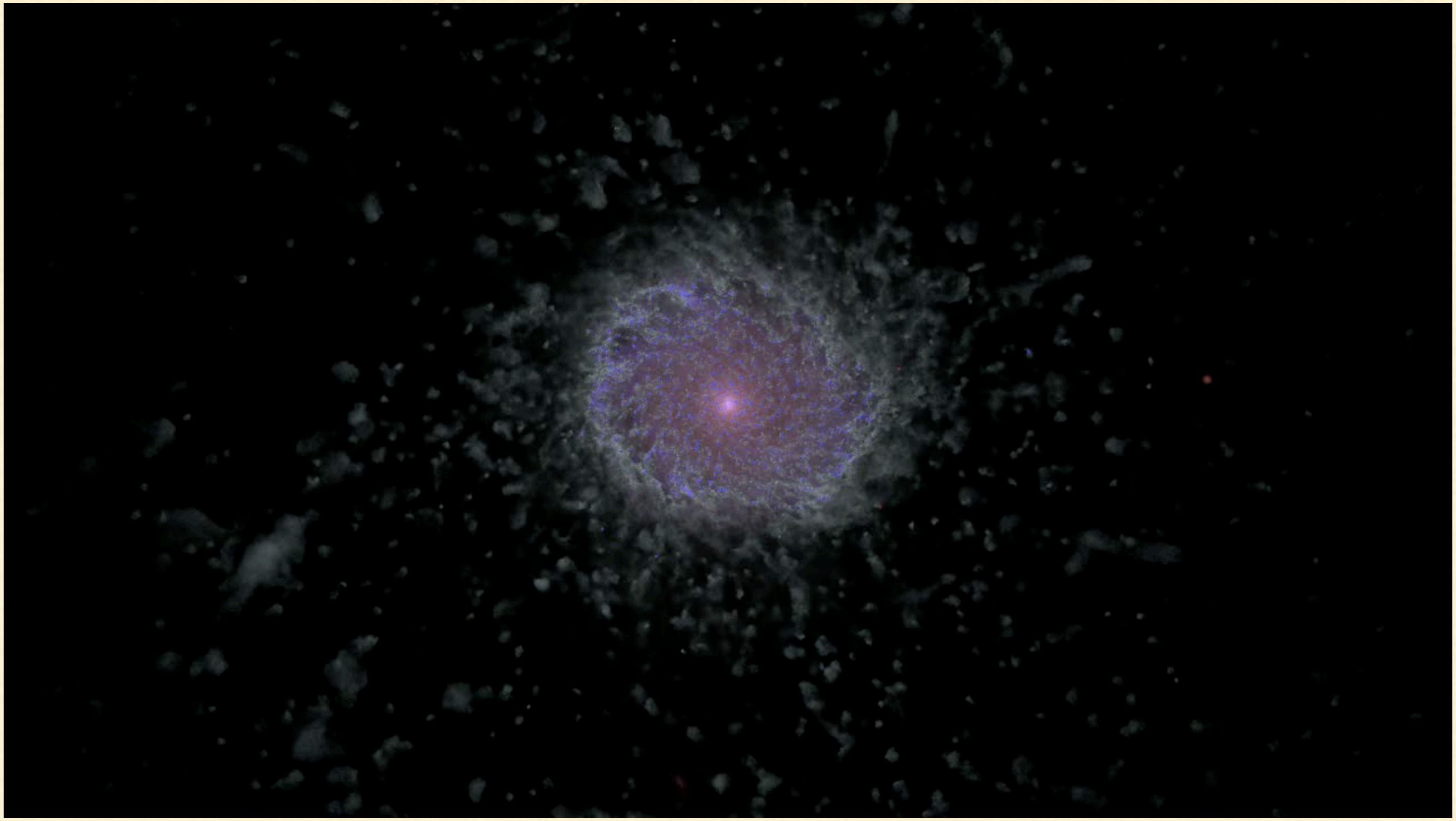
Theoretical Predictions for Galaxy Disk Growth

Alyson Brooks, Rutgers University



The State of the Art

Latest "zoomed-in" runs:

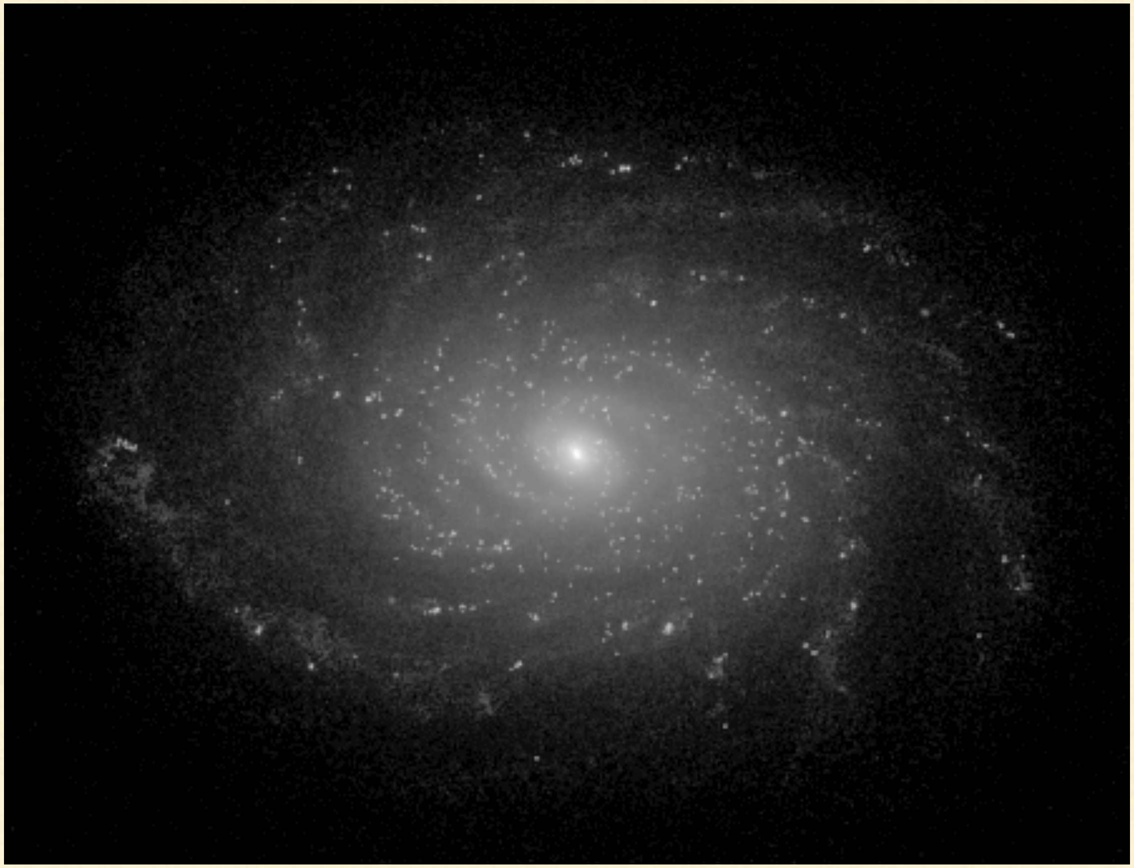
- Resolution 50-160pc ~ GMC scale
- Star particles ~ 1000-10000 M_{sun}
- Cooling (with metal lines+H2) down to 200K
- H2 self-shielding and H2 based SF
- Uniform UV background (mimics reionization)
- Several millions of particles per (main) galaxy at z=0.

These Runs:

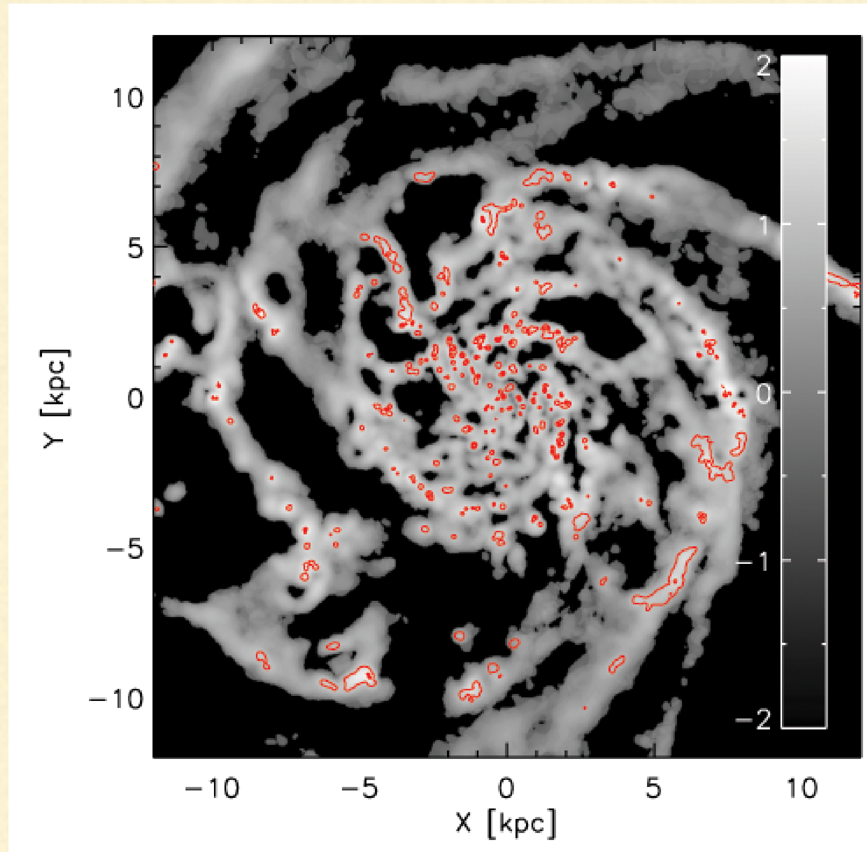
- Gasoline
- N-Body + Smoothed Particle Hydrodynamics (SPH)
- Star particles born with Kroupa IMF
- "Blastwave" feedback model
- SN energy coupled to gas *as thermal energy* only
- Cooling shutoff in neighbor gas particles (adiabatic phase)

