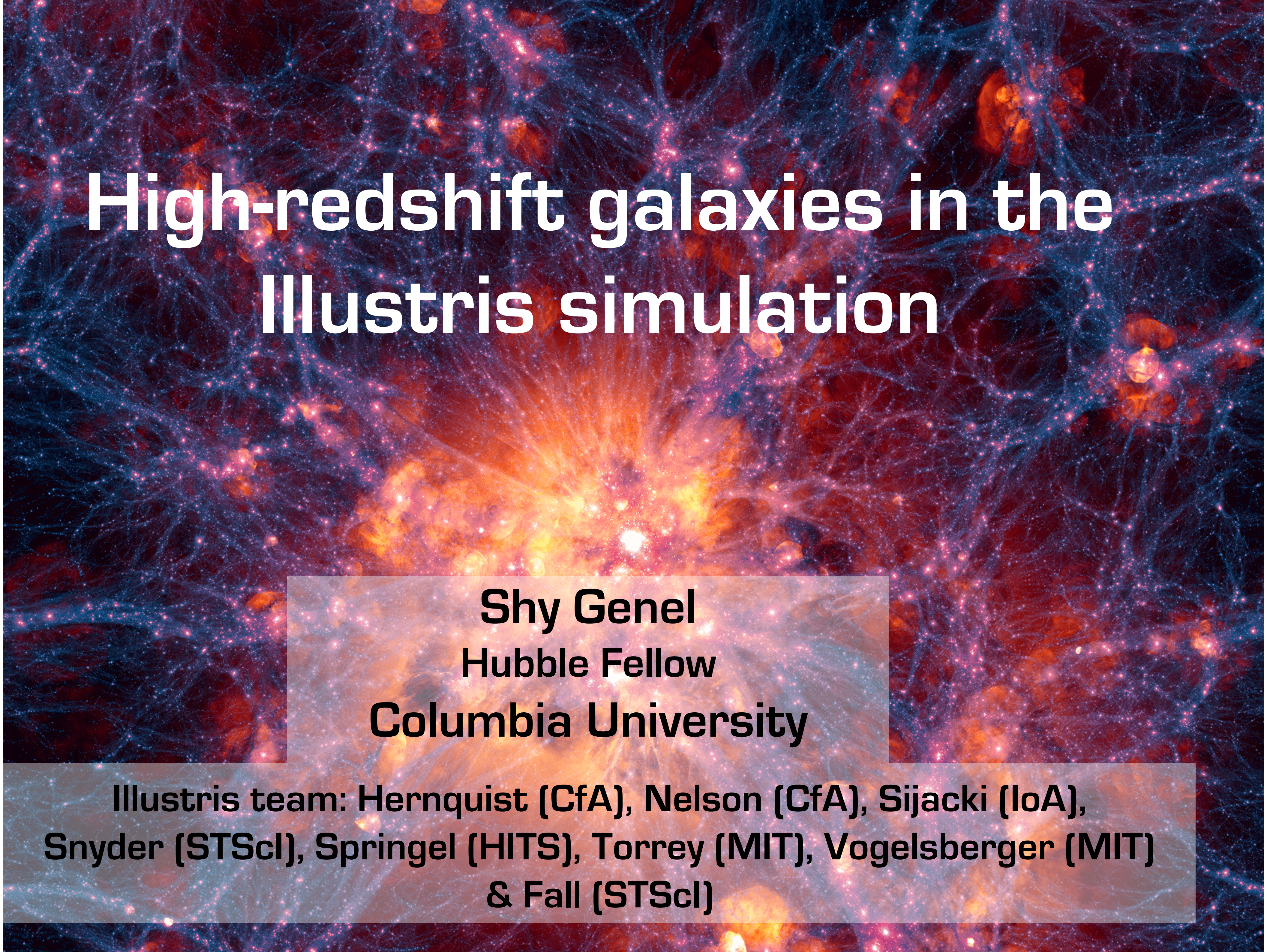


High-redshift galaxies in the Illustris simulation

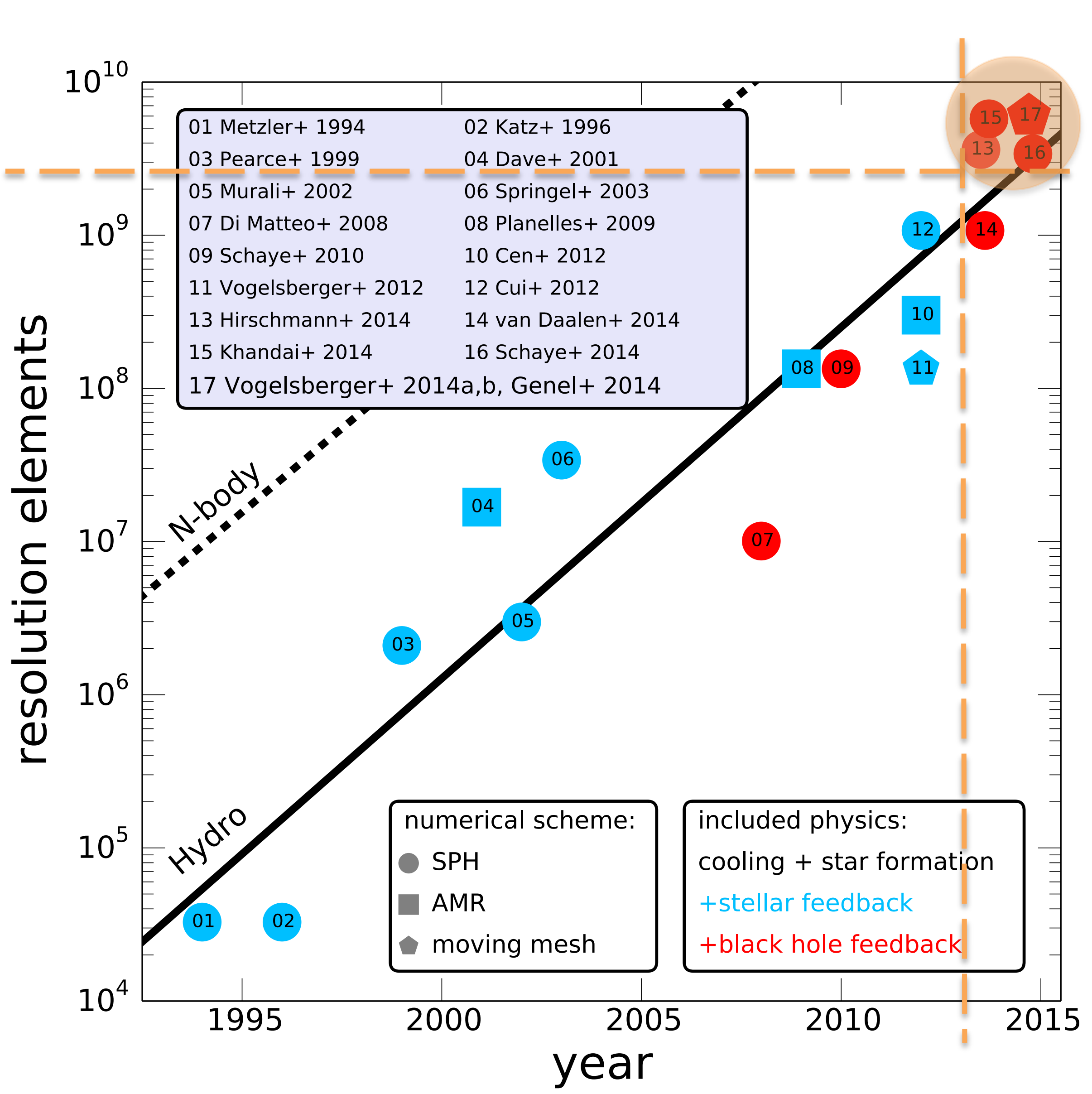
Shy Genel

Hubble Fellow

Columbia University

Illustris team: Hernquist (CfA), Nelson (CfA), Sijacki (IoA), Snyder (STScI), Springel (HITS), Torrey (MIT), Vogelsberger (MIT) & Fall (STScI)

