galaxy size – halo virial radius (R_{200c}) relation of galaxies

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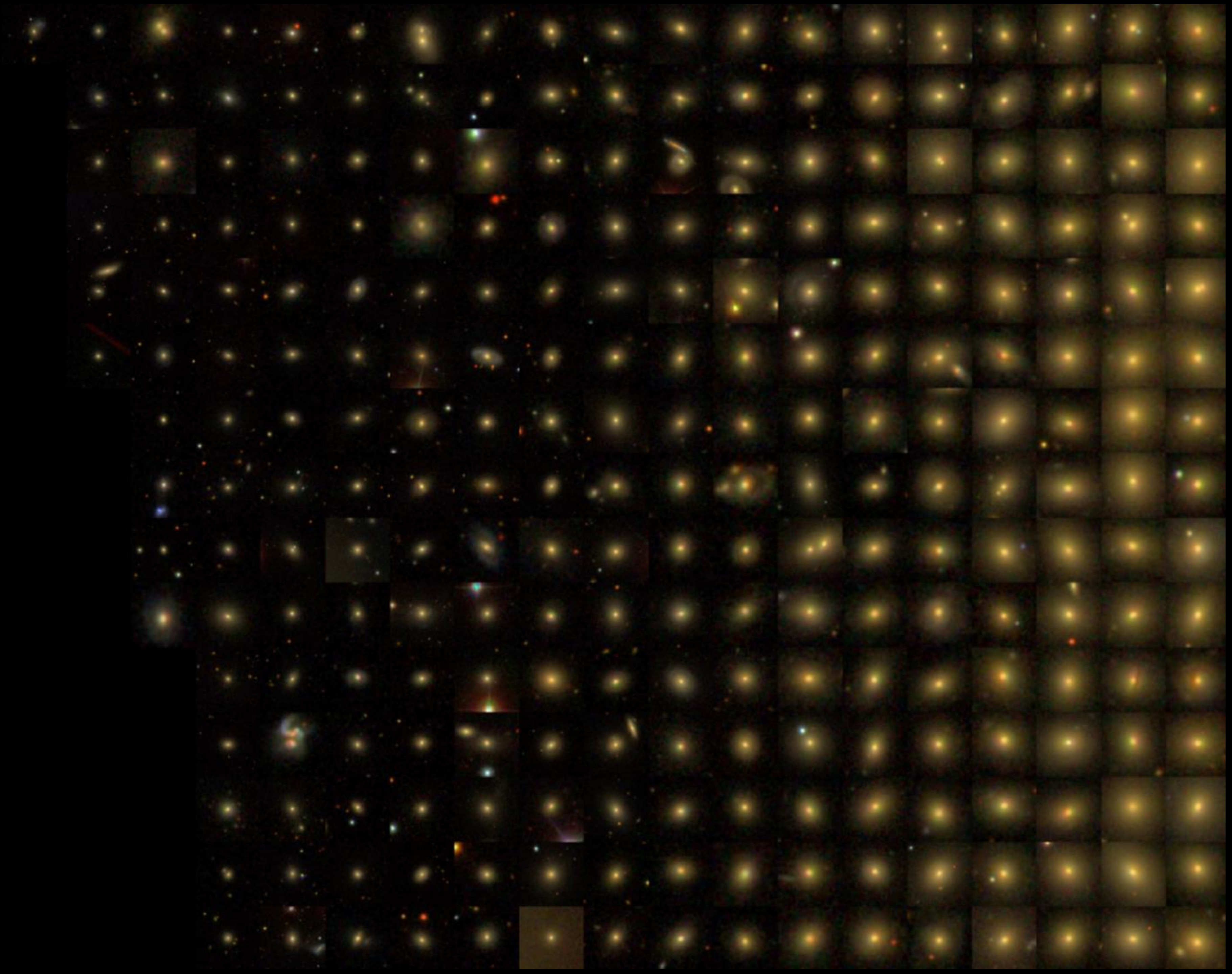
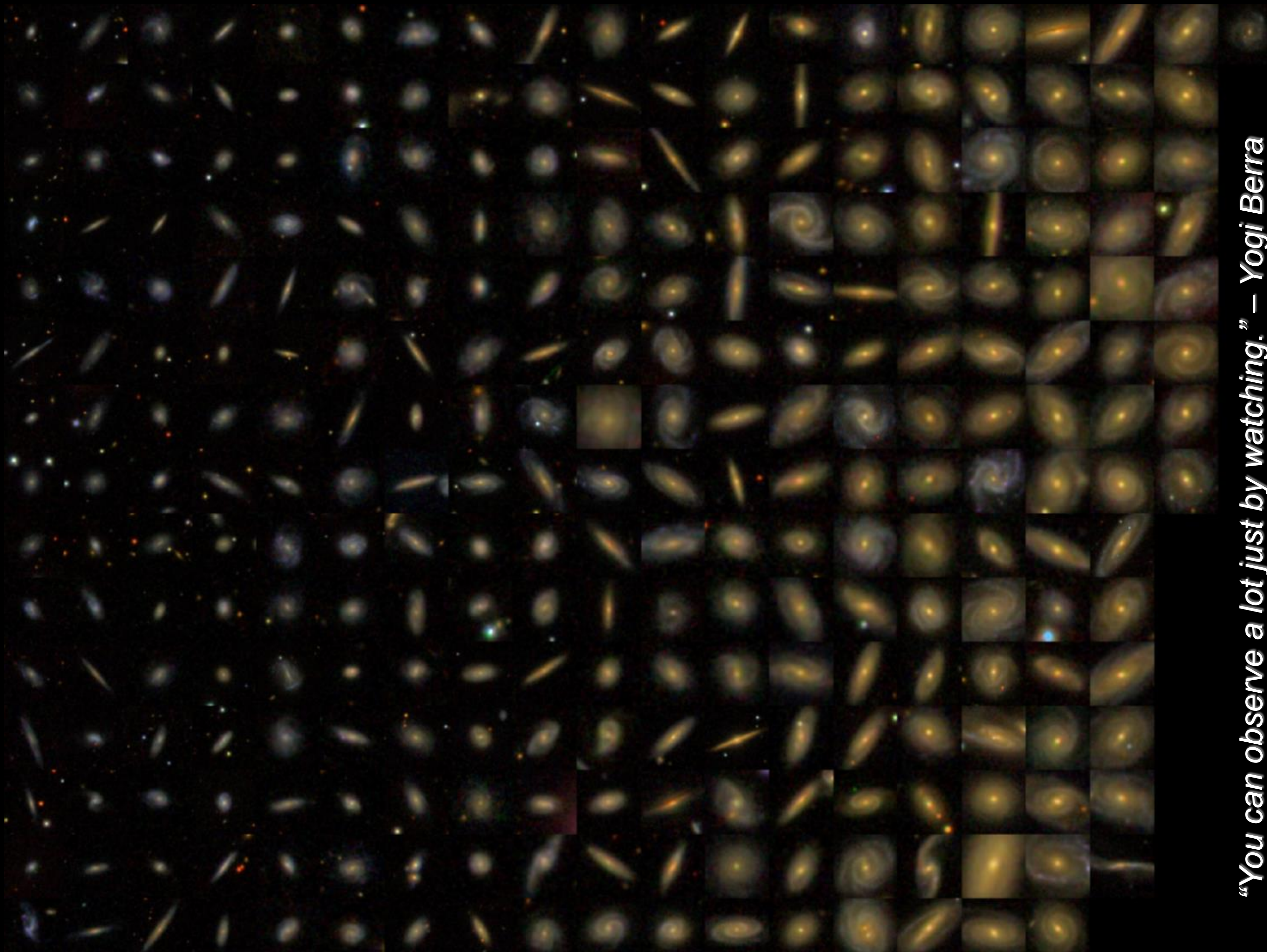
KITP GalHalo conference
16 May 2017