EXAMPLE SPIRAL USED IN THIS WORK

Hα map of MW-mass galaxy

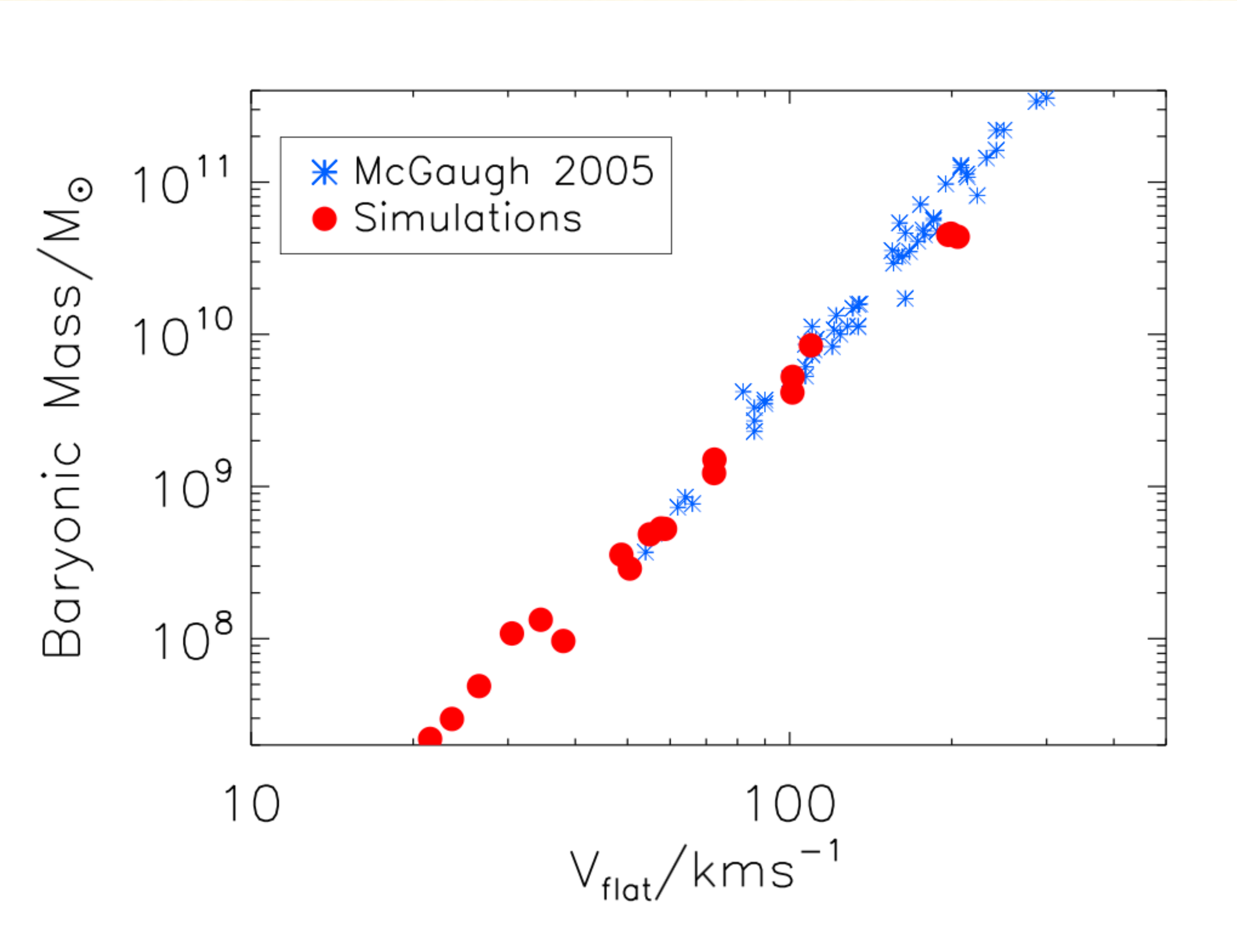


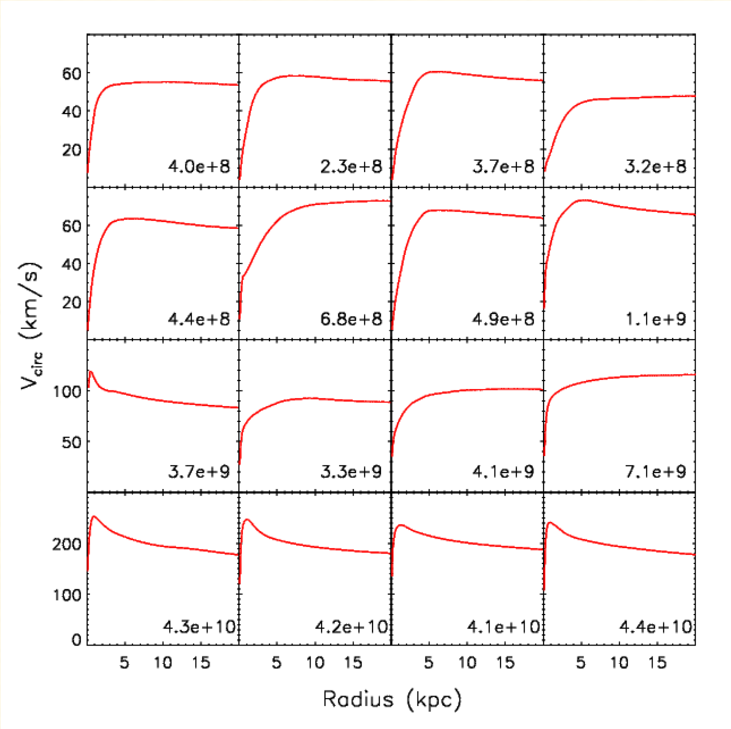
HI & H_2 map of $2x10^{11}$ M_{sun} galaxy



Christensen et al., 2014, MNRAS, 440, 2843

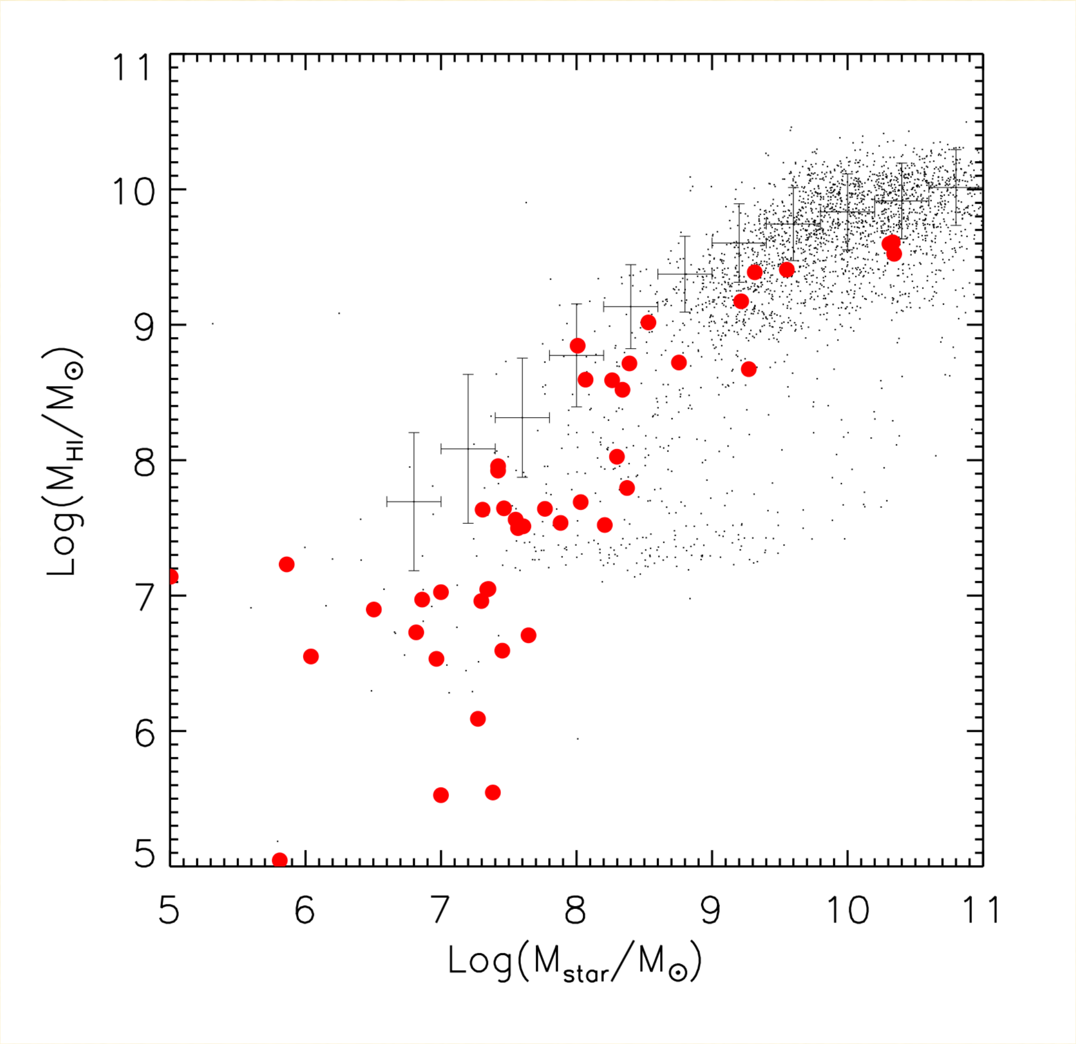
Galaxies Match Observed Scaling Relations





