~~Constraining~~ Solving galaxy formation with gaseous halos

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X-ray Vision workshop: probing the Universe in depth and in detail with X-ray surveyor,
Museum of American Indian, Washington DC, 7 October 2015


David Spergel @DavidSpergel · Sep 24
@dalcantonJD Galaxies have it all: stars, gas, and dark matter
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X-RAY SURVEYOR

X-Ray Vision Workshop

October 6-8, 2015 Washington DC

DETAILS

Presentation Guidelines

The primary topics for the first X-ray Surveyor conference includes:

- Black holes (from seeds to energy feedback in present-day galaxies and clusters)
- Plasma physics in the ISM, supernova remnants, and galaxy clusters
- Cycles of baryons in and out of galaxies
- Star formation regions in the Milky Way and local group
- Physics of the "New Worlds", including star-planet interactions, X-raying atmospheres of Hot Jupiters, stellar winds, pre-main sequence stars, etc.

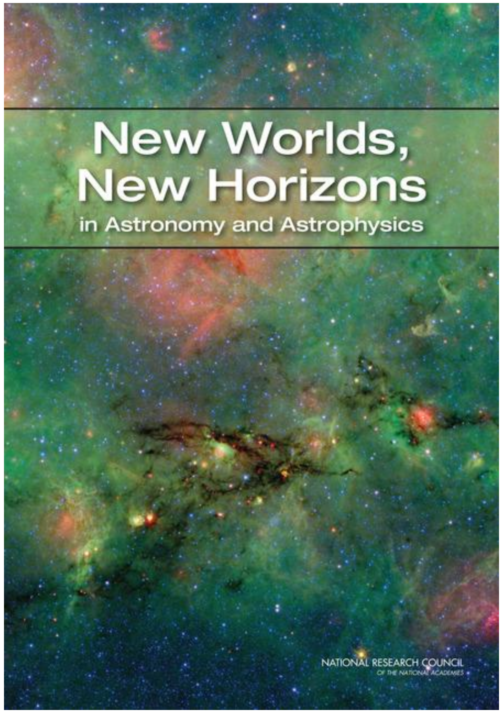
Presenters should:

1. Establish that the presentation topic is of fundamental importance for astrophysics in general, and identify the Big Questions.
2. Identify which aspects of the problem are X-ray observable
3. Establish that X-ray observations (perhaps in conjunction with data from other facilities expected to operate in the 2020s) are critical for solving the Big Questions.
4. Demonstrate that the capabilities of X-ray Surveyor are adequate for carrying out the relevant observations.

Understanding the cosmic order

"The critical constituents of galaxies—dark matter, stars, gas, dust, and supermassive black holes—are strongly coupled to one another.

…while JWST will provide observations on the assembly of galaxies over cosmic time, IXO would obtain X-ray observations of the warm and hot gas in the dark matter halos that surround galaxies."



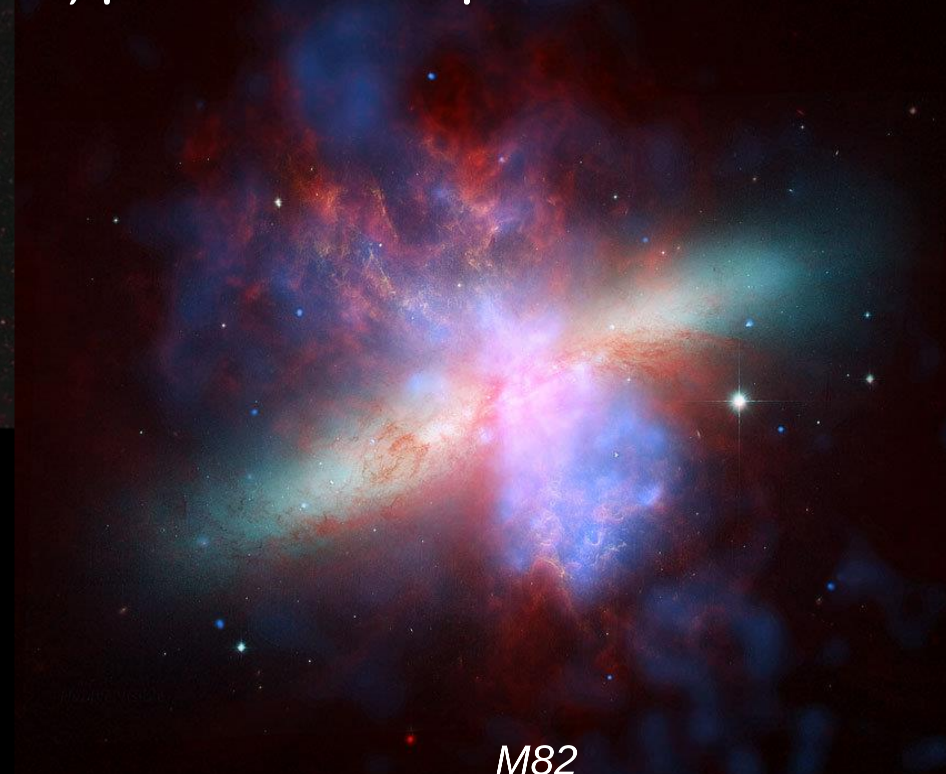
"…This program of observations will move the subject of galaxy evolution from one dominated largely by surveys to one of integrated measurements of the buildup of dark matter, gas, stars, metals, and structure over cosmic time. These observations will lay the foundation for the ultimate aim of a complete ab initio theory of galaxy formation and evolution. "

complexity:
formation of stars and supermassive black holes and associated stellar and AGN feedback are crucial in setting galaxy properties and driving baryons away

in the process they couples ~(sub)-pc scales to ~Mpc scales

NGC 604

(young star forming region region in nearby galaxy M33)
white/blue=optical, magenta=infrared, blue haze= Chandra X-rays

