Nebular HeII emission in extremely metal-poor SF galaxies: IZw18 & SBS0335-052E

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Escape of Lyman radiation from galactic Labyrinths, Crete, Sept 11-14 2018

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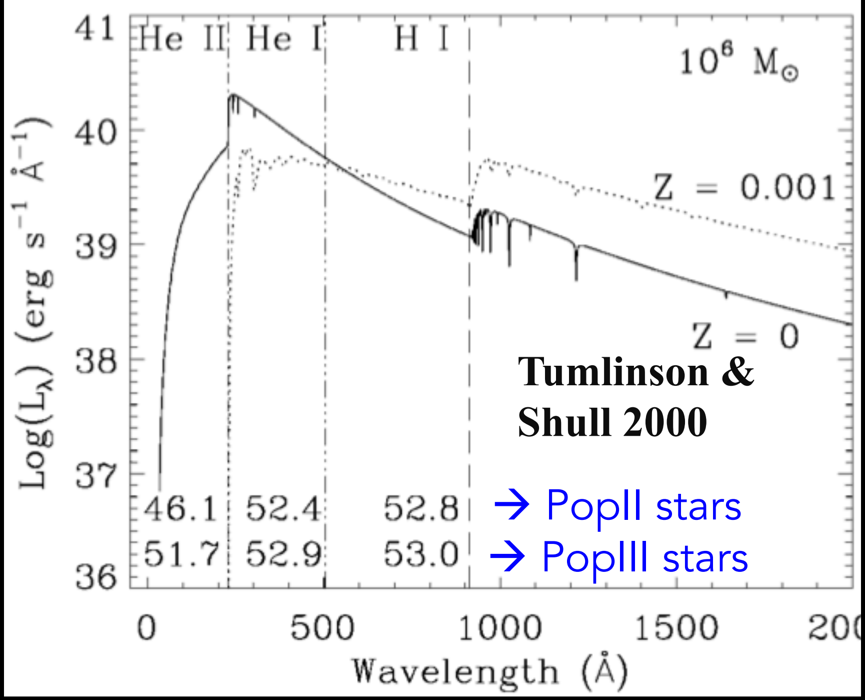
Why study HeII lines ?

- ✔ Nebular HeII emission (λ1640,4686 Å) indicates extremely hard UV-emitting spectrum (E > 54 eV); more frequent observed among SF galaxies at high-z than in local SF objects (e.g. Kehrig+2011; Cassata+2013;). Good tracer of popIII.
- ✔ Expected harder SEDs at lower metallicities, expected in the distant Universe

Z	IMF	Q(H)	Q(HeI)	Q(HeII)
0.	A	46.98	46.75	45.54
0.	B	47.29	47.10	46.26
0.	C	47.98	47.80	47.05
10^{-7}	A	46.94	46.65	43.45
10^{-7}	B	47.30	47.06	45.61
10^{-7}	C	48.01	47.78	46.39
10^{-5}	A	46.90	46.55	42.39
10^{-5}	B	47.30	46.99	44.56
10^{-5}	C	48.02	47.73	45.35

Q(X) [log(photon/s/$M_\odot$)]

Schaerer (2003); see also eg Eldridge+ (2017)



Synthetic spectra of Population II and Population III clusters → PopIII stars can produce many HeII ionizing photons

HeII ionization: important observational clues

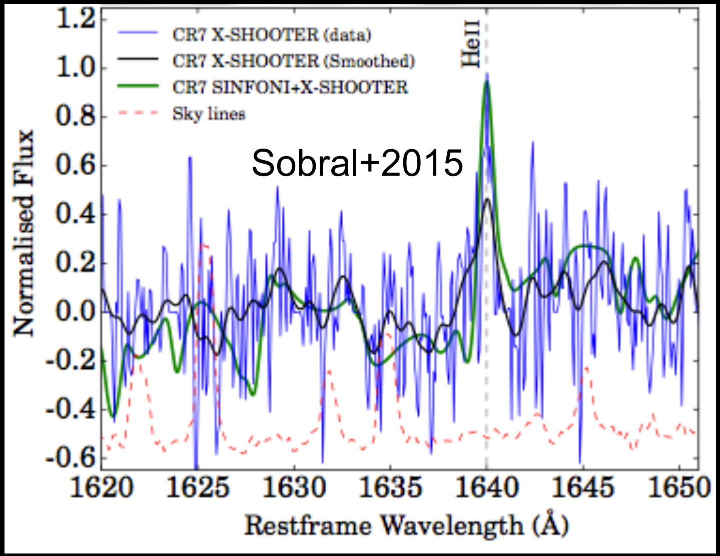
✔ Sources of ionizing radiation (hot Wolf-Rayet (WR) stars, fast shocks, X-ray binaries) have been proposed to explain the HeII ionization in local star-forming systems (e.g., Garnett+1991; Schaerer 1996; Thuan & Izotov 2005; Gräfener & Vink 2015)

But

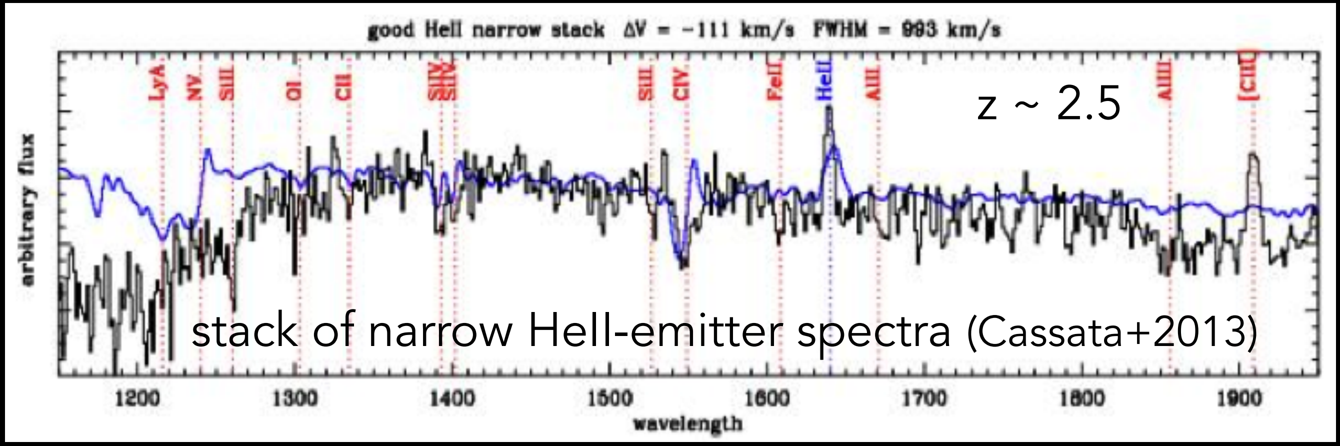
✔ Nebular HeII does not appear to be always associated with WRs and the origin of the HeII ionization in several SF objects remains unclear → (e.g. Guseva+2001; Shirazi & Brinchmann 2012; Kehrig+2013; 2015)

HeII ionization: observational clues

Nebular HeII does not appear to be always associated with WRs → WRs cannot explain the HeII ionization in all cases, particularly at low metallicity (e.g. Guseva+2001; Shirazi & Brinchmann 2012; Kehrig+2013)



