The evolution of massive galaxies from $z = 2$ to the present day

Gabriel Brammer (ESO)

Multi-wavelength views of the ISM at high-redshift
June 30, 2011

The *NEWFIRM* Medium-band survey (NMBS) team:
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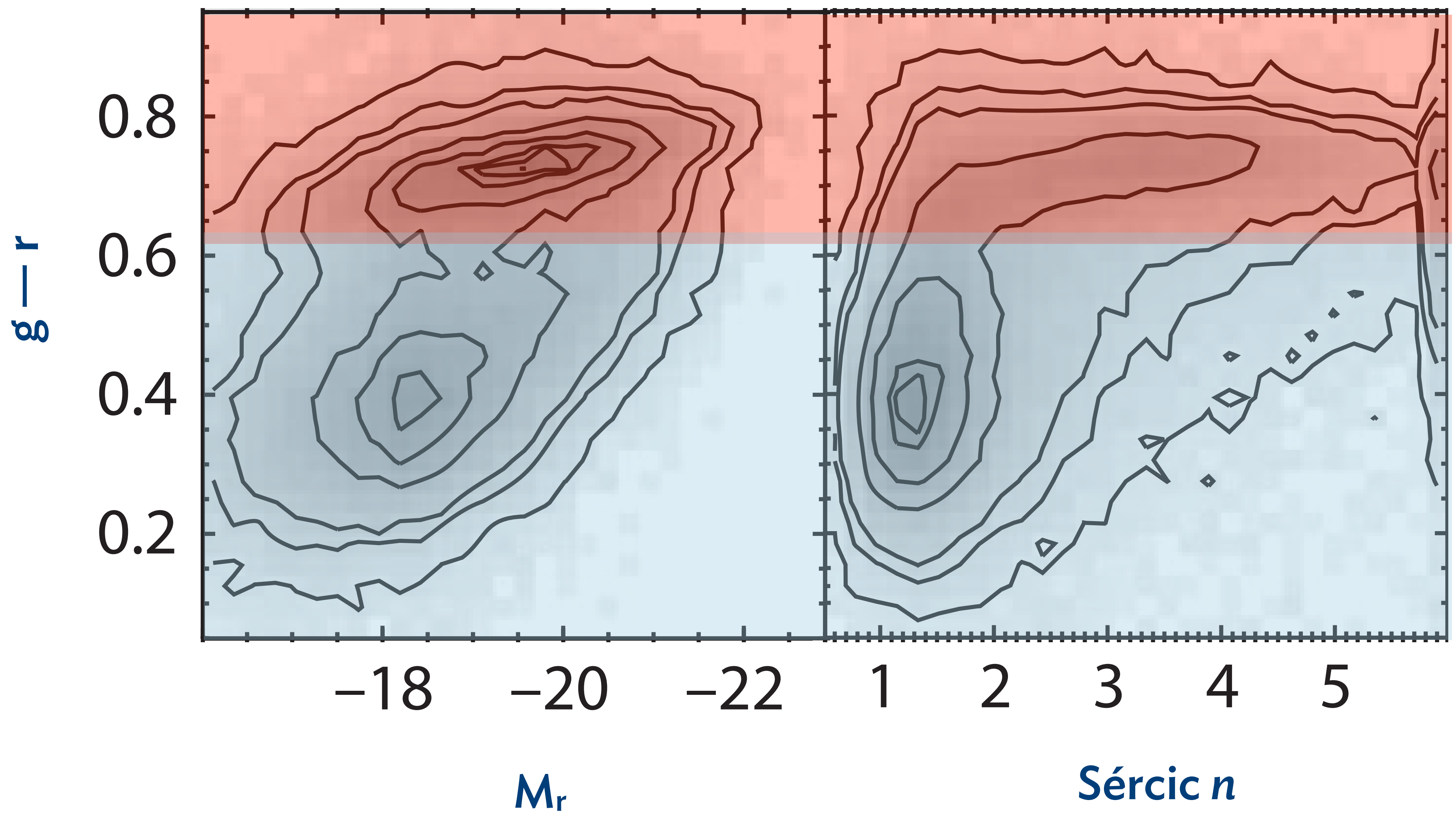
Galaxies in the nearby universe
($z < 0.1$, SDSS)

Blanton & Moustakas (2009 review)

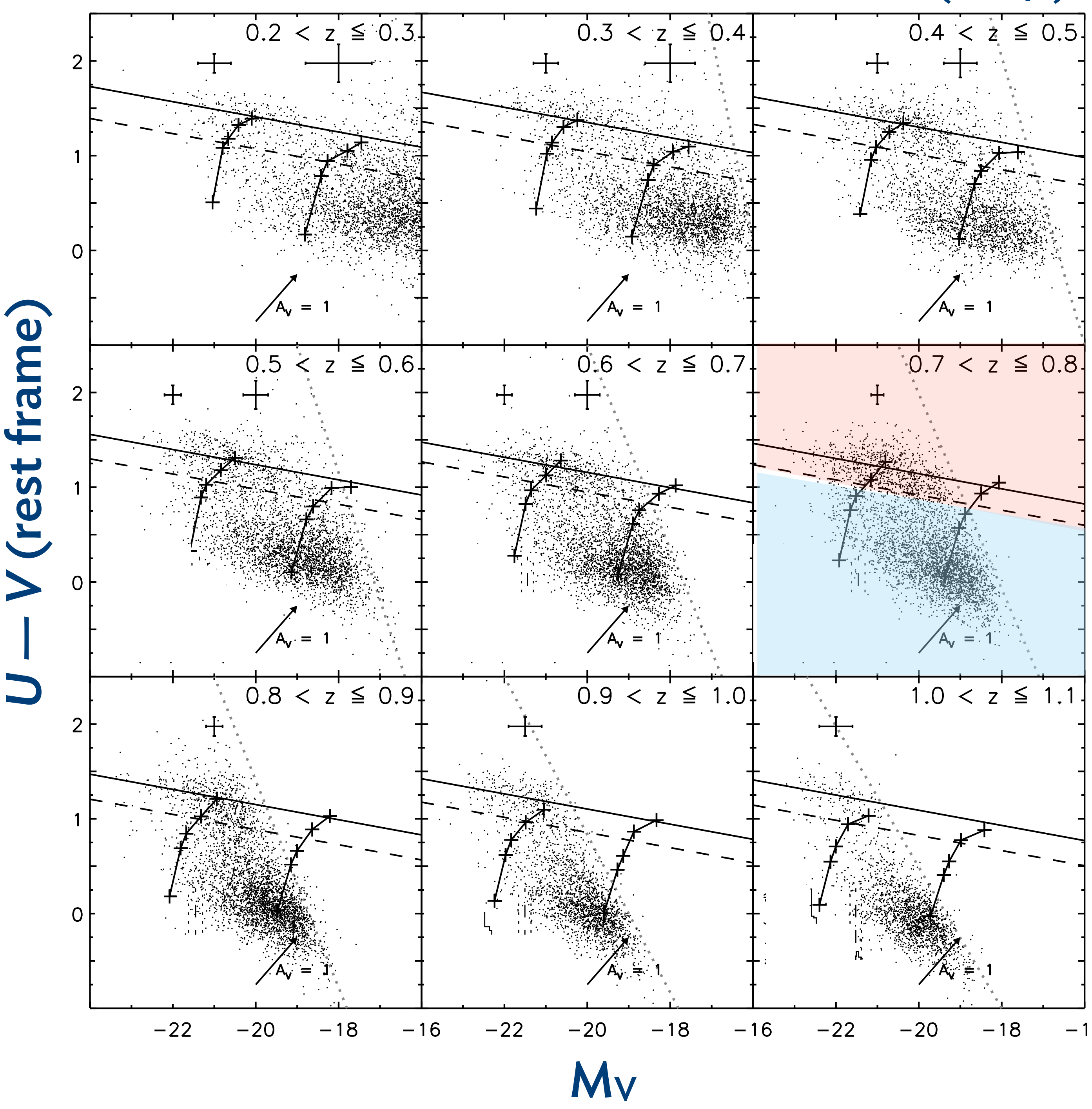


Evolution to z = 1 from deep (optical) surveys

- COMBO-17 (Bell et al. 2004)
  DEEP2 (Willmer et al. 2006; Faber et al. 2007)
  NOAO DWFS (Brown et al. 2007)

- Bimodal galaxy distribution to at least z = 1

Bell et al. (2004a)



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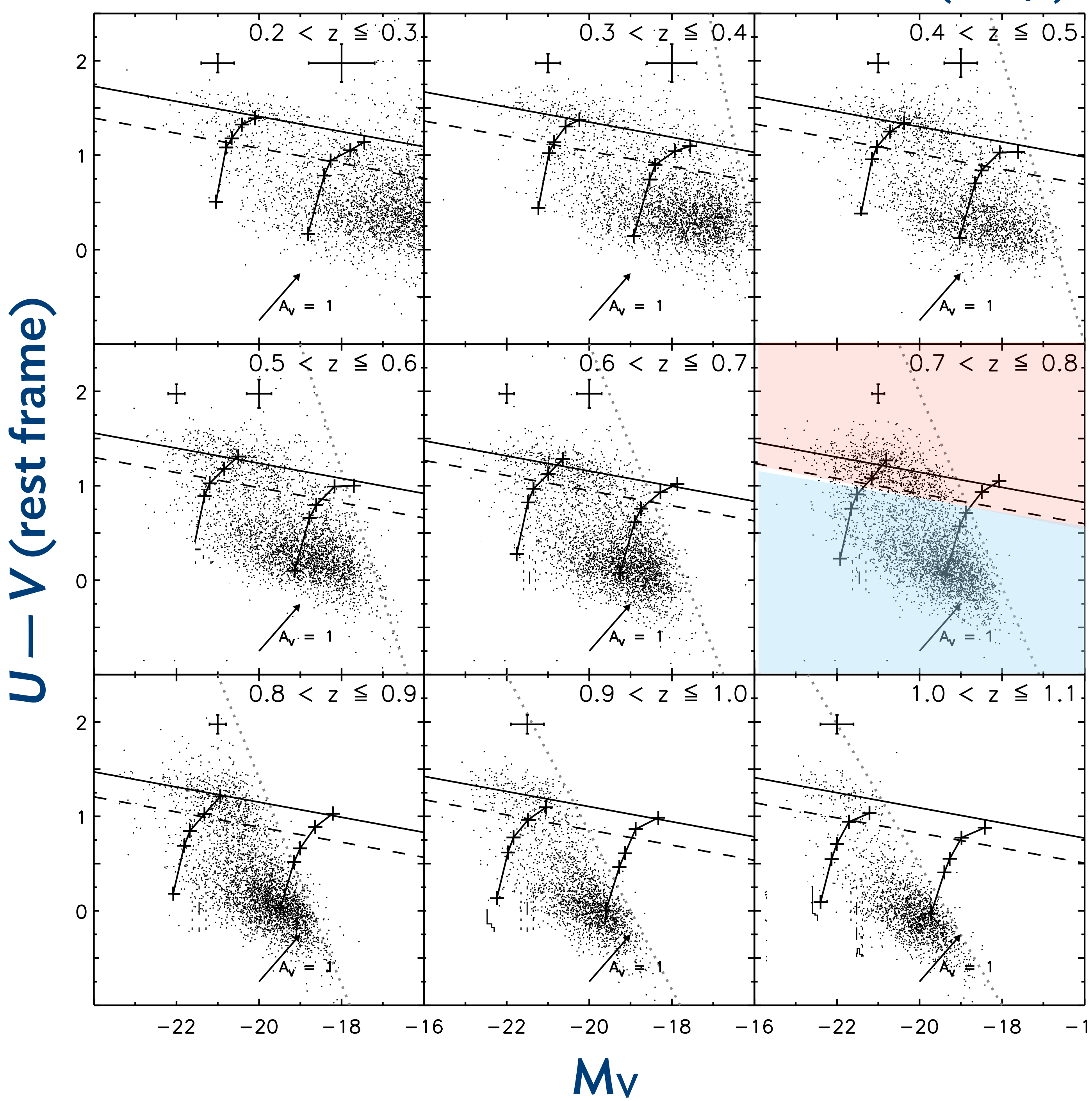
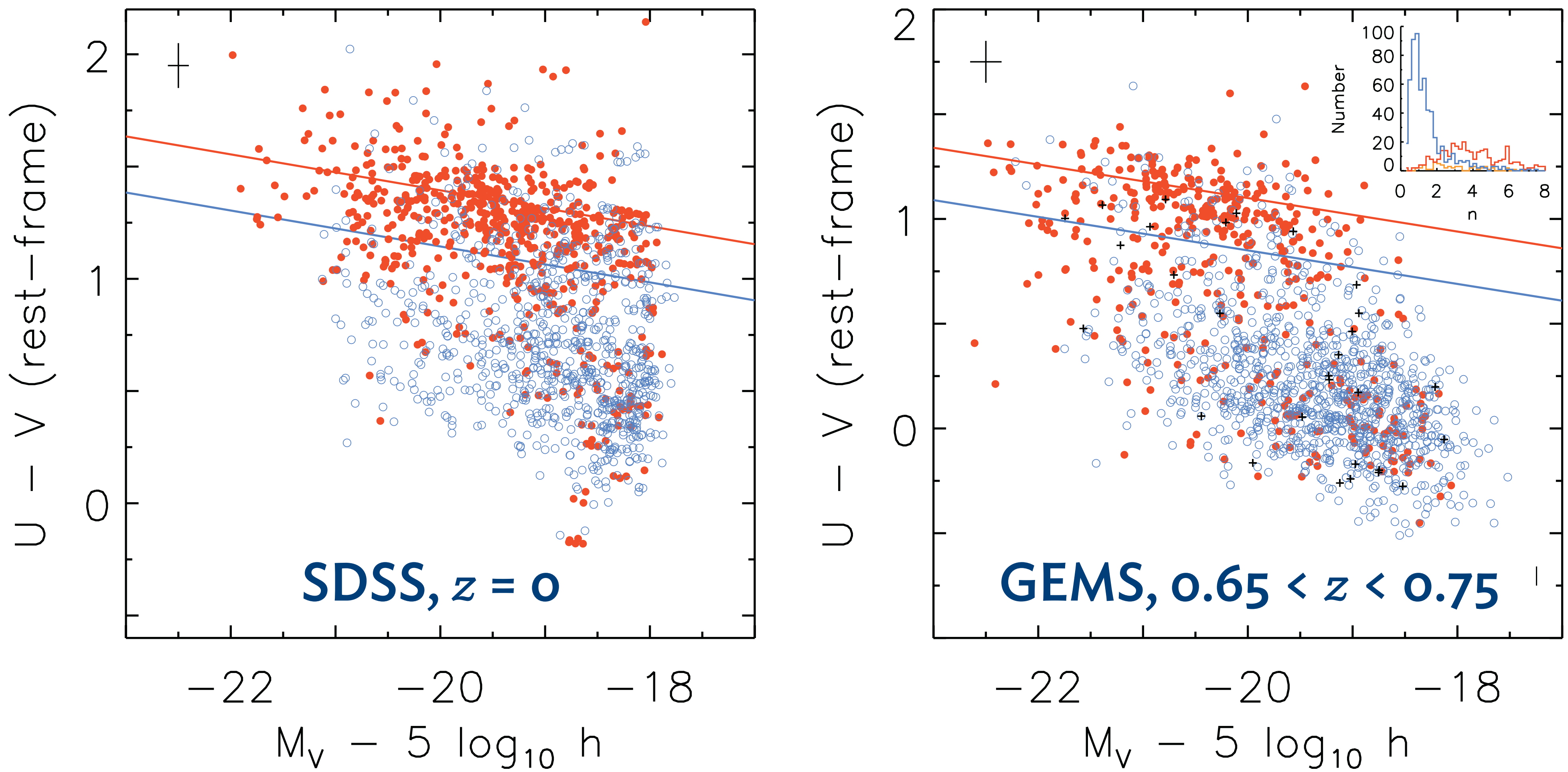
- COMBO-17 (Bell et al. 2004)
  DEEP2 (Willmer et al. 2006; Faber et al. 2007)
  NOAO DWFS (Brown et al. 2007)
- Bimodal galaxy distribution to at least $z = 1$
- Mild color evolution, consistent with passive evolution
- Red/blue luminosity functions:
  - **Mass buildup by a factor of ~2 in red galaxies since z = 1**
    (Bell et al. 2004, Faber et al. 2007)

Bell et al. (2004a)



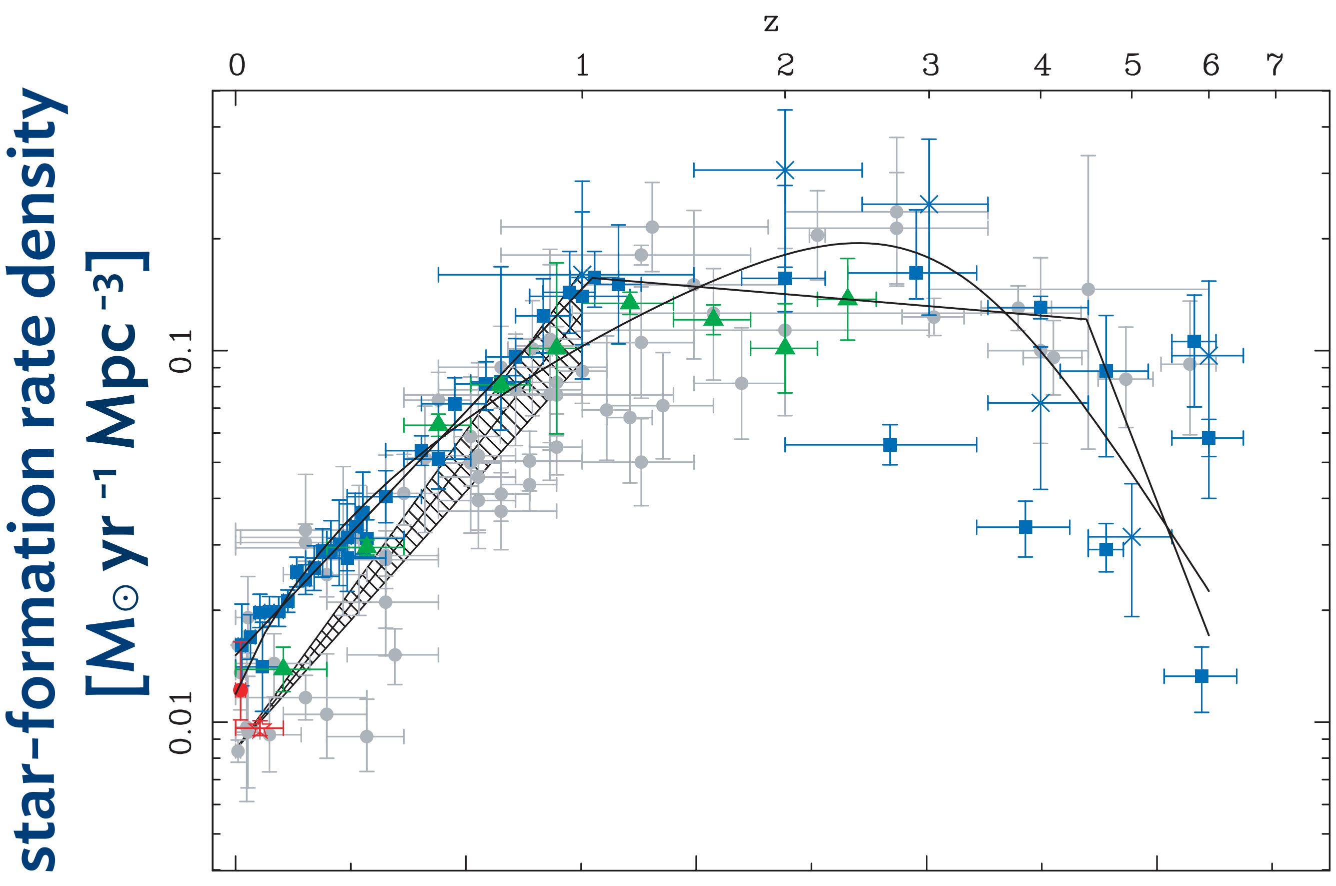
Evolution to z = 1 from deep (optical) surveys

Bell et al. (2004b)



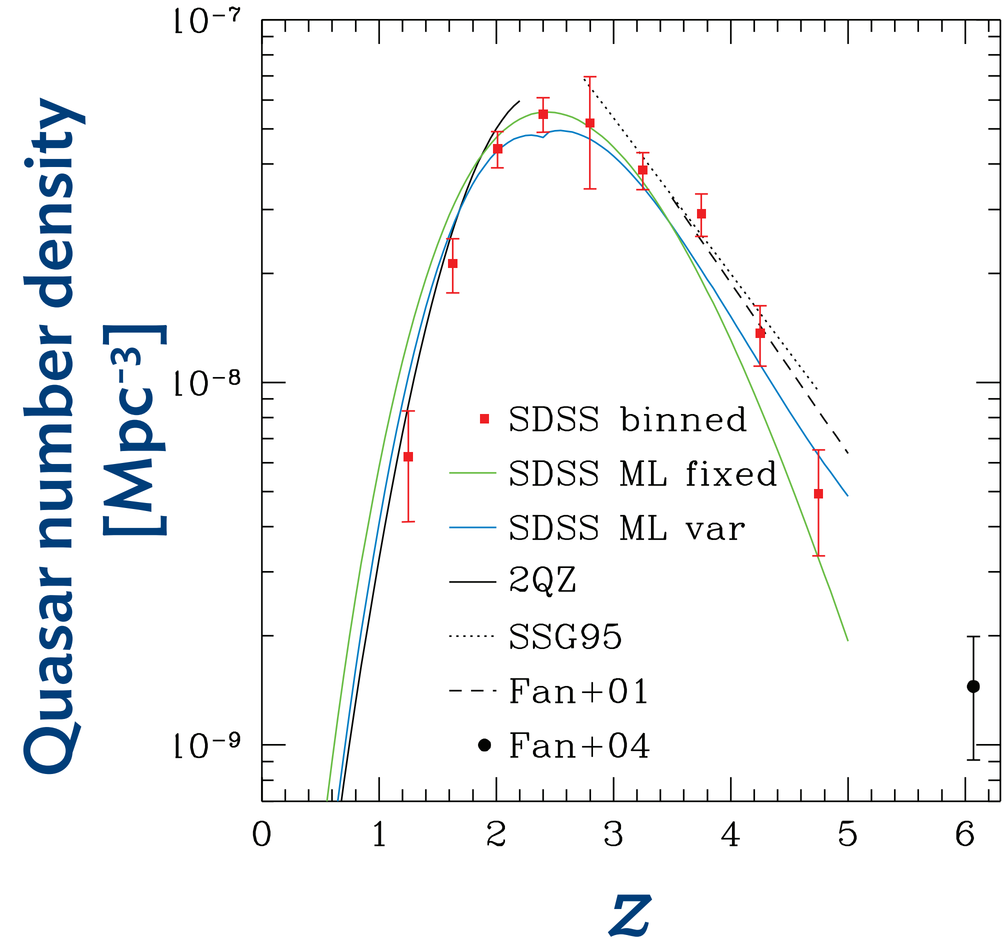
The morphological distribution at z=0.7 looks quite similar to that at z=0.

