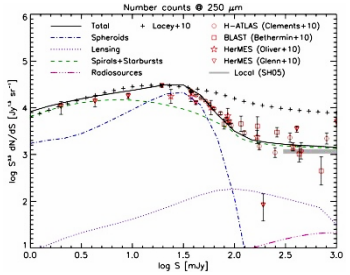
Evolution of *Spheroidal Galaxies* via Semi-Analytic and Semi-Empirical Models

FRANCESCO SHANKAR

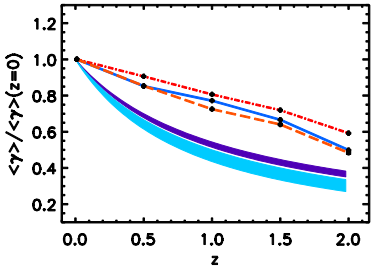
WITH: M. BERNARDI, M. HUERTAS-COMPANY, S. MEI, L. DELAYE, M. STRINGER, F. FONTANOT, P. MONACO, A. CATTANEO, R. LICITRA, A. RAICHOOR, R. SHETH, G. NOVAK

WHAT I WILL DISCUSS:

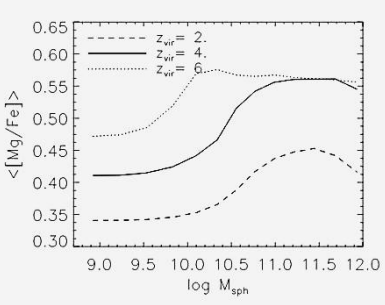
Monolithic vs Hierarchical:
Mass Evolution



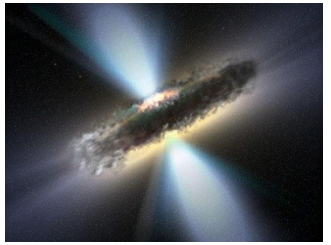
Monolithic vs Hierarchical:
Size Evolution



Monolithic vs Hierarchical:
Metallicity



Monolithic vs Hierarchical:
Central Black Holes



….FOR BULGE-DOMINATED GALAXIES STILL OPEN DEBATE, EVEN *AFTER 30 YEARS* OF DEDICATED RESEARCH…

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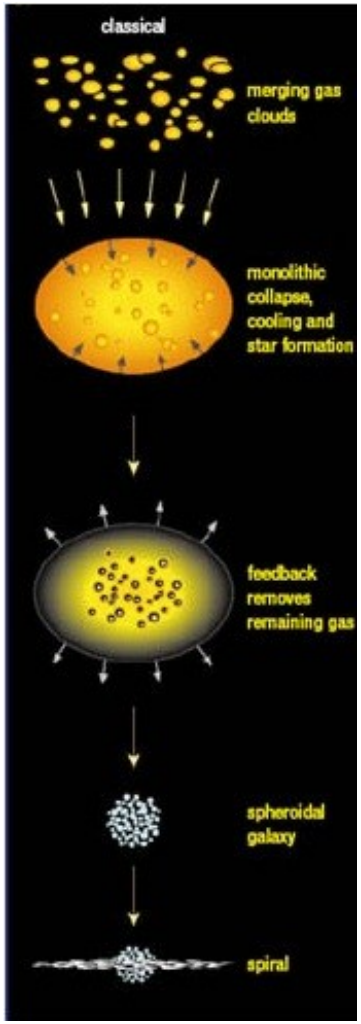
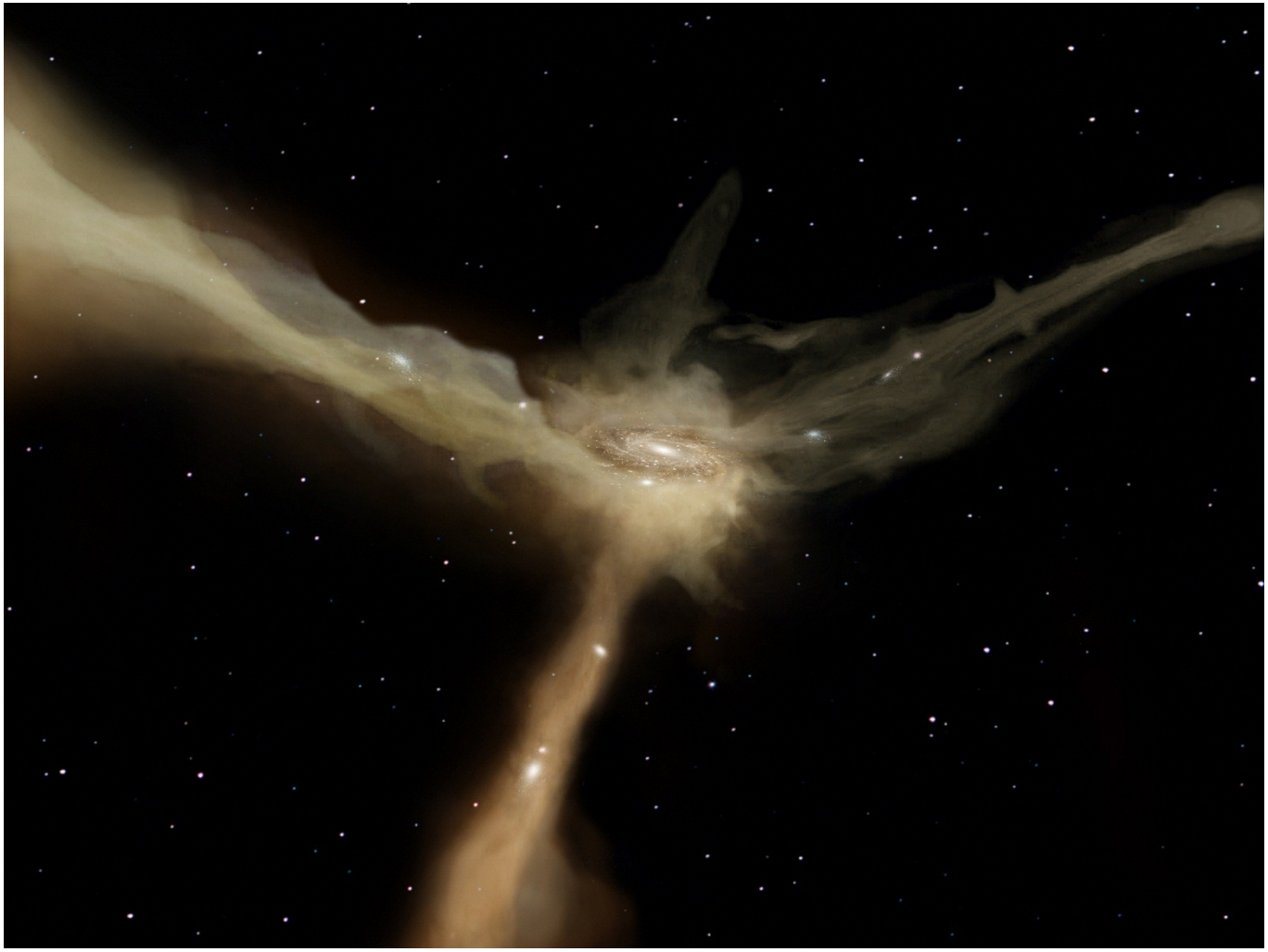
BROADLY SPEAKING TWO COMPETING SCENARIOS:

MONOLITHIC



CREDIT: F. COMBES

…DISCS FROM COLD FLOWS AND
BULGES FROM CLUMPS VIA DYNAMICAL FRICTION
(e.g. Bower+06; Dekel+09; Bournaud+11; etc)….



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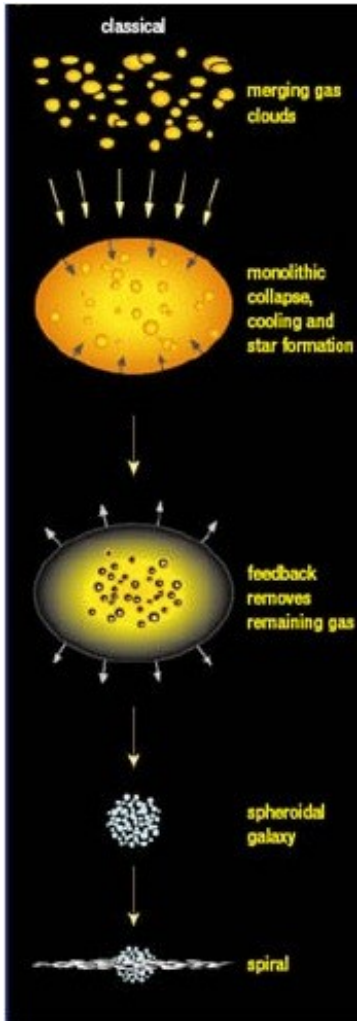

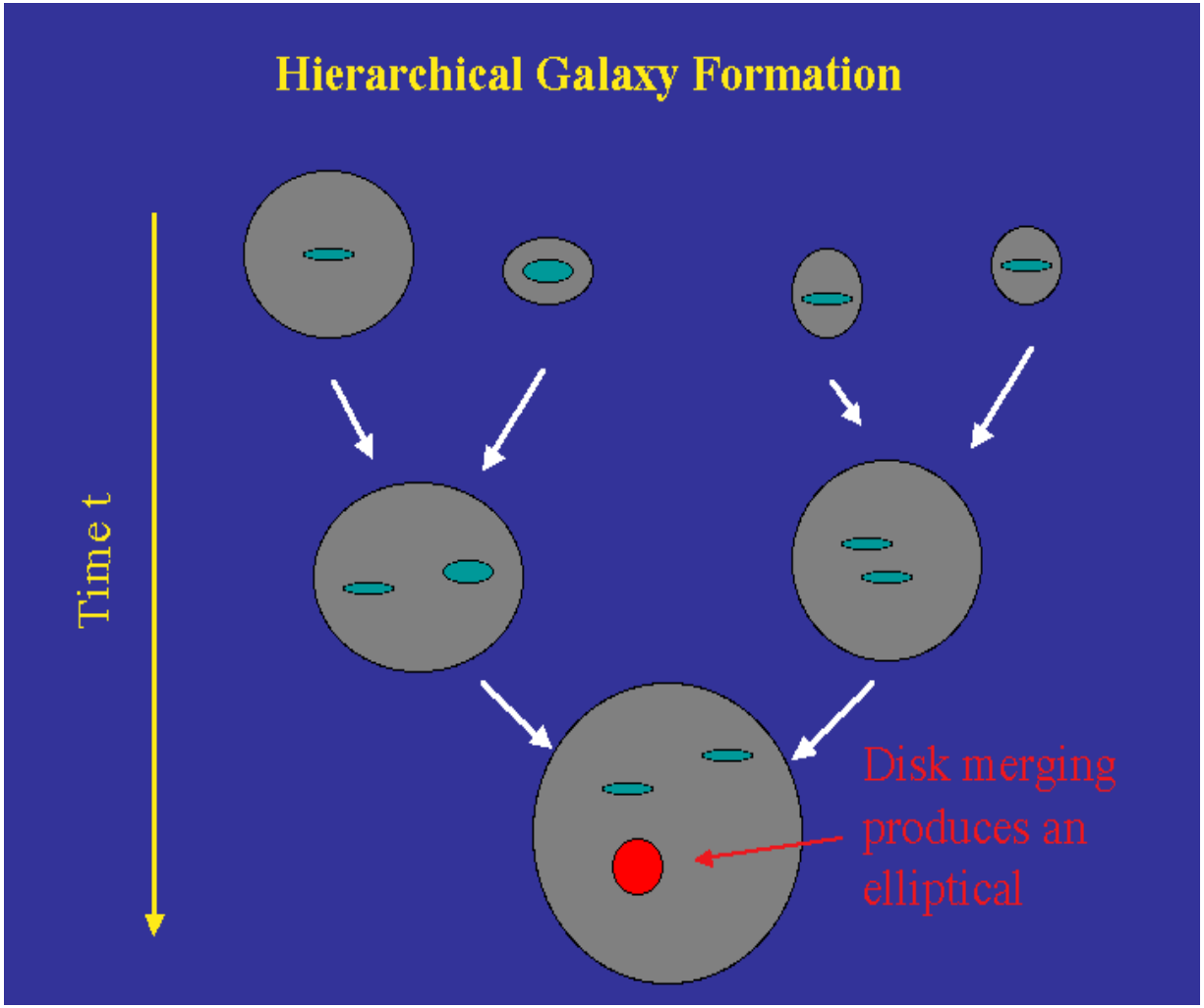

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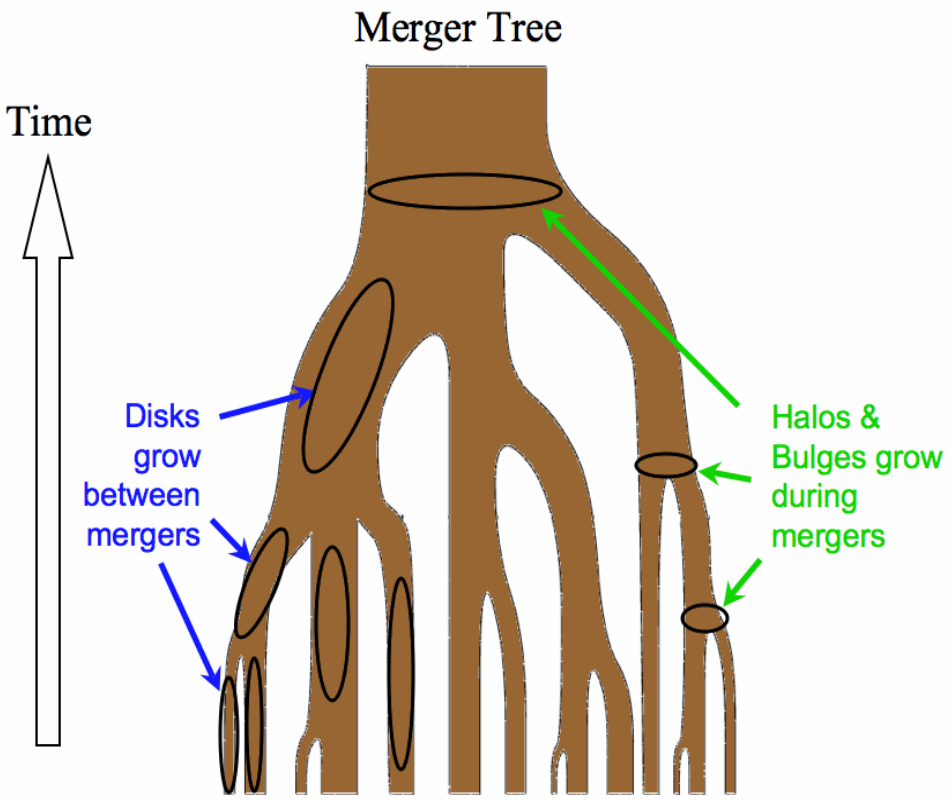

Whittle et al.

