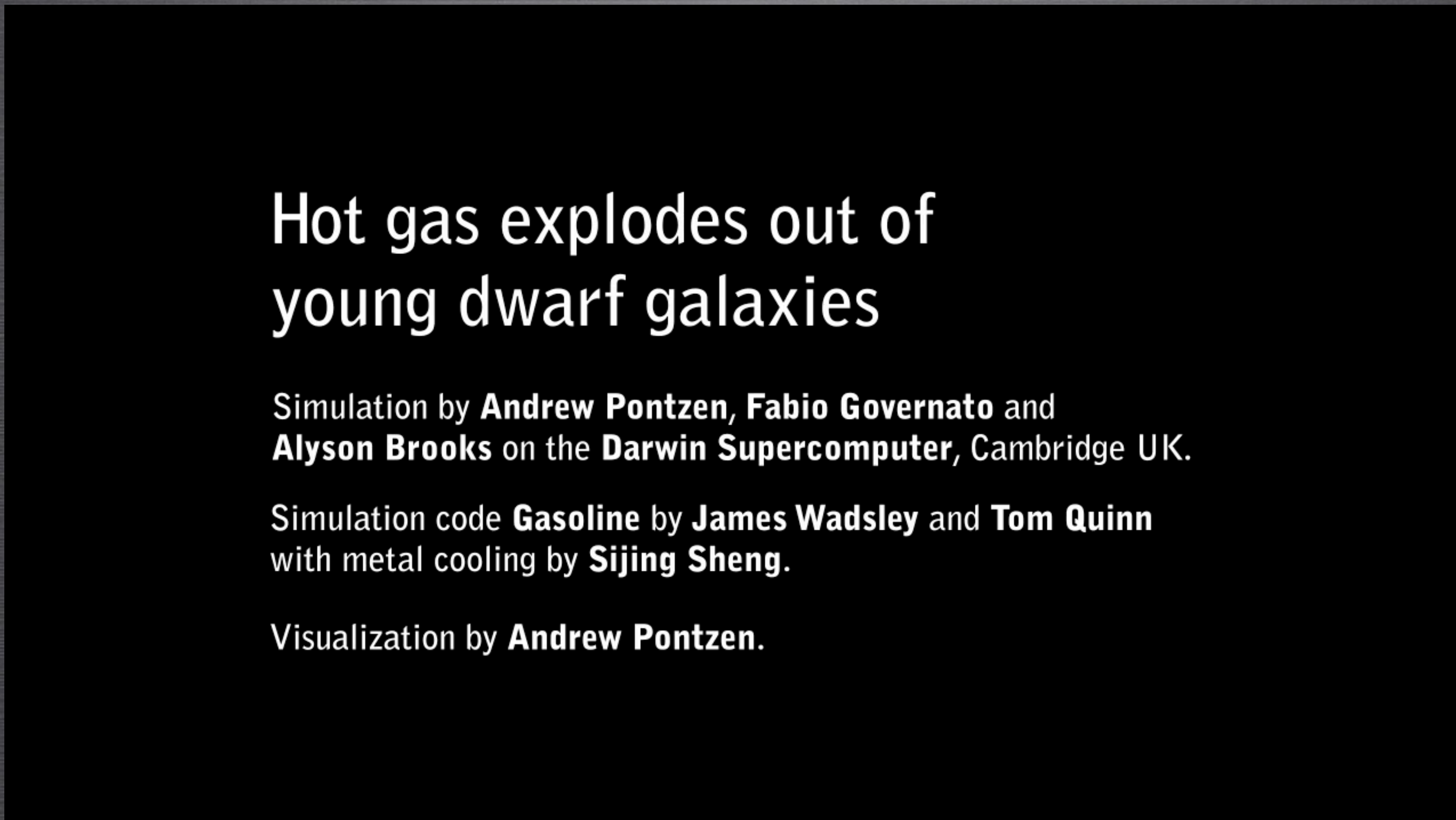
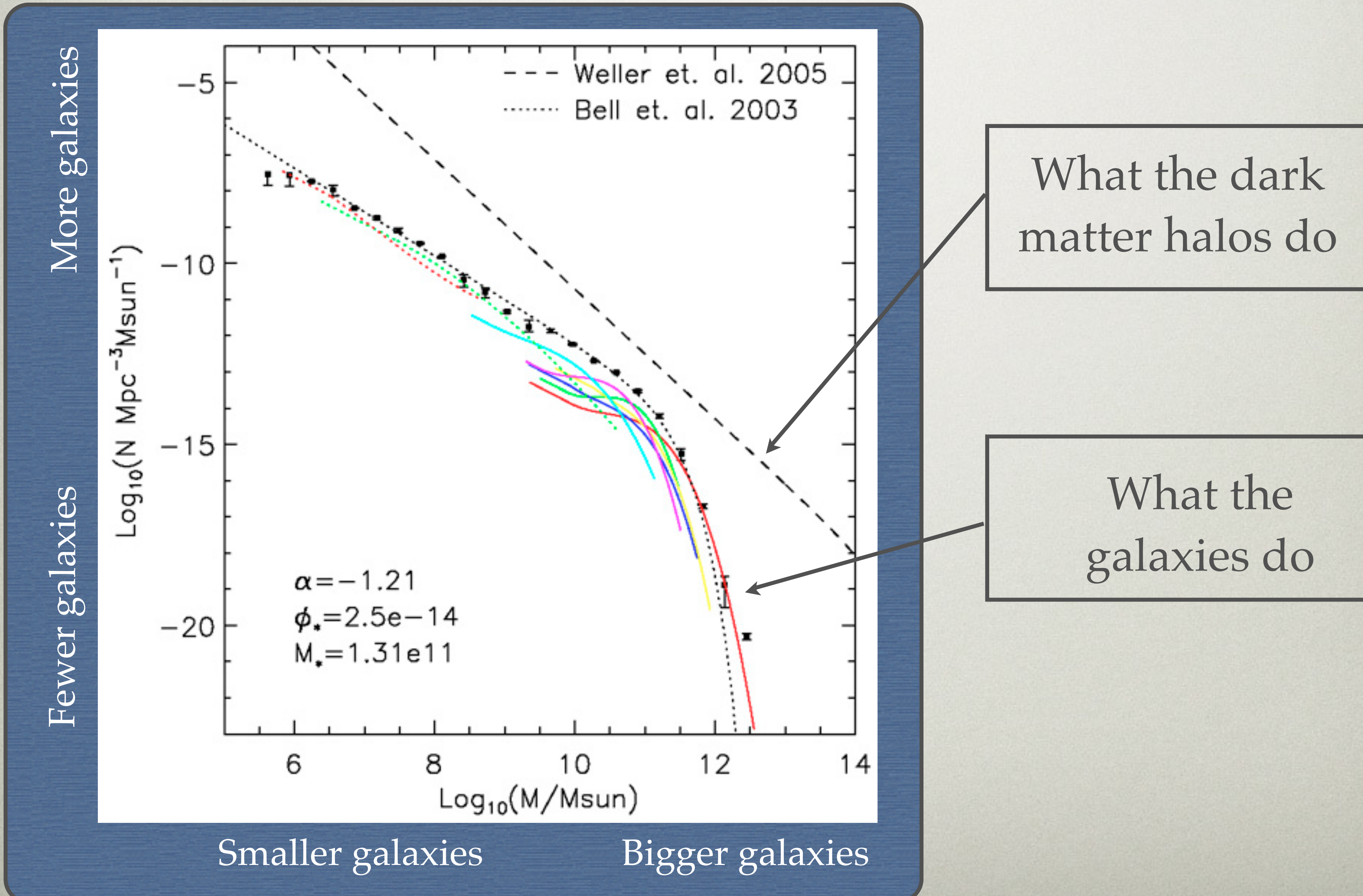
The Role of Feedback in Galaxy Scaling Relations



Alyson Brooks
Rutgers, the State University of New Jersey

In collaboration with the University of Washington's N-body Shop™
makers of quality galaxies

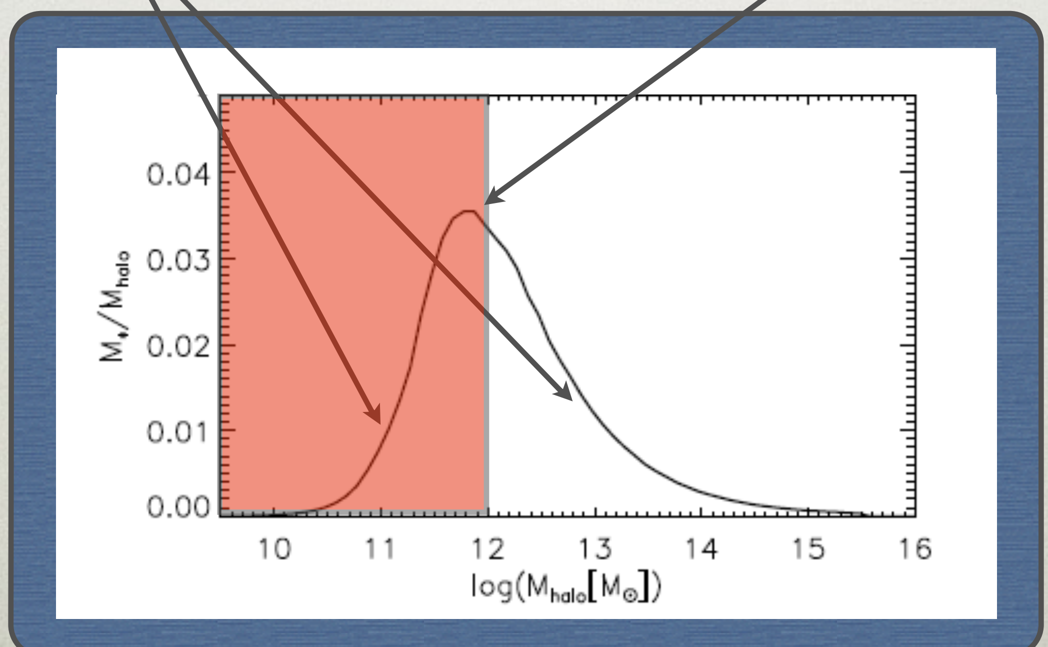
The Light from Galaxies Doesn't trace the dark matter



Star Formation varies with Galaxy Mass

Galaxies smaller & bigger than the Milky Way are bad at making stars

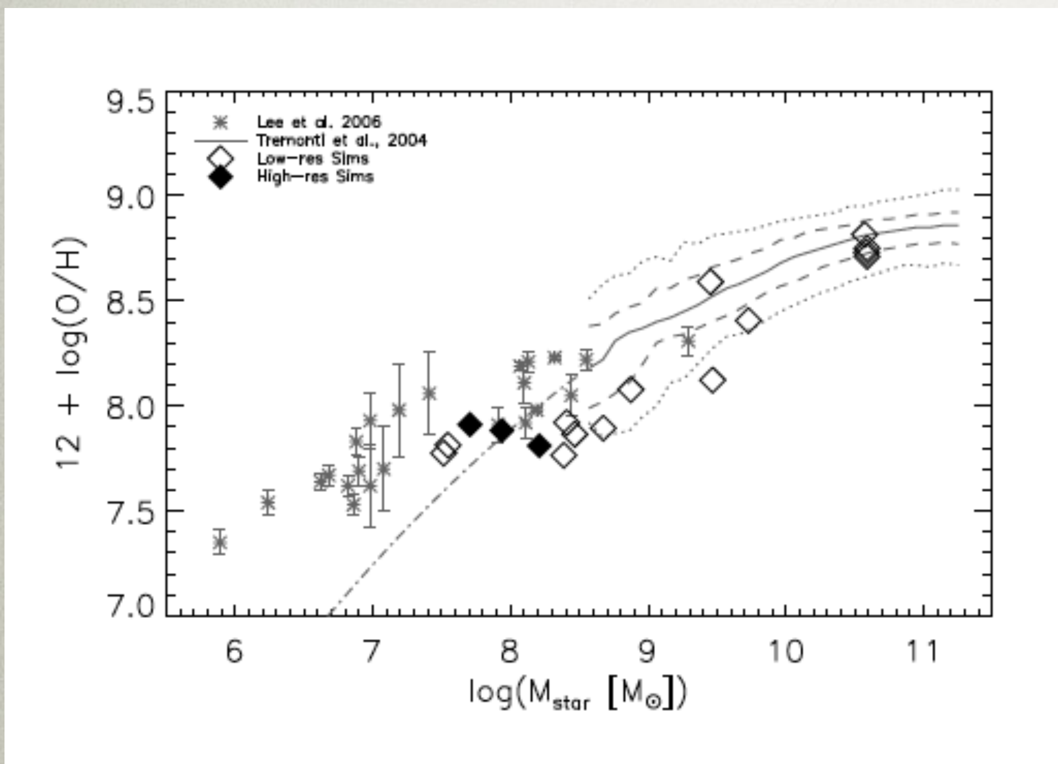
Galaxies like the Milky Way are best at making stars