‘Uniform-box’ cosmological simulations



Horizon-AGN,
Eagle,
Magneticum Pathfinder,
MassiveBlack-II,
& Illustris:

A new era of hydrodynamical cosmological simulations:

Thousands of resolved massive galaxies

Genel et al. 2014

The Illustris Simulation

Vogelsberger, SG, et al. 2014
Genel et al. 2014
Sijacki et al. 2015

- A (106.5 Mpc)^3 box run to z=0
  - 10 M>$10^{14}M_{sun}$ halos @ z=0
  - >10^3 M≈$10^{12}M_{sun}$ halos @ z=0

Public data release: April 1
http://www.illustris-project.org

- Baryonic resolution: $1.3\times10^6\ M_{sun}$
- Resolution elements: 2×1820^3
- Gravitational spatial resolution: 0.7-1.4 ckpc
- N-body+hydro on an unstructured moving mesh with with Arepo
- Galaxy formation physics (SF, winds, AGN...)

Vogelsberger, SG, et al. 2013

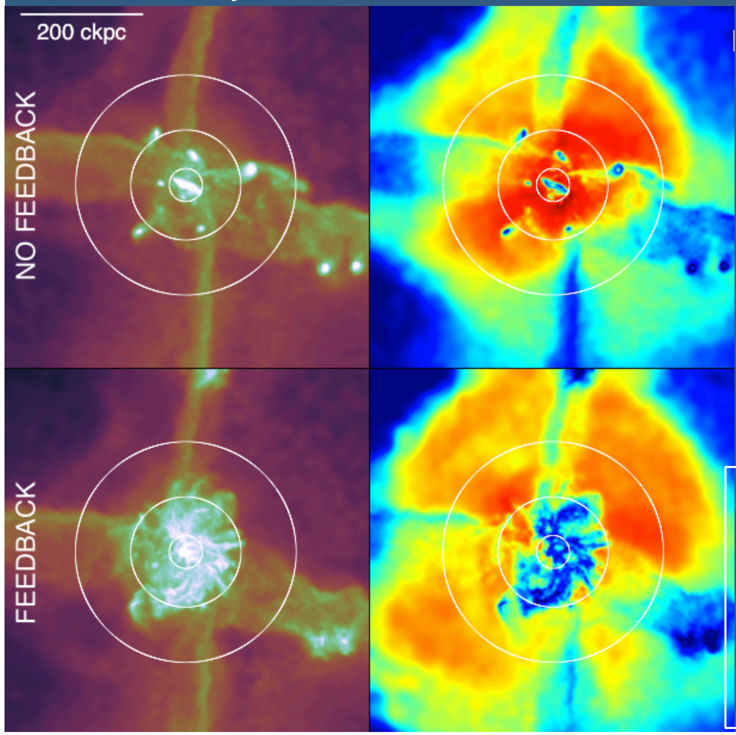
Galaxy formation physics

Tuned to address the overcooling problem:

