The connection between halos and galaxy structural properties

rachel somerville
Rutgers University &
Center for Computational Astrophysics,
Flatiron Institute

flat
rotation dominated
~half SF, half Q
some cold gas

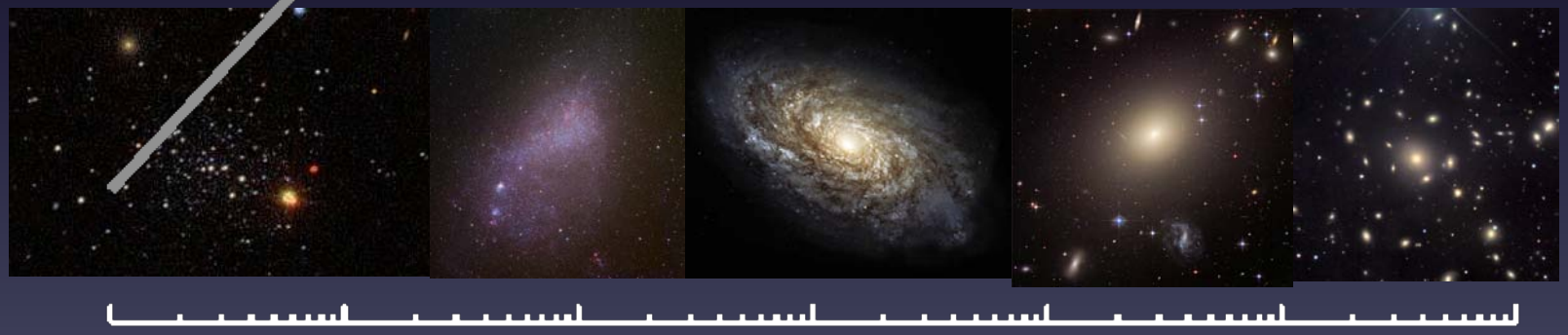
flat
rotating
SF
gas rich

round
very little rotation
quiescent
little cold gas

intrinsic
scatter
<0.16 dex
(Tinker +2017)

M_*/M_h

?



10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15}

halo mass (M_{sun})

open questions

- why do we see a trend between galaxy (halo) mass and galaxy structural/kinematic properties?
- what is the origin of the dispersion in galaxy structural properties at fixed stellar/halo mass?
- what halo property is most predictive of galaxy structural properties?
- (how) is m_*/M_h correlated with galaxy structural parameters?

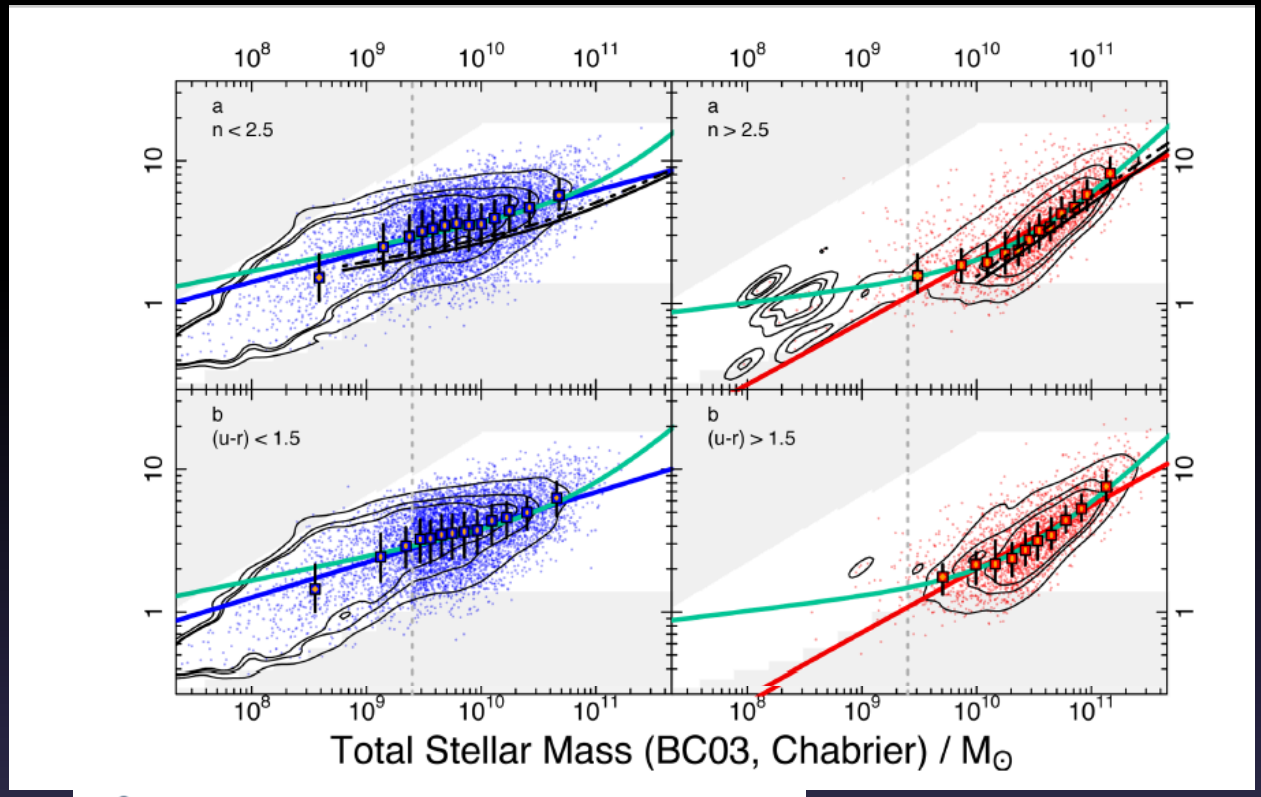
observed size-mass relation at z~0

disks

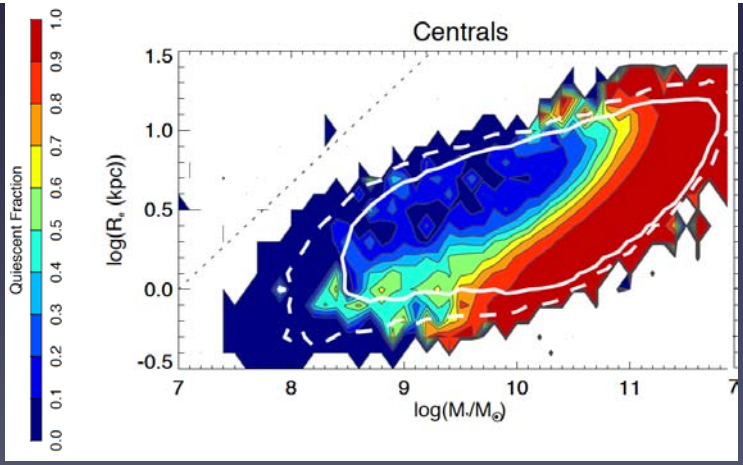
blue/
SF

spheroids

red/
quiescent

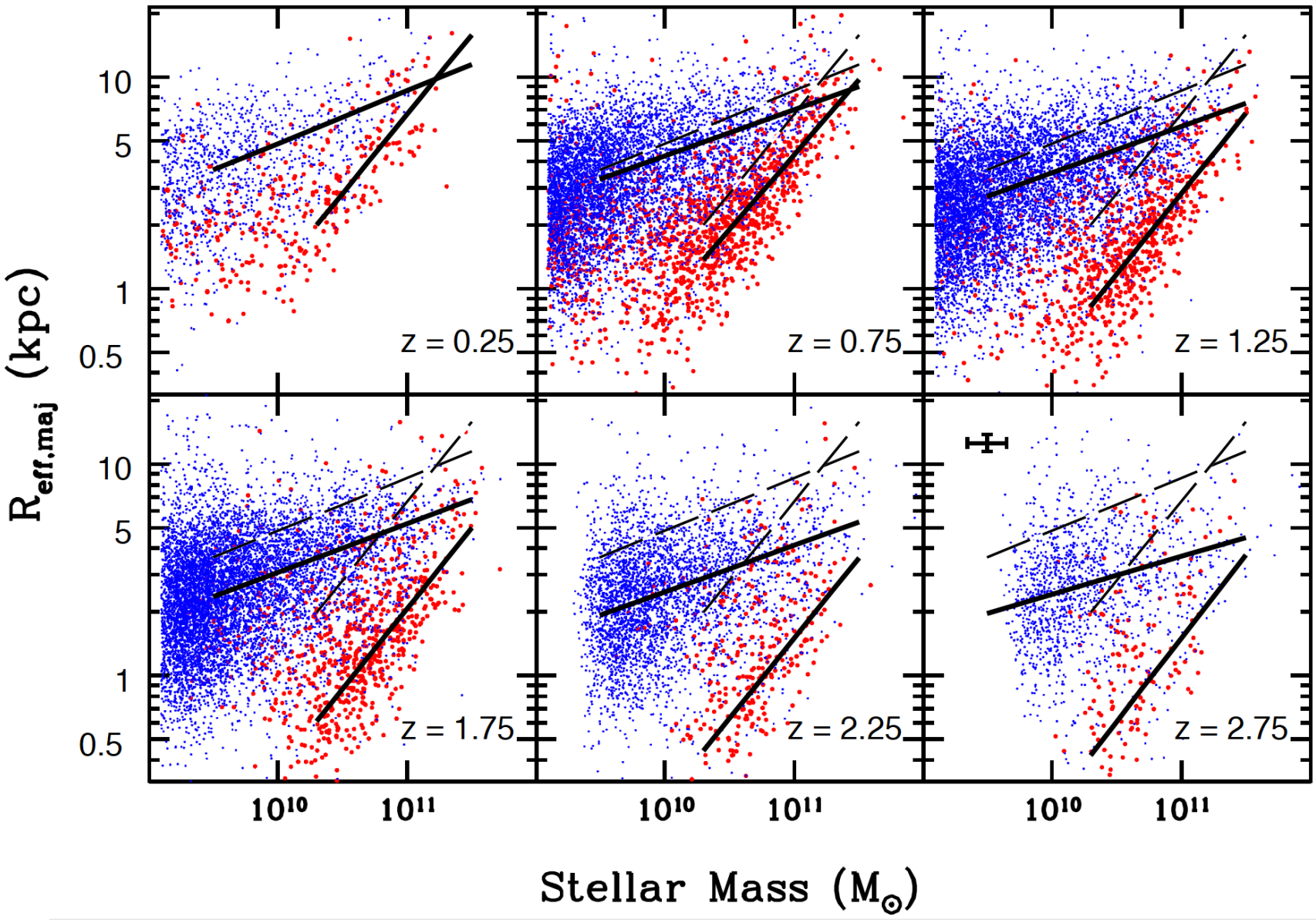


Lange et al. 2014



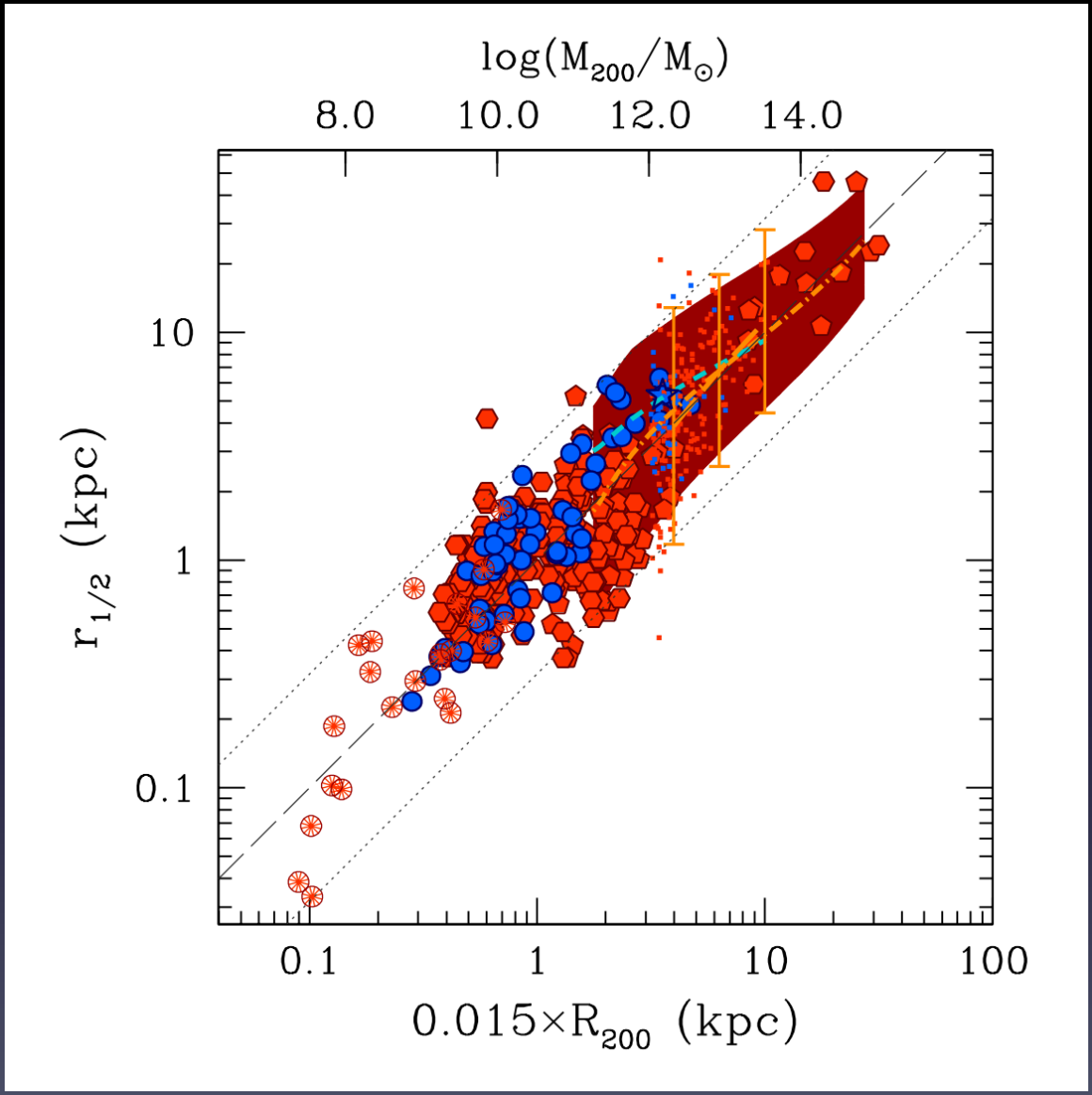
Omand et al. 2014

size mass relation evolution for star forming and quiescent galaxies



van der Wel et al. 2014

the stellar radius halo radius connection



galaxy radius is proportional to halo radius over almost 3 orders of magnitude!
~independent of galaxy type

