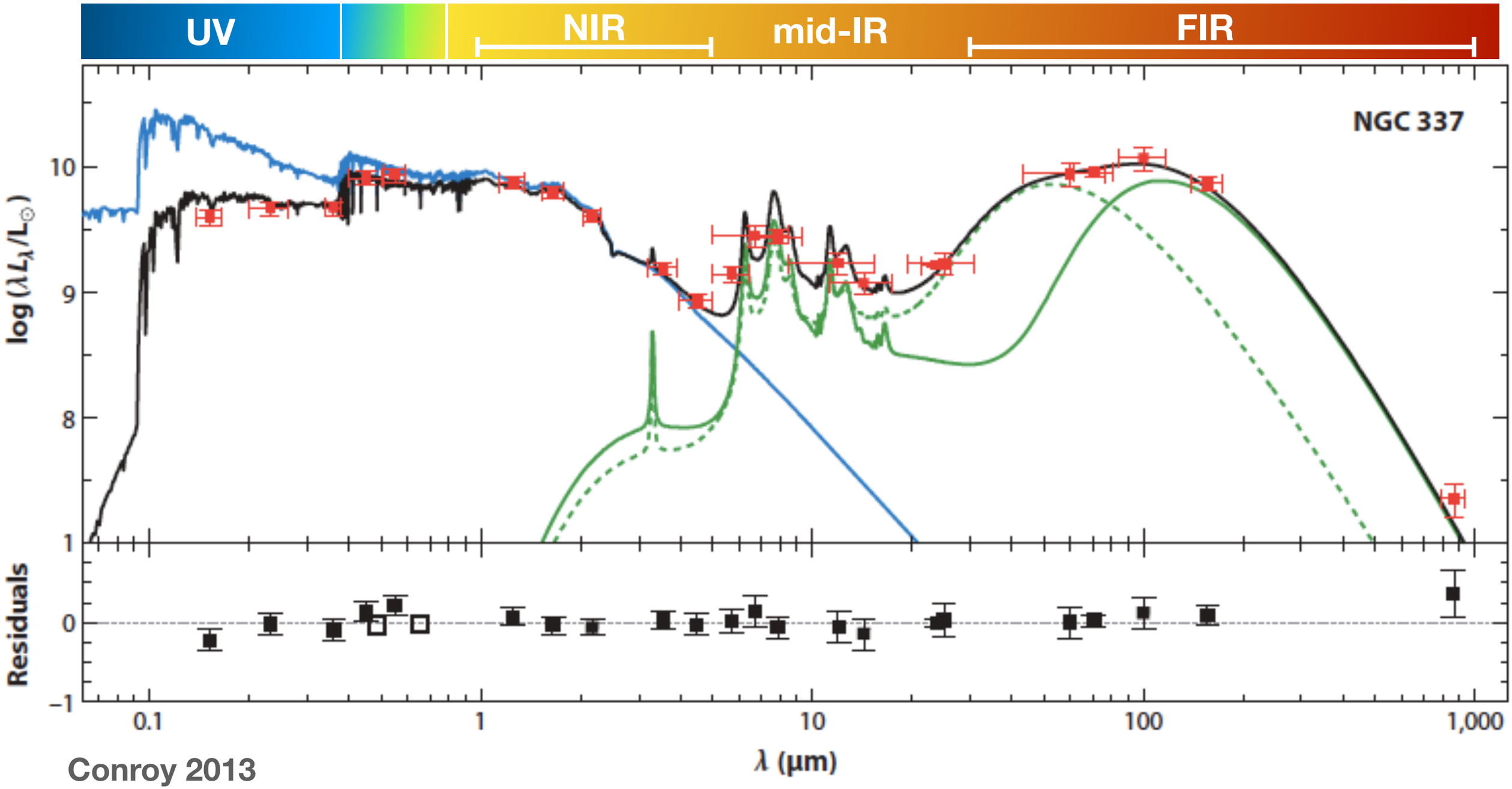
Turning it the other way around: estimate galaxy properties from observed SEDs



Conroy 2013

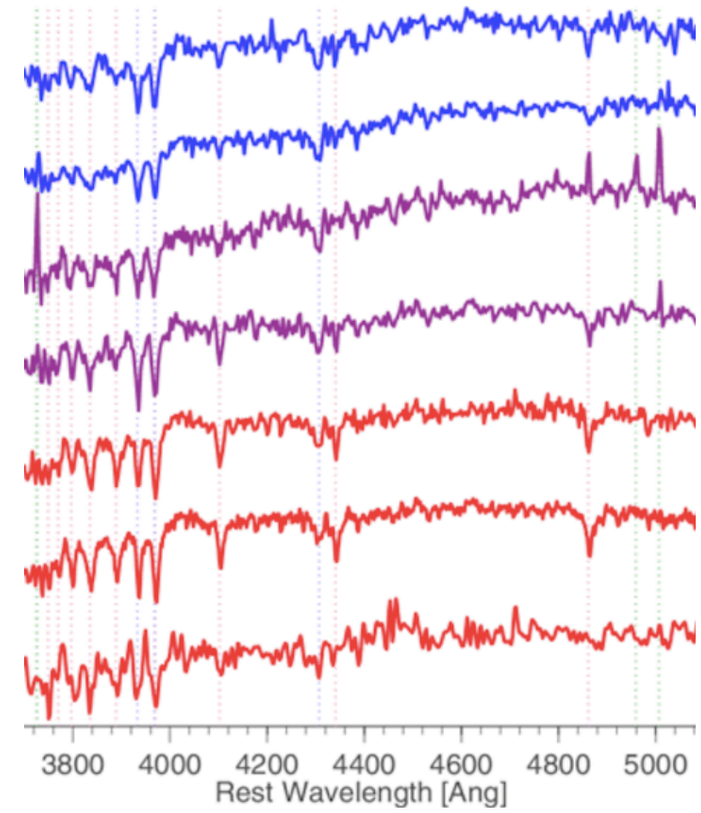
Turning it the other way around: estimate galaxy properties from observed SEDs

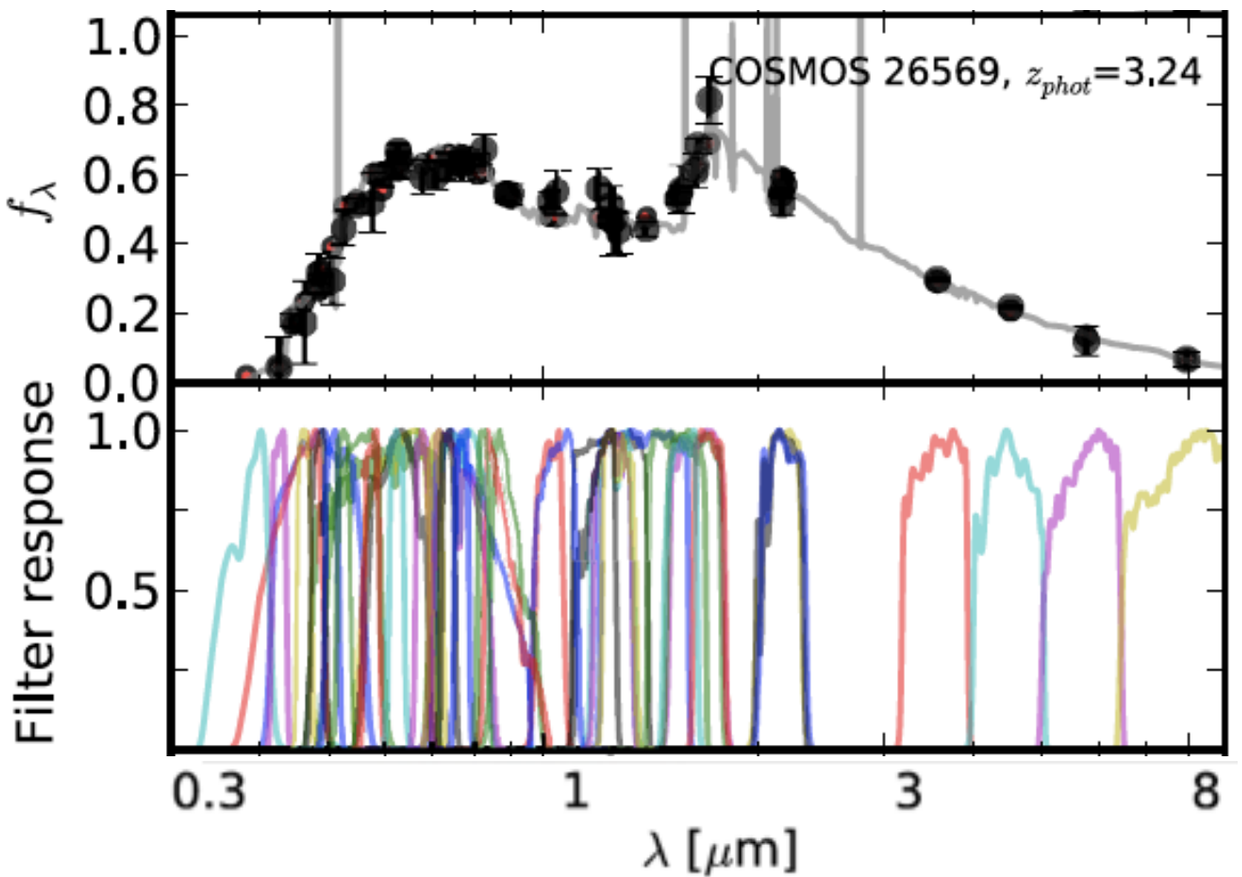
What do we have:

- ☐ spectra
  (or spectral features / indices)

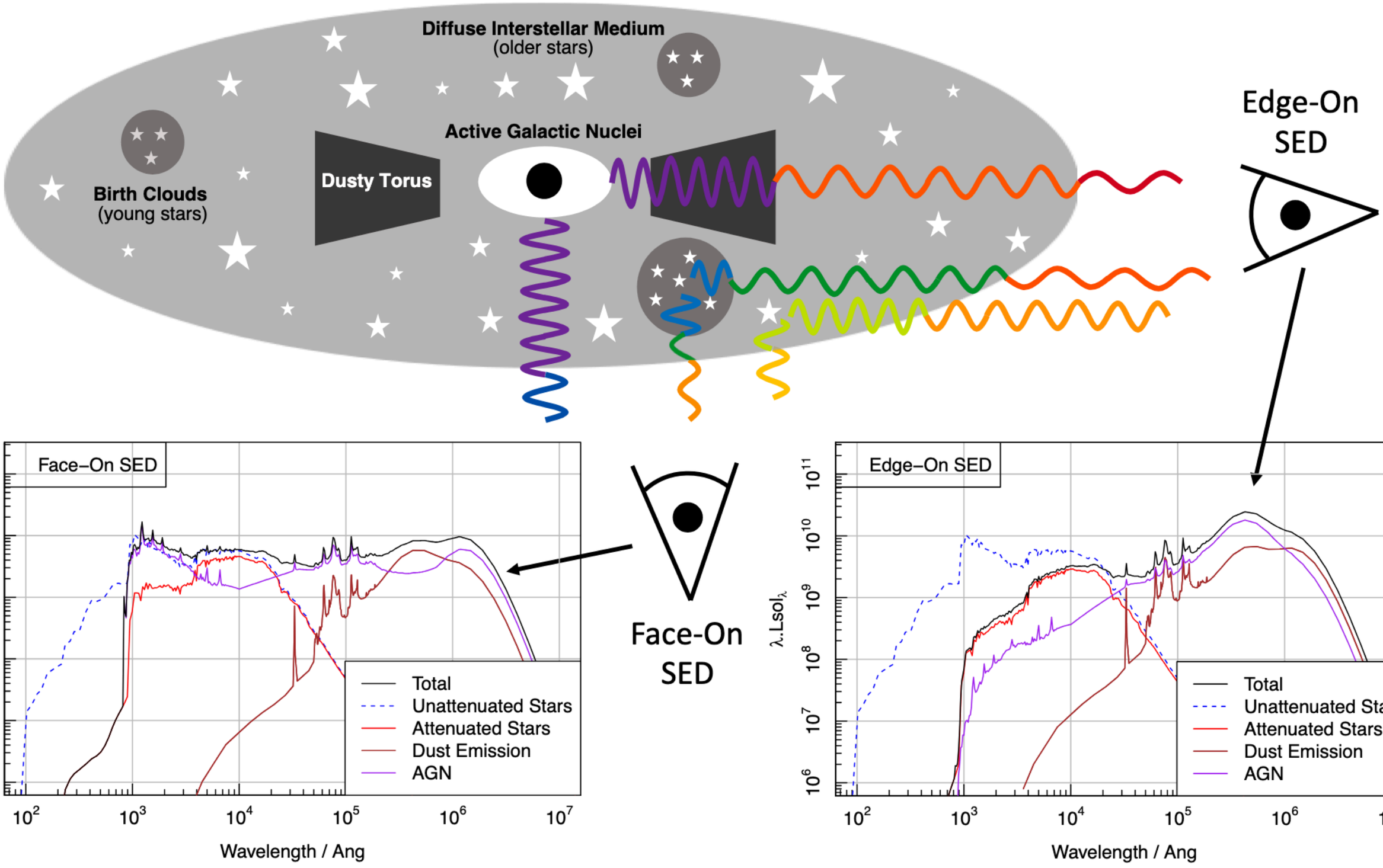
- ☐ color (broad/medium/
  narrow-band SEDs)

(resolved / unresolved ?)





Turning it the other way around: estimate galaxy properties from observed SEDs



Turning it the other way around: estimate galaxy properties from observed SEDs

What do we have:

- ☐ spectra
  (or spectral features / indices)
- ☐ color (broad/medium/
  narrow-band SEDs)

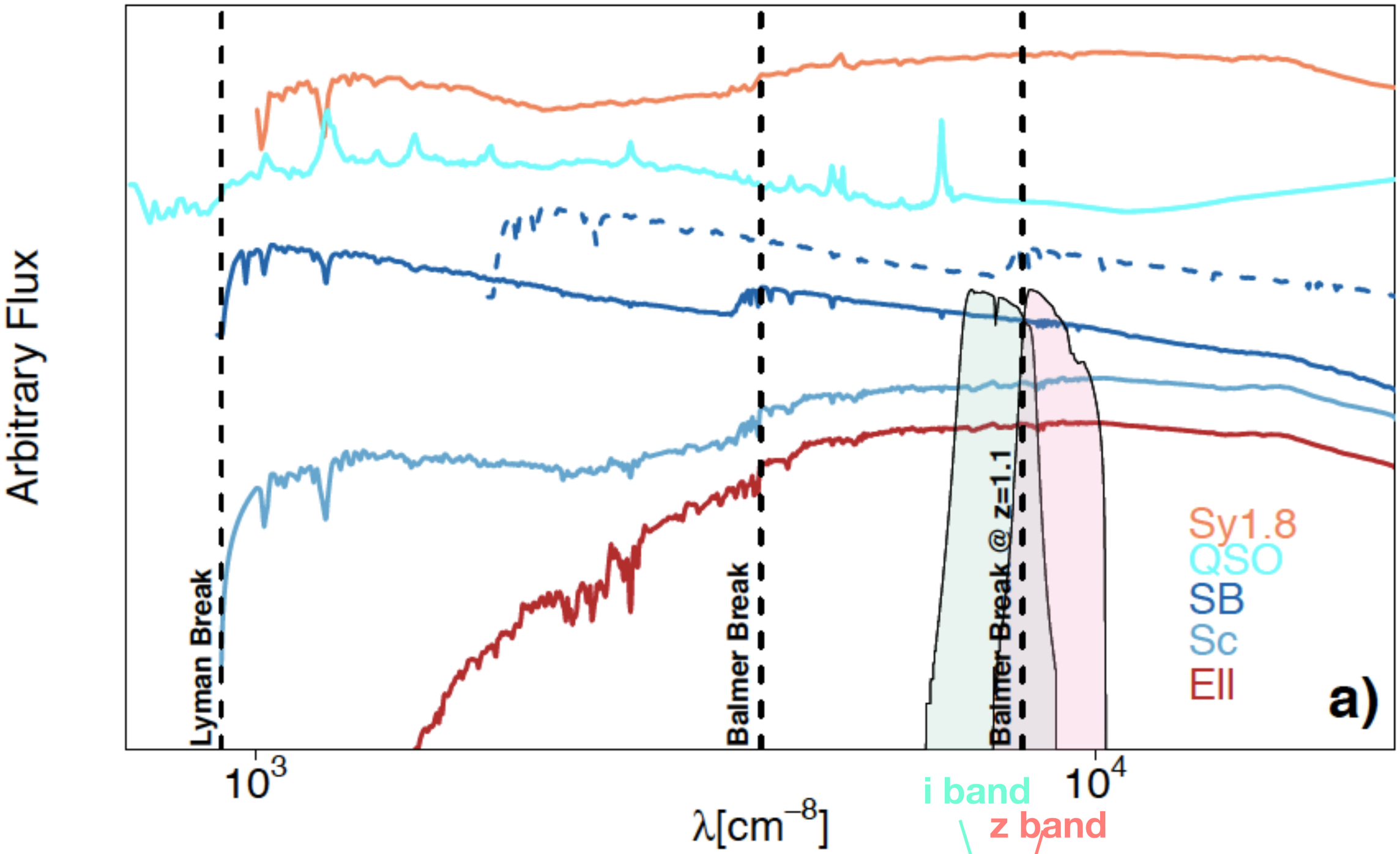
(resolved / unresolved ?)

What do we want:

- ☐ stellar mass
- ☐ stellar age / SFH / SFR
- ☐ metallicity (stellar / gas)
- ☐ dust mass / temperature
- ☐ AGN ?
- ☐ galaxy redshift
- ☐ ...

Photometric redshift

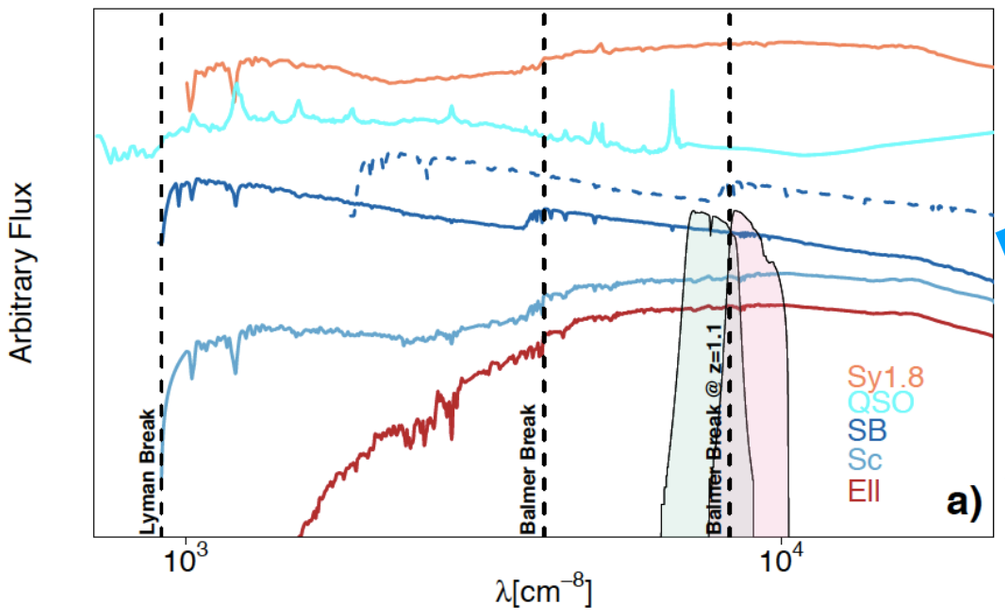
many approaches, but main principle is:

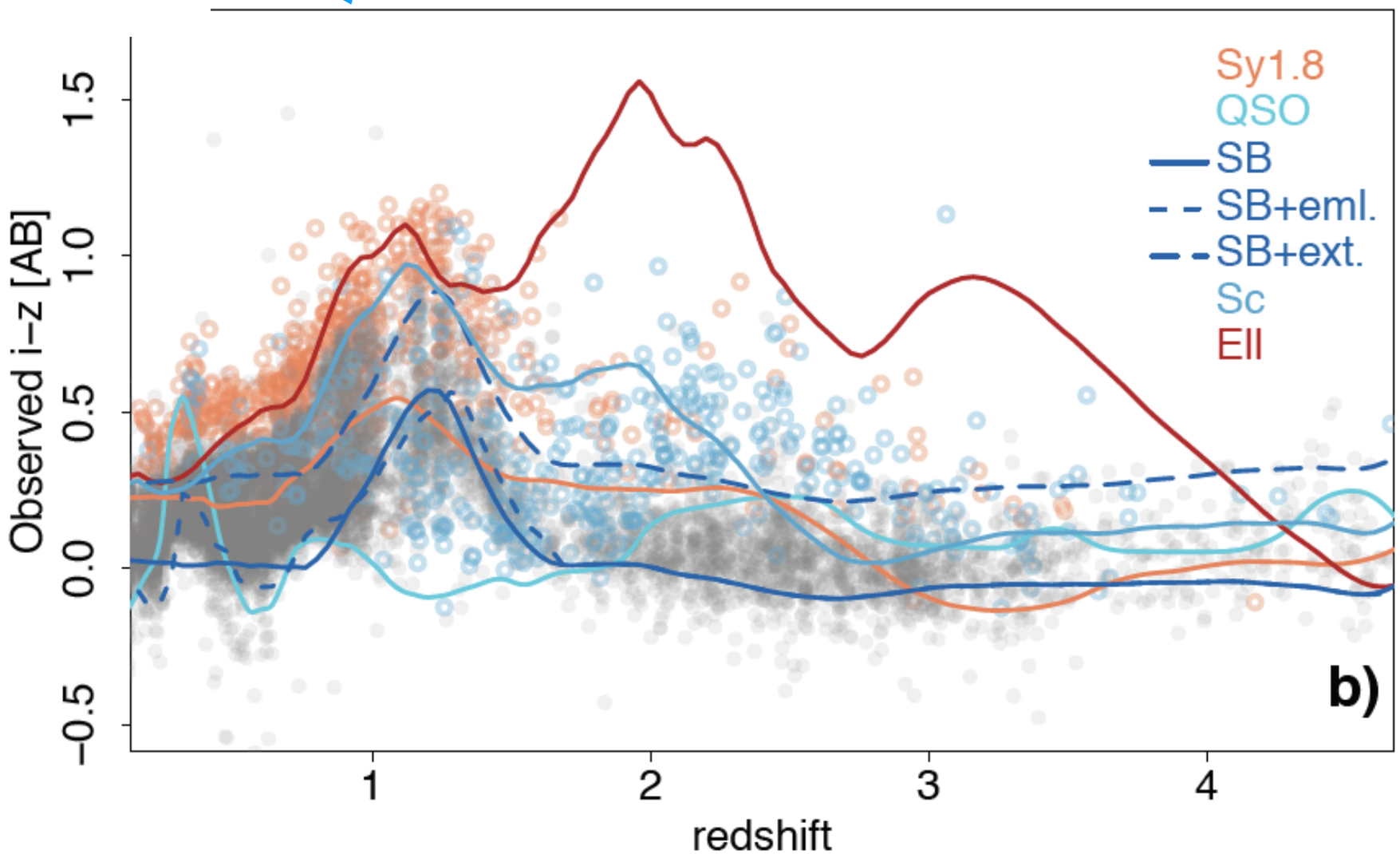


Salvato et al. 2018

one color: i - z (observed)

