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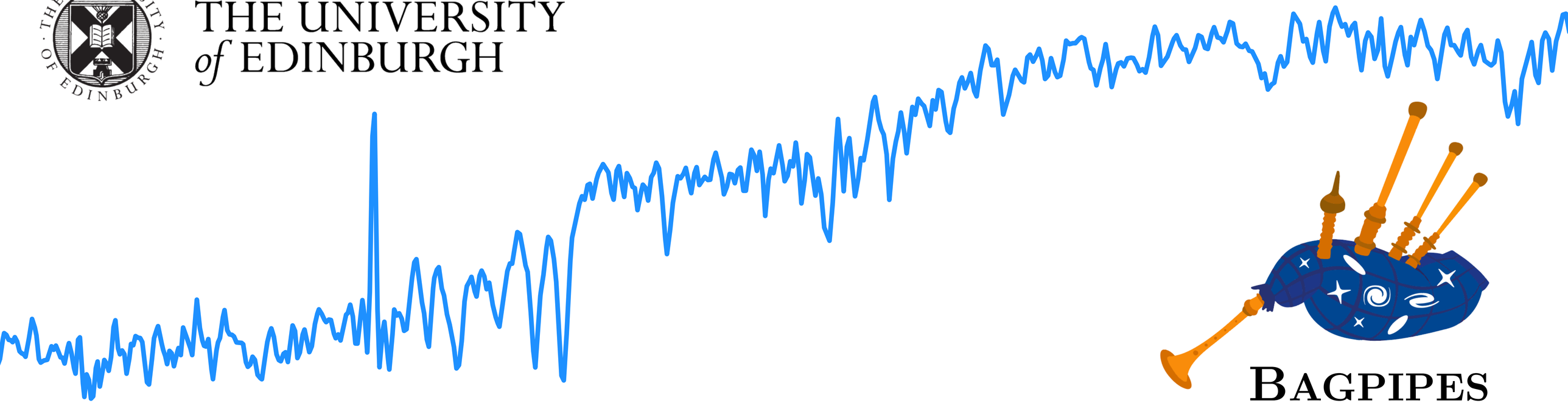

BAGPIPES

The Star Formation Histories of Massive Quiescent Galaxies

Adam Carnall, Leverhulme Early Career Fellow 2020

In collaboration with: Ross McLure, Jim Dunlop, Joel Leja, Ben Johnson, Vivienne Wild + The VANDELS Team

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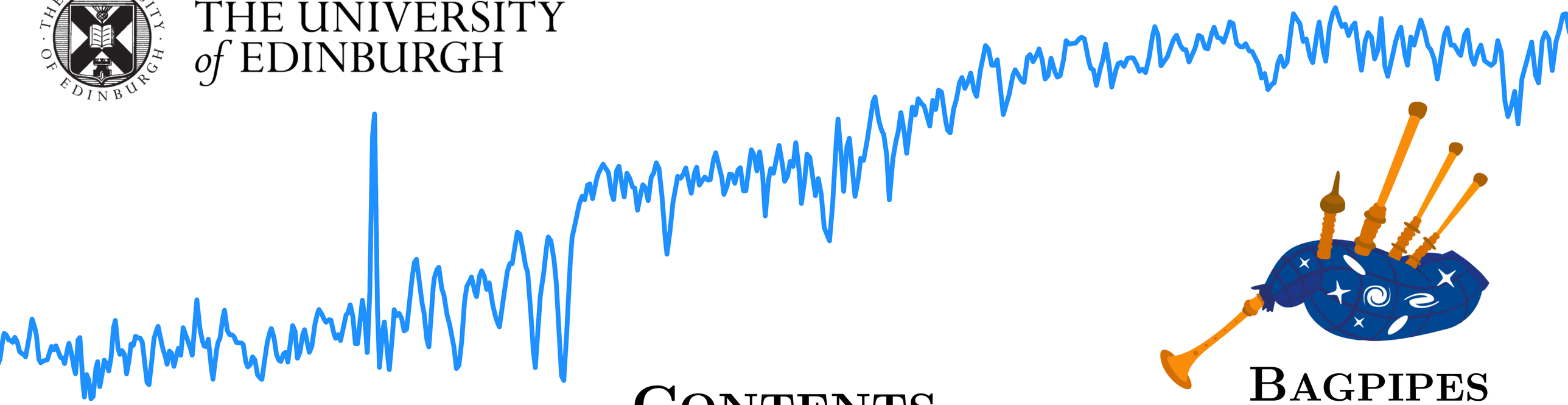
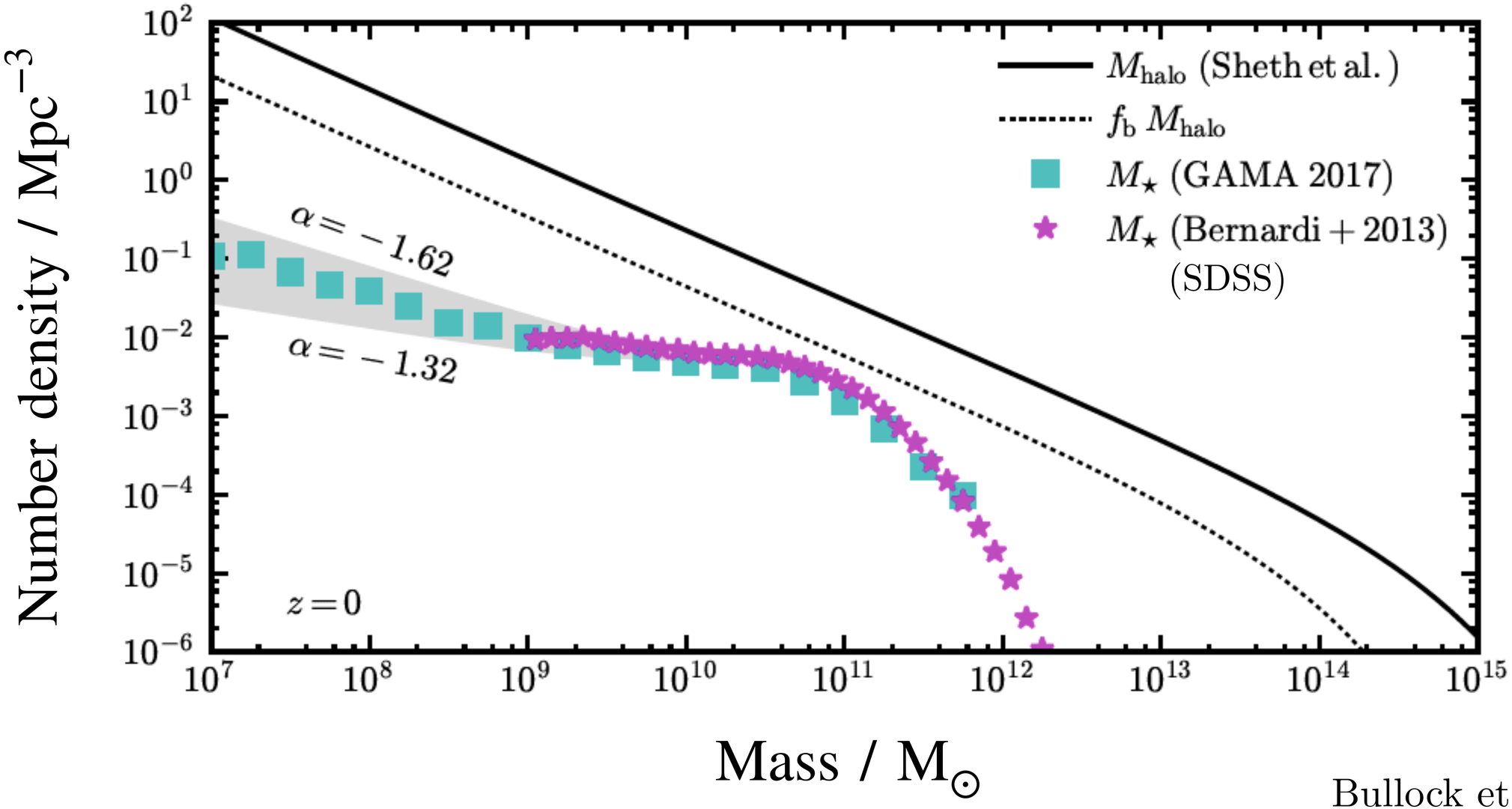


BAGPIPES

CONTENTS

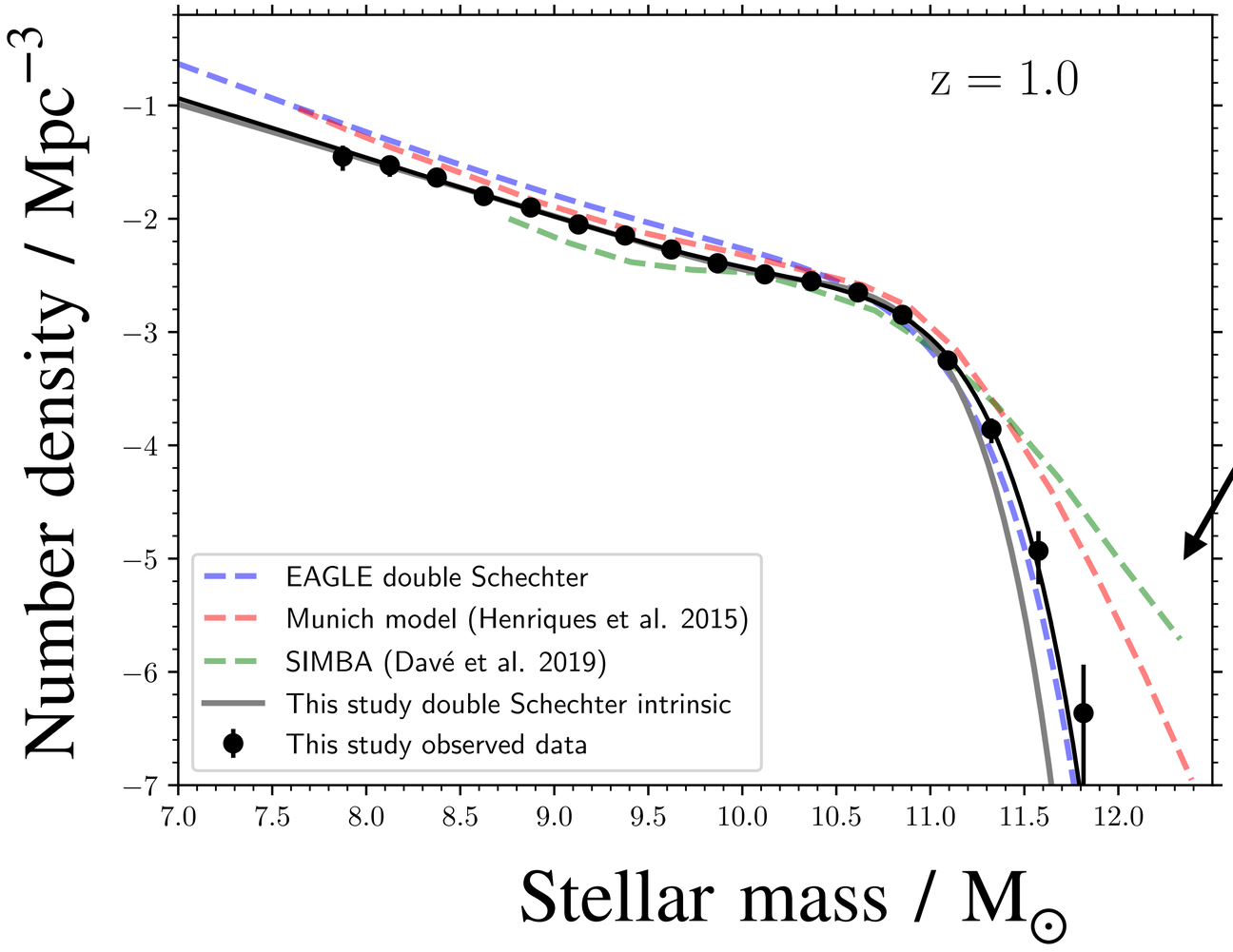
- Motivation
- Bagpipes: a new Bayesian SED fitting code
- Measuring star-formation histories from photometry
- VANDELS spectroscopy of massive quiescent galaxies at $1.0 < z < 1.3$
- Searching for the first massive quiescent galaxies

Modelling Galaxy Evolution



Bullock et al. (2017)

Modelling Galaxy Evolution



Large uncertainties due to small box sizes

McLeod et al. (in prep.)

Introduction to Bagpipes

New public Python code for generating realistic model galaxy spectra and fitting these to spectroscopic and photometric observations, described in Carnall et al. (2018).

bagpipes.readthedocs.io

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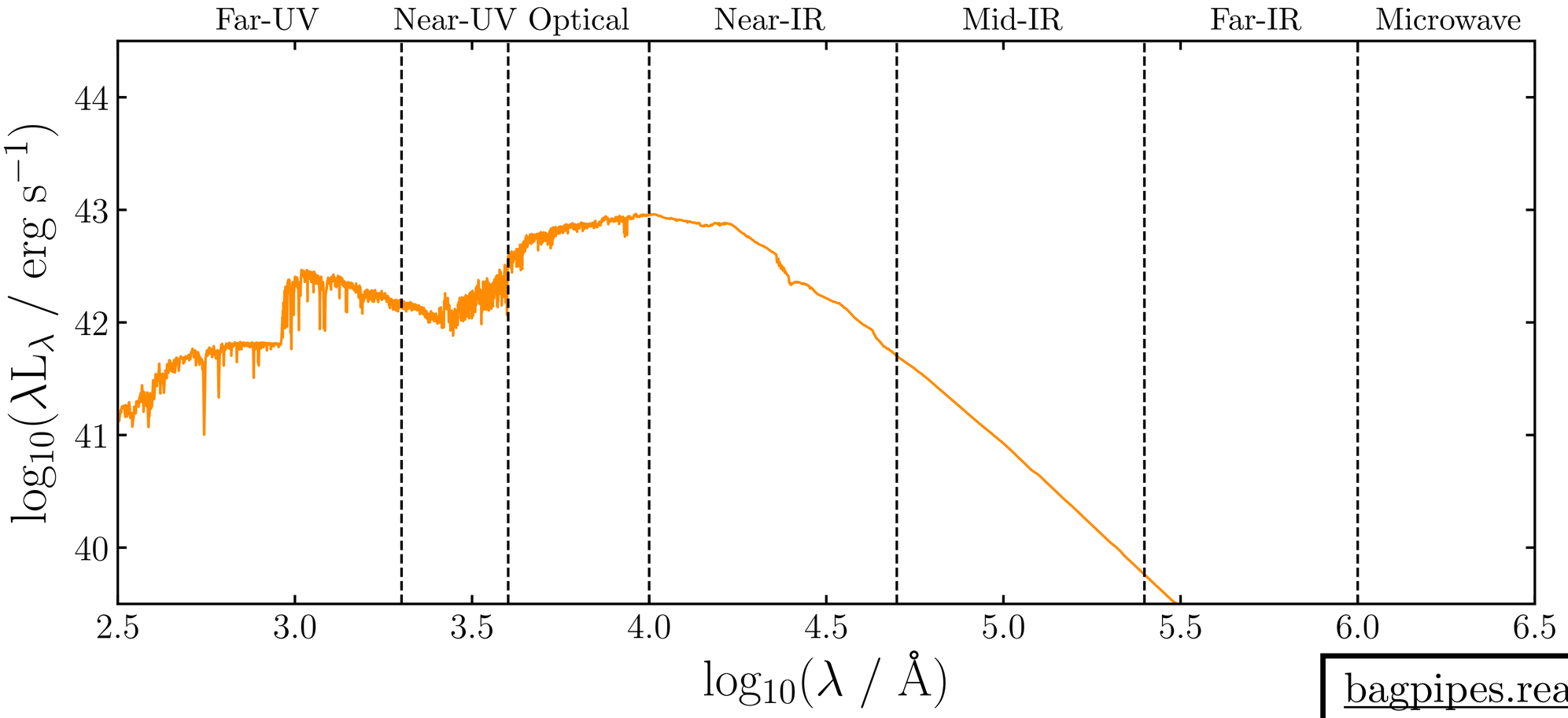

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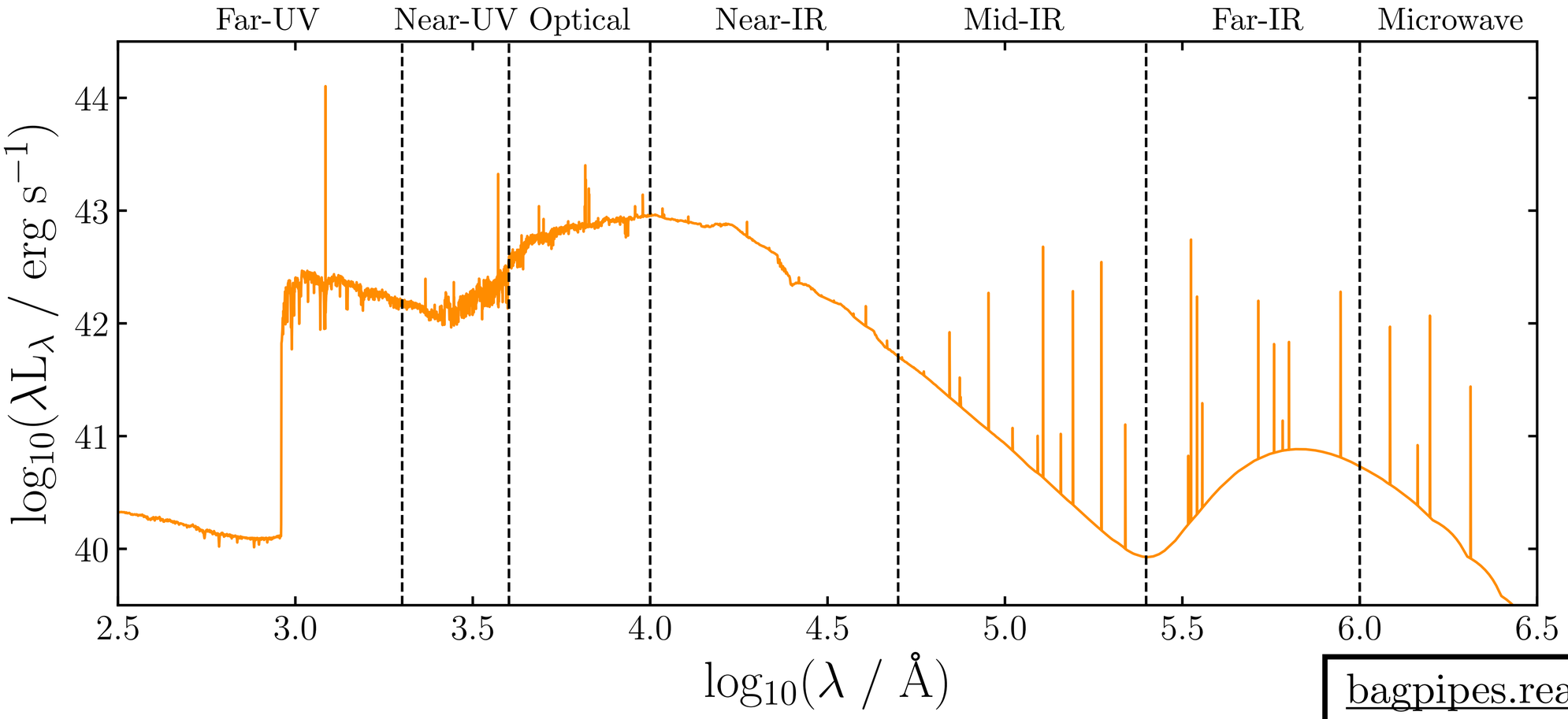