Baryonic Tully-Fisher Relation

Galaxies Match Observed Scaling Relations



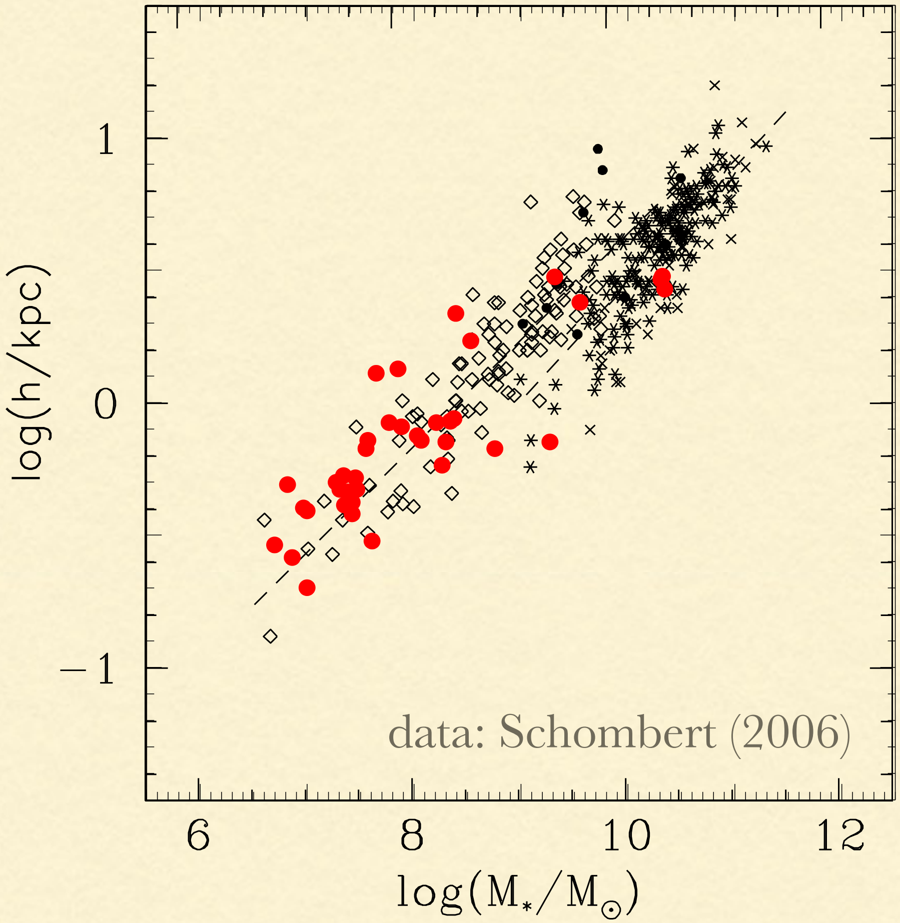
M_{HI} vs M_{star} Relation

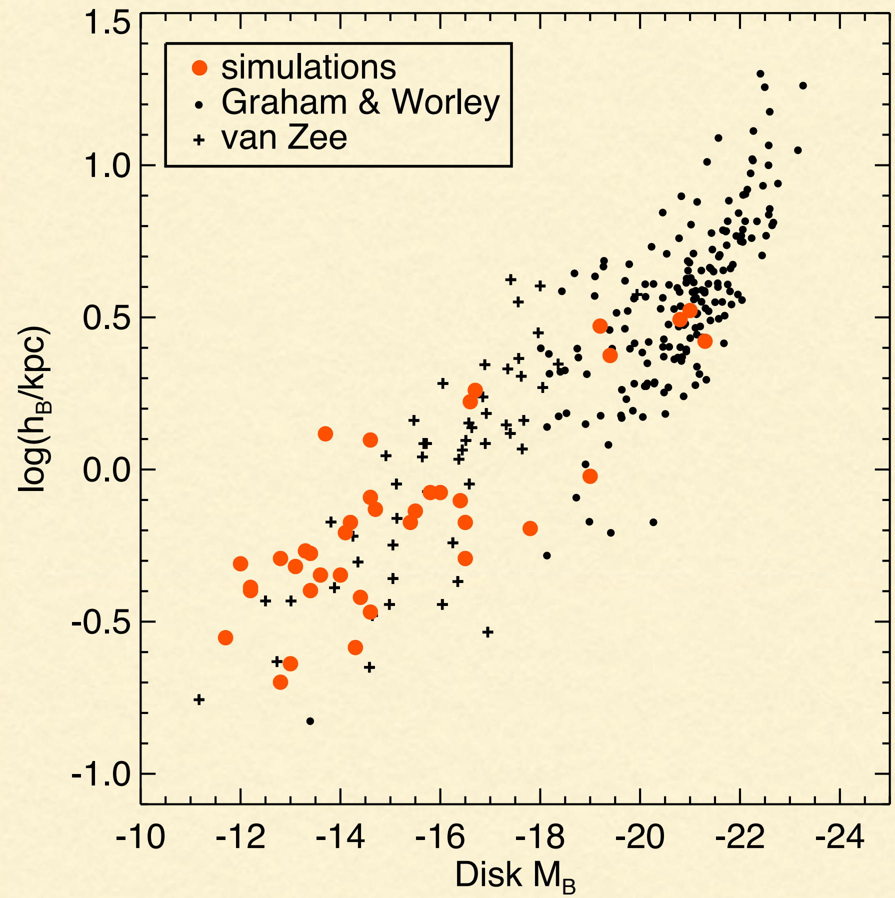
red = simulations

black points = data from J. Rosenberg

crosses = relation from Maddox et al. 2014

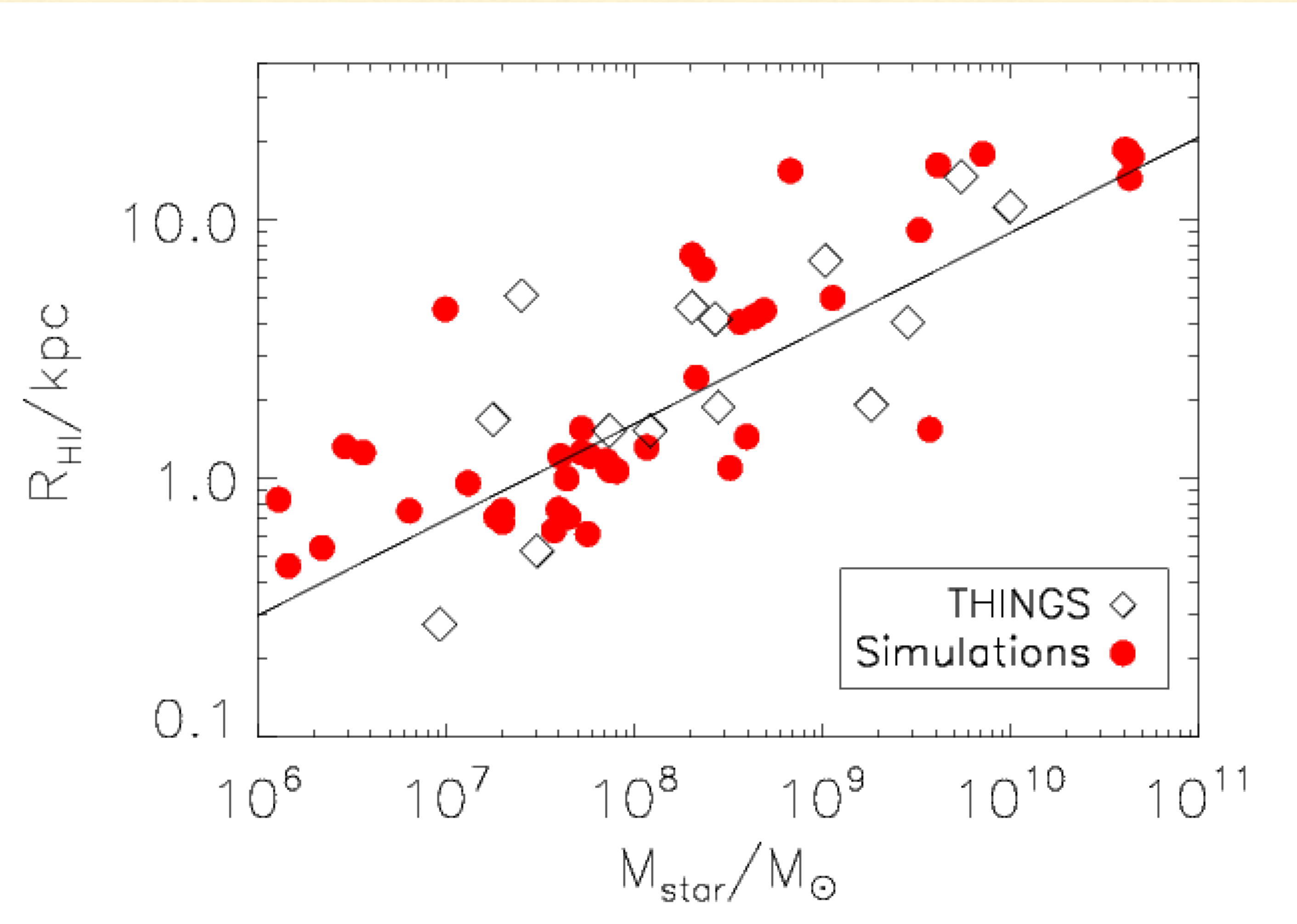
GALAXIES MATCH OBSERVED SCALING RELATIONS





Teyssier, Brooks, et al. (in prep)

Galaxies Match Observed Scaling Relations



Outermost HI data vs M_{star}

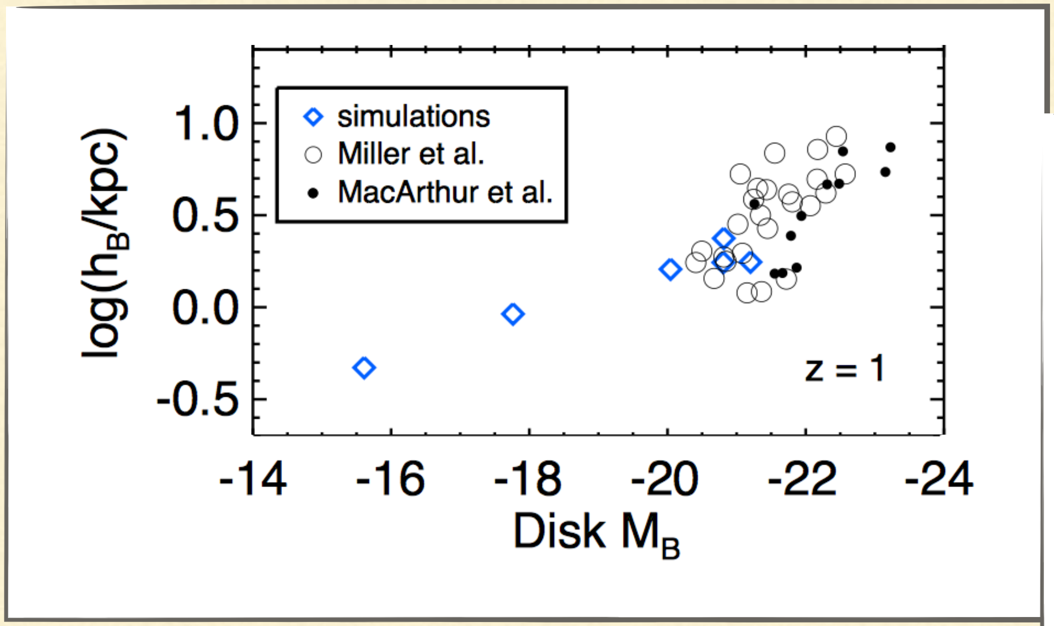
red = simulations

black line = fit to THINGS data from Brook & diCintio (submitted)

Do the Relations Also Match at High z?

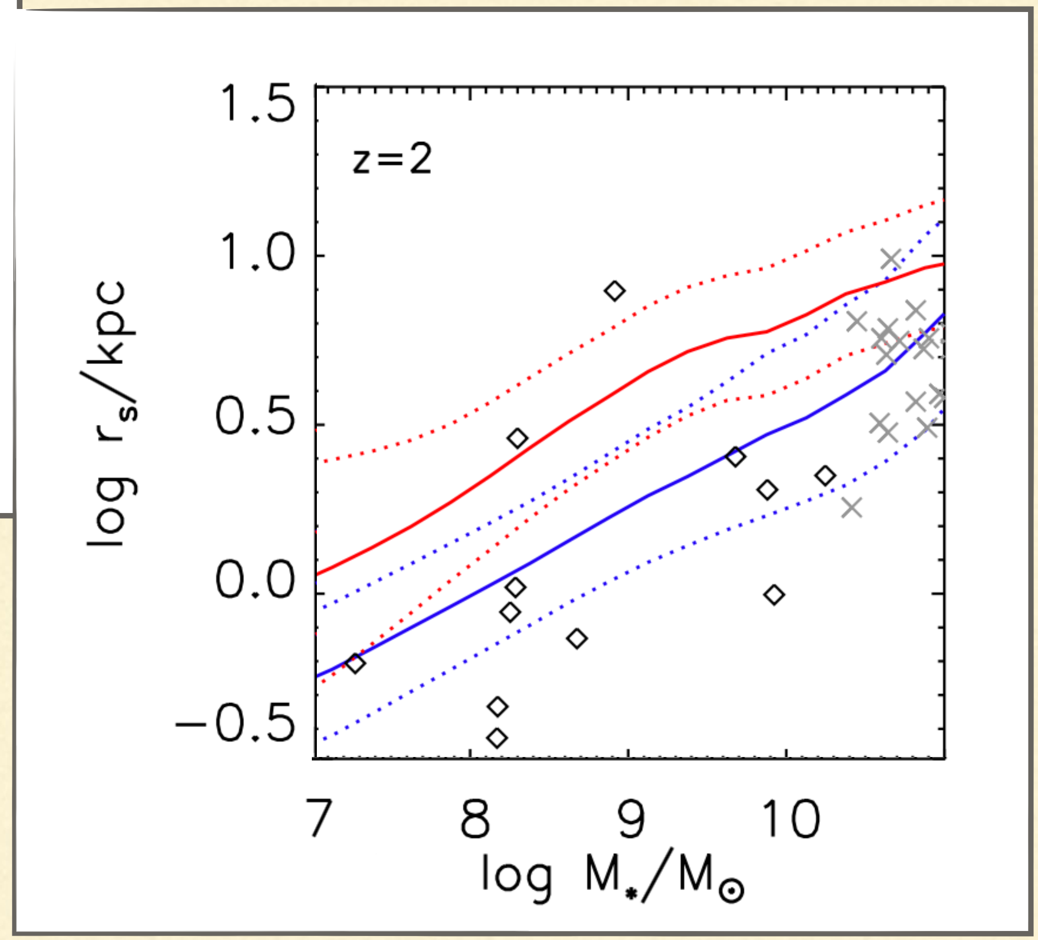
- One would hope that the prescriptions that lead to a good match at the final time will hold across all times

