Merger Histories of LCDM Galaxies: Disk Survivability and the Deposition of Cold Gas via Mergers

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Galaxy Evolution: Emerging Insights and Future Challenges
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Based on Stewart et al. 2008b (**arxiv.org/abs/0811.1218**), Stewart et al. 2009 (in prep)

Outline

- Introduction
- dN/dt vs. z (Too many high-z mergers?)
- Mergers vs. Disk Survival
- Baryonic Galaxy Assembly (via mergers)
- Conclusions

Introduction:

There is a concern about the survivability of disk galaxies in ΛCDM cosmology:

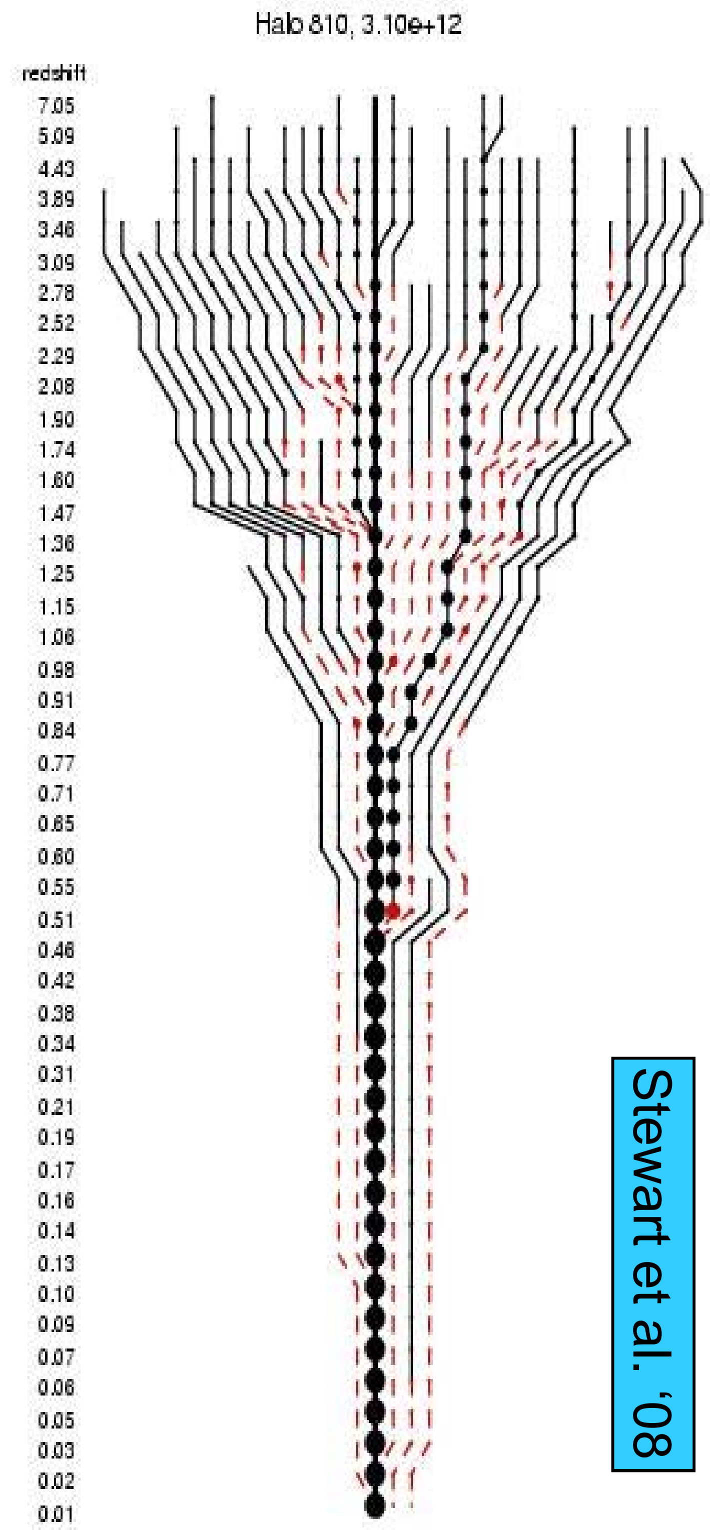
- Dark Matter Halos form by mergers.
- Mergers still turn disk-type galaxies into thick, flared, more bulge-dominated systems. (eg. Mihos & Hernquist ‘94, Kazantzidis et al. ‘07, ‘08; Purcell et al. ’08b)
  - And Yet: Majority of Milky-Way sized DM halos contain disk-dominated galaxies (z=0). (eg. Weinmann et al. ‘06; Choi et al. ‘07; Park et al. ‘07; Ilbert et al. ‘06.)
- Merger Rate increases with redshift.
  - And Yet: Large thick disk-like galaxies observed at z~2. (eg. Förster Shreiber ‘06; Genzel et al. ‘06; Shapiro et al. ‘08.)

How is all this compatible?

DM Merger Trees

- DM only, ΛCDM, N-Body simulation.
- 80 h^{-1}Mpc Box, σ_8=0.9, 512^3 particles
- m_p=3.16x10^8 $h^{-1}M_\odot$ (better resolution than Millennium.)
- **A**daptive **R**efinement **T**ree code. 512^3 cells, refined to max. of 8 levels. h_{peak} ~ 1.2 h^{-1}kpc (Kravtsov et al. '97)
- Focus on host masses ranging from 10^{11}-10^{13} $h^{-1}M_\odot$ (~15,000 halos at z=0, ~9,000 halos at z=2.)
- Complete to 10^{10} $h^{-1}M_\odot$

Example merger tree for a ~ MW-size halo (z=0). Time runs downward, circles proportional to R_vir. Black=field halo, red=subhalo. The main progenitor is the bold center line.



Stewart et al. '08

Merger Rate evolution with z.

