

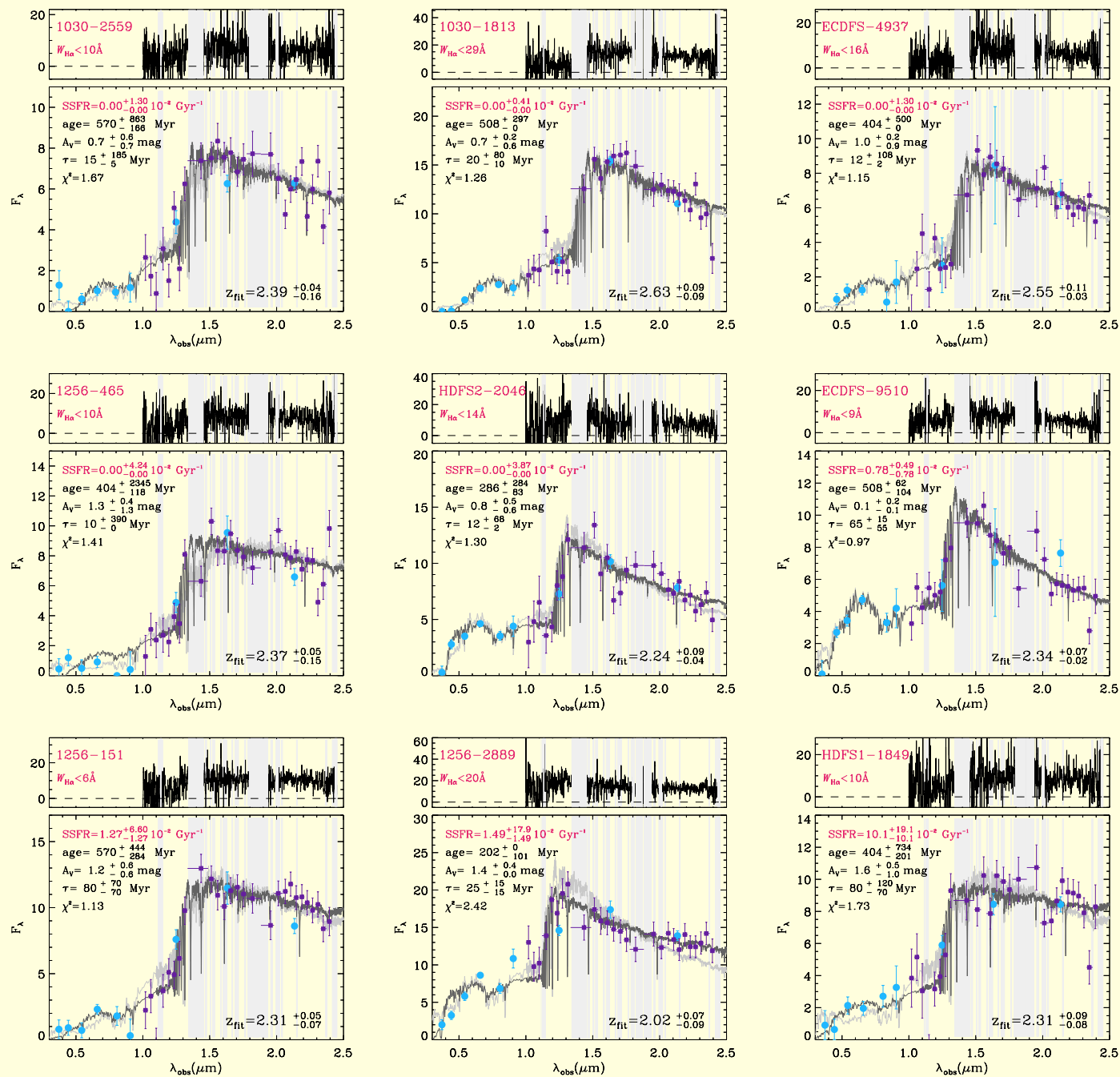
A red sequence of massive field galaxies at $z \sim 2.3$

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Gregory Rudnick (NOAO), Edward N. Taylor (Leiden), Natascha M.
Förster Schreiber (MPE), Eric Gawiser (Rutgers), Ivo Labbé (OCIW),
Paulina Lira (Univ. de Chile), Stijn Wuyts (CfA) & the MUSYC team

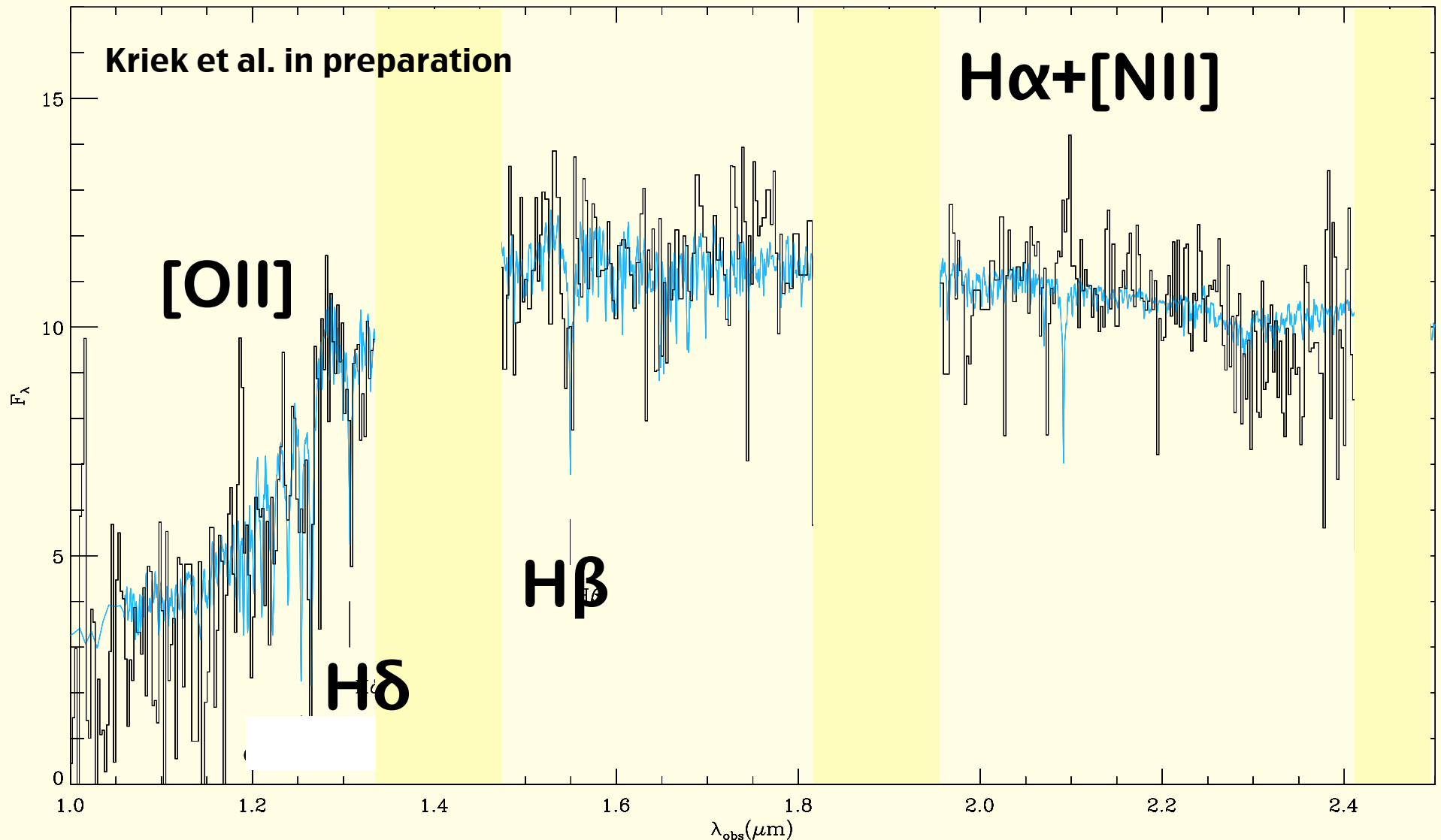
Is a red sequence already in place beyond $z=2$?

- ◆ **Identification of galaxies with quiescent stellar populations beyond $z=2$**
- ✿ **(e.g., Franx et al. 2003, Labbe et al. 2005, Daddi et al. 2005, Cimatti et al. 2008)**

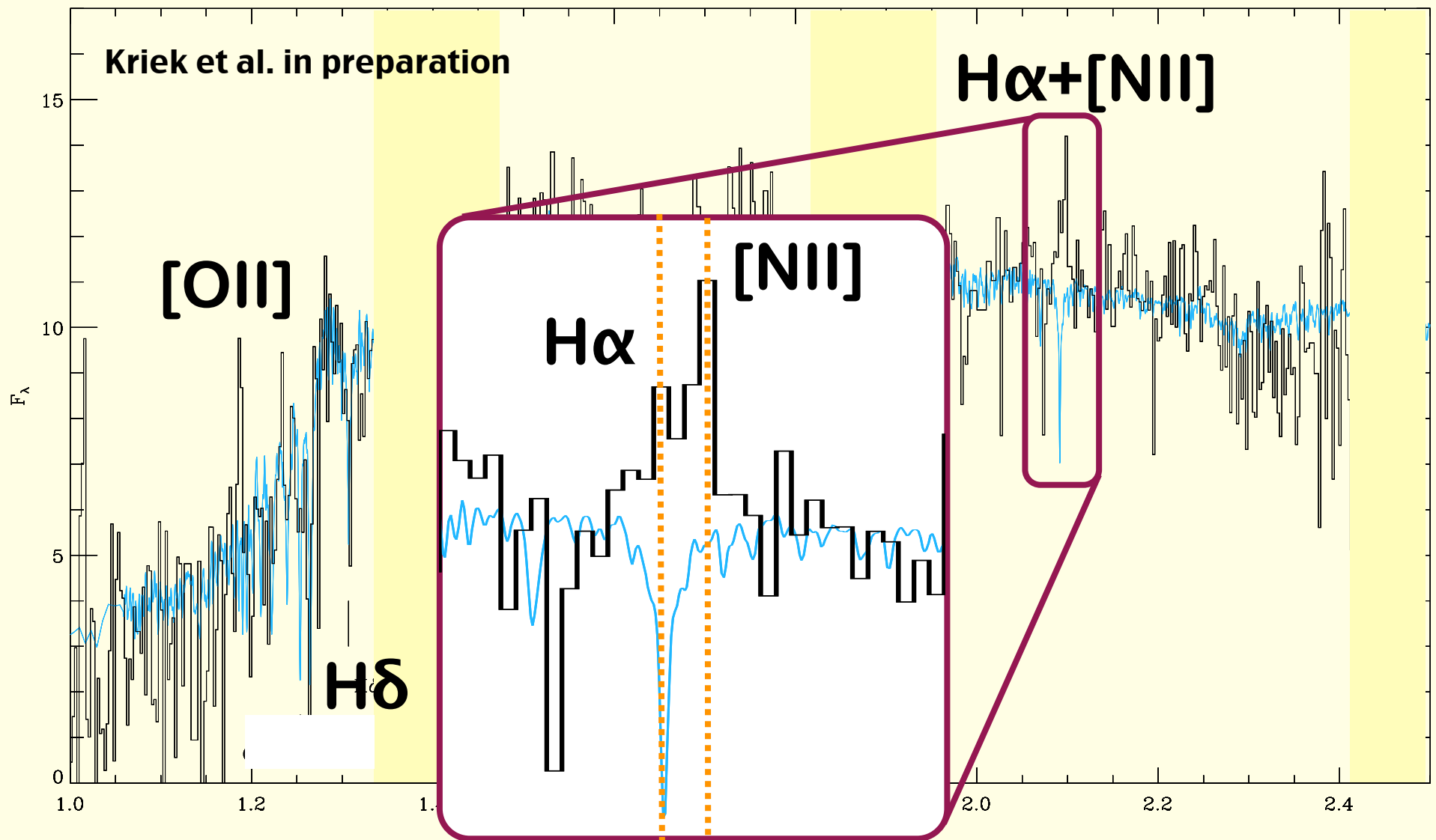


Kriek et al. 2006

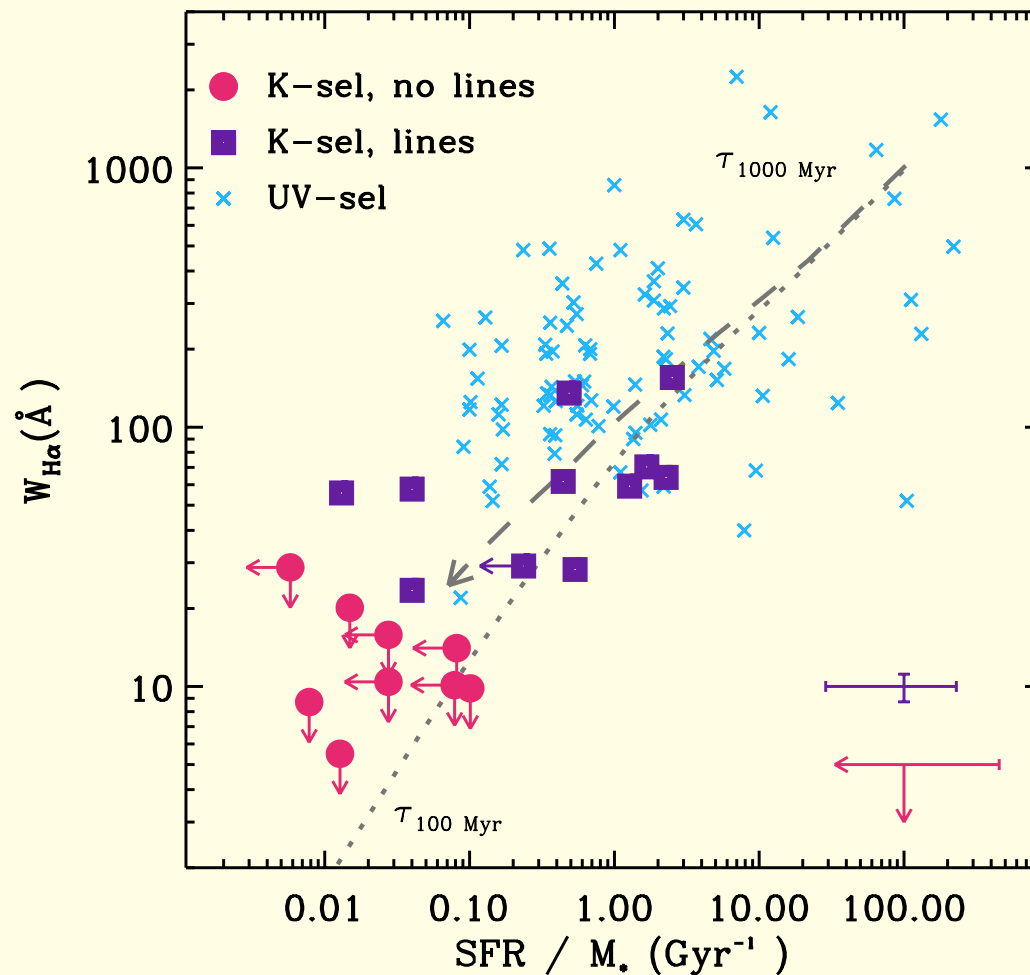
30 hour spectrum of a massive, quiescent galaxy at $z \sim 2.2$



