Diagnostics of Feedback & Environmental Processes in the Evolution of Cluster & Field Galaxies

Richard Ellis

Caltech

Massive Galaxies, Tucson *Nov 1st 2006*

Key Issues

- In understanding evolution of massive galaxies, need to distinguish between, and relate, galactic-scale `feedback' *and* externally-driven environmental processes: both are important

- Major questions:

    - mass & environmental dependence of SF & assembly
    - what limits growth of massive galaxies?
    - origin of morphology-density relation: nature of S0s

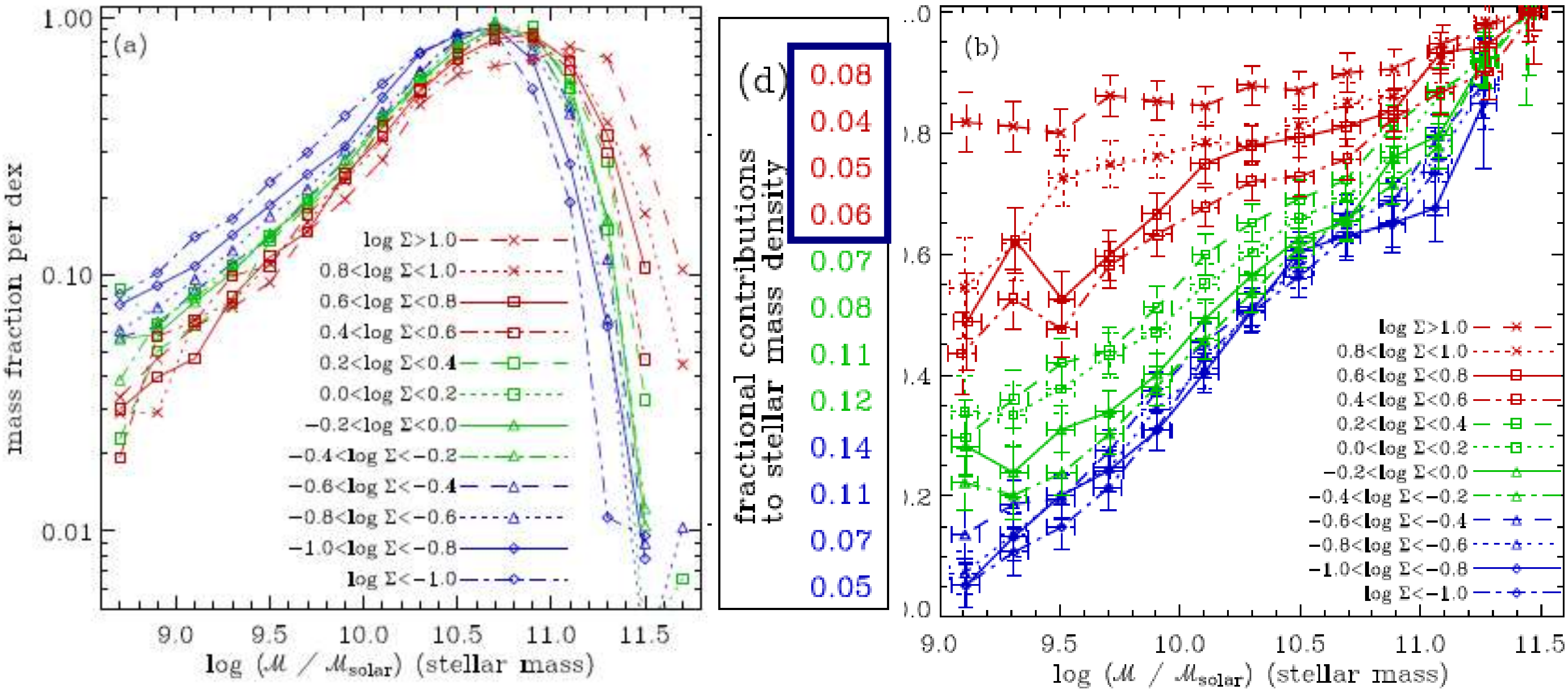
- Detailed studies of $z < 1$ field & rich clusters important

- Resolved dynamical studies play a unique role

With: Sean Moran, Lauren MacArthur (Caltech), Kevin Bundy (Toronto), Tommaso Treu (UCSB), Pieter van Dokkum (Yale) + DEEP2 team

Importance of Environment: Σ (Mpc^{-2})

Mass fn: Φ (M, Σ) f(Σ) Fraction in red light

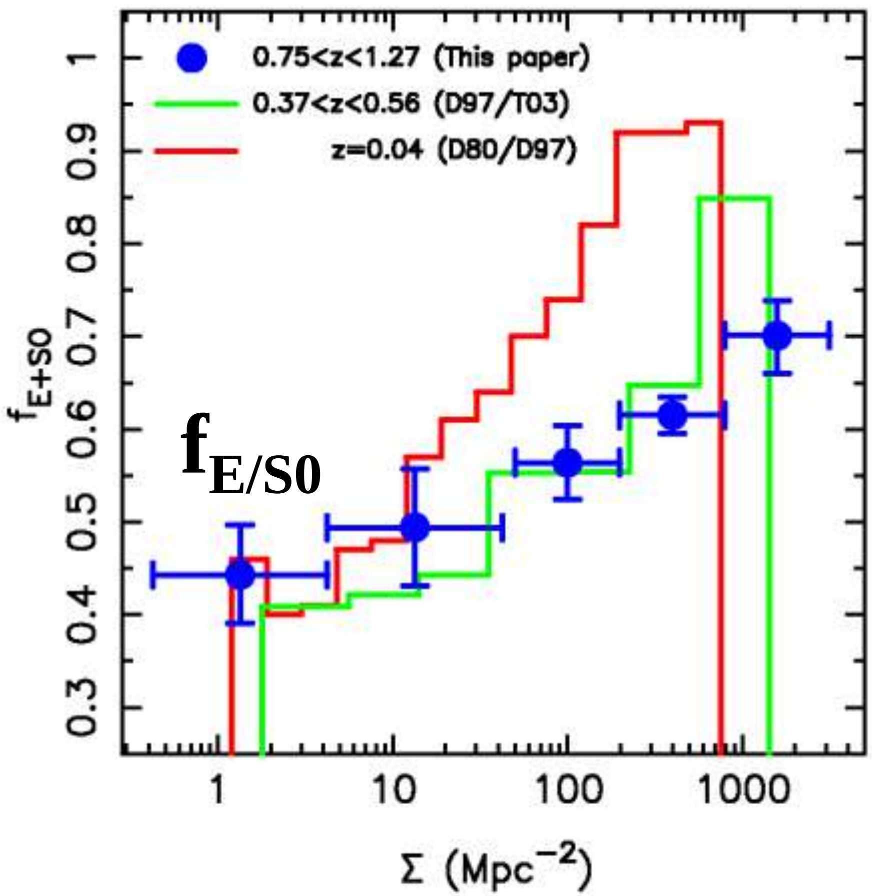


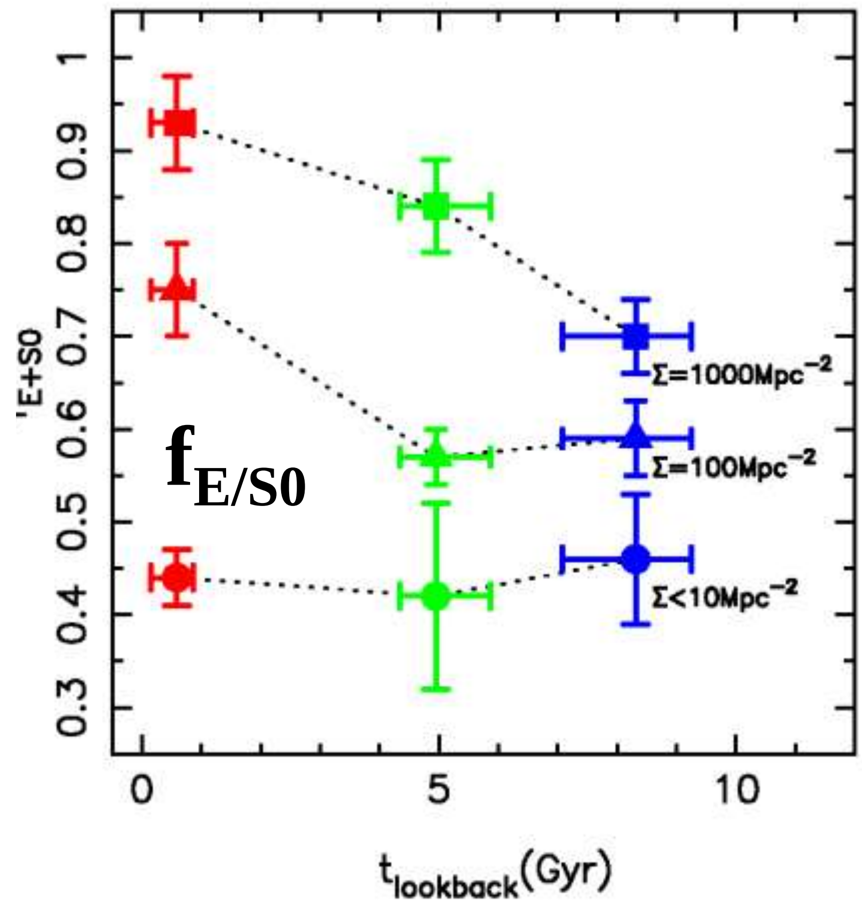
~25% of all stars at z~0 are in ellipticals (75% in spheroids)
Most are in massive galaxies whose mass function is correlated with Σ25% of stellar mass is in dense environments (lg Σ > 0.4)

Baldry et al (astro-ph/0607648)

Evolution of Morphology Density Relation

Smith et al Ap J 620, 78 (2005)





Environmental density Σ plays key role in governing morphological mix:

- Continued growth in high Σ but delay for lower Σ regions
- Slower conversion of spirals to S0s with only Es at z > 1?

Dynamical Studies of z<1 Galaxies

Applications at intermediate z:

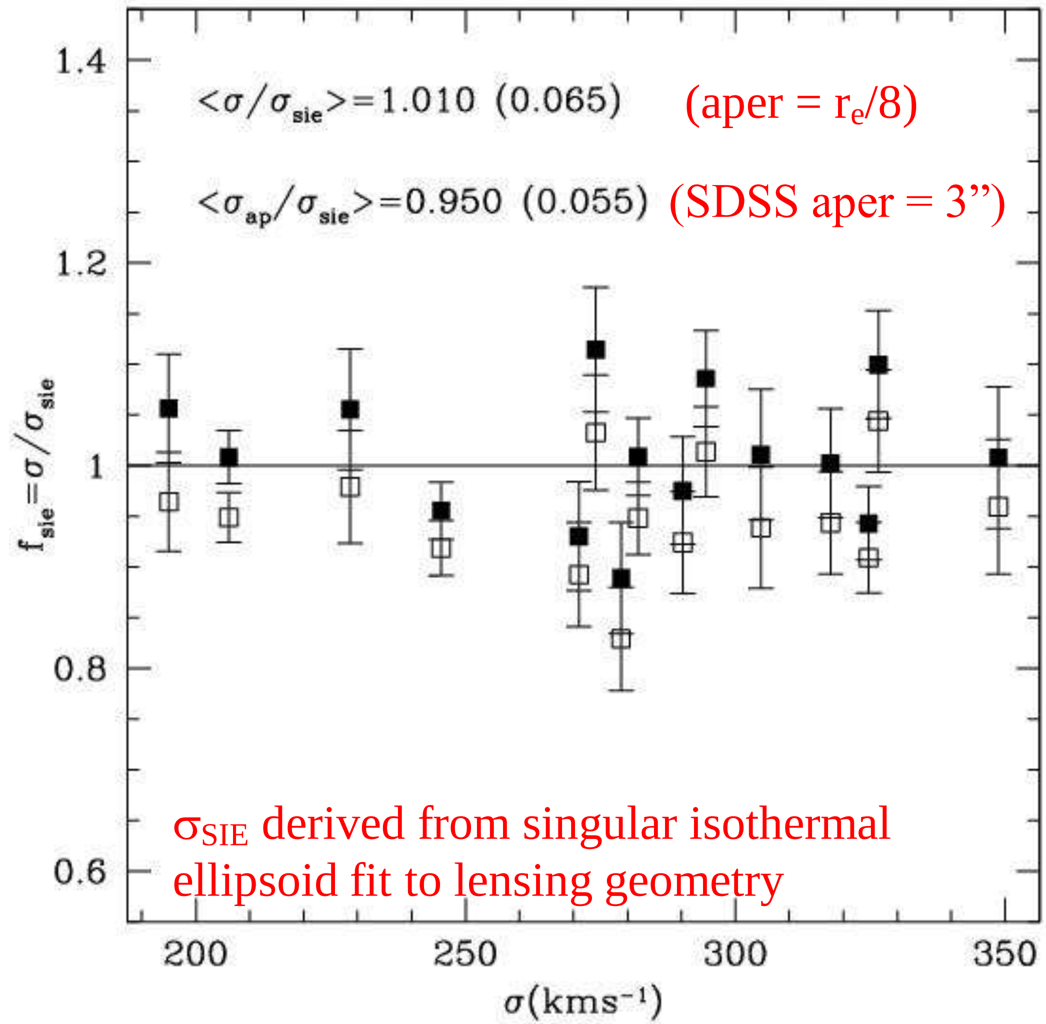
- Spheroidal galaxies: FP yields M/L ratios of field & cluster galaxies as function of mass, environmental density and redshift. Can compare dynamical and stellar masses and determine growth rates
- Disk galaxies: Scatter on TF relation can test effects of environment

(in progress..)

- *Es vs S0s: Absorption line rotation curves can provide a more robust dynamical distinction c.f. morphology*
- *Bulges: FP can define mass growth rate (c.f. AGN)*

All relevant in quantifying environmental & feedback effects

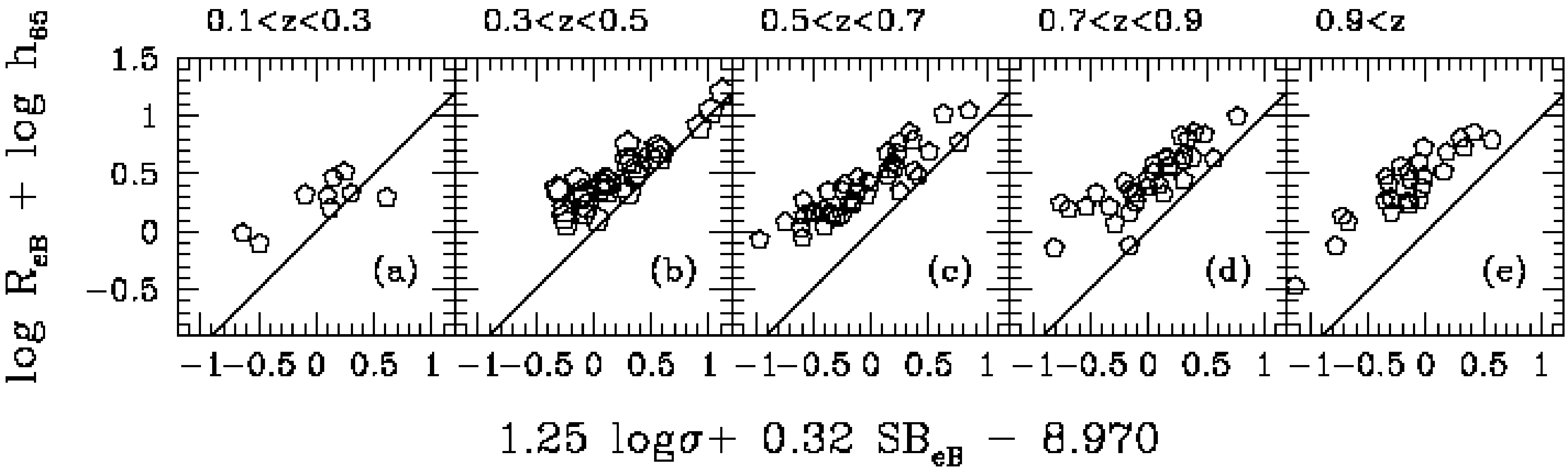
Lensing & Dynamical Masses Correlate Well



Koopmans & Treu Ap J 611, 739 (2004); Treu et al Ap J 640, 662 (2006)

