# Clues on Massive Galaxy Formation at z~2.5 from Near-Infrared Spectroscopy

**Mariska Kriek (Leiden/Yale)**

Pieter van Dokkum, Marijn Franx, Garth Illingworth, Eric Gawiser, Ivo Labbe, Paulina Lira, Danilo Marchesini, Ryan Quadri, Meg Urry,Greg Rudnick, Ned Taylor & the MUSYC collaboration

University of California, Berkeley
December 4 2006

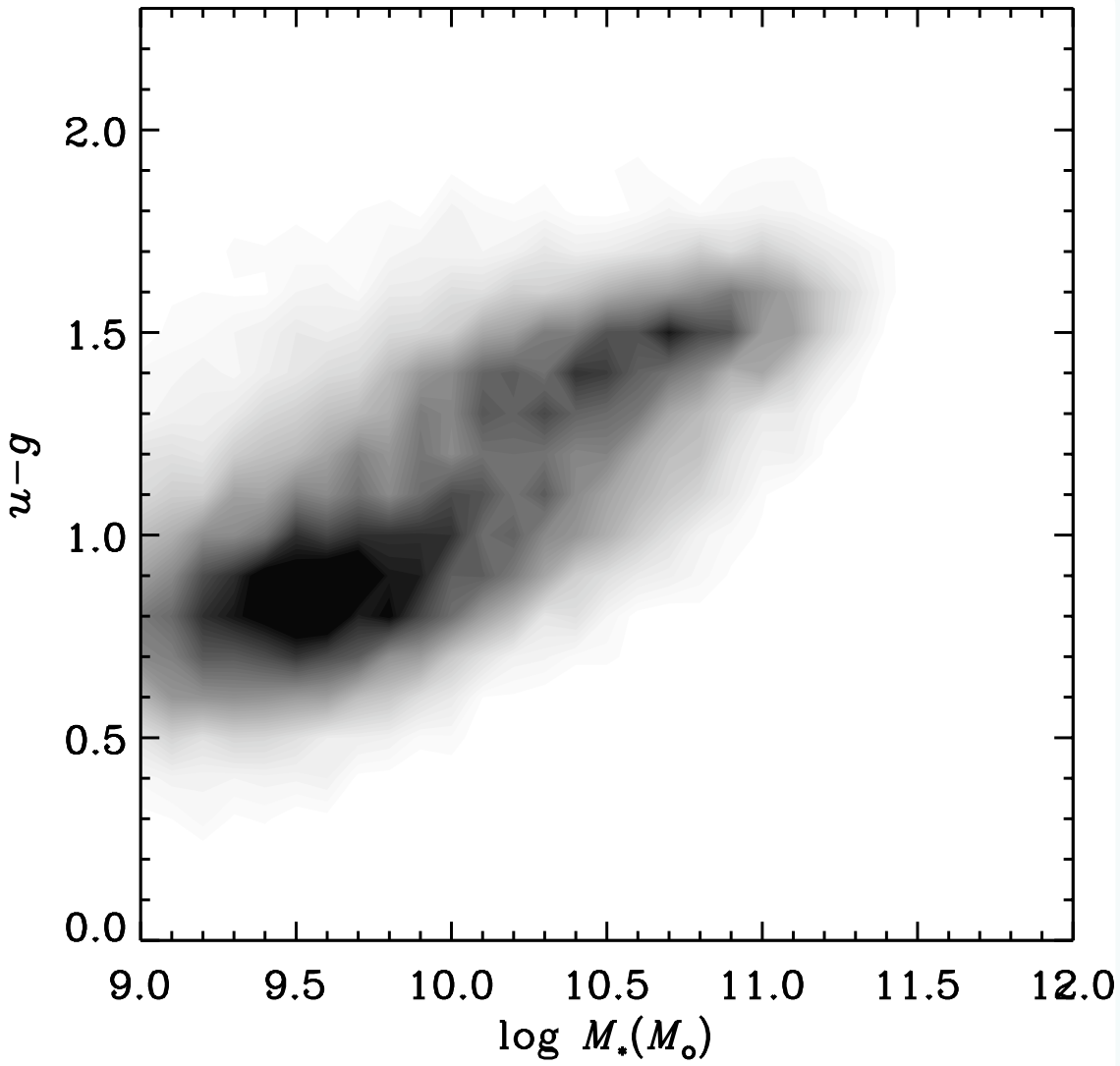
# Galaxies in the local universe



Blue star-forming disk galaxies

"red and dead" early type galaxies

# Galaxies in the local universe




NYU value added catalogue (Blanton et al. 2005)

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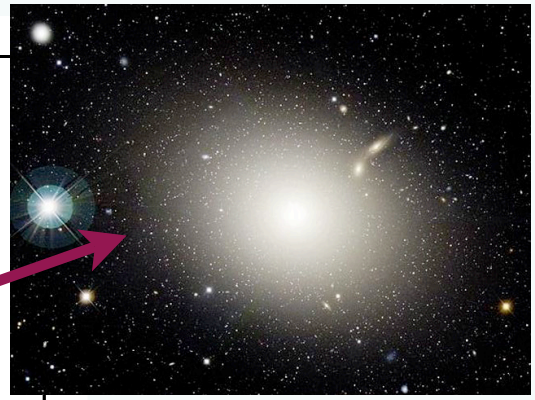

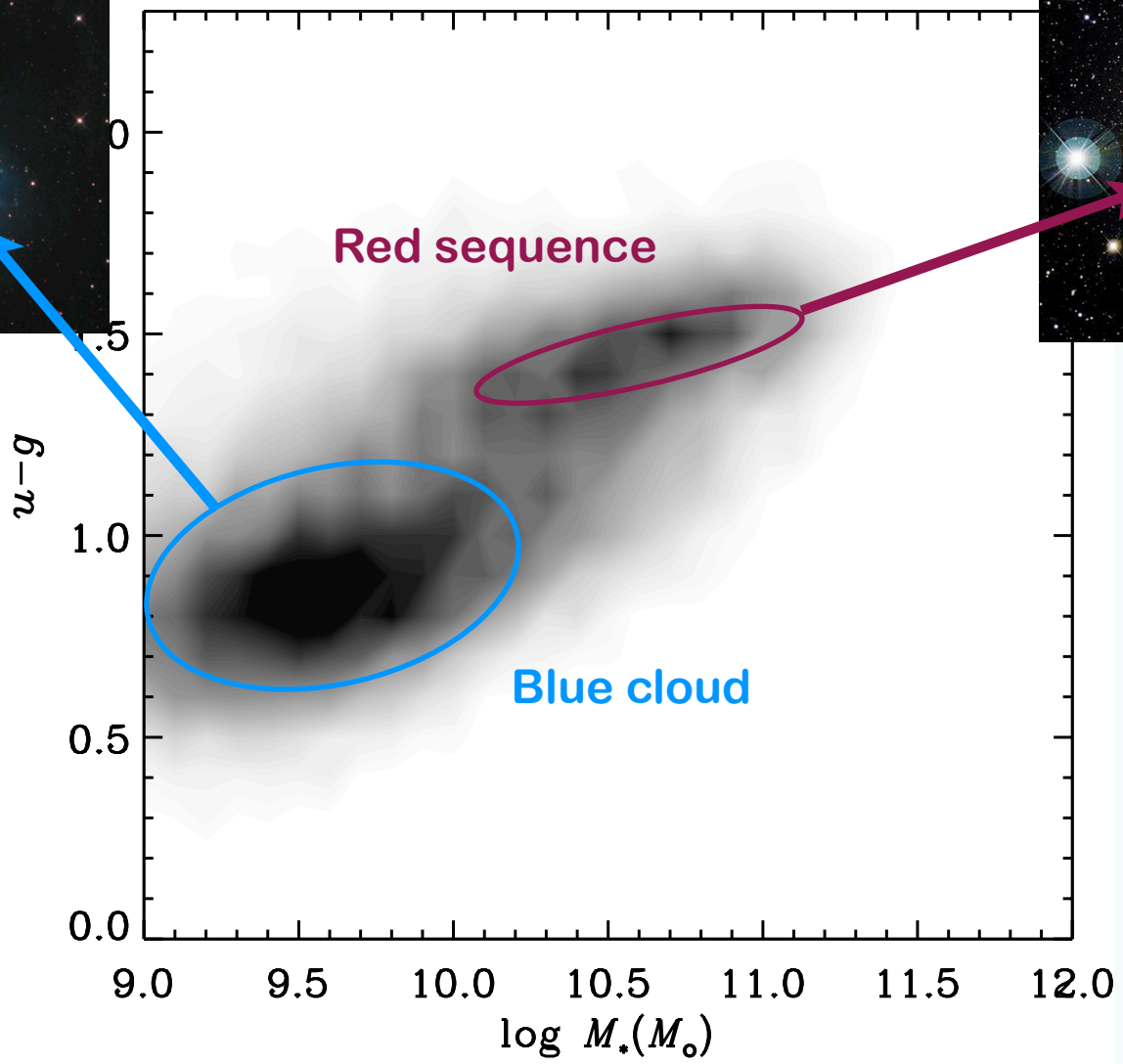


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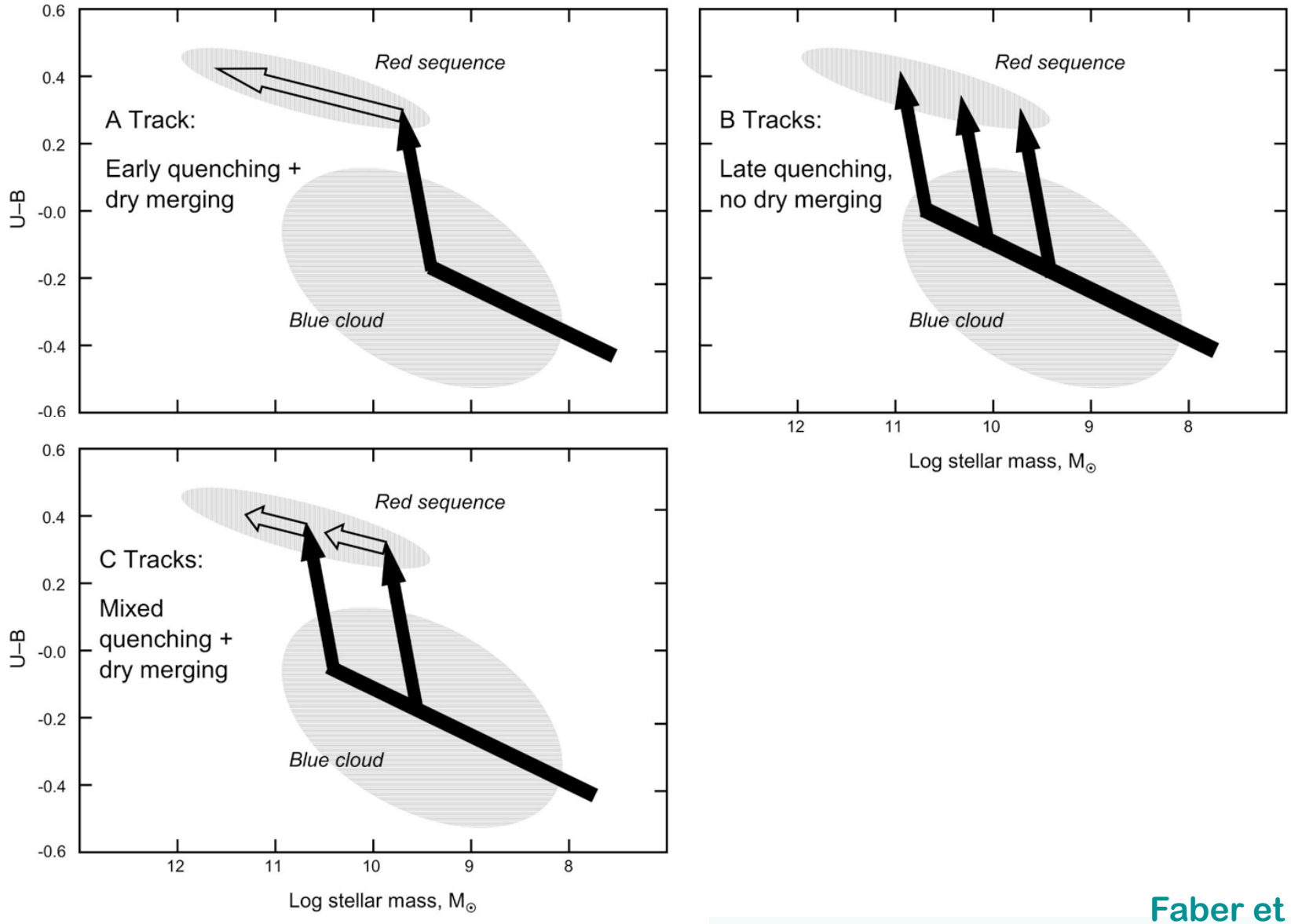
# Build-up of the red sequence




Faber et al. 2005

# Motivation

- When was the star formation in massive galaxies quenched?
- What mechanism is responsible for the migration of blue star forming galaxies to the red sequence?

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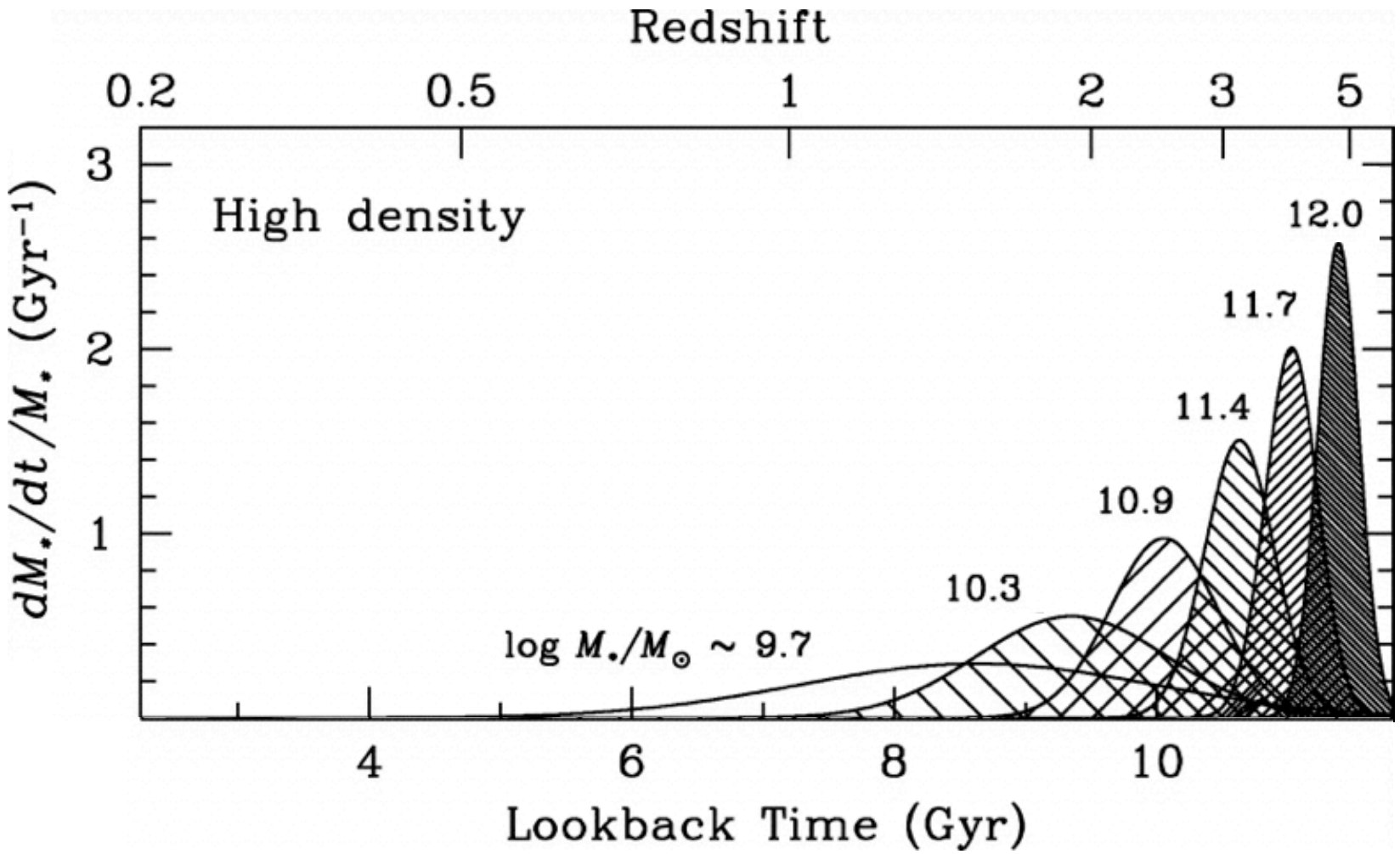
# Star formation history of galaxies

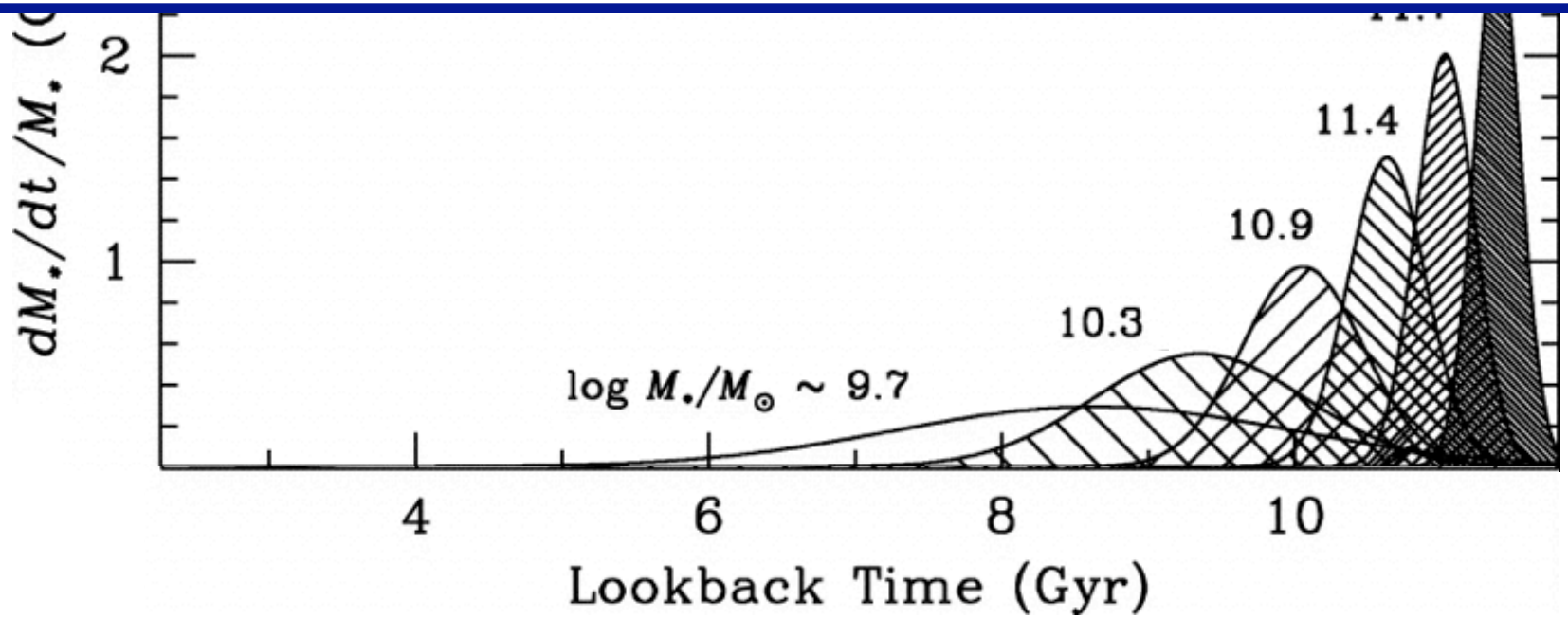



Thomas et al. 2005

# Star formation history of galaxies

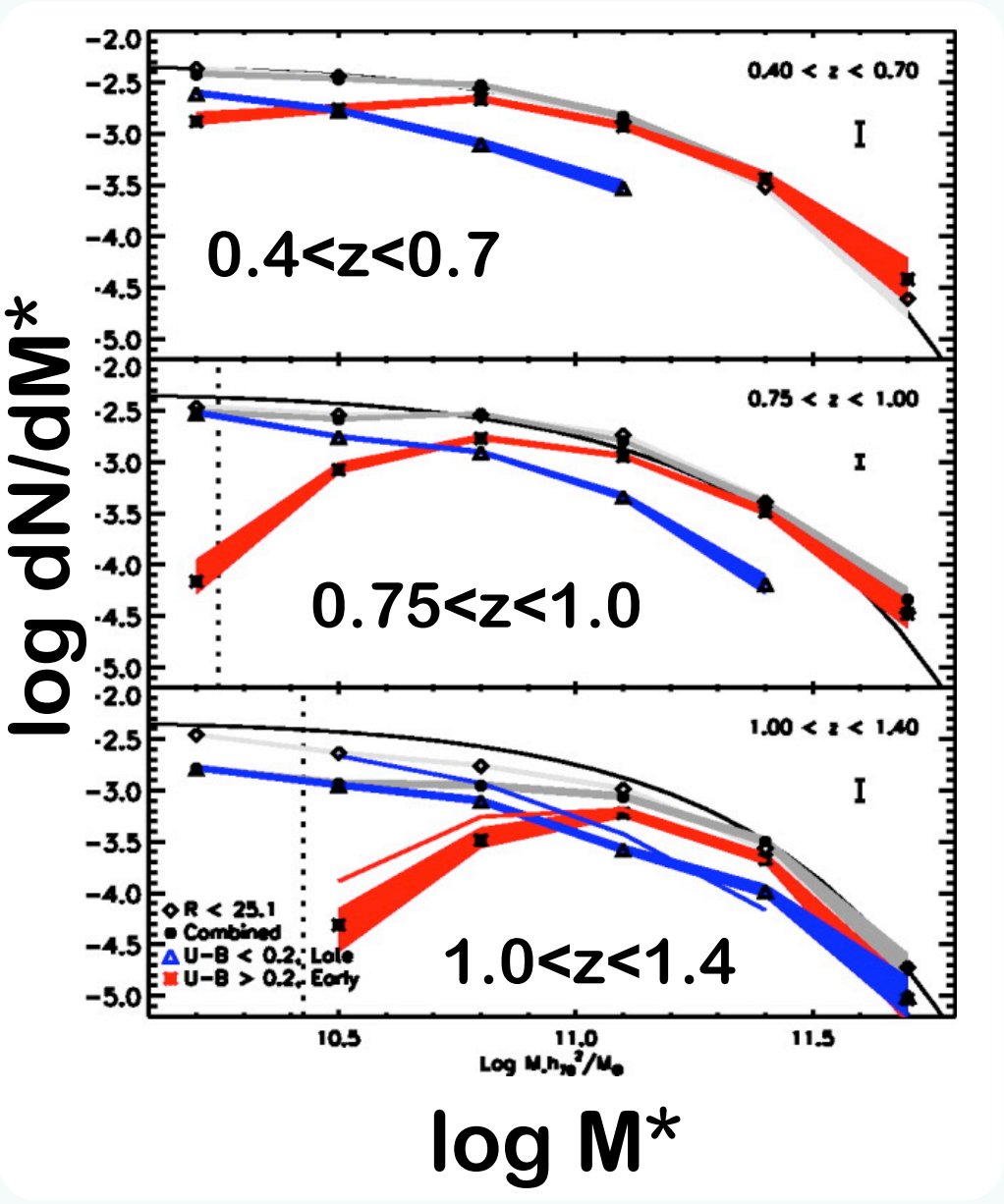
Problems:

1. Model assumptions
2. What were the stellar masses of these galaxies at the time the stars were formed?




Thomas et al. 2005

# Direct information at high redshift




More massive galaxies form their stars at higher redshift

Bundy et al. 2005

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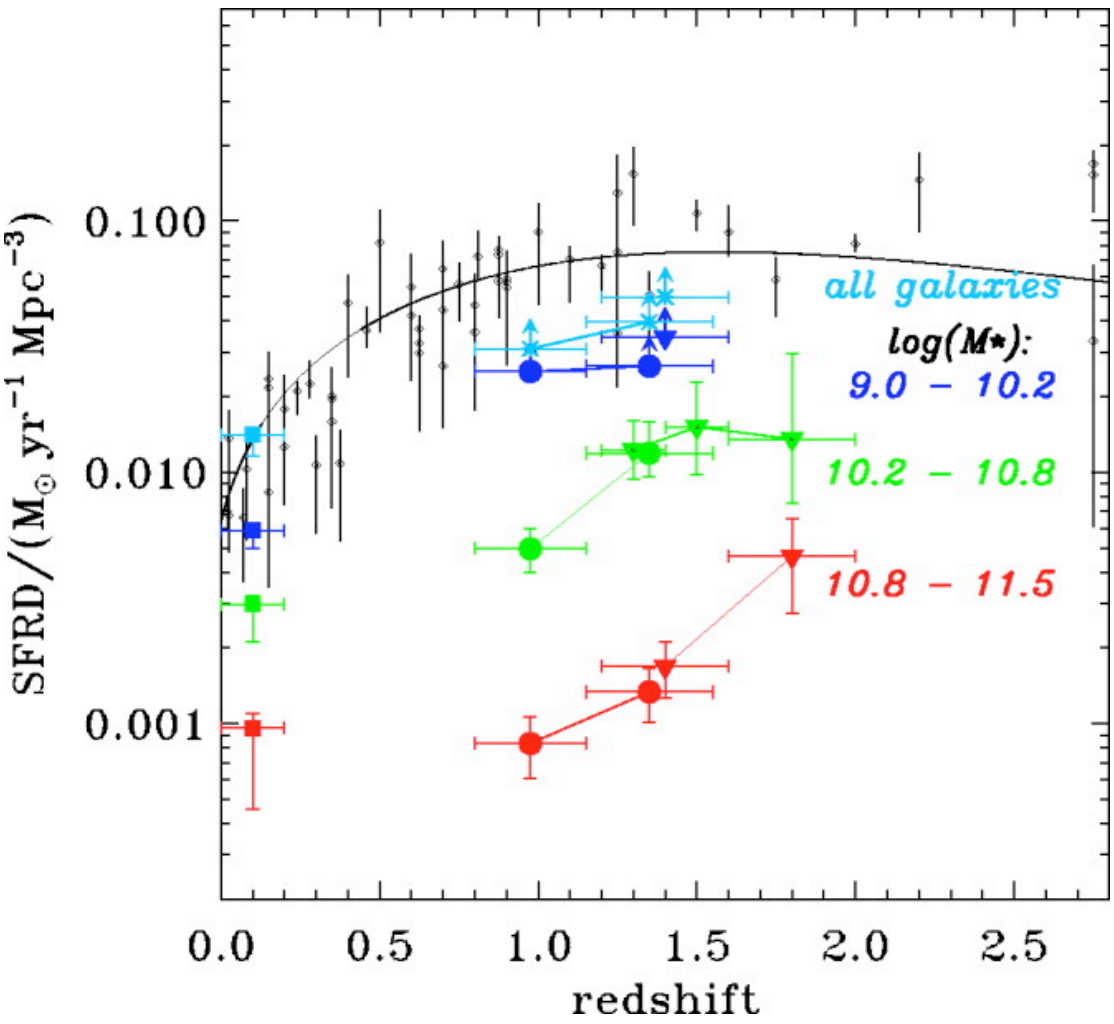
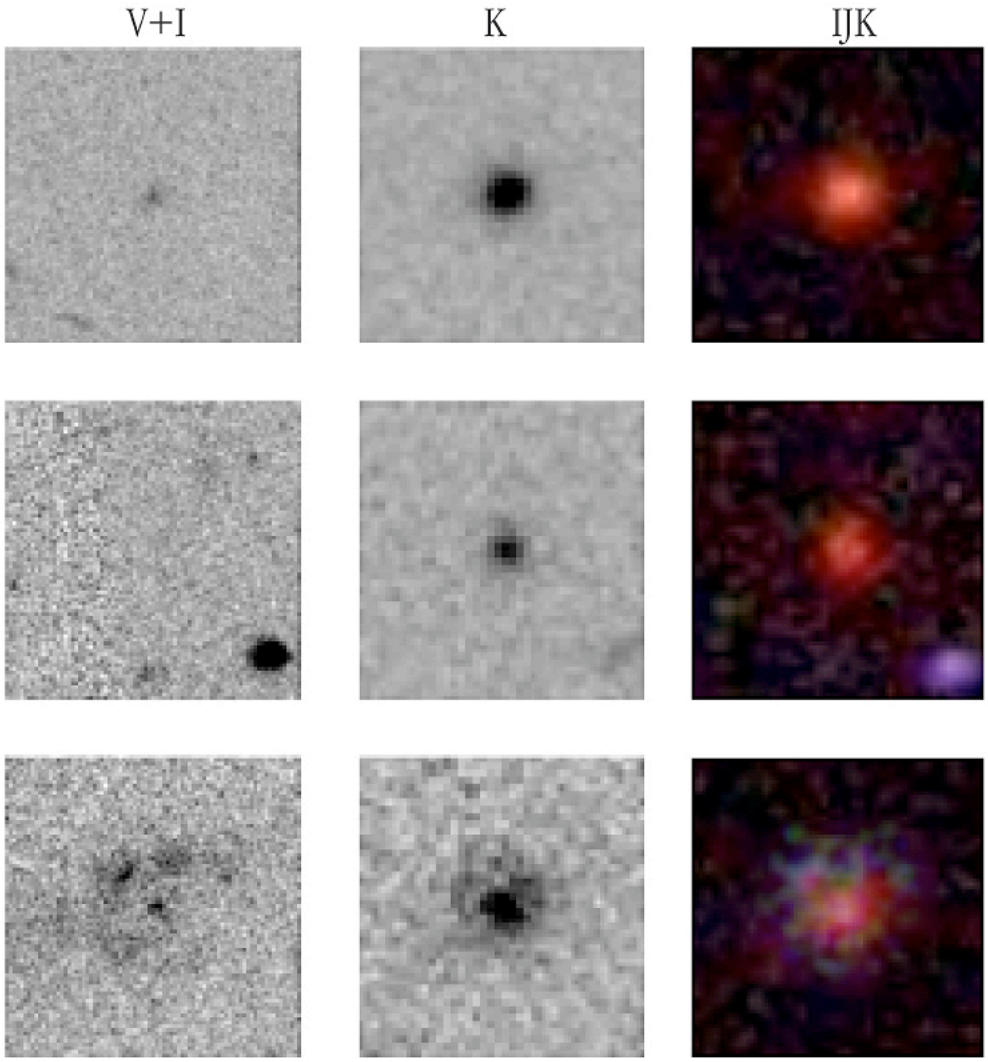



**More massive galaxies form their stars at higher redshift**

Juneau et al. 2005

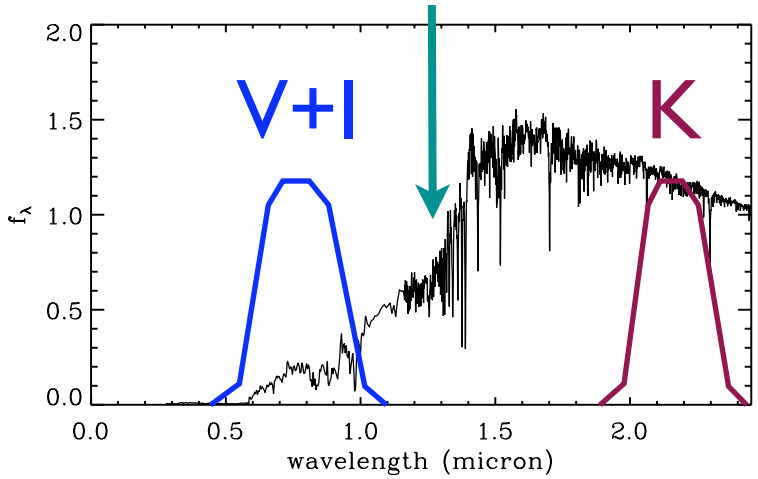
# Do evolved galaxies exist at even higher redshift?




