Determining the Stellar Ages of the First Galaxies

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erc European Research Council

11th Sept. 2019, Extremely Big Eyes on the Early Universe, Rome

Searching for the first galaxies...

1.

When did the first stars and galaxies form?

2.

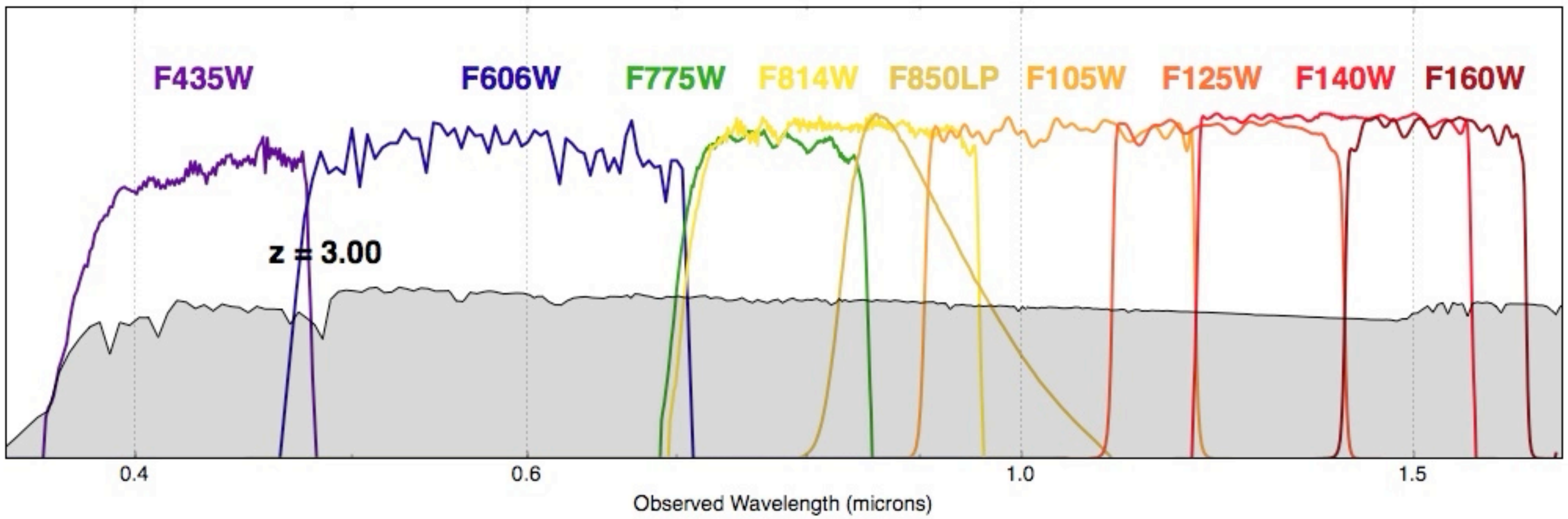
How many galaxies are there at a given luminosity?

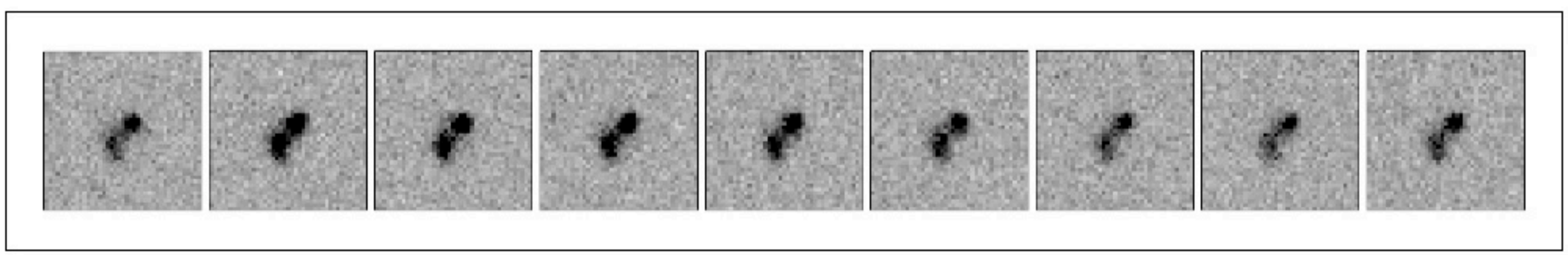
3.

Do galaxies emit enough ionising photons?

see also: Oesch+2012, McLure+2013, Atek+2015, Bouwens+2015, Finkelstein+15, McLeod+2016, Livermore+2017