SLACS data suggests remarkable uniformity in isothermal mass profiles to z~1

Mass-Dependent FP Evolution



142 GOODS z_{850}<22.4 spheroidals: HST sizes, Keck dispersions

If $\log R_E = a \log \sigma + b\, SB_E + \gamma$

Effective mass $M_E \propto \sigma^2 R_E / G$

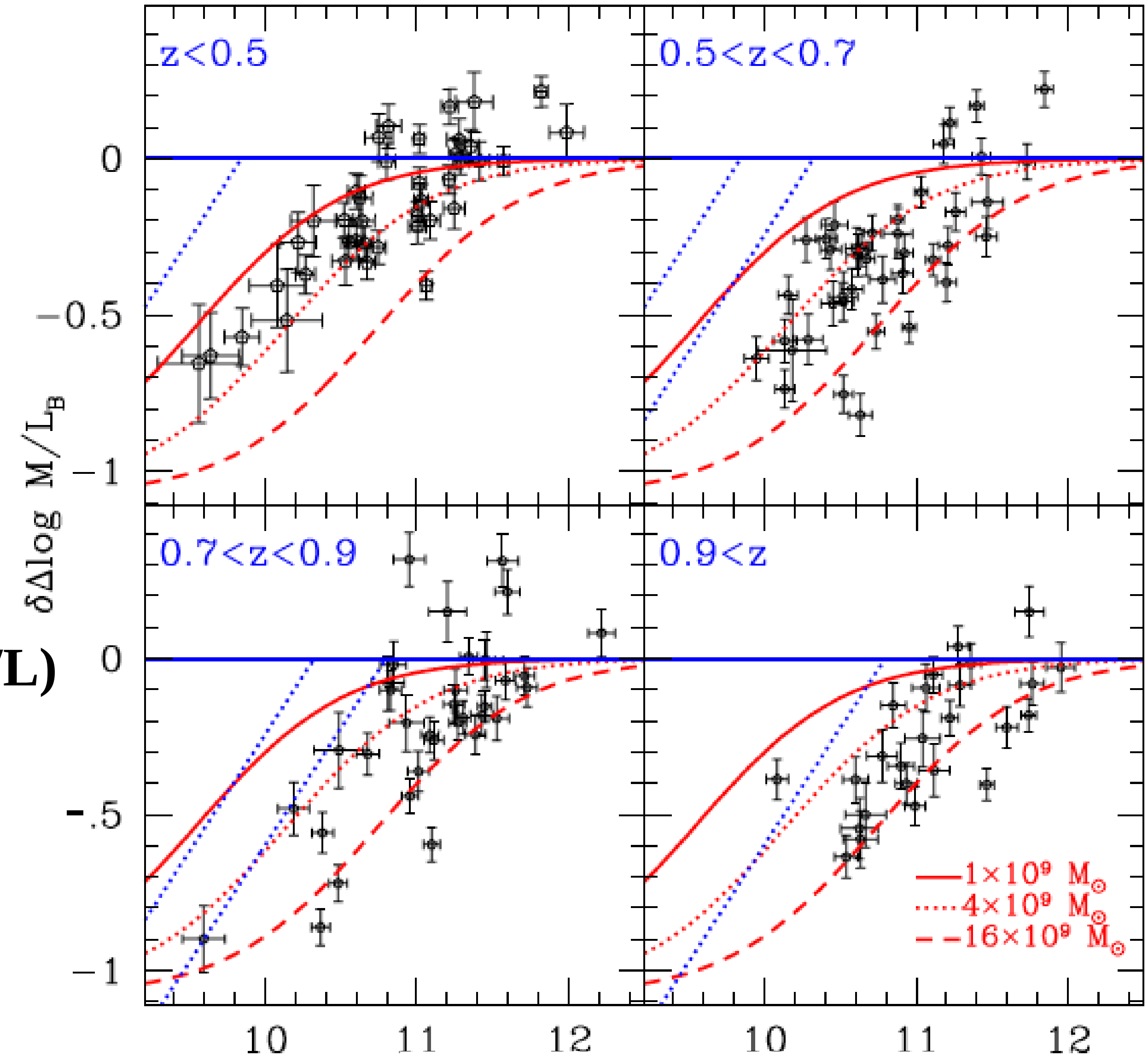
For fixed slope, change in FP intercept $\Delta\gamma^i \propto \Delta \log (M/L)^I$

Treu et al Ap J 633, 174 (2005)

Recent Growth in Low Mass Spheroidals

“age”

δΔ(M/L)

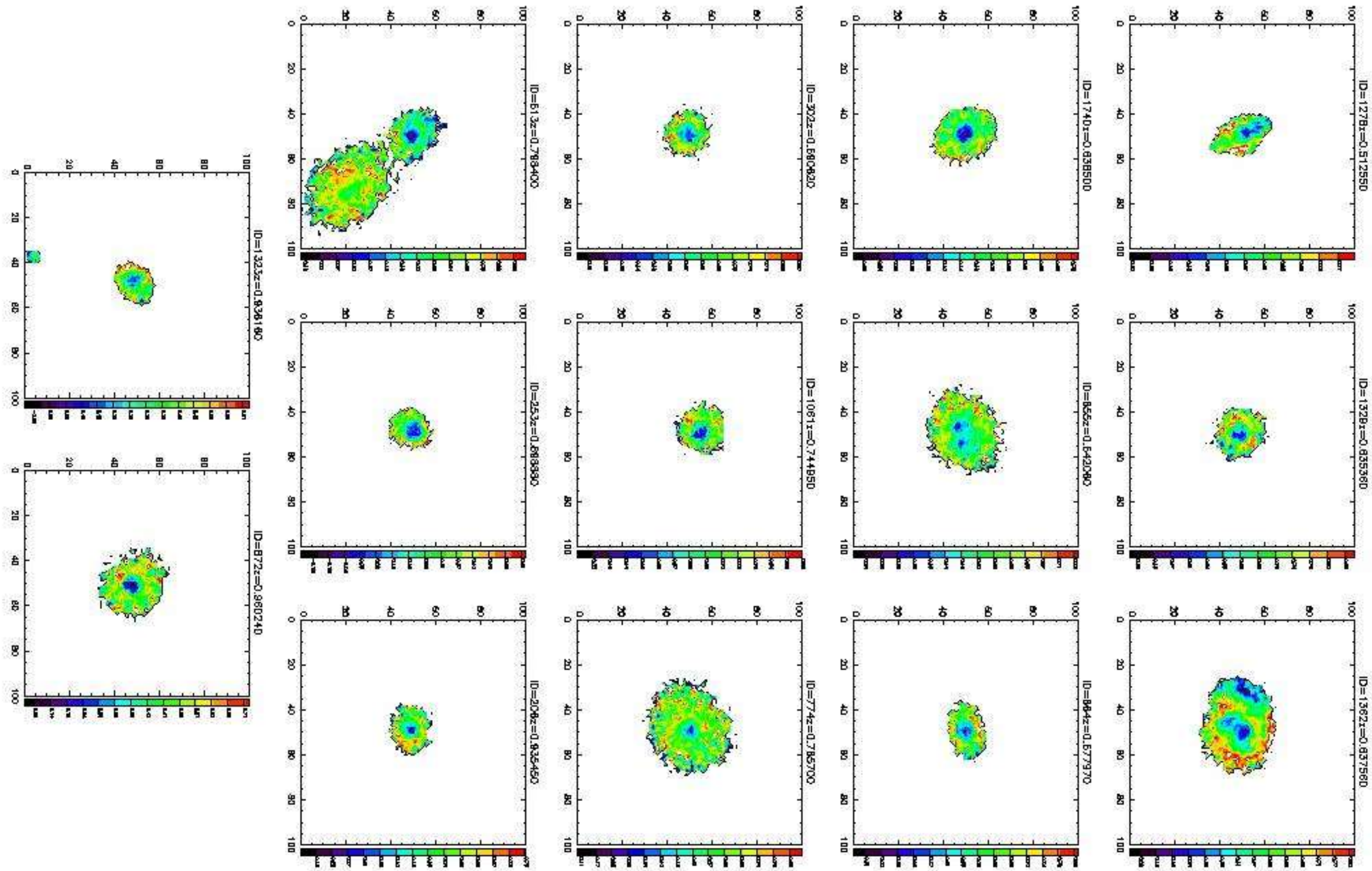


dynamical mass

High mass spheroidals (>$10^{11.5}$ M☉) have <1% growth in young stars since z~1.2

Lower mass systems (< 10^{11} M☉) show 20-40% growth

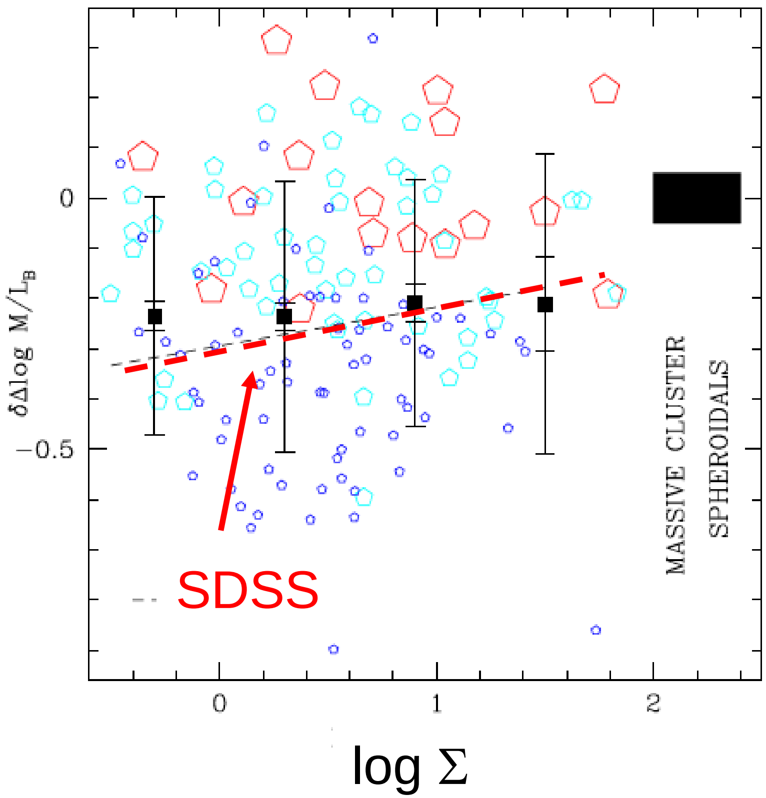
Caught in the Act: Blue Core Spheroidals



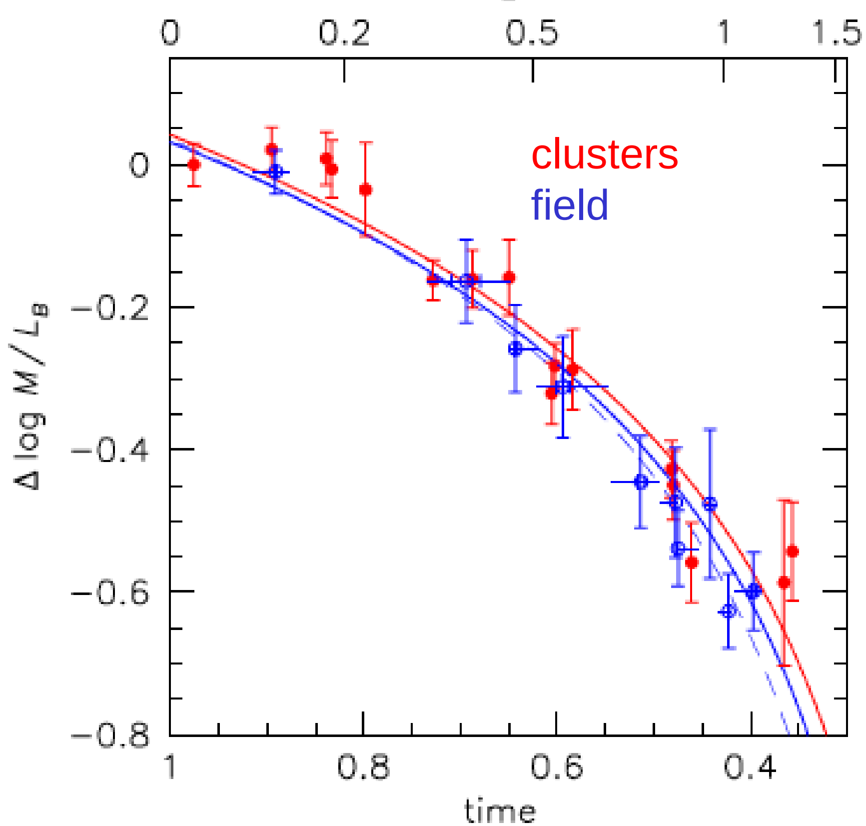
14/163 E+S0 have blue cores (defined s.t. rest frame δ(B-V) <-0.2)
Similar confirmation from galaxies with strong Hδ absorption

Environmental Dependence of FP Evolution: I

Treu et al Ap J 622, L5 (2005)



v Dokkum & vd Marel (astro-ph/0609587)

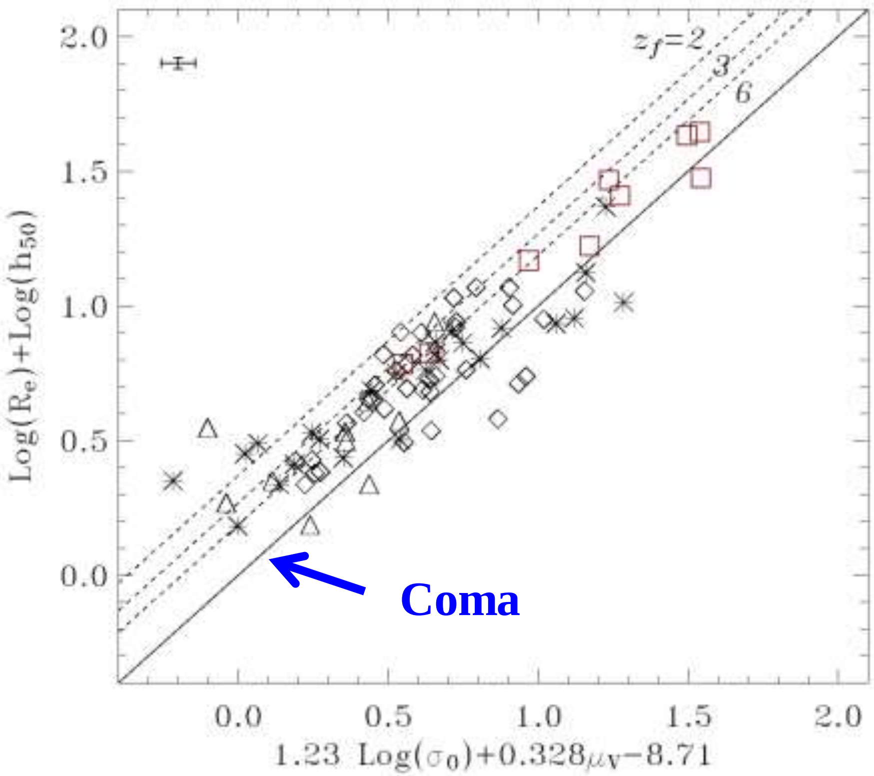


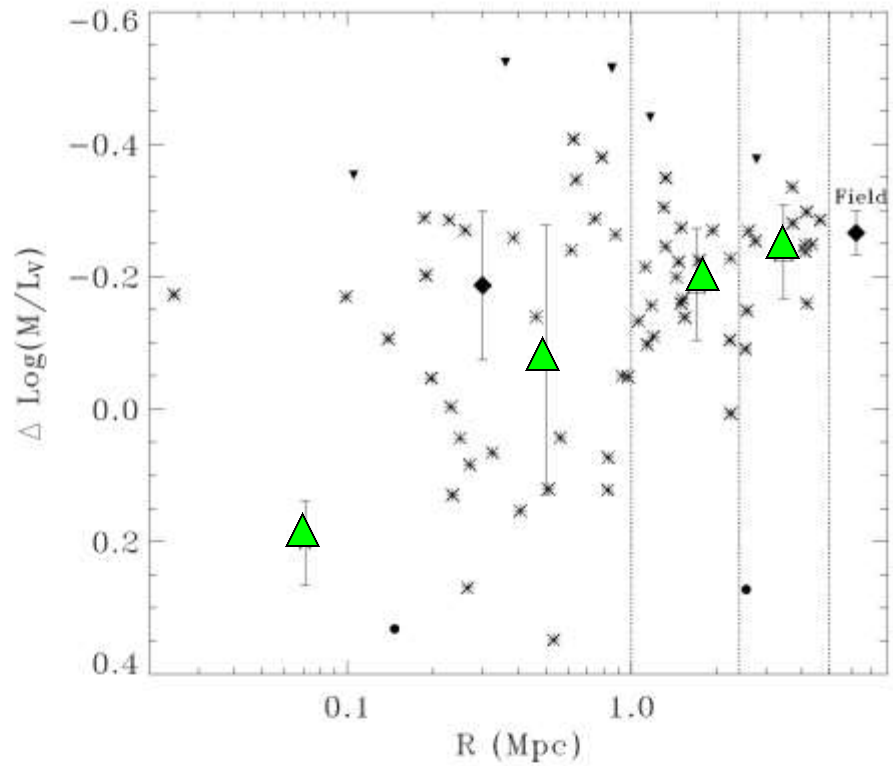
Only marginal trends seen with density (including SDSS):

- mass-dependent growth is a galactic-scale phenomenon?

- age differential (field vs cluster) ~ 0.4 Gyr @ z~0 (4%)

Environmental Dependence of FP Evolution: II



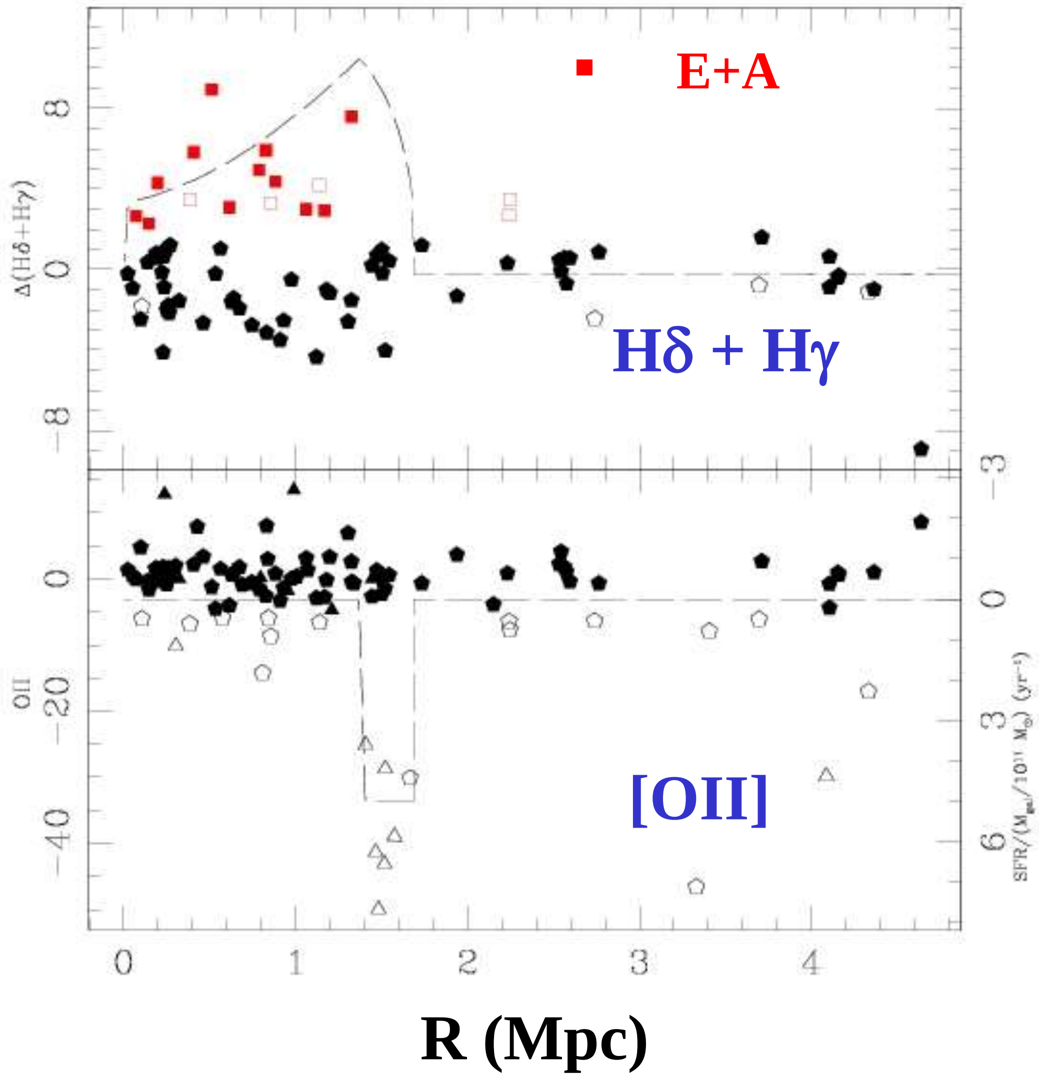


Radial dependence of FP: 71 spheroidals in Cl0024+16 (z=0.40)
Spheroidals in core are passively evolving since $z_F > 2$
Outermost spheroids have <u>younger</u> stellar pop^n ($\Delta t > 0.6$ Gyr)

