Dust Extinction in Star-forming Galaxies from near-IR Spectroscopy

Domínguez et al. 2013, ApJ, 763, 145

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& the WISP team

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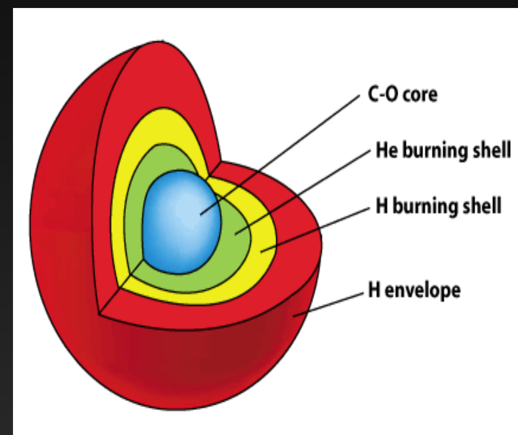
April 23-25, 2018

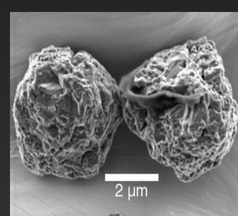
What is and where is dust produced?

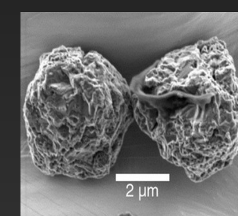
Asymptotic-giant-branch stars

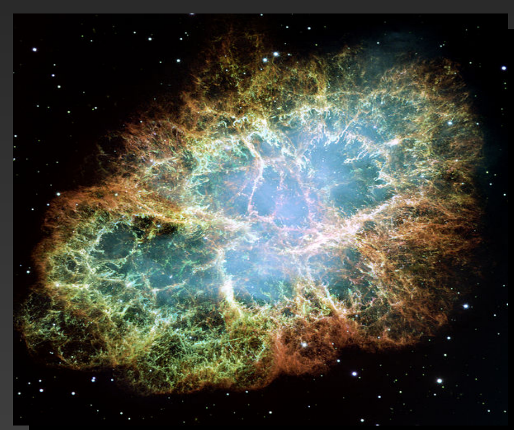
ISM

ISM









ISM

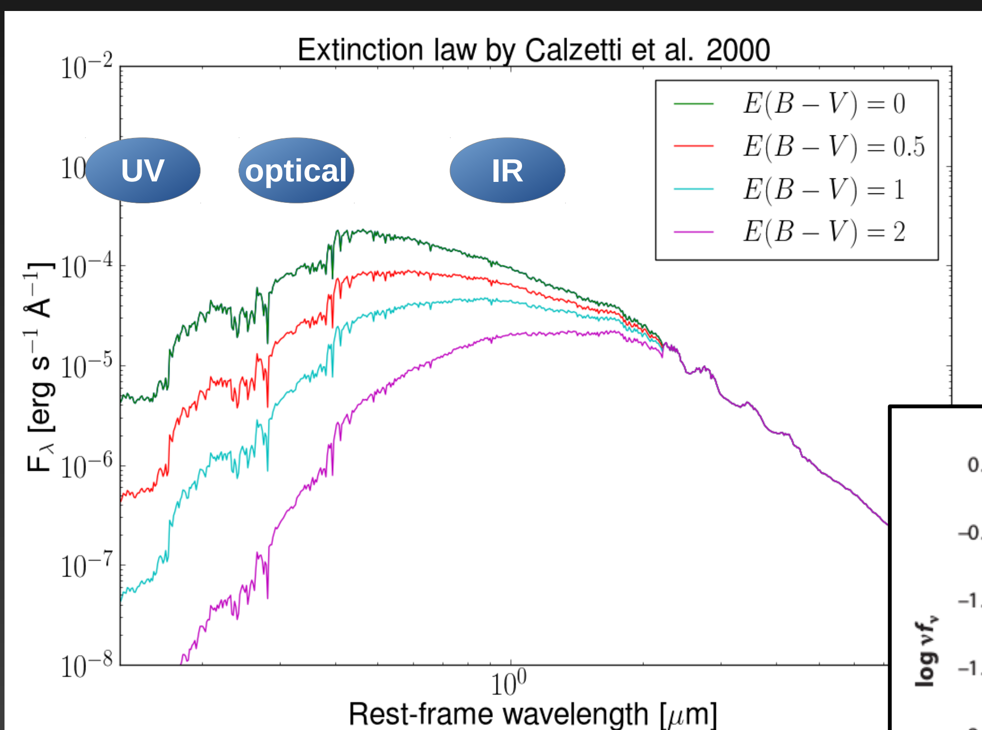
ISM

Supernovae

Effects of the interstellar dust

Dimming

Reddening



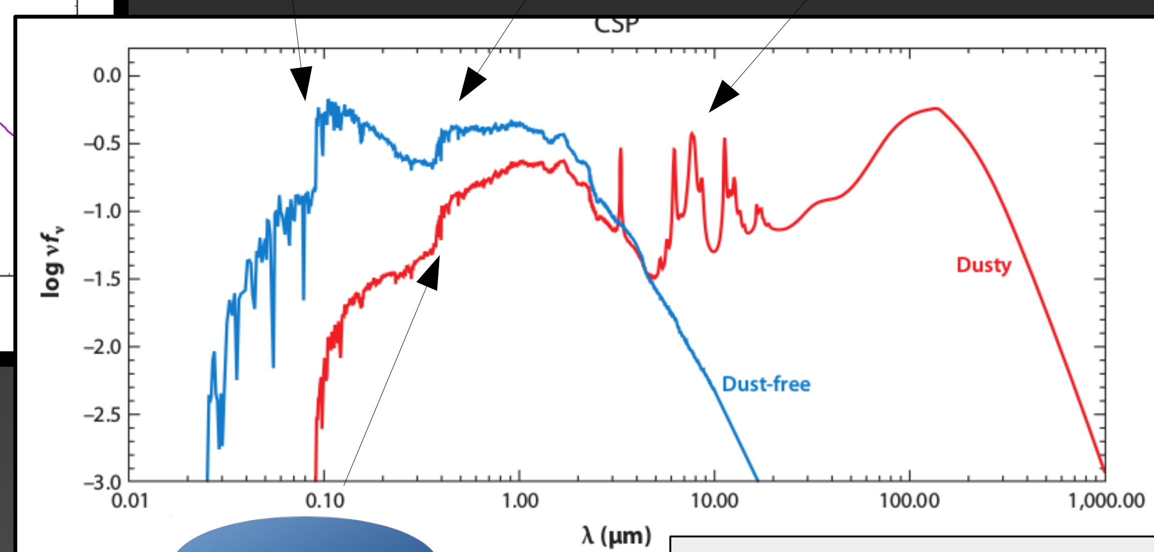
Color index

$$E_{B-V} = (B-V)_{\rm observed} - (B-V)_{\rm intrinsic}$$

Ly break, 912 Å

Ba break, 3646 Å

PAH

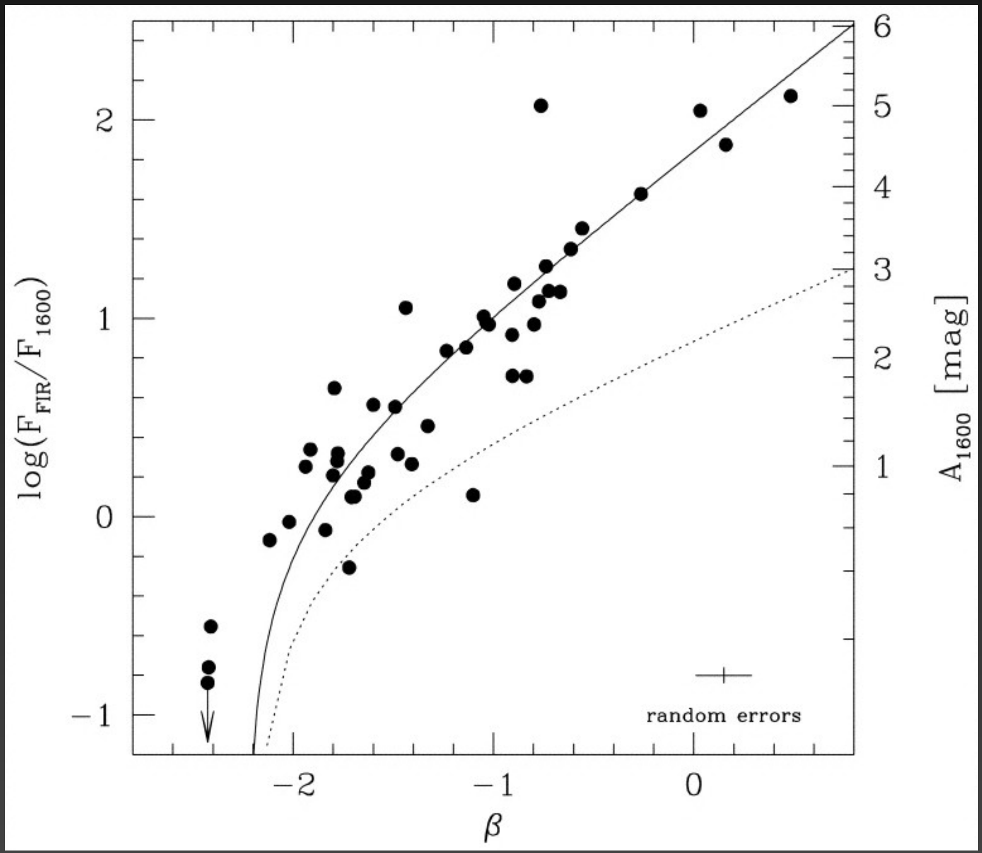


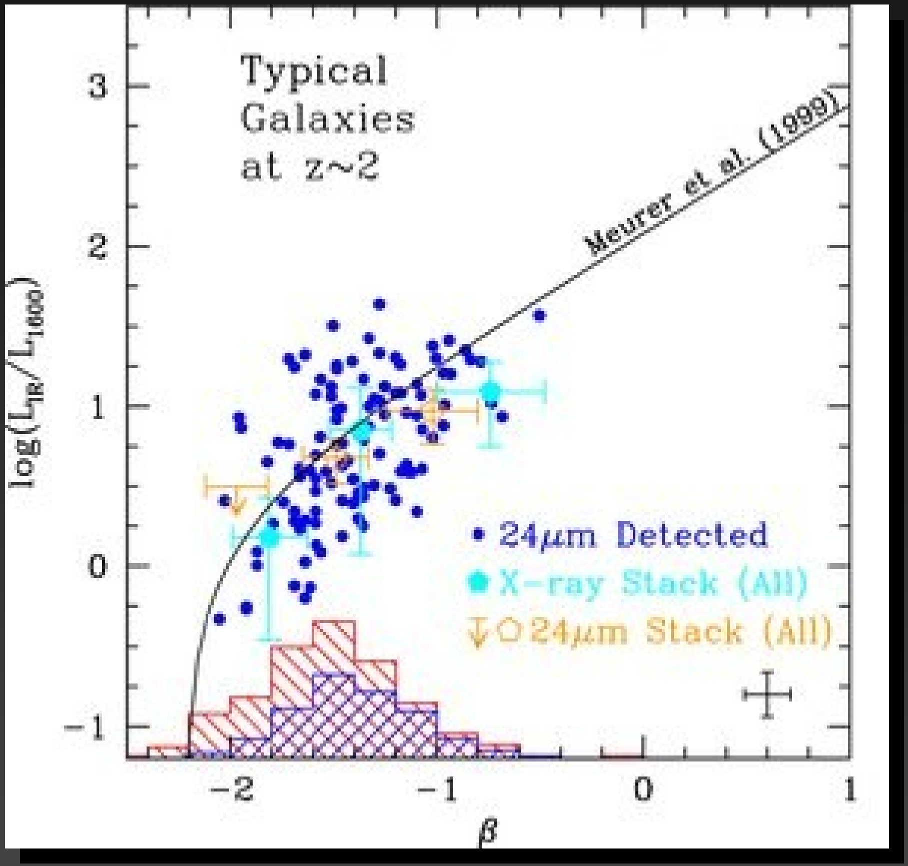
D4000, 4000 Å

Conroy 2013

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)





$f_\lambda \propto \lambda^\beta$ **(from ~1300 Å to 3500 Å)**

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 → 2	4 → 2	5 → 2	6 → 2
Name	Hα	Hβ	Hδ	Hγ
Wavelength (Å)	6563	4861	4341	4102

