Science Achievements of the DEEP2 & AEGIS surveys

by

Koo, Faber, and the DEEP & AEGIS Teams

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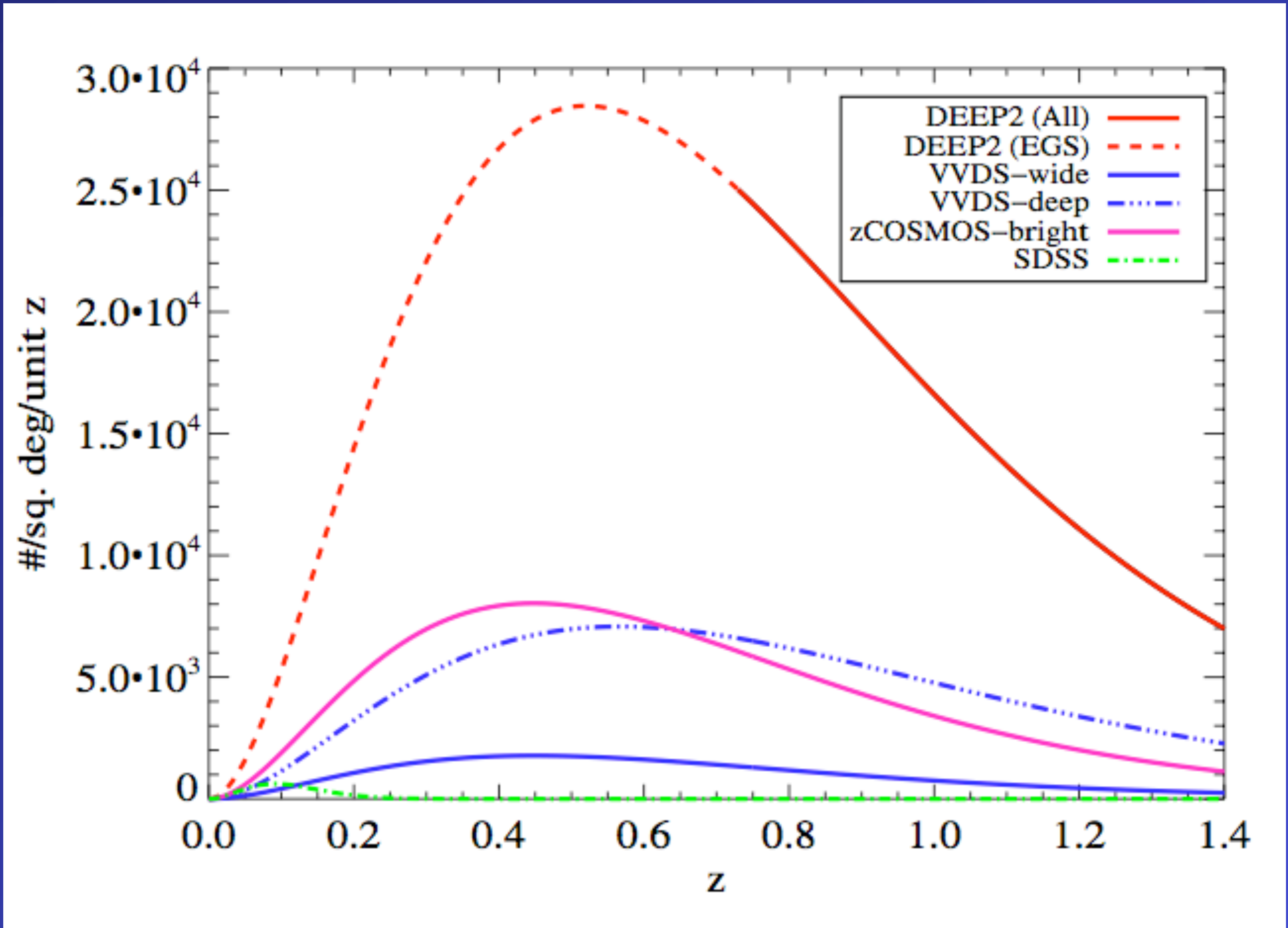
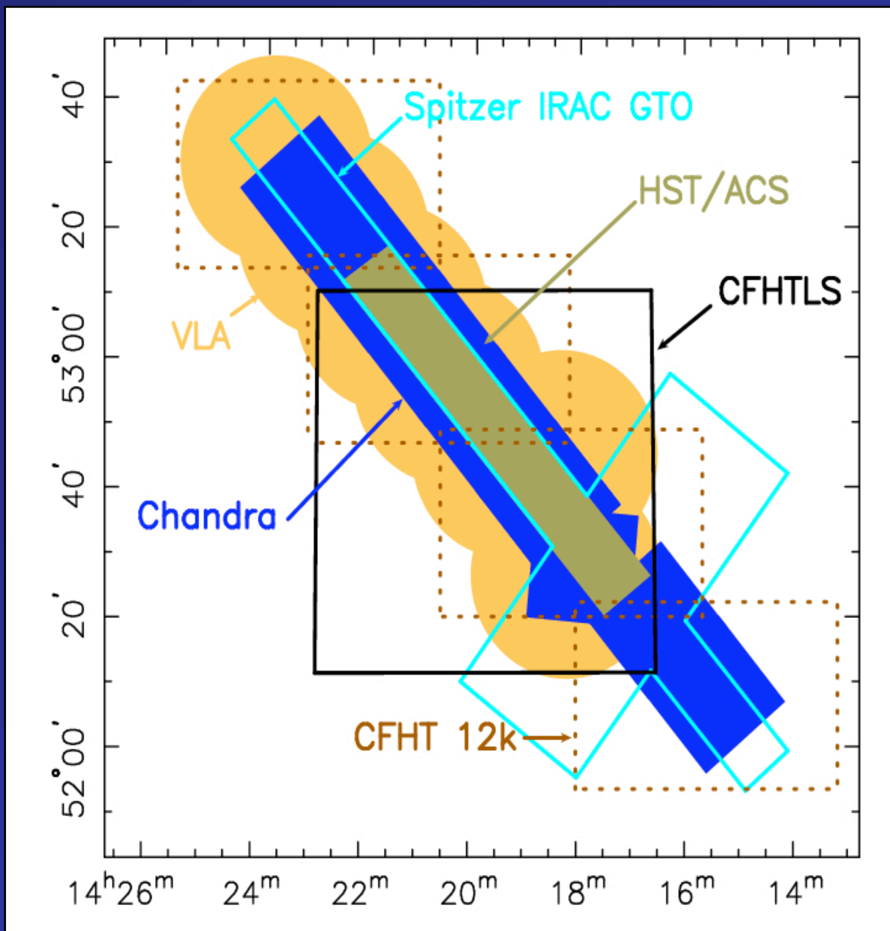
DEEP2 basics

- **Officially finished:**
  - 53,000 spectra
  - Four fields, 3 square degrees
  - 39,000 with Quality 3 or 4 redshifts
  - Reliability > 98%

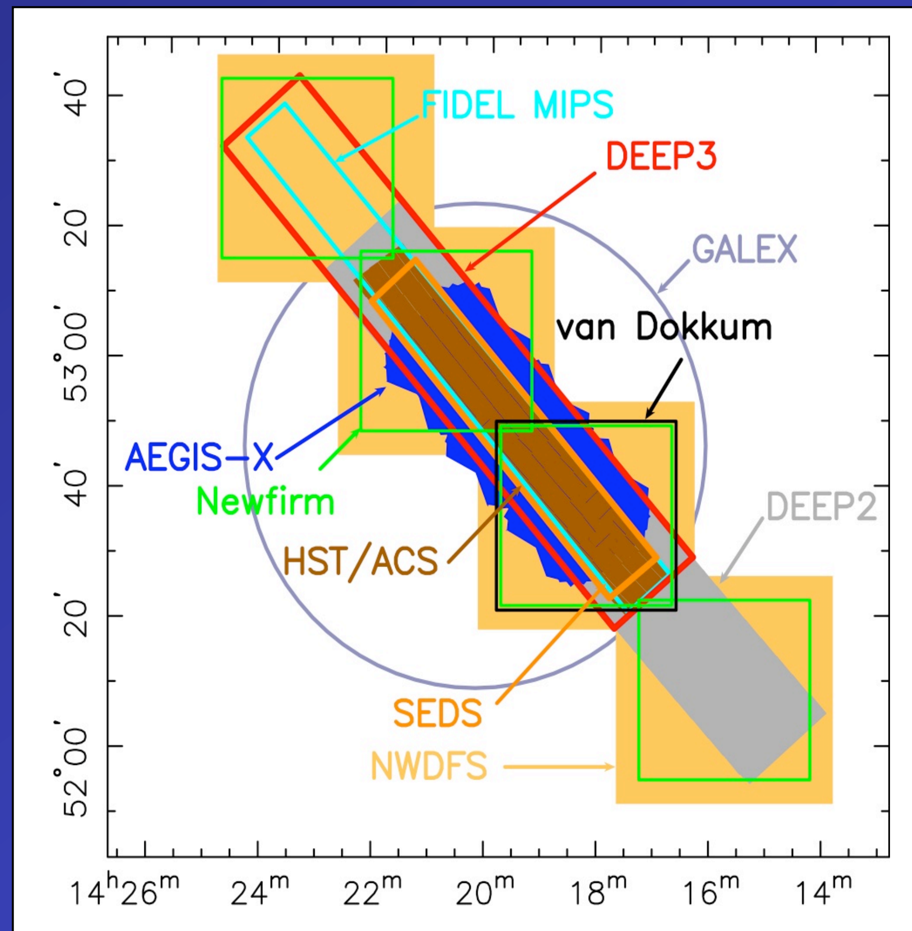
Sampling density on the sky compared to other surveys