Moran et al Ap J 634,977 (2005)

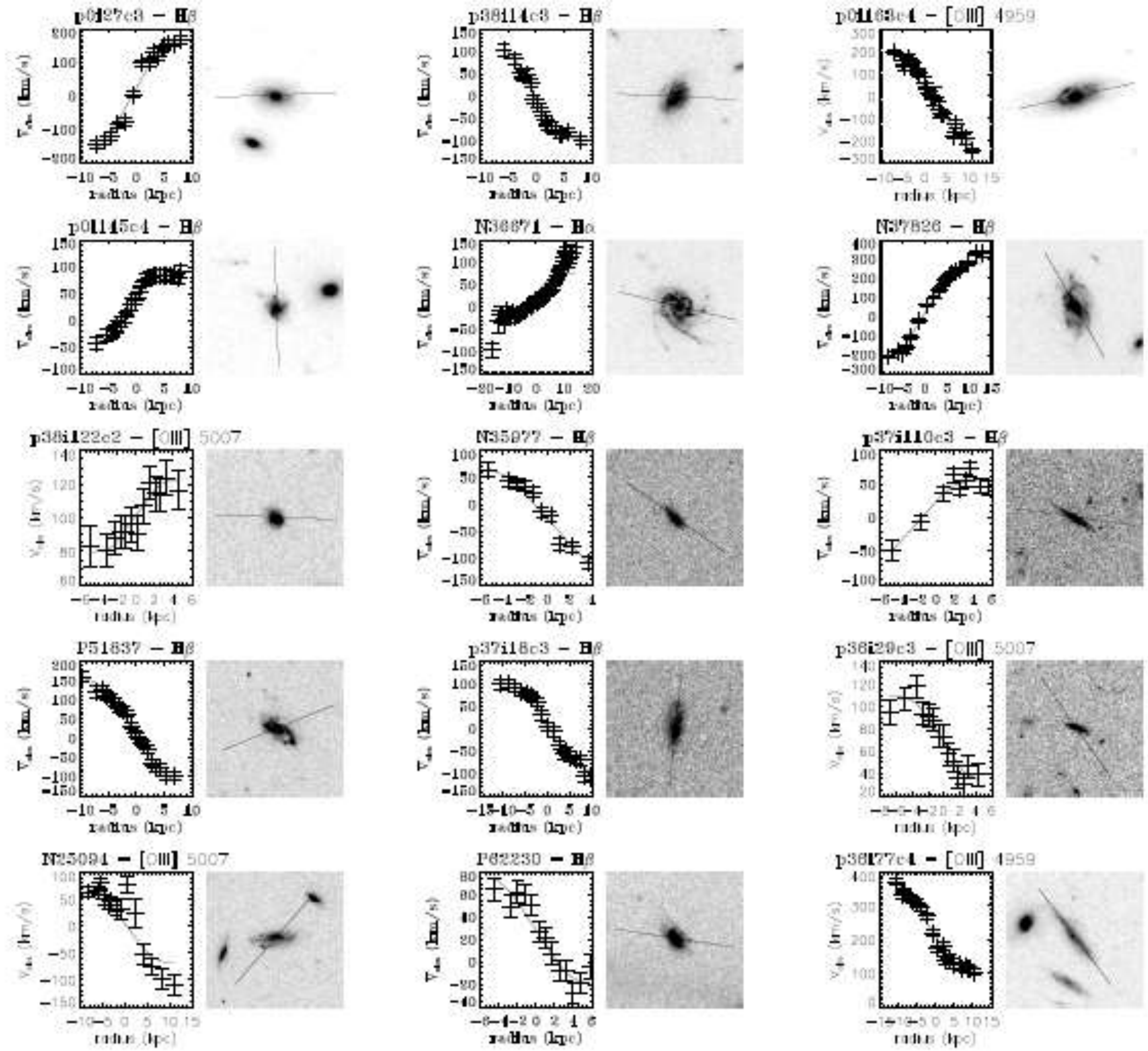
Radial Trends in Spheroidals: Diagnostics of SF

- Sharp onset of [OII] emitters at R_{VIRIAL}~1.5Mpc
- Subsequently enhanced Balmer absorption (Hδ)
- Recently-arrived field galaxies interact with ICM in cluster environs
- Model illustration: 200 Myr burst at R_{VIRIAL} involving 1% burst by mass
- "Environmental rejuvenation" as important as mass-dependent trends



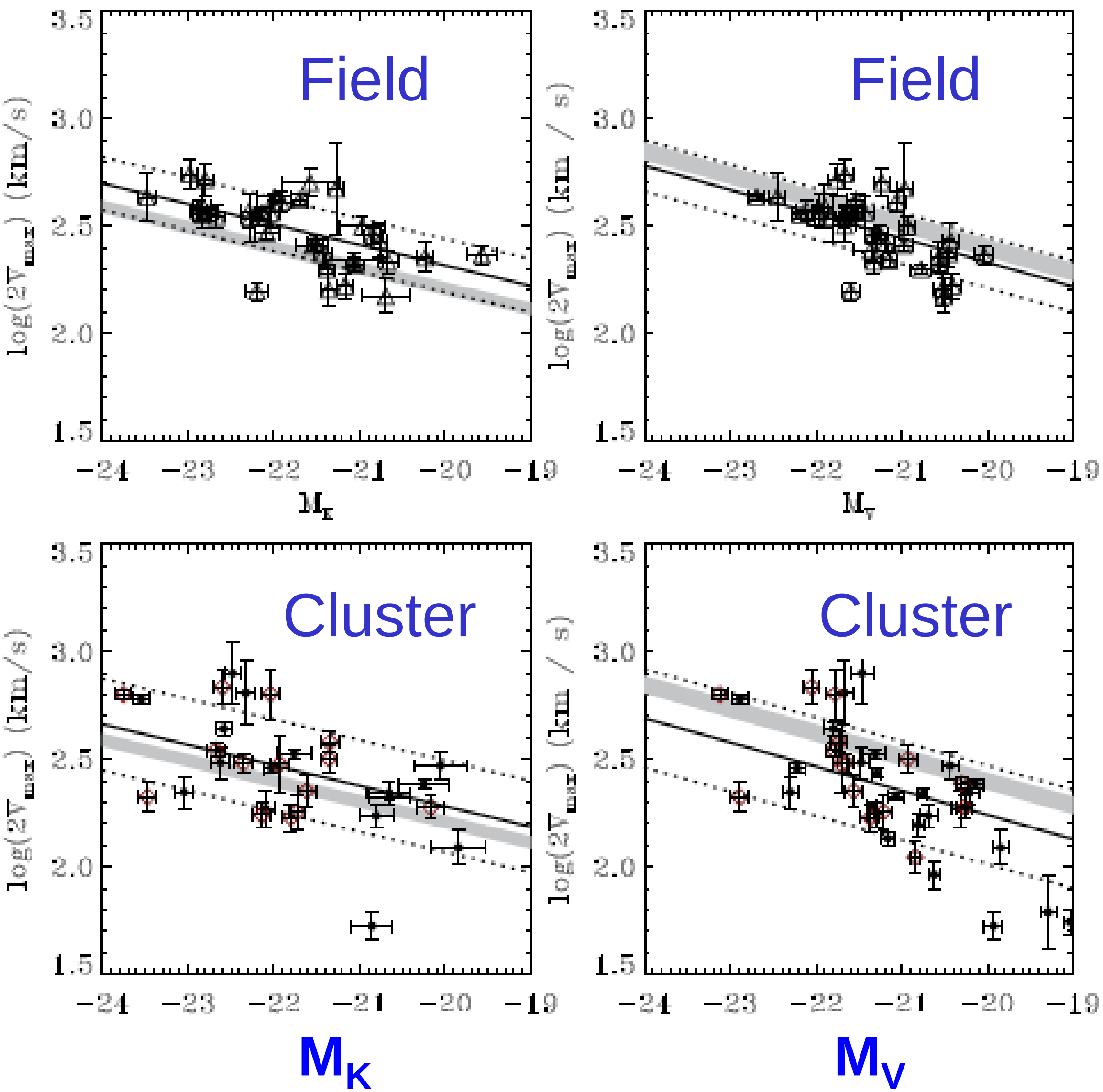
Field spheroidals undergo final activity during infall

Effect of Environment on Disk Galaxies



Rotation curves for matched sample of ~100 z~0.5 cluster & field spirals

Disturbed Dynamics in Cluster Spirals



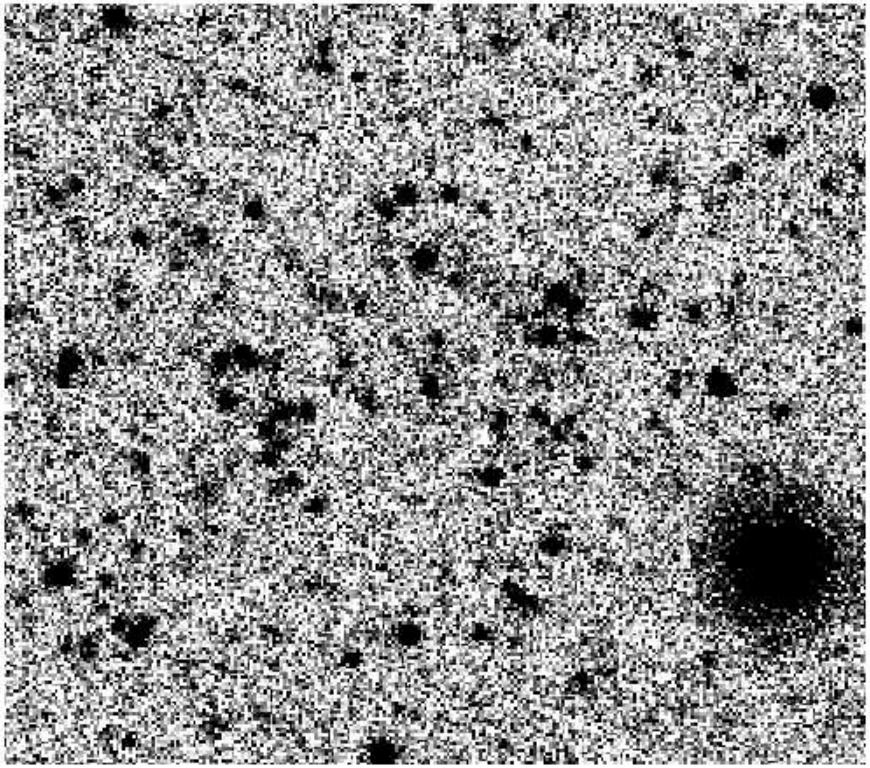
Scatter in cluster TF relation is 2 × that in field!

Effect same in both V and K band so not due to M/L (or dust): kinematic origin (spatial dependence suggests harassment)

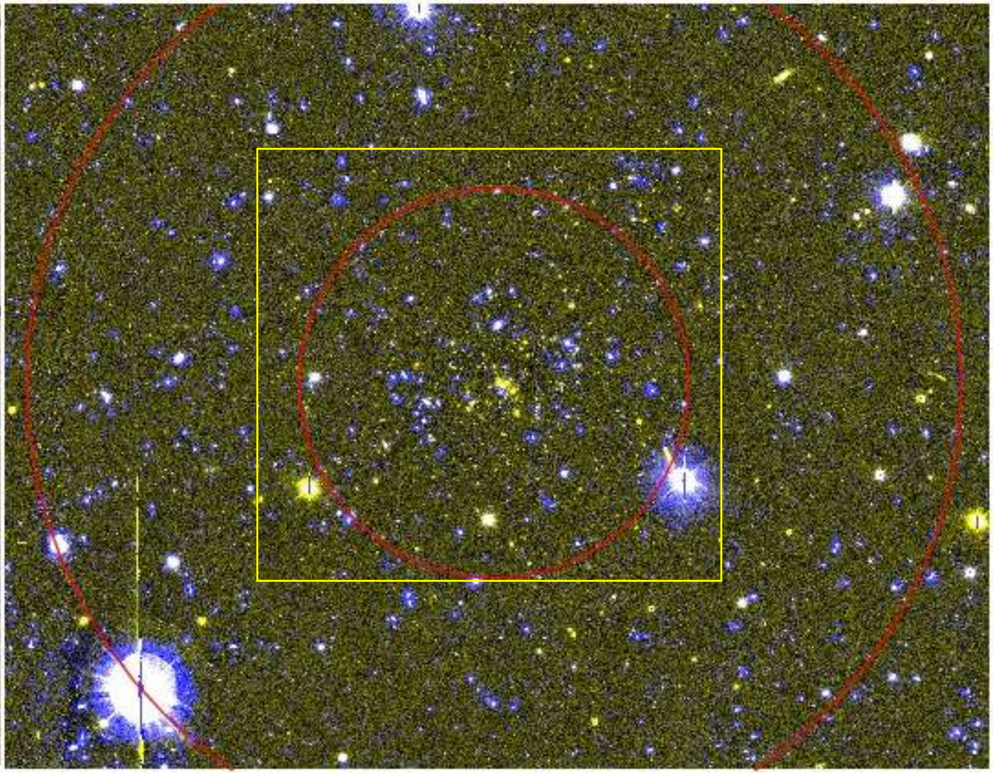
Moran et al. 2006, ApJ submitted

Spirals to S0s?
GALEX Finds a `Smoking Gun'

NUV (2500Å) observed for 15ks (Cl0024+16) & 45ks (MS0451-03)
Probes MS star formation on finer timescales (10^7-10^8 yrs)