Zeer rode compacte sterrenstelsels in HDF–S



Balmer + 4000 Angstrom Break




Labbe et al. 2003

# Motivation

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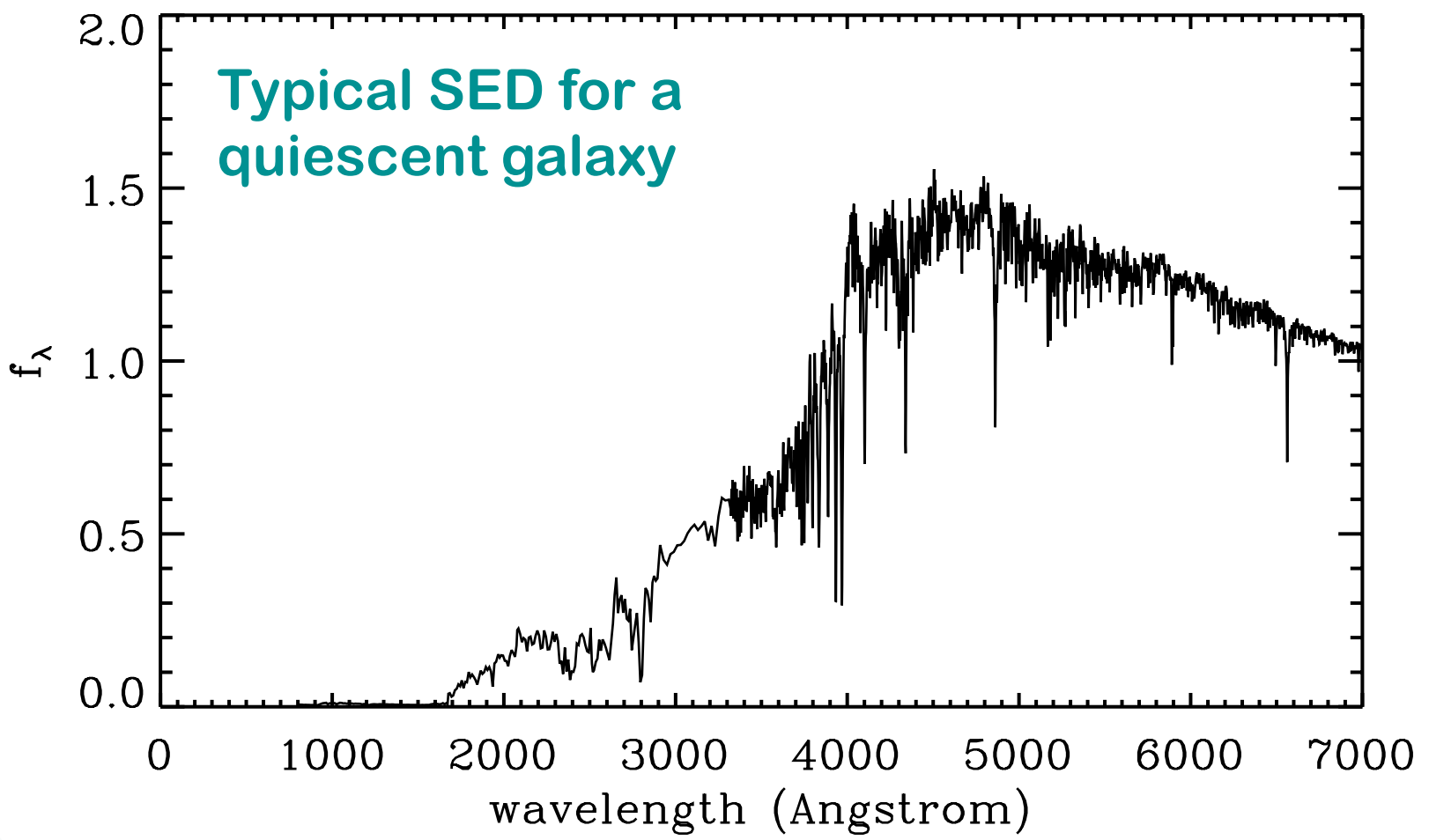
# Why is it so difficult to obtain redshifts for z>2 quiescent galaxies?



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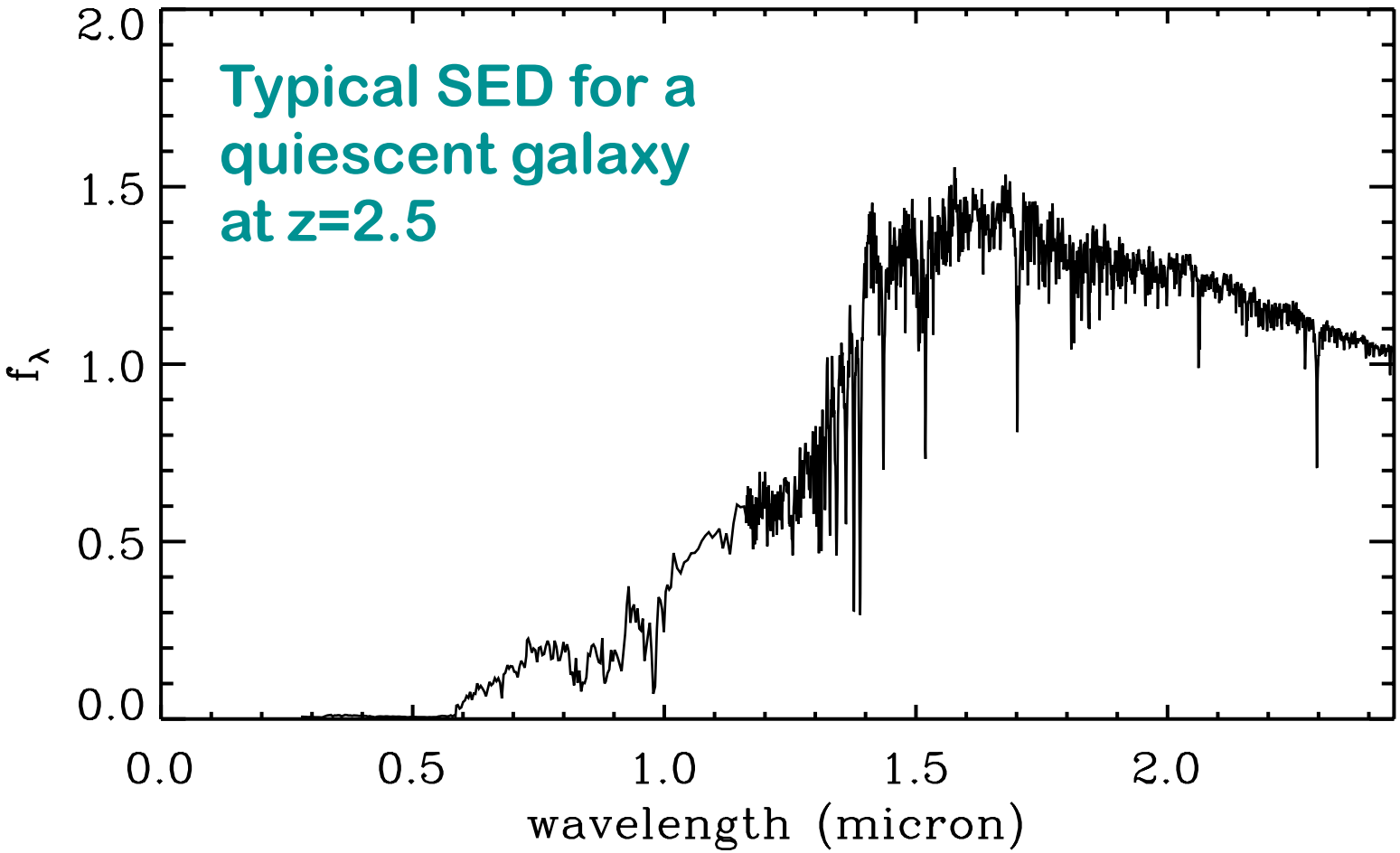

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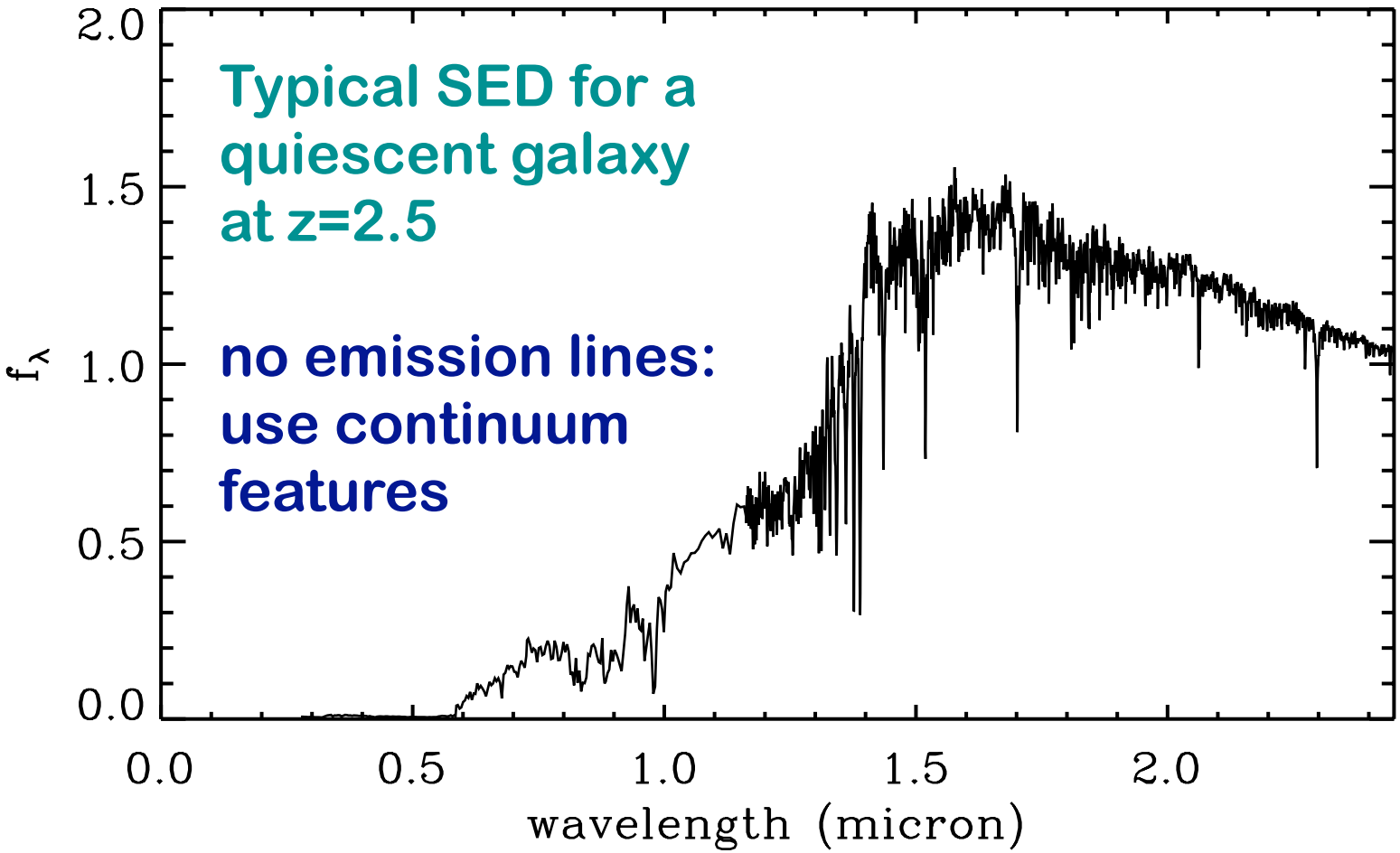

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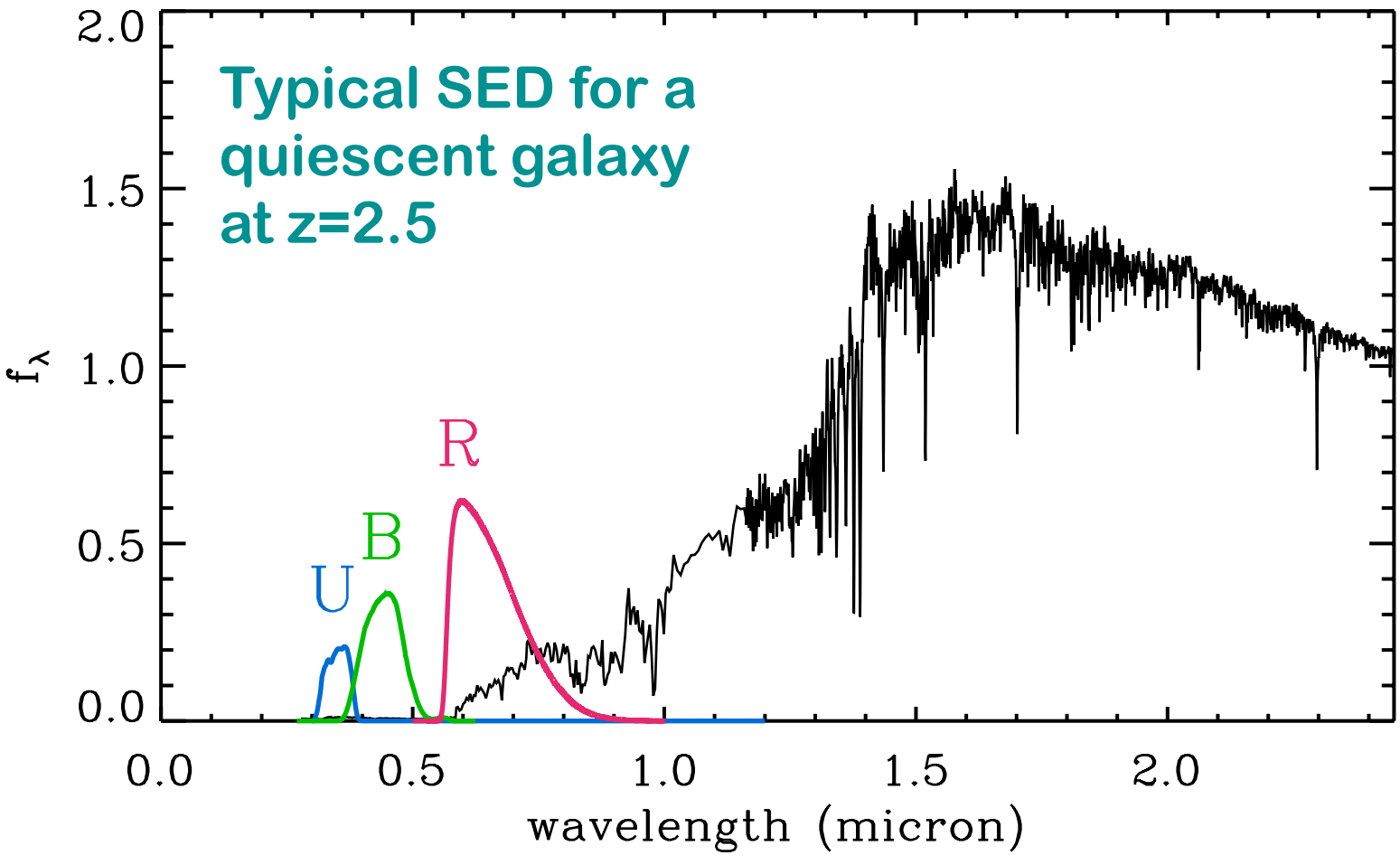

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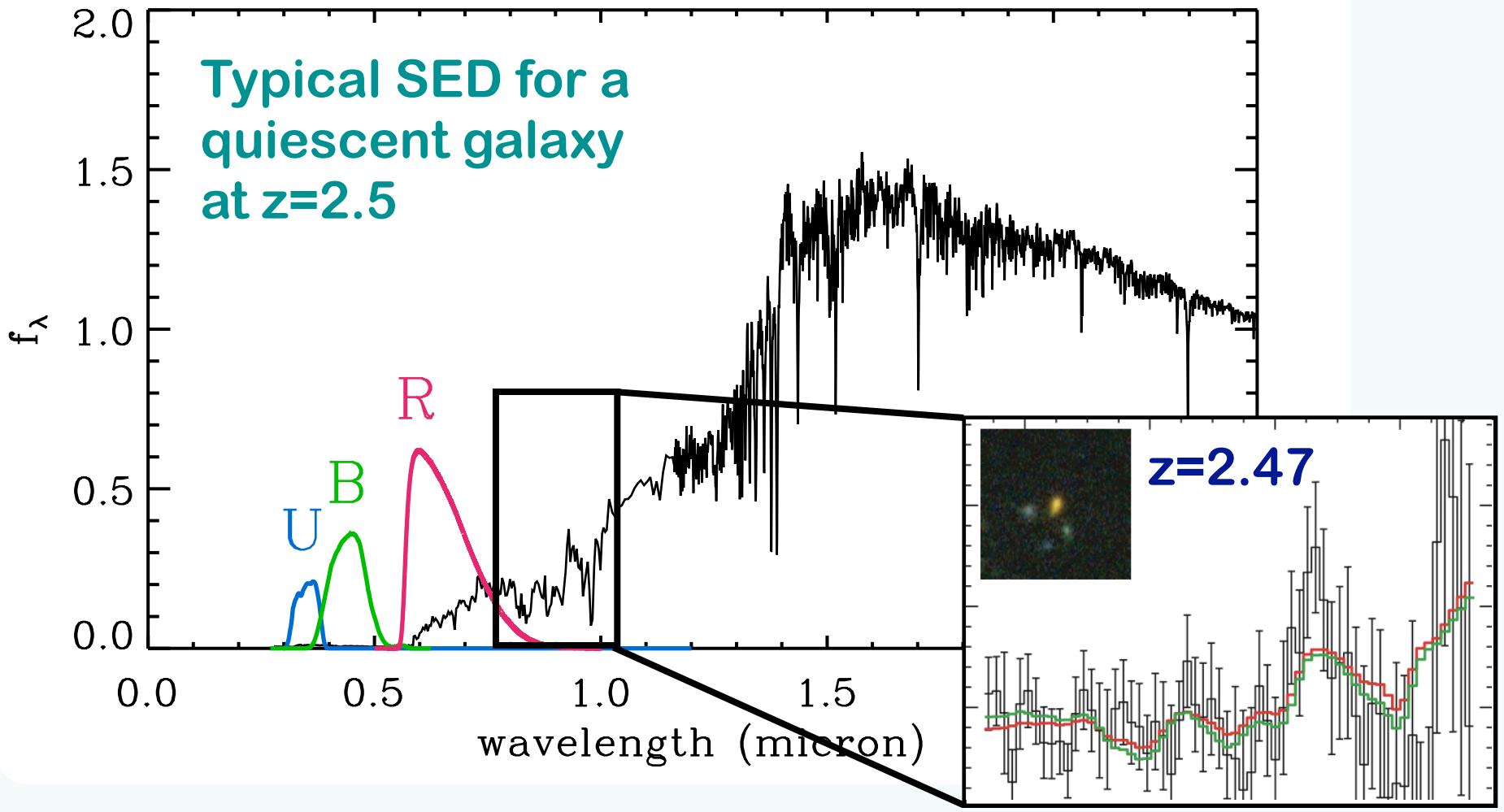


Daddi et al. 2005

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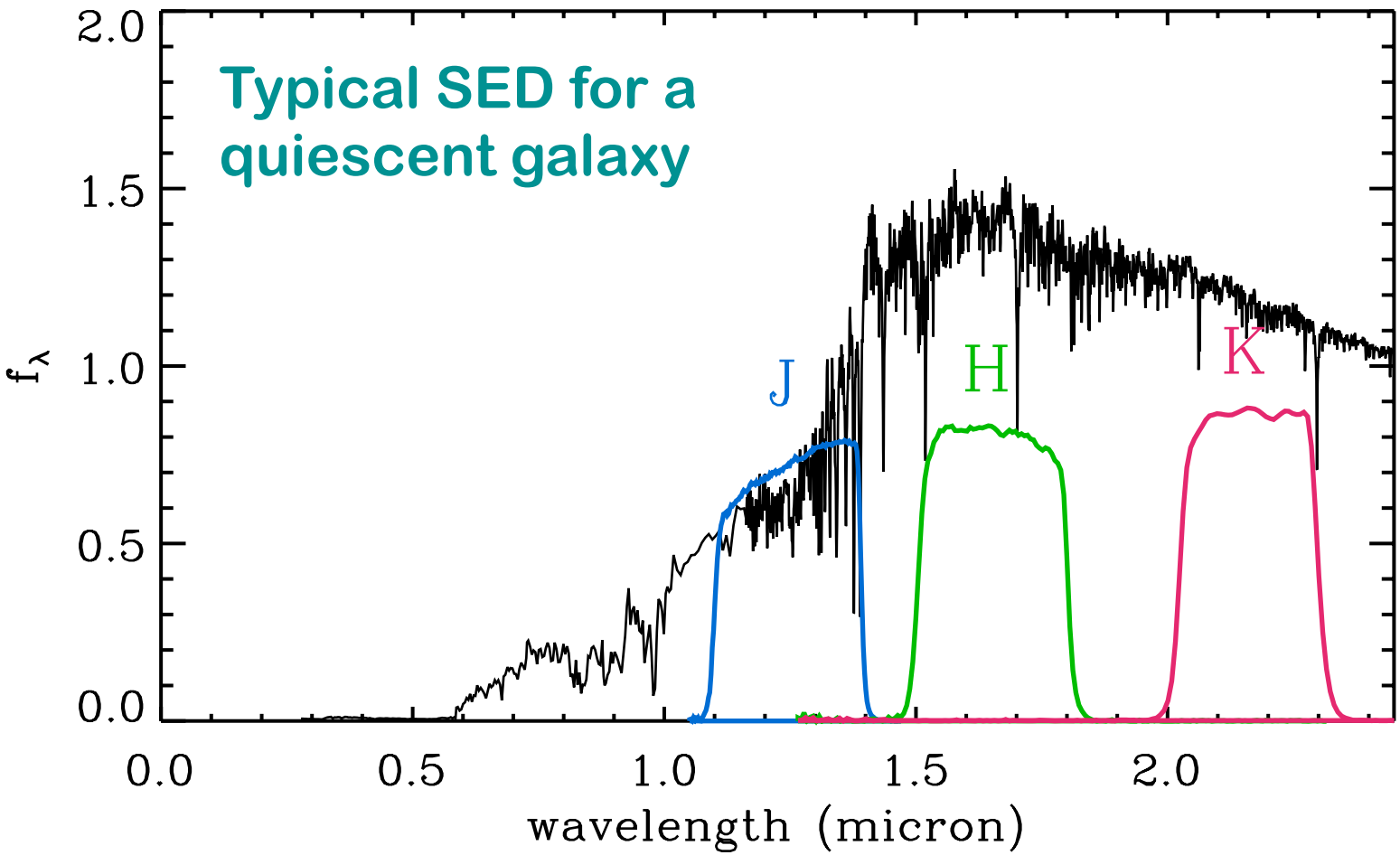
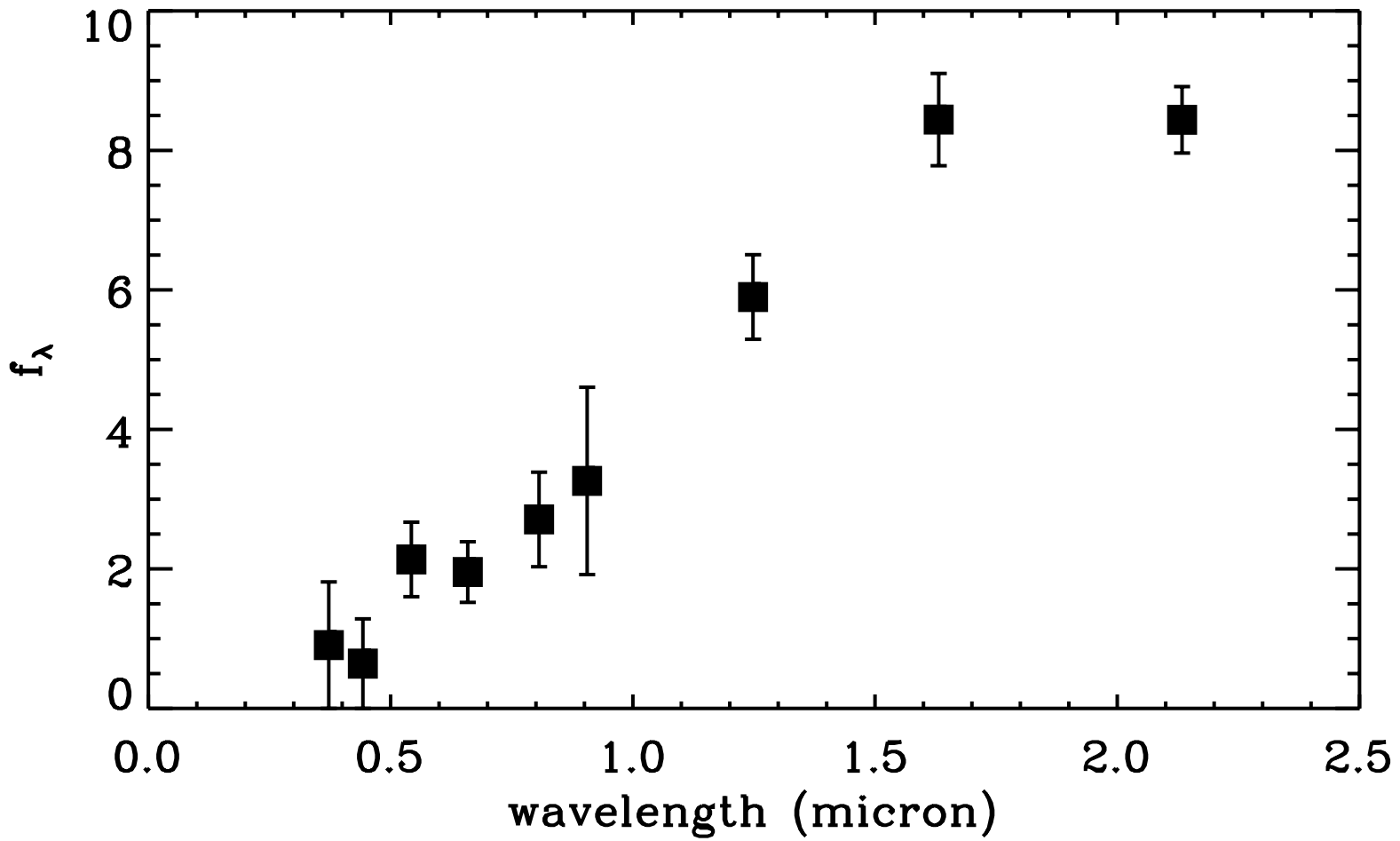