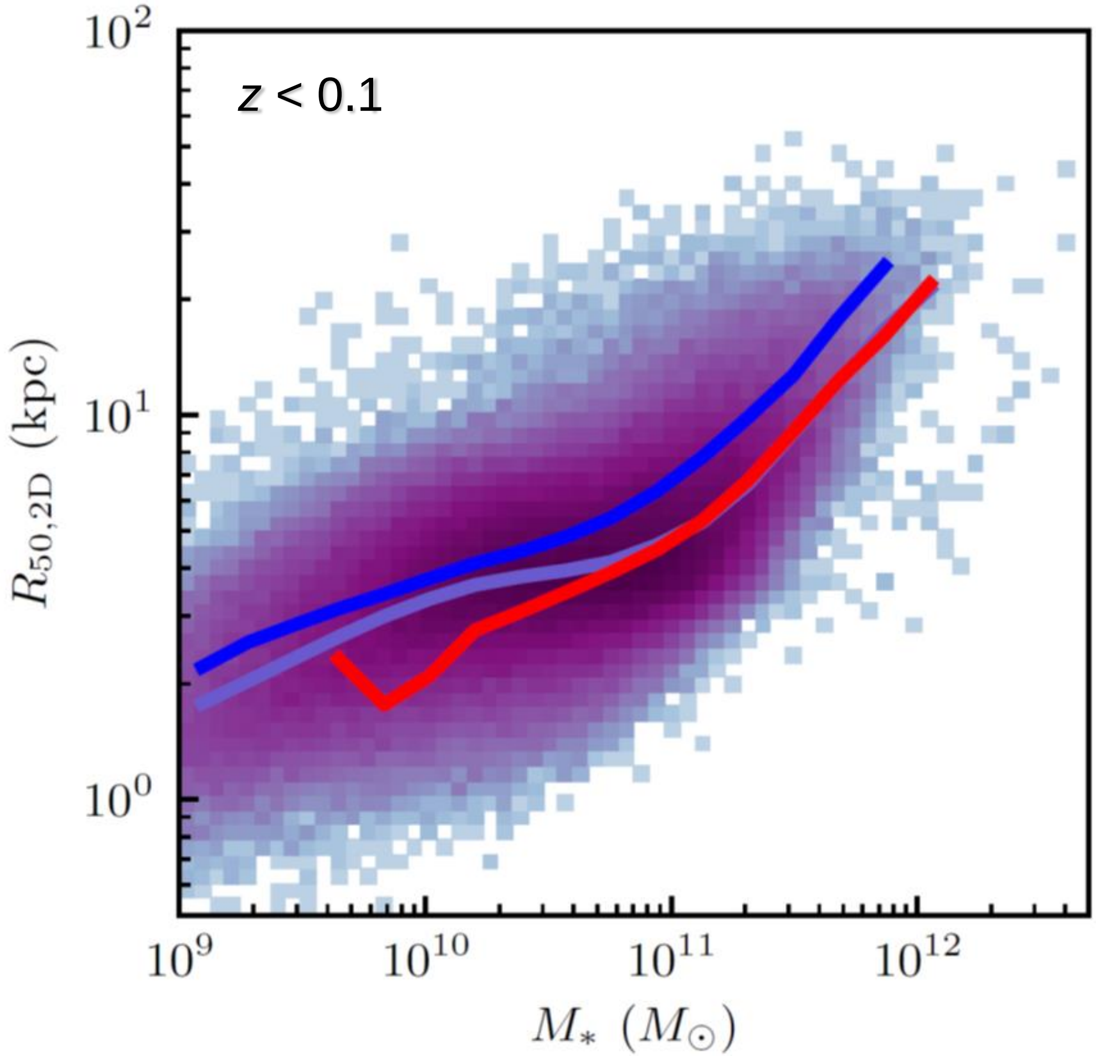


"You can observe a lot just by watching." – Yogi Berra

galaxy size – stellar mass relation of SDSS galaxies

e.g., Shen et al. 2003; Bernardi et al. 2010, 2014, and many, many others

projected circularized stellar half-mass radius of galaxies



galaxy stellar mass

all median
Ell, T < −3 median
Scd, T > 4 median

$$T = -4.6 \times P(\mathrm{Ell}) - 2.4 \times P(\mathrm{S0}) + 2.5 \times P(\mathrm{Sab}) + 6.1 \times P(\mathrm{Scd})$$

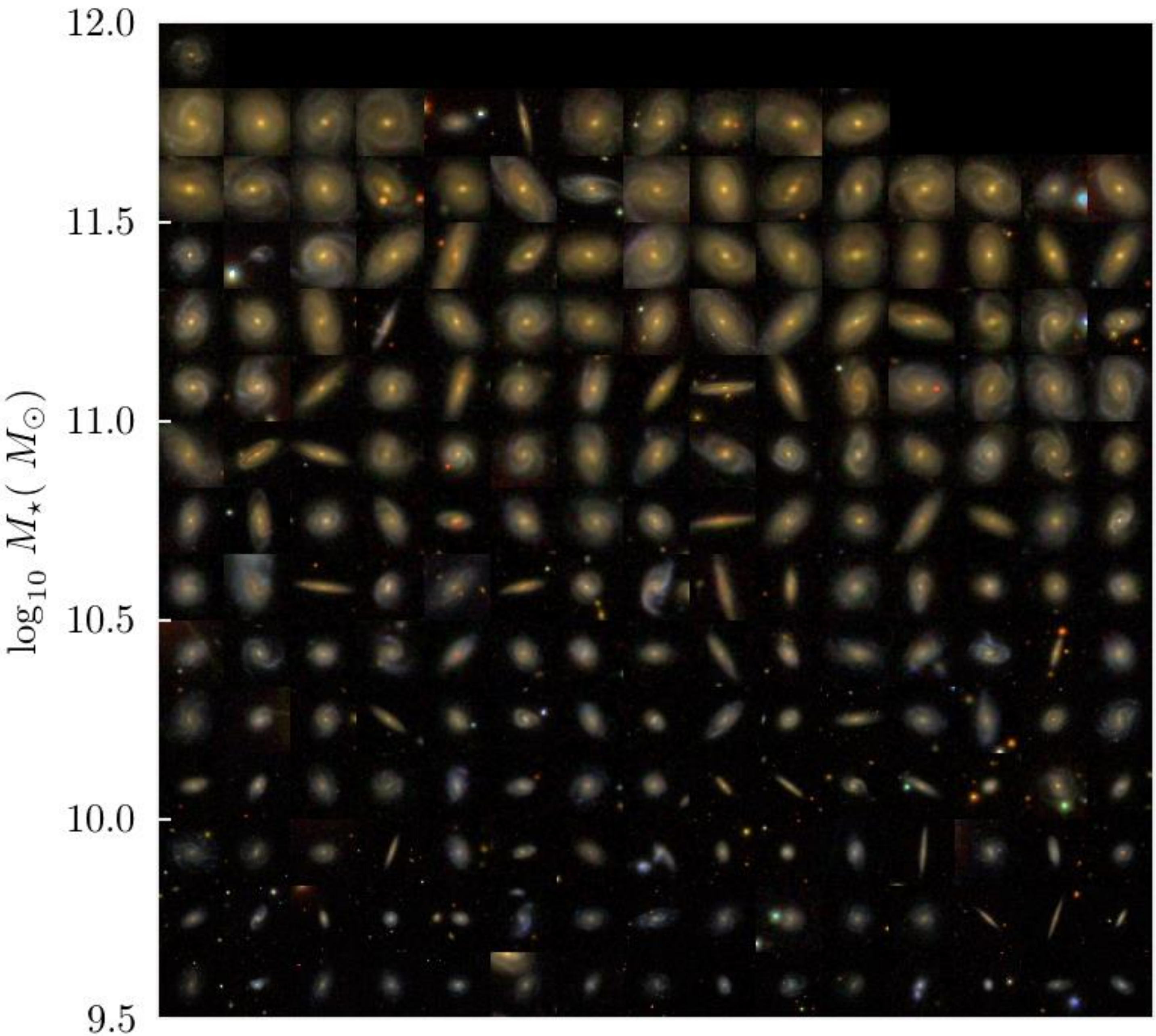
magenta 2d histogram = distribution of z<0.1 SDSS galaxies

Lines show medians for elliptical and Sc-Sd late type galaxies using morphology probabilities from Huertas-Company+ '13)

