Examining Basic Assumptions in Semi-Analytic Models

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How Do Galaxies Form?

- No ab initio models exist-- heuristic approaches, requiring parameters, needed for *all* models.
- More assumptions + parameters = less computation. Huzzah!
- Goal: Learn about physics (not match data, or convince observers!)

How far can we push a heuristic approach, and still learn something about the physics?

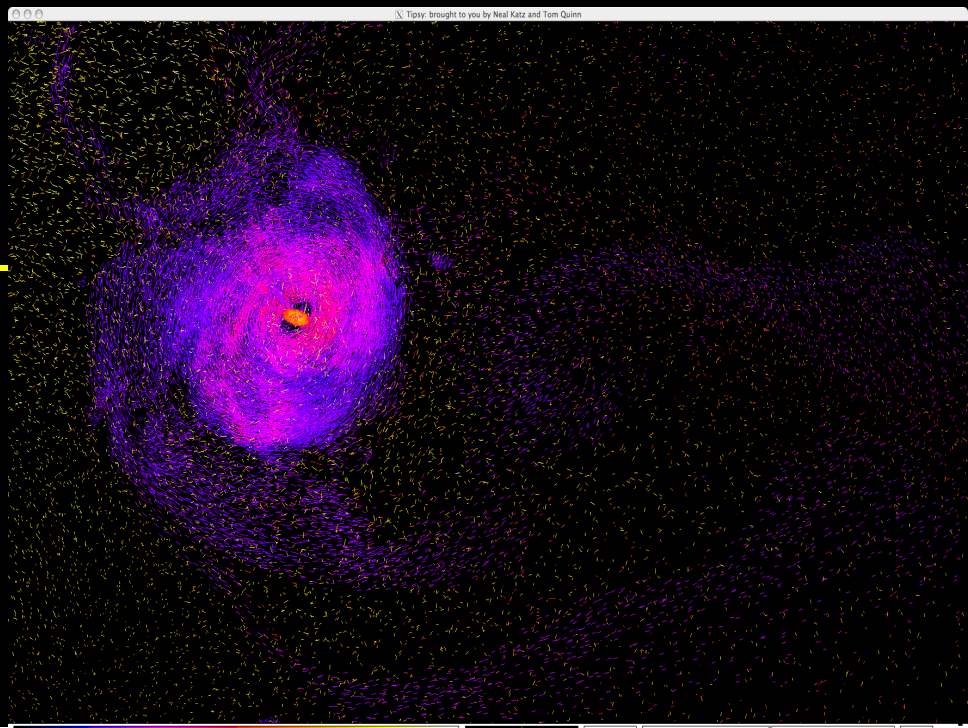
Parameters and Assumptions

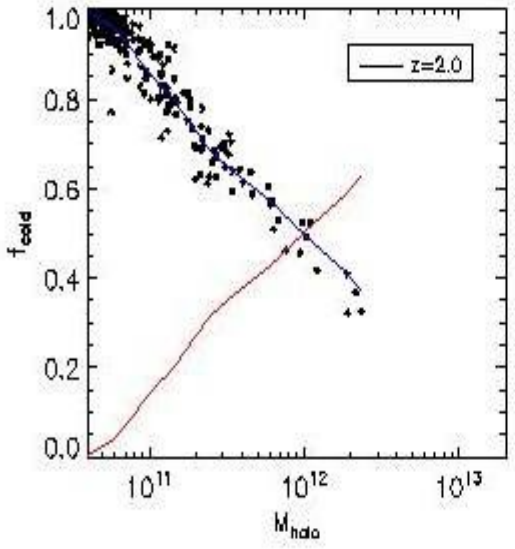
- Besides many parameters, SAMs must make key physical assumptions:
- - Spherical symmetry
- - Gas redistribution
- - Timescales
- - Where to add feedback
- - ...

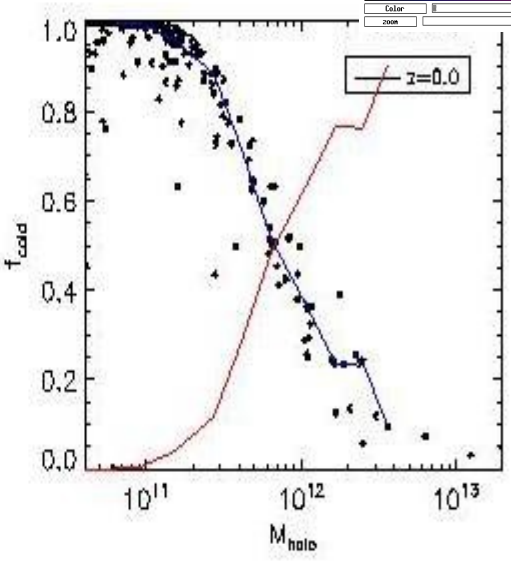
- These assumptions strongly affect predictions! But are they robust?

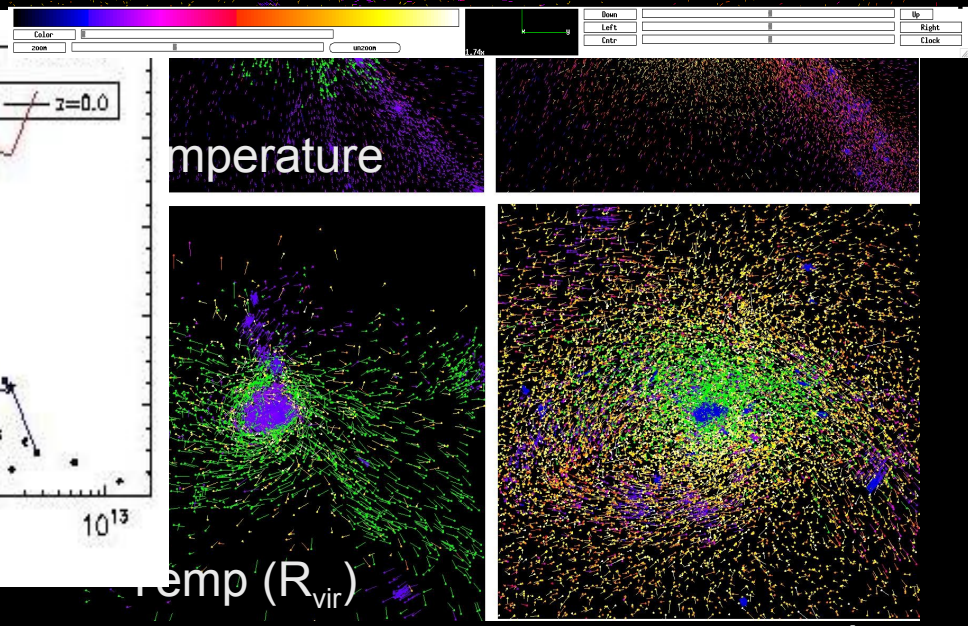
Accretion

- **Accretion** occurs via:
  -Hot mode (slow: t_{cool})
  Cold mode (fast: t_{ff})
- Governed by halo mass.
- 3-D filamentarity enhances cold mode.