Stewart et al. '08b
(arXiv: 0811.1218)

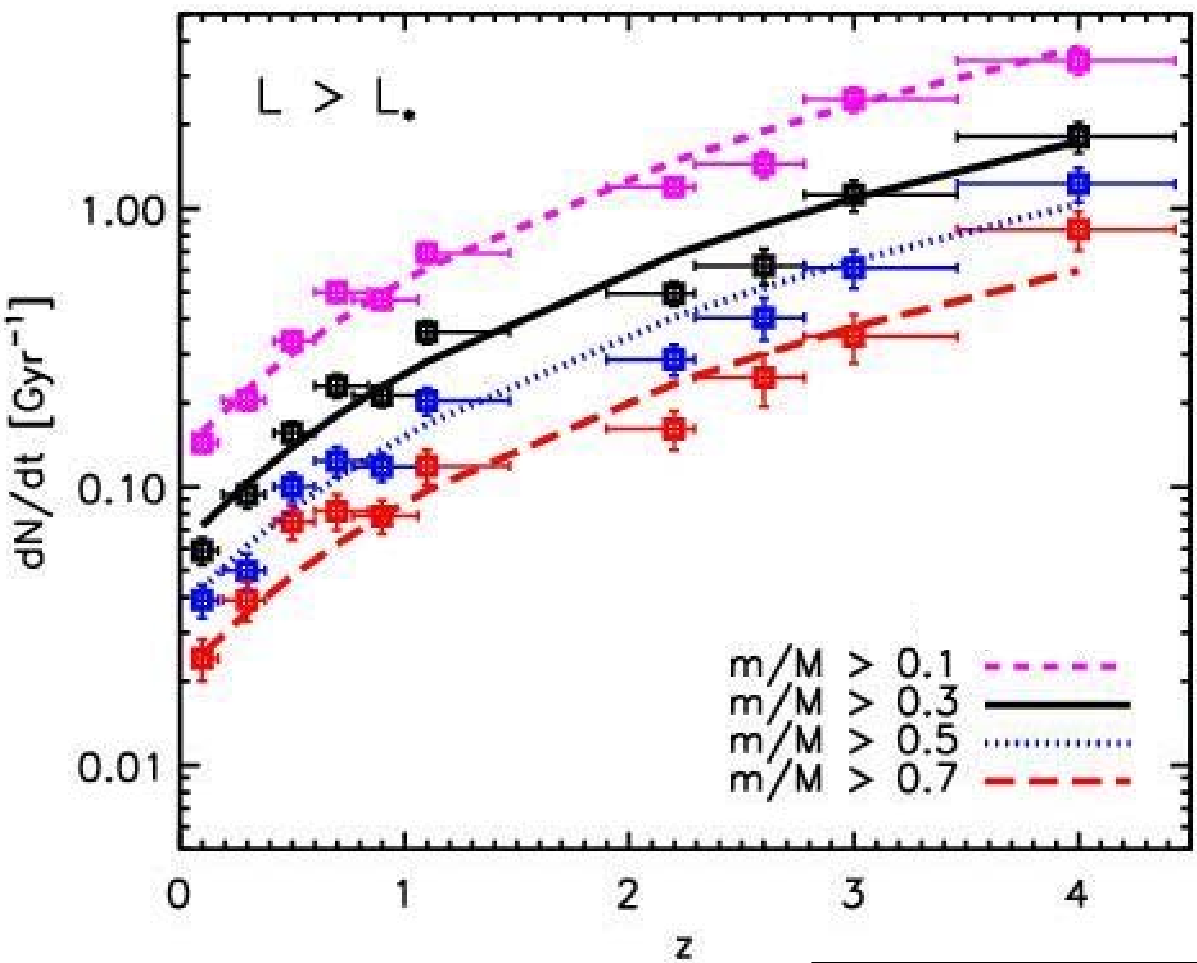
dN/dt vs. z

(Number with a merger larger than m/M)

(Use number density matching to associate halos with ~L* galaxies from observed luminosity function)

Predict: Strong evolution with redshift ~ (1+z)^2.2.

Worry: does this contradict observational evidence for flat merger fraction with redshift ? (e.g. Lotz et al. ‘08, Jogee et al. ‘08)



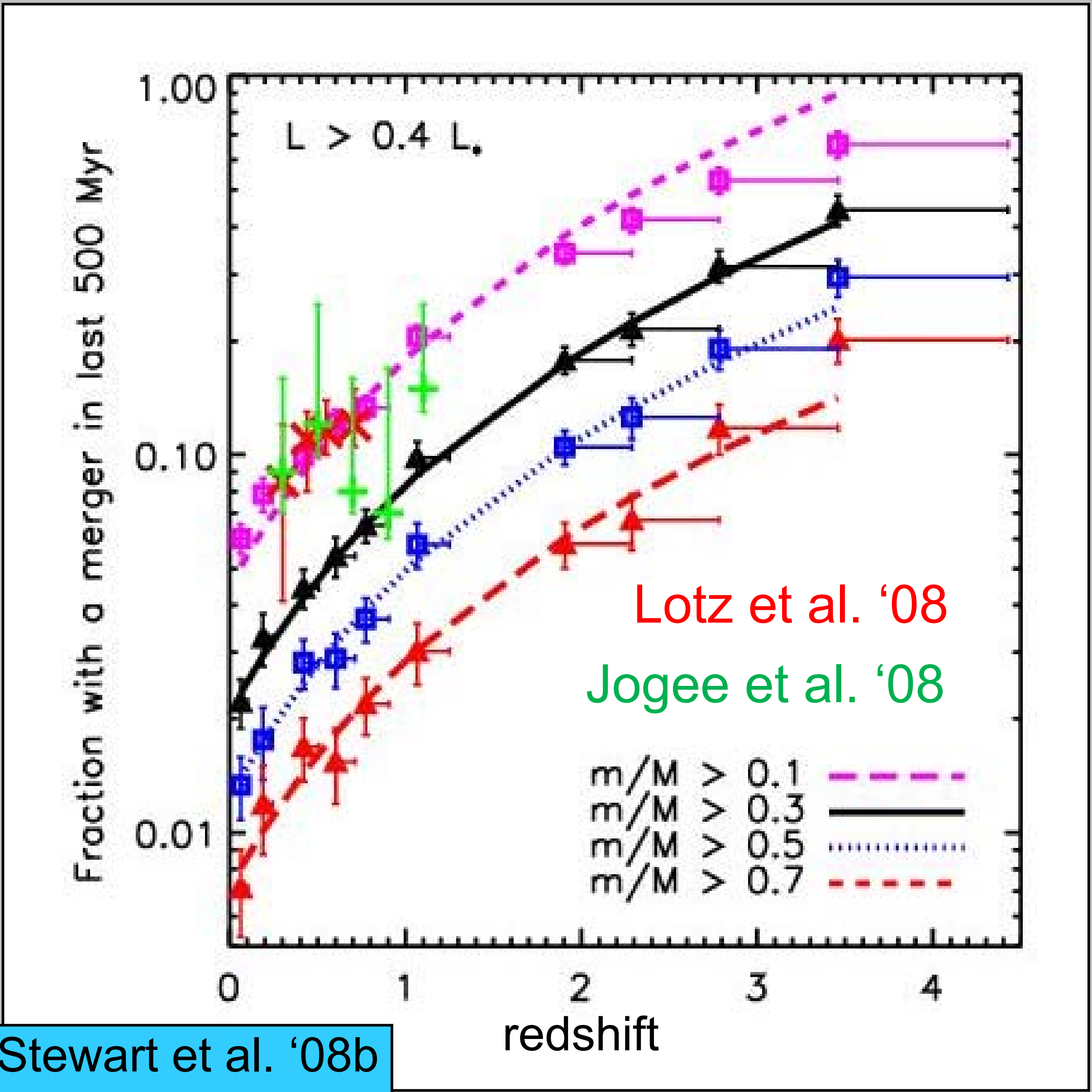
Stewart et al. ‘08b

$$(r \equiv m / M)$$

$$\frac{dN}{dt} \propto (1/r)^{0.5}(1-r)^{1.3} M^{0.15}(1+z)^{2.2}$$

Merger Fraction in past 500 Myr*.

