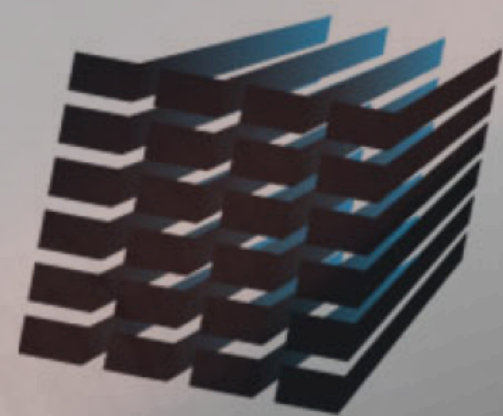




MUSE
multi unit spectroscopic explorer

**Sterrewacht
Leiden**

EXPLORING HEII1640 EMISSION LINE PROPERTIES AT $z=2-4$

THEMIYA NANAYAKKARA

@themiyan

Jarle Brinchmann, Leindert Boogaard, Rychard Bouwens, Sebastiano Cantalupo, Anna Feltre, Wolfram Kollatschny, Raffaella Anna Marino, Michael Maseda, Jorryt Matthee, Mieke Paalvast, Johan Richard, Anne Verhamme, and The MUSE Consortium

What is so special about Hell???





Pop III
Stars

(Top heavy IMF)

$E > 54.4 \text{ eV}$

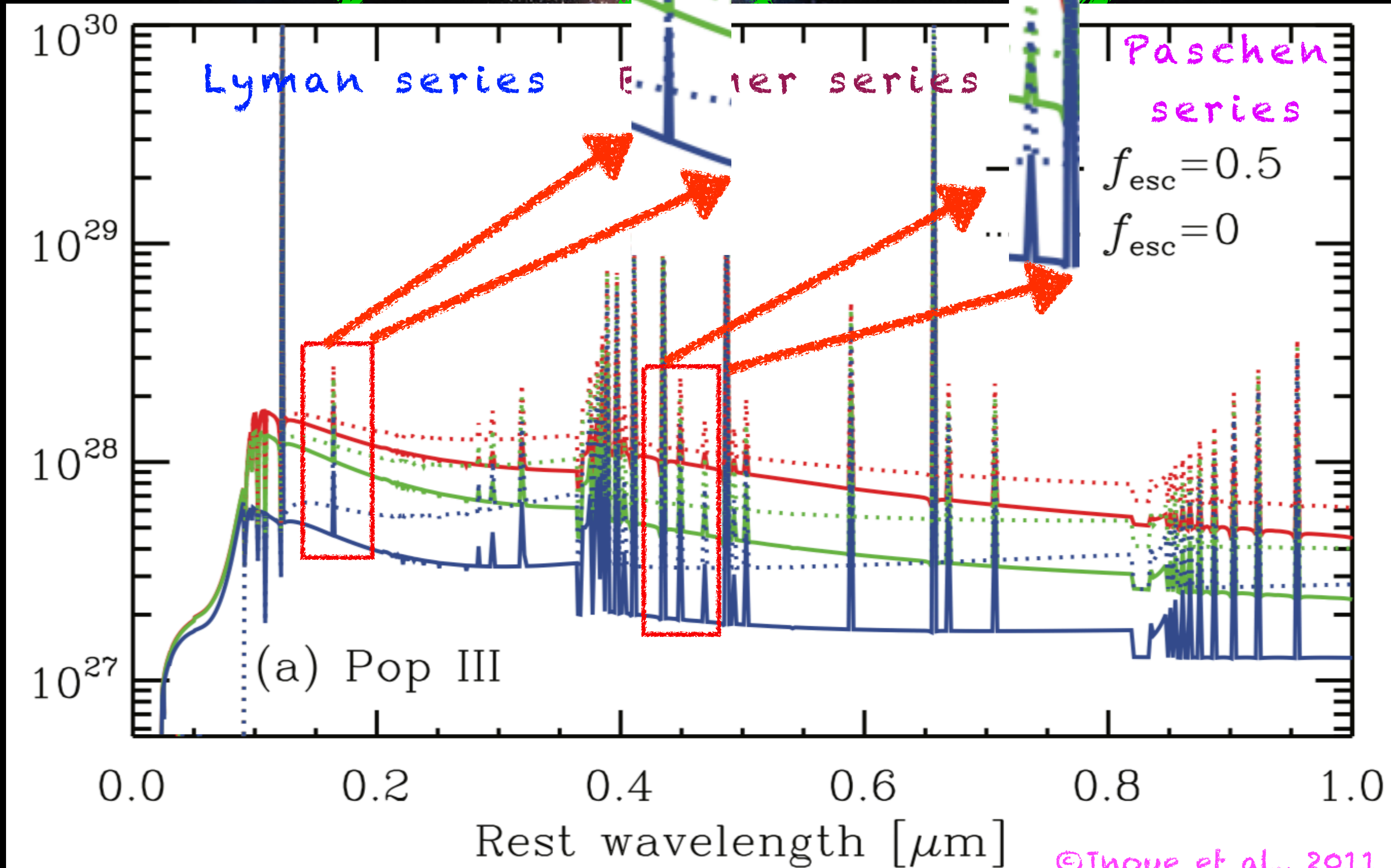
Cooling processes
dominated by Ly- α
and HeII



Pop III
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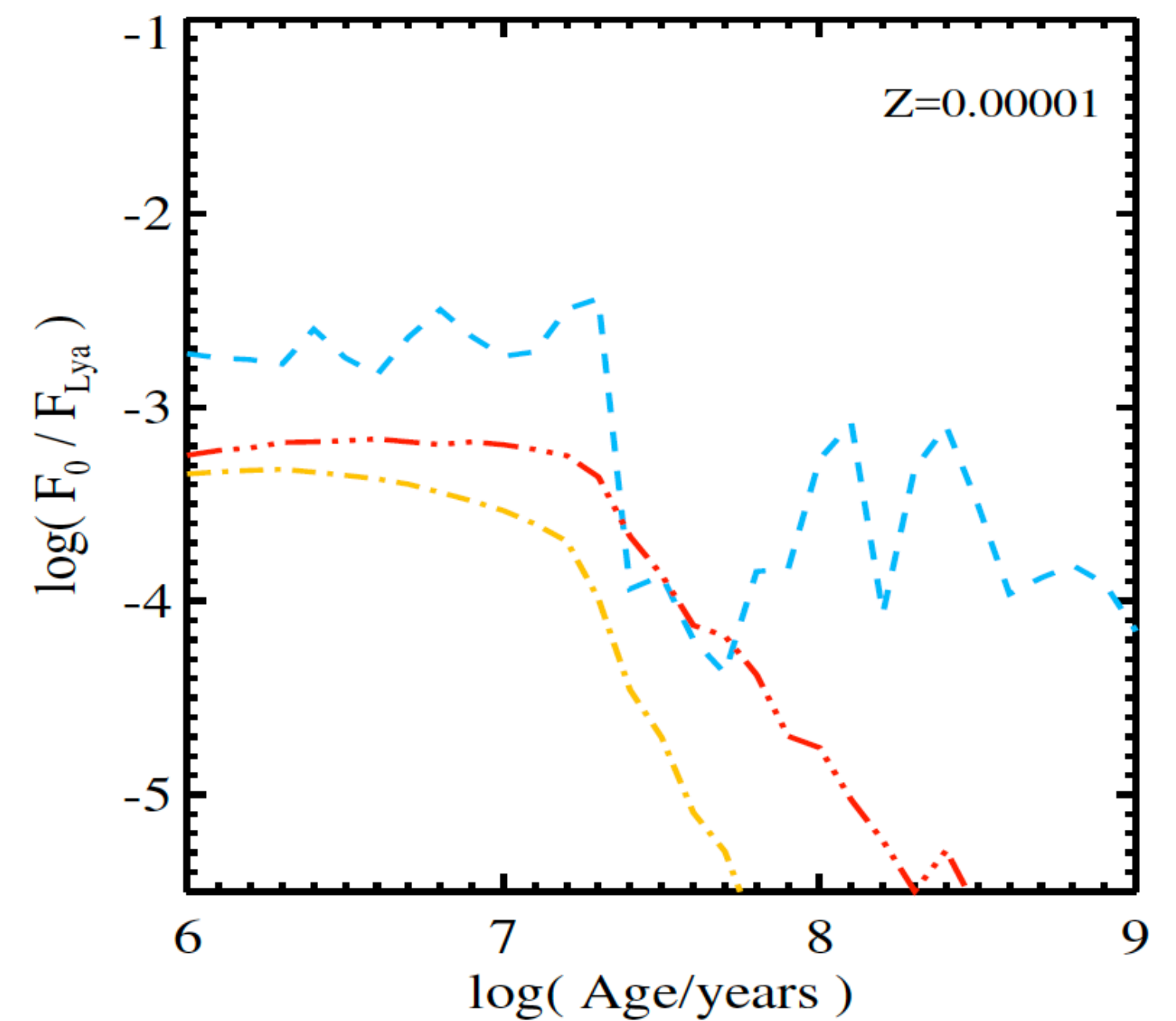
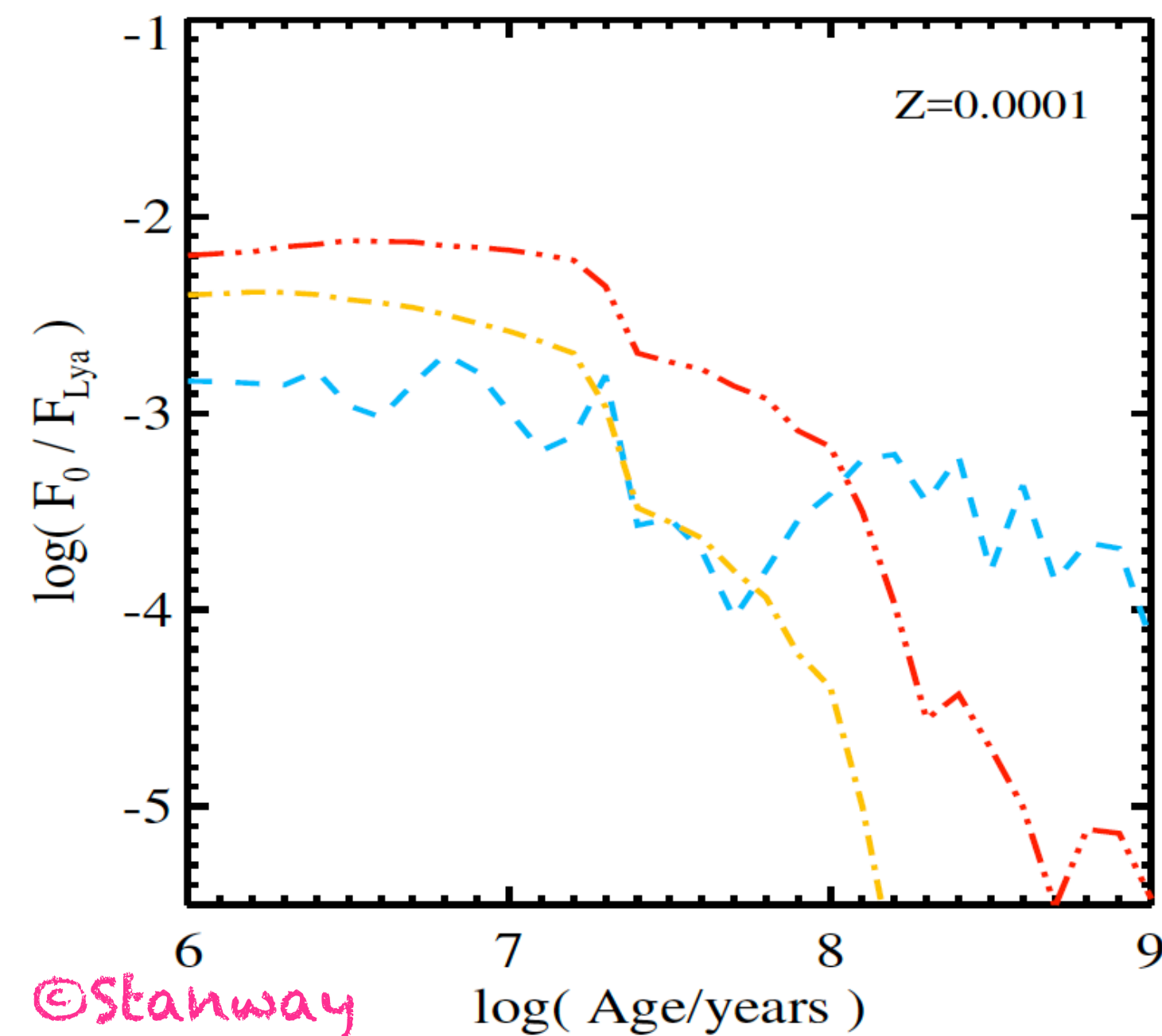
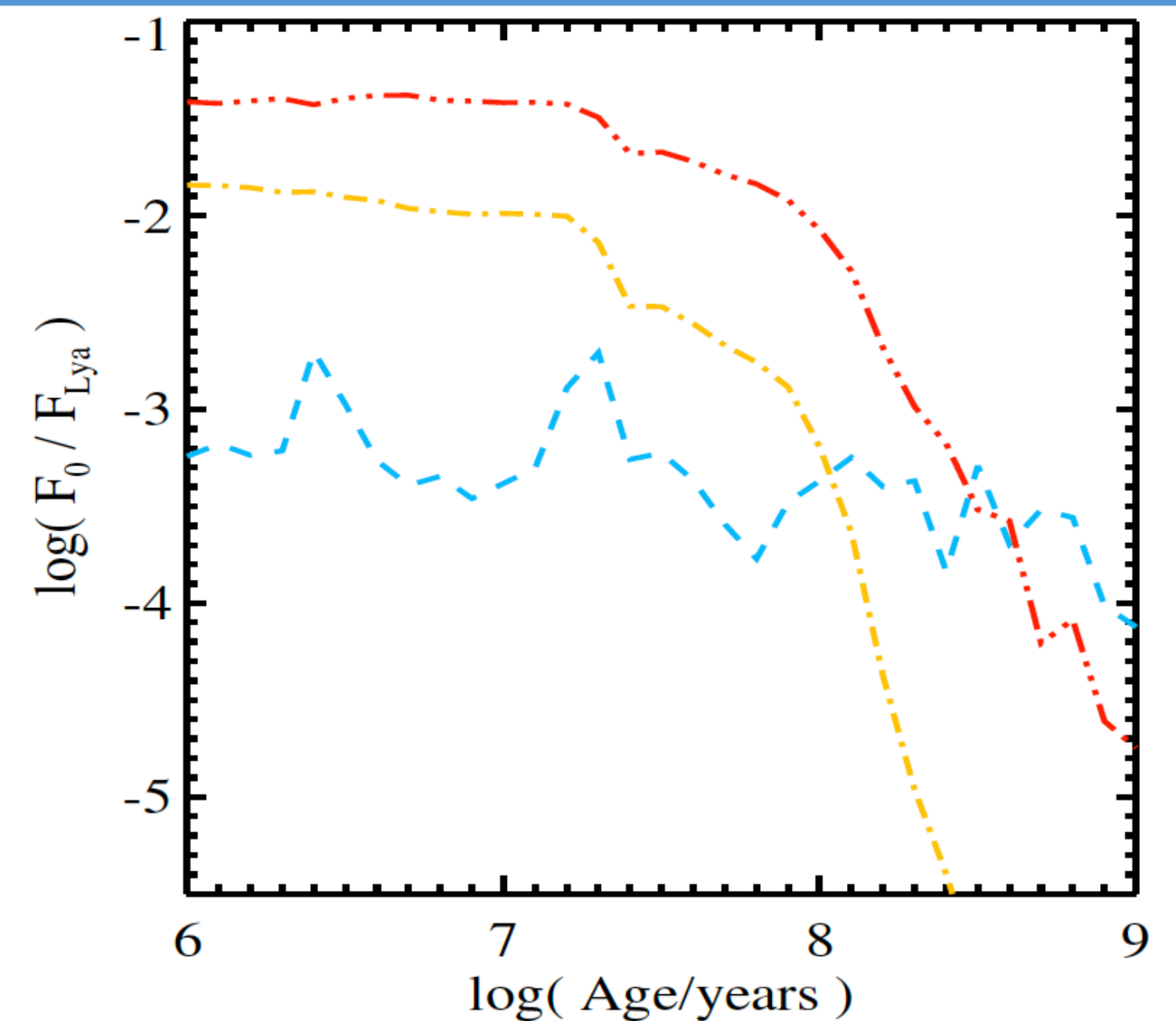
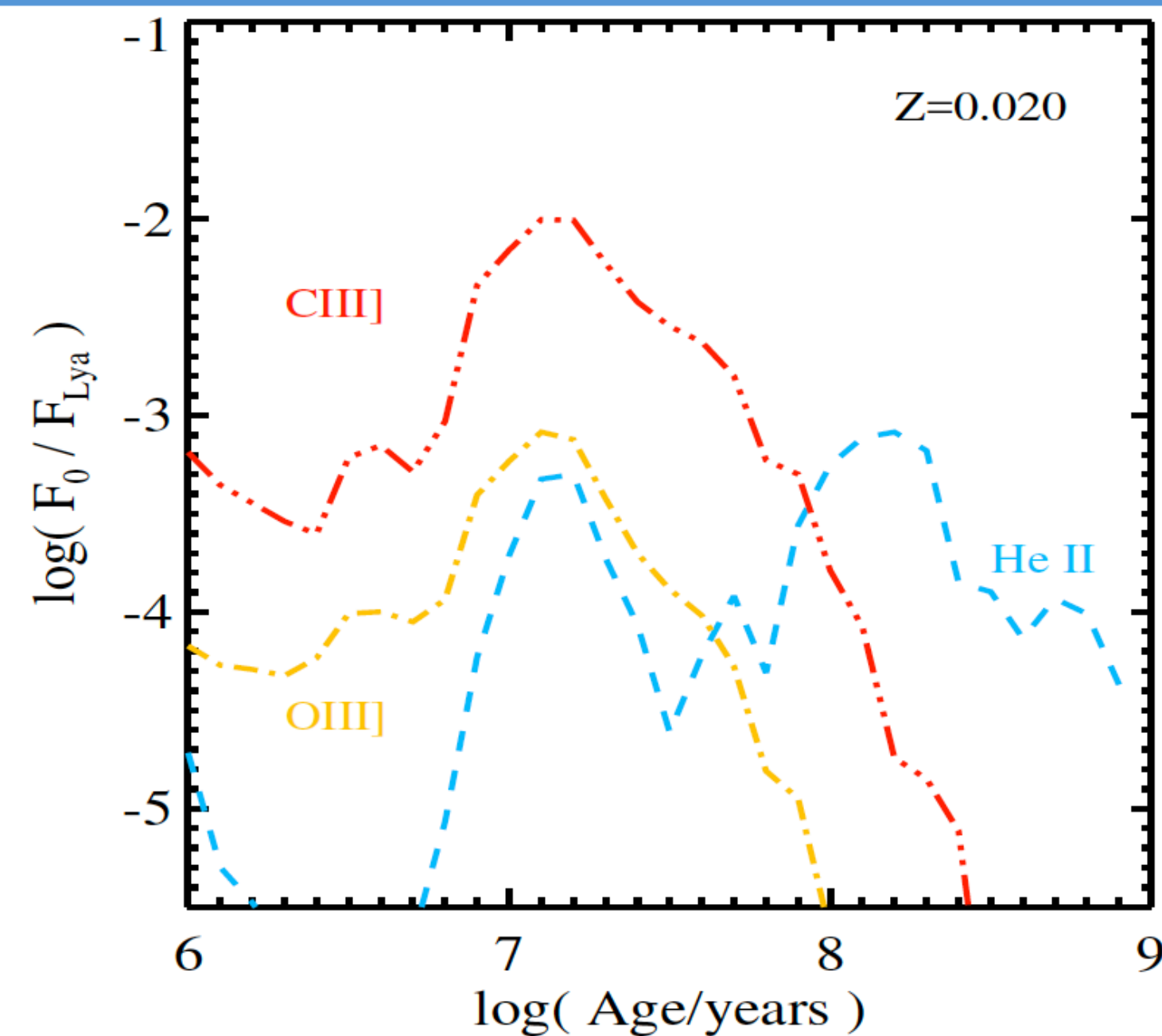
$E > 54.4 \text{ eV}$