cosmic SFRD & z=0 M_*-M_h

- Galactic winds

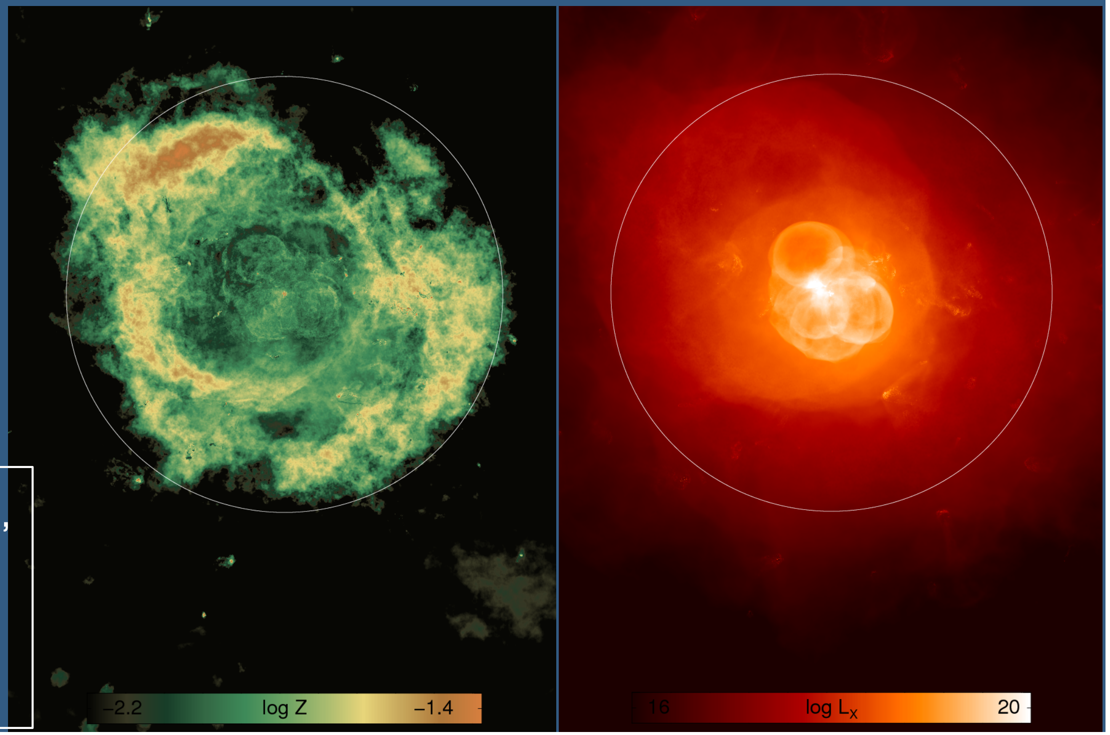
density temperature



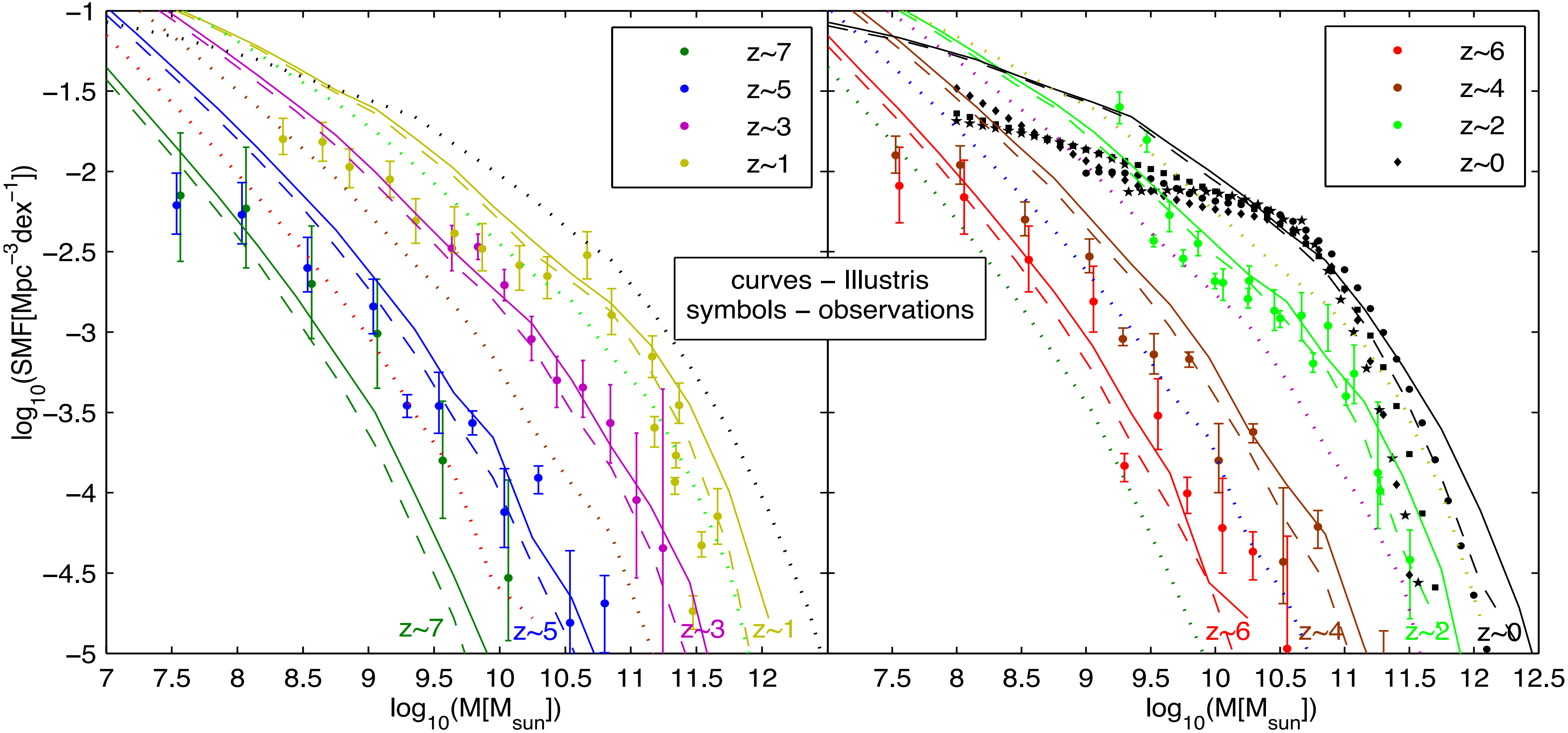
Nelson, SG, et al. 2014

- Black Holes

metallicity xray luminosity



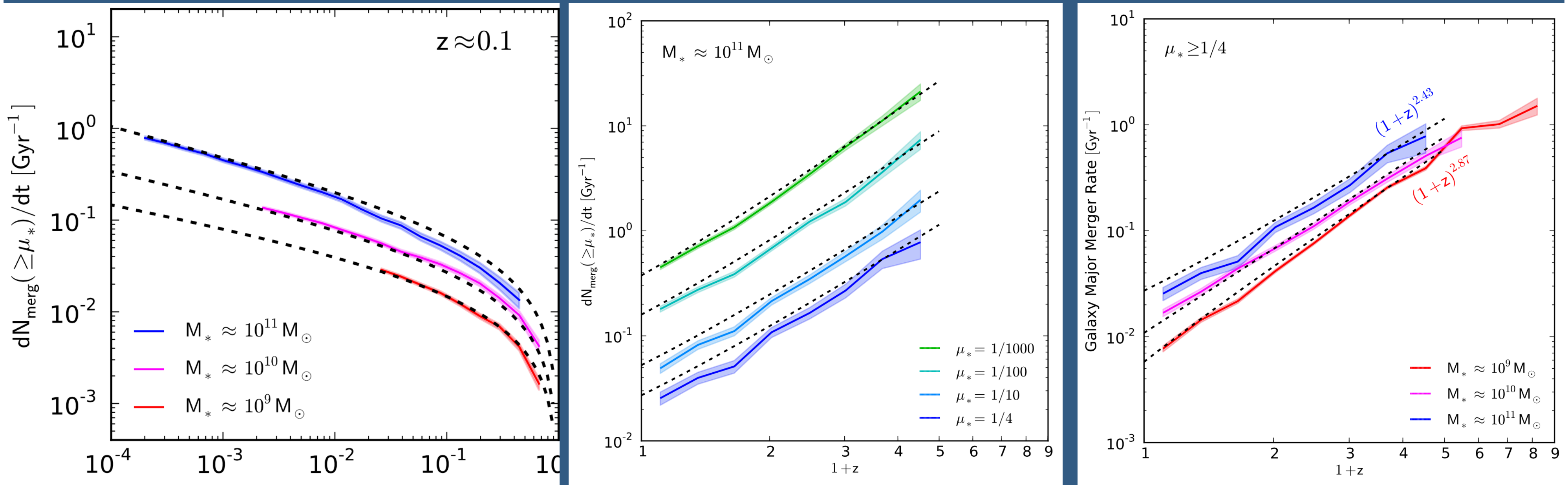
Stellar mass functions @ 0 ≤ z ≤ 7



Genel et al. 2014

The galaxy merger rate

Rodriguez-Gomez, SG, et al. 2015

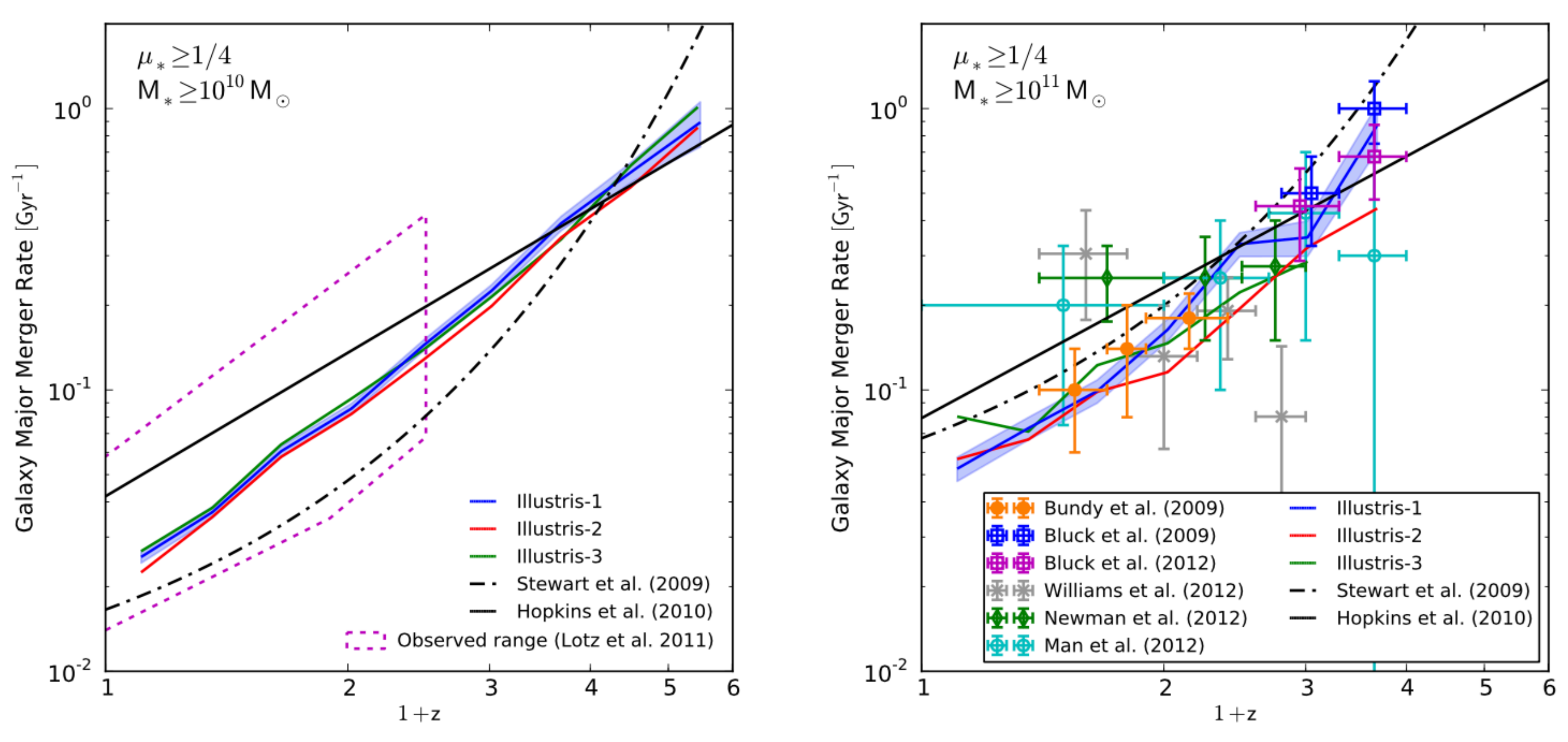


$$A(z)\left(\frac{M}{10^{10}\mathrm{M}_\odot}\right)^{\alpha(z)}\left[1+\left(\frac{M}{M_0}\right)^{\delta(z)}\right]\mu^{\beta(z)+\gamma\log_{10}\left(\frac{M}{10^{10}\mathrm{M}_\odot}\right)}$$

(The DM halo merger rate: $A\left(\frac{M_0}{\tilde{M}}\right)^{\alpha}\xi^{\beta}\exp\left[\left(\frac{\xi}{\tilde{\xi}}\right)^{\gamma}\right]\left(\frac{d\delta_c}{dz}\right)^{\eta}$)