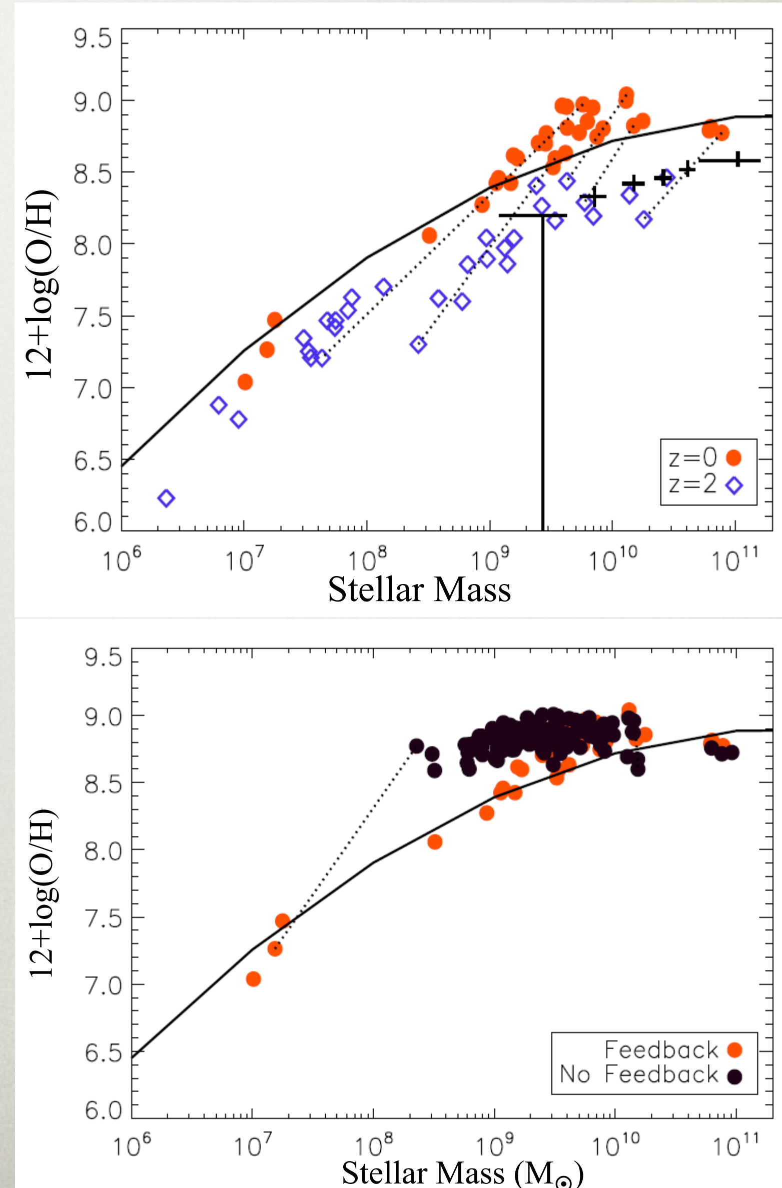
WHY?!?

Guo et al. (2010)

A Second Line of Evidence



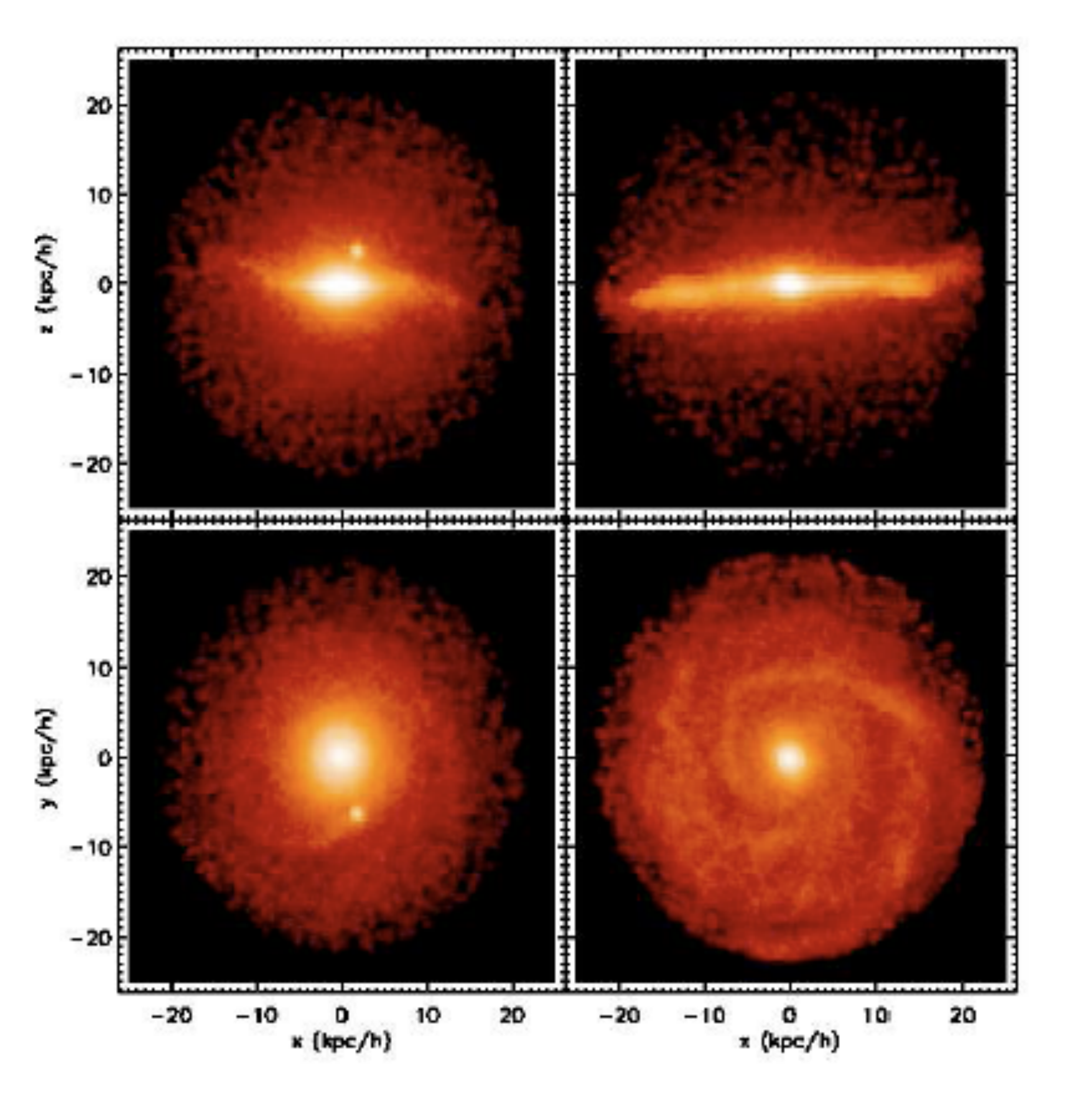
Christensen et al. (2014)



Brooks et al. (2007)

We've known for a while that feedback is necessary

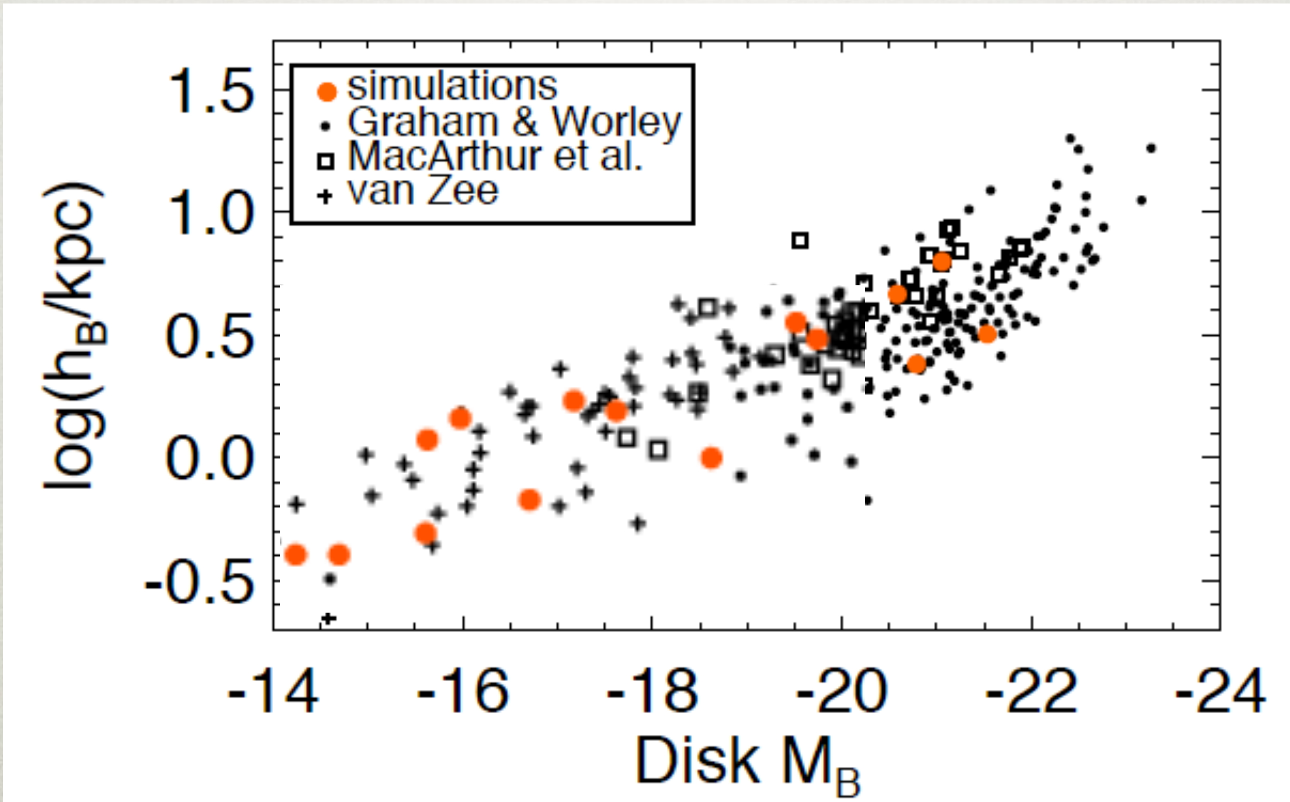
No feedback



feedback

Zavala et al. (2008)
Scannapieco et al. (2008)

Disk Sizes are No Longer a Challenge



Size-Luminosity (Brooks et al. 2011)

Simulations Now Match Everything

Towards a more realistic population of bright spiral galaxies in cosmological simulations

Michael Aumer[1,2] ⋆, Simon D.M. White[1], Thorsten Naab[1], Cecilia Scannapieco[3]
[1]*Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany*
[2]*Excellence Cluster Universe, Boltzmannstr. 2, 85748 Garching, Germany*
[3]*Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, 14482 Potsdam, Germany*