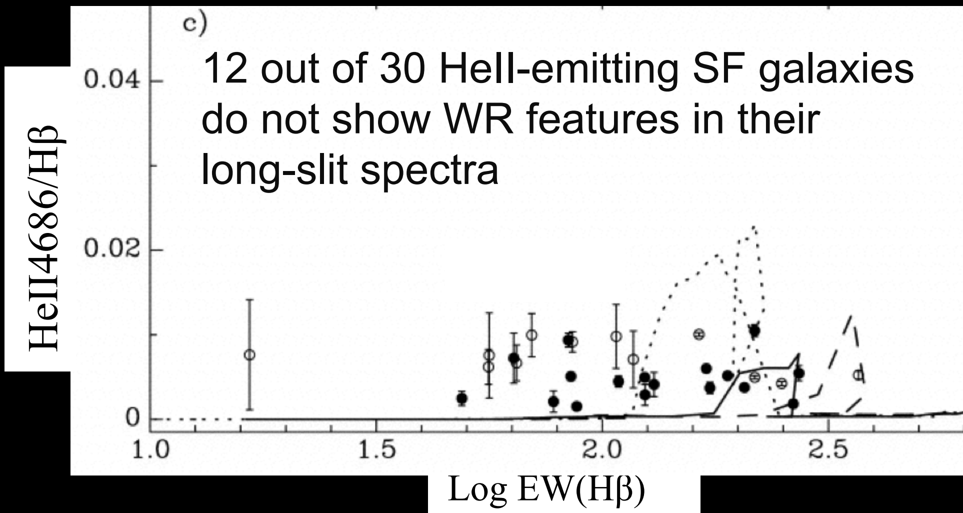
CR7 (the brightest Lyα emitter at z = 6.6): WR stars interpretation controversial. PopIII stars or MBH (e.g. Sobral+2015; Agarwal +2017; Bowler+2017), but see low signal in new data analysis (Sobral+ 2017) !!



Stellar population models including WRs do not reproduce the properties of the narrow HeII emitters. Peculiar stellar population or popIII stars ? (see also Grafener & Vink 2015)

HeII ionization in the local Universe: observational clues

Guseva et al. (2000)



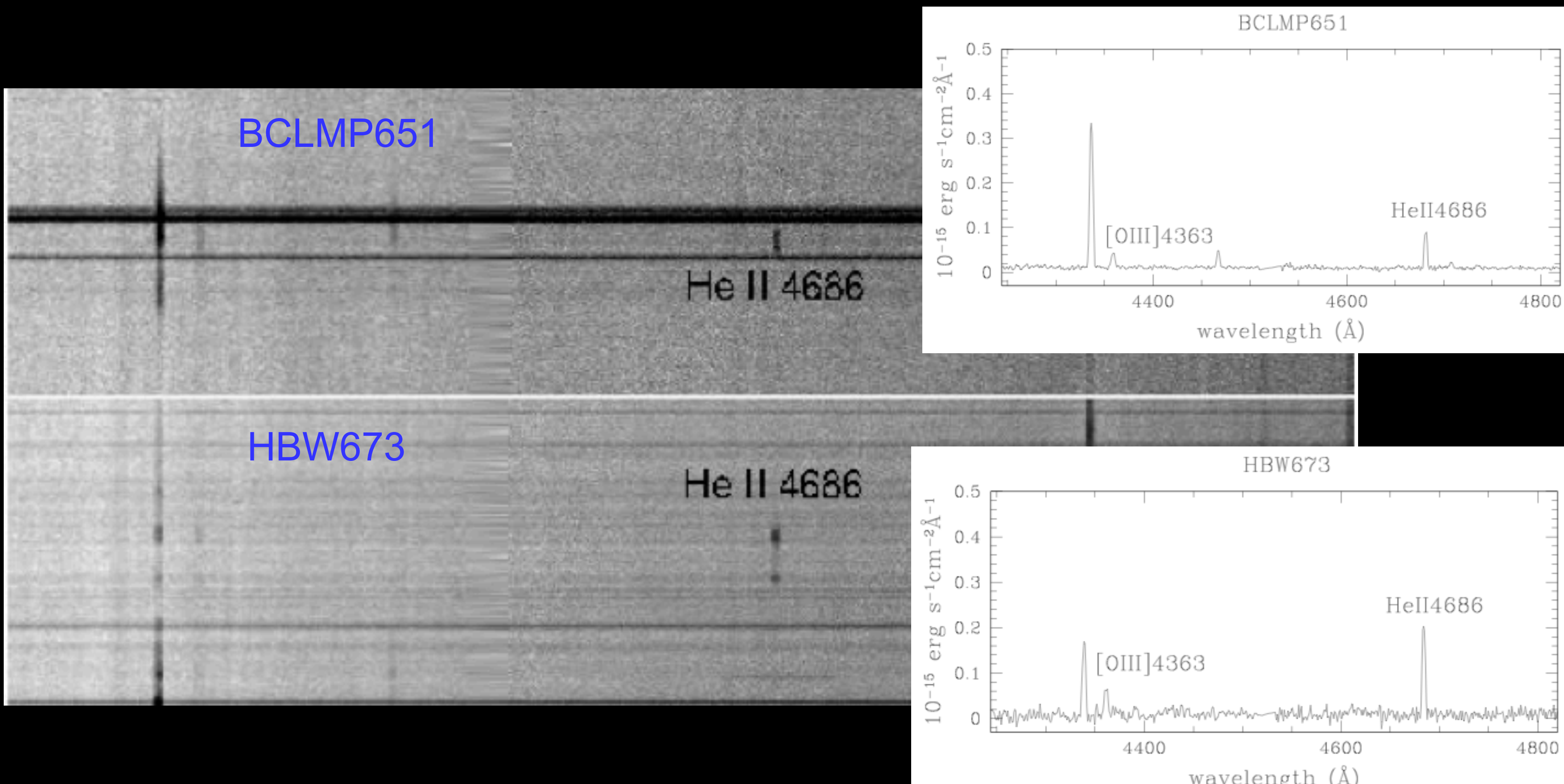
galaxies with detected and nondetected WR features are indistinguishable and other mechanisms for the origin of nebular HeII need to be invoked

Shirazi & Brinchmann (2012): 40% of the HeII-emitting SF galaxies from SDSS do not show WR signatures → lack of WR features does not seem to be a S/N issue

HeII ionization in the local Universe: observational clues

The origin of the nebular HeII still remains difficult to understand in many cases

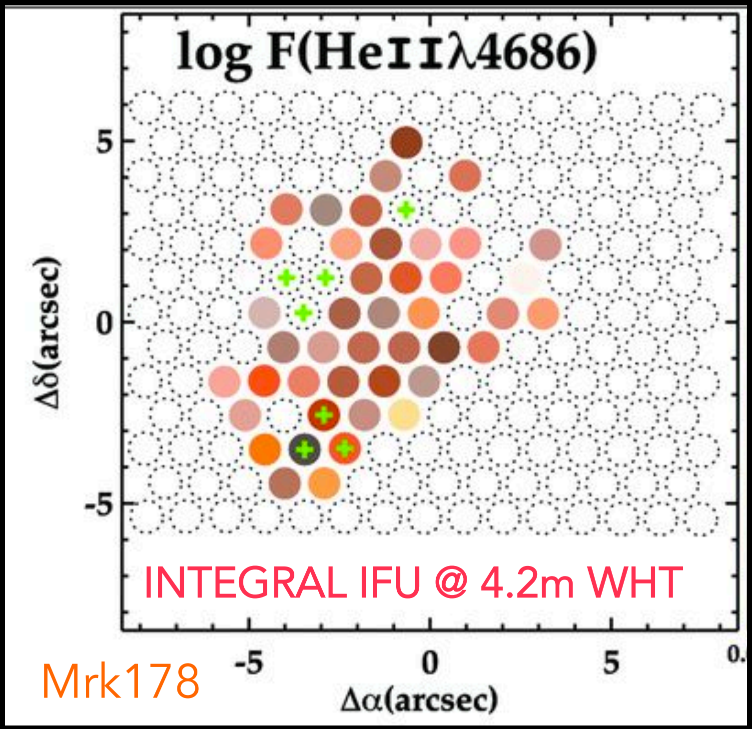
GMOS/GEMINI spectroscopy of HeII nebulae in M33 (Kehrig, Oey, Crowther+2011)