The galaxy merger rate

Rodriguez-Gomez, SG, et al. 2015



- Illustris matches typical observed merger rates,

  however,

- Some observational work find qualitatively opposite trends

Genel et al. 2014

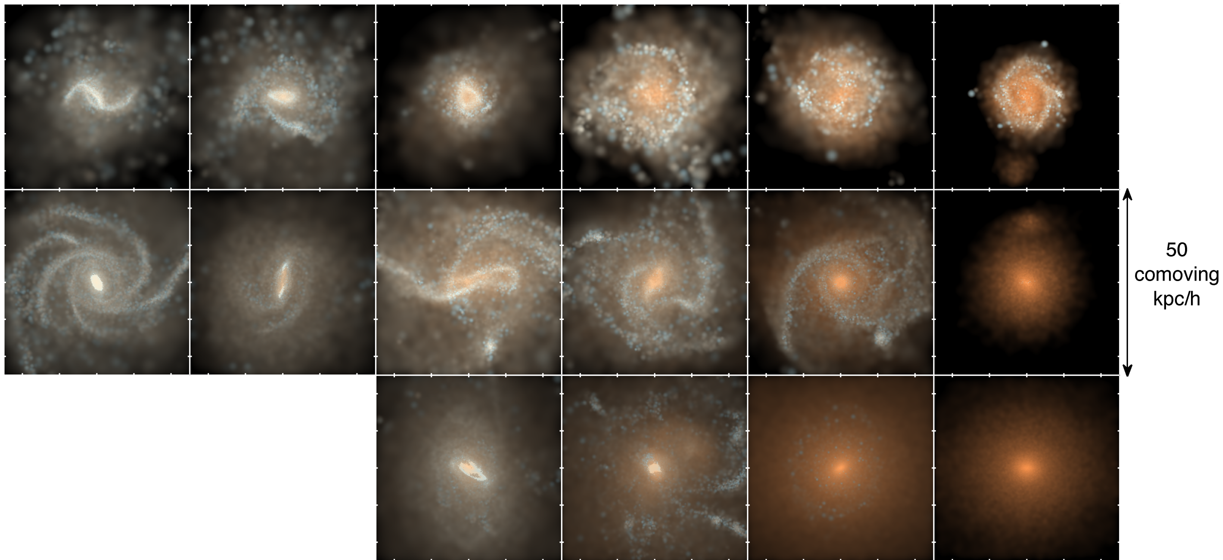
Massive galaxies @ $0 \leq z \leq 5$

z=5 z=4 z=3 z=2 z=1 z=0

$M_* \approx 10^{10.5} M_{sun}$

$M_* \approx 10^{11.0} M_{sun}$

$M_* \approx 10^{11.5} M_{sun}$

