Dust Extinction in Star-forming Galaxies at $0.75<z<1.5$ from HST/WFC3 Spectroscopy

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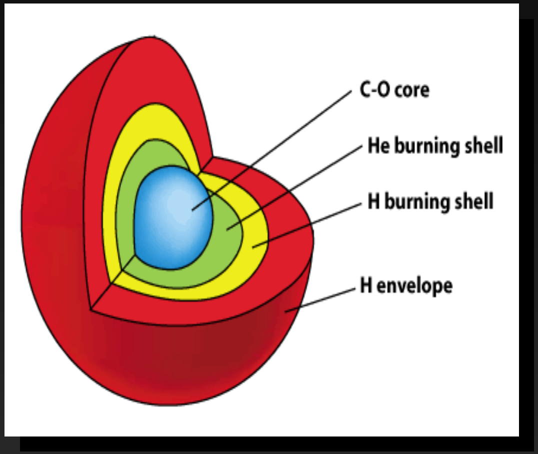
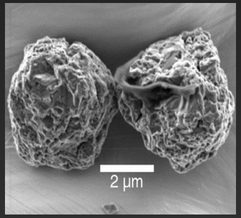
What is and where is dust produced?

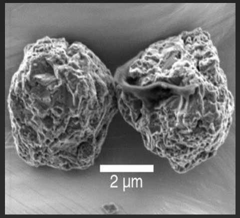
ISM

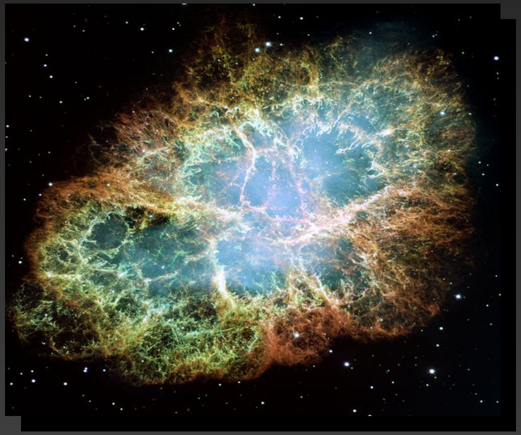
Asymptotic-giant-branch stars

ISM







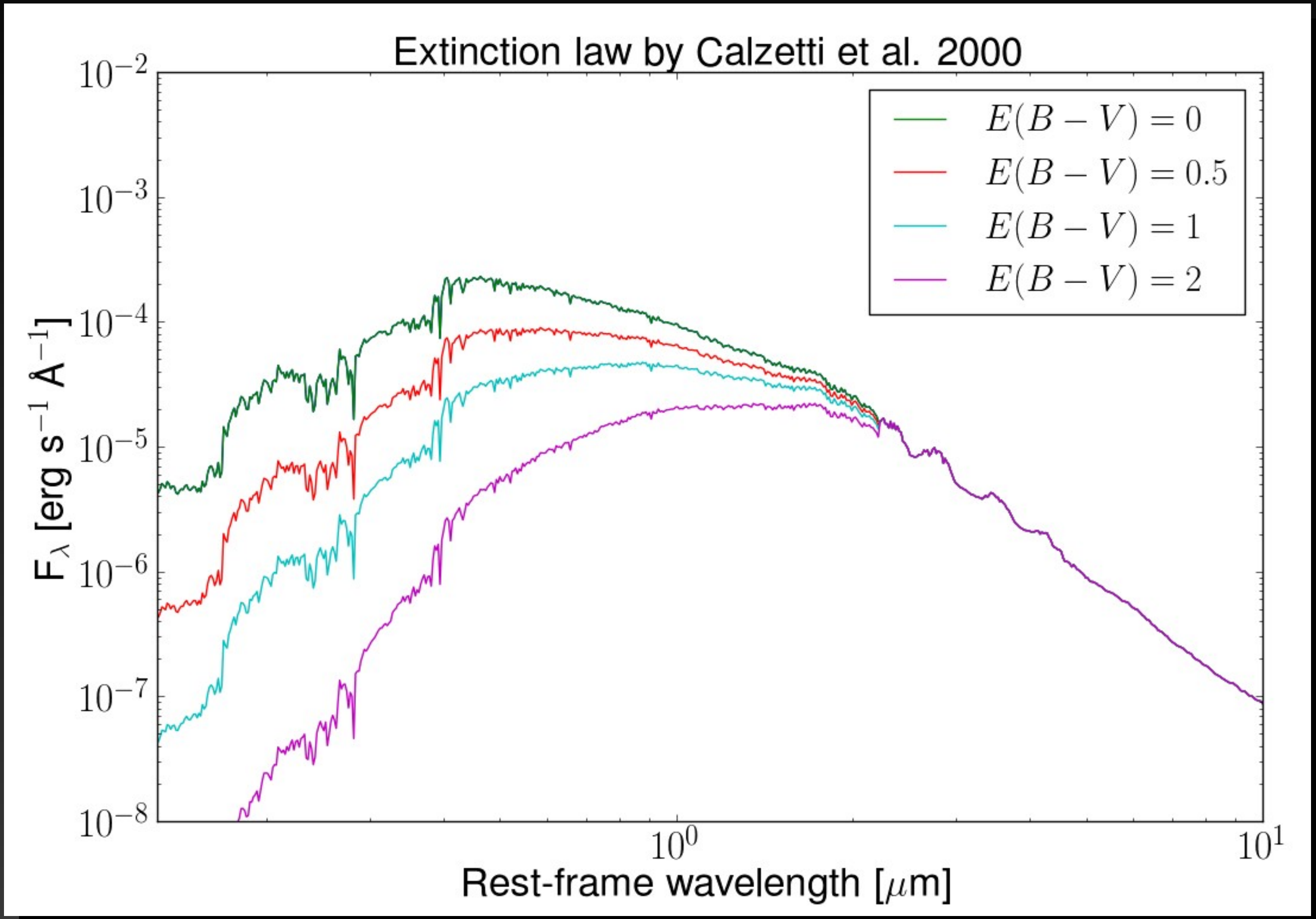


Supernovae

ISM

ISM

Effects of the interstellar dust

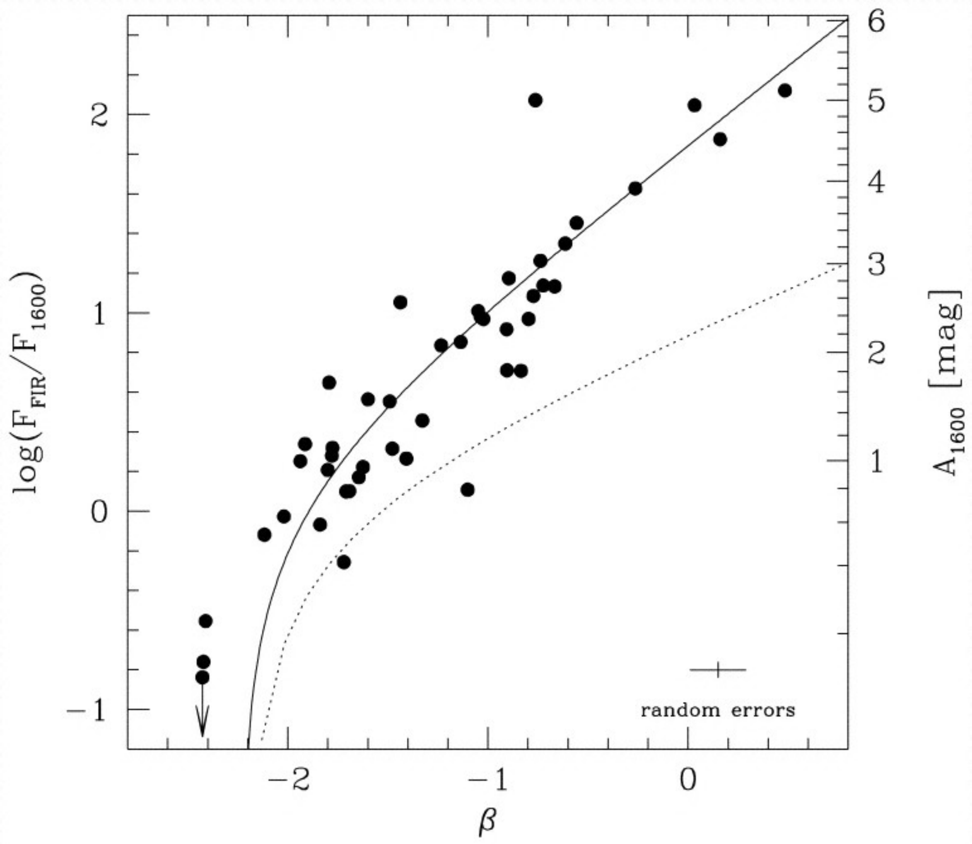


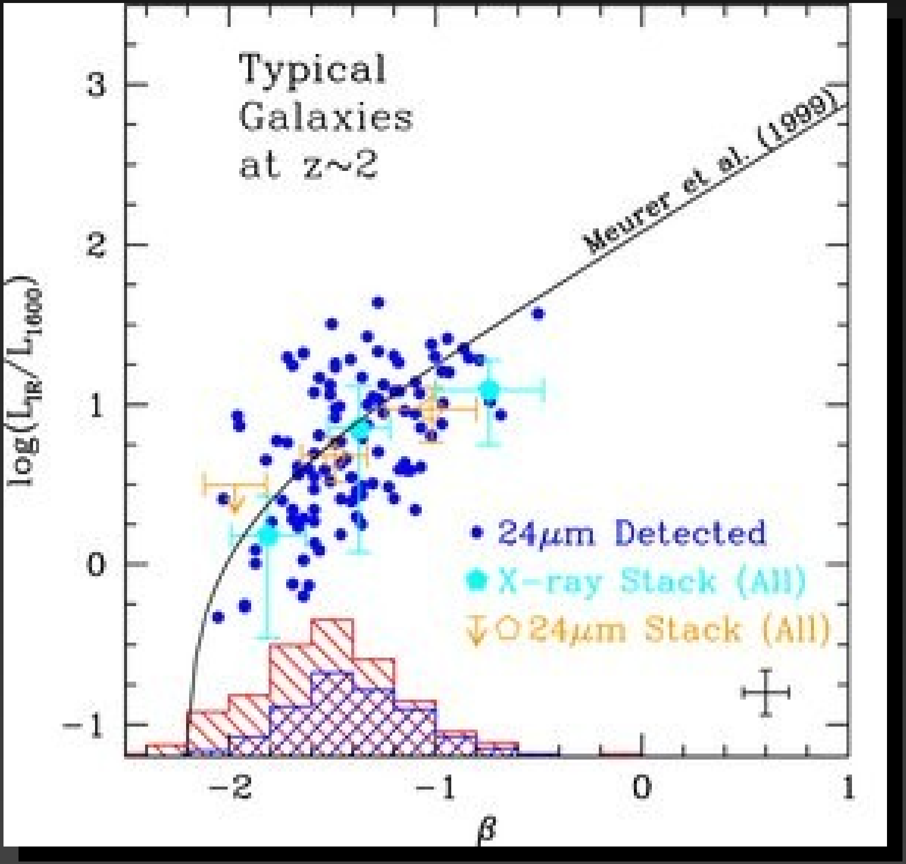
Dimming

Reddening

Methodologies for studying dust extinction

UV slopes and infrared observations that probes stellar-continuum extinction (e. g. Meurer et al. 1999; Reddy et al. 2010; Bouwens et al. 2011)





Methodologies for studying dust extinction

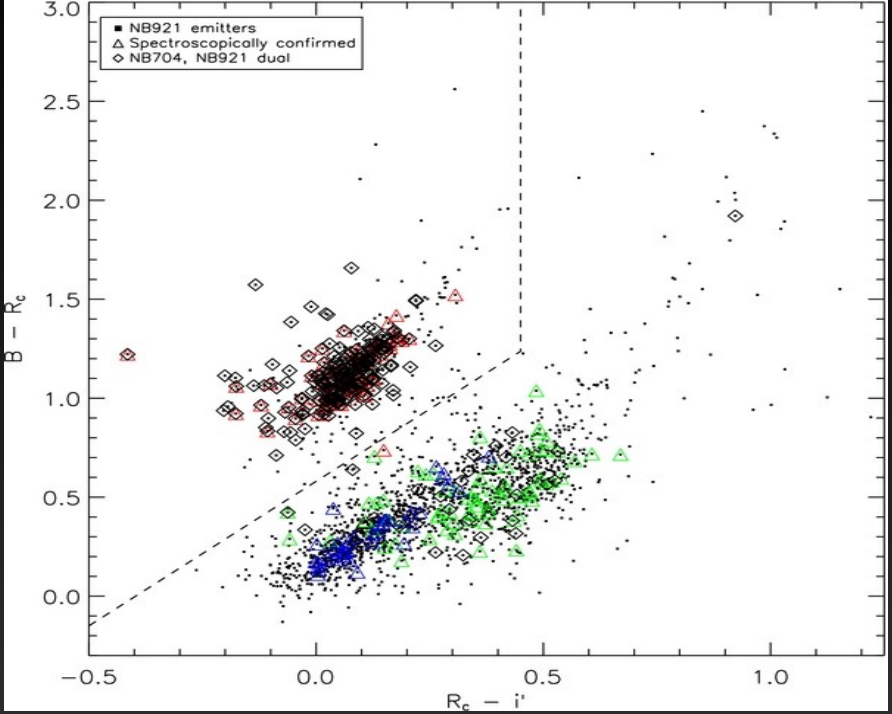
