The Formation of Cluster Red Sequence Galaxies

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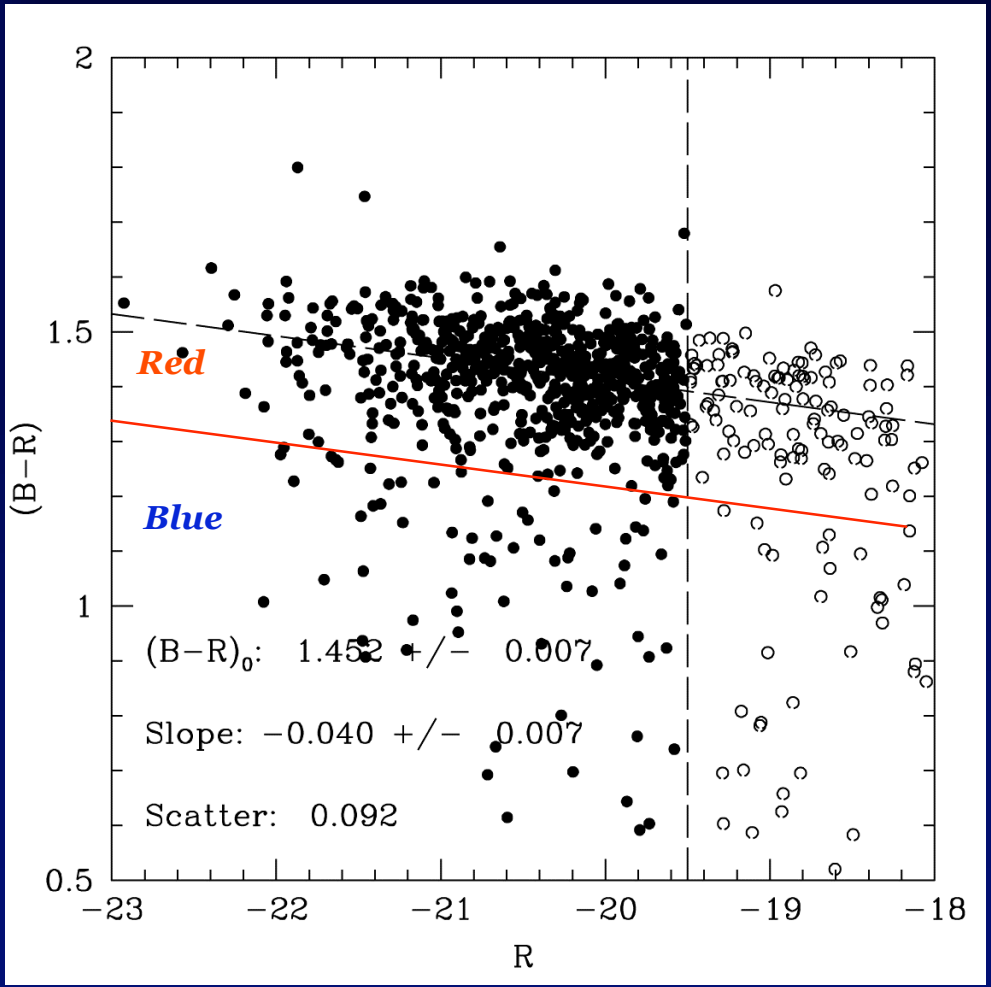
- Russell Smith John Lucey
- Steve Allanson
- Coma/Hectospec team, esp. Ron Marzke

"Red Sequence" of Cluster Galaxies



Red galaxies hide the "fossil record" of ~ half of the star formation in the Universe.

What is responsible for the tilt and scatter of the scaling relations?

How did the red sequence come to be populated?

Ages, Metallicities & α-Enhancements from Spectra

- Measure "Lick" indices
  (typically Hβ, Hγ, Hδ, several Fe lines, Mgb)

- Compare with model grids
  e.g. Thomas/Maraston et al.

- Yields ("luminosity-weighted") ages, metallicity, α-enhancement

Cluster Samples

- Red and emission-free but not morphologically-selected.

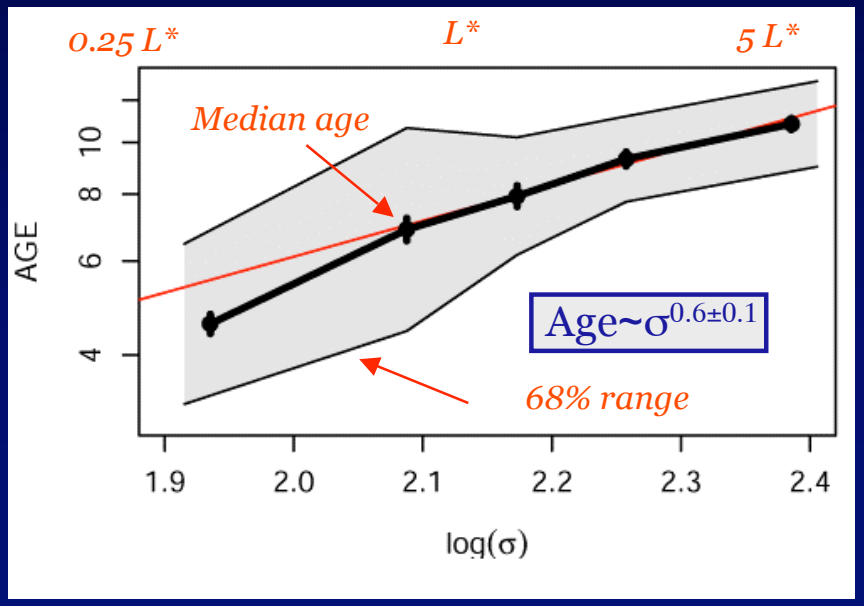
- NOAO Fundamental Plane Survey
  - 93 rich clusters, bright galaxies
- Shapley Clusters
  - 3 rich clusters - deep AAOmega - Smith et al
- Coma Cluster Survey - see *Alistair Graham* Poster
  - Deep Hectospec - see *Russell Smith* Poster