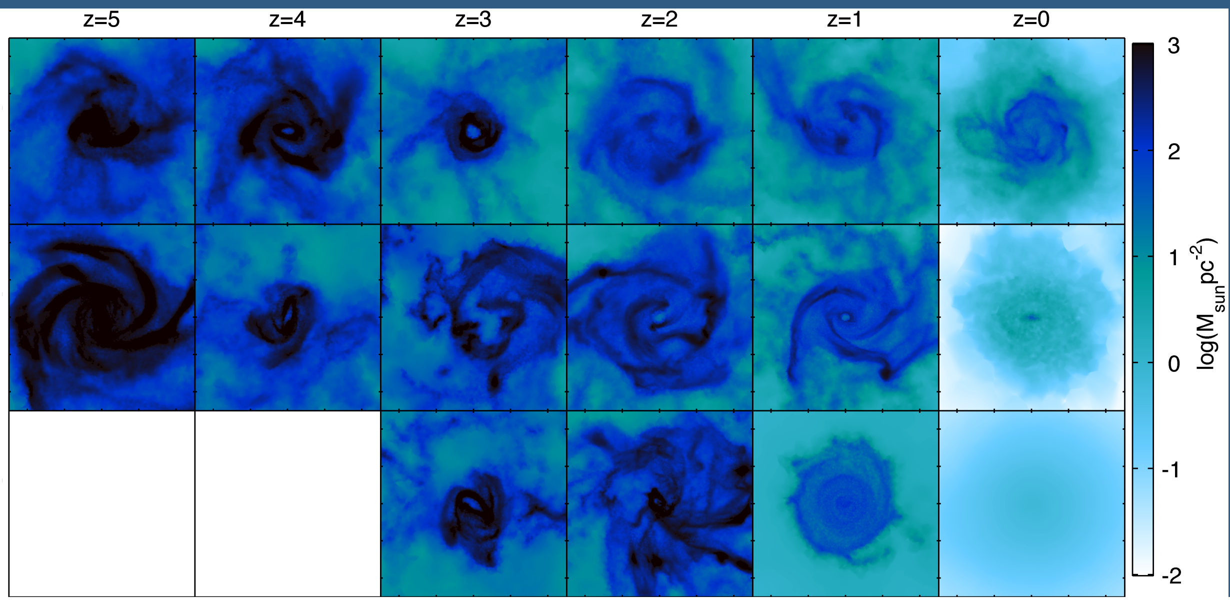


Stars

$M_* \approx 10^{10.5} M_{sun}$

$M_* \approx 10^{11.0} M_{sun}$

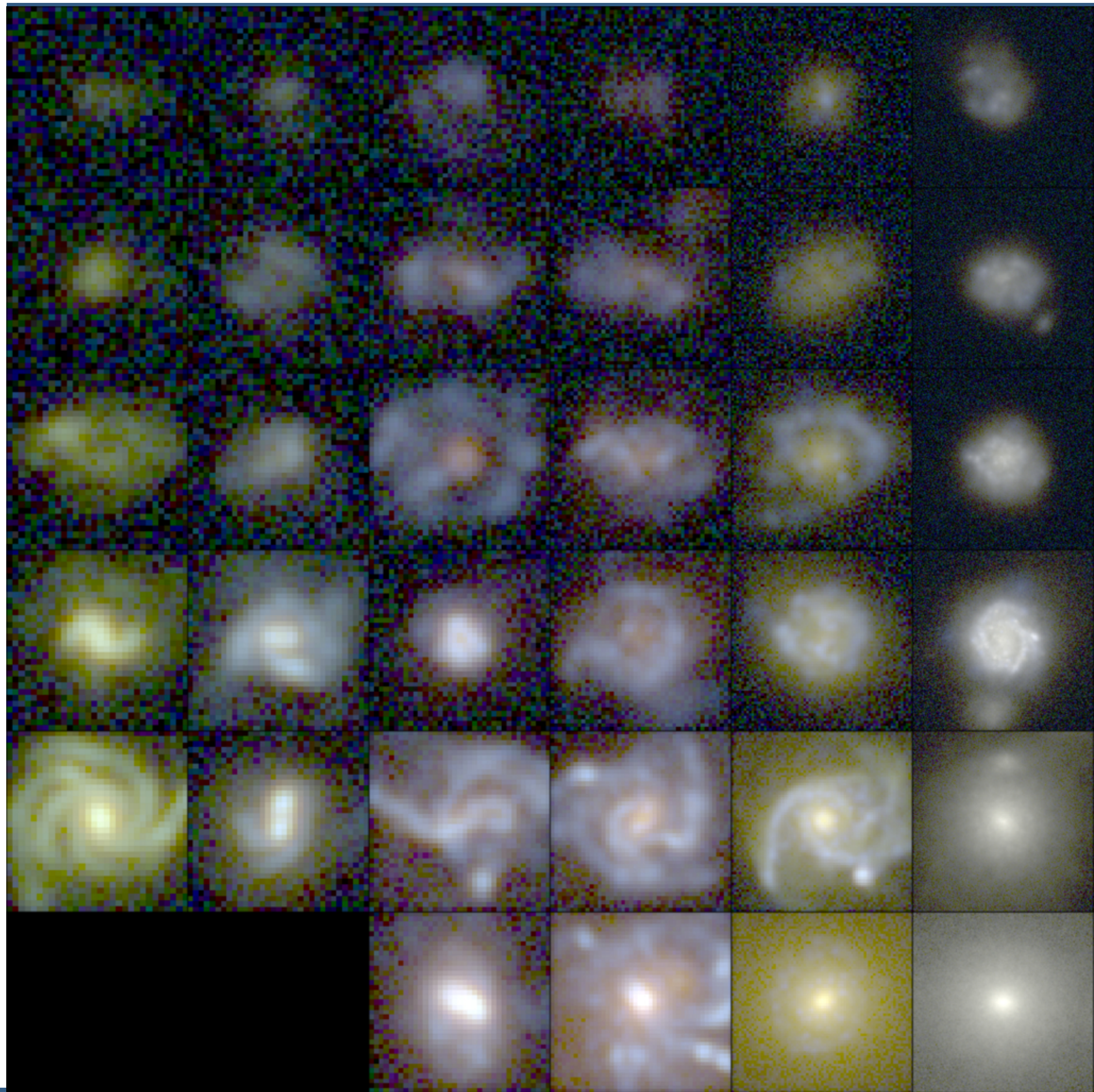
$M_* \approx 10^{11.5} M_{sun}$



Gas

HUDF mock observations

Genel et al. 2014
Snyder et al. in prep.

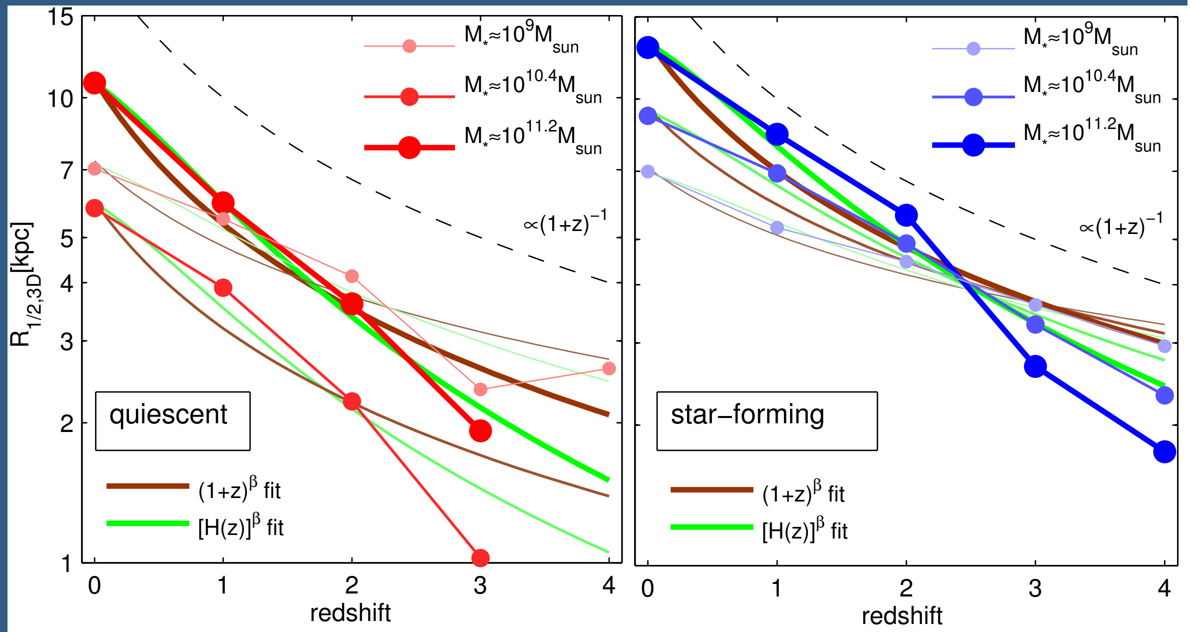


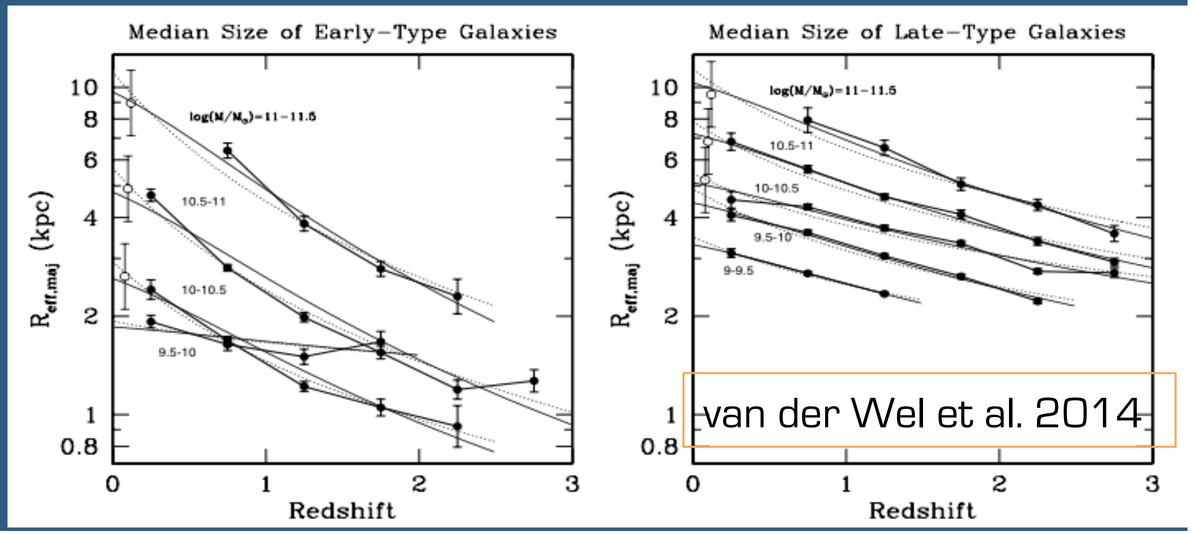
- Clumpy galaxies
- Redder centers
- Disks & spheroids

Genel et al. in prep.

