"The Progenitors of Today's Ultra-Massive Galaxies Across Cosmic Time"

DANILO MARCHESINI (Tufts University)

Adam Muzzin (Kavli-Cambridge), Mauro Stefanon (Leiden Univ.), **Cemile Marsan** (Tufts),
the UltraVISTA and NMBS collaborations

Marsan, Marchesini, et al., 2015, ApJ, 801, 133
Marchesini, et al., 2014, ApJ, 794, 65

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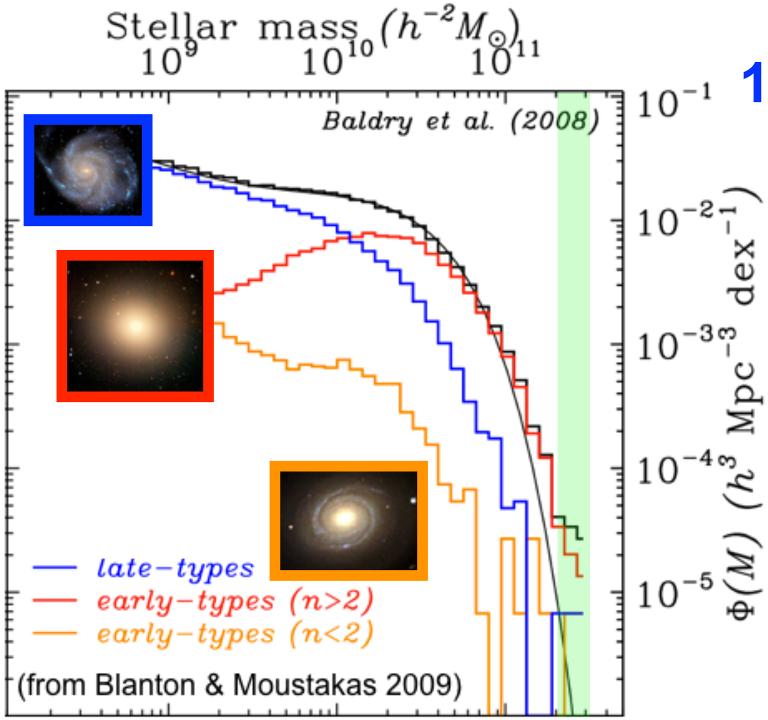
Back at the Edge of the Universe: March 15-19, 2015 - Sintra, Portugal

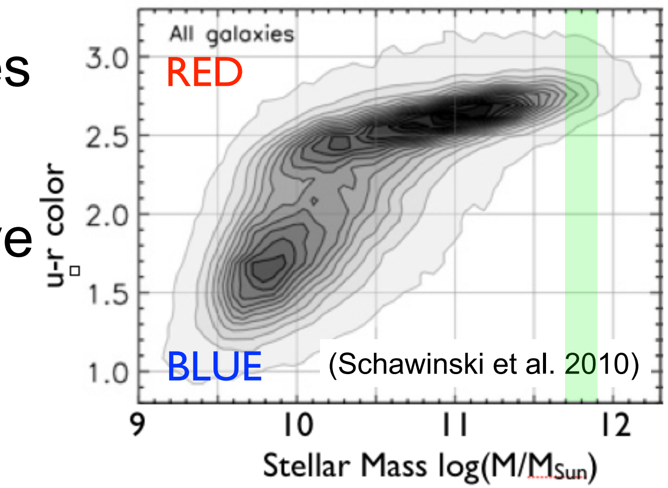
Properties of today's most massive galaxies



(from Blanton & Moustakas 2009)

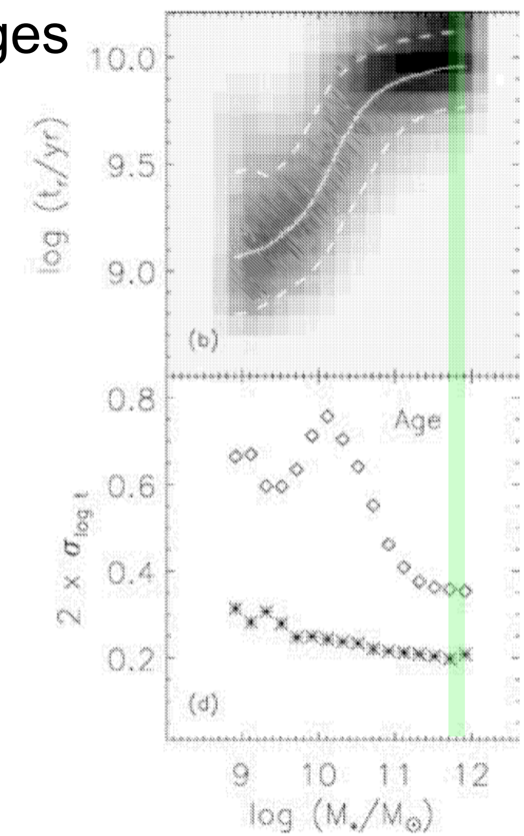
1. Early-type morphologies

2. Populate the extreme massive end of the red sequence



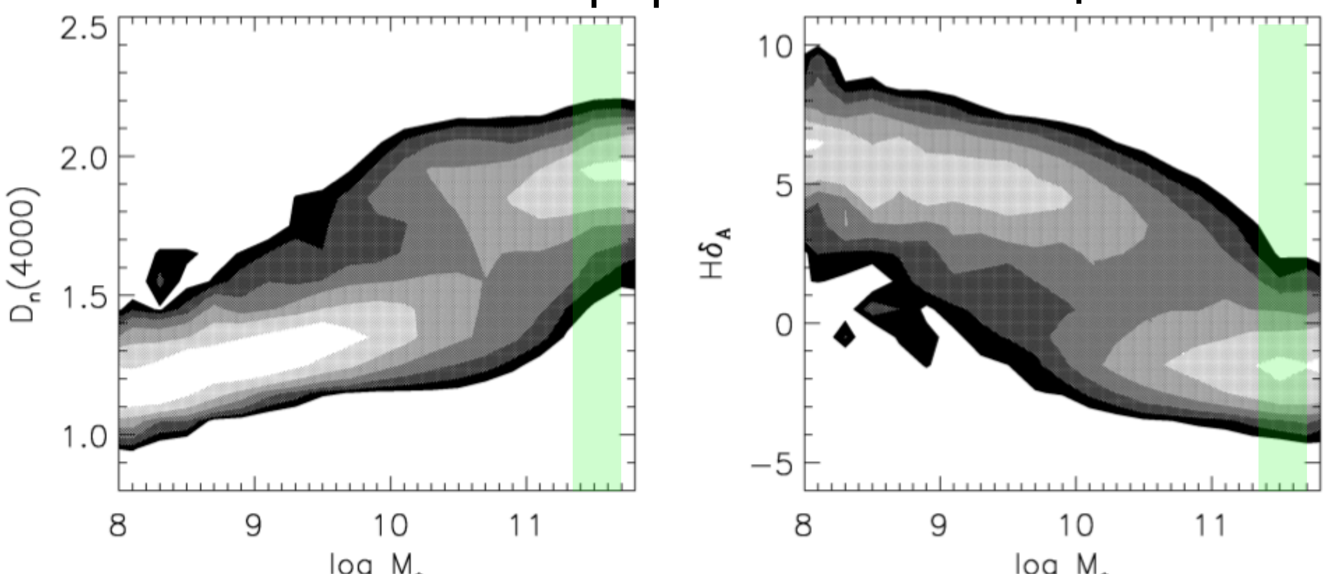
(Schawinski et al. 2010)

3. Old mean stellar ages



5. Little dust and enhanced alpha/Fe ratios

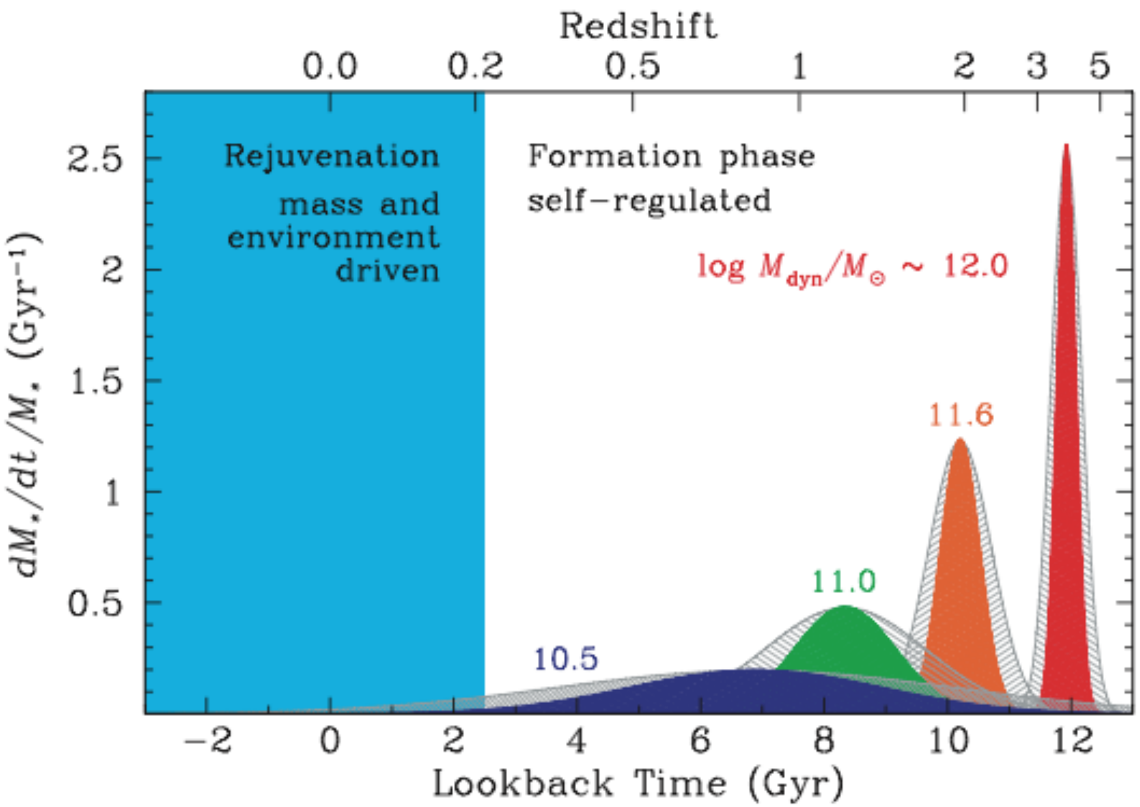
4. Quiescent stellar populations



(Kauffmann et al. 2003)

(Gallazzi et al. 2005,2006; Thomas et al. 2005,2010)

Properties of today's most massive galaxies

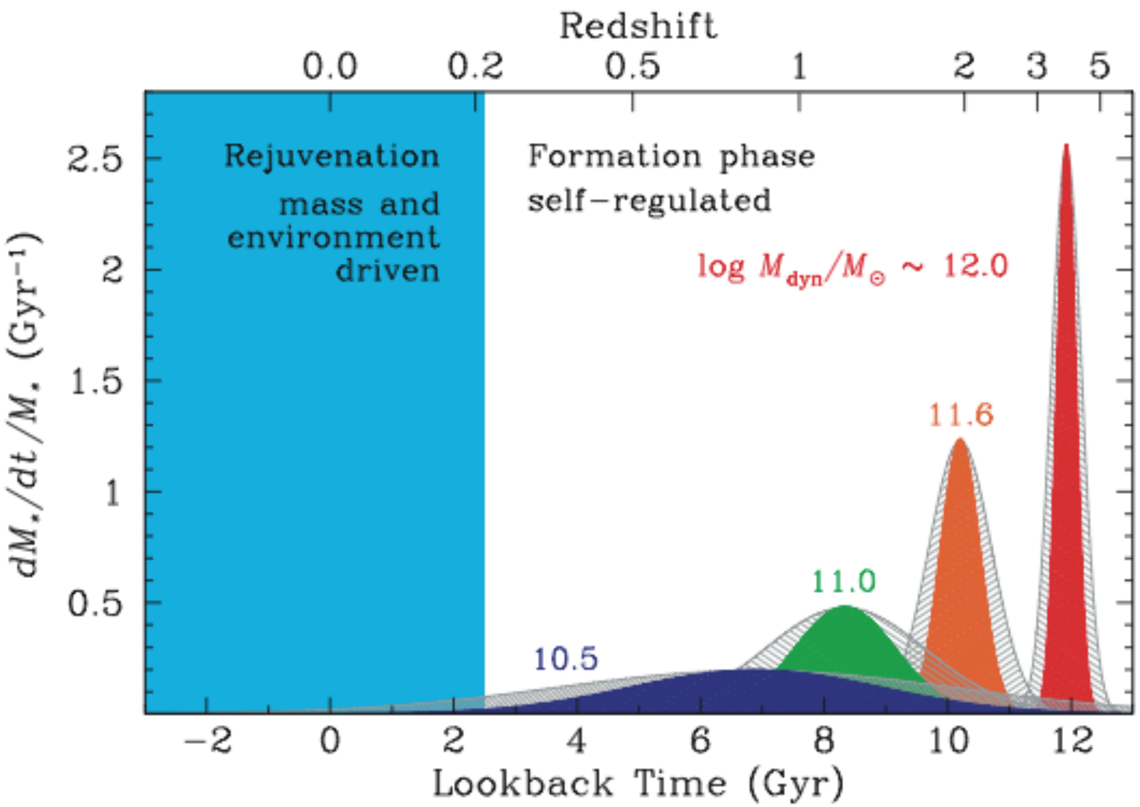


Downsizing:

From archeological studies of local galaxies, more massive galaxies must have started forming stars at earlier times with shorter timescales: **most stars in local most massive galaxies must have formed at z>2 (in the first 3 Gyr), through short (<1 Gyr) and intense bursts of star formation**.

(Thomas et al. 2005, 2010)

Properties of today's most massive galaxies



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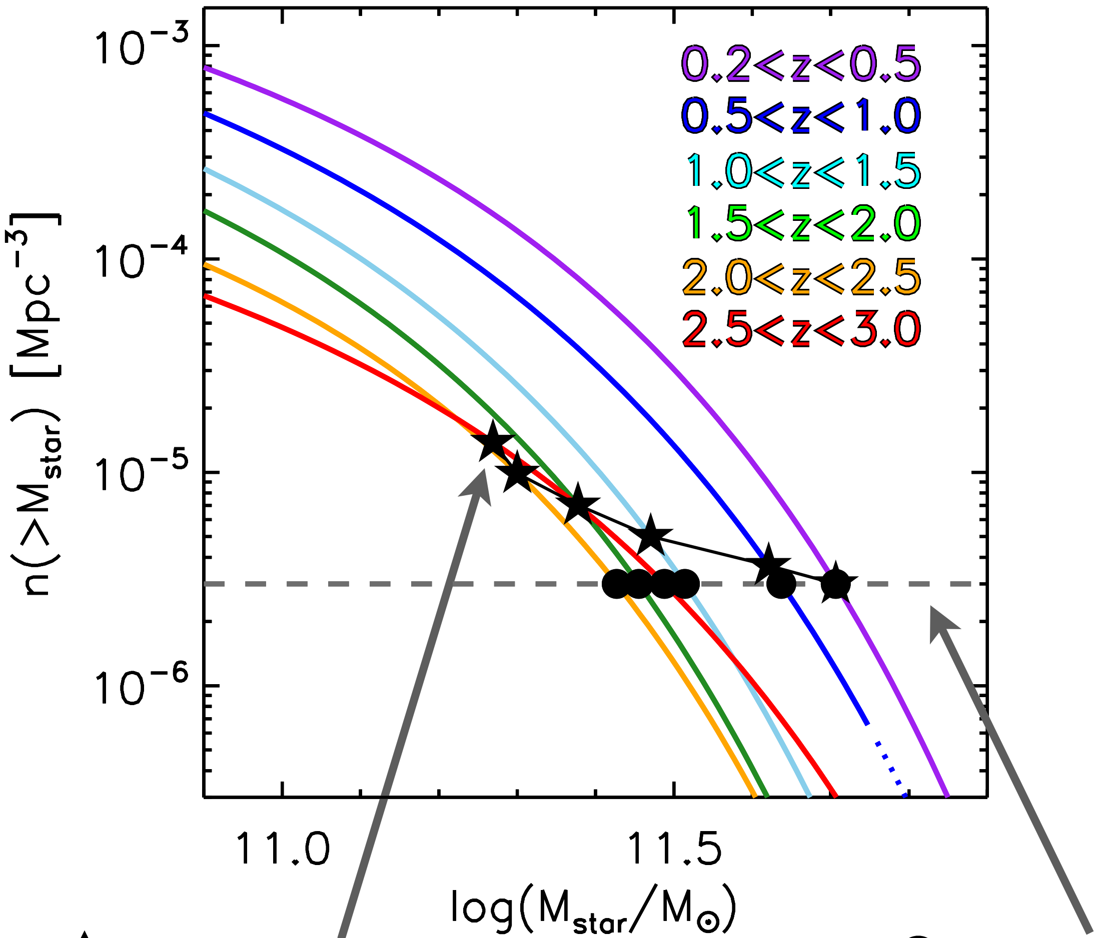
One would like to directly connect local most massive galaxies to their progenitors in the early universe.

