The rise and fall of disks in cosmological simulations

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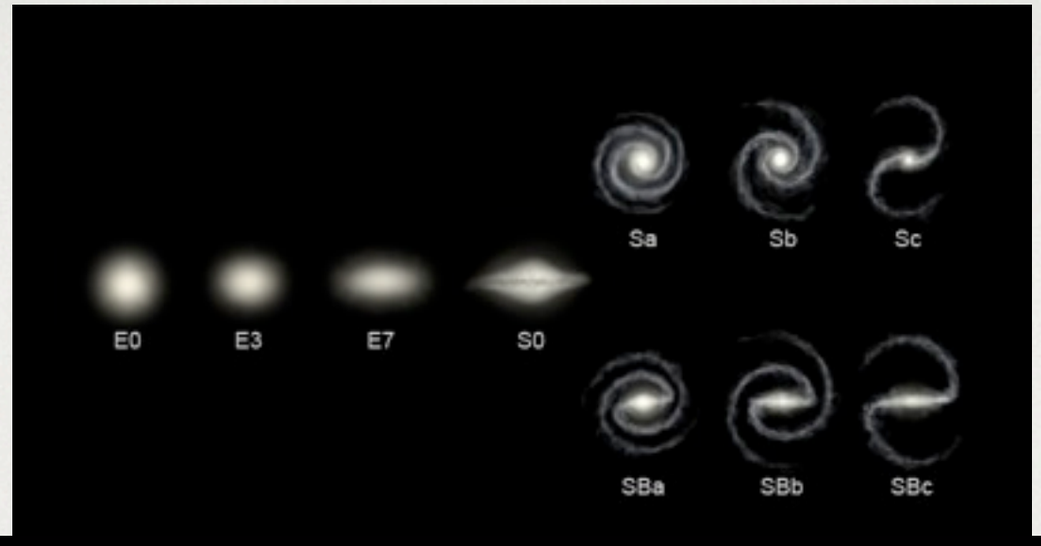
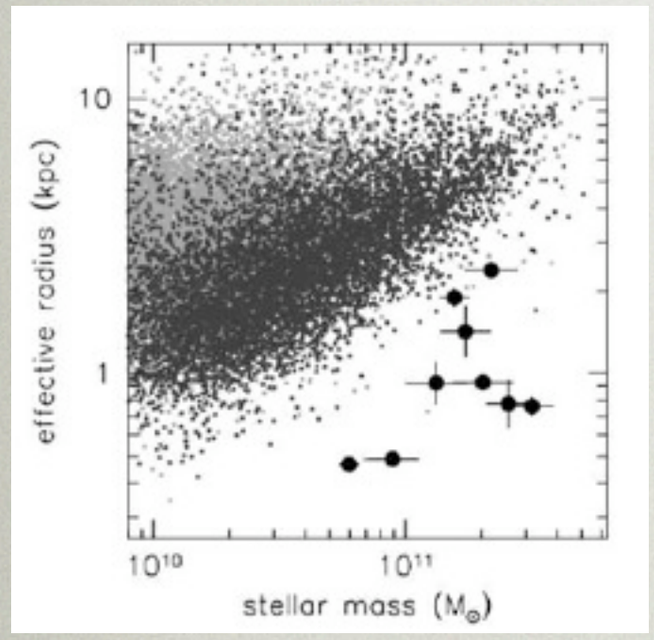


(Franx et al. 2008, Kriek et al. 2009, Szomoru et al. 2011)

Established Hubble sequence at z~2

Red & Dead

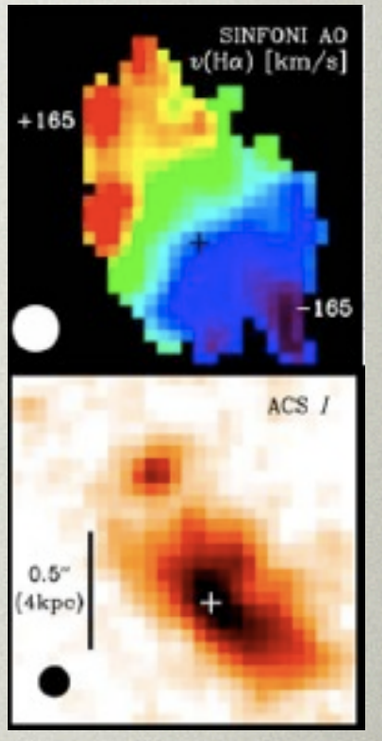
Strongly star-forming (~150 Msun/yr)



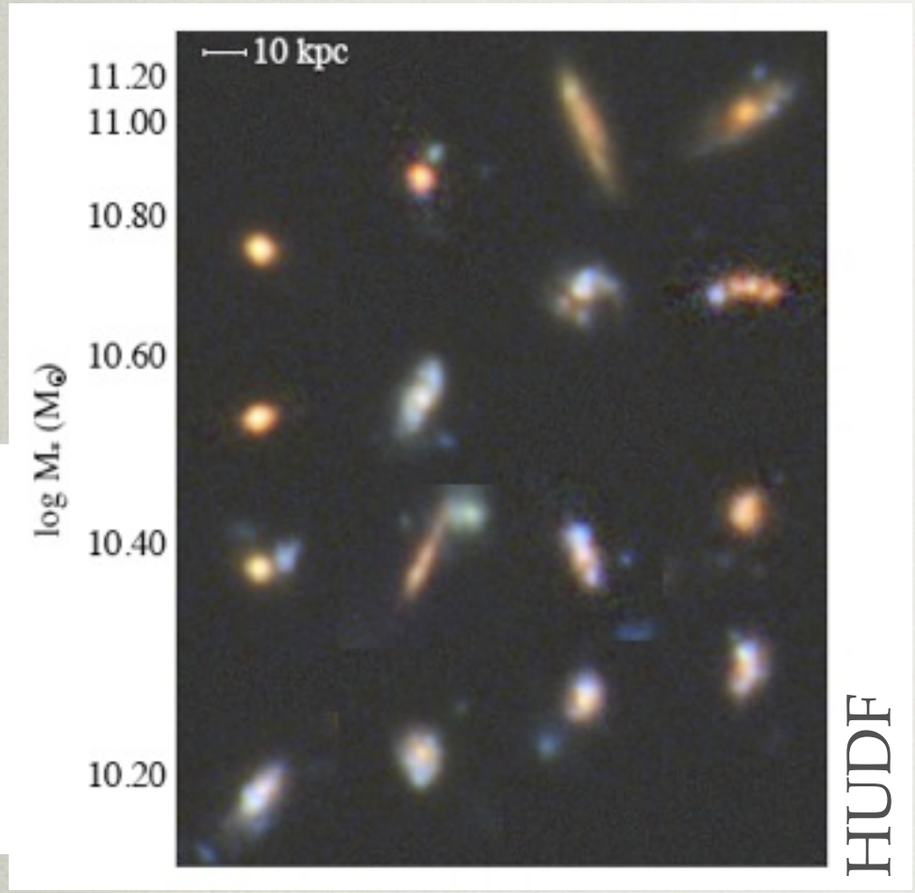
Kriek+ '06
van Dokkum+ '08

Ultra-compact
R_e~1 kpc

Extended disks
R_h~4kpc



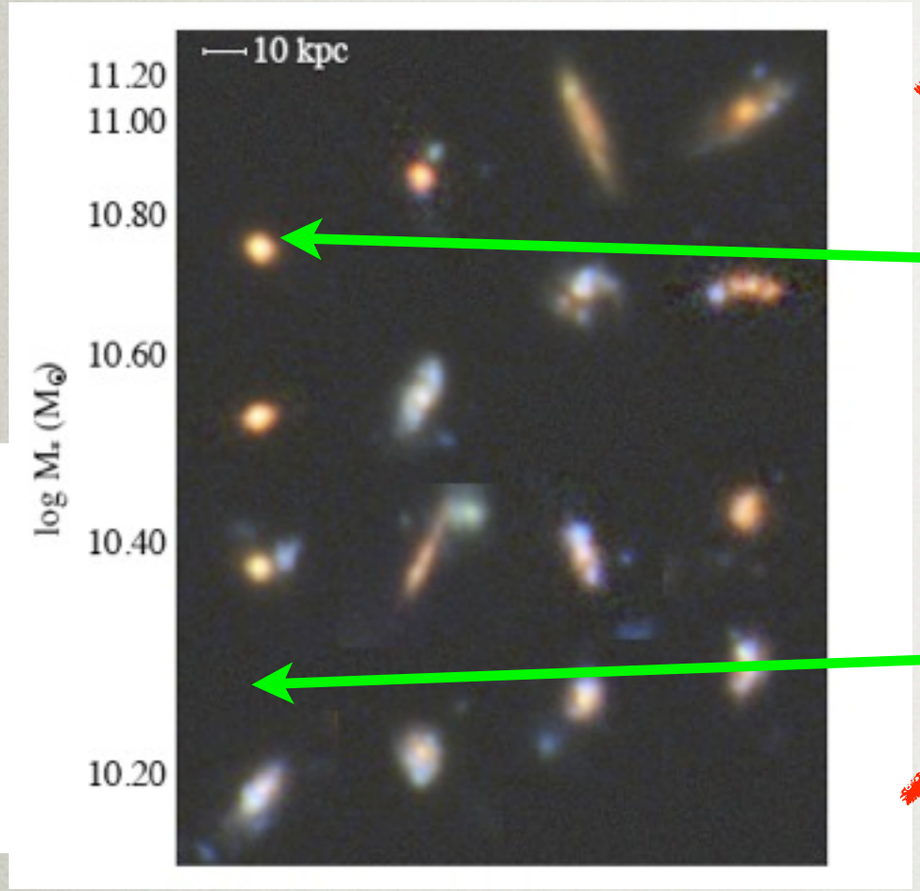
Genzel 2006,
Forster-Schreiber+ '06,'10
Wrhight+, 07
Bouche+ '07 / Cresci+ '09
Law+ '09