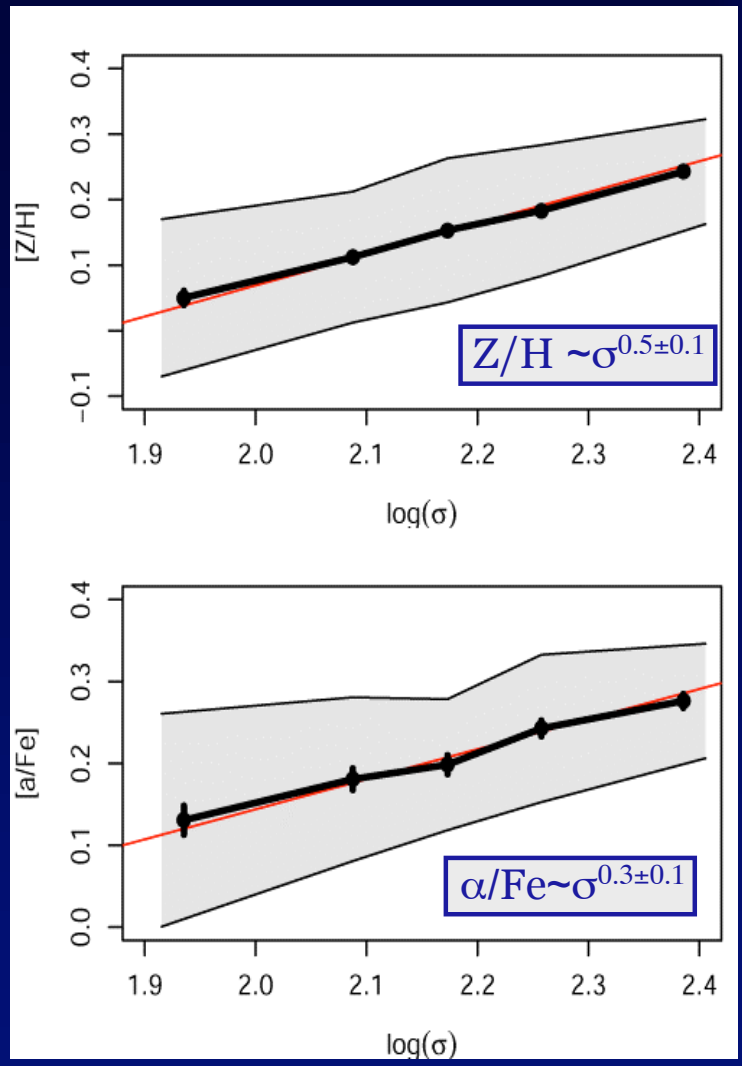
Stellar Populations as a function of Velocity Dispersion, σ

Scaling Relations for Age, Metallicity, α/Fe

σ is the driving scaling parameter, little residual dependence on stellar mass.

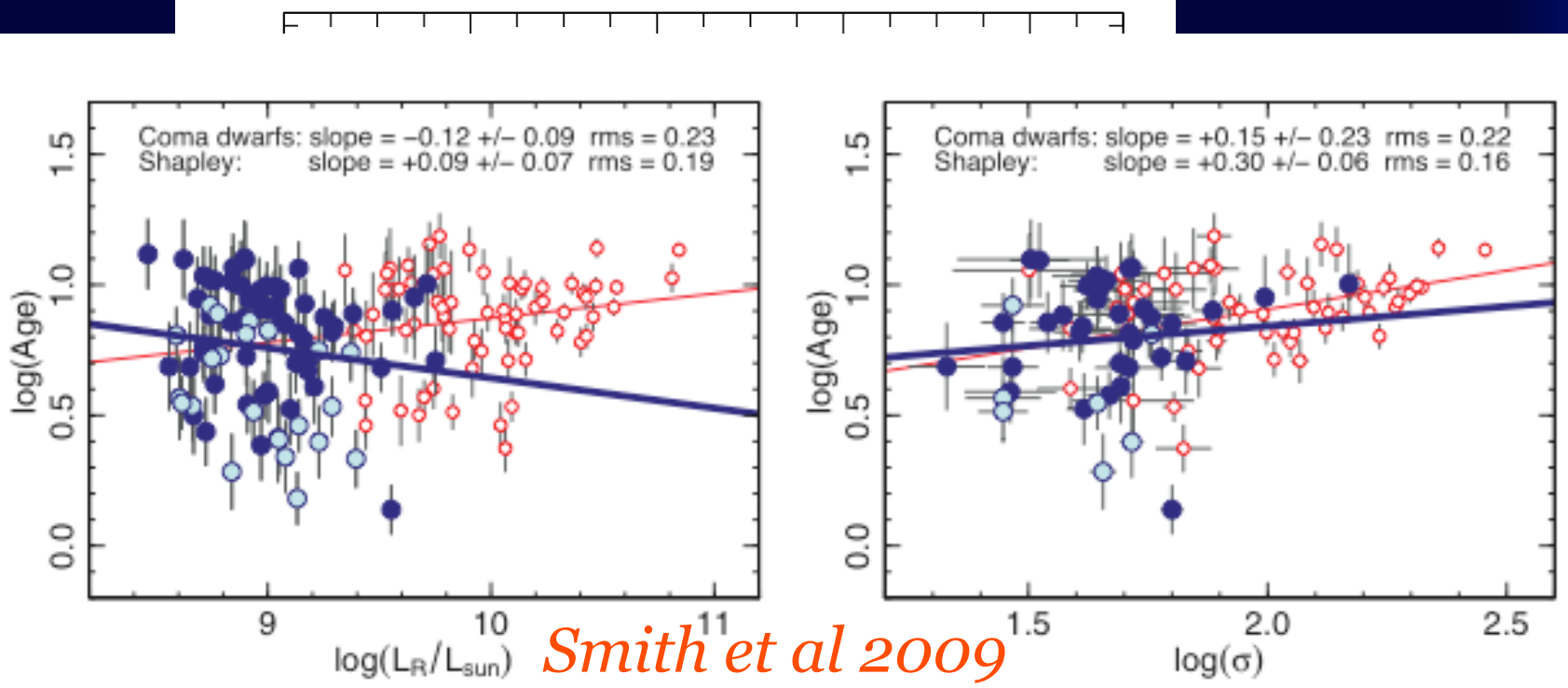
Smith, Lucey, MH 09, submitted



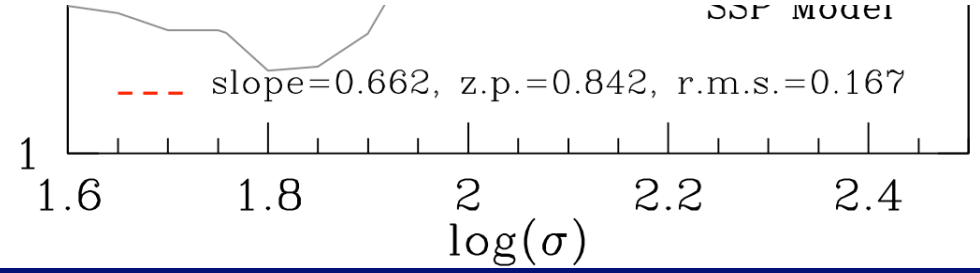


Nelan, Smith, MH et al. 2005

The End of Downsizing?