Selection of the Progenitors of Local Ultra-Massive Galaxies (UMGs)

(SMFs from Muzzin, Marchesini, et al. 2013; UltraVISTA DR1)

(Marchesini et al. 2014)



★ Abundance matching
(Behroozi, Marchesini, et al. 2014)

● Fixed cumulative number density
(e.g., Brammer, DM, et al. 2011)

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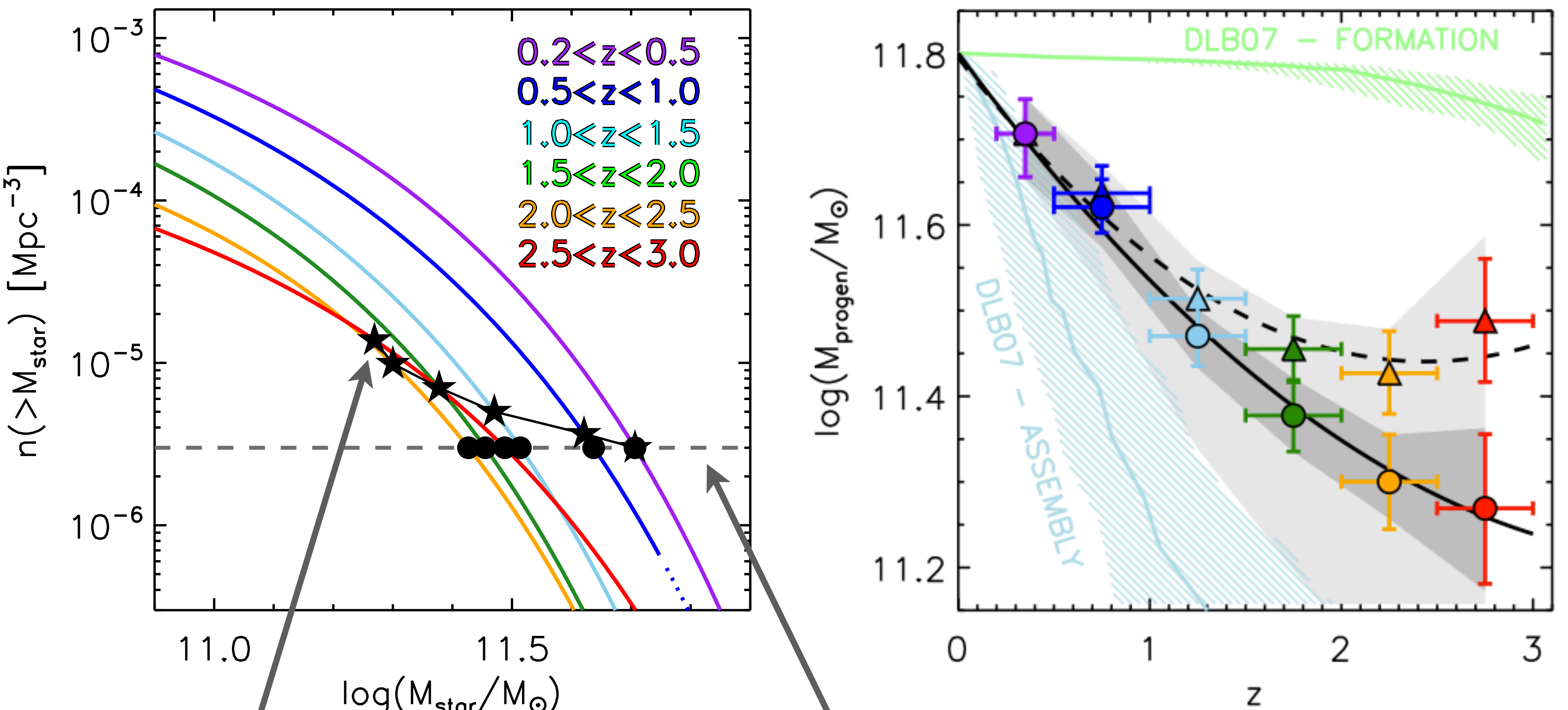

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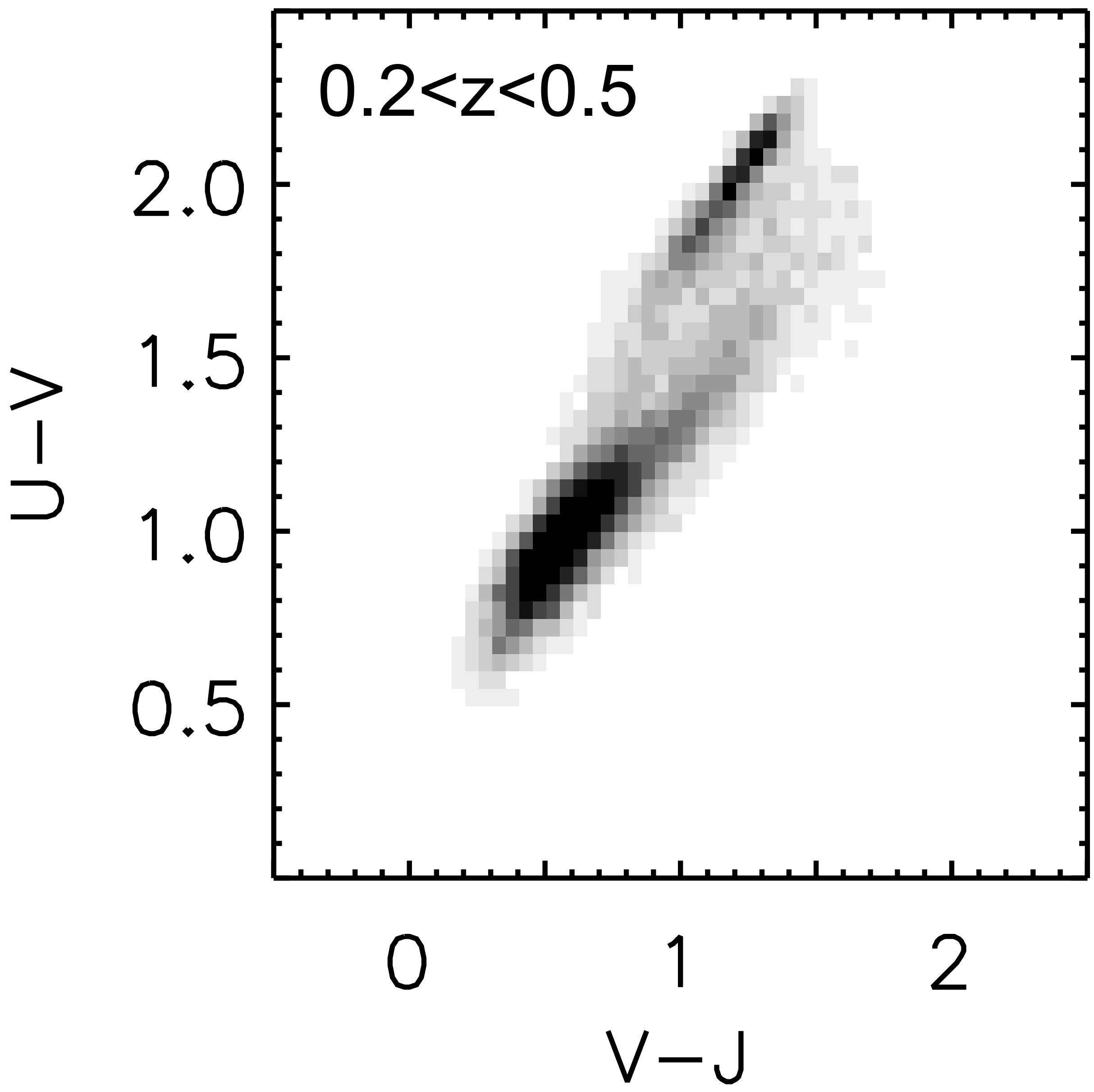
- **z~0 UMGs** defined as galaxies with $M_{star}=6\times10^{11}$ Msun, i.e., **$\log(M_{star}/M_{Sun})=11.8$** (Kroupa)
- Mass growth by a factor of ~2 from z=3 to z=0 using fixed cumulative number density.
- **Mass growth is** a factor of **~3.6 from z=3 to z=0** using **abundance matching** techniques

The UVJ diagram and separation of Quiescent and Star-forming Galaxies



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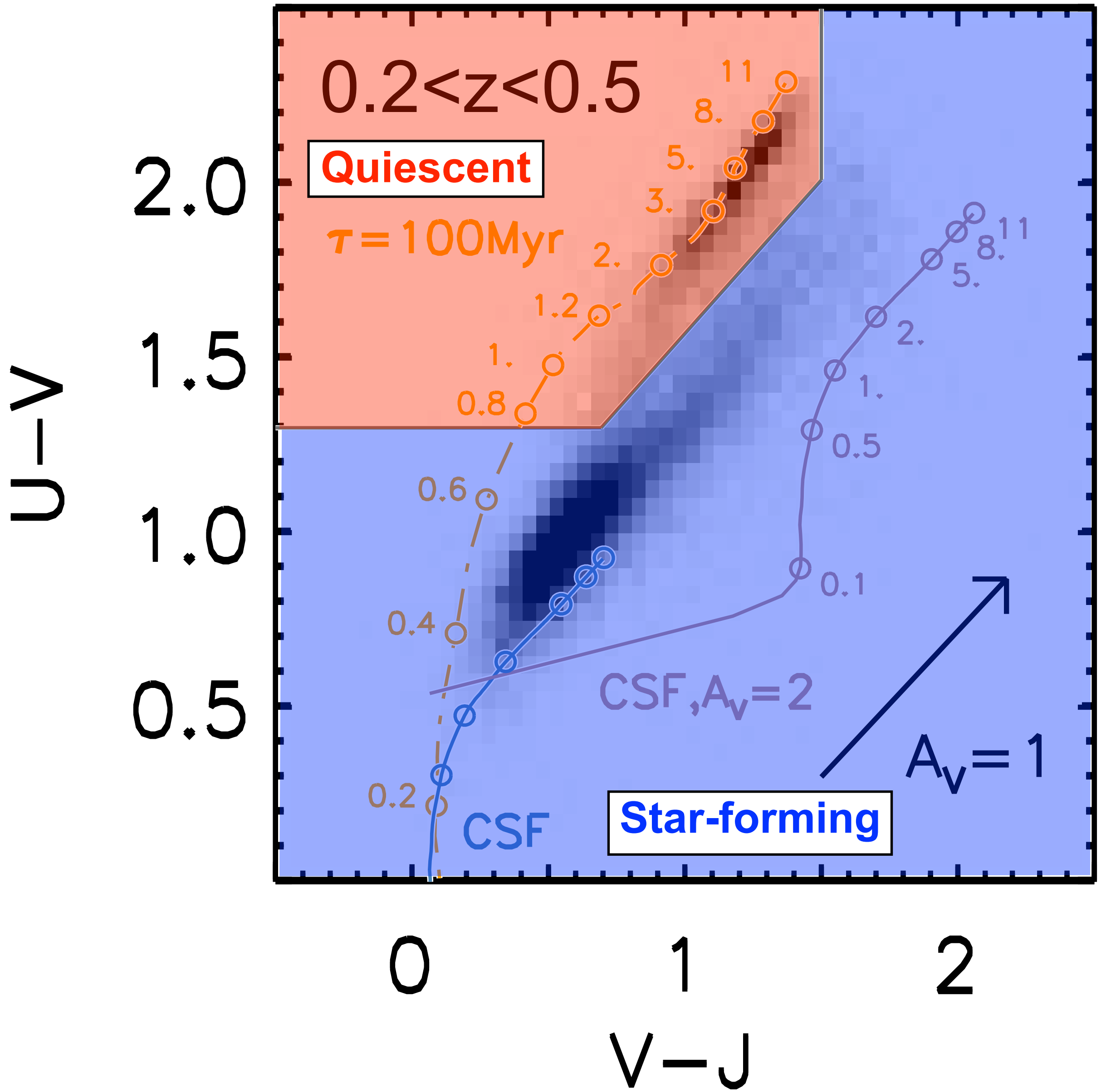
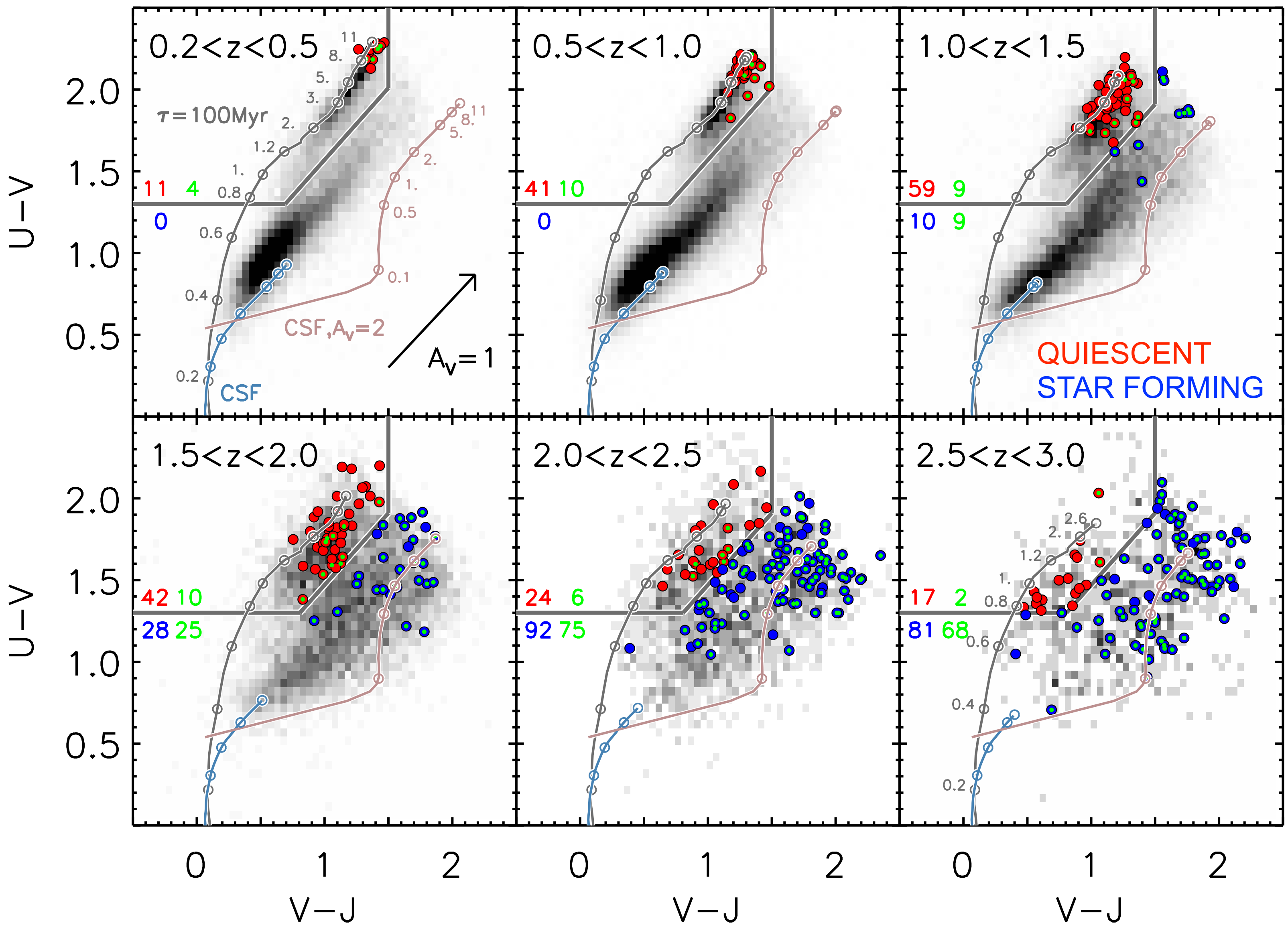


Evolution of Progenitors in the UVJ diagram

(Marchesini et al. 2014)