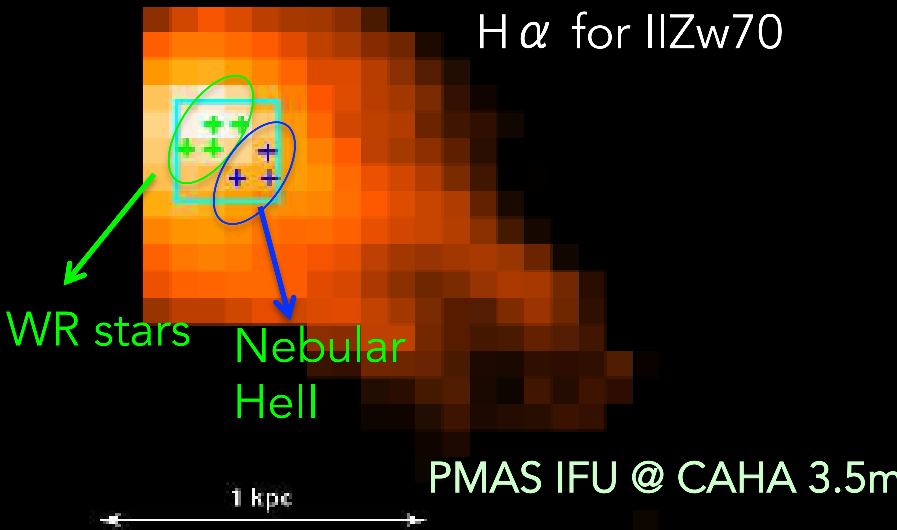
2 new HeII nebulae in M33 not associated with any hot massive star

HeII ionization in local Universe galaxies with IFUS

(Z ~ 10% $Z_\odot$) and IIZw70 (Z ~ 15% $Z_\odot$): HeII emission is extended and goes much beyond the location of WR stars



Kehrig,Vilchez+2013



Kehrig,Vilchez+2008

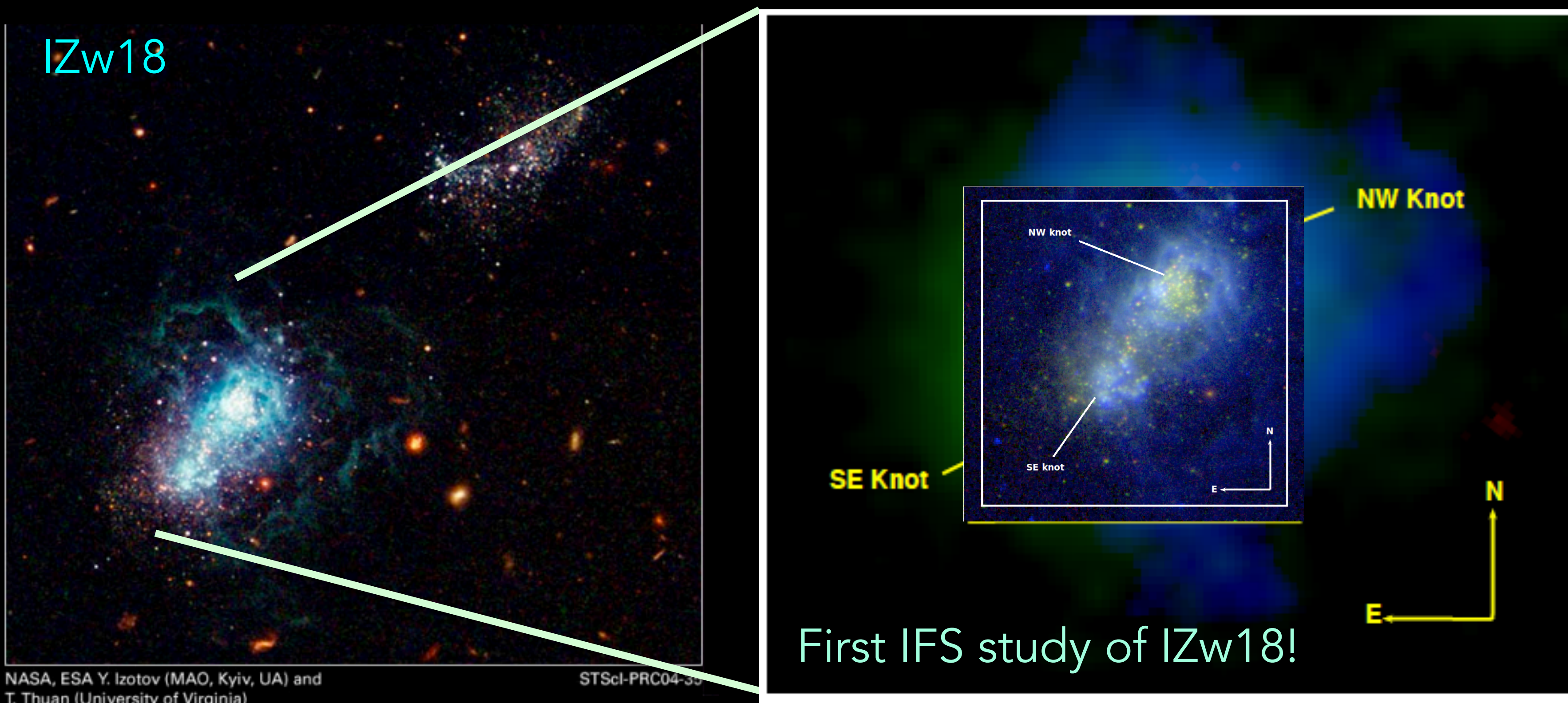
Measured spatial separation between WR stars and the HeII-emitting zone (see also Izotov+2006; Herenz+2017), and where the non-detection of WR features is unlikely to be an effect of the weakness of WR bumps (see also Shirazi & Brinchmann 2012)

IFS study of IZw18

Kehrig, Vilchez et al. (2015,2016)

The nearby lowest-metallicity (Z~0.0004) SF galaxy and our best local analog of faraway starbursts (e.g. Skillman & Kennicutt 1993; Vilchez & Iglesias-Paramo 1998)

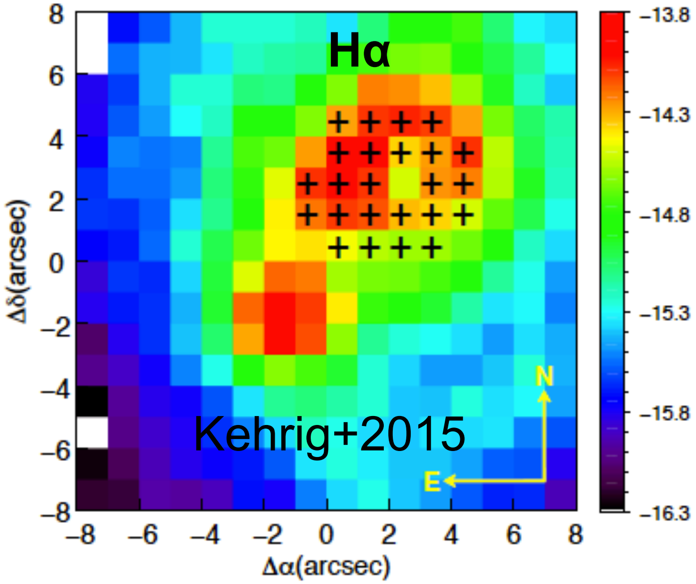
Natural local counterpart of distant HeII-emitters!