Size-mass-SFR-redshift

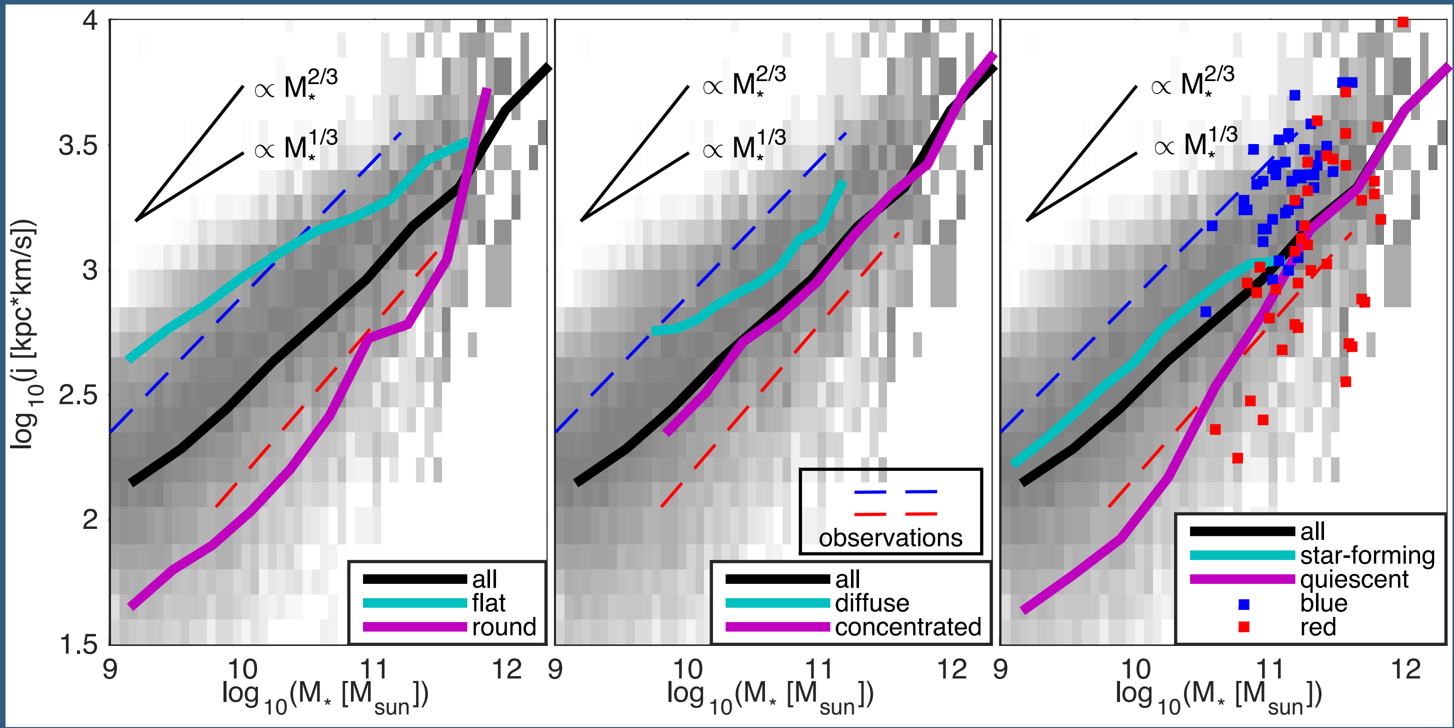
- Observed trends qualitatively reproduced:
  - Quiescent galaxies are smaller
  - Sizes of quiescent galaxies evolve faster
  - Sizes of more massive galaxies evolve faster
  - Evolution is better described by $H(z)^{\beta}$ than $(1+z)^{\beta}$, like for DM halos





Genel et al. 2015

Galaxy angular momentum



- Specific angular momentum of the stars correlates with galaxy mass
- Separate relations for late-types and early-types, each with a slope close to (2/3)
- Overall relation is shallower, (at least in part) due to changing mix between late- and early-types with mass

Galaxy angular momentum

Genel et al. 2015

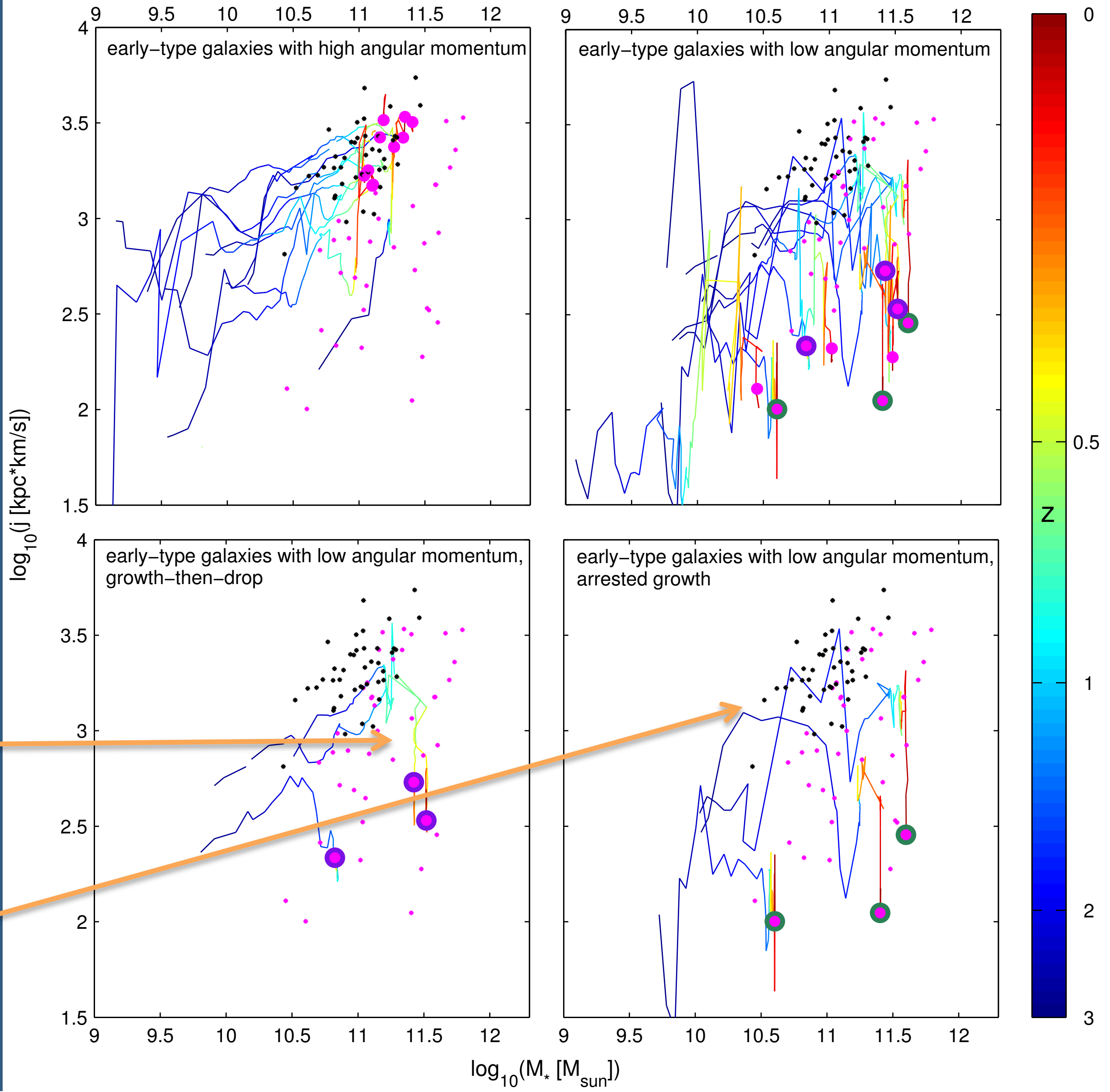
- Almost all galaxies have high specific angular momentum (j) at high redshift