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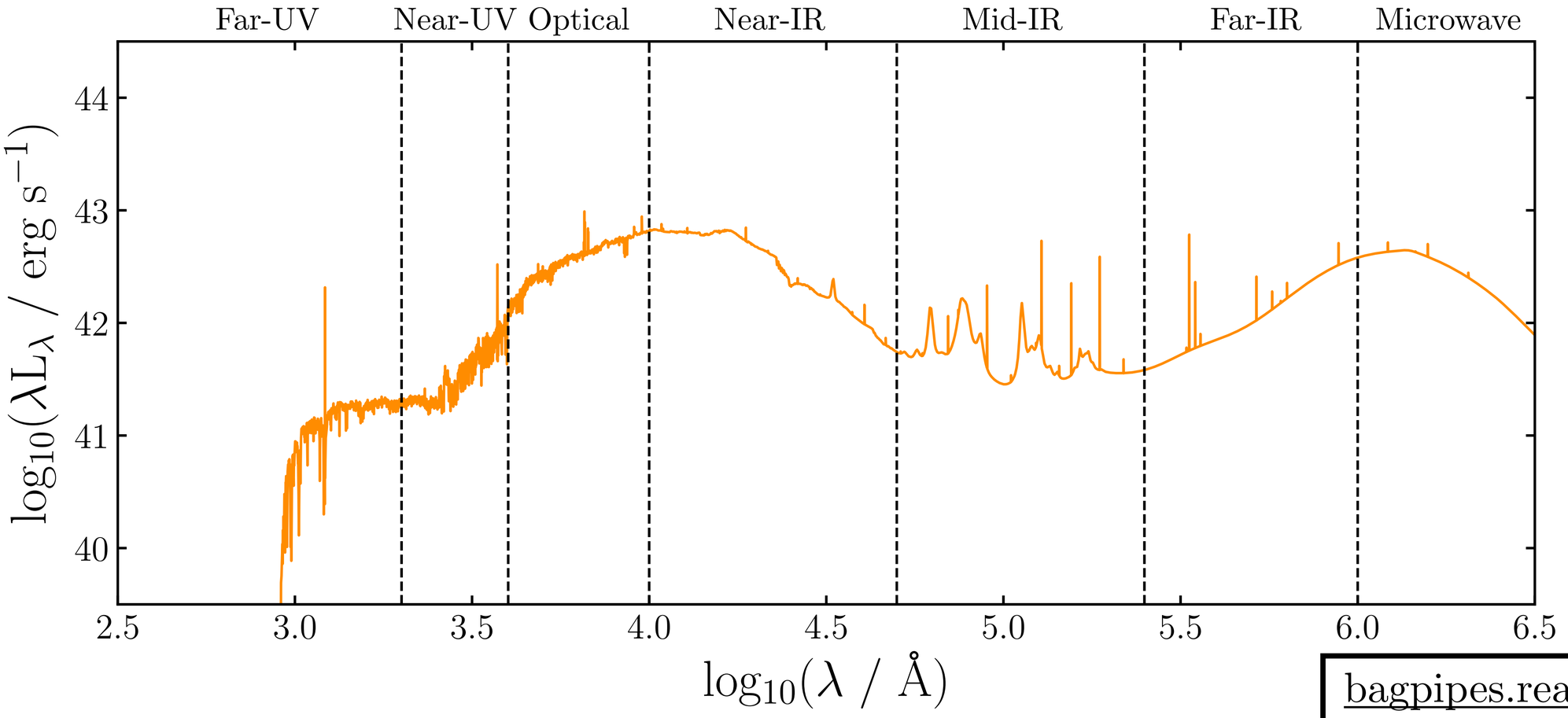

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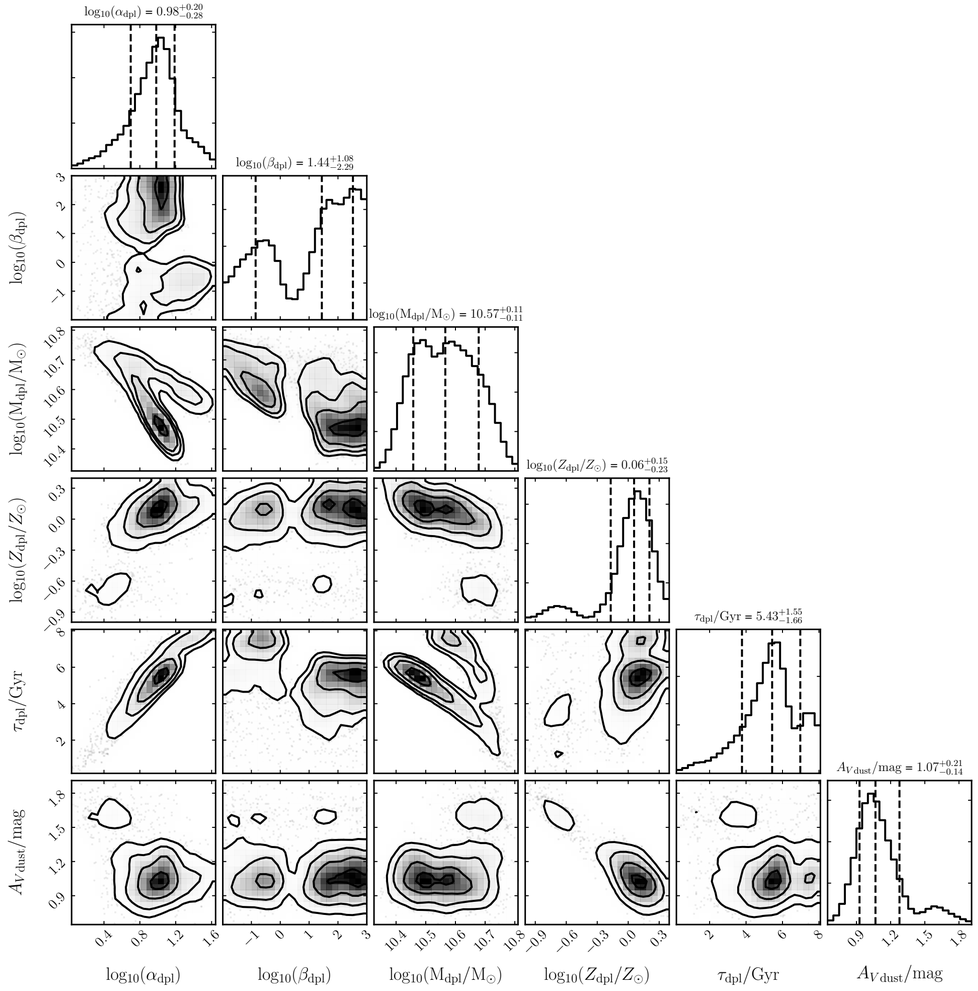
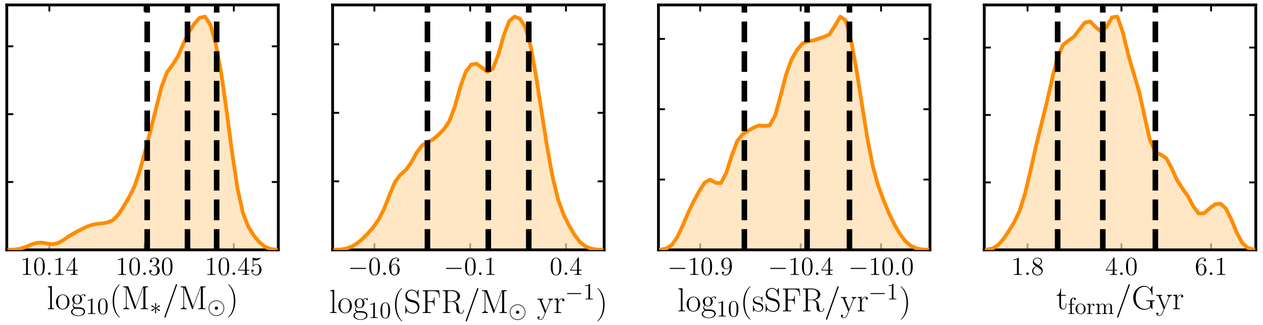
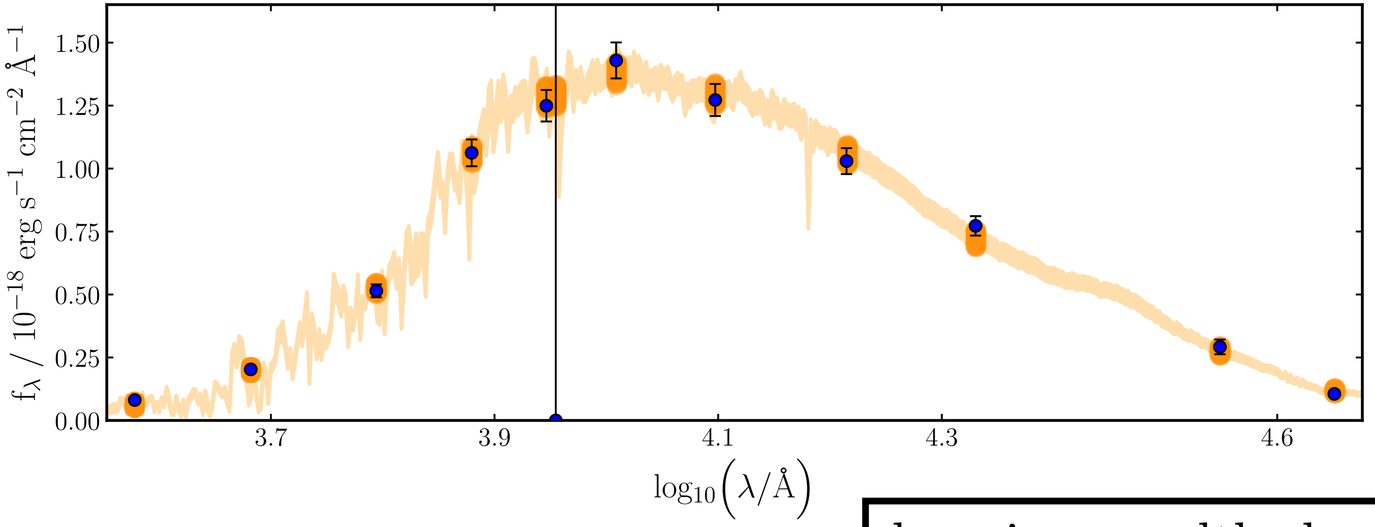






bagpipes.readthedocs.io

Introduction to Bagpipes

New public Python code for generating realistic model galaxy spectra and fitting these to spectroscopic and photometric observations, described in Carnall et al. (2018).

- Easy installation: "**`pip install bagpipes`**"
- Open source at GitHub: https://github.com/ACCarnall/bagpipes
- Documentation: https://bagpipes.readthedocs.io + iPython notebooks on GitHub
- Active development: e.g. recent addition of Iyer et al. (2019) Gaussian Process SFHs

The Ages of Massive Galaxies

The Ages of Massive Galaxies

Messier 87

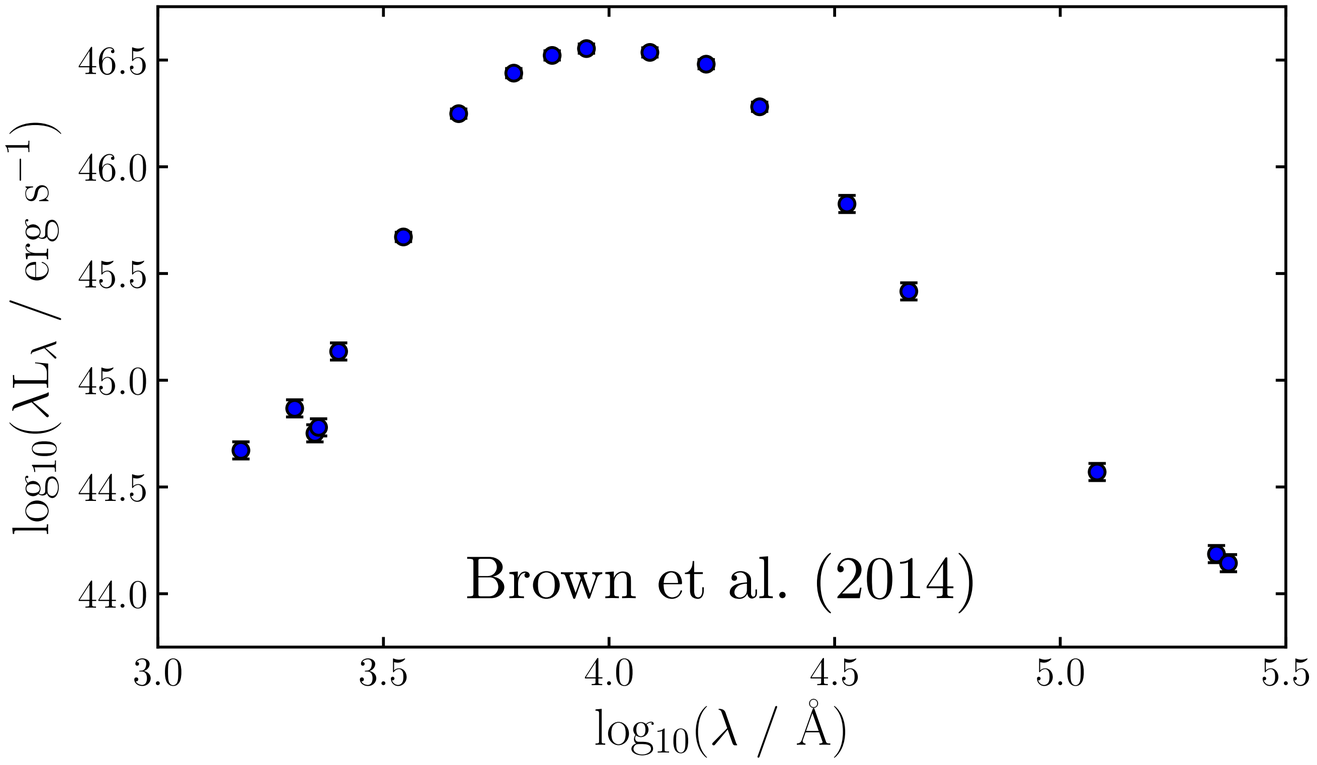
Aged ?? Years

The Ages of Massive Galaxies

Messier 87

Aged ?? Years

The Ages of Massive Galaxies



Messier 87

Aged ?? Years

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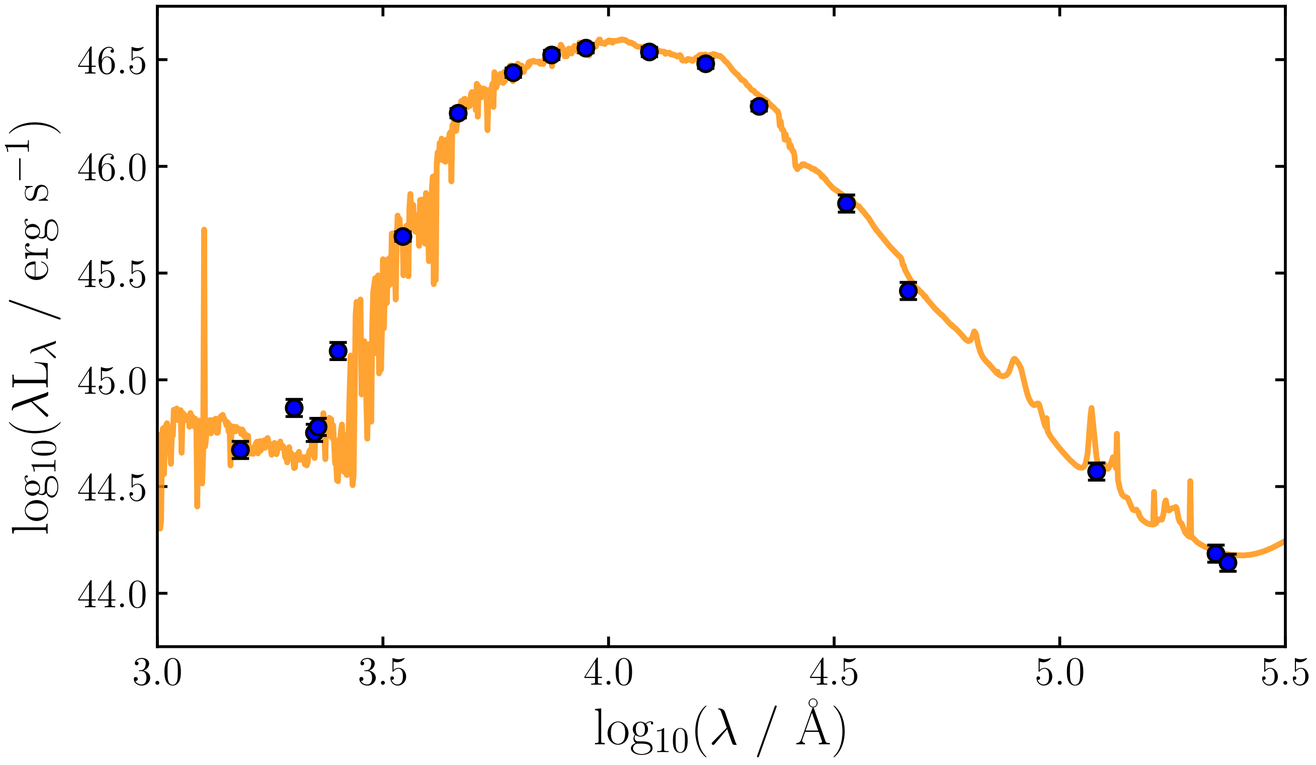
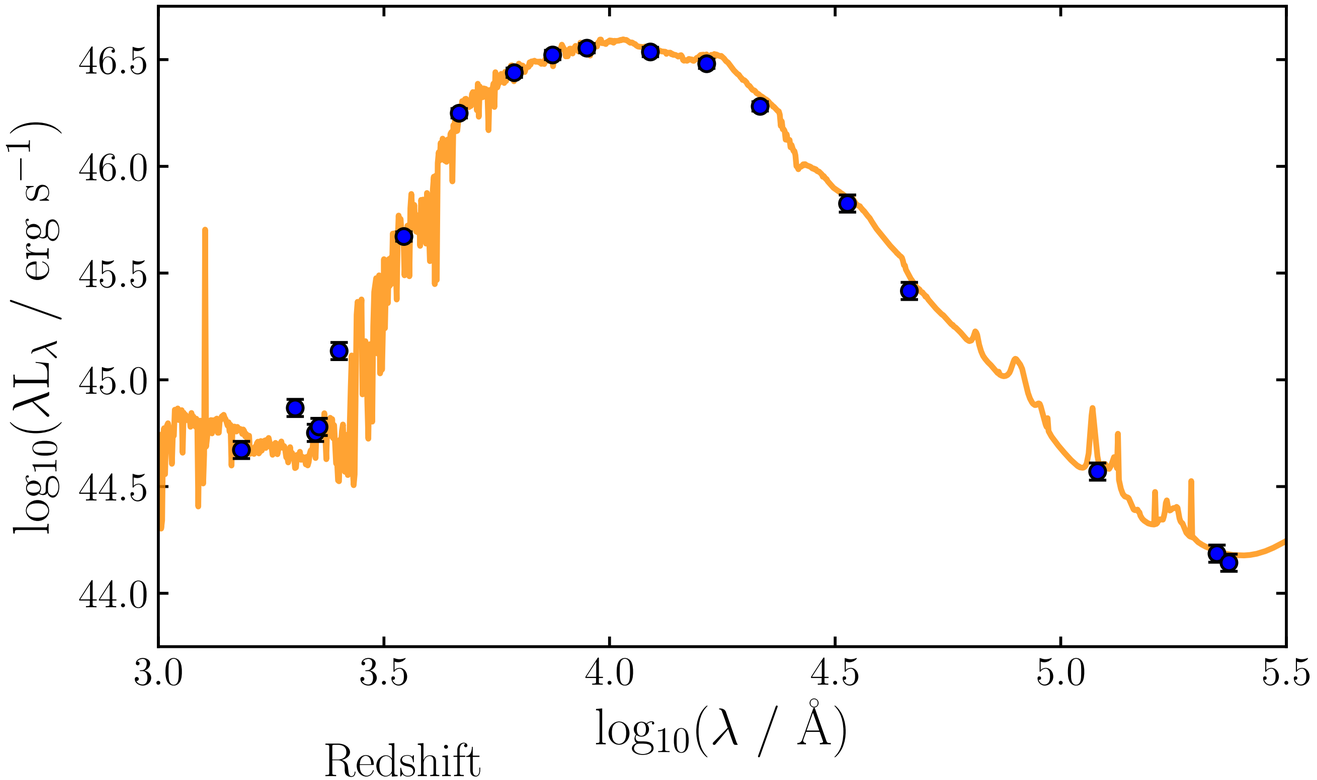
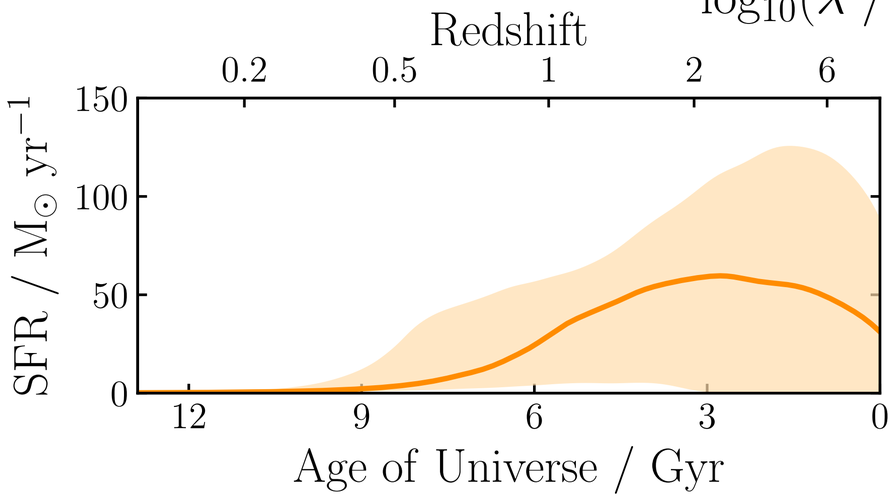