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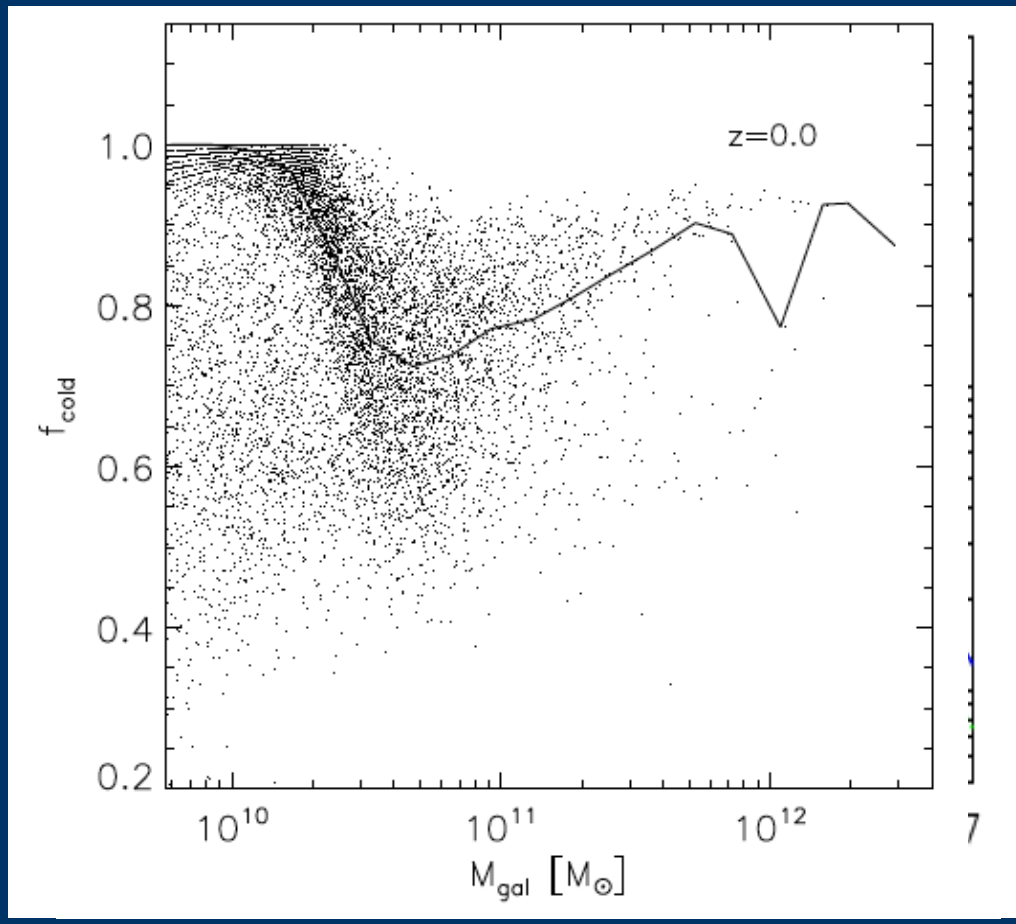
Geometry & Accretion

Spherical models under-estimate cold mode.

Important around L_*!

How much? Depends on assumed timescale, gas profile.

Cold mode dominates global accretion at all redshifts, masses



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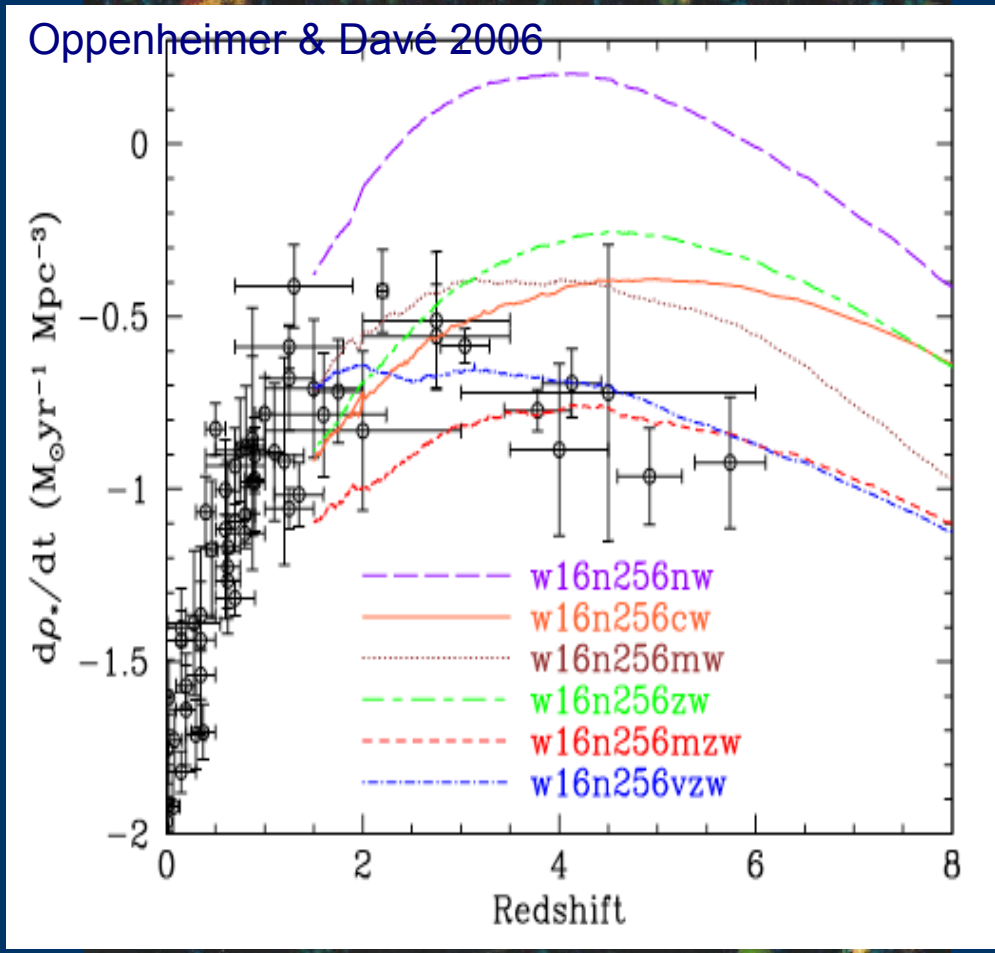
Geometry & Overcooling

Cold mode is rapid, so early galaxies form too many stars.

Early SAMs had trouble getting enough big early galaxies – e.g. "Christmas tree" model for LBGs.