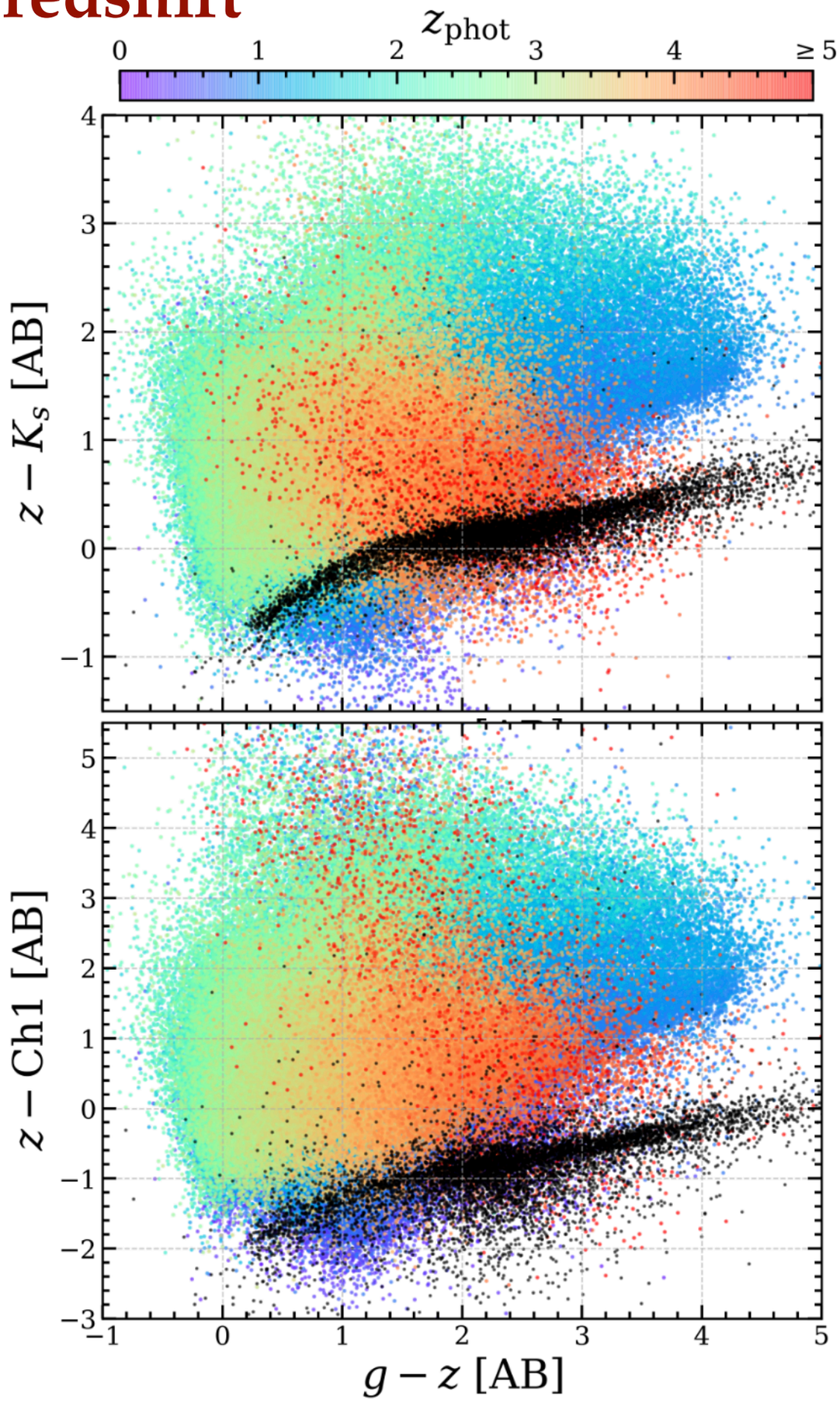
Photometric redshift





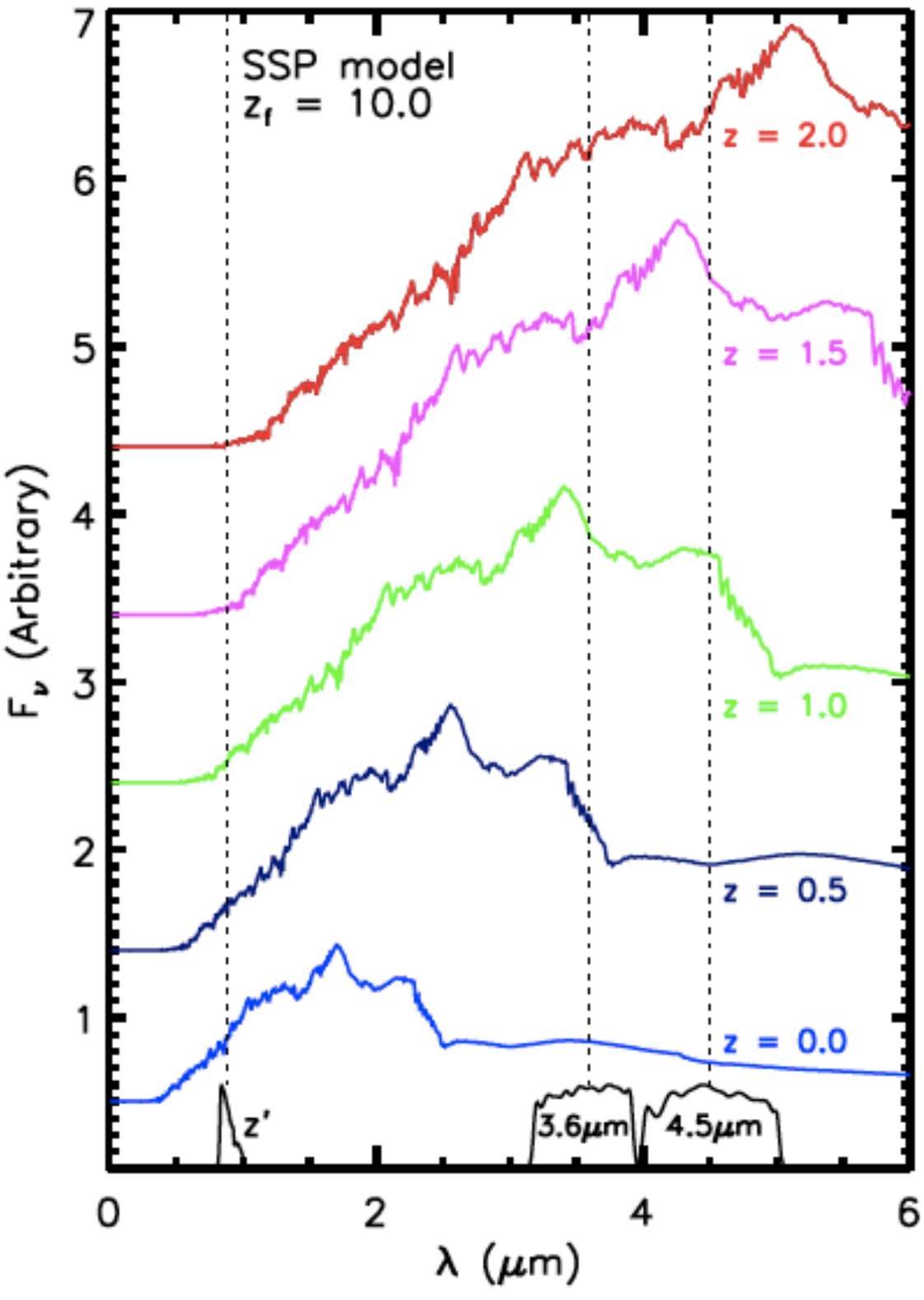
Salvato et al. 2018

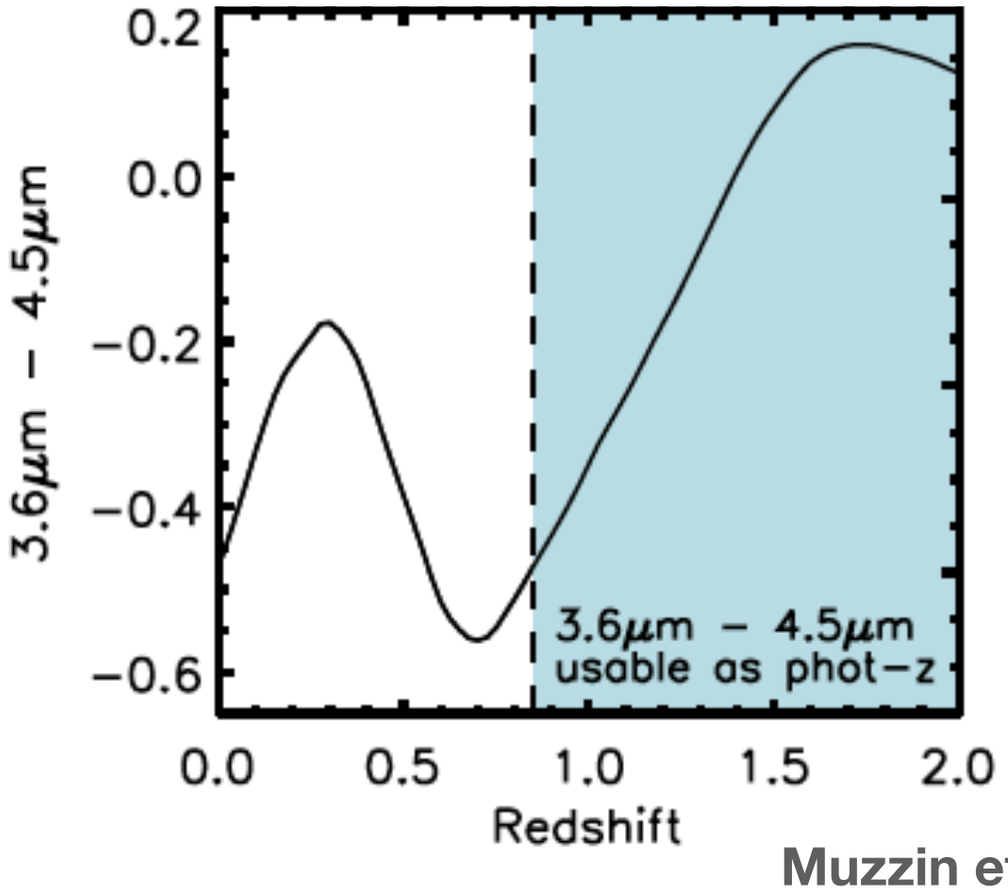
Photometric redshift



Photometric redshift

with one color…

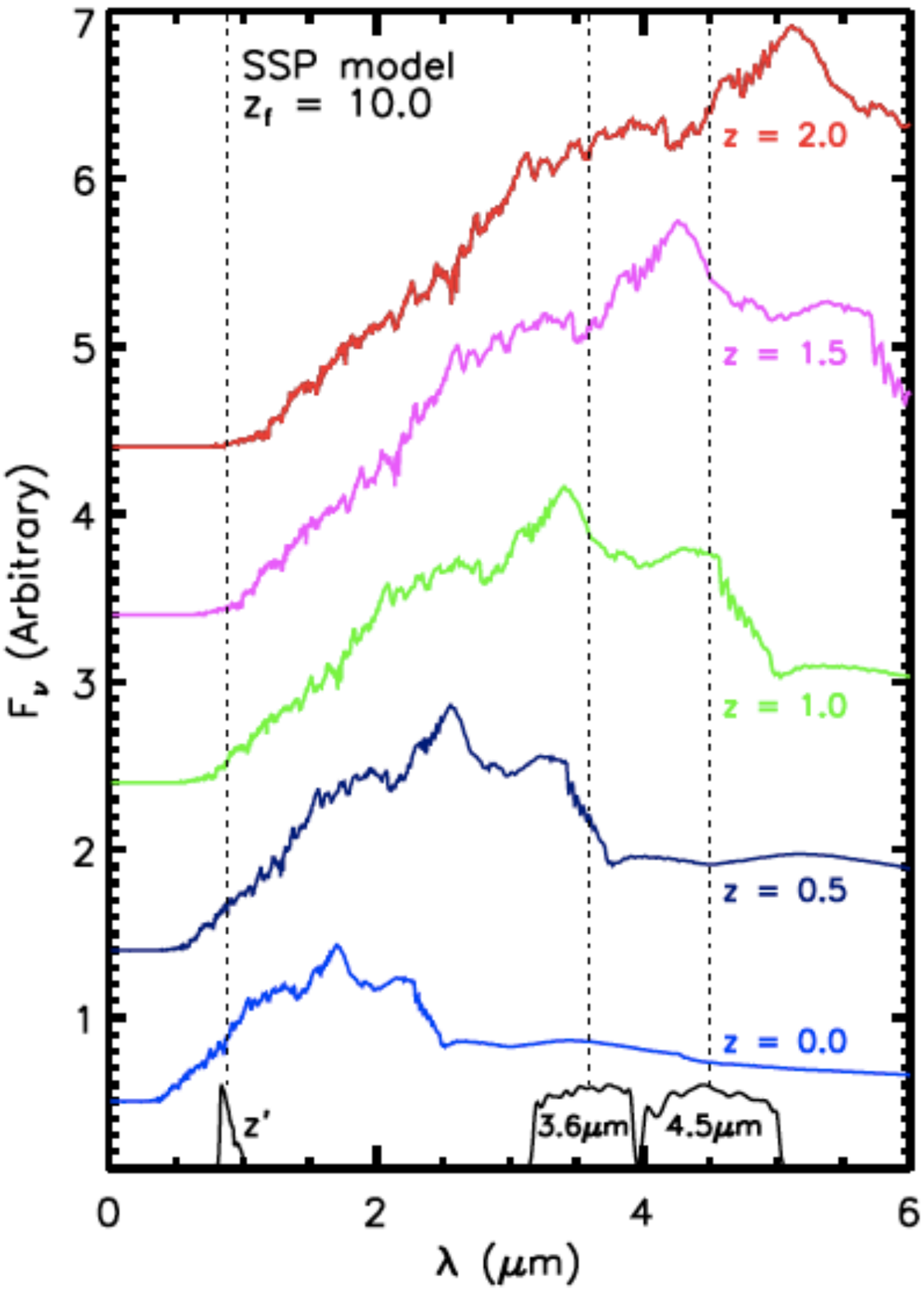




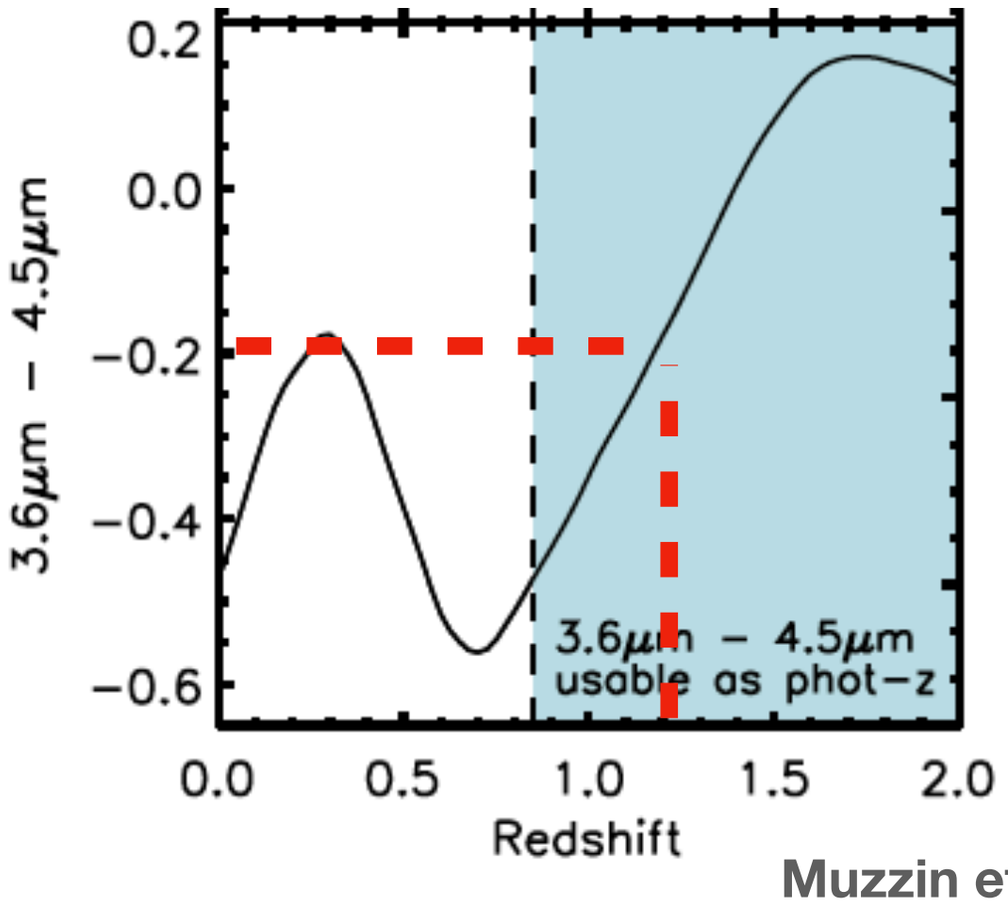
Muzzin et al. 2013

Photometric redshift

with one color…



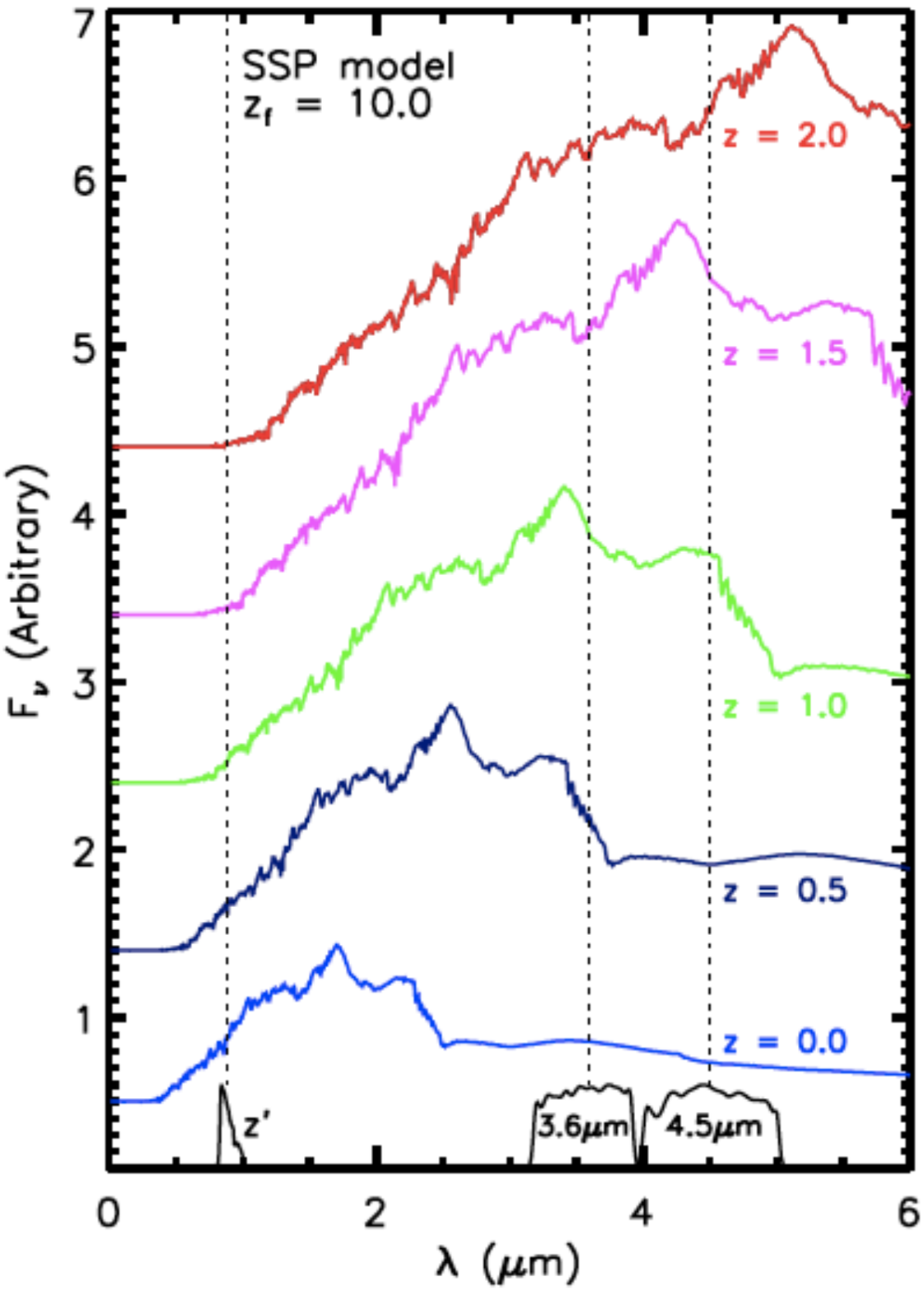
z>1.2

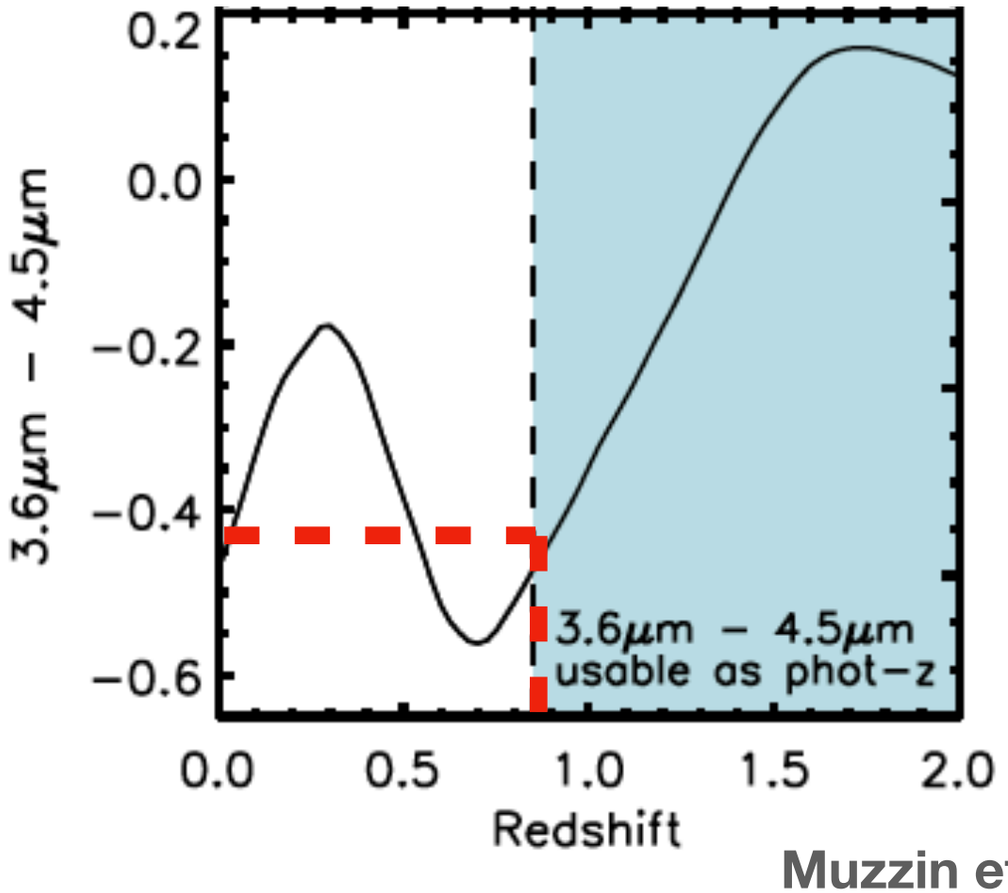


Muzzin et al. 2013

Photometric redshift

with one color…

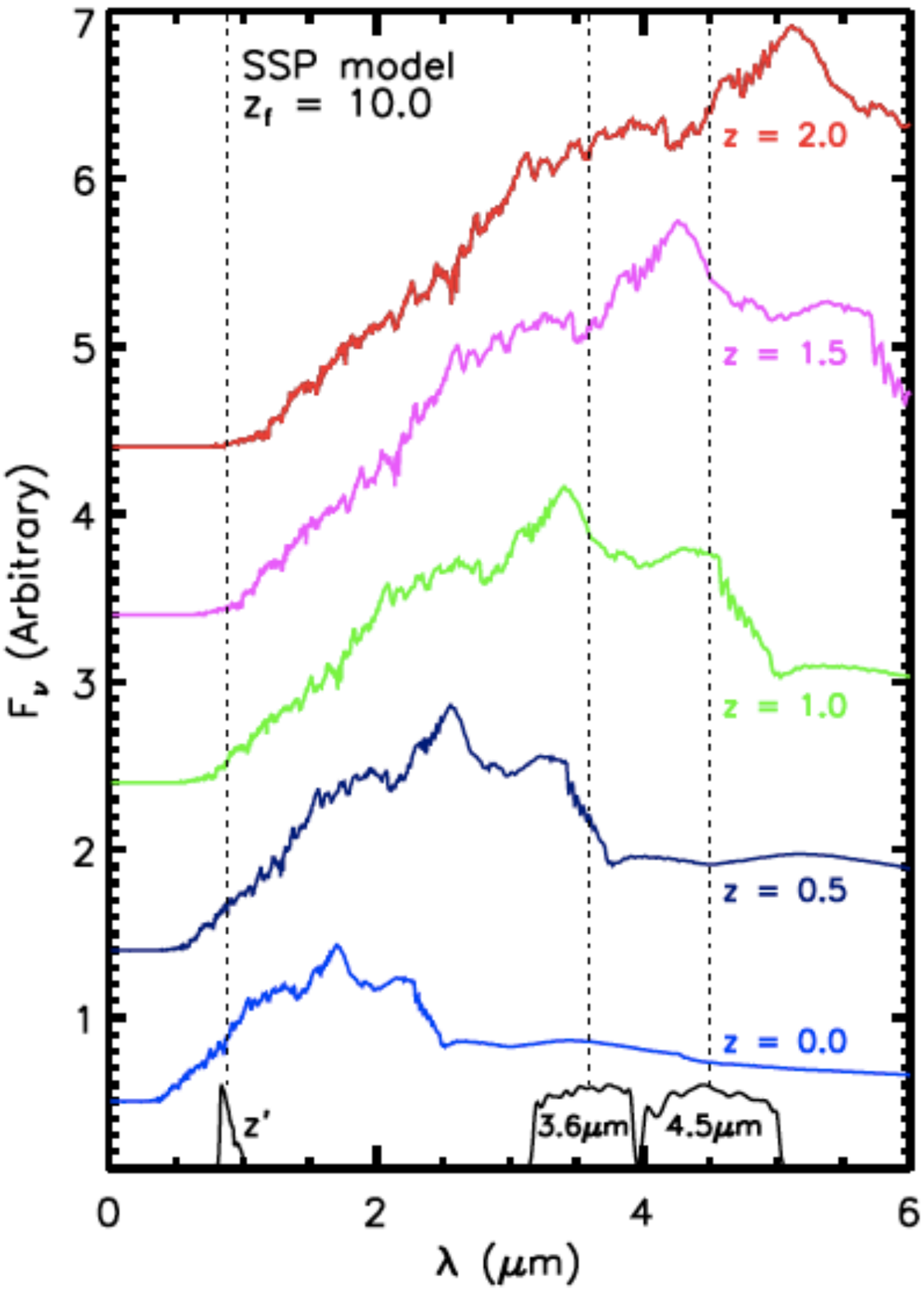


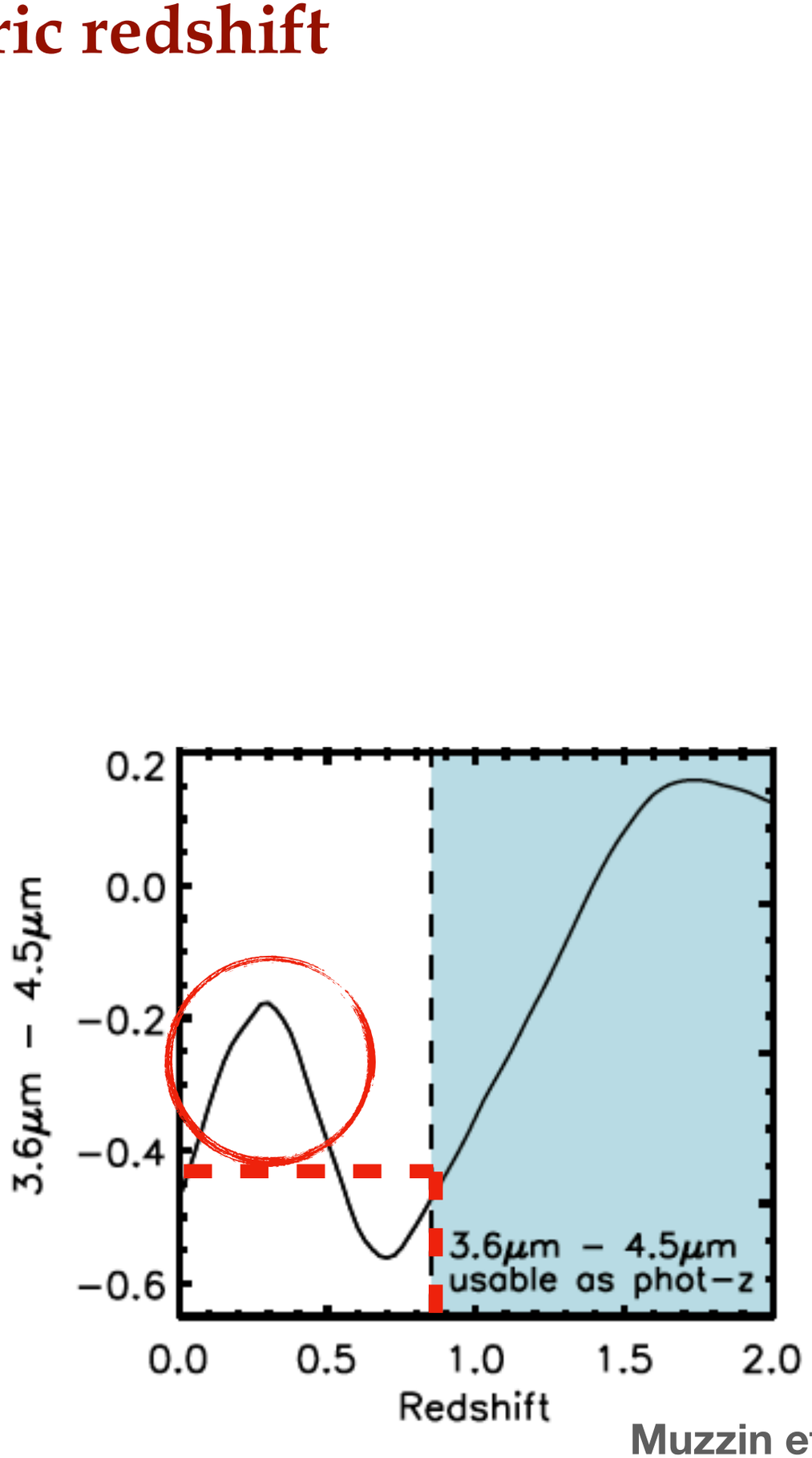


Muzzin et al. 2013

Photometric redshift

with one color…

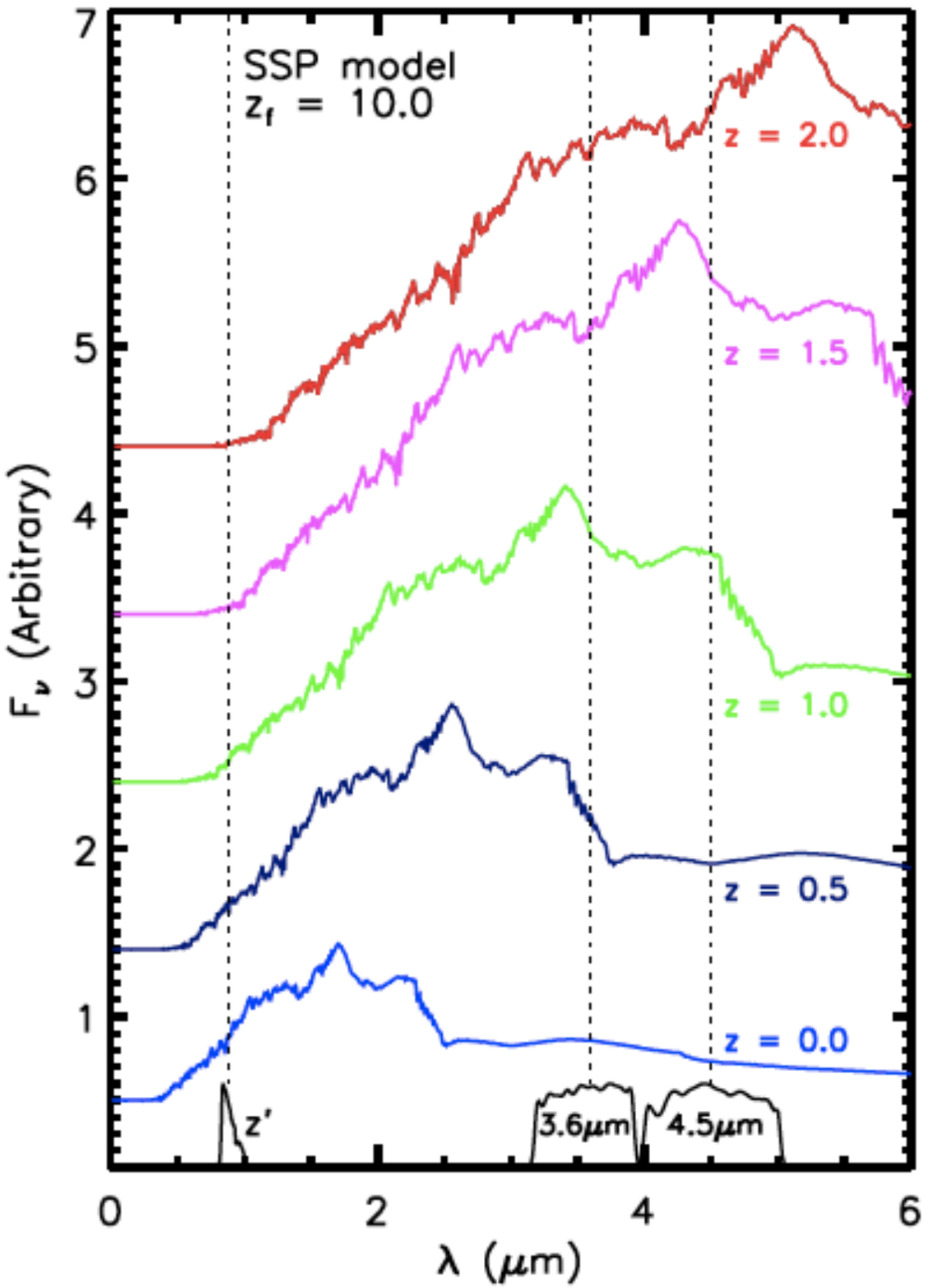




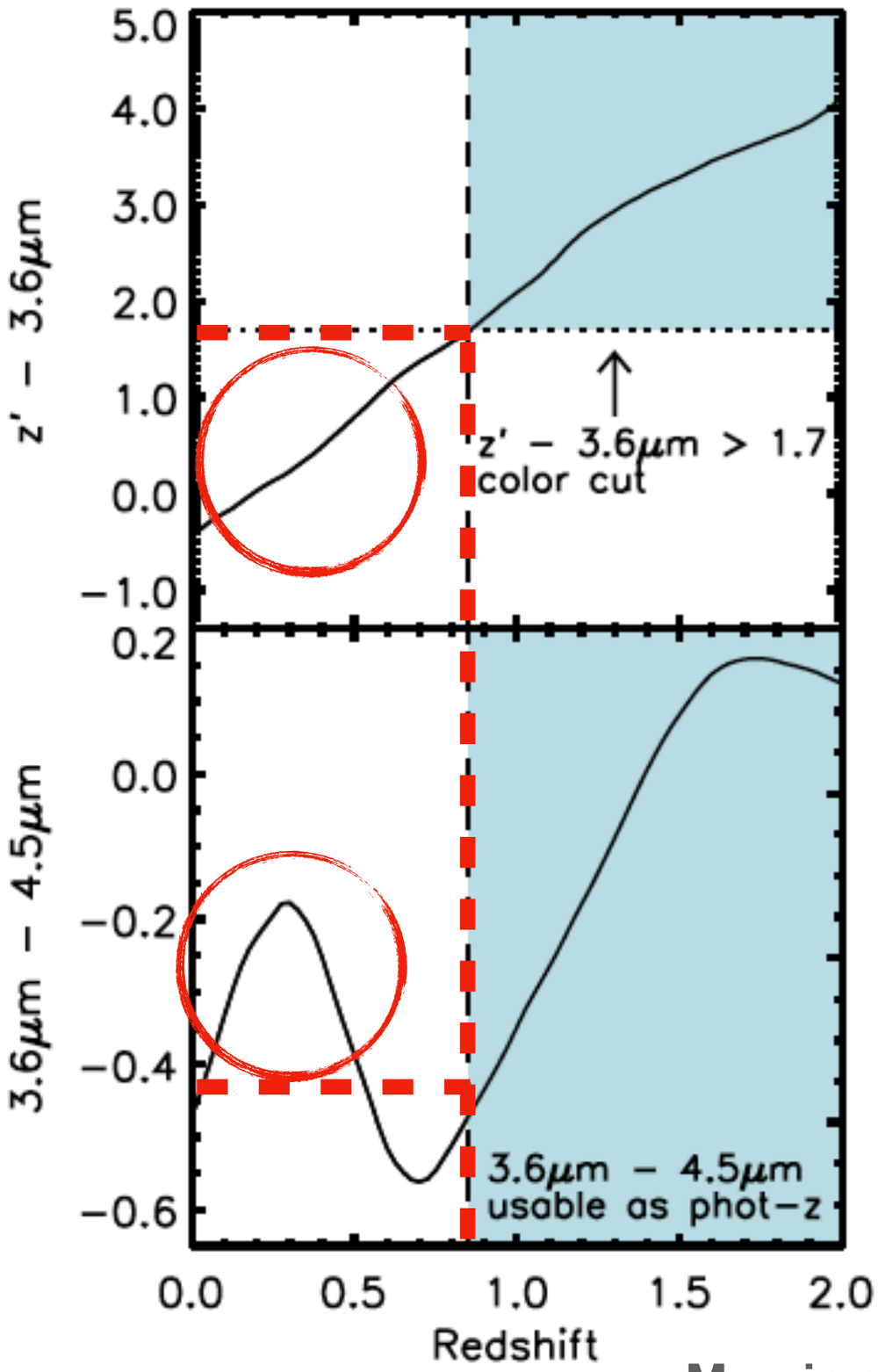
Muzzin et al. 2013

Photometric redshift

… or maybe two



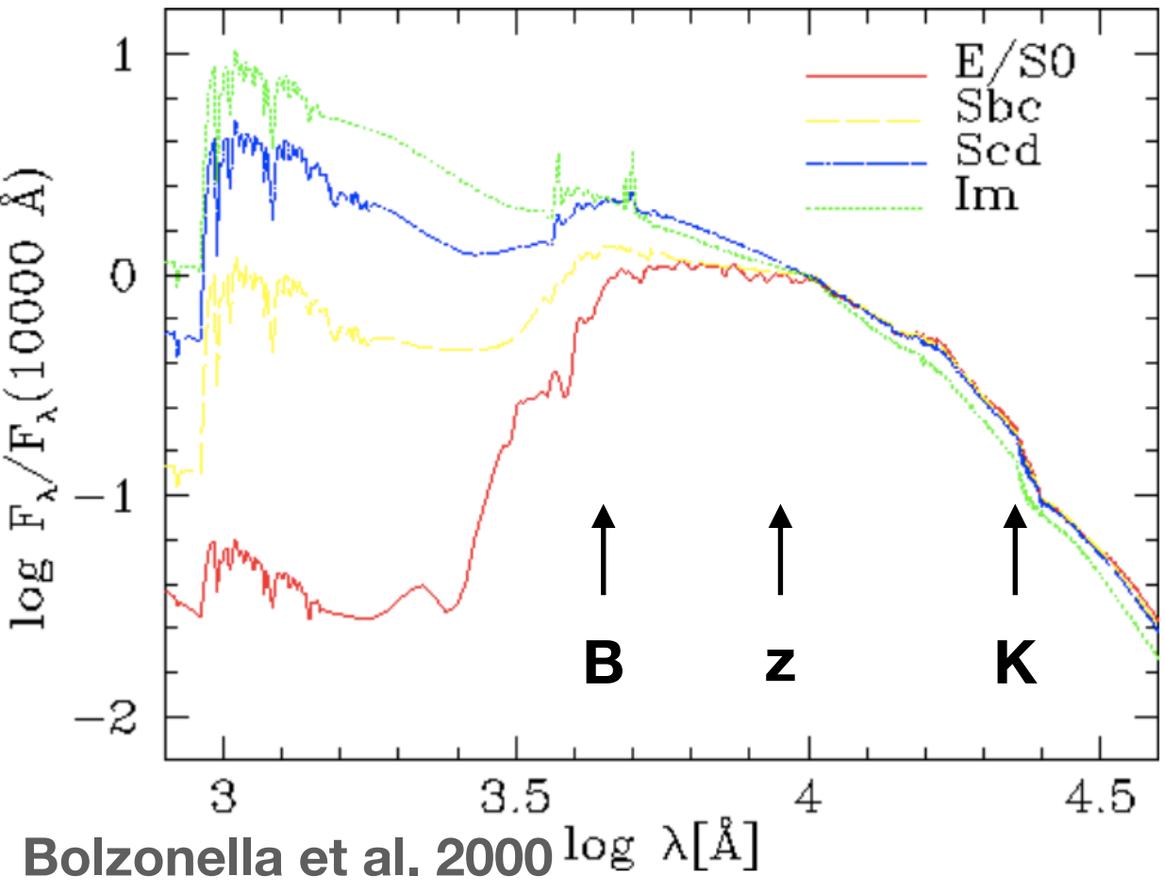
z>0.9



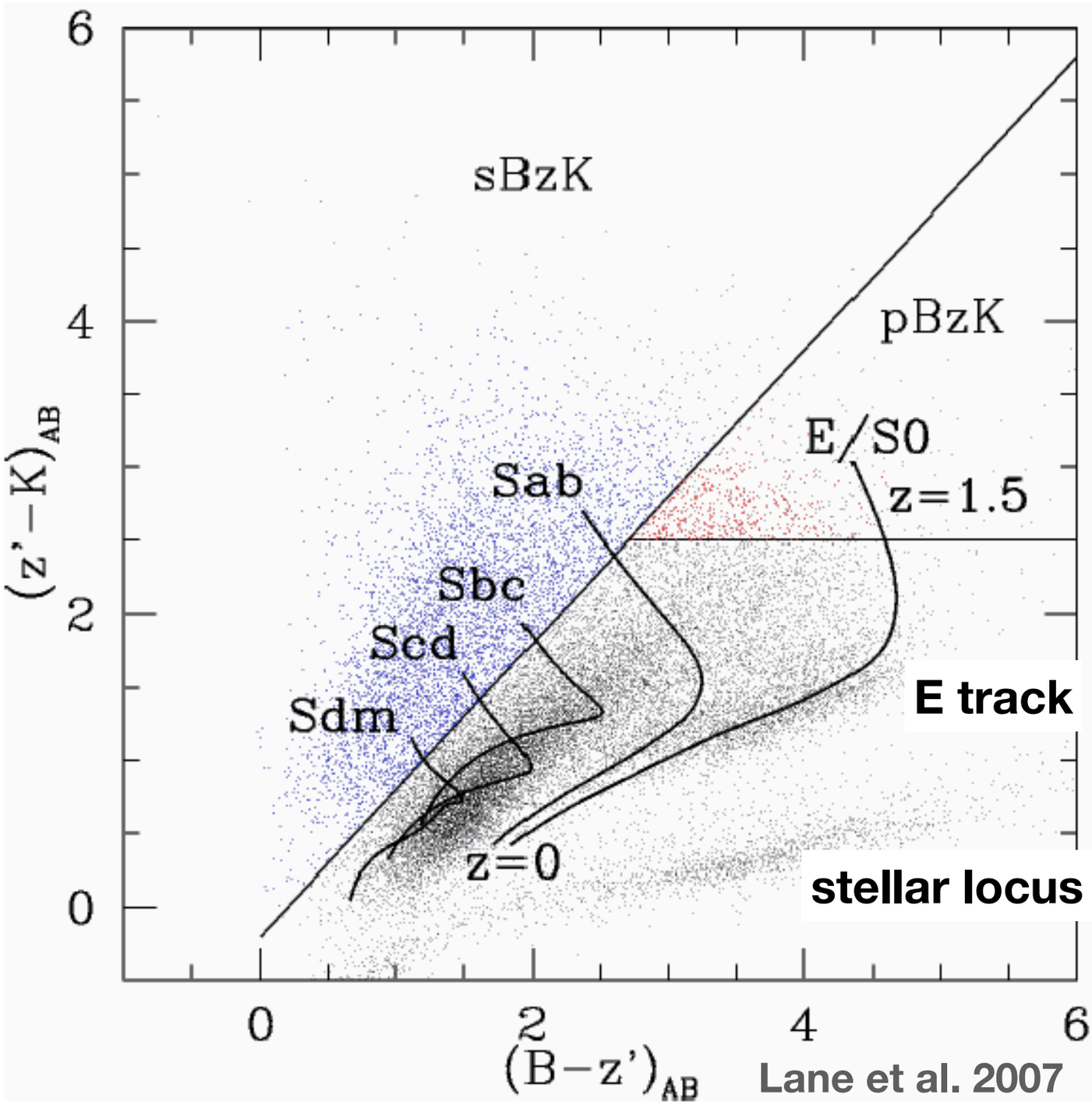
Muzzin et al. 2013

Photometric redshift

… or maybe two



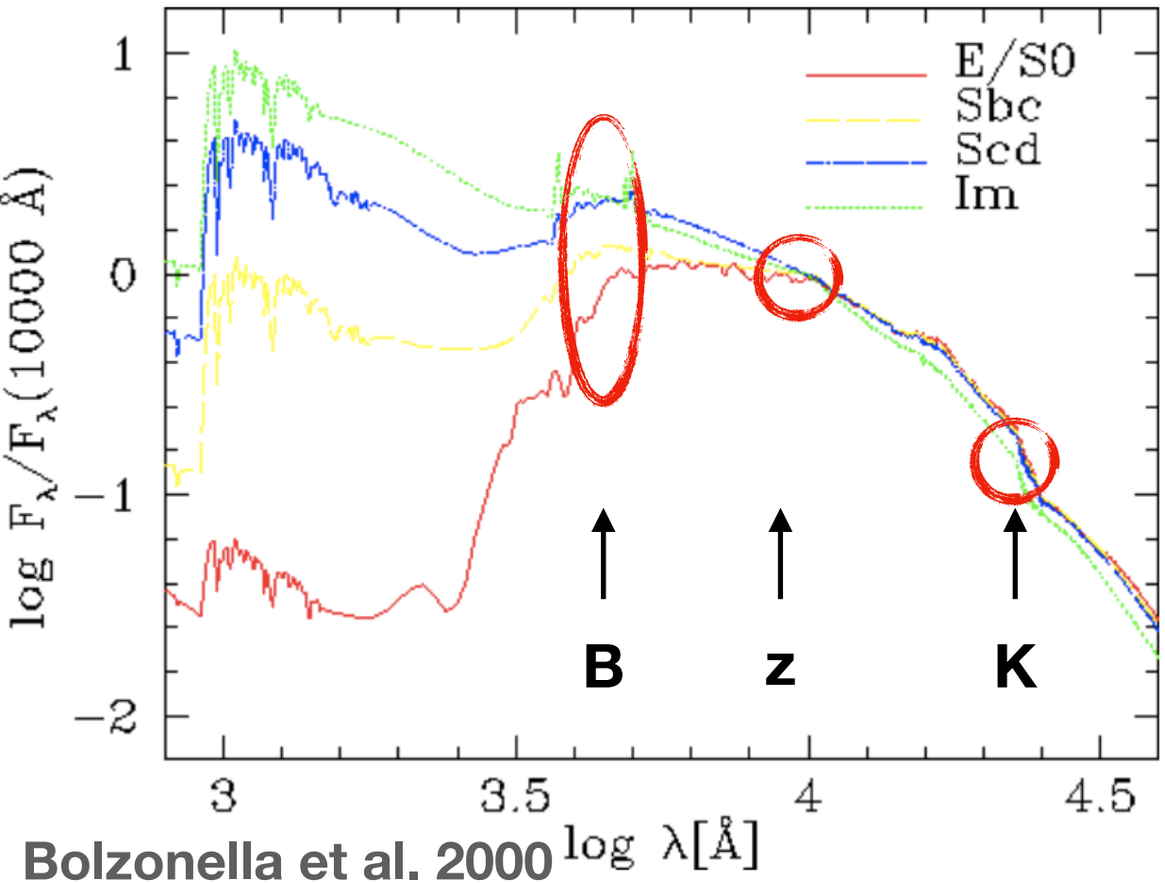
Bolzonella et al. 2000



Lane et al. 2007

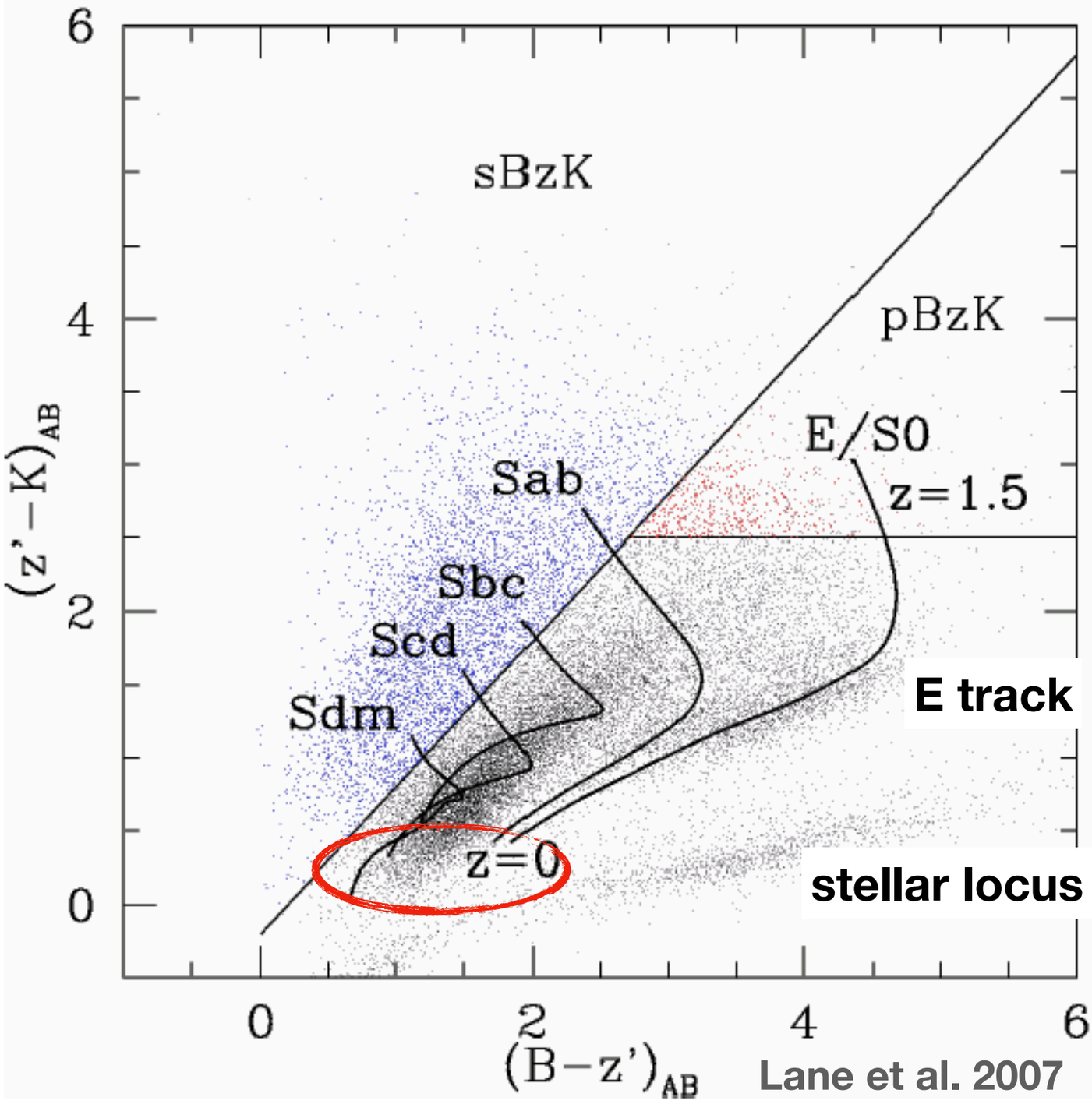
Photometric redshift

… or maybe two



Bolzonella et al. 2000

z>1.5

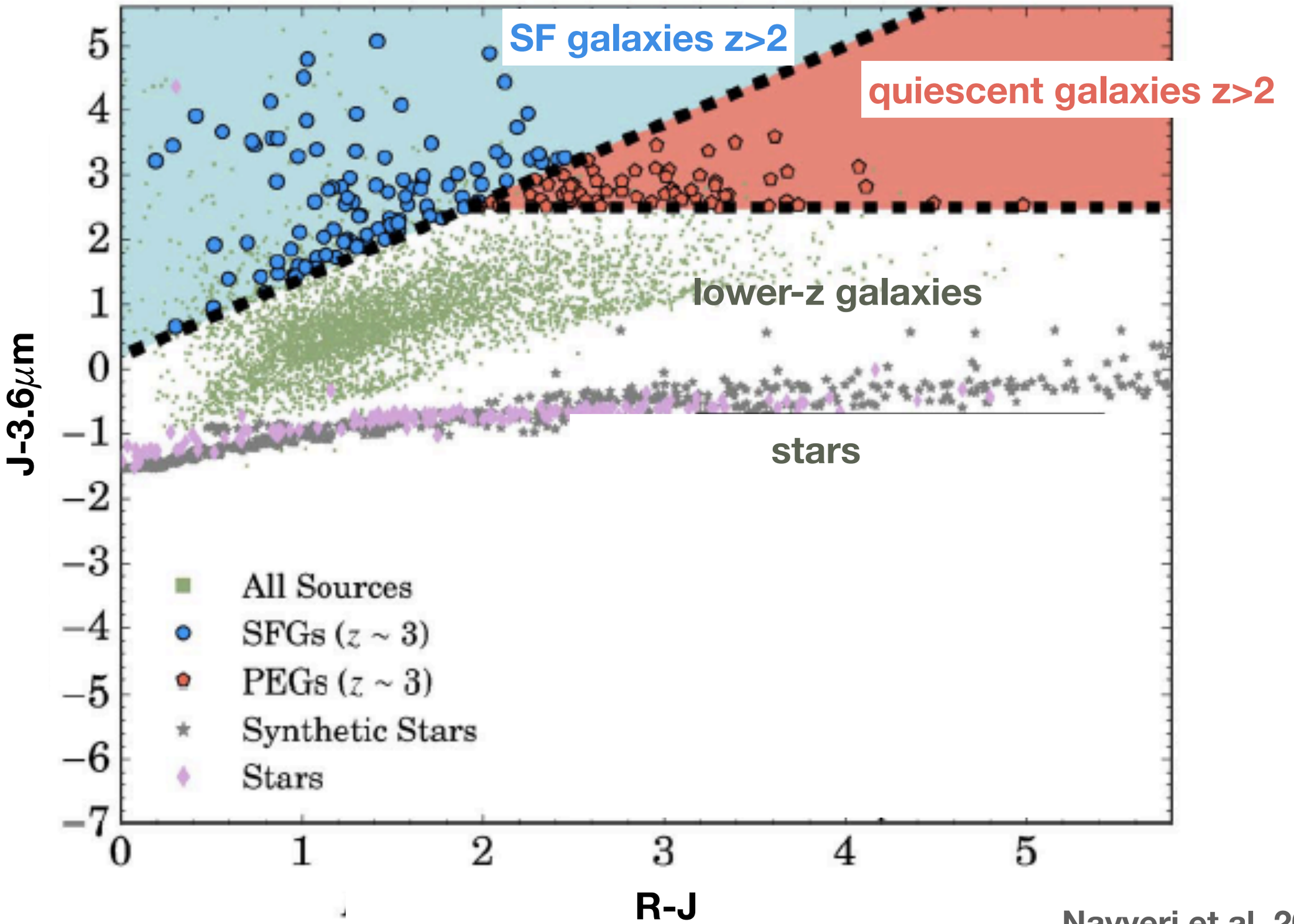


Lane et al. 2007

Photometric redshift

… or maybe two

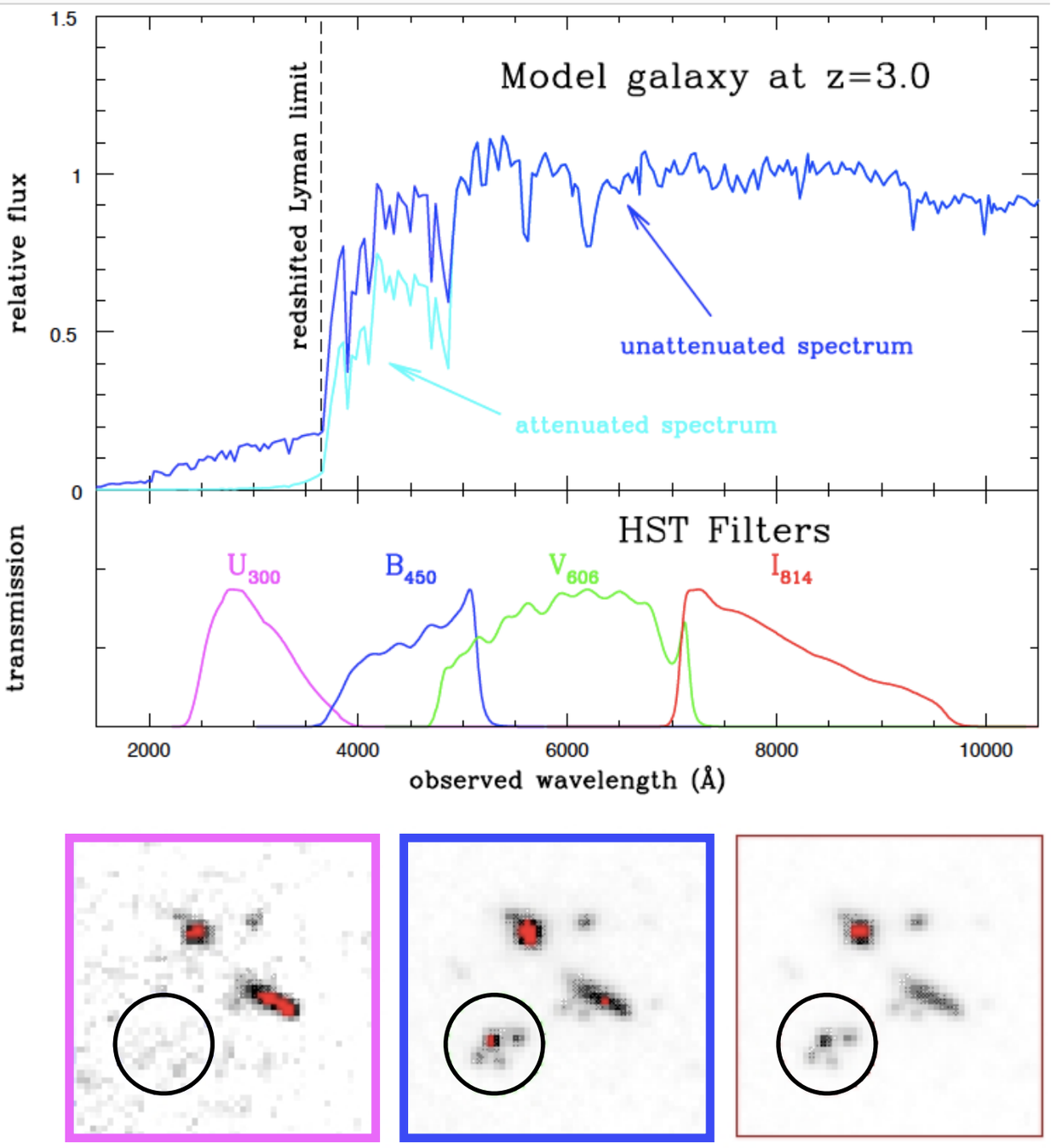
z>2



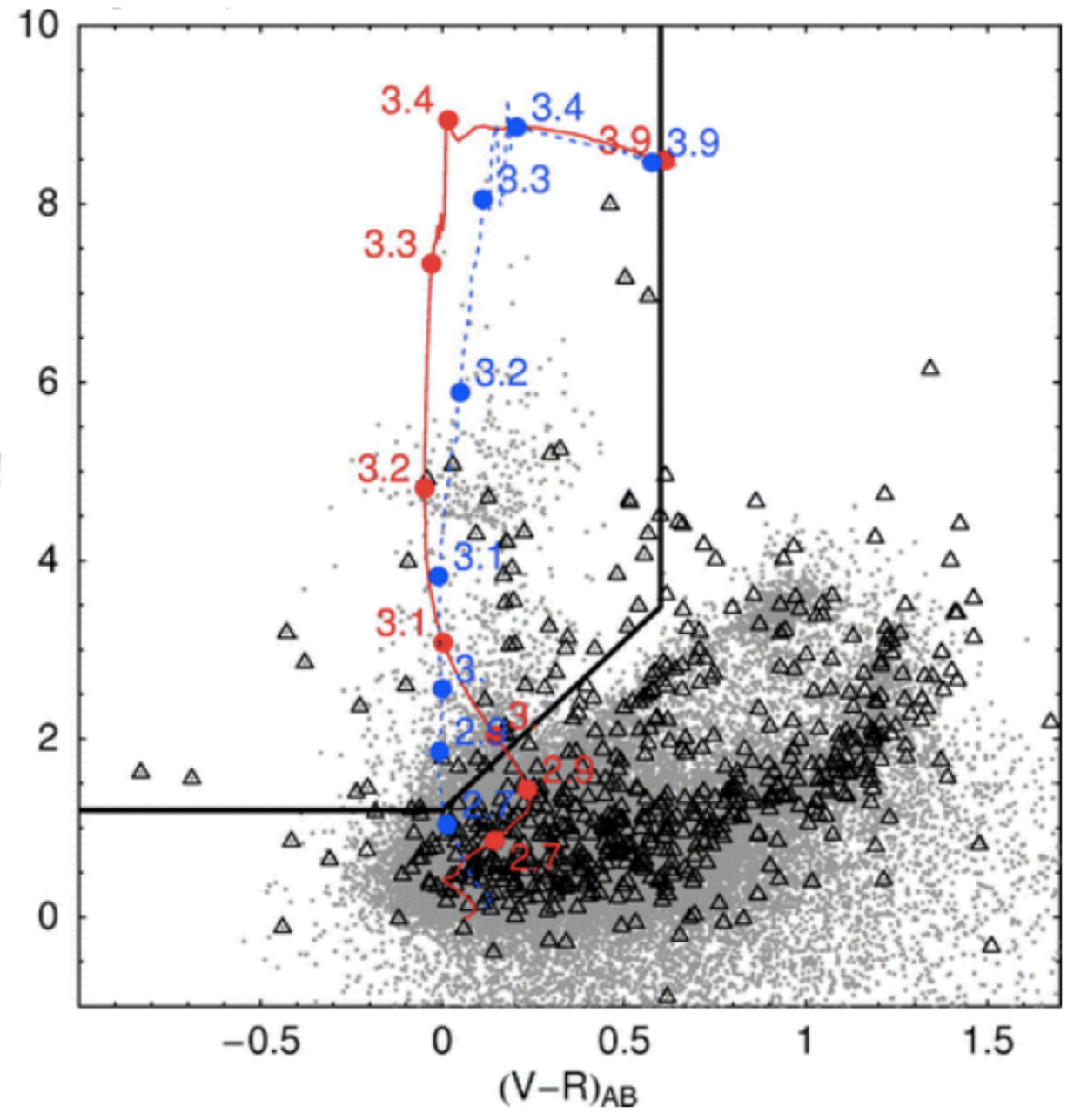
Nayyeri et al. 2017

Photometric redshift

… or maybe two



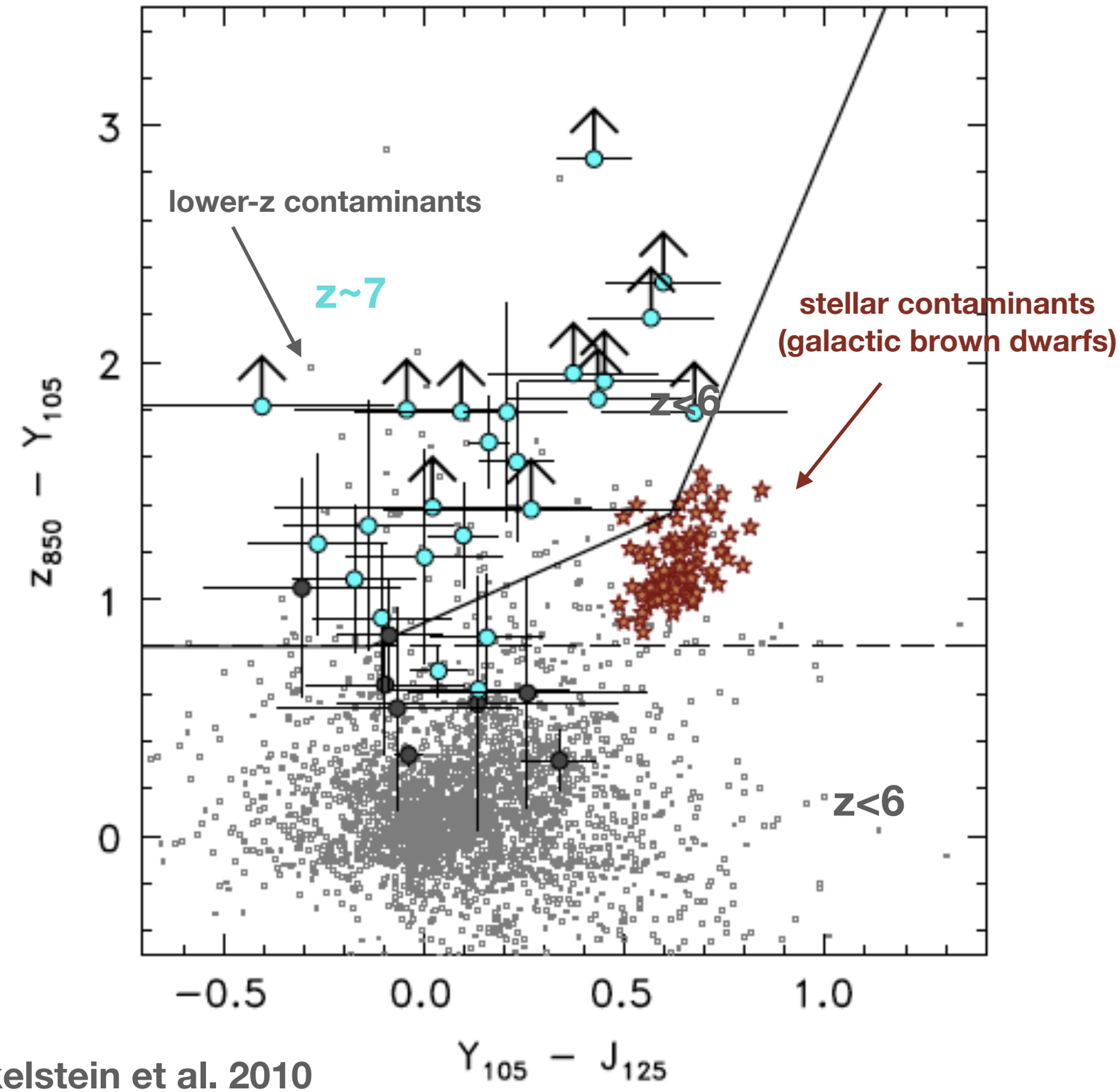
z>3



Steidel et al. 1996, Dickinson 1998

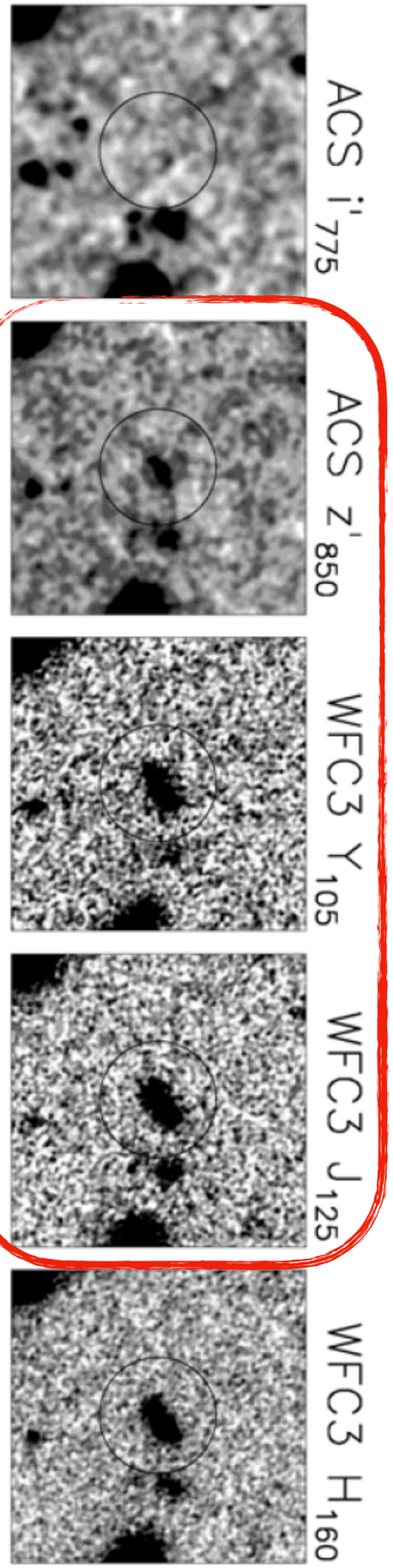
Photometric redshift

… or maybe two



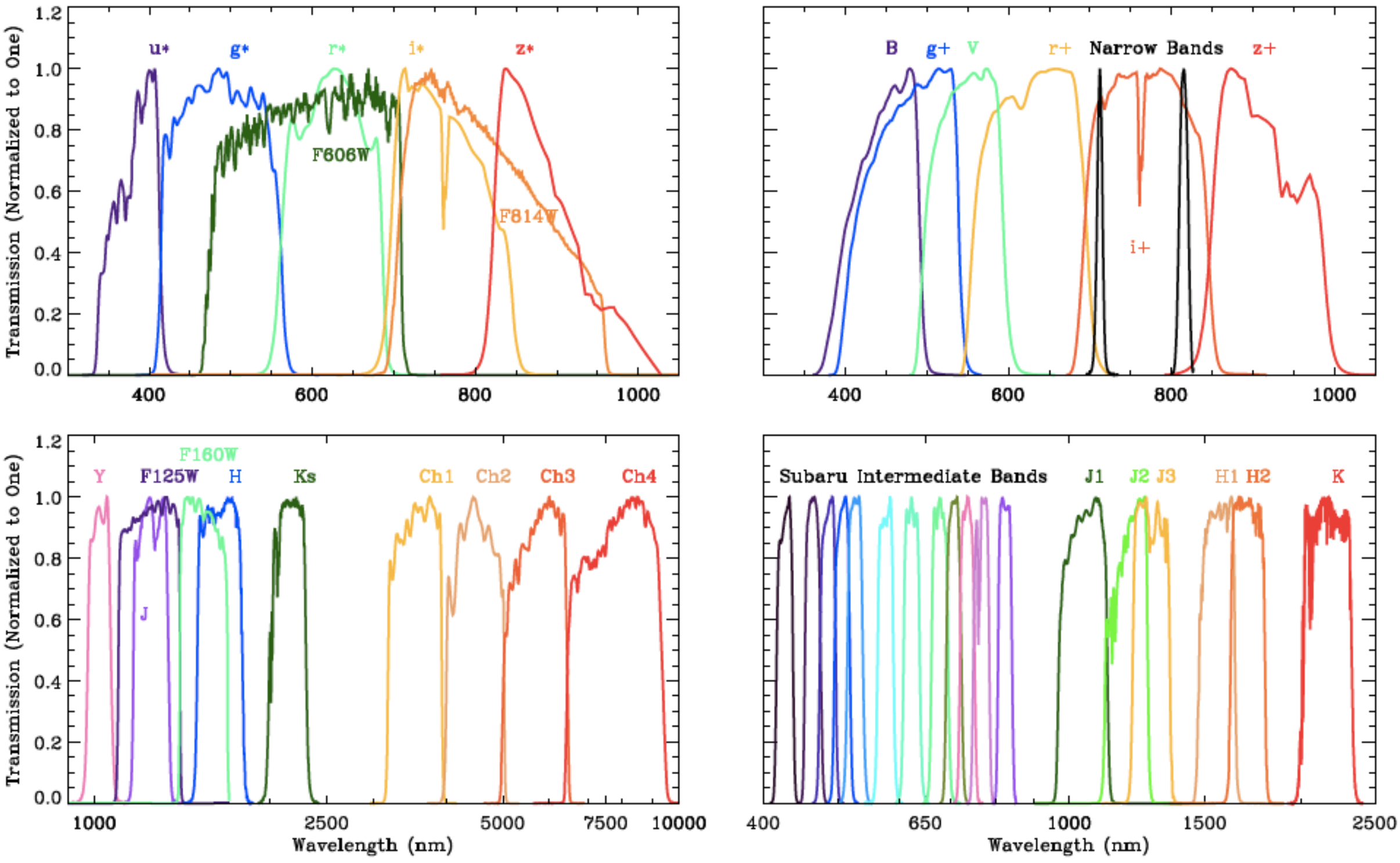
Finkelstein et al. 2010

z>6



Photometric redshift

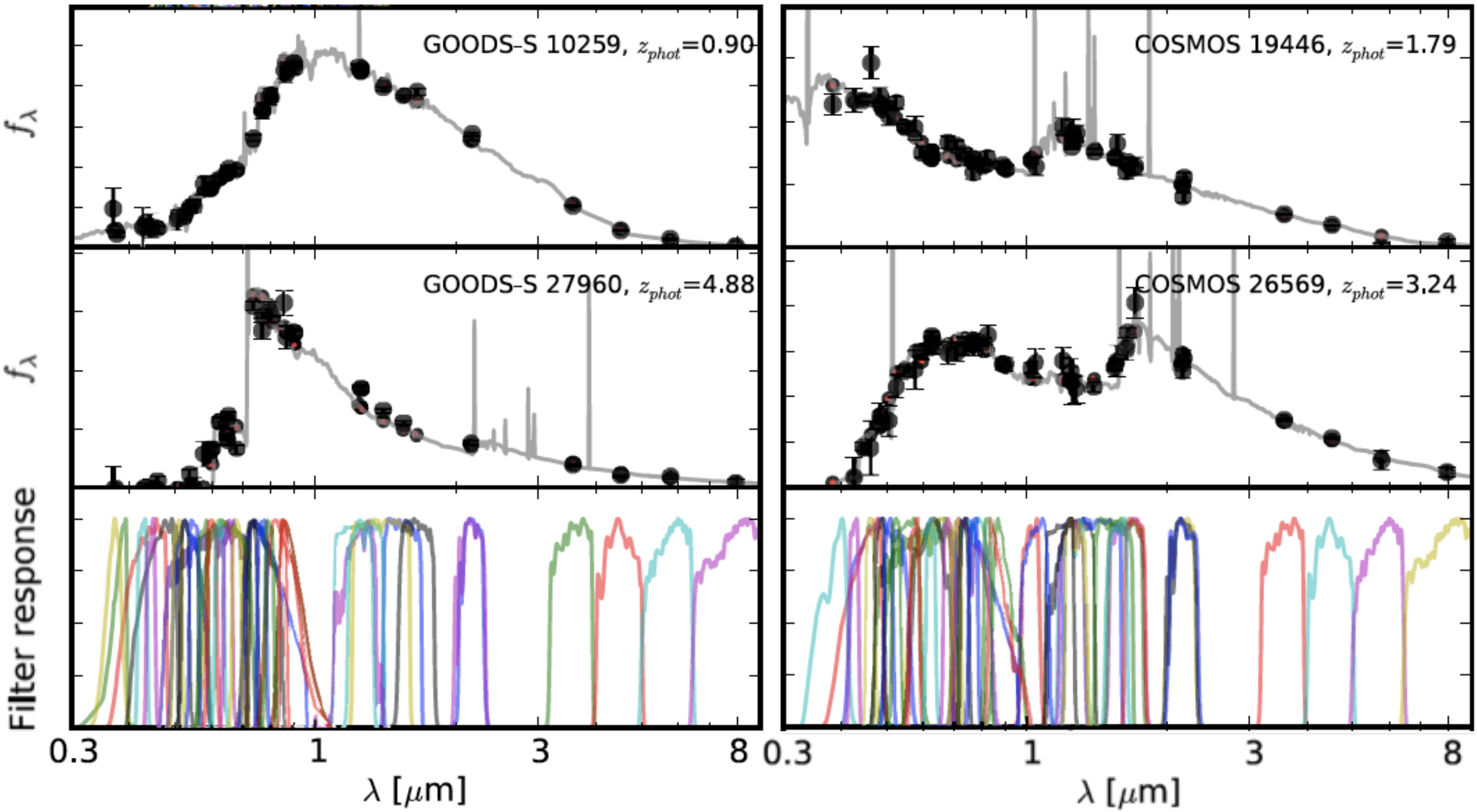