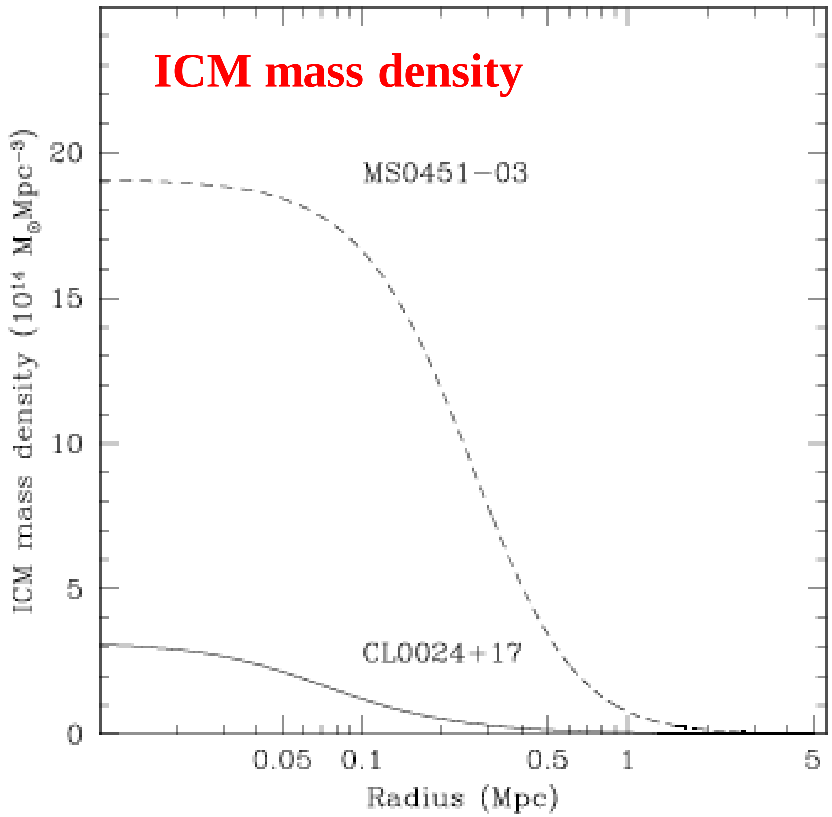


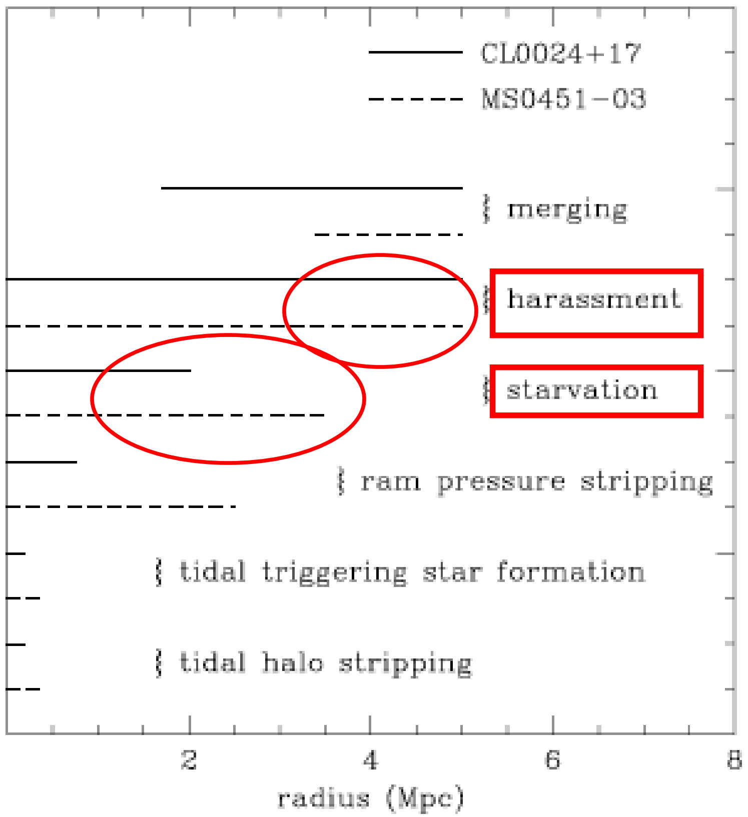
GALEX NUV



GALEX NUV - CFHT I

Two Complementary Clusters



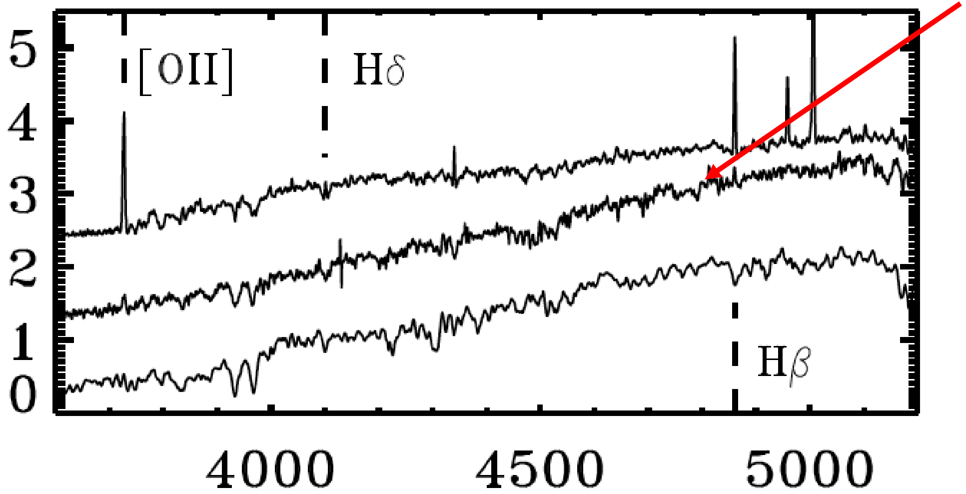


Clusters chosen to be very different in their X-ray properties

MS0451-03 has 8× luminosity and 2× temperature of Cl0024+16

Influence of ICM on infalling galaxies will occur at different radii

Passive Spirals: In Transition to S0s

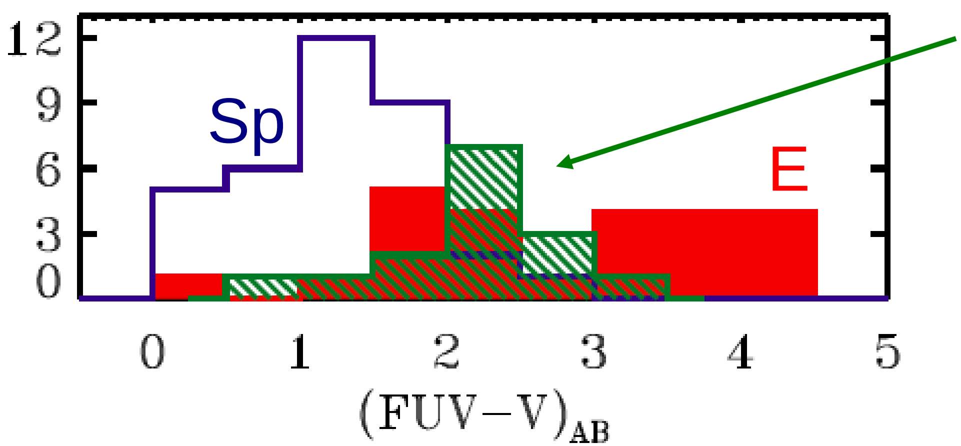


No optical emission (OII <5 Å)

- lack of star formation

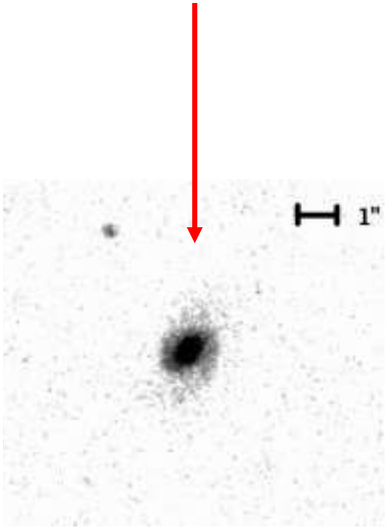
Visible spiral structure

- no major disruption to the structure of the galaxy (e.g. major merger)



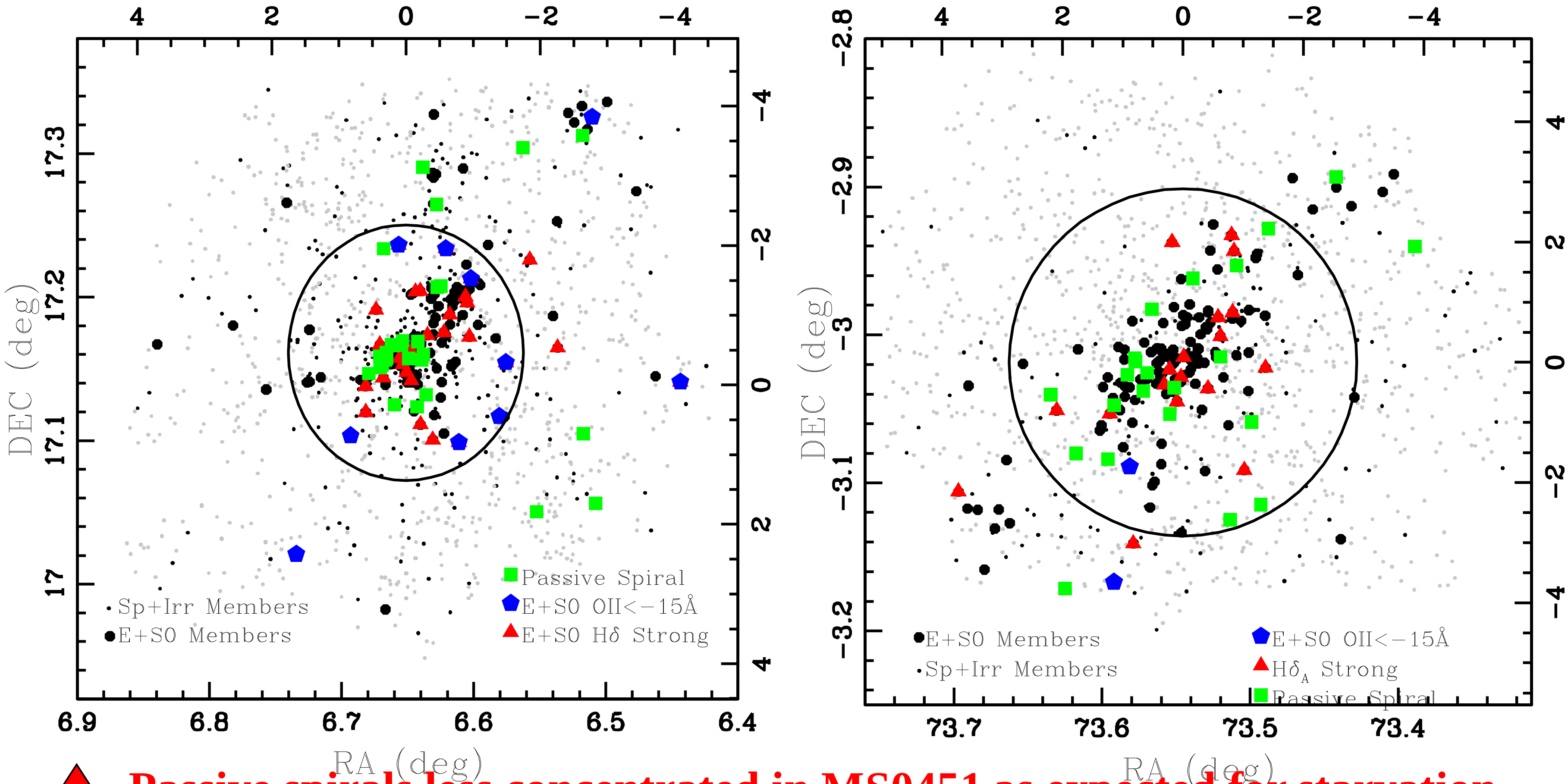
But strong FUV emission!

Passive spirals caught in final decline in SFR in last 10^7-10^8 yr



Moran et al Ap J 641, L97 (2006)

Passive Spirals: Cl 0024 vs. MS 0451



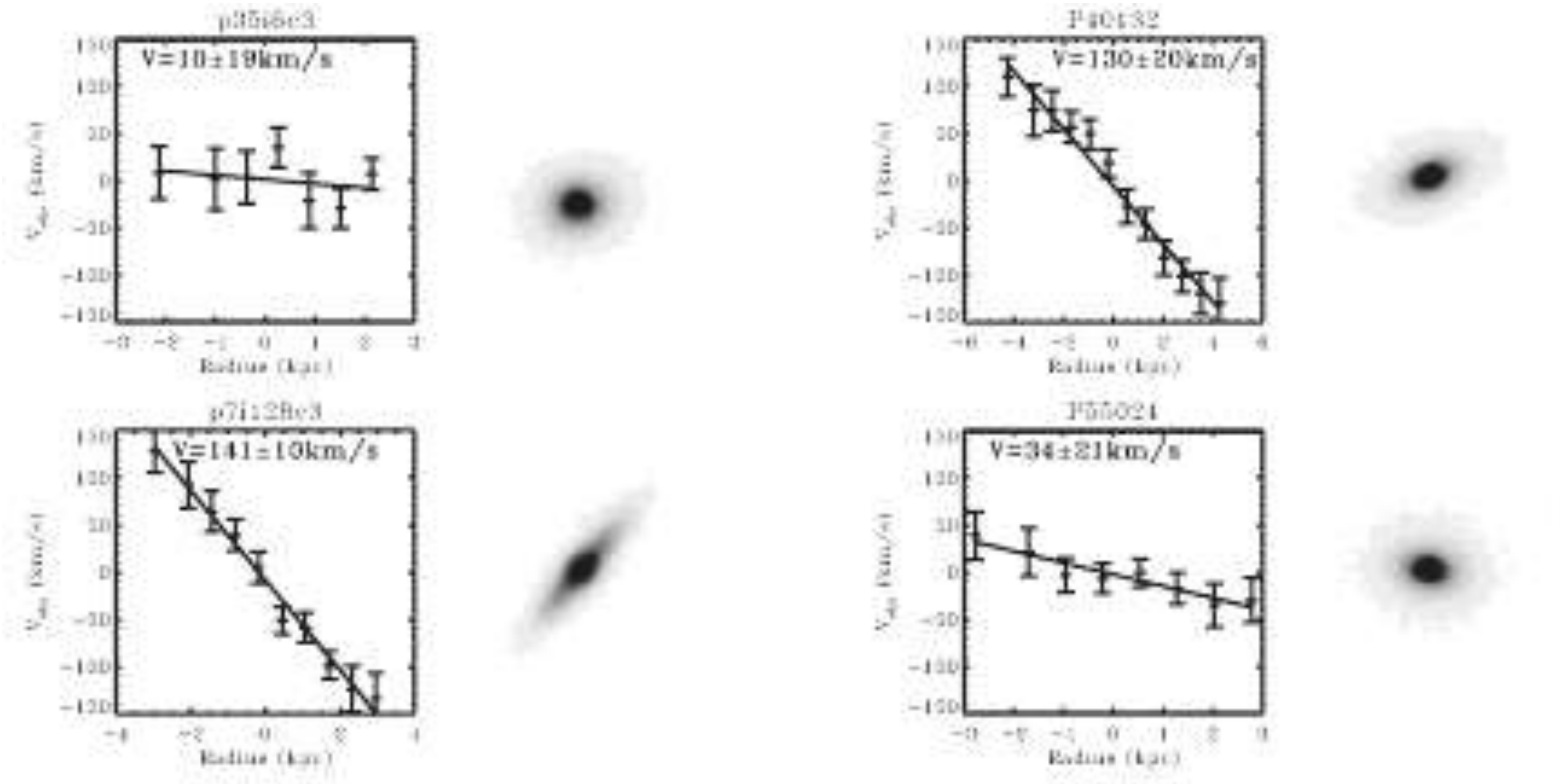
- Passive spirals less concentrated in MS0451 as expected for starvation
- Abundances ÷ timescales sufficient for production of local S0s

Watching Growth of S0s: Absorption Line Dynamics

Can we dynamically separate Es and S0s to z~1?

v_{ROT}, σ, e for: Cl0024/MS0451: 72 E/S0s z ~ 0.4-0.5

GOODS-N: 40 Field E/S0s 0.4<z<0.6



Dynamically-classified S0s:

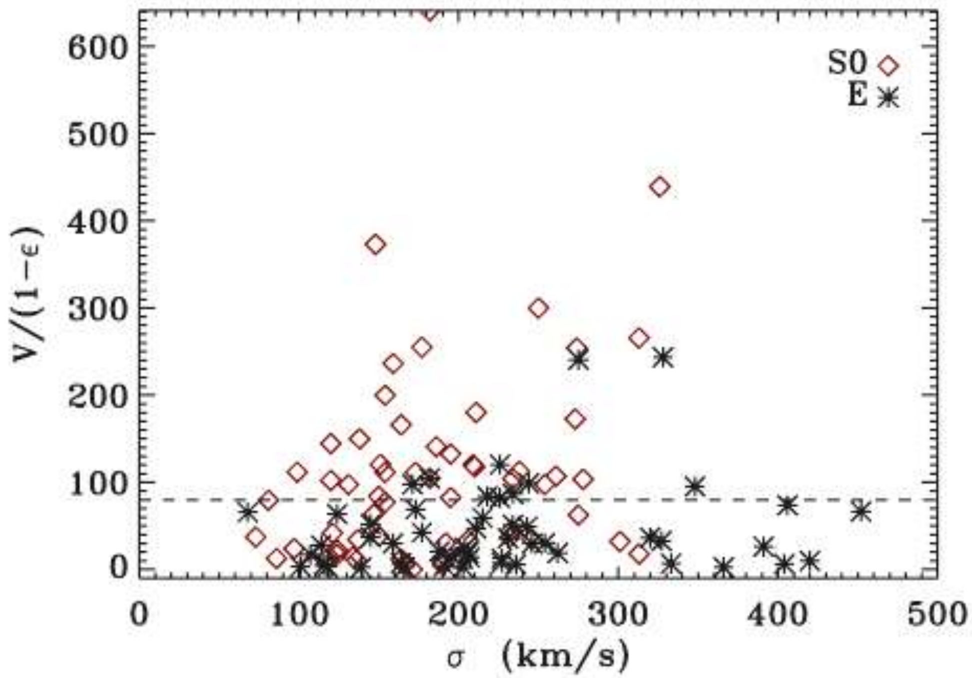
Find v/(1-ε) vs σ is best discriminator

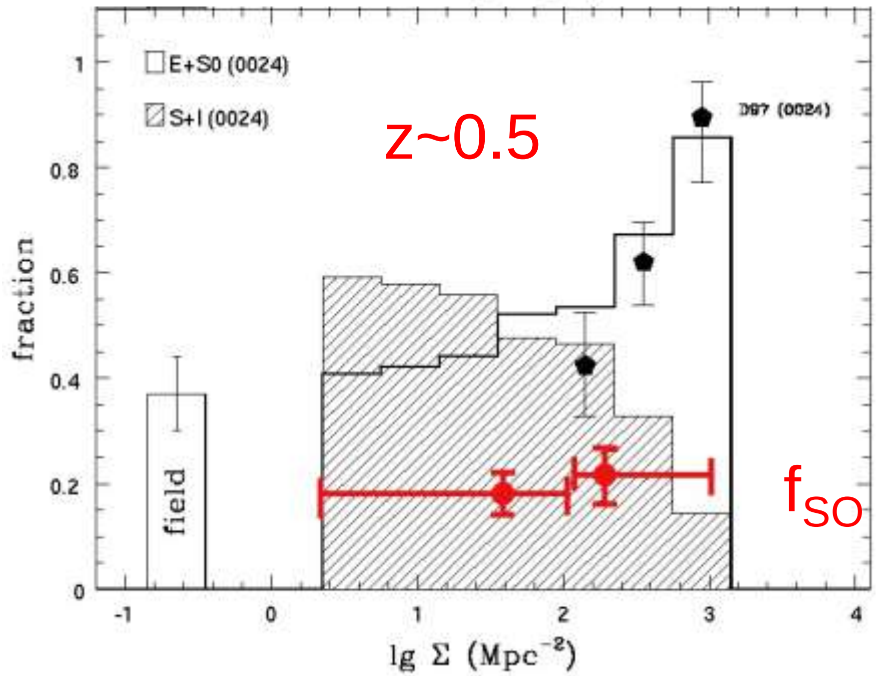
Using this find:

f(S0) ~20±5% at z~0.5 over 0.5< lg Σ < 2.5

At z=0 Dressler found f(S0)>40% in this Σ range: significant growth!

