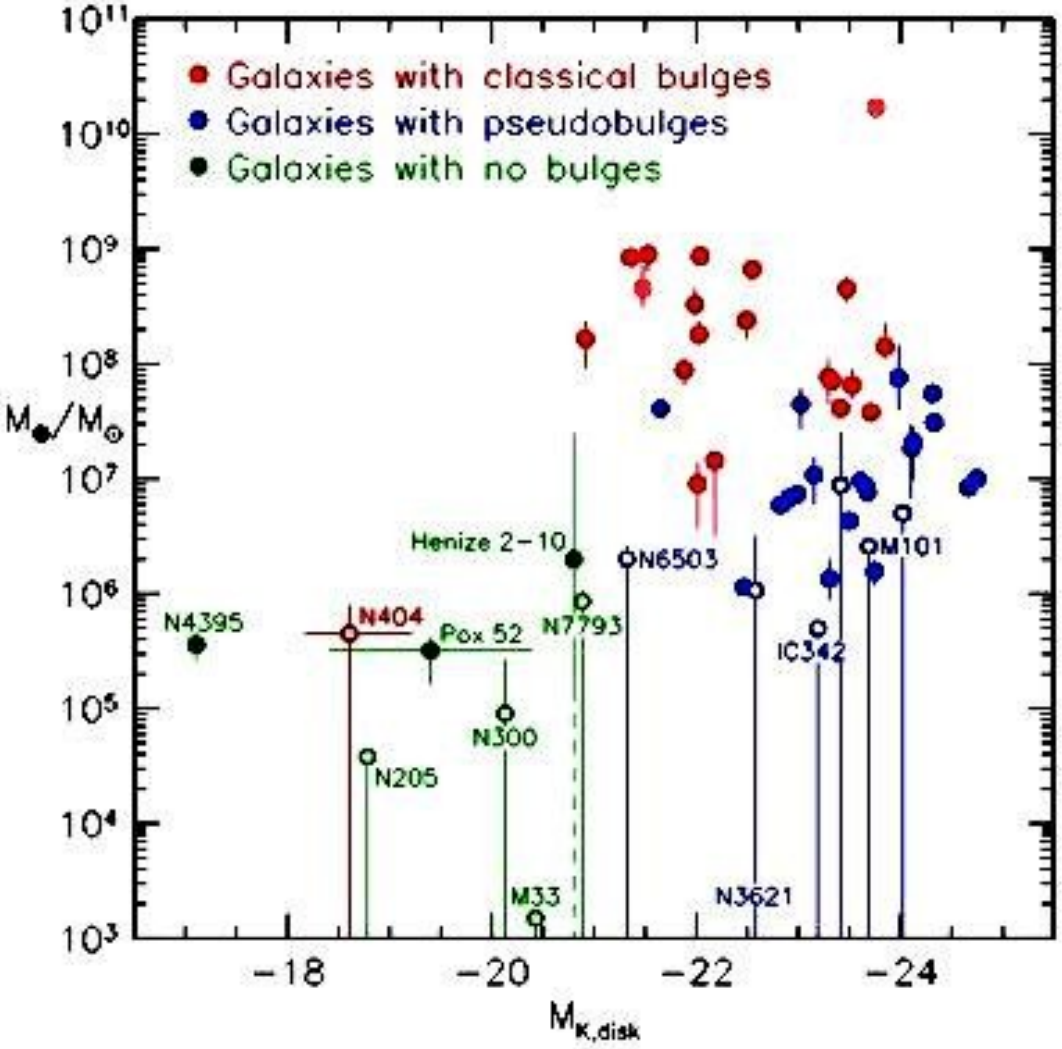
Is this real? On more general grounds:



BUT see Läsker et al. 2014!!

Kormendy & Ho 13

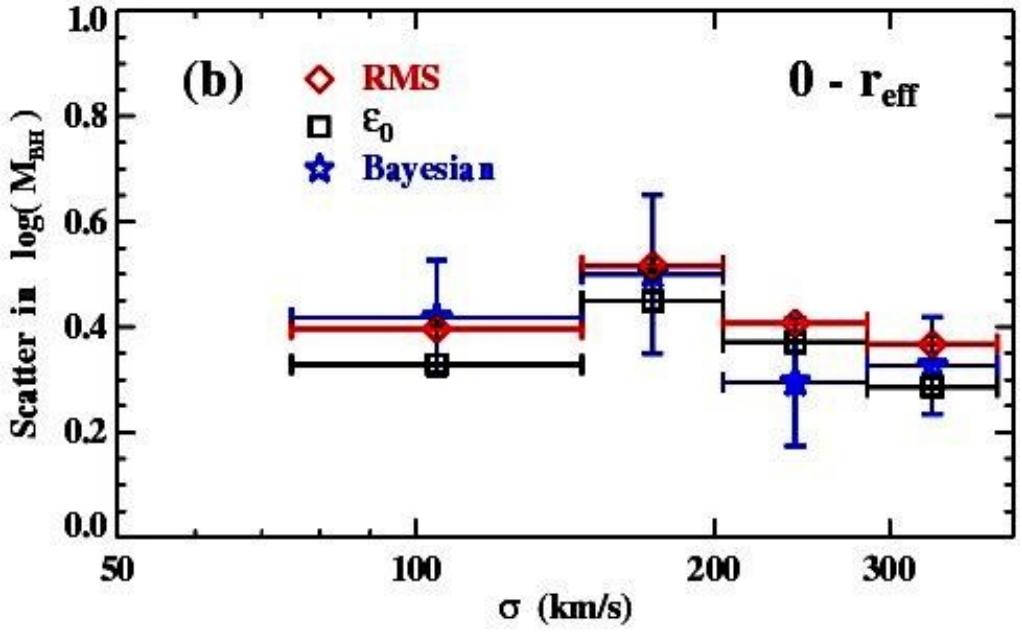
Is there a correlation with disc?

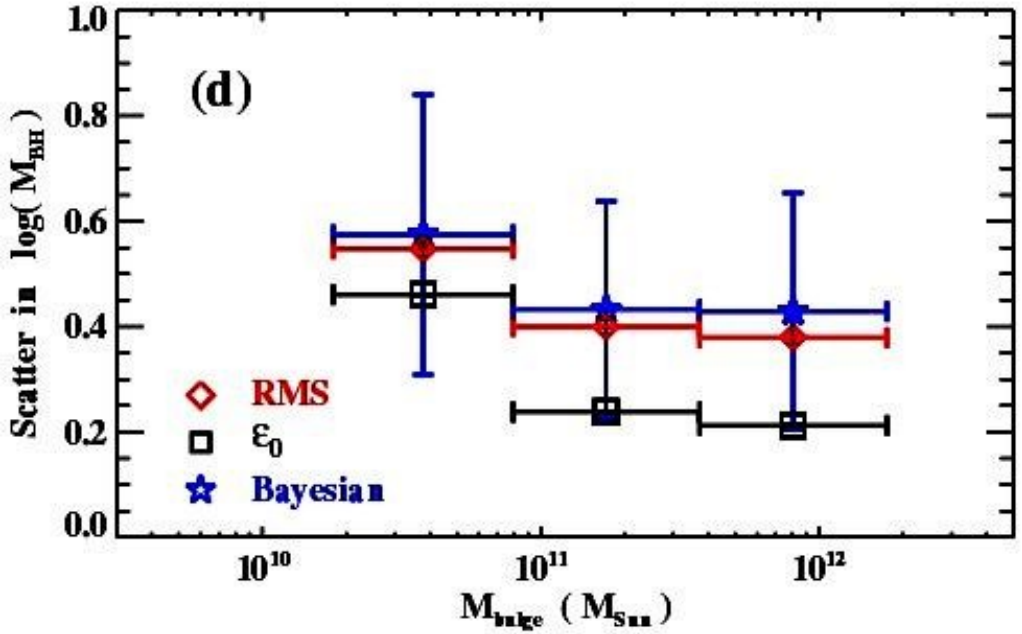


BUT see Läsker et al. 2014!!

Kormendy & Ho 13

The Mbh-sigma: The most fundamental?



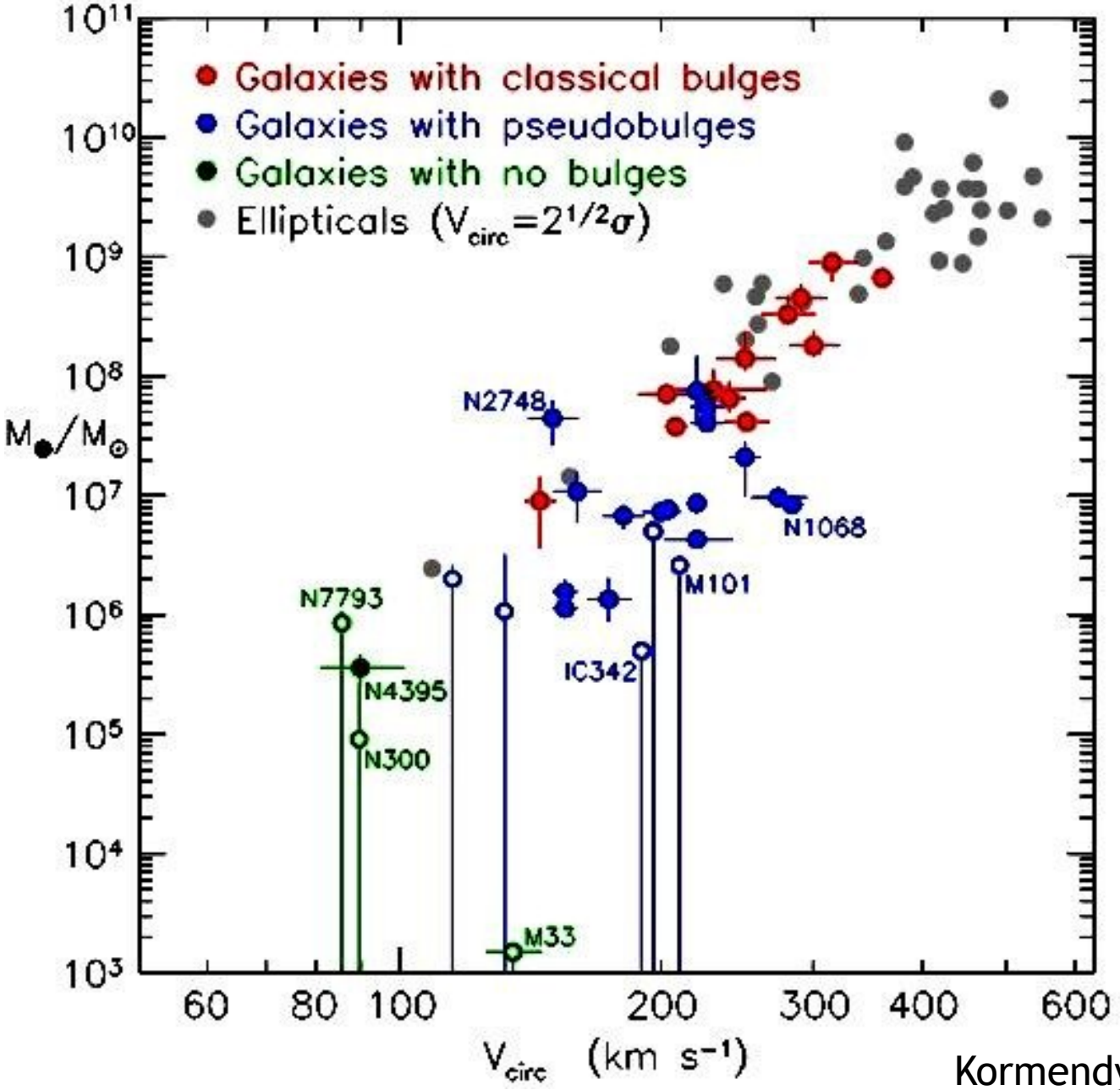


Scatter always
Ranging within
0.3-0.5 dex

First study differential:
possible evidence
for decrease at
high masses,
still unsecure and only
in Mbulge!

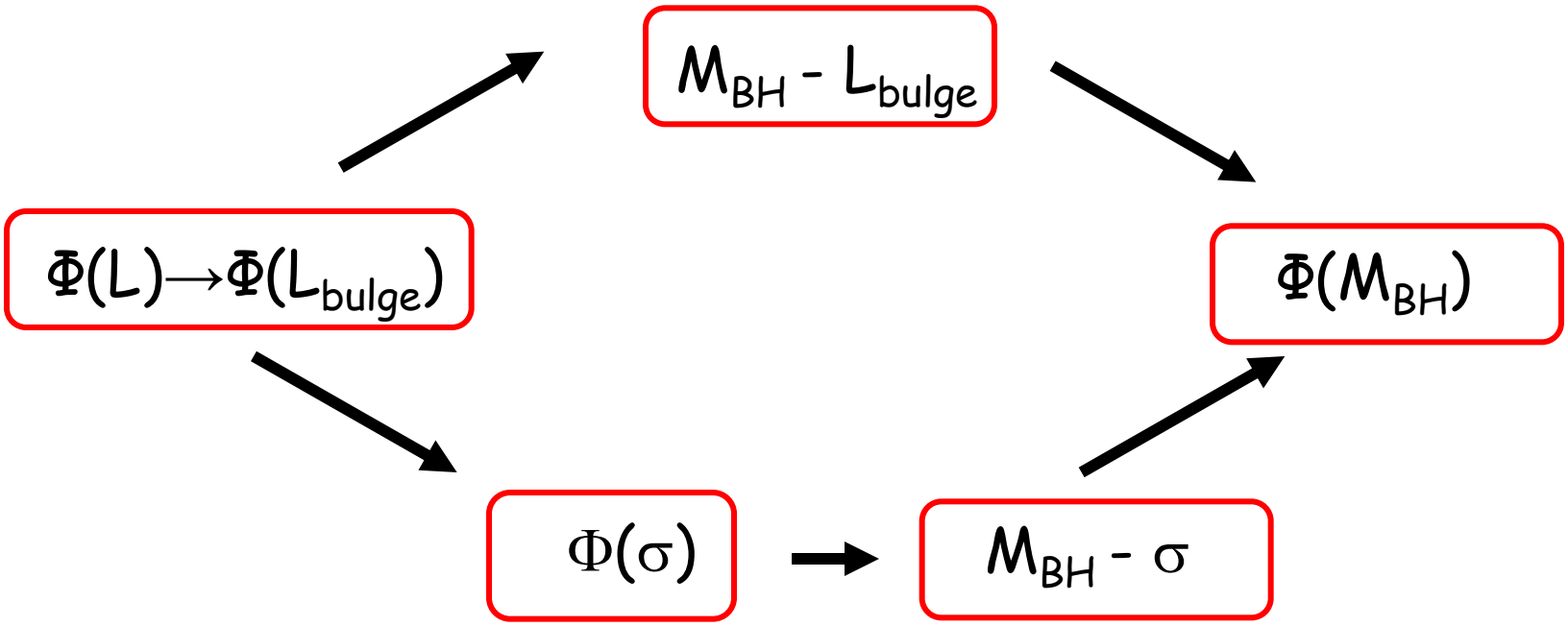
McConnell+Ma 13

Is there a correlation with DM halo?

