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

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Based on Stewart et al. 2008 (arxiv.org/abs/0711.5027) , Stewart et al. 2008b, c (both in prep)

Outline

- Introduction
- Universal Merger Rate
- 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:

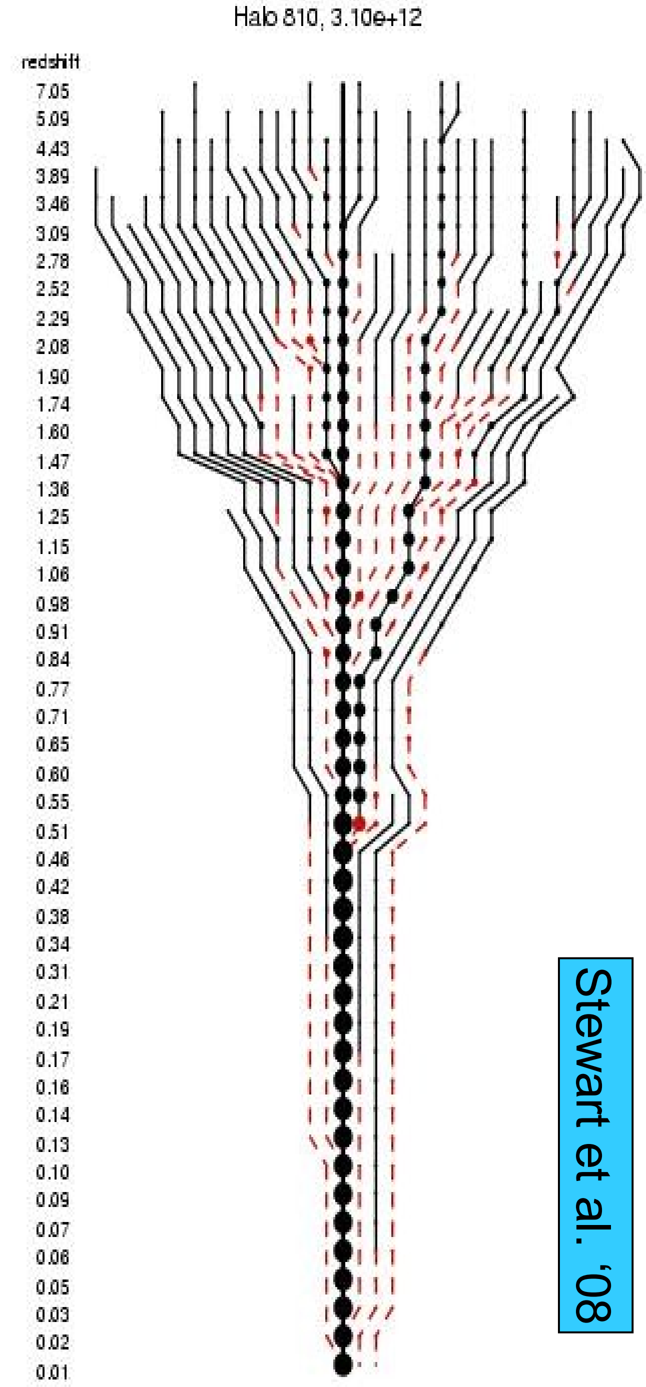
- Dark Matter Halos form by mergers.
- Major mergers turn disk-type galaxies into thick, flared, more bulgy systems. (eg. Mihos & Hernquist ‘94, Kazantzidis et al. ‘07, ‘08; Purcell et al. ’08b)
  - And Yet: Majority of Milky-Way sized DM halos contain thin disk-dominated galaxies (z=0). (eg. Weinmann et al. ‘06; Choi et al. ‘07; Park et al. ‘07; Ilbert et al. ‘06.)
- Merger Rate increases with redshift.
  - And Yet: Large 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, $\boldsymbol{\sigma_8}$=0.9, 512^3 particles
- $m_p = 3.16 \times 10^8\ h^{-1}M_\odot$ (better resolution than Millennium.)
- **A**daptive **R**efinement **T**ree code. 512^3 cells, refined to max. of 8 levels. $h_{\mathbf{peak}}$ ~ 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 $10^{10}\ h^{-1}M_\odot$

See, eg. Stewart et al. '08 (galaxy size halos)
Berrier, Stewart et al. '08 (cluster size halos)



Stewart et al. '08

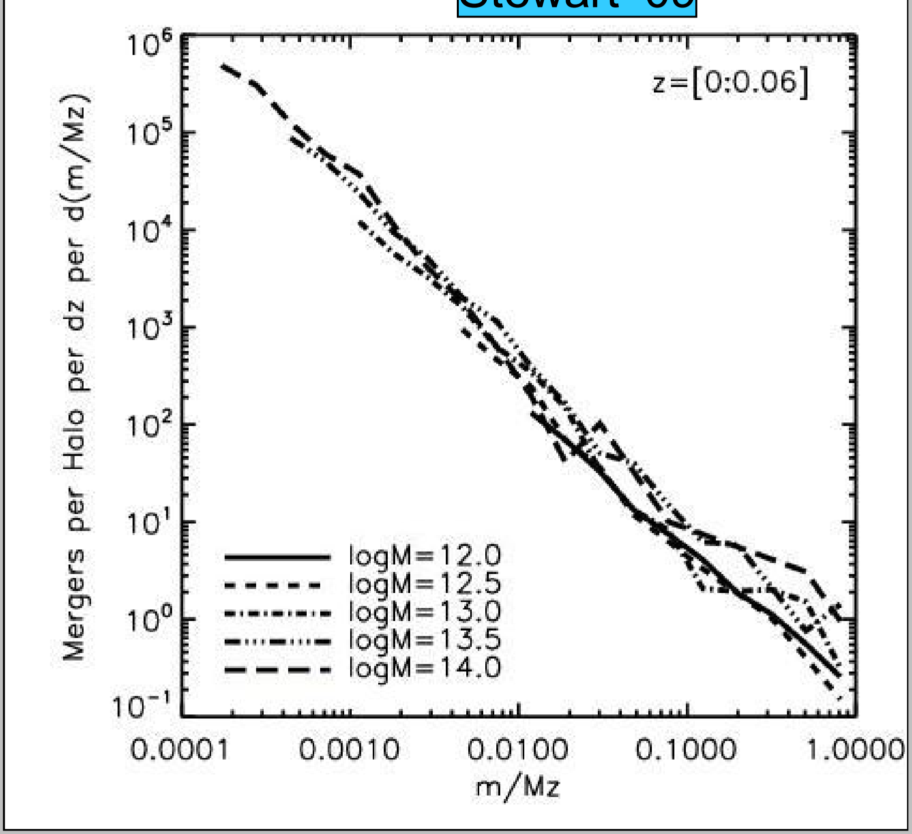
Universal Merger Rate

Stewart et al. (in prep)

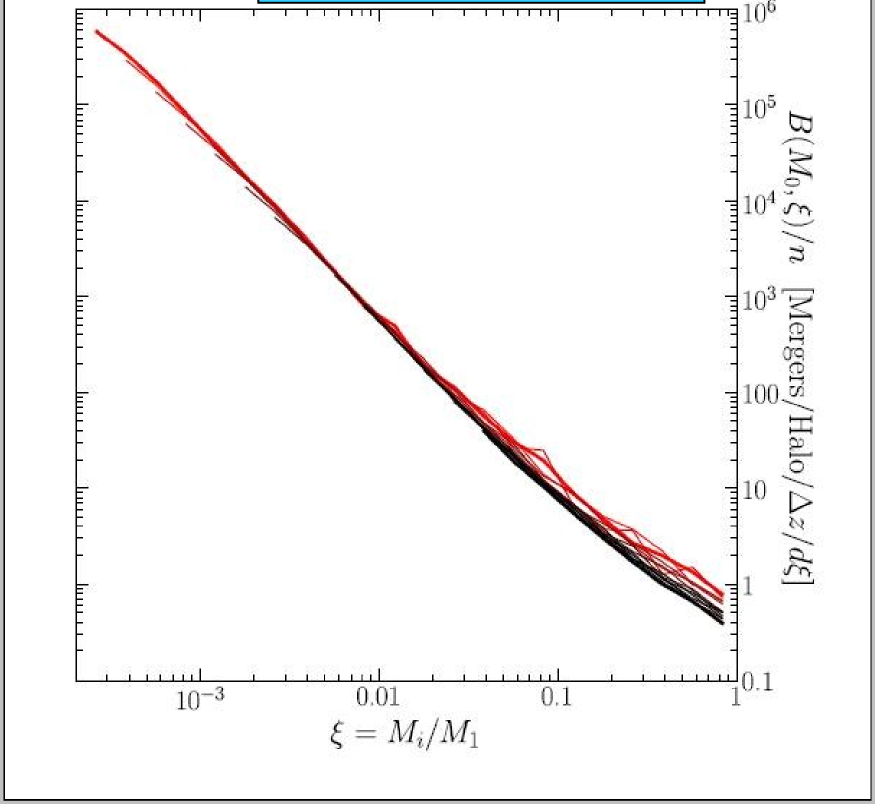
Fakhouri & Ma DM Merger Rate

- There appears to be a fairly universal merger rate (FM08).
- To first order, we find the same result, despite different :
  1) simulations **2)** halo finding methods **3)** merger tree construction.