Kravtsov 2013
see also Shibuya et al. 2015
Huang et al. 2017

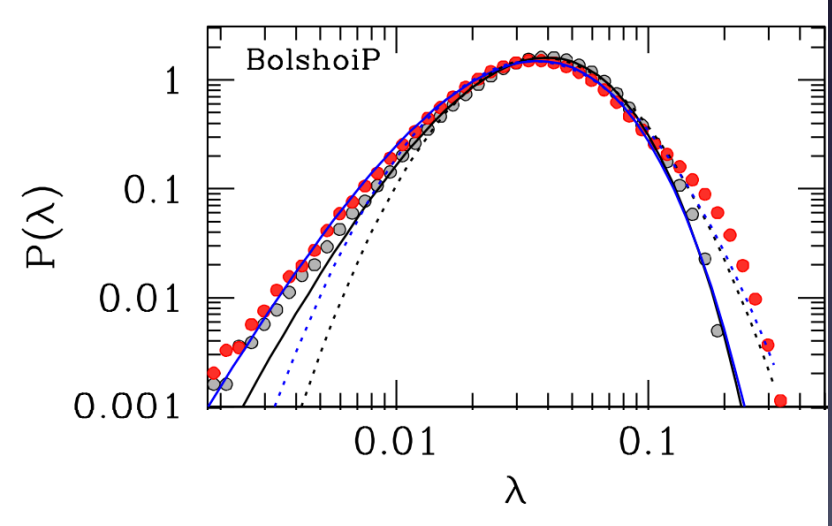
Halo Spin

Peebles definition

$$\lambda_{\rm P} = \frac{J|E|^{1/2}}{GM_{\rm vir}^{5/2}},$$

Bullock definition

$$\lambda_{\rm B} = \frac{J}{\sqrt{2}M_{\rm vir}V_{\rm vir}R_{\rm vir}},$$



distribution is close to log-normal
Peebles and Bullock definitions at z=0 are v. similar – but they evolve somewhat differently with cosmic time.

dotted=lognormal

Rodriguez-Puebla et al. 2015

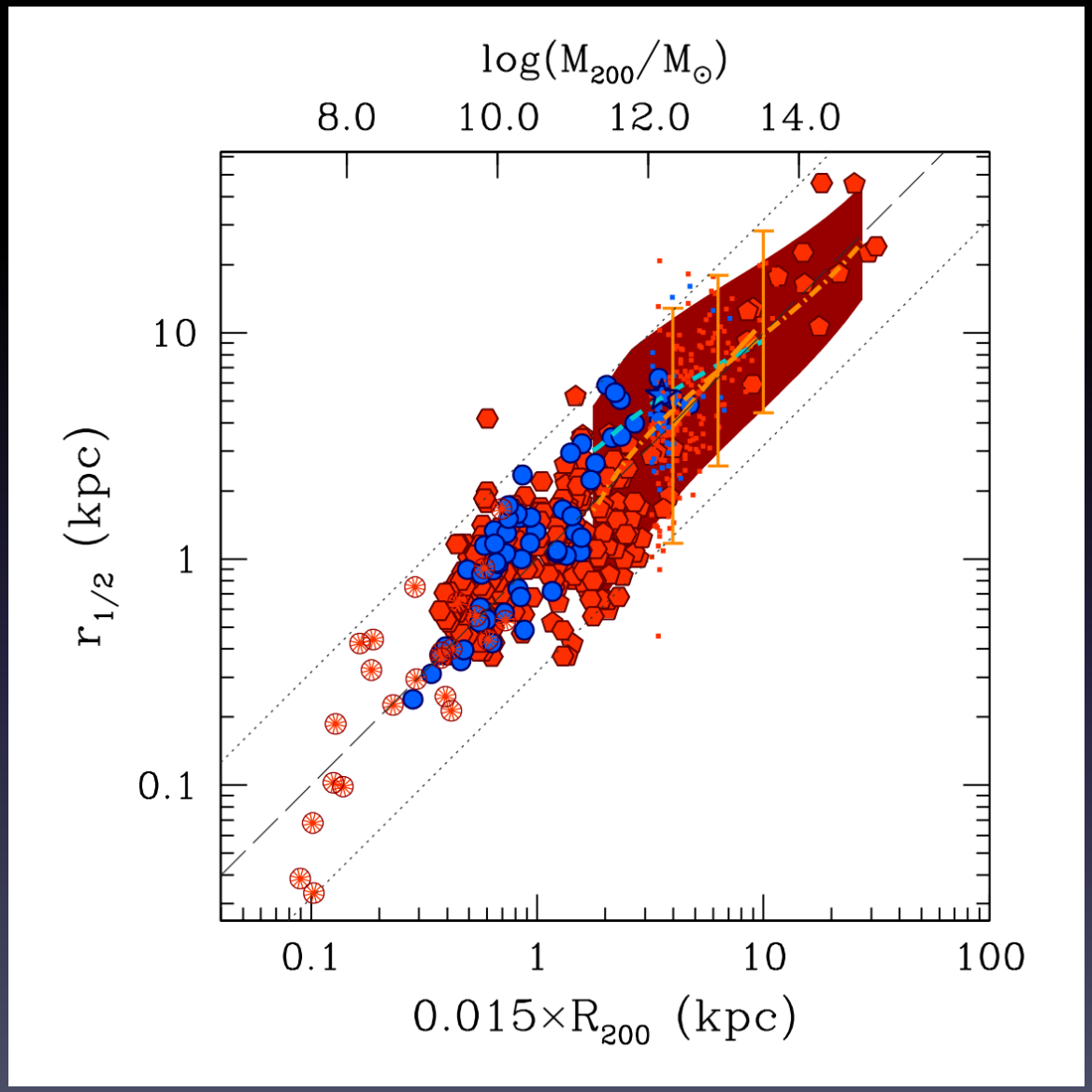
angular momentum partition ansatz

$$r_d \sim \lambda R_H f(c, \lambda, f_d)$$

- smoothly accreted gas ~ conserves its specific angular momentum
- disks form with exponential radial profiles
- density profile may get modified a bit by 'baryonic contraction' (or expansion!)

Blumenthal et al. 1986
Dalcanton et al. 1997
Mo, Mao & White 1998
Somerville et GEMS 2008
Dutton et al. 2011

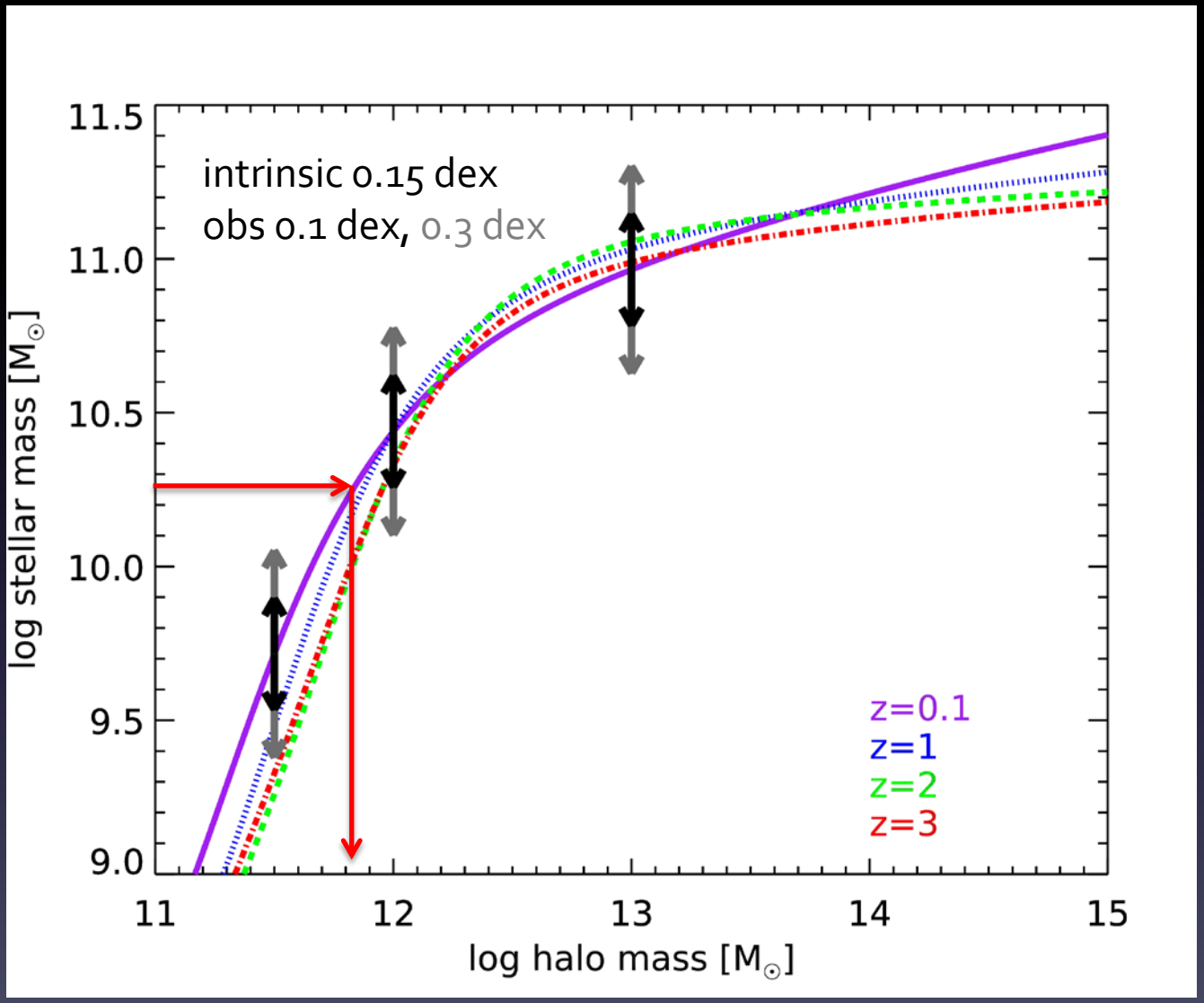
adopted in many/most SAMs



dispersion in galaxy size is similar to dispersion in halo spin parameter

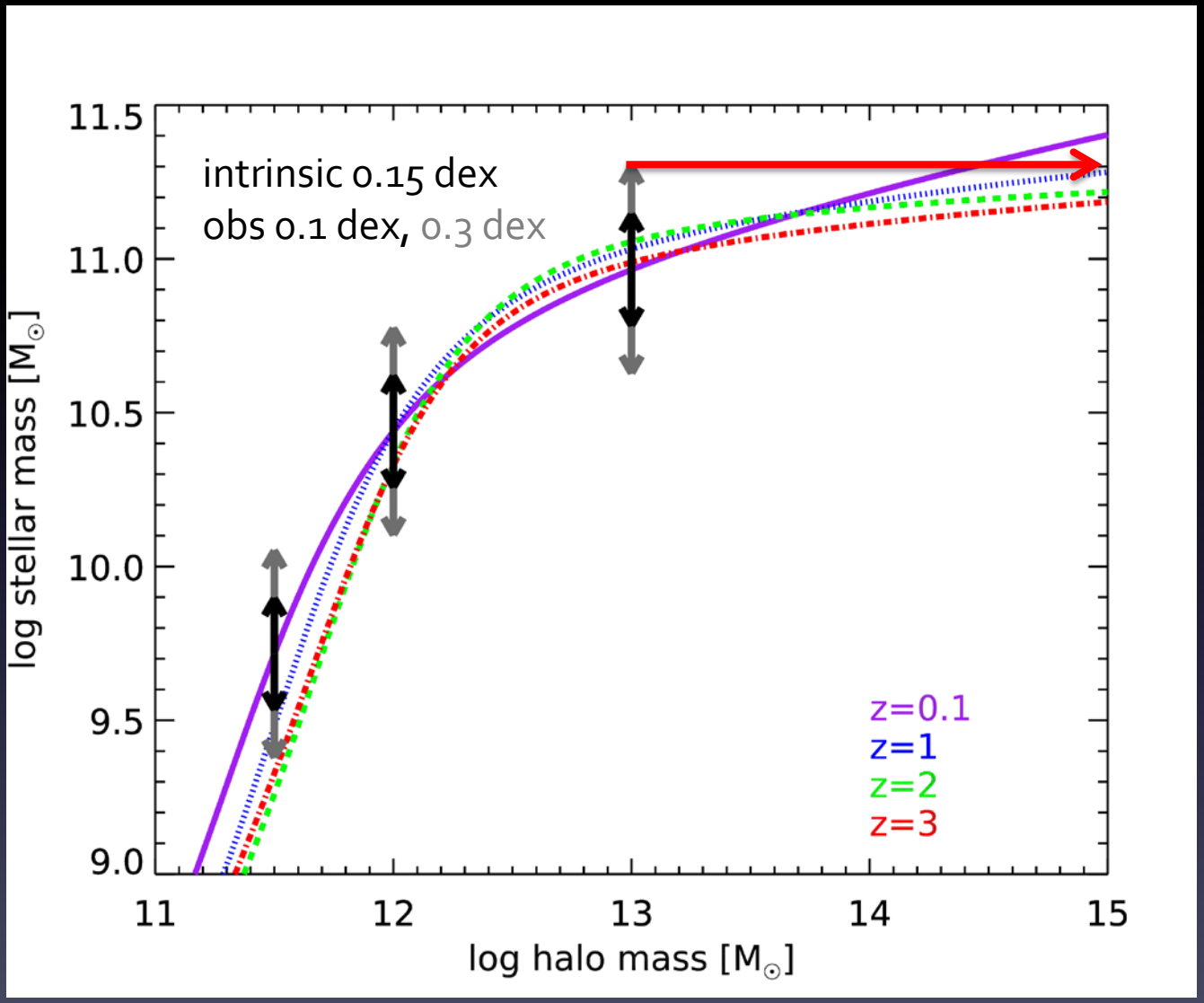
Kravtsov 2013

backwards modeling



SMHM relation from Behroozi et al. 2013

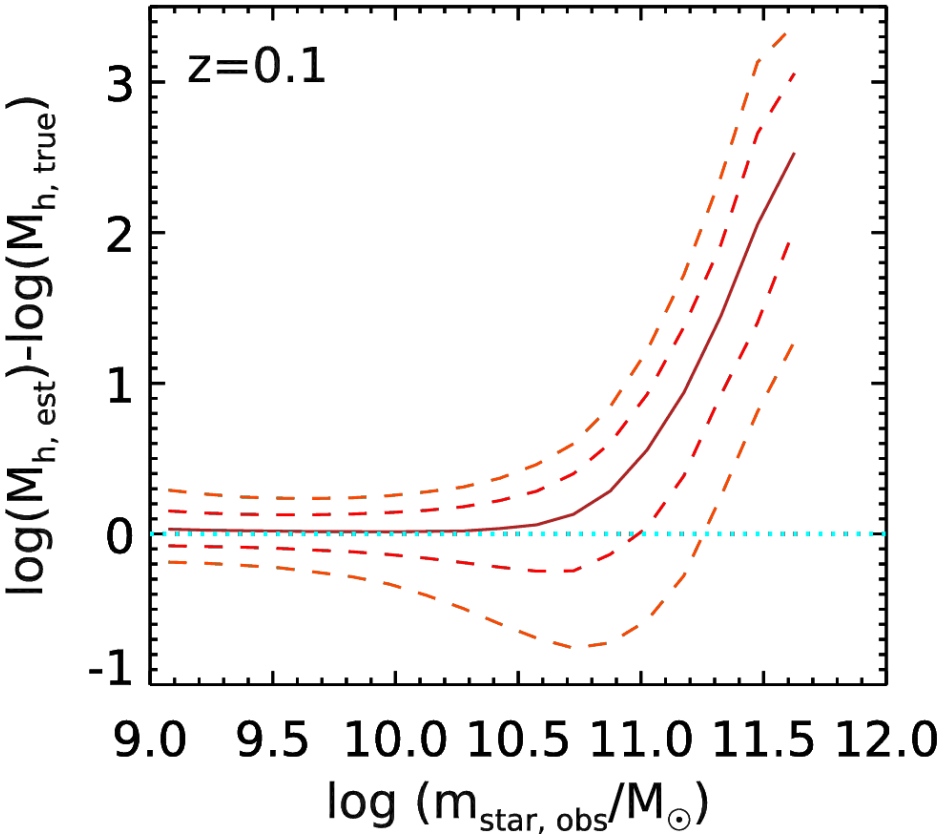
beware backwards modeling!