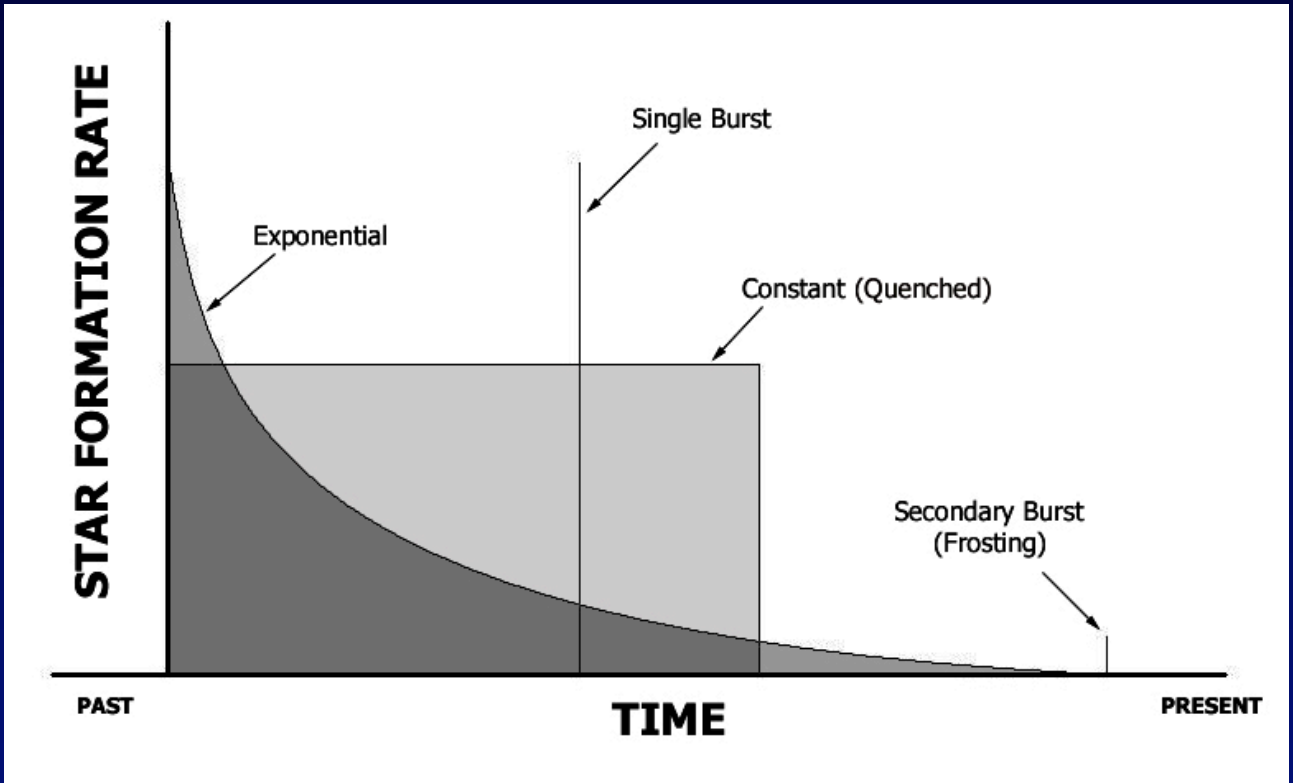


Smith et al 2009



Ages from Balmer Lines

… are *luminosity-weighted* ages. Could be



Very hard to distinguish these possibilities with spectra

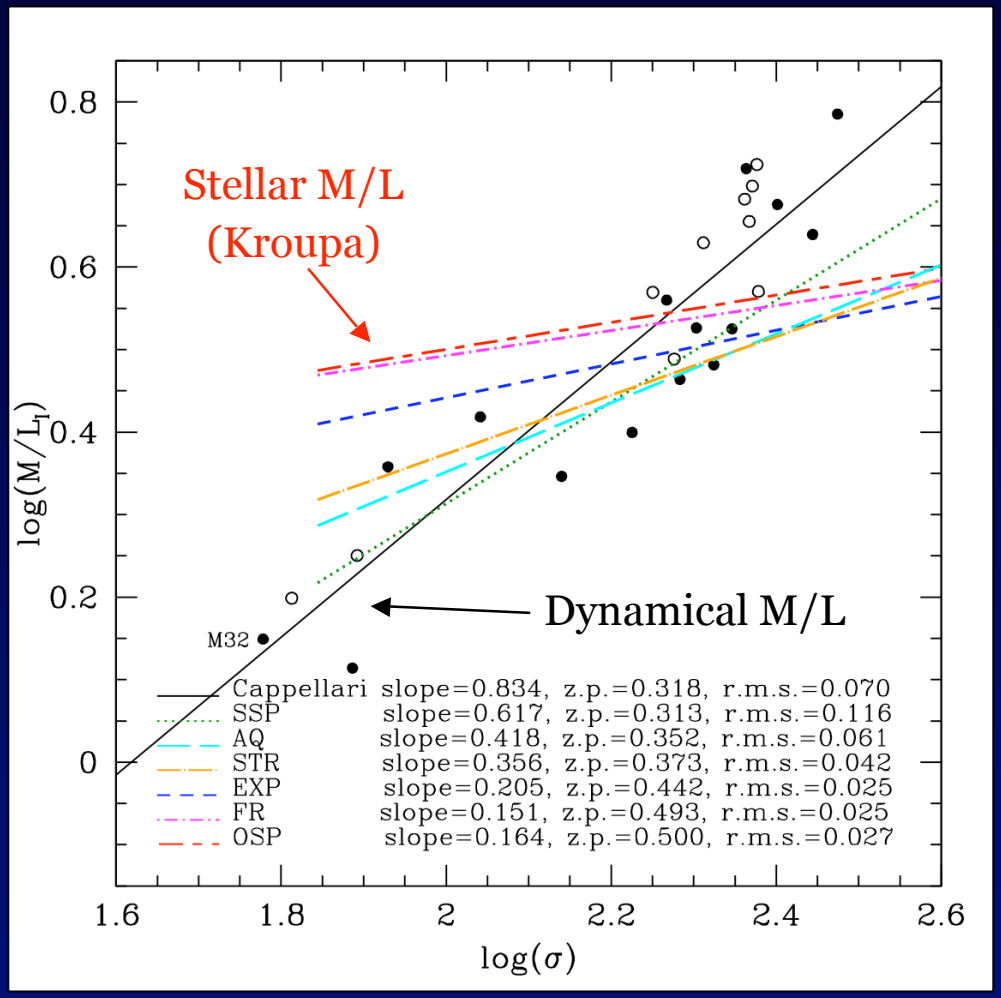
Ages from Balmer Lines

Fit absorption linestrength indices with different star formation histories.