SEMI-ANALYTIC MODELS:
EVOLVE GALAXIES ALONG THE DARK MATTER MERGER TREES FOLLOWING MANY PHYSICAL RECIPES

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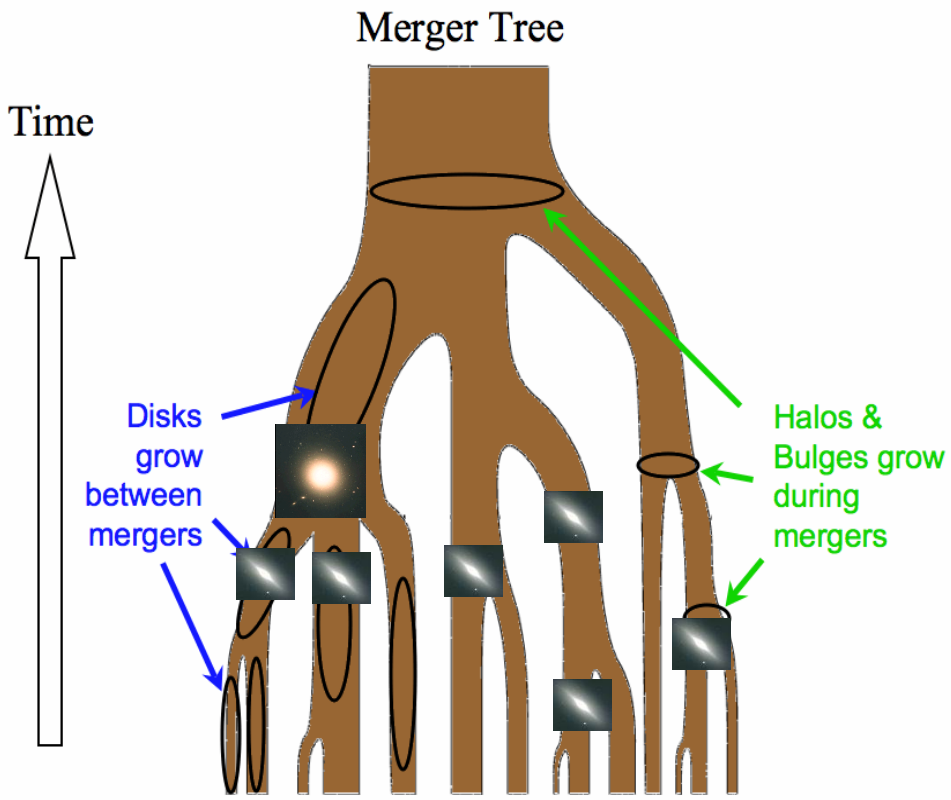

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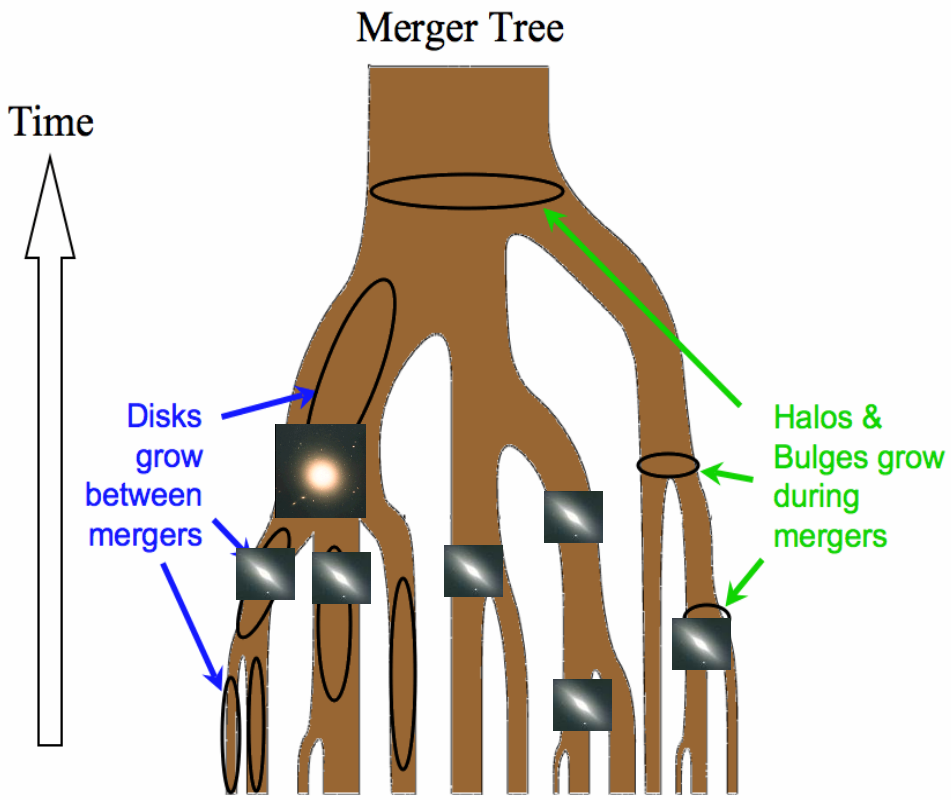

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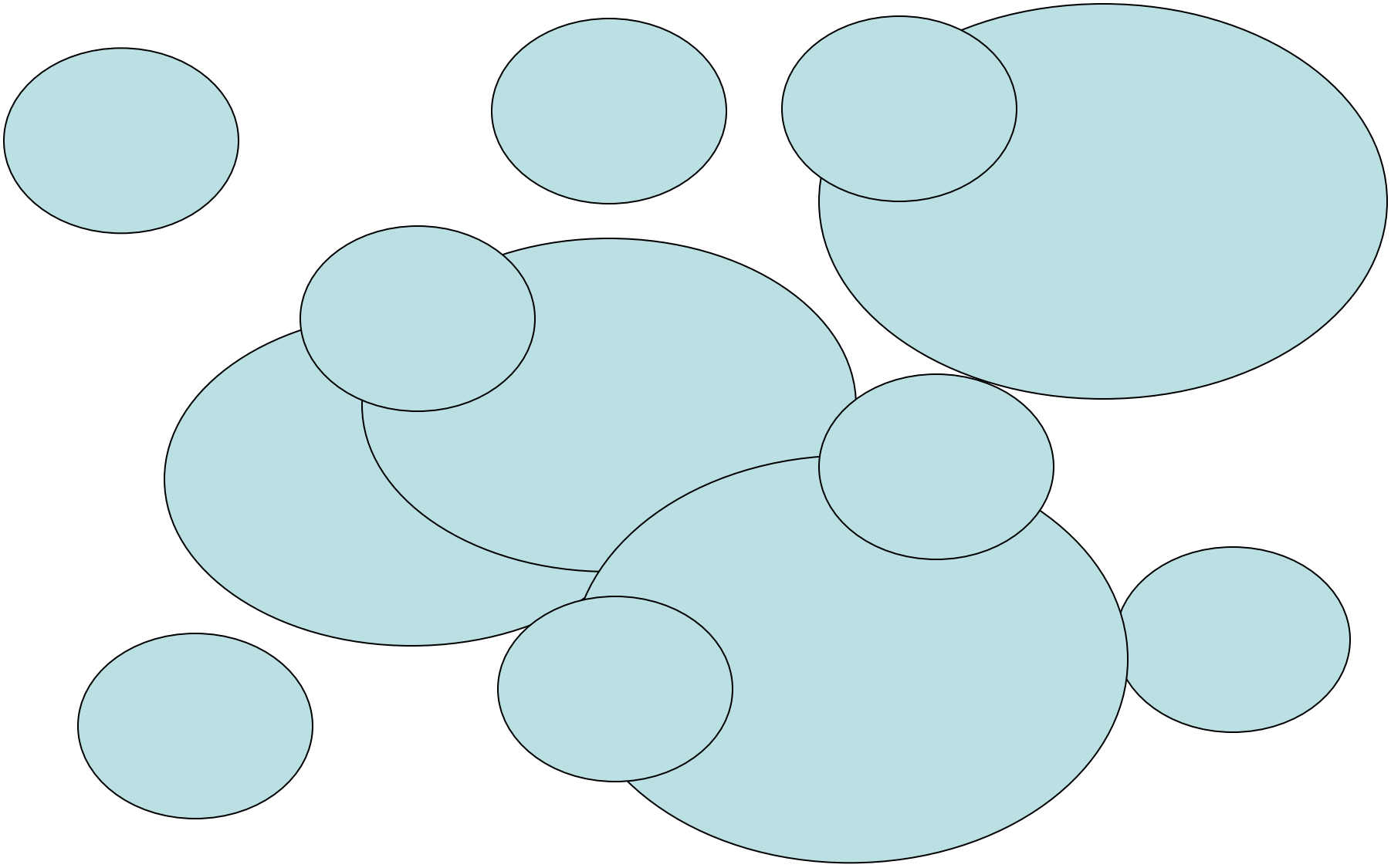
SEMI-ANALYTIC MODELS: EVOLVE GALAXIES ALONG THE DARK MATTER MERGER TREES FOLLOWING MANY PHYSICAL RECIPES

ONE CAVEAT:

-MANY PARAMETERS/PHYS. RECIPES →DEGENERACIES: THERE ARE MODELS WHICH CAN REPRODUCE SAME OBSERVABLES WITH JUST *OPPOSITE* INPUT ASSUMPTIONS!

ABUNDANCE MATCHING MODELS, HOW DO THEY WORK?

WE CHOOSE TO PLACE GALAXIES AND BHs IN HALOs TO REPRODUCE THE MEASURED STATISTICS AND CLUSTERING (SPATIAL DISTRIBUTION)



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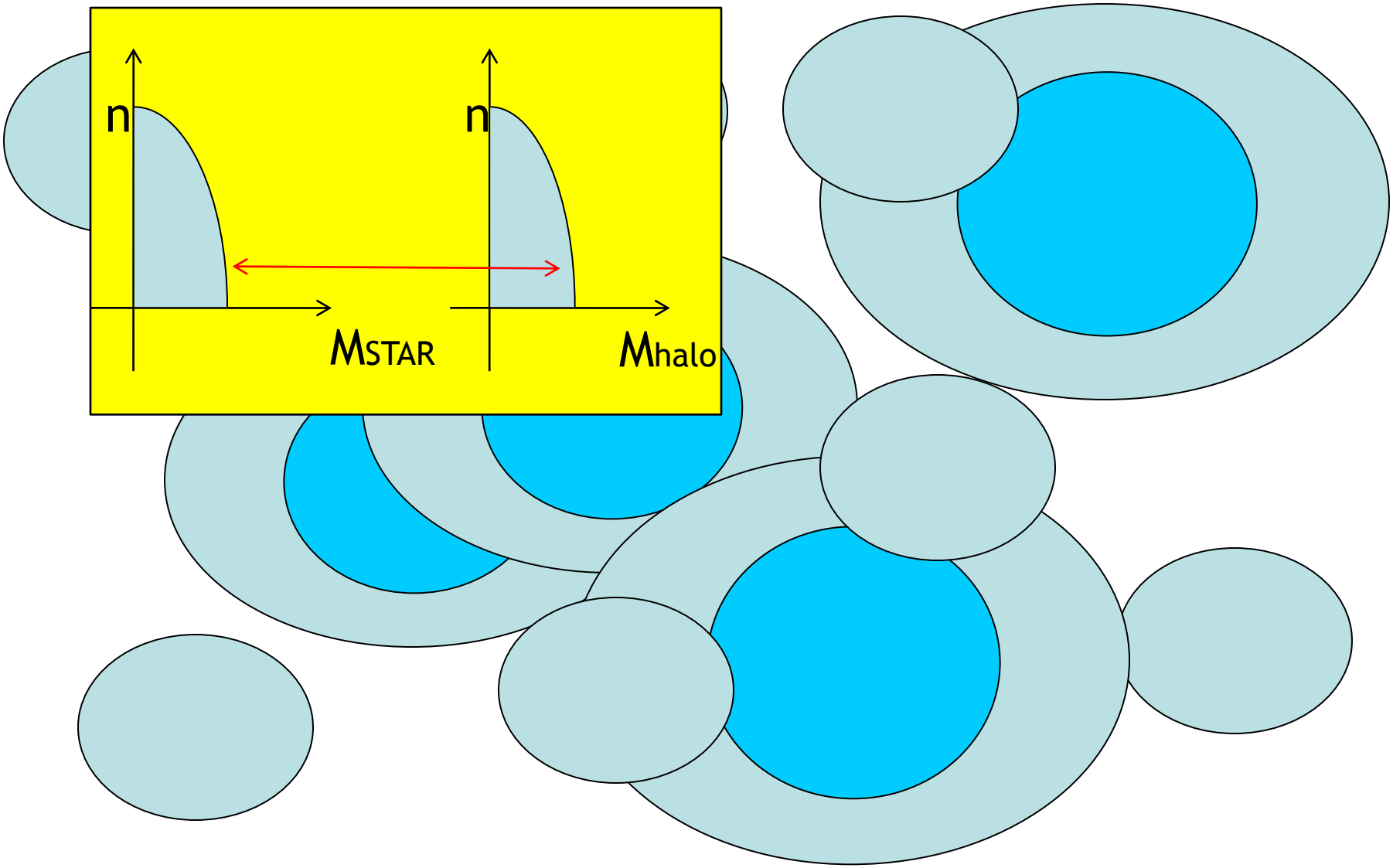