Promising method..extending it to larger samples & higher z





Downsizing in Field Galaxies

Palomar+DEEP2 survey of mass assembly in field galaxies (Bundy et al astro-ph/0512465)

Unique survey: DEEP2 spectroscopic z's, IR-based stellar masses (K_{AB}<21.5), 4 fields spanning 1.5 deg^2, 8000g

Related morphological study in GOODS (Bundy et al Ap J 621, 625 2005)

<u>Results</u>

- Little growth in massive quiescent galaxies; most evolution at lower mass: mirrored by decline in SF component
- Detection of `quenching mass' M_Q above which SF ceases (as determined by any of morphology, color, OII)
- Strong evolution in this threshold mass: $M_Q \propto (1+z)^{3.5}$
- Little environmental density dependence in threshold mass

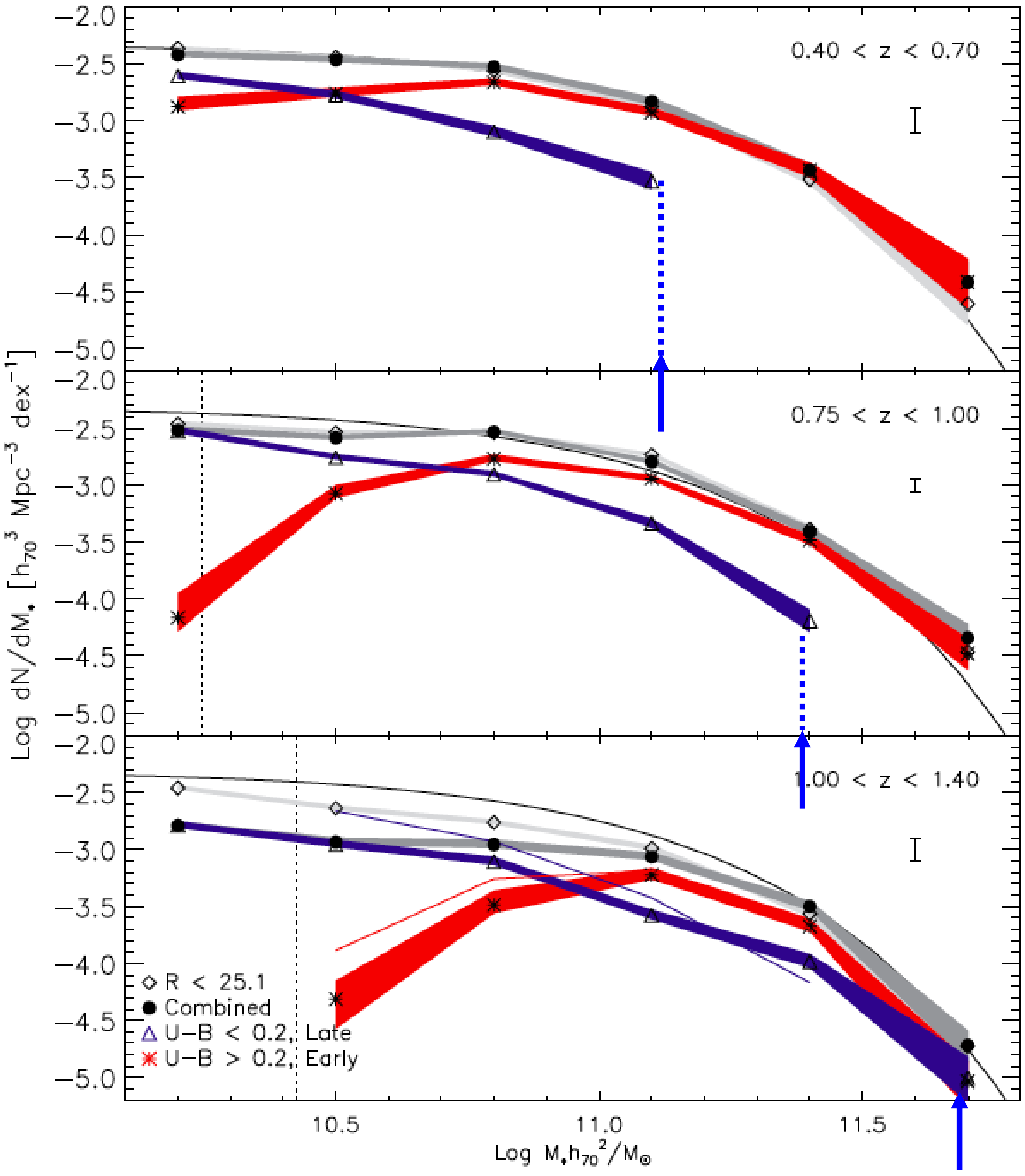
Downsizing & Star Formation

- Using rest-frame U-B color as a discriminant, a threshold stellar mass is apparent above which there is no SF

- Mass threshold increases from ~10^{11} $M_\odot$ at z~0.3 to ~$10^{12} M_\odot$ at z >1

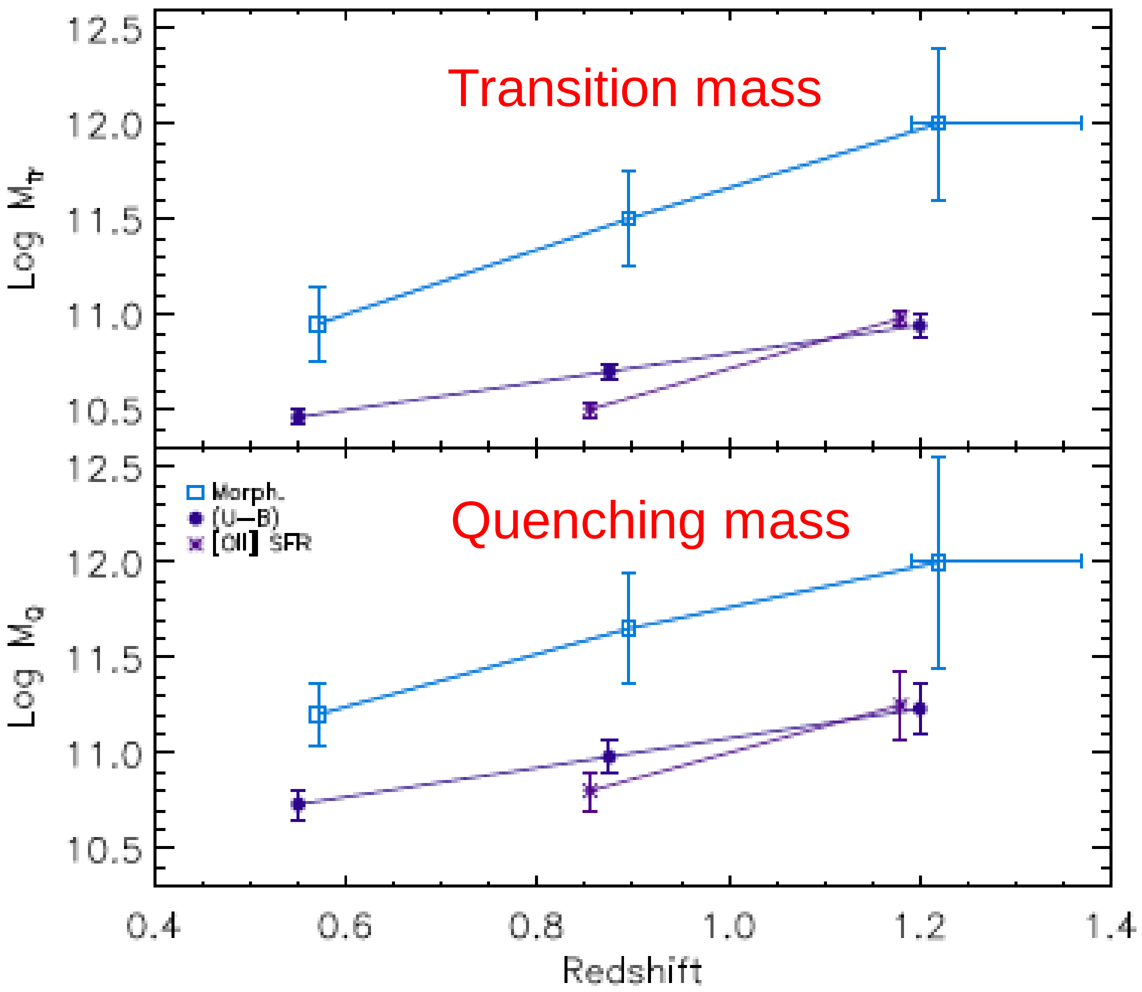
- Stable from field-to-field (V/bin~2.10^6 Mpc^3)

- Little change for high mass quiescent galaxies over z<1



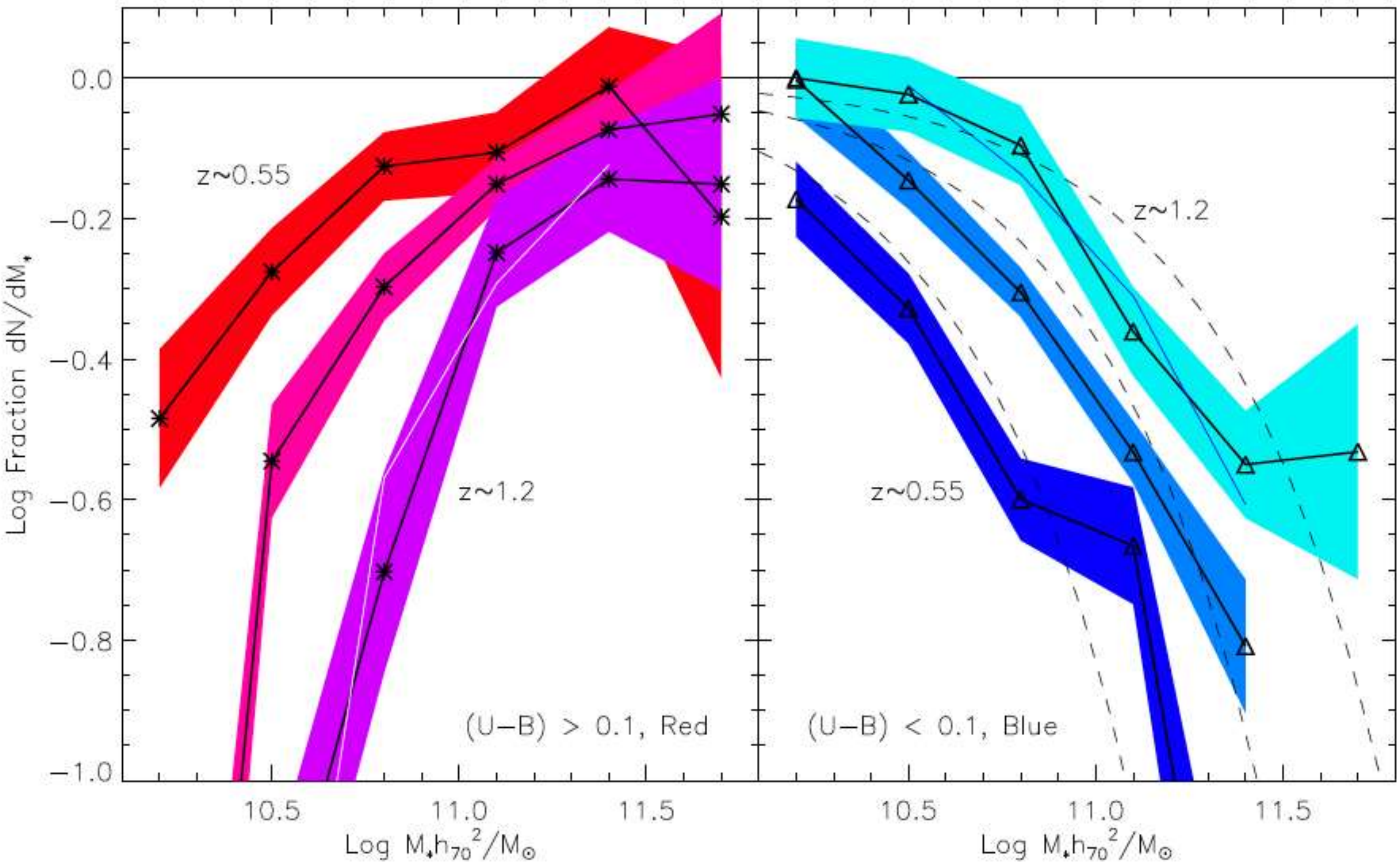
Bundy et al (astro-ph/0512465)

Evolution of Threshold Mass



Although SF cut-off can be defined in various ways, increase of mass with z is a robust result

The `Declining Blues' become the `Rising Reds'

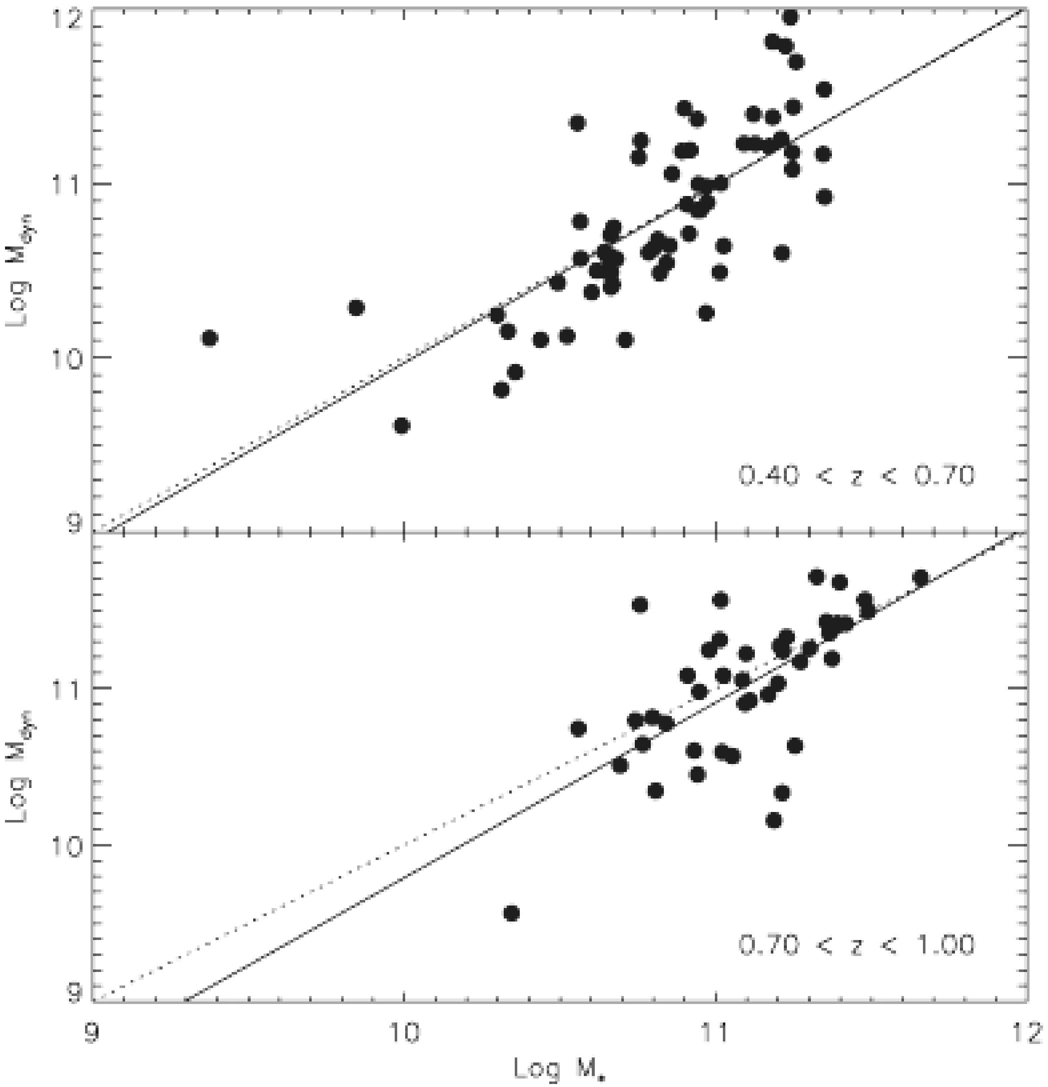


Inconsistent with dominant assembly from dry mergers

Testing Mass Assembly Dynamically

For 142 GOODS-N morphologically-selected spheroidals we can directly compare IR-based stellar masses with dynamical ones (Bundy et al in prep)

This allows us to estimate dynamical mass functions for a very large sample of spheroidals in GOODS