Extended Groth Strip Data Sets: DEEP2



Phase I



Phase II

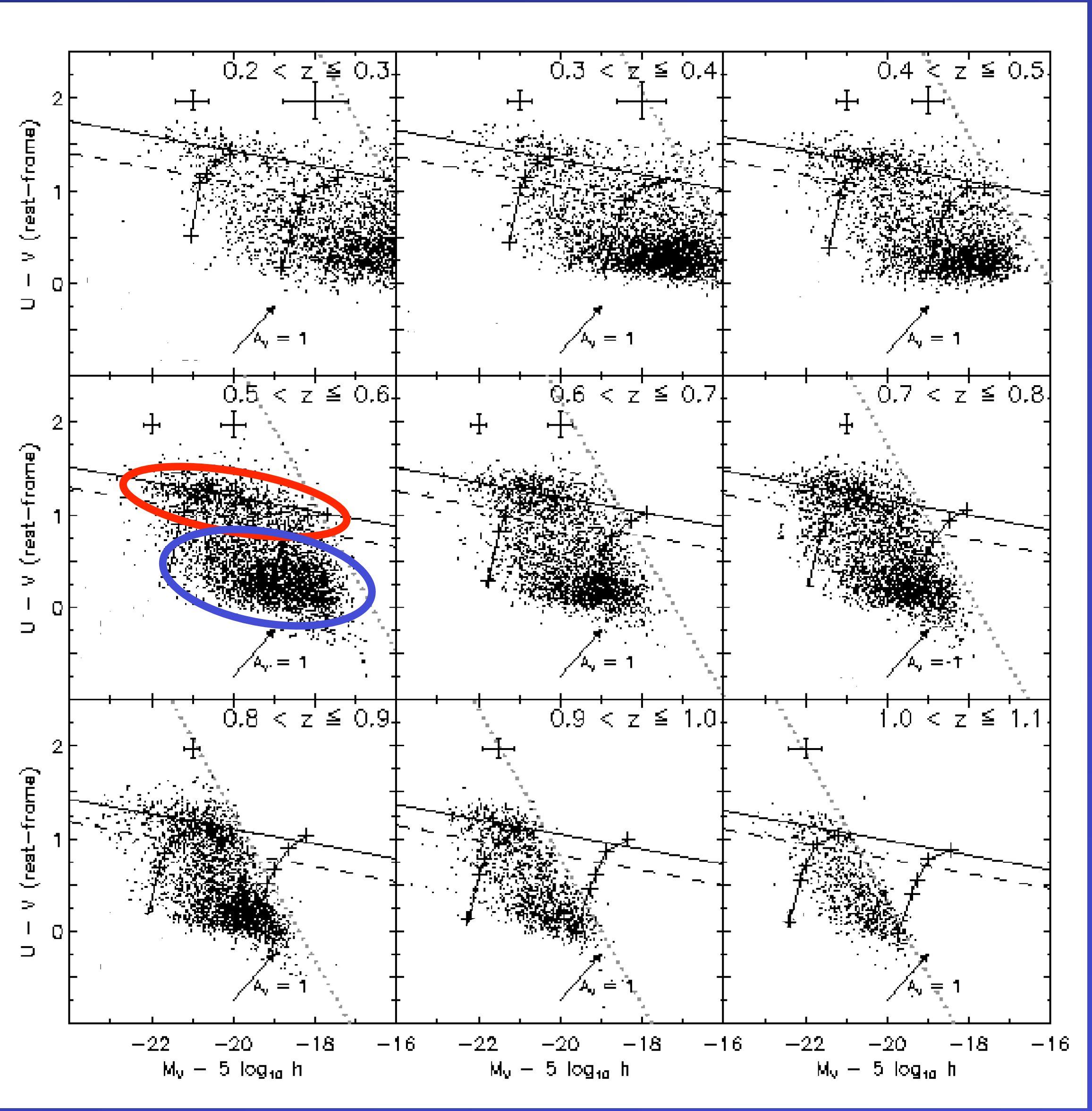
EGS is also a CANDELS field.

Color bimodality persists out to beyond z ~ 1

Combo-17 survey:

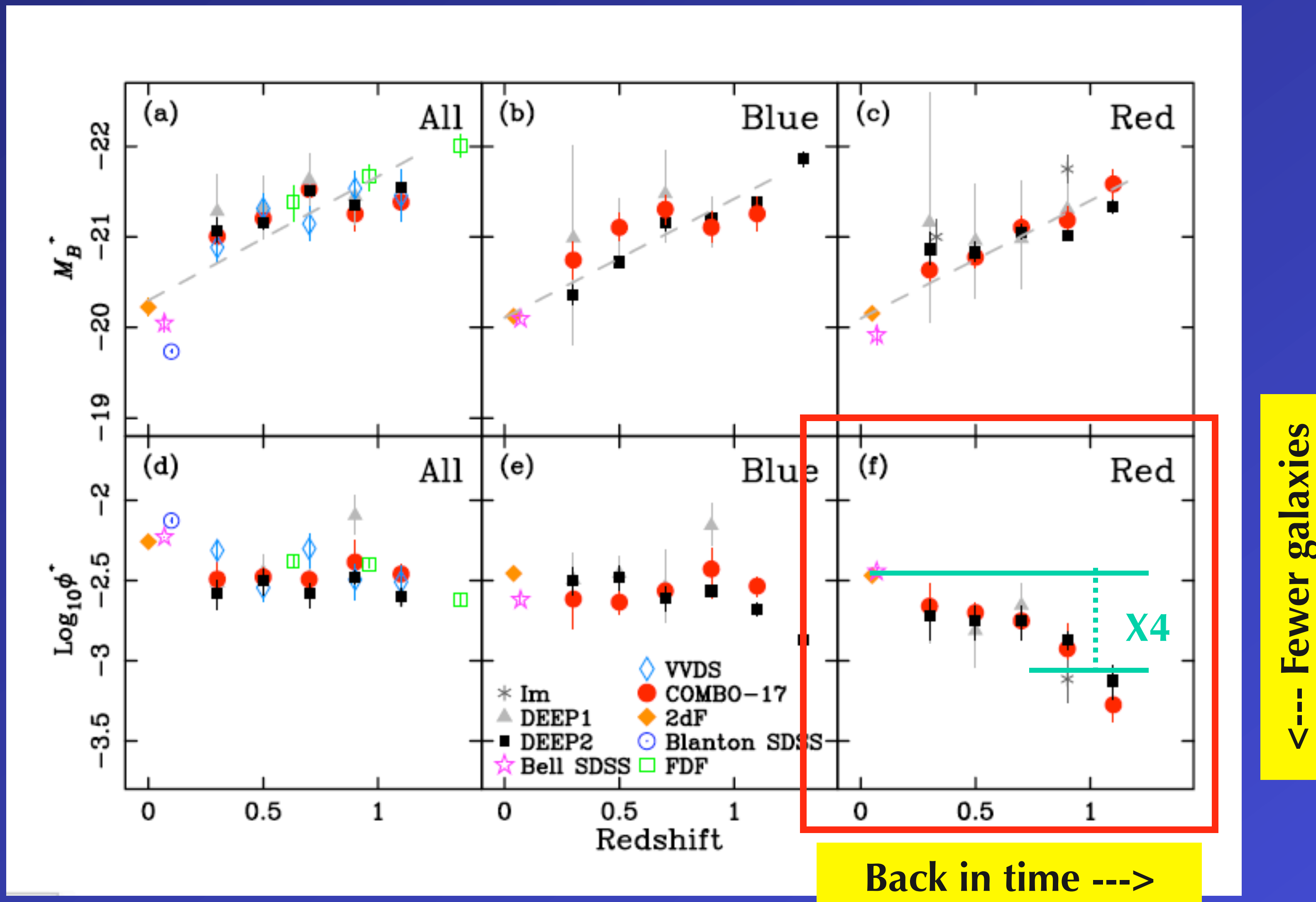
- 25,000 galaxies
- R-band selected to R = 24
- 17-color photo-z's

Similar results from DEEP2.



Bell et al. 2004

DEEP2 and COMBO-17: At least half of all L* spheroidal galaxies were quenched *after* z = 1



Bell et al. 2004, Willmer et al. 2006, Faber et al. 2007

Formation of the Red Sequence

- Red sequence continues to grow at late times (Faber et al. 2007)
- Only available pool to draw from is the *BLUE CLOUD*. Hence, galaxies must be moving from the blue cloud to the red sequence due to a decline in star-formation

Theories for Quenching Central Galaxies

External (halo-based) model:

- Massive halo quenching: truncation of "cold flows" and conversion of cold gas to hot halos
  - Critical halo mass $M_{crit} \sim 10^{12}\ M_{\odot}$ (Blumenthal et al., Keres et al., Dekel et al., many others)

Internal models:

- Stellar feedback – starburst
- AGN feedback

Possibly driven by mergers

- Secular evolution
- Disk instability

"Morphological" quenching

What is the quenching mechanism?

- Quenching is a *gradual process* that lasts billions of years. It is not a sudden event, as shown by the *scarcity of K+A galaxies* (Yan et al. 2008)

- This is evidence against **sudden** gas evacuation, such as would be caused with AGNs

