Feedback in a 100Mpc box: the Illustris simulation

Shy Genel

ITC/Harvard

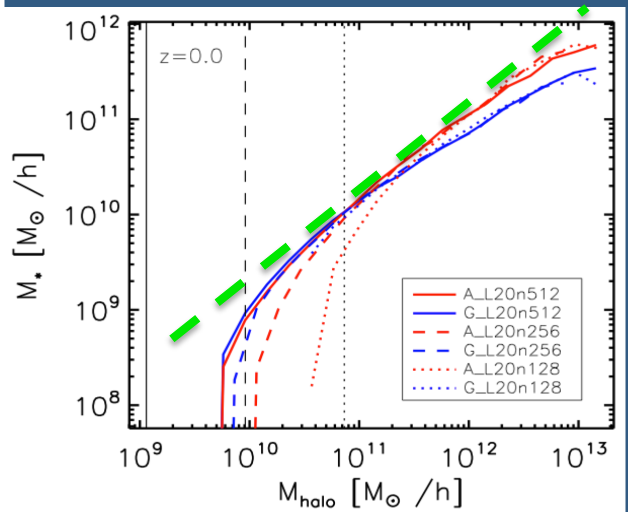
Hernquist, Sijacki, Springel, Torrey, Vogelsberger

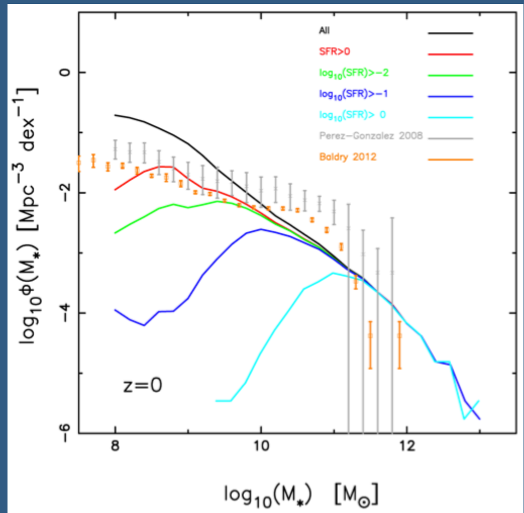
Can realistic galaxies form in ΛCDM?

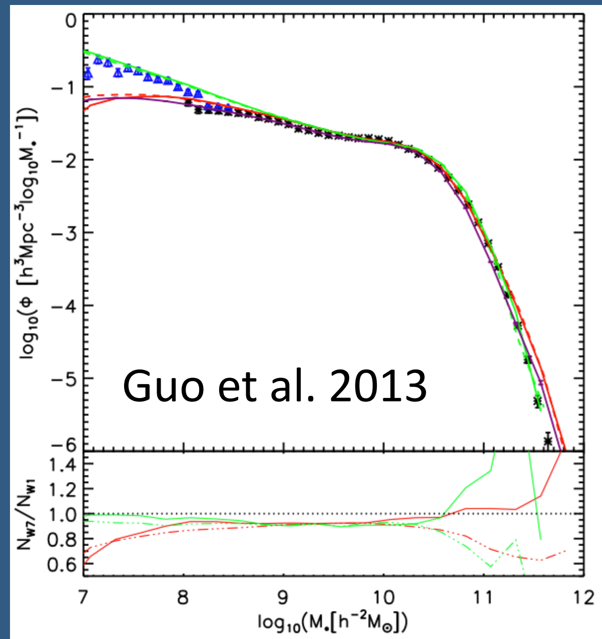
Khandai et al. 2014

SAM

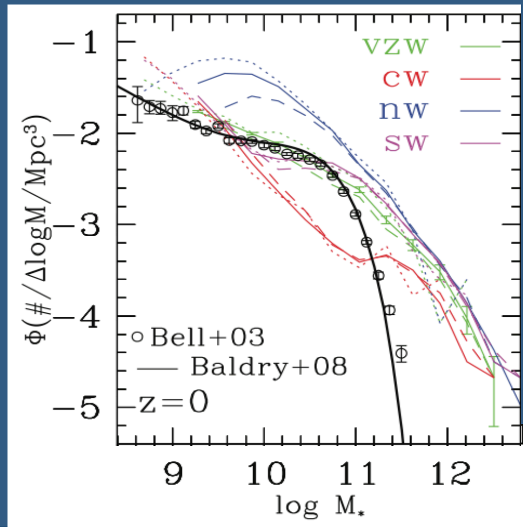
Hydro, no winds







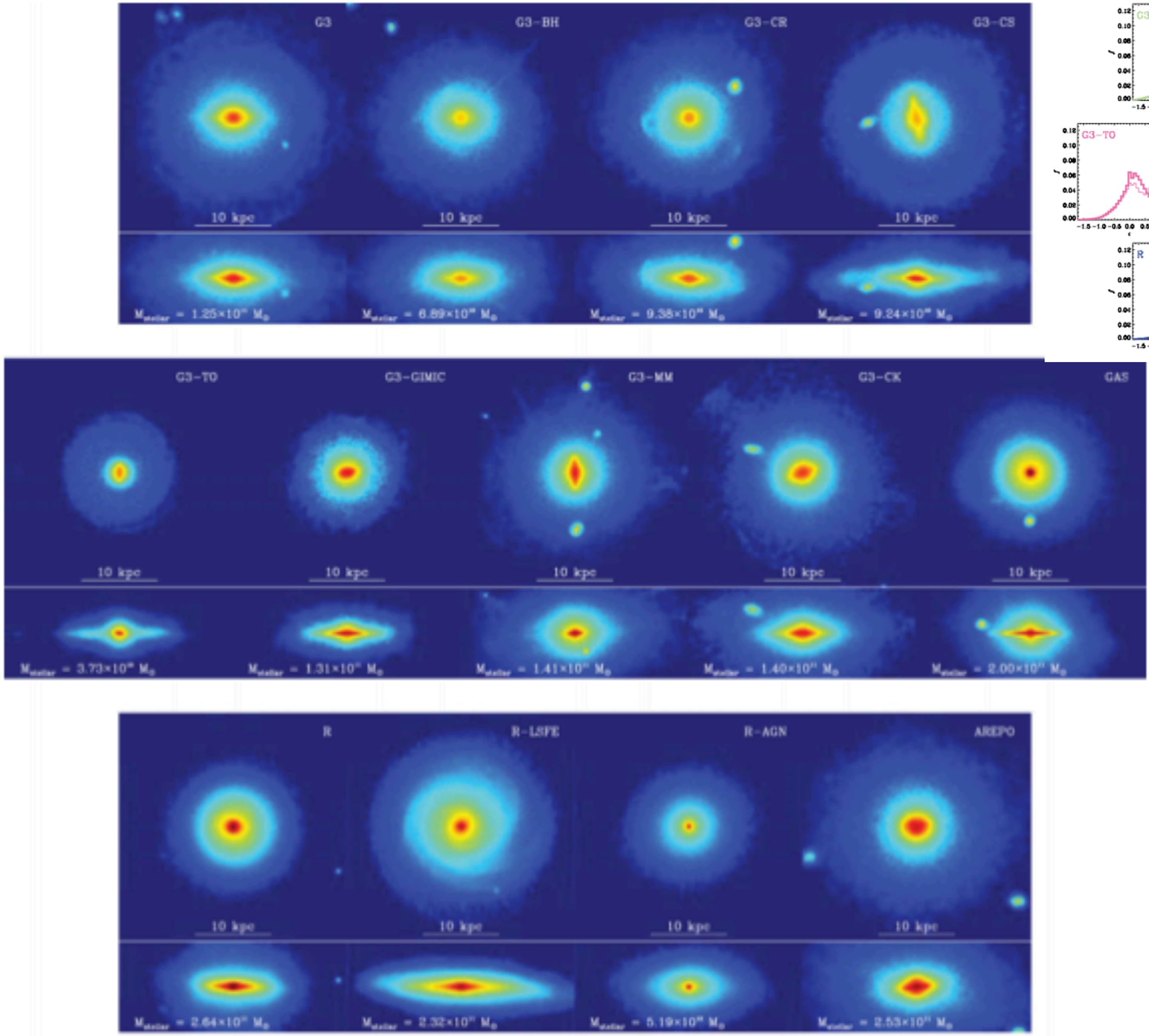
Hydro, with winds

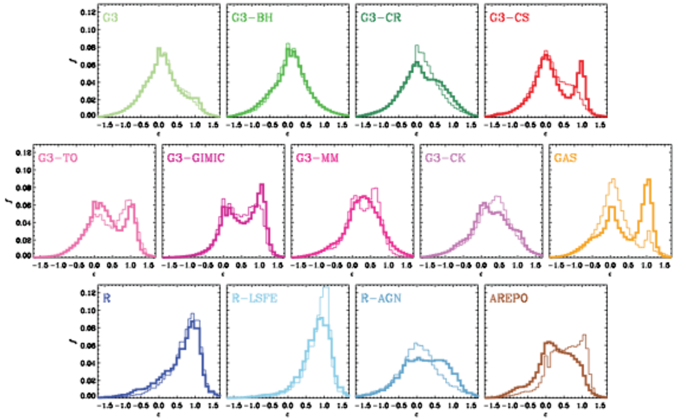


Kereš et al. 2012

Davé et al. 2011

Can realistic galaxies form in ΛCDM?





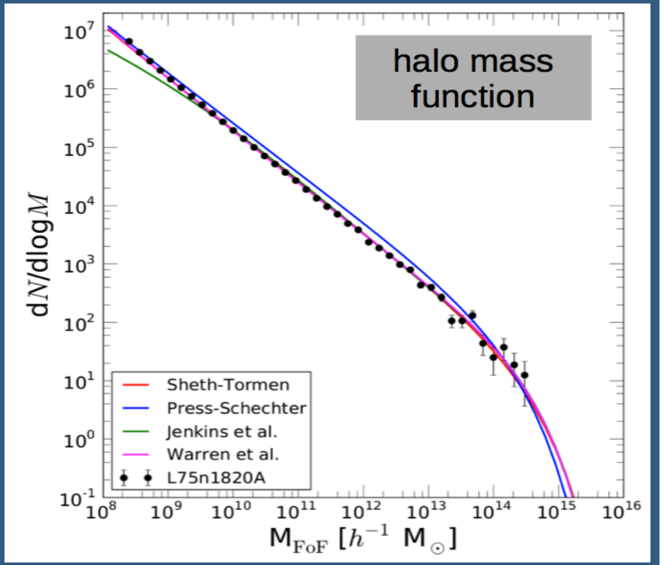
Scannapieco et al. 2012

"Aquila" comparison project:

Problem forming a disk, even with feedback

The Illustris Simulation

- A (106.5 Mpc)^3 box run to z=0
- Baryonic resolution: 1.3×10^6 M$_{sun}$
- Resolution elements: 2×1820^3
- N-body+hydro with Arepo



- Galaxy formation physics (SF, winds, AGN…)
- Gravitational spatial resolution: 0.7-1.4 ckpc
- WMAP-7 cosmology
- 10 M>10^{14}M$_{sun}$ halos @ z=0
- >10^3 M≈10^{12}M$_{sun}$ halos @ z=0

Vogelsberger, Genel et al. 2013

Galaxy formation physics

- Galactic winds

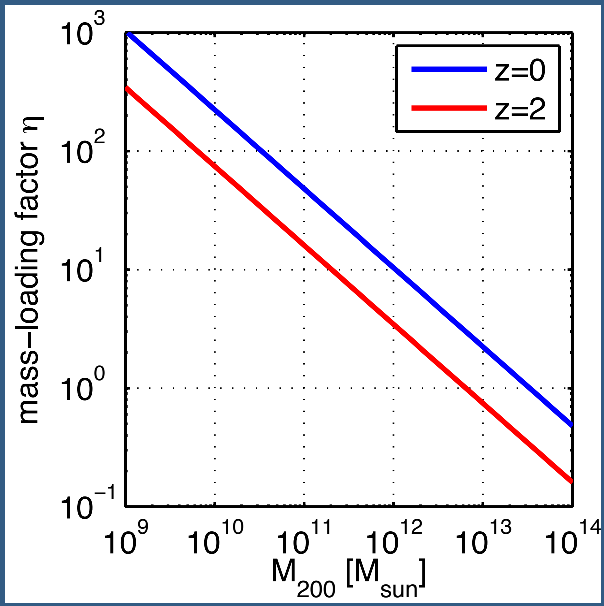
(à-la Springel & Hernquist 2003)

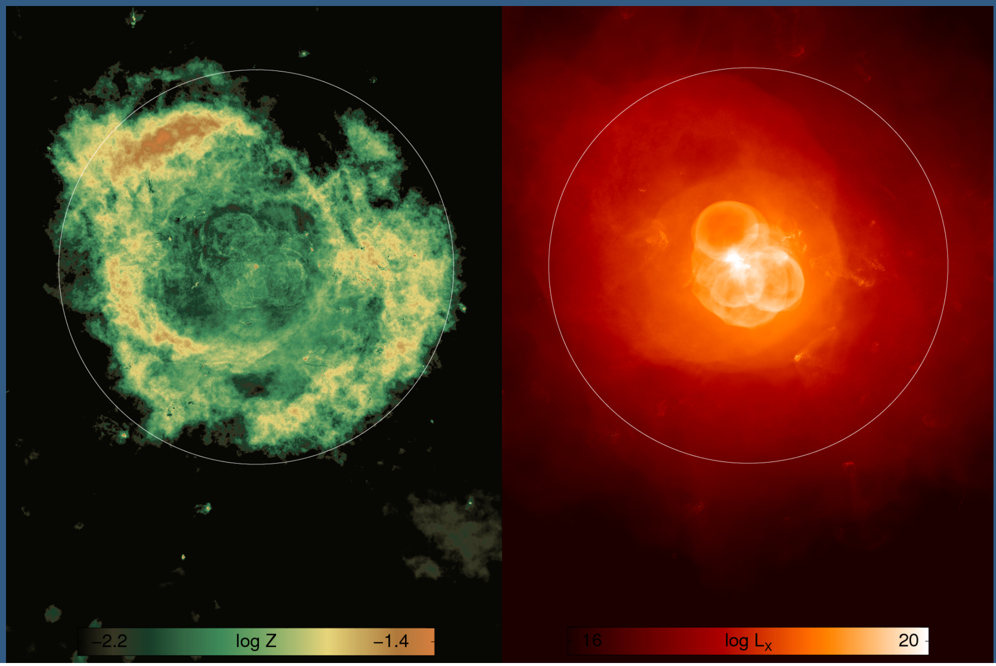
  - Kinetic
  - Energy scaling, using 1.1×10^{51}erg/SN
  - Decoupled

- Black Holes

(à-la Springel 2005, Sijacki 2007)