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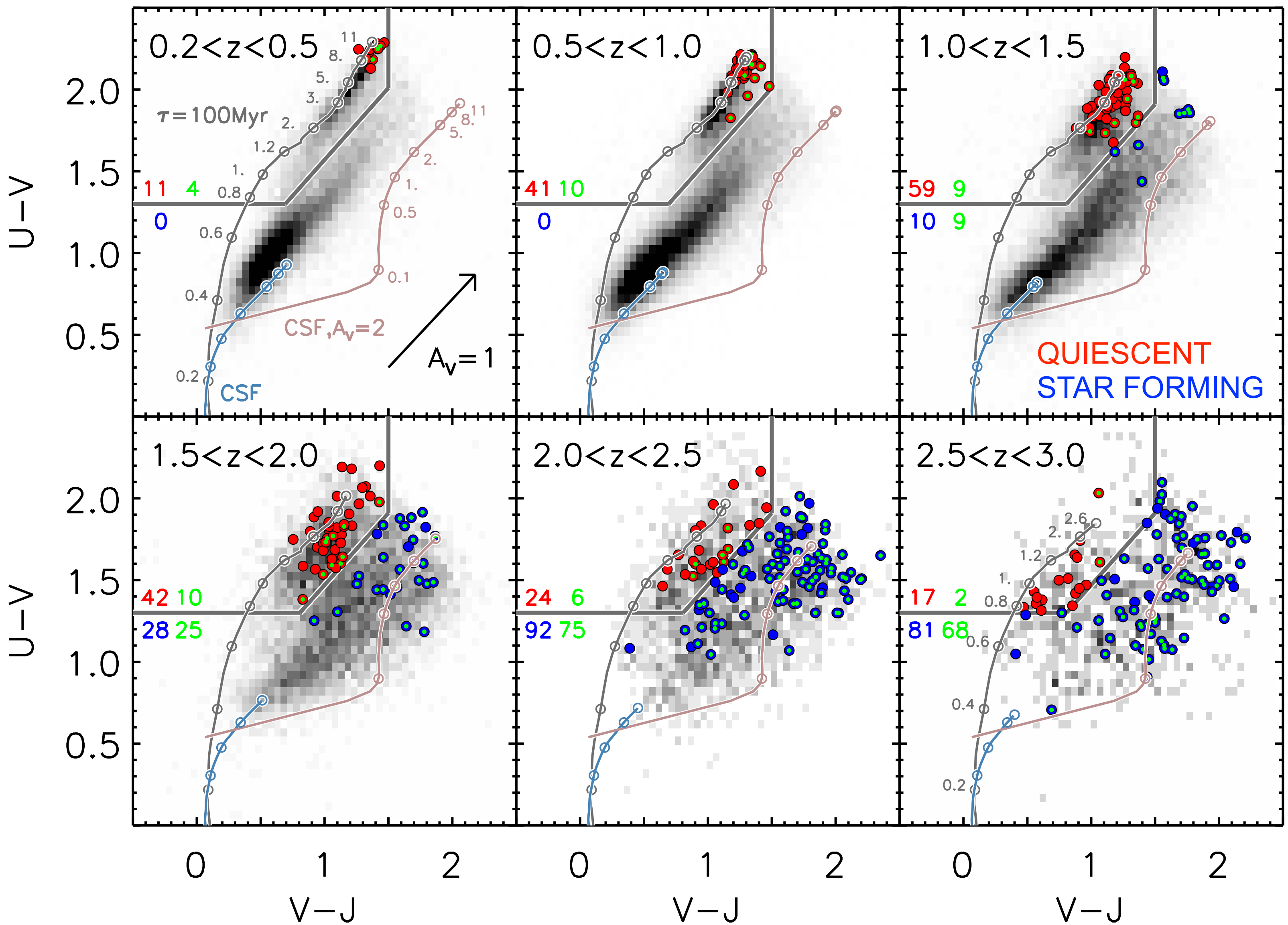
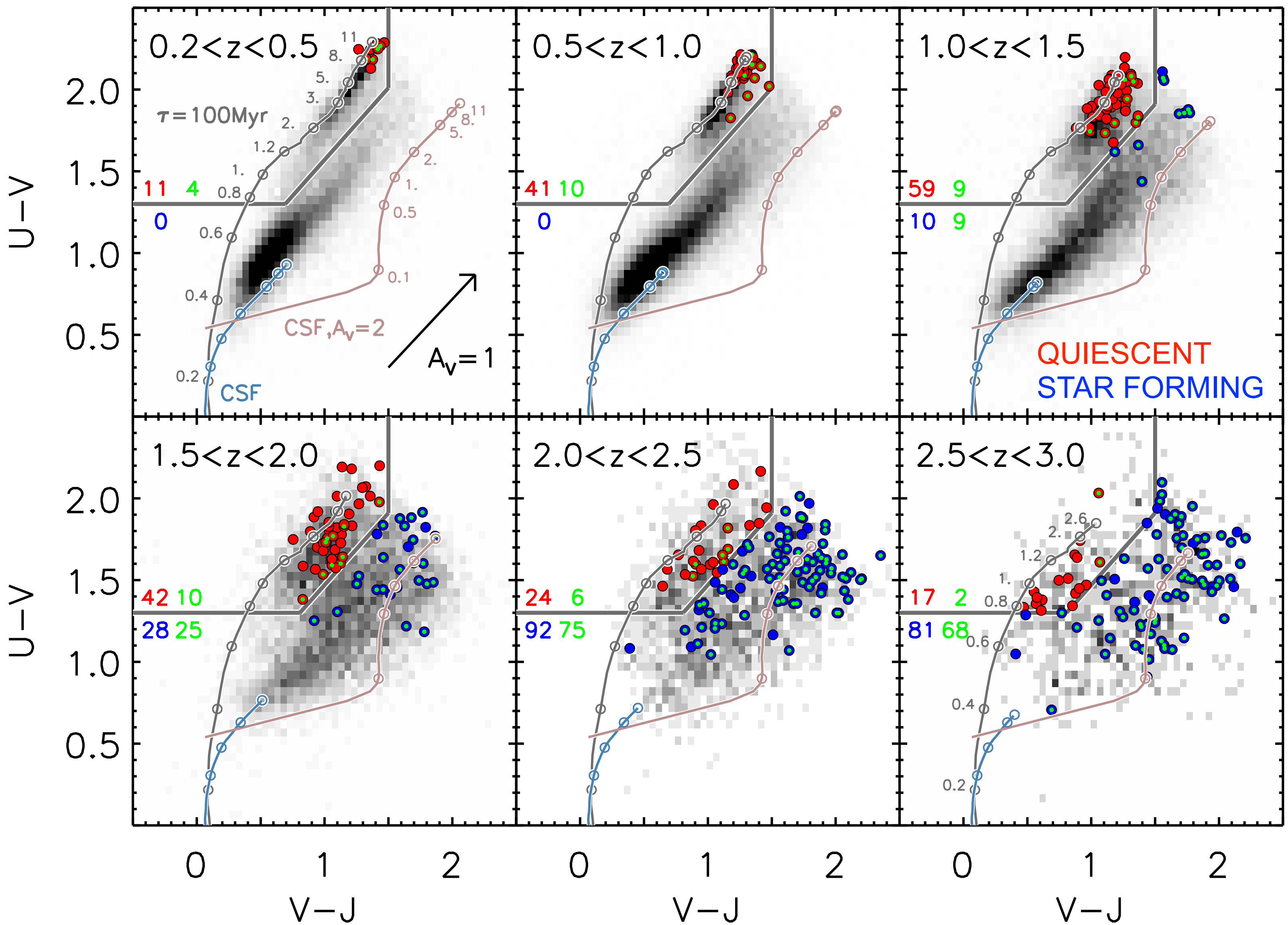


- **At z<1, all progenitors are quiescent**, and constitute a very homogeneous population. At high-z, the contribution from star-forming galaxies progressively increases, with the **progenitors' population dominated by star-forming galaxies at 2<z<3**.

Evolution of Progenitors in the UVJ diagram

(Marchesini et al. 2014)



- **Aging of the quiescent population** clearly detected.

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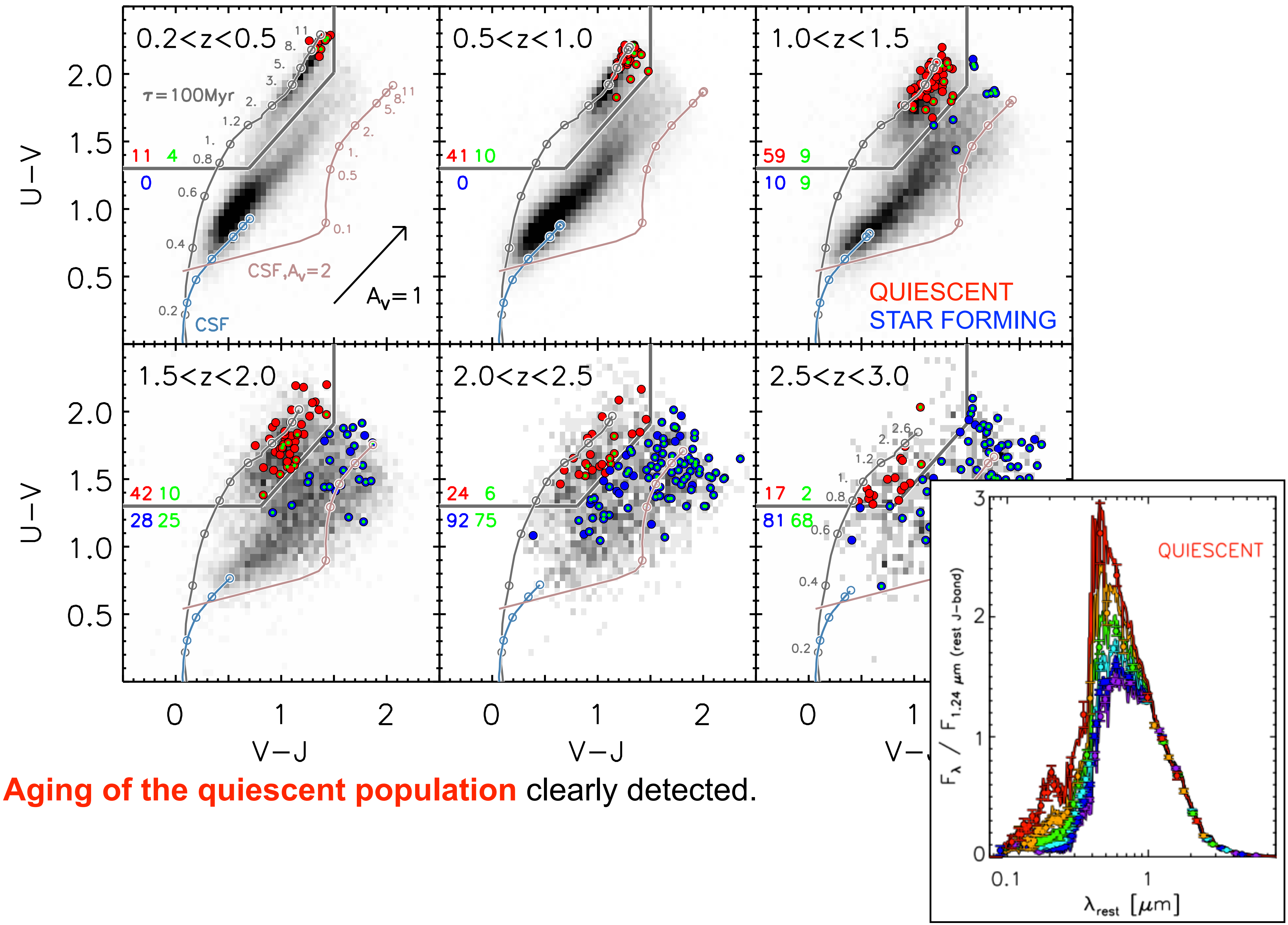

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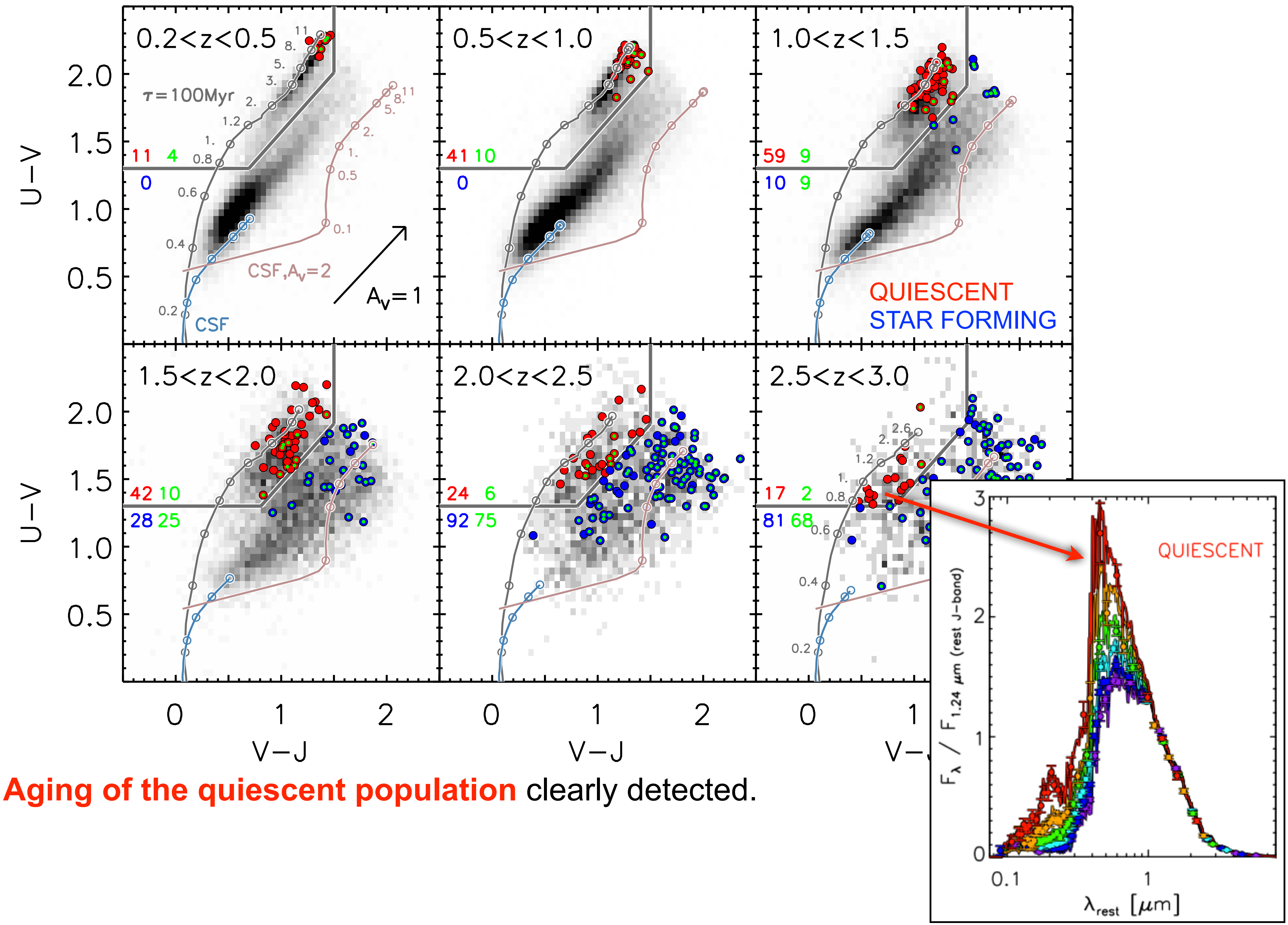

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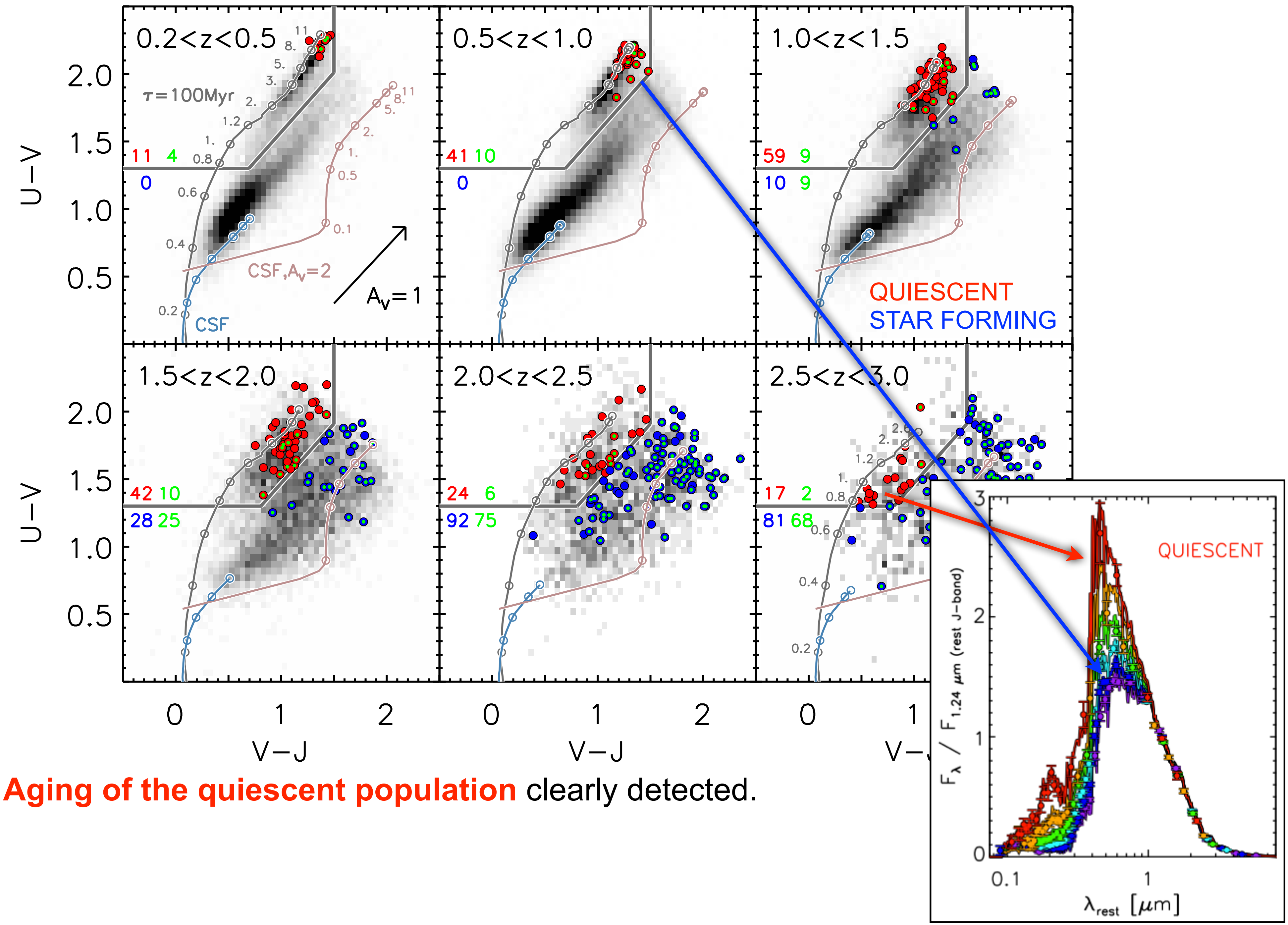

