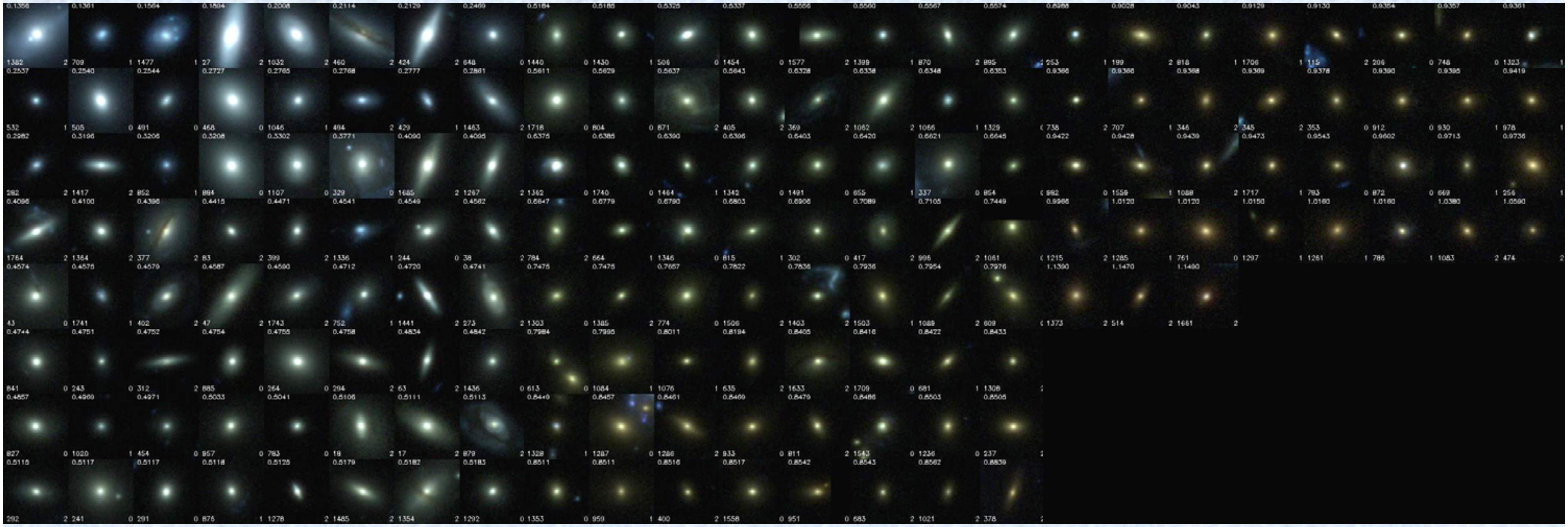
Recent Star formation in early-type galaxies



Tommaso Treu (UCSB)

Outline

- Introduction:
  - Colors vs Morphology
    - E vs S0
- Fossil evidence
  - Scaling relations
  - Spectral diagnostics
- The distant Universe
  - Scaling relations
  - Spectral diagnostics
- Conclusions

Early-type galaxies. Definitions

- Early-type galaxies = E+S0, i.e. morphology
- Other authors use the term to indicate color (red) or spectral (quiescent) classification.
- NOT EQUIVALENT

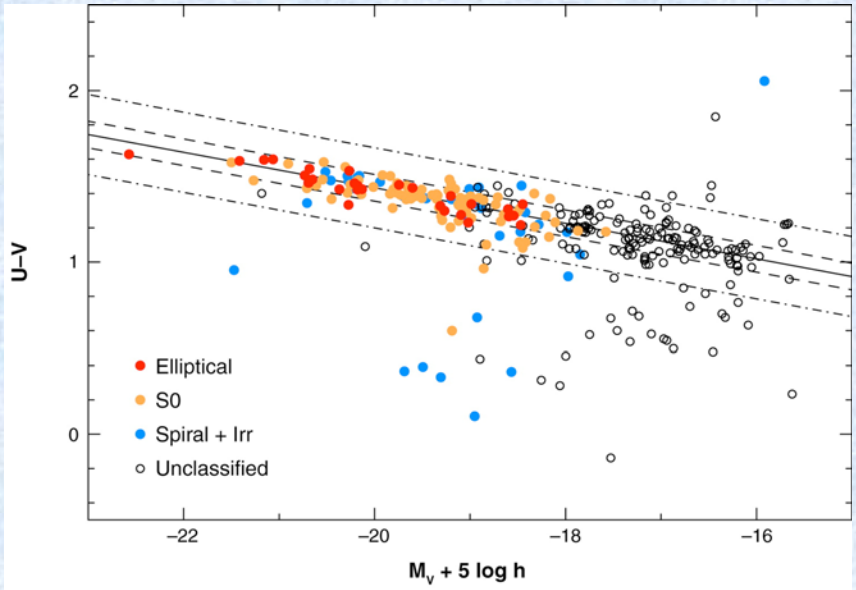
	"MOR" (devauc)	COL	SPE
"MOR"	100%	70%	81%
COL	58%	100%	87%
SPE	55%	70%	100%

In the local universe; Bernardi et al. 2006

Fossil evidence

Fossil evidence: the color-magnitude relation

- Tightness of the c-m relation implies:
  - Stellar population are co-eval
  - Stellar populations are old
- Slope of the color magnitude relation is due to:
  - Metallicity
  - Age

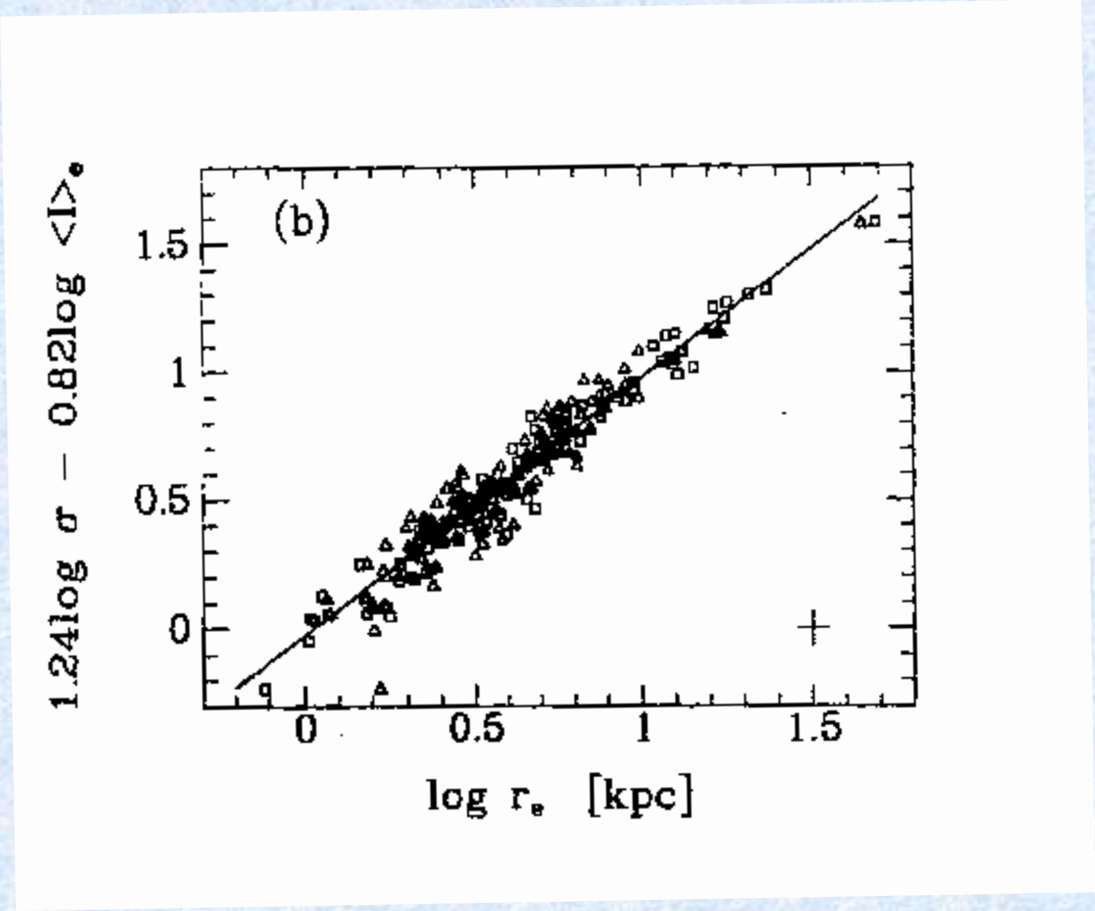


Renzini A. 2006.
Annu. Rev. Astron. Astrophys. 44:141–92

Bower et al. 1992, 1998

Fossil evidence: The Fundamental Plane

- Empirical correlation between size, luminosity and velocity dispersion
- Gives "effective M/L" at "effective mass"
- Tightness = synchronicity/old