  - Bondi accretion & mergers
  - Thermal ('quasar-mode'), bubble ('radio-mode'), and radiative feedback

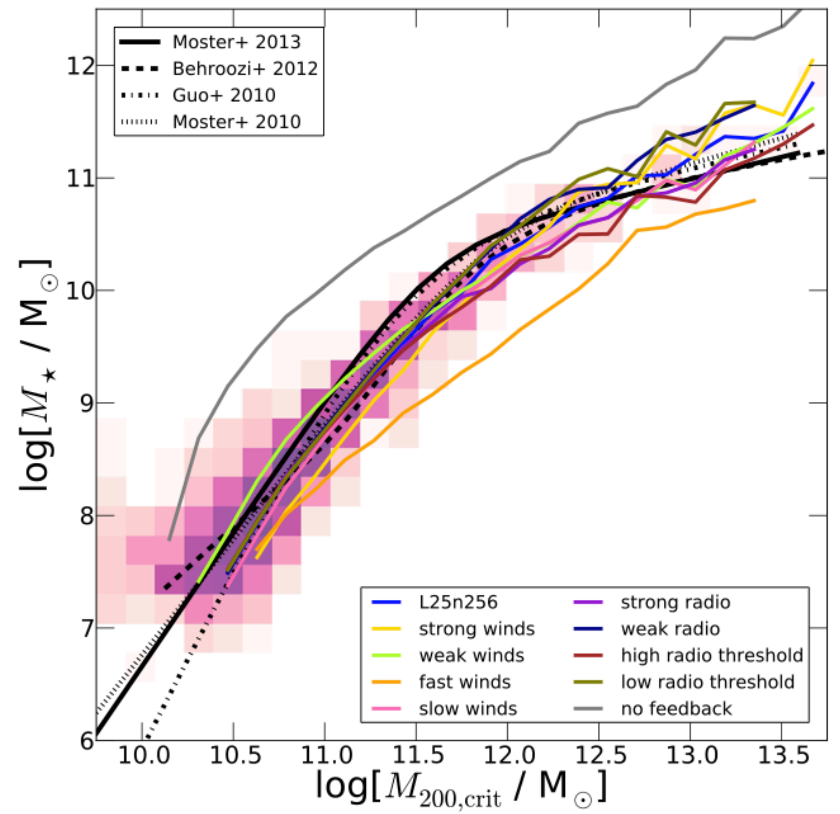




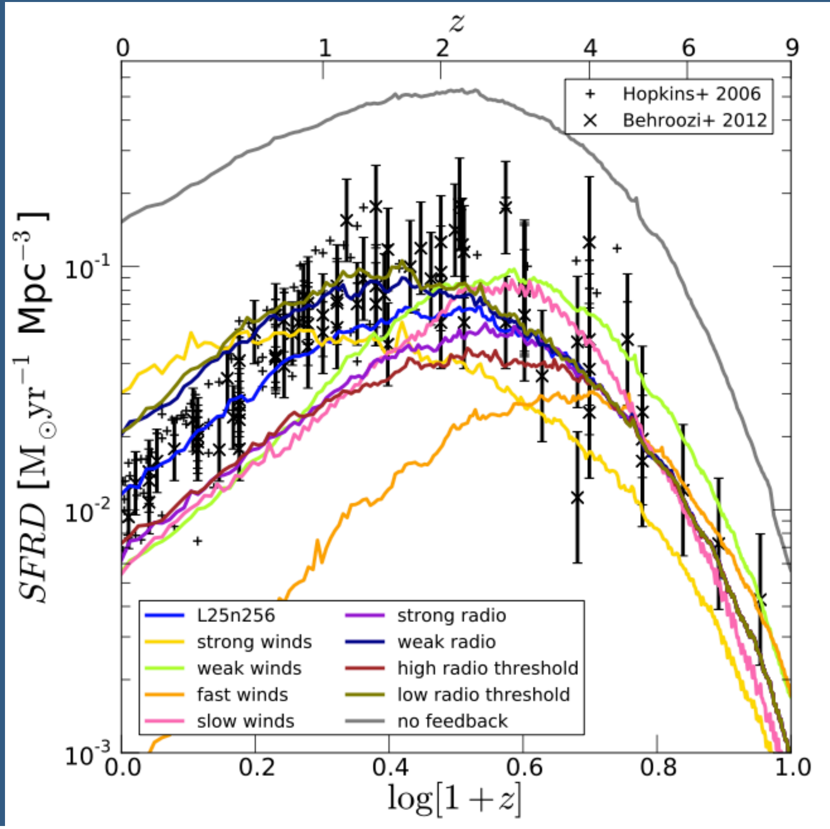
Tuning feedback parameters

Constraints used for tuning feedback parameters:

Baryon conversion efficiency



Cosmic SFR density



Vogelsberger, Genel et al. 2013

stars

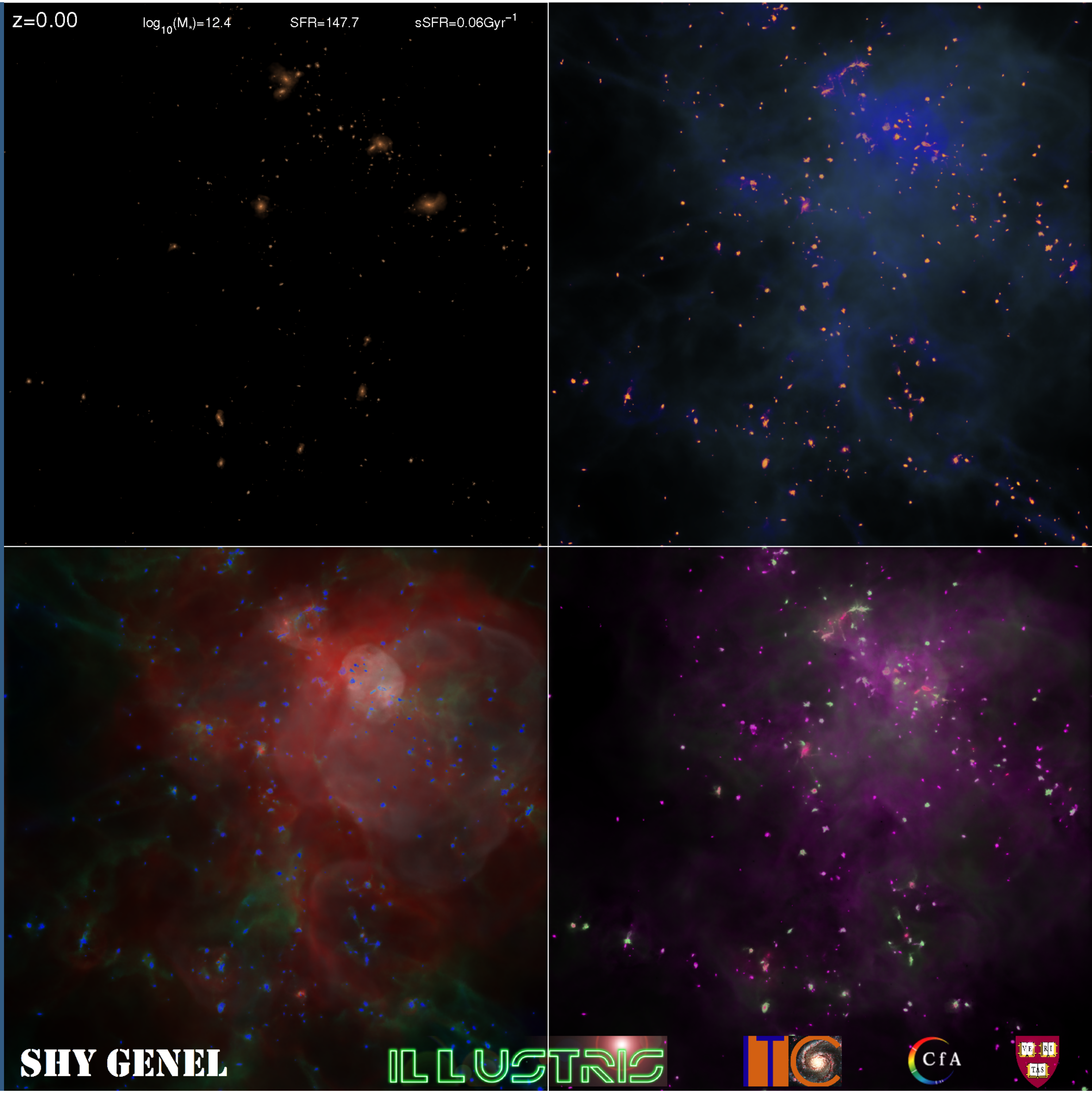
ρ_{gas}

T_{gas}

Z_{gas}

stars

ρ_{gas}



T_{gas}

Z_{gas}

Results

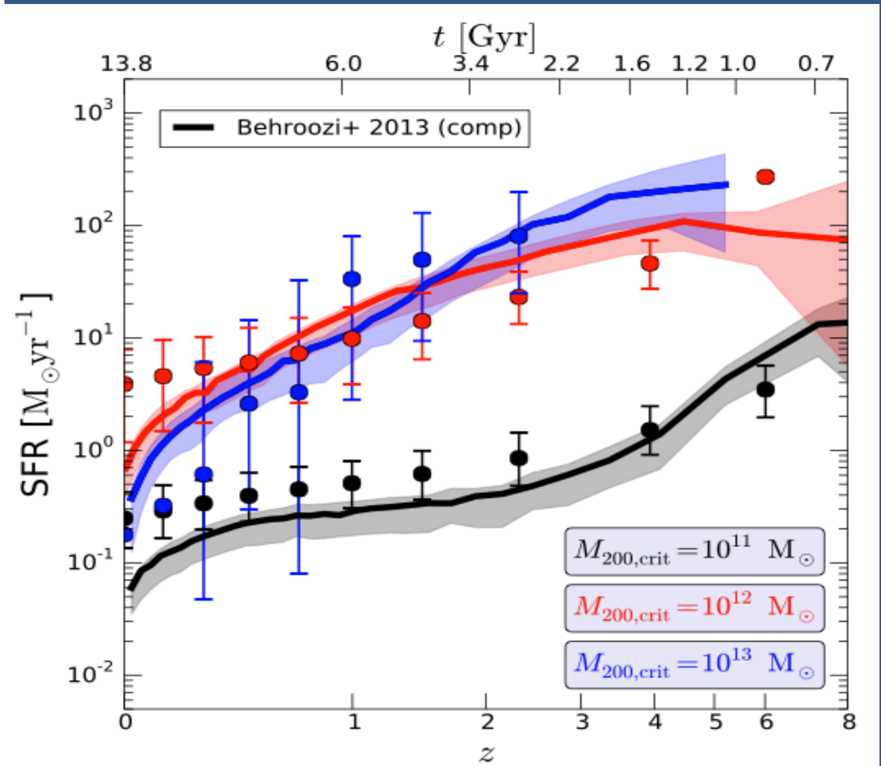
I. Galaxy bimodality

Cosmic star-formation rate history

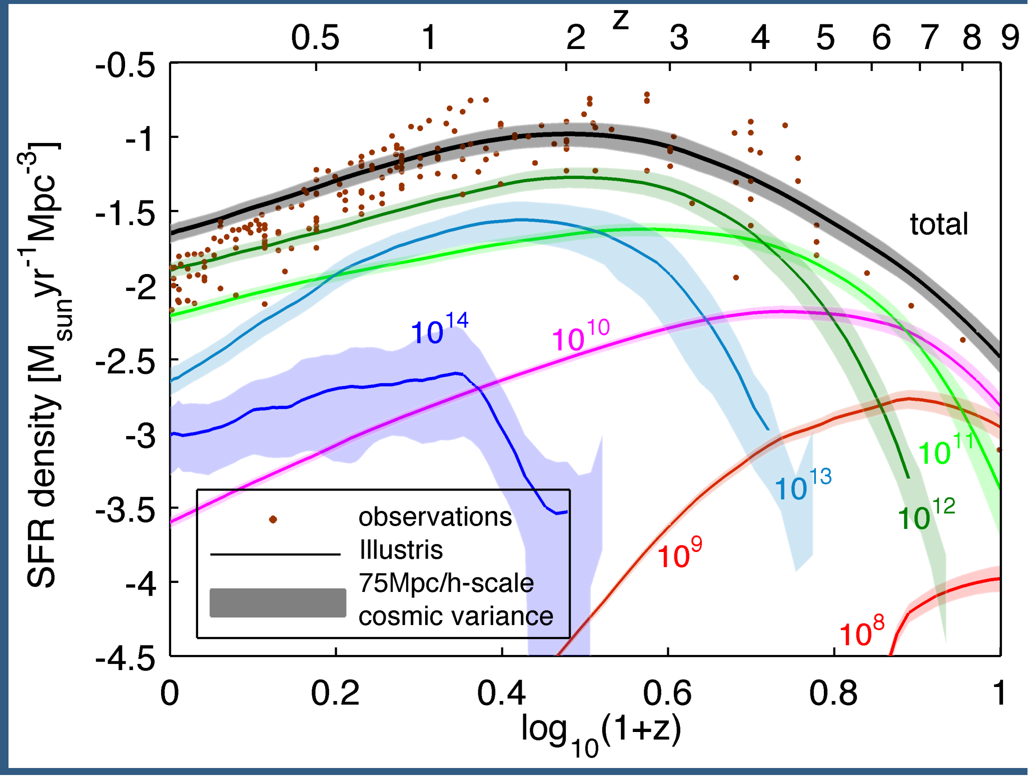
Contributions from different halo masses reproduced well,