Emission-line ratios such as Balmer emission lines that probes HII-regions extinction (e. g. Kennicutt et al. 1992; Hopkins et al. 2001; Brinchmann et al. 2004; Garn & Best 2010).

Transition of n	$3 \rightarrow 2$	$4 \rightarrow 2$	$5 \rightarrow 2$	$6 \rightarrow 2$
Name	Hα	Hβ	Hδ	Hγ
Wavelength (Å)	6563	4861	4341	4102

Balmer series

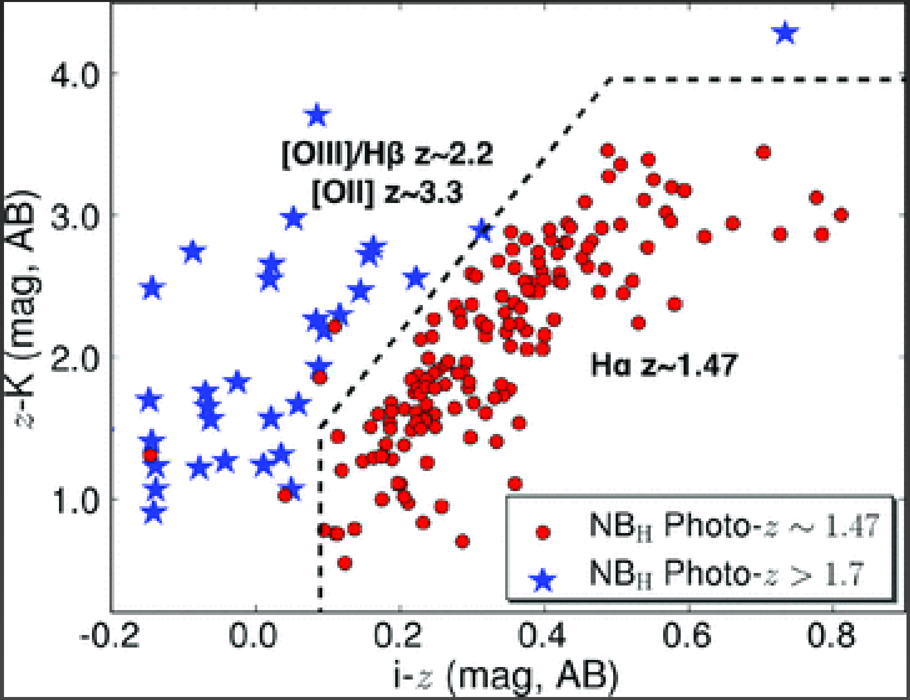
$$E(B-V) = \frac{2.5}{k(\lambda_{H\beta}) - k(\lambda_{H\alpha})} \log_{10}\left[\frac{(H\alpha/H\beta)_{obs}}{(H\alpha/H\beta)_{int}}\right]$$

Dust extinction at z>0.5 from emission-line ratios



Ly et al. 2012 at z ~ 0.5 → combination of photometry and spectroscopy

Sobral et al. 2012 at z ~ 1.5 → Hα/[O II] with [O II] being significantly dependent on metallicity.

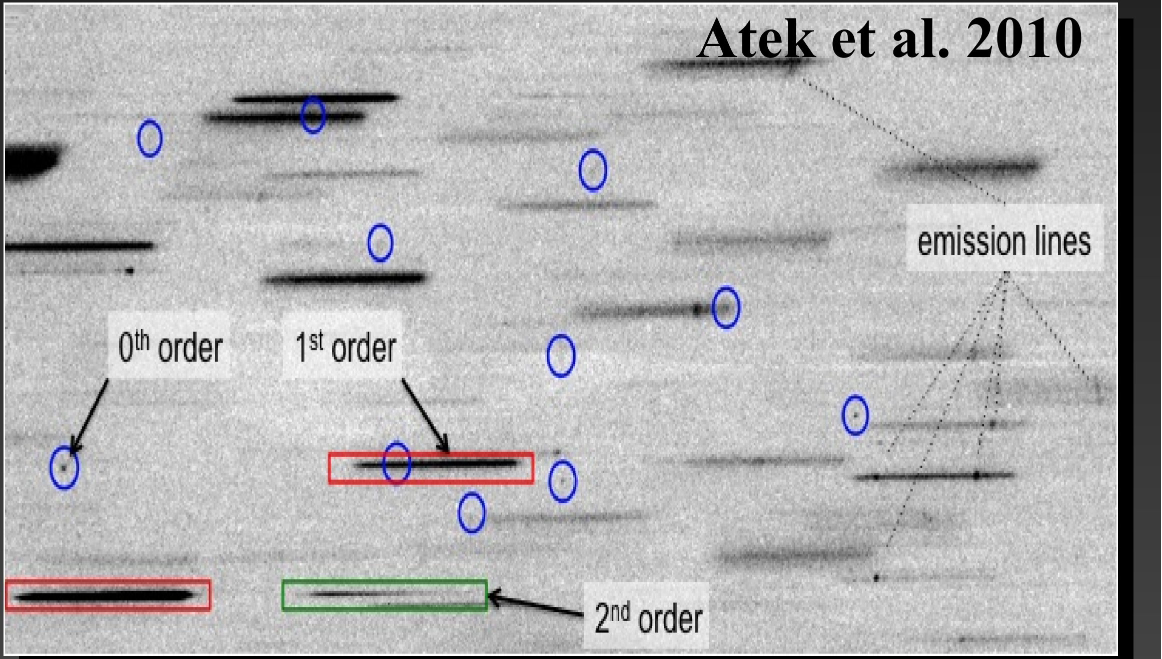


The WFC3 Infrared Spectroscopic Parallel (WISP) survey

Pure parallel Hubble Space Telescope program (PI Matthew Malkan) > 900 orbits, ~ 200 high-latitude fields. The faintest galaxies are 3 times fainter than galaxies previously studied at z ~ 1.5.