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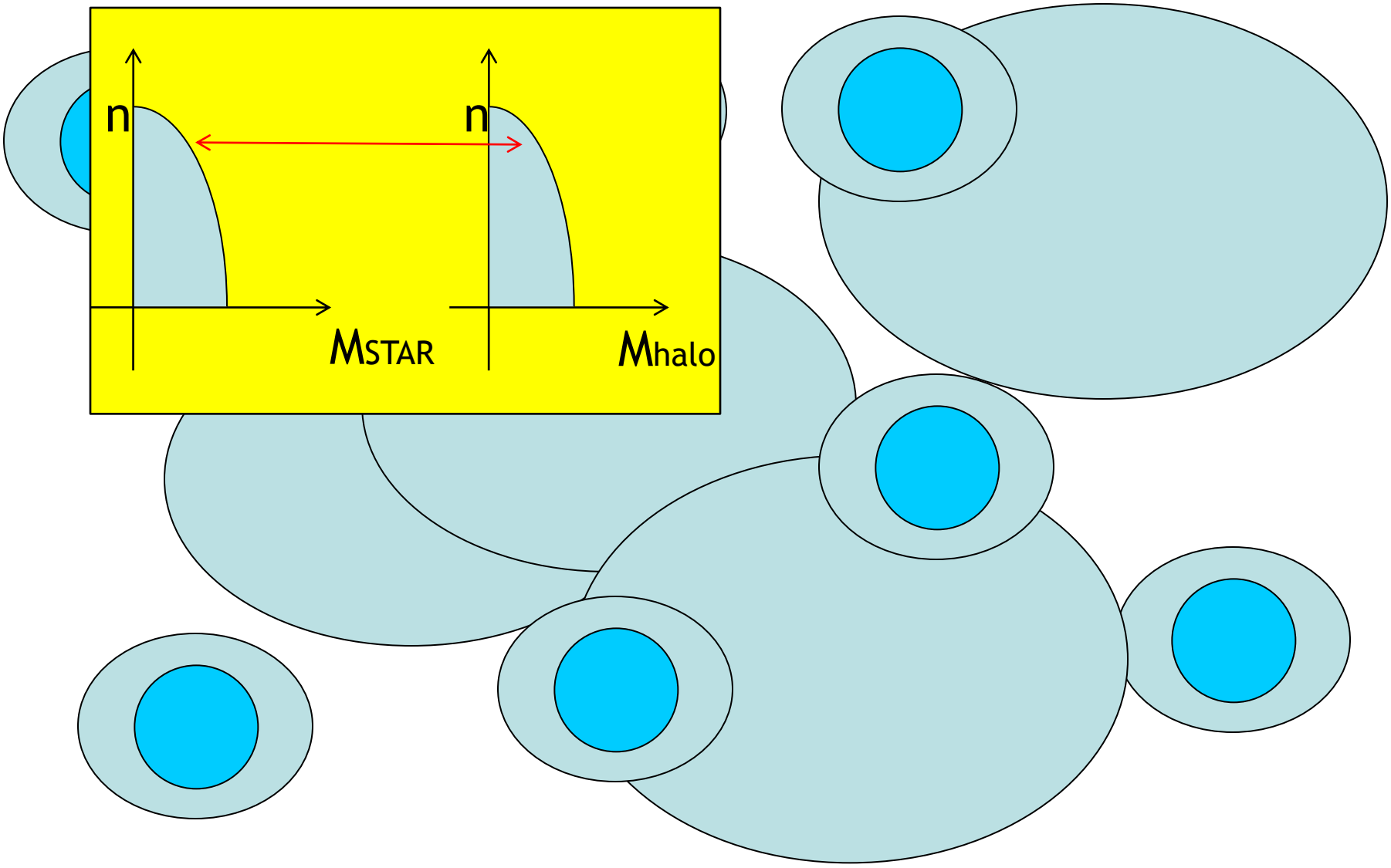

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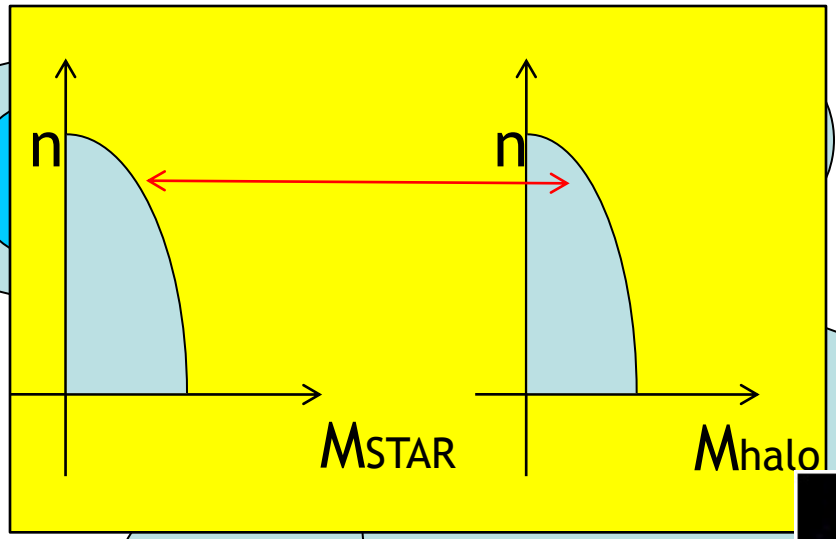
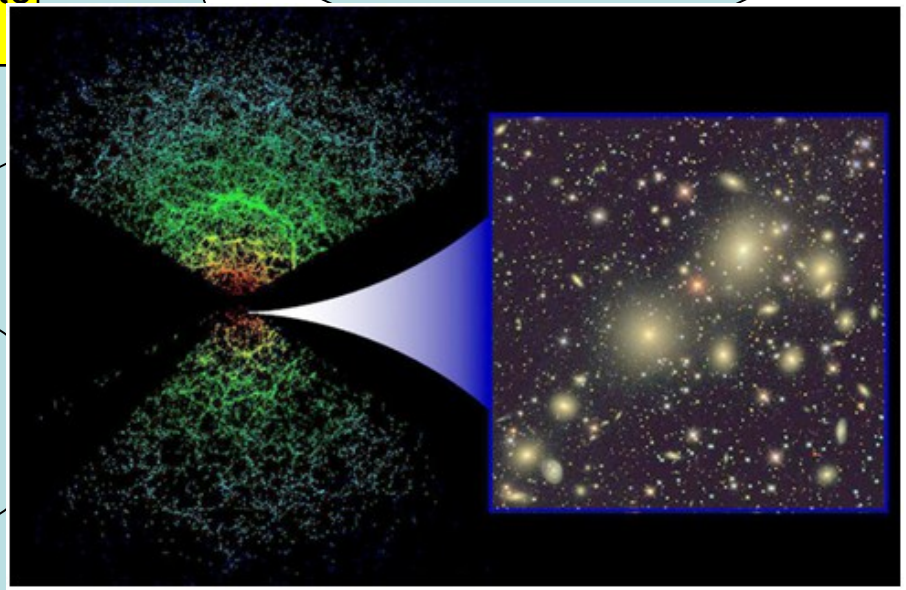
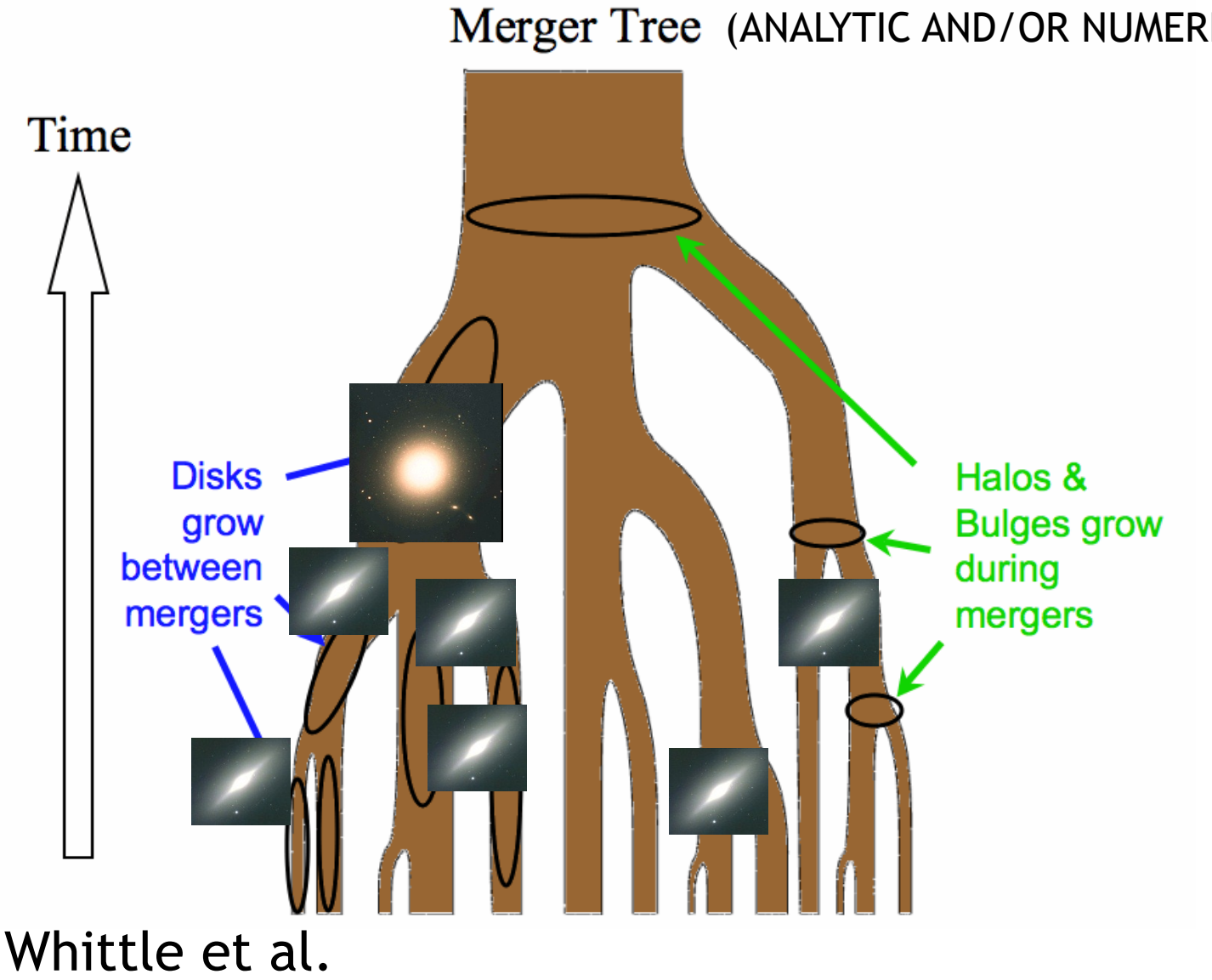




ONCE HALOES HAVE BEEN SEEDED, GALAXIES EVOLVE ALONG THE DARK MATTER TREES, MERGING AND CHANGING MORPHOLOGY



Merging galaxies and growing Bulges in models:

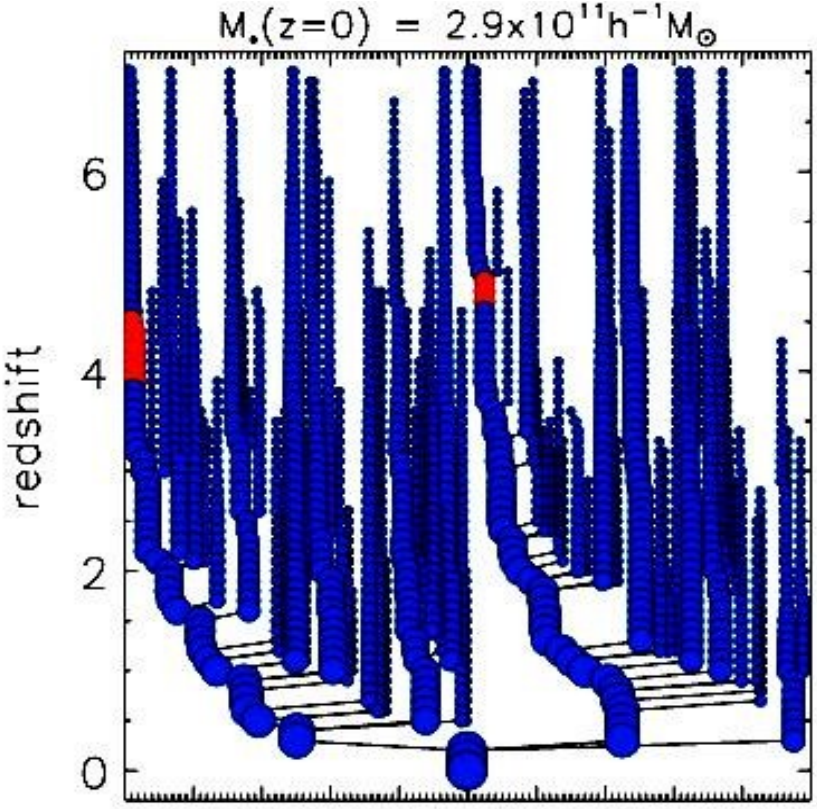
<u>MINOR merger</u>:
only stars in the remnant bulge

<u>MAJOR merger</u>:
all stars+gas form a bulge=elliptical

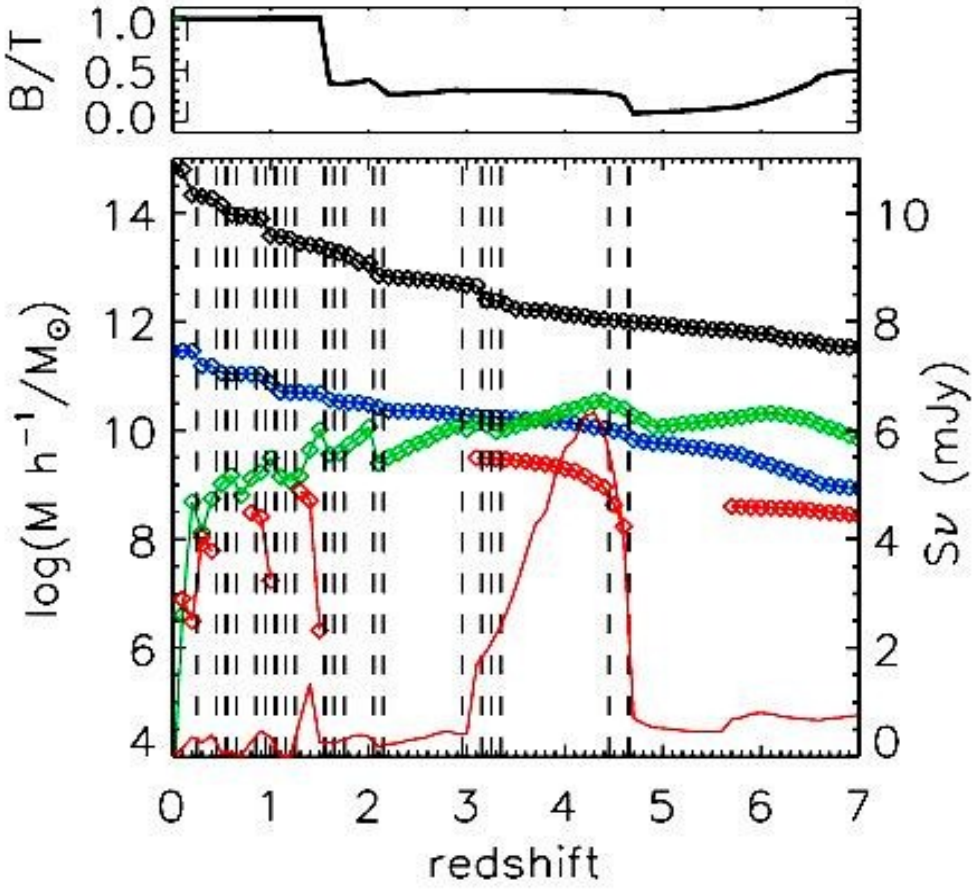
Bulges grow also through disk-instability
←→PSEUDO-bulges or stronger instabilities!

Monolithic vs Hierarchical:
Mass Evolution

Fraction of stellar mass formed in hierarchical models



Gonzalez+11



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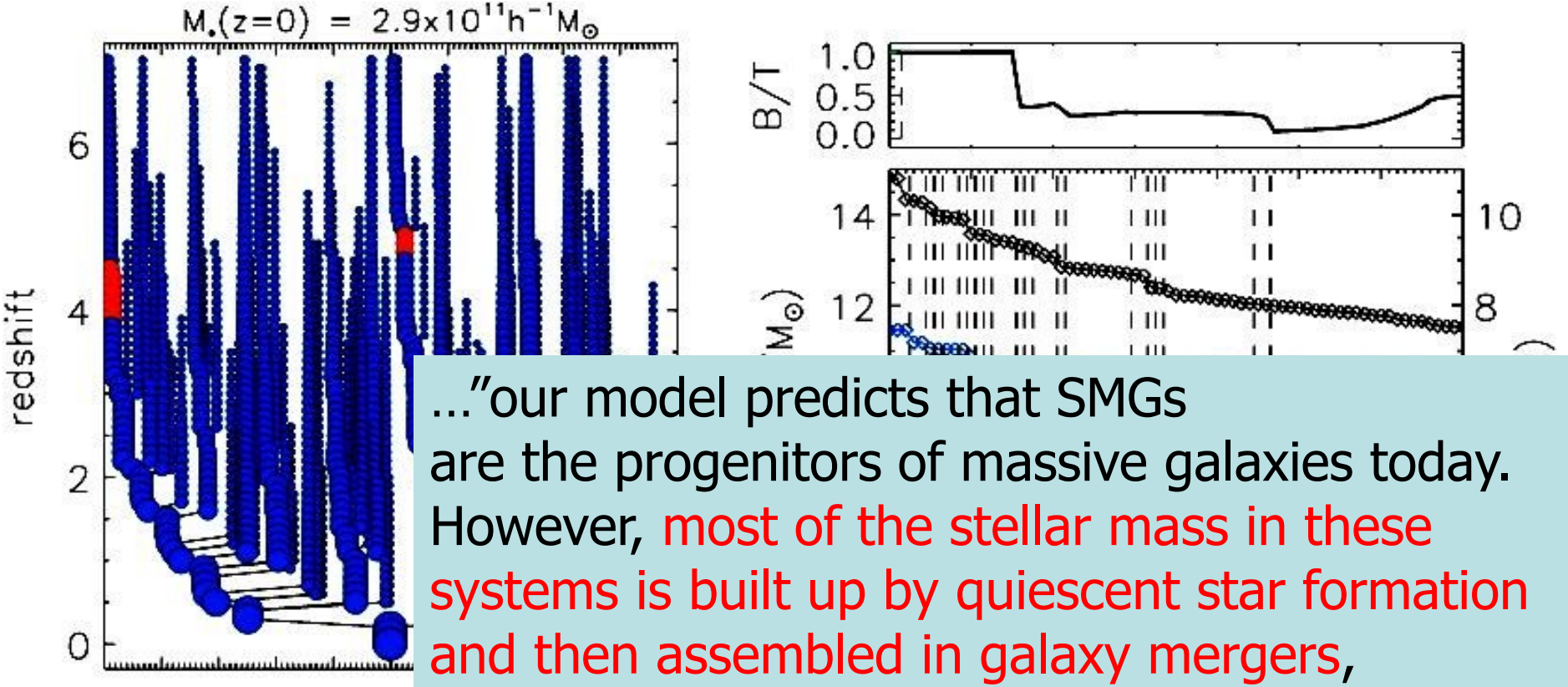
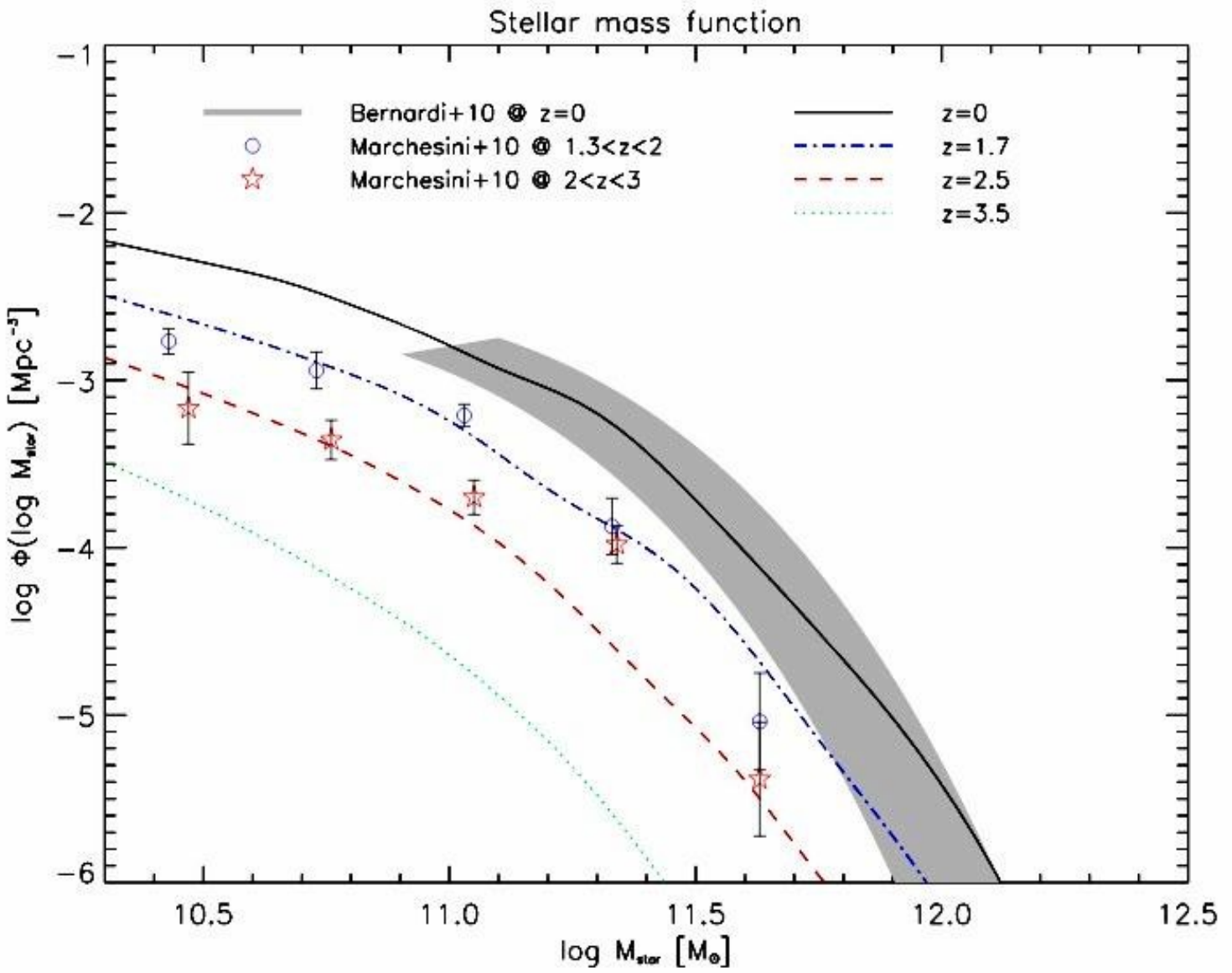