In reality, problem is opposite: Need lots of *early feedback.*

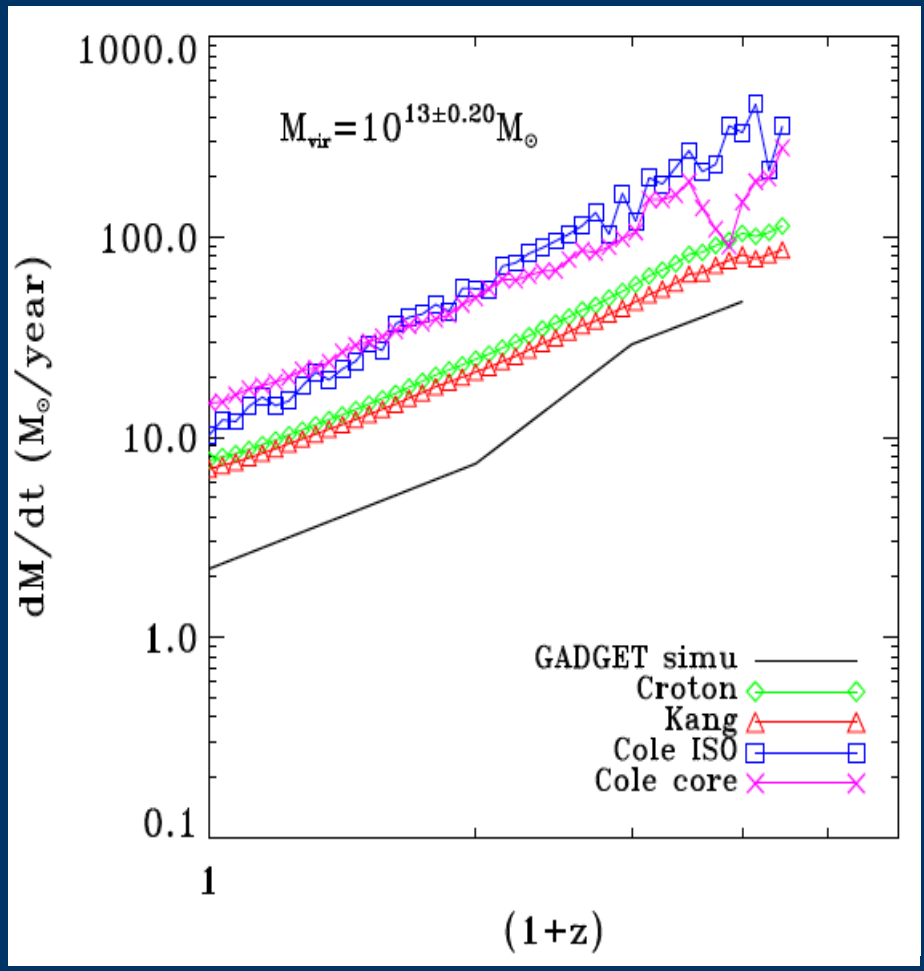


Geometry & Downsizing

Large galaxies form stars early+fast in cold mode, then SF slows as they become hot mode dominated.

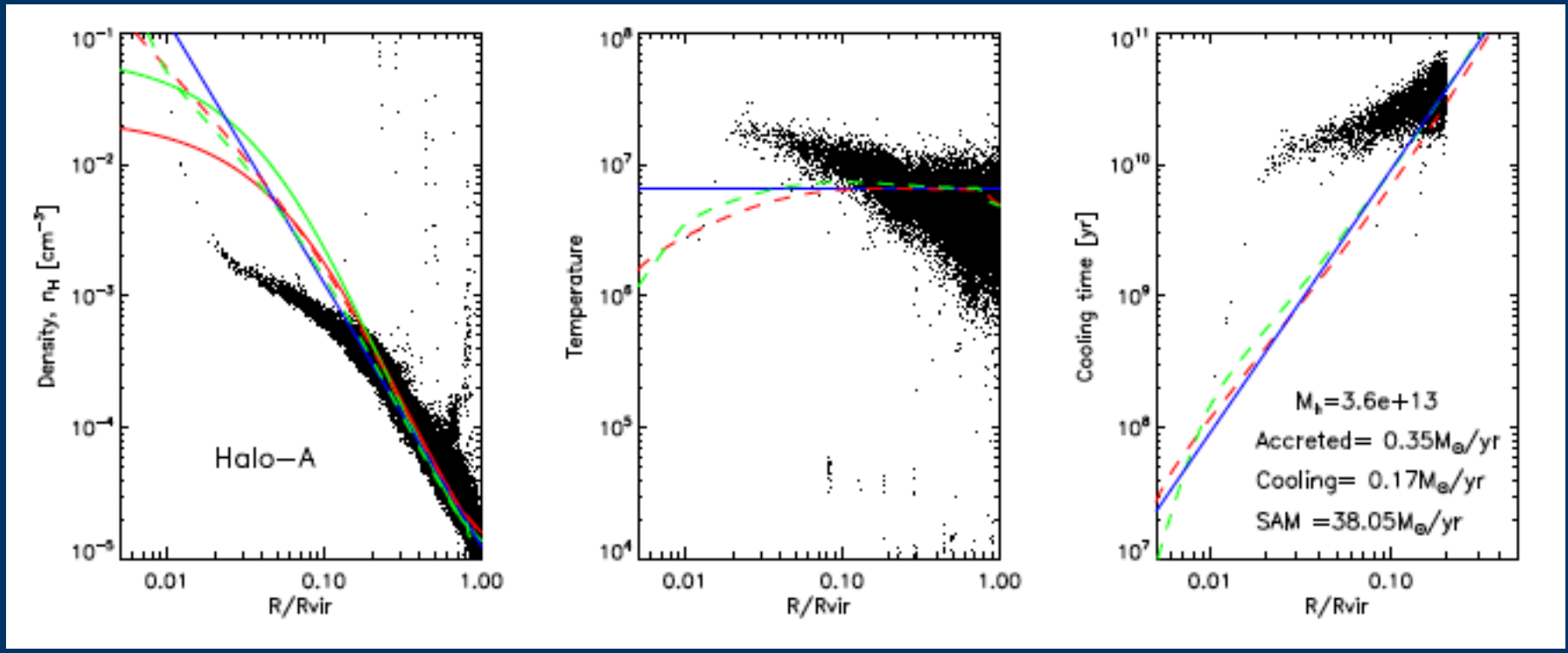
But it doesn't slow enough – need “AGN feedback”.

How much? Depends on assumptions about gas (re)distribution...