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

Fossil evidence: the tilt of the Fundamental Plane

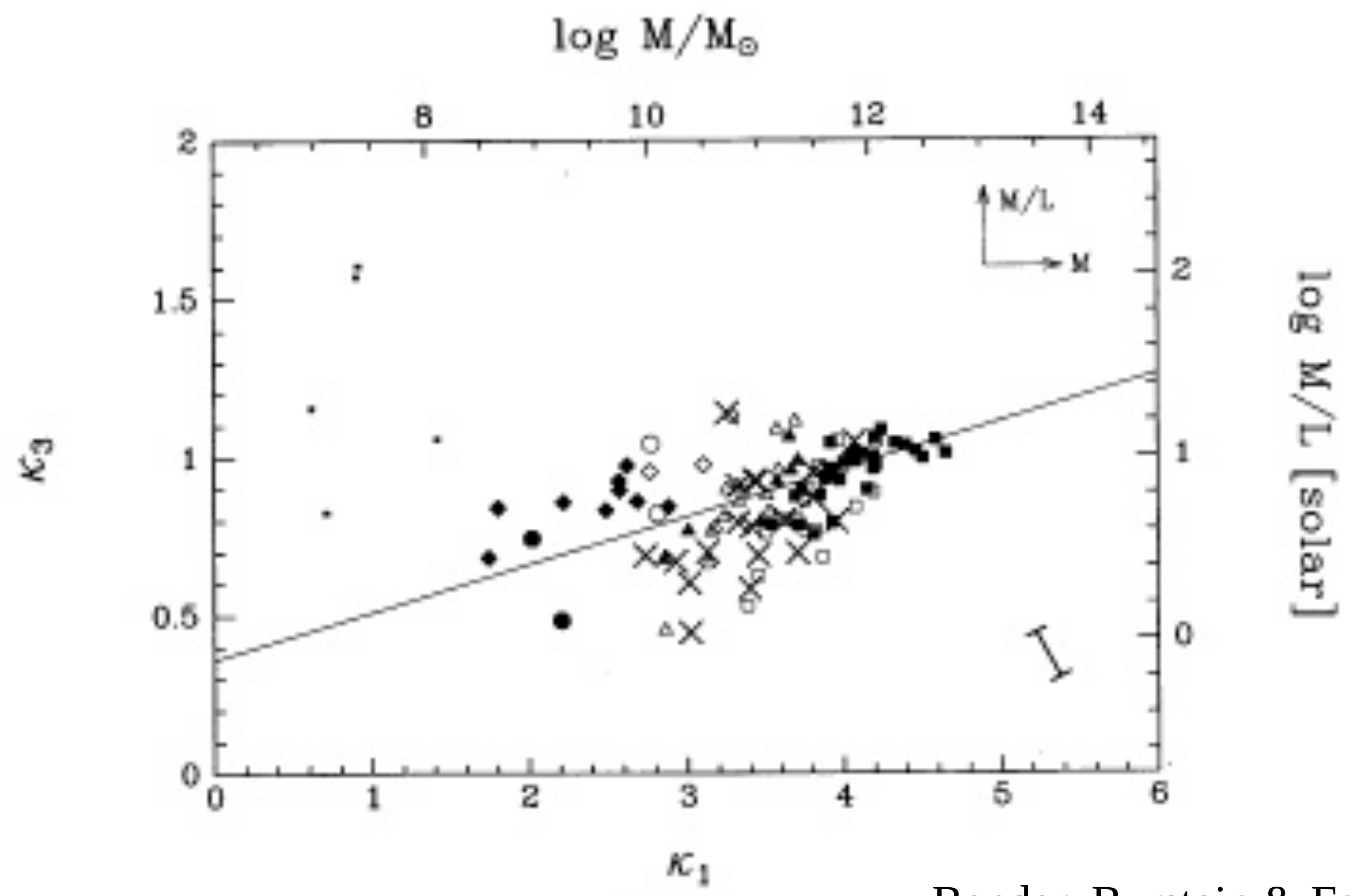


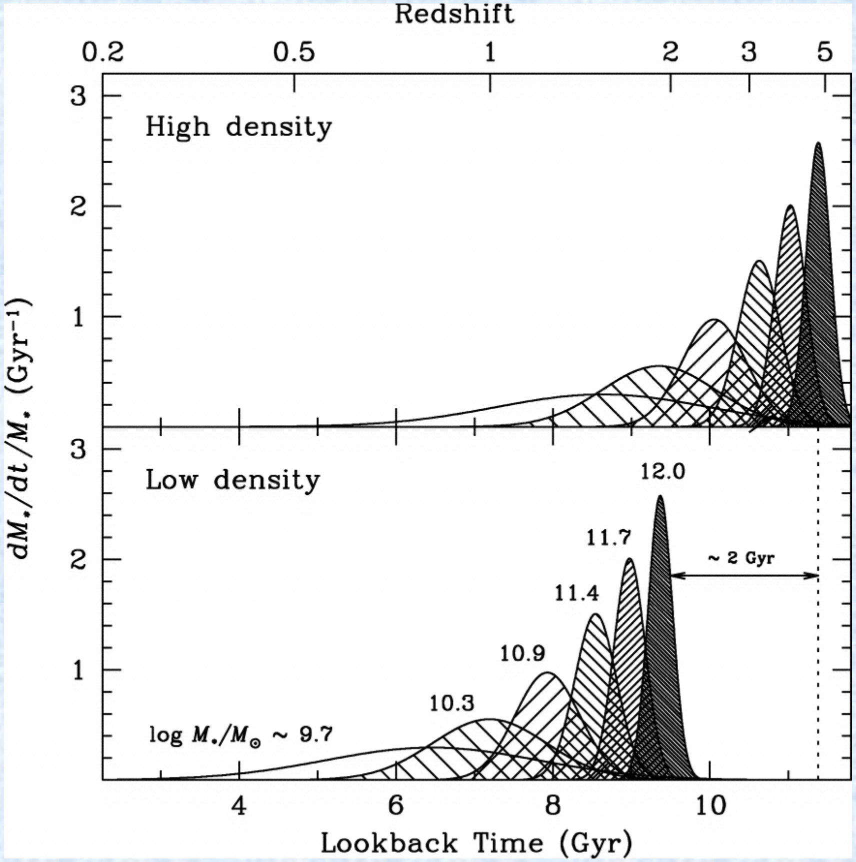
FIG. 2*a*

Bender, Burstein & Faber 1992

Tilt due to age/metallicity/structure trends vs mass

Fossil Evidence: spectral analysis

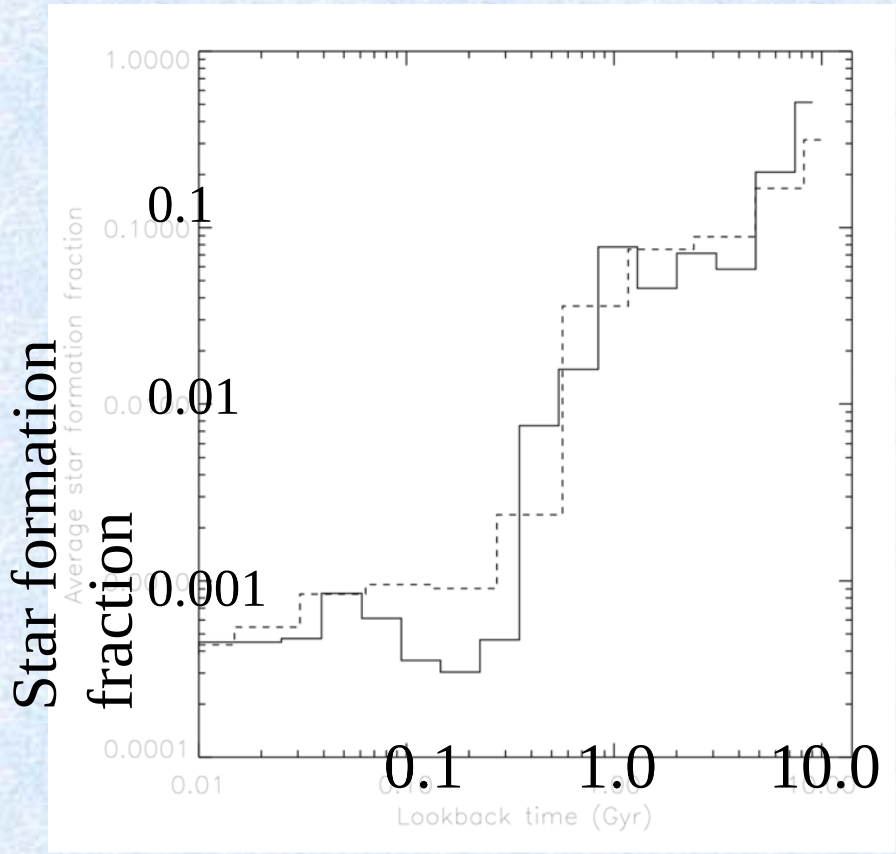
- Comparing Lick indices (Balmer lines, Mg, Fe) with models:
- SSP Age of the stellar populations is a function of mass:
  - Log t/Gyrs = 0.427 + 0.053 log M/Msun
- And to second order environment



Thomas et al. 2005

Fossil Evidence: full spectral analysis

- Full spectral analysis is computationally challenging (models are hard)
- Tools are being developed to reconstruct star formation history based on full spectral information

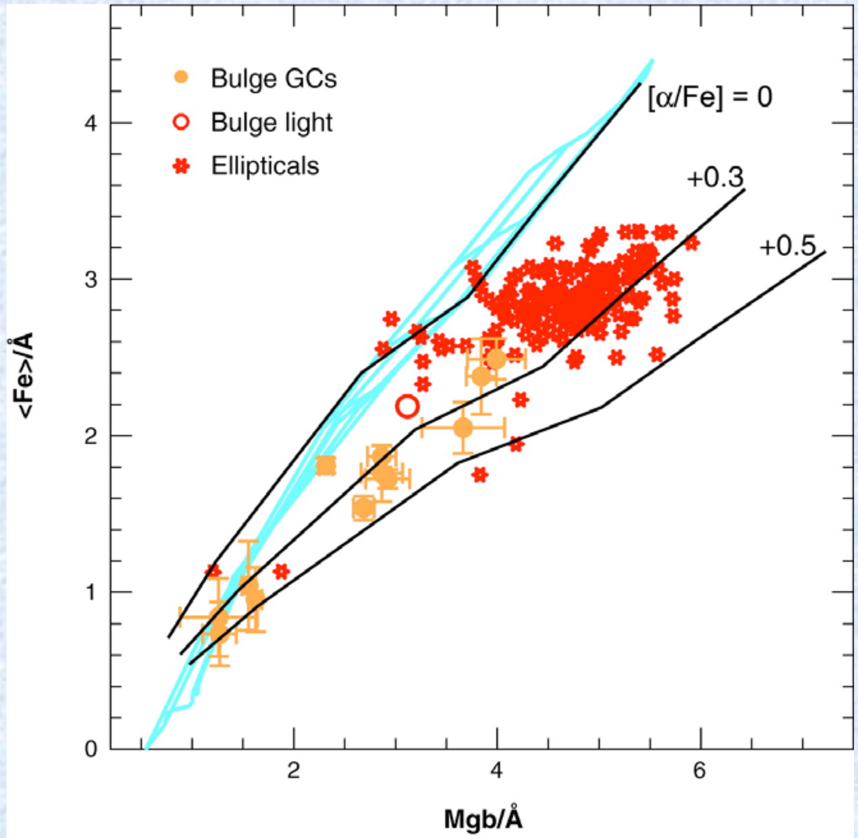


Look-back time (Gyrs)