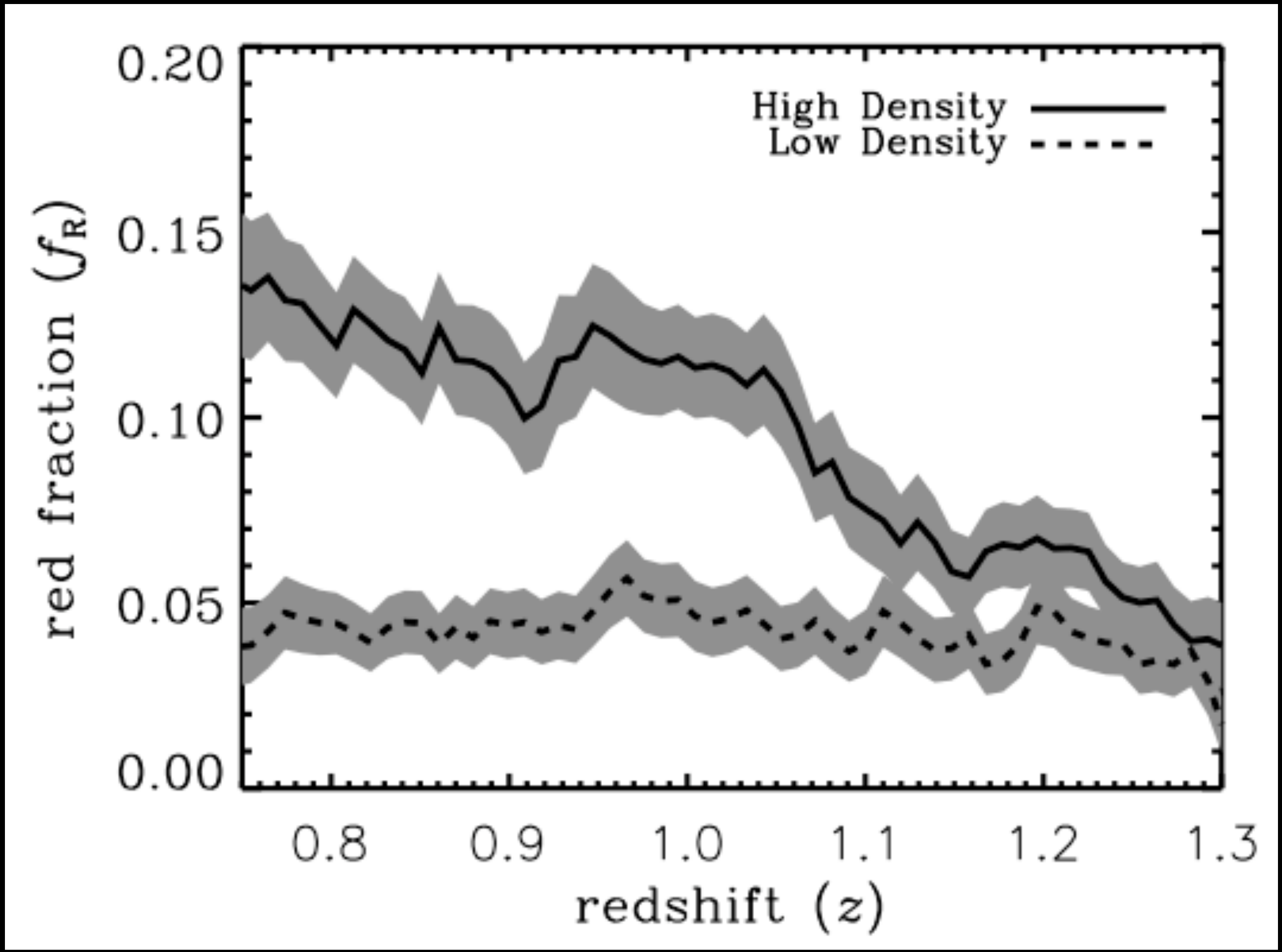
- Quenching starts first *in denser environments* (Cooper et al. 2006)

- There thus appears to be an *environment threshold* of some kind that begins to be crossed in dense environments around $z \sim 2$

- Massive red-sequence galaxies quench first. These are probably centrals. The faint end of the red sequence forms later, via *satellite quenching.* (Bundy et al. 2007, Huang et al., in prep.)
  - The central-satellite distinction is important for galaxy evolution.

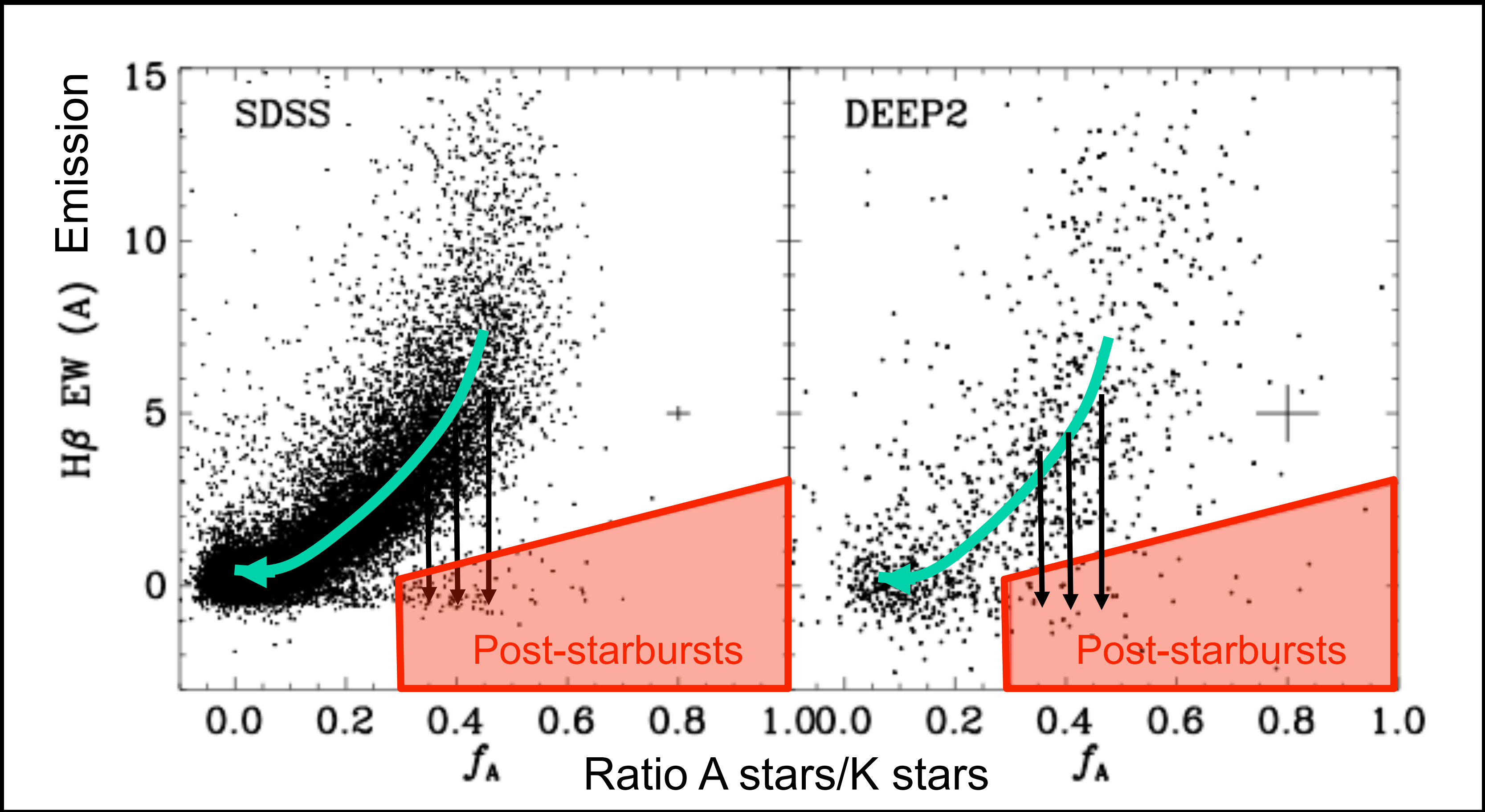
There is strong evidence for massive halo quenching at $z < 1$.

Major quenching in high-density environments starts near z = 1.3



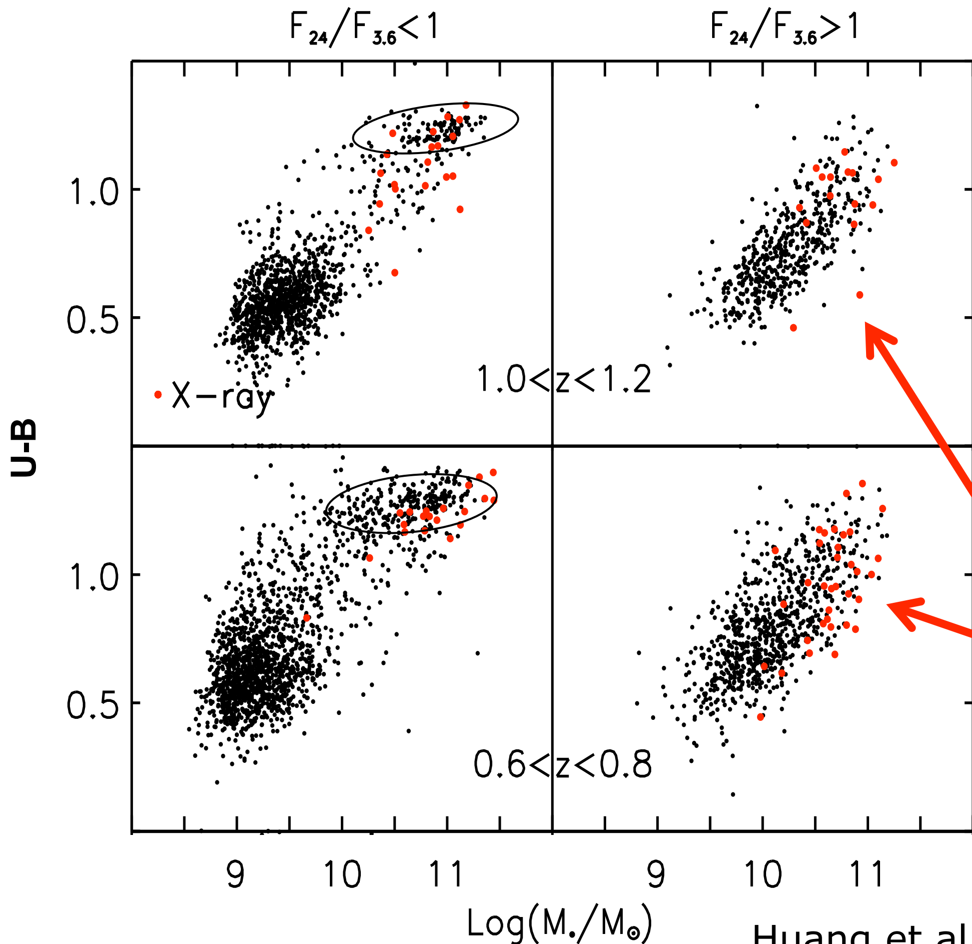
Cooper et al. 2006

Post-starburst galaxies are rare.
Most galaxies quench gradually.