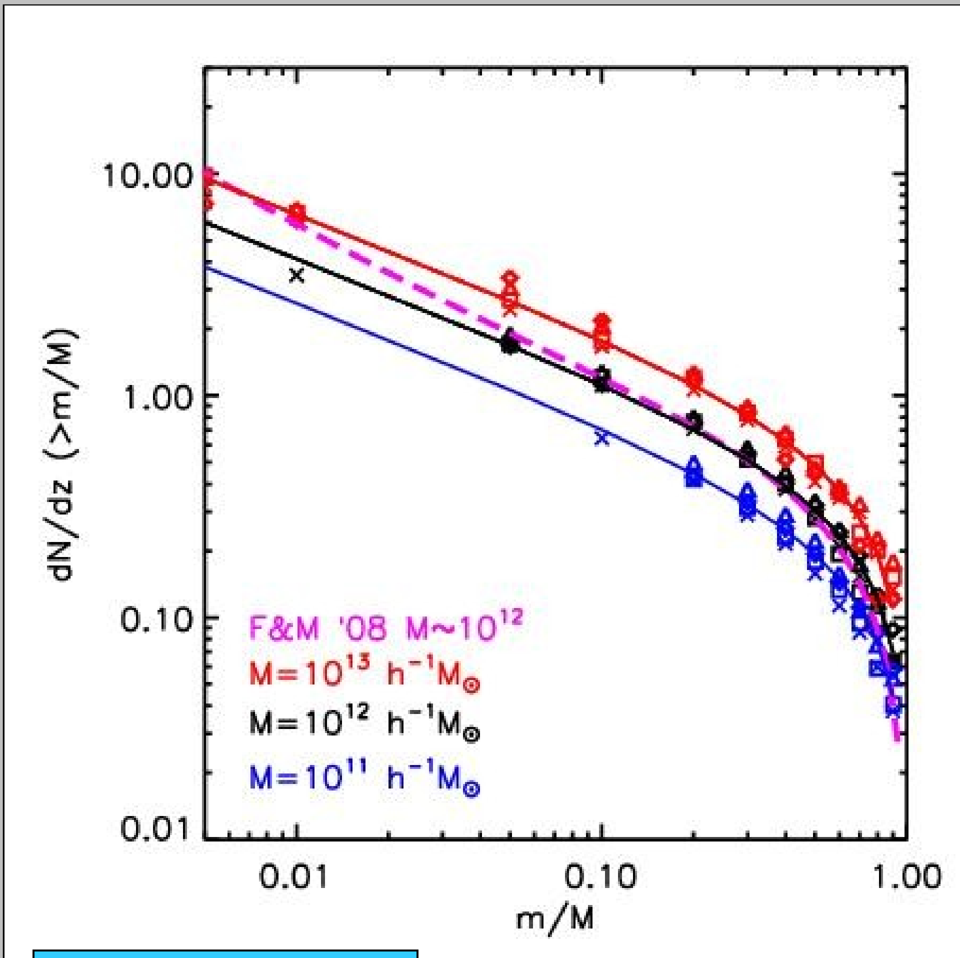
Stewart '09



Fakhouri & Ma 2008



Fakhouri & Ma Comparison



Stewart et al. ‘08b

Differences:

- Stronger mass dependence
- Note that we explore redshift evolution more directly.
- Emphasize higher mass ratios (1:10 – 1:1)

○ r > 0.7, we are ~ 2 times higher.

○ r < 0.01, we are ~ 2 times lower.

○ r ~ 0.1 (where it counts) both fits agree very well!

Fitting Function:

- Fit based on dN/dz, instead of d²N/dz d(m/M)

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

$$\frac{dN}{dt} \quad \frac{dN}{dz} \propto (1/r)^{0.54}(1-r)^{0.72}M^{0.2} \quad z)^{2.2}$$

Merger Rate evolution with z.

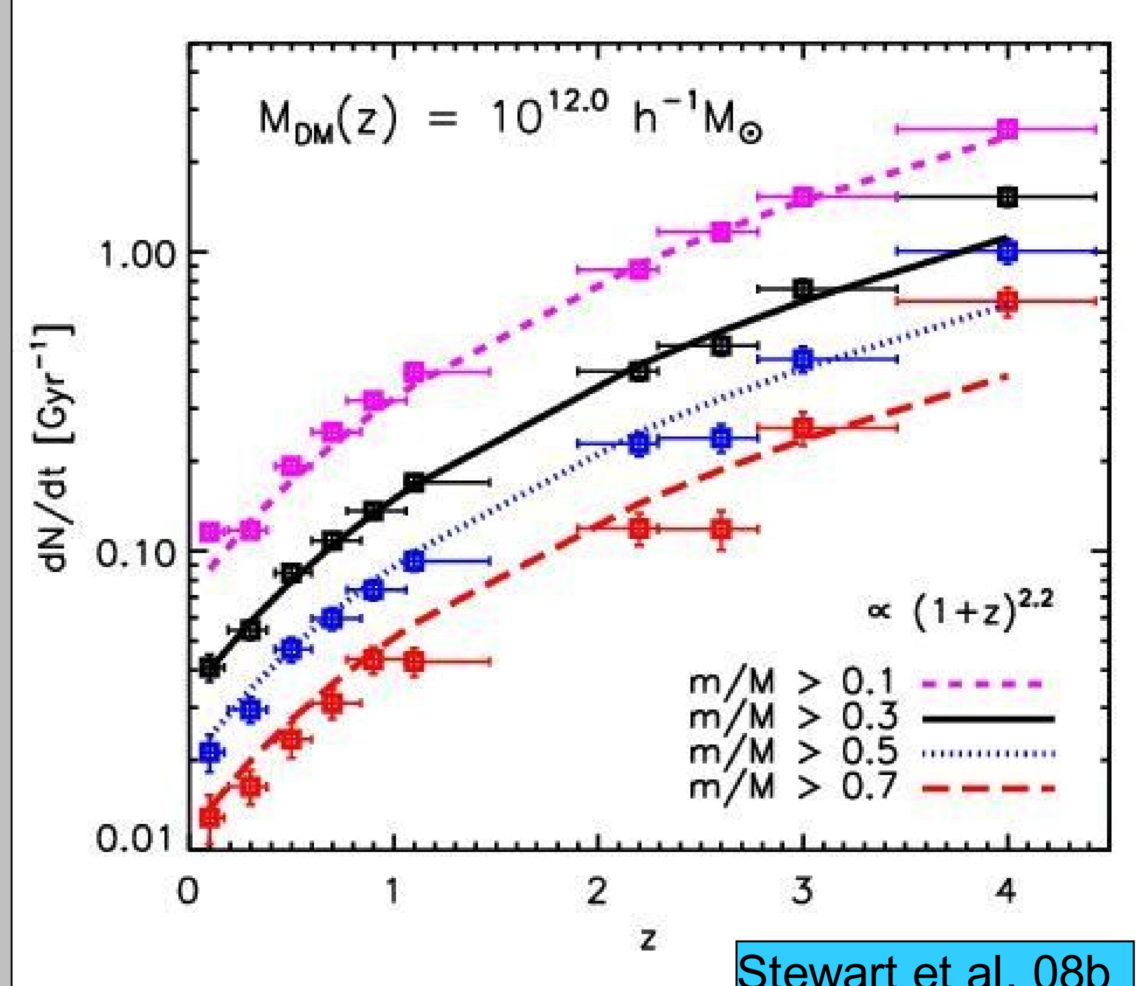
Stewart et al. 08b

dN/dt vs z :

(Number with merger larger than m/M)

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)

