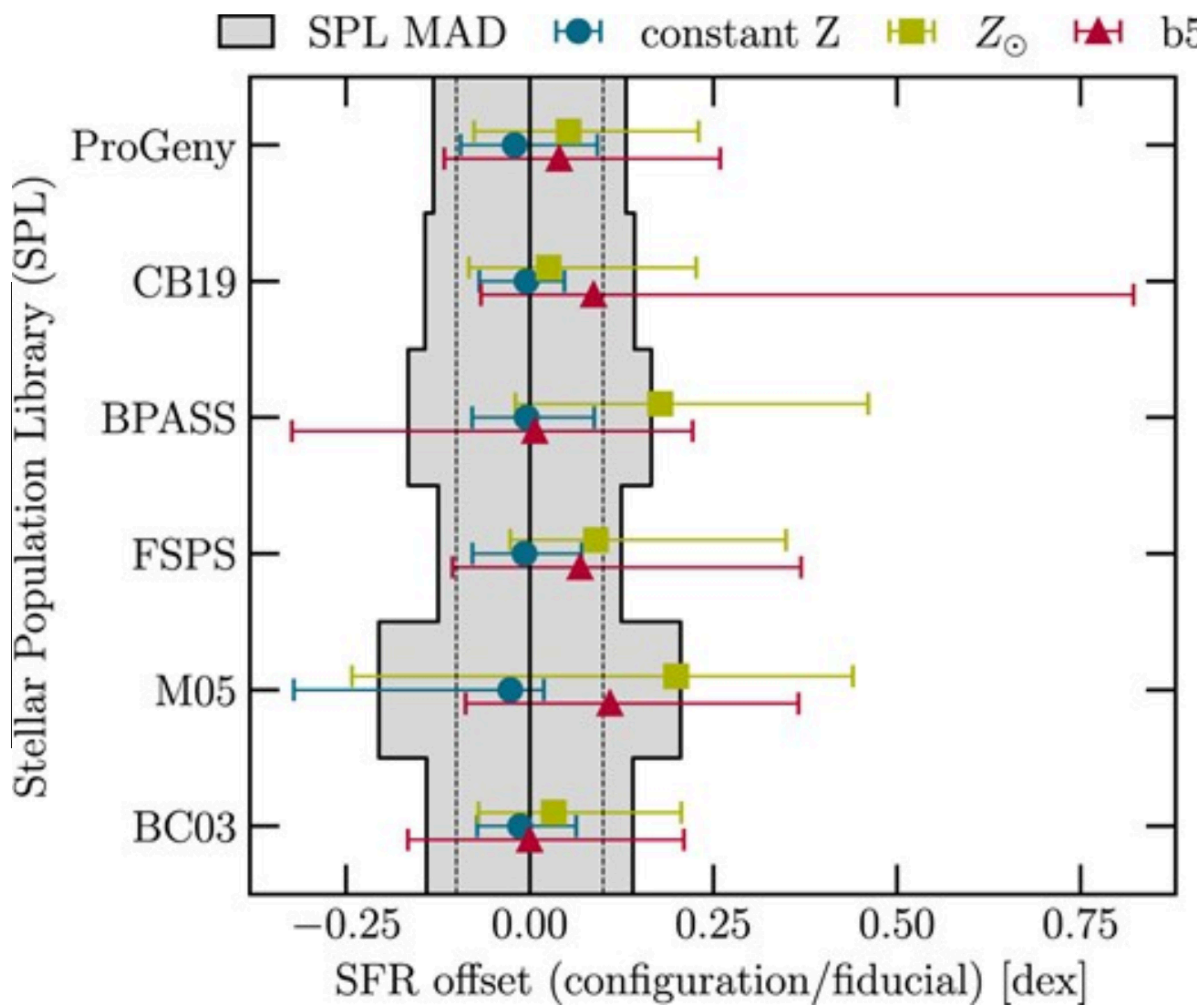
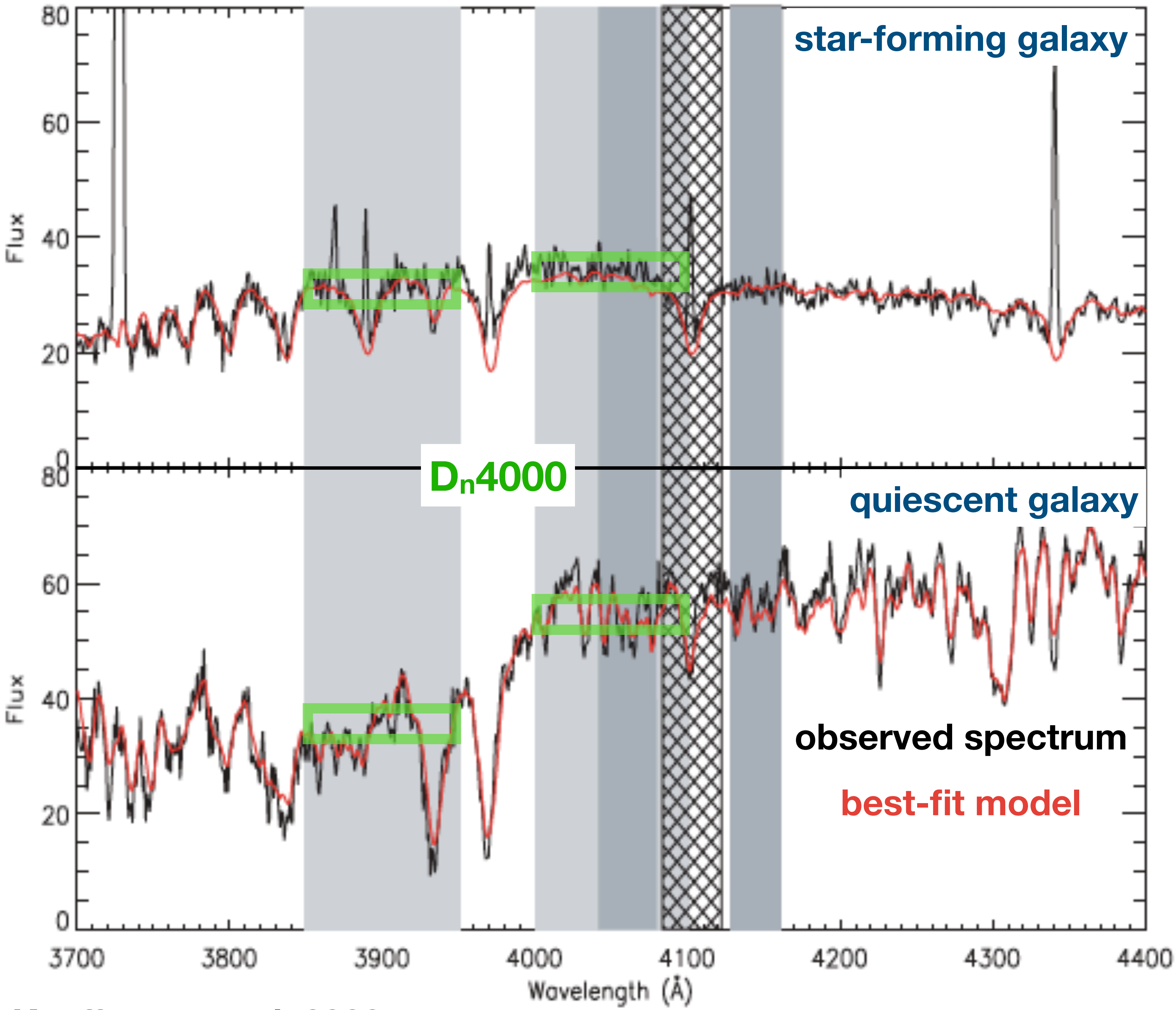
Star formation rates



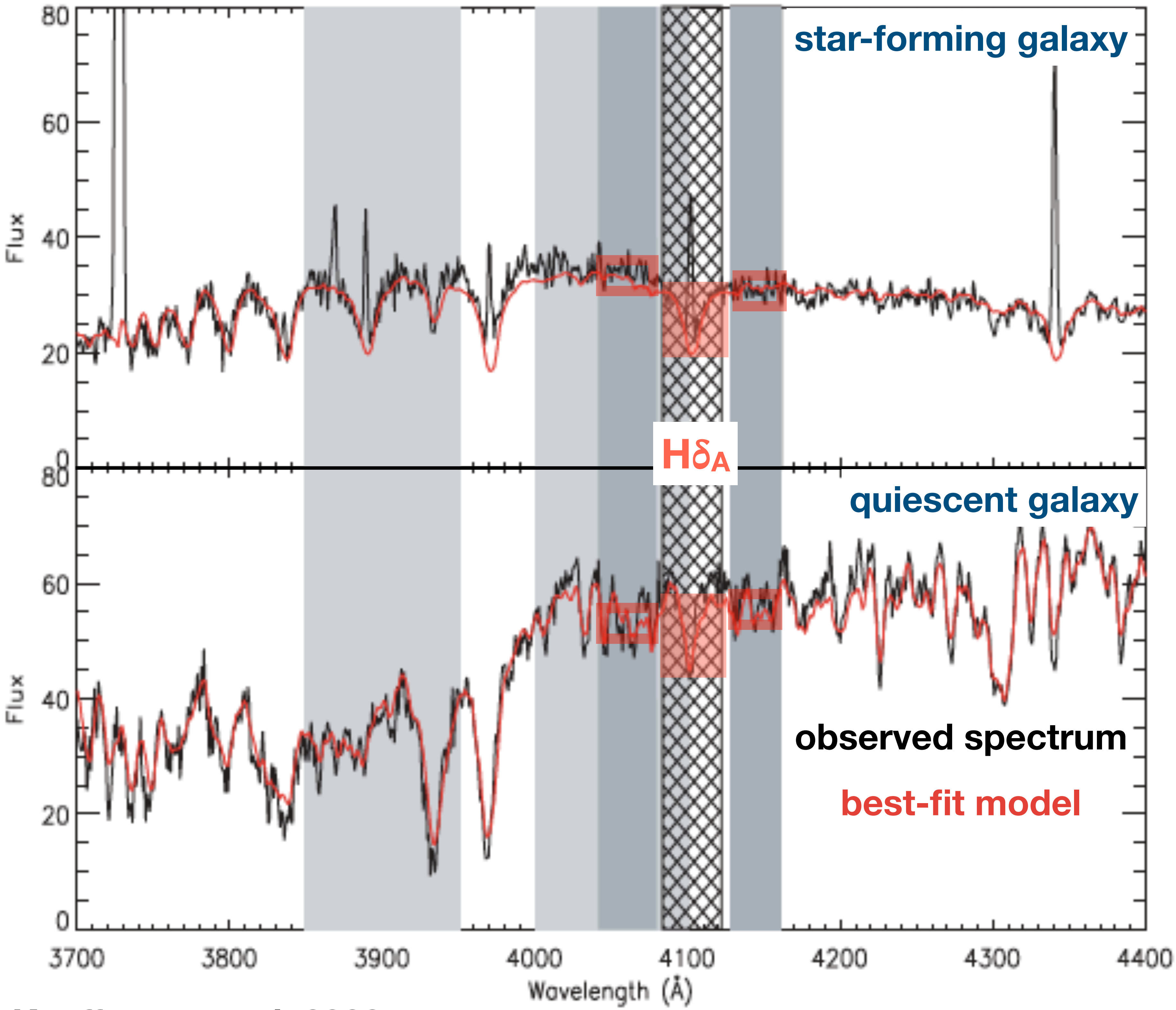
Bellstedt & Robotham 2025

Stellar ages, star formation histories and metallicities



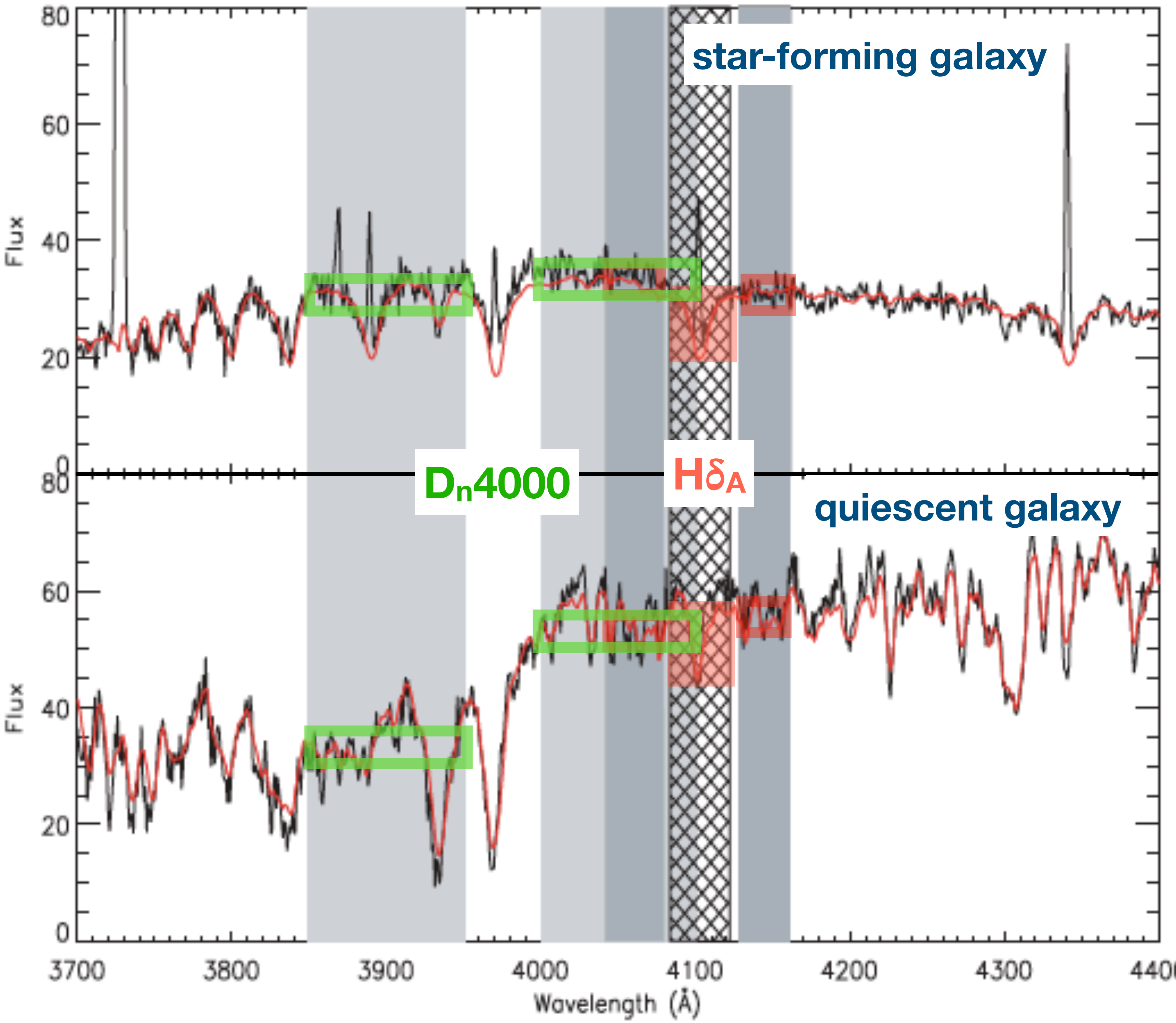
Kauffmann et al. 2003

Stellar ages, star formation histories and metallicities



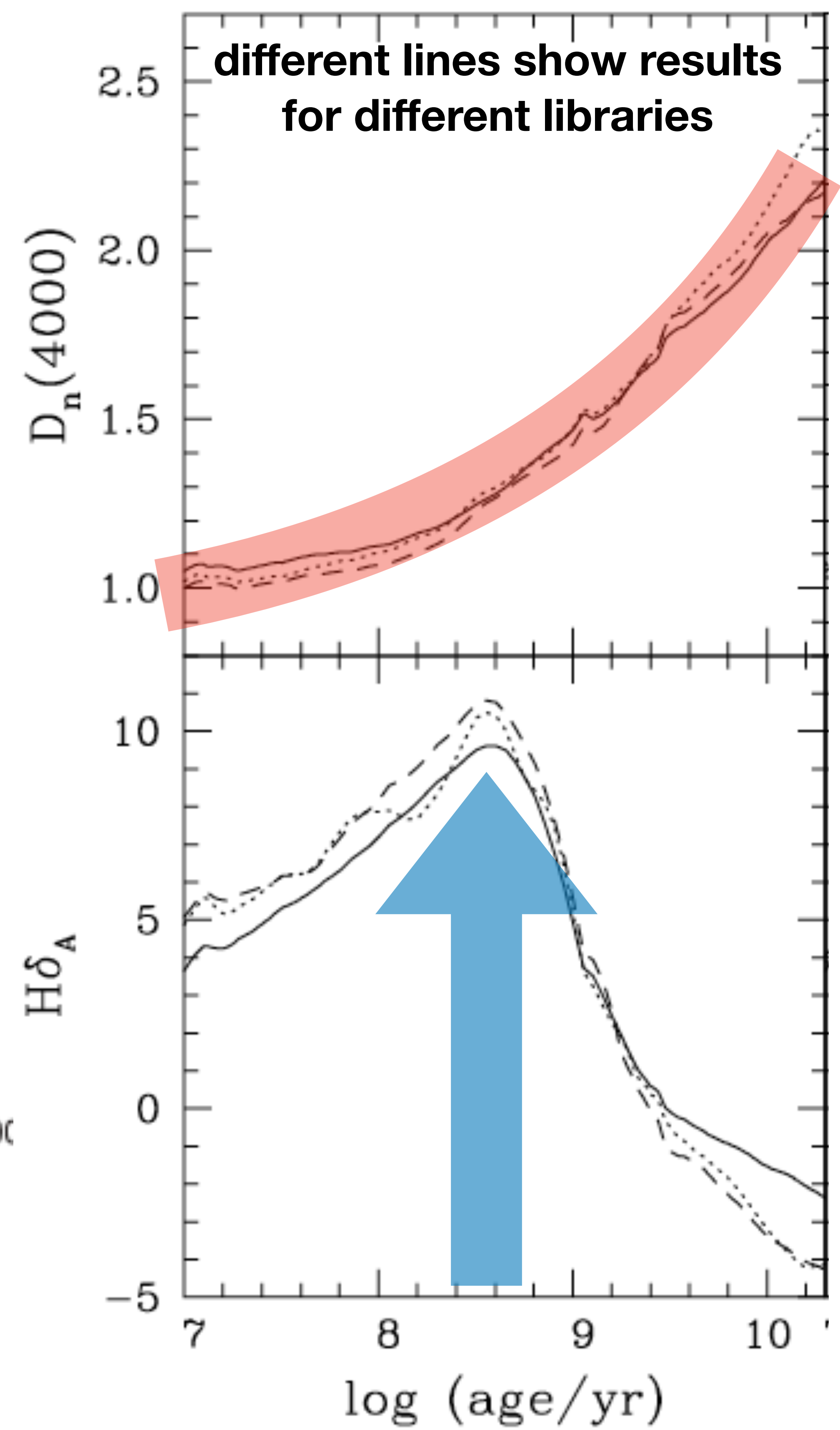
Kauffmann et al. 2003

Stellar ages, star formation histories and metallicities

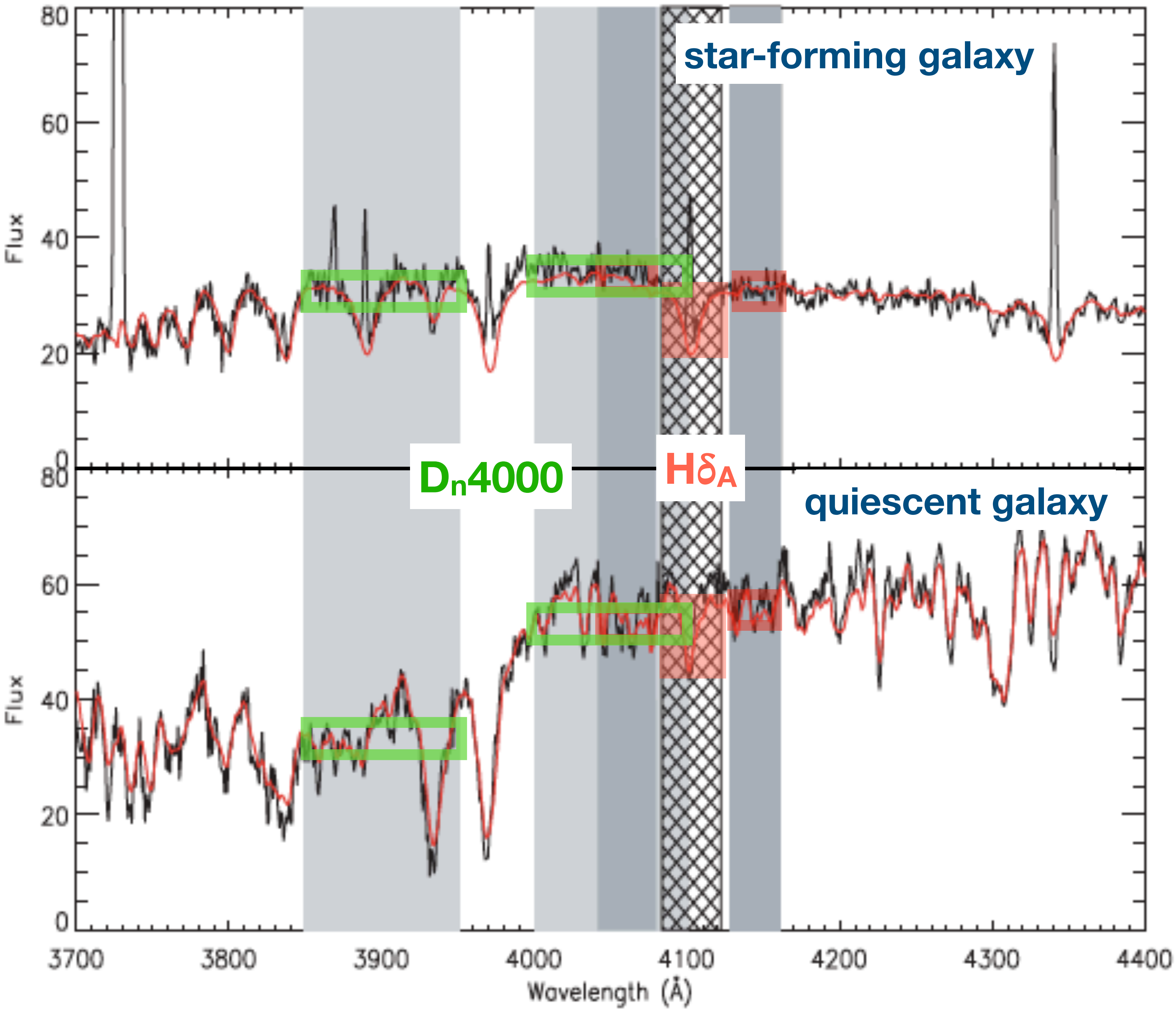


Kauffmann et al. 2003

age dependence

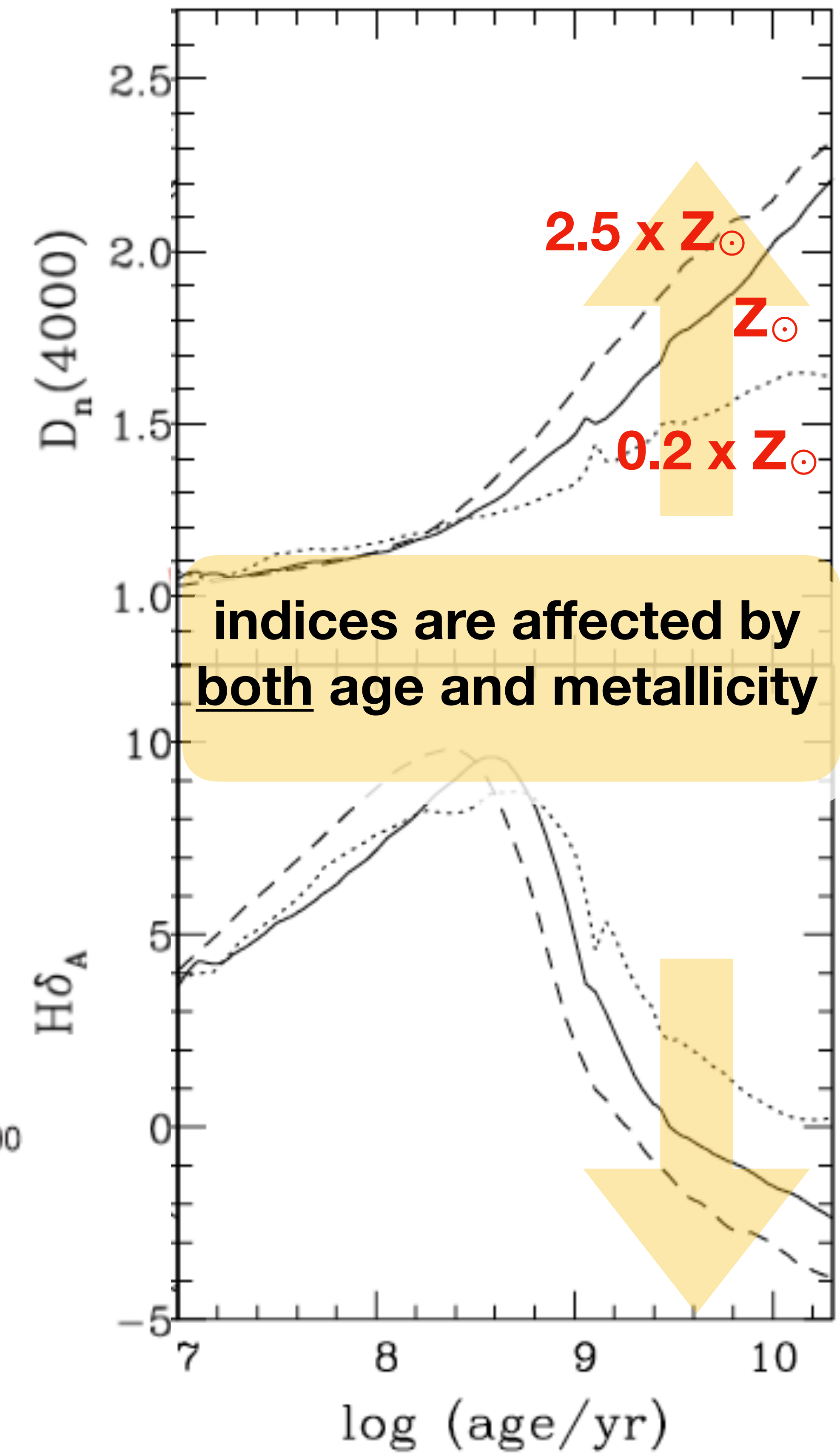


Stellar ages, star formation histories and metallicities



Kauffmann et al. 2003

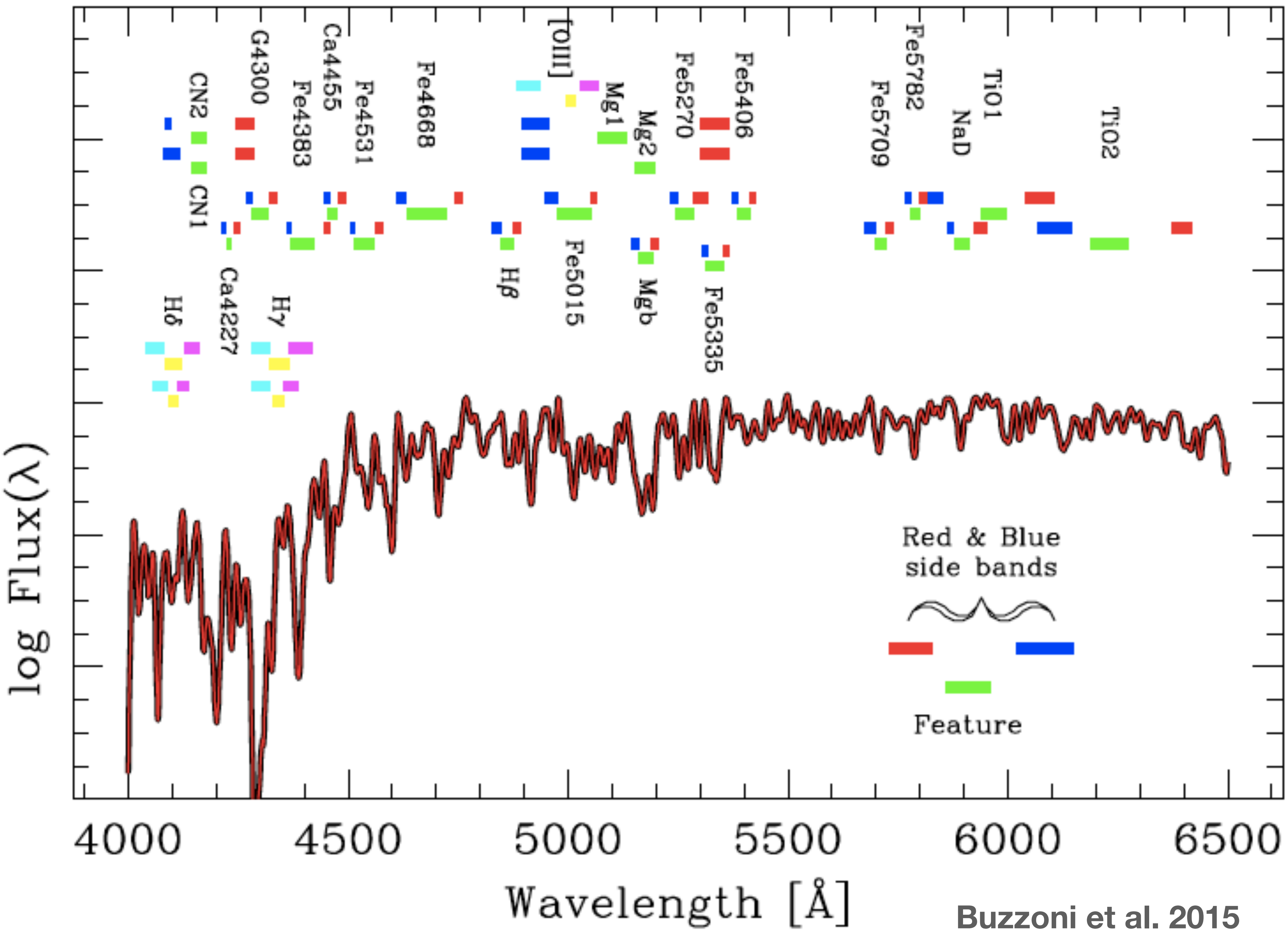
metallicity dependence



indices are affected by <u>both</u> age and metallicity

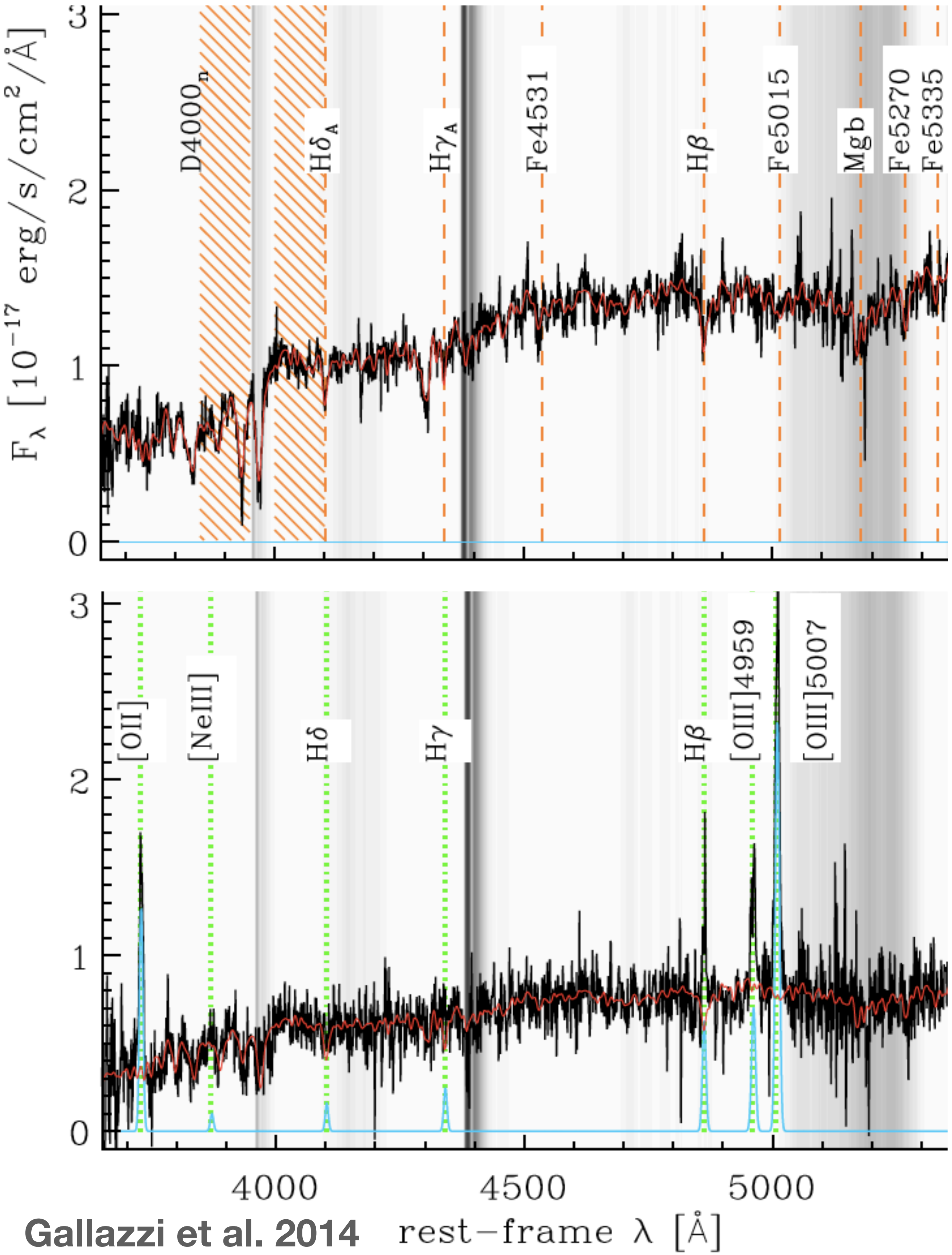
Stellar ages, star formation histories and metallicities