Yan et al. 2008, following Quintero et al. 2005

The red sequence appears first at high mass



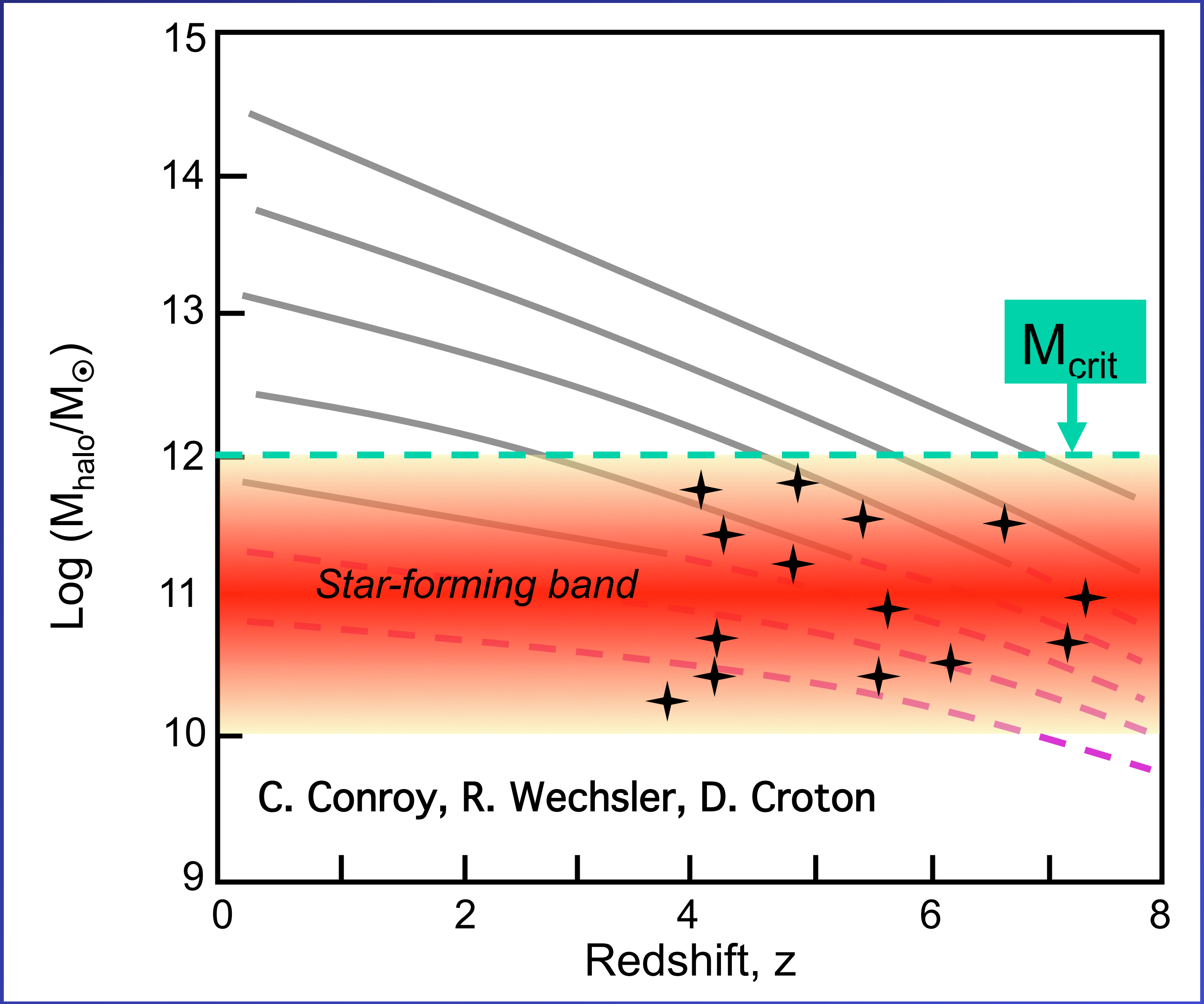
Huang et al., in prep

Also Bundy et al. 2007, Ilbert et al. 2010, and others

24 mu detected sources in these two panels.

A new set of photoz's with 3% accuracy complete to K_{AB} = -20

Quenching first at high mass is consistent with a halo upper mass limit for SFR: M_{crit}.

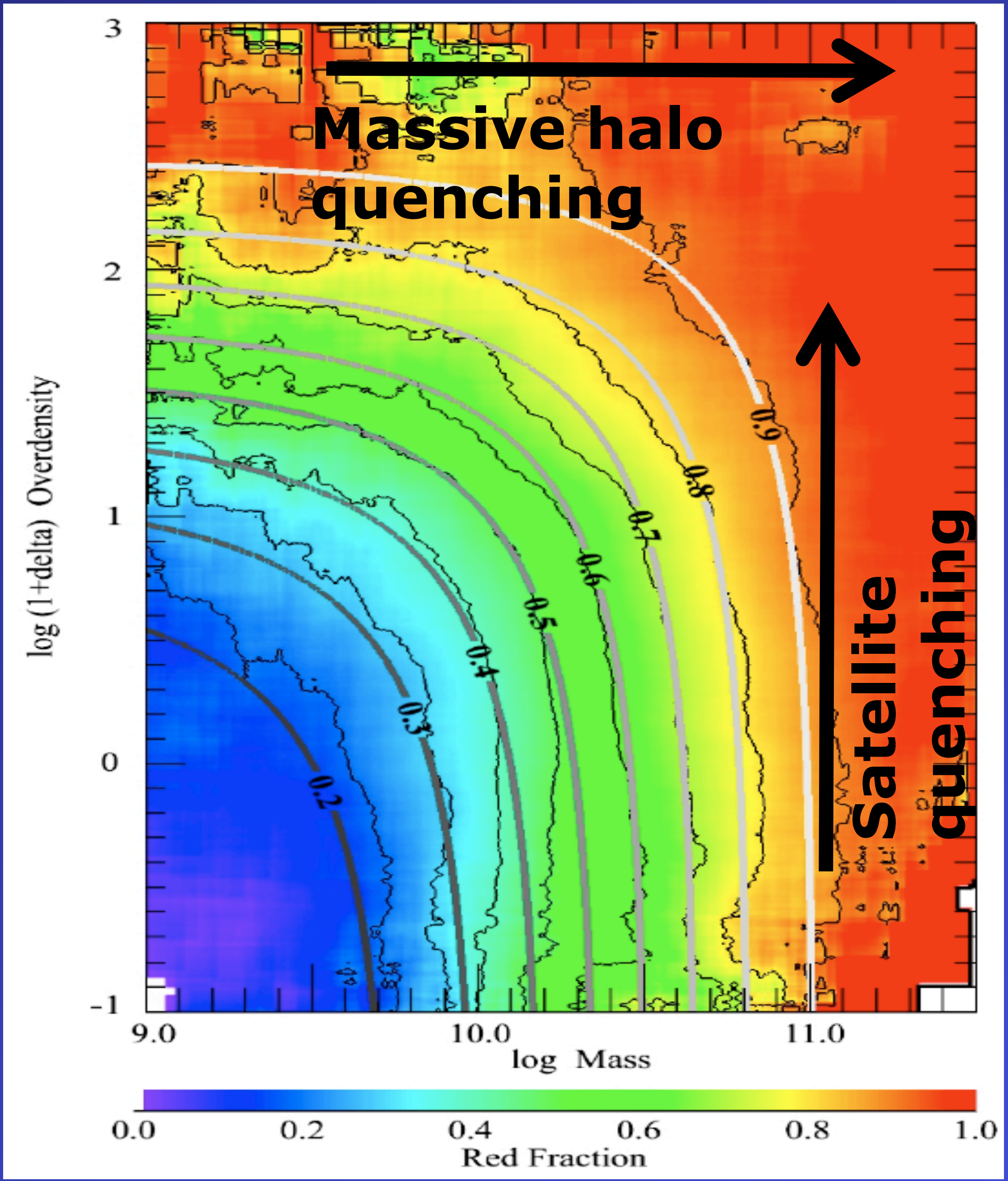


- Quenching fraction as a function of stellar mass and local overdensity

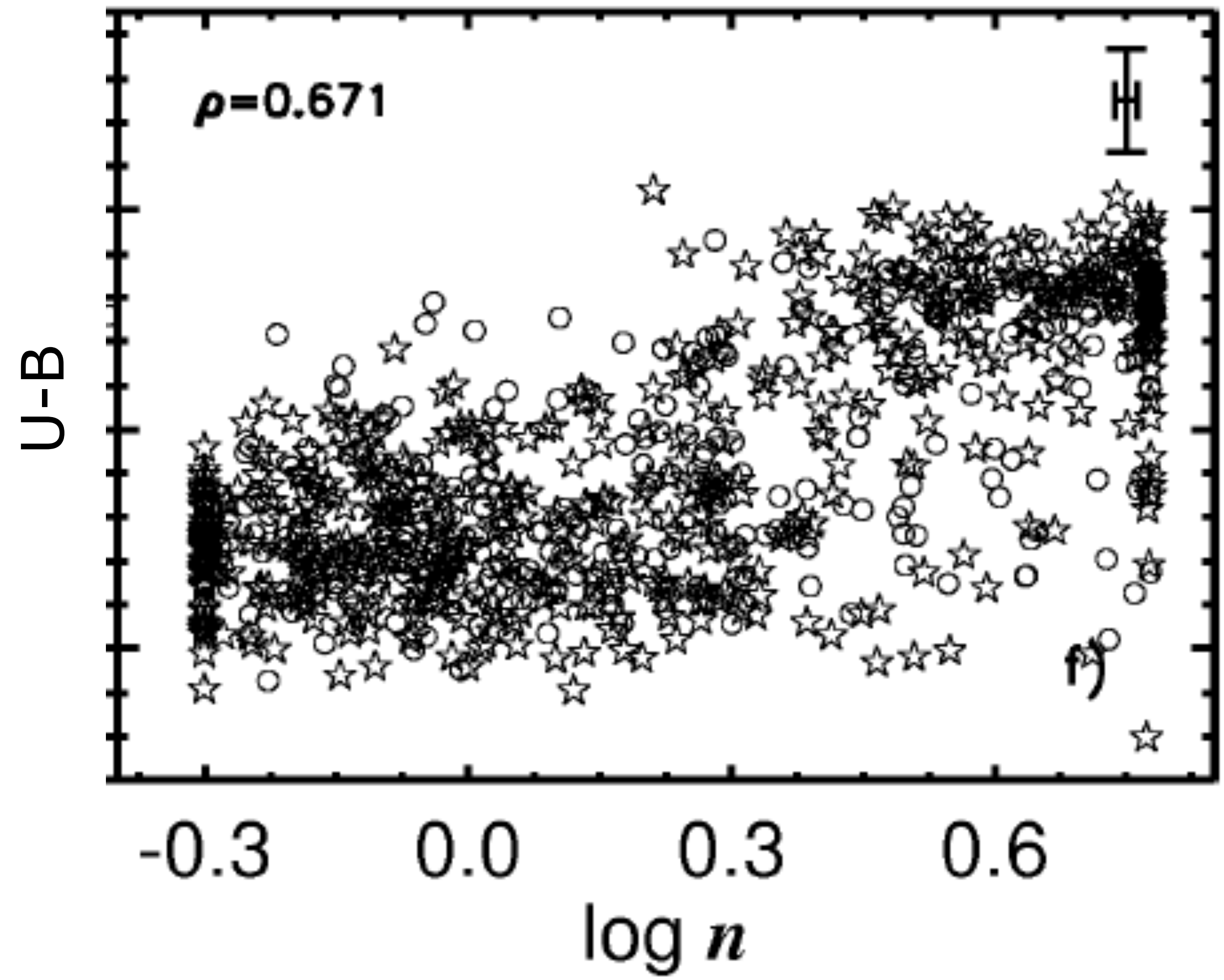
- Stellar mass is used as a proxy for halo mass.