Balmer series

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

The Balmer decrement of Sloan Digital Sky Survey galaxies

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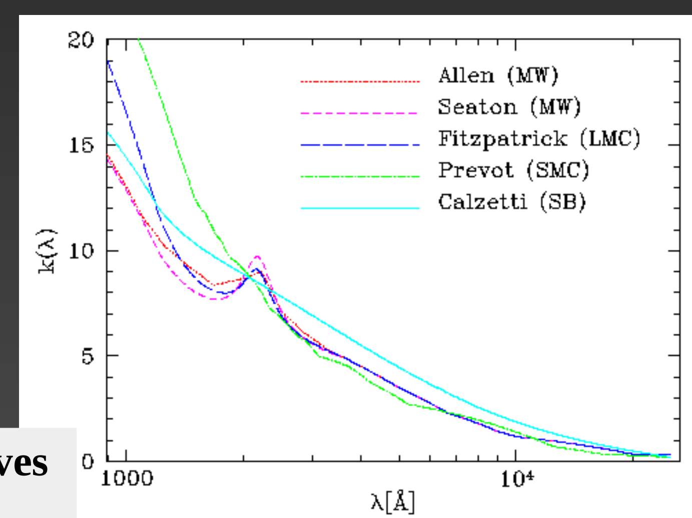
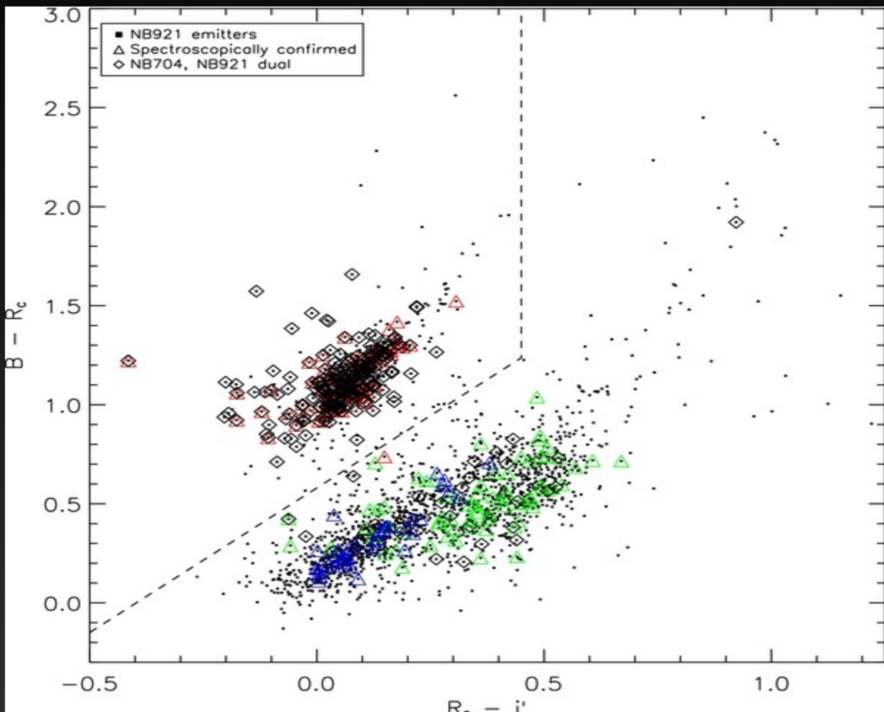
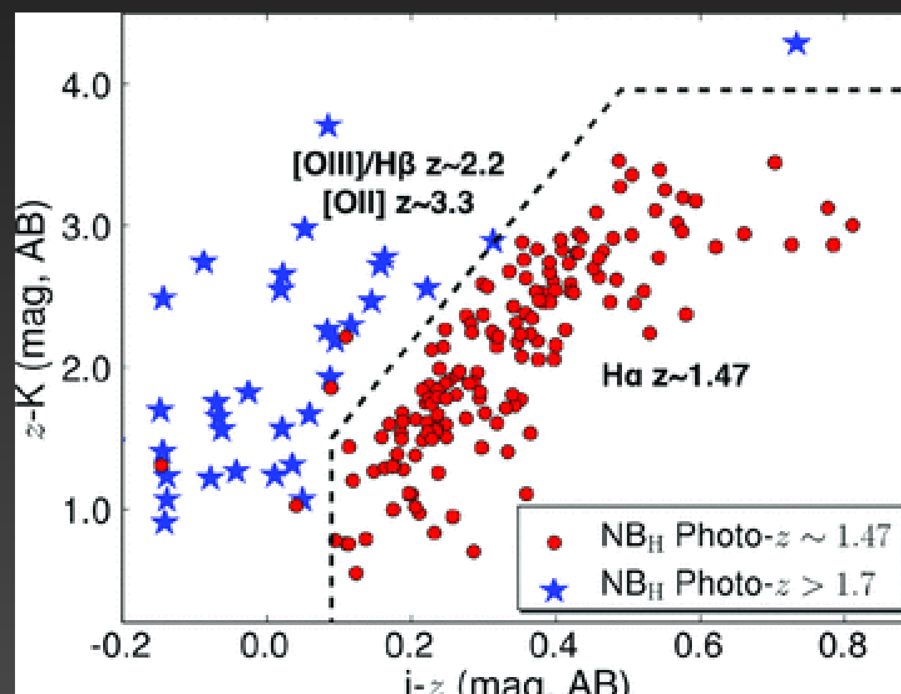


Empirical extinction curves from Hyperz manual

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

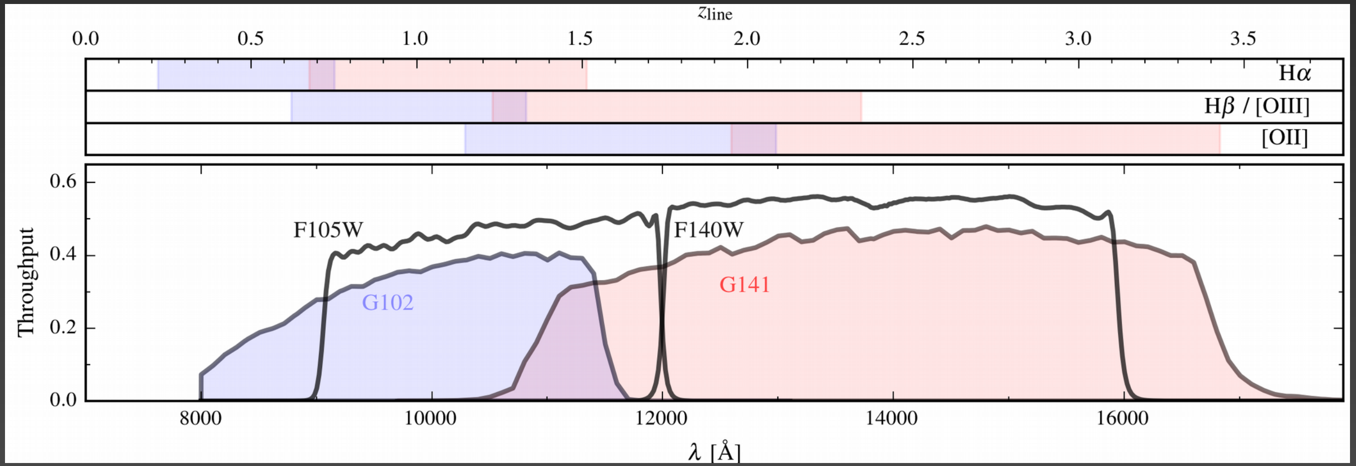
- Pure parallel Hubble Space Telescope program (PI Matthew Malkan, UCLA) with more than 1500 orbits, approximately 390 high-latitude fields observed so far.

- The faintest galaxies are 3 times fainter than galaxies previously studied at z ~ 1.5.

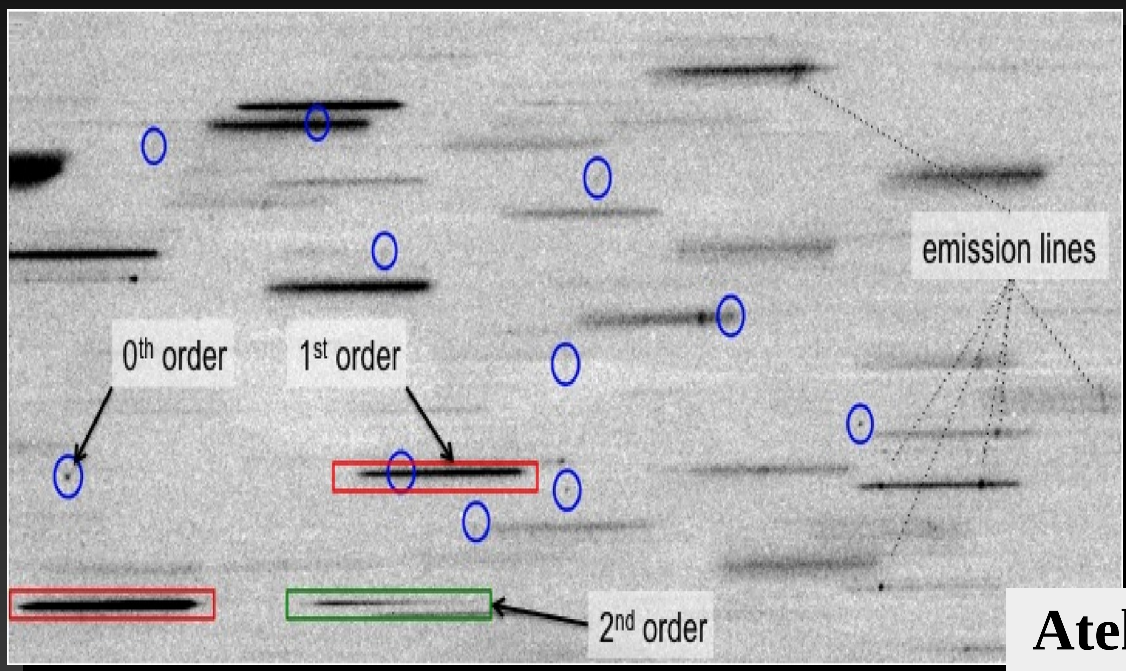
GRISMS near-IR spectroscopy

G102: 0.80 ≤ λ ≤ 1.17 µm (R ~ 210)
G141: 1.11 ≤ λ ≤ 1.67 µm (R ~ 130)