- Early-type galaxies at z=0 with low angular momentum may:

- rapidly lose their j

or

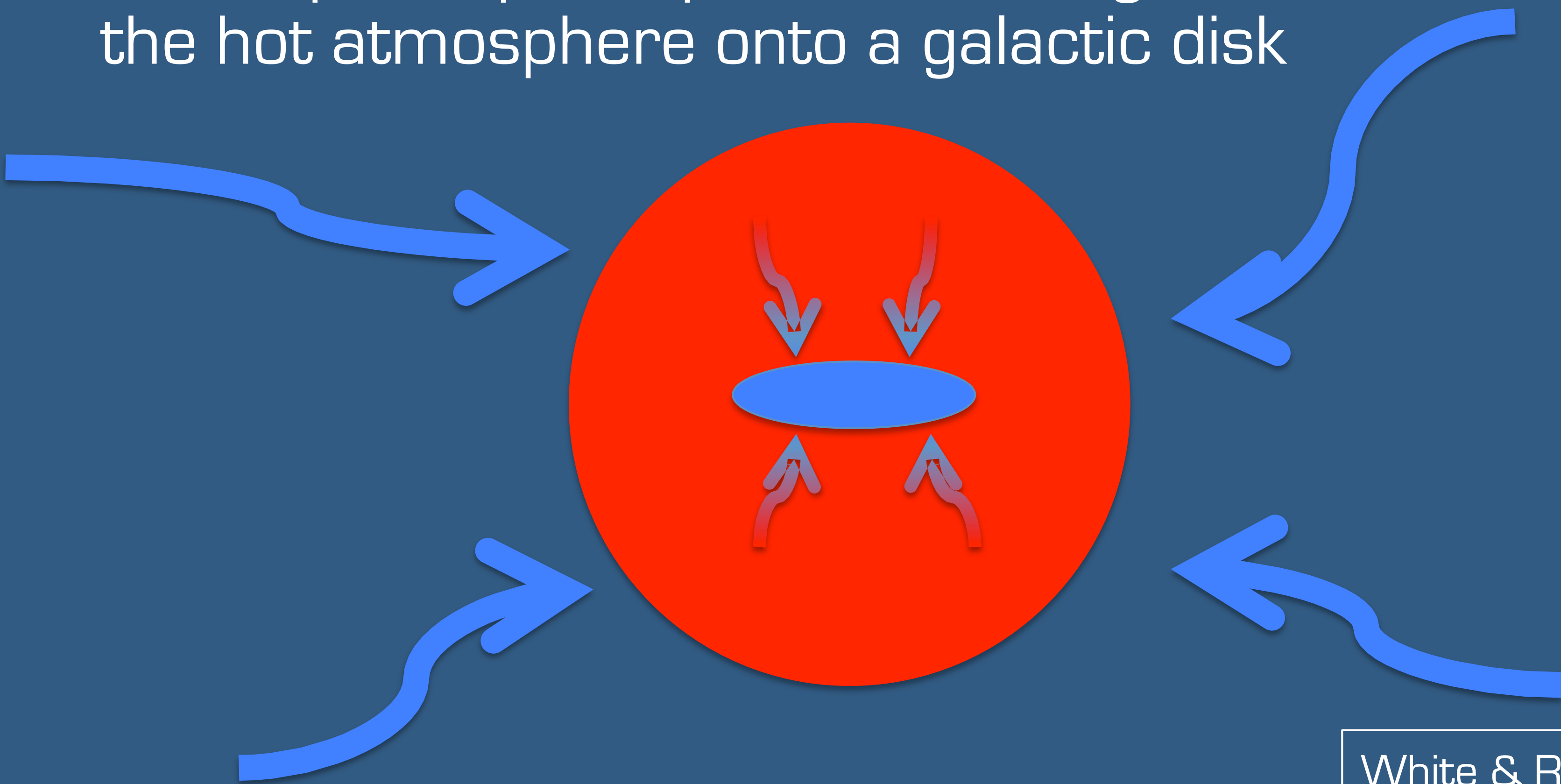
- stop gaining j



How do galaxies get their baryons?

The classical picture:

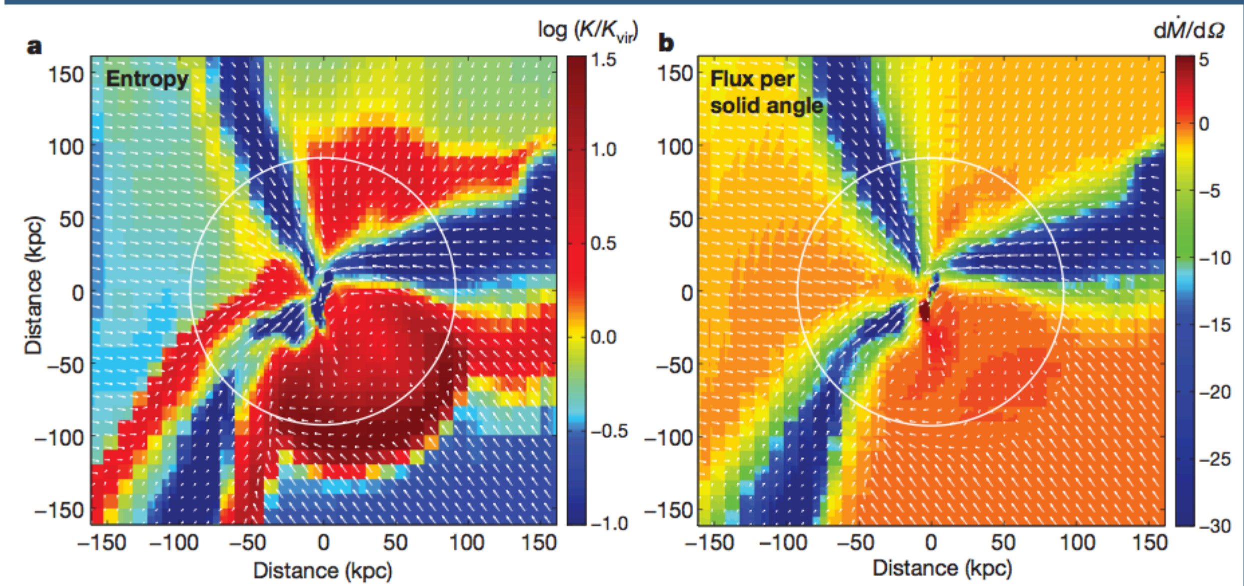
- Shock-heating at the virial radius
- Subsequent quasi-spherical cooling from the hot atmosphere onto a galactic disk