Messier 87

Aged ?? Years

The Ages of Massive Galaxies



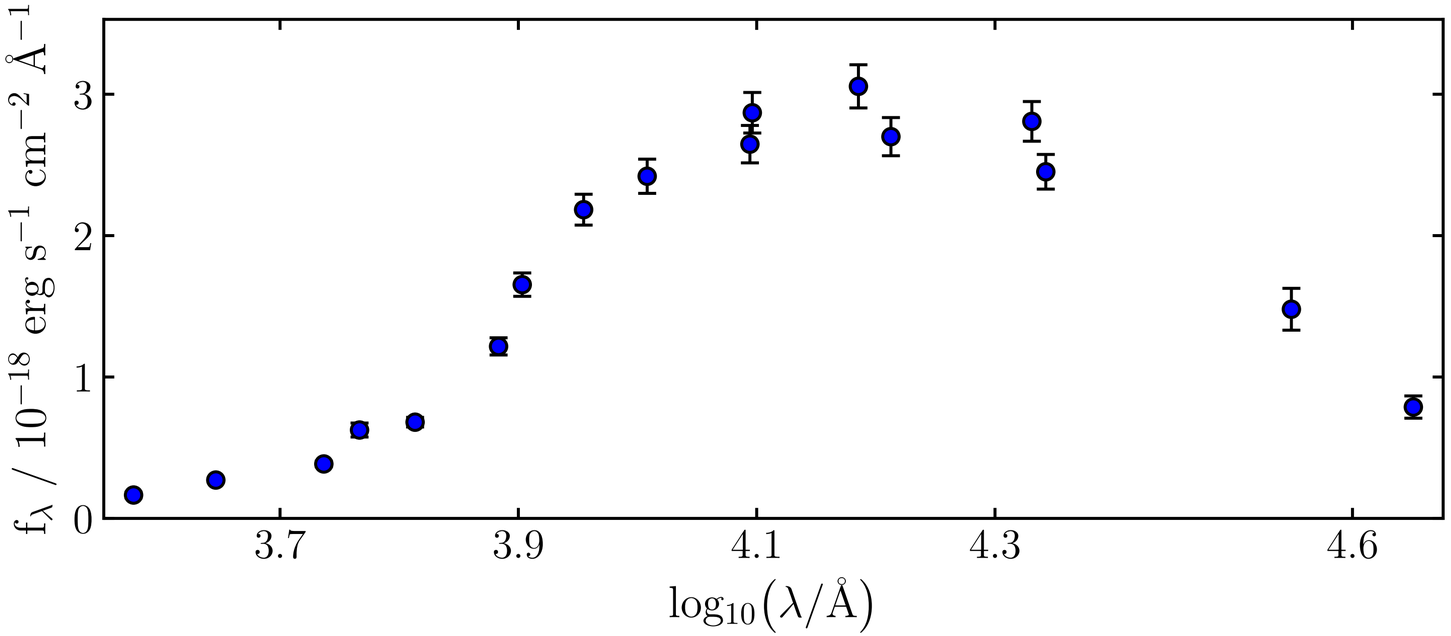


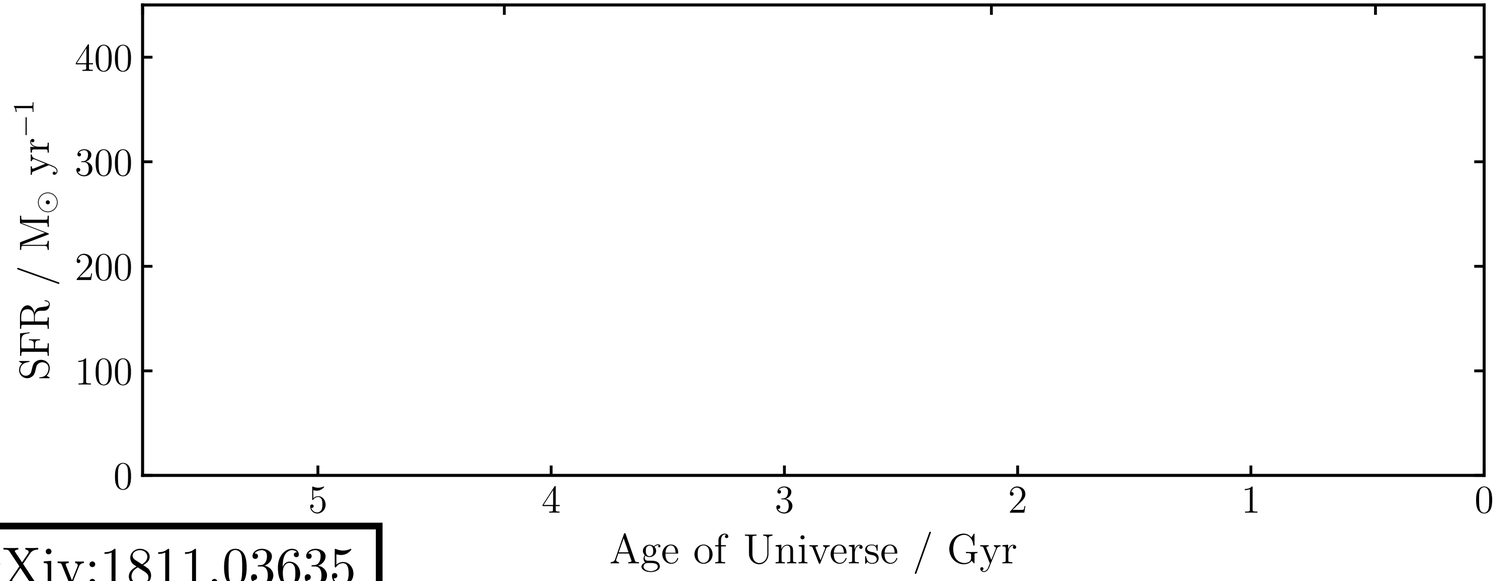
$$z_{\rm form} = 1.7^{+1.1}_{-0.7}$$

Messier 87

Aged $9.6^{+1.5}_{-2.0}$ *Gyr*

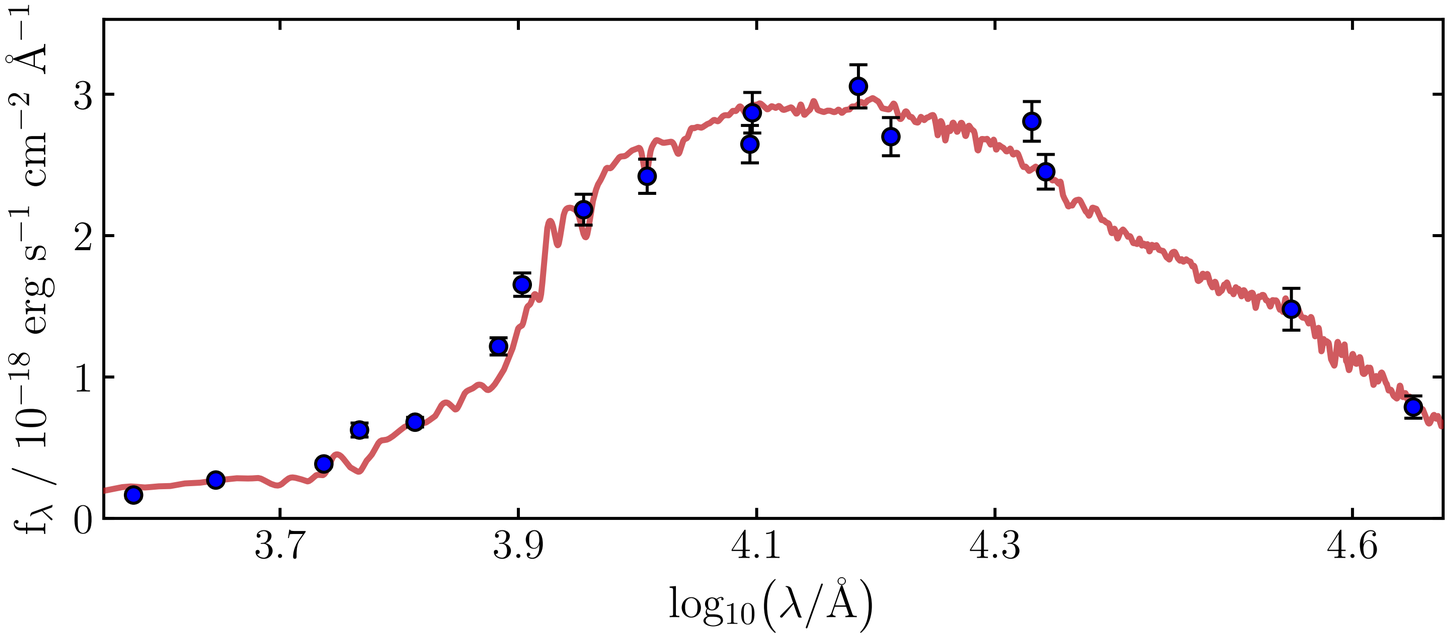
Problems with Photometry

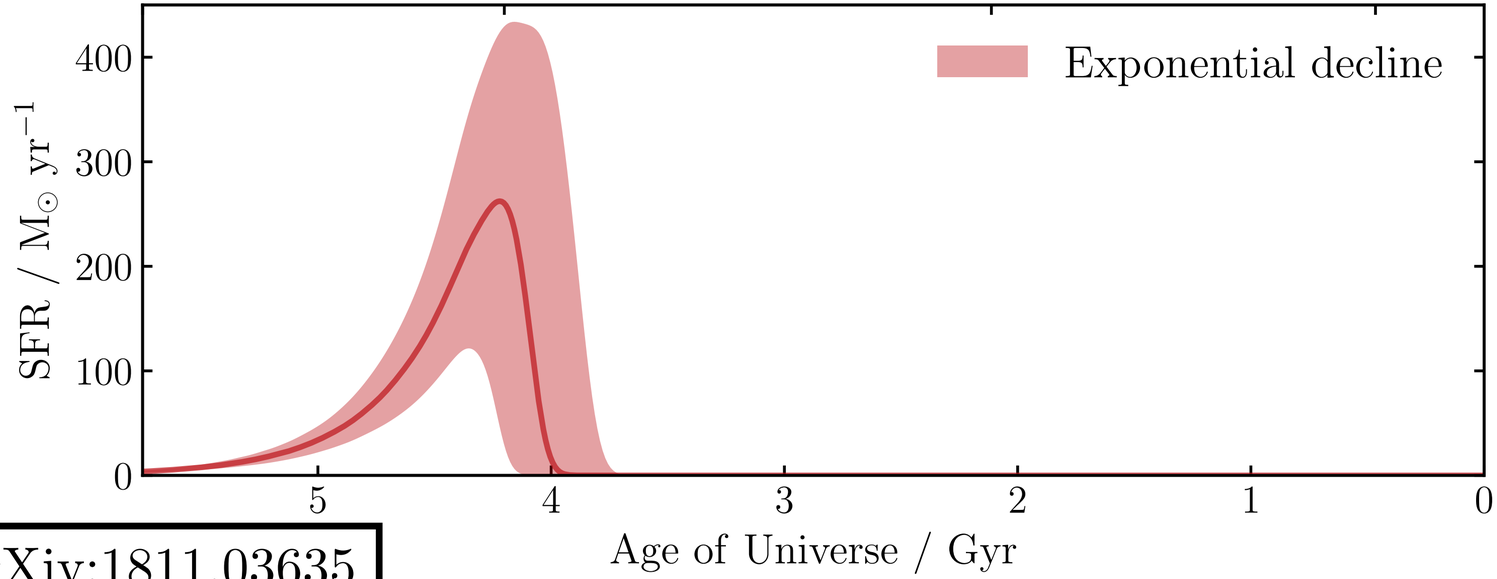




arXiv:1811.03635

Problems with Photometry





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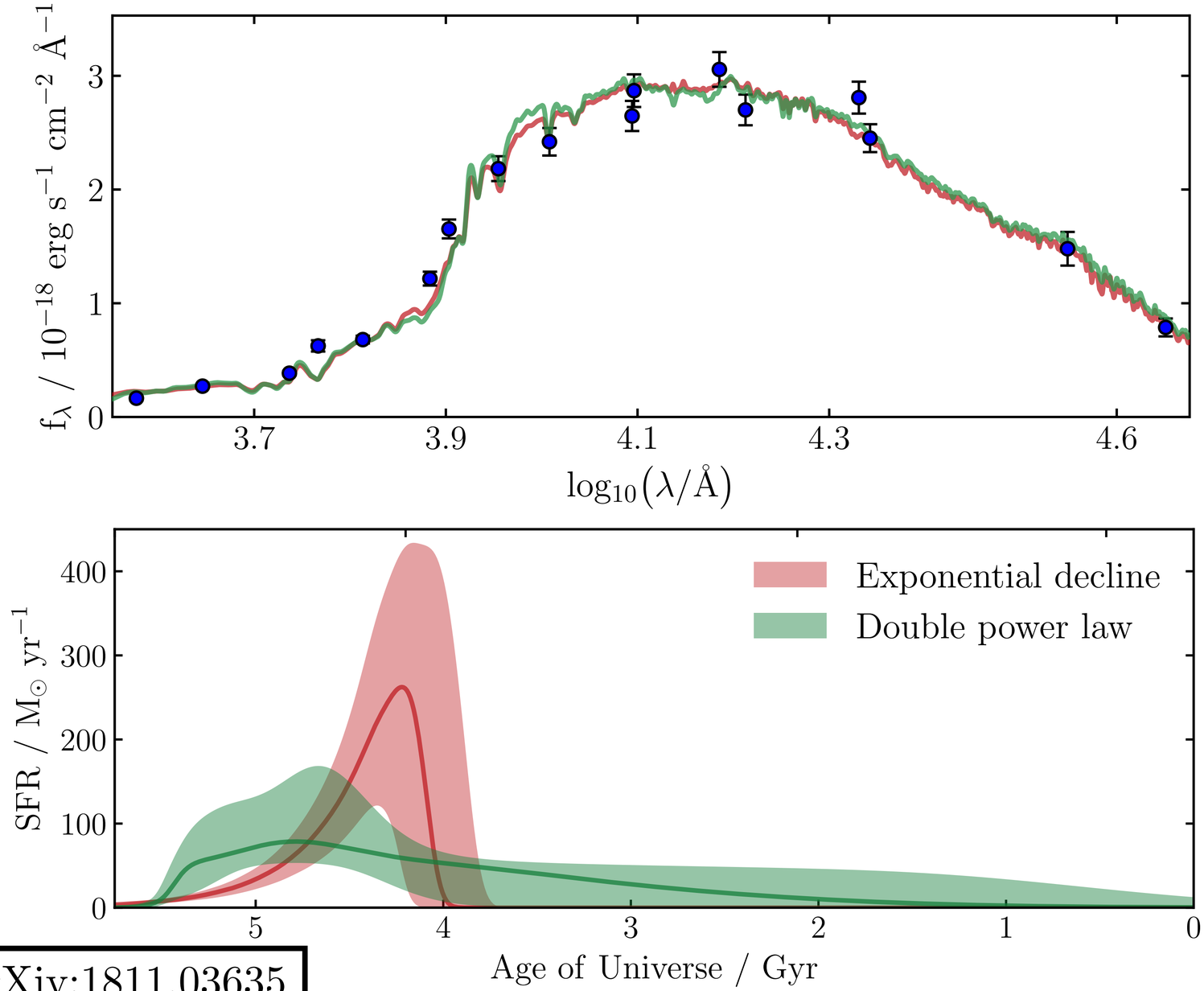

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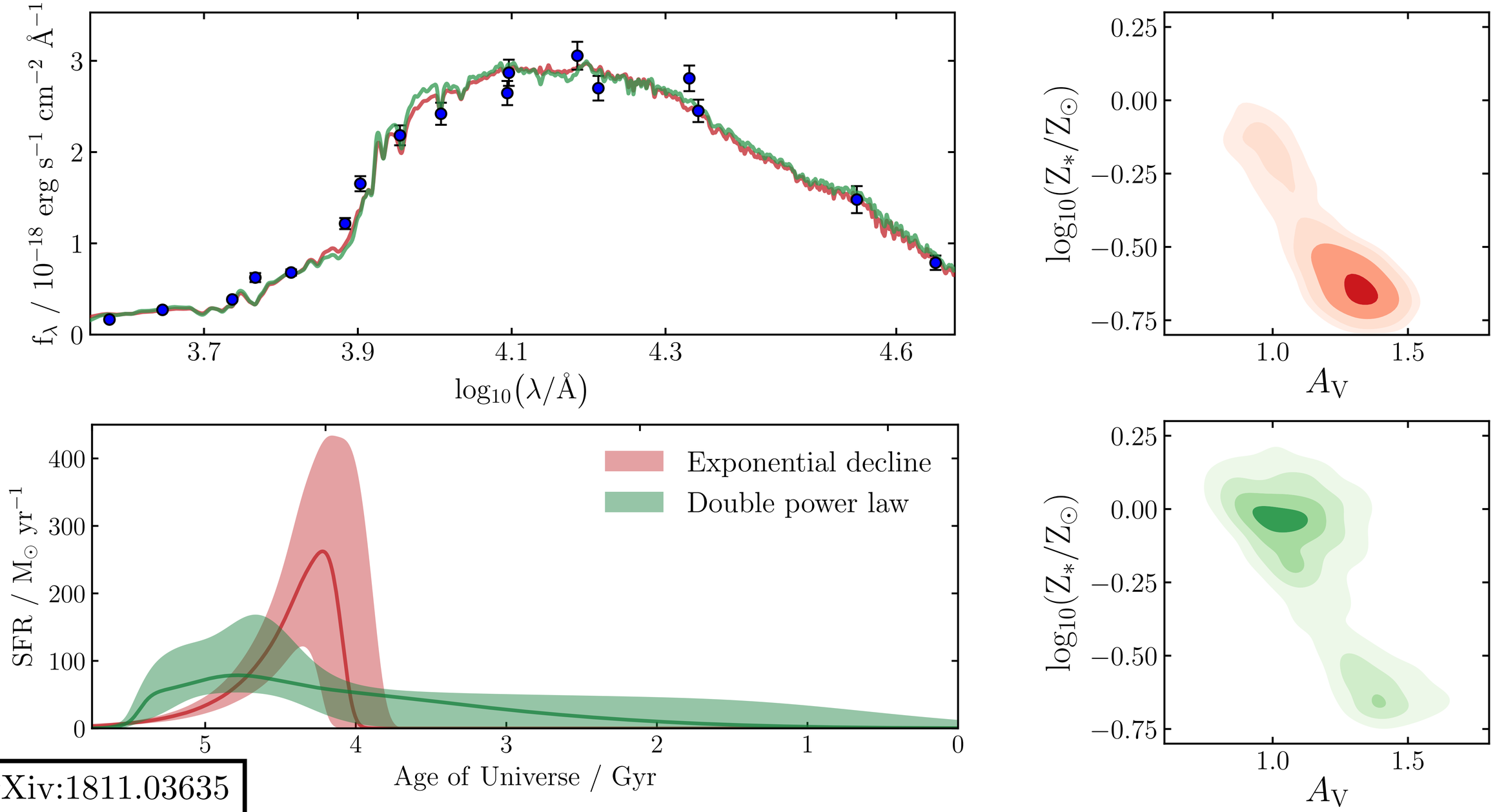