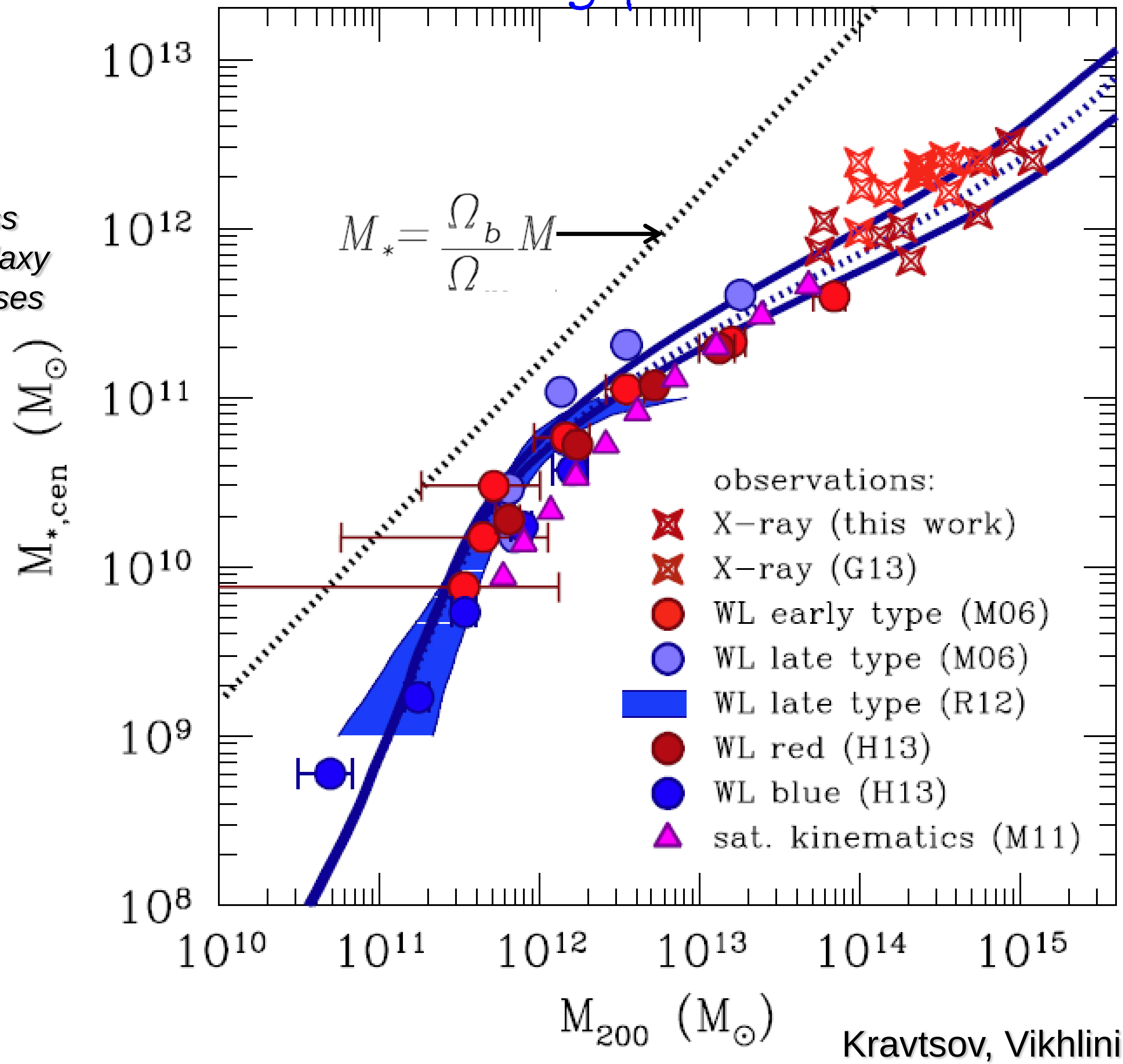


M82

Cyan-green-yellow – young stars optical (HST)
Red, magenta – dust/PAH emission IR (Spitzer)
Blue – hot gas, X-ray (Chandra)

The stellar mass-halo mass relation reflects imprints of strong feedback

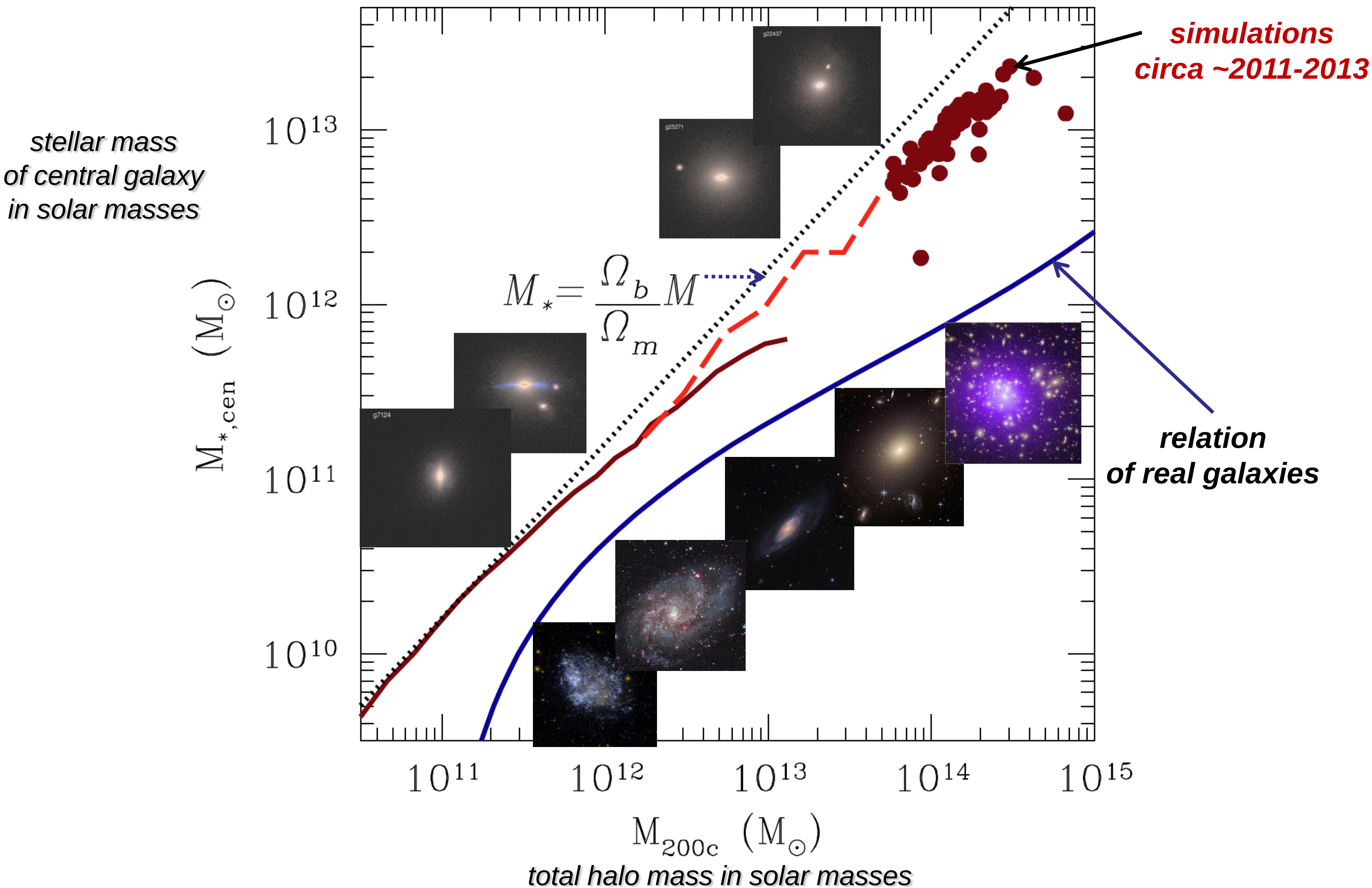
stellar mass
of central galaxy
in solar masses



total halo mass

Kravtsov, Vikhlinin, Meshsheryakov
arxiv/1401.7329

cosmological simulations including cooling only or weak feedback do not produce a pronounced characteristic mass