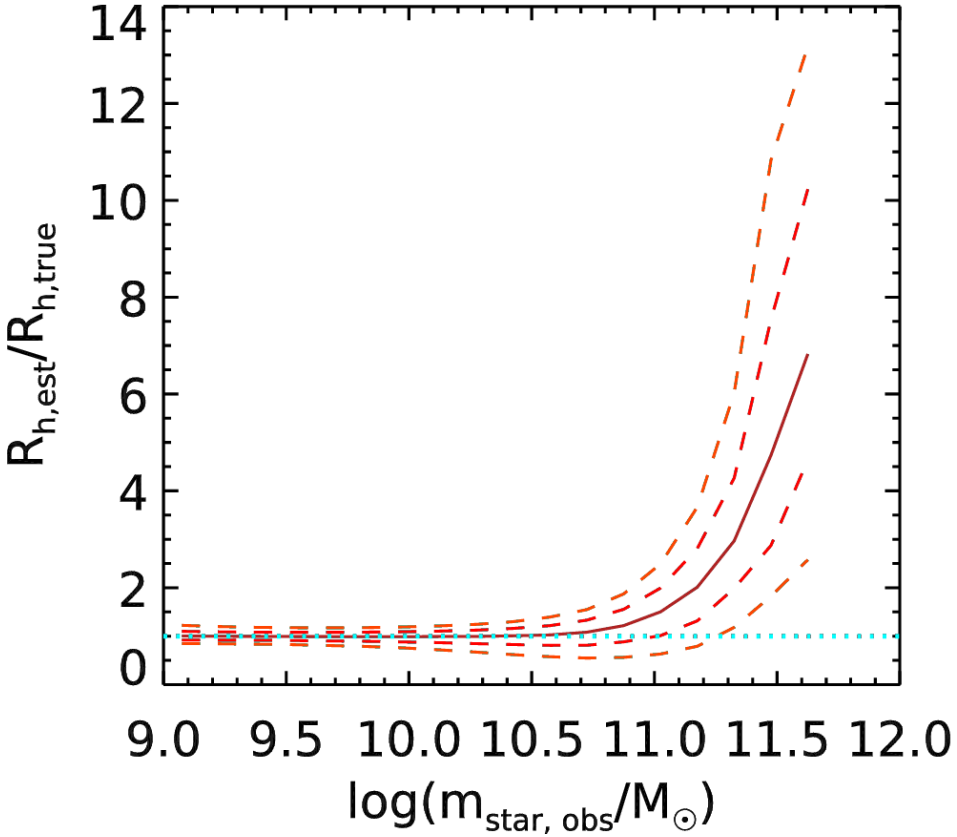
SMHM relation from Behroozi et al. 2013

‘backwards modeling’ applied to a SHAM mock catalog with scatter

bias in estimated halo mass

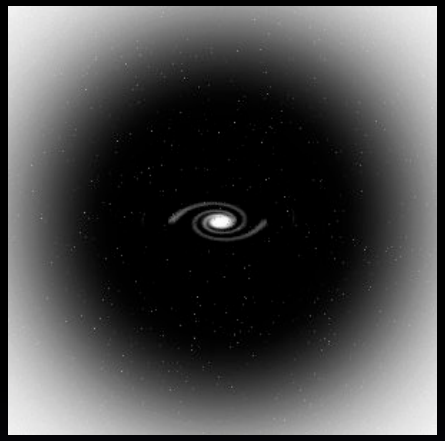


bias in estimated halo virial radius



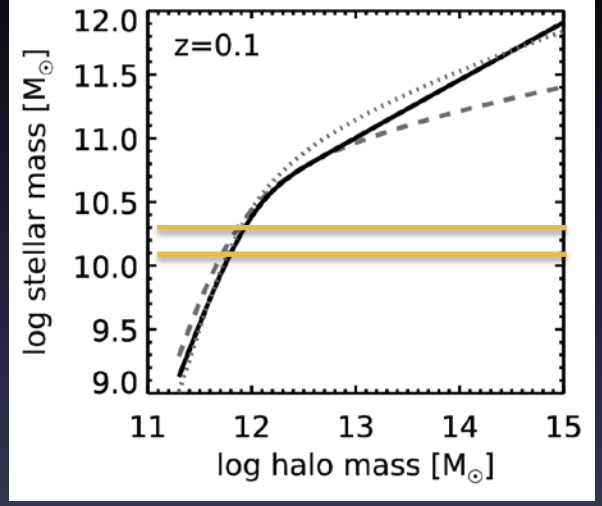
rss et al. 2017

intrinsic scatter 0.15 dex
observational scatter 0.1 dex
Behroozi et al. 2013 SMHM relation

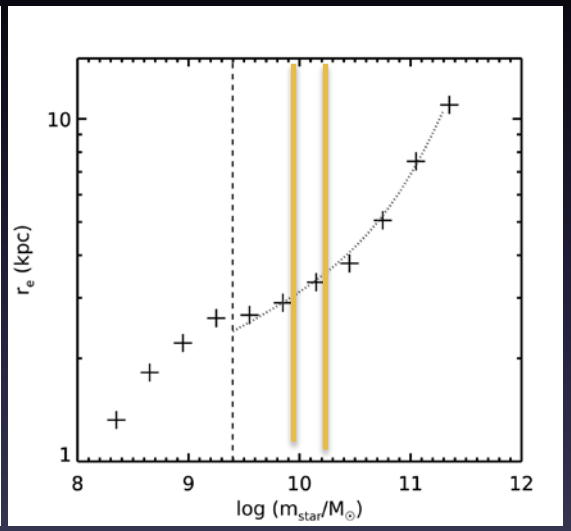


Bolshoi-Planck halo catalog contains halo & sub-halo masses, spin parameters, and radii

Introducing the 'forward modeling' approach



assign stellar masses to halos (including scatter & errors)



compare $\langle R_h \rangle$ or $\langle \lambda R_h \rangle$ for halos with observed radii for galaxies in a stellar mass bin

$$\mathrm{SRHR} = \frac{\langle r_e(m_*) \rangle}{\langle R_h(m_*) \rangle}$$

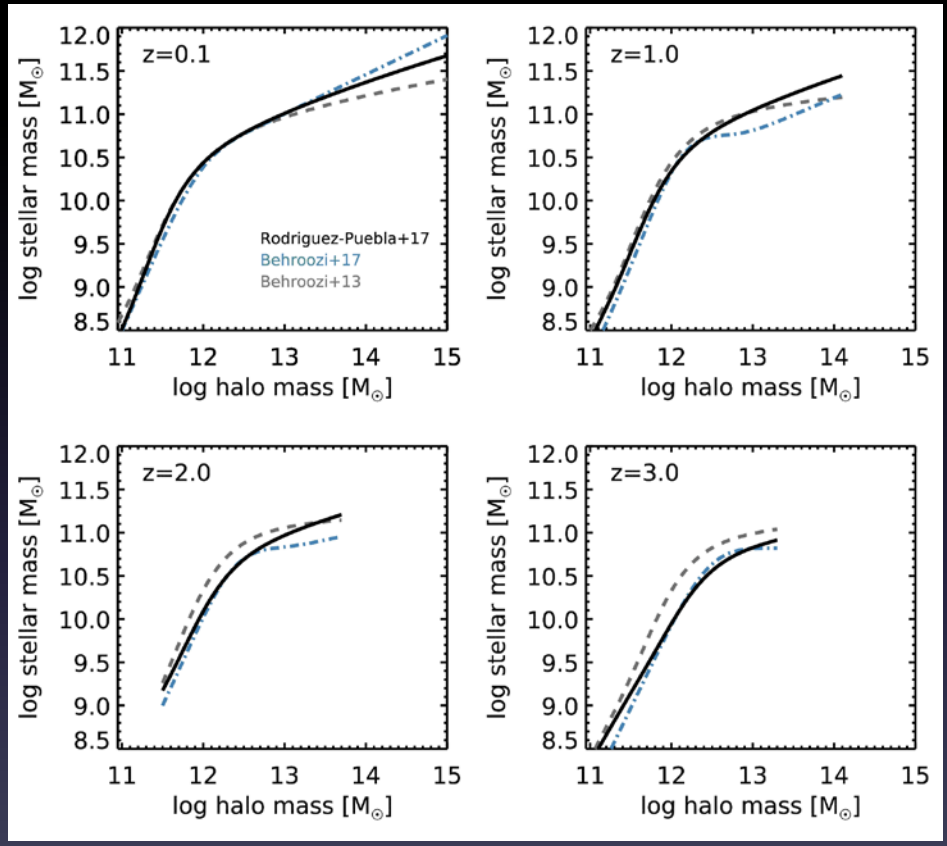
$$\mathrm{SRHR}\lambda = \frac{\langle r_e(m_*) \rangle}{\langle \lambda R_h(m_*) \rangle}$$

(in what follows, angle brackets denote medians)

rss et al. arXiv:1701.03526

simulations & SHAM

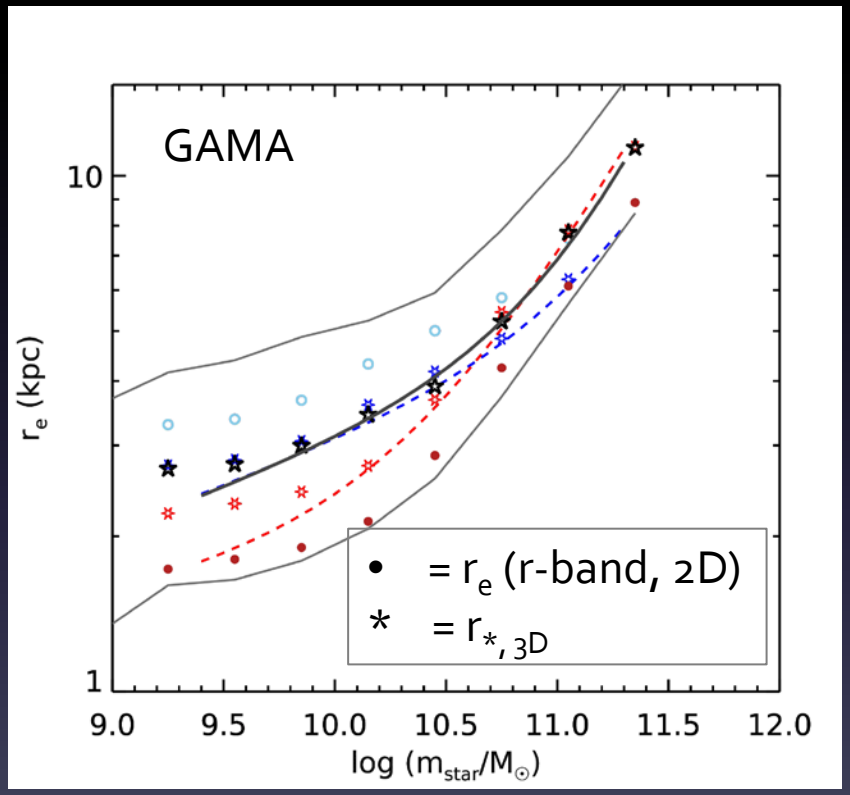
- Bolshoi-Planck N-body simulations (Rodriguez-Puebla et al. 2015)
- ROCKSTAR (sub-)halo catalogs (Behroozi et al. 2013)
- SHAM from Rodriguez-Puebla et al. (2017) – includes dispersion in SMHM relation



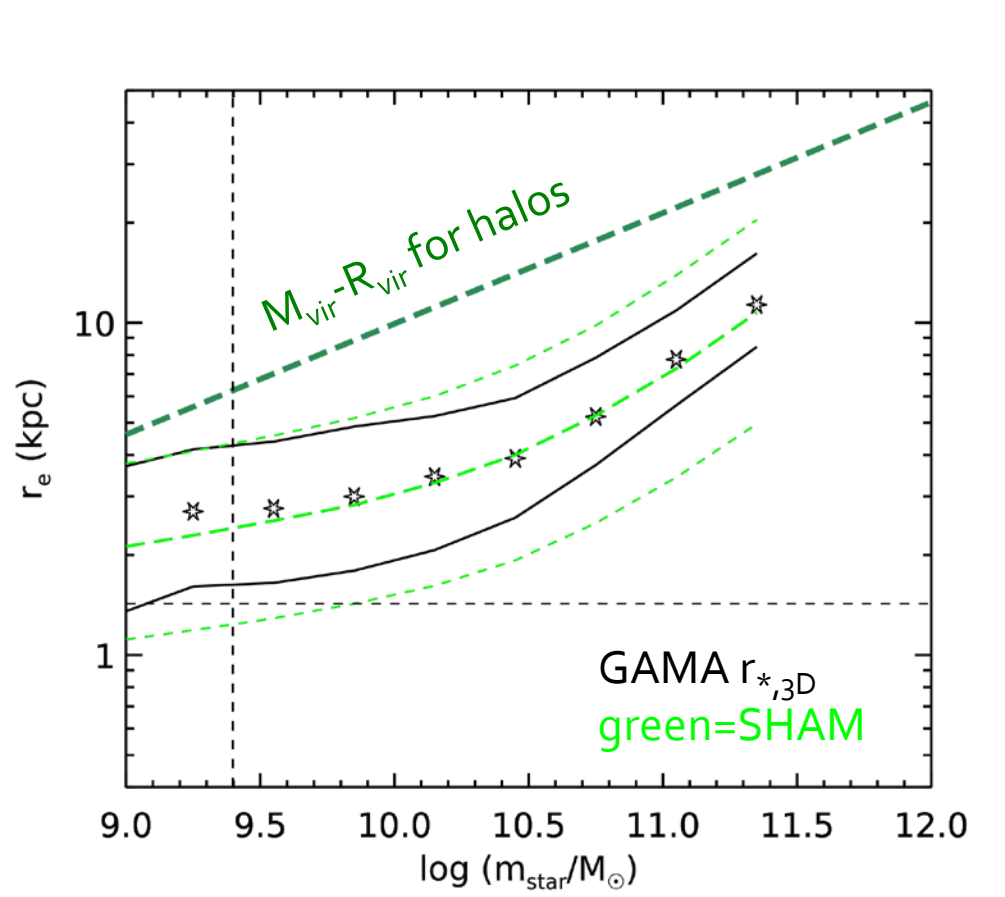
rss et al. arXiv:1701.03526

observations

- GAMA (DR2; Liske et al. 2015) (r<19.8; 144 deg. sq.; 0.01<z<0.12)
- CANDELS (Koekemoer et al. 2011; Grogin et al. 2011) H_{160}<24.5; 0.1<z<3)
- single component Sersic fits to light profiles (r_e, n_s)
- type-dependent conversion from 2D half-light to 3D half stellar mass radii



