GNIRS & the Distant Universe

Gemini Science Meeting 2012

July 20, 2012

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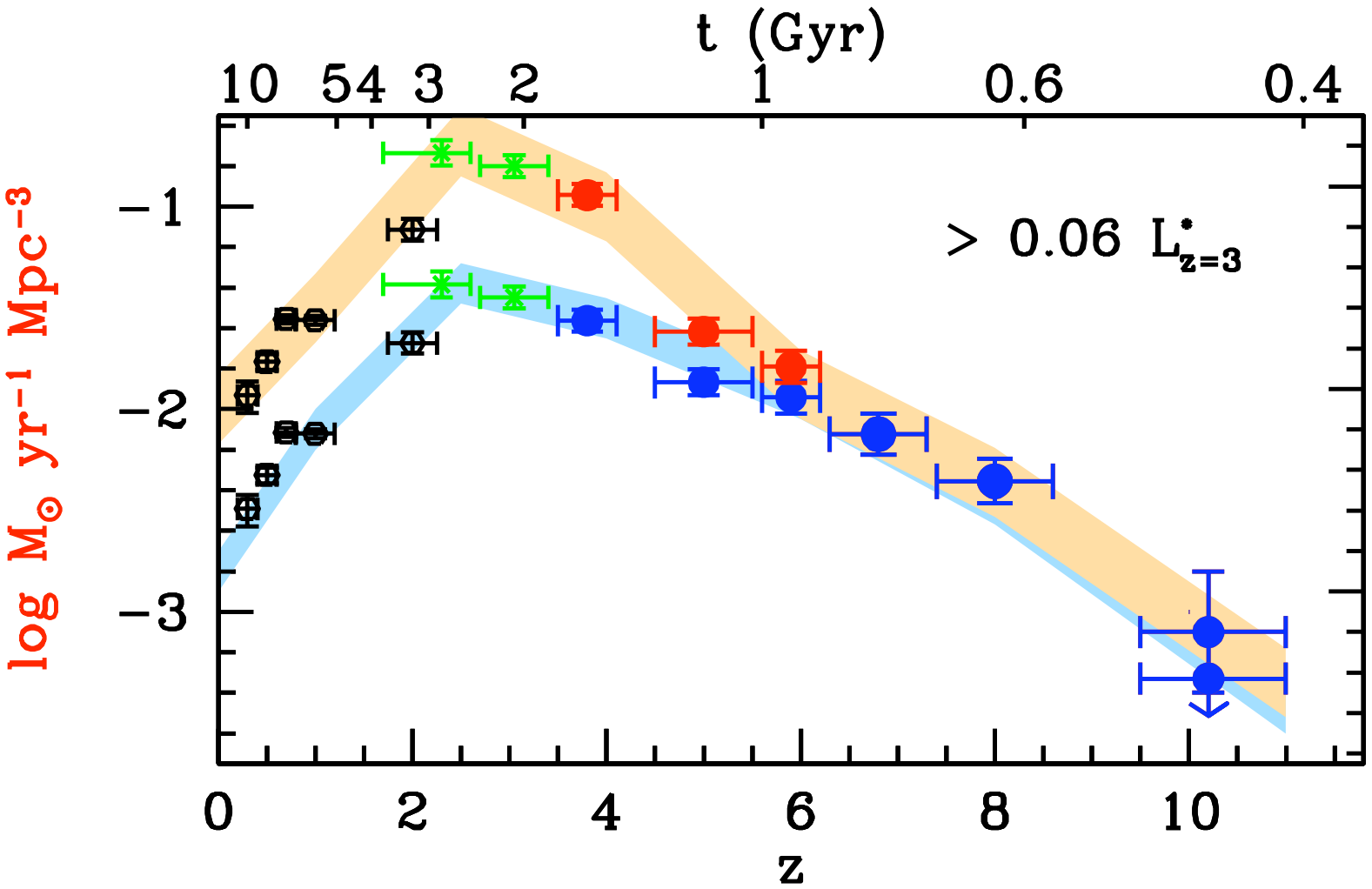
Pieter van Dokkum (Yale)
Adam Muzzin (Leiden)
Rachel Bezanson (Yale)
&
the MUSYC collaboration

Star formation history of the Universe

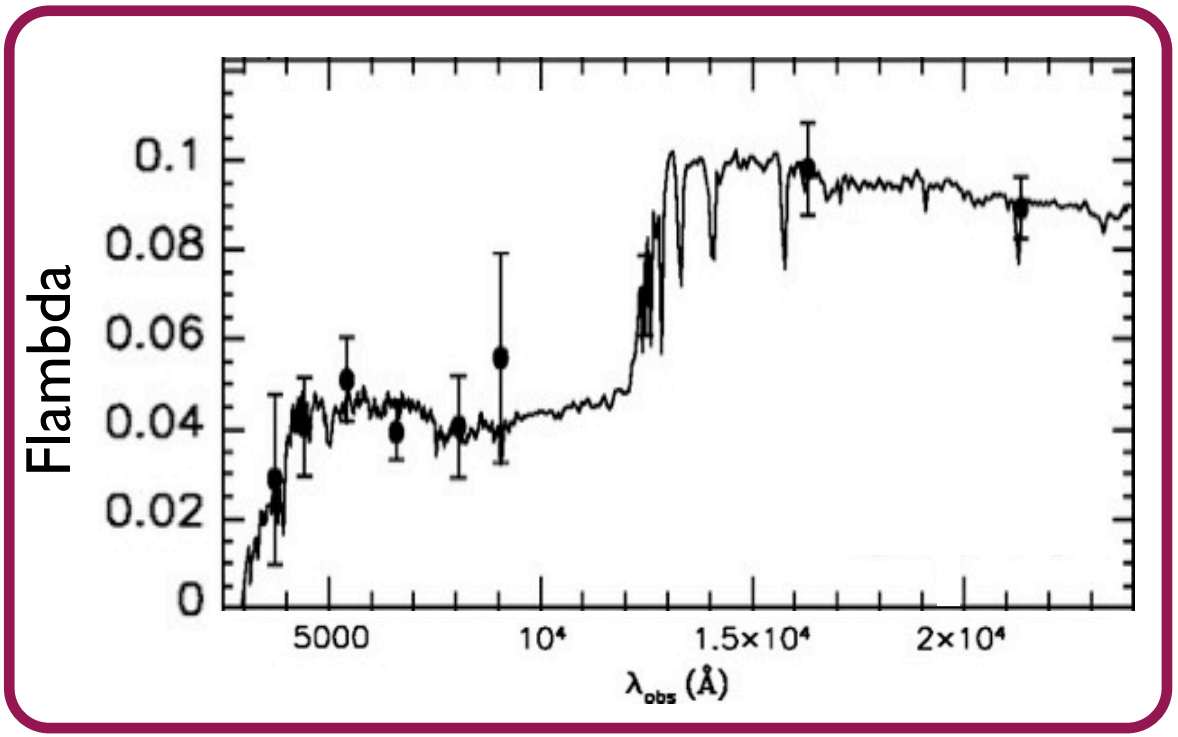


Bouwens et al. (2011)

Why is GNIRS the ideal instrument to observe galaxies at z=2-3?

Typical massive galaxy at 2<z<3 is red

- Optically red
  - J-K = 2.48
  - $(U-V)_0$=0.62
- Faint in the observed optical
  - R_{AB} = 25.9



van Dokkum et al. 2006

Beyond the limits of optical spectroscopy

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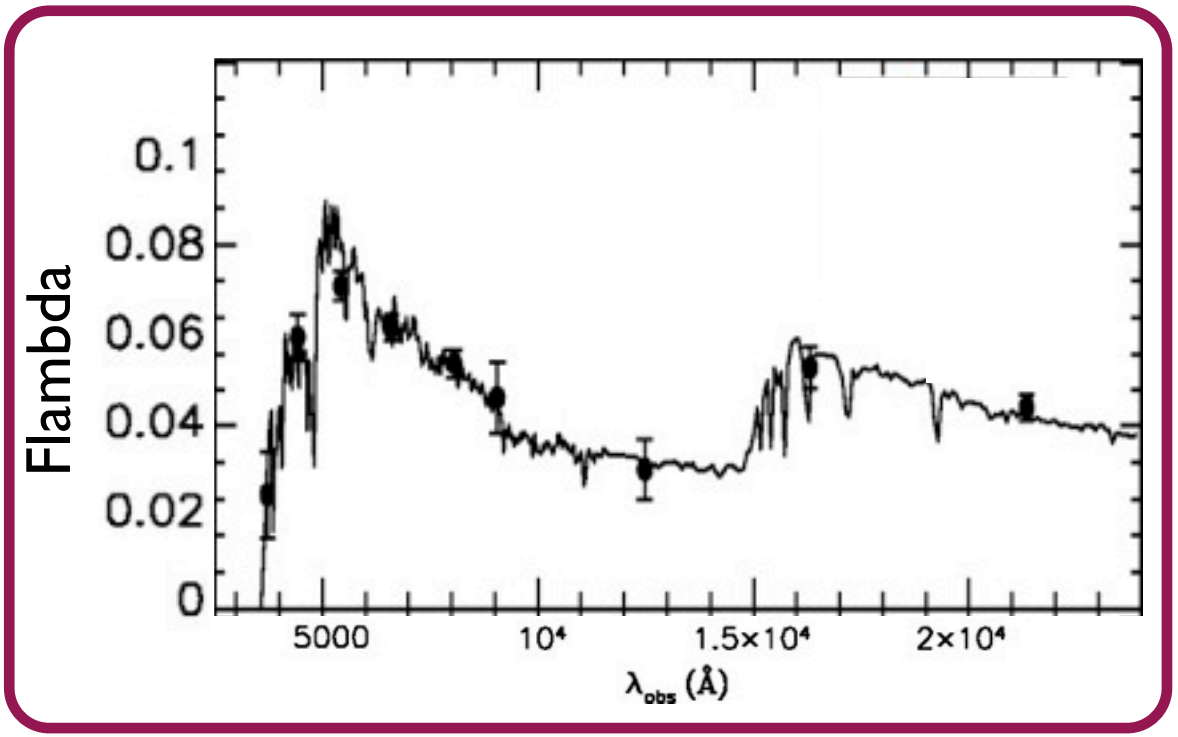

van Dokkum et al. 2006

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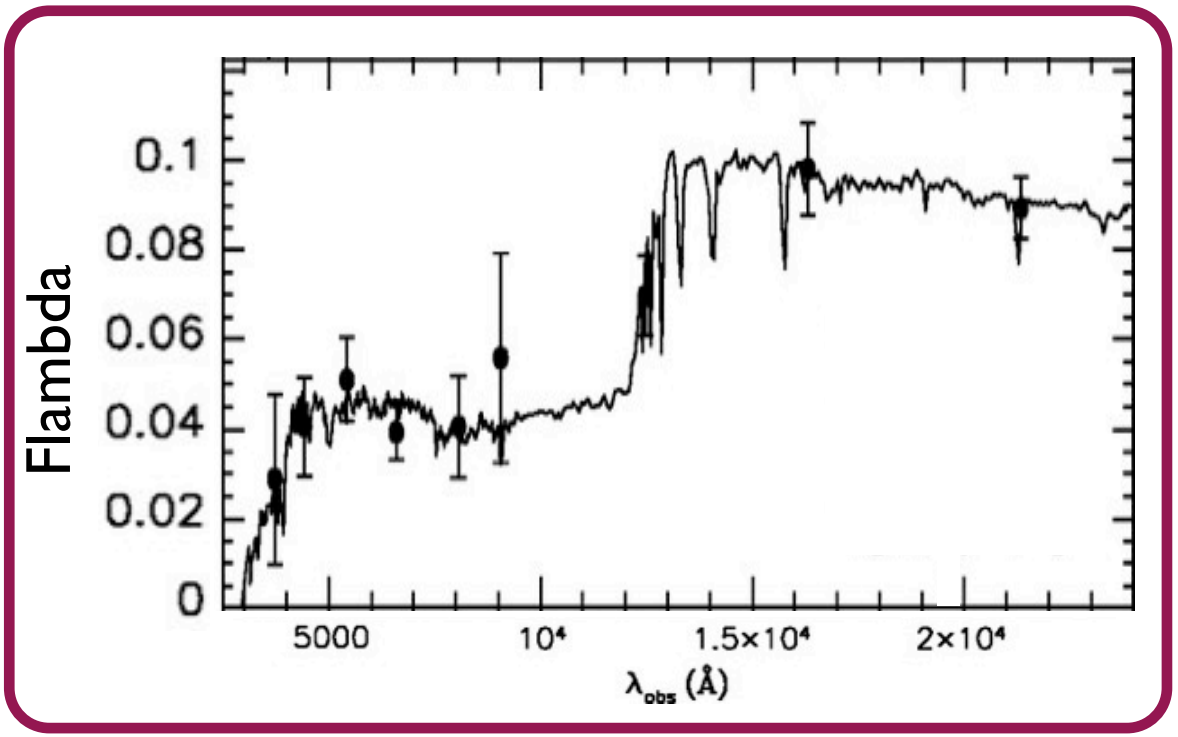
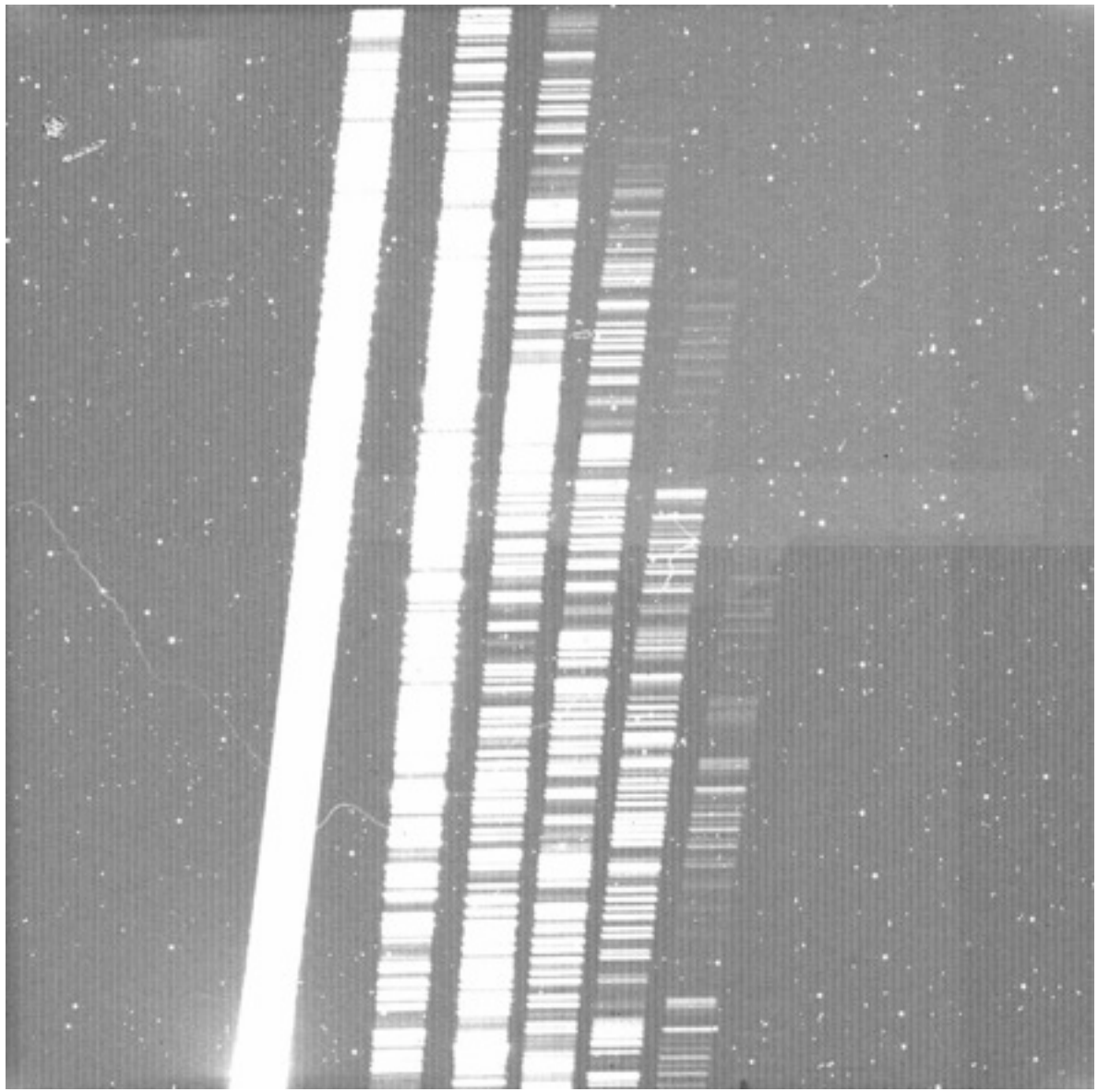


van Dokkum et al. 2006

Beyond the limits of optical spectroscopy

Full near-infrared wavelength coverage



Targeted lines for z ≈ 2.3

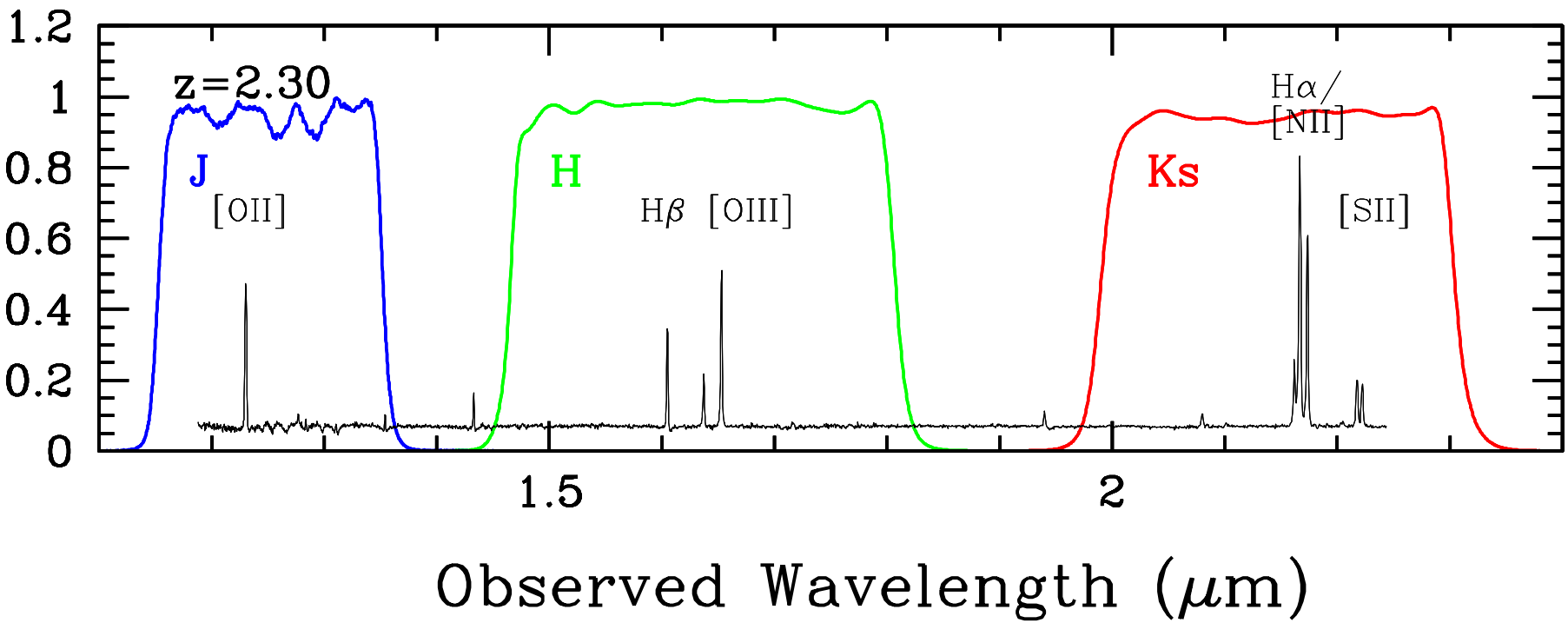
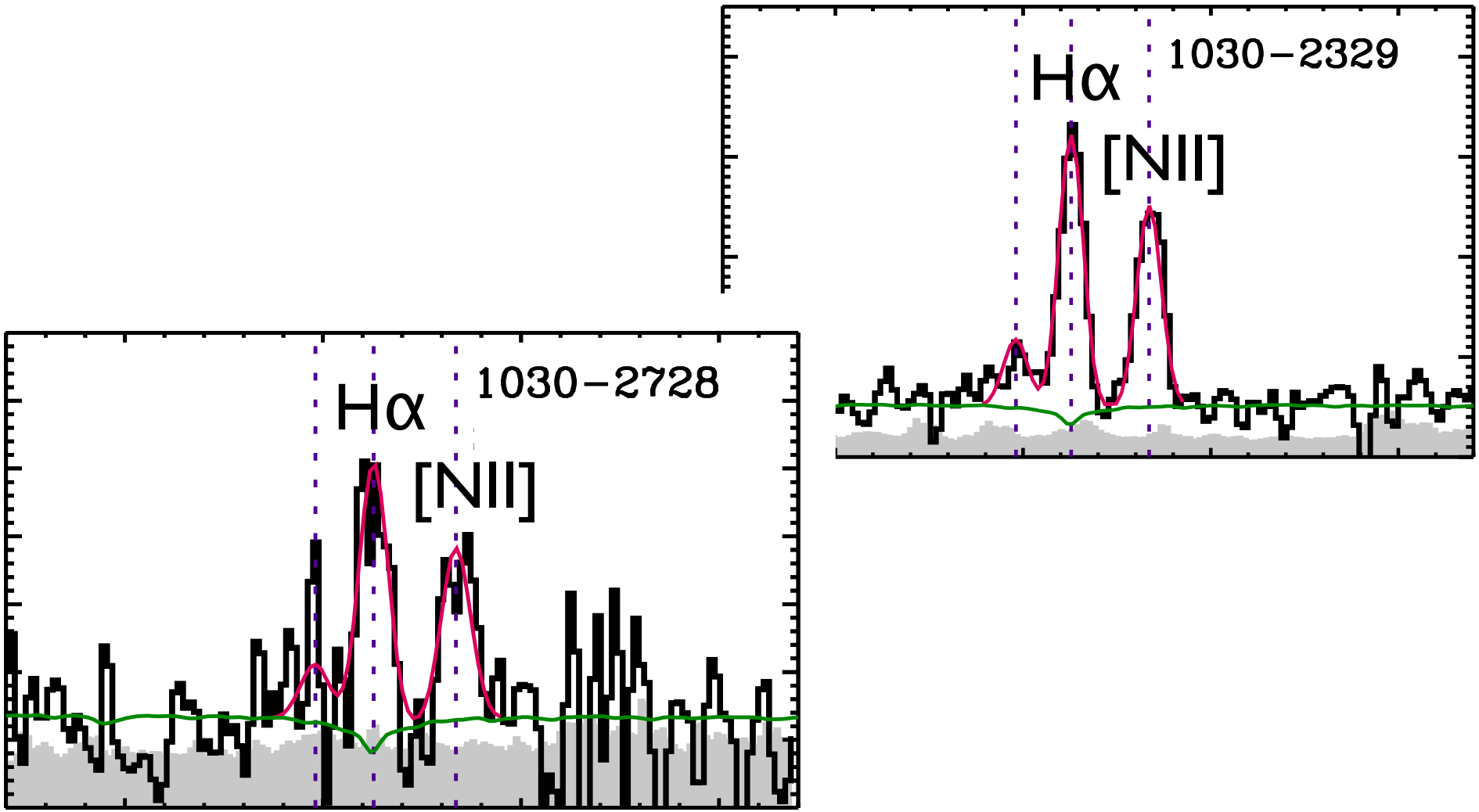


Figure from A. Shapley

A GNIRS Survey for massive galaxies at $z \approx 2.3$

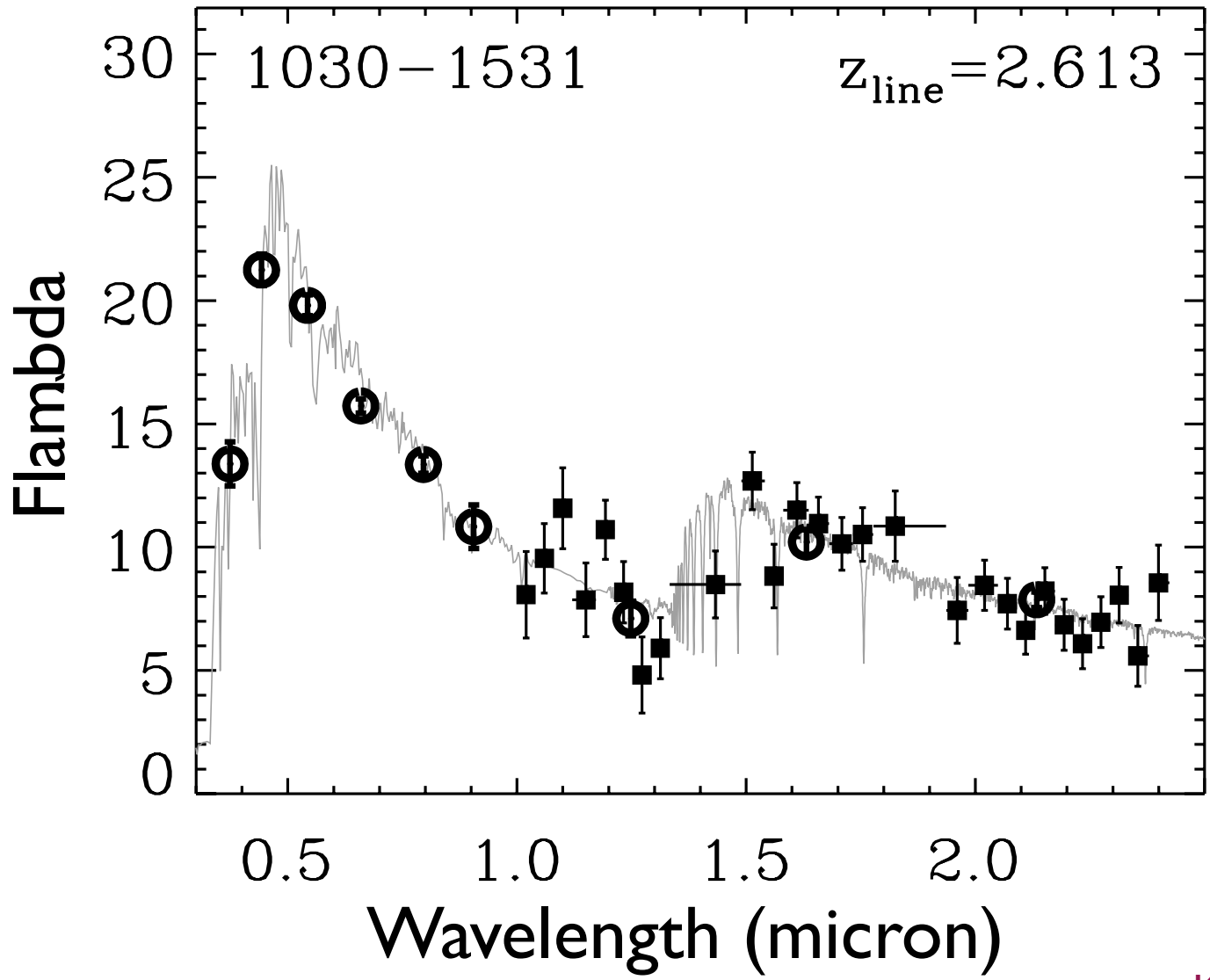
- Selection:
  - MUSYC survey: UBVRIzJHK photometry
  - $K_{vega} < 19.7$
  - $2 < z_{phot} < 3$
- Total sample: 36 galaxies
- Follow-up: SPITZER/IRAC, SPITZER/MIPS, Magellan/LDSS3, HST/NICMOS, Keck/NIRC2-AO
- Fully reduced spectra and data products available at: www.astro.berkeley.edu/~mariska

Examples of emission line spectra



Kriek et al. (2007)

Examples of continuum spectra



Kriek et al. (2008)