- This functional fit matches many trends in galaxy properties vs redshift.

- Peng et al. 2011. See also J Woo talk later this meeting.

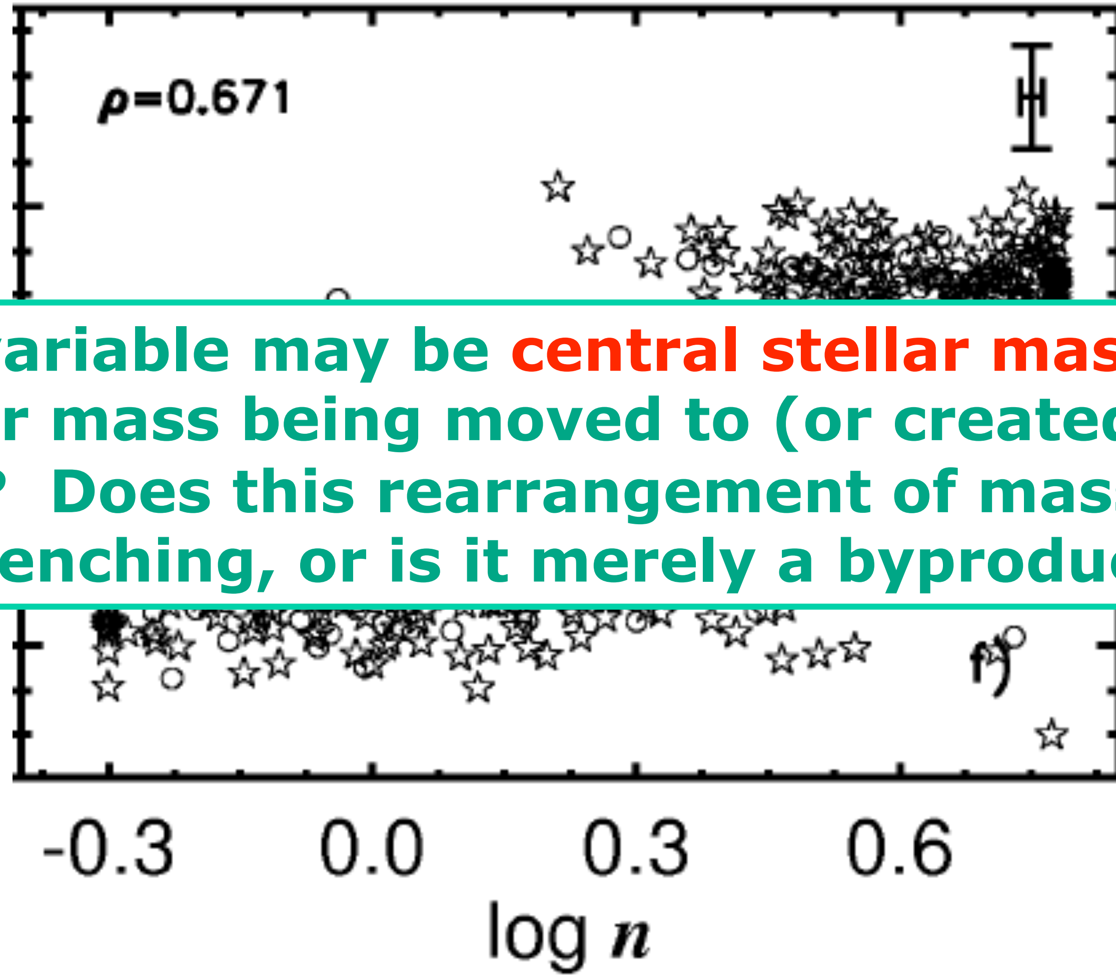


Alternative view: quenching is caused by **internal** galaxy structural properties



Cheung et al. 2011 using Sersic indices from GIM2D fits by Simard to AEGIS HST images. See also Schiminovich et al. 2007, Bell 2008, Bell et al. 2011, and various Sloan papers.

Alternative view: quenching is caused by **internal** galaxy structural properties



The real variable may be central stellar mass density. Is stellar mass being moved to (or created at) the center? Does this rearrangement of mass *cause* quenching, or is it merely a byproduct?

Cheung et al. 2011 using Sersic indices from GIM2D fits by Simard to AEGIS HST images. See also Schiminovich et al. 2007, Bell 2008, Bell et al. 2011, and various Sloan papers.

Theories for Quenching Central Galaxies

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Internal models:

- ~~Stellar feedback – starburst~~ } ~~Possibly driven by mergers~~ **SLOW!**
- AGN feedback
- Secular evolution
- Disk instability

} "Morphological" quenching + Bulge building

Star formation varies smoothly and predictably

- Star-formation is tightly correlated with stellar mass
  - Scatter is <0.3 dex (1-sigma) (Noeske et al. 2007a)

- Abrupt fall-off at high mass corresponds to creation of red sequence

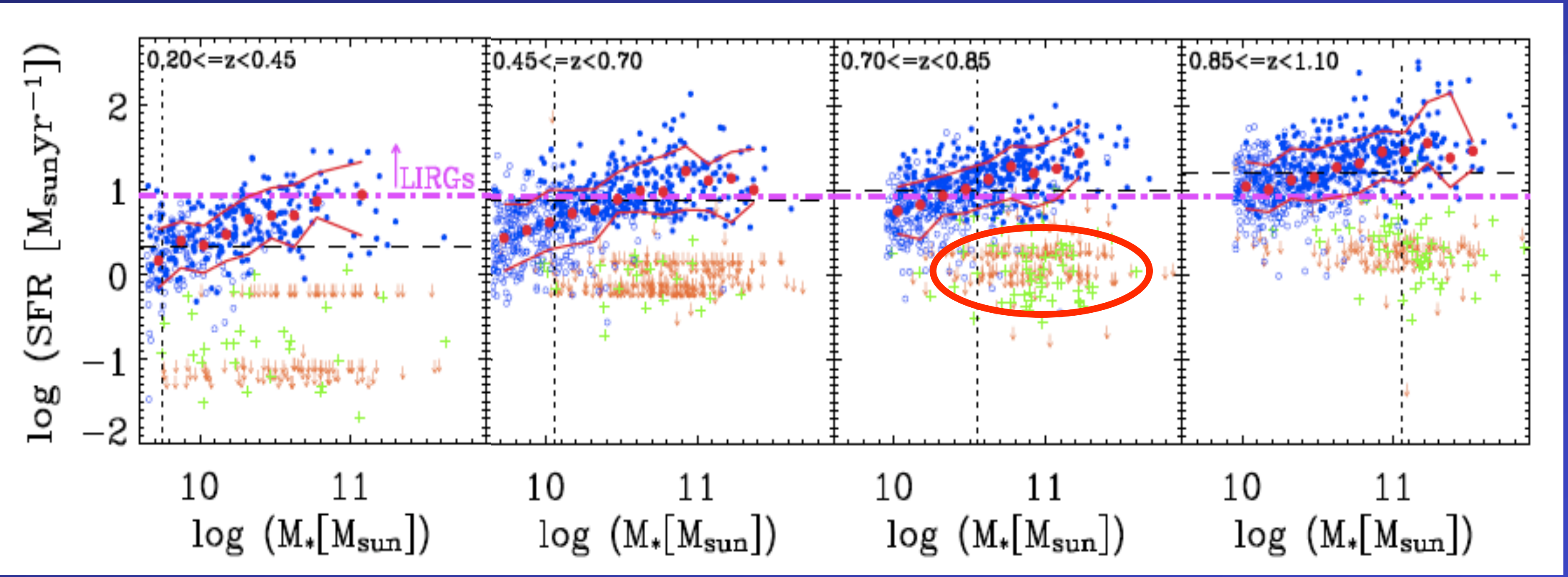
- A simple model fits the data after z~3: (Noeske et al. 2007b)
  - 1-d family of star-forming trajectories, labeled by stellar mass today
  - More massive galaxies have more rapid declines and start earlier

- Thus star-formation is a wave that starts in massive galaxies and sweeps downward to small ones at late times. ***DOWNSIZING!***

- Observed scatter matches that of semi-analytic models that *include* merger-driven SFR! Nevertheless, only a few percent of stars in models are triggered by merger events (Kollipara et al., in prep)

Most star-formation is "quiescent" and is well correlated with stellar mass.