Cooling processes
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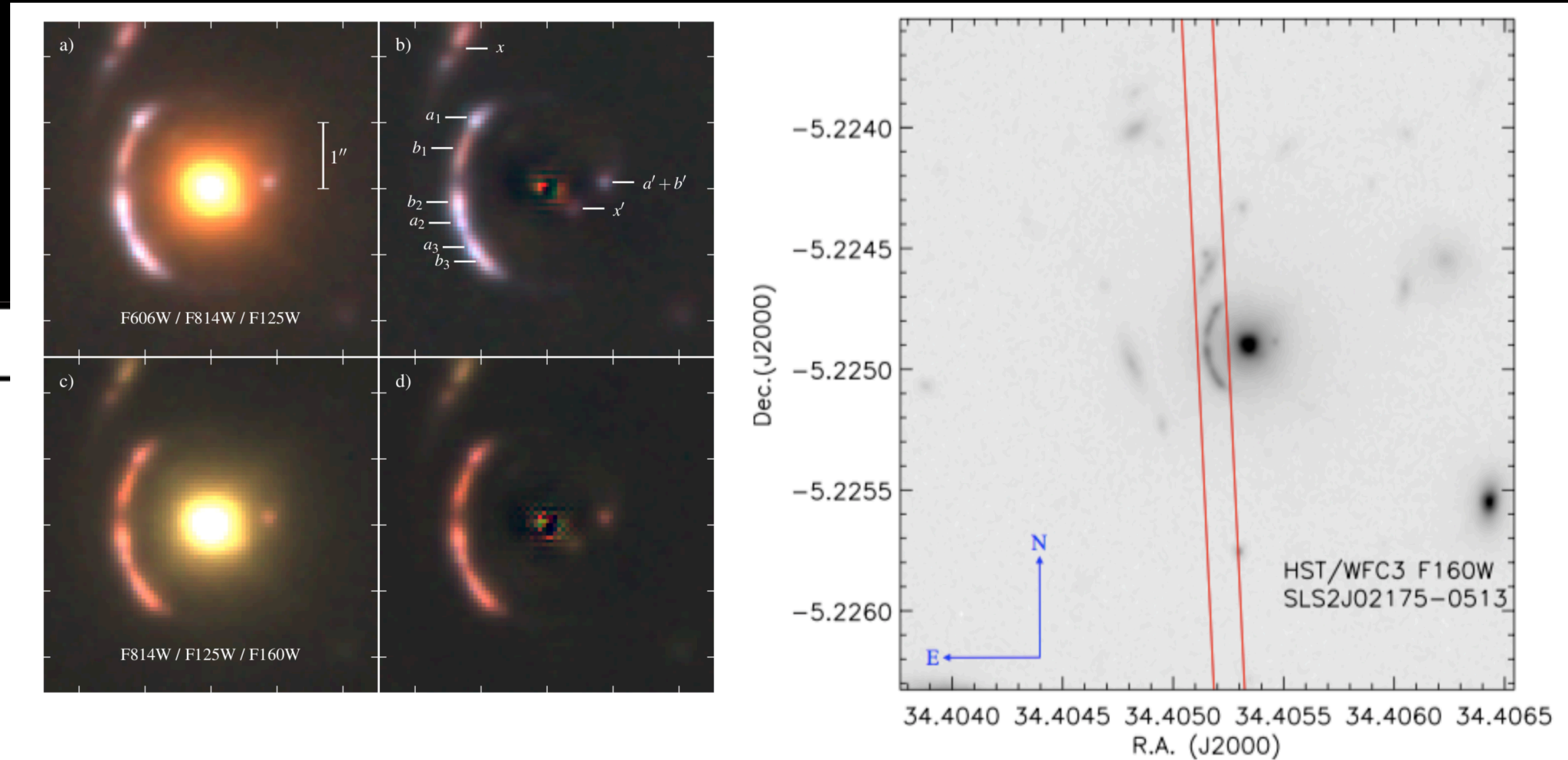
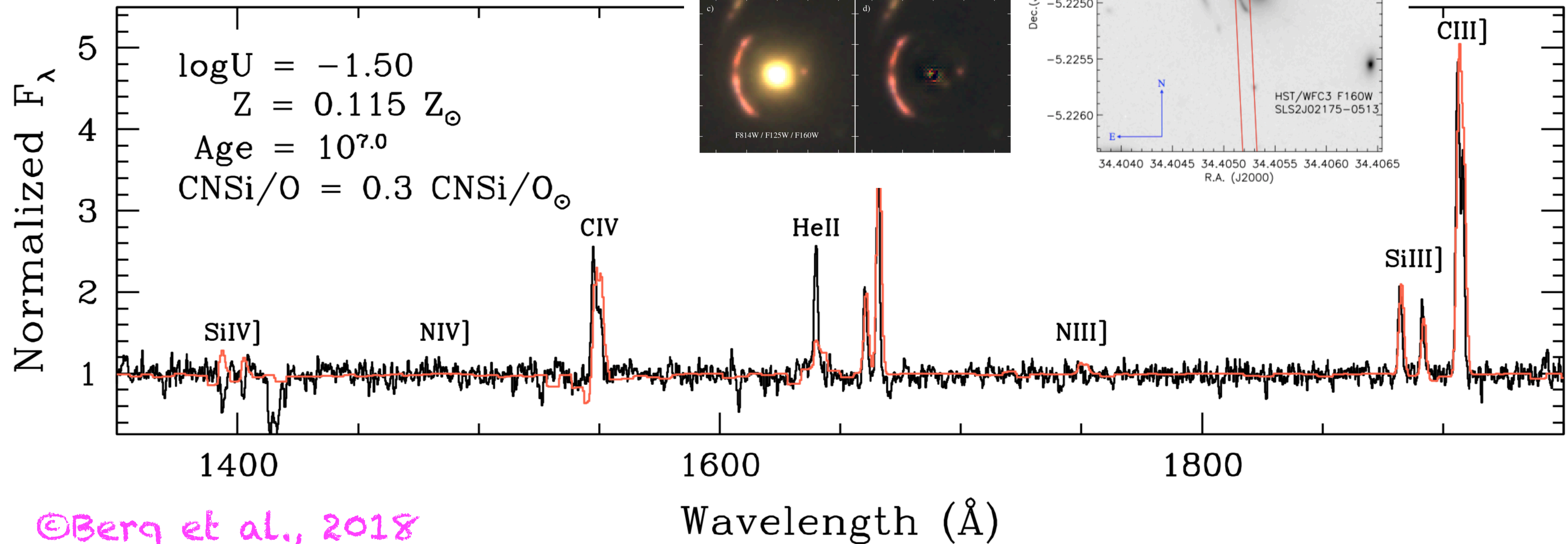


and in more moderate systems...