Tojero et al. 2007

Fossil Evidence. Caveats. I: age-metallicity degeneracy

- Metallicity and age produce very similar effects for old stellar populations, on:
  - Colors
  - M/L
  - Spectral indeces
- Tilt and slope of FP and CM could be due to either
- Small scatter could be due to anticorrelation (Trager et al. 2000)



Renzini A. 2006.
Annu. Rev. Astron. Astrophys. 44:141–92

Renzini 2006

Fossil Evidence. More caveats

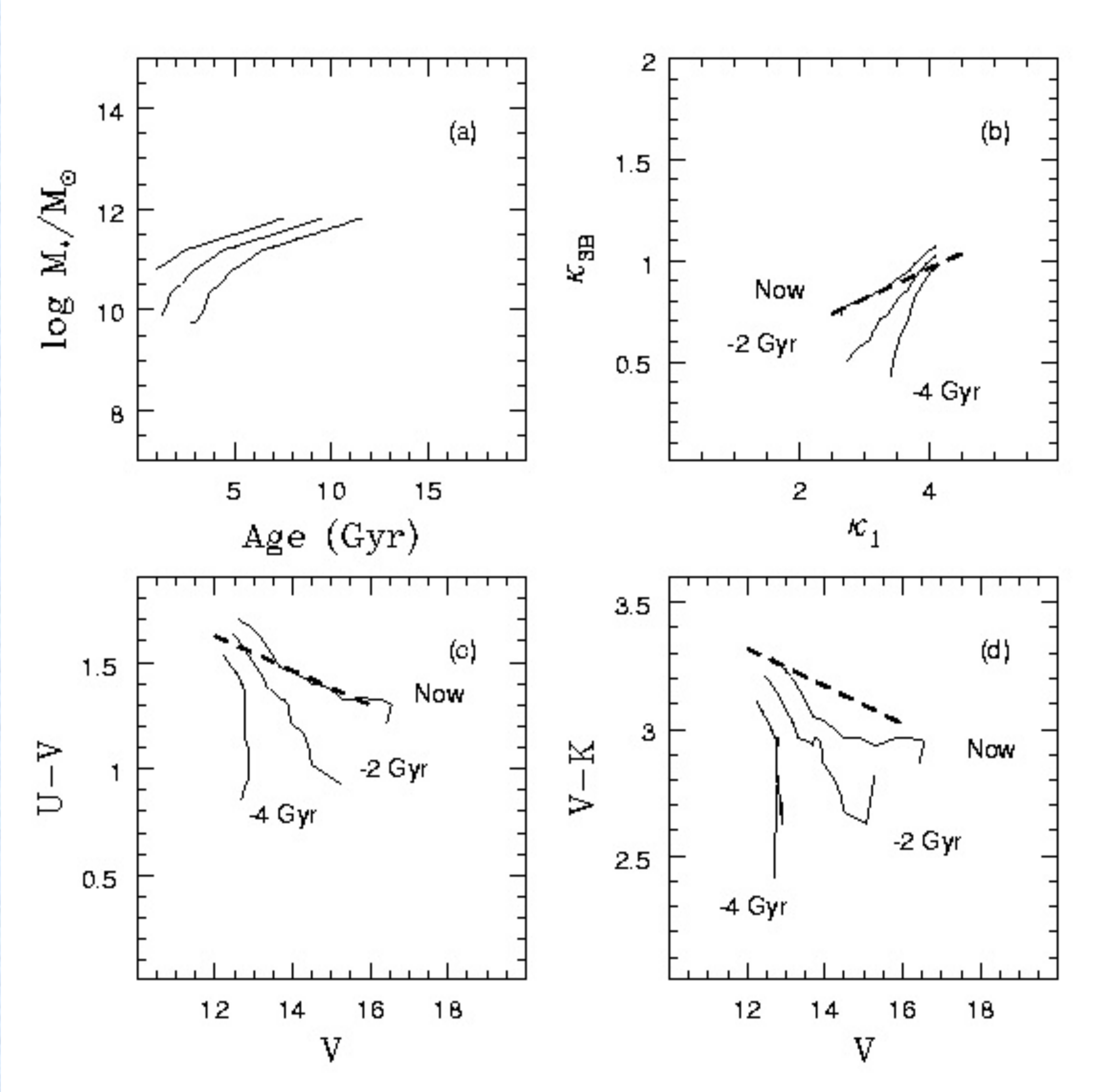
- Most studies assume single stellar populations, which are effectively “luminosity weighted” stellar populations
- A small fraction of young stars can mimic overall intermediate ages (“frosting”).Hard to disentangle.
- Stellar ages from Balmer lines may be affected by old metal rich horizontal branch stars. Other subtleties in the models.

Fossil Evidence. Summary

- Most stars are old (~10 Gyrs).
- Age and metallicity appear to increase with stellar mass.
- Overabundance of alpha elements in massive systems seem to imply short star formation time scales (~1 Gyr).
- Cluster E/S0 have somewhat older stellar populations than their field counterparts