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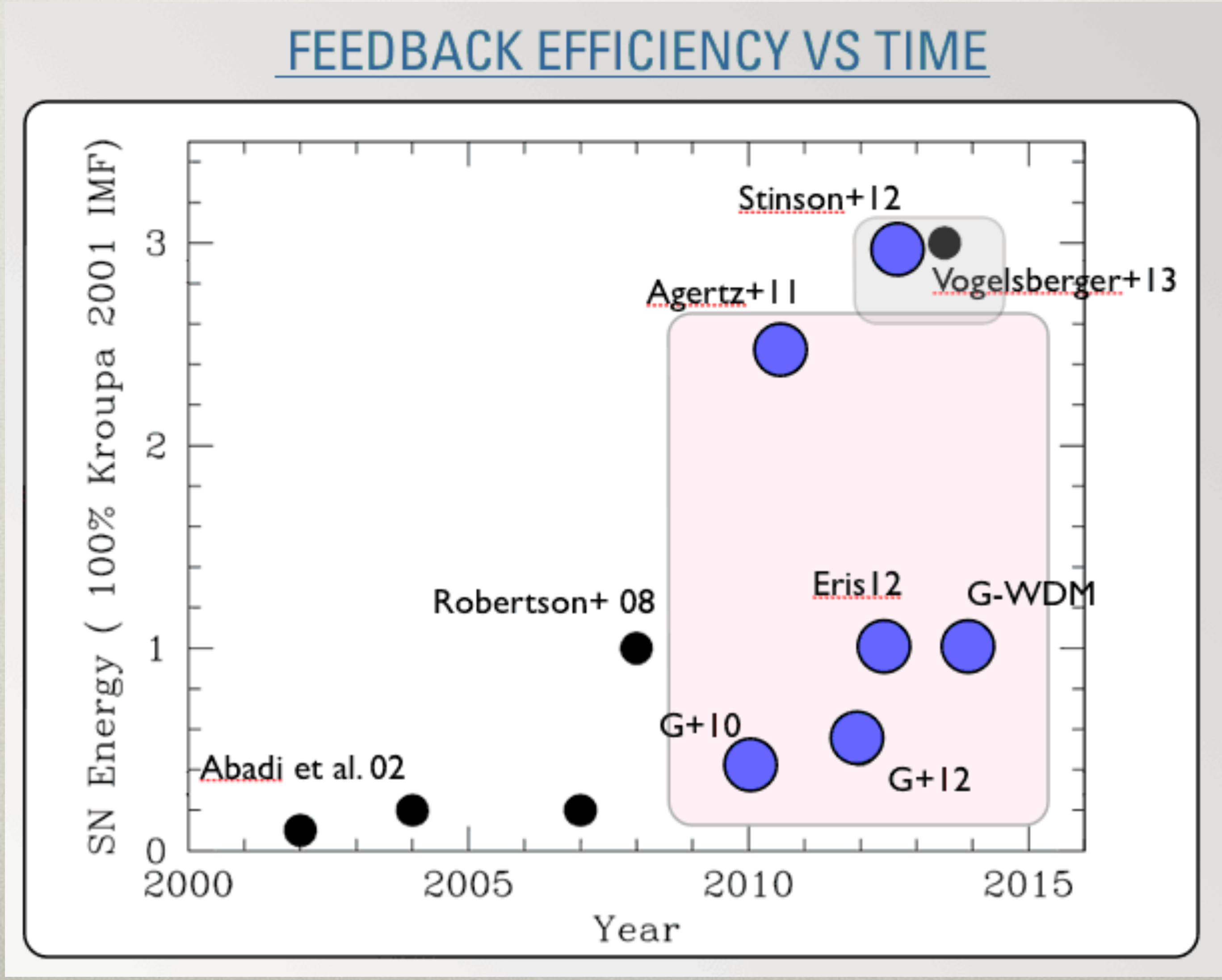
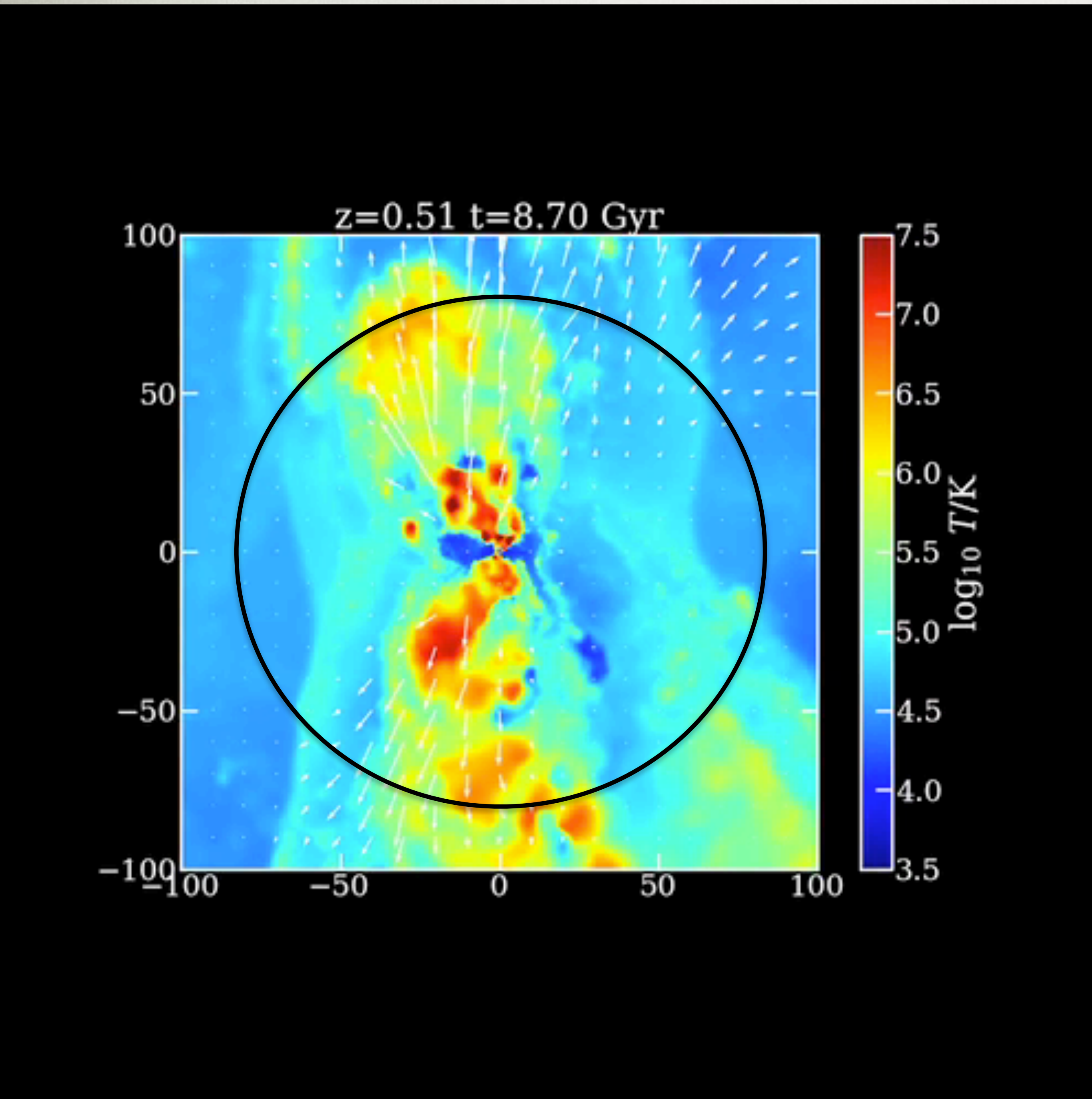
ABSTRACT
We present an update to the multiphase SPH galaxy formation code by Scannapieco et al. We include a more elaborate treatment of the production of metals, cooling rates based on individual element abundances, and a scheme for the turbulent diffusion of metals. Our SN feedback model now transfers energy to the ISM in kinetic and thermal form, and we include a prescription for the effects of radiation pressure from massive young stars on the ISM. We calibrate our new code on the well studied Aquarius haloes and then use it to simulate a sample of 16 galaxies with halo masses between 1×10^{11} and $3 \times 10^{12} M_\odot$. In general, the stellar masses of the sample agree well with the stellar mass to halo mass relation inferred from abundance matching techniques for redshifts $z = 0 - 4$. There is however a tendency to overproduce stars at $z > 4$ and to underproduce them at $z < 0.5$ in the least massive haloes. Overly high SFRs at $z < 1$ for the most massive haloes are likely connected to the lack of AGN feedback in our model. The simulated sample also shows reasonable agreement with observed star formation rates, sizes, gas fractions and gas-phase metallicities at $z = 0 - 3$. Remaining discrepancies can be connected to deviations from predictions for star formation histories from abundance matching. At $z = 0$, the model galaxies show realistic morphologies, stellar surface density profiles, circular velocity curves and stellar metallicities, but overly flat metallicity gradients. 15 out of 16 of our galaxies contain disk components with kinematic disk fraction ranging between 15 and 65 %. The disk fraction depends on the time of the last destructive merger or misaligned infall event. Considering the remaining shortcomings of our simulations we conclude that even higher kinematic disk fractions may be possible for ΛCDM haloes with quiet merger histories, such as the Aquarius haloes.

How to Match Everything (More Feedback, please)



Outflows!



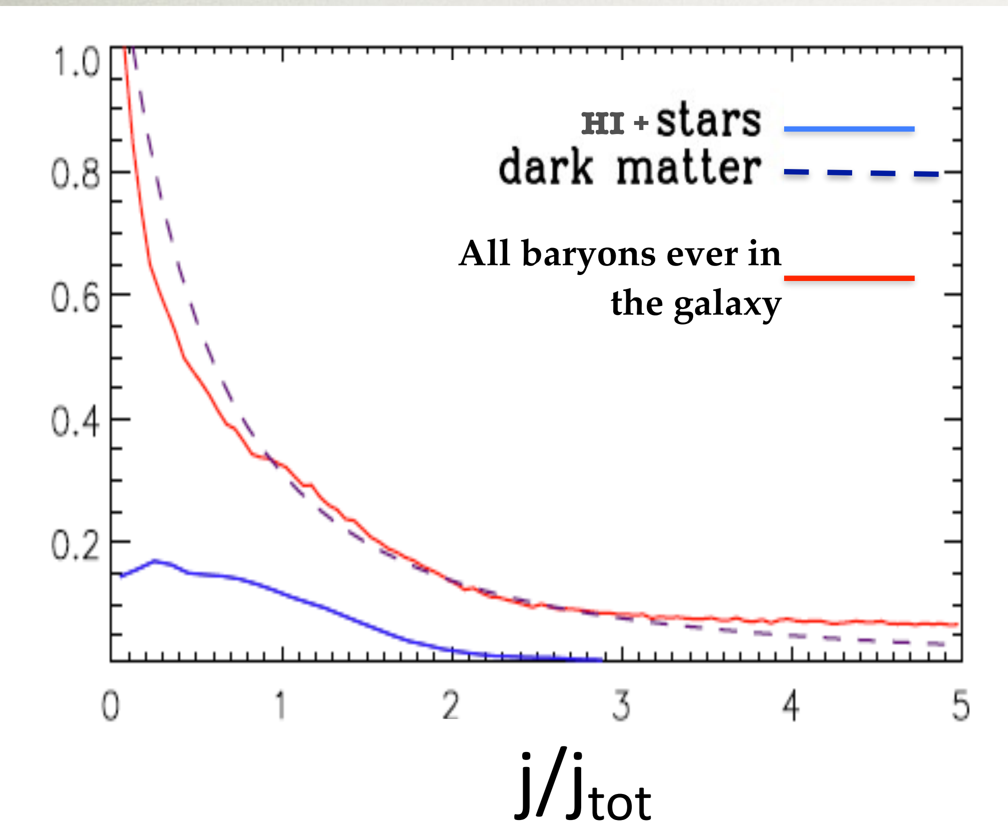
M_{vir} ~ 10^{10} M_{sun}
"dwarf galaxy"

Edge-on disk orientation

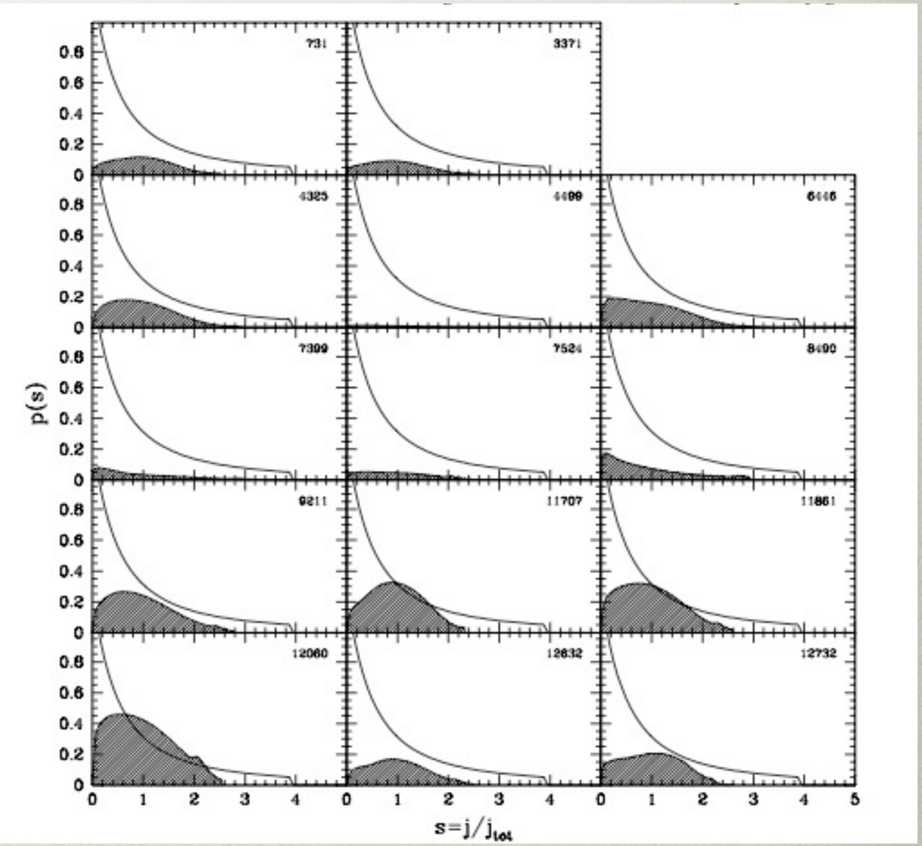
(arrows are velocity vectors)

Brook et al., 2011, MNRAS, 415, 1051

Outflows Remove Low Angular Momentum Gas (and Make Bulgeless Disks)

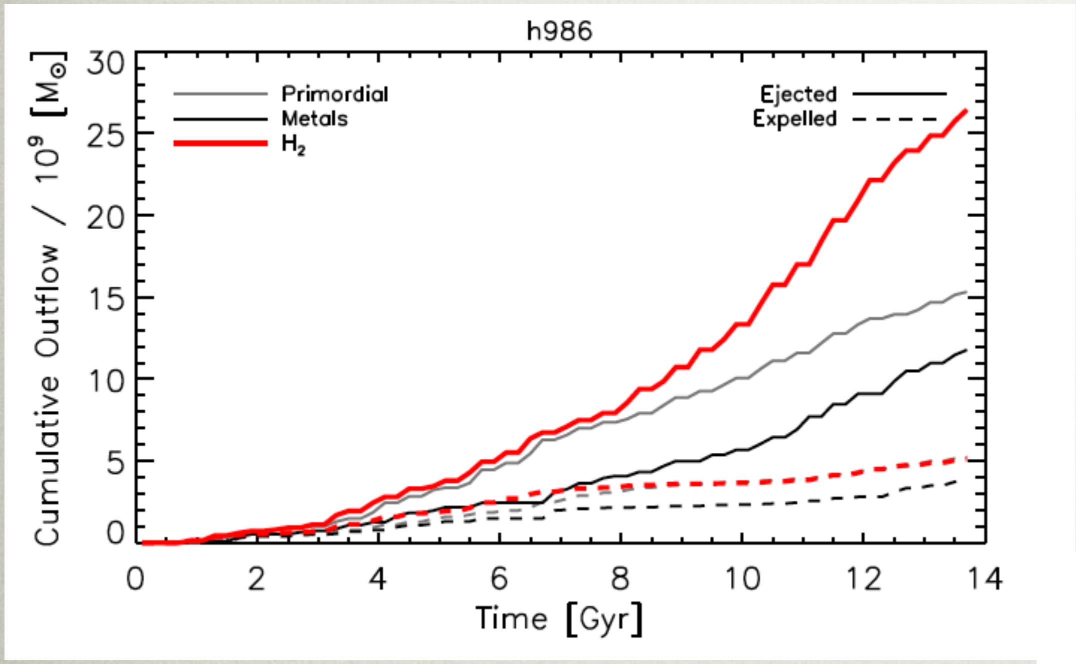


Brook et al., 2011, MNRAS, 415, 1051

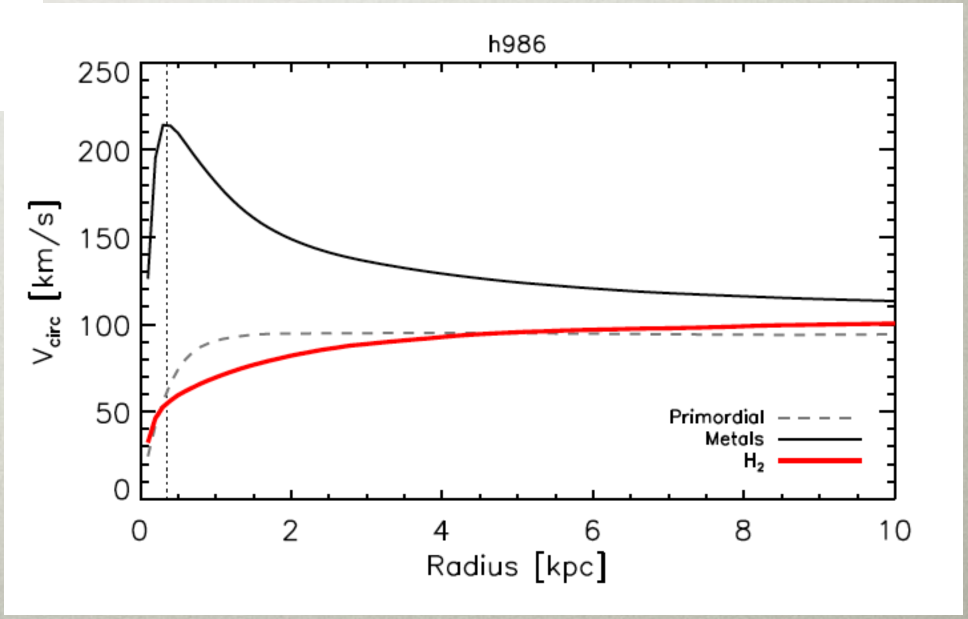


van den Bosch et al. (2001)