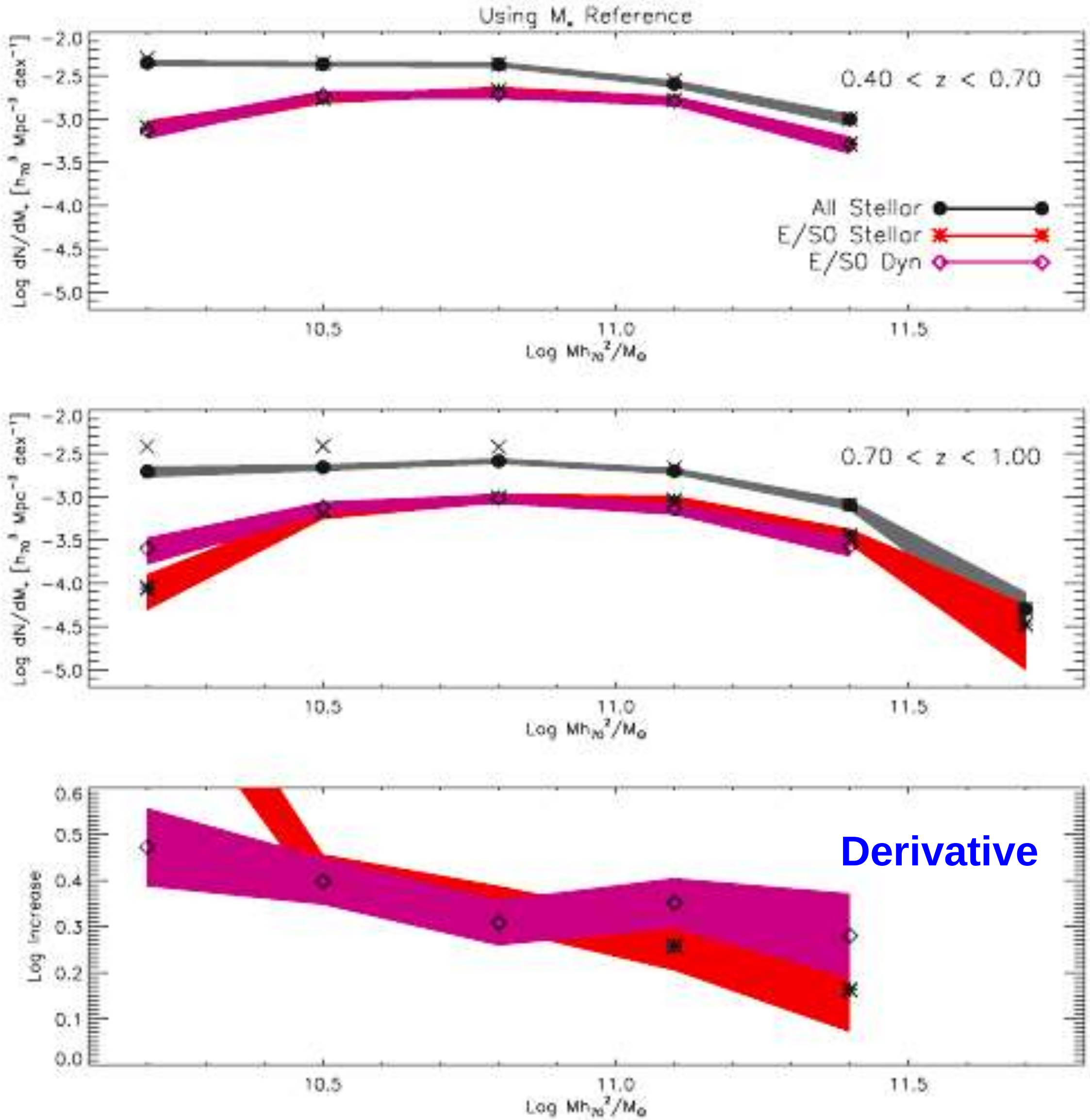


Downsizing in Mass Assembly

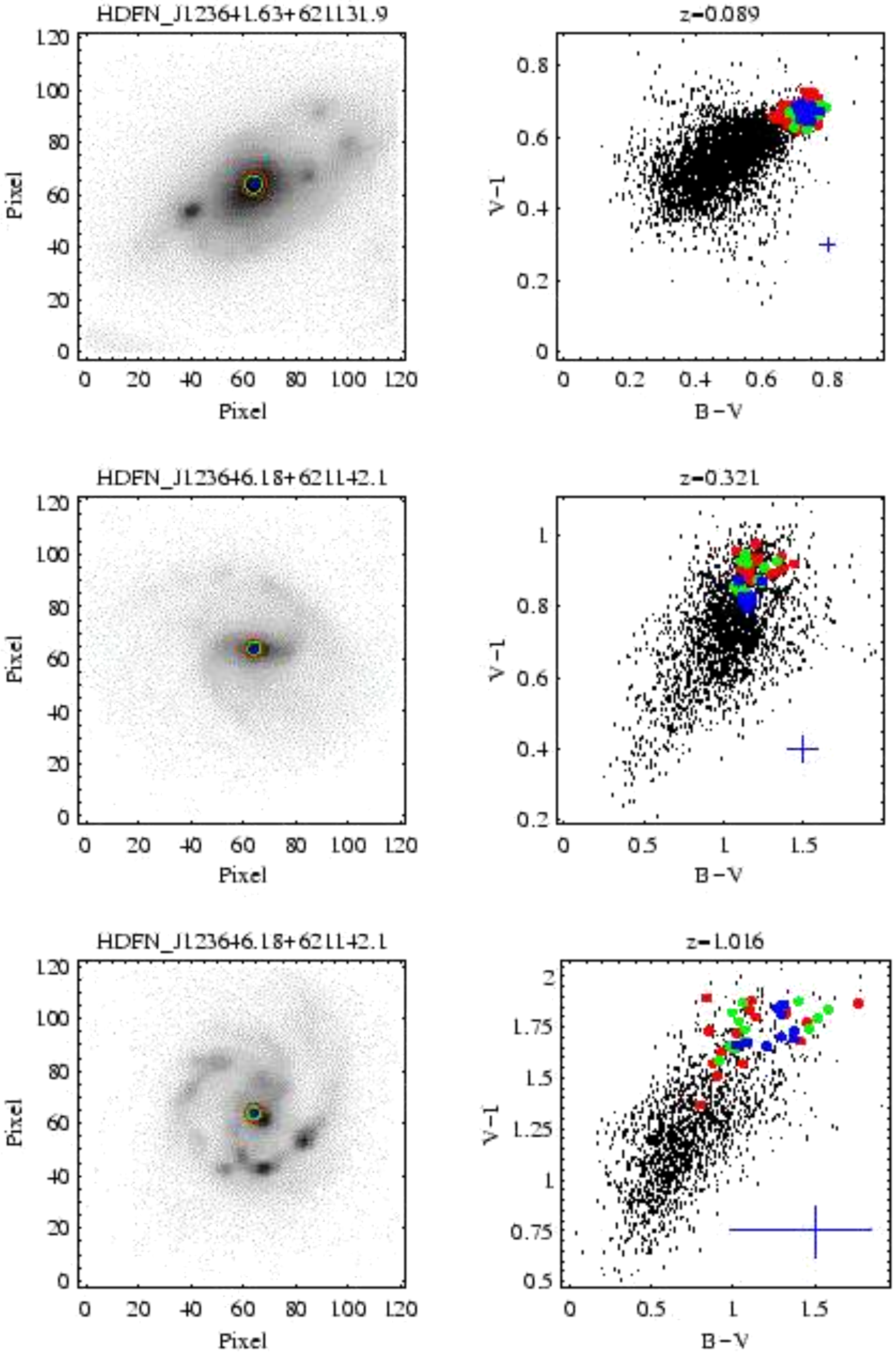
Distinguish between downsizing in *SF suppression* and that in *assembly*:

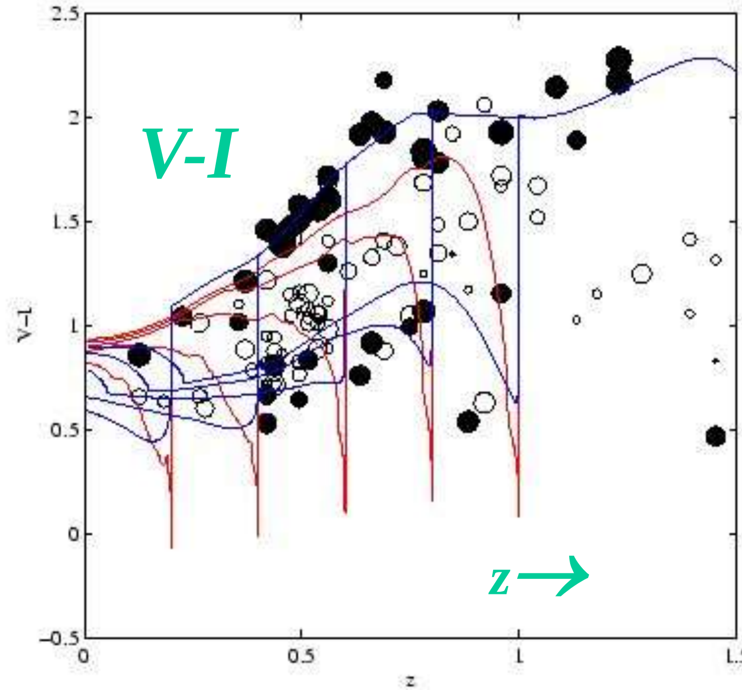
Construct <u>time derivative</u> of mass function: growth as a function of mass both dynamically and via stellar masses.

Similar trend:
low mass spheroidals grow much faster than high mass ones



Bulge Assembly

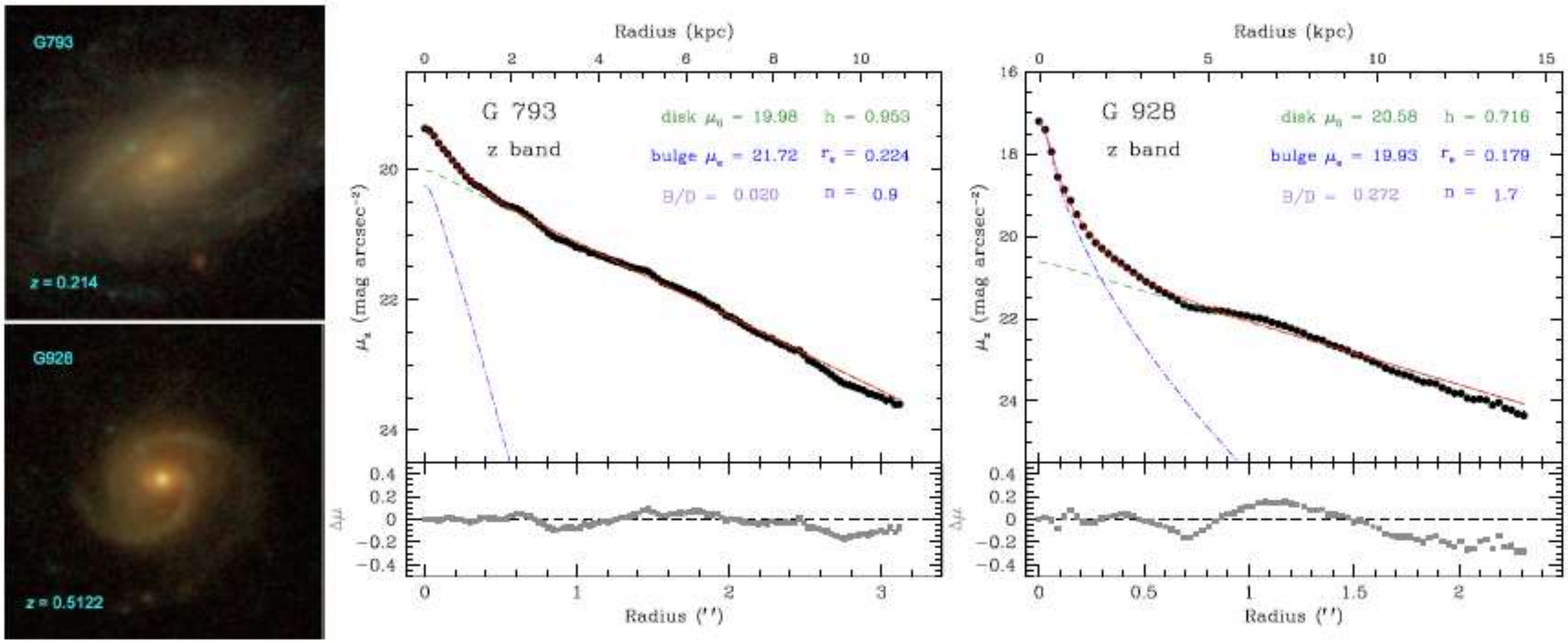




HDF bulges (˚) are bluer & more diverse in their colors than most passively-evolving spheroidals (•)

Ellis, Abraham & Dickinson ApJ 551, 111 2001

Fundamental Plane of Intermediate z Bulges: I



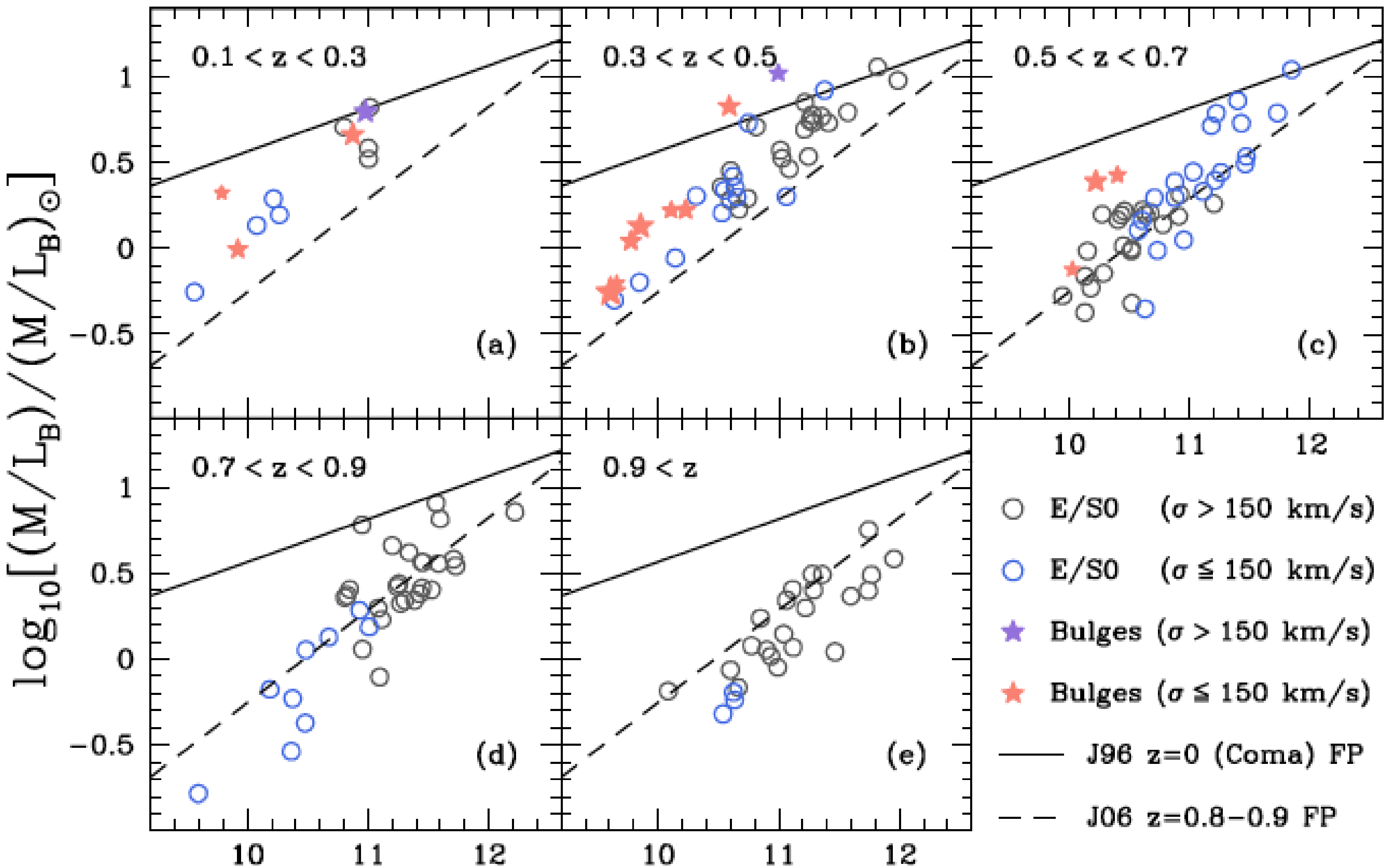
GOODS sample: N~60 bulges 0.2<z<0.6

HST photometric bulge/disk decomposition

Keck: bulge stellar velocity dispersions, disk rotation

MacArthur et al (in prep)

Fundamental Plane of Intermediate z Bulges: II



Bulges follow trends located for low mass Es: continued growth

Conclusions

- Dynamical data offers valuable insight into the processes that govern the assembly history of galaxies, complementing larger photometric analyses

- Environmentally-driven processes are just as important as, and maybe independent of, galactic-scale feedback effects

- Detailed case studies of clusters offer valuable insight into the processes involved: e.g. passive spirals & the continued production of S0s - a significant fraction of red light today

- Data on `downsizing' in field samples offers many puzzles for theorists: M_Q (z), weak Σ dependence

- Dynamical evidence suggests downsizing is not just related to suppression of SF but may extend also to assembly

The Fundamental Plane for Spheroidals: Empirical correlation between size, L and σ_*

Considerably superior as a tracer of evolving mass/light ratio:

<u>Dynamical mass</u>:

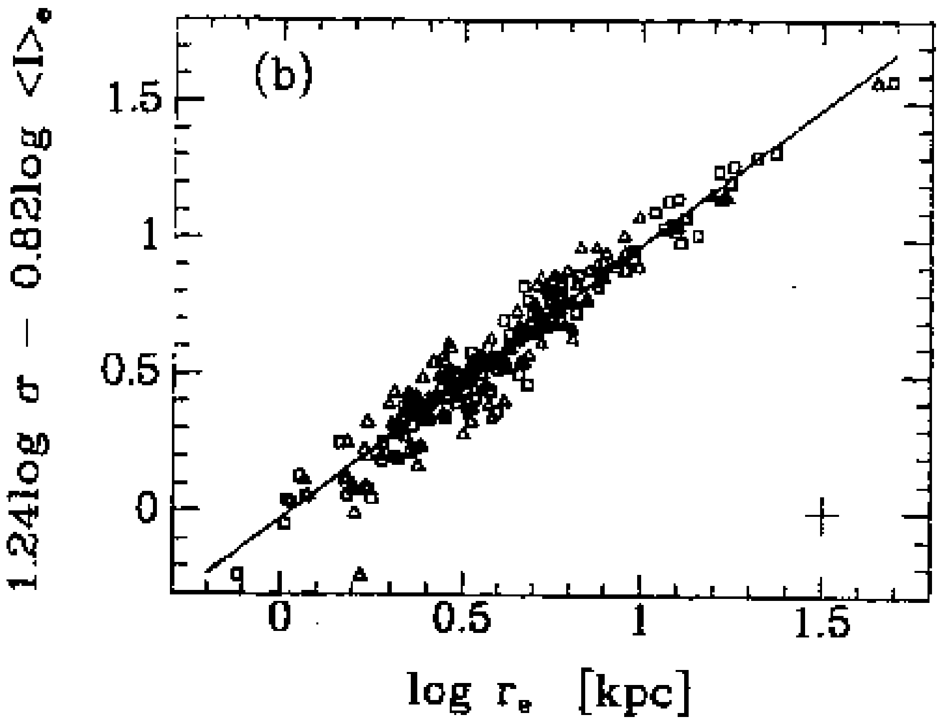
- no IMF dependence

- Closer proxy for halo mass

<u>Tough to measure:</u>

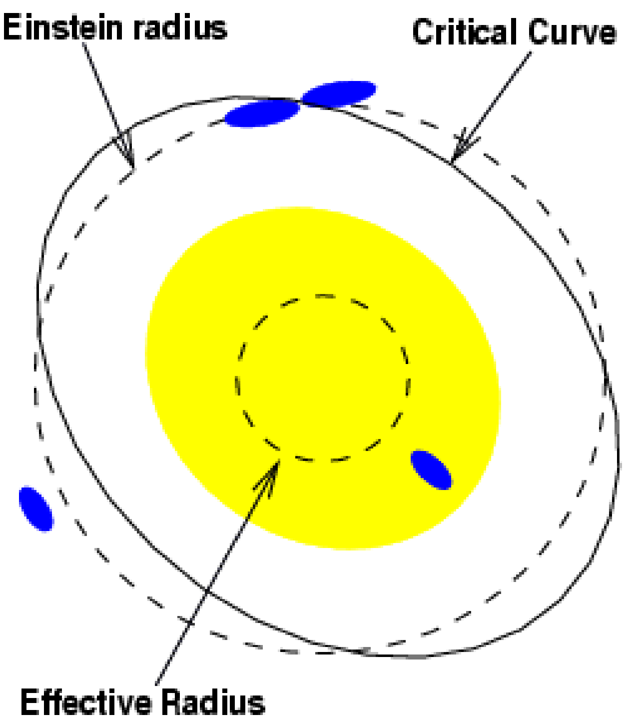
- σ demands high s/n spectra

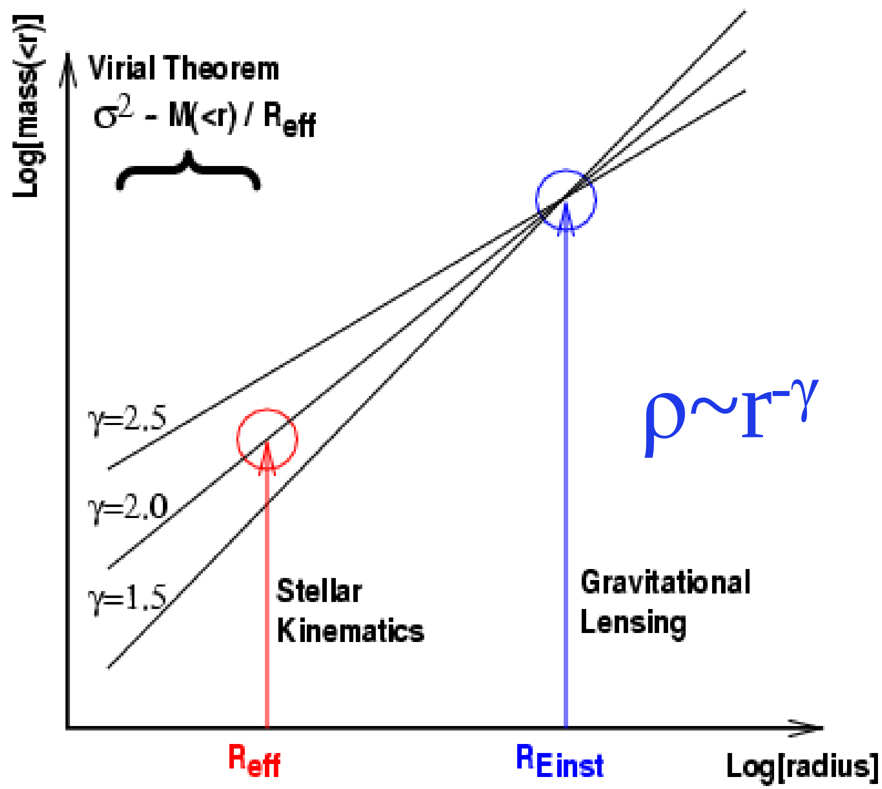
- large samples difficult



Dressler et al. 1987; Djorgovski & Davis 1987;
Bender Burstein & Faber 1992; Jorgensen et al. 1996