from Neal Katz

Cooling and Accretion in Large Halos



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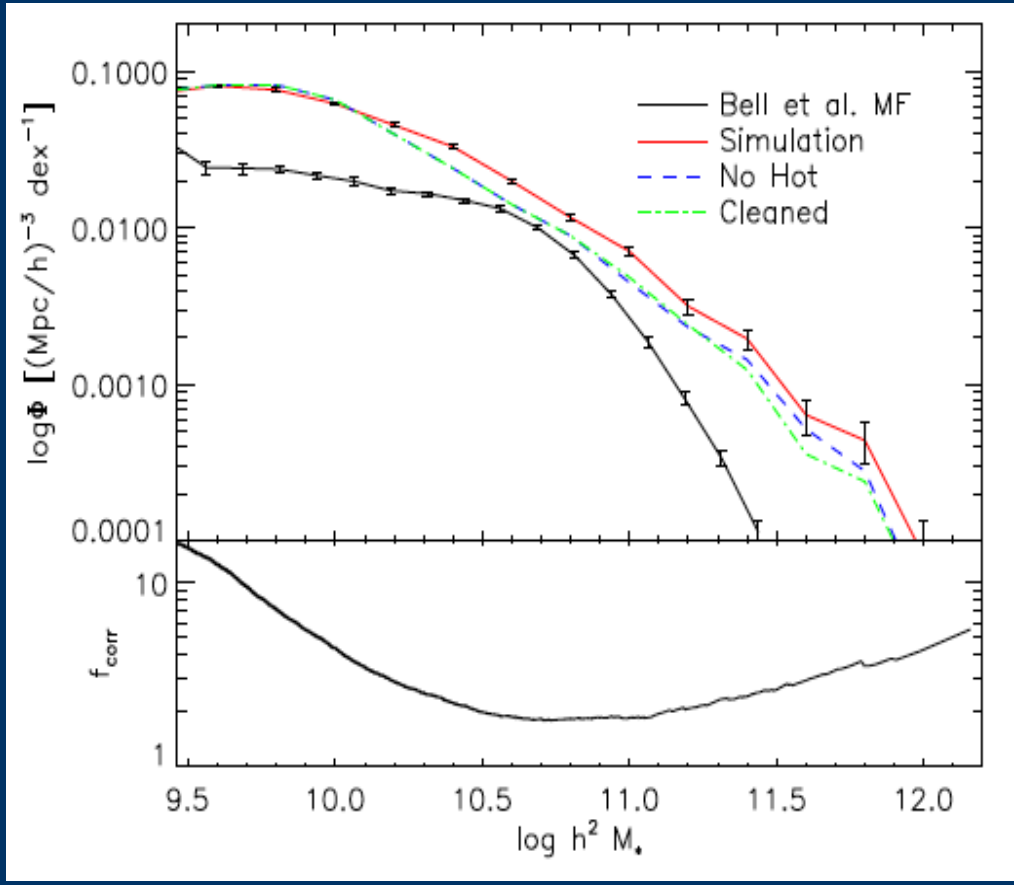
Density profiles suppressed in center.
Accretion rate much lower than Croton etal SAM.

Can AGN Feedback fix the stellar mass function?

If AGN feedback oper-ates only on "hot mode" (eg radio mode), then: NO.

It works in (some) SAMs since hot mode overly strong.

Need to prevent early SF that dry merges.



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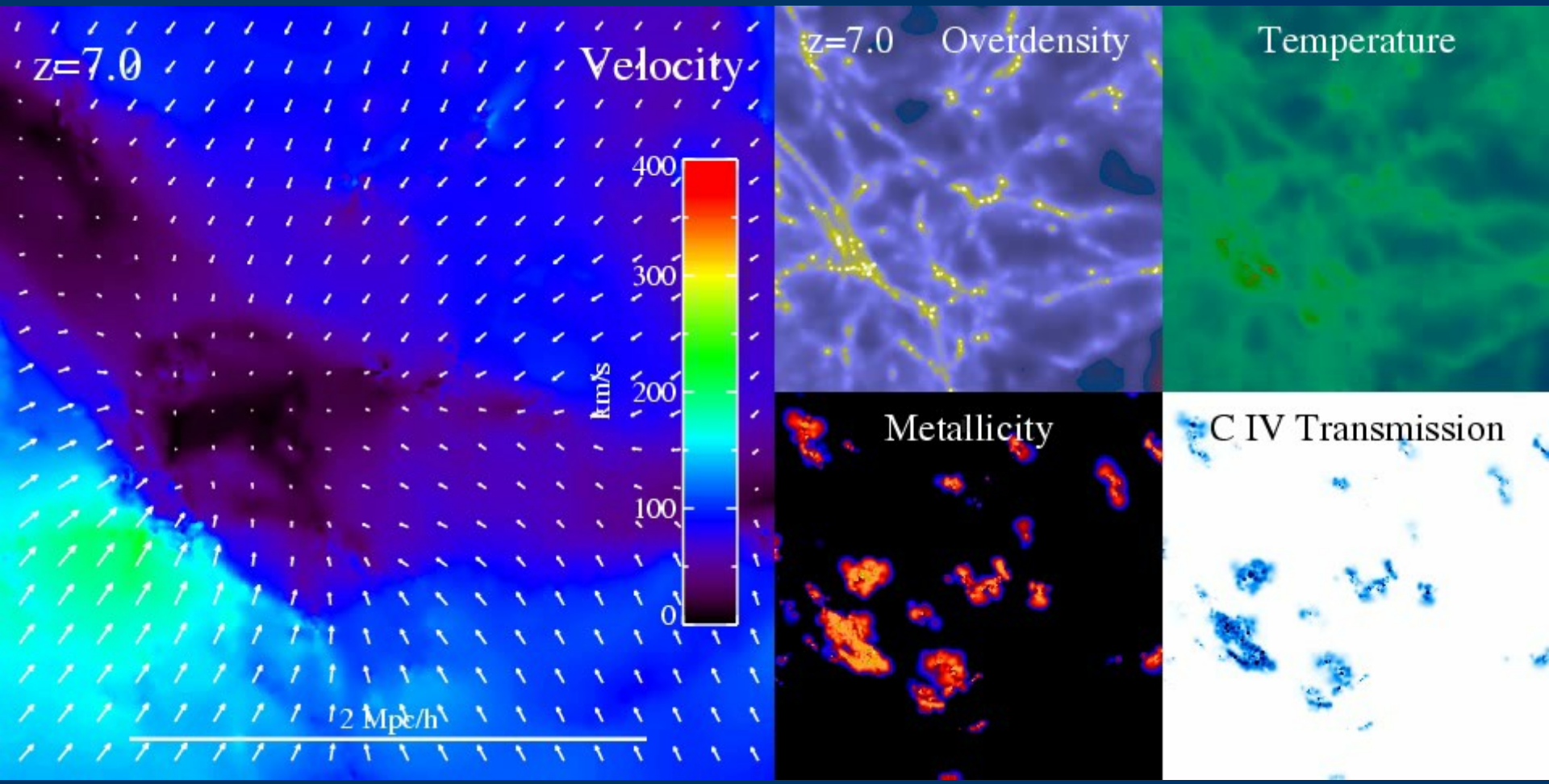
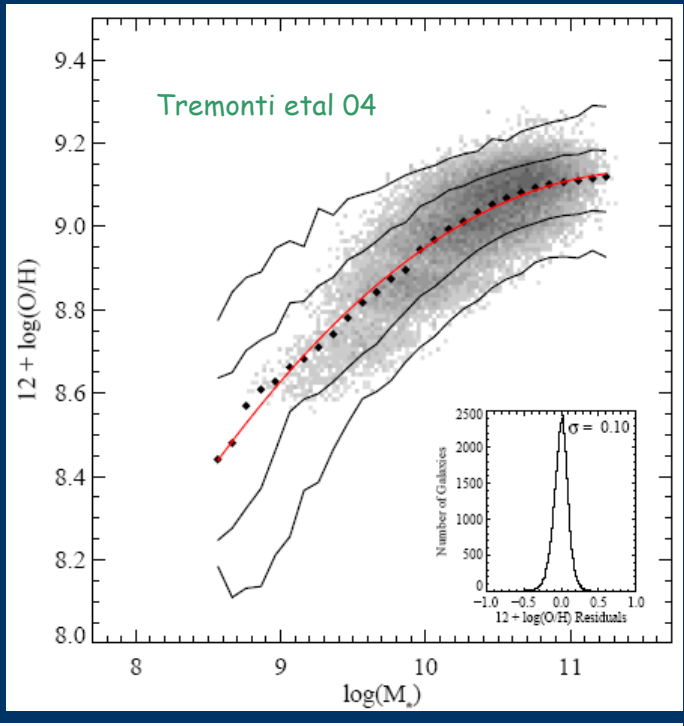
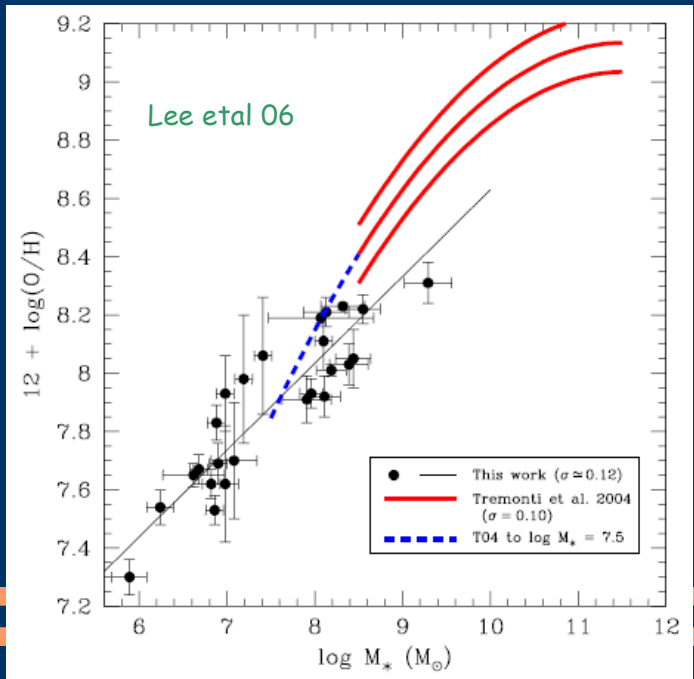
Geometry also critical for Feedback