High z Stellar Disk Sizes Match

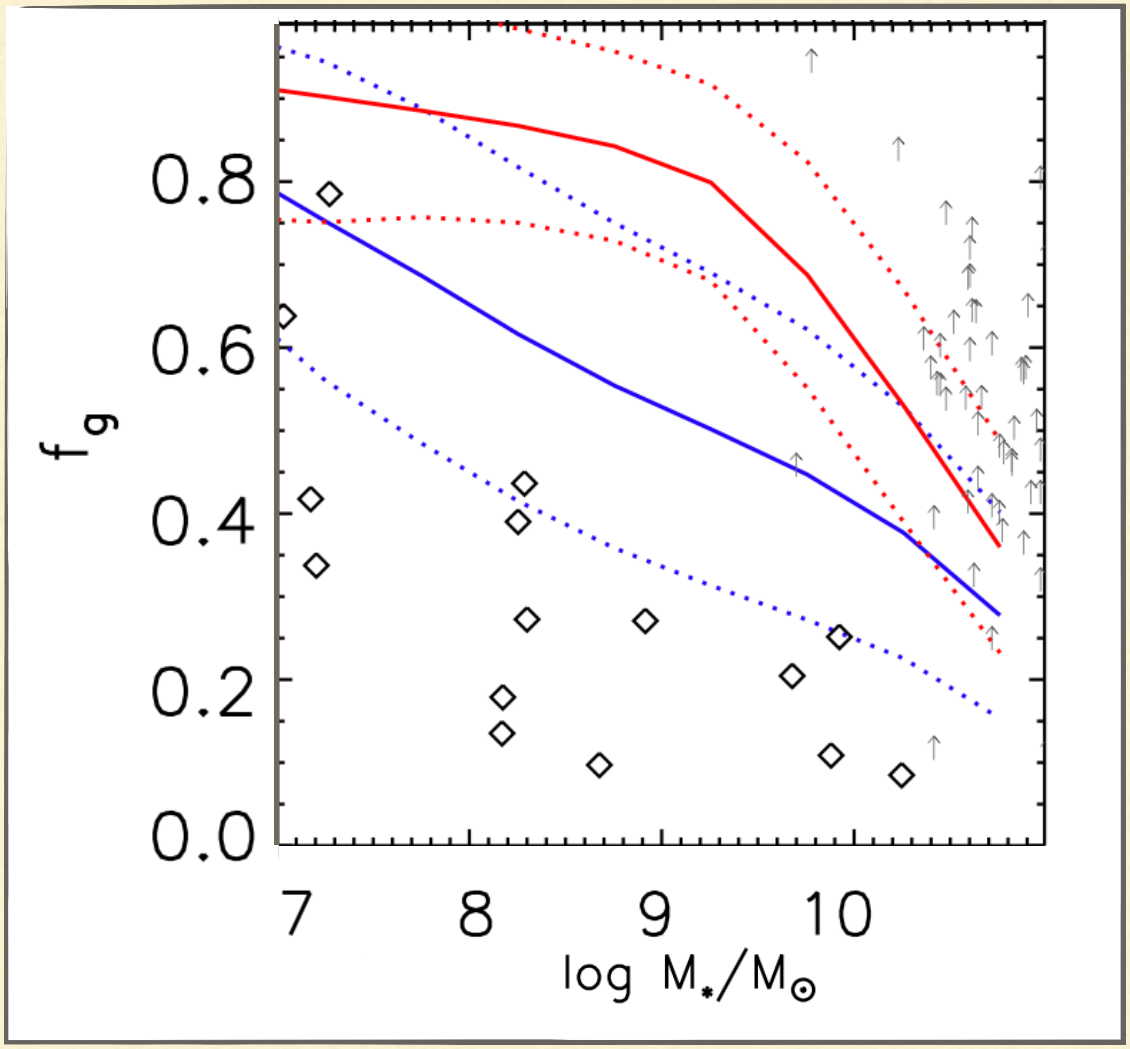


Brooks et al. (2011)

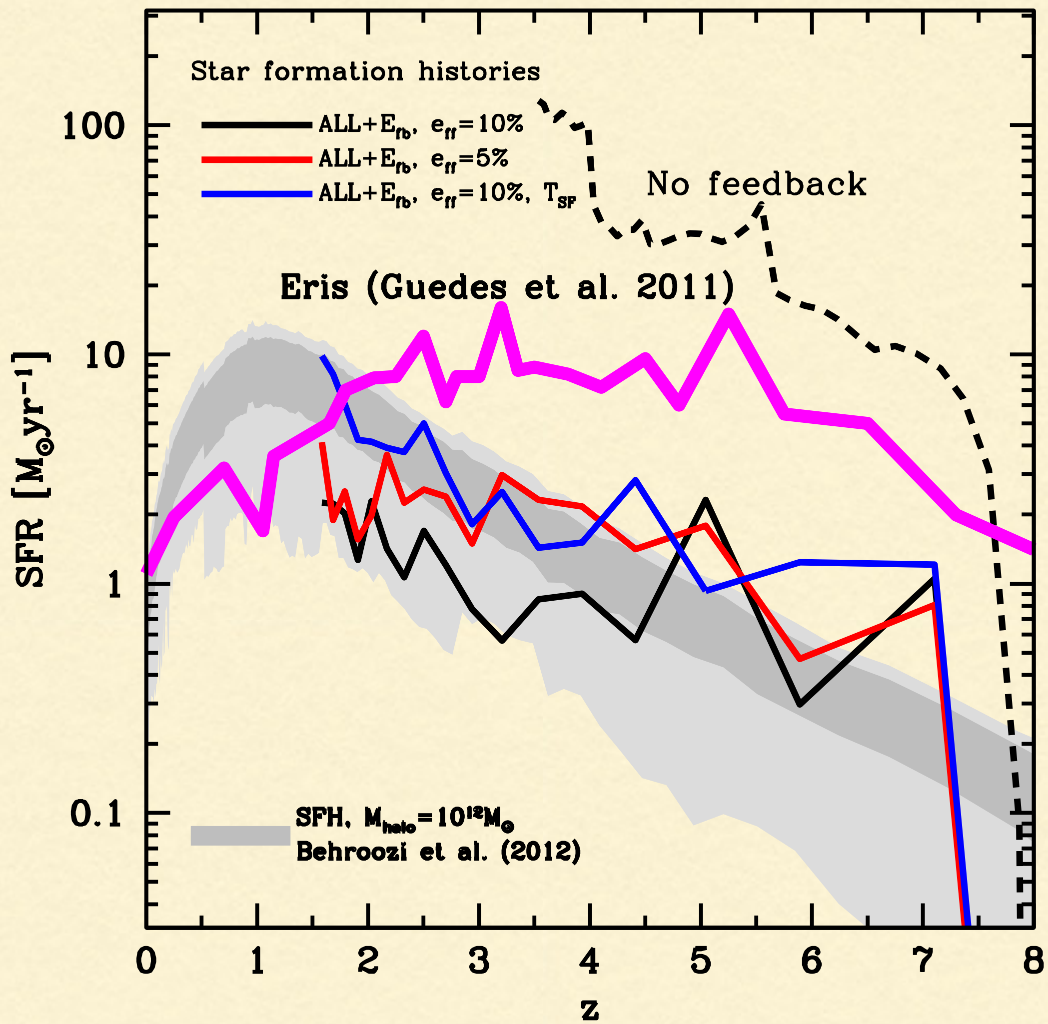
Berry et al. (2015)



But Gas Fractions…



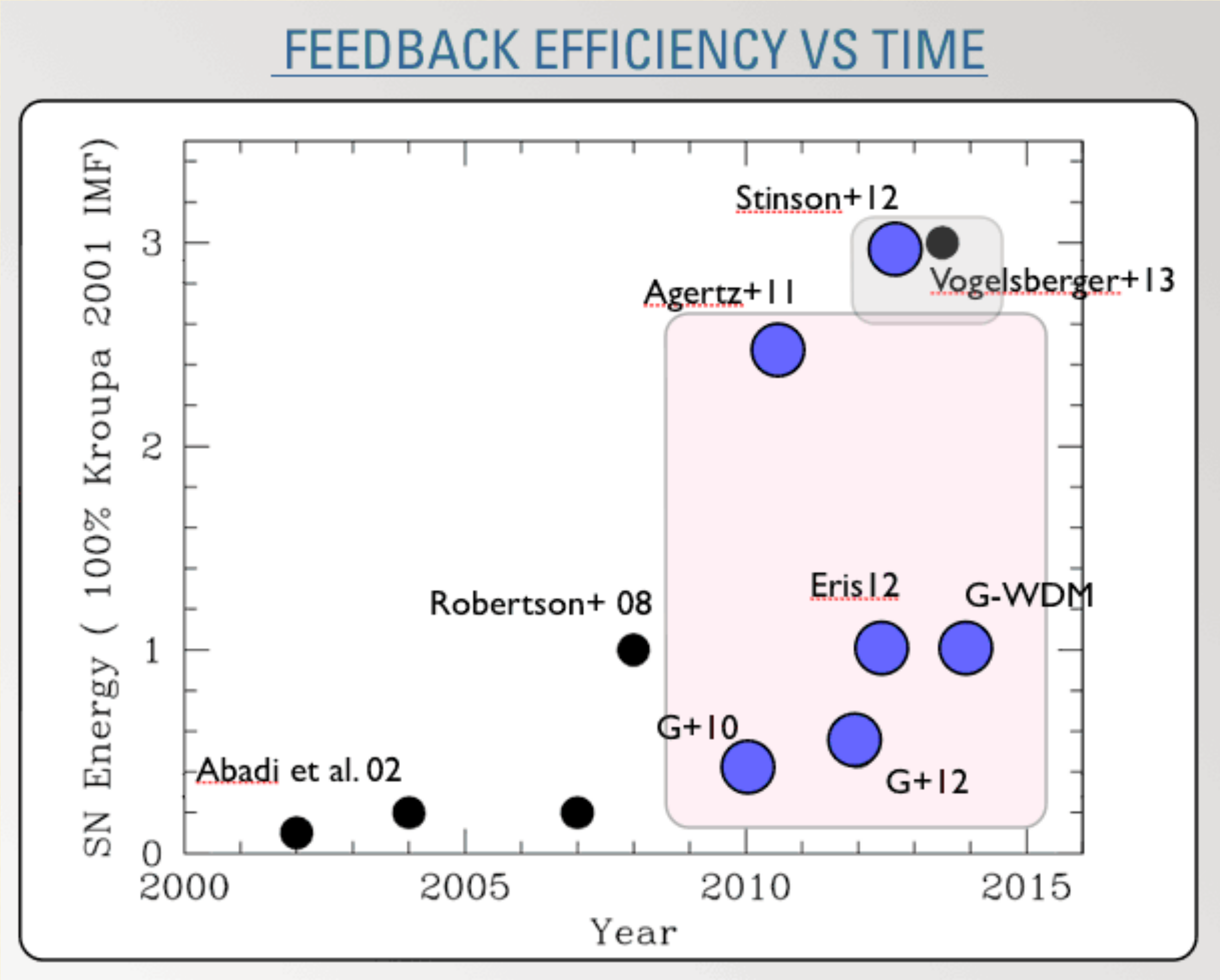
z=0 Match does not Guarantee High z match