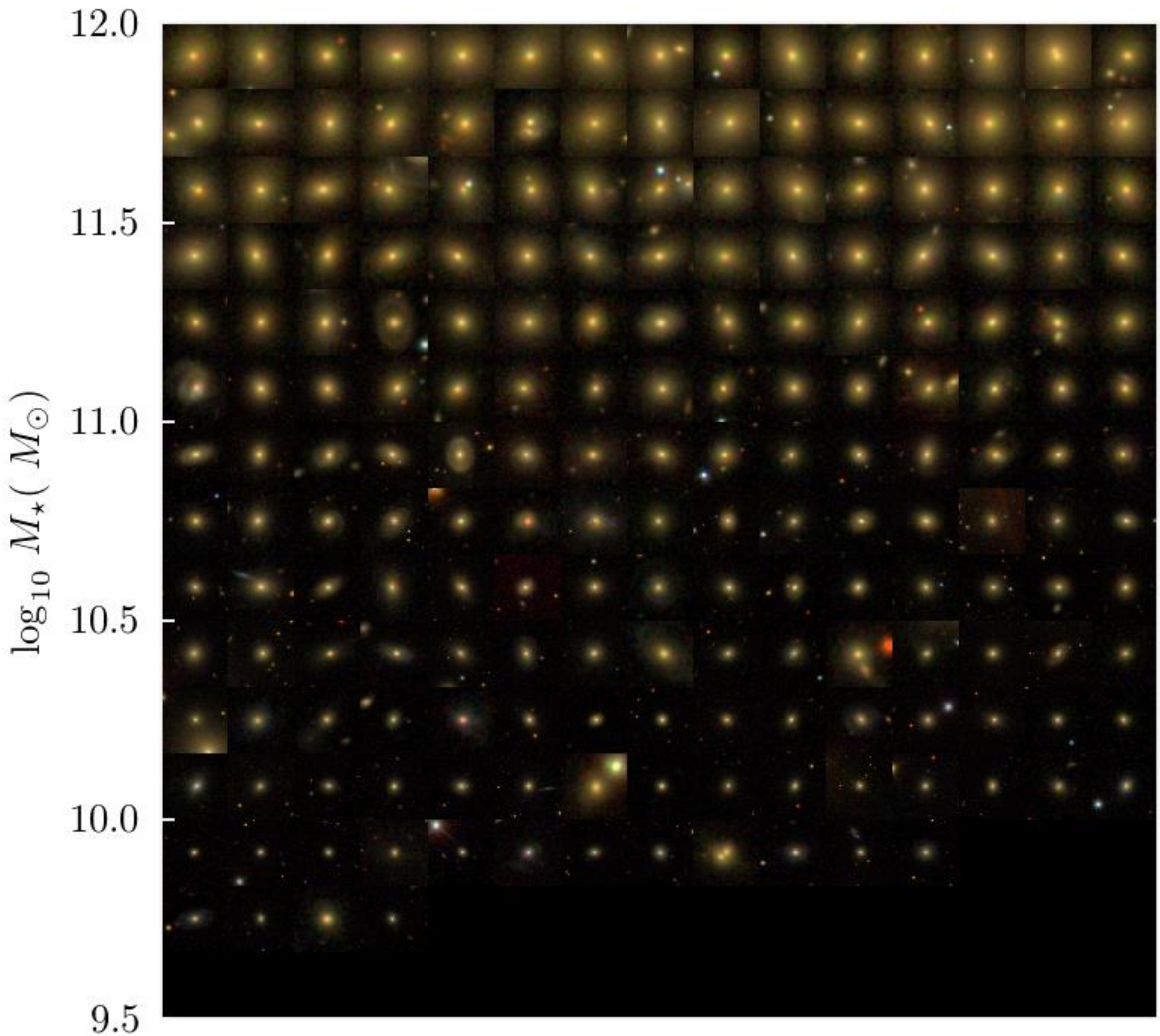
sizes and luminosities from improved SDSS photometry of Meert, Bernardi+2015
L->M* using Bell+ '03 fits

http://www.physics.upenn.edu/~ameert/SDSS_PhotDec

Randomly selected galaxies in the disk sample (T>4)

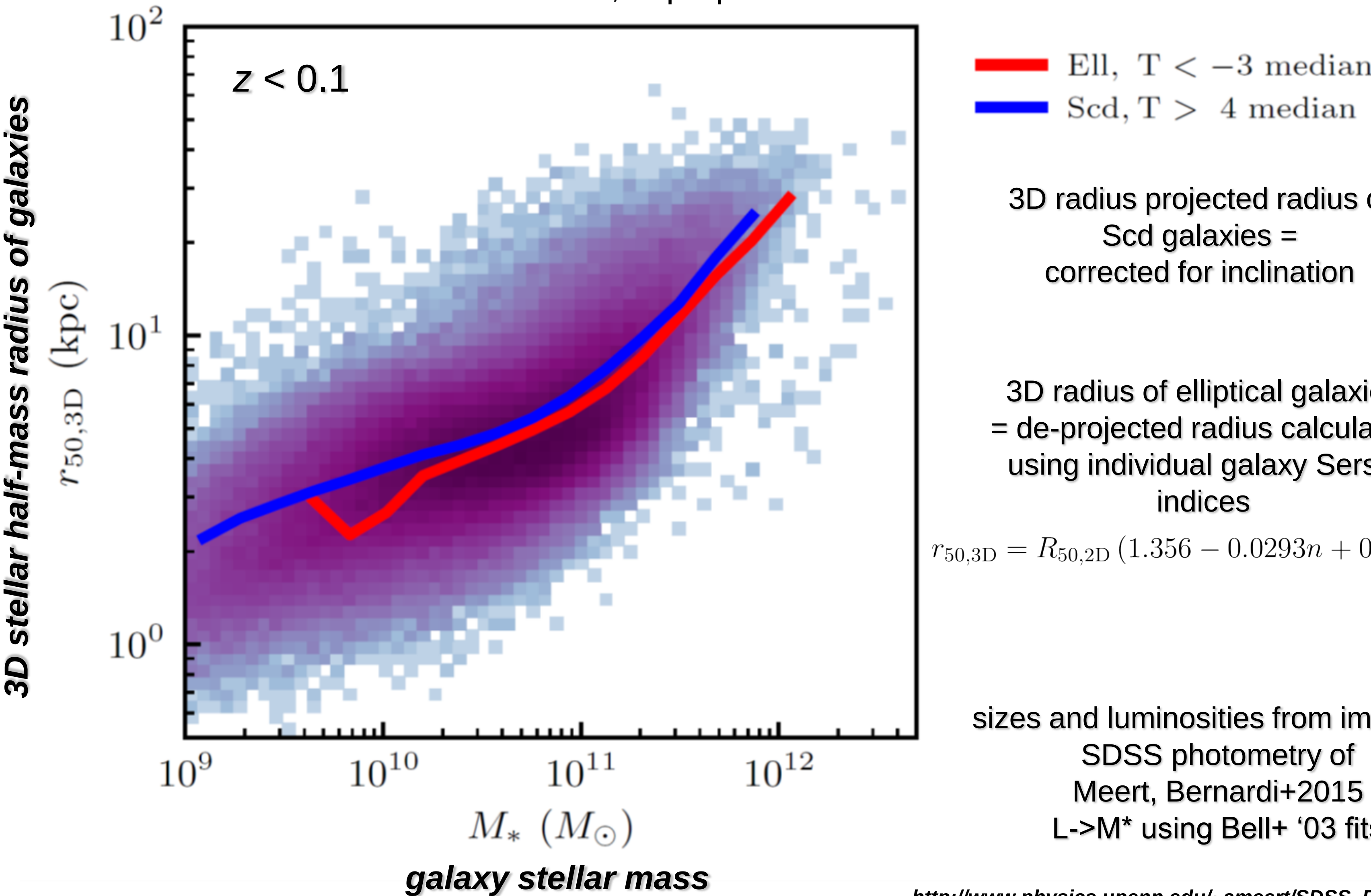


Randomly selected galaxies in the ellipticals sample (T<-3)



galaxy size – stellar mass relation of SDSS galaxies with sizes of spheroidal galaxies de-projected to 3d

Kravtsov 2017, in prep.



3D radius projected radius of Scd galaxies = corrected for inclination

3D radius of elliptical galaxies = de-projected radius calculated using individual galaxy Sersic indices