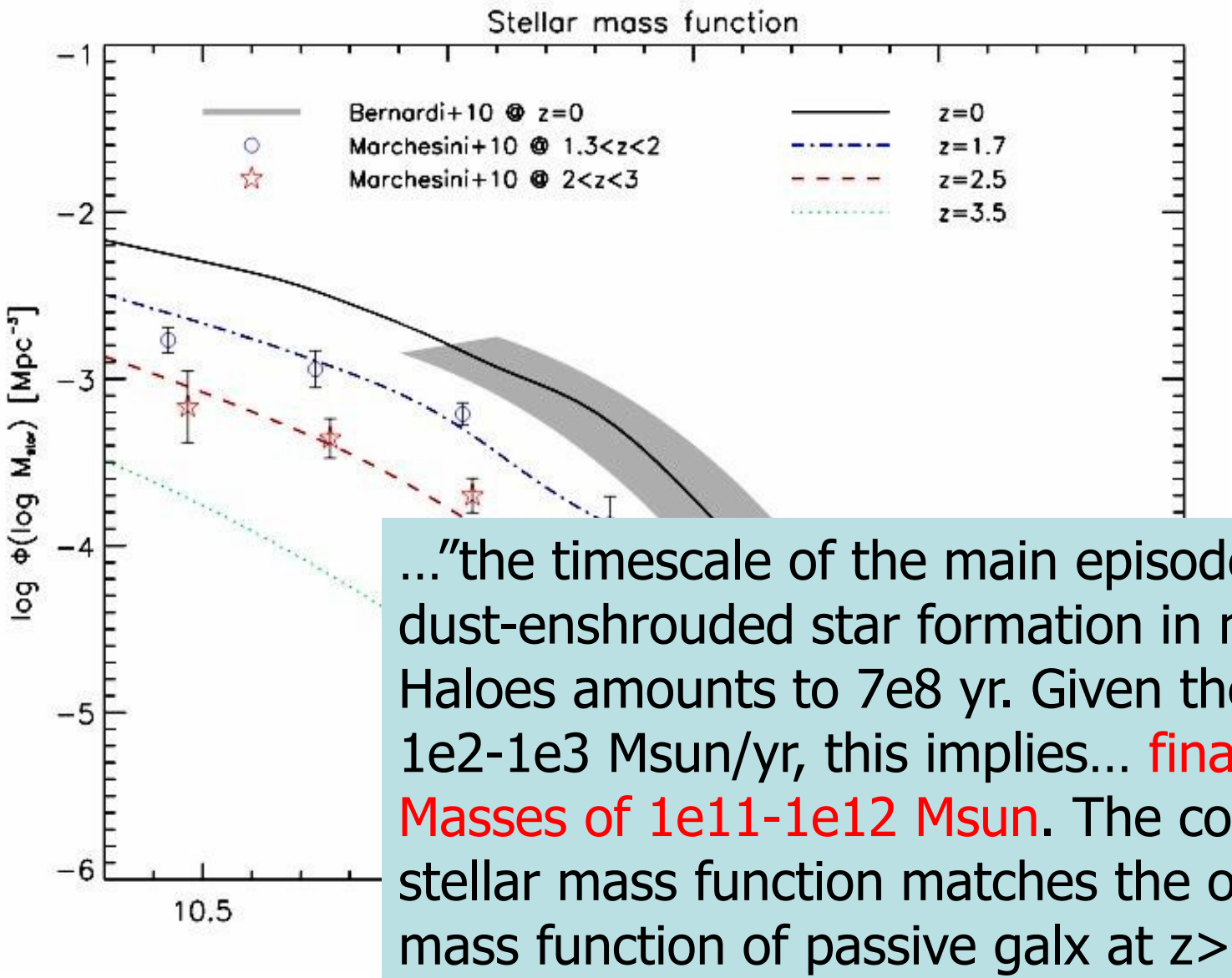
…"our model predicts that SMGs are the progenitors of massive galaxies today. However, most of the stellar mass in these systems is built up by quiescent star formation and then assembled in galaxy mergers, making the contribution of long-lived stars formed during the SMG phase typically very small." Gonzalez+11

Fraction of stellar mass formed in «in-situ» models



Lapi+11

Fraction of stellar mass formed in «in-situ» models



Lapi+11

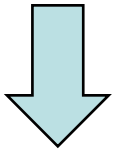
…"the timescale of the main episode of the dust-enshrouded star formation in massive Haloes amounts to 7e8 yr. Given the SFR of 1e2-1e3 Msun/yr, this implies… final stellar Masses of 1e11-1e12 Msun. The corresponding stellar mass function matches the observed mass function of passive galx at z>1." Lapi+11

Monolithic vs Hierarchical:
Size Evolution

How do we decide how large a spheroid is going to be?

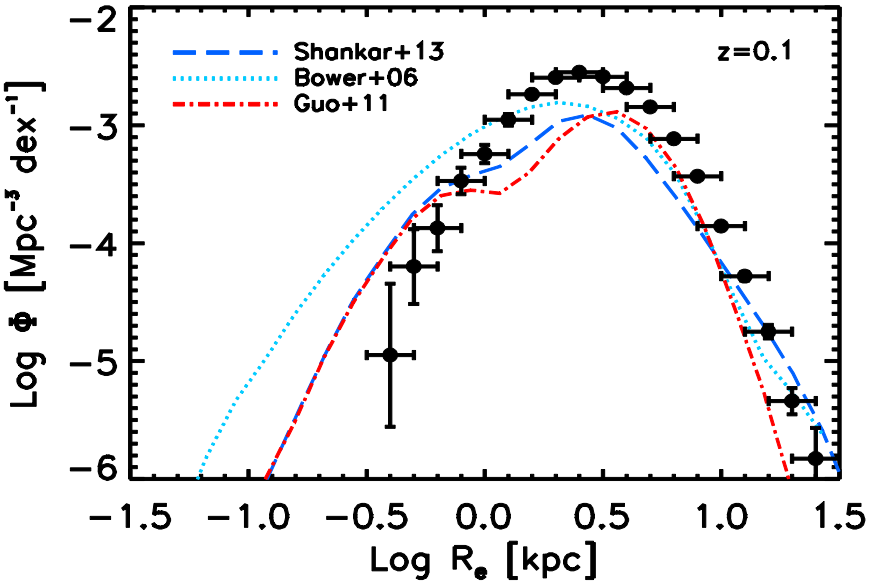
For mergers through conservation of energy :

$$E_{FIN} = E_1 + E_2 + E_{orb} + E_{diss} + E_{diff} \cdots$$



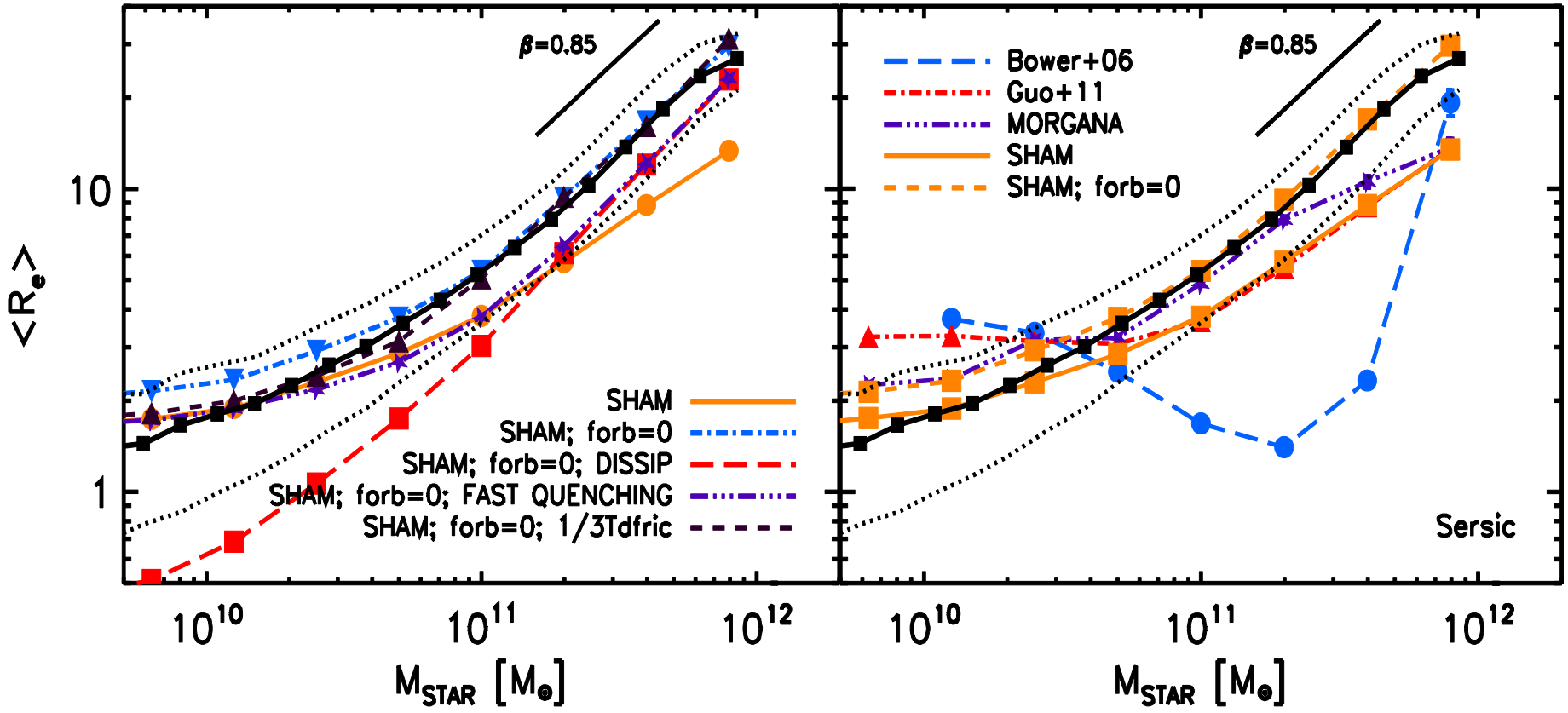
$$\frac{G(M_1+M_2)^2}{R_{..}} = \frac{G(M_1)^2}{R_1} + \frac{G(M_2)^2}{R_2} + k\frac{G(M_1+M_2)}{R_1+R_2}$$

Similar Eq. for **disc instabilities**, but M_1 and M_2 are replaced by bulge and disc masses, less efficient!



Constraining Successful Hierarchical Models cannot be achieved by only comparing with the size function and/or the Re-Mstar relation…

FS, Mei, Huertas-Company et al. 13b, to be submitted



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How do we decide how large a spheroid is going to be?

In «in-situ» Models through mass loss :

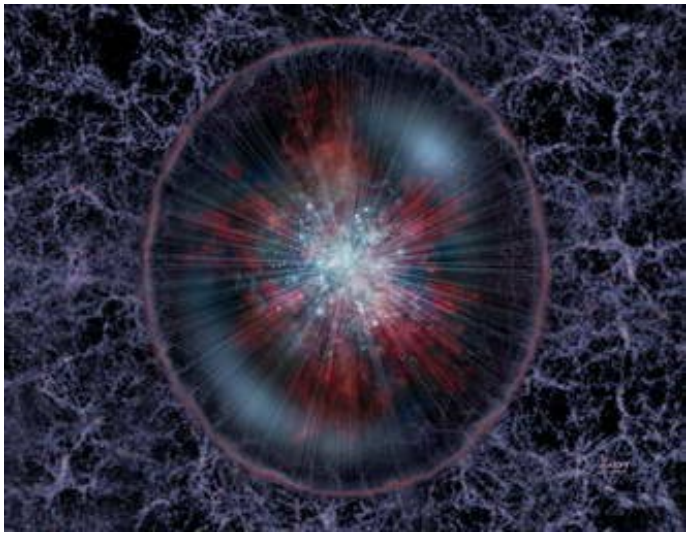


Image Credit:
PPARC/David Hardy

$$R_{IN} = R_{DISSIP}$$

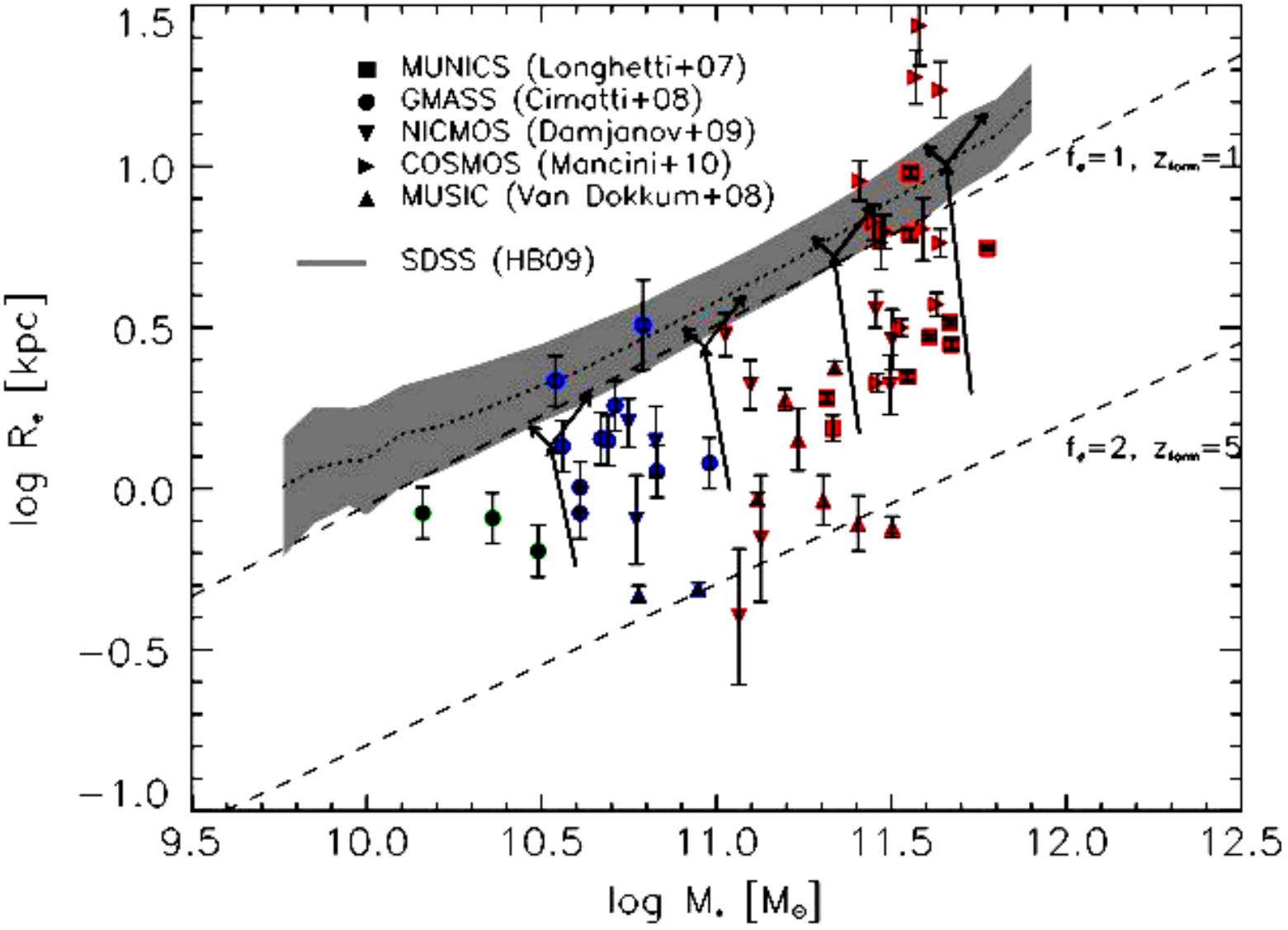
Fan et al. 2008, 2010

$$R_{FIN} = R_{IN} / (1 - M_{LOST}/M_{FIN})$$

For impulsive ejections when mass loss on timescales shorter than dynamical!