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



The WFC3 Infrared Spectroscopic Parallel (WISP) survey

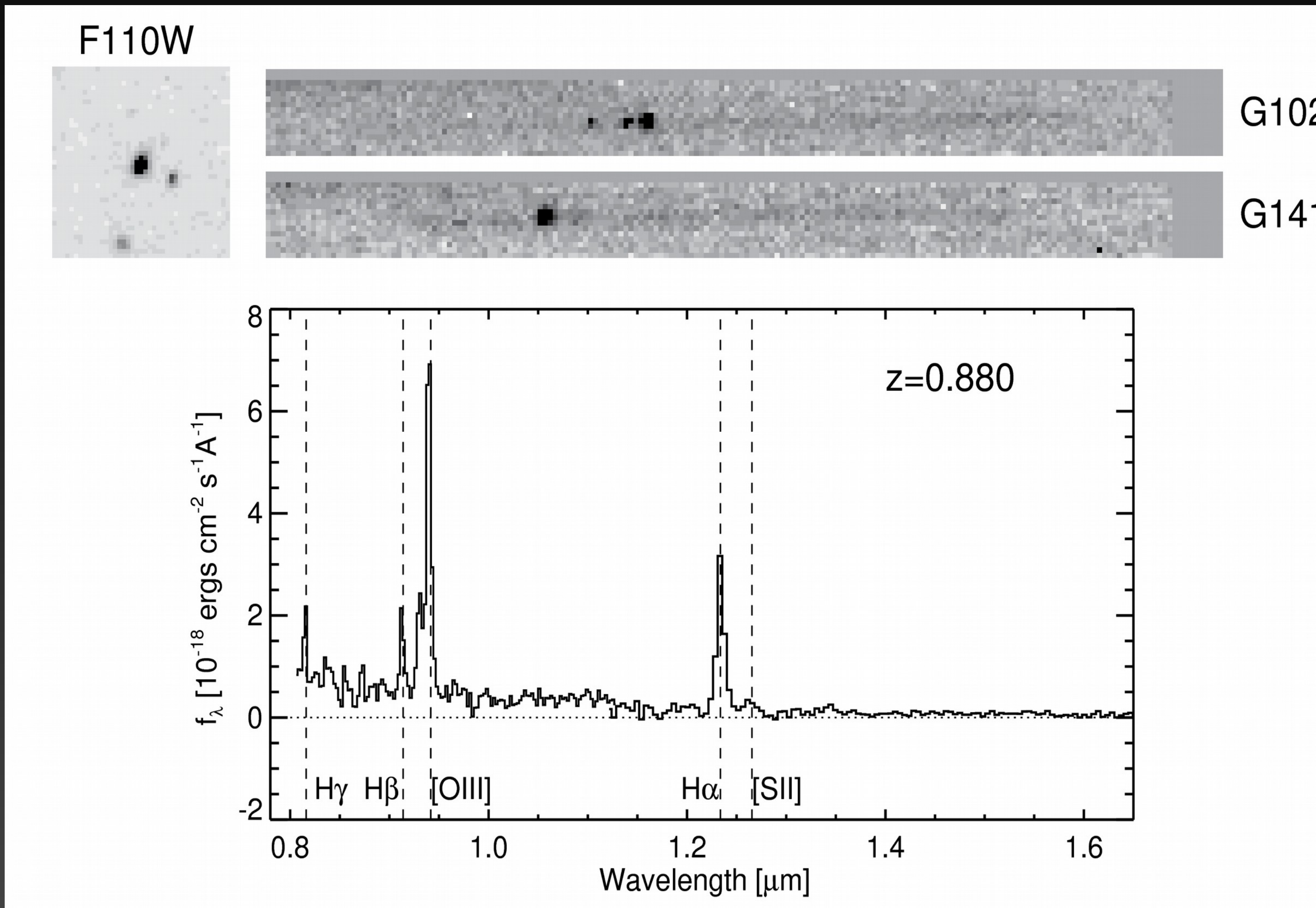


Atek et al. 2010

Example of different spectral features in one G141 grism image.

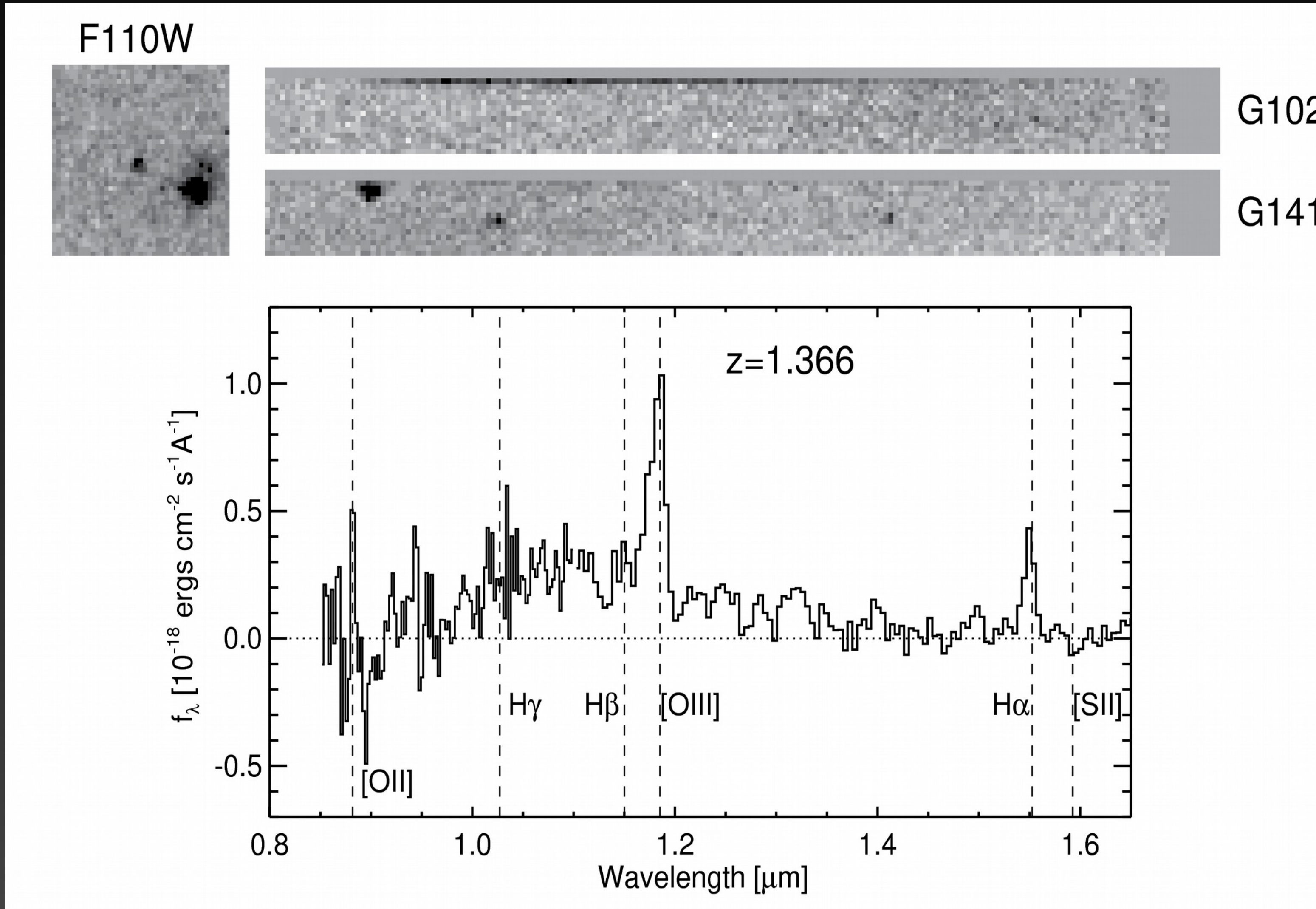
Field of view IR Channel: 123 x 136 arcsec