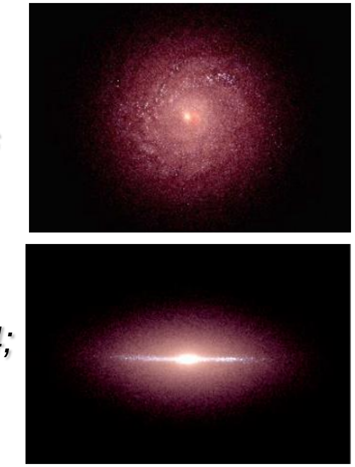


galaxy formation simulation with low sf efficiency and fiducial feedback model (inefficient feedback)

Temperature distribution of baryonic matter in a region around forming galaxy

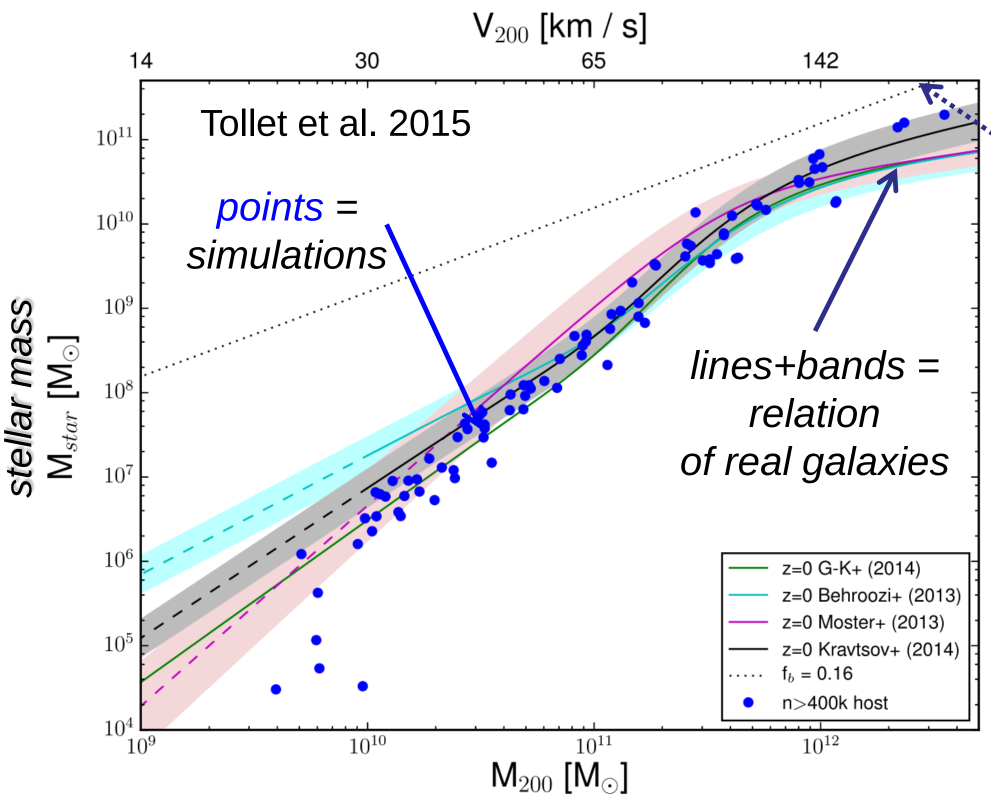
Agertz & Kravtsov arxiv/1404.2613

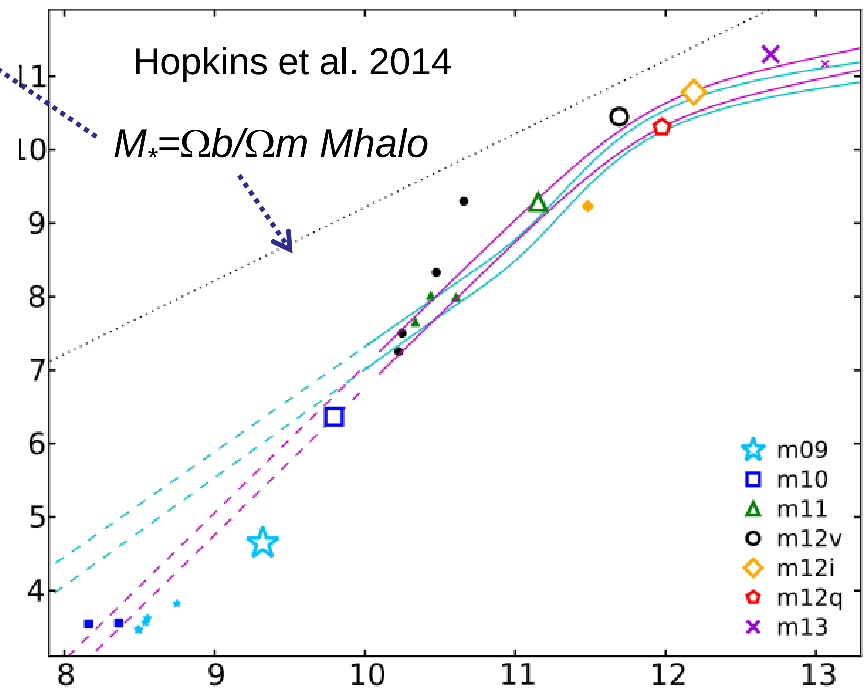
recent progress



mostly due to re-examination of star formation-feedback implementations in light of HST observations of high-z galaxies which showed that star formation at z>2 needs to be strongly suppressed

Guedes+ 11; Governato+ 10,11,12; Brook+ 2012; Stinson+ 13; Hummels & Bryan ’12; Hopkins+ 2014; Ceverino+’14; Trujillo-Gomez+ 14; Uebler+ 14;Salem+ 14; Agertz & Kravtsov ’14, 15
see recent review by Somerville & Dave 2015, ARAA (arxiv/1412.2712)