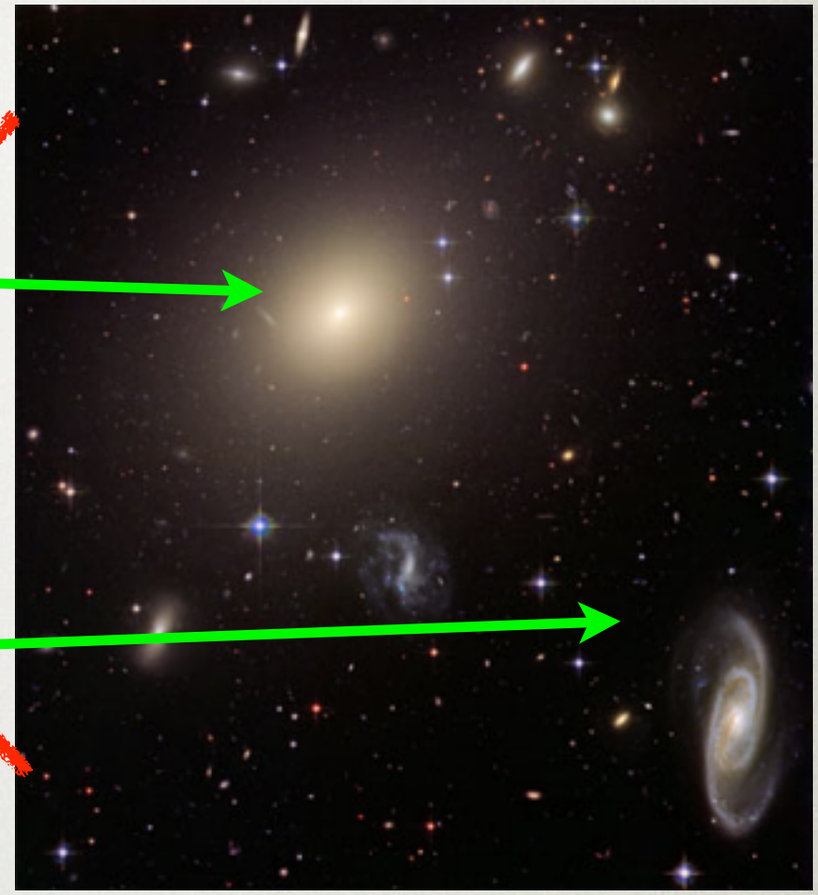
(Szomoru et al. 2011)

Morphologies are a transient phenomena

(Ellis 1998, Steinmetz & Navarro 2002)



(Szomoru et al. 2011)

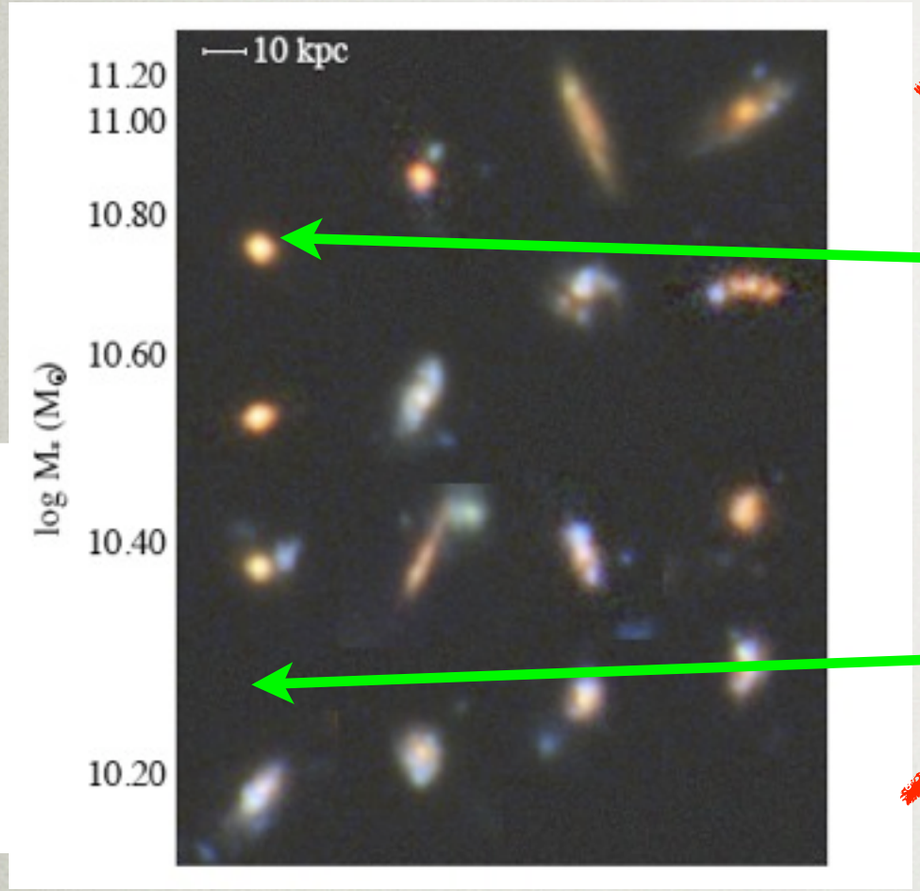


GASS 3505: a gas-rich "red and dead" galaxy

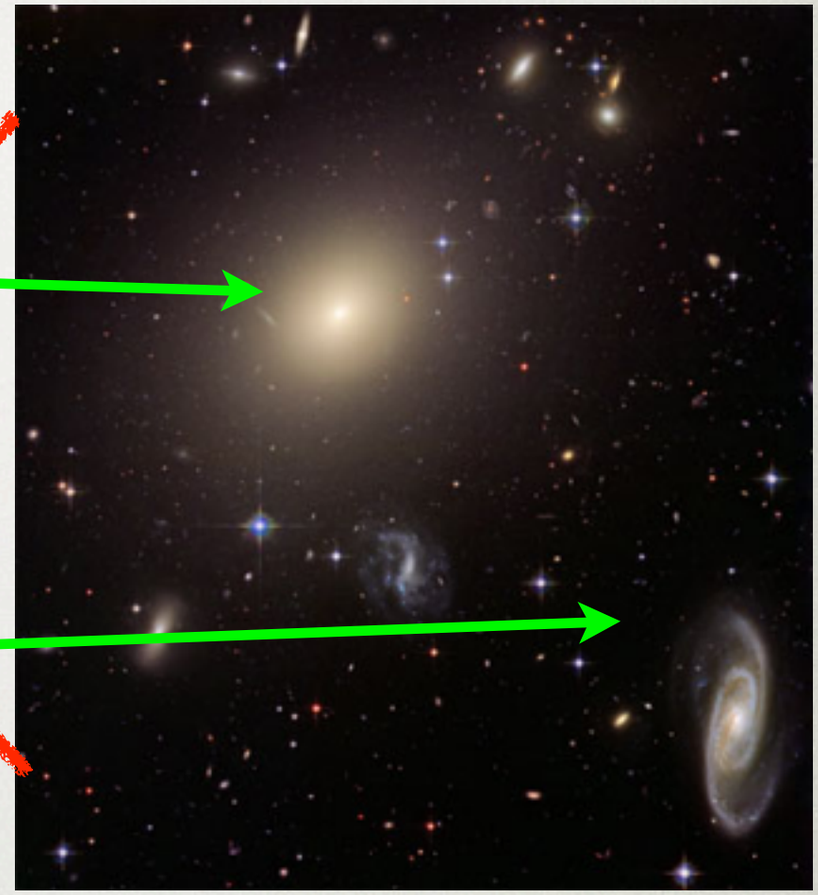
(Credits: Barbara Catinella)

Morphologies are a transient phenomena

(Ellis 1998, Steinmetz & Navarro 2002)