… no spectral index is a pure age or metallicity indicator

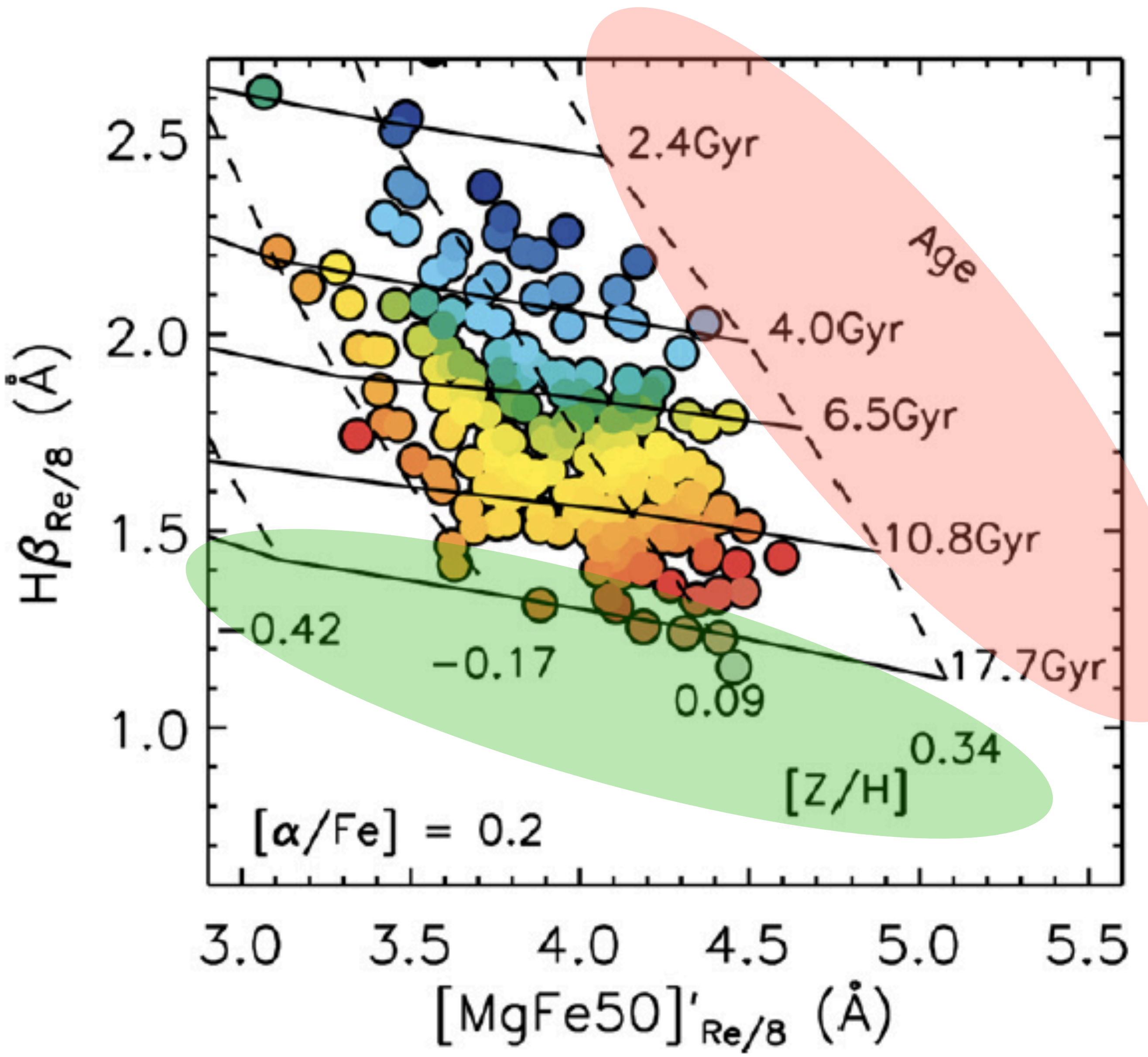


Buzzoni et al. 2015

Stellar ages, star formation histories and metallicities



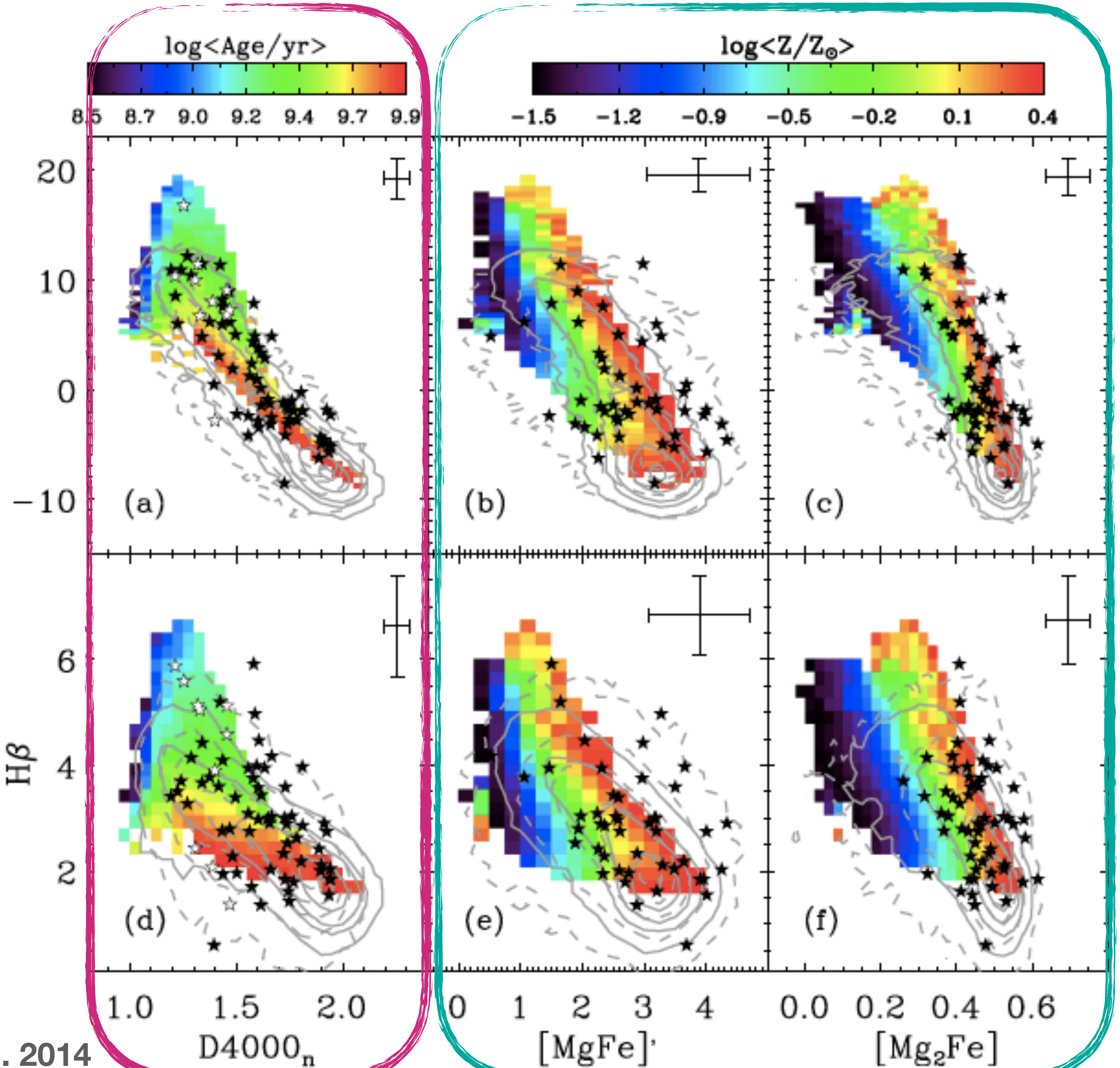
Gallazzi et al. 2014



McDermid et al. 2014

… but combinations of indices (grids) can estimate age and metallicity

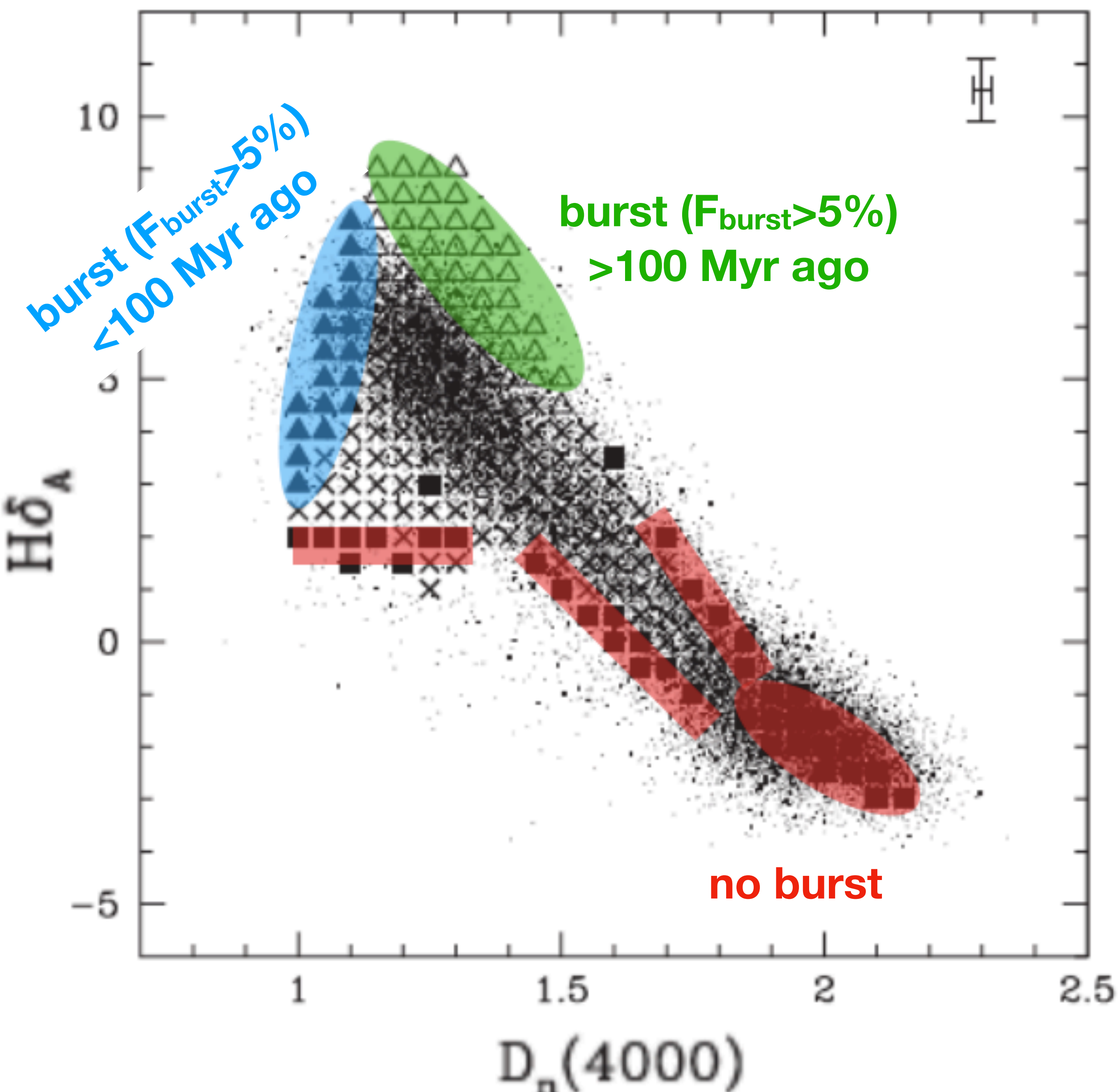
Stellar ages, star formation histories and metallicities



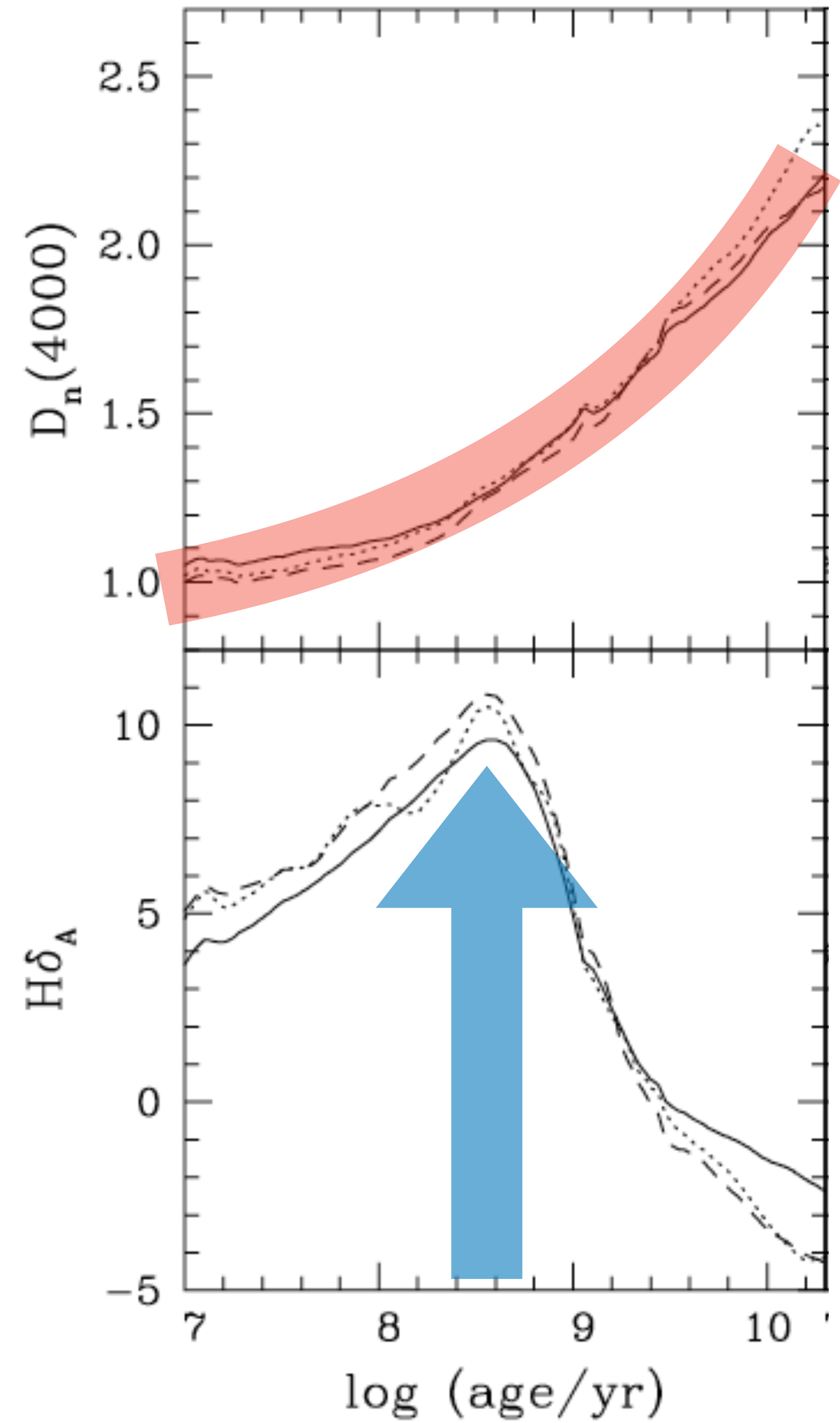
Gallazzi et al. 2014

Stellar ages, star formation histories and metallicities

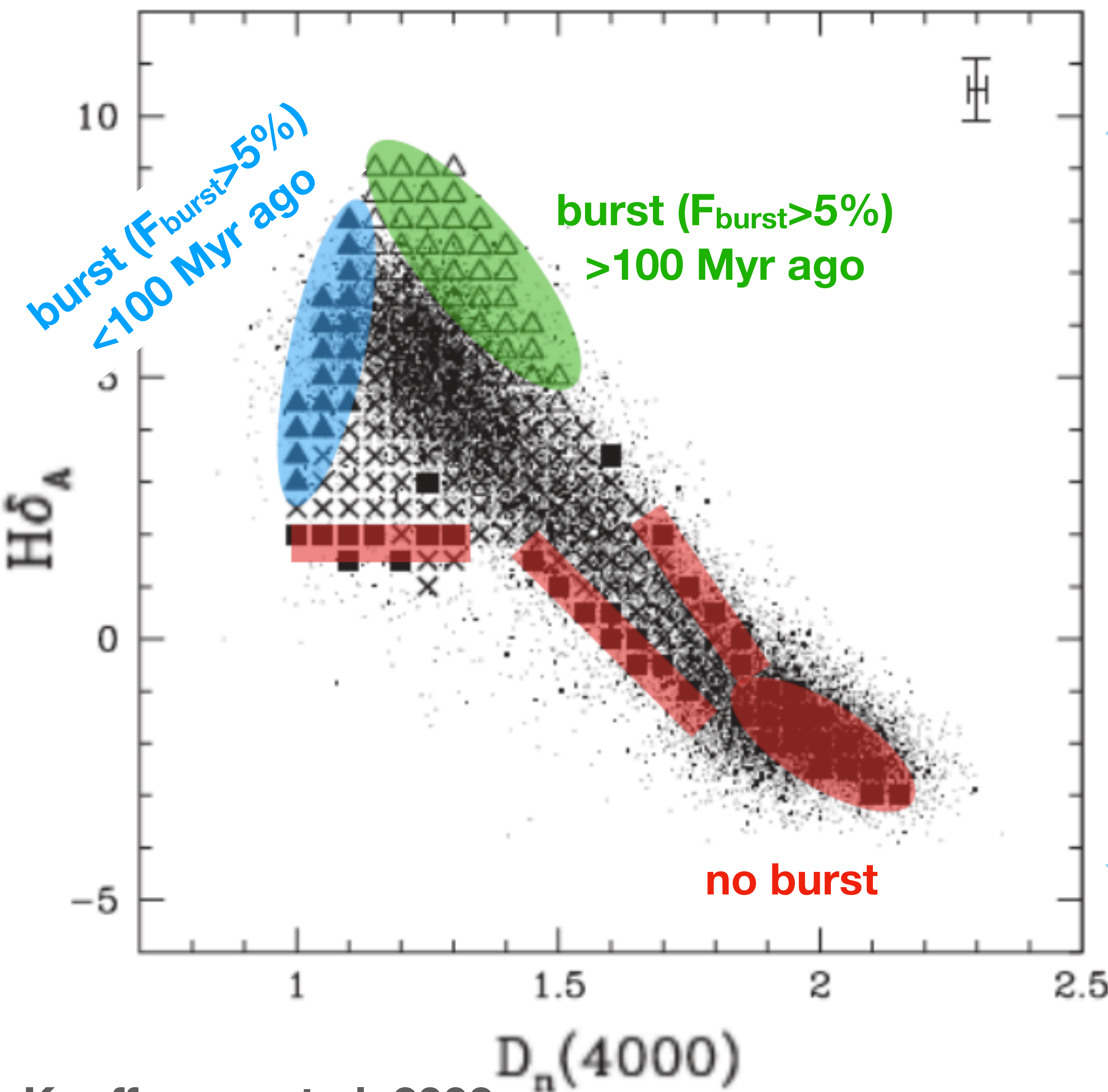
rough constraints on (recent) SFH



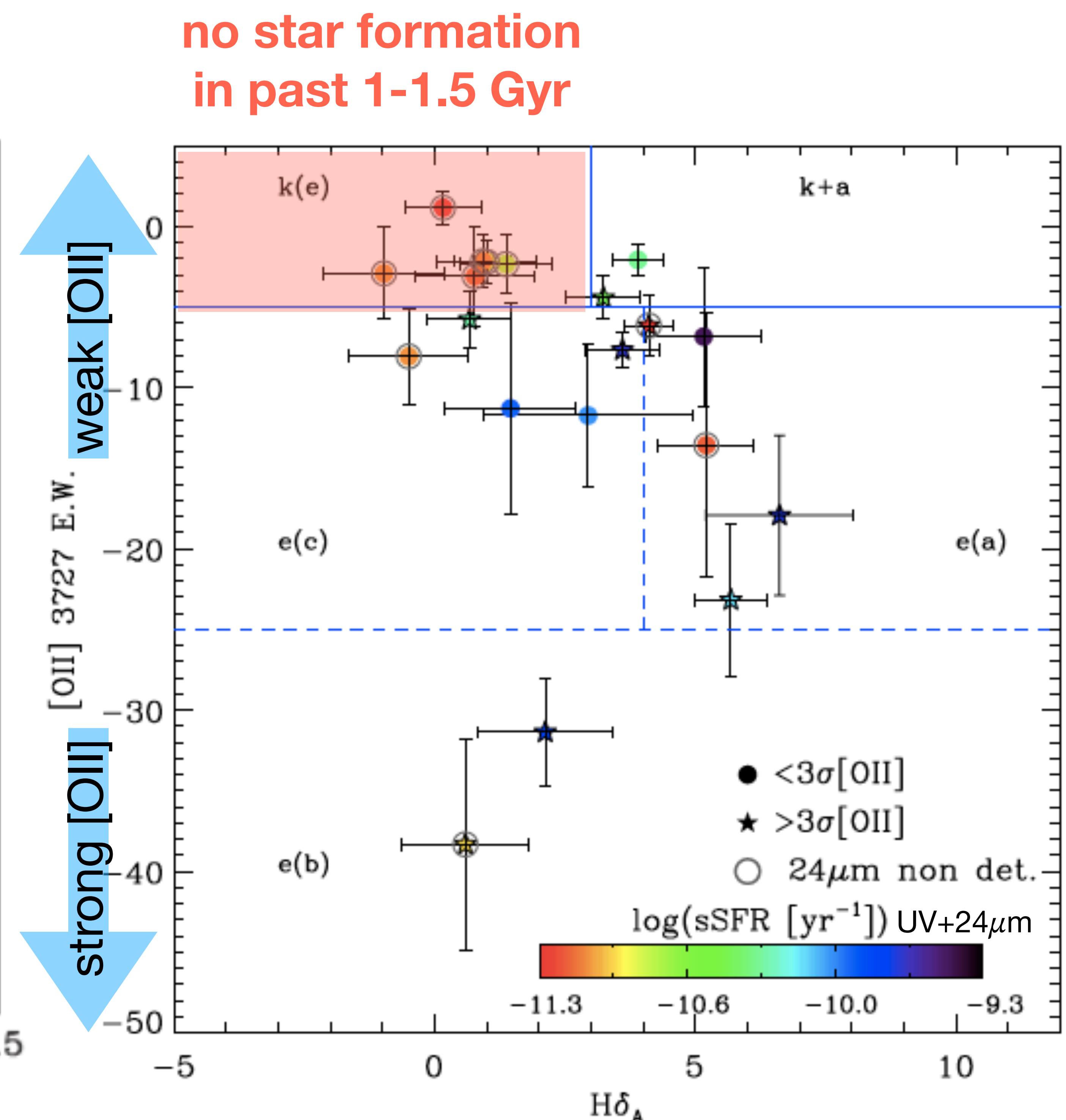
Kauffmann et al. 2003



Stellar ages, star formation histories and metallicities

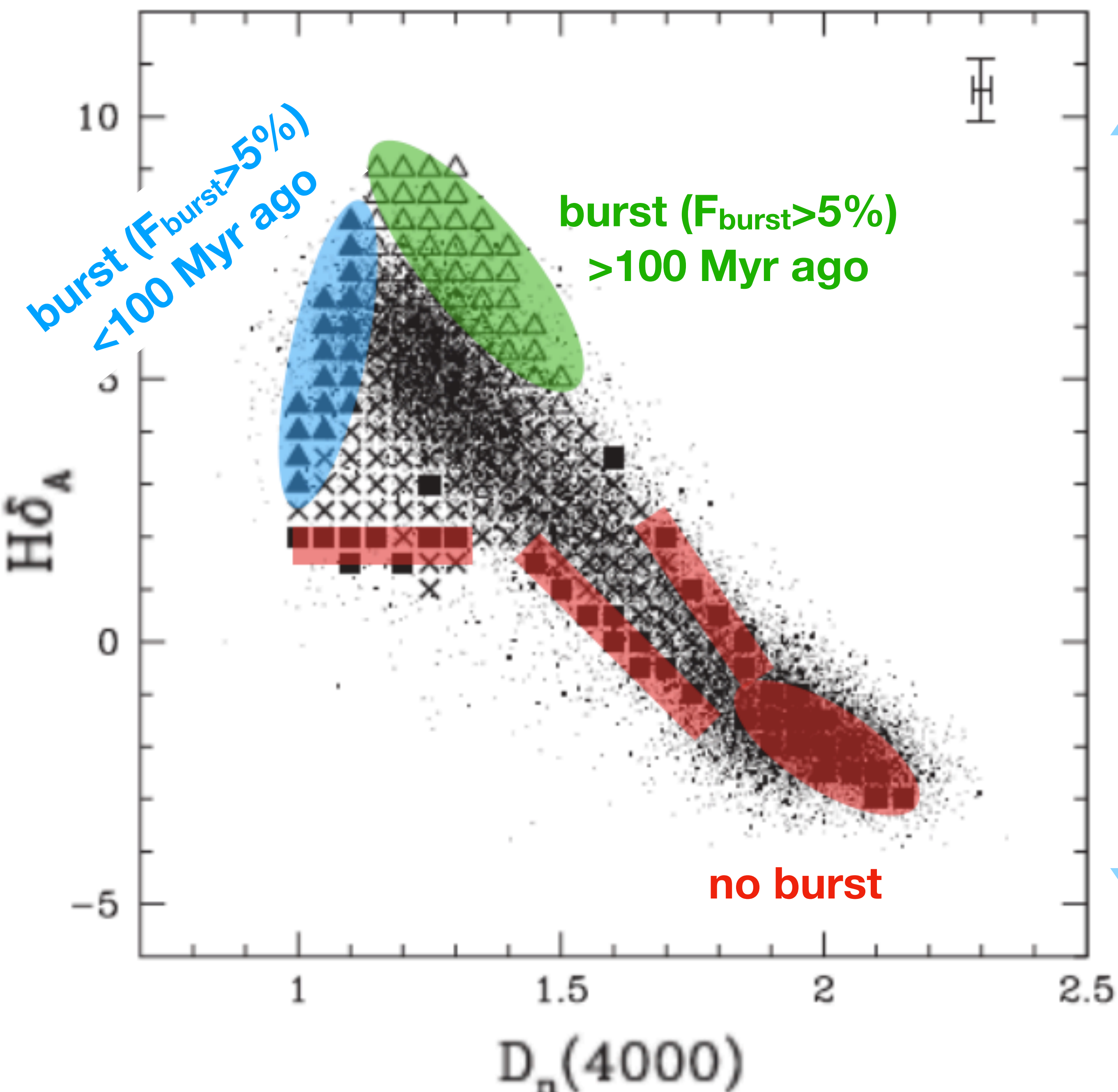


Kauffmann et al. 2003



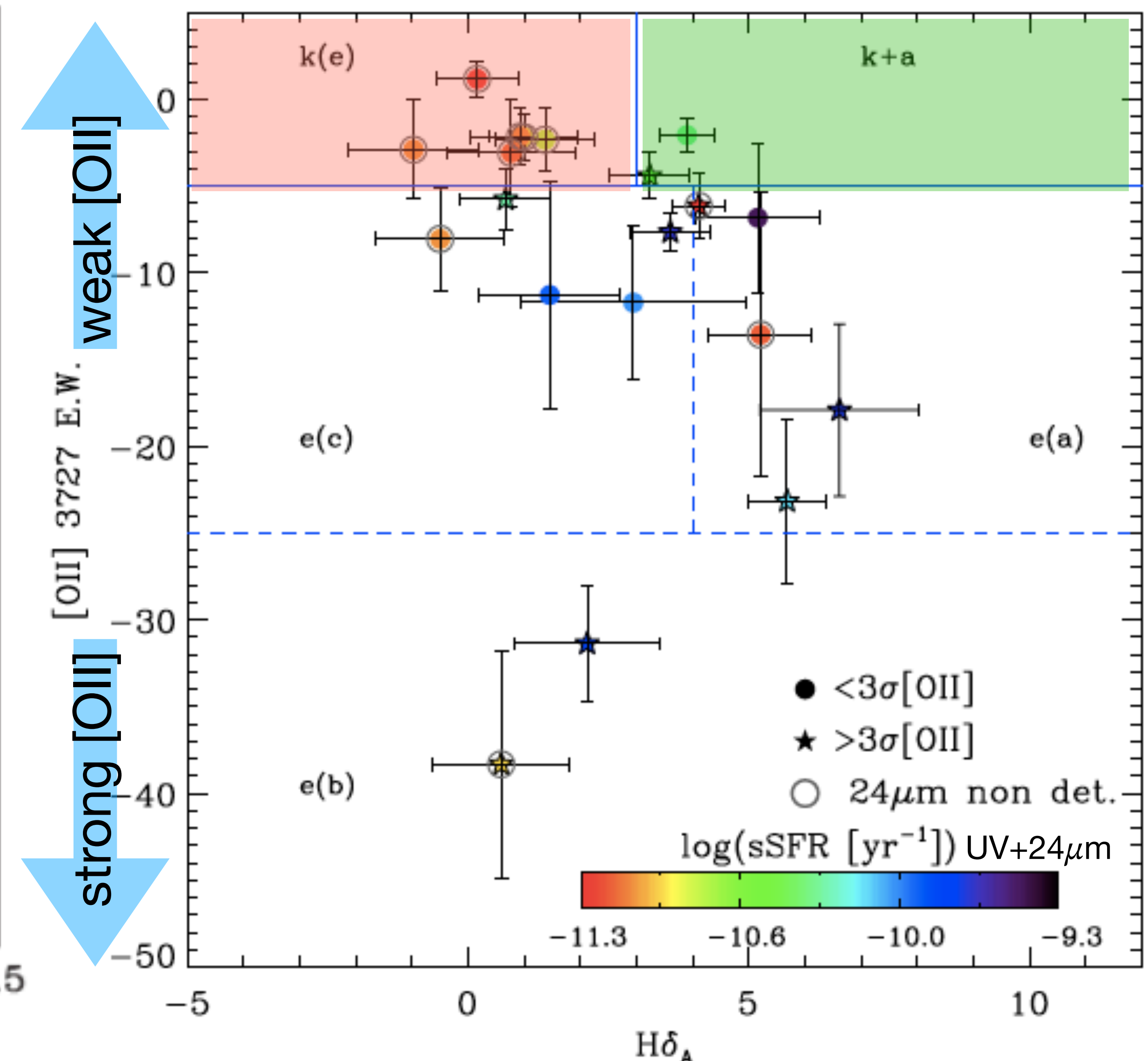
Gallazzi et al. 2014
(Poggianti et al. 2009)