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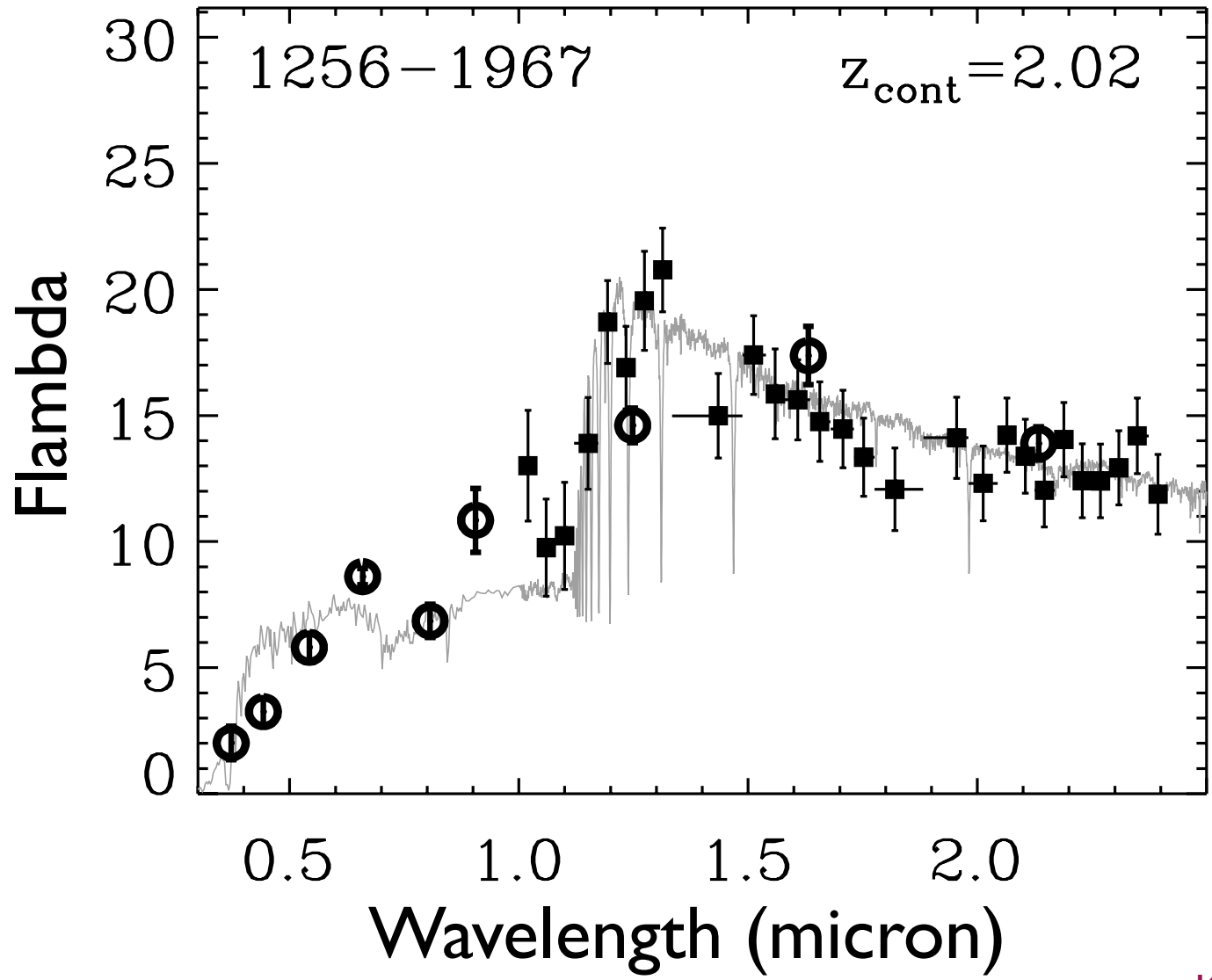

Kriek et al. (2008)

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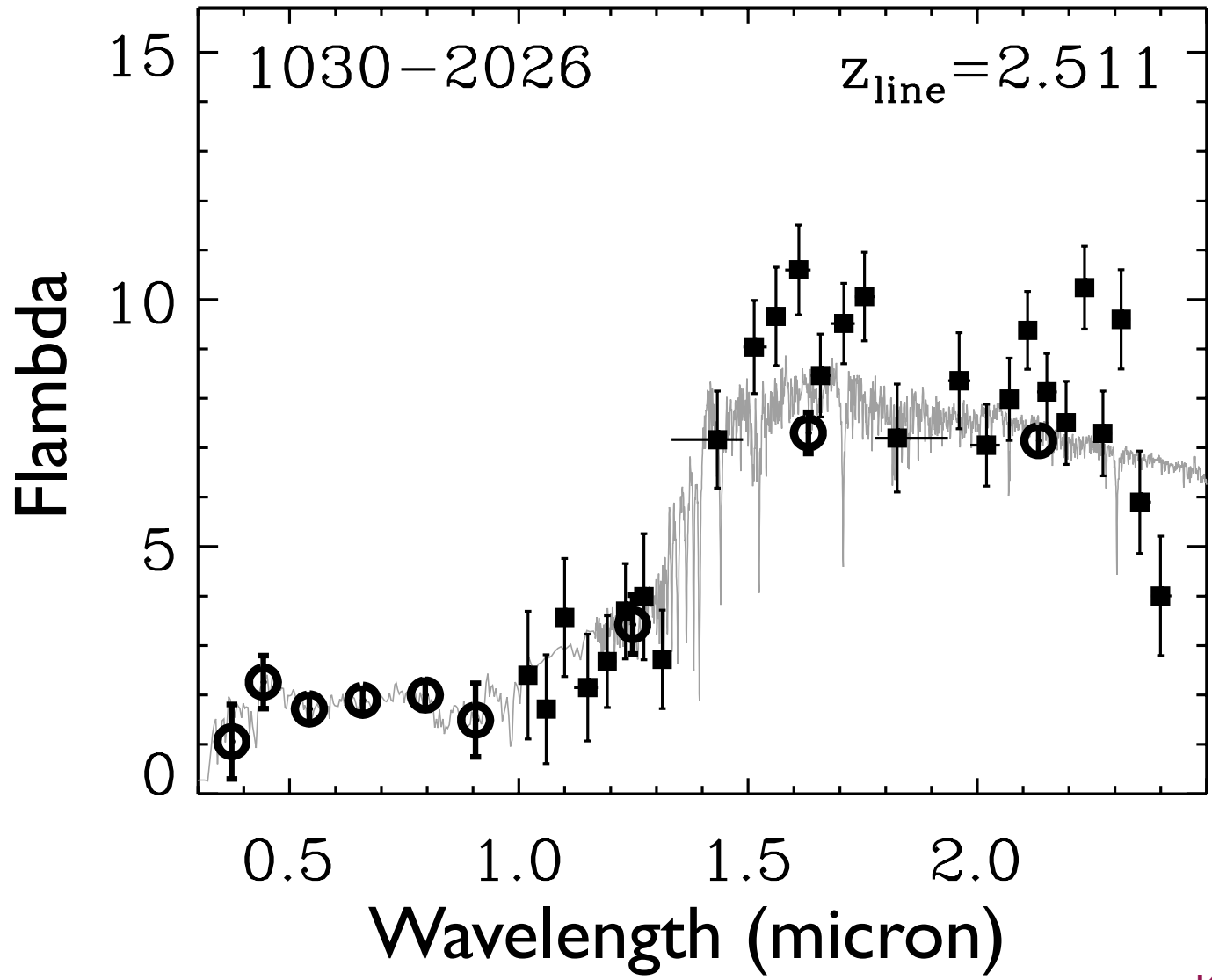

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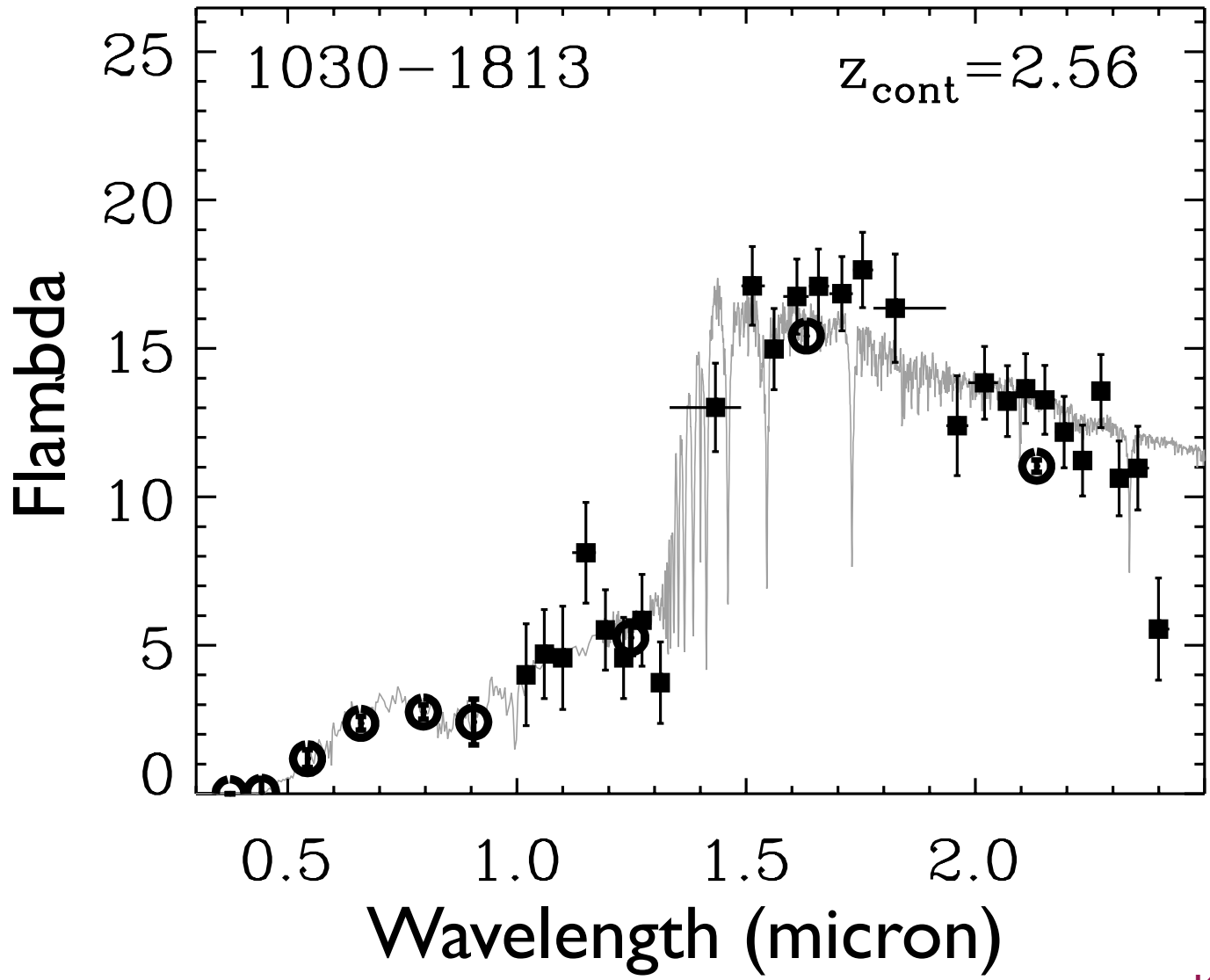
Examples of continuum spectra



Kriek et al. (2008)

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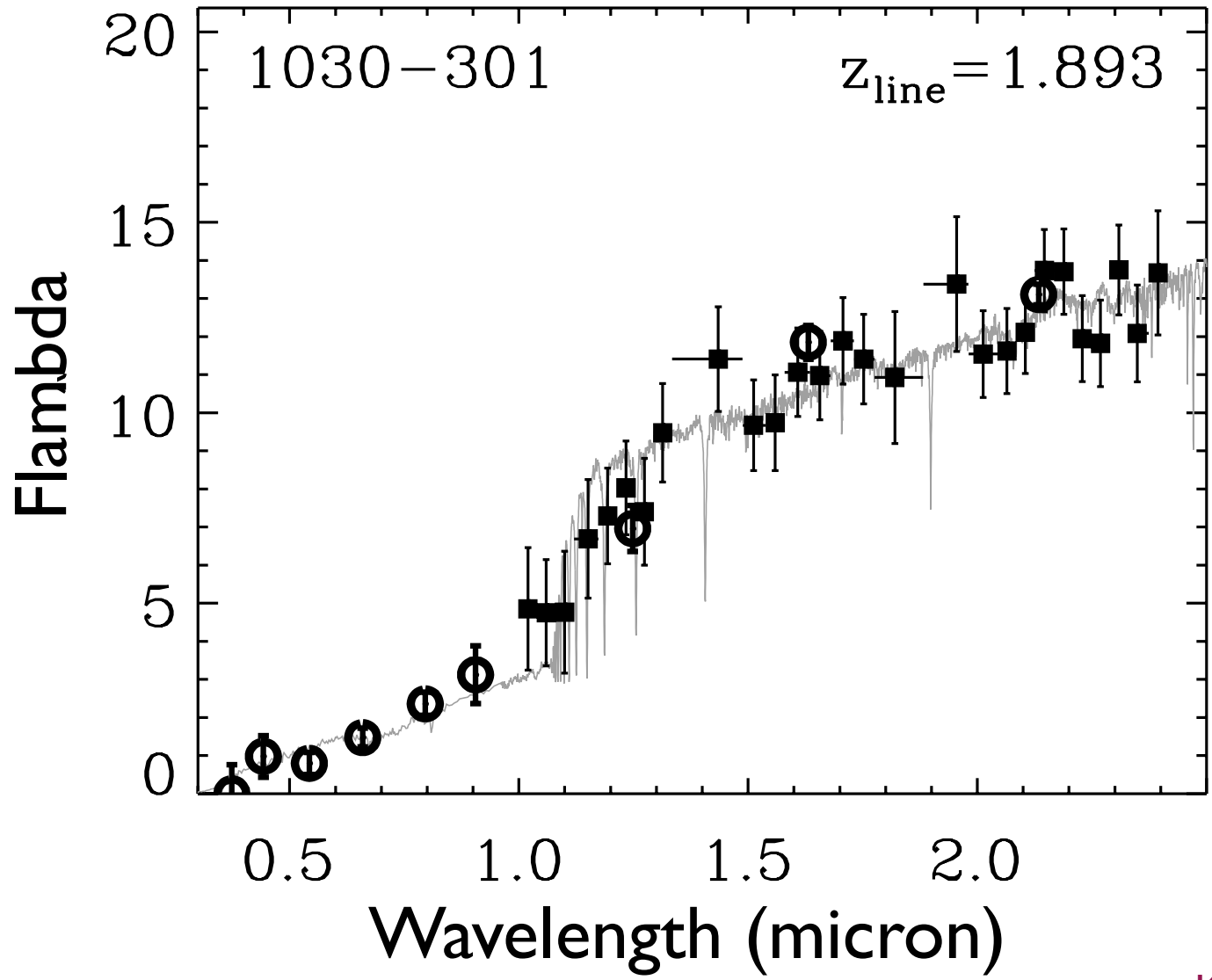

Kriek et al. (2008)

Overview

- 8 galaxies at $z < 2$
- 28 galaxies at $2 < z < 3$

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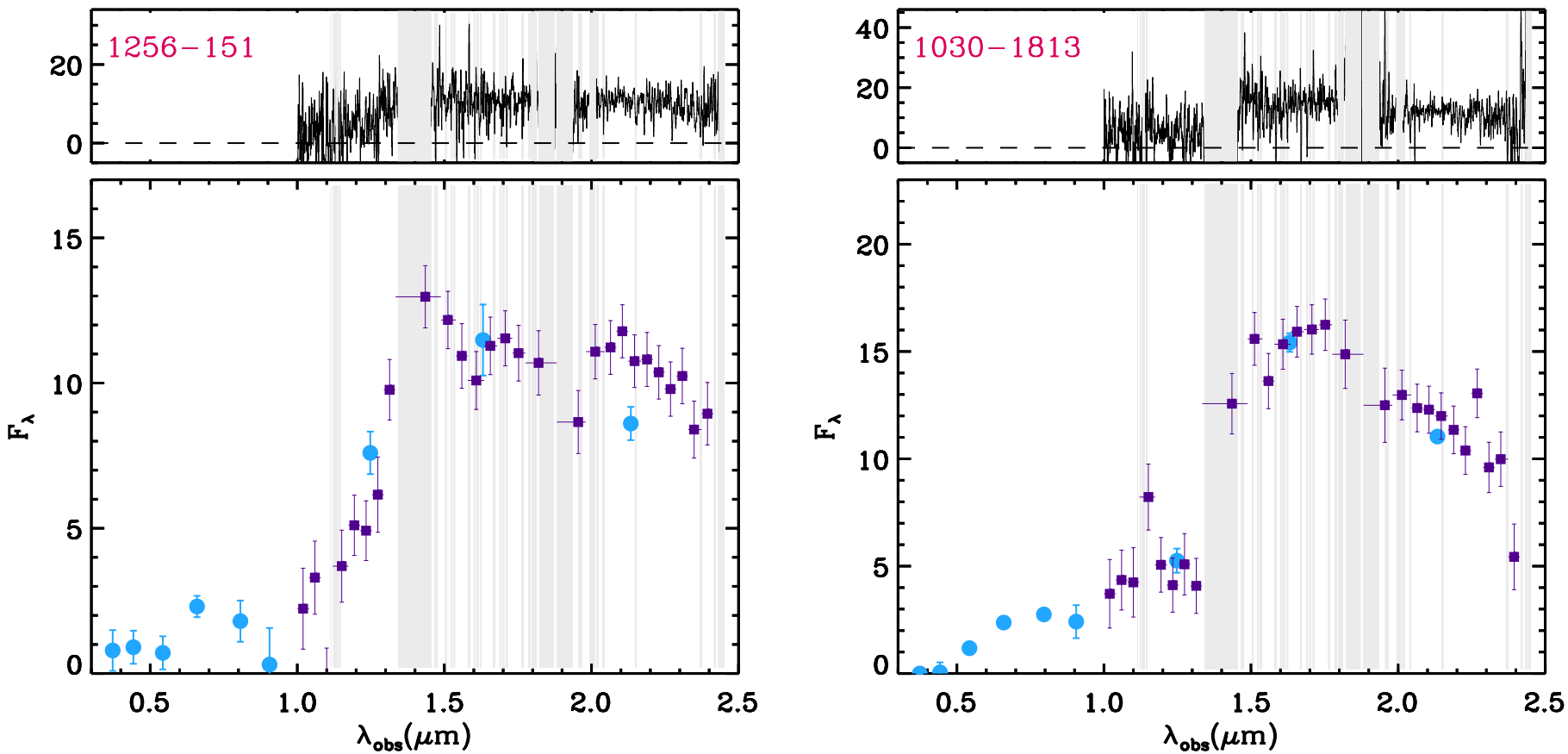
- 28 galaxies at $2 < z < 3$
  - 11 Galaxies without detected emission lines

Galaxies without detected emission lines



Kriek et al. (2006)

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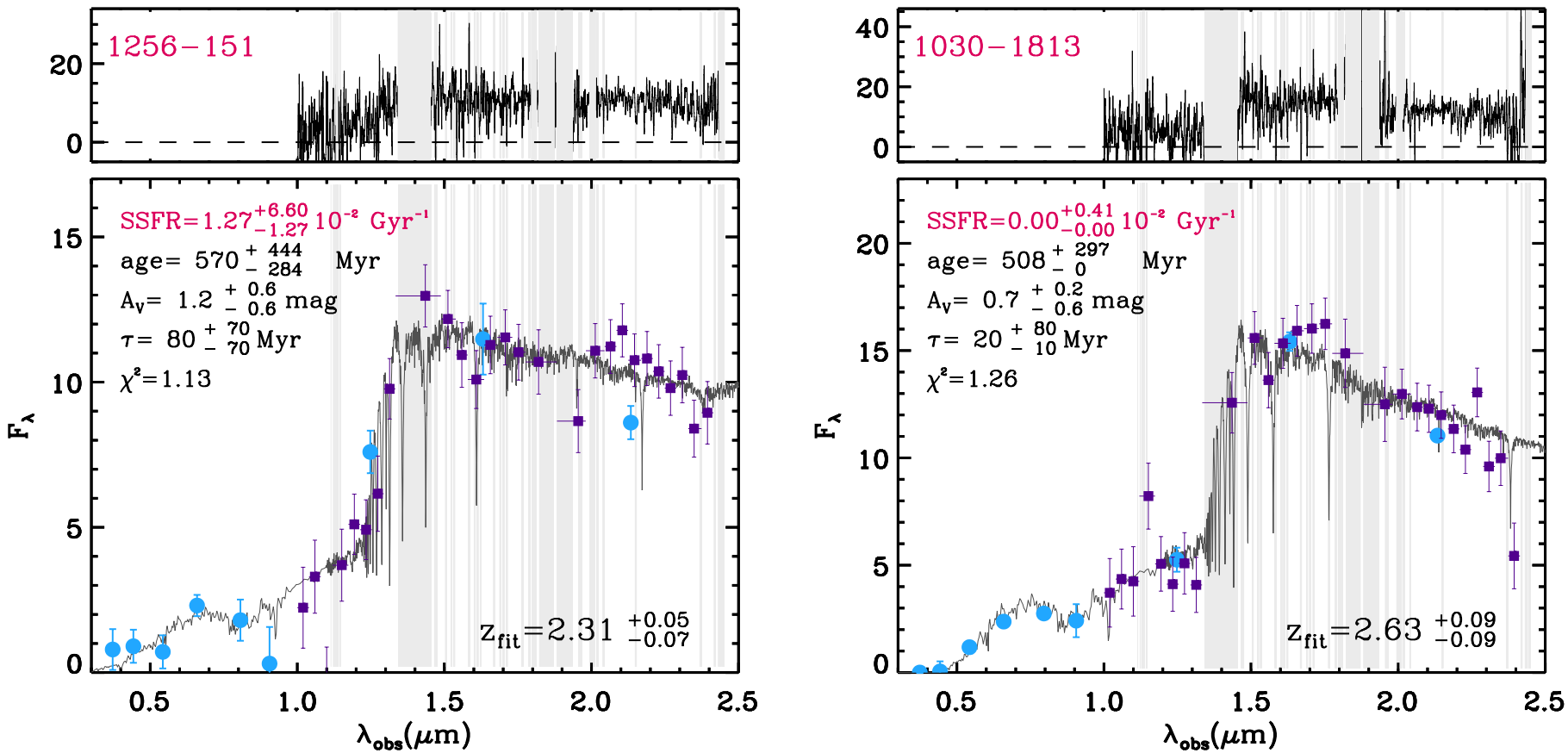
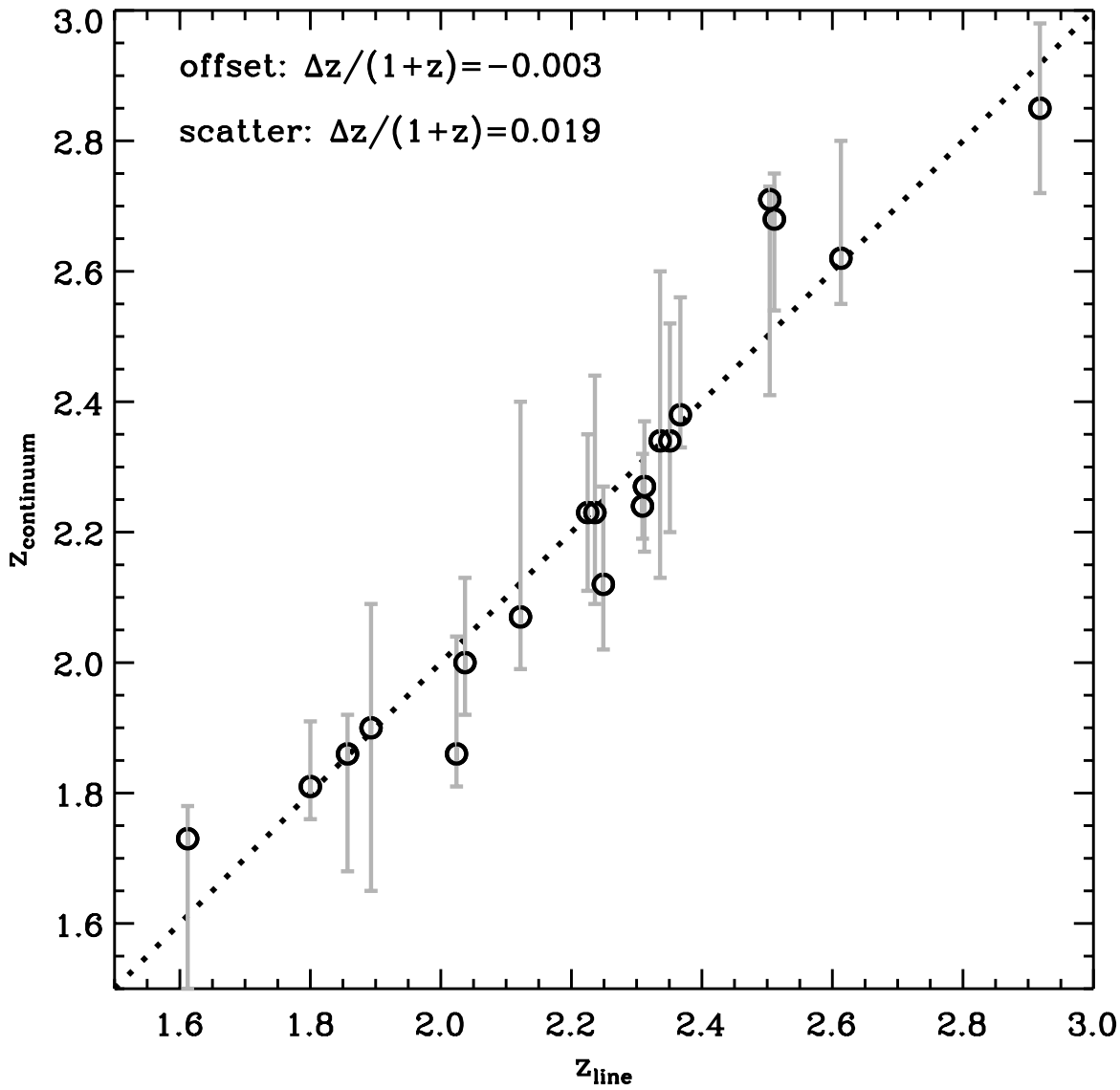


Kriek et al. (2006)

Continuum redshifts

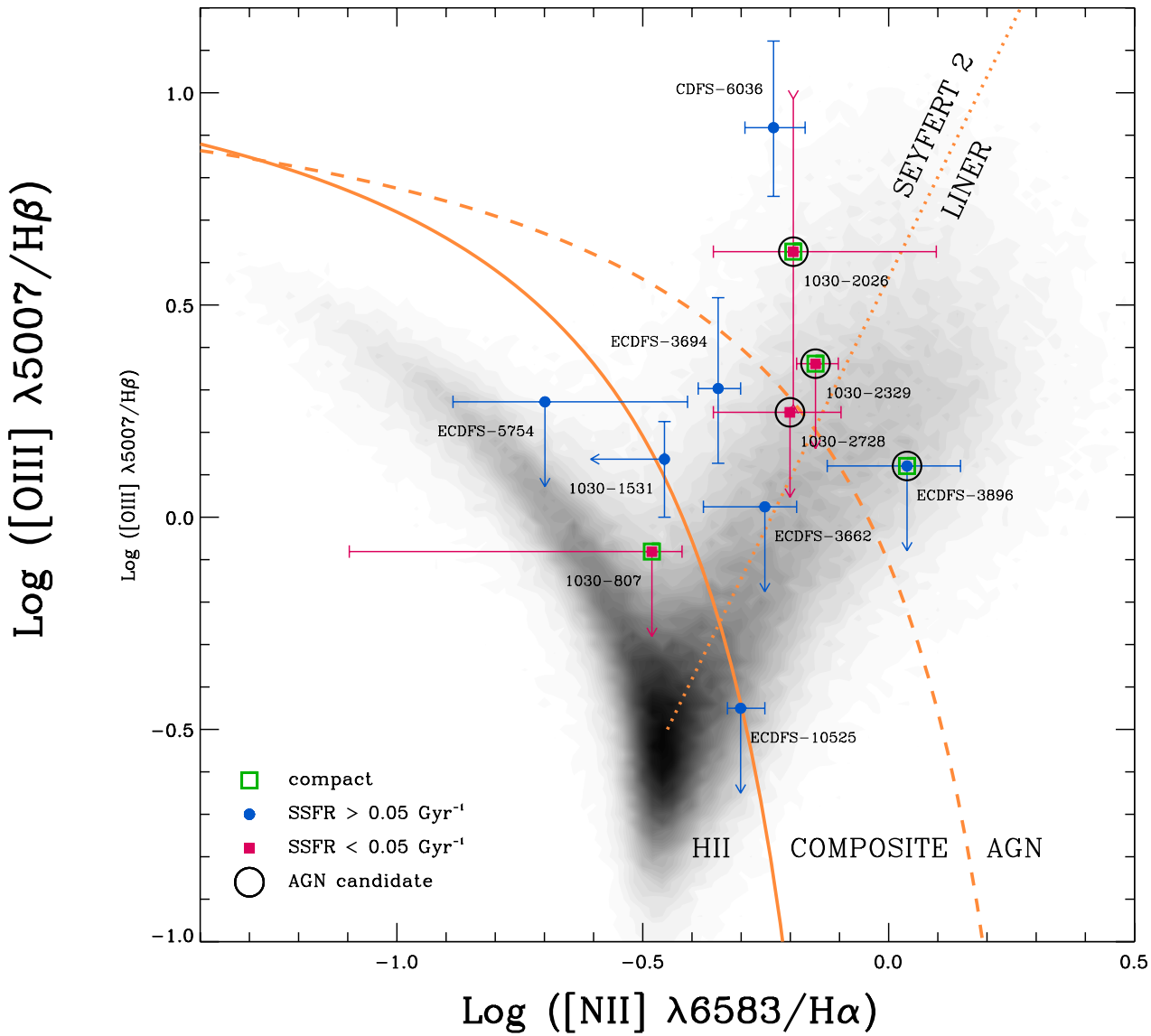


Kriek et al. (2008)

Overview

- 8 galaxies at $z < 2$
- 28 galaxies at $2 < z < 3$
  - 11 Galaxies without detected emission lines
  - 17 Emission line galaxies (see Kriek et al. 2007)

Emission line galaxies: AGN or star forming?