Predict:

- Colours
- M/L ratios
- Fundamental Plane

Stellar M/L vs Dynamical M/L



Old SSP,

Exponential SFR:

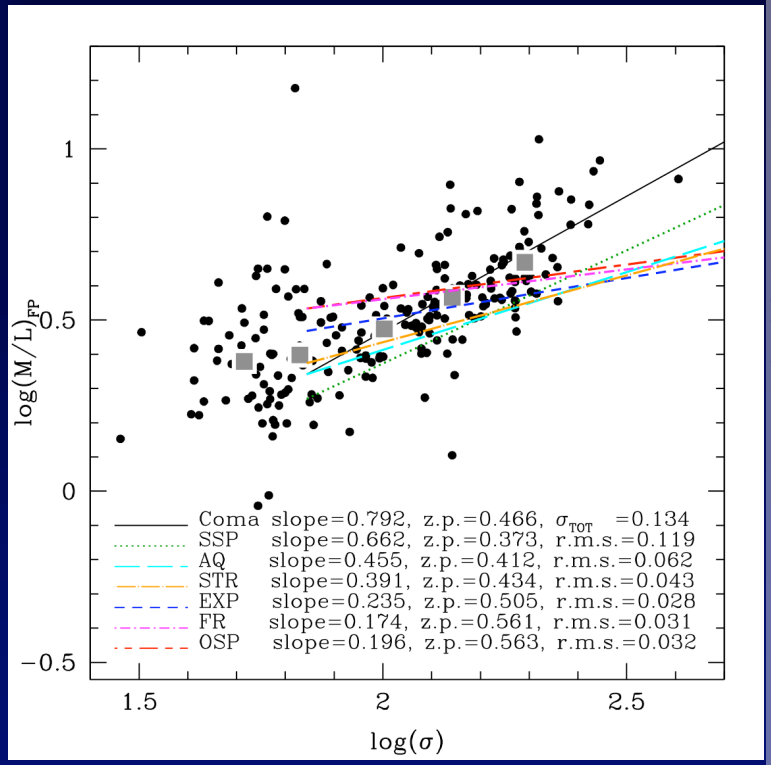
$M_*/L > M_{dyn}/L$

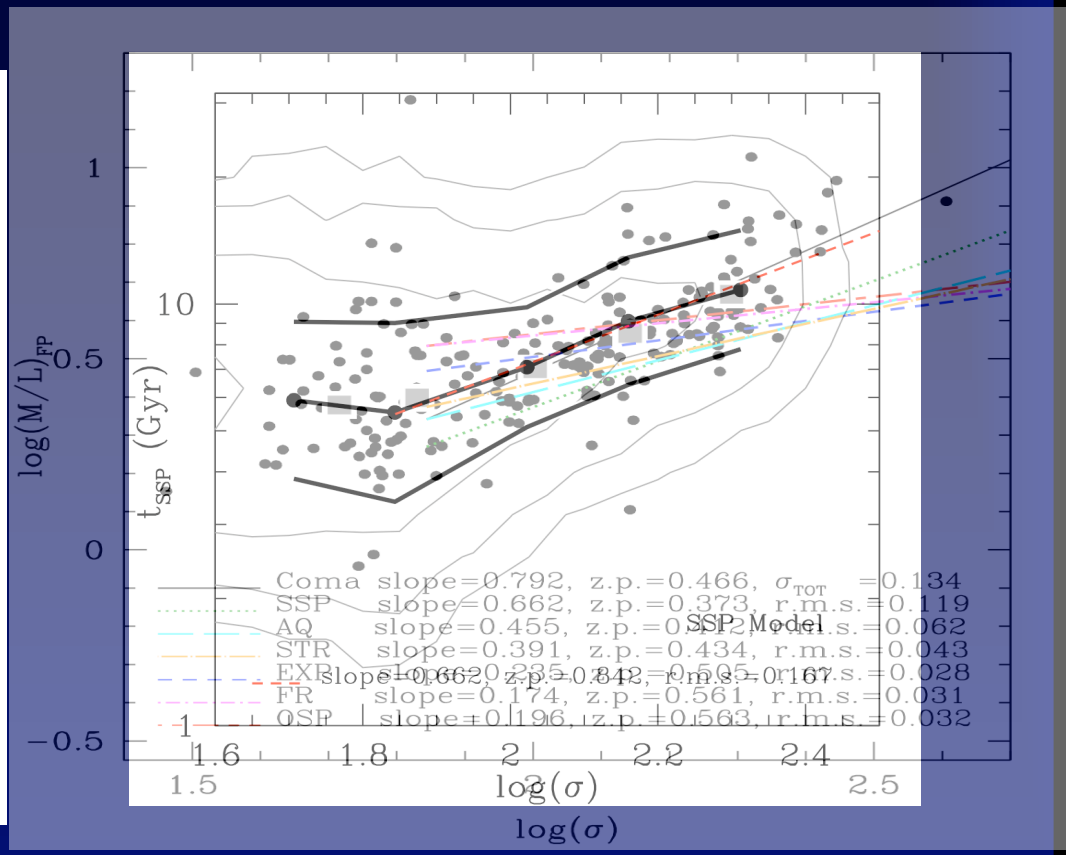
Quenched: OK

Young SSP: OK

Allanson, MH, Smith & Lucey 2009

Age as the source of FP tilt and scatter





Frosting disfavoured

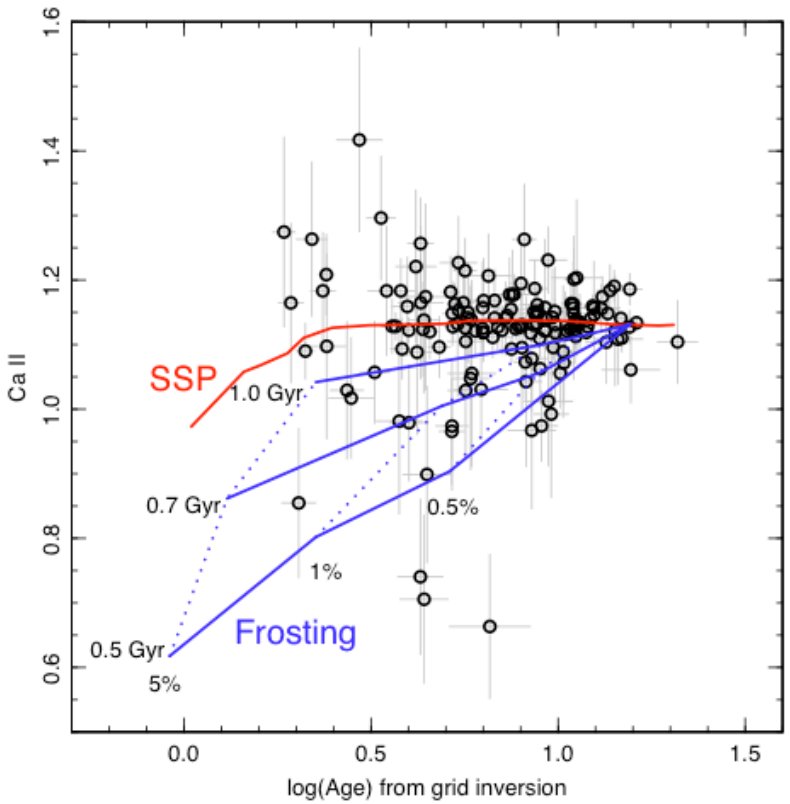


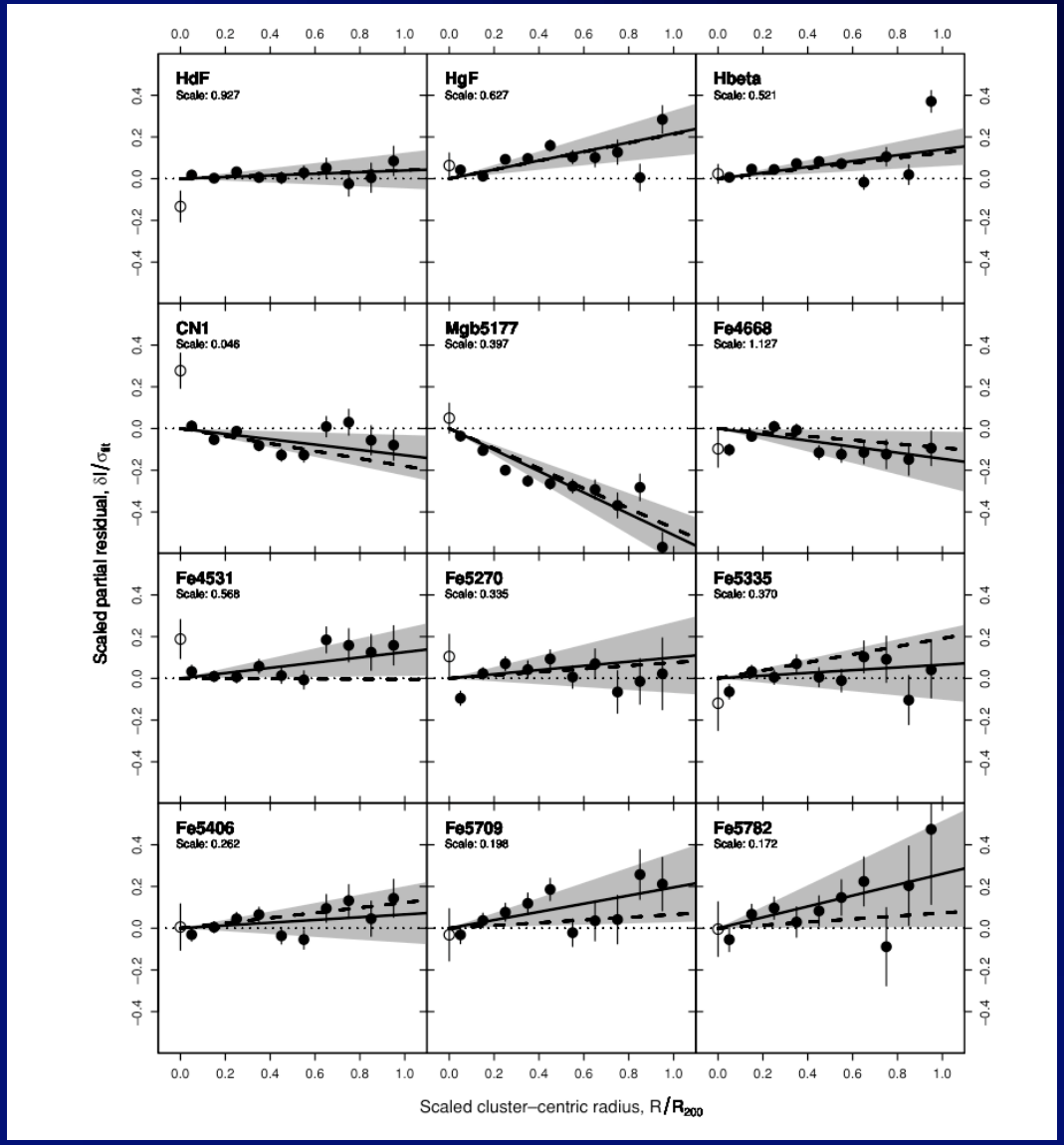
Figure 6. The Rose Ca II index for galaxies with errors smaller than 0.15, compared to the SSP-equivalent age. The grid indicates the expected behaviour for frosting by secondary bursts of age 1.0, 0.7 and 0.5 Gyr (solid lines top to bottom), and mass-fractions 5, 1 and 0.5 per cent (dotted lines, left to right), with the remaining mass in a 13 Gyr base population. The upper track shows predictions for SSPs, demonstrating the stability of Ca II for ages >1 Gyr. Although a few galaxies fall in the region of the frosted models, *on average* the SSP-equivalent ages of young galaxies are not driven by secondary bursts in the past Gyr.

Rose CaII index disfavours <1 Gyr "frosting" as the explanation for most young *cluster* RSGs.

(In contrast to field from e.g. UV?)