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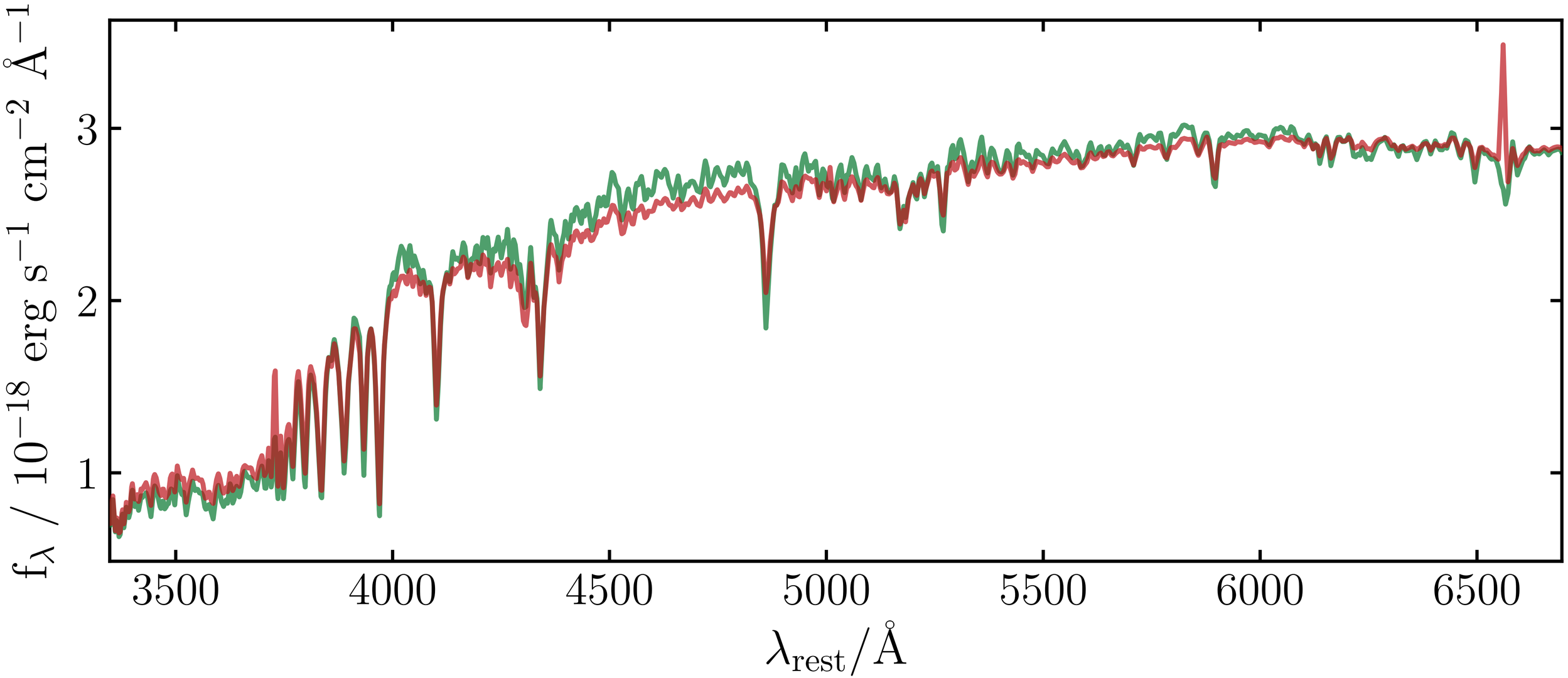
Solutions with Spectroscopy



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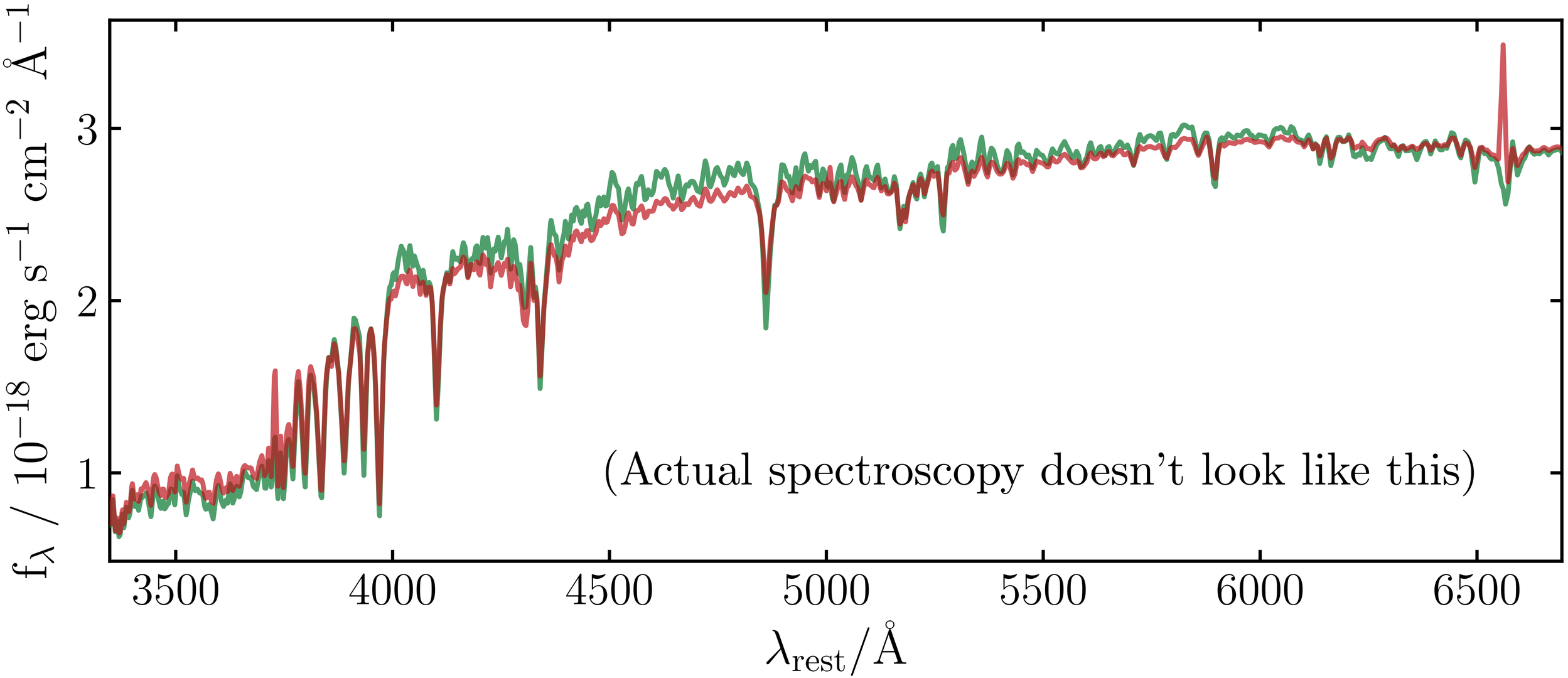


VANDELS

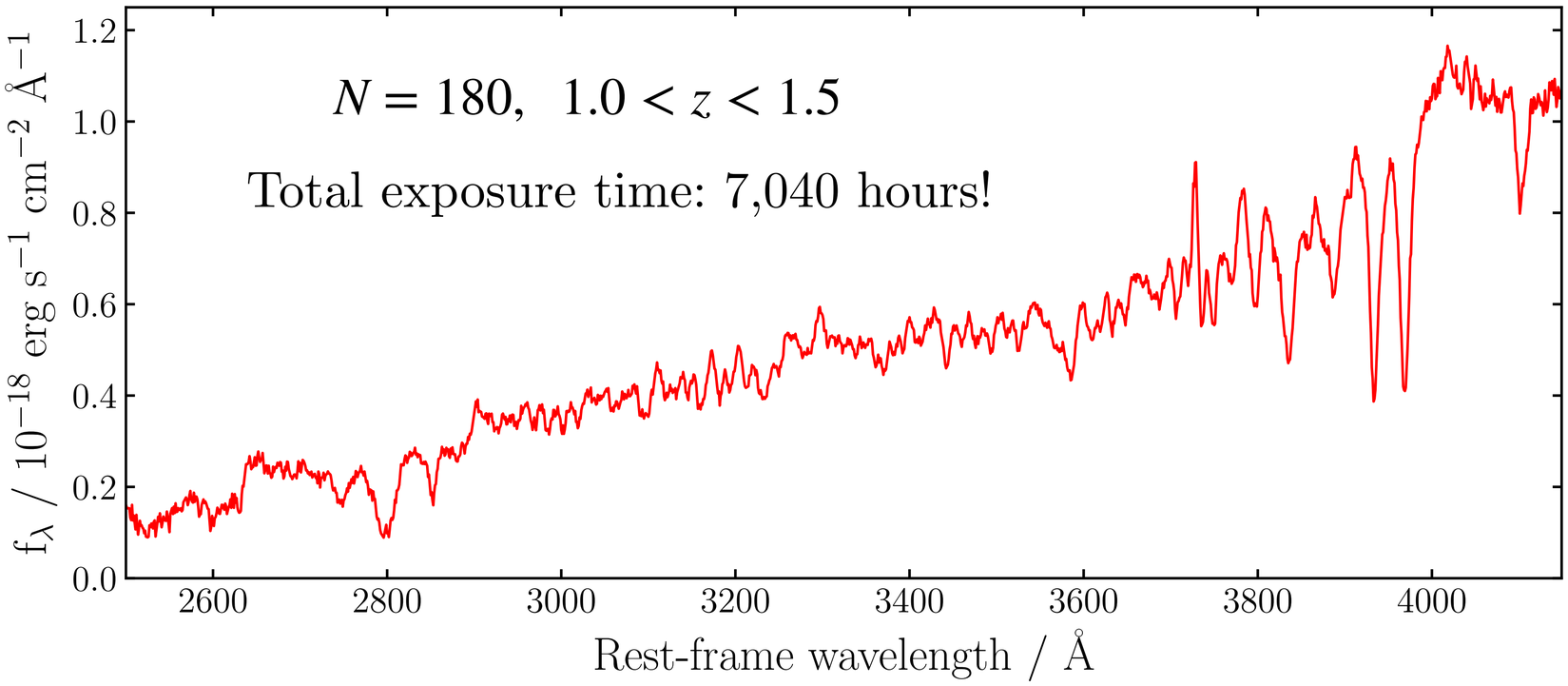
ESO VIMOS public spectroscopic survey of UDS and CDFS

2100 galaxies with average integration time of 45 hours

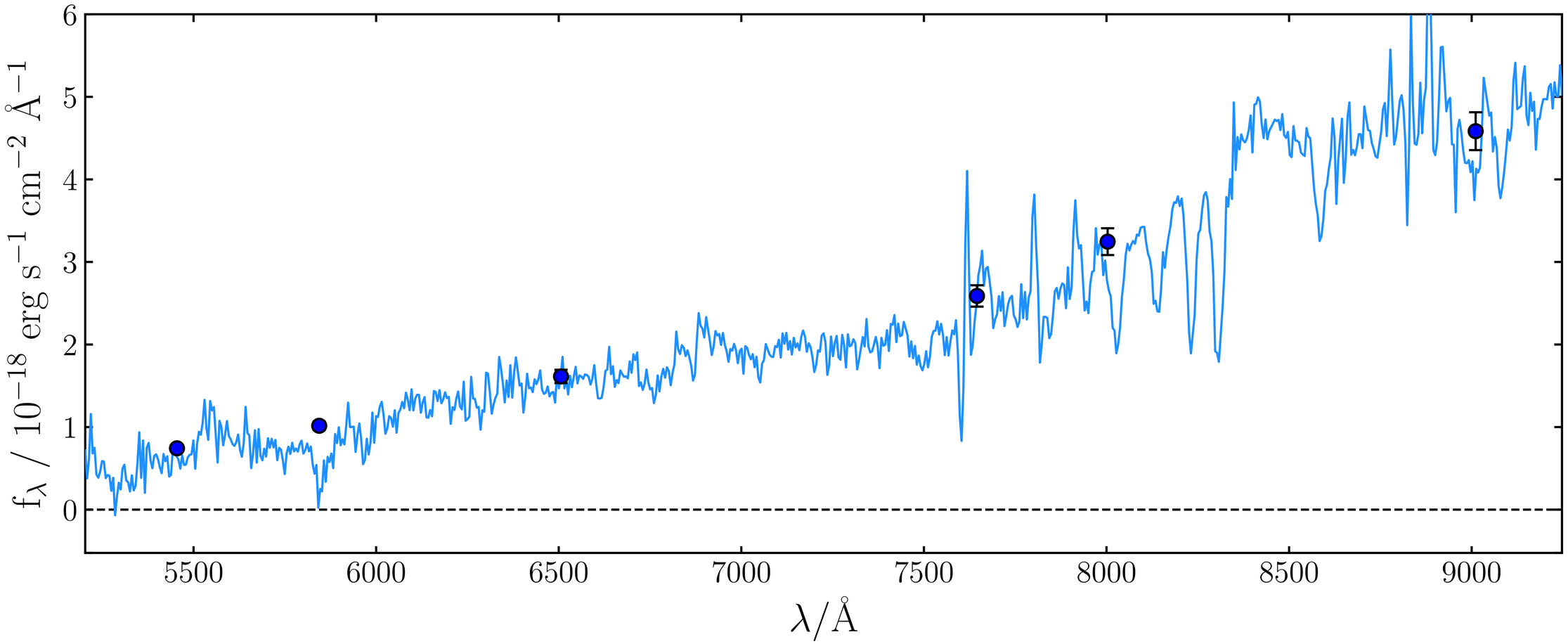
High-SNR spectroscopy for physical parameter recovery

McLure et al. (2018)
Pentericci et al. (2018)
https://vandels.inaf.it
DR3 released Nov 2019

13 per cent (268) are massive quiescent galaxies at $1.0 < z < 2.5$



Combining Spectroscopy with Photometry



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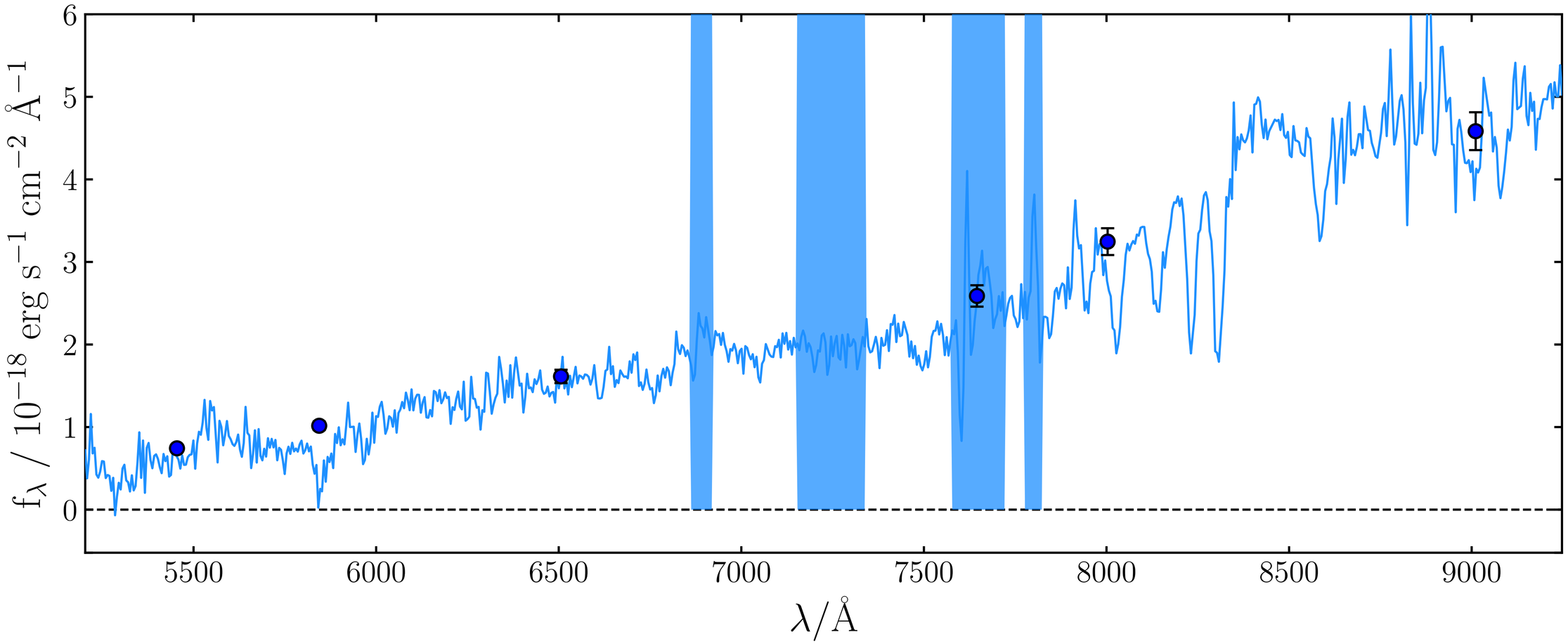

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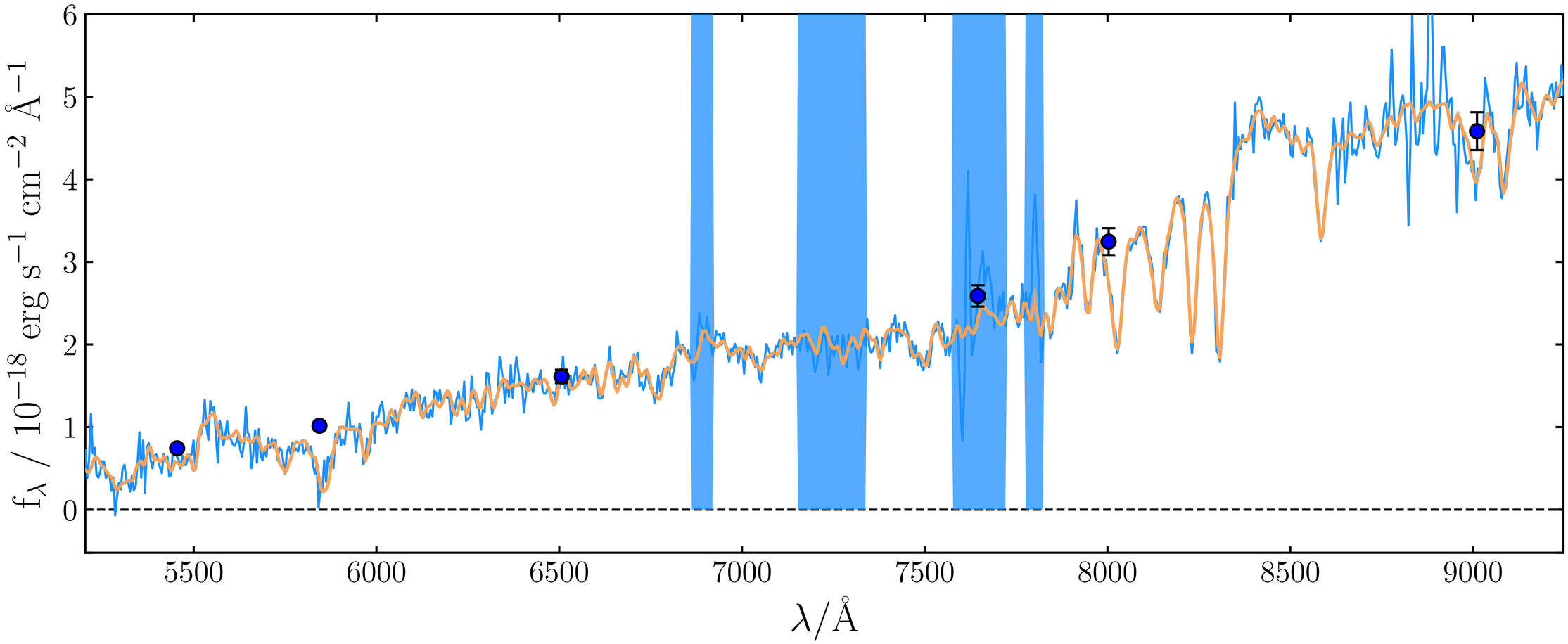