we do not attempt to split by galaxy type in our analysis

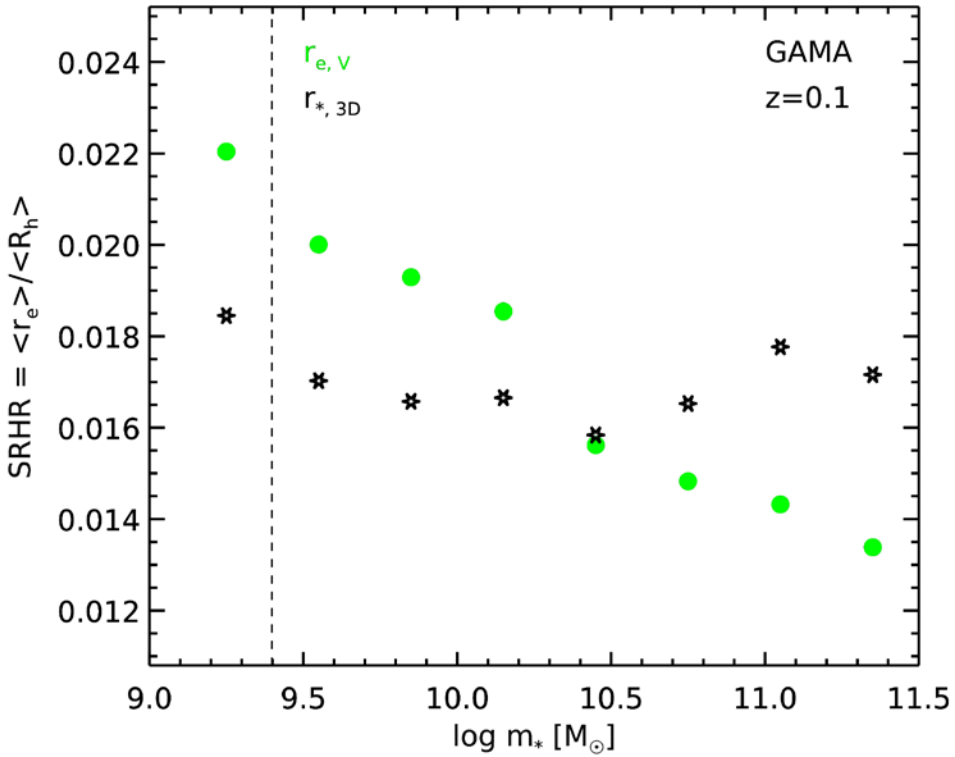


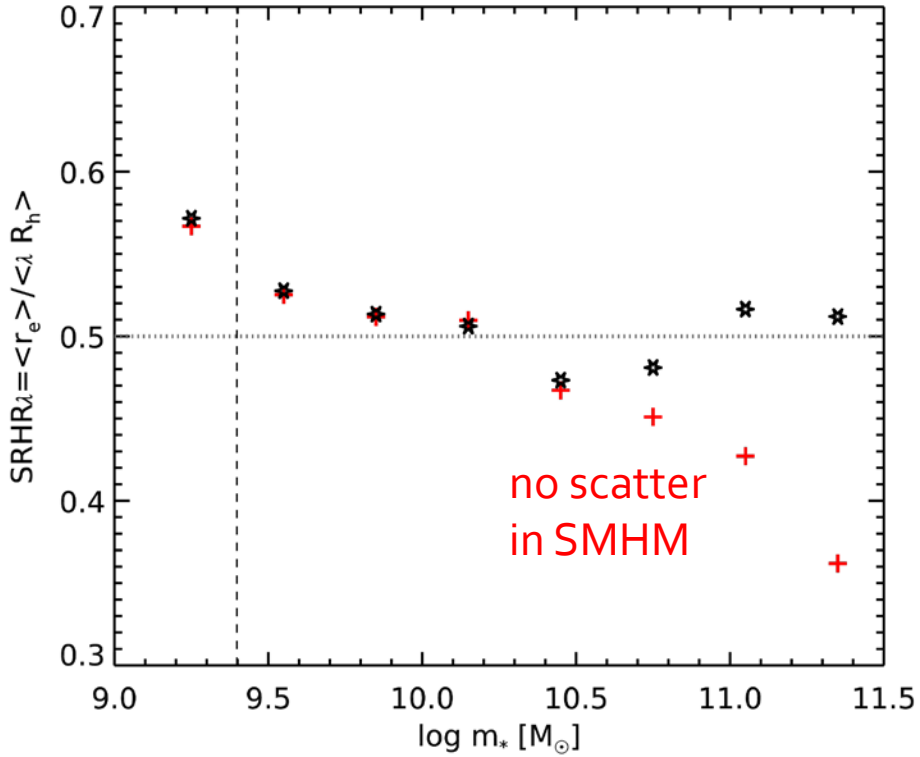
using a constant value of SRHR=0.018 or SRHRλ=0.5, the slope of the size-mass relation appears to be beautifully reproduced by the SHAM!

lines show 16th & 84th percentiles in r_e or λR_h

rss et al. 2017

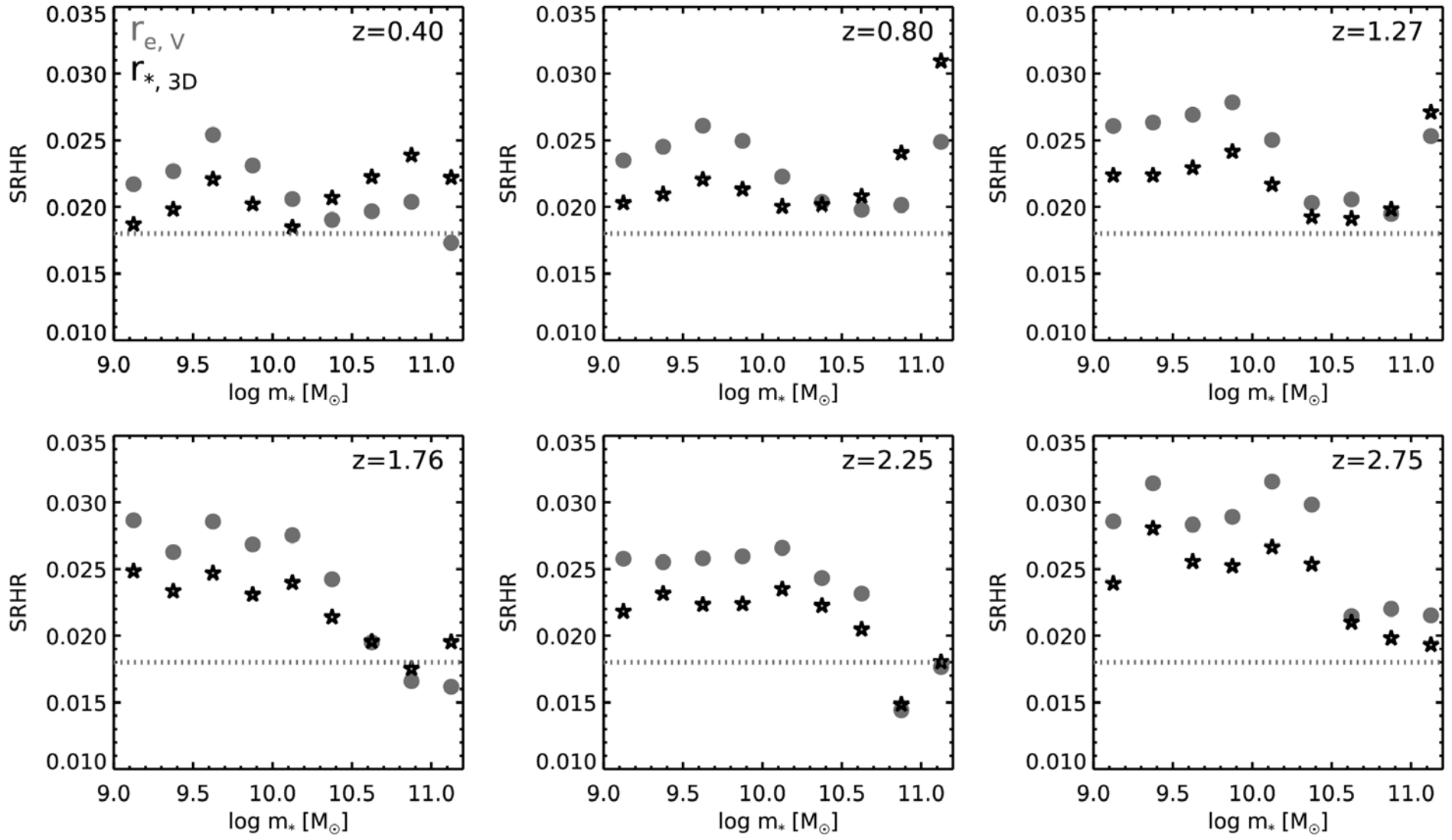
surprisingly, SRHR and SRHRλ have no significant stellar mass dependence across a range of bins mostly populated by SF disk-dominated galaxies to mostly quiescent spheroid-dominated galaxies





rss et al. 2017

at high redshift, the stellar mass dependence appears stronger, with massive galaxies having lower values of SRHR. SRHR has decreased slightly over time for lower masses



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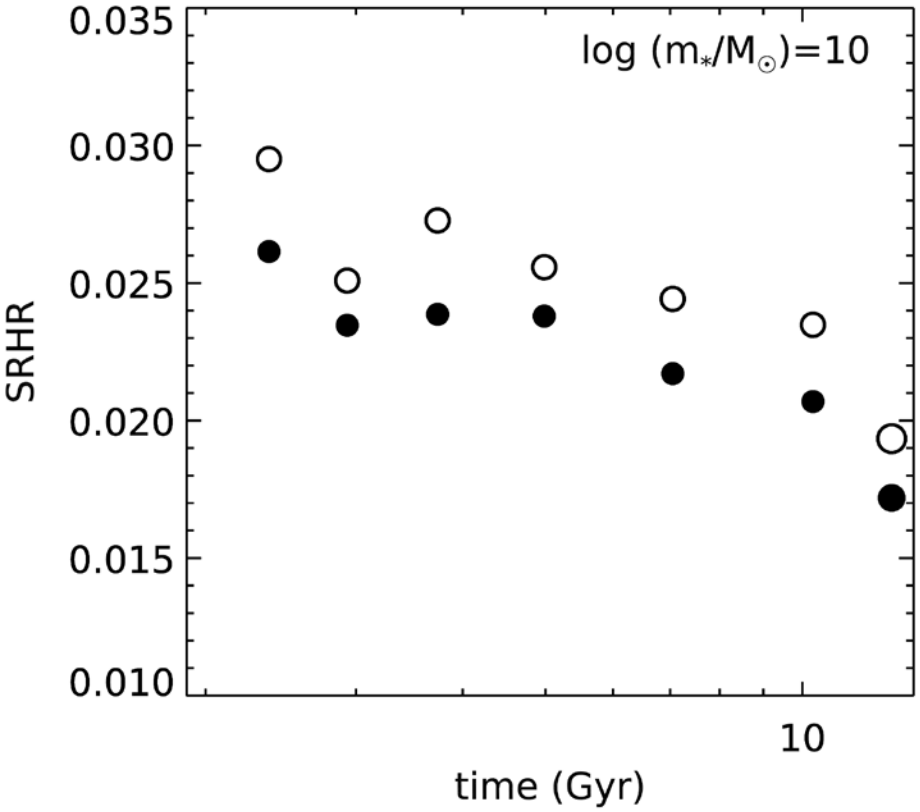
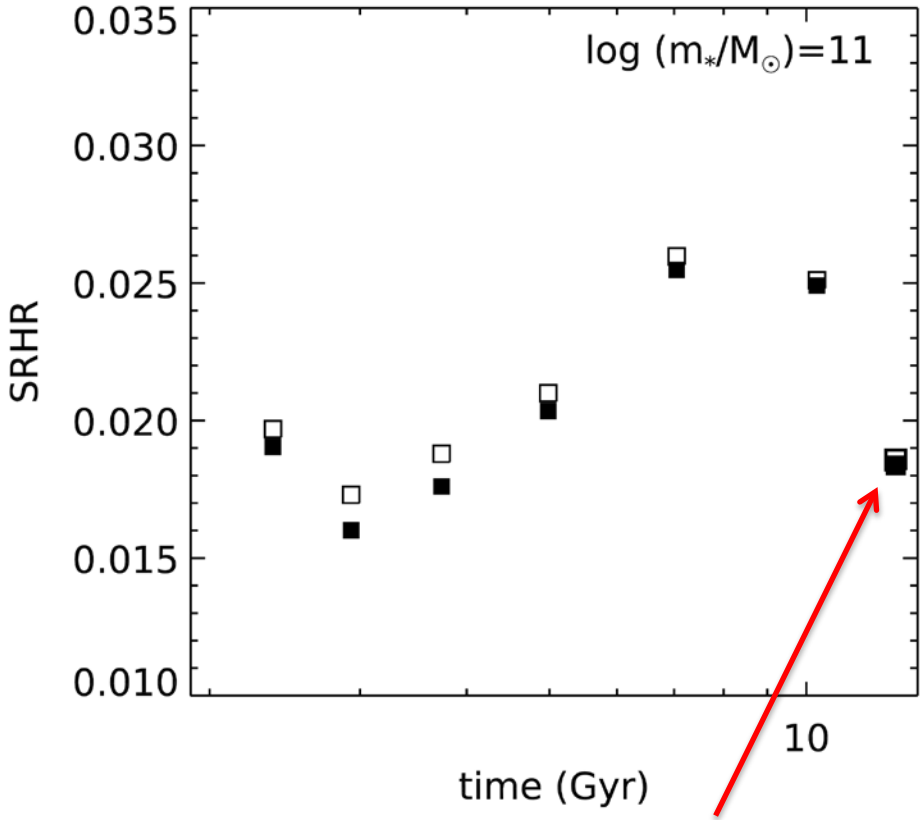
mild decrease for low-mass galaxies