*Sometimes used as an estimated timescale for morphological disruption.



Stewart et al. '08b

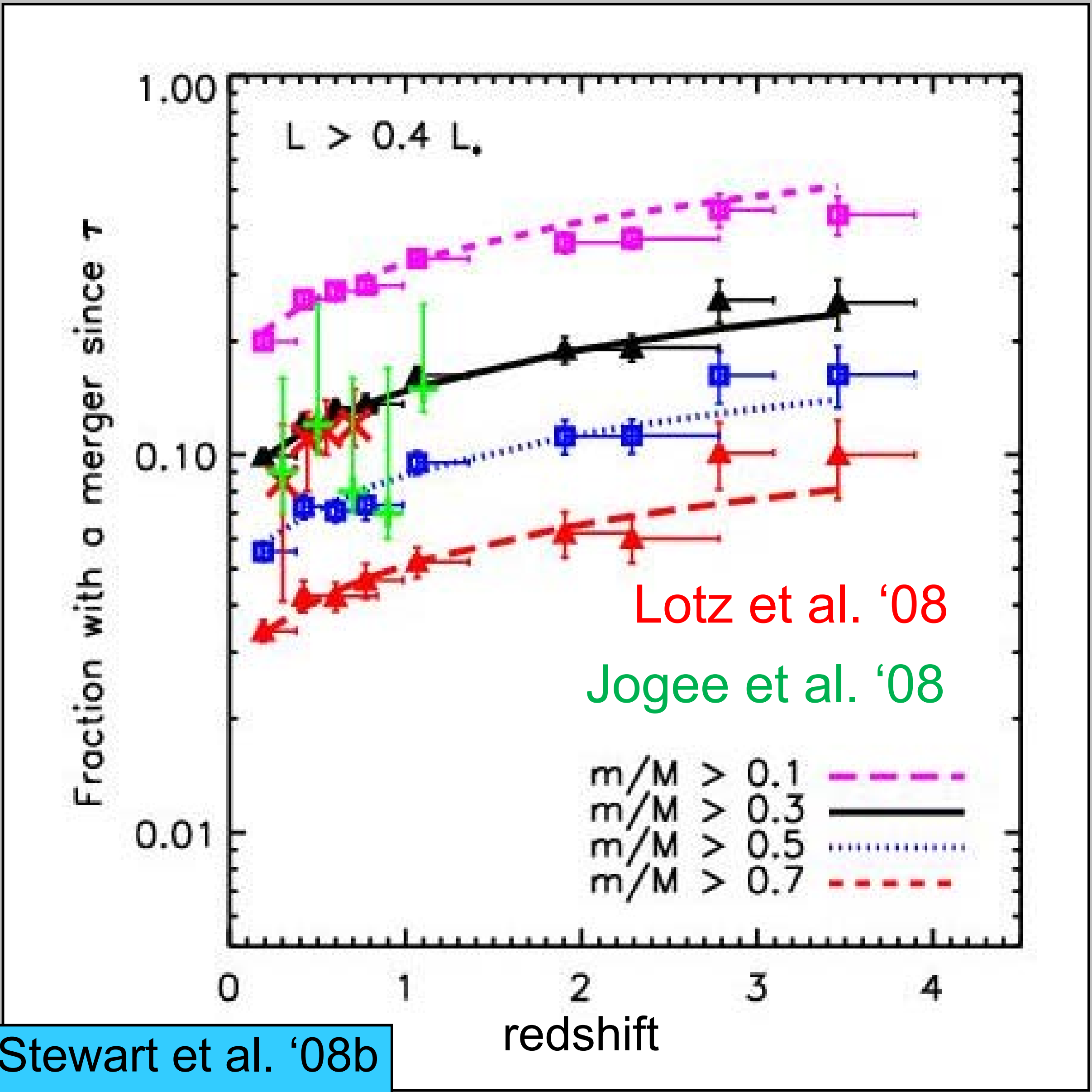
Use number density matching to associate halos with ~0.4L* galaxies from observed luminosity function (e.g. Faber et al. 07)

Consistent with observations for 1:10, minor + major mergers.

Suggests much higher fraction at high redshift.

Merger Fraction in past dynamical time*.

*Use halo dynamical time as a proxy for morphological dynamical time.



Stewart et al. '08b

Use number density matching to associate halos with ~0.4L* galaxies from observed luminosity function (e.g. Faber et al. 07)

Consistent with observations for 1:3, major mergers.

Shows relatively flat redshift evolution.