but in the best studied extragalactic deep fields, much more than two colors…



Nayyeri et al. 2017

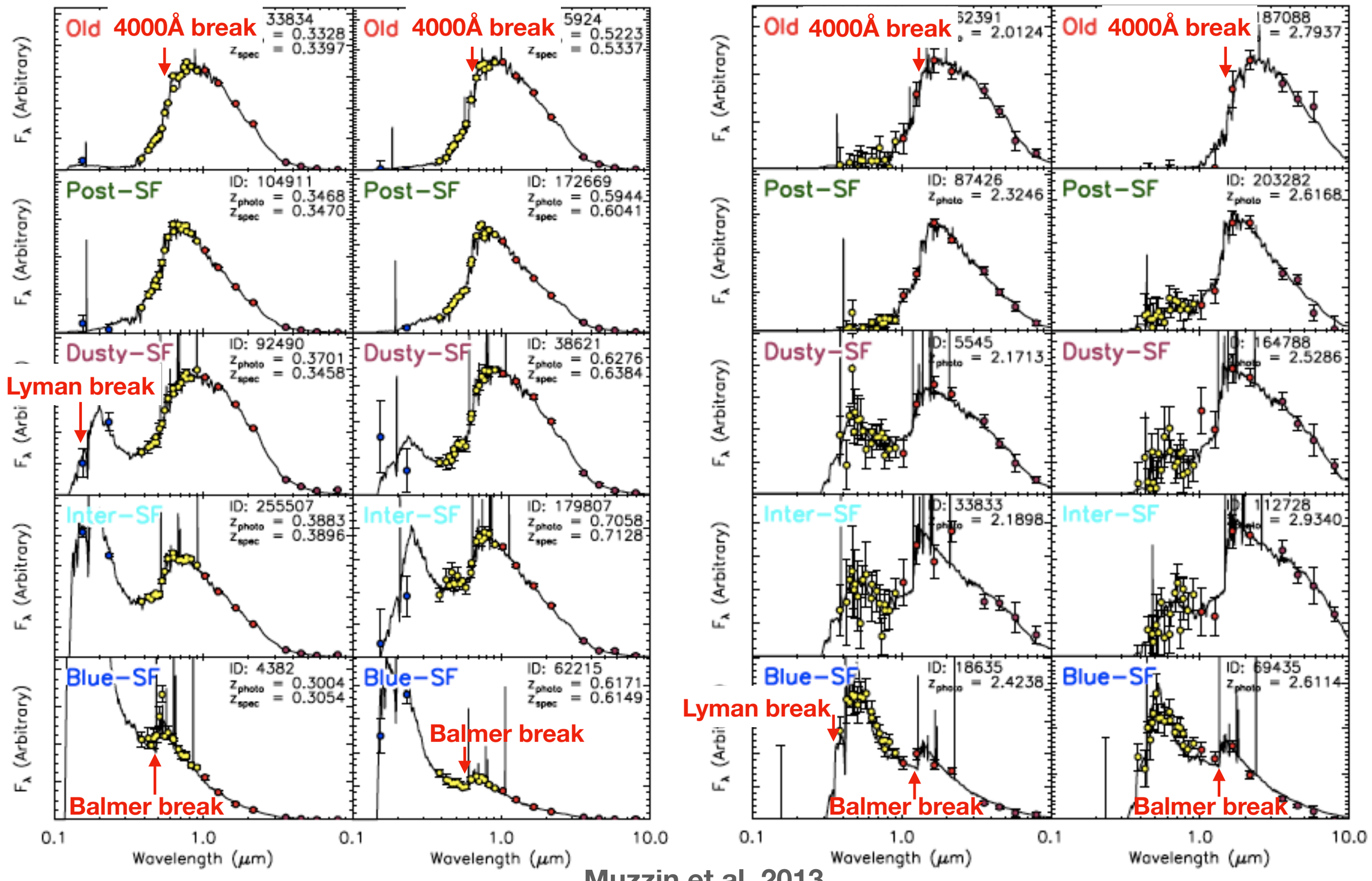
Photometric redshift

going full spectral coverage



Skelton et al. 201

Photometric redshift

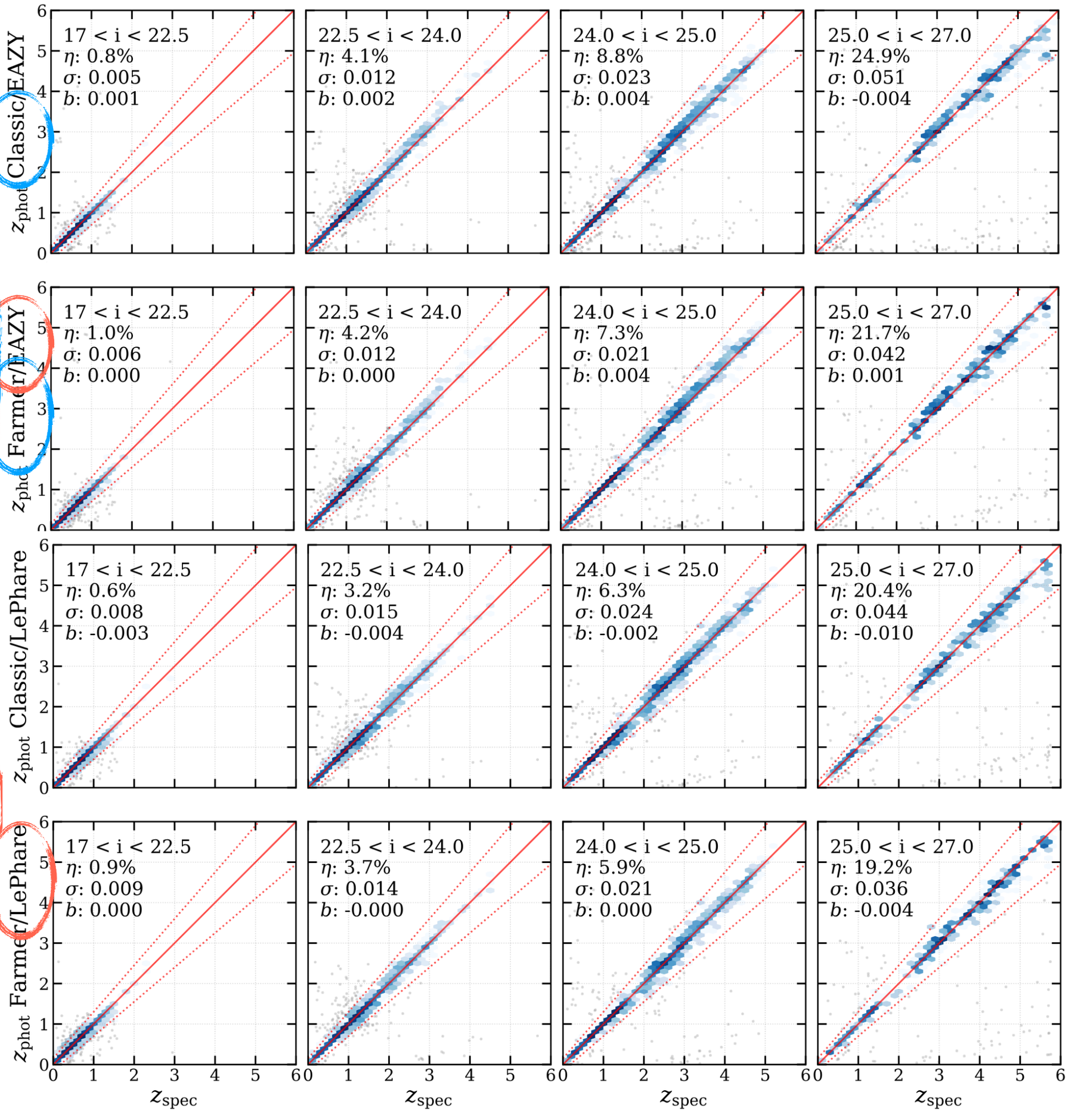


Muzzin et al. 2013

Photo-z accuracies

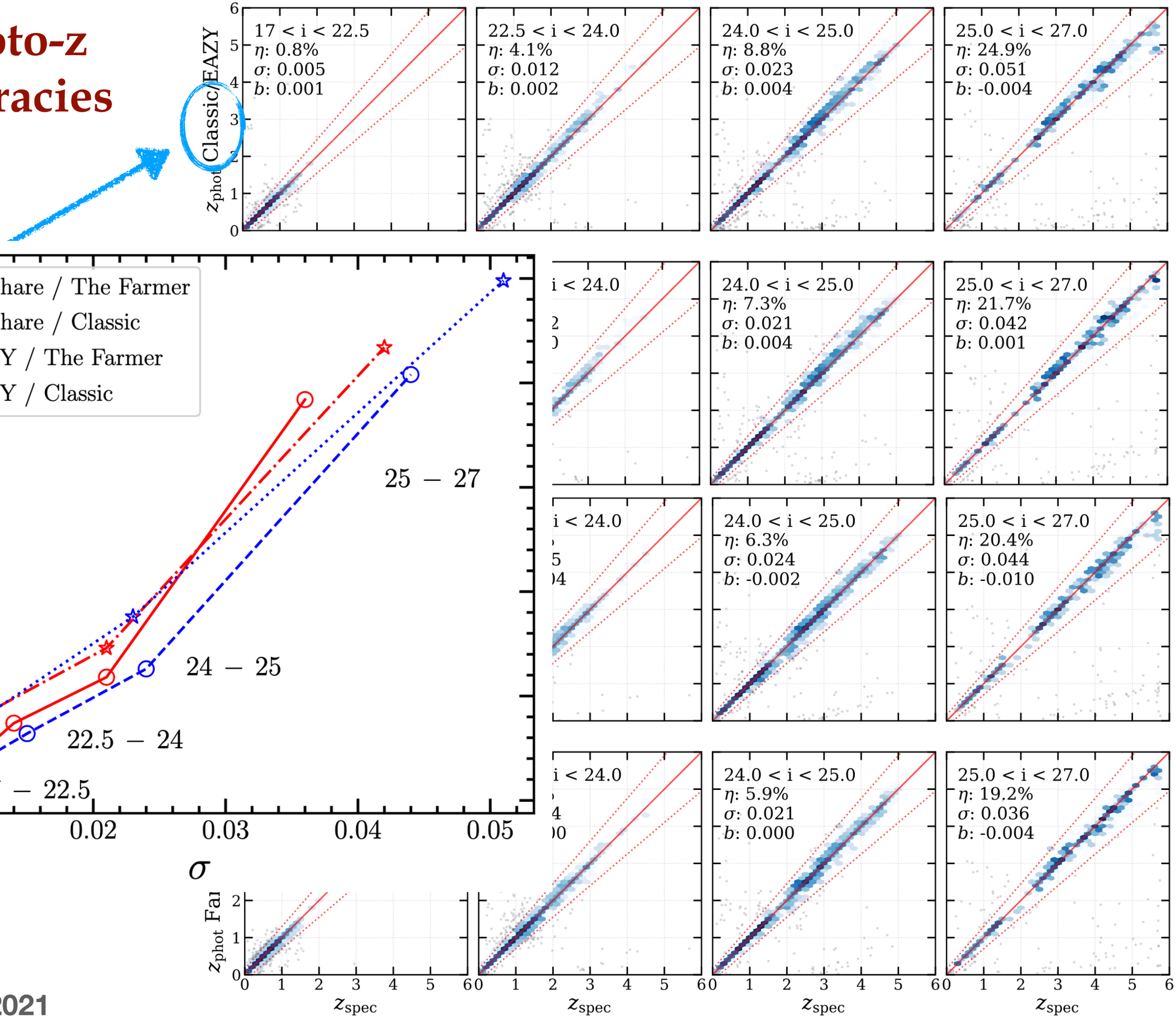
two different
SED determinations
(photometric measurements)

two different
photo-z codes



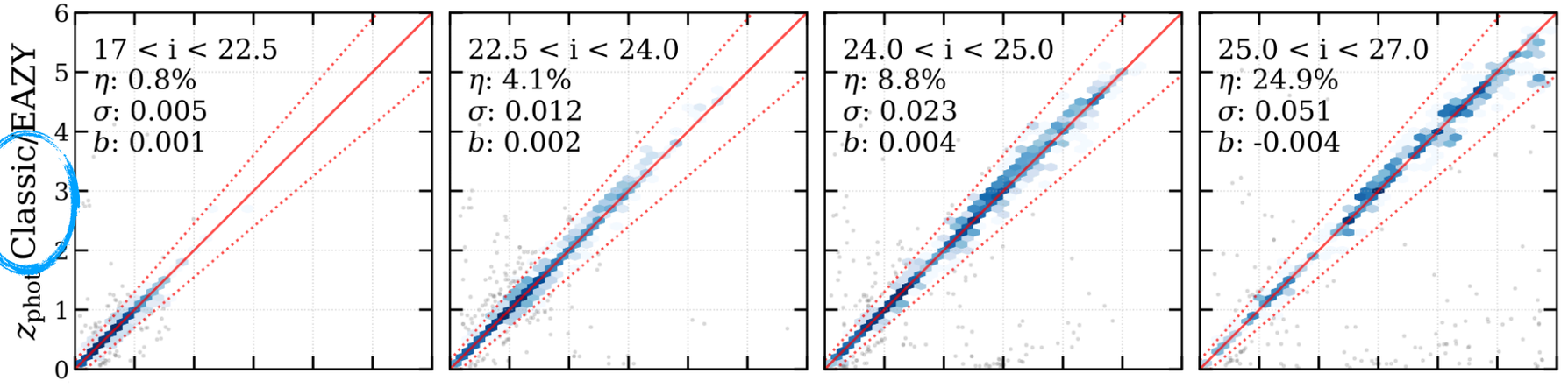
Weaver et al. 2021

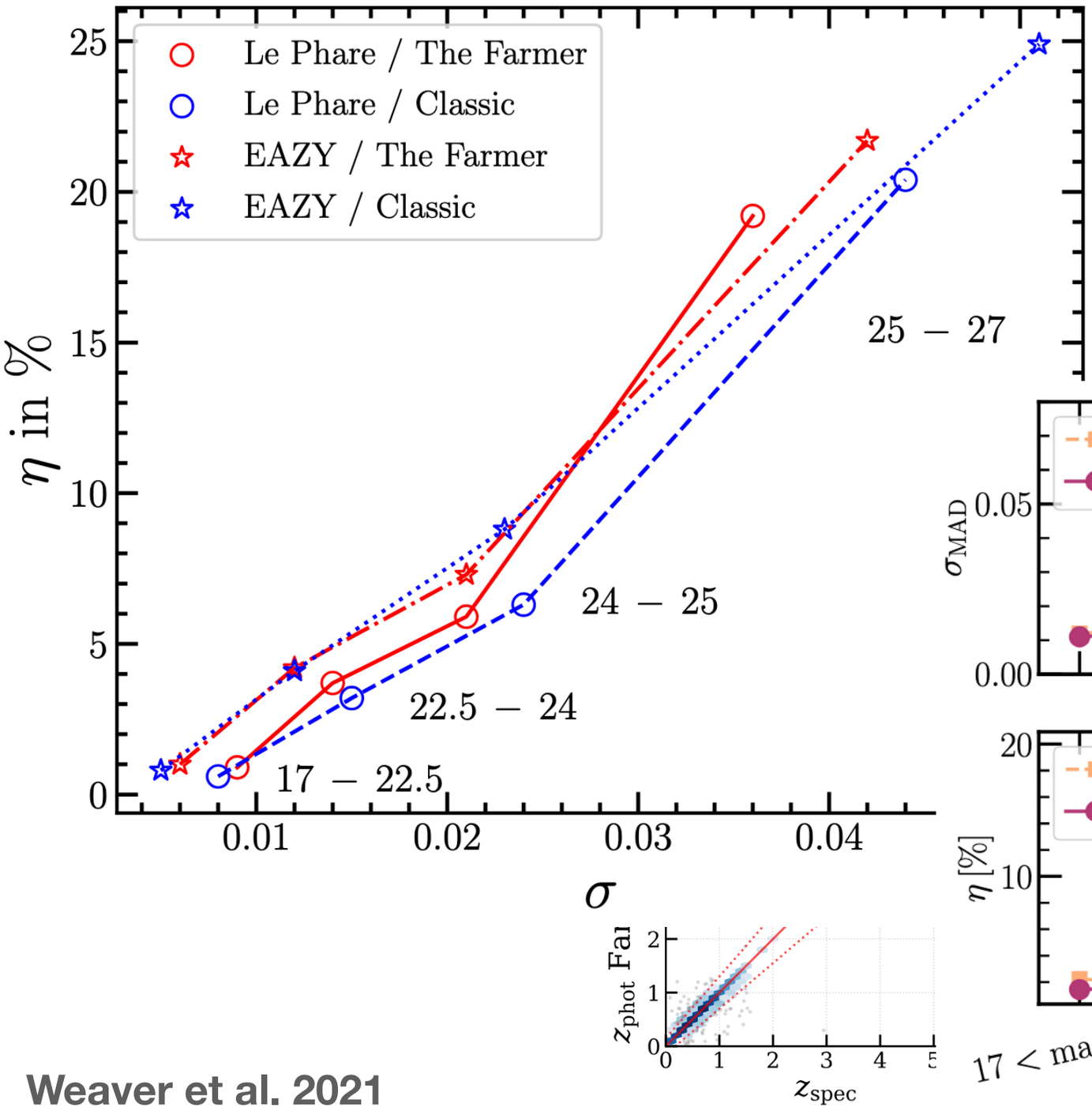
Photo-z accuracies

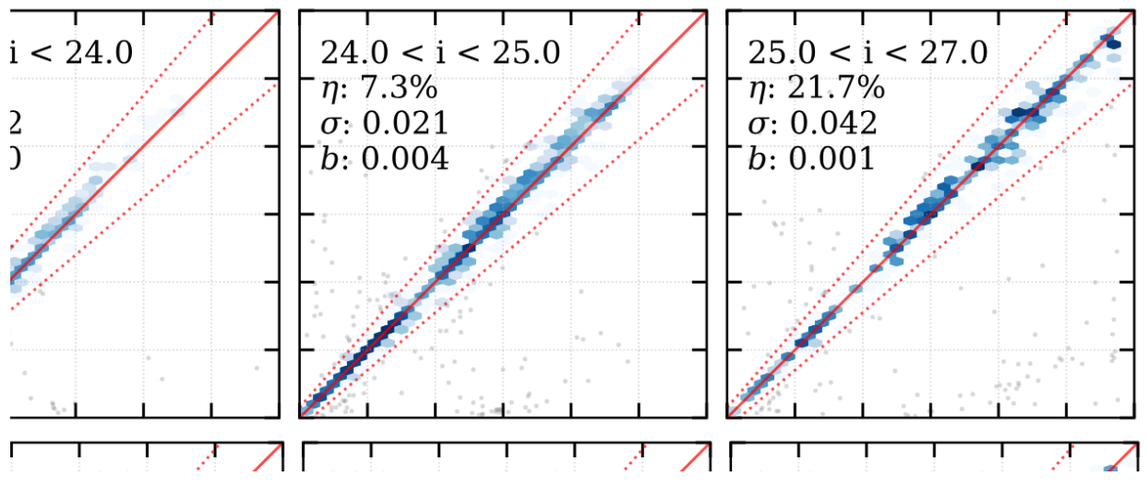


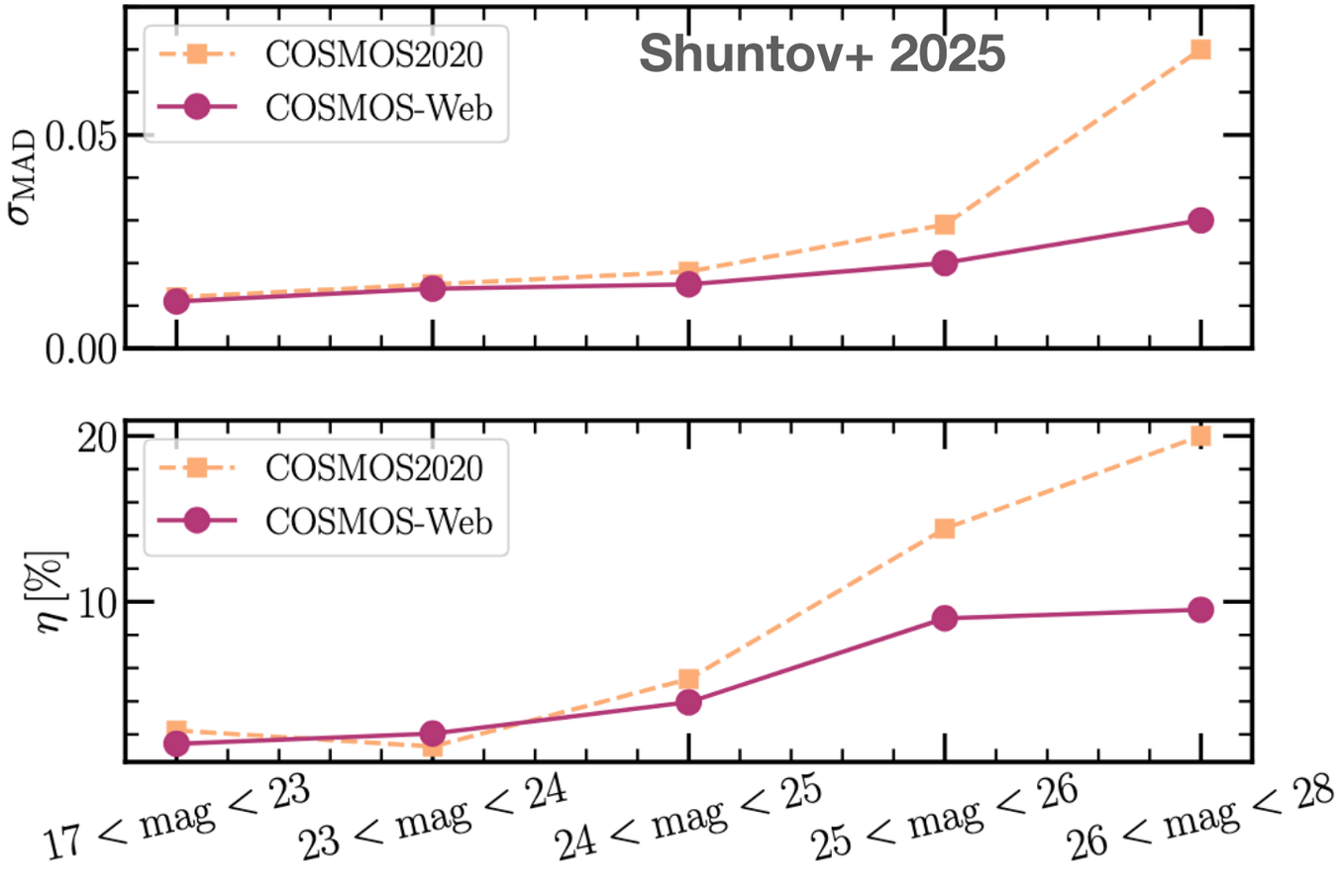
Weaver et al. 2021

Photo-z accuracies





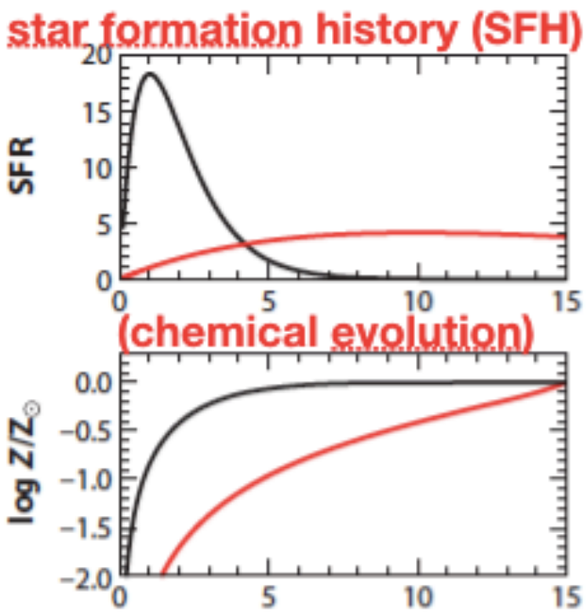


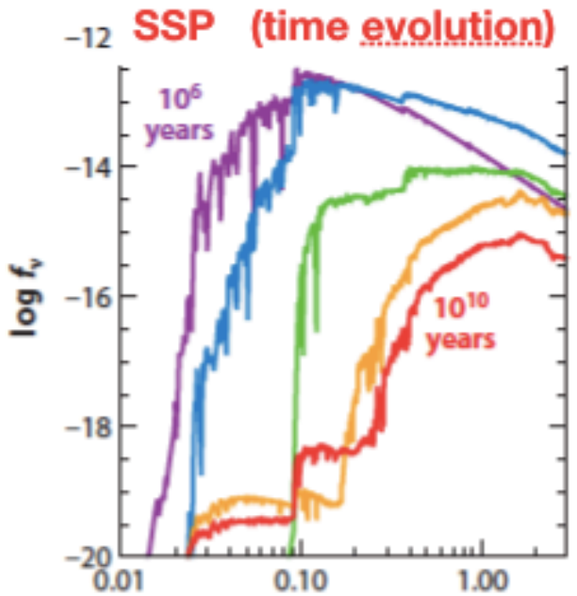


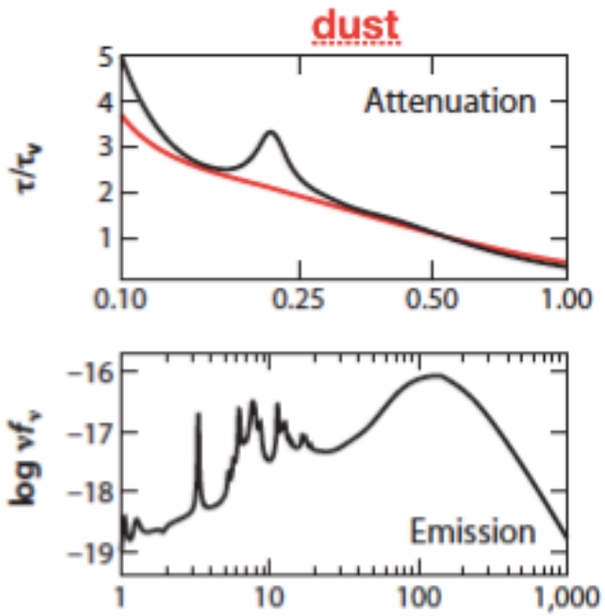
Weaver et al. 2021

Stellar population properties

a couple things to keep in mind…







Conroy 2013

CSP

energy balance

dust attenuation

dust emission

$$f_{\rm CSP}(t) = \int_{t'=0}^{t'=t} \int_{Z=0}^{Z_{\rm max}} \left({\rm SFR}(t-t') P(Z, t-t') f_{\rm SSP}(t', Z) e^{-\tau_d(t')} + A\, f_{\rm dust}(t', Z) \right) {\rm d}t'\, {\rm d}Z$$

SFH

chemical evolution

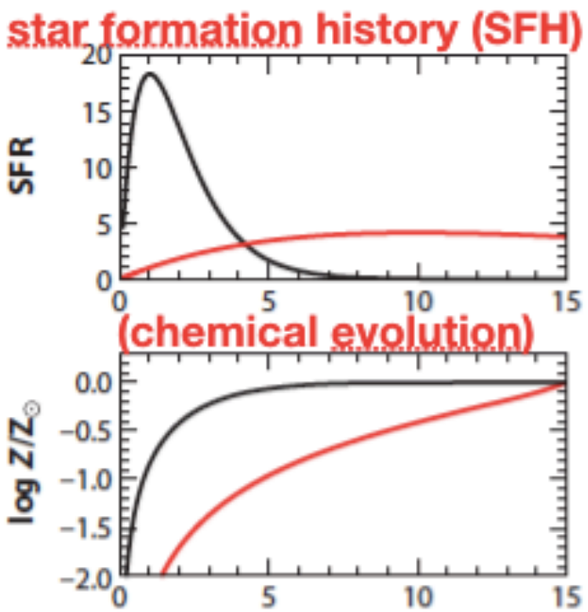
SSP spectra

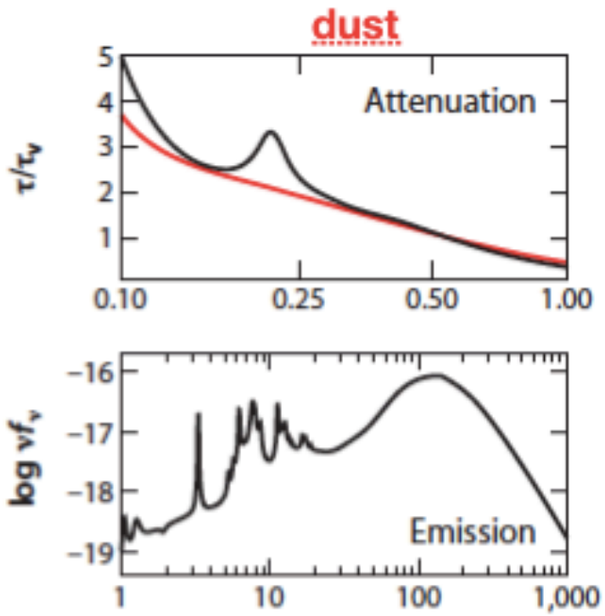
SSP age

SSP metallicity

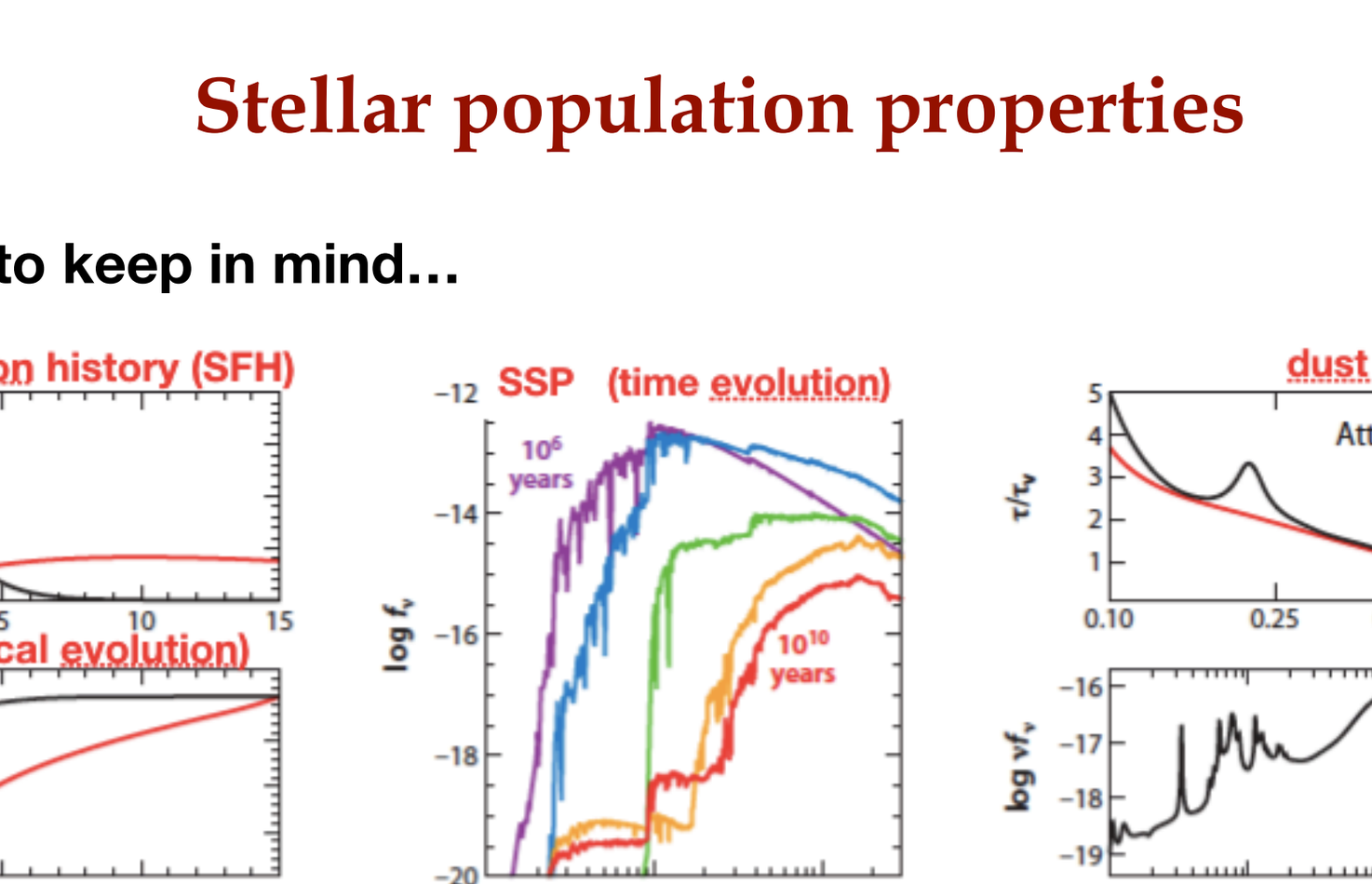
Stellar population properties

a couple things to keep in mind…





Conroy 2013



degeneracies between age/SFH, metallicity, dust

energy balance

dust attenuation

dust emission

$$f_{\rm CSP}(t) = \int_{t'=0}^{t'=t} \int_{Z=0}^{Z_{\rm max}} \left(\mathrm{SFR}(t-t') P(Z, t-t') f_{\rm SSP}(t', Z) e^{-\tau_d(t')} + A\, f_{\rm dust}(t', Z) \right) \mathrm{d}t'\, \mathrm{d}Z$$