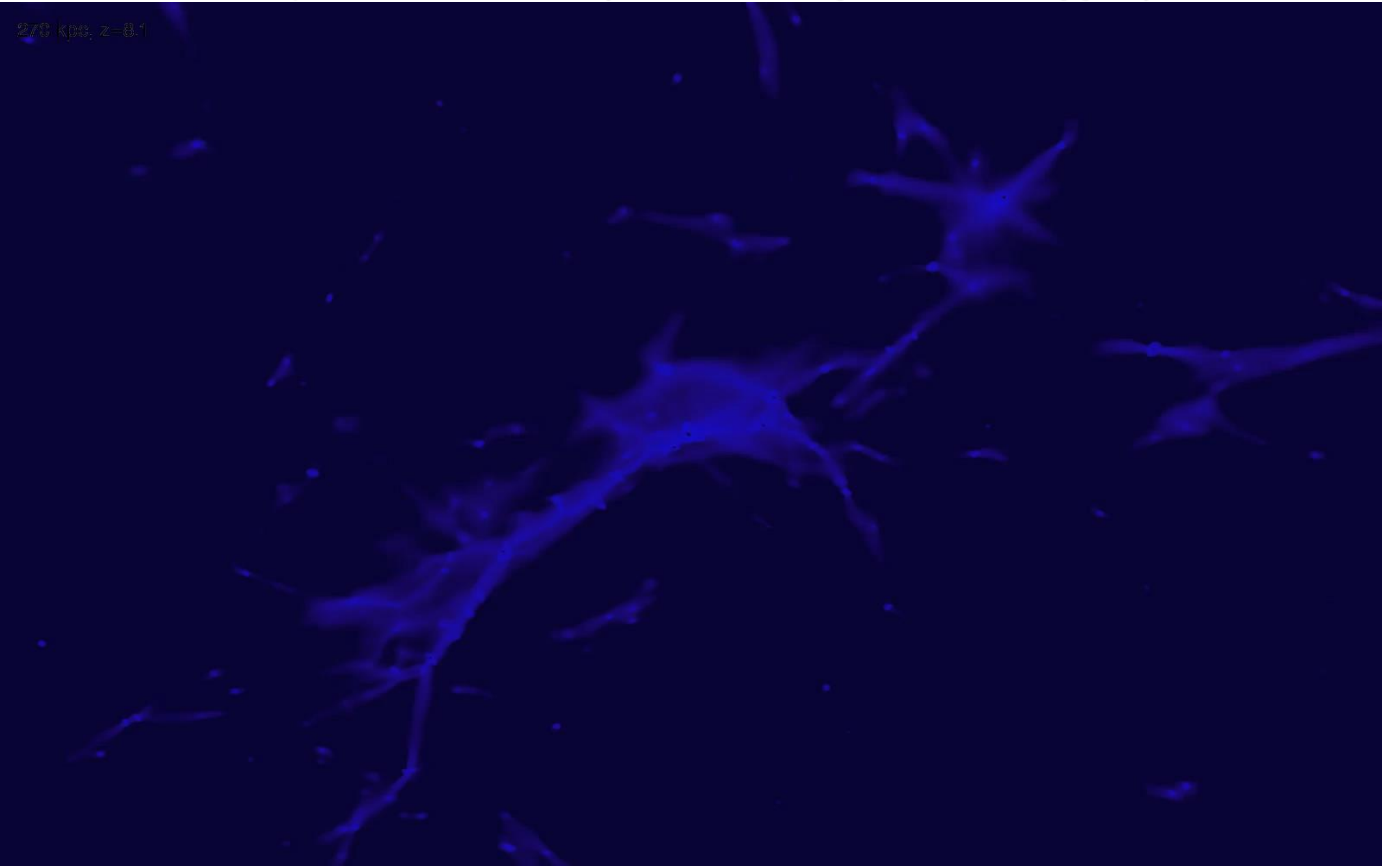




total halo mass in solar masses

galaxy formation simulation with high sf efficiency and fiducial feedback model (efficient feedback)

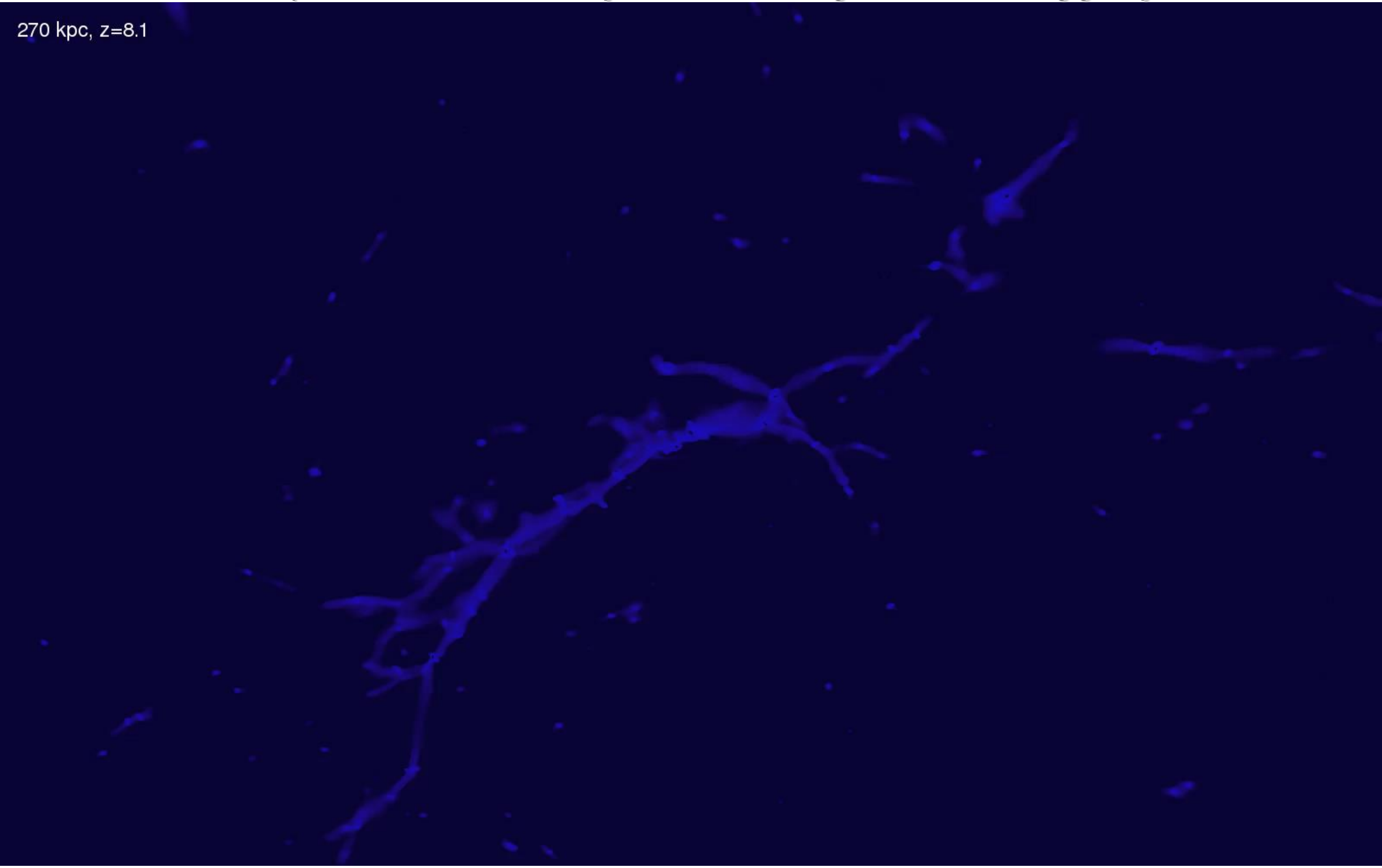
temperature distribution of baryonic matter in a region around forming galaxy