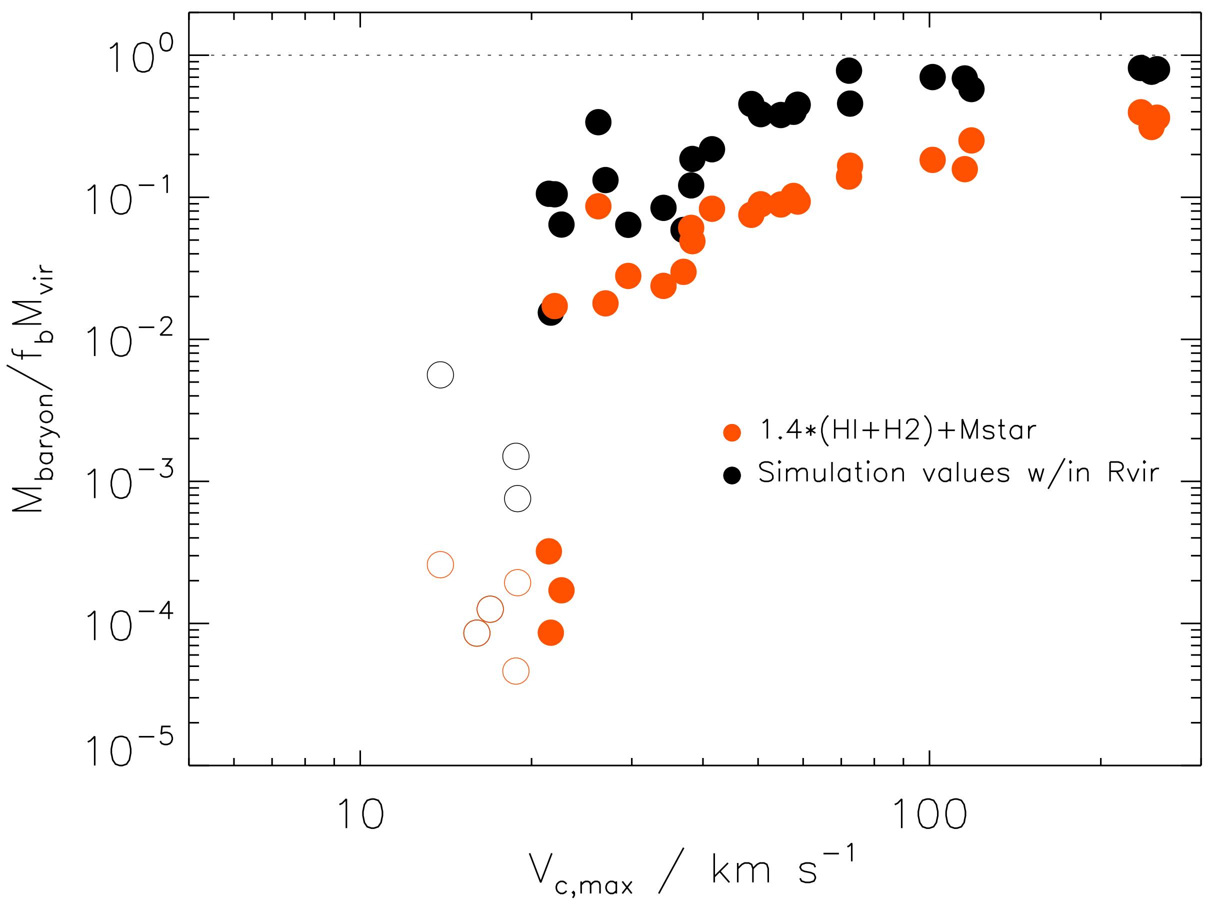
Outflows Reduce the Central Concentrations in Larger Galaxies



Christensen et al. (2014)

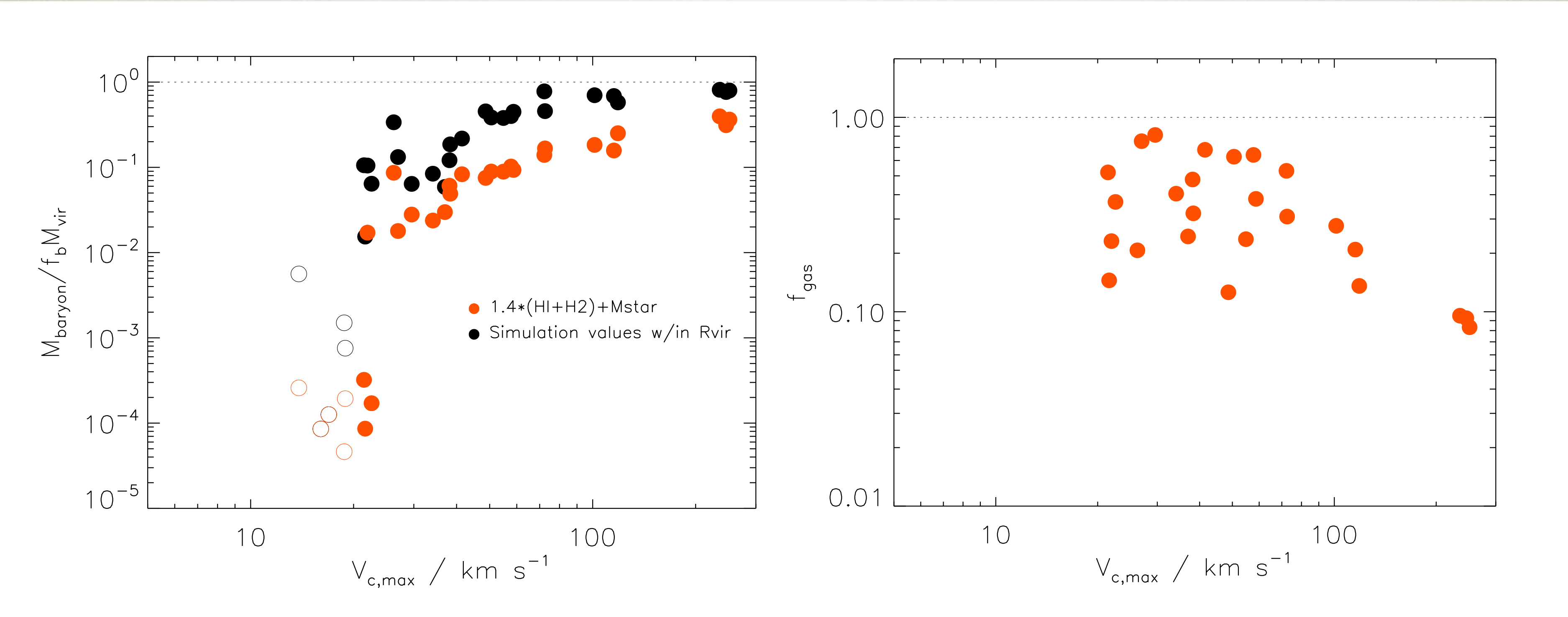


The Baryon Fraction as a Function of Halo Mass

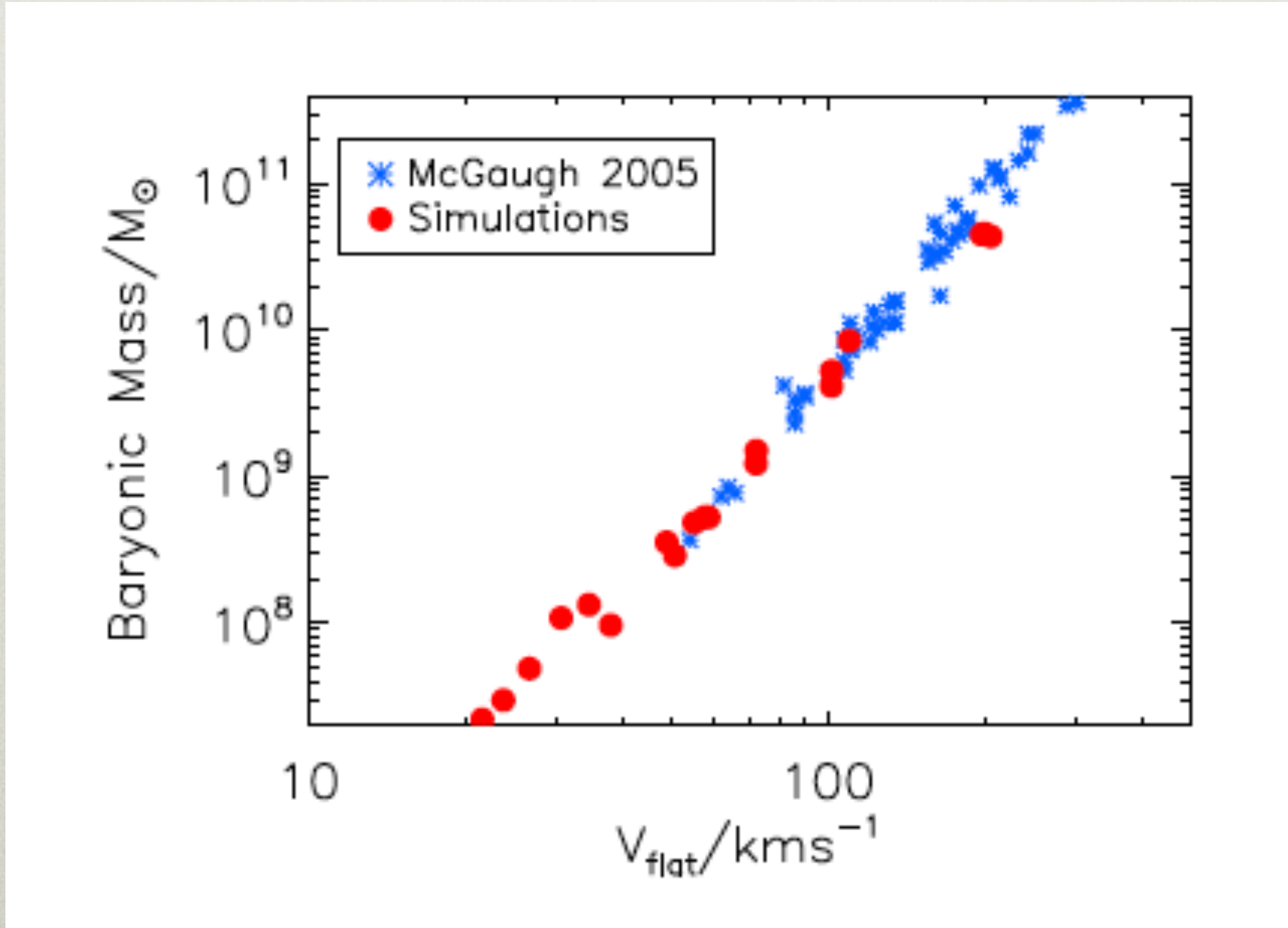


see also Munshi et al. (2013)