Searching for the first galaxies…



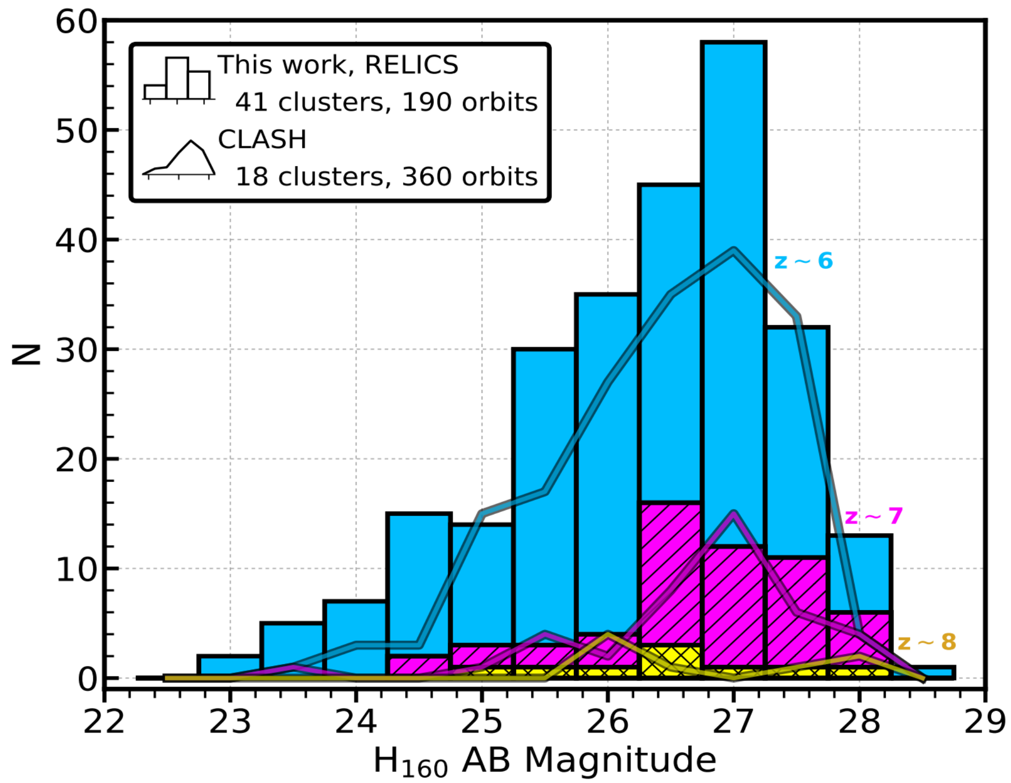


Credit: XDF team

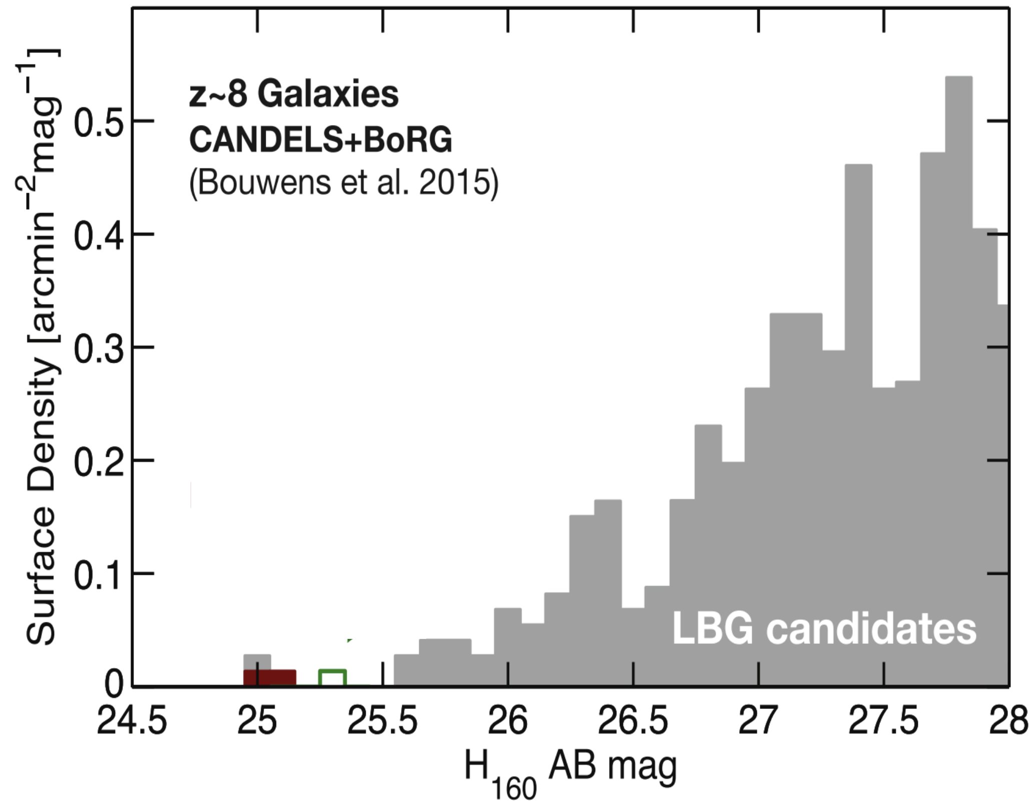
see also: Oesch+2012, McLure+2013, Atek+2015, Bouwens+2015, Finkelstein+15, McLeod+2016, Livermore+2017

Searching for the first galaxies…

Salmon+2018



Roberts-Borsani+2015



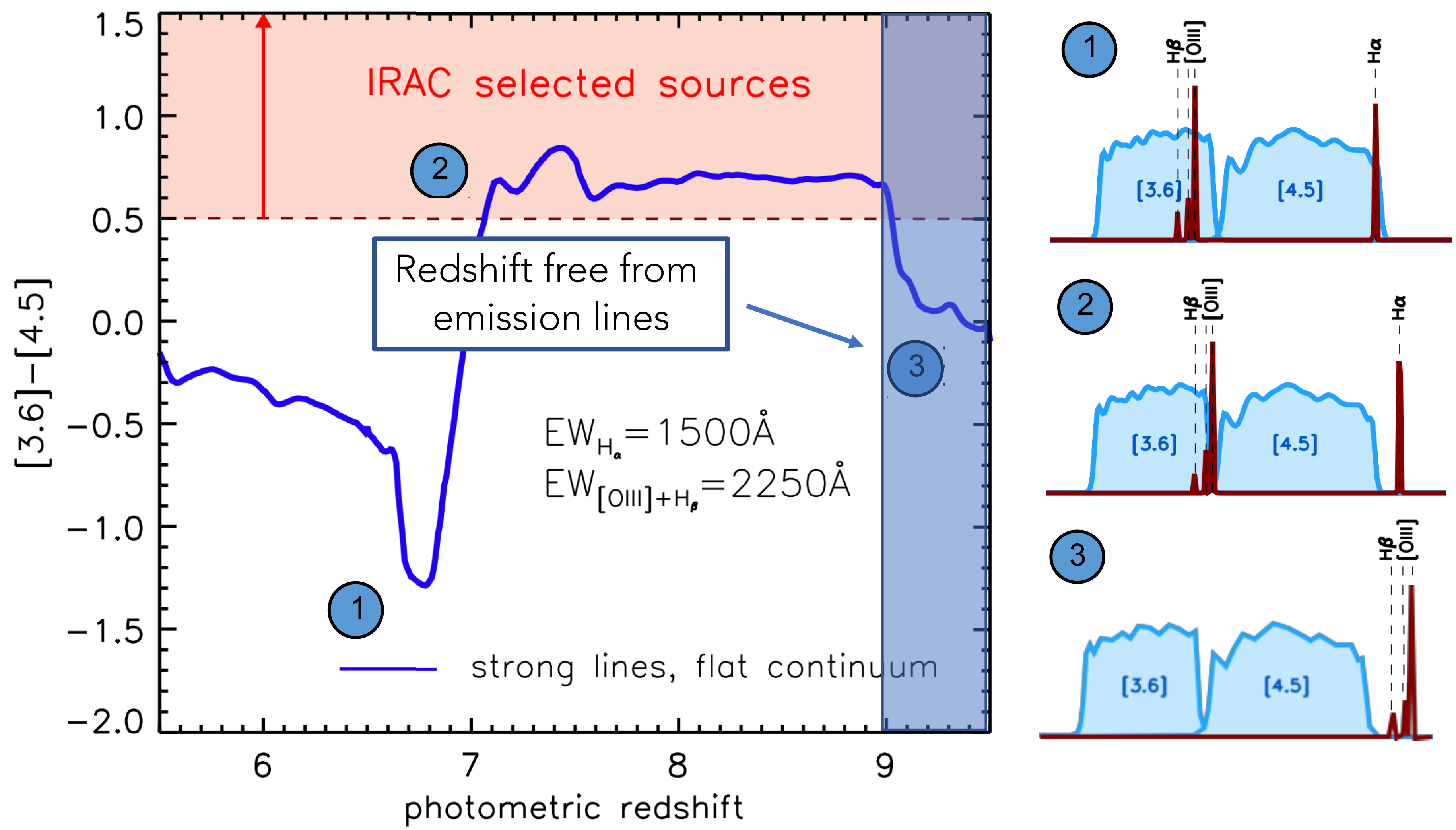
The dropout technique has given us hundreds of candidates at z>6 with which to characterise the Reionisation Epoch.

see also: Oesch+2012, McLure+2013, Atek+2015, Bouwens+2015, Finkelstein+15, McLeod+2016, Livermore+2017

An alternative approach…

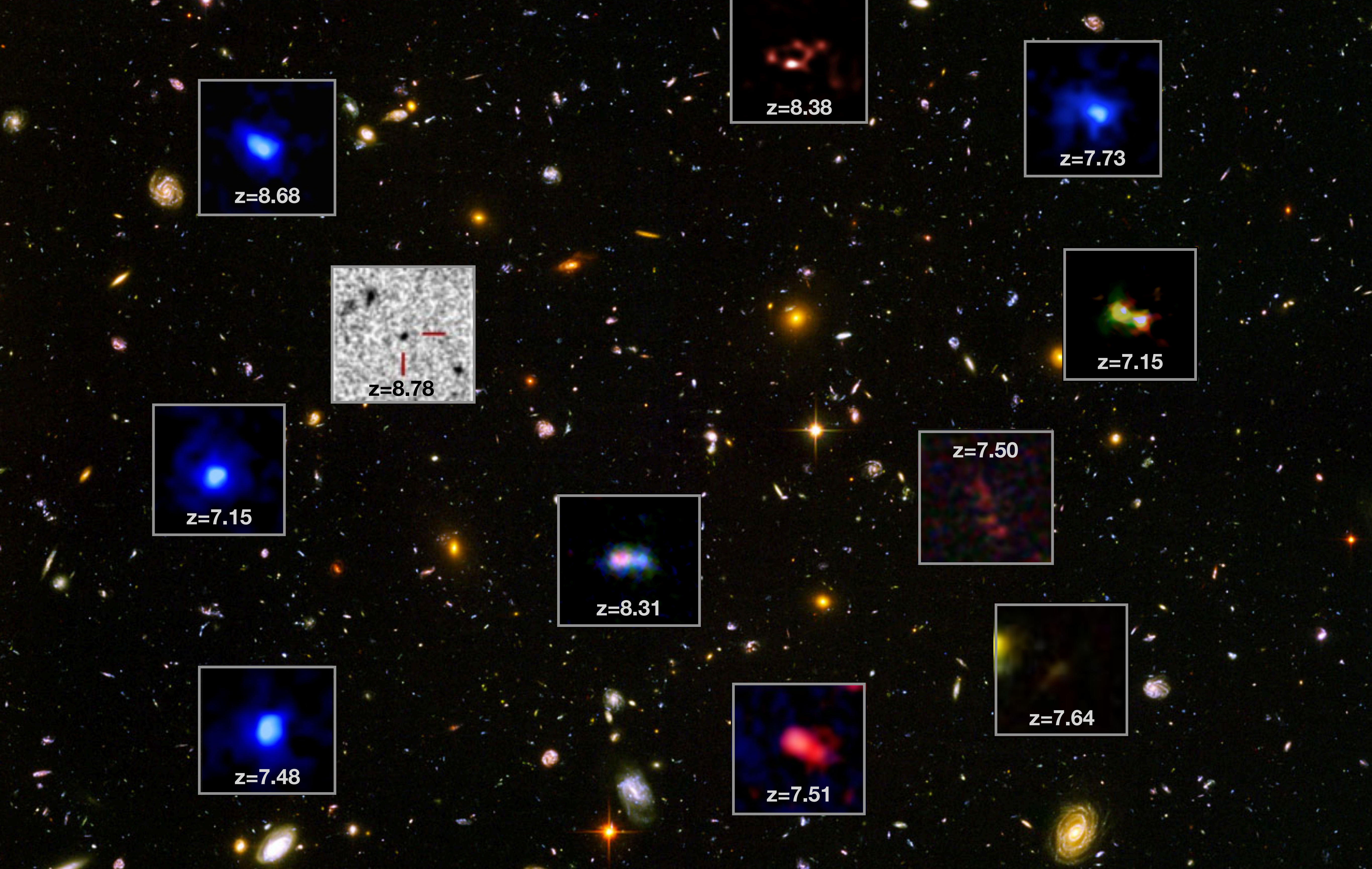
At high-z, Spitzer/IRAC bands probe the rest-frame optical. Strong nebular emissions lines (Hα, [OIII] 5007 Å and Hβ) can pollute the bands to produce a well-defined 3.6-4.5 μm vs redshift relation.