SFH

chemical evolution

SSP spectra

SSP age

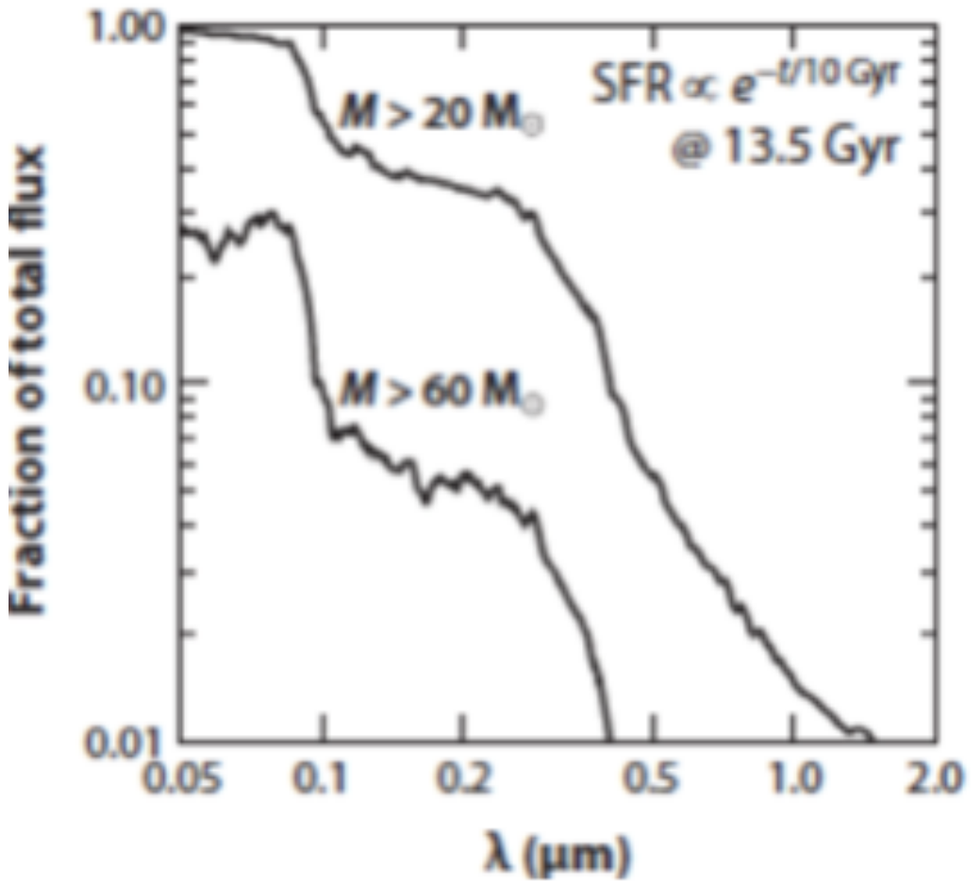
SSP metallicity

Furthermore …

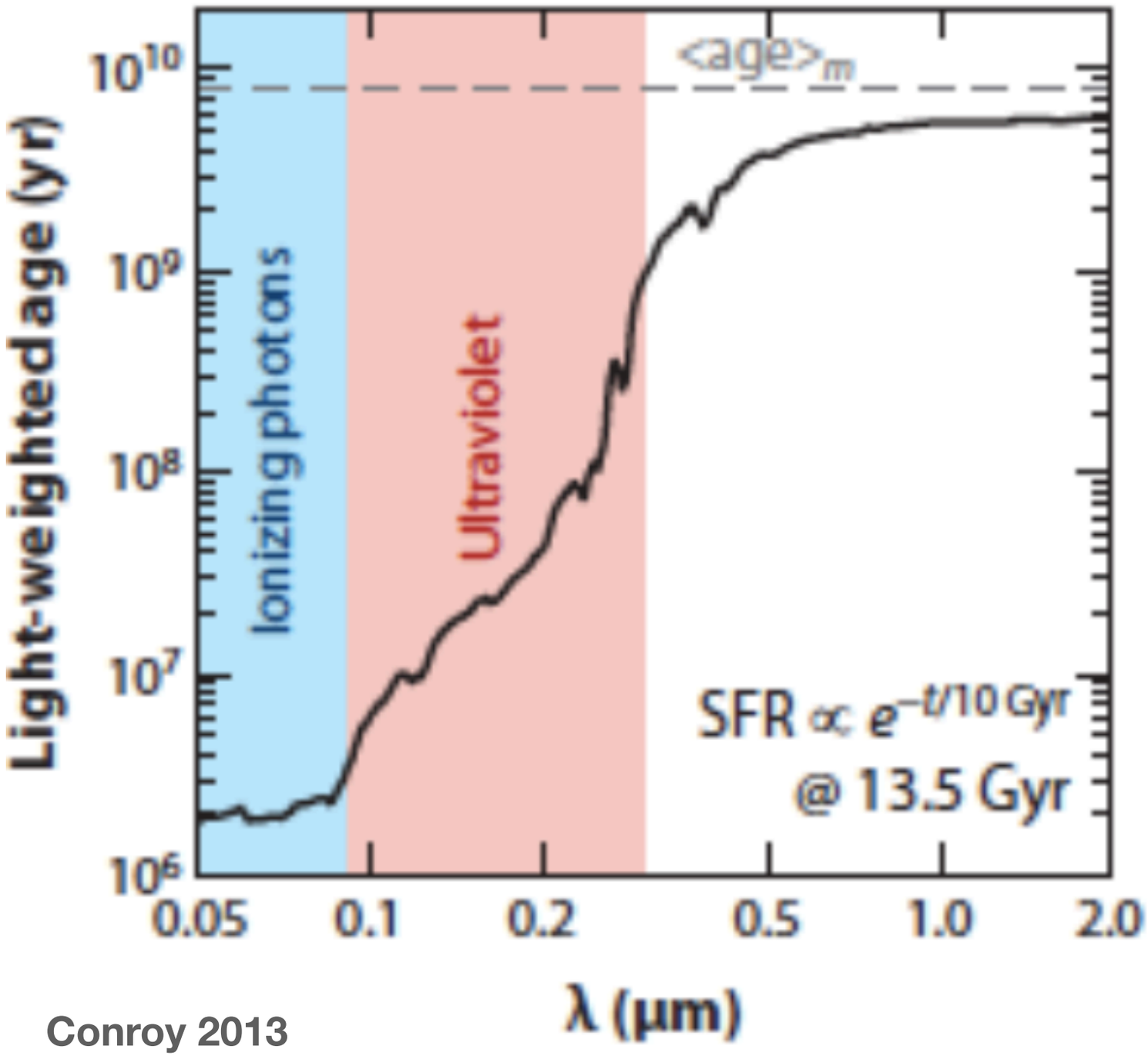
Mass- and light-weighted ages

dust free

SFR(t) ∝ $e^{-t/10\ Gyr}$



light- vs. mass-weighted age as a function of wavelength at 13.5 Gyr

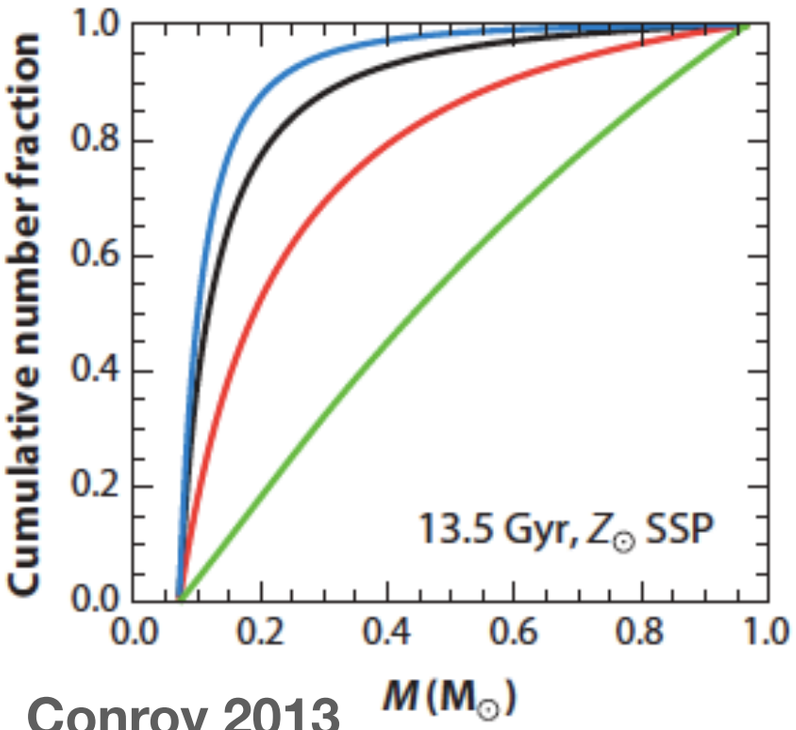


Conroy 2013

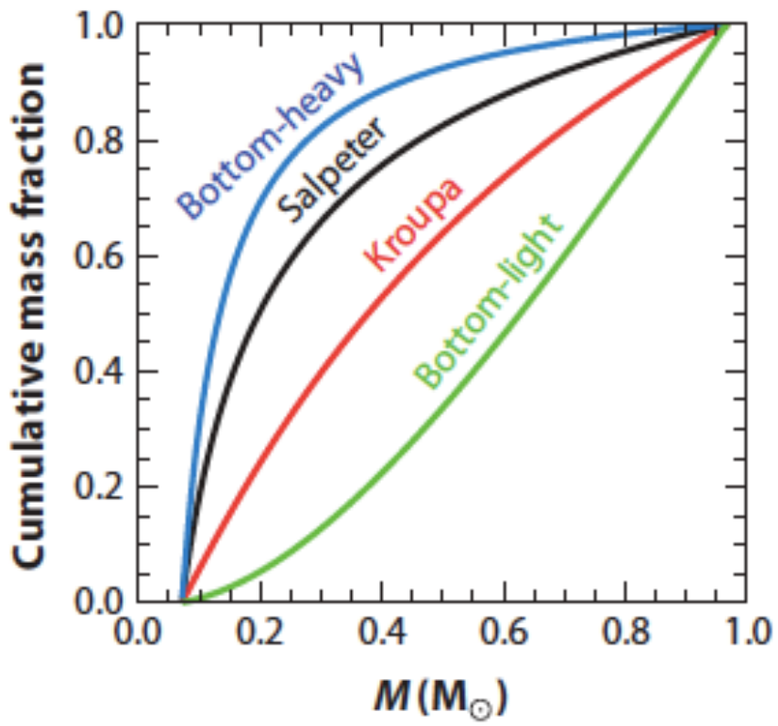
Contribution of stars of different mass to total stellar mass and flux

SSP at t = 13.5 Gyr

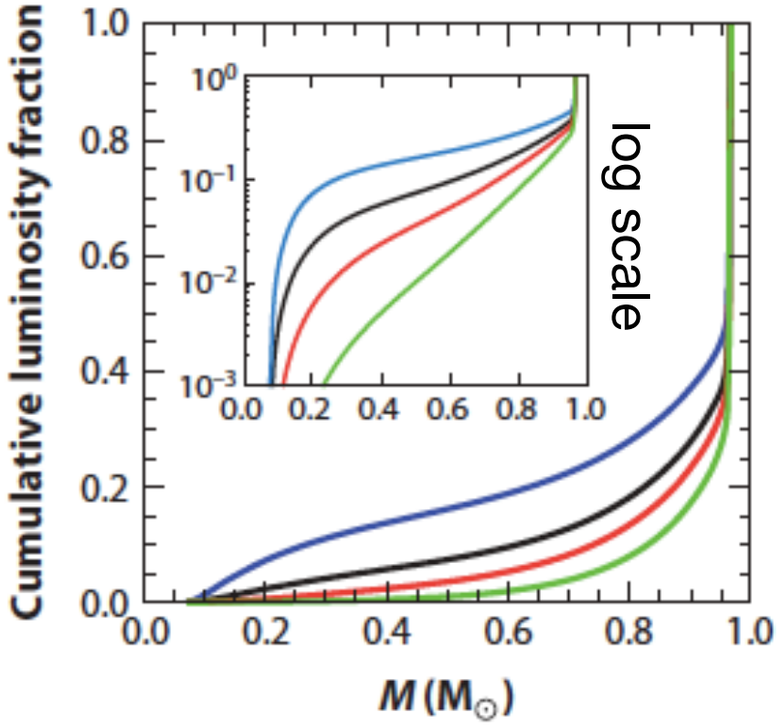
contribution to number of stars



total stellar mass

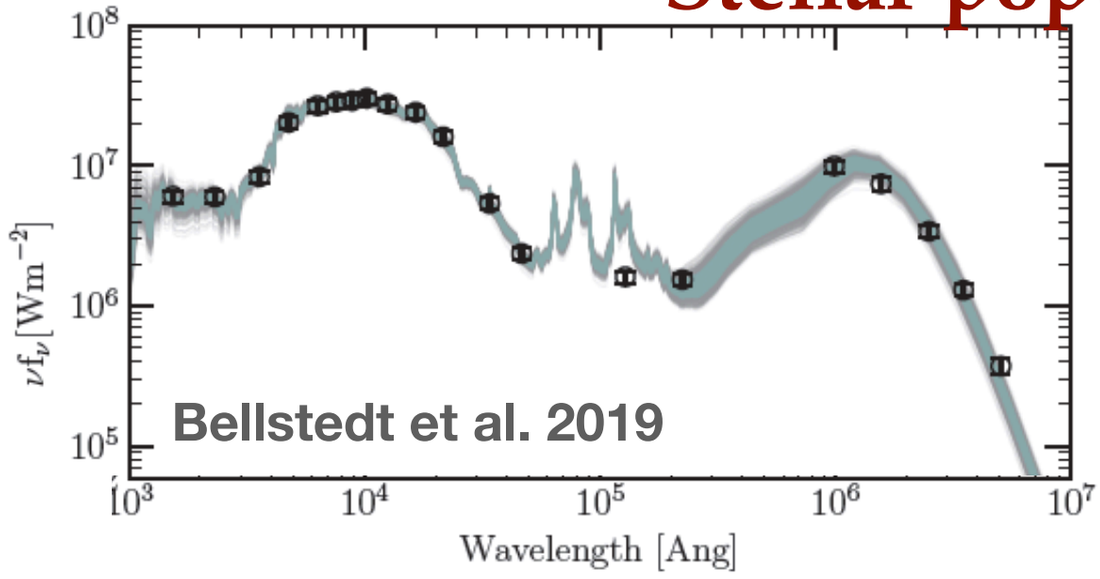


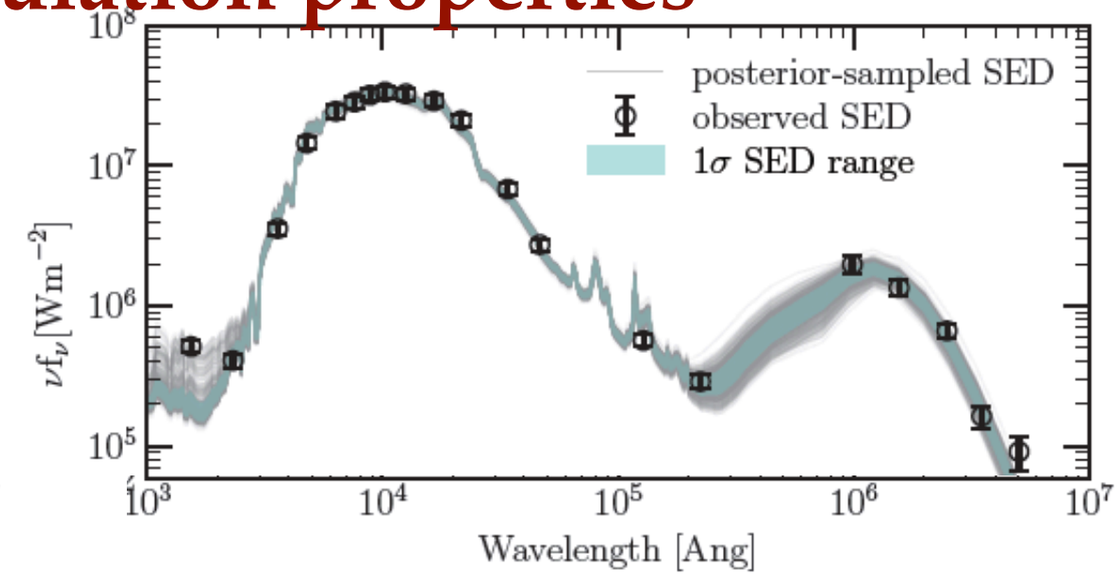
total luminosity



Conroy 2013

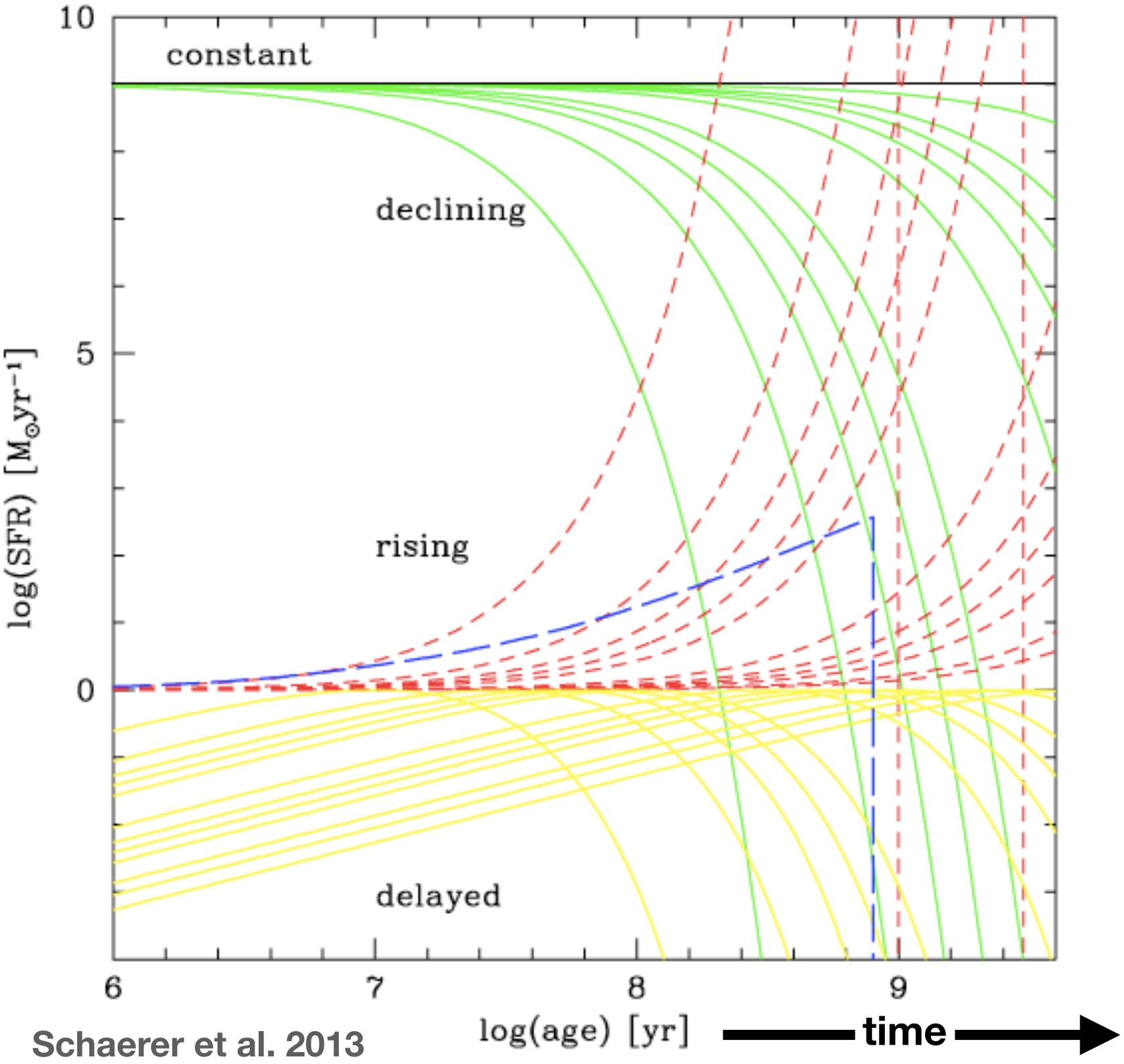
Stellar population properties





Stellar population properties

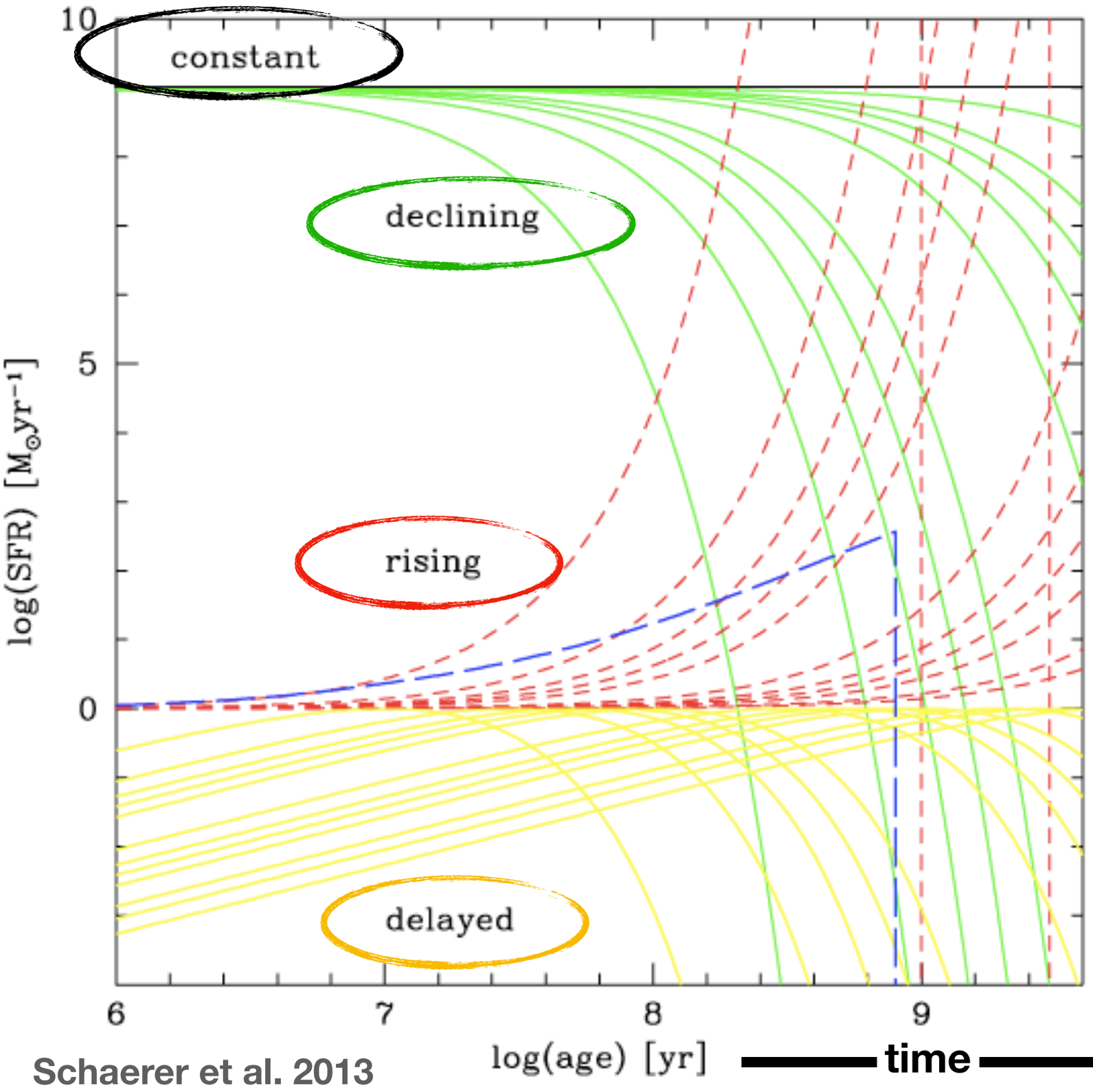
parametric star formation histories



Schaerer et al. 2013

Stellar population properties

parametric star formation histories



Schaerer et al. 2013

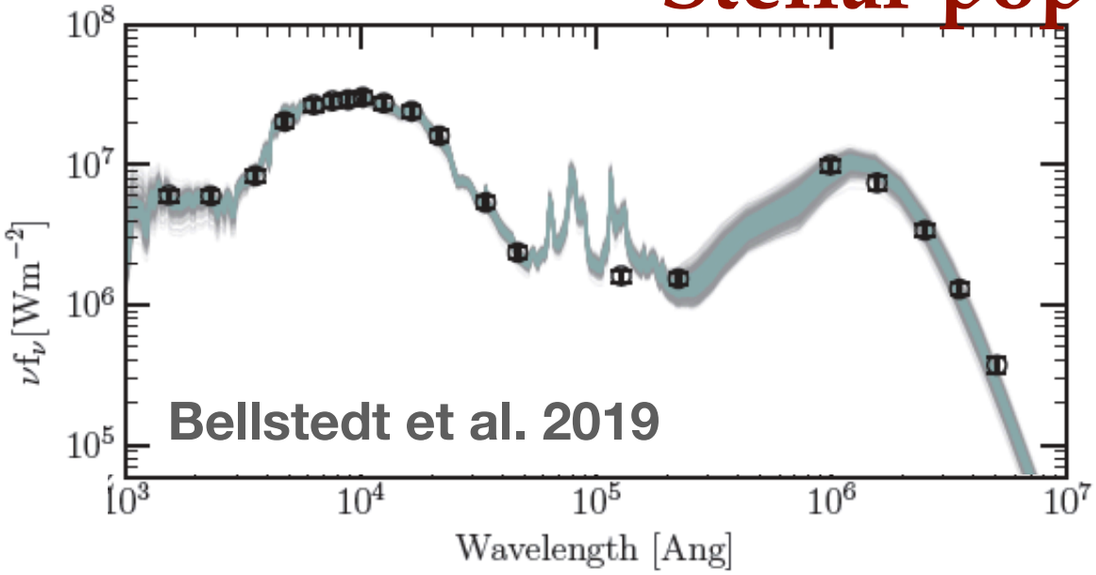
SFR(t) = constant

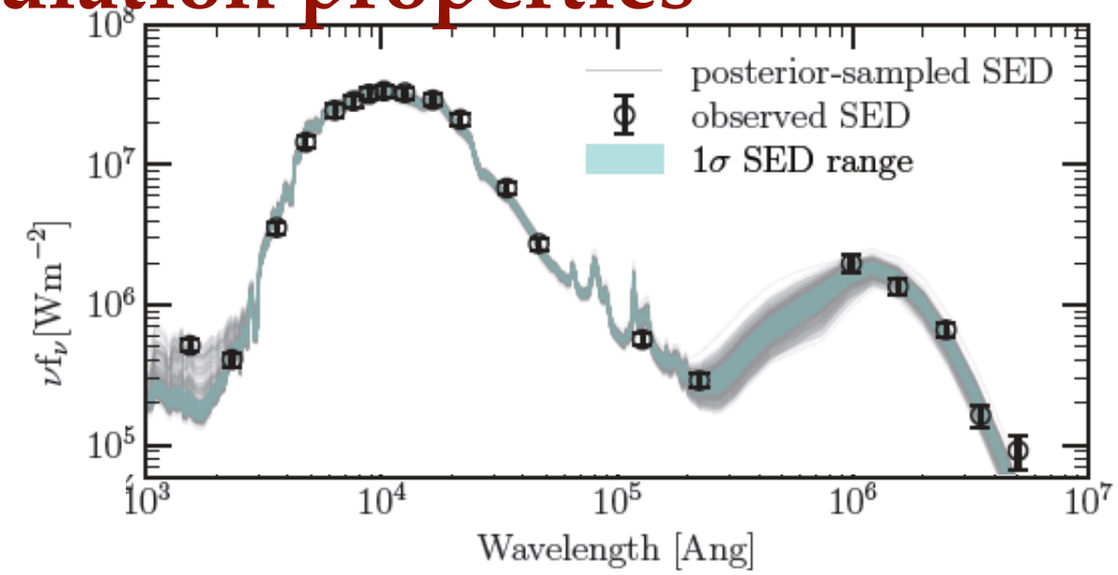
SFR(t) ∝ $e^{-t/\tau}$

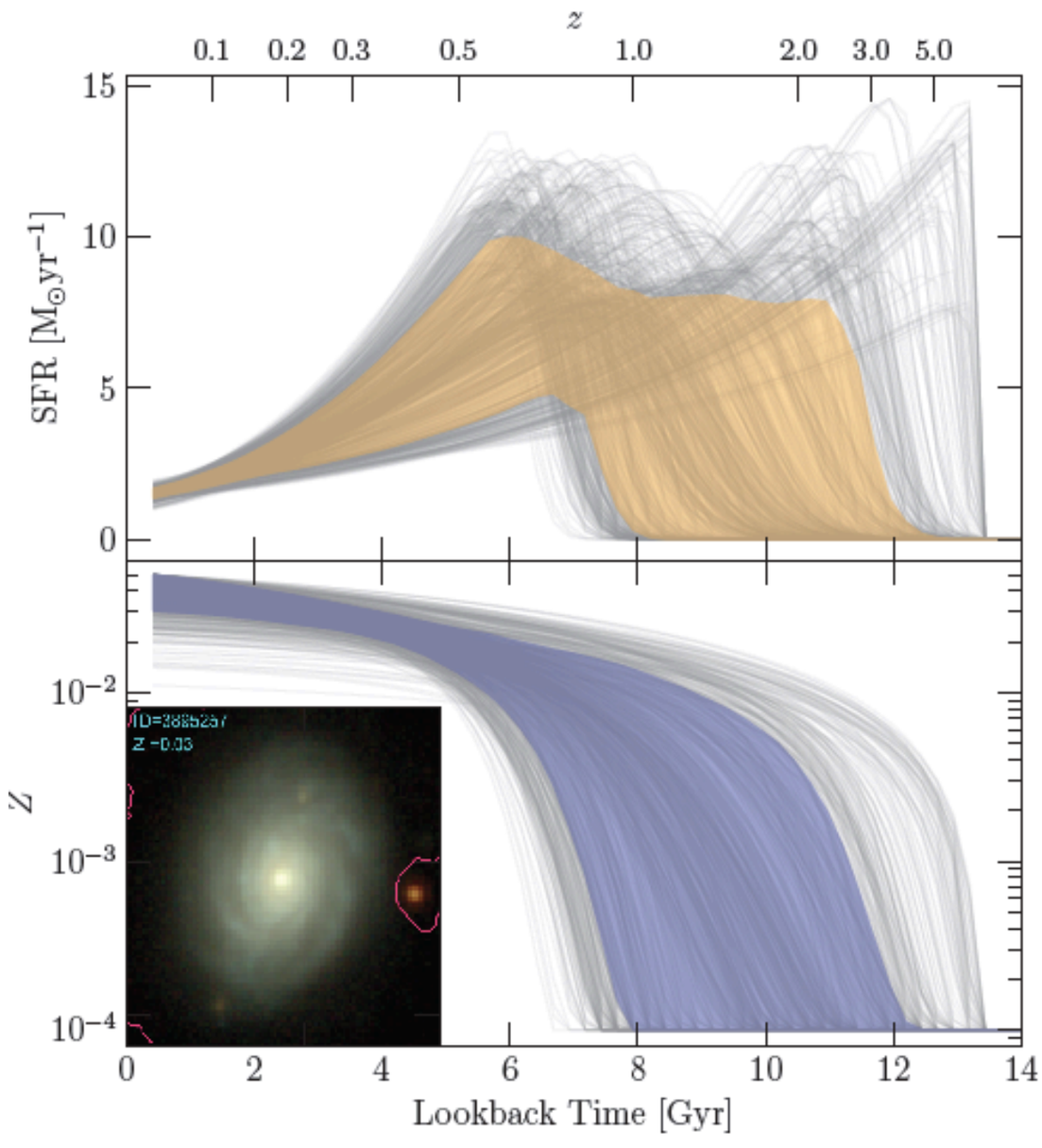
SFR(t) ∝ $e^{t/\tau}$

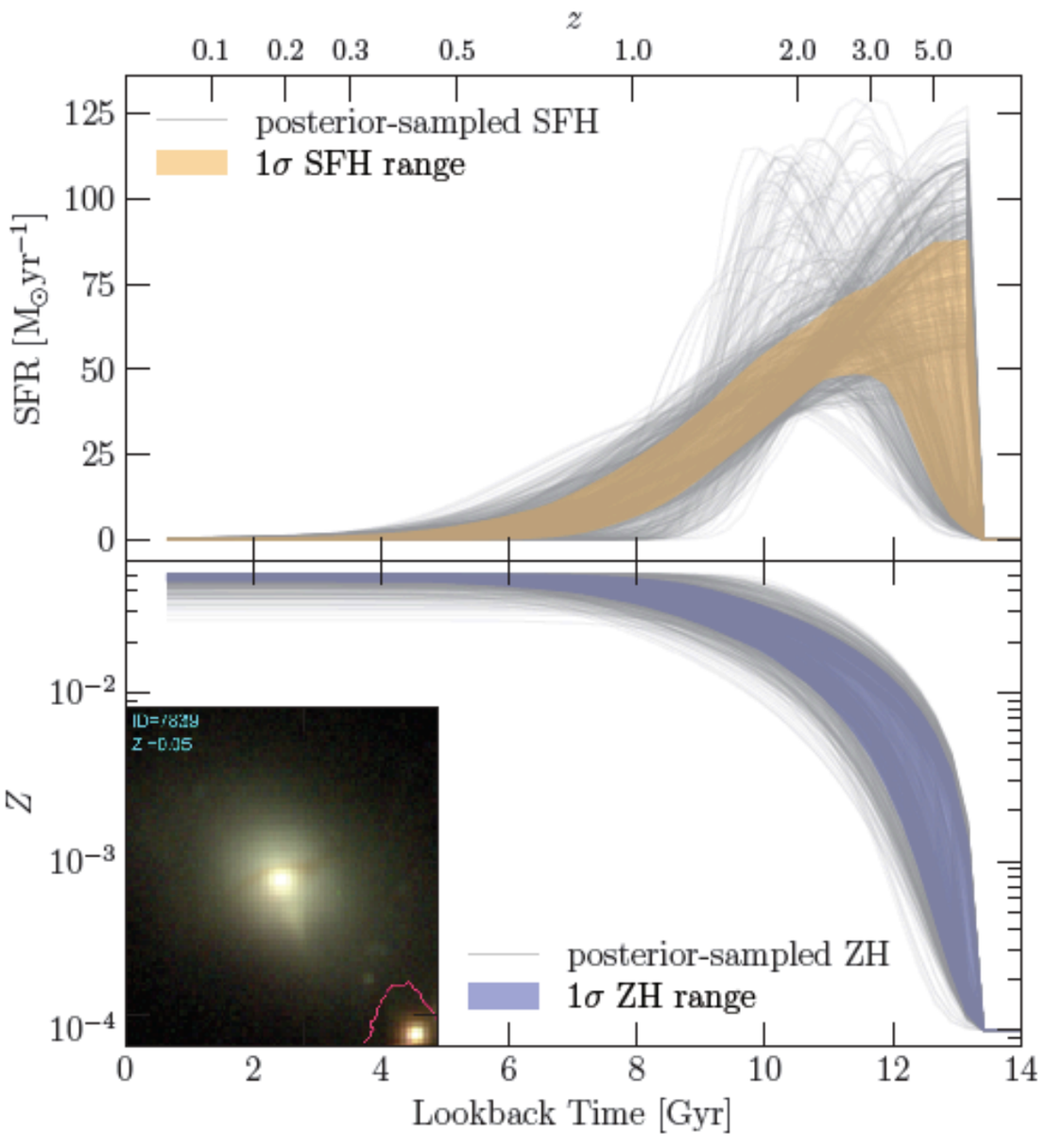
SFR(t) ∝ t $e^{t/\tau}$

Stellar population properties

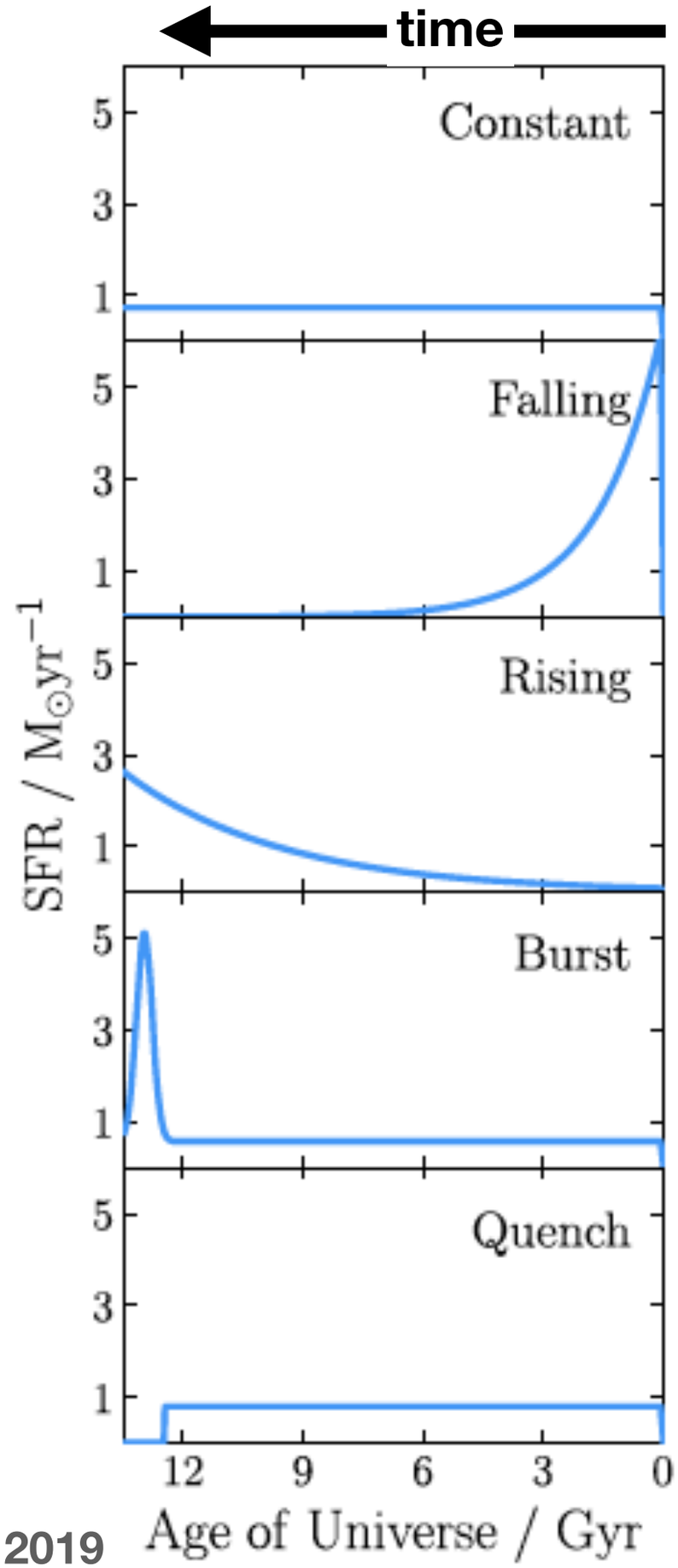








SFH dependence and mismatch



Carnall et al. 2019

SFR(t) ∝ $e^{-t/\tau}$ **SFR(t) ∝ t $e^{-t/\tau}$** **SFR(t) ∝ $[(t/\tau)^{\alpha} + (t/\tau)^{-\beta}]^{-1}$**

Tau Delayed DPL

time

Constant

Falling

Rising

Burst

Quench

SFR / $M_{\odot} yr^{-1}$

Age of Universe / Gyr

Age of Universe / Gyr

Carnall et al. 2019

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Tau Delayed DPL

time

Constant

Falling

Rising

Burst

Quench

(a)

one example galaxy from SAM
on cosmological simulation

SFR ($M_\odot$/yr)

(b)

Z ($Z_\odot$)

look−back time (Gyr)

Pacifici et al. 2012

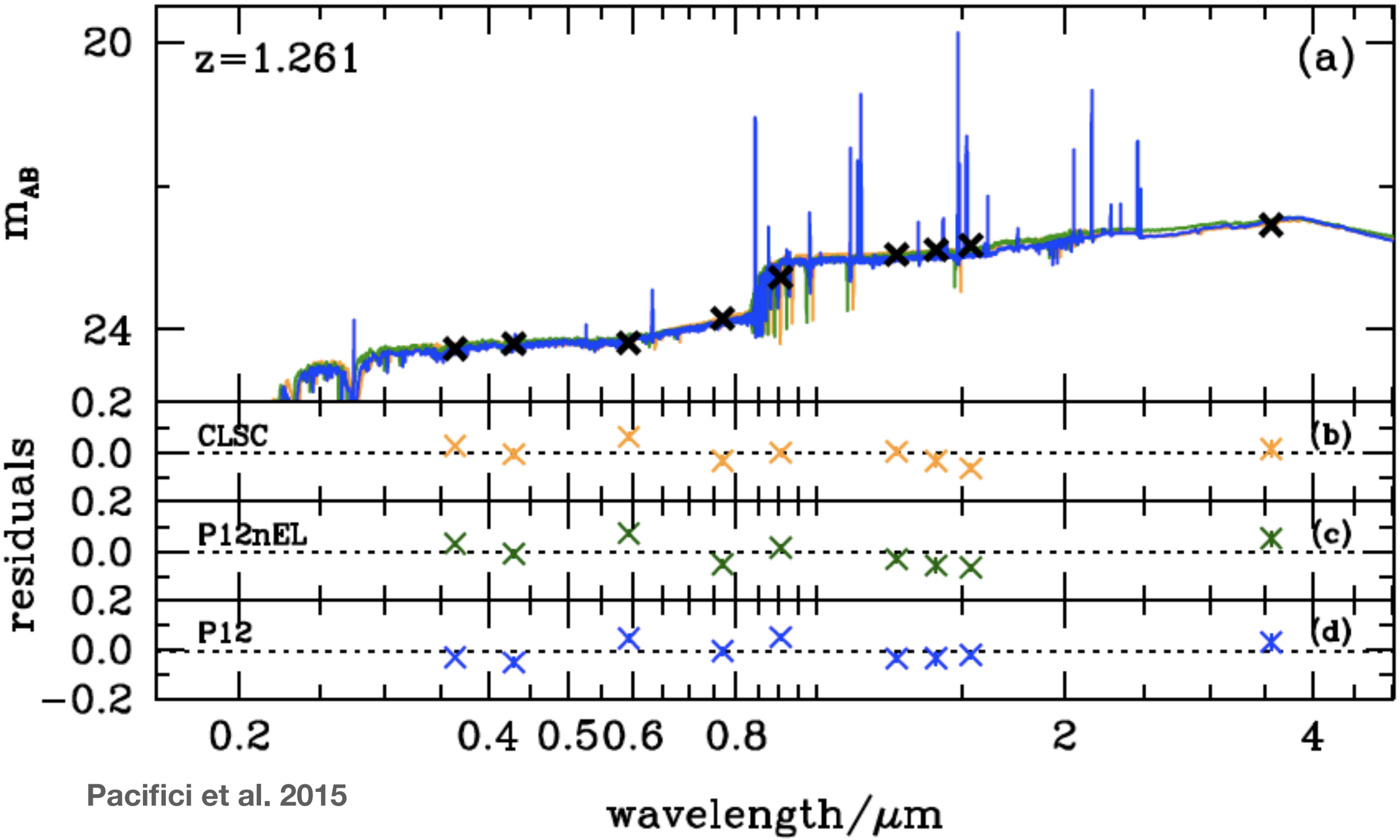
time

Age of Universe / Gyr

Carnall et al. 2019

Age of Universe / Gyr

Broad-band SED fitting for stellar population properties



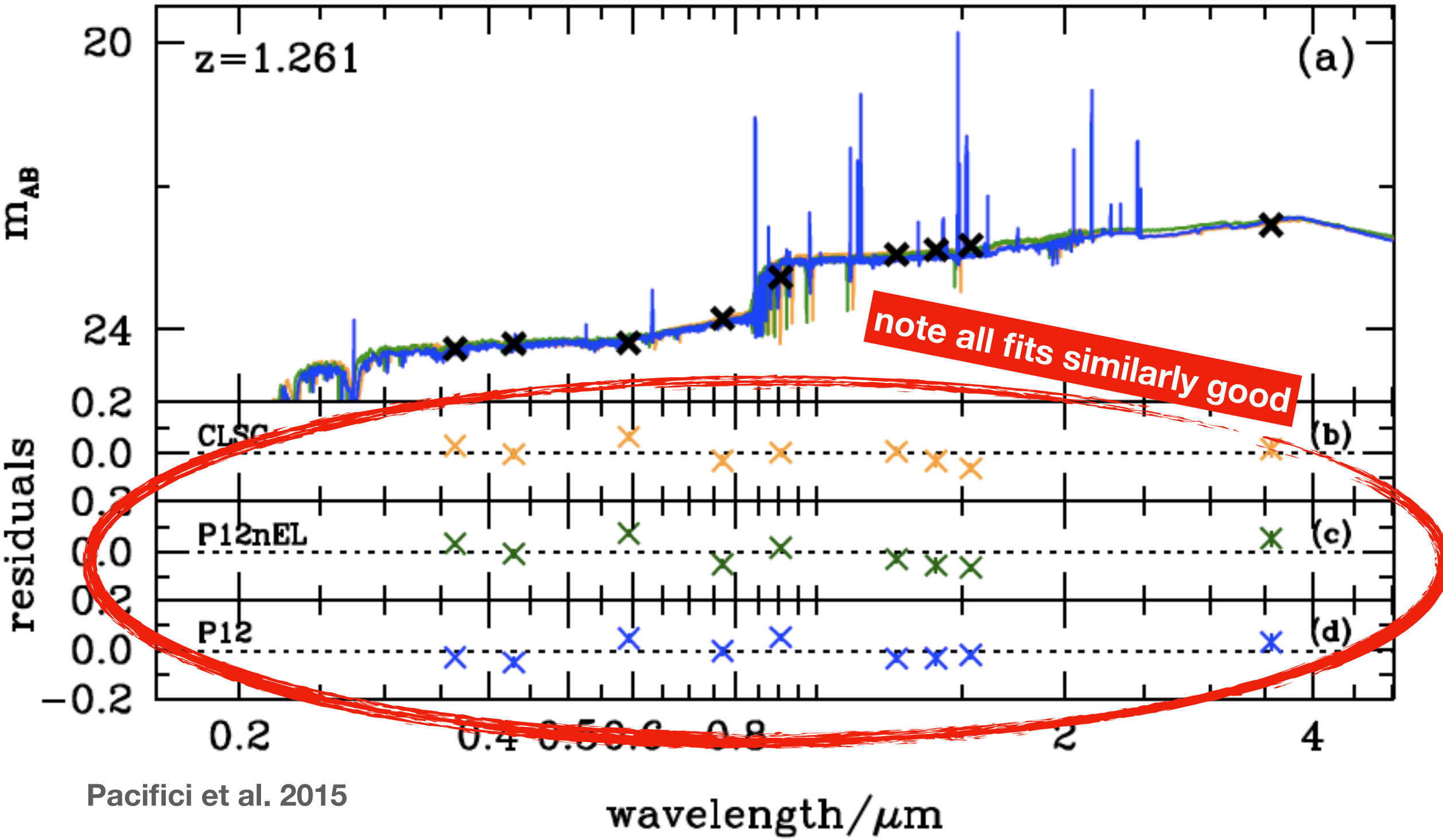
Pacifici et al. 2015

standard modeling with parametric SFHs, single metallicity, no emission lines

more realistic SFH, chemical evolution, dust attenuation modeling

more realistic SFH, chemical evolution, dust attenuation modeling , plus emission lines