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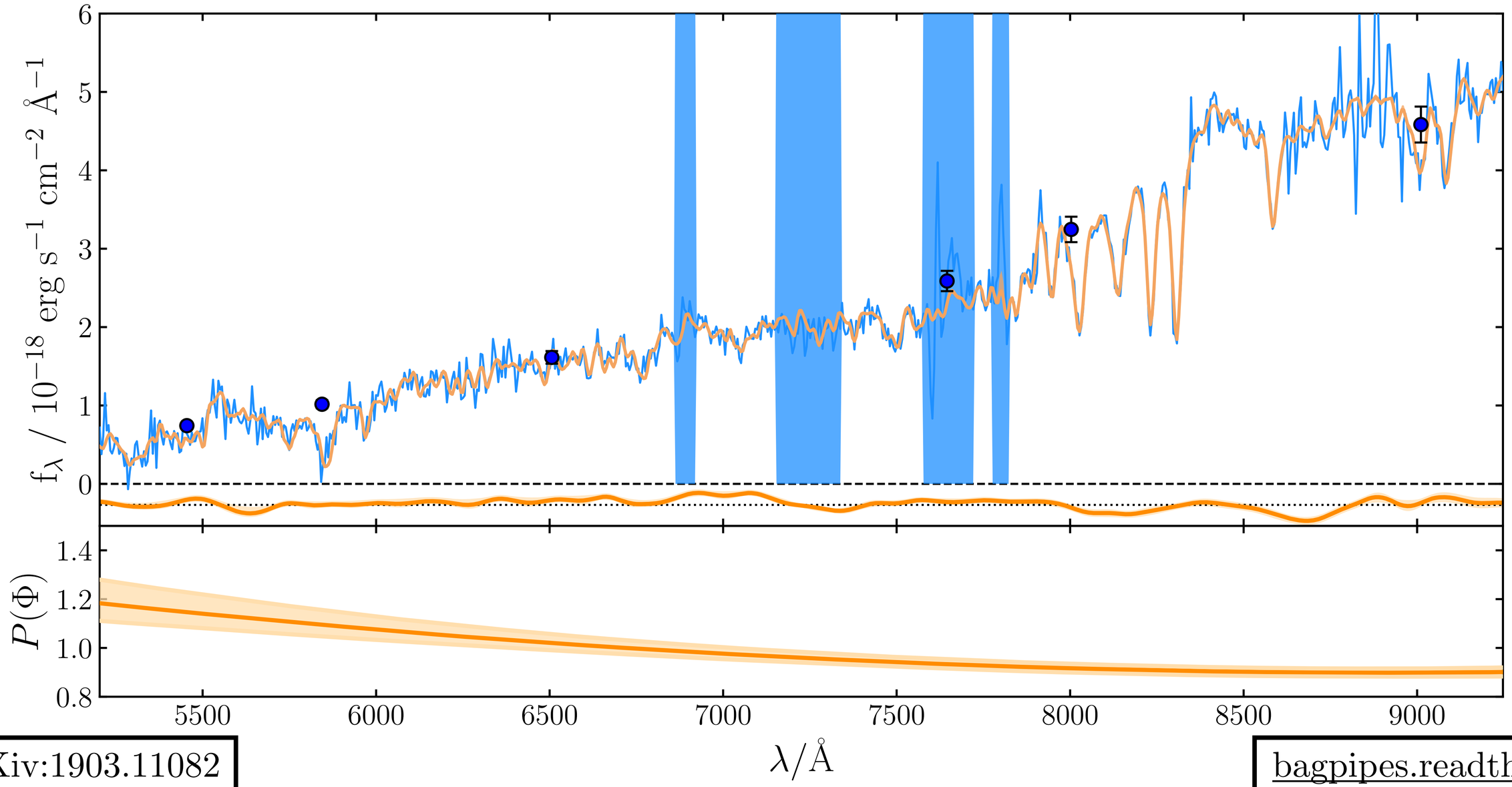

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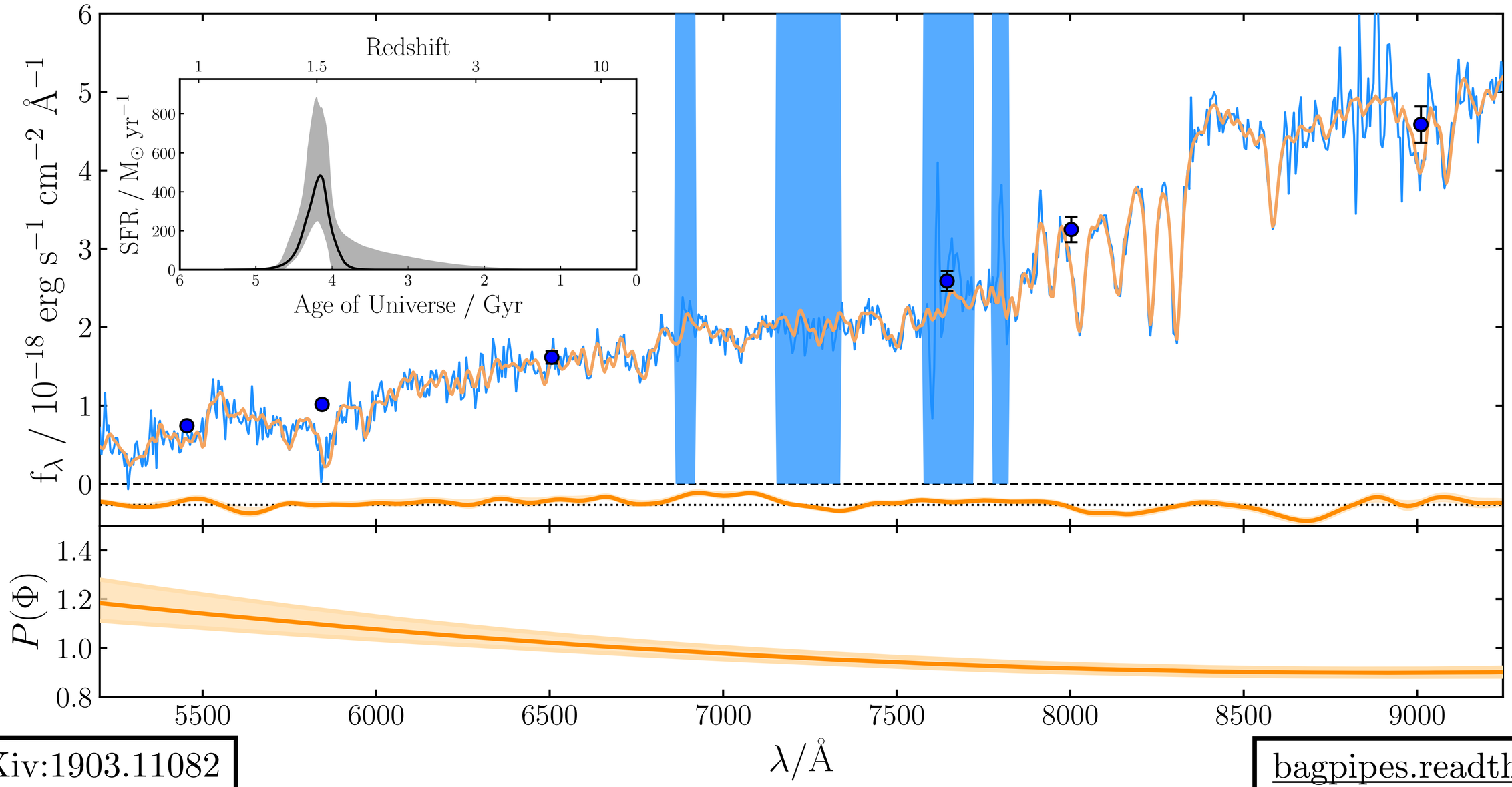

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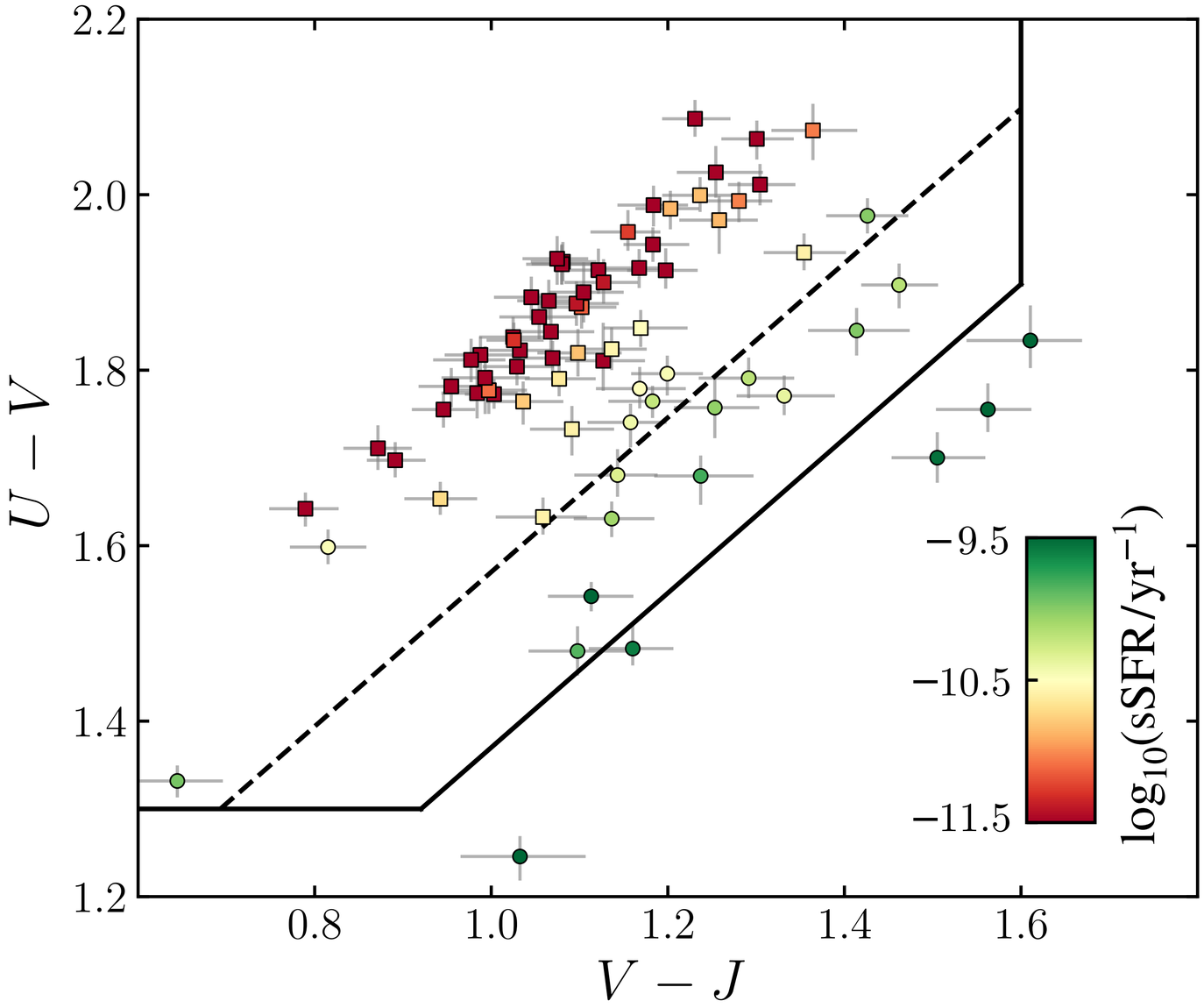
Trends with UVJ Colours



$1.0 < z < 1.3$

$M_* > 10^{10.3}\,\mathrm{M}_\odot$

arXiv:1903.11082

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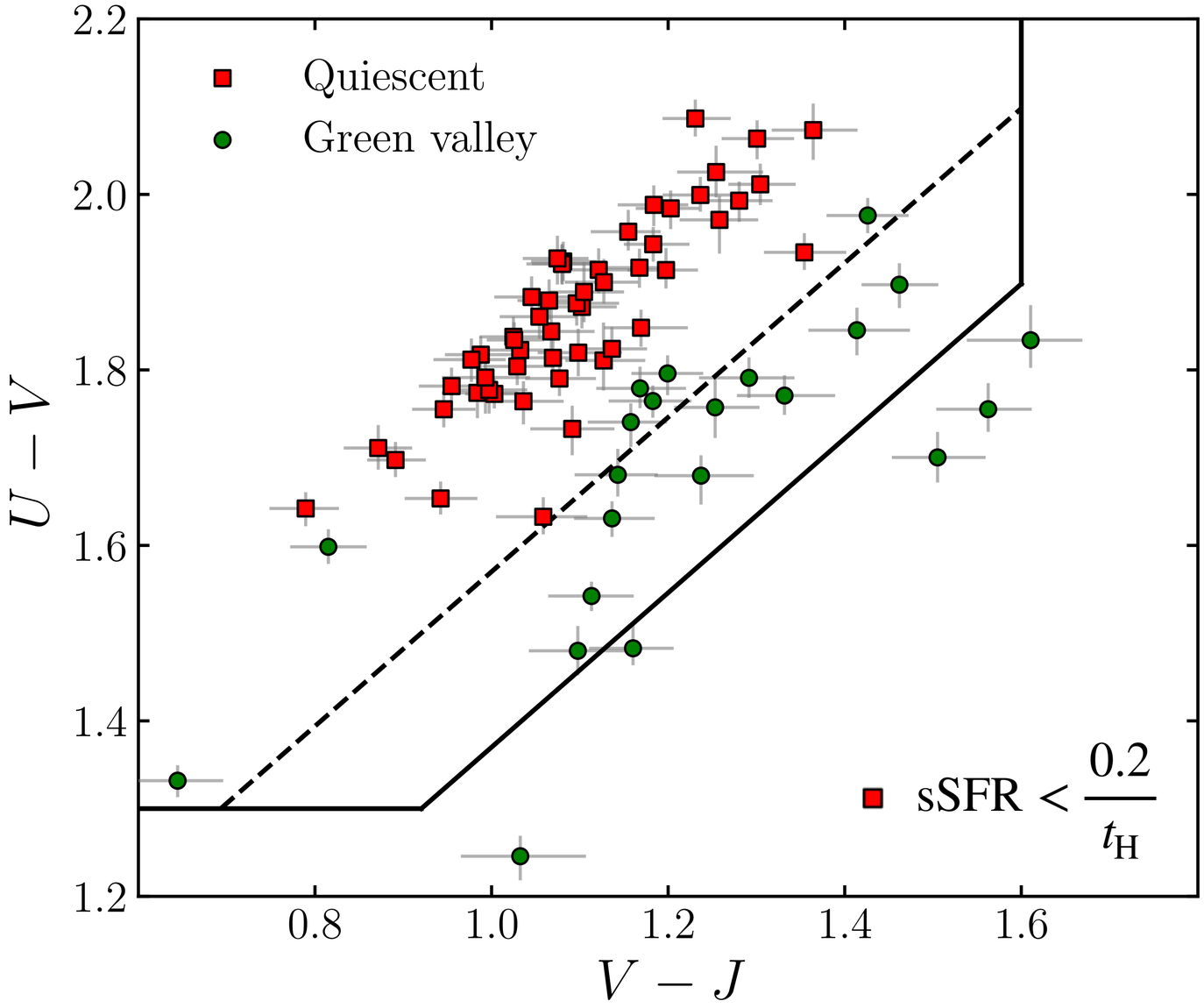
Trends with UVJ Colours



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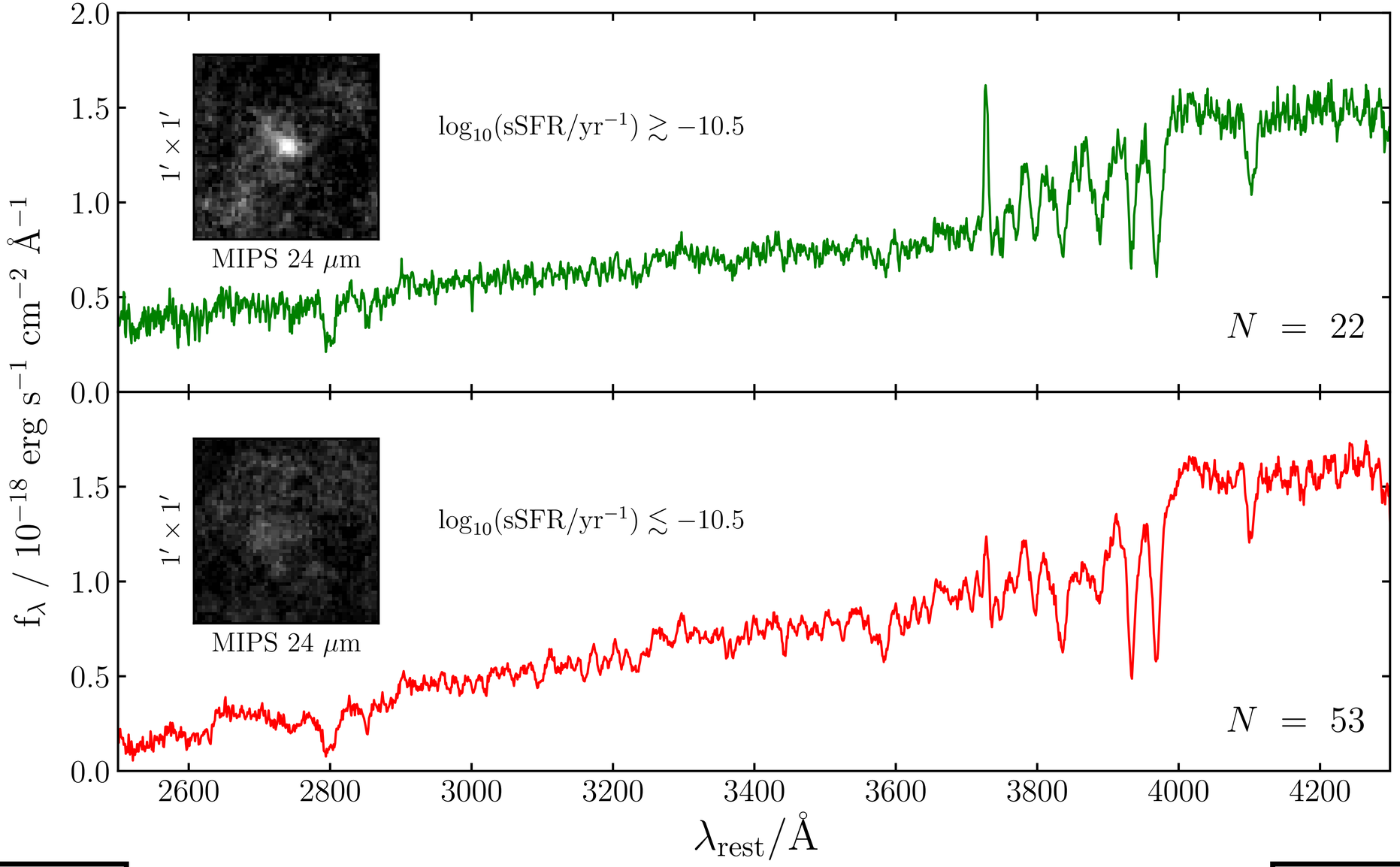