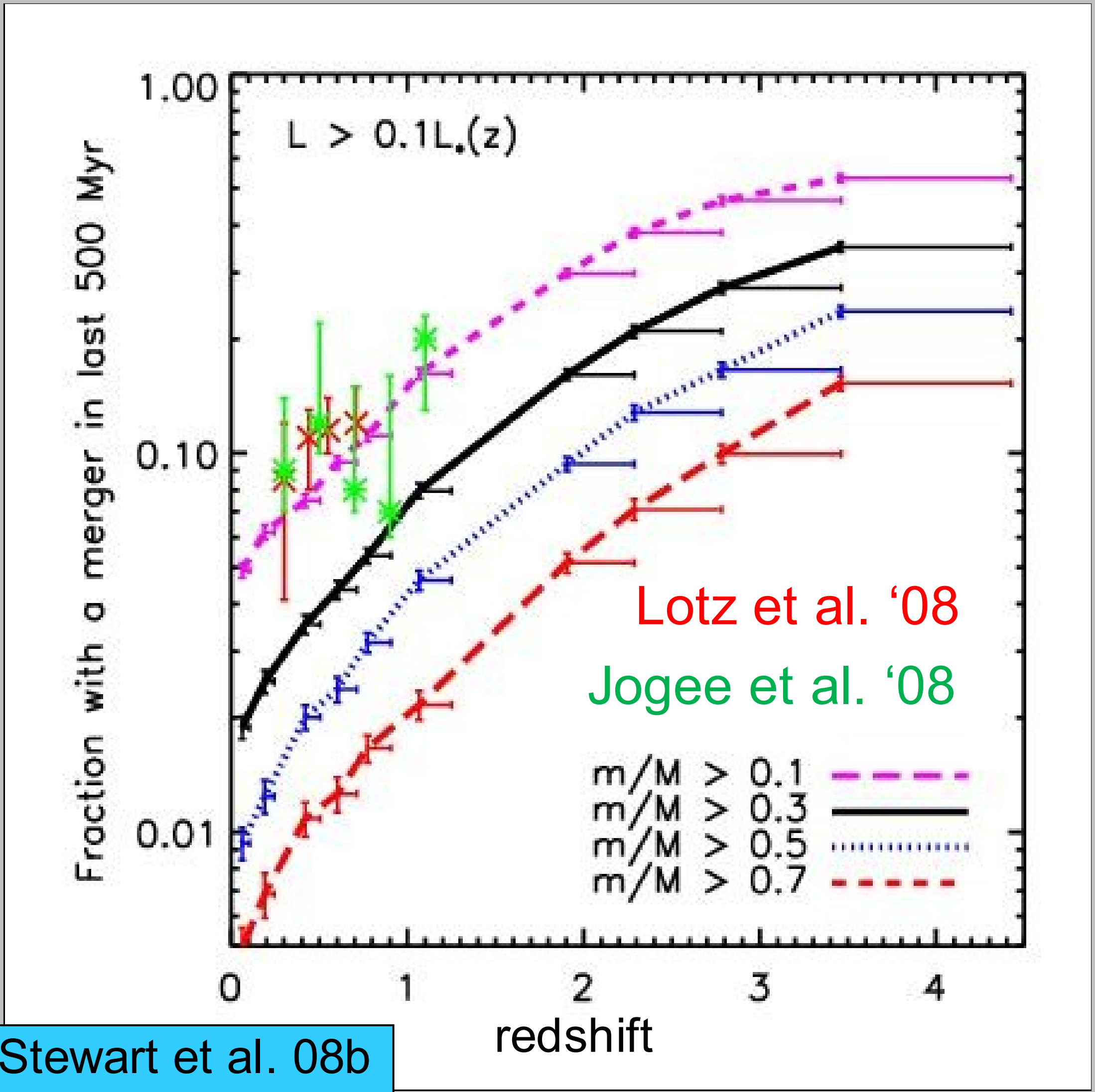


Stewart et al. 08b

$$\frac{dN}{dt} \propto \left(1/r\right)^{0.54}(1-r)^{0.72}M^{0.2}(1+z)^{2.2}$$

Merger Fraction in past 500 Myr*.

*Sometimes used as an estimated timescale for morphological disruption.



Stewart et al. 08b

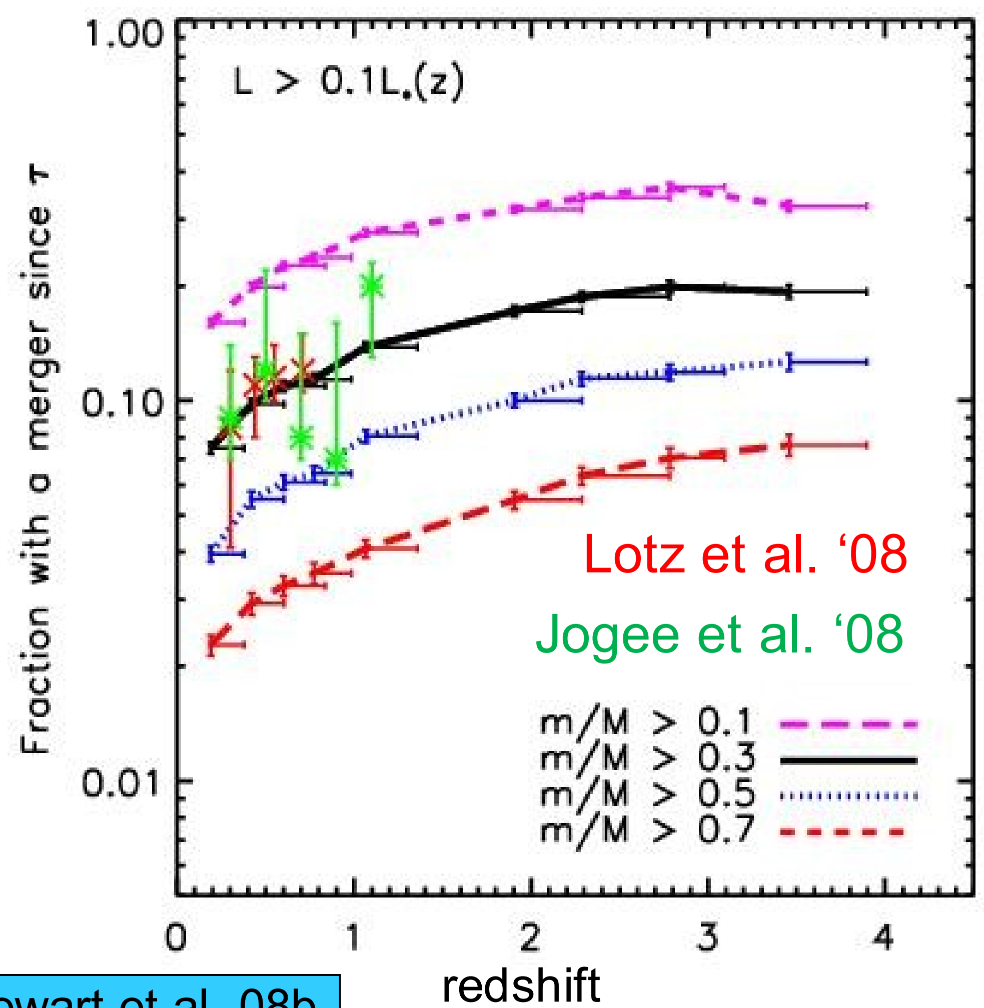
Use number density matching to associate halos with ~0.1L* galaxies from observed luminosity function (e.g. Faber et al. 07)

Agrees reasonably well 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 dyn. time.



Stewart et al. 08b

Use number density matching to associate halos with ~0.1L* galaxies from observed luminosity function (e.g. Faber et al. 07)

Agrees reasonably well with observations, for 1:3 major mergers.

Shows relatively flat redshift evolution.

Merger Histories versus Disk Survivability

Stewart et al. '08

Where does a halo's mass come from?

- Comparison to theoretical EPS predictions reasonably close to N-Body, considering mass definitions

$M \sim 0.1 * M_0$

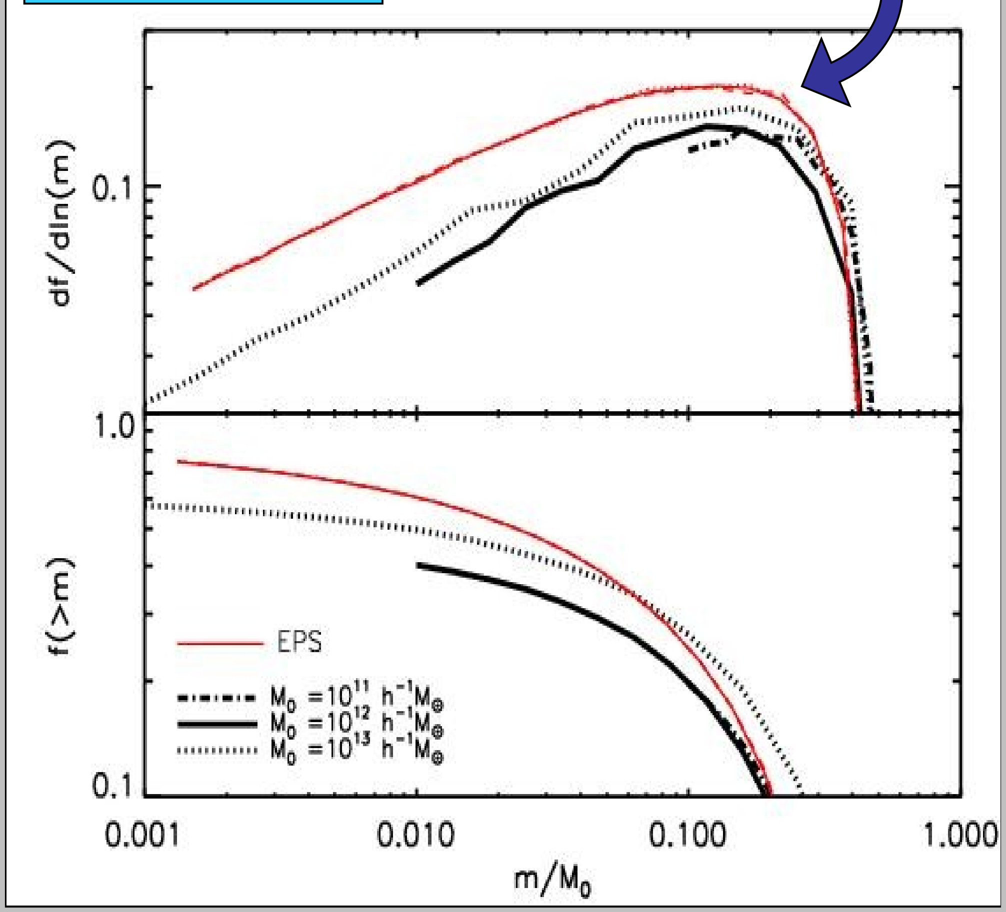
Stewart et al. '08

- Largest contribution to final halo mass comes from mergers with $m/M_0 \sim 10\%$