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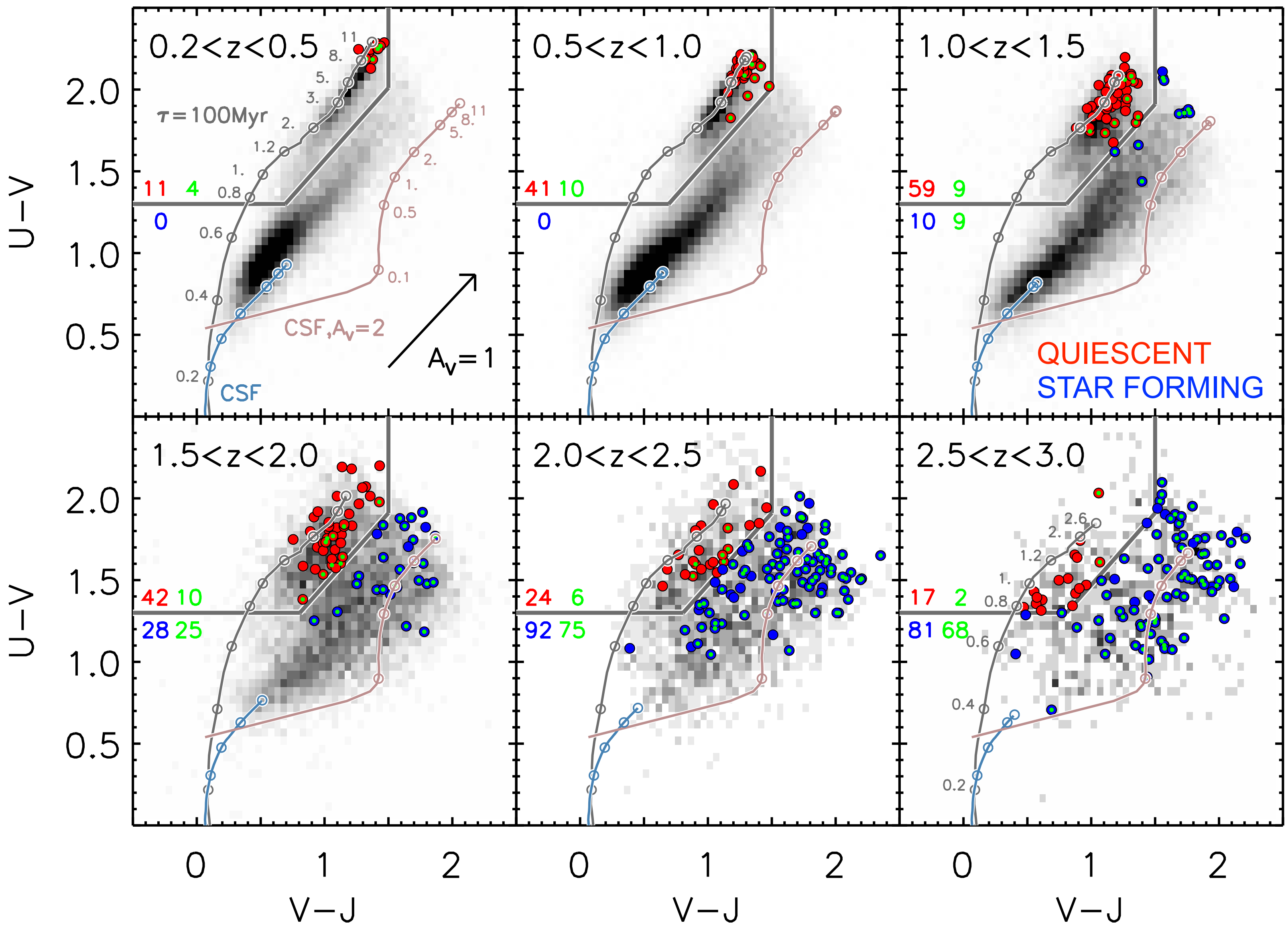
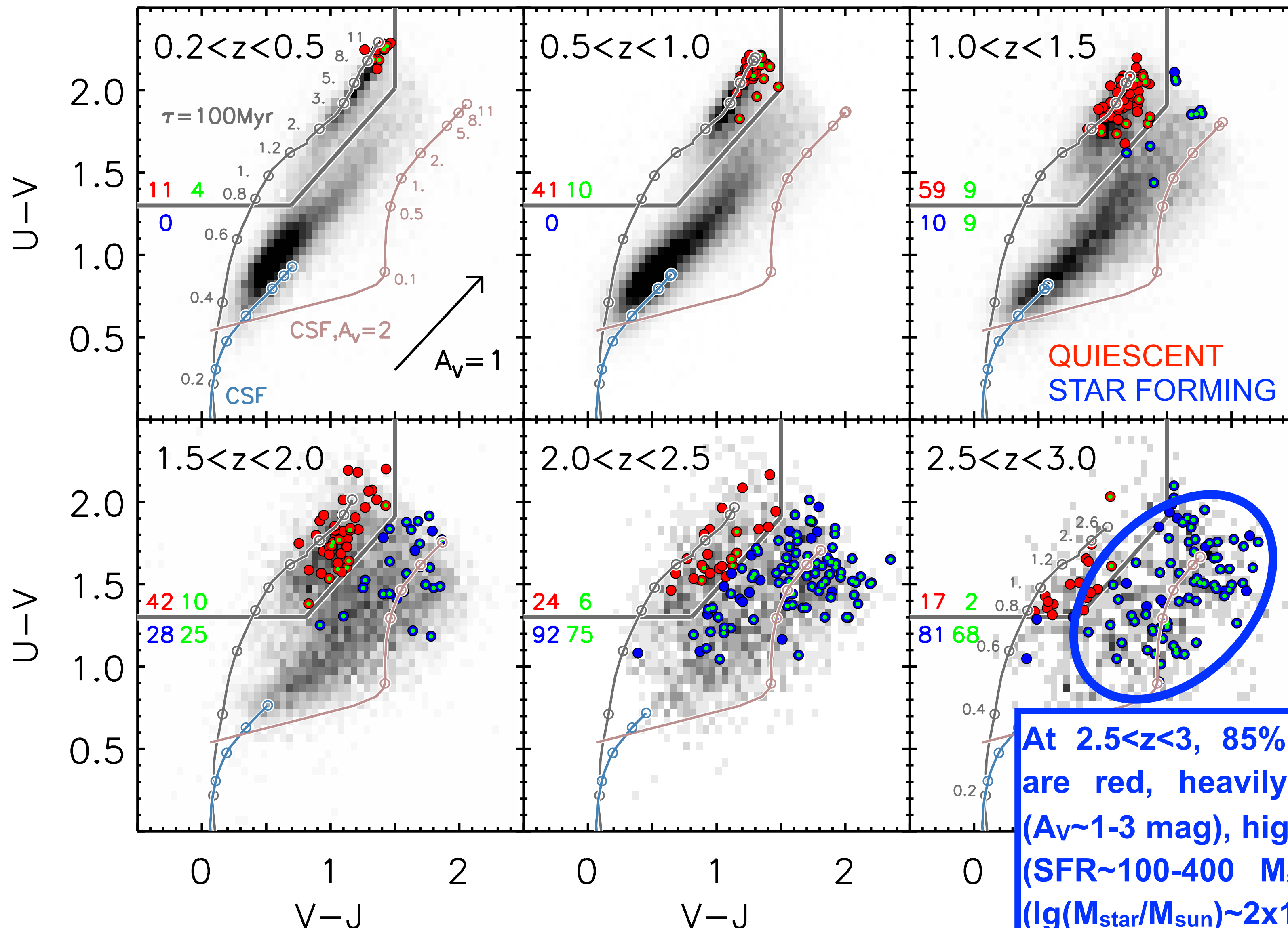


- **Aging of the quiescent population** clearly detected.
- The **star-forming progenitors are very dusty**, confirmed by their ubiquitous detection in the MIPS 24 micron data (green).

Evolution of Progenitors in the UVJ diagram

(Marchesini et al. 2014)



At 2.5<z<3, 85% of progenitors are red, heavily dust-obscured (A_V~1-3 mag), highly star-forming (SFR~100-400 M_{sun}/yr), massive (lg(M_{star}/M_{sun})~$2x10^{11}$) galaxies.

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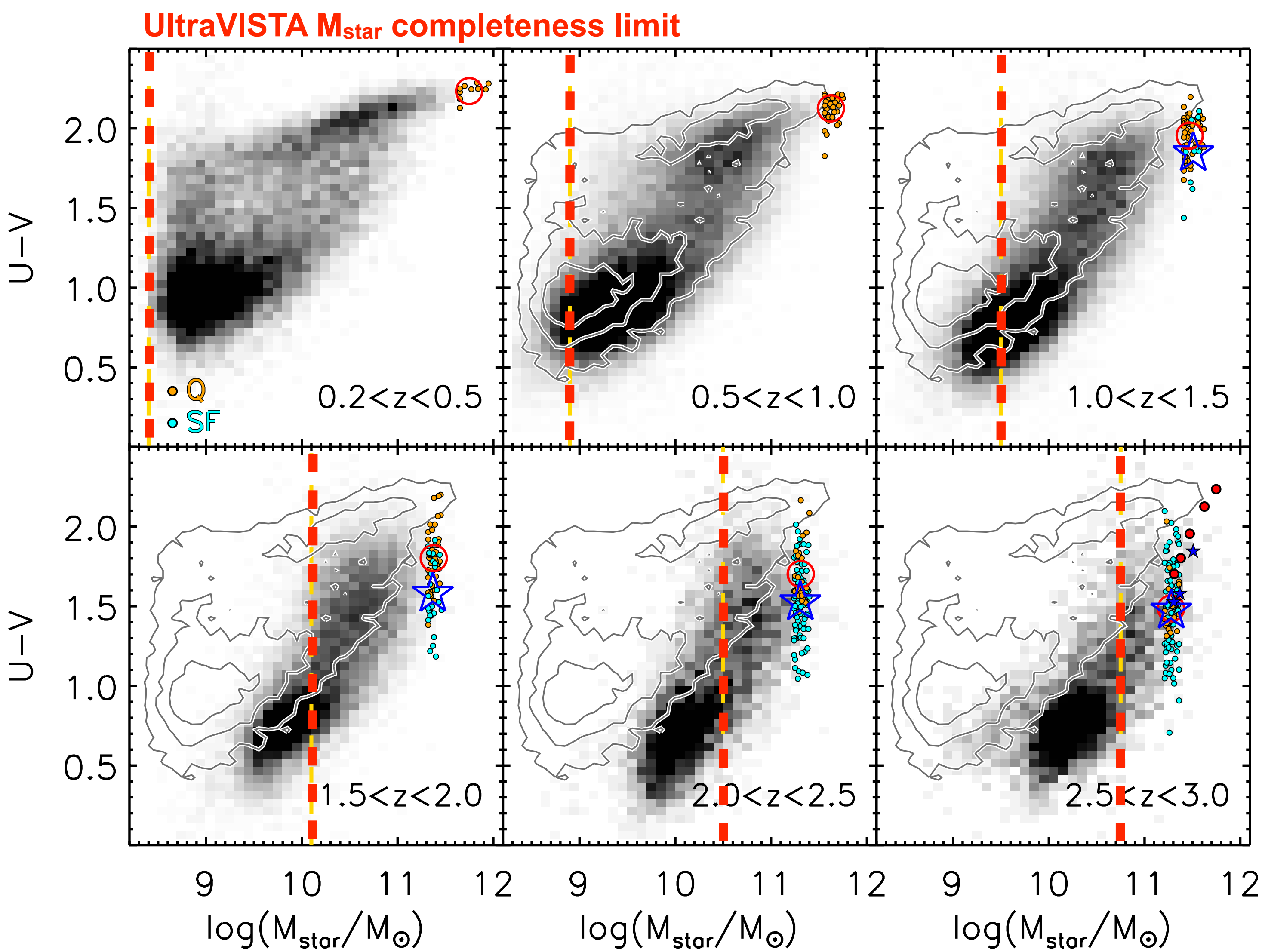
Color versus Stellar Mass Diagram

(Marchesini et al. 2014)



- The **star-forming progenitors** have **never lived on the blue cloud since z=3**.

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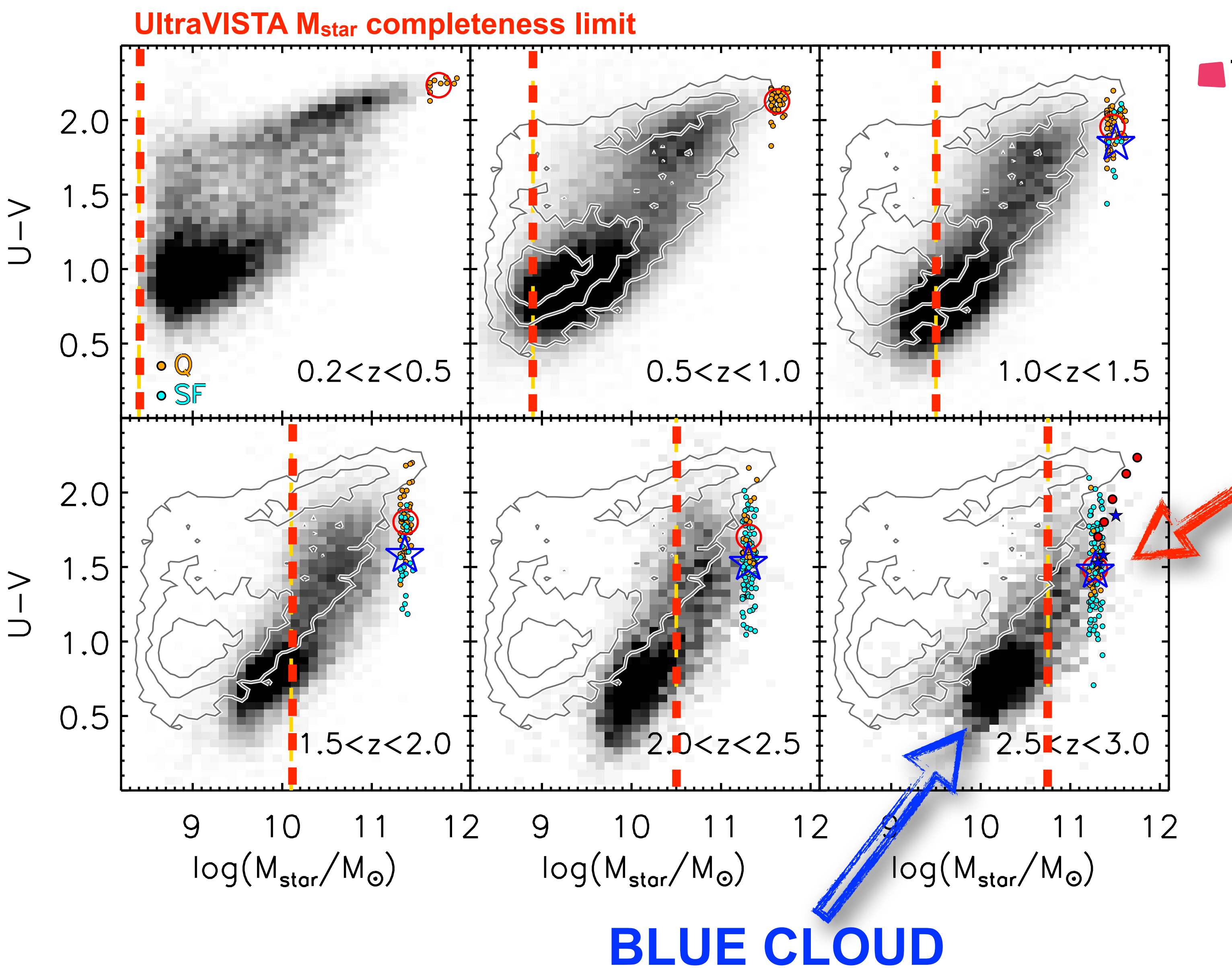

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Quiescent and **star-forming** progenitors have **similar** median rest-frame **U-V colors at 2.5<z<3**.