30 hour spectrum of a massive, quiescent galaxy at $z \sim 2.2$

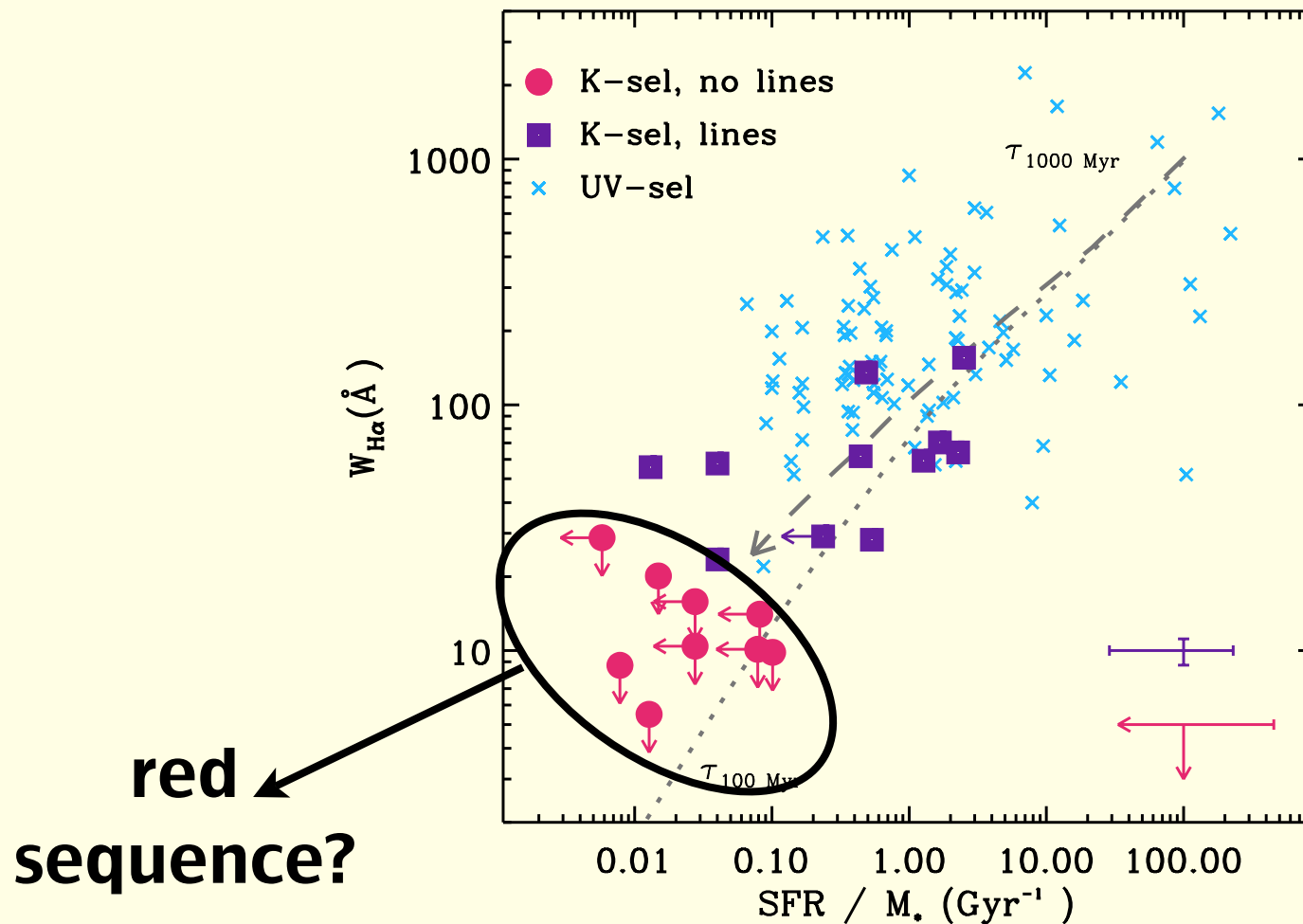


Stellar populations of $z \sim 2.3$ galaxies



Kriek et al. 2006

Stellar populations of $z \sim 2.3$ galaxies

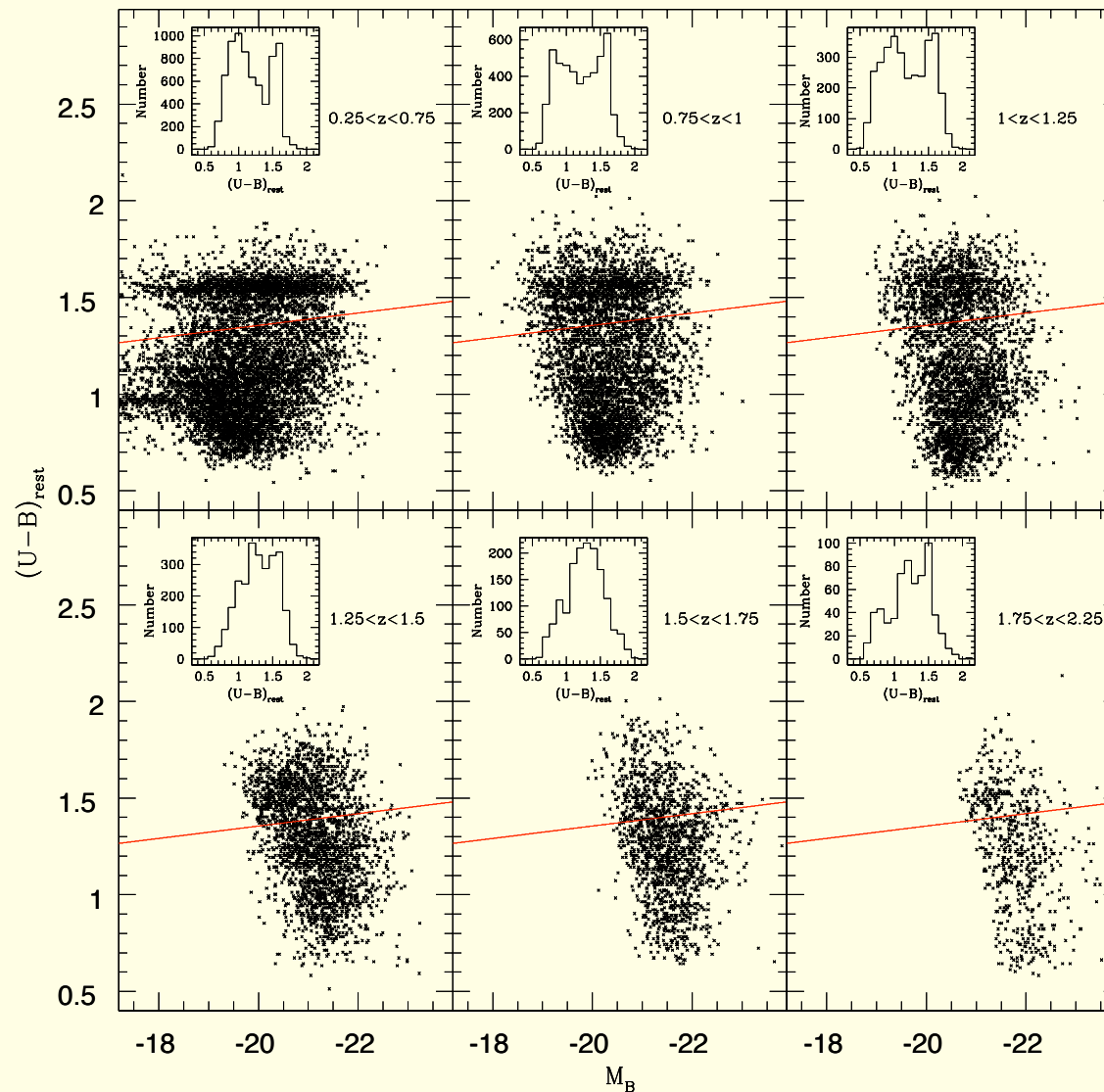


Kriek et al. 2006

Is a red sequence already in place beyond $z=2$?

- ◆ **Identification of galaxies with quiescent stellar populations beyond $z=2$**
 - ❖ (e.g., Franx et al. 2003, Labbe et al. 2005, Daddi et al. 2005, Cimatti et al. 2008)
- ◆ **Several studies show that the red sequence disappears at $z>1.5$**
 - ❖ (e.g., Conselice et al. 2005, Cirasuolo et al. 2008)

The disappearance of the red sequence at $z > 1.5$?



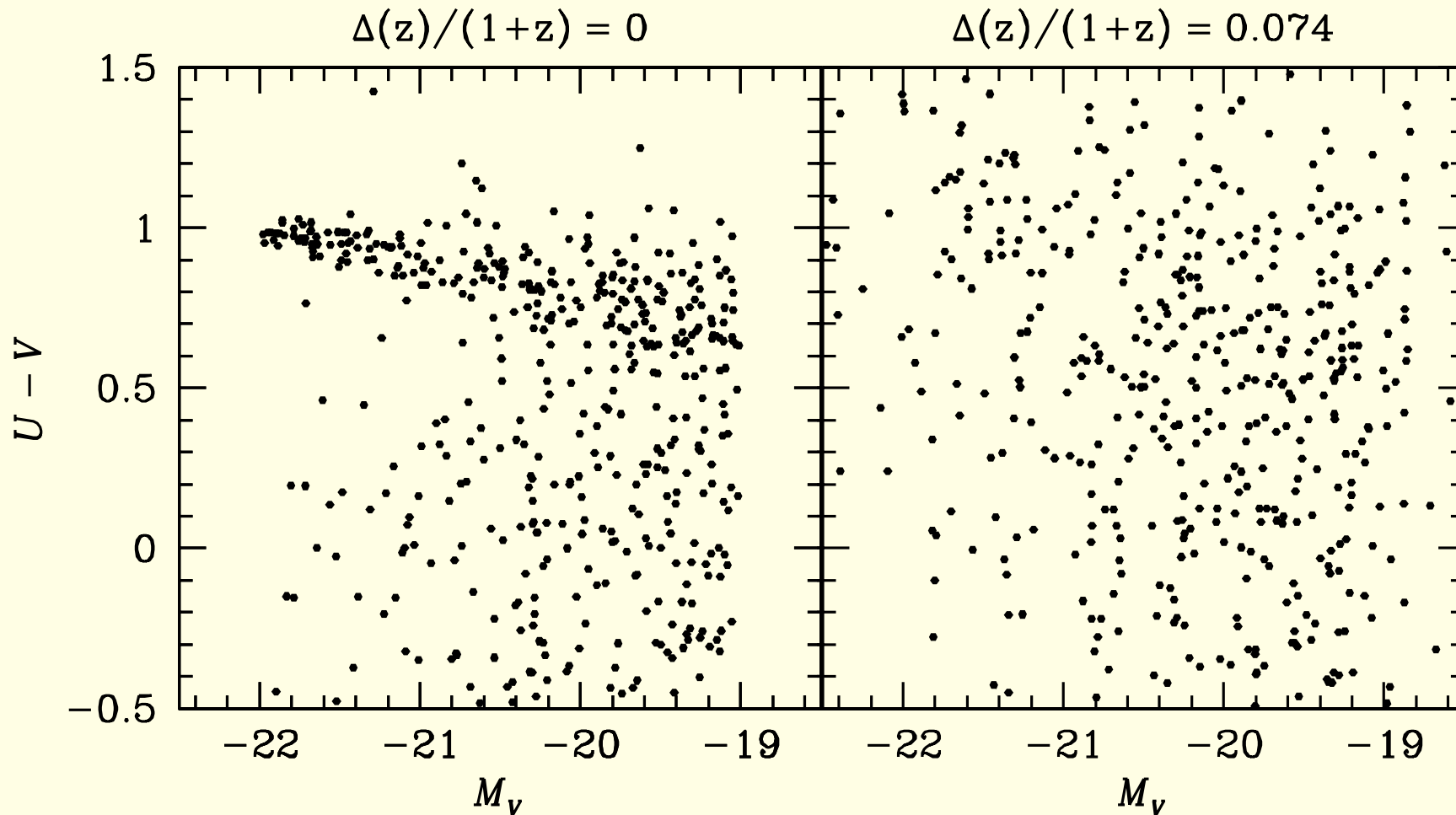
Cirasuolo et al. 2008

Is a red sequence already in place beyond $z=2$?