$10^{13}\ h^{-1}M_\odot$ halos built up from $\sim 10^{12}\ h^{-1}M_\odot$ mergers

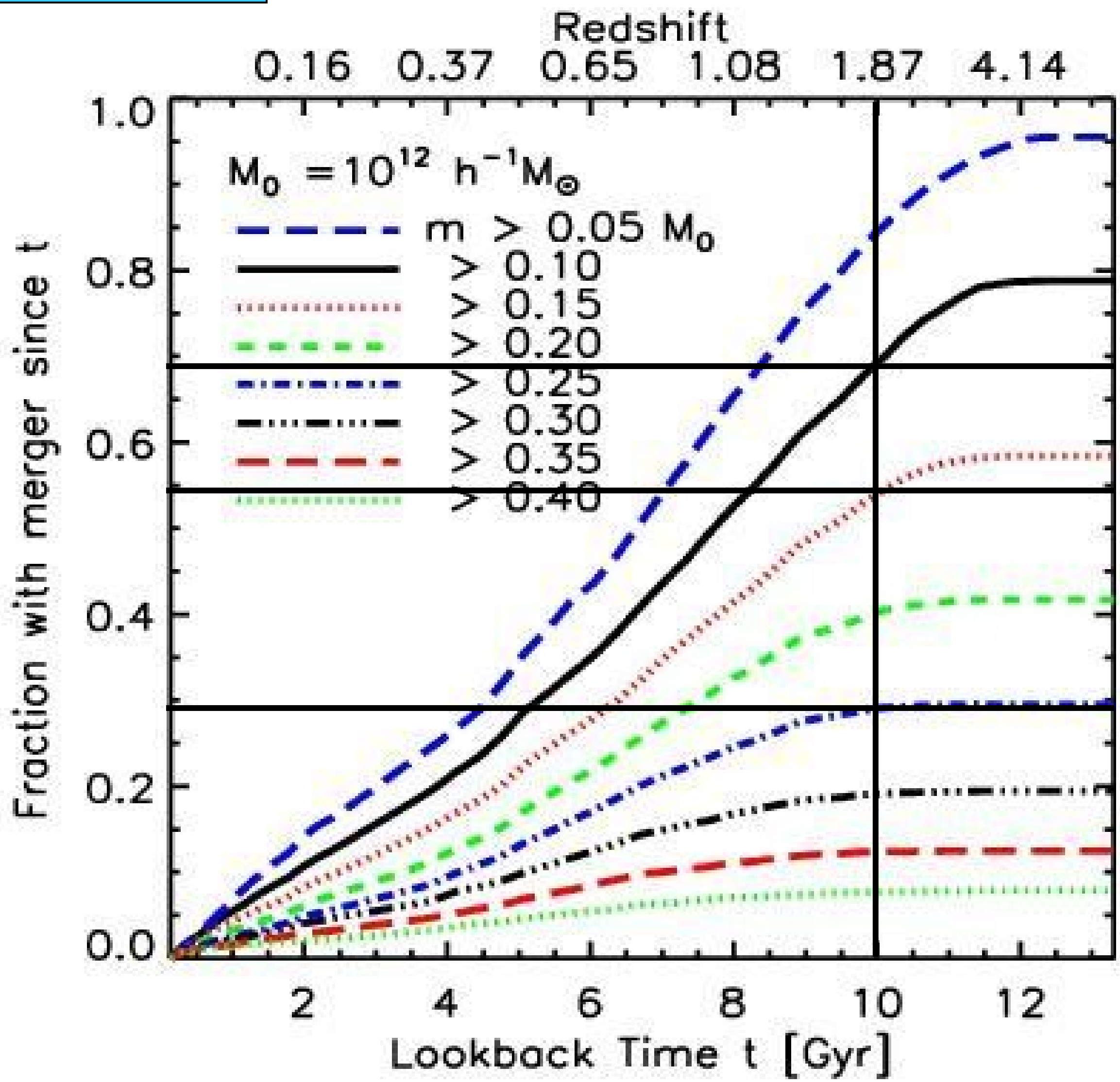
$10^{12}\ h^{-1}M_\odot$ halos built up from $\sim 10^{11}\ h^{-1}M_\odot$ mergers

$10^{11}\ h^{-1}M_\odot$ halos built up from $\sim 10^{10}\ h^{-1}M_\odot$ mergers



How often do mergers occur in $10^{12}h^{-1}M_\odot$ halos?

Stewart et al. '08



By strict mass cut, in last ~10 Gyrs :

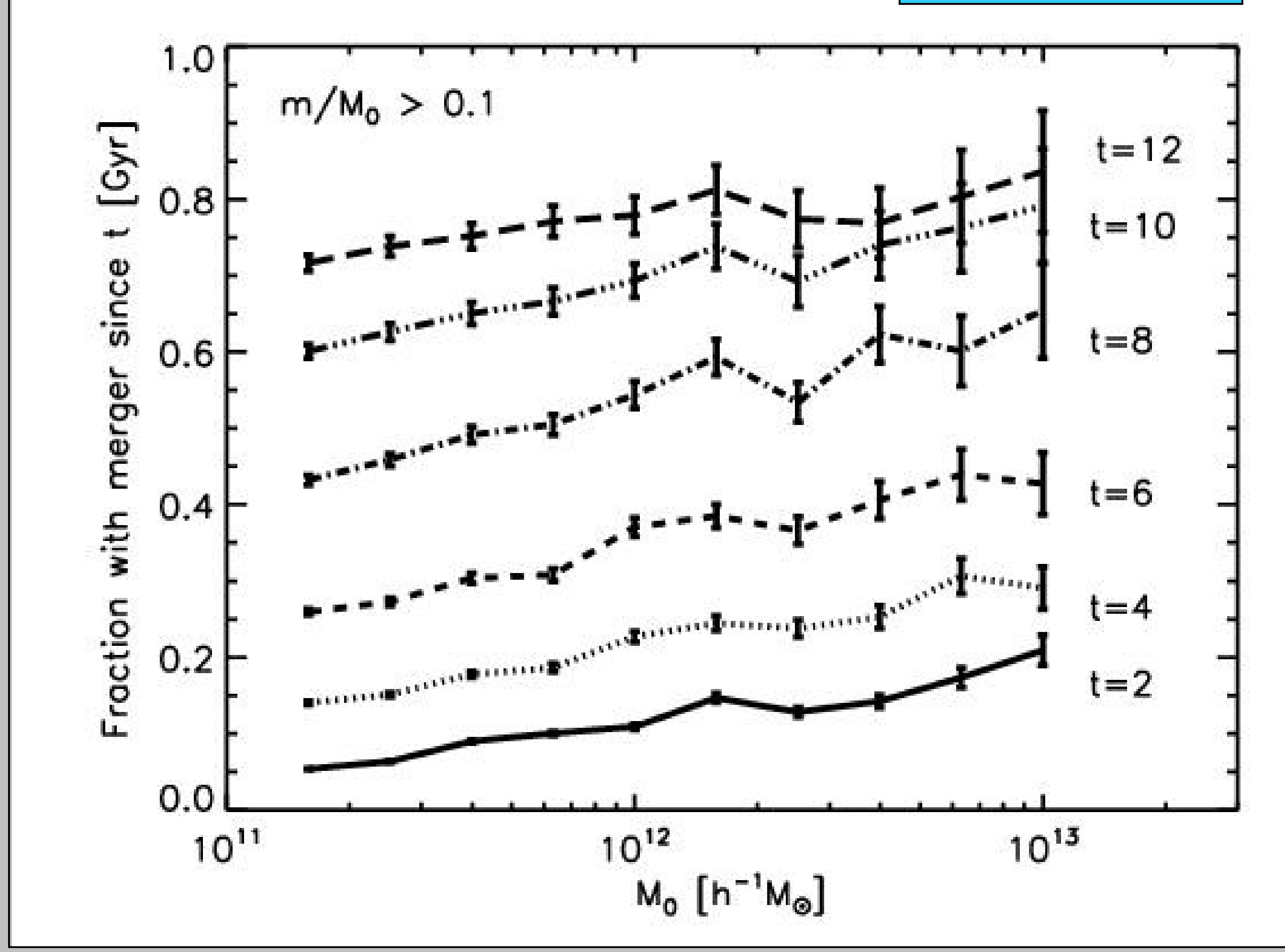
- ~ 70% of halos: m > 1.0×10^{11}
- ~ 50% of halos: m > 1.5×10^{11}
- ~ 30% of halos: m > 2.5×10^{11}

Is there a trend with mass? (from 10^{11}-10^{13})

1 word answer:
"Nope."

2 word answer:
"Only slightly."