Half of the star formation in the universe takes place between 1 < z < 3



Hopkins & Beacom (2006)

Richards et al. 2006



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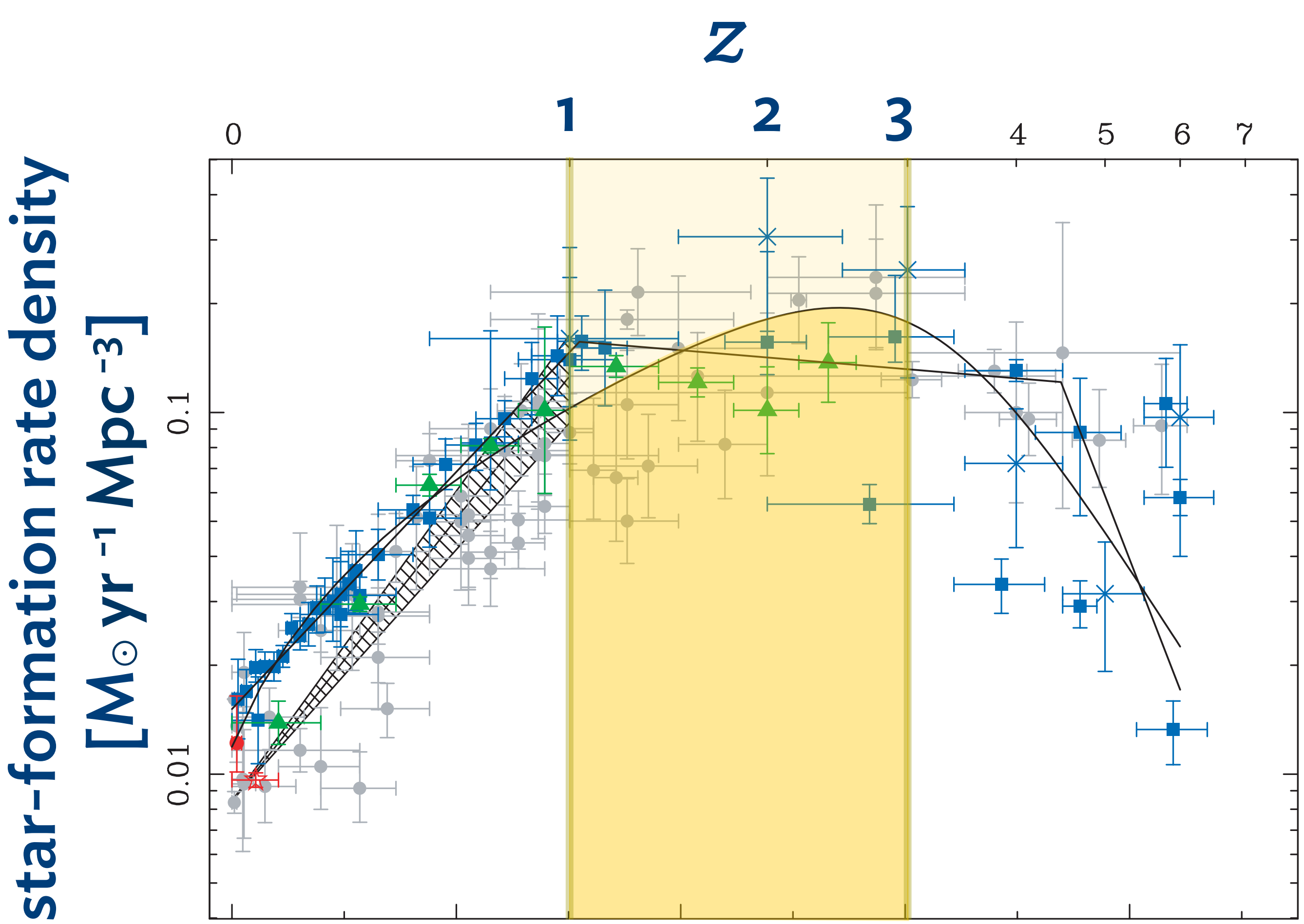

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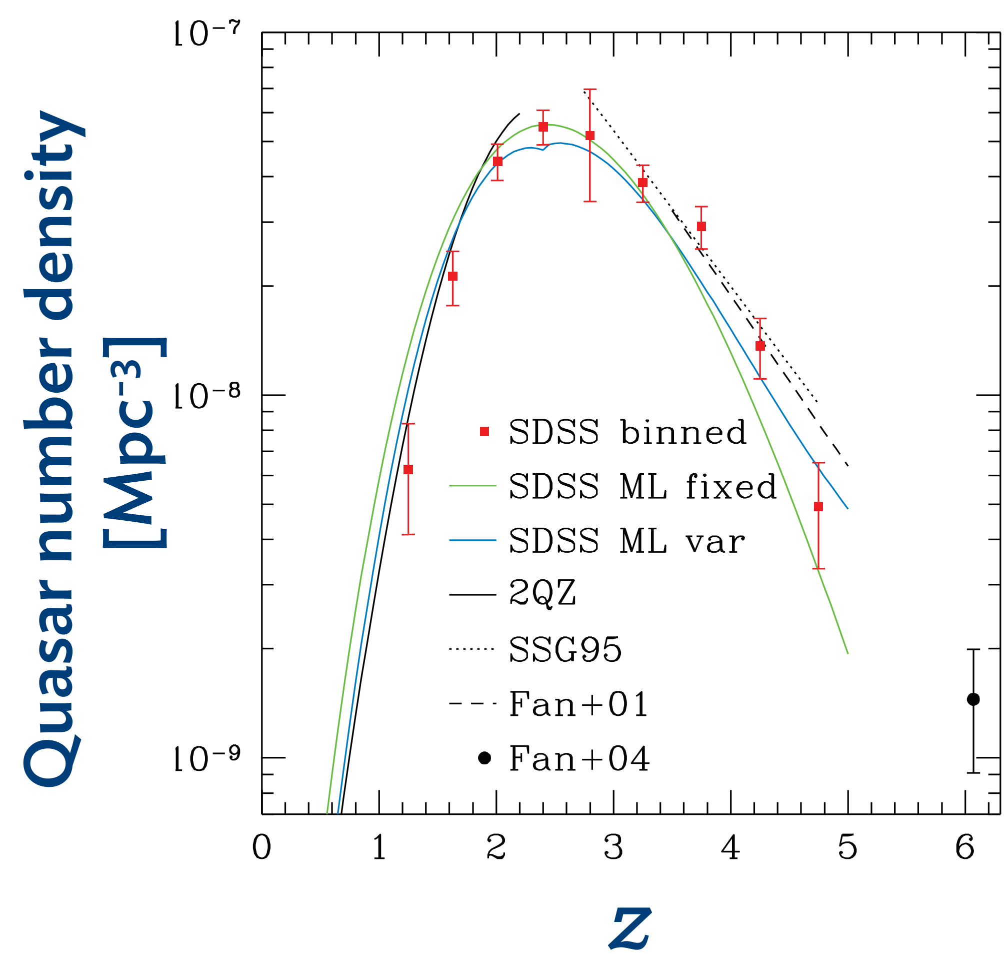

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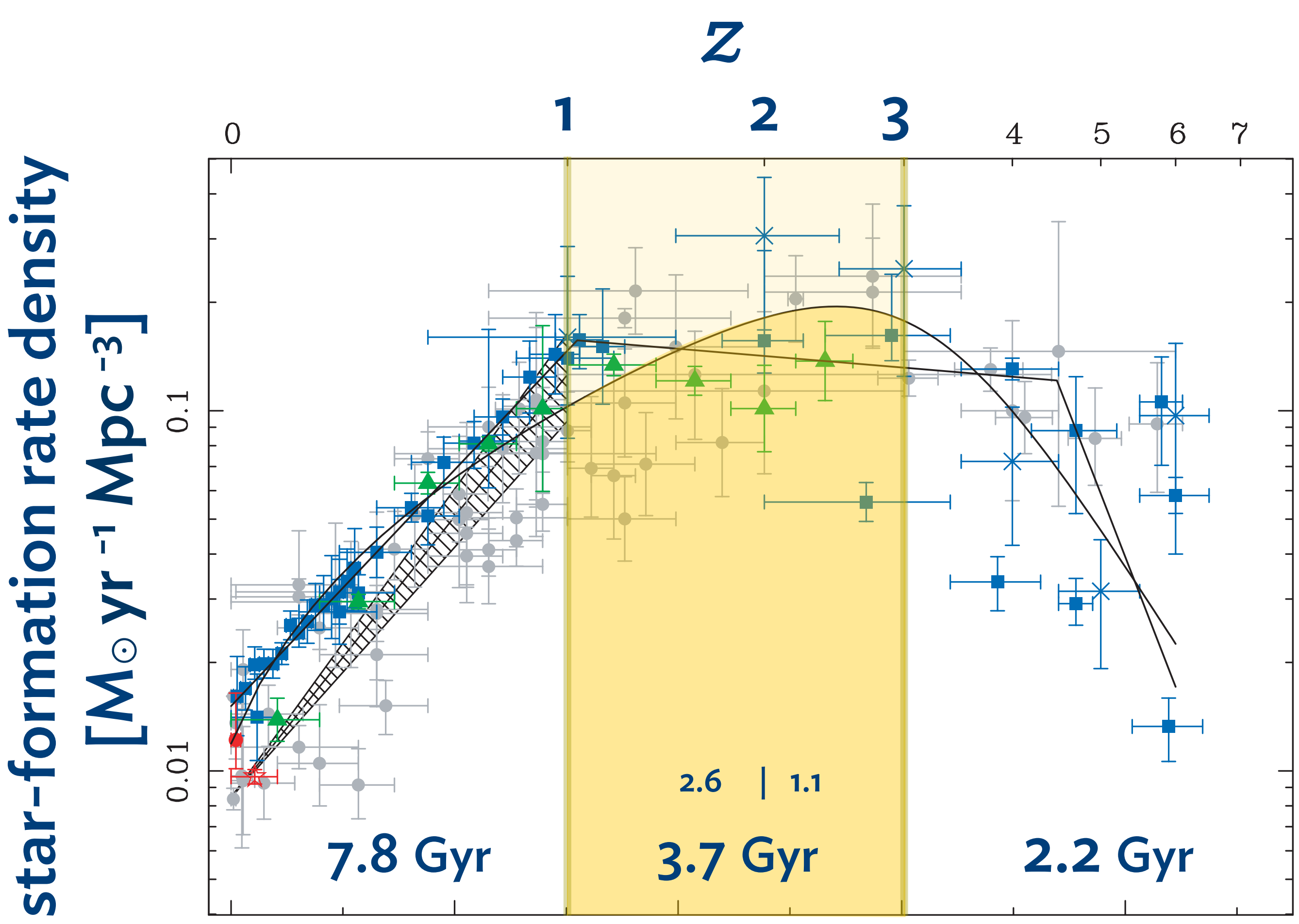

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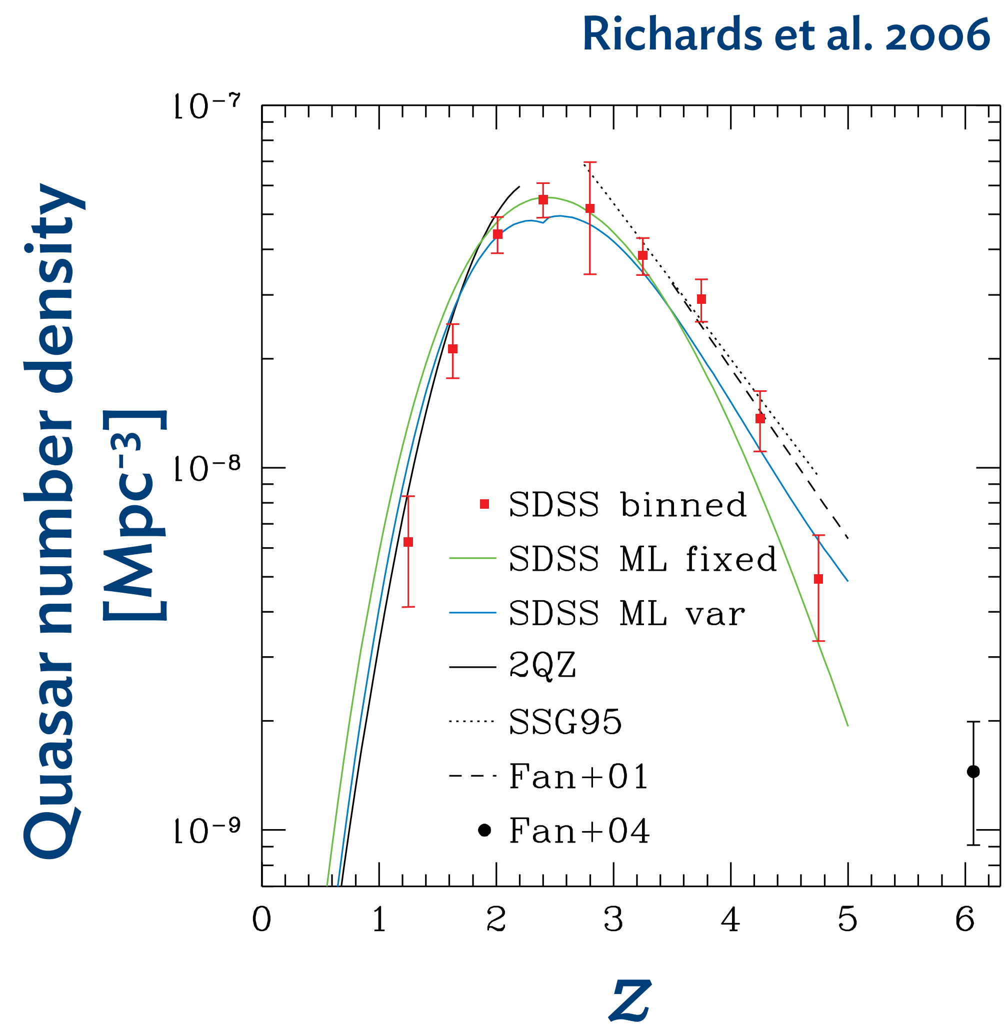
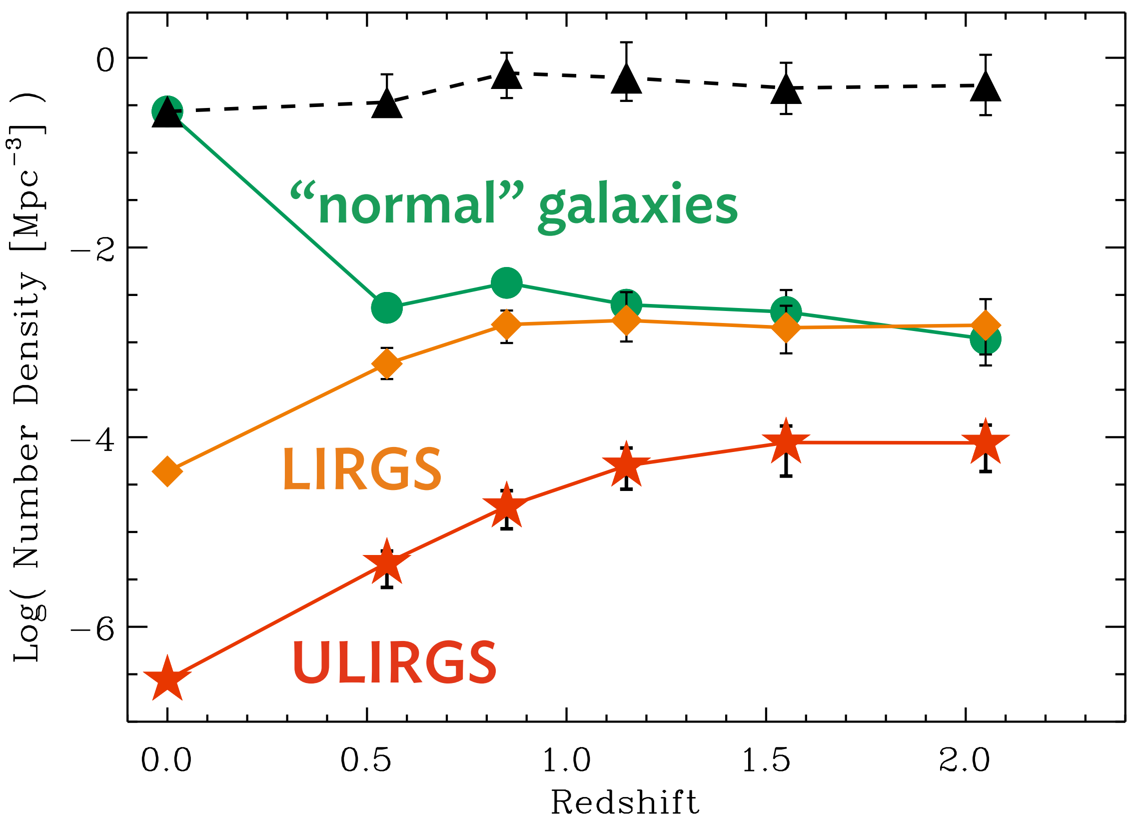
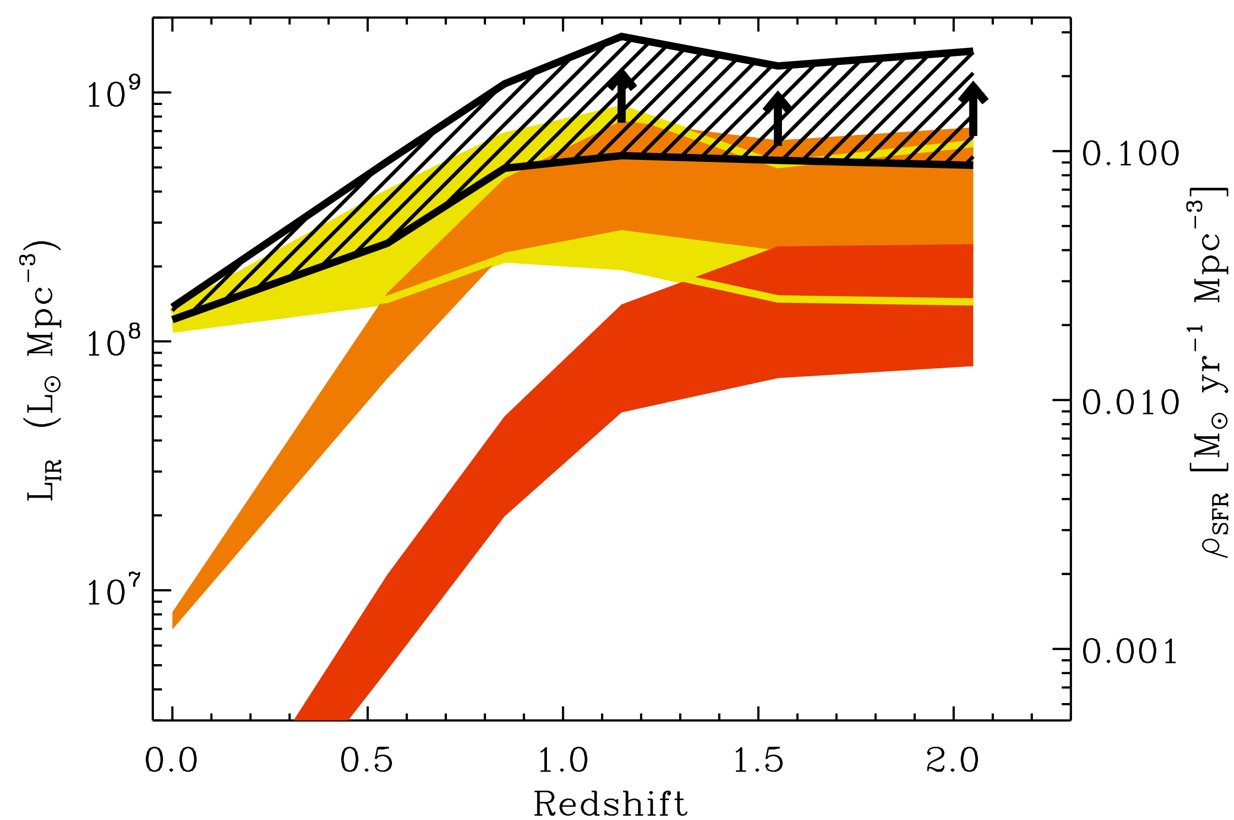


The number of IR-luminous galaxies increases with *z* (U/LIRGS, sub-mm galaxies, DOGs, etc.).