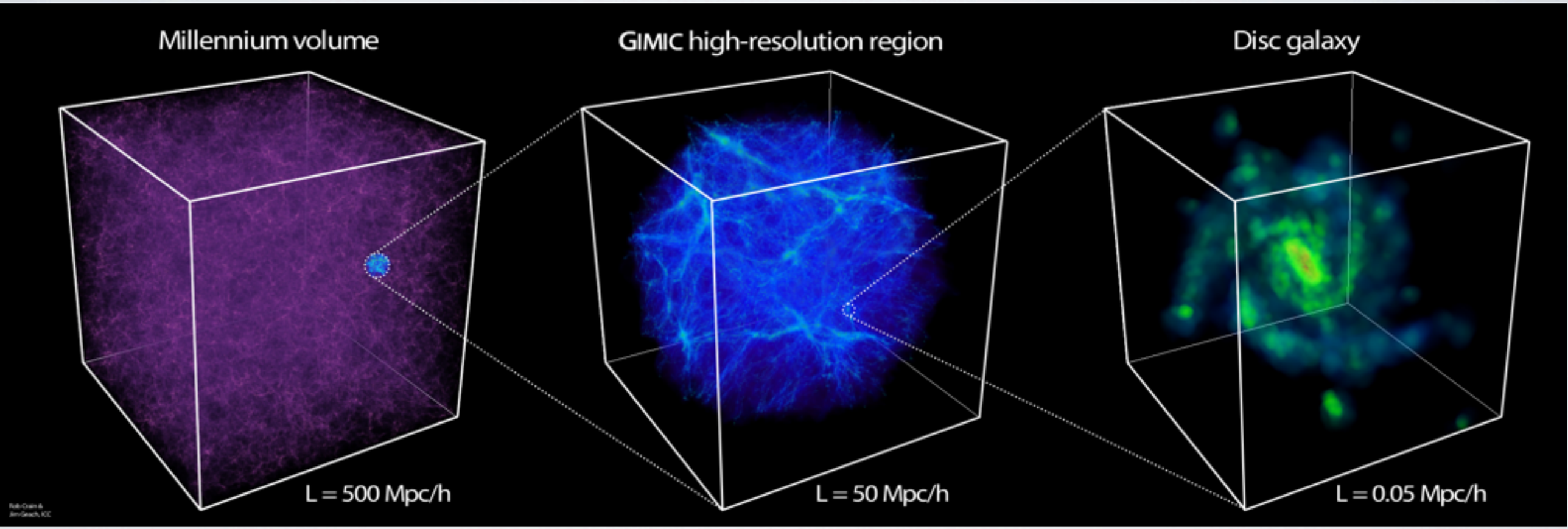
(Szomoru et al. 2011)



- How do populations of galaxies at different z compare?
- Where/What are they descendants?

Galaxies-Intergalactic Medium Interaction Calculation

...or GIMIC simulations



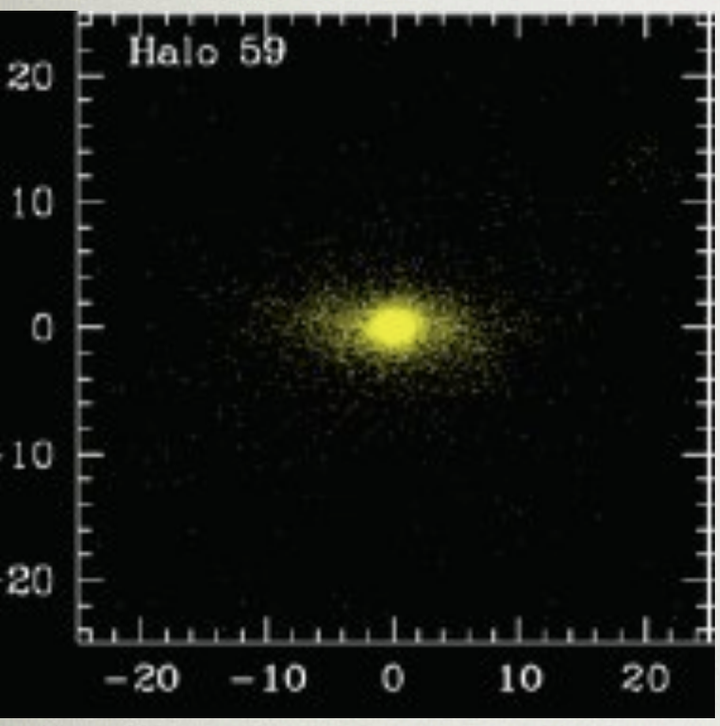
- **Gadget-3 SPH/Nbody code**
- **Metal cooling, photoionization, star formation, kinetic (stellar) feedback, chemodynamics**

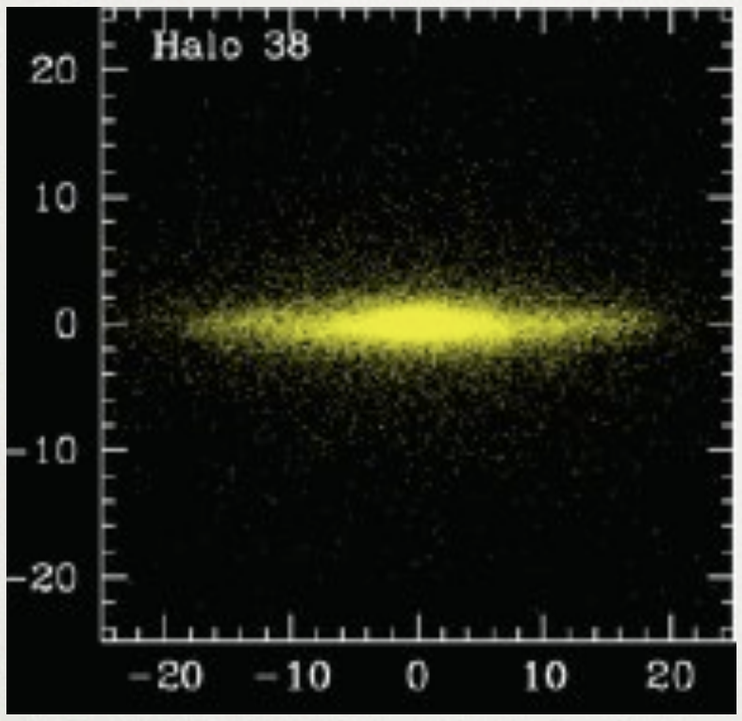
- **Low/High Resolution runs** (m_p^{gas} (high res) ~ 1.45 10^6 $h^{-1}M_{sun}$)

- **Sampling of different environments: +2σ, +1σ, 0σ, -1σ, -2σ <ρ>**

Crain et al. 2009

Sampling the Hubble Sequence in simulations



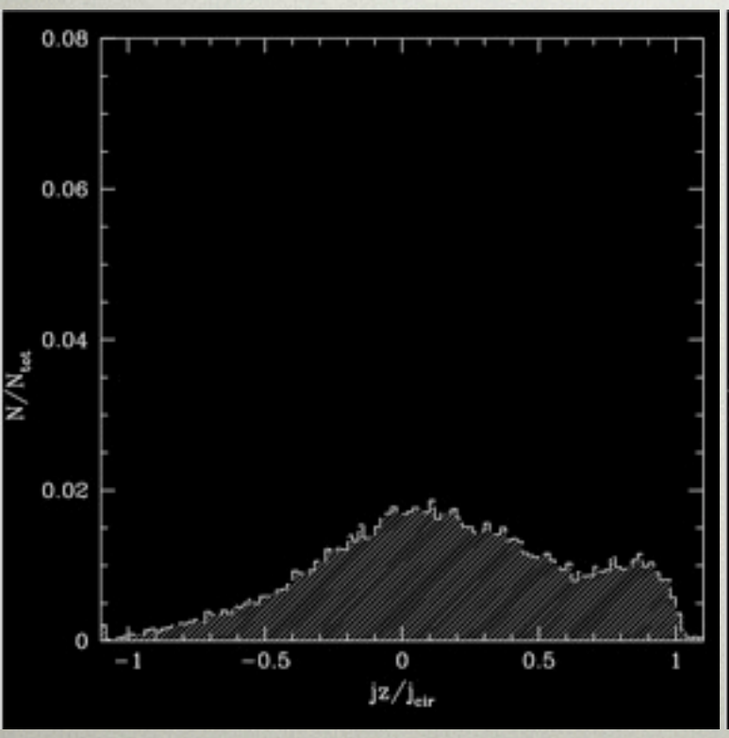


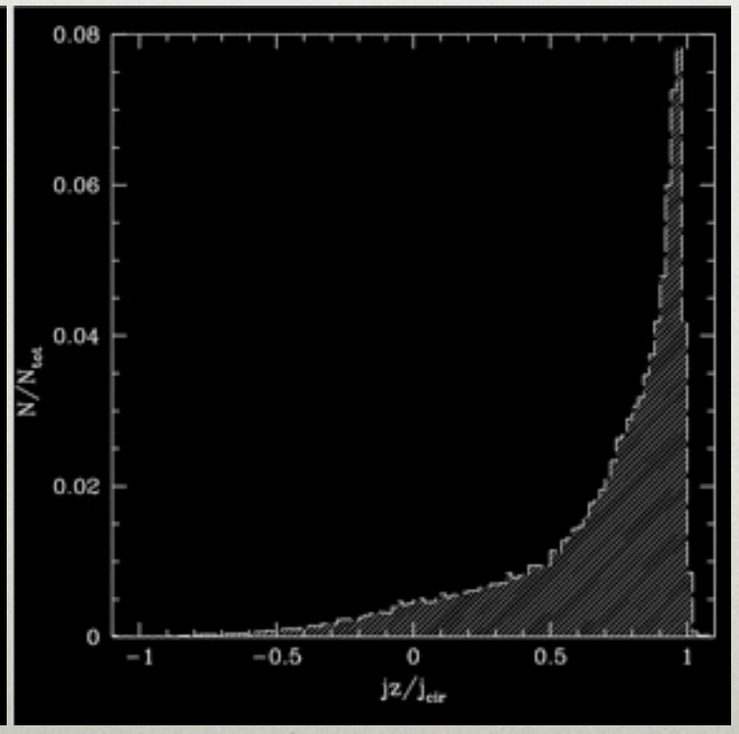
Morphology estimator:

$$\kappa_{rot} = \frac{\sum m_i \, j_{zi}^2 \, / R_i^2}{\sum m_i \, V_i^2}$$

Amount of k. energy on ordered rotation around z-axis

Total kinetic energy





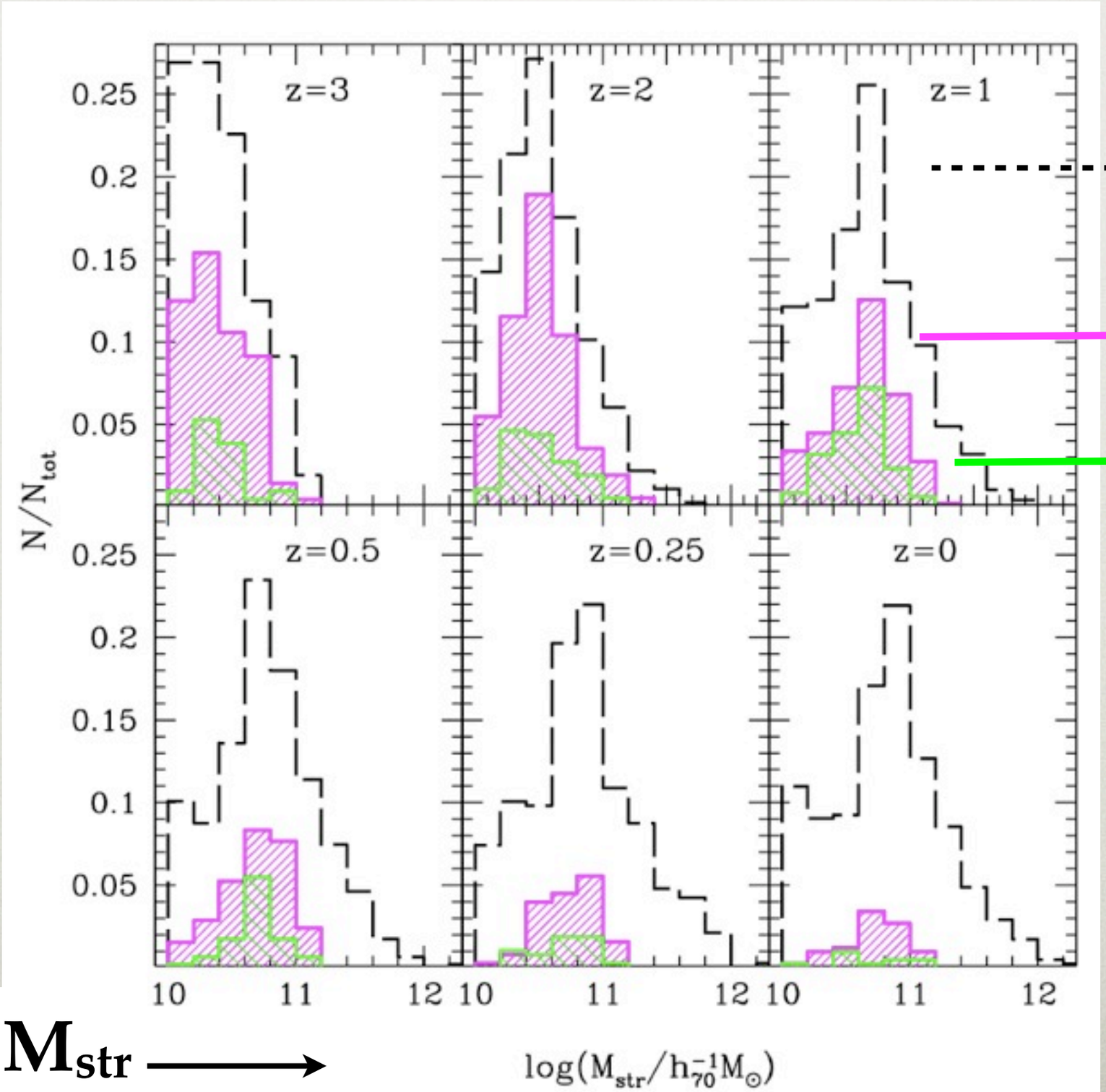
- κ_{rot}>0.7 are disk dominated galaxies with B/T<0.2.
- Because is based on the specific angular momentum, κ_{rot} correlates very well with λ_R (mass weighted, projected specific angular momentum, Emsellem+ 2007)

Results

The evolution of disk galaxies across cosmic time

Massive disk galaxy populations across time:
Stellar masses

Sample: all galaxies with $M_* > 10^{10}\ M_{sun}$



All

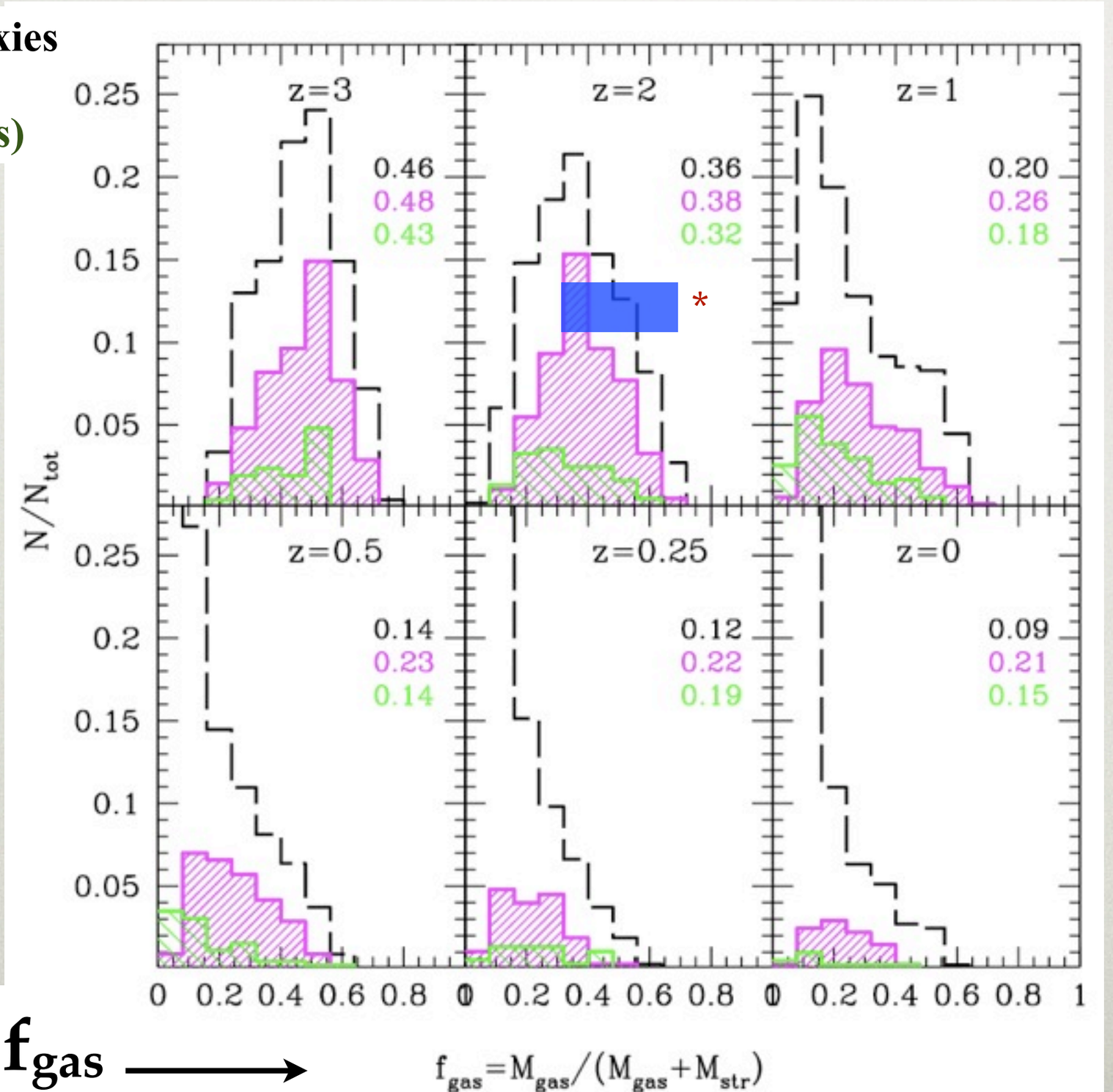
Disks (krot >0.7)

Disks (satellites)