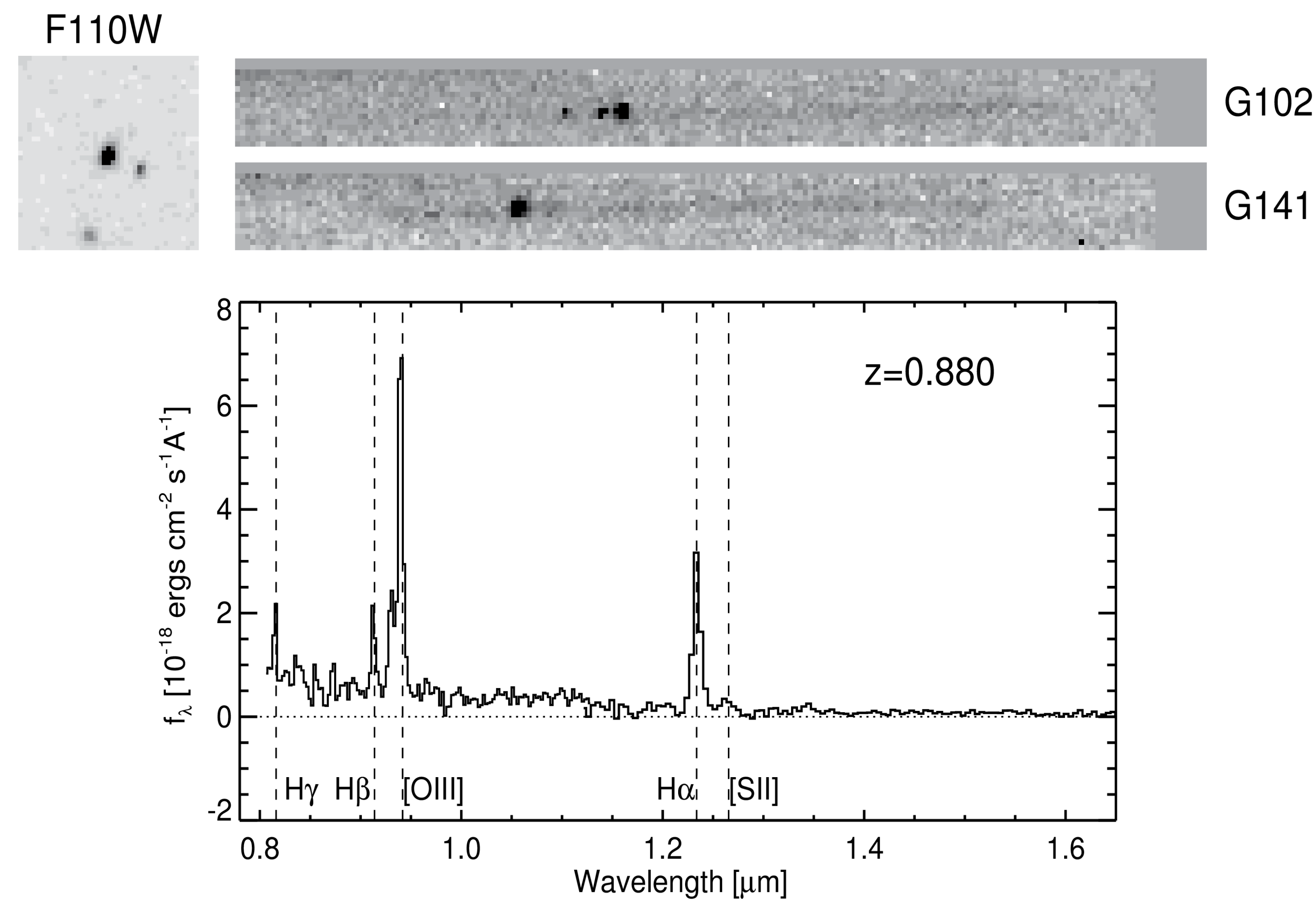
G102: $0.80 \le \lambda \le 1.17$ µm (R ~ 210)
G141: $1.11 \le \lambda \le 1.67$ µm (R ~ 130)

Direct-imaging photometry:
F475X, F600LP, F110W, F160W
and IRAC 3.6 µm



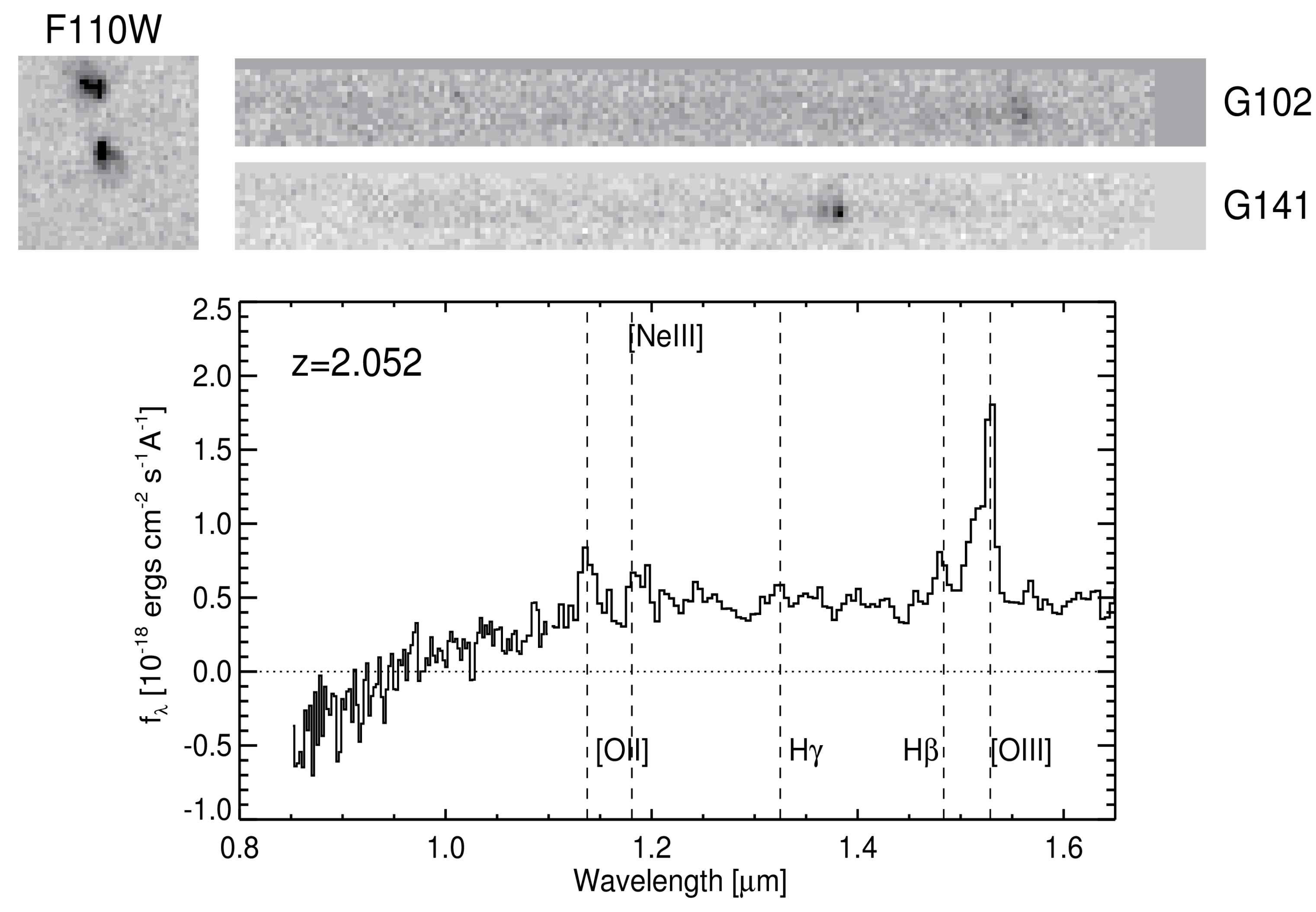
Example of different spectral features in one G141 grism image.