The WISP survey



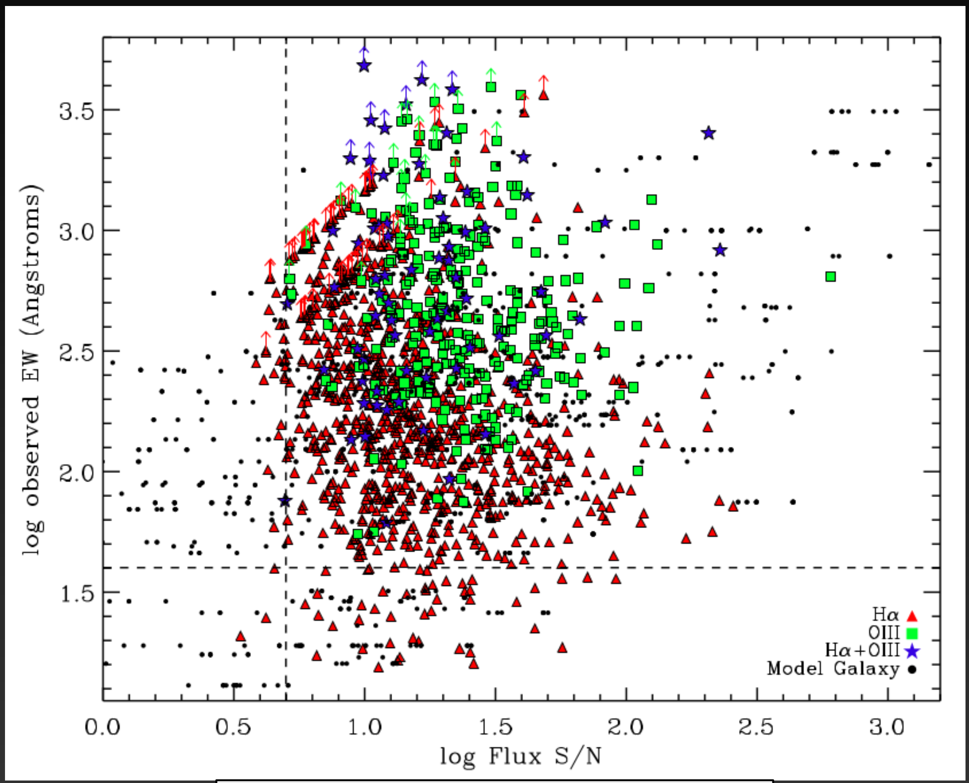
Atek et al. 2010

The WISP survey



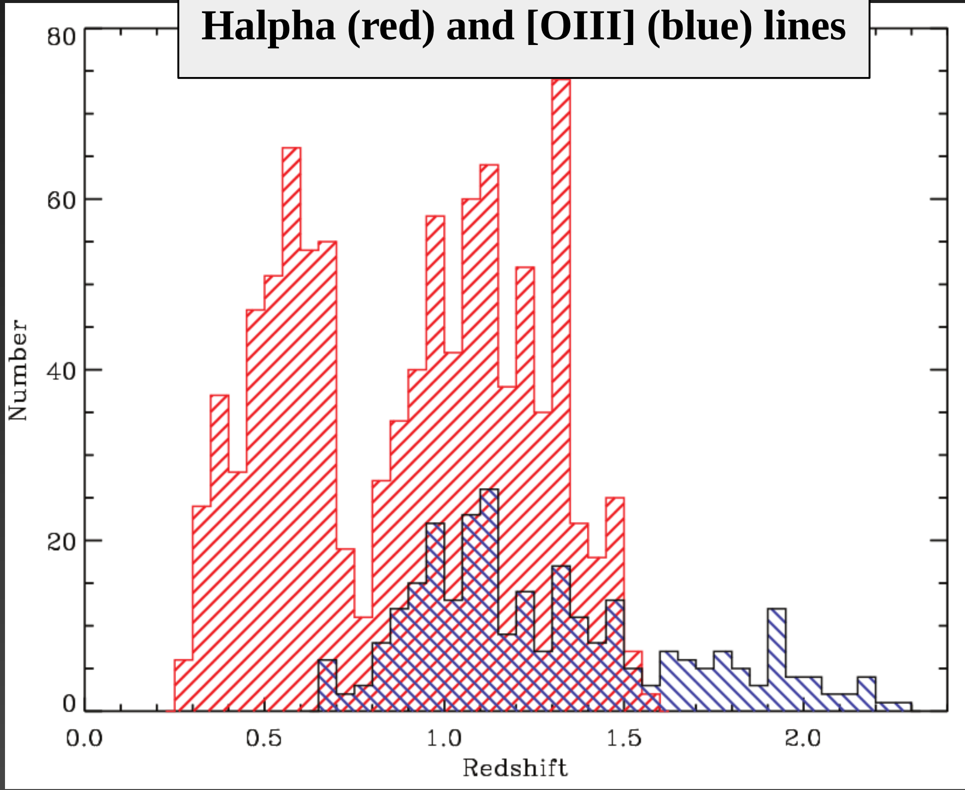
Atek et al. 2010

General properties of WISP galaxies



EW versus flux signal/noise

Redshift distribution of Halpha (red) and [OIII] (blue) lines

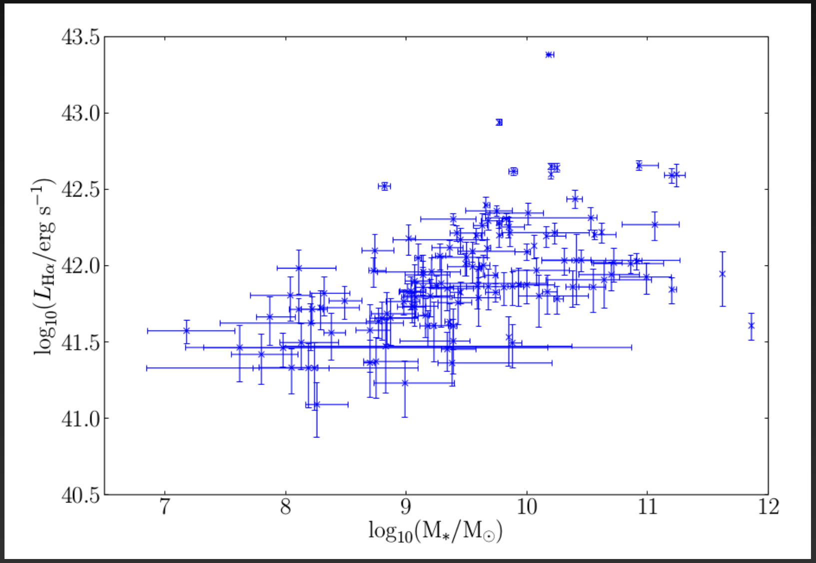


Colbert et al. 2013

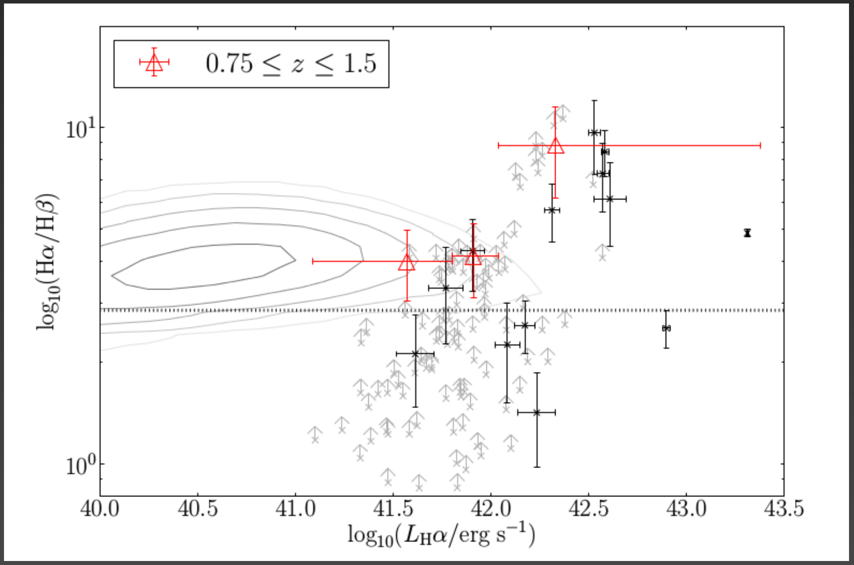
Galaxy spectra stacks at 0.75 ≤ z ≤ 1.5

312 galaxies in 17 fields where both Hα and Hβ fall simultaneously in the WISP spectral coverage → 128 galaxies after cleaning

Halpha Luminosities vs. Stellar Masses



Balmer decrement vs. Halpha Luminosities



Galaxy spectra stacks at 0.75 ≤ z ≤ 1.5

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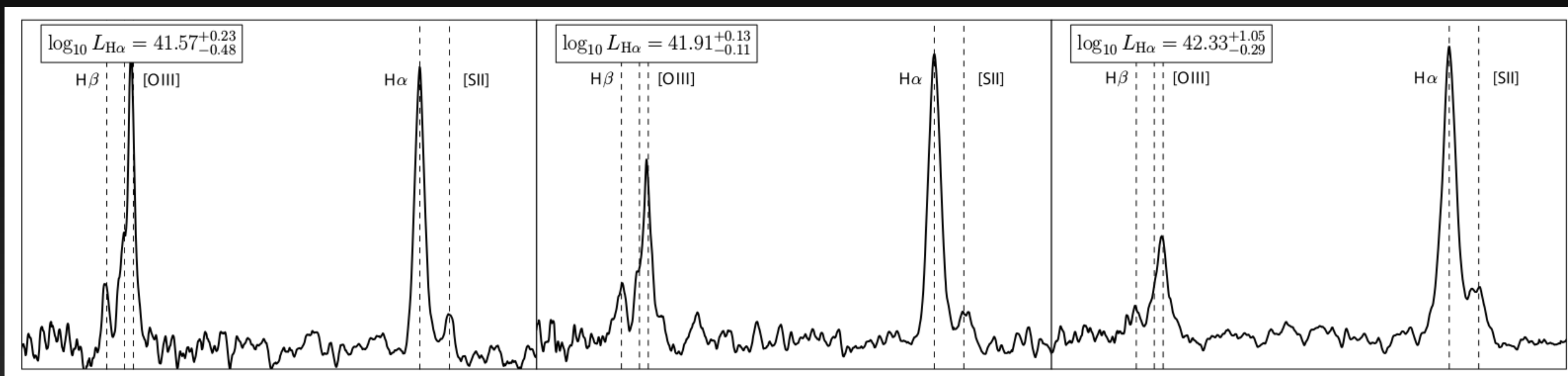
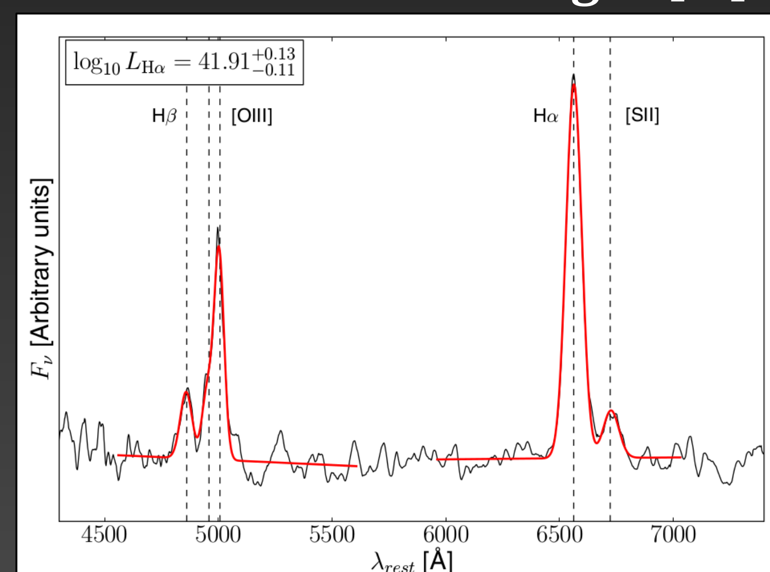


Luminosity bins

Rest-frame wavelength [Å]



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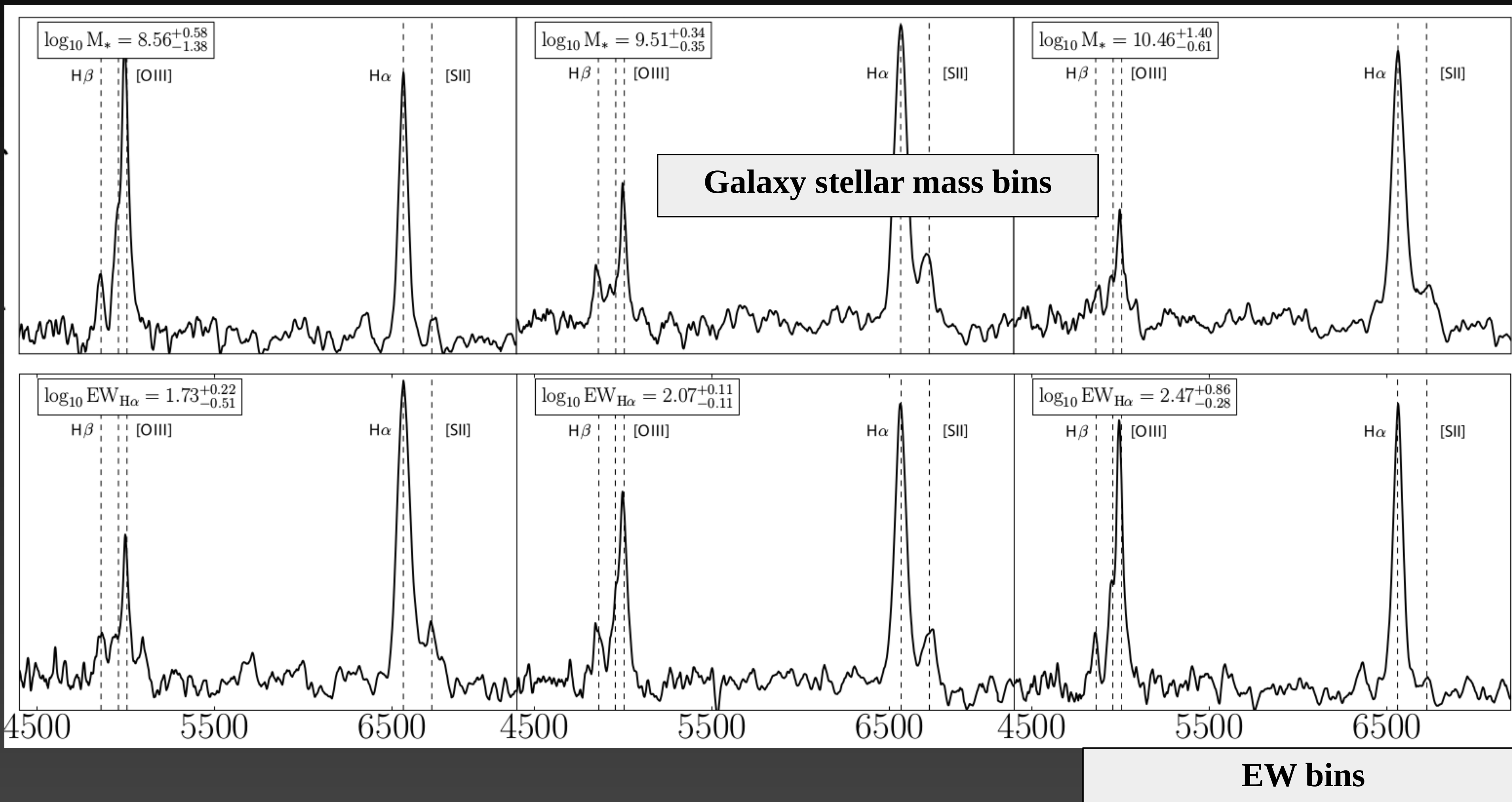
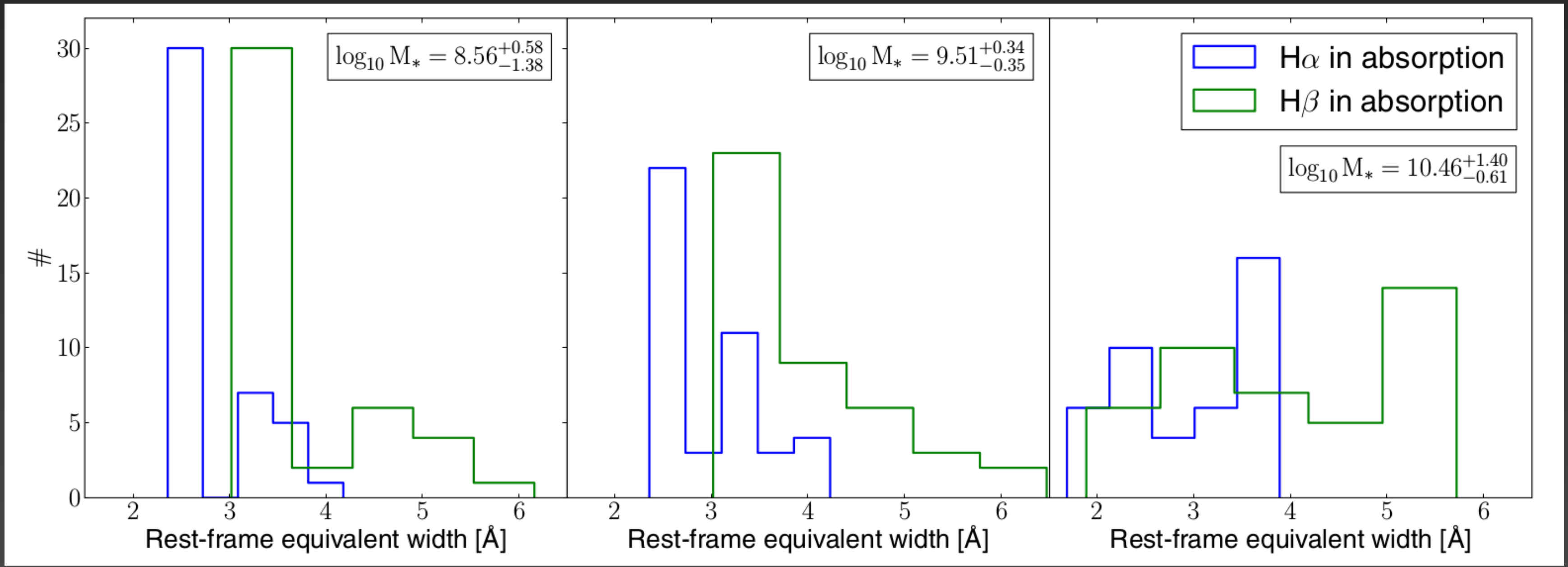