Stellar ages, star formation histories and metallicities



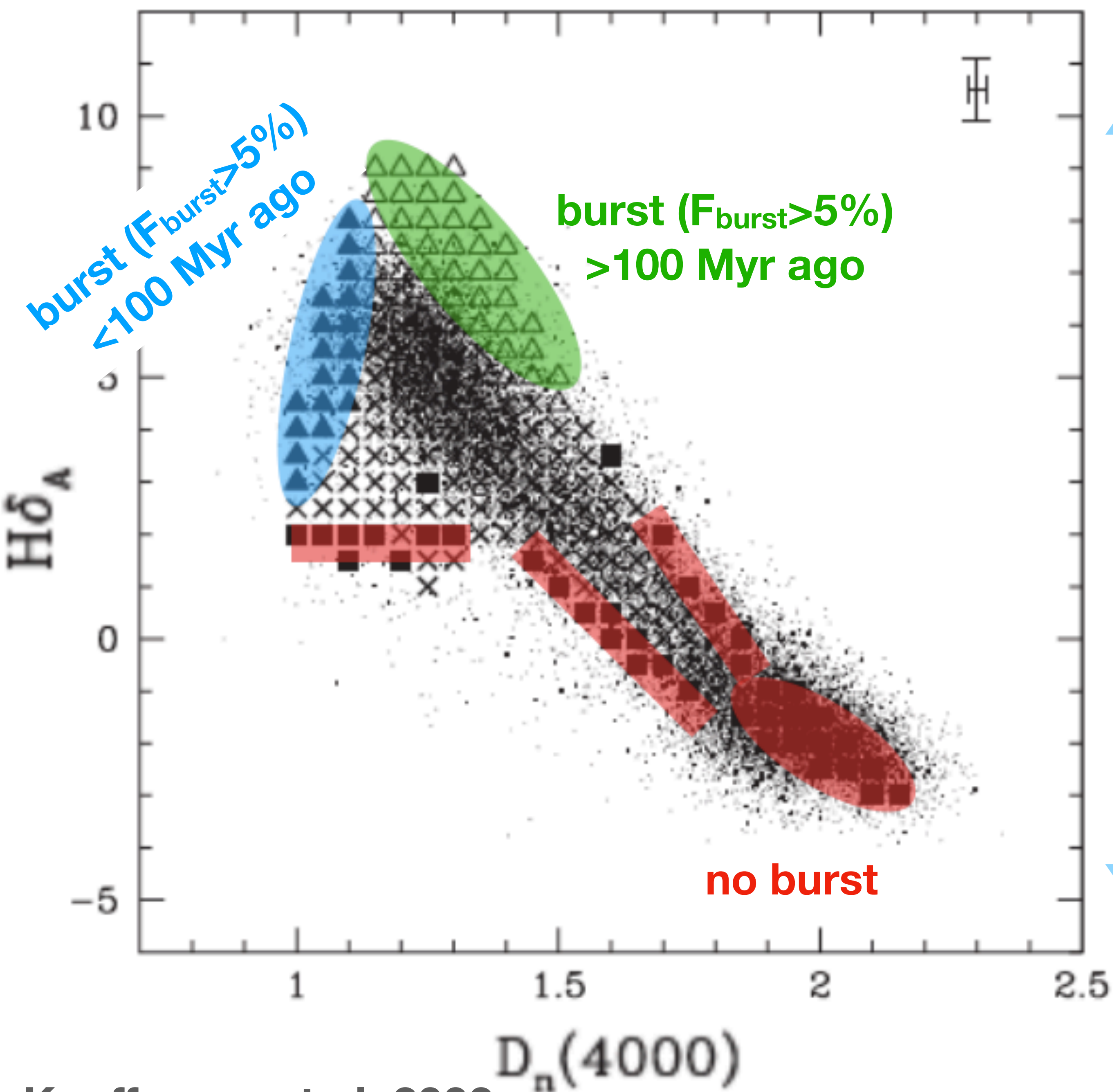
Kauffmann et al. 2003

no [OII], strong Hδ: SF terminated between 50 Myr and 1.5 Gyr



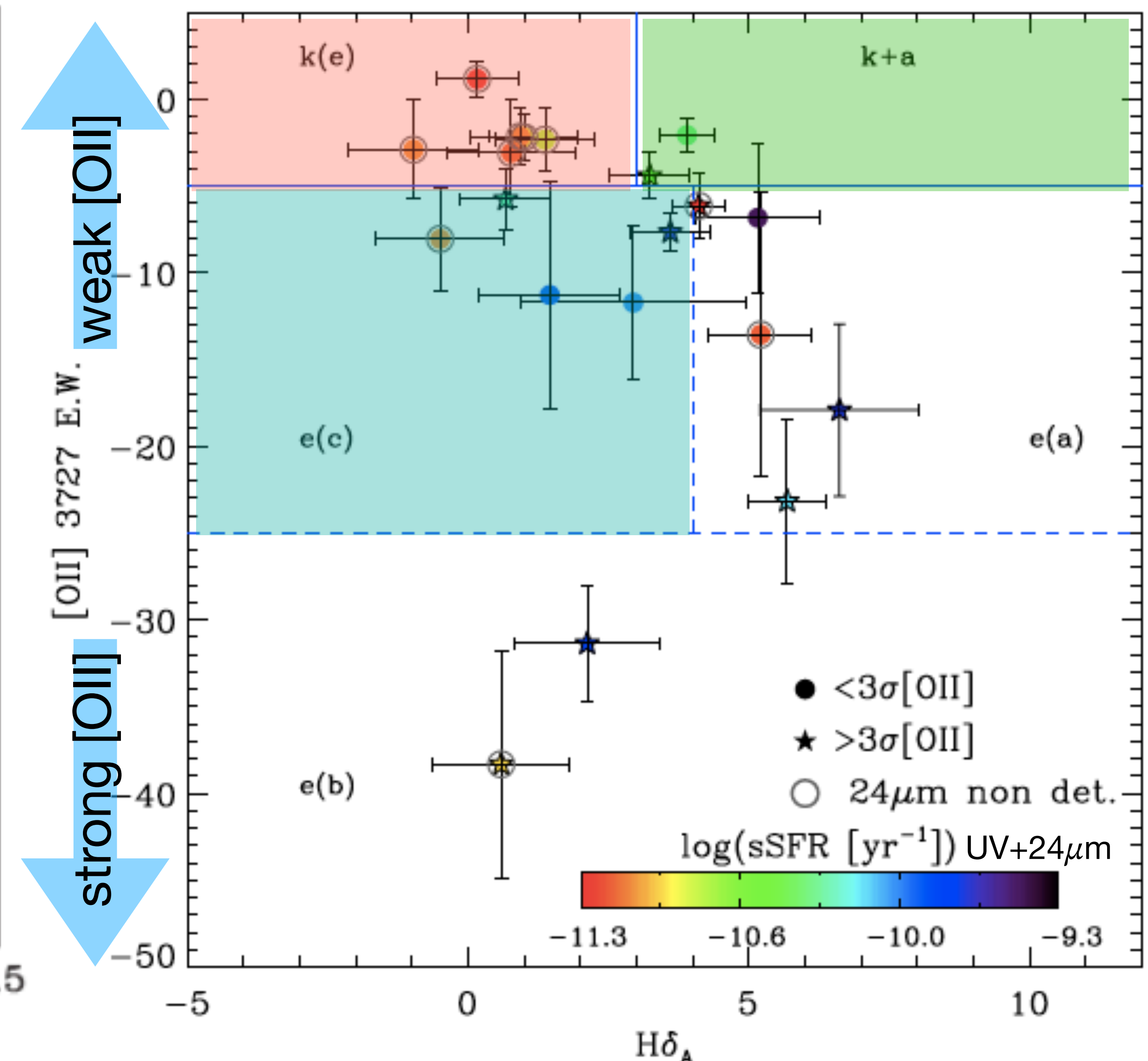
Gallazzi et al. 2014
(Poggianti et al. 2009)

Stellar ages, star formation histories and metallicities



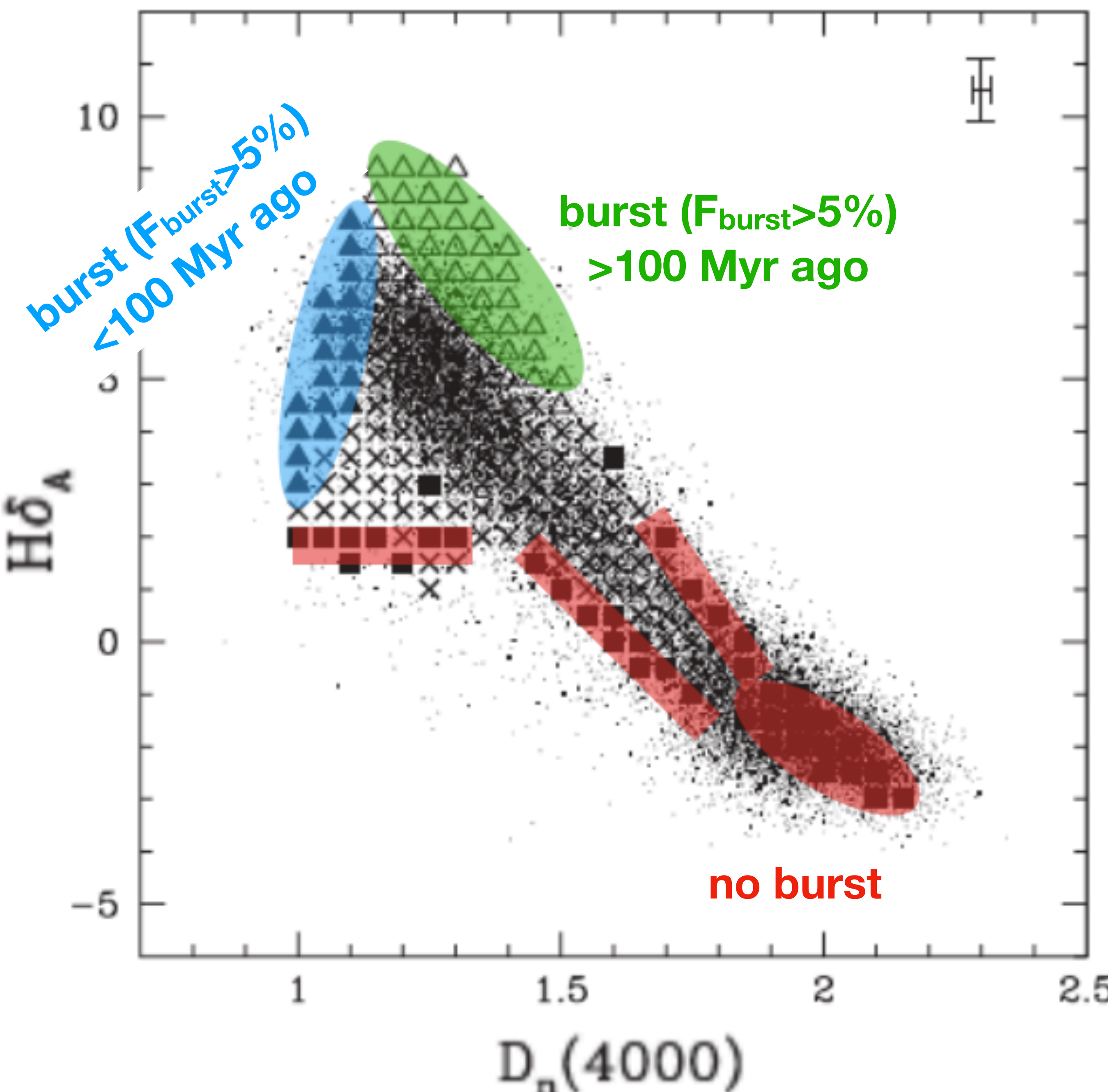
Kauffmann et al. 2003

moderate [OII], weak Hδ: continuous SF with no sudden variation



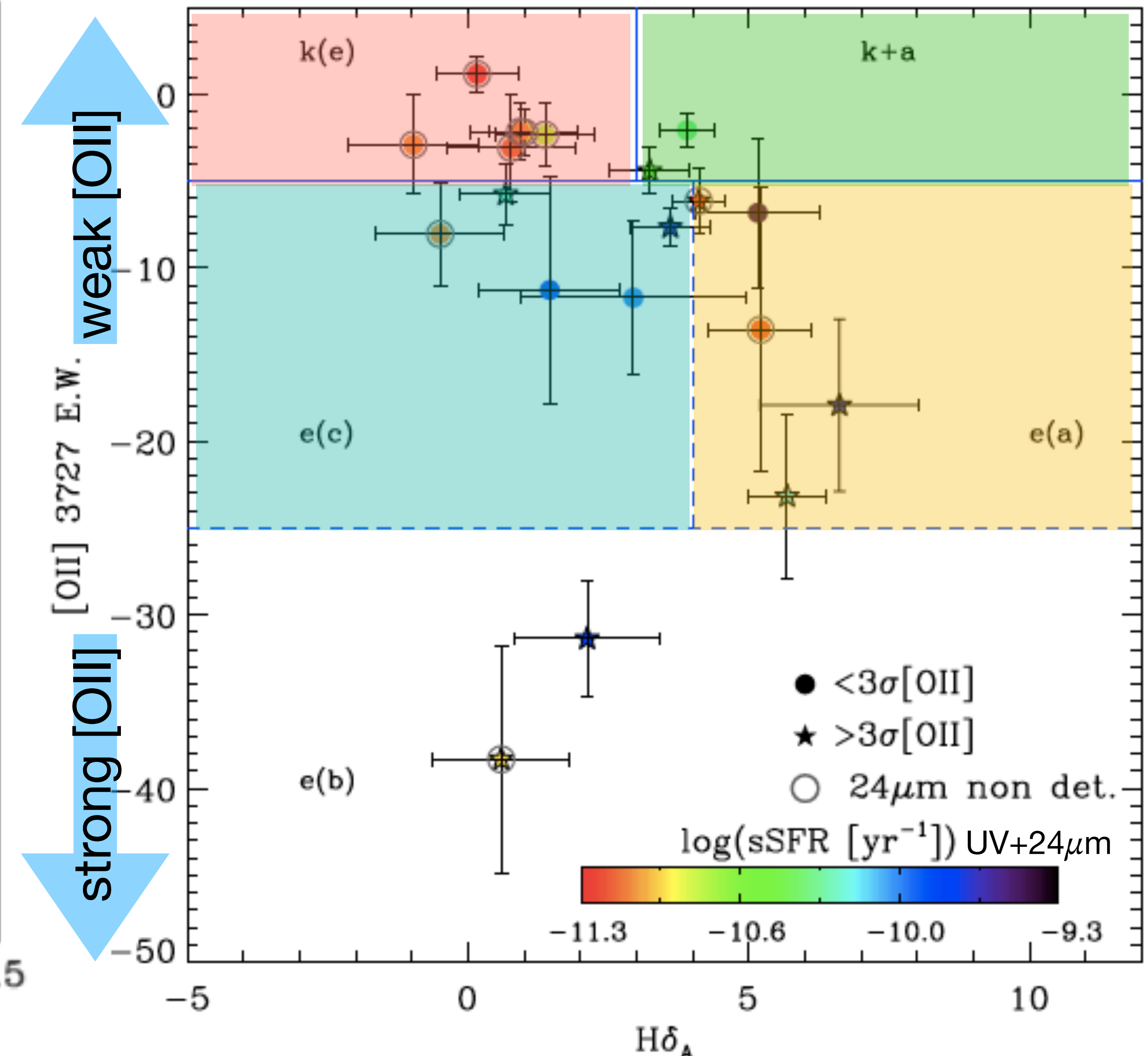
Gallazzi et al. 2014 (Poggianti et al. 2009)

Stellar ages, star formation histories and metallicities



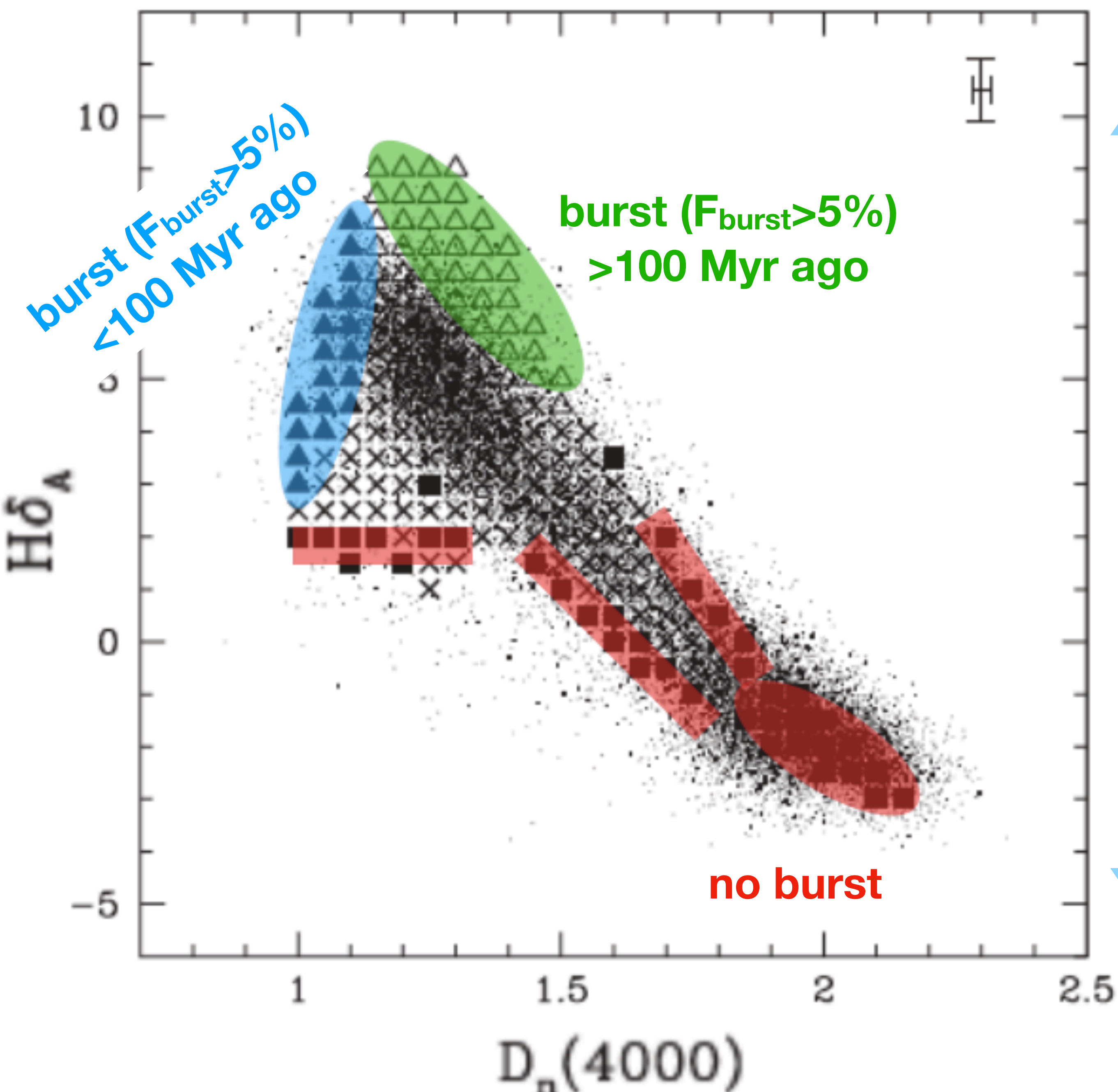
Kauffmann et al. 2003

(at low z) dusty ongoing starbursts?
(or post-starbursts with residual SF)



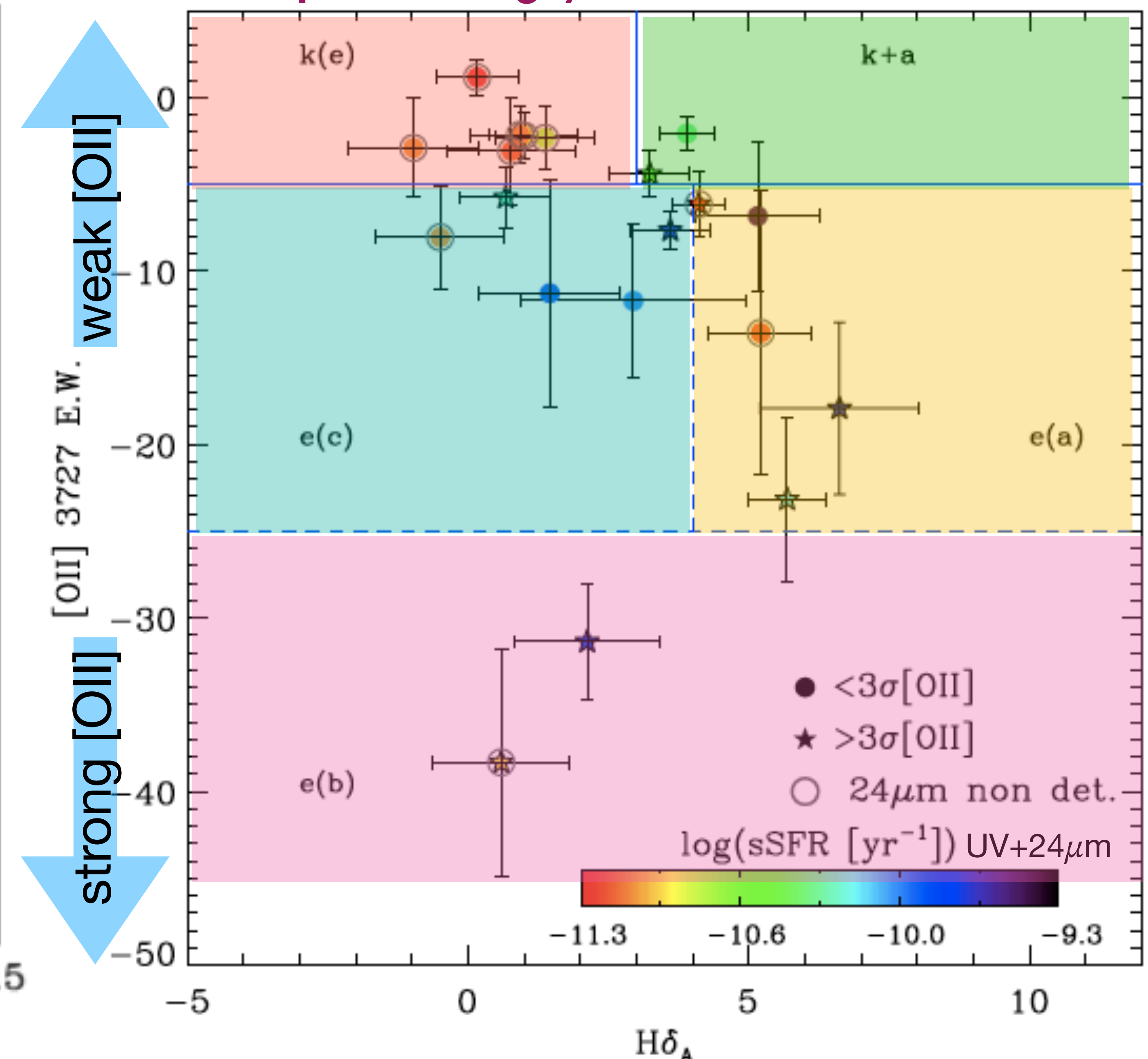
Gallazzi et al. 2014
(Poggianti et al. 2009)

Stellar ages, star formation histories and metallicities



Kauffmann et al. 2003

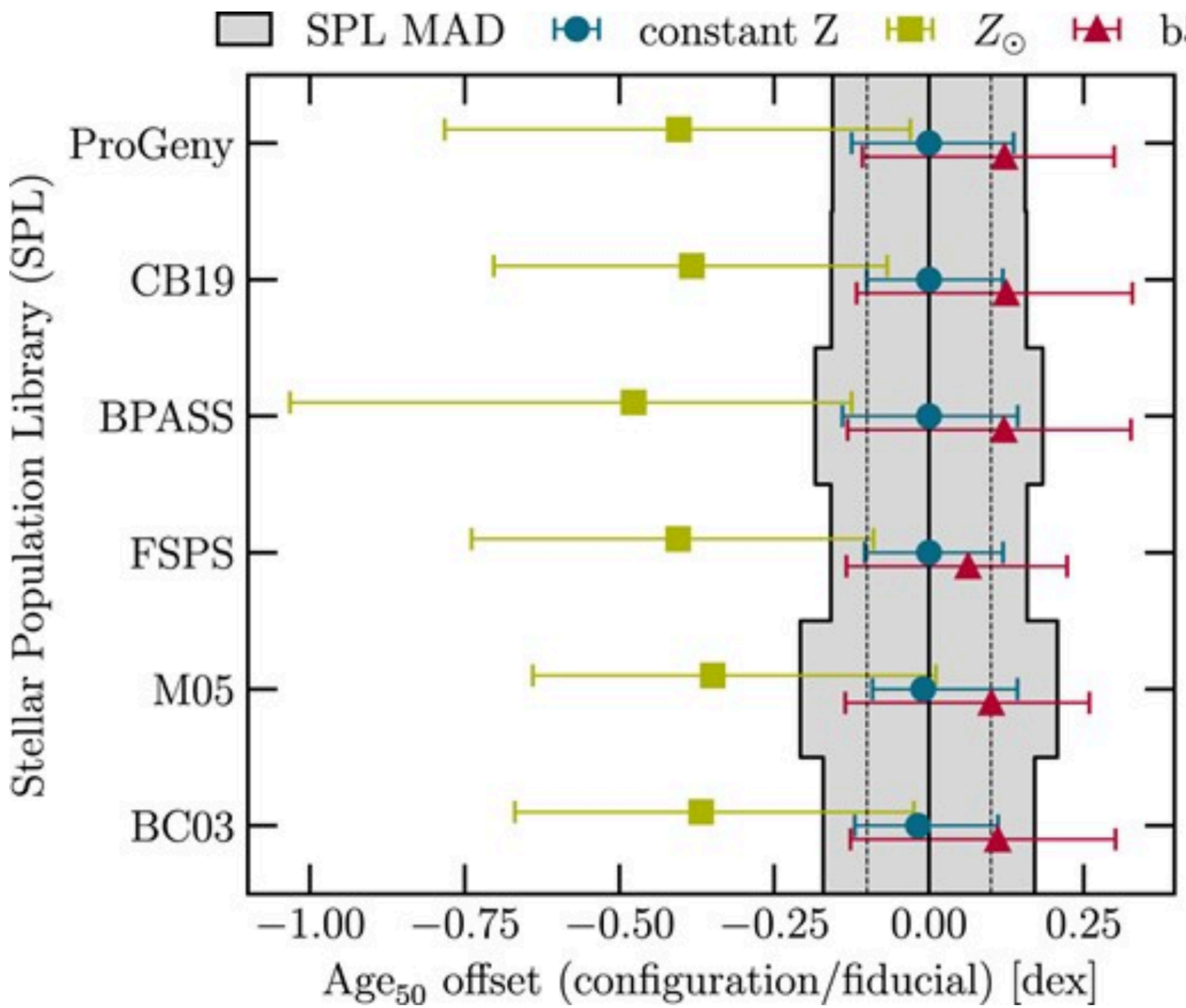
strong emission-line starbursts (current SF > past average) **and/or low extinction**



Gallazzi et al. 2014
(Poggianti et al. 2009)

<u>Broad</u> stellar population age / specific star formation rate

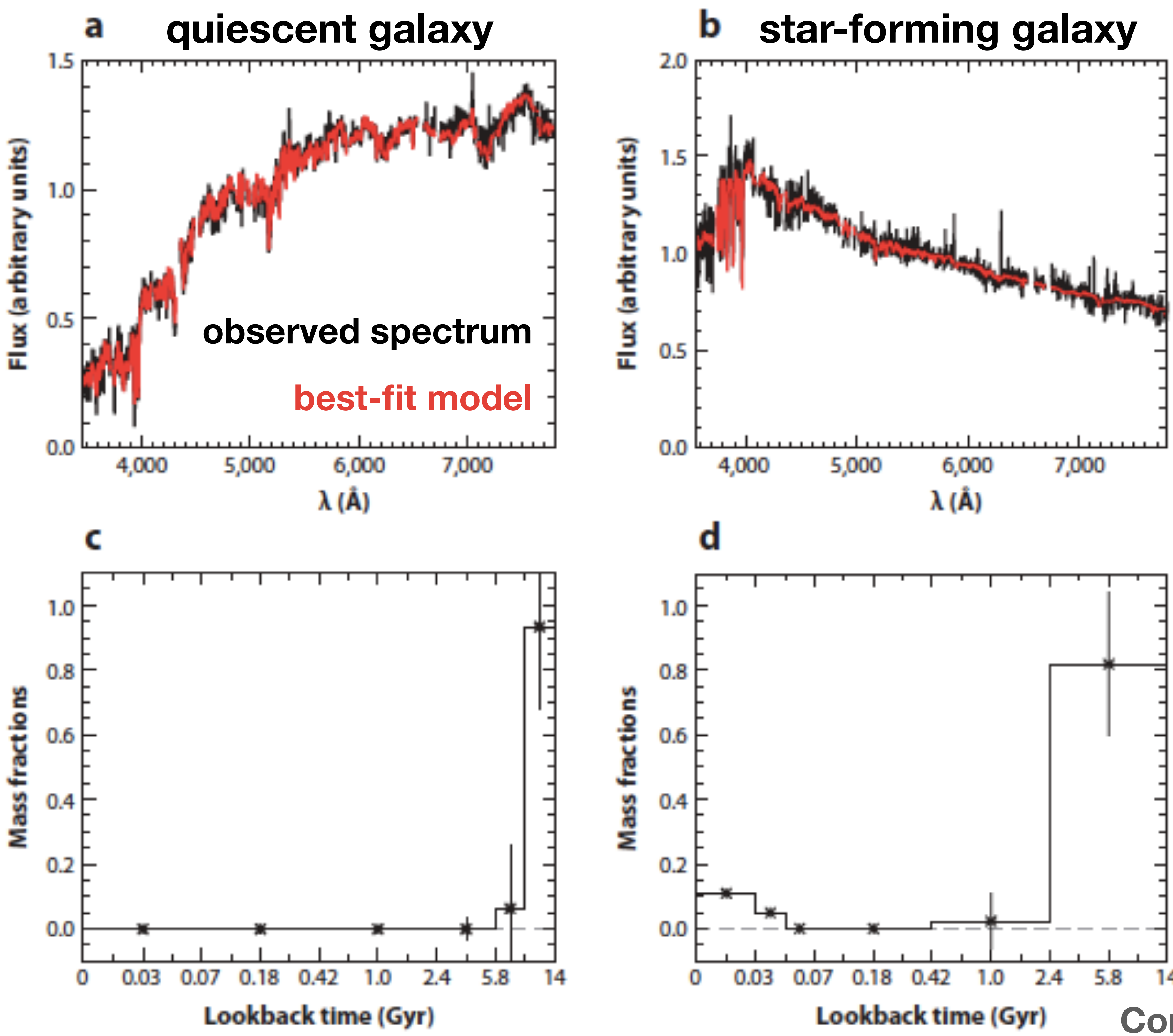
age estimates from SED modeling - dependence on SPS models and priors