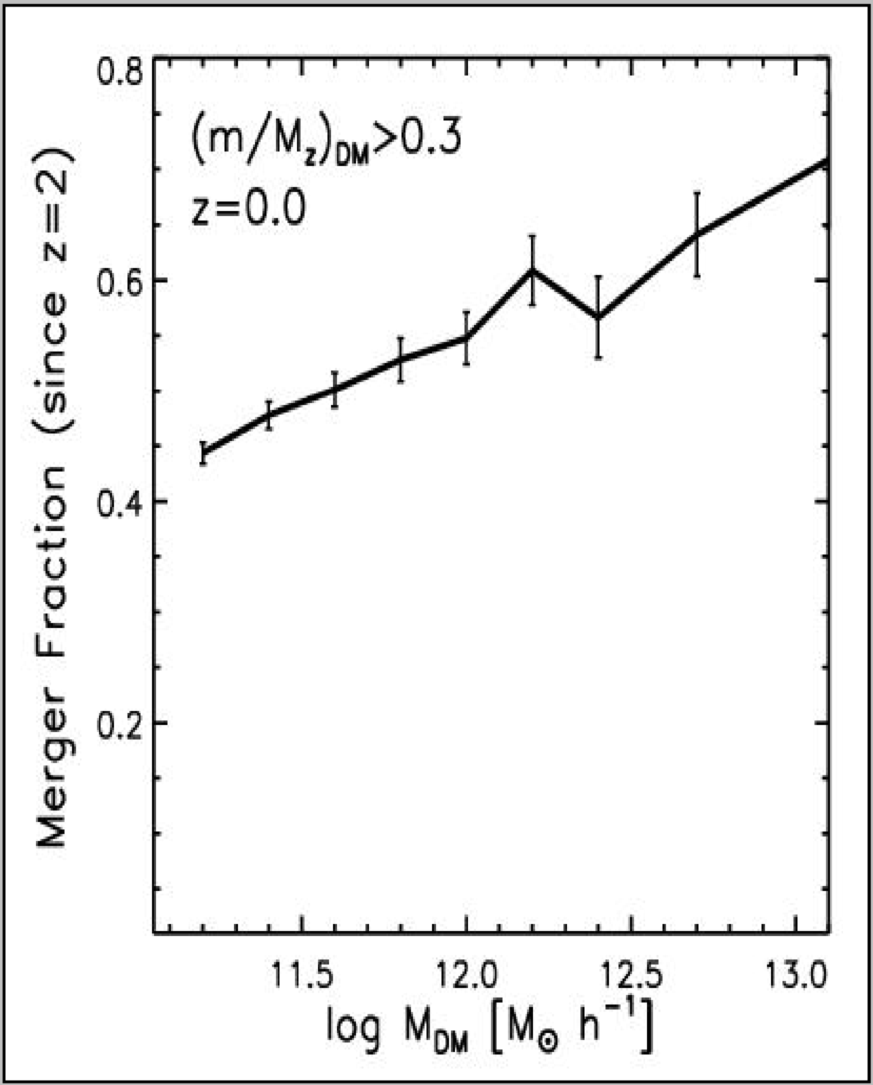
Merger Histories
versus
Disk Survivability

Fraction halos with >1/3 mergers that hit the disk since z=2

While merger fractions seems consistent with observations...

Fraction that have **ever** had a major merger (since z=2) seems problematic…

(~55% for MW-size halos)



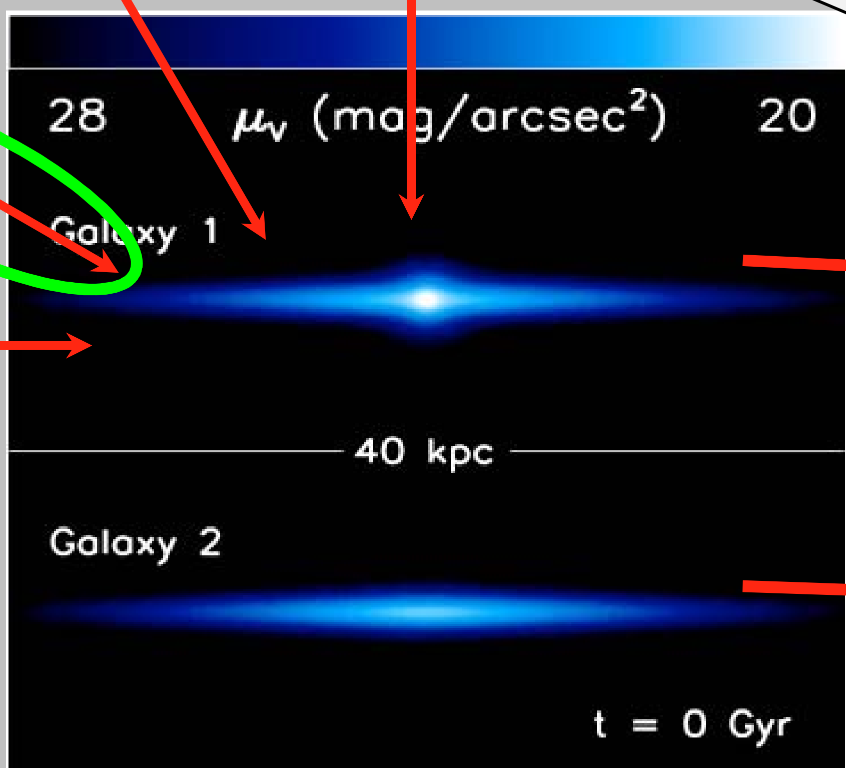
Purcell et al. ’08b (see poster):

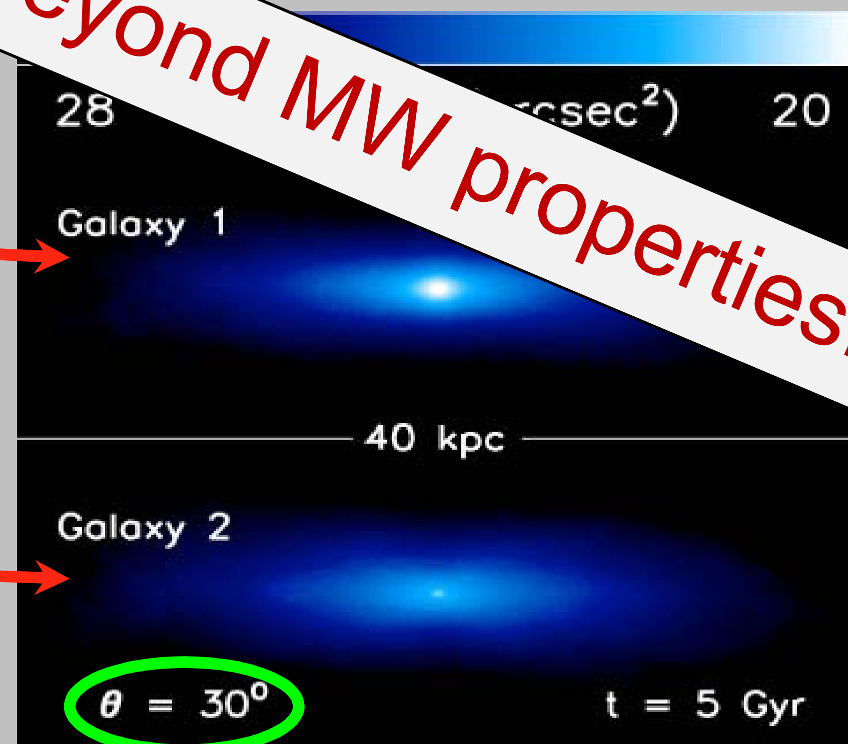
1:10 merger heats the disk beyond MW properties.