The WISP survey



Atek et al. 2010

The WISP survey



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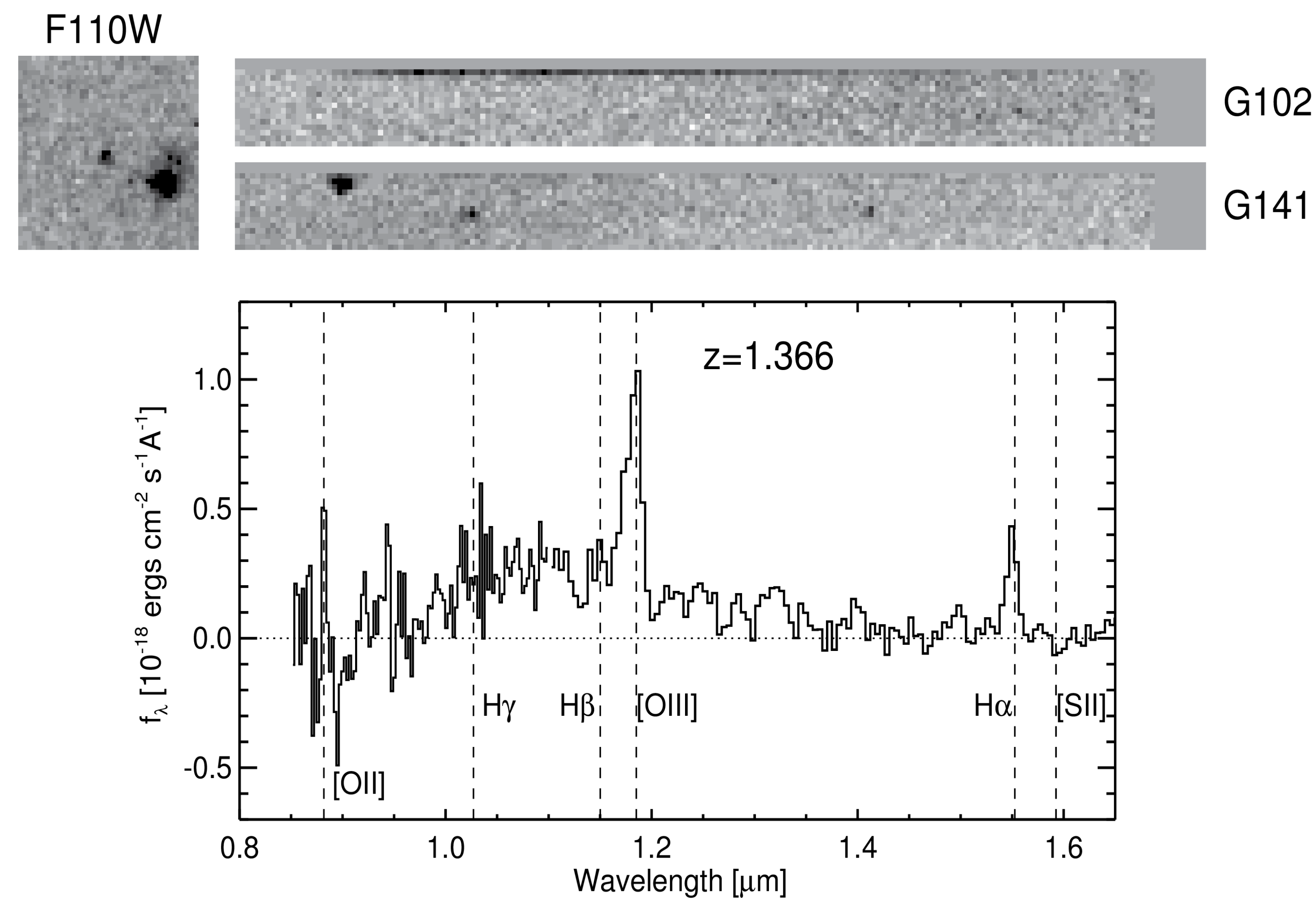
The WISP survey



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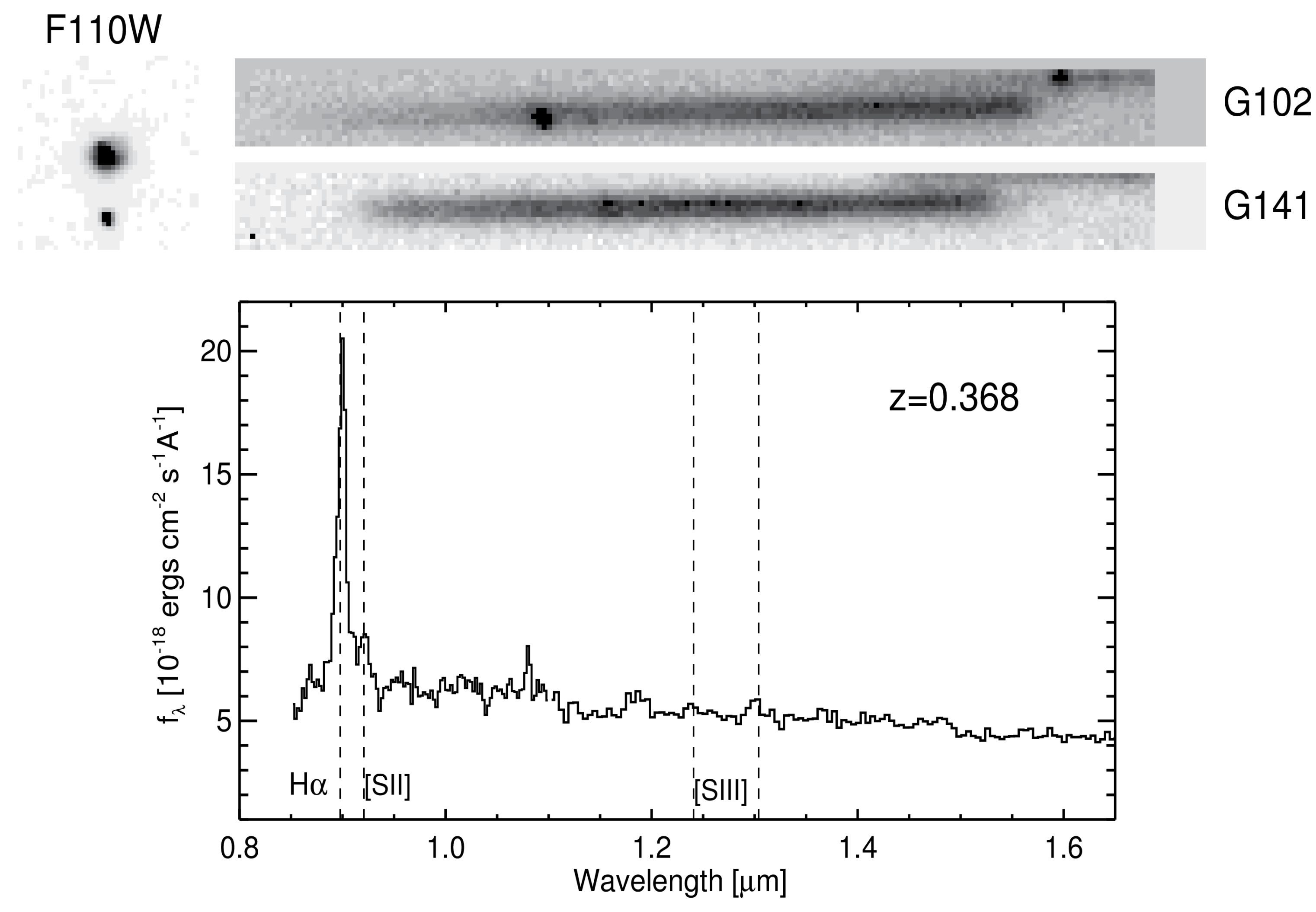
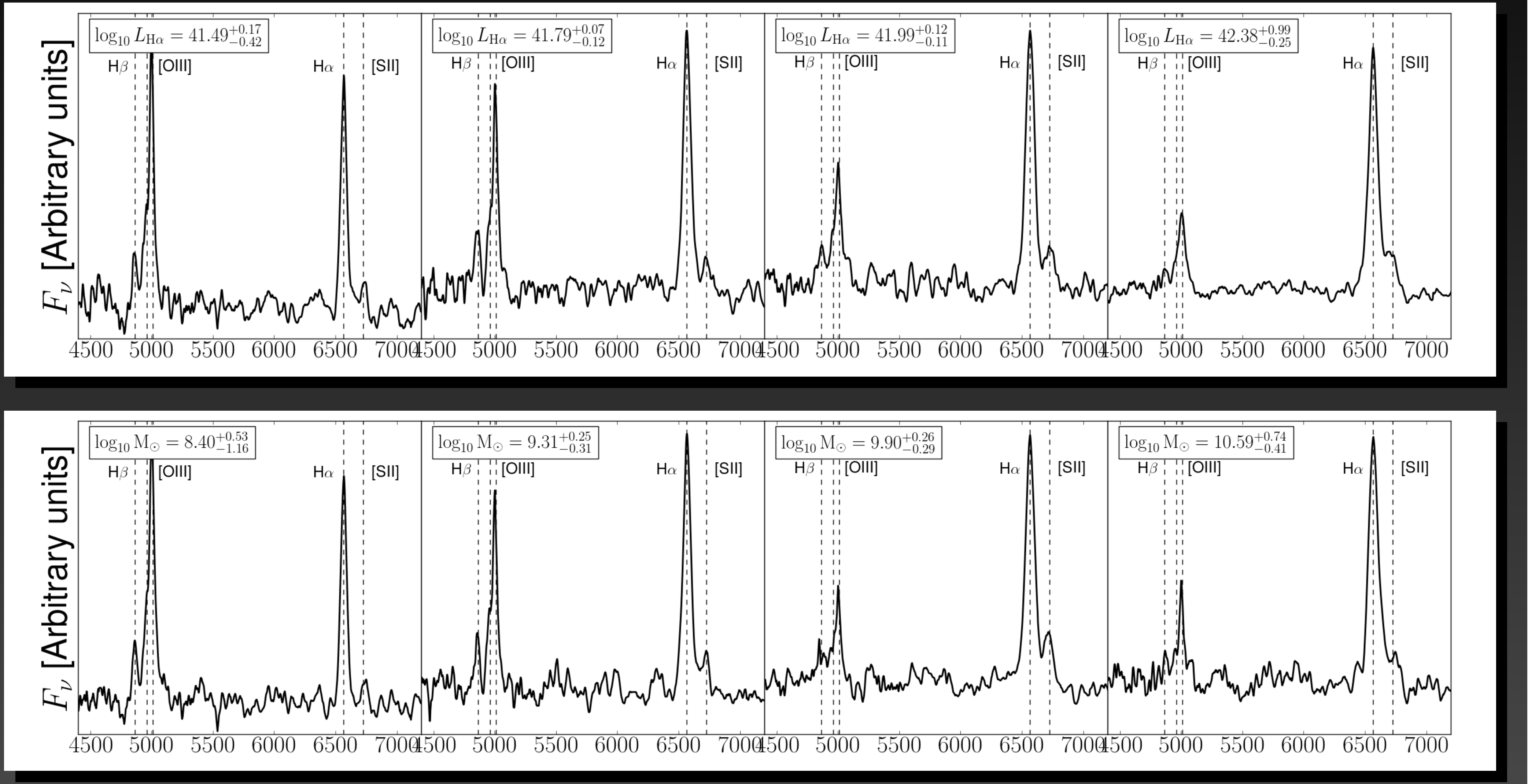
The WISP survey