- ◆ Identification of galaxies with quiescent stellar populations beyond $z=2$
 - ❖ (e.g., Franx et al. 2003, Labbe et al. 2005, Daddi et al. 2005, Cimatti et al. 2008)
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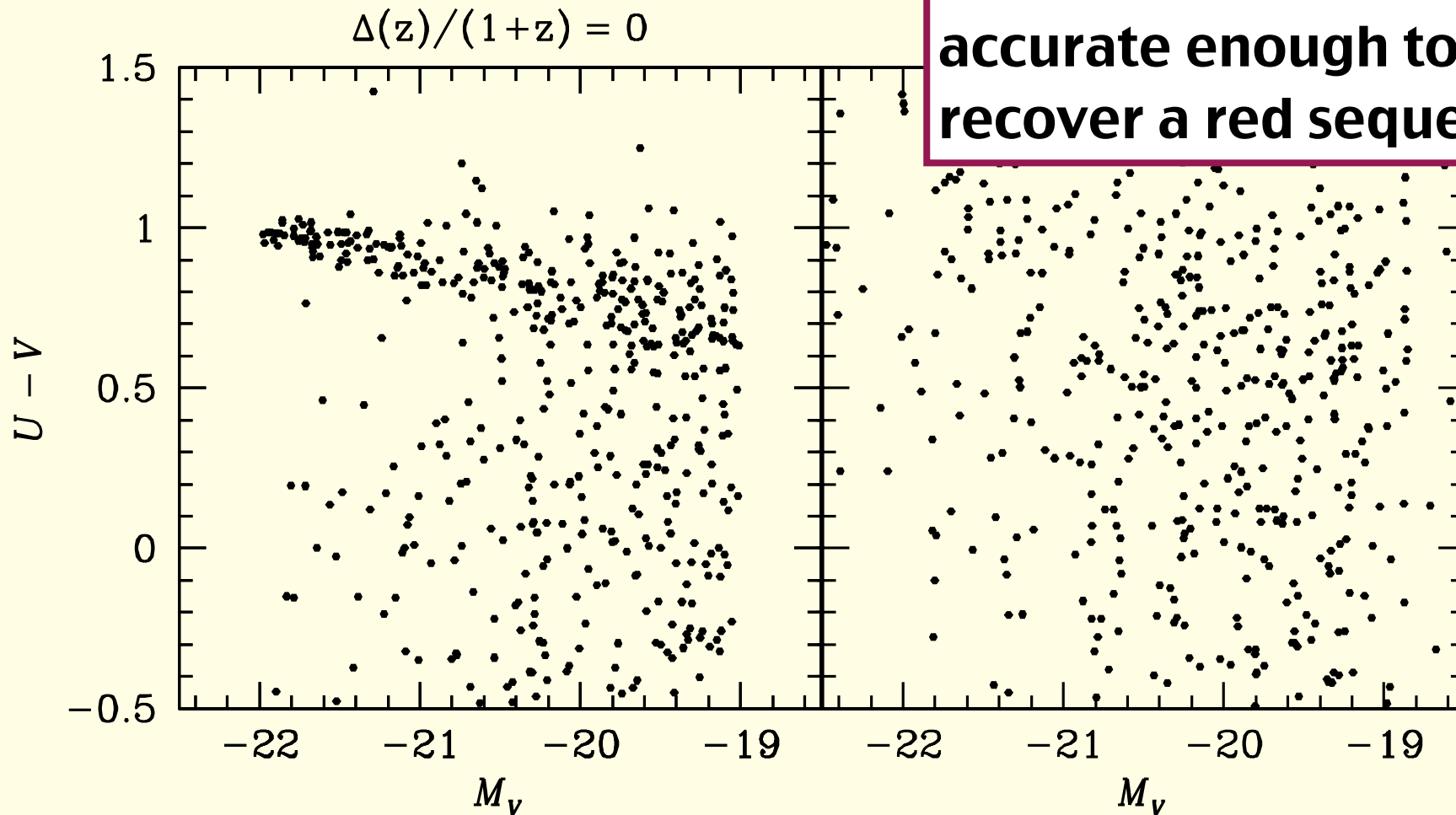
Contradiction?

Is it possible to recover a red sequence with only broadband photometry?



Is it possible to recover a red sequence with only broadband photometry?

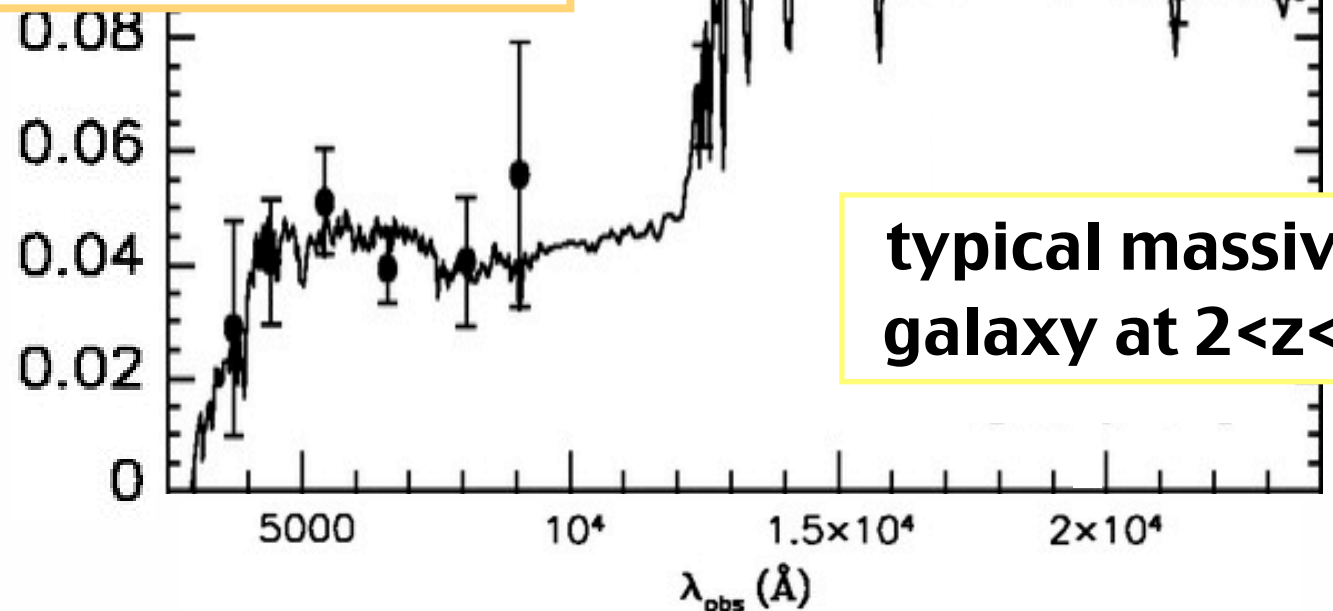
Rest-frame colors not accurate enough to recover a red sequence



What is needed to recover a possible red sequence at $z > 2$?

- ❖ Spectroscopic survey
- ❖ mass-limited sample
- ❖ Near-infrared spectroscopy

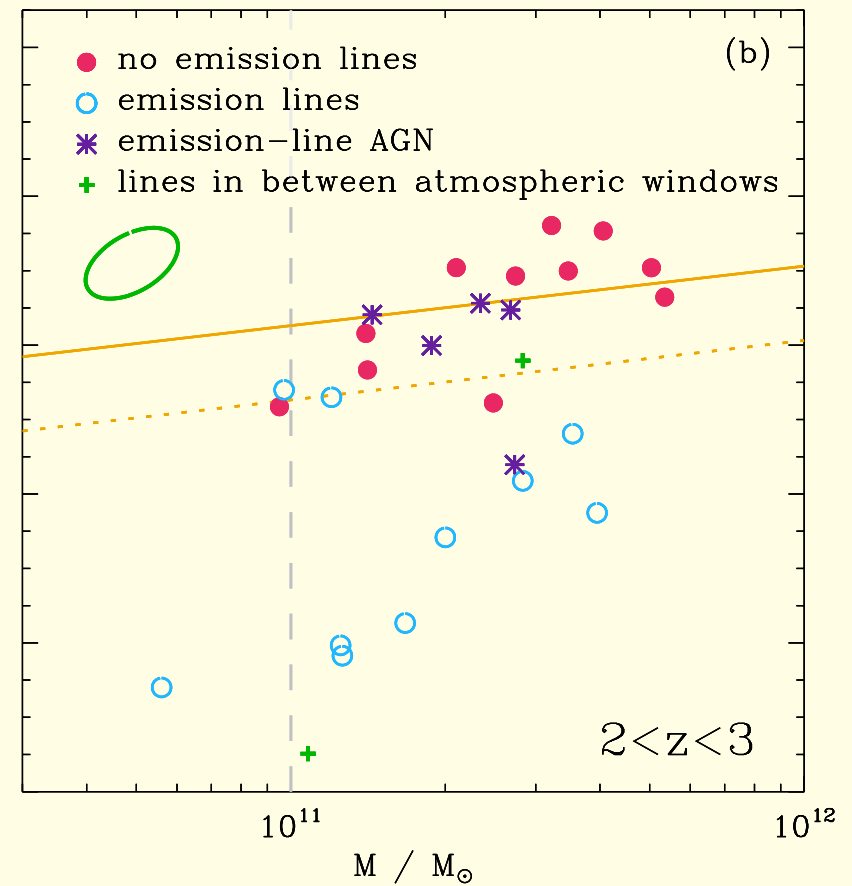
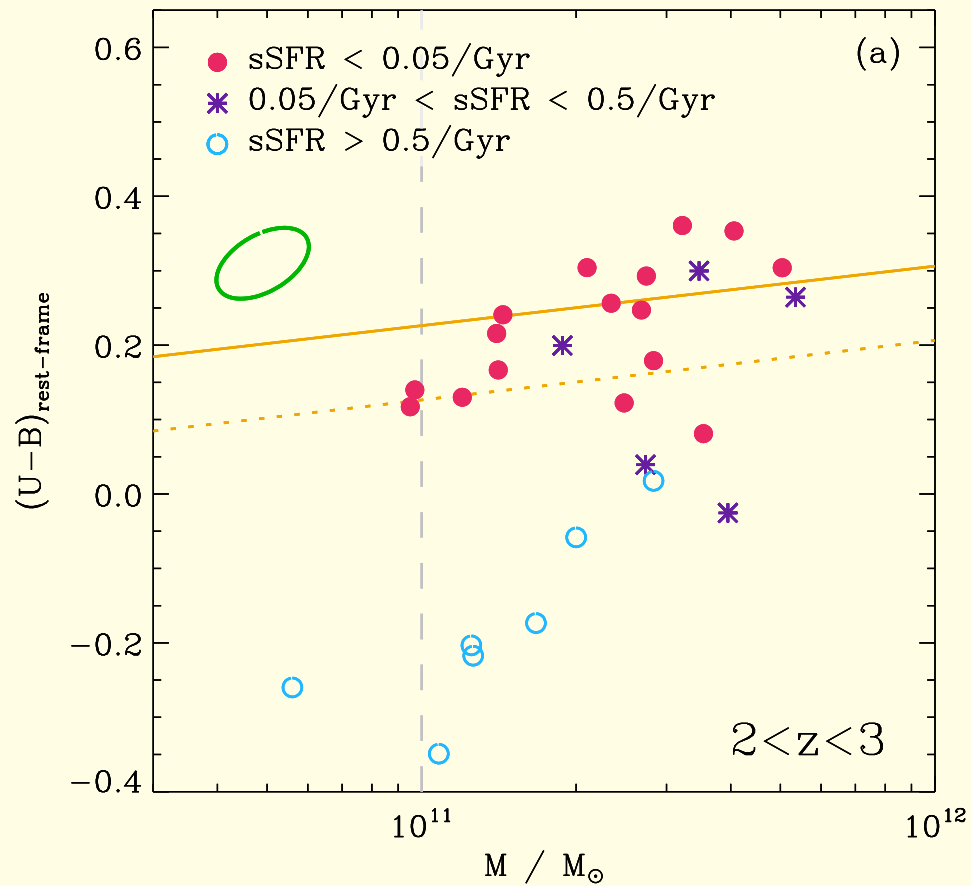
van Dokkum et al. 2006