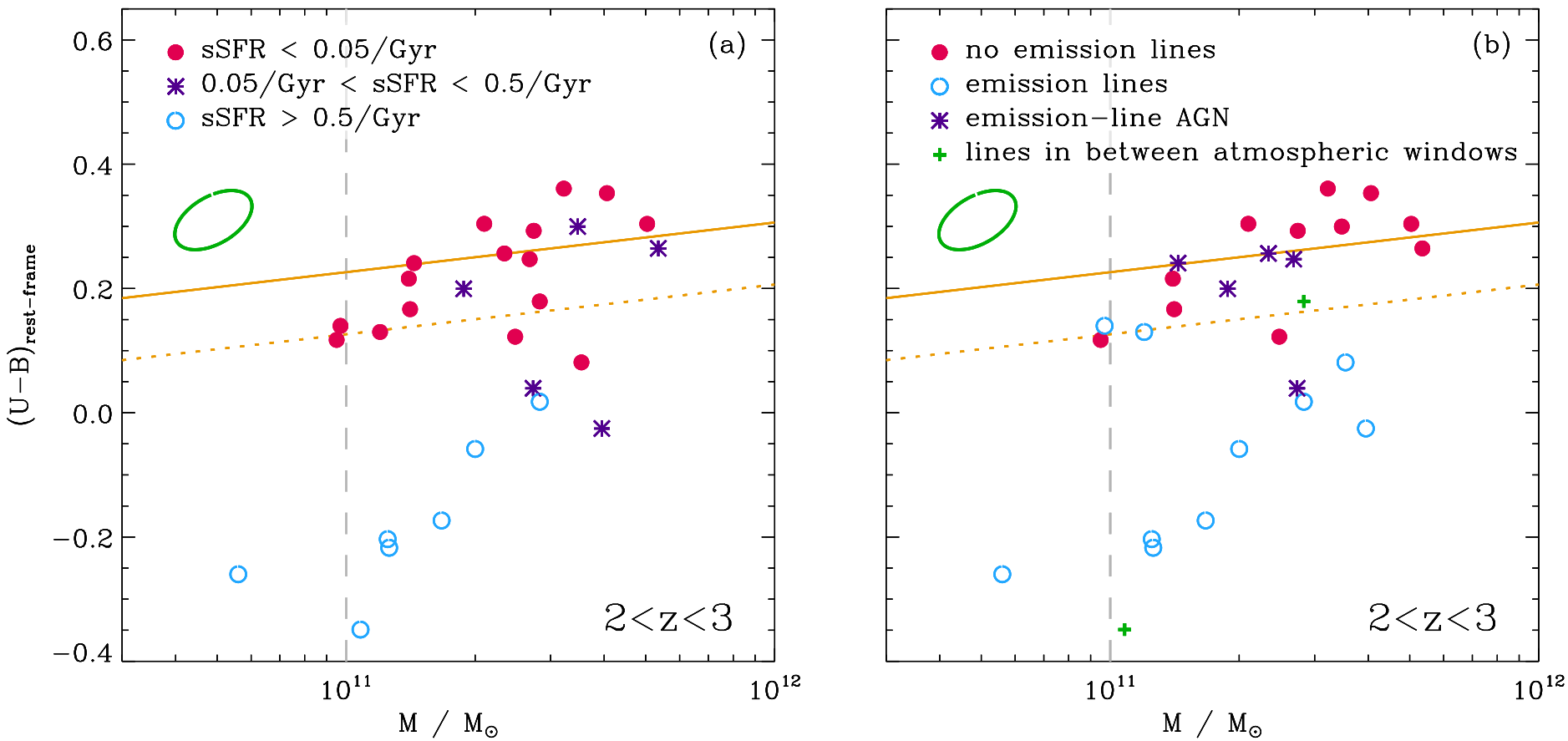


Kriek et al. (2007)

Overview

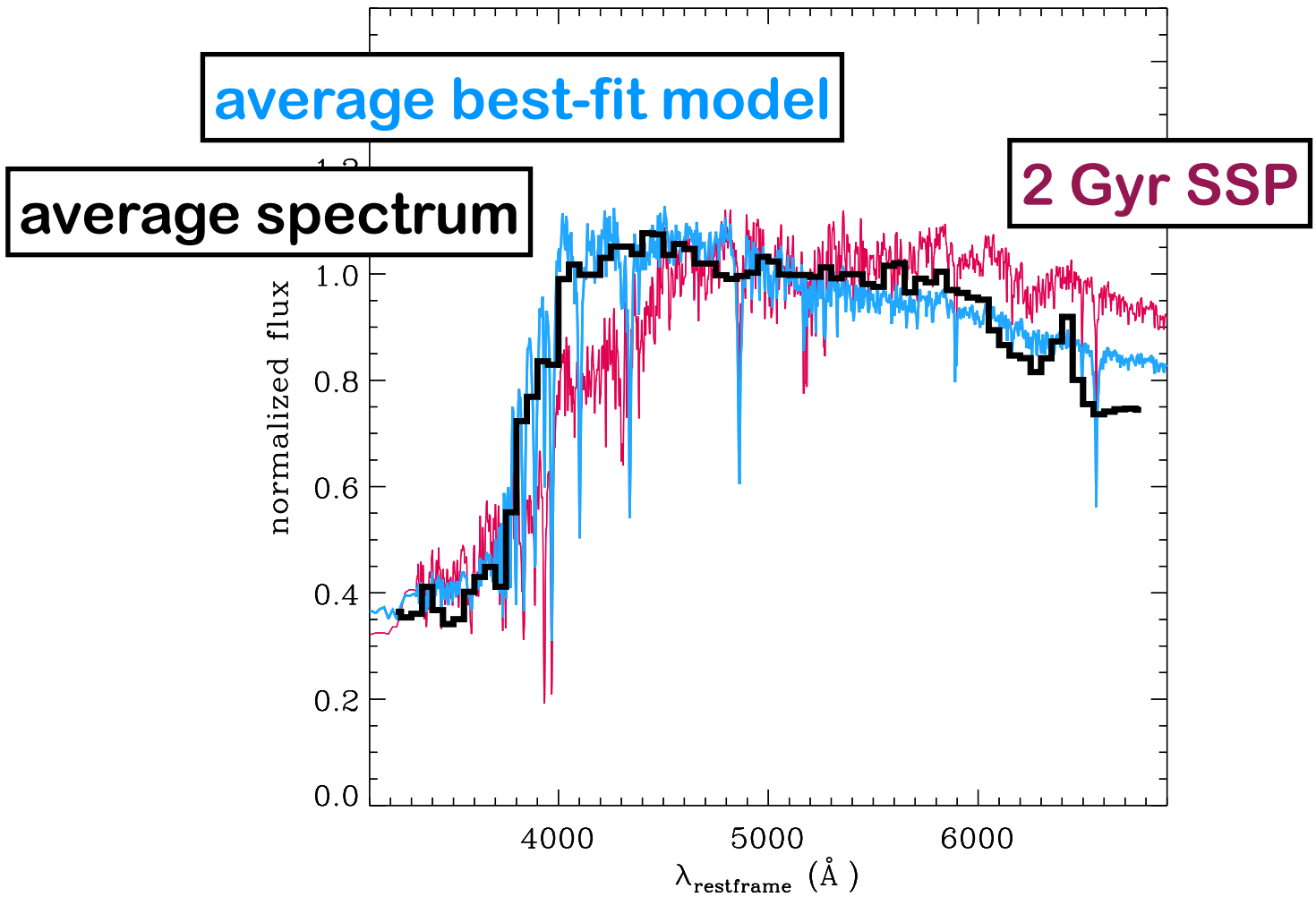
- 8 galaxies at $z < 2$
- 28 galaxies at $2 < z < 3$
  - 11 Galaxies without detected emission lines
  - 17 Emission line galaxies
    - 12 star-forming galaxies
    - 5 AGN host galaxies

A Red Sequence at z ≈ 2.3 ?



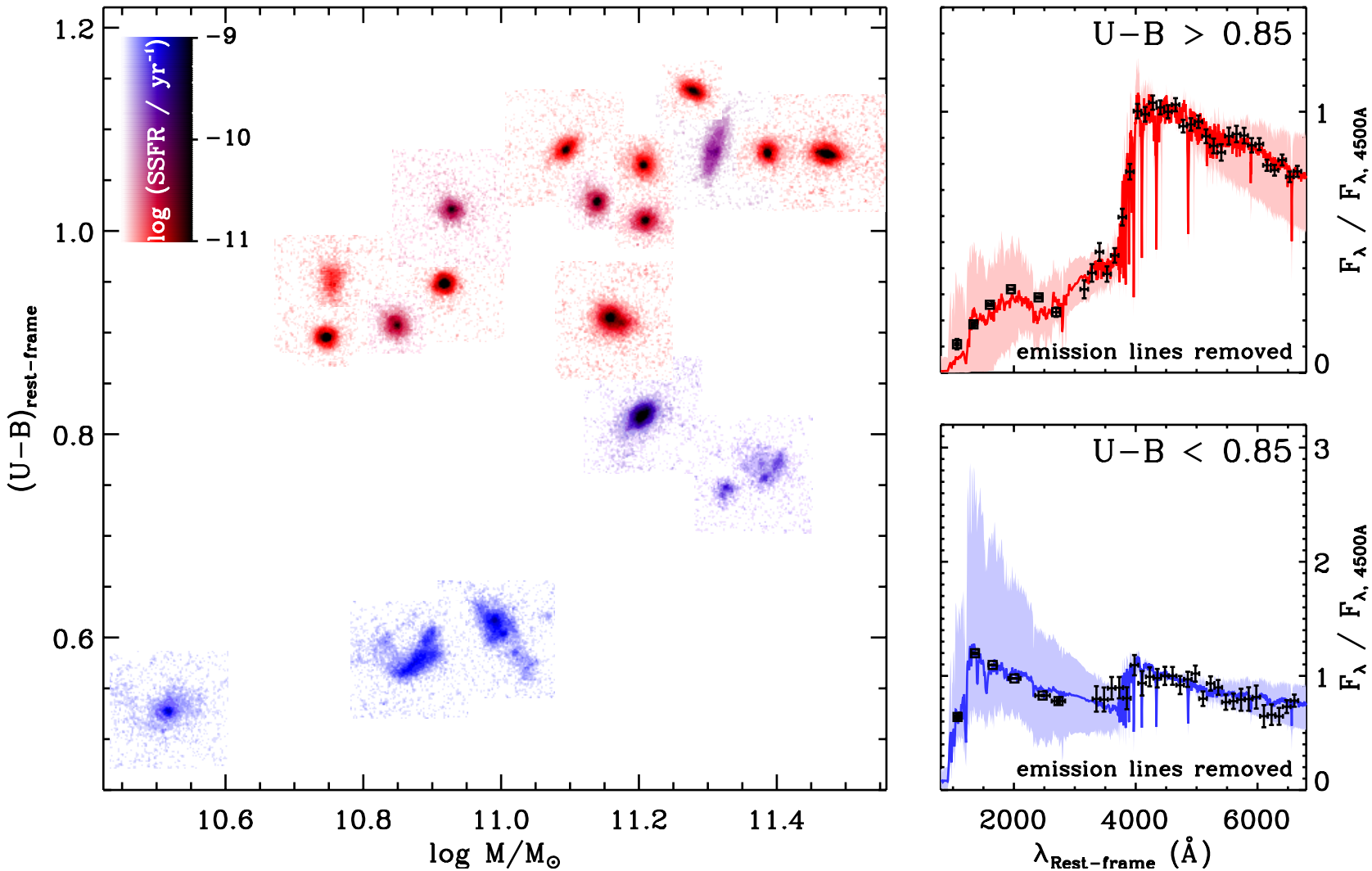
Kriek et al. (2008)

Red Sequence Galaxies at z ≈ 2.3



Kriek et al. (2008)

Massive galaxy distribution at z ≈ 2.3



Kriek et al. (2009)

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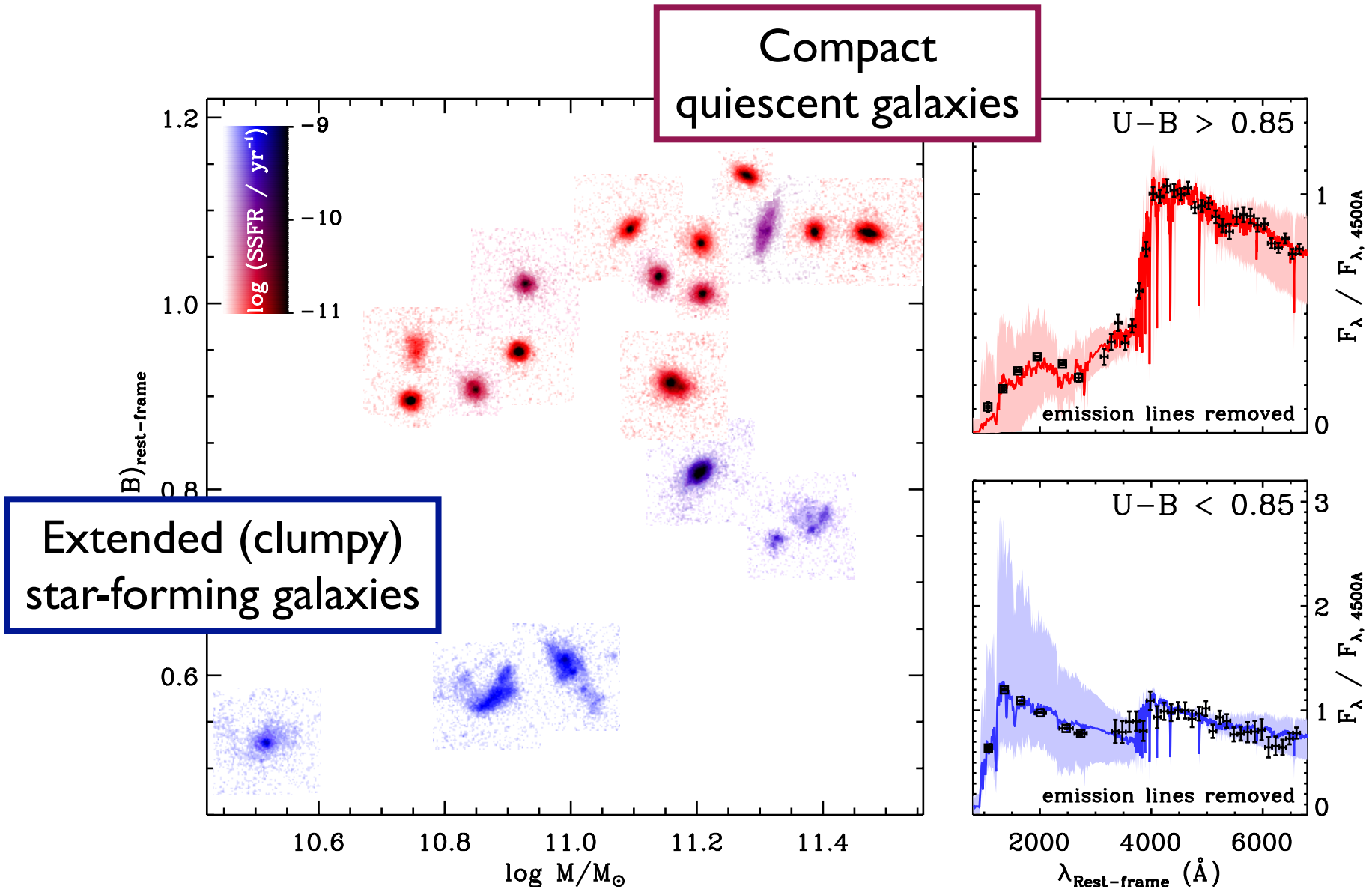
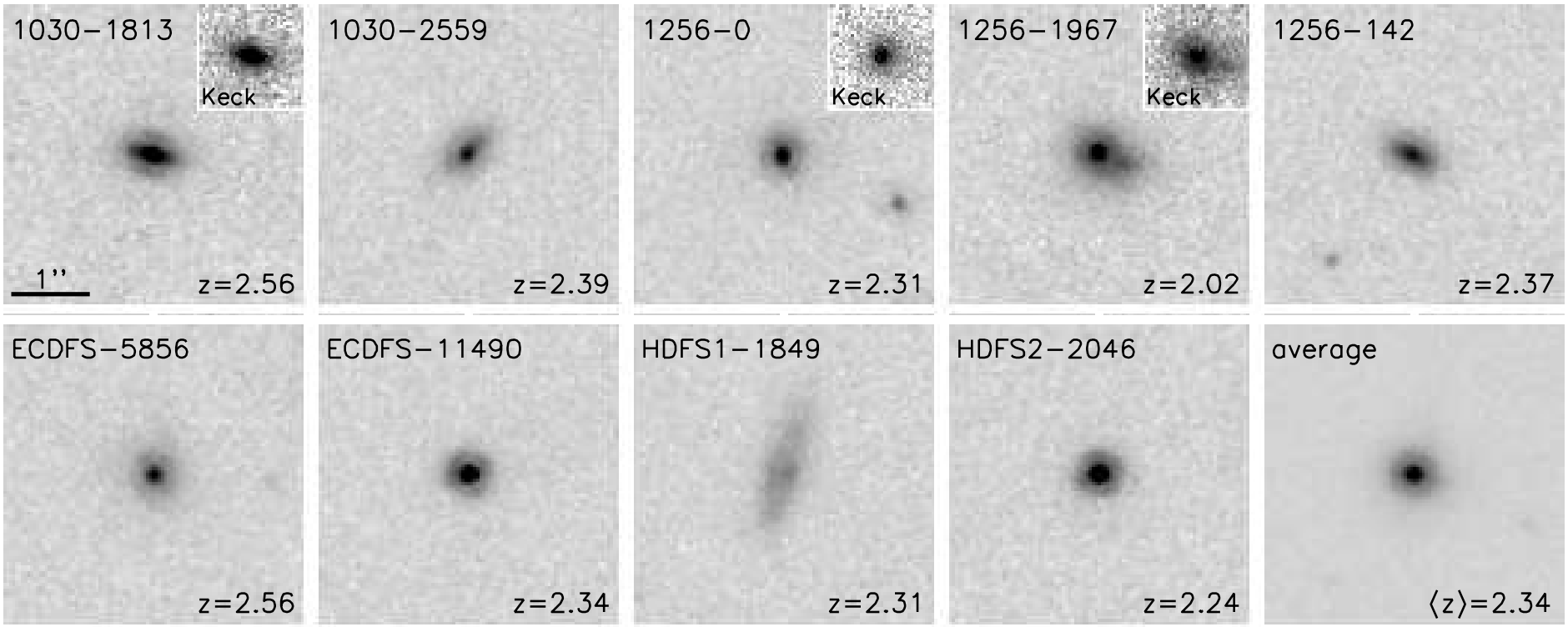


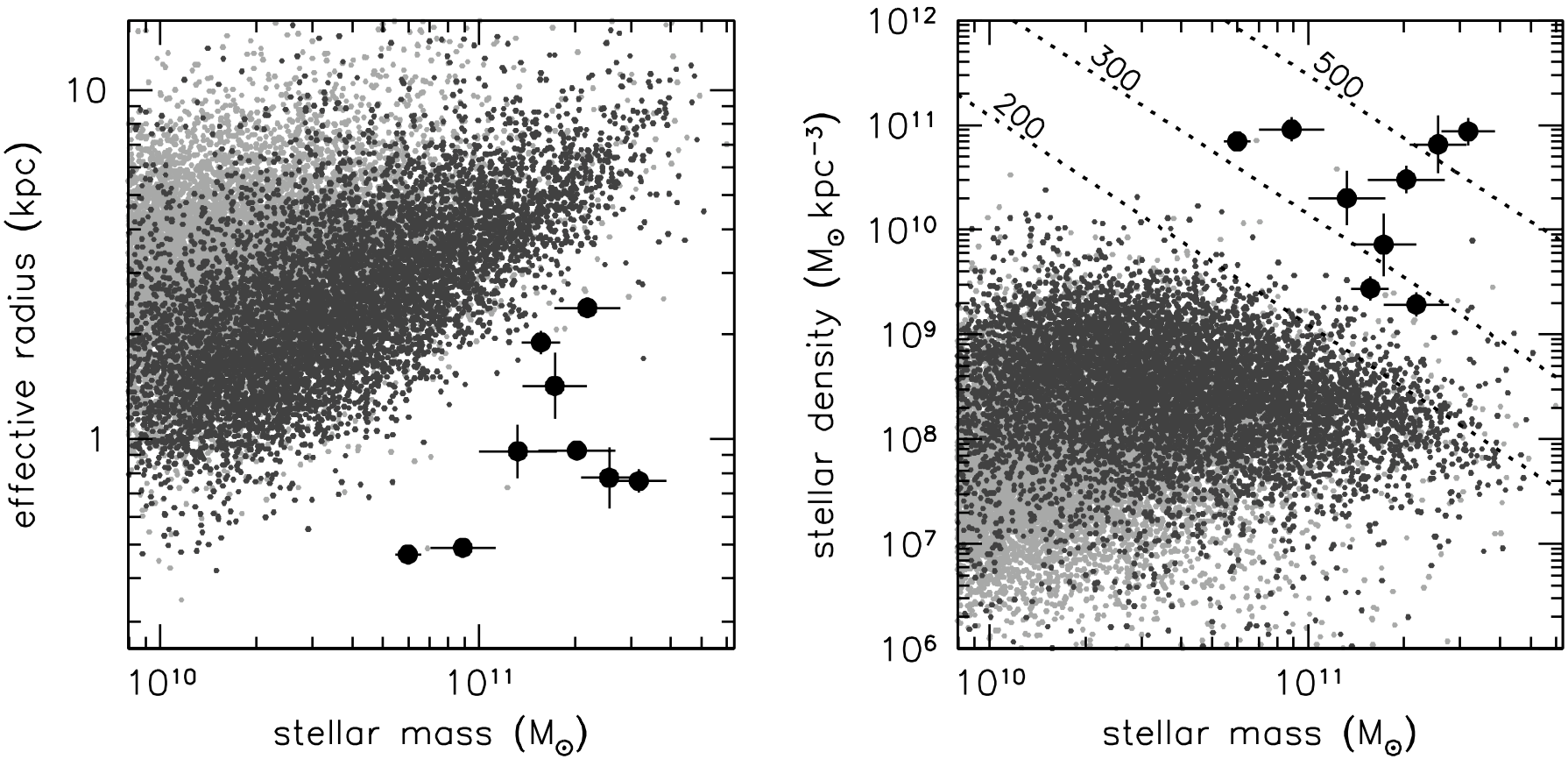
Kriek et al. (2009)

Morphologies of massive, quiescent galaxies at z ≈ 2.3



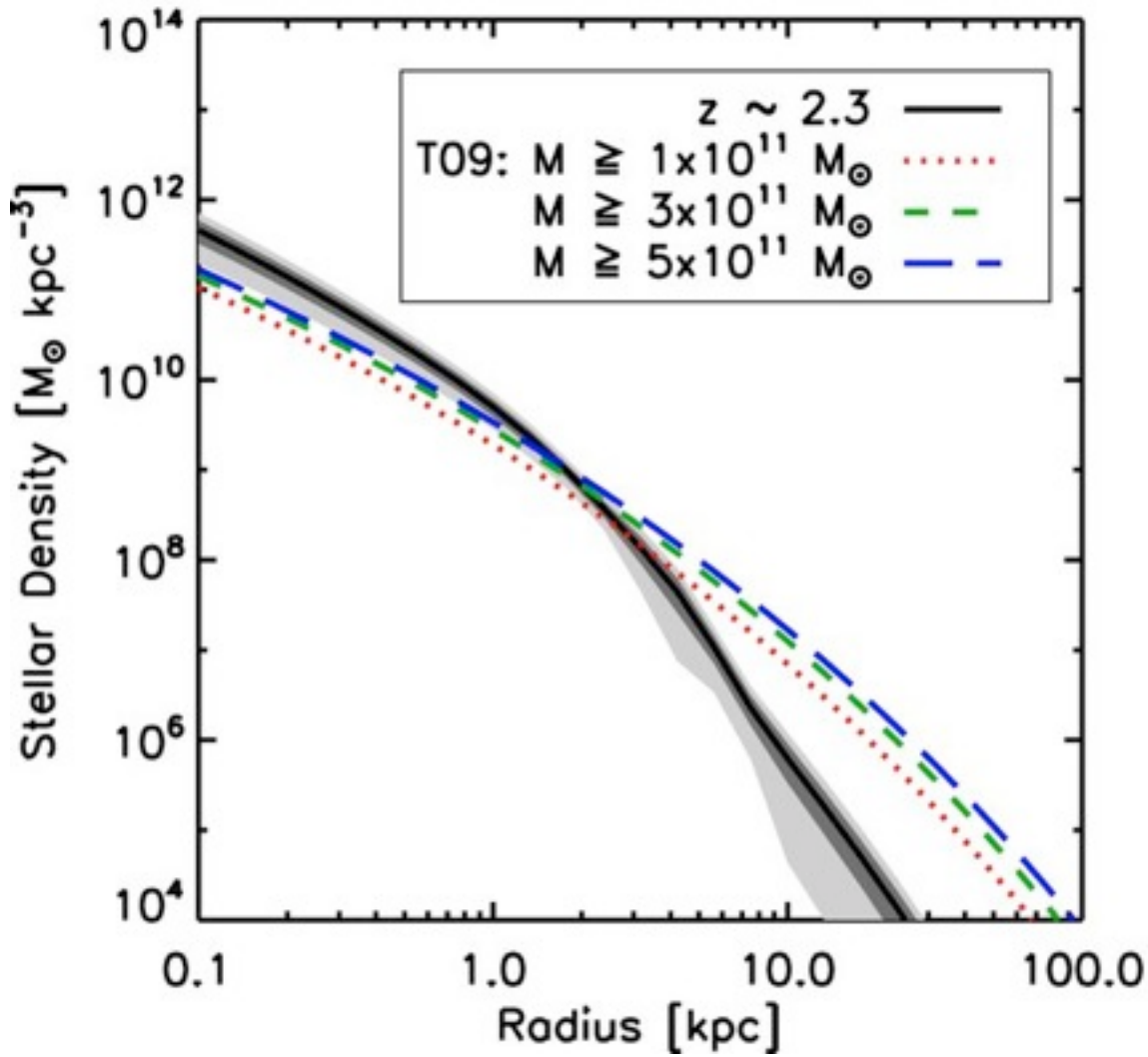
van Dokkum et al. (2008)

Structural evolution from z ≈ 2.3 to the present



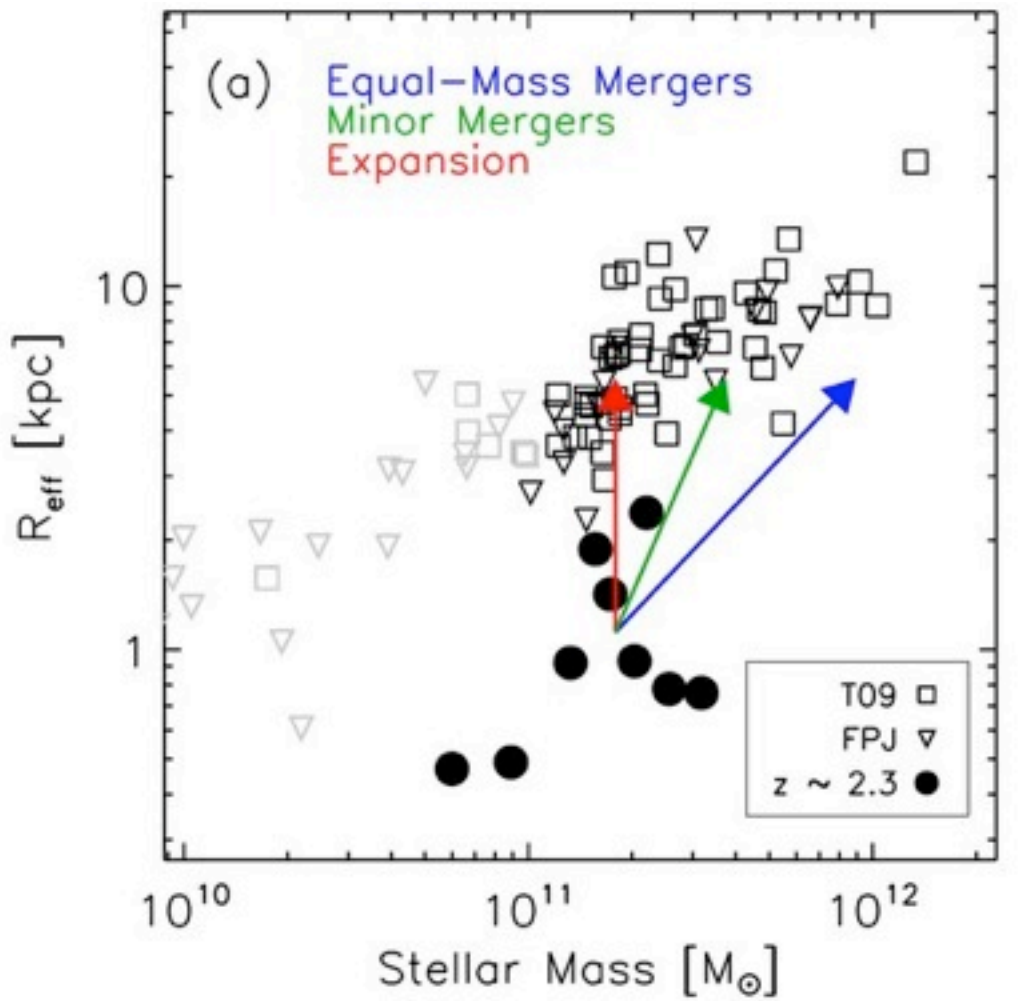
van Dokkum et al. (2008)

Inside-out growth



Bezanson et al. (2009)

Inside-out growth due to minor mergers?