Atek et al. 2010

Galaxy stacks at $0.75 \leq z \leq 1.5$

312 galaxies in 17 fields where both Hα and Hβ fall simultaneously in the WISP spectral coverage → 129 galaxies after cleaning



Rest-frame wavelength [Å]

Emission-line contamination

- Hα and Hβ absorption (~ 25% in Hβ); BC03 models

- [N II] (~ 15% in the worst case); Erb et al. 2006

- AGNs; BPT diagram

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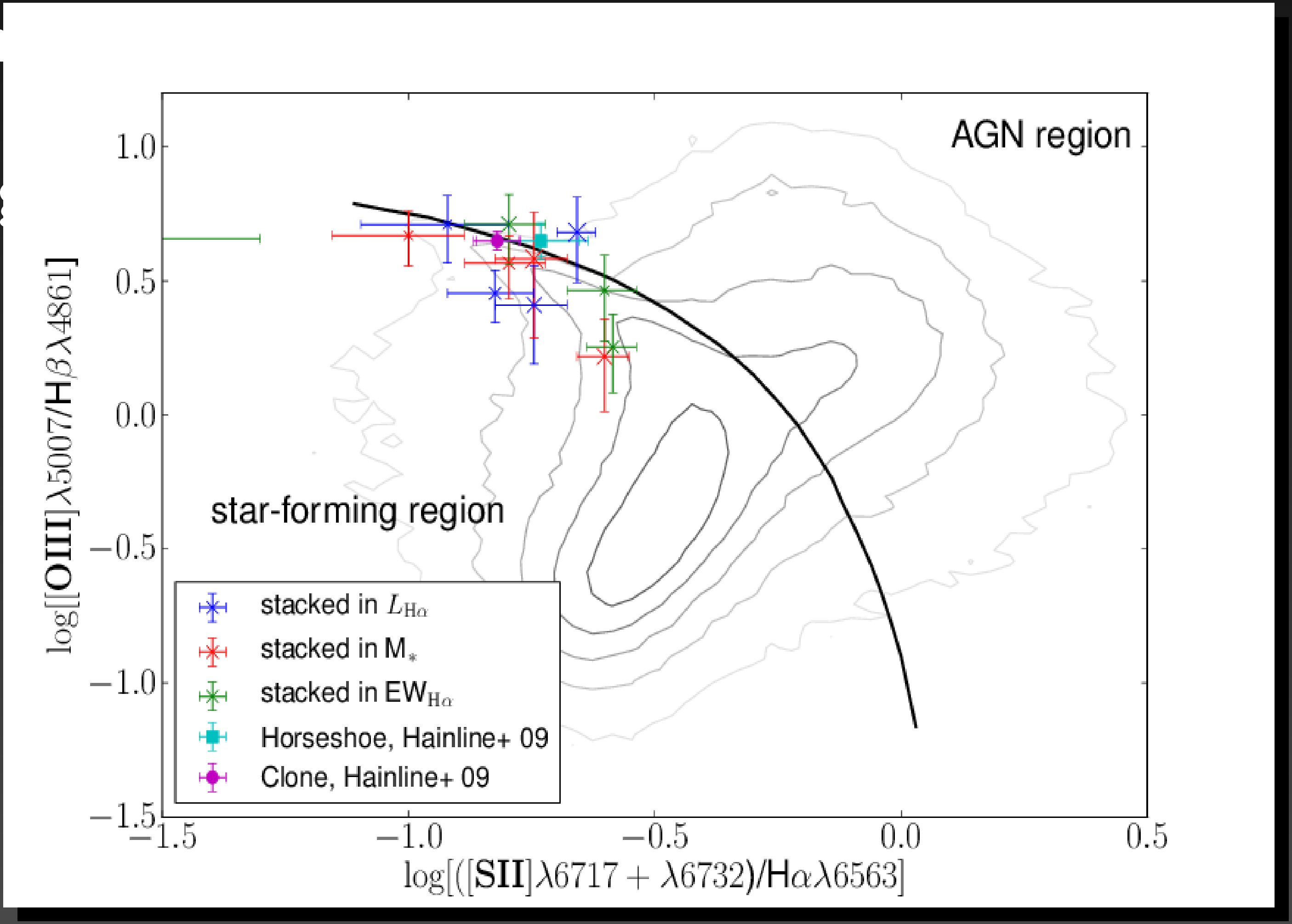
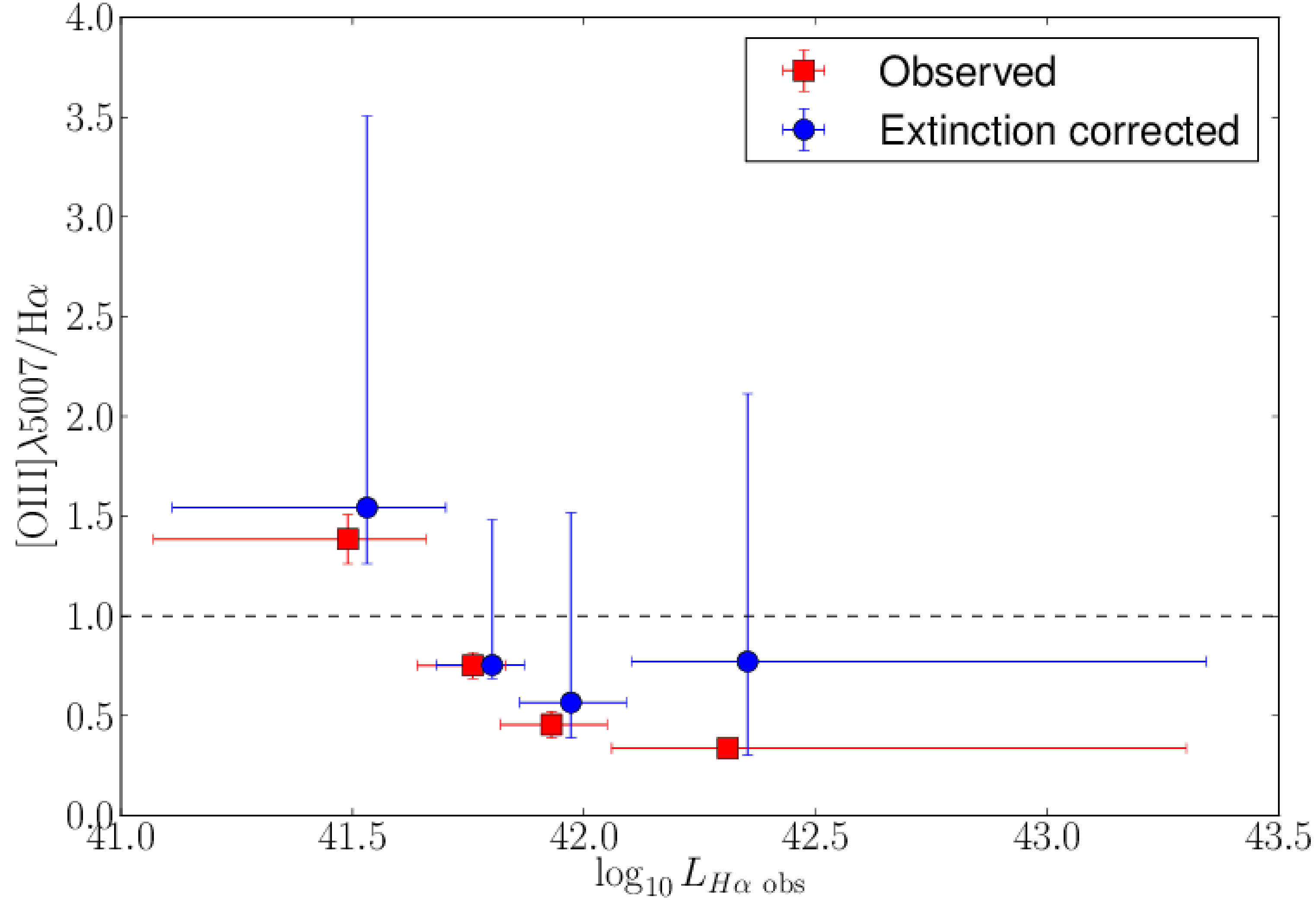
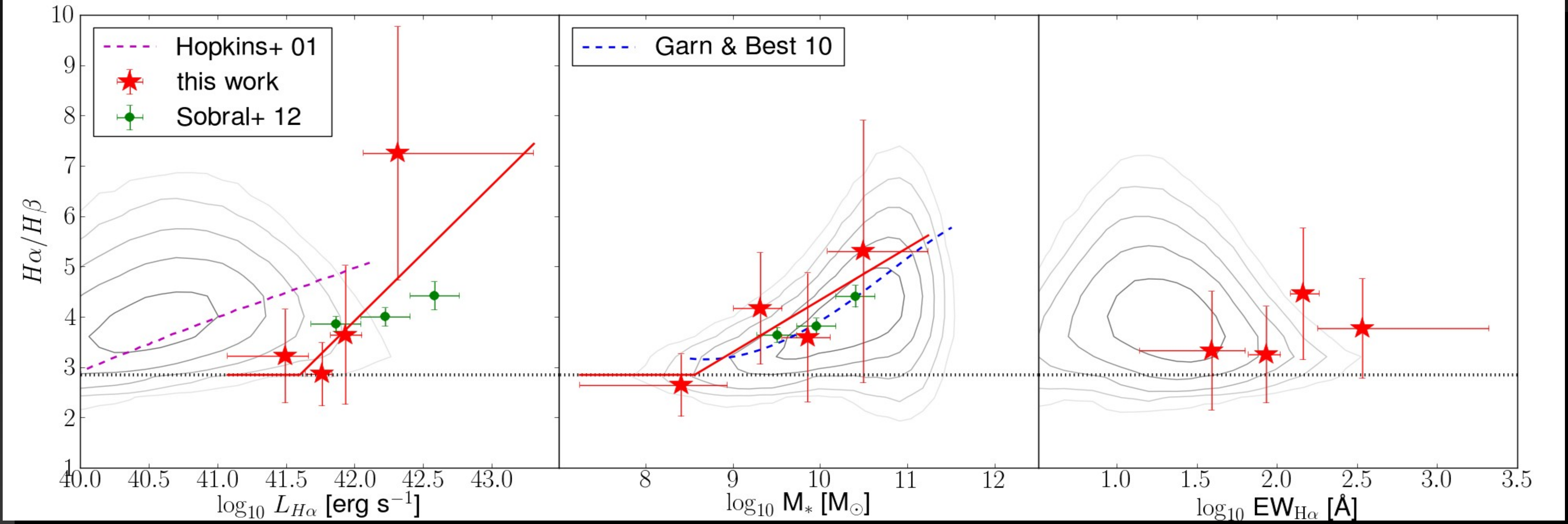