Magnelli et al. (2011)

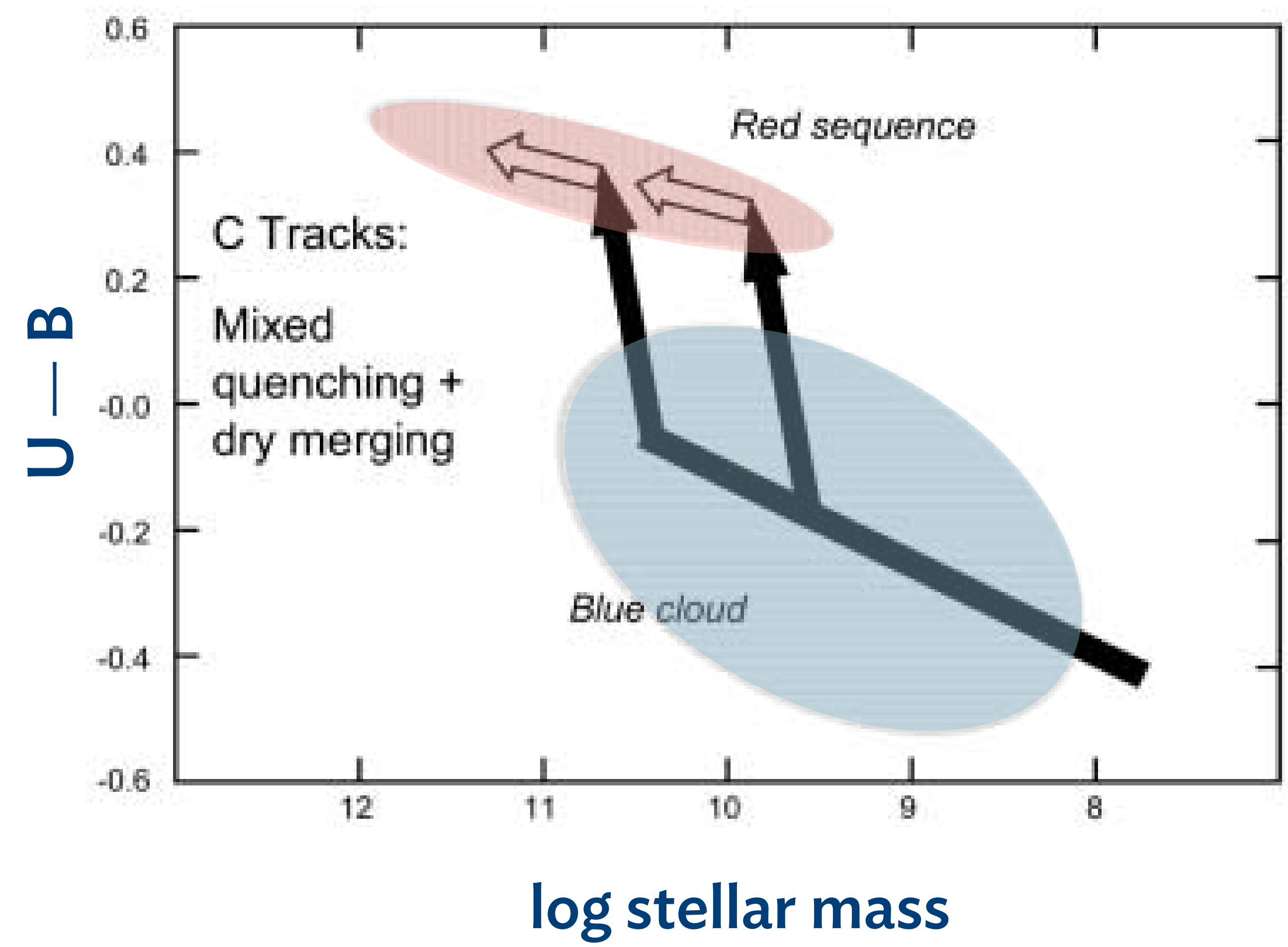


~50% of star-formation at z~1 occurs in LIRGS ($L_{IR} = 10^{11} - 10^{12}\ L_\odot$)

Open questions

- Two distinct types are observed to $z = 1$. How far does the separation extend?
- What is the extent of migration between the blue to red sequences (e.g. quenching), and how does it happen?
- How are red & dead galaxies formed at early times?

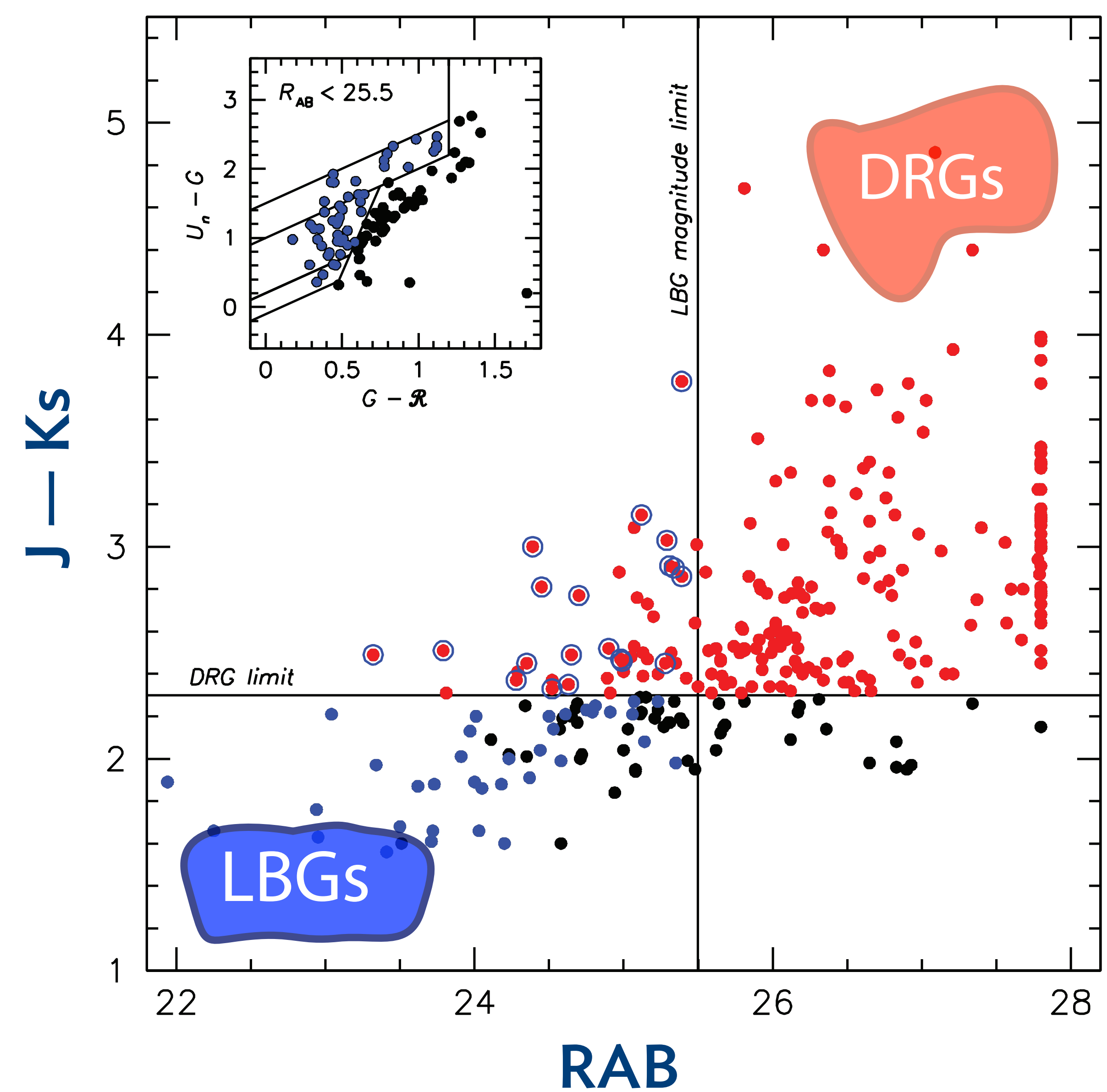
Faber et al. (2007)



Mass-complete (>10^{11} $M_\odot$) sample

- Mass-complete sample at 2 < *z* < 3 from the K-selected MUSYC survey *(van Dokkum et al. 2006)*
- **~70% DRGs**, 20% LBGs
- Most mass would be missed by rest-UV selection, though UV selection is probably more complete at *z* ~ 3.5 *(Brammer & van Dokkum, 2007)*

van Dokkum et al. (2006)



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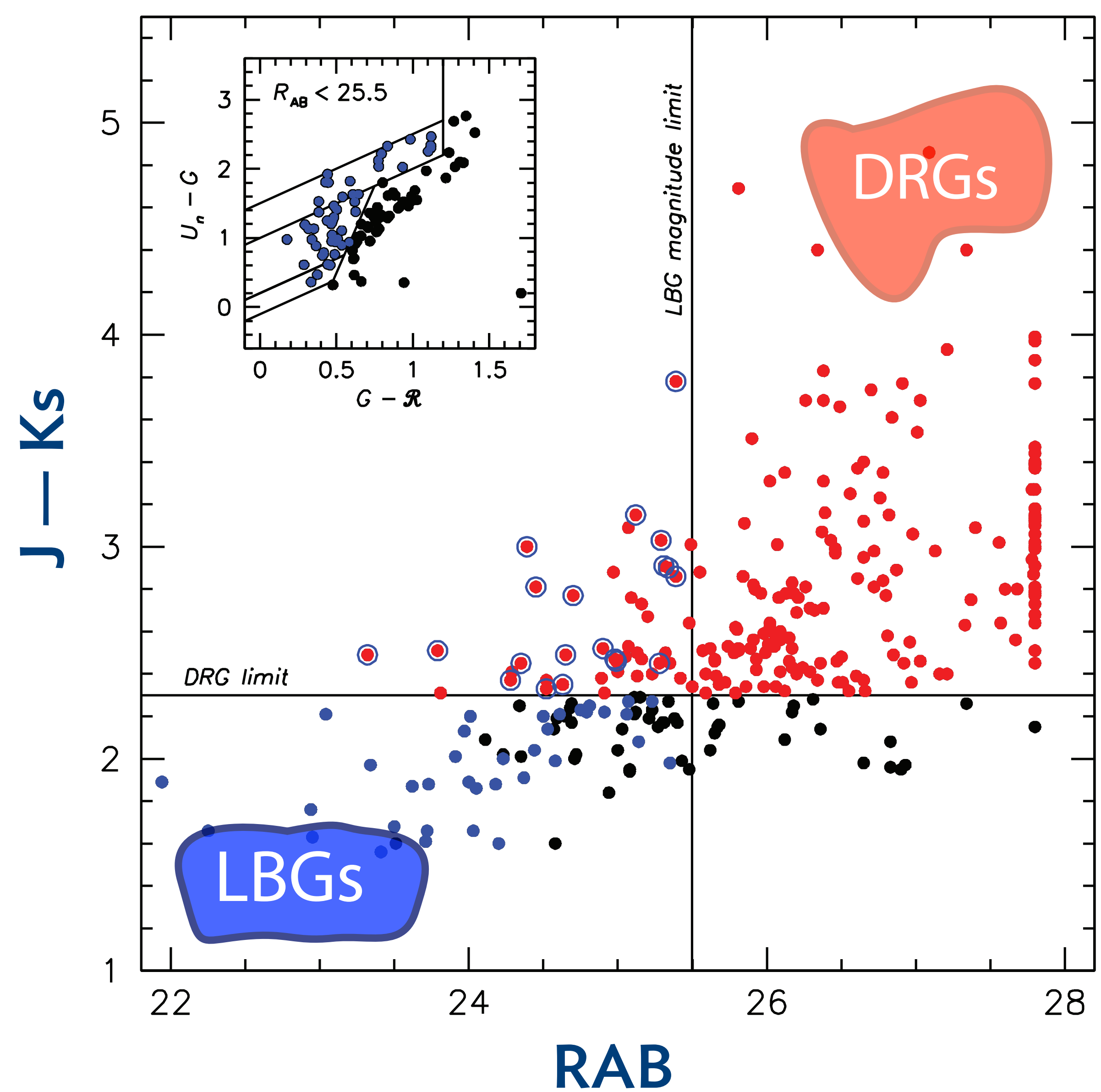
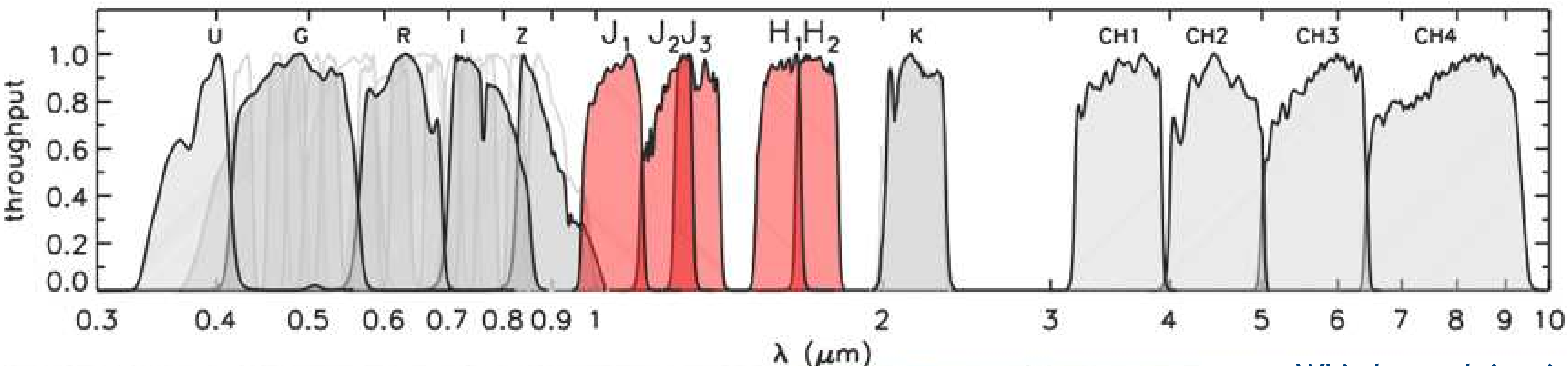
- Defining mass-limited samples depends critically on **accurate photometric redshifts**

van Dokkum et al. (2006)



The NEWFIRM Medium-Band Survey: 2% photometric redshift accuracy at z~2



Whitaker et al. (2011)

- **75 night large survey** with the Mayall 4m telescope at Kitt Peak (PI: van Dokkum)
- Photometry in **5 custom filters**, each roughly half the width of standard *J* & *H*
- K < 22.8, 2 x 30’ x 30’ fields **(AEGIS, COSMOS)**

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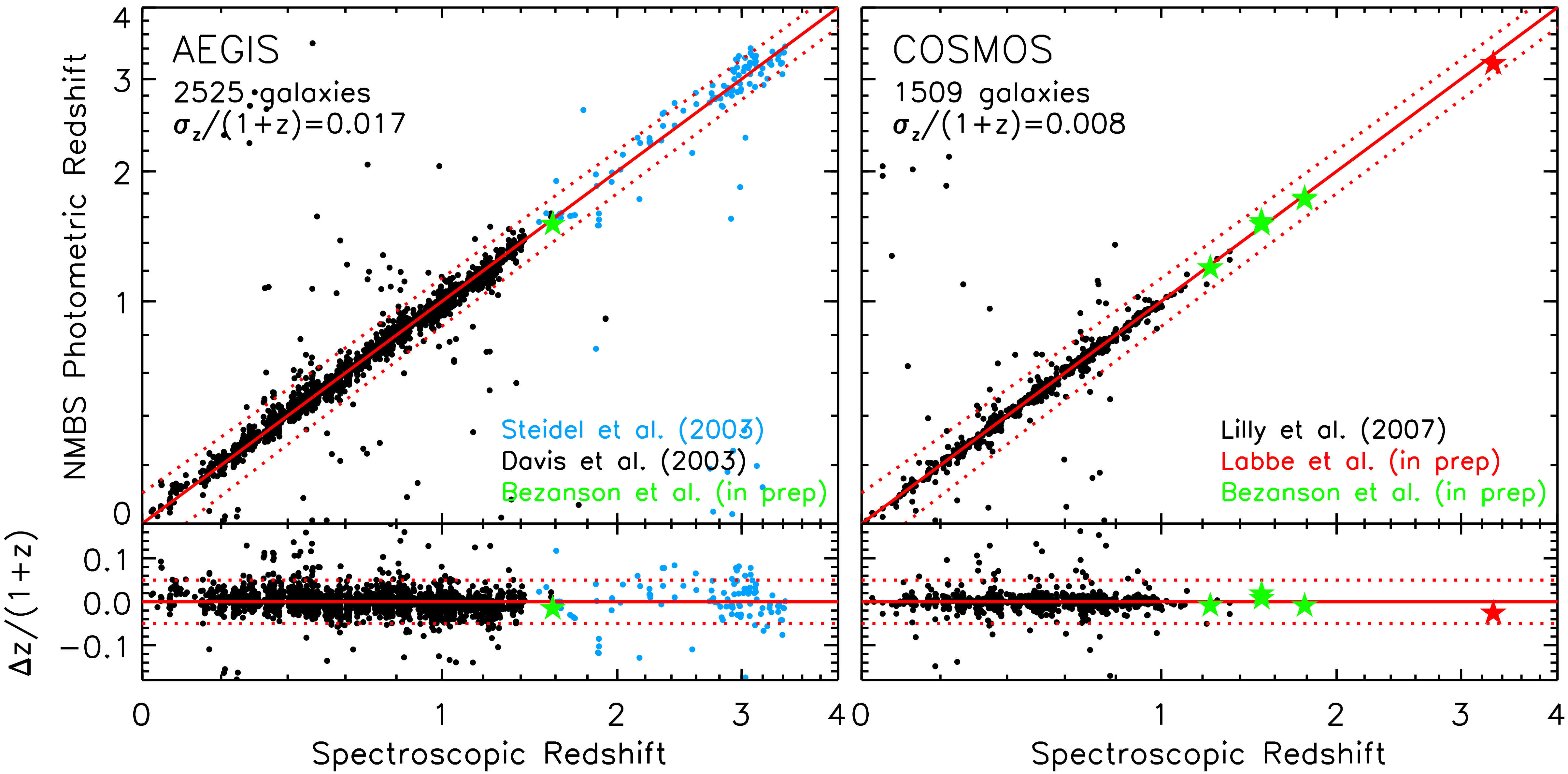
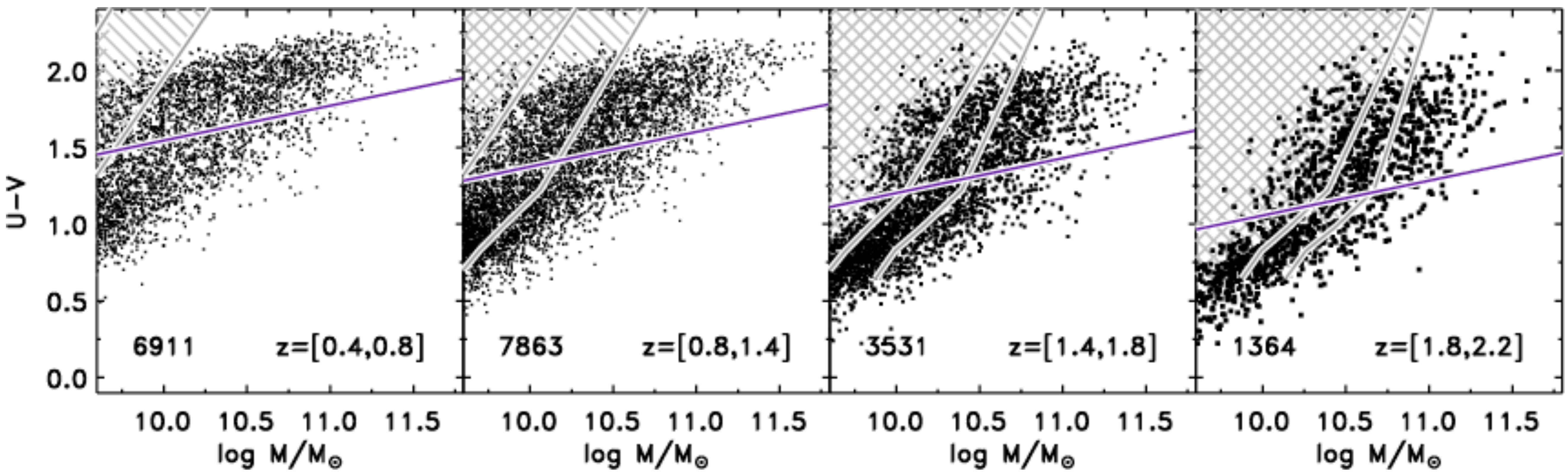


Whitaker et al. (2011)

The color-mass distribution at 0 < z < 2.2

Brammer et al. 2011



- The NMBS is complete to log $M/M_\odot$~10.6 at z < 2.