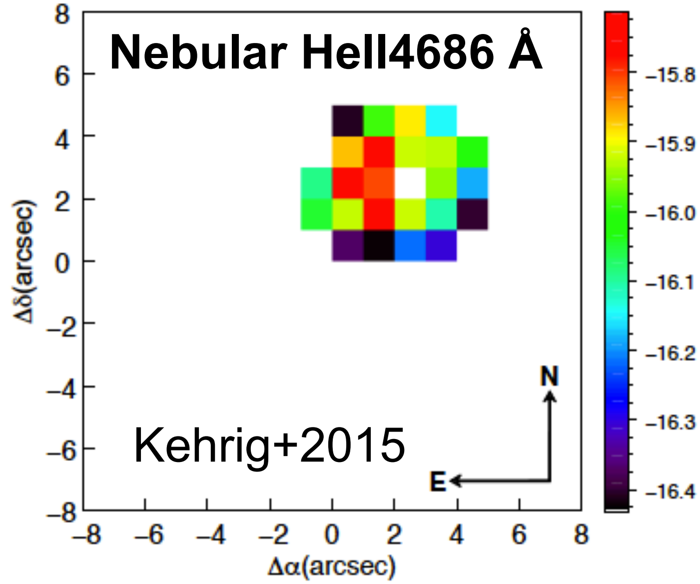


FOV ~ 1.4 kpc x 1.4 kpc

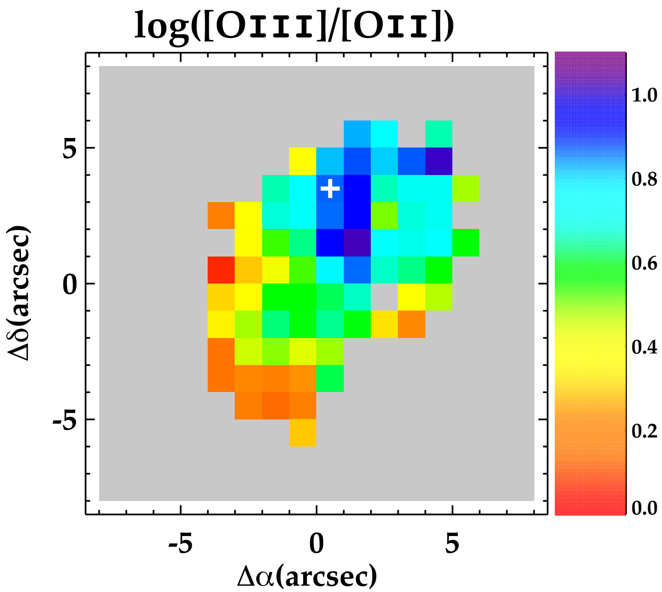
Optical spectra: PMAS IFU @ CAHA 3.5m telescope

We discovered a large nebular HeII4686-emitting region





1″/spaxel ~ 88 pc/spaxel @ D=18.2 Mpc



Kehrig, Vilchez+2015, ApJL

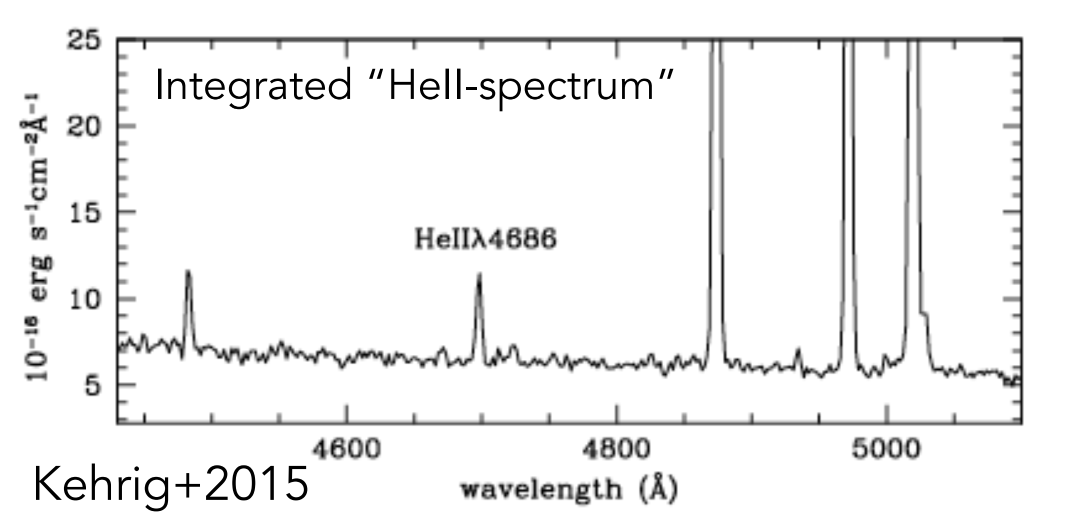
NW knot and thereabouts:

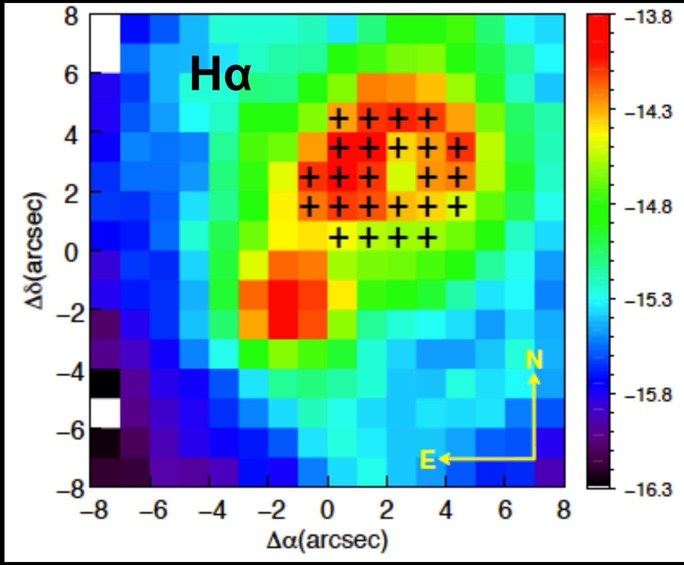
- ✔ Most of higher-Te[OIII] (> 22000 K) spaxels
- ✔ Higher excitation gas and ionization parameter
- ✔ Nebular HeII-emitting region

Existence of a harder radiation field

Our IFU data reveal for the first time: total spatial extent and precise location of the nebular HeII region, and the corresponding total HeII-ionizing flux in IZw18!

What is the main source powering nebular HeII emission in IZw18 ?





Total L(HeII4686)$_{obs}$ ➔ Q(HeII)$_{obs}$ = Total HeII-ionizing photons flux

$$Q(\text{He II})_{\text{obs}} = (1.33 \pm 0.08) \times 10^{50} \text{ photon s}^{-1}$$

Conventional HeII-ionizing sources (WRs, shocks, X-ray binaries) are not sufficient to explain the observed HeII emission in IZw18.

Peculiar very hot stars in IZw18 are required to explain the HeII ionization

metal-free ionizing stars (like PopIII stars; Yoon+2012) ? (see also Senchyna+2017)

The extended HeII λ4686 emission in the extremely metal-poor galaxy SBS 0335-052E seen with MUSE★

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Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **480**, 1081–1095 (2018)
Advance Access publication 2018 July 19