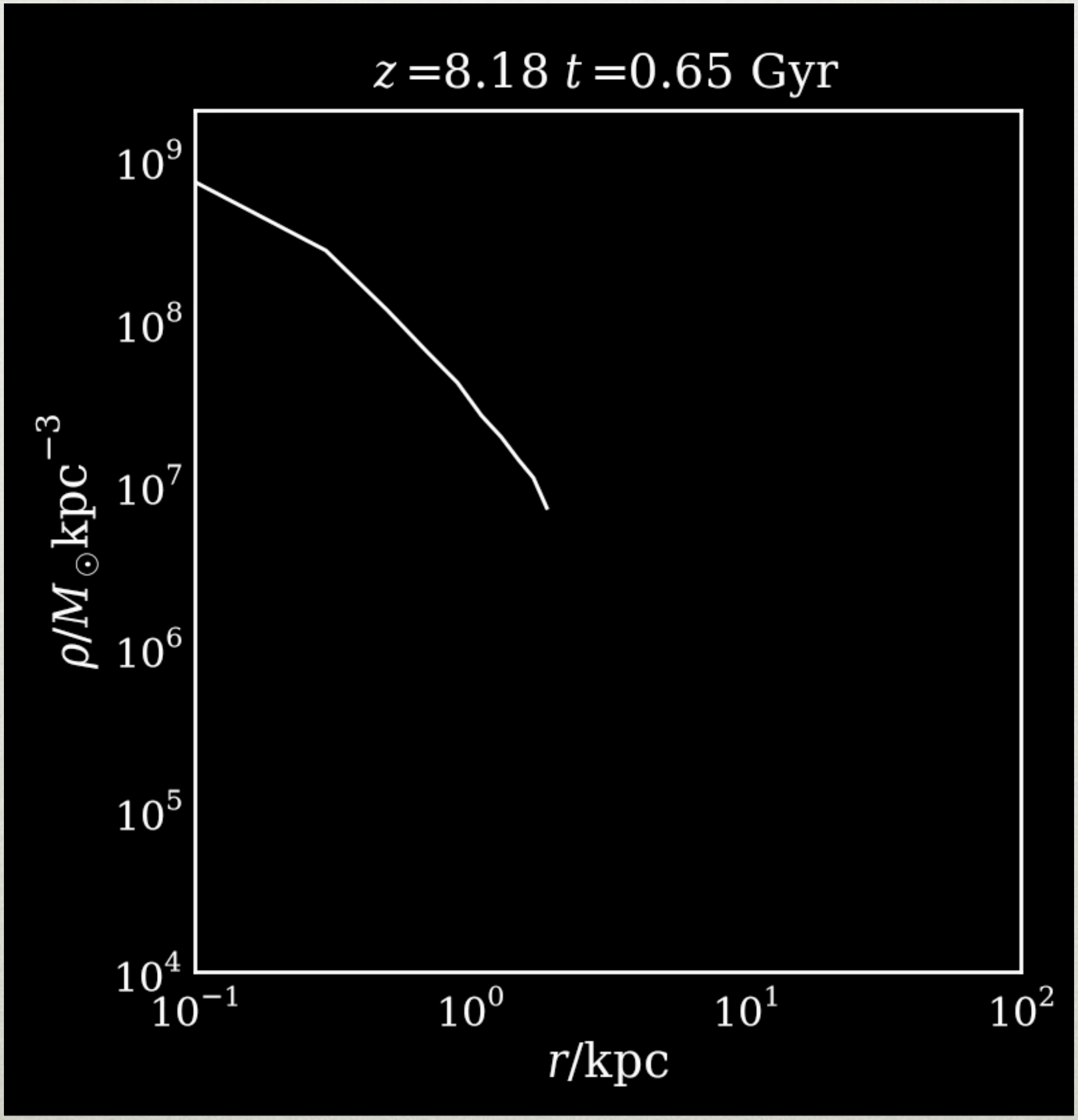
You can lose 90% of your Baryons and be Gas Rich



There is a Tight Trend in Baryonic Mass with Halo Mass

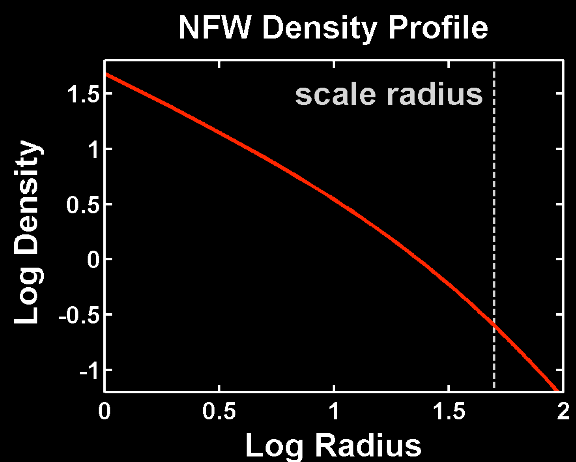


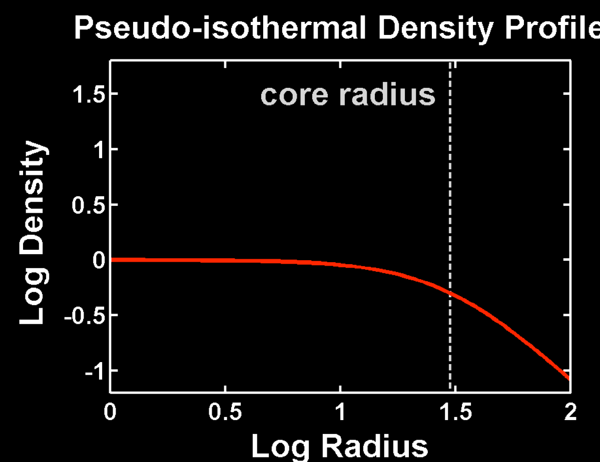
Creation of a Dark Matter Core



See also: Navarro et al. 1996; Read & Gilmore 2005; Mashchenko et al. 2006, 2008; Pasetto et al. 2010; de Souza et al. 2011; Cloet-Osselaer et al. 2012; Maccio et al. 2012; Teyssier et al. 2012; Ogiya & Mori 2012

The Cusp/Core Problem



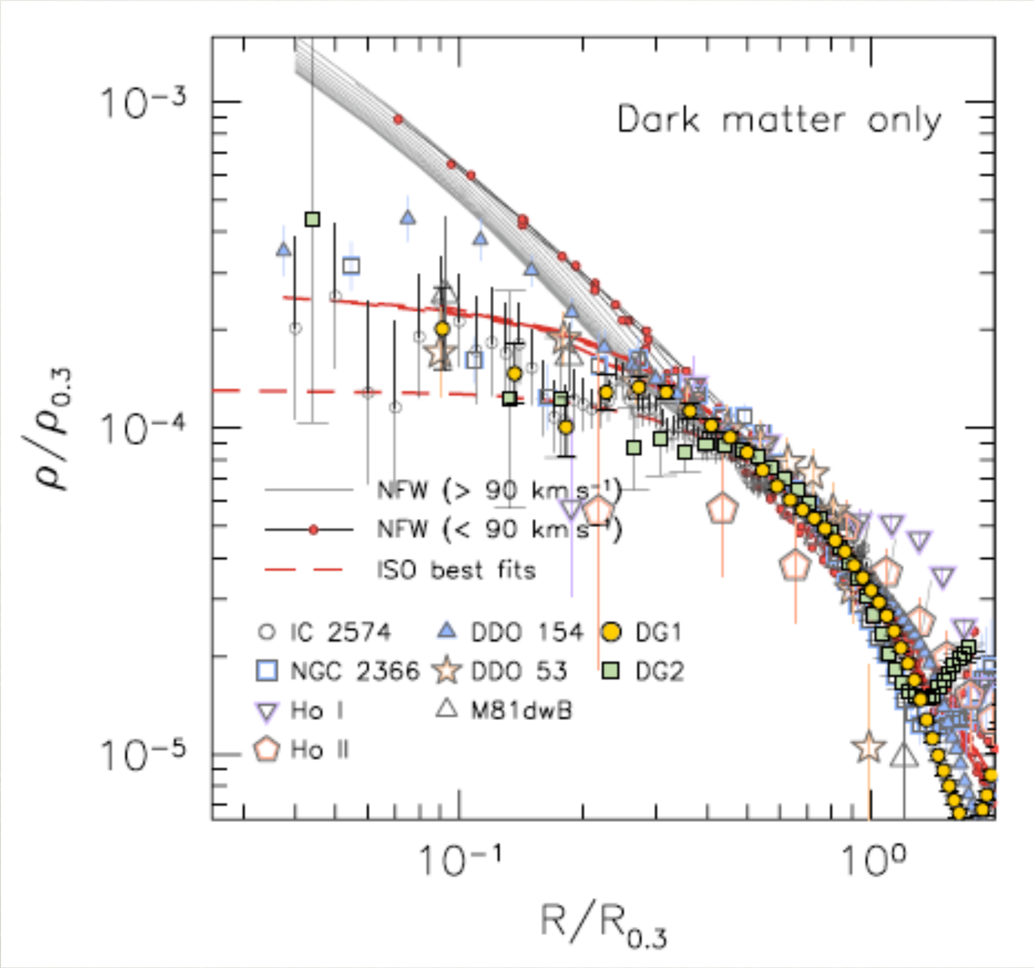


Parameterize density profile as $\varrho(r) \propto r^{-\alpha}$

Simulations predict $\alpha \sim 1$ (central cusp)

Observations show $\alpha \sim 0$ (constant-density core)

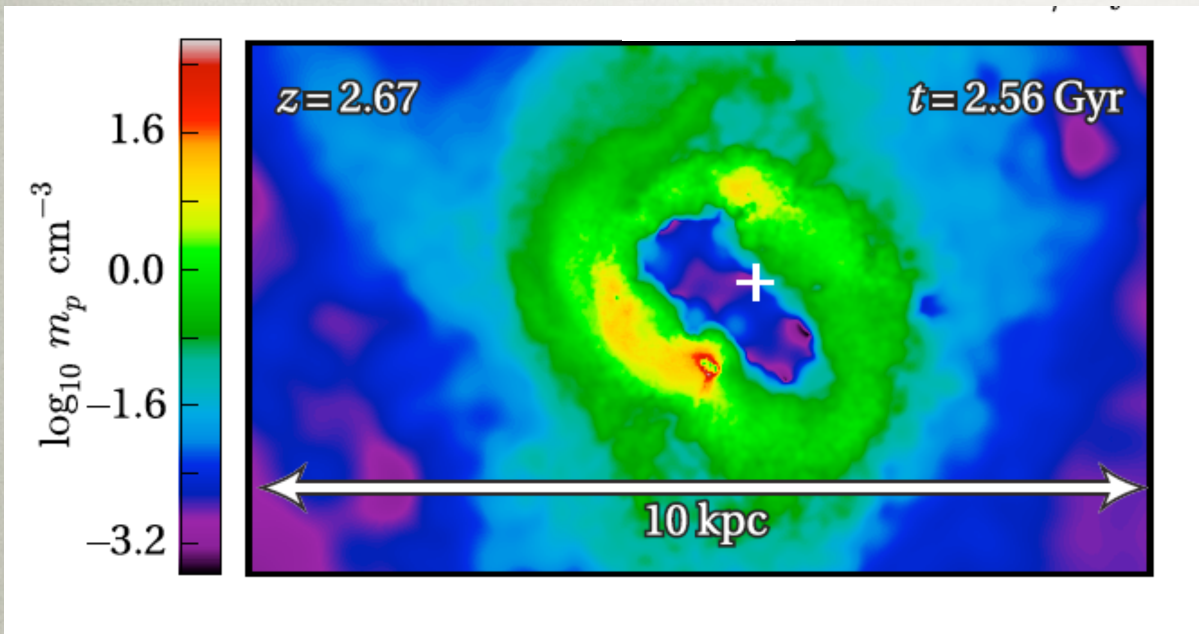
Creation of a Dark Matter Core

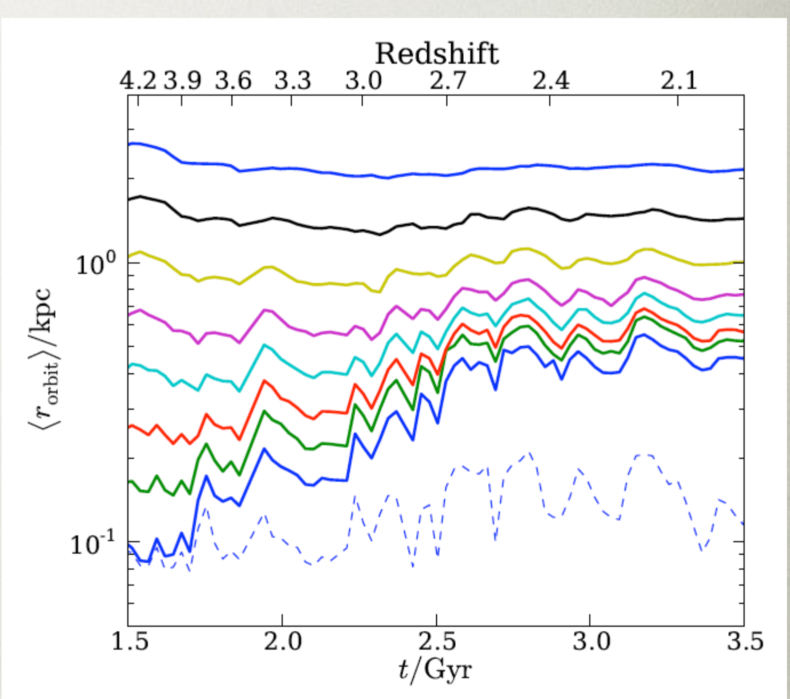


Oh et al., 2011, AJ, 142, 24

See also: Navarro et al. 1996; Read & Gilmore 2005; Mashchenko et al. 2006, 2008; Pasetto et al. 2010; de Souza et al. 2011; Cloet-Osselaer et al. 2012; Maccio et al. 2012; Teyssier et al. 2012; Ogiya & Mori 2012

How are Cores Created?