AEGIS: Star-forming “main sequence”

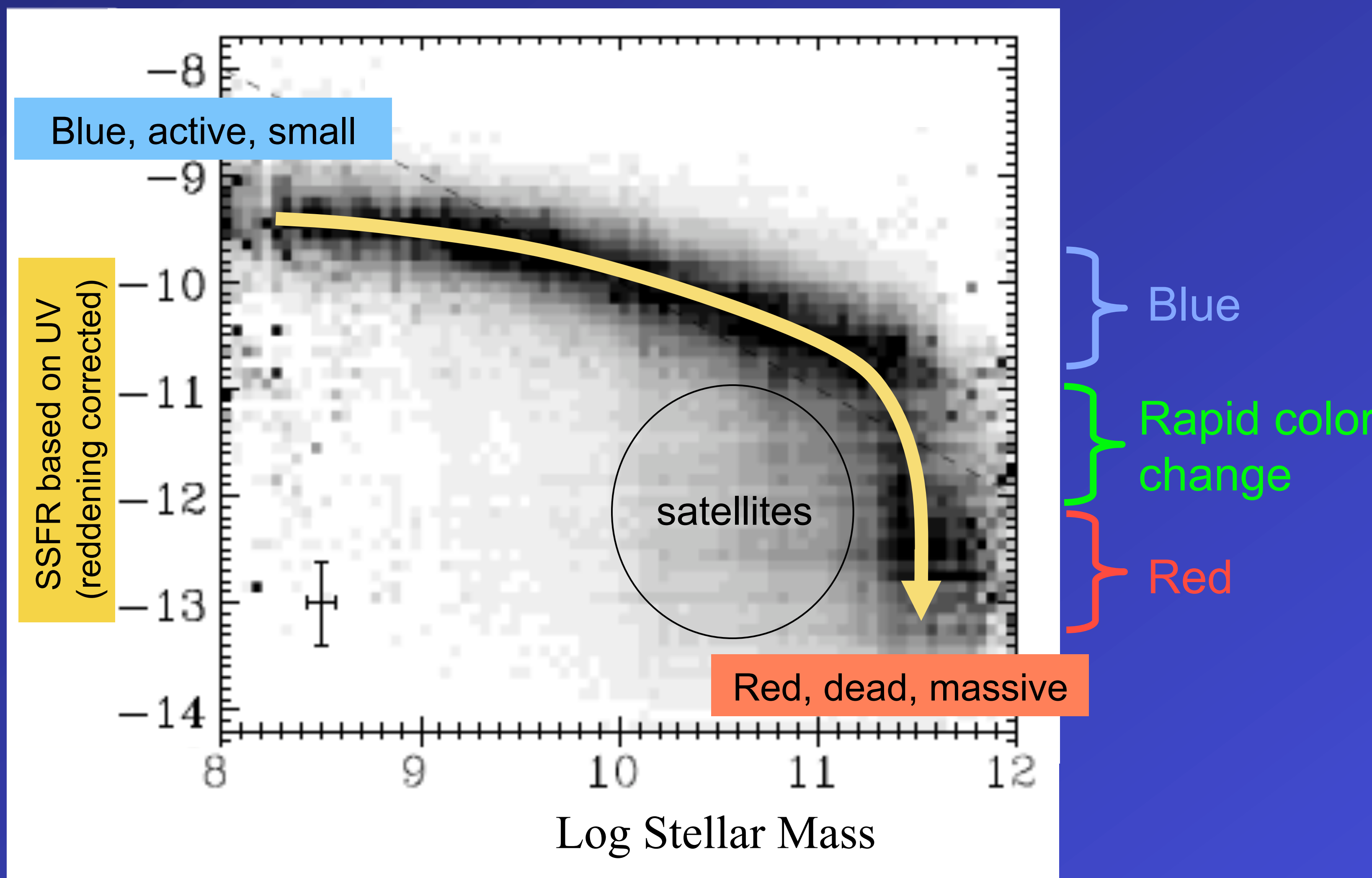


Noeske et al. 2007

τ-model sequence:

- Star formation declines exponentially in each galaxy
- Bigger galaxies turn on sooner and decay faster
- Downsizing!

SDSS+GALEX: Similar trend based on absorption-corrected UV flux



Salim et al. 2007

The role of major mergers and AGN

- Major mergers do not increase rapidly back in time (Lotz et al. 2008, in prep)

- High-star-forming galaxies are not preferentially disturbed (Kollipara et al., in prep). The pair-enhanced SFR rate is < 2x (Lin et al. 2007)

- AGN are found in massive galaxies in blue cloud, GV, and RS (Nandra et al. 2007)

- Typical AGN are not noticeably correlated with disturbed galaxies (Pierce et al. 2008)

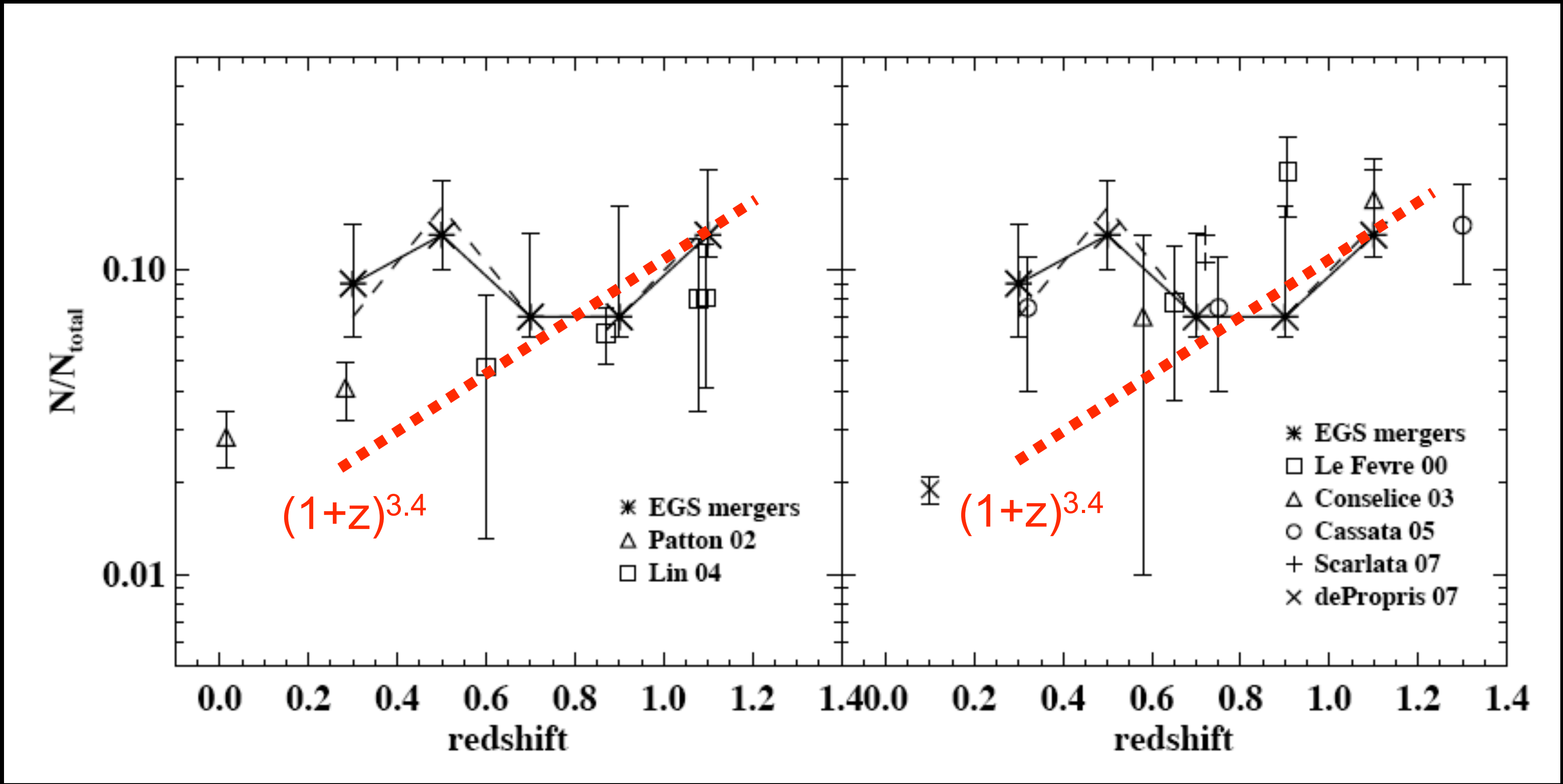
BUT….