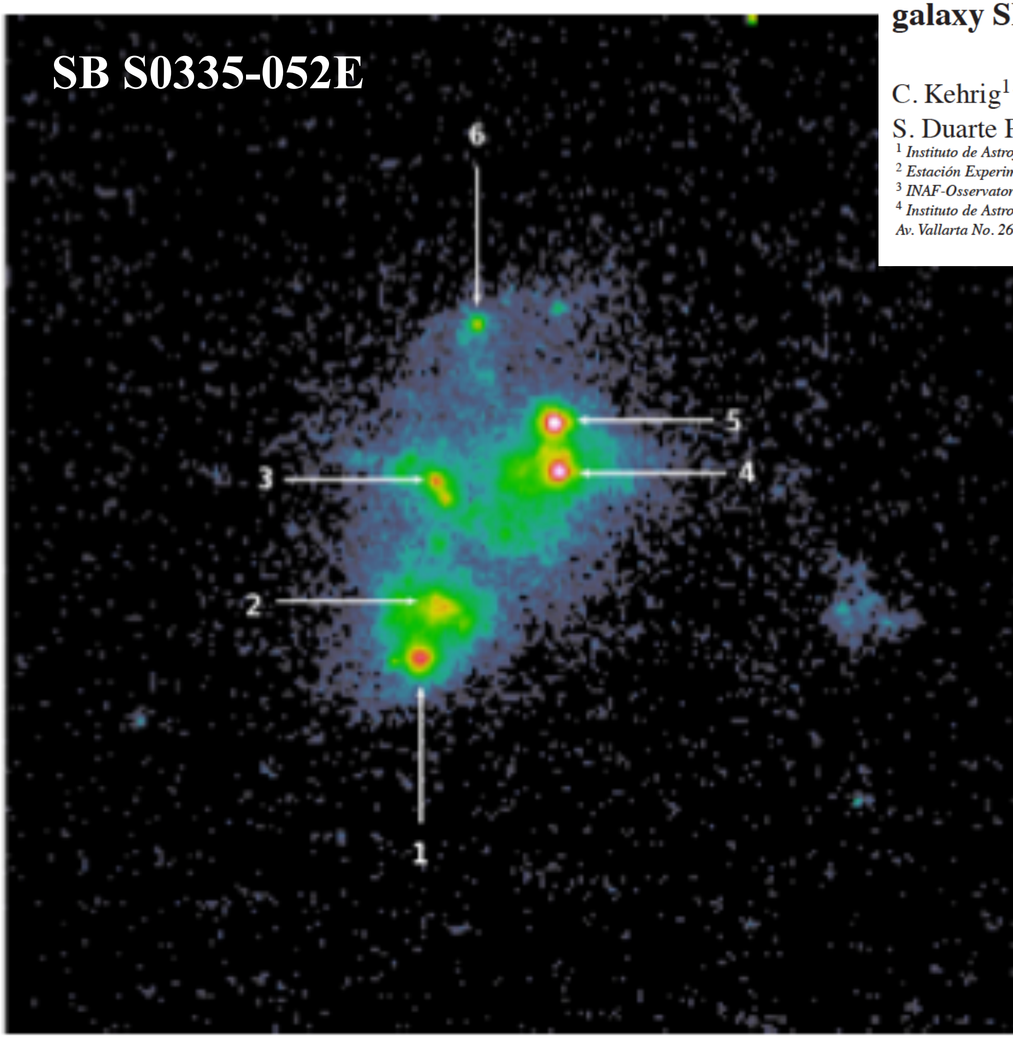


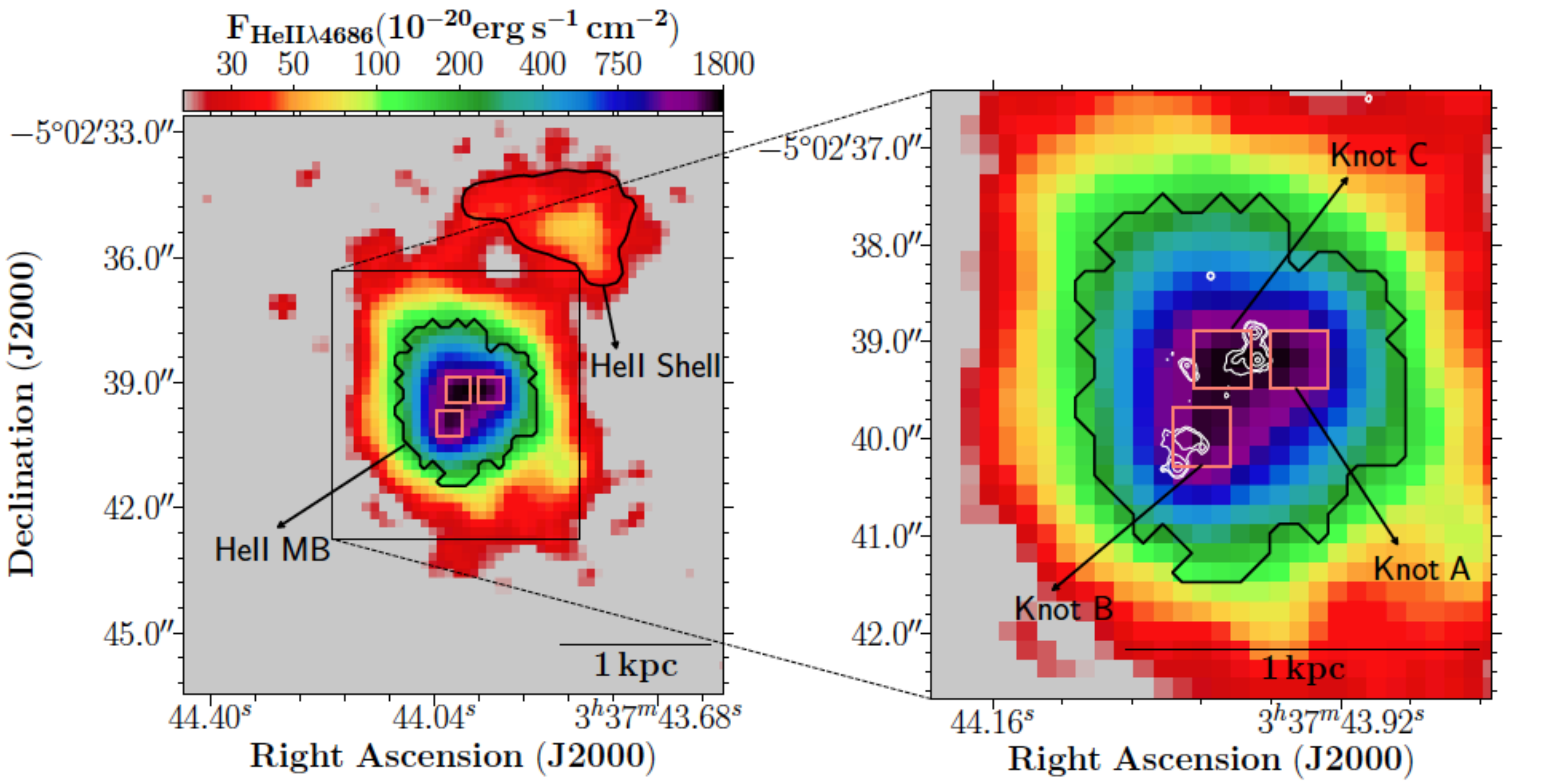
Figure 1. HST ACS/F220W archival image of SBS 0335-052E (HST Proposal ID 10575; PI: G.Östlin). The brightest SSCs as identified by Thuan et al. (1997) are labeled. The image is 6" × 6". North is up and east is to the left.