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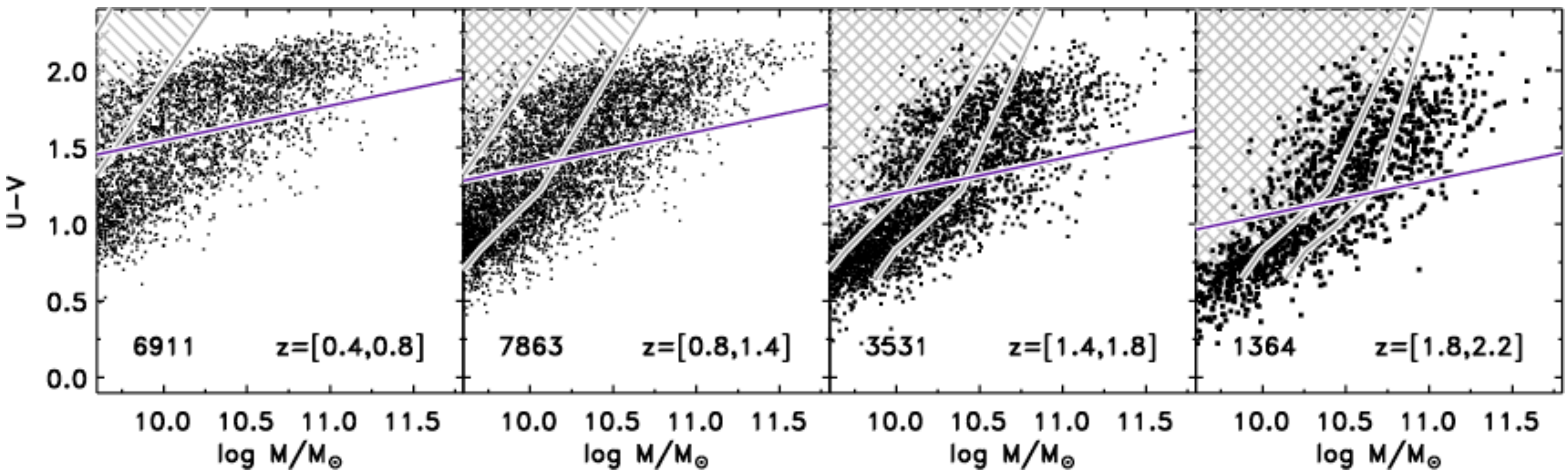
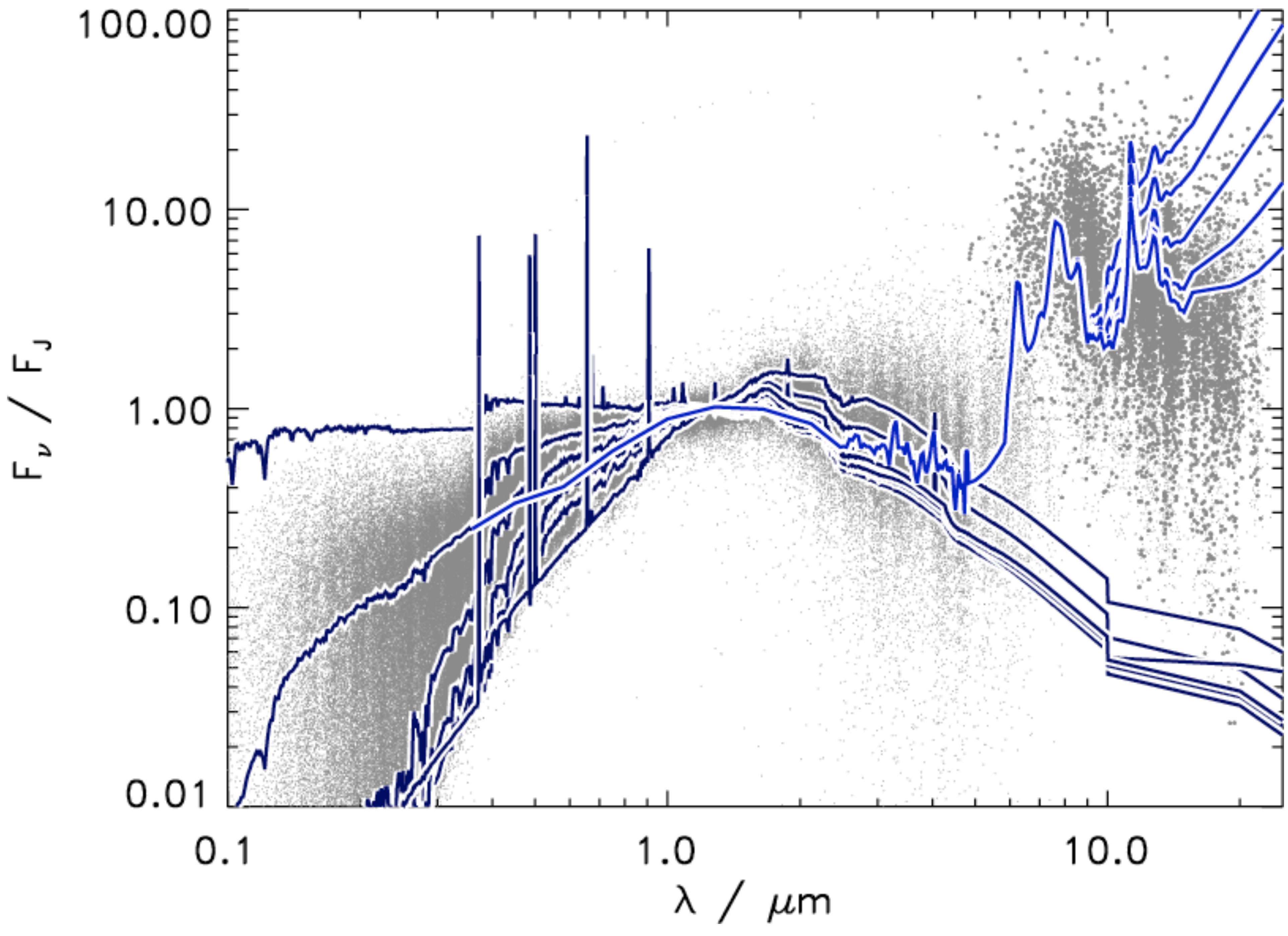


- Where is the **star-formation** occurring on this plot?

UV emission reprocessed by dust and reëmitted at 24μm



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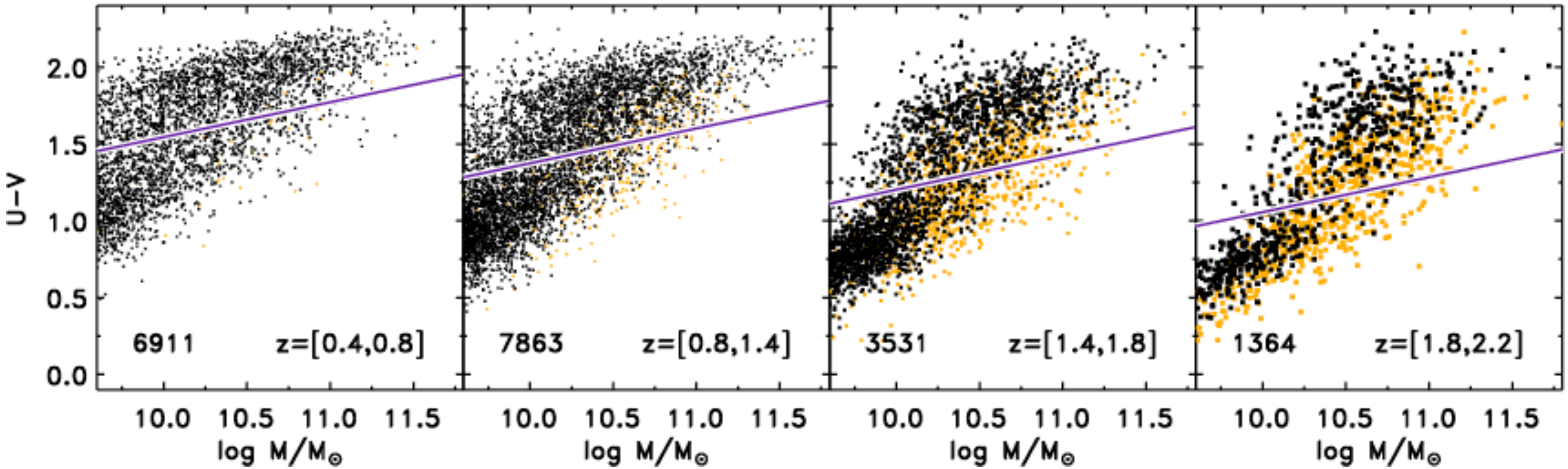
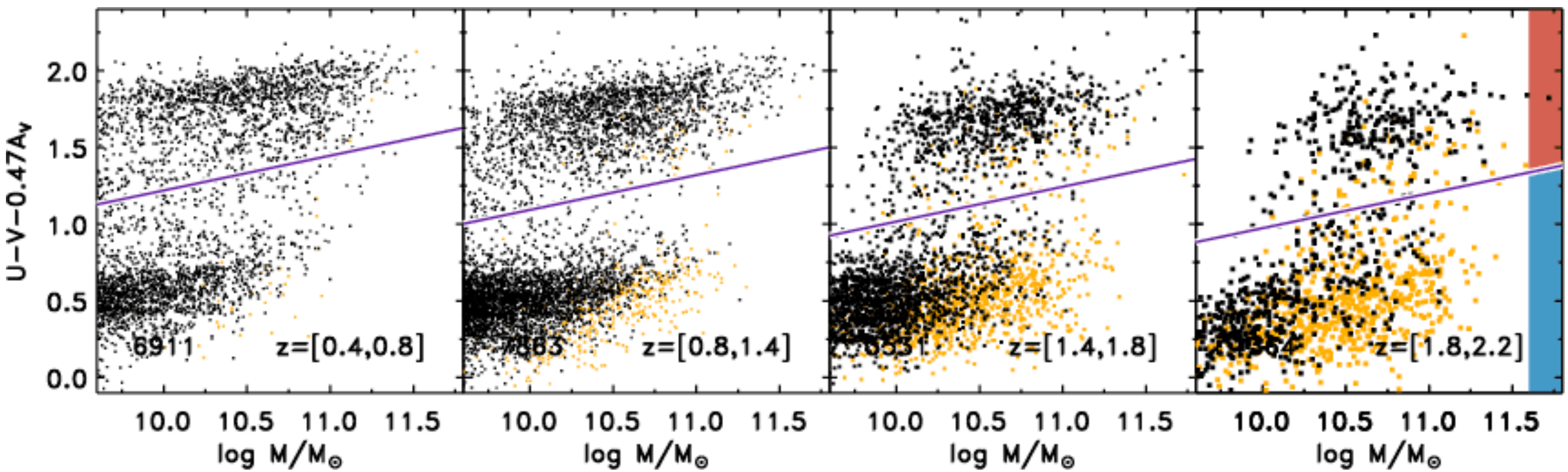


- Where is the star-formation occurring on this plot?
- **There are massive red galaxies with high SFR (> 40 $M_\odot$/yr) at z > 1.**

The color-mass distribution at 0 < z < 2.2

Brammer et al. 2011



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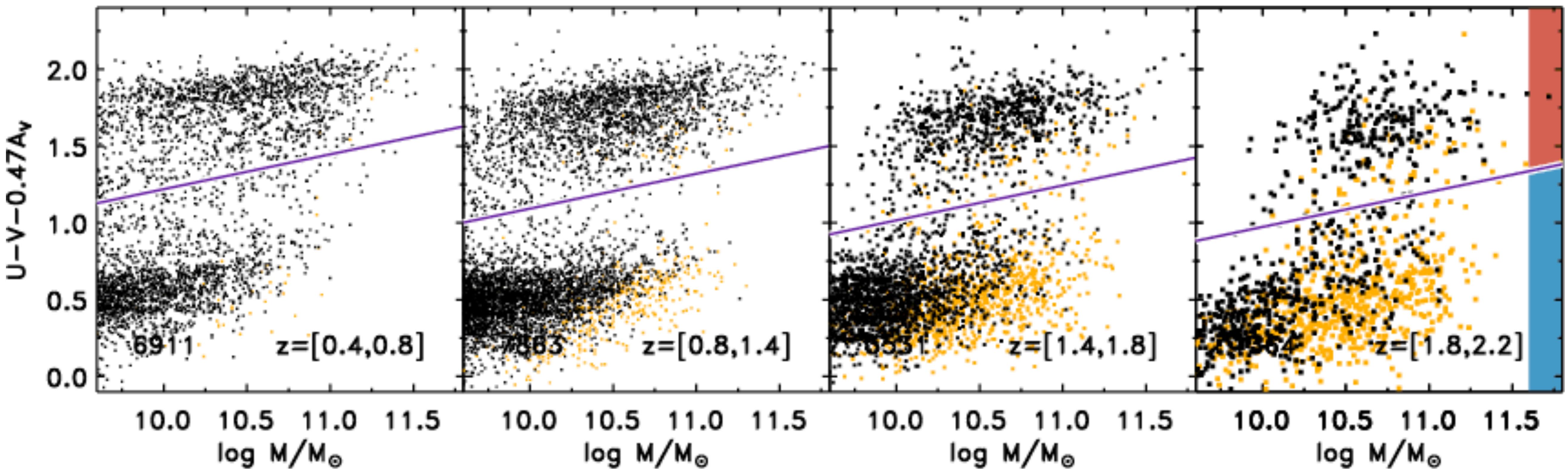
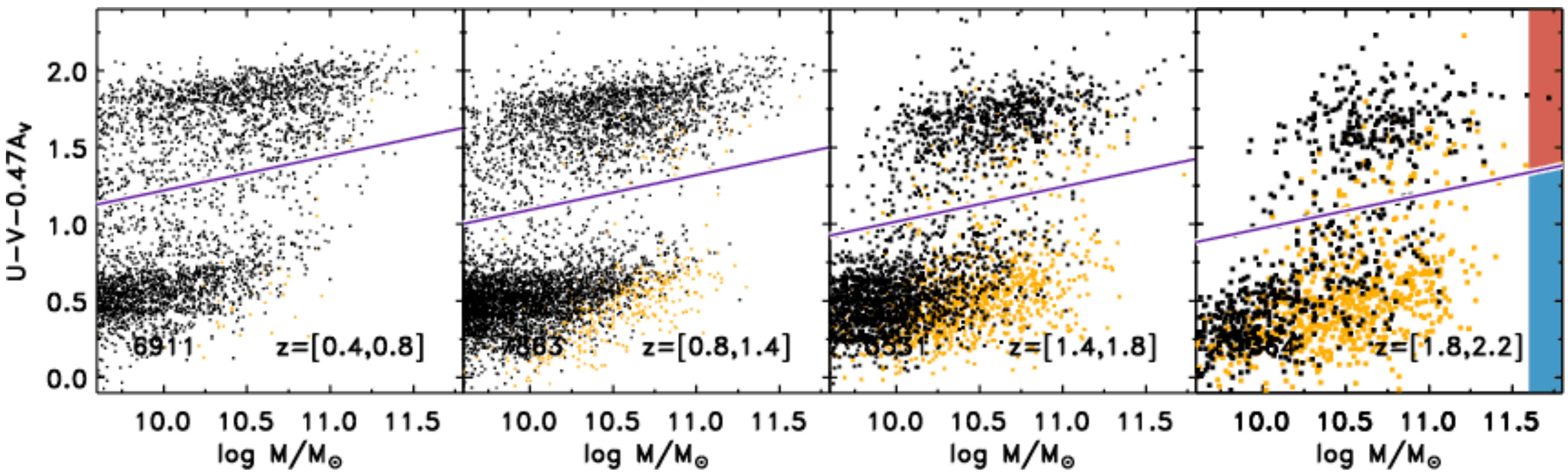
Brammer et al. 2011



- Massive star-forming galaxies are IR-luminous, suggesting that they are quite dusty.

The color-mass distribution at $0 < z < 2.2$

Brammer et al. 2011

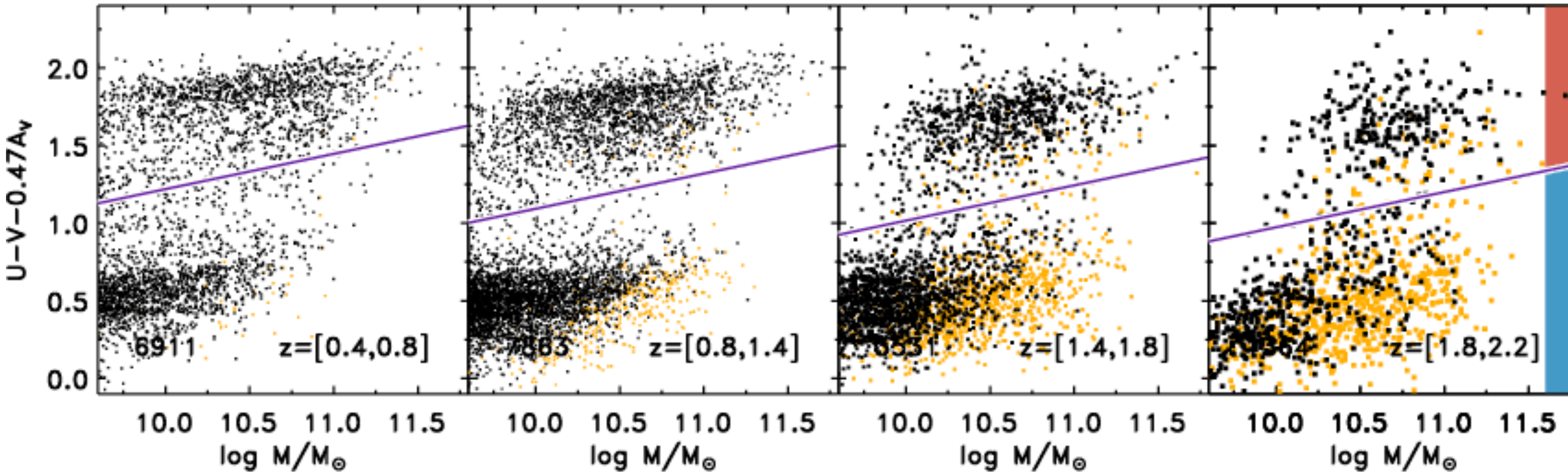


- Massive star-forming galaxies are IR-luminous, suggesting that they are quite dusty.