# Motivation

- When was the star formation in massive galaxies quenched?
  - Beyond z>2? (e.g., Labbe et al. 2005, Reddy et al. 2005/2006, Daddi et al. 2005)
  - Problems:
    - Most studies rely on photometric redshifts
    - Mostly broadband photometric studies

# Why are broadband photometric studies not sufficient?



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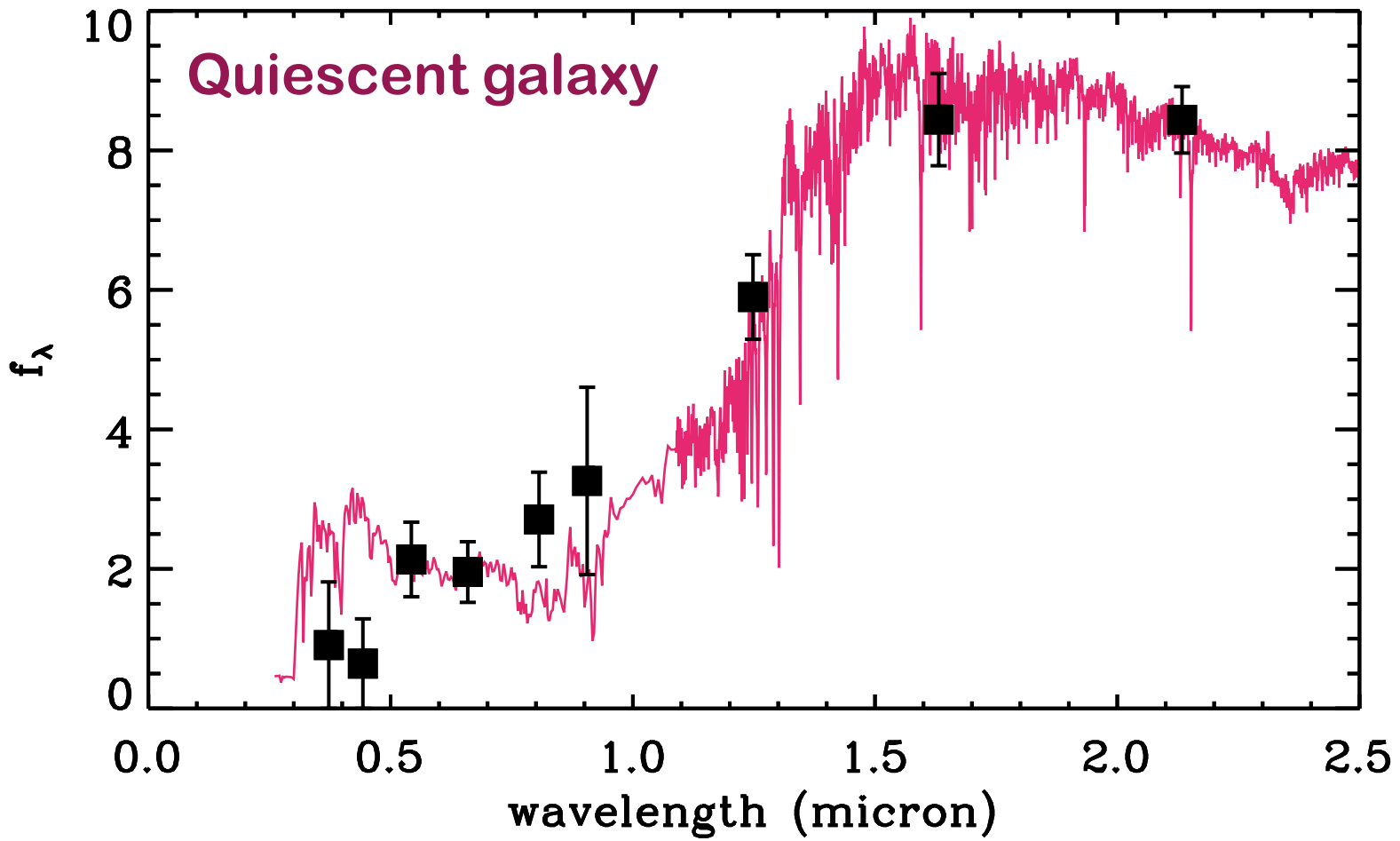

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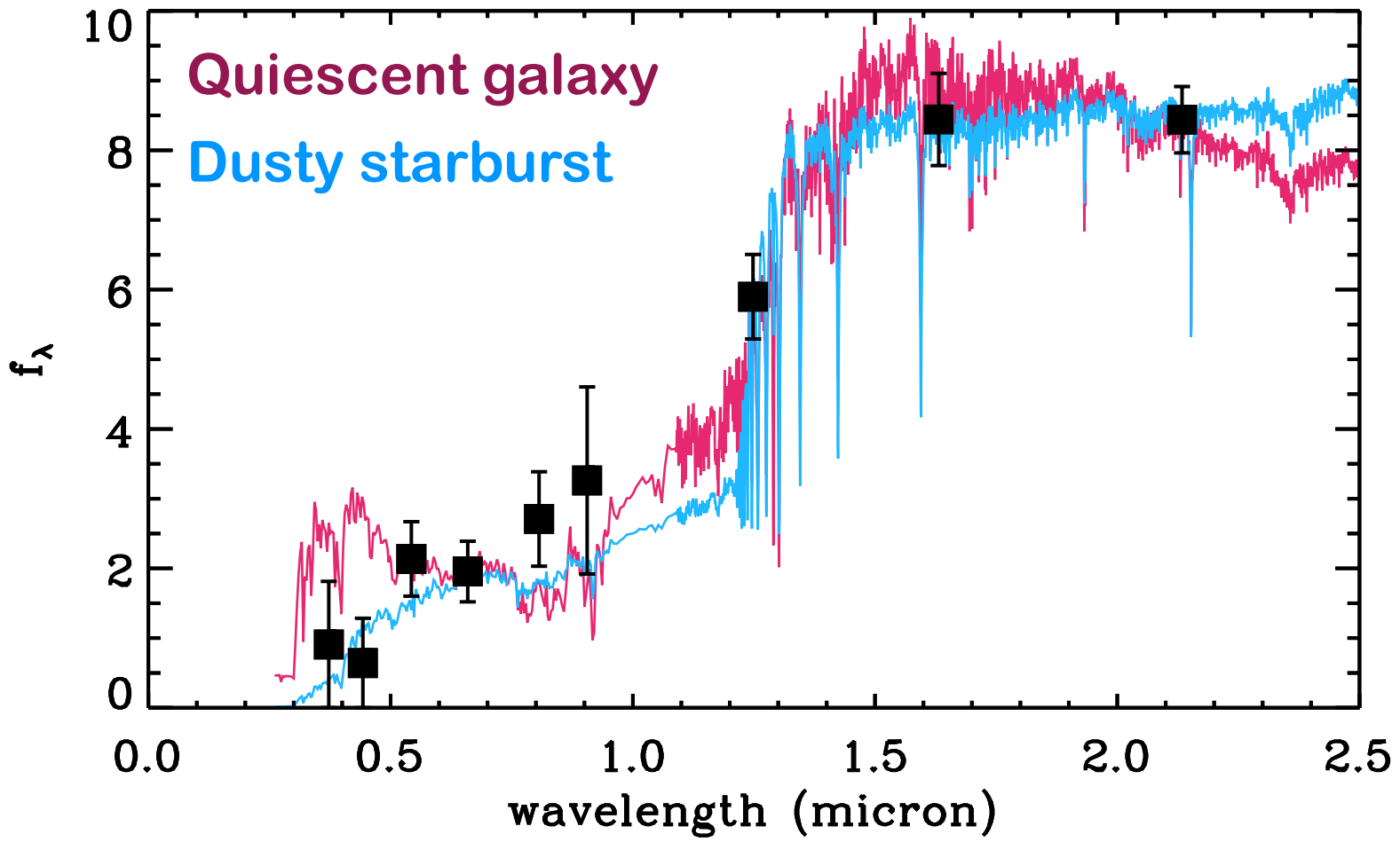
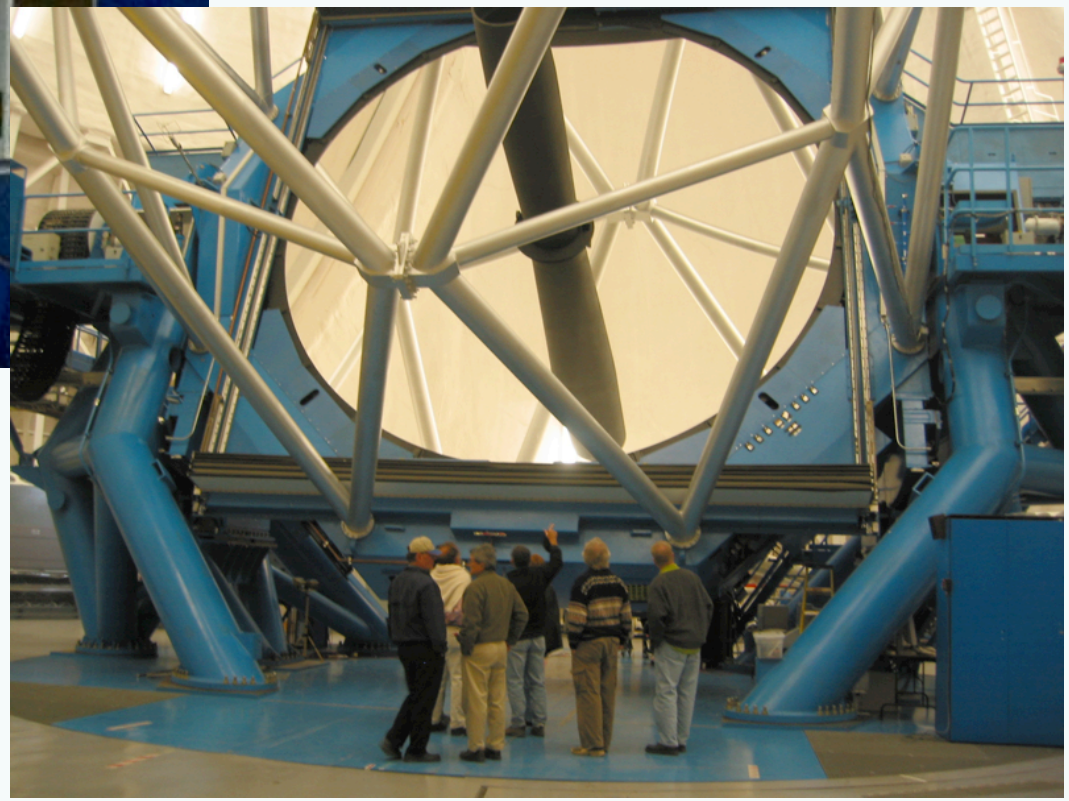


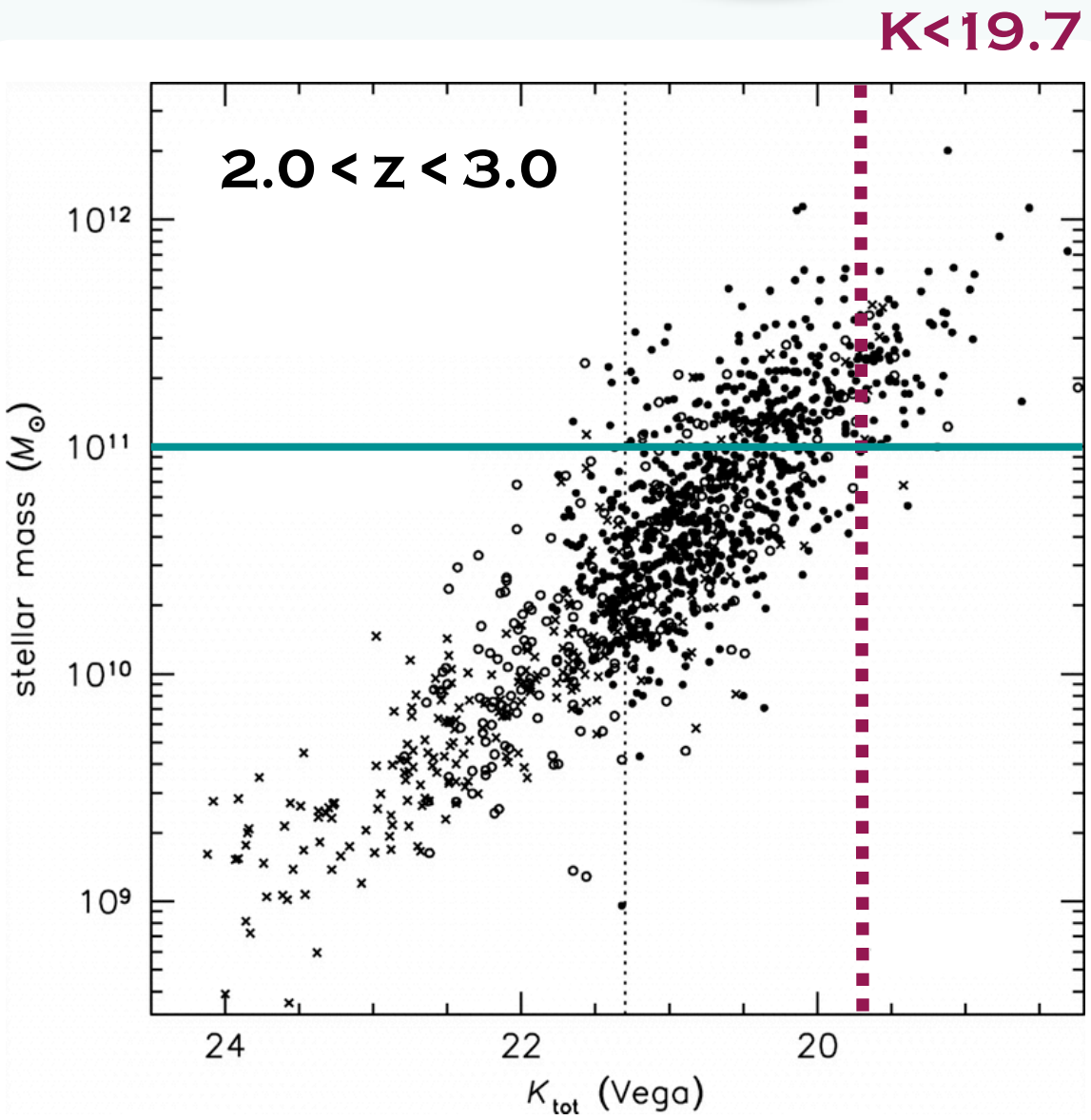
# Spectroscopic survey of massive galaxies at z~2.5 with Gemini/GNIRS

# GNIRS survey overview

- **Observation:** x-disperser 1-2.5 micron
- **Selection**
  - 2.0 < z_phot < 2.7 (MUSYC photometry)
  - K-selected (<19.7)

# Stellar mass vs. K-magnitude



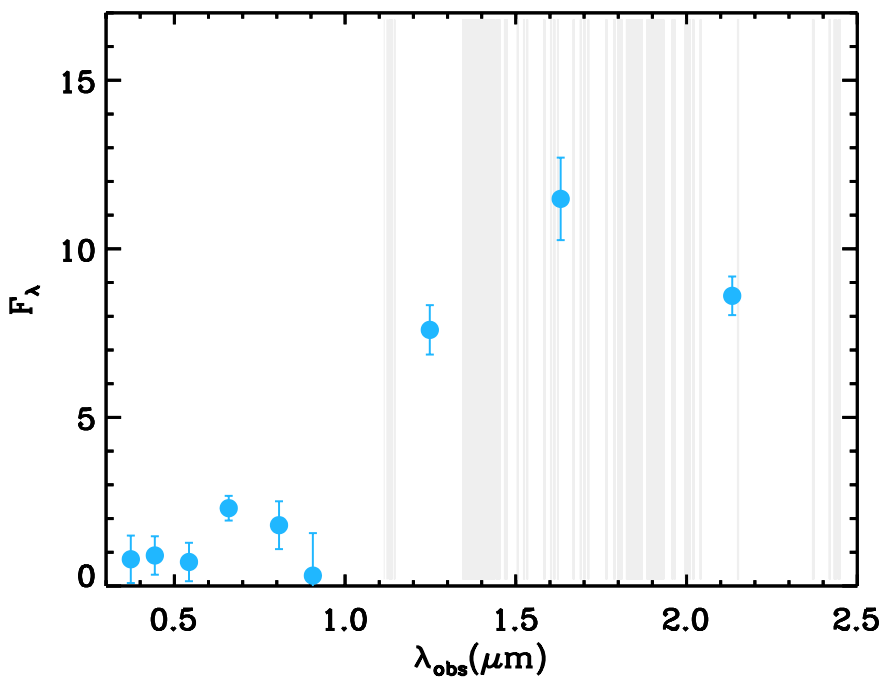

M > $10^{11}$ $M_\odot$

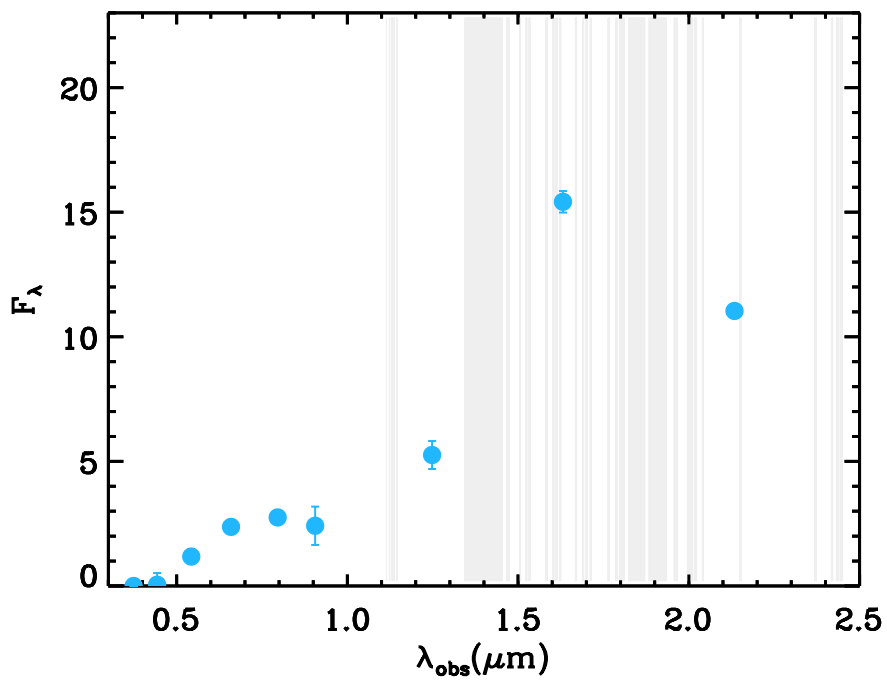
van Dokkum et al. 2006

# GNIRS survey overview

- **Observation:** x-disperser 1-2.5 micron
- **Selection**
  - 2.0 < z_phot < 2.7 (MUSYC photometry)
  - K-selected (<19.7)
- **Sample: 26 Galaxies (+ 4 nights in Dec)**
  - 6 galaxies with 1.8 < z_spec < 2.0
  - 20 galaxies with 2.0 < z_spec < 2.7
- **Follow-up:** NIRSPEC, SINFONI, NIRC2-AO, NICMOS, IRAC, MIPS, LDSS3

# Galaxies without detected Hα emission



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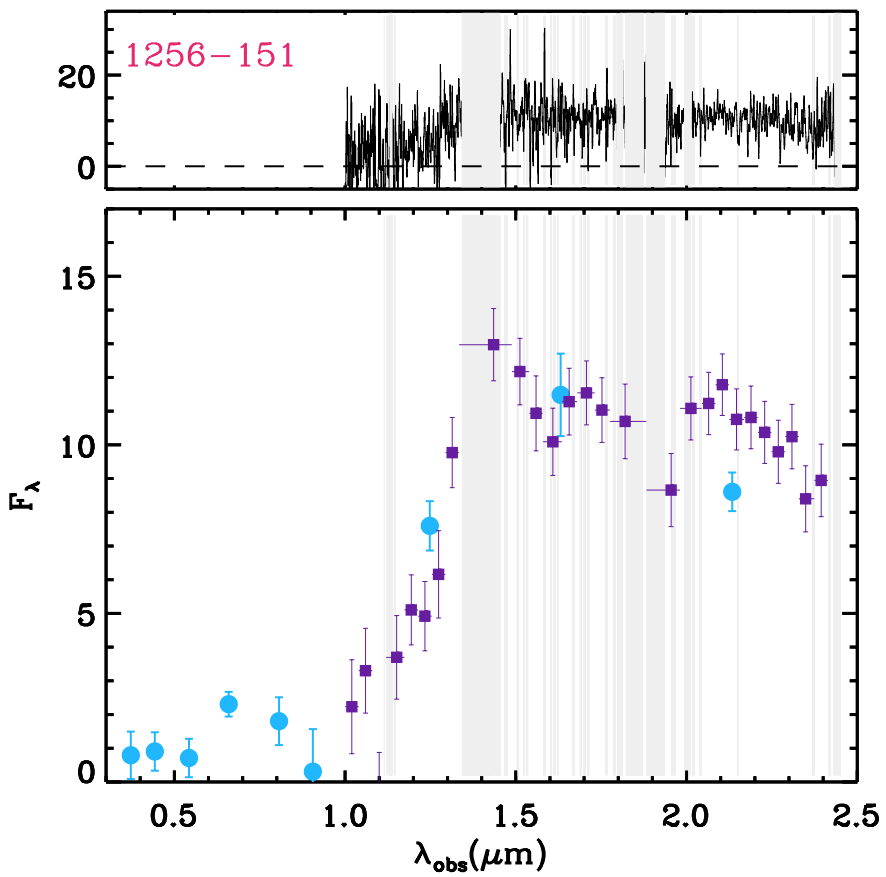


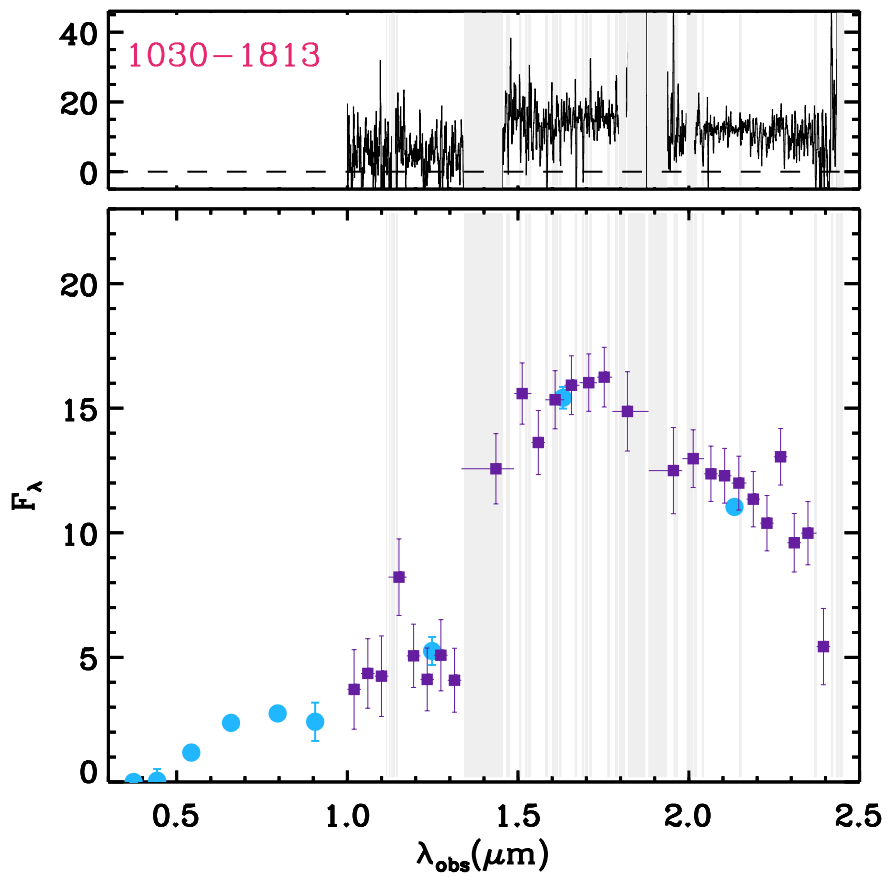

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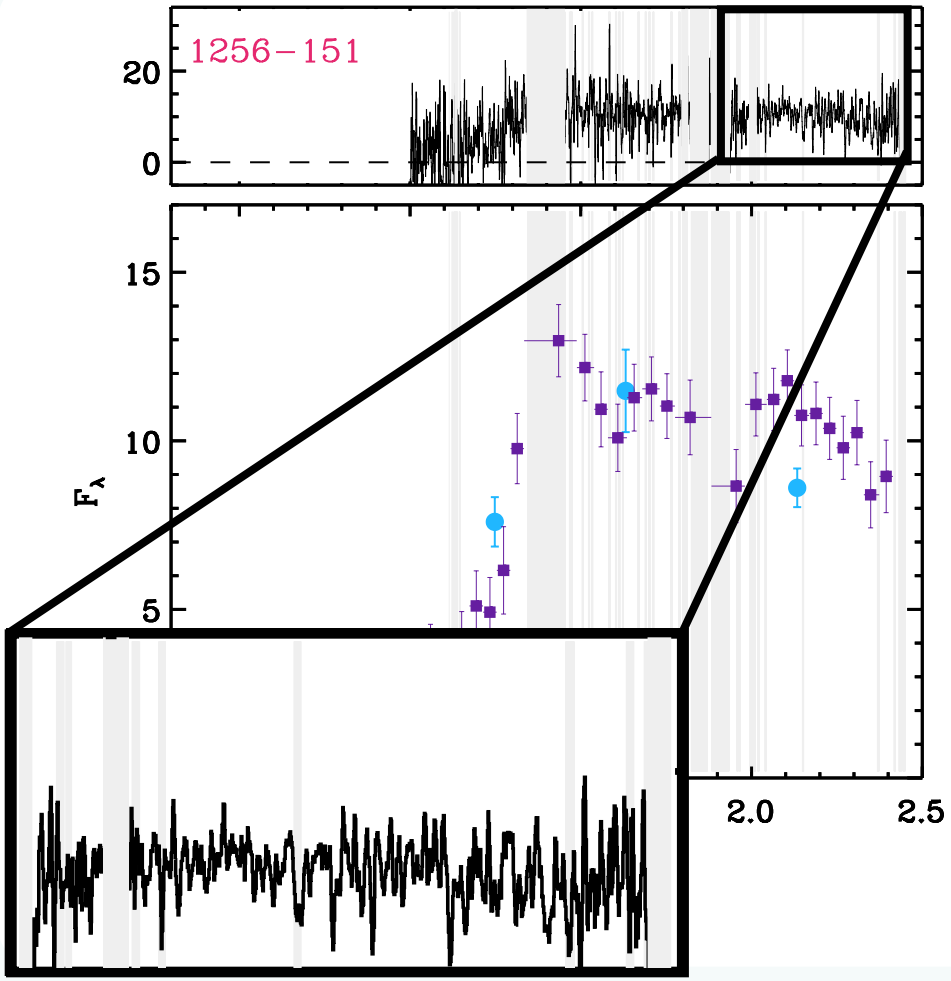