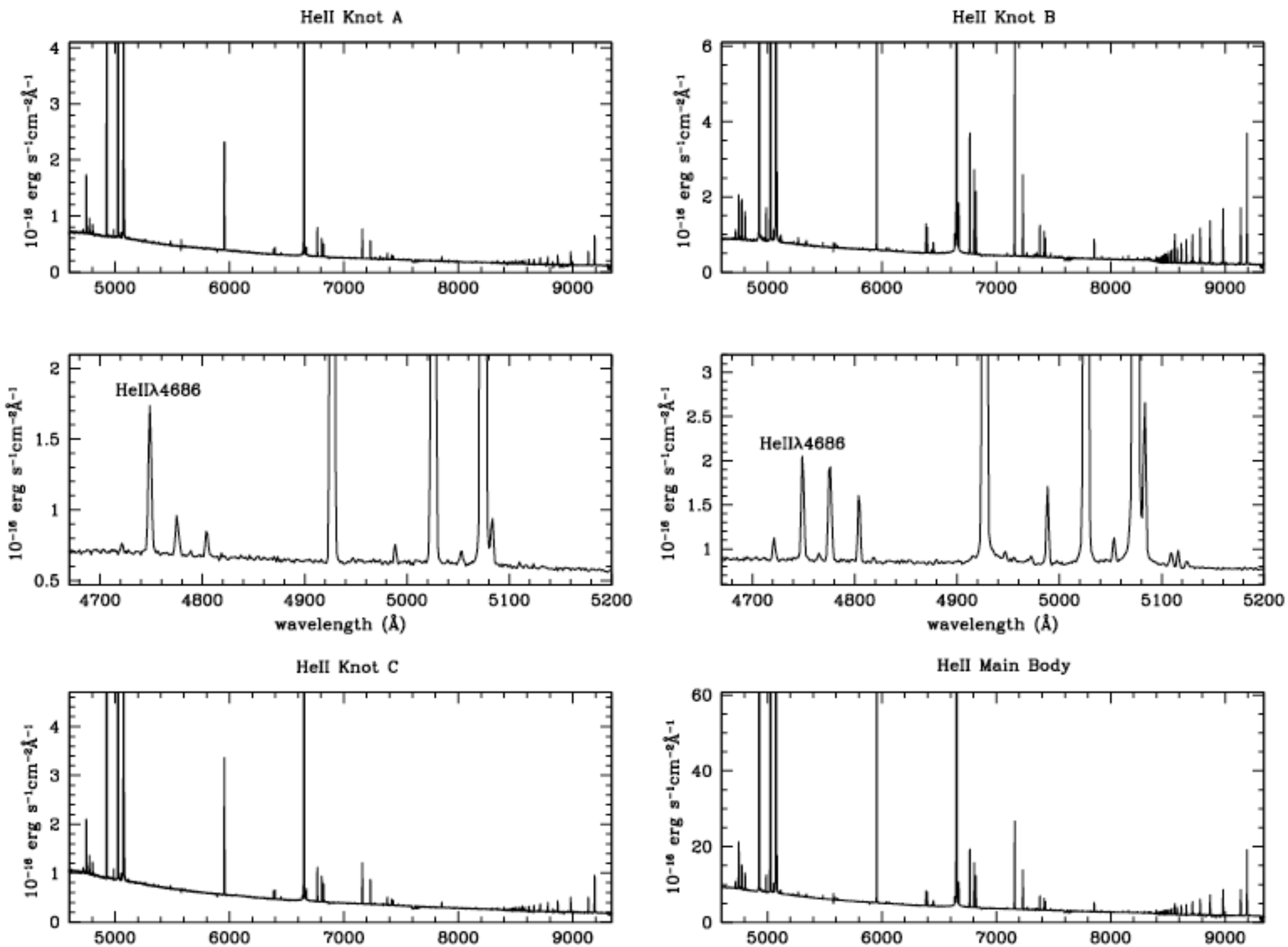
12+log(O/H) ~ 7.2–7.3 (~3 - 4% $Z_{\odot}$)
e.g. Izotov+1990;Melnick+ 1992; Izotov+1999; Papaderos+ 2006).

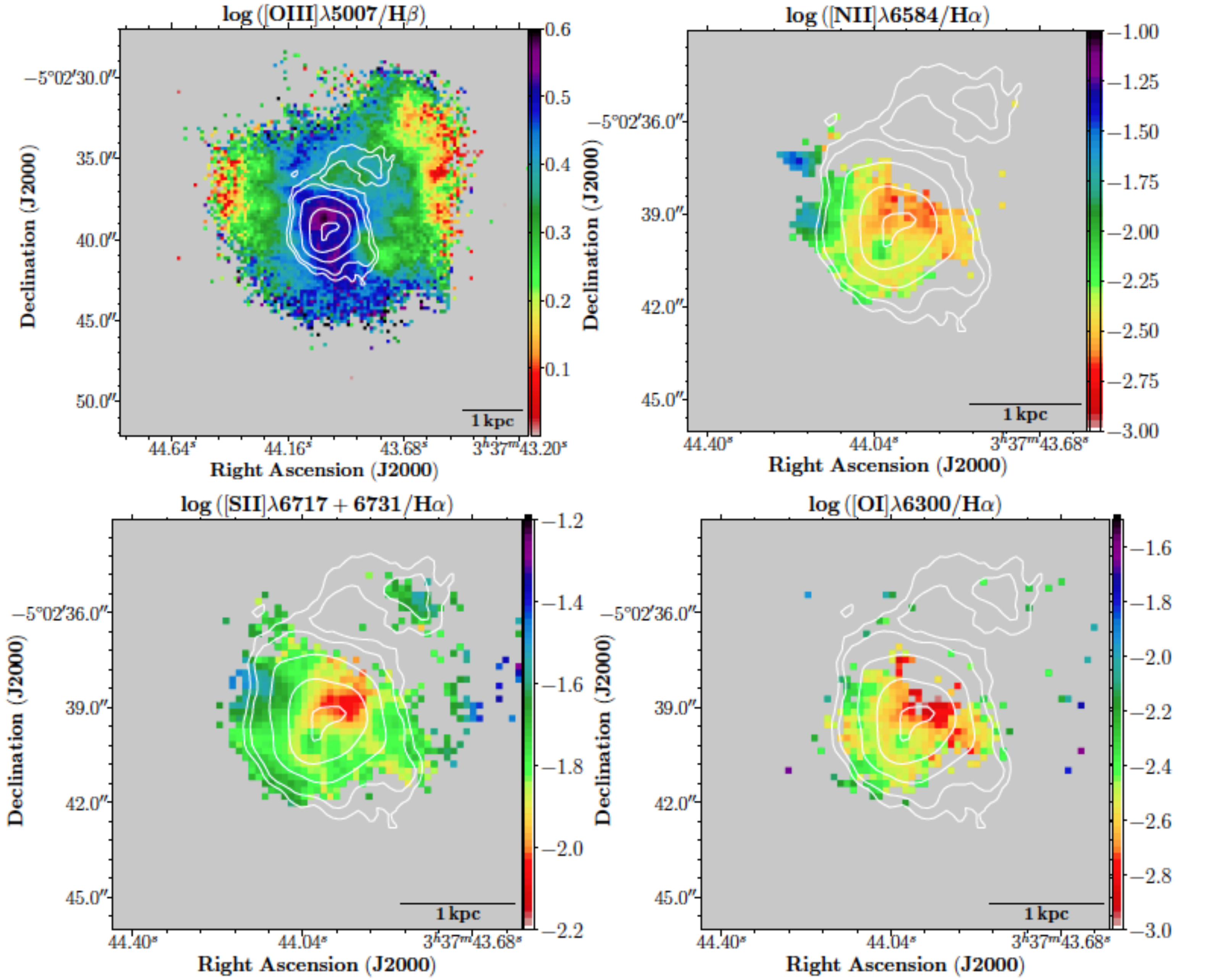
Among the most metal-poor SF galaxies with nebular HeII emission in the local Universe.

Herenz+ Poster SBS 0335-052E
Herenz et al (2017)

MUSE
ESO Program
ID 096.B-0690A (PI: M.Hayes)


$F_{HeII\lambda4686}(10^{-20}erg\,s^{-1}\,cm^{-2})$
30 50 100 200 400 750 1800
−5°02′33.0″
36.0″
39.0″
42.0″
45.0″
Declination (J2000)
44.40s
44.04s
3h37m43.68s
Right Ascension (J2000)
HeII Shell
HeII MB
1 kpc
−5°02′37.0″
38.0″
39.0″
40.0″
41.0″
42.0″
Knot C
Knot A
Knot B
1 kpc
44.16s
3h37m43.92s
Right Ascension (J2000)


HeII Knot A
HeII Knot B
HeIIλ4686
HeIIλ4686
HeII Knot C
HeII Main Body
wavelength (Å)
wavelength (Å)
10⁻¹⁶ erg s⁻¹cm⁻²Å⁻¹



igure 7. Line ratio maps of SBS 0335-052E: [OIII]λ5007/Hβ, [NII]λ6584/Hα, [SII]λ6717,6731/Hα, [OI]λ6300/Hα. Only line fluxes with S/N (per pixel) >