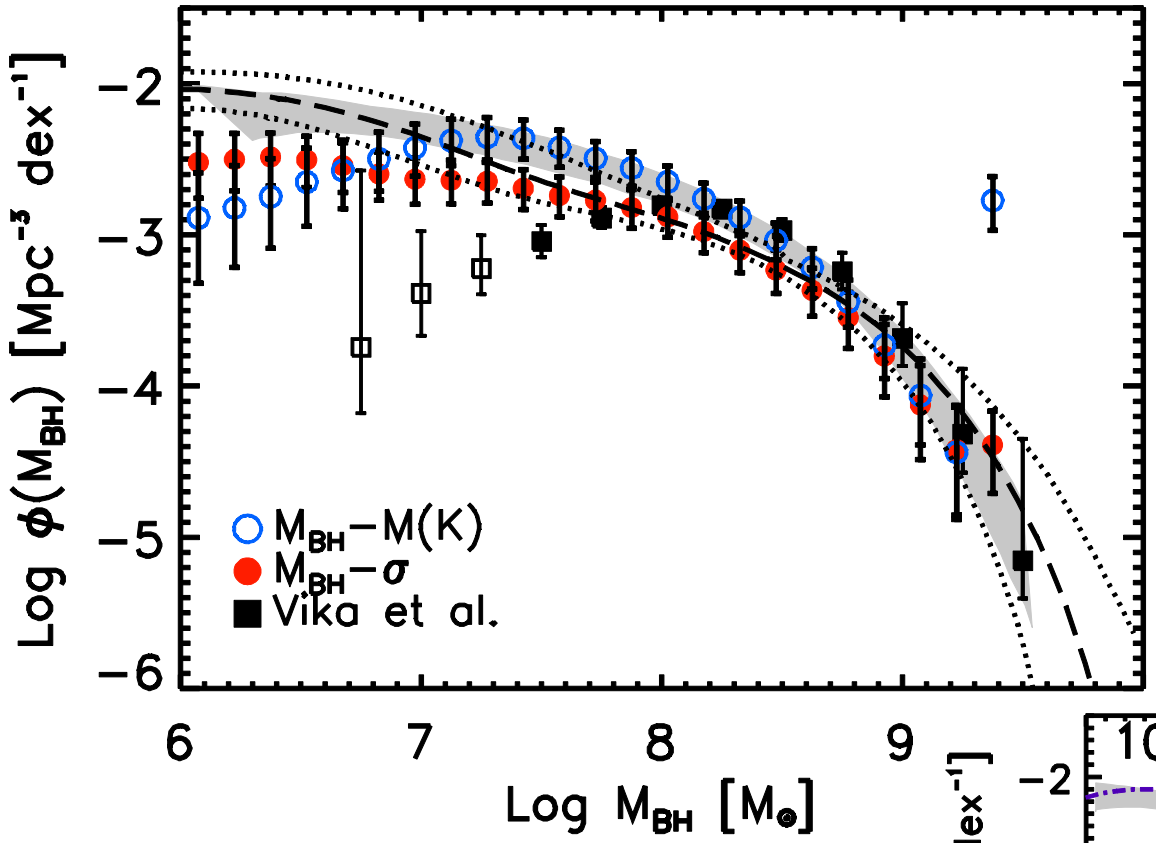


Kormendy & Ho 13

How many SMBH? How Massive?

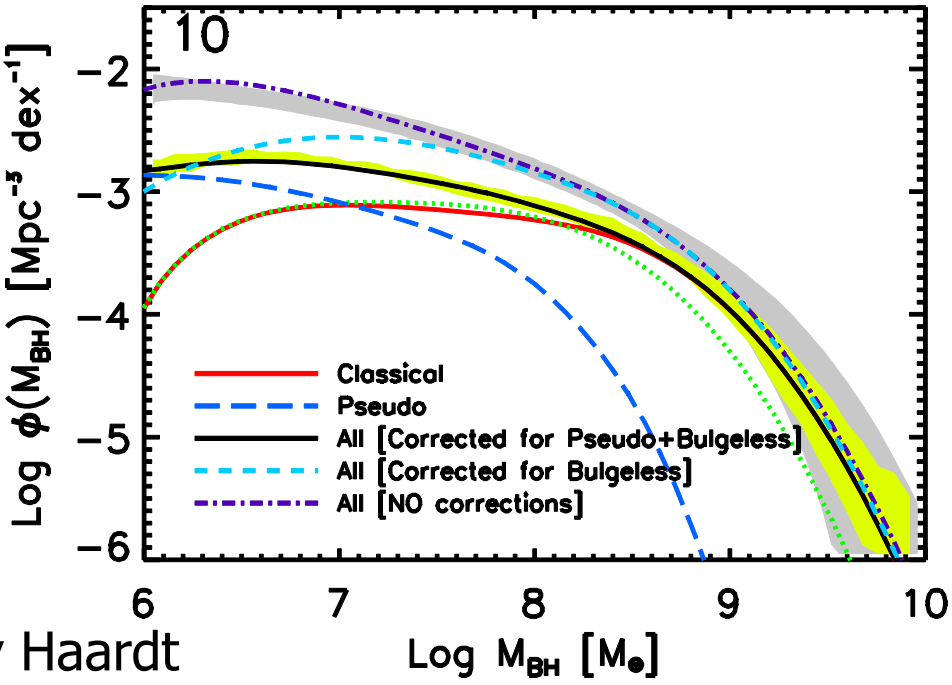


Several caveats: scatter, relations, variables, color change, bulge fractions, methodology, etc…



Different methodology different results at (low!) masses

Different «populations»:
Pseudo bulges, nuclear Star clusters, ….
Though mainly affecting (again!) low masses



See talks by Hirschmann, (seed BHs) by Haardt

Semi-Empirical Models:

Accretion, Clustering, Redshift Evolution

The Continuity Equation

$$\frac{\partial n(M_{BH},t)}{\partial t} = -\frac{\partial}{\partial M_{BH}}\left[\left\langle \frac{dM}{dt}(M_{BH},t)\right\rangle n(M_{BH},t)\right] + \frac{dS}{dt}_{in} - \frac{dS}{dt}_{out}$$

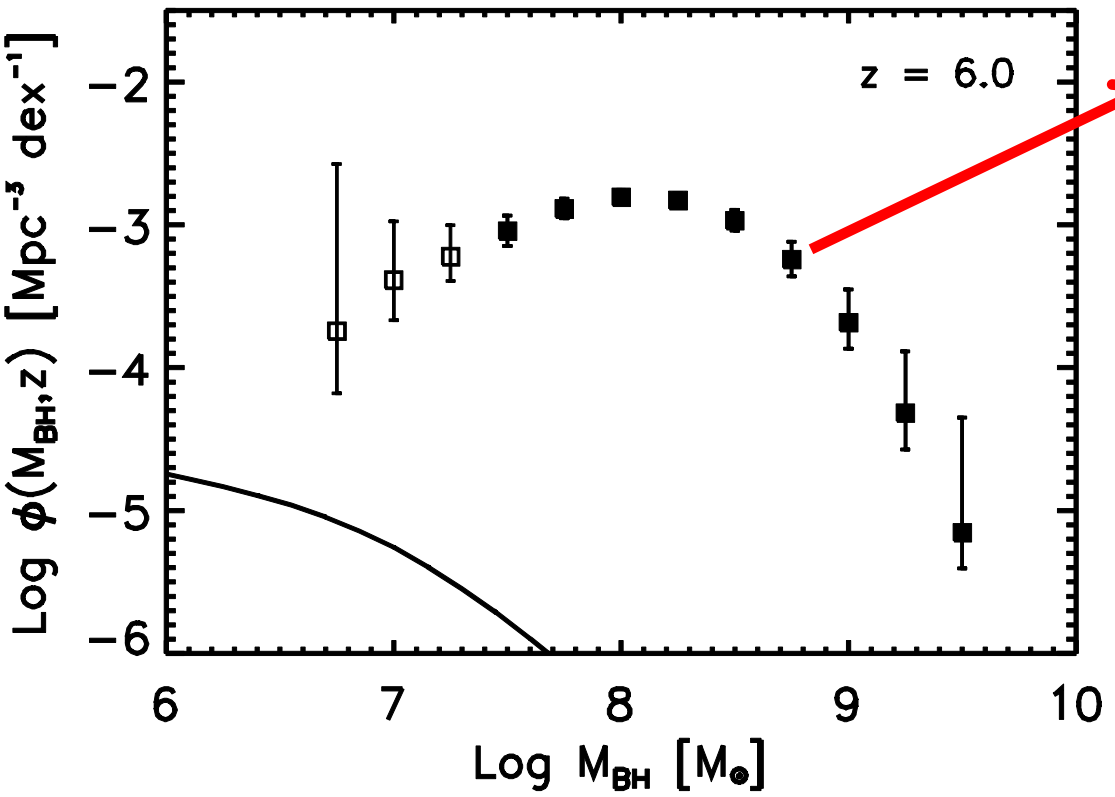
Accretion Term: proportional to $P(\lambda, M_{BH},t)$/radiative efficiency; The sum of all active BHs must give you the observed AGN LF!

Merger Term: at the rate implied by hierarchical mergers of DM haloes

See Raimundo's Talk!

Main references : Cavaliere et al. (1971); Soltan (1982); Small & Blandford (1992); Salucci et al. (1999)

Empirically predicting BH Mass Function



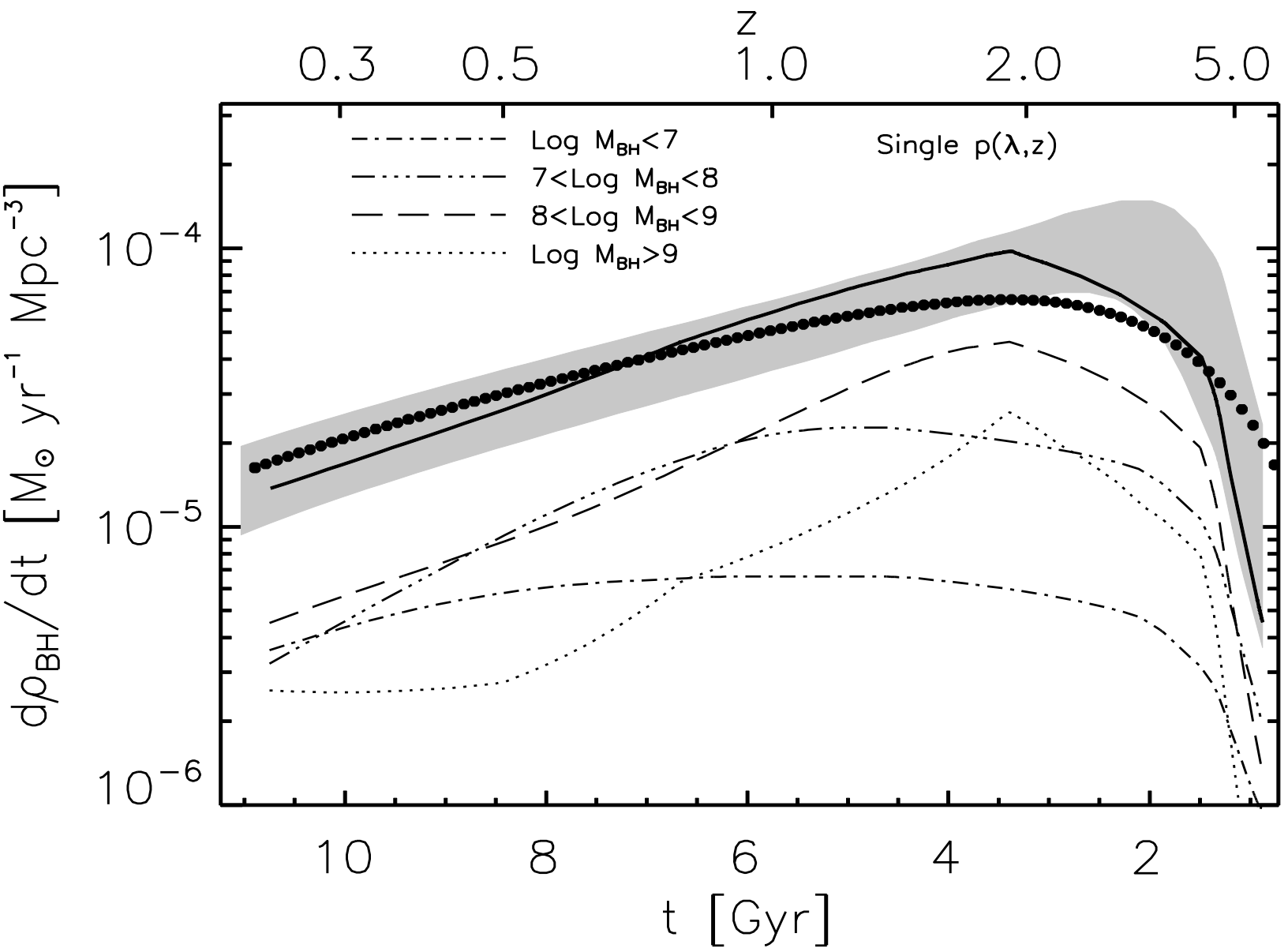
Local BH Mass Function

CONTINUITY EQUATION MODELS OF THE BH POPULATION

$$\frac{\partial n(M_{BH},t)}{\partial t} = -\frac{\partial}{\partial M_{BH}}\left[\left\langle \dot{M}(M_{BH},t)\right\rangle n(M_{BH},t)\right] + \dot{S}_{in}(M_{BH},t) - \dot{S}_{out}(M_{BH},t)$$

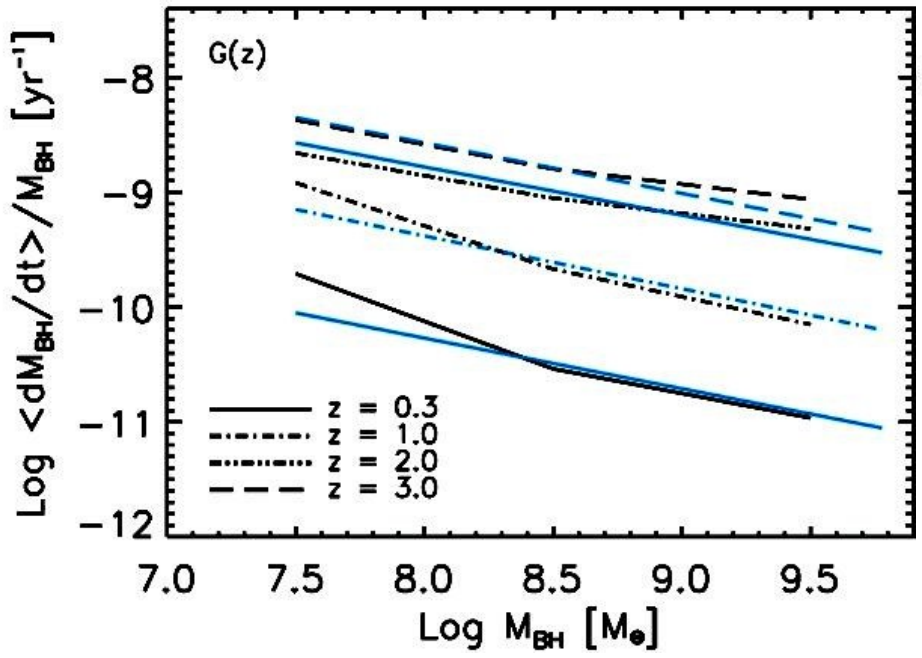
Marconi+04; Yu&Lu04; FS+04,09,13

Same evolution as in SFR, with Magorrian ratio!