except too much SF in 10^{11}-$10^{12}M_{sun}$ halos @ z<~1

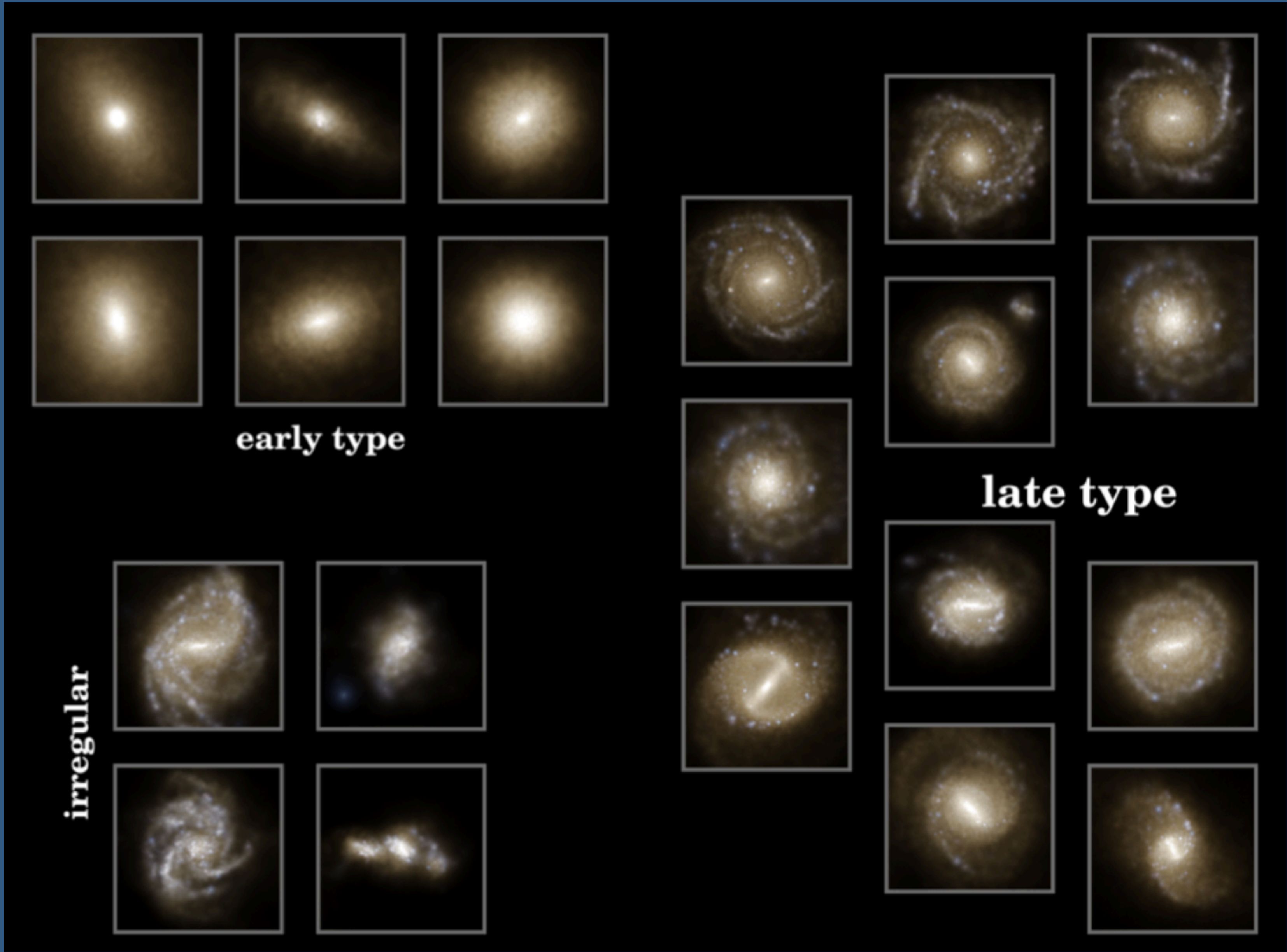
SFR in different halo masses



Cosmic SFR density

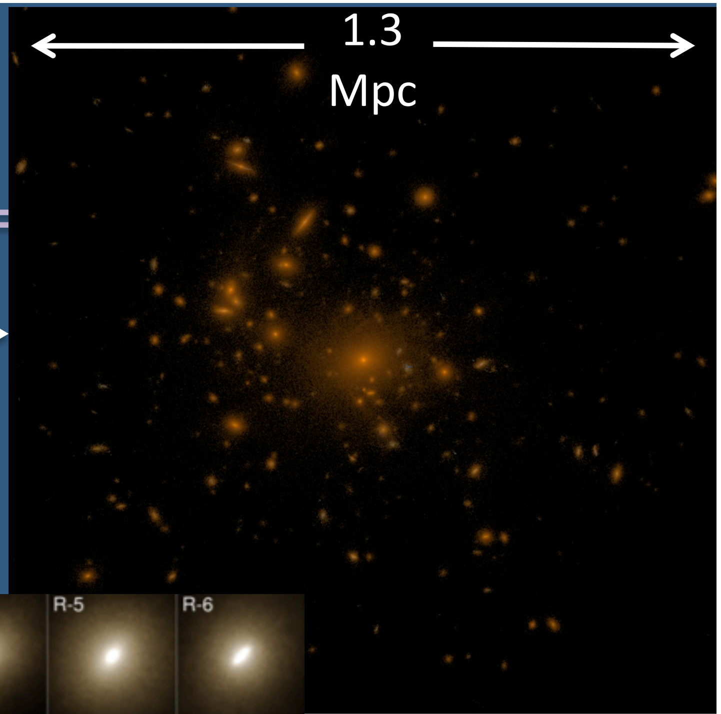


Galaxy morphological bimodality

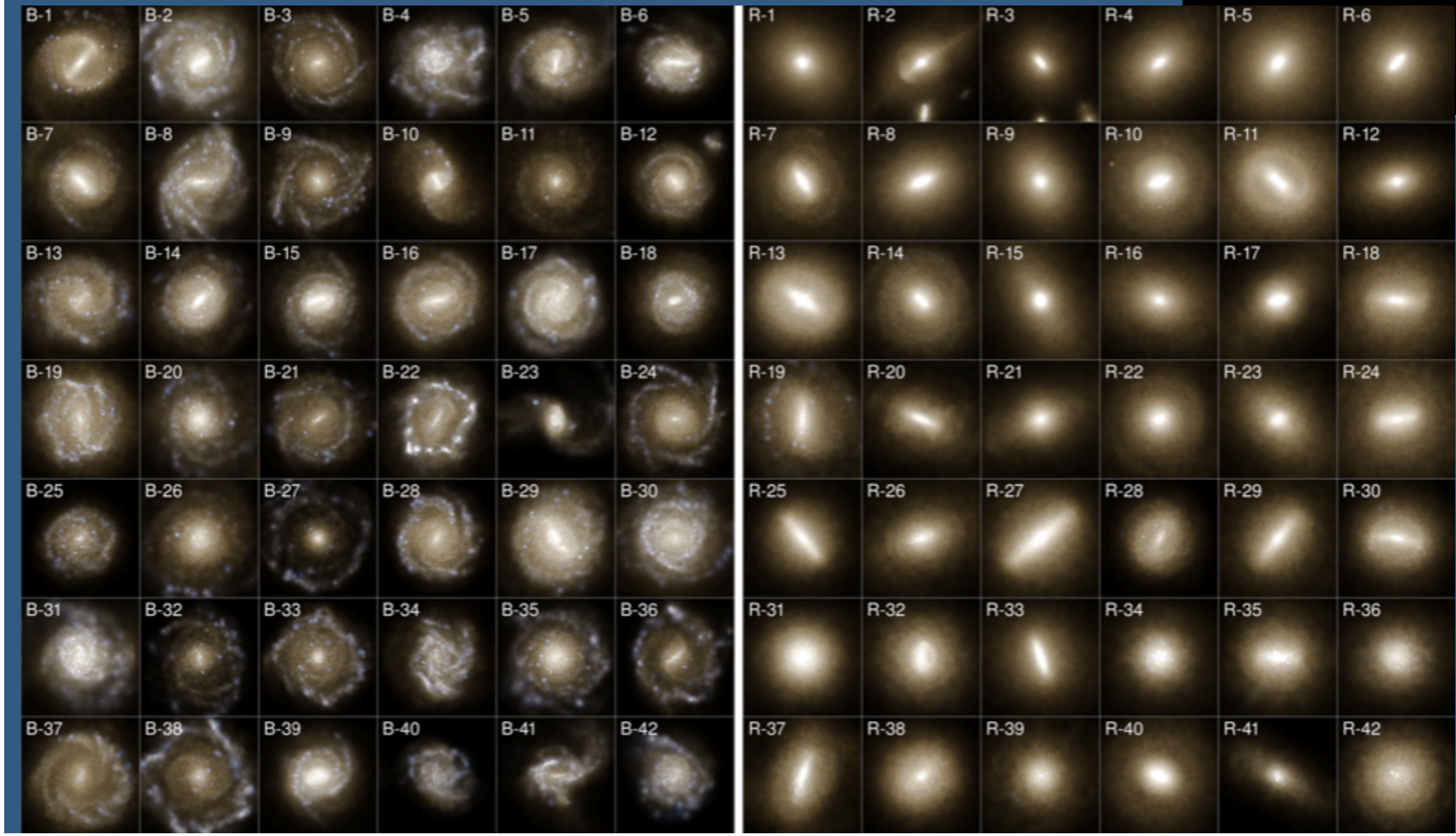


Galaxy bimodality

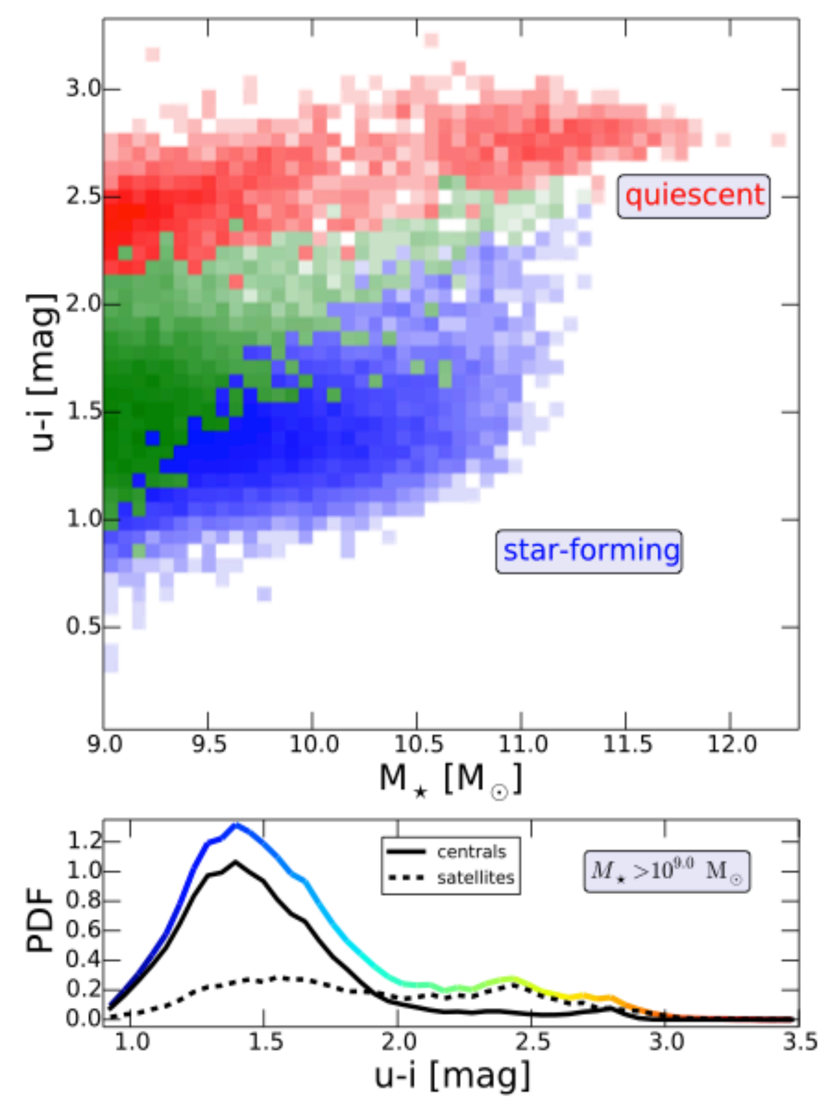
$2\times10^{14}M_{sun}$ halo

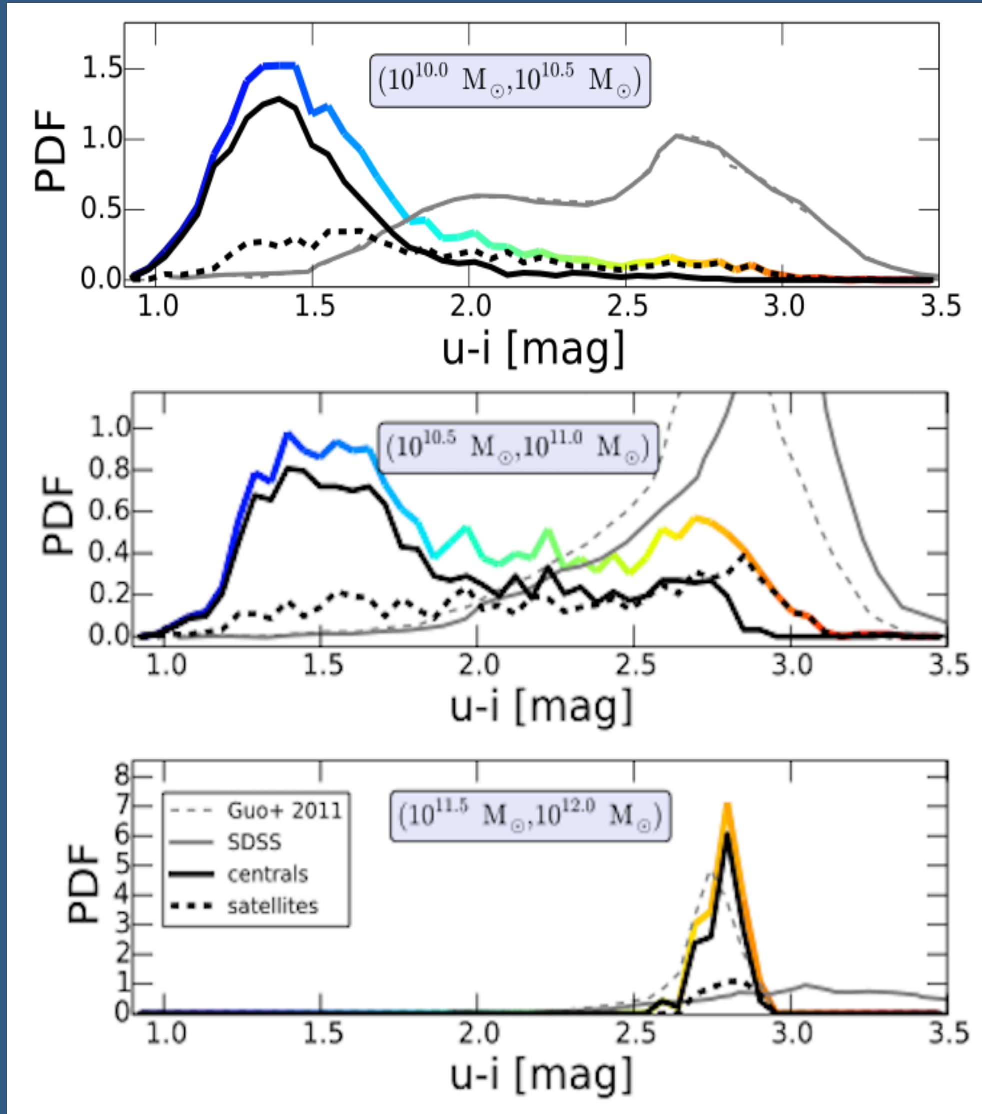


$10^{12\text{-}13}M_{sun}$ halos

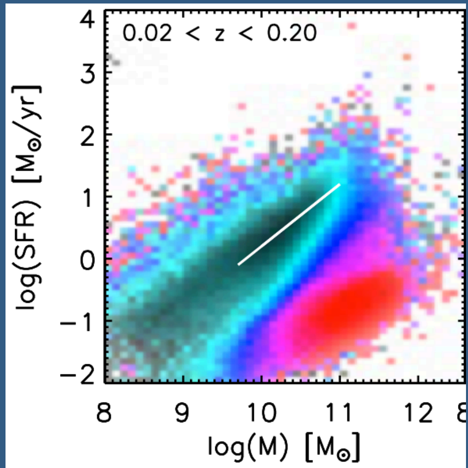


Galaxy color bimodality