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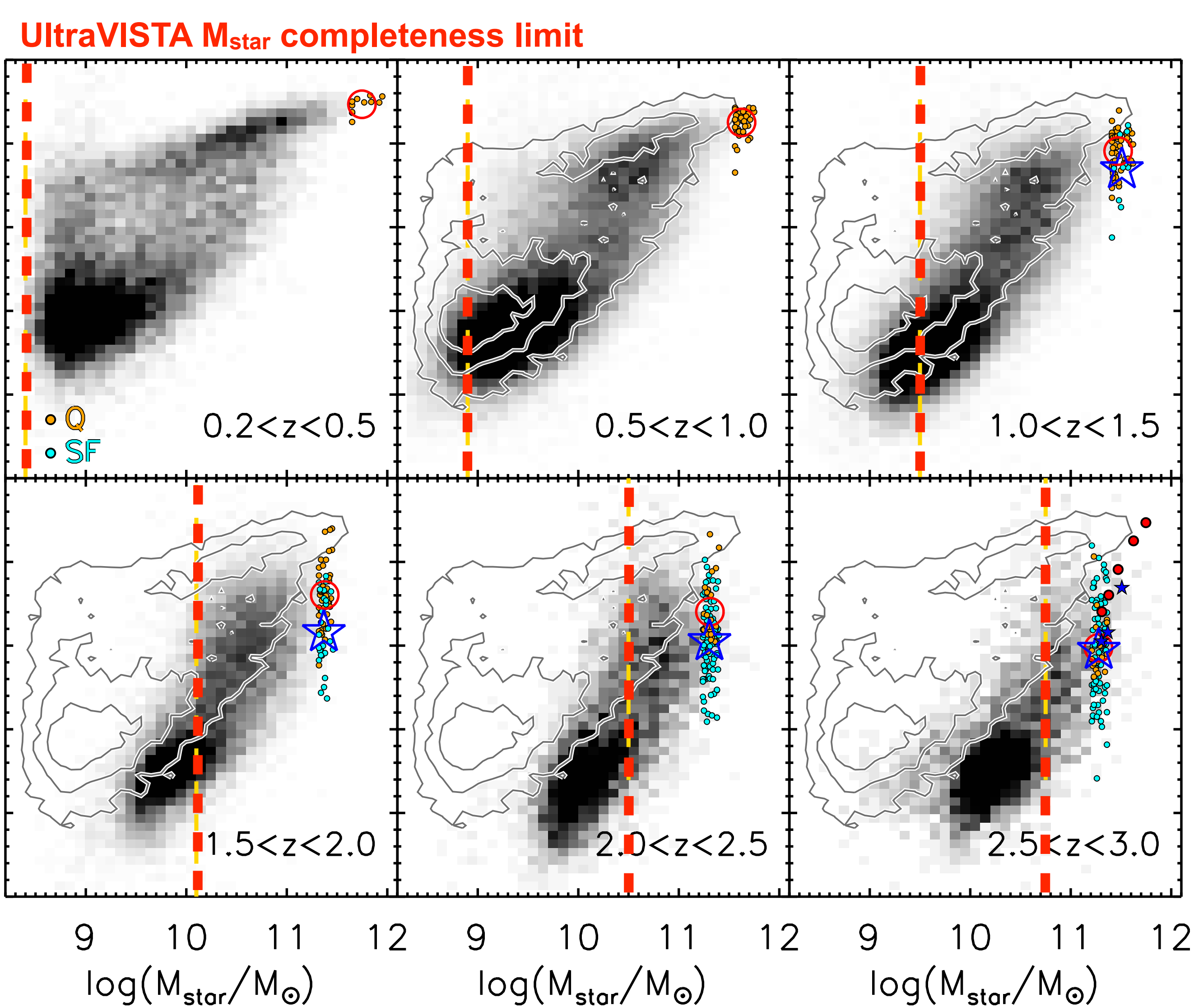

- The **star-forming progenitors** have **never lived on the blue cloud since z=3**.
- The **very massive end of the local red-sequence** is **in the process of assembling between z=3 and z=1**
  Most of the star-forming progenitors quench in the 2.6 Gyr from z=2.75 to z=1.25. By z=1, all star-forming progenitors have quenched.

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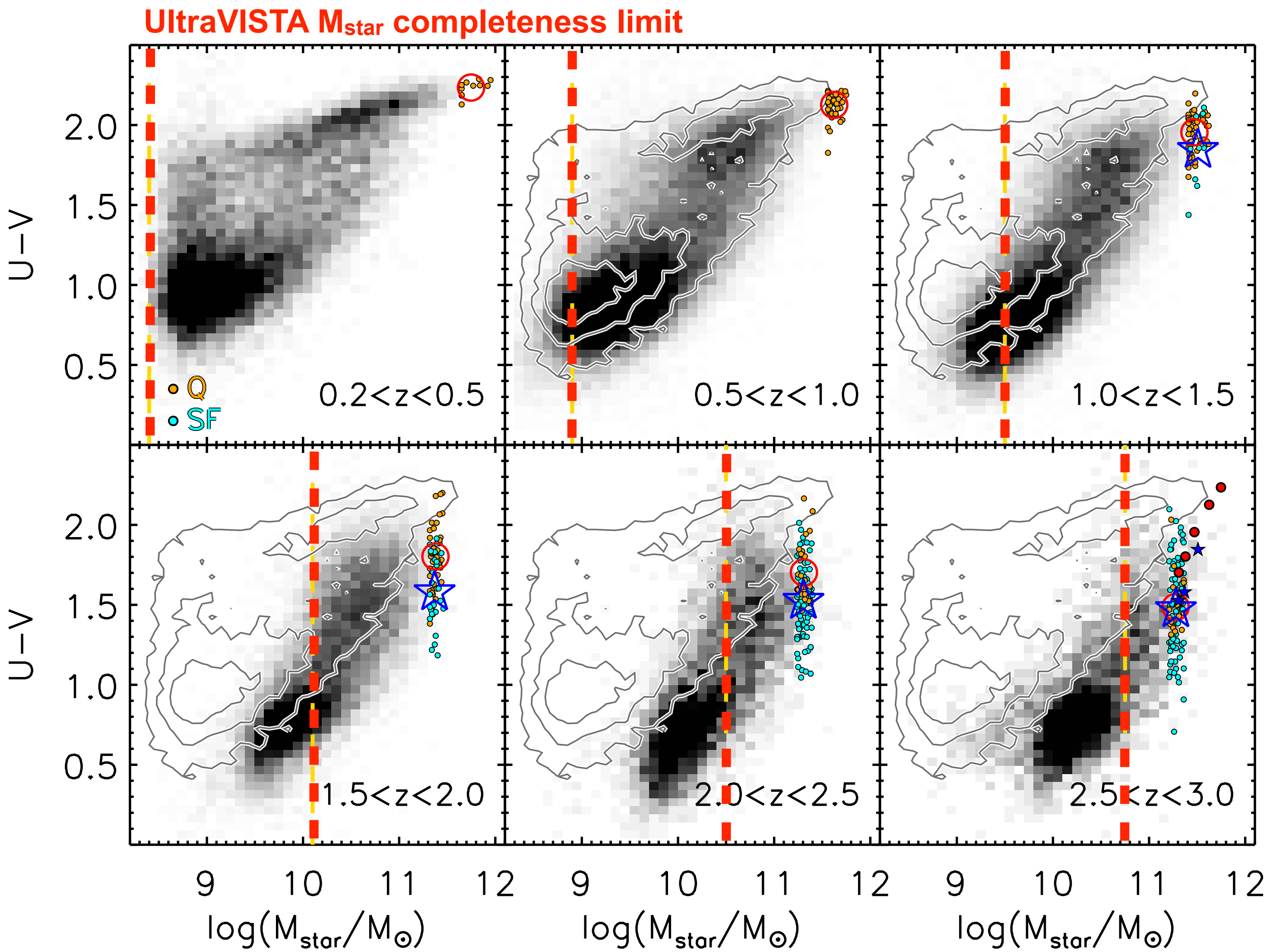

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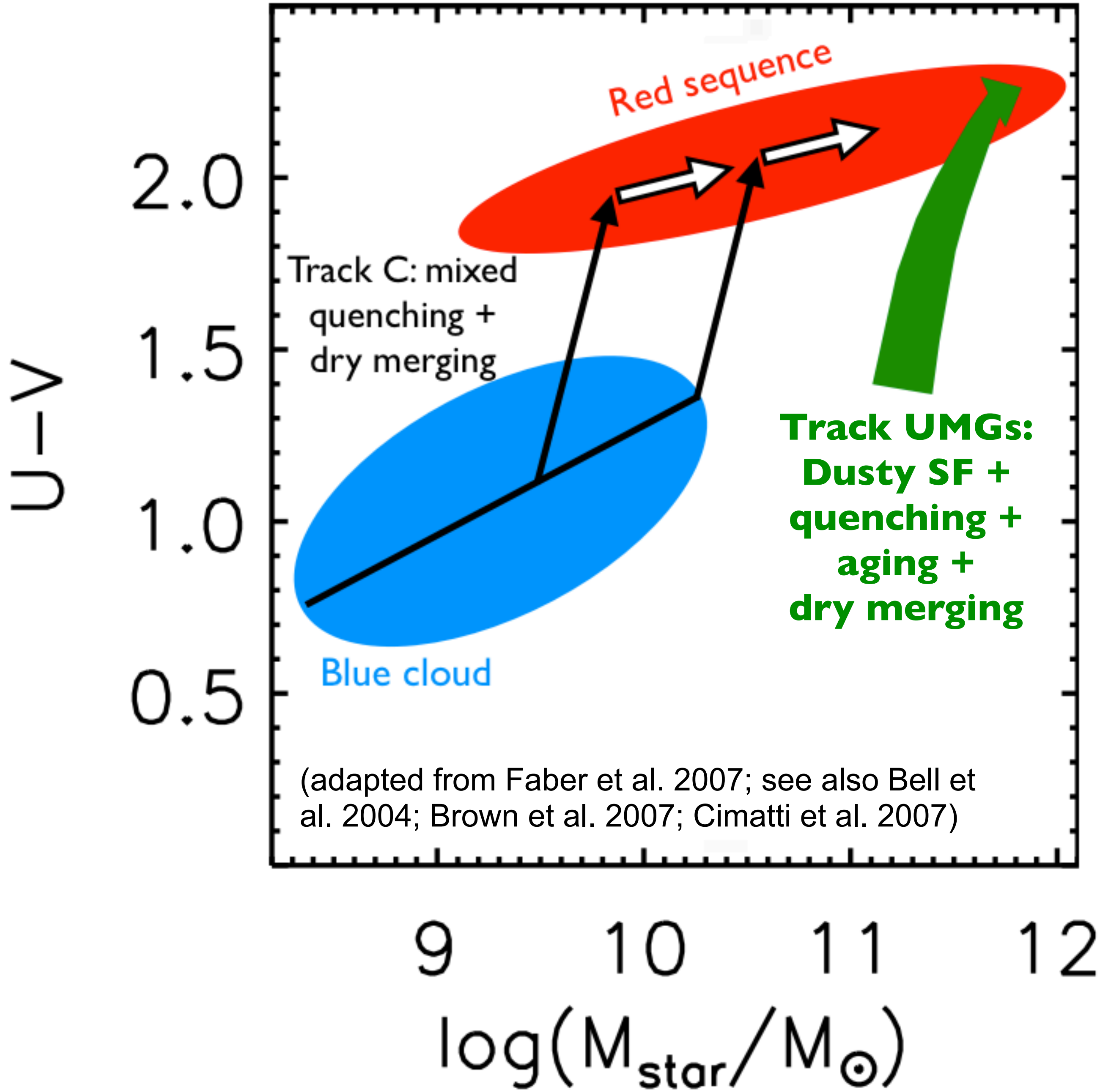
- **First direct proof in the early universe of the results and implications of the archeological studies of local UMGs**, i.e., inferred median z_{form}~1.9 from age of local UMGs, and 1.1<z_{form}<4.2 from the spread in age (~20%, i.e., 1.8-2 Gyr). Our results are in **remarkably good agreement with these fossil records** (Gallazzi et al. 2006).

Alternative evolutionary path for the formation of local UMGs



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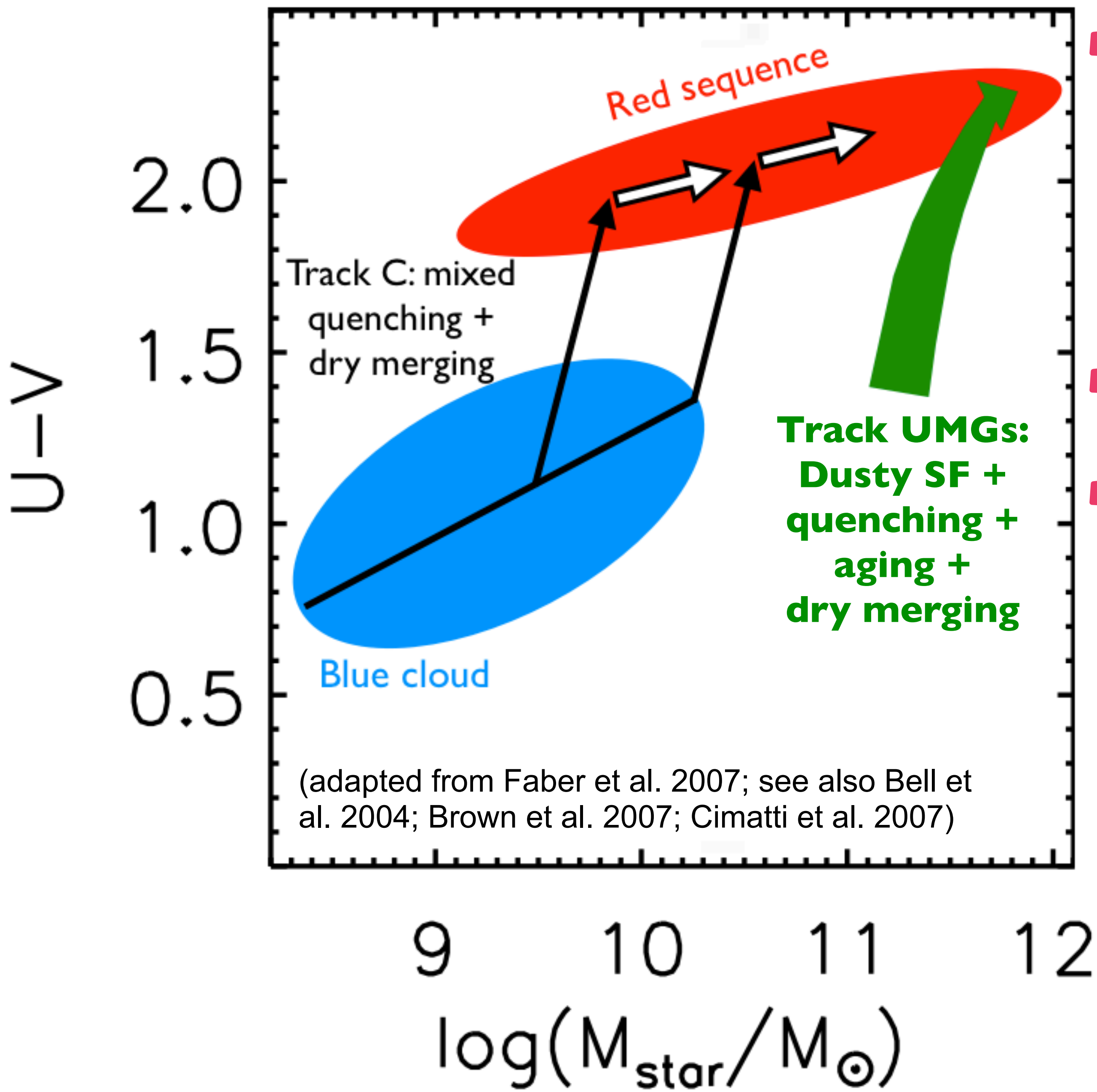

- **Early mass assembly** and stellar growth in a short and intense dusty burst of star formation - **progenitors as red, heavily dust-obscured, star-forming galaxies**.
- After quenching, **progenitors redden due to aging**.
- **Additional growth** (mass and size) **from dry** (?) **merging**.