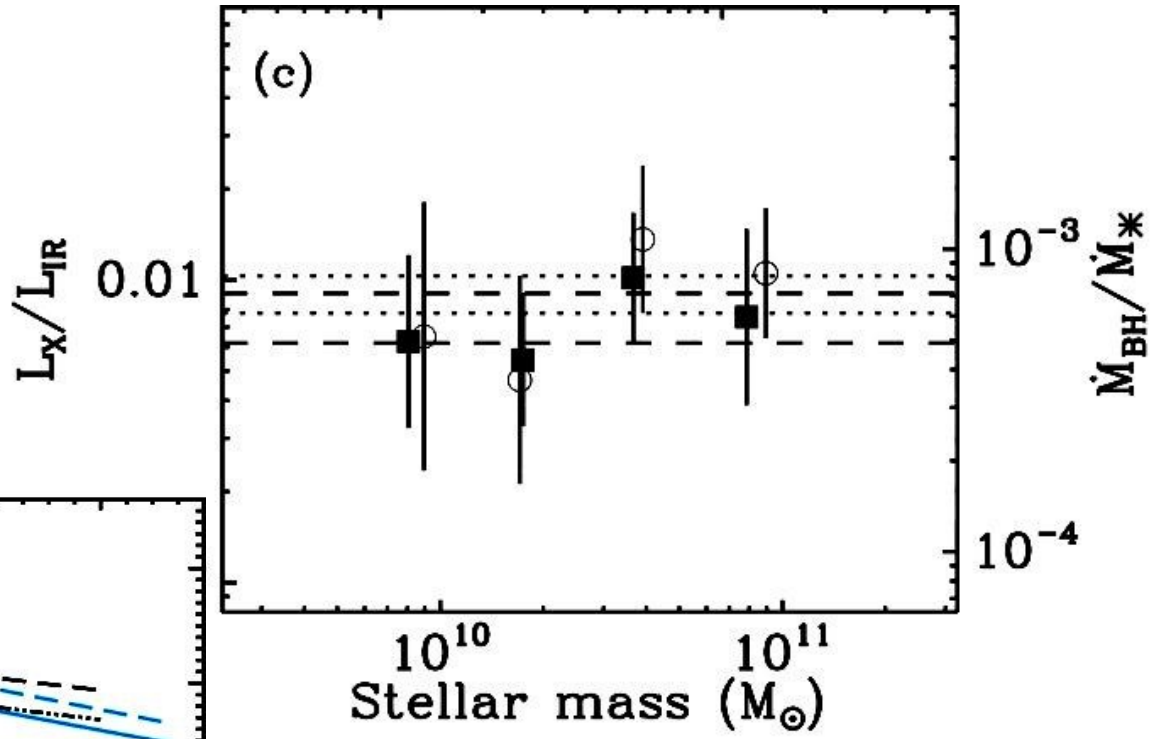


Marconi+04;Merloni+04;Hopkins+07;Silverman+08;Zhang+09;FS+09

A step further: correlating SSFR to Specific BH growth!



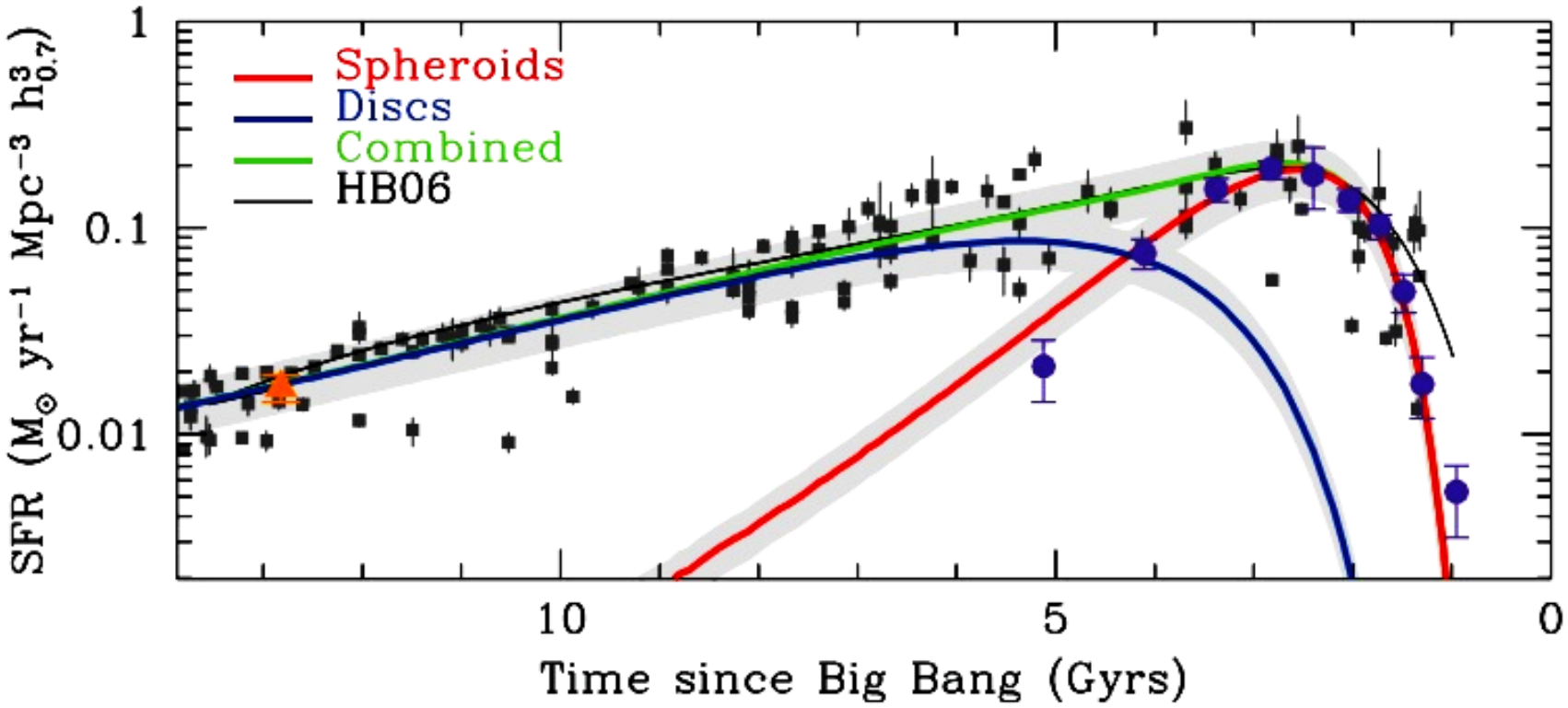
FS+13



Mullaney+12

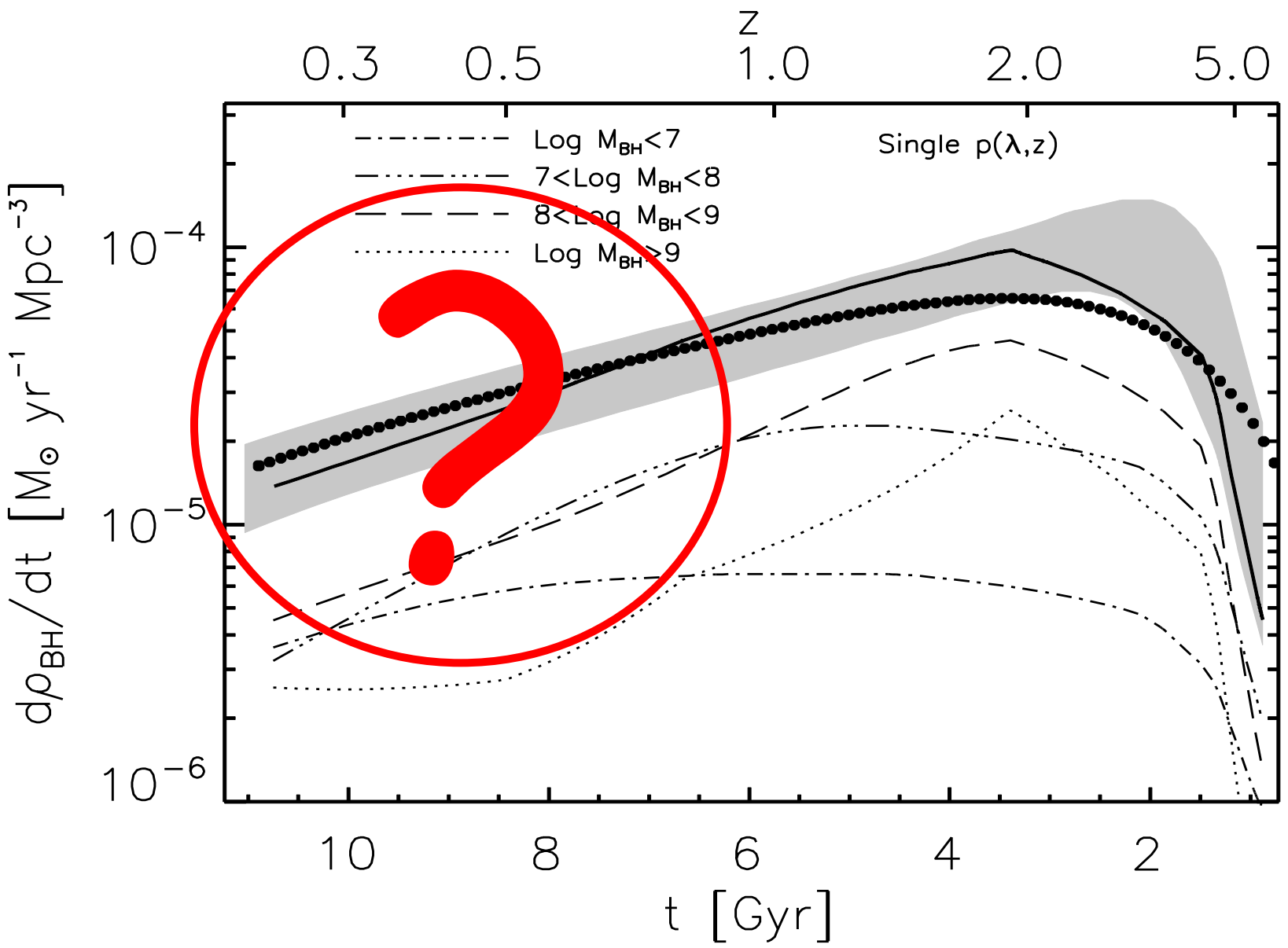
See Rodighiero's Talk!

Most of the SFR in Discs at z<1 or so…



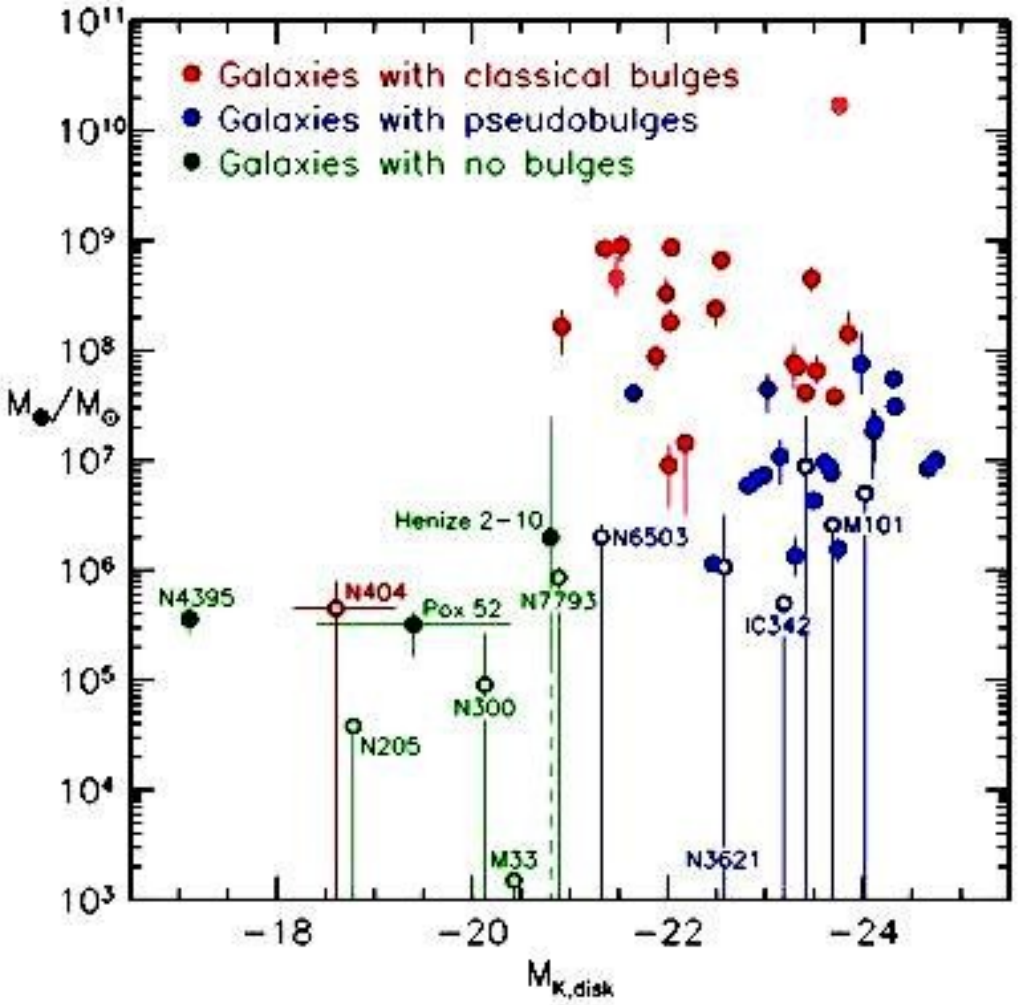
Driver+13

Same evolution as in SFR, with Magorrian ratio!