The distant universe

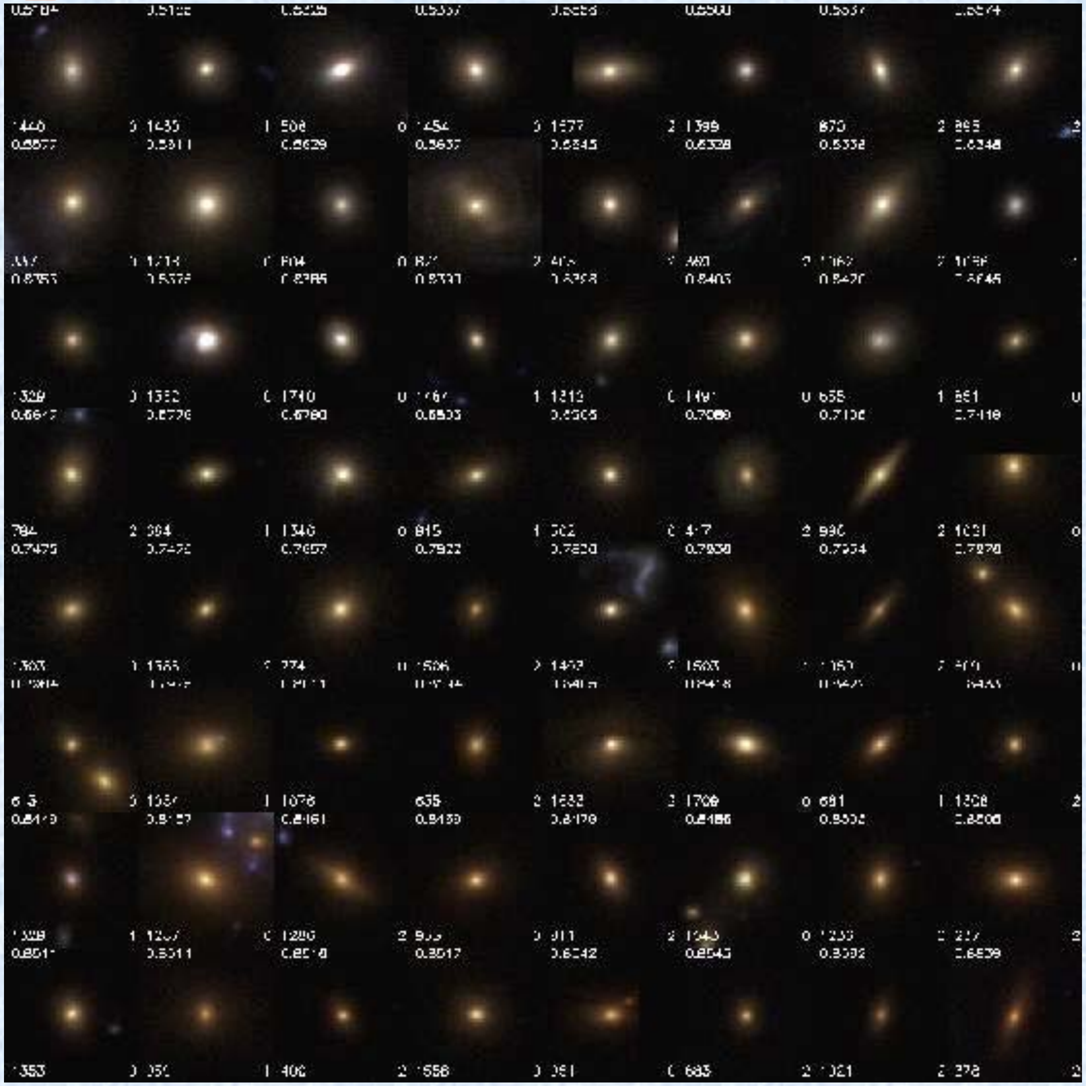
Evolution of Scaling Laws



Treu 2001

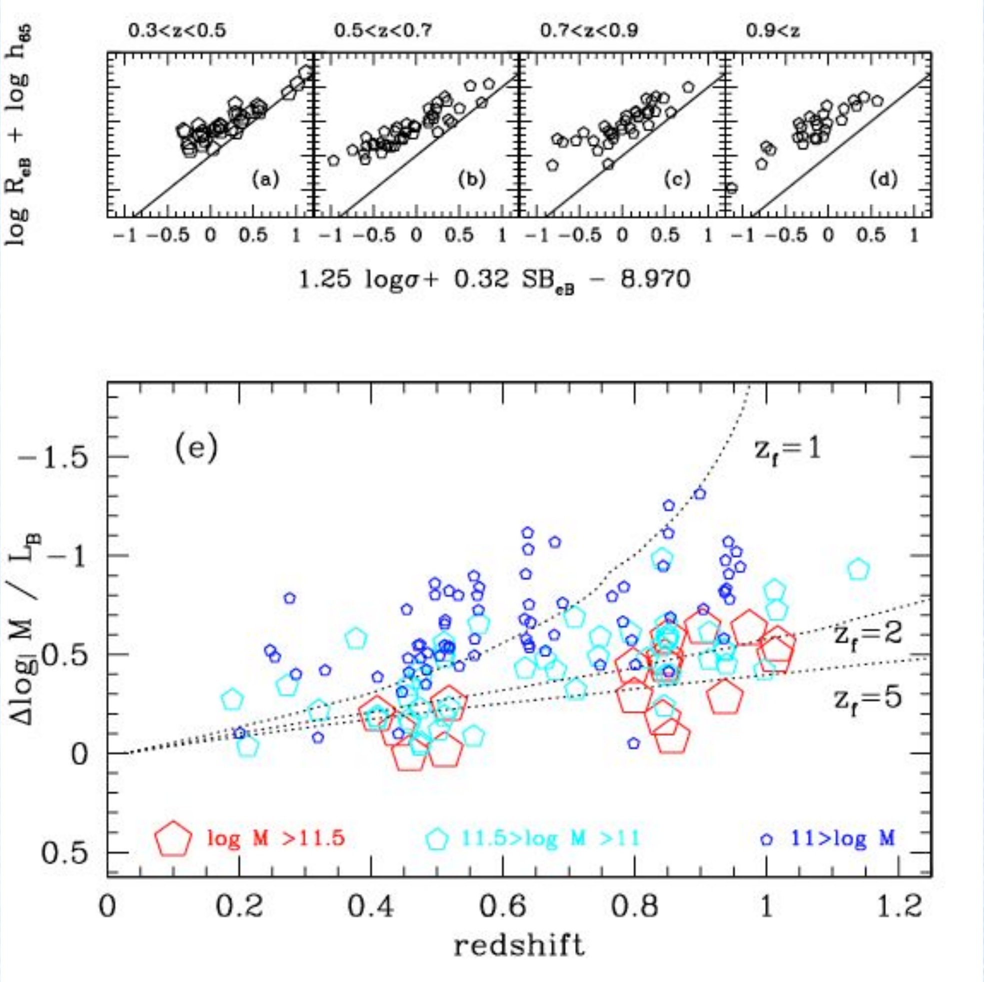
Evolution of E+S0. Sample Selection

- Magnitude selected: z(AB)<=22.43
- Morphologically selected from HST images in the z-band: E, S0, E/S0
- Total sample: 165 E+S0s, with same color distribution as the parent sample of 307 E+S0s



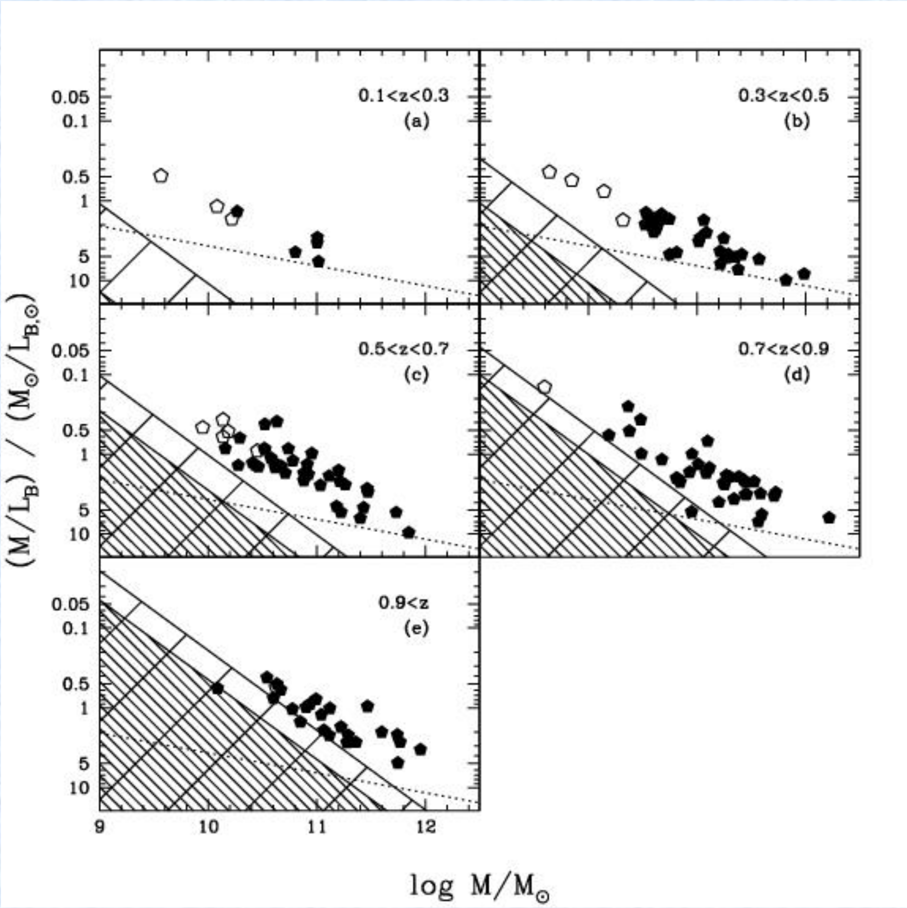
Evolution of Mass to Light ratios

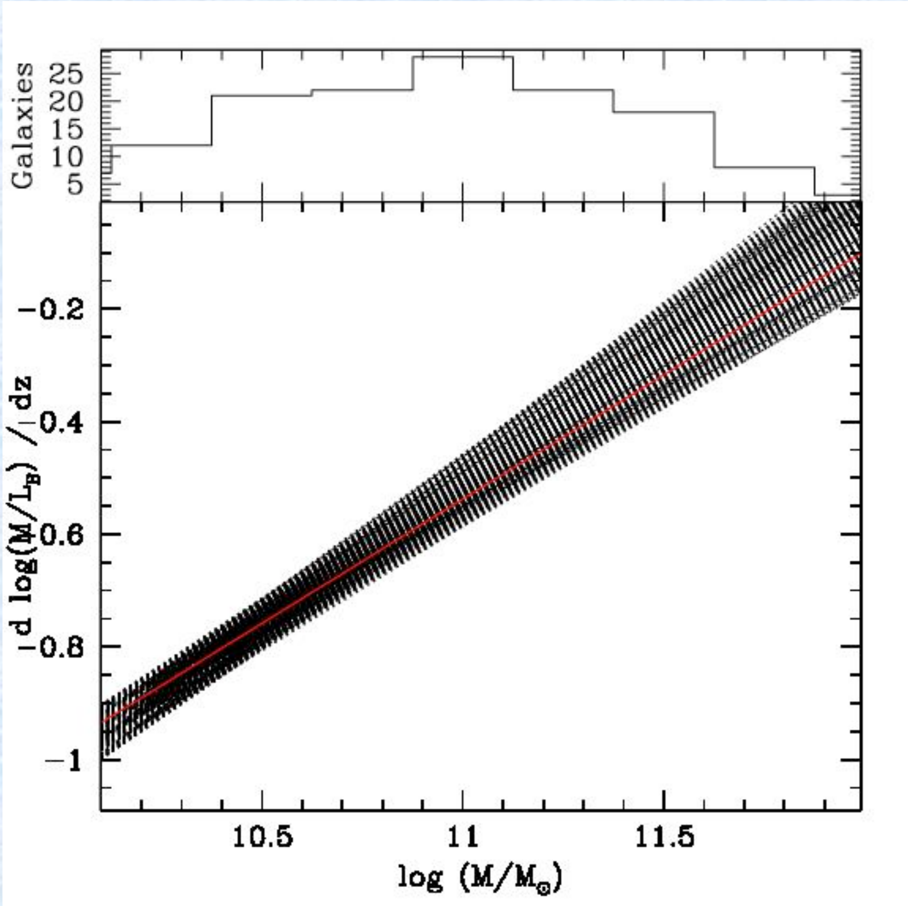
- Evolution of mass to light ratio is a function of dynamical mass
- More massive galaxies evolve slower than less massive ones, i.e. older stars ("downsizing")