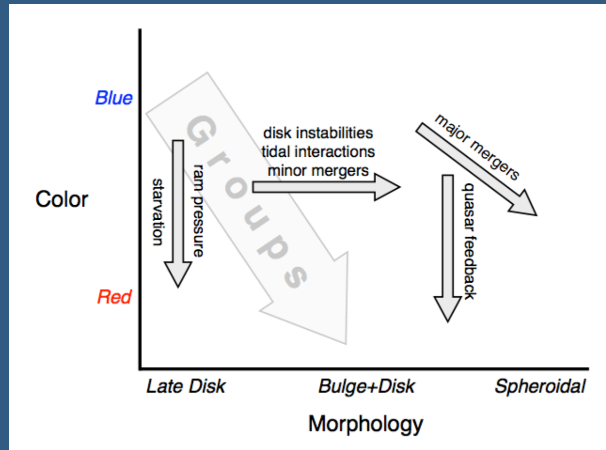




SF activity and galaxy structure at z=0

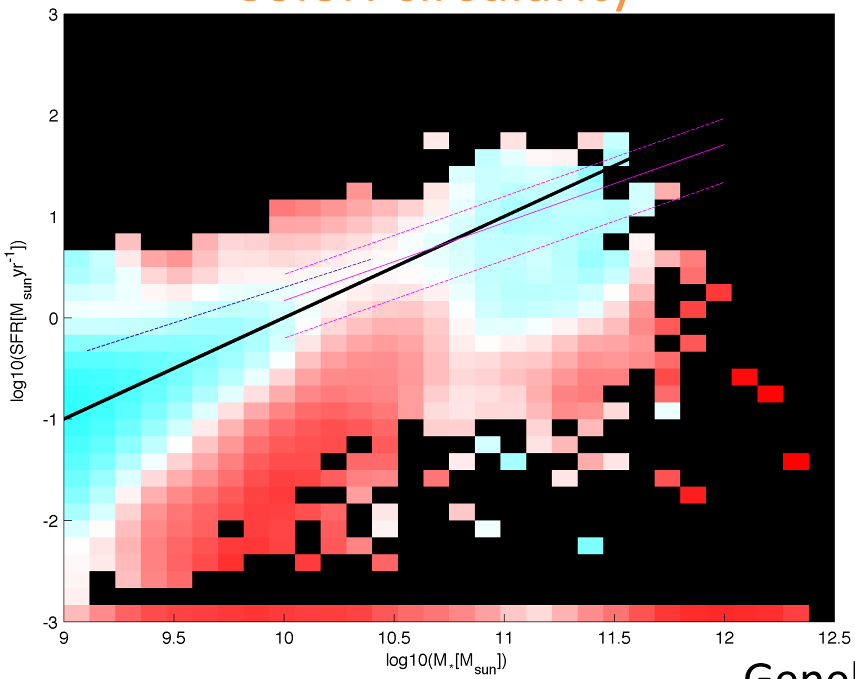


Wuyts+ 2011

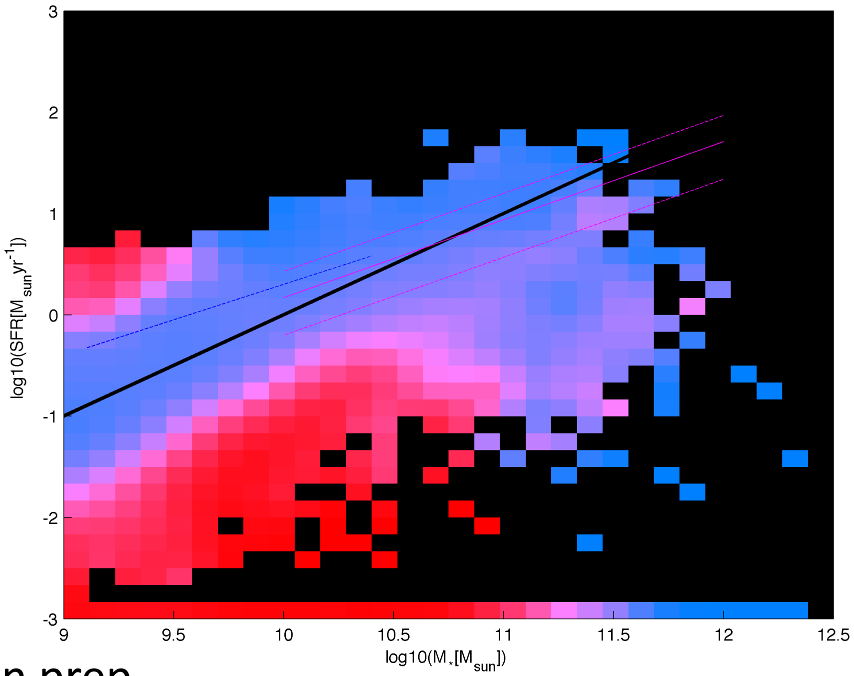


George+ 2013

Color: circularity



Color: satellite fraction

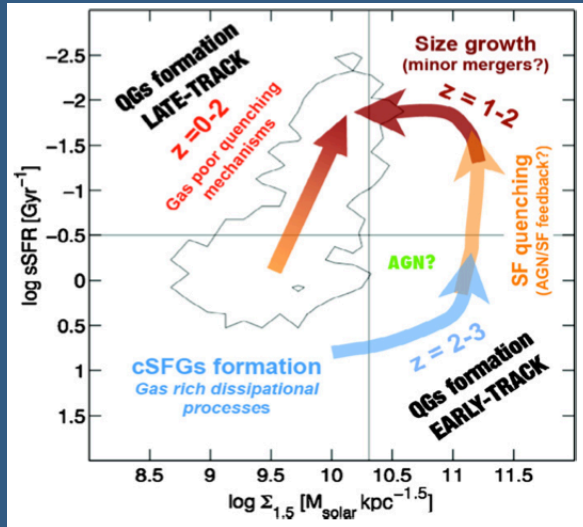


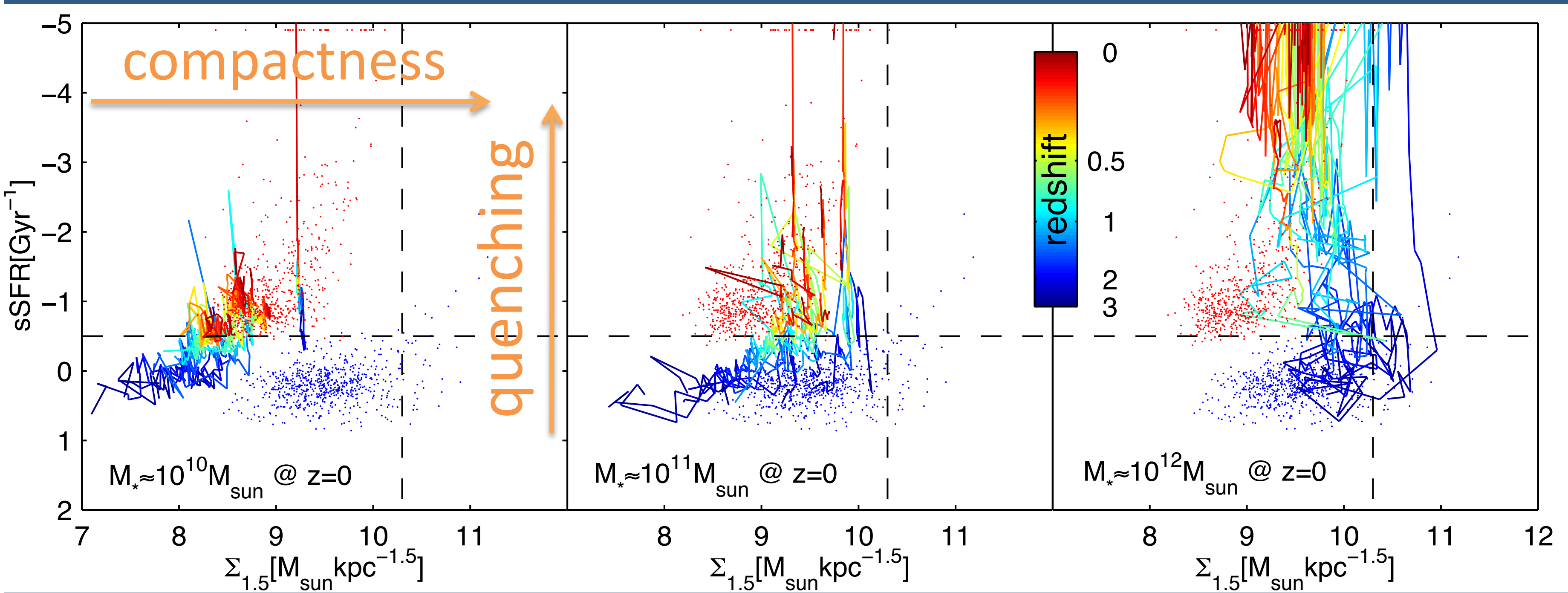
Genel et al. in prep.

Co-evolution of size and SFR

Barro+ 2013

- Massive galaxies quench early on, and then `inflate'
- Low-mass galaxies quench later, and gradually `compact'