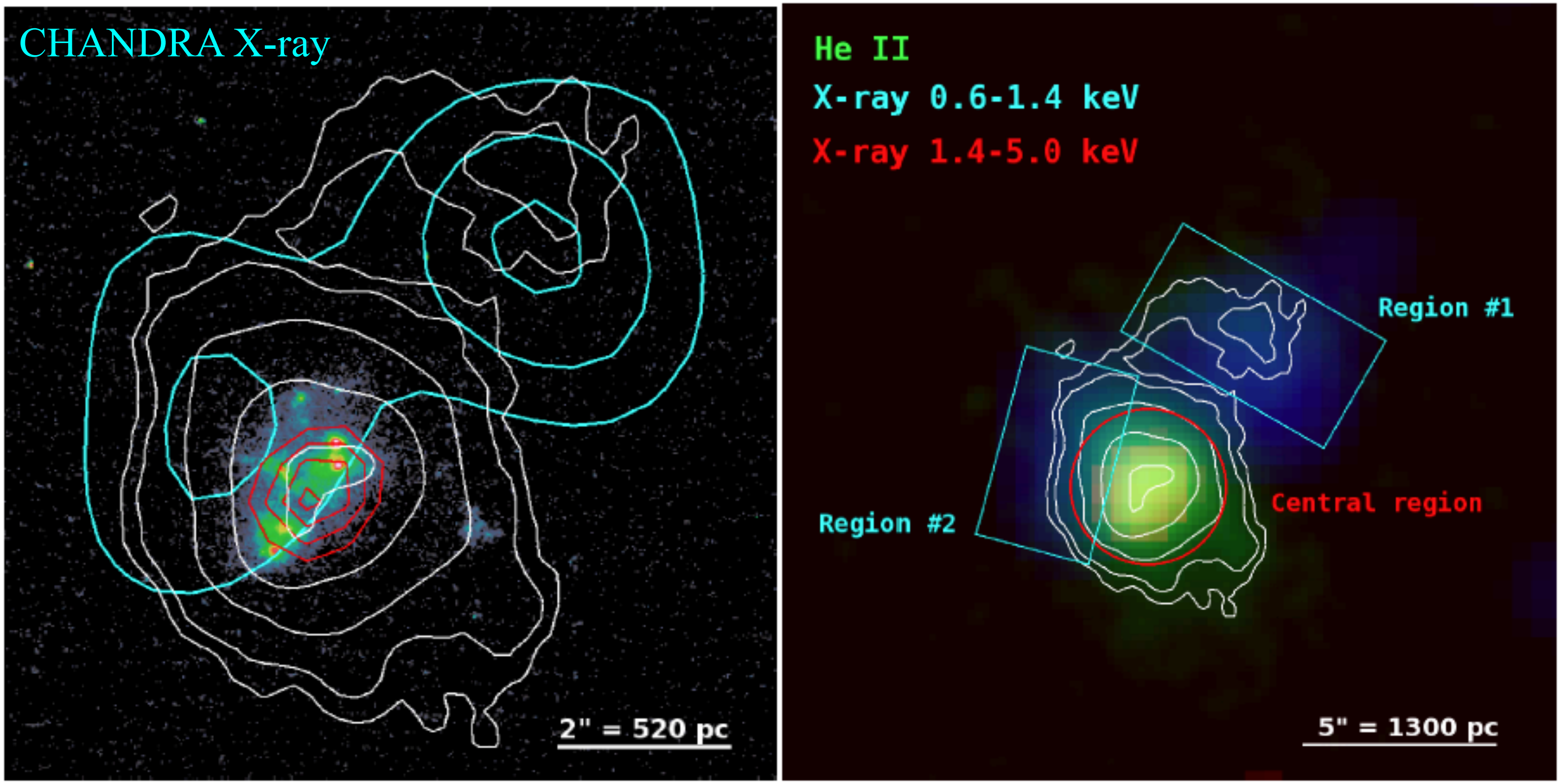


Figure 5. Left panel: Soft (cyan lines) and hard (red lines) X-ray contours overlaid on the HST ACS/F220W image of SBS 0335-052E. Right panel: Colour composite image of SBS 0335-052E in three bandpasses (blue = soft X-rays, red = hard X-rays, green = HeIIλ4686 flux image). In both panels, the white curves represent the isocontours of the HeIIλ4686 emission line flux. North is up and east is to the left.

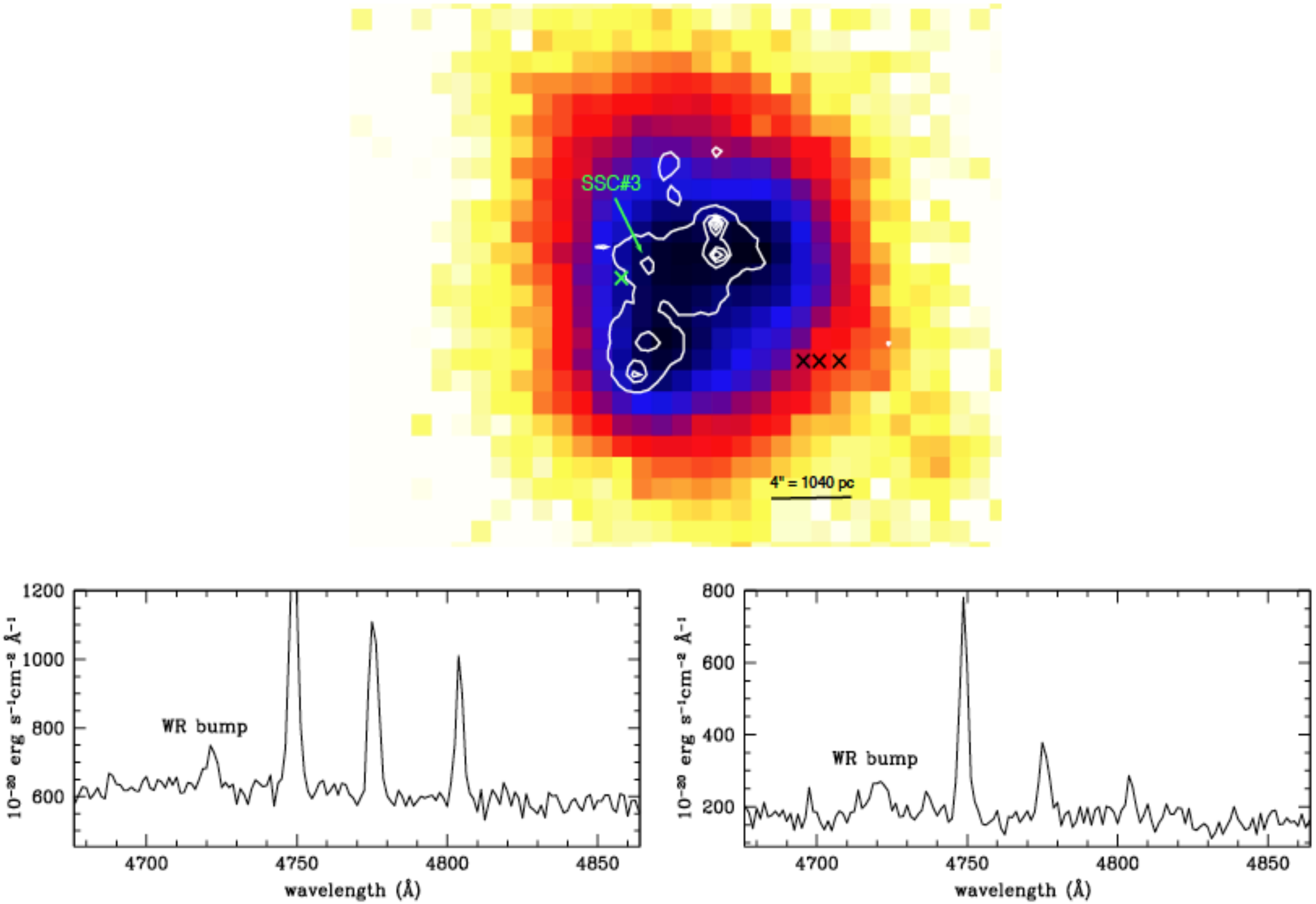


Figure 8. *Top panel*: Nebular HeIIλ4686 map centered on the massive young SSCs whose positions are represented by the white countours. The crosses indicate the location of the WR knots detected in this work. *Bottom row*: spectra showing the WR bumps. *Bottom-left panel*: spectrum of the spaxel nearby SSC#3, indicated by the green cross in the *top panel*; *Bottom-right panel*: spectrum obtained by adding the emission from the 3 spaxels marked with black crosses in the *top panel*.