Stewart et al. '08

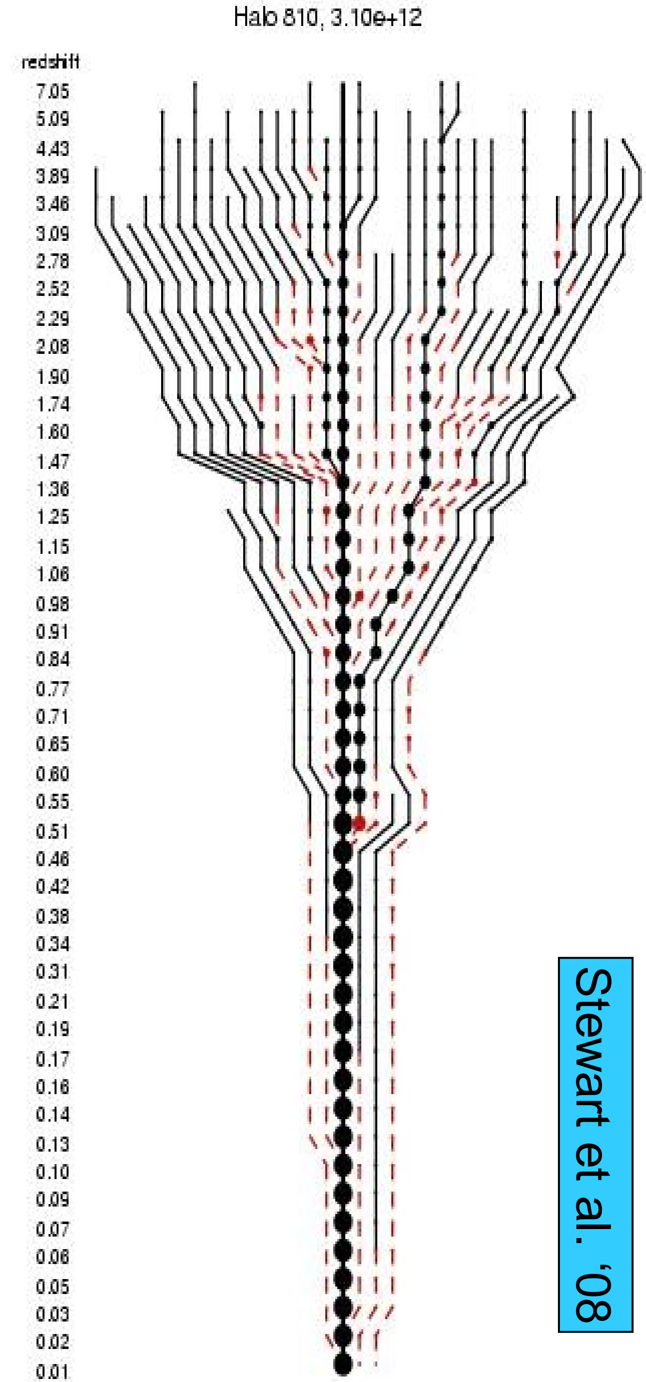


Section Sum-up :

~70% of Milky Way-sized halos have had a > $10^{11}\ h^{-1}M_\odot$ merger in the past 10 Gyr.

Since we presume that most Milky Way size halos are disk-dominated, these results imply that…

A $10^{11}\ h^{-1}M_\odot$ dark matter halo merger cannot destroy a typical Galactic disk, or we have a serious problem



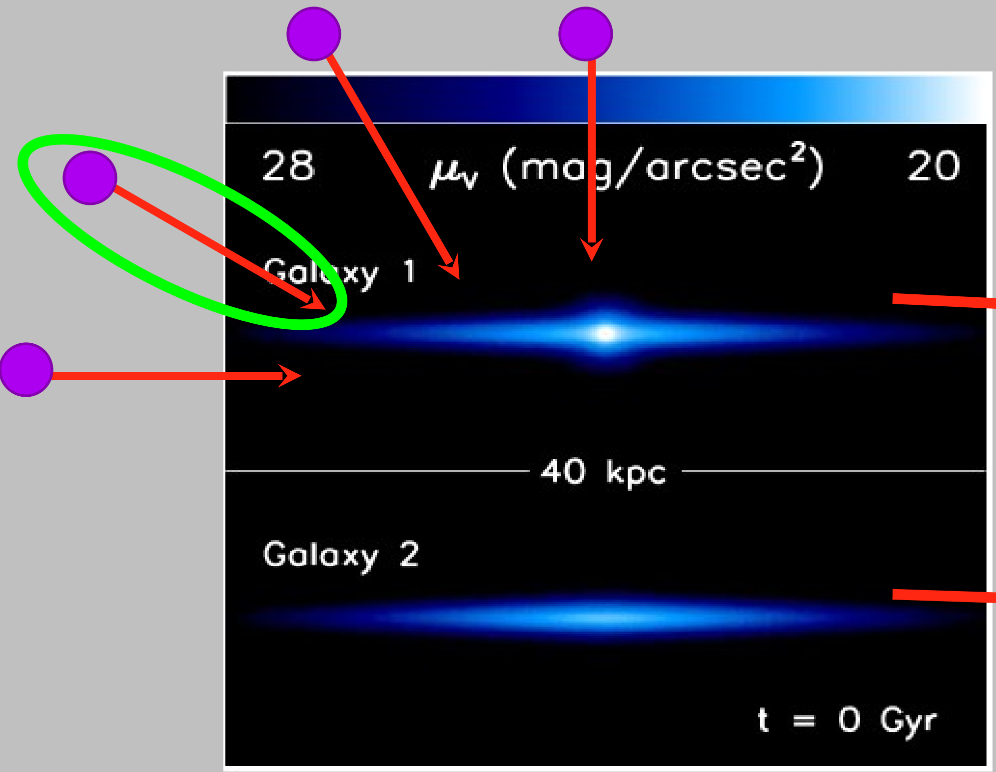
Stewart et al. '08

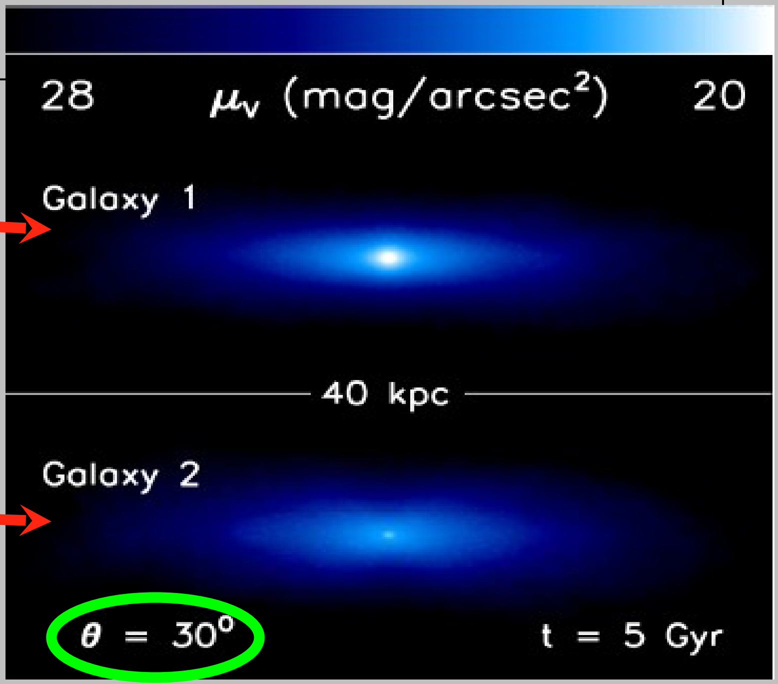
Purcell et al. '08b (in prep):

- Results:
- z_{thin}: 0.4 kpc → 1-2kpc
  (and creates z_{thick}= 4-6kpc)
- σ_{tot}: 50km/s → 70-120 km/s
  (MW is ~ 35-40 km/s)

Quick simulation facts:

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



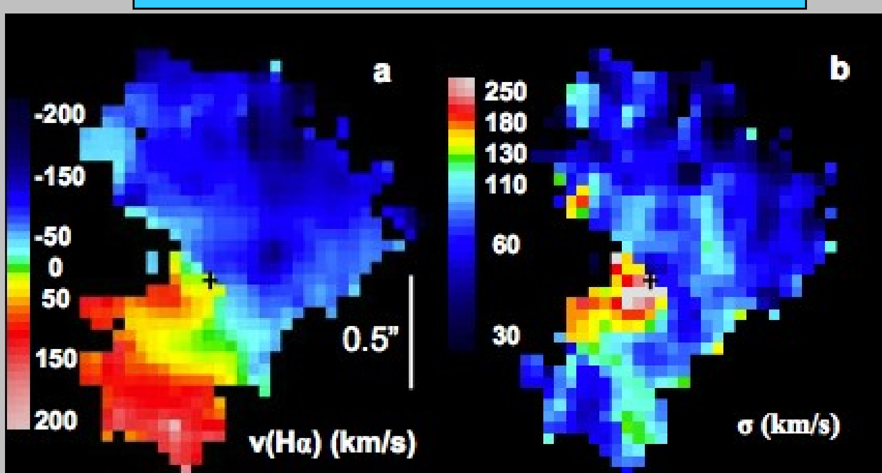


Gas Rich Mergers: the Solution?