Bellstedt & Robotham 2025

Stellar ages, star formation histories and metallicities

with sufficient spectral coverage and spectral resolution can attempt reconstruction of the SFH

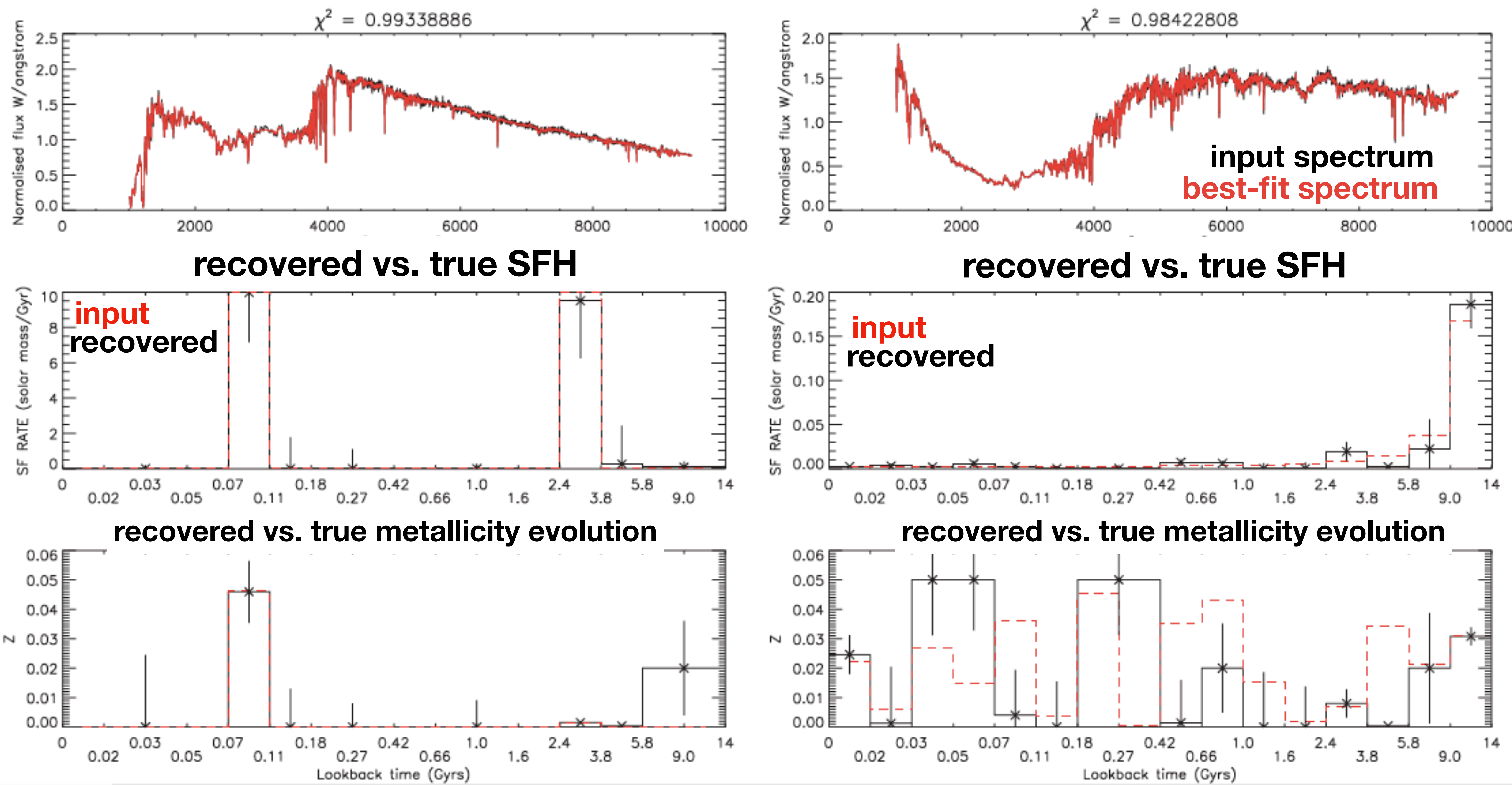


Conroy 2013

Stellar ages, star formation histories and metallicities

with sufficient spectral coverage and spectral resolution
can attempt reconstruction of the SFH

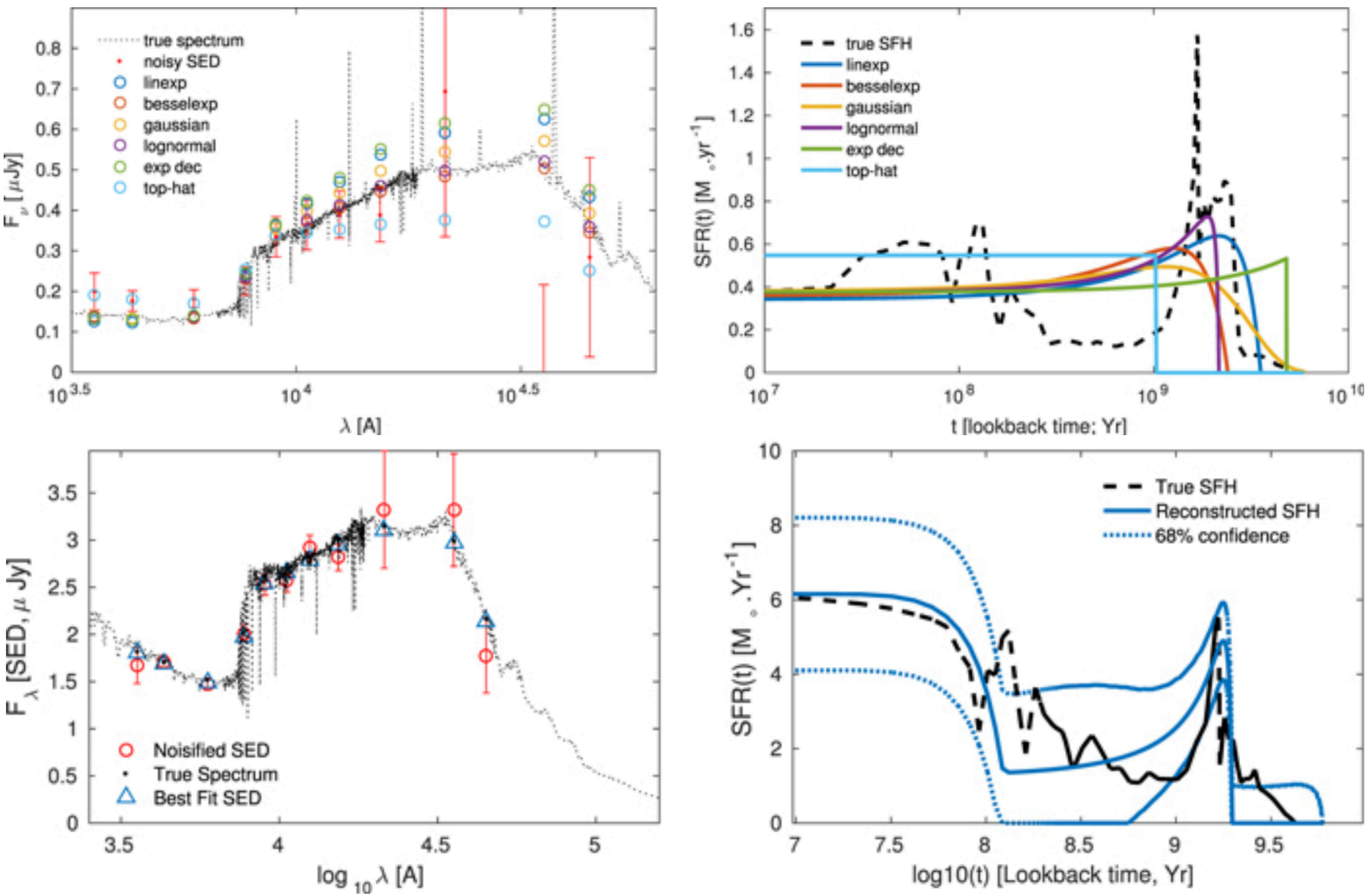
performance on synthetic galaxies



Tojeiro et al. 2007

Stellar ages, star formation histories and metallicities

with sufficient spectral coverage and spectral resolution can attempt reconstruction of the SFH