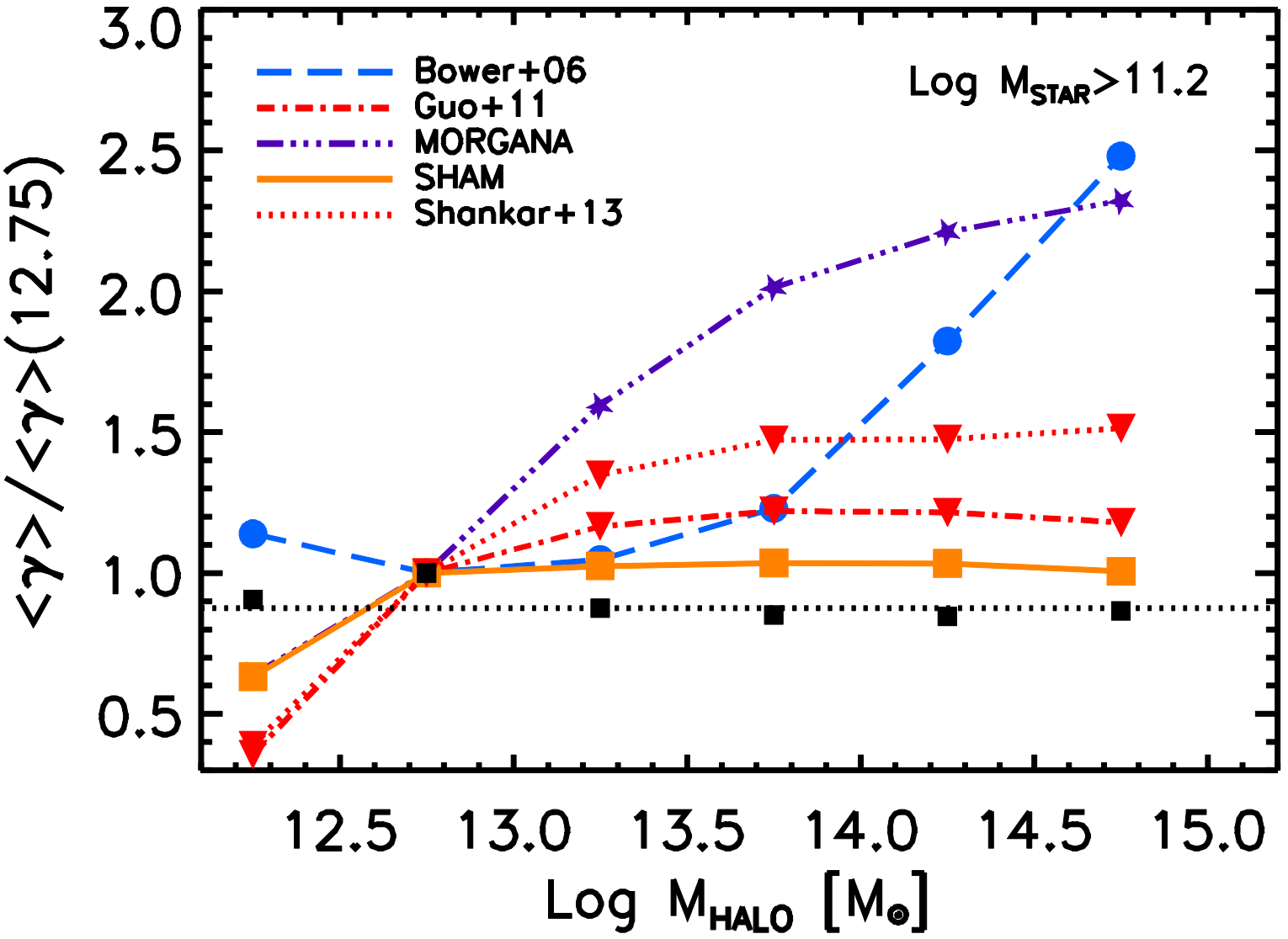
SIZE EVOLUTION: In-situ Models

Fan et al. 2008,2010



Environment may break Degeneracies!!

see Strazzullo, …



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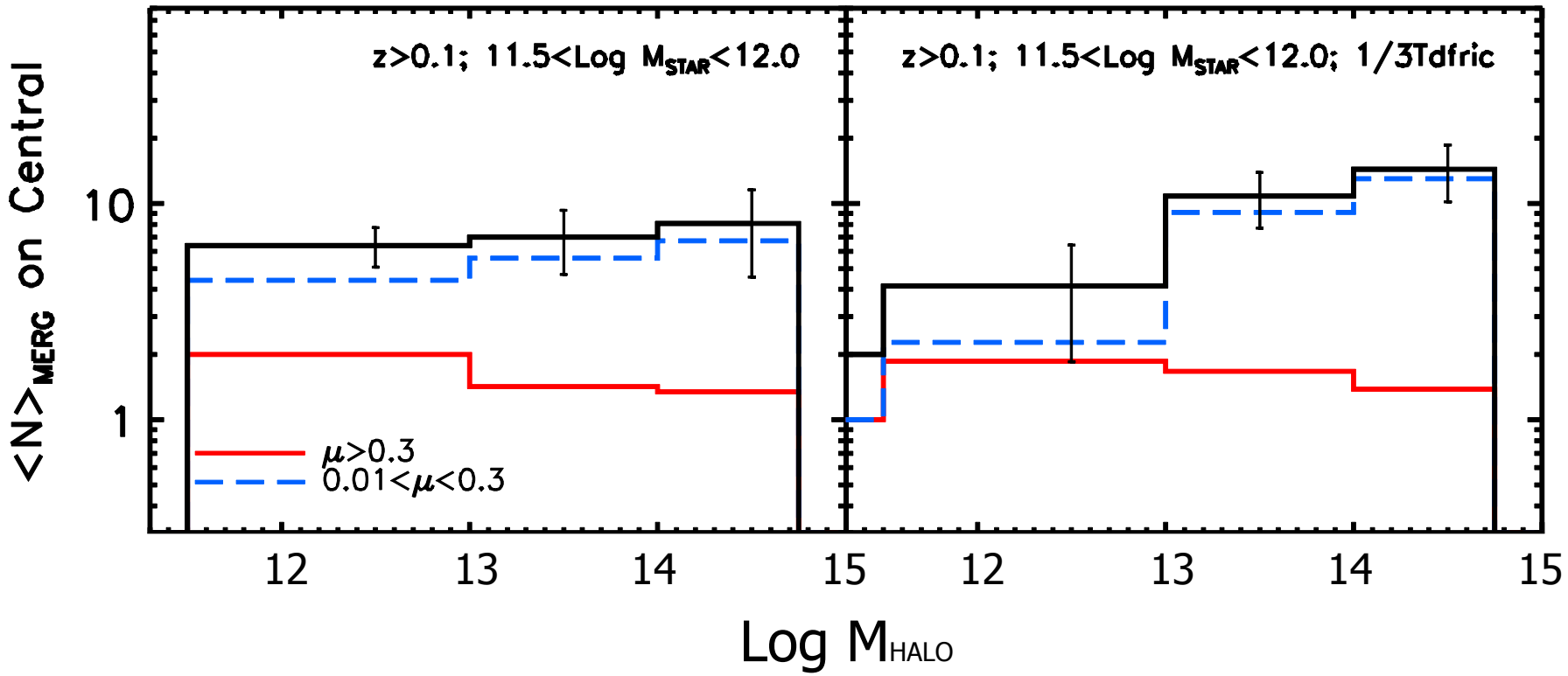
-1- Mergers
Why do some models show strong dependence?

Mergers at fixed stellar mass may not play much of a role…



Why do some models show strong dependence?

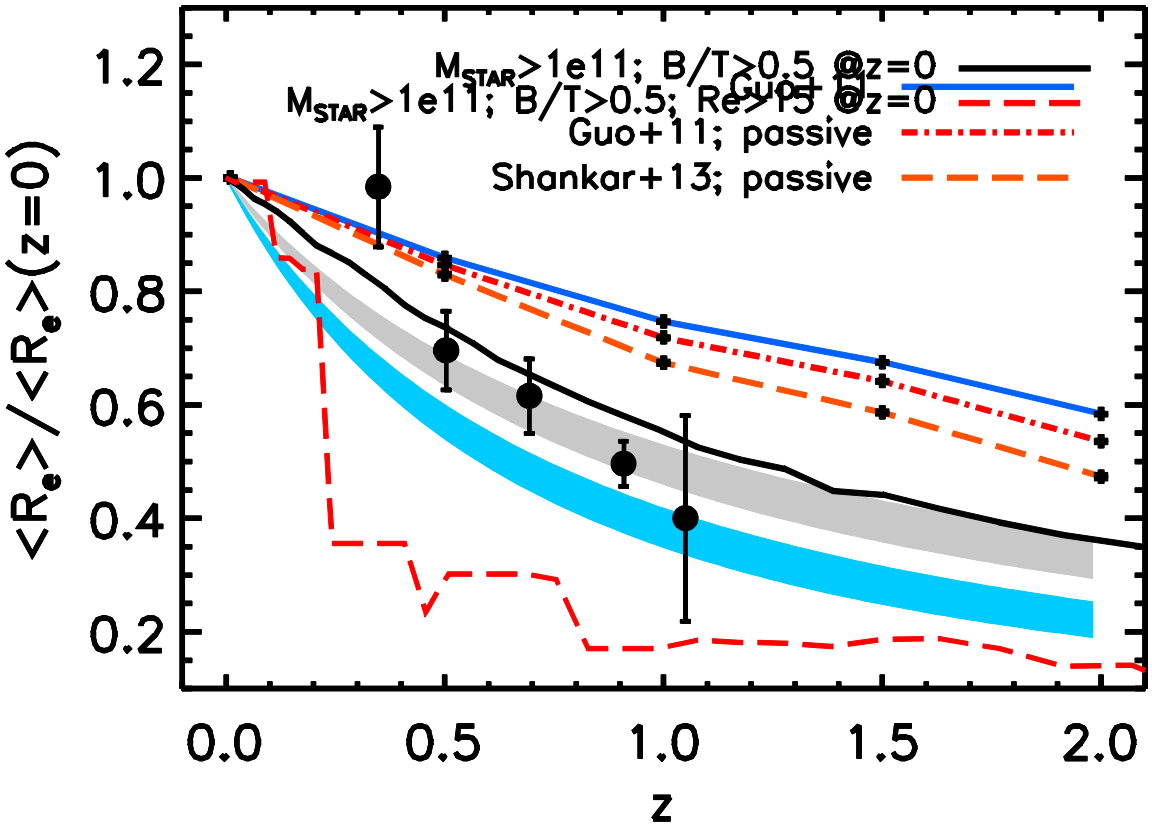
-1- Mergers

-2- Strong Disc Instabilities

-3- Gas dissipation in mergers

SIZE EVOLUTION: Strong, but no so strong...

see Buitrago, Johansson, Laporte, Puchwein, Stringer, van de Sande, ...