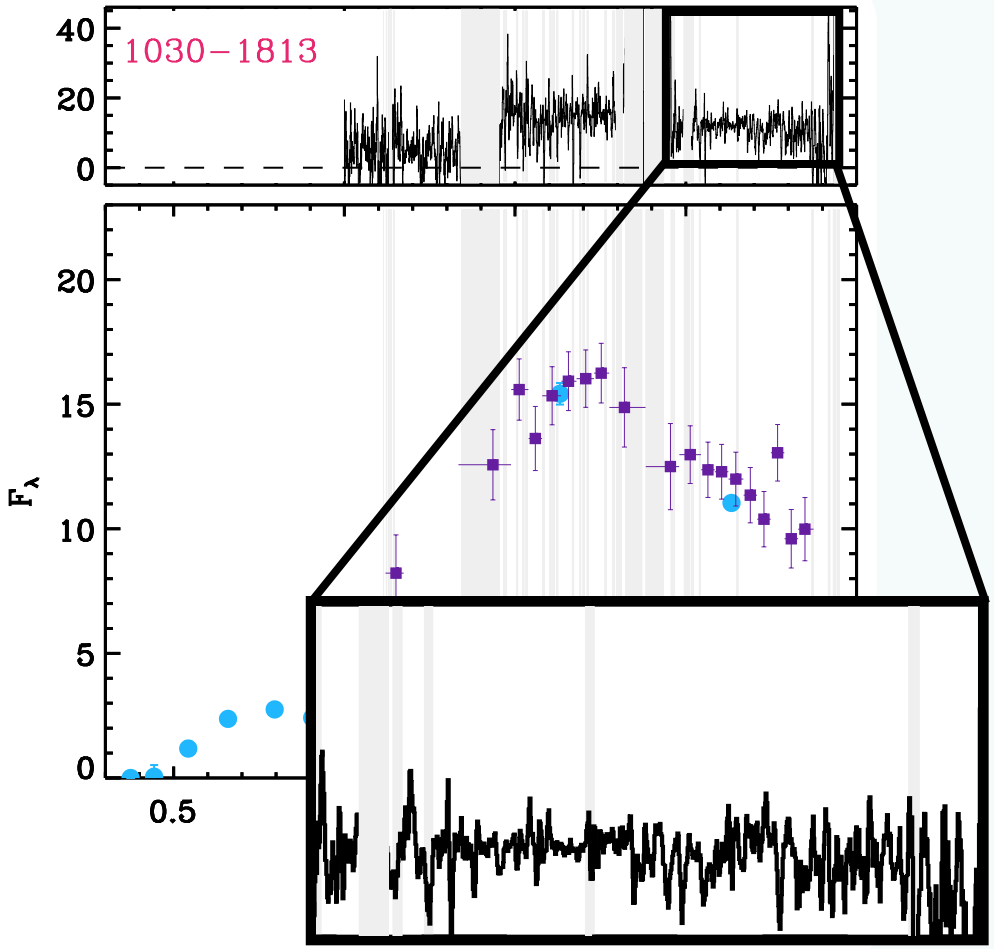

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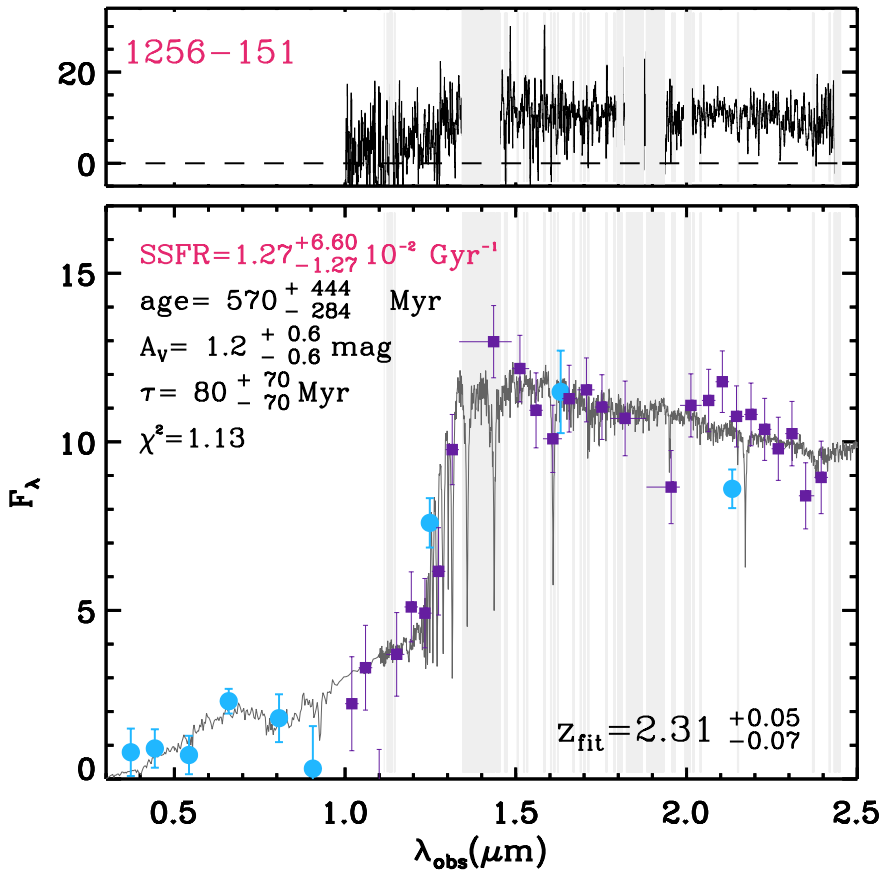
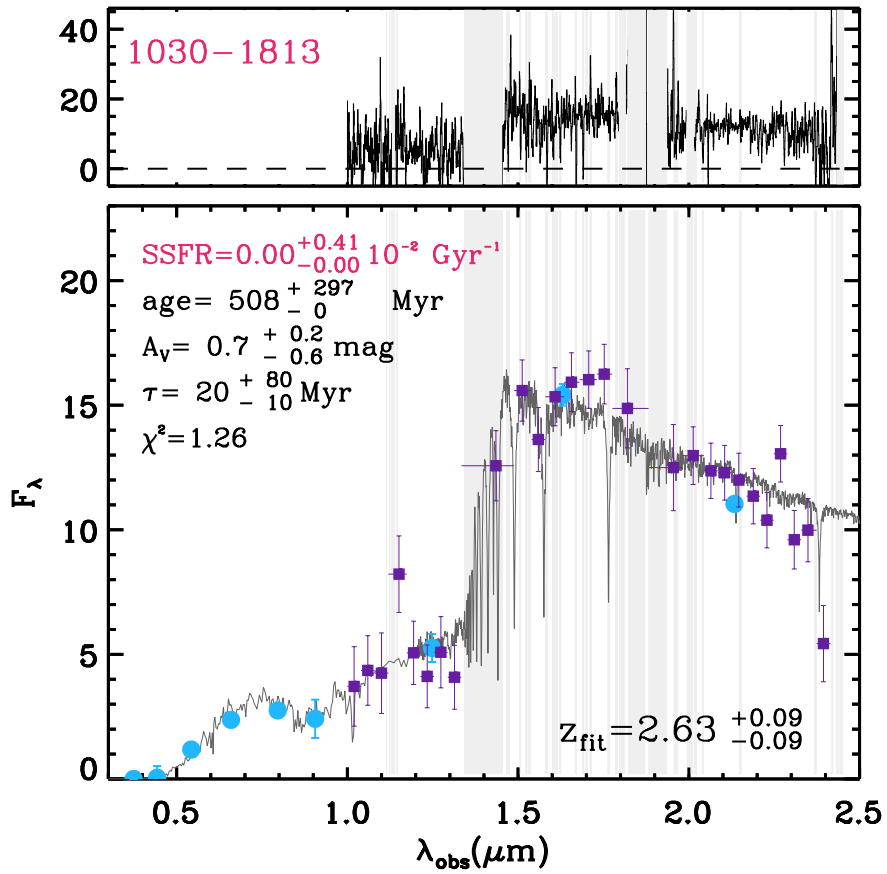
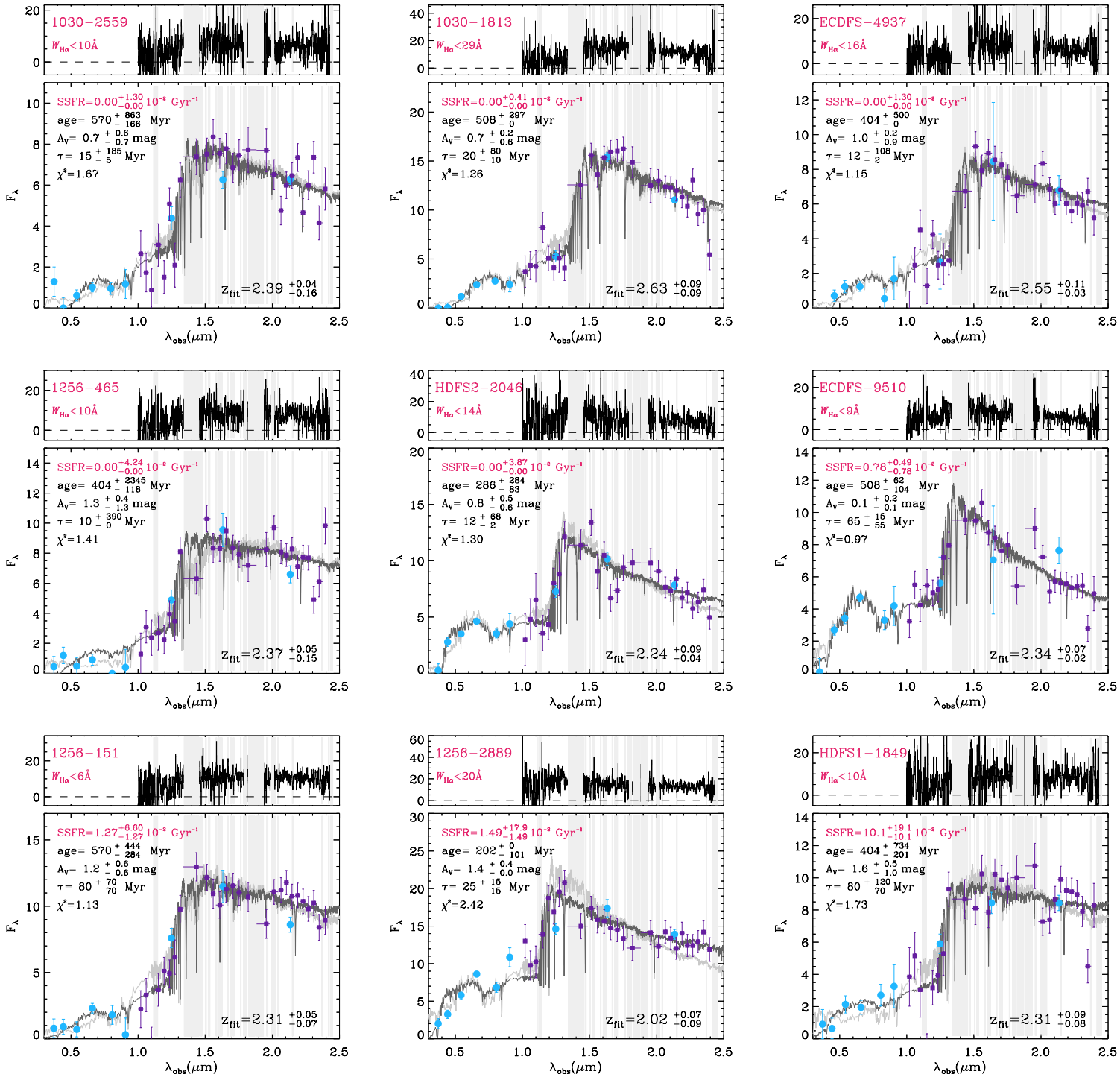


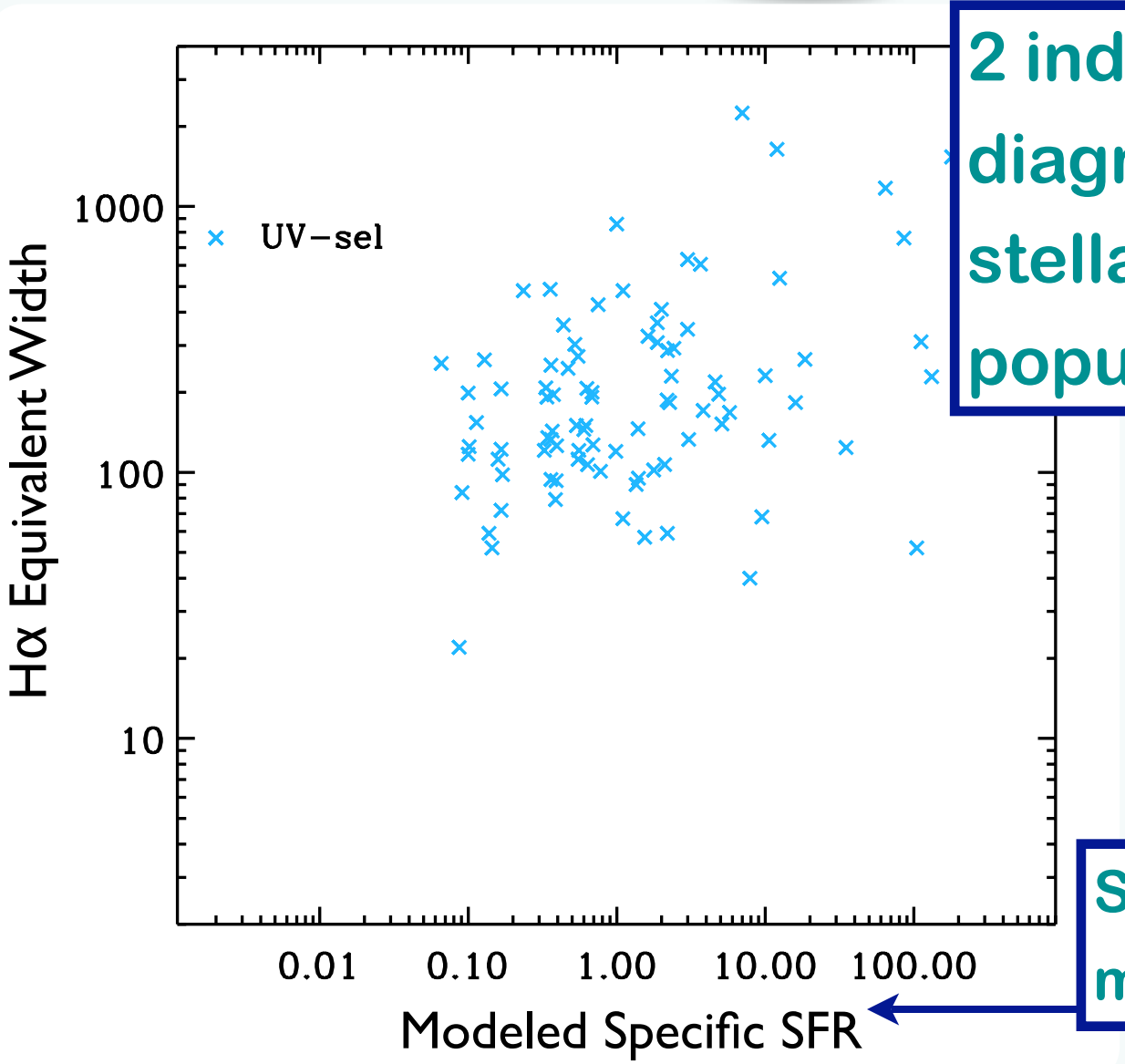



Kriek et al. 2006b


- No Hα detection
- Large Balmer Breaks
- Best fit to spectra: low SFRs

Kriek et al. 2006b

# Stellar populations in galaxies at z~2.3




2 independent diagnostics for stellar populations

Stellar continua modelling

Erb et al. 2006, Kriek et al. 2006b

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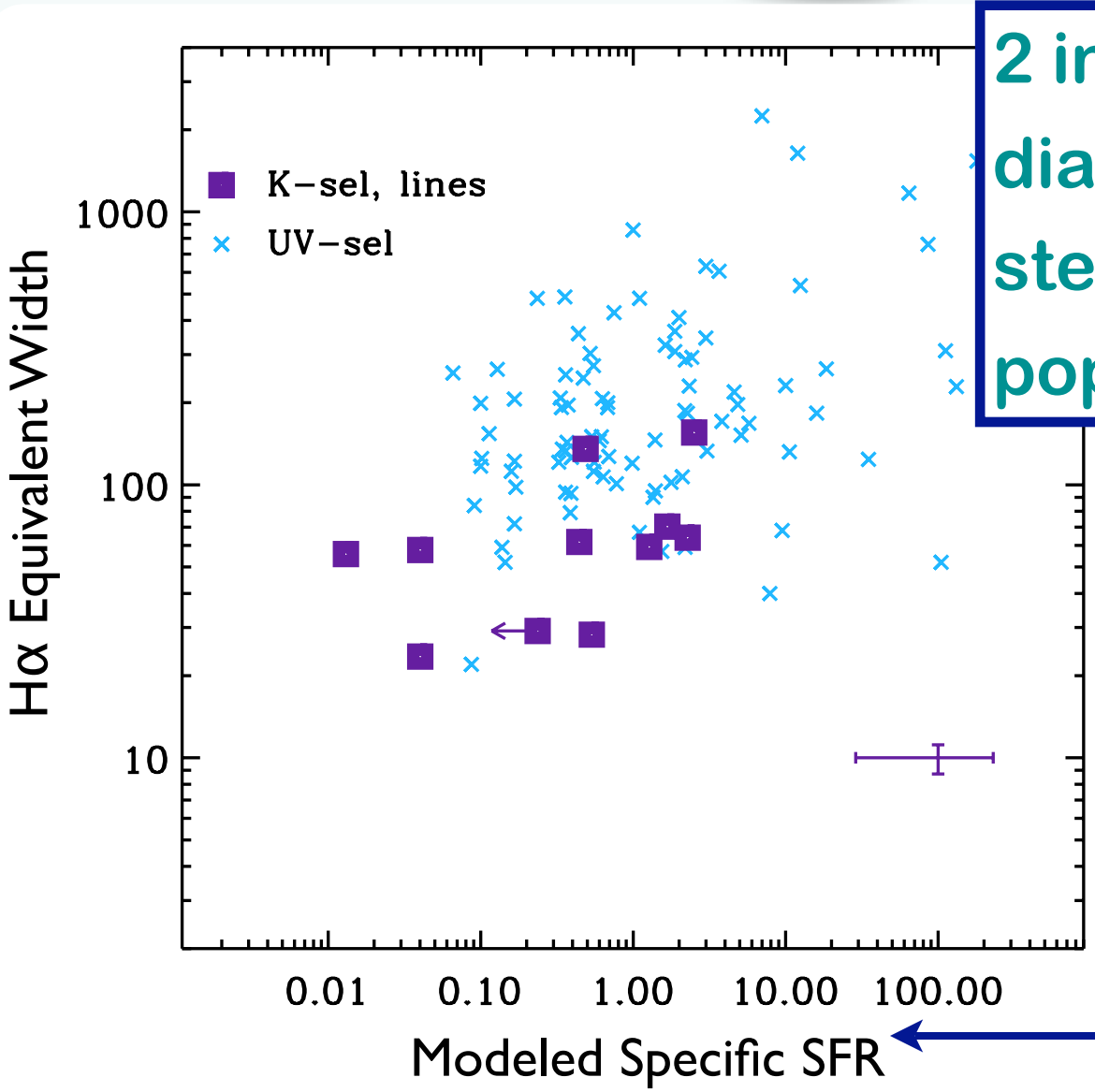


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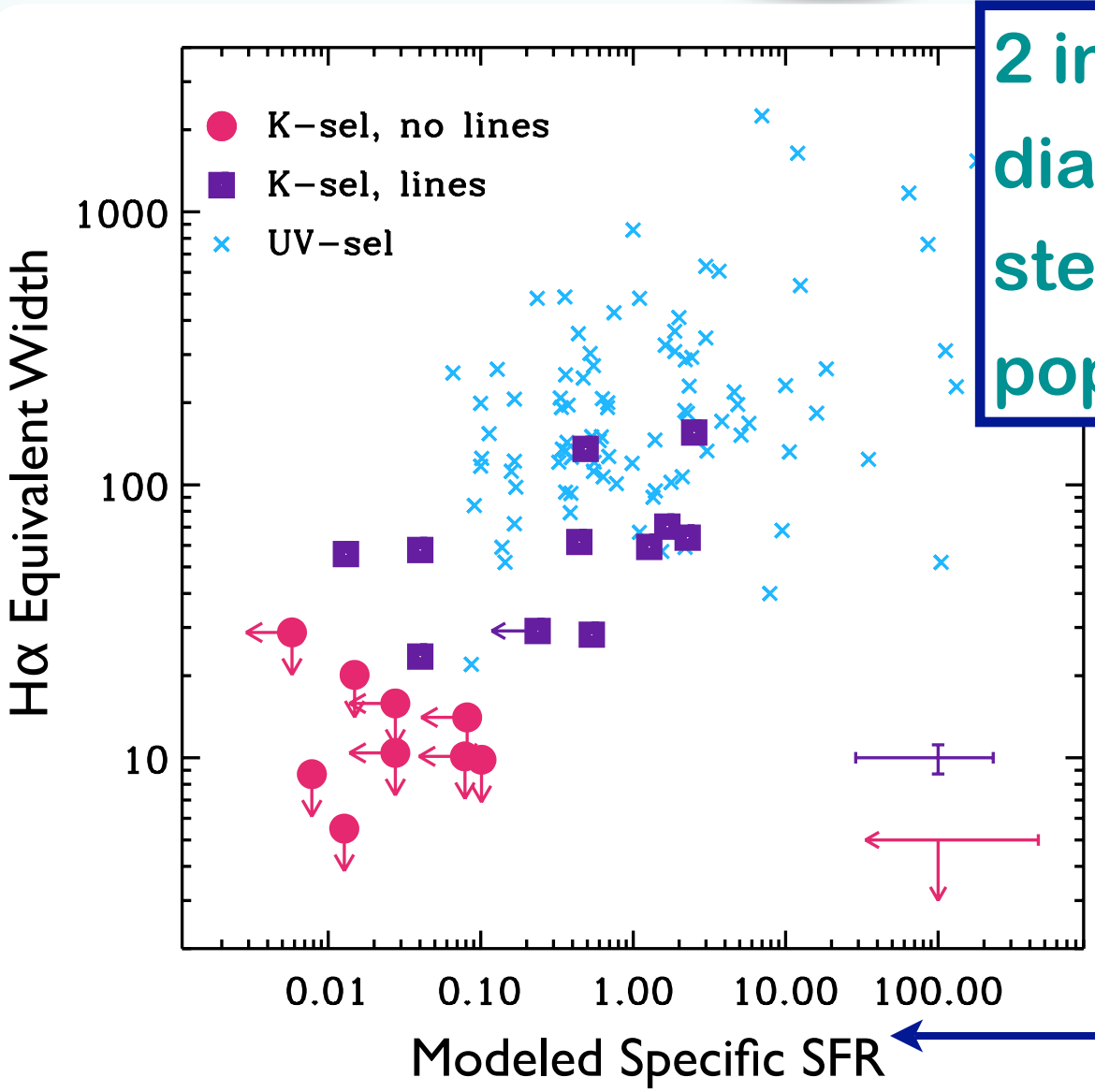


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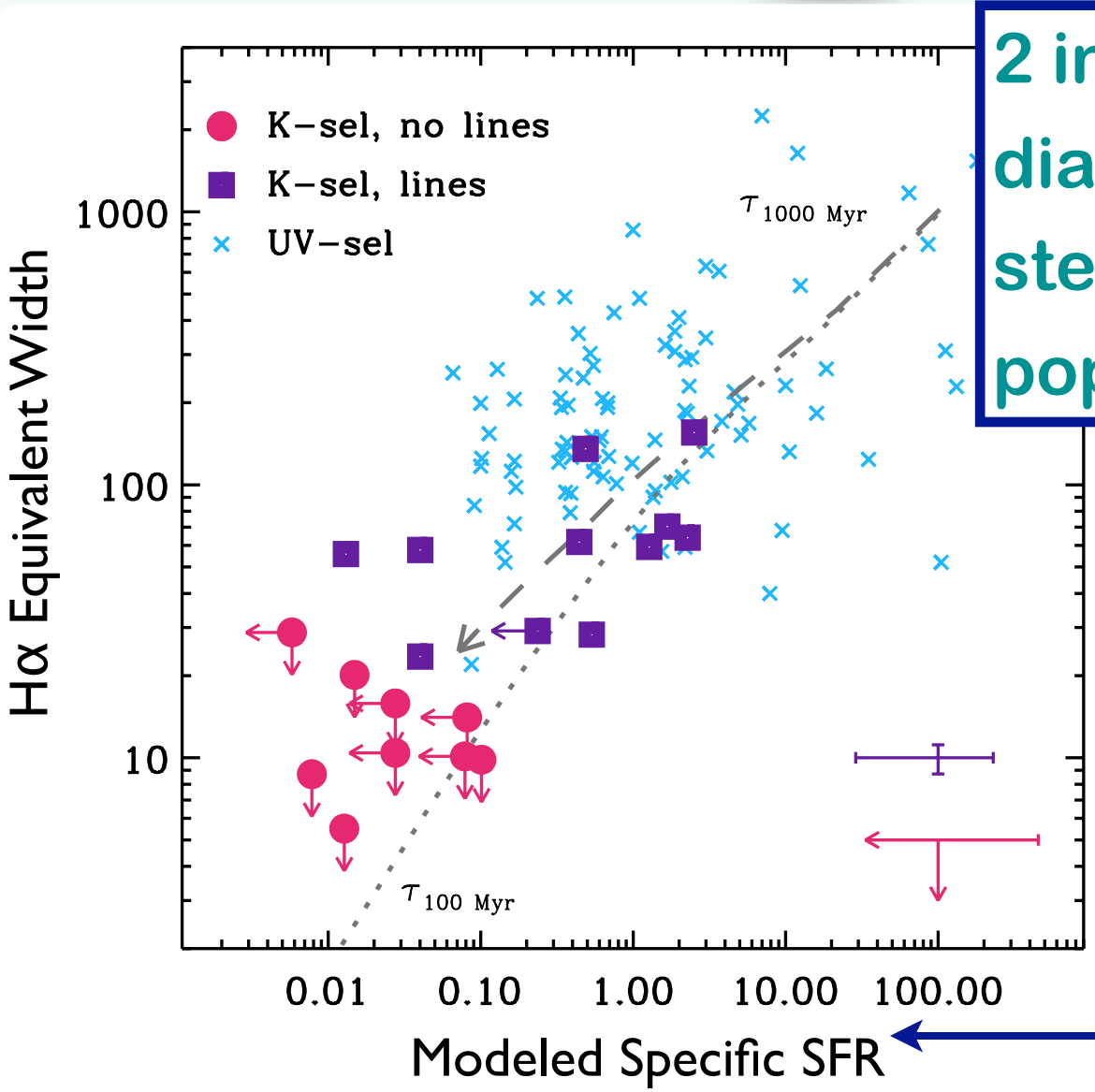
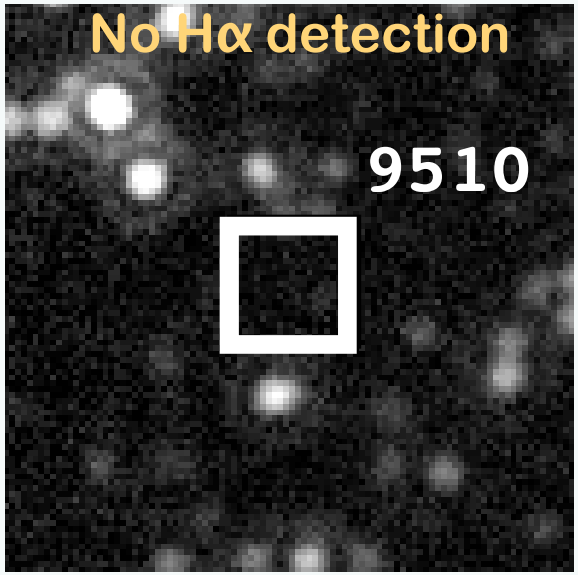