A Public NIR spectroscopic survey for massive galaxies at $z \sim 2.5$

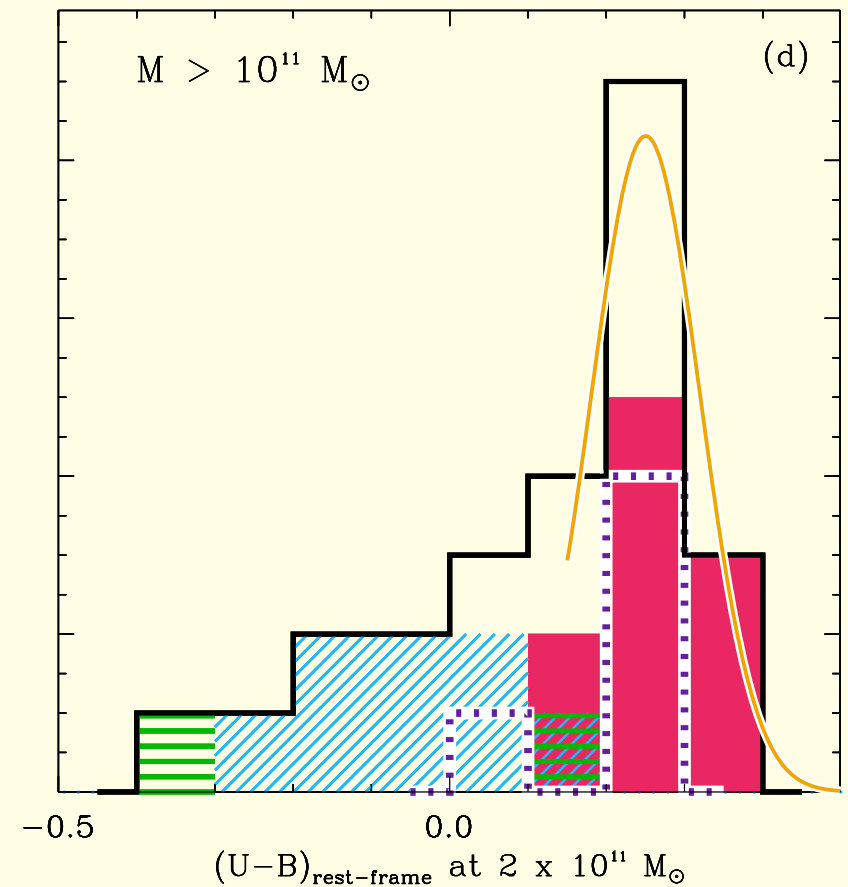
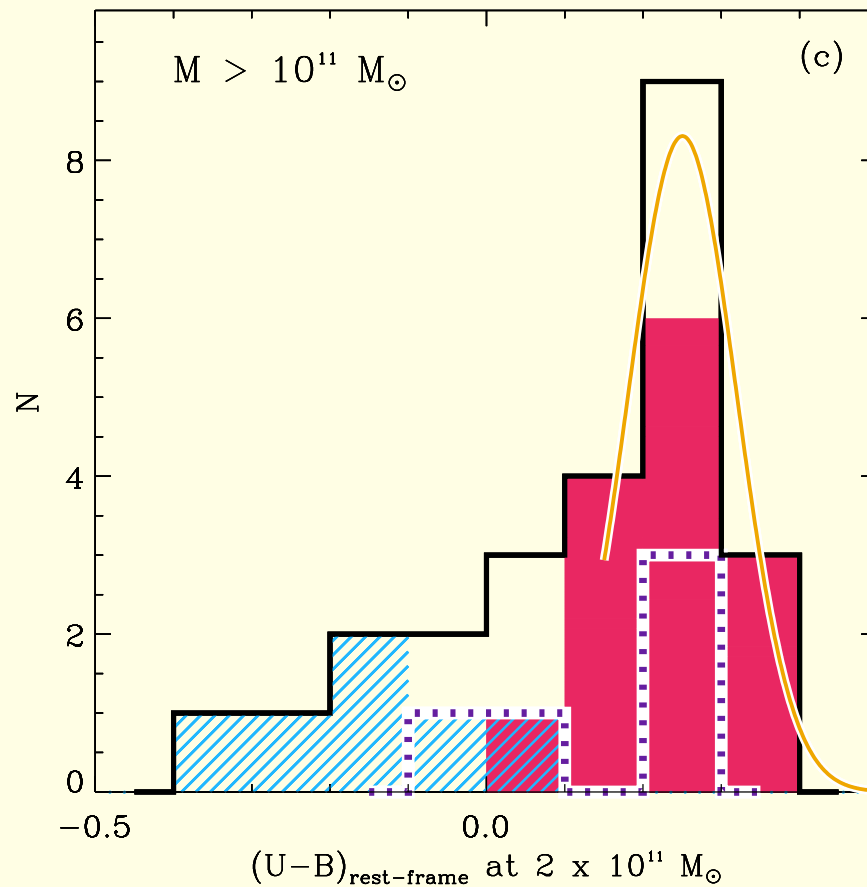
- ◆ Selection: $2 \lesssim z_{\text{phot}} \lesssim 3$; $K < 19.7$; MUSYC survey
- ◆ Observations: **GNIRS** X-dispersed spectra; 1–2.5 μm
- ◆ Sample: **36 galaxies**
 - ❖ 10 galaxies at $z < 2$
 - ❖ 11 galaxies at $2 < z < 3$ with little or no star formation
 - ❖ 5 AGN hosts at $2 < z < 3$, with mainly quiescent stellar populations
 - ❖ 10 star burst galaxies at $2 < z < 3$
- ◆ Public: www.astro.princeton.edu/~mariska
- ◆ Follow-up: **Keck/NIRSPEC+NIRC2-AO, VLT/SINFONI, HST/NICMOS, Spitzer/IRAC+MIPS, Magellan/LDSS3**

A Red Sequence at $z \sim 2.3$?



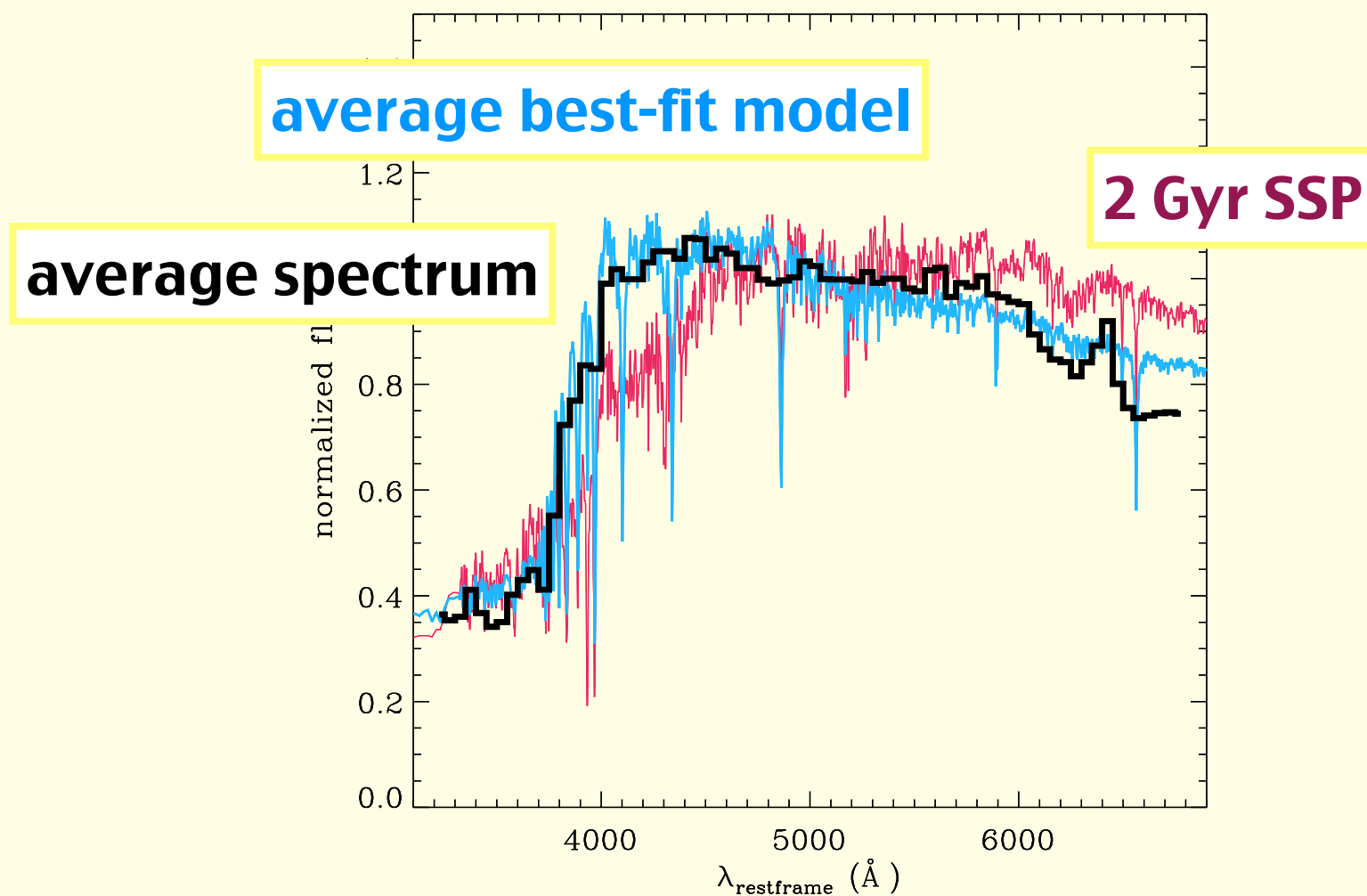
Kriek et al. submitted

A Red Sequence at $z \sim 2.3$?