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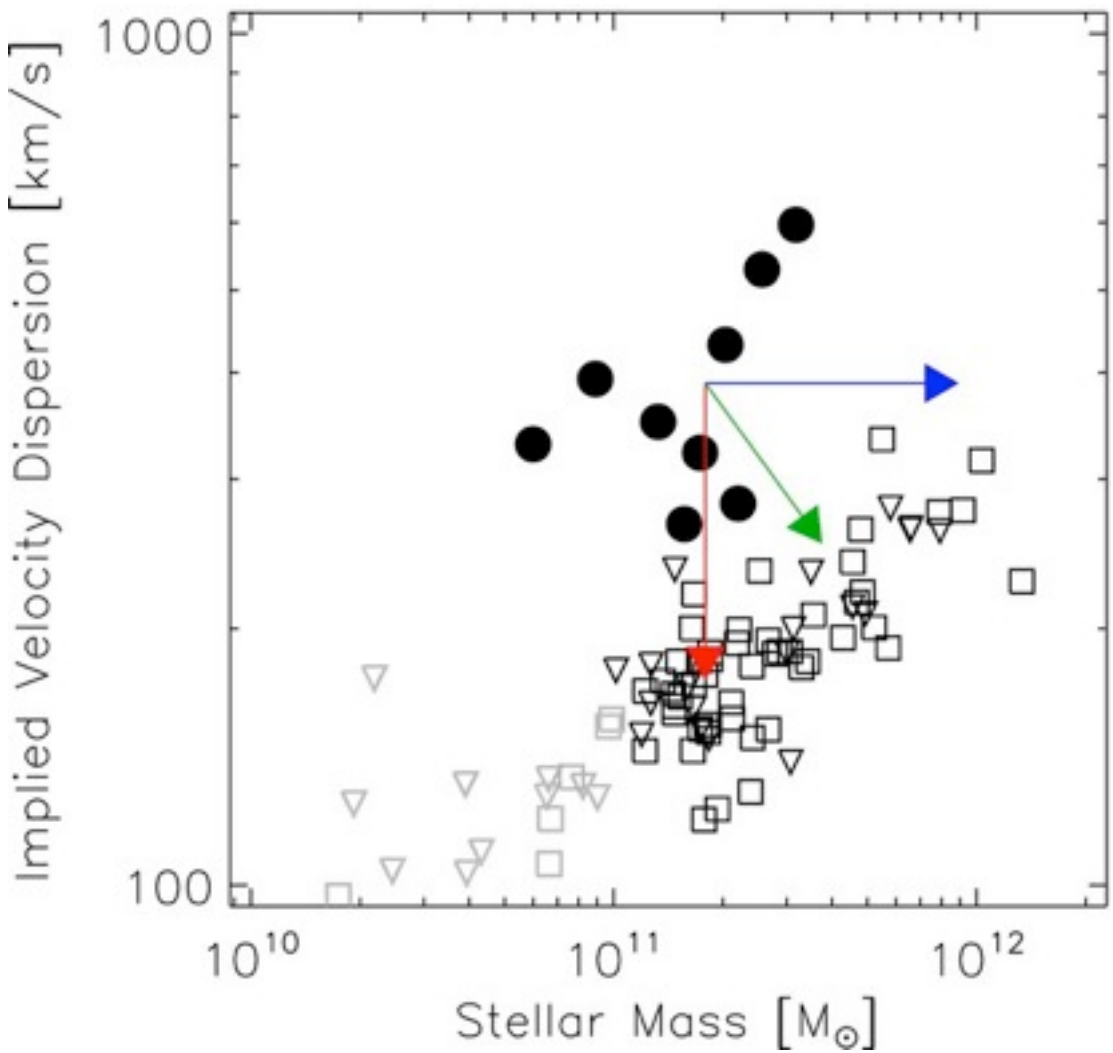
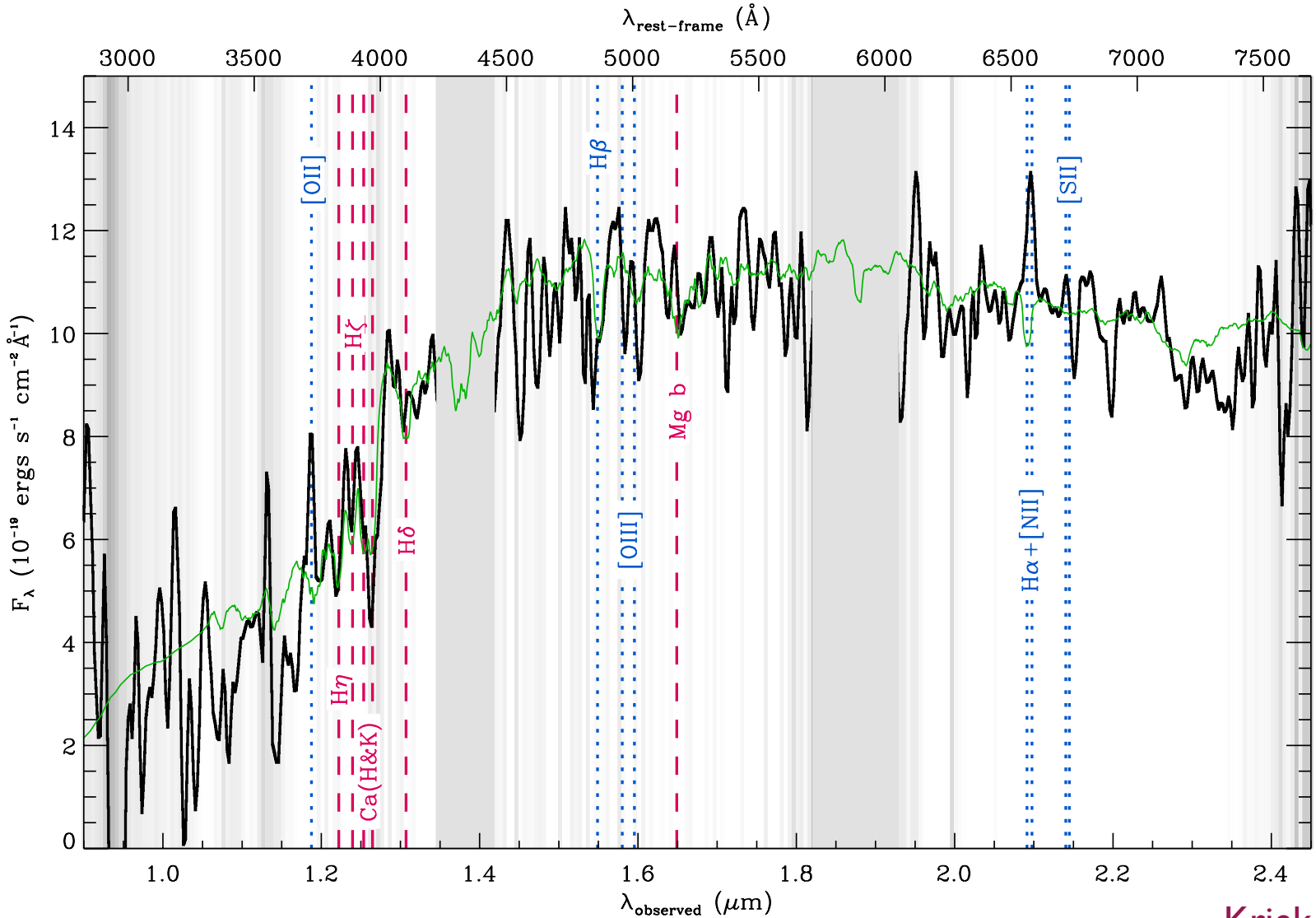


Bezanson et al. (2009)

29 hrs GNIRS spectrum of a quiescent galaxy at z=2.2



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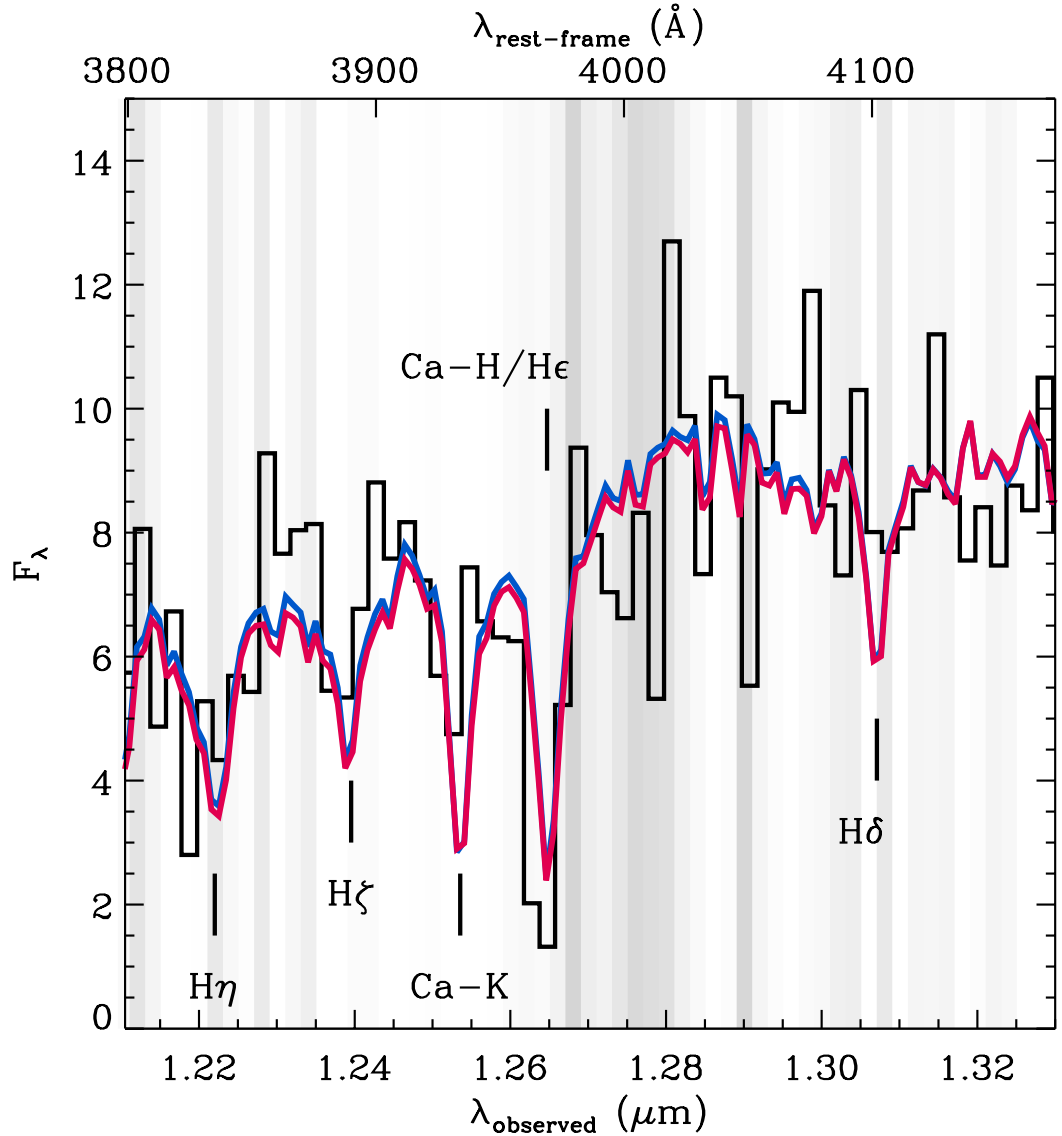
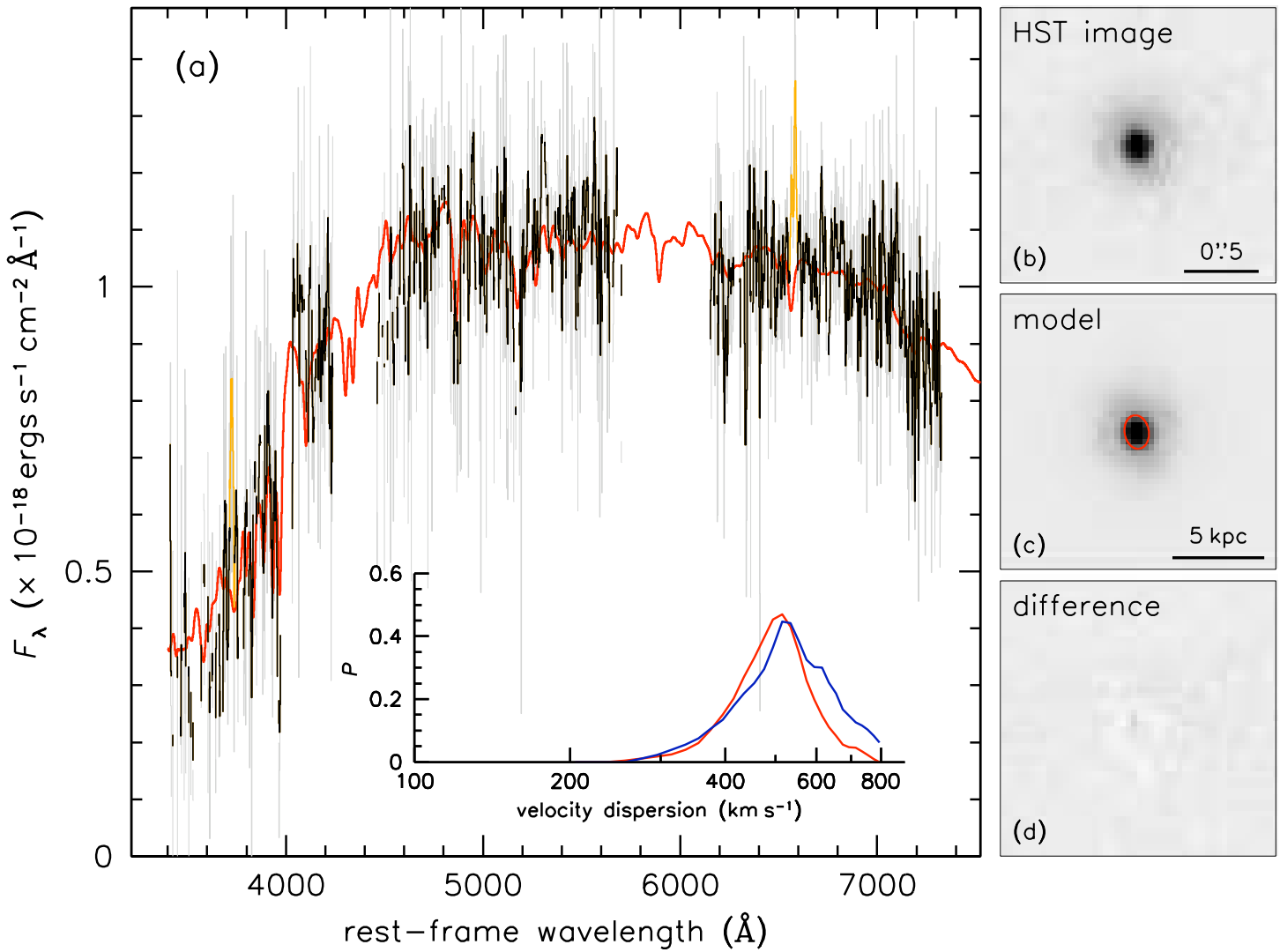


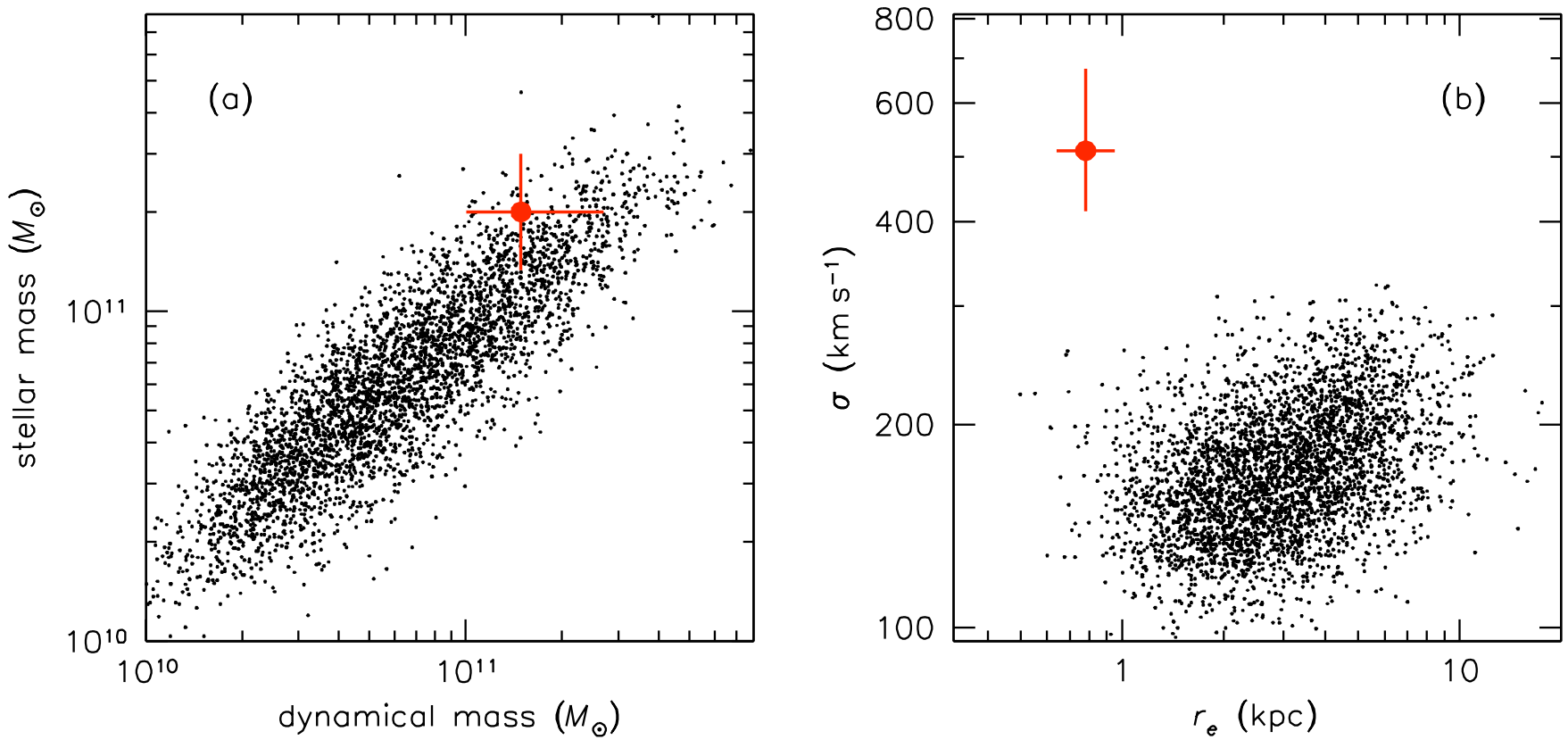
Kriek et al. (2009)

A high velocity dispersion for at z=2.2 galaxy



van Dokkum et al. (2009)

Comparison to local galaxies



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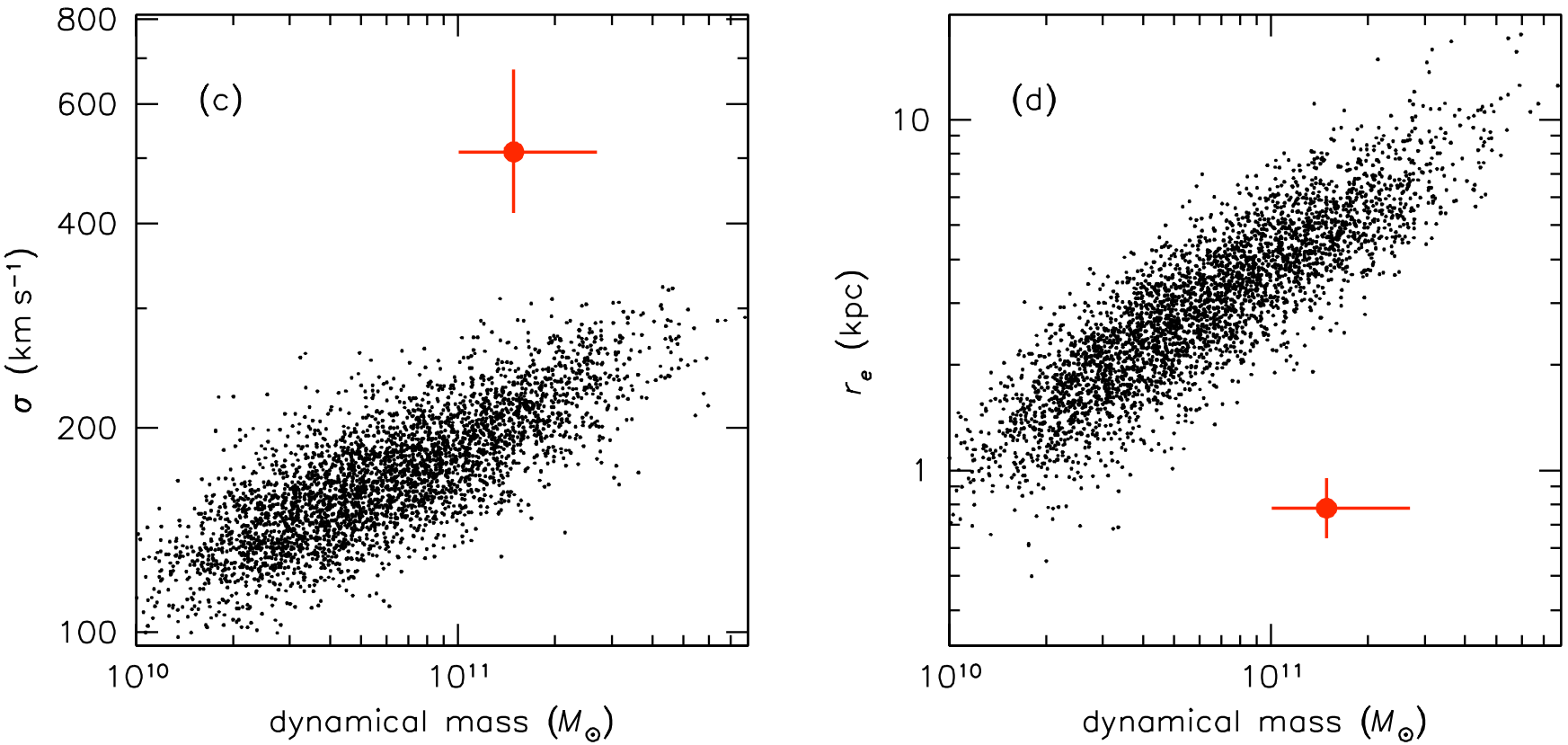
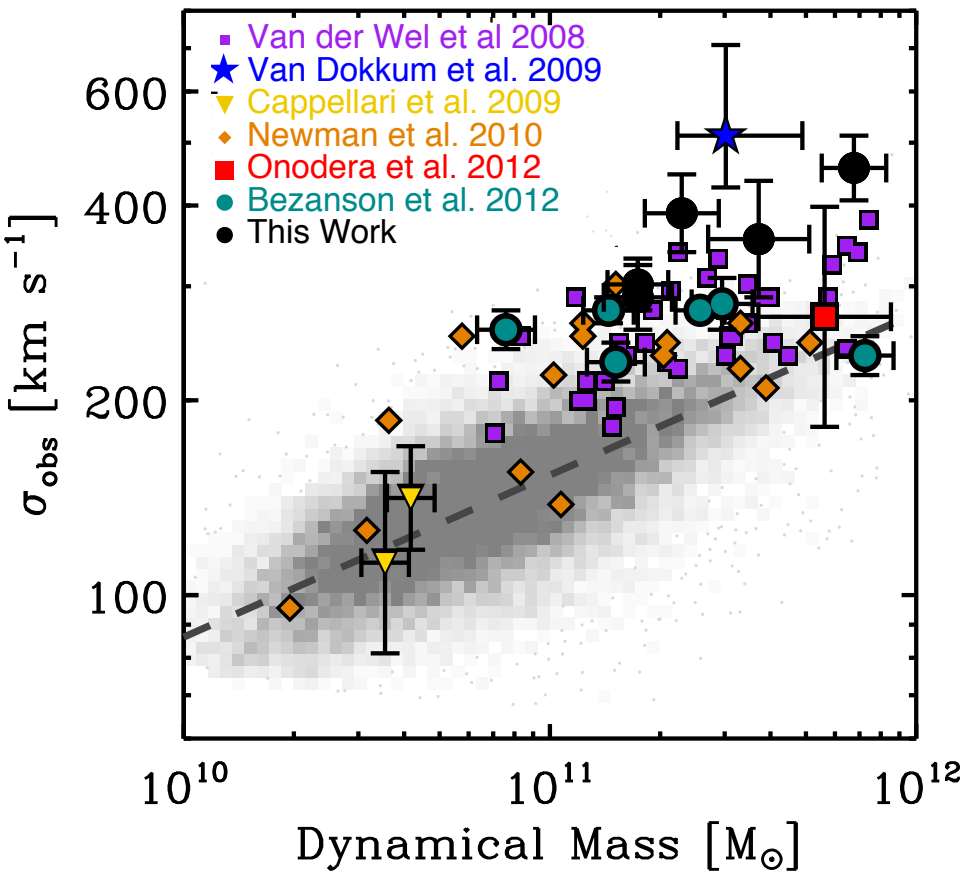
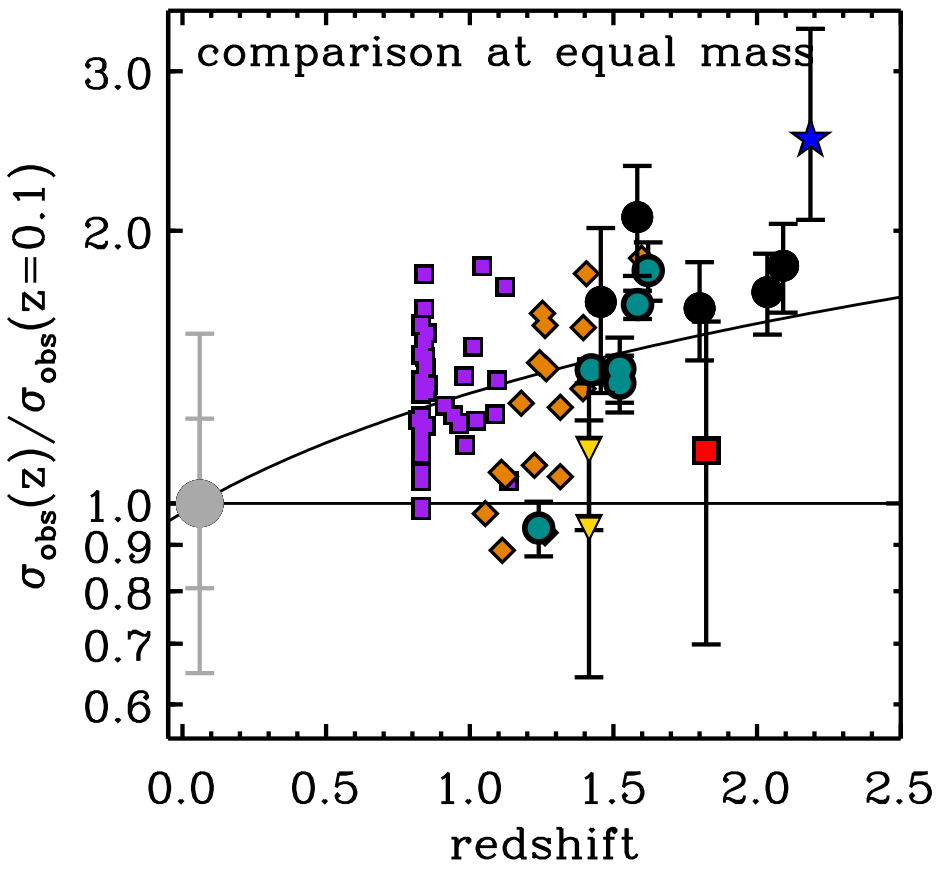


van Dokkum et al. (2009)