Example: Mass-Metallicity Relation

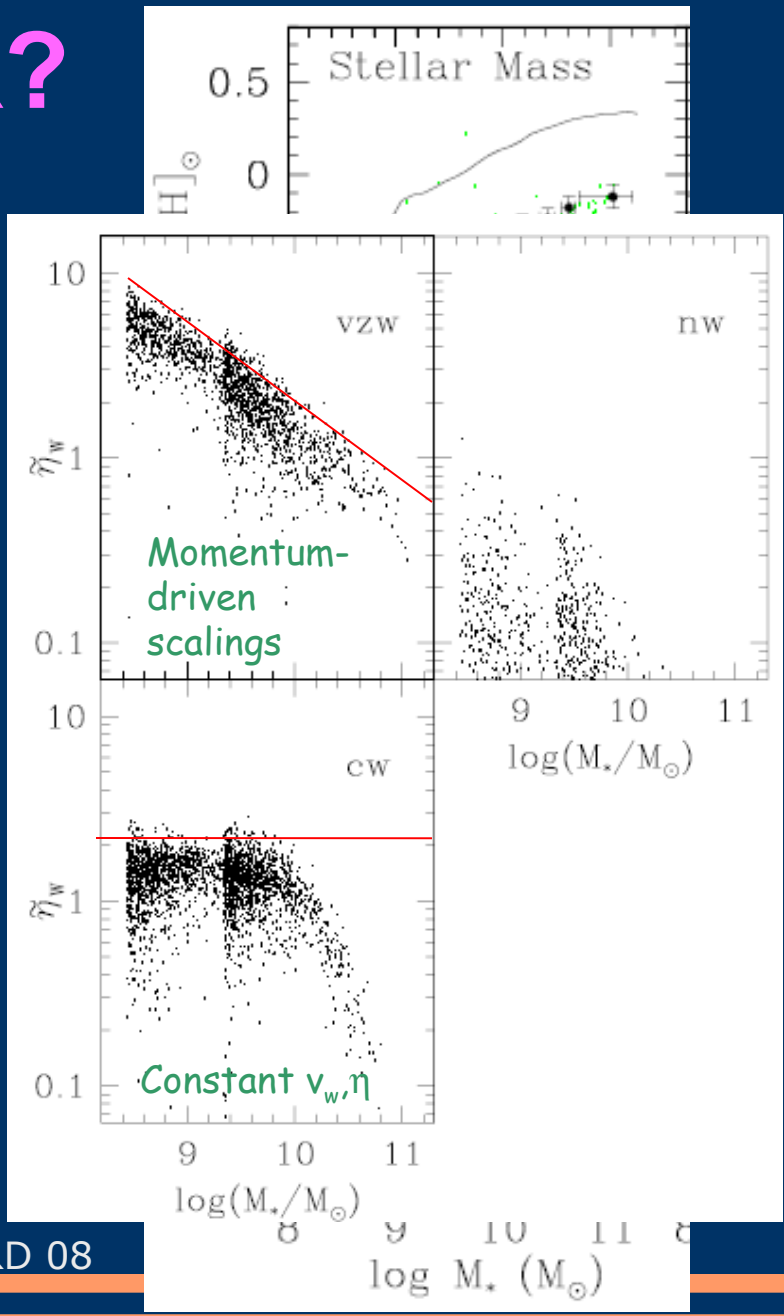
- Observed: $Z_{gas} \propto\propto M_*^{0.3}$, $M_* \sim 10^6 \rightarrow 10^{10.5} M_\odot$ then flattens. $\sigma \approx 0.1$.
- Conventional thinking:
  - Z_{gas} reflects current stage of gas reservoir processing.
  - Winds carry metals more easily out of small galaxies (Dekel & Silk 86).
- WRONG !!! (according to our sims)





What Drives the MZR?

- Model with constant wind speed does not match MZR!
- Momentum-driven scalings matches z~2 data.
- MZR is an *equilibrium state* of gas accretion (ACC) vs. star formation (SFR).
- $Z_{eq} = y\ SFR/ACC \approx y/(1+\eta_{eff})$.
- Wind speed is (mostly) irrelevant!
- vzw: $\eta \sim M_*^{-1/3} \sim v_c^{-1} \Rightarrow Z(M_*) \sim M_*^{1/3}$, as observed!