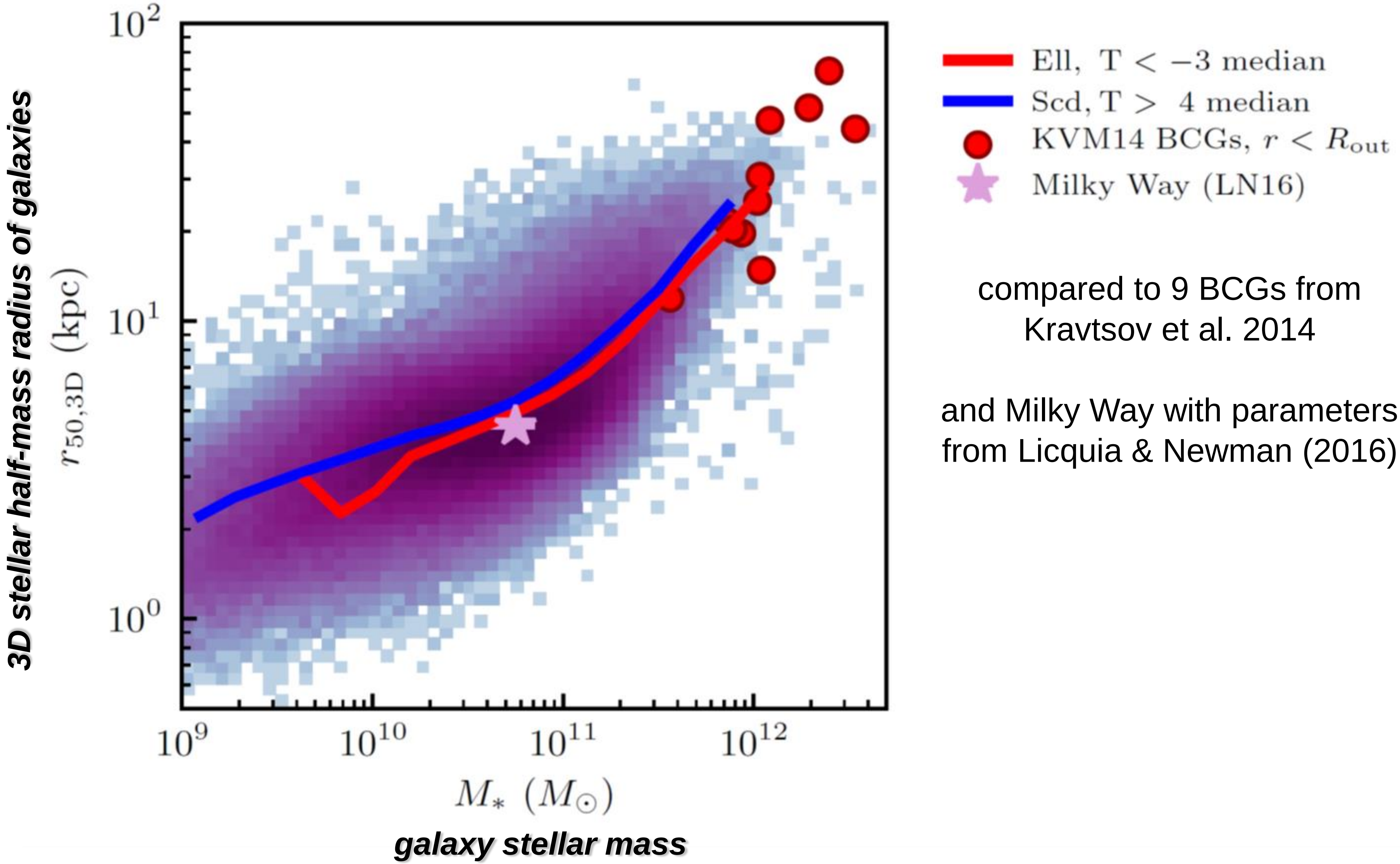
$$r_{50,3D} = R_{50,2D}\,(1.356 - 0.0293n + 0.0023n^2)$$

sizes and luminosities from improved SDSS photometry of Meert, Bernardi+2015
L->M* using Bell+ '03 fits

http://www.physics.upenn.edu/~ameert/SDSS_PhotDec

Galaxy size – stellar mass relation of SDSS galaxies

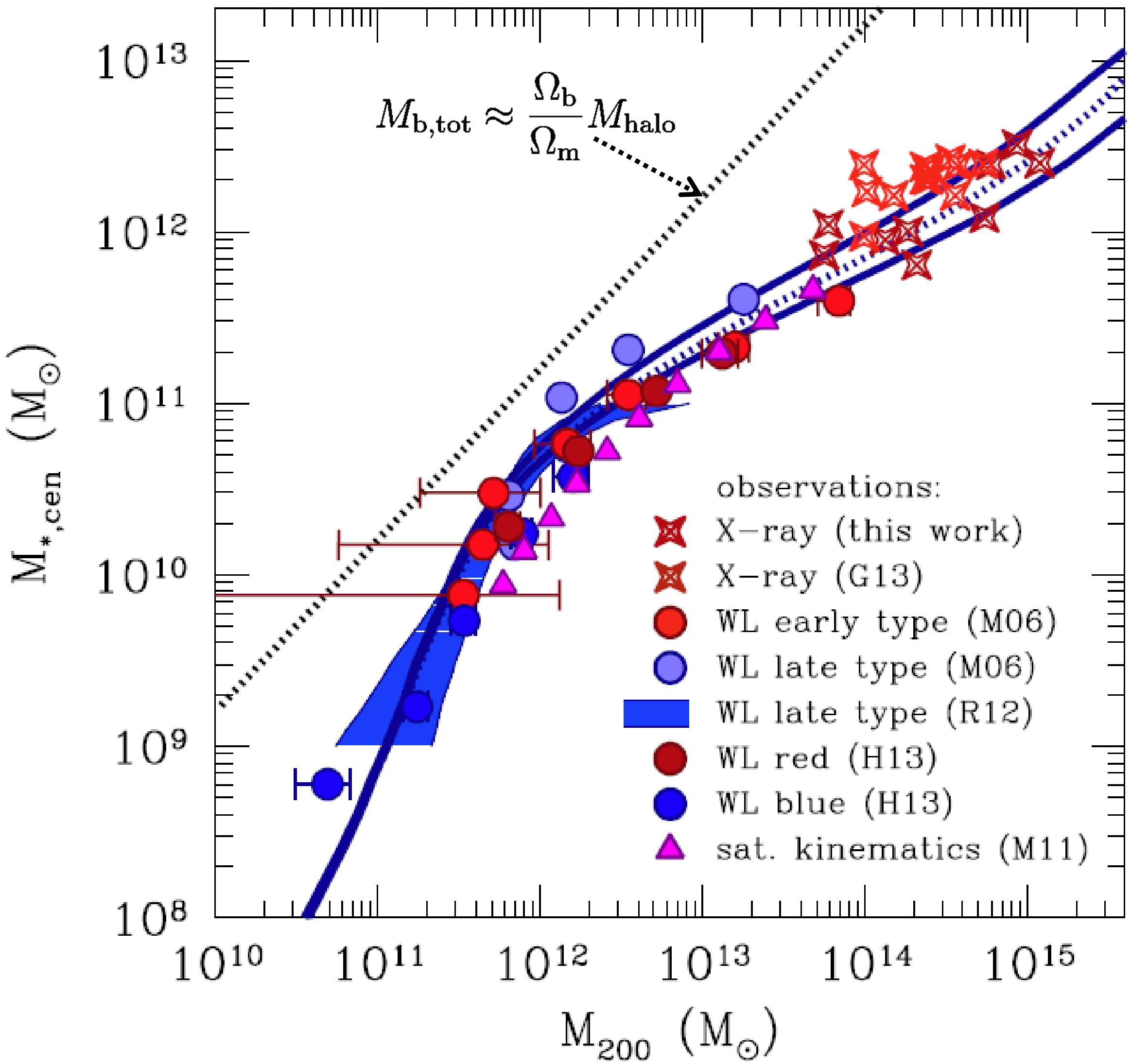
3d half-light radii of disk and spheroidal galaxies are not too different



compared to 9 BCGs from Kravtsov et al. 2014

and Milky Way with parameters from Licquia & Newman (2016)