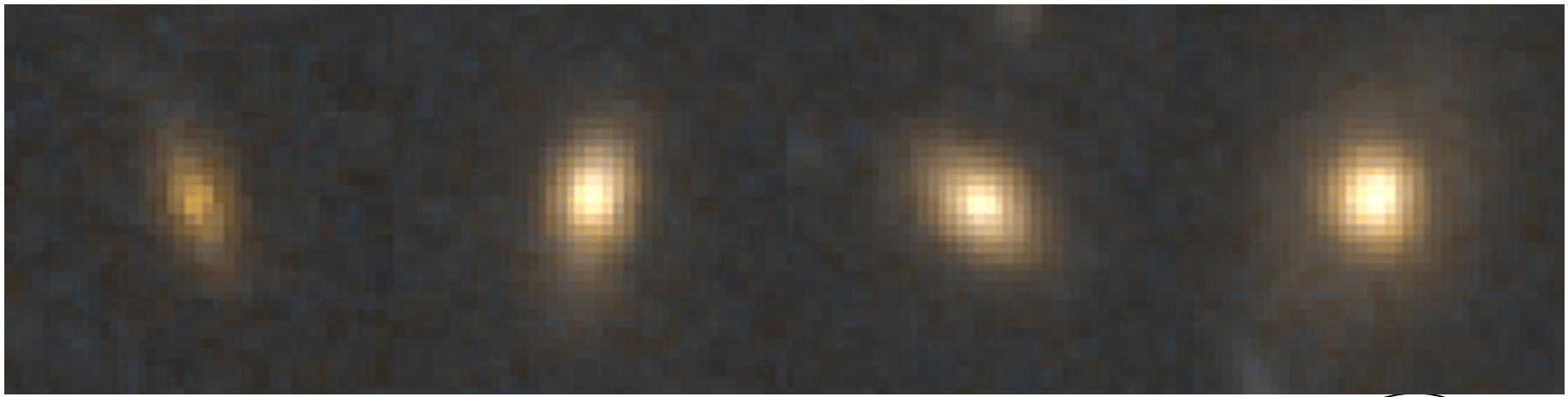
Compilation of different dynamical galaxy studies

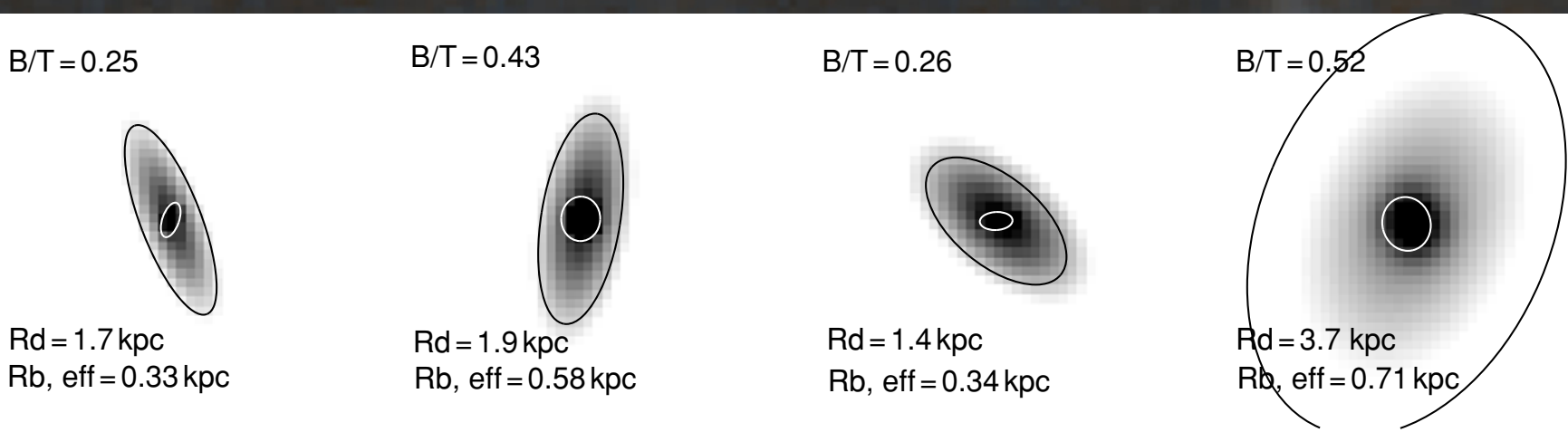




van de Sande, Kriek et al. in prep

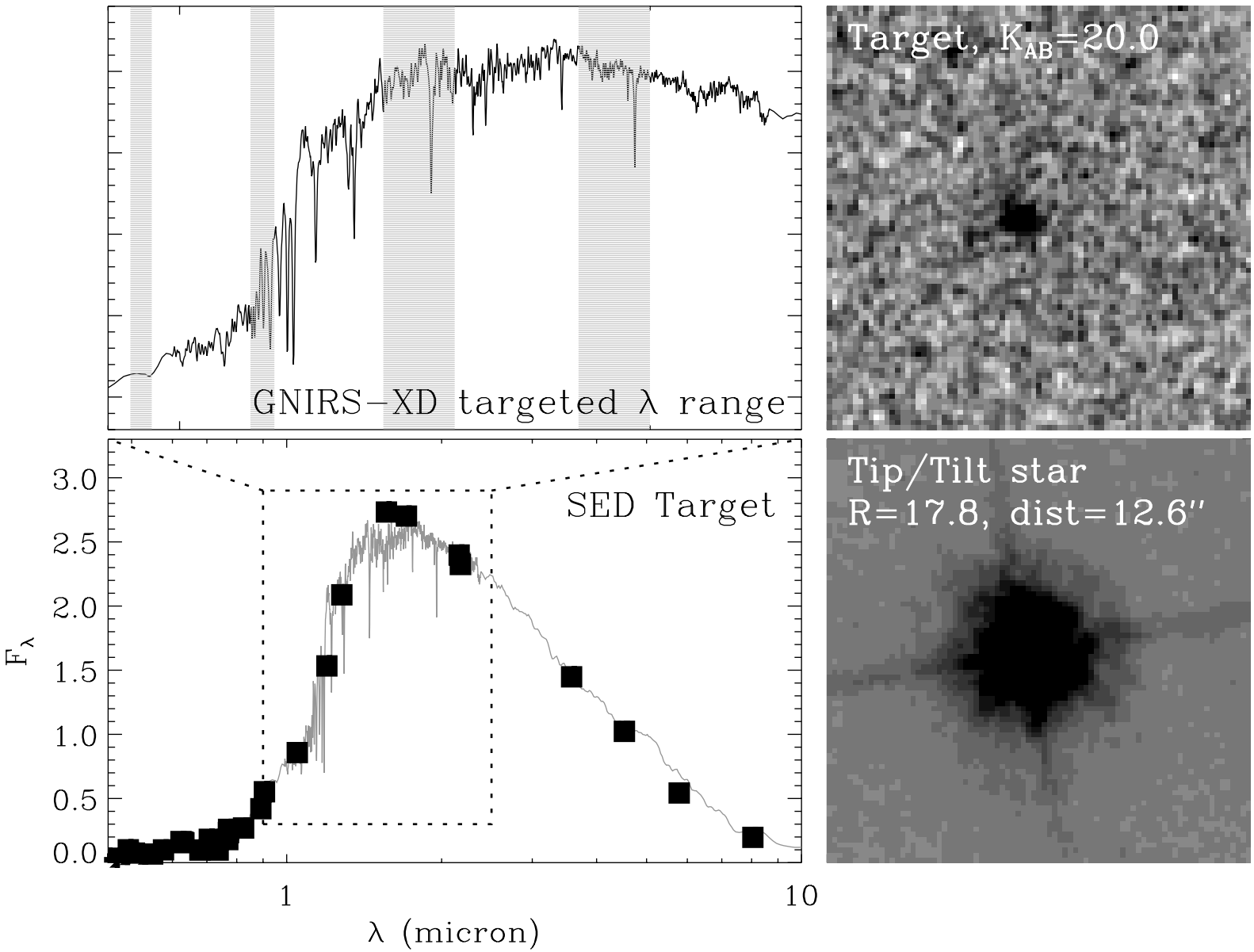
Are compact quiescent galaxies disk dominated?





van der Wel et al. (2011)

Resolved kinematics



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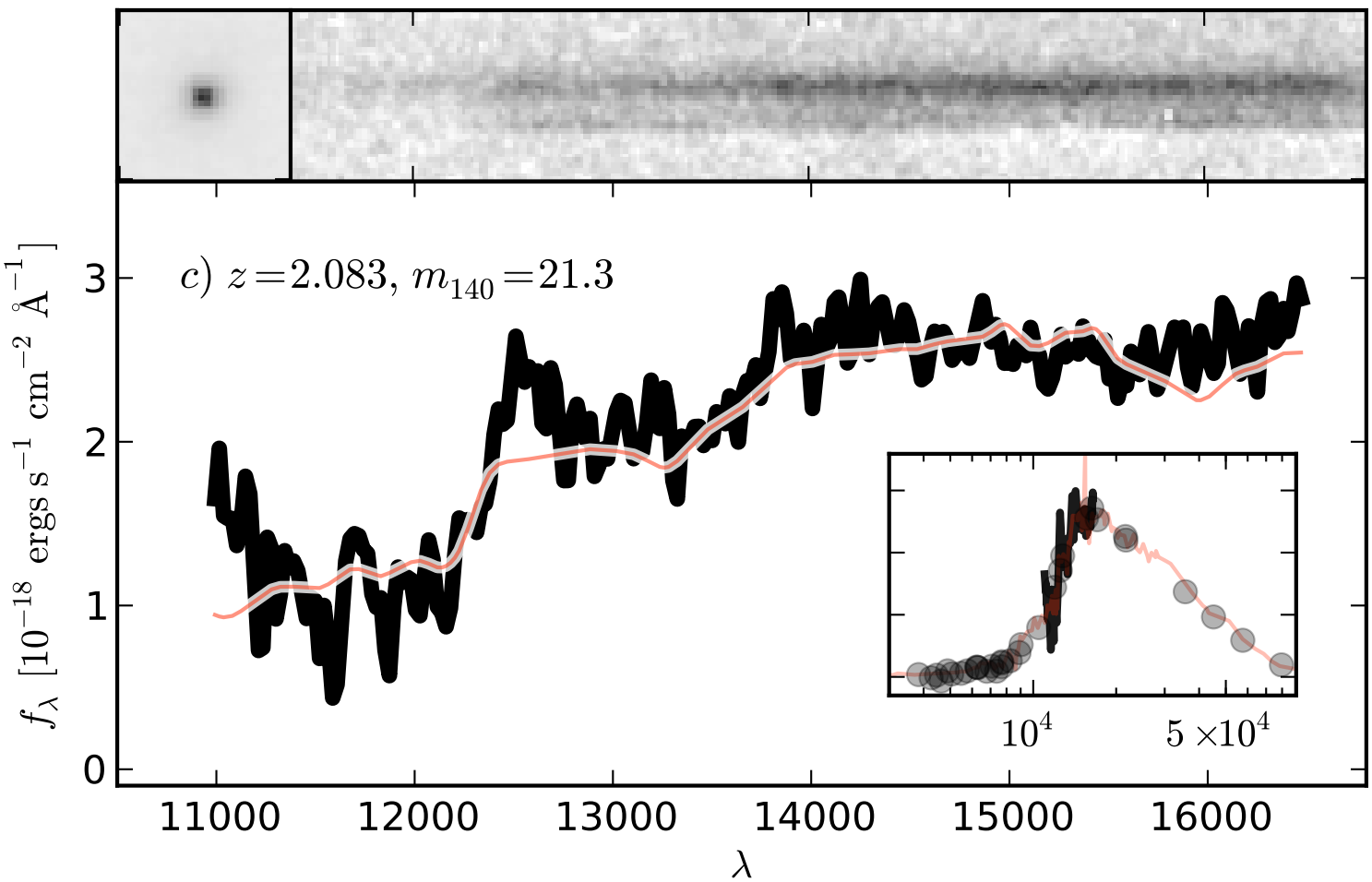
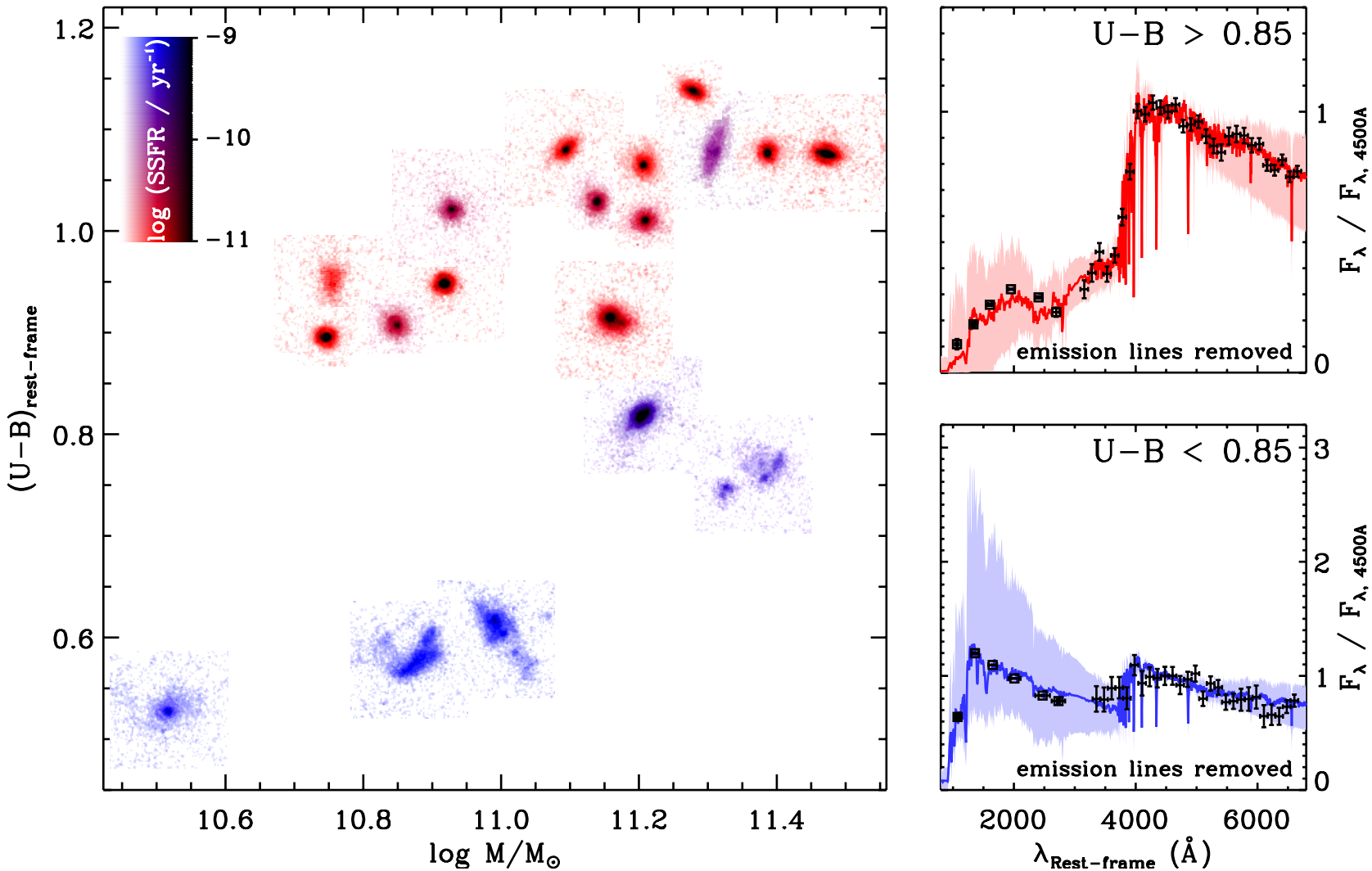


Brammer et al. (2012)

Massive galaxy distribution at z ≈ 2.3



Kriek et al. (2009)

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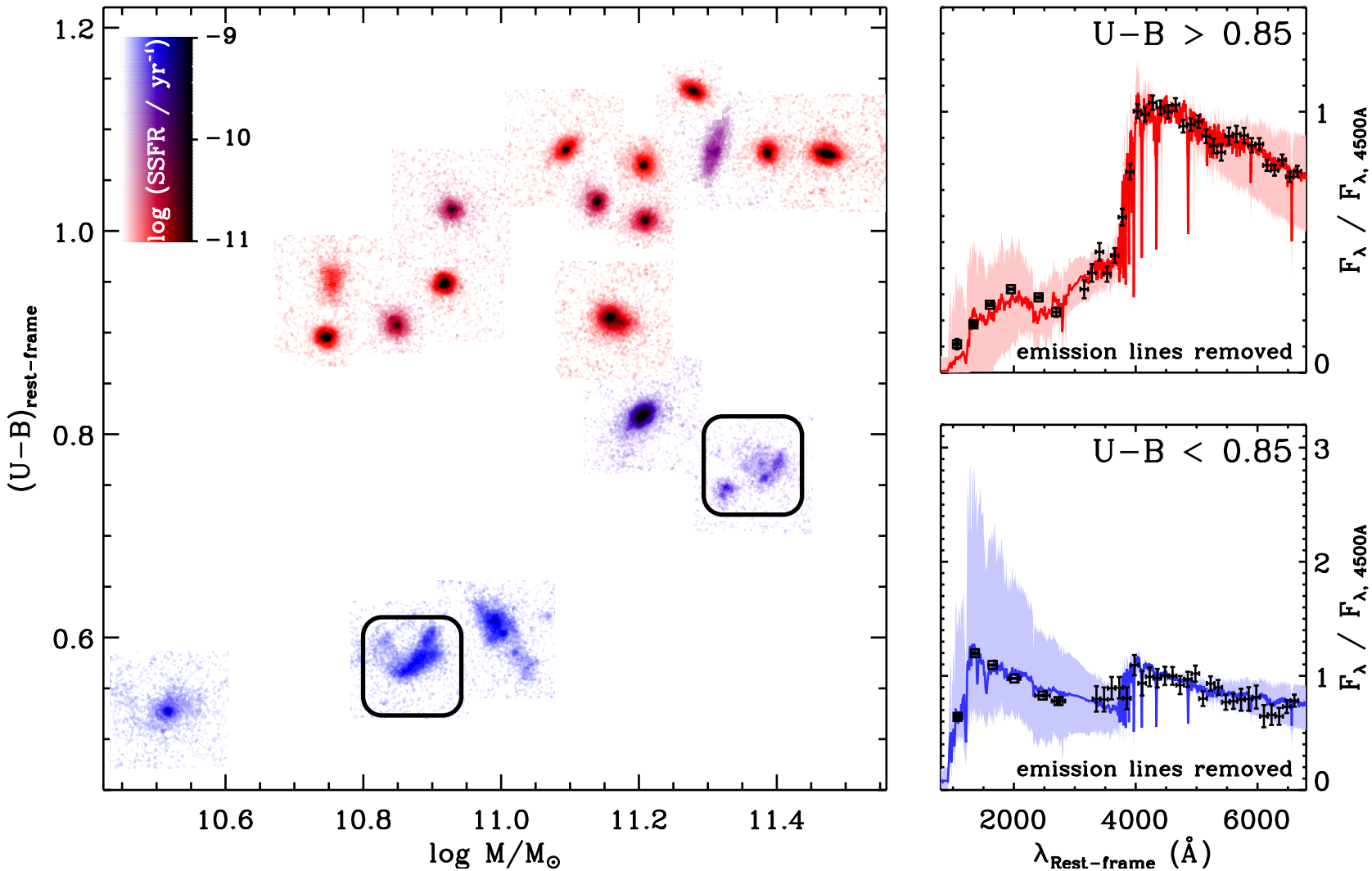
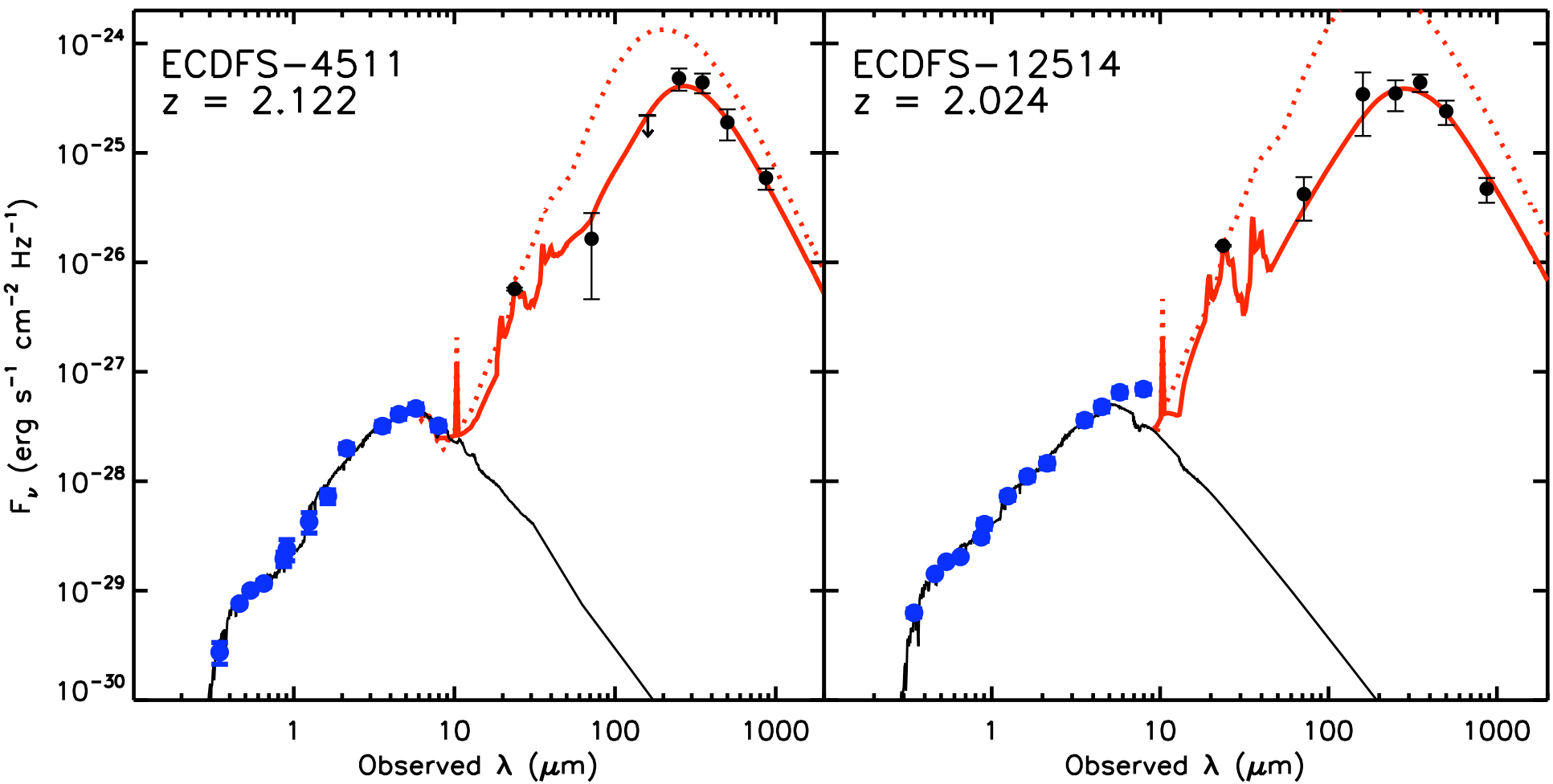


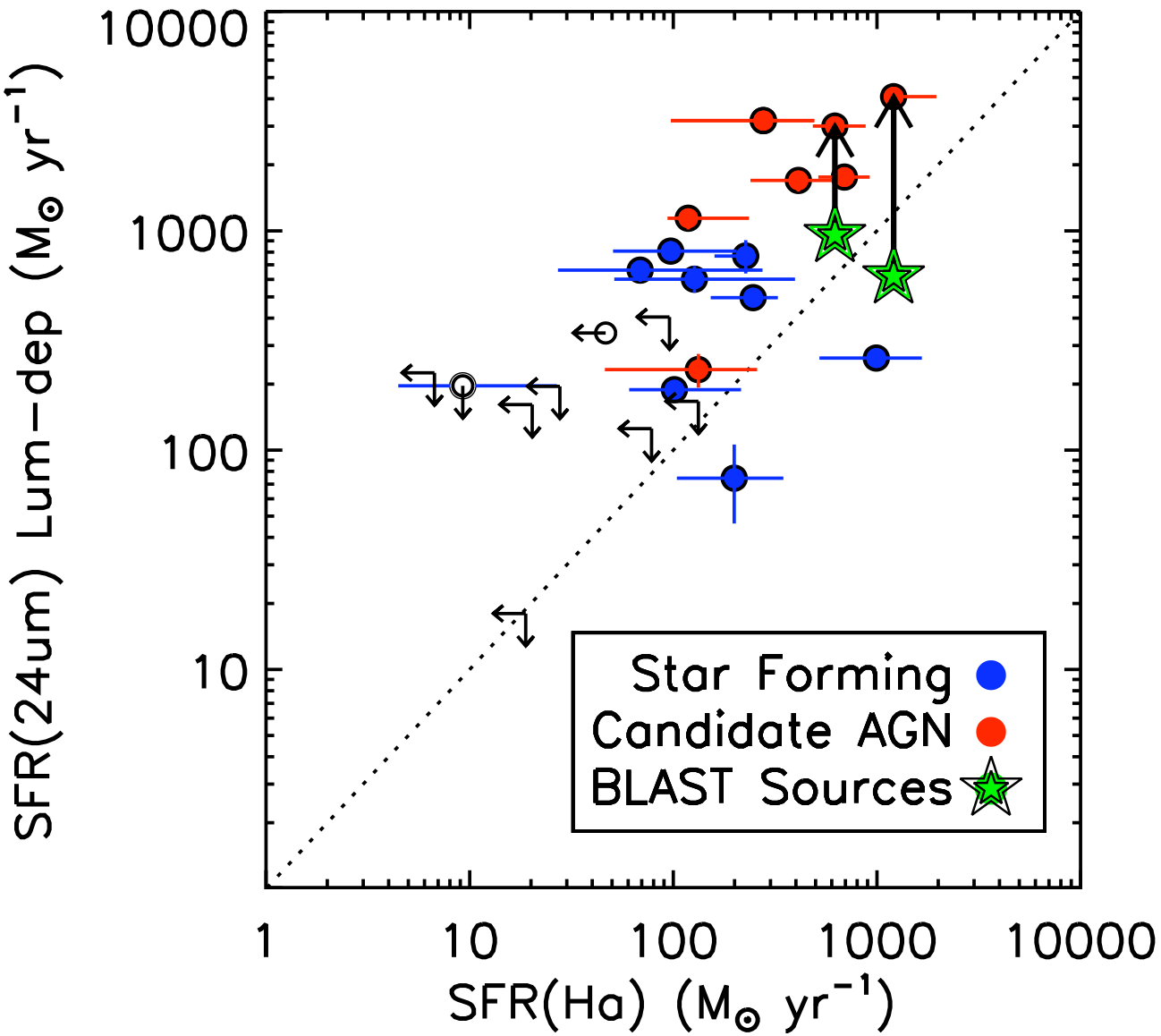
Kriek et al. (2009)