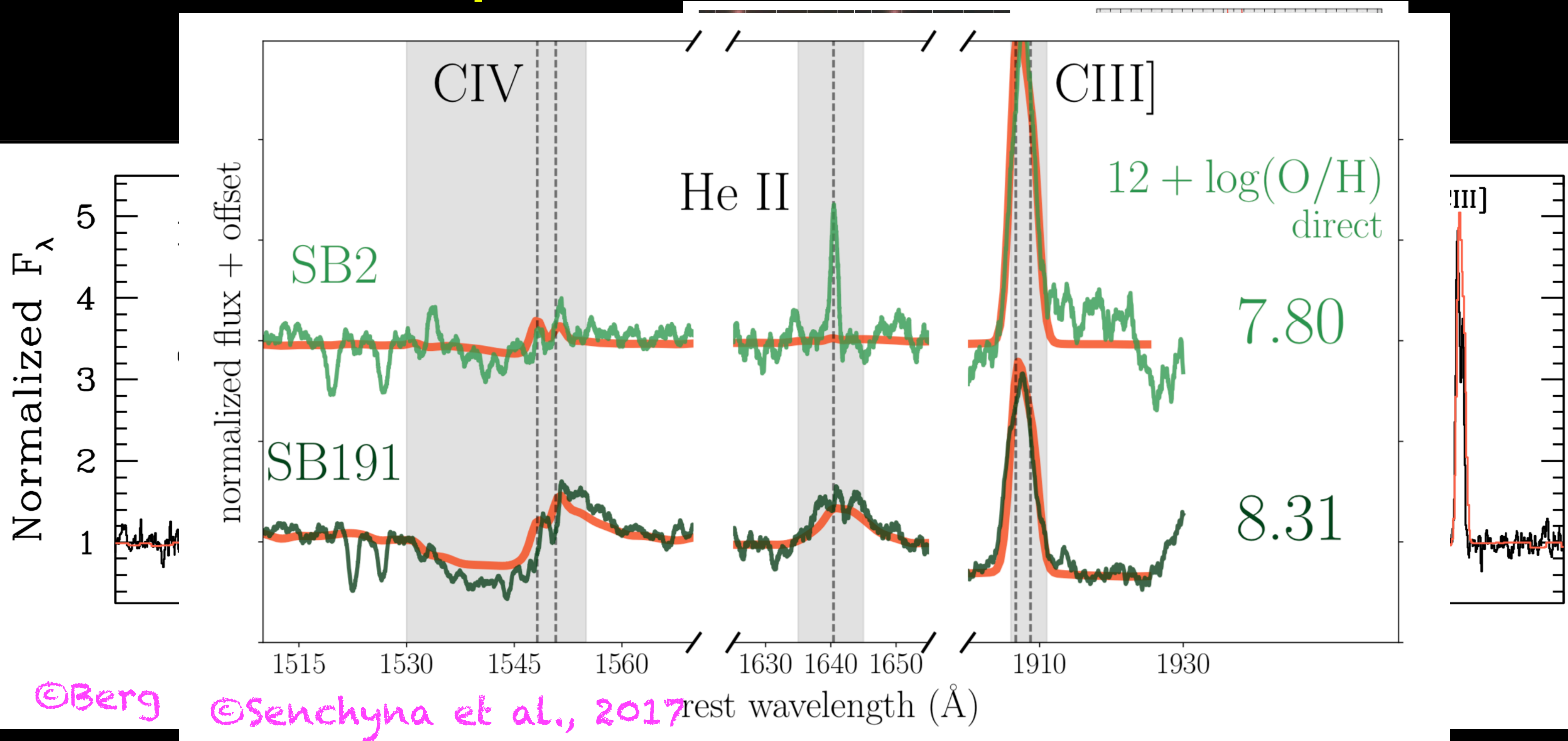
**He II may
become the
most dominant
emission line
at lower
metallicities**



Current stellar population/photoionisation models fail to predict the observed HeII features



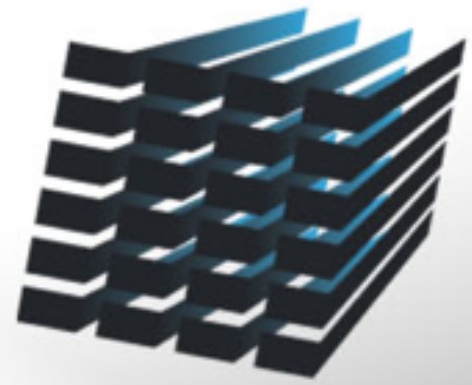
Current stellar population/photoionisation models fail to predict the observed He II features



He+ ionising photons can be produced via multiple mechanisms, so some solutions include:

- Decrease Z/mass threshold to produce W-R stars  Binaries
VMS
- Include contribution from X-Ray Binaries  XRB population synthesis
- Increase N of Young massive stars  IMF variations
- Consider contributions from Shocks and AGN  Sub-dominant AGN

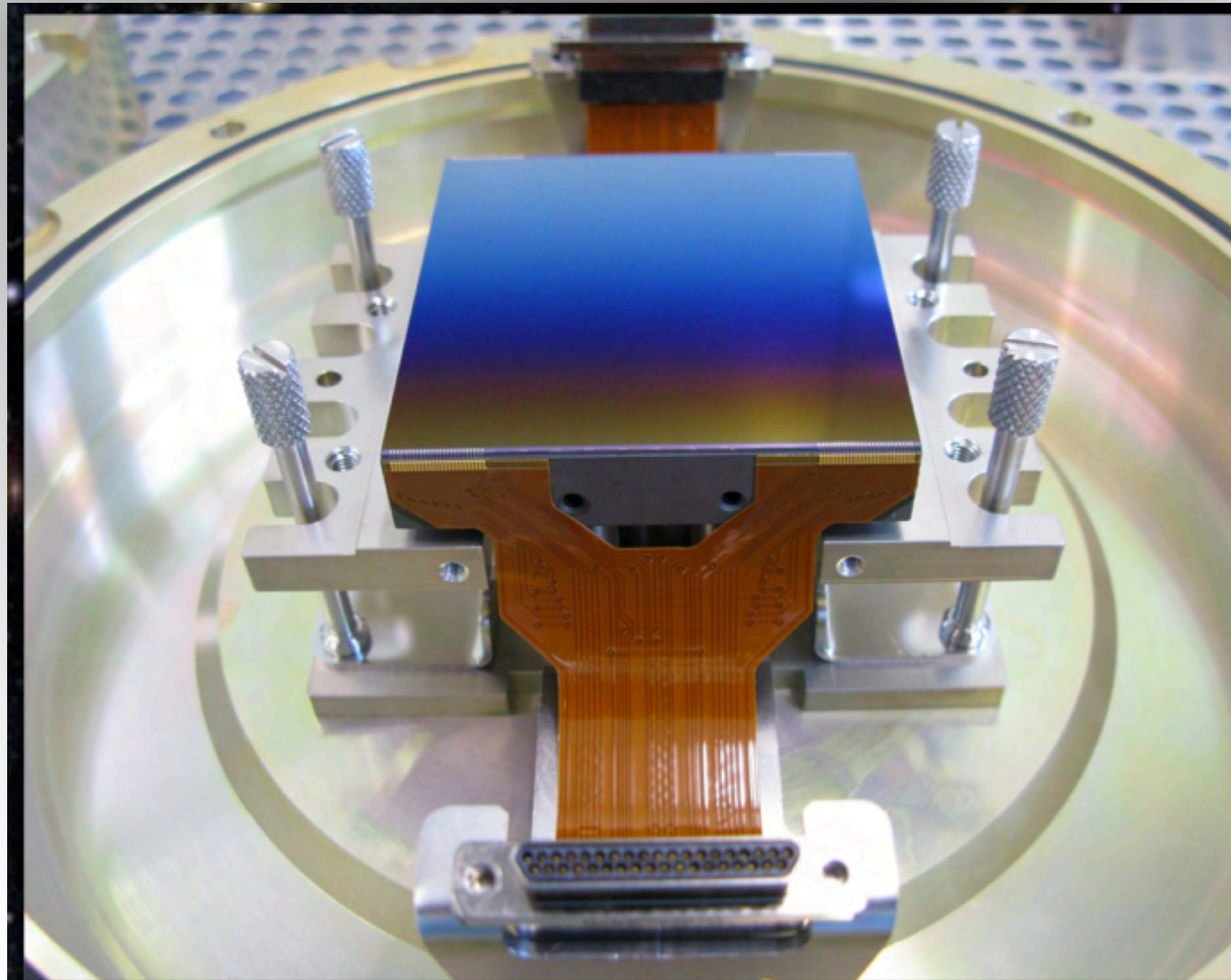
Testing these models and providing constraints requires Hell emitters in a variety of conditions



MUSE
multi unit spectroscopic explorer



ETH



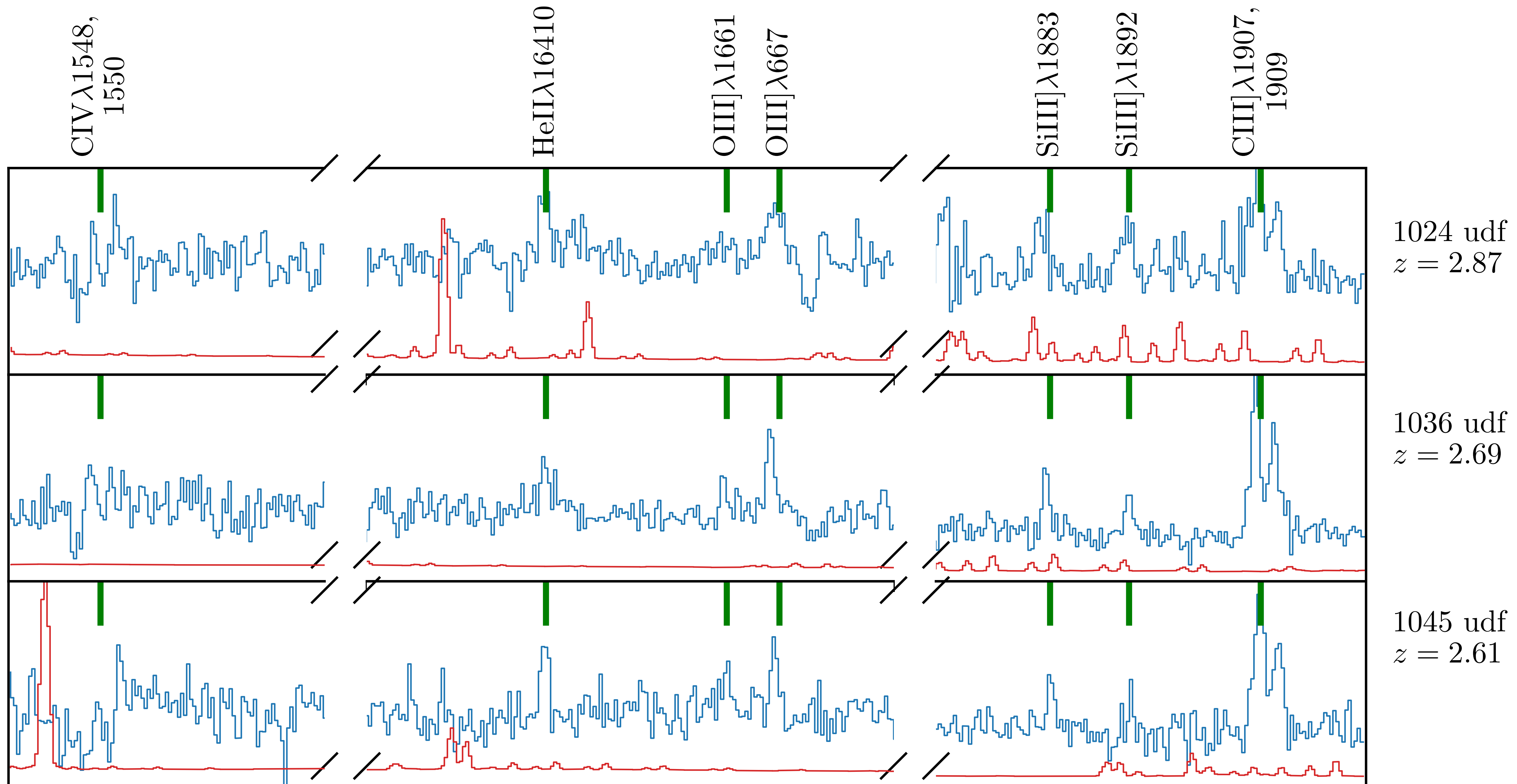
Part I: Sample Construction

We use multiple GTO pointings with deep exposures to identify any HeII λ 1640 emitters