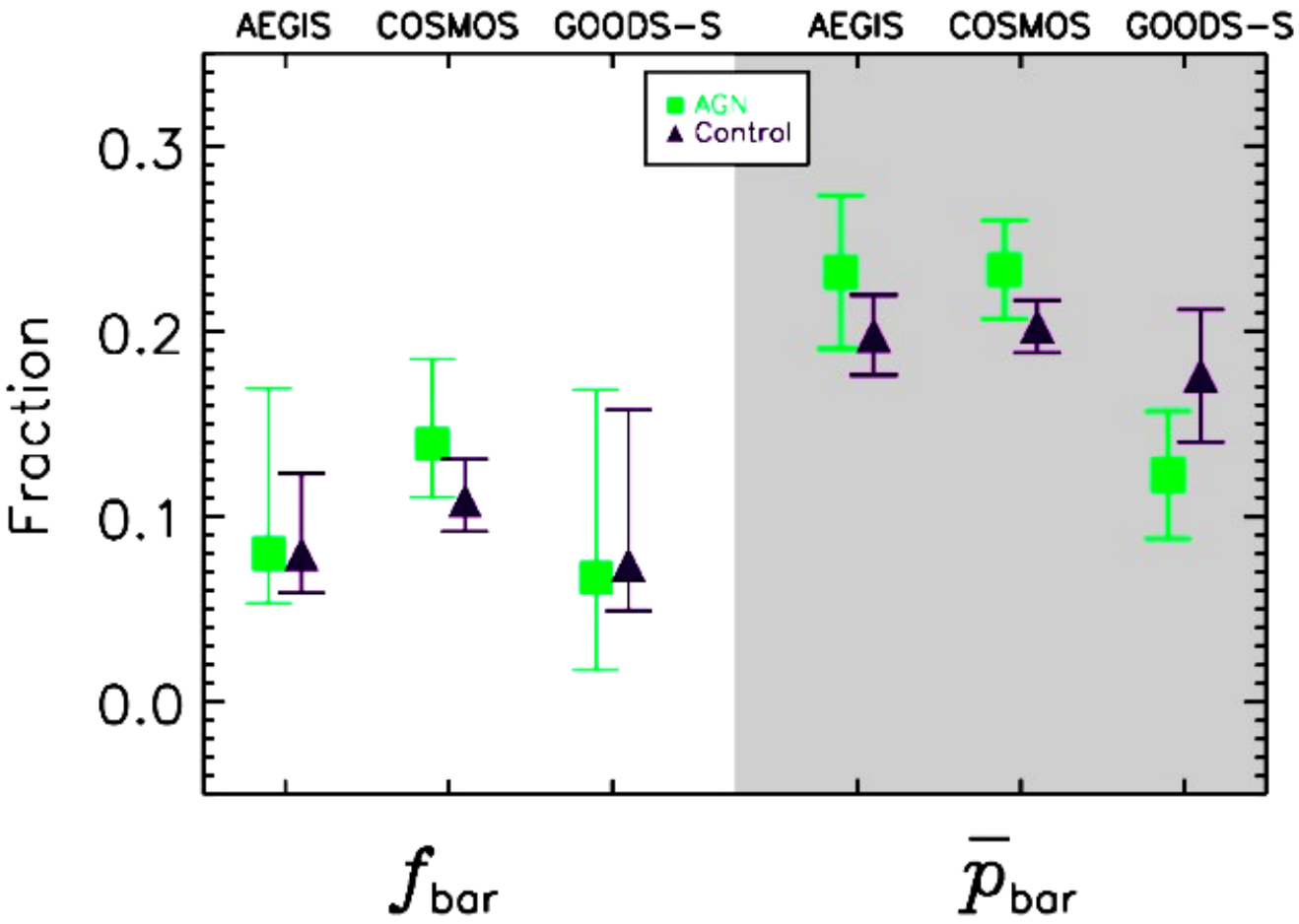
Marconi+04;Merloni+04;Hopkins+07;Silverman+08;Zhang+09;FS+09

Is there a correlation with disc?



Kormendy & Ho 13

Is the emergence of bars responsible for triggering AGN at low z?



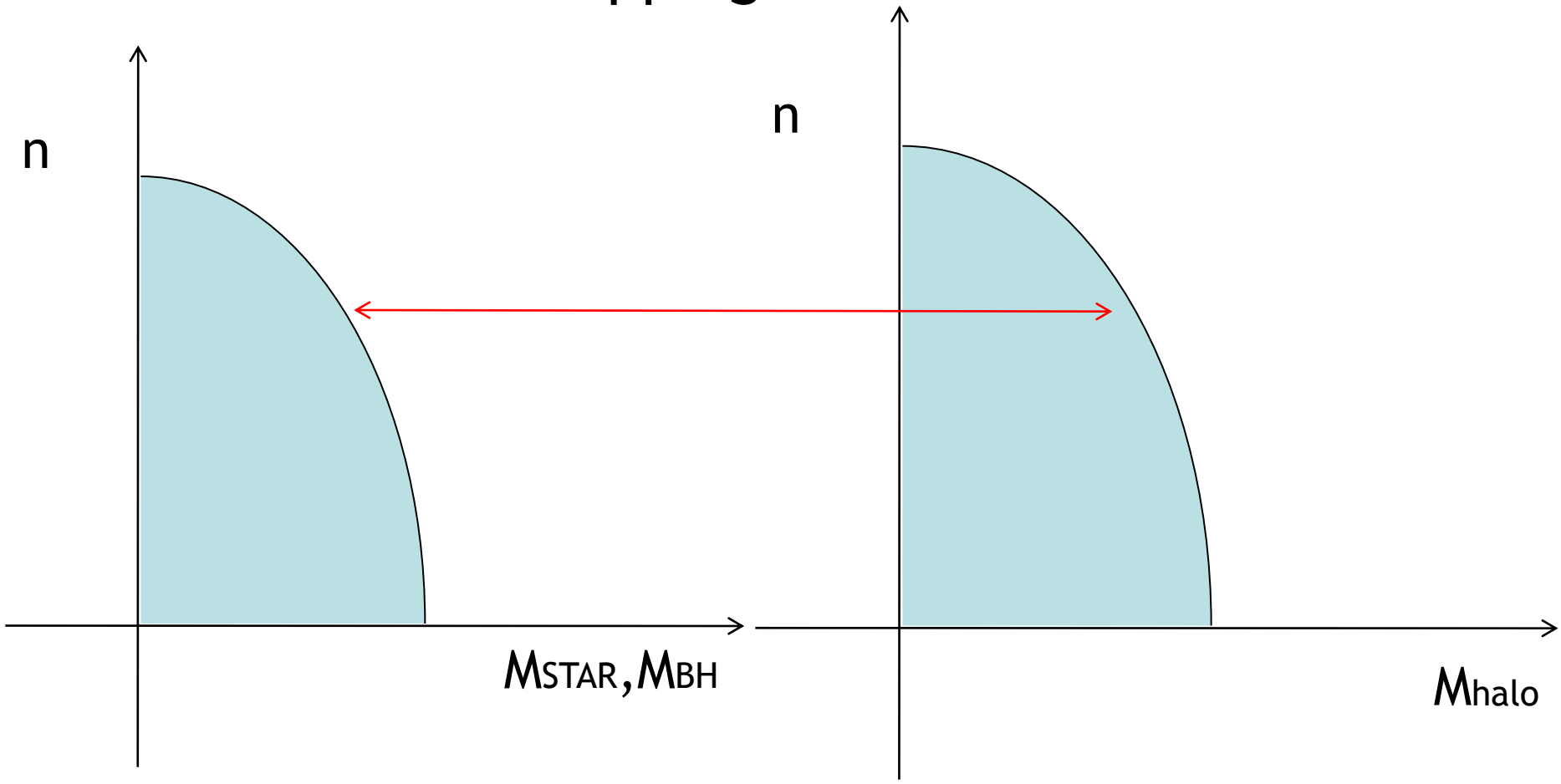
Cheung+14; see also Cisternas+14

Semi-Empirical Models:
Accretion, Clustering, Redshift Evolution

Haiman&Hui01; Martini&Weinberg; Gilli+07; White+08; Shen 09; Wyithe & Loeb 10; Bonoli, FS+10; FS+10

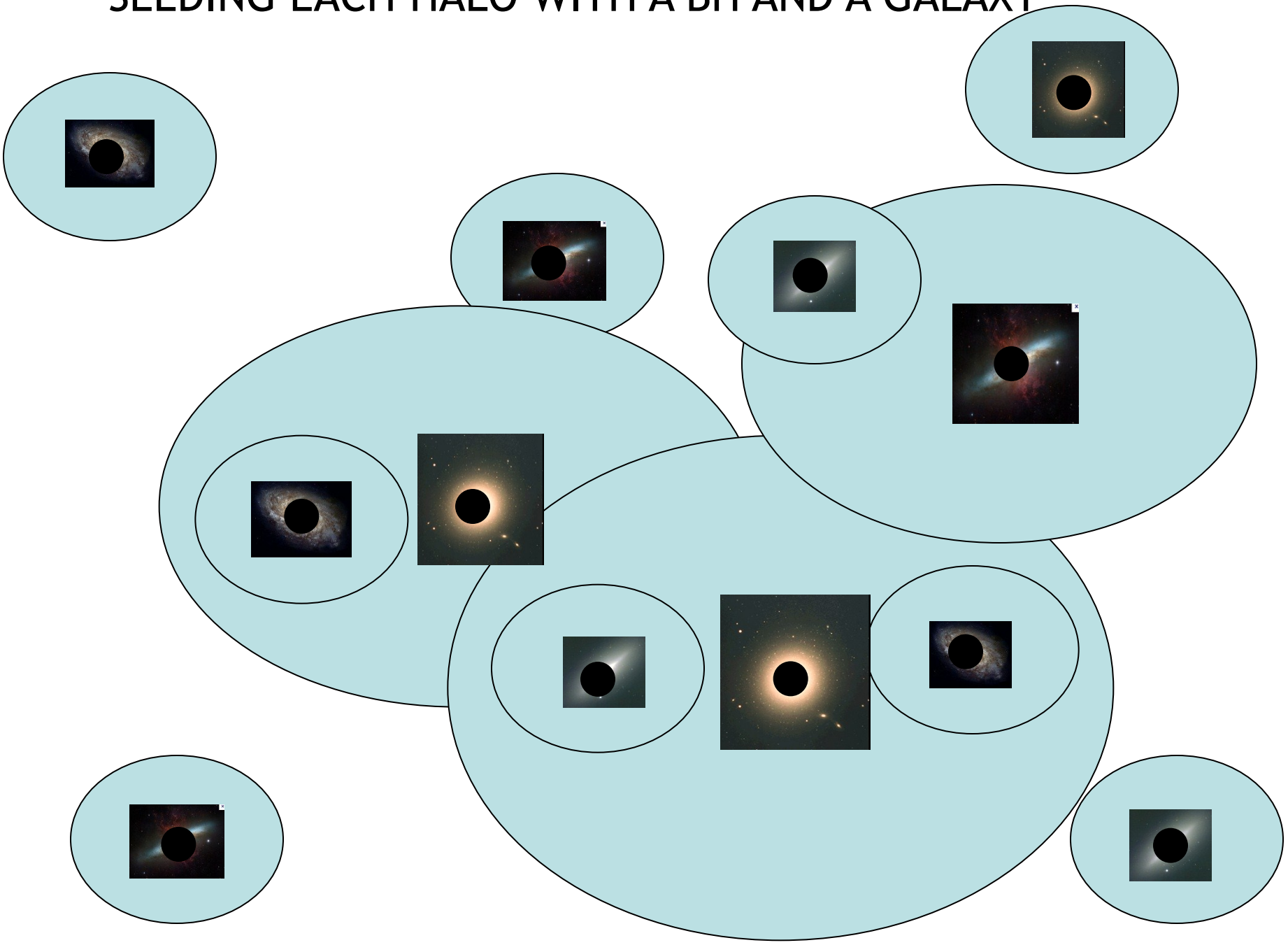
See, e.g., talks by Allevato, Cappelluti, etc…

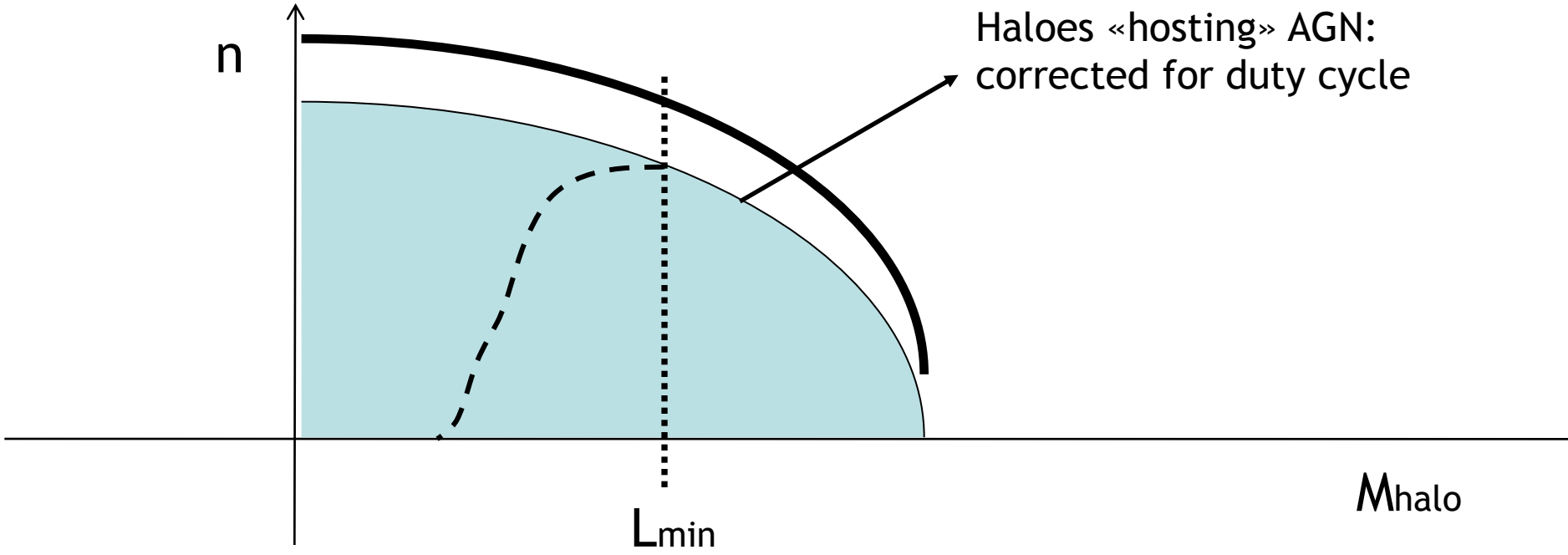
From BHMF to mapping with Dark Matter Haloes!