Treu et al. 2005a

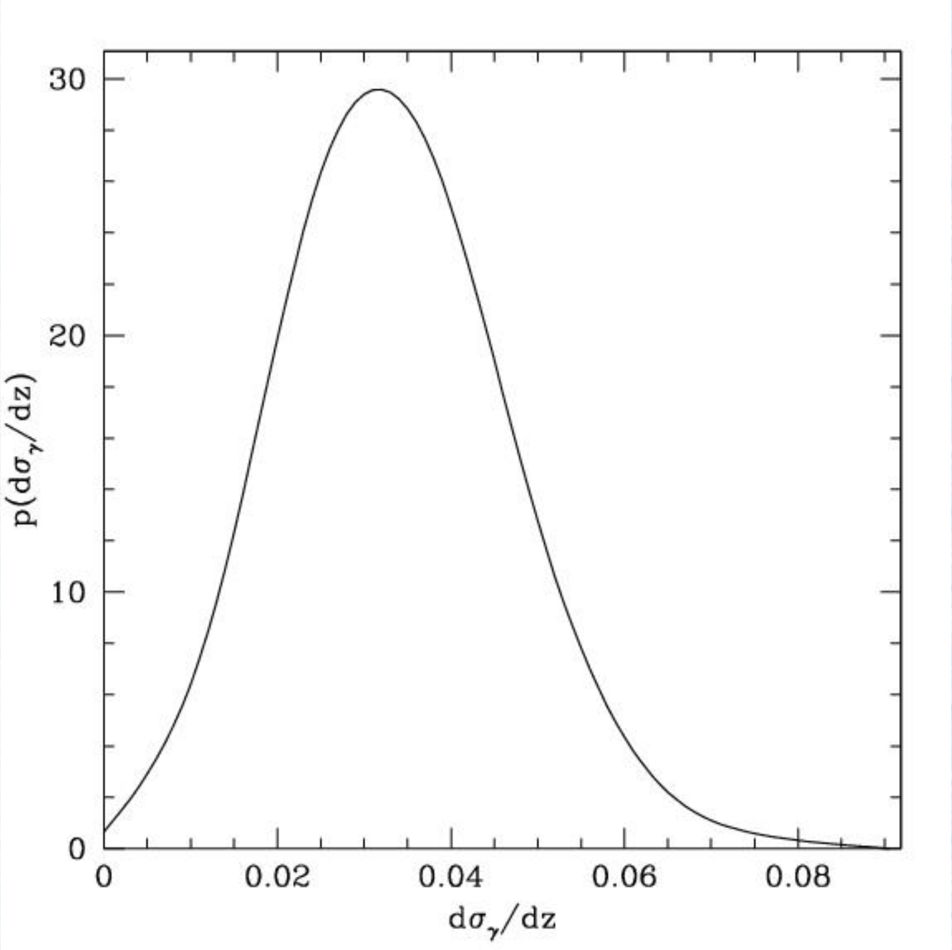
Accounting for selection effects…





Treu et al. 2005b

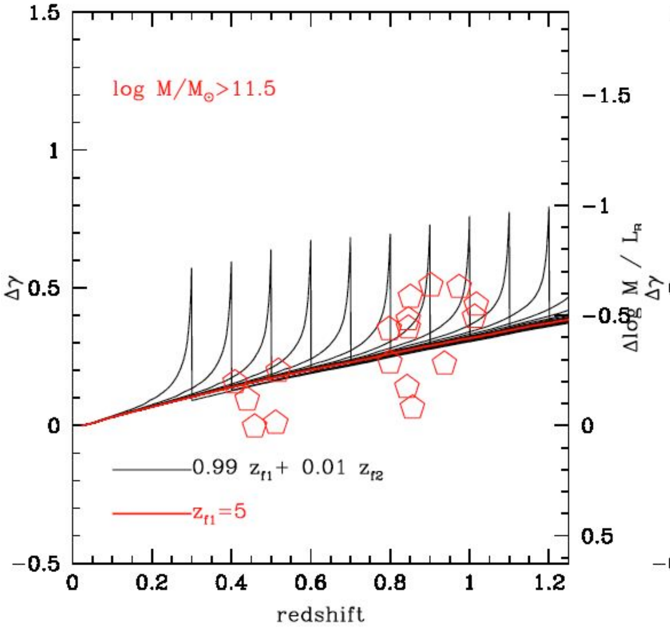
Intrinsic scatter of the FP increases with redshift