- z_{thi}... → 1-2kpc
  (and cr... 1.6kpc)
- σ_{tot}: 50km/s → ... /s
  (MW is ~ 35-40 km/...

Quick simulation facts:

- 6 million particles
- ε = 100pc (DM), 50pc (Stars)
- 1:10 mergers.
- variety of inclination angles.
- Only stars + DM. **(No gas!)**



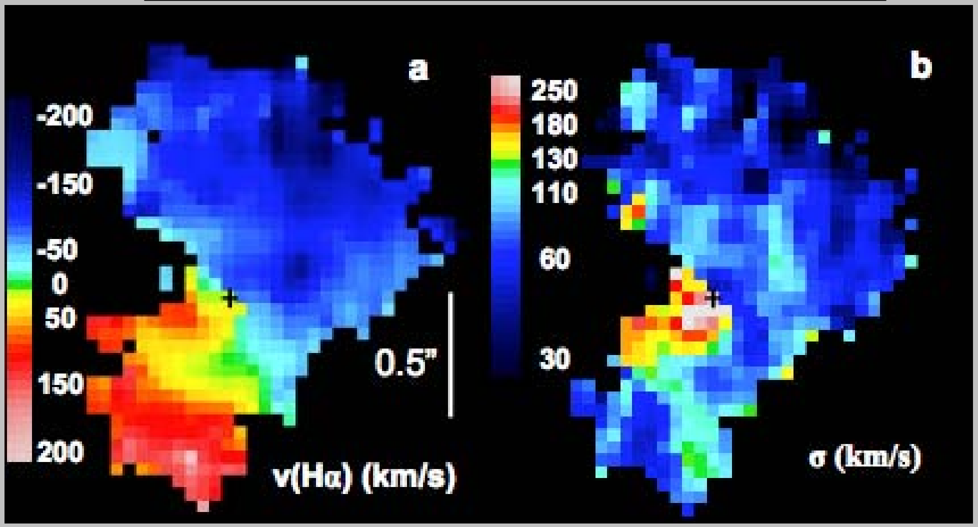


Gas Rich Mergers: the Solution?

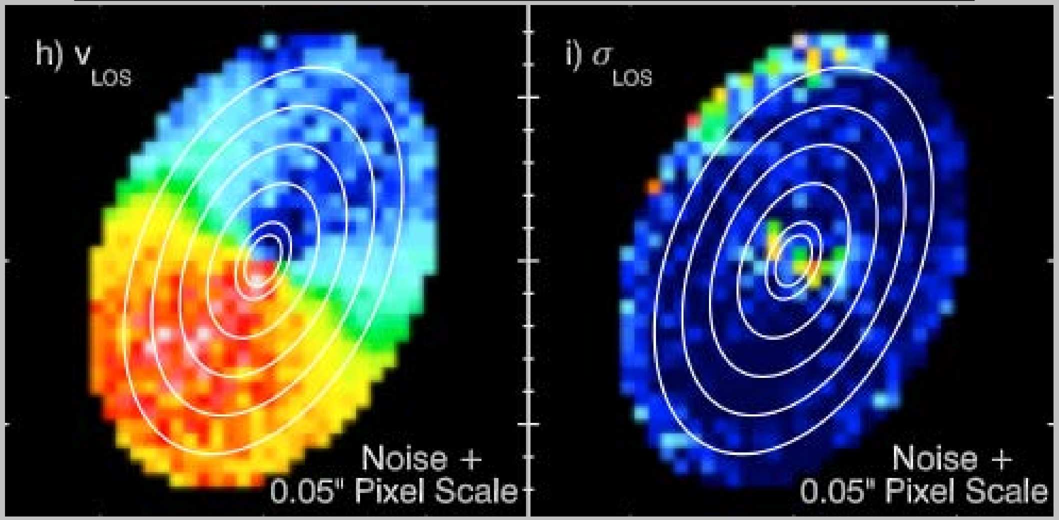
- Gas rich minor mergers help form rotationally supported gaseous disk galaxies.
- Given a sufficiently high gas fraction (f_{gas}> 50%), even major mergers (3:1) quickly reform into a disk.
  (Springel & Hernquist ‘05, Robertson et al. ’06, Hopkins et al. ‘08)

Example: Observed disk galaxy at z~2 resembles simulated gas-rich merger remnant:

Observation (Genzel et al. ’06)



Simulation (Robertson & Bullock ’08)



The baryonic assembly of galaxies via mergers

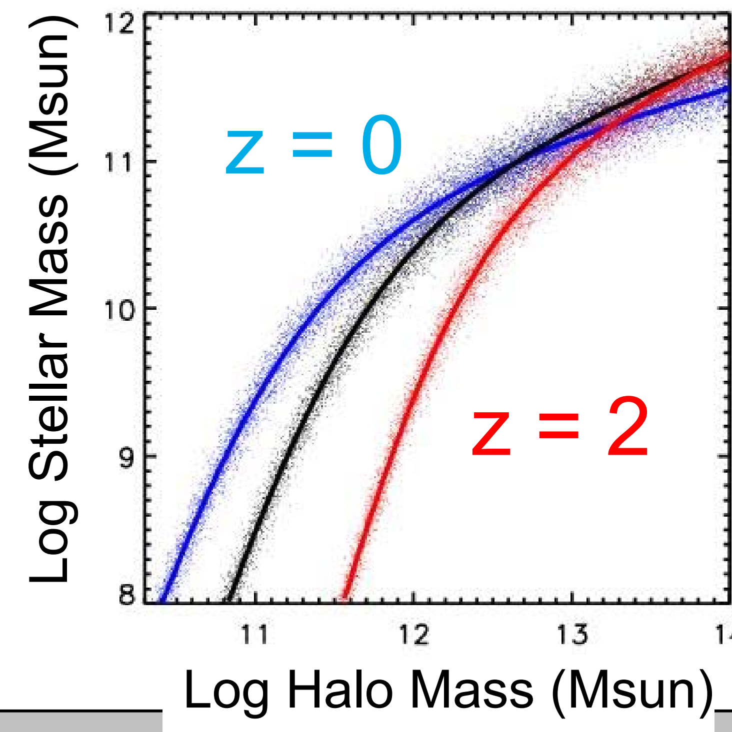
Stewart et al. 09 (in prep)

1. DM halo merger trees
2. Empirical Stellar Mass -- Halo Mass relation (Conroy & Wechsler 2008)
3. Empirical Gas Mass -- Stellar Mass relation (e.g. McGaugh 2005; Erb et al. 2006)

Step 2: Stellar Masses.