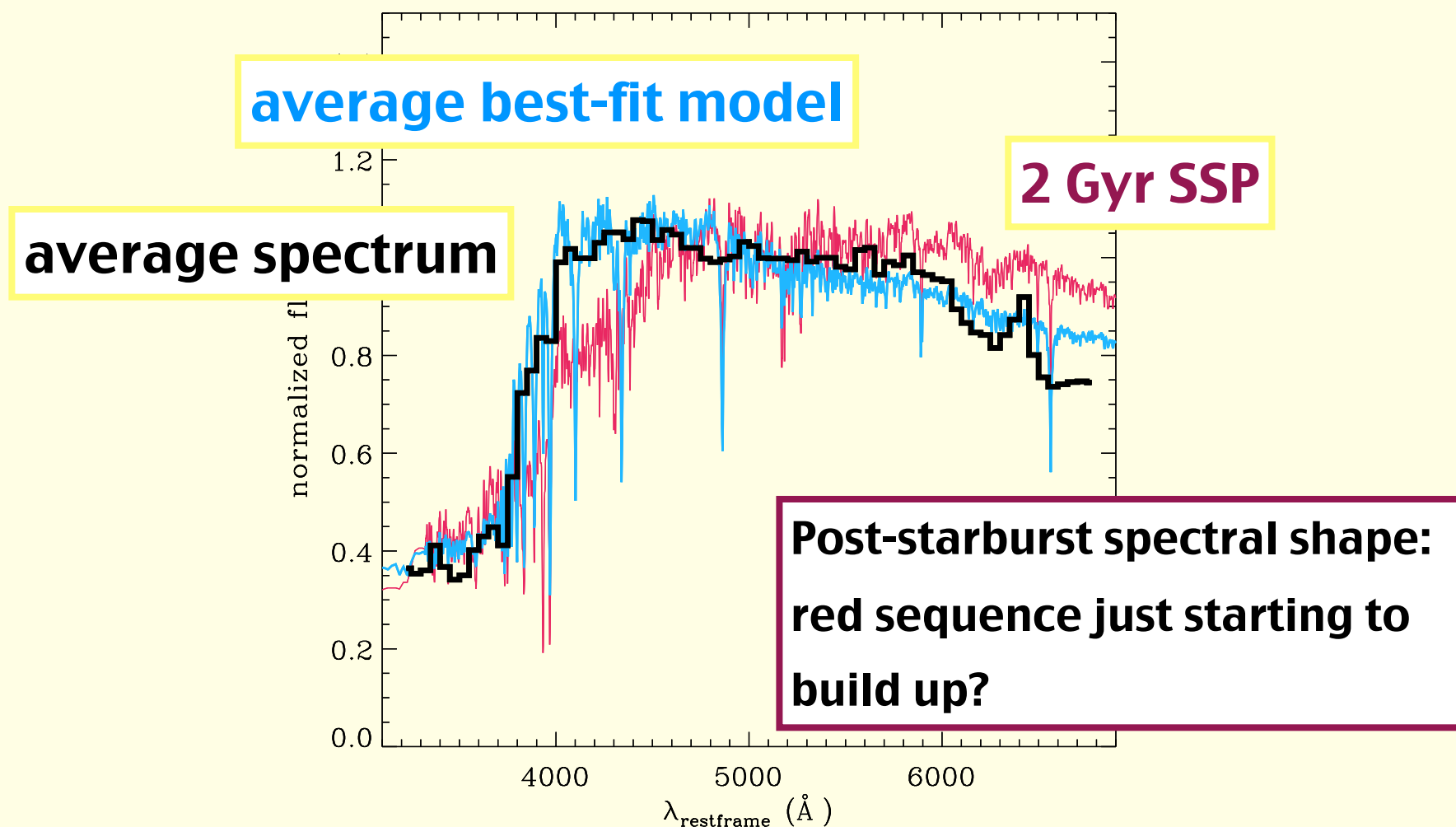
Kriek et al. submitted

Red-sequence galaxies at $z \sim 2.3$



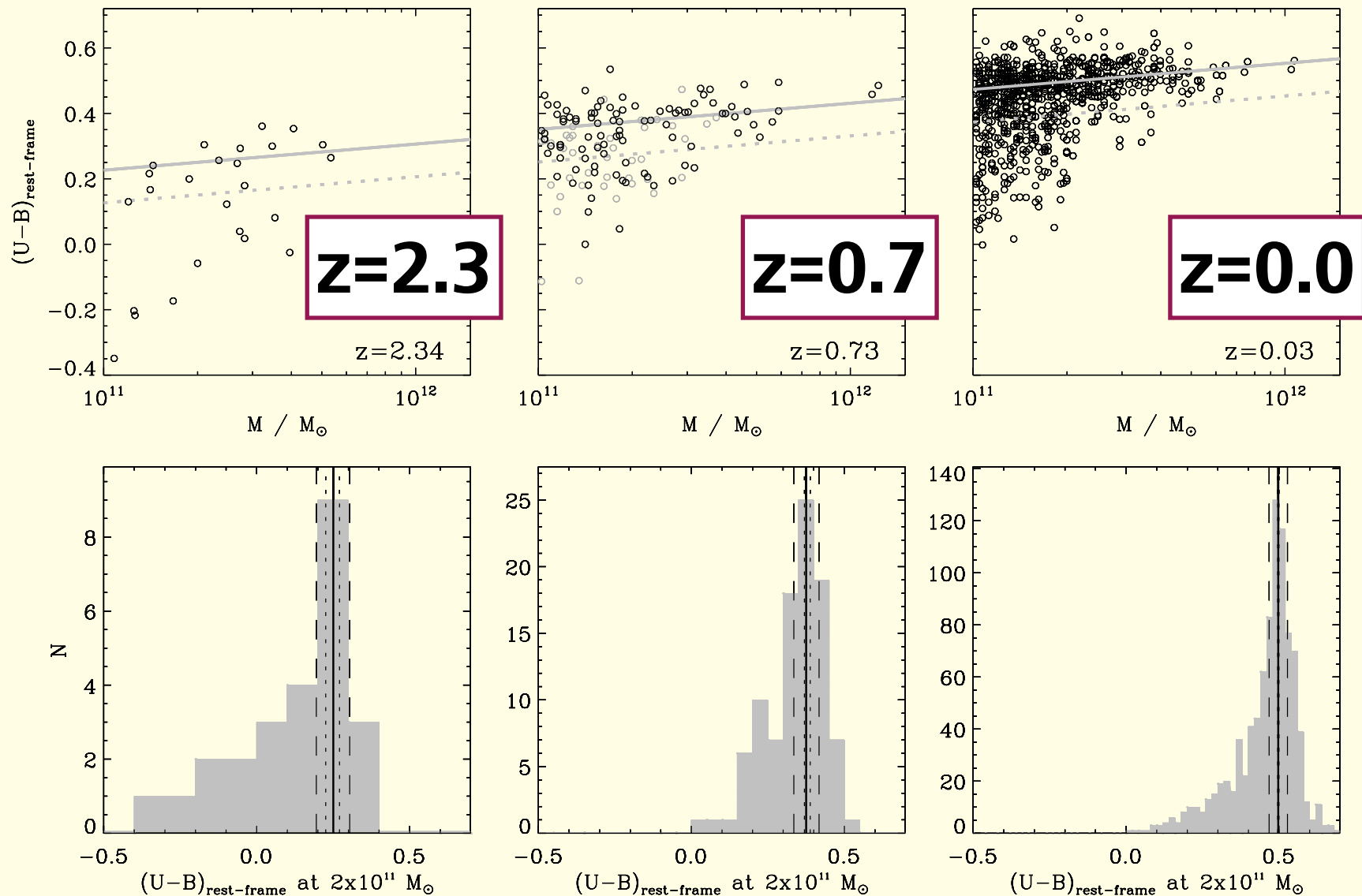
Kriek et al. submitted

Red-sequence galaxies at $z \sim 2.3$

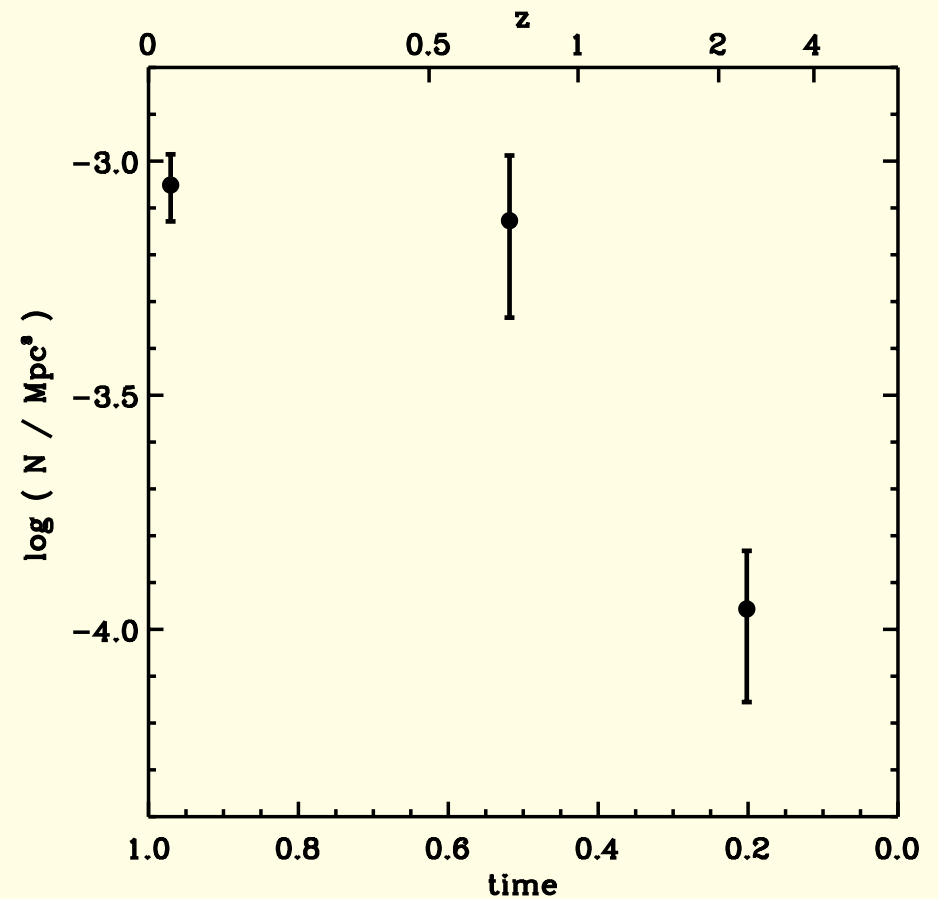
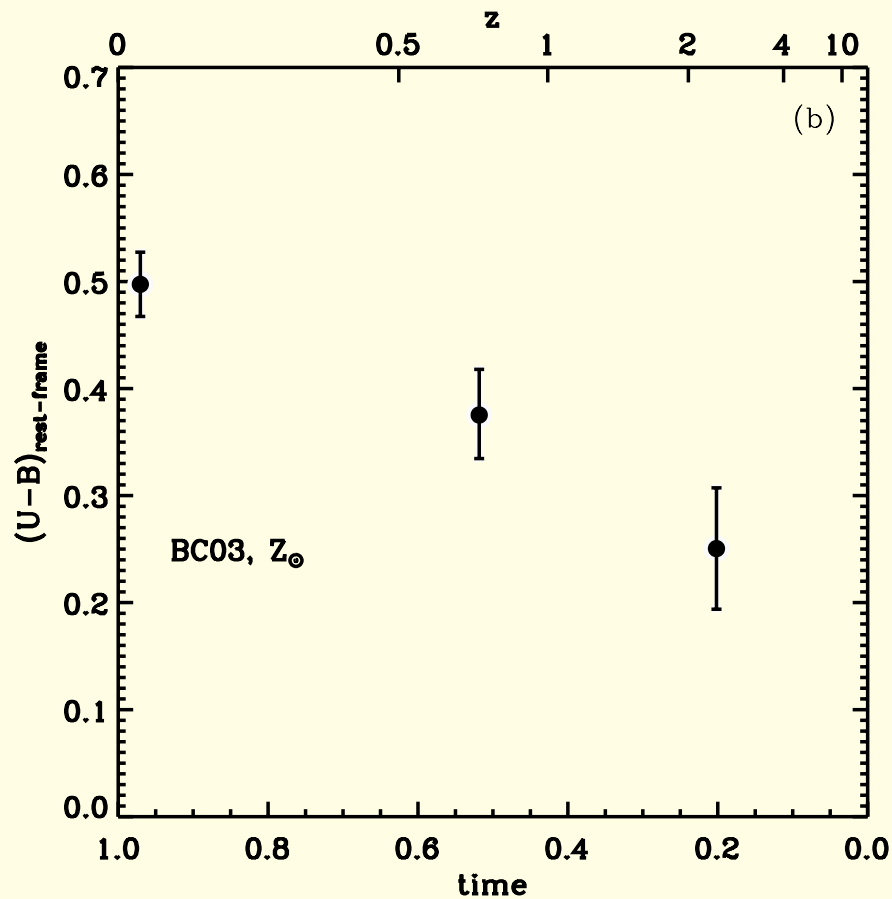


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Comparison to low-z spectroscopic mass-limited samples

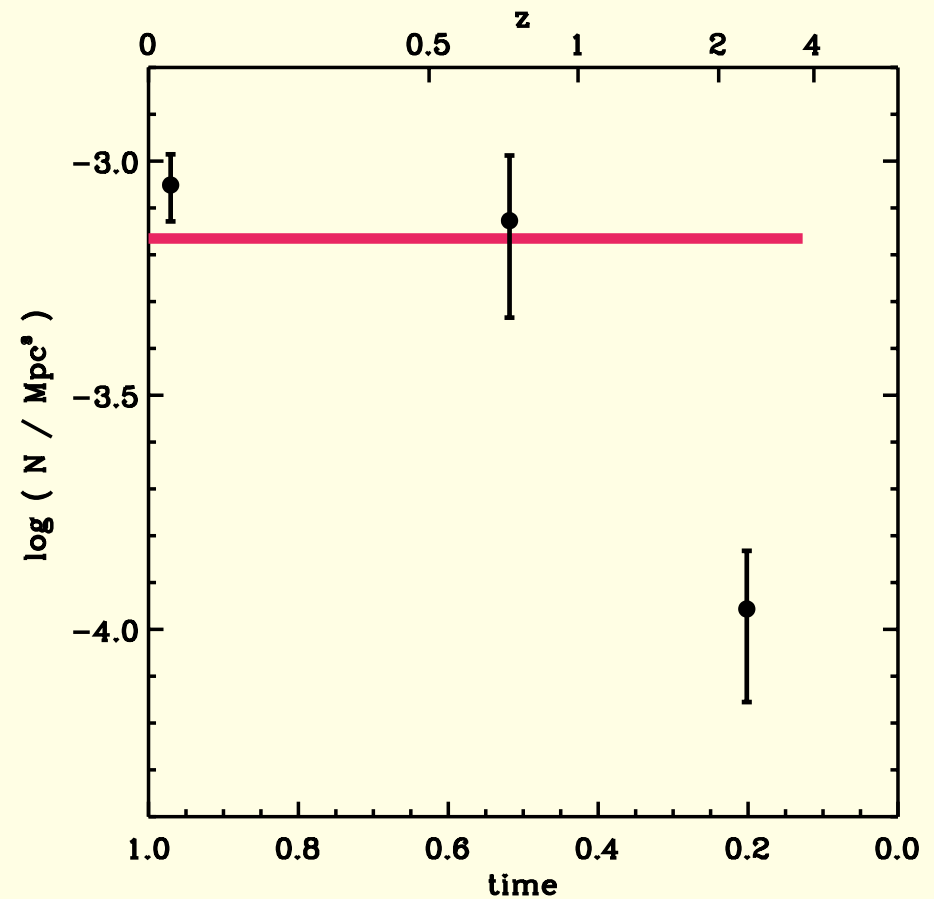
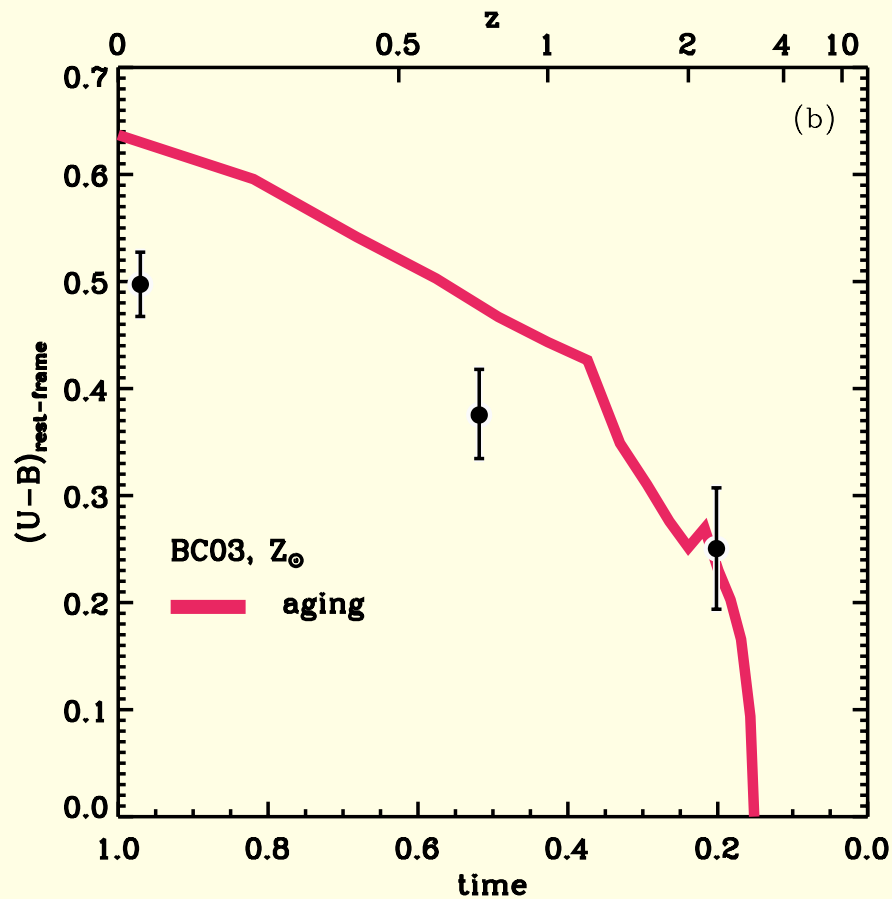