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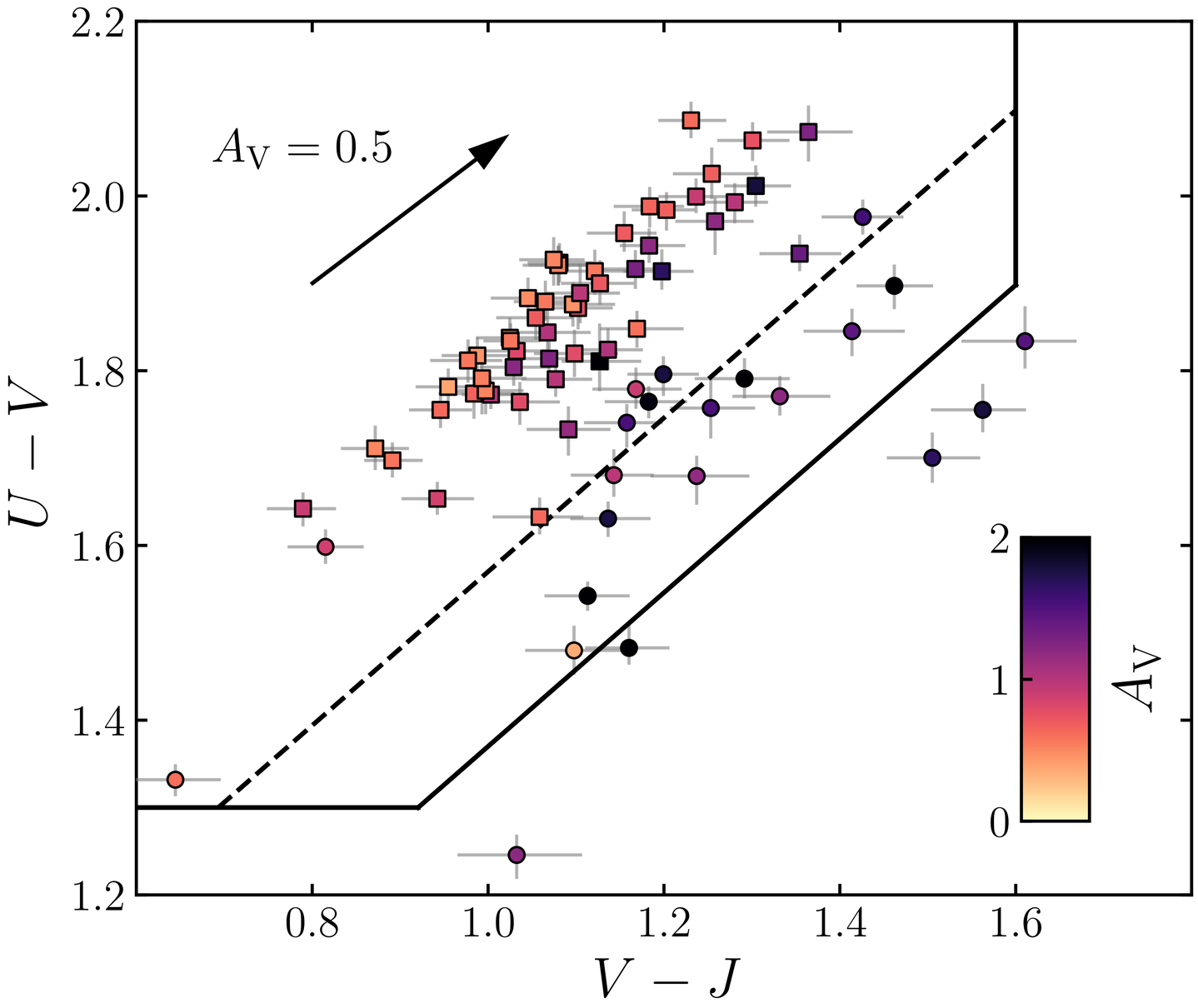

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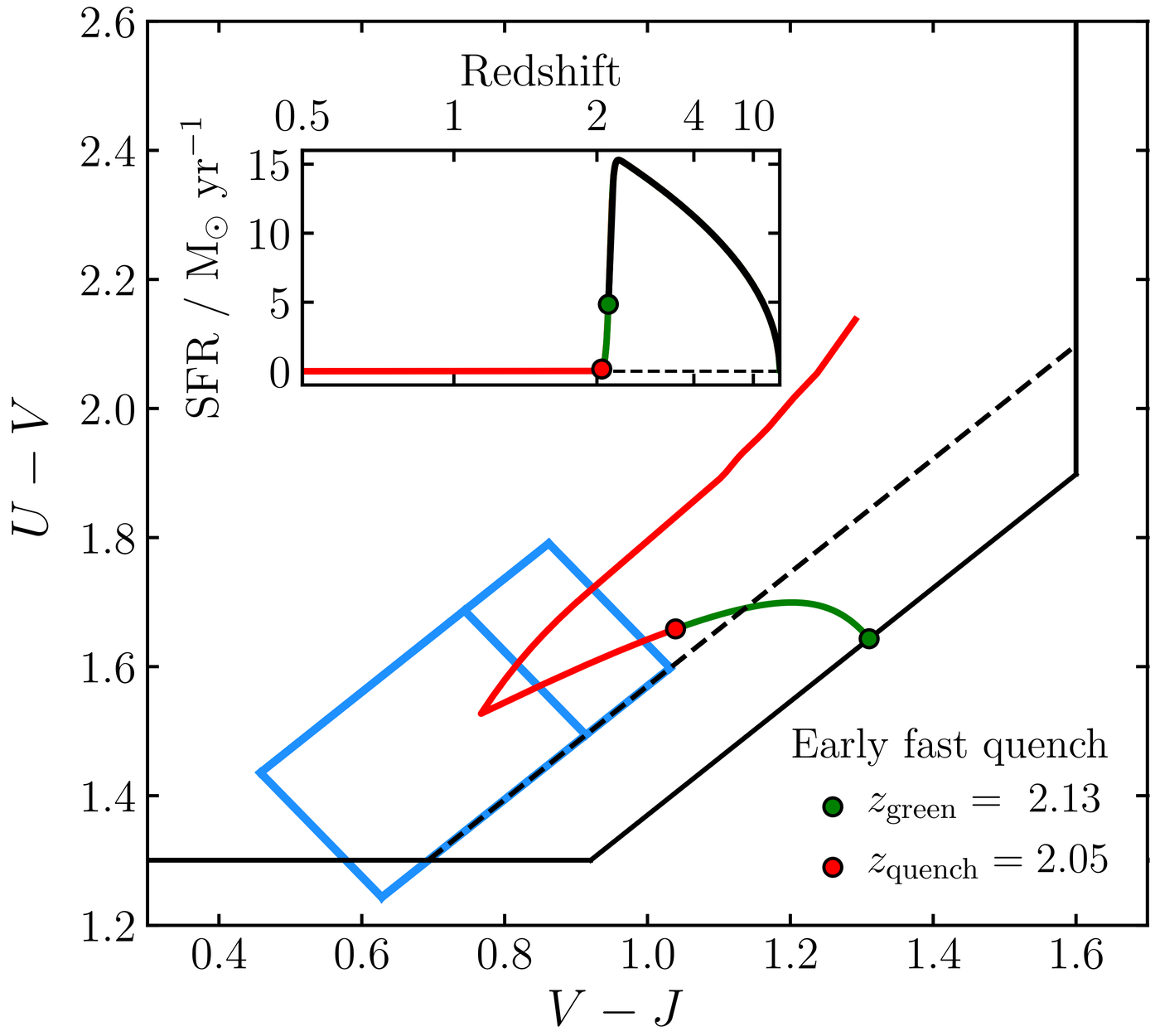
Time Evolution of UVJ Colours



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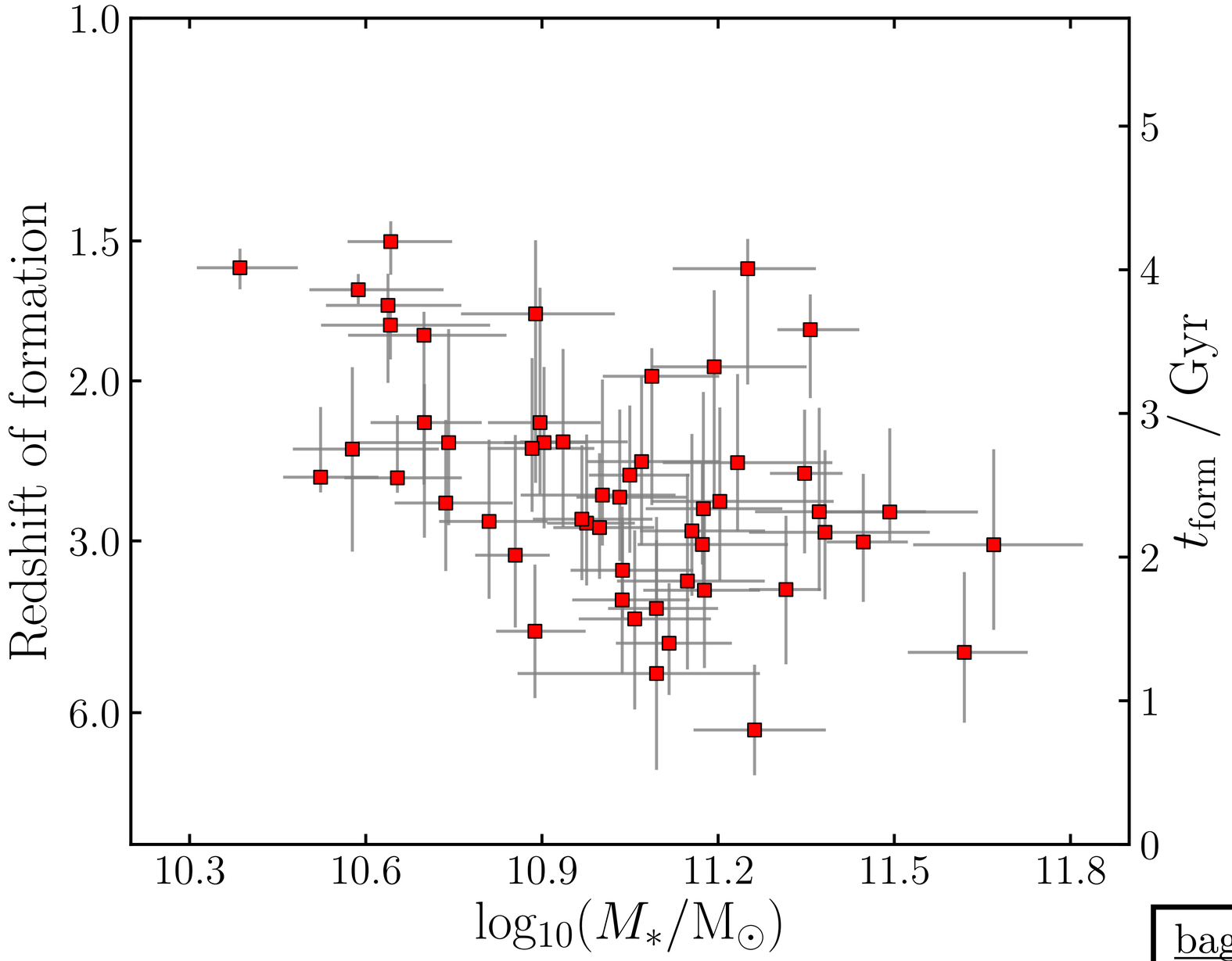
Formation Redshifts



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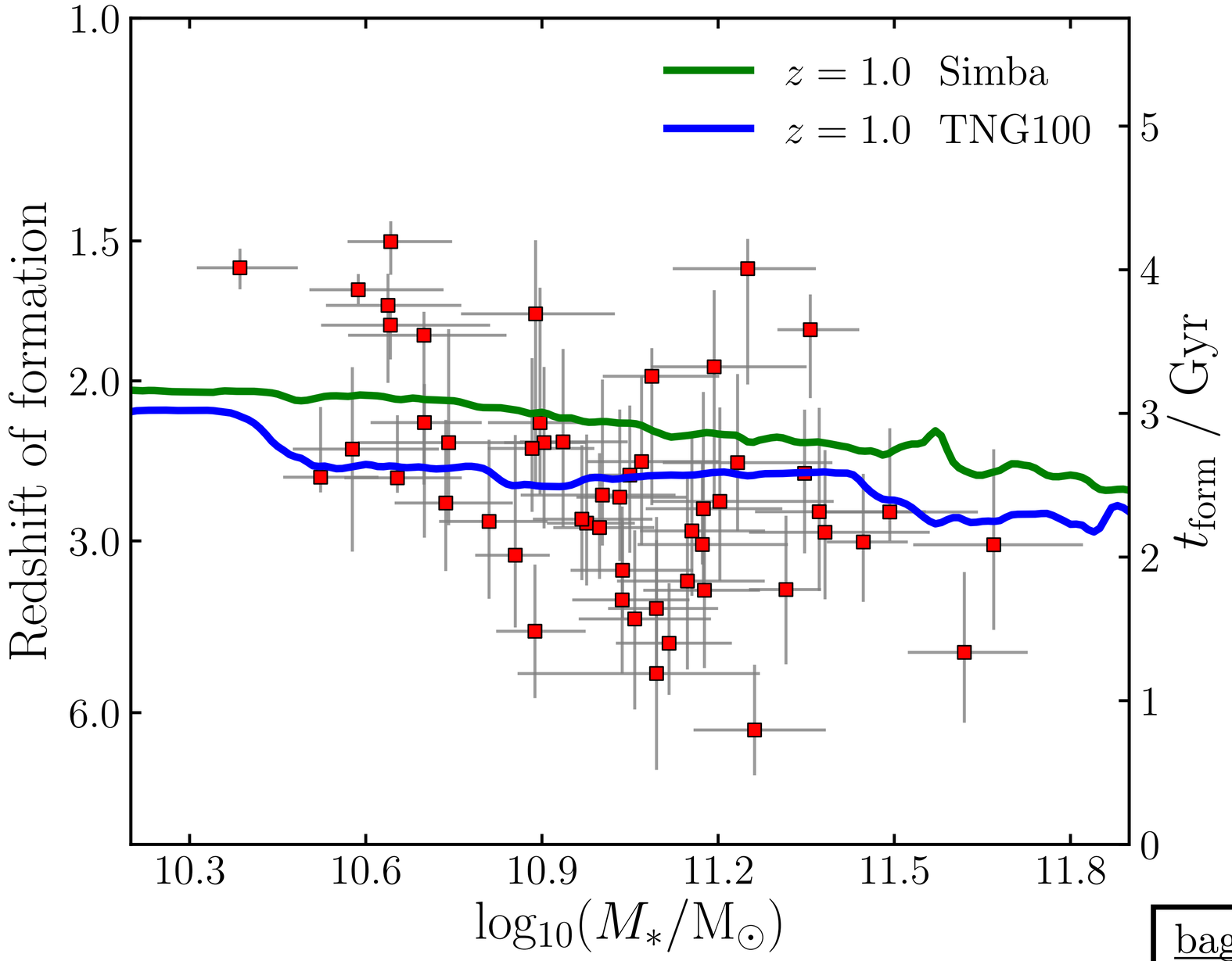

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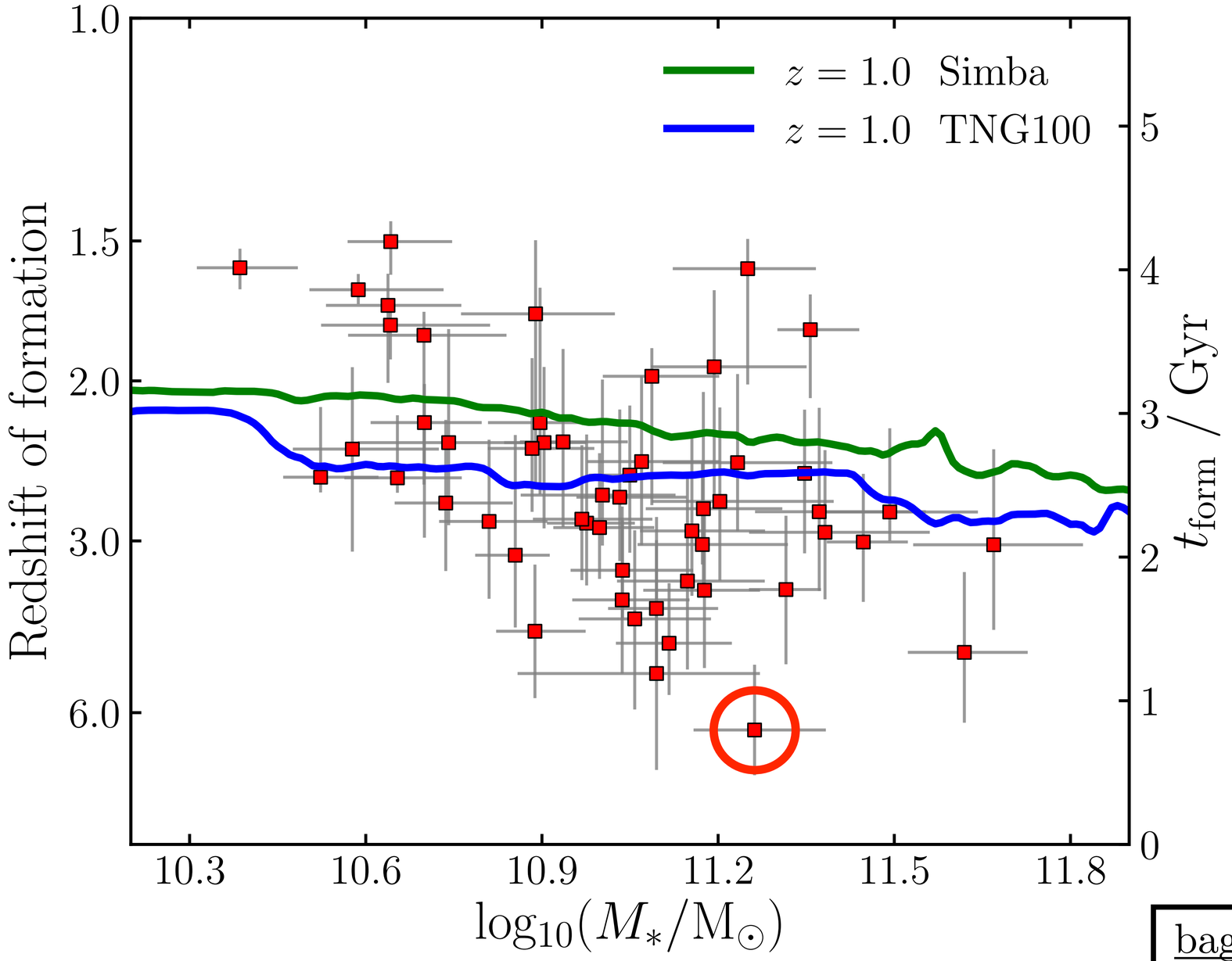

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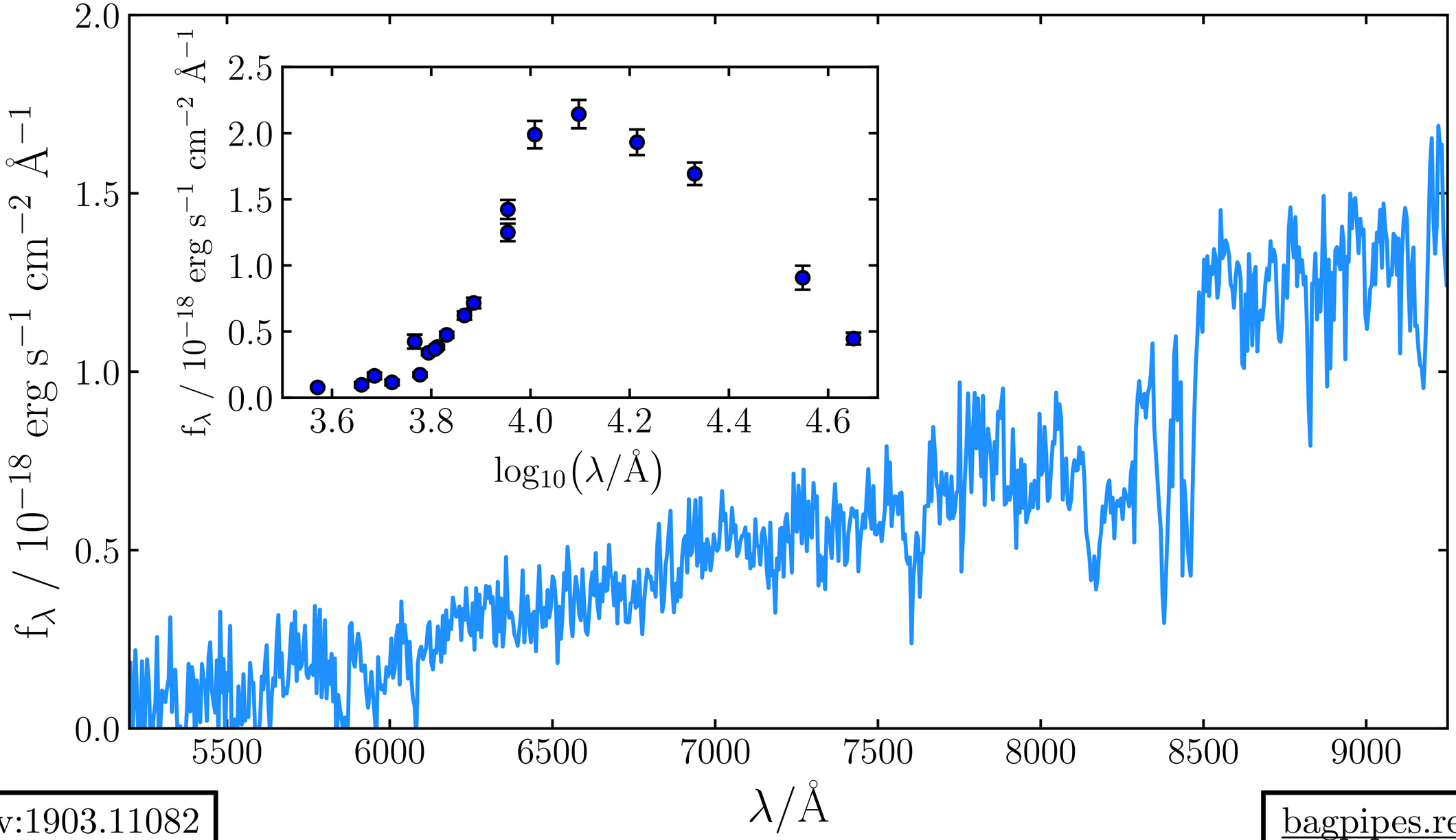
The Oldest Galaxies at $z=1$