Roberts-Borsani+2015



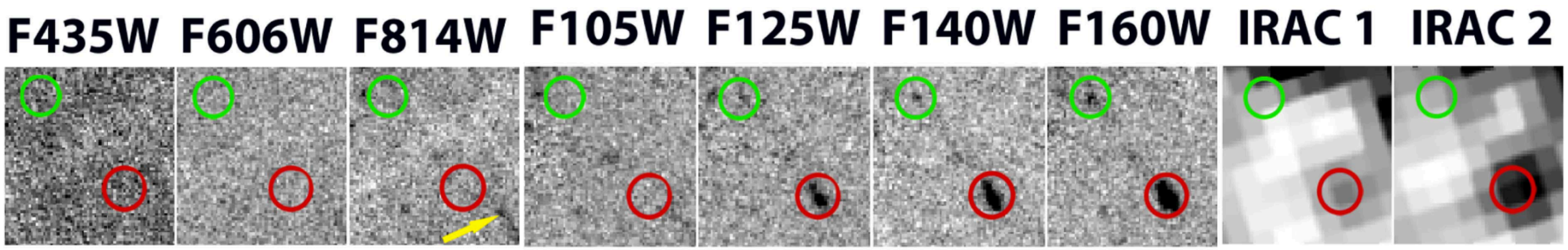
see also: Labbé+2013, Smit+2015

Spectroscopic galaxies at z=7-9
with red IRAC colours



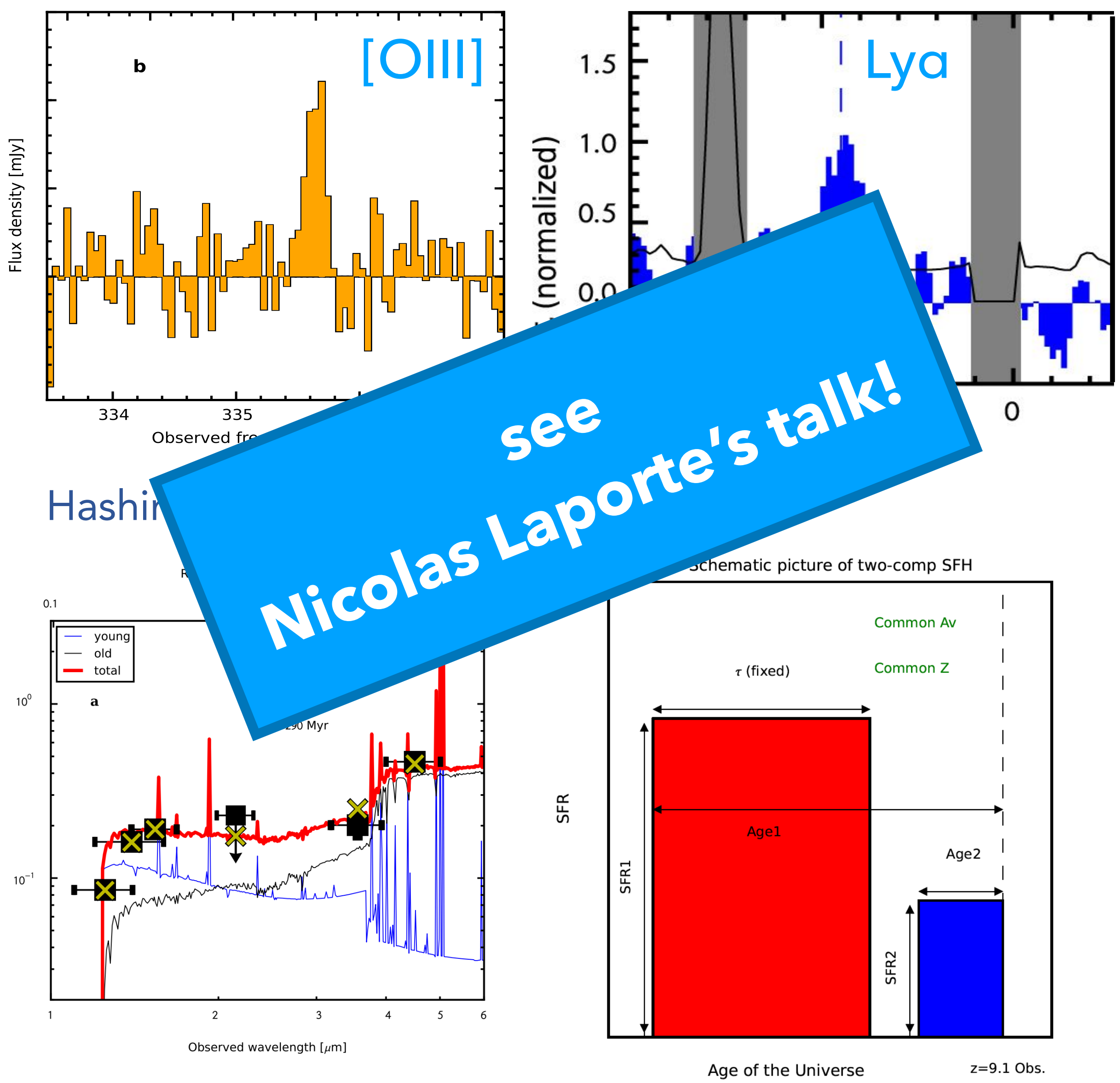
Finkelstein+2013, Watson+2015, Oesch+2015, Zitrin+2015, Roberts-Borsani+15, Stark+17, Hoag+2017, Laporte+2017, Tamura+2019, Hashimoto+2019, Laporte+(2019, in prep.)