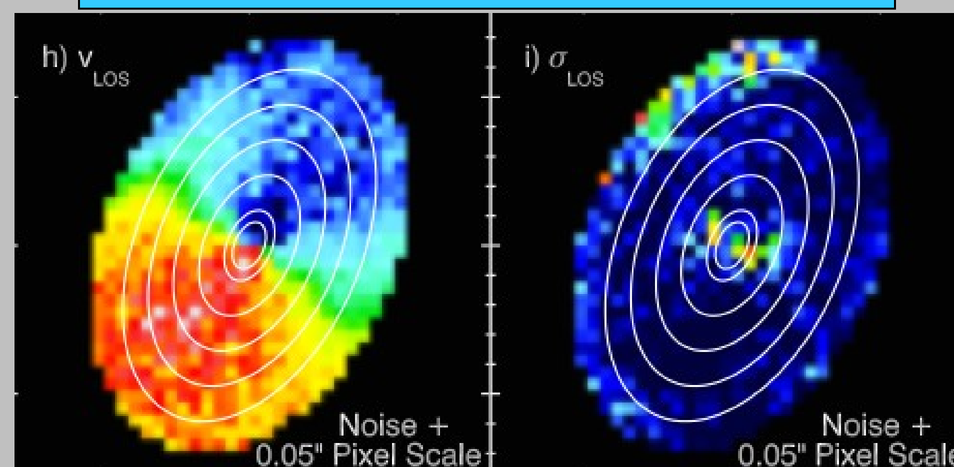
- Gas rich minor mergers help form rotationally supported gaseous disk galaxies.
- Given a sufficiently high gas fraction (f_{gas}> 50%), even major mergers (3:1) quickly reform into a disk.
(Robertson et al. ’06, Hopkins et al. ‘08)

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

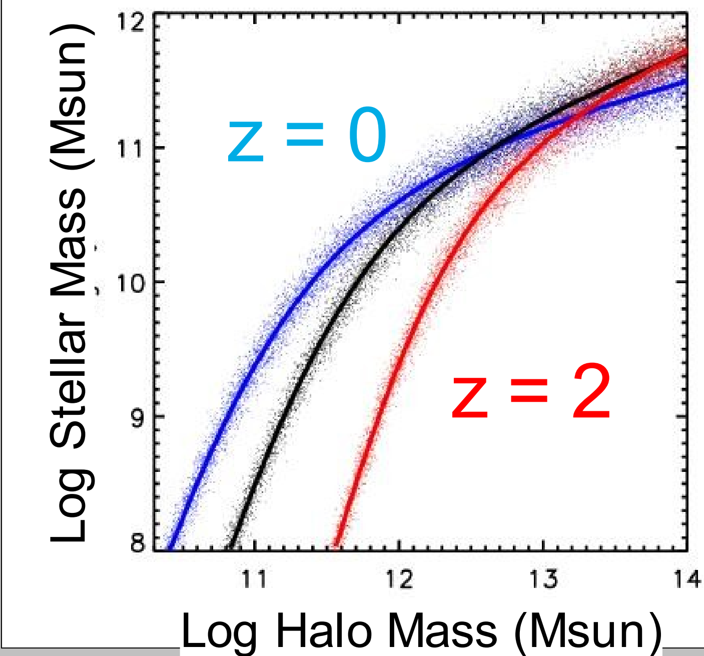
Stewart et al. 08c

- DM halo merger trees
- Empirical Stellar Mass -- Halo Mass relation (Conroy & Wechsler 2008)
- Empirical Gas Mass -- Stellar Mass relation (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.)

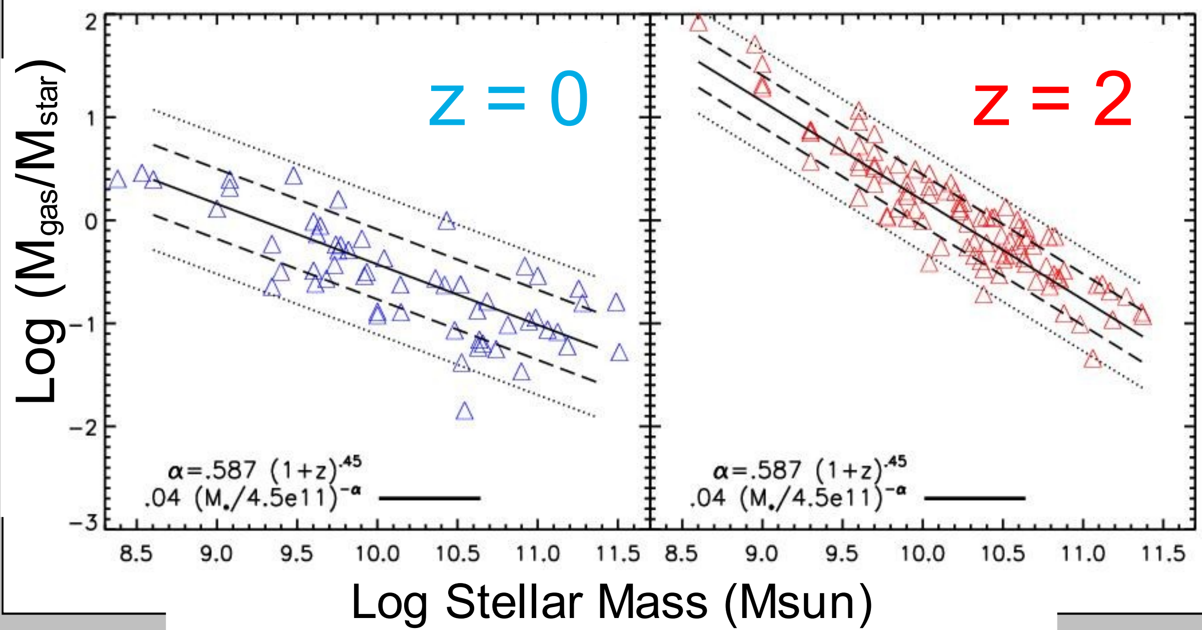
- Conroy & Wechsler 2008



Step 3: Gas Masses.

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

(See also Dutton '06)



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

- Seems problematic…

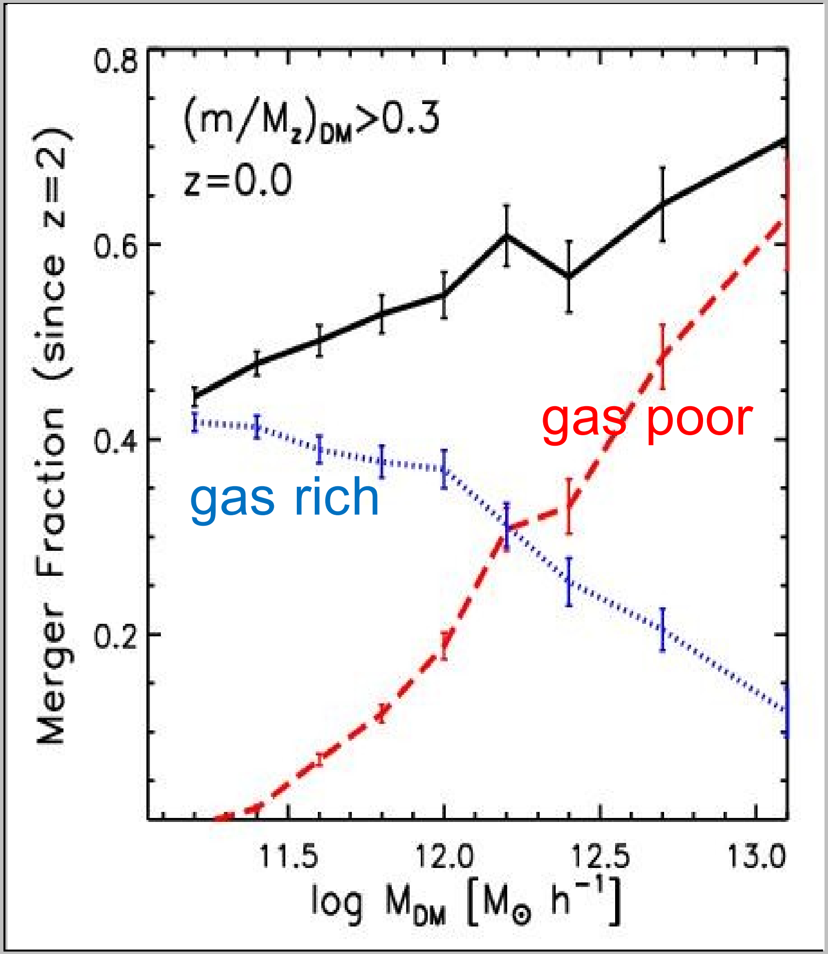
But what if we only look at gas rich* vs. gas poor* mergers?

Small halos → gas rich mergers

Large halos → gas poor mergers

May explain disk survival?