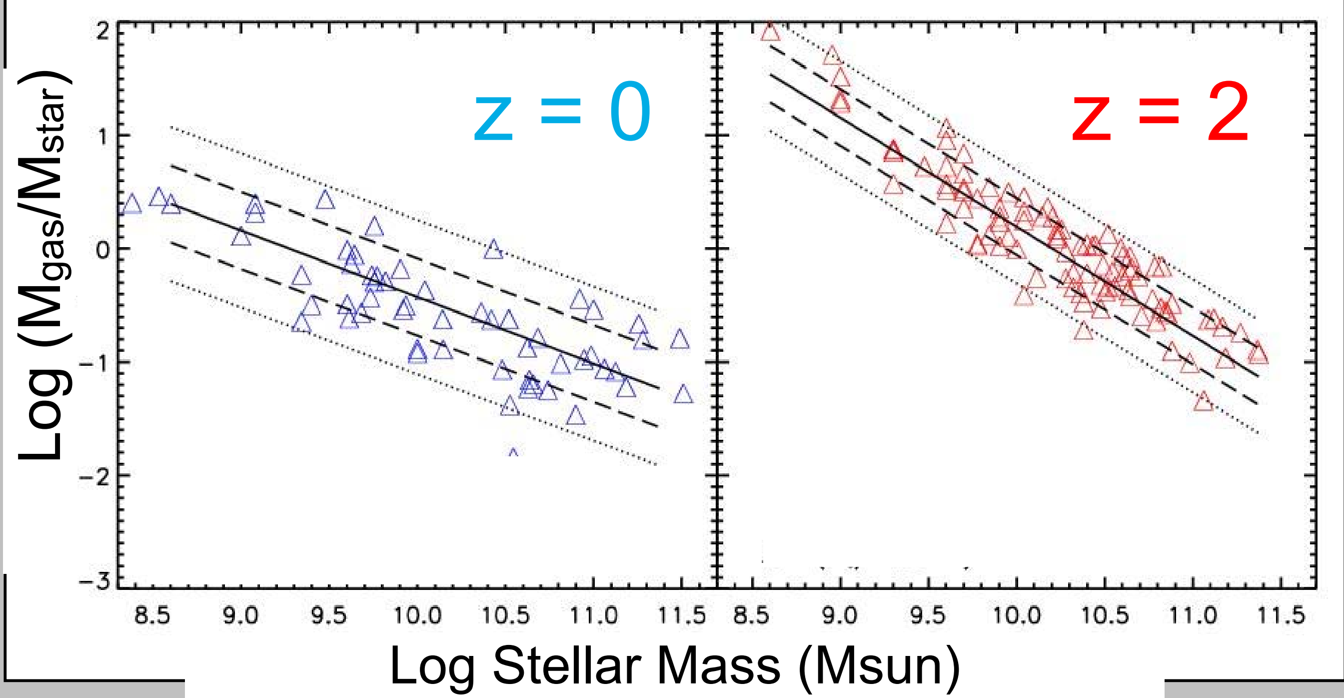
- Use number density matching to statistically assign an average stellar mass, given DM mass (and redshift). (data from Conroy & Wechsler 2008.)

- Conroy & Wechsler 2008



Step 3: Gas Masses.

- Use observations of galaxies at z=0 (e.g. McGaugh '05) and z~2 (Erb et al. '06) to estimate M_{gas}, given M_{star} , z (out to z=2).



Merger Fraction revisited:
(> 1/3 mergers that hit the disk)

- Seems problematic…

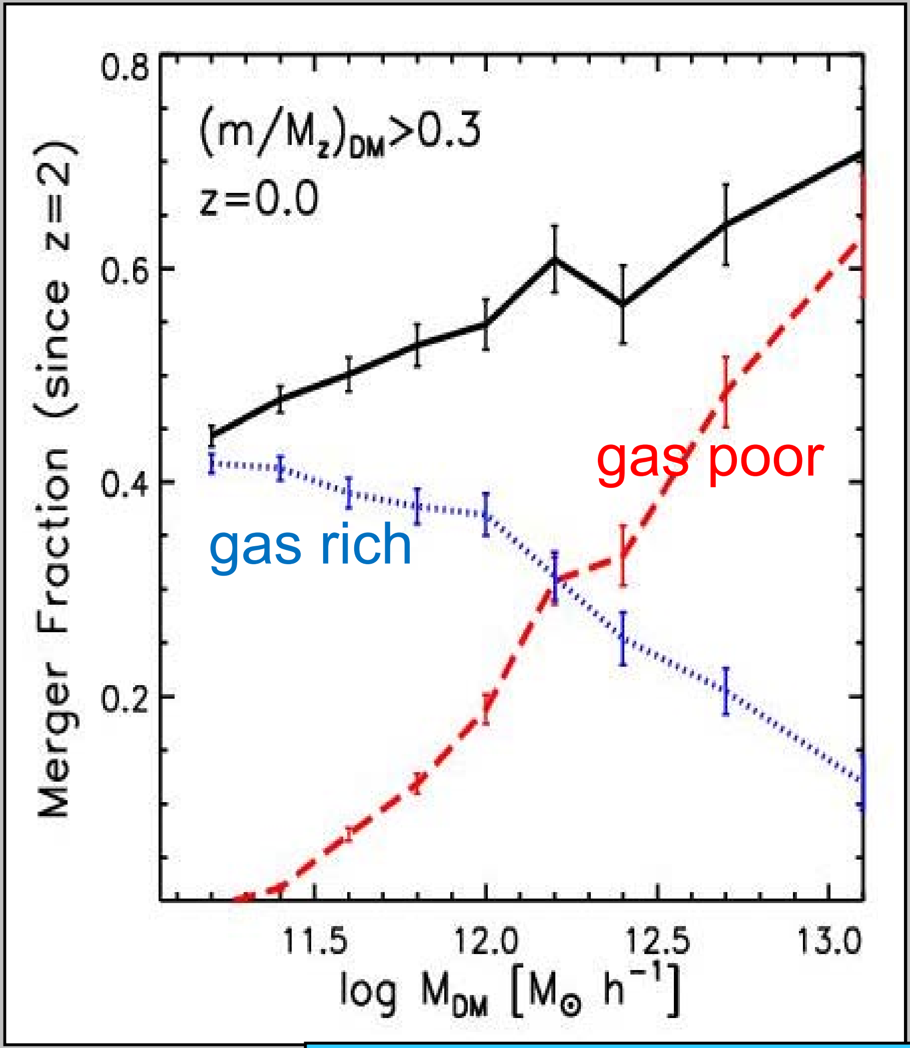
But what if we only look at gas rich* vs. gas poor* mergers?