Field name	FOV ^a	Exposure Time (h)	Nc ^b	Ns ^c
UDF10	1' $\times$ 1'	31.00	122	0
UDF MOSAIC	3' $\times$ 3'	10.00	431	6
HDFS	1' $\times$ 1'	27.00	139	3
Groups COSMOS 30	1' $\times$ 1'	9.75	35	1
Groups COSMOS 34	1' $\times$ 1'	5.25	7	0
Groups COSMOS 84	1' $\times$ 1'	5.25	13	0
Groups COSMOS 114	1' $\times$ 1'	2.20	2	0
Groups VVDS 189	1' $\times$ 1'	2.25	1	0
Quasar J2321	1' $\times$ 1'	9.00	13	0
Quasar Q0422	1' $\times$ 1'	20.00	25	3
Quasar UM287	1' $\times$ 1'	9.00	11	0

We use multiple GTO pointings with deep exposures to identify any HeII $\lambda 1640$ emitters

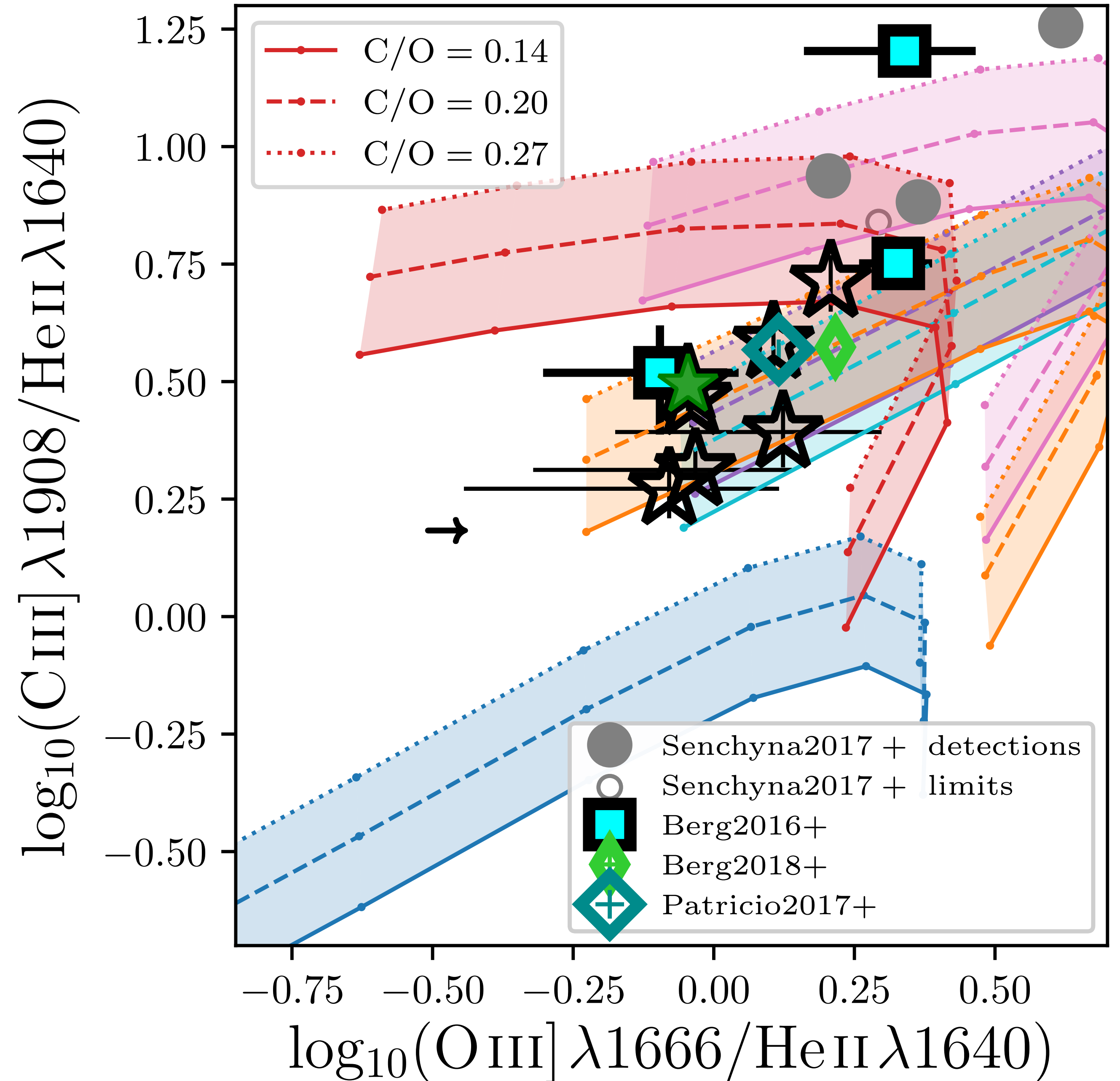
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Part II: Analysis



When compared to Gutkin+2016 models, most galaxies in our sample fall within the line ratios occupied by the models.



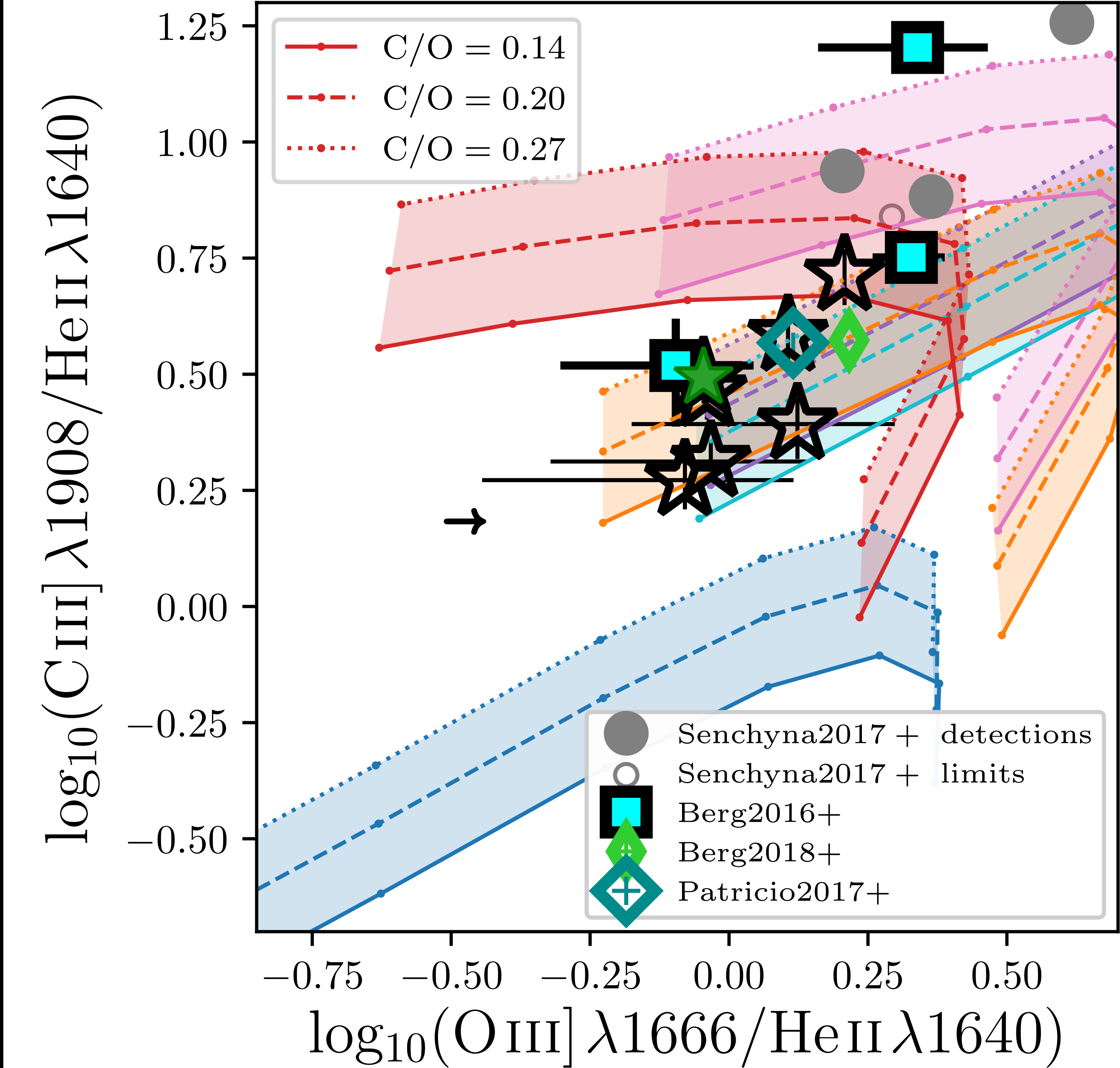


When compared to Gutkin+2016 models, most galaxies in our sample fall within the line ratios occupied by the models.

- note:
- a large variety in model parameters
 - only single stars

Parameter	Sampled values
Z_{ISM}	0.0001, 0.0002, 0.0005, 0.001, 0.002, 0.004, 0.006, 0.008, 0.010, 0.014, 0.017, 0.020, 0.030, 0.040
$\log U_{\text{S}}$	-1.0, -1.5, -2.0, -2.5, -3.0, -3.5, -4.0
ξ_{d}	0.1, 0.3, 0.5
$\log(n_{\text{H}}/\text{cm}^{-3})$	1, 2, 3, 4
$(\text{C}/\text{O})/(\text{C}/\text{O})_{\odot}$	0.10, 0.14, 0.20, 0.27, 0.38, 0.52, 0.72, 1.00, 1.40
$m_{\text{up}}/M_{\odot}$	100, 300

©Gutkin+2016



©Nanayakkara+(2019)

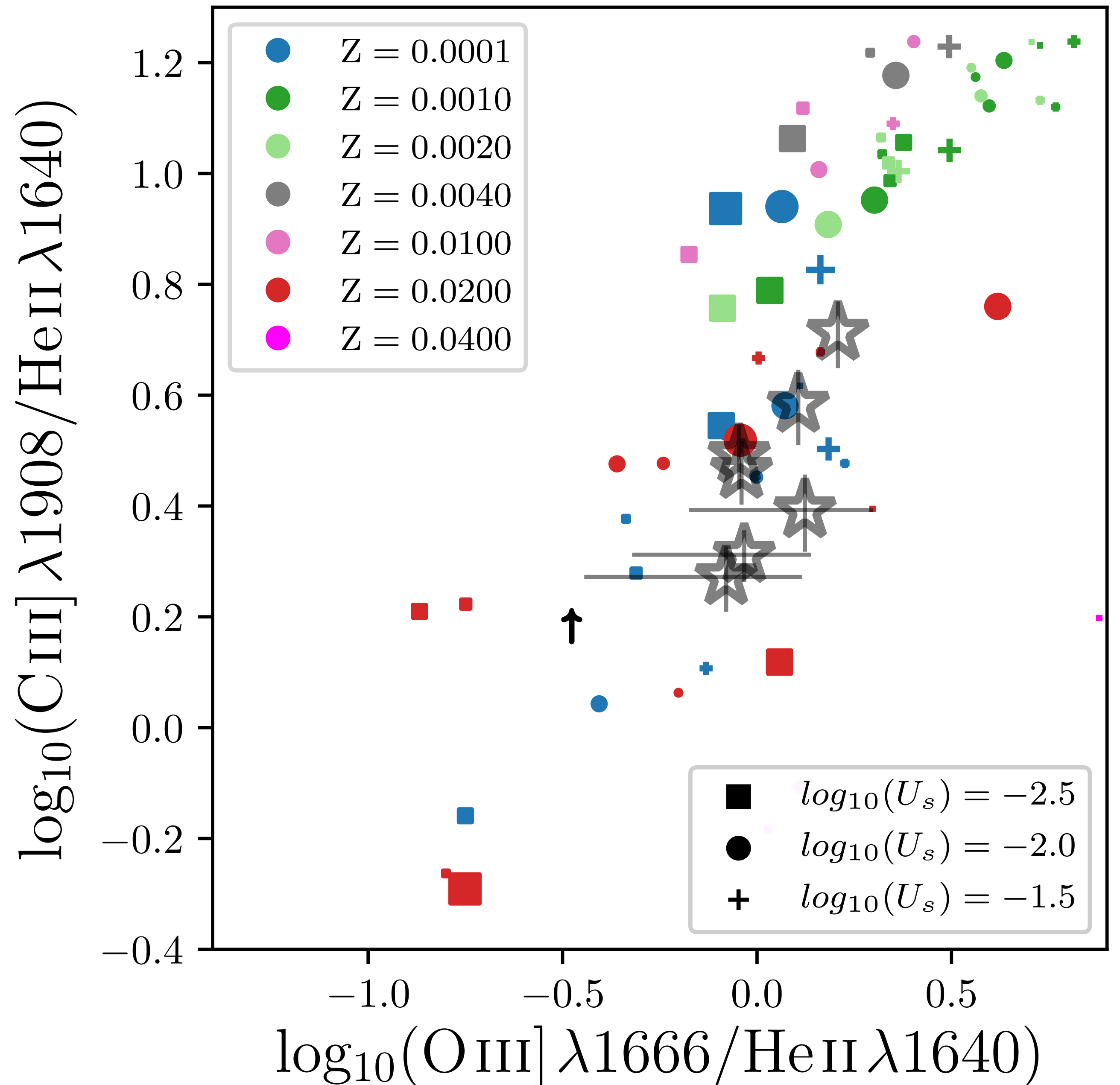
Considering effects
of binary stars
introduces added
complexity to the line
ratio diagnostics.