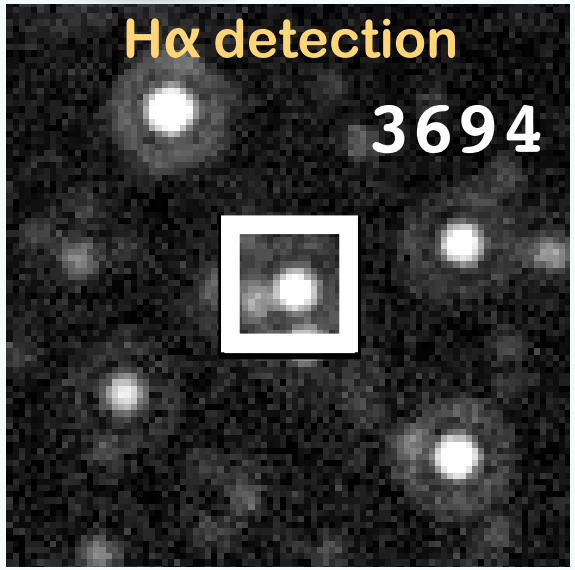

2 independent diagnostics for stellar populations

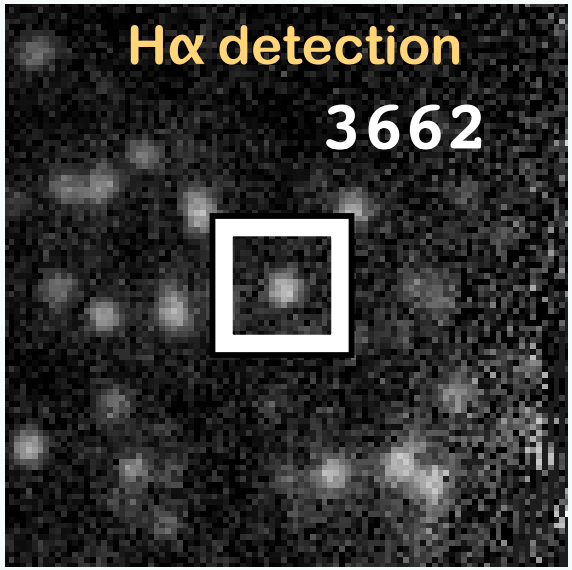
Stellar continua modelling

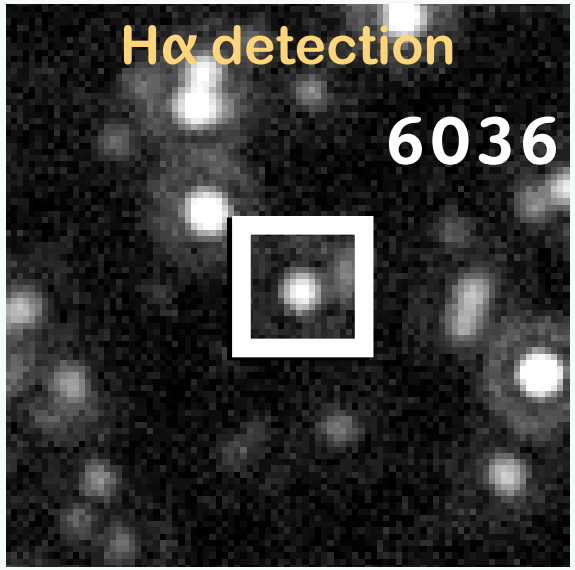
Erb et al. 2006, Kriek et al. 2006b

# Did we miss obscured star formation?



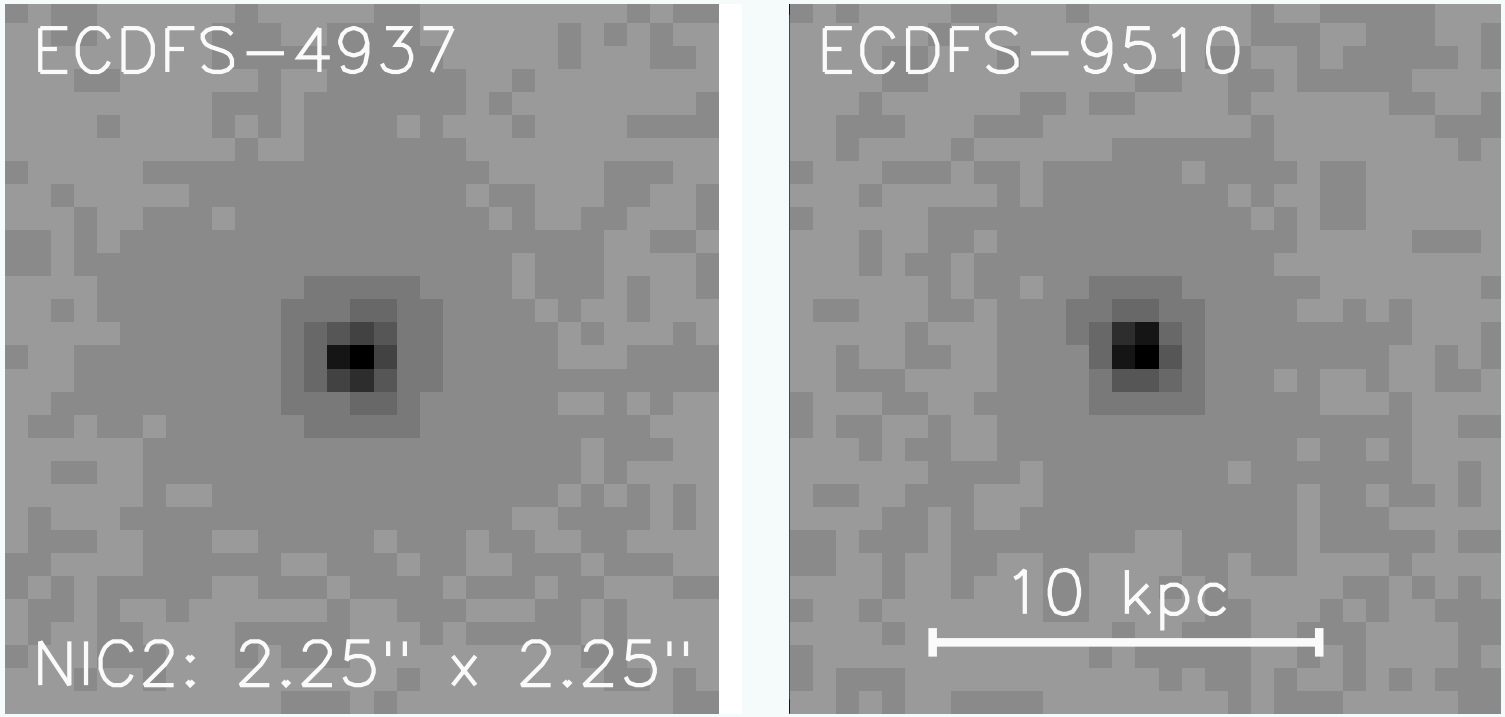




**MIPS 24 micron imaging**

Kriek et al. in preparation

# Morphologies of quiescent z~2.3 galaxies




Kriek et al. in preparation

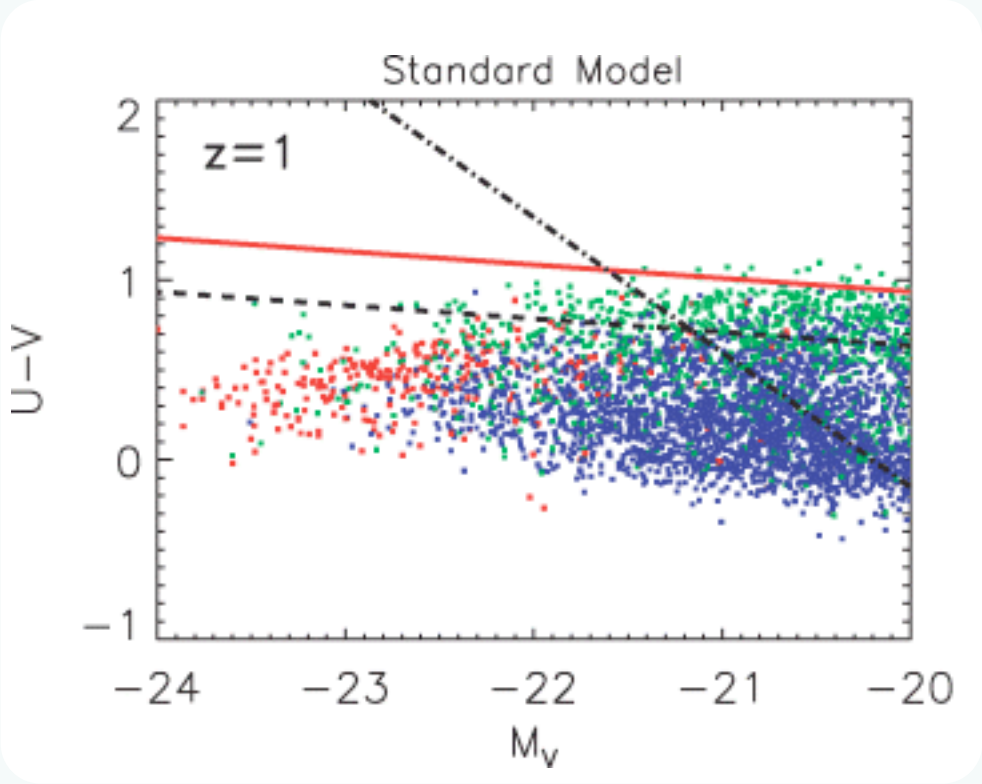
# Motivation & Conclusion

- When was the star formation in massive galaxies quenched?
  - In a substantial part of the massive galaxies at z~2.3 the star formation is already strongly suppressed

# Motivation

- When was the star formation in massive galaxies quenched?
  - In a substantial part of the massive galaxies at z~2.3 the star formation is already strongly suppressed
- **What mechanism is responsible for this quenching?**
  - **AGN feedback? (Croton et al. 2006, Bower et al. 2006, Hopkins et al. 2006)**

# Why do models need AGN feedback?




**All massive galaxies are blue**

Cattaneo et al 2006

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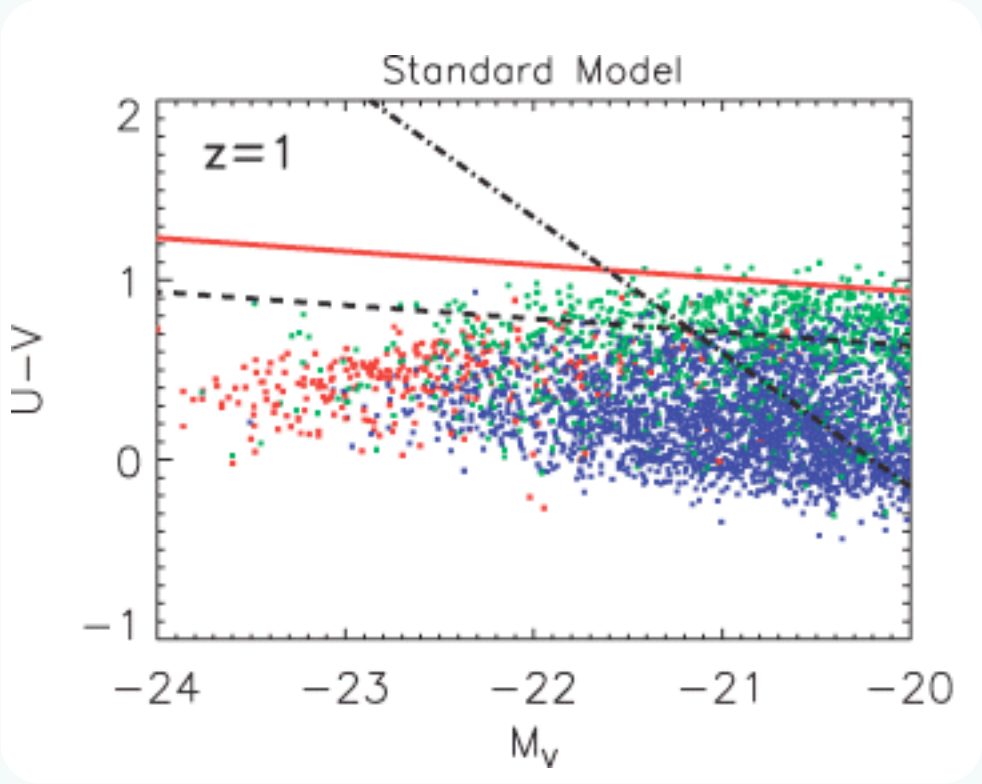


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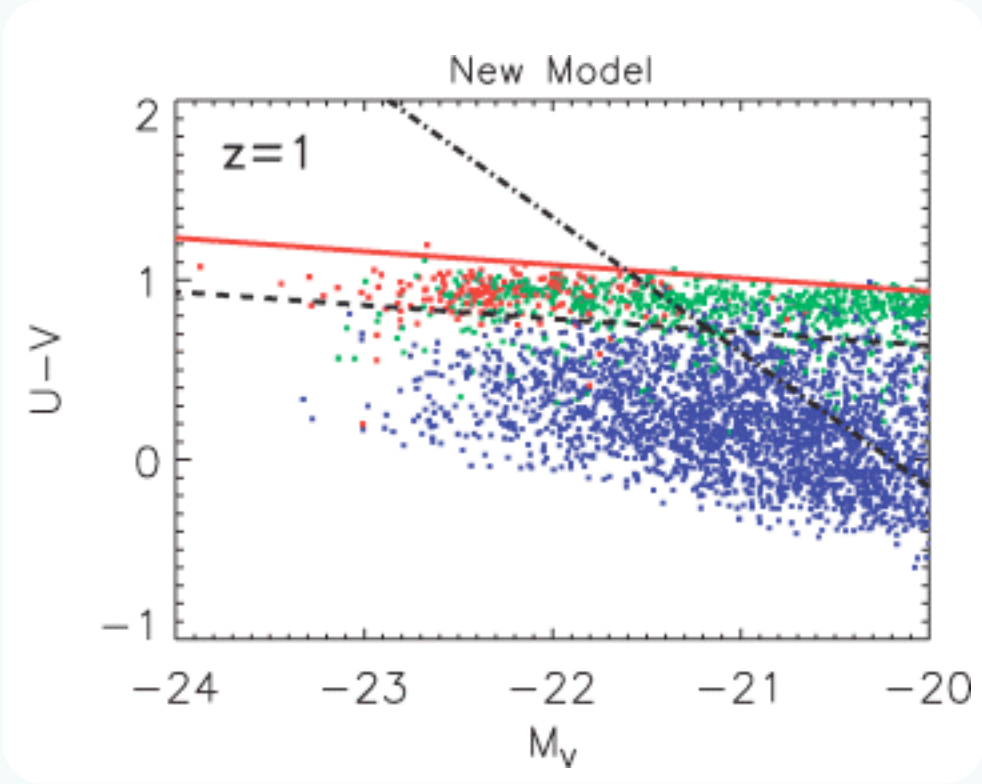


Massive galaxies are both blue and red

Cattaneo et al 2006

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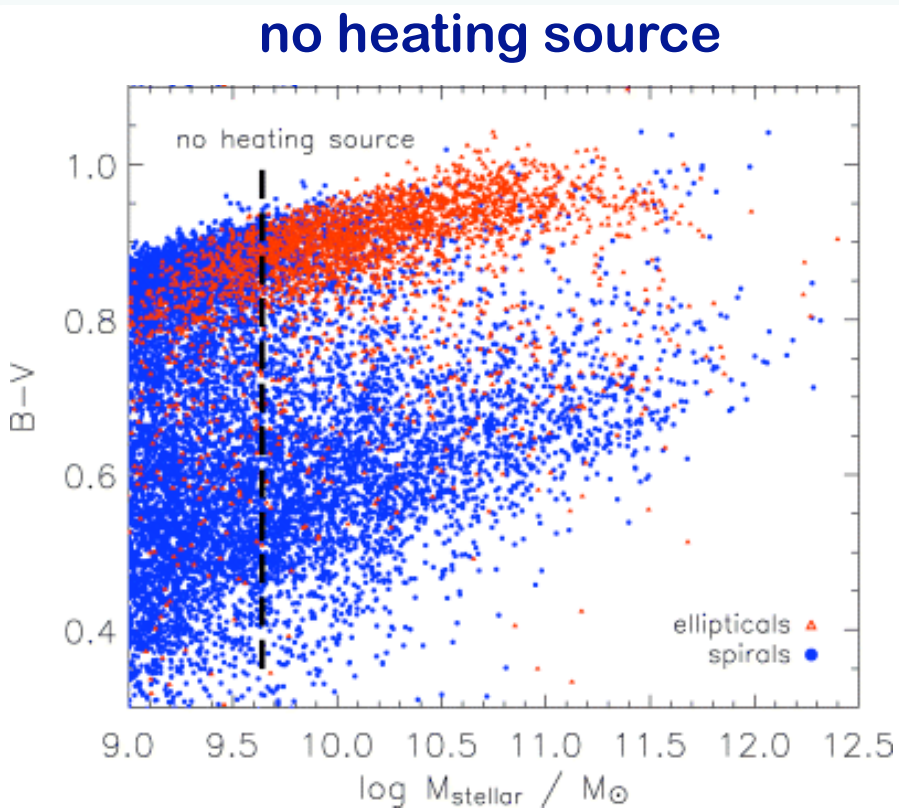
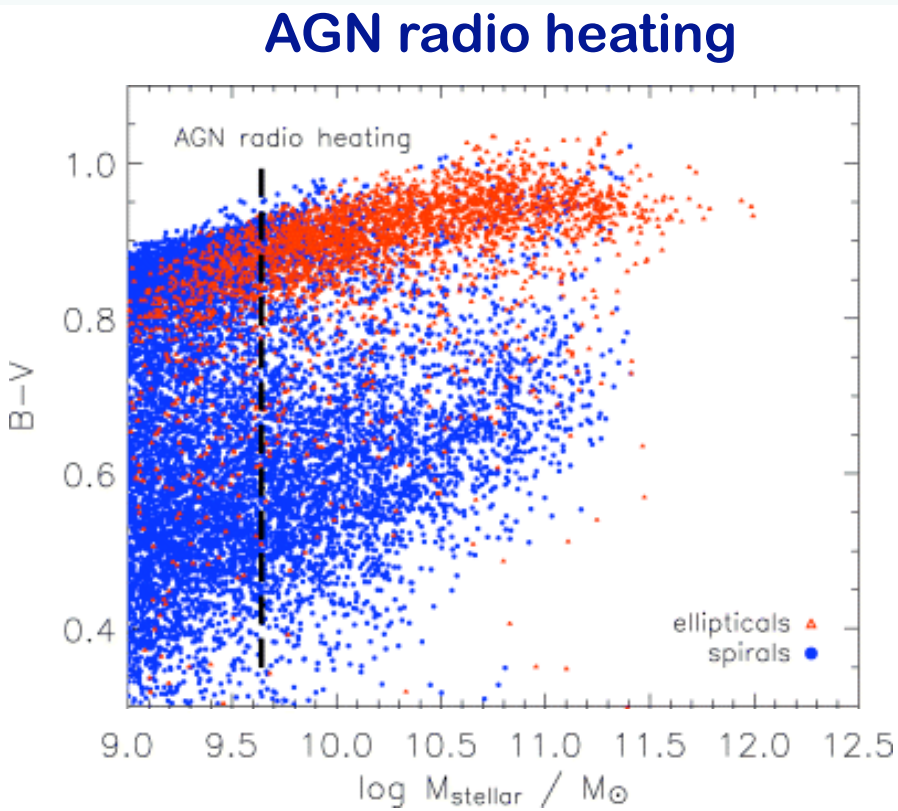
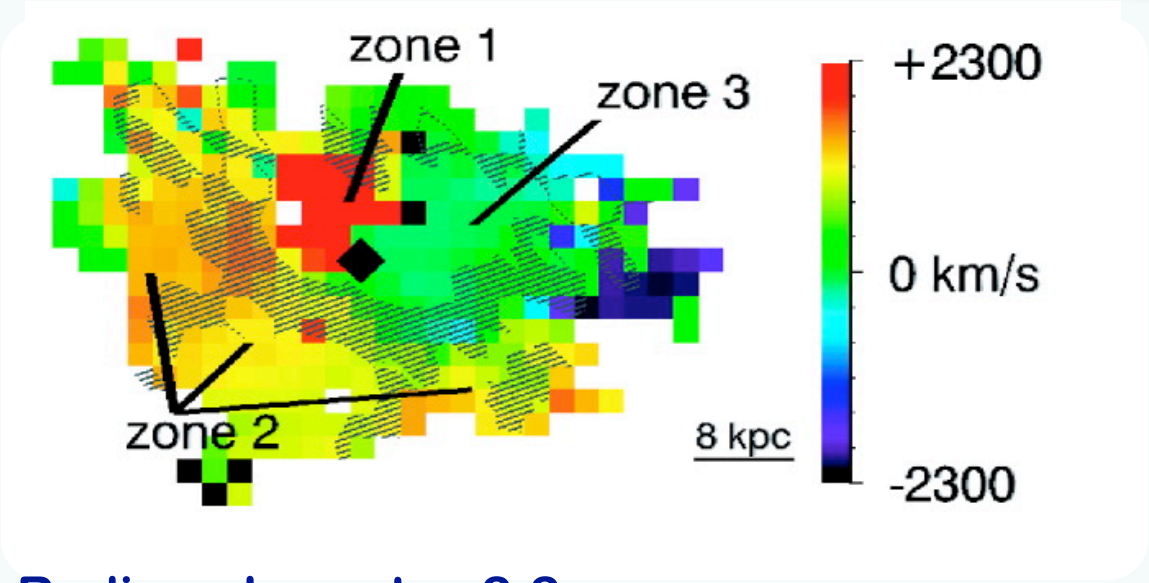


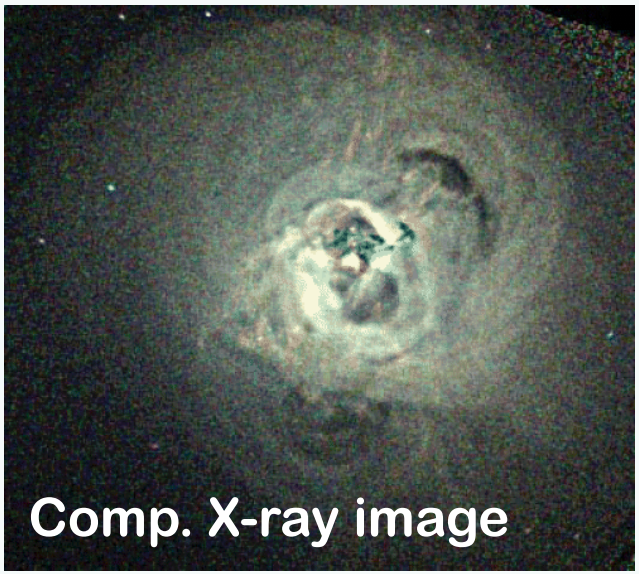




Croton et al 2006

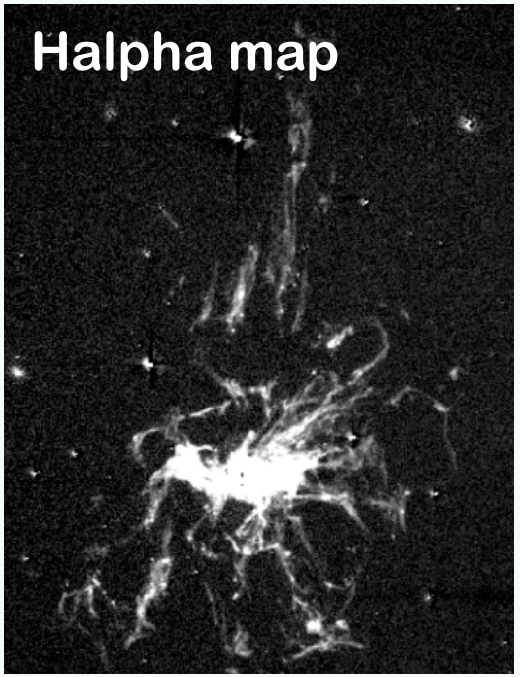
# Examples of AGN feedback




Radio galaxy at z=2.2
(Nesvadba et al. 2006)




Perseus (Fabian+)



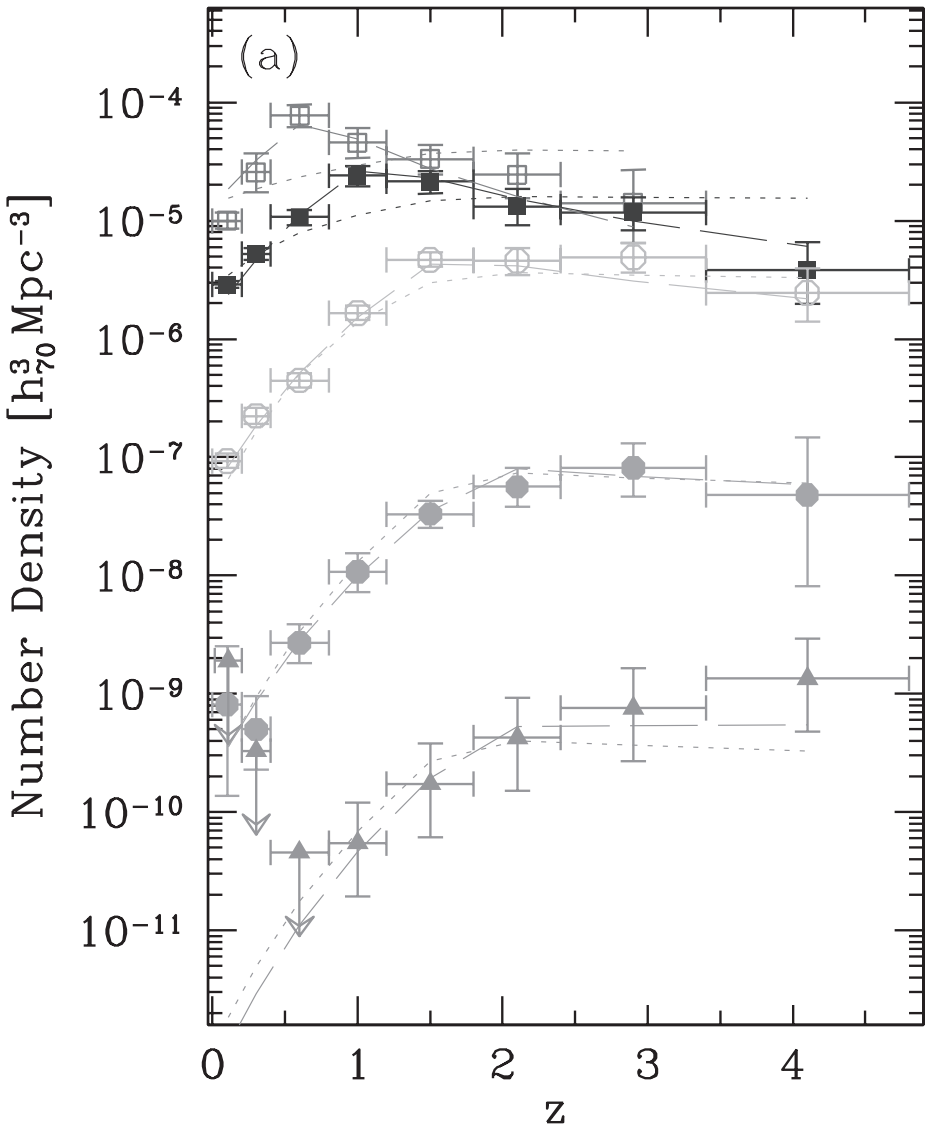
# Motivation

- When was the star formation in massive galaxies quenched?
  - In a substantial part of the massive galaxies at z~2.3 the star formation is already strongly suppressed
- **What mechanism is responsible for this quenching?**
  - **AGN feedback? (Croton et al. 2006, Bower et al. 2006, Hopkins et al. 2006)**

# Motivation

- When was the star formation in massive galaxies quenched?
  - In a substantial part of the massive galaxies at z~2.3 the star formation is already strongly suppressed
- **What is the role of AGNs in the star formation history of galaxies?**

# Downsizing of AGN




Log L Range

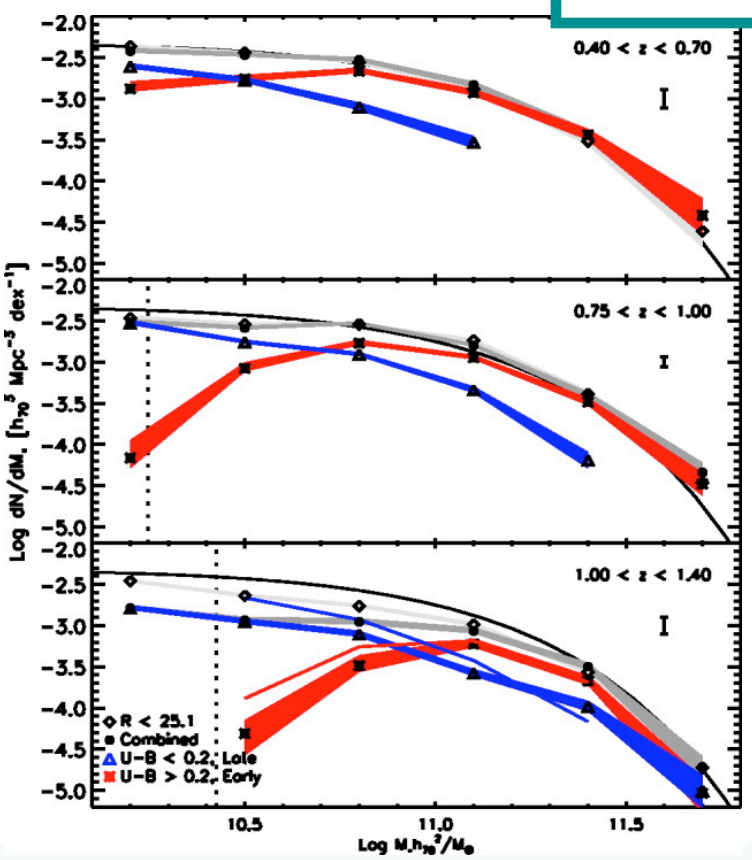
- >46.0
- 45.0–46.0
- 44.0–45.0
- 43.0–44.0
- 42.0–43.0