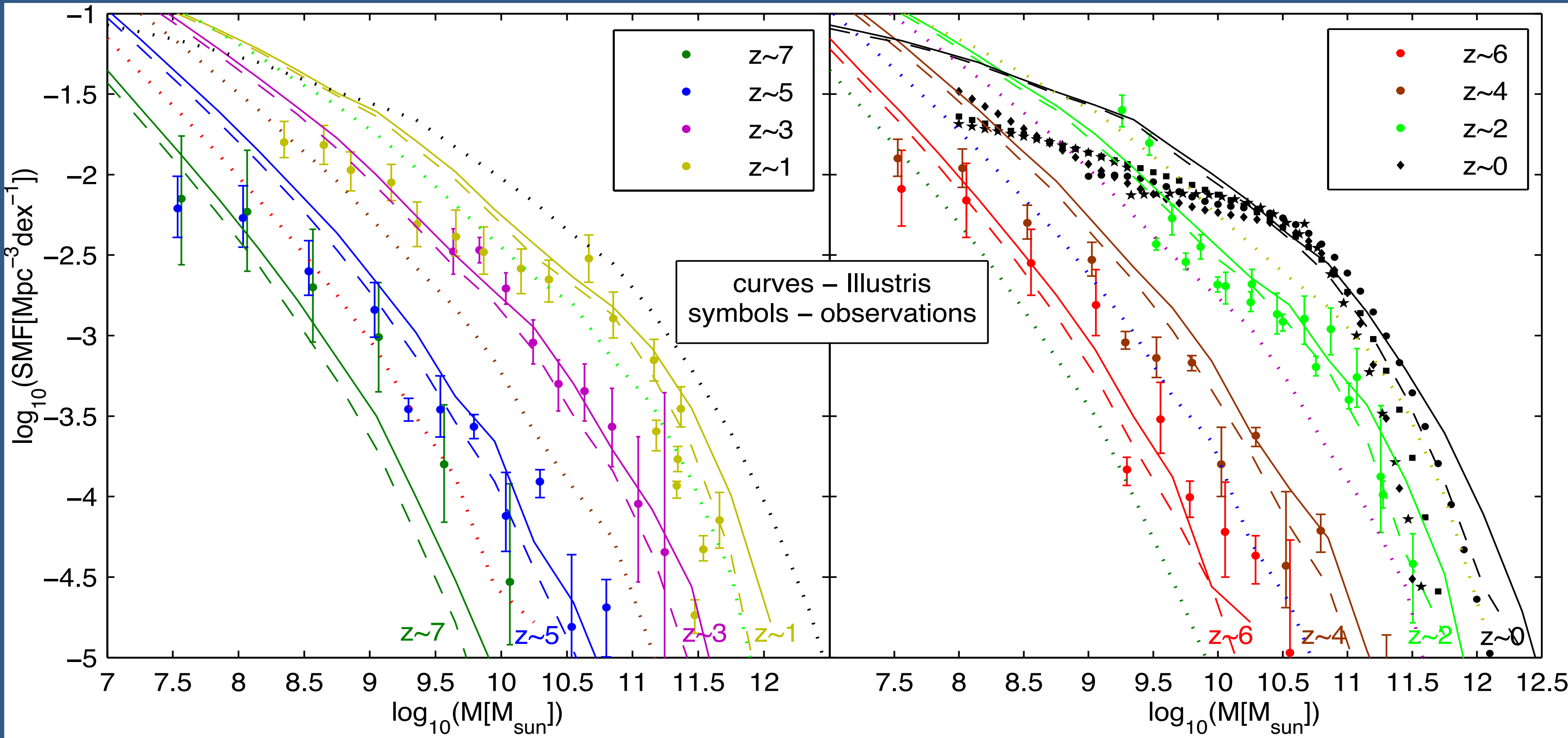




Results

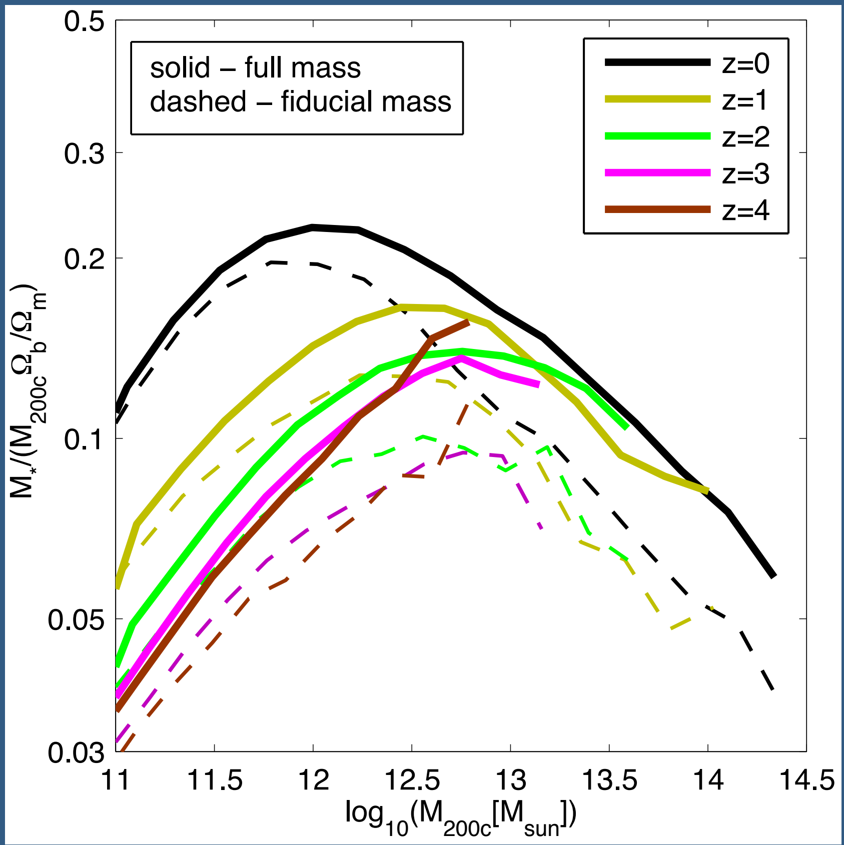
II. High-z galaxies

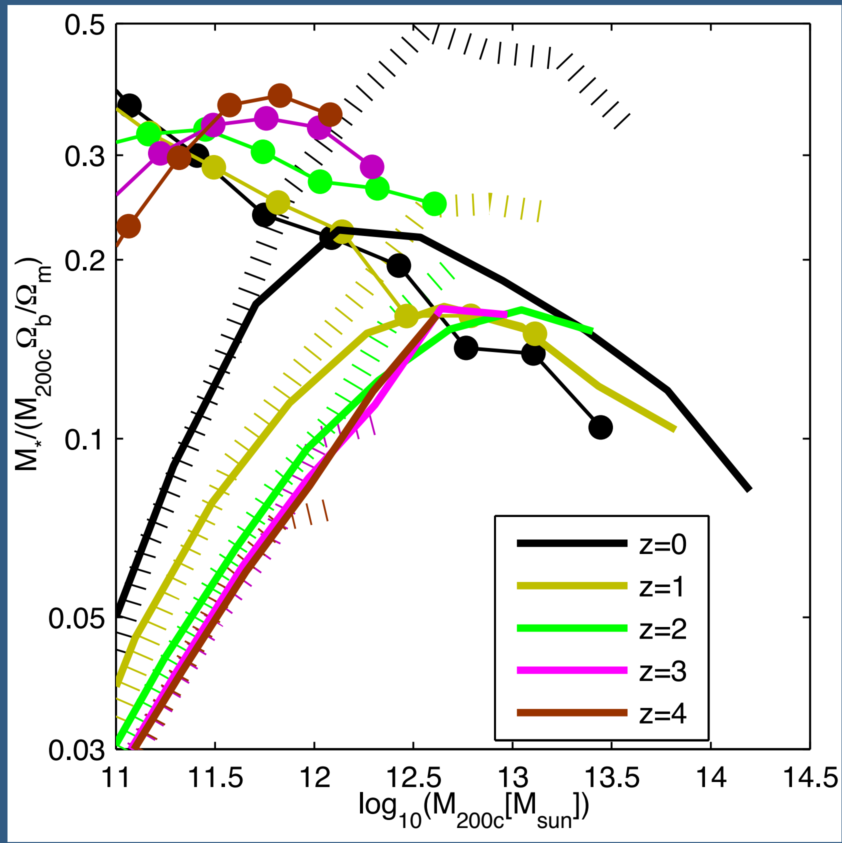
Stellar mass functions @ 0 ≤ z ≤ 7



- Potential caveats:
  - Faint-end slope too steep
  - Suppression at massive-end too weak @ z<1

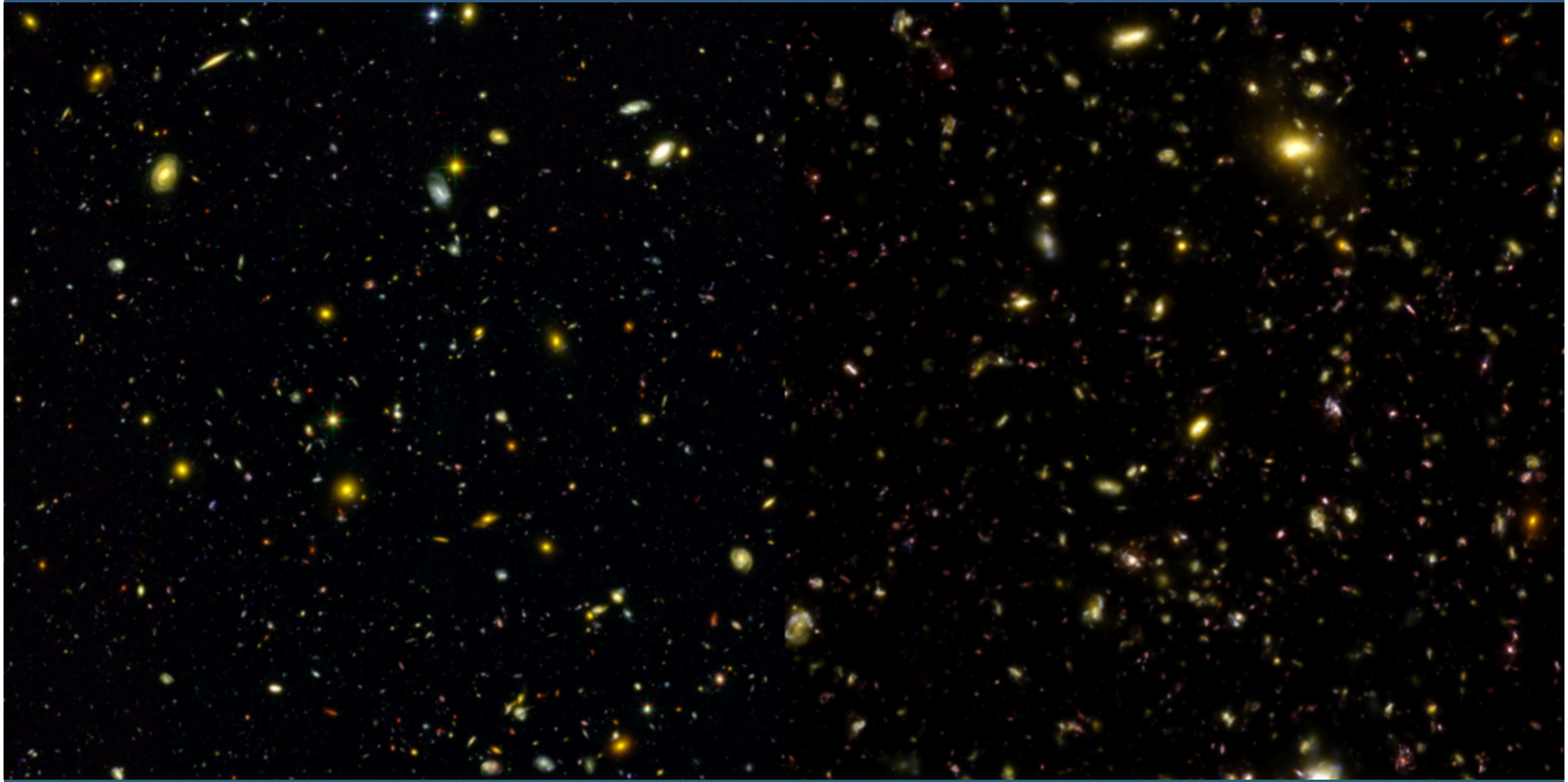
M_*-M_{halo} relation @ $0 \leq z \leq 4$





- Low-mass end: normalization increases with cosmic time
- High-mass end: no redshift evolution – conspiracy of galactic winds and AGN?

Mock HUDF



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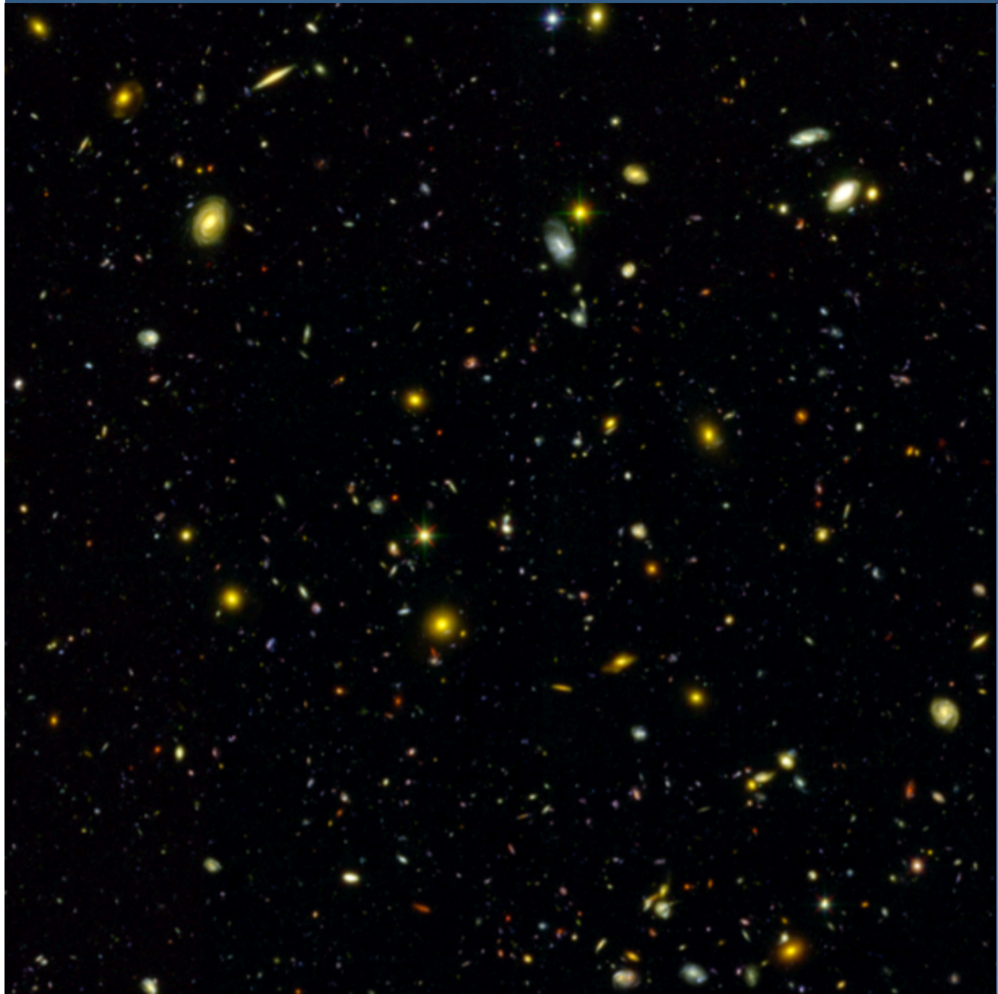
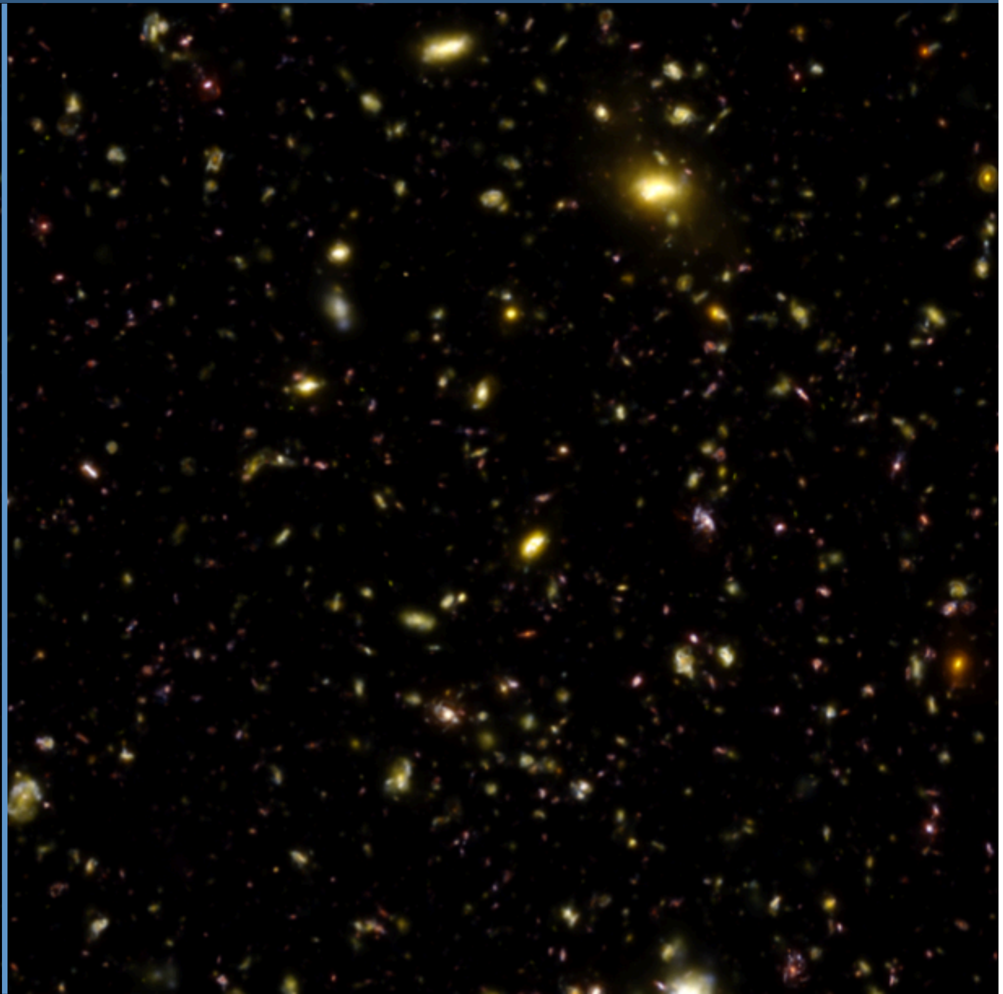