Small halos → gas rich mergers

Large halos → gas poor mergers

May explain disk survival?

(e.g. Robertson et al. '06)

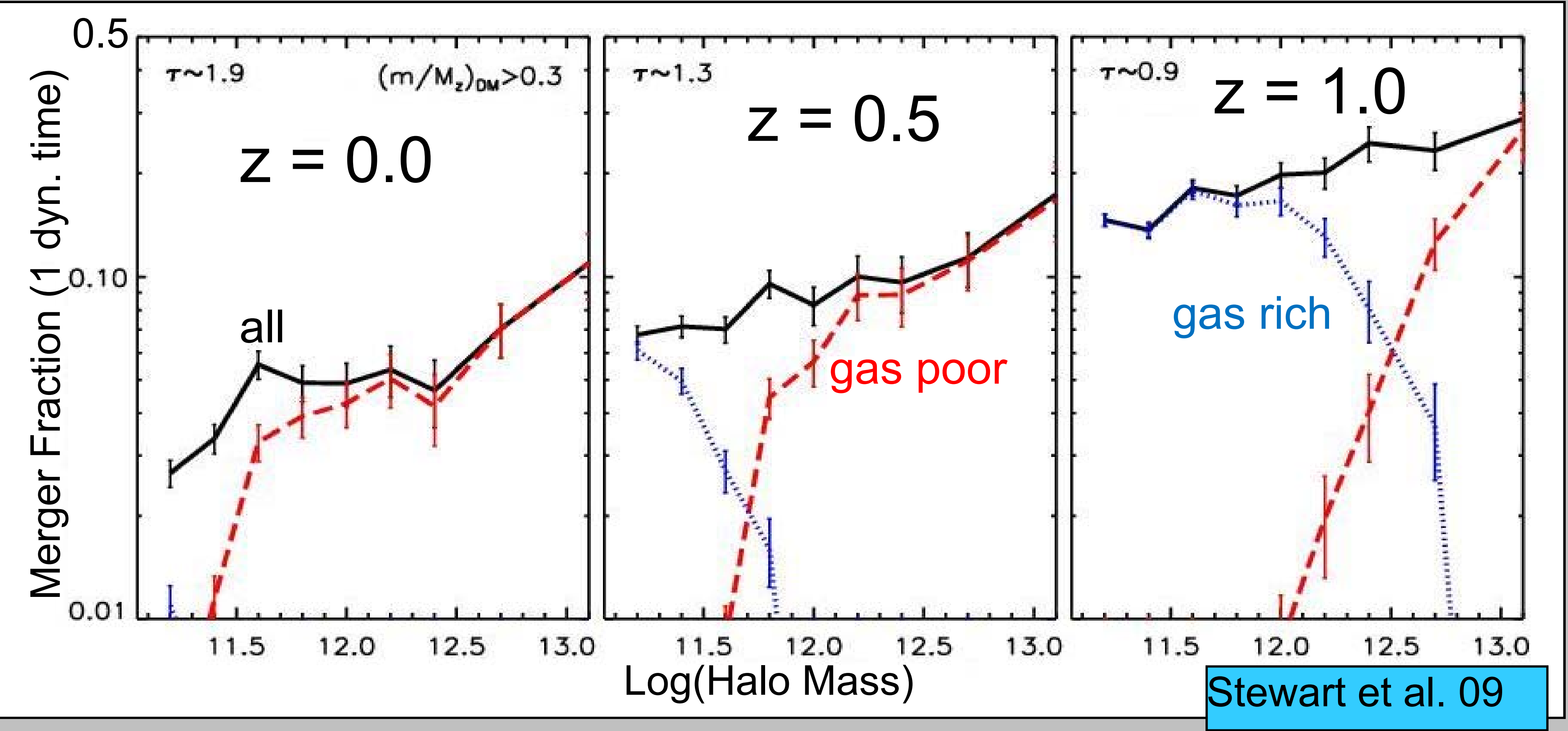


Stewart et al. 09 (in prep)

* Definitions:

- "Gas Poor" : both galaxies with gas fraction < 50%
- "Gas Rich" : both galaxies with gas fraction > 50%

Gas Rich/Poor Merger Fractions vs. z



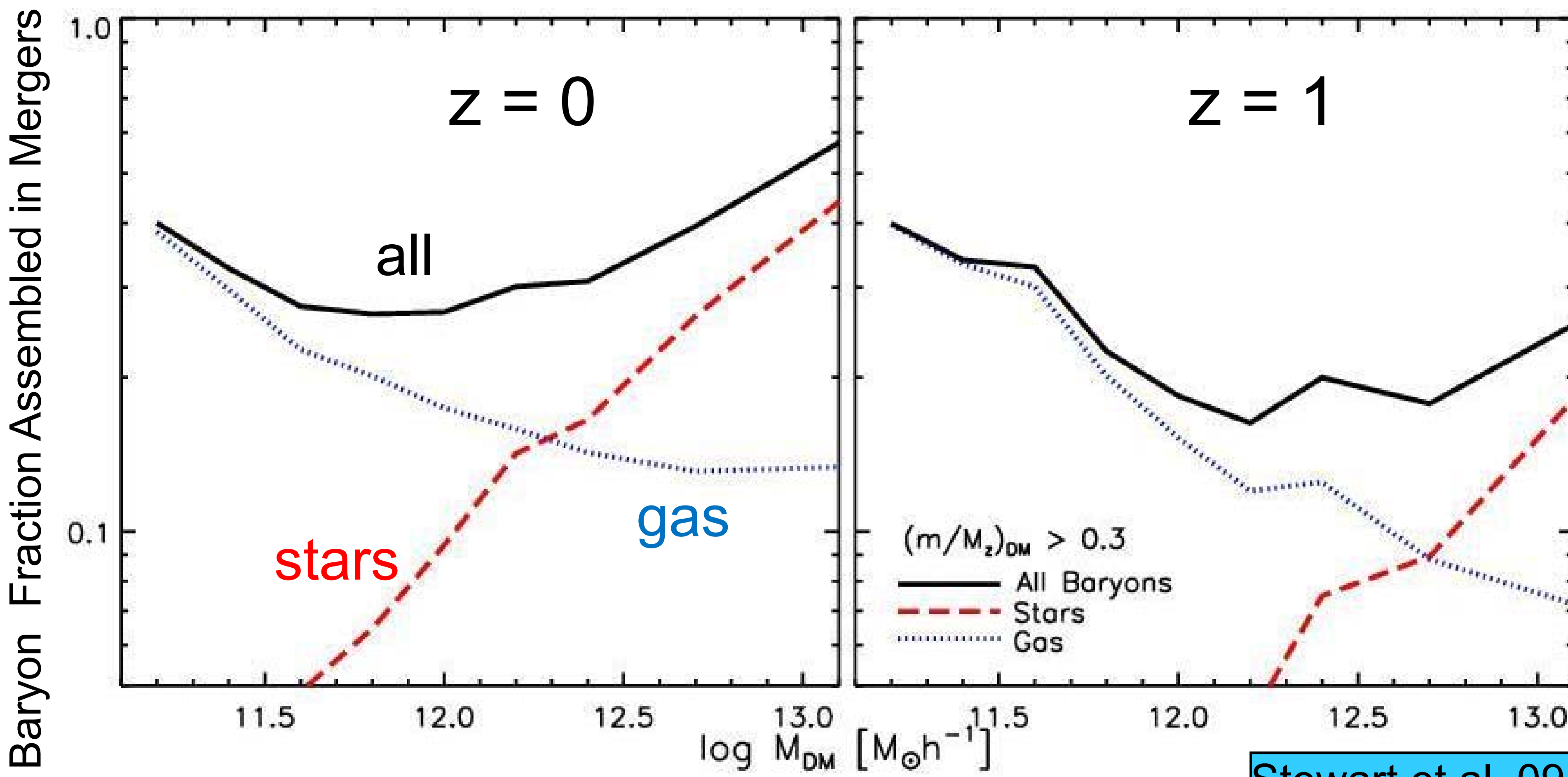
Note transition mass above/below which gas rich/poor mergers dominate. (~$10^{11.2}$, z=0 ; ~$10^{11.6}$, z=0.5 ; ~$10^{12.7}$, z=1)