- “Dry” mergers likely *do* create pure spheroidals on red sequence

- AGN likely *are* important for “maintenance mode” on the red sequence

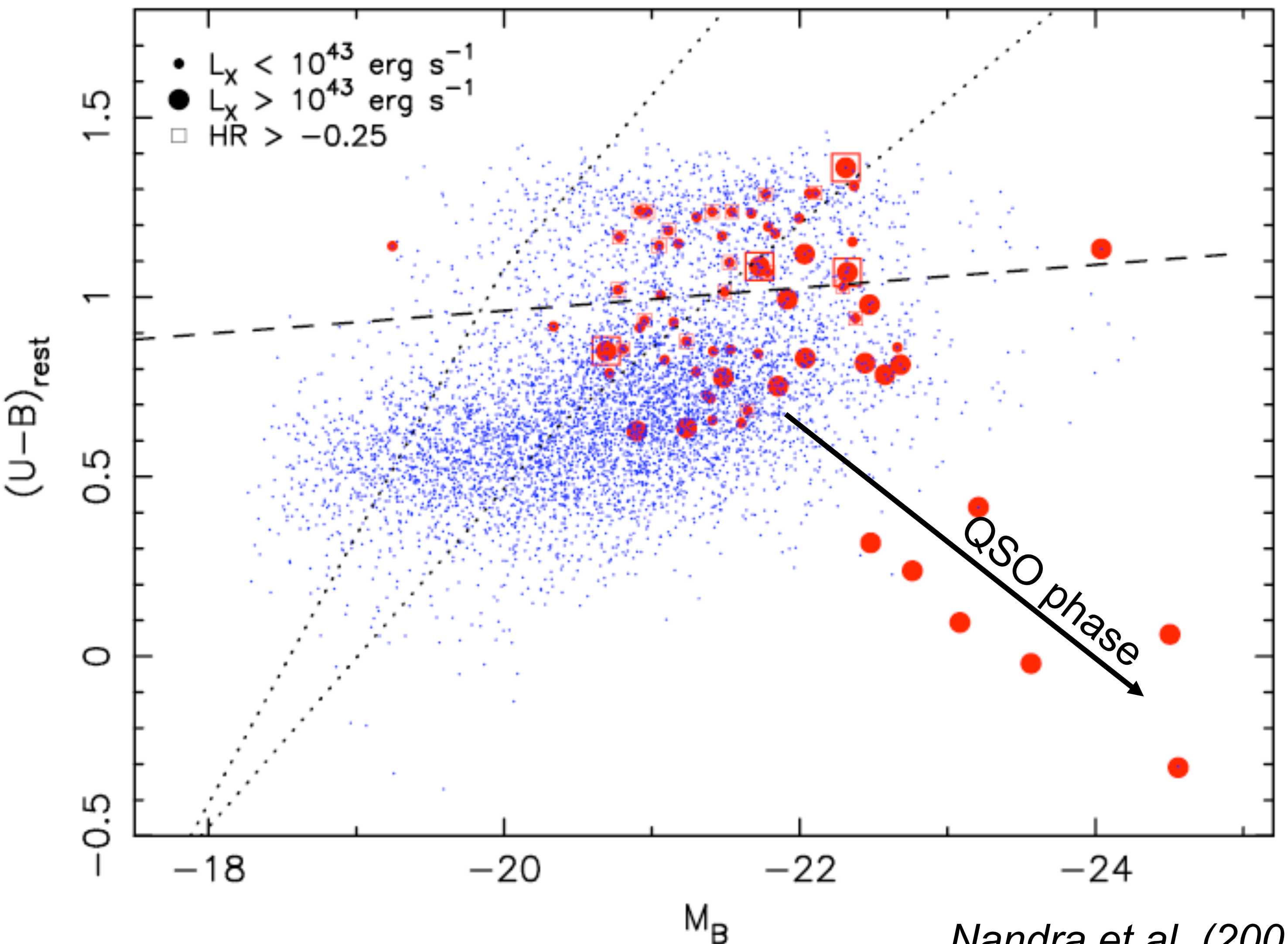
- High-luminosity QSO phase *may* be associated with mergers

Mergers do not rise rapidly back in time



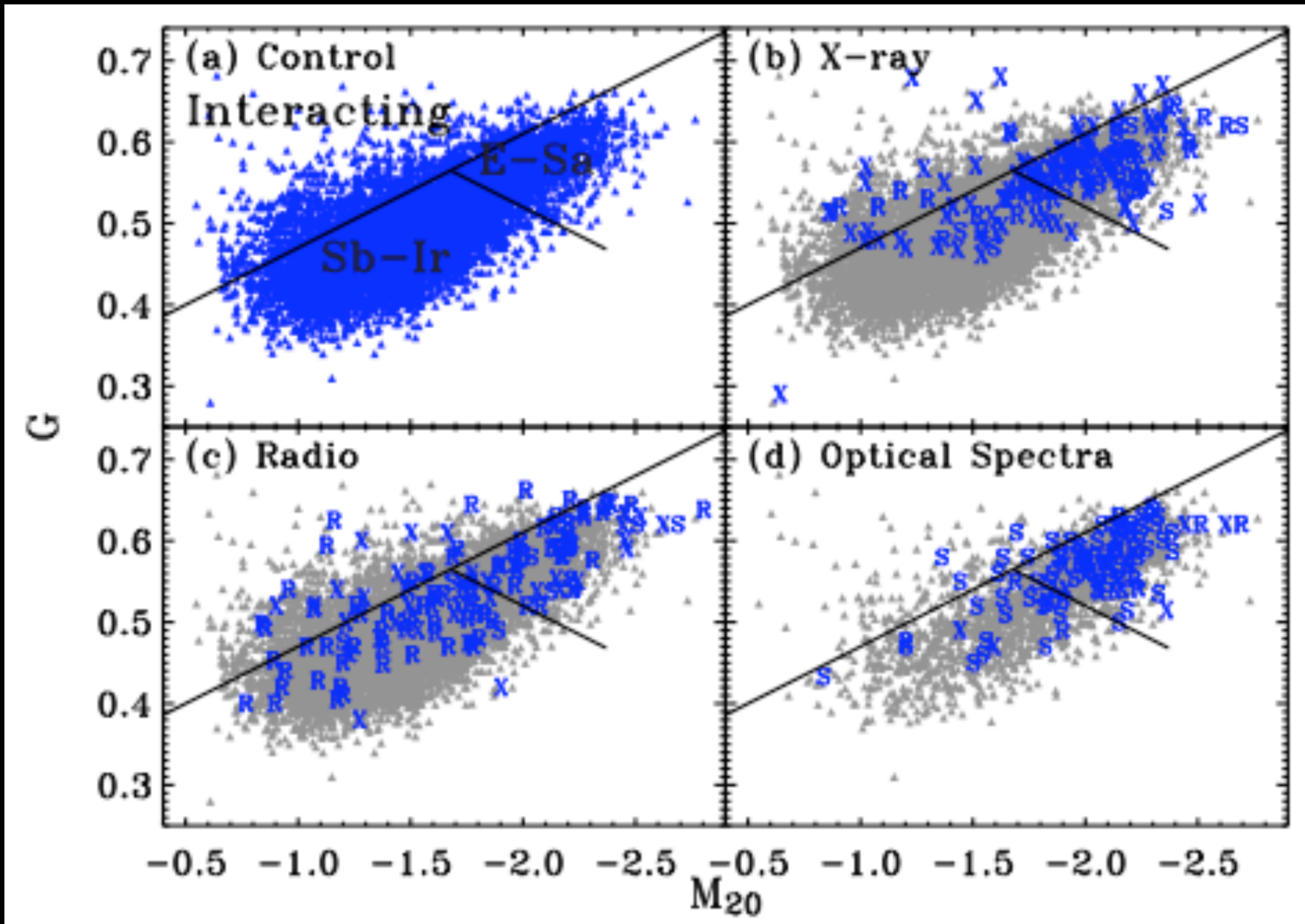
AEGIS: Lotz et al. 2008

X-ray AGNs are found in massive galaxies



Nandra et al. (2007)

AGNs are NOT preferentially in mergers



Pierce et al. 2008

The origin of early-type galaxy scaling laws

- Raw rotation speeds of star-forming galaxies are low on average, but there is a large random component (Kassin et al. 2007)

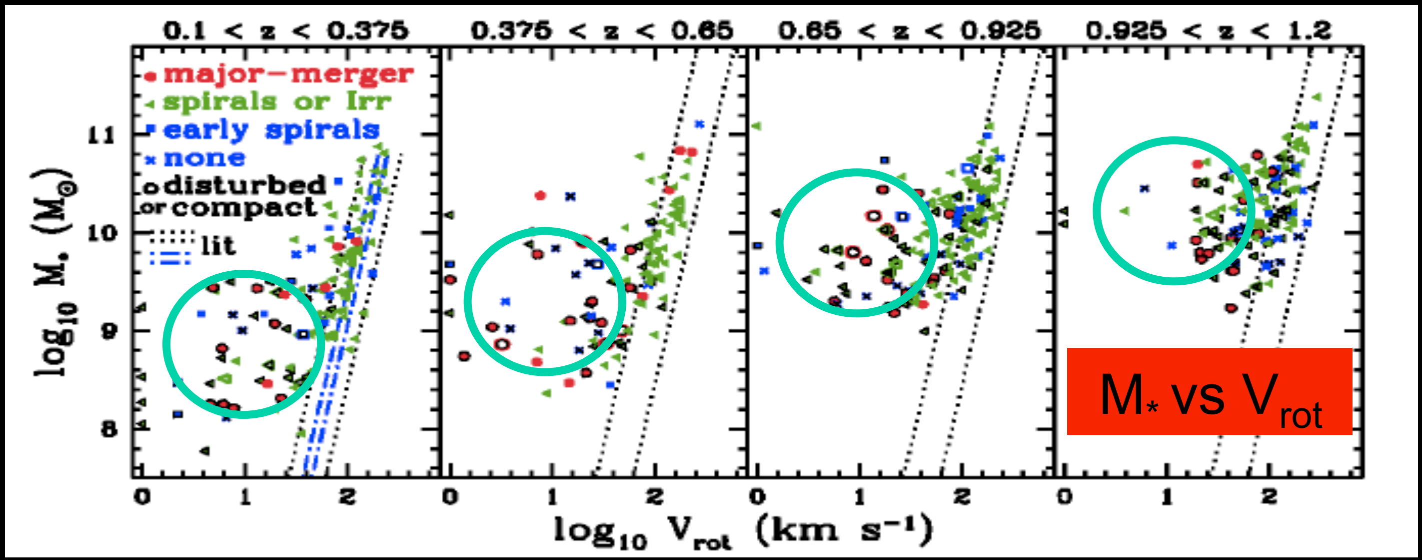
- $S_{0.5}$ is a theoretically motivated combination of rotation and random motions (Weiner et al. 2006)

- Using $S_{0.5}$ brings all star-forming galaxies to the same Tully-Fisher line, including mergers and irregular-looking objects

- This line is the same as the local Faber-Jackson line for spheroidal galaxies

The Faber-Jackson relation (for recent arrivals on the RS) comes from the TF relation of pre-existing star-forming galaxies