Evolution of the Red Sequence



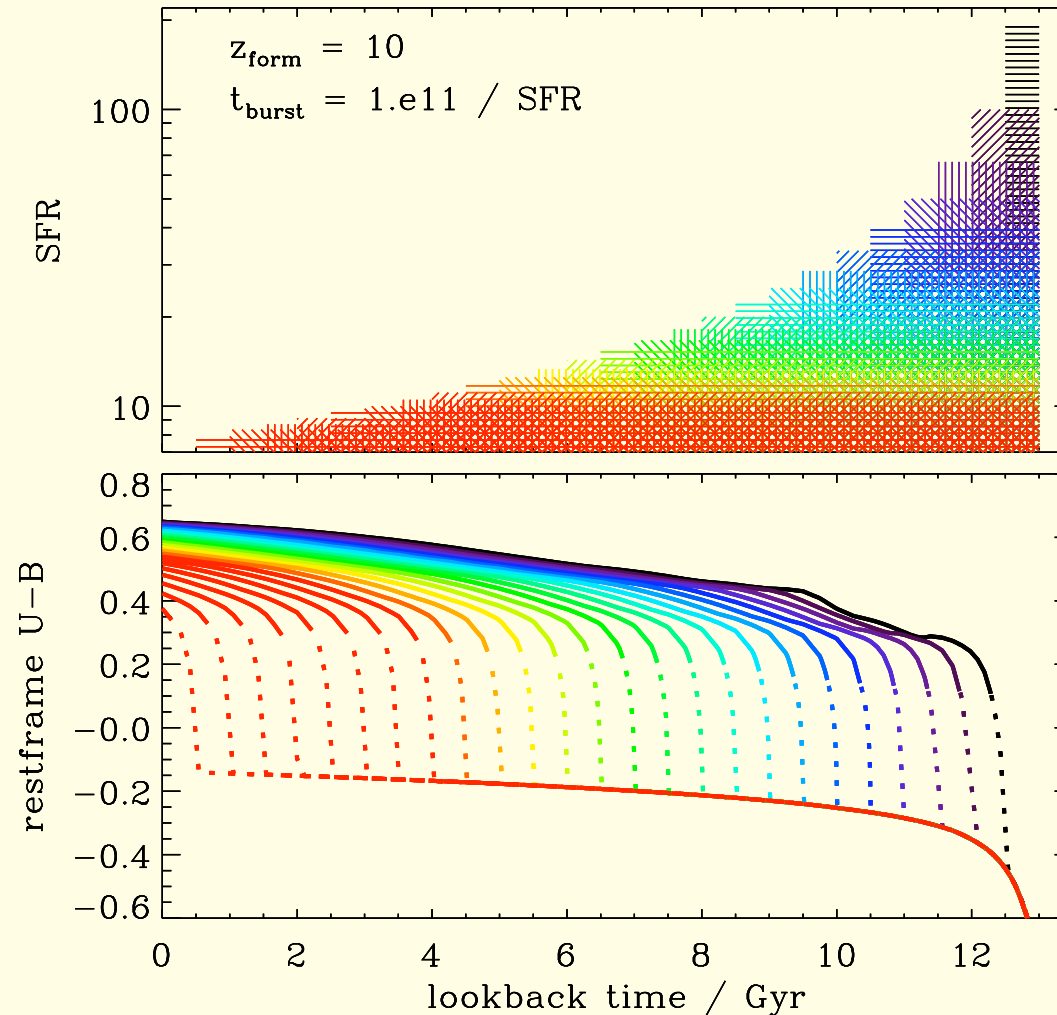
Kriek et al. submitted

Evolution of the Red Sequence

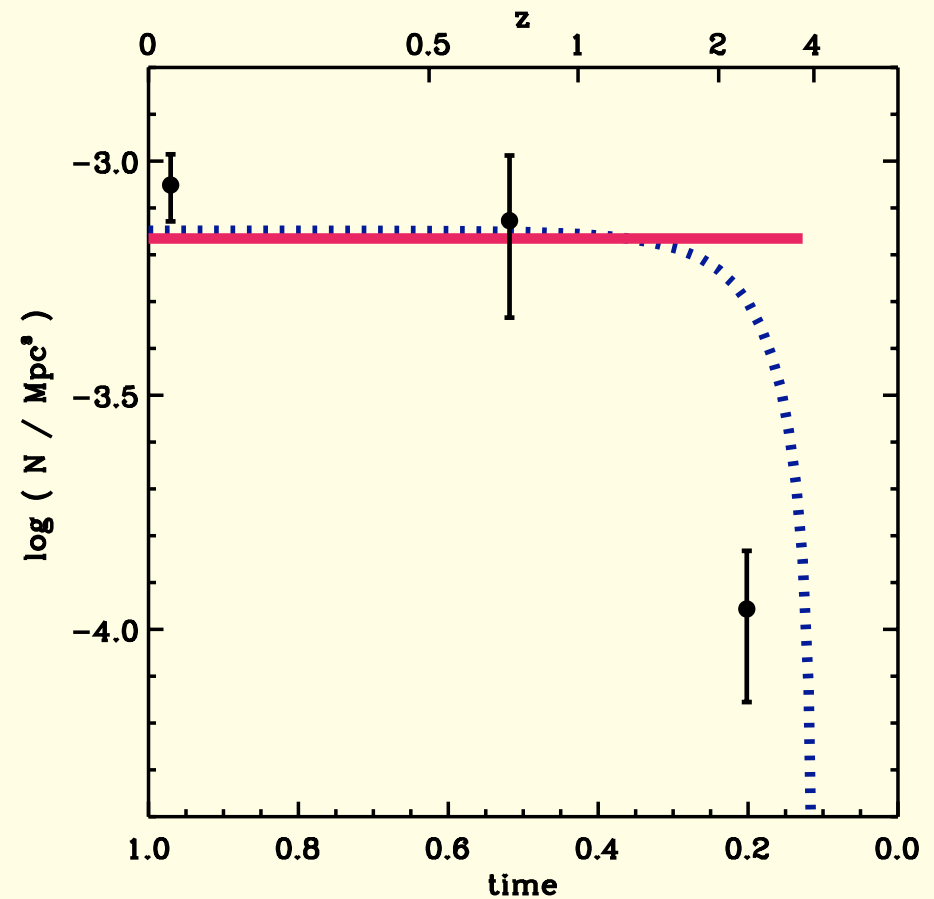
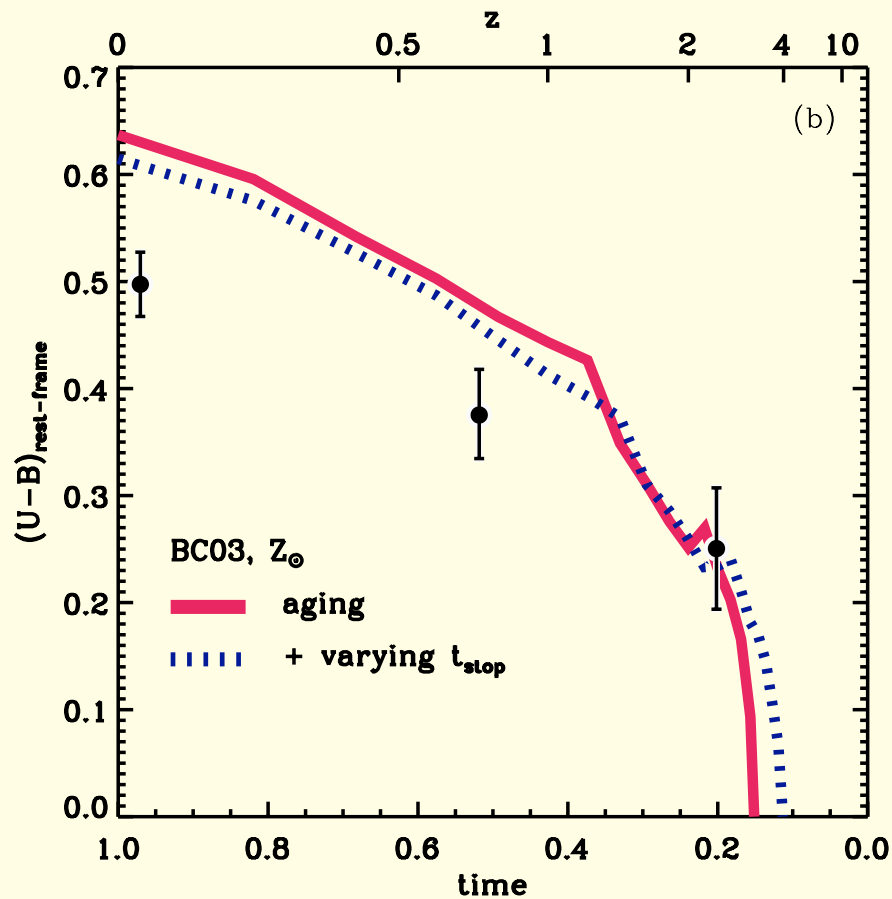


Kriek et al. submitted

Growth of the Red Sequence

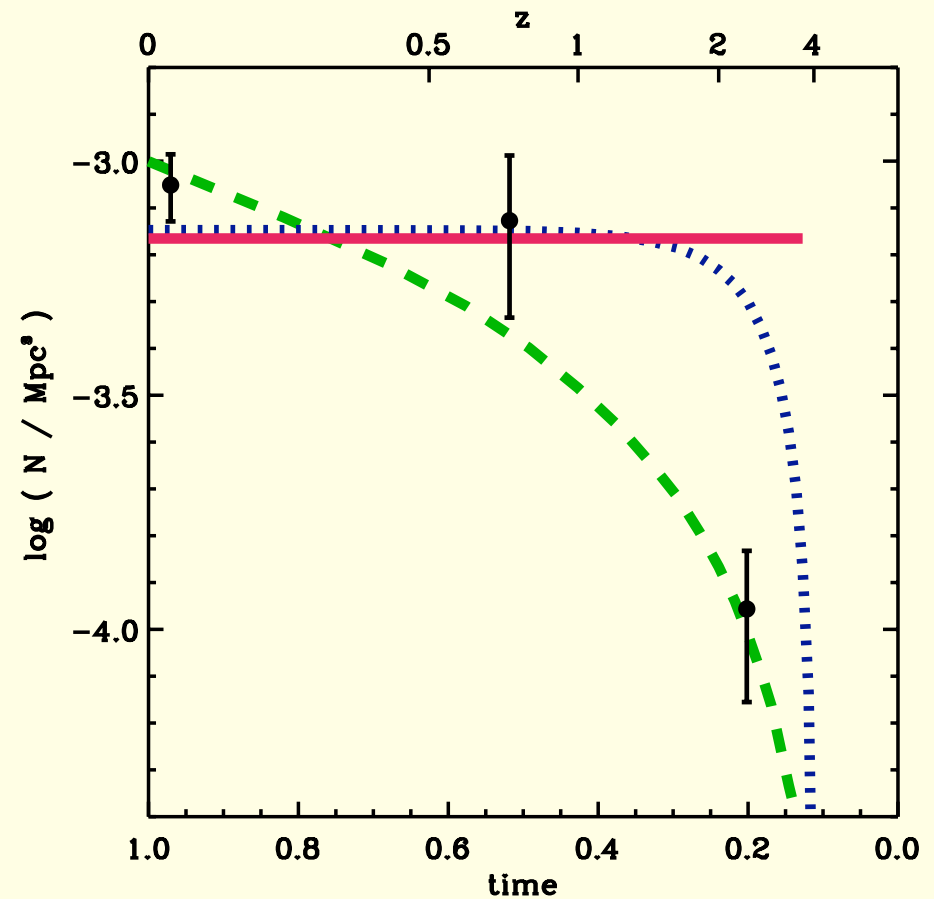
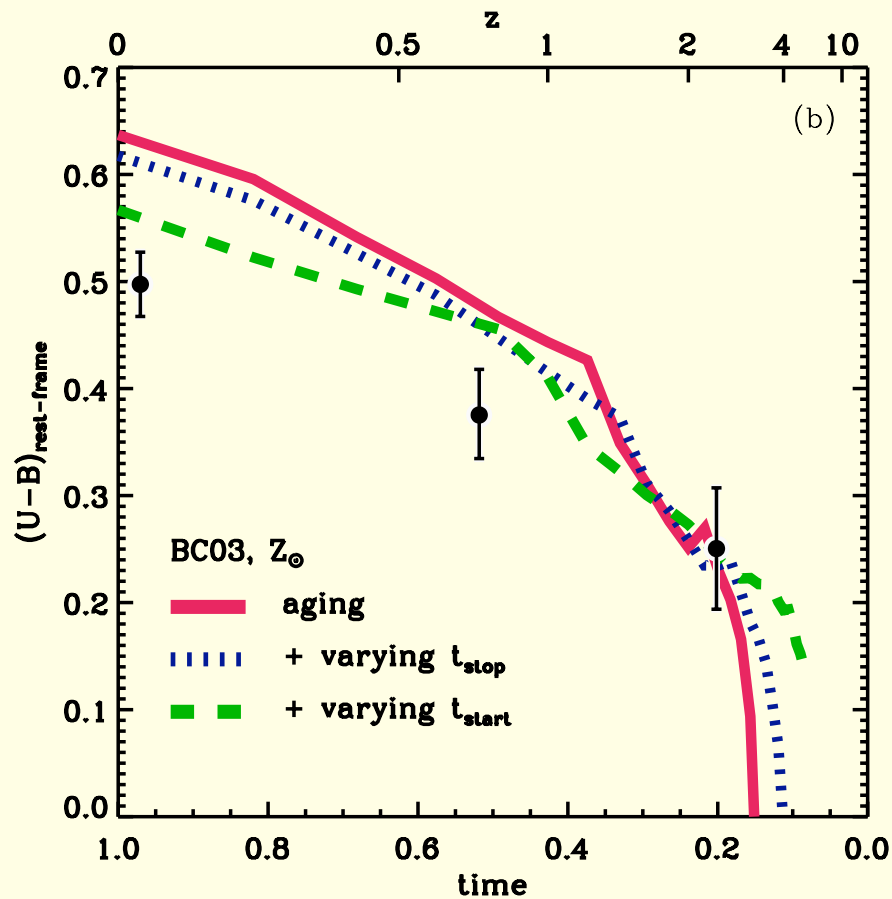