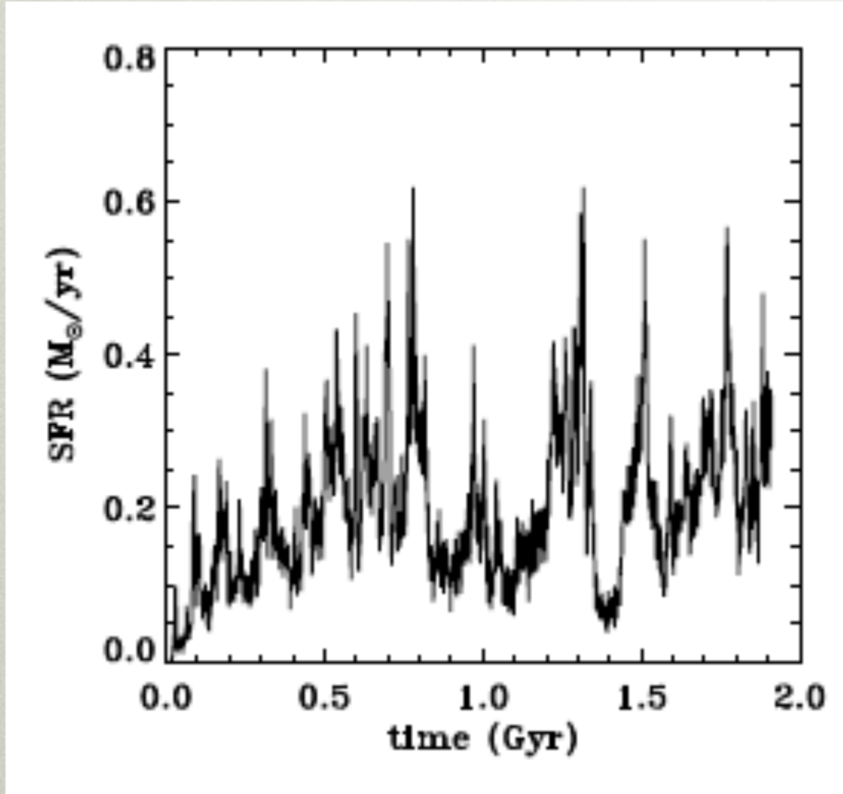


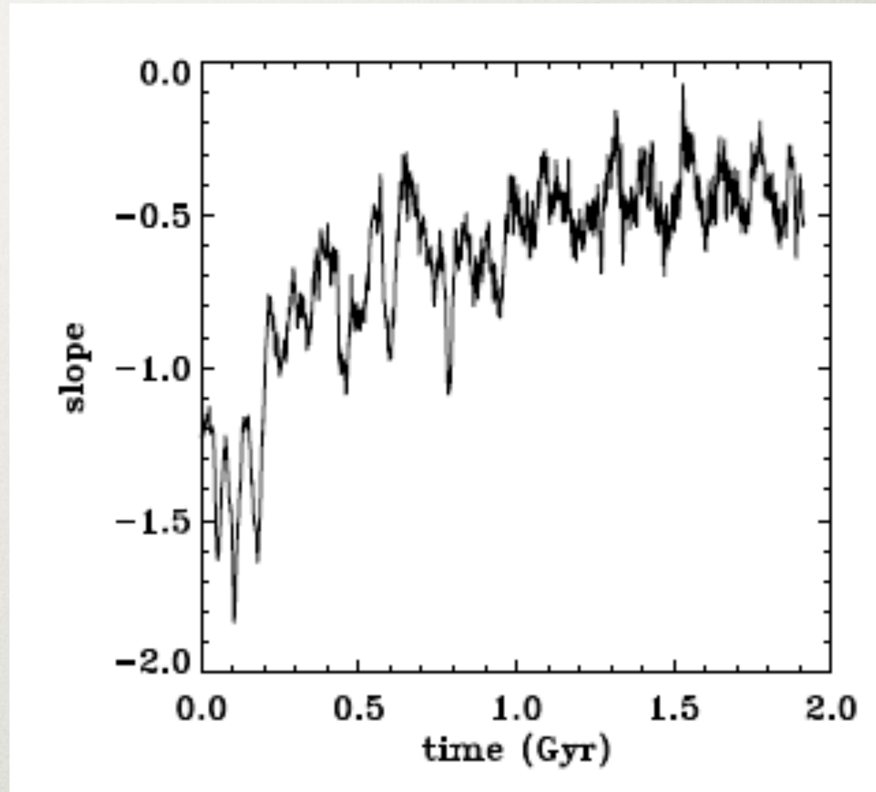


Pontzen & Governato (2012), MNRAS, 421, 3464, arXiv:1106.0499

Cores Found By Many

Teyssier et al. (2013), RAMSES (AMR) code



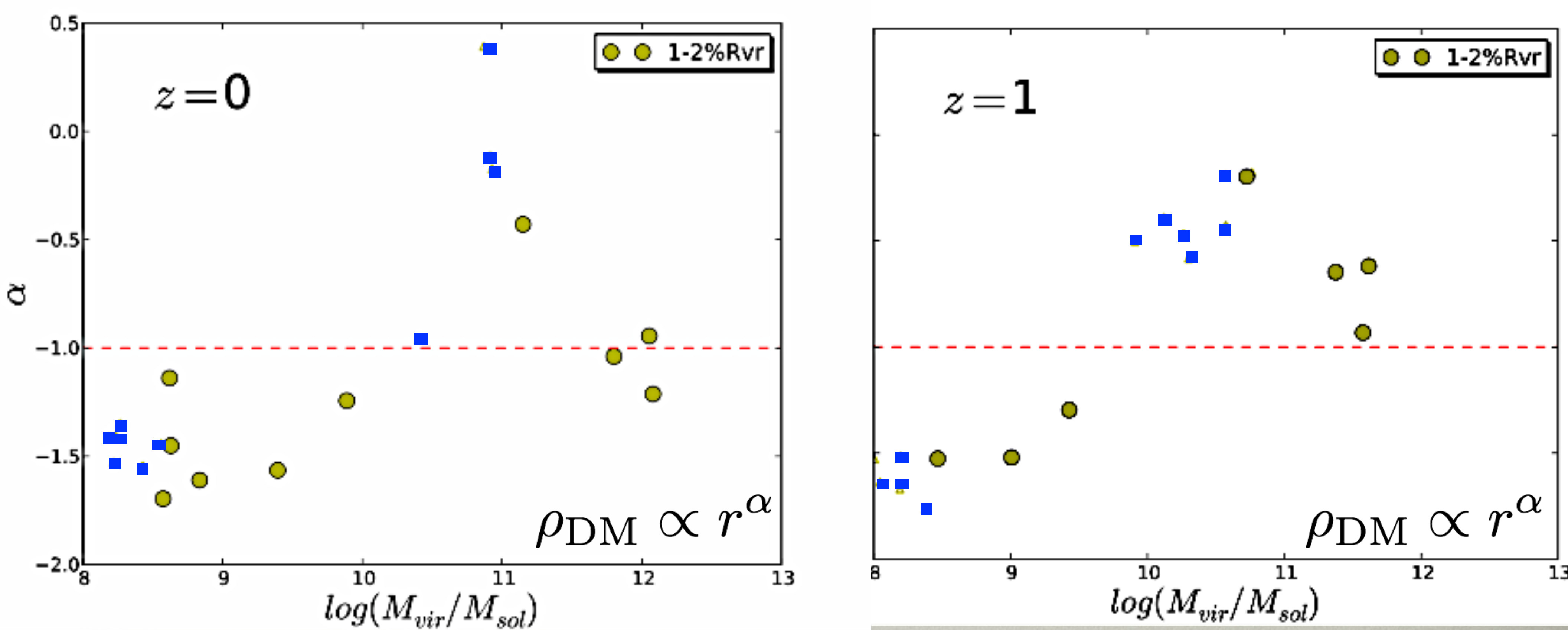


- Navarro et al.,1996, MNRAS, 283, L73
- Read & Gilmore 2005, MNRAS, 356, 107
- Mashchenko et al.,2006, Nature, 442, 539
- Mashchenko et al., 2008, Science, 319, 174
- Pasetto et al., 2010, A&A, 514, A47
- Ogiya & Mori 2012, arXiv:1206.5412
- de Souza et al., 2011, MNRAS, 415, 2969
- Cloet-Osselaer et al., 2012, MNRAS, 423, 735
- Maccio et al., 2012, ApJ, 744, L9
- Teyssier et al., 2013, MNRAS, 429, 3068

Cores Found By Many

Overall in FIRE, cores form only in a limited range of halos masses: $\sim 10^{10}$-10^{11}Msun (halos hosting galaxies with $M_* \sim 10^6$-10^9 Msun).

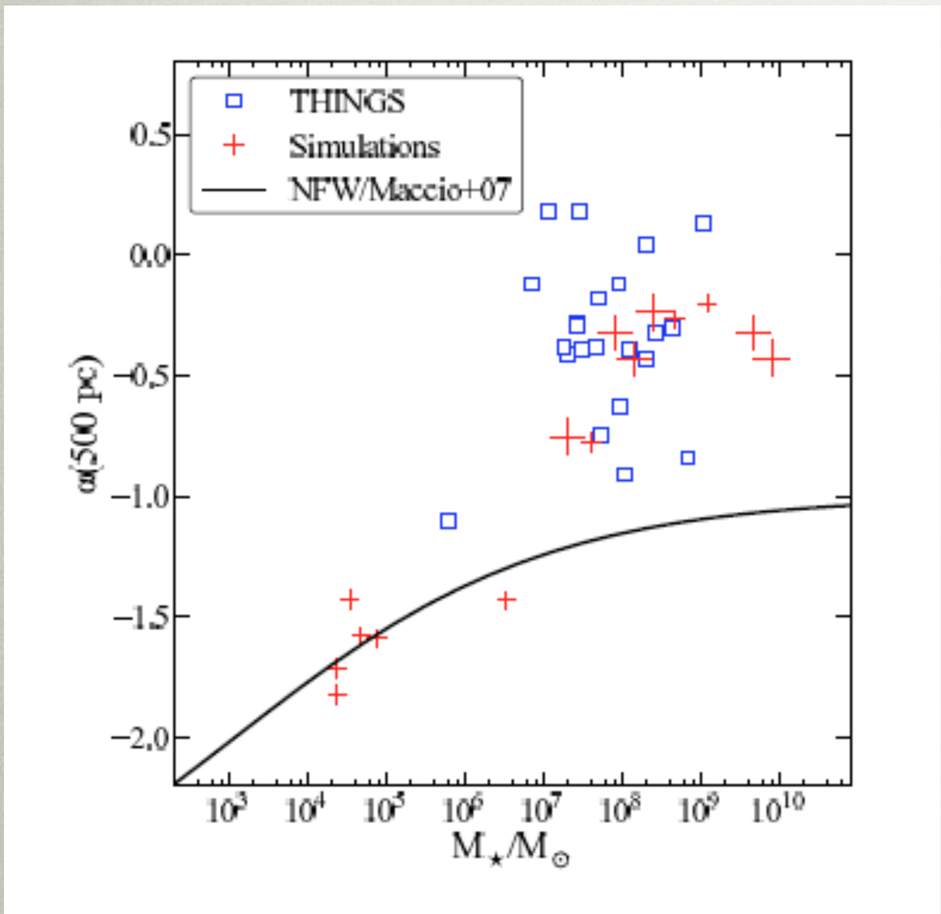
~MW mass halos are also affected: very little or no adiabatic contraction!

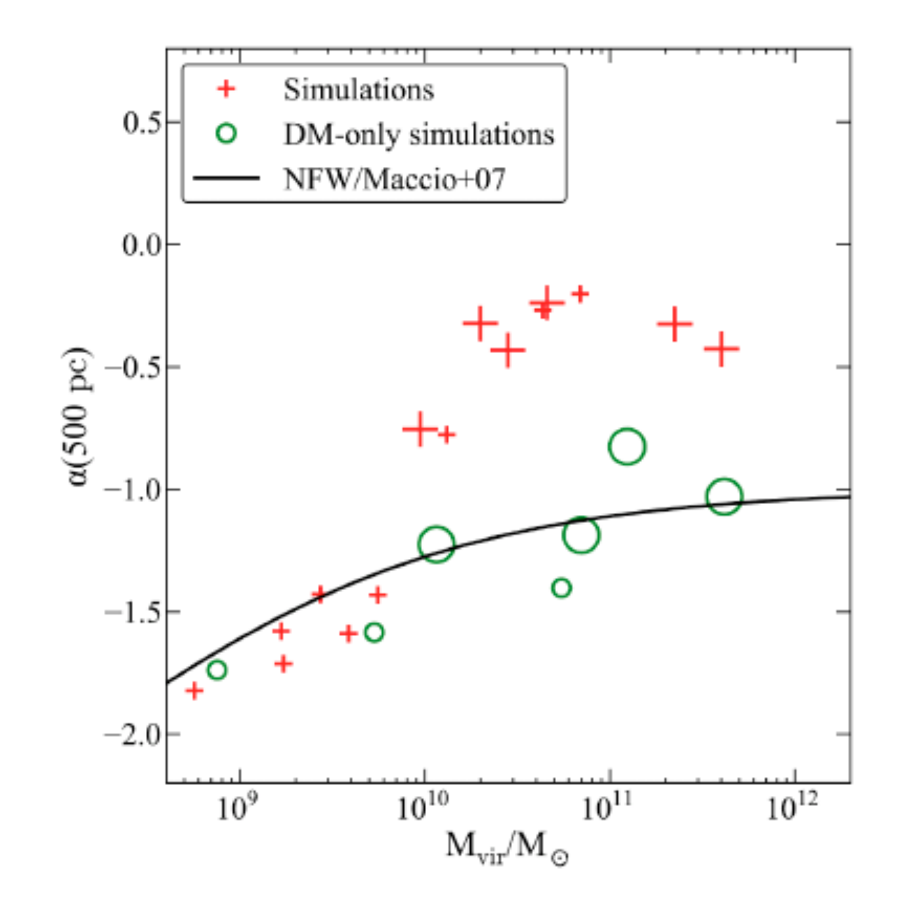


T.-K. Chan et al., in preparation

Core Creation varies with Mass!