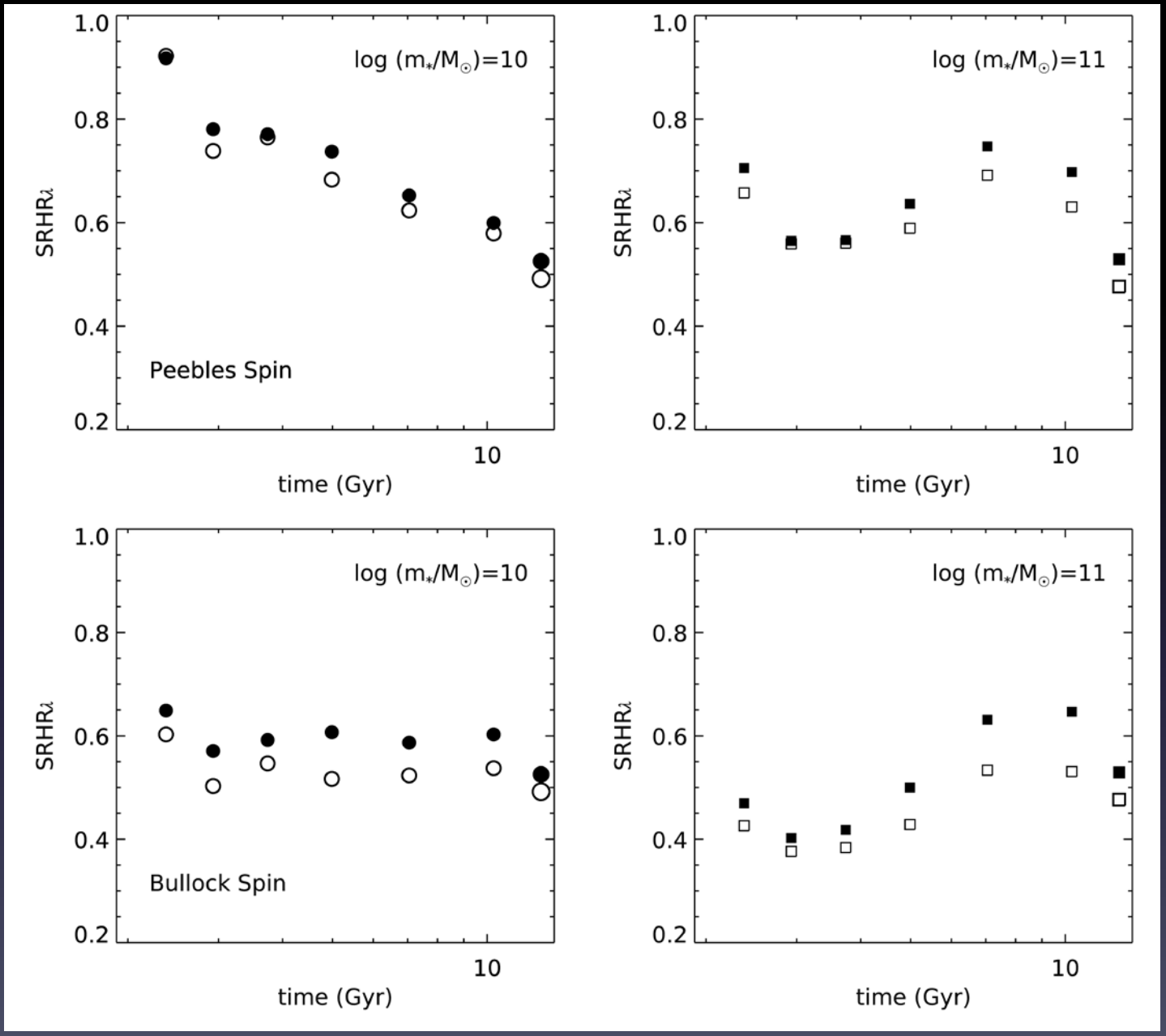
mild increase for massive galaxies



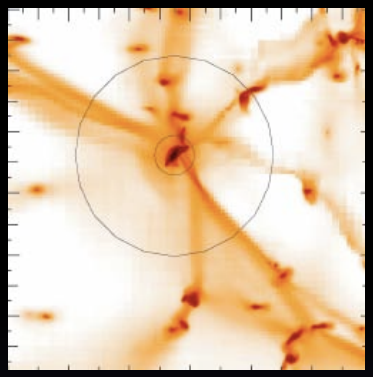


sizes underestimated due to extended light/second component?

rss et al. 2017


log (m*/M⊙)=10
log (m*/M⊙)=11
Peebles Spin
Bullock Spin
SRHRλ
time (Gyr)
1.0
0.8
0.6
0.4
0.2
10

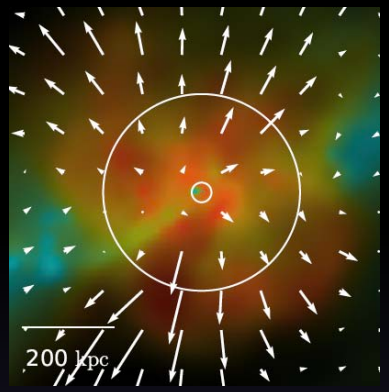
gas accretes along filaments
most stars form in situ



massive stars & SNae
heating and winds

cooling & accretion quenched
mass growth through dry mergers

AGN feedback
heating & winds



gas content
is key for
structure!

photoionization/
photoevaporation

no HI
cooling

10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15}

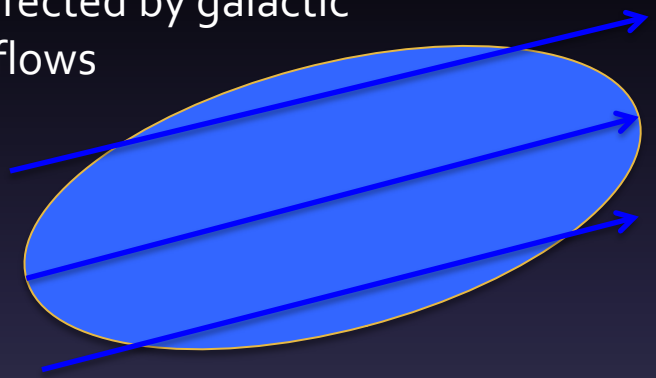
halo mass (M_{sun})

cartoon after van Dokkum et al. 2015; Cappellari 2015

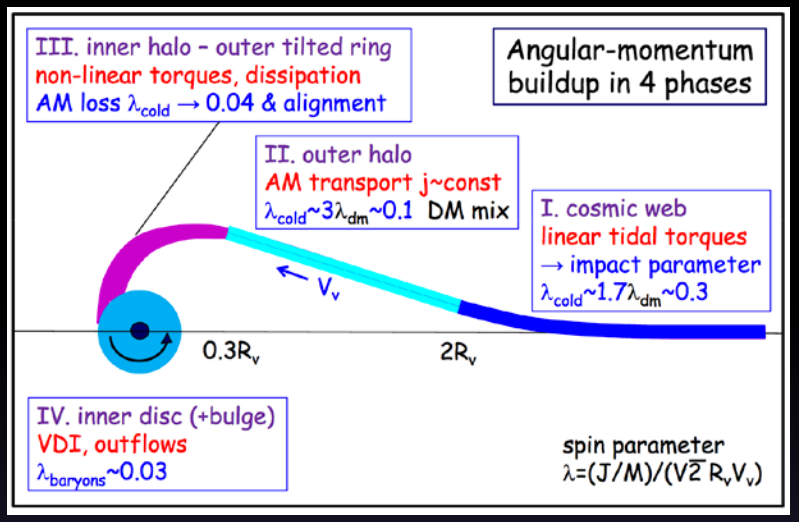
galaxies grow through "cold stream" accretion along filaments

j of accreting material is ~2-3 times larger than j_{halo}

j_* affected by galactic outflows



$\Delta \log r_e \sim 0.3\, \Delta \log m_*$



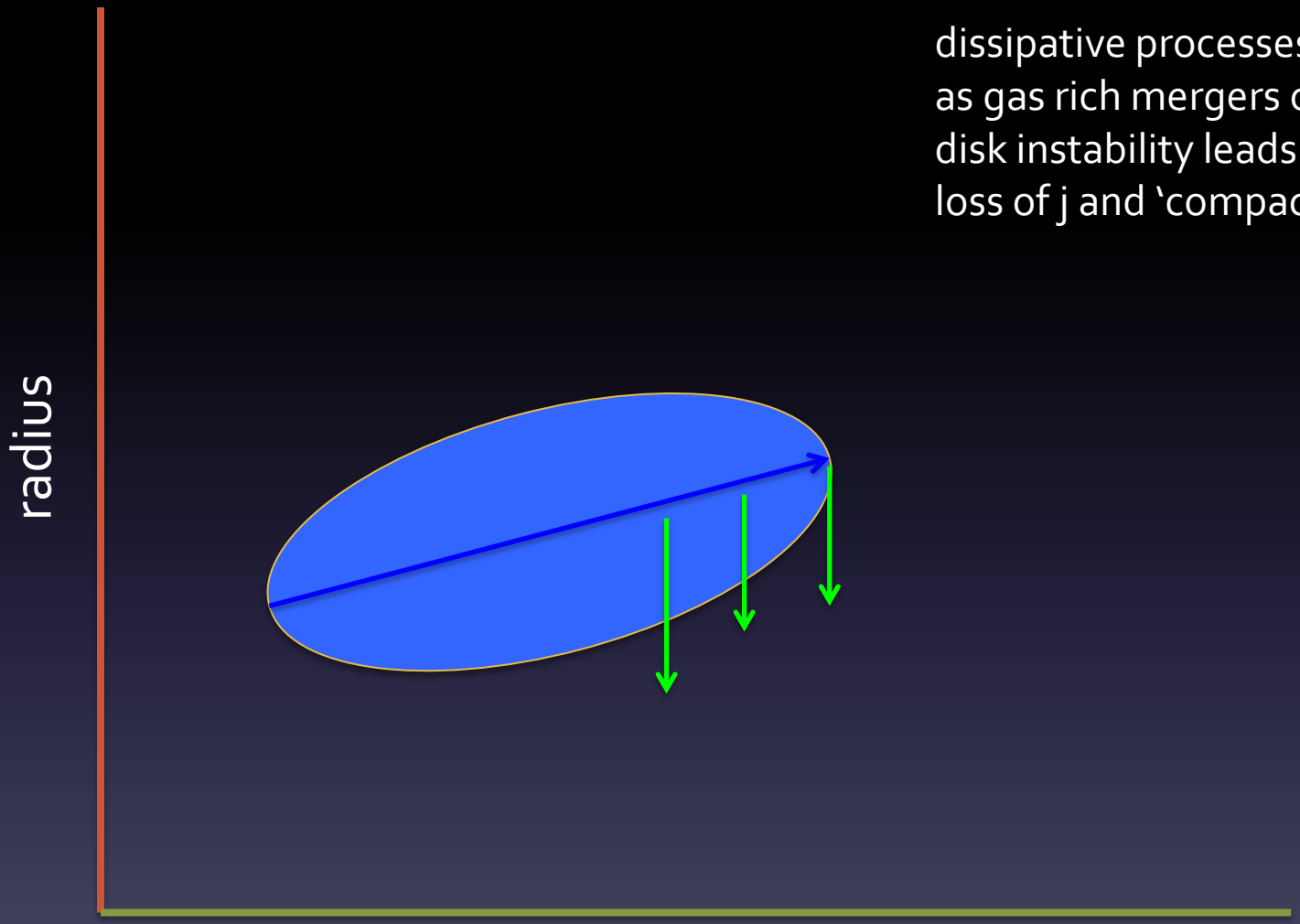
Danovich et al. 2014

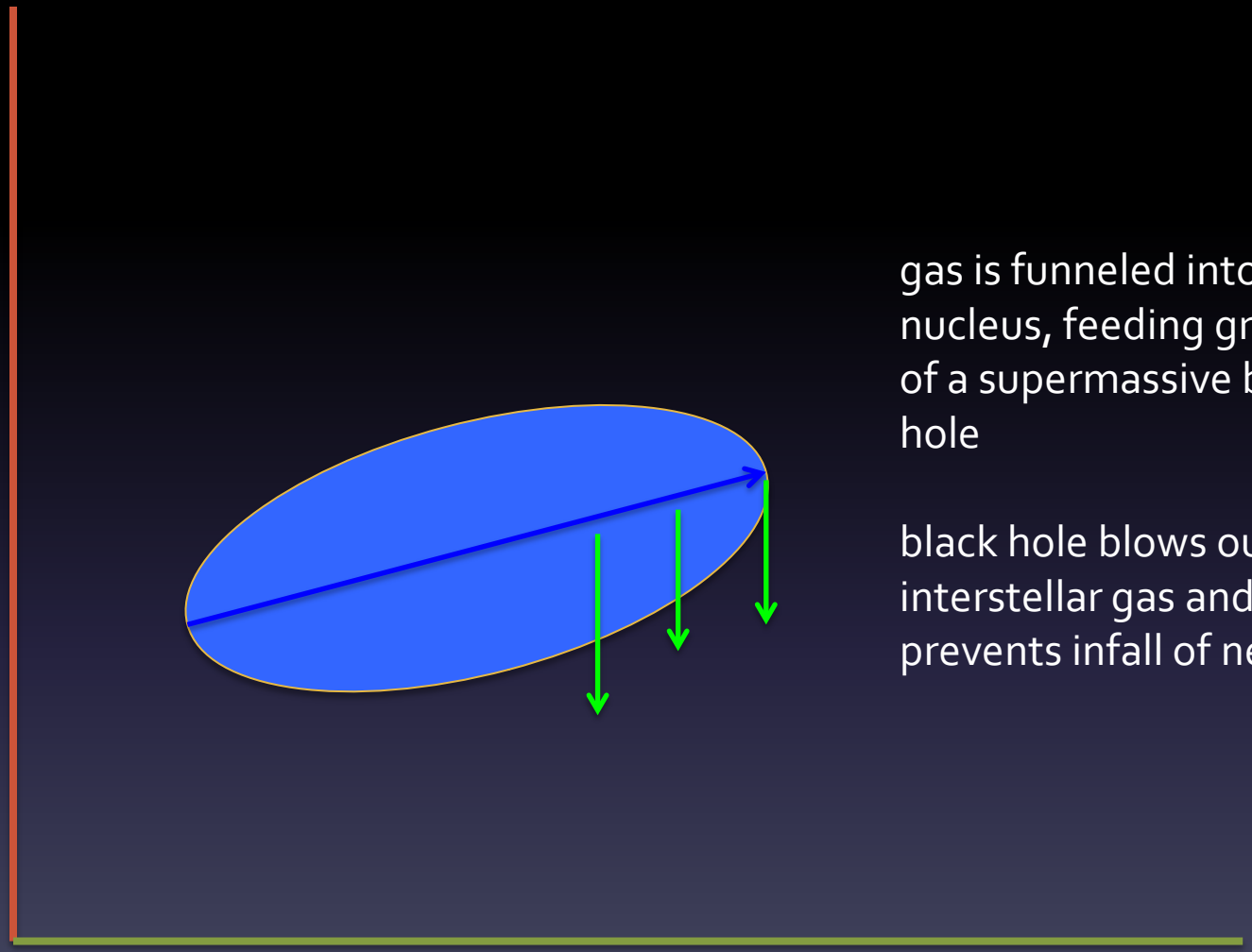
Brooks et al. 2008
Stewart et al. 2013
Stevens et al. 2017
Zjupa & Springel 2017

radius

stellar mass

dissipative processes such as gas rich mergers or disk instability leads to loss of j and ‘compaction’