IRAC excess due to older stellar populations: MACSJ1149-JD1



Zheng+2012,2017

VLT/X-SHOOTER + ALMA/BAND 7

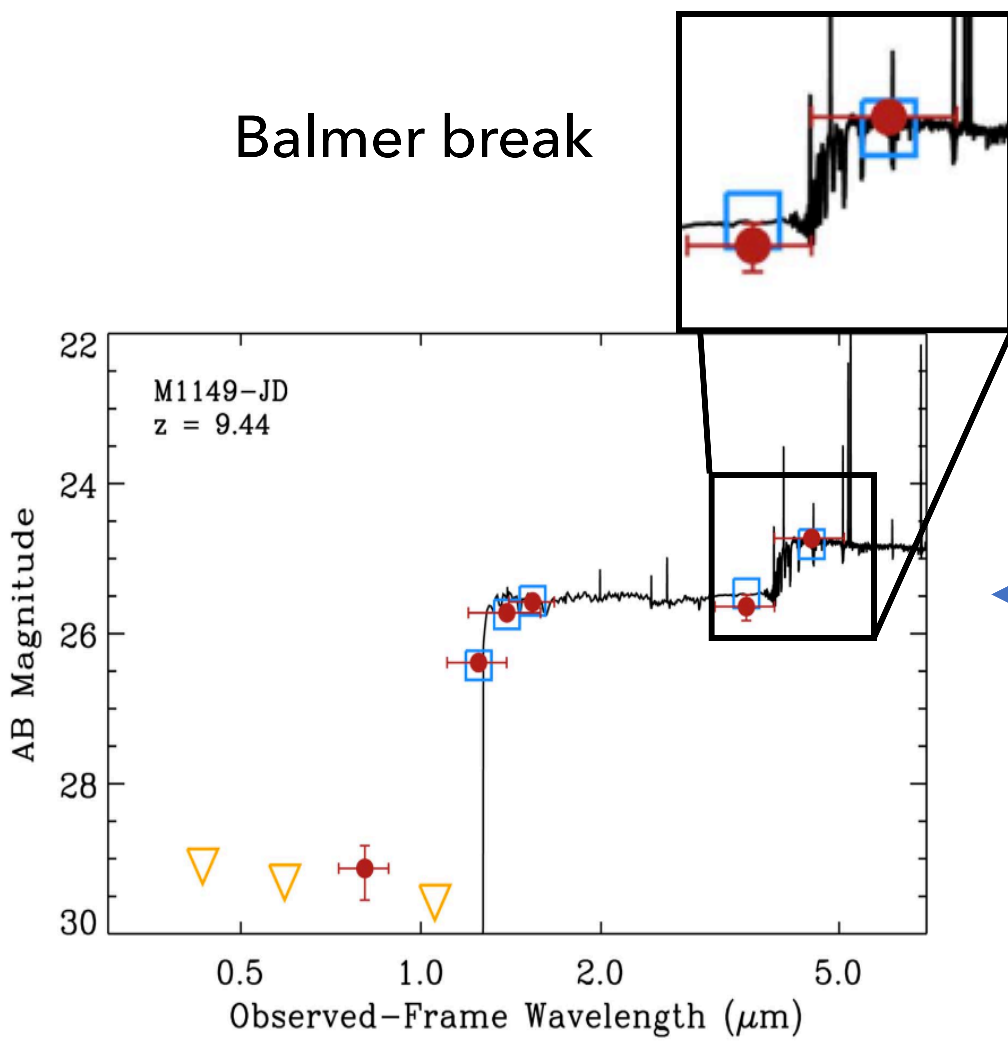


- A bright, strongly amplified galaxy from CLASH/Frontier Fields with H_{160}~25 AB.
- Spectroscopic observations with ALMA ([OIII] 88μm) and VLT/X-Shooter (Lyman-α) place the galaxy at z=9.11.
- SED modelling and secure redshift suggest the IRAC-excess is due to a Balmer-break cause by older stellar population formed at z~15.

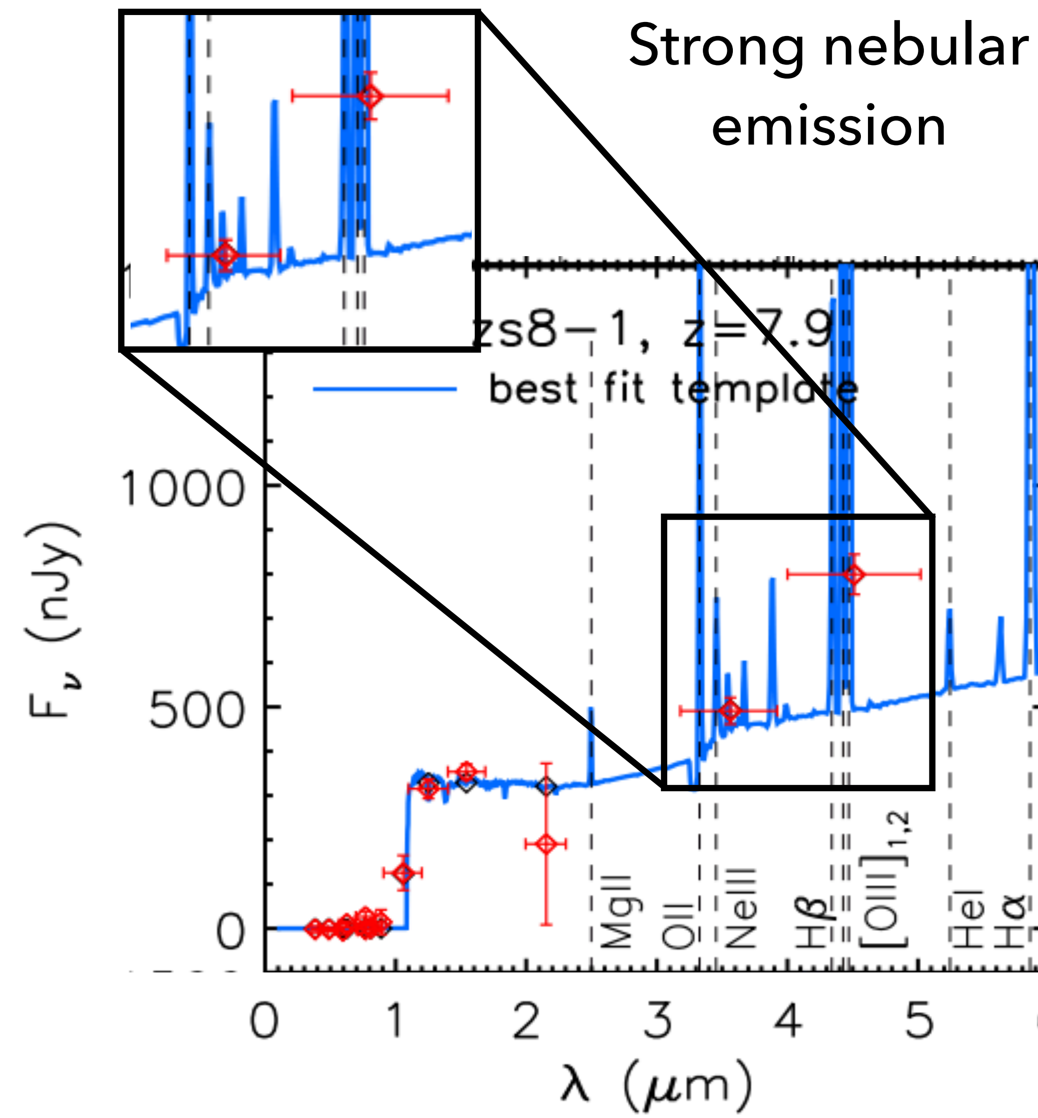
Is nebular emission the sole cause of IRAC-excess at z>7?

Spitzer/IRAC [3.6] and [4.5] micron bands boosted by different parts of the rest-frame optical spectrum: strong nebular emission lines or Balmer breaks?