Emission-line contamination

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



Emission-line contamination

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

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

TABLE 2

OXYGEN ABUNDANCES AND GAS FRACTIONS

Bin	Stellar Mass[a] (10^{10} $M_\odot$)	$F_{H\alpha}$[b] (10^{-17} ergs s^{-1} cm^{-2})	$F_{[N II]}$[b] (10^{-17} ergs s^{-1} cm^{-2})	N2[c]	12 + log (O/H)[d]	M_{bar}[e] (10^{10} $M_\odot$)	μ_{gas}[f]	y_{eff}[g]
1....................	0.27 ± 0.15	20.5 ± 0.5	<1.2	<−1.22	<8.20	2.7 ± 1.7	0.85 ± 0.12	<0.027
2....................	0.71 ± 0.17	13.9 ± 0.3	1.4 ± 0.2	$-1.00^{+0.07}_{-0.09}$	$8.33^{+0.07}_{-0.07}$	2.1 ± 0.6	0.63 ± 0.12	0.013 ± 0.003
3....................	1.5 ± 0.3	18.7 ± 0.4	2.7 ± 0.3	$-0.85^{+0.05}_{-0.06}$	$8.42^{+0.06}_{-0.05}$	3.2 ± 1.1	0.48 ± 0.19	0.010 ± 0.002
4....................	2.6 ± 0.4	15.9 ± 0.4	2.6 ± 0.3	$-0.78^{+0.05}_{-0.05}$	$8.46^{+0.06}_{-0.05}$	4.0 ± 0.9	0.33 ± 0.12	0.007 ± 0.001
5....................	4.1 ± 0.6	24.3 ± 0.5	5.3 ± 0.4	$-0.66^{+0.03}_{-0.04}$	$8.52^{+0.06}_{-0.05}$	6.6 ± 1.1	0.36 ± 0.10	0.009 ± 0.002
6....................	10.5 ± 5.4	27.0 ± 0.4	7.4 ± 0.3	$-0.56^{+0.02}_{-0.02}$	$8.58^{+0.06}_{-0.04}$	13.1 ± 5.6	0.22 ± 0.11	0.007 ± 0.001

[a] Mean and standard deviation of stellar mass from SED fitting; we use a Chabrier (2003) IMF.
[b] Fluxes of Hα and [N II] λ6584 from the composite spectra.
[c] $N2 \equiv \log(F_{[N II]}/F_{H\alpha})$.
[d] Oxygen abundance from N2, using the calibration of Pettini & Pagel (2004).
[e] Mean and standard deviation of the baryonic mass $M_{gas} + M_\star$, with gas masses determined from the Schmidt law as described in the text.
[f] Mean and standard deviation of the gas fraction $\mu = M_{gas}/(M_{gas} + M_\star)$.
[g] Effective yield $y_{eff} = Z/\ln(1/\mu)$.

Erb et al. 2006

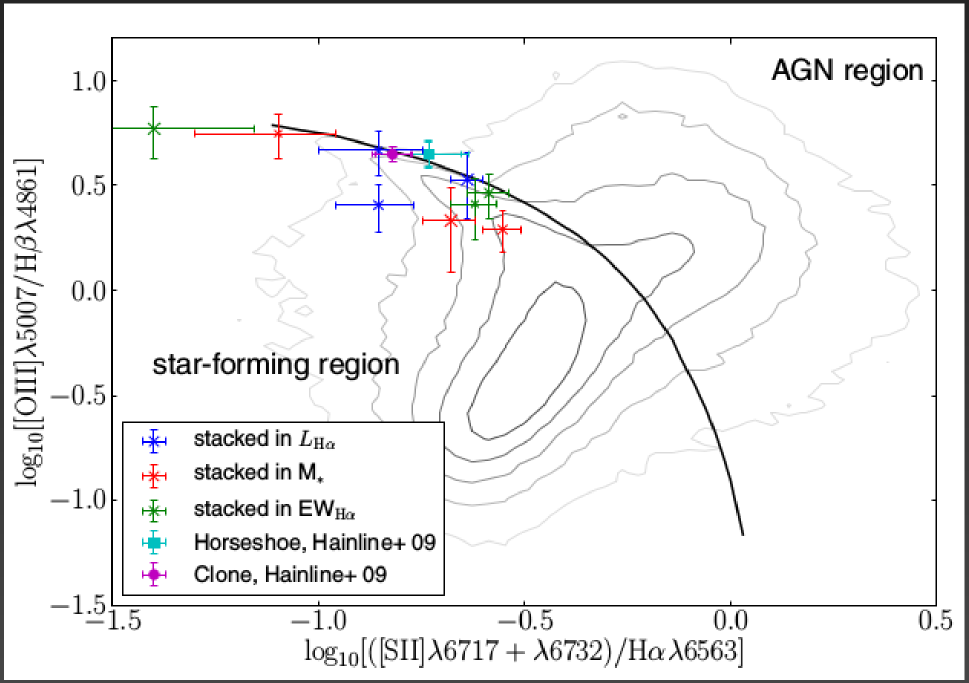
Emission-line contamination

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

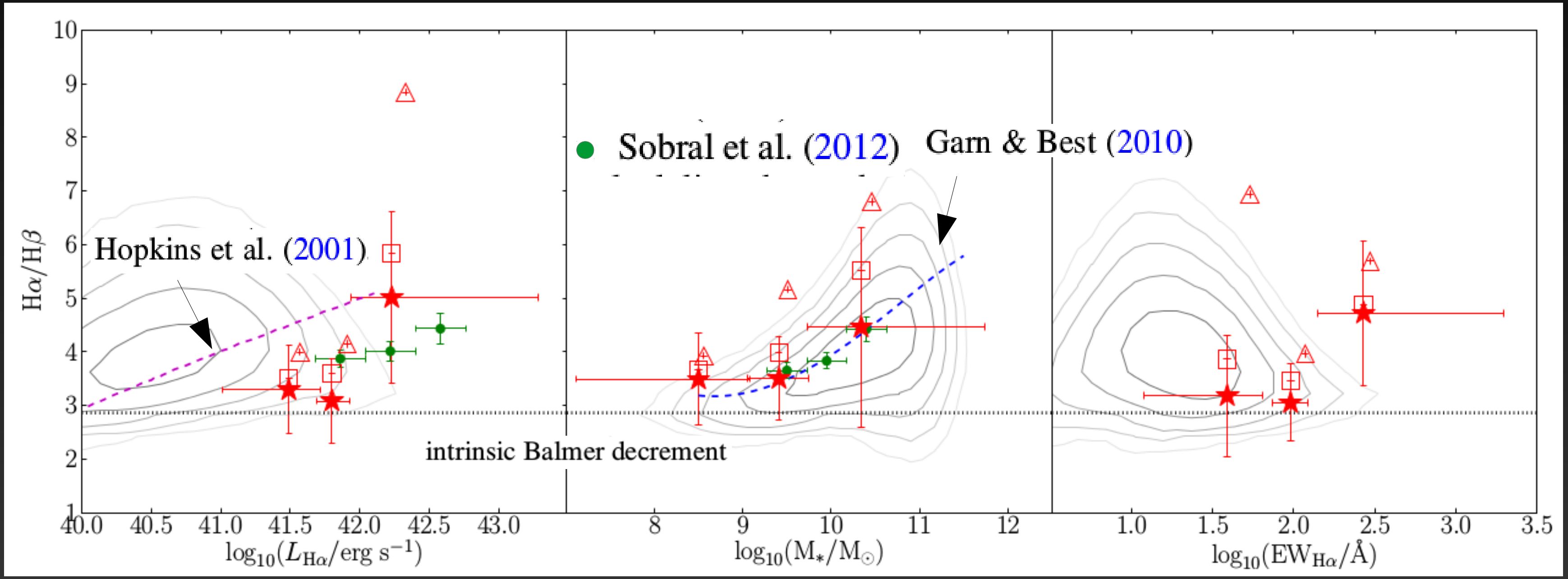
- [N II] (~ 15% in the worst case); Erb et al. 2006

- AGNs; BPT diagram

BPT diagram



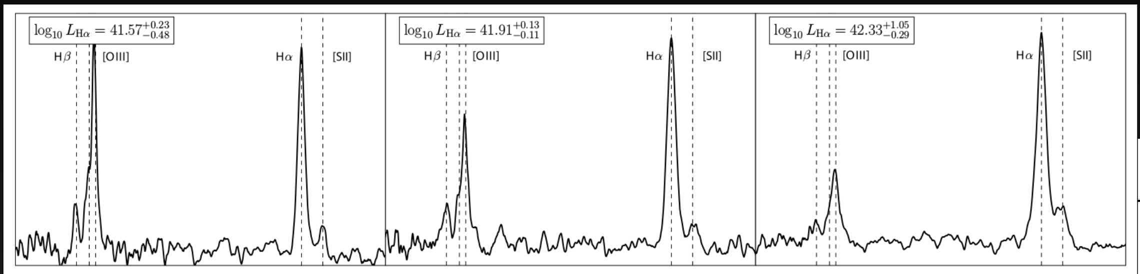
Balmer decrements at z ~ 1

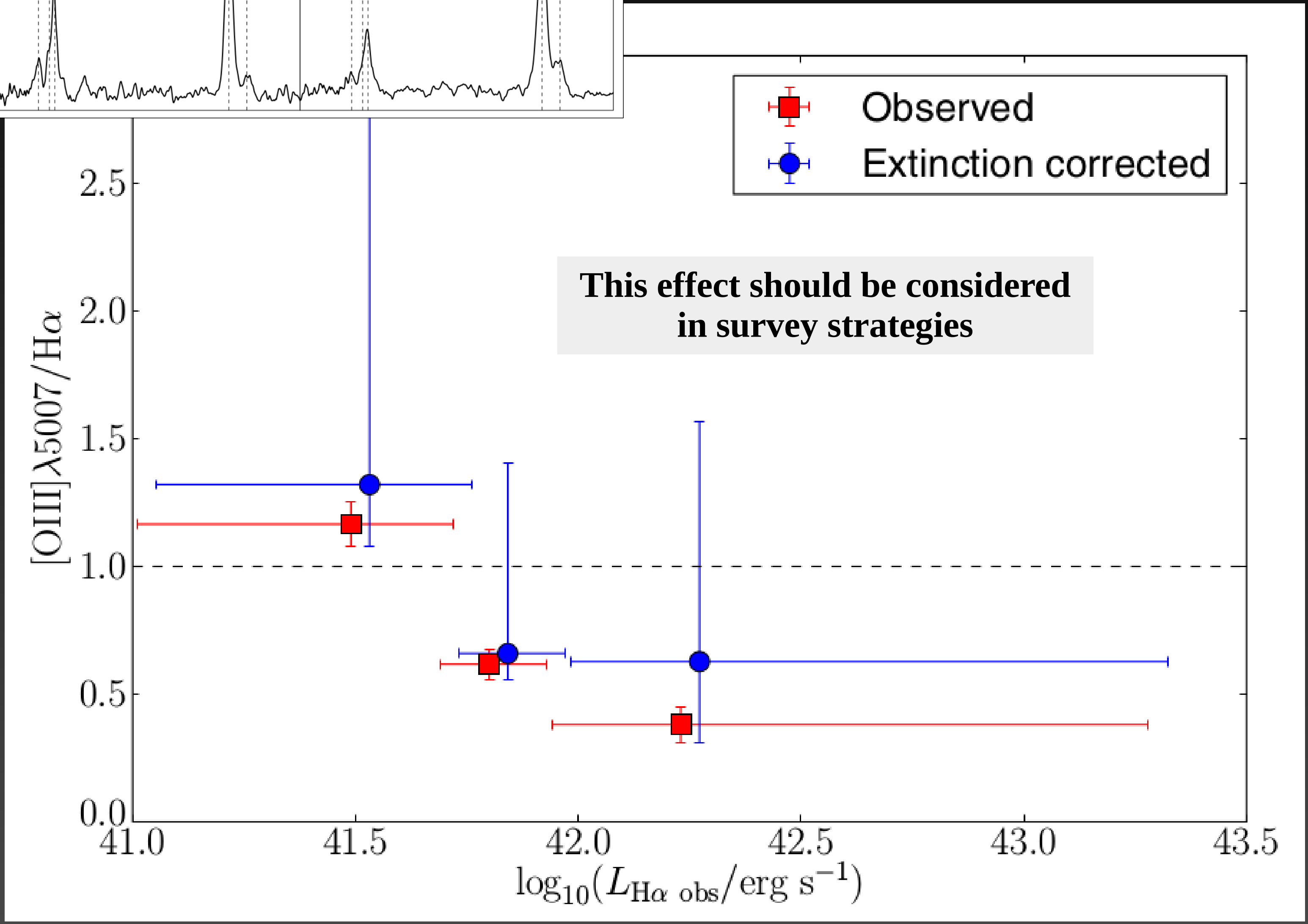


Balmer decrement versus Halpha luminosity, galaxy stellar mass, and Halpha EW

Important Conclusion: Typical assumption of assuming constant extinction for all luminosity overestimate the extinction for faint galaxies.