Models from BPASSv2.0

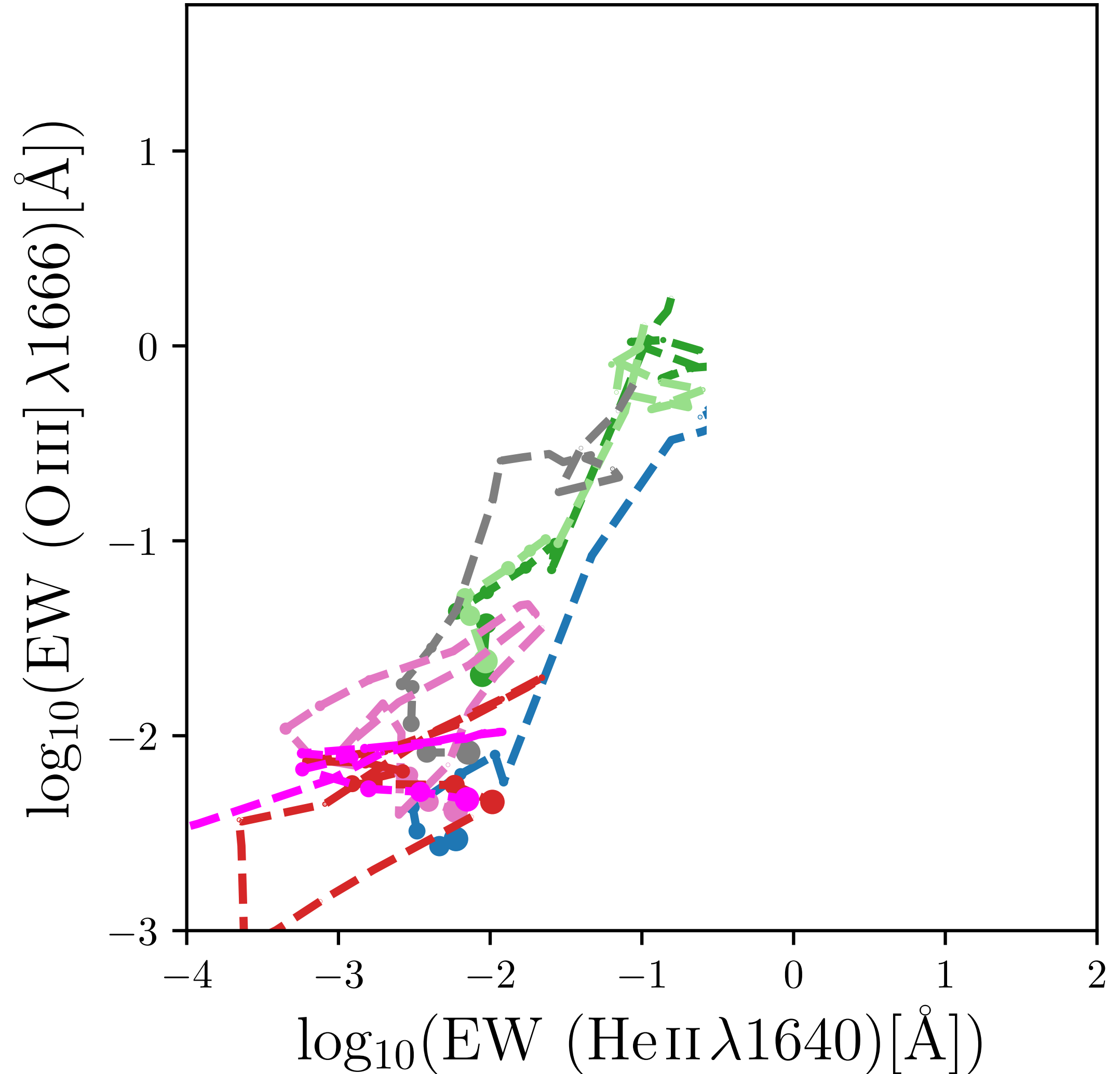
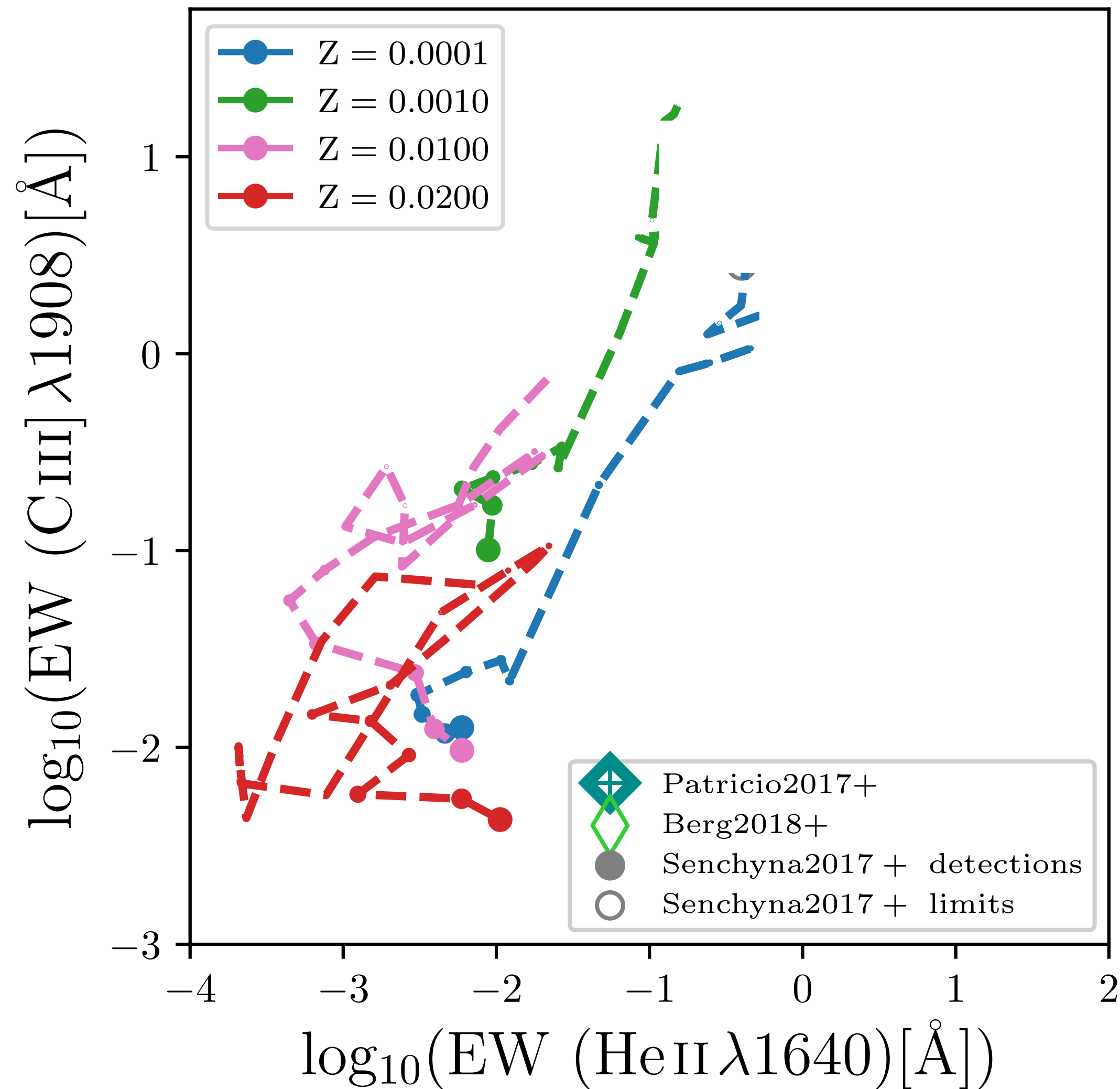
Xiao+2018

note:

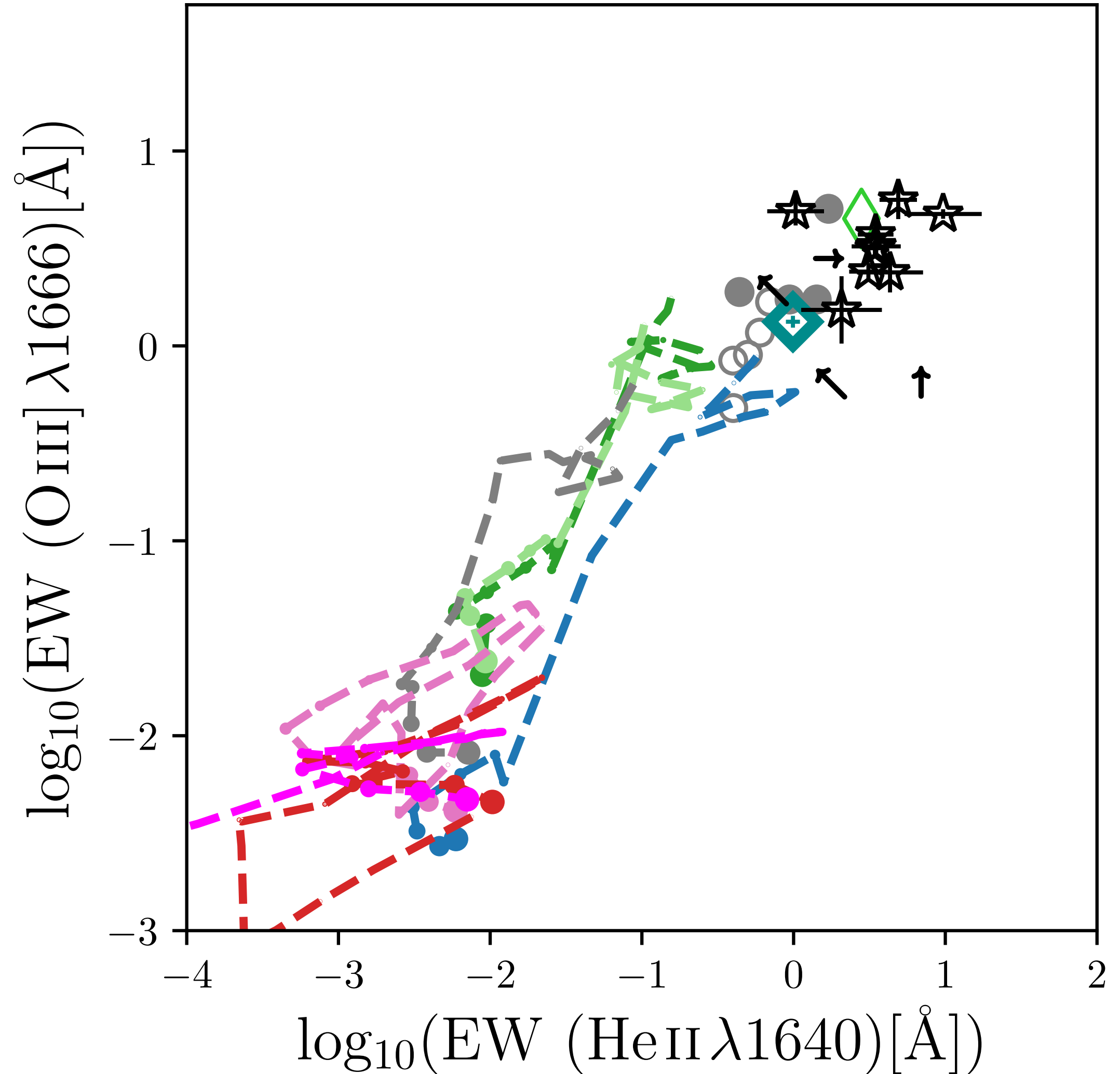
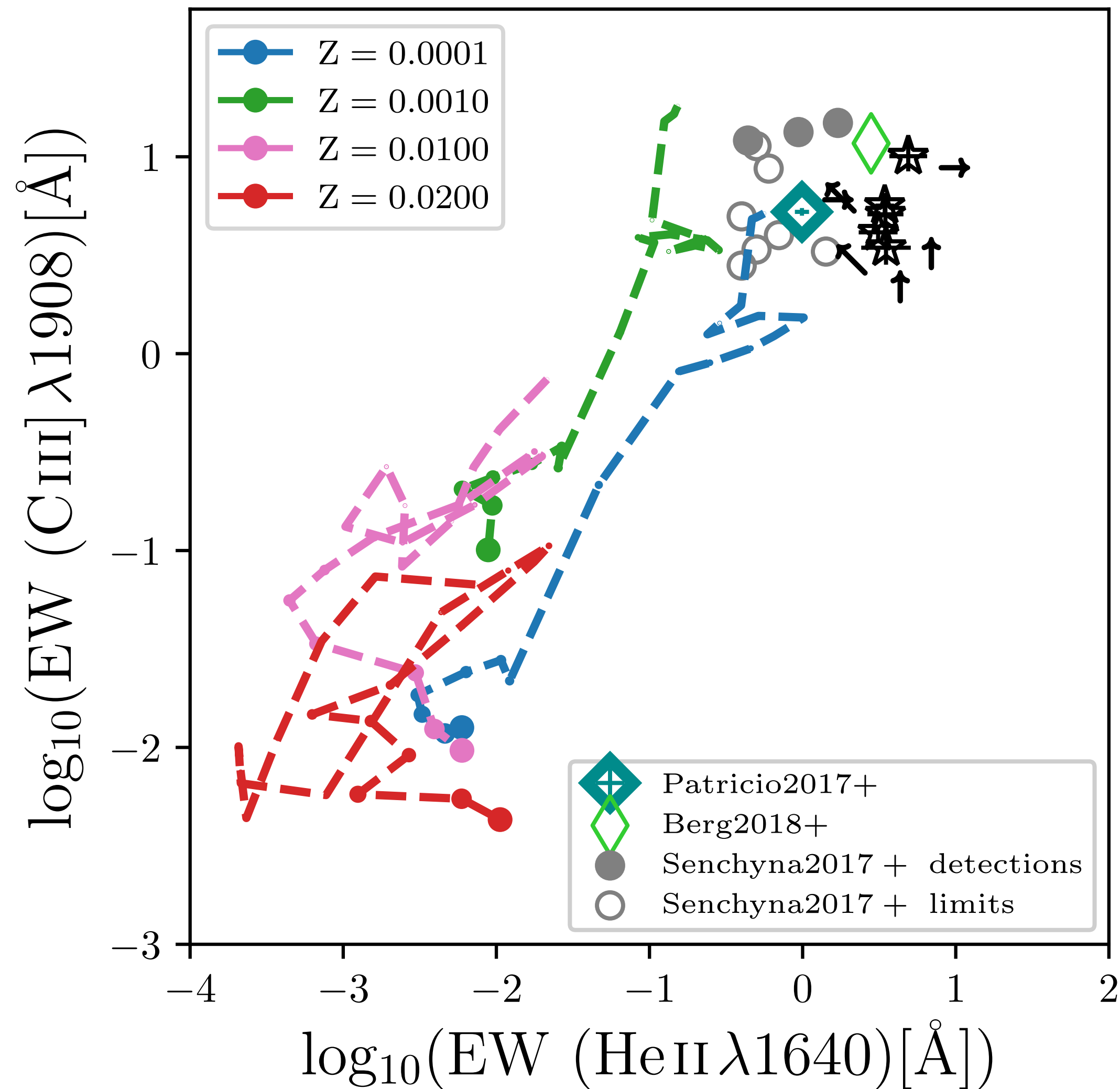
- dust effects not considered