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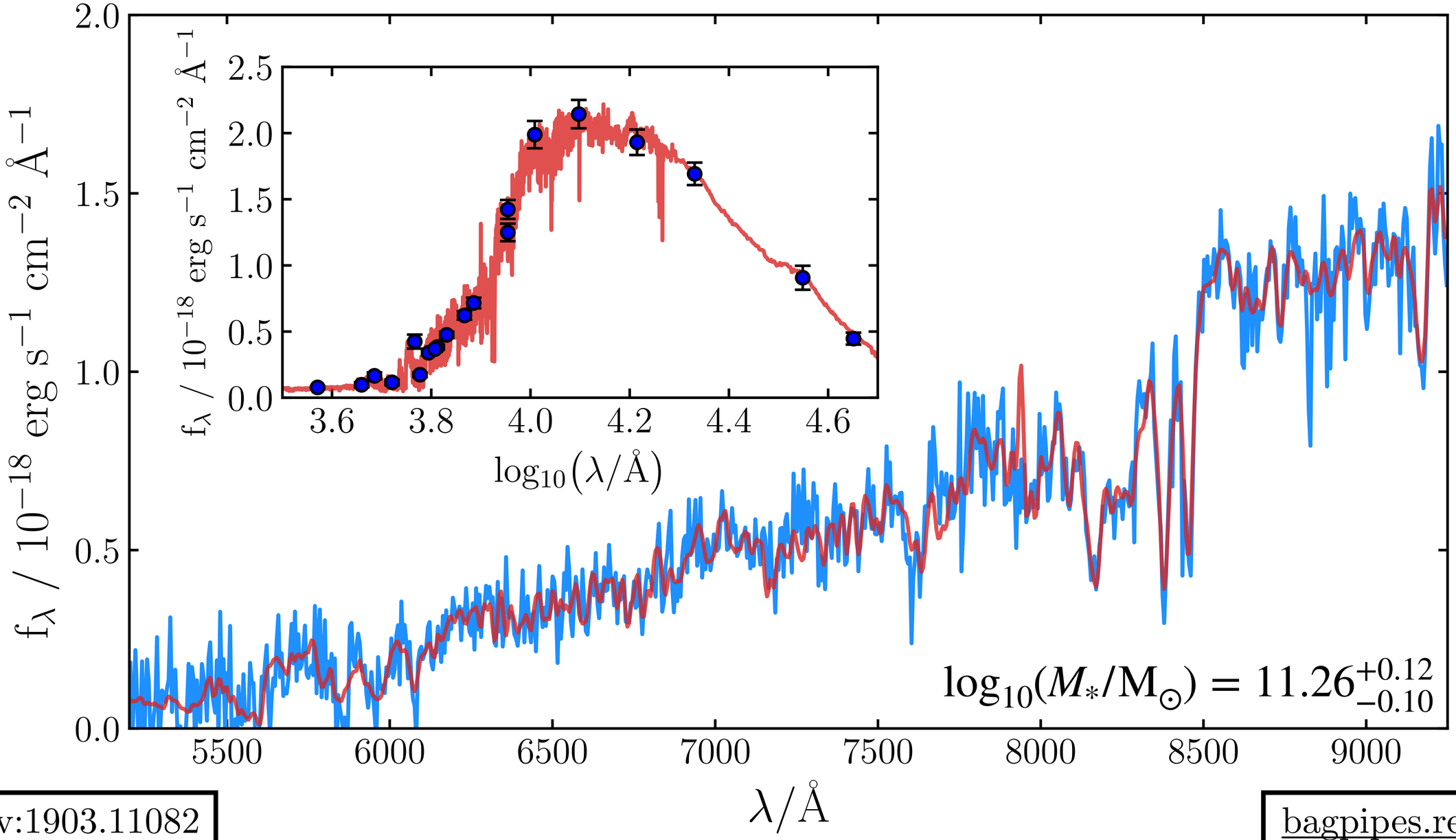

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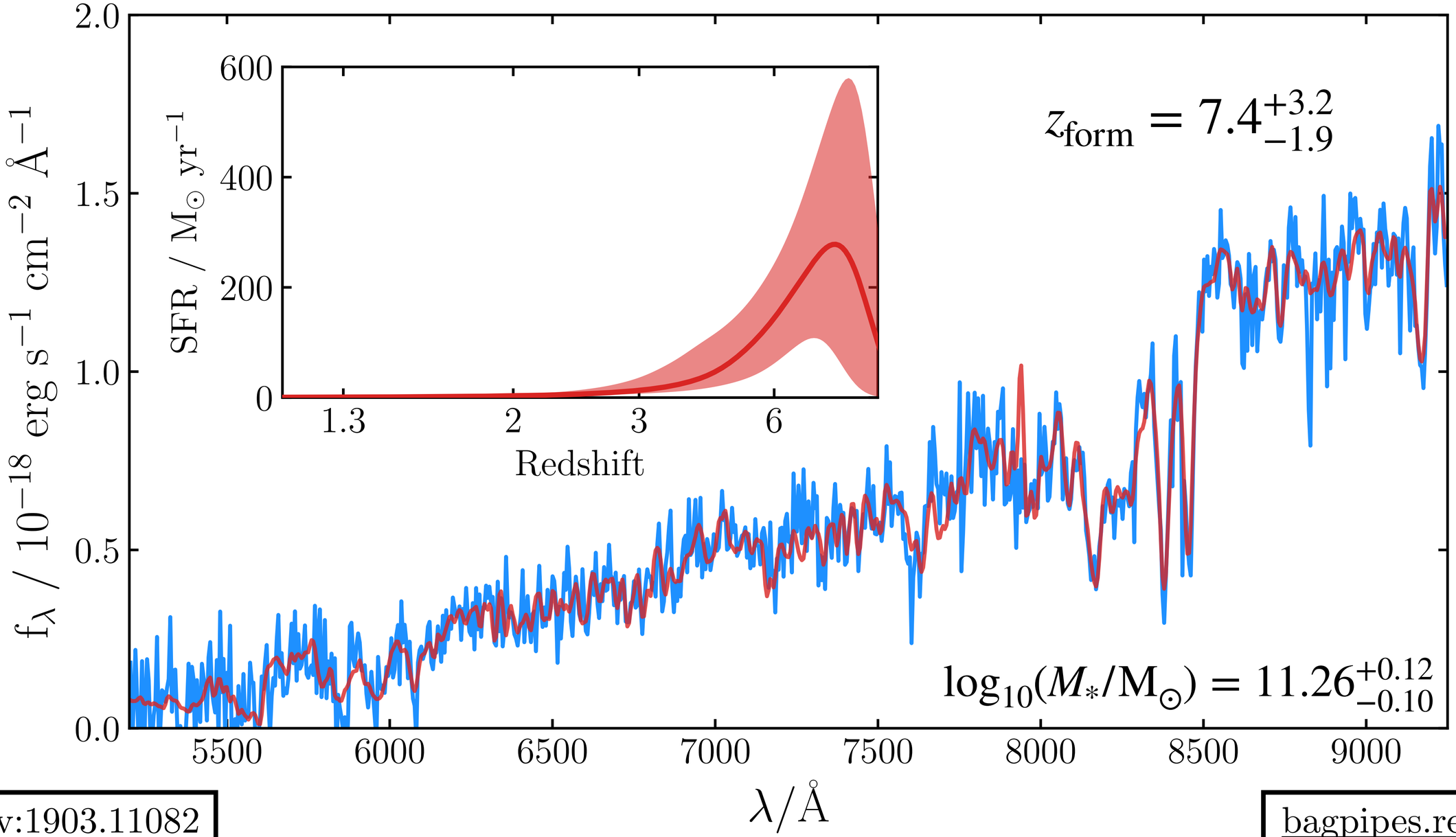

arXiv:1903.11082

bagpipes.readthedocs.io

The Oldest Galaxies at $z=1$

LETTERS TO NATURE

A 3.5-Gyr-old galaxy at redshift 1.55

James Dunlop*, John Peacock†, Hyron Spinrad‡, Arjun Dey§, Raul Jimenez†, Daniel Stern‡ & Rogier Windhorst||

* Institute for Astronomy, Department of Physics and Astronomy, The University of Edinburgh, Edinburgh EH9 3HJ, UK
† Royal Observatory, Edinburgh EH9 3HJ, UK
‡ Astronomy Department, University of California, Berkeley, California 94720, USA
§ NOAO/KPNO, 950 North Cherry Avenue, Tucson, Arizona 85726, USA
|| Department of Physics and Astronomy, Arizona State University, Tempe, Arizona 85287-1504, USA

($J = 20.5 \pm 0.1$ mag, $H = 19.5 \pm 0.1$ mag; Fig. 1*a*) revealed that, if its red $R-K$ colour was in part due to a redshifted 4,000 Å break (the most prominent spectral feature displayed by an old stellar population at optical wavelengths), this feature must lie at observed wavelength $\lambda_{obs} < 1.2\,\mu$m, constraining the redshift to $z < 2$.

Finally, on 31 August and 1 September 1995 we re-observed 53W091 for a total of 4 hours, again with LRIS on the 10-m Keck Telescope (Fig. 1*b*). The spectrum produced by co-adding all 5.5 hours of integration is shown in Fig. 1*c*, plotted in the rest frame of the radio galaxy assuming $z = 1.552$. This unambiguous redshift was deduced from numerous absorption lines and two strong spectral breaks (at rest wavelength λ_{rest} =2,635 and 2,897 Å), features whose existence in the near-ultraviolet spectrum of the Sun and other low-mass dwarfs is long-established[19], and which are evident in the ultraviolet spectra of low-redshift ellipticals such as M32 (Fig. 1*c*). This is, to our knowledge, the first time that such a high galaxy redshift has been derived successfully from late-

Dunlop et al. (1996)

The Highest Redshift Quiescent Galaxies

Carnall et al. (2020): photometric selection and physical properties of $2 < z < 5$ massive quiescent galaxies

arXiv:2001.11975

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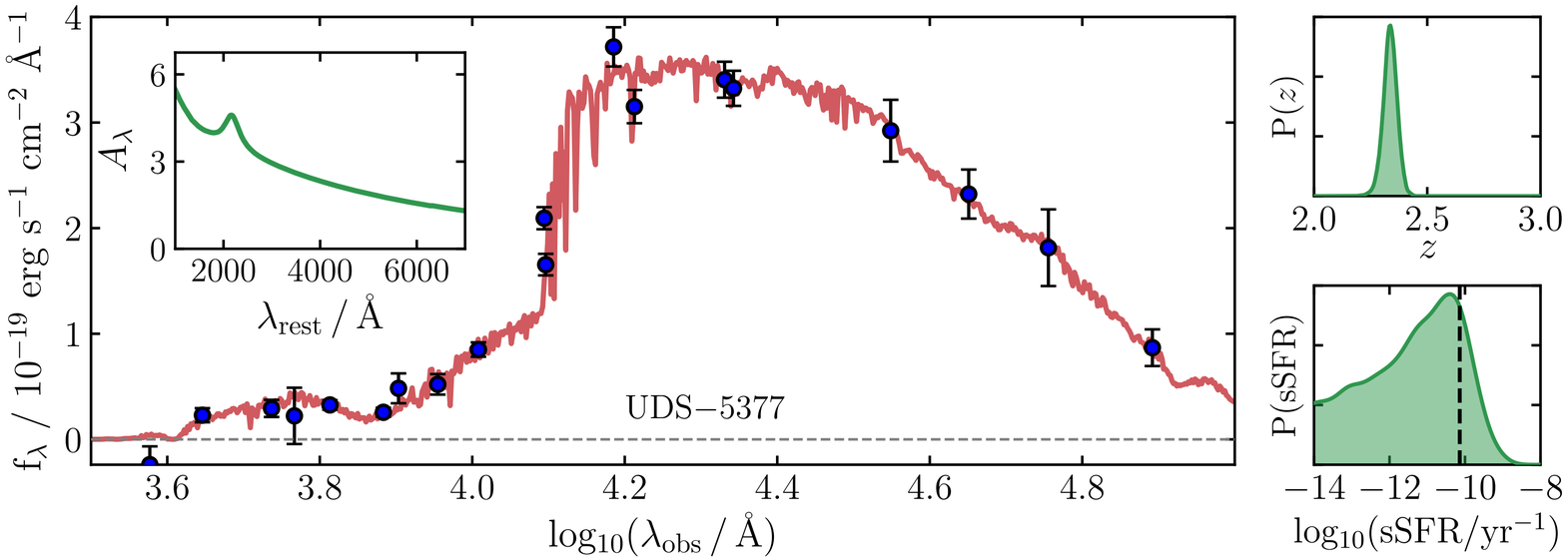

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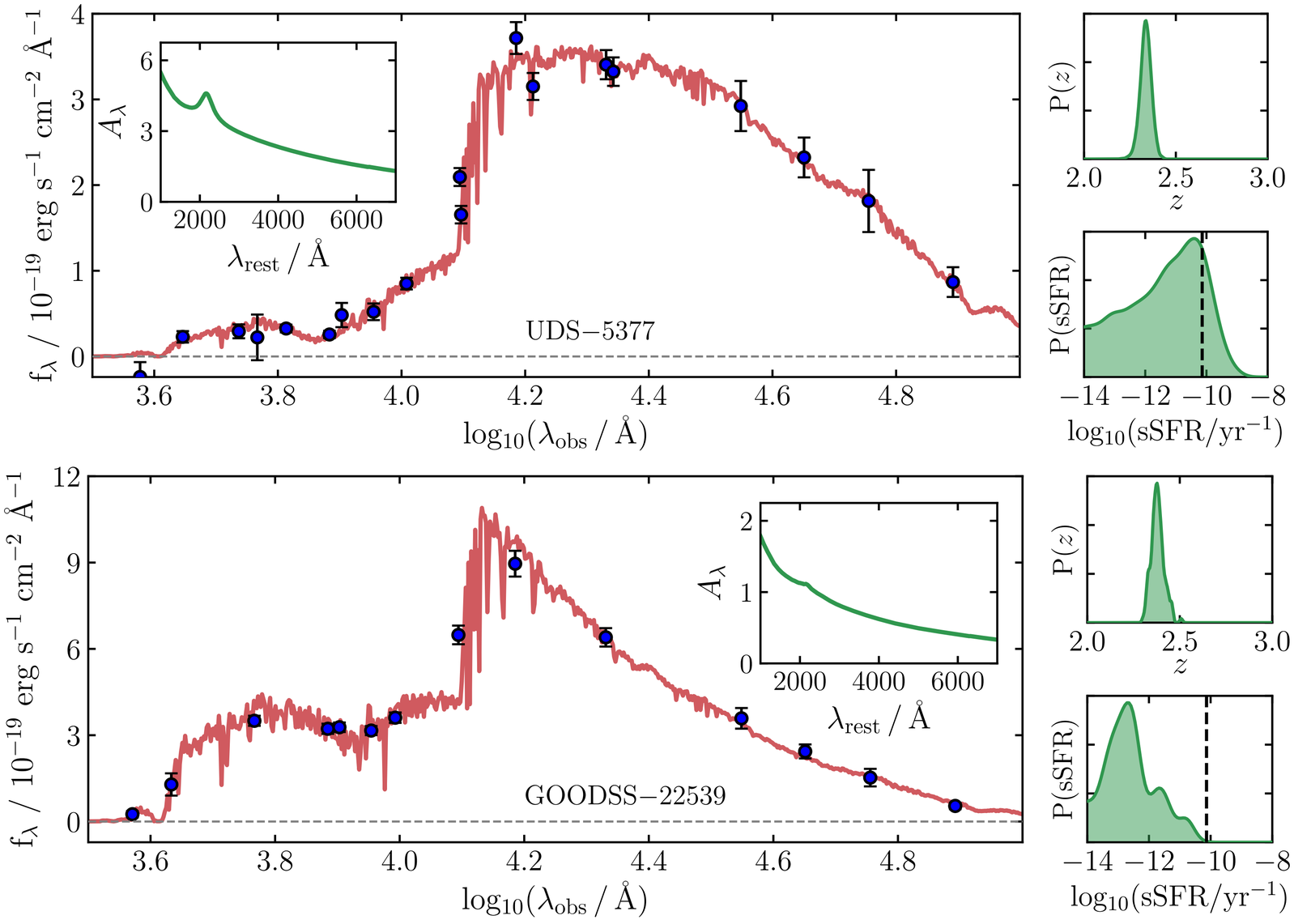

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The Highest Redshift Quiescent Galaxies

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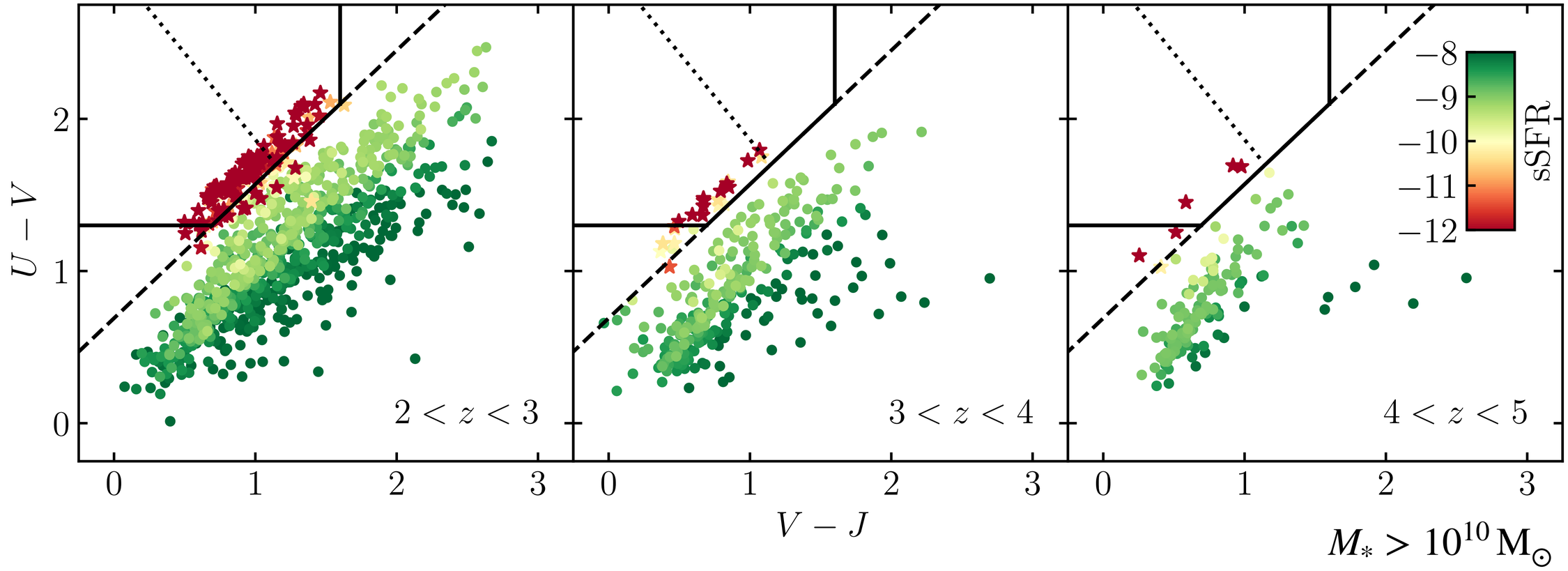