(Robertson et al. '06)

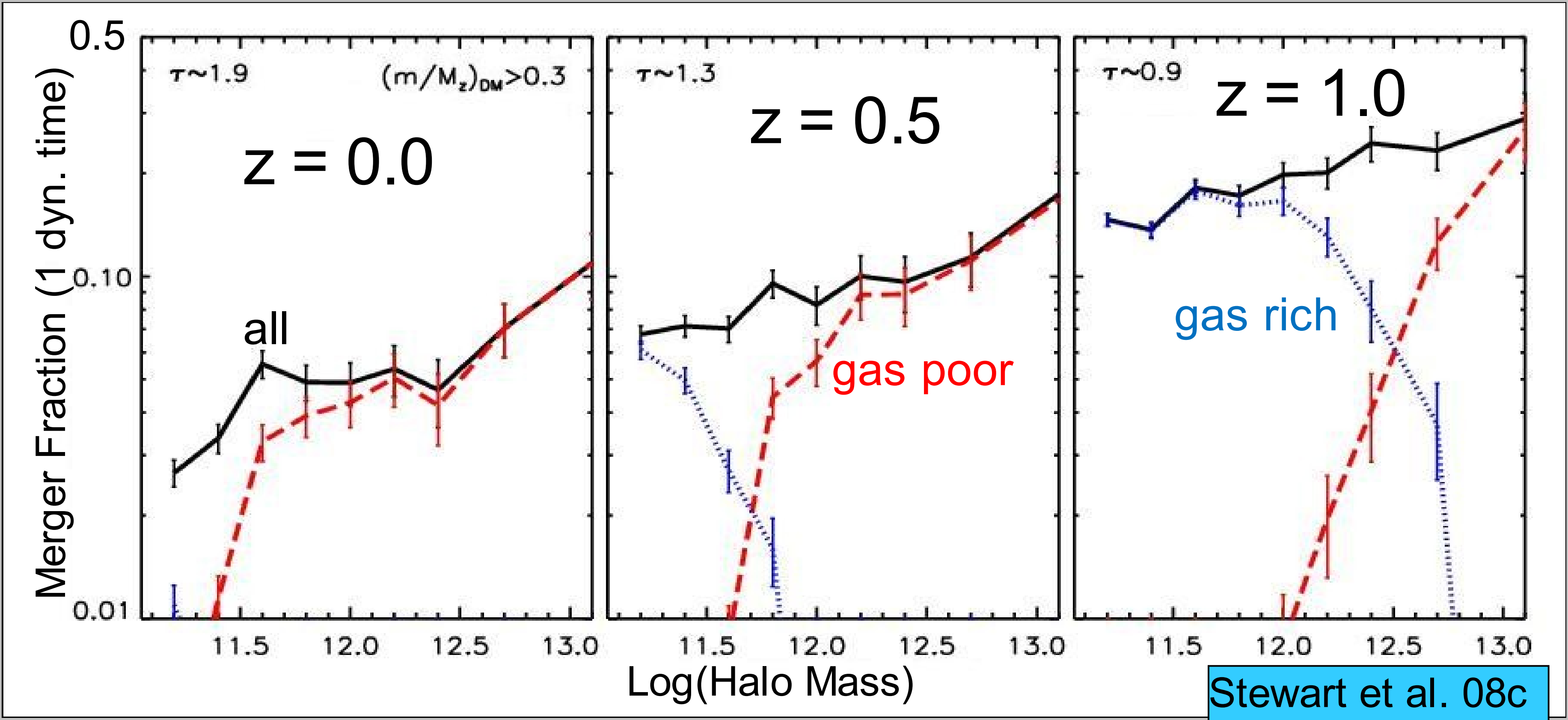


Stewart et al. 08c

* Definitions:

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

Gas Rich/Poor Merger Fractions vs. z



Stewart et al. 08c

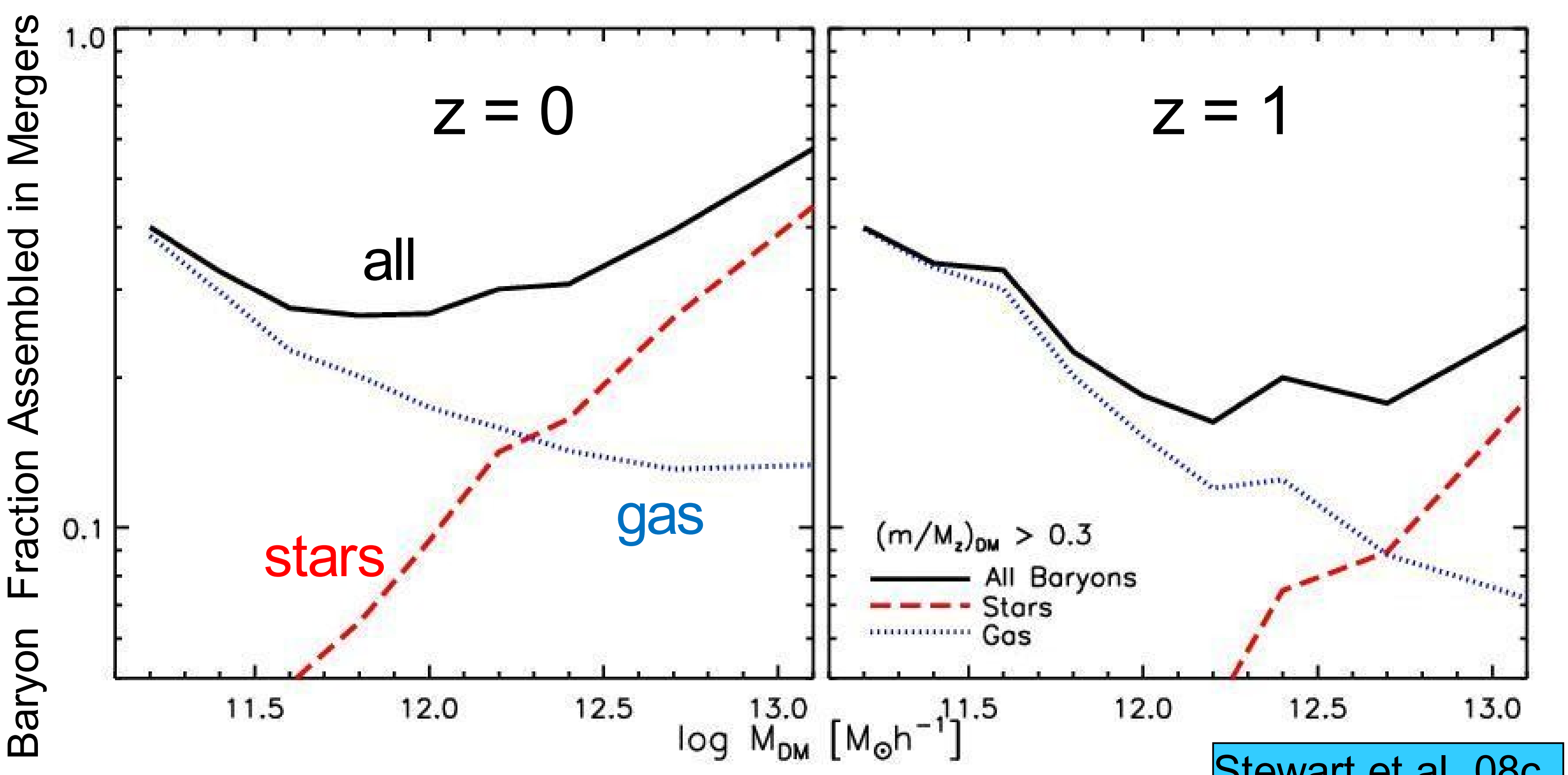
Note transition mass above/below which gas rich/poor mergers dominate. ($<10^{11.2}$, z=0 ; $\sim10^{11.6}$, z=0.5 ; $\sim10^{12.7}$, z=1)

Gas rich mergers at high redshift → “cold flows” ?

Baryonic Mass Assembly

How do galaxies get their mass (in mergers)?

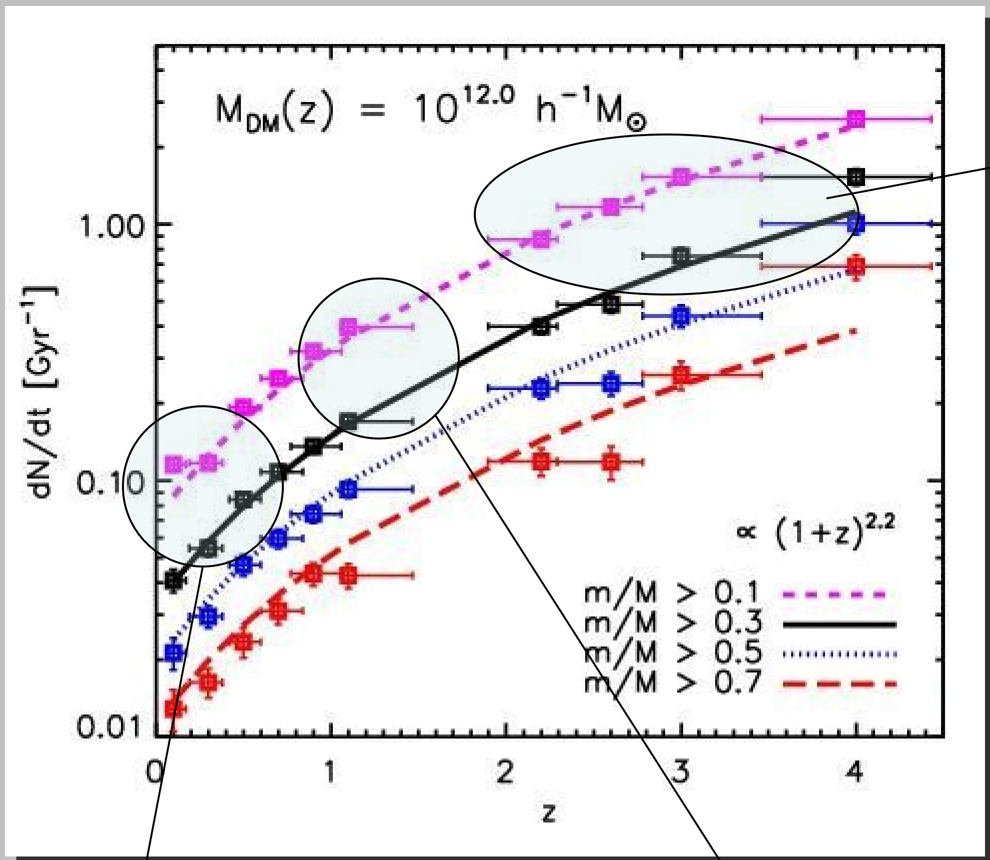
- **~30% of cold baryons in MW-mass galaxies accreted directly in >1:3 gas-rich mergers (since z~2)**



Stewart et al. 08c

- Consider the DM merger rate for a 10^{12} $M_\odot$ halo:

Section Sum-up :



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:

- Our simulation confirms the nearly universal merger rate of Fakhouri & Ma ’08 (to first order). However, there are 2nd order differences (eg. stronger Mass dependence). Given the differences in halo finding and methods, this is quite encouraging.