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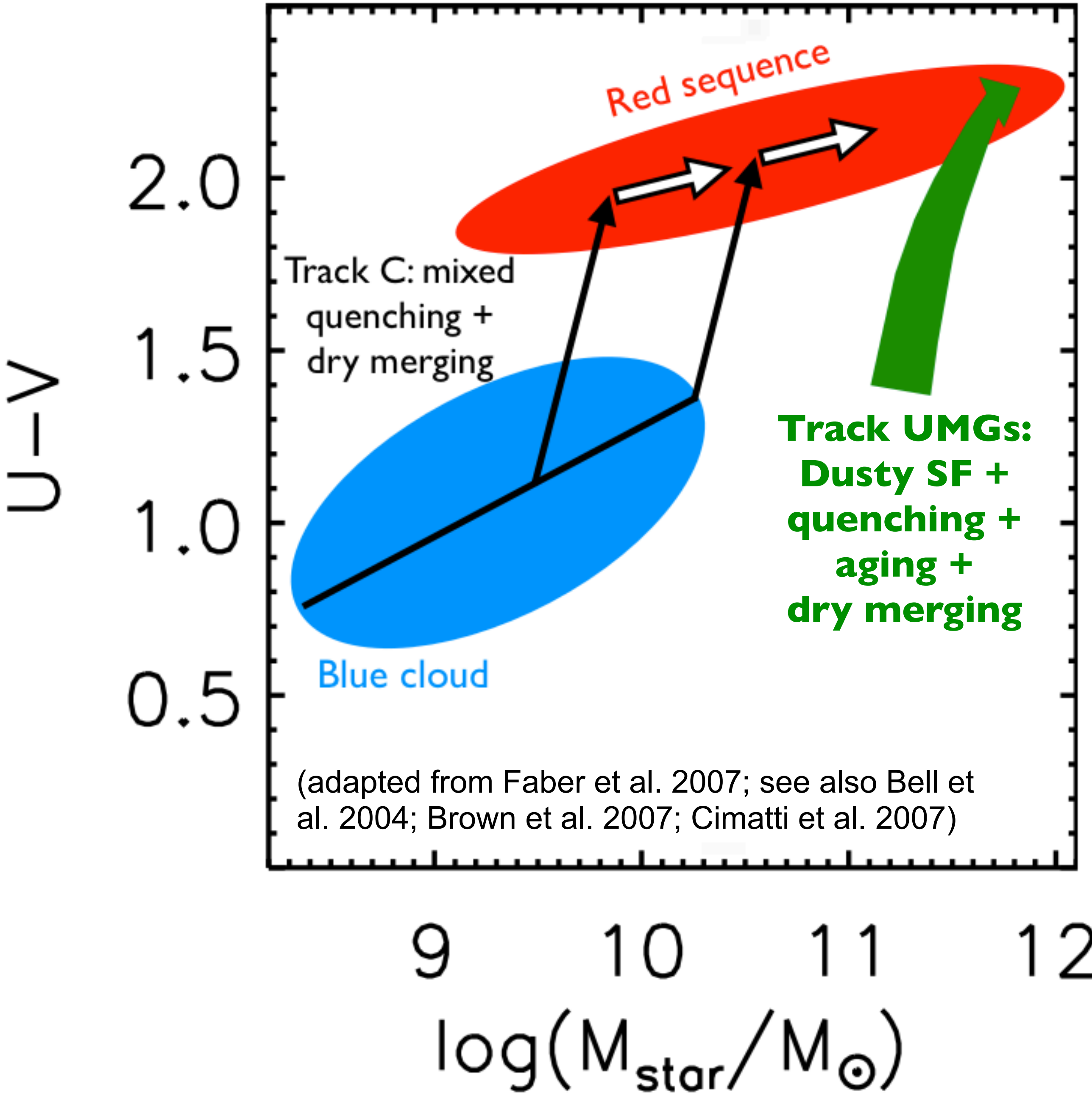

(adapted from Faber et al. 2007; see also Bell et al. 2004; Brown et al. 2007; Cimatti et al. 2007)

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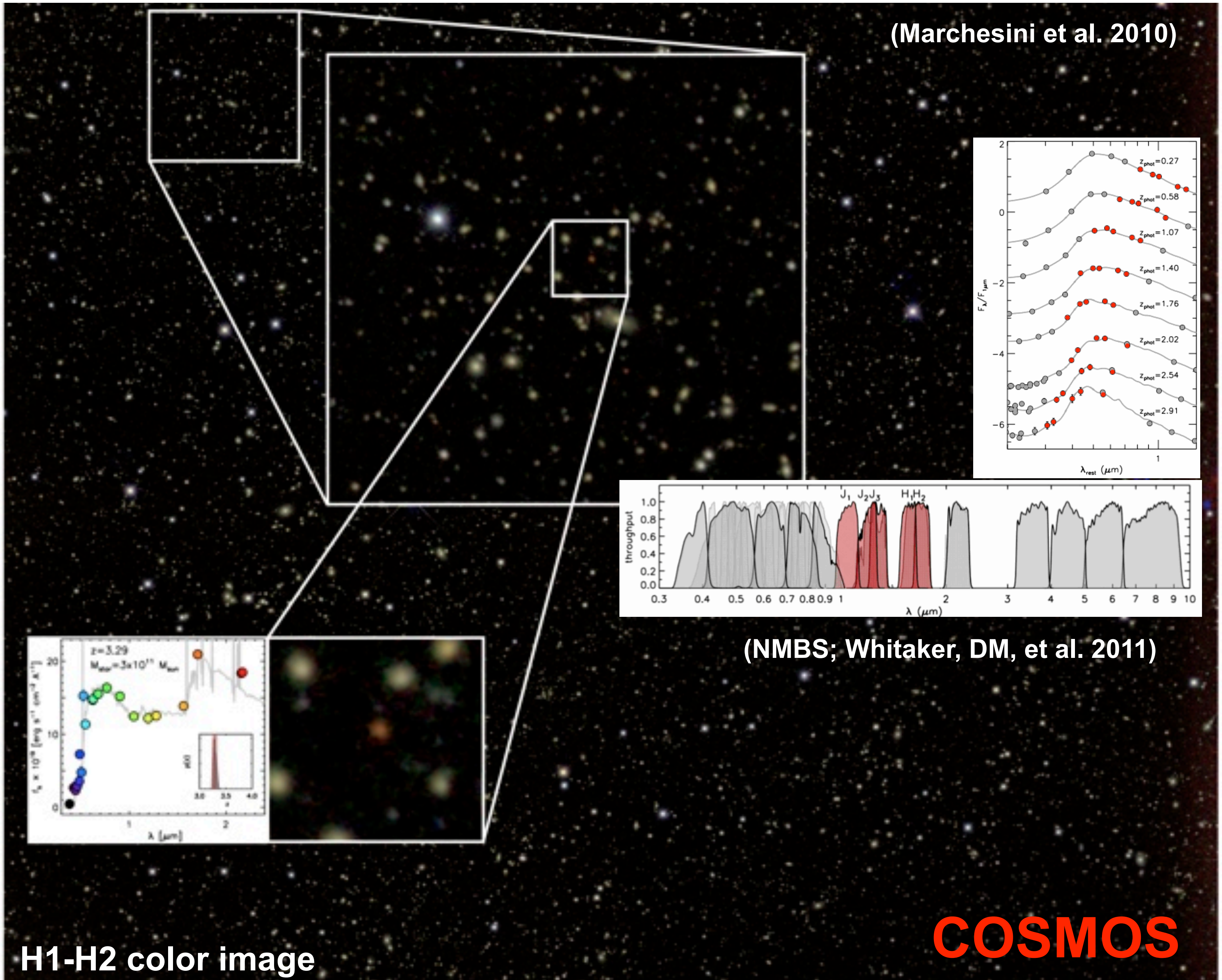
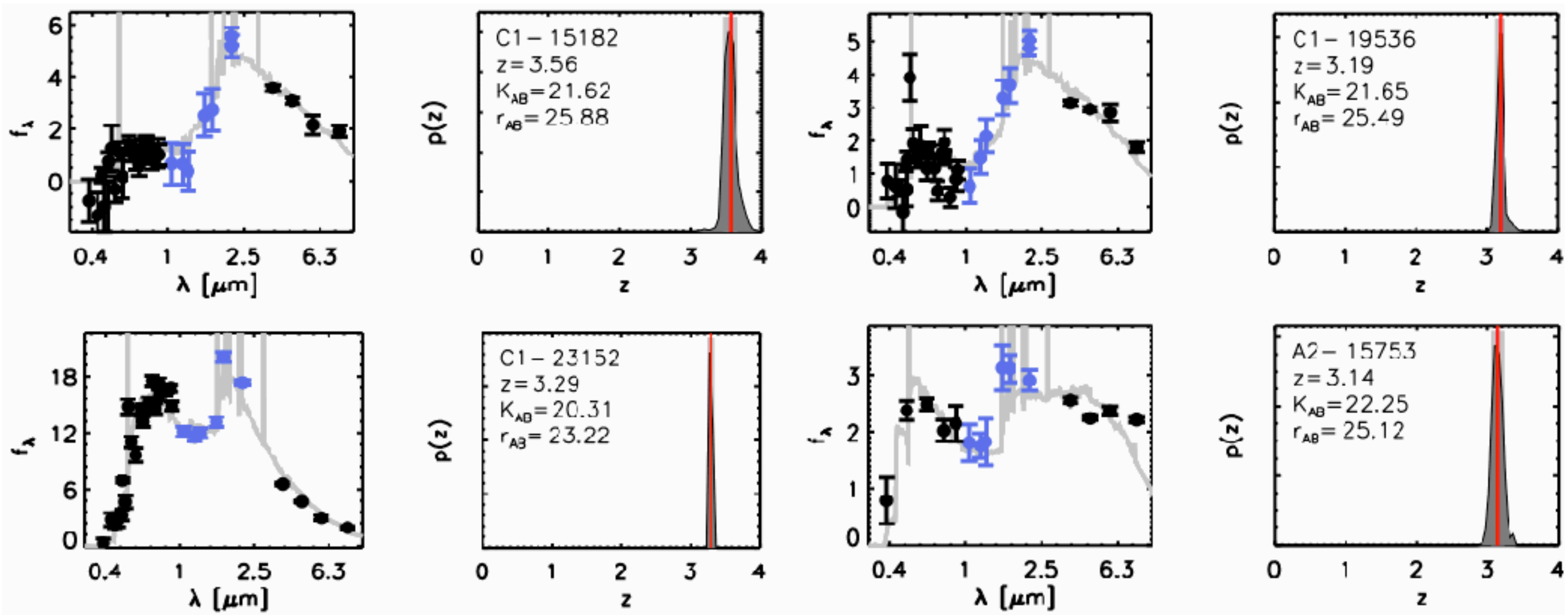
What about the progenitors at z>3?

Searching for Very Massive Galaxies at z>3 in the NEWFIRM Medium-Band Survey (NMBS)



Stellar Mass-complete Sample of Galaxies at 3<z<4 from the NMBS

(Marchesini et al. 2010; see talk by Lee Spitler using zFOURGE for lower mass galaxies)



- **14 galaxies at 3<z<4 with $M_{star}>10^{11.4}$ $M_{sun}=2.5\times10^{11}$ M_{Sun}** in COSMOS and AEGIS over an effective area of 0.44 deg^2
- ~50% with ages consistent with age of the universe (~1.6-2.1 Gyr)
- **~30% have SFRs** (from SED modeling) **consistent with no star formation activity; ~30% have large SFRs**, a few hundreds M_{sun}/yr
- **First robust evidence** of **existence of very massive galaxies at z>3** and of **large diversity in properties among this population**.

Spectroscopy of 3<z<4 Massive Galaxies

(PhD Thesis of Tufts student Cemile Marsan)

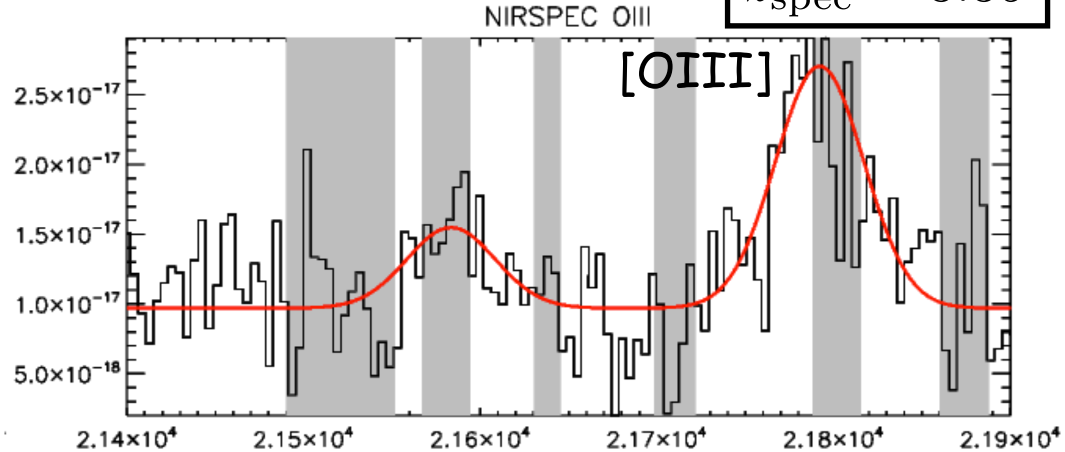
- Spectroscopic confirmation required to break the ambiguity between massive 3<z<4 galaxies and massive, OLD AND DUSTY galaxies at z<3

Spectroscopy of 3<z<4 Massive Galaxies

(Marsan, Marchesini, et al., 2015)

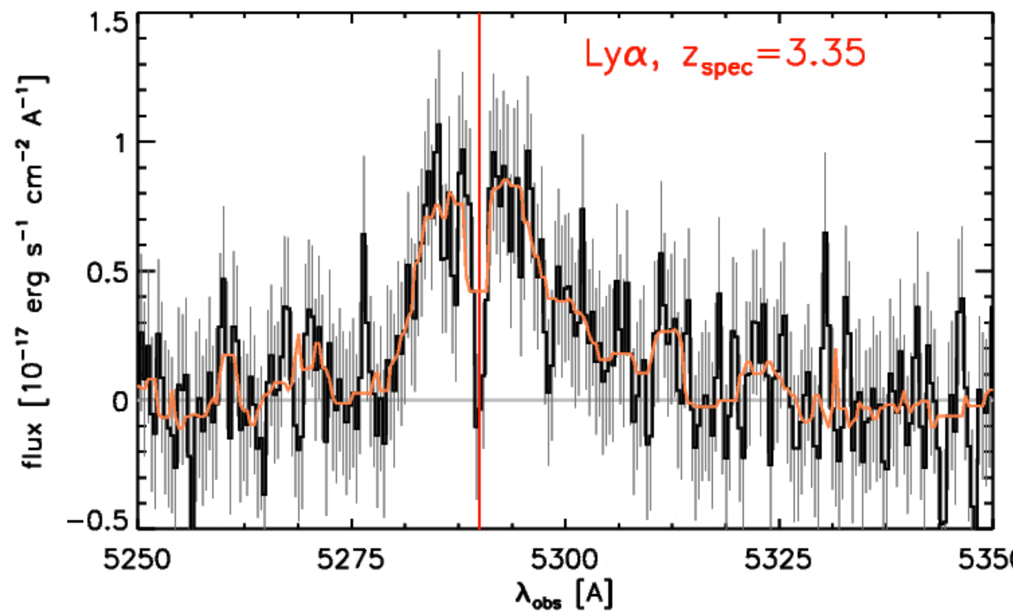
$z_{\rm phot} = 3.29 \pm 0.06$

$z_{\rm spec} = 3.35$



- NIR spectroscopy w/ Keck-NIRSPEC
- UV-NIR spectr. w/ VLT-Xshooter
- OPT spectr. from GTC
- ACS grism spectroscopy

(tentative CIV in emission also detected)



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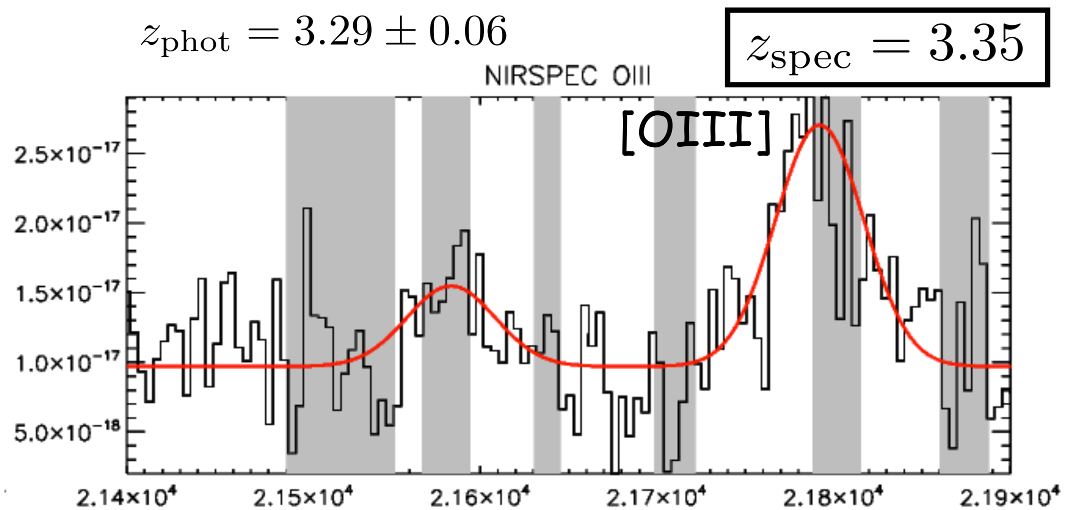