HST

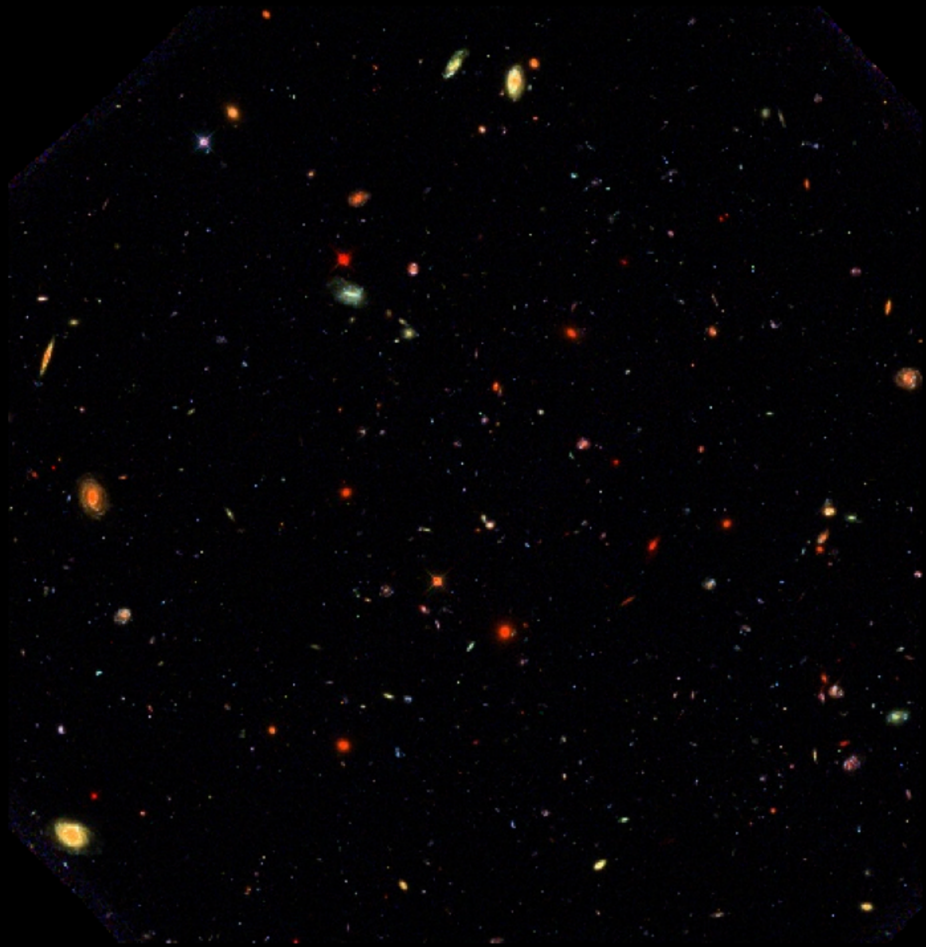


Illustris

Mock HST Deep Fields

old simulations

→ *too many stars*

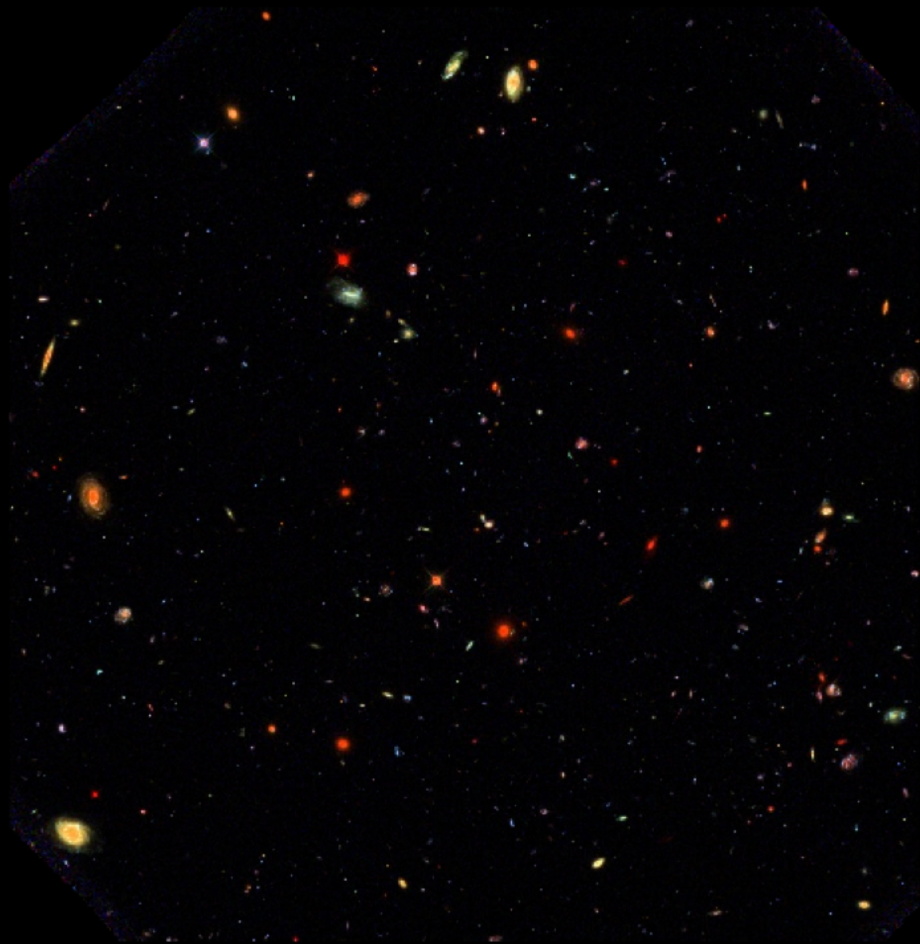


HST observation

Mock HST Deep Fields

+ metal line cooling
+ stellar mass loss

→ *even more (young) stars*

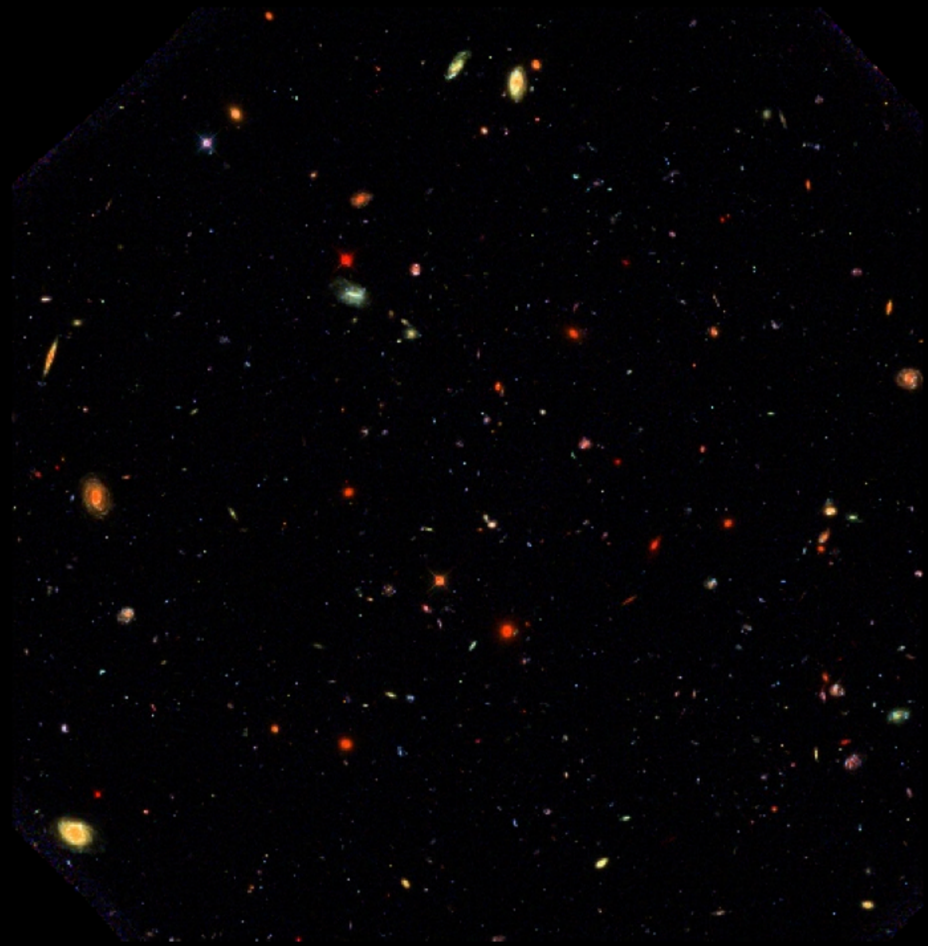


HST observation

Mock HST Deep Fields

+ SNII feedback

→ *too many blue galaxies*

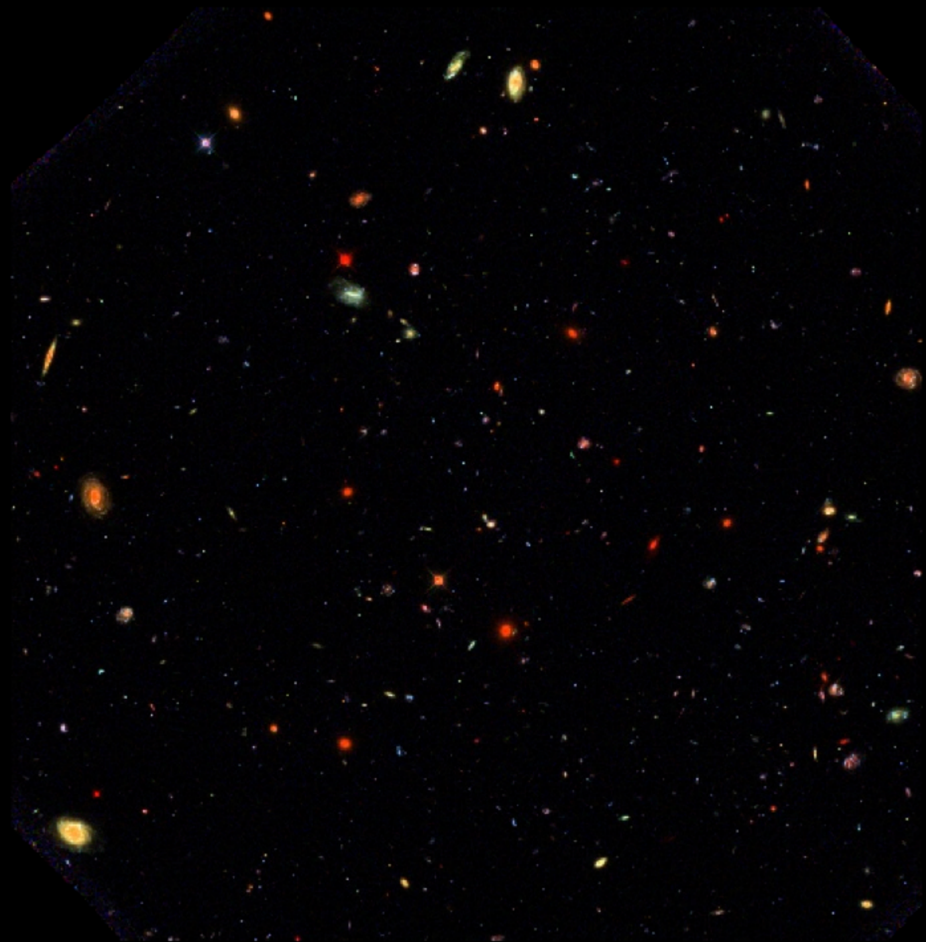


HST observation

Mock HST Deep Fields

+ AGN feedback

→ *reasonable population*



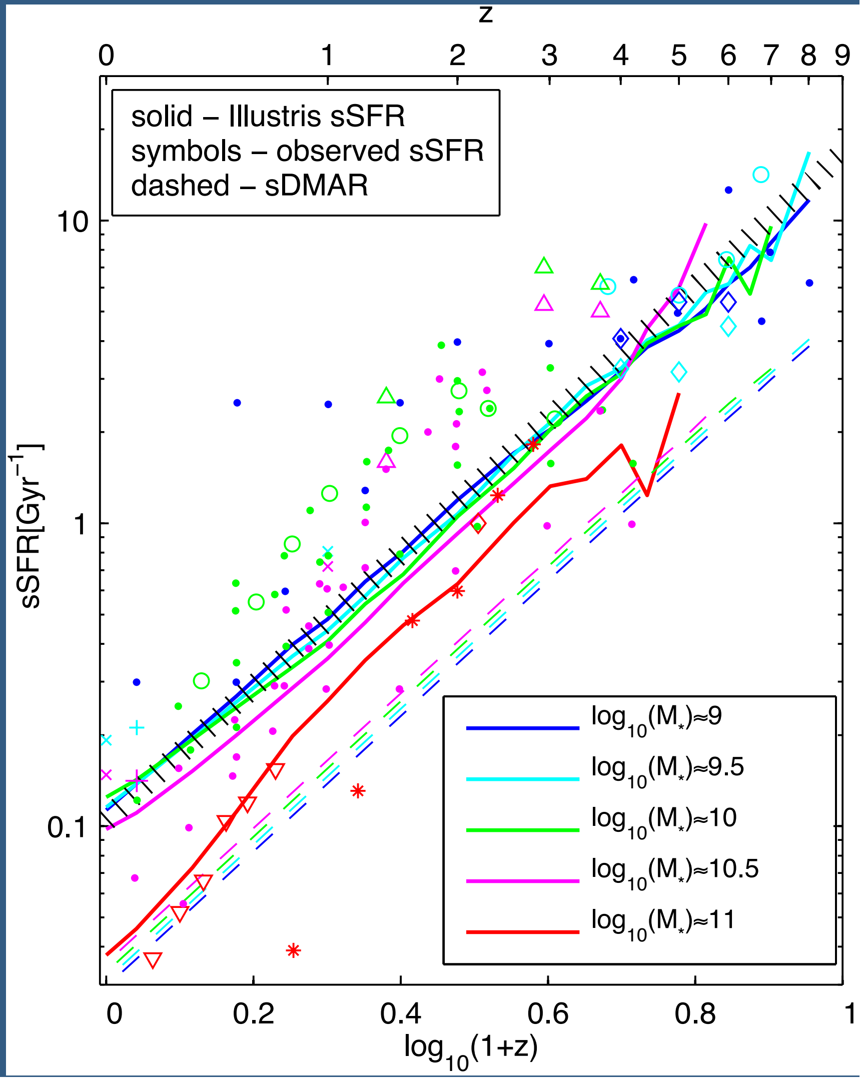
HST observation

Specific star-formation rates

- Observed 'bump' at z~1-3 not reproduced by any hydrodynamical simulation, including Illustris