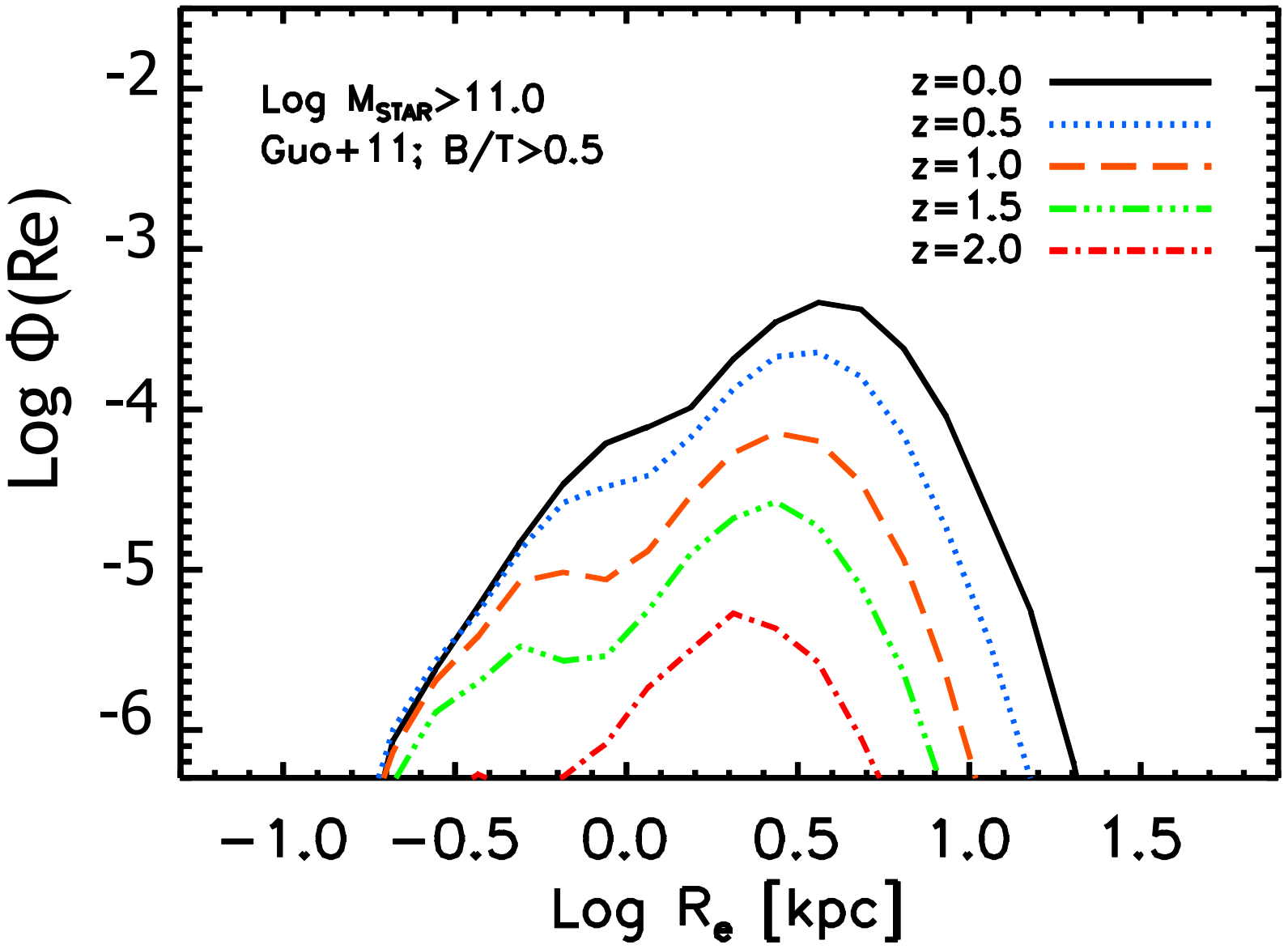


Size Evolution at fixed stellar mass is much weaker than observed...

FS et al. 13c, in prep.

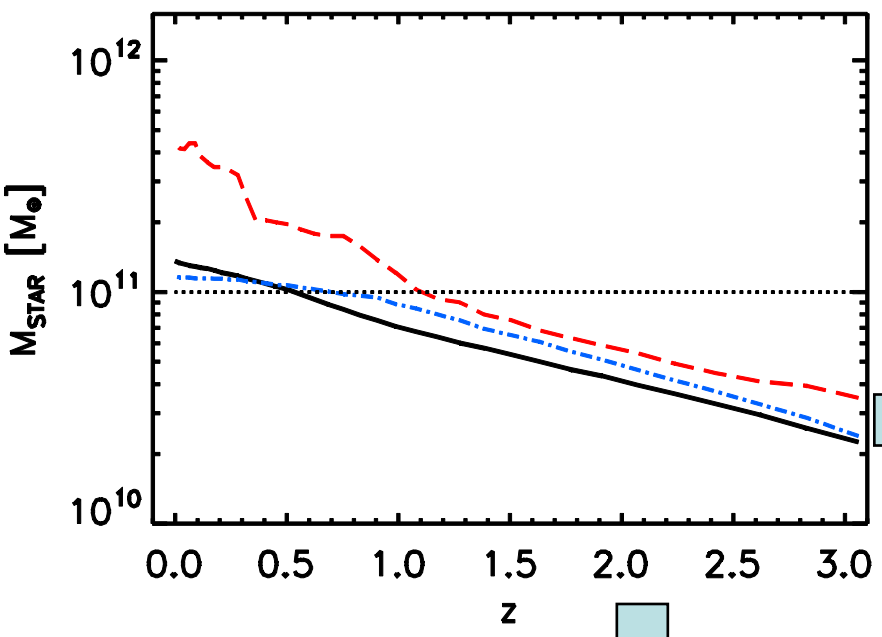
SIZE EVOLUTION: Progenitor Bias

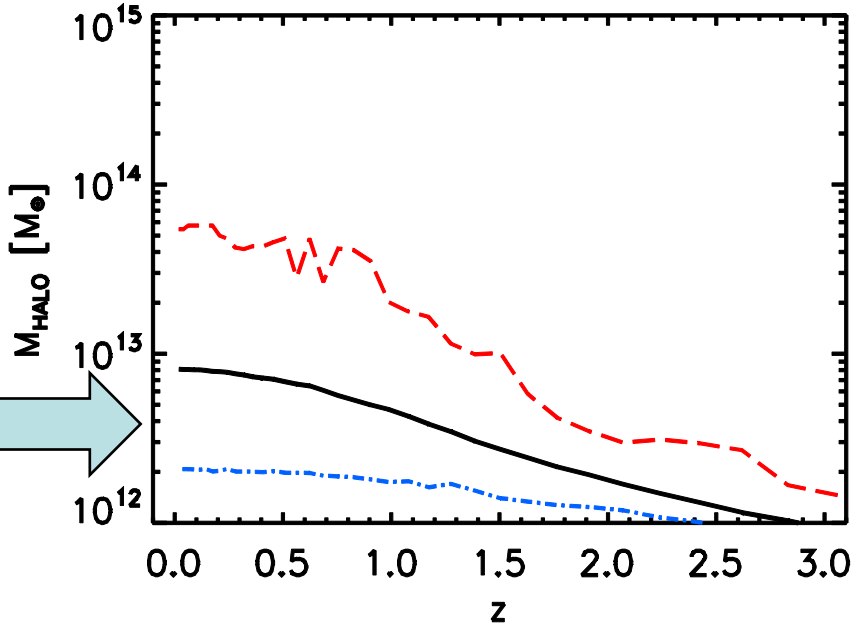
see Lopez-Sanjuan, Trujillo, …

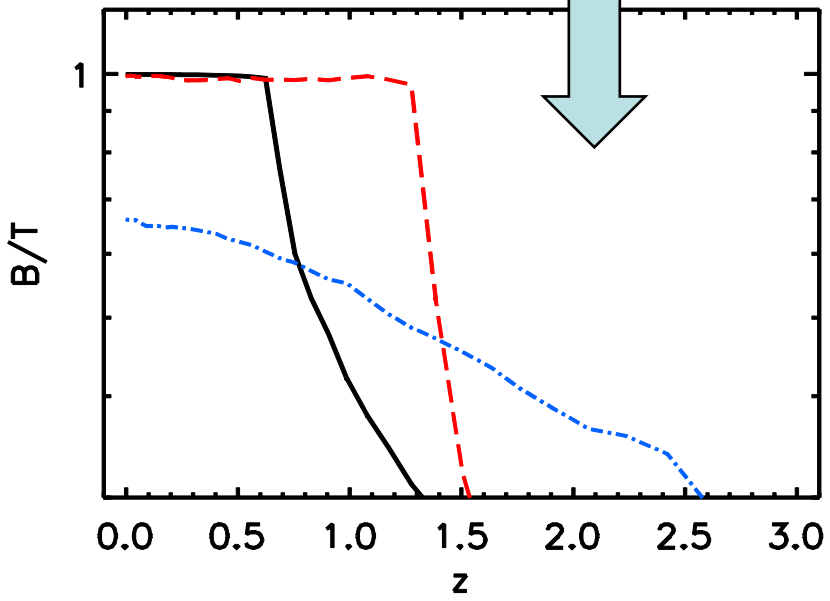


FS et al. 13c, in prep.

New bulge-dominated galaxies enter the selection via mergers and disc instab.



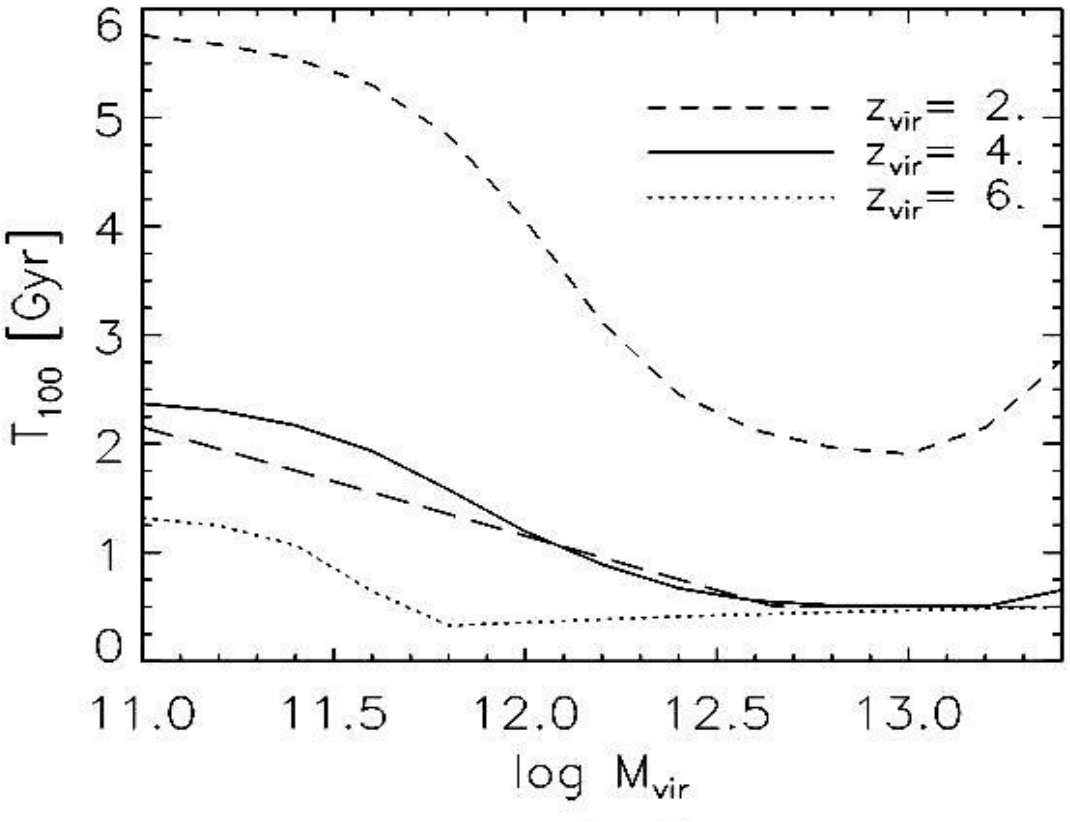




Monolithic vs Hierarchical:
Metallicity

Complementary to talk by R. Yates

Granato+04



<u>Short and intense</u>
bursts of star formation produce alpha enhancements
(in their model shut down via AGN feedback!)
Duration of 0.5 Gyr

see Maraston, Thomas, …

Monolithic vs Hierarchical:
Central Black Holes

…TO FURTHER COMPLICATE THE WHOLE PICTURE, CLEAR EVIDENCE OF MASSIVE DARK OBJECTS AT THE CENTER OF MOST BULGED LOCAL GALAXIES