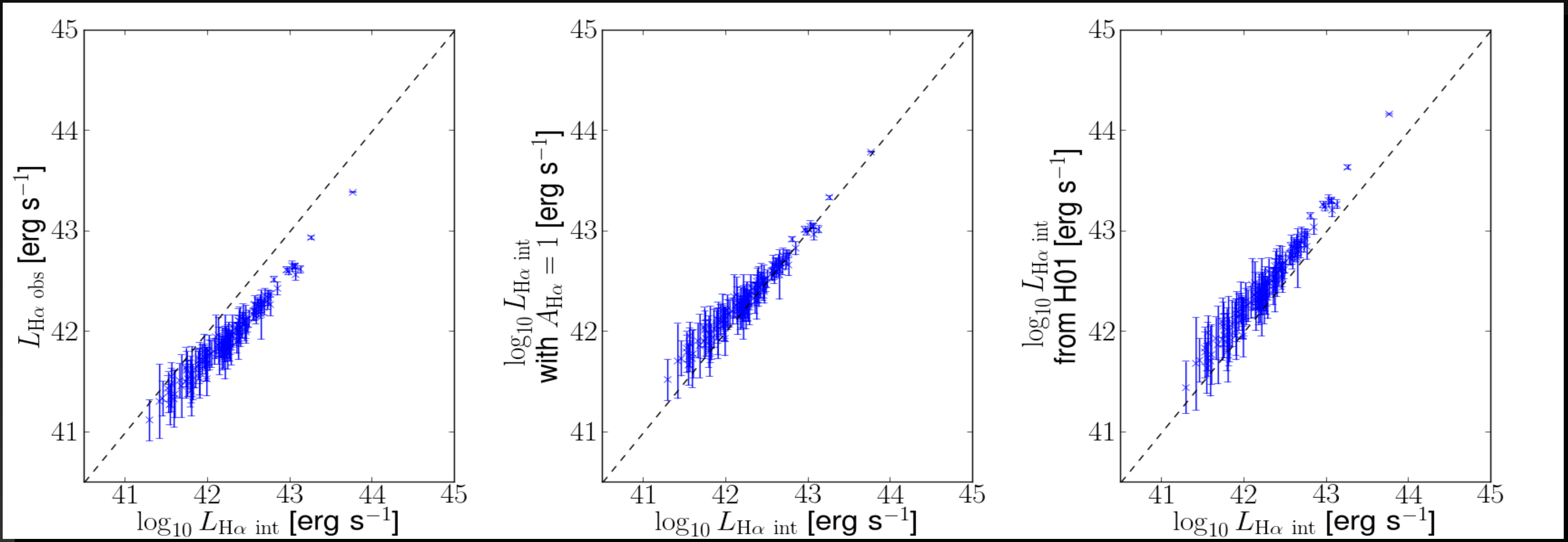
Galaxy stacks at 0.75 ≤ z ≤ 1.5



Balmer decrements at z ~ 1

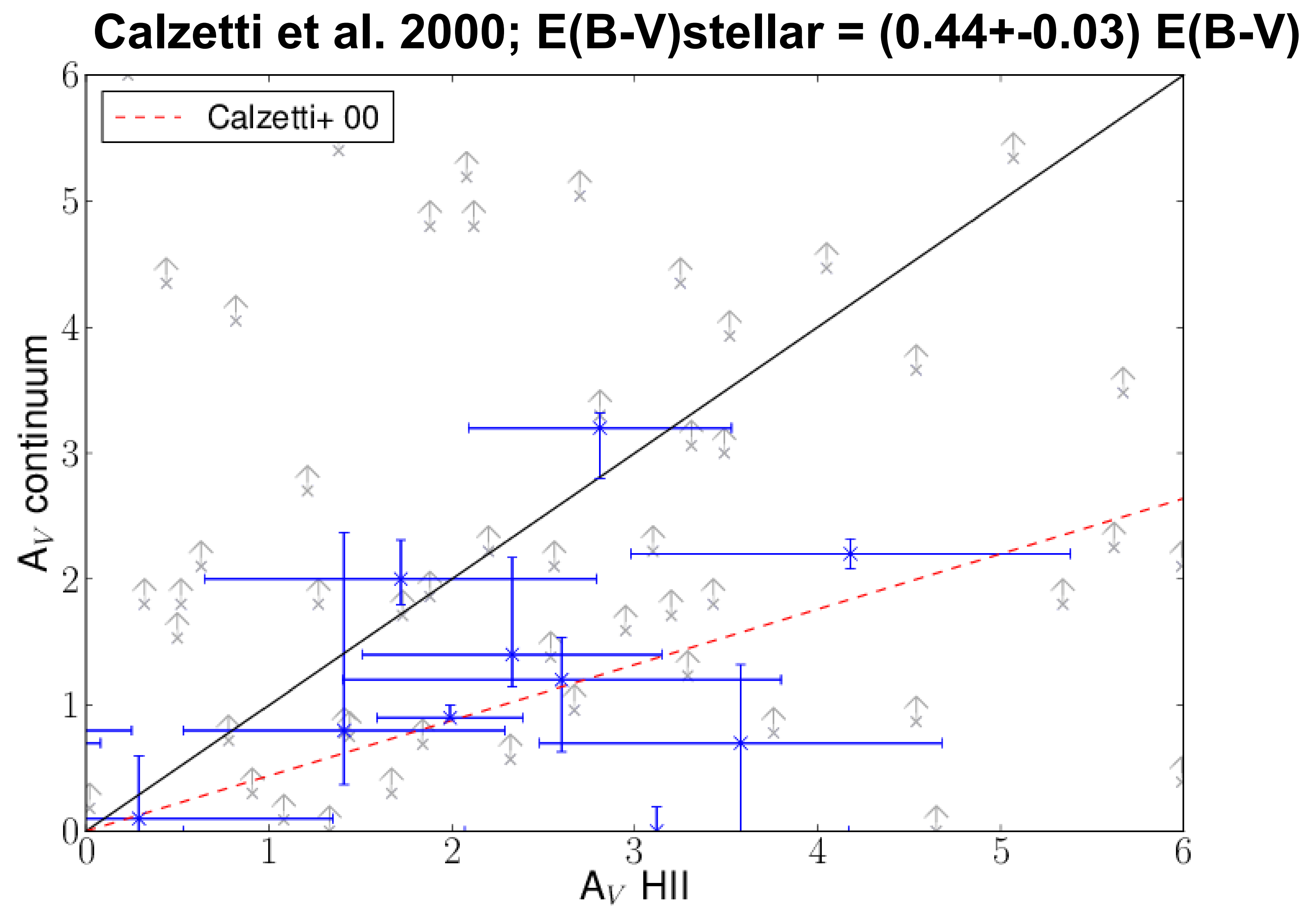


Dust extinction at z ~ 1



Assuming Calzetti et al. 2000 attenuation law

Stellar vs. HII extinction



Conclusions

1.- The Hα/[O III] ratio is dependent on observed Hα luminosity.