Agertz & Kravtsov ‘14, ‘15, arxiv/1509.00853

galaxy formation simulation with low sf efficiency and boosted feedback model (efficient feedback)

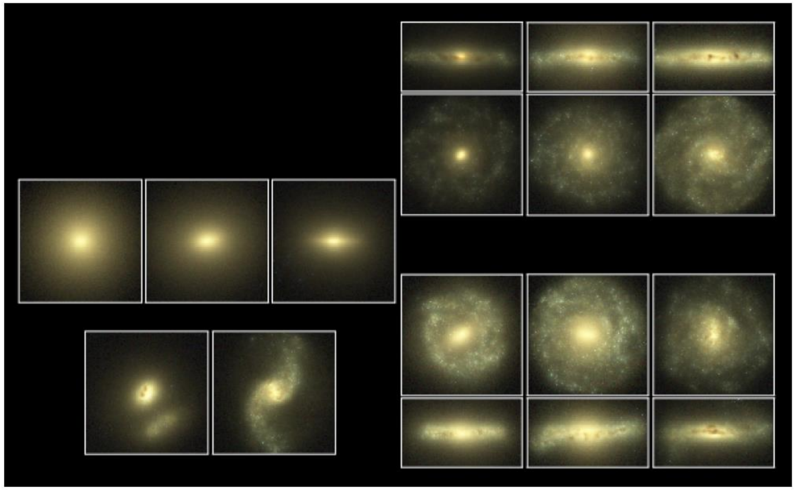
temperature distribution of baryonic matter in a region around forming galaxy



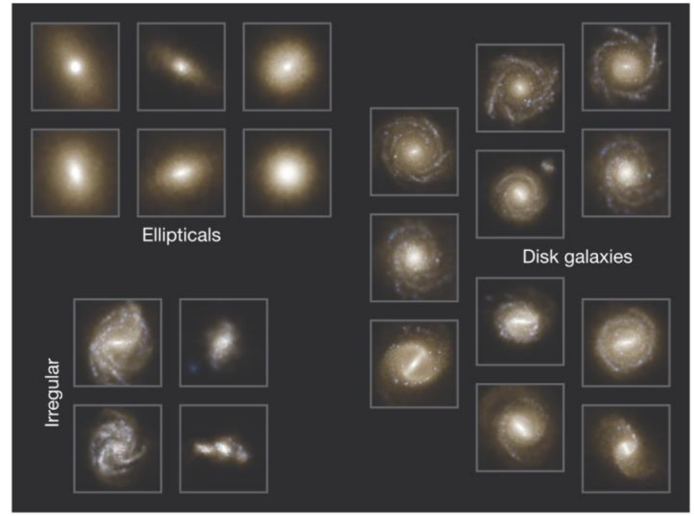
Agertz & Kravtsov '14, '15, arxiv/1509.00853

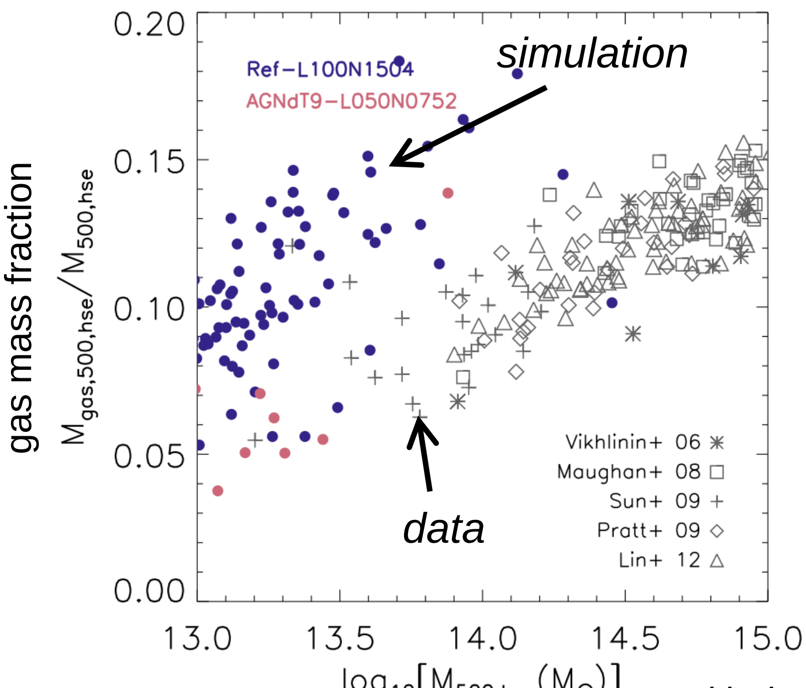
current simulations reproduce stellar component, but generally fail to reproduce gas halos