M_*-Mhalo relation



stellar mass of central galaxy

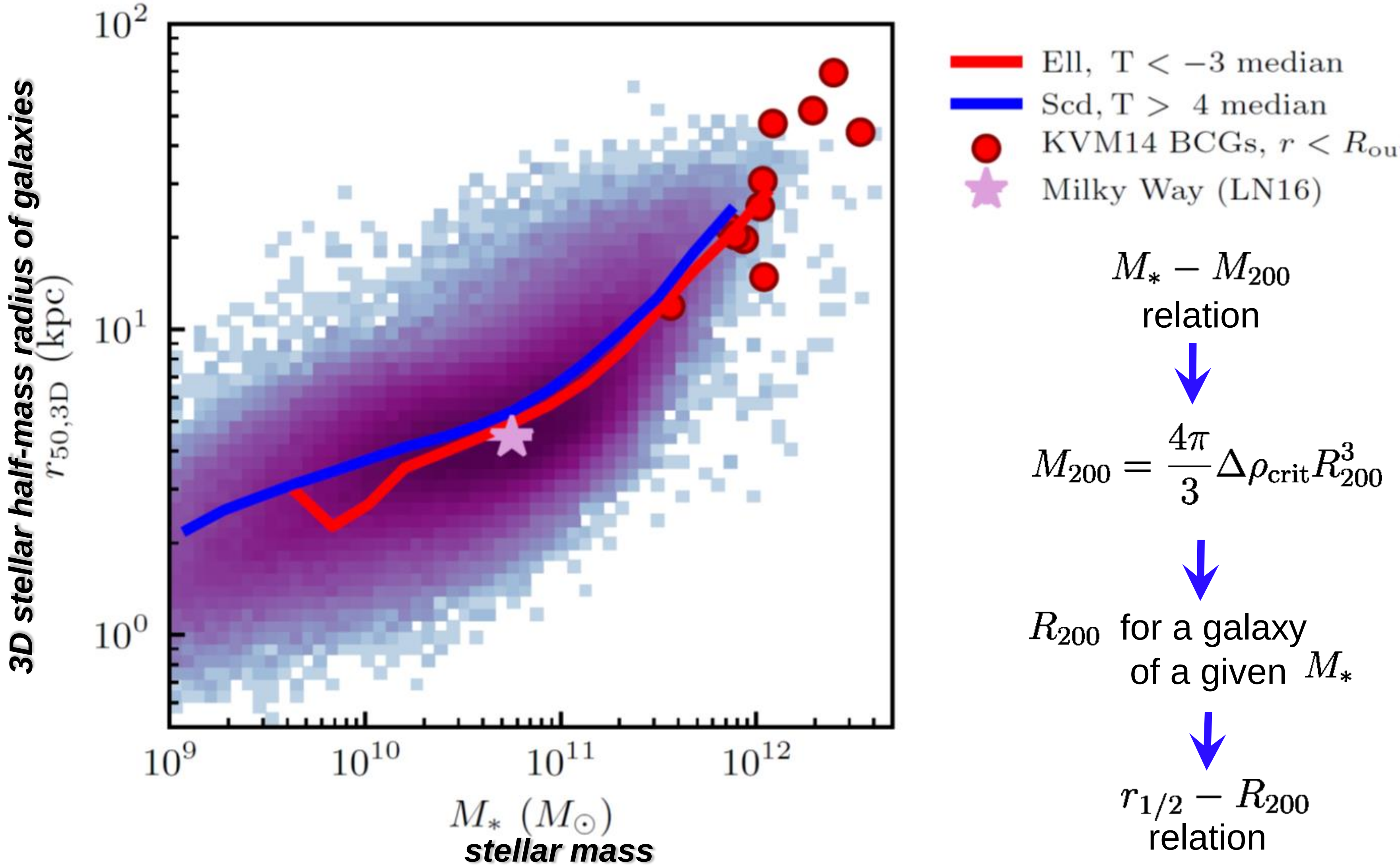
halo mass enclosing Δ=200ρ_{crit}

abundance matching using stellar mass function of Bernardi et al. '13 (Kravtsov et al. '14; also Shankar et al. '14)

dotted line – no scatter
solid lines – with scatter
<M|Mh> and <Mh|M*>*

Kravtsov, Mescheryakov & Vikhlinin
arxiv/1401.7329

Converting to size – virial relation



$M_* - M_{200}$
relation

↓

$$M_{200} = \frac{4\pi}{3}\Delta\rho_{crit}R_{200}^3$$

↓

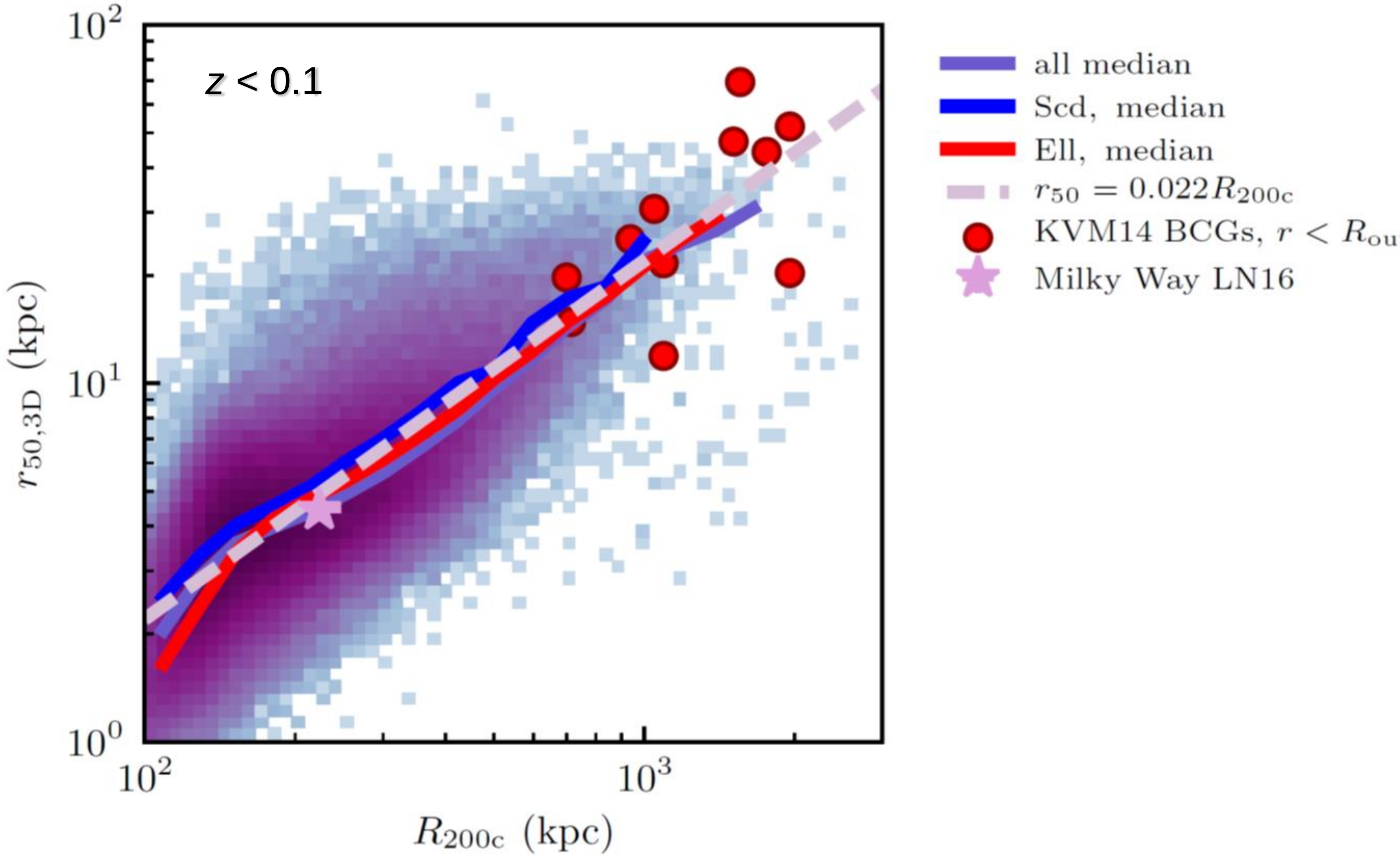
R_{200} for a galaxy
of a given M_*

↓

$r_{1/2} - R_{200}$
relation

galaxy size – virial radius relation of the SDSS galaxies

both late- and early-type galaxies in SDSS follow a remarkably <u>linear relation</u> between 3d half-light radius and R_{200c}. (Kravtsov 2013; 2017; Huang+ ‘17; Somerville+ ‘17)