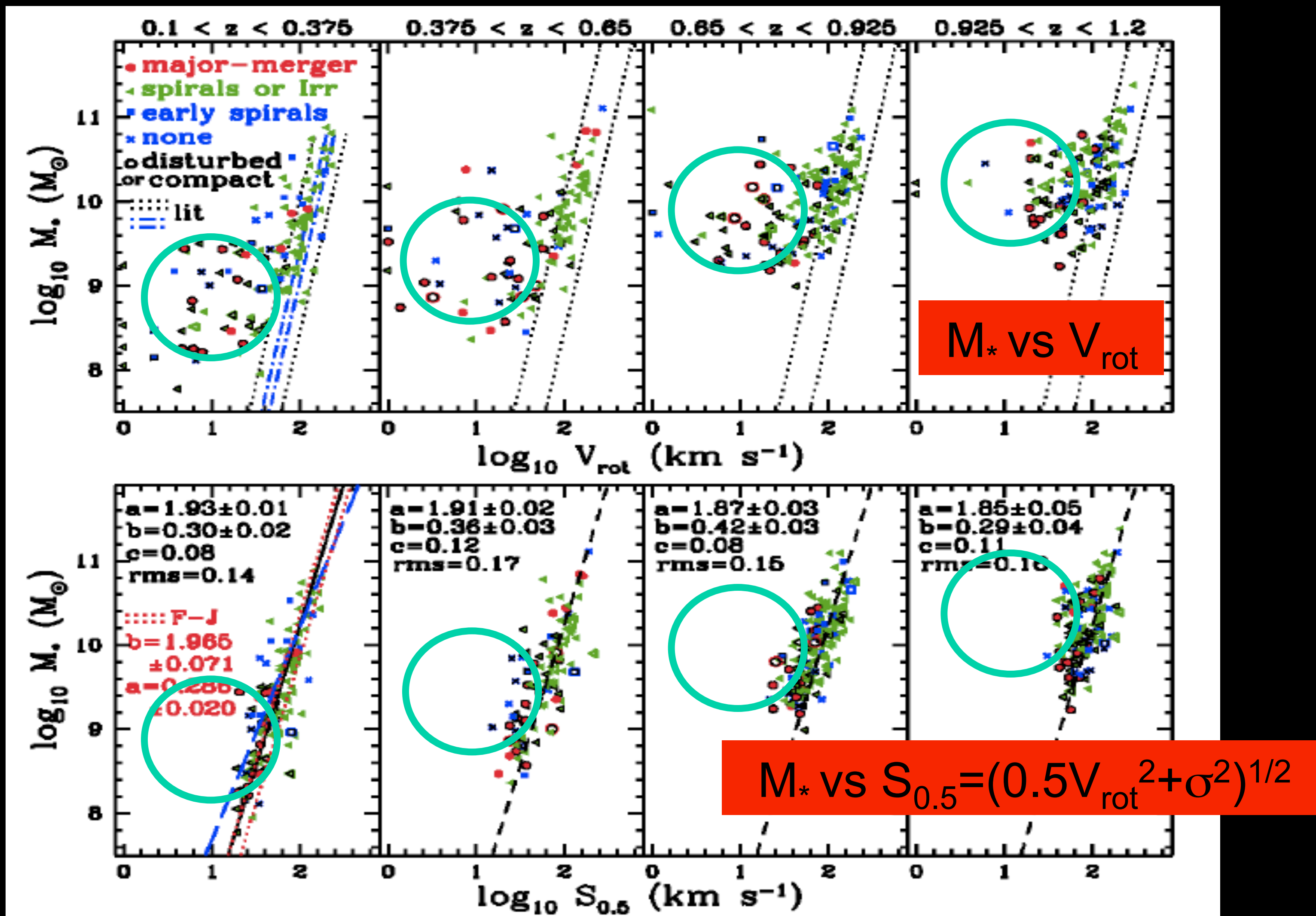
The M_*-σ^4 relation: $S_{0.5}$ makes sense of pecs+mergers



Raw rotation speed V_{rot}

Kassin et al. 2007, after Weiner et al. 2006

The M_*-σ^4 relation: $S_{0.5}$ makes sense of pecs+mergers



Kassin et al. 2007, after Weiner et al. 2006

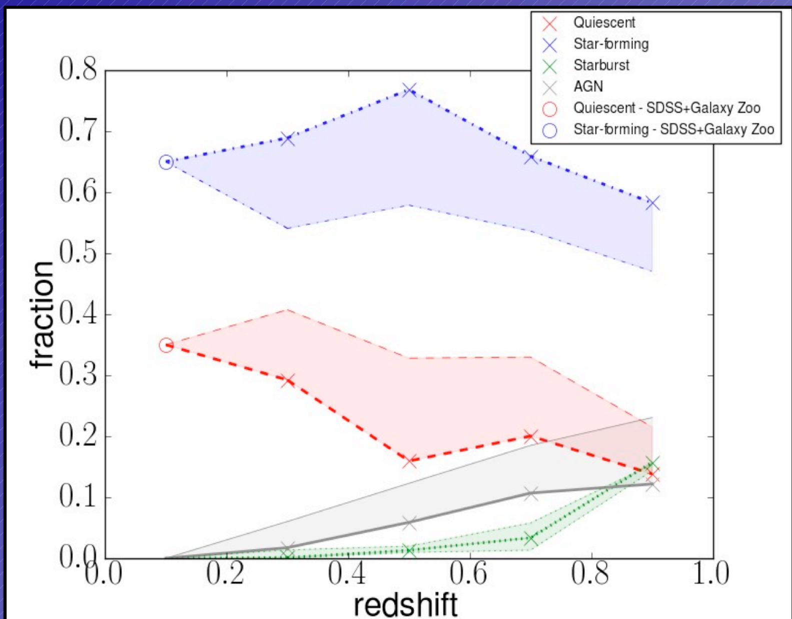
Broad conclusions from DEEP2 and AEGIS

- Hierarchical clustering is consistent with downsizing if there is an upper edge to the “star-forming band”
- A major determiner of a galaxy’s star-formation rate is its dark-halo mass at each redshift. Mergers and disturbances were unimportant
- This gives rise to a mass sequence in which a galaxy’s stellar mass today is closely correlated with its past evolutionary history, and thus its properties today
- The roots of galaxy scaling relations of many galaxies were laid down during their star-forming phase
- Why bulges grow -- and SFR stops – is still a mystery.

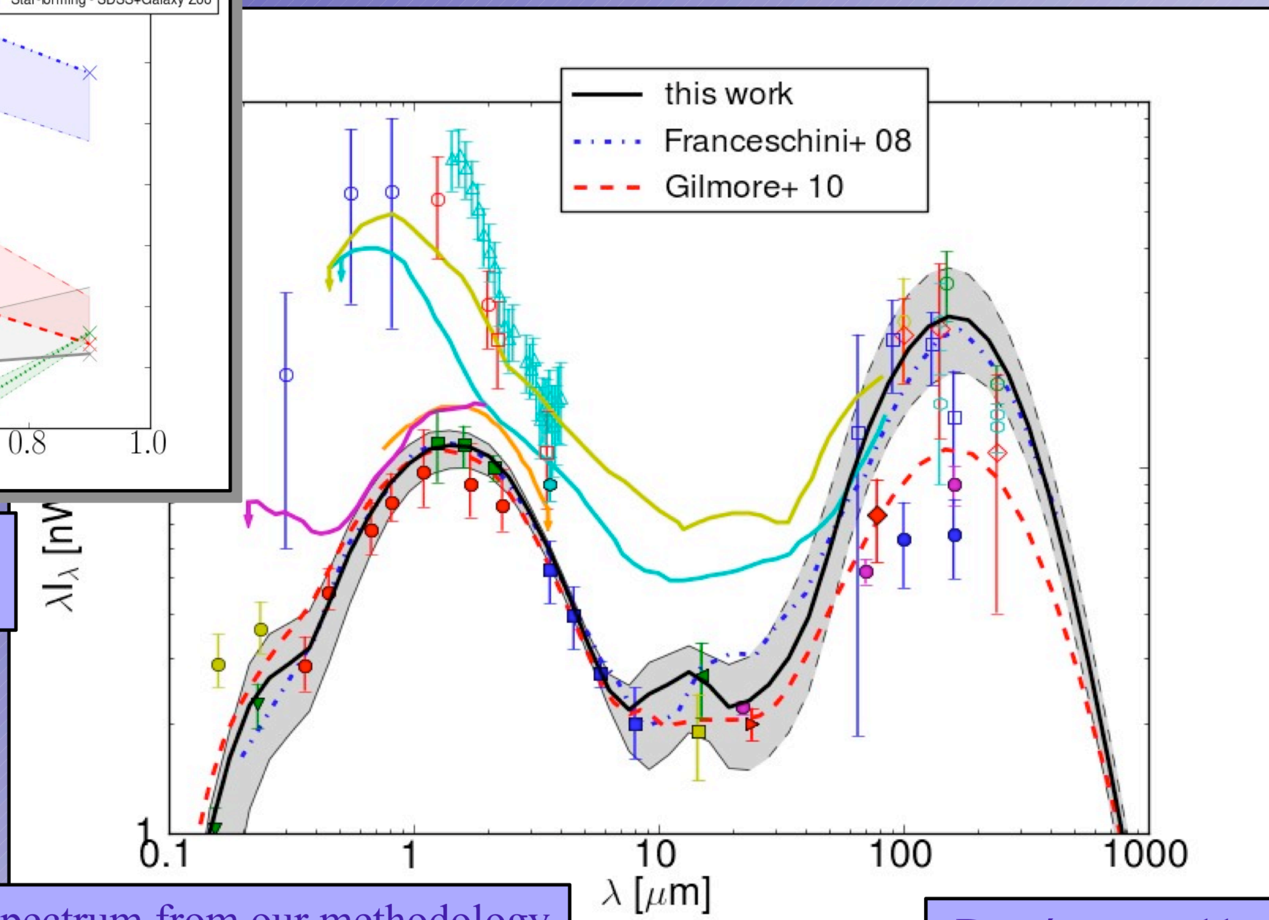
Recent and ongoing projects

- Extragalactic background light: Dominguez et al. (2011)

Extragalactic background light from AEGIS SED-type fractions



Galaxy SED-type fractions based on 25 SWIRE templates



Extragalactic background light spectrum from our methodology compared with observations and others independent modelings

Domínguez+ 11

Recent and ongoing projects

- Extragalactic background light: Dominguez et al. (2011)
- DEEP3: more redshifts, better environments, rare sources
- CANDELS: deep VIJH imaging with WFC3 and ACS
- NEWFIRM: photoz's for z ~ 2 galaxies
- Future near-IR spectra with MOSFIRE on Keck

EGS/AEGIS will be a premier field for studying morphologies, structure, and AGN activity of z ~ 2 galaxies