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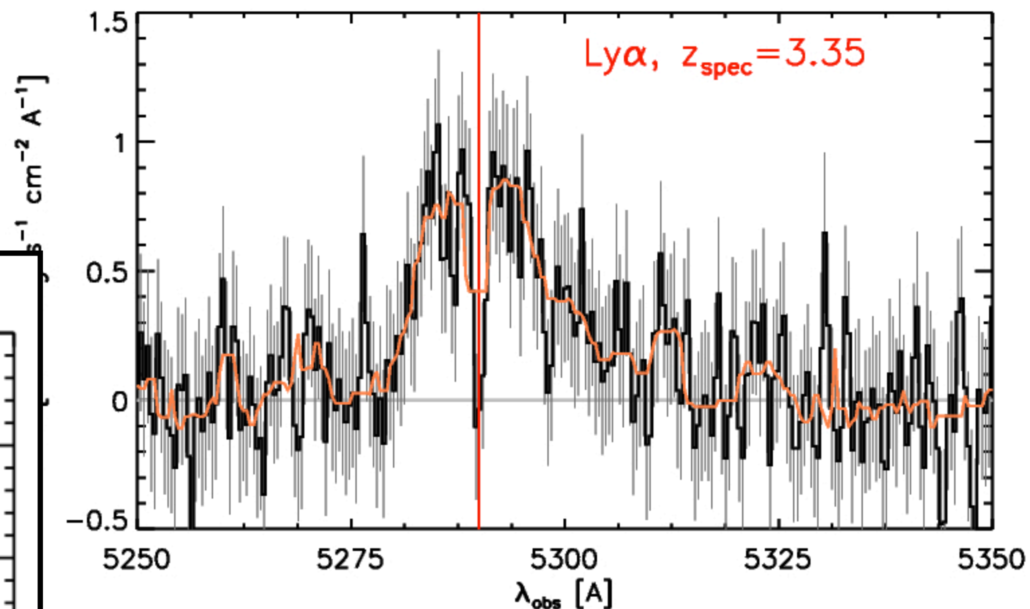
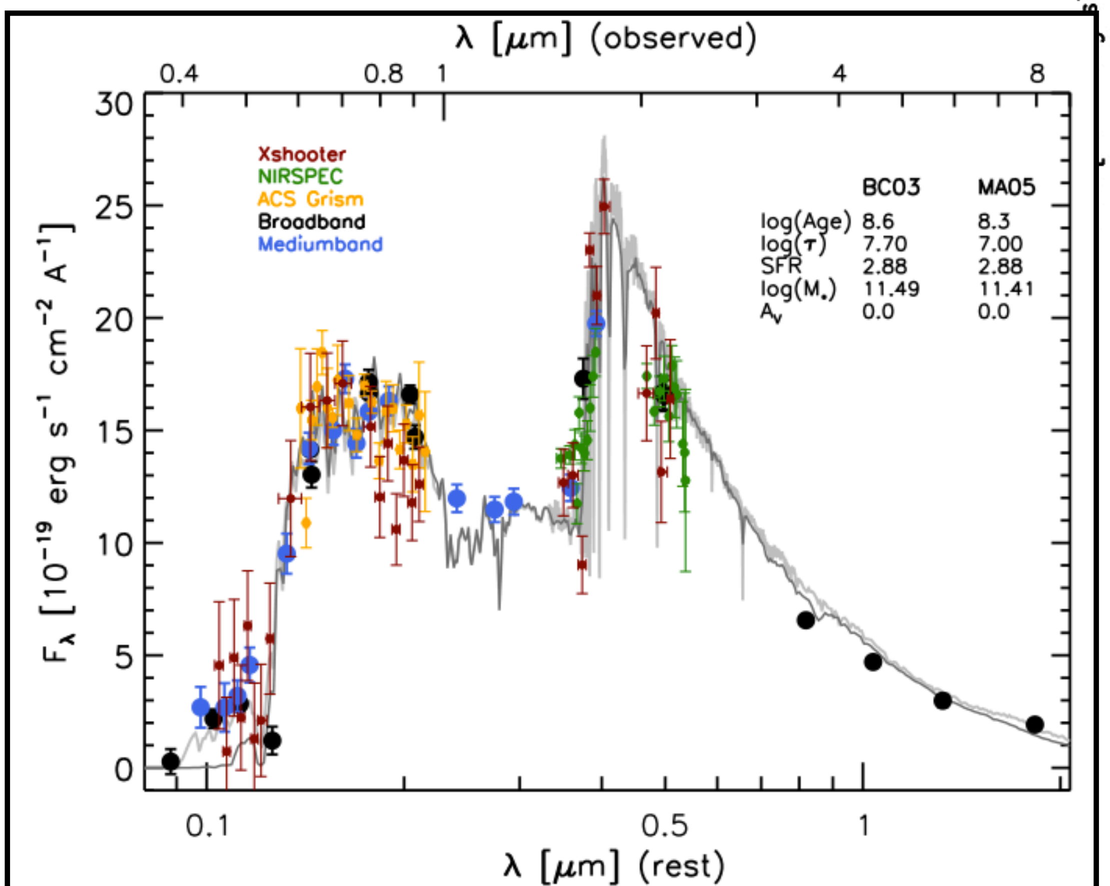




$M_{star} = 3\times10^{11}$ M_{sun} (Kroupa IMF)

SFR=3 M_{sun} yr^{-1} (<7 M_{sun} yr^{-1})

A_V=0

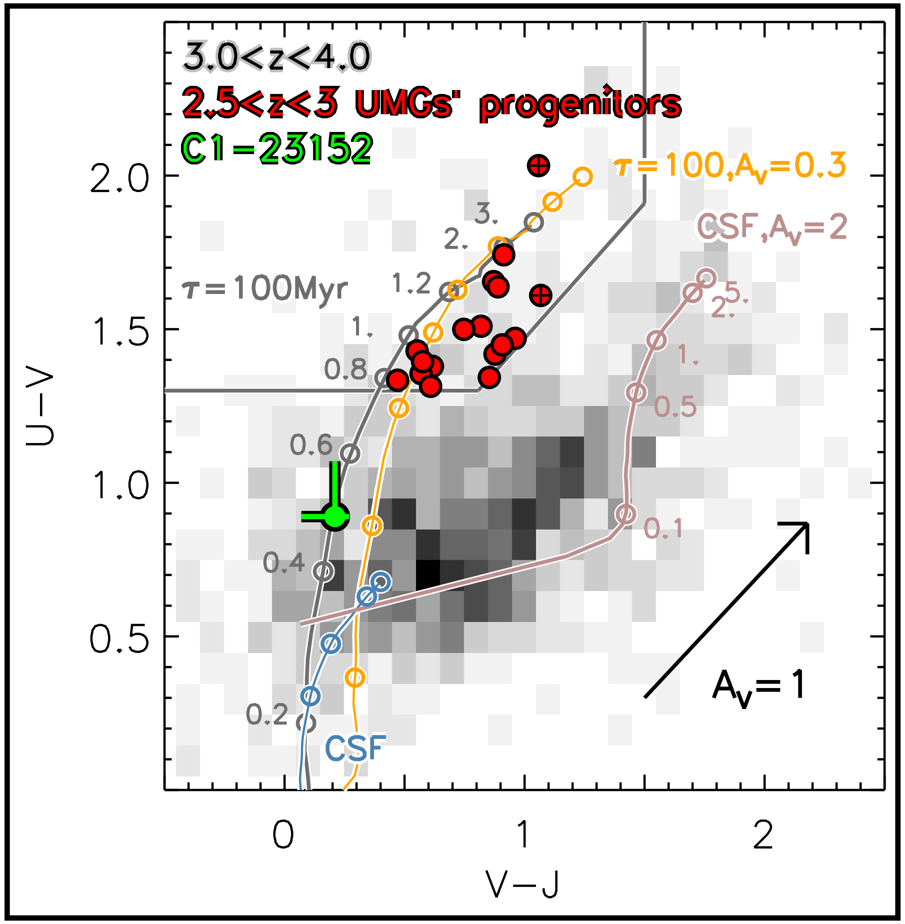
log(sSFR yr^{-1}) ~ -11

age~400 Myr

tau ~ 50 Myr

Spectroscopy of 3<z<4 Massive Galaxies

(Marsan, Marchesini, et al., 2015)



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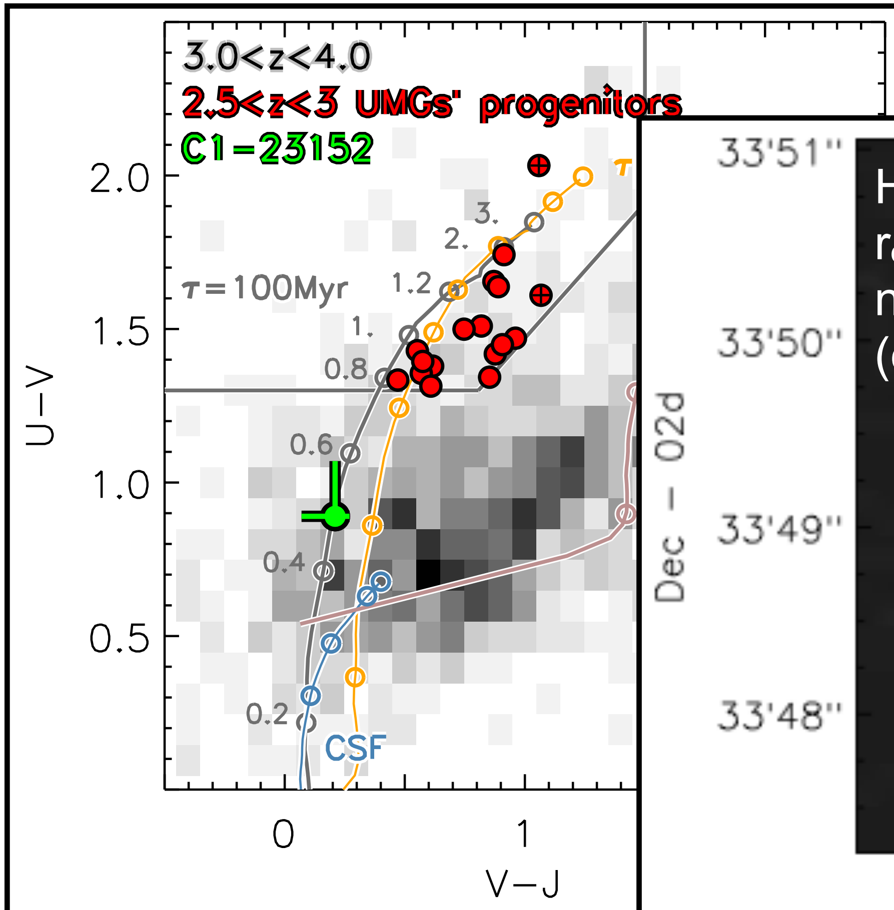

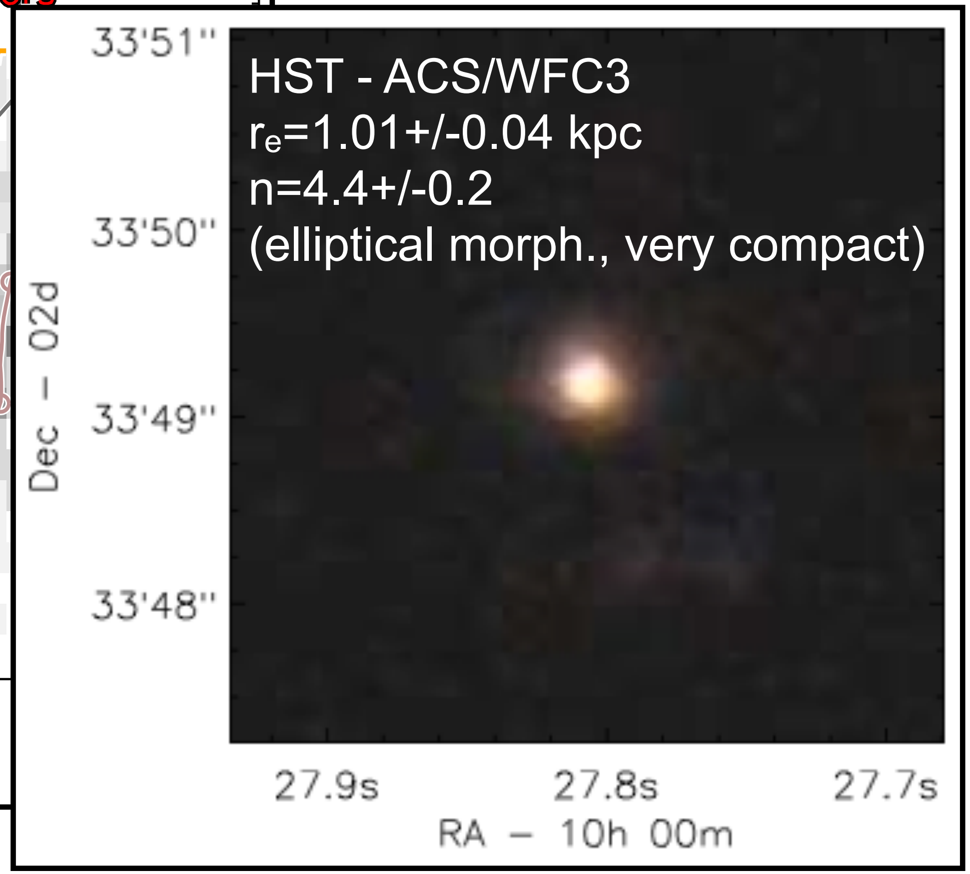

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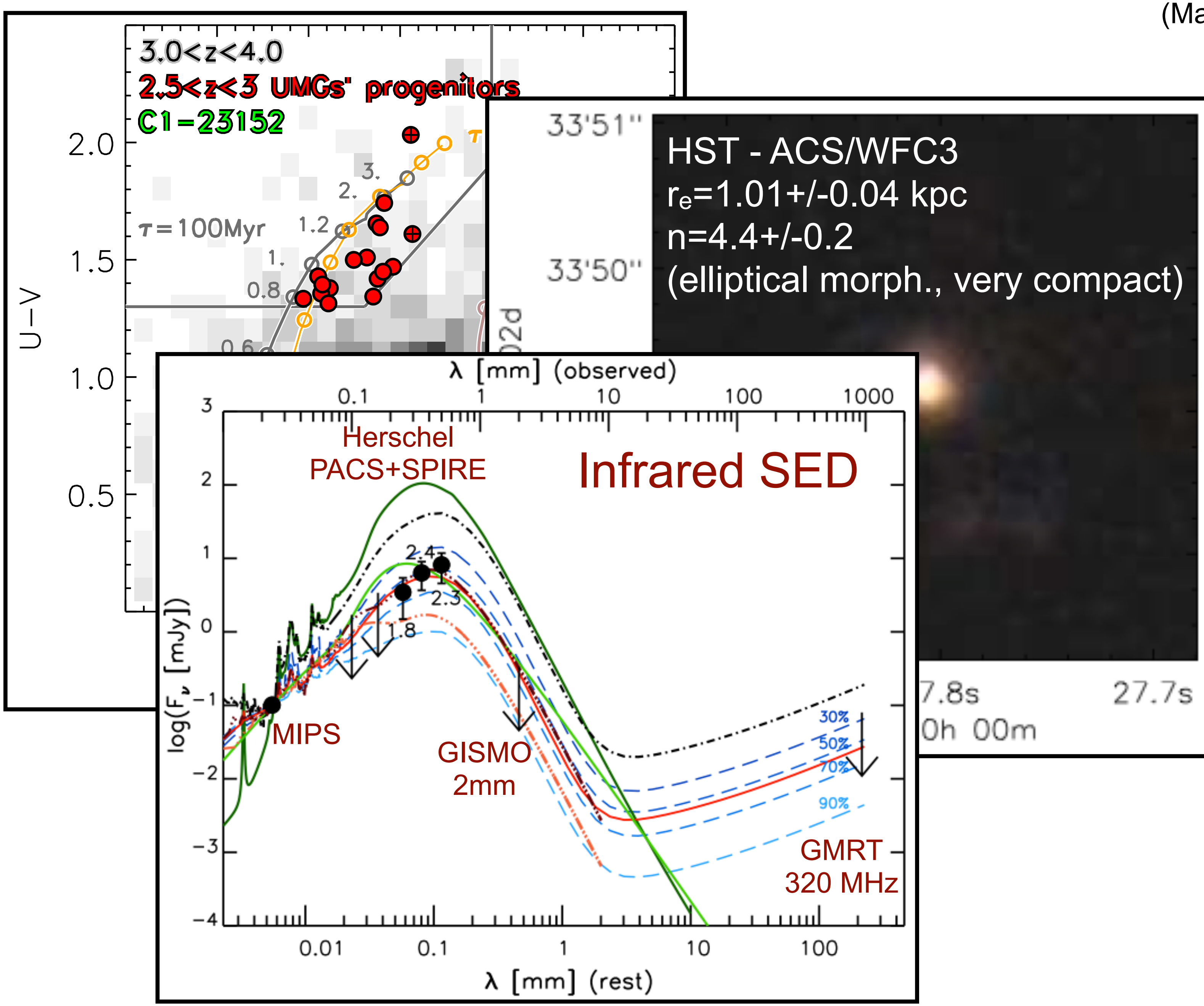