Disks are typically ~2.5x more massive at z=0

Massive disk galaxy populations across time:
Gas fractions

All massive galaxies
Disks
Disks (satellites)

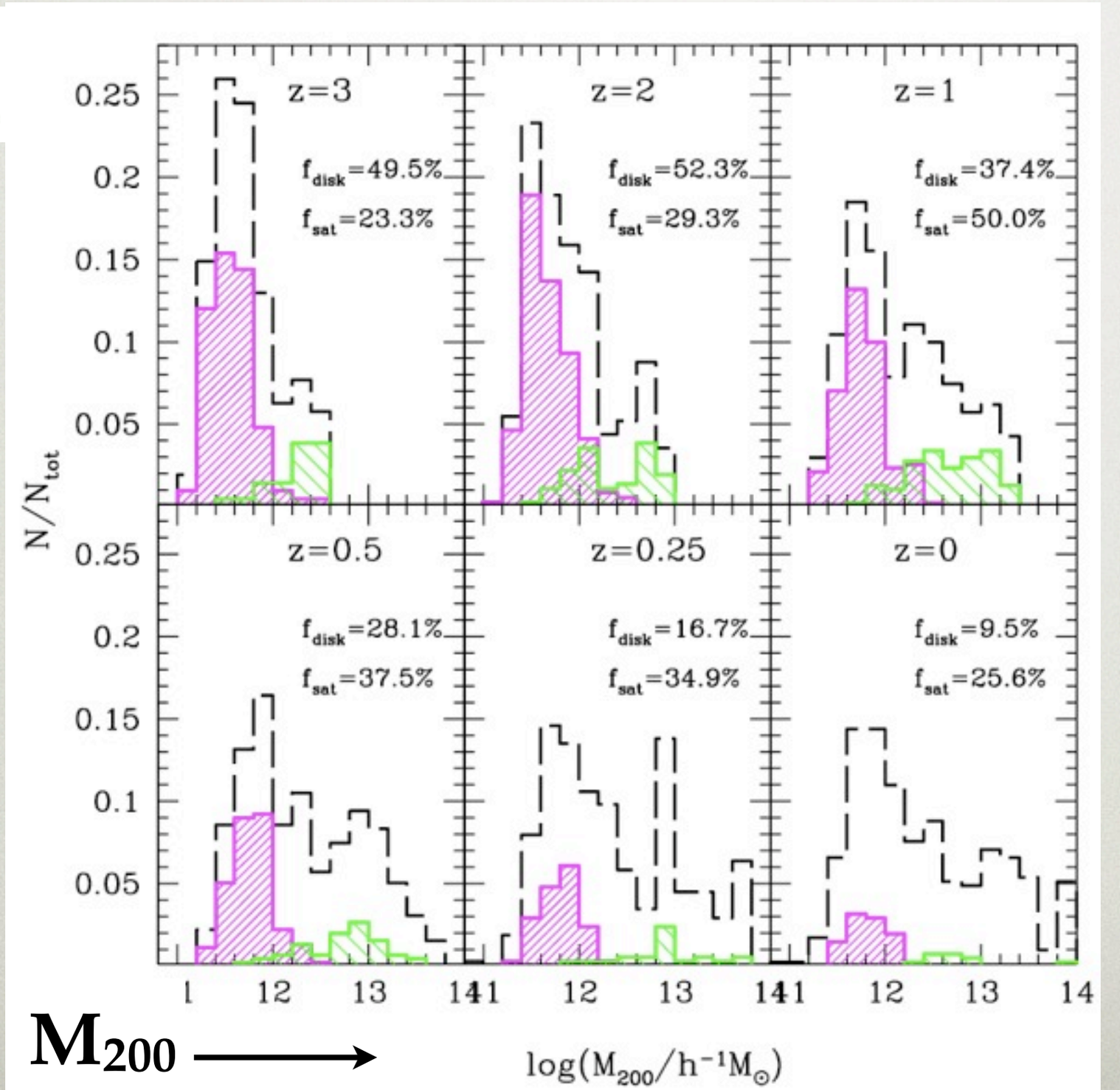


* Richardson+ 2011

Disk galaxies were more gas rich in the past

Massive disk galaxy populations across time:
Dark matter halos

All
Disks
Disks (satellites)

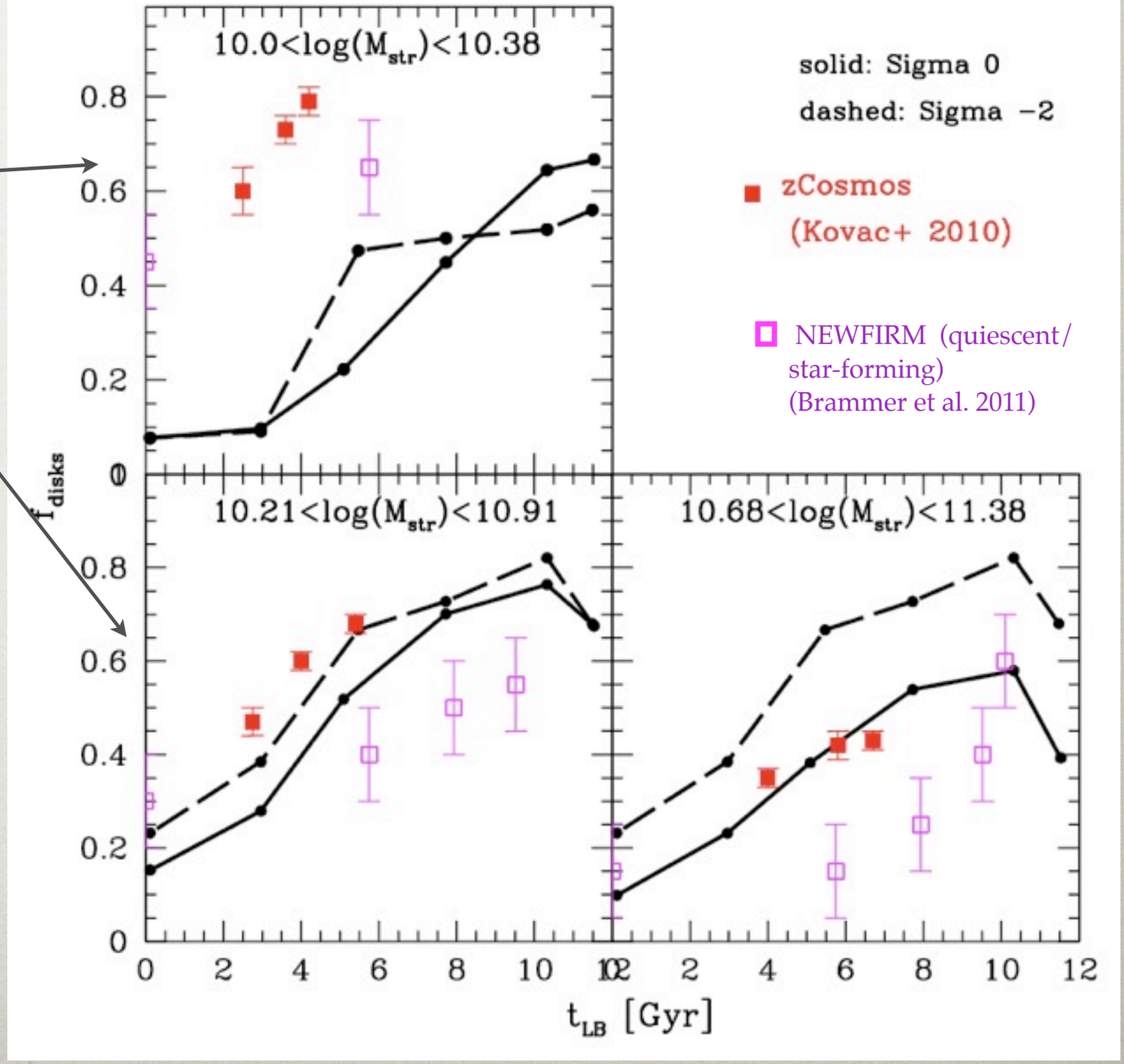


Disks tend to populate the same virial mass halos at any redshift (peak of cooling efficiency/ galaxy formation efficiency, Guo et al. 2010)