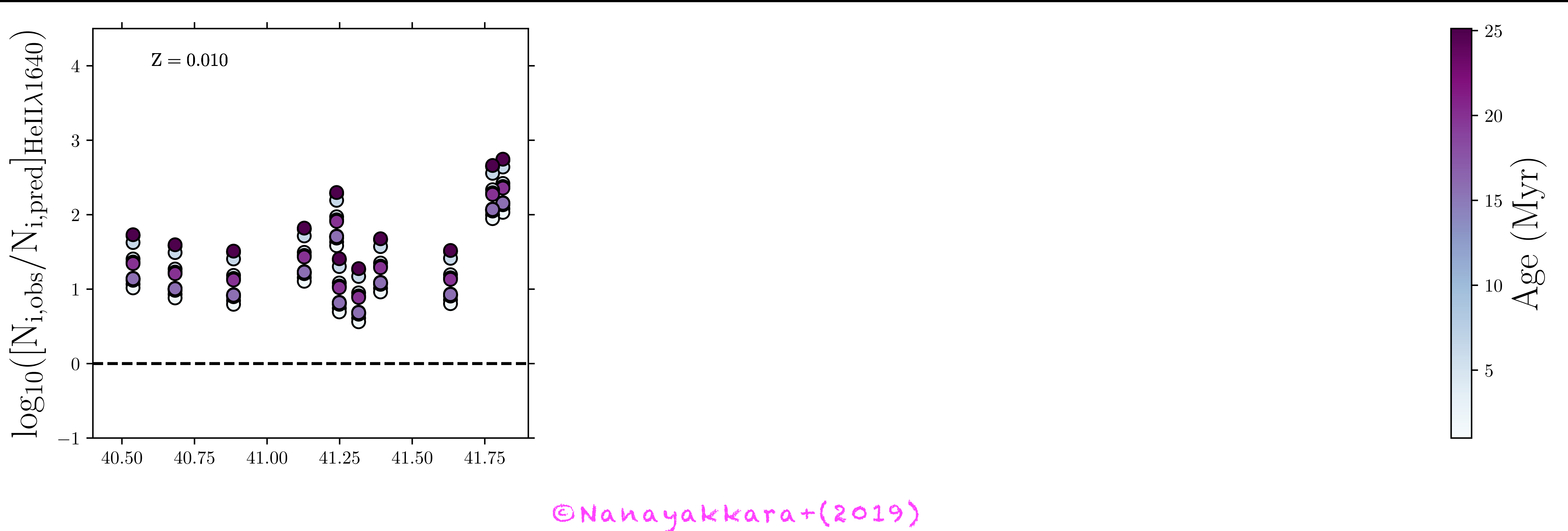
The Equivalent-widths are largely under predicted even with extremely low-Z high U models



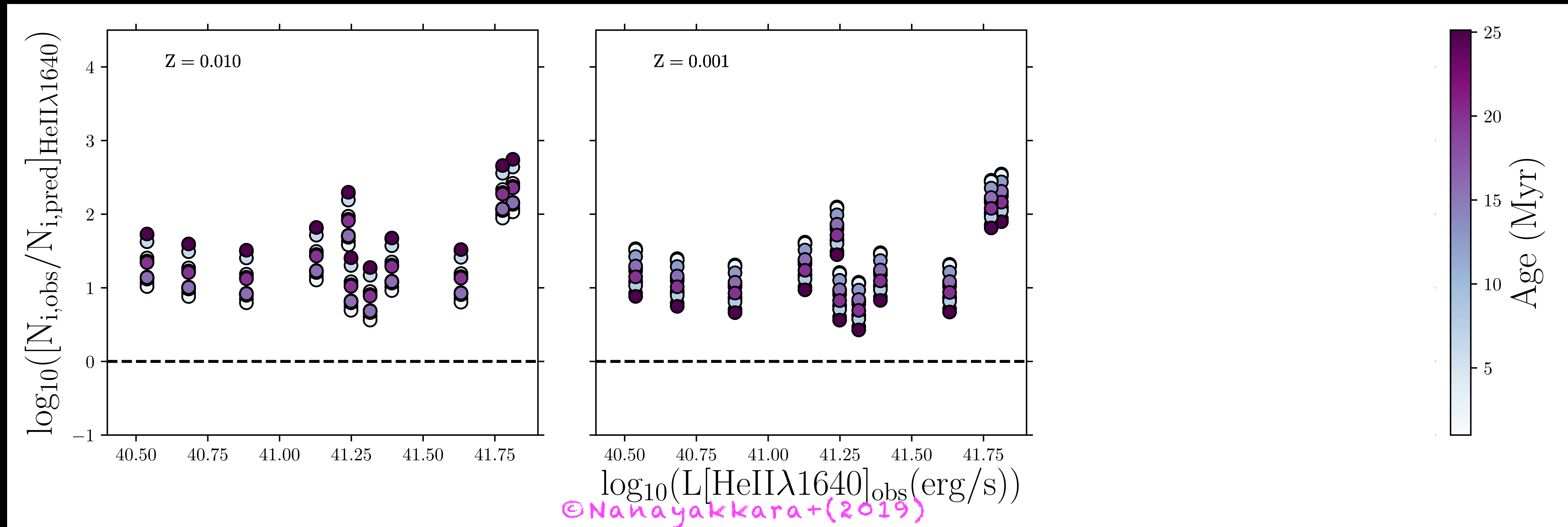
The Equivalent-widths are largely under predicted
even with extremely low-Z high U models



1 / 200th $Z_{\odot}$ binary stellar models are required to match observed vs predicted numbers of He^+ ionising photons

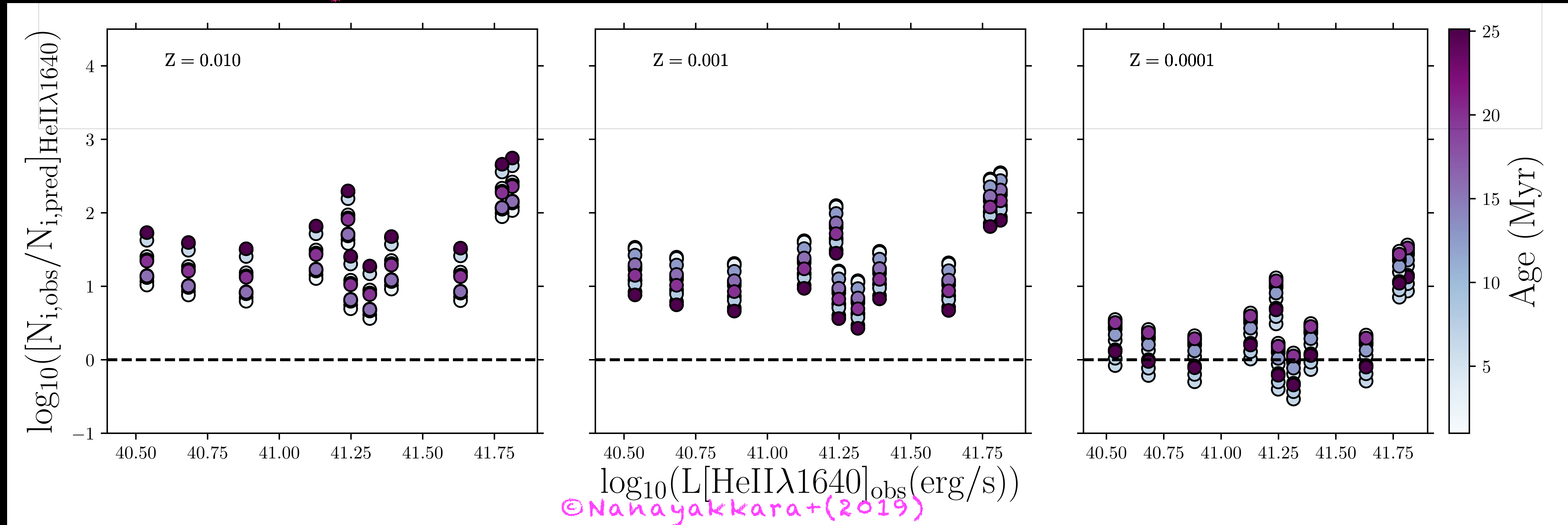


1 / 200th $Z_{\odot}$ binary stellar models are required to match observed vs predicted numbers of He^+ ionising photons