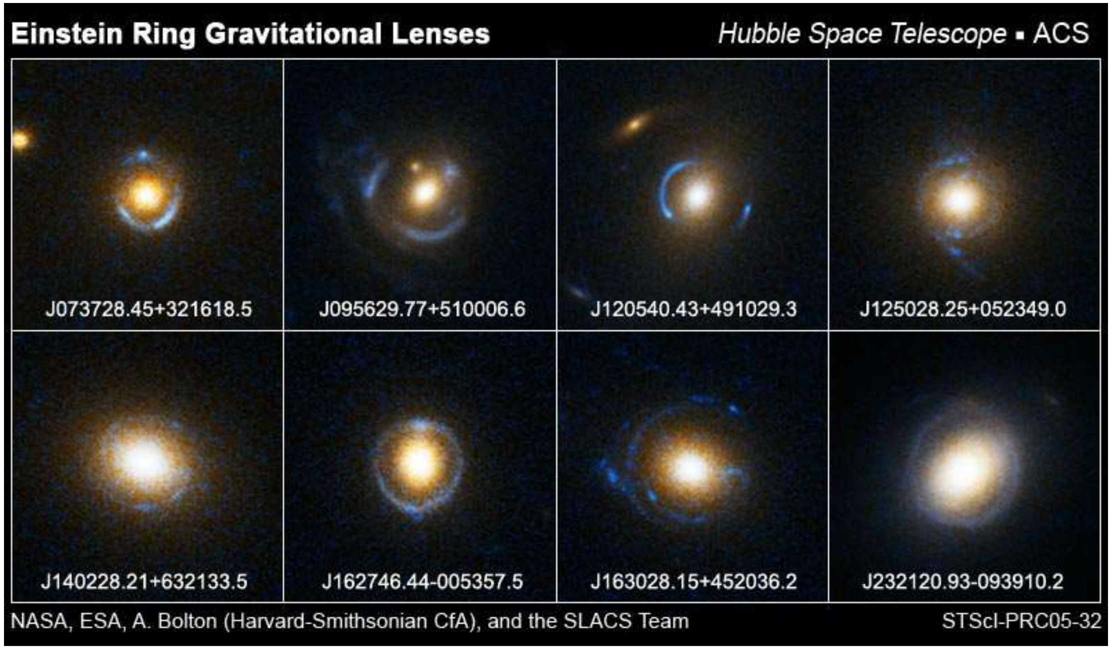
Combining Lensing & Stellar Dynamics

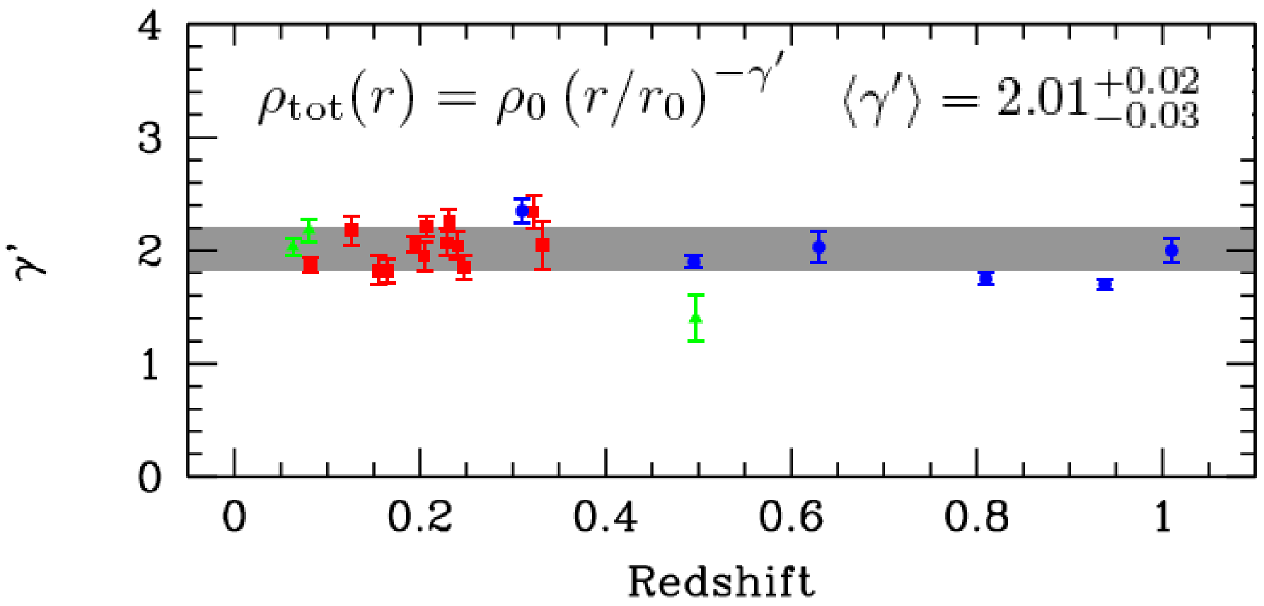




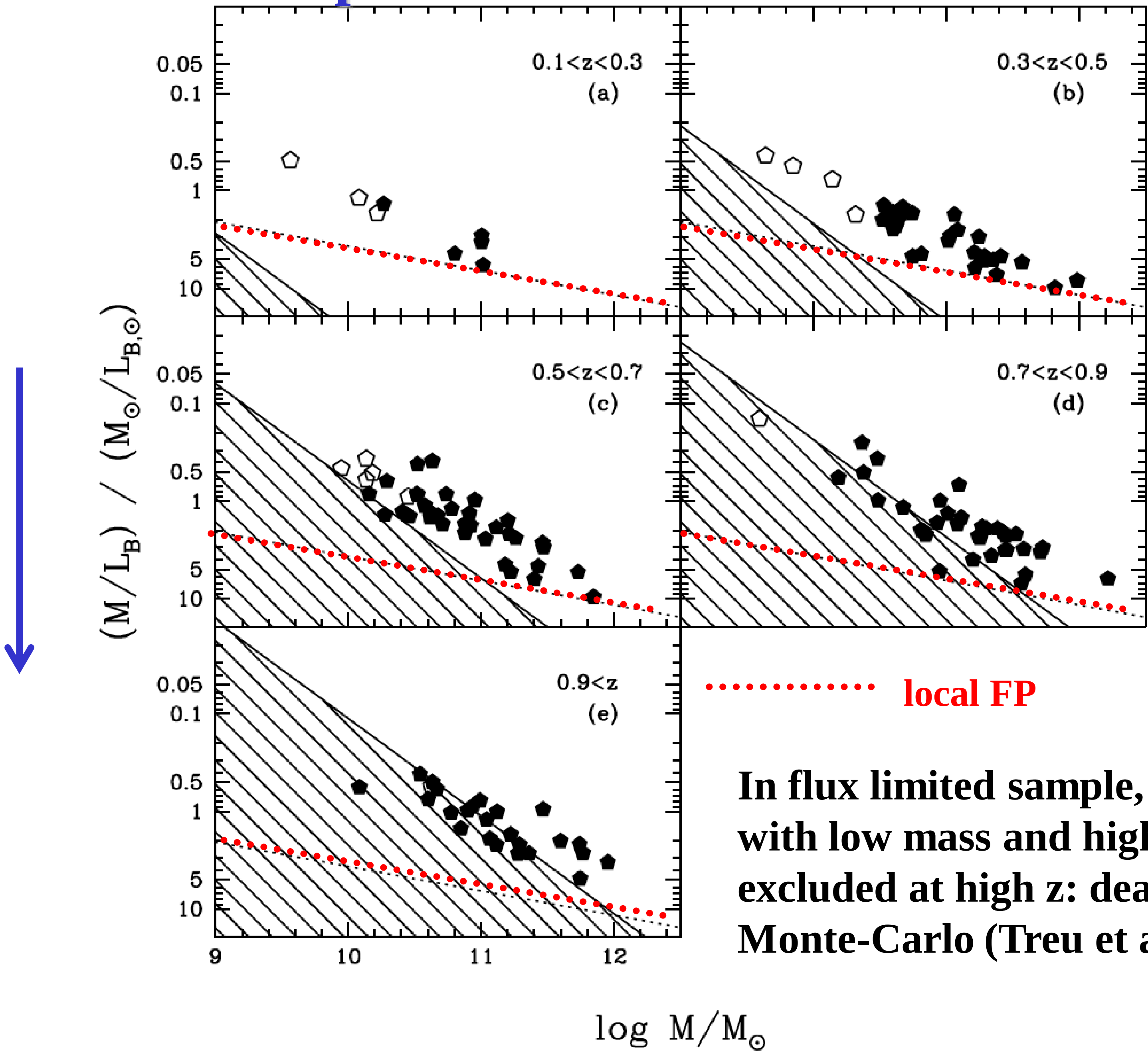
On galactic scales, lensing and stellar dynamics provide complementary constraints on the mass distribution. In combination, therefore, they constrain the slope, γ, of the total mass distribution

Remarkable Uniformity in Total Mass Profile



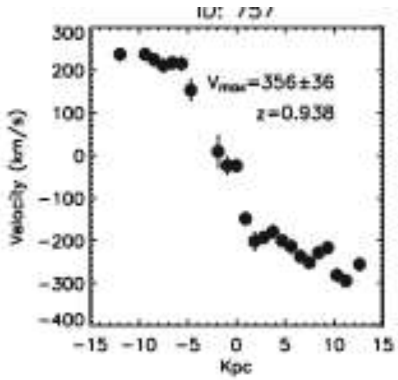


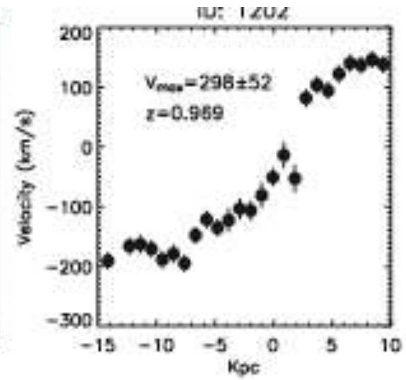
Proper Account of Selection Biases

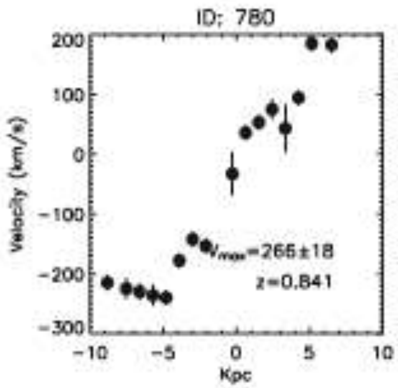


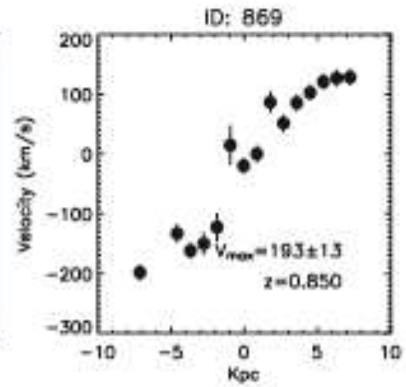
In flux limited sample, objects with low mass and high M/L are excluded at high z: dealt with full Monte-Carlo (Treu et al 2005b)