- Merger rate agrees fairly well with observed “morphologically disturbed” fractions, for first order estimates of merger timescale.

- Disks **must** be able to survive **some** major* mergers (*either merger ratio > 1:3, or m > 10^{11} $h^{-1}M_{\odot}$).

- 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.

- 30% of baryons in ~L* galaxies are accreted directly from >1:3 gas-rich mergers (since z~2) → empirically motivated “cold flows.”

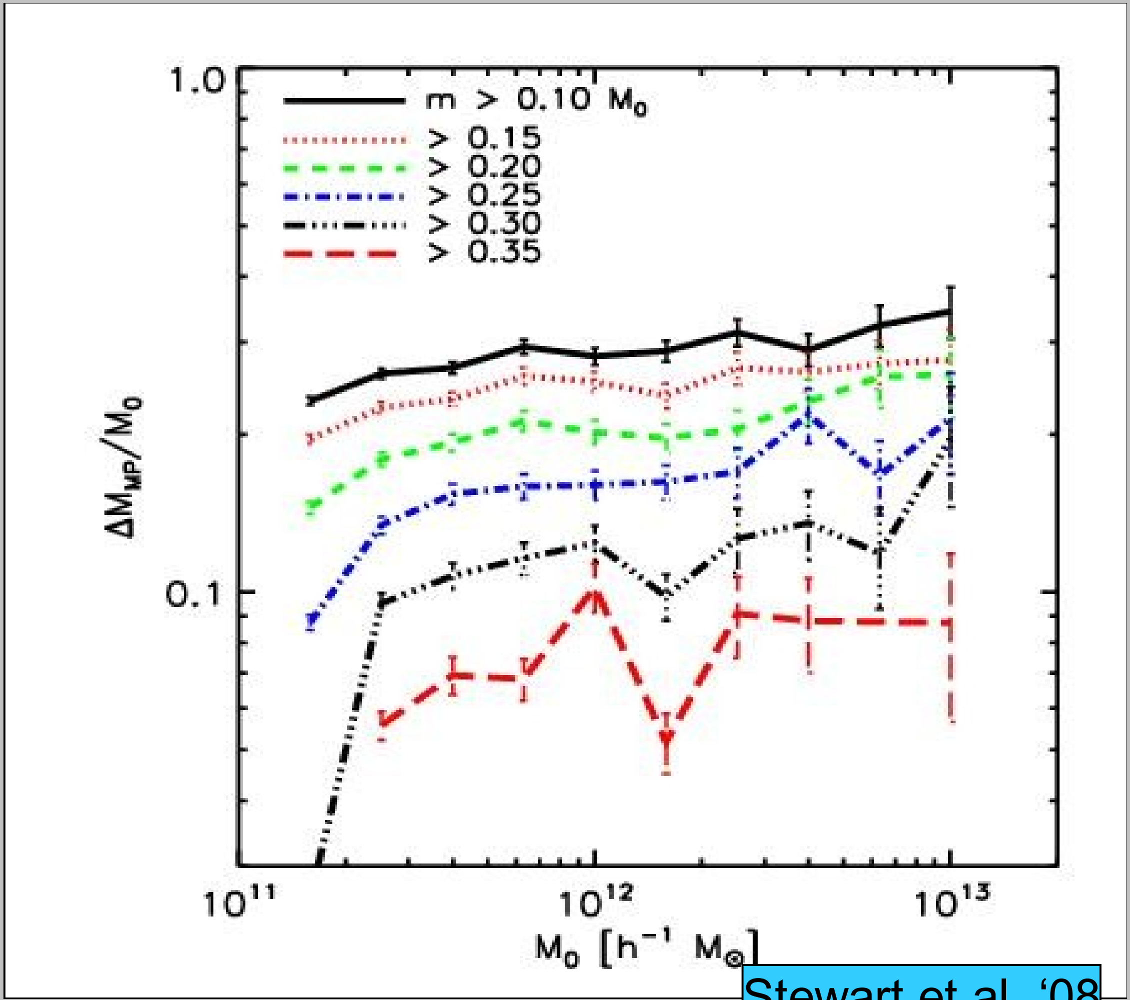
Could a disk have formed afterwards? (Mass accretion since last major merger)

Given a halo with mass M_0 at z=0…

which we know has experienced at least 1 merger of mass > m …

What fraction of M_0 was accreted AFTER the most recent merger > m?

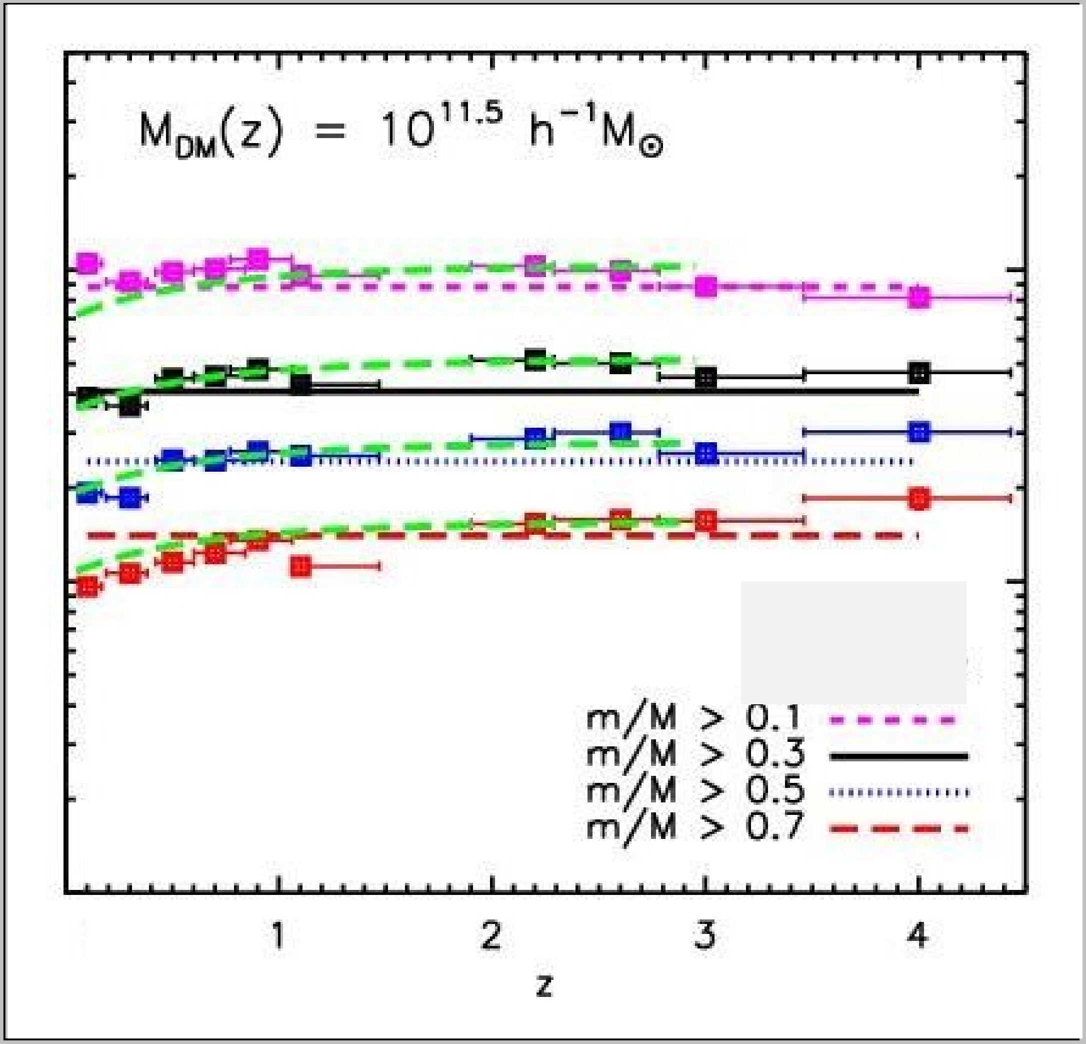
At most, only ~30%



Stewart et al. '08

These systems probably cannot subsequently re-grow a sizeable disk (from accreted material from subsequent galaxy mergers)

dN/dz vs. z



- To first order, dN/dz is consistent with completely flat redshift evolution.
- To second order, dN/dz proportional to $d(\delta_c)/dz$.
- Again, similar to findings in F&M '08