Smith, Lucey, MH 2007

Stellar Populations as a function of Environment



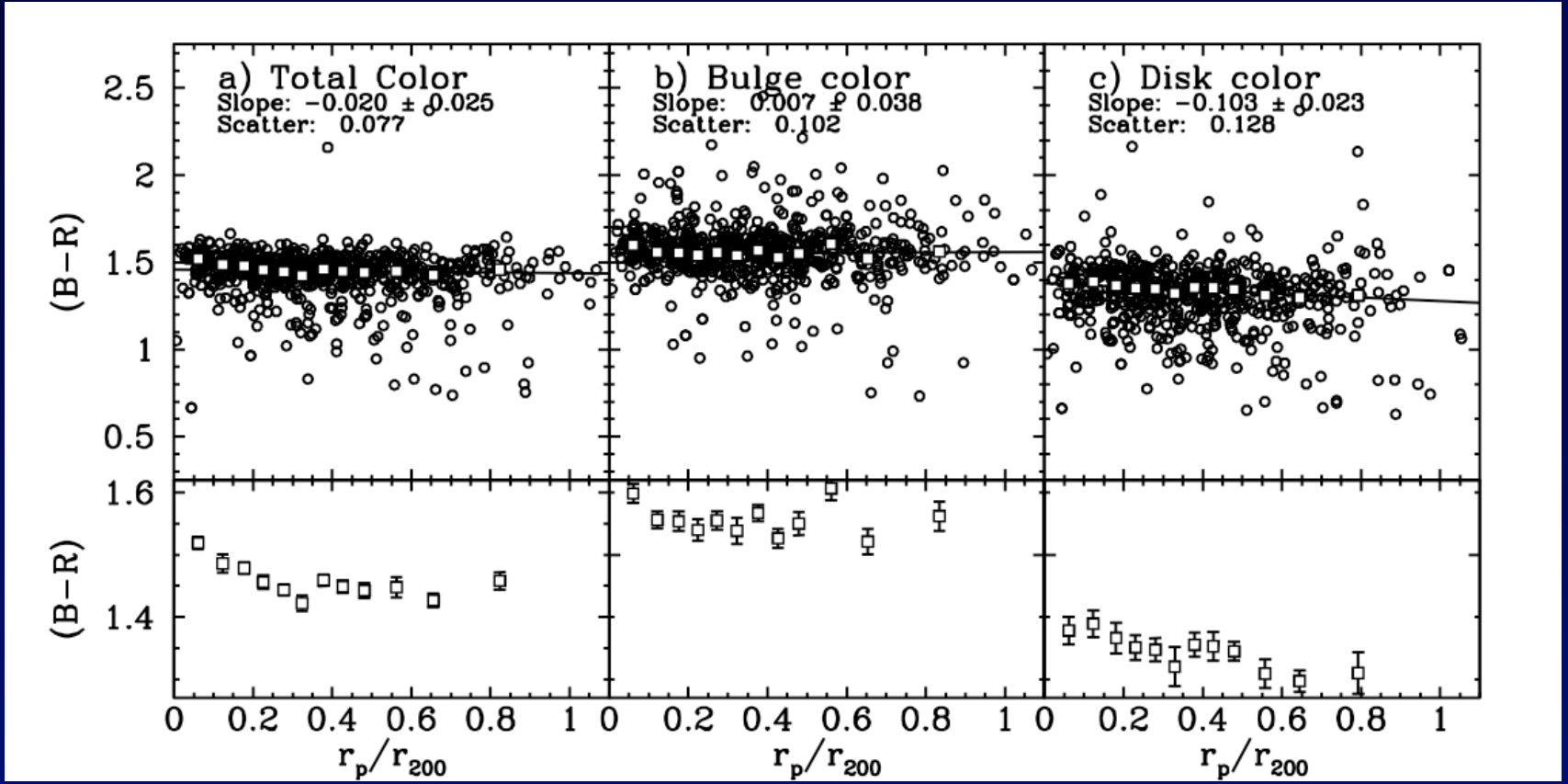
Smith et al 2006 (NFPS)

Environment

For giant galaxies, *weak* dependence on environment:

RSGs at the virial radius are 20% younger (and less α-enhanced) than their counterparts in the core.

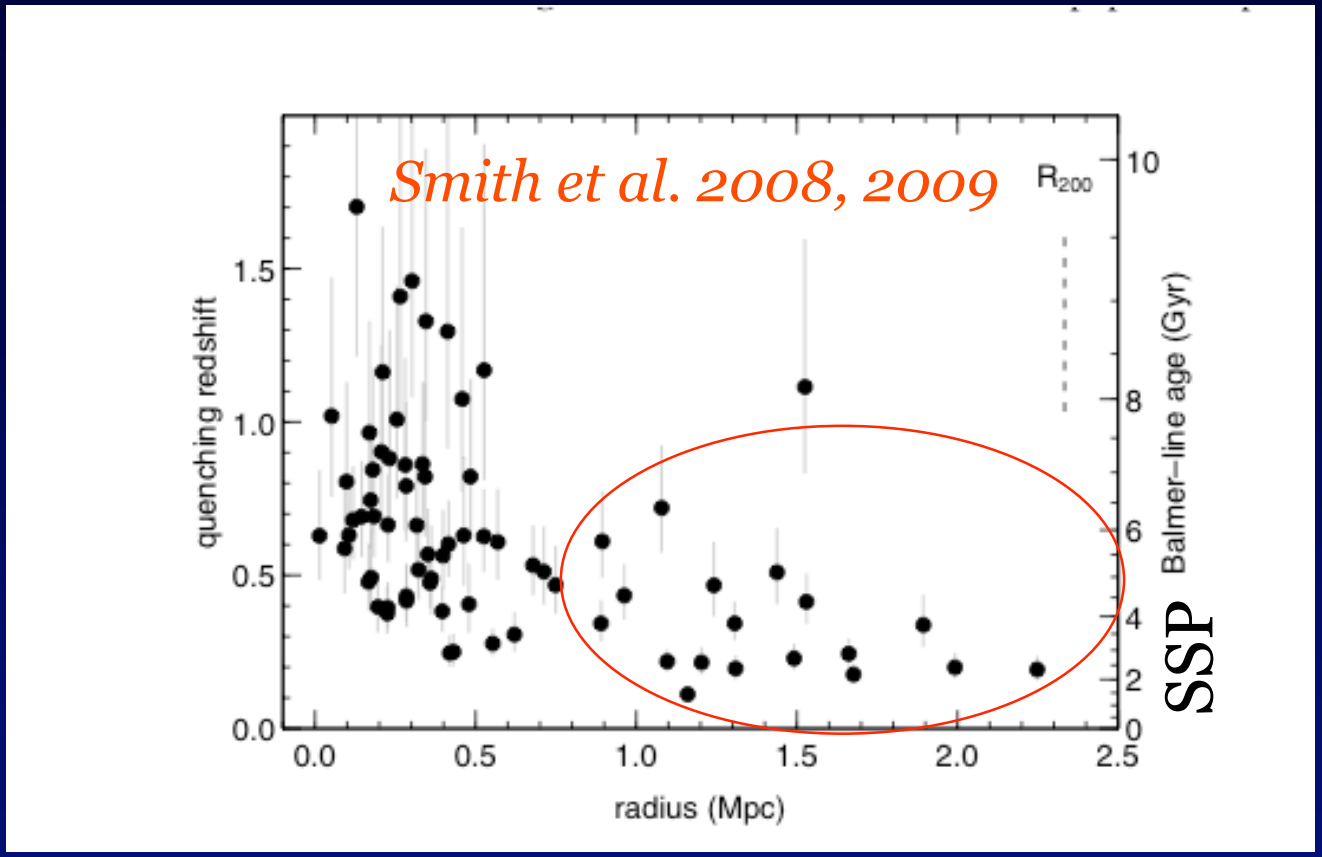
Colors of Bulges and Disks



For bright galaxies, only disks depend on radius

NFPS - MH, Stevenson, Smith et al. 2009, in prep

Recently-quenched Coma RSG dwarfs



Recently-quenched Coma dwarfs

Coma RSG dwarfs consistent with having been “quenched” within the last 1-2 Gyr.

Morphologically, most of the recently-quenched galaxies appear to be early-type with Sersic n ~ 2 (but ~30% do have disks).

Modelling quenching

- Track orbits of haloes in N-body simulations of clusters

- Apply simple prescriptions for "cluster-centric" physics
  e.g. "Quenching" when crossing the virial radius

- Make predictions for realistic galaxy orbits (backsplash), projection effects etc.