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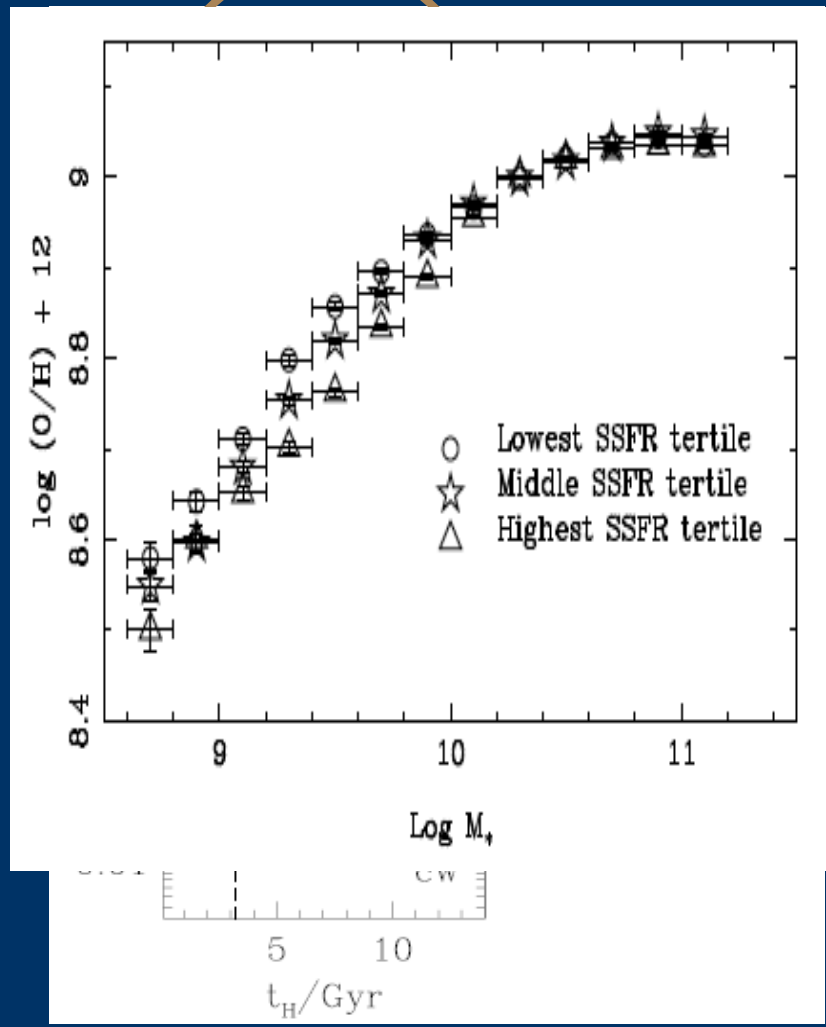
MZR Scatter

- Lee etal 06: Dekel&Silk scenario over-produces scatter at low M*.
- In "equilibrium model", scatter comes from departures from Z_{eq} from stochastic accretion.
- Timescale to return to Z_{eq}: $t_d = ACC/M_{gas}$.
- *Small $t_d \Rightarrow\Rightarrow$ low scatter.*
- SF'ing gals lie below MZR.



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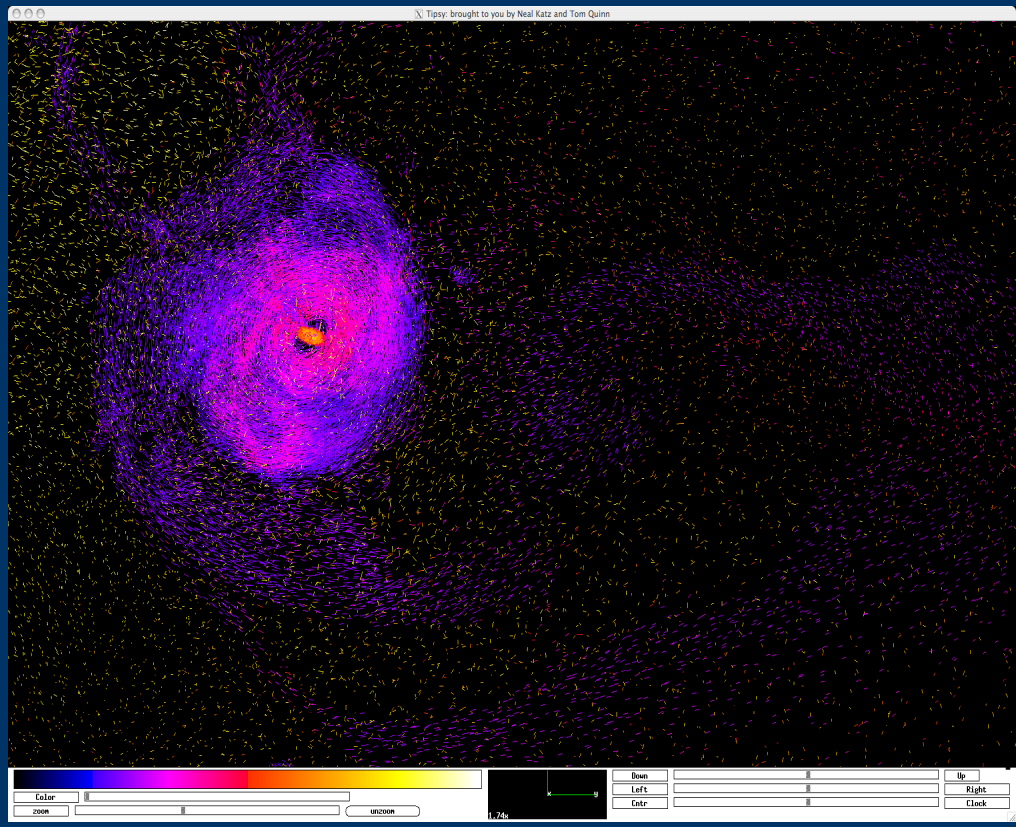
Why was the old MZR interpretation wrong?

- *Geometry.*
- Old interpretation: SN energy distributed spherically in halo.
- New: Outflows blow holes; energy escapes!



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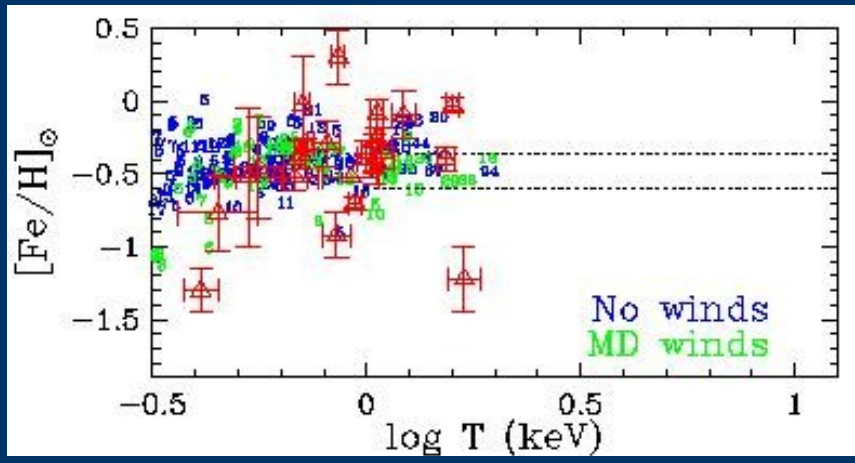
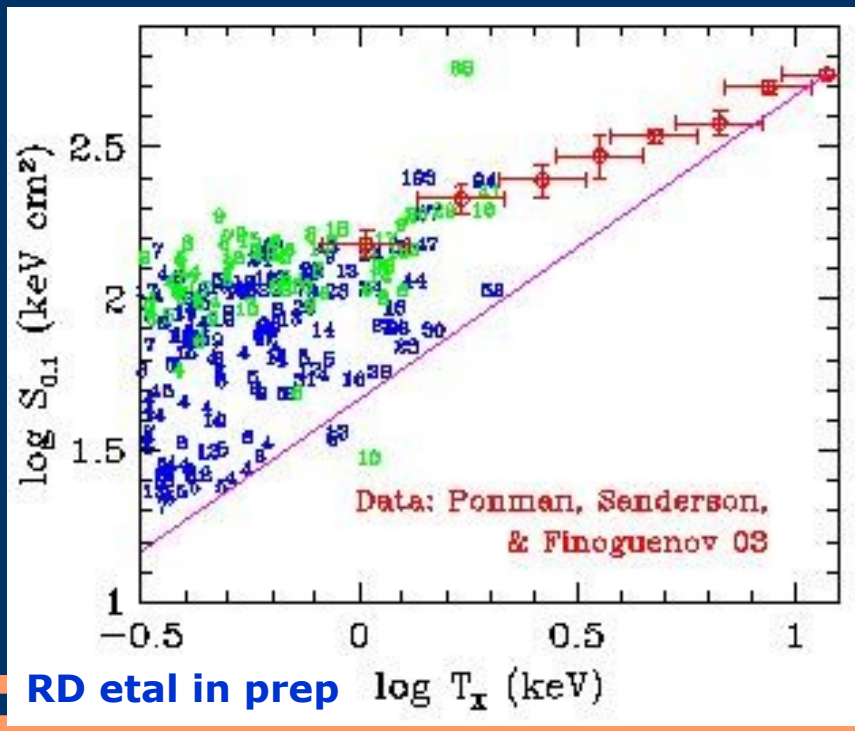
Summary