because SF varies with mass





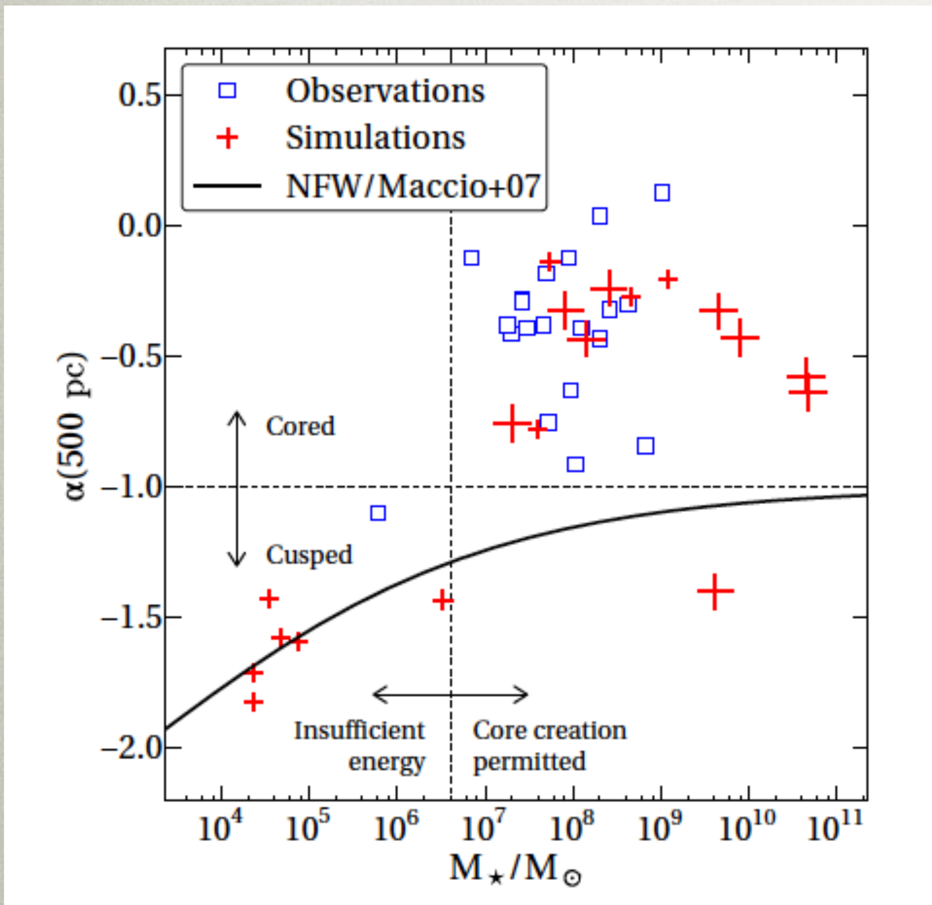
Galaxies in the THINGS survey have average α~-0.3

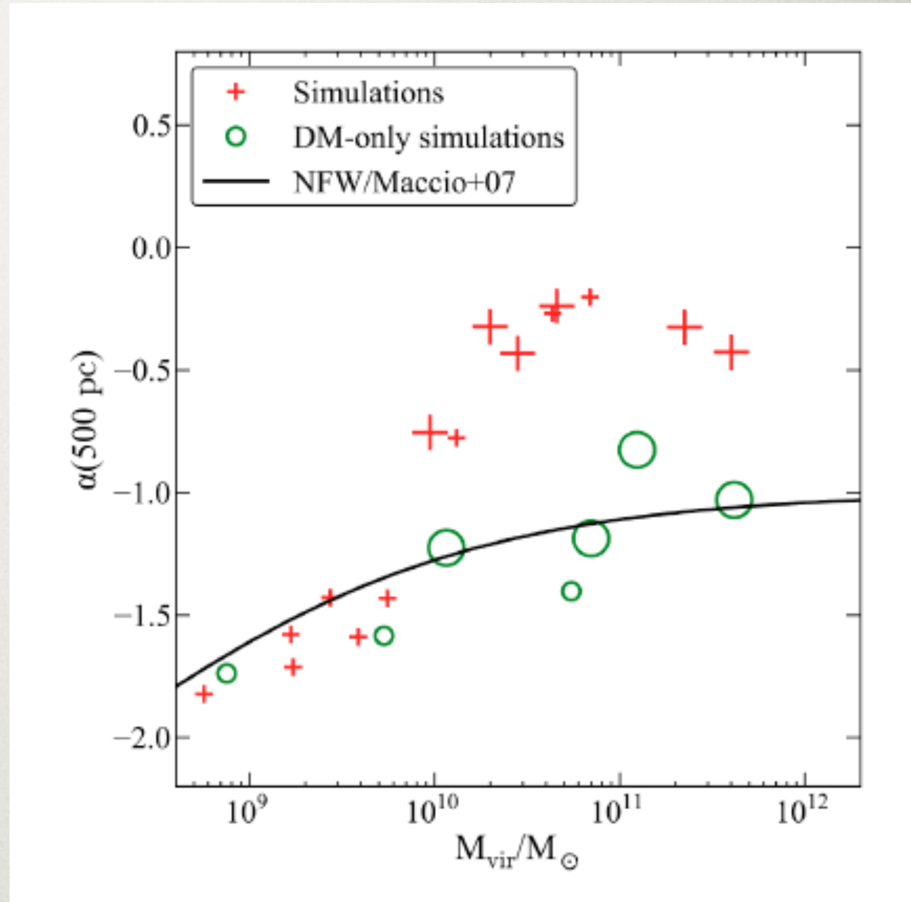
Lower mass galaxies do not undergo repeated bursts of SF; retain cusps

Governato et al., 2012, MNRAS, 422, 1231

Core Creation varies with Mass!

because SF varies with mass





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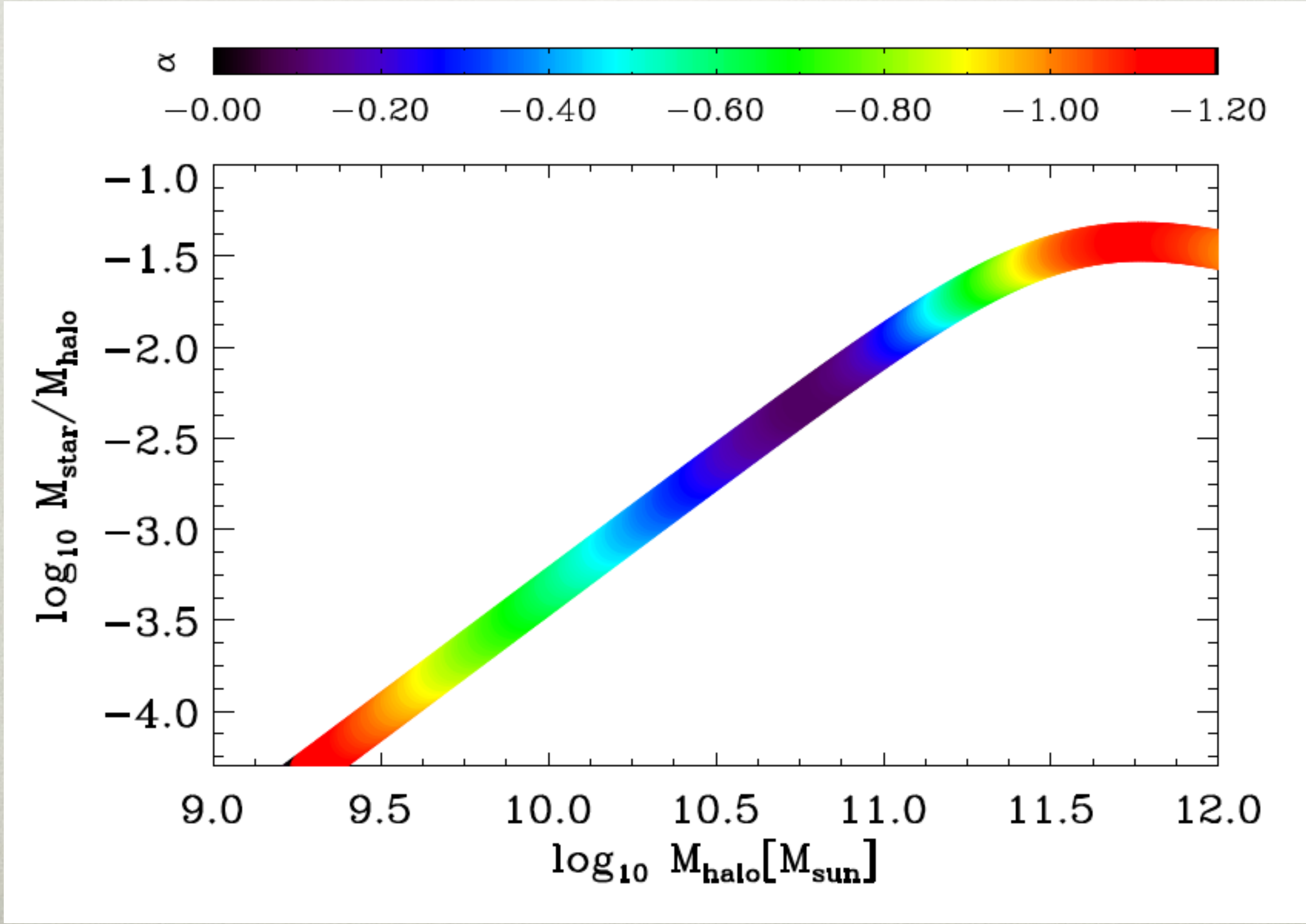
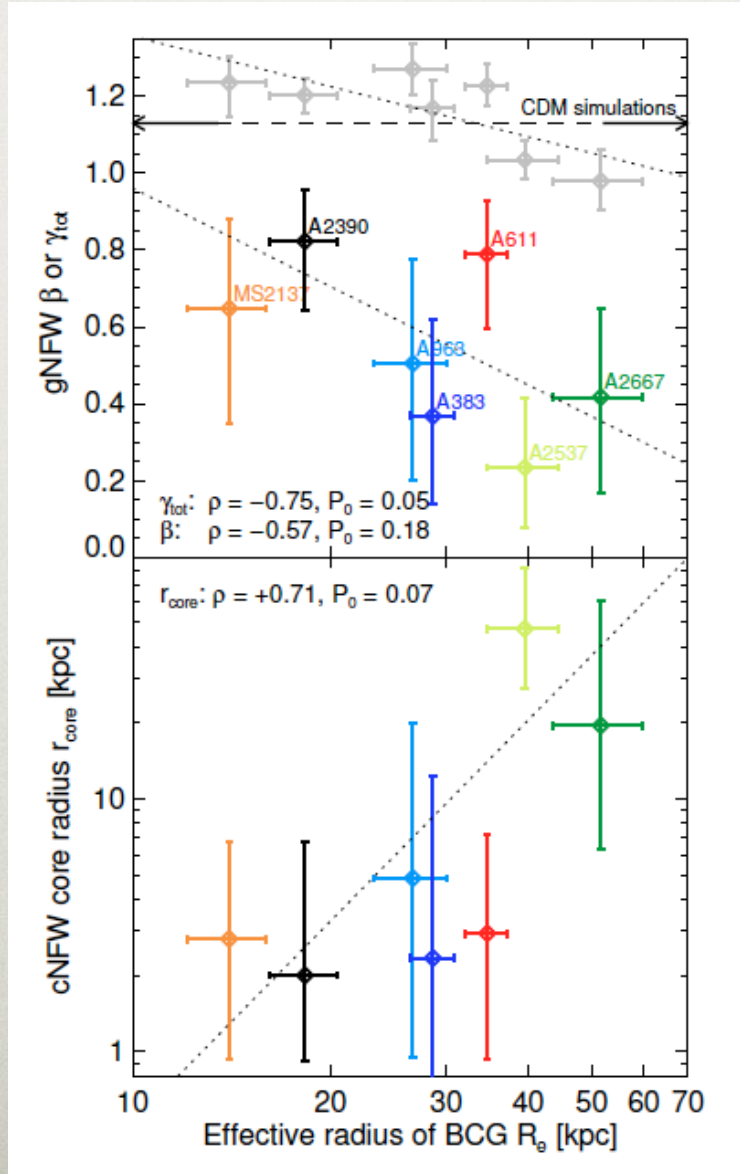
Governato et al., 2012, MNRAS, 422, 1231

Density Slope as a Function of Stellar/Halo Mass



di Cintio et al. (2014)

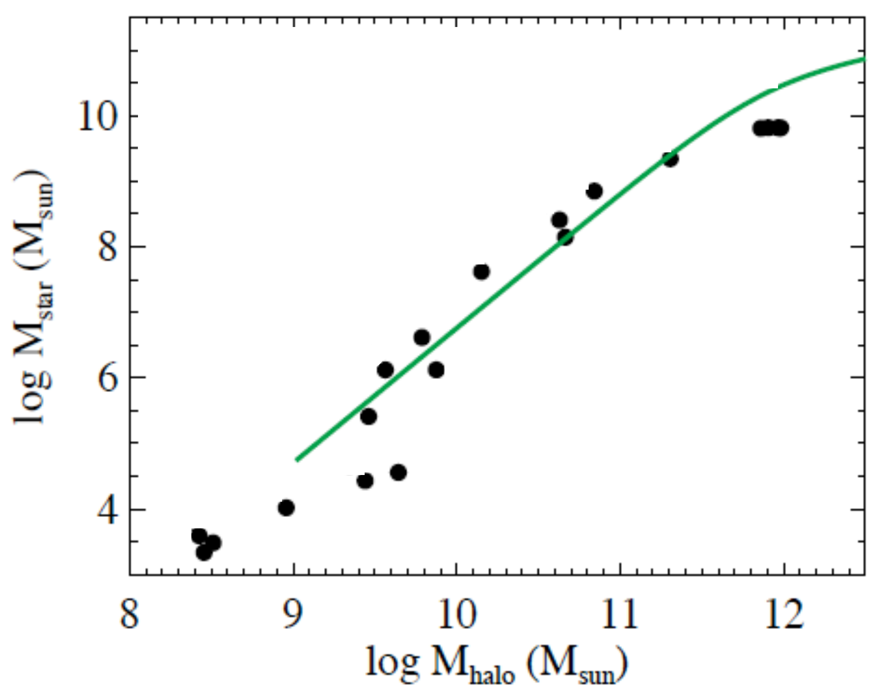
What Happens at Higher Masses?