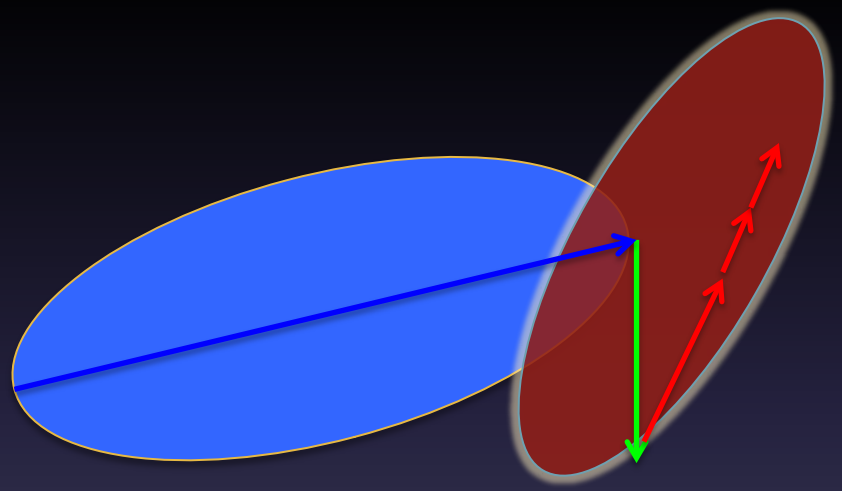




gas is funneled into the nucleus, feeding growth of a supermassive black hole

black hole blows out interstellar gas and/or prevents infall of new gas

$\Delta \log r_e \sim 2\, \Delta \log m_*$

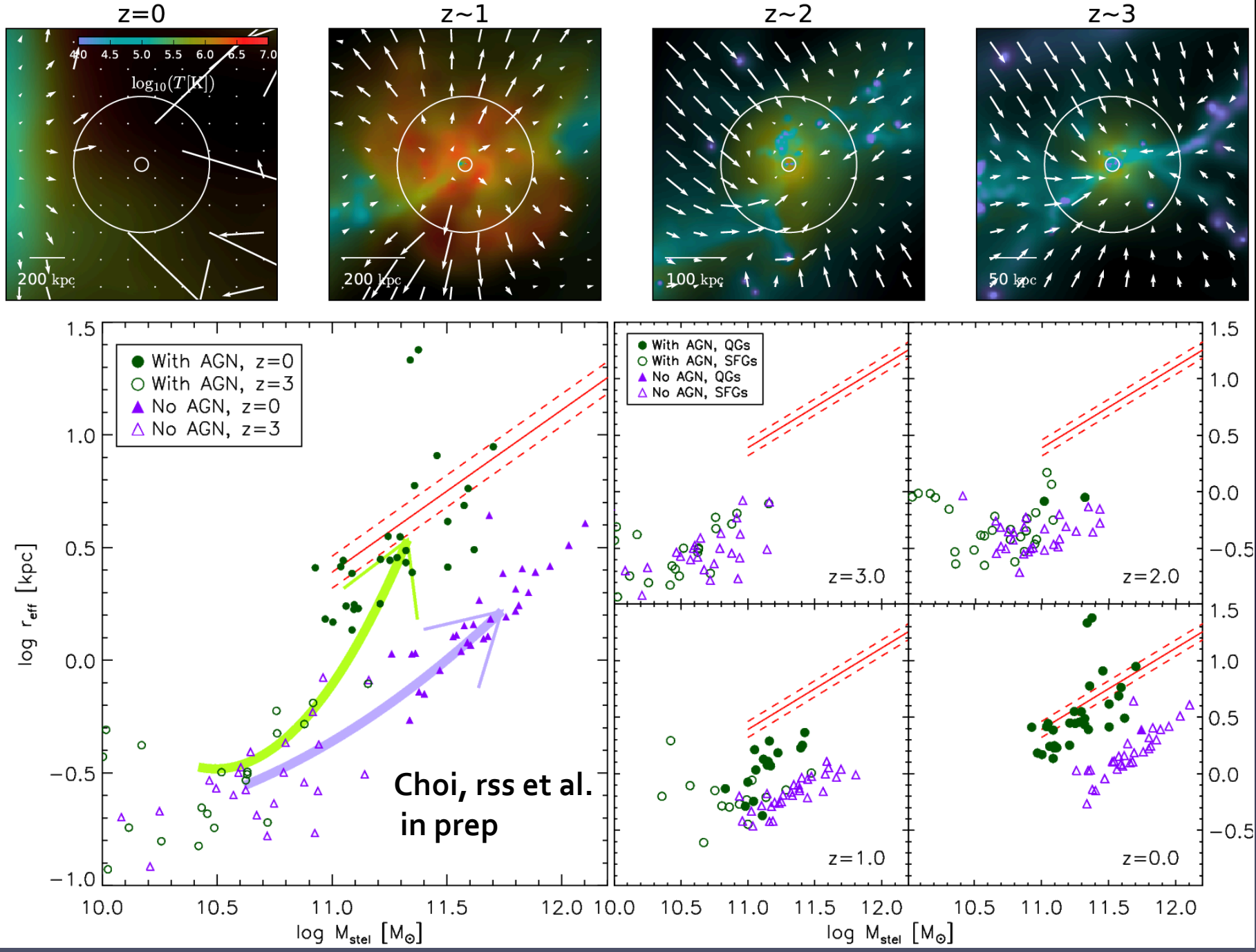


radius

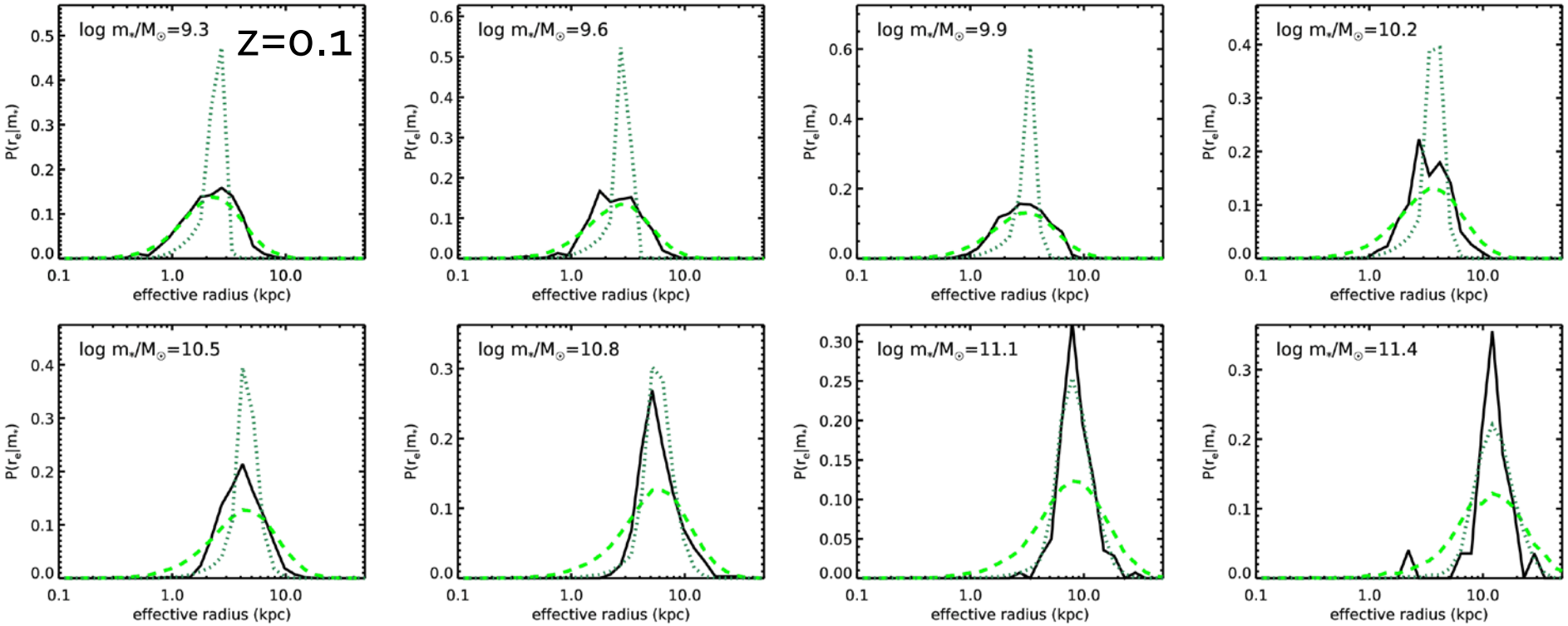
stellar mass

'quenched' galaxies grow by (mostly minor) gas-poor mergers (Naab et al. 2009; Porter et al. 2014)

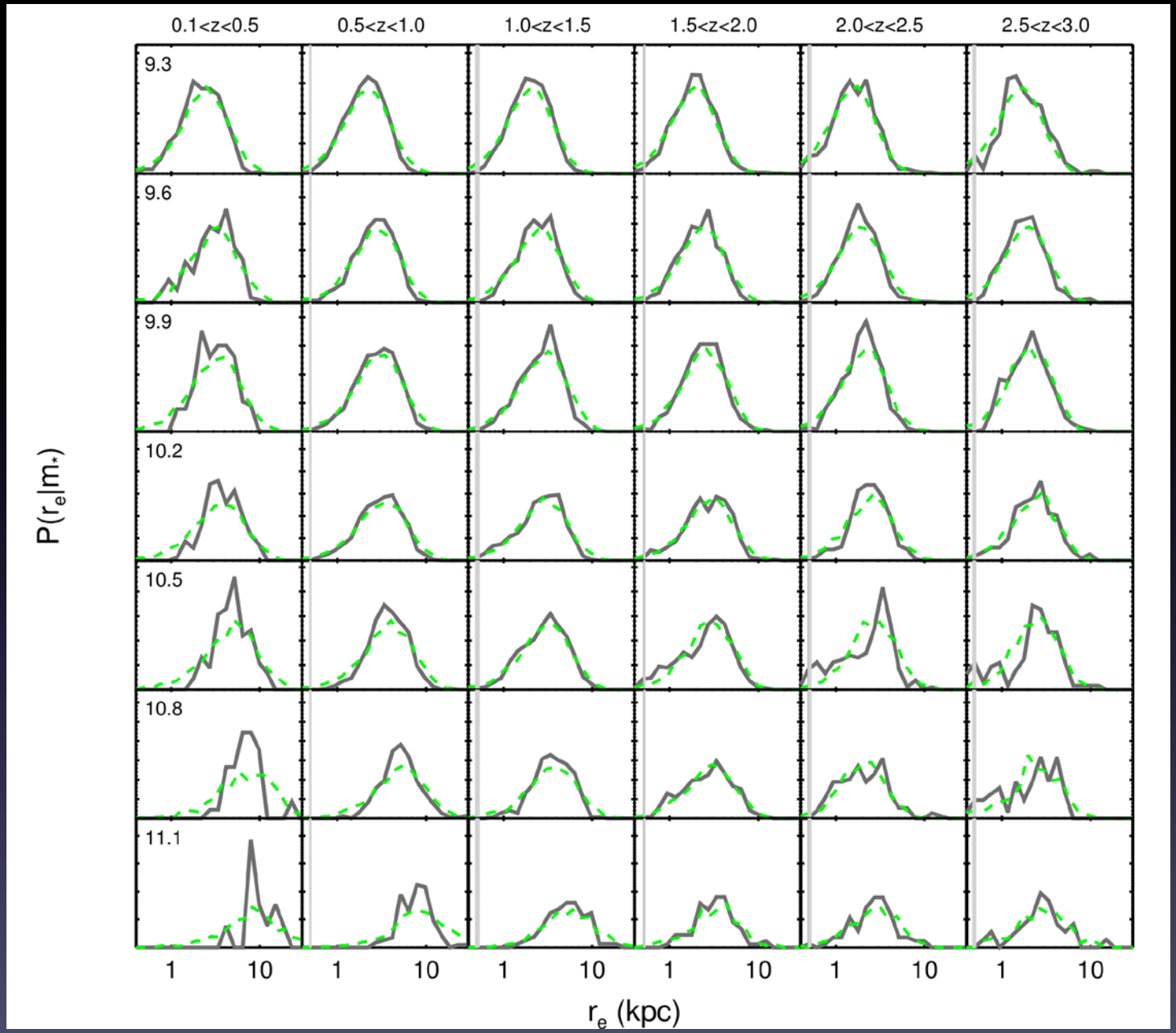
Brennan, Choi, rss et al.



conditional distribution of λR_h in stellar mass bins looks very similar to observed conditional size distribution for low mass bins
in higher mass bins, SHAM distribution is *broader* than observed ones



dotted: SHAM $P(R_h|m_*)$
green dashed: SHAM $P(0.5\lambda R_h|m_*)$
black: $P(r_{*,3D}|m_*)$ GAMA



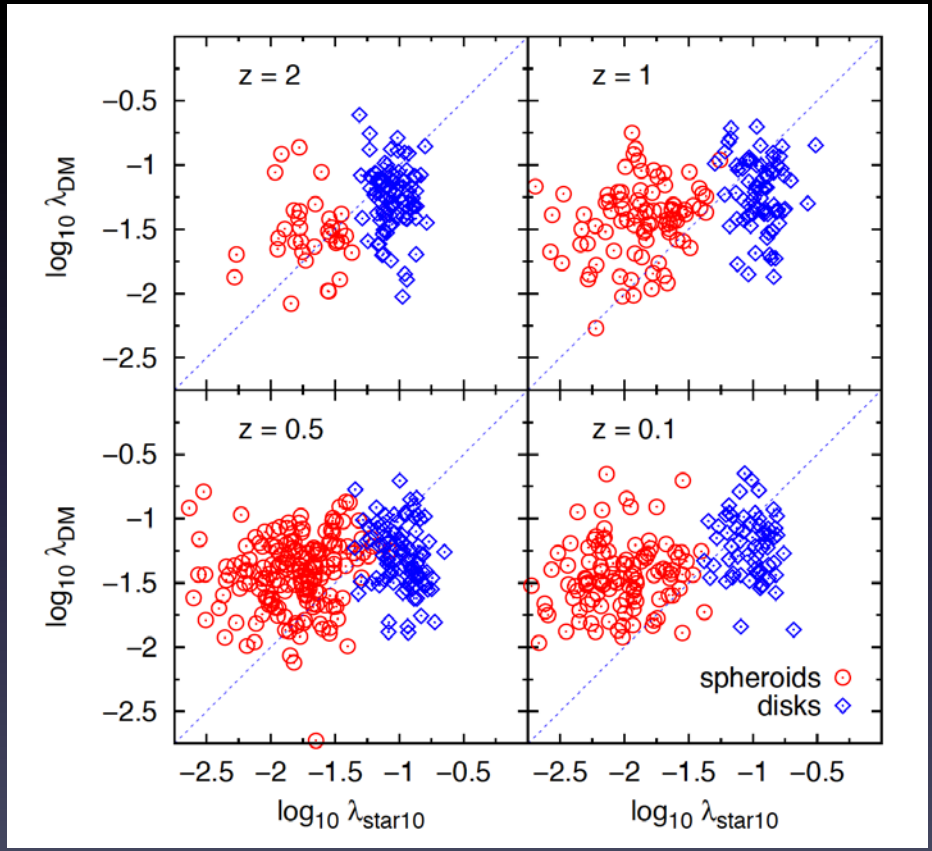
rss et al. 2017

why is this surprising?