Broad-band SED fitting for stellar population properties



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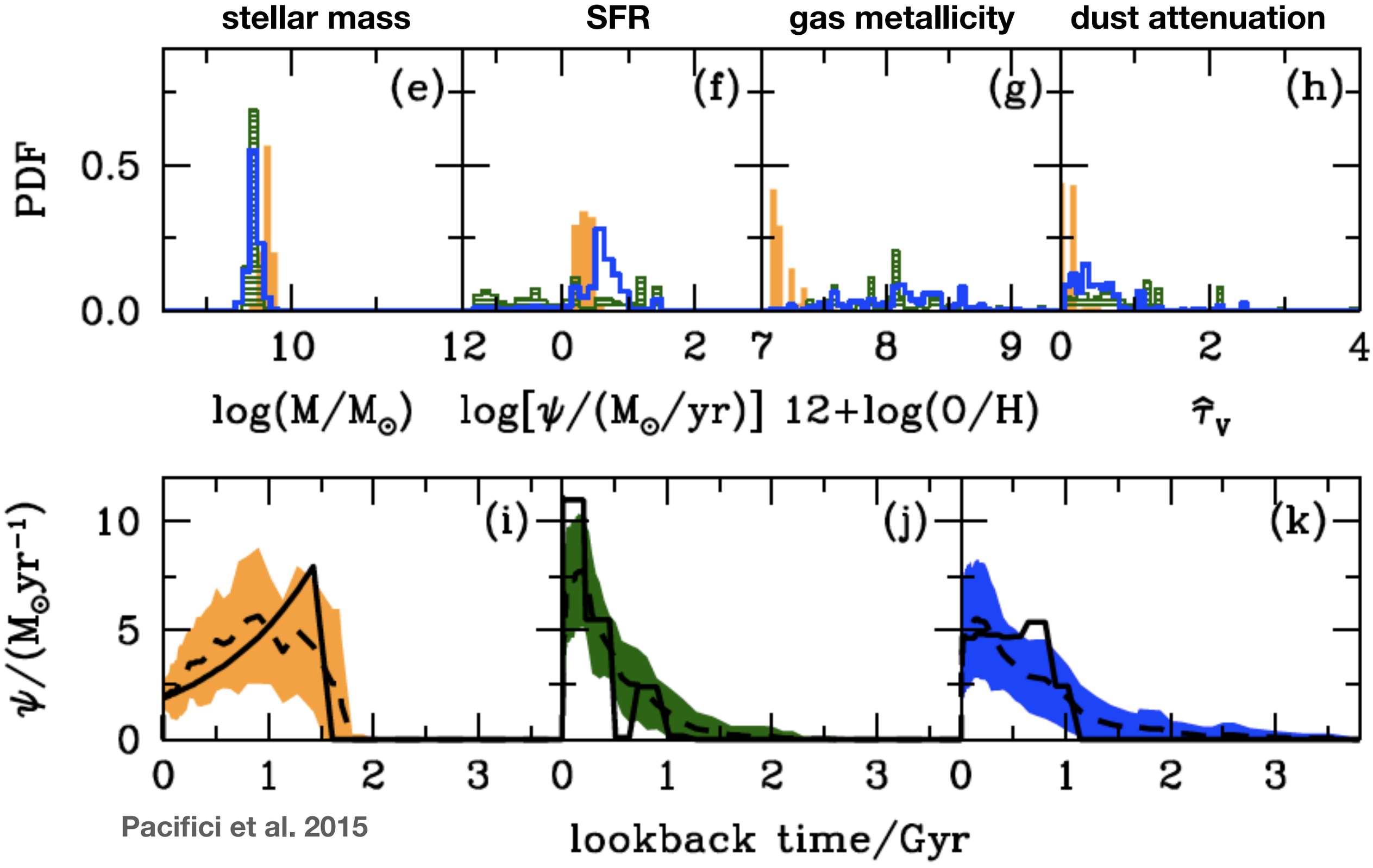
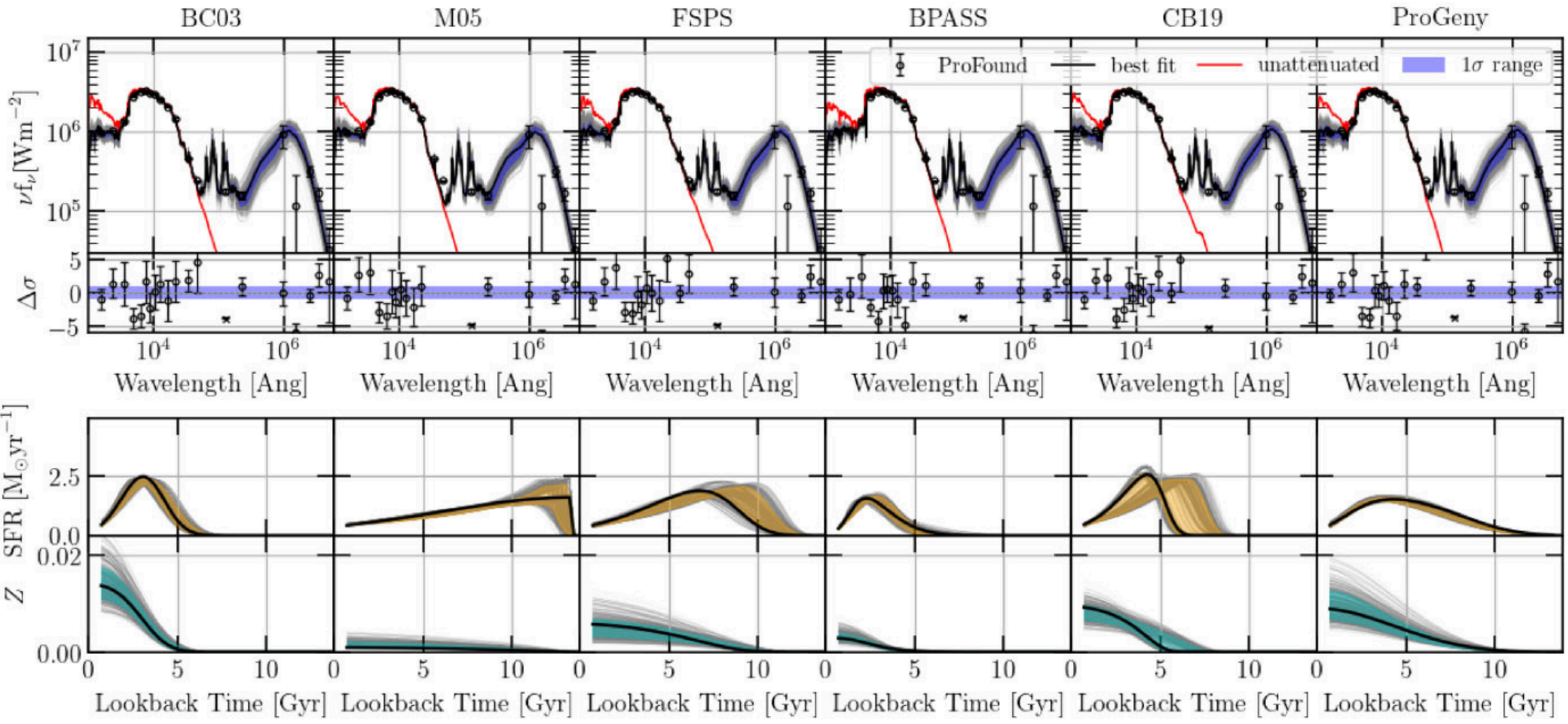
Broad-band SED fitting for stellar population properties

... but quite different retrived parameters



Pacifici et al. 2015

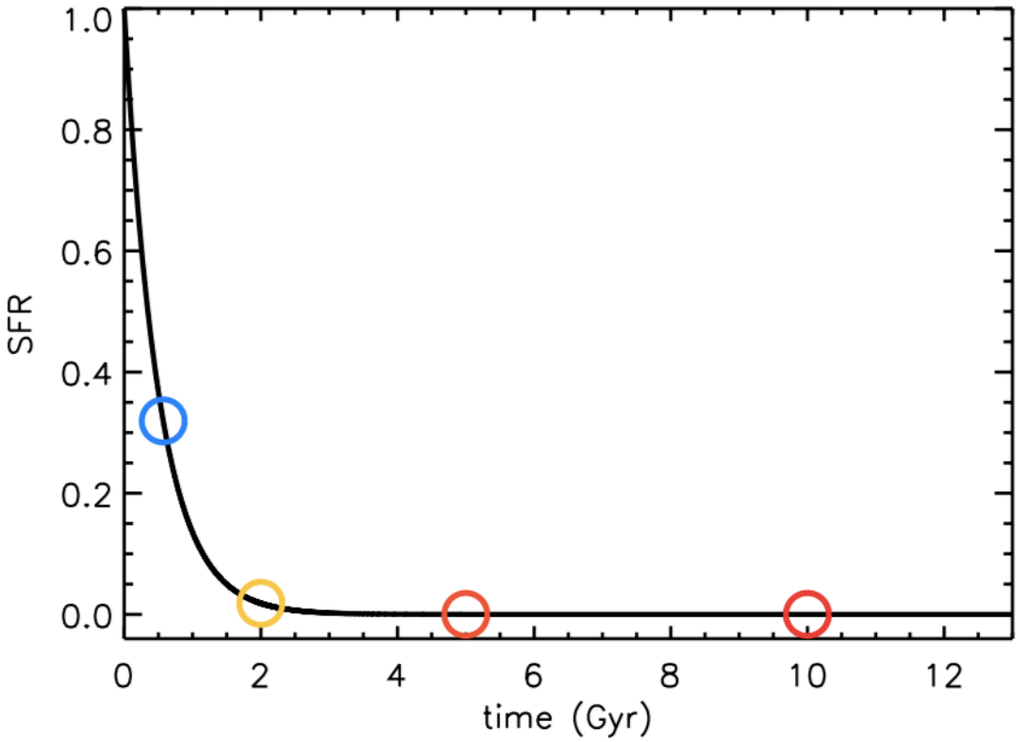
dependence on the adopted stellar population library

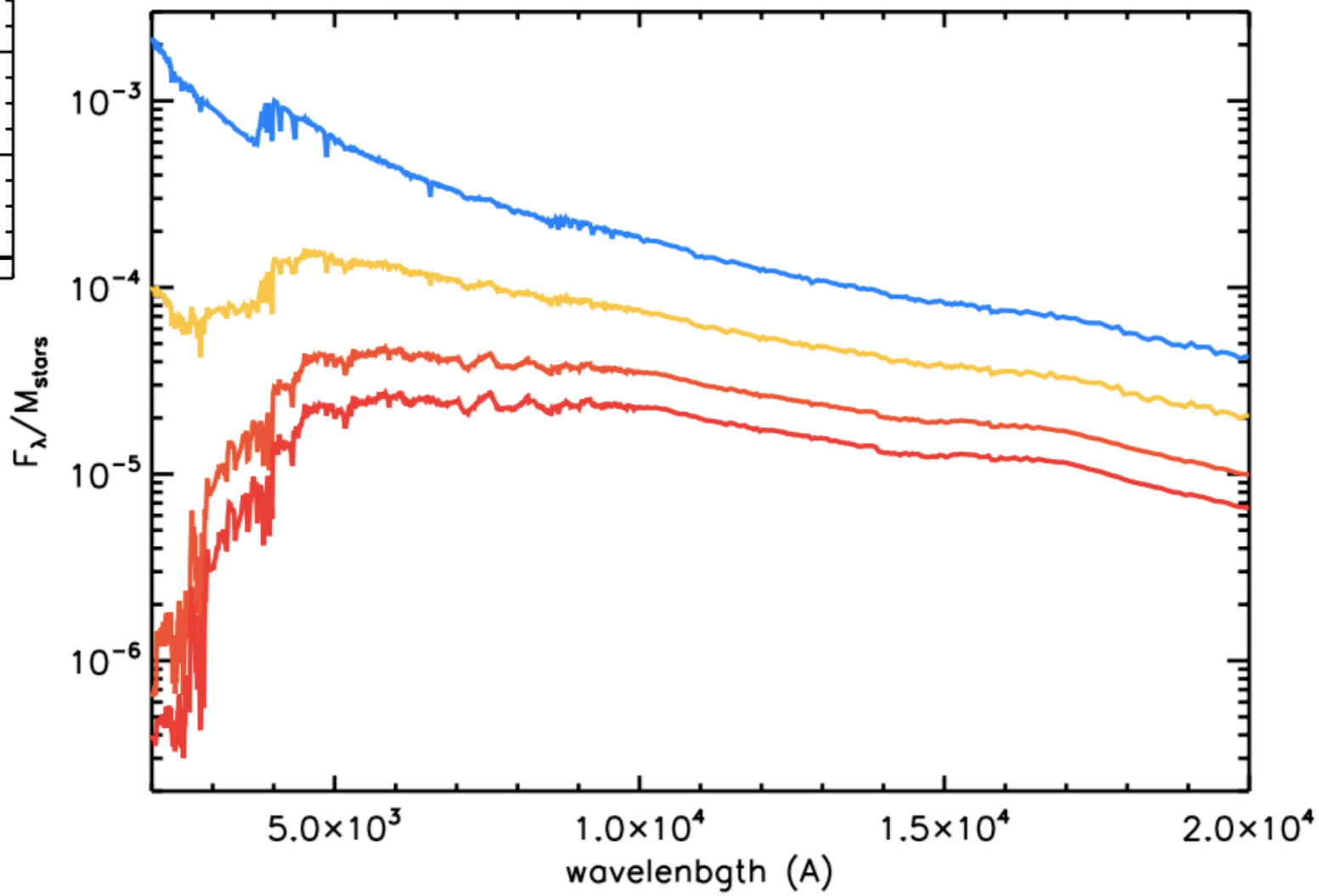


Bellstedt & Robotham 2025

Stellar mass

Mass to light ratio (M/L) correlates with galaxy color → can get a stellar mass estimate even from one (well chosen) color (and one magnitude) only





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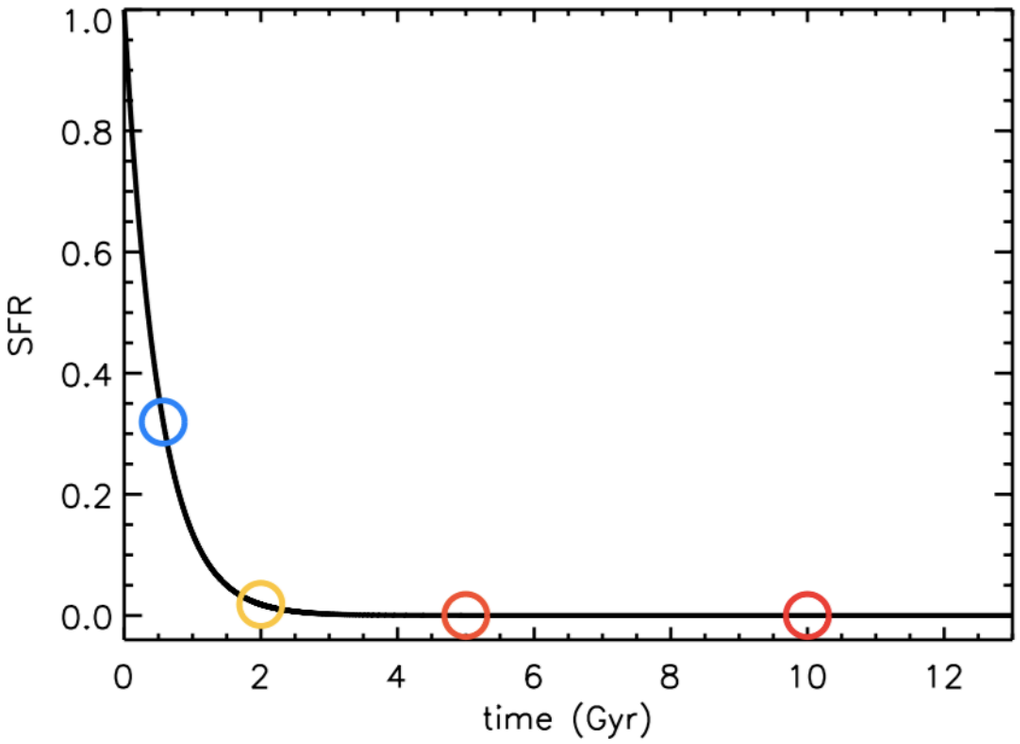

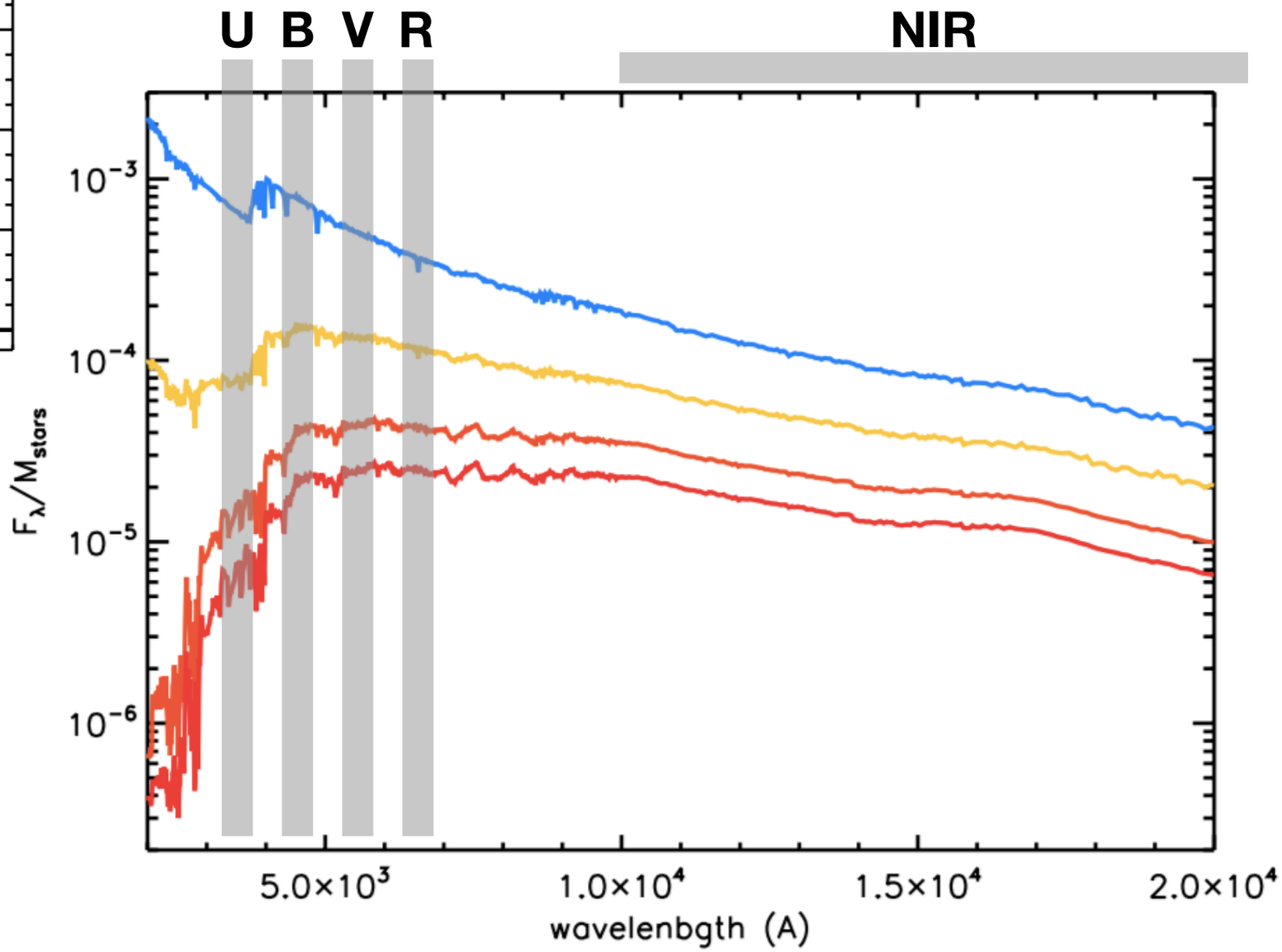

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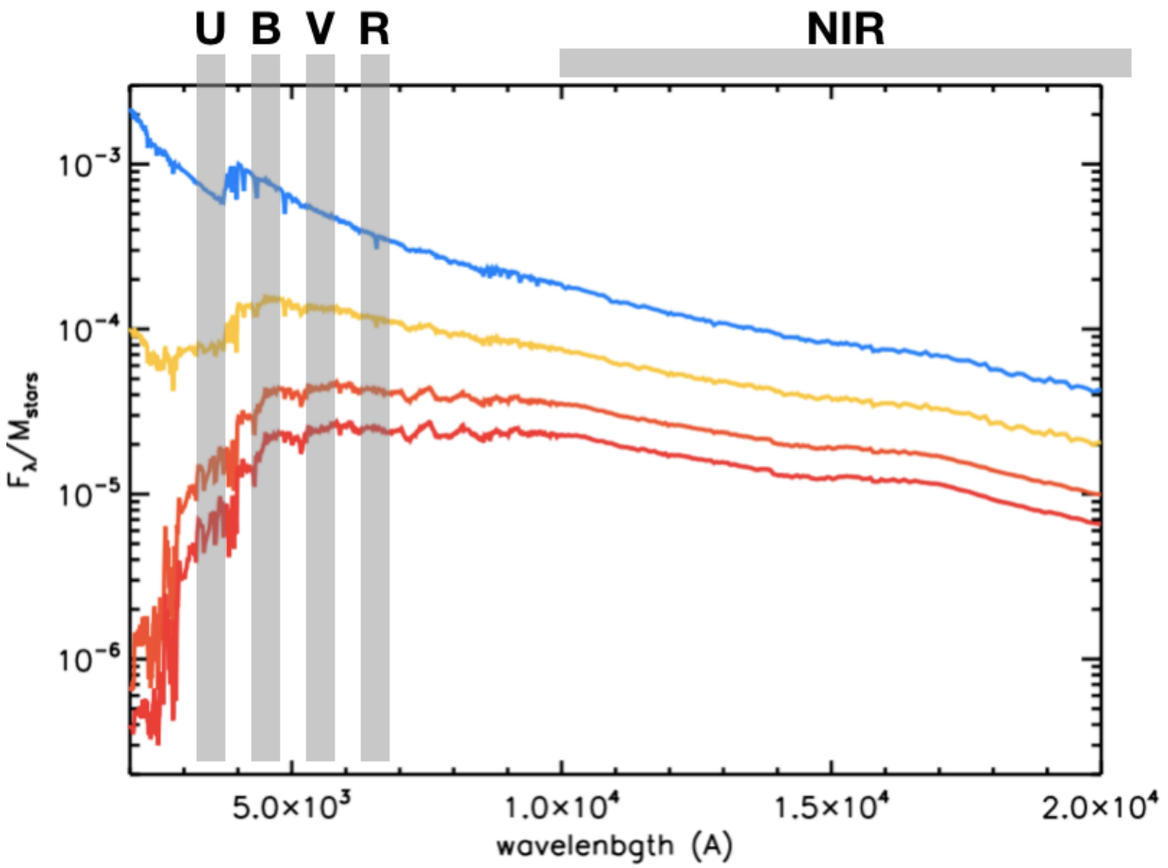
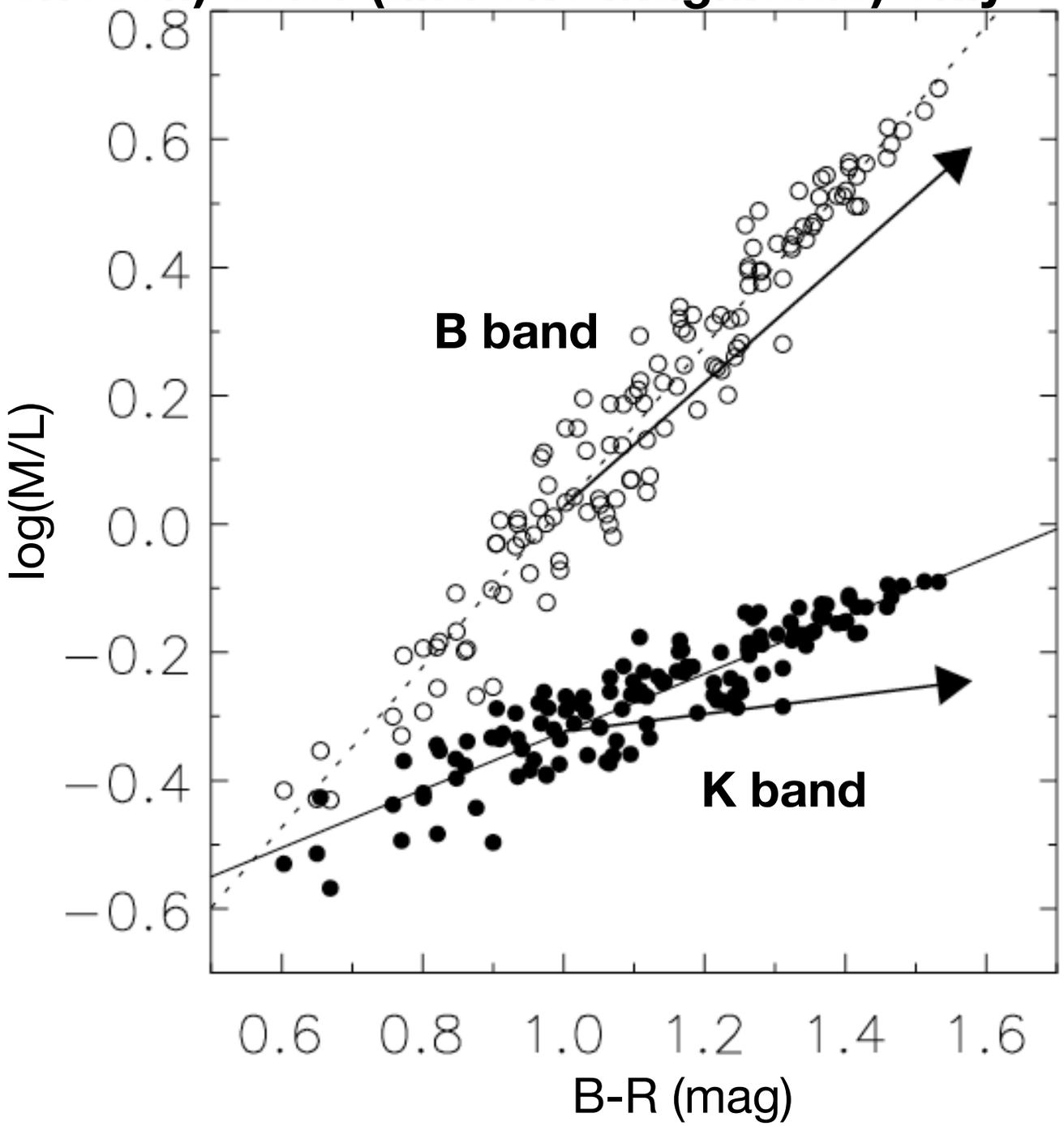
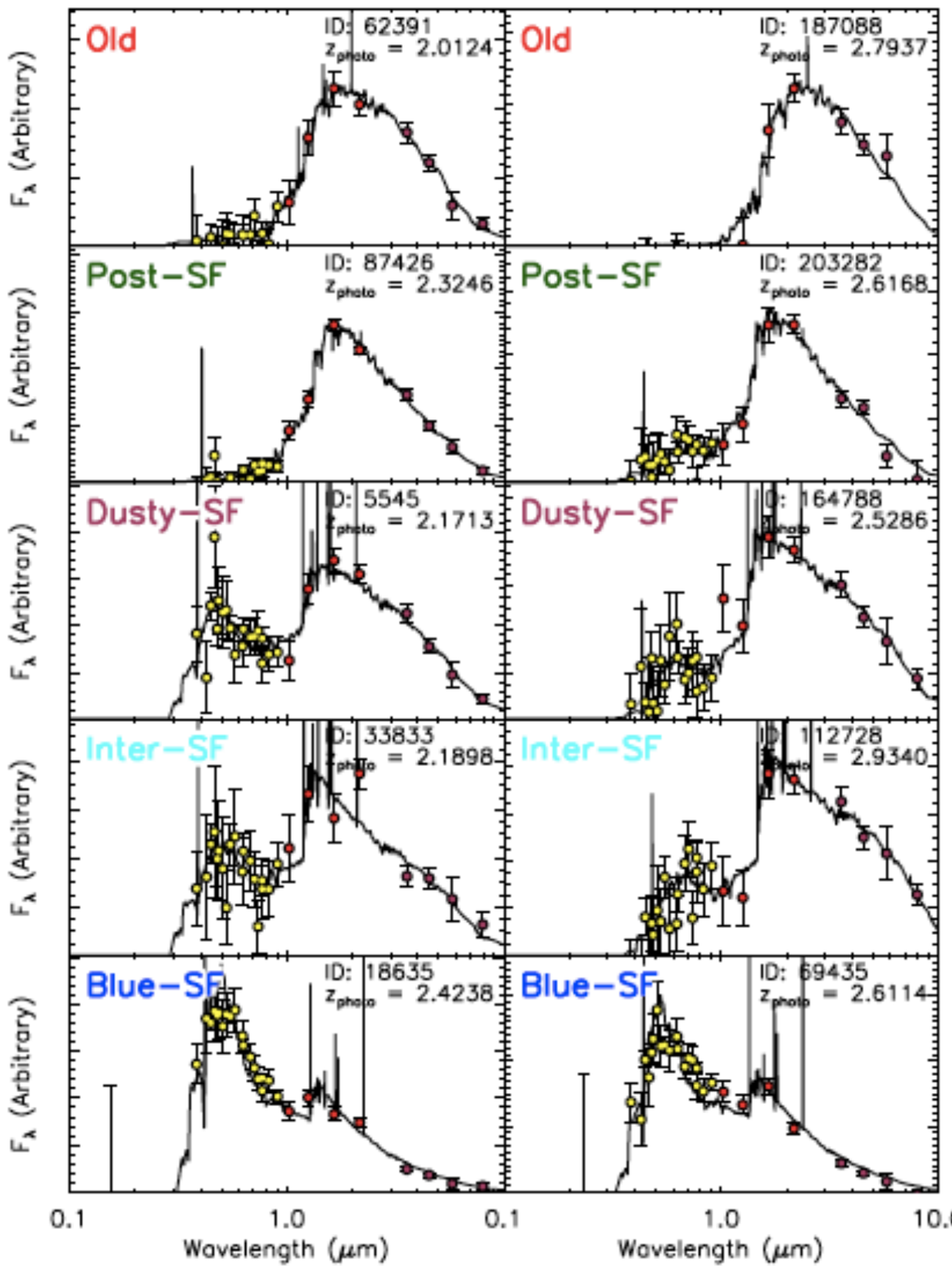




Bell & de Jong 2001

Stellar mass

going full spectral coverage

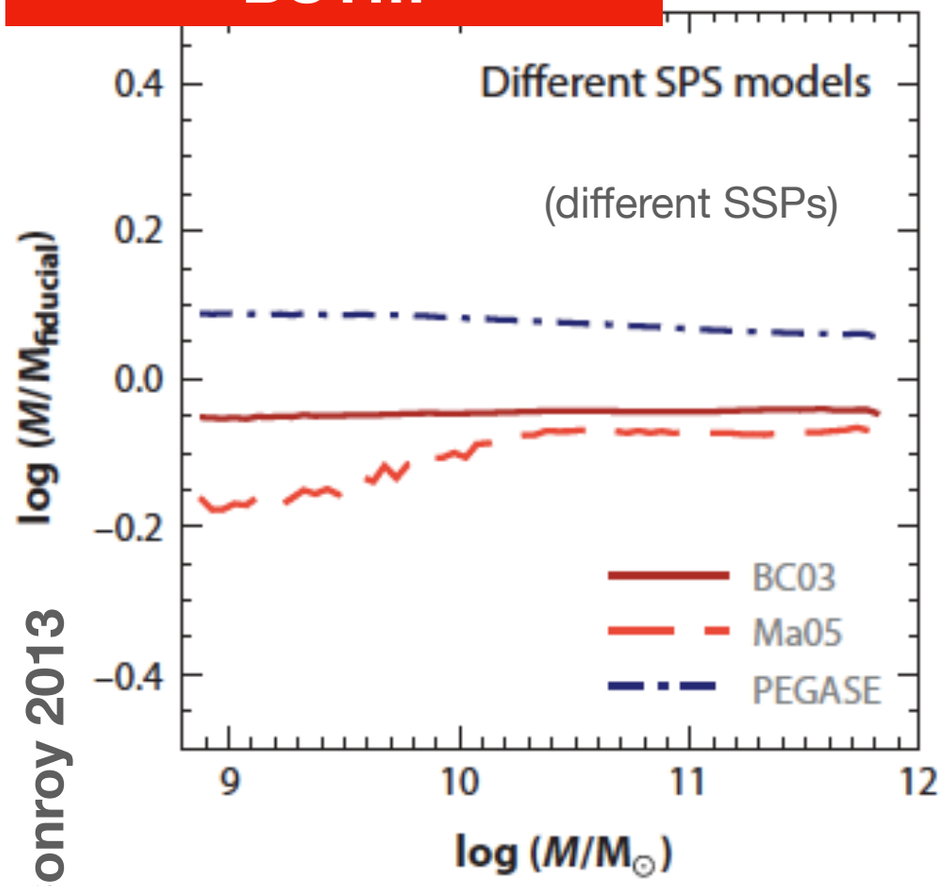


mass estimates are determined essentially from flux scaling of the best-fitting template (i.e., M/L ratio determination and overall normalization from SED)

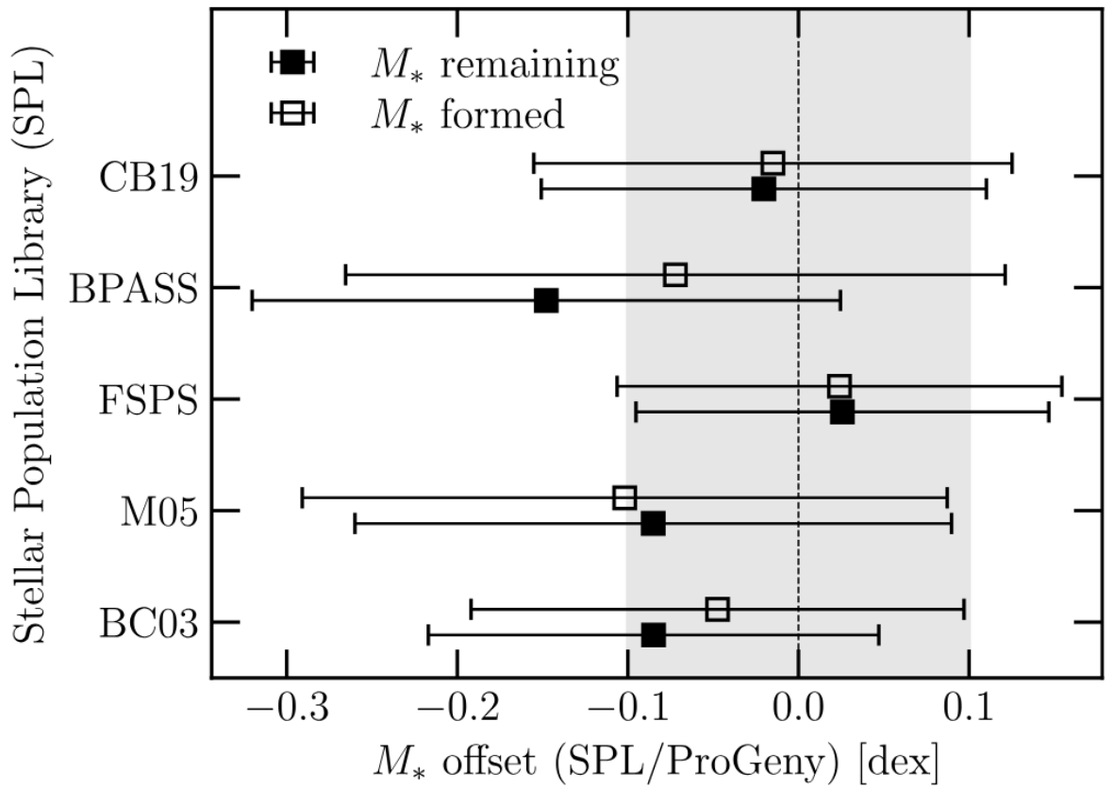
Muzzin et al. 2013

Stellar mass

BUT…



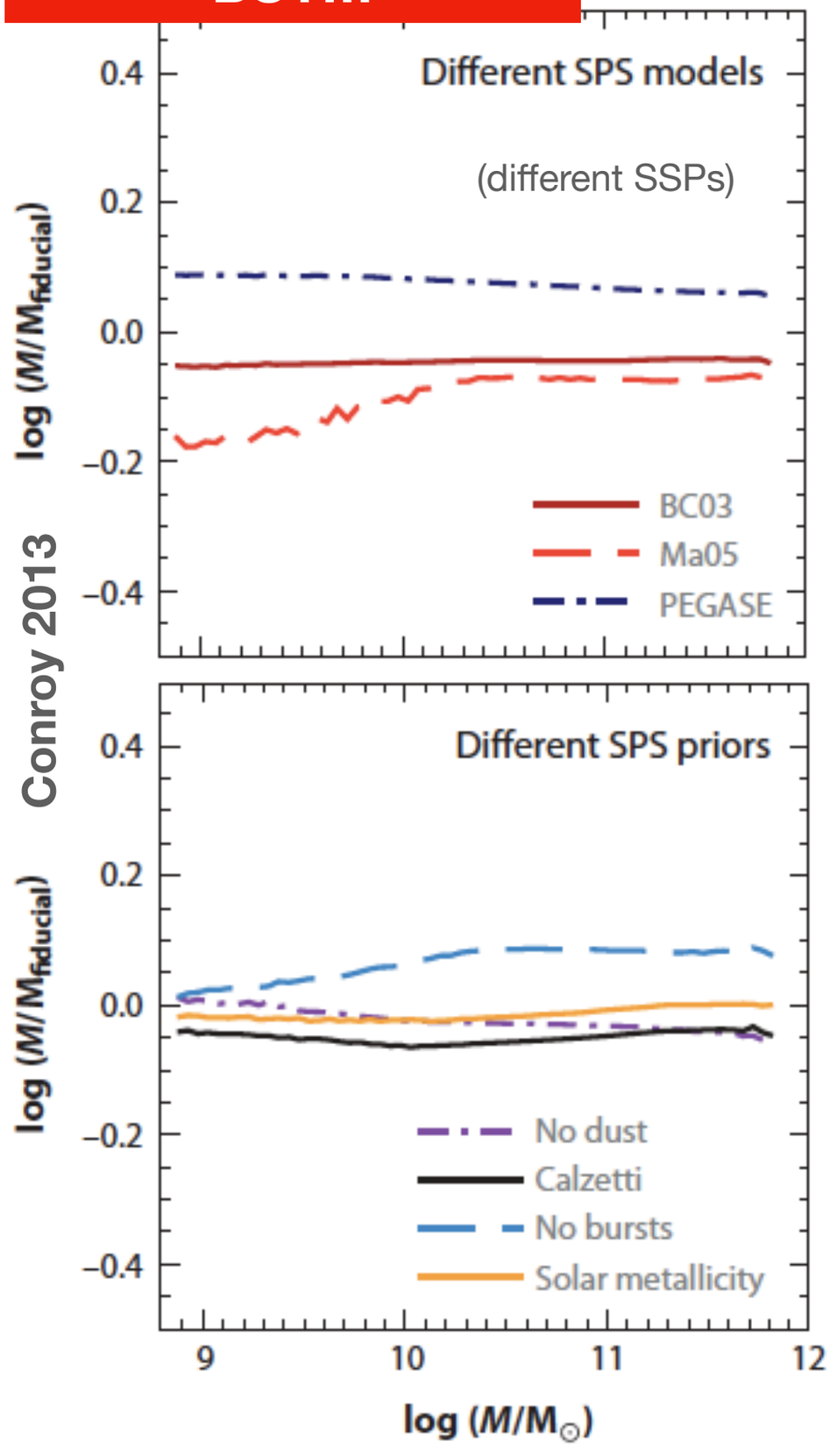
Conroy 2013



Bellstedt & Robotham 2025

Stellar mass

BUT…



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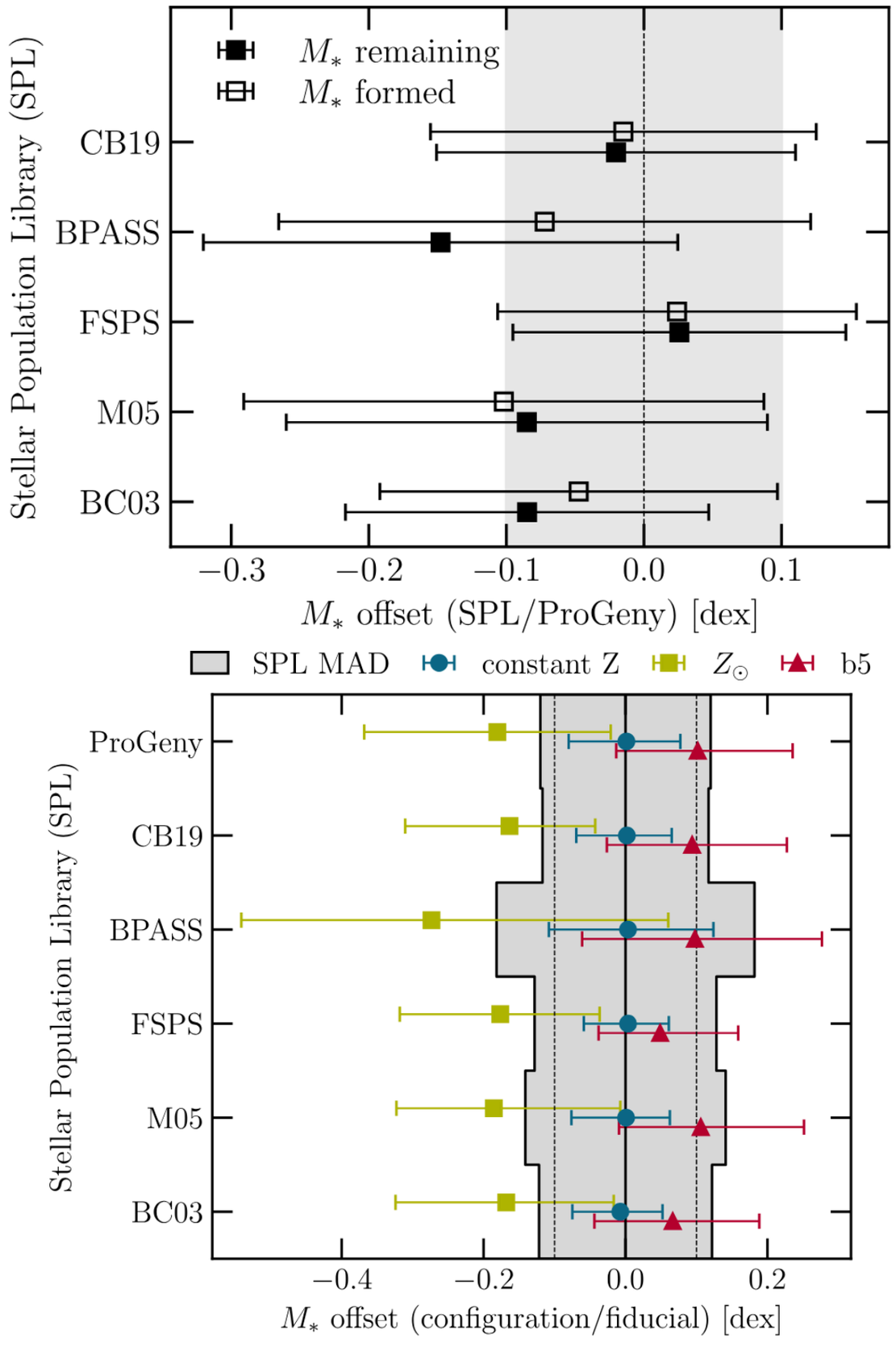
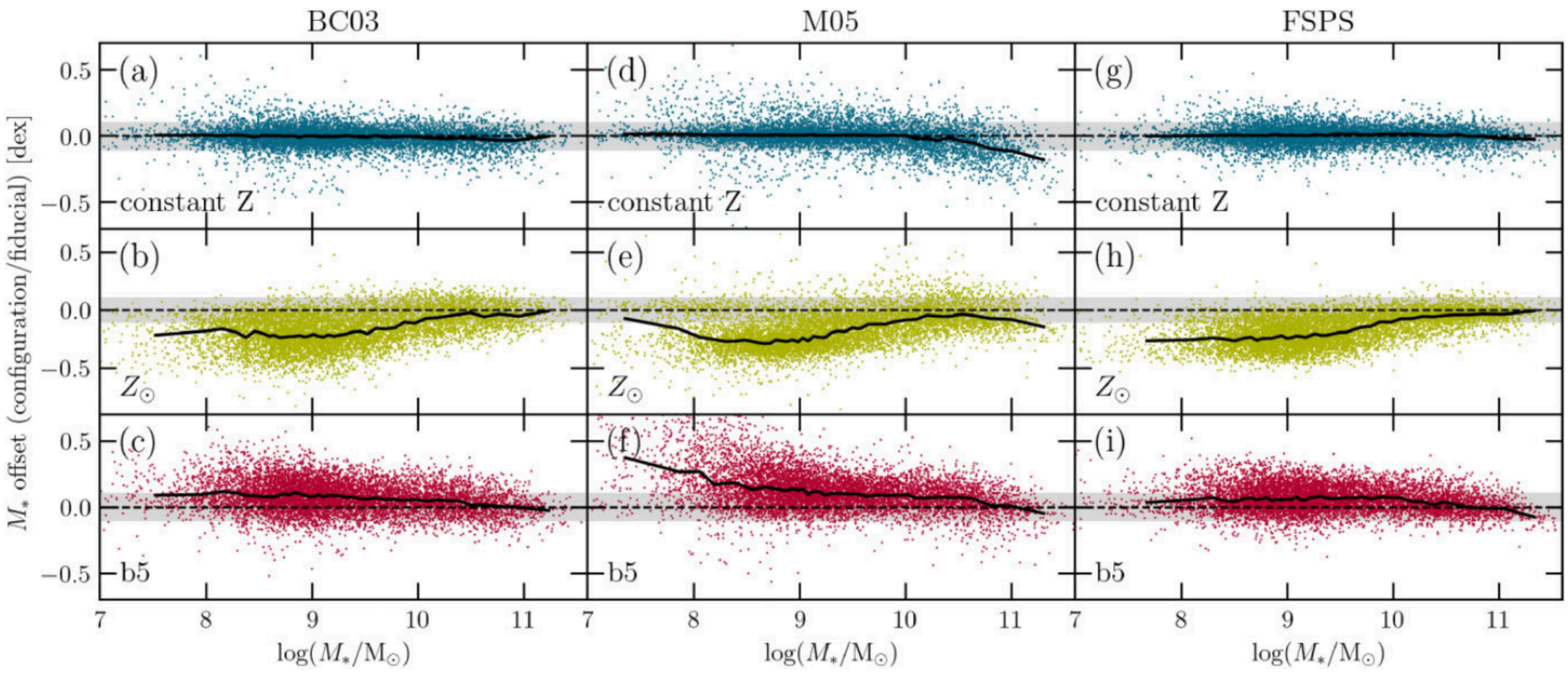