Balmer break



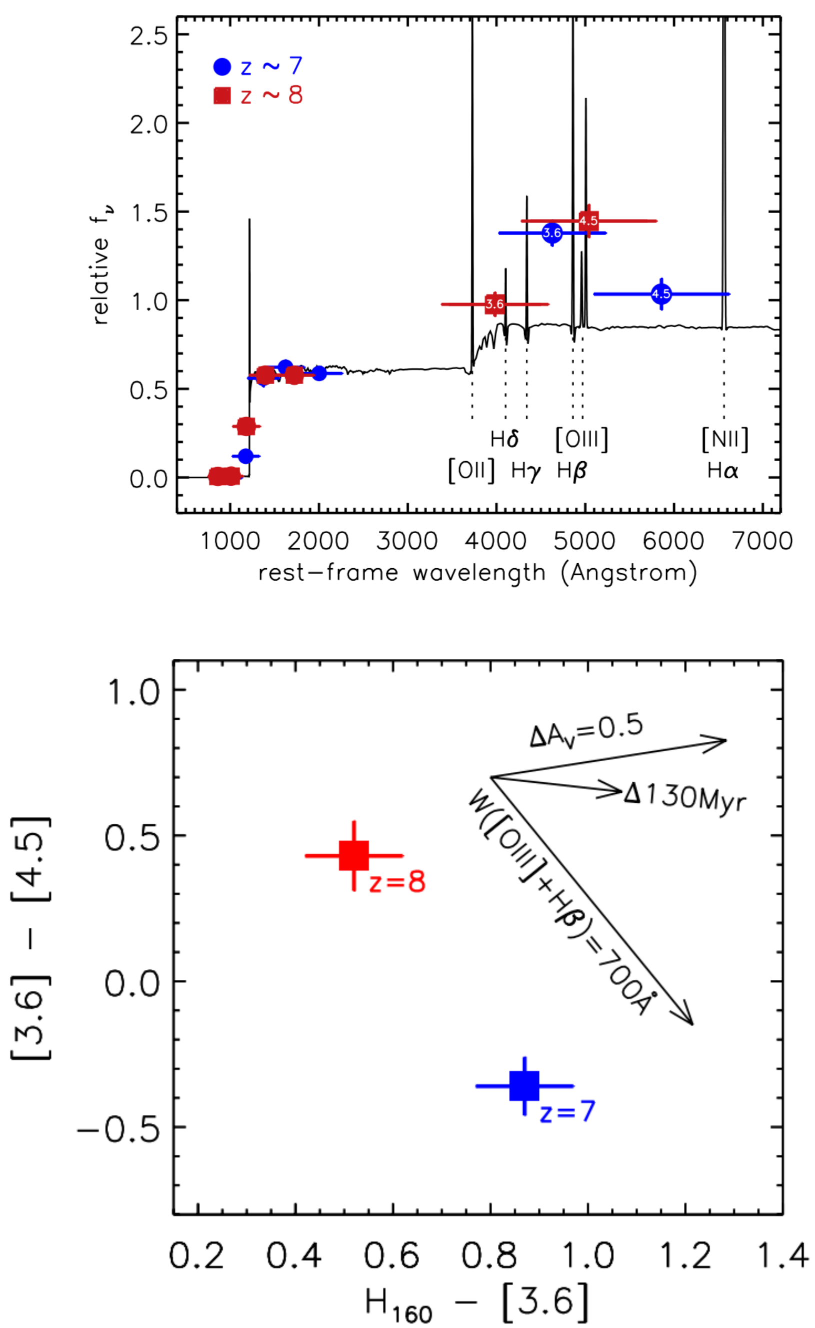
Strong nebular emission



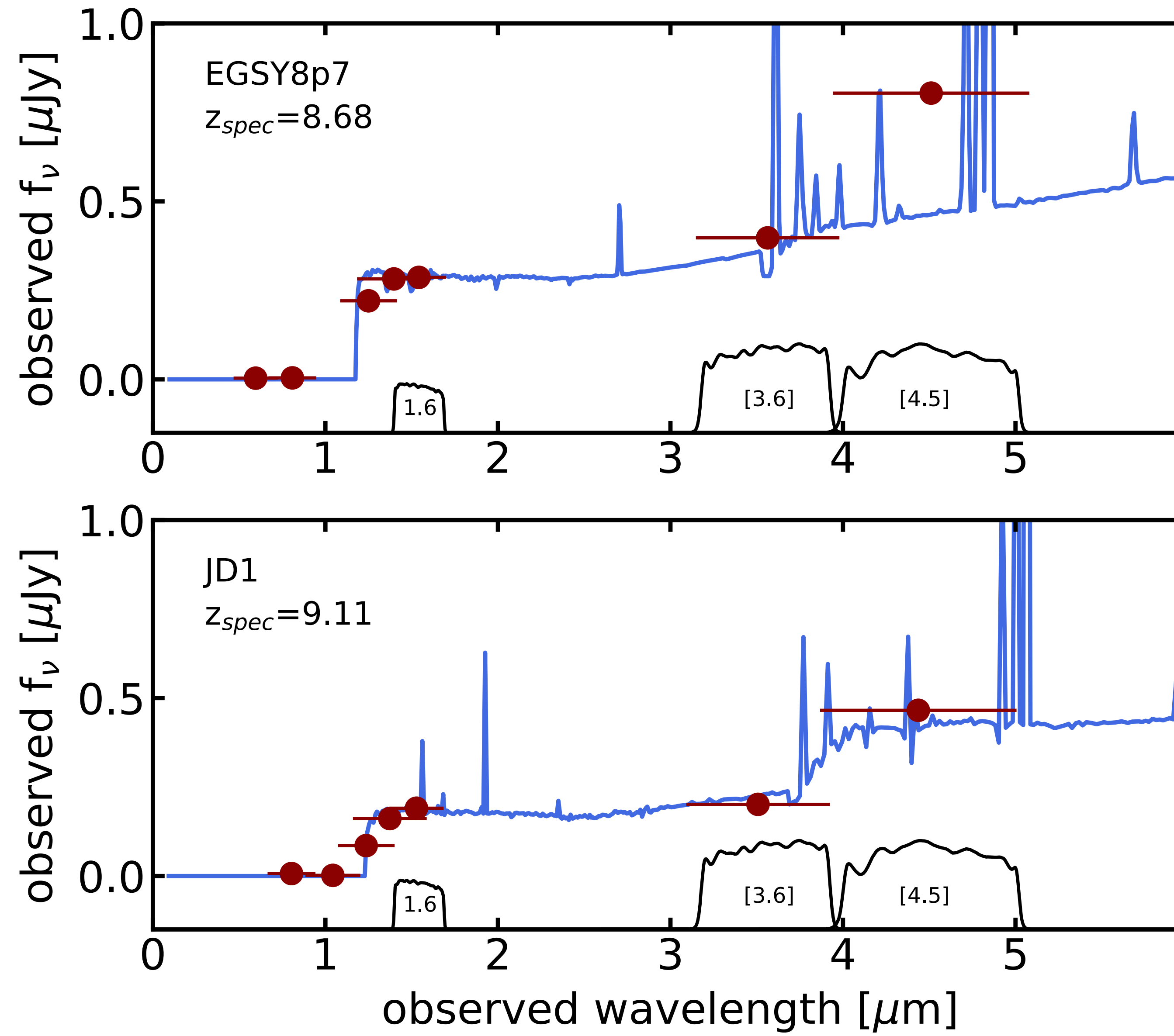
see also: Labbé+2013, Smit+2015, Roberts-Borsani+2015

Can old stars reproduce Spitzer/IRAC colours?

Luckily, we have spectroscopically-confirmed galaxies with IRAC-excesses due to both nebular line emission (EGSY8p7; Roberts-Borsani+2015, Zitrin+2015) and a Balmer break (JD1; Hashimoto+2018) to test this picture.



Labbé+2013



Roberts-Borsani, Ellis, Laporte (in prep.)