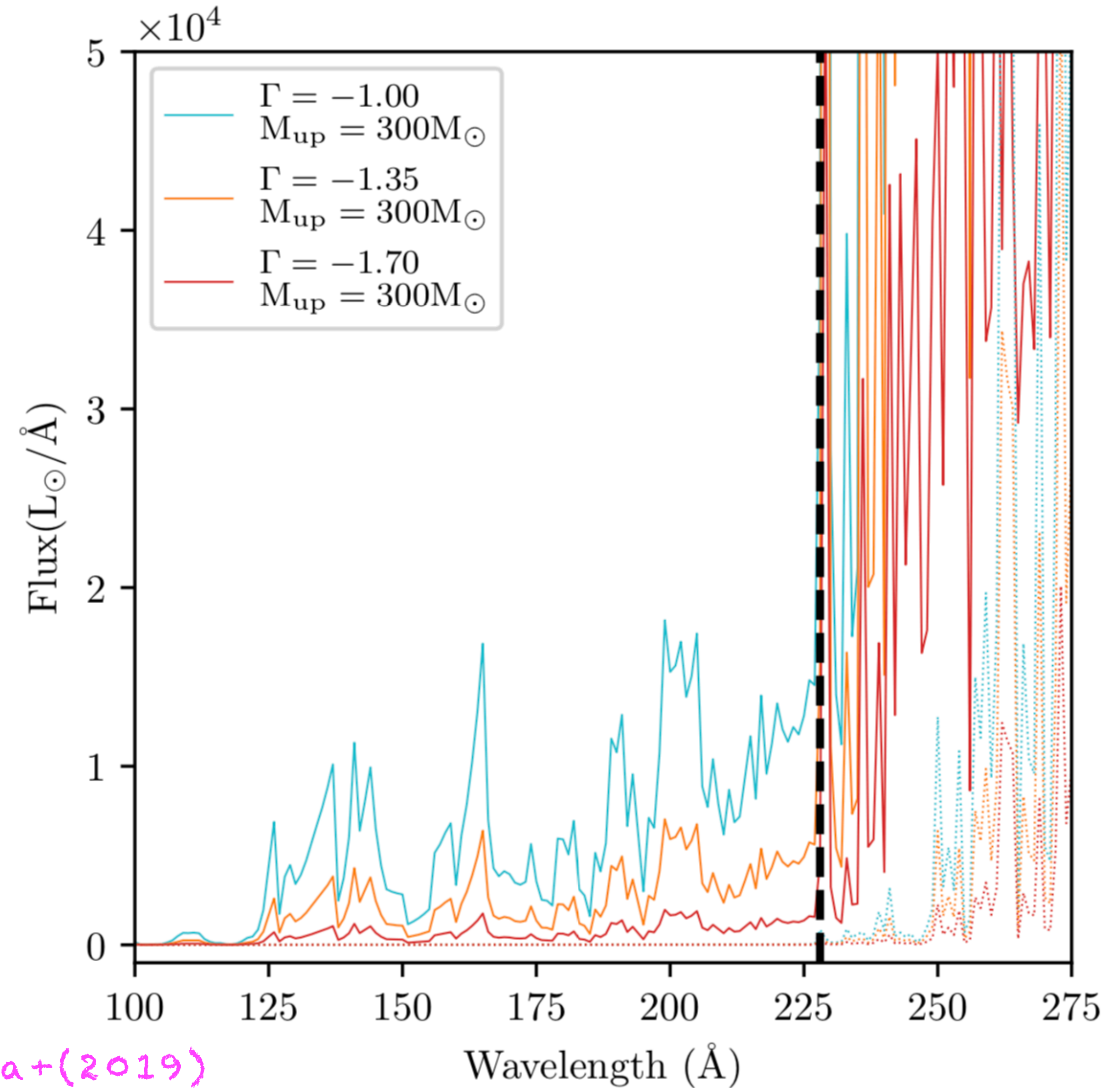
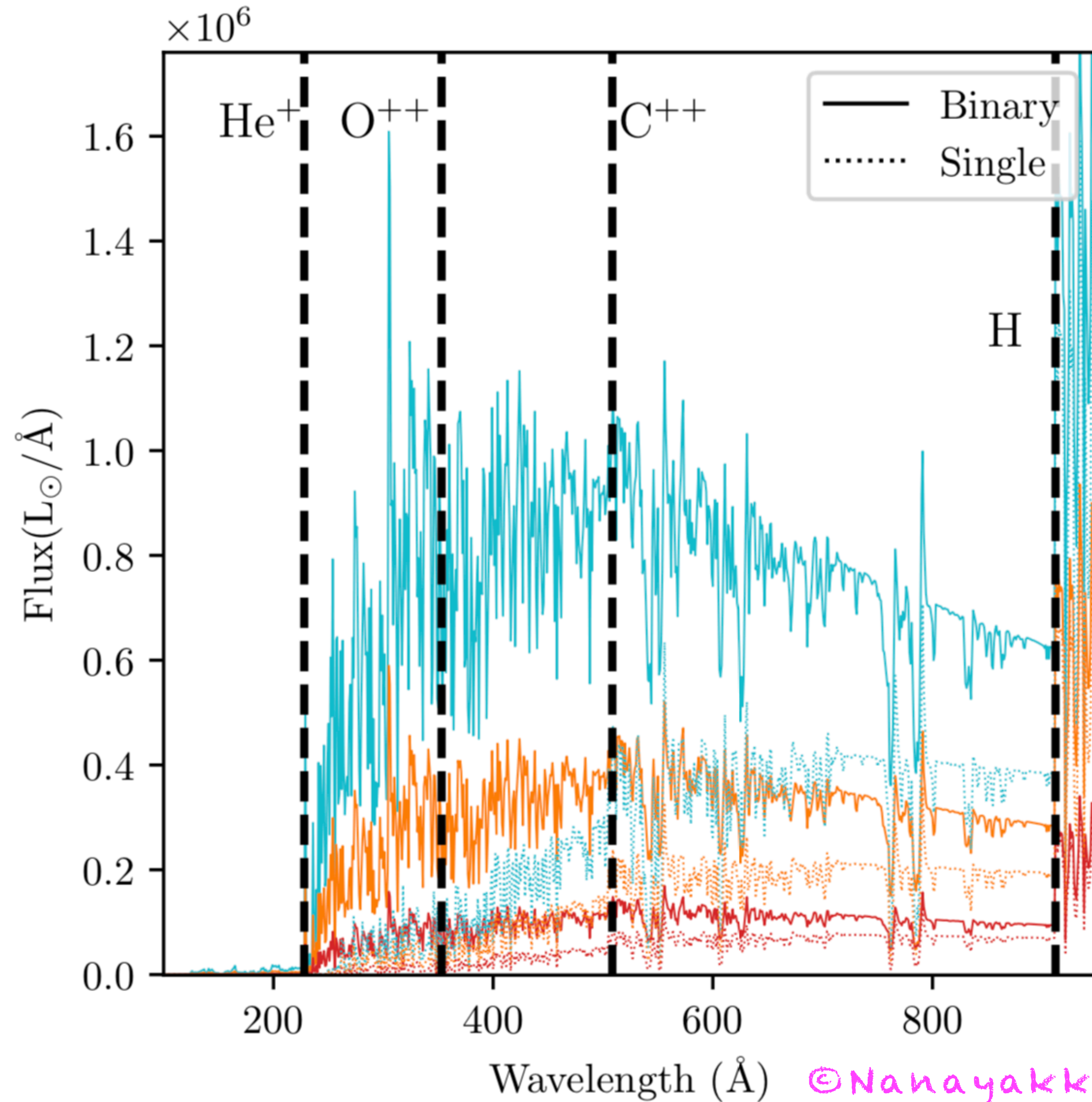


1/200th $Z_{\odot}$ binary stellar models are required to match observed vs predicted numbers of He^+ ionising photons

This is in contrast to relatively higher metallicities inferred by line ratio diagnostics

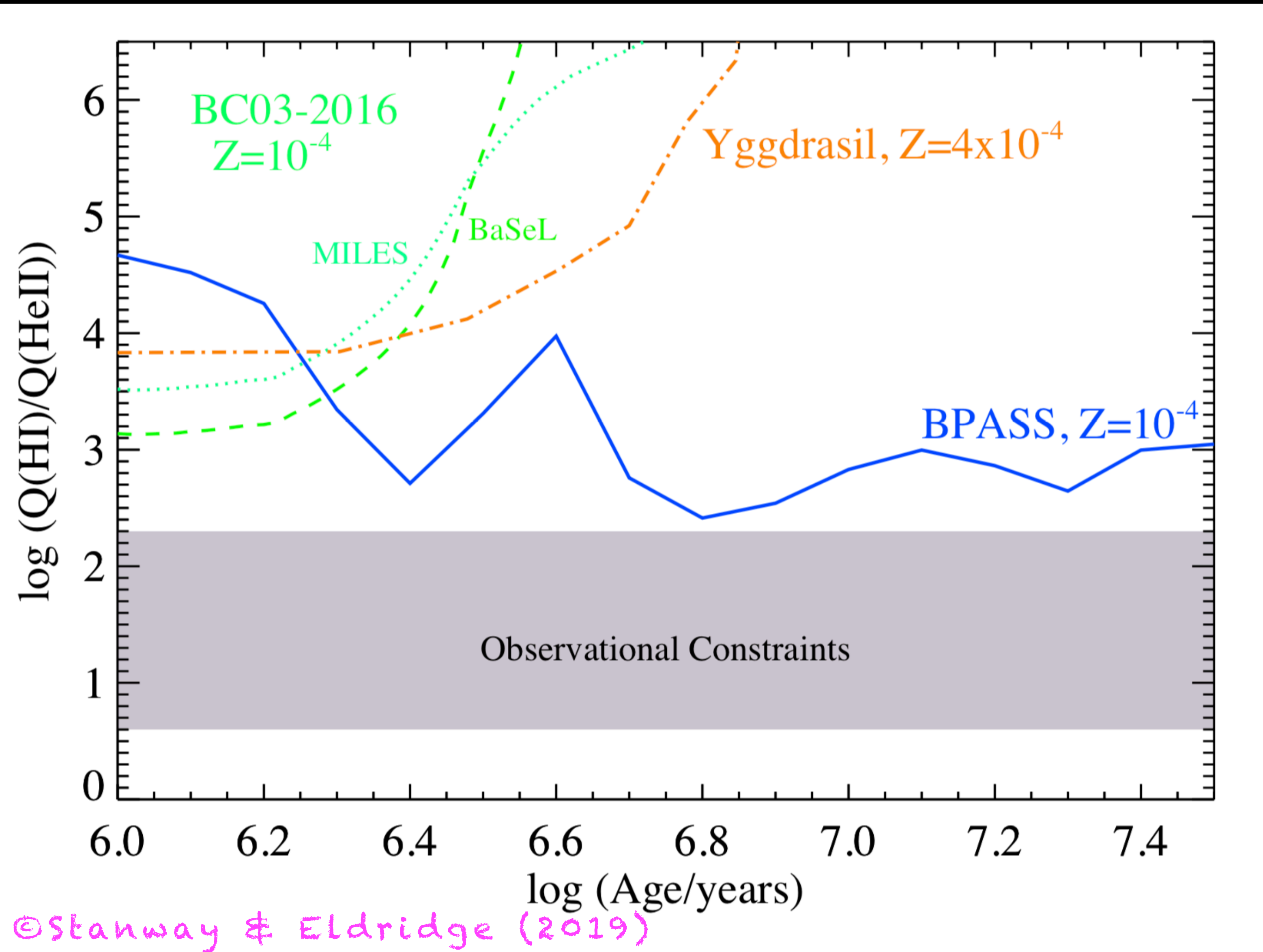


We lack a comprehensive understanding of stellar spectra in the FUV
which may contribute to lack in mechanisms producing of
 $E_{\text{photon}} > 54 \text{ eV}$



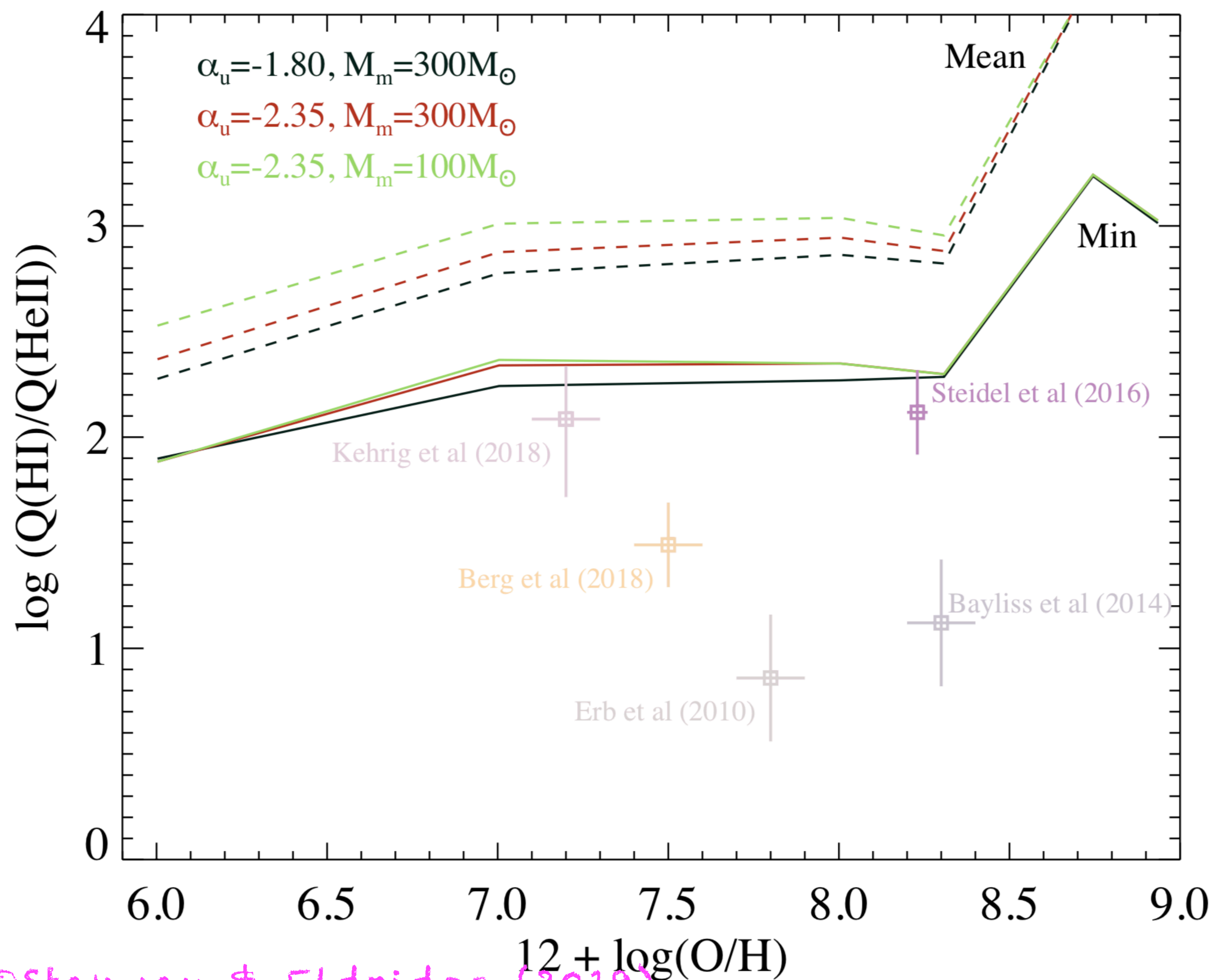
©Nanayakkara+(2019)