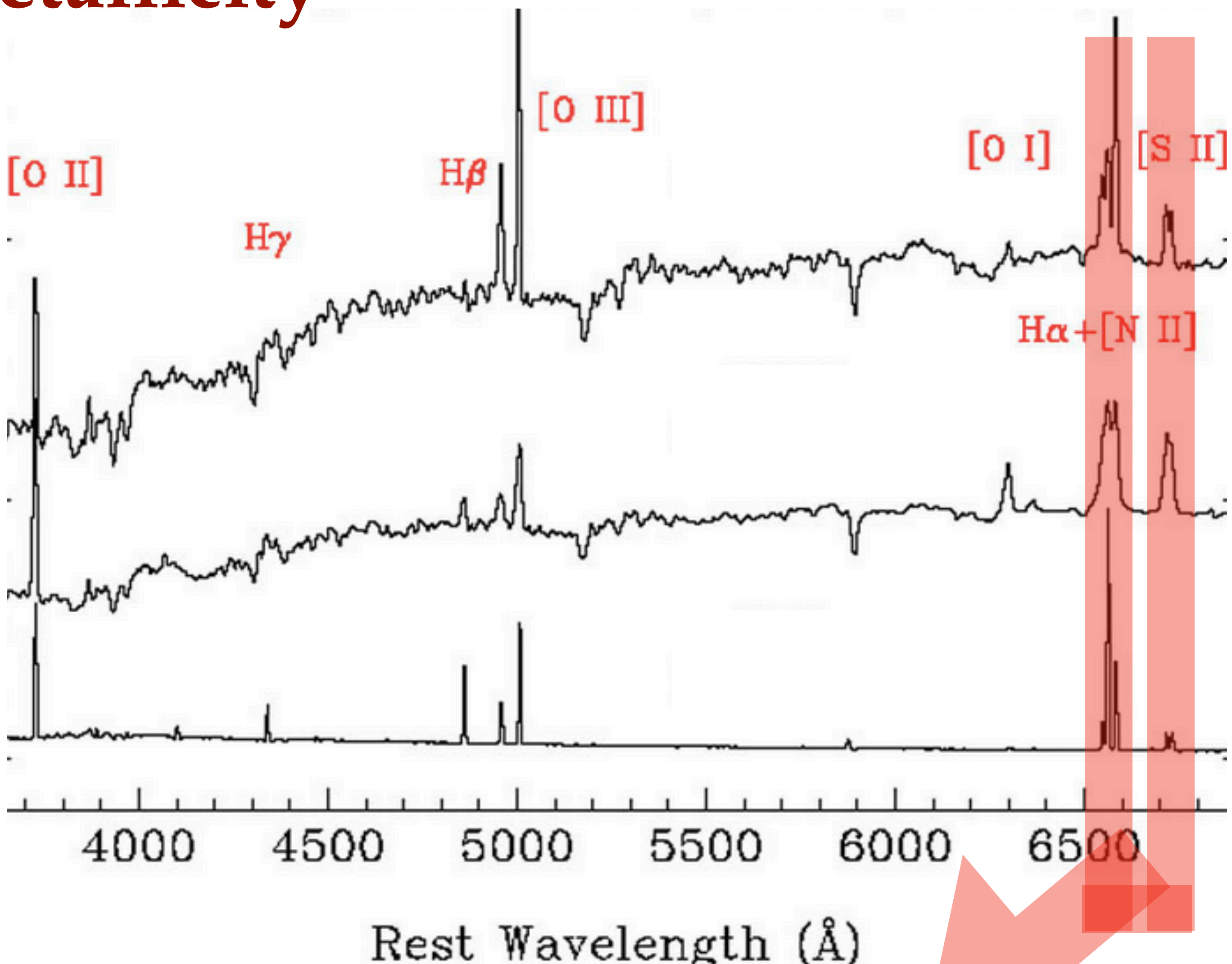


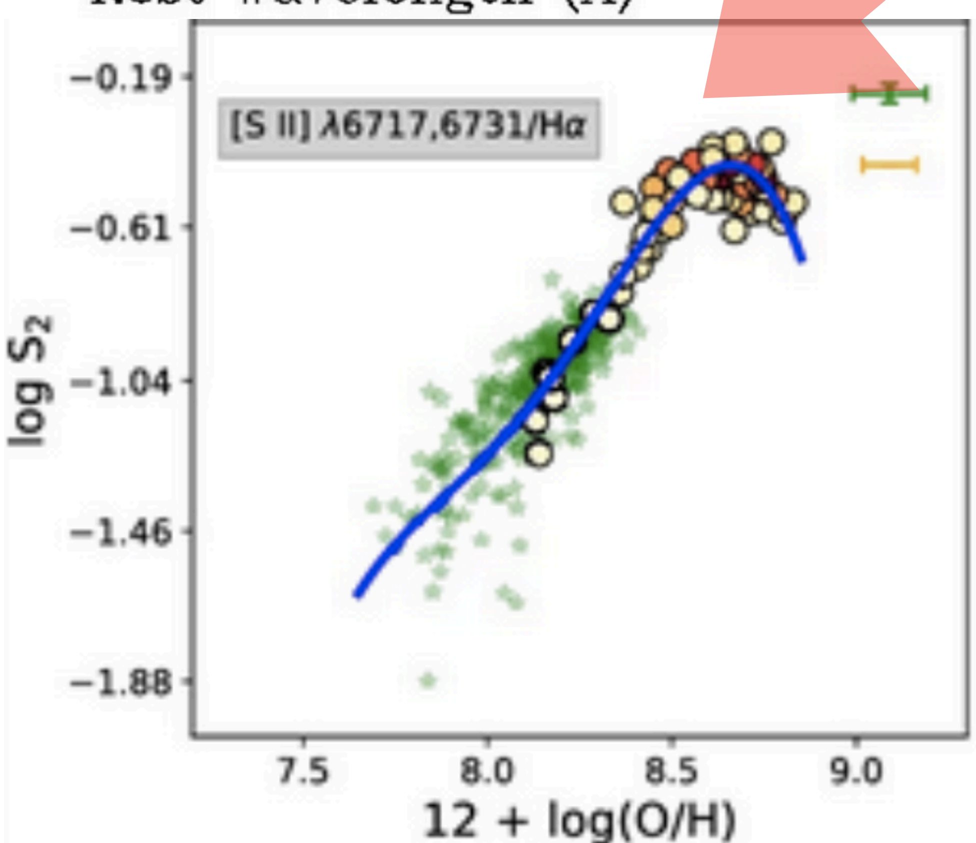
Iyer & Gawiser 2017

Gas metallicity

via strong emission line flux ratios

Different calibrations involving different lines

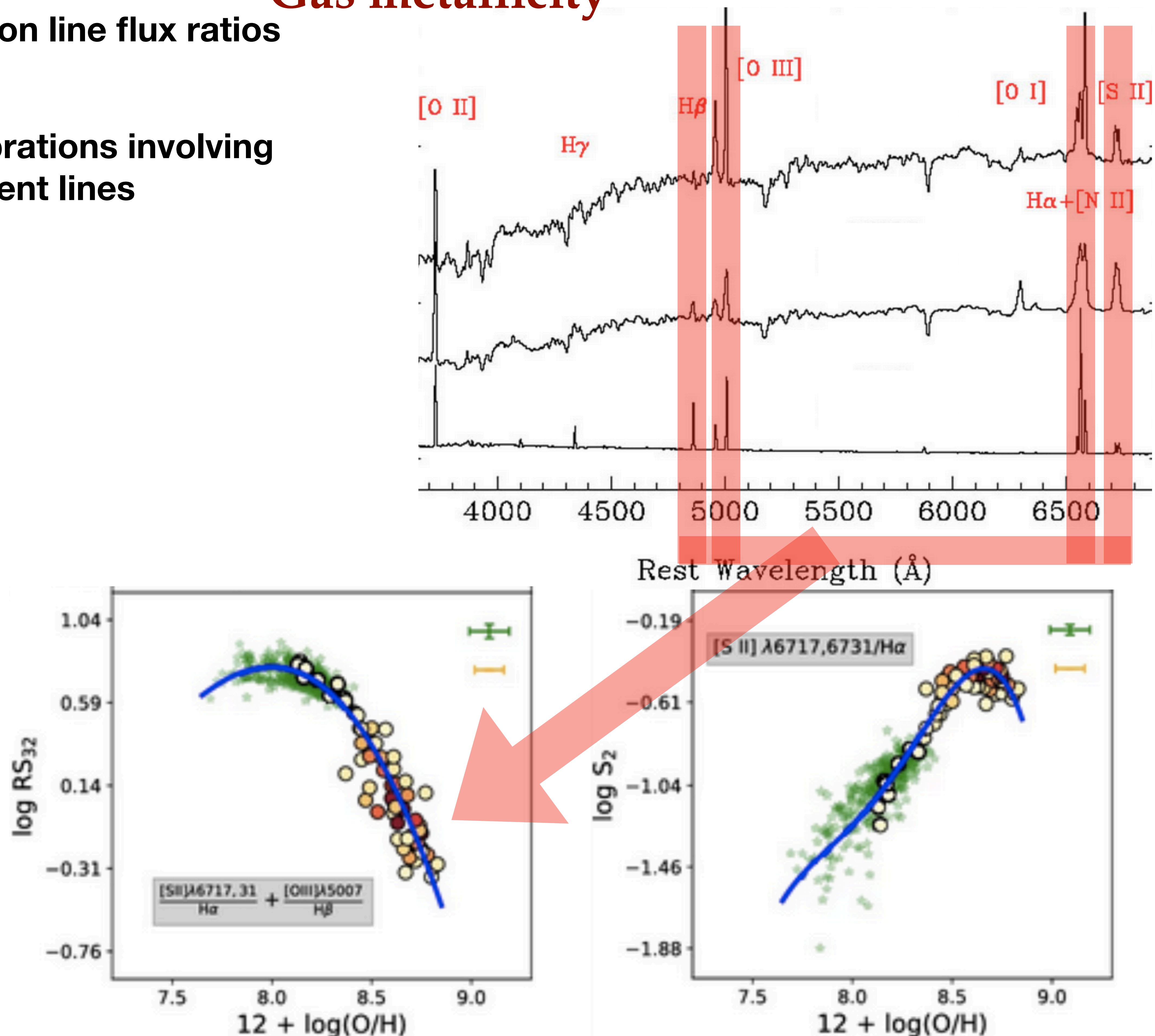




Gas metallicity

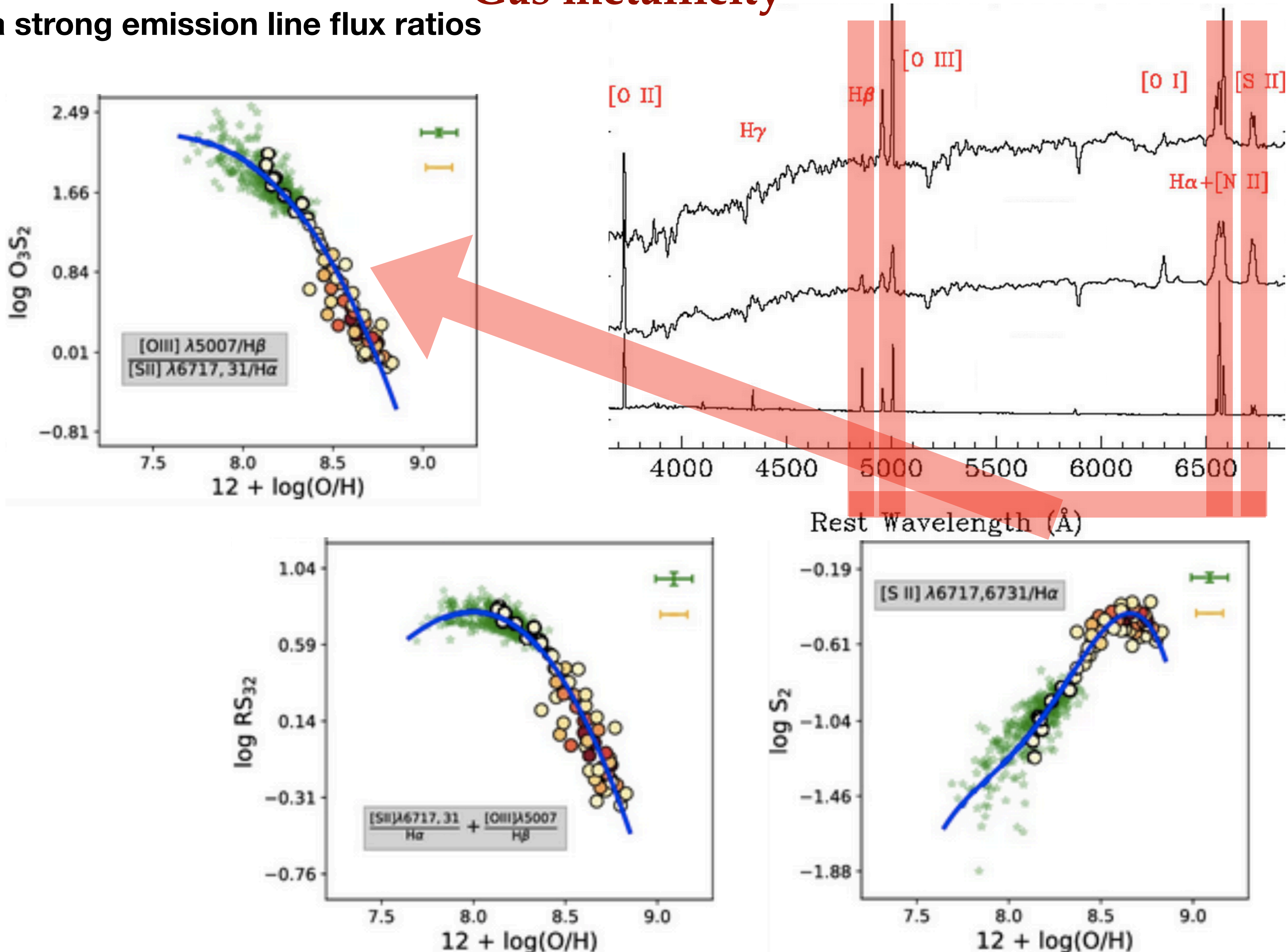
via strong emission line flux ratios

Different calibrations involving different lines



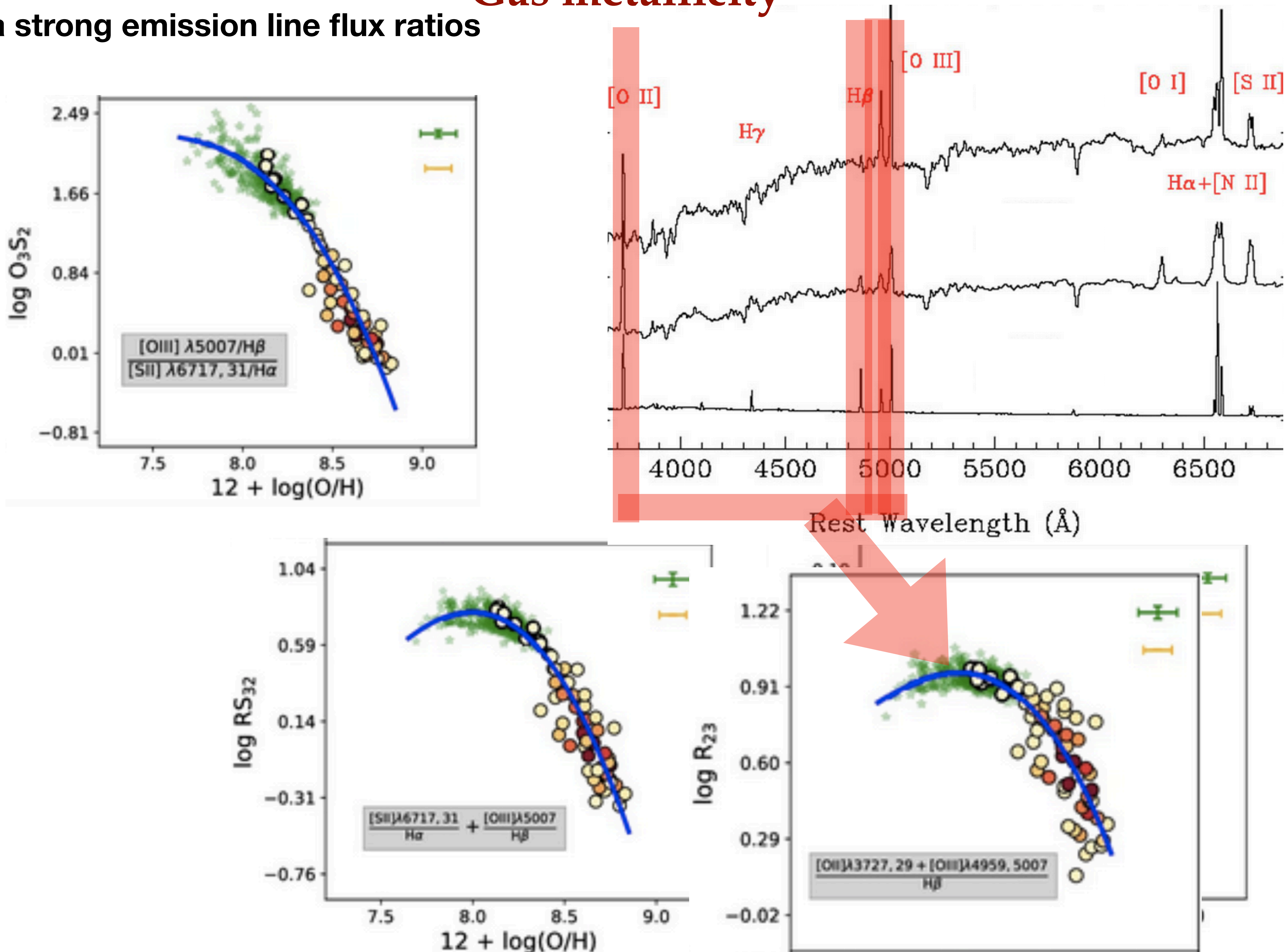
Gas metallicity

via strong emission line flux ratios



Gas metallicity

via strong emission line flux ratios



Gas metallicity

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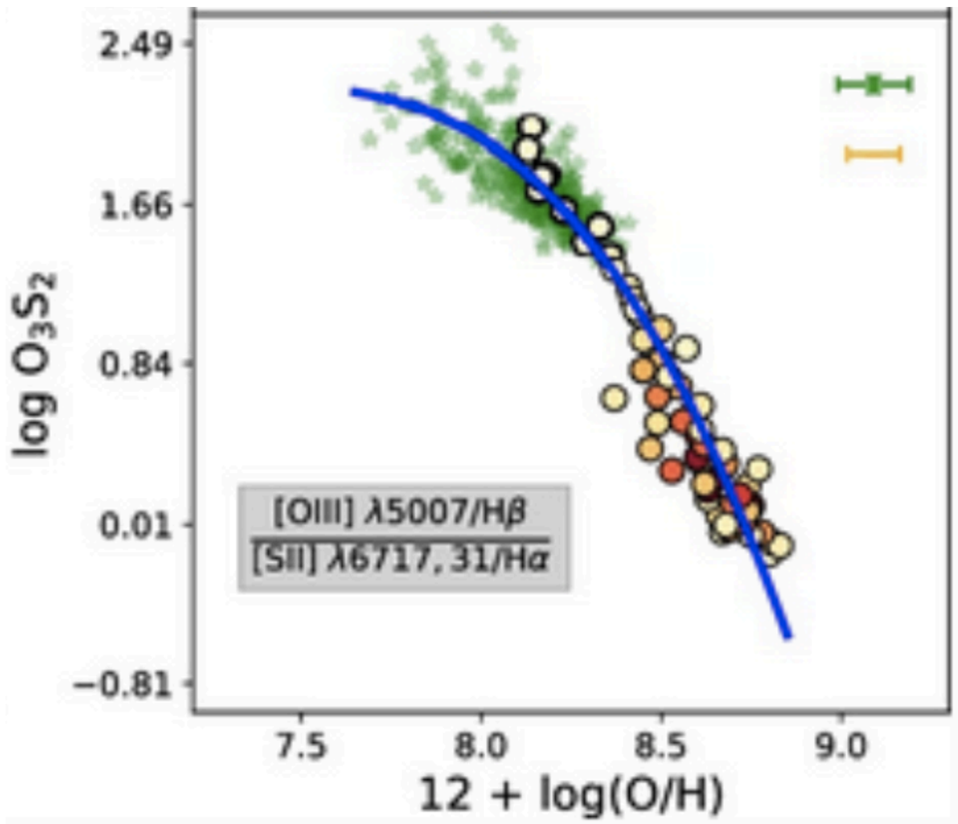
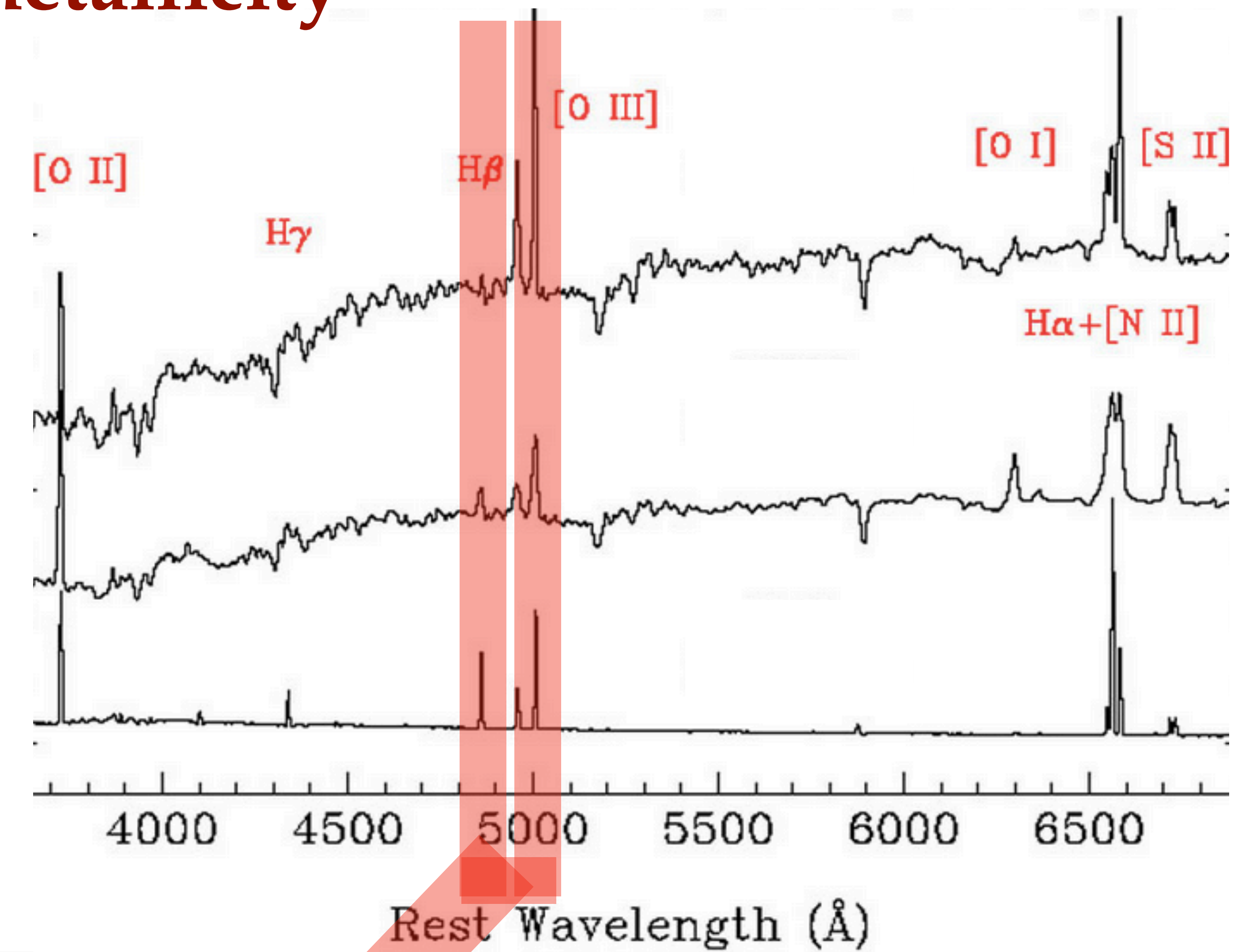
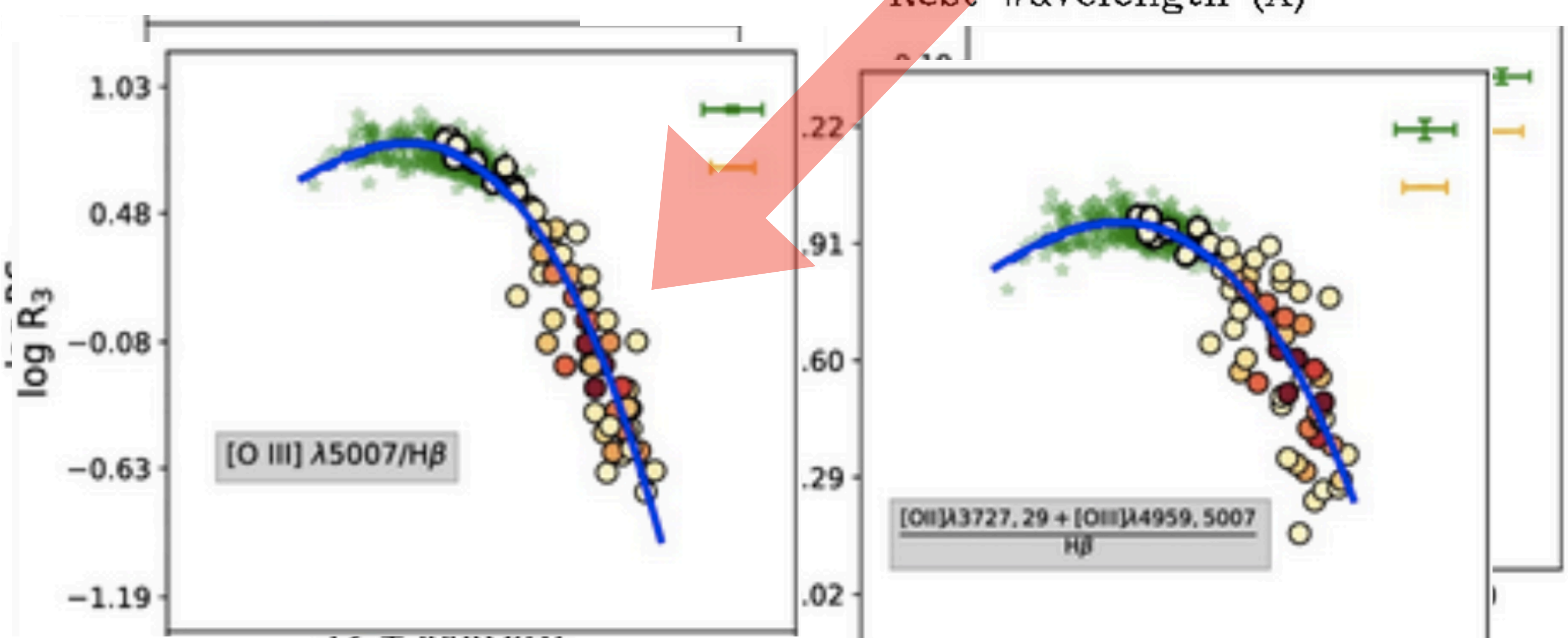
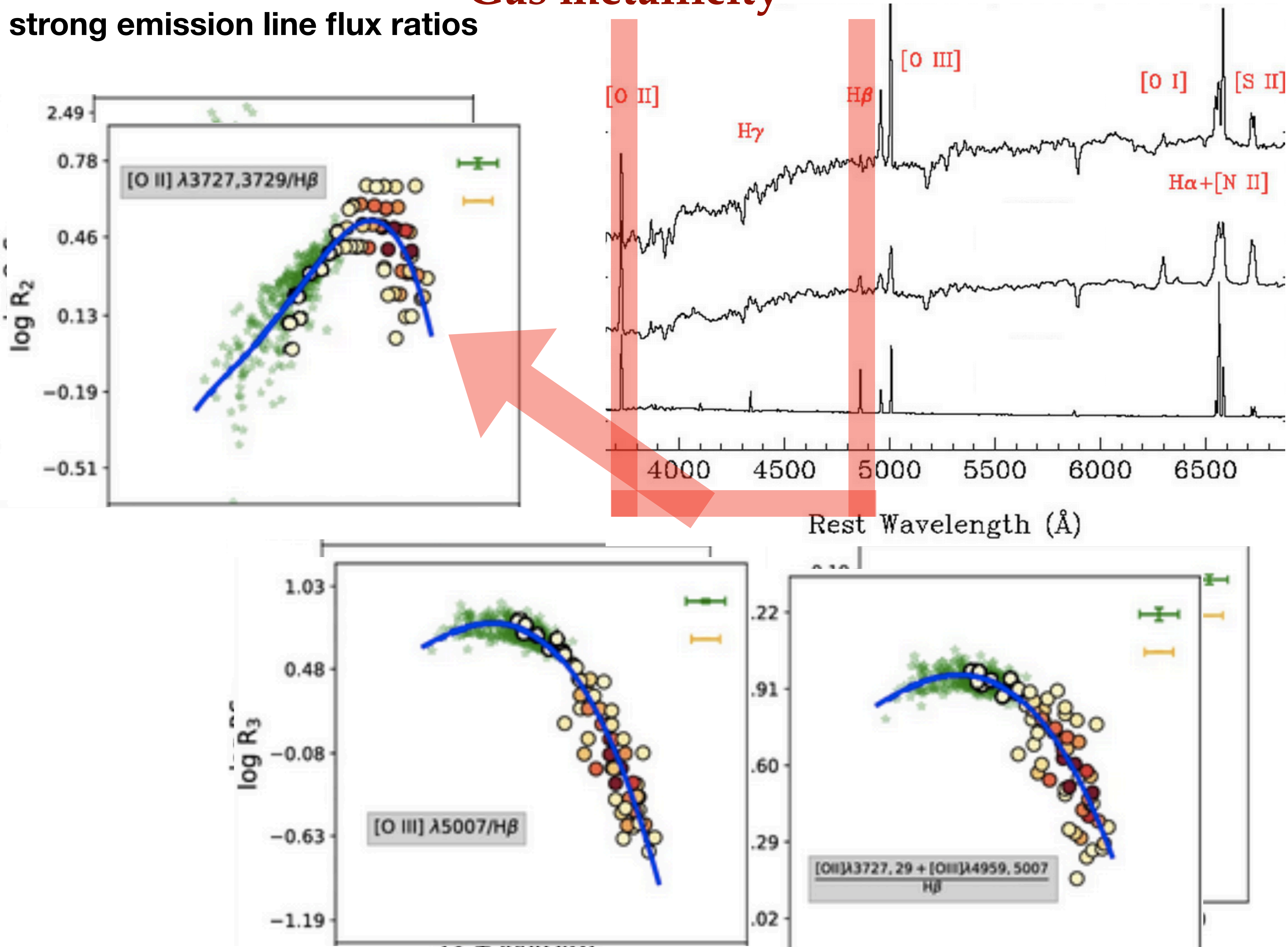






Gas metallicity

via strong emission line flux ratios



Gas metallicity

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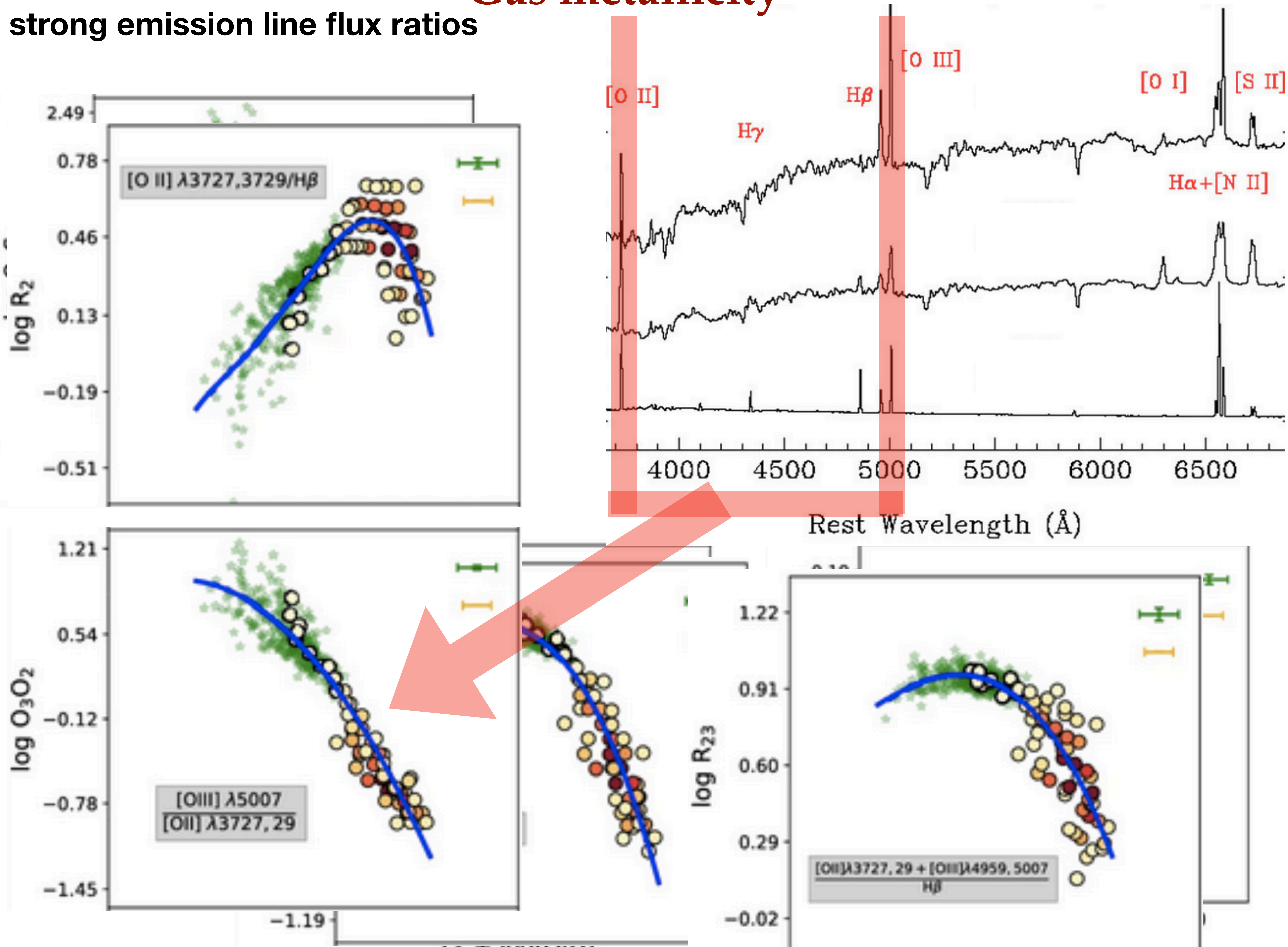

Gas metallicity

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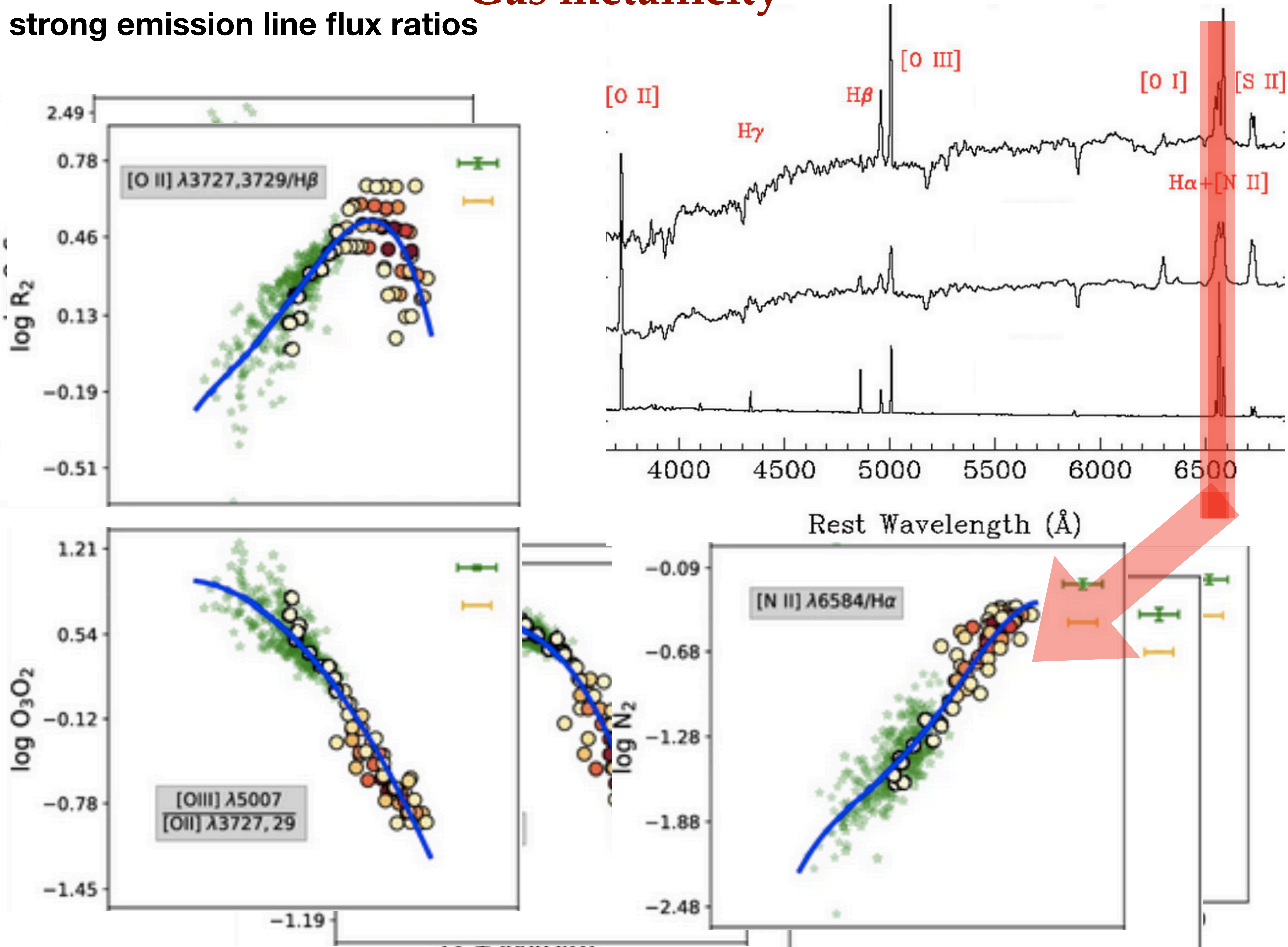
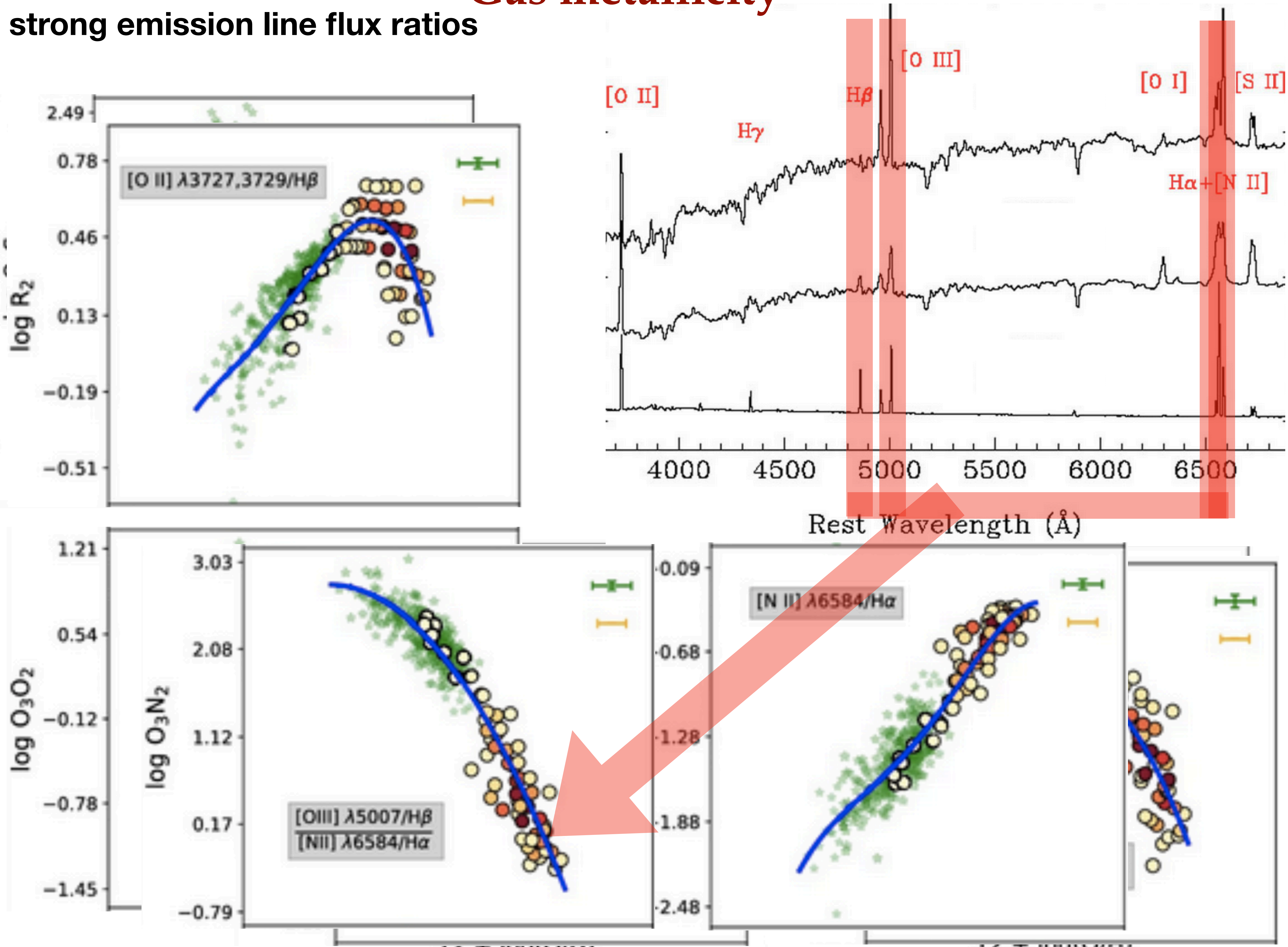
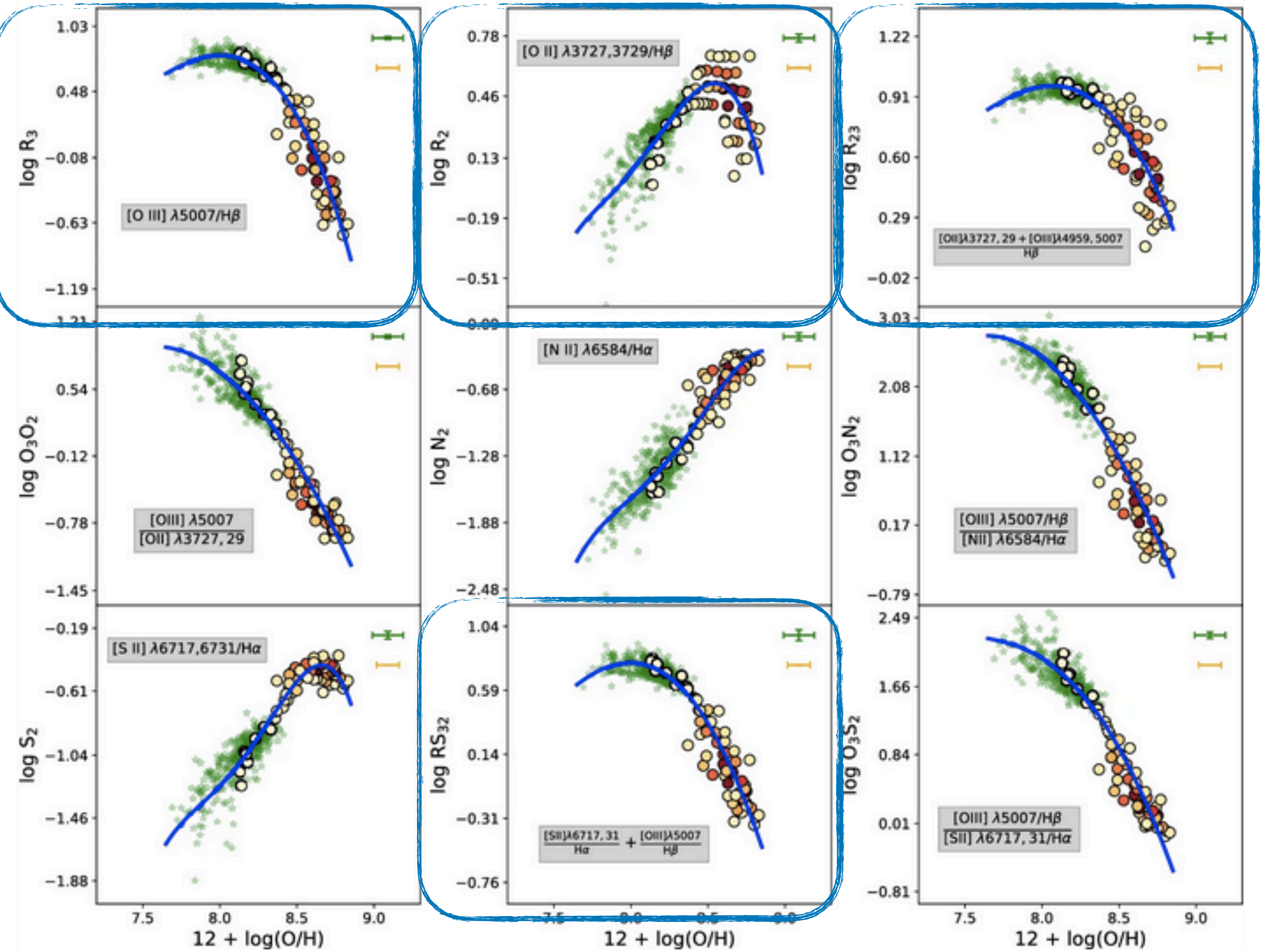


Gas metallicity

via strong emission line flux ratios



Gas metallicity

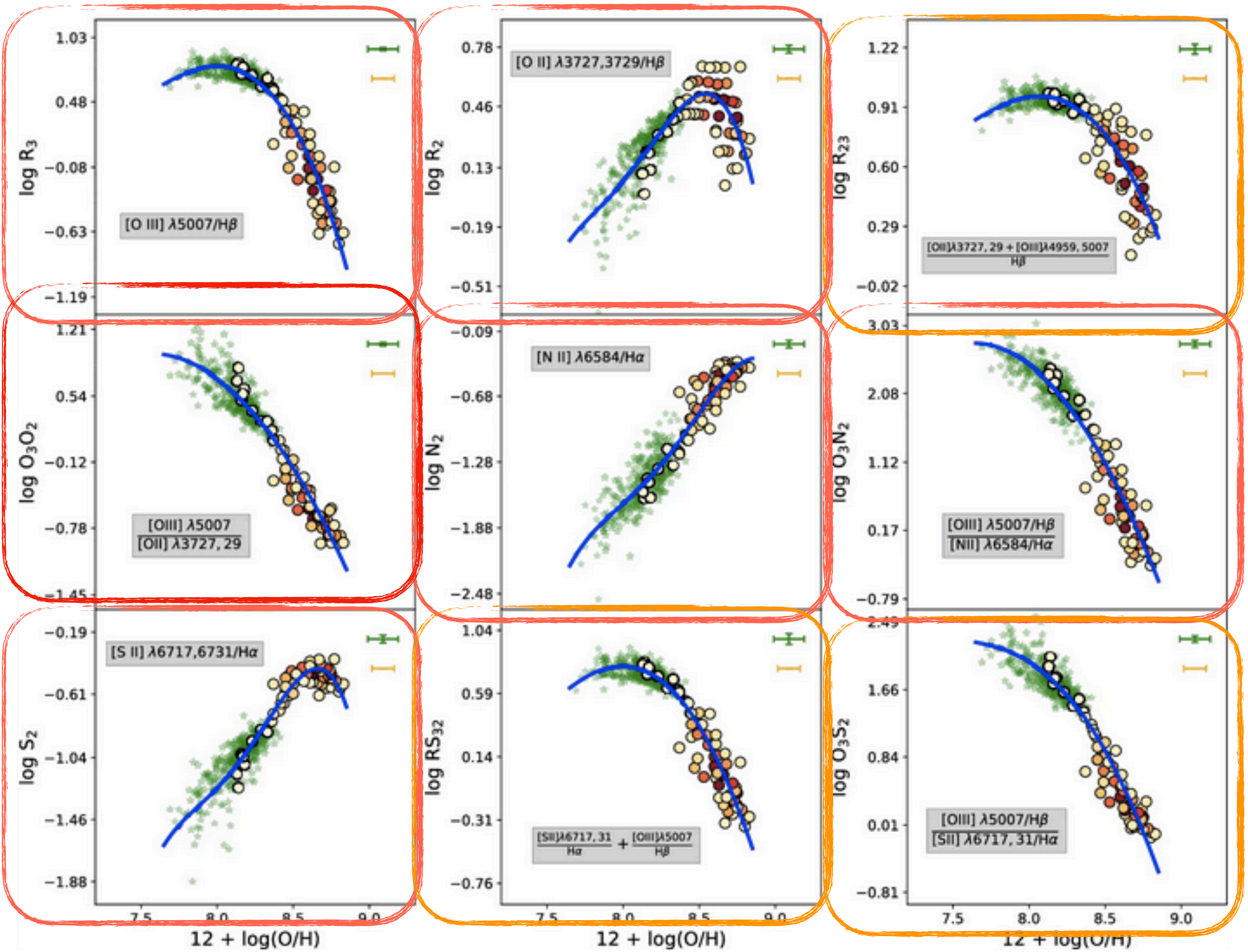


BUT…

- double valued

Maiolino & Mannucci 2019

Gas metallicity

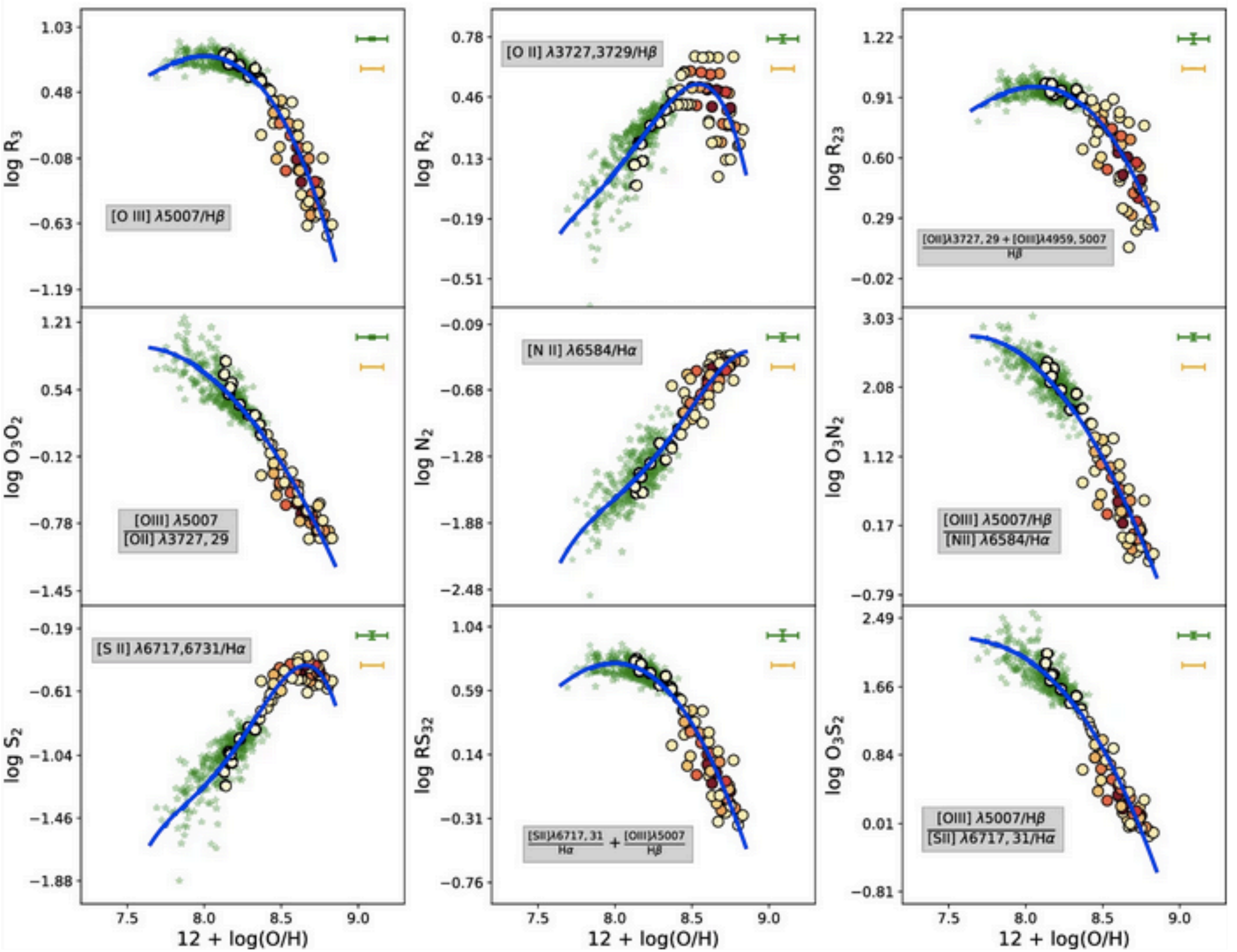


BUT…

- double valued
- secondary/strong dependence on ionization parameter

Maiolino & Mannucci 2019

Gas metallicity



BUT…

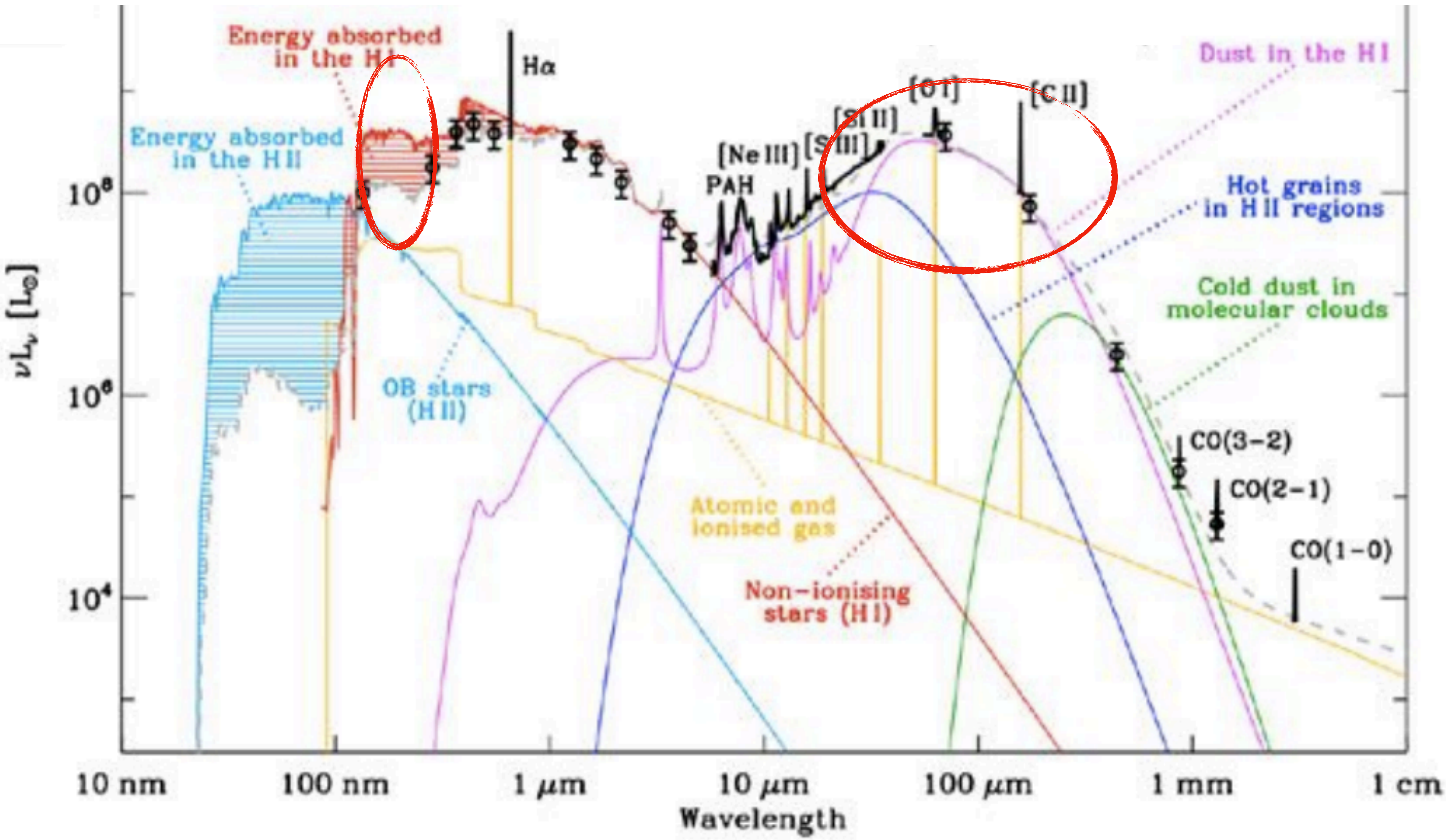
- double valued
- secondary/strong dependence on ionization parameter
- … …