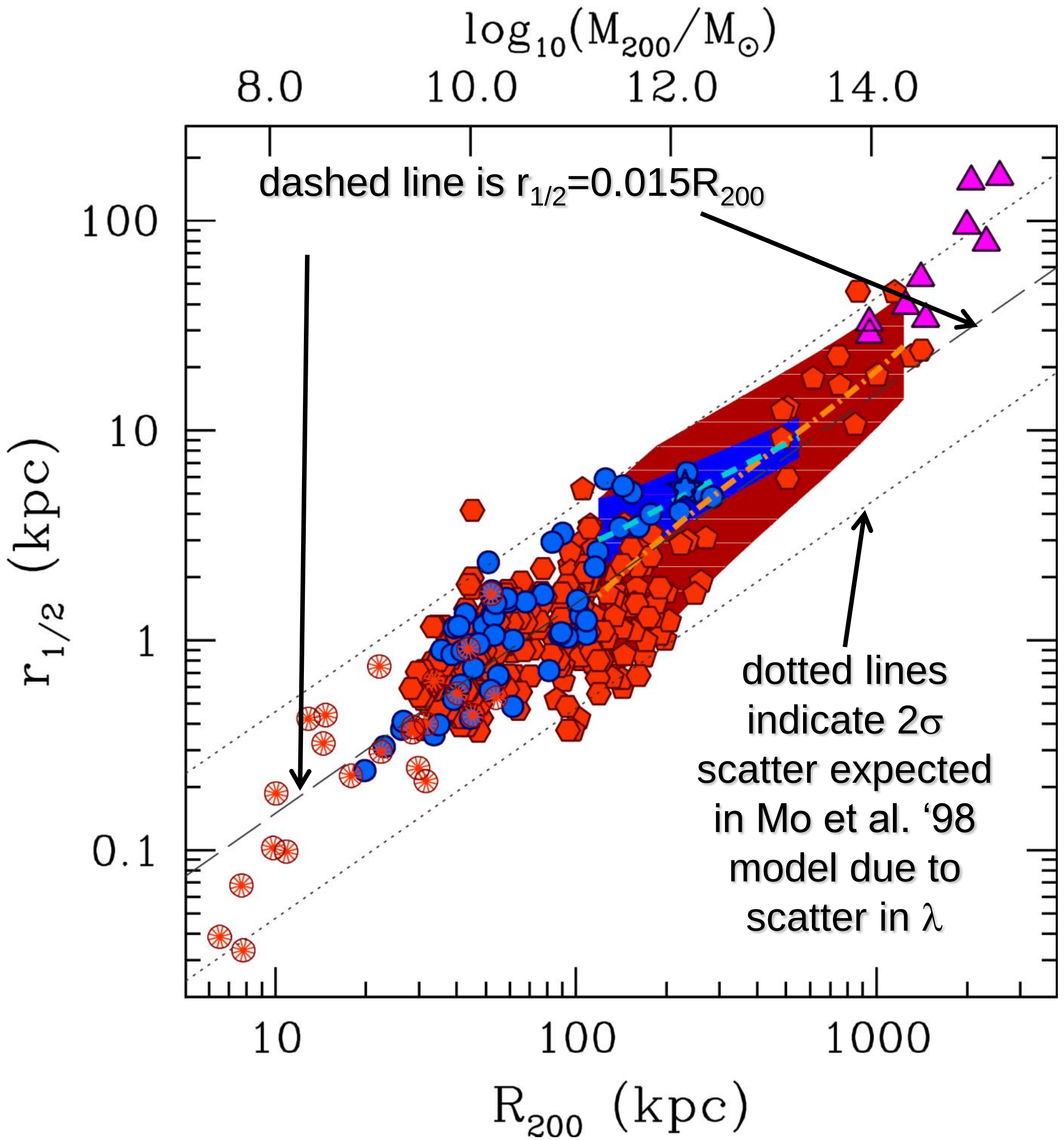


3D stellar half-mass radius of galaxies

halo virial radius

Size-virial radius relation of galaxies

Kravtsov 2013, ApJL 764, 31; Kravtsov et al. 2014, arxiv/1401.7329



Samples of galaxies chosen to cover a wide range of stellar masses and morphologies:

blue points = late type galaxies from the THINGS and LITTLE THINGS samples (Leroy et al. '09; Zhang et al. '12)

red points = spheroidal galaxies from different sources (Hilker & Misgeld '11; Szomoru et al. '12, etc.)

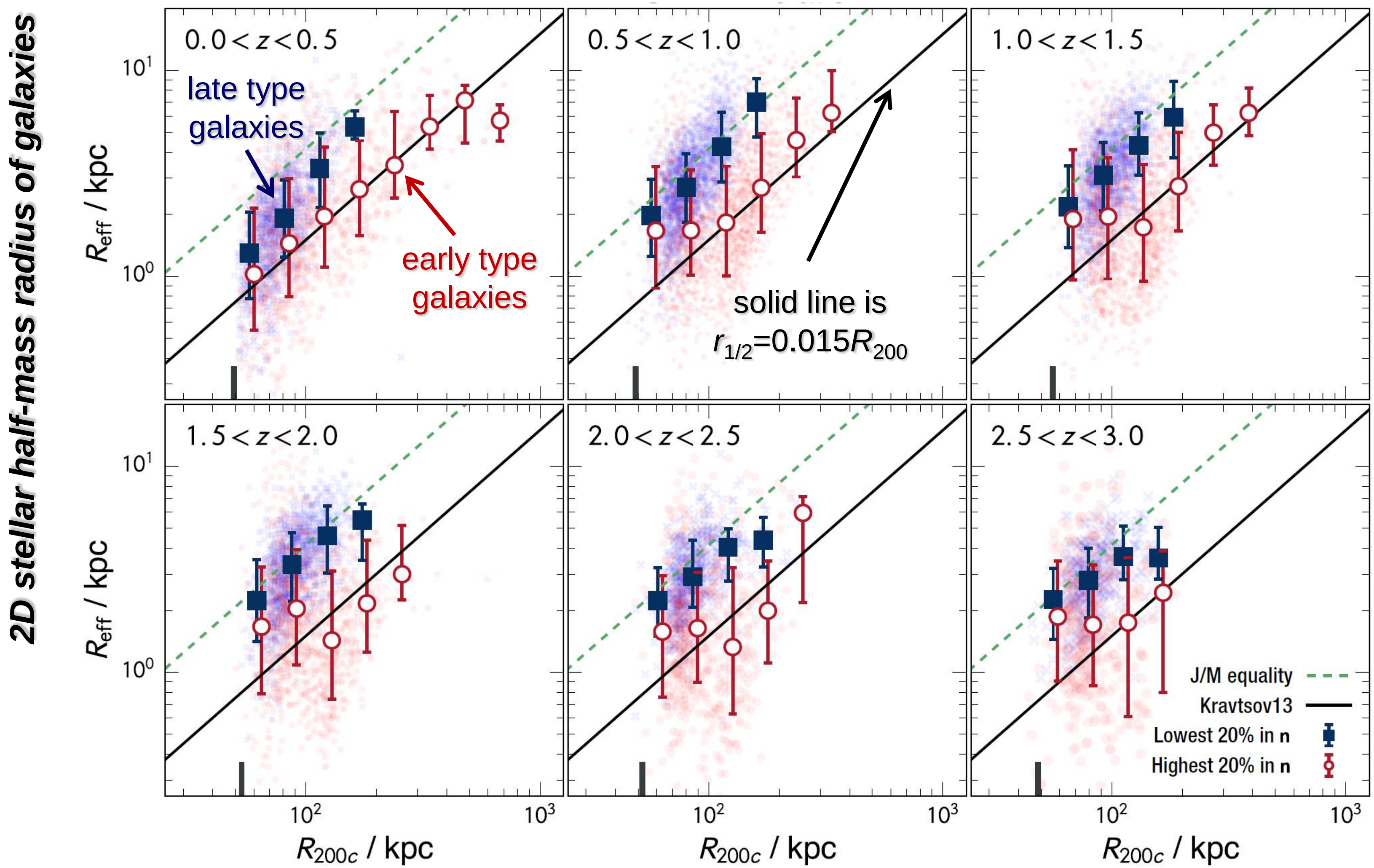
blue and orange lines are median relations for the late and early type galaxy samples of Bernardi et al.'12 and Szomoru et al. '12

magenta points = BCGs from Kravtsov, Vikhlinin & Mescheryakov '14

galaxy size – stellar mass relation: evolution

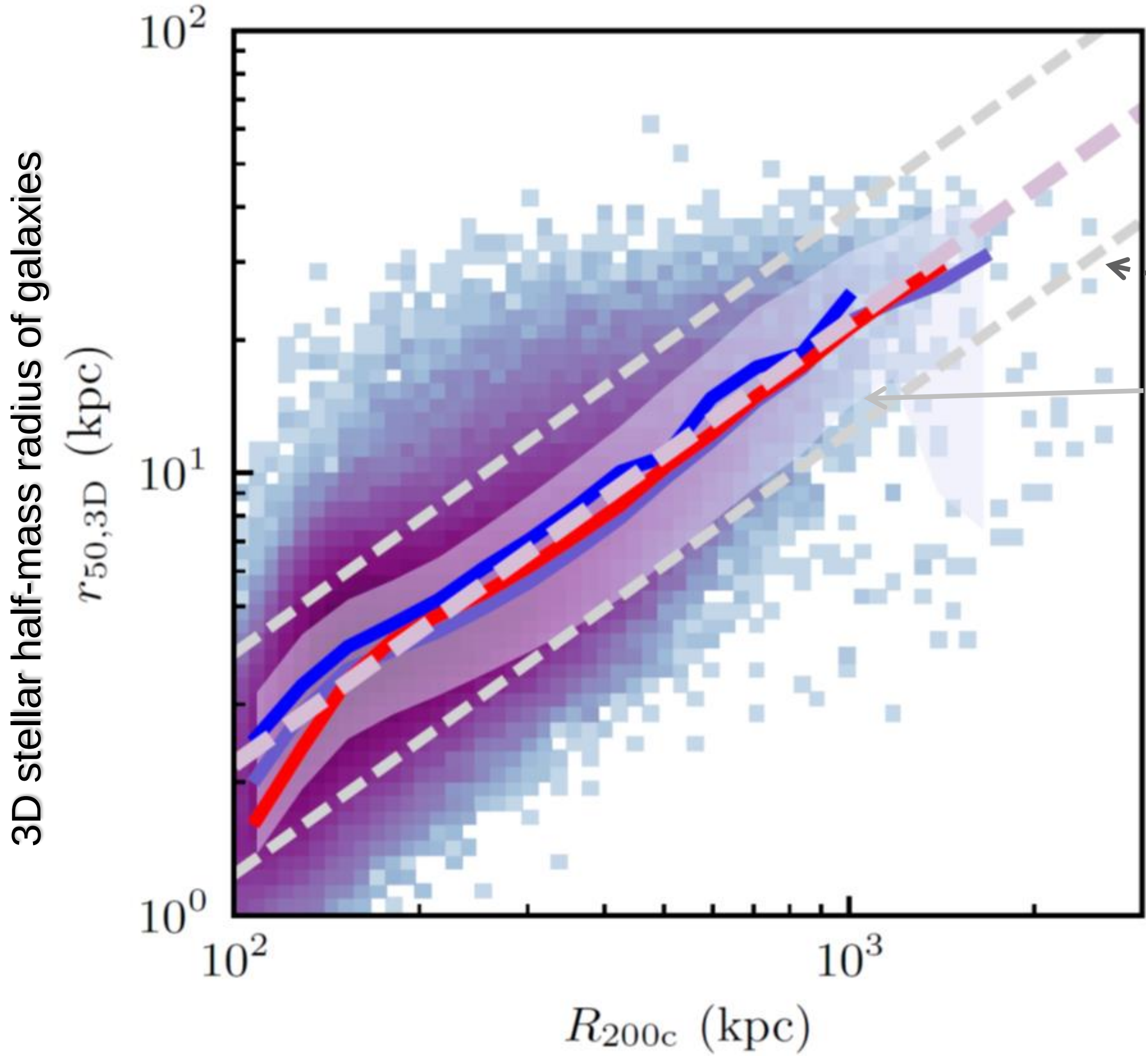
Kawamata+ 2014, Schibuya+ 2015
Huang, Fall+ 2017, ApJ 838, 6; Somerville+ arxiv/1701.0352;