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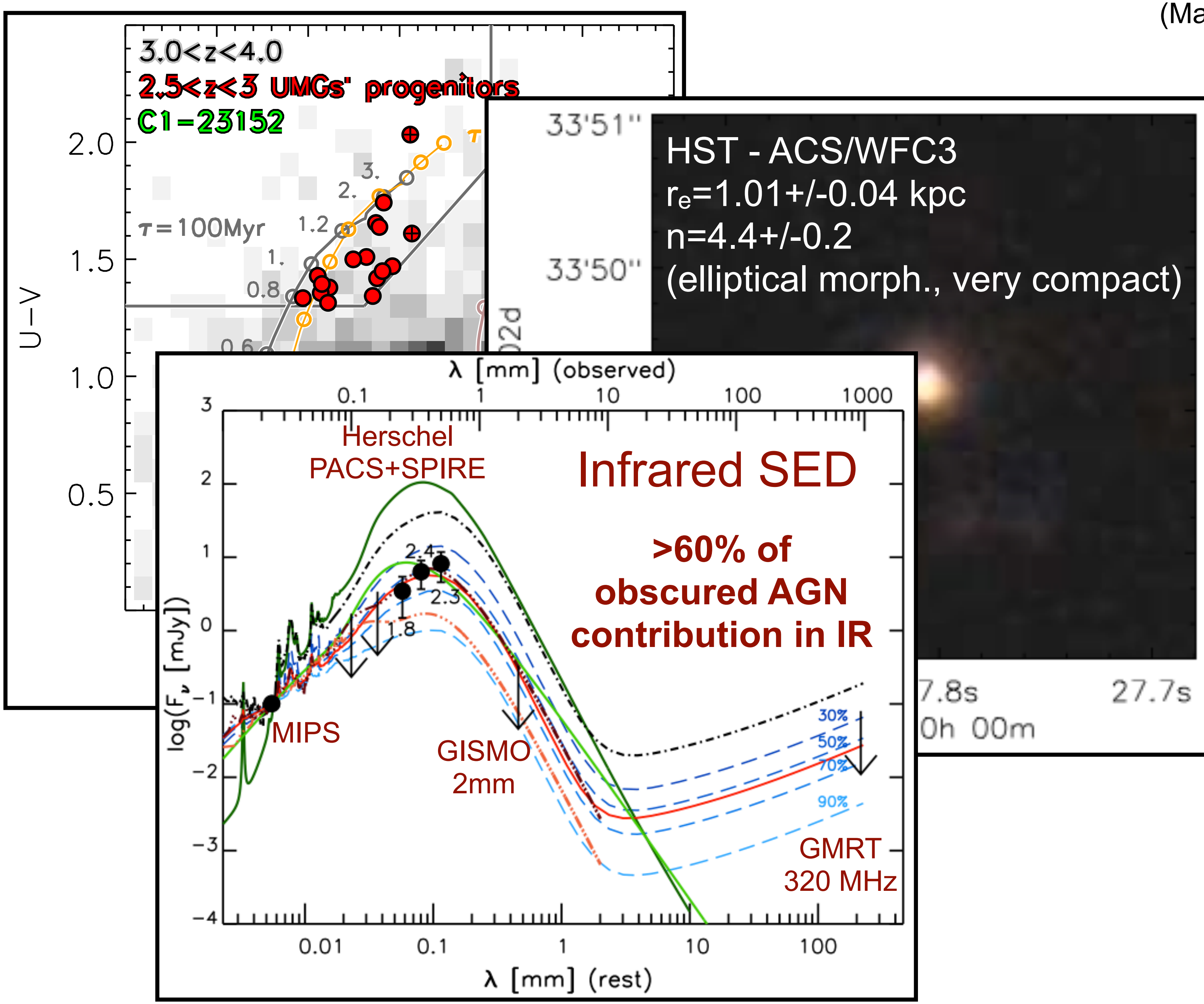
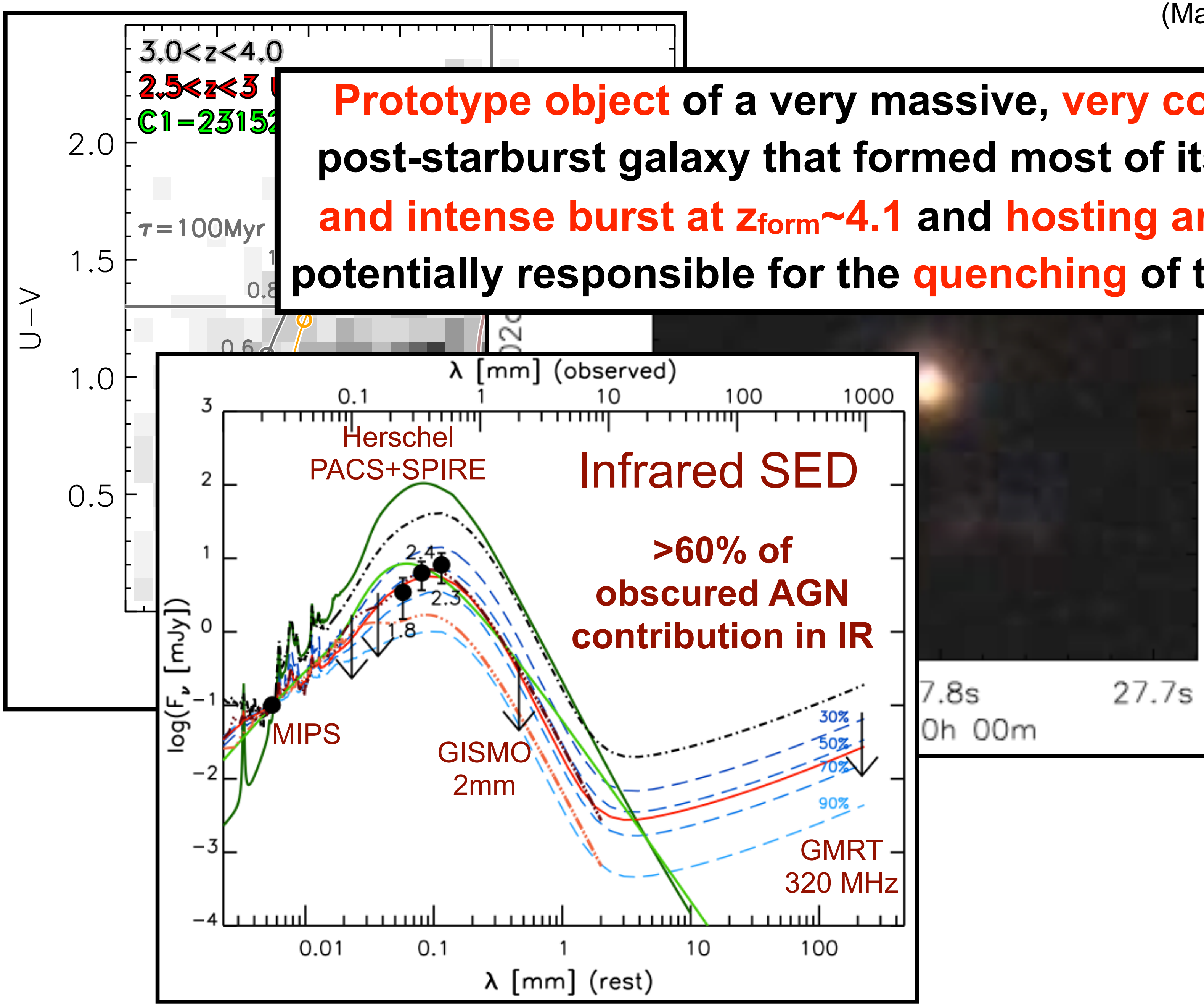


Spectroscopy of 3<z<4 Massive Galaxies

(Marsan, Marchesini, et al., 2015)

Prototype object of a very massive, **very compact**, (almost) post-starburst galaxy that formed most of its stars in a **short and intense burst at z_{form}~4.1** and **hosting an obscured AGN**, potentially responsible for the **quenching** of the star-formation.



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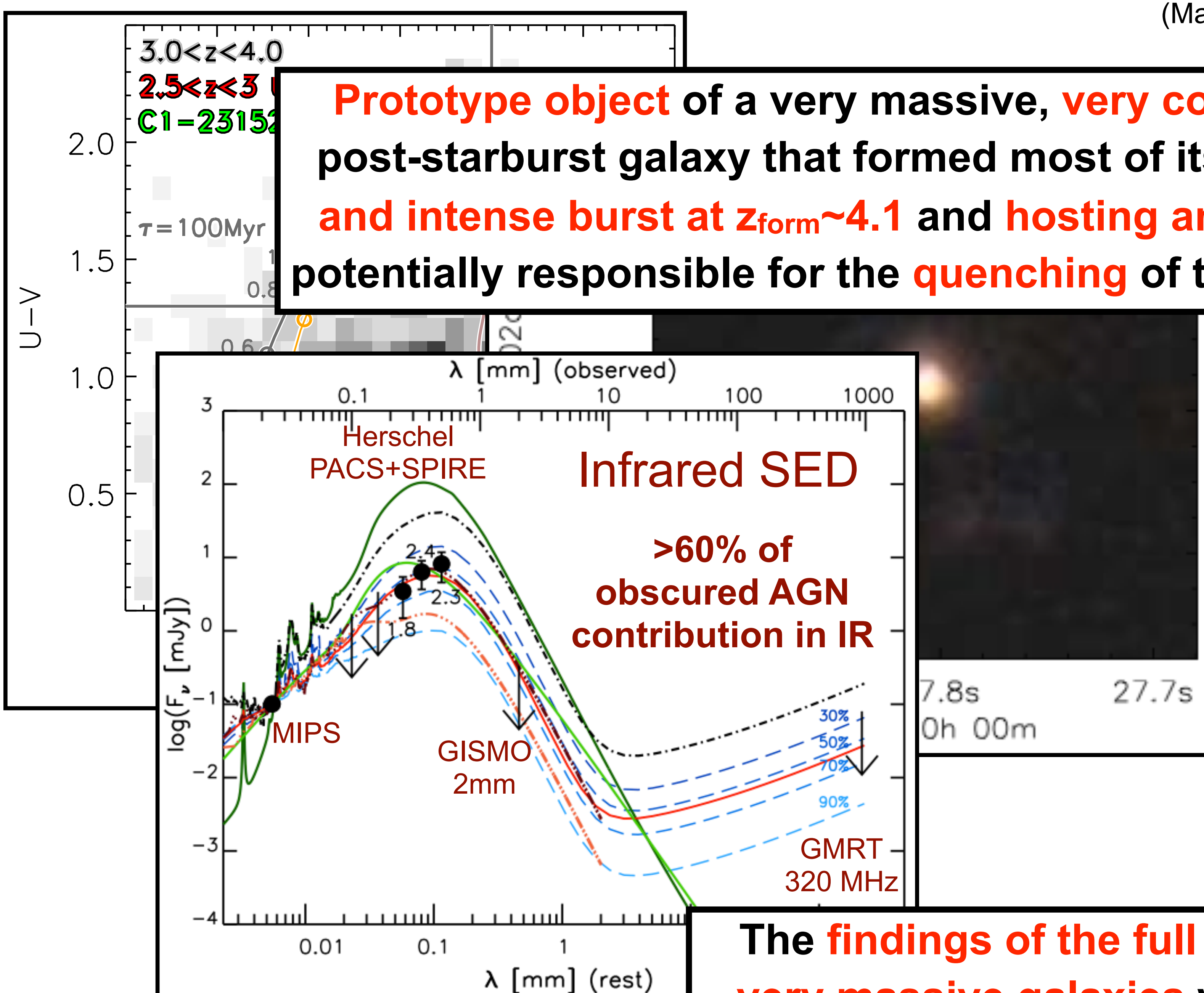
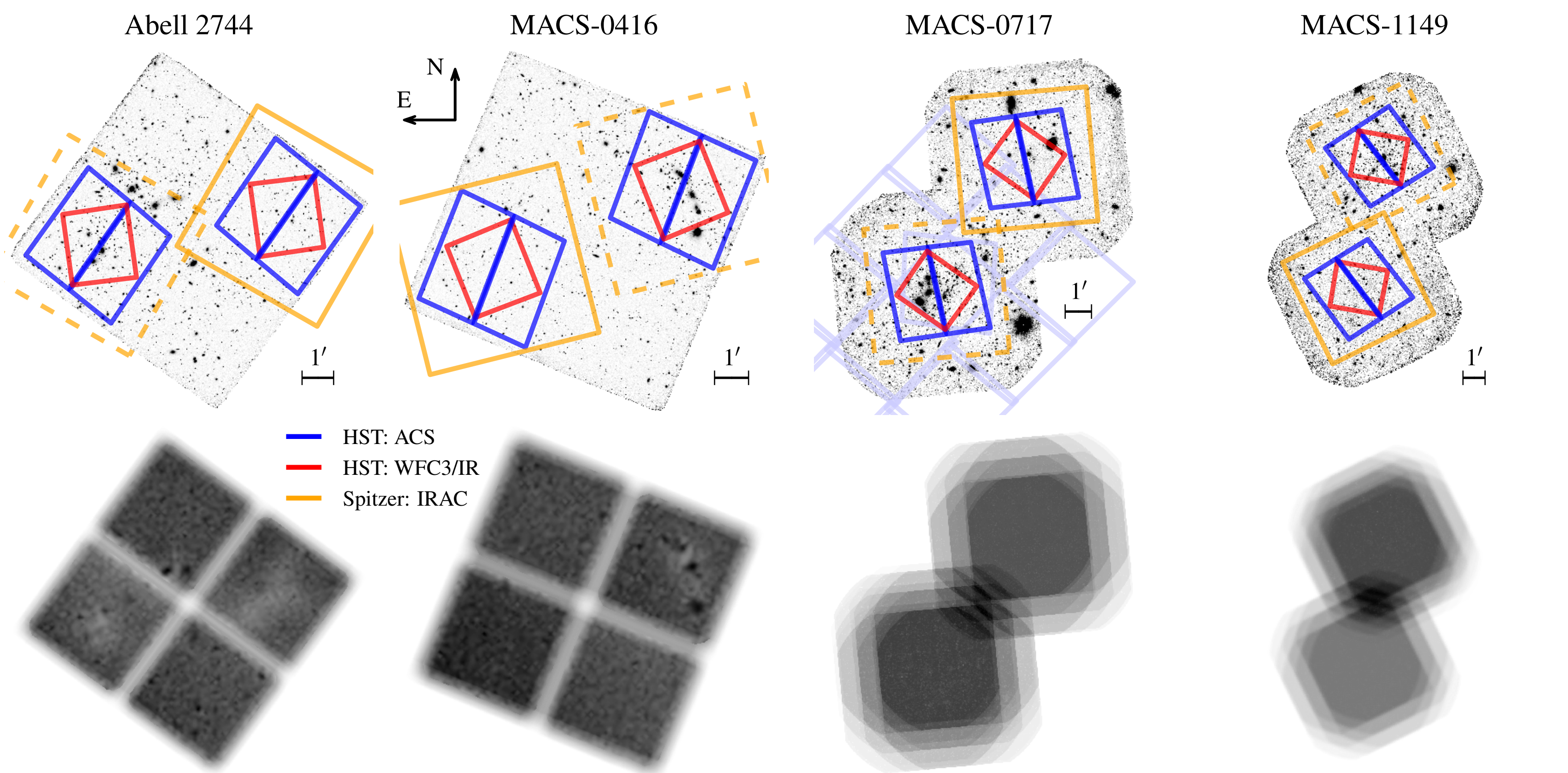


The **findings of the full sample of 3<z<4 very massive galaxies** will be published before the end of the summer - **stay tuned...**

Ultra-deep K-band coverage of HFF

PIs: Brammer & Marchesini



- 160 hrs of VLT+HAWK-I (P92, P95).
  A2744, MACS-0416 observed in P92: reduced mosaics publicly released (FWHM=0.4", depth 26.3 AB 5-sigma); AS1063 and A370 scheduled in P95
- 14 hrs of KECK+MOSFIRE (2015A) on MACS-0717 and MACS-1149
  Currently FWHM=0.4"-0.6", ~0.3-1 mag shallower than A2744/MACS0416...
  but 2 more Keck nights to be proposed for in 2015B for completion...

Summary

- The **evolution of the progenitors of local UMGs** has been **investigated since z=3 with UltraVISTA**, providing a complete and consistent picture of how the most massive galaxies in the local universe have assembled in the last 11.4 Gyr.
- **Local UMGs have grown** by 0.56 dex, 0.45 dex, and 0.27 dex from z=3, z=2, and z=1, respectively, to z=0, growing **by a factor of ~2-3.6 in the last 11.4 Gyr**.
- At z<1, the progenitors are all quiescent, while at z>1 the contribution from star-forming galaxies progressively increases.
- **At 2<z<3, the progenitors are dominated by massive (~2x10^{11} M_{Sun}), dusty (A_V~1-2.2 mag), star-forming (SFR~100-400 M_{Sun}/yr) galaxies**.
- **At z=2.75, ~15% of the progenitors are quiescent, with properties typical of massive, young, post-starburst galaxies with little dust extinction and strong Balmer breaks and large intrinsic scatter in U-V colors**.
- The very massive end of the local red-sequence population had been mostly assembled between z=3 and z=1, in good agreement with the typical formation redshift and scatter in age from fossil records.
- **The progenitors of z~0 UMGs have never lived on the blue cloud since z=3**, challenging previously proposed pictures for the formation and evolution of local massive spheroids.
- Presented **first spectroscopic confirmation of an ultra-massive galaxy at z>3** (z_{spec}=3.351) with M_{star}=3x10^{11} M_{Sun}, compact (r_e=1 kpc) and n~4.4, hosting a powerful hidden AGN, with z_{form}~4.1: prototype of the progenitors of local most massive ellipticals.