Relative fraction of disks evolves with redshift

Disks galaxies were more frequent in the past

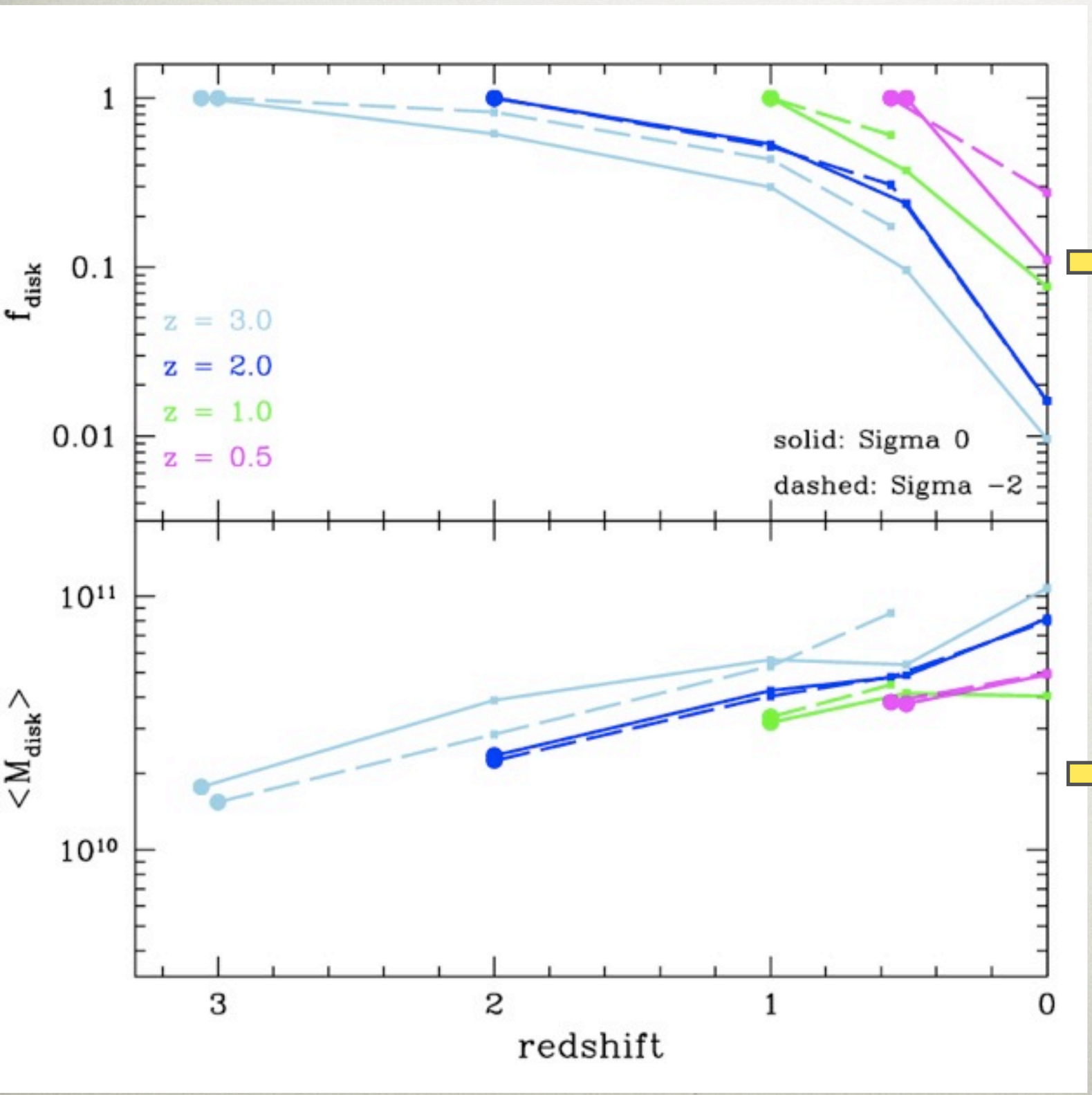
Steep decline in fraction of disks for z<1



Driven by decline in gas accretion with time?

(S. Lilly's talk)

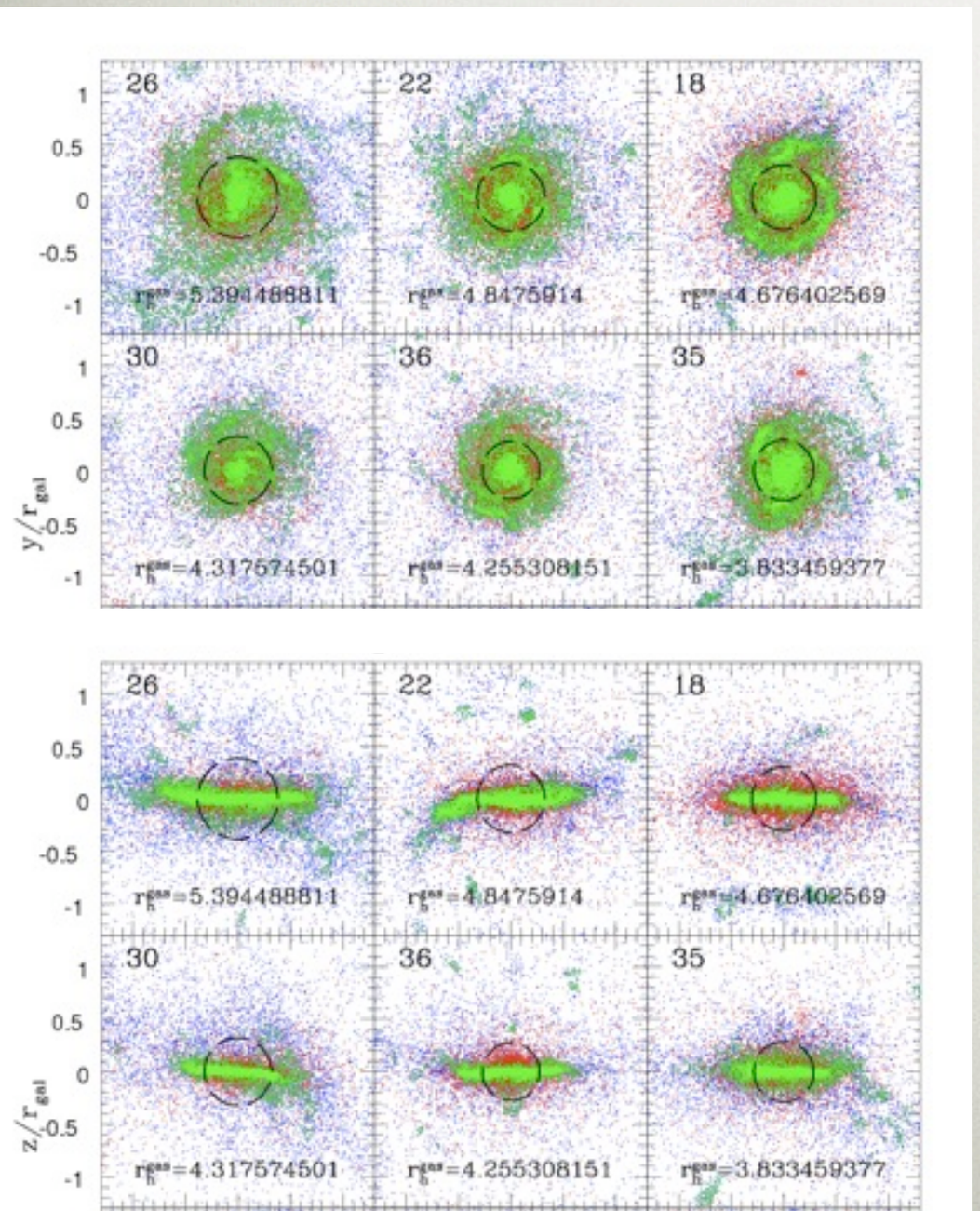
Disk population descendants



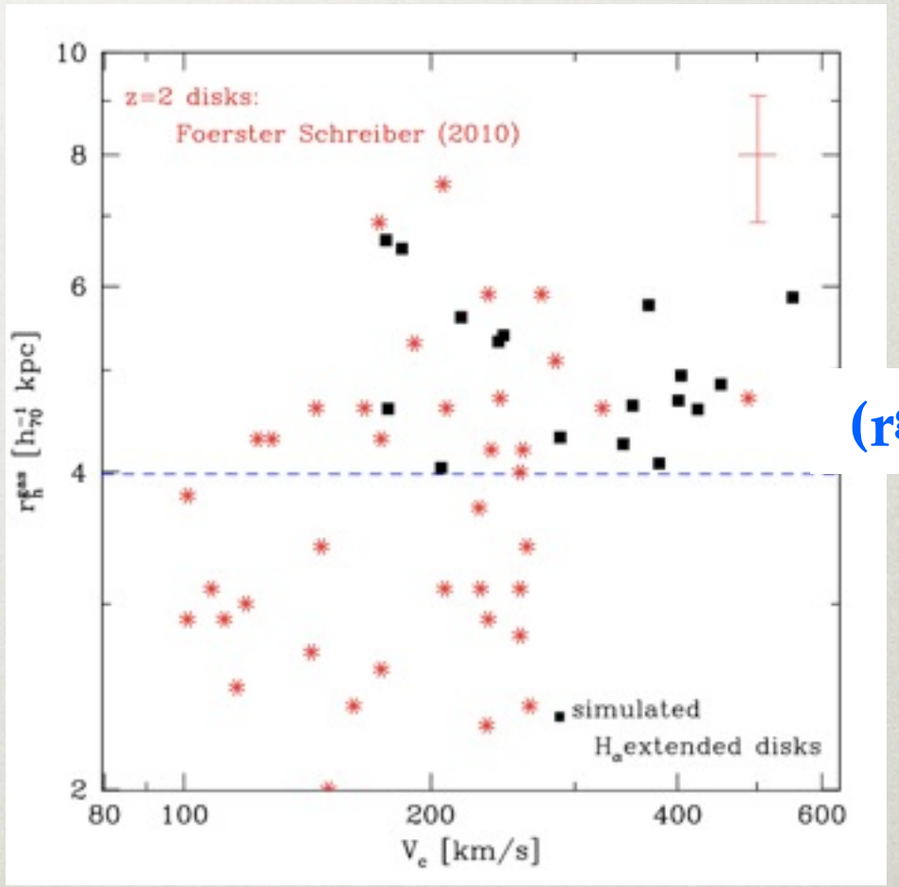
Disk population evolving continuously:
~50% of disks at z=2 remains as disks at z=1. Less than 2% will be disk dominated at present time