[OIII]/Halpha ratios

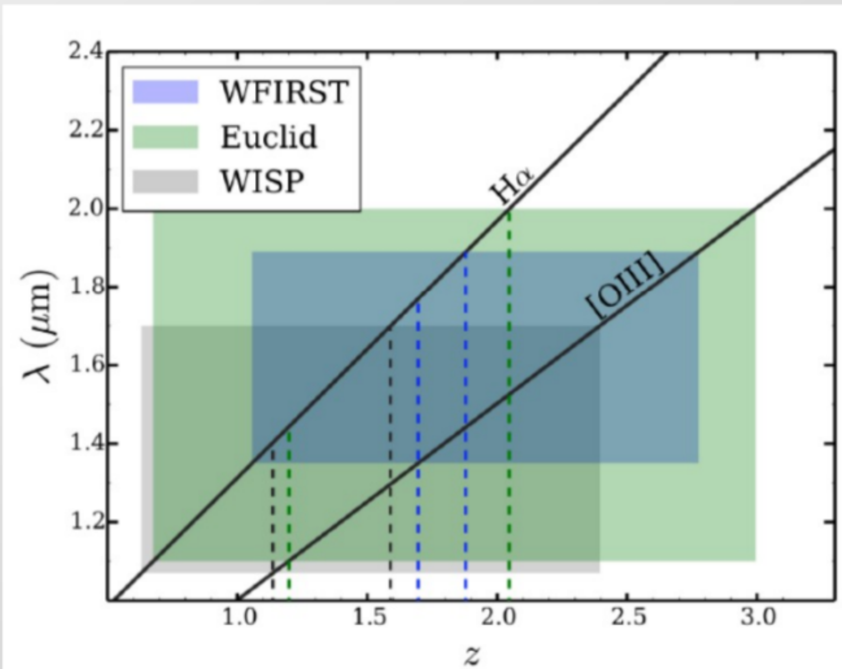




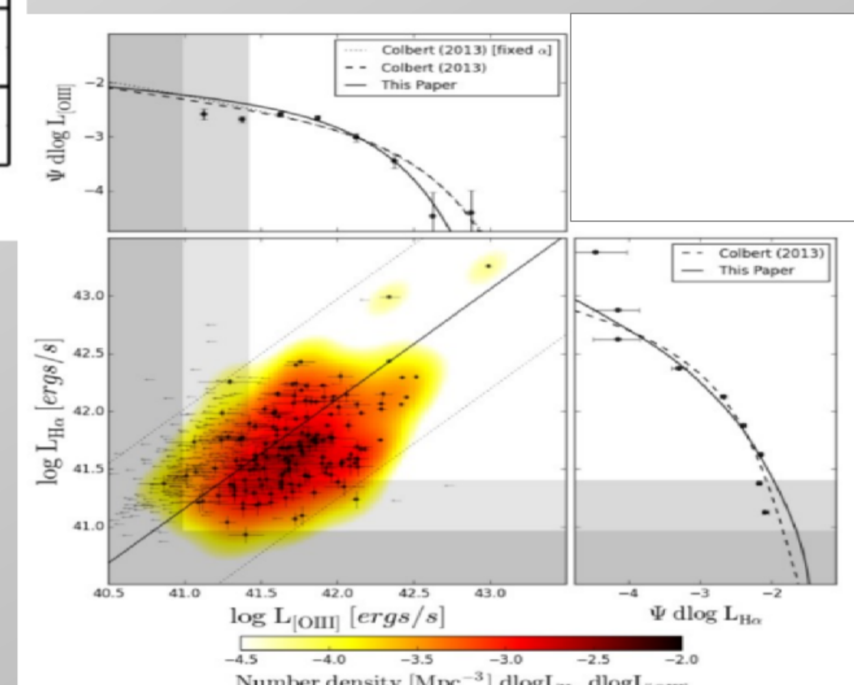
This effect should be considered in survey strategies

The future of near-IR surveys from space

Guiding Future IR Grism Surveys



WISP sample significantly increasing with time but also Euclid, WFIRST, DESI, eBOSS, 4MOST, ...



Mehta et al. (2015)

Summary and Conclusions

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

2.- 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.

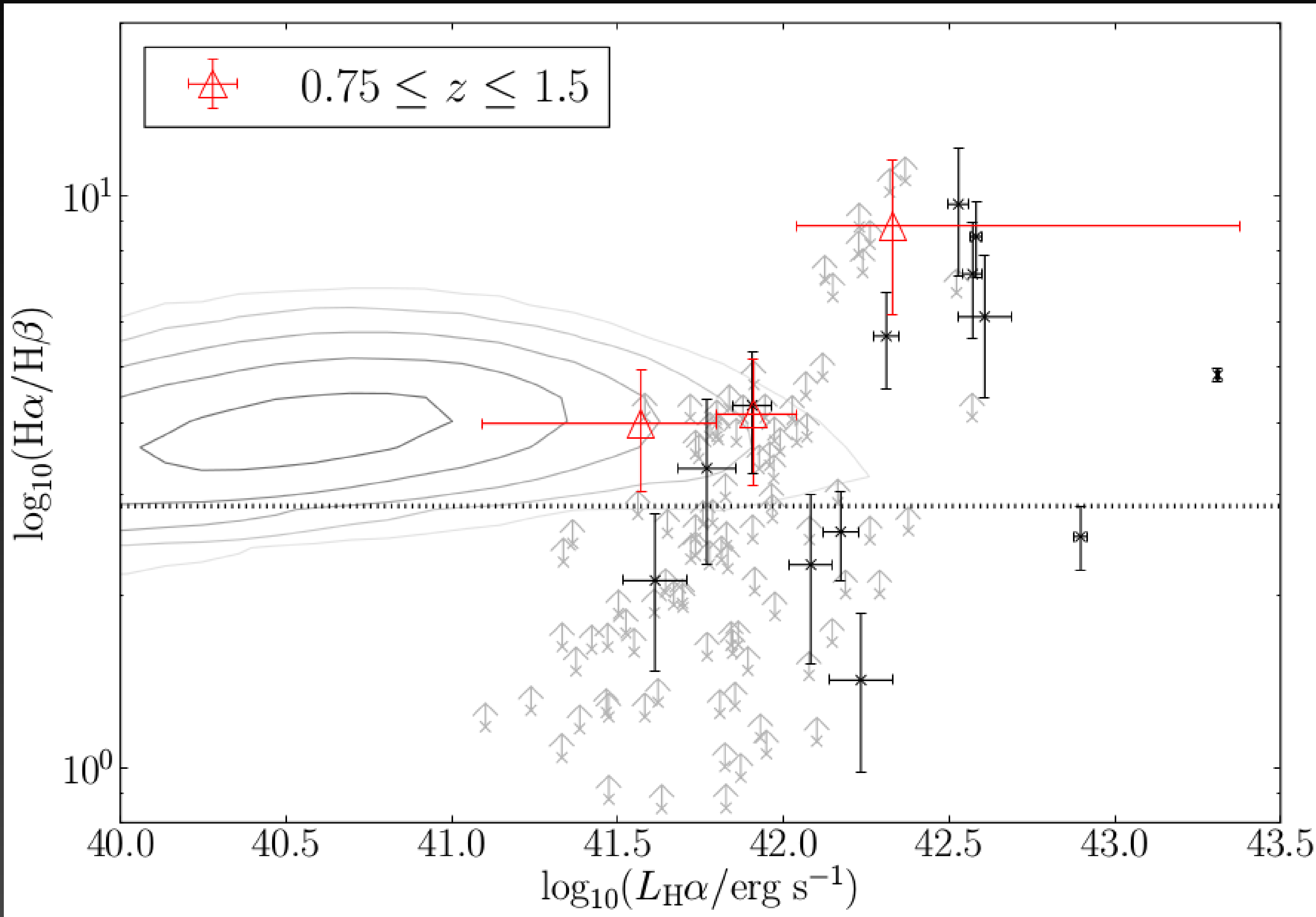
3.- The typical procedure of assuming a constant extinction for all luminosity significantly overestimate extinction for the lower luminosity galaxies.

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

5.- WISP will improve these measurements in the near future.

6.- EUCLID and WFIRST will improve these measurements in the longer term future.

Backup



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

Backup

Table 1
Emission-line Ratios of Stacked Spectra in $0.75 \leqslant z \leqslant 1.5$

$\langle \log_{10} X \rangle$	([S II] $\lambda6717 + \lambda6732$)/H$\alpha$ $\lambda6563$	[O III] $\lambda5007$/Hβ $\lambda4861$
Stacks binned in Hα luminosity, $X = L_{\mathrm{H}\alpha}/\mathrm{erg\,s^{-1}}$		
$41.57^{+0.48}_{-0.23}$	0.14 ± 0.04	4.65 ± 1.10
$41.91^{+0.11}_{-0.13}$	0.14 ± 0.03	2.55 ± 0.66
$42.33^{+0.29}_{-1.05}$	0.23 ± 0.02	3.37 ± 1.18
Stacks binned in galaxy stellar mass, $X = M_*/M_\odot$		
$8.56^{+1.38}_{-0.58}$	0.08 ± 0.03	5.58 ± 1.32
$9.51^{+0.35}_{-0.34}$	0.28 ± 0.03	1.95 ± 0.44
$10.46^{+0.61}_{-1.40}$	0.21 ± 0.03	2.15 ± 0.92
Stacks binned in Hα equivalent width, $X = \mathrm{EW}_{\mathrm{H}\alpha}/\mathrm{Å}$		
$1.73^{+0.51}_{-0.22}$	0.24 ± 0.03	2.58 ± 0.84
$2.07^{+0.11}_{-0.11}$	0.26 ± 0.03	2.91 ± 0.69
$2.47^{+0.28}_{-0.86}$	0.04 ± 0.03	5.89 ± 1.63

Note. These are the values for plotting the BPT diagram shown in Figure 6.