Gas rich mergers at high redshift → "cold flows" ?

Baryonic Mass Assembly

How do galaxies get their mass (in mergers)?

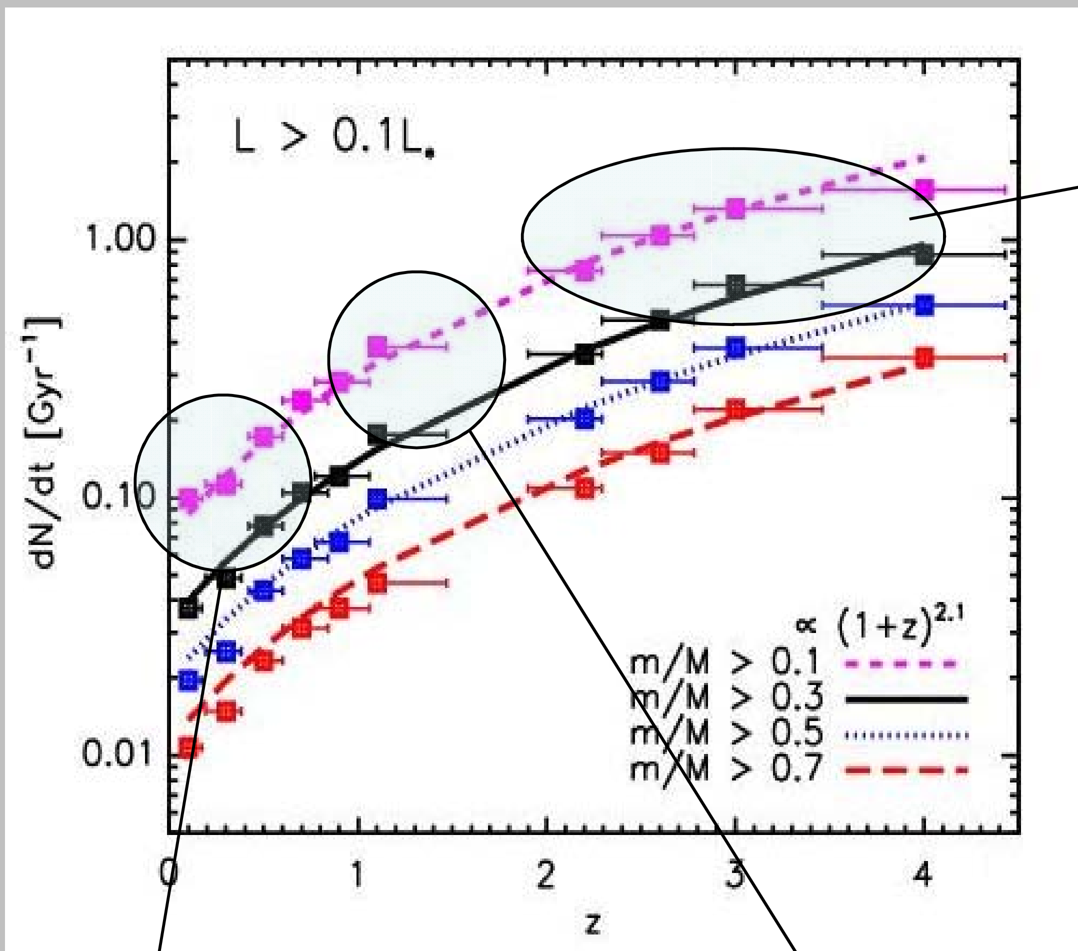
- **~30% of cold baryons in MW-mass galaxies accreted directly in >1:3 mergers since z~2 (~20% gas, ~10% stars)**



Stewart et al. 09

- Consider the DM merger rate for a >0.1 L* galaxy-halo:

Summary:



Merger rate high, but nearly ALL of them are **very** gas rich.

May explain assembly of massive, gas-rich disk galaxies at z~2.

(Robertson & Bullock 2008)

Merger rate low.

Mergers gas poor (destroys disks)

Merger rate increasing.

So is the gas rich merger fraction.

Conclusions:

1. Merger fractions agree to first order with observed “morphologically disturbed” fractions, but a detailed comparison depends on uncertain merger timescales.

2. Disks **must** be able to survive **some** major mergers to explain the observed disk fractions for MW-size halos.

3. If gas rich (f_{gas}>50%) major mergers **do** result in disk-dominated galaxies, gas rich/poor merger histories seem promising for disk survival. (Explains mass-morph. relation?) eg. Nearly all mergers into MW-size halos are gas rich at z>1.

4. 20% of baryons in ~L* galaxies are accreted **as gas** (10% as stars) via >1:3 mergers (since z~2) → empirically motivated “cold flows.”