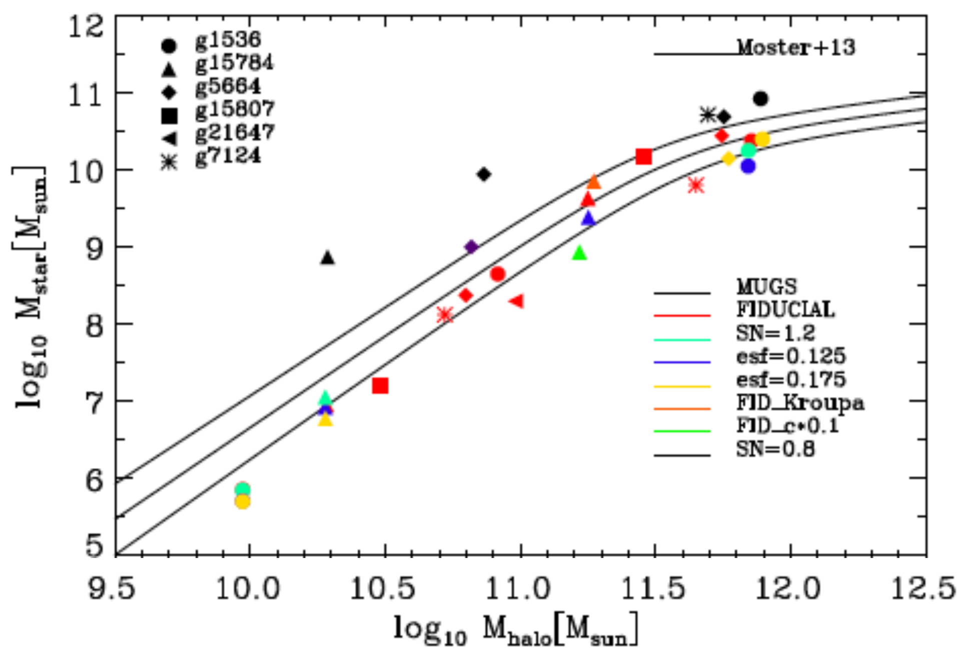


Newman et al. (2013)

Primary Motivation: Stellar Mass to Halo Mass

(Munshi et al. 2013)





(di Cintio et al. 2014)

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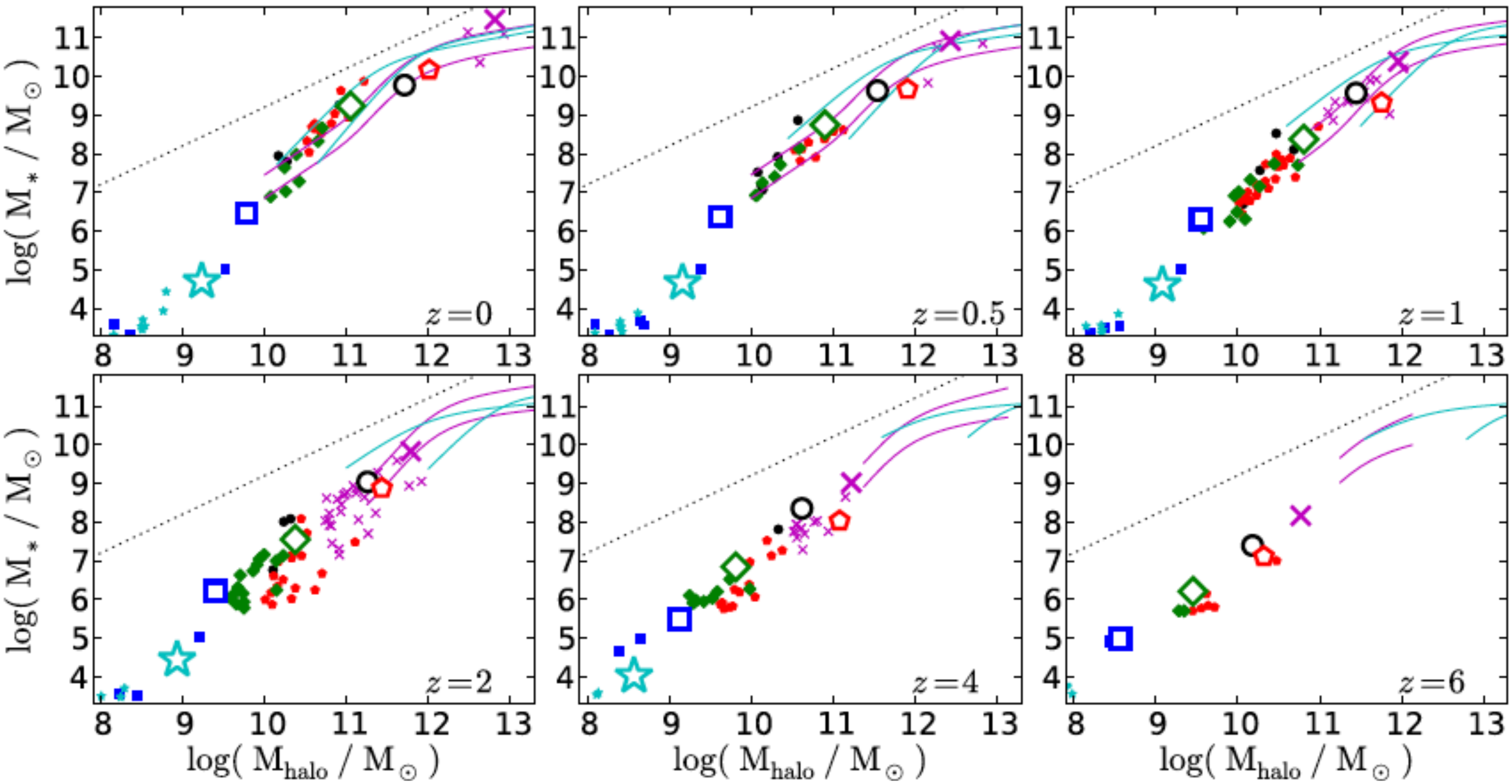
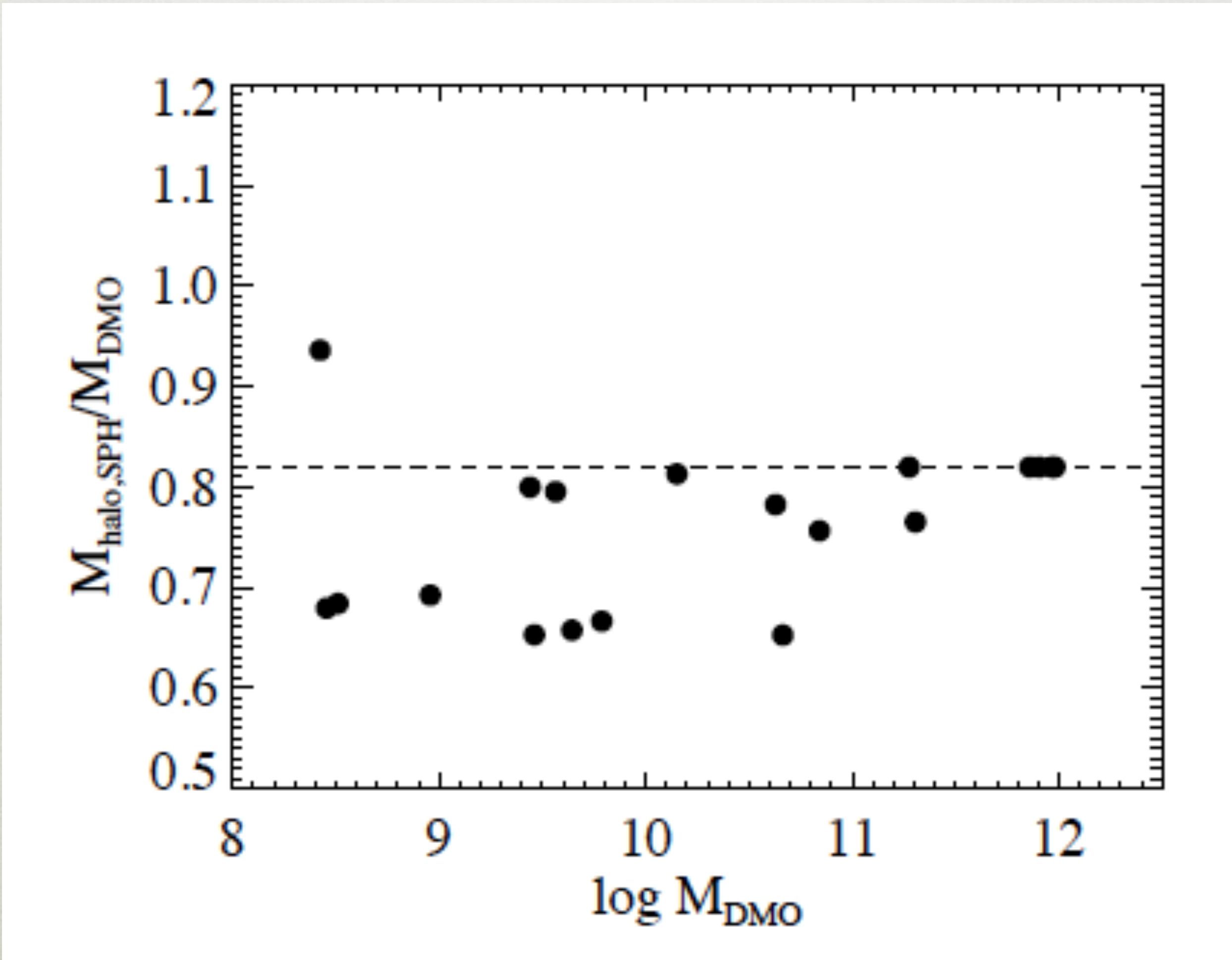


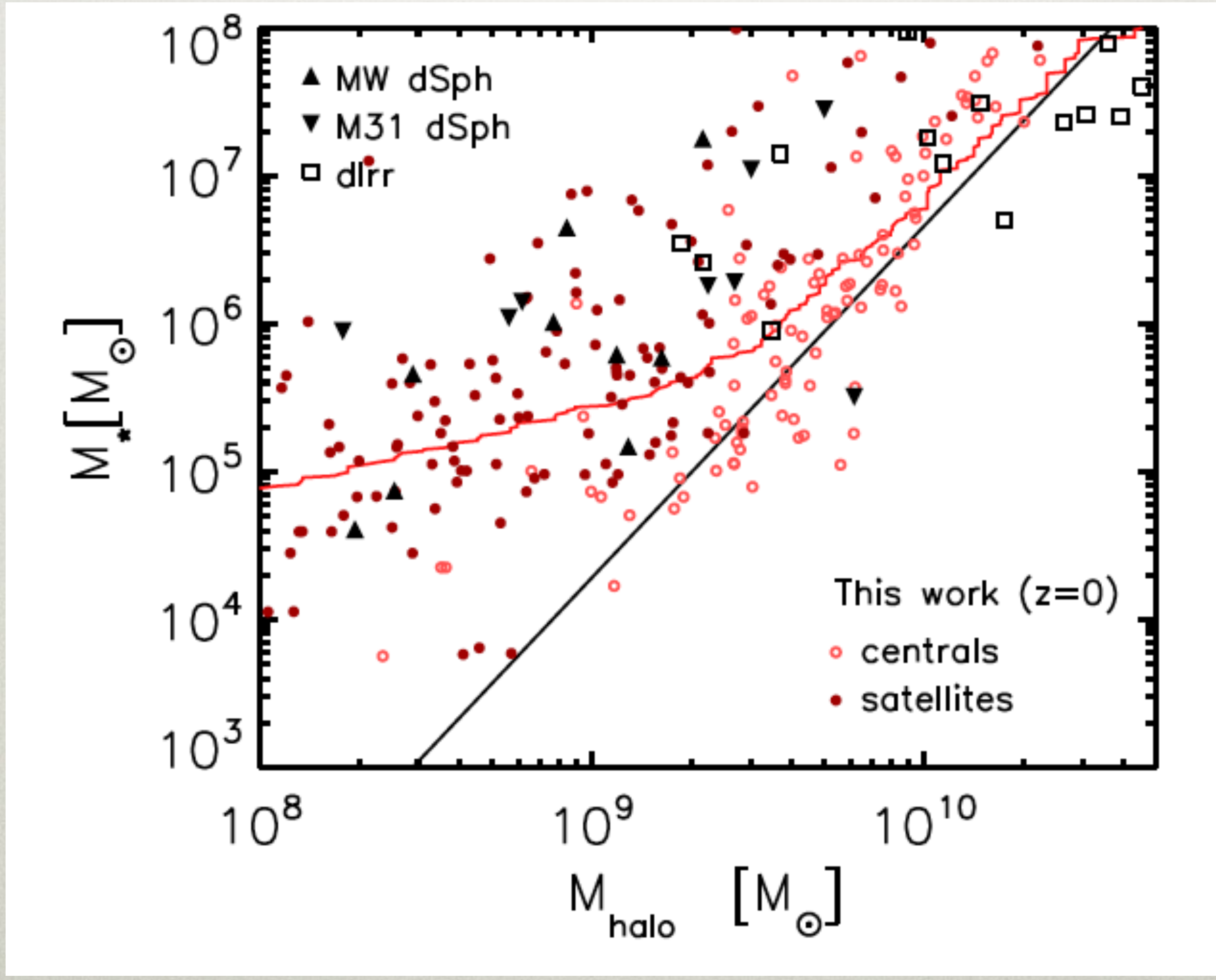
(Hopkins et al. 2013)

But Feedback Can Even Alter the Halo Mass



Munshi et al. (2013)

Caveat Emptor



Sawala et al. (2014)

The Future of Simulations

- (1) More physically motivated feedback (e.g., young stars)
- (2) Details of the ISM; gradients
- (3) Galactic winds

Conclusions

Simulations keep improving! (motivated by higher resolutions)

A more realistic treatments of SF leads to more realistic galaxies

Feedback is necessary to match a slew of observed galaxy scaling relations, e.g.:

- **disk sizes**
- **bulge sizes**
- **metallicities**
- **gas fractions**
- **stellar mass to halo mass**
- **dark matter cores**

Detailed ISM properties and galactic winds will be the best constraints of the feedback models