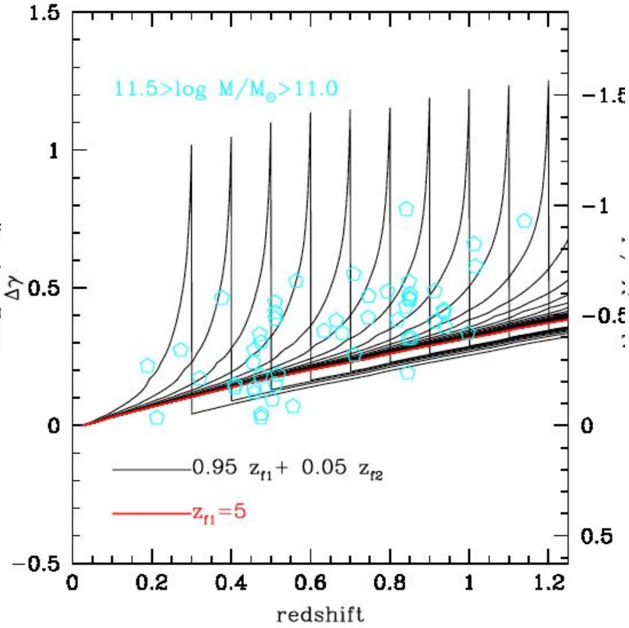


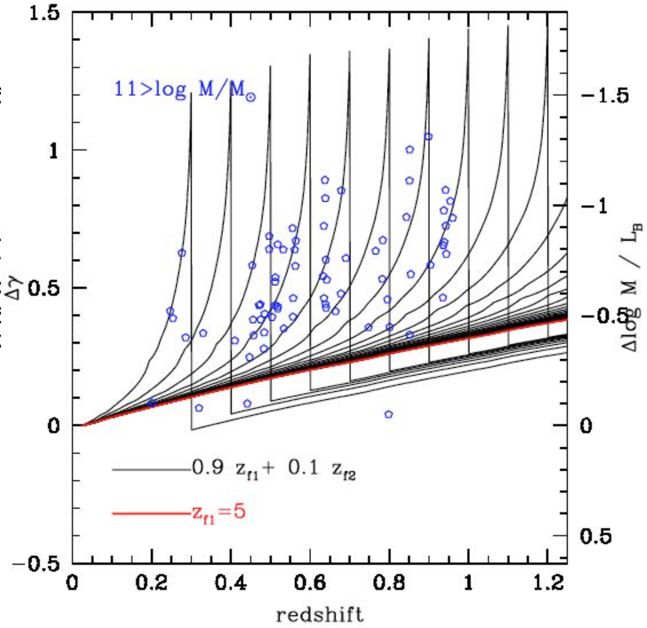
Treu et al. 2005b

Downsizing star formation

Log M>11.5 | **11.5>Log M>11** | **11<Log M**



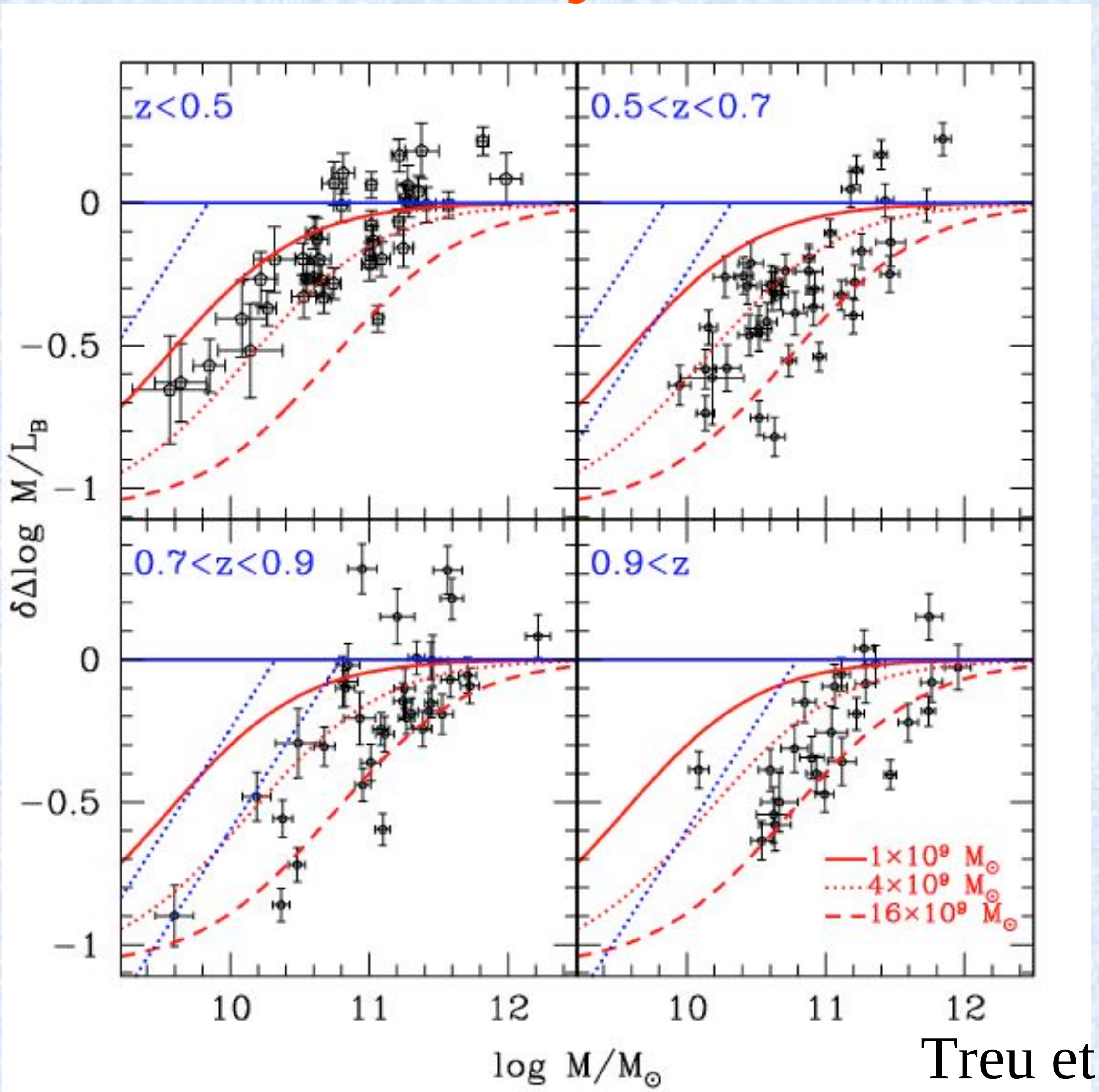




Young stars <1% | **Young stars ~5%** | **Young stars up to 20-40%**

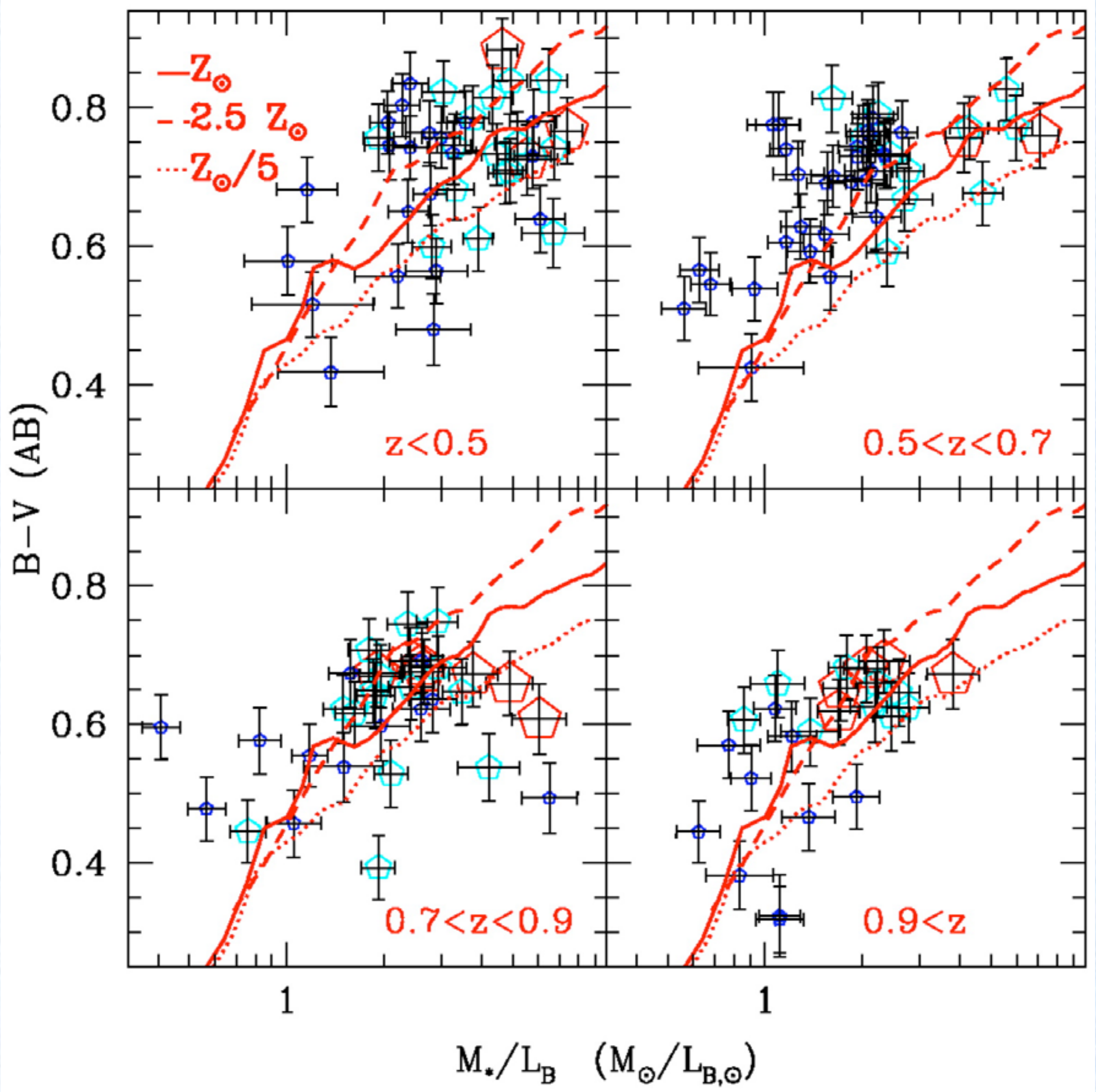
Treu et al. 2005b

Secondary bursts



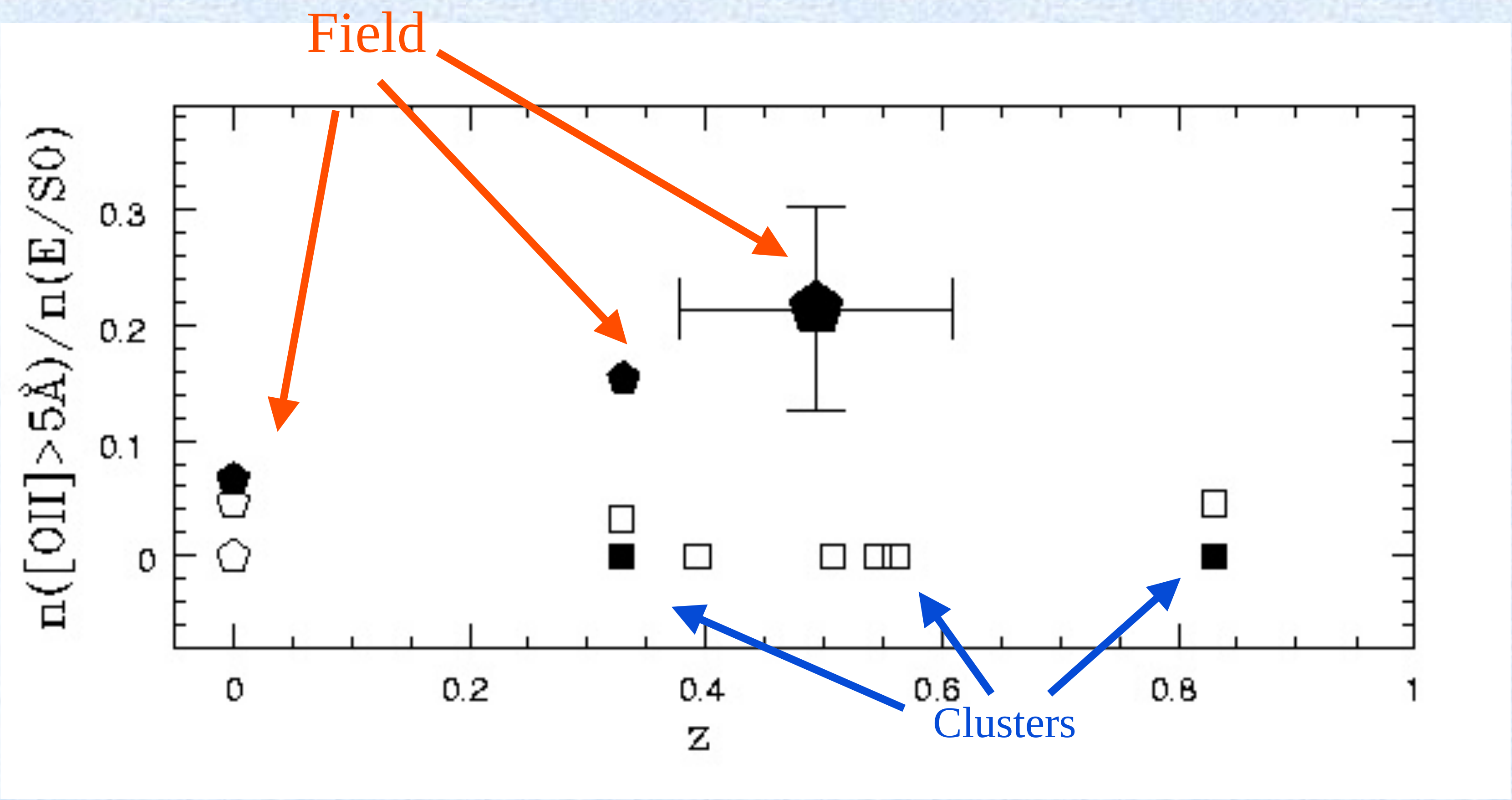
Treu et al. 2005a

Independent evidence: colors



Treu et al. 2005a

Independent evidence: [OII] emission



46 bright E/S0 at z=0.1-0.73

Treu et al. 2002

OII as a star formation diagnostic

How much mass in secondary burst?