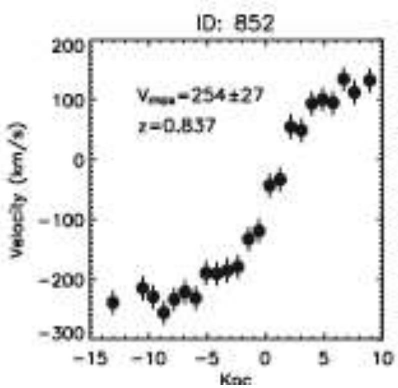
Dynamics of GOODS-N Spirals

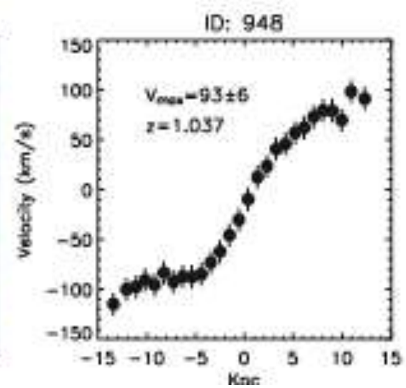






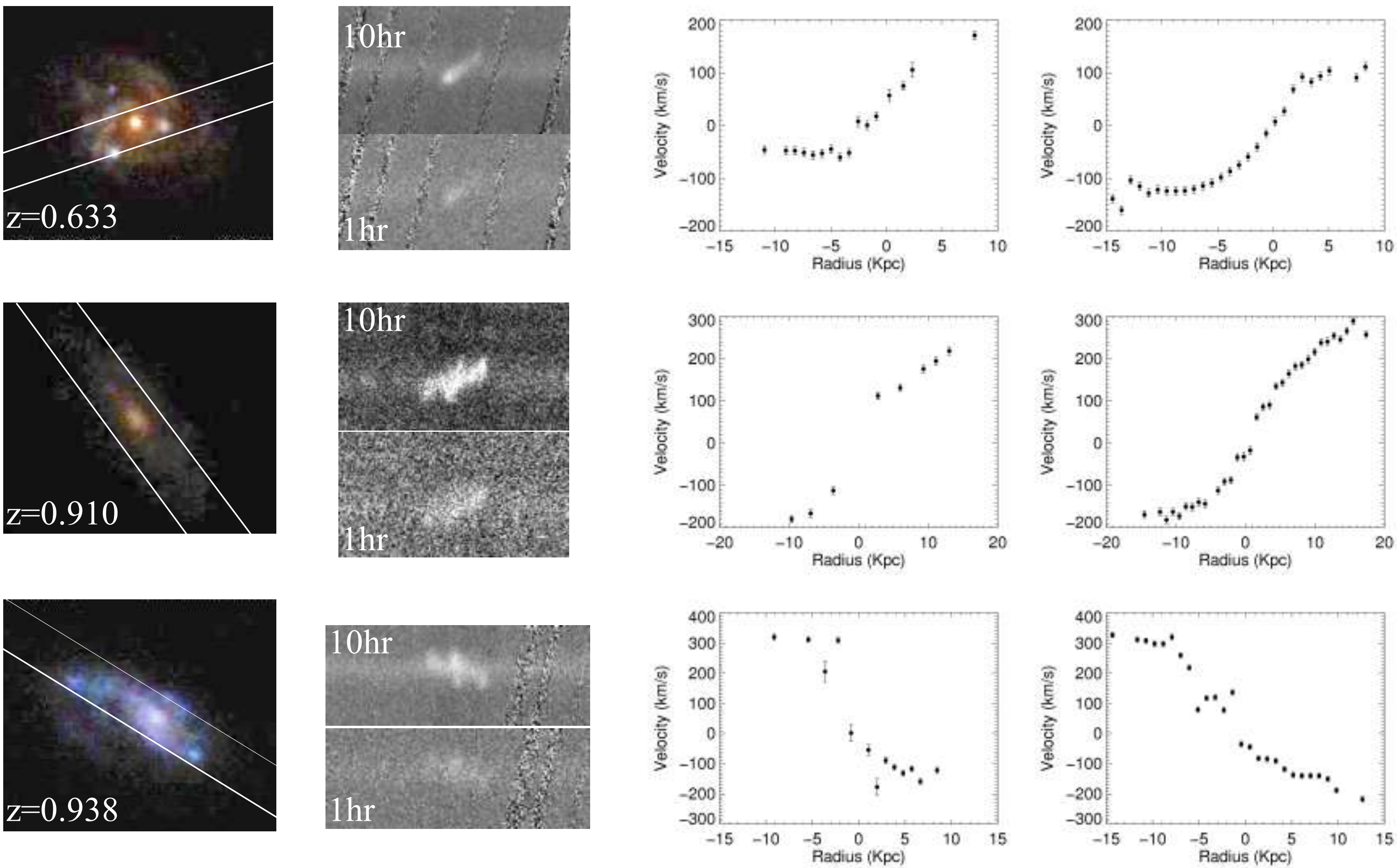




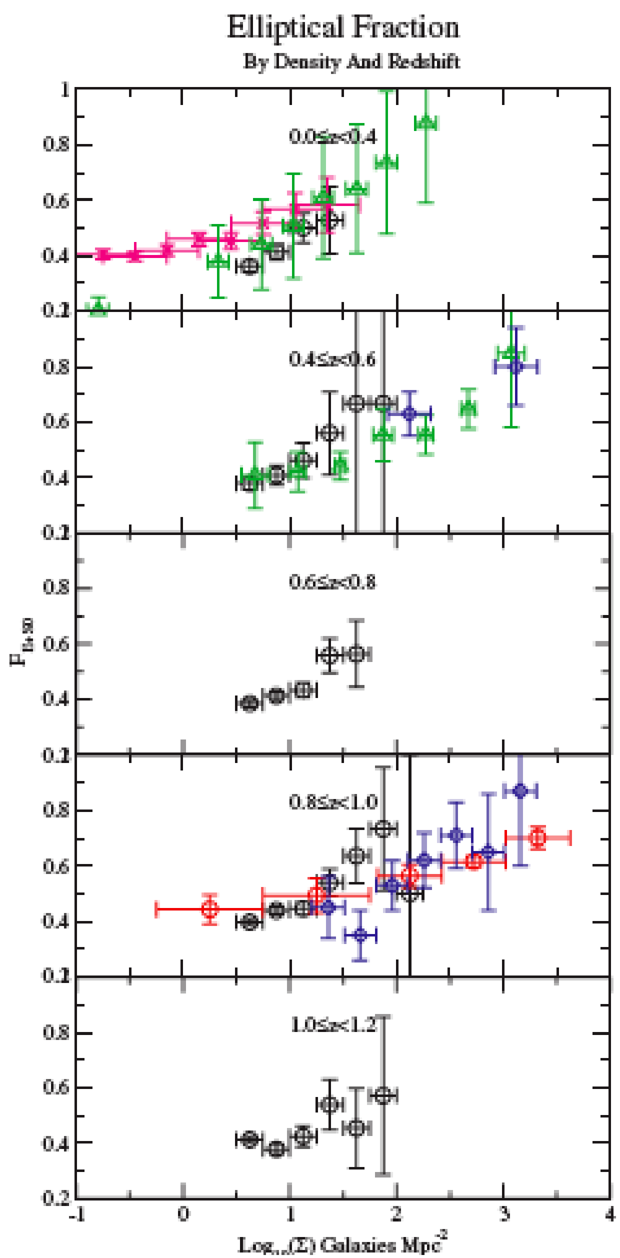


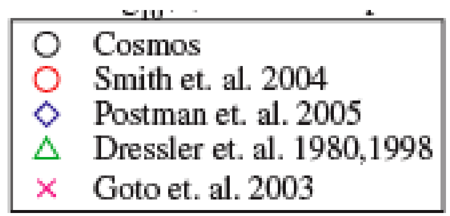
Rotation Curves: Benefits of Long Integrations

ACS *viz* Image | DEIMOS Spectra | 1hr Rotation Curve | 10hr Rotation Curve

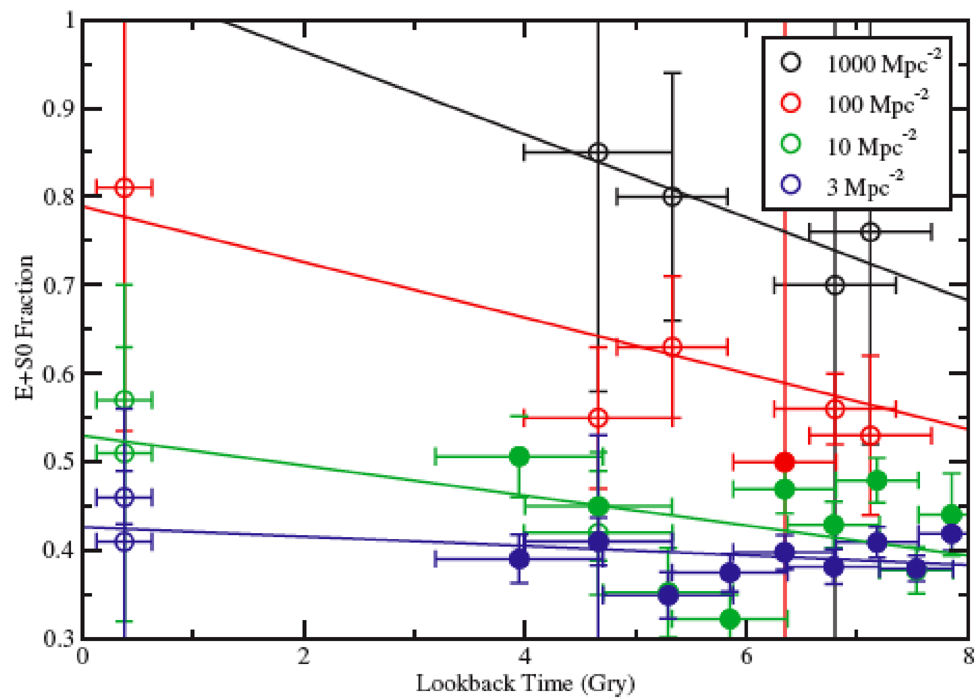


T-Σ from COSMOS 2deg² HST survey



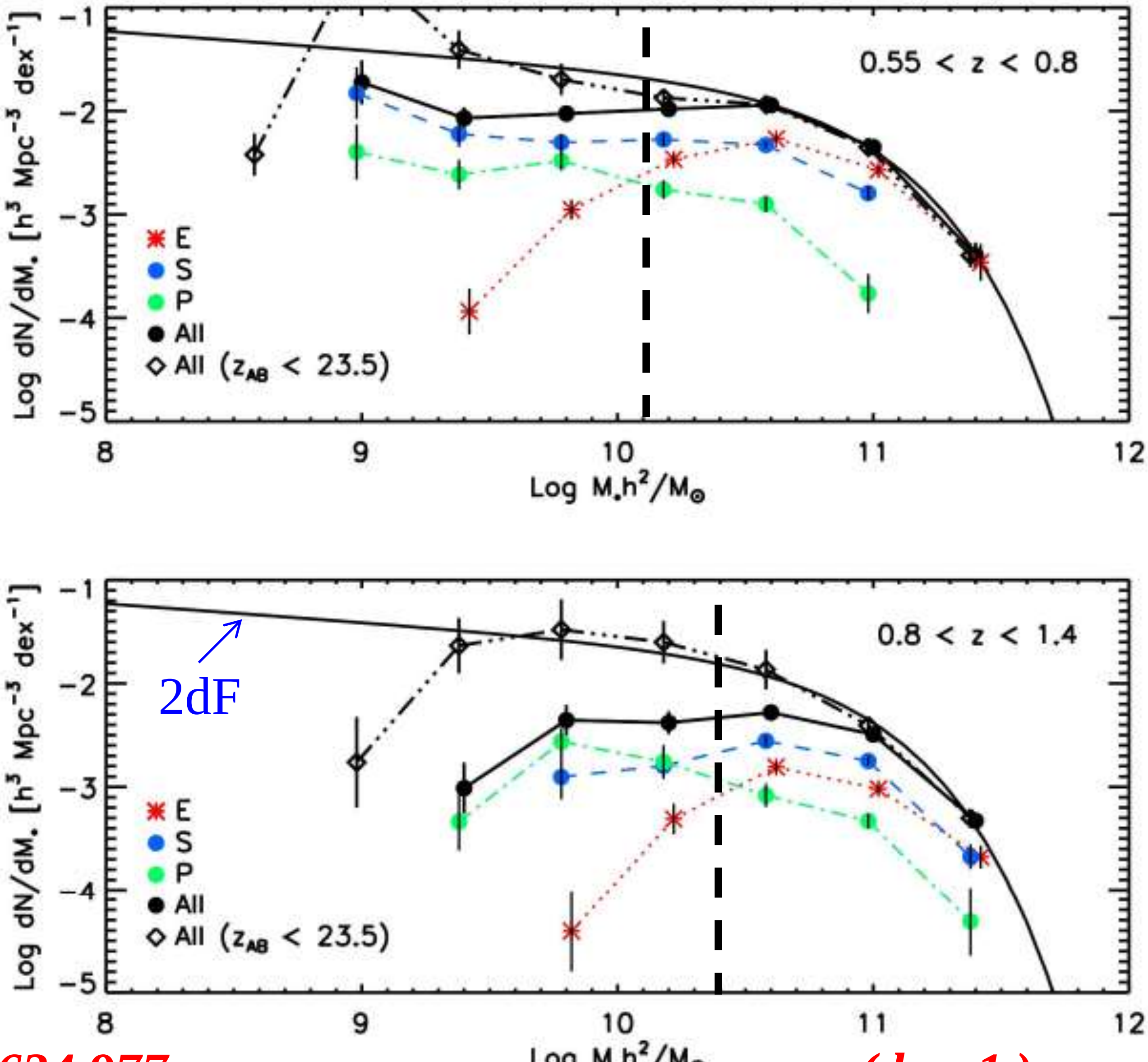


Capak et al (Ap J submitted)



Stellar Mass Assembly by Morphological Type

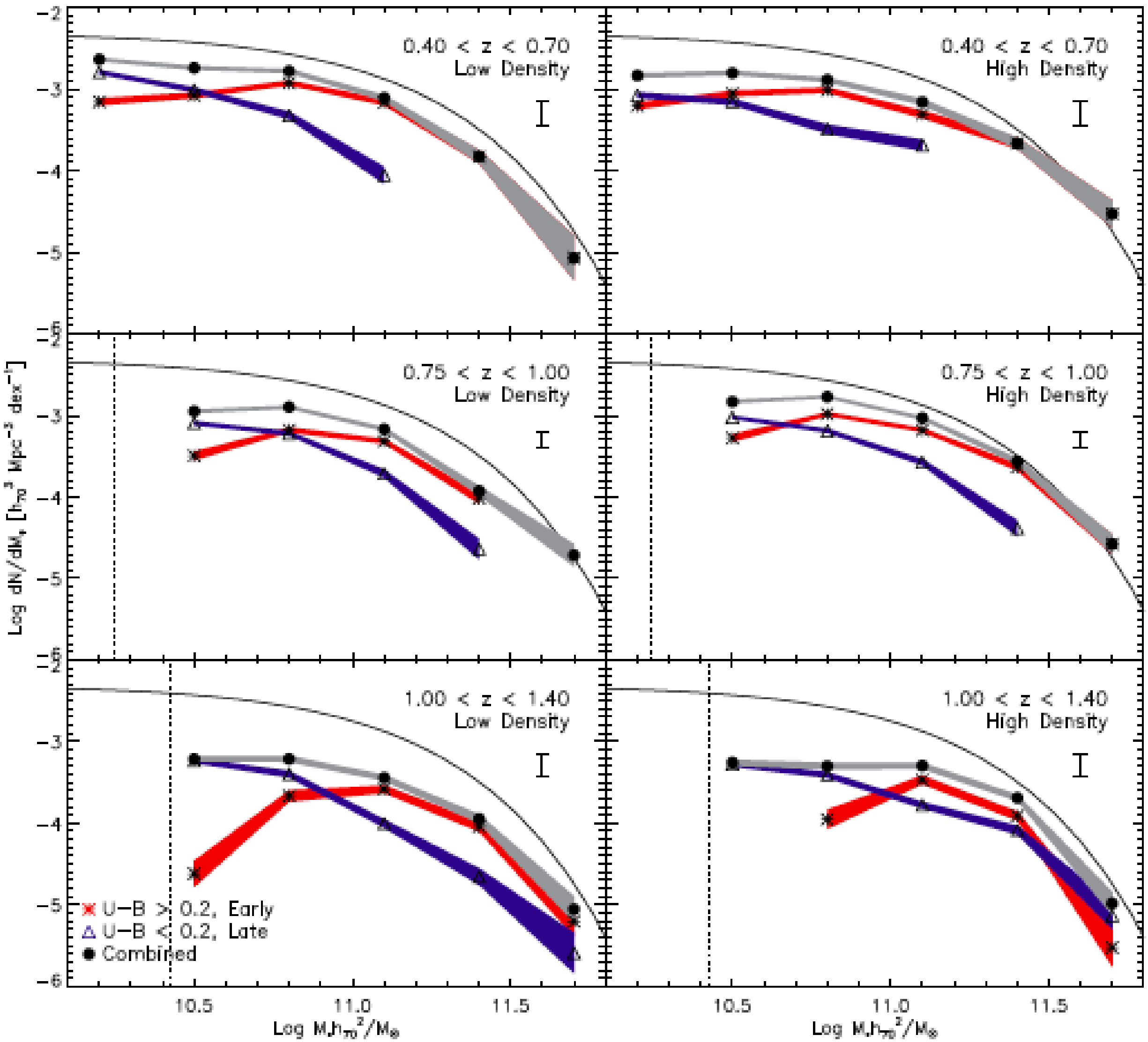
- No significant evolution in massive galaxies since z~1 (c.f. Fontana, Drory et al)
- Modest decline with z in abundance of massive spheroidals, most change at lower mass (c.f. Treu et al)
- Bulk of associated evolution is in massive Irrs



Bundy et al (2005) Ap J 634,977

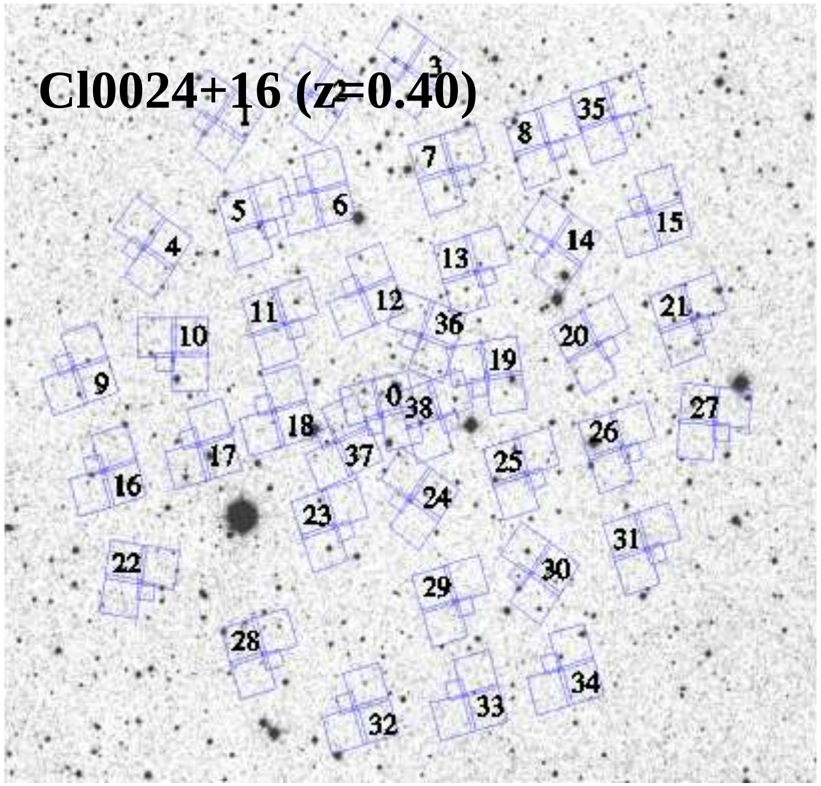
(h = 1)

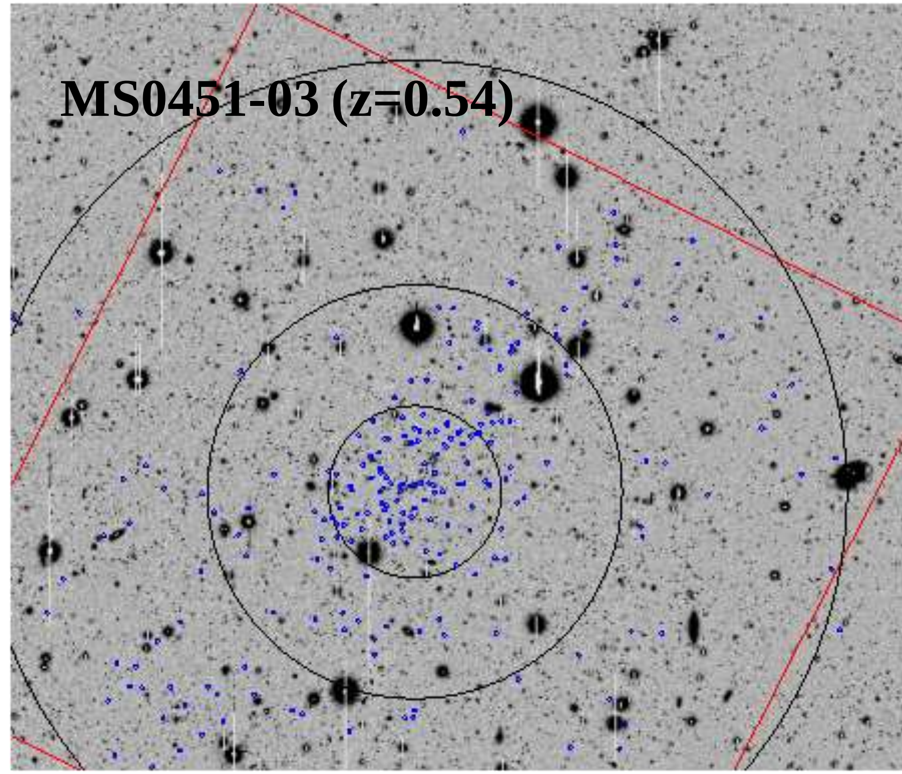
Downsizing Doesn't Depend on Environment



Is this consistent with merger-driven activity?

Detailed Environmental Studies in Two Clusters





HST, GALEX, CFHT/Palomar BVRJK, MIPS to turn-around r~5 Mpc

Morphologies for 4000 galaxies to F814W(Vega)=22.5

DEIMOS spectra of 3000 gals, 800 members (σ, v_{rot} for ~240 members)

I- Treu et al (2003) Ap J 591, 54 - morphology-density relation

II- Kneib et al (2004) Ap J 598, 804 - DM mass profile

III - Moran et al (2005) Ap J 634, 977 - environmental study of spheroidal FP

IV- Moran et al (2006) Ap J 641, L79 - `passive spirals' - a smoking gun

V - Moran et al (submitted) - environmental study of spiral TF relation