movie courtesy O. Agertz

How to Match Everything, Including the High z M_{STAR}-M_{HALO} Relation

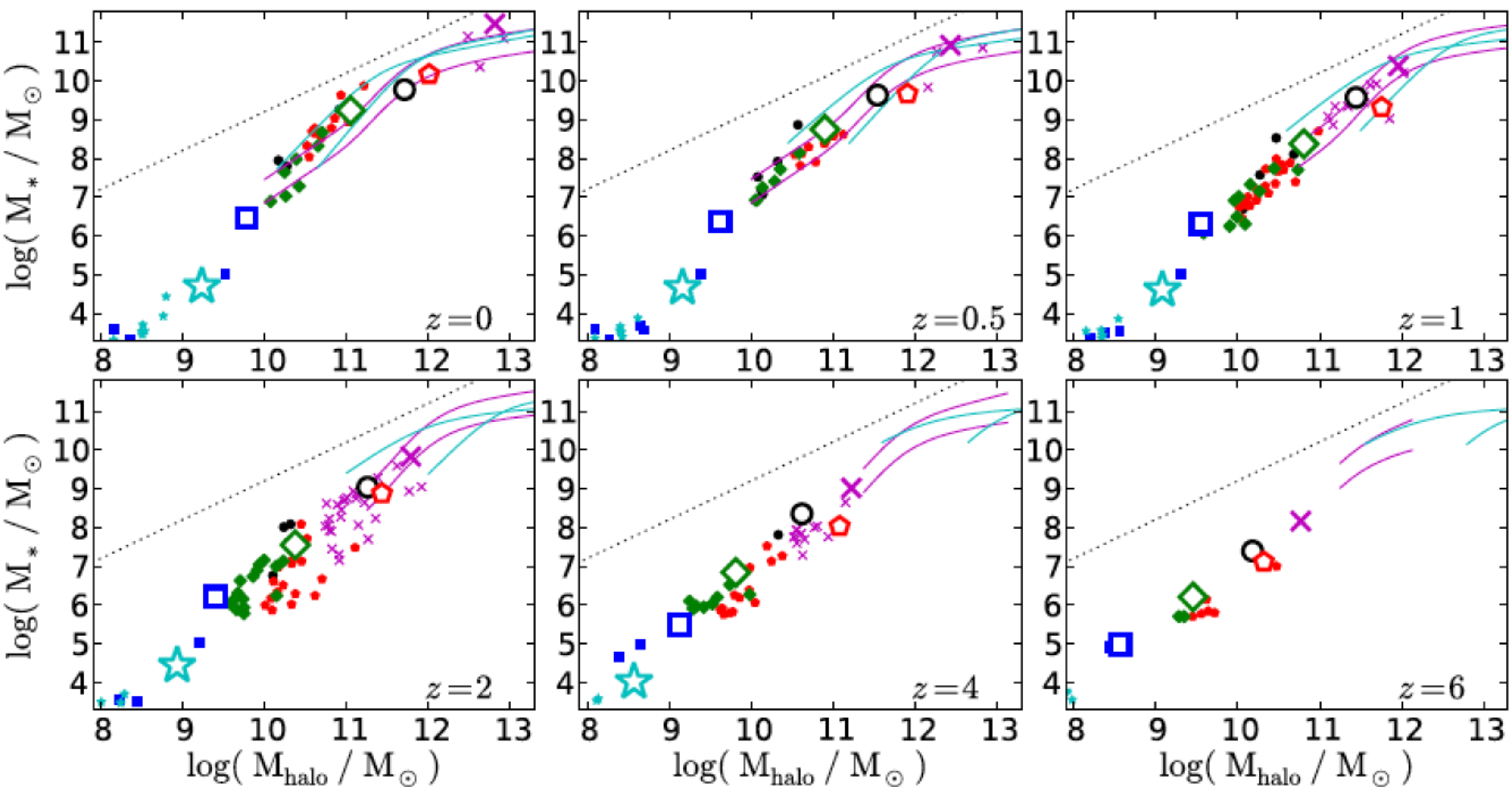
More feedback, please



Using the Full Range of Available Feedback

- Supernovae — the go to since the dawn of feedback, but massive stars don't go SNe until ~4Myr after the star particle is born
- Stellar winds — momentum injection from winds of massive stars (up to 1000 km/s)
- UV ionization — formation of HII regions
- Radiation pressure — momentum injection from scattering off dust grains (*highly debated*)

YOUNG STAR FEEDBACK MATCHES EVERYTHING?



(FIRE simulations, Hopkins et al. 2014)

YOUNG STAR FEEDBACK MATCHES EVERYTHING?

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

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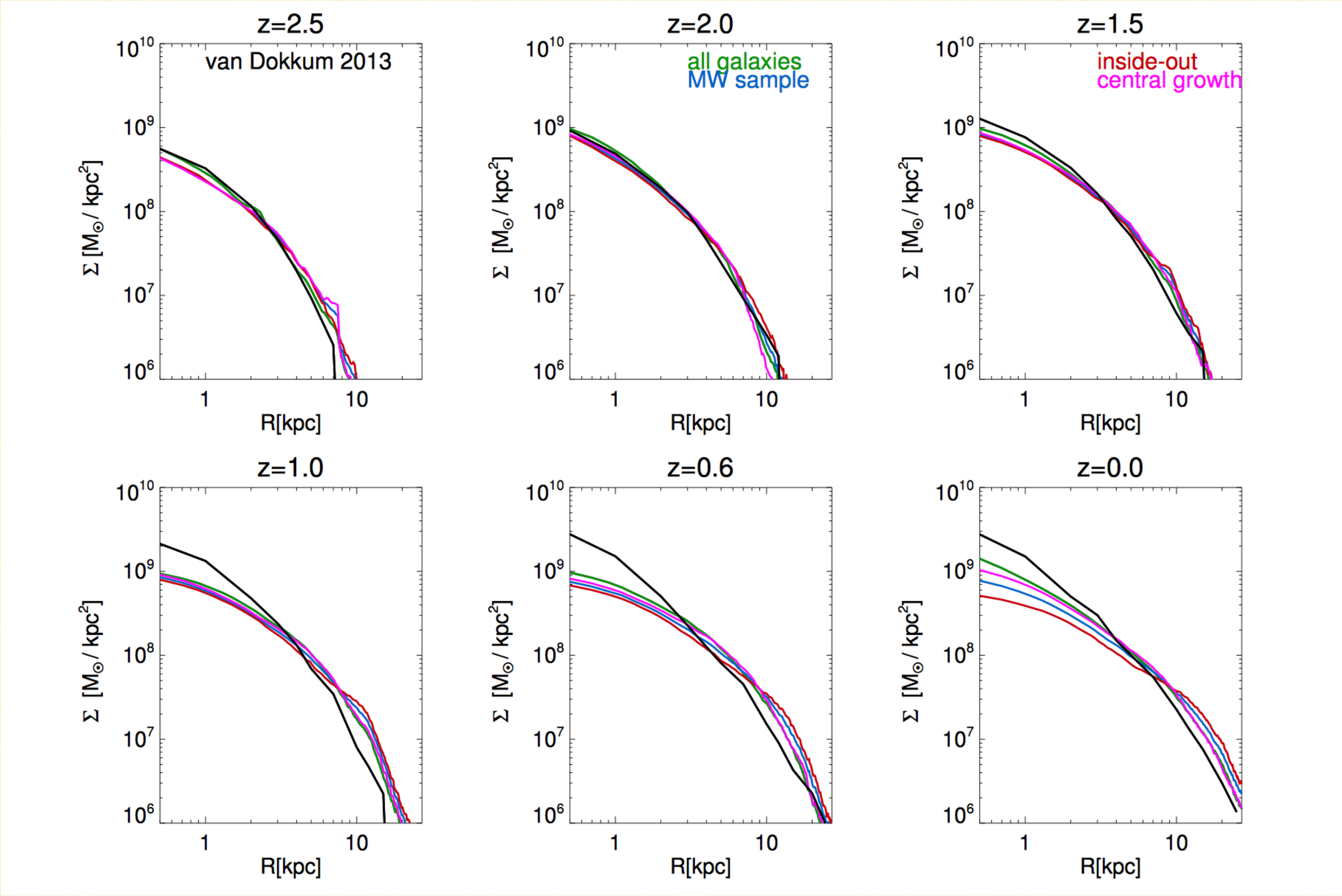
Accepted 2013 July 03. Received 2013 July 02; in original form 2013 March 28

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.