- There is a “blue sequence”, distinct from the red sequence, whose colors are determined largely by **dust** (Labbé et al. 2007, Wuyts et al. 2007, Brammer et al. 2009, Brammer et al. 2011)

The color-mass distribution at 0 < *z* < 2.2

Brammer et al. 2011



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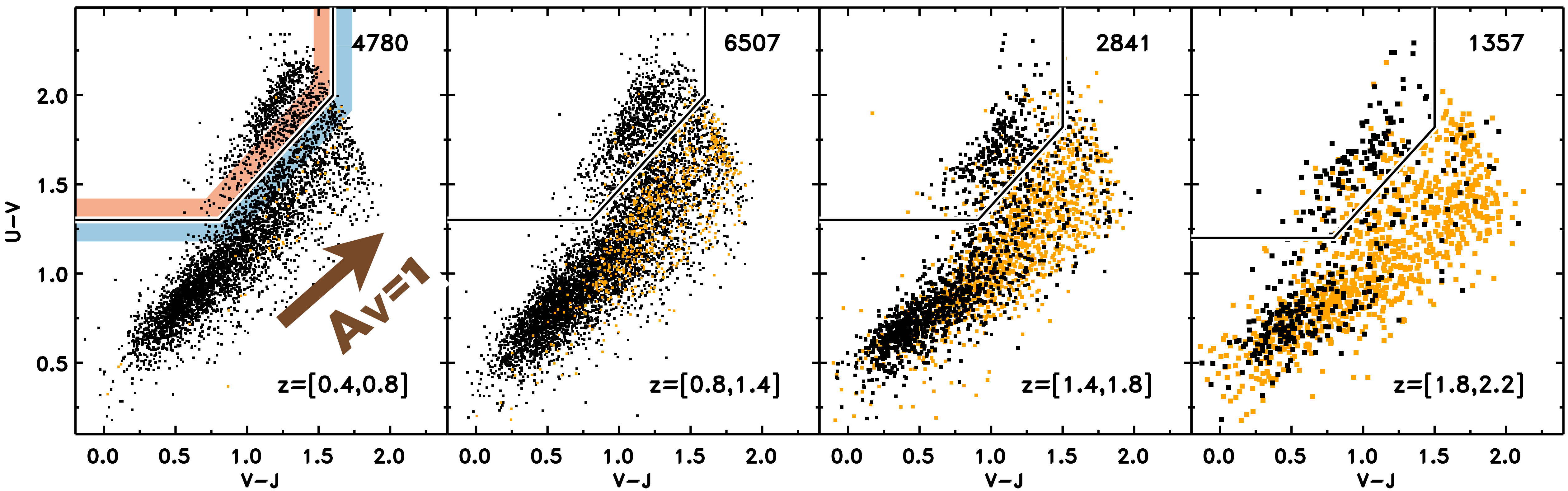
- There is recent evidence that the quiescent red sequence is in place at $z \sim 2$ from small **spectroscopic** samples (Kriek et al. 2006/09, Cassatta et al. 2008).
  Detecting it photometrically requires NMBS redshift accuracy and SED sampling

A_V suffers from systematics but the separation of the quiescent and SF populations is robust



- Rely rather on an empirical separation based on the U-V and V-J rest-frame colors (Labbé et al. 2007, Wuyts et al. 2007, Williams et al. 2009)

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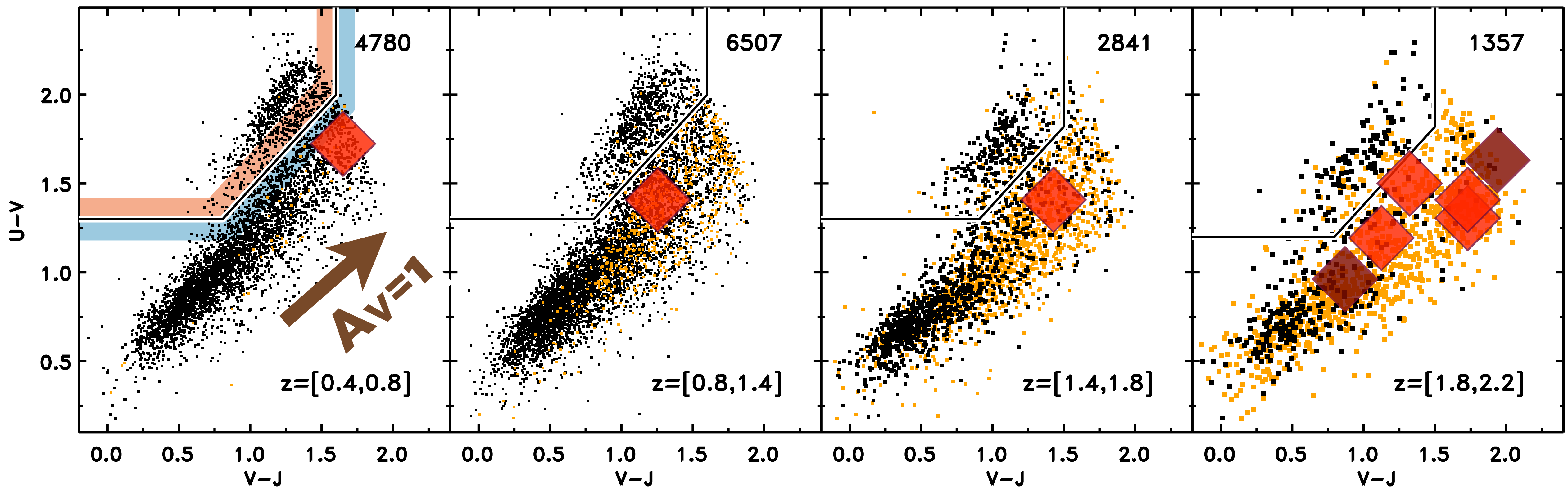

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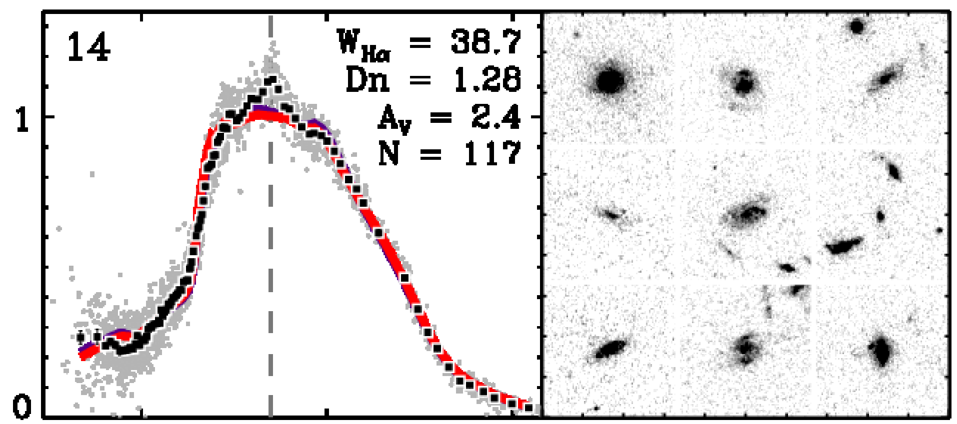
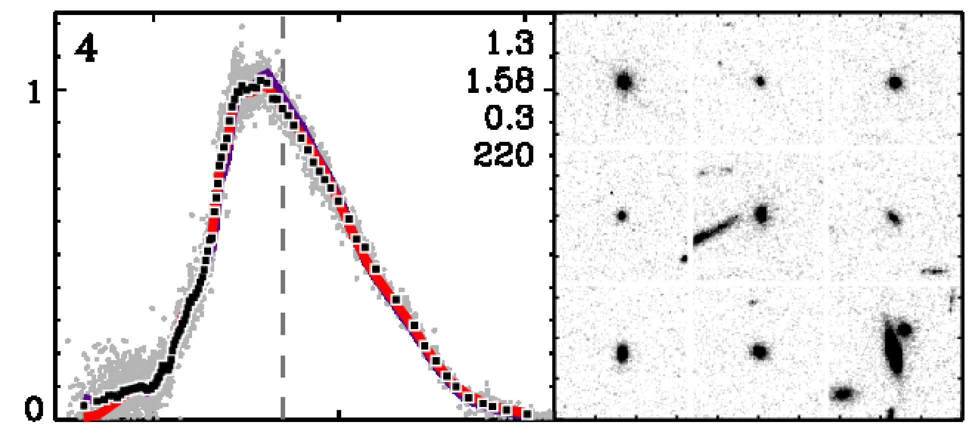
- **COSBO (COSMOS/MAMBO, Bertoldi et al. 2007)**
  9 sub-mm galaxies covered by the NMBS

The NMBS photometric redshifts are precise enough to detect Hα in composite SEDs.

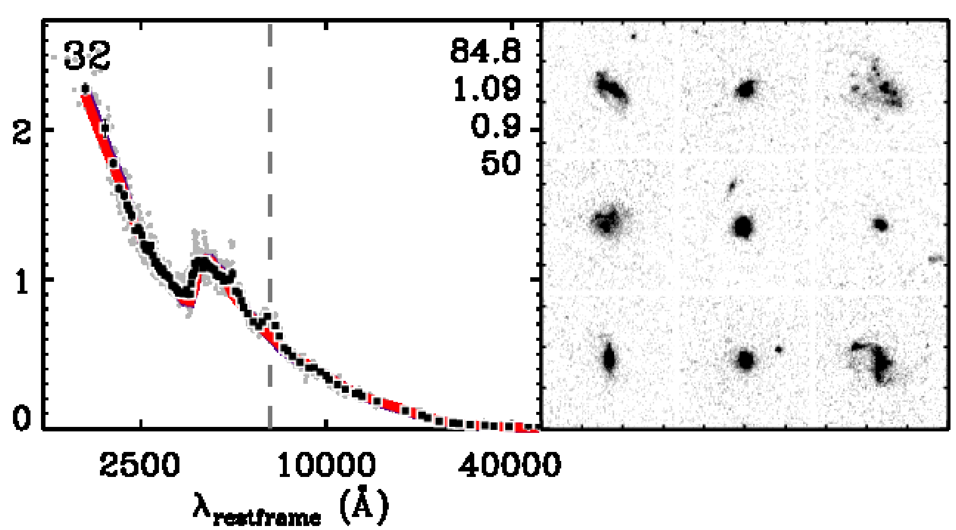
Star-forming and dusty



Quiescent



Star-forming



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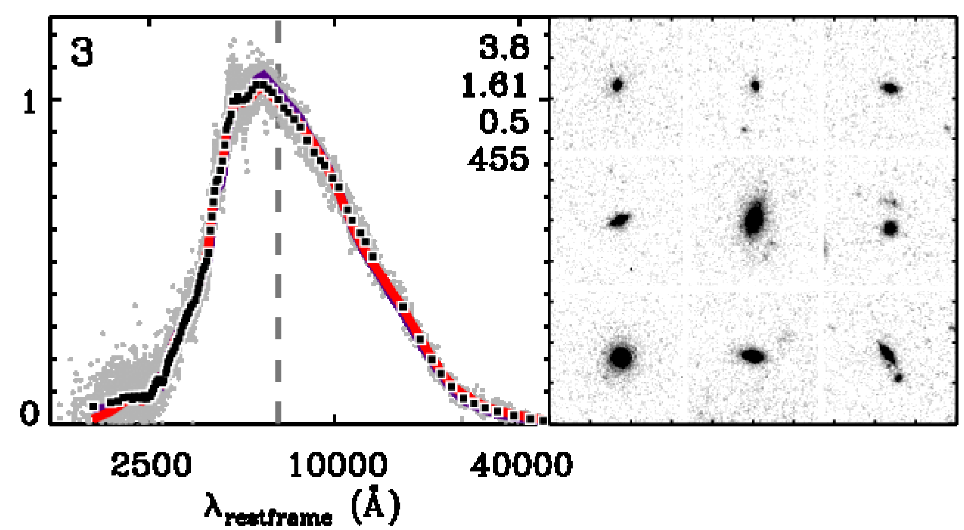
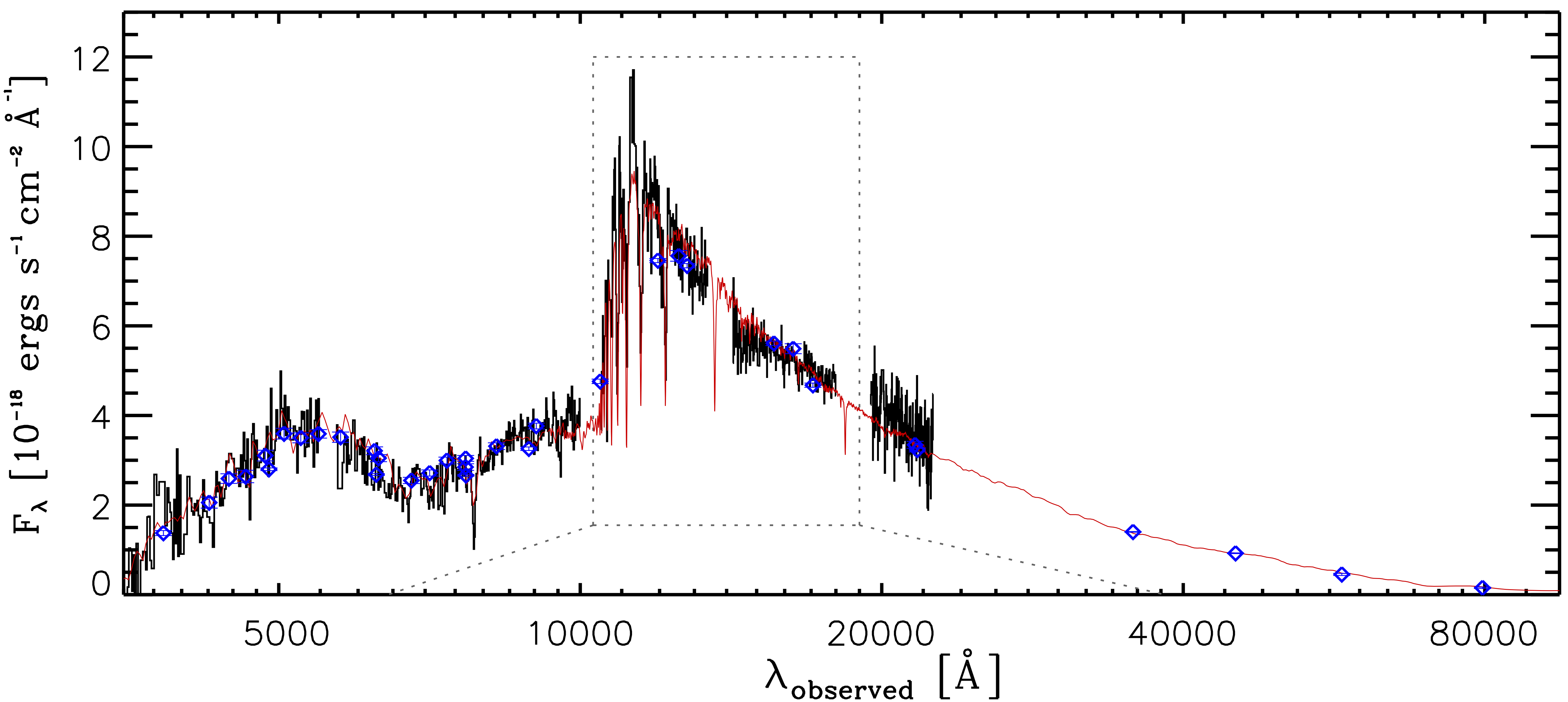


Kriek et al. 2011

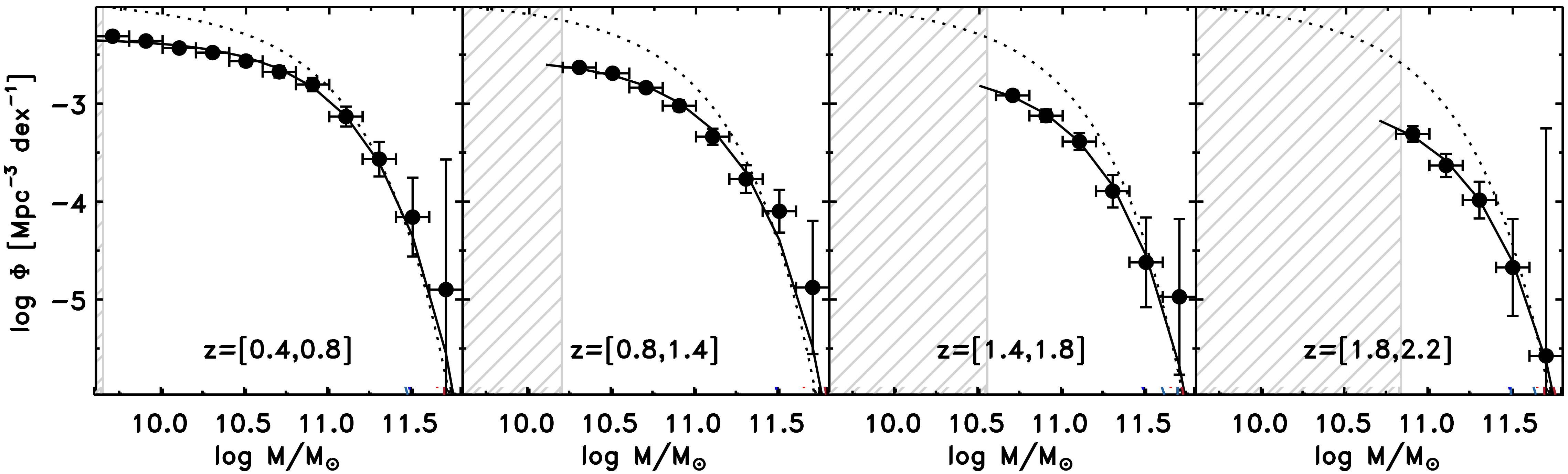
Proof-of-concept

- **X-Shooter** spectrum of COSMOS-7447 *(van de Sande et al. 2011)*
  - z = 1.8, log M/M$_\odot$ = 11, SFR = 0.002 M$_\odot$/yr , σ = 294 km/s



A quantitative study of the evolution of massive galaxies: number and mass densities

Brammer et al. 2011



The extreme massive end of the stellar mass function is roughly in place already at z=2 (and even at z>3 ; *Marchesini et al. 2009+10*)

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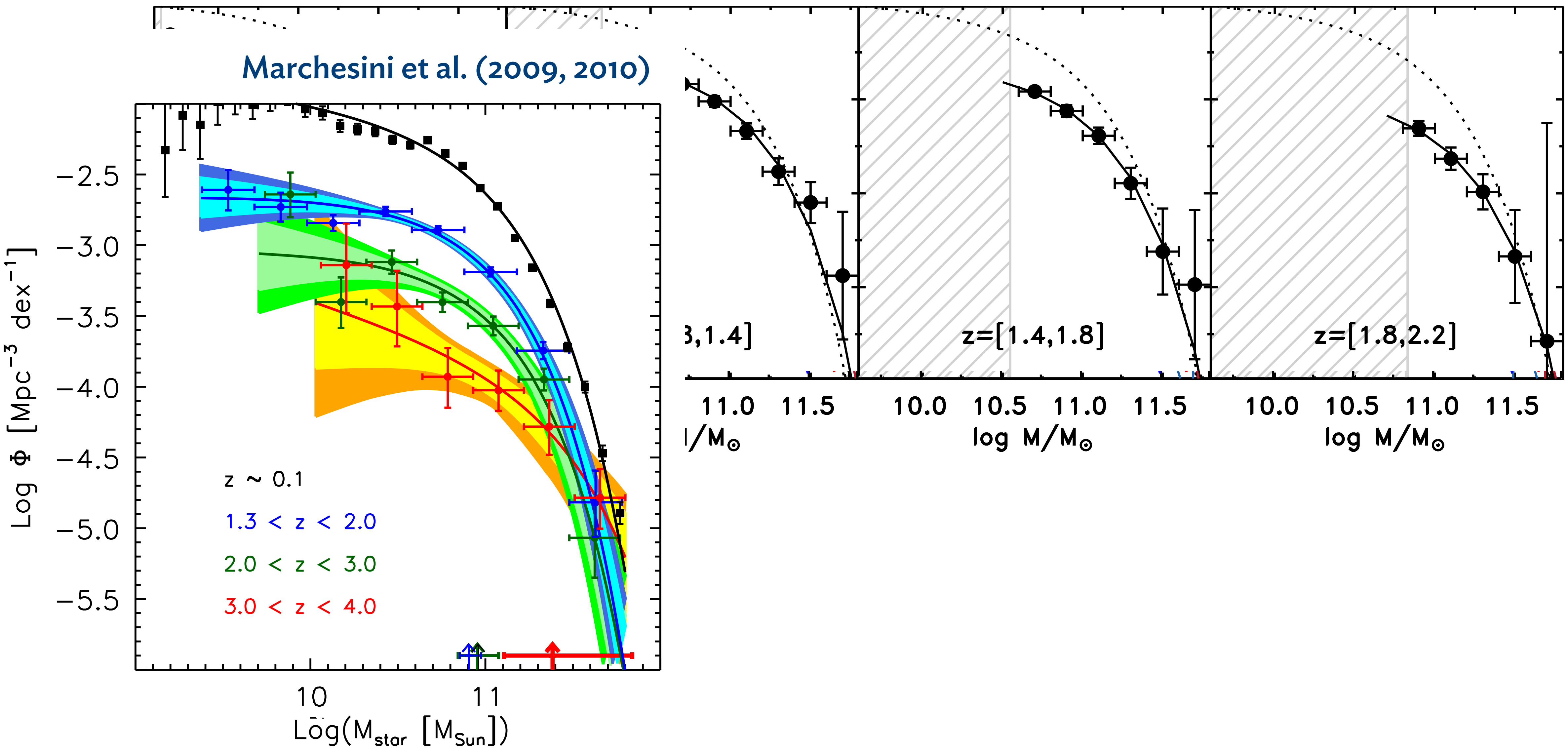