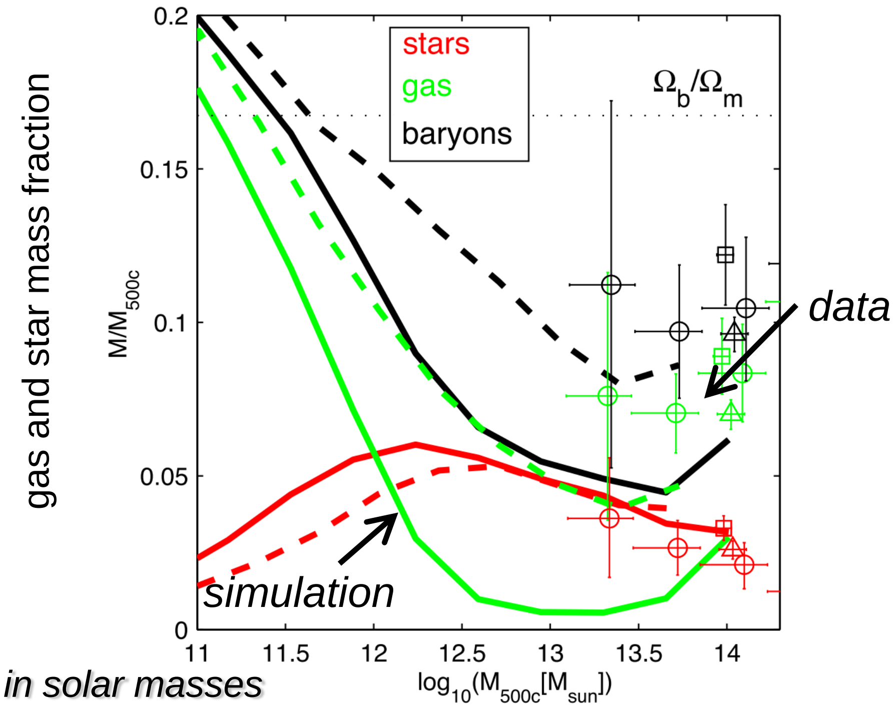
Schaye et al. 2015; “EAGLE” simulation



Genel et al. 2014; “Illustris” simulation







total halo mass in solar masses

But the "just right" feedback simulation is "just wrong" when it comes to CGM

MgII column density maps at different redshifts in 4 simulations

Cameron Liang
(U.Chicago)

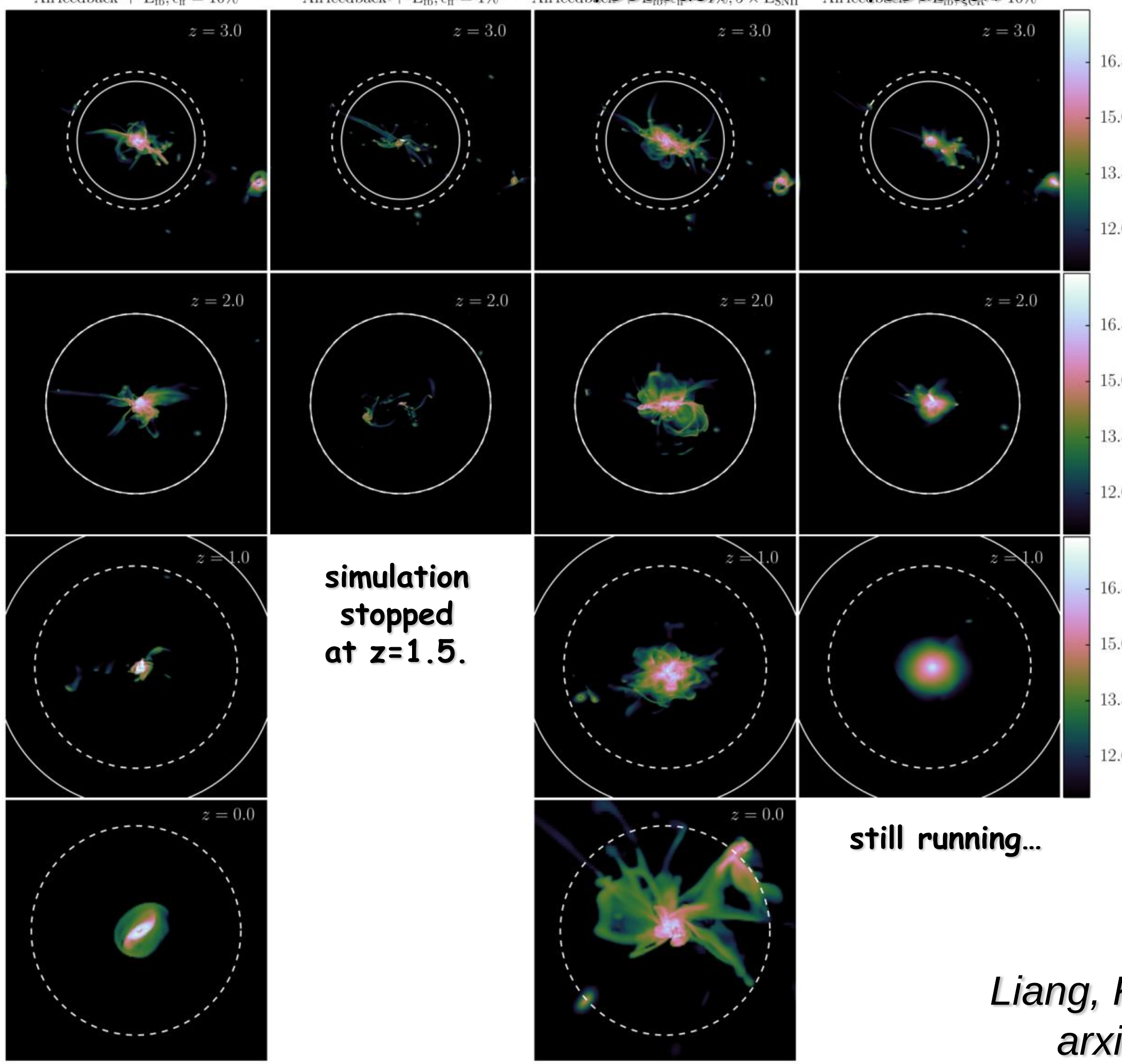
fiducial "just right" feedback | low sf efficiency "weak feedback" | "strong feedback" | SNe+cosmic ray feedback

z=3

z=2

z=1

z=0



simulation stopped at z=1.5.

still running…

solid circles = virial radius

dashed circles = $4r_s$

where r_s is the scale radius of the halo where log. slope of halo density profile is -2

for a halo concentration c_{vir}: $r_s = R_{vir}/c_{vir}$ for rationale see More, Diemer & Kravtsov, arxiv/1504.05591