Scaled up cool galaxies at z ≈ 2.3



Muzzin et al. (2010)

24 micron as SFR indicator



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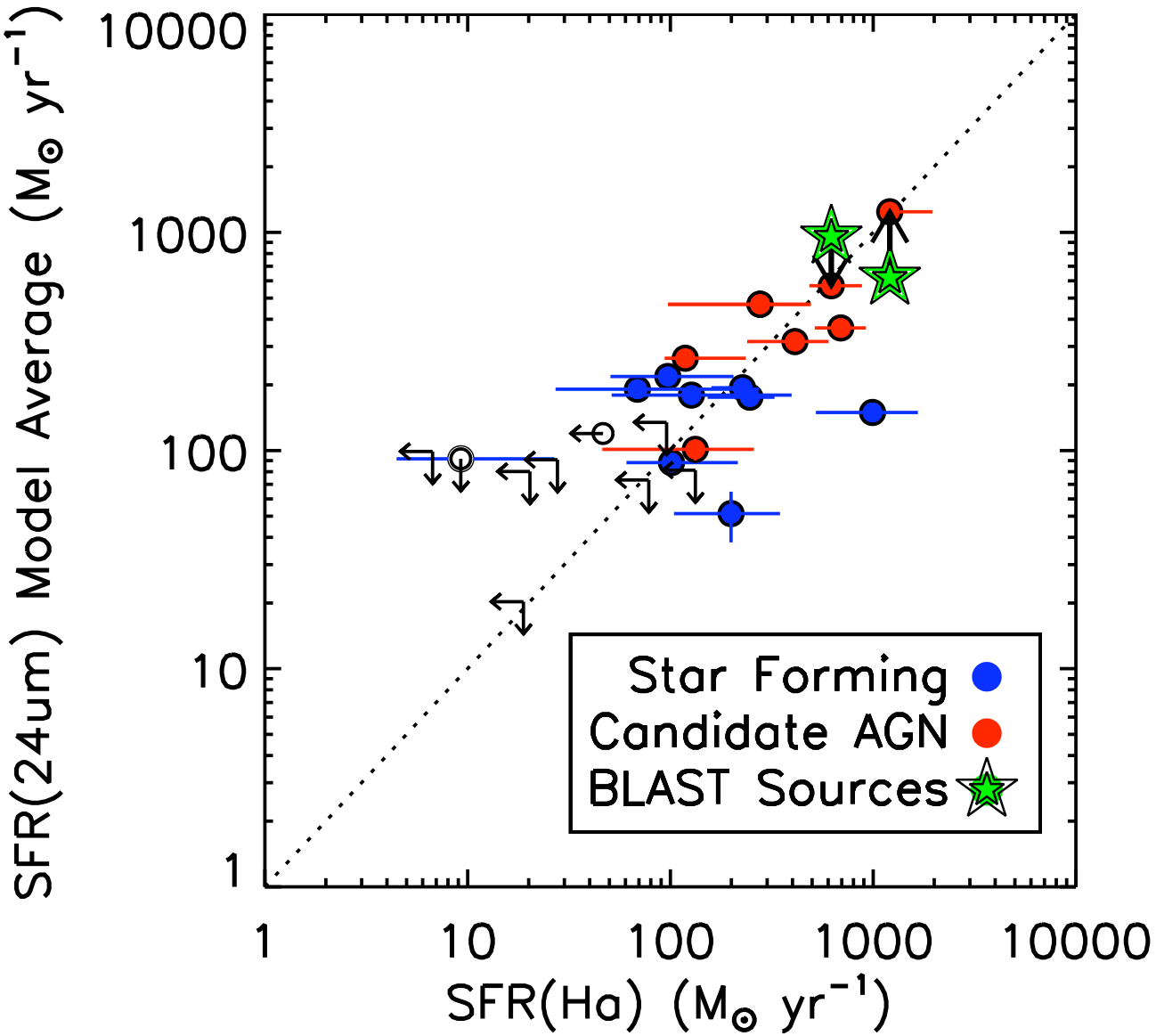
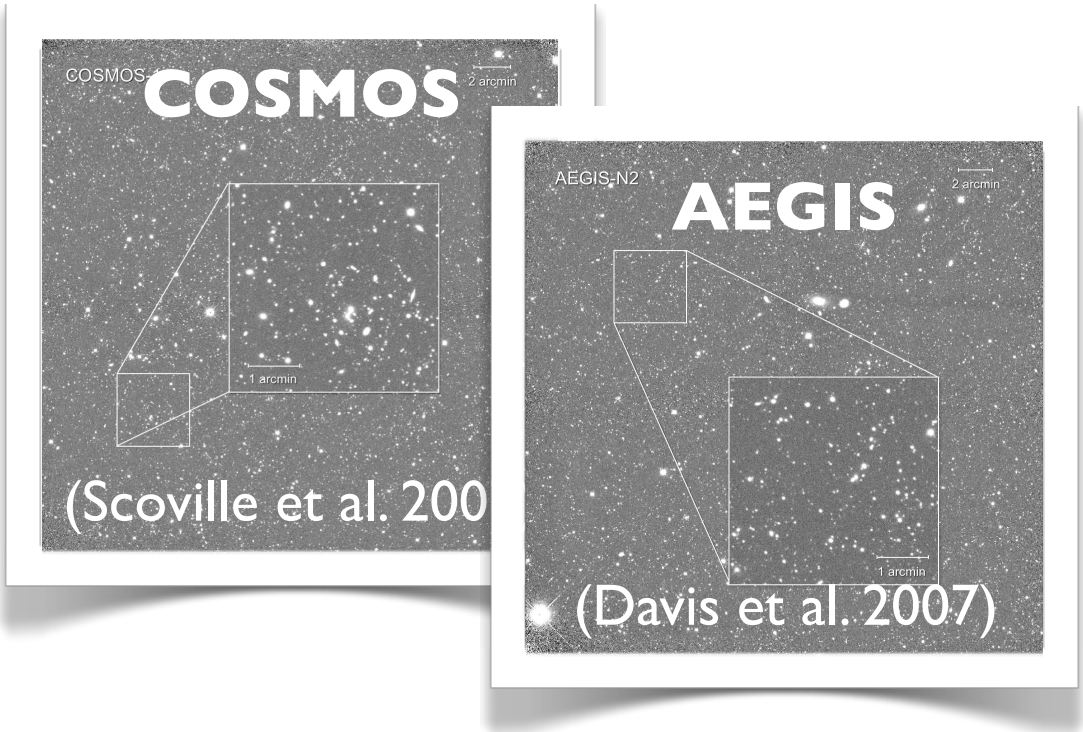


Muzzin et al. (2010)

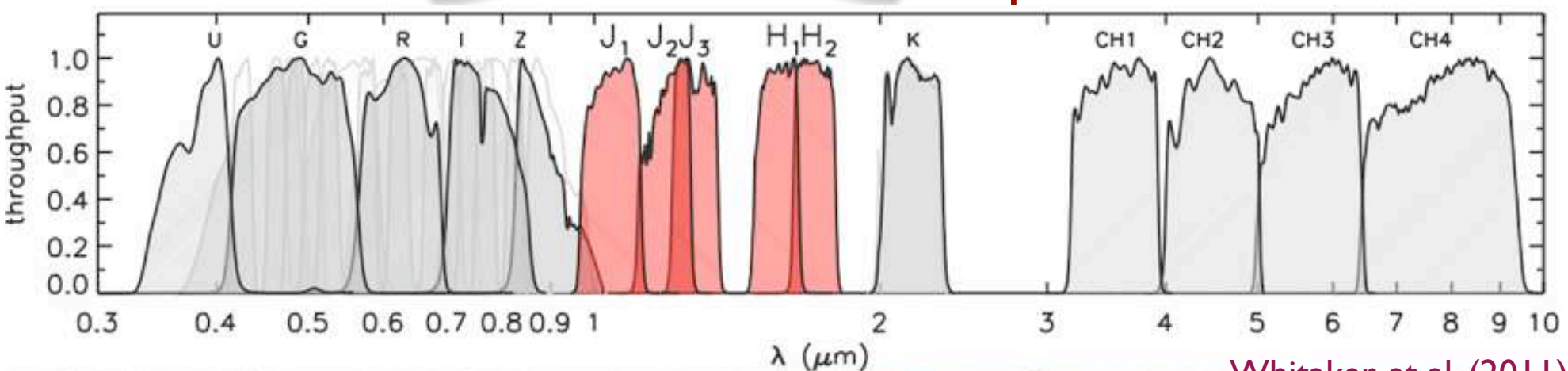
Problems
GNIRS z~2.3 galaxy survey

- Photometric properties of parent galaxy sample poorly constrained
- Limited area of photometric survey
- Sample biased to the brightest galaxies
- Limited ancillary data

The NEWFIRM Medium-Band Survey

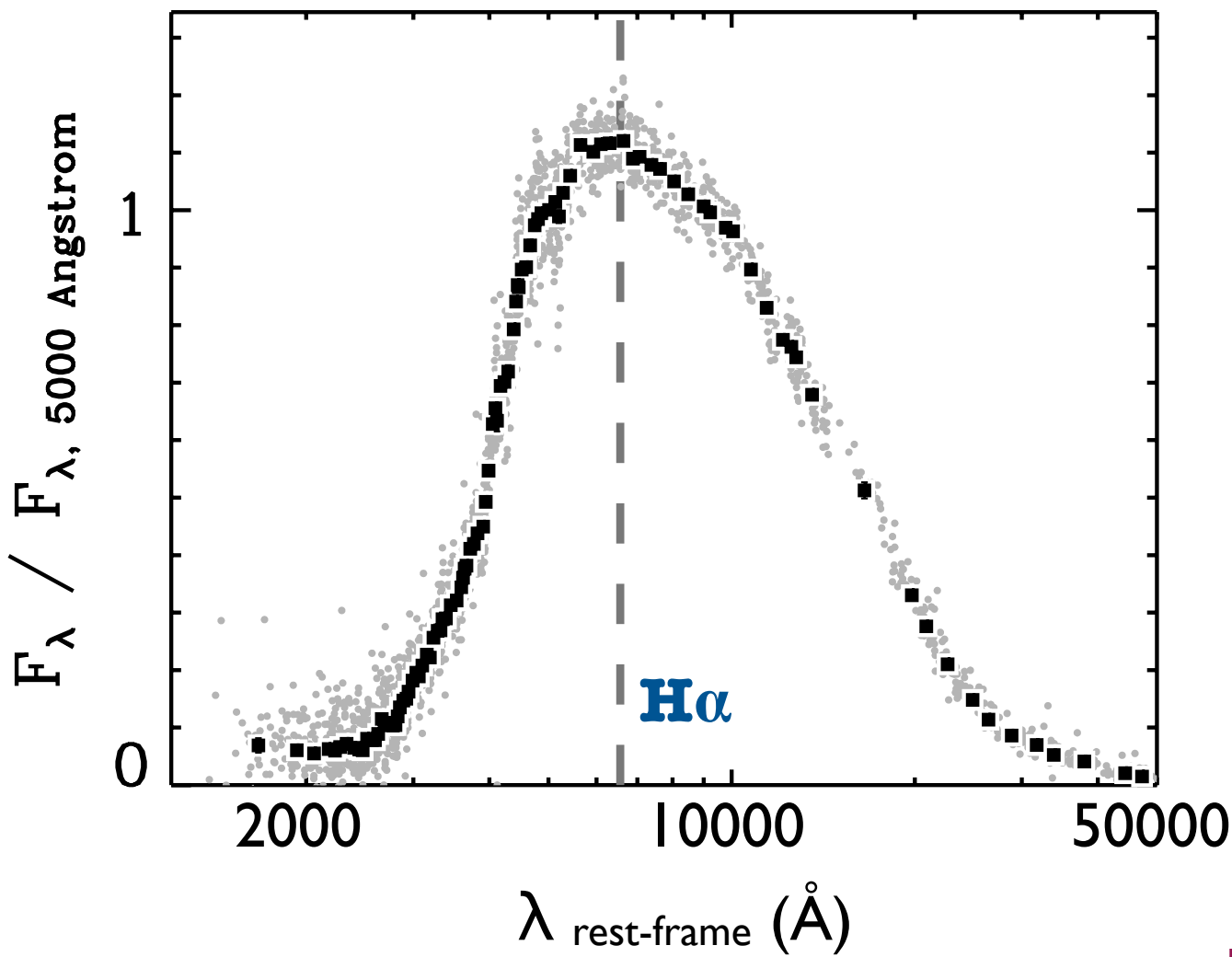


- 5 custom NIR filters
- ≈ 0.4 square degrees
- FUV-IR photometry
- $\Delta z/(1+z) \approx 0.01\text{-}0.02$
- Images and catalogs public



Whitaker et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



Kriek et al. (2011)

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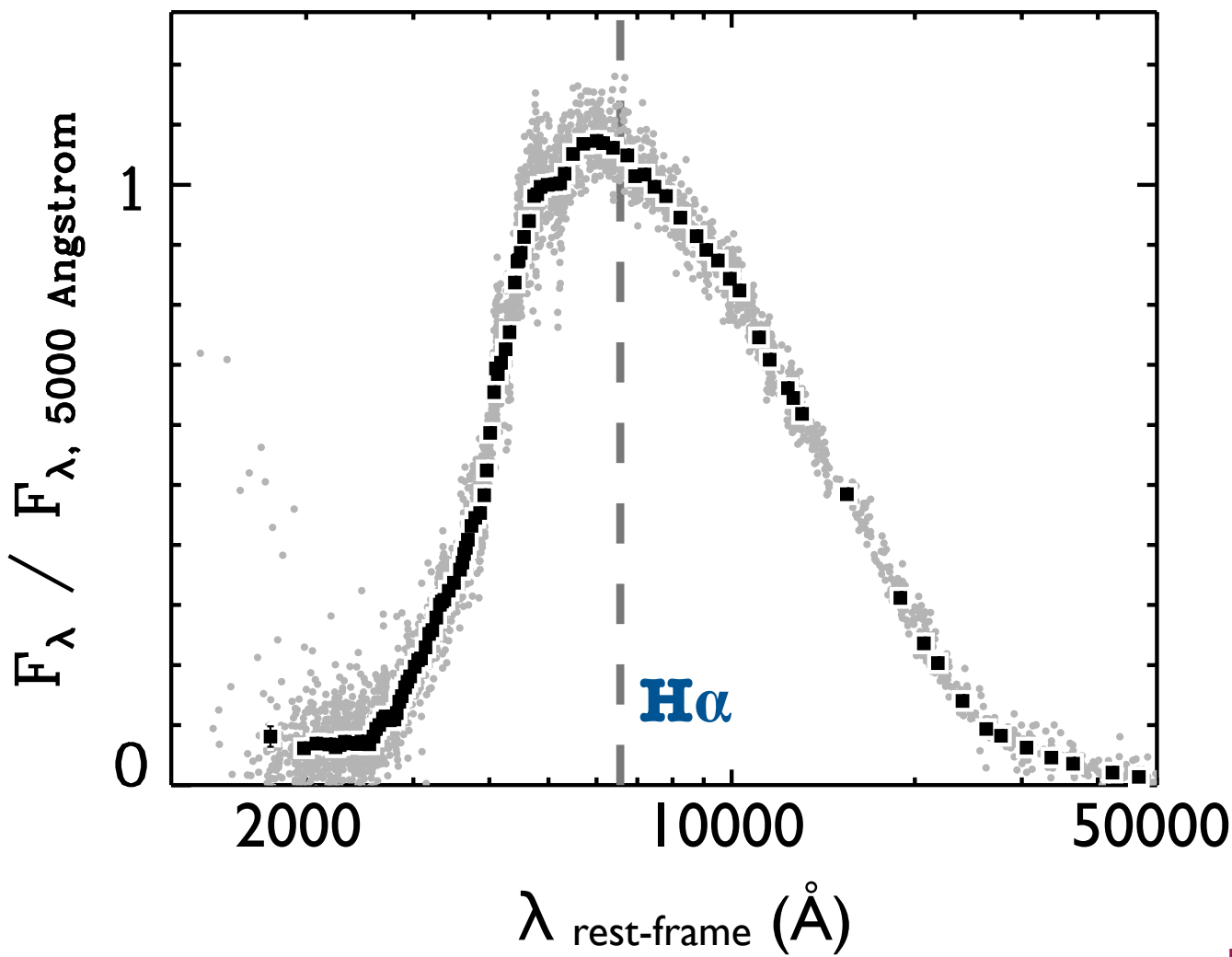

Kriek et al. (2011)

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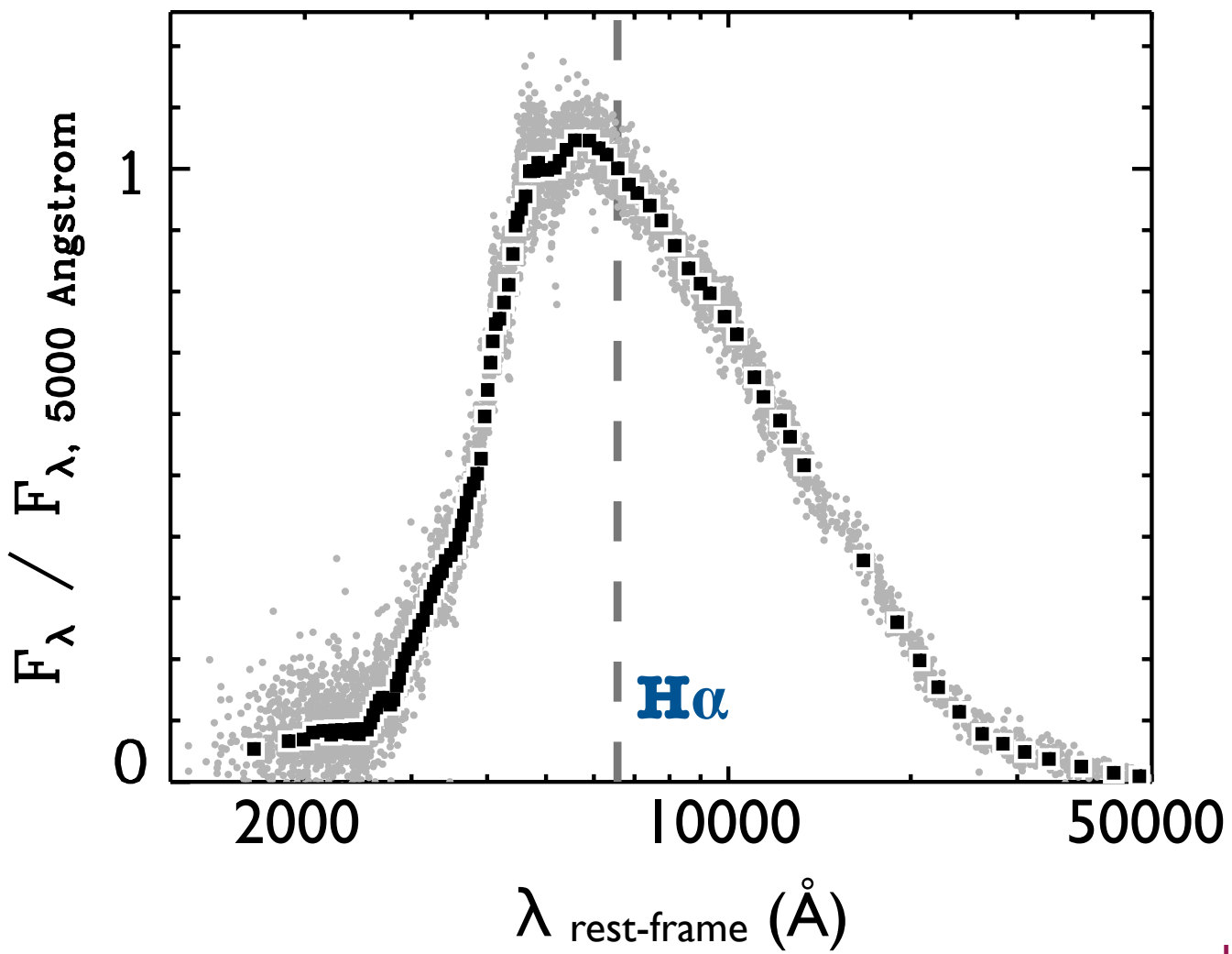

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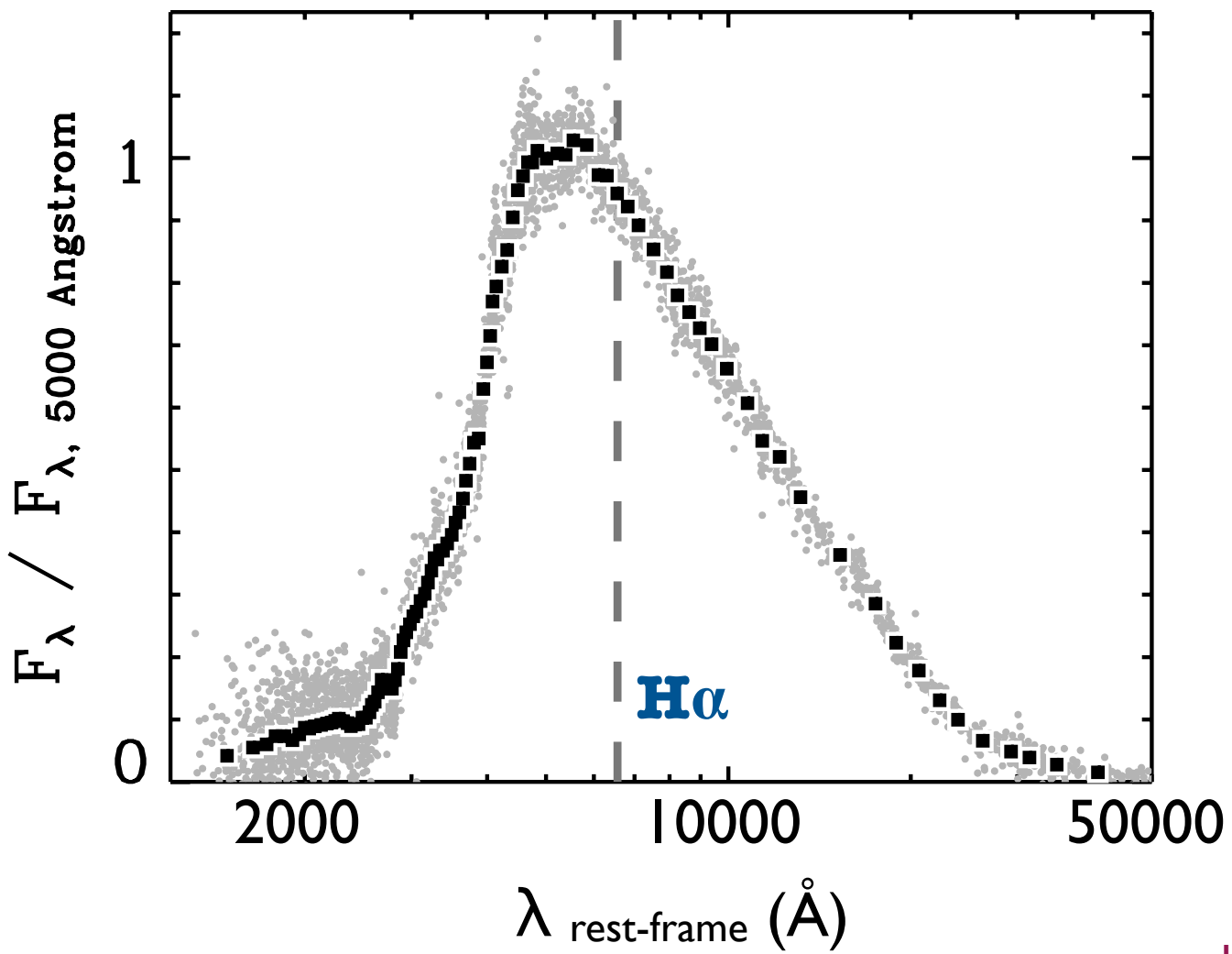

Kriek et al. (2011)

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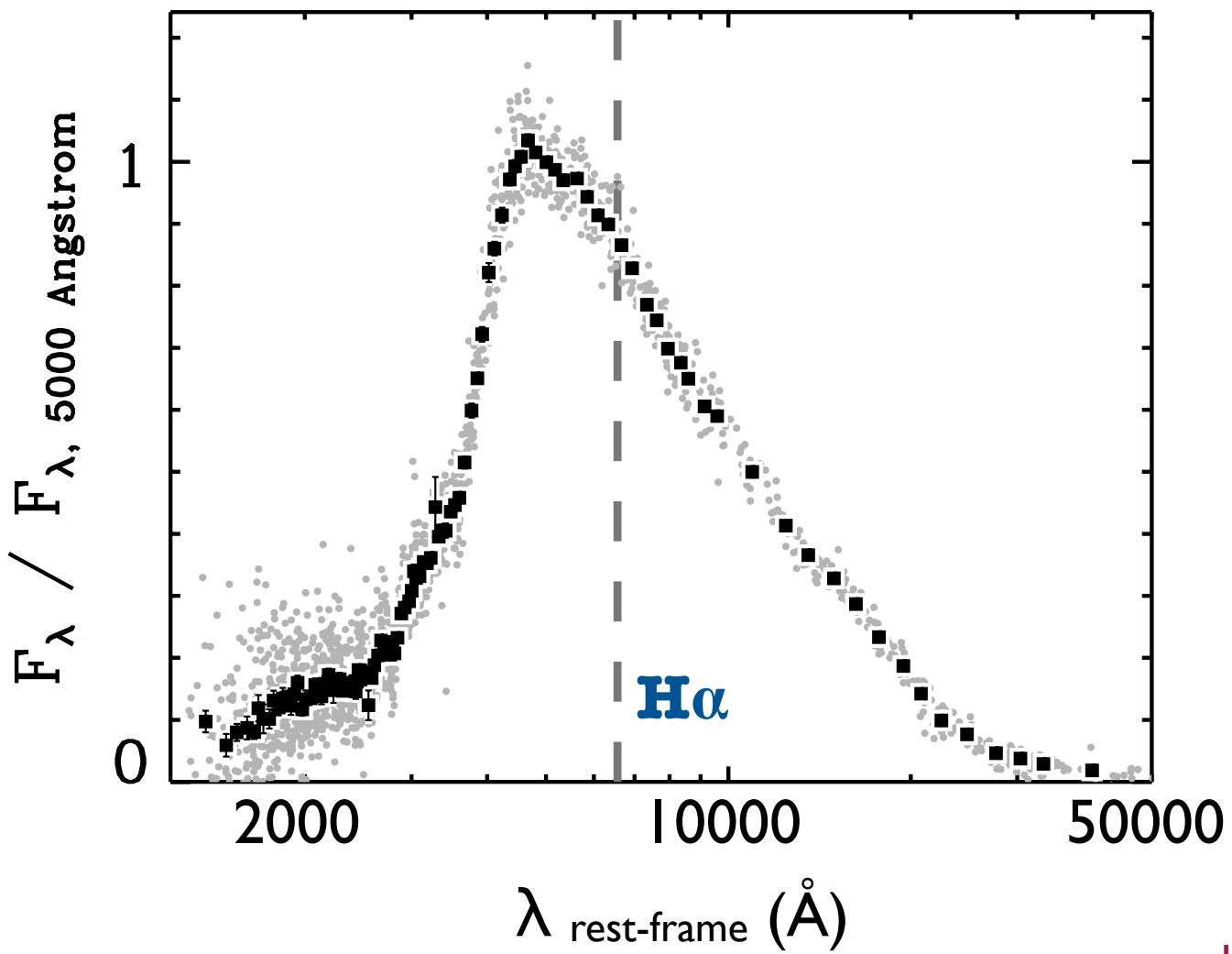