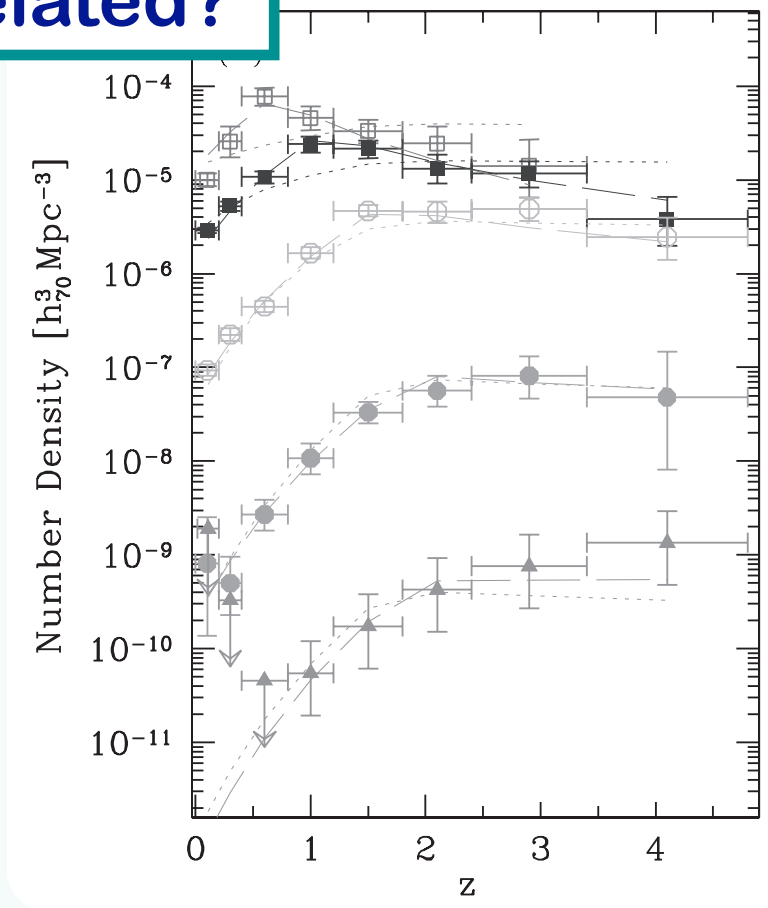
**The density of more luminous AGNs peaks at higher redshift than the density of less luminous AGNs**

Hasinger et al. 2005

# Downsizing of AGN & stellar populations

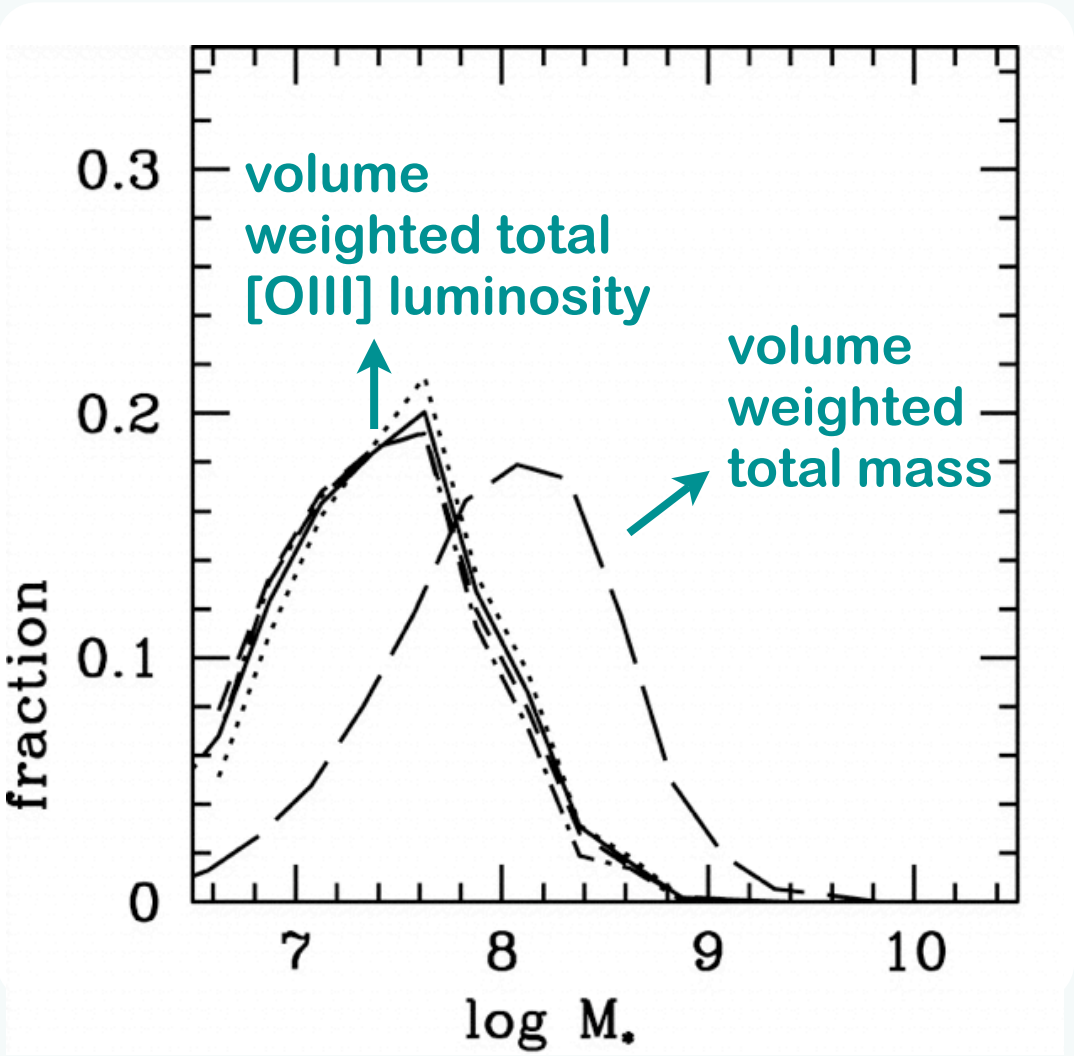
**How are these two behaviors related?**



# Downsizing of AGN & stellar populations

Distribution over black hole mass for all type 2 AGN

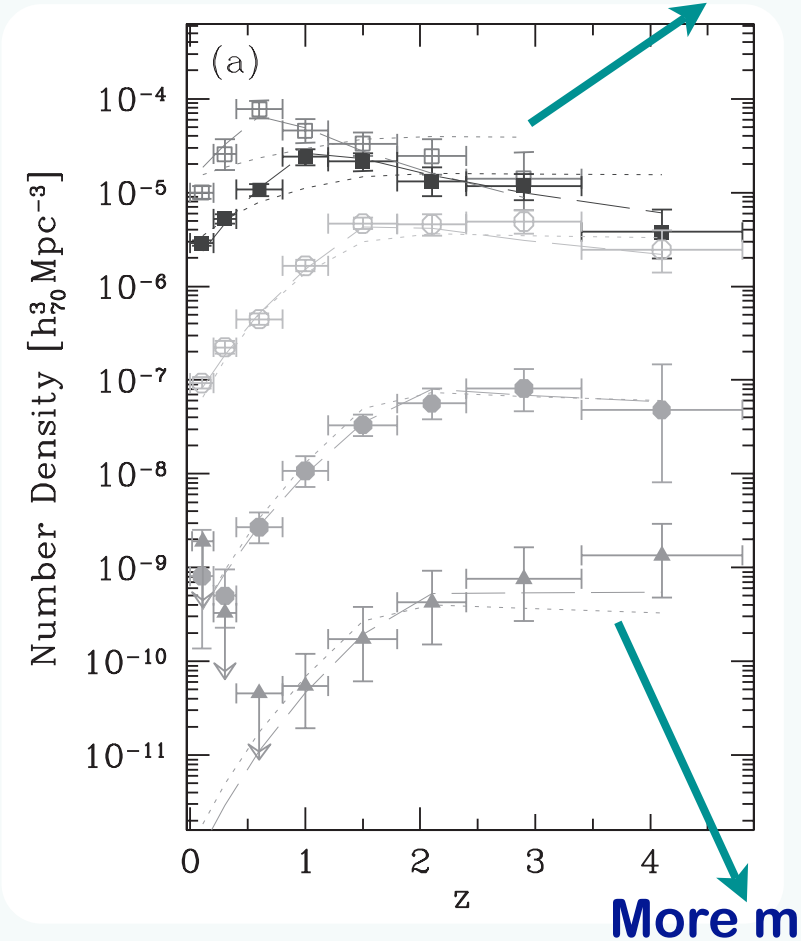



The downsizing of AGNs may reflect the decrease of the mass of actively accreting black holes with redshift

Heckman et al. 2004

# Downsizing of AGN & stellar populations

Less massive black holes



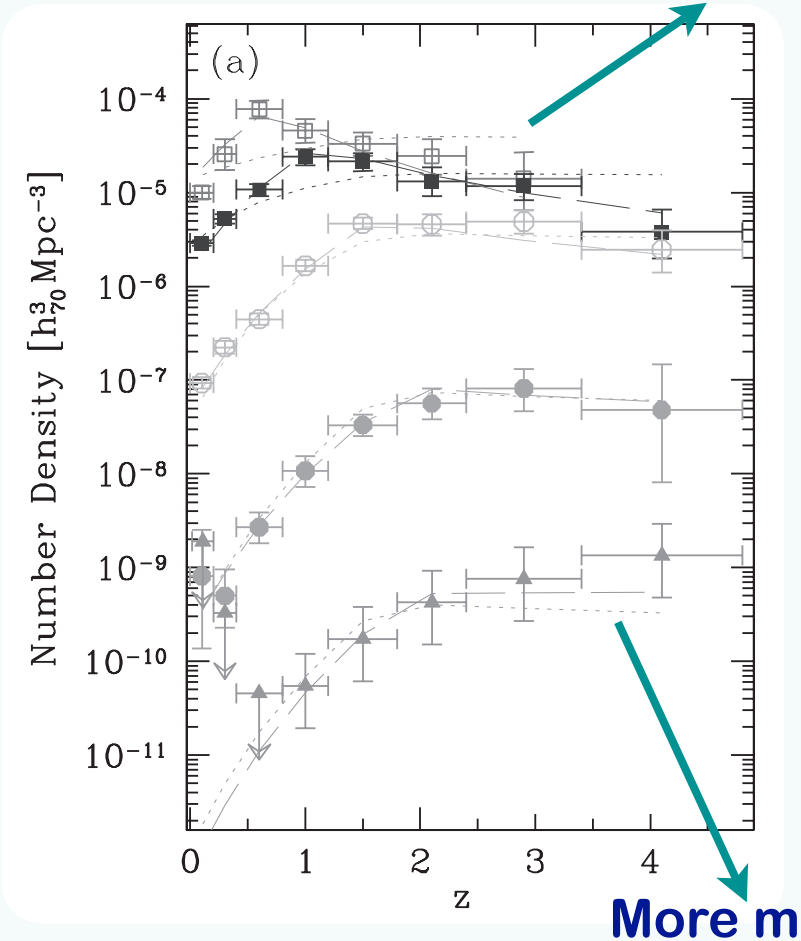

More massive black hole

**The downsizing of AGNs may reflect the decrease of the mass of actively accreting black holes with redshift**

Hasinger et al. 2005; Heckman et al. 2004

# Downsizing of AGN & stellar populations

Less massive black holes




More massive black holes

The downsizing of AGNs may reflect the decrease of the mass of actively accreting black holes with redshift

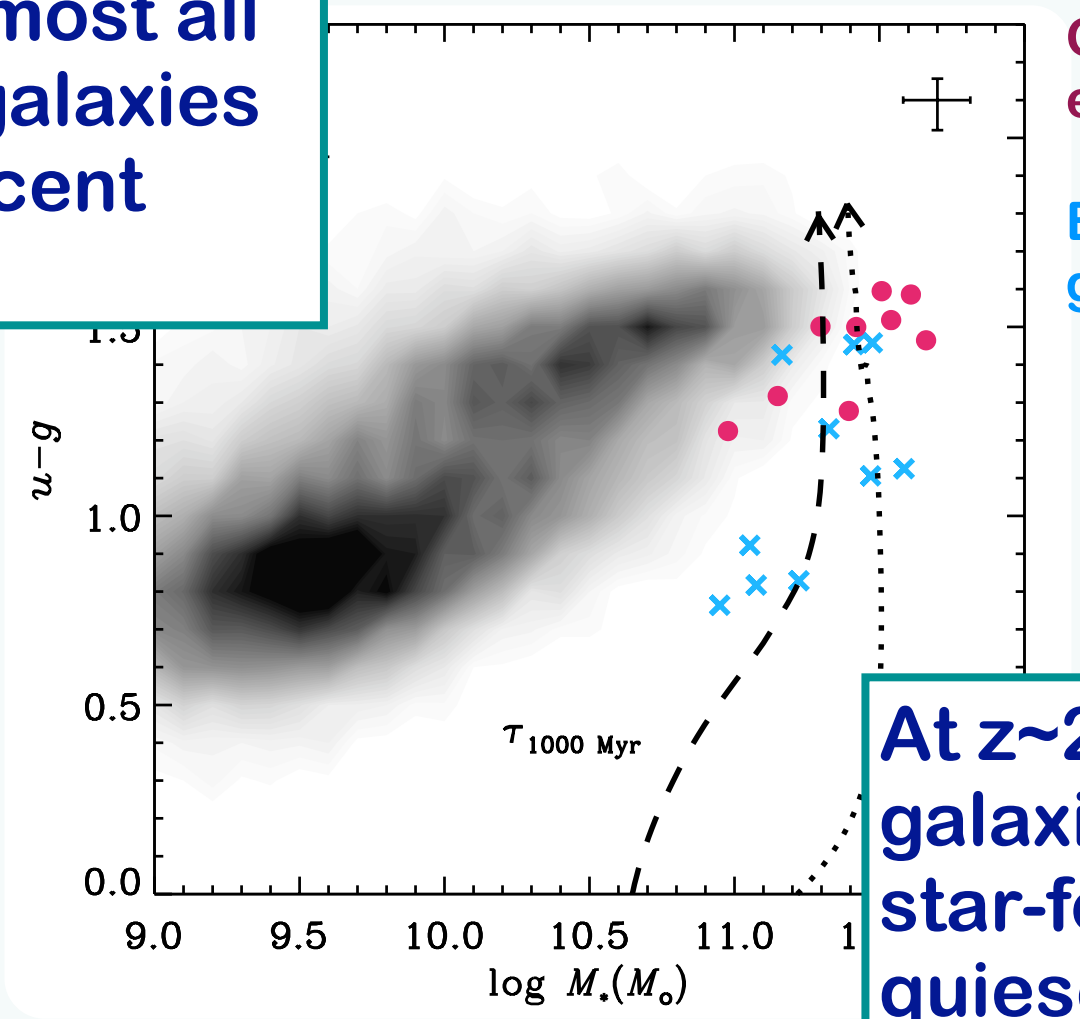
$M_{BH} \sim M^*$

Does this mass-scale traces the mass-scale at which galaxies are quenched?

Hasinger et al. 2005; Heckman et al. 2004

# Massive galaxies at z~2.3

At z~0 allmost all massive galaxies are quiescent systems



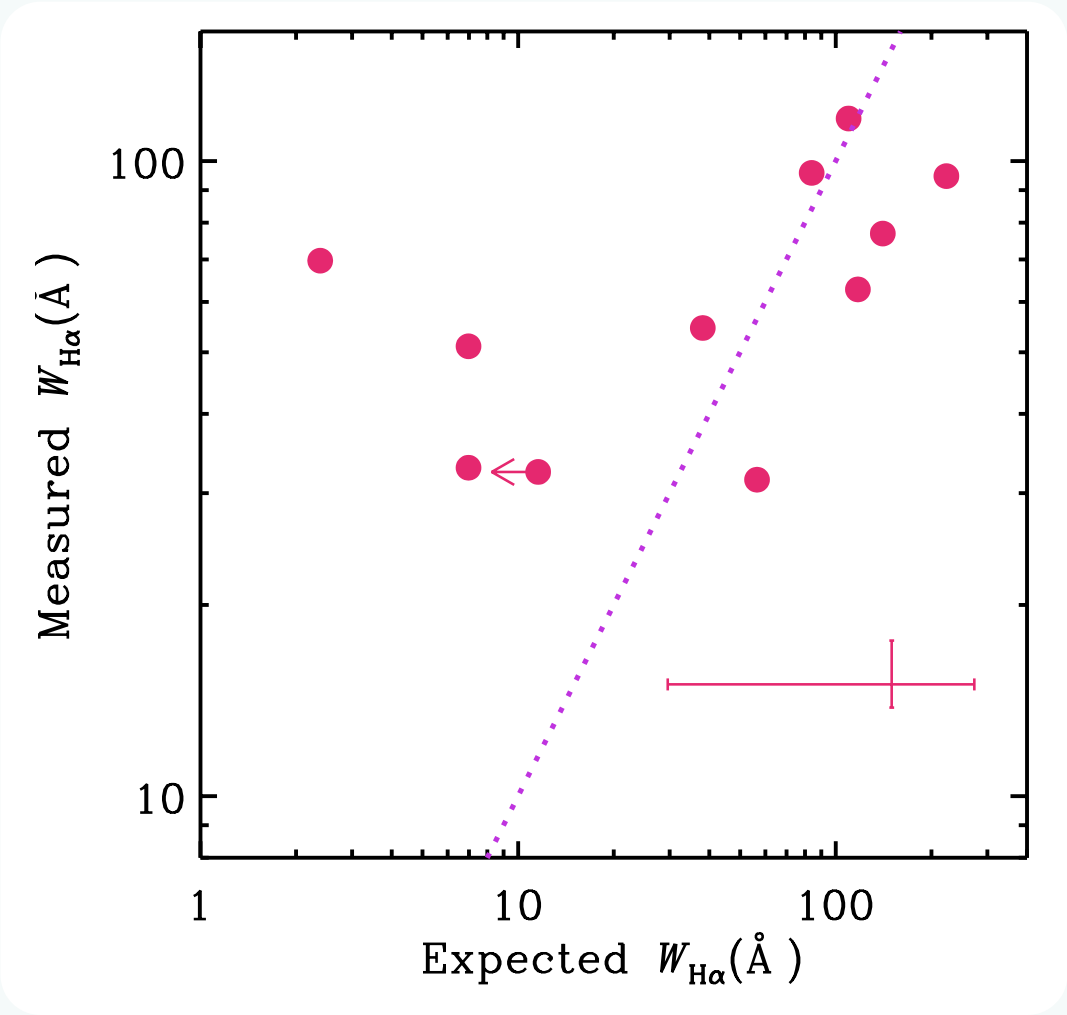

Galaxies without emission lines

Emission-line galaxies

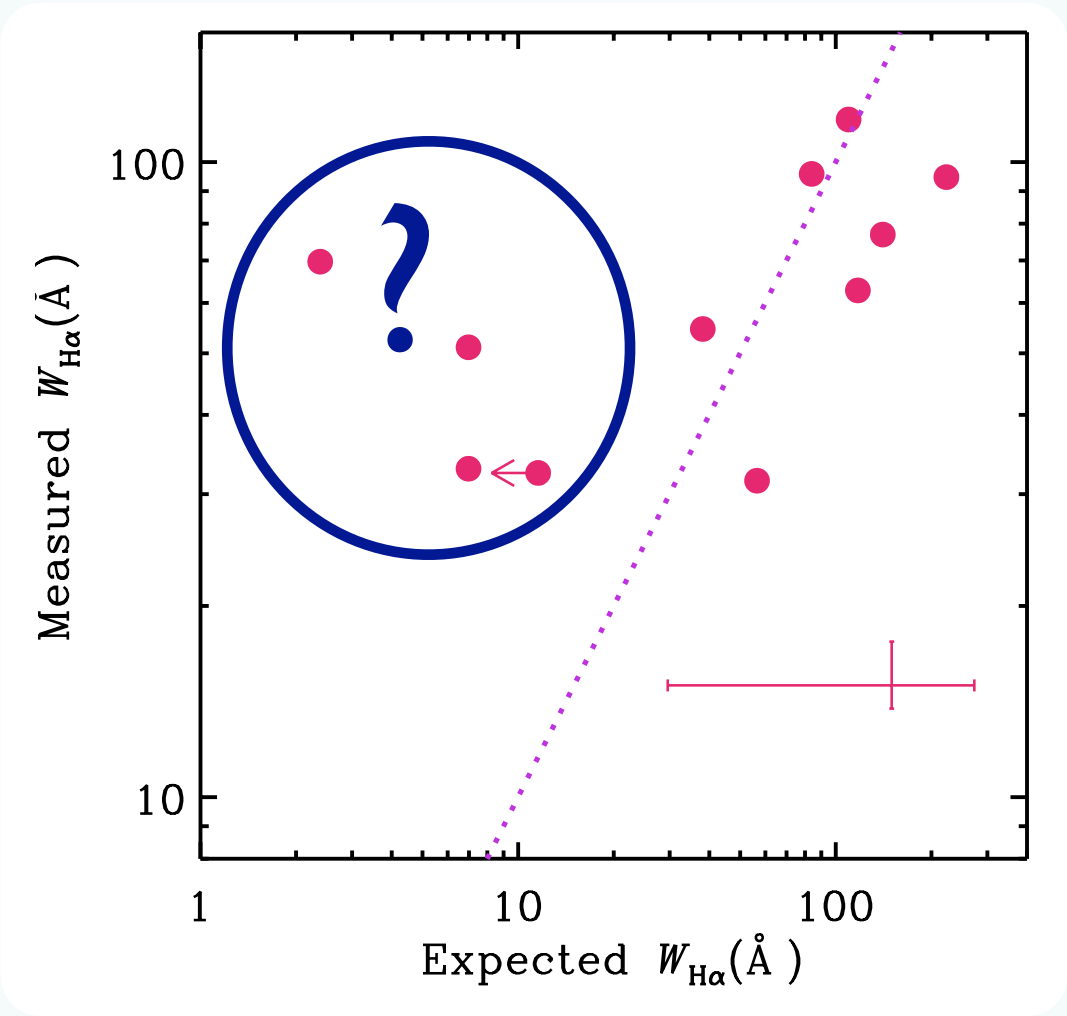
AGNs?