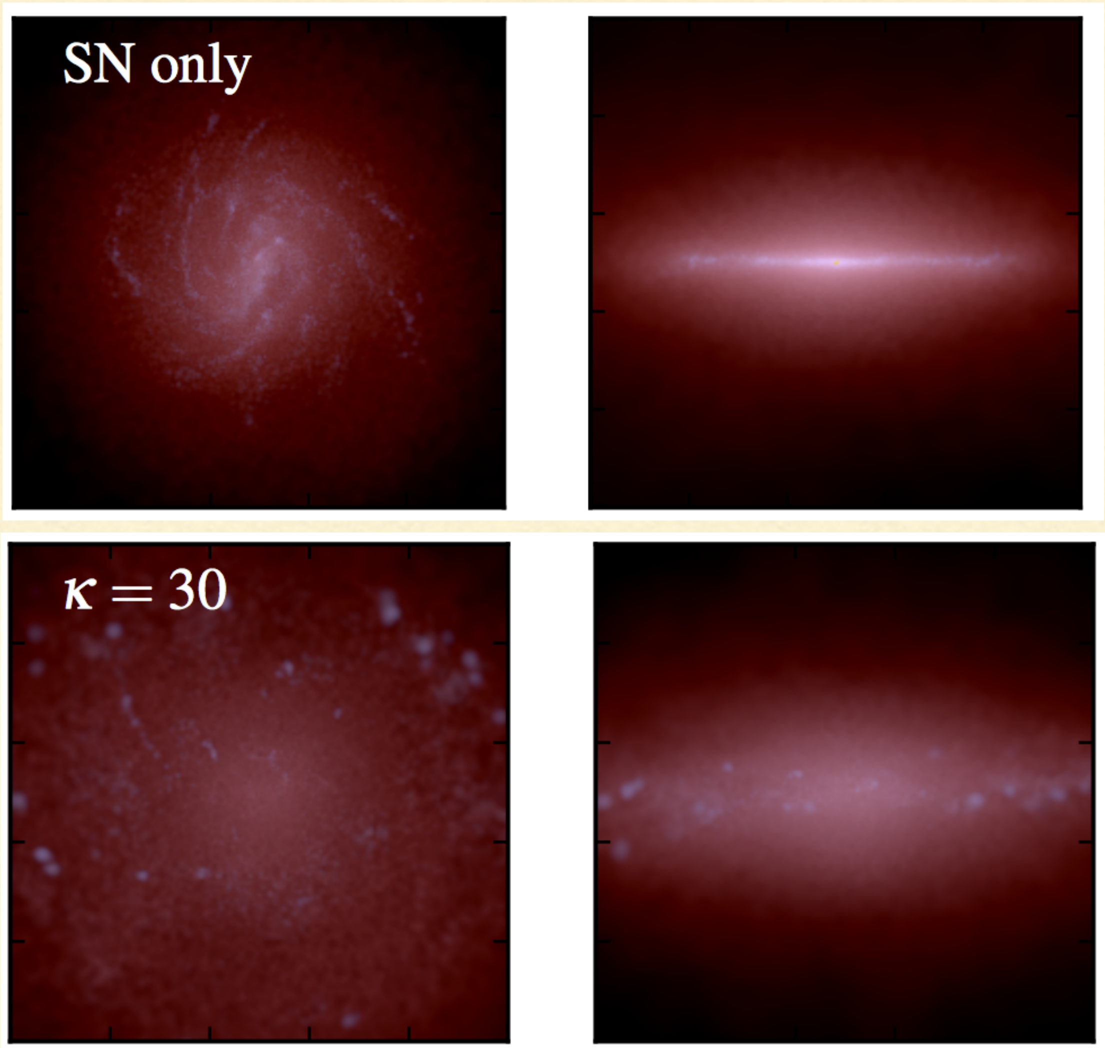
The Devil is in the Details

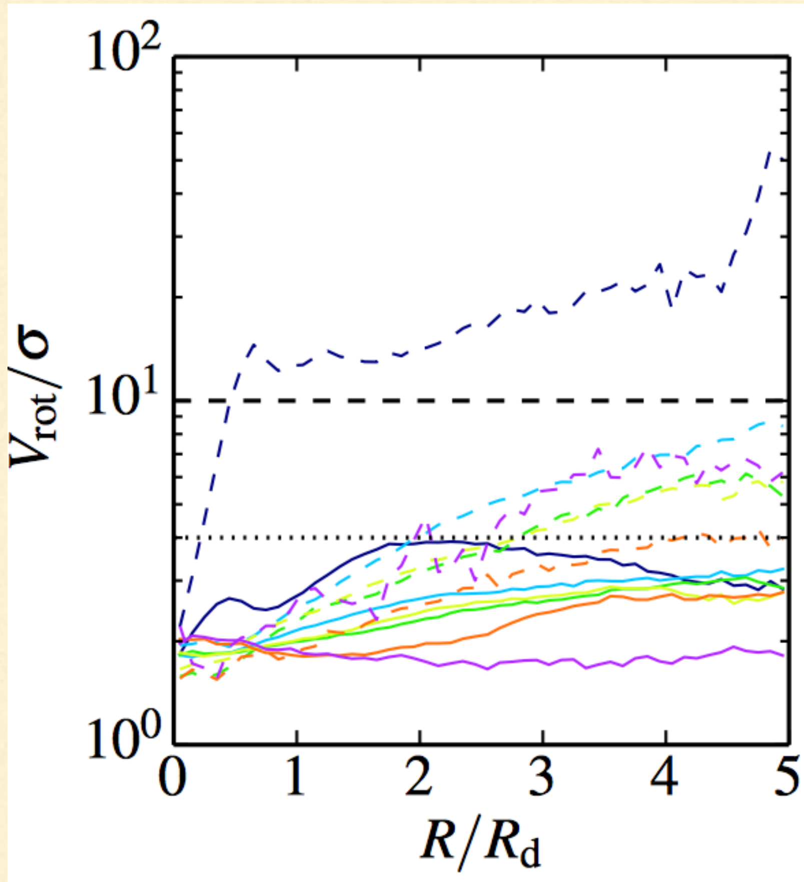
Simulated MW-mass galaxies show too much outer disk growth, not enough central mass growth compared to observations



Aumer et al. (2014), data from van Dokkum et al. (2013)

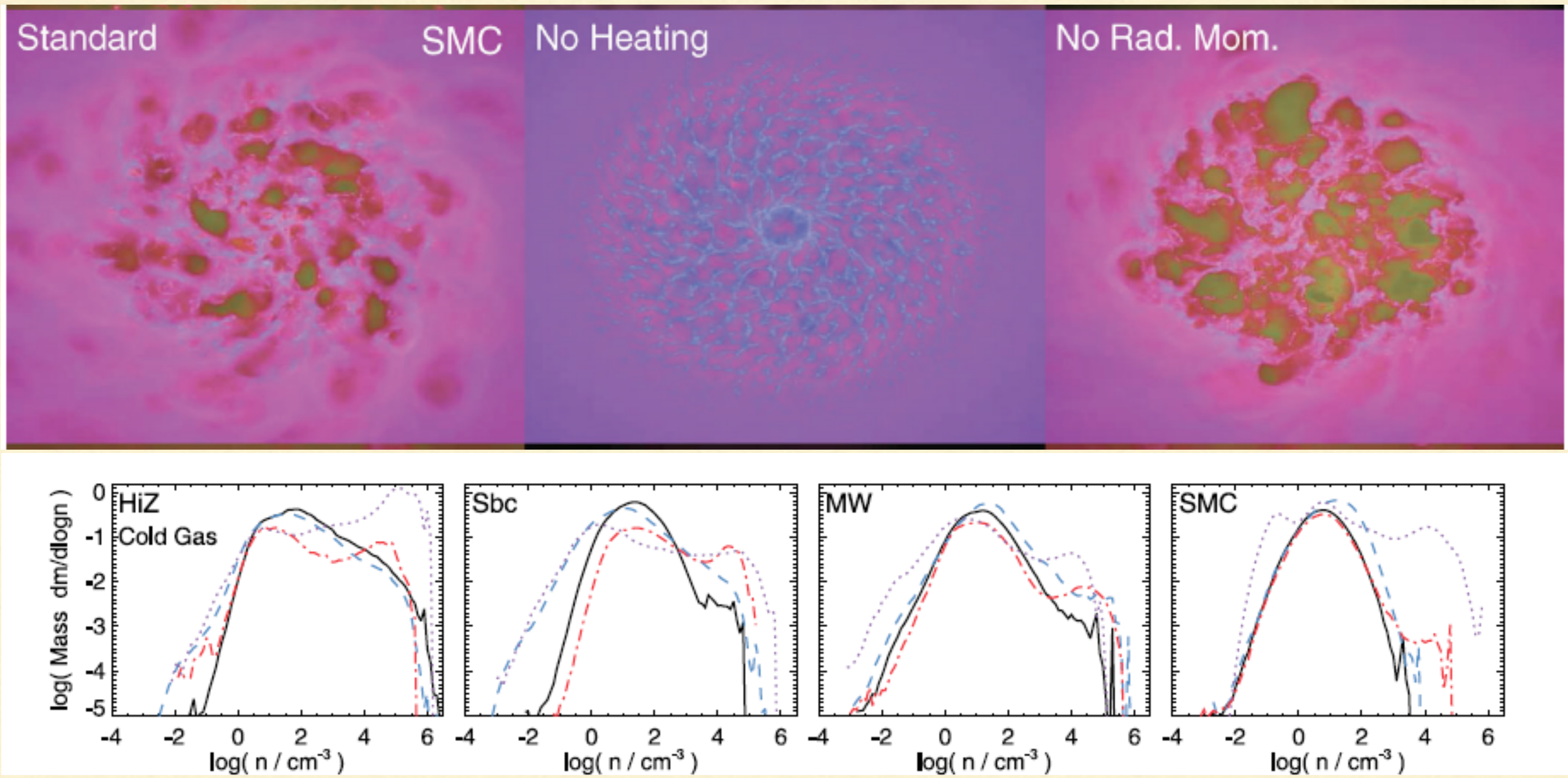
Young Star Feedback can't Make Thin Disks





Roskar et al. (2014)

The Next Challenge: Matching the Details of the ISM



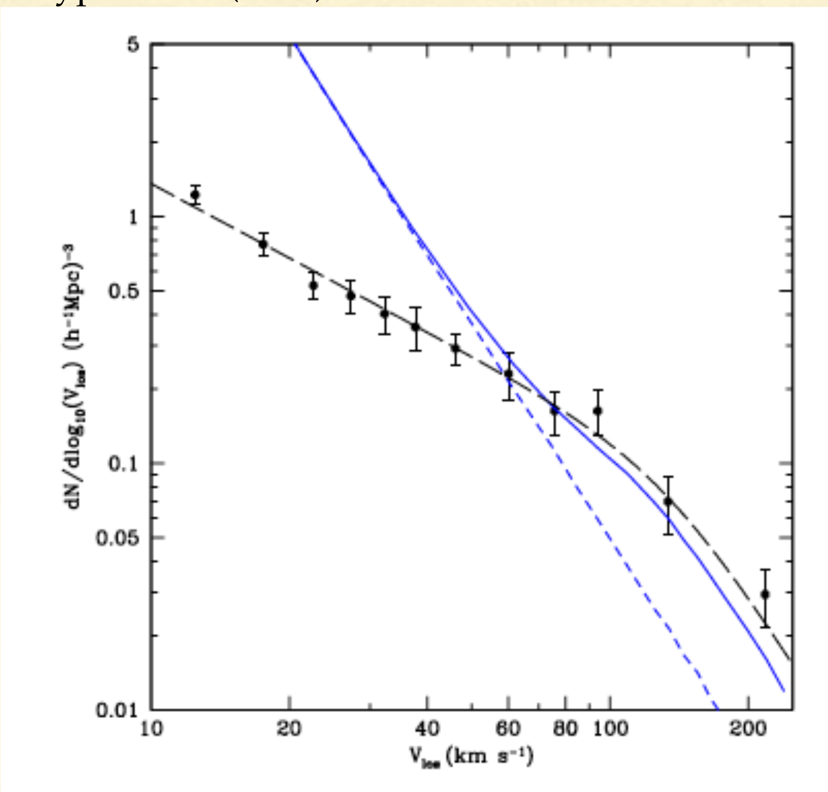
Hopkins, Quatert, & Murray, MNRAS, 421, 3488 (2012)

The Take Away

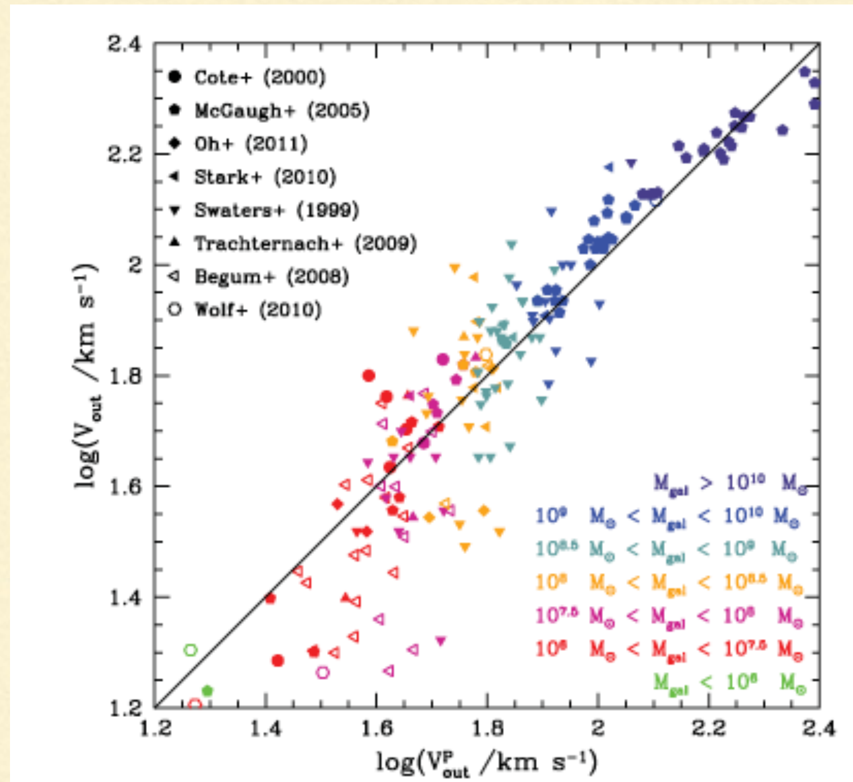
- Simulators can make galaxies that match a lot of observed scaling relations as a function of z, and match the M_{star} — M_{halo} relation
- This does not mean we get everything right — we're still struggling to understand the details of stellar feedback
- Constraints will come from matching properties of (1) the ISM and (2) galactic winds, as a function of redshift