- MMW-type models with either contraction or expansion would predict larger scatter (Desmond & Wechsler 2015; 2017)
- large scatter seen in λ_{DM} vs. $\lambda_{baryons}$ in hydro sims

wait for F. Jiang talk!

spin of dark matter halo



Teklu et al. 2015

spin of stars

summary

- intrinsic and observational scatter in SMHM must be properly accounted for in linking galaxy and halo properties
- relationship between galaxy size and halo virial radius shows hints of:
  - decrease with stellar mass above a critical mass (few 10^{10} M_{sun}) at z>1
  - decrease over cosmic time for galaxies below m_{crit}
  - increase with cosmic time for galaxies above m_{crit}
- dispersion in galaxy size at fixed mass is similar to dispersion in halo spin

with thanks to

Peter Behroozi, Joel Primack, Avishai Dekel, Sandy Faber, David Koo, & the CANDELS team

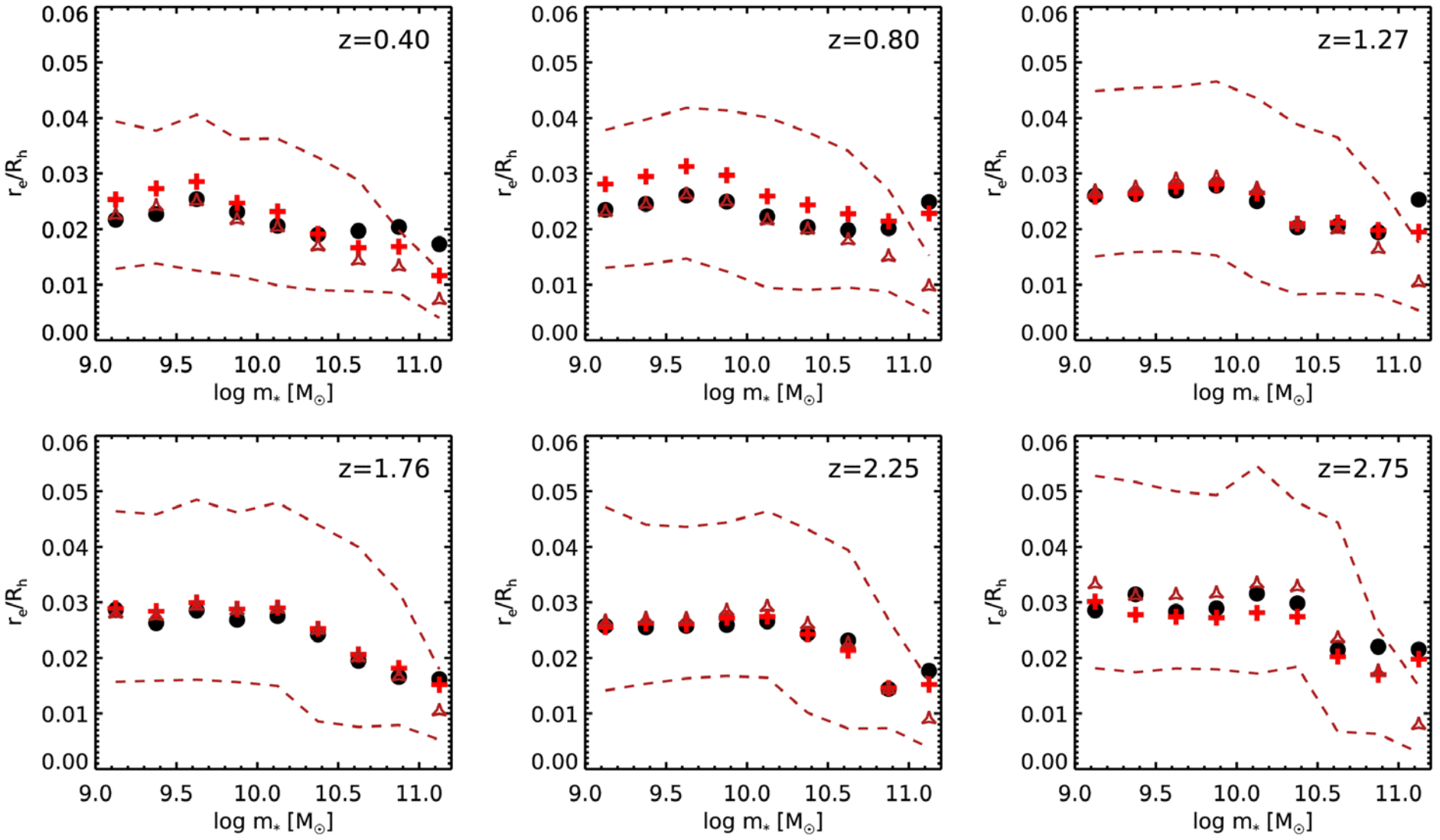
Ryan Brennan, Viraj Pandya, Ena Choi

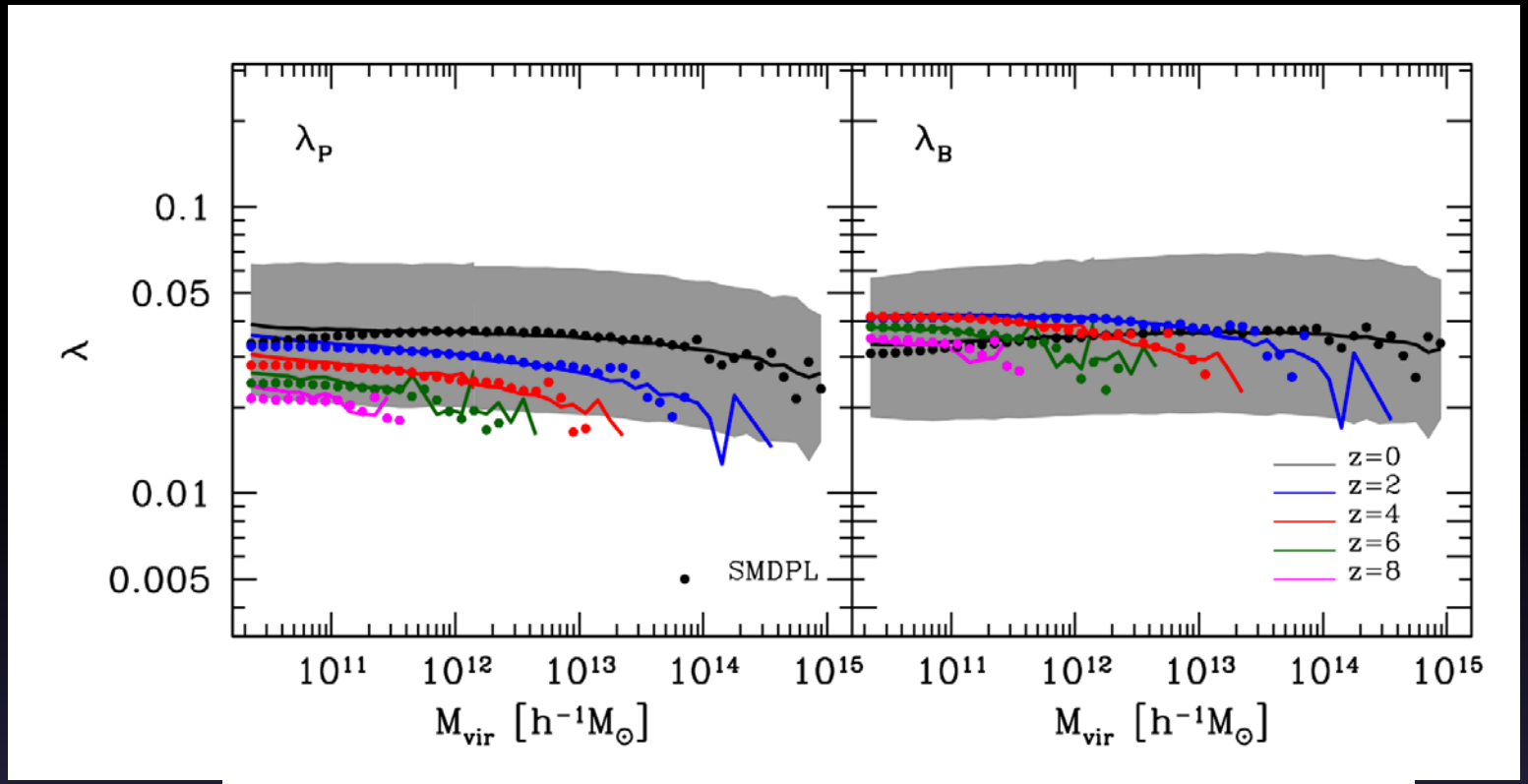
the organizers of this meeting!

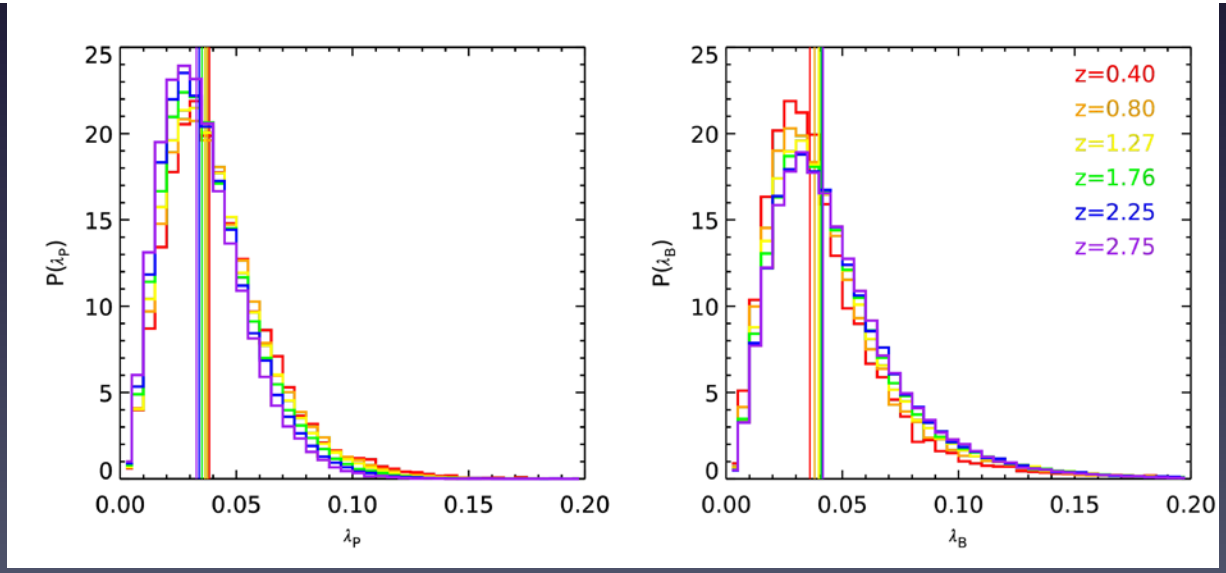
The End

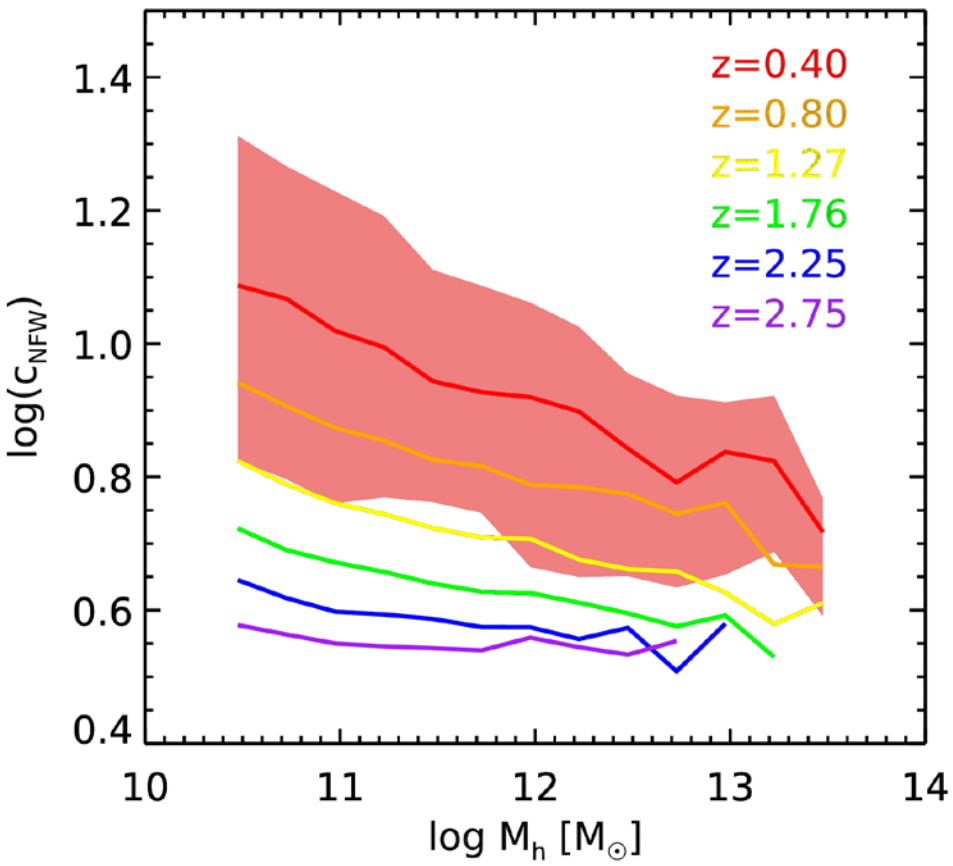
red crosses: Huang et al. published results;
red triangles: Huang et al. using our halo mass definition & B13 SMHM relation