The combination of multiple line diagnostics can help…

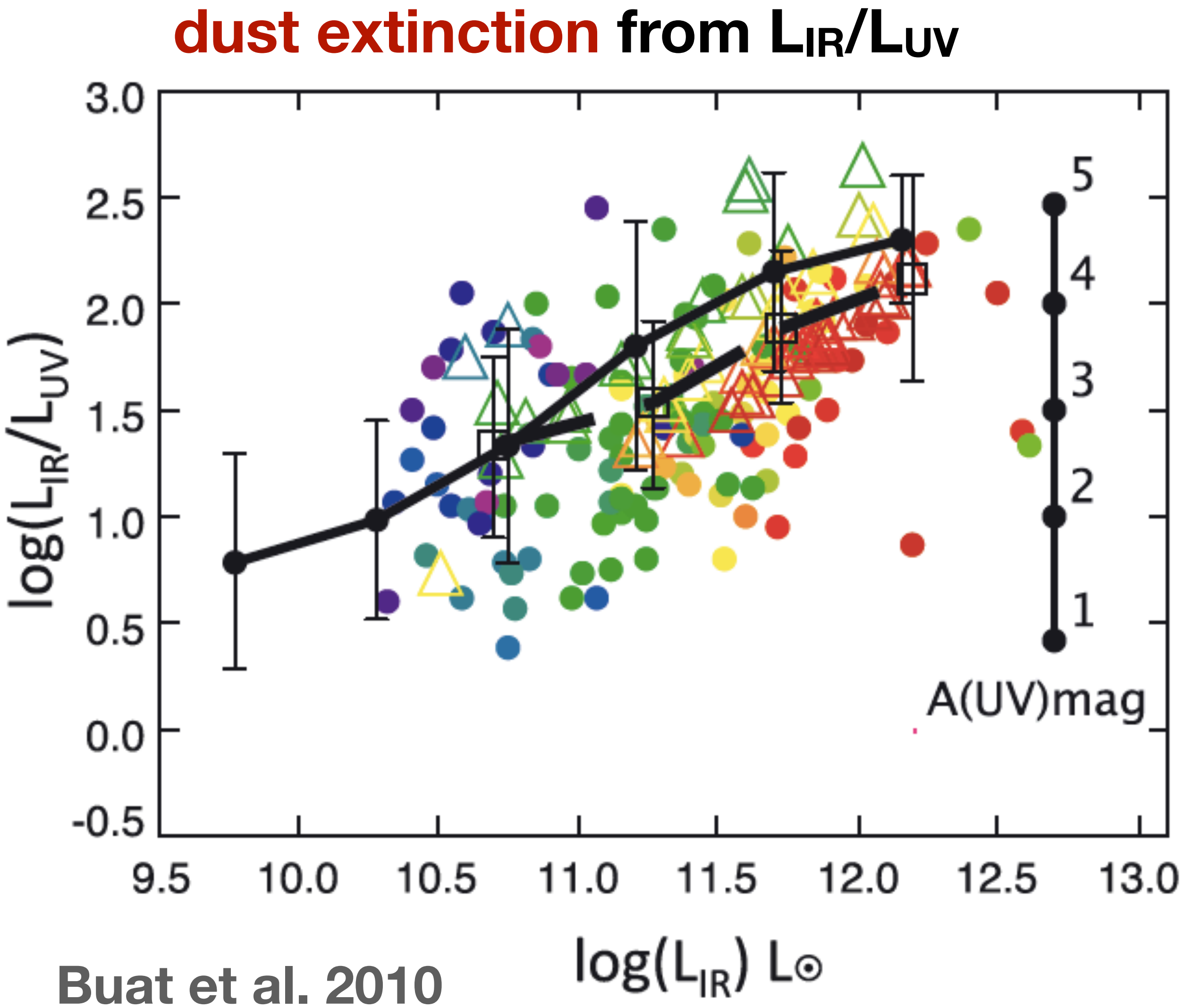
Maiolino & Mannucci 2019

dust extinction

Dust



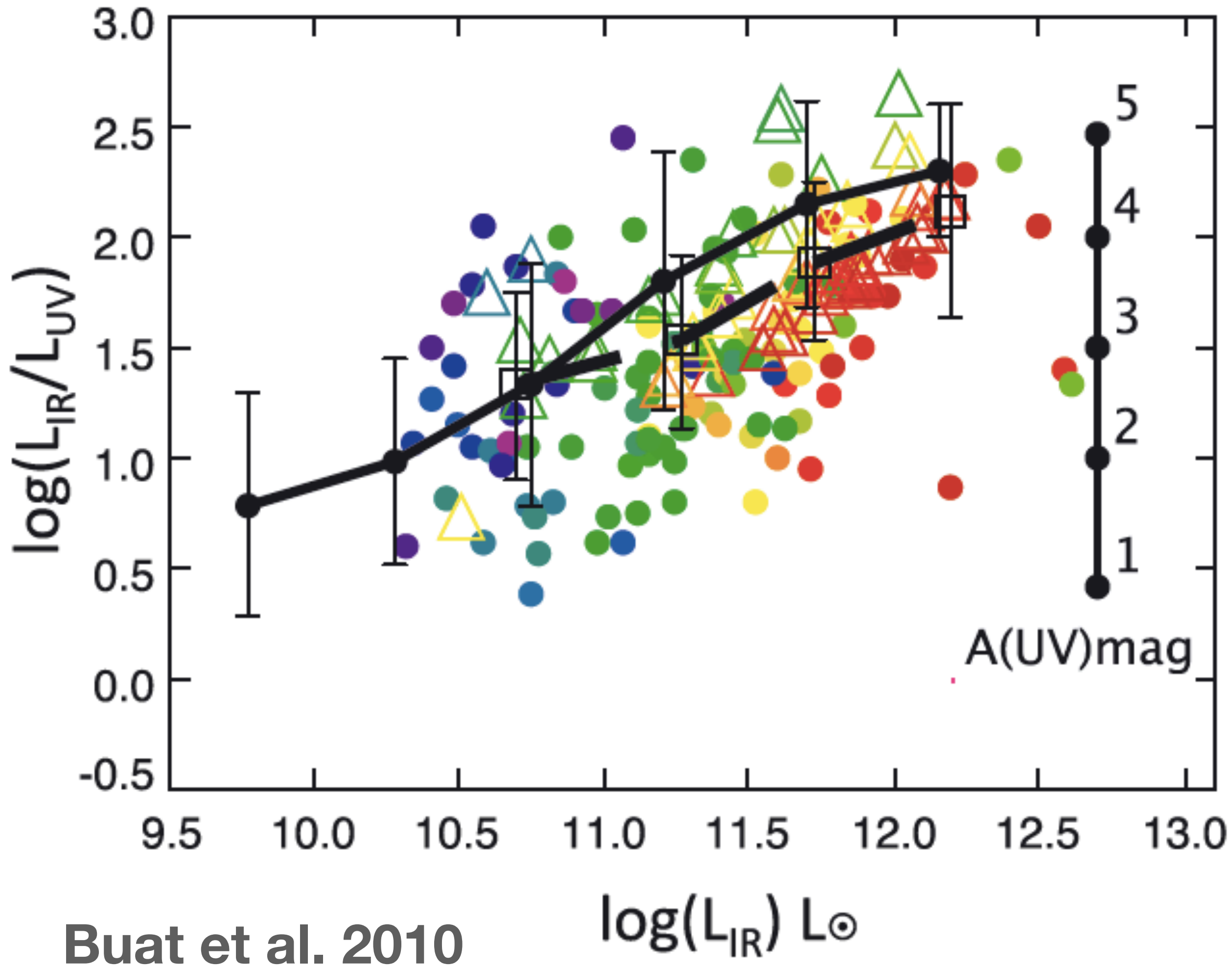
Dust



Buat et al. 2010

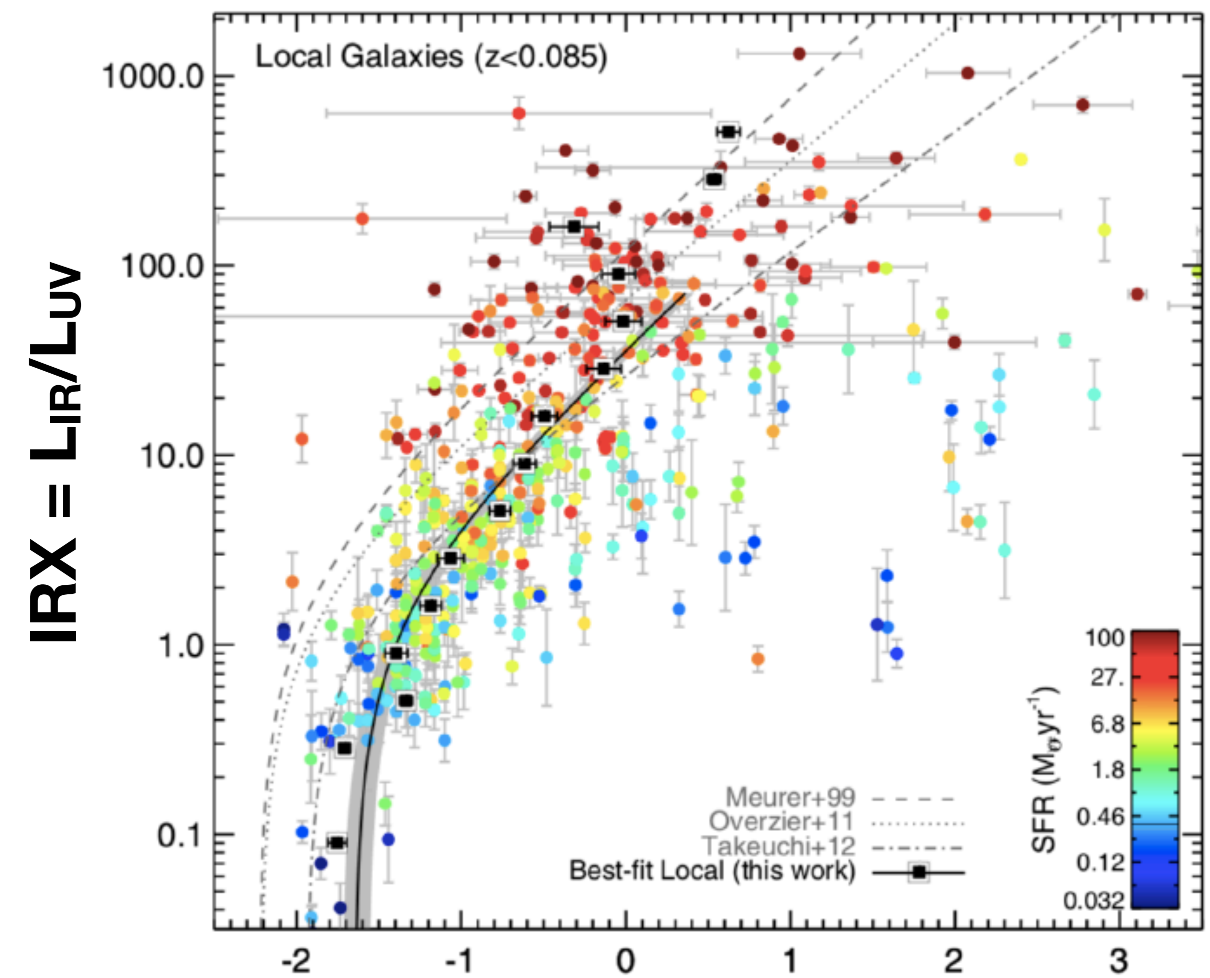
Dust

dust extinction from L_{IR}/L_{UV}



Buat et al. 2010

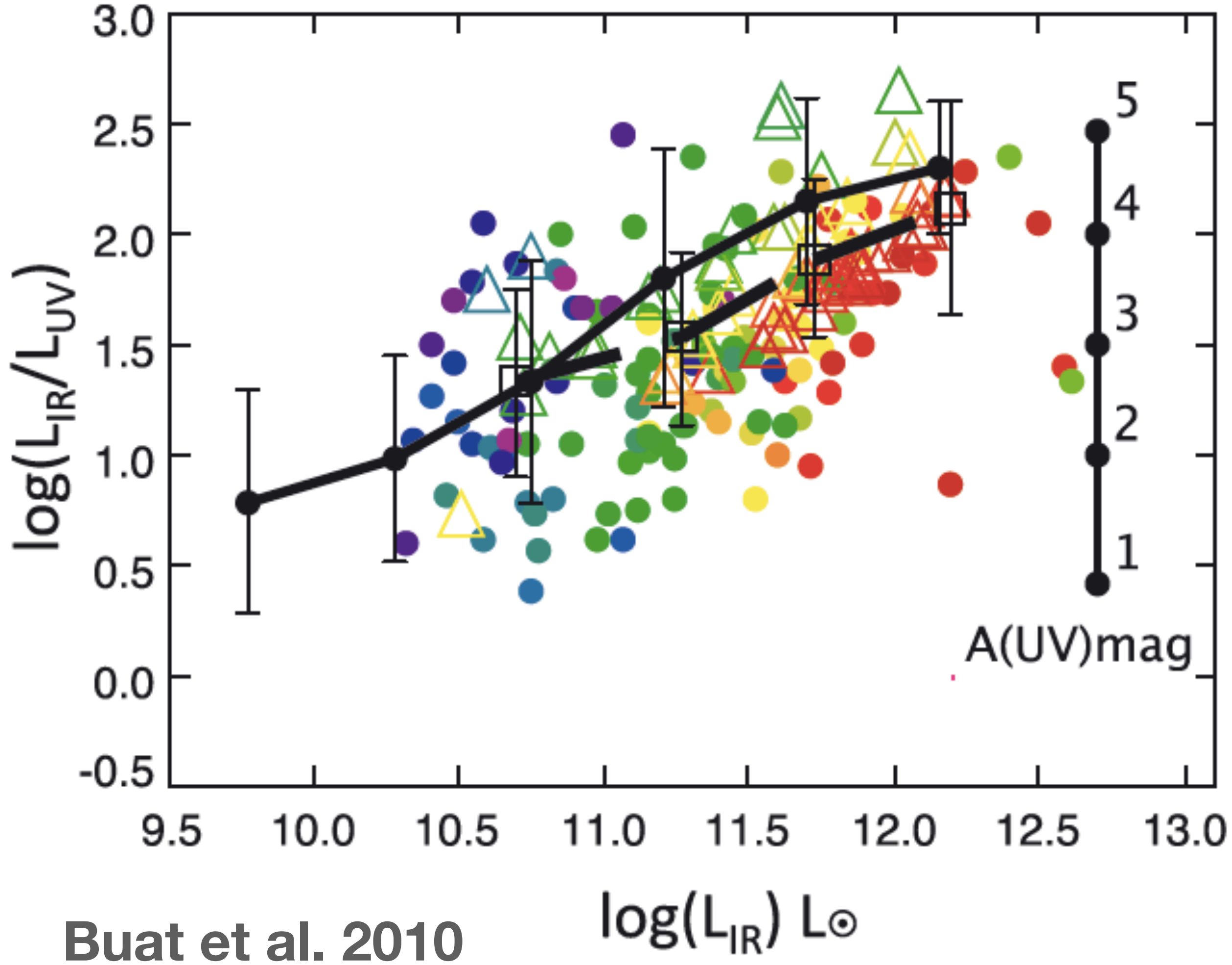
dust extinction from UV slope



Casey et al. 2014 **UV slope β**

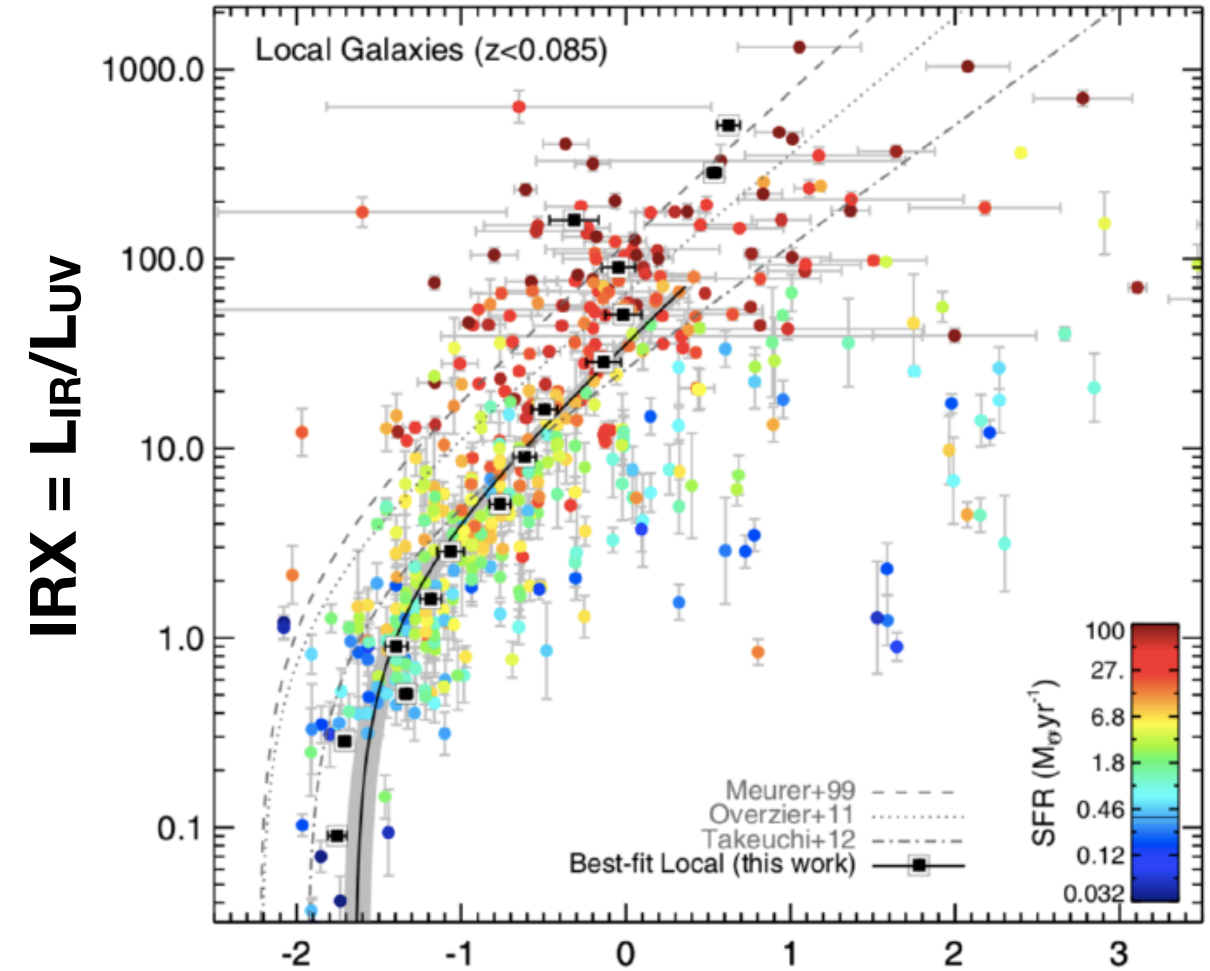
Dust

dust extinction from L_{IR}/L_{UV}



Buat et al. 2010

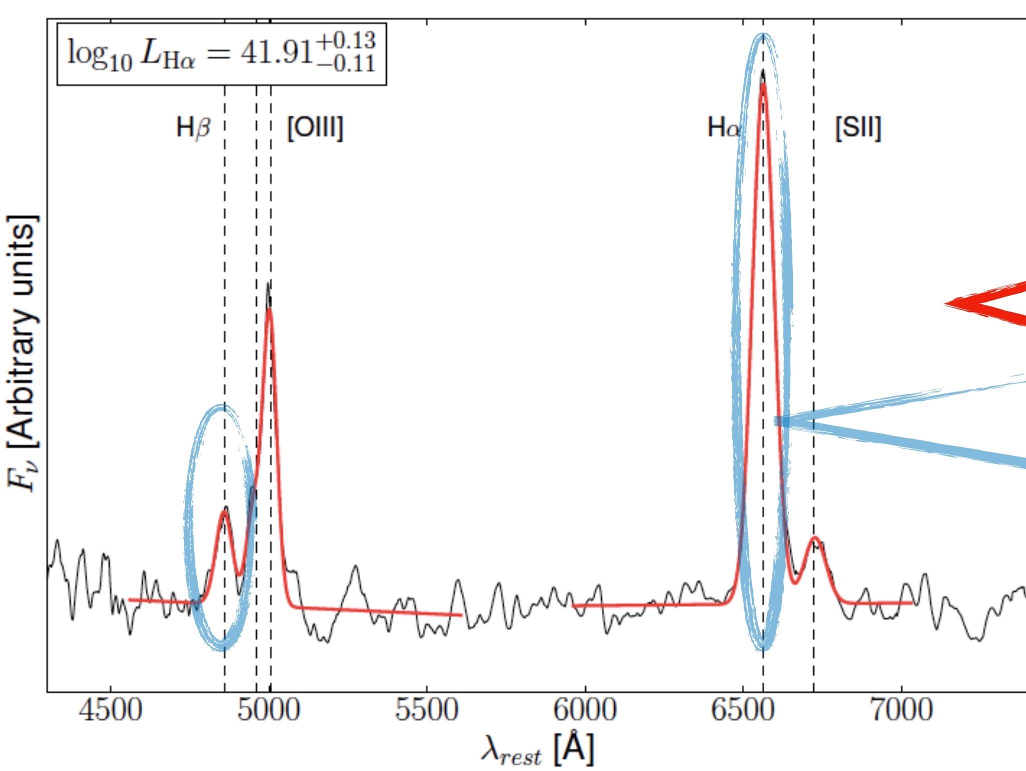
dust extinction from UV slope



Casey et al. 2014

UV slope β

dust extinction from Balmer decrement

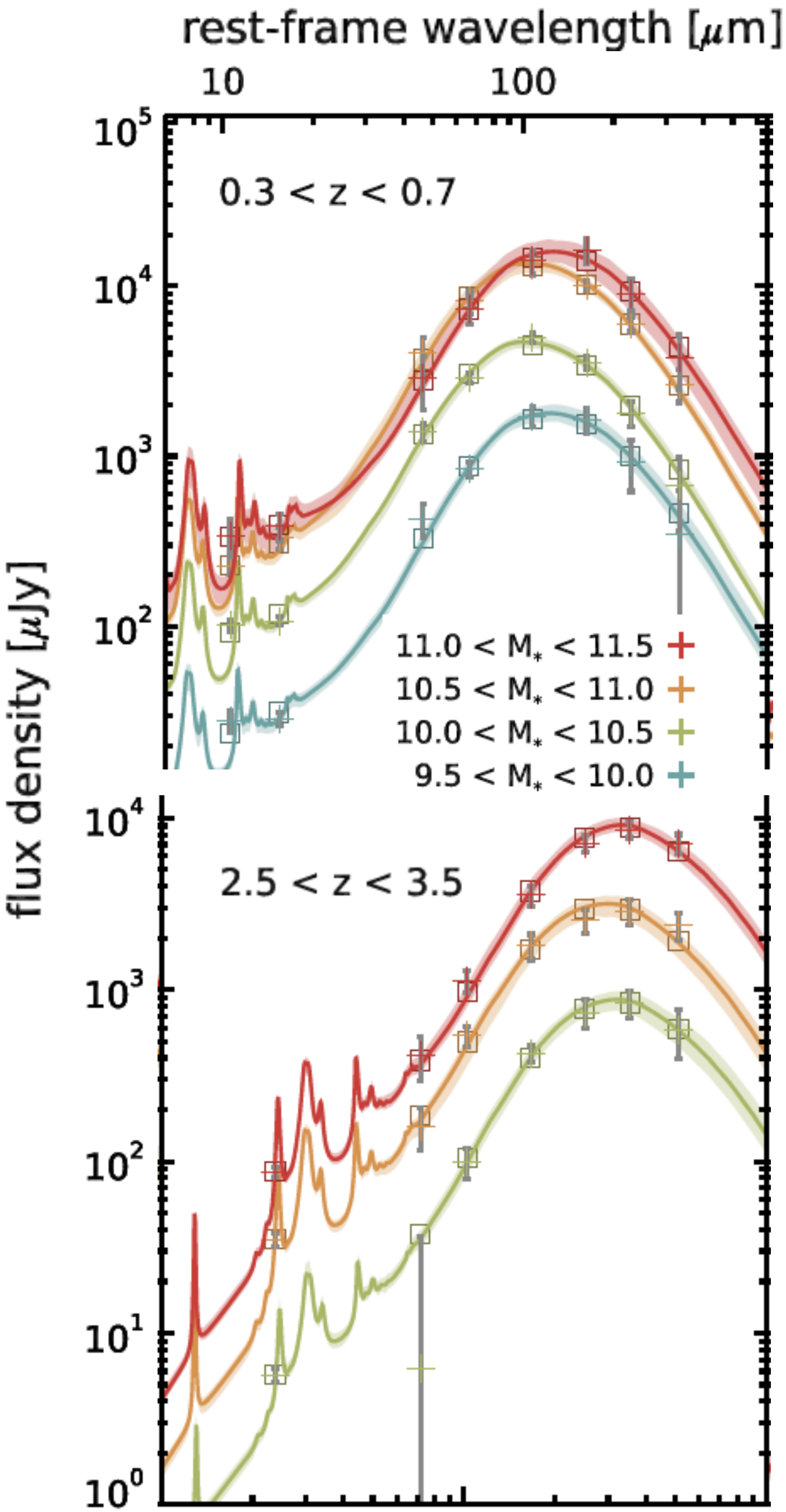


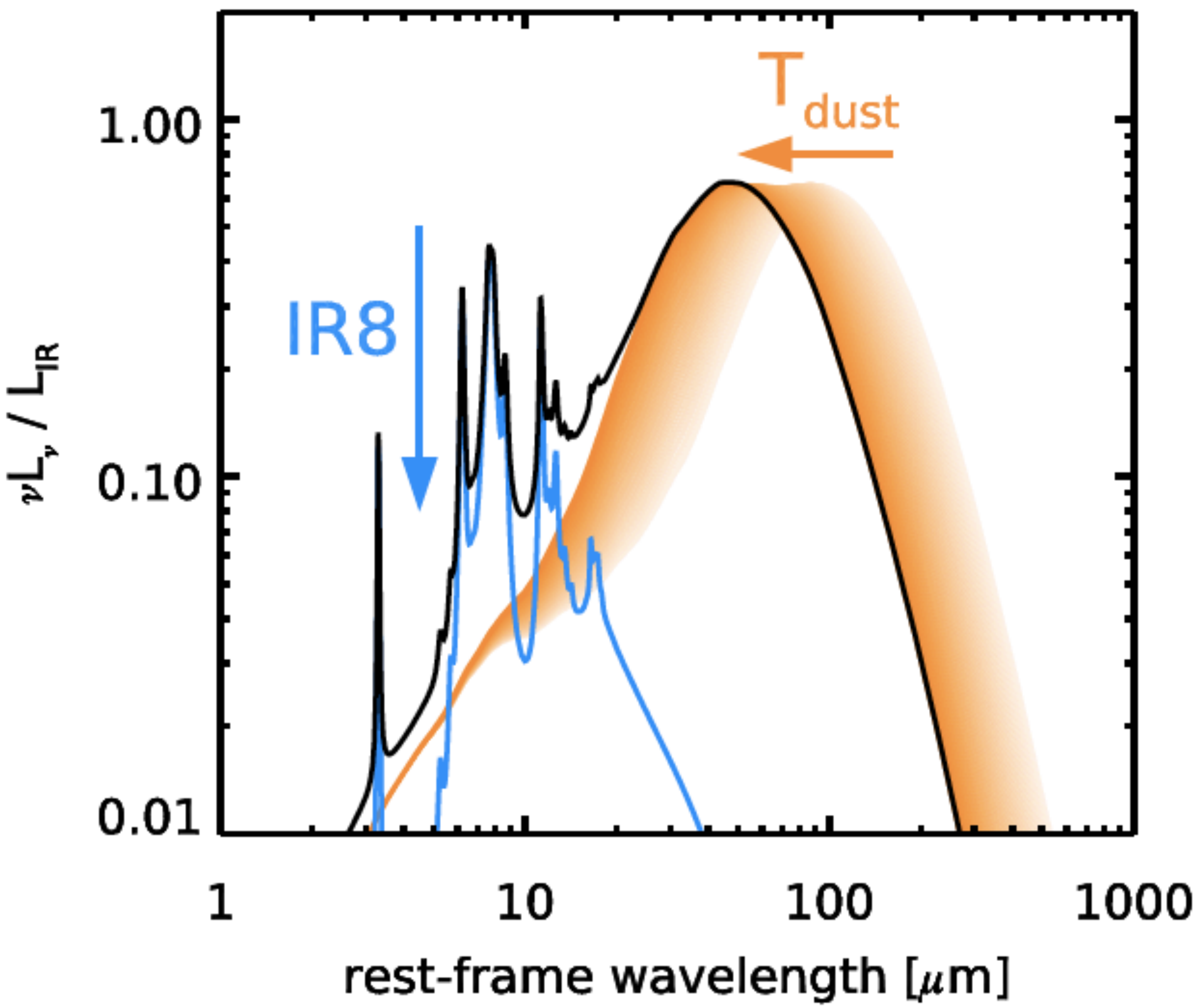
Balmer decrements are the flux ratios of the emission components of Balmer lines relative to Hβ: $D_{34}=F(H_\alpha)/F(H_\beta)$, $D_{54}=F(H_\gamma)/F(H_\beta)$, …