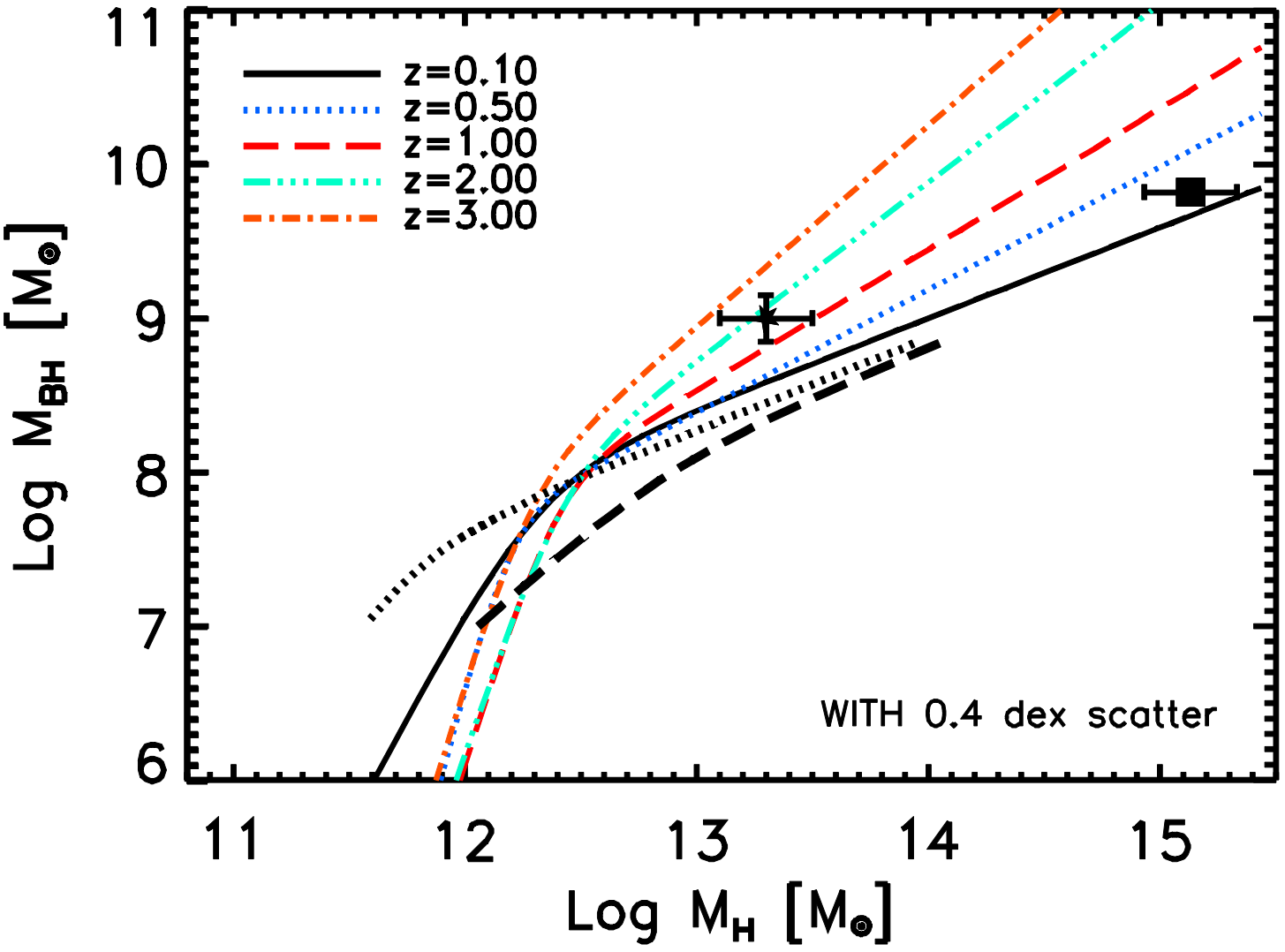
Rank Ordering: --> median relation Mstar,MBH-Halo mass

SEEDING EACH HALO WITH A BH AND A GALAXY

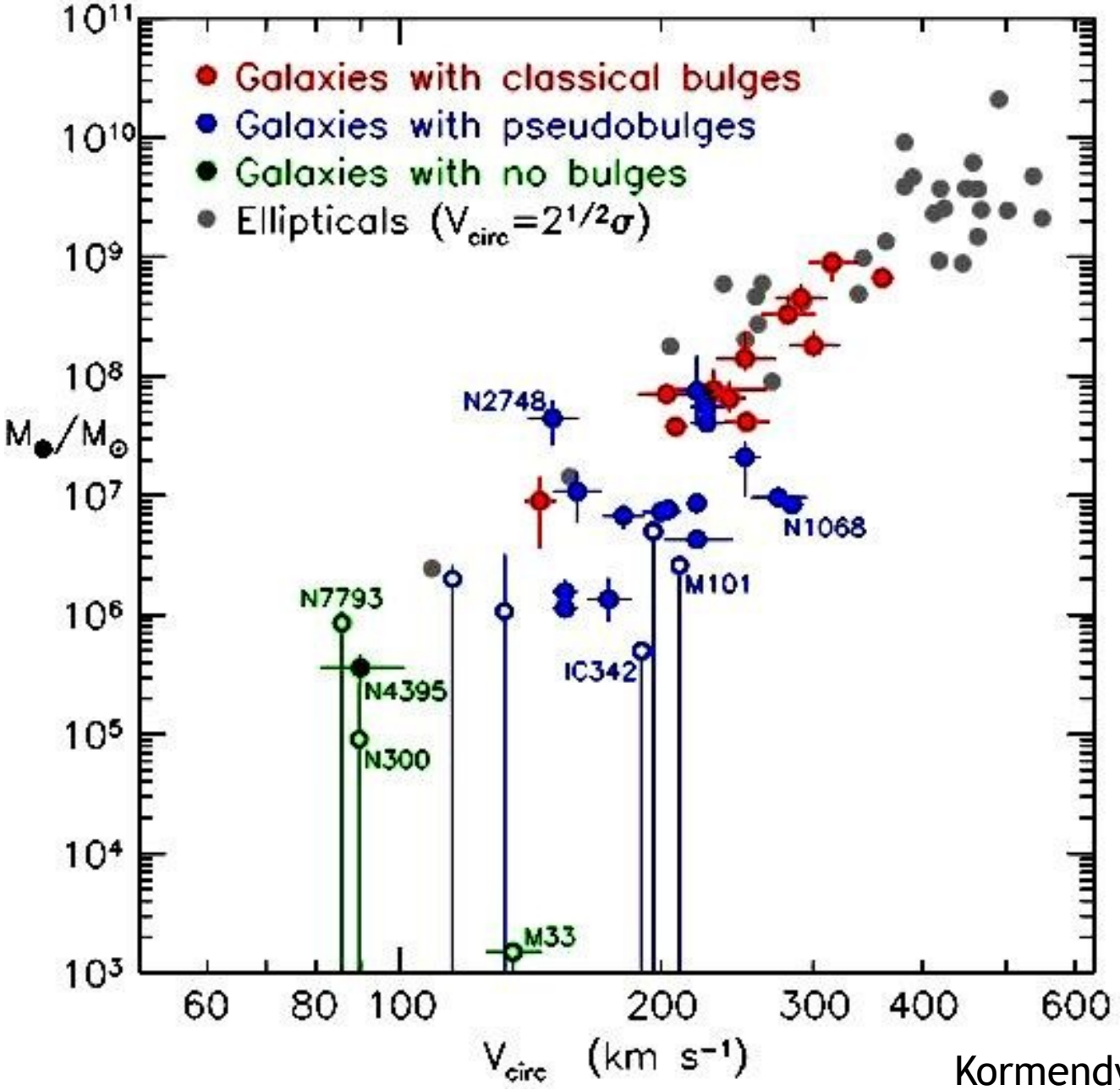




If there is substantial scatter, many low mass haloes will enter the selection and lower the inferred clustering (bias)

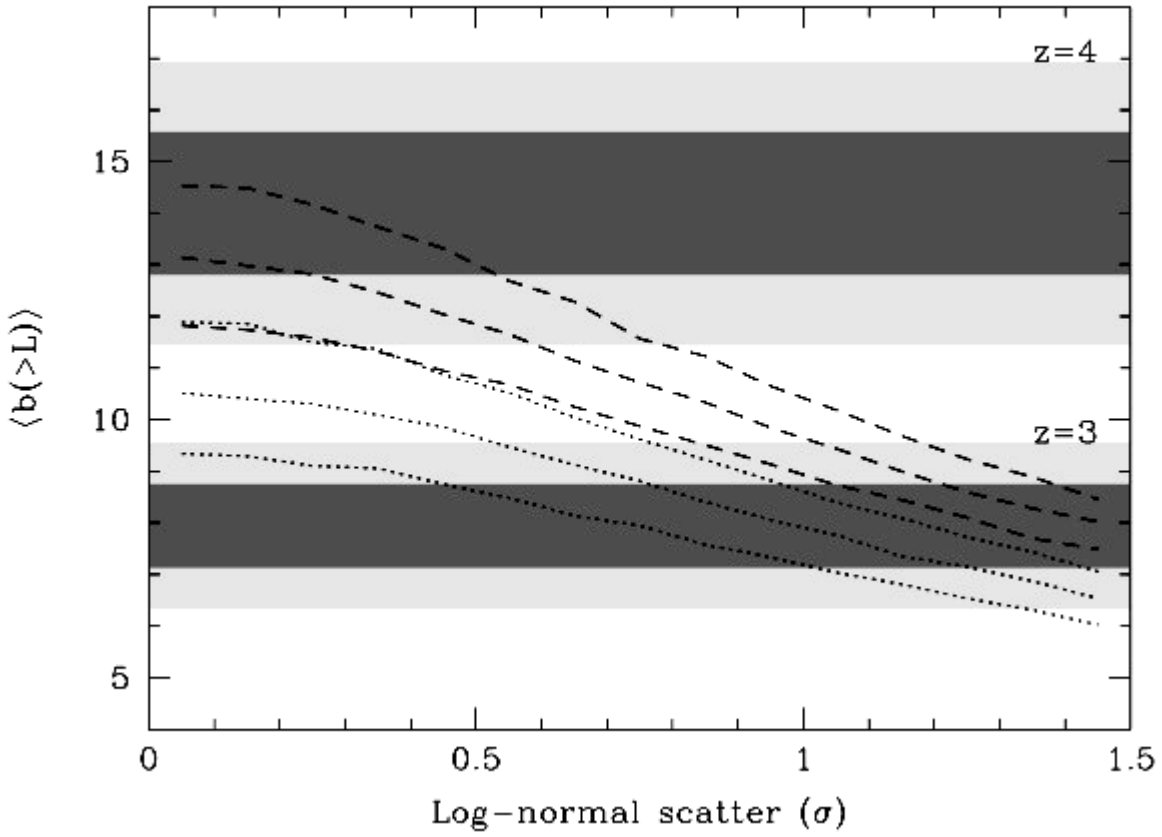

z=0.10
z=0.50
z=1.00
z=2.00
z=3.00
WITH 0.4 dex scatter
Log M_{BH} [$M_\odot$]
Log M_H [$M_\odot$]
11
10
9
8
7
6
11
12
13
14
15

Is there a correlation with DM halo?