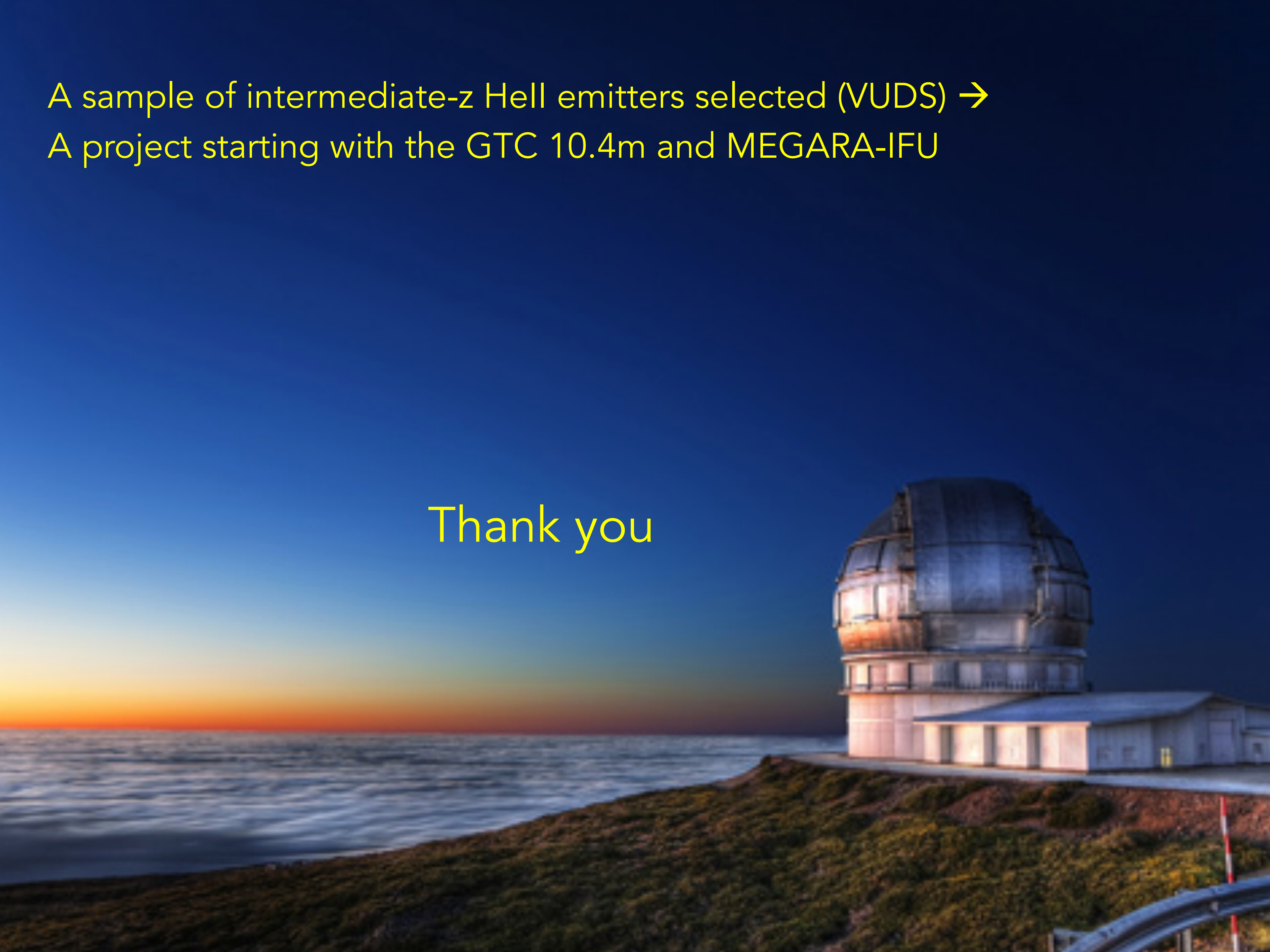
IMF [a]	Z (Z/Z$_\odot$) [b]	Q(HeII) photon s^{-1}	
		Single	Binary
imf100-100[c]	10^{-5} (0.05 %)	1.40× 10^{49}	7.89× 10^{50}
	10^{-4} (0.5 %)	6.45× 10^{48}	3.40× 10^{50}
	0.001 (5 %)	5.05× 10^{46}	2.18× 10^{49}
imf100-300[c]	10^{-5} (0.05 %)	1.20× 10^{49}	7.37× 10^{50}
	10^{-4} (0.5 %)	6.16× 10^{48}	3.48× 10^{50}
	0.001 (5 %)	4.30× 10^{46}	2.39× 10^{49}
imf135all-100[d]	10^{-5} (0.05 %)	5.01× 10^{48}	2.09× 10^{50}
	10^{-4} (0.5 %)	2.29× 10^{48}	8.97× 10^{49}
	0.001 (5 %)	1.77× 10^{46}	5.94× 10^{48}
imf135-100[e]	10^{-5} (0.05 %)	6.87× 10^{48}	2.71 × 10^{50}
	10^{-4} (0.5 %)	3.10× 10^{48}	1.16× 10^{50}
	0.001 (5 %)	2.40× 10^{46}	7.68× 10^{48}
imf135-300[e]	10^{-5} (0.05 %)	6.59× 10^{48}	2.79× 10^{50}
	10^{-4} (0.5 %)	2.98× 10^{48}	1.27× 10^{50}
	0.001 (5 %)	2.30× 10^{46}	8.99× 10^{48}
imf170-100[f]	10^{-5} (0.05 %)	2.60× 10^{48}	7.22× 10^{49}
	10^{-4} (0.5 %)	1.16× 10^{48}	3.07× 10^{49}
	0.001 (5 %)	8.77× 10^{45}	2.13× 10^{48}
imf170-300[f]	10^{-5} (0.05 %)	2.58× 10^{48}	7.62× 10^{49}
	10^{-4} (0.5 %)	1.15× 10^{48}	3.43× 10^{49}
	0.001 (5 %)	8.70× 10^{45}	2.46× 10^{48}

[a] IMFs are labelled following the BPASSv2.1 designation (Eldridge et al. 2017)
[b] BPASS models assume Z$_\odot$=0.02 for consistency with their empirical mass-loss rates which were scaled from this value.
[c] imf100-100: α_1=-1.30 (0.1-0.5 M$_\odot$), α_2=-2.00 (0.5-100 M$_\odot$); imf100-300: as imf100-100 but with M_{up}=300 M$_\odot$
[d] Salpeter IMF with M_{up}=100 M$_\odot$
[e] These are the default IMFs recommended by Eldridge et al. (2017); imf135-100: α_1=-1.30 (0.1-0.5 M$_\odot$), α_2=-2.35 (0.5-100 M$_\odot$); imf135-300: as imf135-100 but with M_{up}=300 M$_\odot$
[f] imf170-100: α_1=-1.30 (0.1-0.5 M$_\odot$), α_2=-2.70 (0.5-100 M$_\odot$); imf170-300: as imf170-100 but withM_{up}=300 M$_\odot$

Derived for SB S0335-52E:
Integral HeII nebular emission
=> HeII ionization budget
Q(HeII)$_{int}$=3.17 x 10^{51} photon/s

The HeII ionization budget of SB S0335-052E could be only reproduced either by:
-Single rotating stars metal-free stars models
-Binary population of very low metallicity (Z~10^{-5}) BPASS top heavy IMF models

Challenging implications for state of the art models, in line with our previous IZw18 results & recent findings (z~2, Berg+ 2018)


A sample of intermediate-z HeII emitters selected (VUDS) →
A project starting with the GTC 10.4m and MEGARA-IFU
Thank you