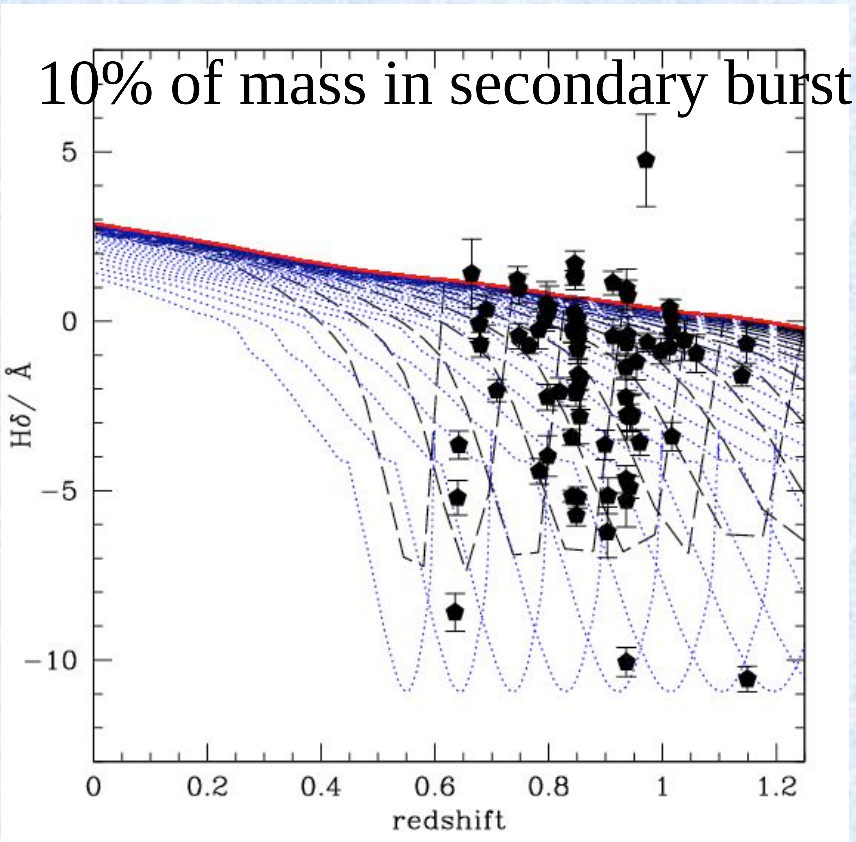
$$P(OII)=\langle n\rangle\langle t\rangle/Dt$$

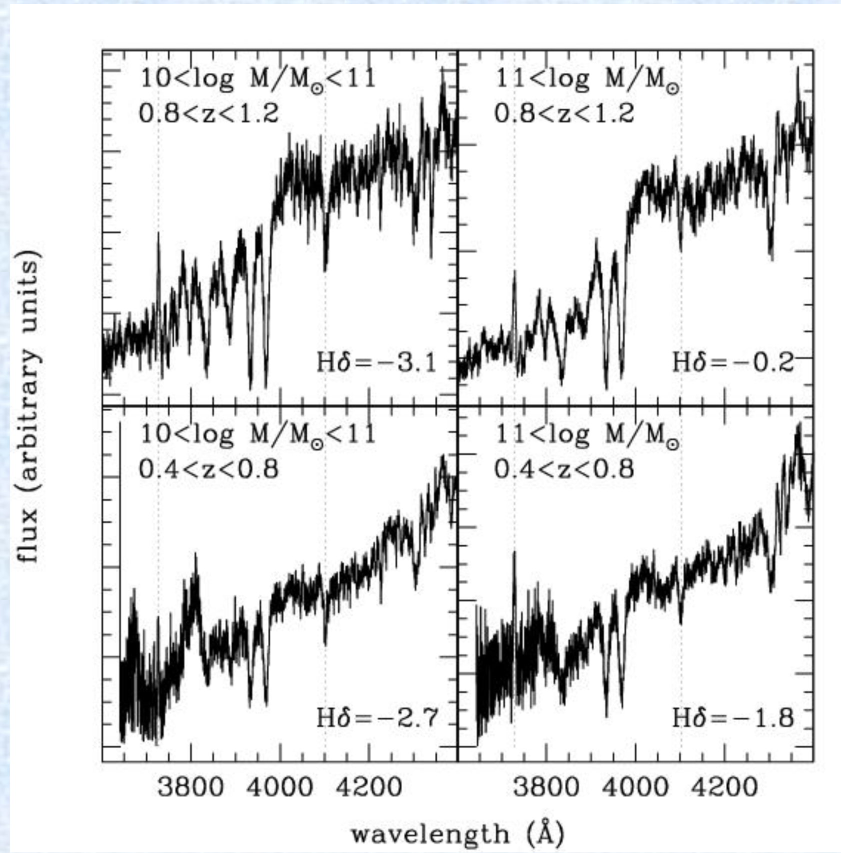
$$M(OII)=\langle n\rangle\langle t\rangle\langle dM/dt\rangle=P(OII)Dt\langle dM/dt\rangle$$

$$M(OII)=5x10^{8}-5x10^{9}$$

Treu et al. 2002

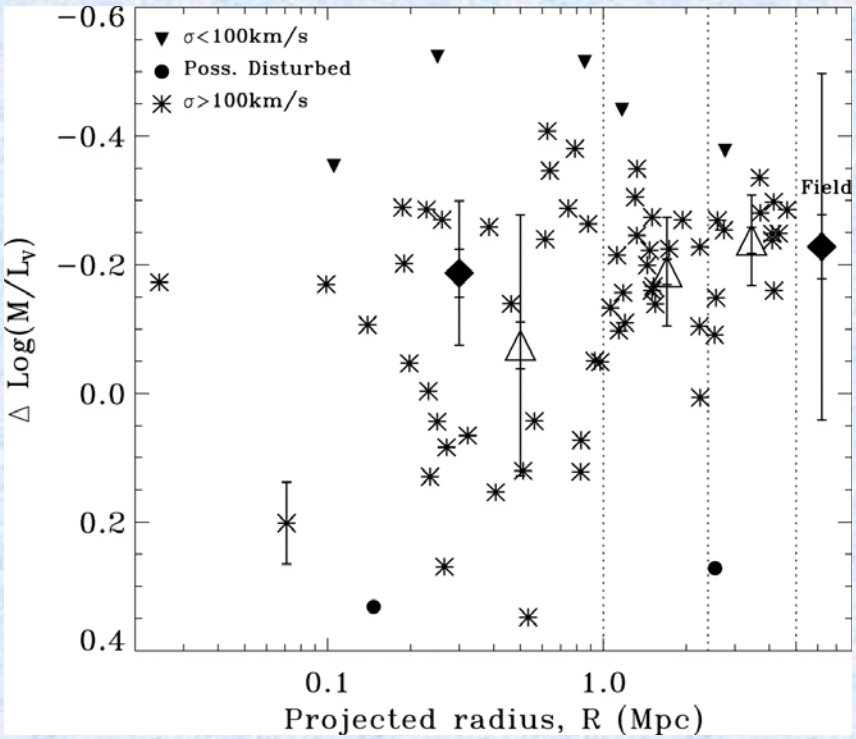
Independent evidence: Balmer absorption

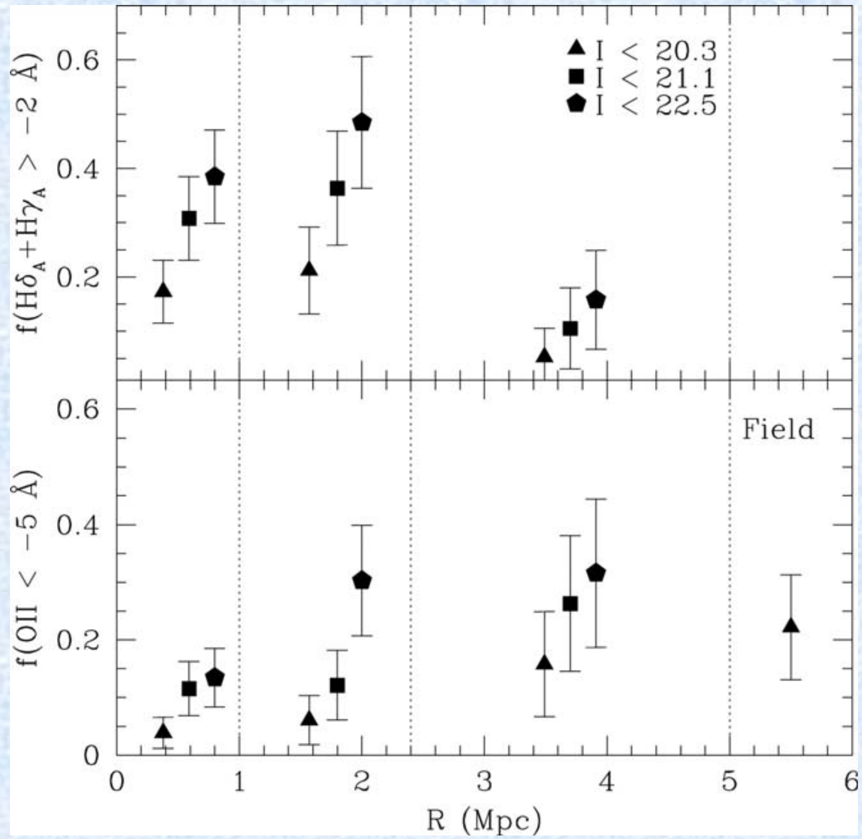




Fraction with OII emission (~0.2) > locally (0) Treu et al. 2005b

How about in clusters?

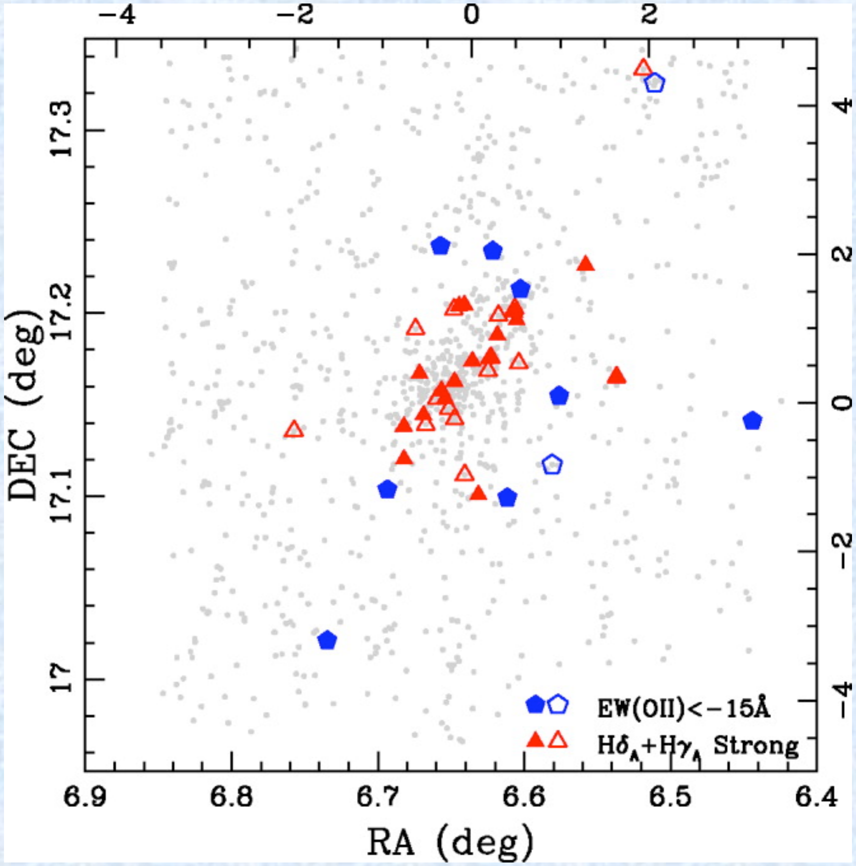




Moran et al. 2005

How about in clusters?