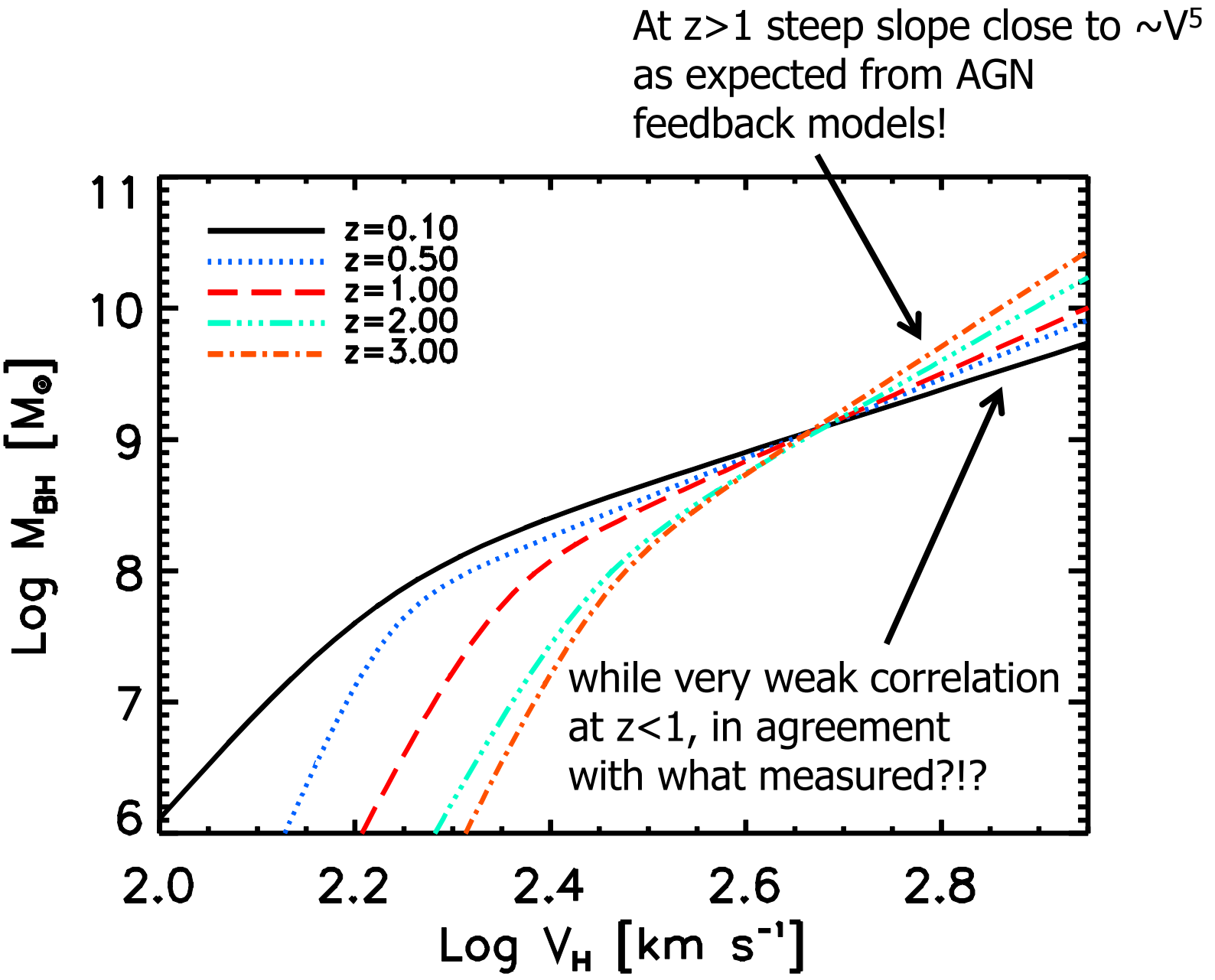


Kormendy & Ho 13

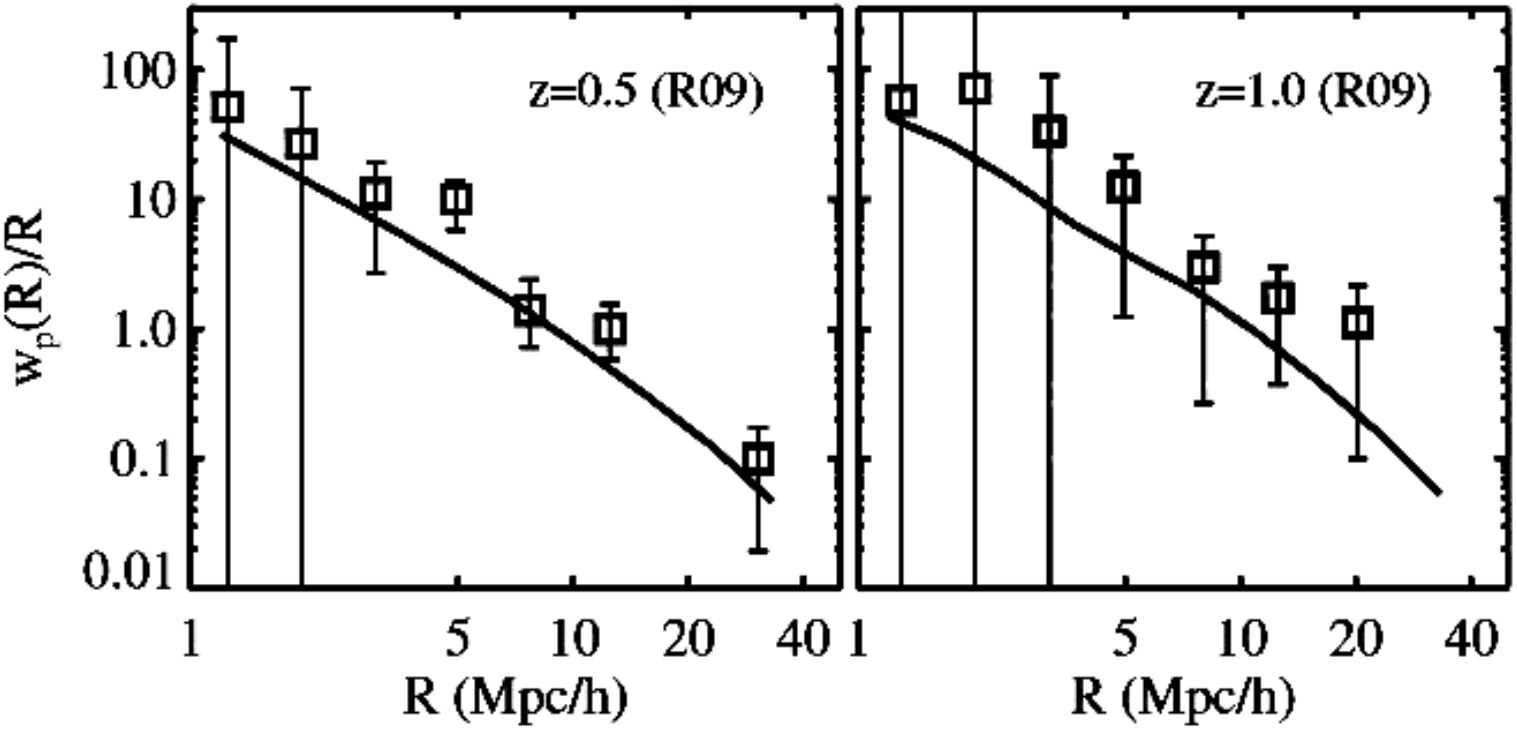
Just the opposite at z>3: very large scatter and duty cycles require limited scatter <0.3 dex for luminous QSOs



White+08; see also Shen 09; Wyithe & Loeb 10; Bonoli, FS+10; FS+10


At z>1 steep slope close to ~V5
as expected from AGN
feedback models!
z=0.10
z=0.50
z=1.00
z=2.00
z=3.00
while very weak correlation
at z<1, in agreement
with what measured?!?
Log MBH [M⊙]
Log VH [km s-1]
11
10
9
8
7
6
2.0
2.2
2.4
2.6
2.8

A BASIC ABUNDANCE MATCHING MODEL IS BROADLY CONSISTENT WITH AT LEAST THE LARGE SCALE CLUSTERING OF QUASARS



CONROY & WHITE 13

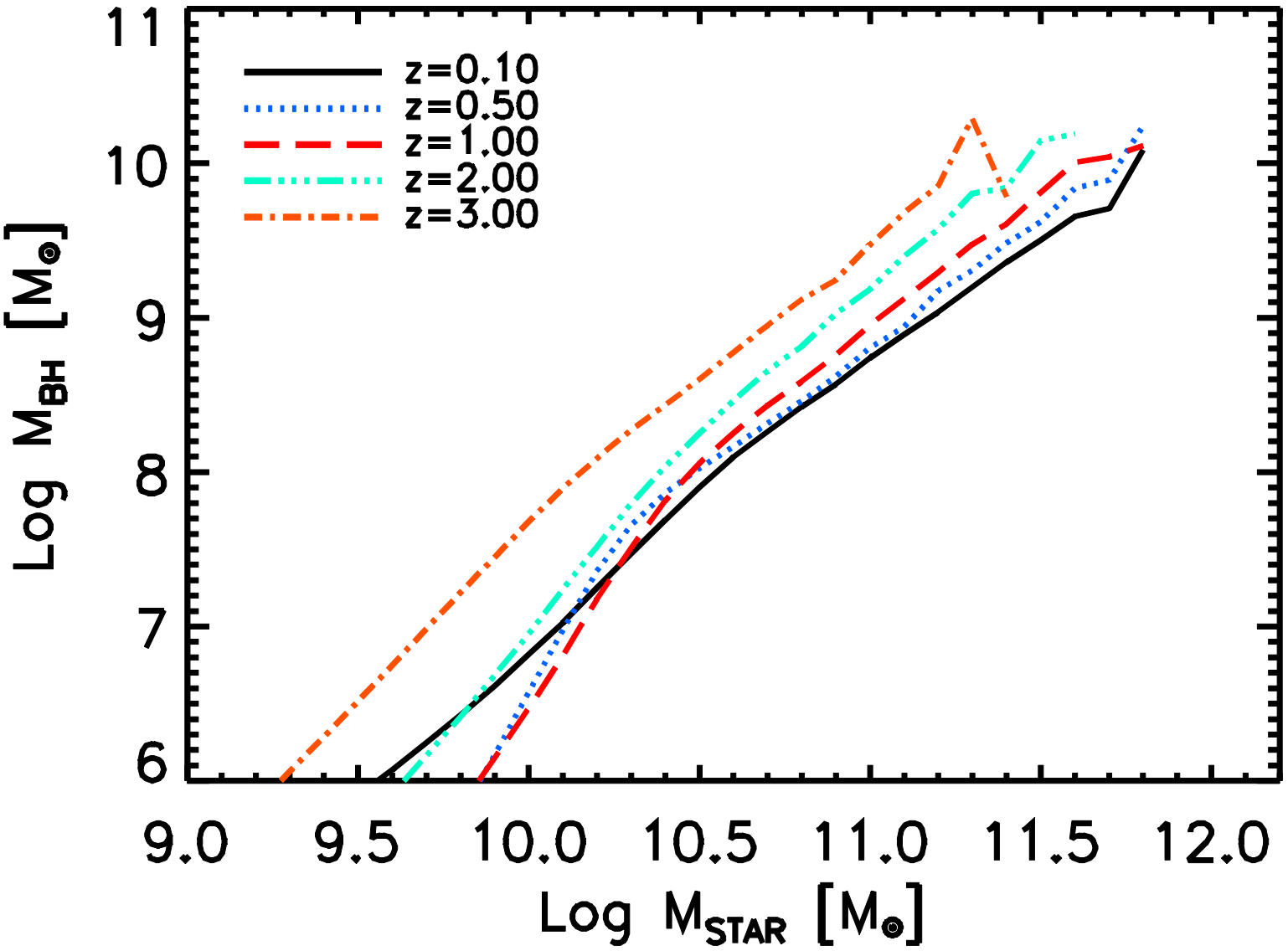
see also Gilli+; Hickox+; Magliocchetti+ and many others…

SMALL AND LARGE SCALES INFORMS US ON THE RELATIVE PROBABILITIES FOR SATELLITES AND CENTRALS TO BE ACTIVE

Semi-Empirical Models:

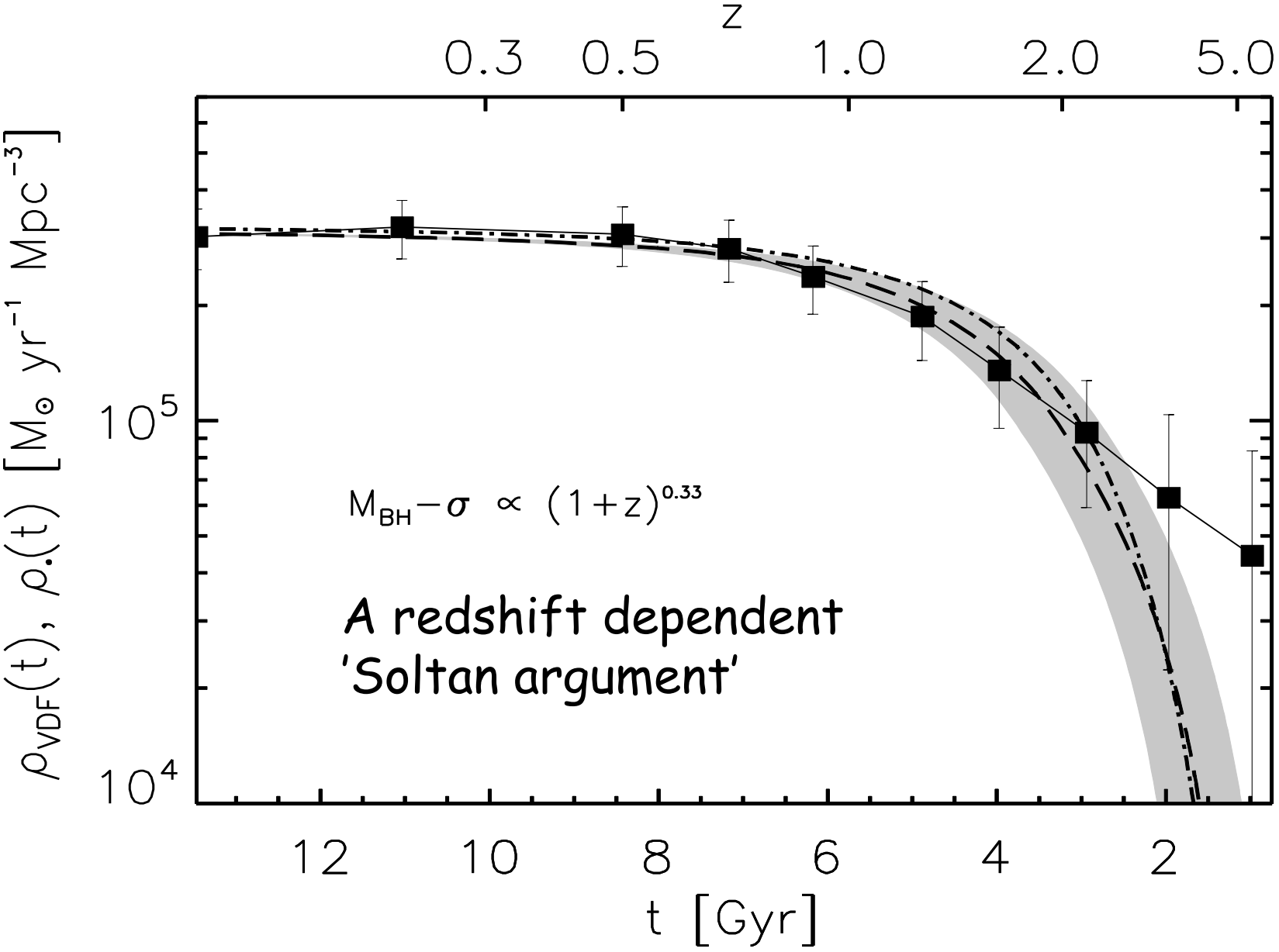
~~Accretion, Clustering,~~

Redshift Evolution



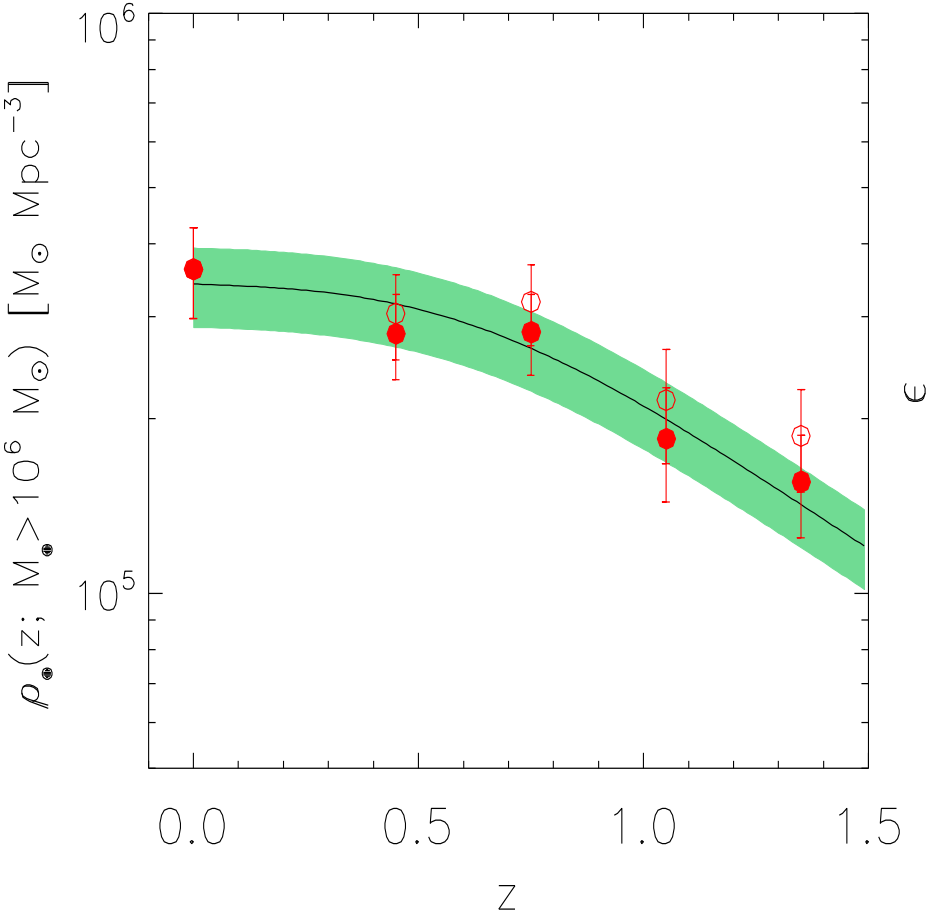
See talks by, e.g., Vignali, Valiante, …

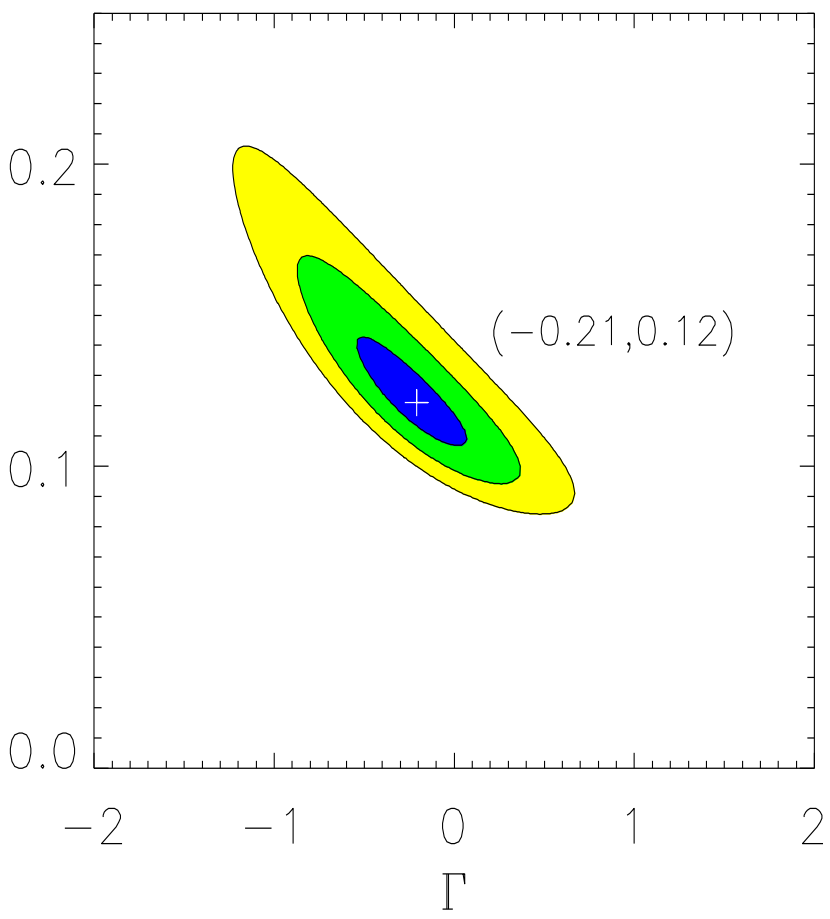
In the Mbh-sigma nearly absent!