Bellstedt & Robotham 2025

different SPS models

different SPS priors

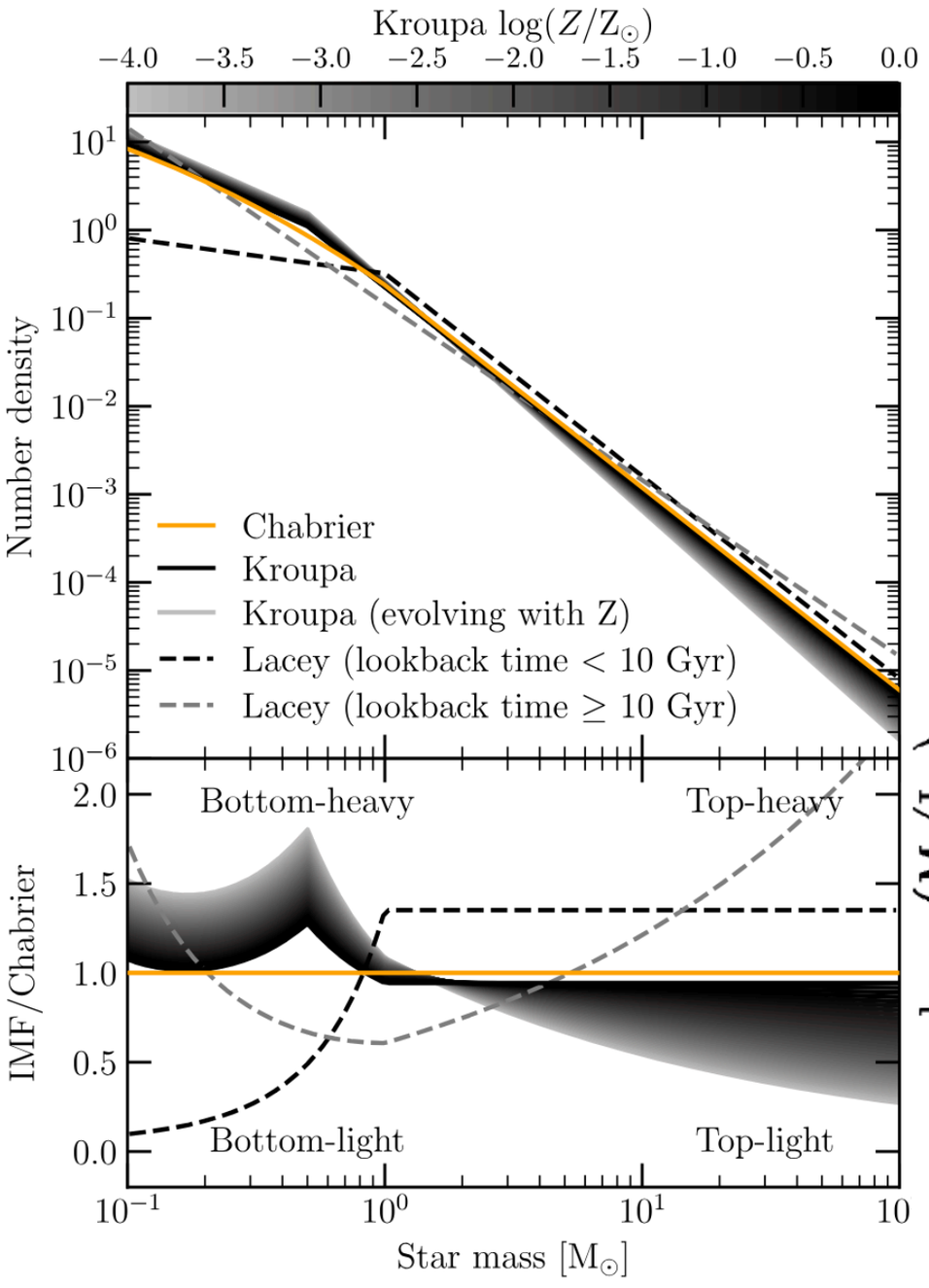


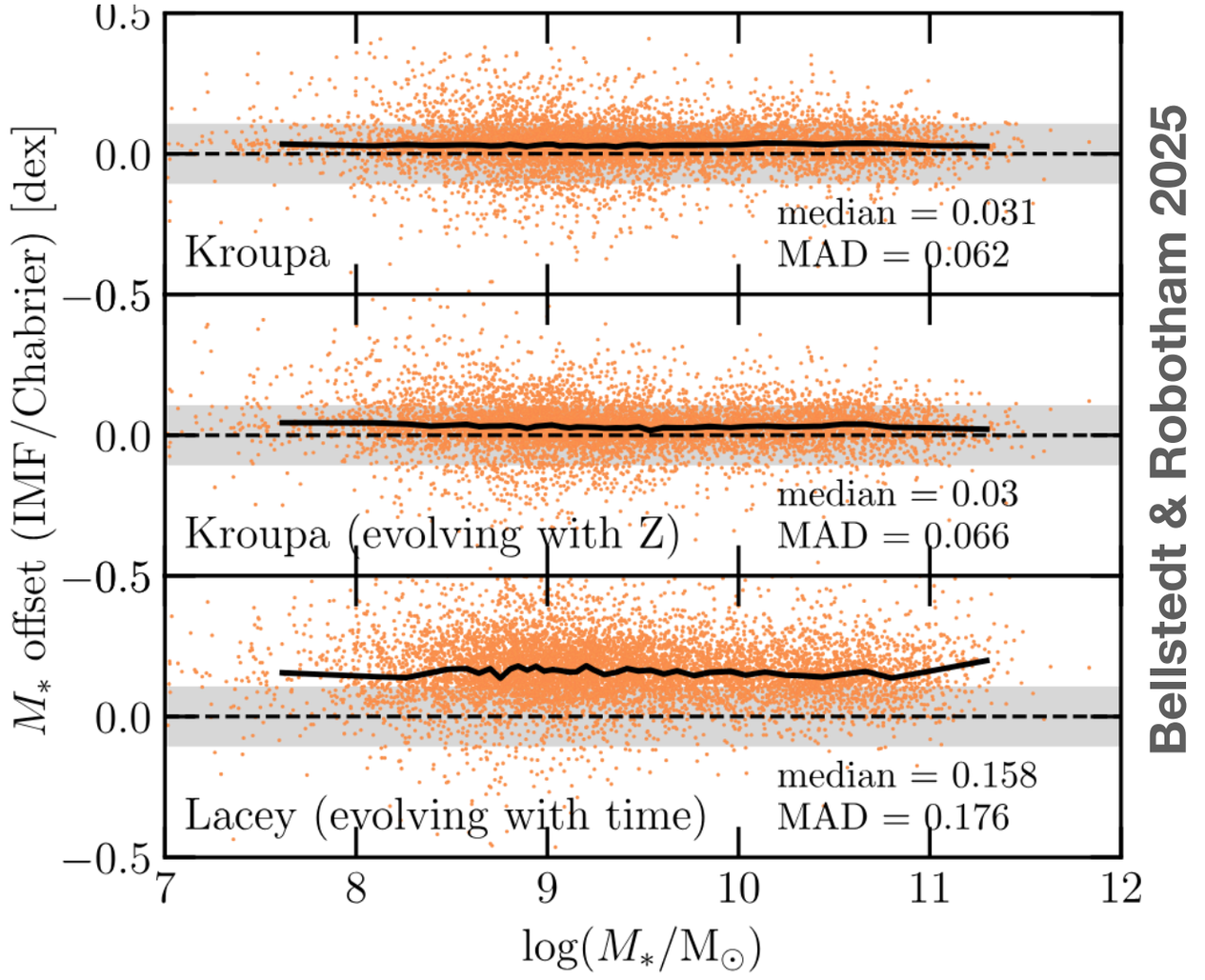
Bellstedt & Robotham 2025

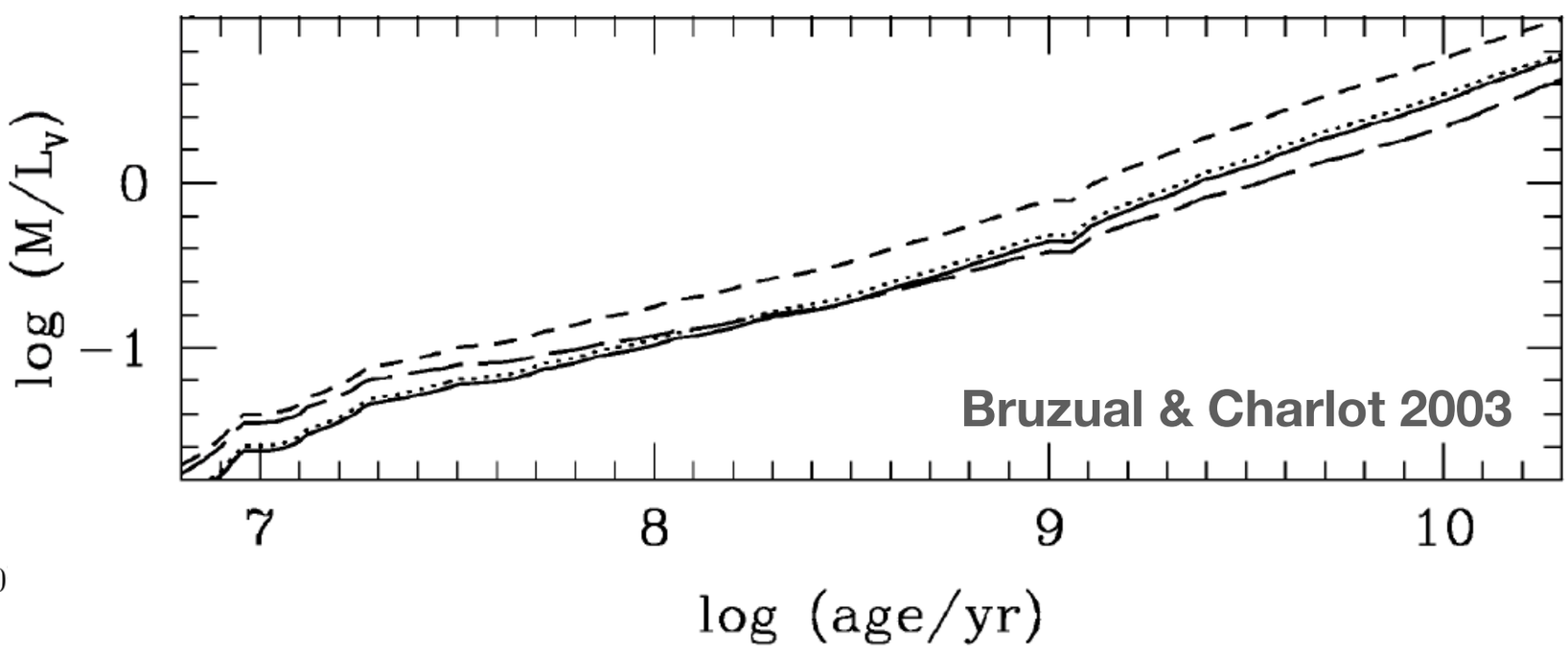
Stellar mass

BUT…

Impact of the IMF

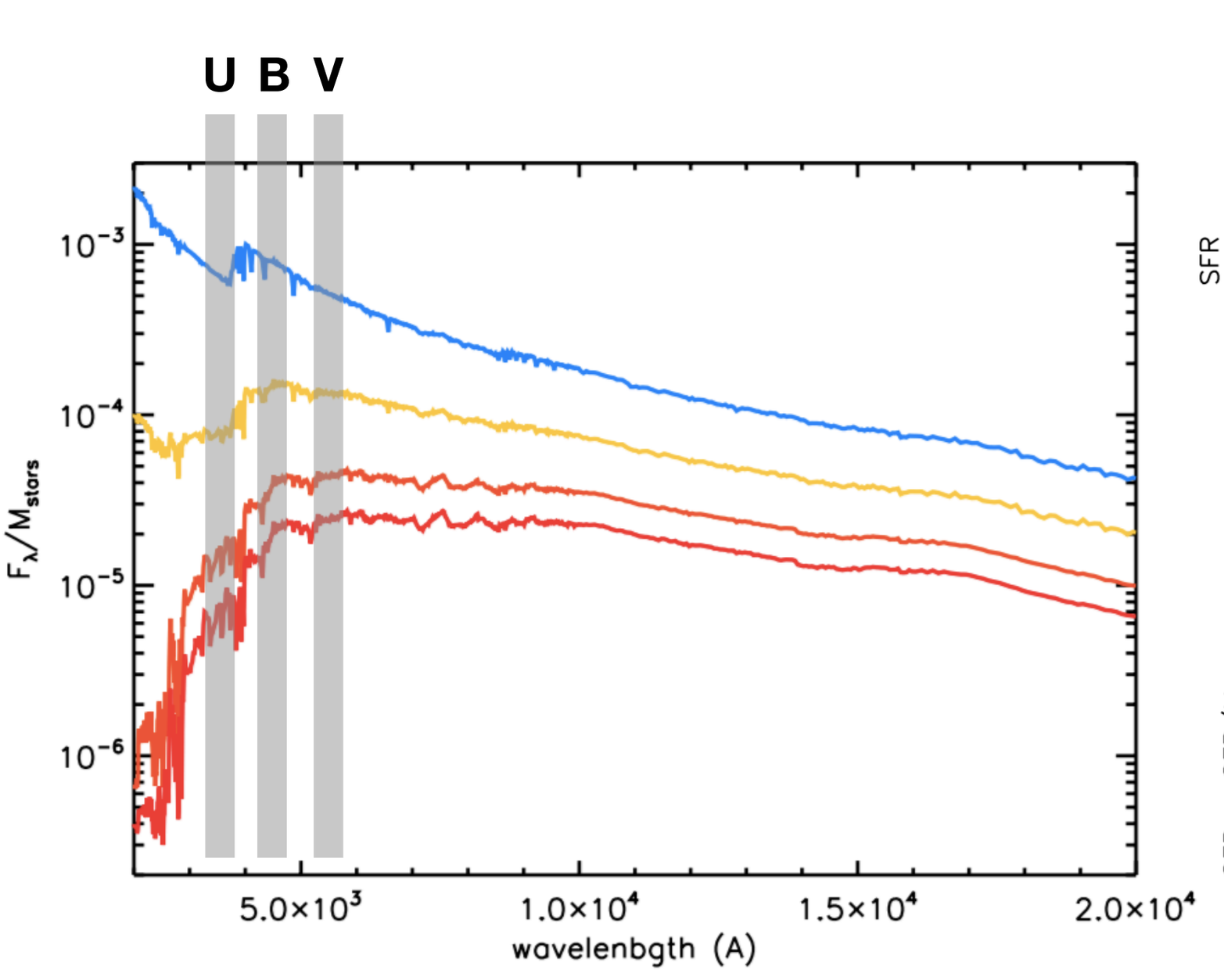


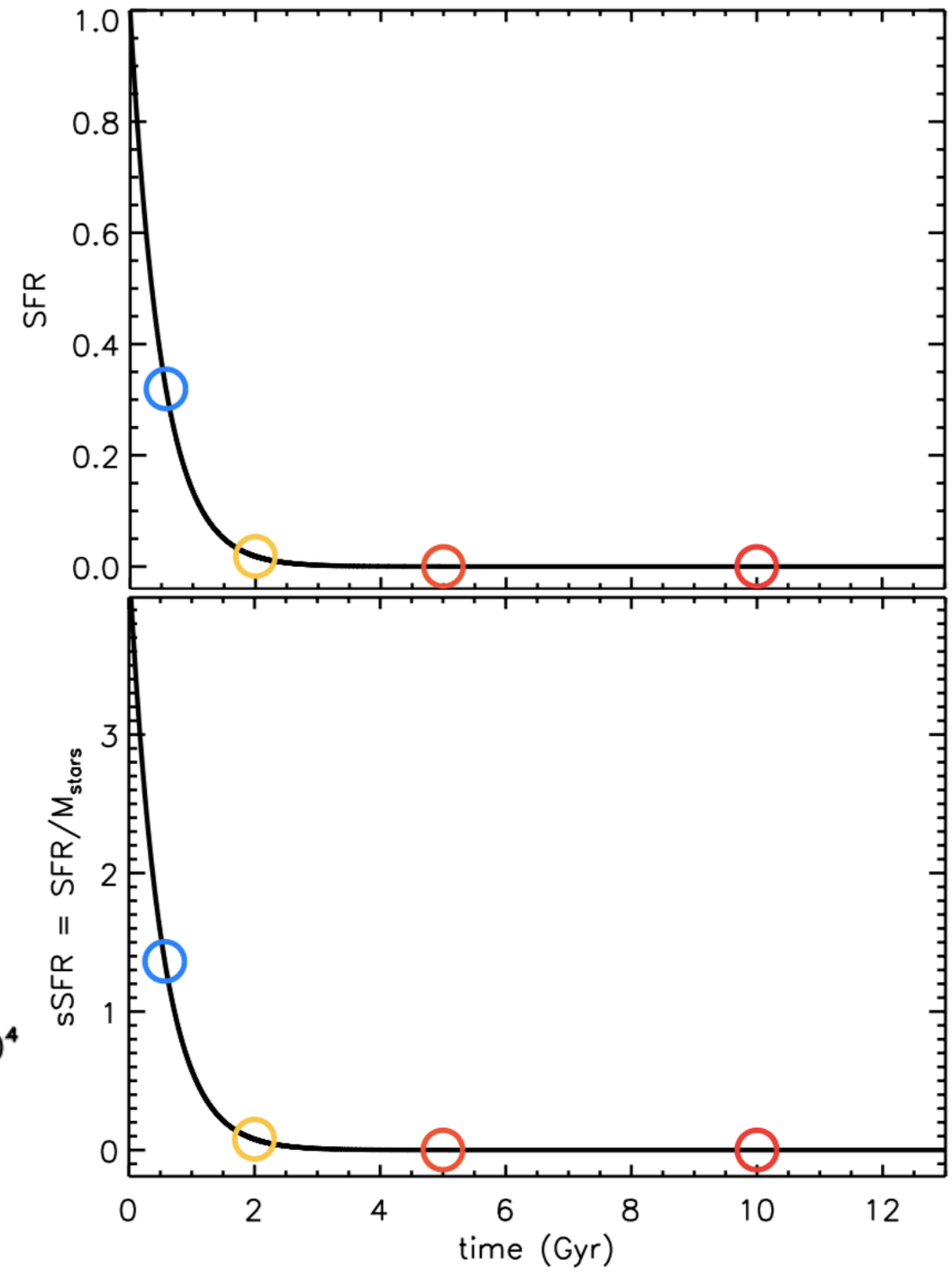




Broad stellar population age / specific star formation rate

intrinsic colors of a stellar population correlate with age / sSFR
→ constrain stellar population properties with one color… ?





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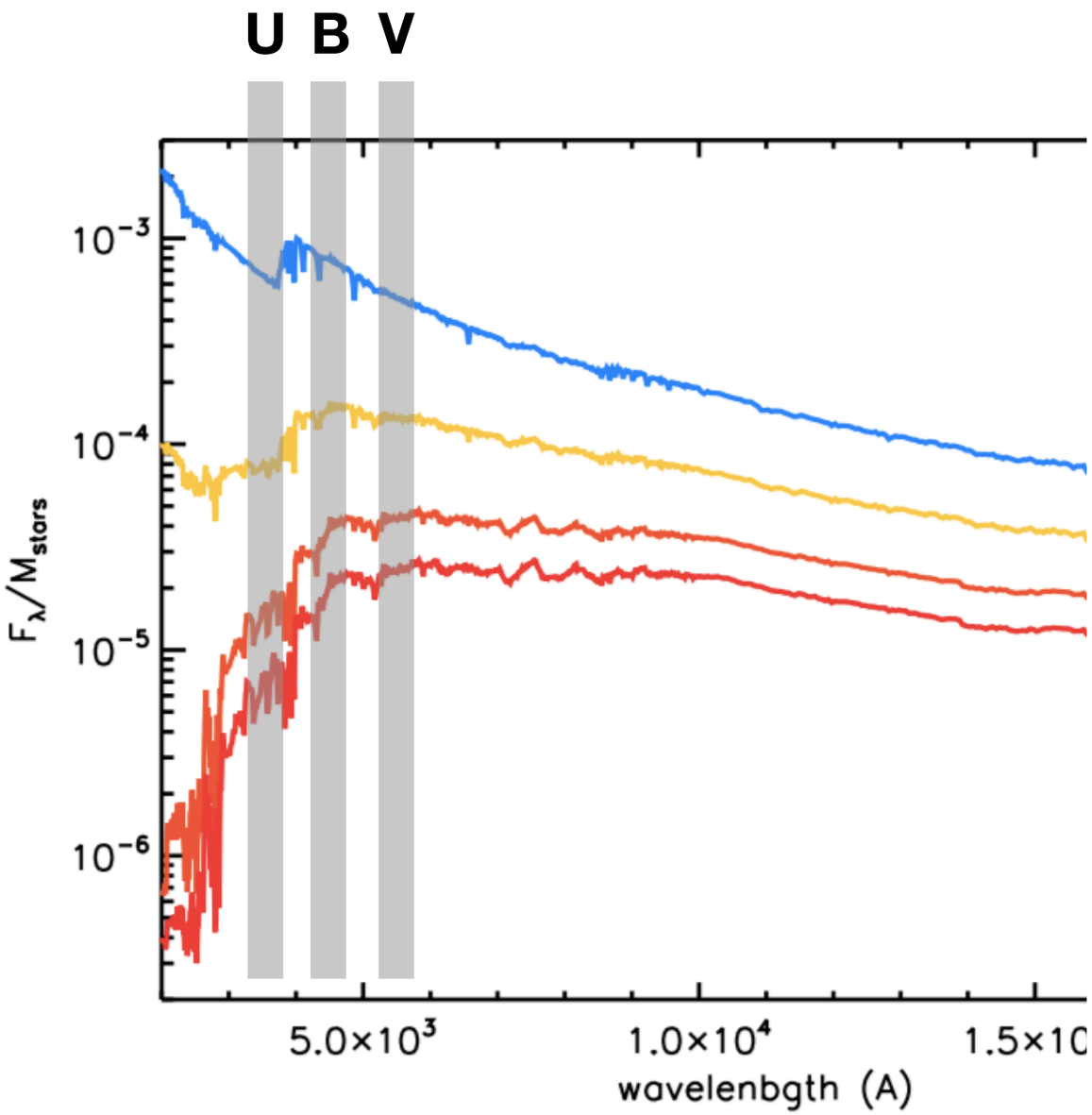

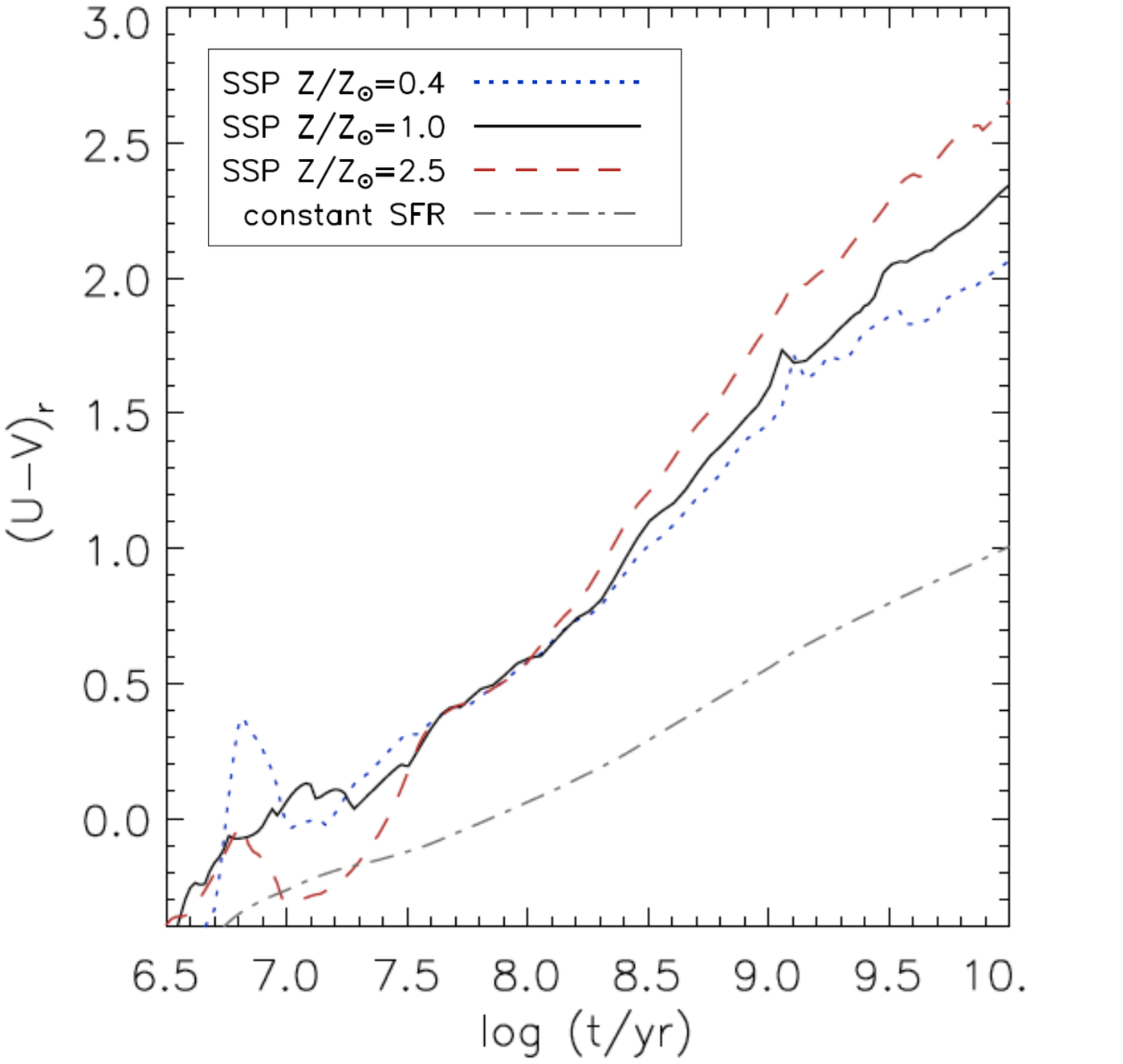

Hernán-Caballero et al. 2013

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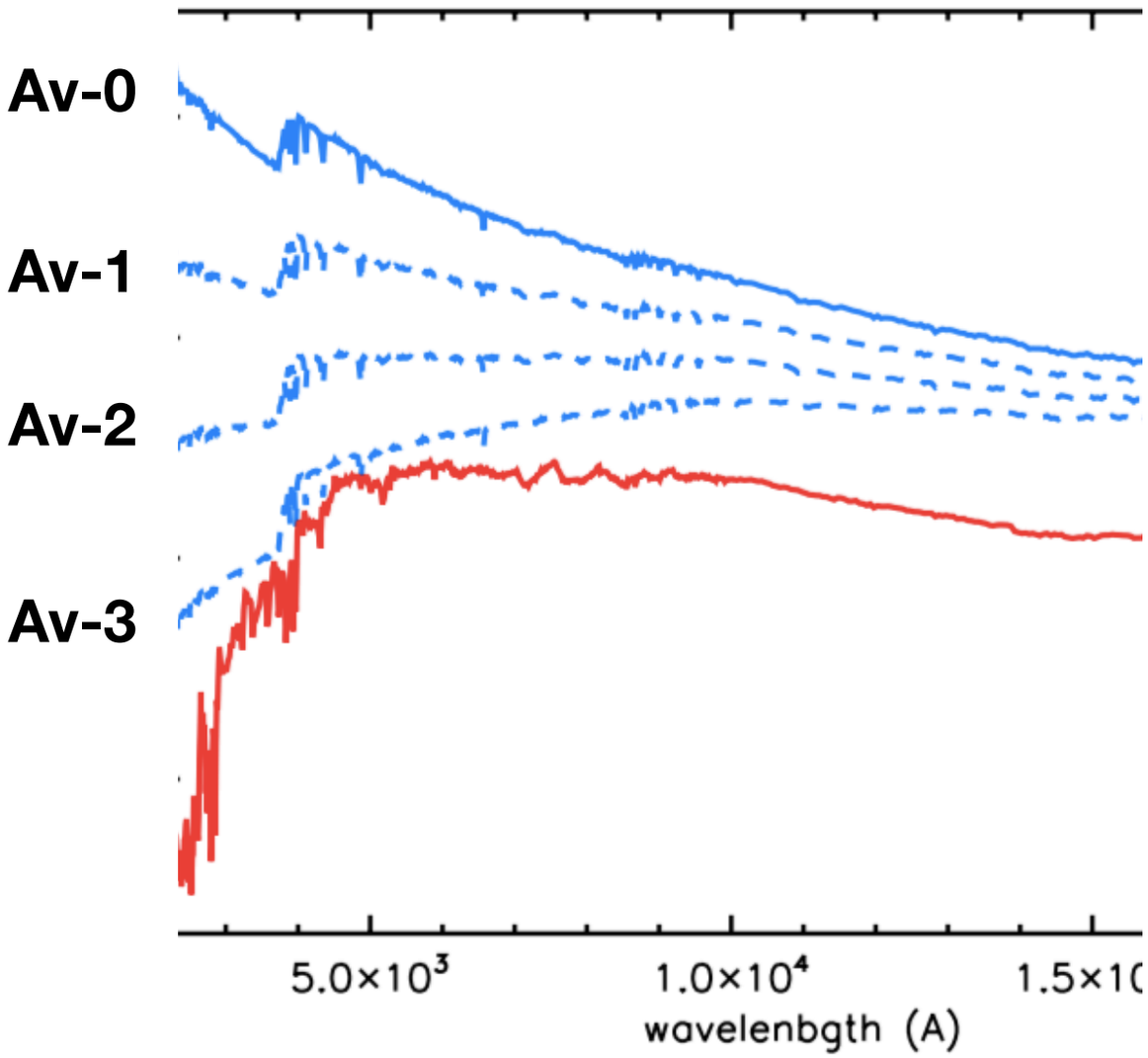
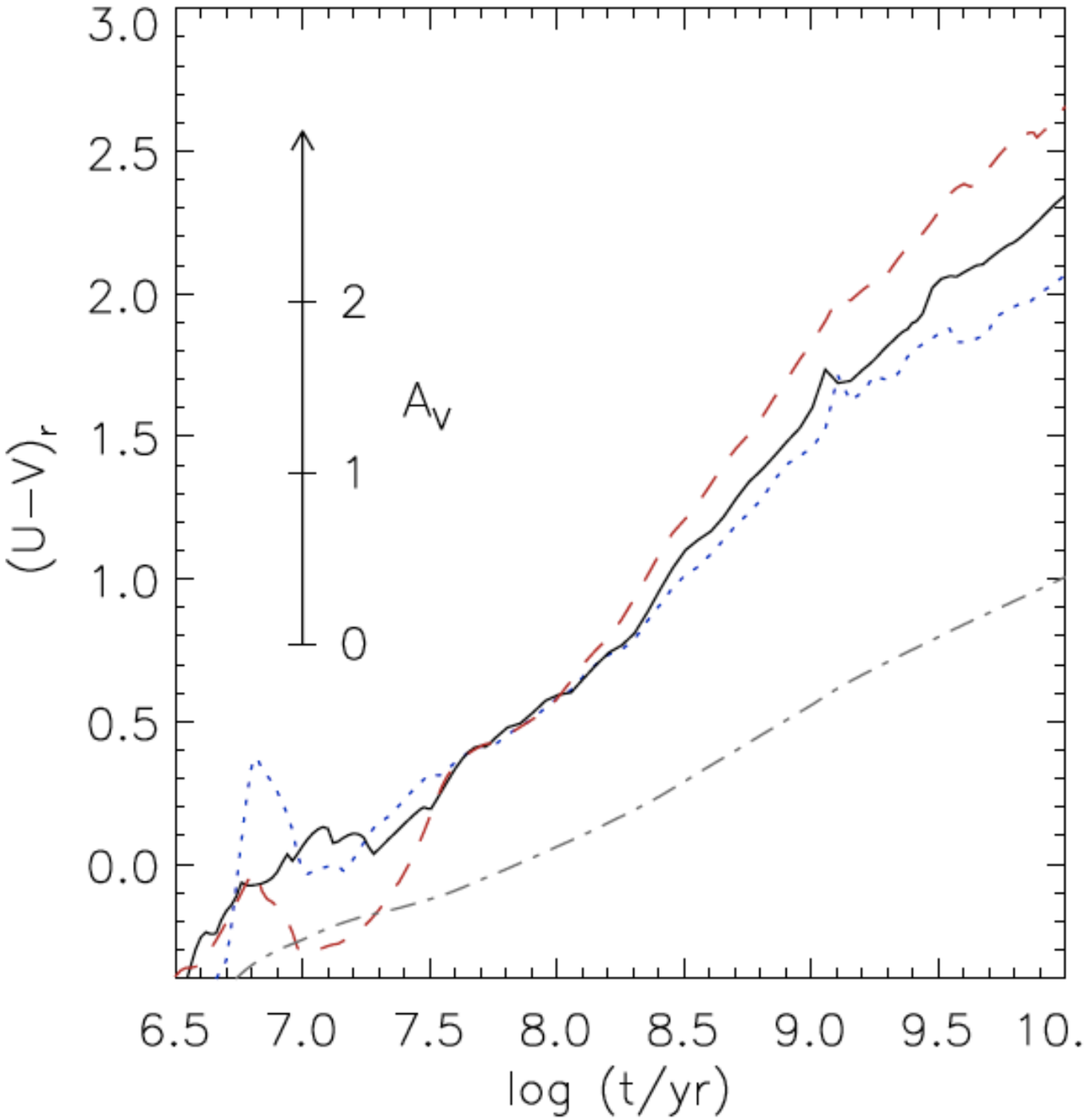
BUT beware of dust !





Hernán-Caballero et al. 2013

Broad stellar population age / specific star formation rate

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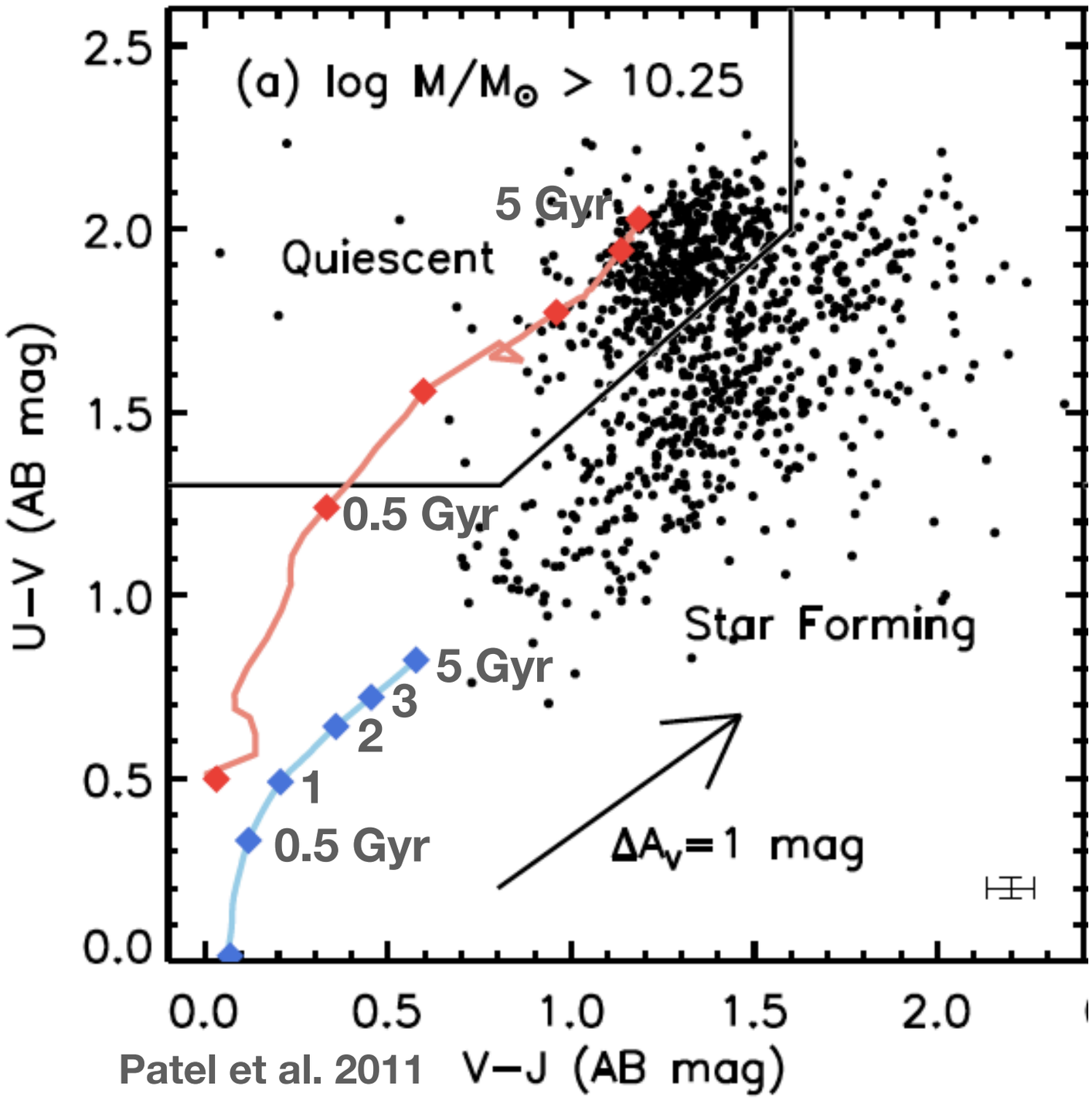
→ constrain stellar population properties with one color… ?

BUT beware of dust !

The combination of UV/optical and NIR (restframe!) colors may do the trick



Patel et al. 2011

Broad stellar population age / specific star formation rate

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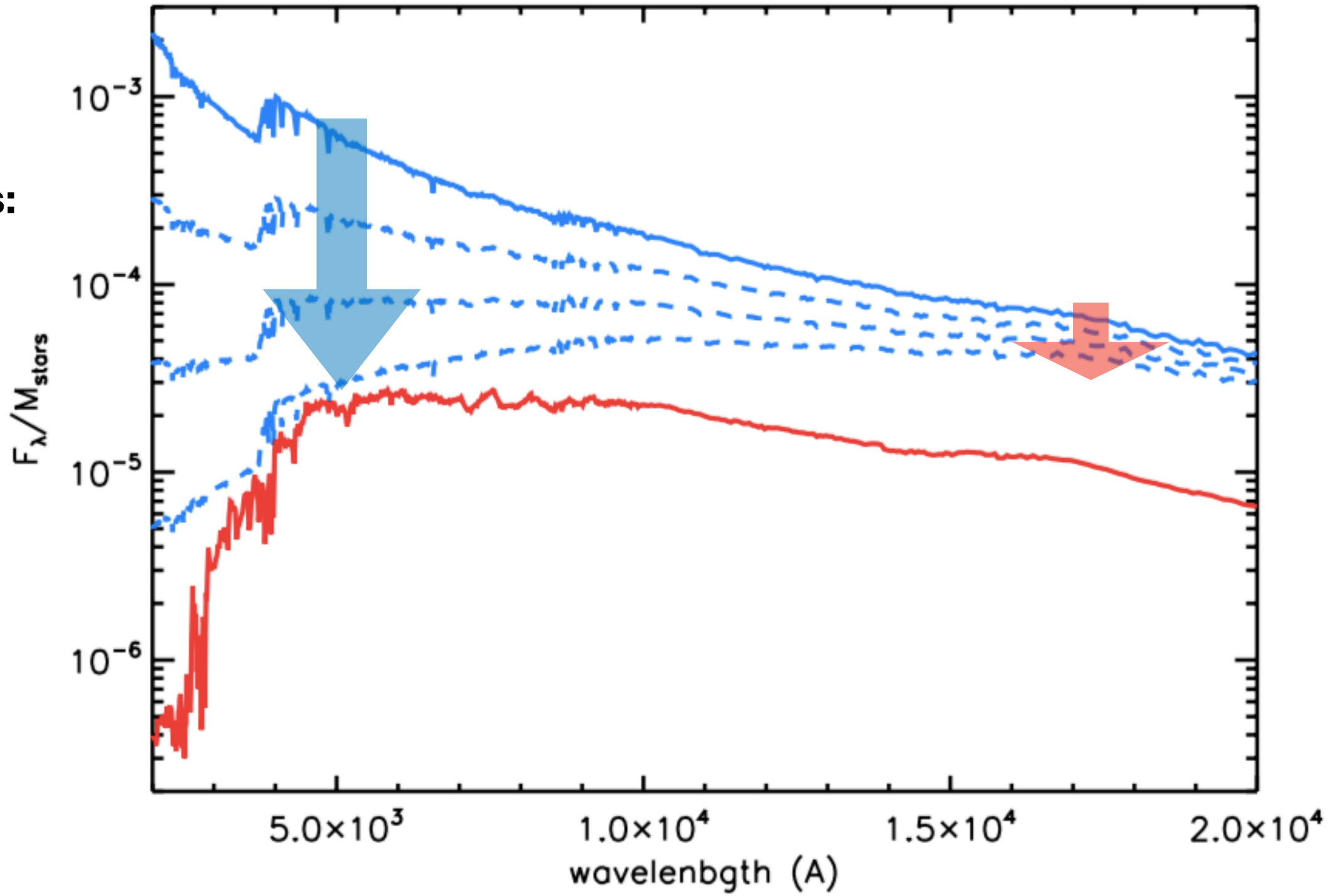
How it works:



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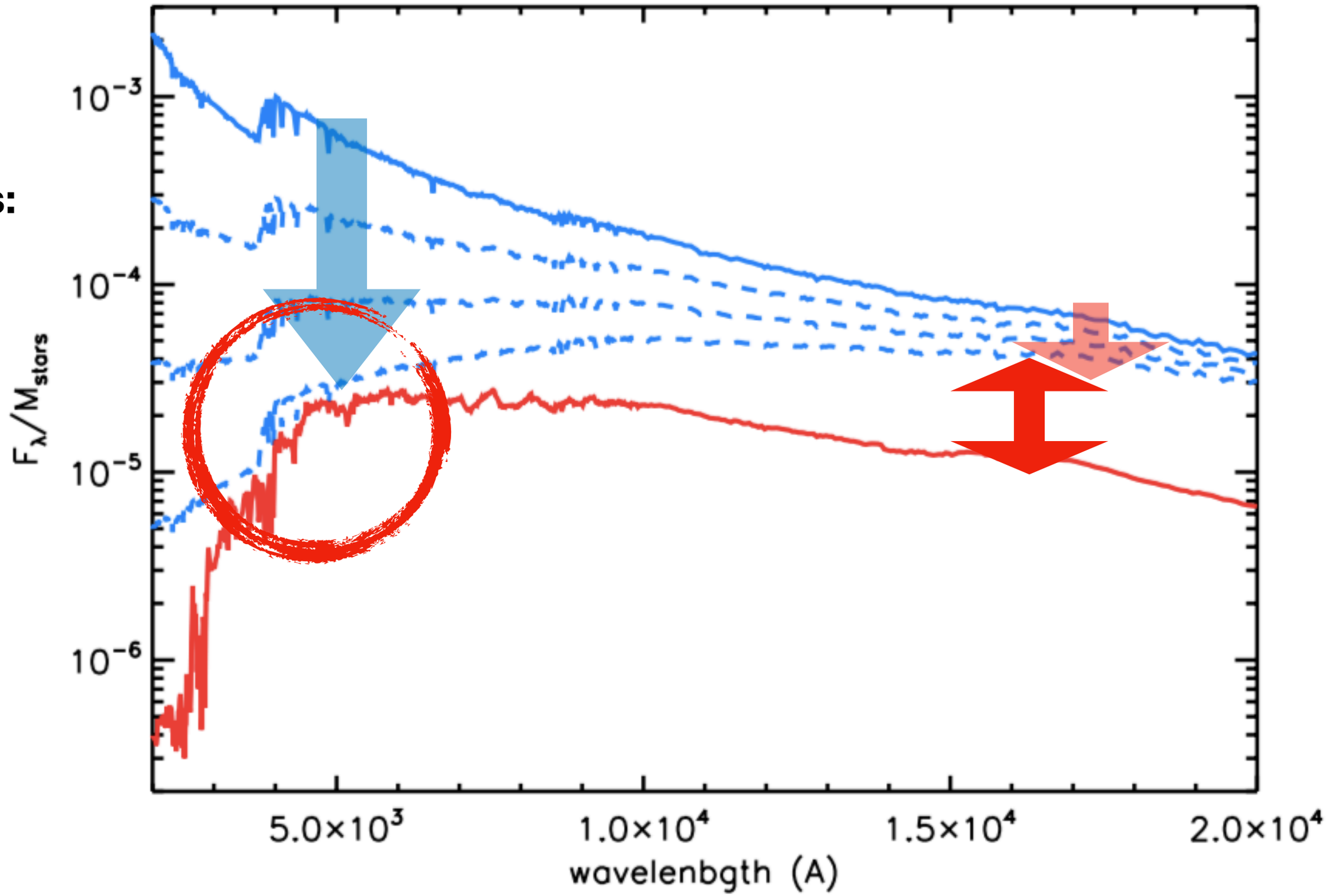

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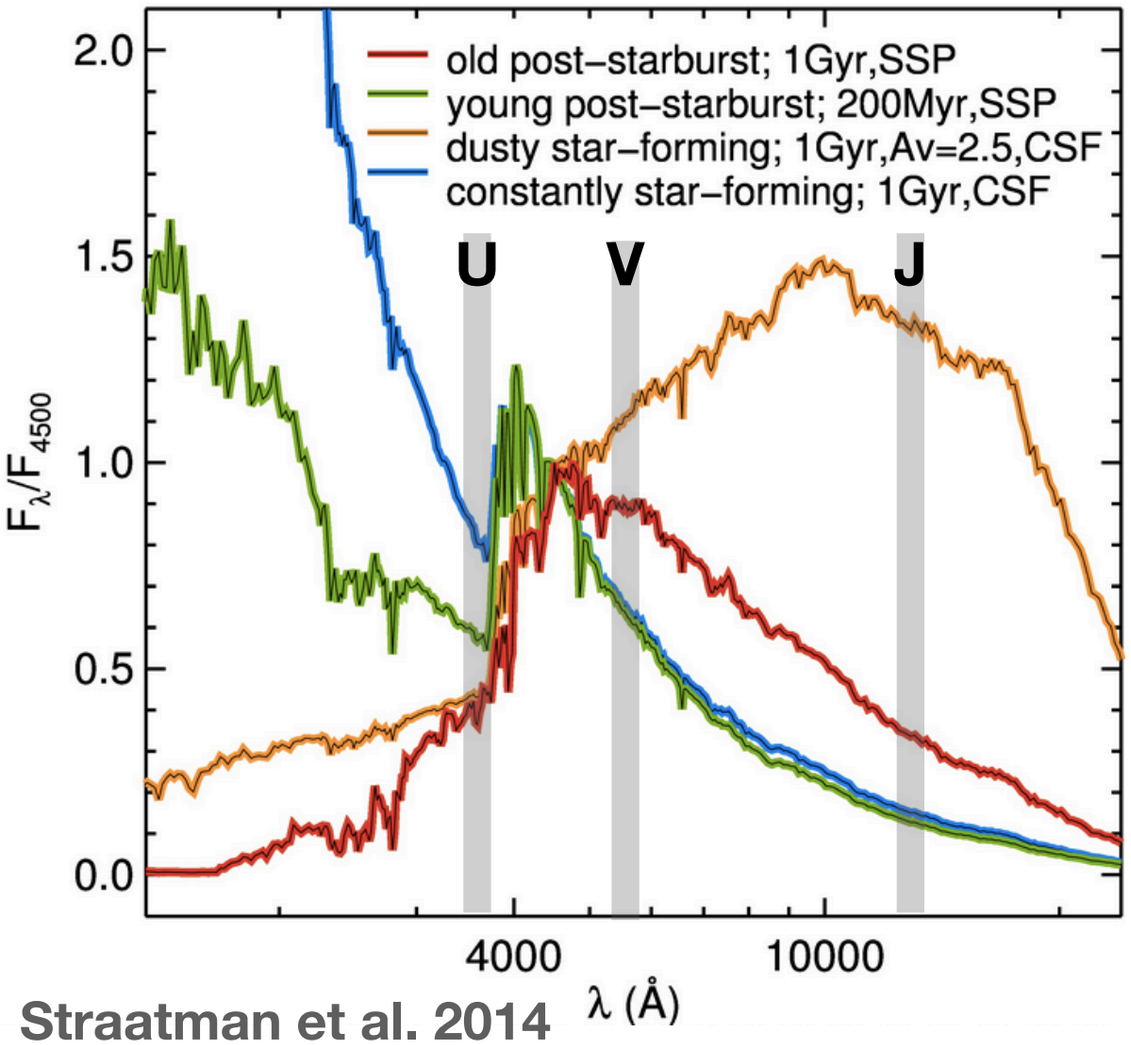
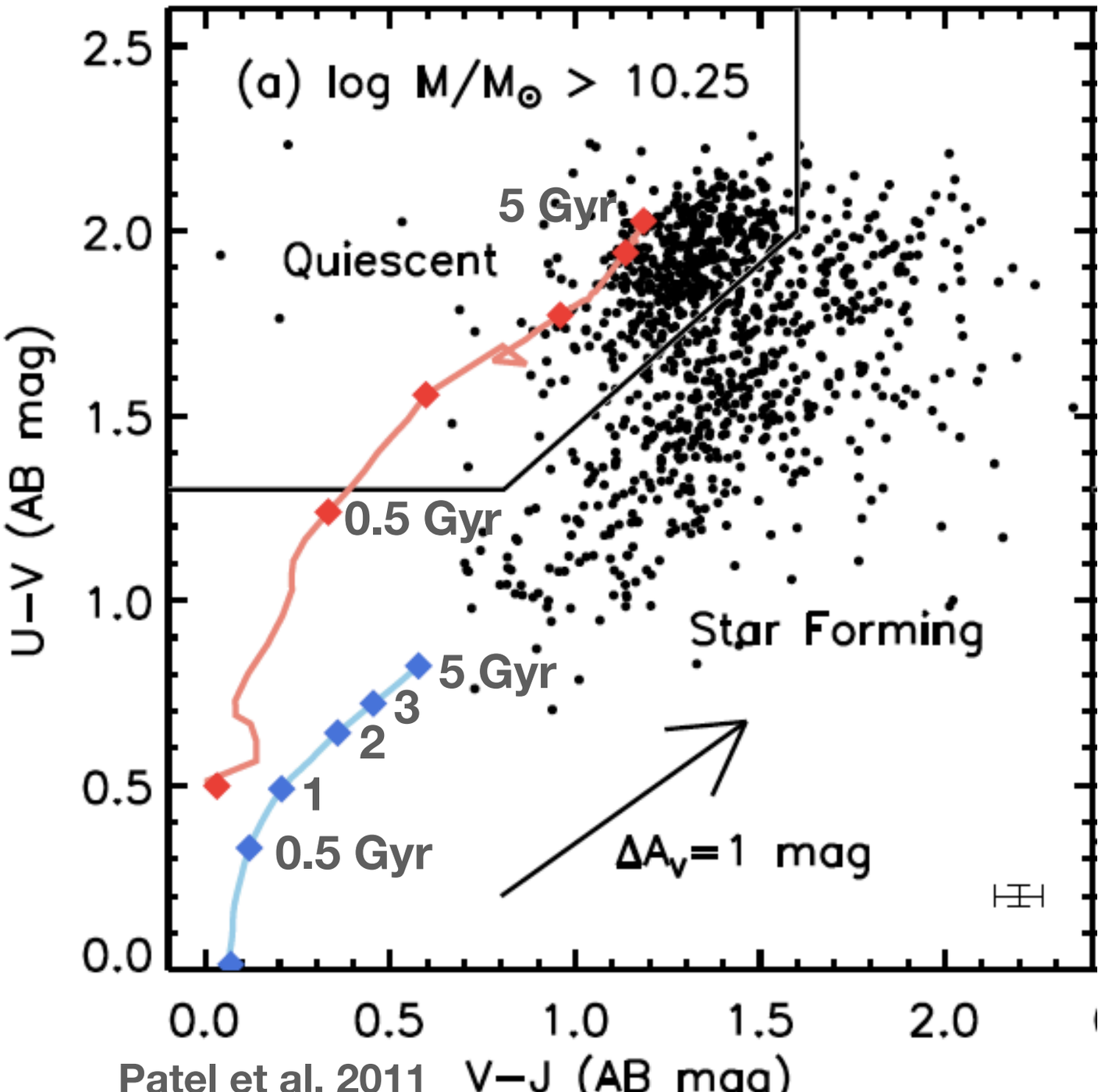