White & Rees 1978

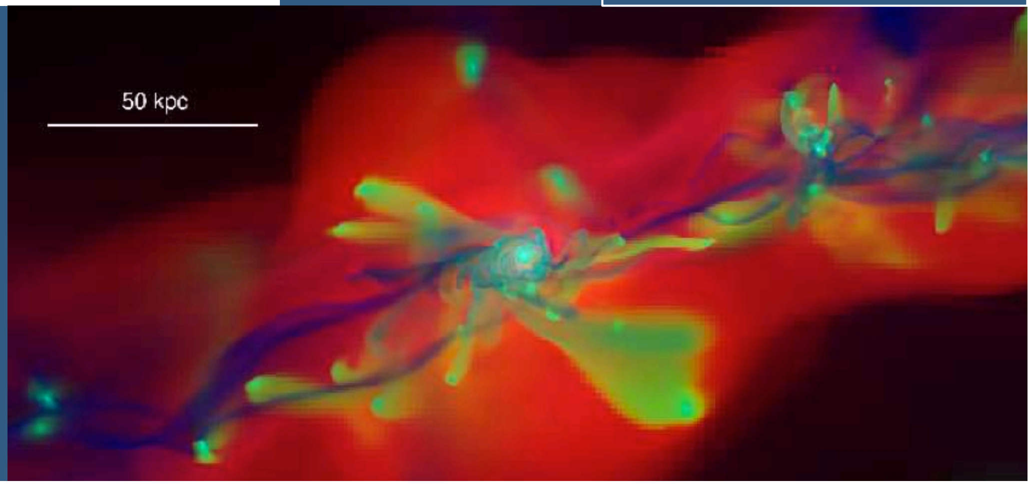
How do galaxies get their baryons?

A decade-old paradigm shift(?): 'cold accretion'



Dekel et al. 2009

Agertz et al. 2009

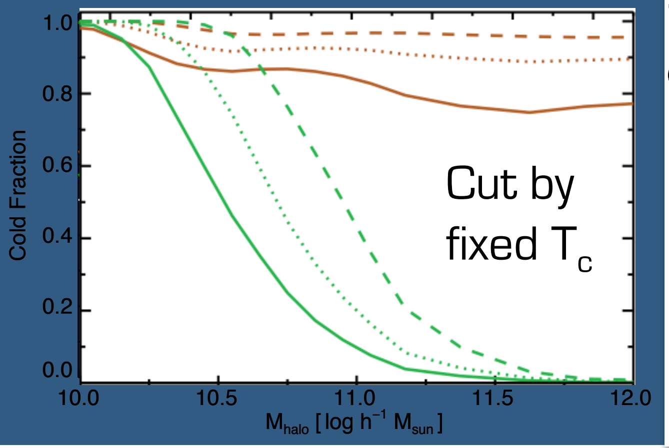


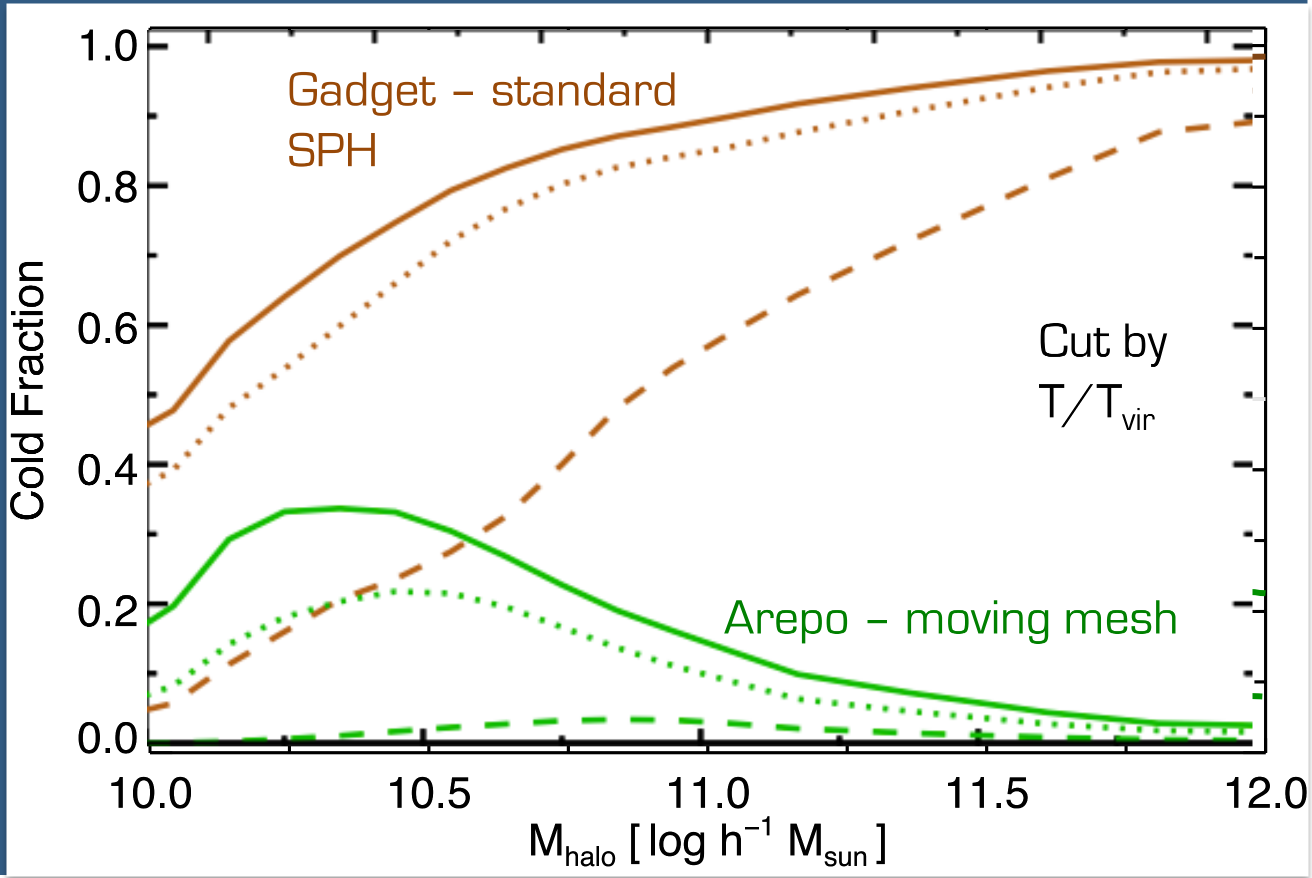
Nelson et al. 2013

Cold mode fraction of galaxy gas

- For 'smooth' gas only: hot-dominated everywhere at $10^{10}<M[M_{sun}]<10^{12}$

- Cold fraction dropping to ~0 at $M \approx 10^{12} M_{sun}$





Halo gas structure @ z=2

Nelson, SG, et al. 2015

- 10 zoom-in simulations of $10^{12}M_{sun}$ halos @ z=2, without feedback!
- Higher resolution reveals increasingly complex structures