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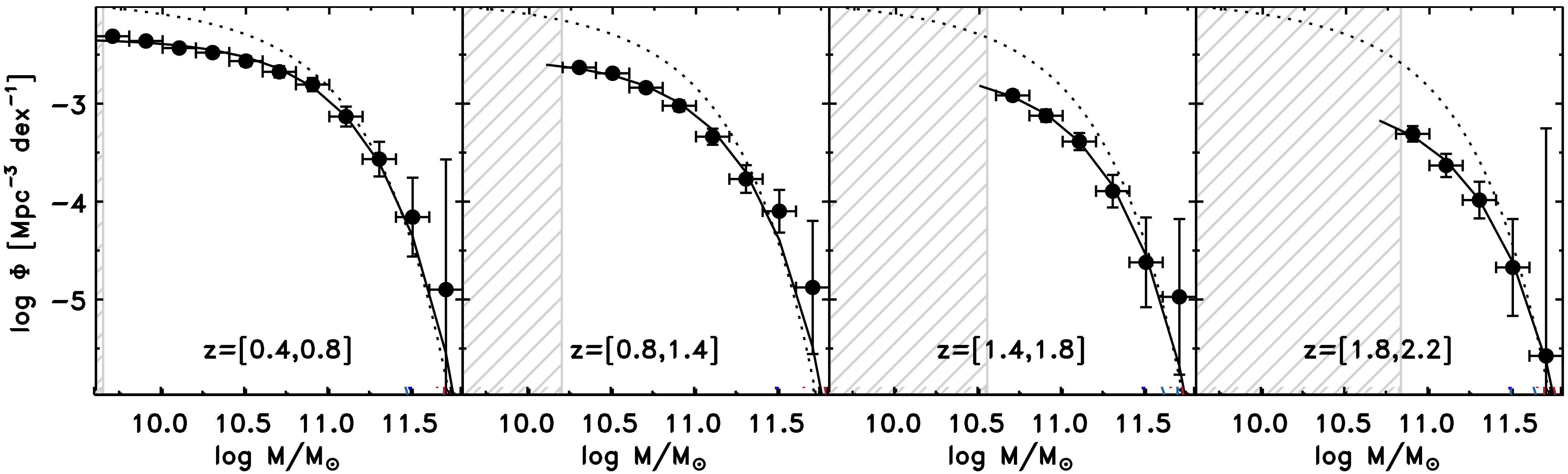

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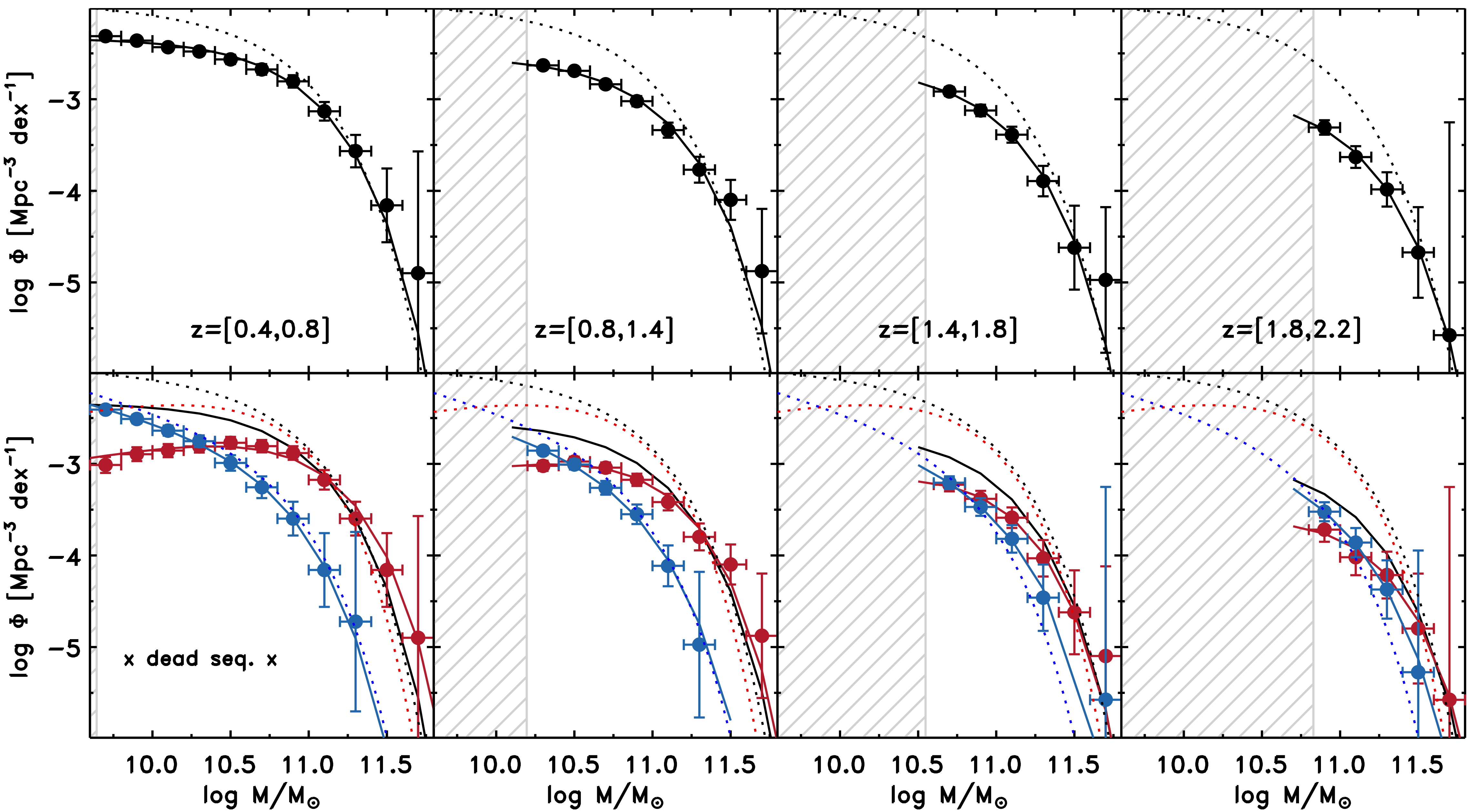
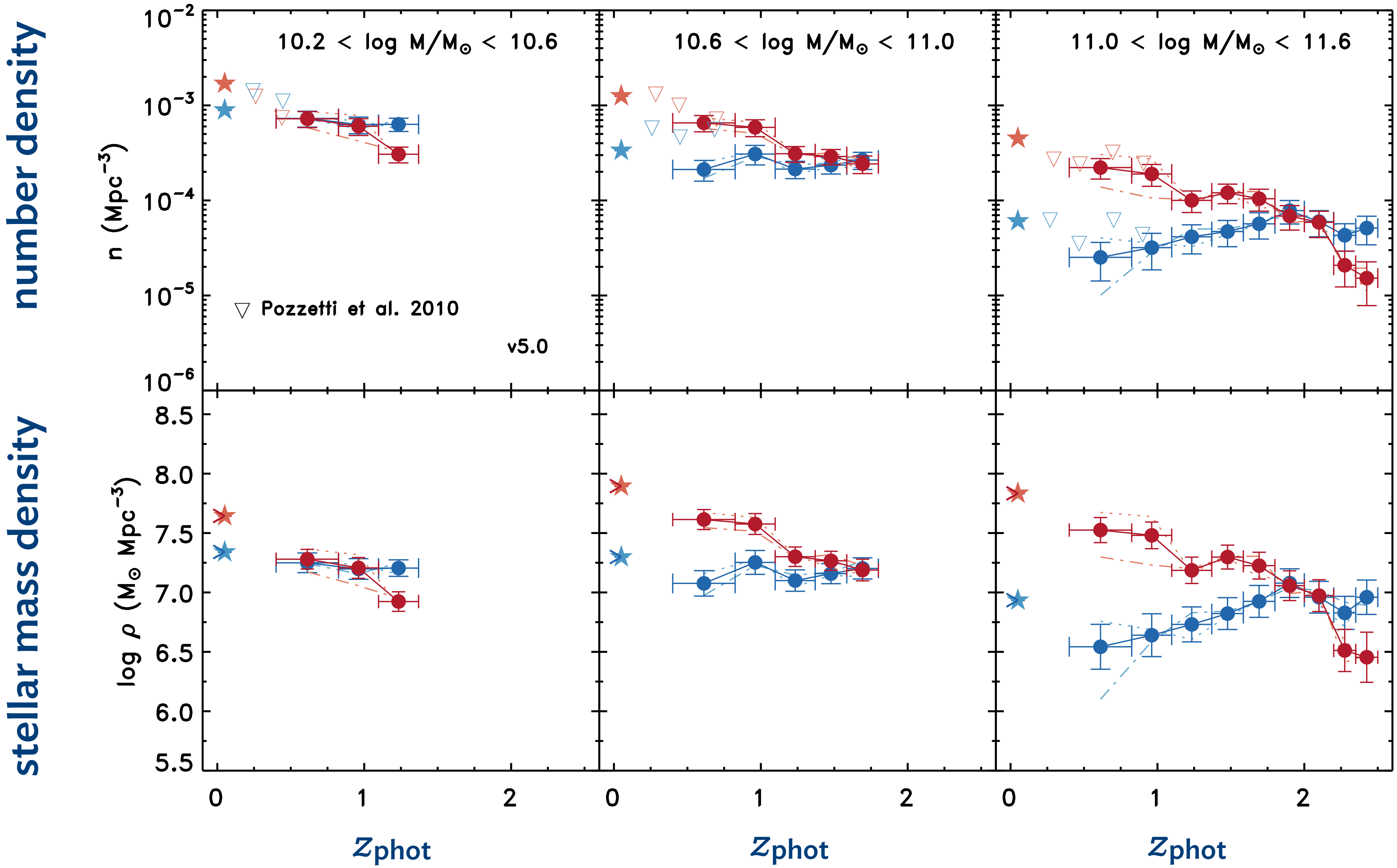


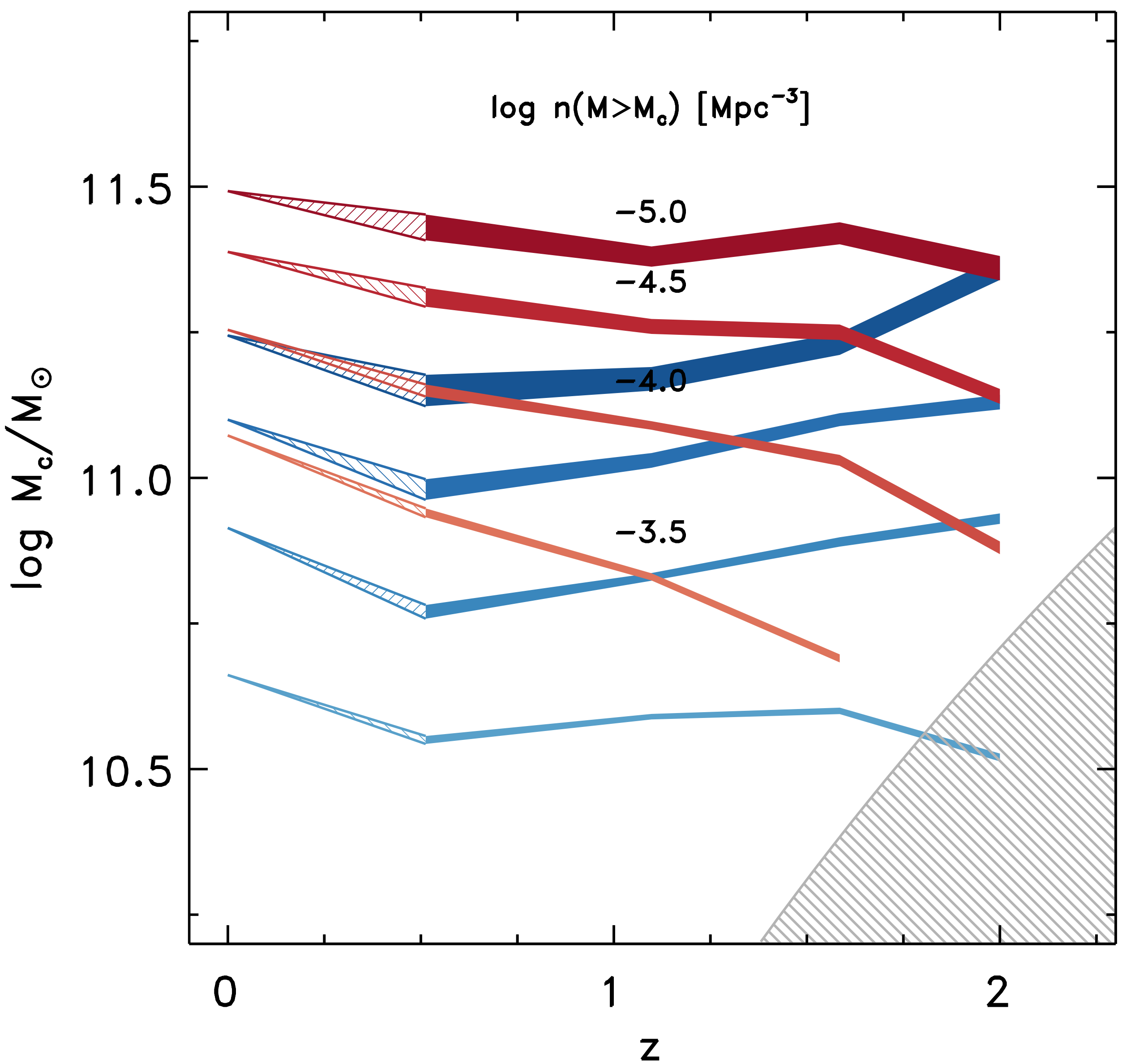
Quiescent galaxies account for most of the evolution in the mass function since z=2.2

The density of star-forming galaxies is roughly flat with time. That of quiescent galaxies increases by ~0.5 dex/dz.

Brammer et al. 2011



The results: the average quiescent galaxy above 10^{11} $M_\odot$ grows by a factor of ~2 since z=2



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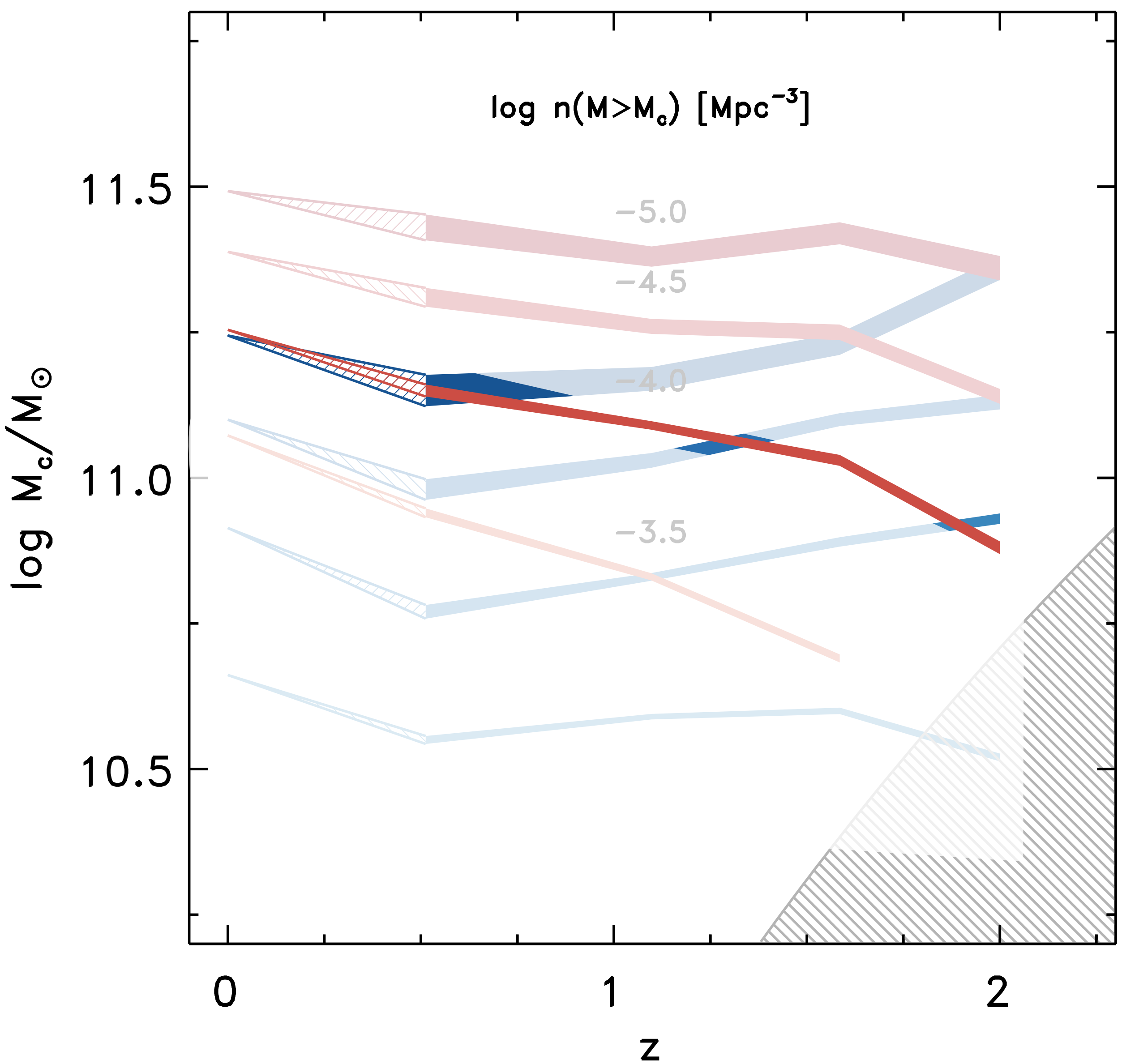

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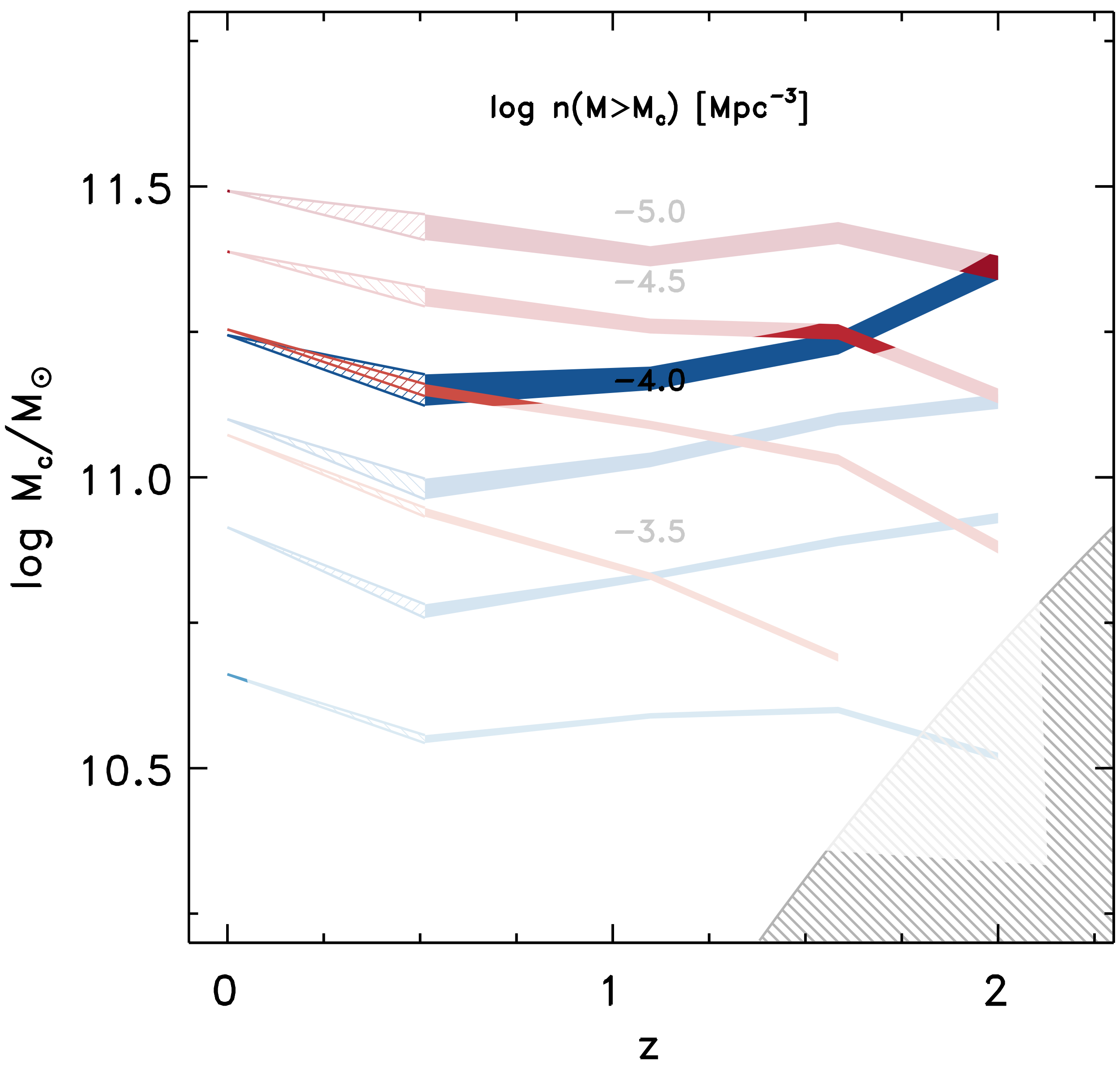
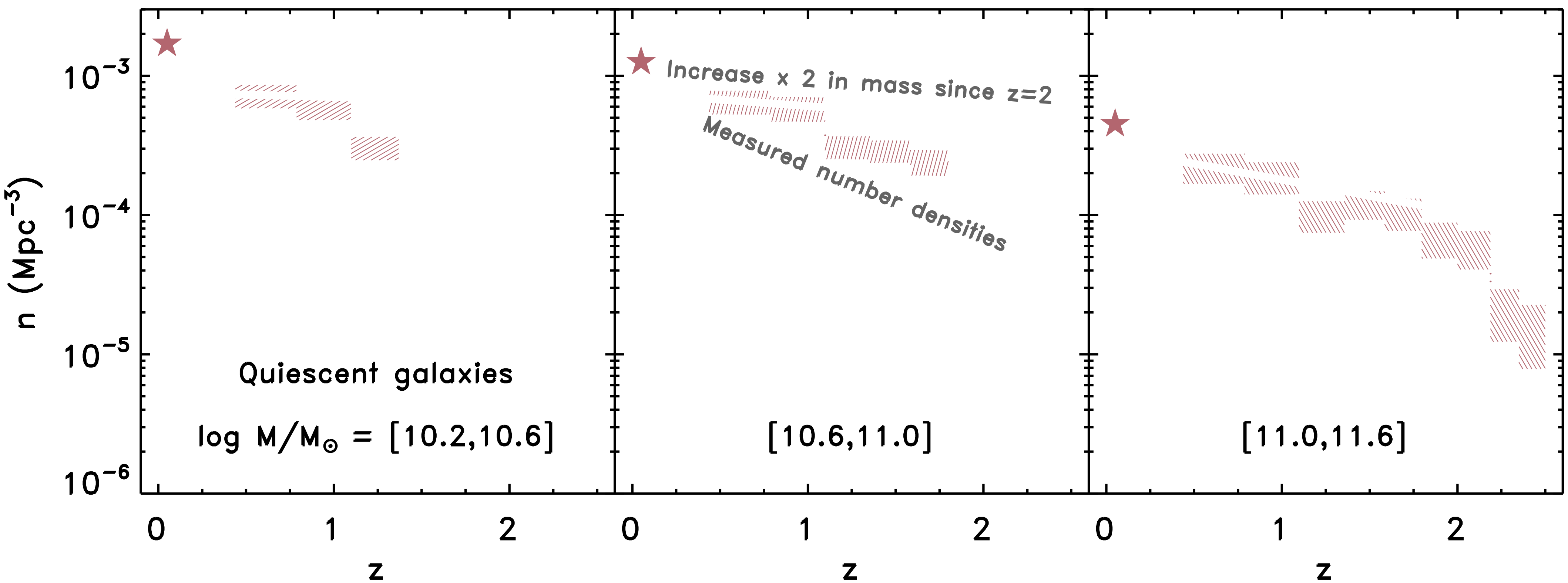


- Perhaps there is also evidence for quenching at extreme masses.