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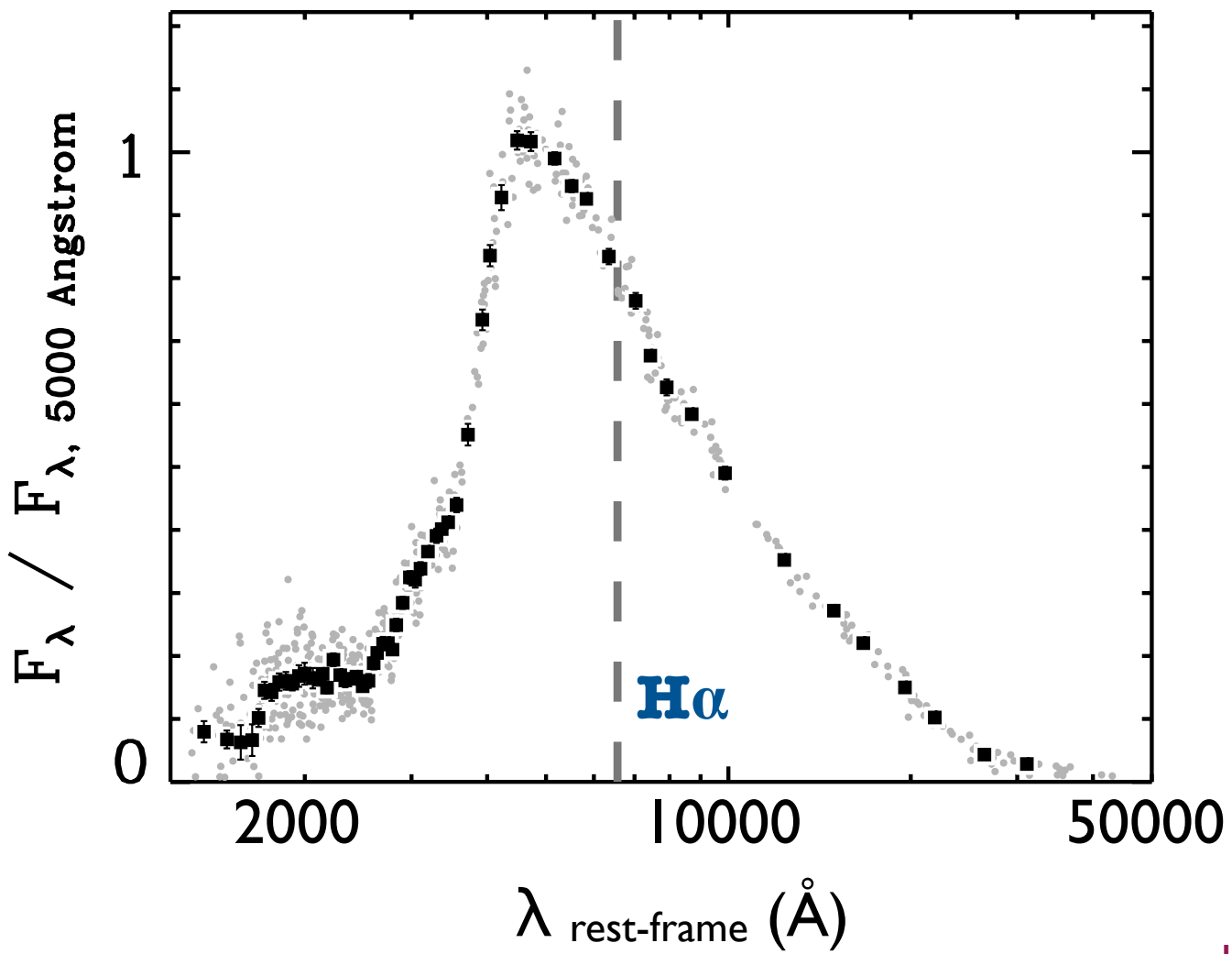

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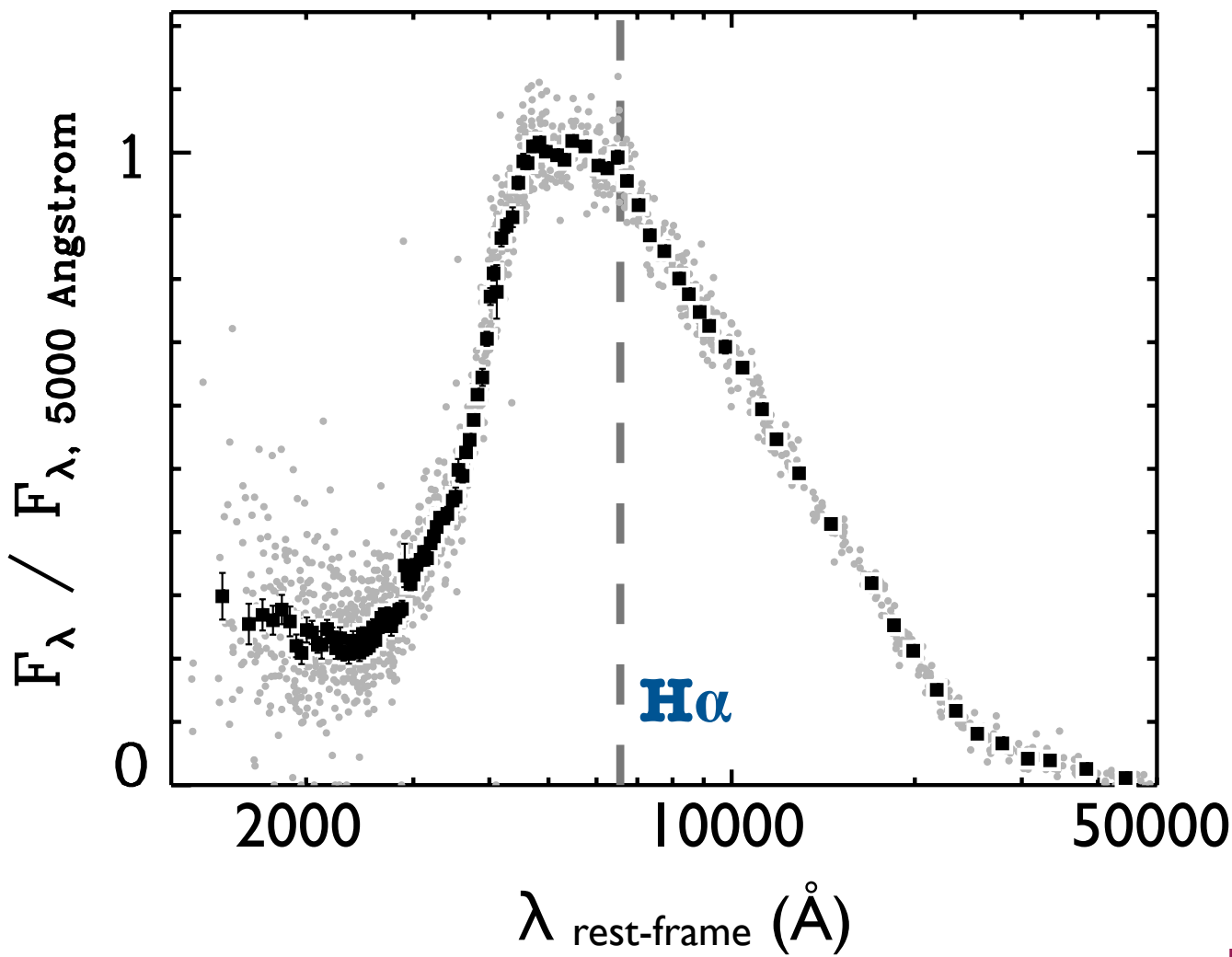
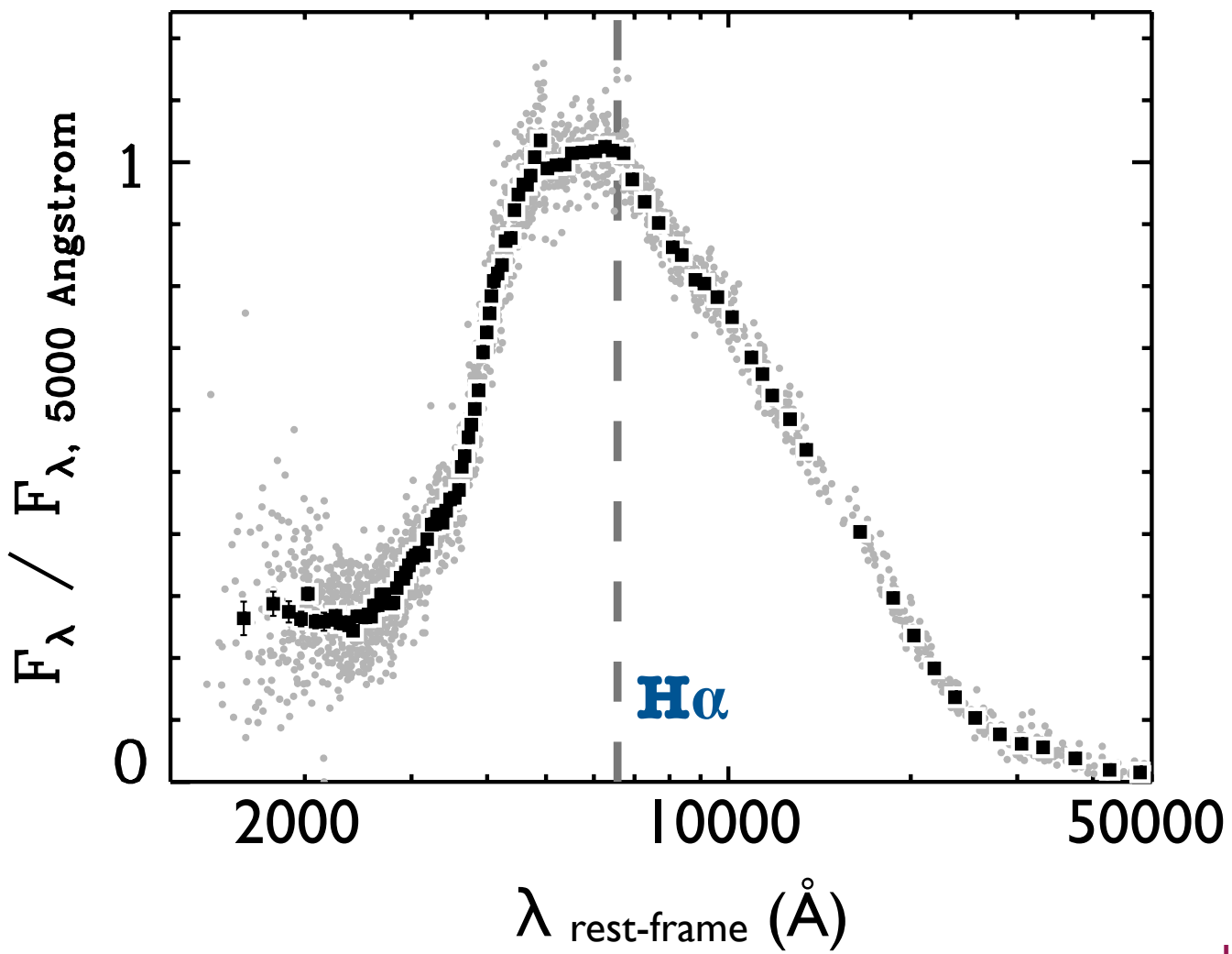


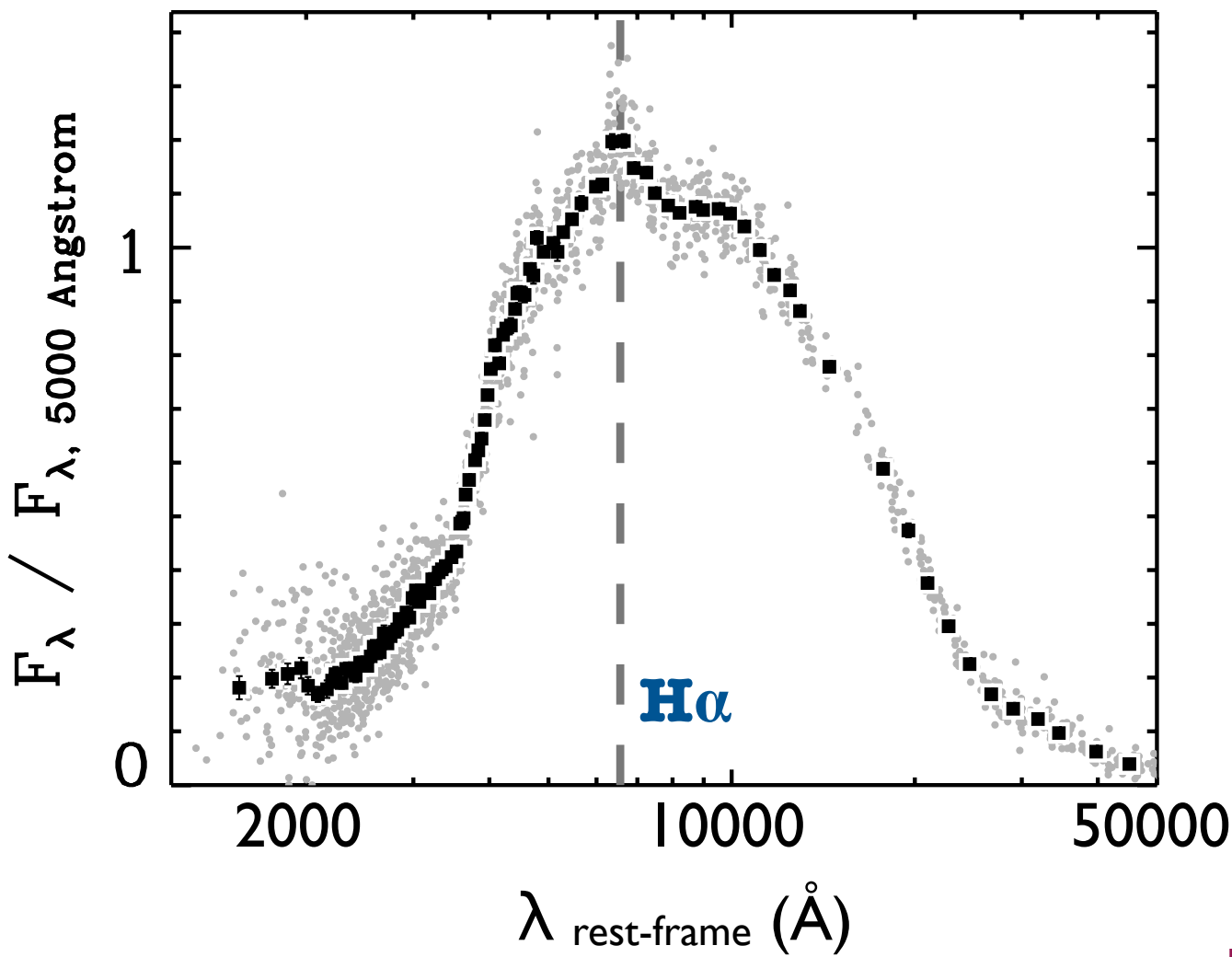
Kriek et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



Kriek et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



Kriek et al. (2011)

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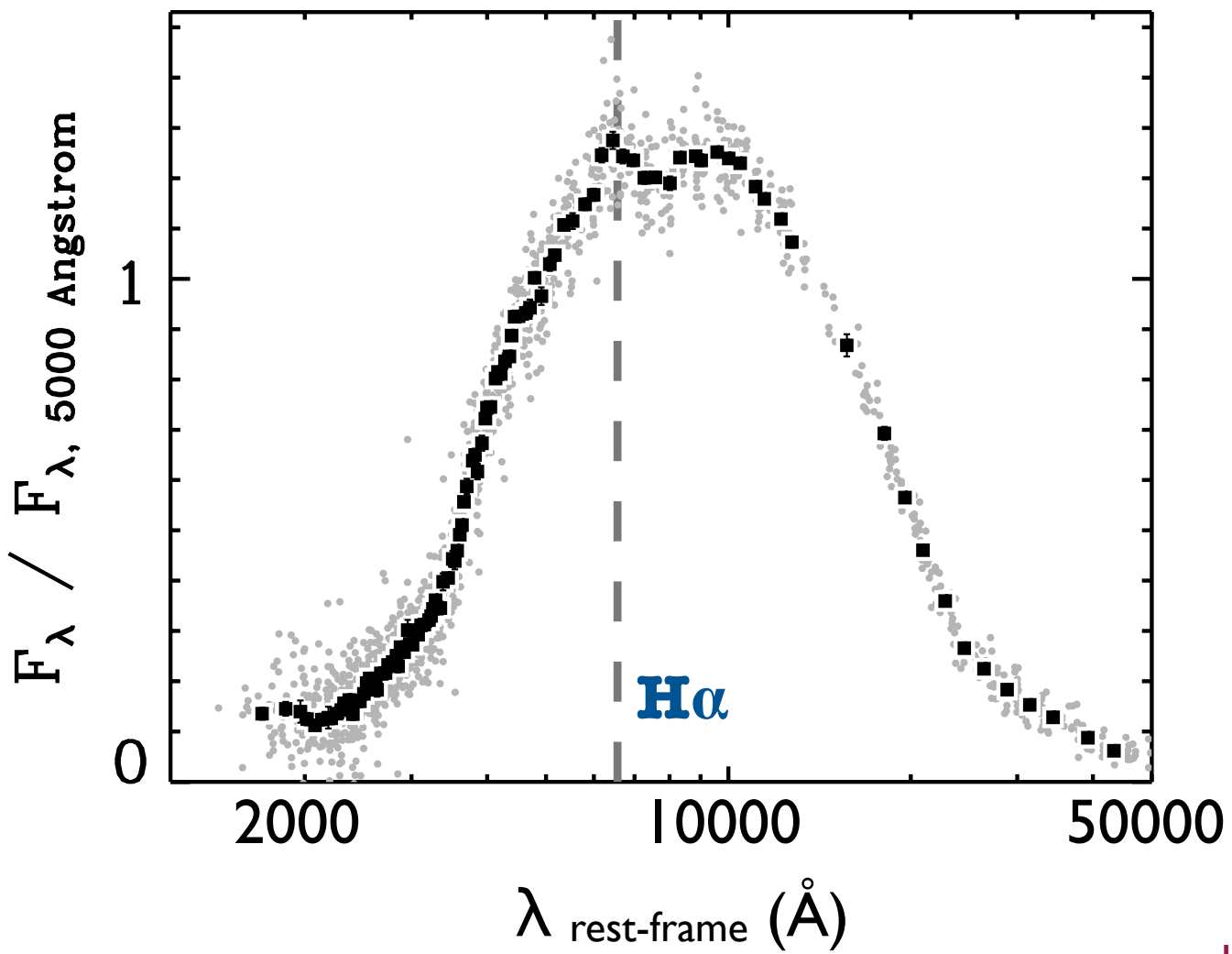
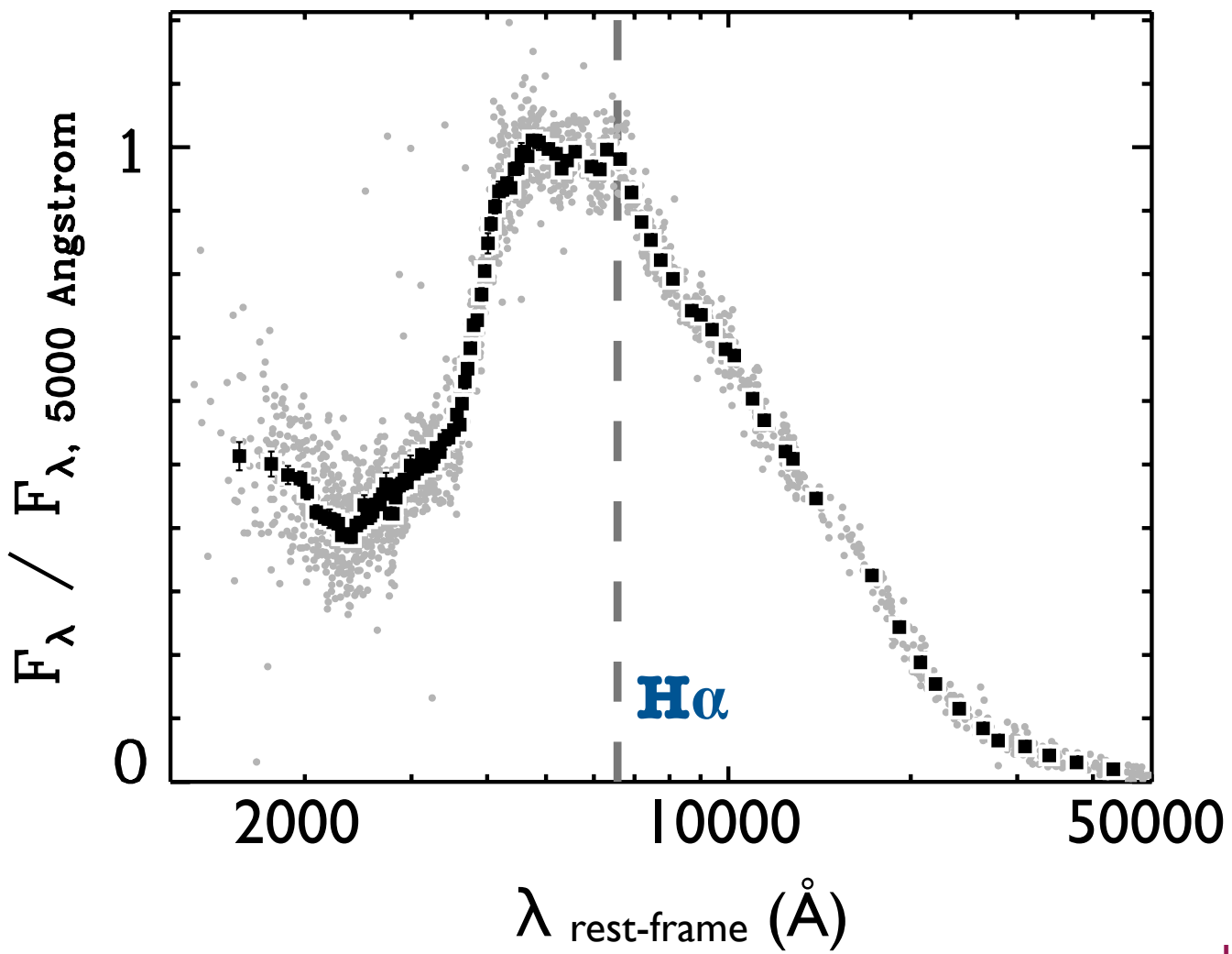


Kriek et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



Kriek et al. (2011)

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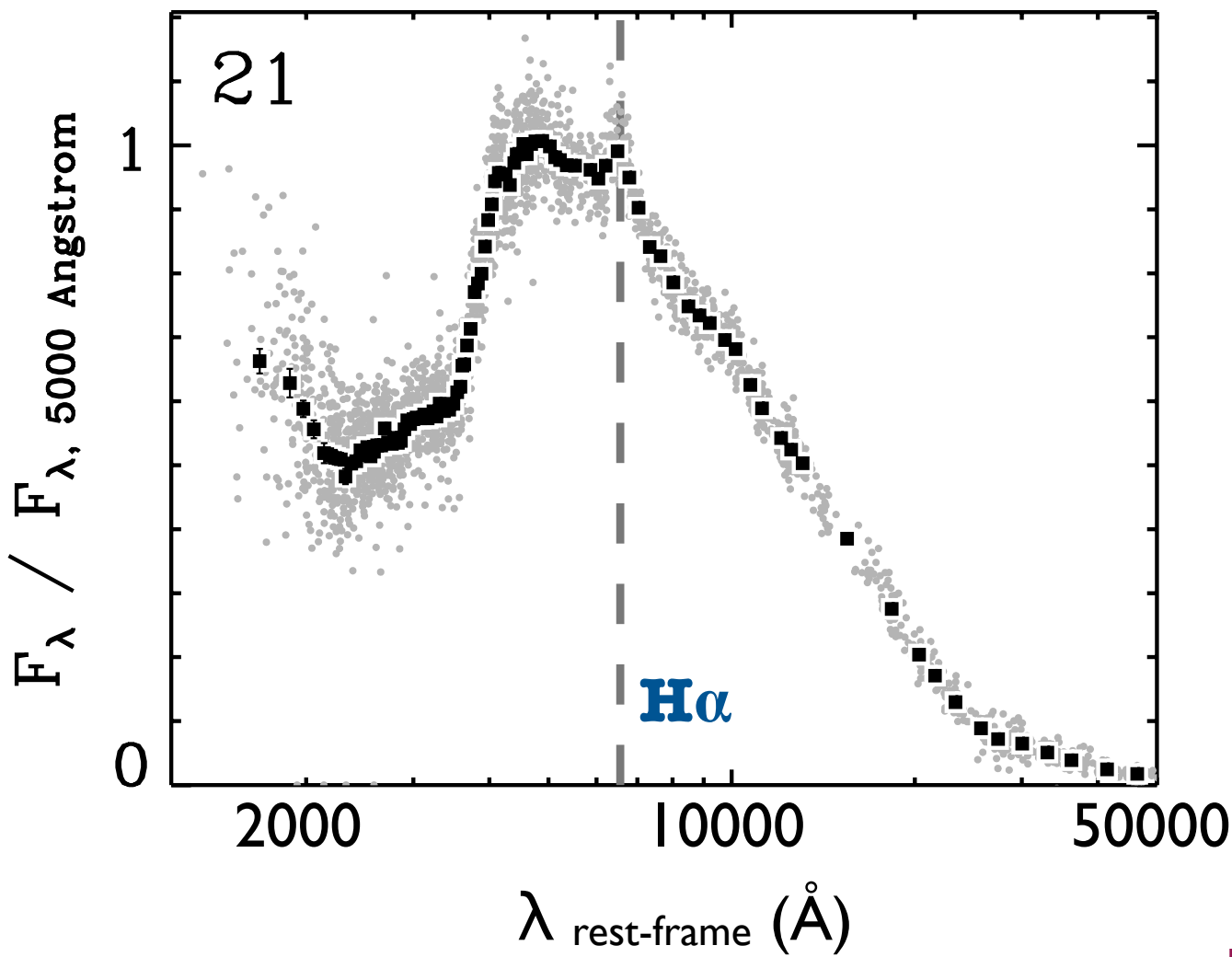

Kriek et al. (2011)