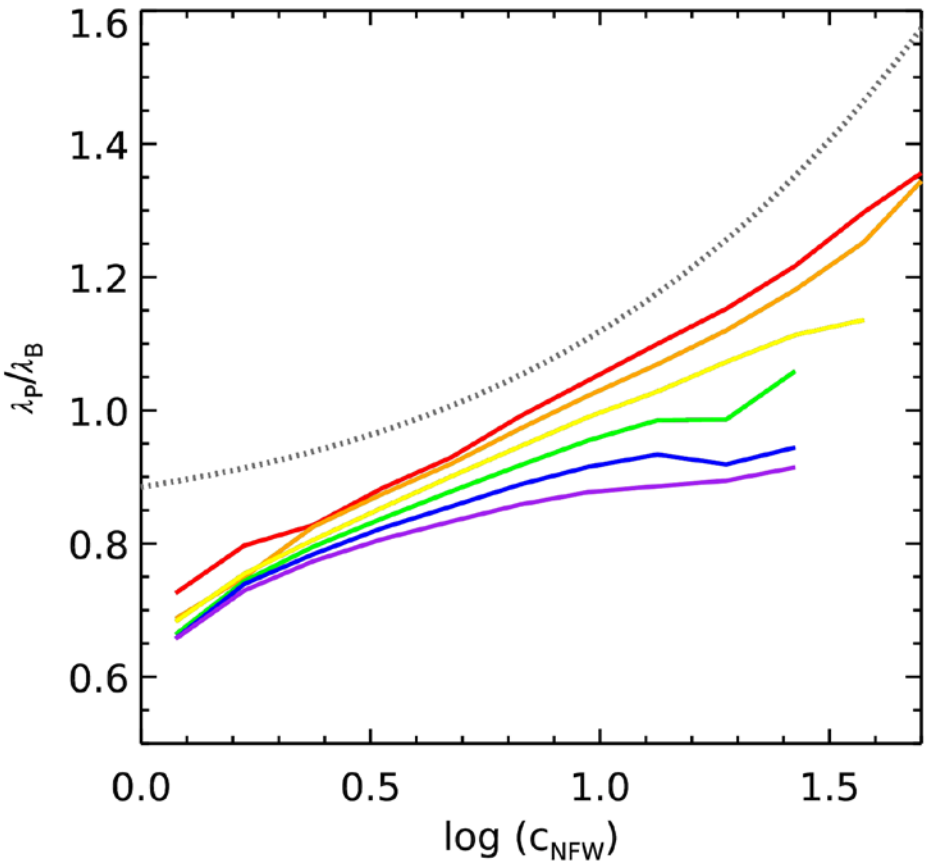
black dots: our analysis



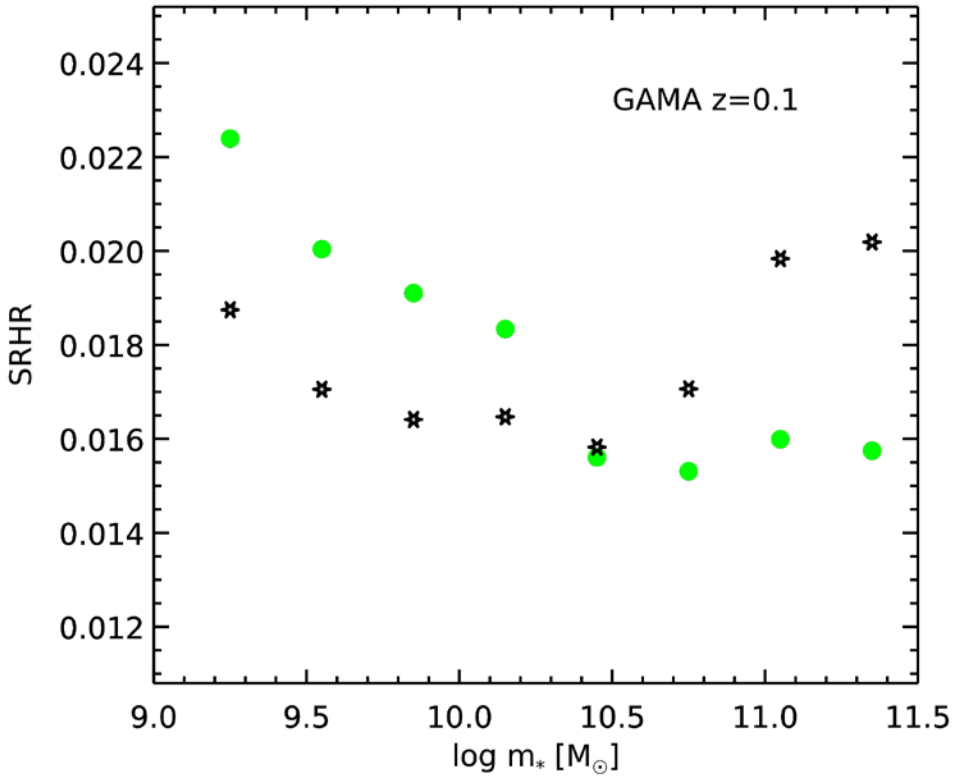

λ_P
λ_B
λ
0.1
0.05
0.01
0.005
SMDPL
z=0
z=2
z=4
z=6
z=8
10^{11} 10^{12} 10^{13} 10^{14} 10^{15}
M_{vir} $[h^{-1}M_\odot]$

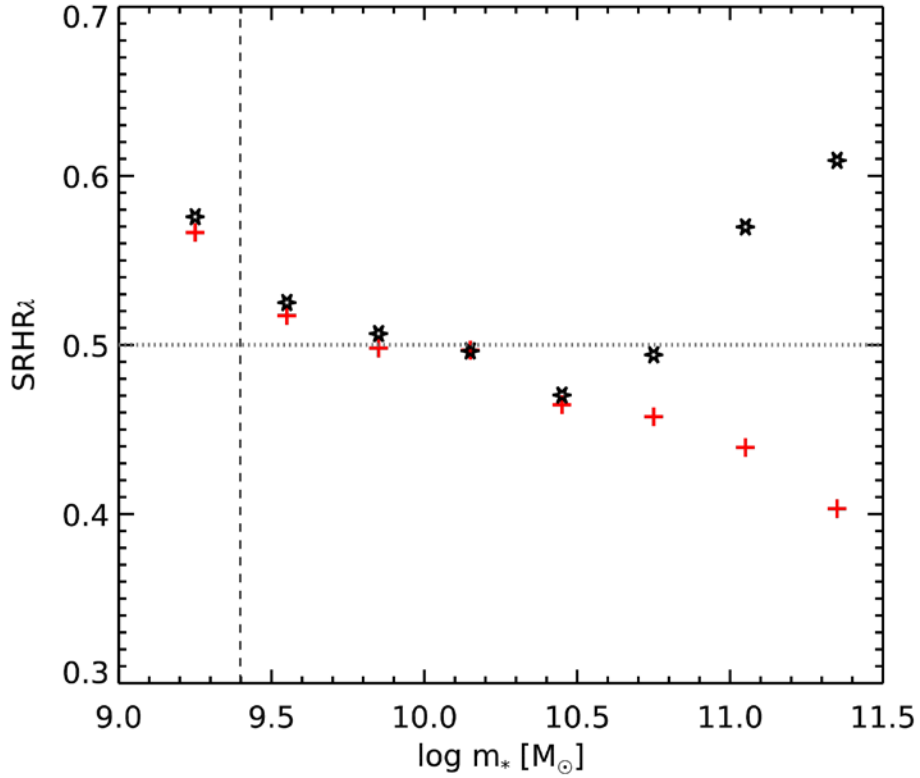

$P(\lambda_P)$
$P(\lambda_B)$
0 5 10 15 20 25
0.00 0.05 0.10 0.15 0.20
λ_P
λ_B
z=0.40
z=0.80
z=1.27
z=1.76
z=2.25
z=2.75

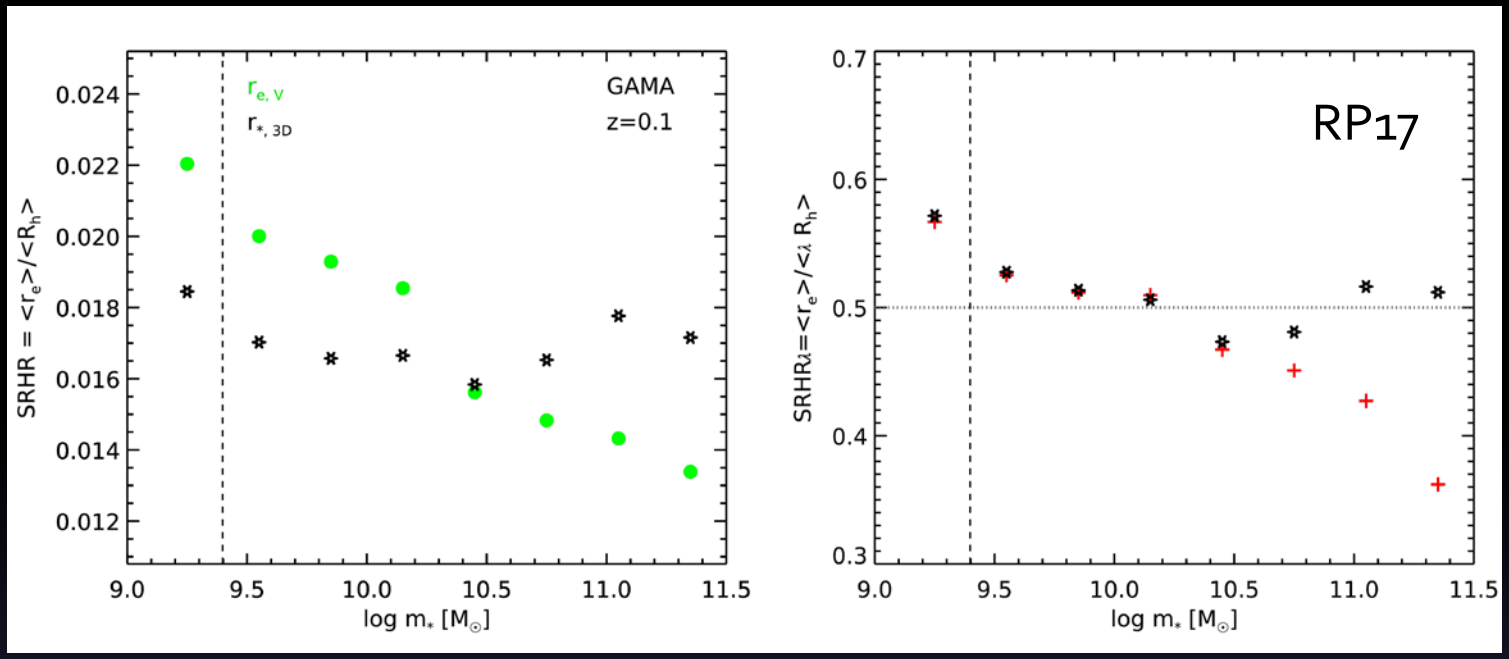

z=0.40
z=0.80
z=1.27
z=1.76
z=2.25
z=2.75
log(c_NFW)
log M_h [M_⊙]
1.4
1.2
1.0
0.8
0.6
0.4
10
11
12
13
14

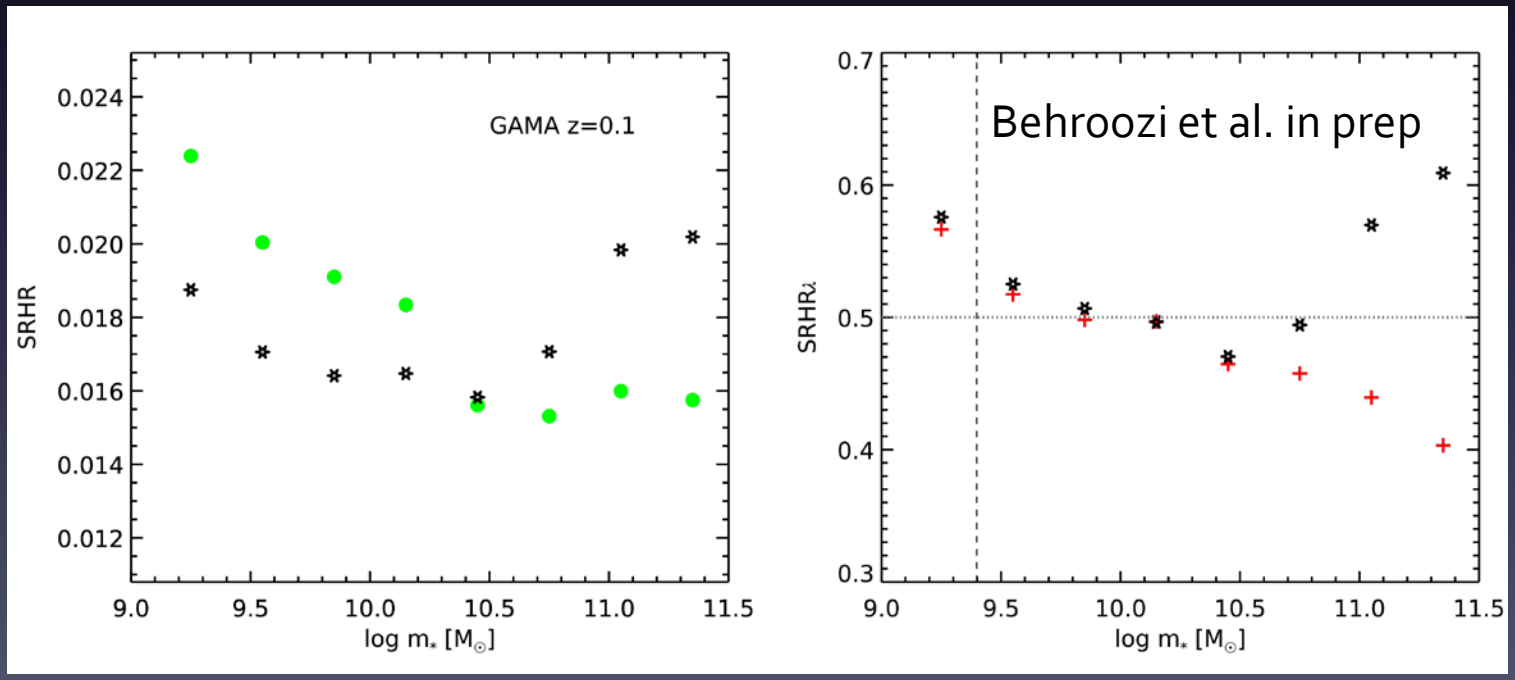

λ_P/λ_B
log (c_NFW)
1.6
1.4
1.2
1.0
0.8
0.6
0.0
0.5
1.0
1.5

using Behroozi et al. in prep SMHM relation (with Bernardi+13 SMF)






GAMA
z=0.1
$r_{e,V}$
$r_{*,3D}$
SRHR = <r_e>/<R_h>
log m_* [$M_\odot$]
RP17
SRHRi=<r_e>/<i R_h>
log m_* [$M_\odot$]


GAMA z=0.1
SRHR
log m_* [$M_\odot$]
Behroozi et al. in prep
SRHRi
log m_* [$M_\odot$]