- Simulated evolution follows closely the DM halo accretion rates

- Mass dependence reversed between halos and galaxies, as observed



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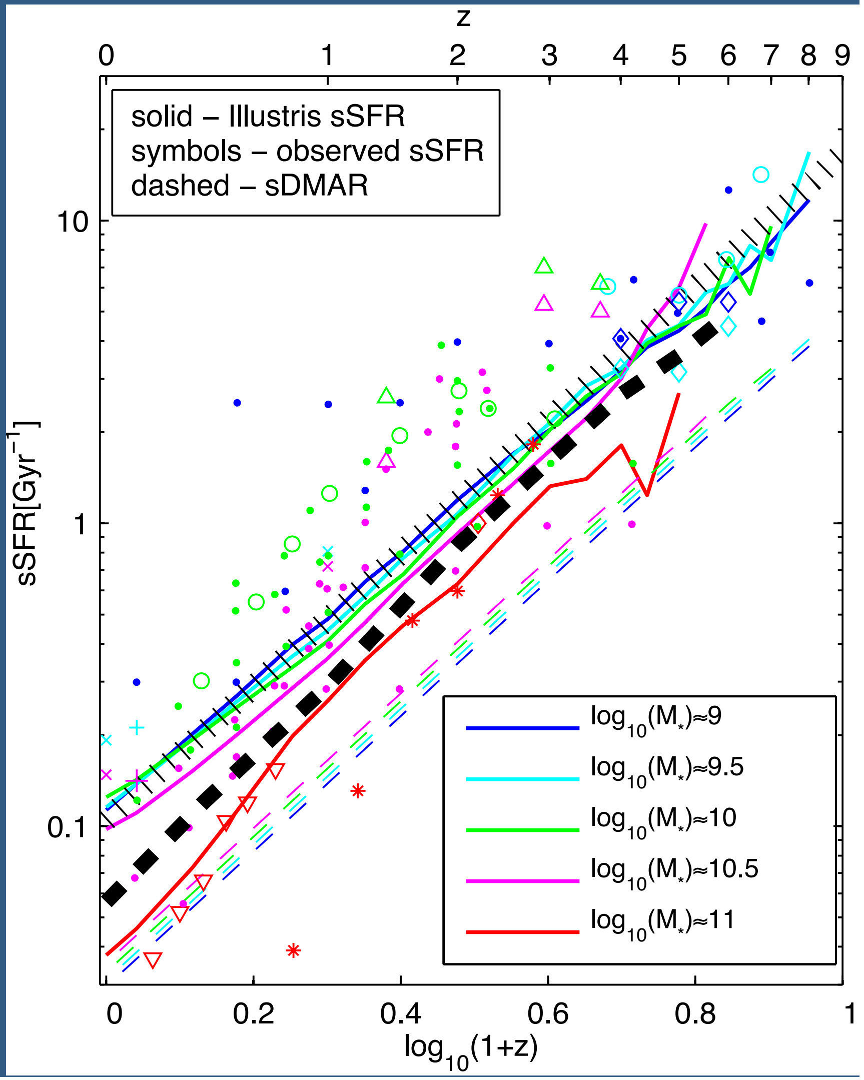


Results

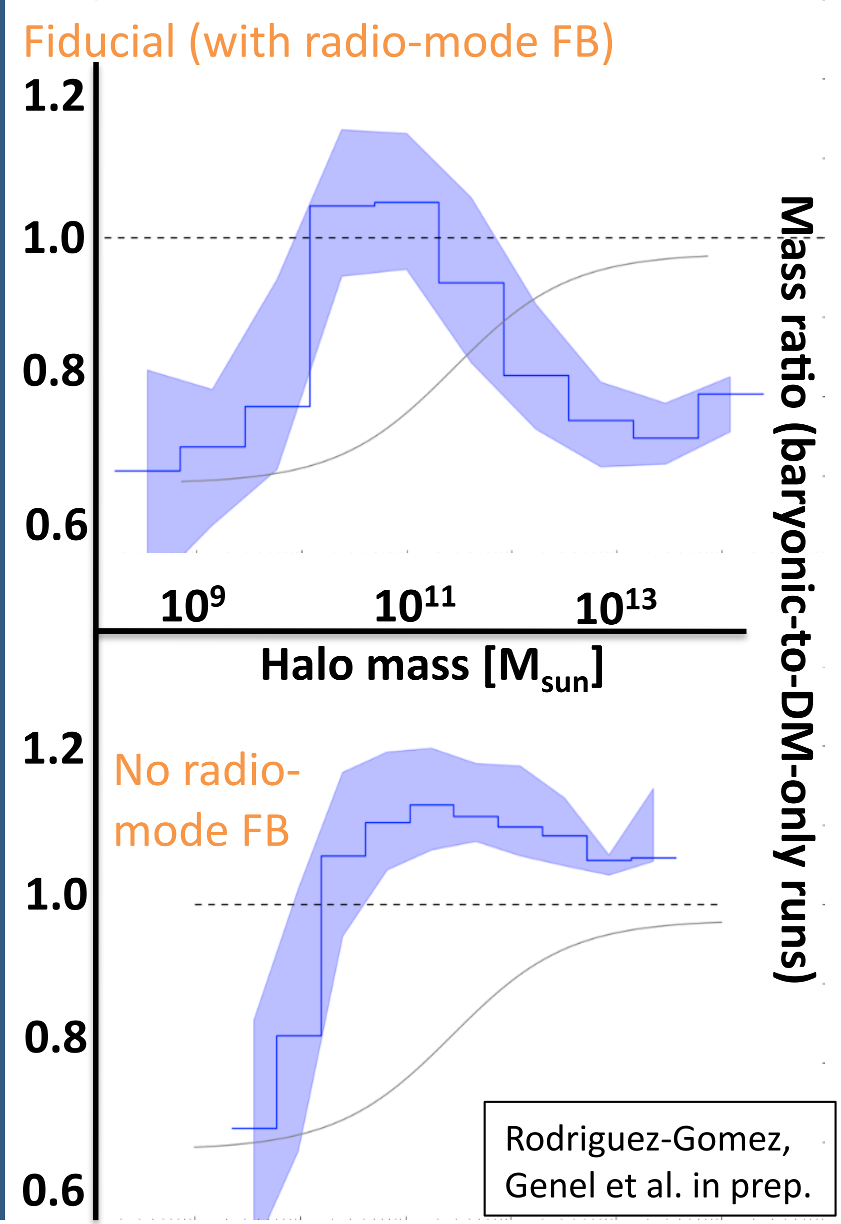
III. Baryonic effects on matter distribution

Baryonic effects on halo masses

• Hydrodynamics, cooling, galactic winds, AGN – all affect halo masses, at difference mass scales

• Strong sensitivity to the included physics and to their implementation

• Both enhancement and suppression of halo masses are possible



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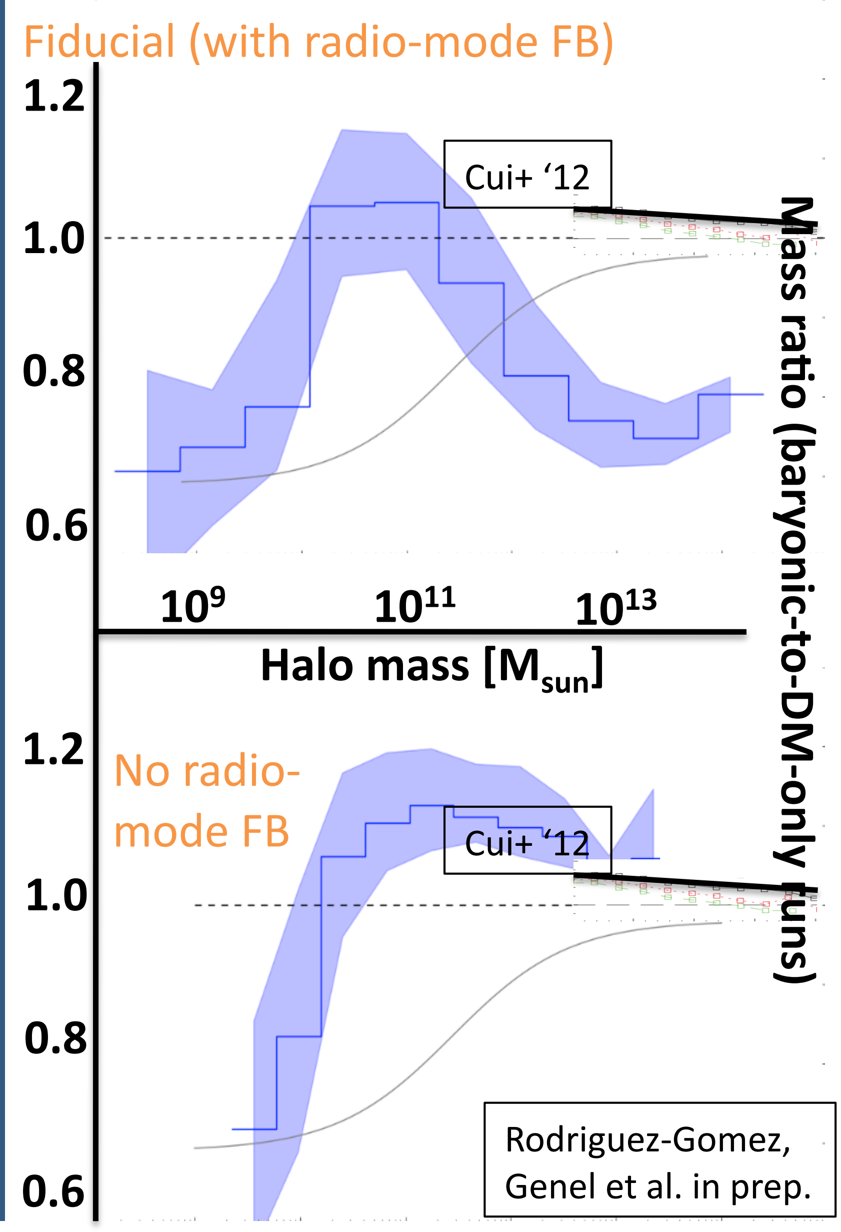

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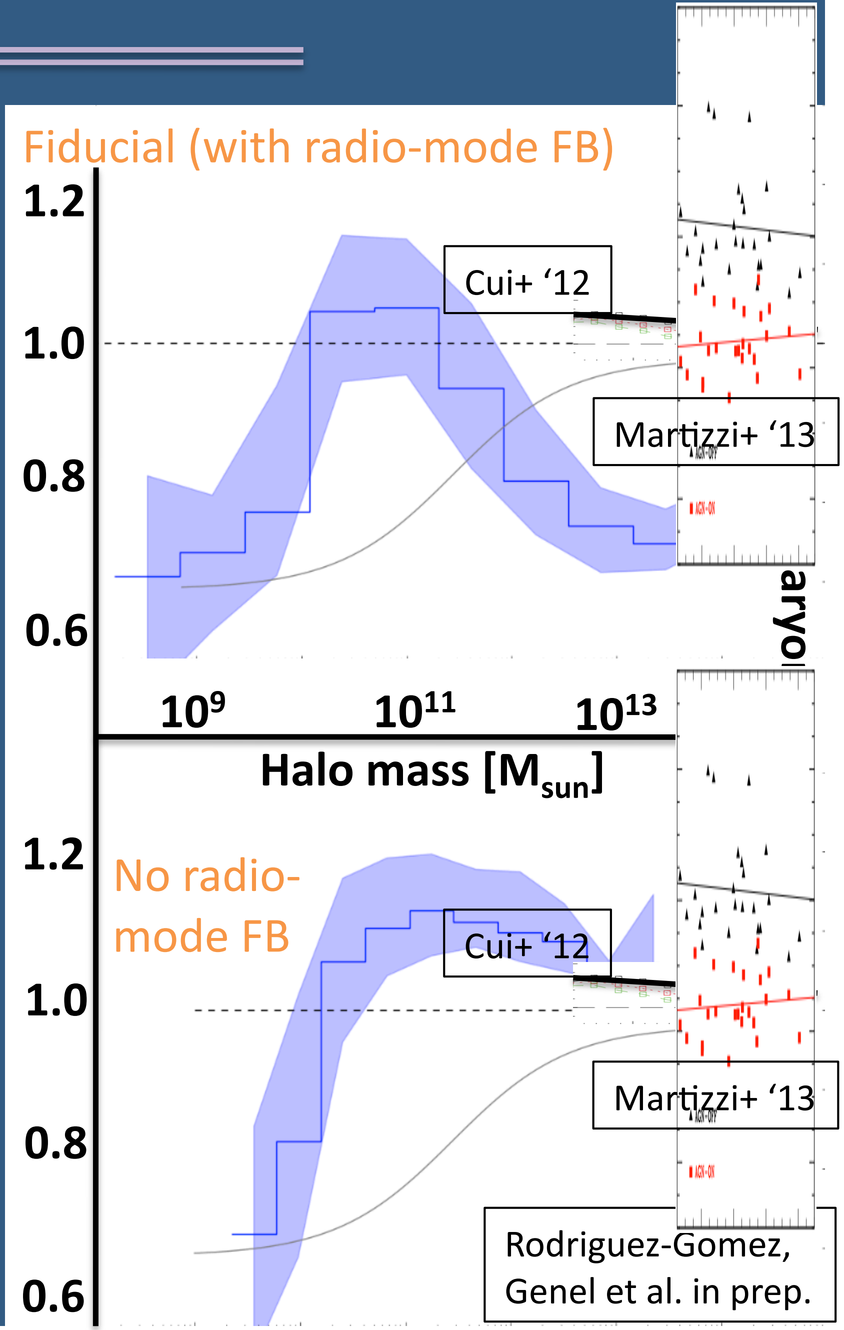
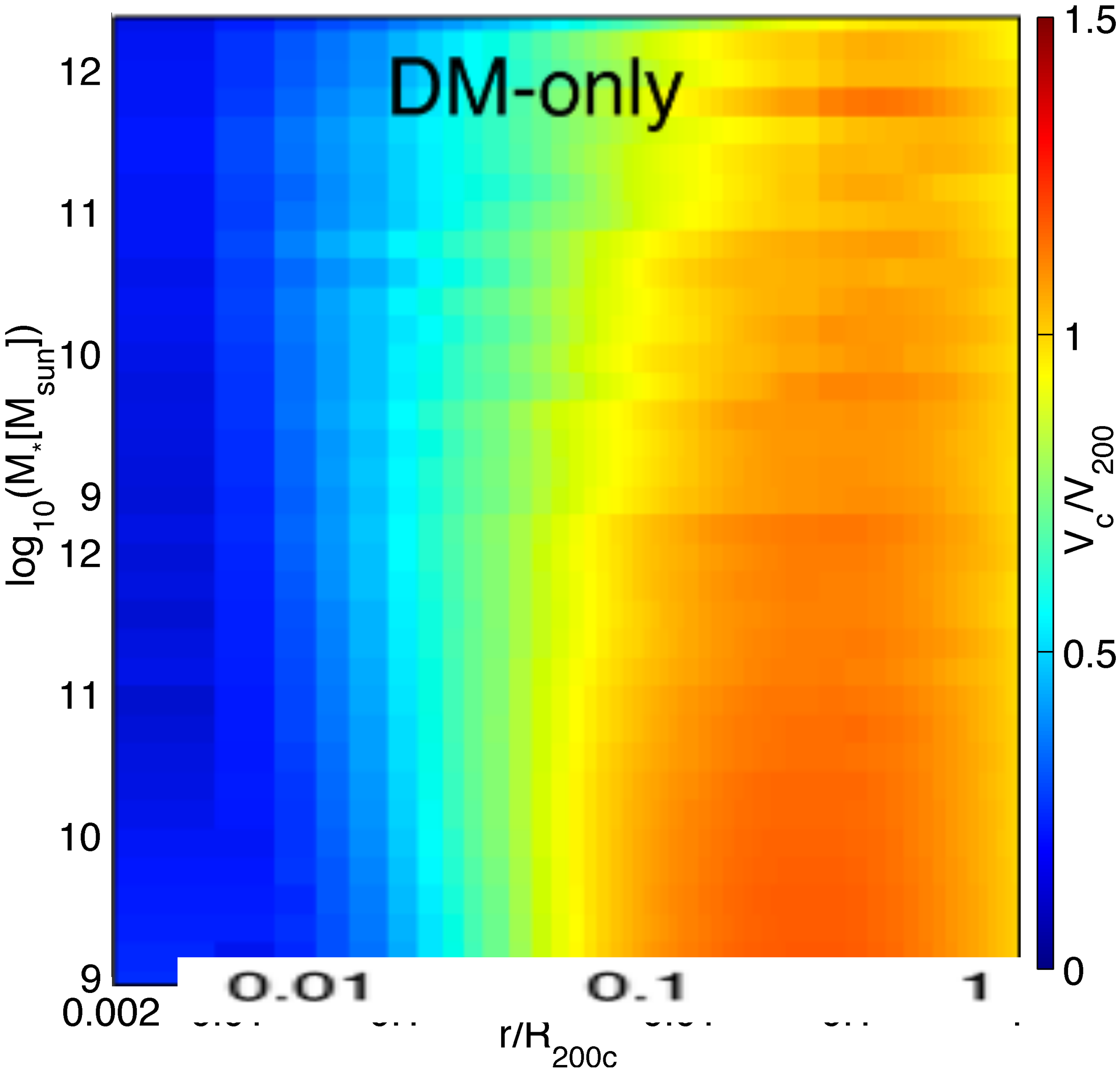