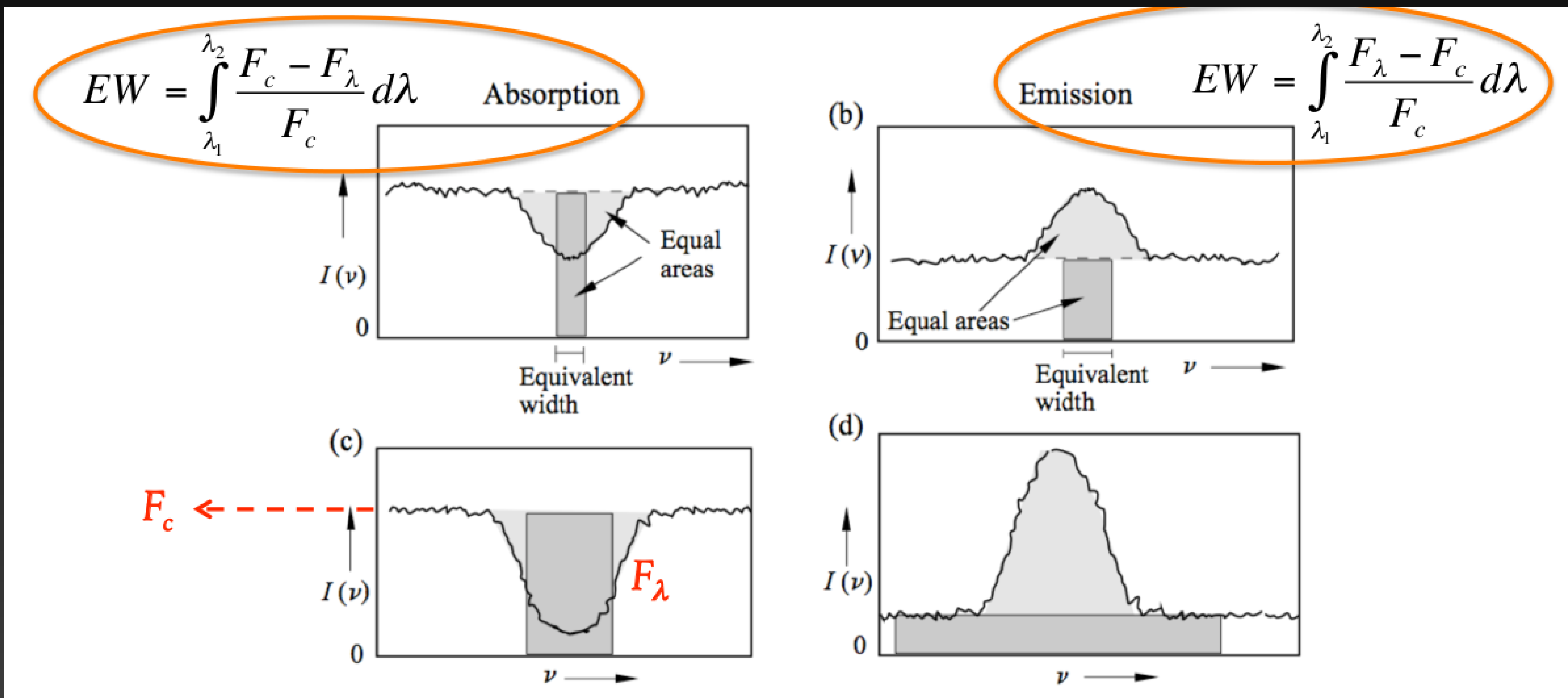
Backup

Table 2
Dust Properties for WISP Galaxies

N[a]	$\langle\log_{10}(X)\rangle$	H_α/H_β[b]	H_α/H_β[c]	H_α/H_β[d]	$E(B-V)$[e] (mag)	$A_{H\alpha}$[e] (mag)	A_V[e] (mag)
Galaxy spectra stacked in Hα luminosity, $X \equiv L_{H\alpha}/\mathrm{erg\ s^{-1}}$							
43	$41.57^{+0.23}_{-0.48}$	3.99 ± 0.95	3.51 ± 0.85	3.29 ± 0.82	0.12 ± 0.21	0.40 ± 0.71	0.48 ± 0.86
43	$41.91^{+0.13}_{-0.11}$	4.14 ± 1.03	3.59 ± 0.91	3.08 ± 0.79	0.06 ± 0.22	0.21 ± 0.73	0.25 ± 0.89
42	$42.33^{+1.05}_{-0.29}$	8.84 ± 2.66	5.84 ± 1.86	5.01 ± 1.60	0.48 ± 0.27	1.59 ± 0.98	1.94 ± 1.17
Galaxy spectra stacked in stellar mass, $X \equiv M_*/M_\odot$							
43	$8.56^{+0.58}_{-1.38}$	3.92 ± 0.93	3.66 ± 0.87	3.49 ± 0.85	0.17 ± 0.21	0.57 ± 0.71	0.69 ± 0.85
43	$9.51^{+0.34}_{-0.35}$	5.16 ± 1.10	3.99 ± 0.88	3.50 ± 0.78	0.17 ± 0.19	0.57 ± 0.65	0.70 ± 0.78
42	$10.46^{+1.40}_{-0.61}$	6.80 ± 2.79	5.52 ± 2.29	4.46 ± 1.86	0.38 ± 0.36	1.26 ± 1.22	1.54 ± 1.47
Galaxy spectra stacked in rest-frame Hα equivalent width, $X \equiv \mathrm{EW}_{H\alpha}/\mathrm{Å}$							
43	$1.73^{+0.22}_{-0.51}$	6.93 ± 2.16	3.86 ± 1.36	3.18 ± 1.13	0.09 ± 0.30	0.30 ± 1.01	0.36 ± 1.23
43	$2.07^{+0.11}_{-0.11}$	3.96 ± 0.90	3.46 ± 0.80	3.05 ± 0.72	0.06 ± 0.20	0.19 ± 0.67	0.23 ± 0.81
42	$2.47^{+0.86}_{-0.28}$	5.69 ± 1.58	4.88 ± 1.37	4.72 ± 1.35	0.43 ± 0.24	1.42 ± 0.88	1.73 ± 1.05

Notes. All observables are given for nebular properties.
[a] N is the number of stacked galaxy spectra in the bin.
[b] No correction applied.
[c] Corrected only for Hα and Hβ absorption lines (see Section 2.6).
[d] Corrected for Hα and Hβ absorption lines and [N II] contamination (see Section 2.6).
[e] Calculated from the absorption line and [N II] corrected Balmer decrements.

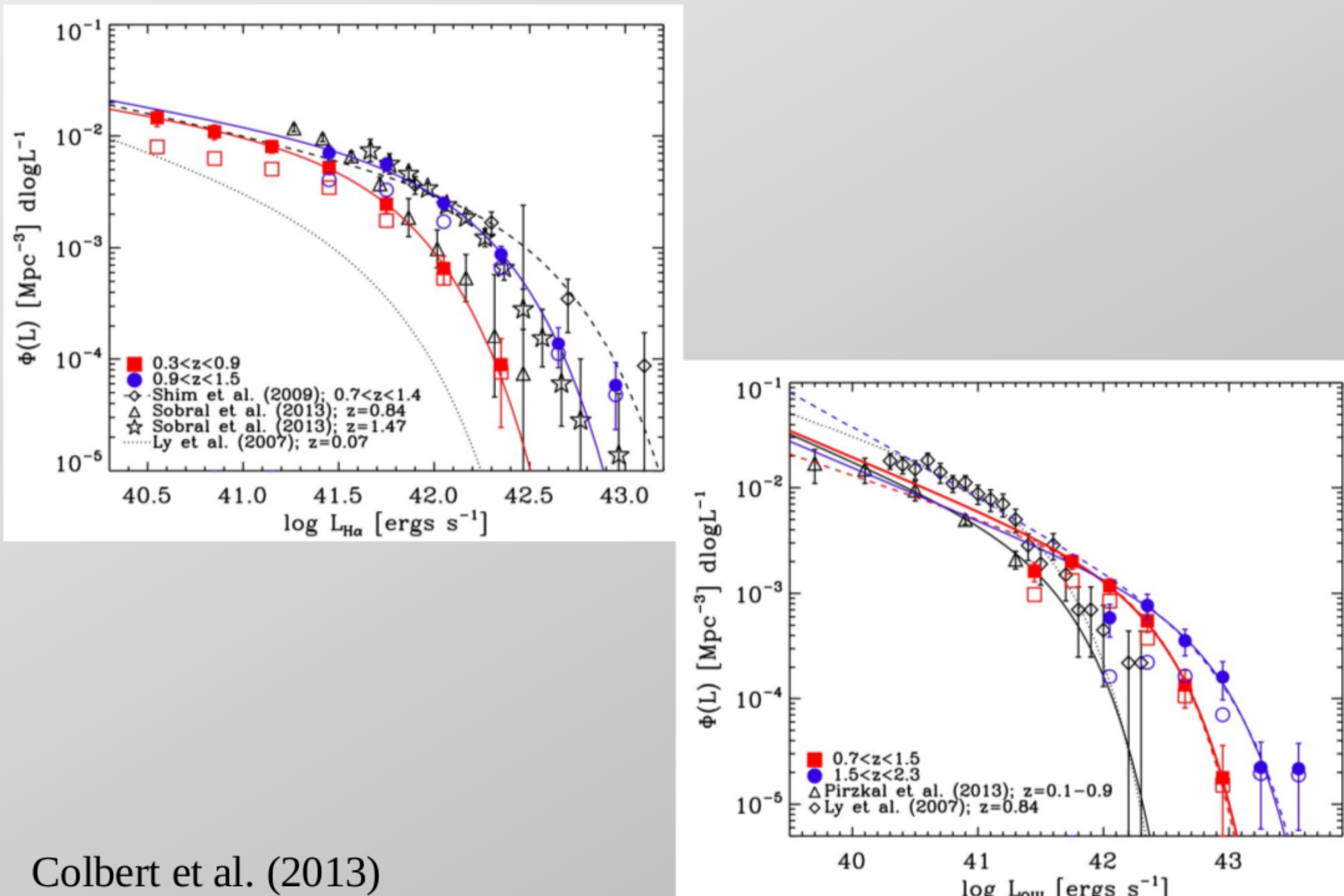
The Equivalent width concept



Santini's lecture

Other WISP science topics (1/3)

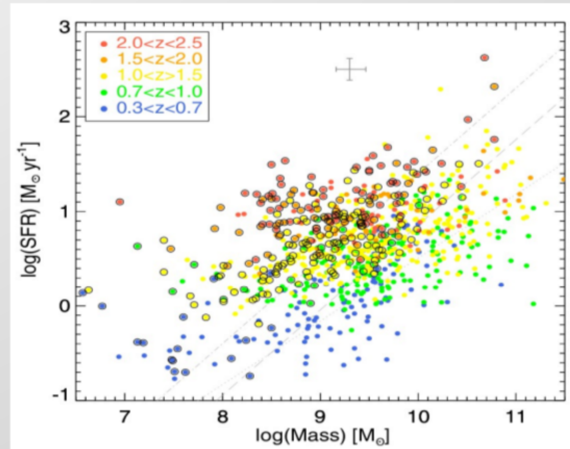
Galaxy Luminosity Functions

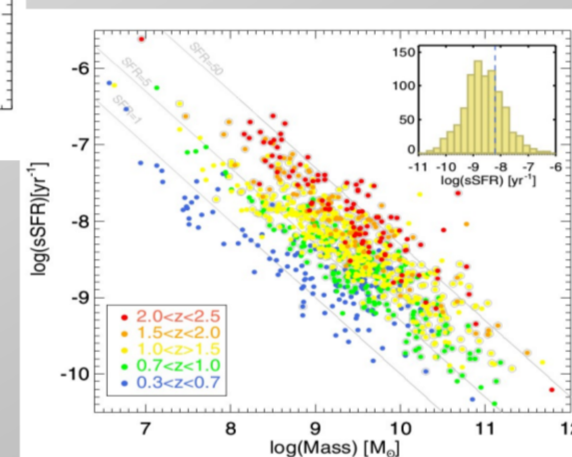


Colbert et al. (2013)

Other WISP science topics (2/3)

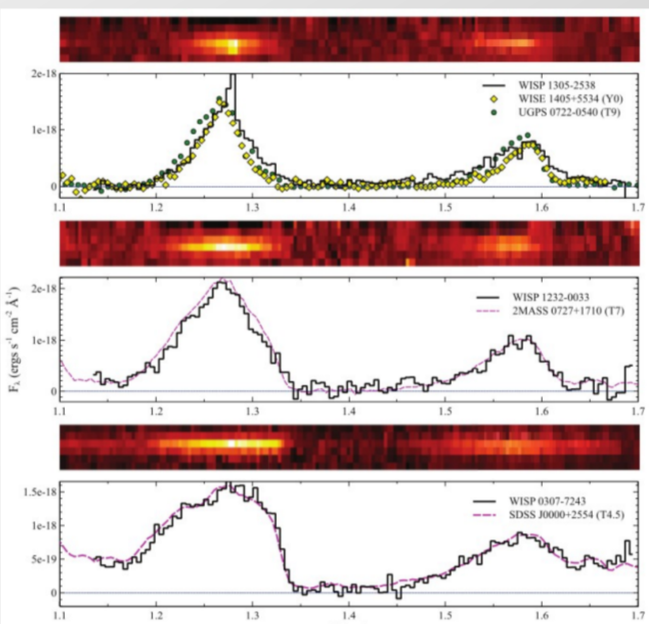
The Star-forming Main Sequence





Atek et al. (2014)