At z~2.3 massive galaxies are both star-forming and quiescent

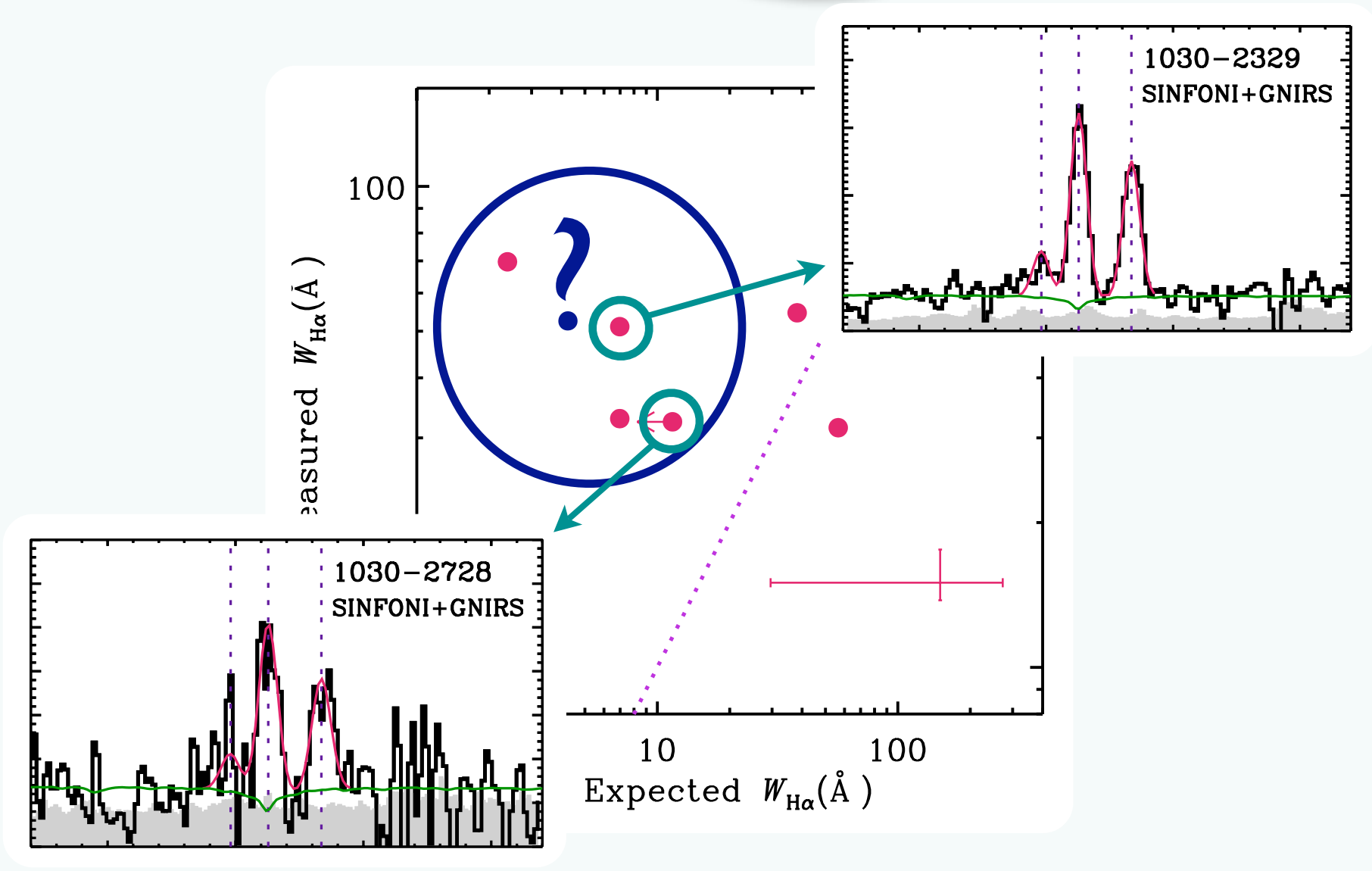
# Emission-line galaxies at z~2.3



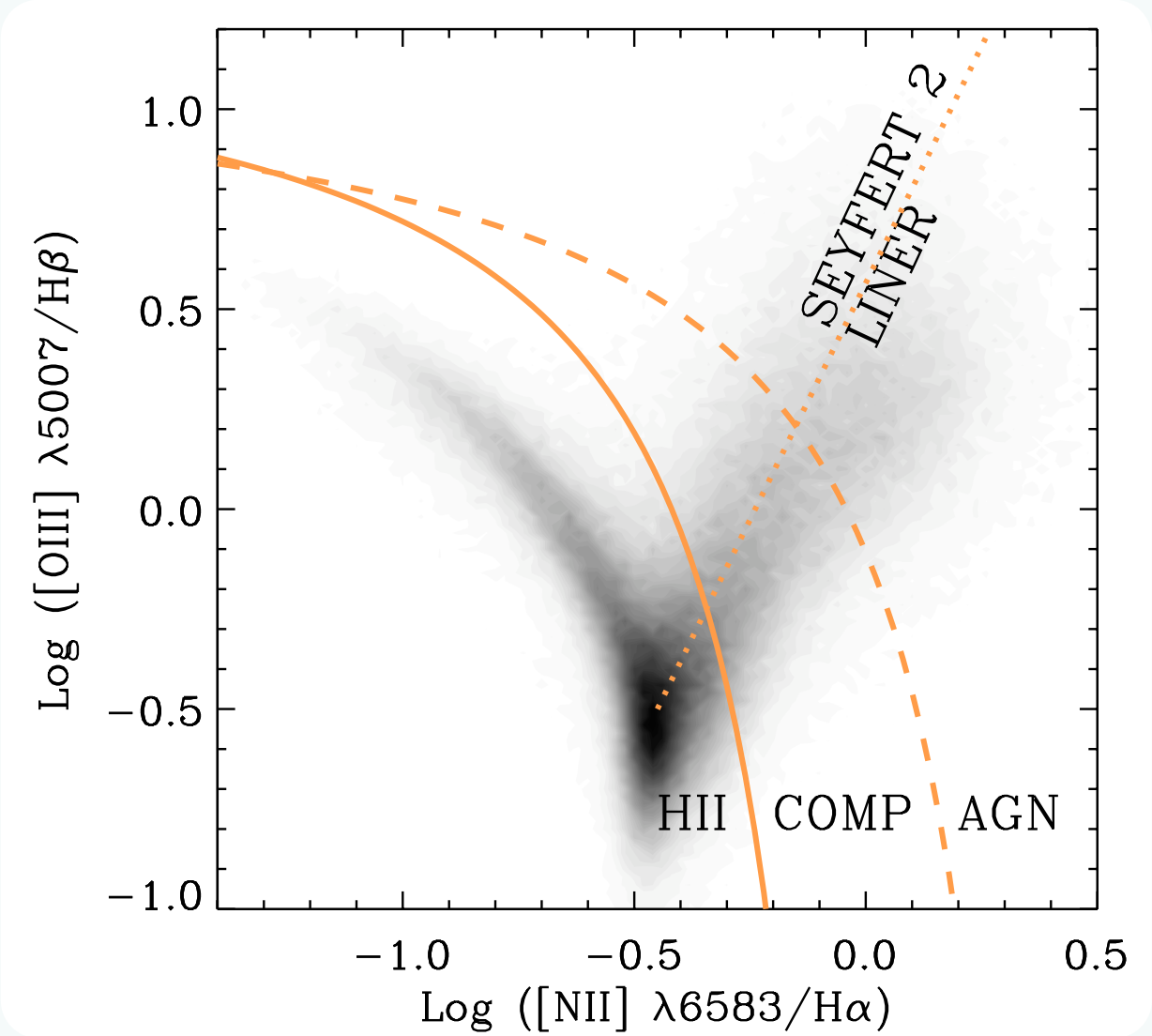
# Emission-line galaxies at z~2.3



# Emission-line galaxies at z~2.3

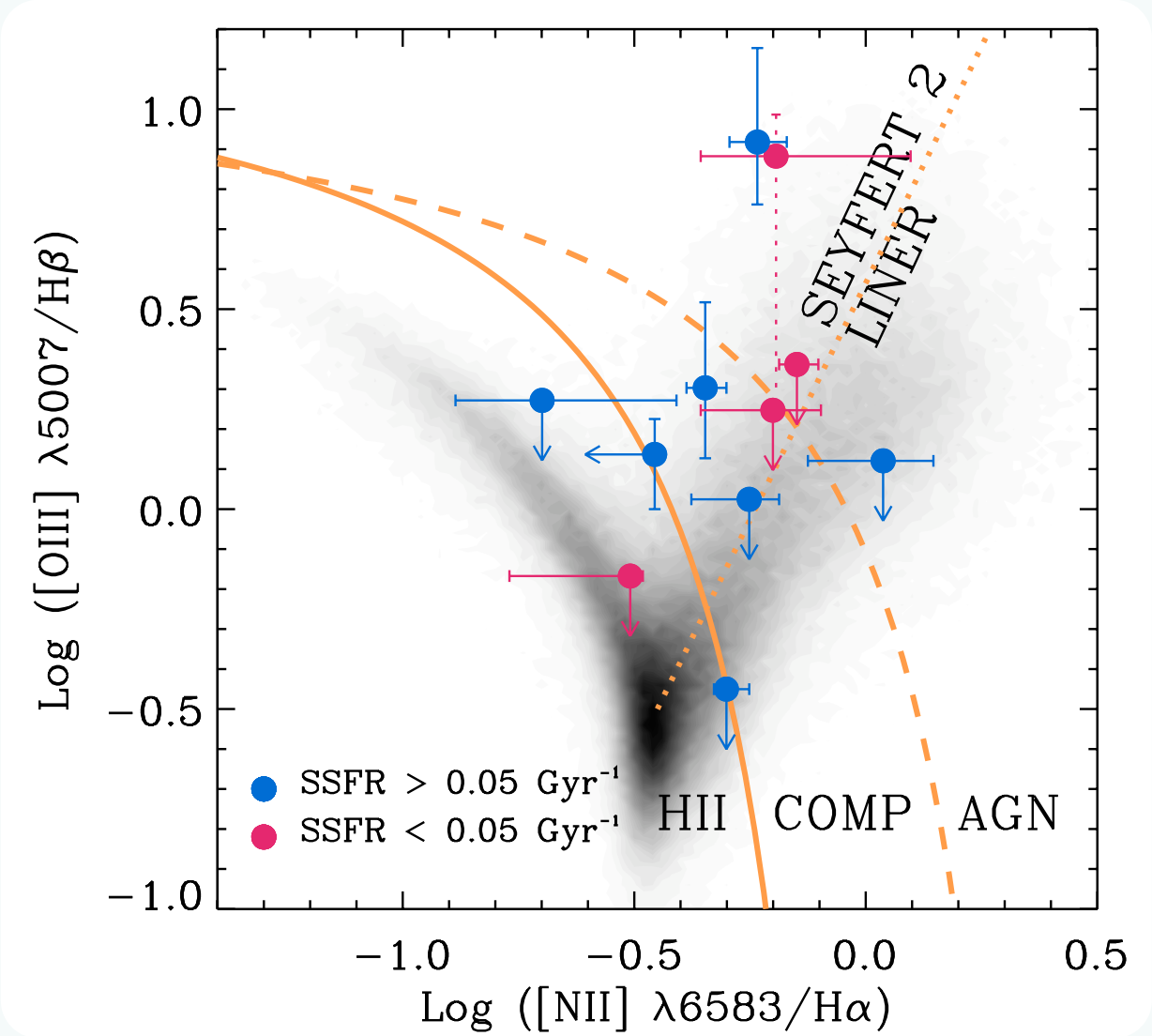


# Origin of the line emission



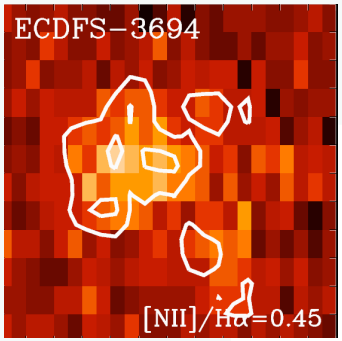

Kauffmann et al. 2003, Kewley et al. 2001

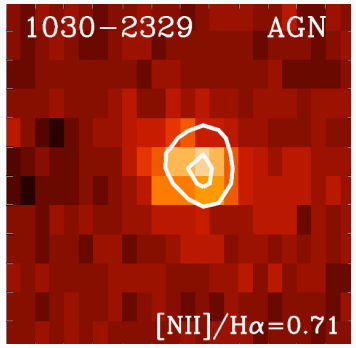
# Origin of the line emission



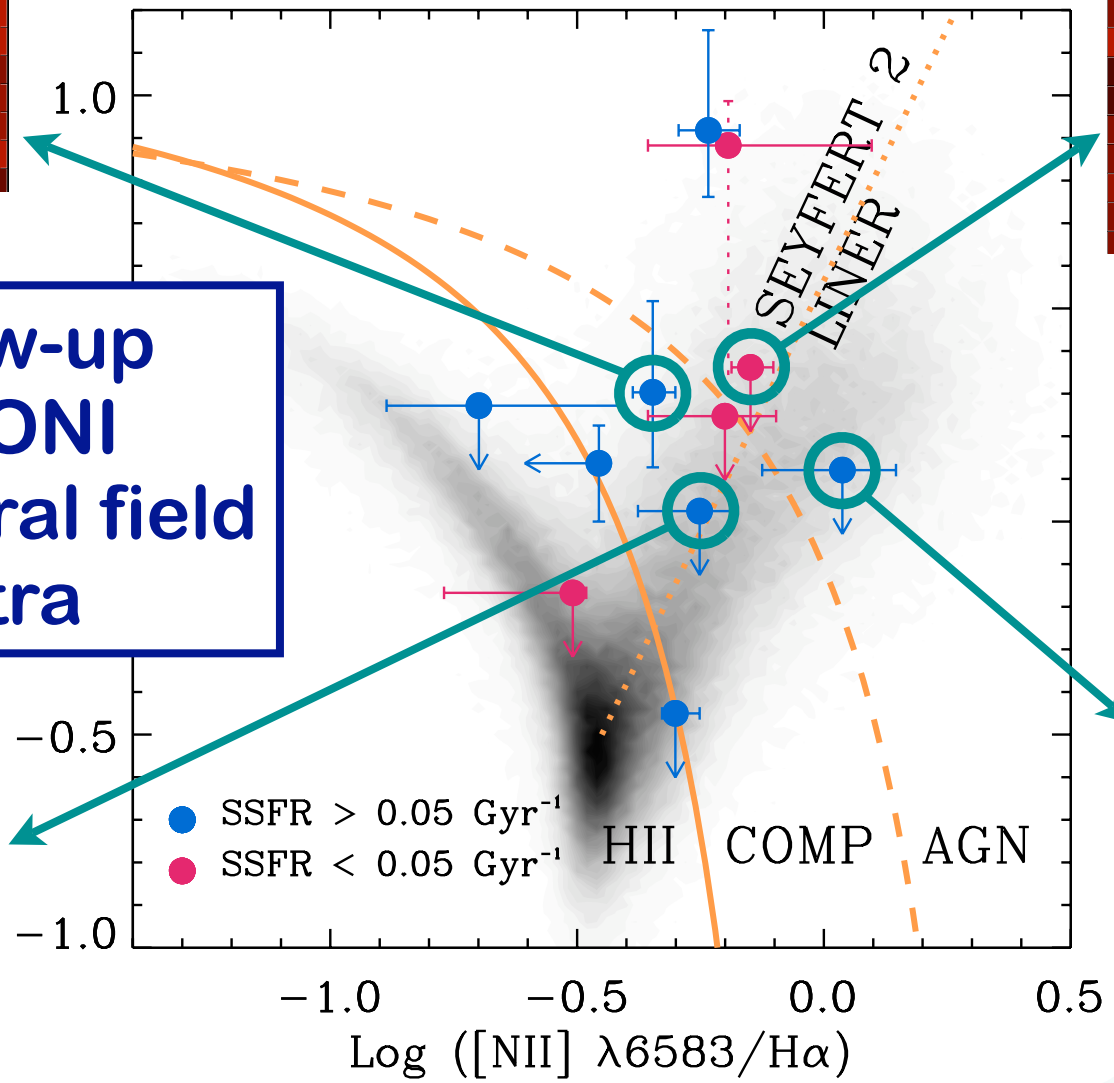

Kauffmann et al. 2003, Kewley et al. 2001, Kriek et al. submitted

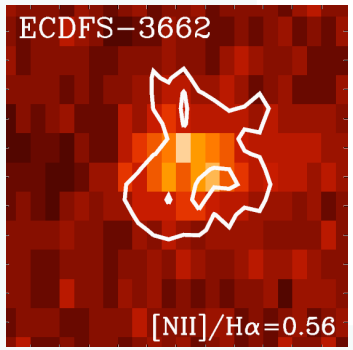
# Origin of the line emission

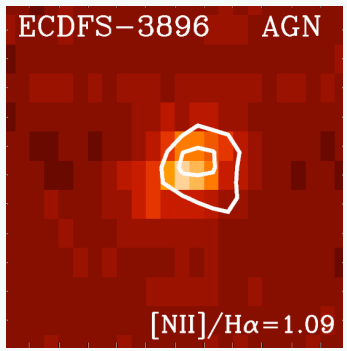



**Follow-up SINFONI integral field spectra**

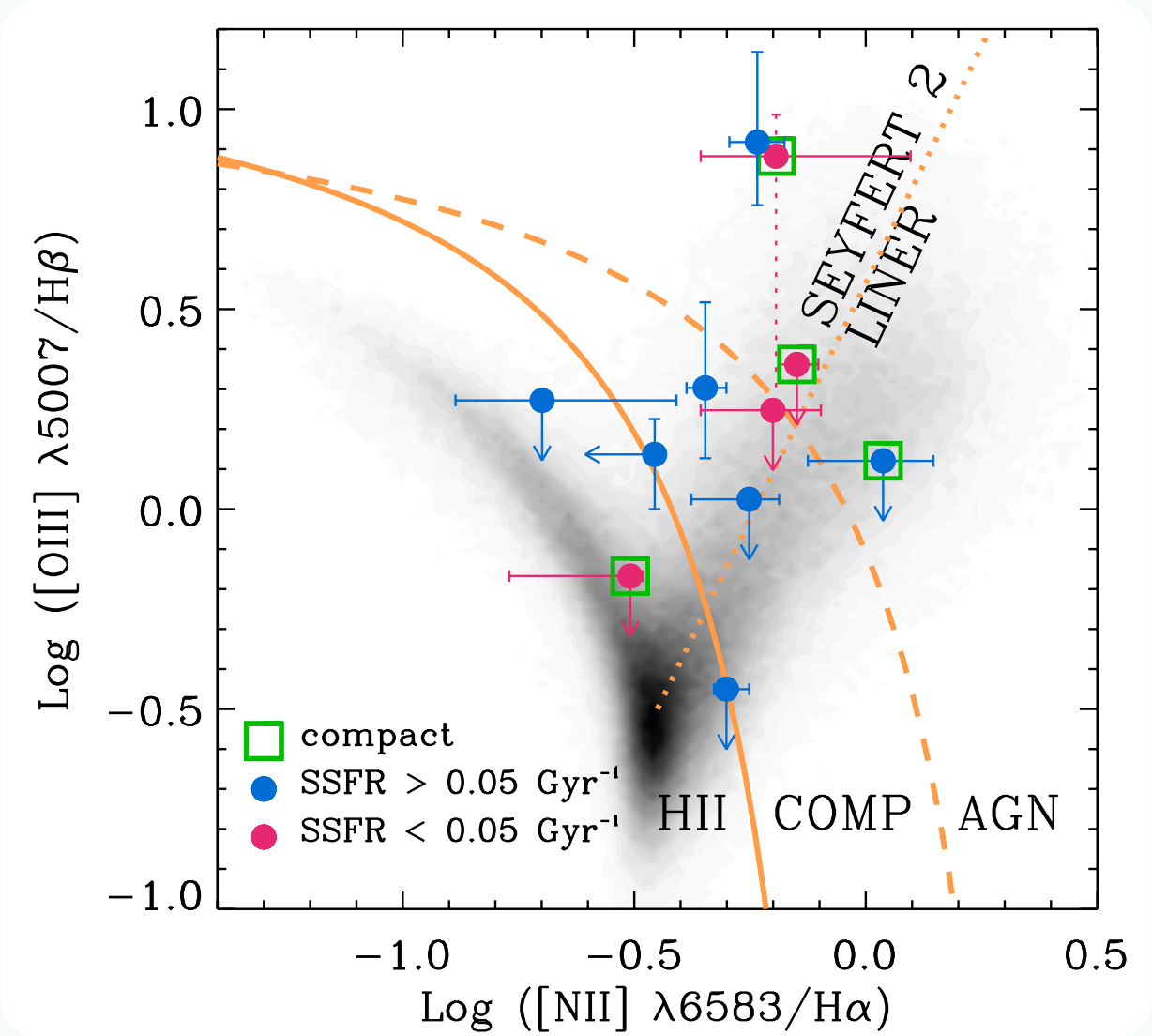



Kauffmann et al. 2003, Kewley et al. 2001, Kriek et al. submitted

# Origin of the line emission

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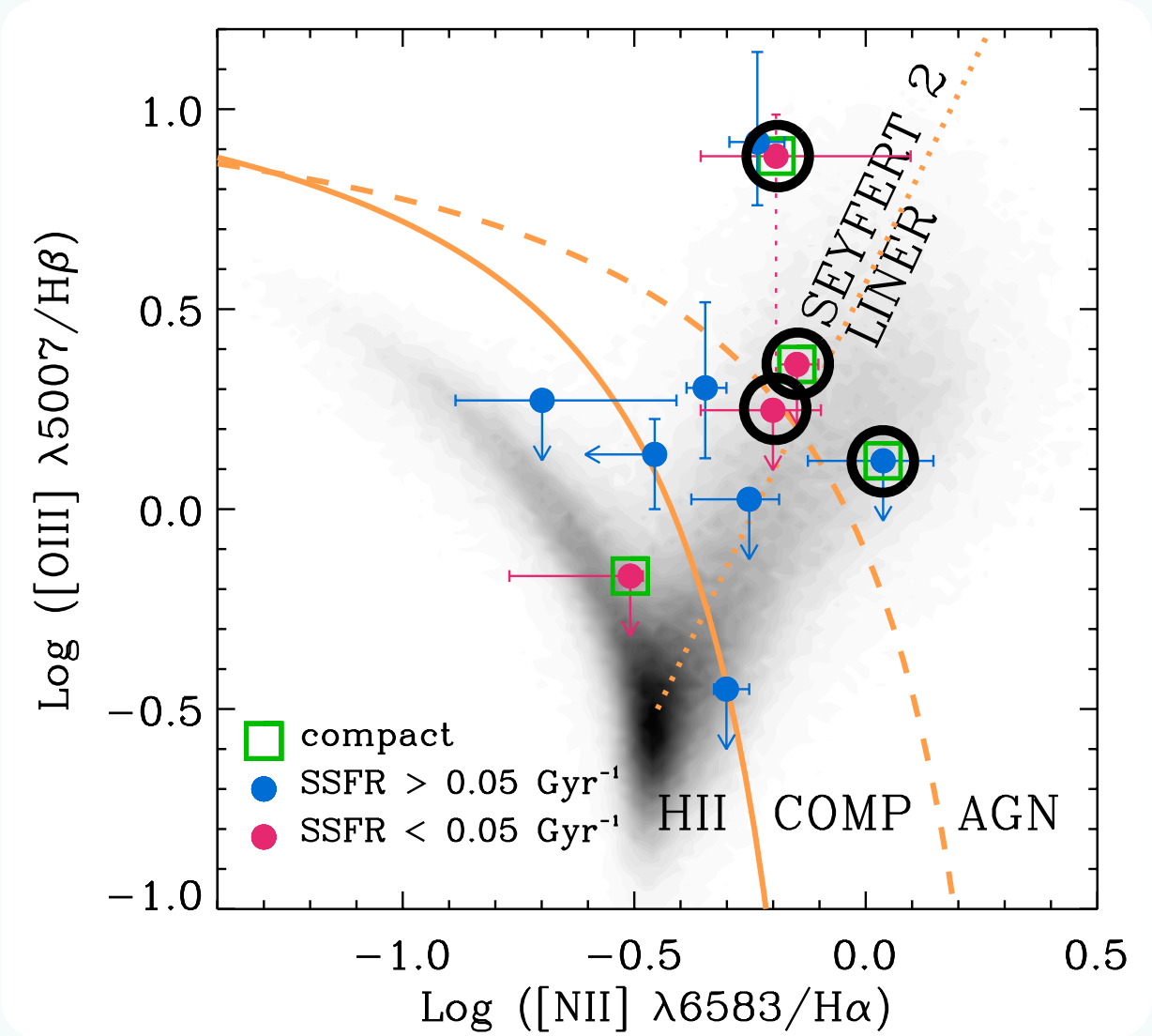
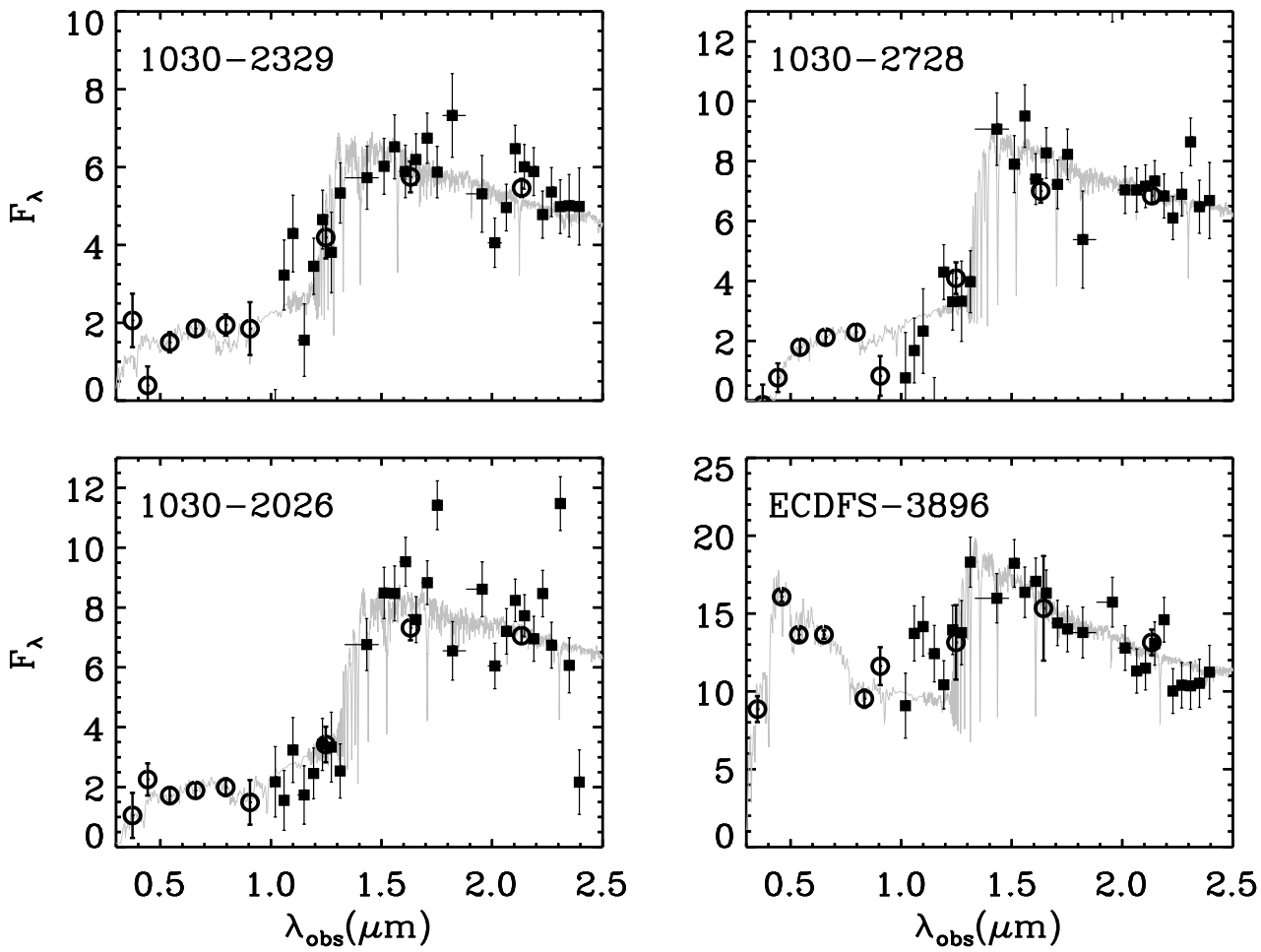



**AGN candidates**

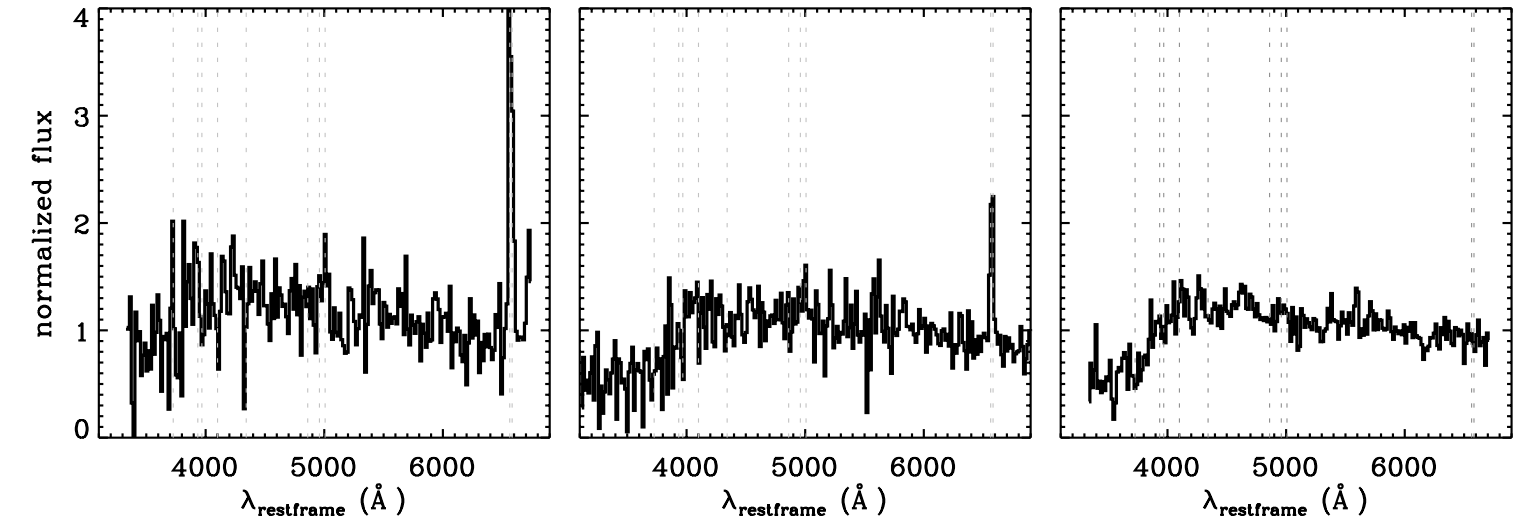
Kauffmann et al. 2003, Kewley et al. 2001, Kriek et al. submitted