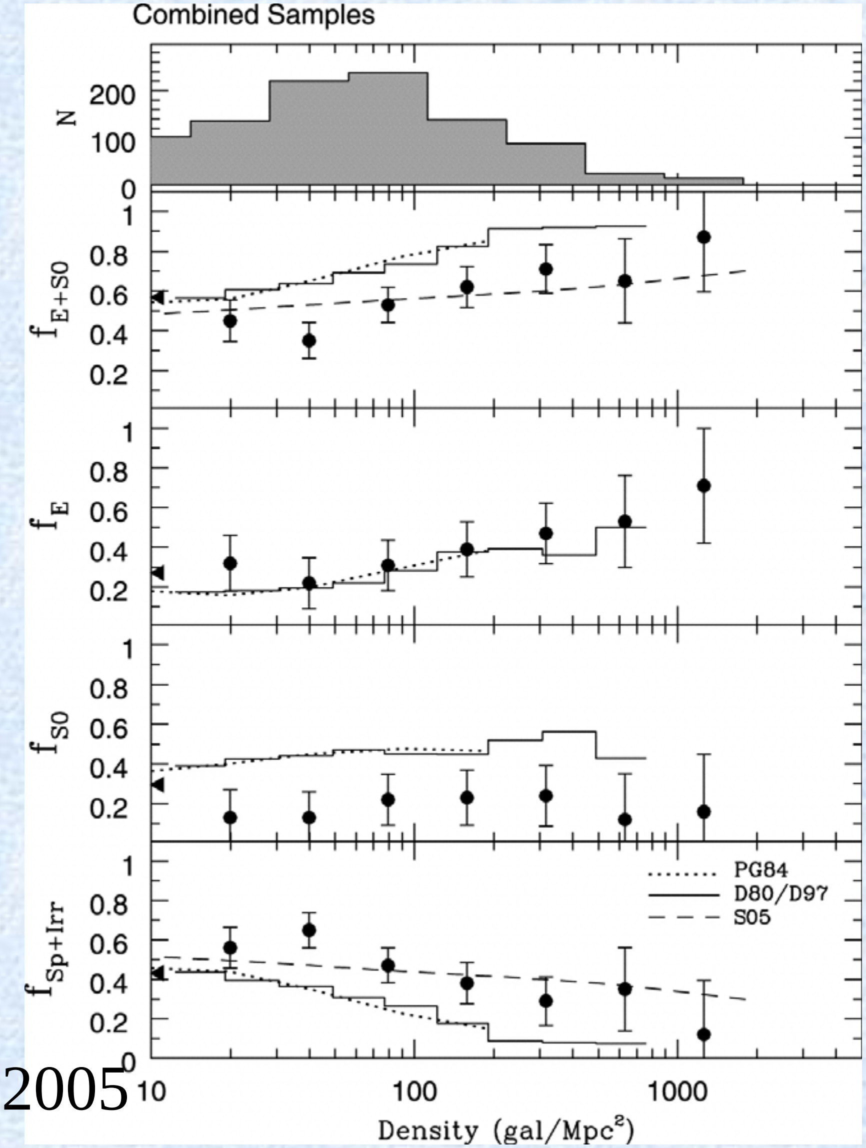
- E+S0 with OII emission are found at the outskirts of clusters
- Interpretation:
  - Infalling E+S0 undergo a short burst of star formation (1% in mass, ~10^8 years) at the periphery of clusters
  - They are then seen as balmer enhanced further in



Moran et al. 2005

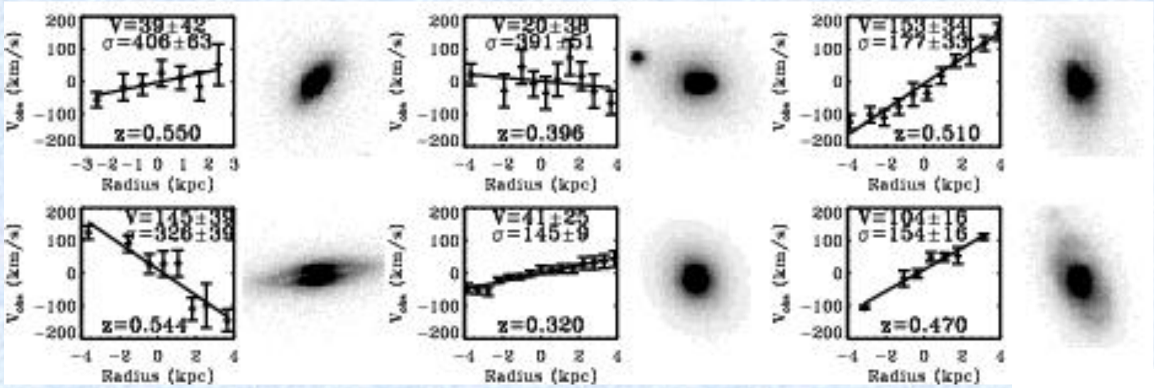
What about S0 vs E?

- The fraction of S0 in clusters appears to decline as a function of redshift
- The fraction of E is approximately constant
- If S0 are formed after E, do they have a different star formation history?
- As far as I know, no conclusive evidence

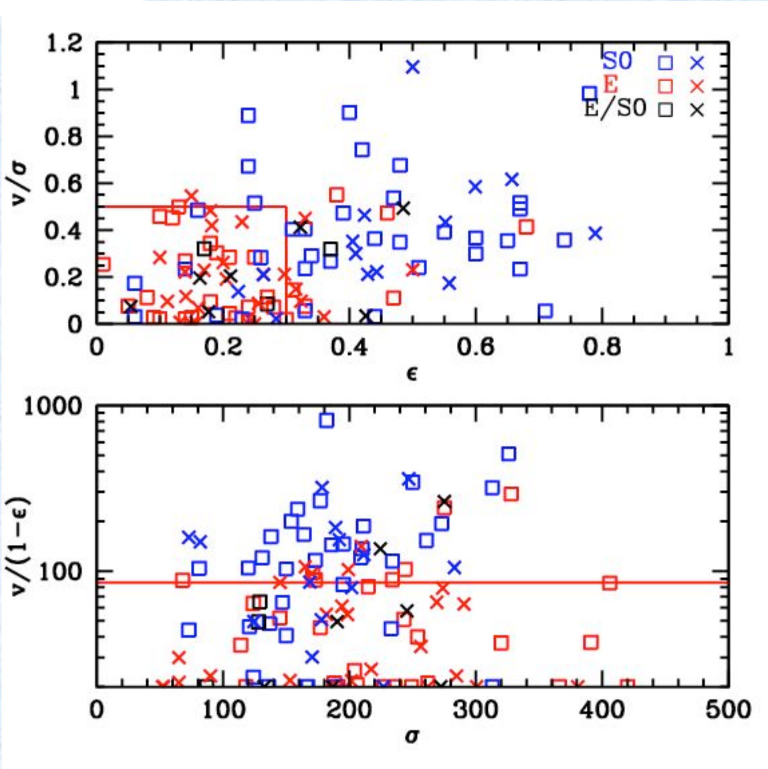


Postman et al. 2005

S0 vs E. Caveat



- It is difficult to distinguish E, S0 and Sa at high -z
  - Surface brightness dimming
  - Loss of resolution
- We need a better classification.
- Trying to define classification based on angular momentum vs pressure support.



Moran et al. 2007

Conclusions

- The majority of stars in early-type galaxies form before redshift 2
- For the most massive galaxies (log M >12) there is virtually no star formation below z=1, <1%
- Smaller galaxies form a significant fraction of their stars at z<1 - in situ, by eating satellites or via gas rich mergers -- as much as 20-40% at log M~10
- Overall, a few 10^9 solar masses of new stars per galaxy are added since z=1
- Stellar populations in the field seem to be somewhat younger than in clusters, although there are not enough data to disentangle environment and mass function effects
- They jury is still out regarding E vs S0. S0 should have some more recent star formation, but not proven…

A question for you…

- The old stellar populations of massive E+S0 are considered a major problem from a galaxy formation point of view.
- What stops gas from cooling and producing new stars?
  - There is plenty of gas around, at the very least mass loss from evolved stellar populations (Ciotti & Ostriker 2007)
- Nowadays AGN feedback is the silver bullet: low levels of AGN activity provide a thermostat that keeps the gas from cooling and stops star formation (e.g. Granato et al. 2004; Croton et al. 2006; Malbon et al. 2007)
- I am no modelers, but it is generally argued that SN cannot do it, because models need feedback when there is no star formation. Can SN from old stars help? Are the recipes commonly used good enough?

Further readings:

- McCarthy 2004, ARA&A, 42, 477
- Renzini 2006, ARA&A, 44, 141

The end