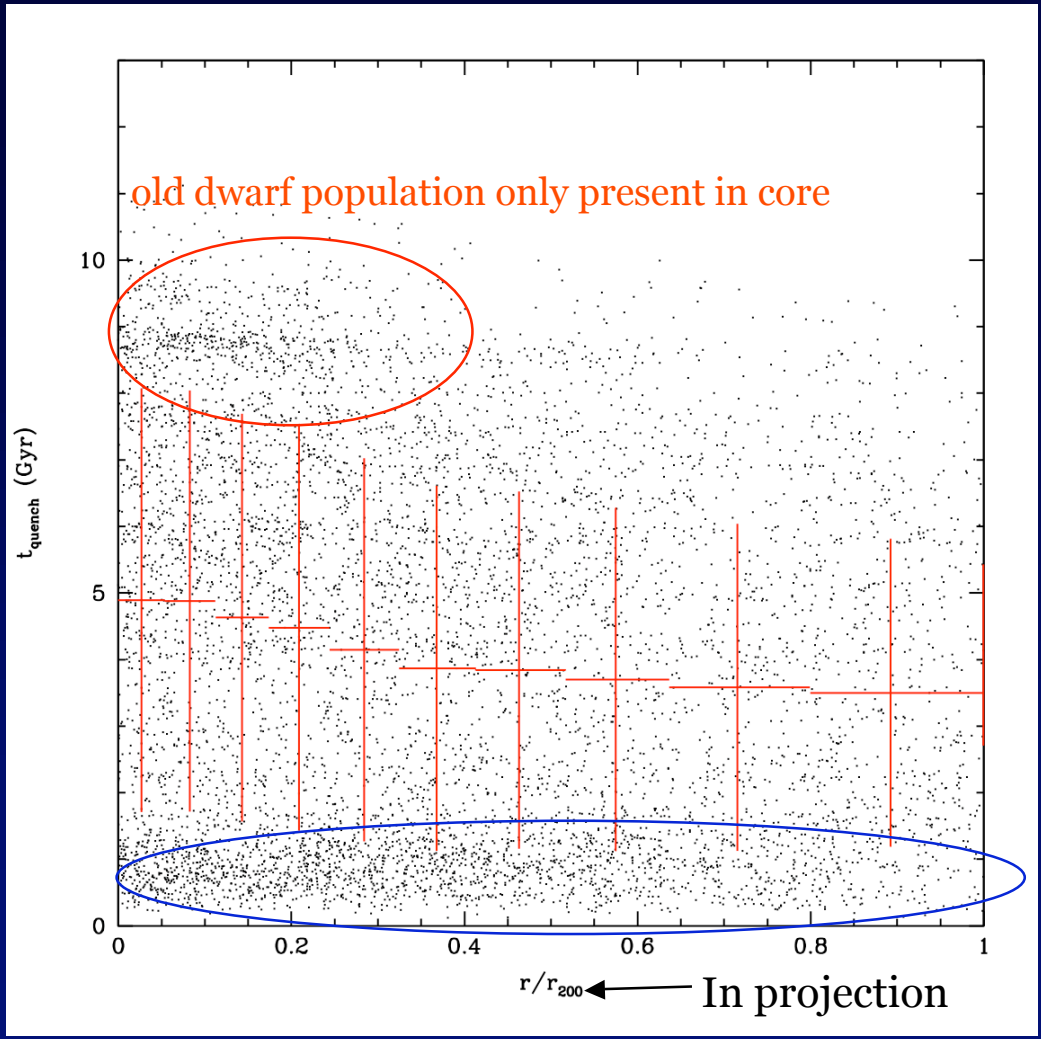
- For giant galaxies, these simple models *overpredict* the observed linestrenth dependence on cluster-centric radius ... but:

Infall times

Dwarf galaxies with

$M_R < -19$

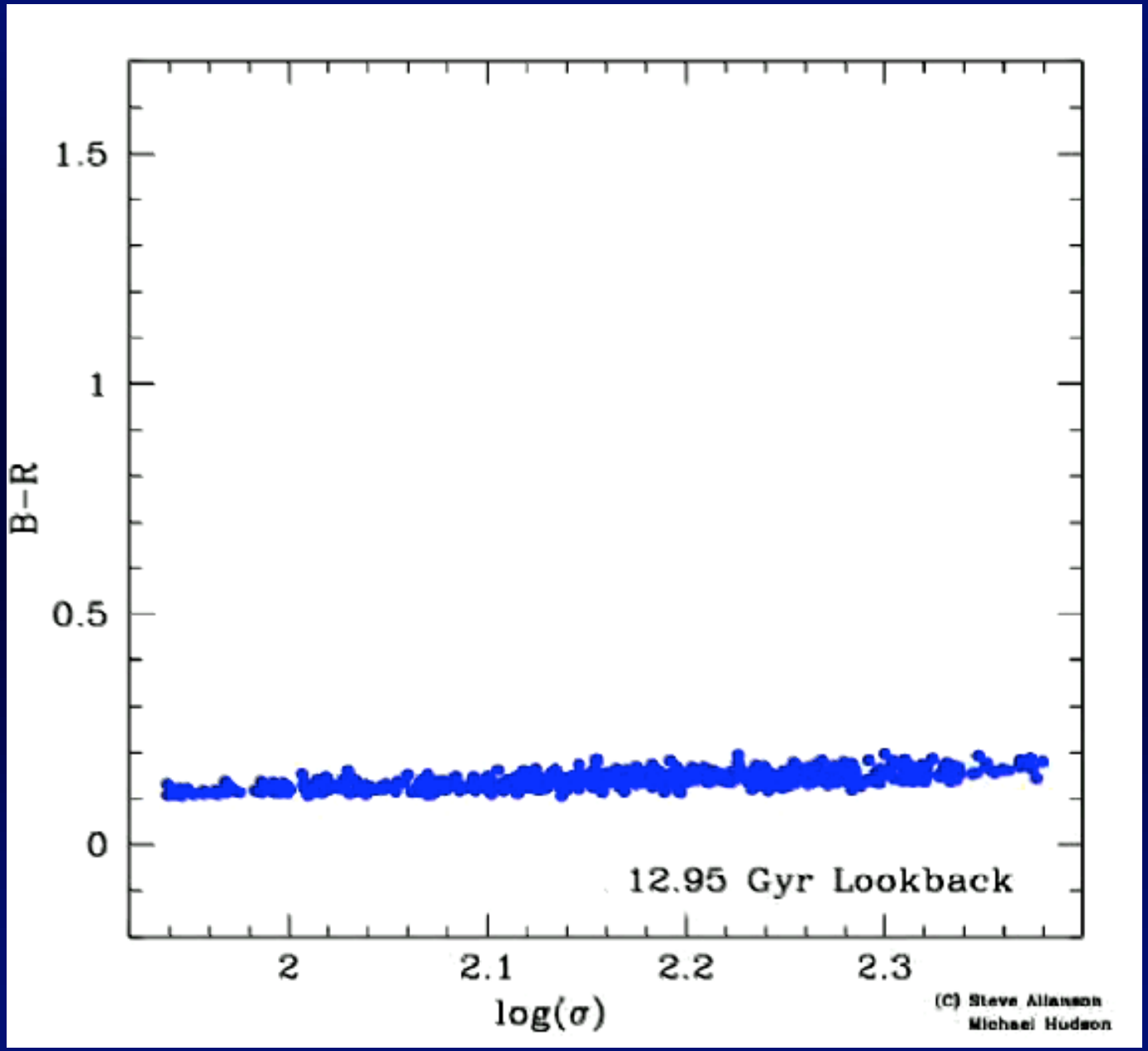
$\sigma \sim 40$ km/s



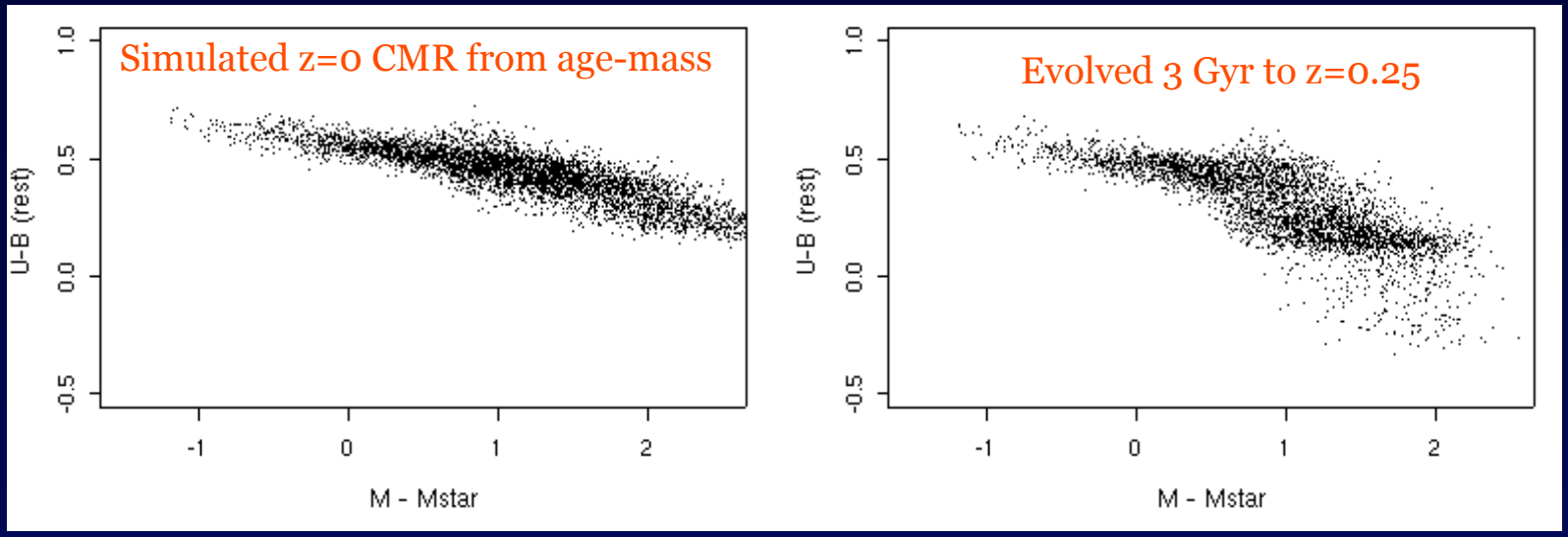
Taranu, MH et al in prep.

Buildup of the red sequence

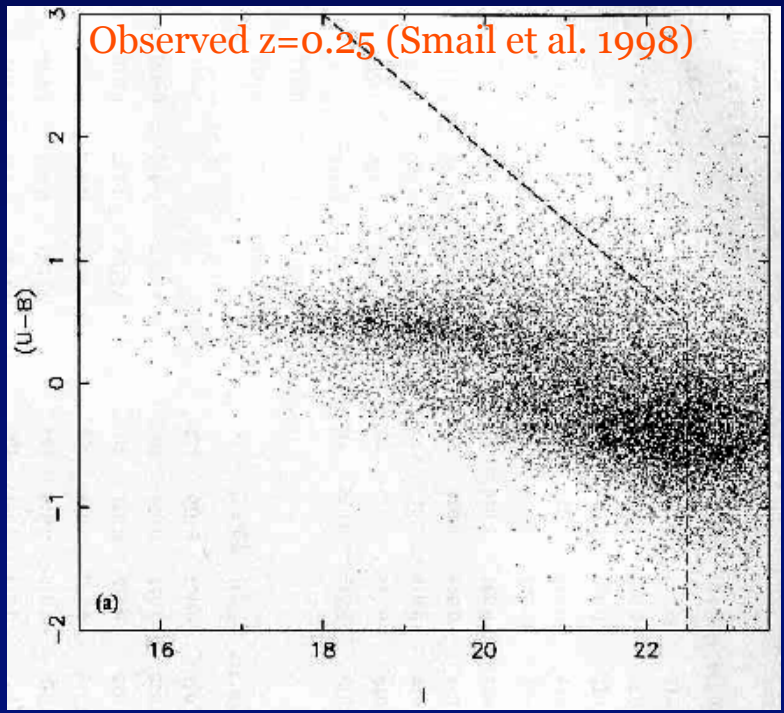
If age is a strong function of mass/velocity dispersion then the red-sequence itself is built “top-down”


1.5
1
0.5
0
B−R
12.95 Gyr Lookback
2
2.1
2.2
2.3
log(σ)
(C) Steve Allanson
Michael Hudson

Red Sequence "Truncation"



- Steep age-mass relation implies a gradual build-up of the red sequence.
- Predicts a truncation/depletion of the red sequence even at modest redshifts, e.g. z~0.25.
- Truncation already observed by Smail et al. 98?
- Truncation at higher mass for higher z: De Lucia et al. 2004; Kodama et al 2004 Goto et al. 2005 …



Cluster Red Sequence Galaxies

- Strong age ("downsizing"), metallicity and α-enhancements along the RSG *velocity dispersion* sequence.
- Downsizing stops at $\sigma \sim 70$ km/s.
- Exponential (and late frosting) models do not fit dynamical M/L, but SSP or Quenched models are good fits.

- Giant RSG ages depend weakly on environment
  - This dependence is mostly in disk component
- Dwarf RSG ages depend strongly on cluster-centric radius
- Simulations suggest that quenching of star formation in dwarfs may happen around the virial radius.