AND NOW FOR SOMETHING DIFFERENT: THE VELOCITY FUNCTION

Klypin et al. (2014)

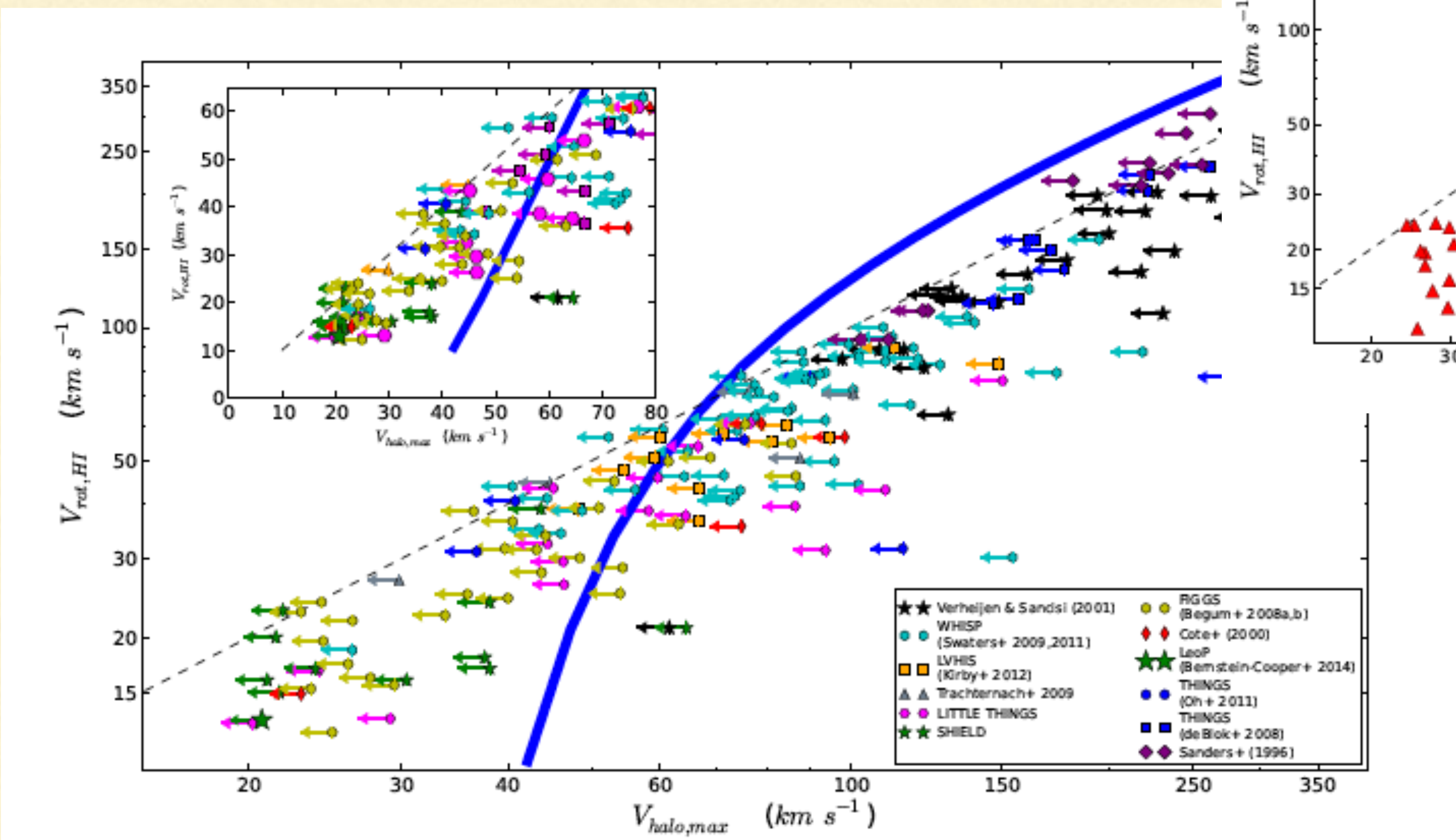


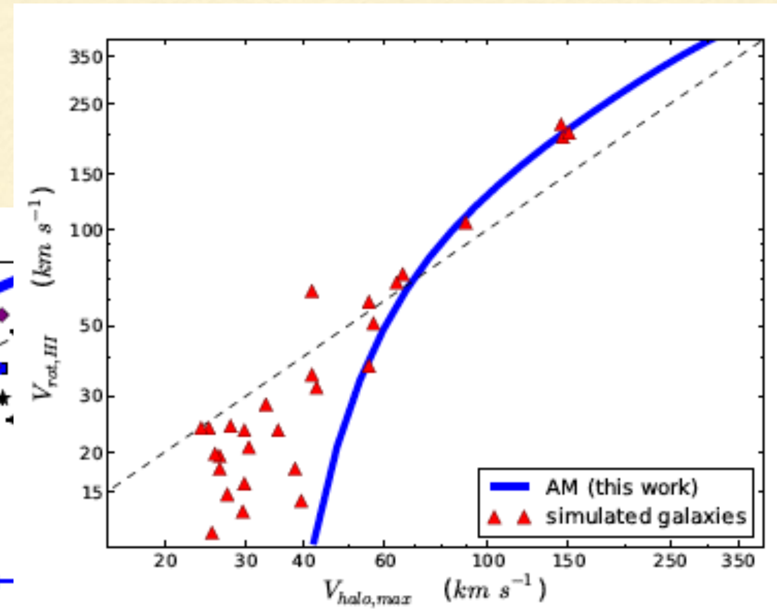
Ferrero et al. (2012)



The observed velocity function of galaxies can either be considered a "missing dwarf problem" for CDM, or and indication that dwarf galaxies are sitting in lower mass halos than predicted

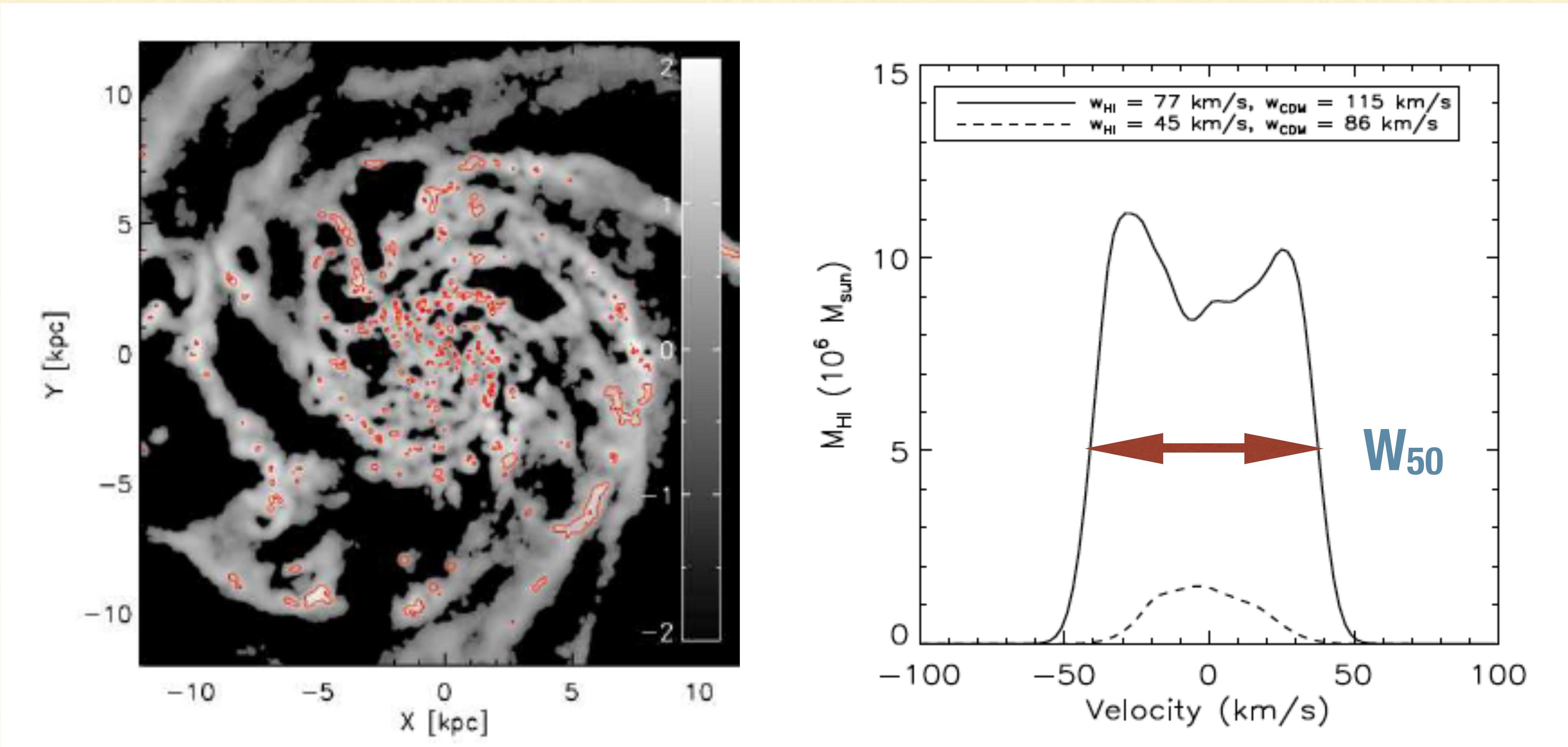
But Simulations with Baryons Agree with Data