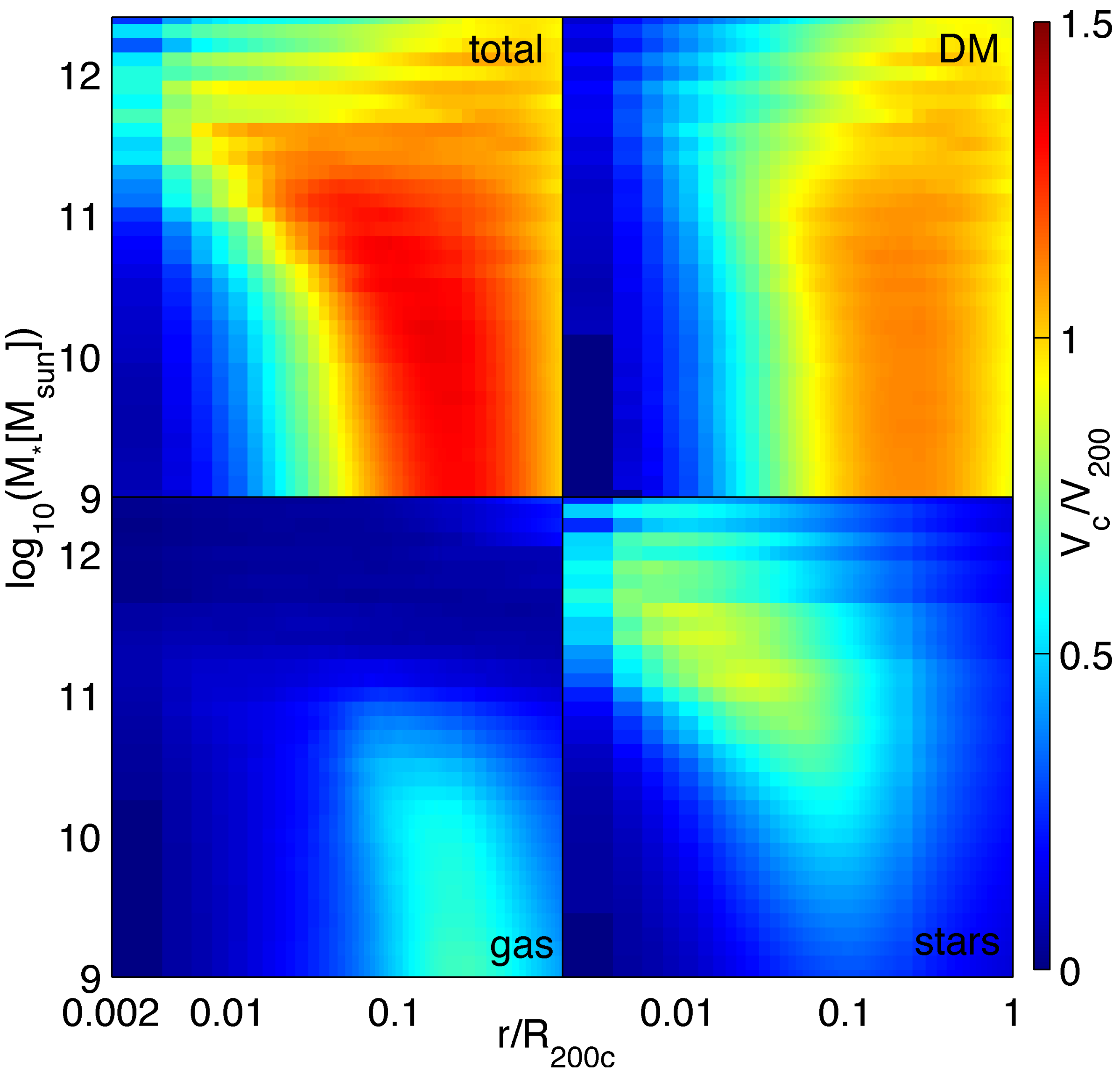
Halo structure – radial profiles

- Circular velocity profiles out to R_{200} for a range of stellar masses
- DM-only simulation ("Illustris-Dark") is matched to hydro simulation to give DM-only profiles as a function of "stellar mass"
- NFW: peak V_c reached @ $r>0.1R_{200}$



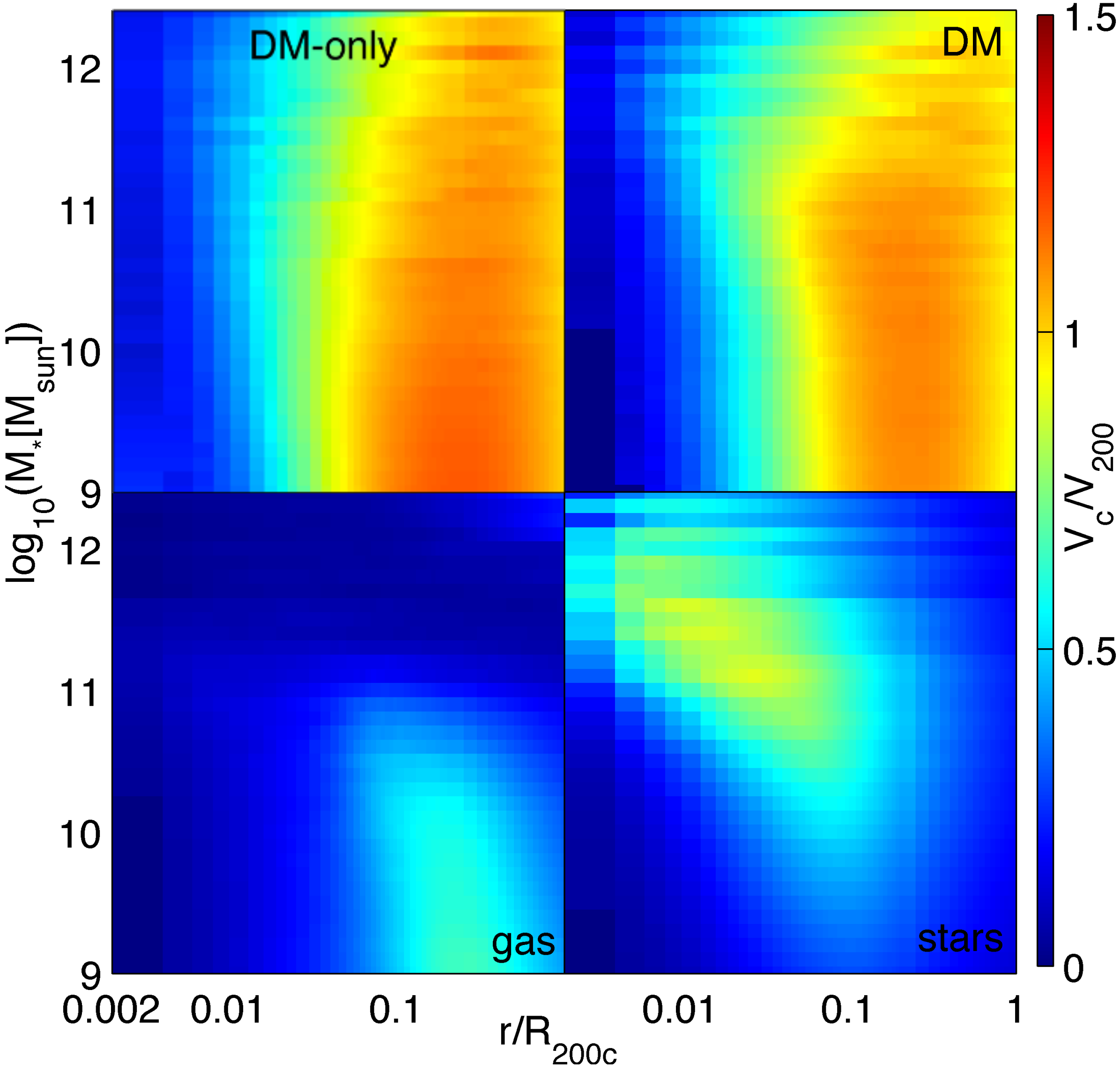
Halo structure – radial profiles

- Circular velocity profiles out to R_{200} for a range of stellar masses
- All profiles within $r<0.1R_{200}$ are rising or flat
- Gas contribution always small
- Baryons (stars) control V_{max} only within $10^{10.5}<M_*<10^{11.5}$



Halo structure – radial profiles

- Circular velocity profiles out to R_{200} for a range of stellar masses
- DM responds to baryons:
  - contraction @ $10^{10.5}<M_*<10^{11.5}$
  - @ $M_*>10^{11.5}$:
    - small-radius contraction
    - large-radius weak expansion



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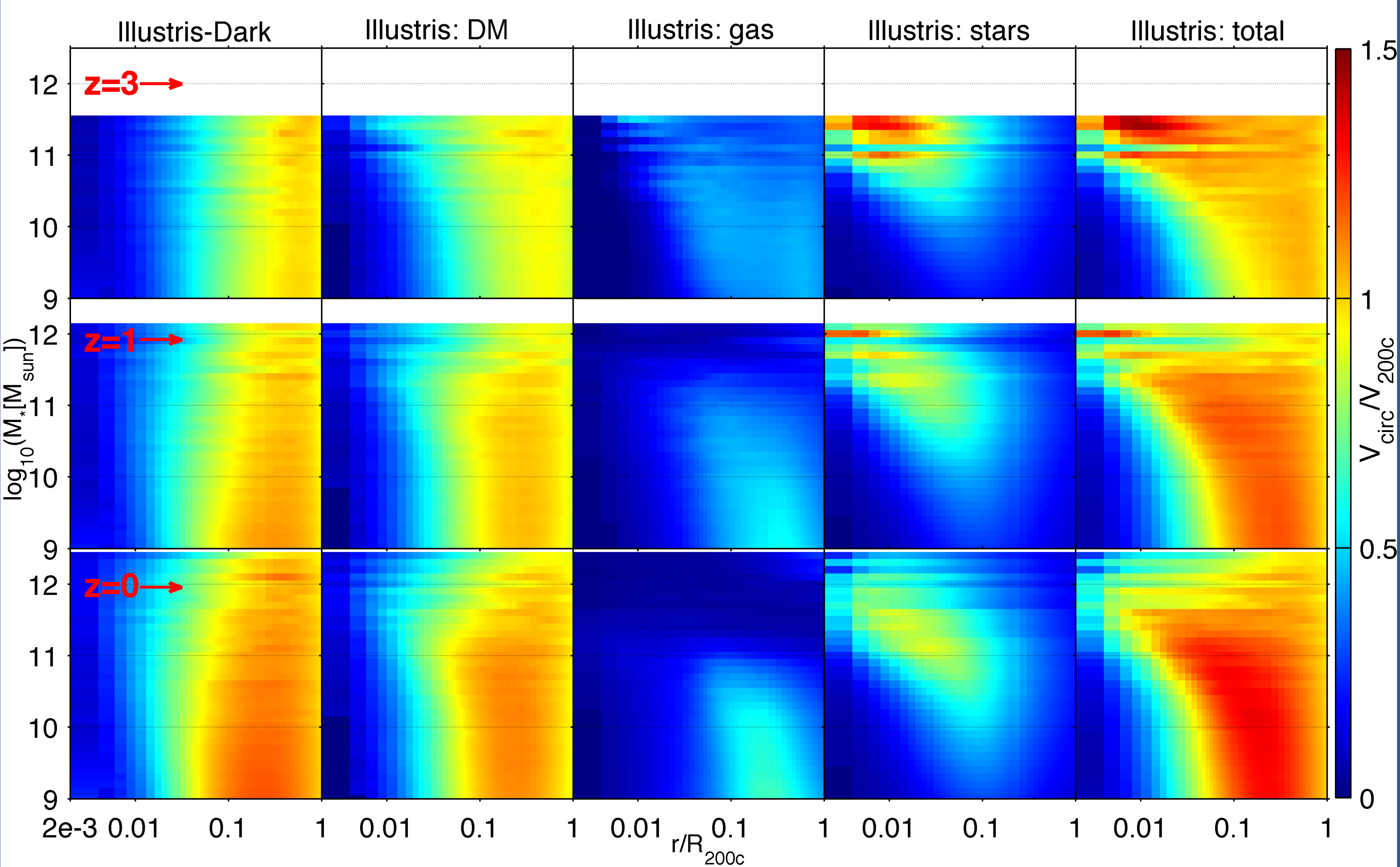

Summary

- Galaxy bimodality can be obtained;
  (currently) only with AGN FB

- Reasonable stellar mass build-up across cosmic time obtained with energy-scaling of galactic winds

- Baryons affect matter distribution in a mass, radius, and redshift-dependent ways

Summary

- We have just recently started to
  - constrain feedback models with hydrodynamical cosmological simulations
  - using a plethora of observations
  - on various scales
  - all combined