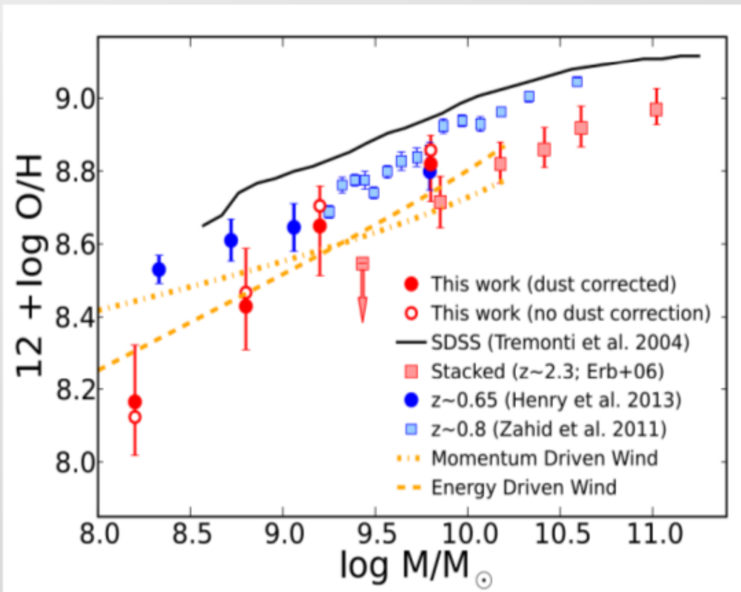
Discovery of Three Distant Cold Brown D



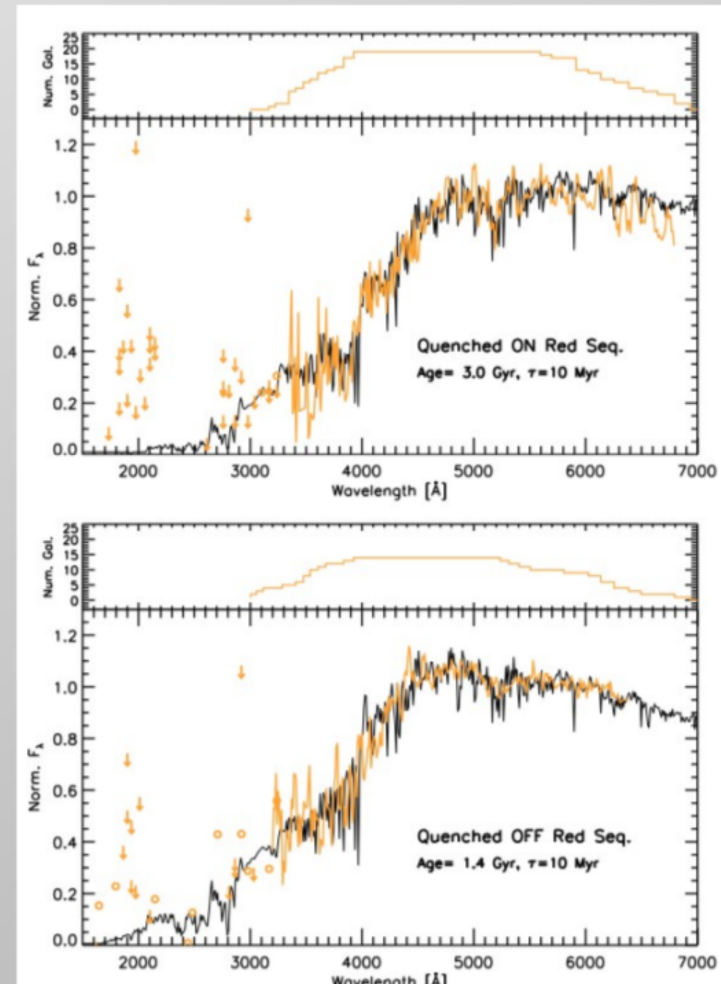
Masters et al. (2012)

Other WISP science topics (3/3)

Mass-metallicity & Early-type Galaxies

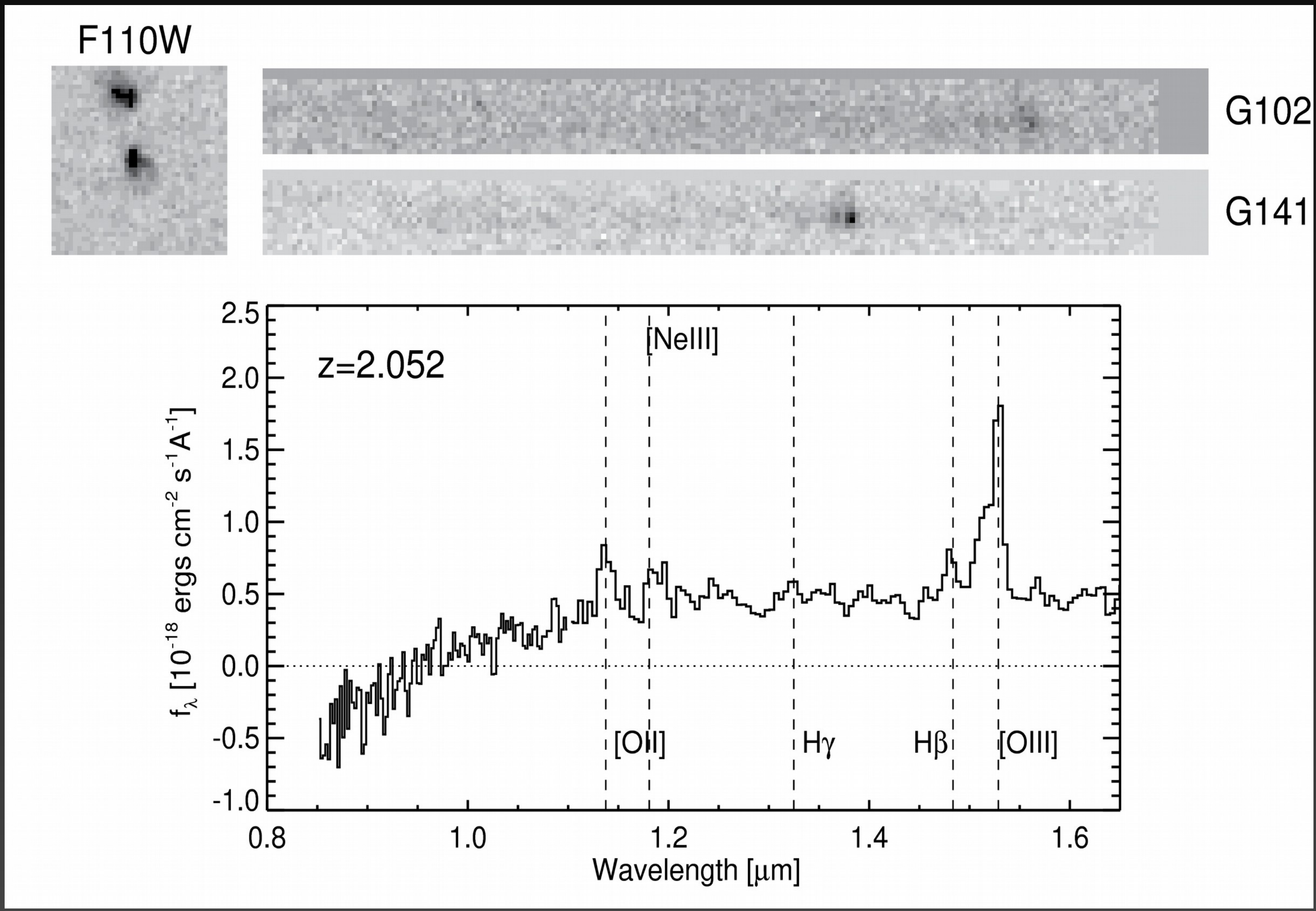


Henry et al. (2013)



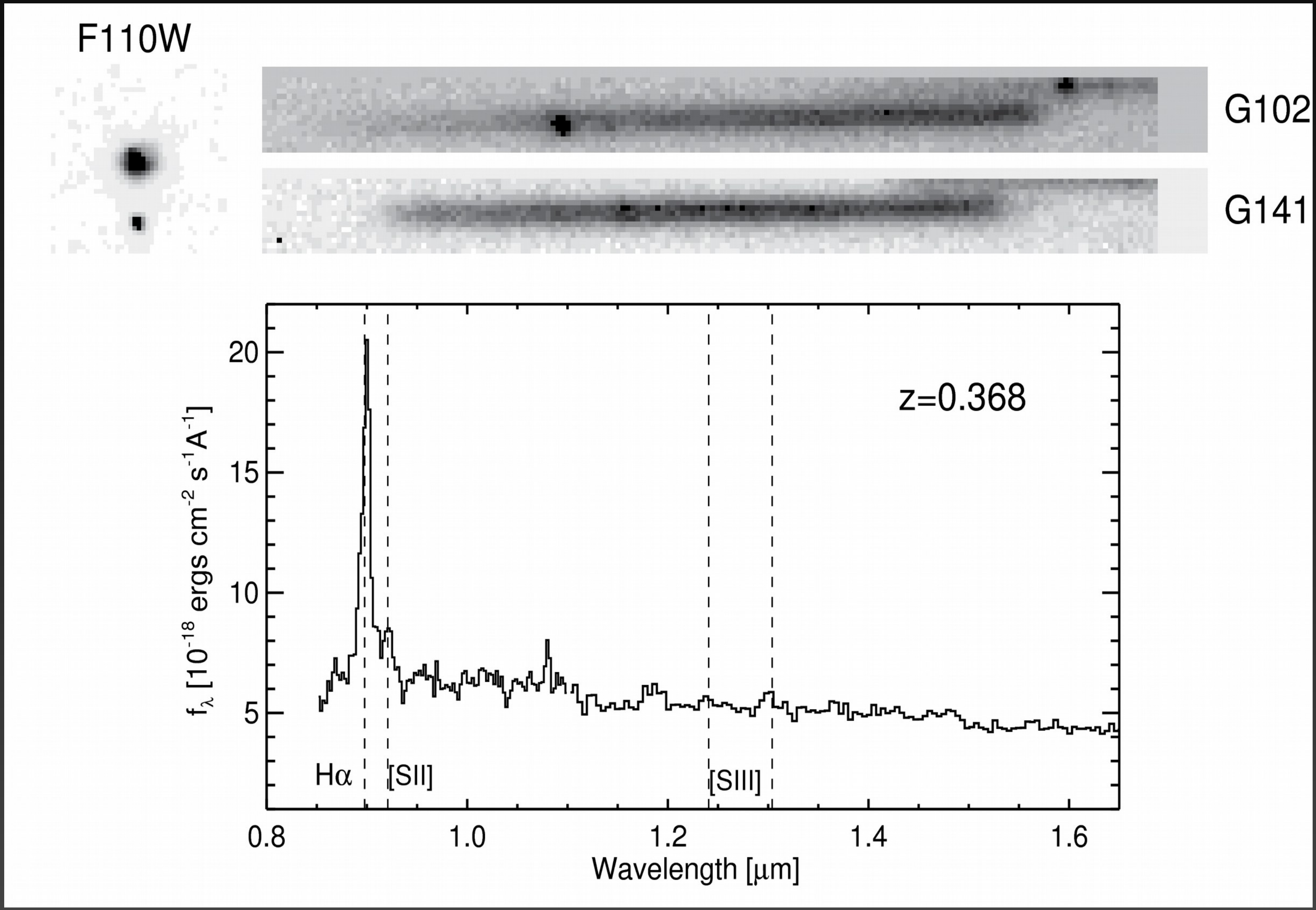
Bedregal et al. (2013)

The WISP survey



Atek et al. 2010

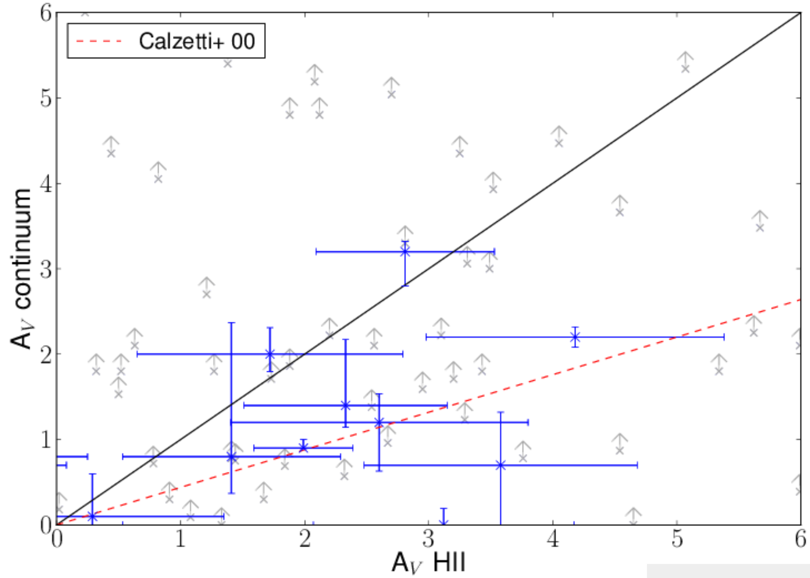
The WISP survey



Atek et al. 2010

Stellar vs. nebular extinction

Calzetti et al. 2000; E(B-V)stellar = (0.44+-0.03) E(B-V)



Stellar extinction versus nebular extinction