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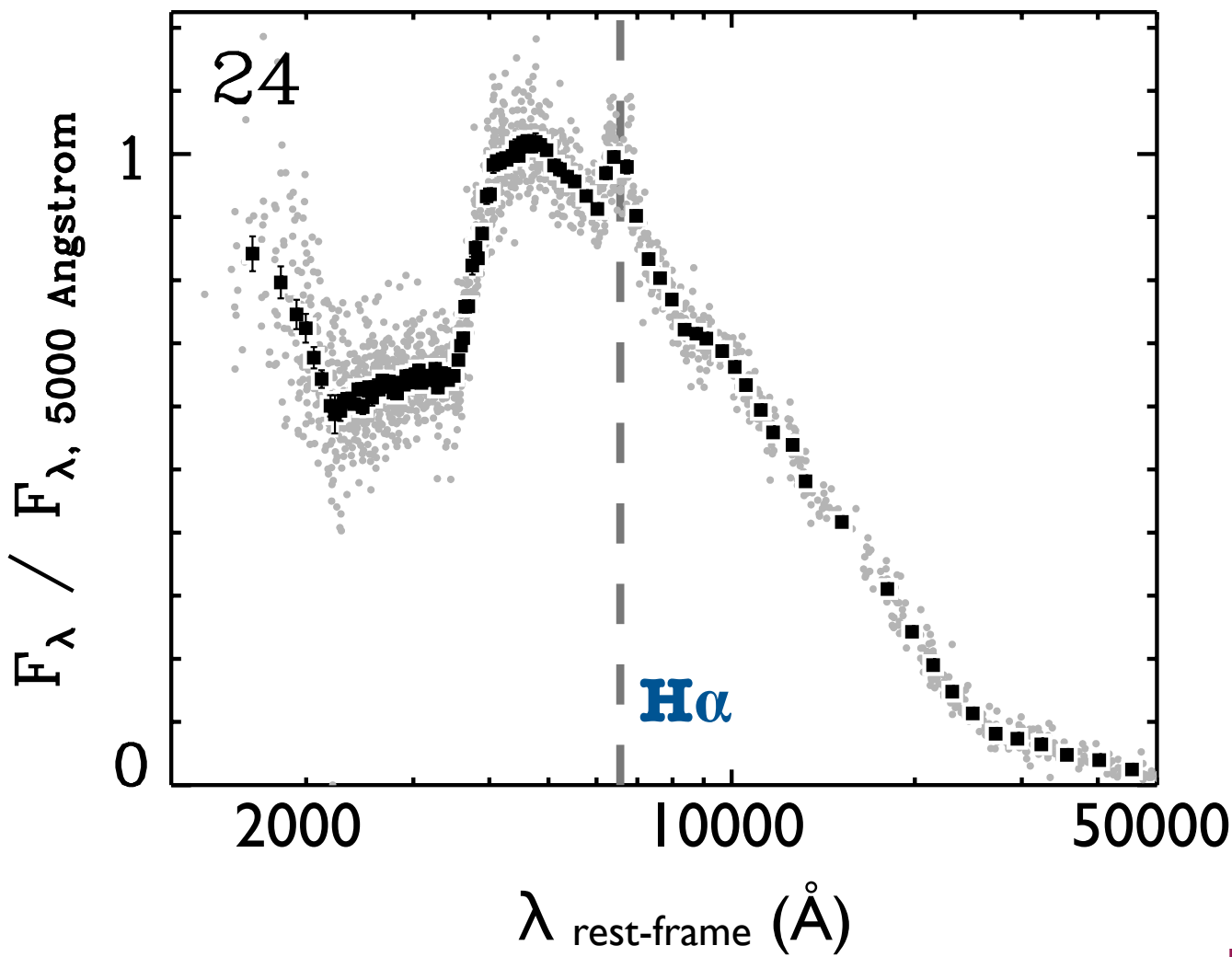

Kriek et al. (2011)

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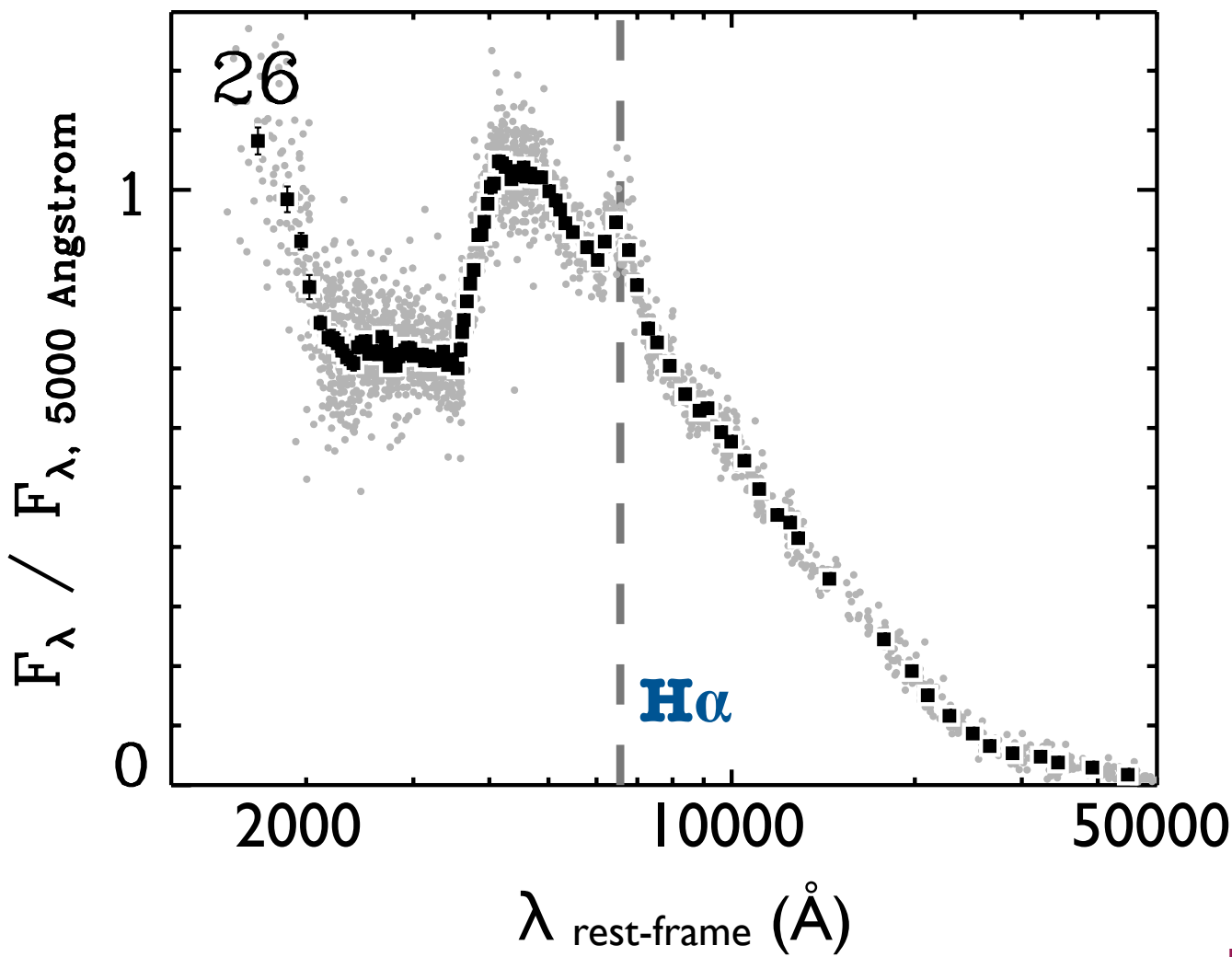
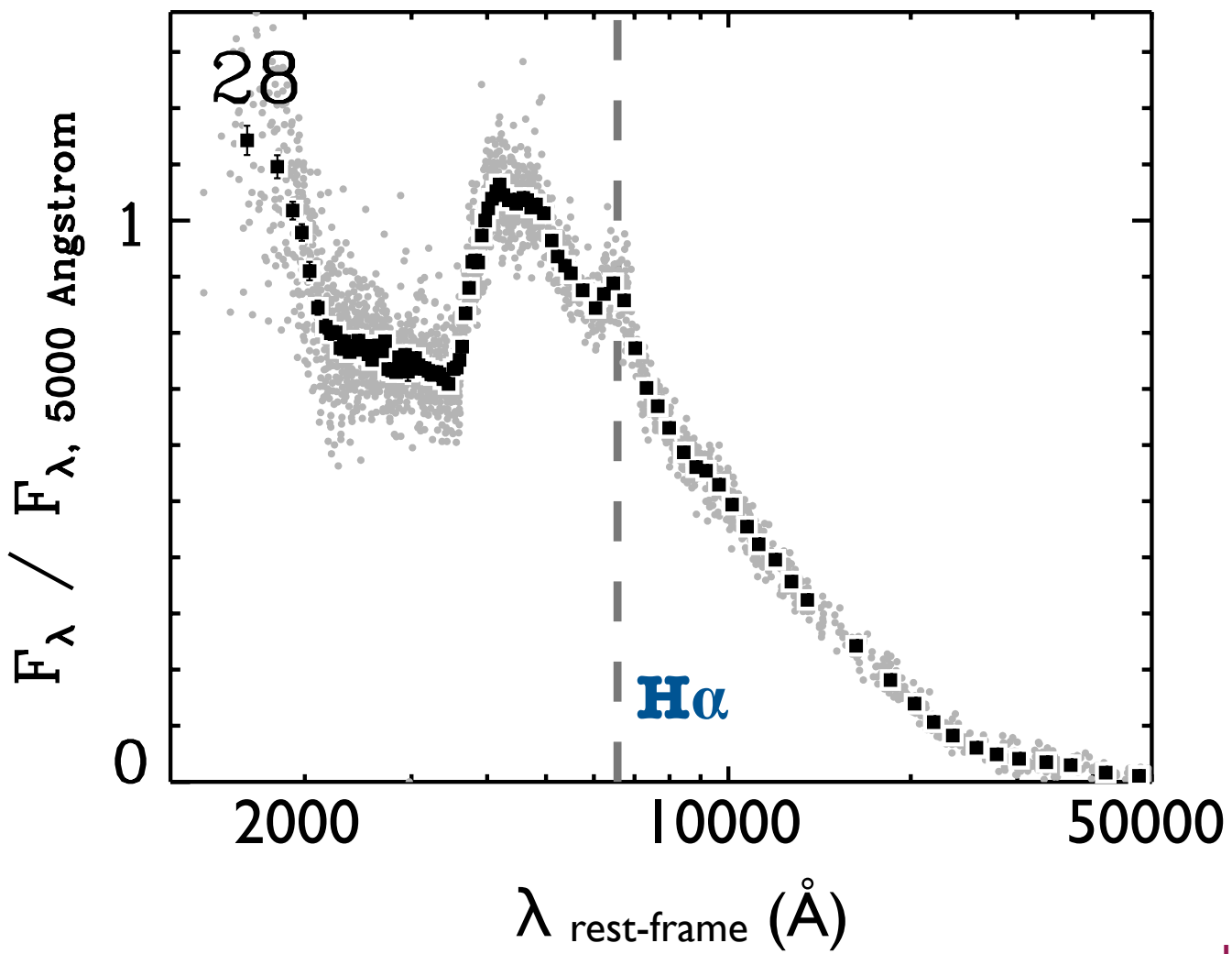


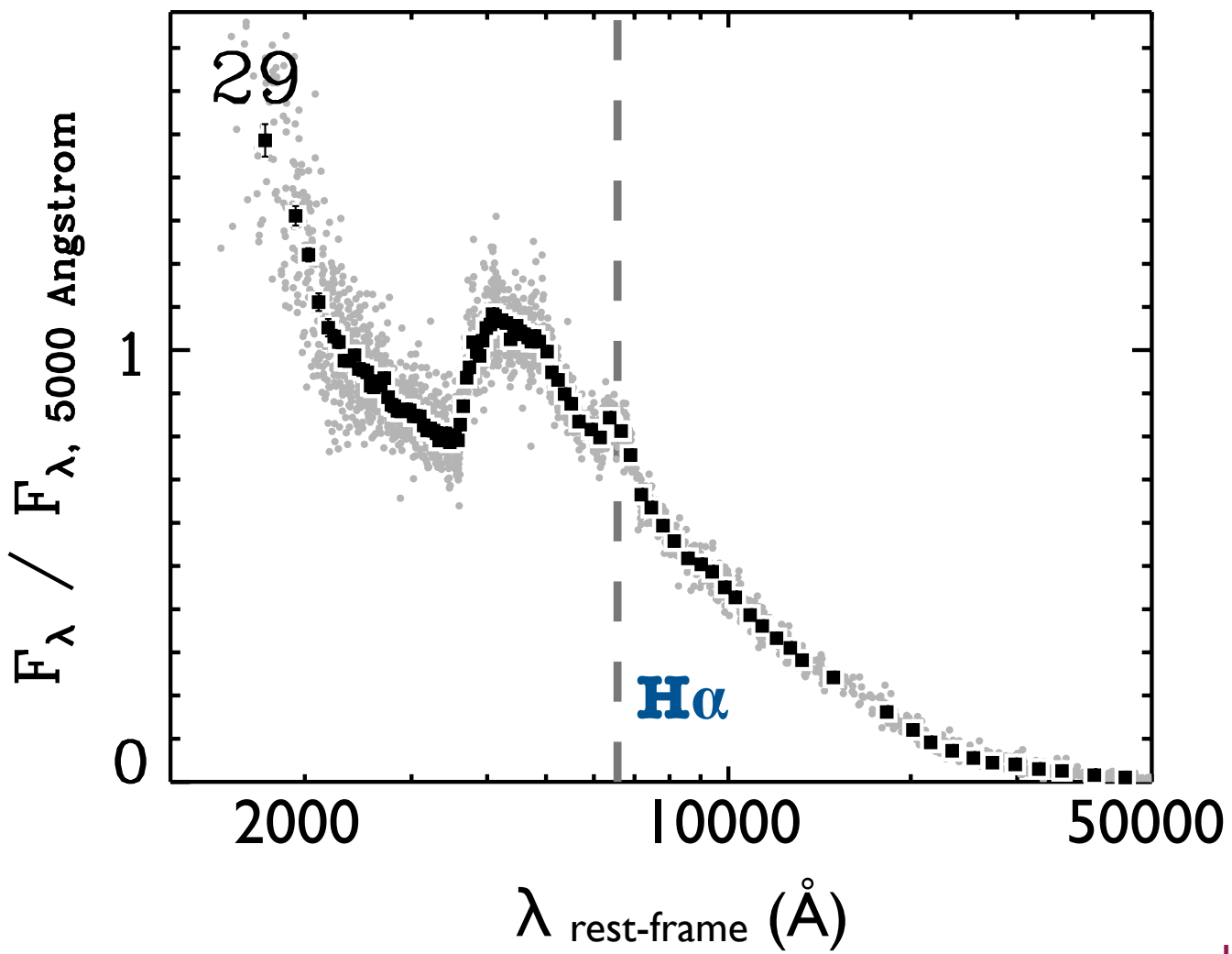
Kriek et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



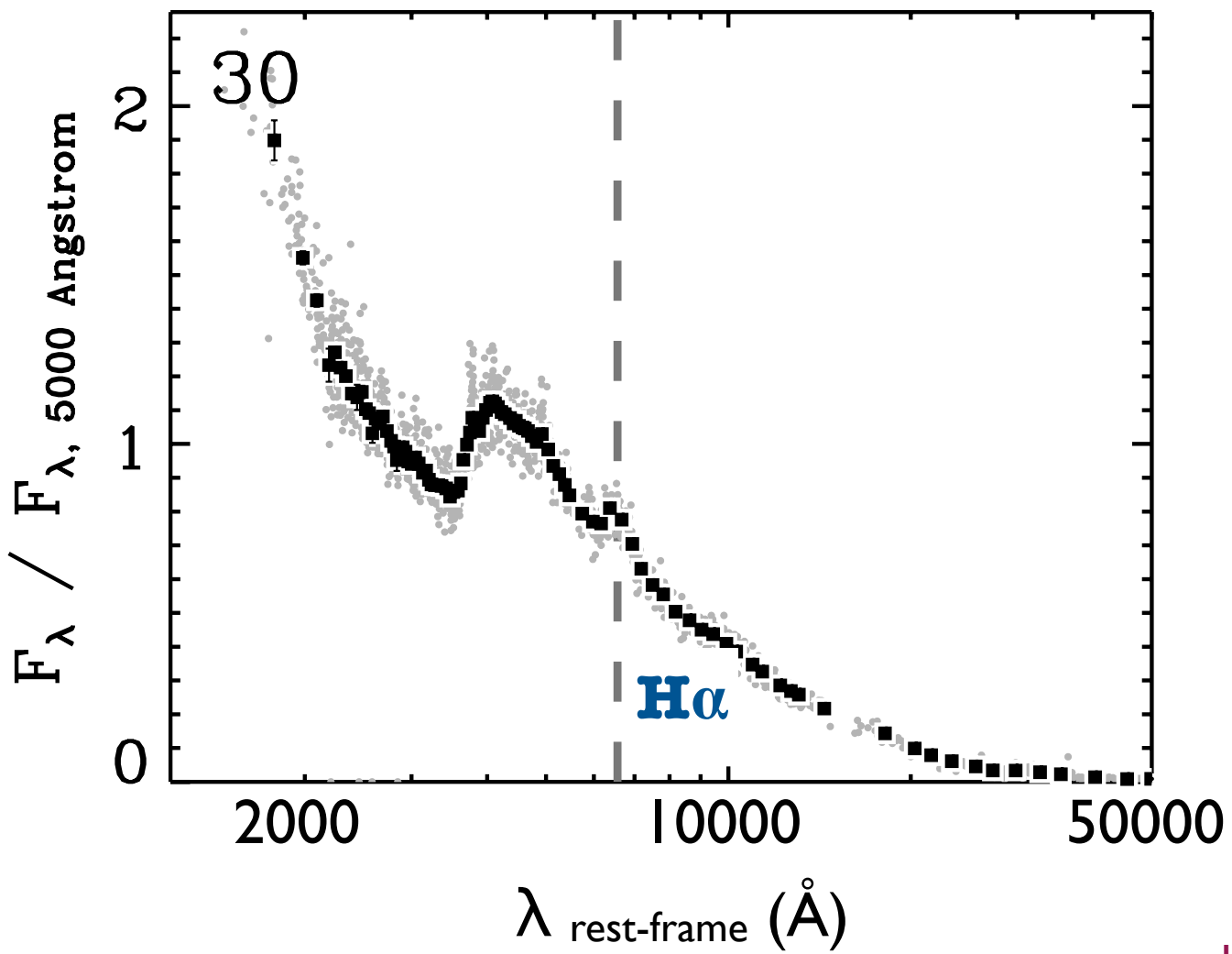
Kriek et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



Kriek et al. (2011)

Galaxy spectral types at 0.5 < z < 2.0



Kriek et al. (2011)

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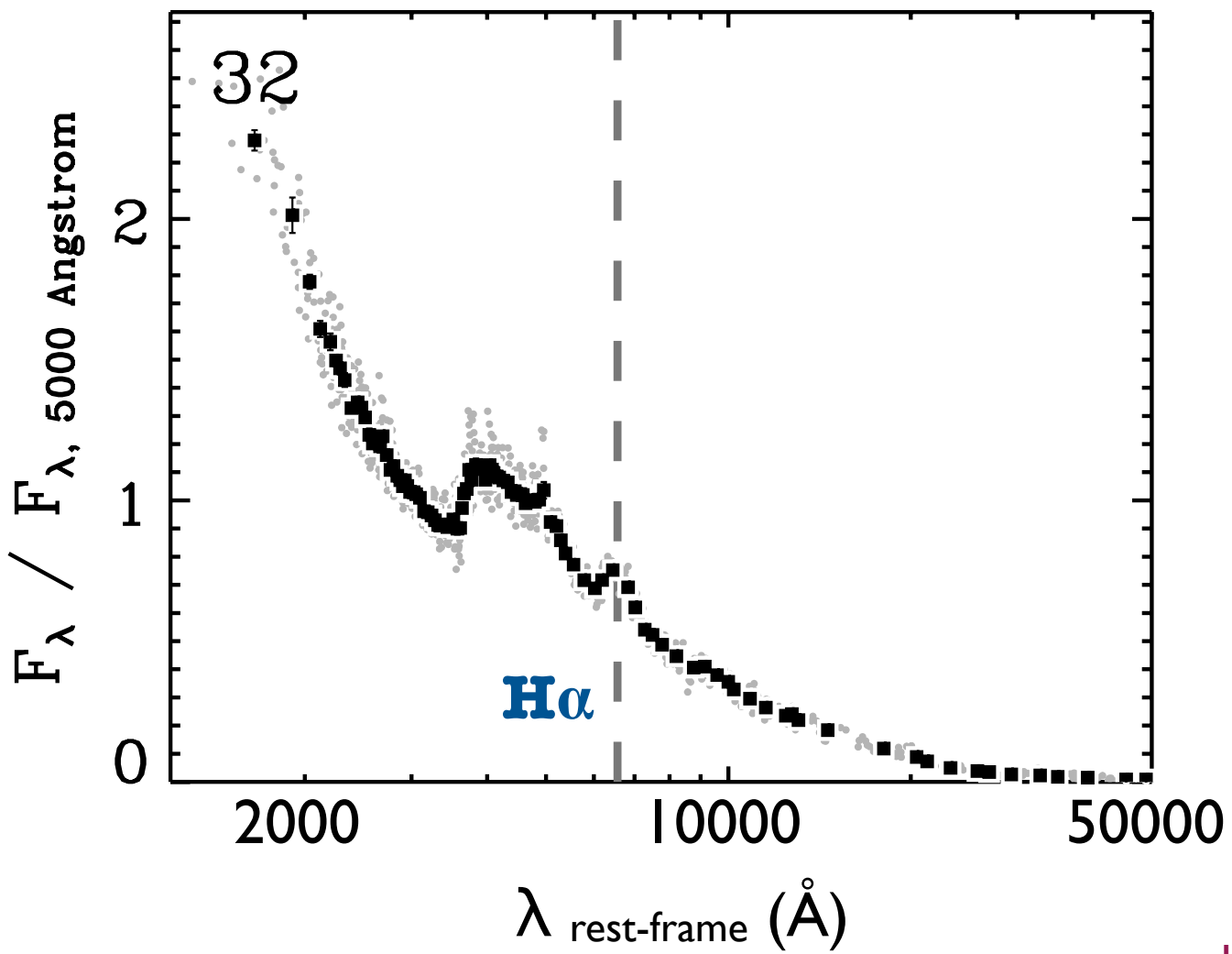
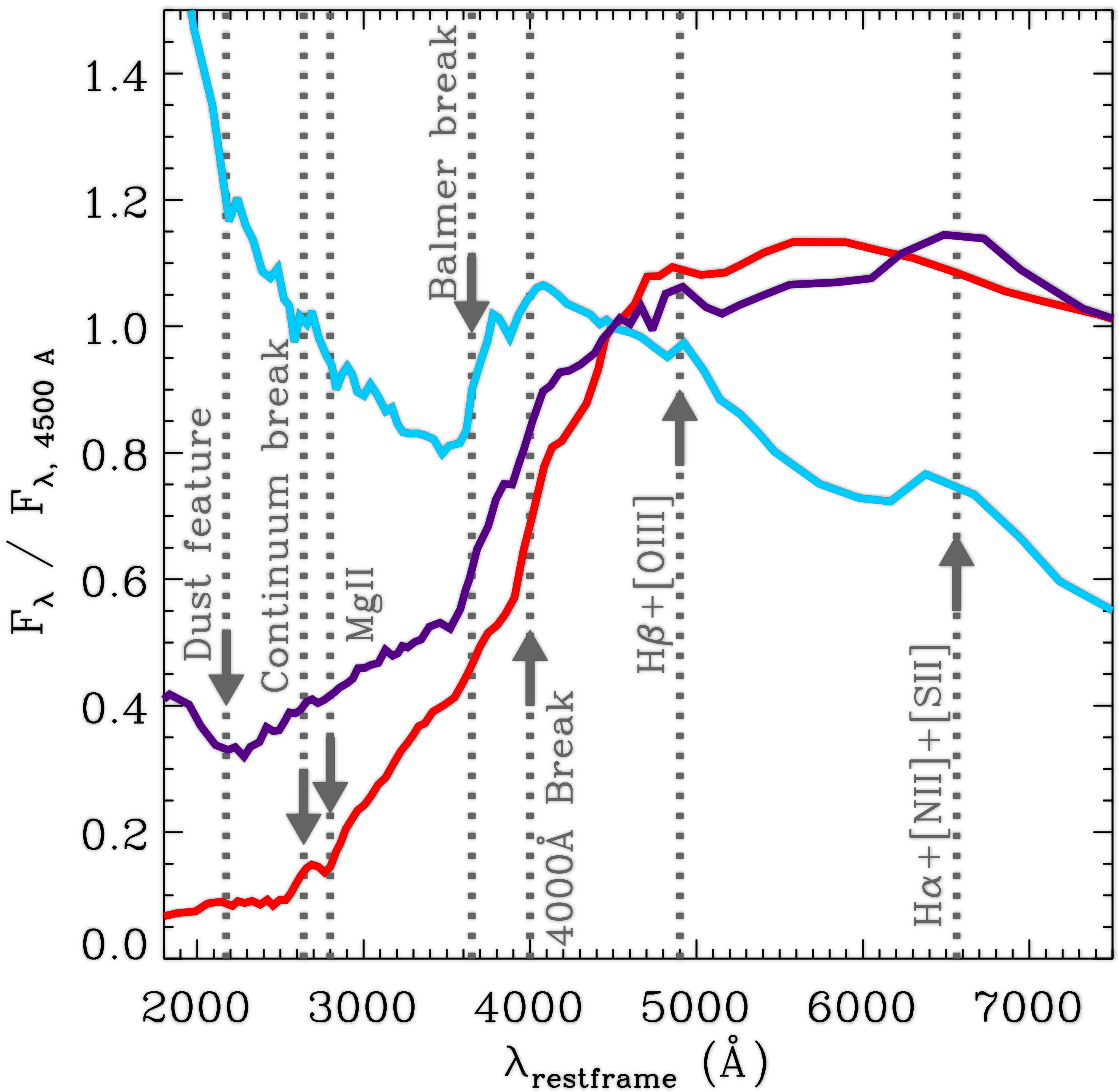


Kriek et al. (2011)

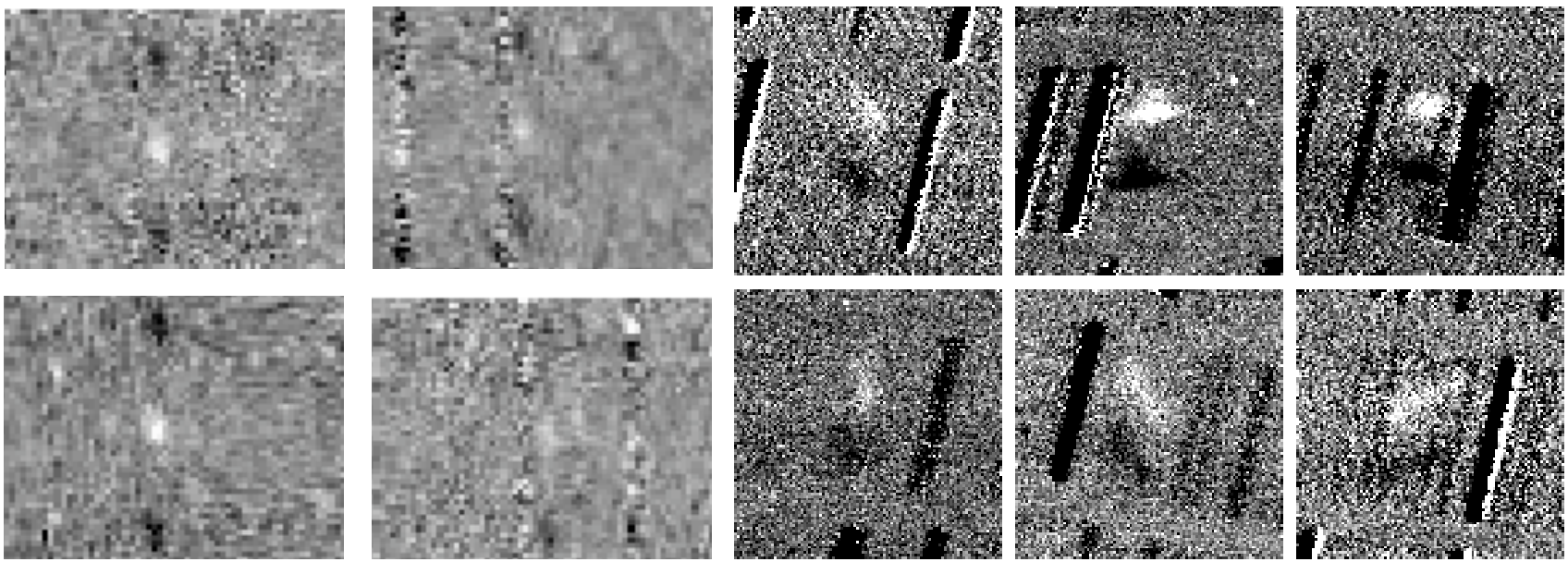
Spectral features



Kriek et al. (2011)

Galaxy properties as a function of spectral type at z ≈1.5

With GNIRS, FIRE and NIRSPEC



Star formation, metallicities, dust, active galactic nuclei

What have we learned using GNIRS?

- Galaxy population at z ≈ 2.3 is quite diverse
- A red sequence of quiescent galaxies was already in place beyond z=2
- Massive quiescent galaxies at z ≈ 2.3 are much more compact than their local analogs
- Massive star forming galaxies at z ≈ 2.3 are scaled up cool galaxies and have large irregular larger morphologies