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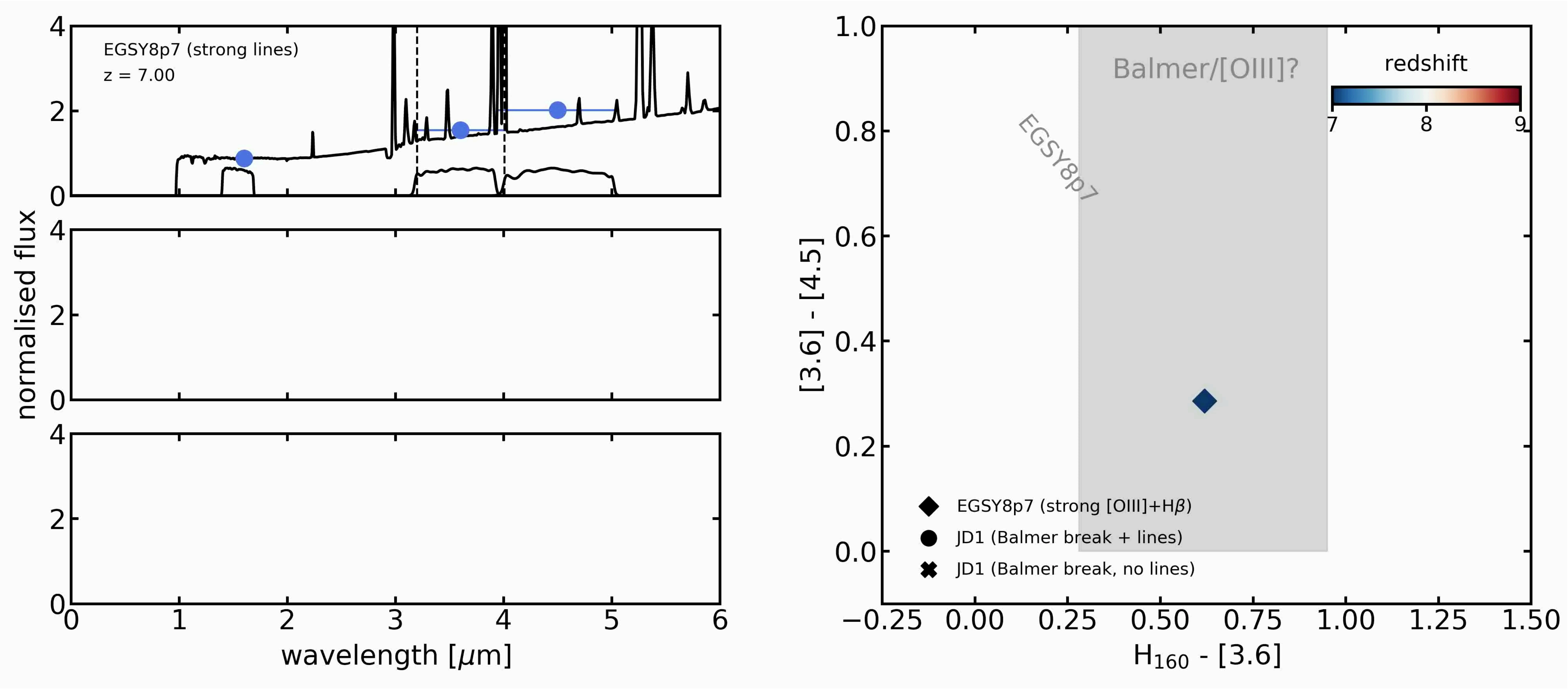

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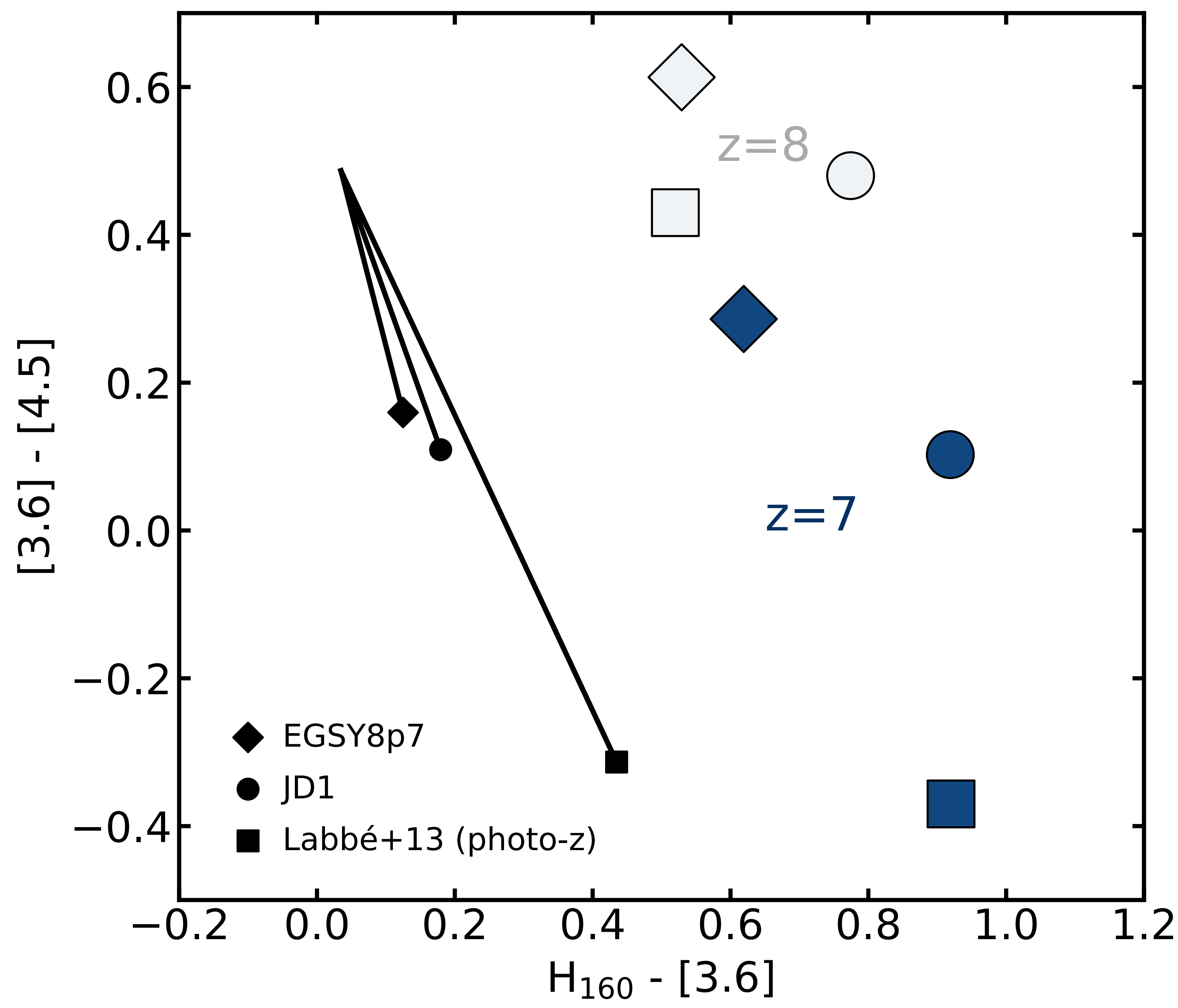

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Can old stars reproduce Spitzer/IRAC colours?

To explore this, we need SED models of various ages that self-consistently incorporate the evolution of stars, gas and metals, nebular emission, and dust production, over a large wavelength range (UV -> FIR/sub-mm). Introducing **Pégase3**.

stellar evolution

- SSP models
- Initial mass function
- stellar yields

dust production

- wavelength-dependent
- size distribution and optical properties of individual dust grains
- silicate + carbonaceous grains included
- projection effects included