arXiv:2001.11975

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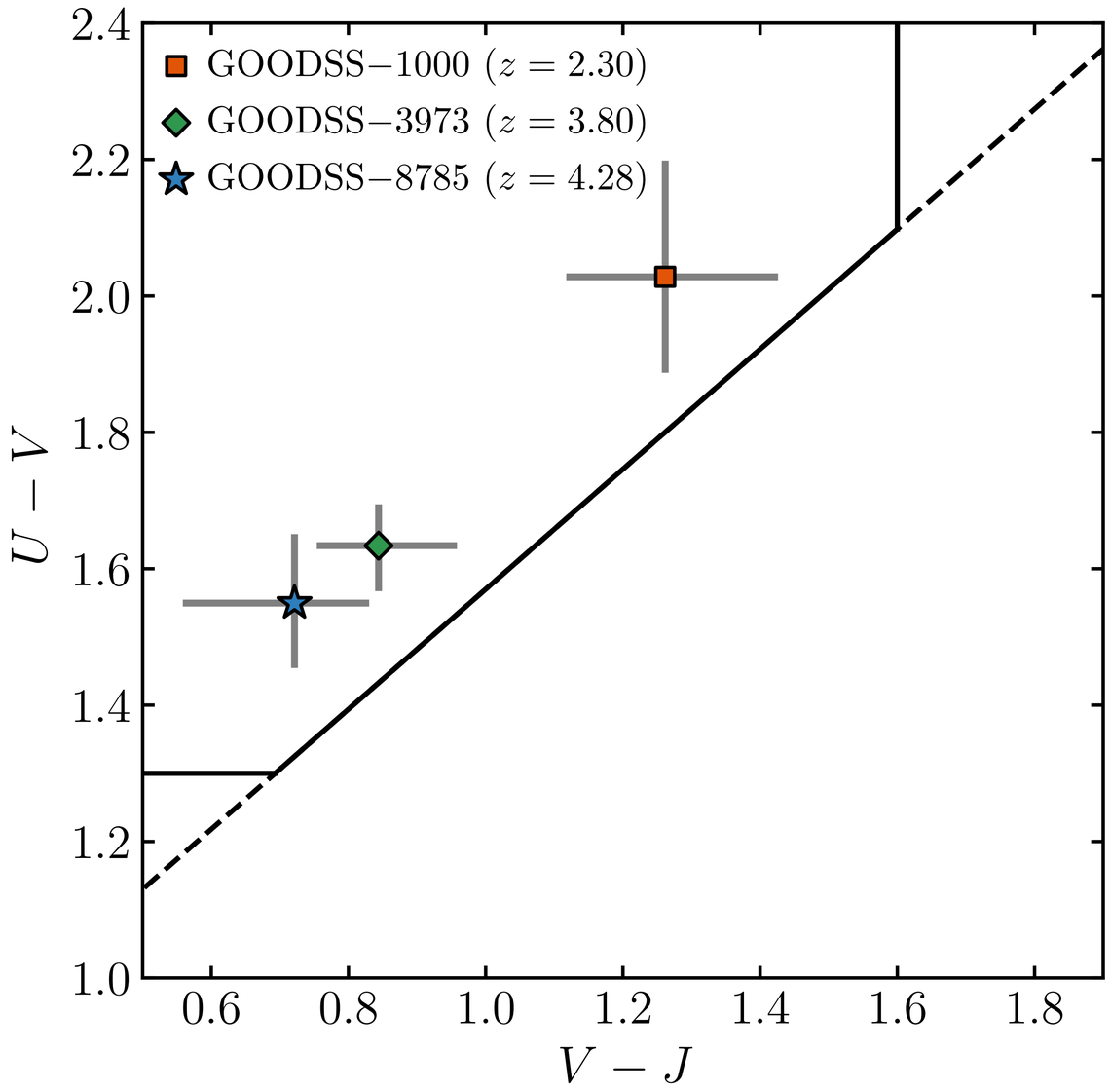

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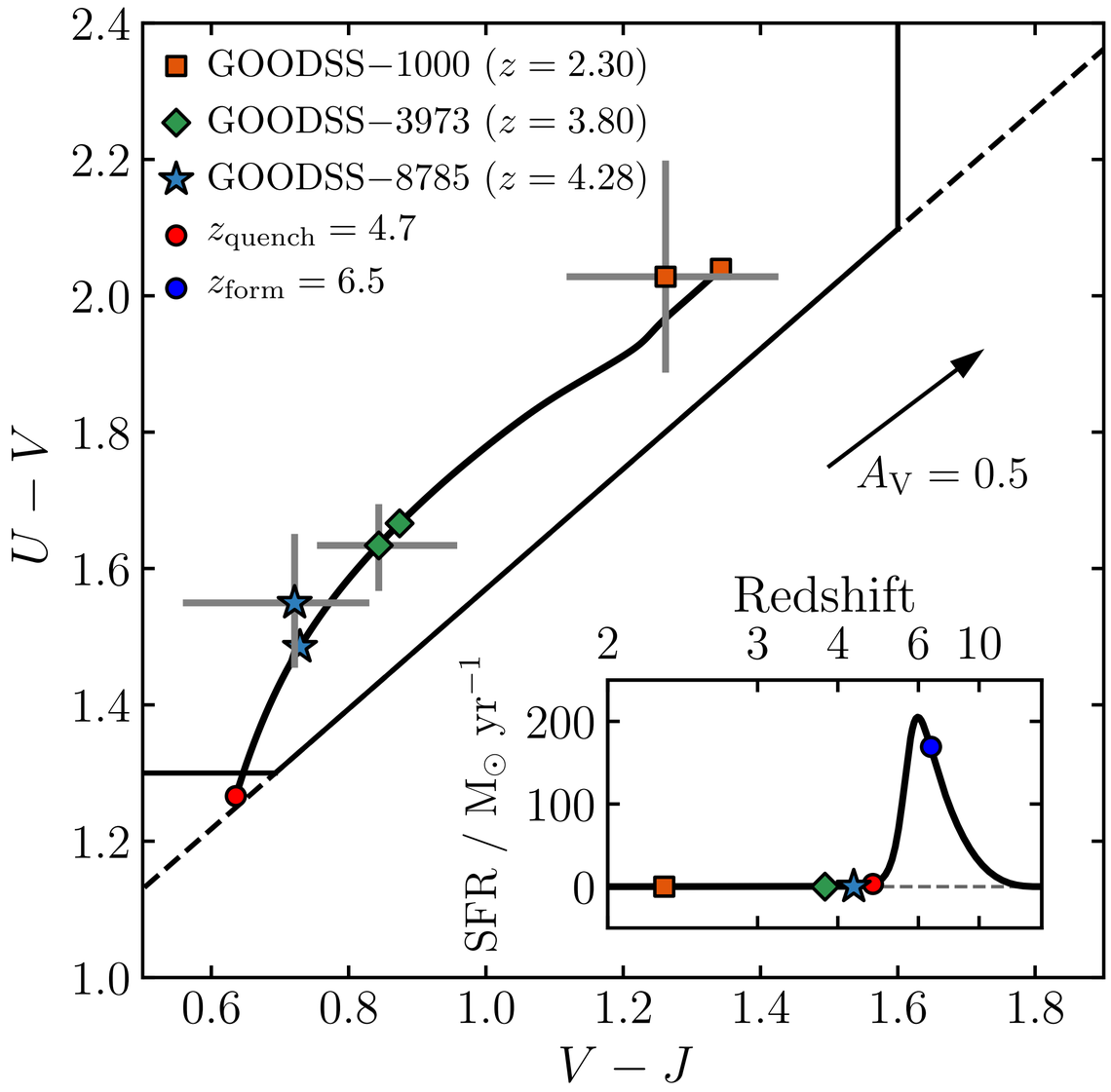

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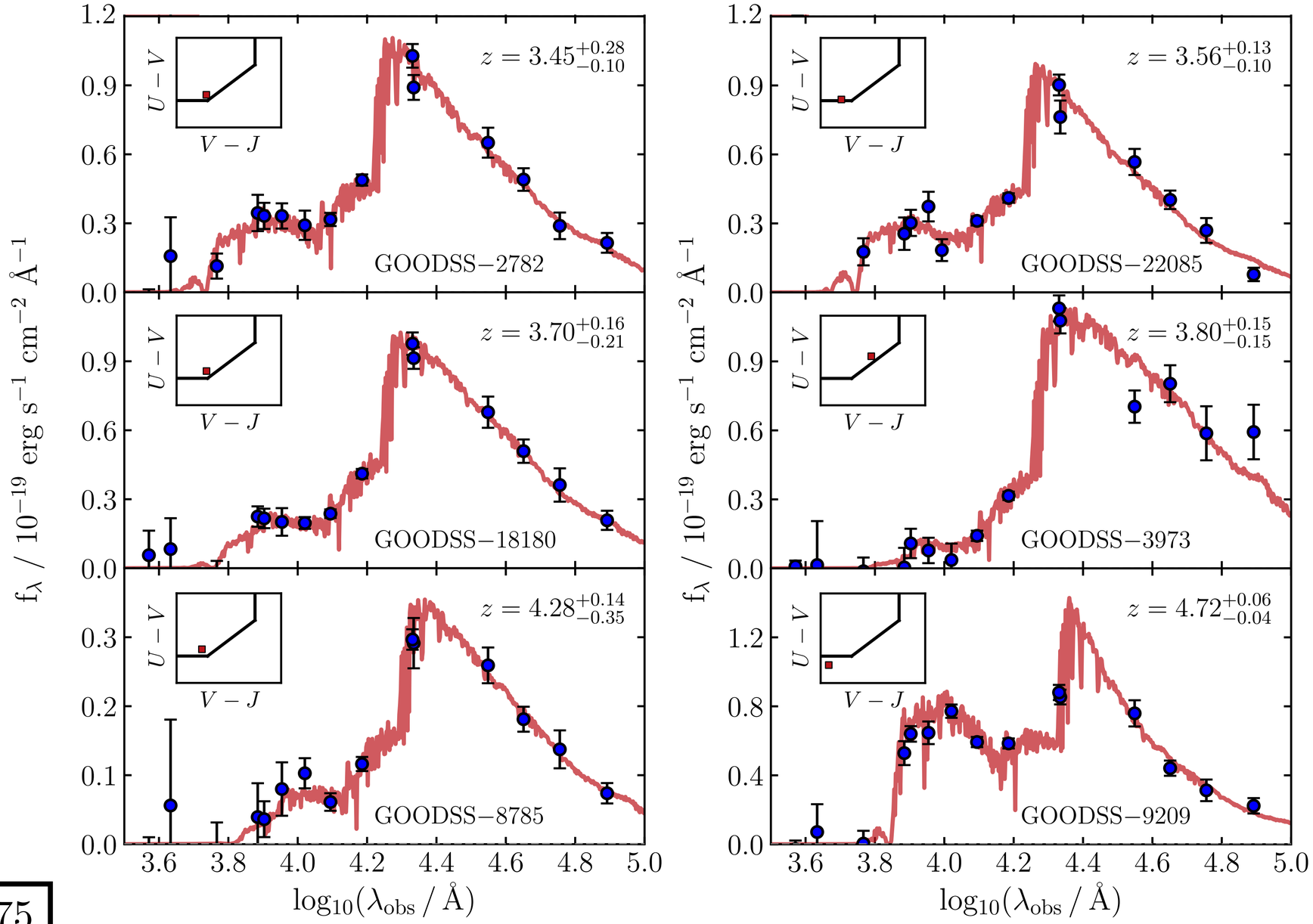

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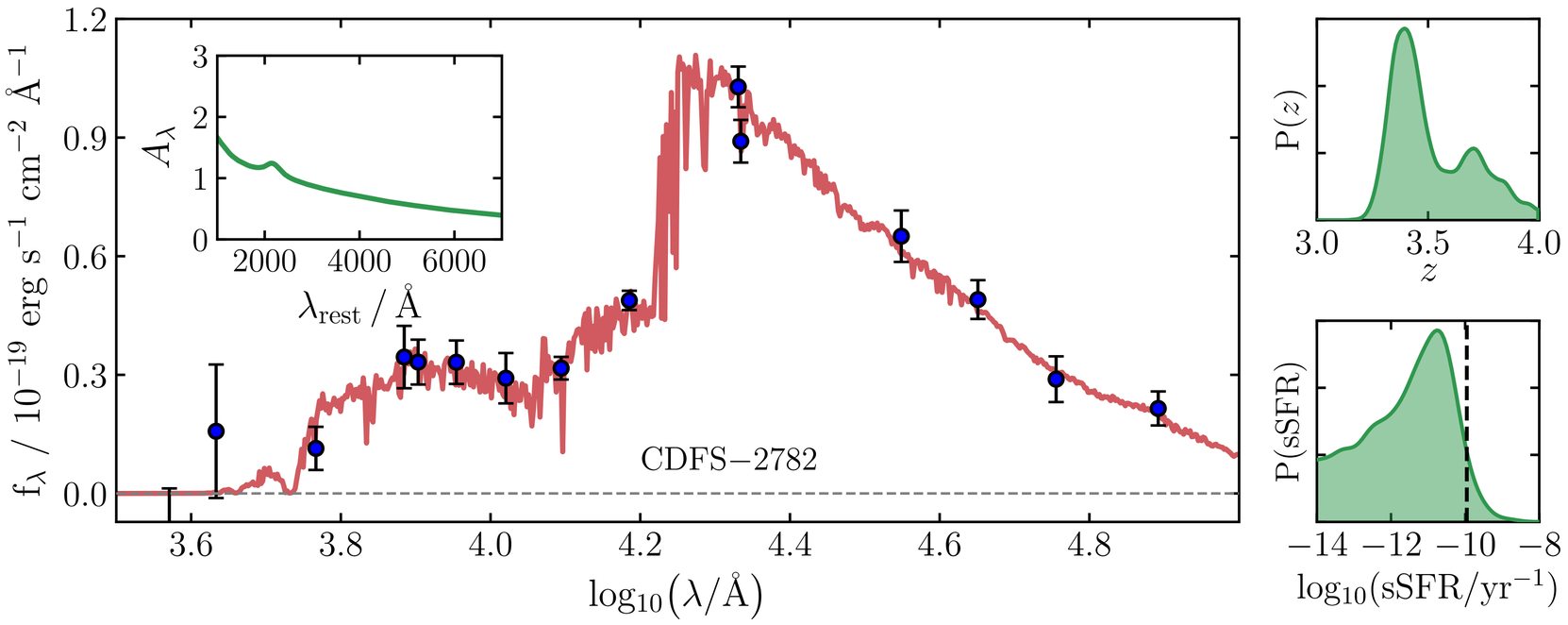

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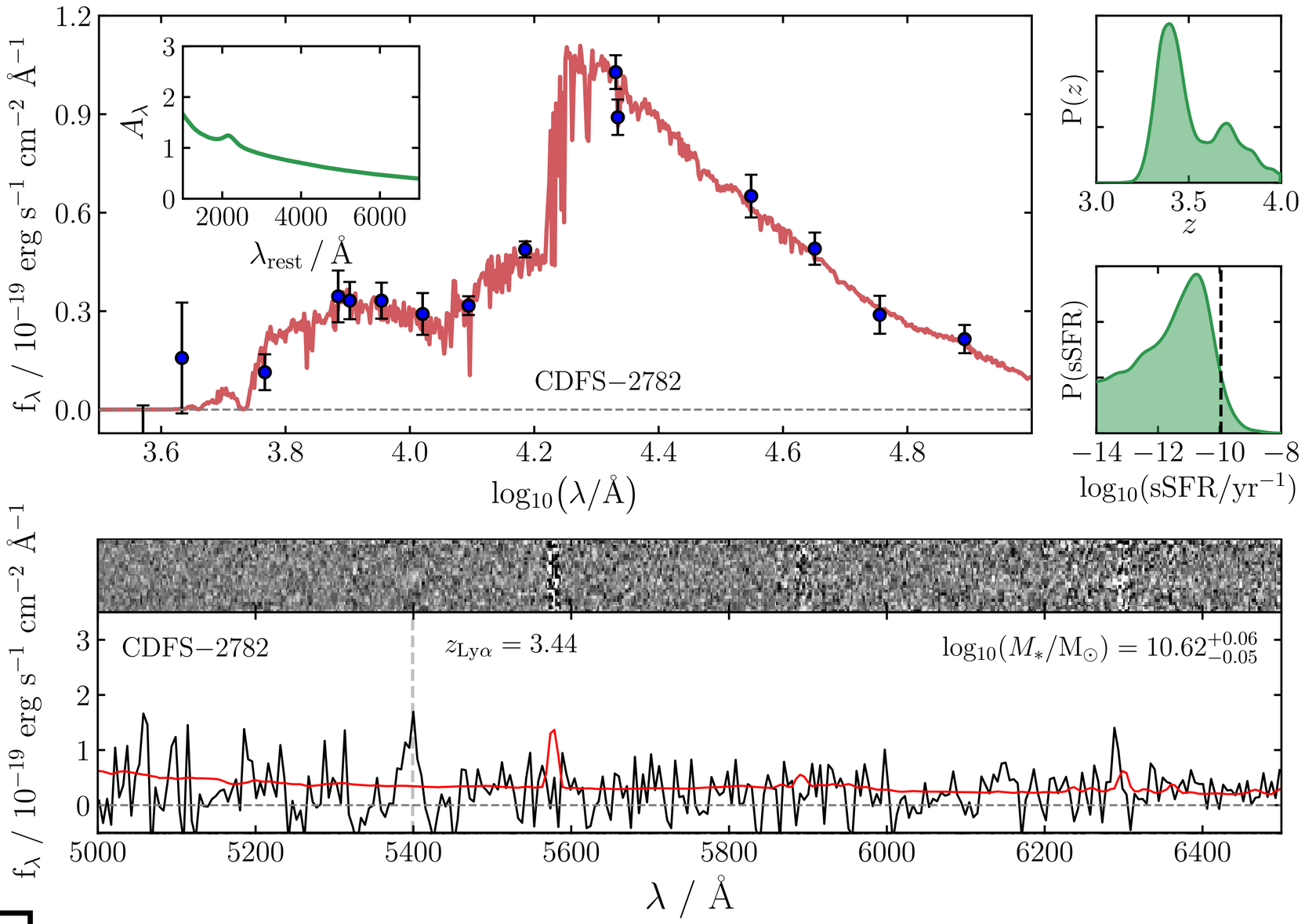

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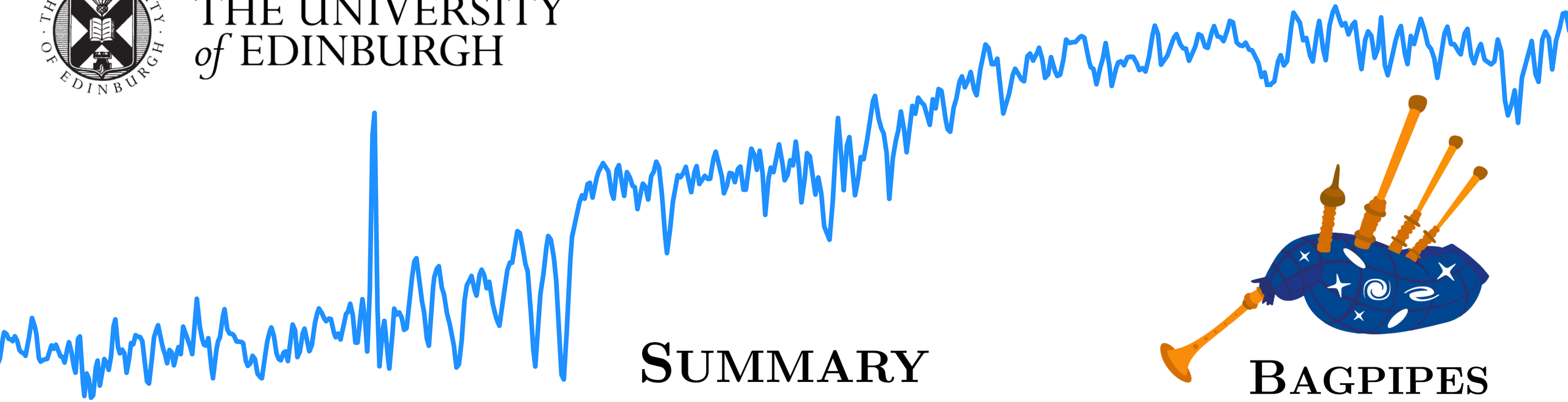

Summary

Bagpipes

Full spectral fitting (spectroscopy + photometry) is a promising way of extracting galaxy physical properties, a careful Bayesian approach with noise modelling makes this possible.

The $z \gtrsim 1$ quiescent population is diverse and interesting, simulations are not yet capturing in detail the evolution of these systems, new insights can come from ages and metallicities.

Current evidence suggests the oldest massive quiescent galaxies formed their mass at $z \sim 6$, spectroscopic follow up of quiescent objects at $z > 3$ is needed to obtain strong constraints.