This somewhat modest growth of stellar mass can also (mostly) explain the steep rise in the mass densities of quiescent galaxies above 10^{11} $M_\odot$.



- Get more change in density for a given change in mass at the massive end due to the exponential end of the mass function.

- There remains a large discrepancy for less-massive quiescent galaxies (later quenching, downsizing, ...)

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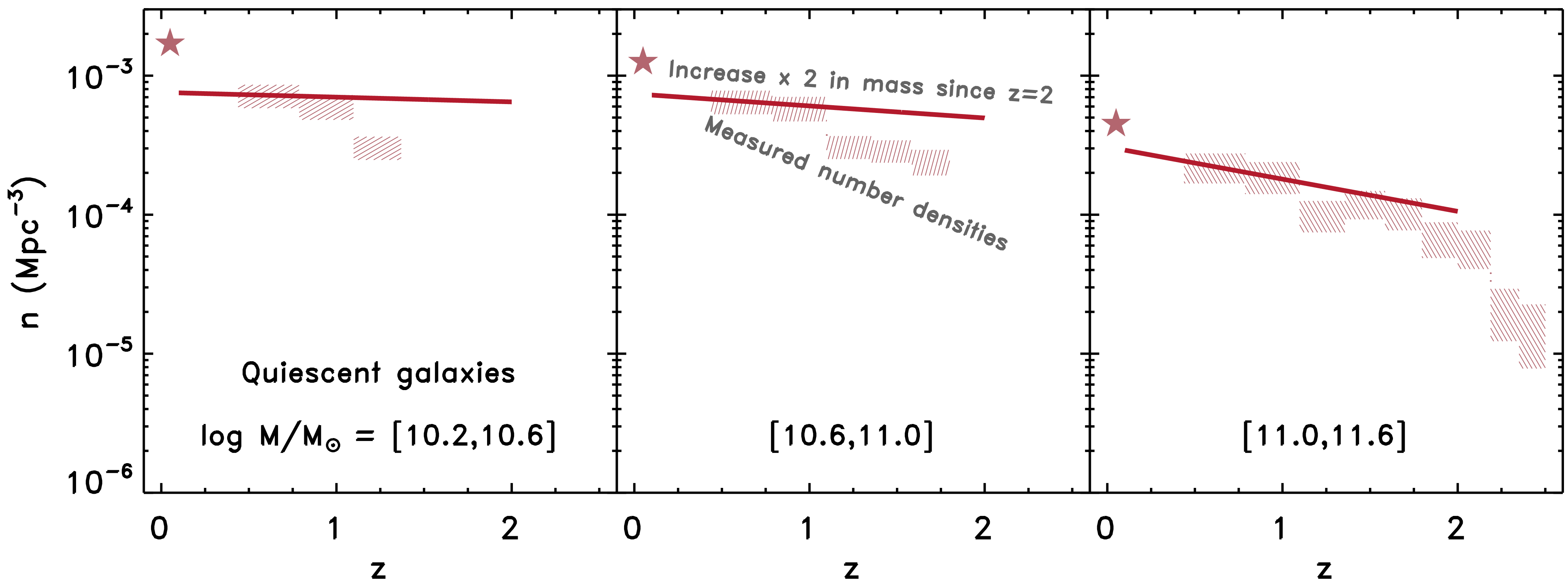

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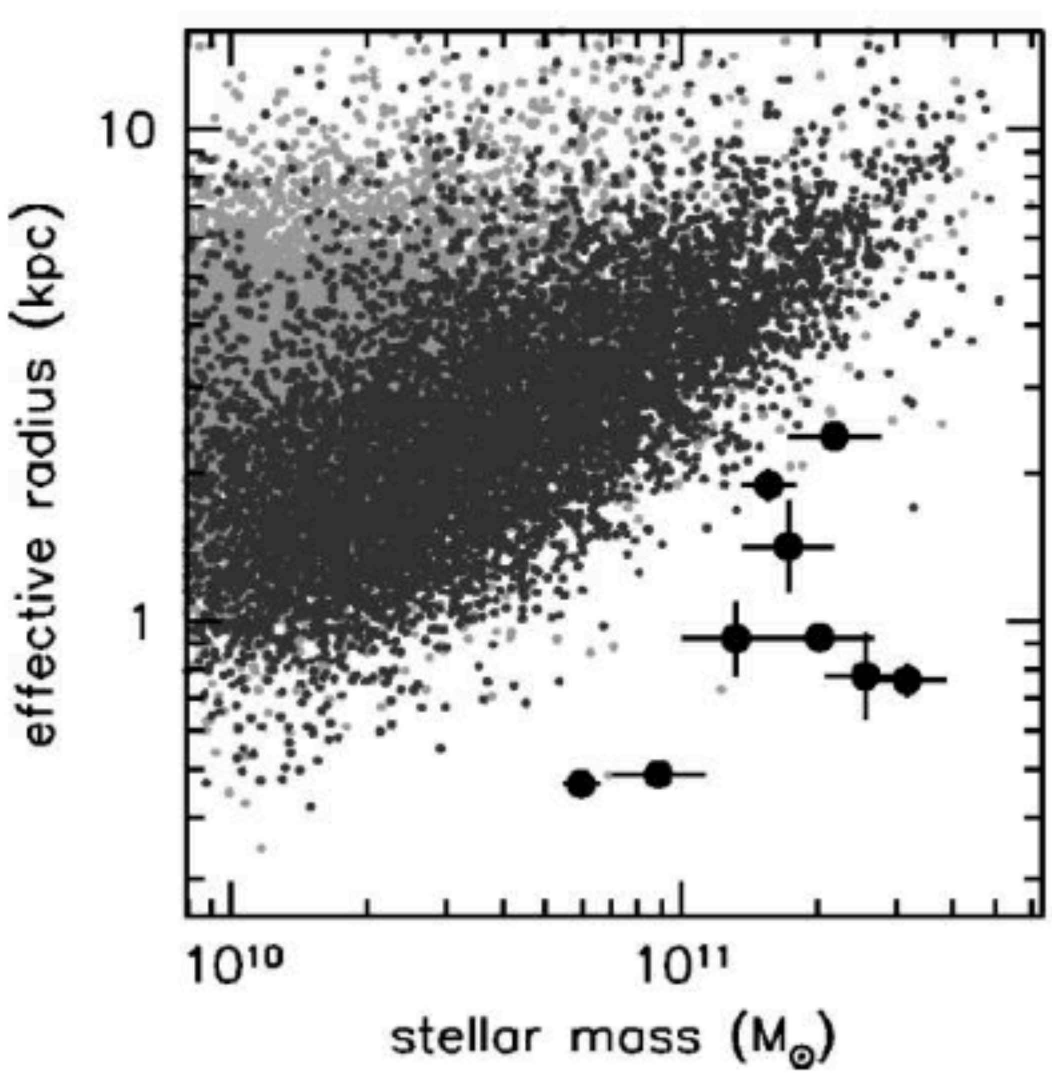
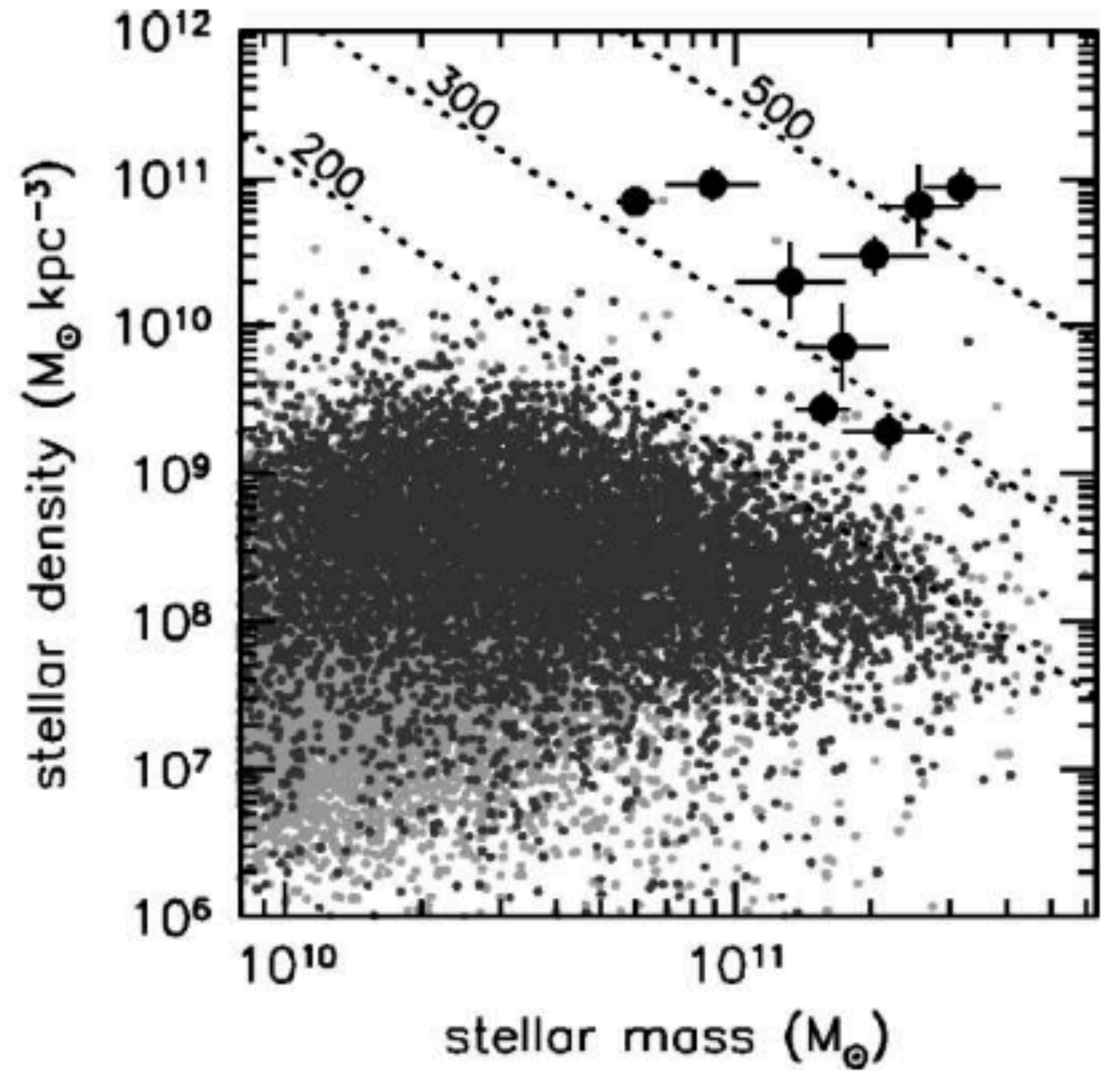
We see similar evolution in the *structure* of massive galaxies.

van Dokkum et al. (2008)





- Massive, quiescent galaxies are **compact** at z=2.0 *(Trujillo et al. 2006, Toft et al. 2007, van Dokkum et al. 2008)*

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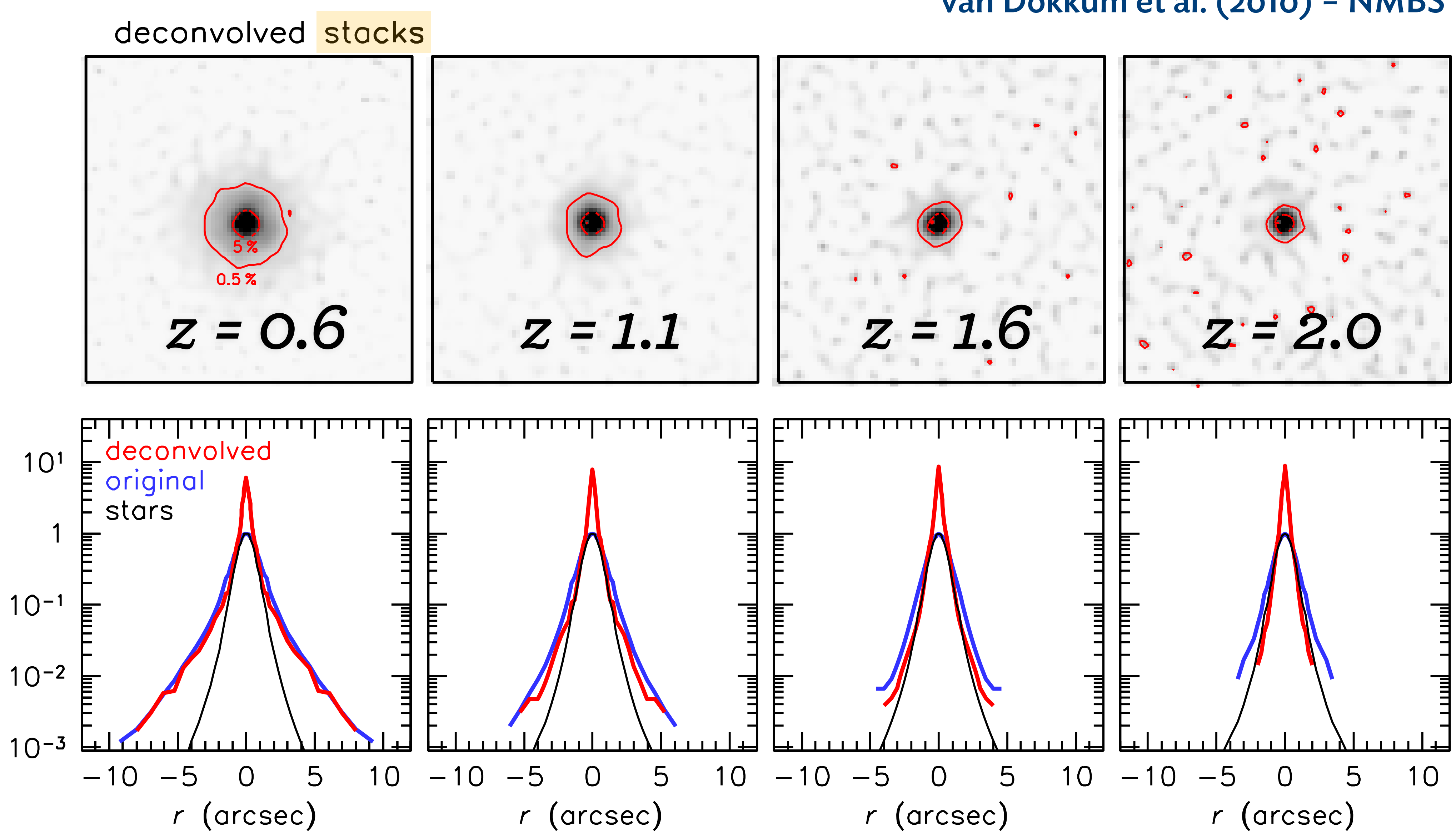
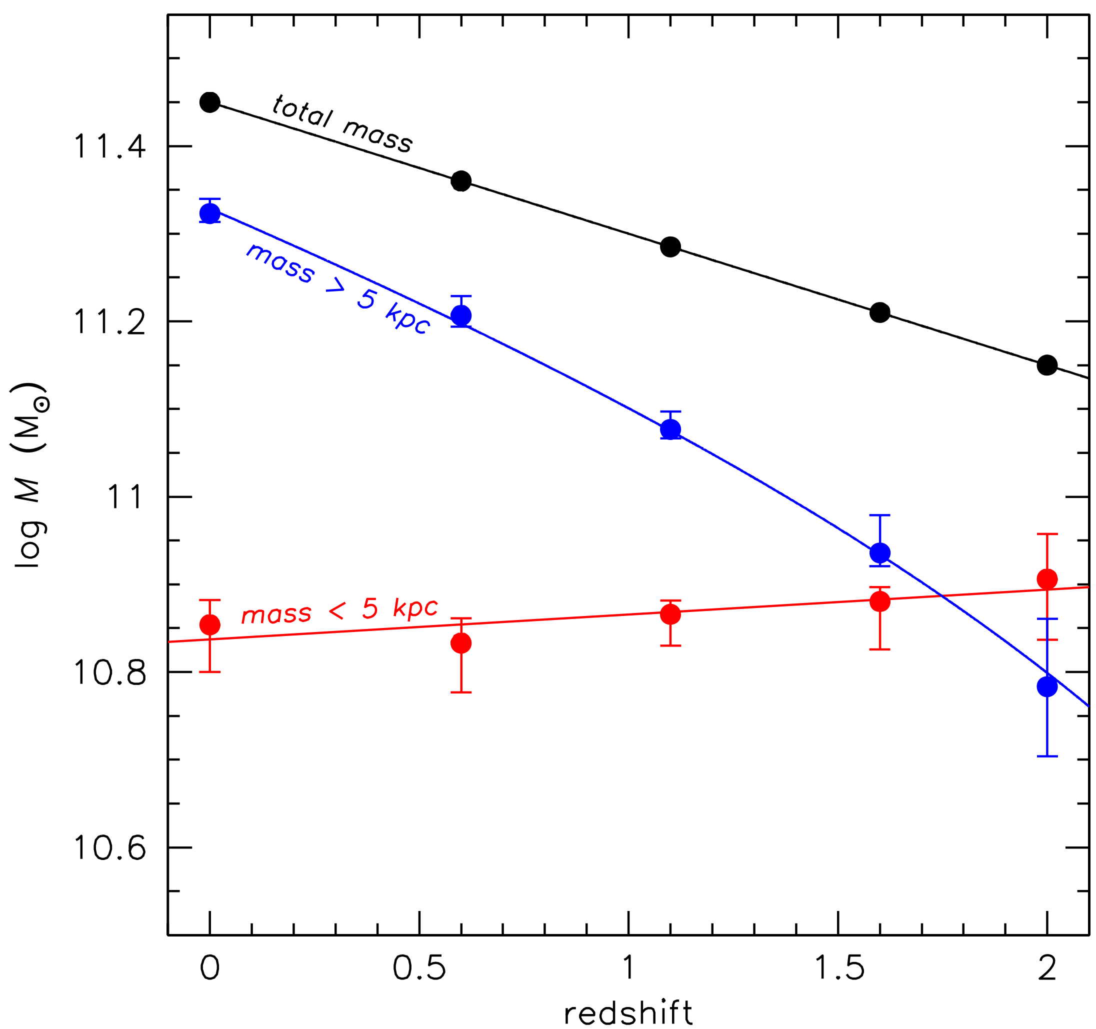
van Dokkum et al. (2010) – NMBS