PÉGASE

Fioc+2019

wavelength coverage

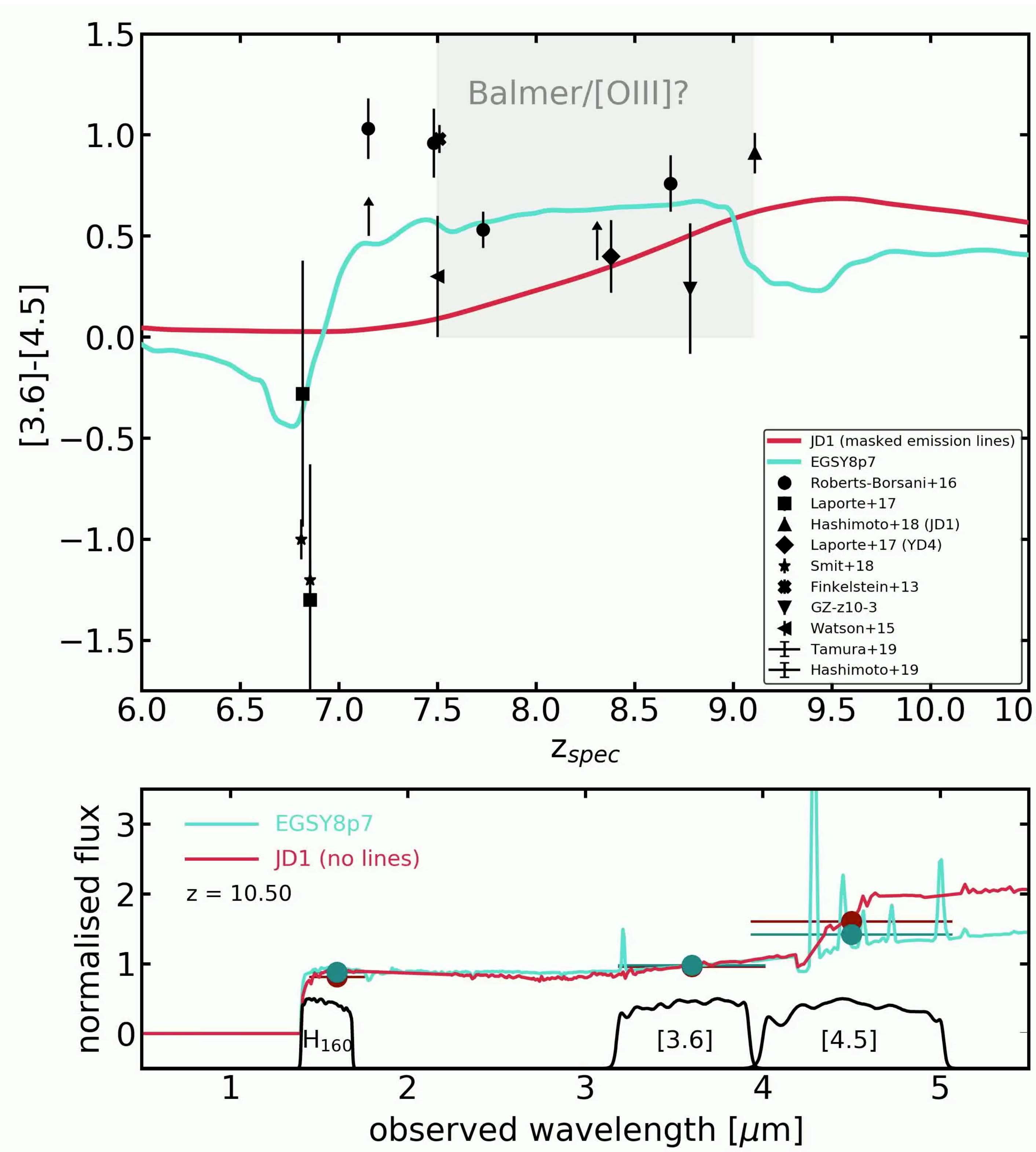
- UV to FIR/sub-mm

nebular emission

- initial metallicity of ISM gas (cooling)
- CLOUDY
- emission of Lyman continuum photons
- includes dust obscuration

for more details see Fioc et al. (2019)

Can old stars reproduce Spitzer/IRAC colours?



Roberts-Borsani, Ellis, Laporte (in prep.)

- Looking at the colour evolution of an intense line emitter and Balmer break galaxy (masked lines).
- Assuming simple Pégase3 models with a Chabrier+2003 IMF, constant SFR, dust and different ages.
- Stellar ages of ~300-600 Myrs can reproduce IRAC colours at z>~8. Thus, the explanation of nebular emission lines as the main/sole source of boosting is perhaps not universal.
- **<u>IMPORTANT</u>: This does not imply one or the other, likely to be a mixture of both!**

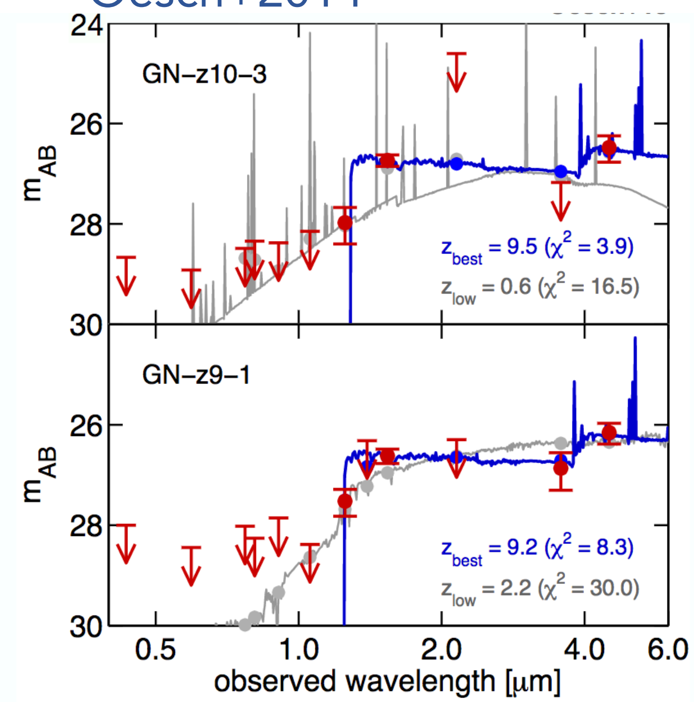
Are older stellar populations prevalent?

Is JD1 an isolated case or are there either known galaxies with evolved stellar populations?

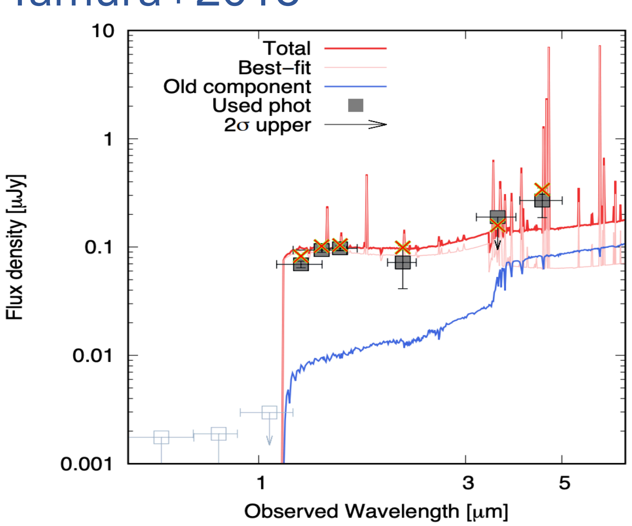
- A handful of candidates from photometry and SED fitting…