High redshift disks tend to populate the massive end of the present day disk galaxy population

Spotting the descendants of z=2 disks in the nearby Universe



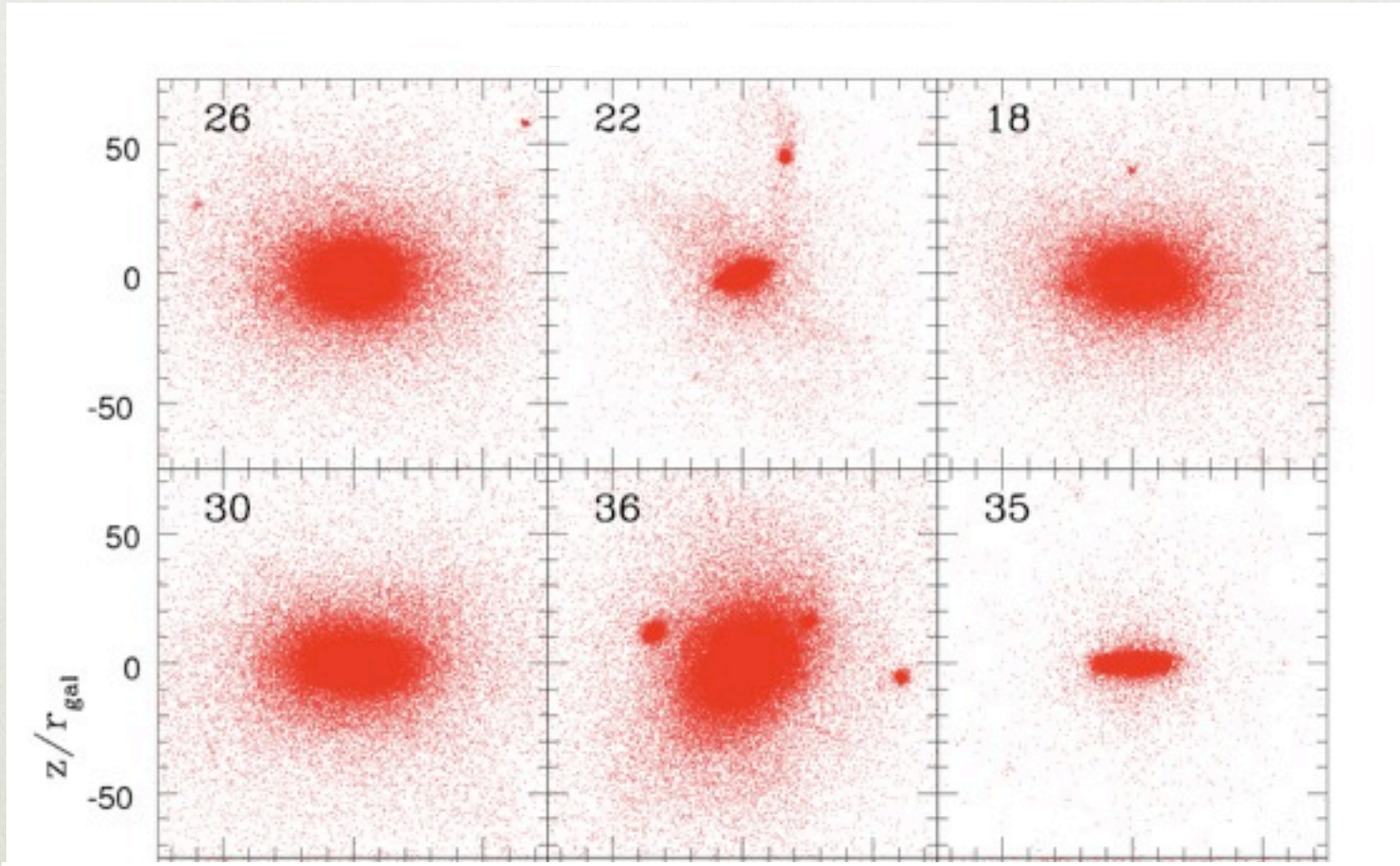
Select massive, extended & star forming disk galaxies at z=2



(r^{gas}_h>4 kpc)

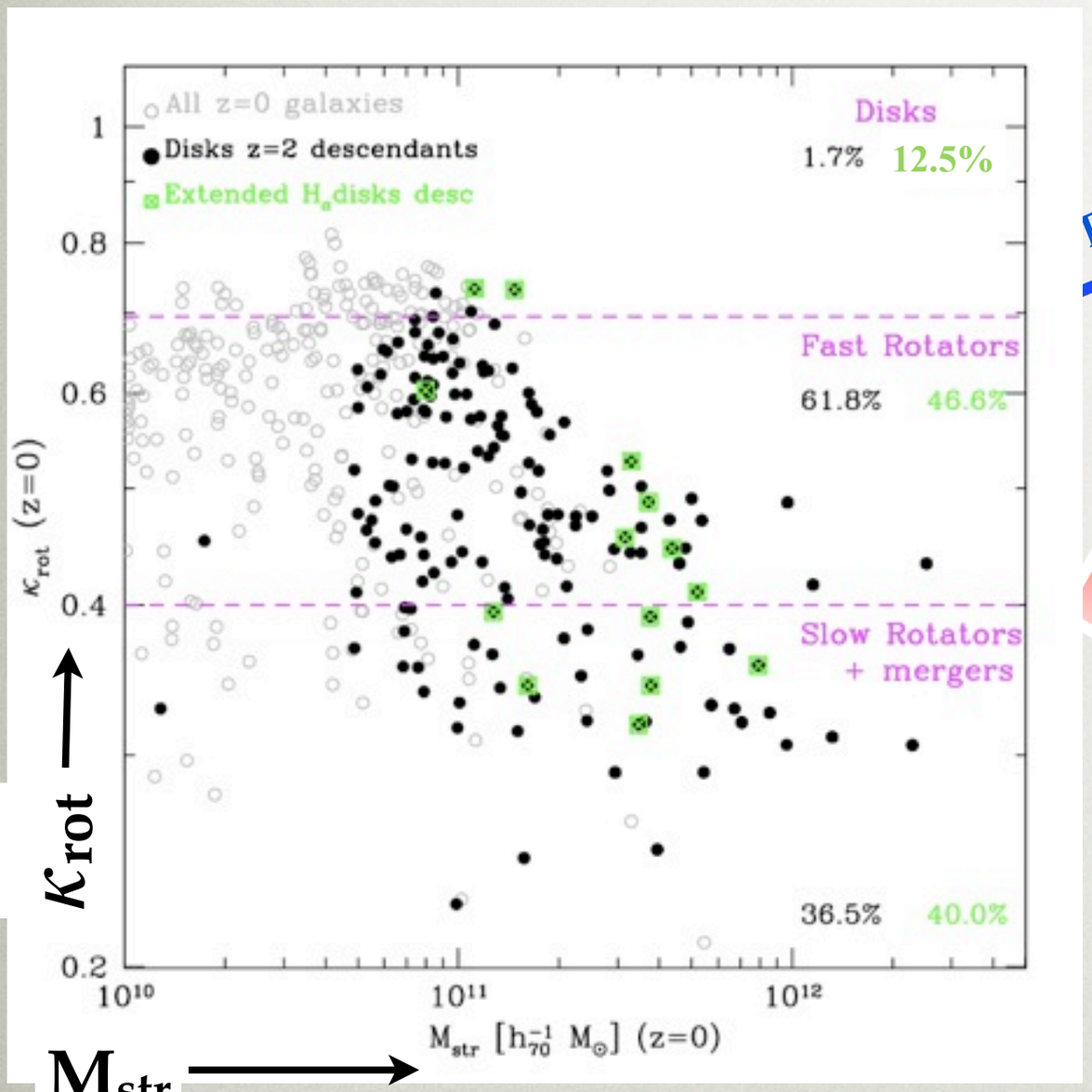
(See Sales et al. 2009 for details about the properties of halos hosting extended disk galaxies at z=2)