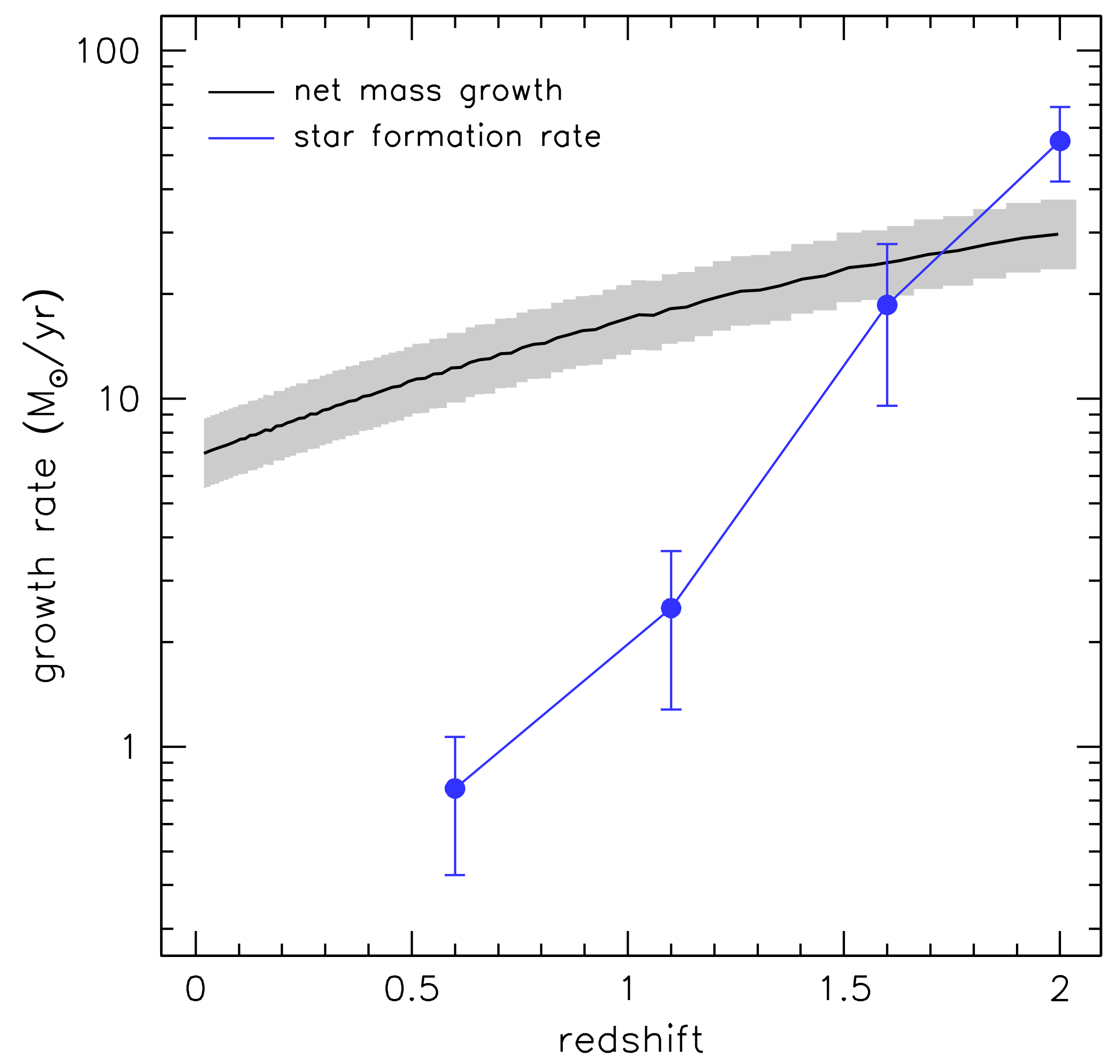


- The **cores** of massive, quiescent galaxies are compact at z=2.0
- **"inside-out"** growth of the outer envelopes

Massive galaxies grow predominantly via mergers since z~1.5

van Dokkum et al. (2010) – NMBS





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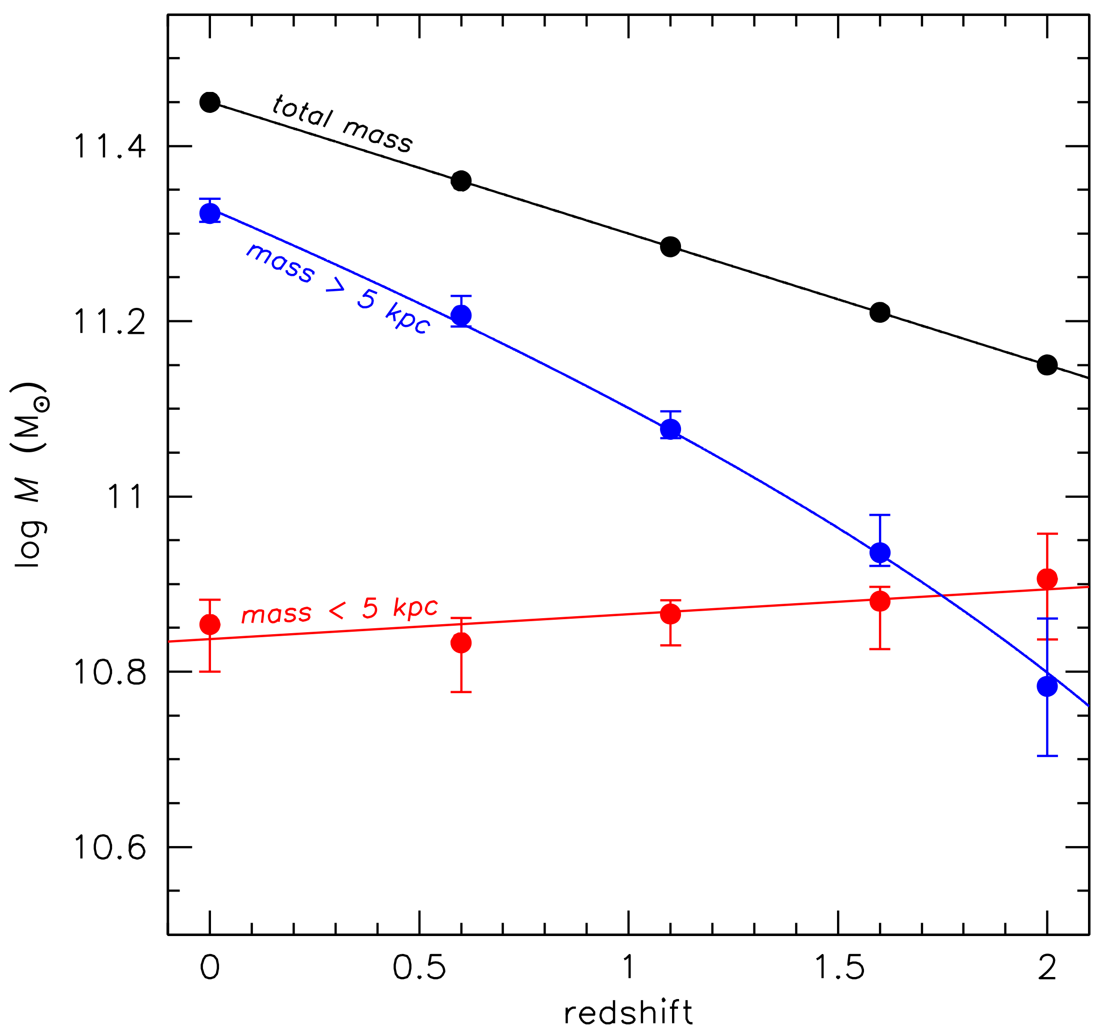
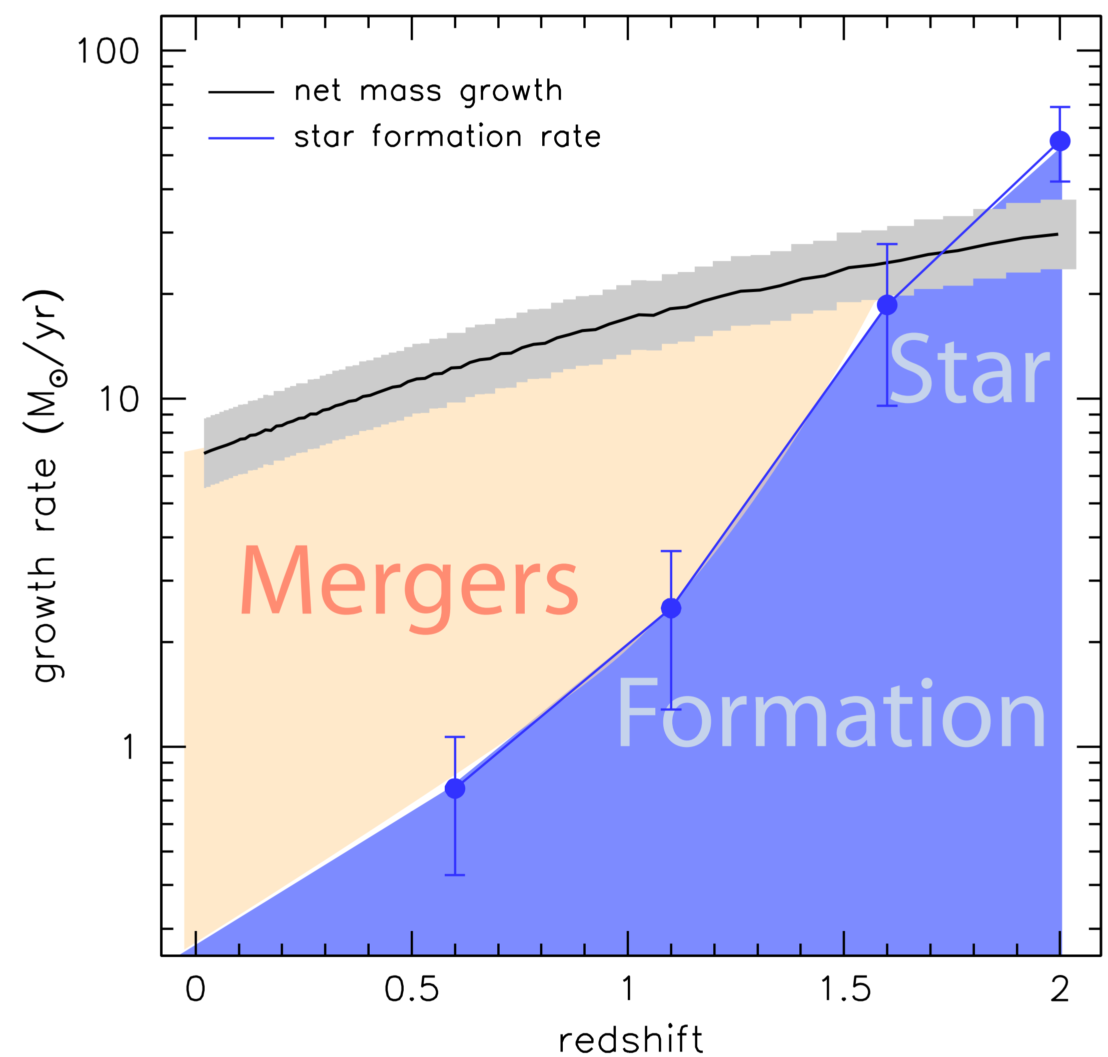




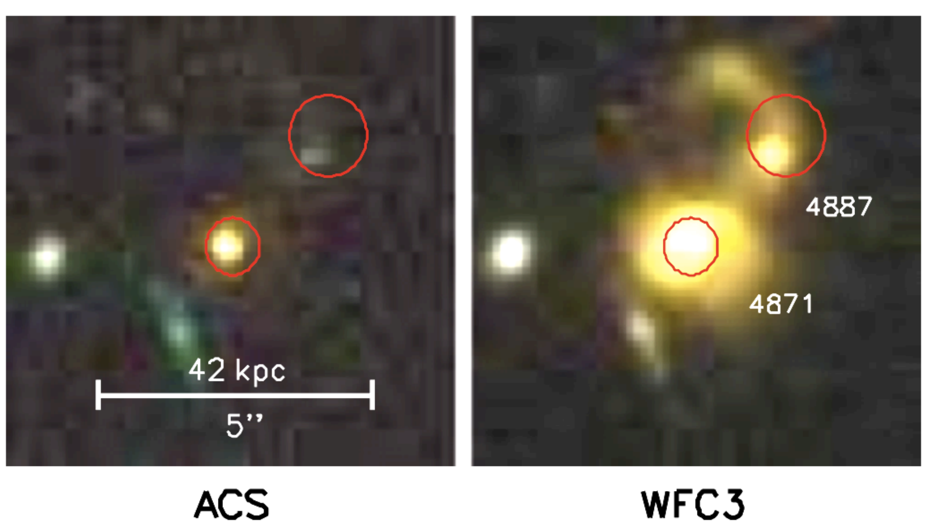
Conclusions

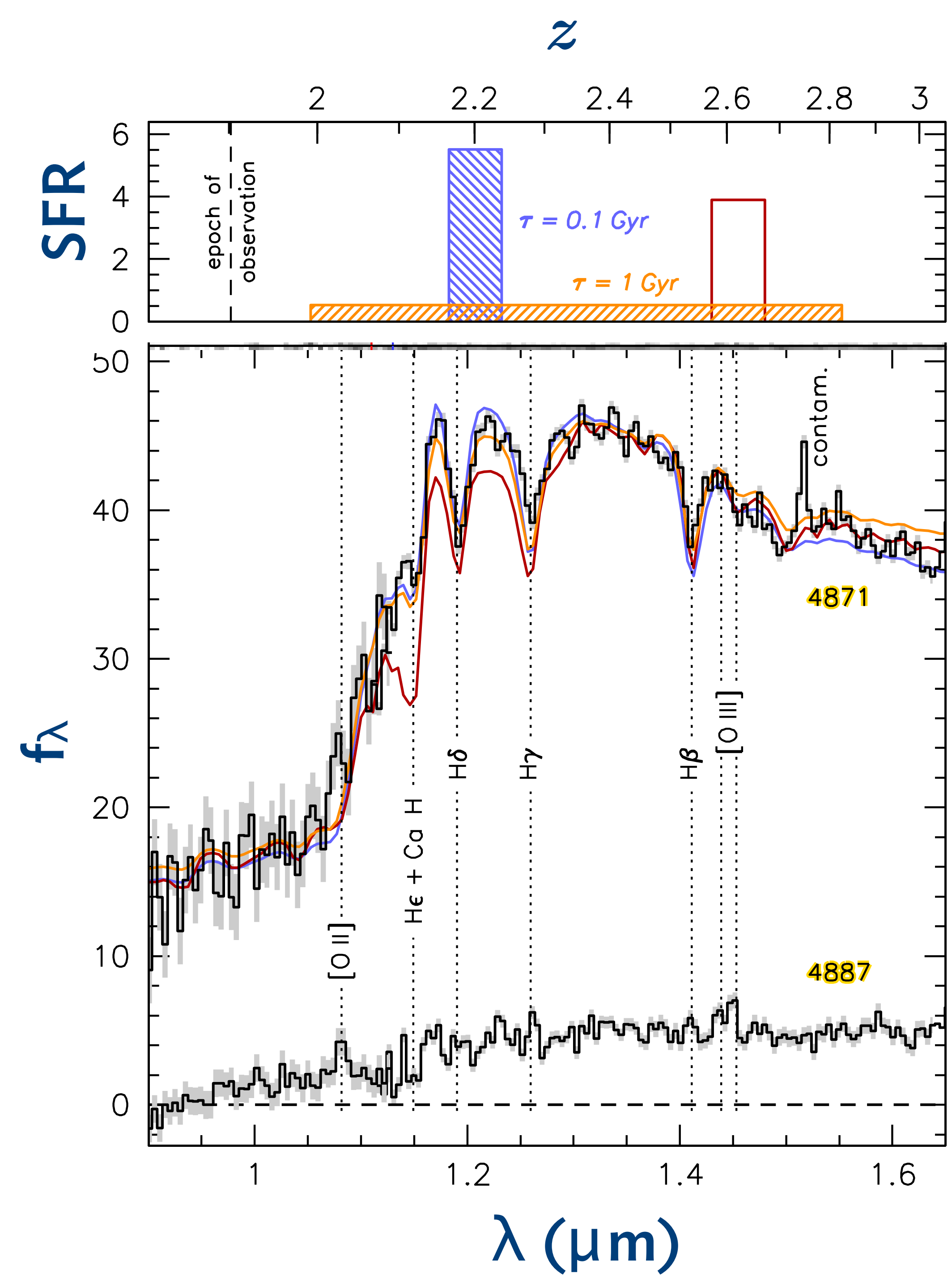
- The galaxy color **bimodality** is in place at least up to z=2.2.
- But it is only apparent after correcting the rest-frame U-V colors for dust, since *all* massive (log $M/M_{\odot}$ >10.5) galaxies are red at z>1.5, but **many (~half) are dusty**.
- The massive, quiescent galaxy population grows **smoothly**, but significantly, from z=2
- Individual galaxies at log $M/M_{\odot}$ >10.5-11 grow in stellar mass by a factor of ~2, with the added mass added primarily to their outer envelopes
- These results for large statistical samples are robust due to precise photo-zs and well-sampled SEDs from 0.1—24μm.

HST Grism spectra: 1.1-1.6μm at *R*~150

- **3D-HST** Survey (see Erica Nelson's talk)
- Rest-frame optical spectroscopy of 9000 galaxies at 1 < *z* < 3

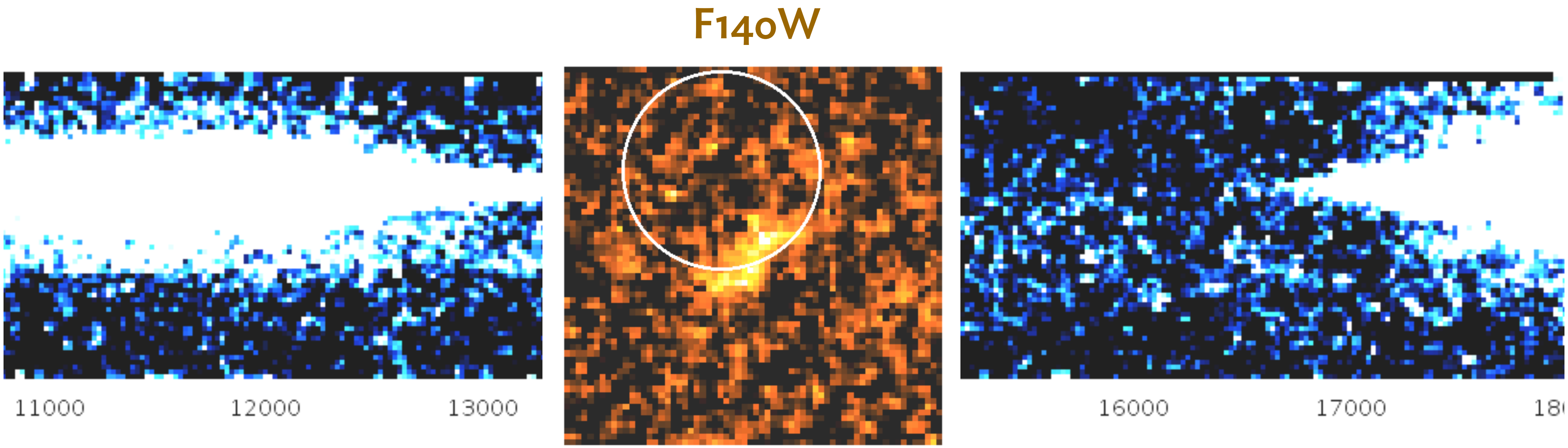
van Dokkum & Brammer (2010)





A blessing and a curse: you get a spectrum of everything!

- **GN20**, SMG z=4.055 (Daddi et al. 2009, J. Hodge's talk)
- Emission line at 1.42 μm = MgII 2800 @ z=4.055



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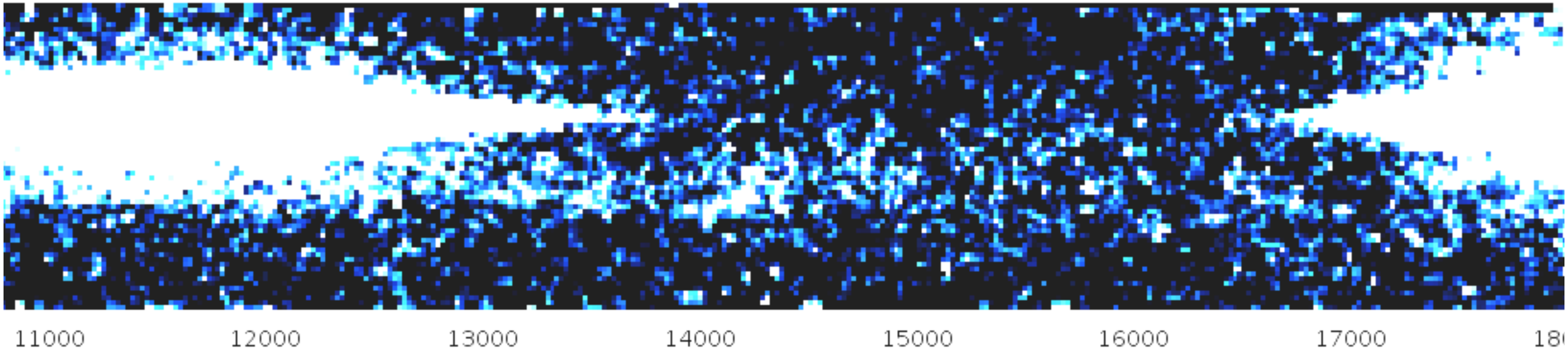


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