Straatman et al. 2014

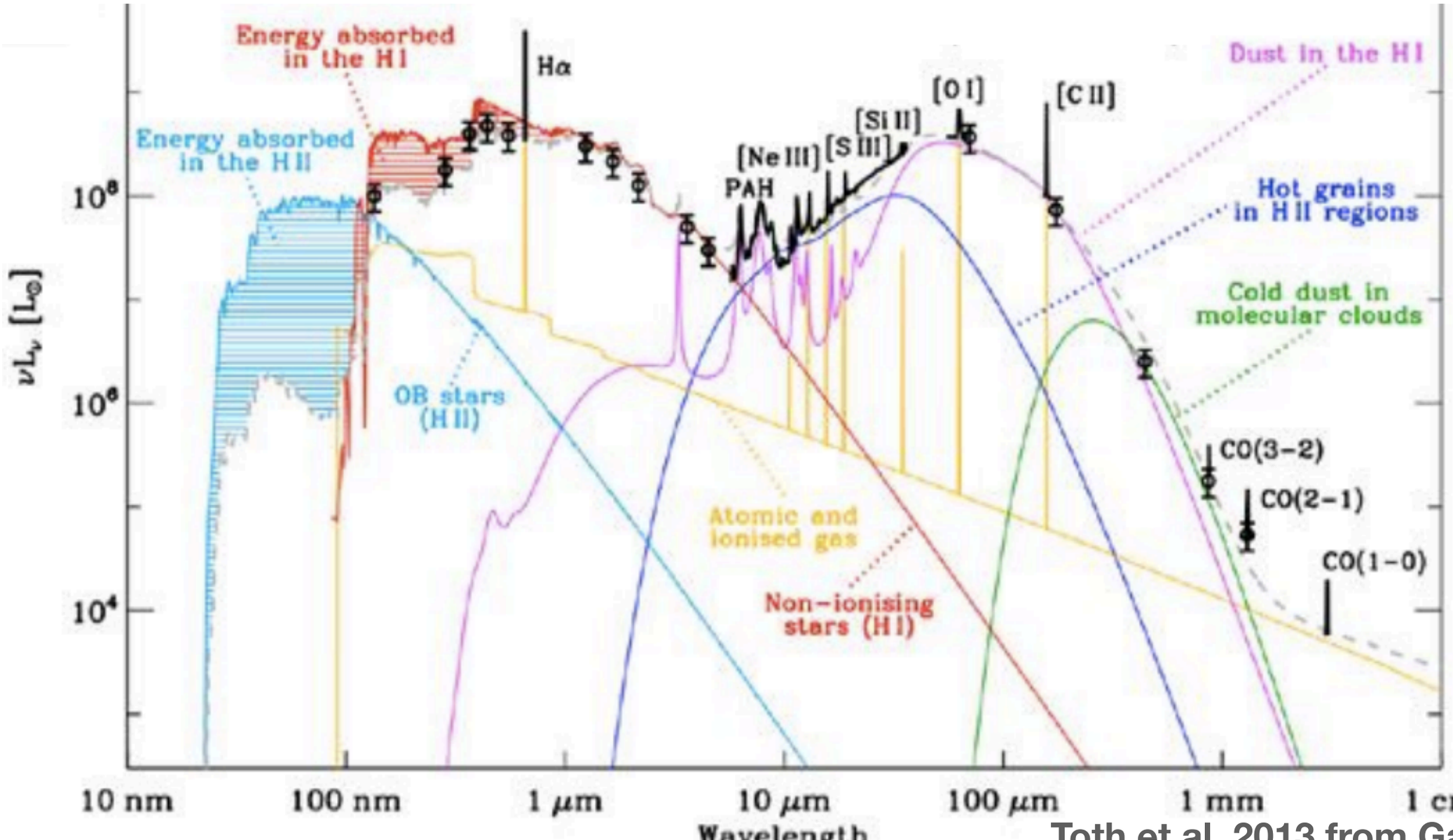


Patel et al. 2011

Star formation rates

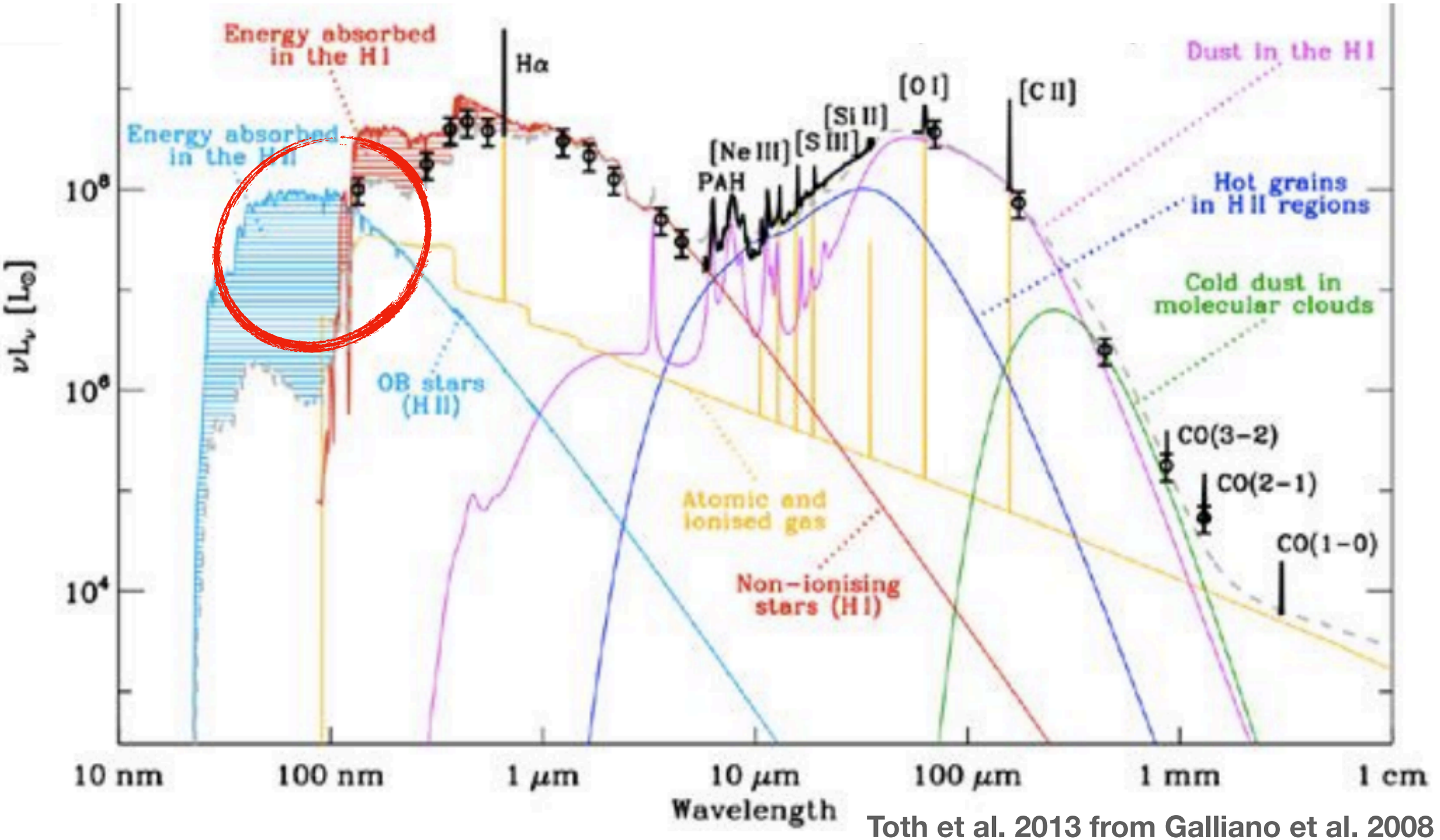
The estimate of the rate at which stars are being formed (on timescales of order 10-100x Myr) in a (unresolved) galaxy relies on measurements of luminosities (continuum or emission line) sensitive to the emission of short-lived (massive) stars.

One then converts the luminosity of massive stars to "the galaxy SFR" with some assumptions (e.g. that SFR has been constant over the timescale of the SFR estimator, that the IMF is "known" (and sampled at all masses) so that the number of massive stars probed can be extrapolated to the total number of stars being formed).



Toth et al. 2013 from Galliano et al. 2008

Star formation rates



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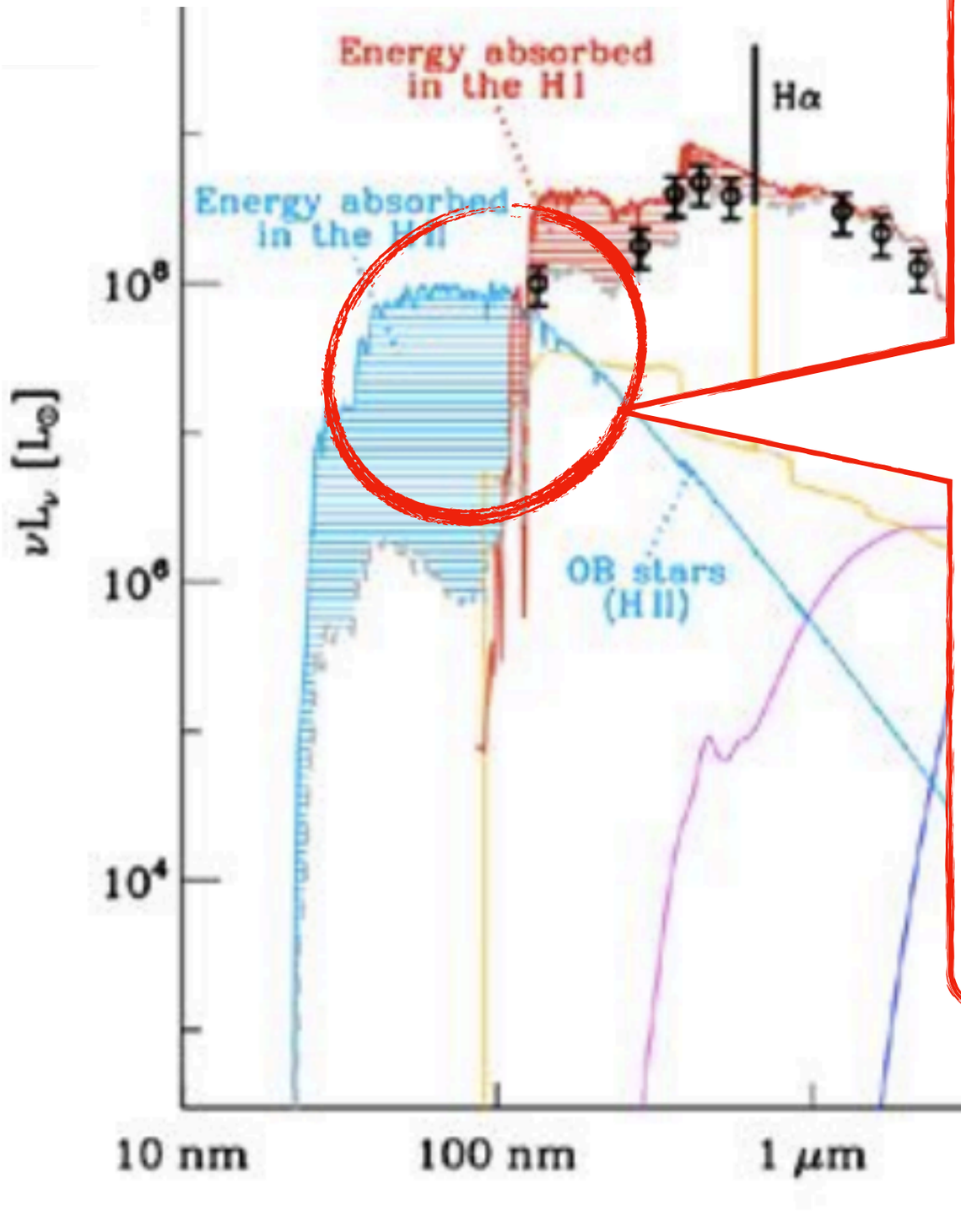

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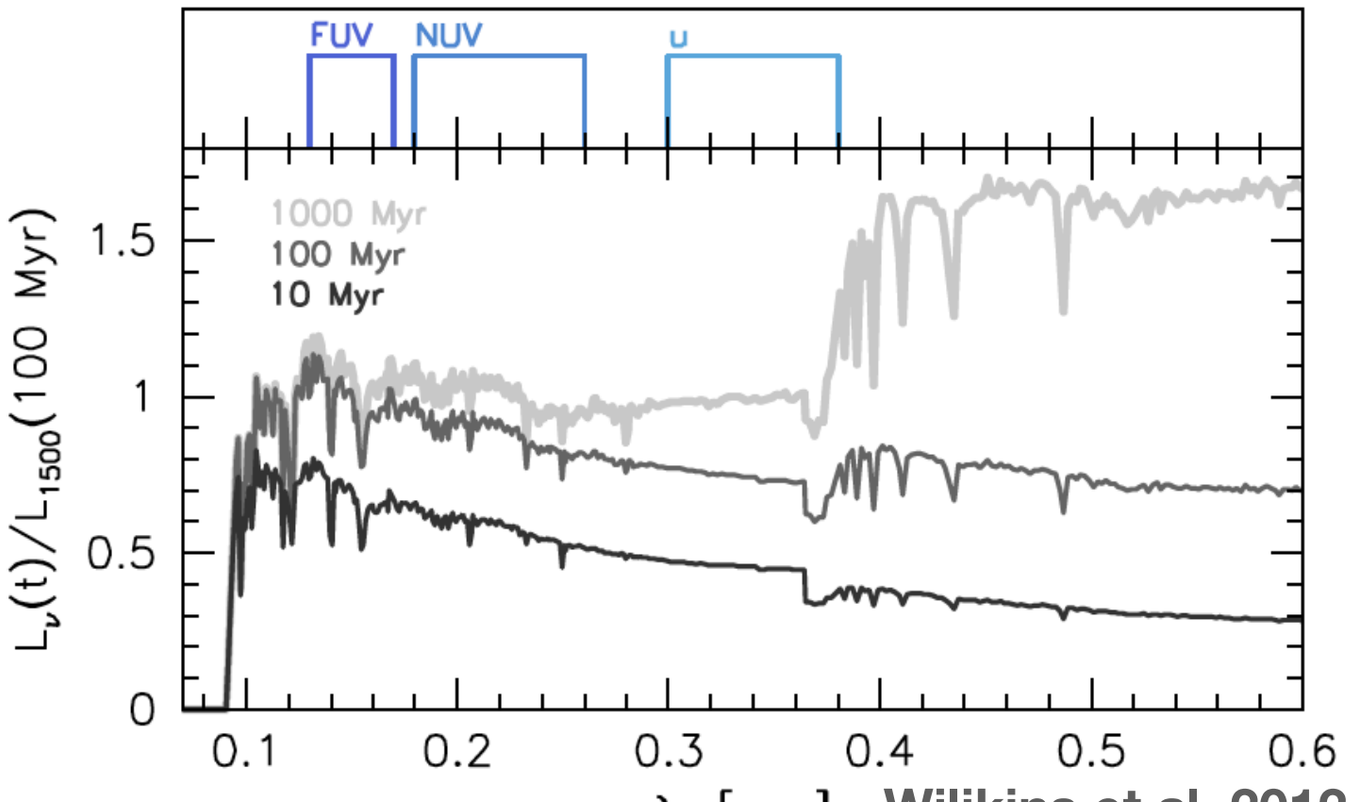


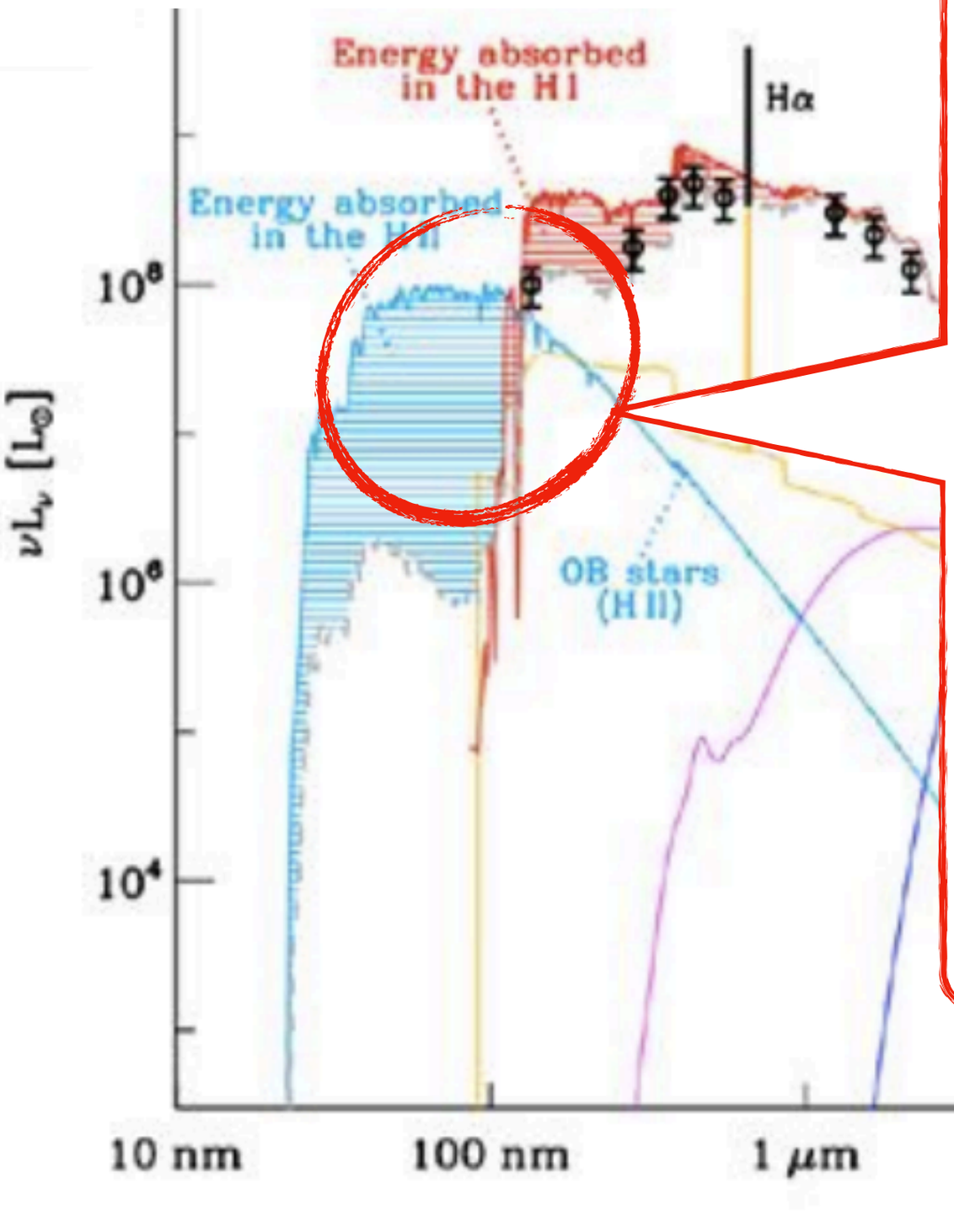
Wilikins et al. 2012

from UV continuum luminosity:

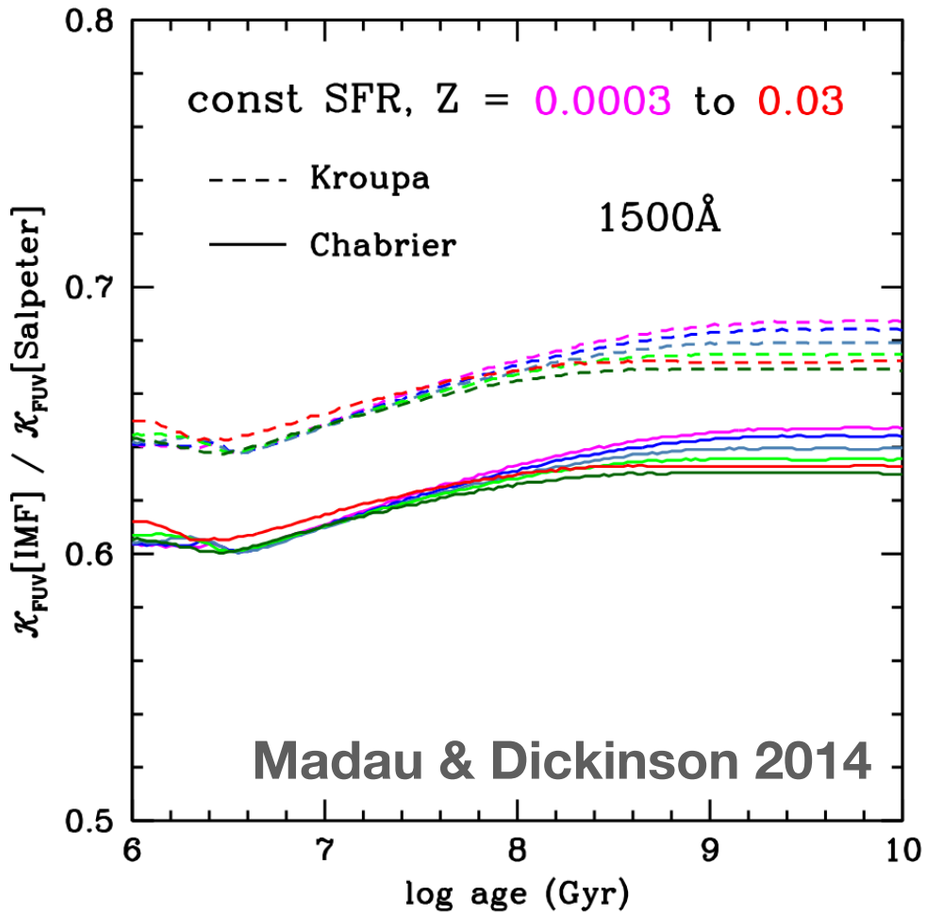
$$\mathbf{SFR_{UV} \propto L_\nu}$$

ν in **1500-2500 Å range**, F**ν** relatively flat, contribution from older populations is small

Star formation rates



SFR/L_{FUV} conversion factors



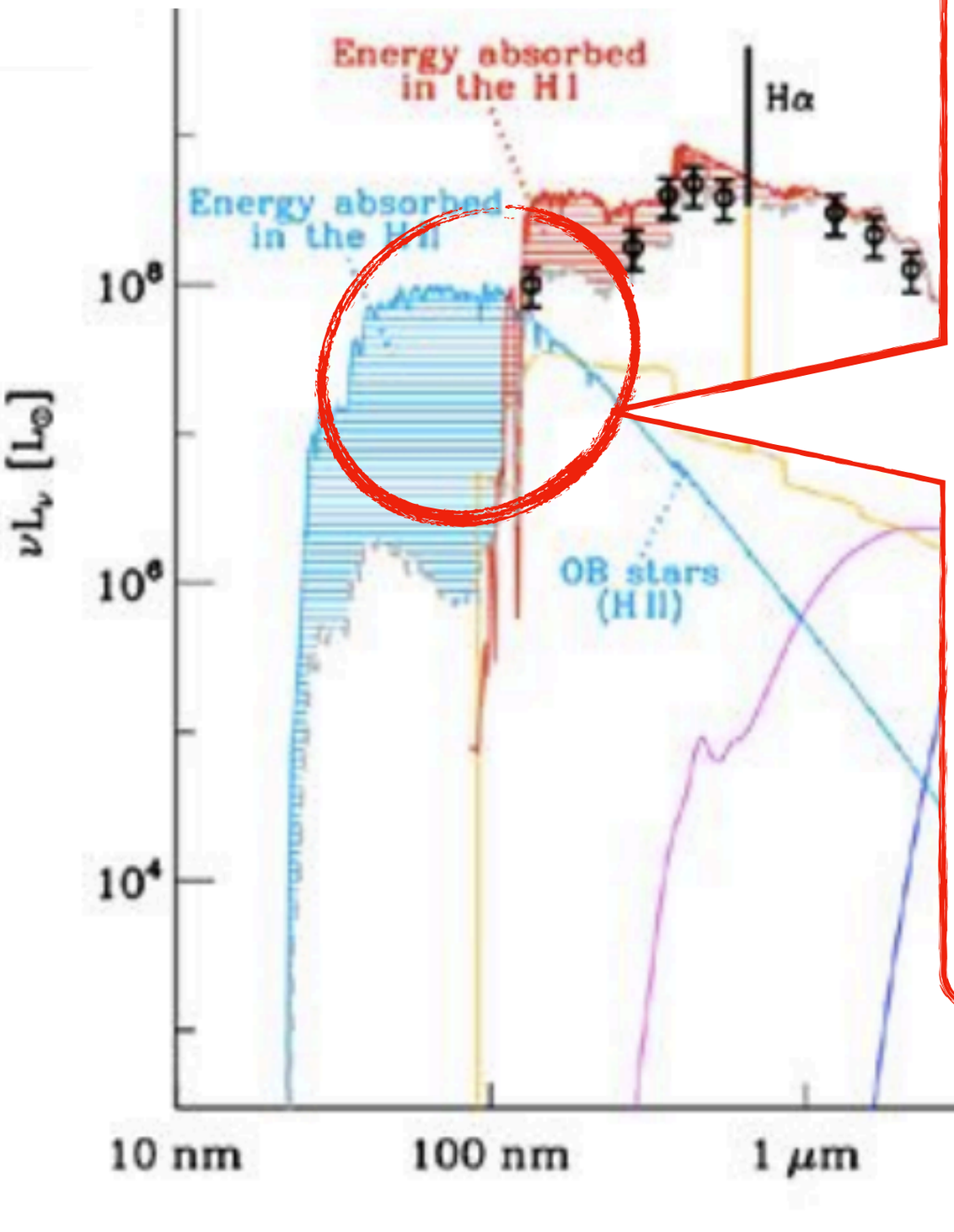
from UV continuum luminosity:

$$\mathbf{SFR_{UV} \propto L_\nu}$$

depends on IMF, metallicity, recent SFH, and …

Toth et al. 2013 from Galliano et al. 2008

Star formation rates



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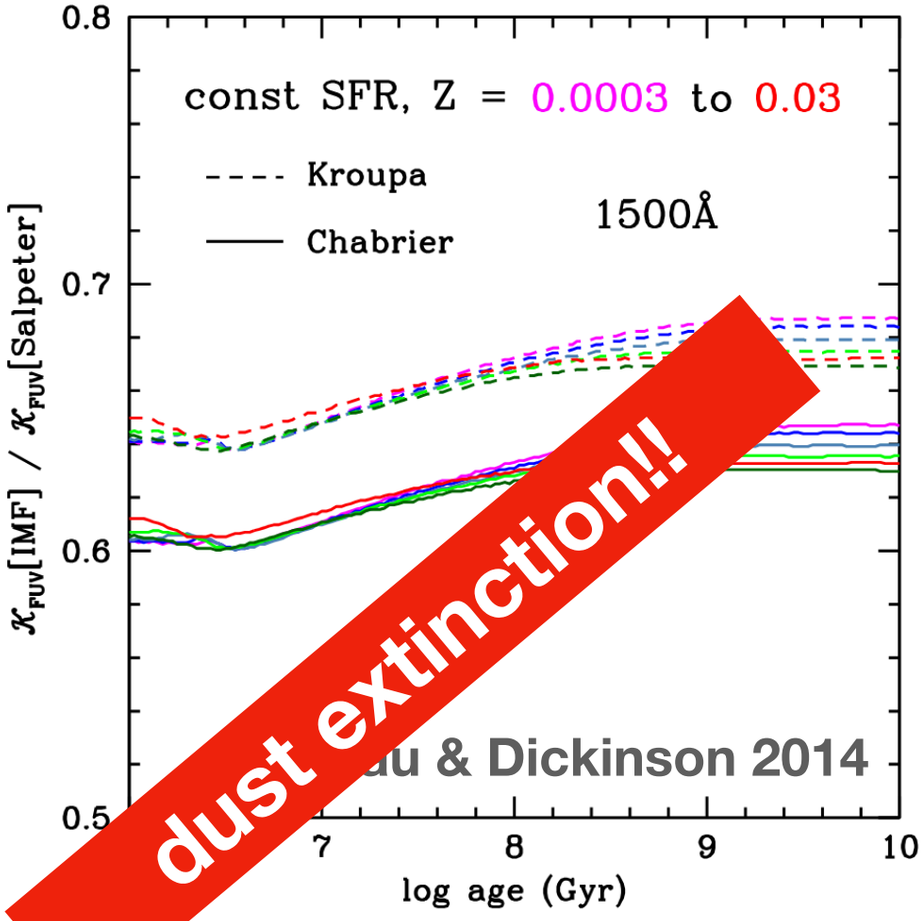

dust extinction!!

Hao, Kennicutt, Johnson, Calzetti, Dale, Moustakas 2011; Murphy, Kennicutt, Calzetti, Dale 2011; Boquien, Calzetti, Kennicutt, Bigiel, Hao, Smith, Relaño 2016; Leroy, Bolatto, Bot, Gordon, Hunt, Kennicutt, Madden, Montiel, Sandstrom, Skibba, Walter 2012; Leroy, Lee, Kennicutt, Chandar, Cook, Dale, Fumagalli, Gil de Paz, Kim, Meidt, Schinnerer, Skibba, Williams 2019; Lee, Kennicutt, Funes, Sakai, Akiyama 2007; Meurer, Heckman, Calzetti 1999; Wu & Dickinson 2014

from UV continuum luminosity:

$$\mathbf{SFR_{UV} \propto L_\nu}$$

depends on IMF, metallicity, recent SFH, and …

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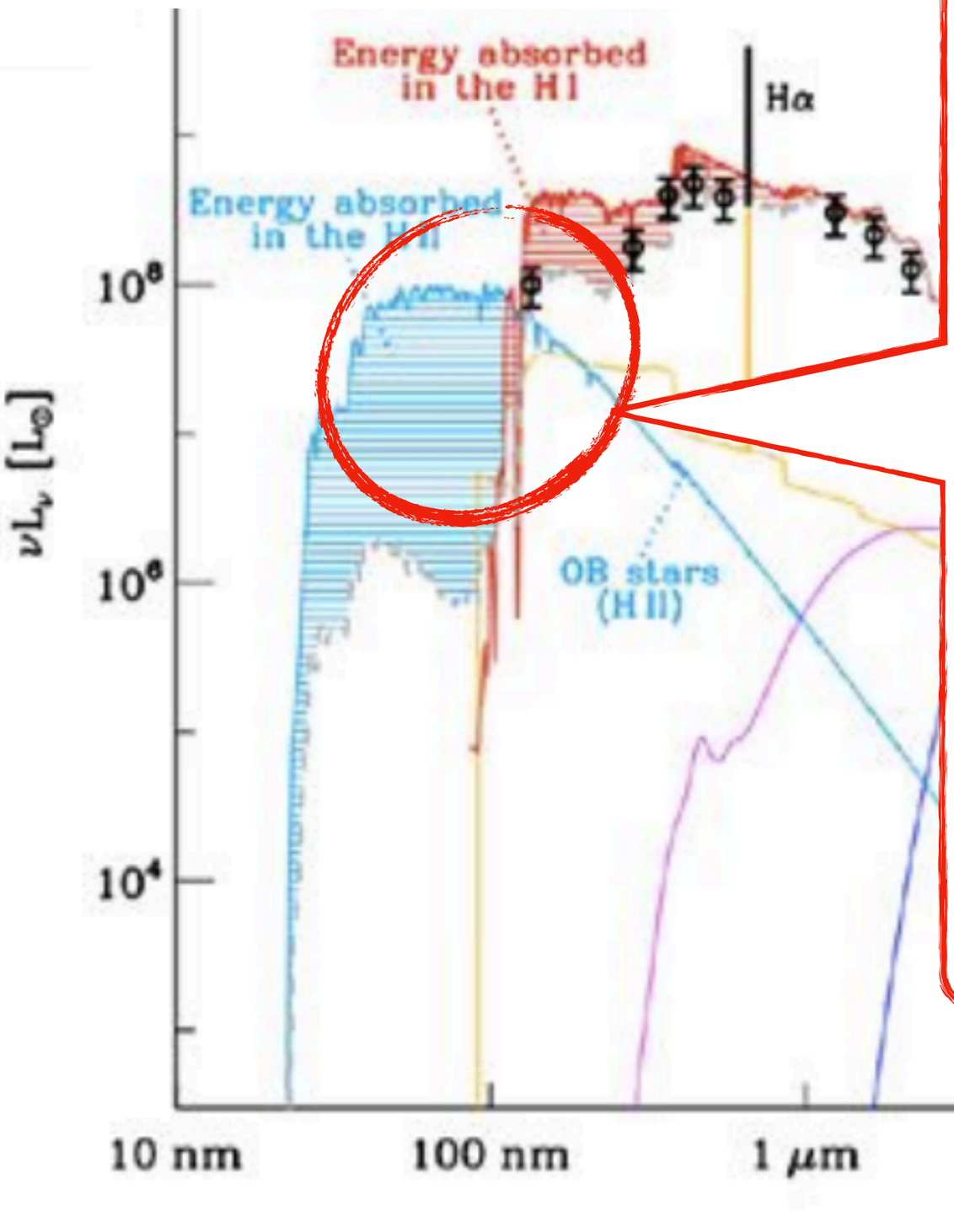
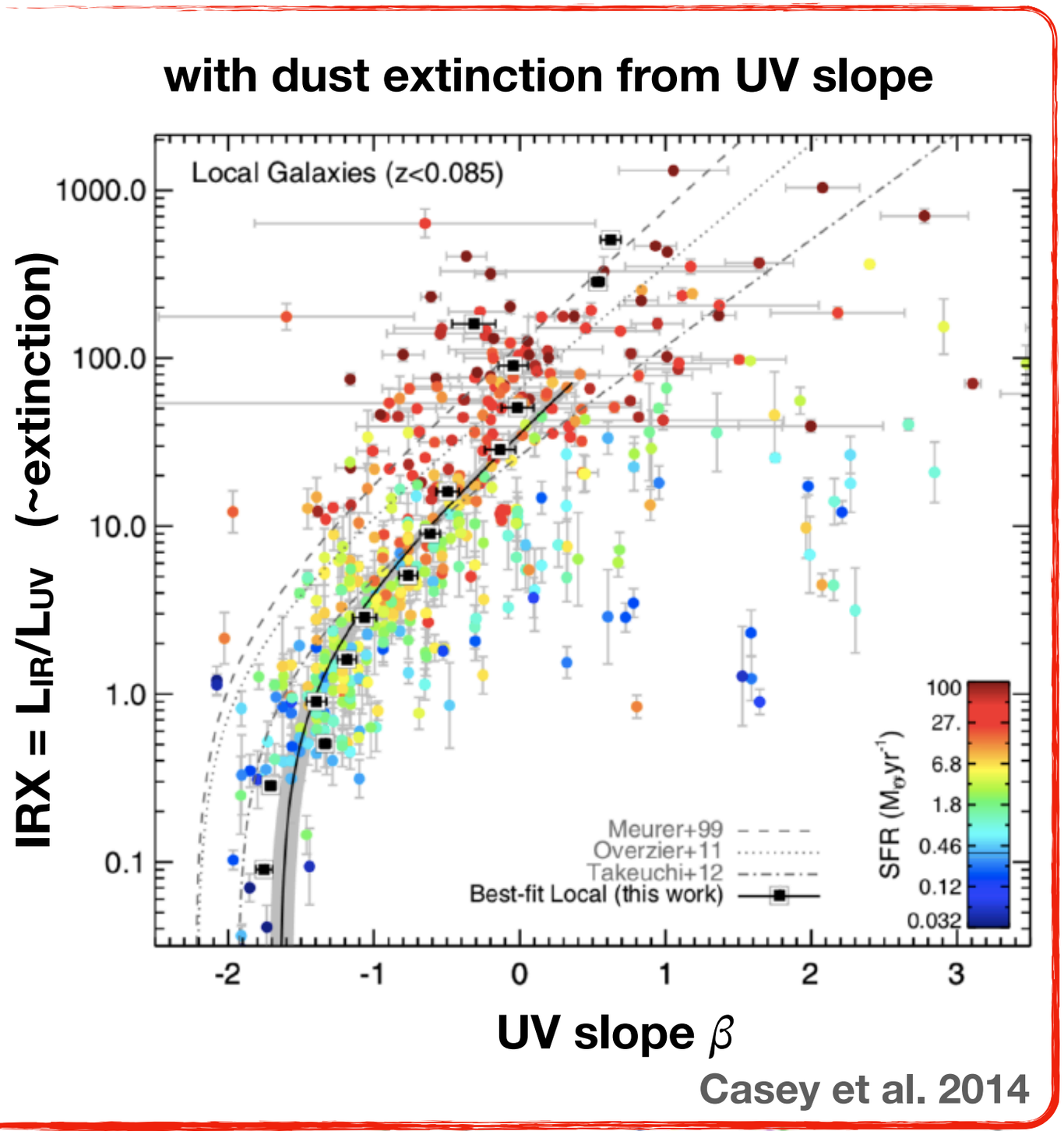
Star formation rates

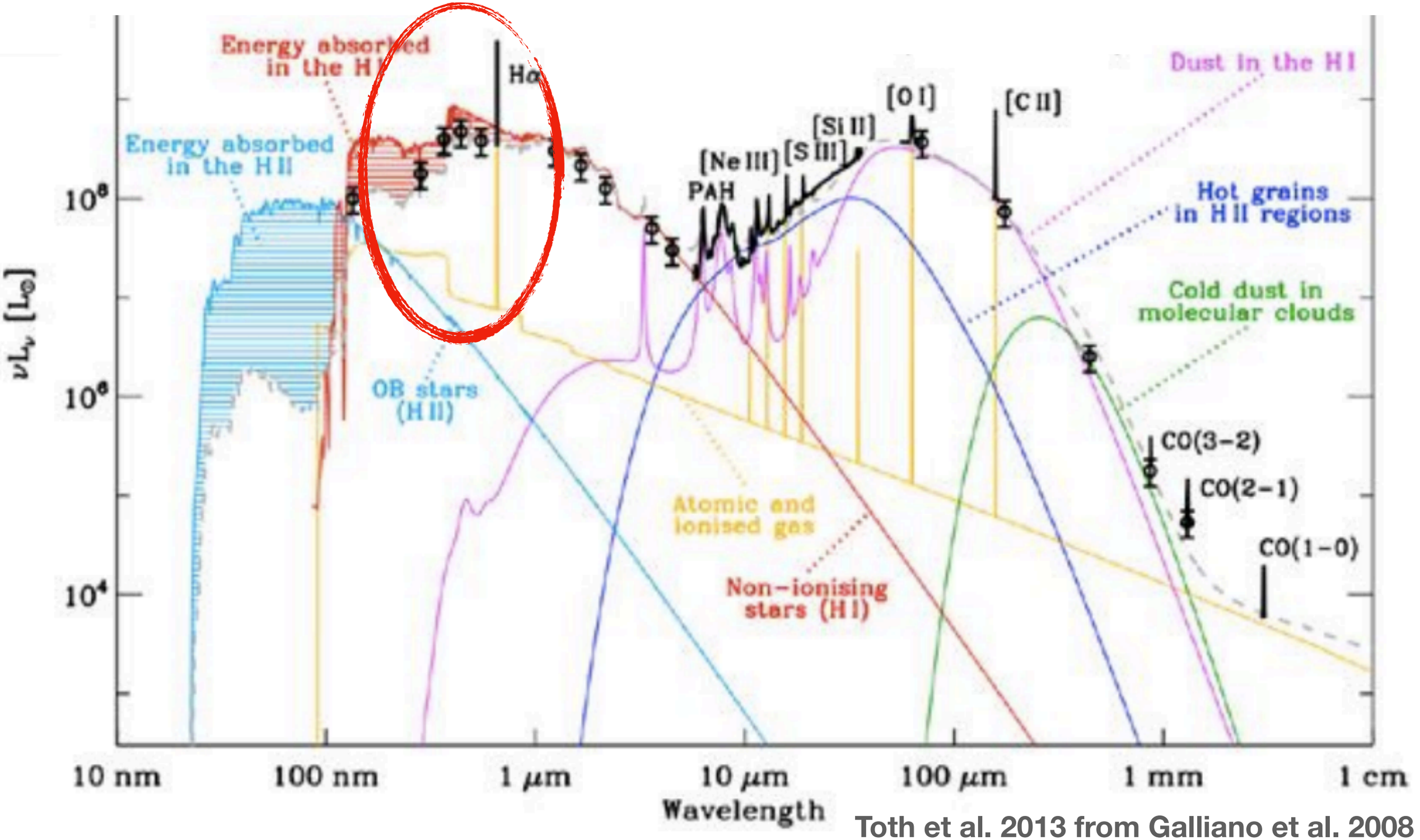




Casey et al. 2014

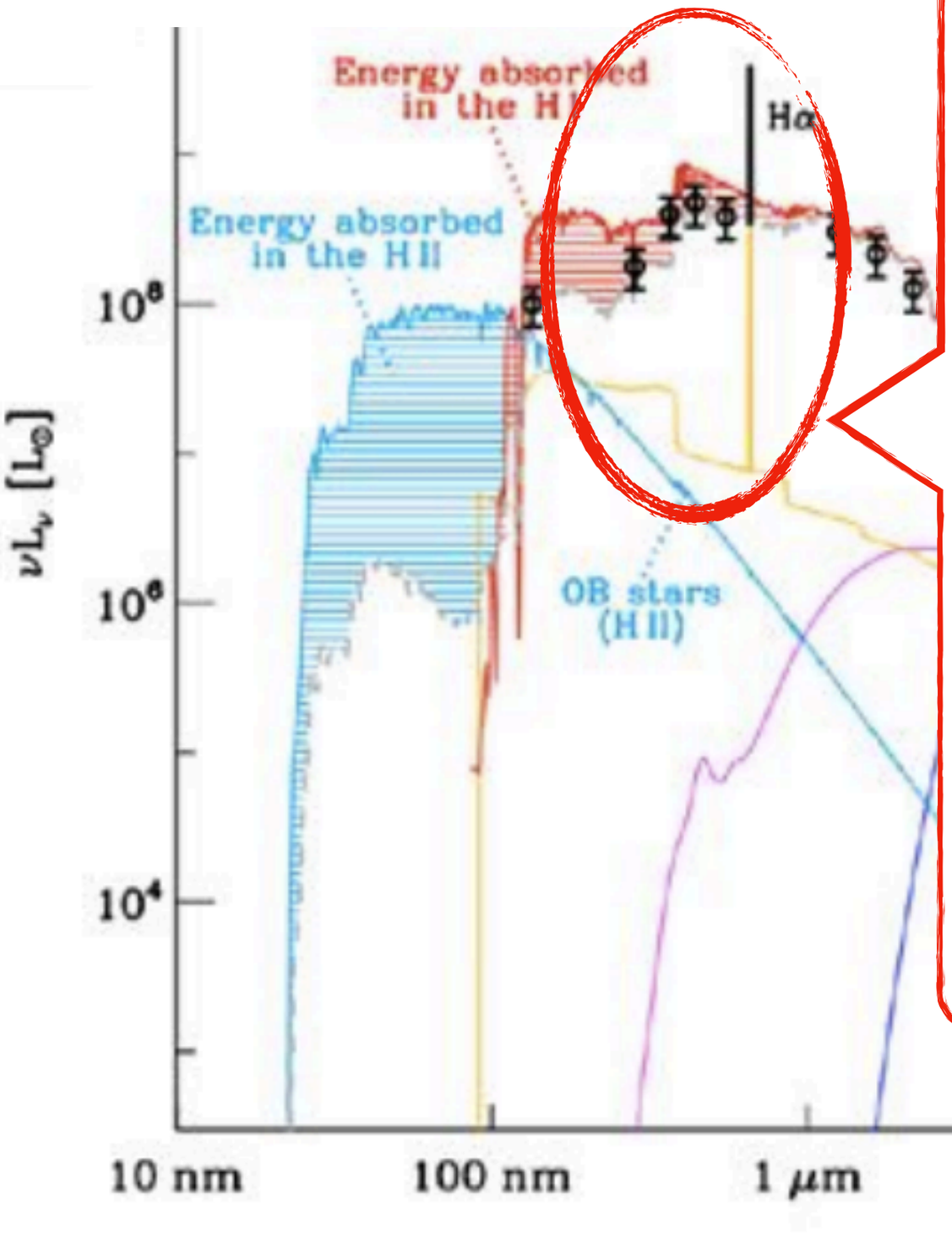
Toth et al. 2013 from Galliano et al. 2008