Spotting the descendants of z=2 disks in the nearby Universe

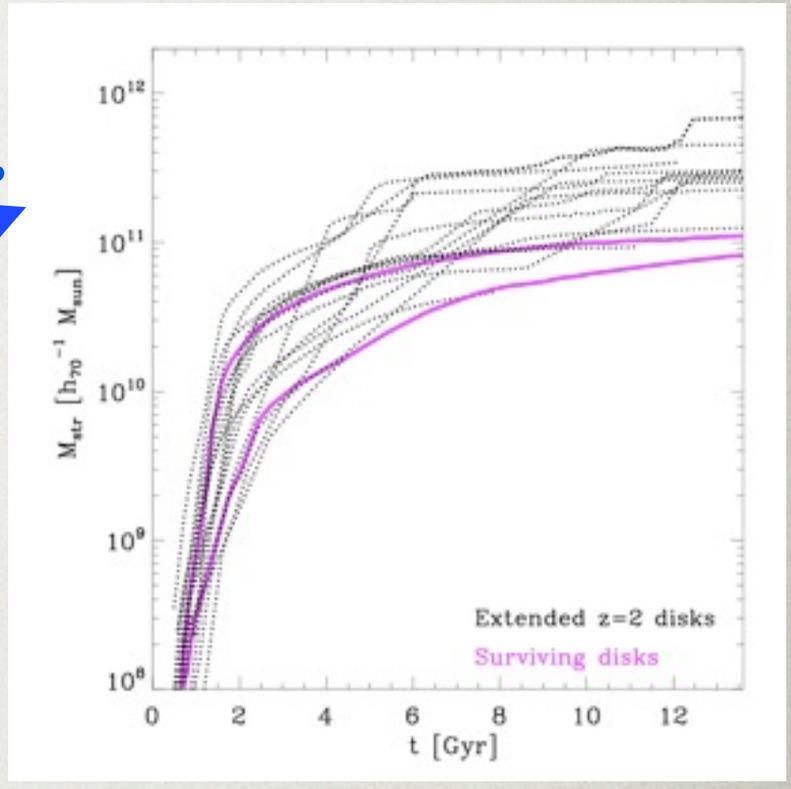


Spotting the descendants of z=2 disks in the nearby Universe

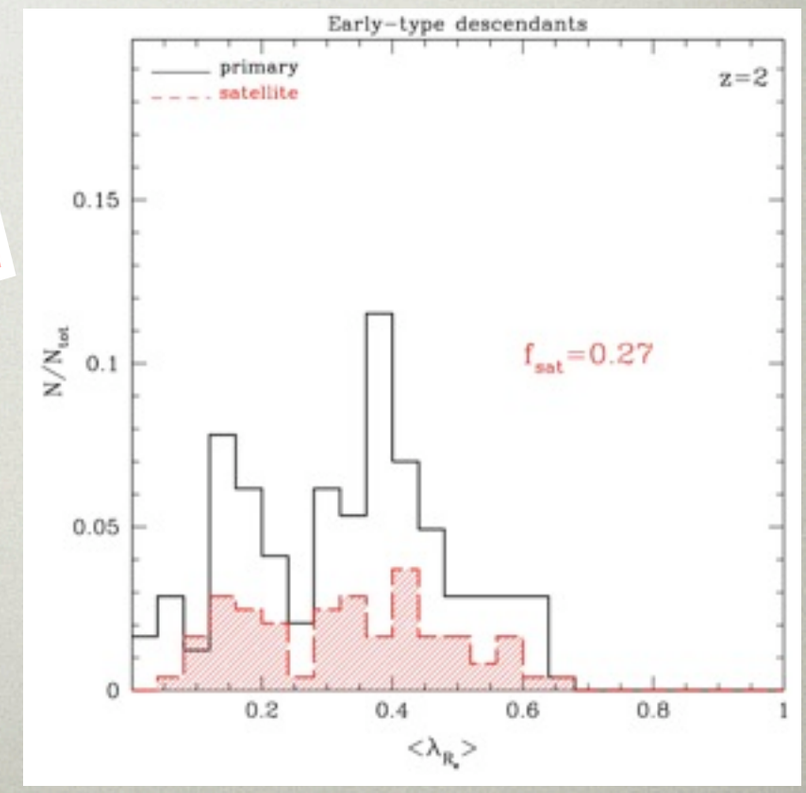
- ~10% of extended Hα disks that managed to avoid merging and violent secular processes conserve today a disk-dominated morphology
- They populate the old/most massive end of today's disk galaxy population



Disk-dominated descendants

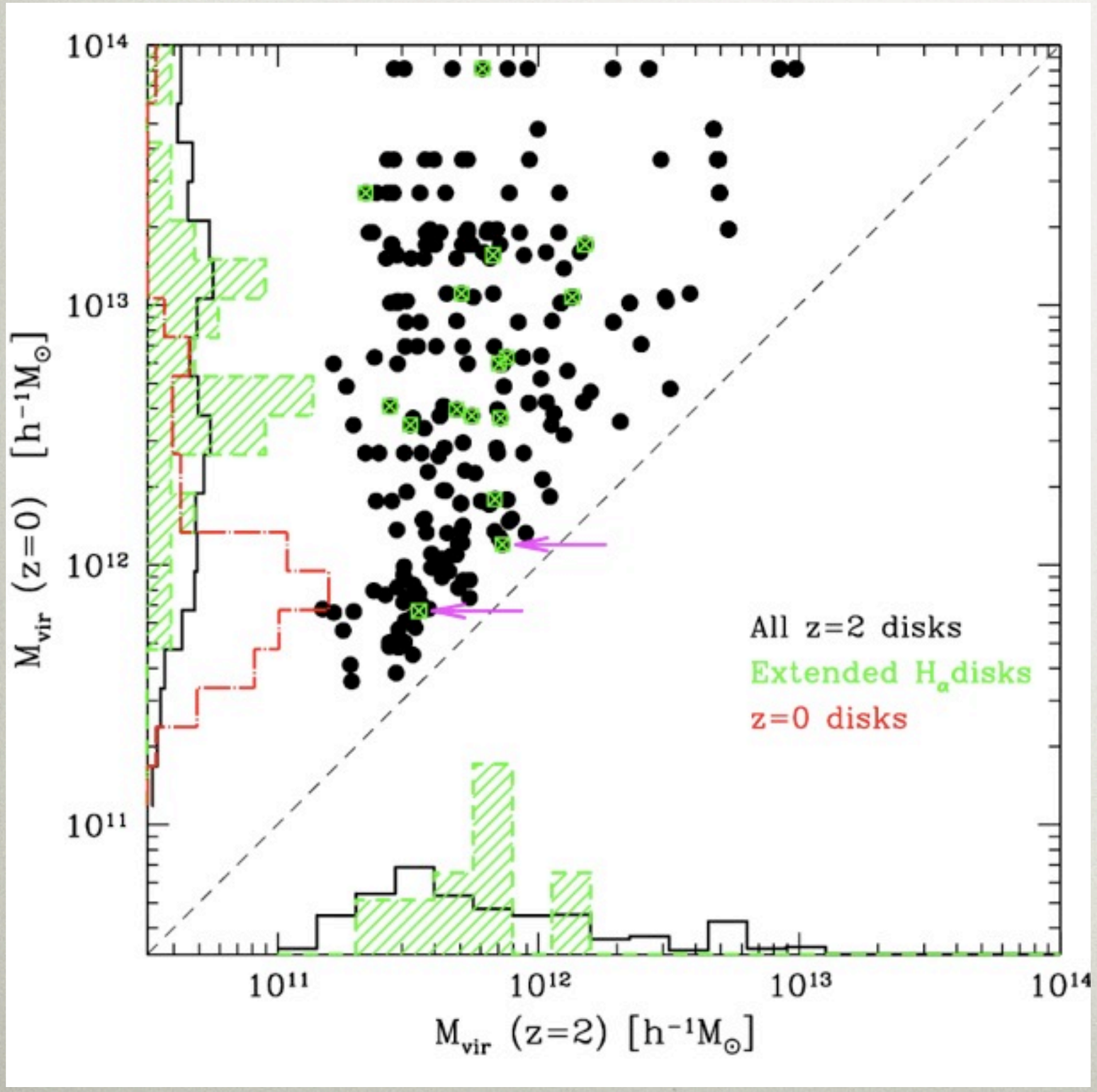


Early-type descendants



- ~90% of extended Hα disks evolve into early type objects
- ~1/3 into slow rotators losing most of their initially high spins
- ~75% can be found today as central galaxies

The present day dark matter halos of extended z=2 disks



- **Halos grew ~1dex from z=2 to z=0: low mass groups ($5x10^{12}$-$2x10^{13}$ M_{sun}) are the preferred sites for the descendants of extended z=2 disks**

- **Disk-dominated galaxies remained in those halos showing the least mass evolution (condition necessary but not sufficient)**

Conclusions

- **Cosmological volume simulations (GIMIC, OWLS, etc) allow to sample the full Hubble Sequence using a *fixed* choice of baryonic physics implementation. Learn by *relative comparison*.**

- **Simulated disks were less massive, more common and more gas rich in the past in good agreement with observations**

- **Morphology is only a transient: only ~2% of (massive) z=2 disks remain as disks at z=0. But it increases to 10% and 20% for disks selected at z=1 and z=0.5**

- **The descendants of extended star-forming disks at z=2 evolved mostly into early type galaxies sitting today in low/moderate mass groups (~10^{13} M_{sun}). 75%/25% are centrals/ satellites. 70%/30% are fast/slow rotators.**

- **Interestingly, ~10% of these extended disks avoided violent halo/galaxy growth and conserve today their disk-dominated morphology. They represent the oldest/most massive extreme of the z=0 disk galaxy population.**