Evolution of the Red Sequence



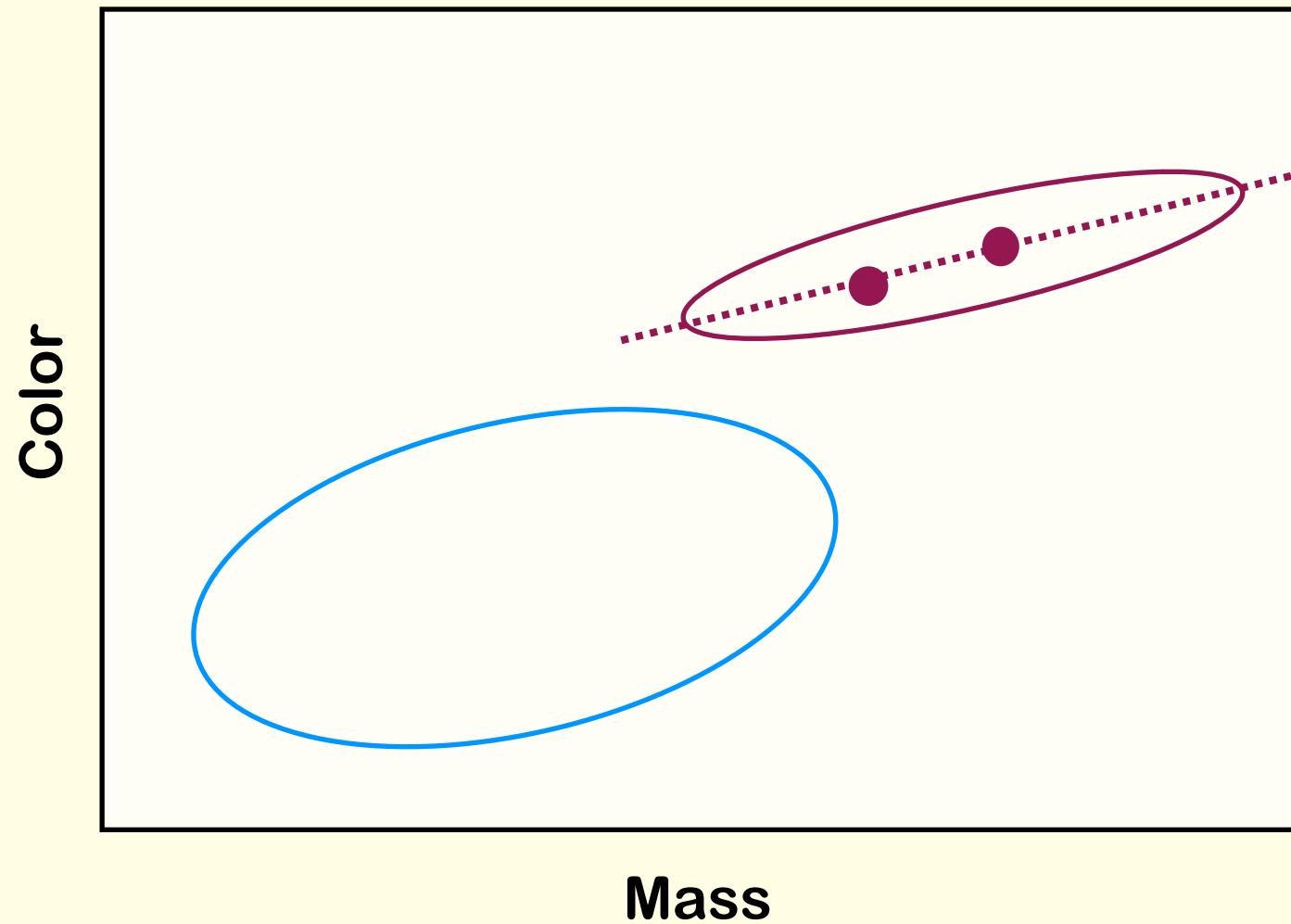
Kriek et al. submitted

Evolution of the Red Sequence

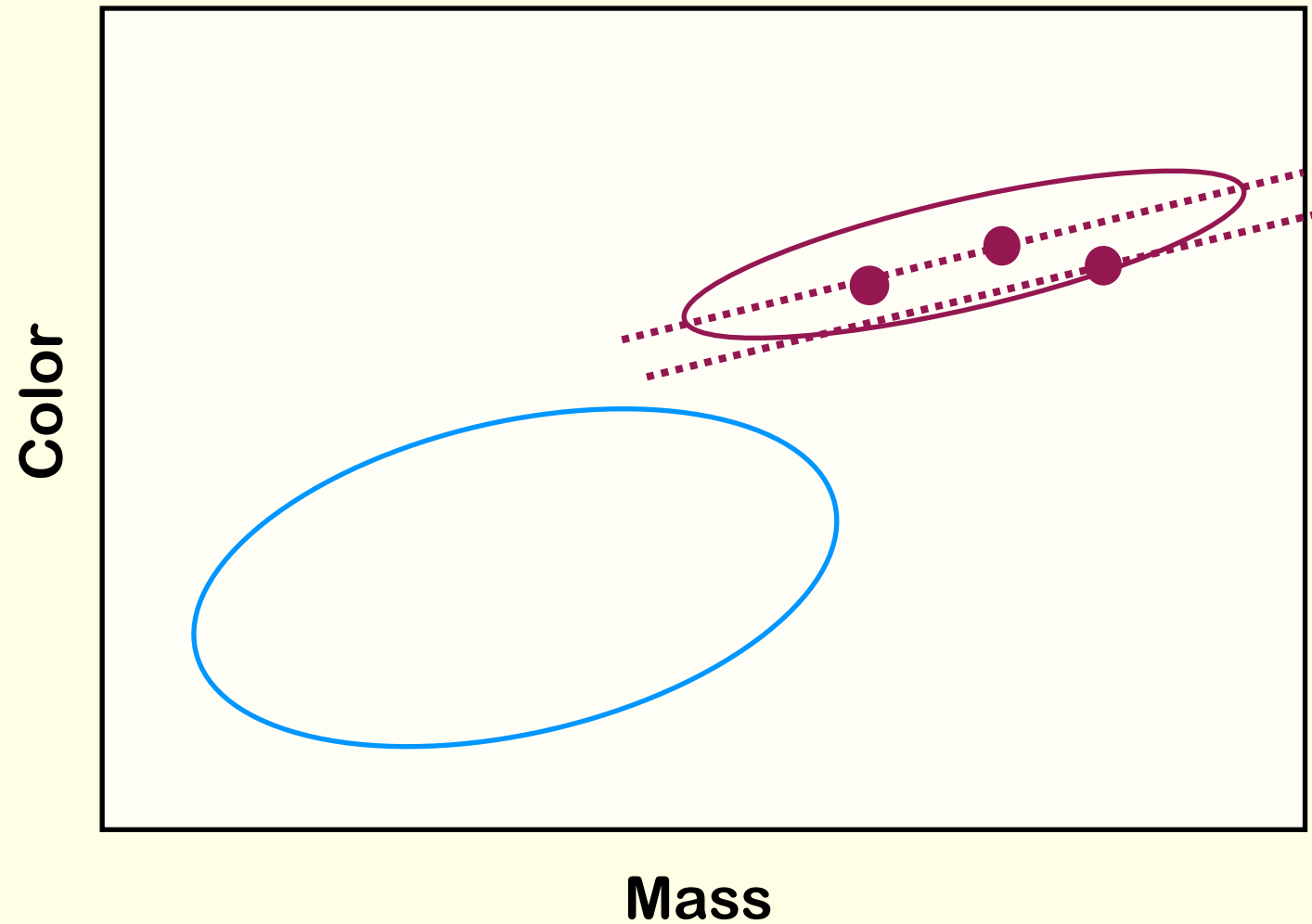


Kriek et al. submitted

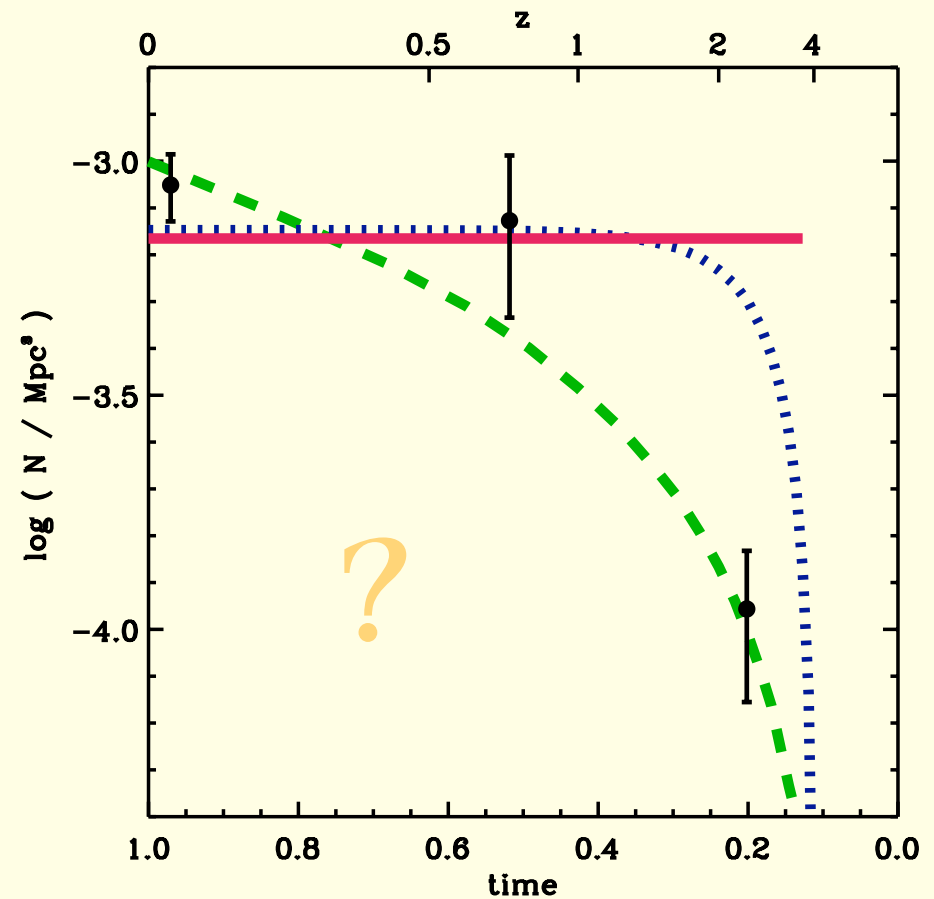
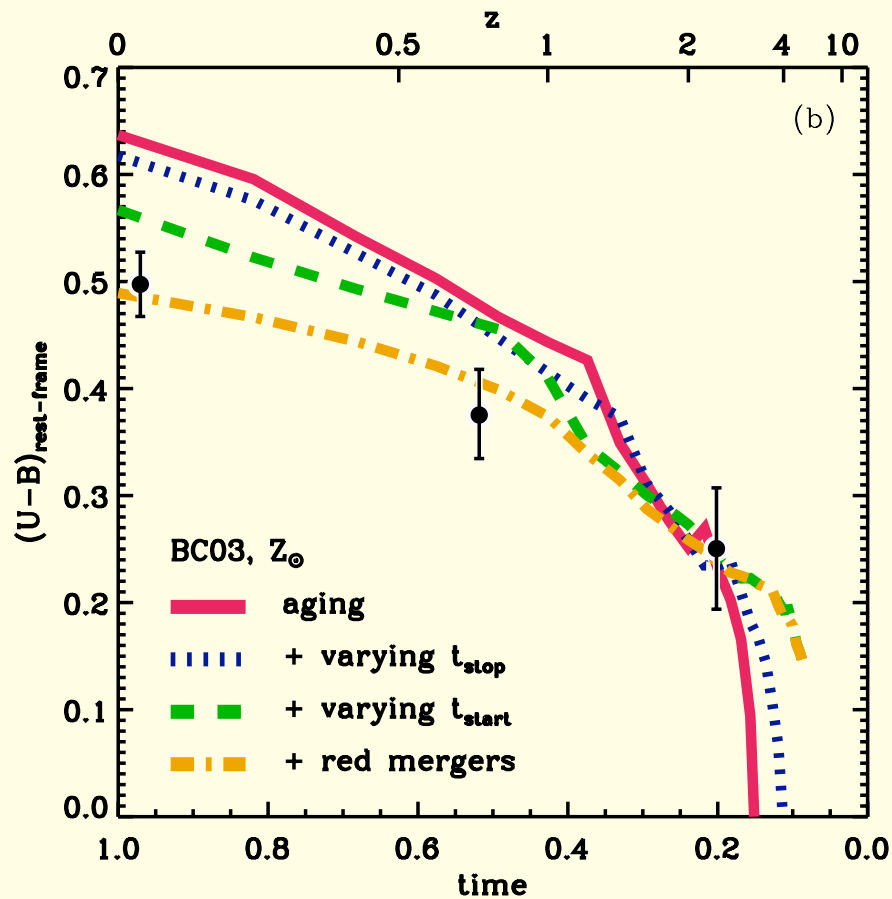
Red mergers