2.- The Balmer decrement is correlated with observed Hα luminosity and galaxy stellar mass at $z \sim 1$. The faintest galaxies are consistent with no dust extinction.

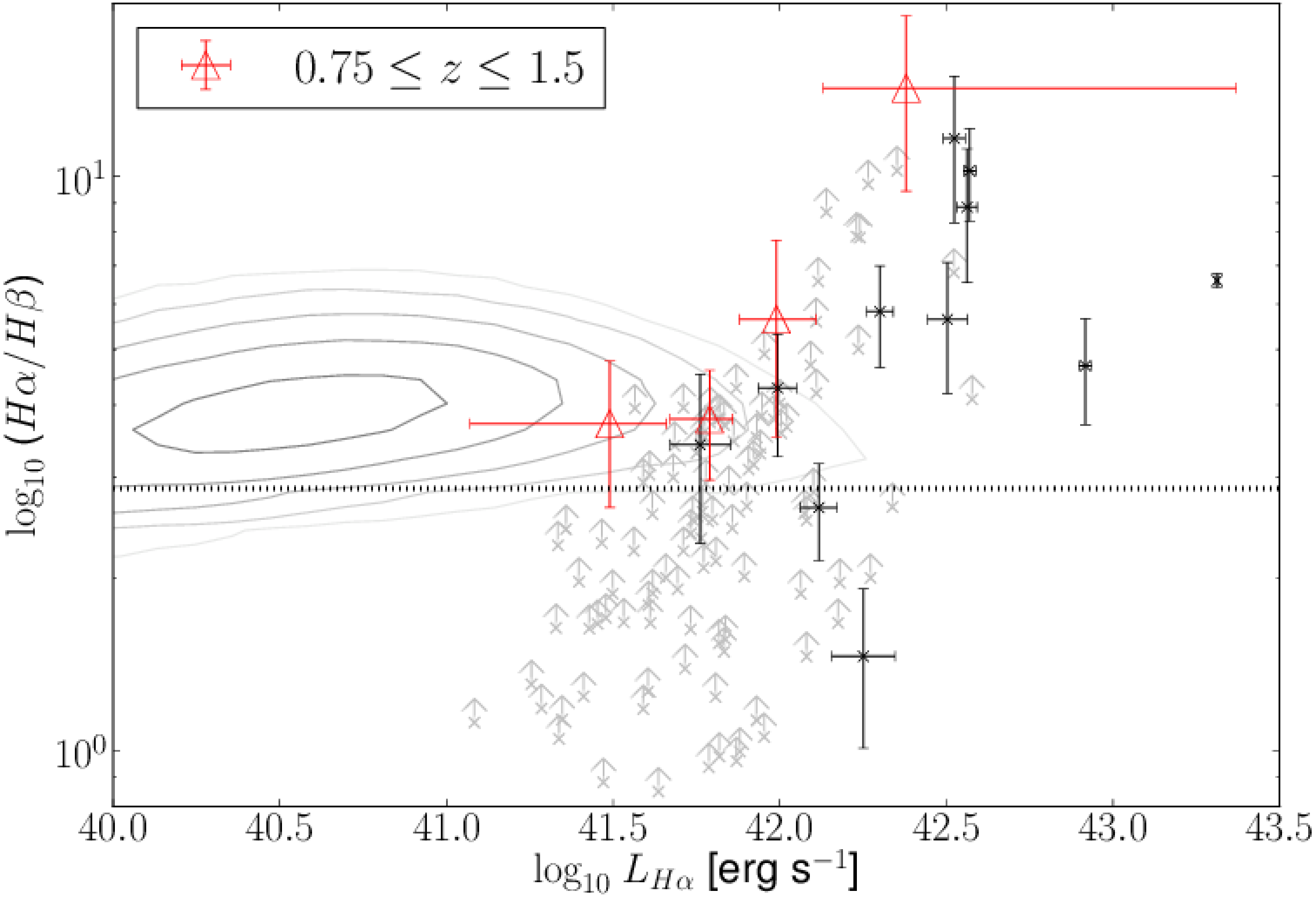
3.- Clear evolution of dust extinction where for a given observed Hα luminosity, galaxies are significantly less extinguished at higher redshifts. No evolution is found with galaxy stellar mass.

4.- The typical procedure of assuming a constant extinction for all luminosity significantly overestimate extinction for the lower luminosity galaxies.

5.- WISP will improve the galaxy statistic more than a factor 10.

6.- WISP will publish results on the galaxy Hα luminosity and mass/metallicity relation very soon.

Backup


$0.75 \leq z \leq 1.5$
$\log_{10}(H\alpha/H\beta)$
10^1
10^0
40.0
40.5
41.0
41.5
42.0
42.5
43.0
43.5
$\log_{10} L_{H\alpha}$ [erg s^{-1}]