galaxies at higher z follow relation close to linear, amplitude evolves slowly, but late and early type galaxy relations are offset from each other



galaxy size – virial radius relation of SDSS galaxies: scatter

scatter in half-mass radius is close to expectation of the Mo, Mao & White (1998) model and distribution of spin parameters of dark matter halos



halo virial radius

shaded band = 68% percentile range of all SDSS galaxies + assuming 0.16 dex scatter in M* at a fixed M200c

$$j_{200} = \lambda R_{200} V_{\rm circ}(R_{200})$$

$$V_{\rm circ}(R) = \sqrt{\frac{GM(<R)}{R}}$$

assume: $j(r_{50}) = j_{200}$

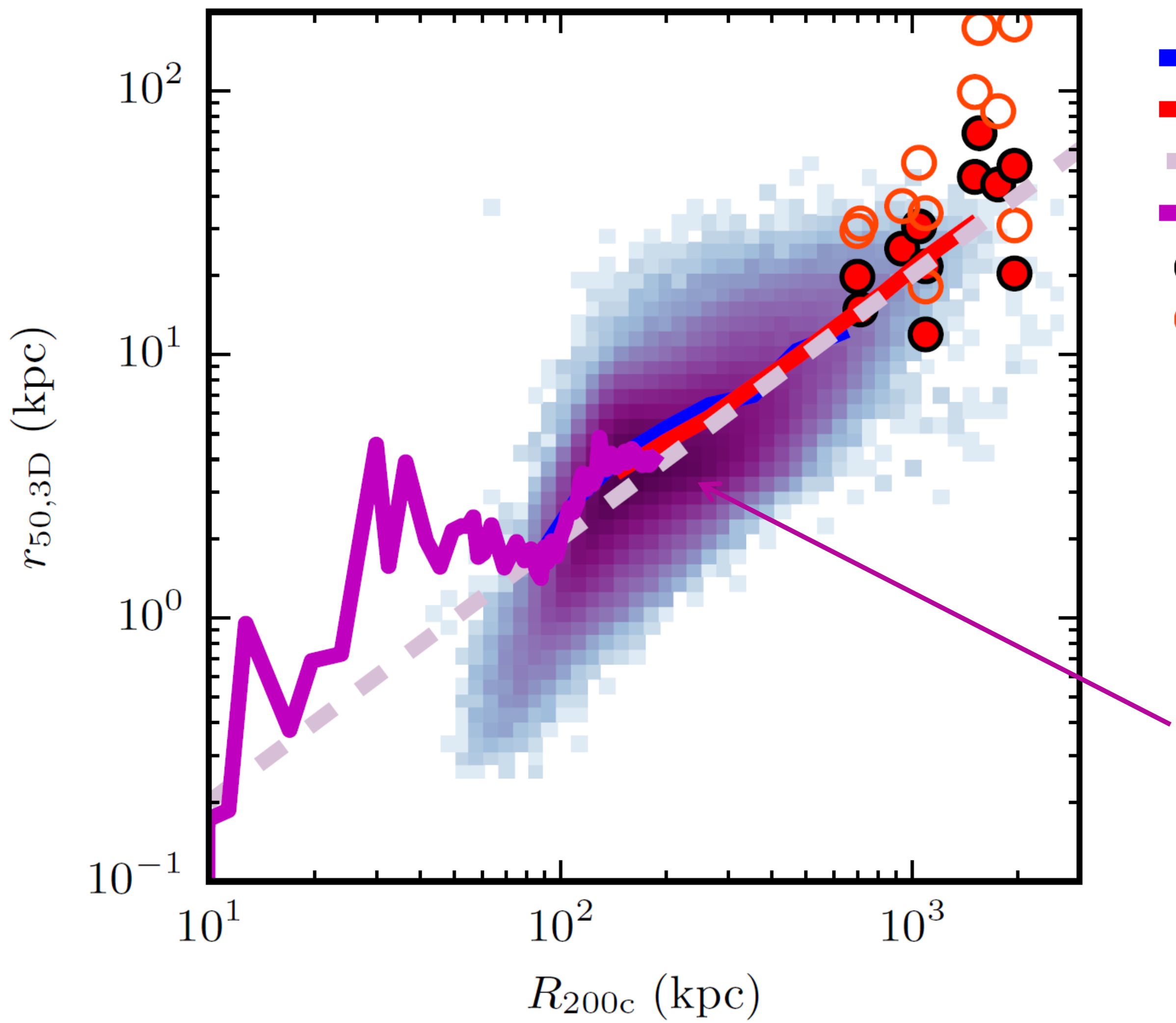
$$\rightarrow r_{50} \propto \lambda R_{200} \frac{V_{\rm circ}(R_{200})}{V_{\rm circ}(r_{50})} \propto \lambda R_{200}$$

simulations predict: $\sigma_{\log_{10}\lambda} \approx 0.25$ dex

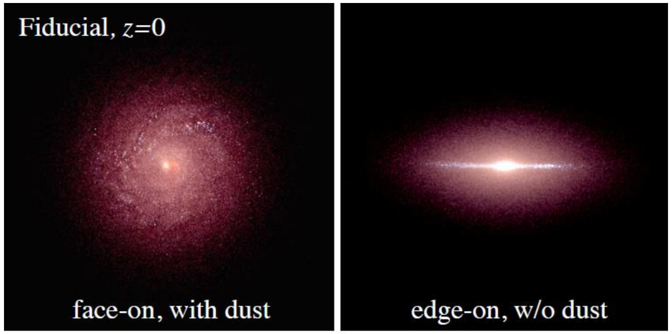
$\sigma_{\ln\lambda} \approx 0.55$

What do simulations say?

Modern galaxy formation simulations with efficient feedback
have galaxies evolving along observed Reff-M* relation;
they roughly follow z=0 r50-R200c relation, with possibly larger r50/R200c at high z
consistent with observations



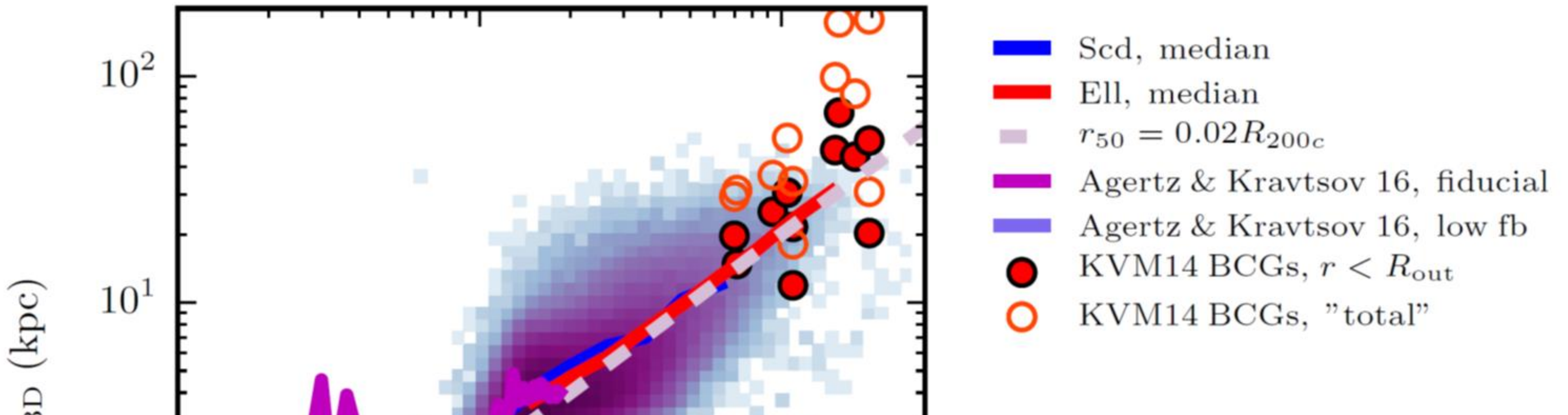
simulation of ~L* galaxy
efficient feedback



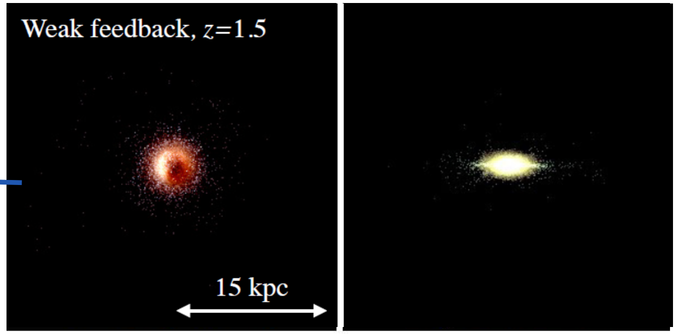
Agertz & Kravtsov 2016
ApJ 824, 79
see also Sokolowska+ '16

What do simulations say?