FS, Bernardi, Haiman 09

Confirmed by Yu & Lu!

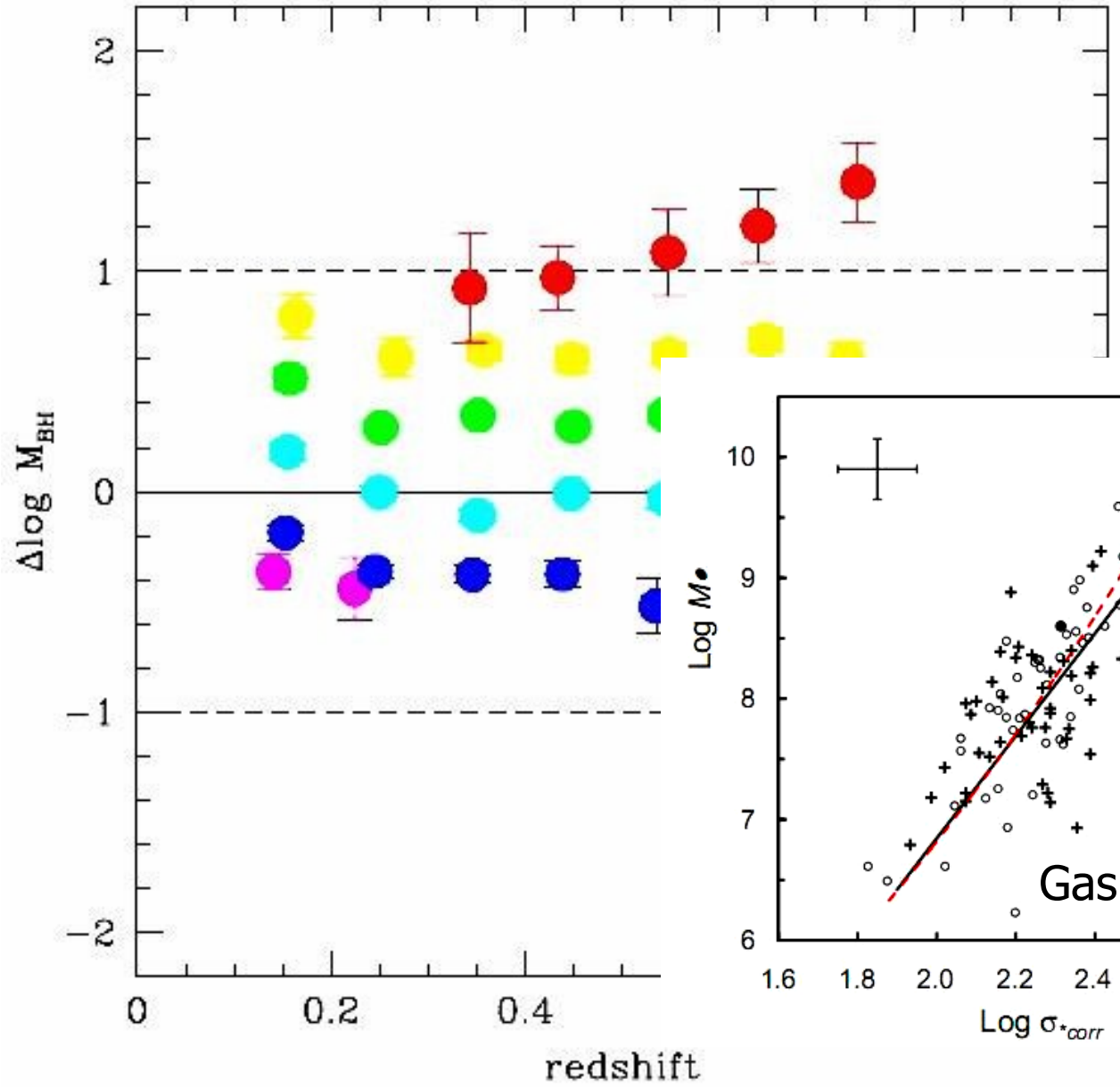


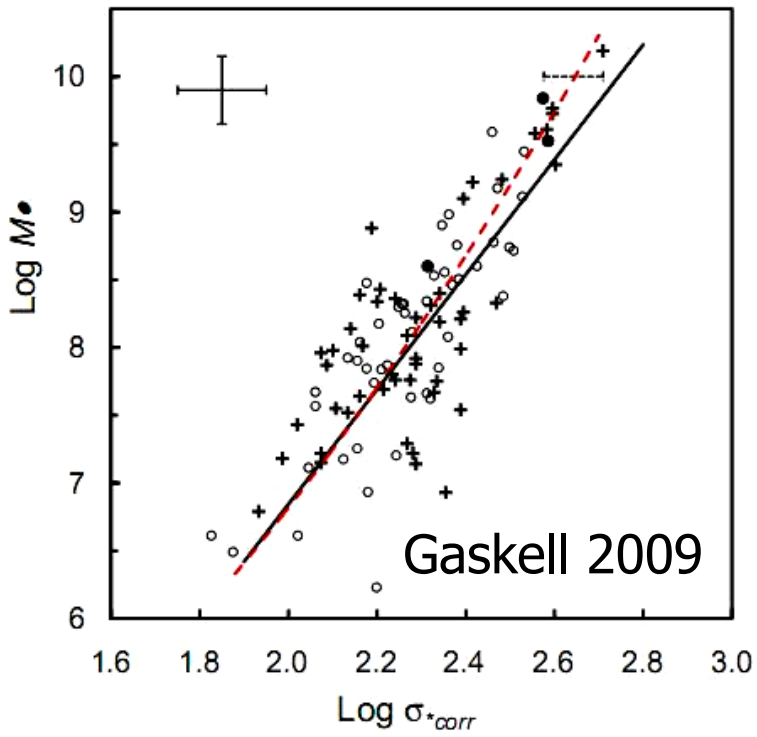


Interestingly, when they repeat for stars they find significant positive Evolution, consistent with Merloni, Decarli….

Zhang, Lu, Yu 2012

And by direct measurements! Reliable?!?

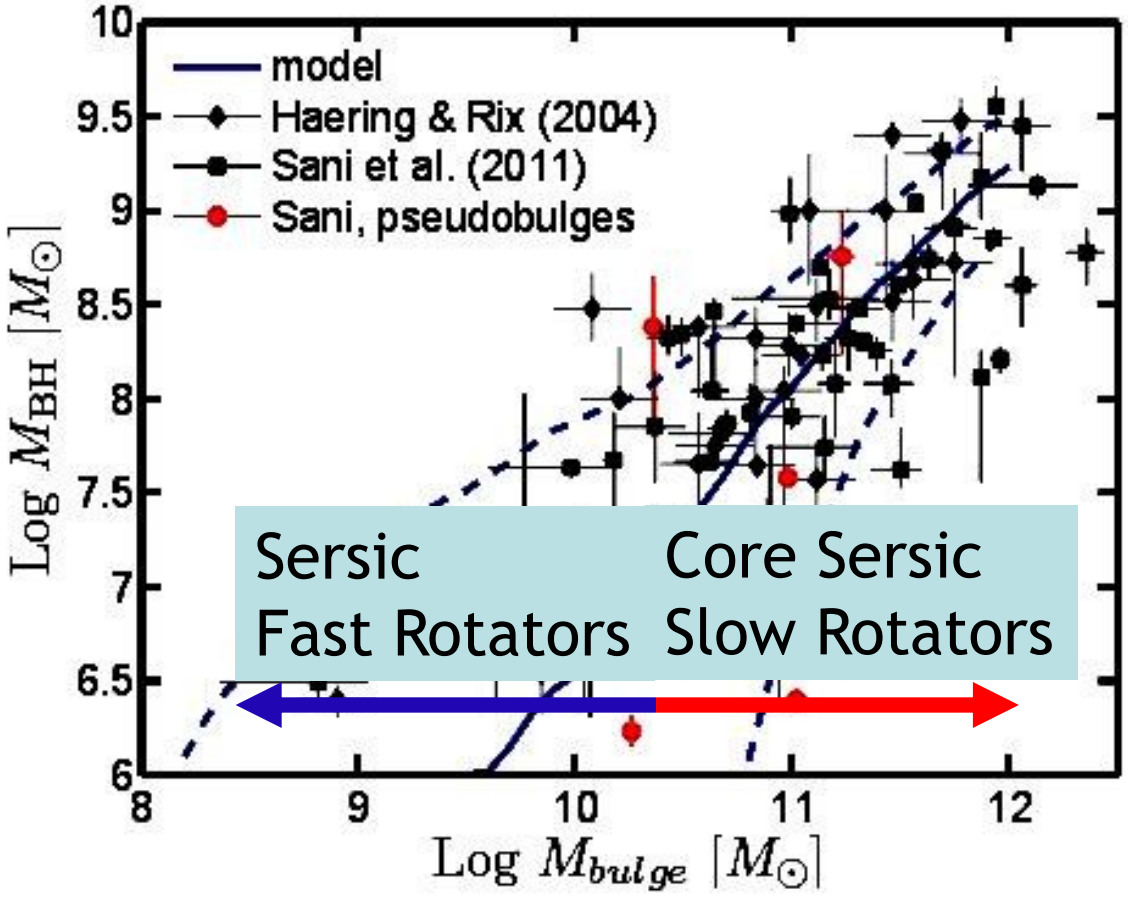




Salviander & Shields 2013

More Advanced Models: **Mergers vs secular accretion**

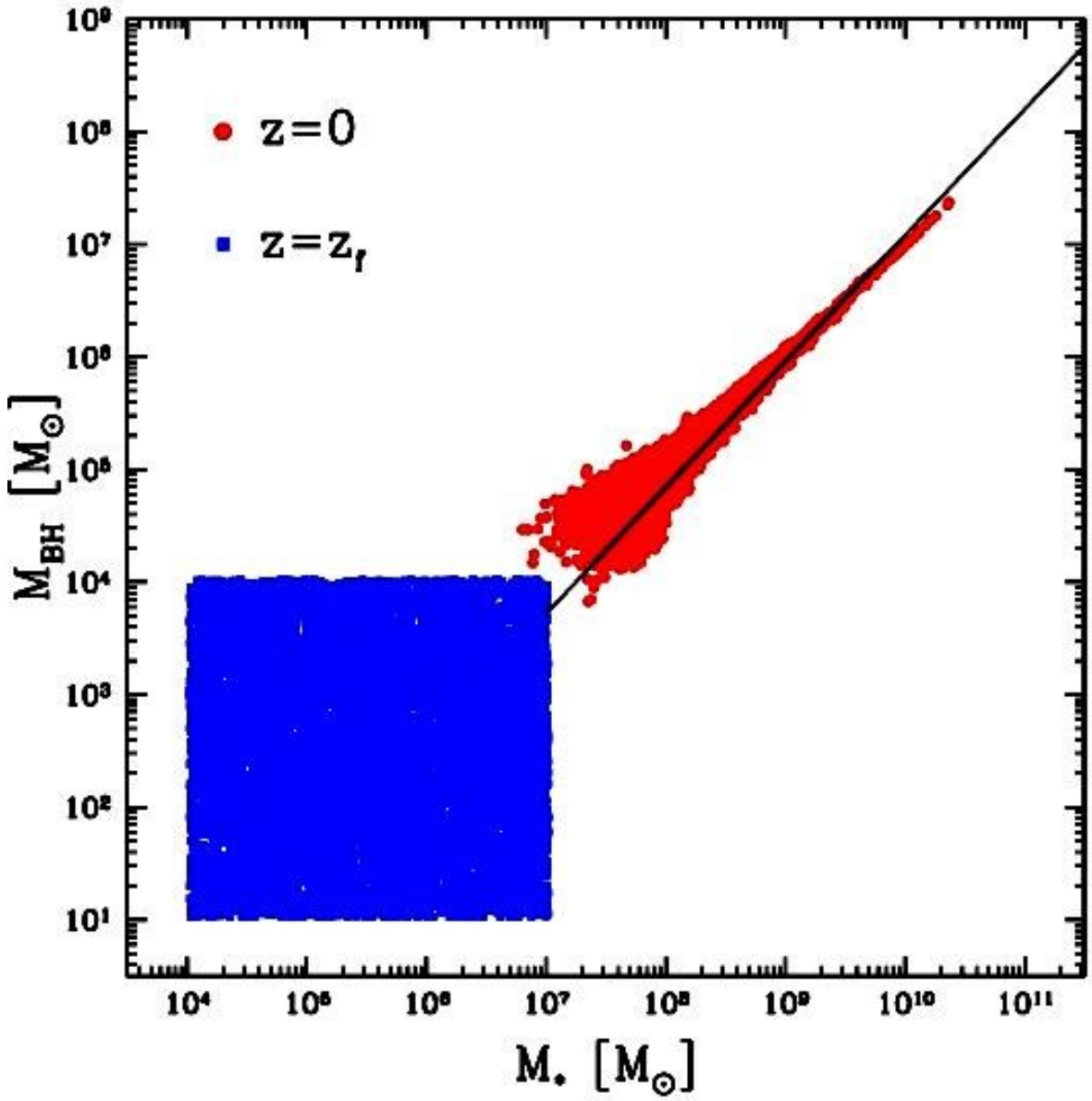
(IMPACT ON SCALING RELATIONS)



Neistein & Netzer 13

In this models ONLY mergers trigger BH growth!