Backup

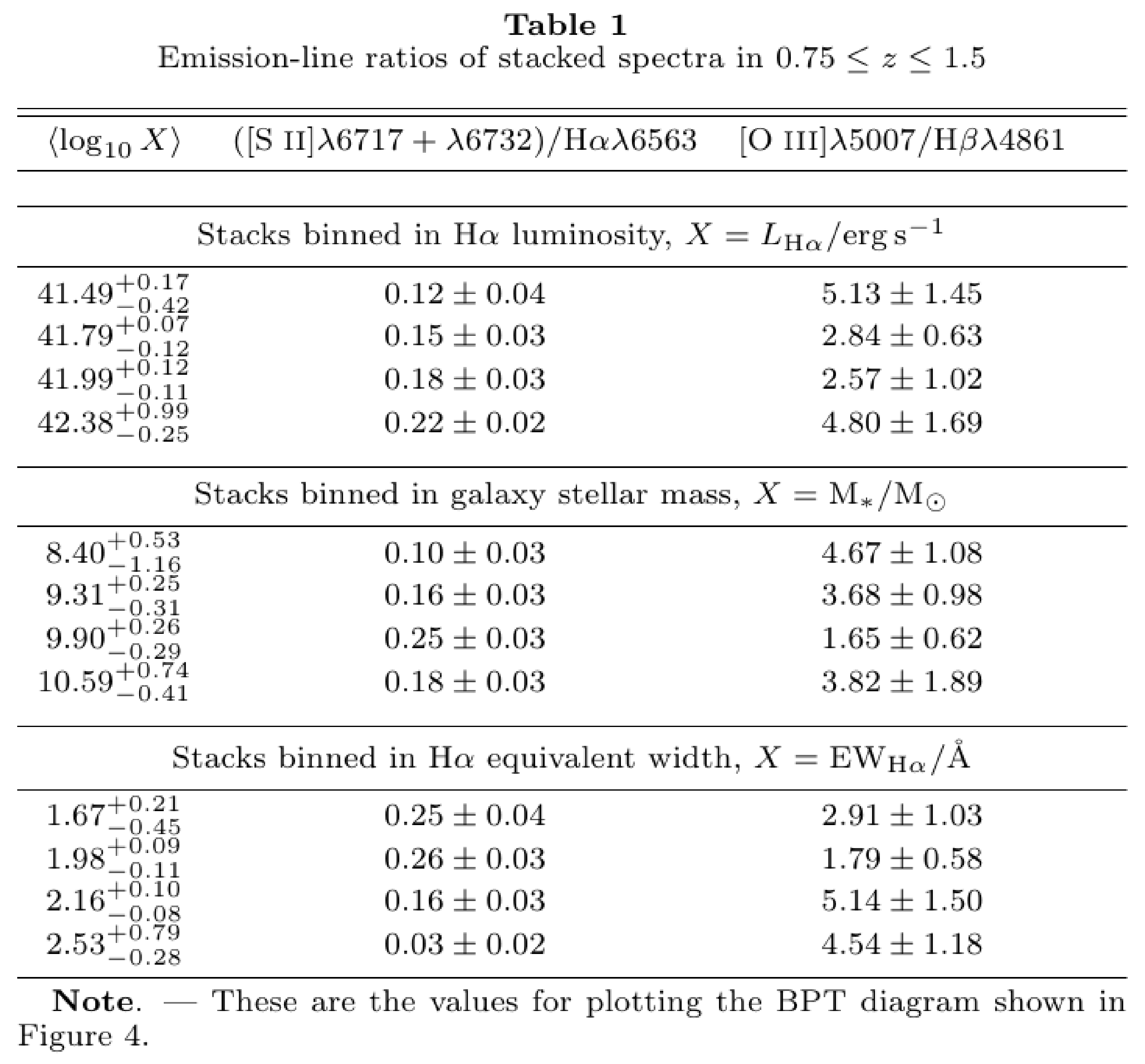


Table 1

Emission-line ratios of stacked spectra in $0.75 \leq z \leq 1.5$

$\langle \log_{10} X \rangle$	([S II]$\lambda6717 + \lambda6732$)/H$\alpha\lambda6563$	[O III]$\lambda5007$/H$\beta\lambda4861$
Stacks binned in Hα luminosity, $X = L_{\mathrm{H}\alpha}/\mathrm{erg\,s^{-1}}$		
$41.49^{+0.17}_{-0.42}$	0.12 ± 0.04	5.13 ± 1.45
$41.79^{+0.07}_{-0.12}$	0.15 ± 0.03	2.84 ± 0.63
$41.99^{+0.12}_{-0.11}$	0.18 ± 0.03	2.57 ± 1.02
$42.38^{+0.99}_{-0.25}$	0.22 ± 0.02	4.80 ± 1.69
Stacks binned in galaxy stellar mass, $X = \mathrm{M}_*/\mathrm{M}_\odot$		
$8.40^{+0.53}_{-1.16}$	0.10 ± 0.03	4.67 ± 1.08
$9.31^{+0.25}_{-0.31}$	0.16 ± 0.03	3.68 ± 0.98
$9.90^{+0.26}_{-0.29}$	0.25 ± 0.03	1.65 ± 0.62
$10.59^{+0.74}_{-0.41}$	0.18 ± 0.03	3.82 ± 1.89
Stacks binned in Hα equivalent width, $X = \mathrm{EW}_{\mathrm{H}\alpha}/\text{Å}$		
$1.67^{+0.21}_{-0.45}$	0.25 ± 0.04	2.91 ± 1.03
$1.98^{+0.09}_{-0.11}$	0.26 ± 0.03	1.79 ± 0.58
$2.16^{+0.10}_{-0.08}$	0.16 ± 0.03	5.14 ± 1.50
$2.53^{+0.79}_{-0.28}$	0.03 ± 0.02	4.54 ± 1.18

Note. — These are the values for plotting the BPT diagram shown in Figure 4.

Backup

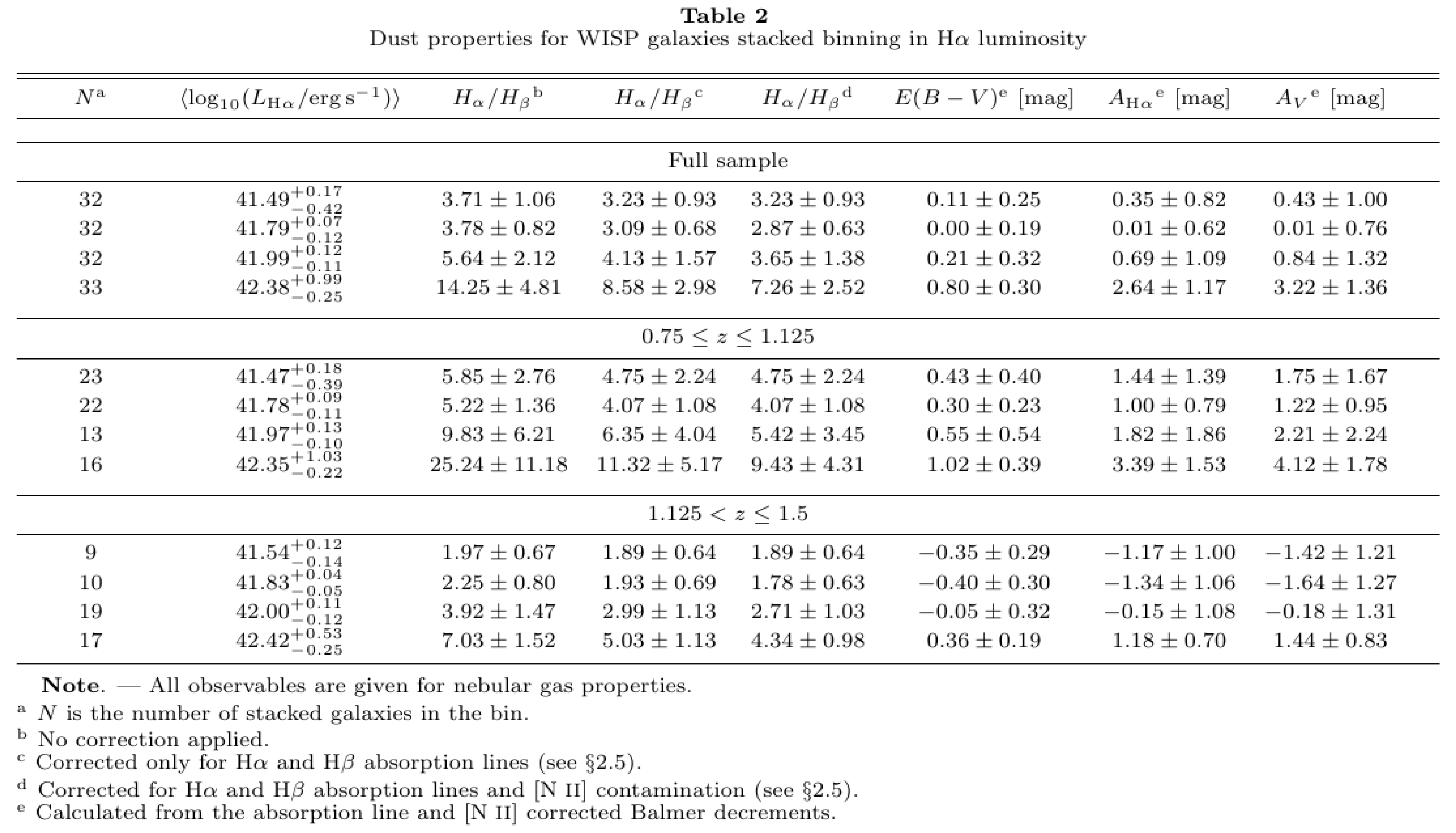


Table 2

Dust properties for WISP galaxies stacked binning in Hα luminosity

N[a]	$\langle \log_{10}(L_{\mathrm{H}\alpha}/\mathrm{erg\,s^{-1}}) \rangle$	H_α/H_β[b]	H_α/H_β[c]	H_α/H_β[d]	$E(B-V)$[e] [mag]	$A_{\mathrm{H}\alpha}$[e] [mag]	A_V[e] [mag]
Full sample							
32	$41.49^{+0.17}_{-0.42}$	3.71 ± 1.06	3.23 ± 0.93	3.23 ± 0.93	0.11 ± 0.25	0.35 ± 0.82	0.43 ± 1.00
32	$41.79^{+0.07}_{-0.12}$	3.78 ± 0.82	3.09 ± 0.68	2.87 ± 0.63	0.00 ± 0.19	0.01 ± 0.62	0.01 ± 0.76
32	$41.99^{+0.12}_{-0.11}$	5.64 ± 2.12	4.13 ± 1.57	3.65 ± 1.38	0.21 ± 0.32	0.69 ± 1.09	0.84 ± 1.32
33	$42.38^{+0.99}_{-0.25}$	14.25 ± 4.81	8.58 ± 2.98	7.26 ± 2.52	0.80 ± 0.30	2.64 ± 1.17	3.22 ± 1.36
$0.75 \leq z \leq 1.125$							
23	$41.47^{+0.18}_{-0.39}$	5.85 ± 2.76	4.75 ± 2.24	4.75 ± 2.24	0.43 ± 0.40	1.44 ± 1.39	1.75 ± 1.67
22	$41.78^{+0.09}_{-0.11}$	5.22 ± 1.36	4.07 ± 1.08	4.07 ± 1.08	0.30 ± 0.23	1.00 ± 0.79	1.22 ± 0.95
13	$41.97^{+0.13}_{-0.10}$	9.83 ± 6.21	6.35 ± 4.04	5.42 ± 3.45	0.55 ± 0.54	1.82 ± 1.86	2.21 ± 2.24
16	$42.35^{+1.03}_{-0.22}$	25.24 ± 11.18	11.32 ± 5.17	9.43 ± 4.31	1.02 ± 0.39	3.39 ± 1.53	4.12 ± 1.78
$1.125 < z \leq 1.5$							
9	$41.54^{+0.12}_{-0.14}$	1.97 ± 0.67	1.89 ± 0.64	1.89 ± 0.64	-0.35 ± 0.29	-1.17 ± 1.00	-1.42 ± 1.21
10	$41.83^{+0.04}_{-0.05}$	2.25 ± 0.80	1.93 ± 0.69	1.78 ± 0.63	-0.40 ± 0.30	-1.34 ± 1.06	-1.64 ± 1.27
19	$42.00^{+0.11}_{-0.12}$	3.92 ± 1.47	2.99 ± 1.13	2.71 ± 1.03	-0.05 ± 0.32	-0.15 ± 1.08	-0.18 ± 1.31
17	$42.42^{+0.53}_{-0.25}$	7.03 ± 1.52	5.03 ± 1.13	4.34 ± 0.98	0.36 ± 0.19	1.18 ± 0.70	1.44 ± 0.83

Note. — All observables are given for nebular gas properties.

[a] N is the number of stacked galaxies in the bin.

[b] No correction applied.

[c] Corrected only for Hα and Hβ absorption lines (see §2.5).

[d] Corrected for Hα and Hβ absorption lines and [N II] contamination (see §2.5).

[e] Calculated from the absorption line and [N II] corrected Balmer decrements.