Liang, Kravtsov & Agertz arxiv/1507.07002

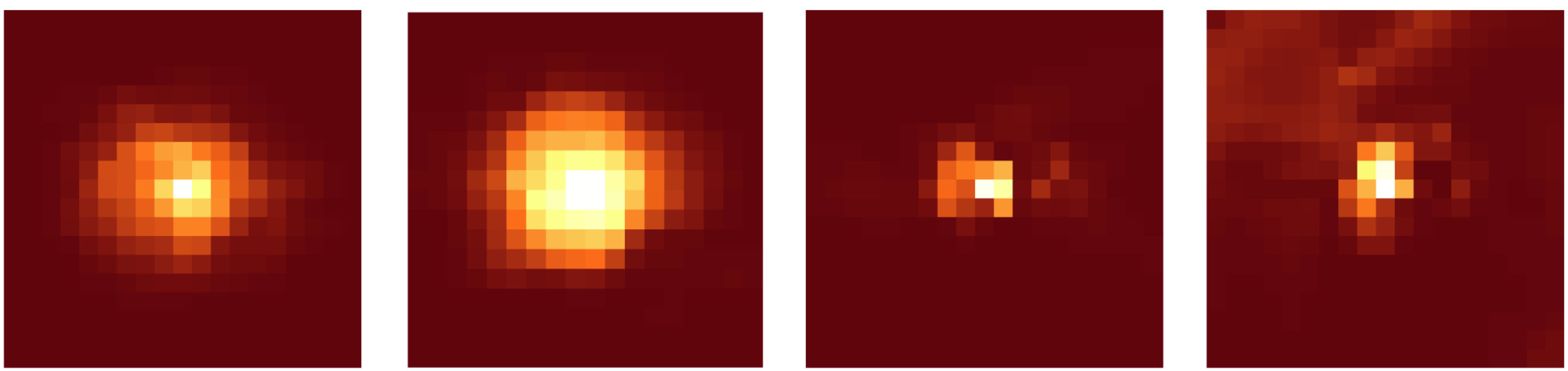
X-ray emissivity maps of gaseous halos of simulations With different star formation parameters and feedback strength

Gaseous halos are taken at z=1.5 (similar differences expected at lower z)

Scales and color maps matched. Brightness corresponds to observed X-surveyor counts in the 0.2-1 keV band (observer frame). Pixel is 0.5 arcsec (~X-surveyor angular resolution = 4.1kpc physical)

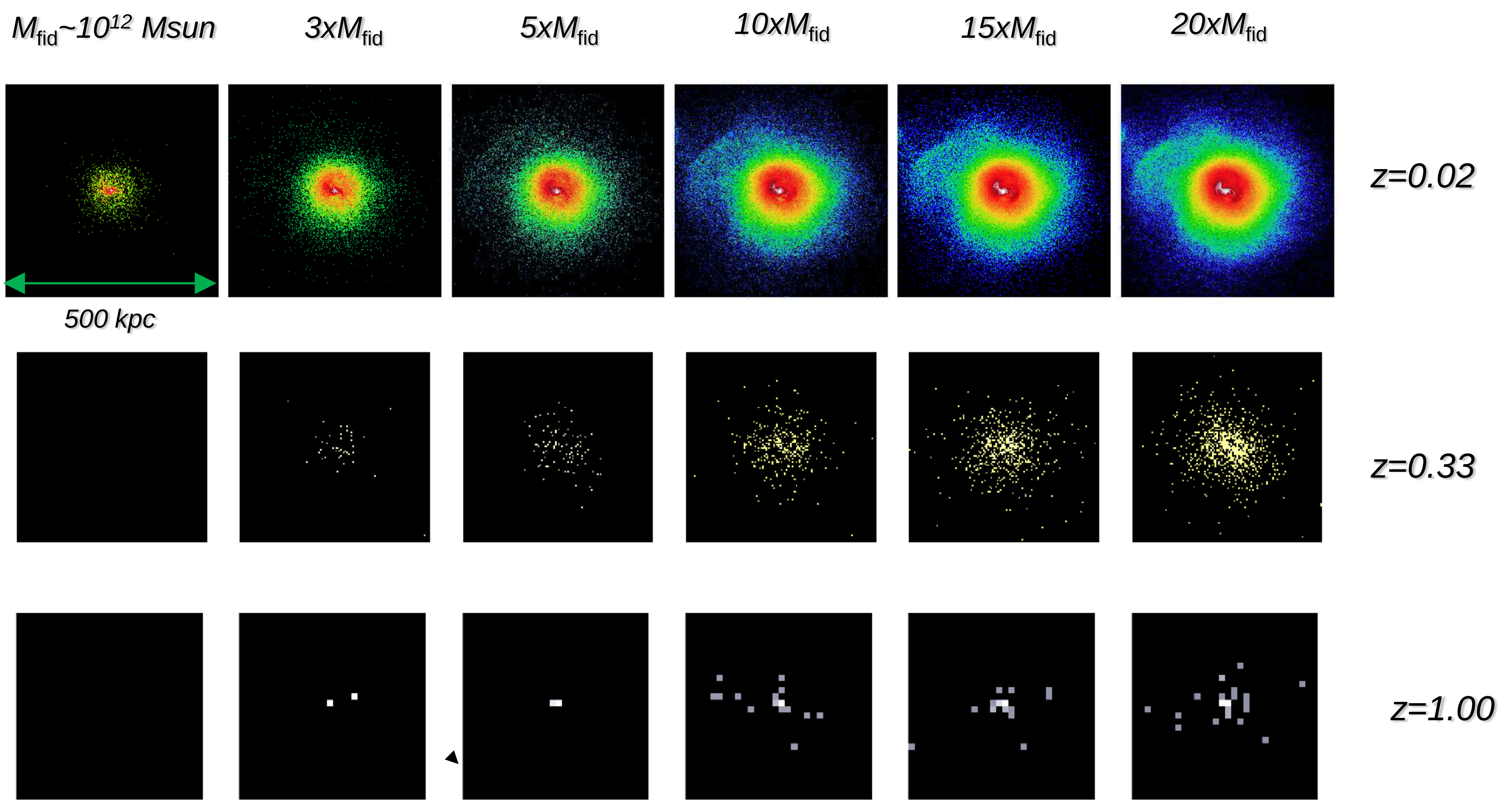
moderate feedback + high sf efficiency (strong outflows)	*moderate feedback + low sf efficiency (weak outflows)*	*strong feedback + low sf efficiency (strong outflows)*	*moderate feedback + high sf efficiency + cosmic rays (strong outflows)*

ratio of counts in these models is 0.15 : 0.91 : 0.09 : 0.83



X-ray surveyor maps of gaseous halos of the fiducial simulation Scaled to different masses

X-ray counts shown are in the 0.2-1 keV band (observer frame) for 100 ksec exposure. Pixel size is 4arcsec for z=0.02, and 0.5 arc sec for z=0.33 and 1.0



summary

- *galaxy formation simulations clearly indicate that stellar and AGN feedback are key processes in formation of galaxies*