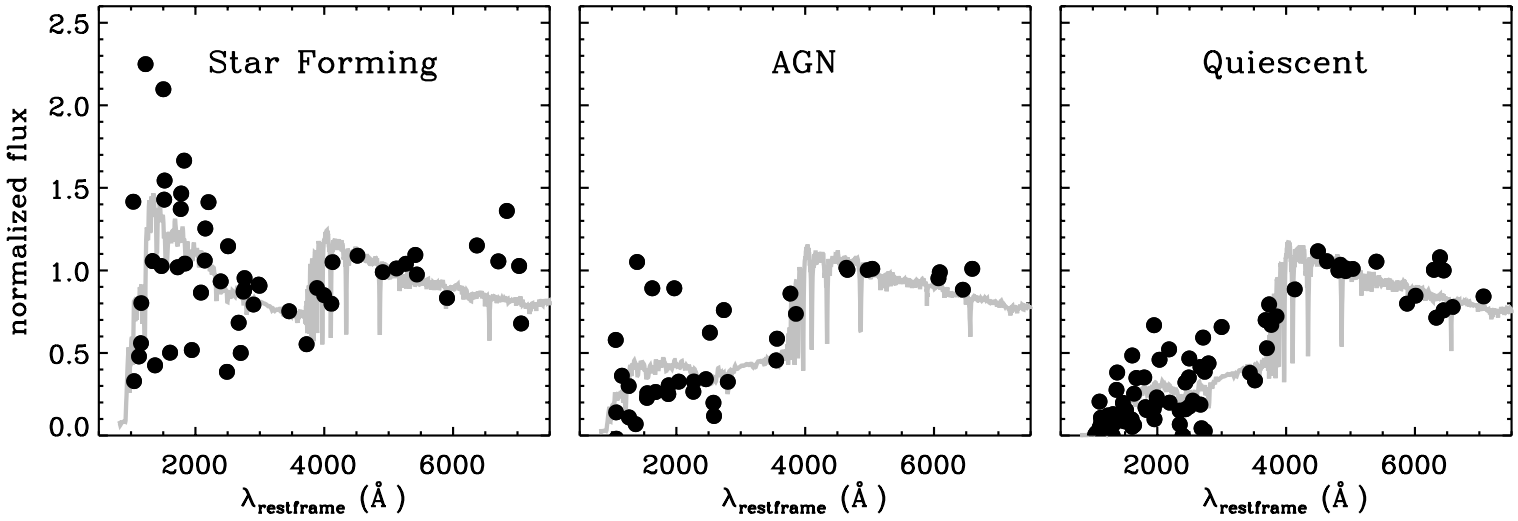
# SEDs of AGN host galaxies




Kriek et al. submitted

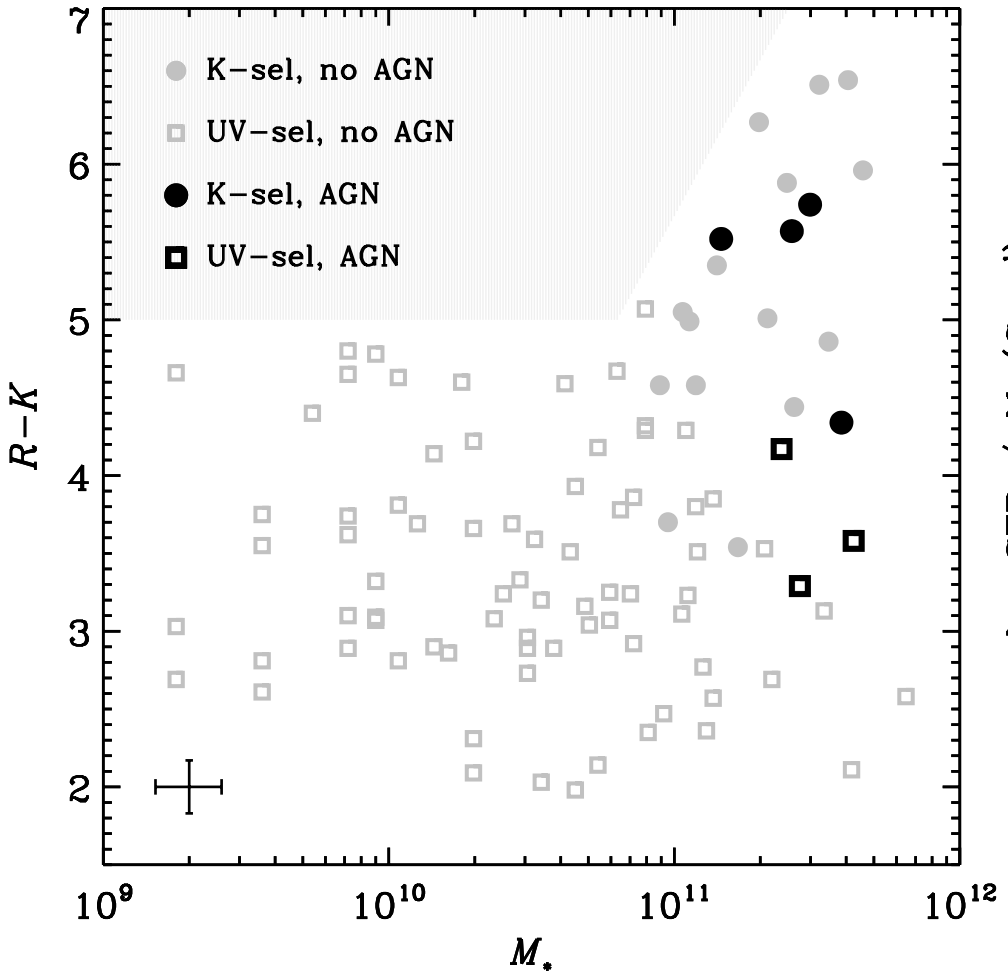
# Stacked spectra and composite SEDs

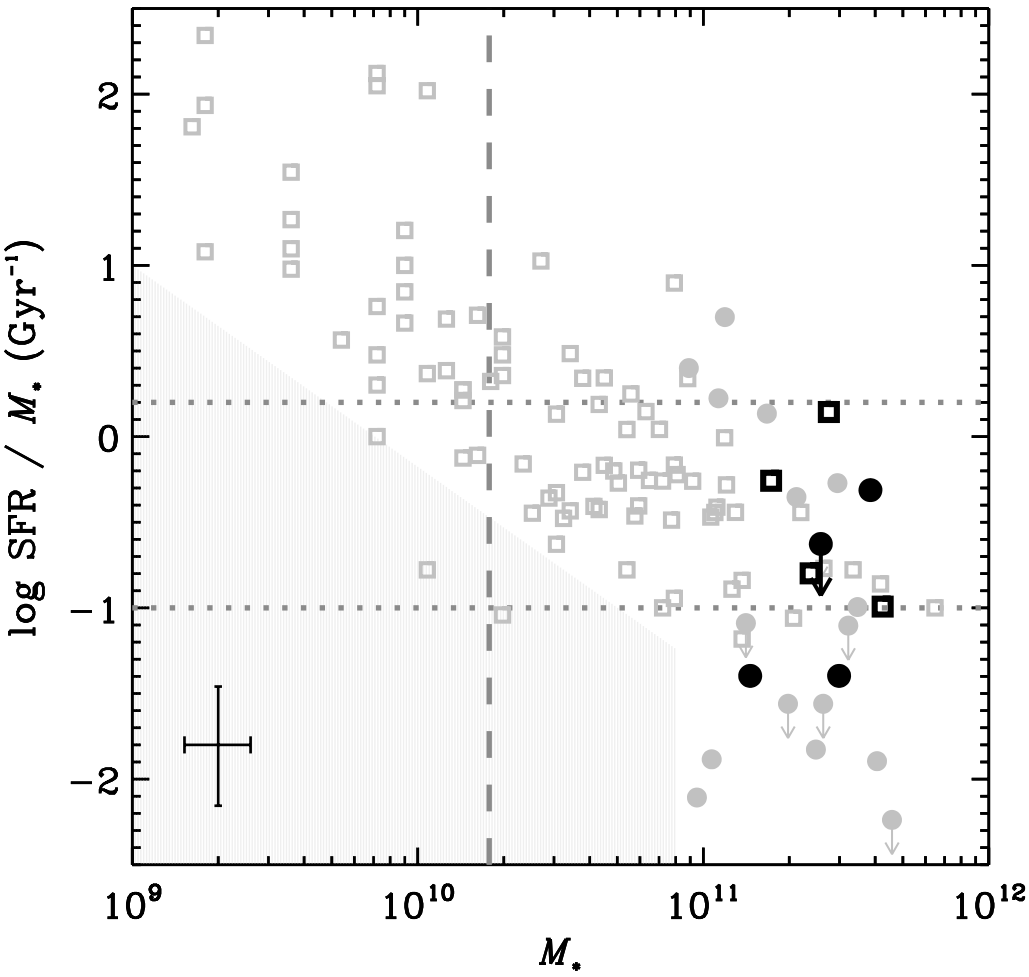



Kriek et al. submitted

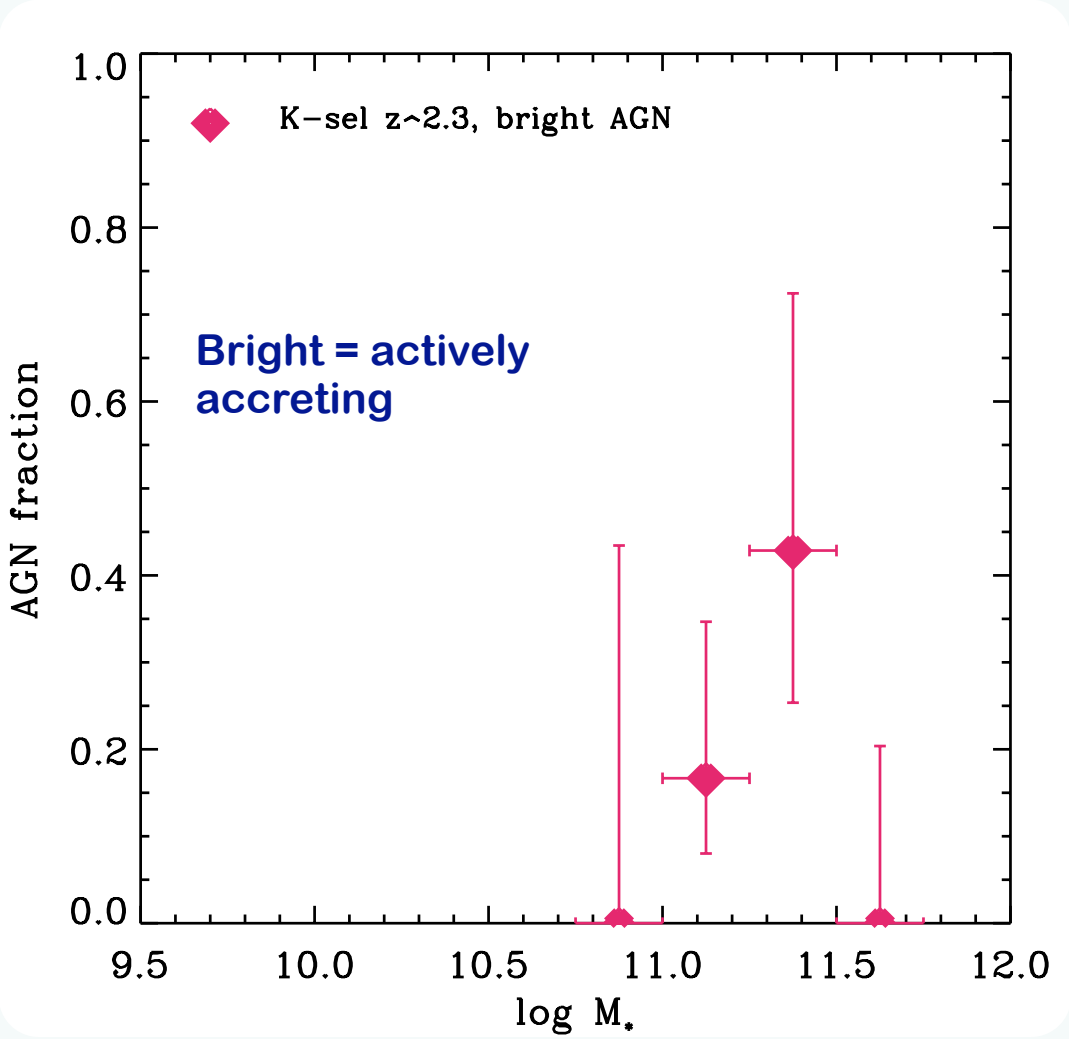
# Stellar masses of AGN hosts



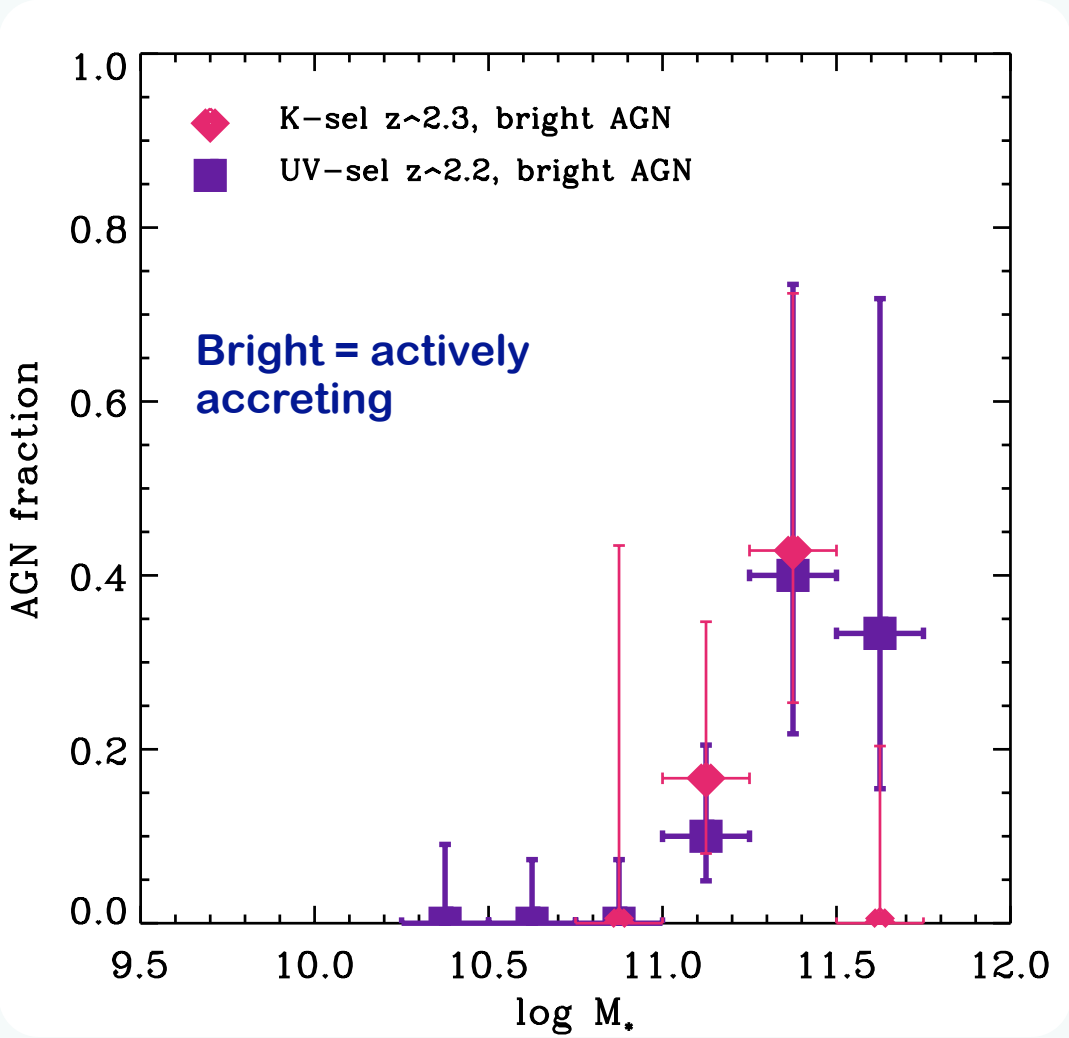

Erb et al. 2006; Kriek et al. submitted

# Downsizing of AGN host galaxies




Kriek et al. submitted

# Downsizing of AGN host galaxies

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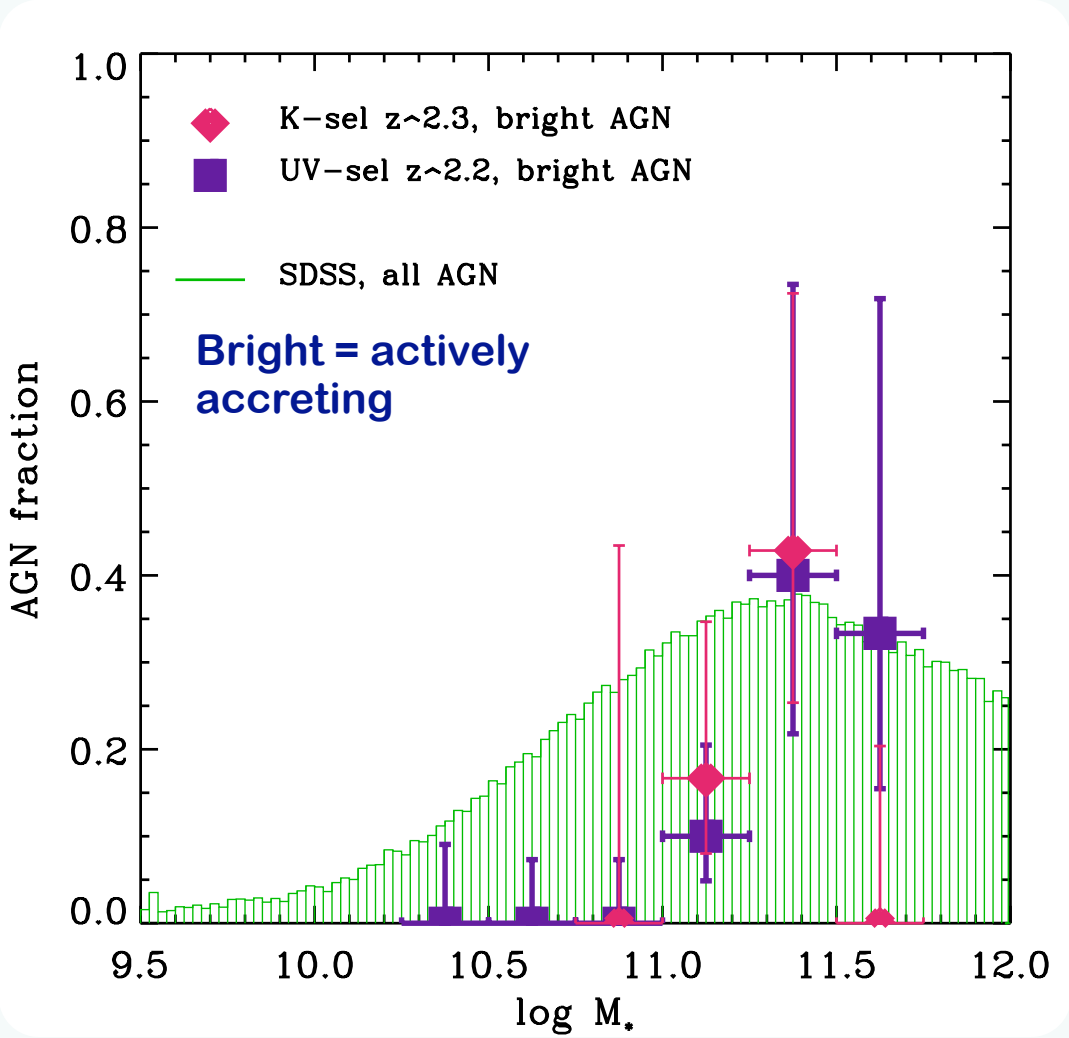
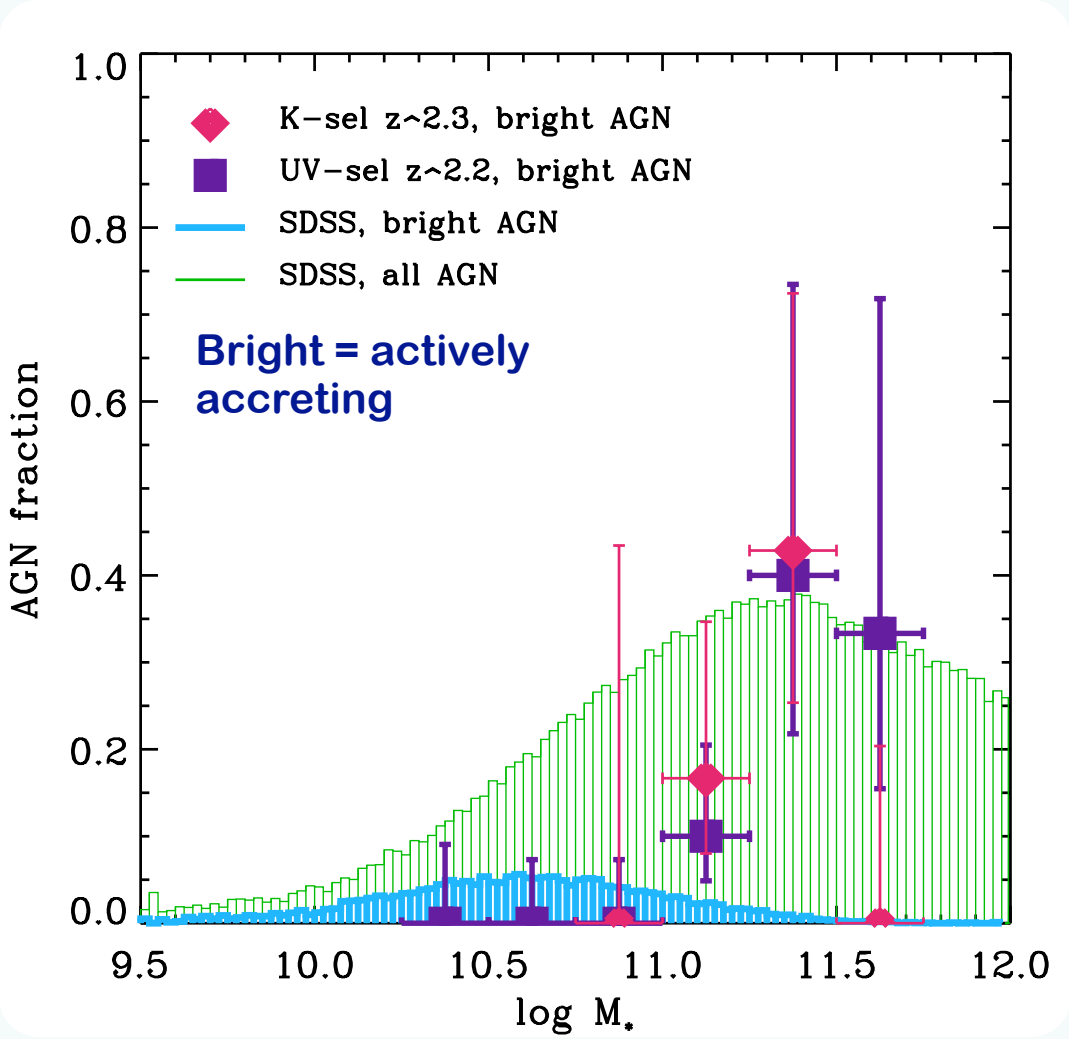



Kauffmann et al. 2003; Erb et al. 2006; Kriek et al. submitted

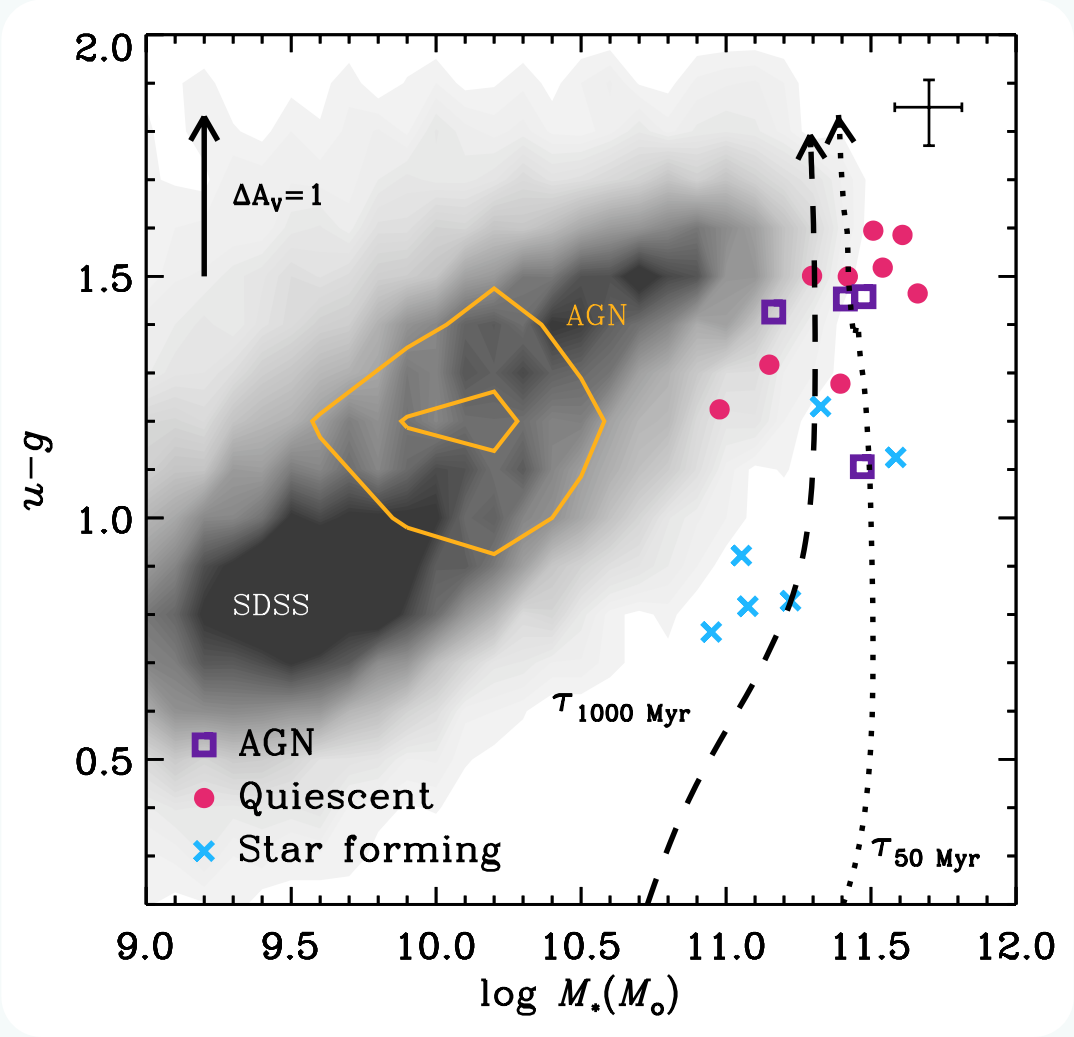
# Downsizing of AGN host galaxies




Comparing low and high redshift samples with the same normalized accretion rate (L_[NII] / M*)

Kauffmann et al. 2003; Erb et al. 2006; Kriek et al. submitted

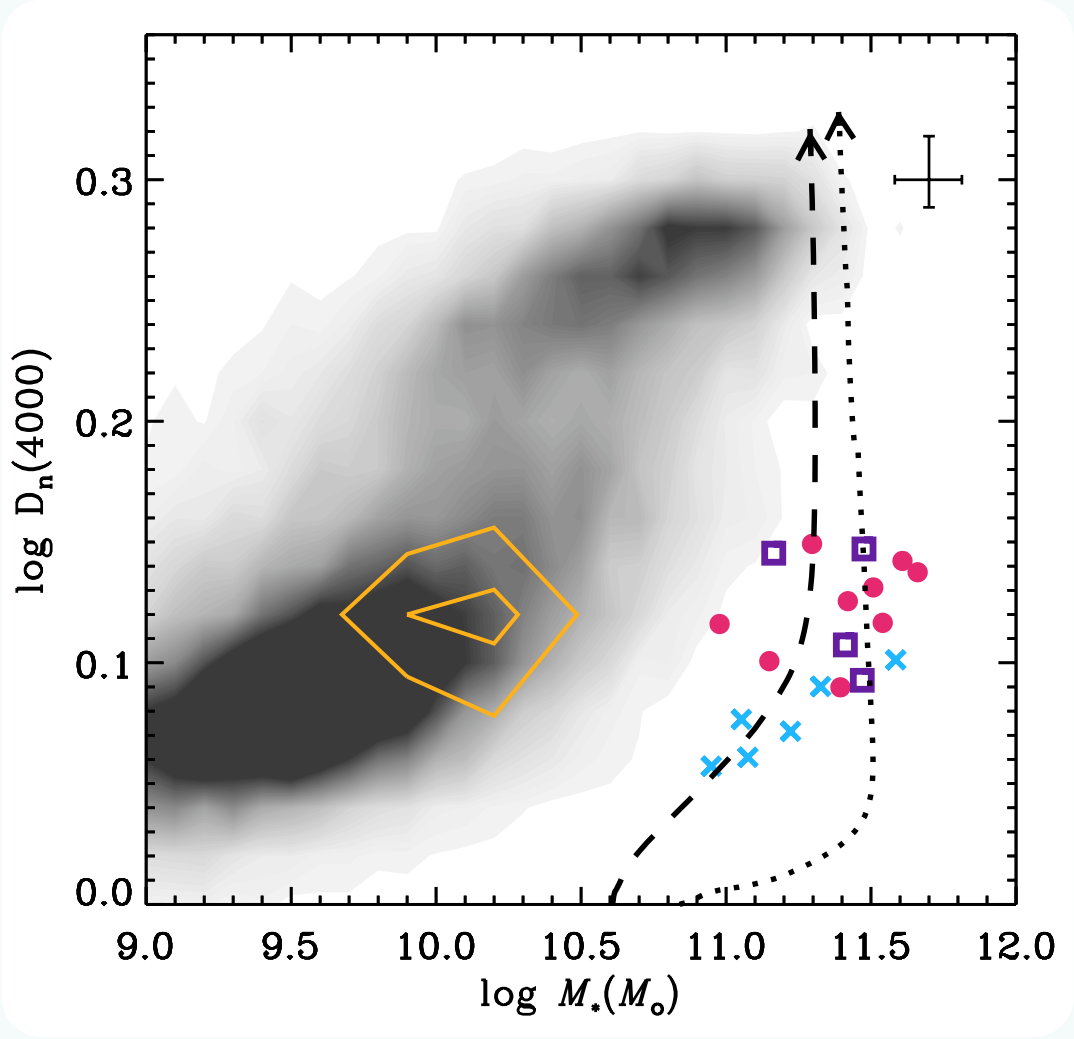
# Actively accreting AGNs




**Actively accreting AGNs may mainly reside in transitional galaxies**

Kriek et al. submitted

# Actively accreting AGNs




**Actively accreting AGNs may mainly reside in transitional galaxies**

Kriek et al. submitted

# Motivation & Conclusions

- When was the star formation in massive galaxies suppressed?
  - In a substantial part of the massive galaxies at z~2.3 the star formation is already strongly suppressed
- What is the role of AGNs in the star formation history of galaxies?
  - AGN host galaxies exhibit cosmic downsizing: related to the decrease of the typical mass-scale at which the star formation in galaxies is quenched
  - Actively accreting AGNs may mainly reside in post-starburst or transitional galaxies