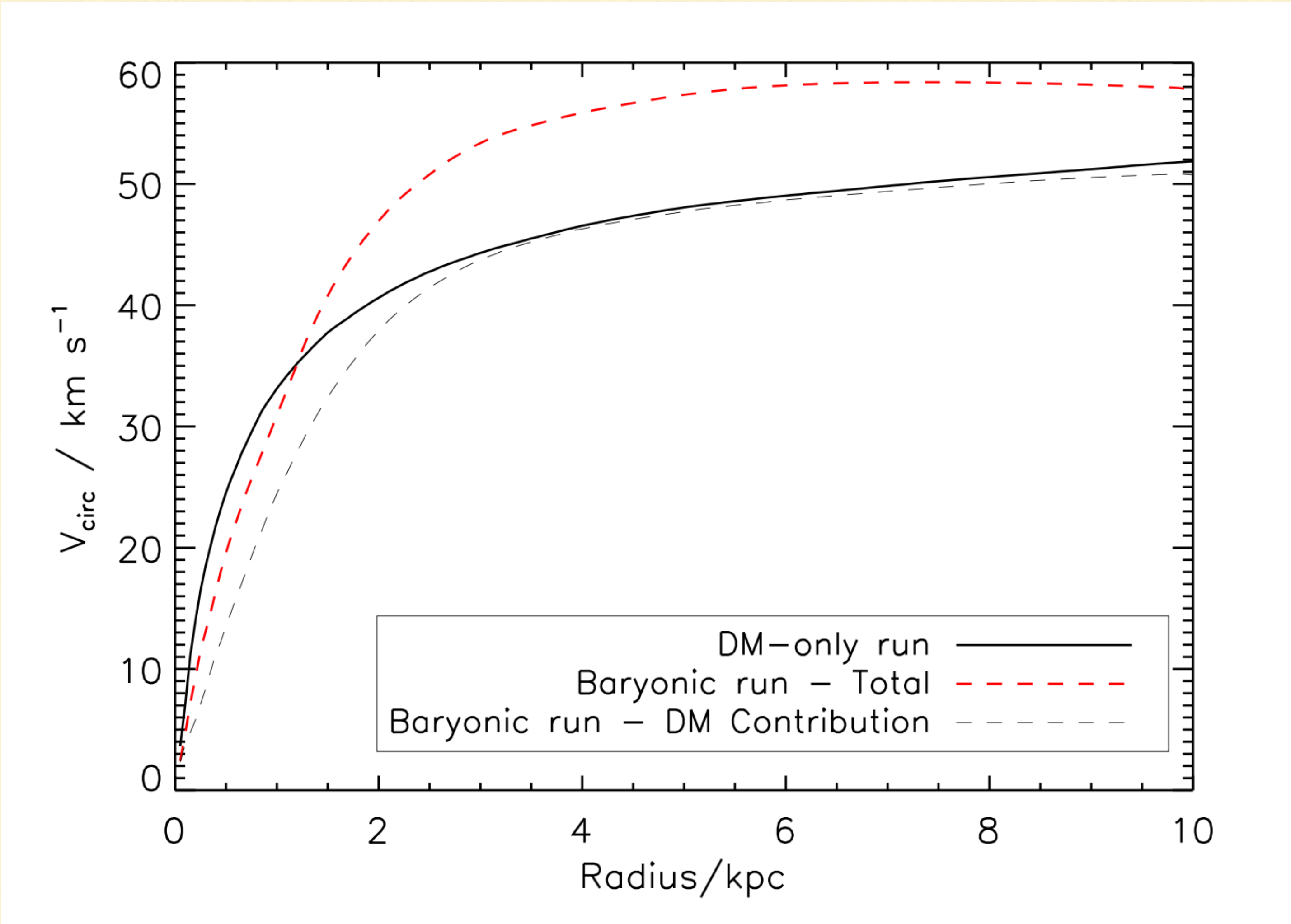


Papastergis et al. (2014)

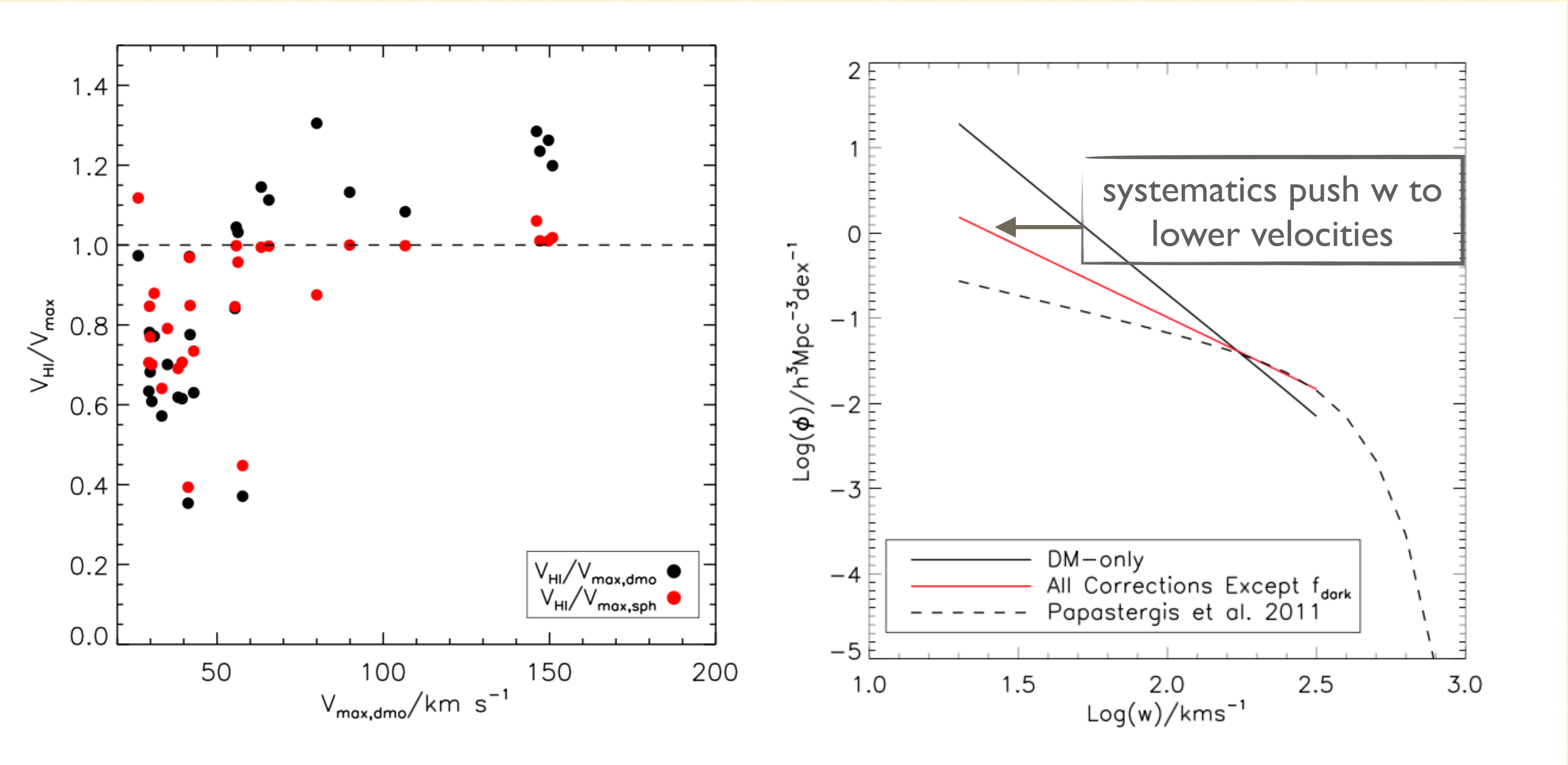
"OBSERVING" THE SIMULATIONS IN HI



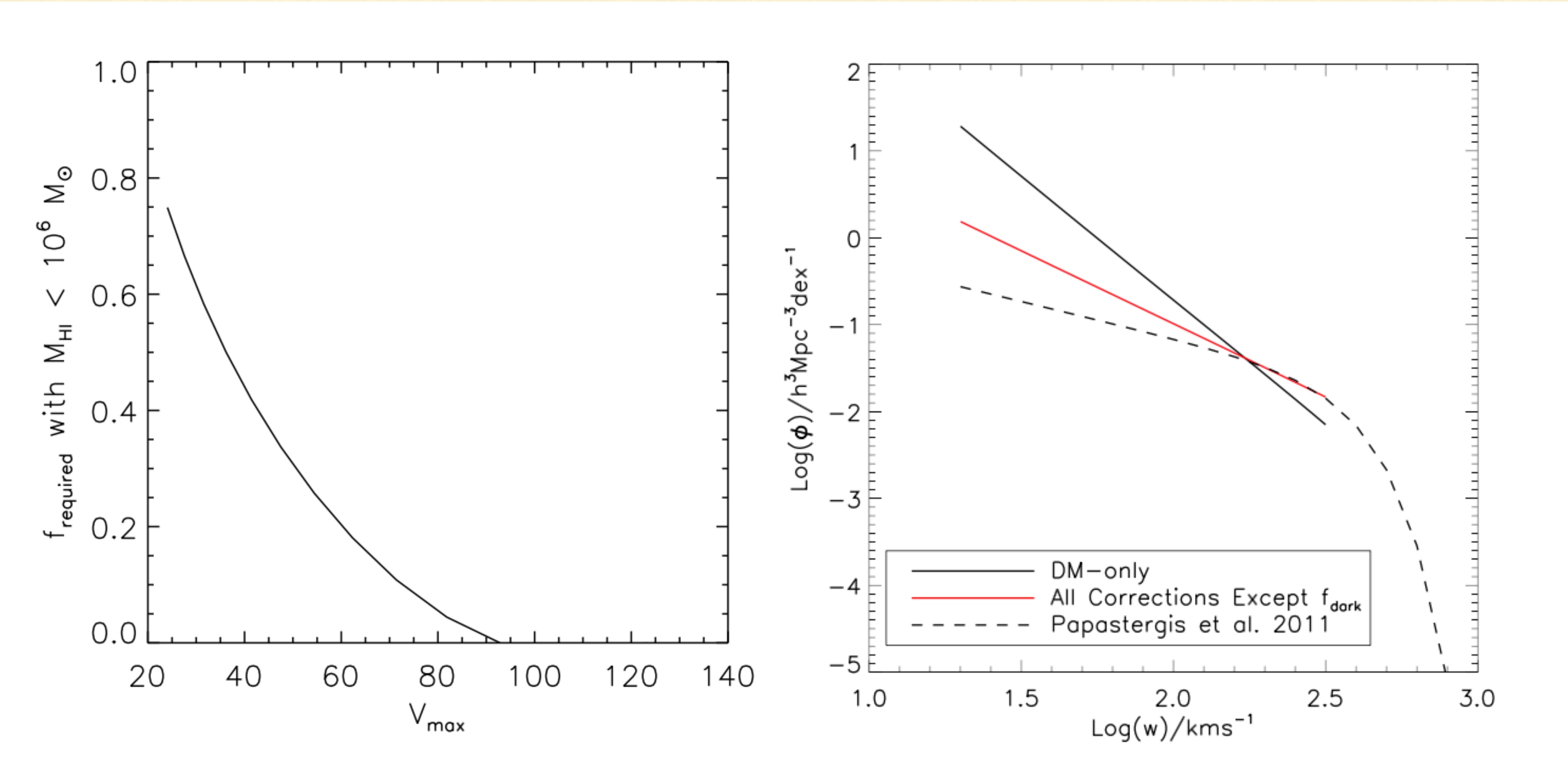
What is the Effect of Dark Matter Core Creation?



Two Primary Culprits: (1) HI Doesn't Trace V_{MAX}



Two Primary Culprits: (2) Dark Halos



CONCLUSIONS

- Simulations can do a very good job of matching a lot of galaxy properties and relations
- Future observations of the evolution of HI in galaxies are necessary to better constrain the simulations
- The successes at z=0 allow for an examination of the HI velocity function
  - HI doesn’t trace full potential well — shifts dwarf galaxies to lower velocities
  - Likely, galaxies below the ALFALFA detection limit make up the remainder of the difference