Star formation rates



Toth et al. 2013 from Galliano et al. 2008

Star formation rates



from UV /optical emission lines tracing ionised gas

Only stars more massive than ~20 $M_\odot$ produce a significant ionising photon flux (the flux is reduced by 100x between 5 and 10 Myr from the star formation burst). Lines more commonly used:

hydrogen recombination lines, most often H_α

$$\mathbf{SFR_{H\alpha} \propto L_{H\alpha}}$$

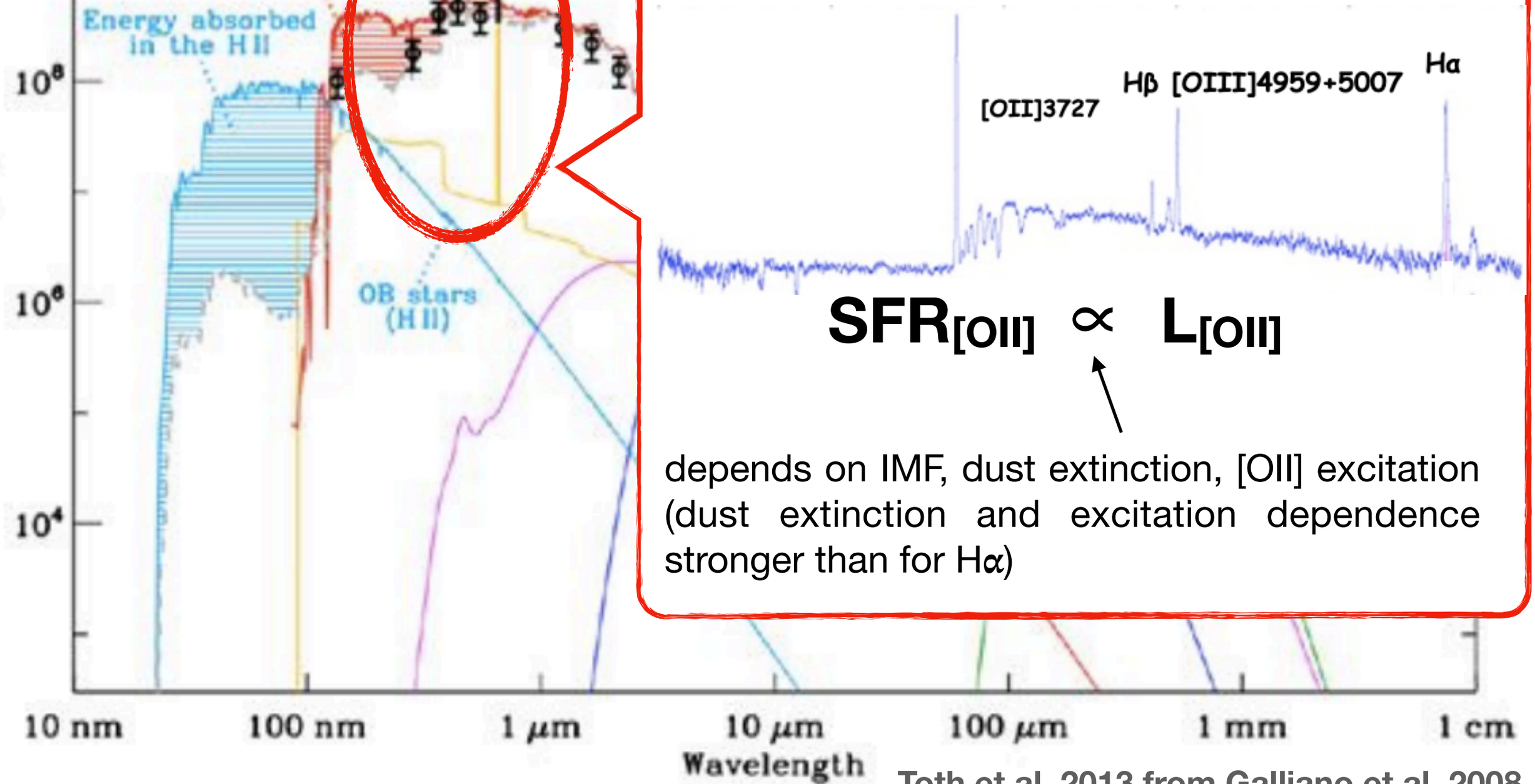
depends on IMF, dust extinction, …

Toth et al. 2013 from Galliano et al. 2008

Star formation rates

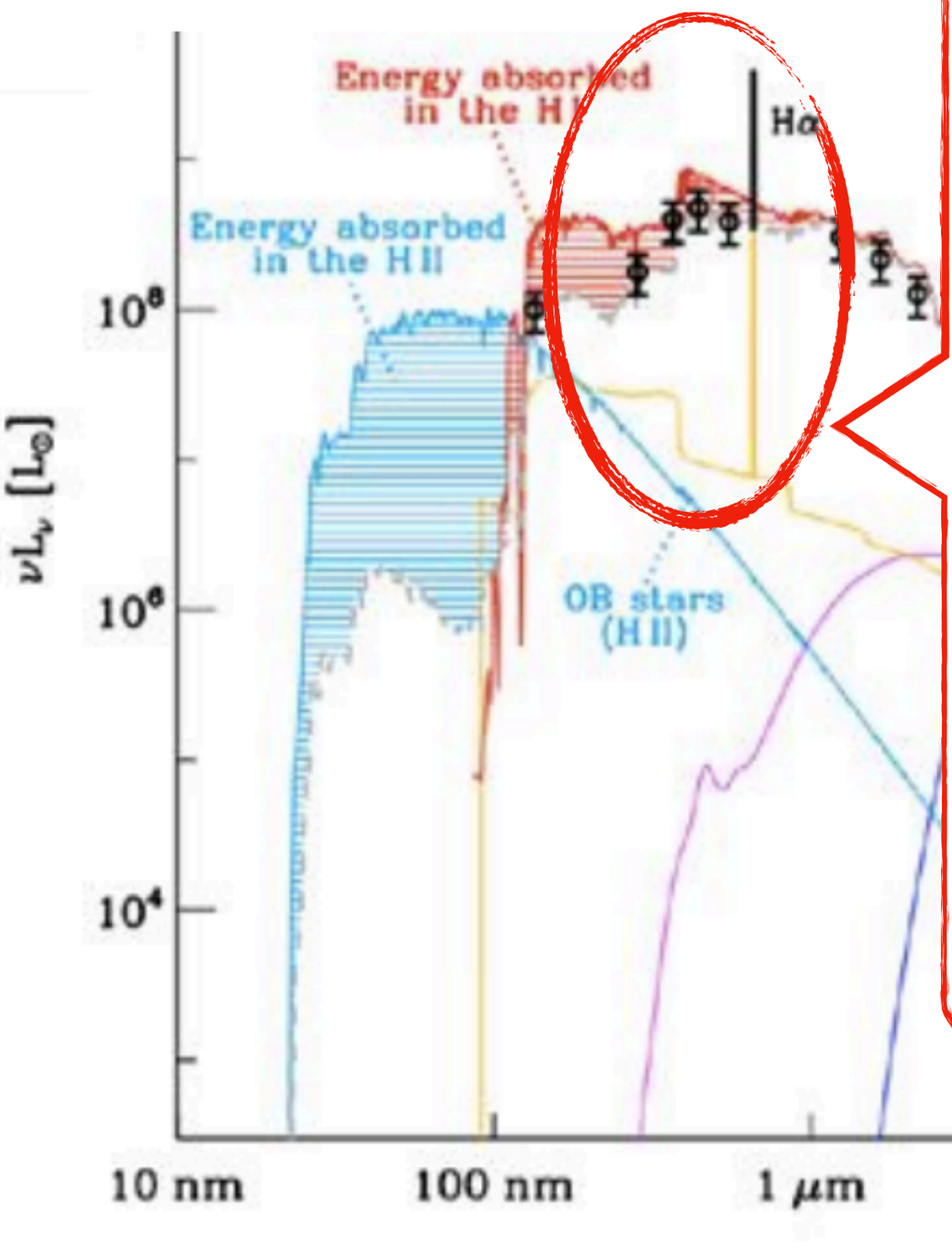
from UV /optical emission lines tracing ionised gas

At z>0.5 the Hα line is shifted out of the visible range. The strongest suitable line is then the [OII] doublet at 3727Å.



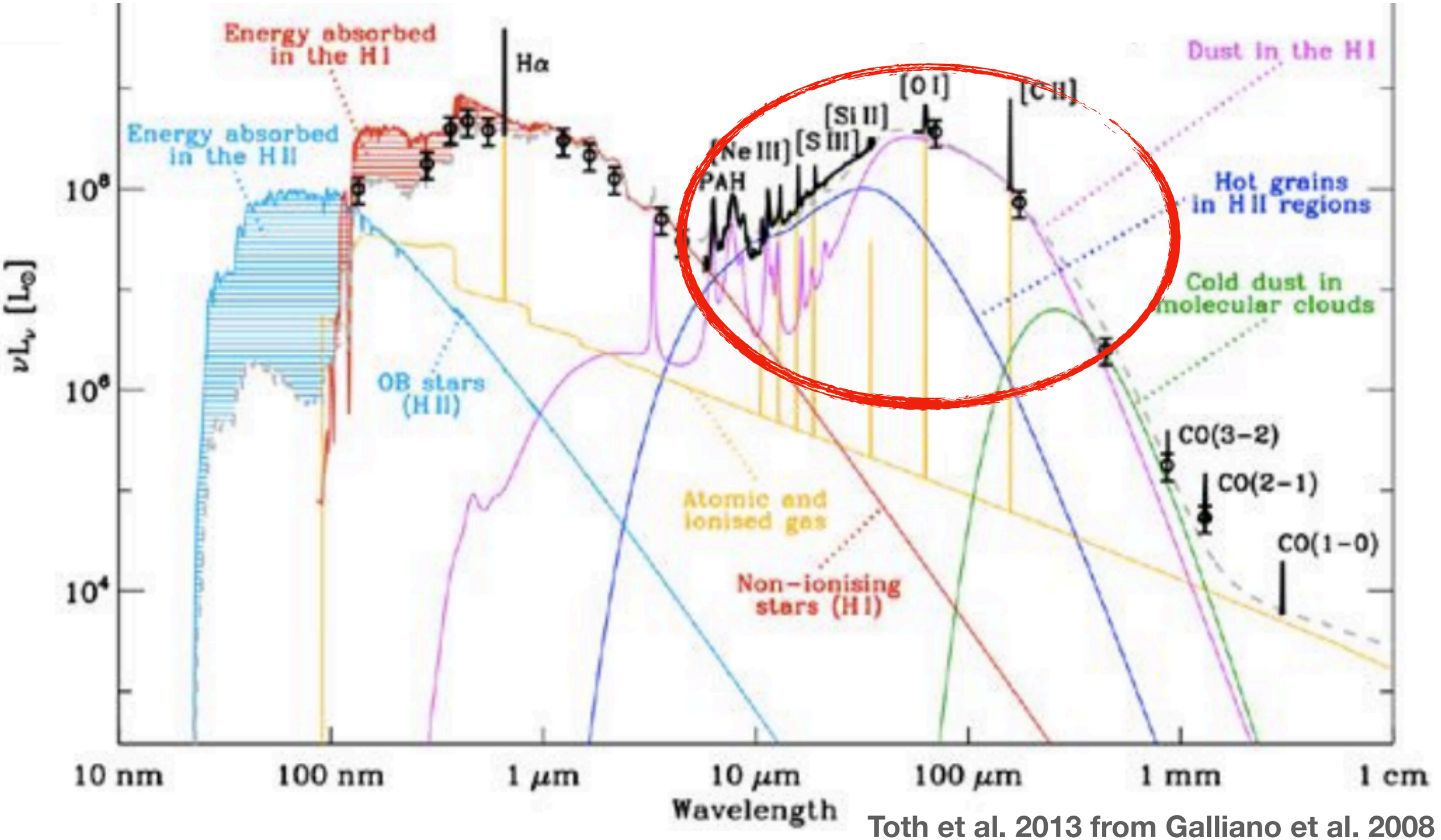
$$SFR_{[OII]} \propto L_{[OII]}$$

depends on IMF, dust extinction, [OII] excitation (dust extinction and excitation dependence stronger than for Hα)



Toth et al. 2013 from Galliano et al. 2008

Star formation rates

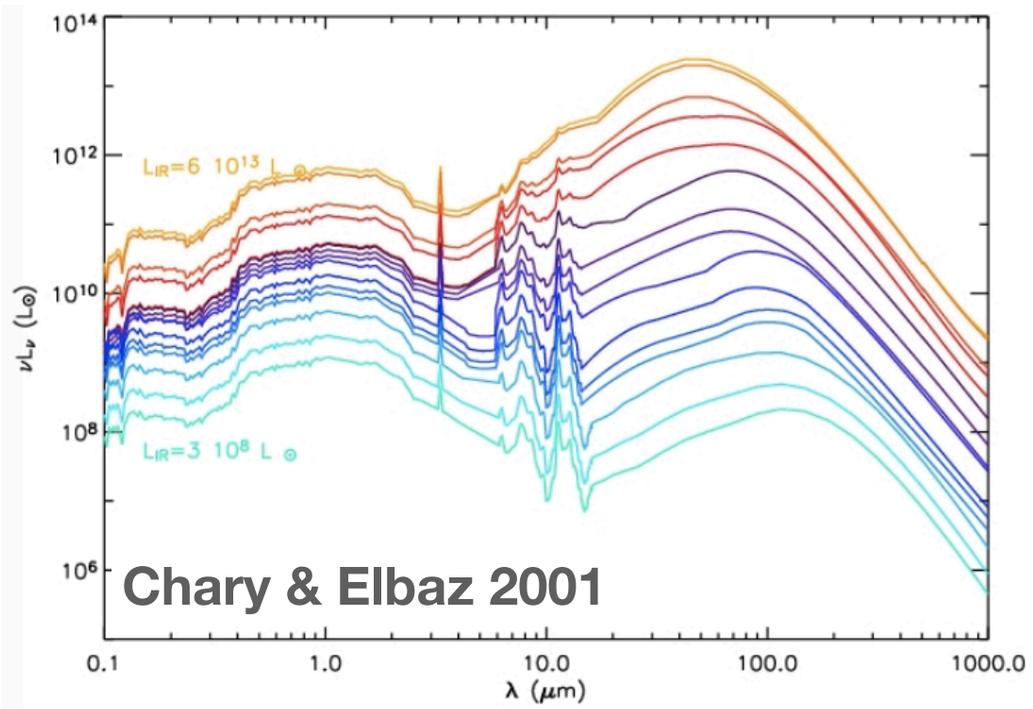


Toth et al. 2013 from Galliano et al. 2008

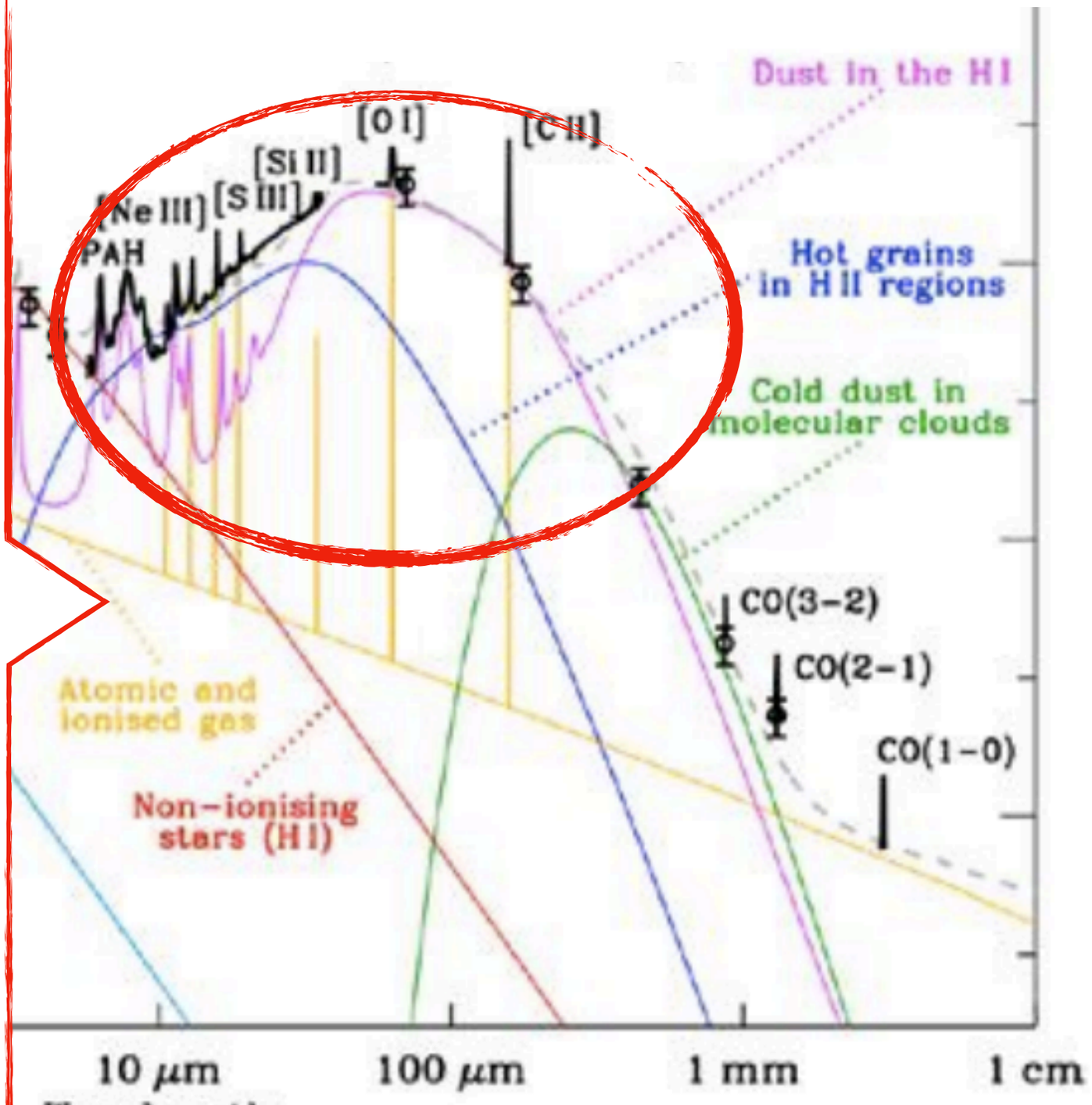
Star formation rates

from IR emission:

from IR luminosity



- **IR SED modeling**
- **single-band IR photometry**

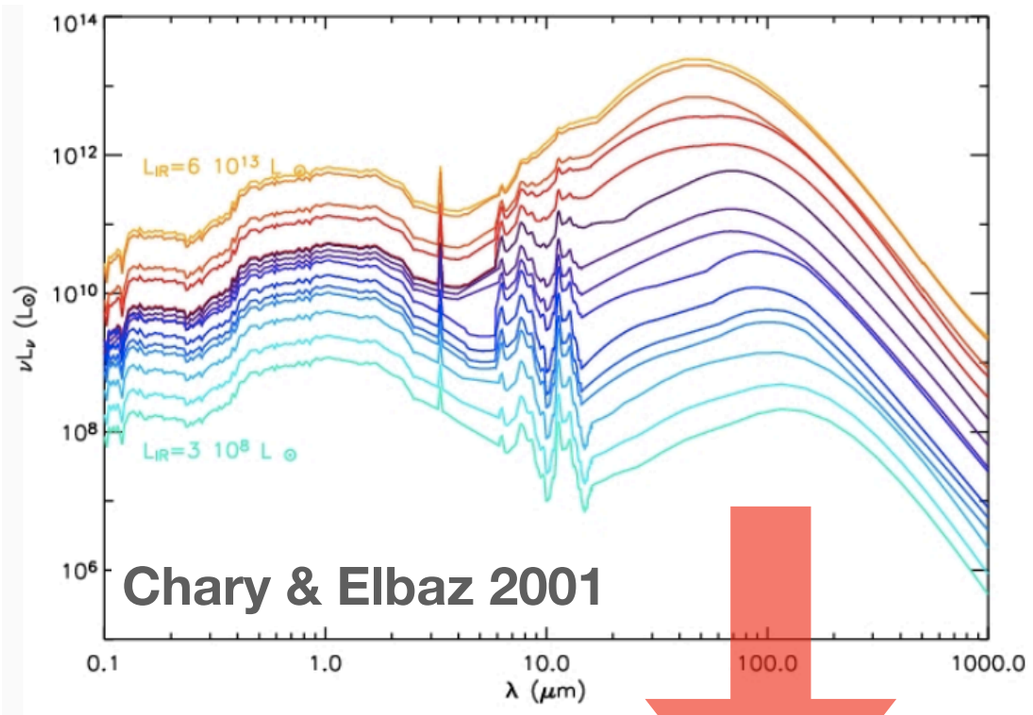


Toth et al. 2013 from Galliano et al. 2008

Star formation rates

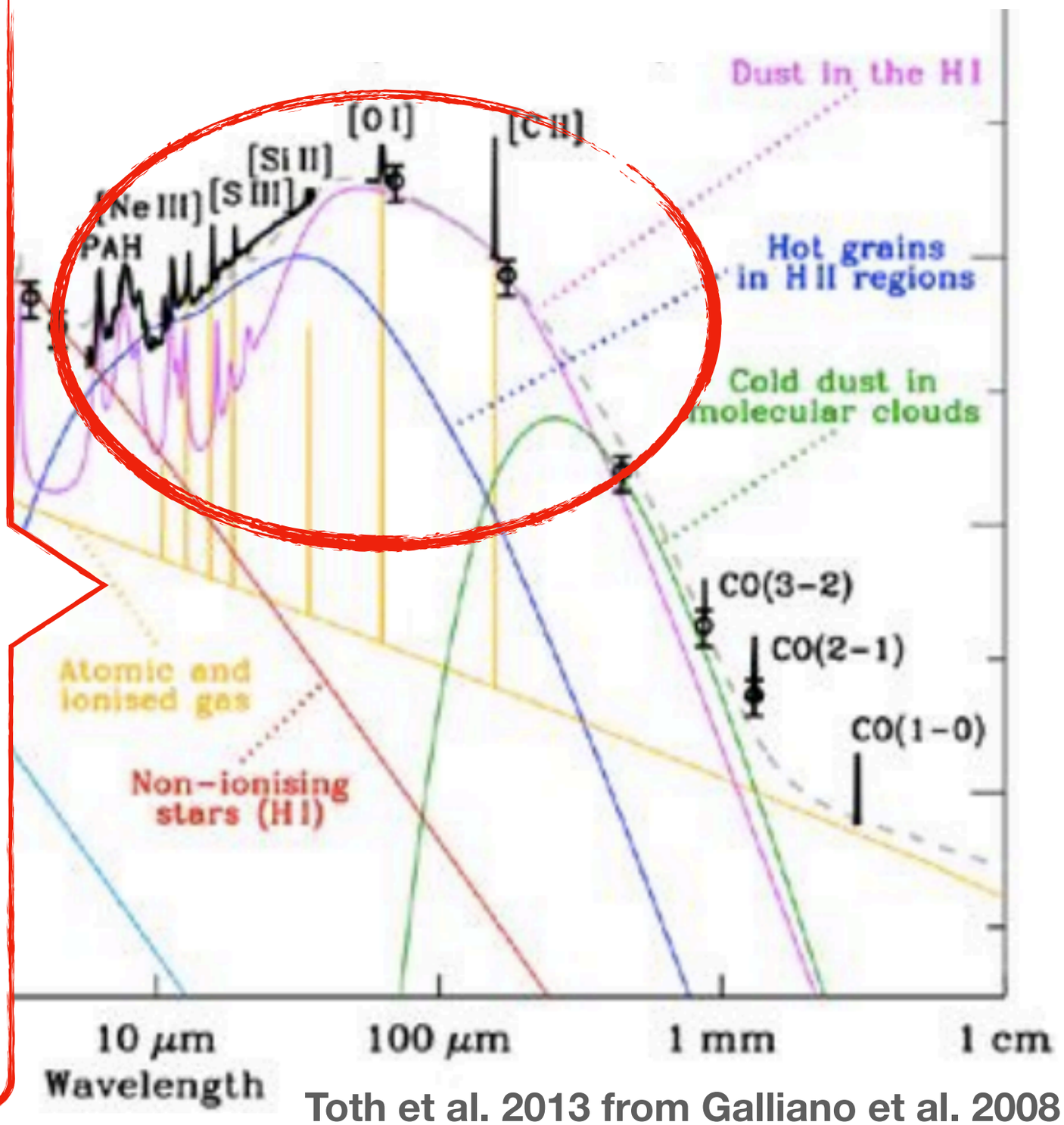
from IR emission:

from IR luminosity



estimate (or extrapolate to) total IR luminosity

$SFR_{IR} \propto L_{IR}$

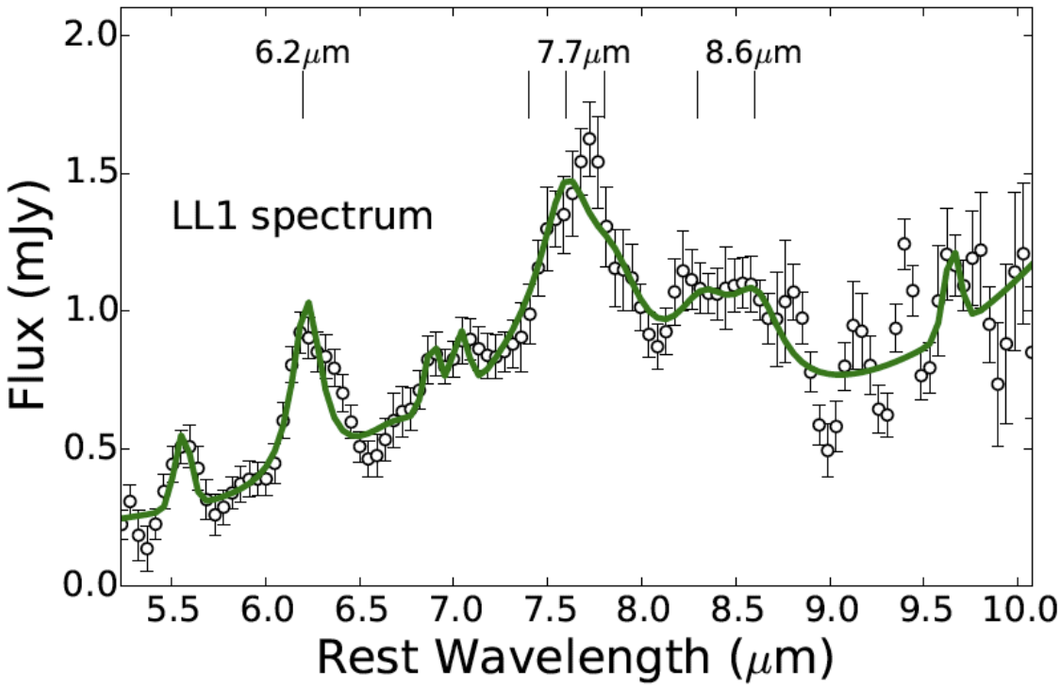


Toth et al. 2013 from Galliano et al. 2008

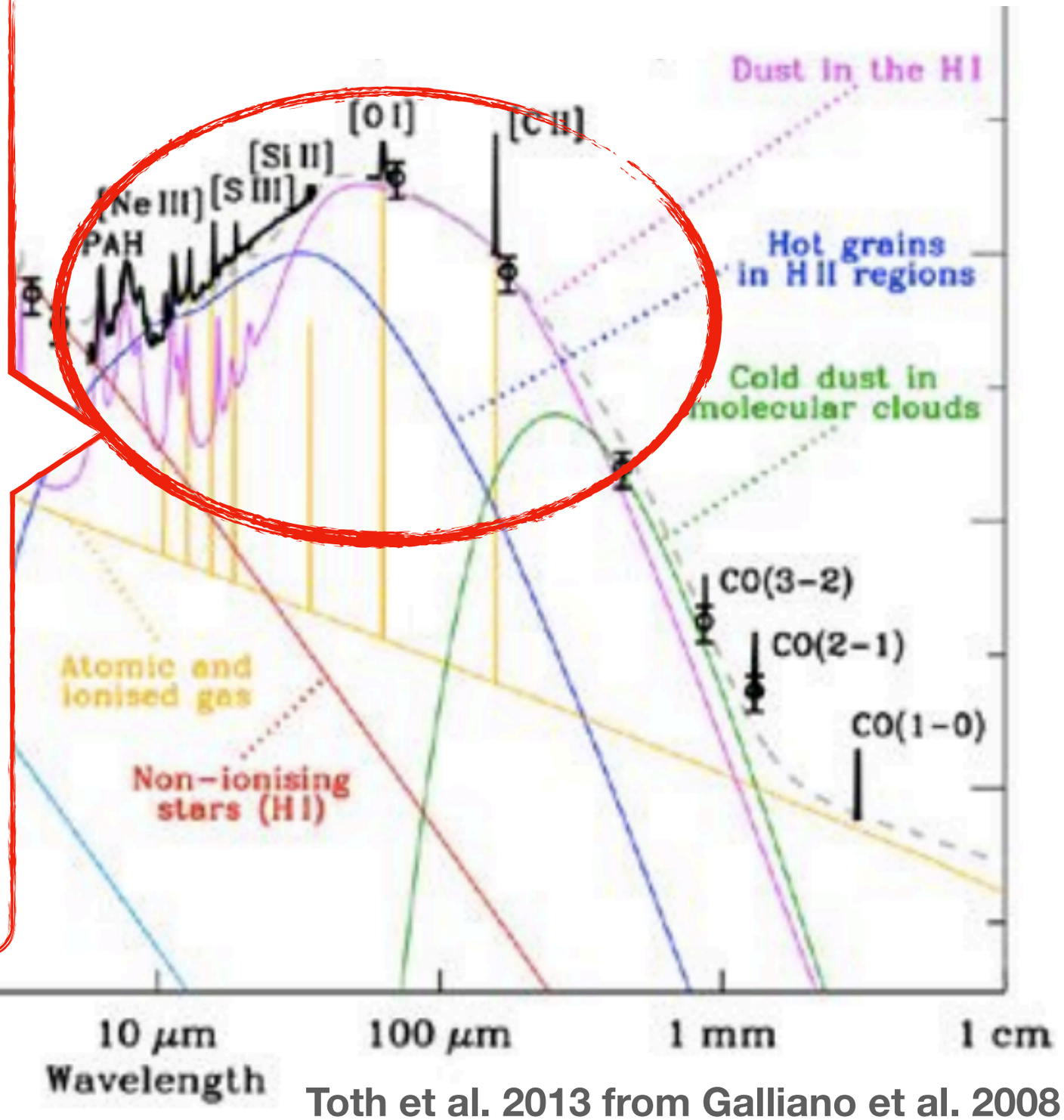
Star formation rates

from IR emission:

from PAH features

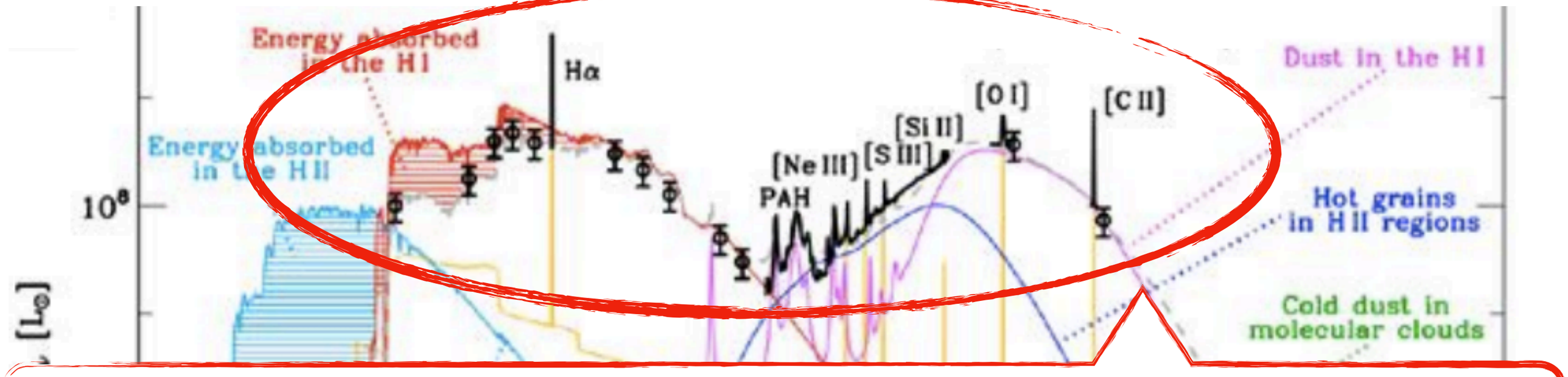


Shipley et al. 2016

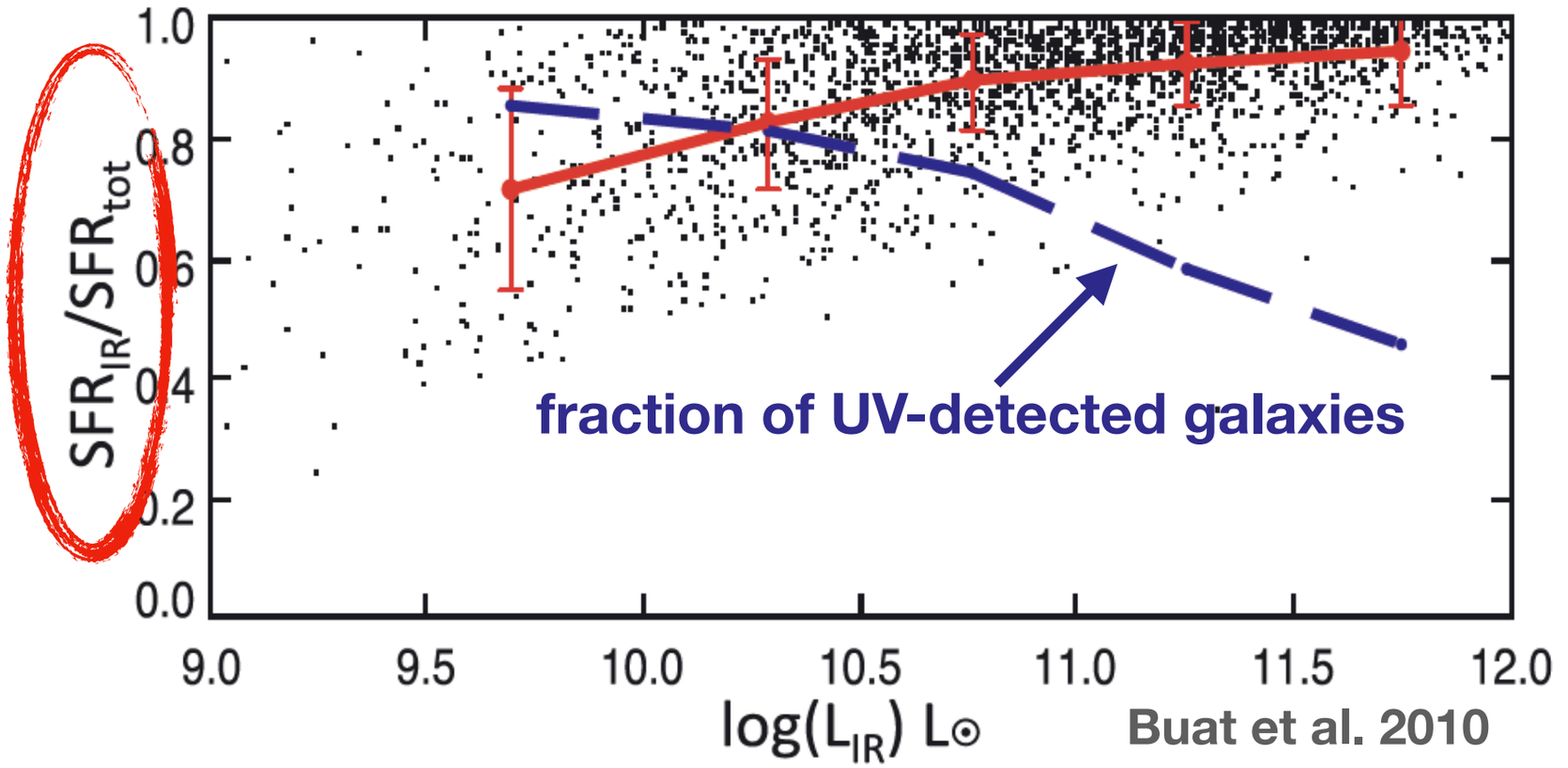


Toth et al. 2013 from Galliano et al. 2008

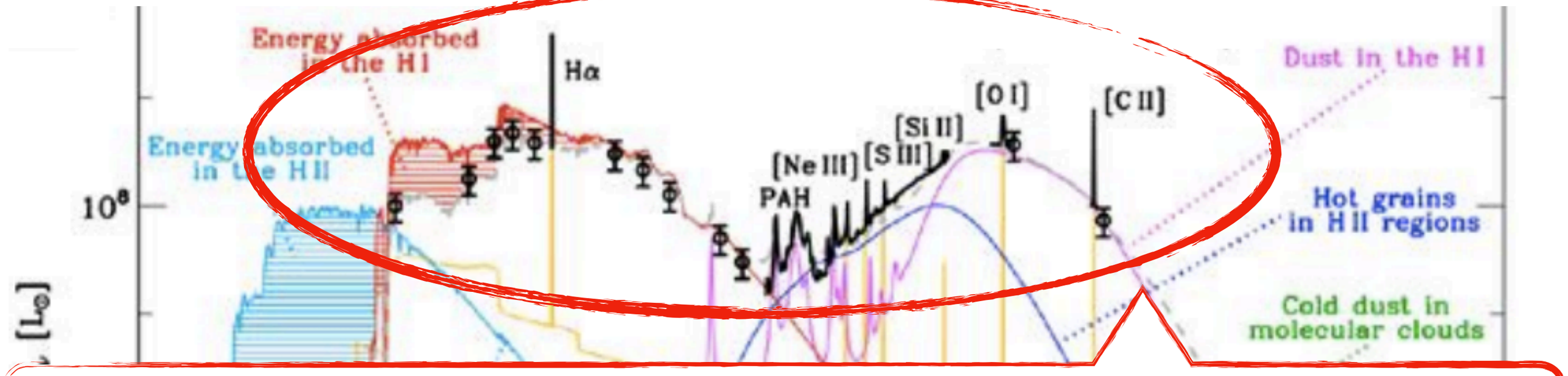
Star formation rates

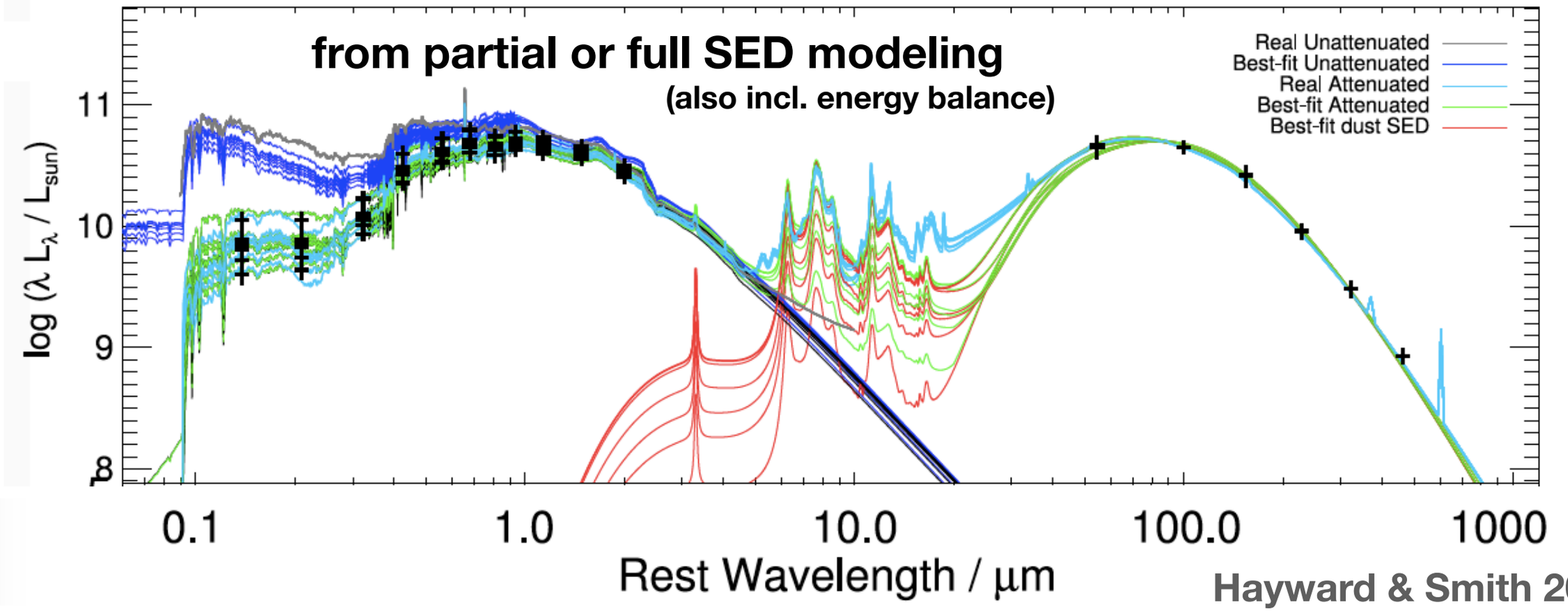


combining UV and IR SFR estimates



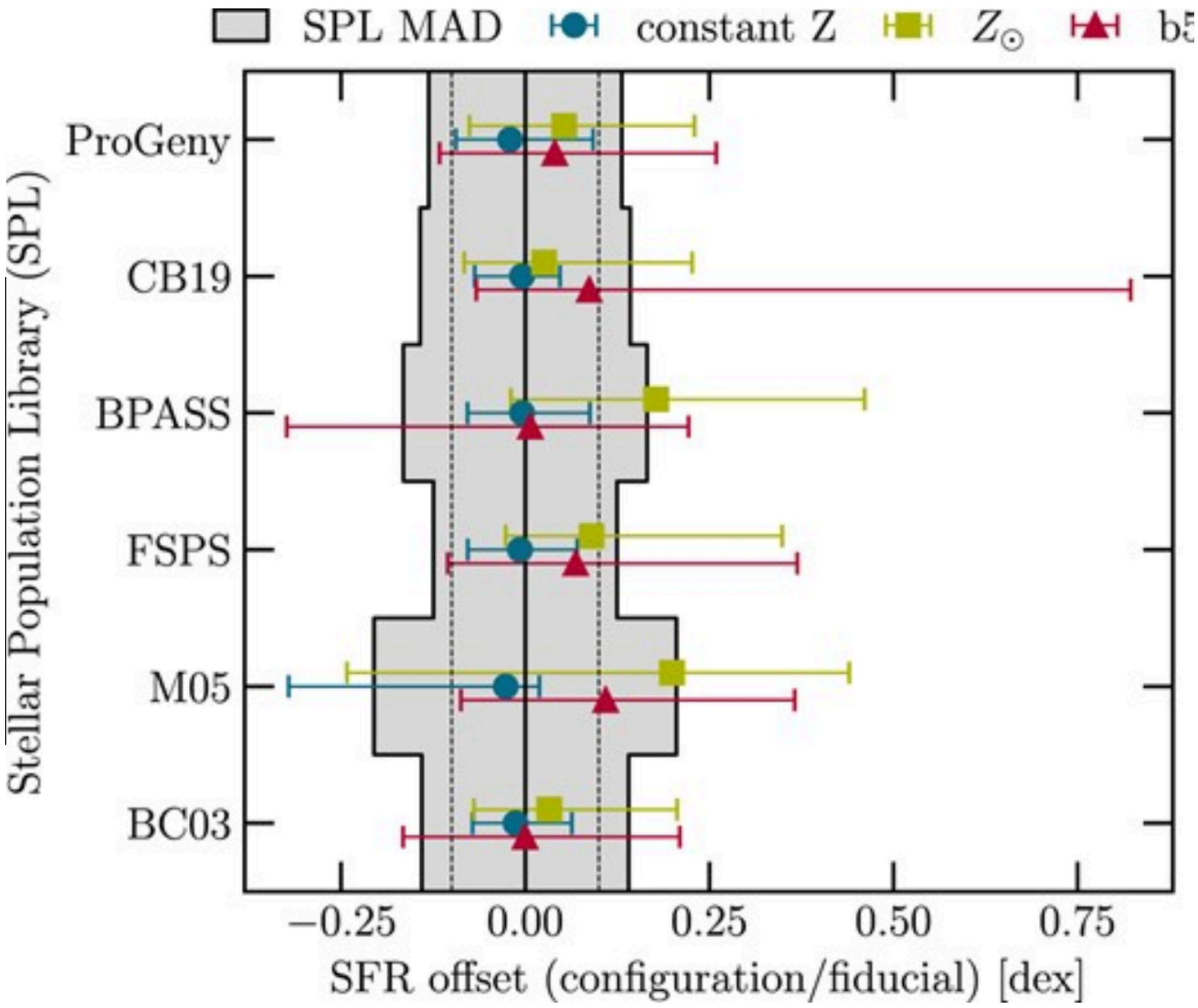
Star formation rates





Hayward & Smith 2014

Star formation rates



Bellstedt & Robotham 2025