$F(H_\alpha)/F(H_\beta)$ is known theoretically (with some assumptions). Dust extinction affects the two lines differently (different wavelengths) ⇒ comparison of observed vs. theoretical value constrains dust extinction

Dust

modeling of the IR SED also constraints dust content and properties (mass, temperature)

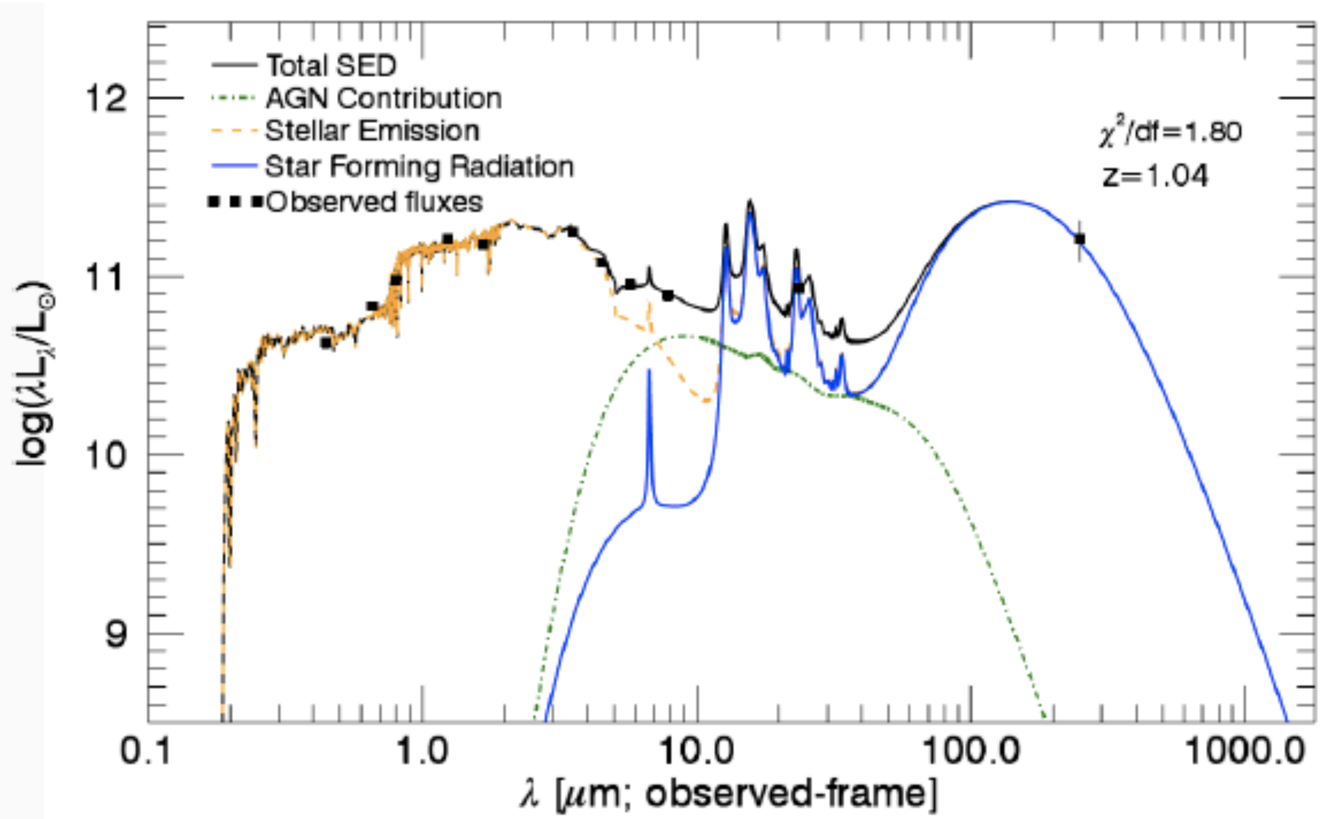


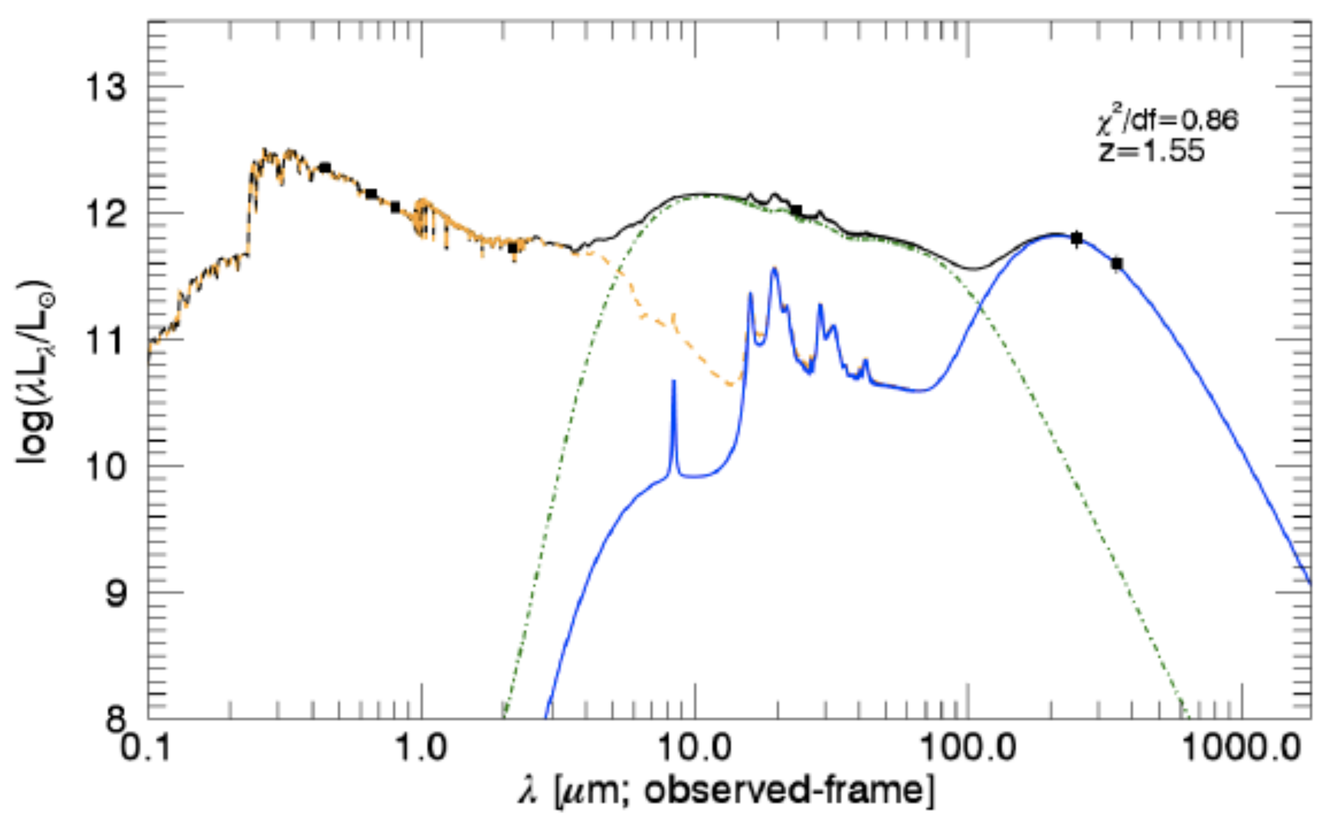


Schreiber et al. 2018

AGN

SED modeling can be used to estimate AGN flux contribution (at the same time constraining the AGN contamination to the SFR estimate)

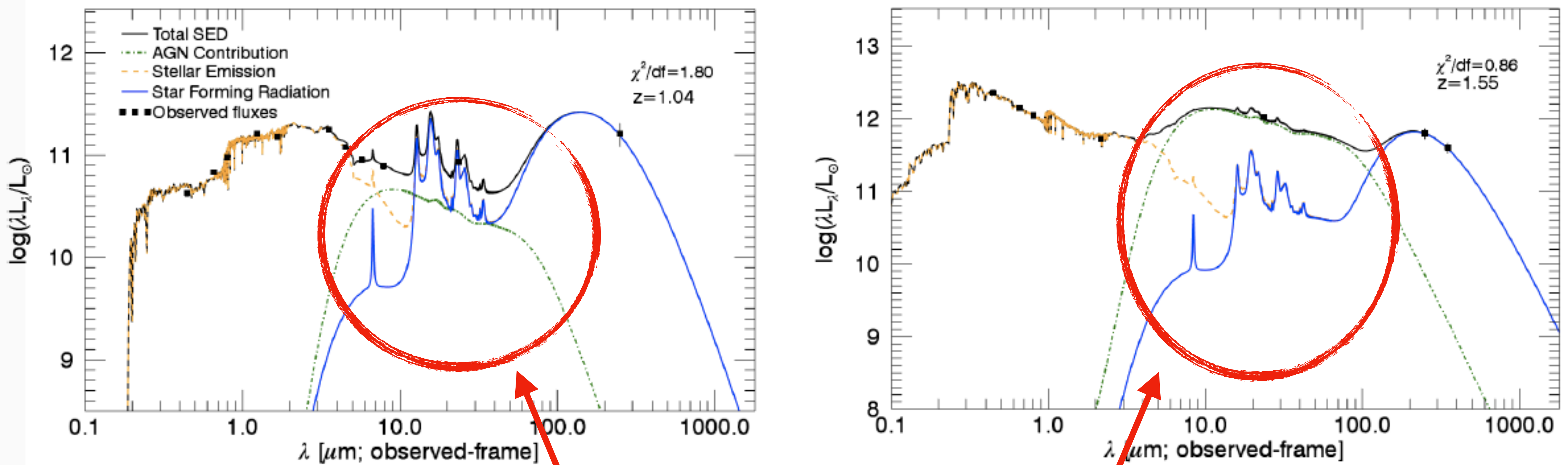




Brown et al. 2019

AGN

2-color selection at NIR/mid-IR wavelengths has also been used for AGN selection



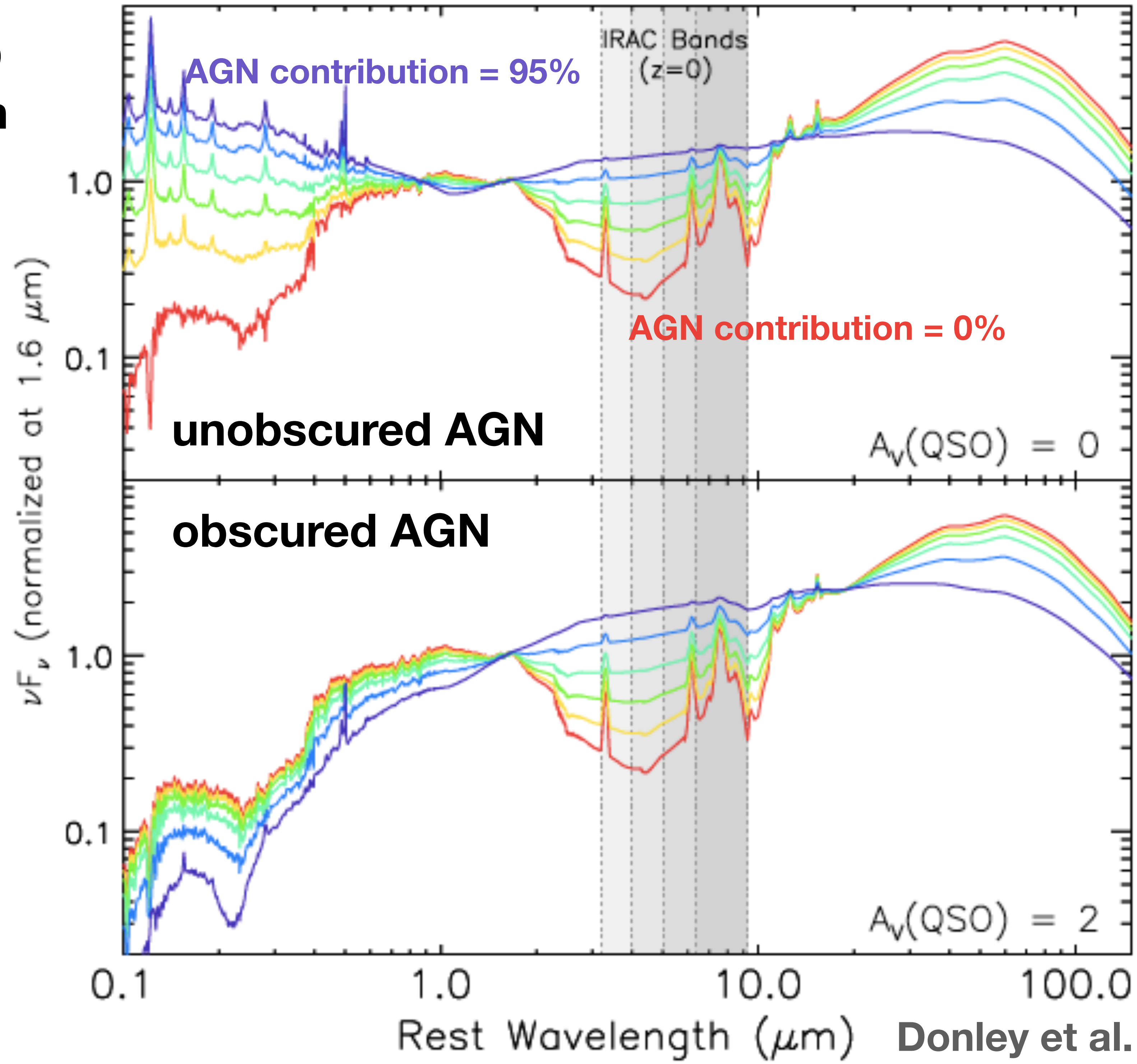
Brown et al. 2019

AGN fills in the dip between stellar emission and dust emission

AGN

2-color selection at NIR/mid-IR wavelengths has also been used for AGN selection

combination of SF + AGN SED with variable AGN contribution (from 0% to 95%) at 1-10 μm



Donley et al. 2012

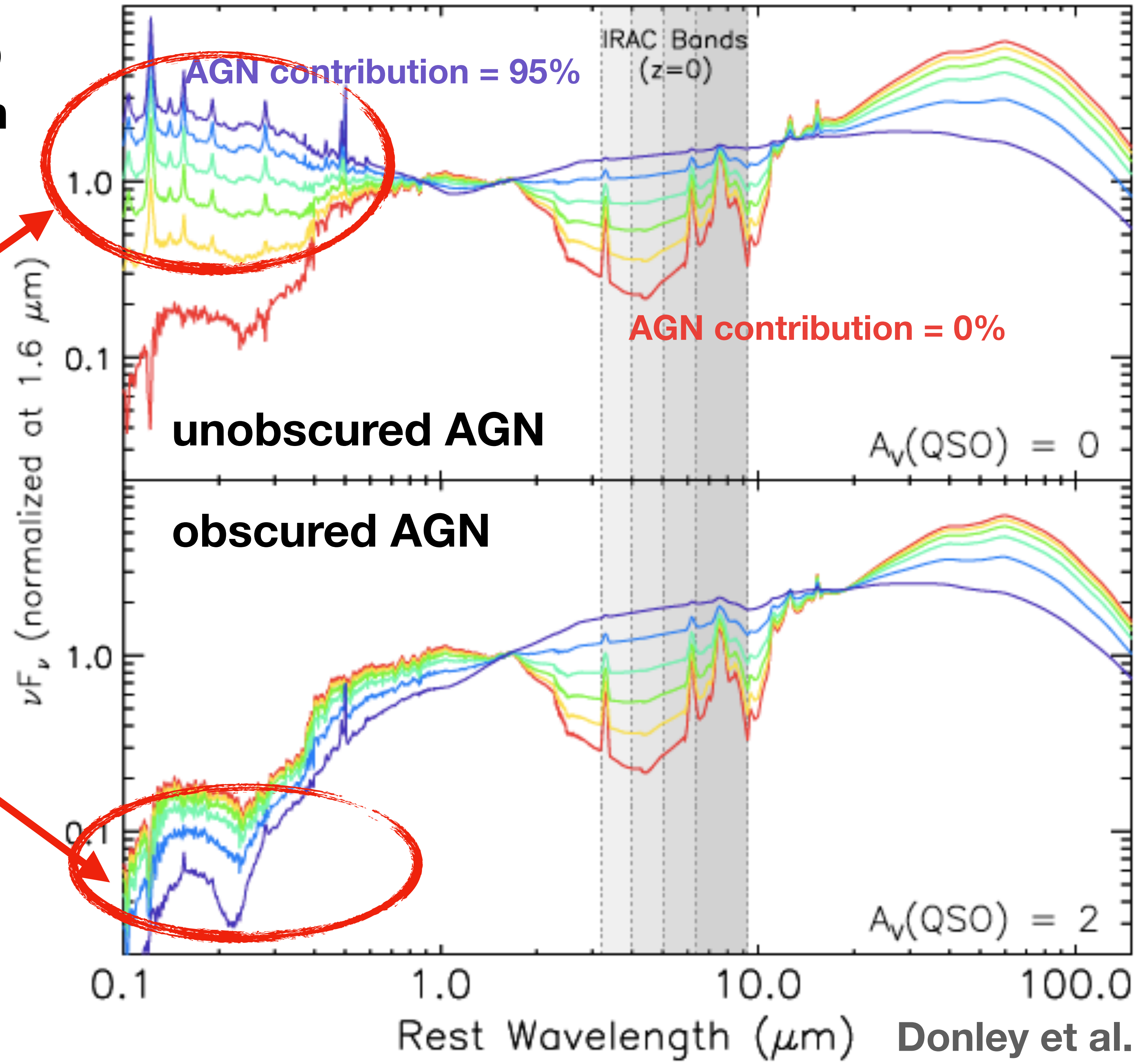
AGN fills in the dip between stellar emission and dust emission

AGN

2-color selection at NIR/mid-IR wavelengths has also been used for AGN selection

combination of SF + AGN SED with variable AGN contribution (from 0% to 95%) at 1-10 μm

luminous obscured and unobscured AGNs have very different SEDs here



Donley et al. 2012

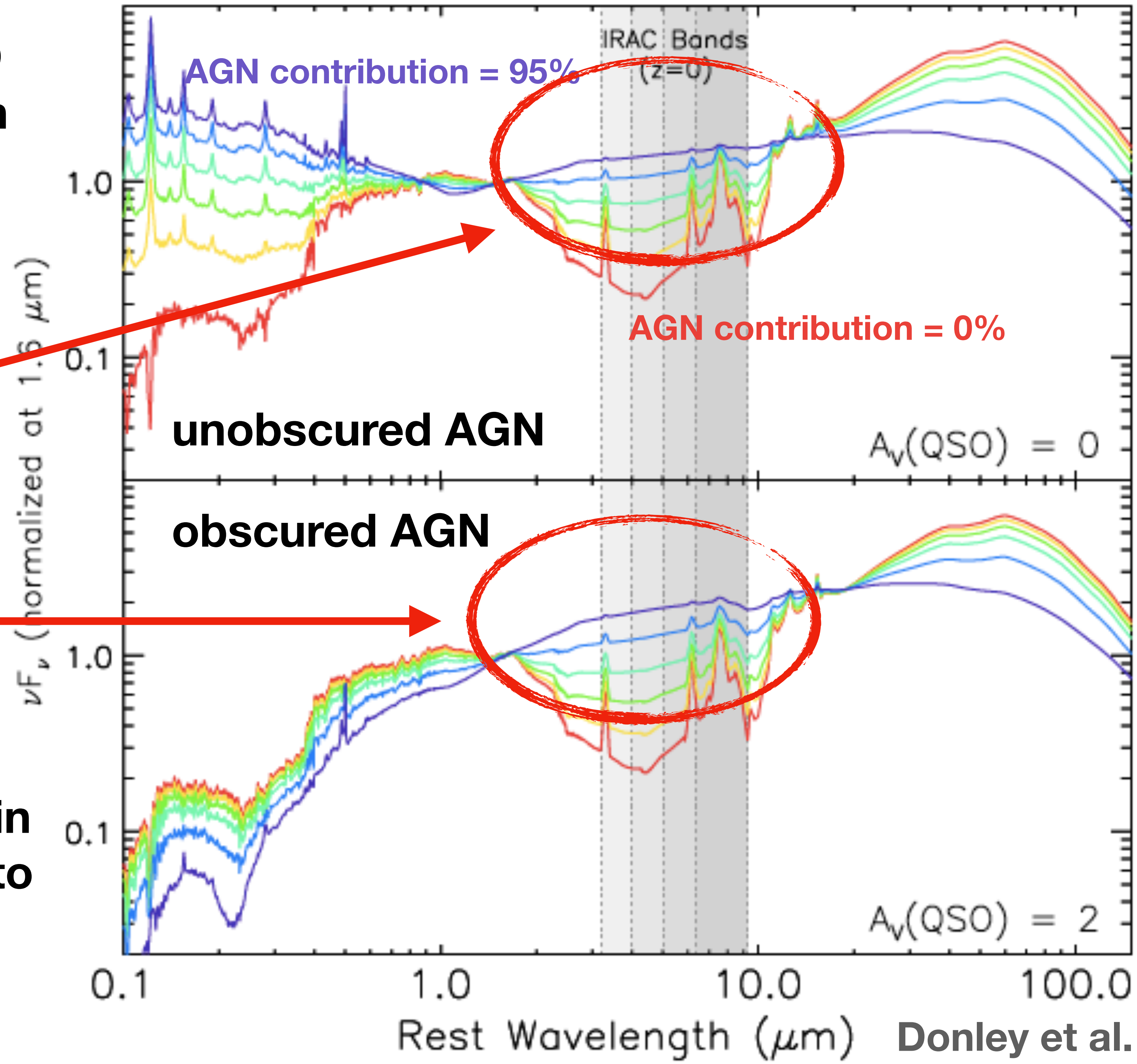
AGN

2-color selection at NIR/mid-IR wavelengths has also been used for AGN selection

combination of SF + AGN SED with variable AGN contribution (from 0% to 95%) at 1-10 μm

but similar power-law behaviour here

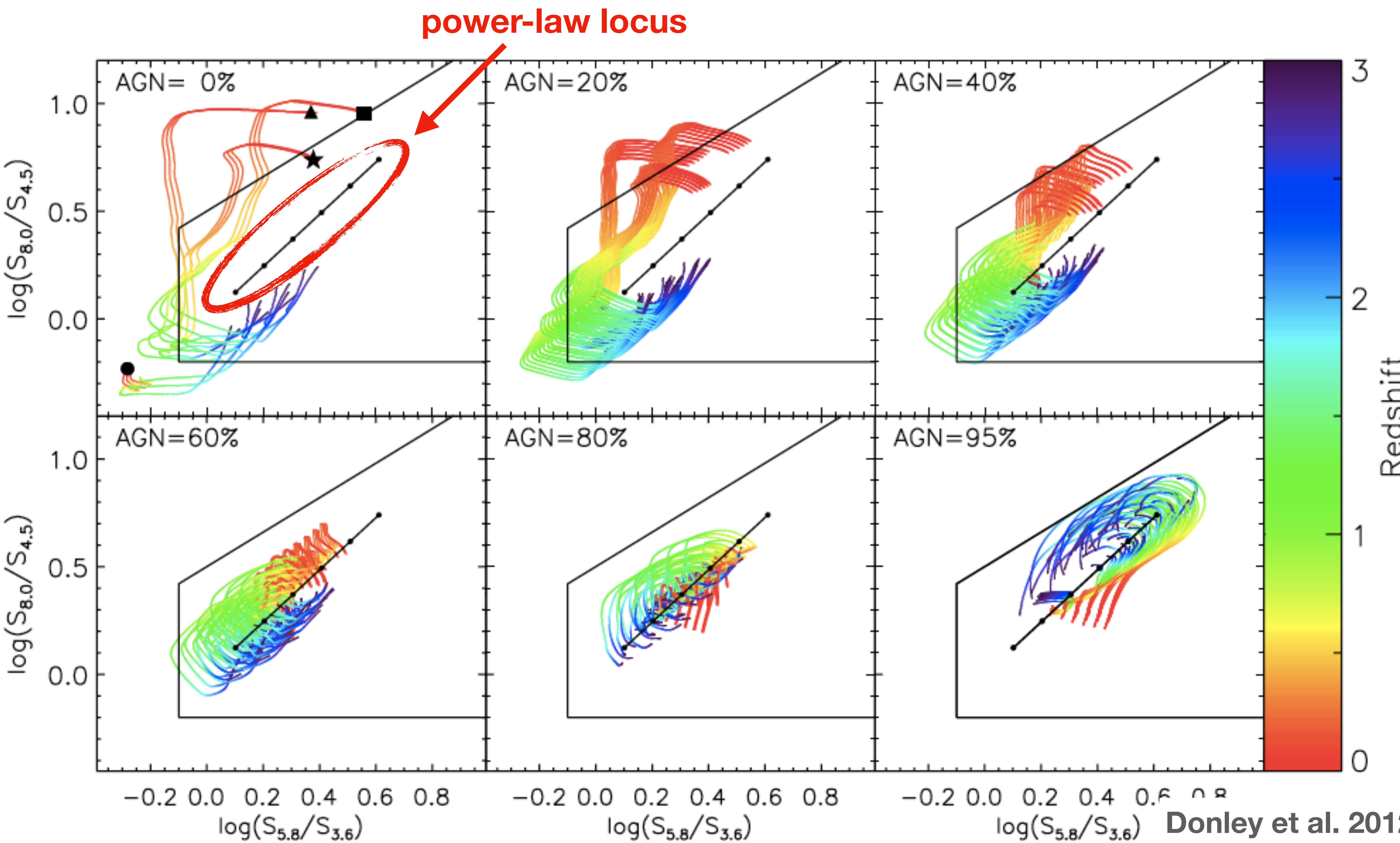
various color selection criteria in the 3-10 μm range exploit this to select mid-IR luminous AGNs



Donley et al. 2012

AGN

2-color selection at NIR/mid-IR wavelengths has also been used for AGN selection



Donley et al. 2012

AGN

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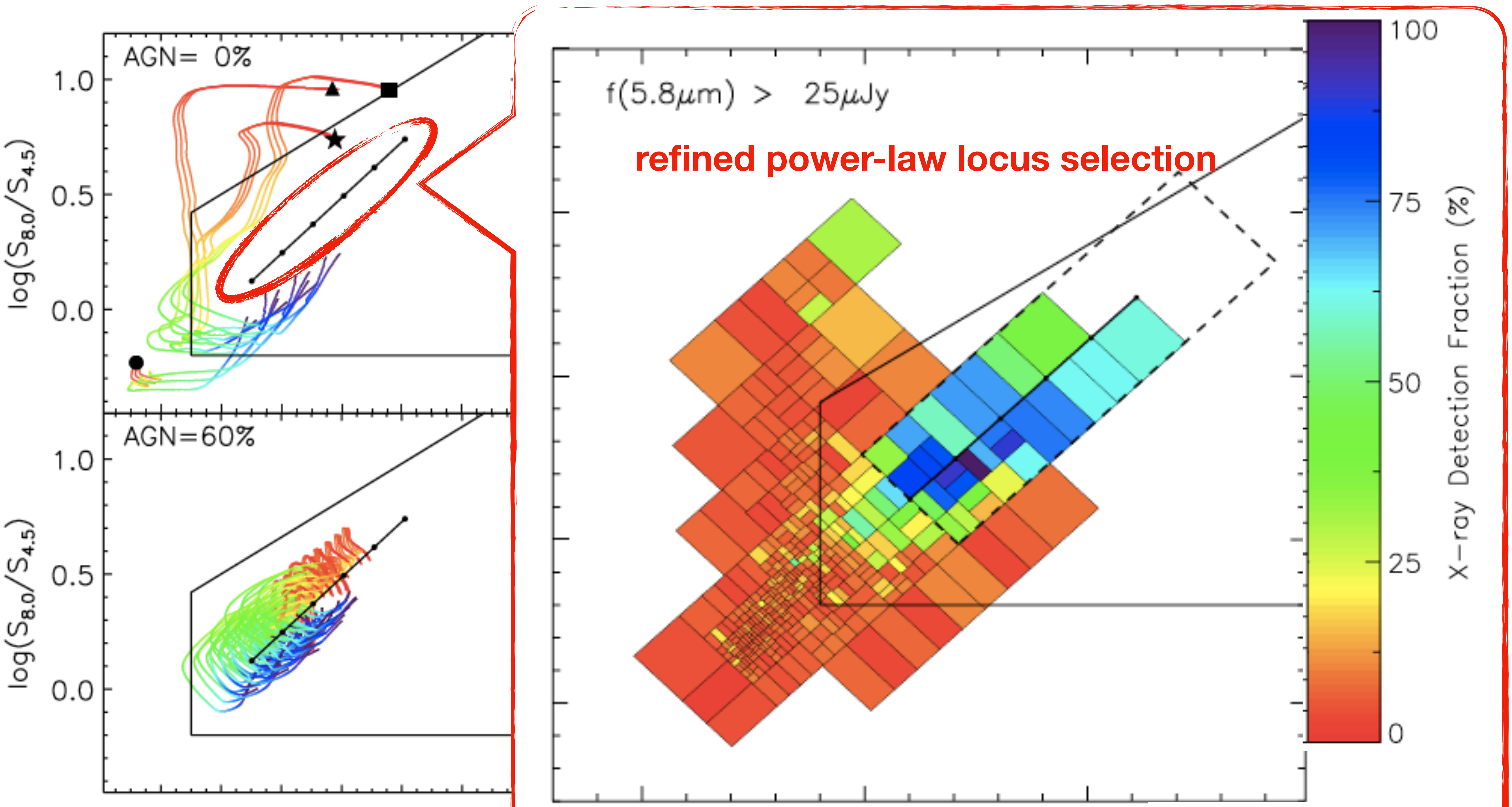
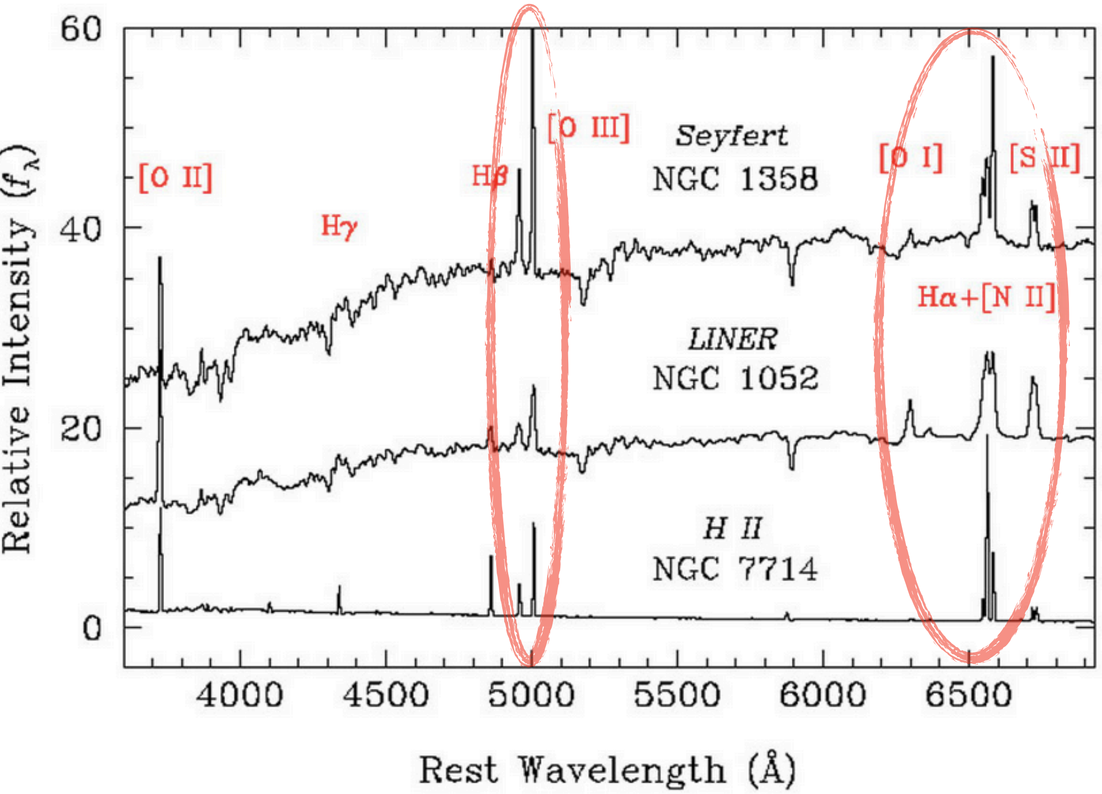