- 3D geometry critical in galaxy formation.
- Basic assumptions in current SAMs renders them non-robust as a predictive tool for galaxy formation physics.
- Simulations give different intuition: Cold mode dominant; need to suppress SF early; must have ejective feedback.
- SAMs are The Future! ... it's just that the future is a long ways off; we need new approaches.

ICM Enrichment + Pre-heating?

- L_X-weighted $[Fe/H]_- \sim 1/3\ Z_\odot$, as observed.
- No winds looks ok, but stellar baryon fraction >> observed; spurious!
- $\Rightarrow$ *Need outflows to spread baryons in ICM.*
- Intragroup gas shows excess entropy over no winds; "pre-heating".
- *ICM is pre-heated to correct levels naturally with outflows.*





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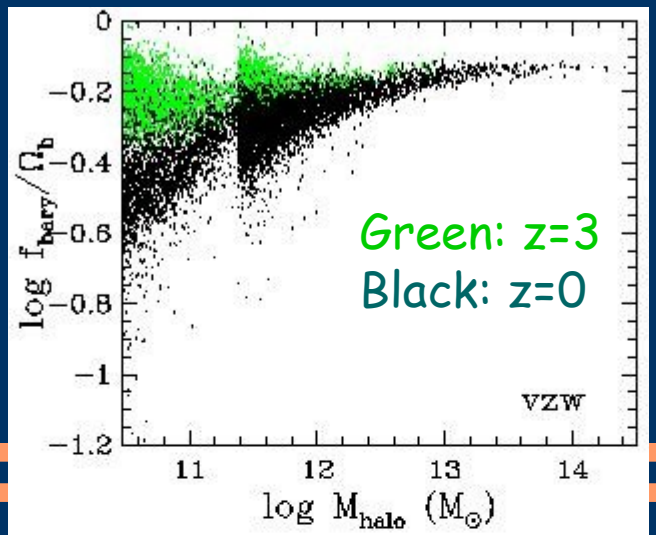
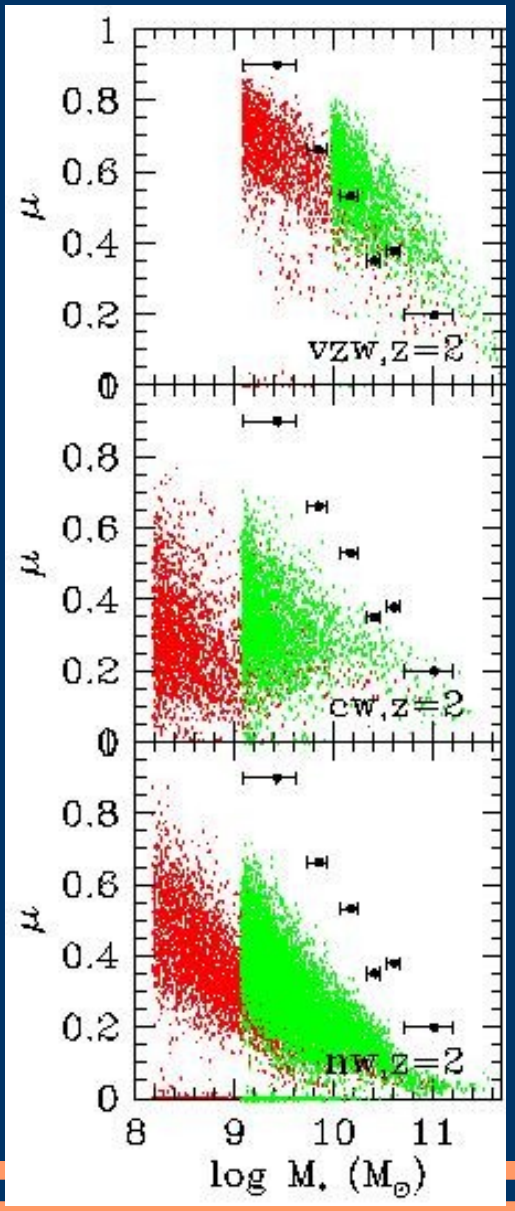
Matches galaxies' gas content?

- $\eta \propto 1/\sigma$ keeps smaller galaxies more gas-rich; decent match to z=2 data (Erb etal).
- Other wind models don't match.
- Baryons ejected from halos: By z=0, ~40% of baryons in MW halo have gone into the IGM!





Matches DLA Kinematics?

- Wide separation (Δ v>v_{rot}) DLAs difficult to reproduce; protogalactic clump infall model fails.
- Momentum-drive winds puff out gas, produces wide-separation systems.