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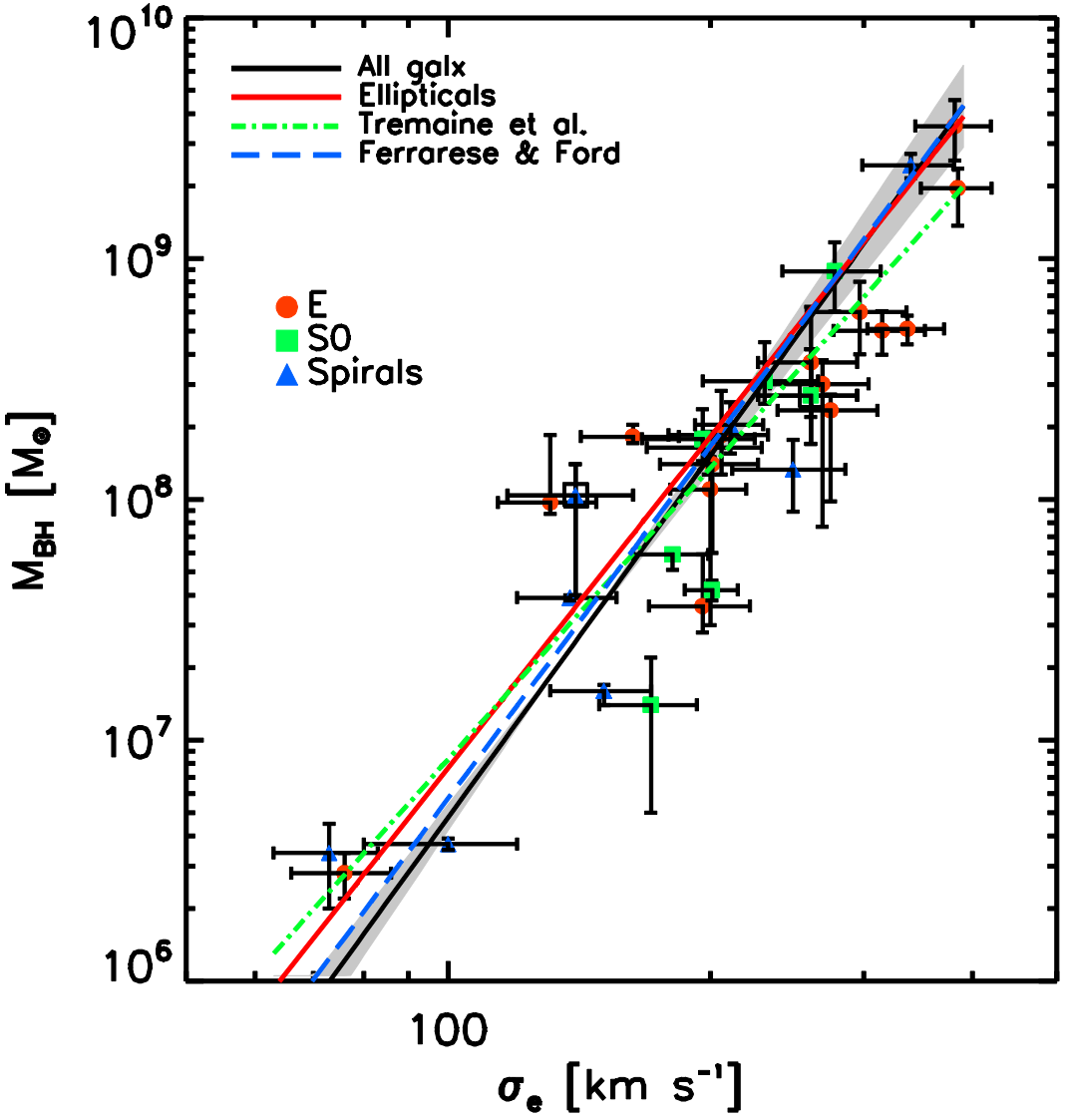

STRONG CONNECTION BETWEEN BH MASS AND HOST GALAXY PROPERTIES; PARTICULARLY IN MASSIVE SPHEROIDS!

FS, Ferrarese et al. 2013, to be submitted

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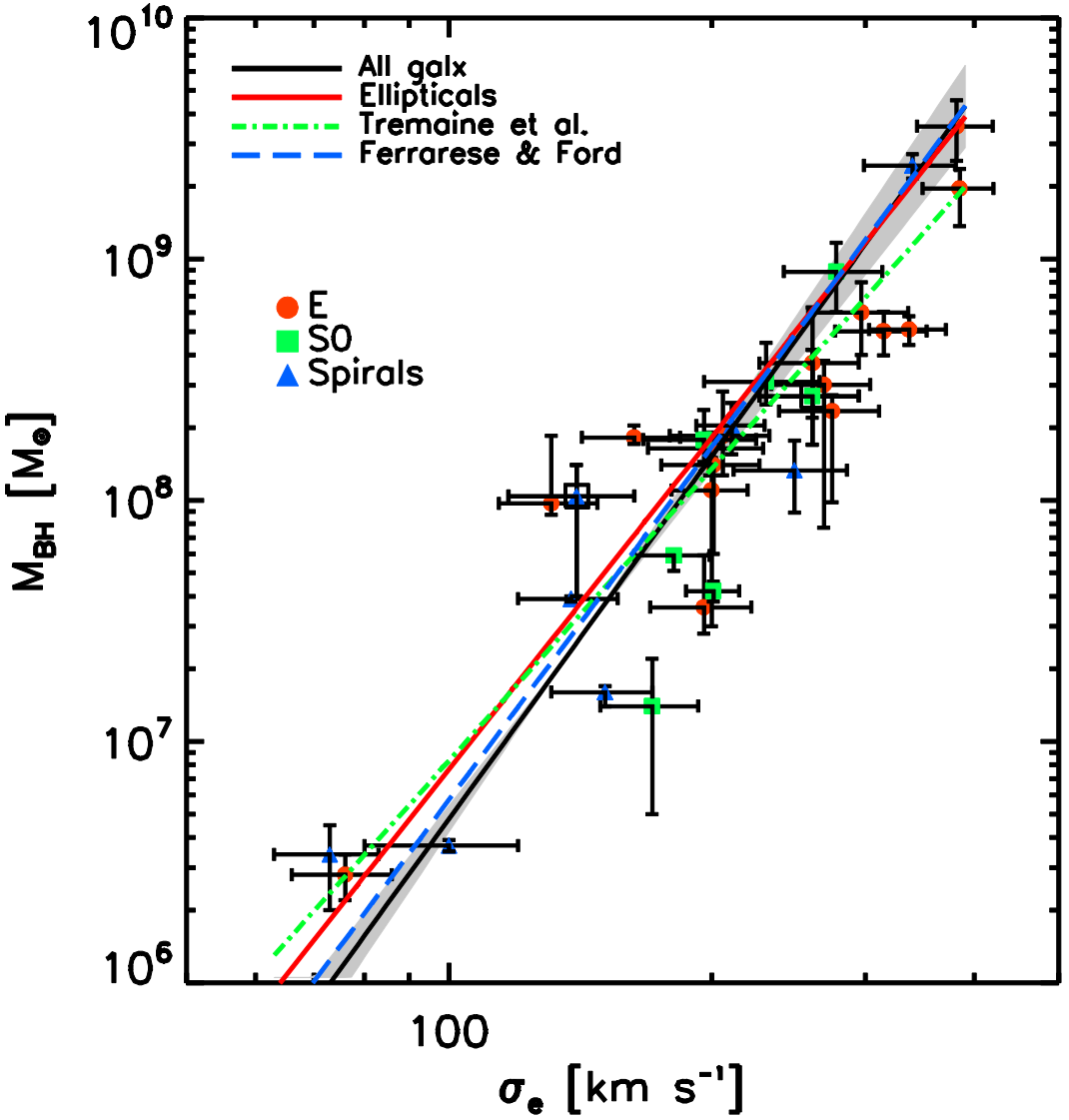
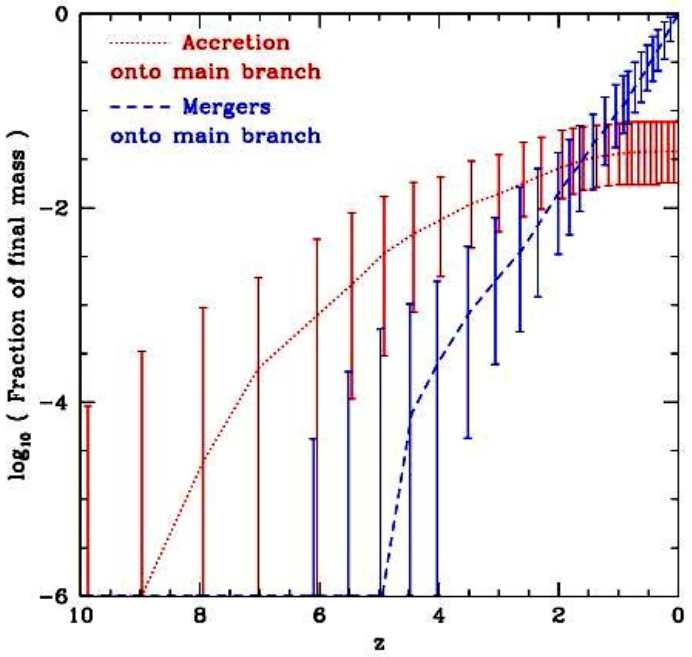


STRONG CONNECTION BETWEEN BH MASS AND HOST GALAXY PROPERTIES; PARTICULARLY IN MASSIVE SPHEROIDS!

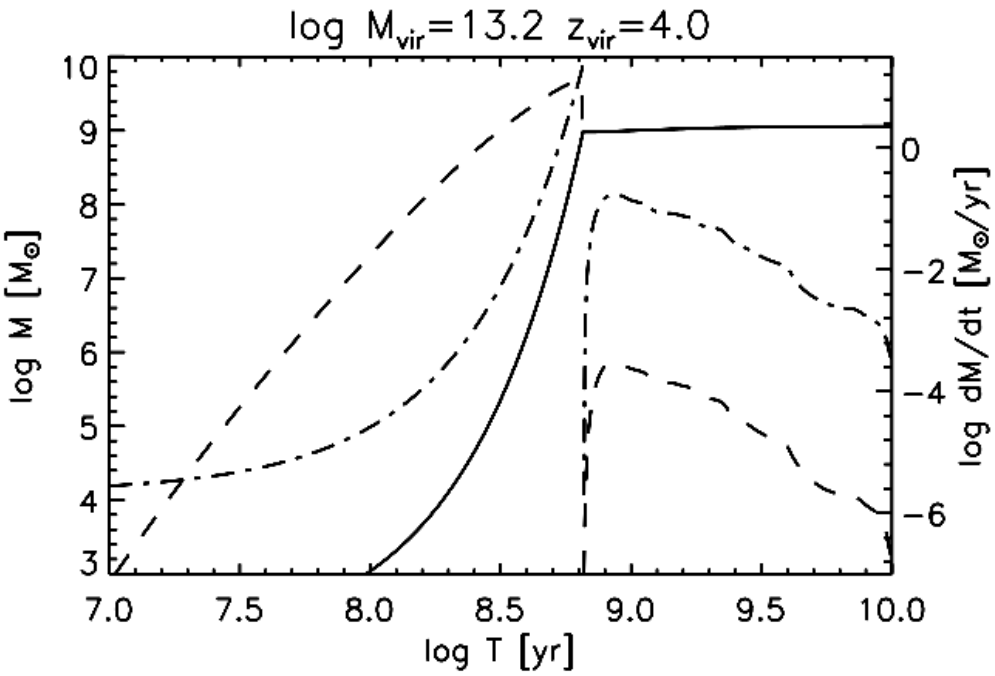
WHATEVER YOUR FAVOURITE MODEL FOR BULGES IS, IT MUST ACCOUNT FOR THE EXISTENCE OF HIGHLY CORRELATED BHS!!

FS, Ferrarese et al. 2013a, to be submitted

AGAIN, STRONG DENERACIES IN MODELS



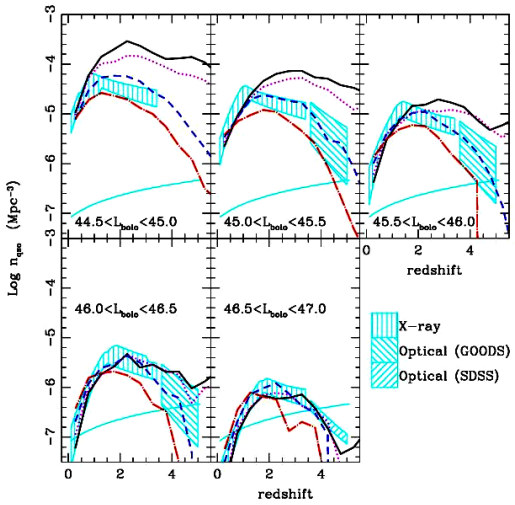
Malbon et al.



Lapi, FS, et al.

``our knowledge on the physics of accretion onto BHs and their interaction with galaxies is still poor to draw firm conclusions''

Fontanot et al.



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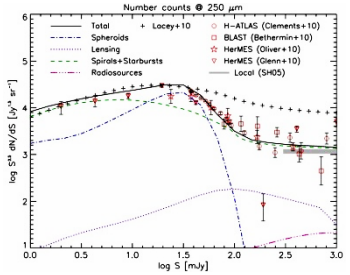

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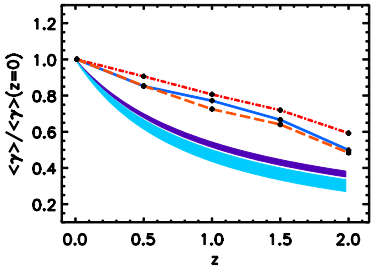

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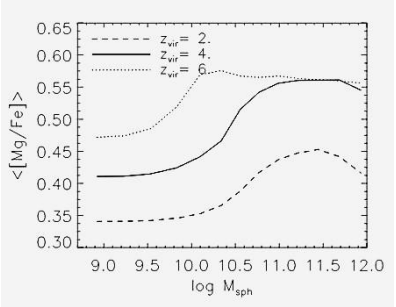

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