Galaxy sizes in simulations depend on feedback being efficient;
Simulations with inefficient feedback produce galaxies that are way too compact
(and have other properties – morphologies, stellar mass, etc – that are inconsistent with observations)

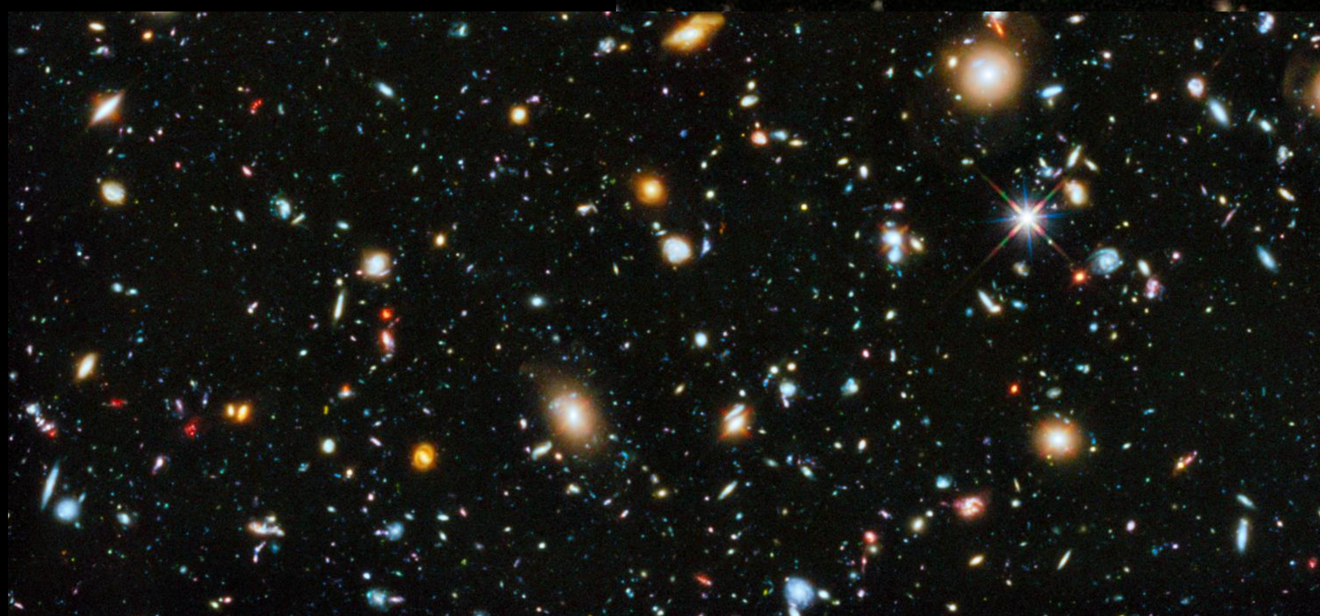


simulation of ~L* galaxy
inefficient feedback

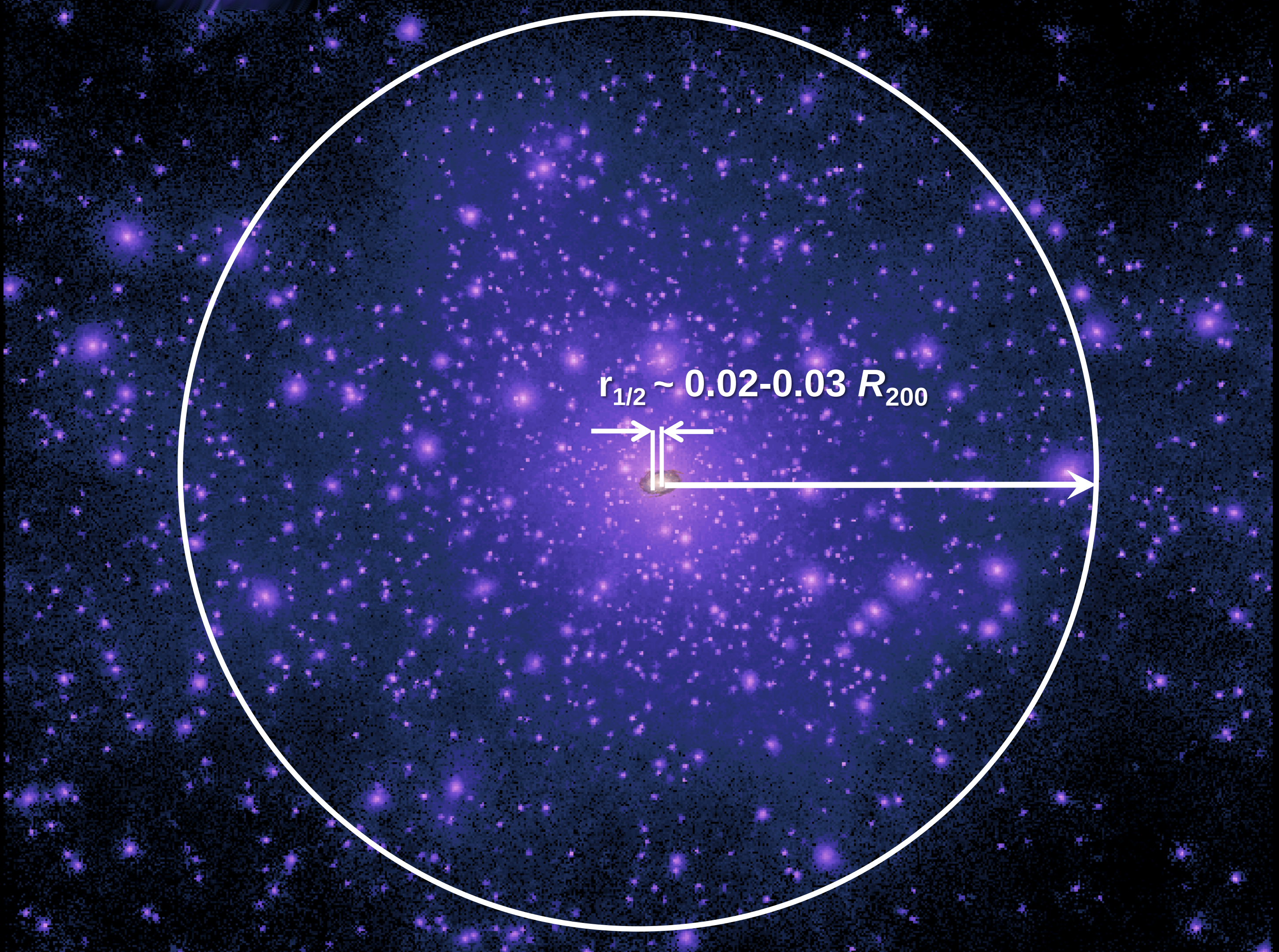


Agertz & Kravtsov 2016
ApJ 824, 79

conclusions: what do these galaxies have in common?



Their half-mass radius of stars is about ~2% of R_{200c}



halo virial mass: $M_{200} = \frac{4\pi}{3} 200 \rho_{\rm crit}(z) R_{200}^3$ ***where*** $\rho_{\rm crit}(z) = \frac{3H^2(z)}{8\pi G}$

conclusions

- normal galaxies on average have half-mass radii of stellar distribution equal to a ~0.02 of the "virial" radius R_{200} (i.e. linear $r_{1/2}$-R_{200} relation), both at z~0 and higher z.

  This is consistent with simple picture of galaxy formation, but we know from simulations that the actual evolution is not simple and is mediated by galactic outflows.
  Why does this work for both late and early type galaxies?

- connecting observed sizes to the halo extent is a useful way to connect galaxy evolution to evolution of host dark matter halos and processes associated with galaxy/halo evolution.

Size-virial relation: Kravtsov 2013, ApJL 764, L31
Kravtsov 2017, in prep.
Modeling: Agertz & Kravtsov, 2016, ApJ 824, 79