Red mergers



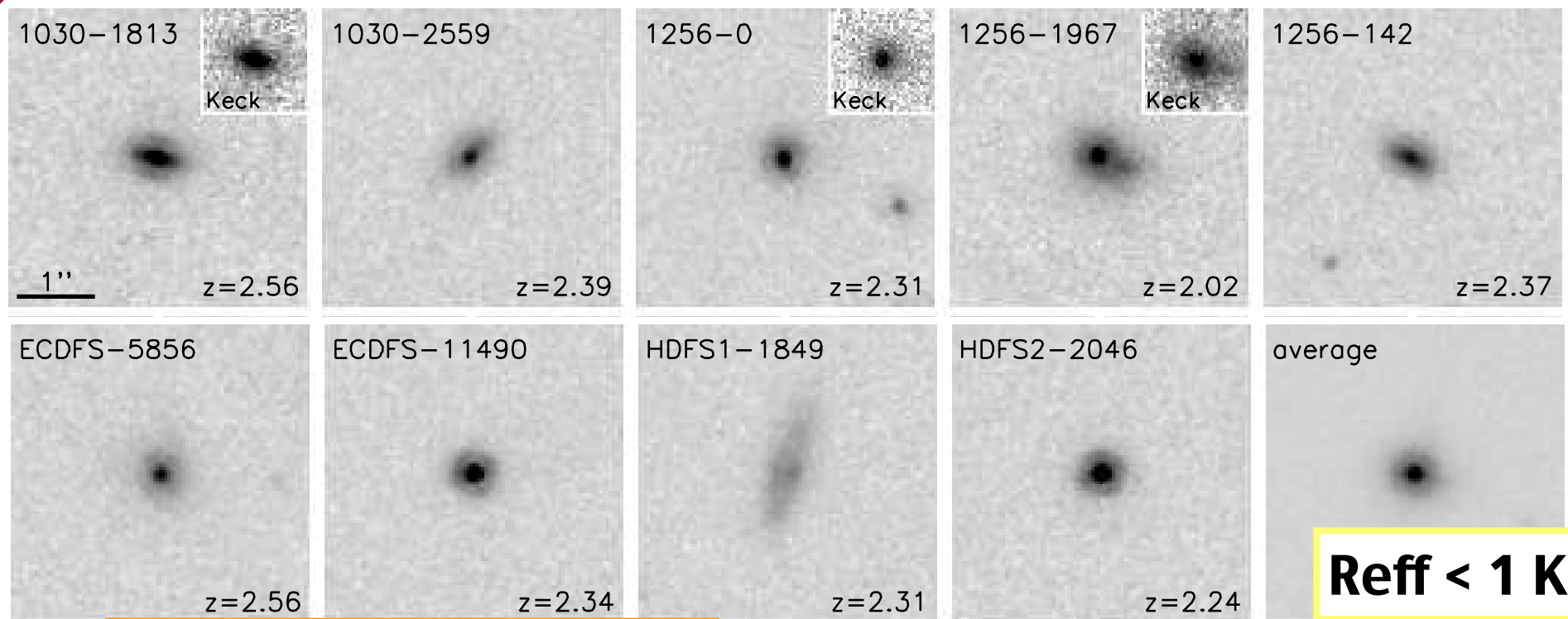
Evolution of the Red Sequence



Kriek et al. submitted

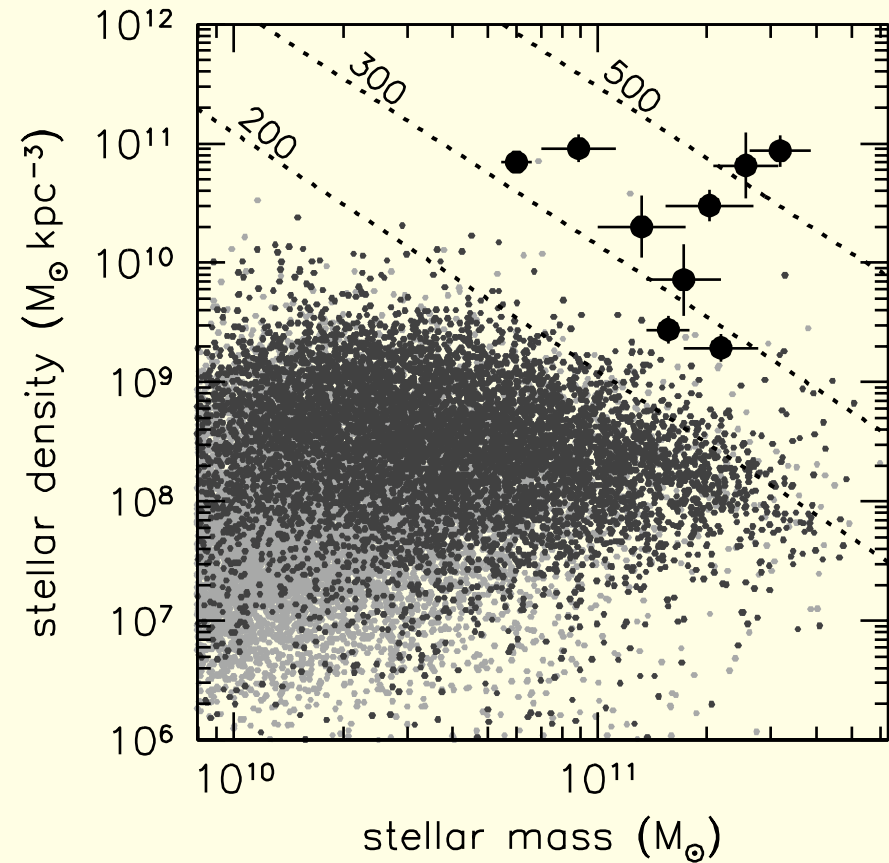
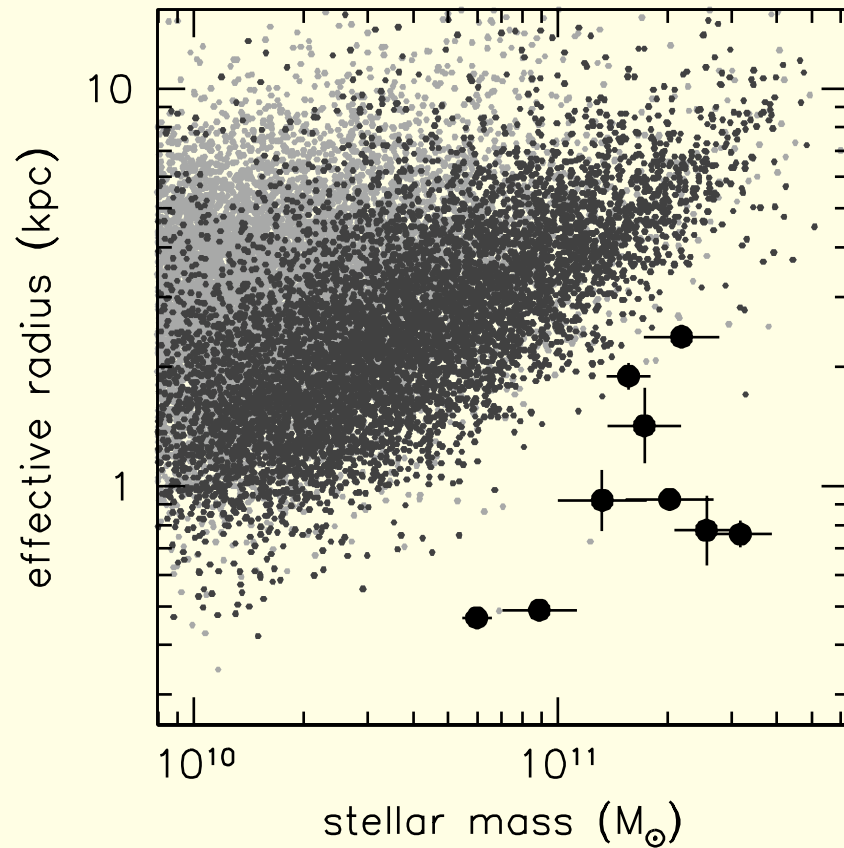
Morphologies of massive quiescent galaxies at $z \sim 2.3$

van Dokkum et al. submitted



See also Trujillo et al. 2006, 2007;
Zirm et al. 2007; Toft et al. 2007;
Cimatti et al. 2008

Sizes and stellar densities of massive quiescent galaxies at $z \sim 2.3$

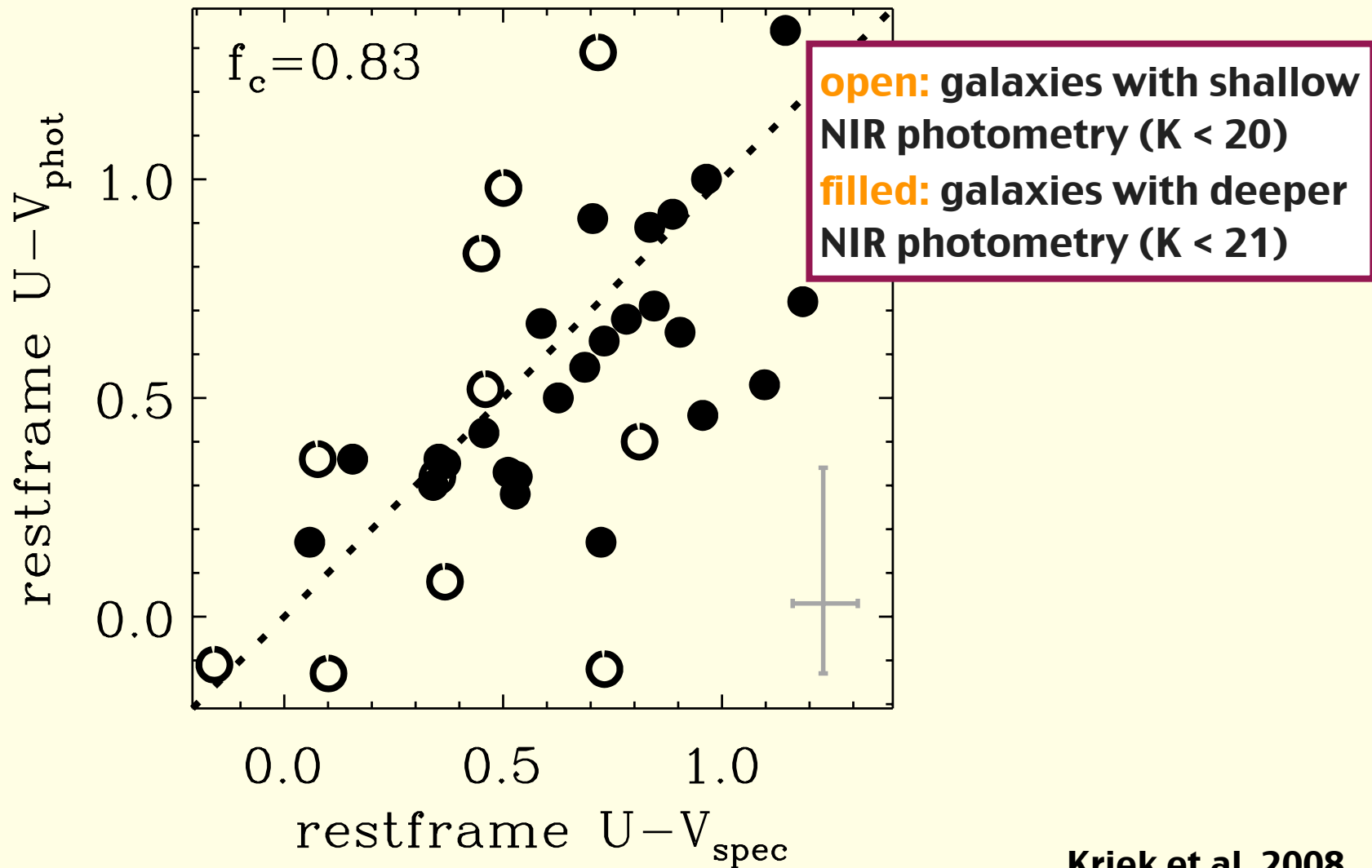


van Dokkum et al. submitted

Summary...

- ◆ A red sequence of massive field galaxies with quiescent stellar populations was already in place at $z \sim 2.3$
- ◆ The massive end of the red sequence grows by a factor of ~ 8 from $z \sim 2.3$ to the present
- ◆ The color evolution of the red sequence is more complicated than just aging
- ◆ The $z \sim 2.3$ red-sequence galaxies still experience active evolution in their future

Is it possible to recover a red sequence with only broadband photometry?



Kriek et al. 2008