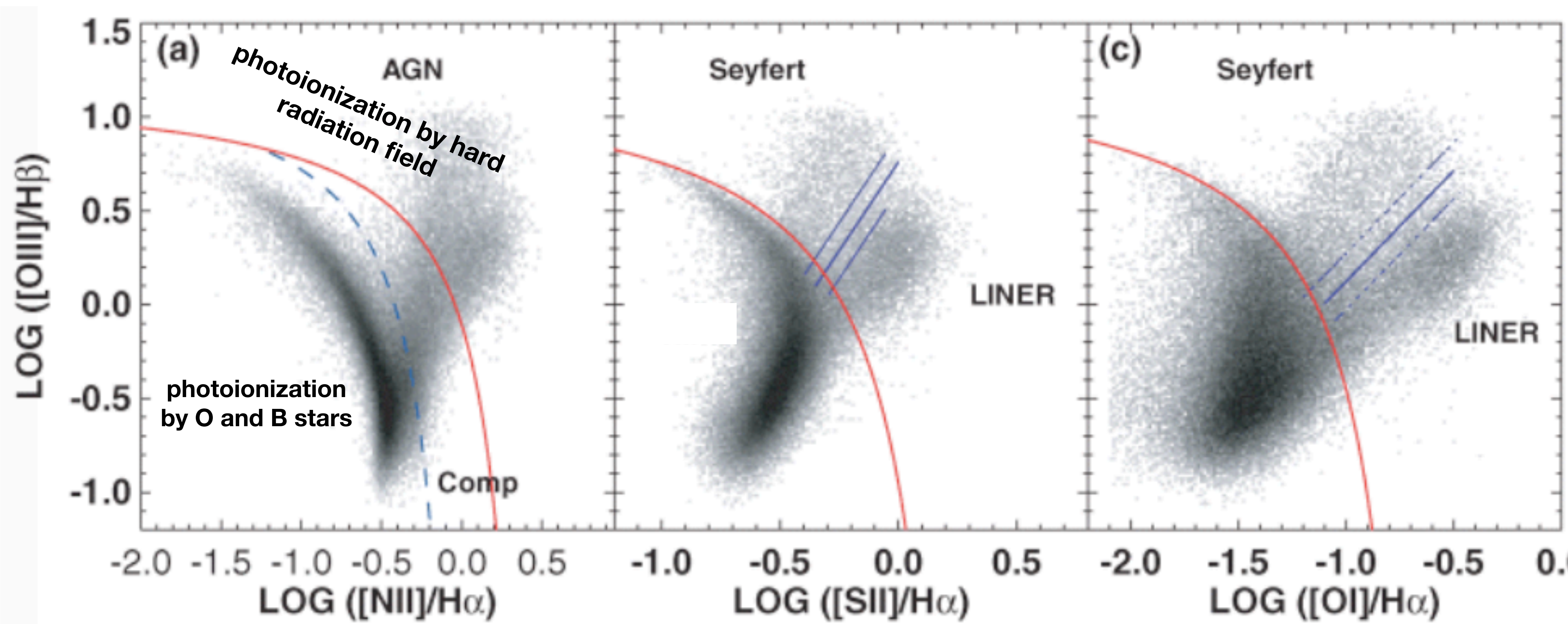
Donley et al. 2012

AGN



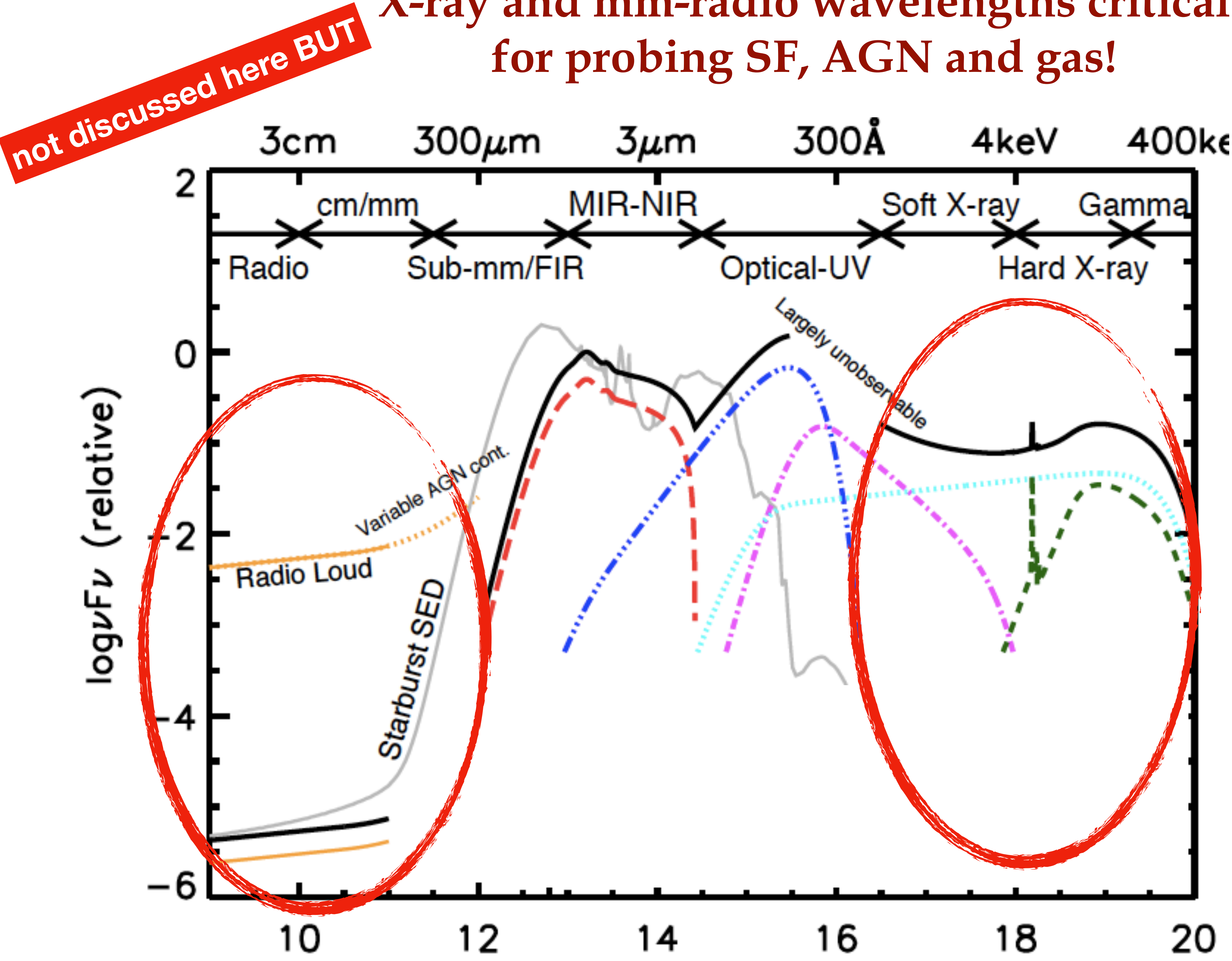
AGN identification by line intensity ratios:
BPT (Baldwin, Philips & Terlevich, 1981) diagram(s)

specific line combinations sensitive to ionization level of the gas, hardness (~mean photon energy) of radiation field, ...

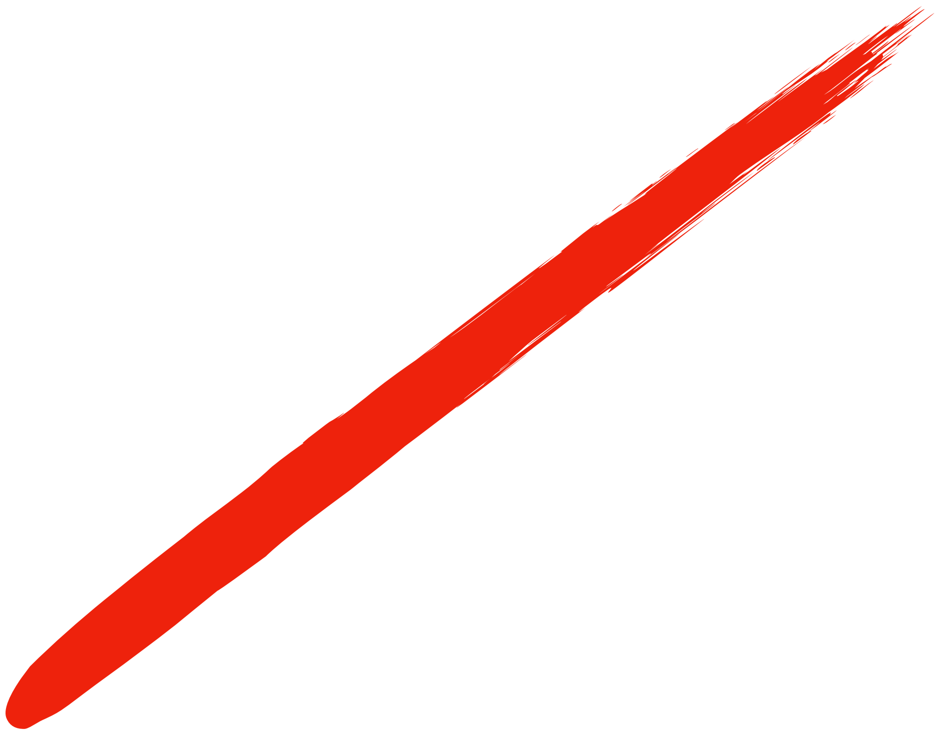


Kewley et al. 2012

X-ray and mm-radio wavelengths critical for probing SF, AGN and gas!



Hickox & Alexander 2018



Mass- and light-weighted ages

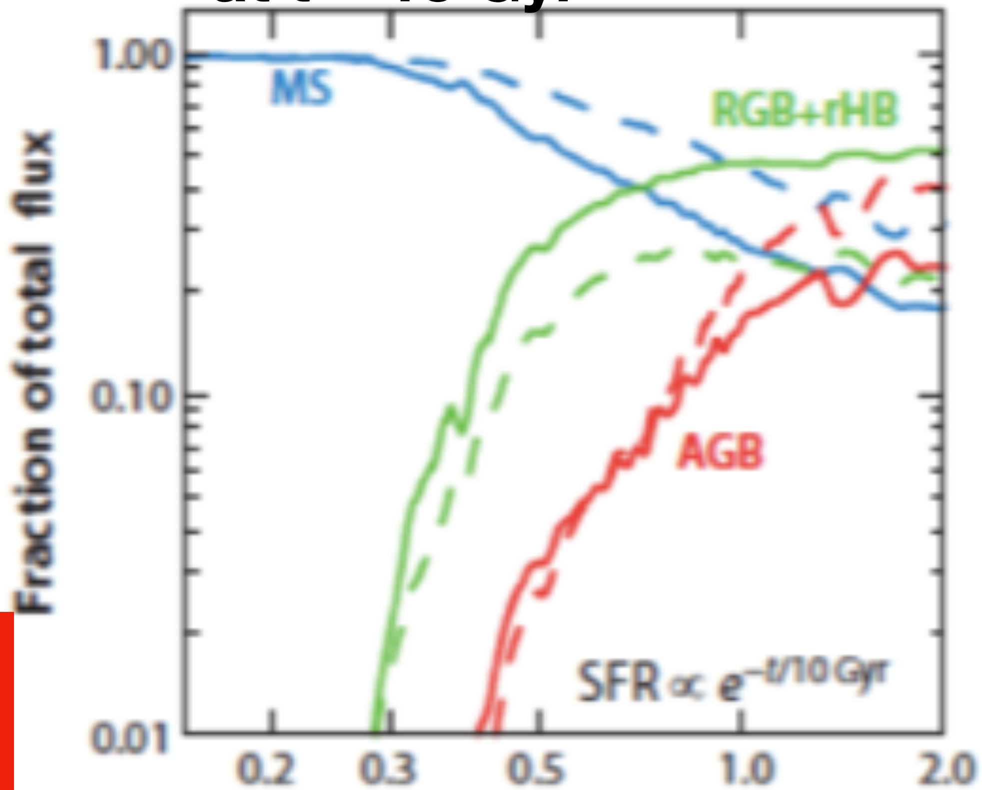
Furthermore ...

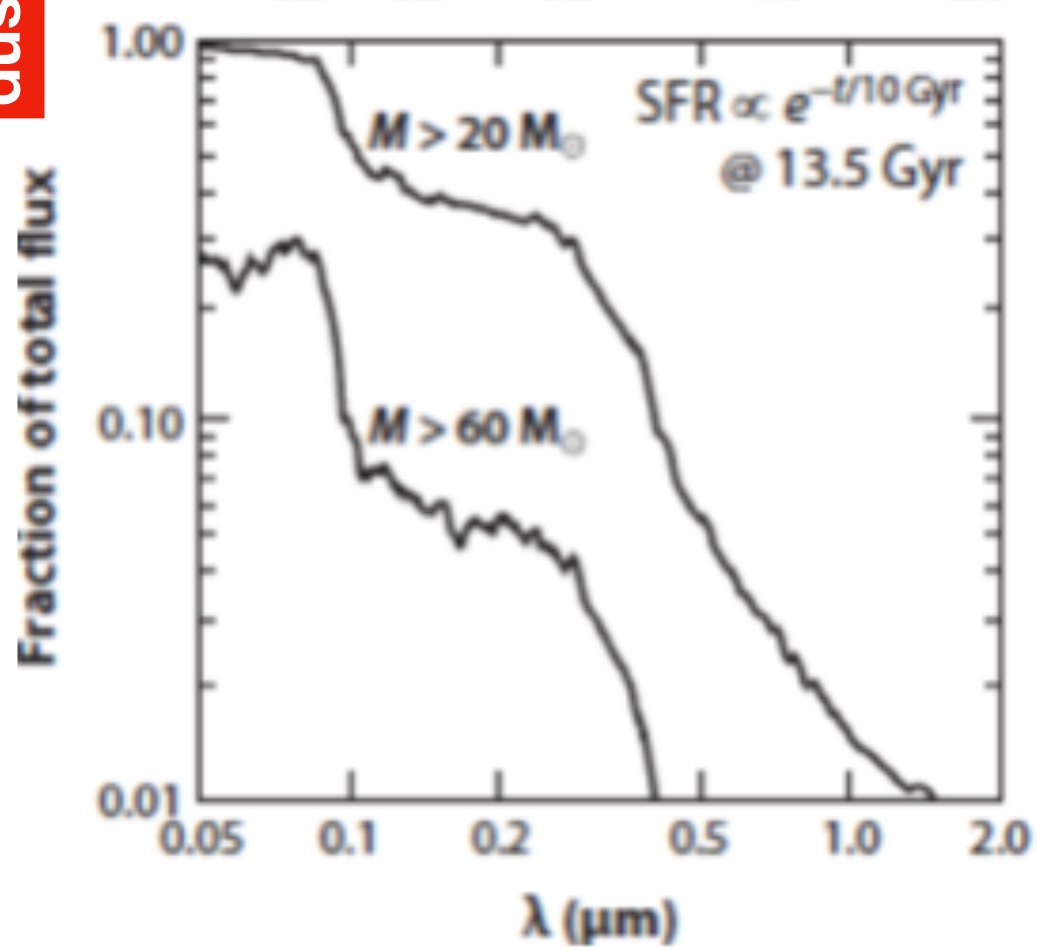
——— at t = 1 Gyr

- - - - - at t = 13 Gyr

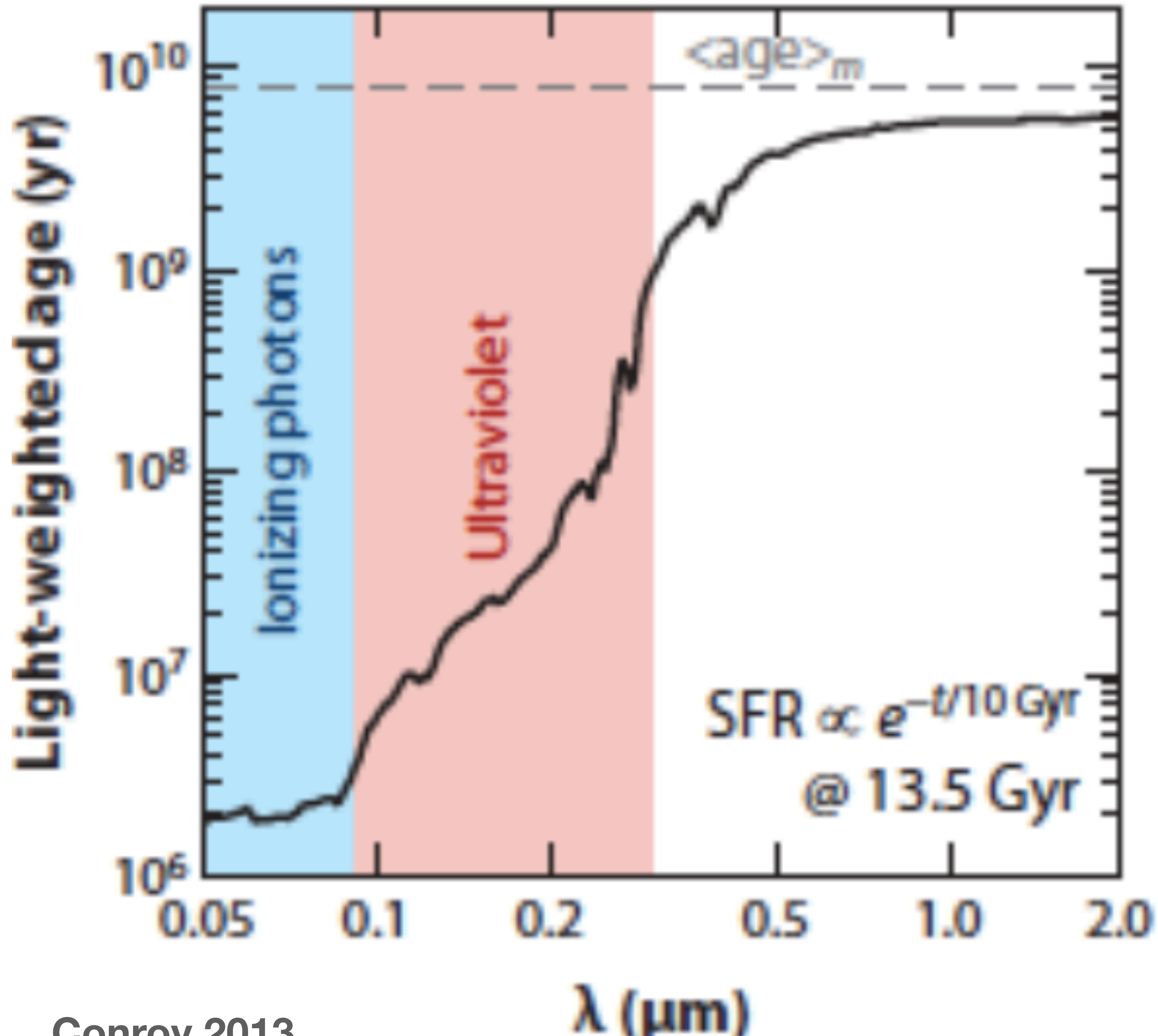
$SFR(t) \propto e^{-t/10\,Gyr}$

dust free



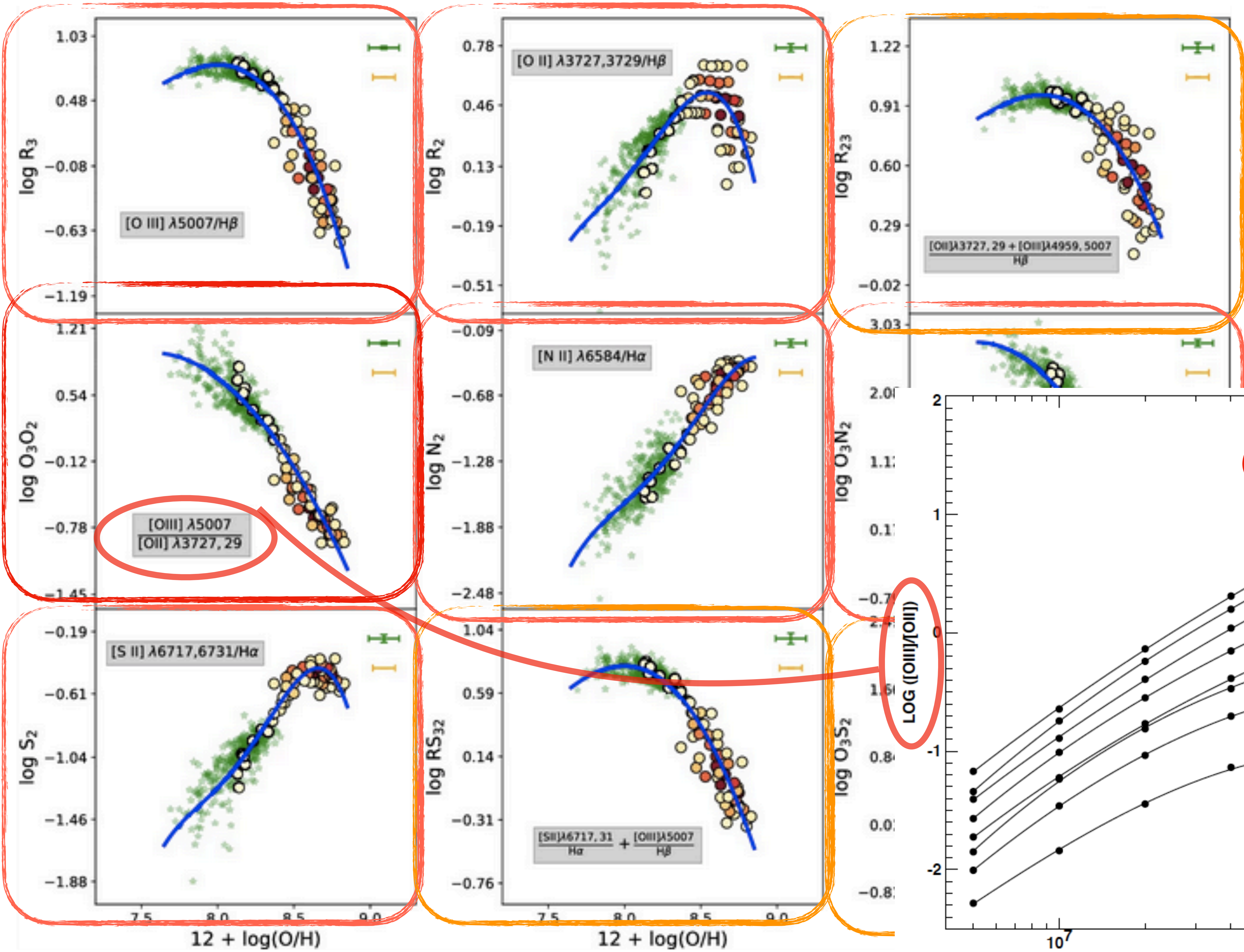


light- vs. mass-weighted age as a function of wavelength at 13.5 Gyr



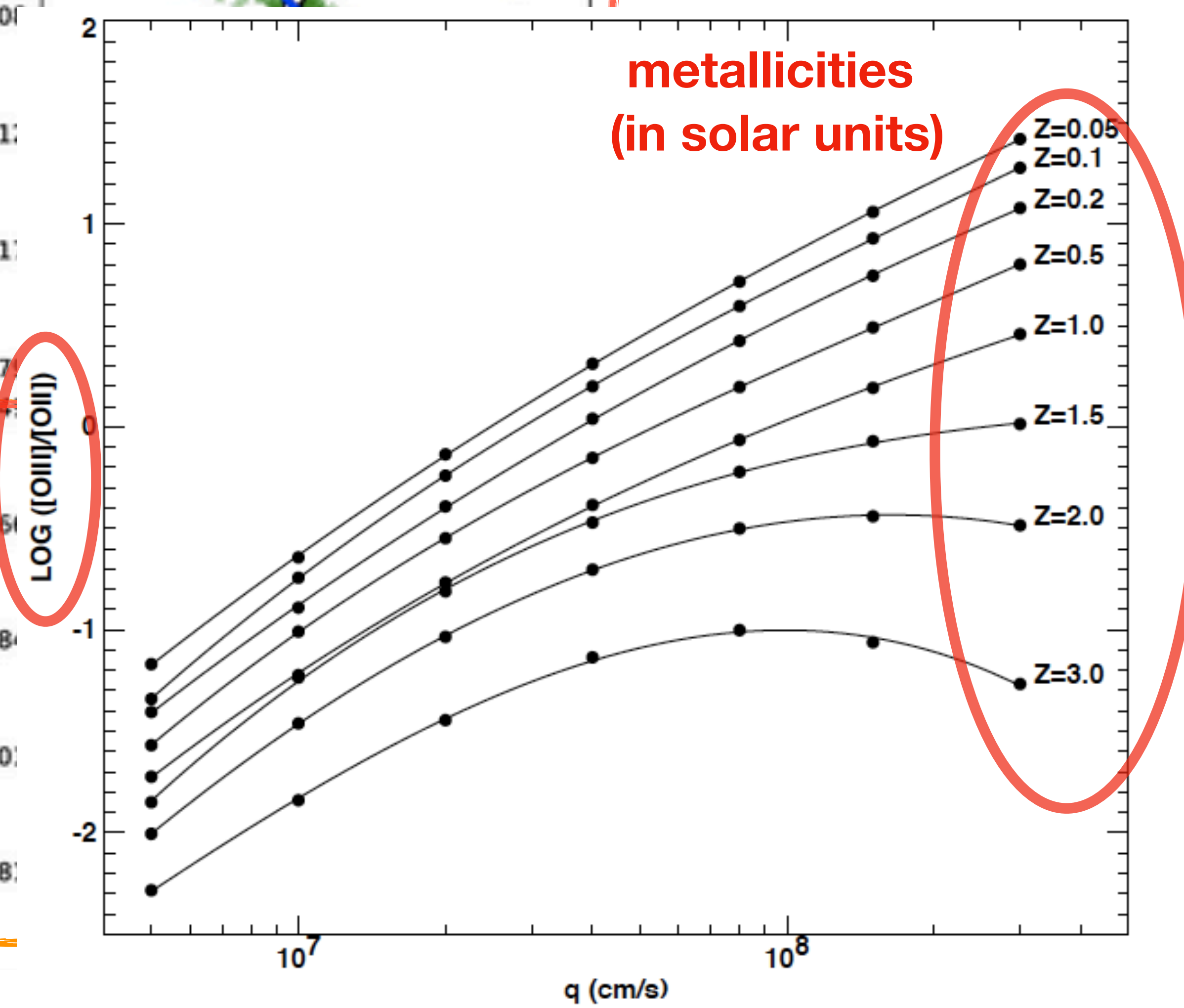
Conroy 2013

Gas metallicity

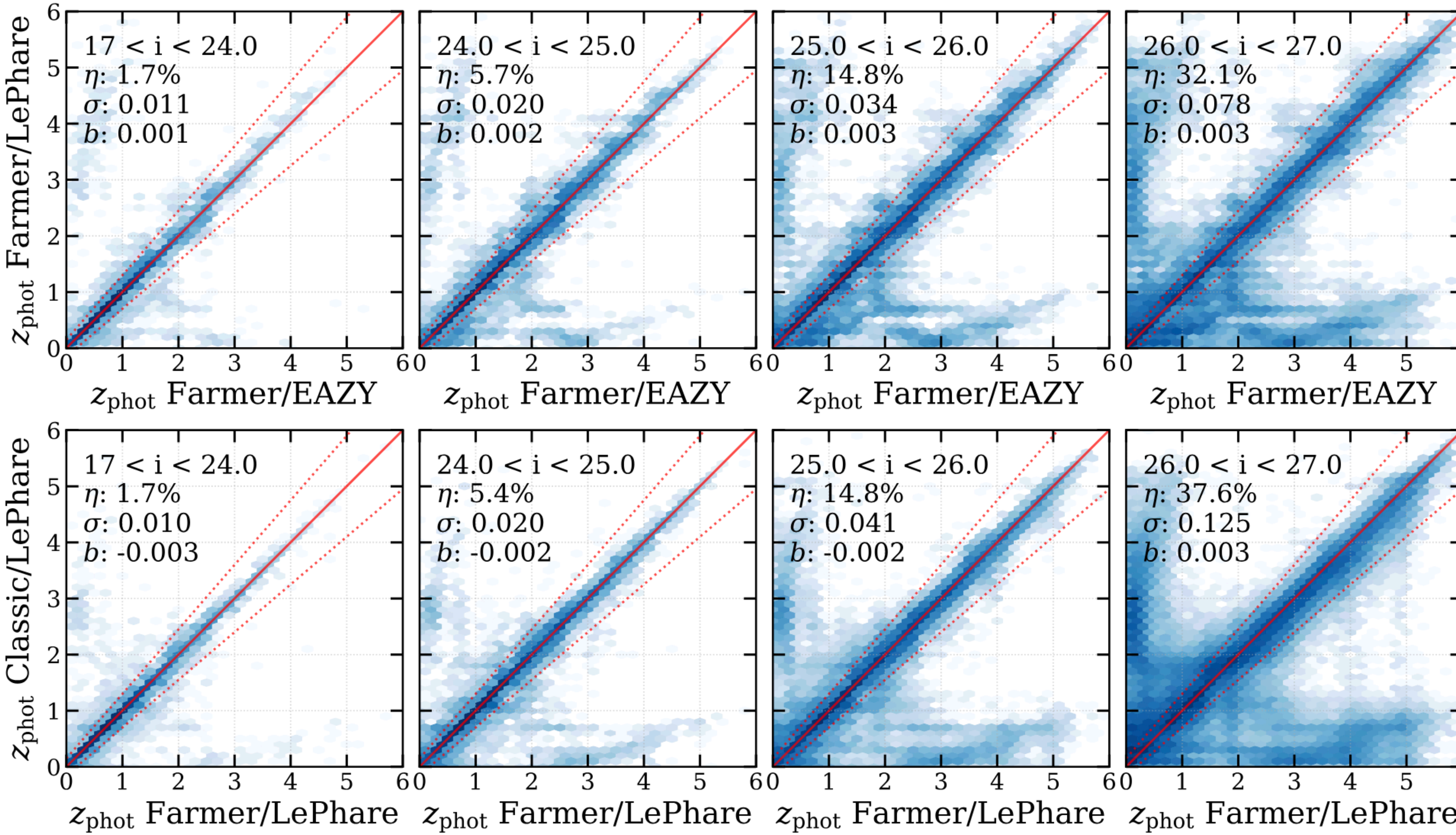


BUT…

- double valued
- secondary/strong dependence on ionization parameter



Maiolino & Mannucci 2019


17 < i < 24.0
η: 1.7%
σ: 0.011
b: 0.001
24.0 < i < 25.0
η: 5.7%
σ: 0.020
b: 0.002
25.0 < i < 26.0
η: 14.8%
σ: 0.034
b: 0.003
26.0 < i < 27.0
η: 32.1%
σ: 0.078
b: 0.003
z_phot Farmer/LePhare
z_phot Farmer/EAZY
17 < i < 24.0
η: 1.7%
σ: 0.010
b: -0.003
24.0 < i < 25.0
η: 5.4%
σ: 0.020
b: -0.002
25.0 < i < 26.0
η: 14.8%
σ: 0.041
b: -0.002
26.0 < i < 27.0
η: 37.6%
σ: 0.125
b: 0.003
z_phot Classic/LePhare
z_phot Farmer/LePhare