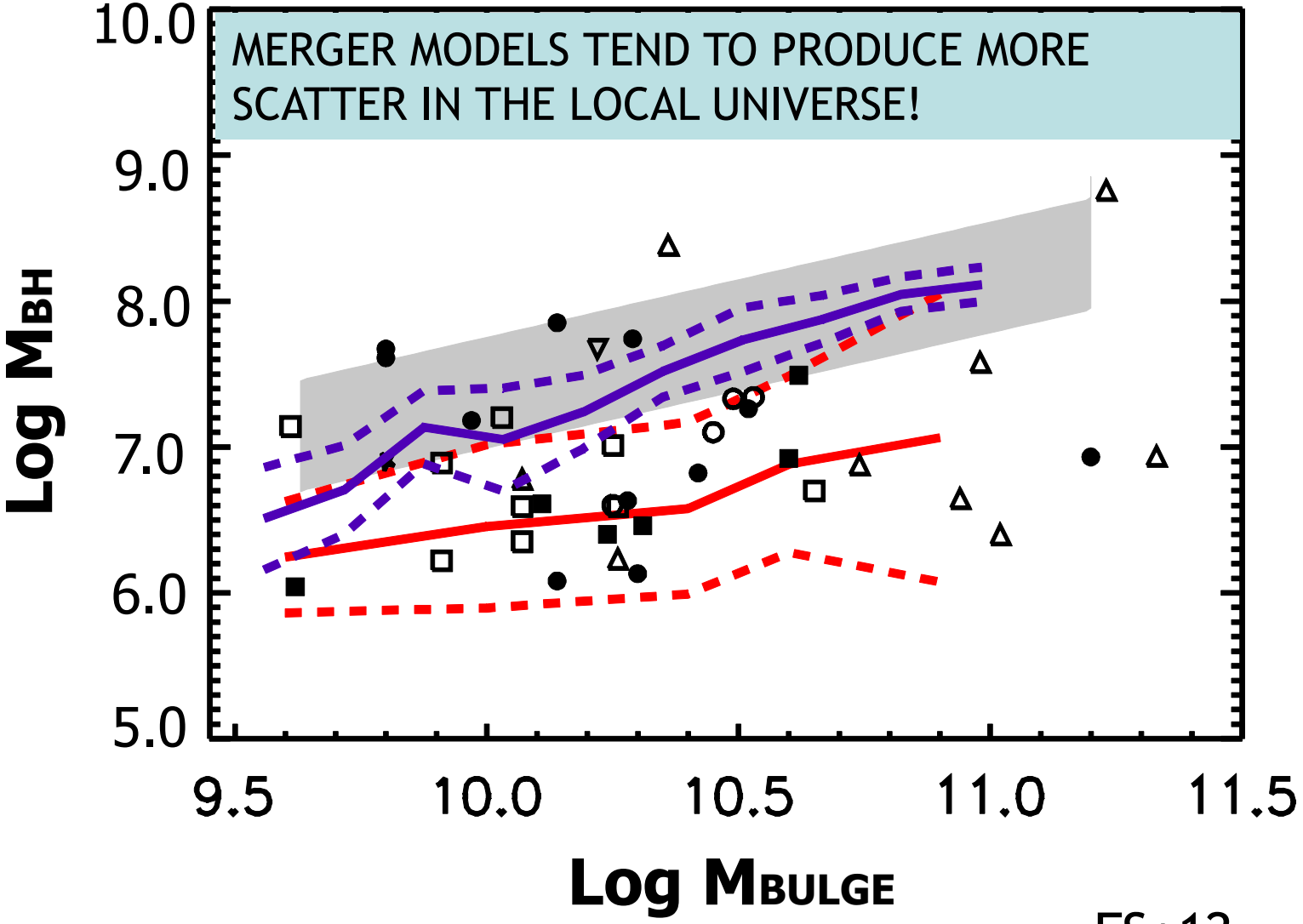
Large scatter at low masses mainly because of inefficiency of mergers, closer to «seed" BH masses!



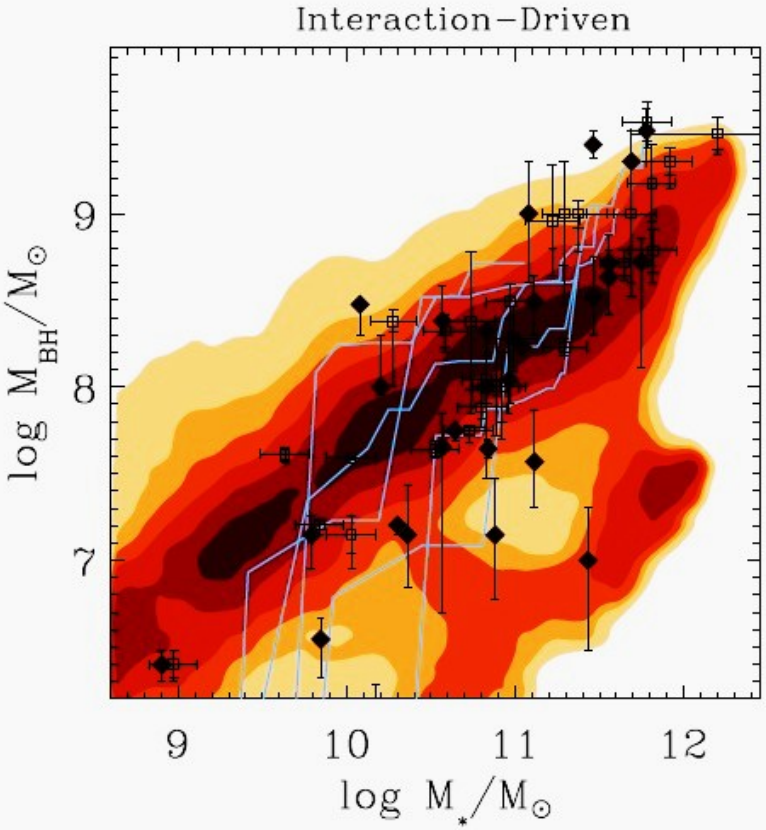
At the other extreme:
Even with NO Accretion,
ONLY mergers at the rate predicted by LCDM can already predict a linear relation!

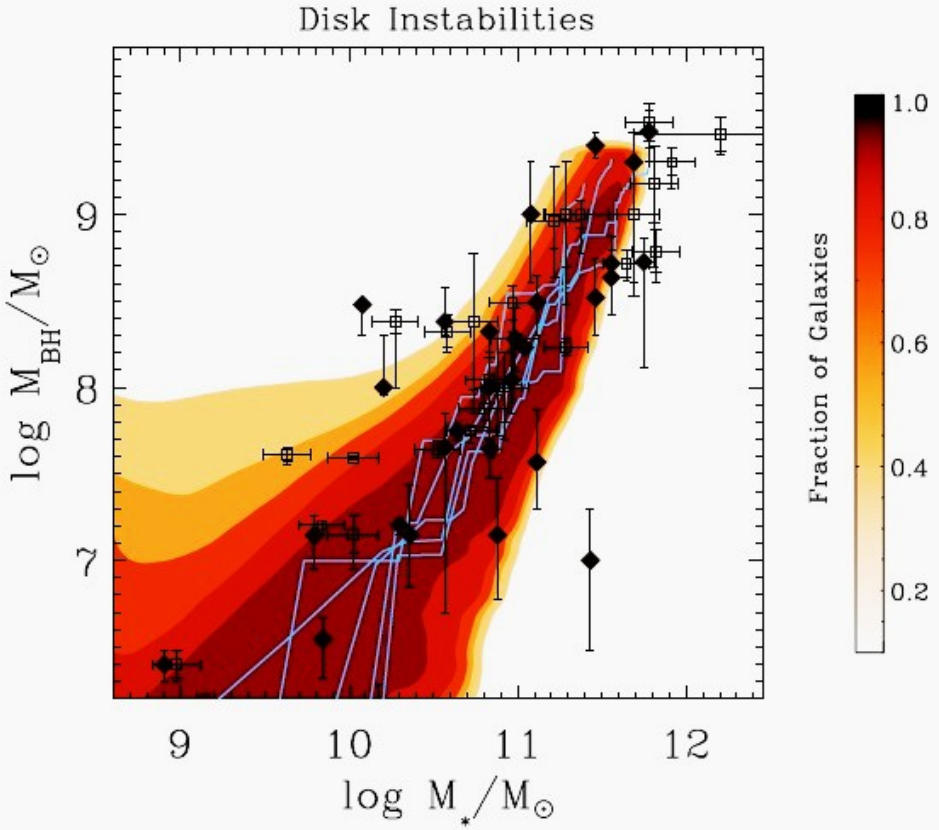
Jahnke+Maccio 11

EFFECTS OF BH GROWTH IN SECULAR EVOLUTION?



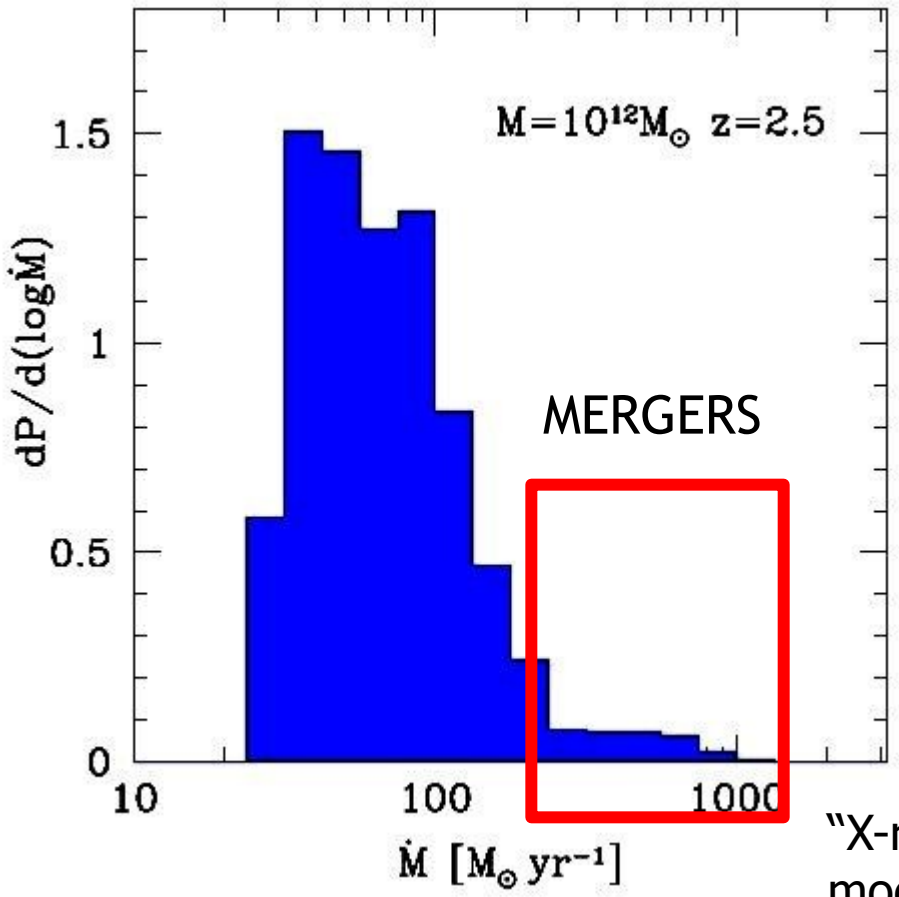
FS+12


Interaction−Driven
log M_BH/M⊙
9
8
7
9
10
11
12
log M*/M⊙


Disk Instabilities
log M_BH/M⊙
9
8
7
9
10
11
12
log M*/M⊙
Fraction of Galaxies
1.0
0.8
0.6
0.4
0.2

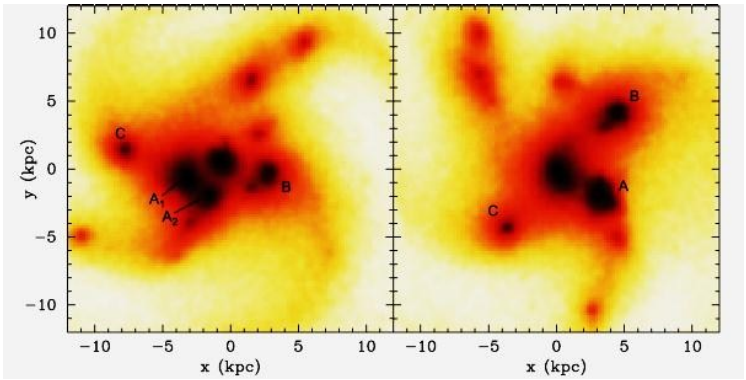
Menci+14

SOME RECENT PROPOSALS FOR IN-SITU BH GROWTH: COLD FLOWS



Dekel+09

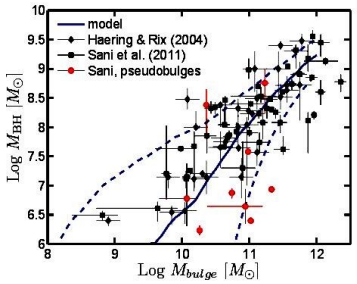
Bournaud,…FS+11



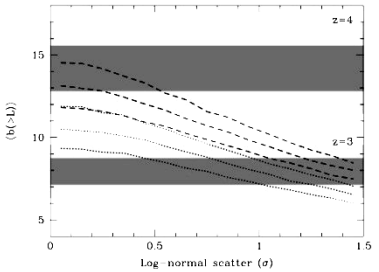
"X-ray data show that … AGN fueling modes at z ~ 1.85---whether violent disk instabilities or secular processes---are as efficient in smooth galaxies as they are in clumpy galaxies." Trump+14

WHAT I DISCUSSED:

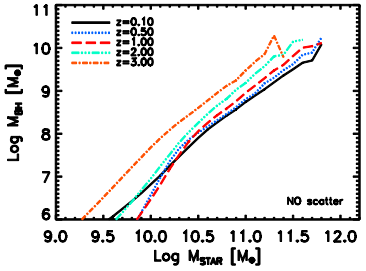
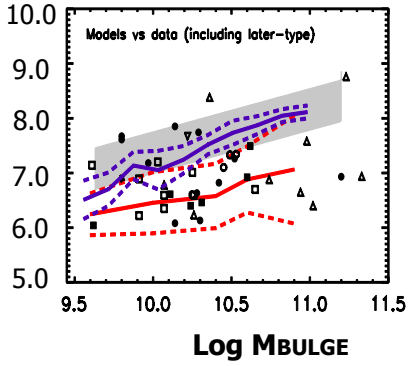
Local Scaling Relations:
Possible breaks, high scatter



Accretion and Clustering:
Evol. w/ SFR, evolving scatter



Evolution with redshift:
Yes Mbh/Mstar, NO Mbh/sigma



Galaxy co-evolution:
Triggering by mergers favoured