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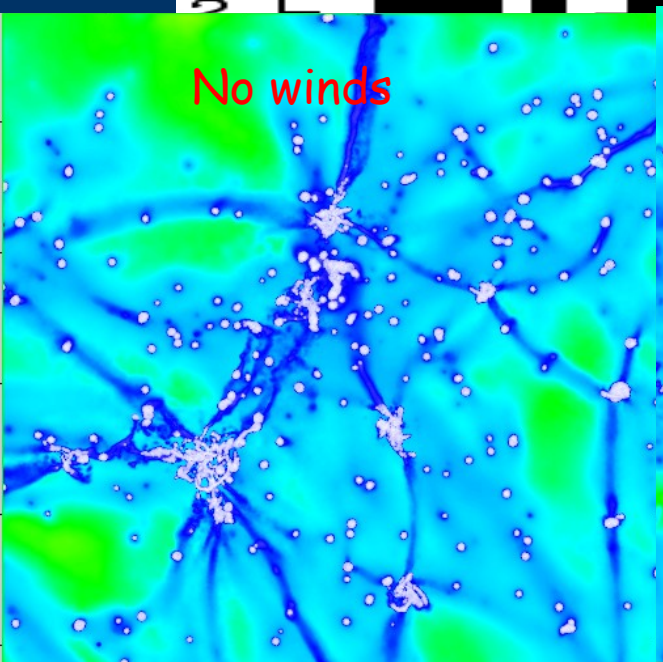
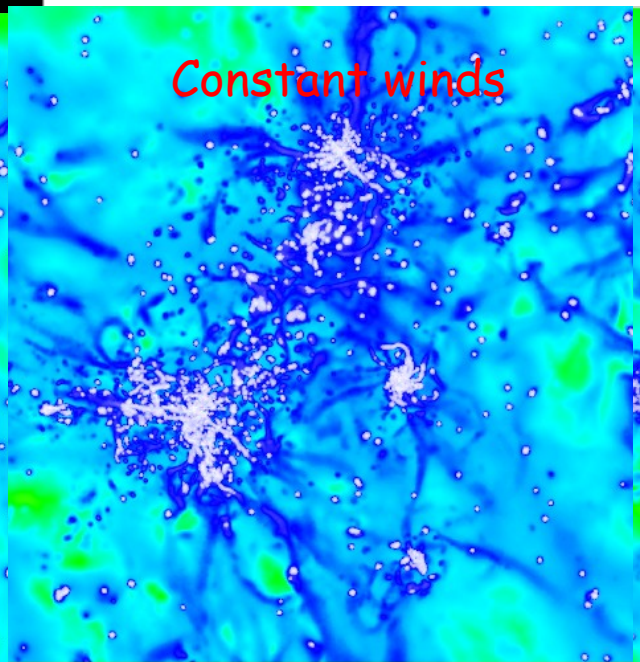
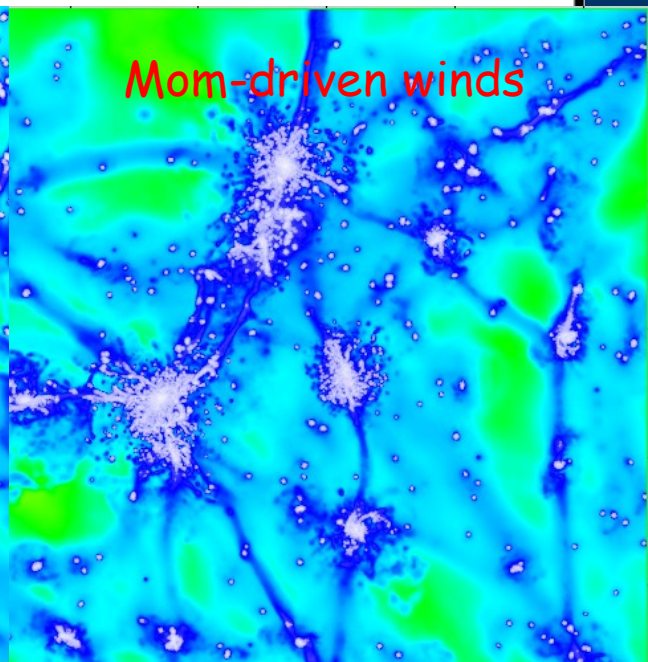
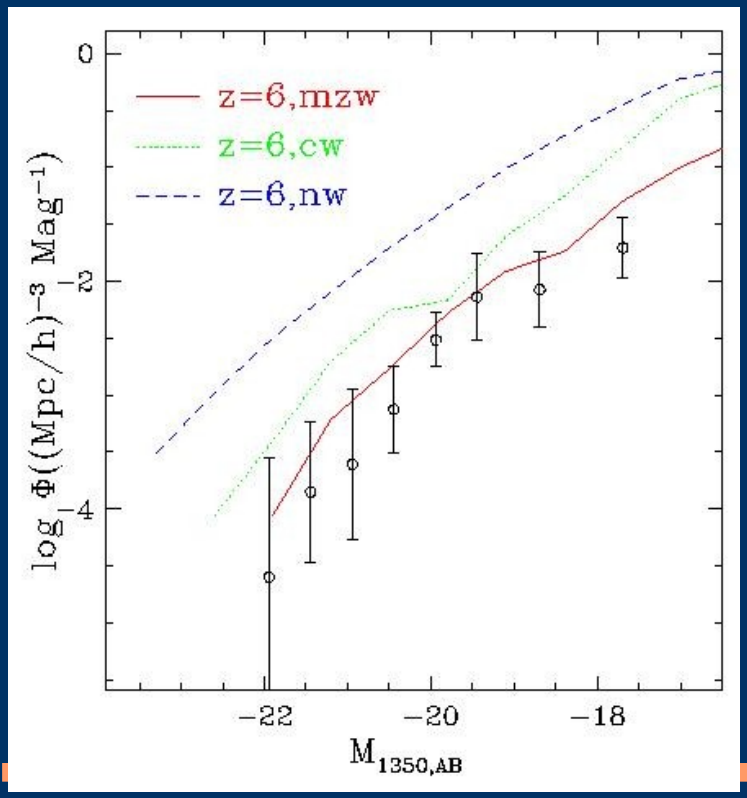


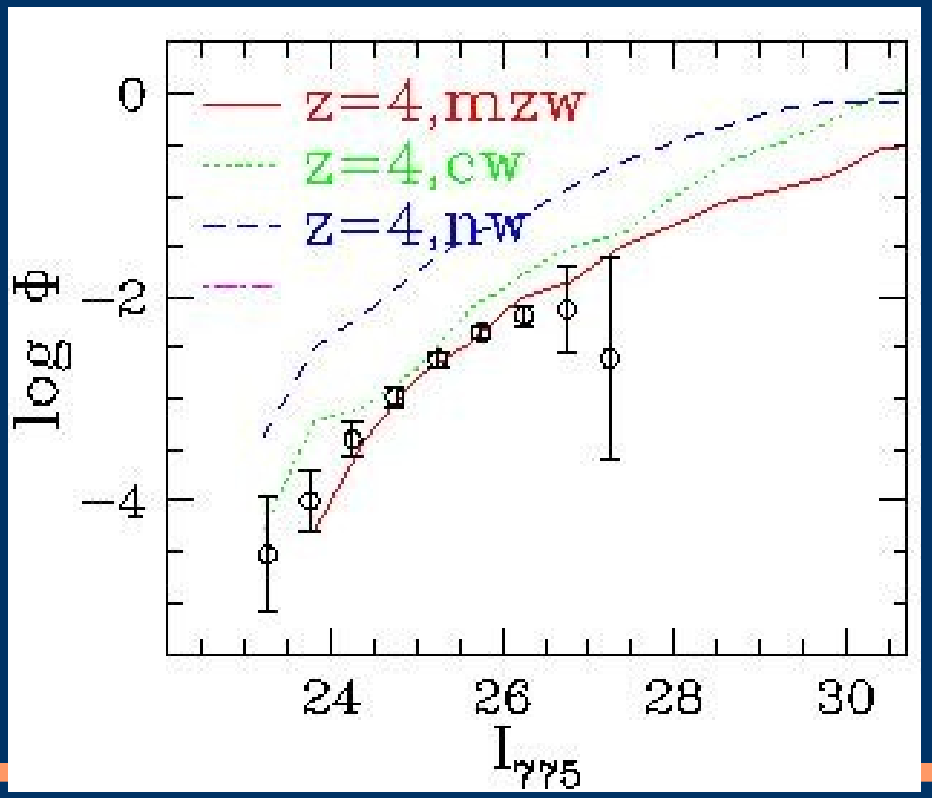




High-z Galaxy Luminosity Functions

- Outflows also affect galaxy properties, particularly early on.
- Large suppression of SF is required to obtain agreement with available data.
- Momentum-driven wind models works well.





RD, Finlator, Oppenheimer 06