- 3 high-z massive galaxies in a 50 Mpc (comoving) box…

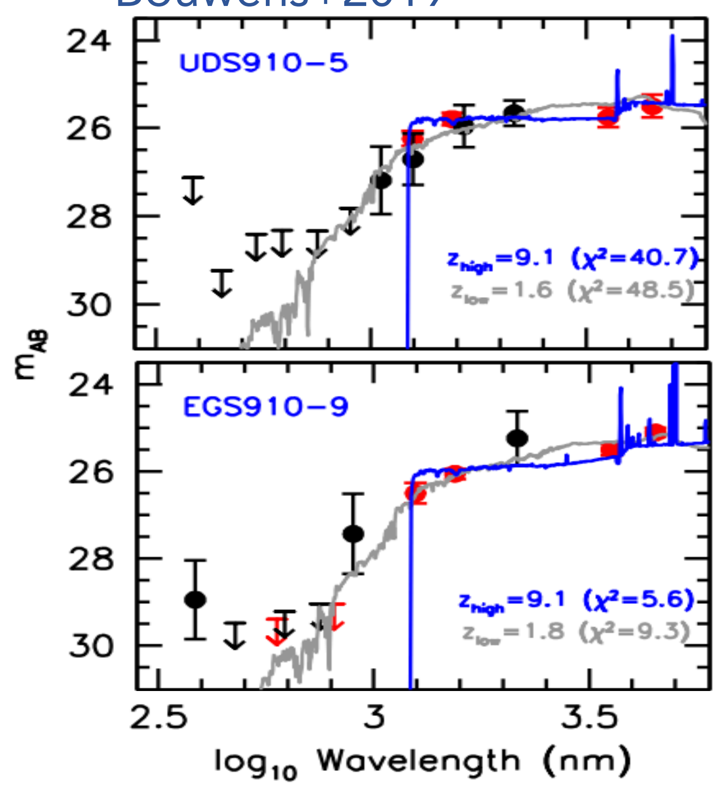
Oesch+2014



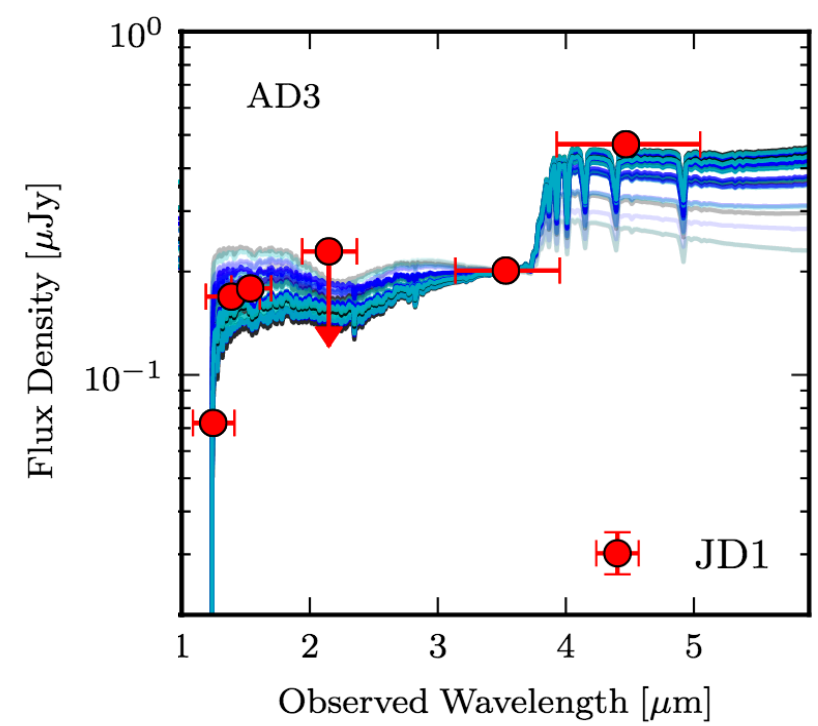
Tamura+2018



Bouwens+2019



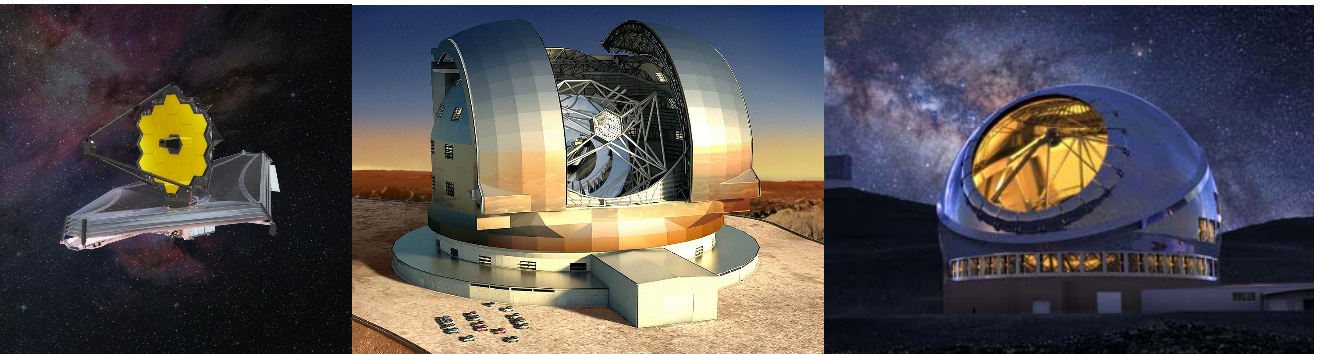
Katz+2018



How do we distinguish at z=7-9?

We need JWST and EXTREMELY BIG EYES!!!

Telescope/Instrument	Wavelength coverage (μm)	Spectral Resolution
TMT/NIRES	1-5	R~100,000
ELT/METIS	2.9-14	R~900-100,000
JWST/NIRSpec	0.6-5.3	R~1,000-2,700

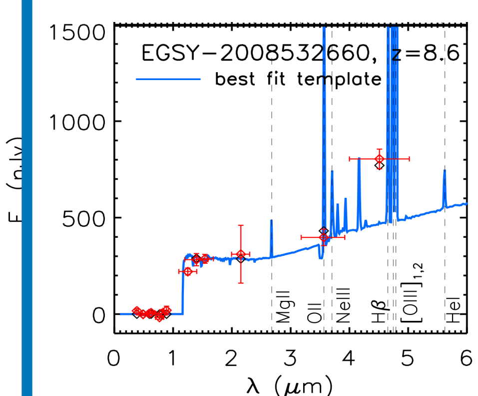


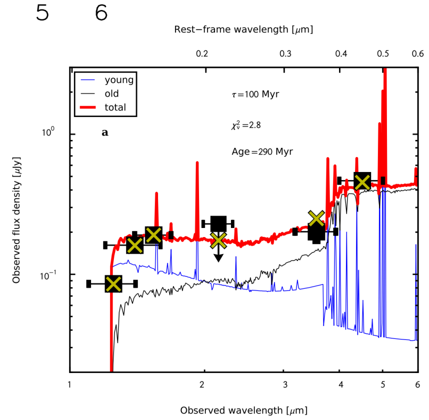
Such observations crucial to determine accurate stellar masses, stellar ages, and constraining the timing of Cosmic Dawn!

Summary & Conclusions

1

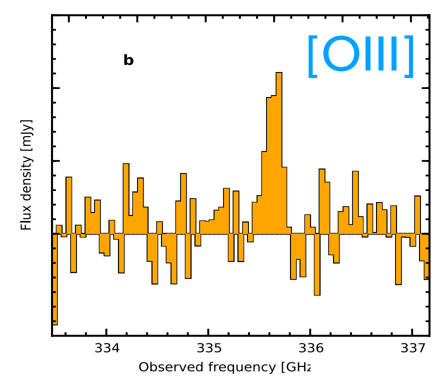
The rest-frame optical provides important information on the stellar populations, ionising conditions and gas of galaxies. At high-z this is probed by Spitzer/IRAC channels.

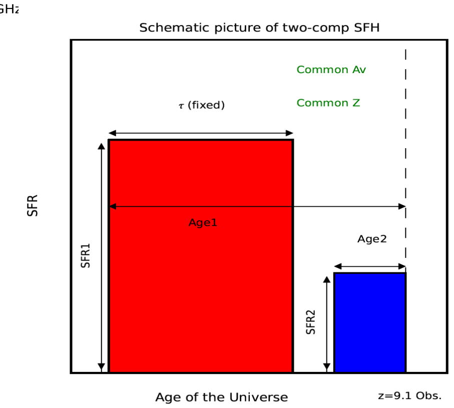




2

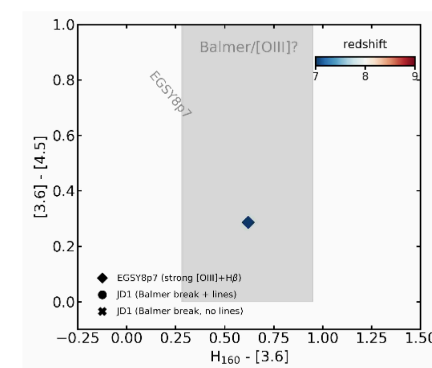
The discovery and modelling of JD1 has placed the universality of emission lines as the main cause of red [3.6]-[4.5] colours in doubt.

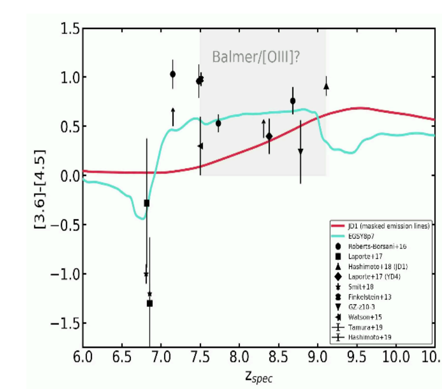




3

Spectroscopic data sets and Pégase3 SEDs suggest IRAC colours can be explained by older stellar populations too. Implications for galaxy ages and timing of Cosmic Dawn.





The arrival of 30m-class telescopes and JWST will aid to distinguish between the two scenarios and help constrain the timing of Cosmic Dawn.