  Current cosmological galaxy formation simulations with phenomenological models for star formation and stellar feedback can produce galaxies with realistic stellar masses, sizes, and morphologies

- *The physics and parameters of star formation and feedback are not yet understood*

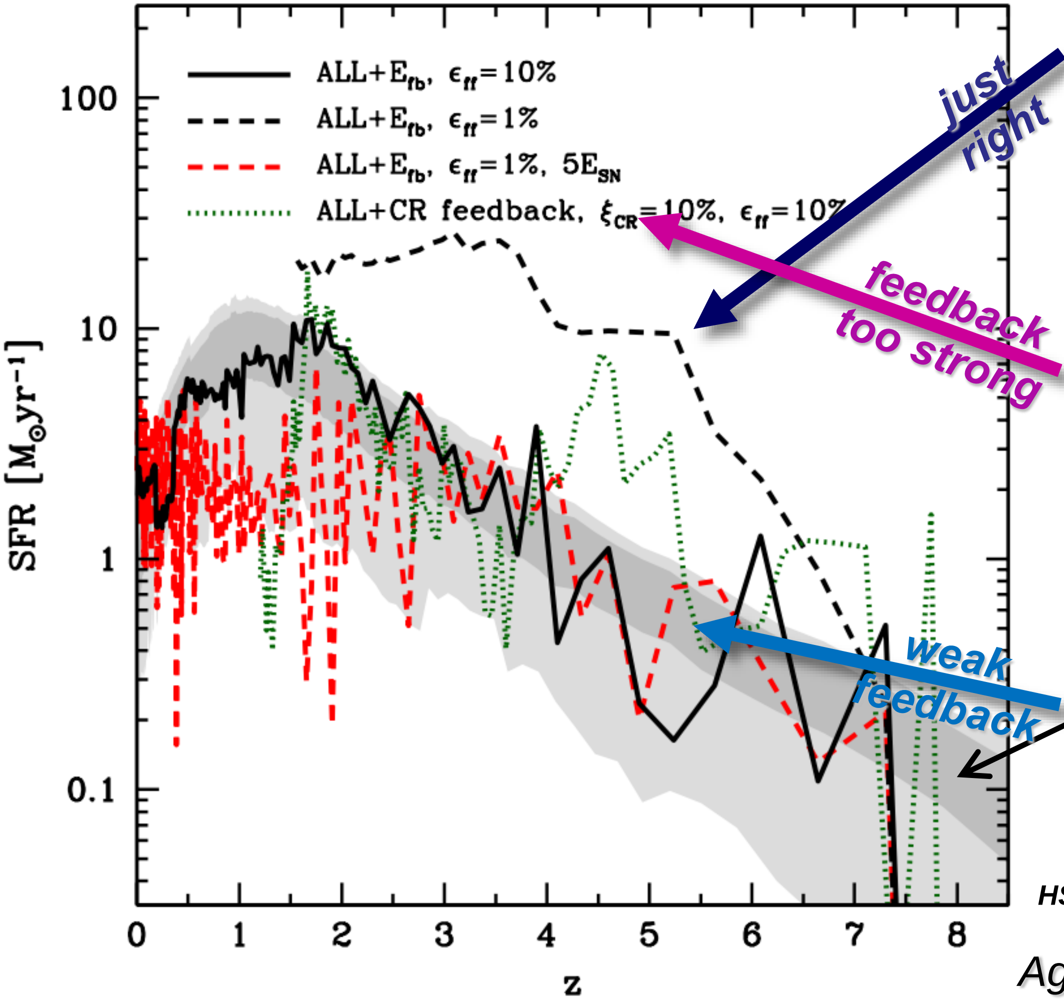
  X-ray view of gaseous halos of galaxies and detailed comparisons with model predictions can greatly aid in understanding these processes and breaking degeneracies between parameters.

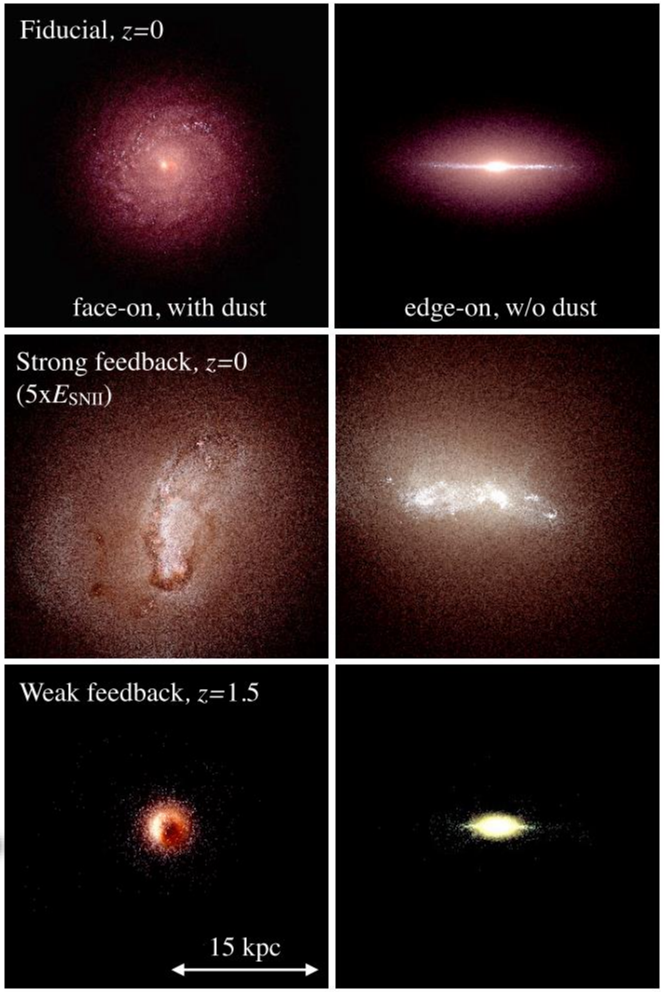
- *UV absorption studies will help, but information about gas mass distribution and thermodynamic properties will be difficult (I think impossible) to extract due to dynamic nature of the UV absorbing gas*

- *Probing gaseous halos is precisely the job for X-ray surveyor, which can provide probe properties of gaseous halos for galaxies around the characteristic mass of the M*-Mhalo relation (Mhalo~10^{12}-10^{13} Msun)*

Star formation histories and stellar mass buildup in runs with different sf efficiency and feedback

star formation rate of the main progenitor of the same halo (M_{200}~$1x10^{12}$ Msun at z=0) in re-simulations with different sf and feedback parameters





HST mockup RGB using F450W, F606W, F814W filter

Agertz & Kravtsov 2015, ApJ 804, 18
arxiv/1404.2613