The lack of hard ionising photons is common for most stellar population models

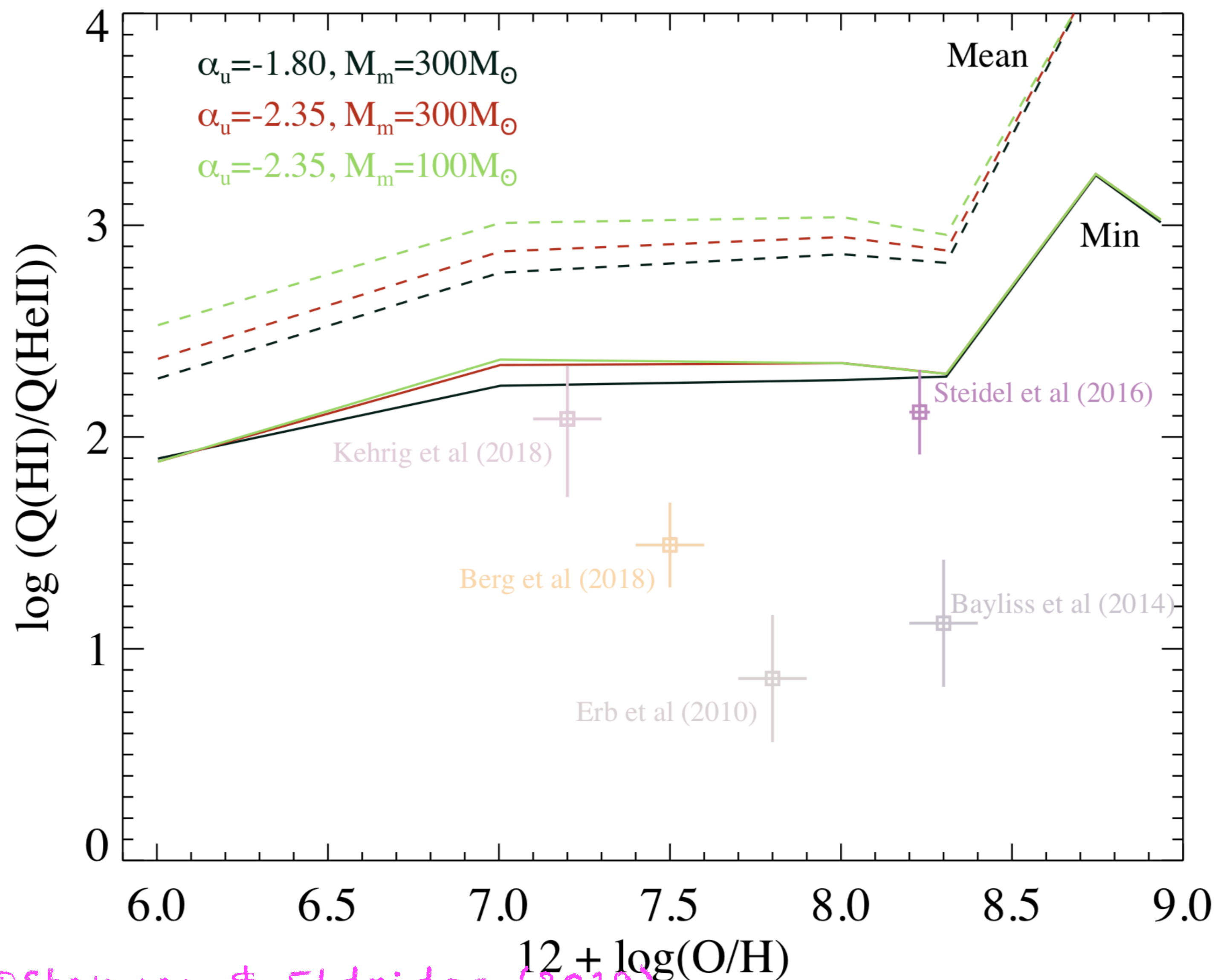


Part III: Where are the missing photons?

Is it variations in the IMF?

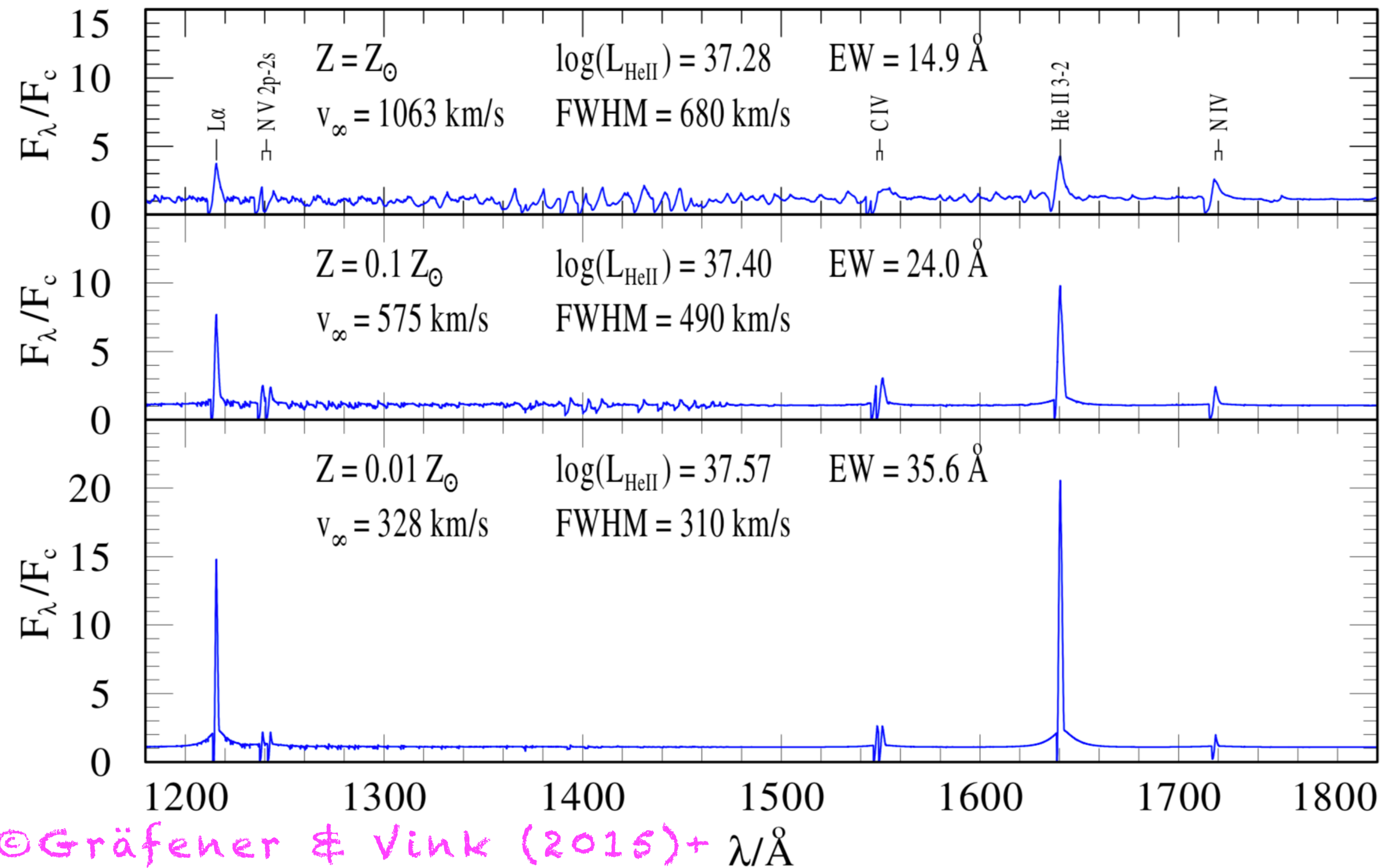


Is it variations in the IMF?

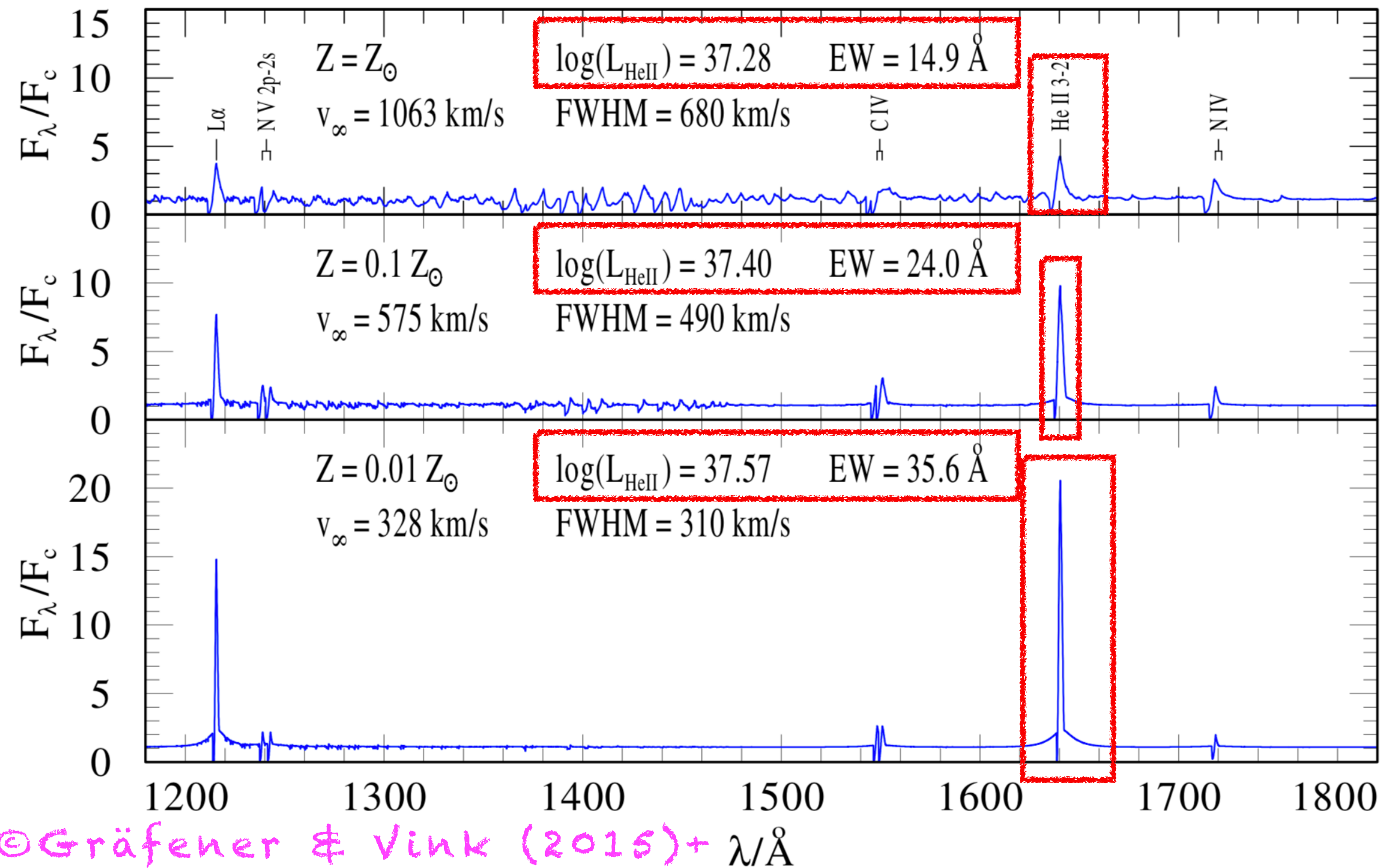


In the context of BPASS even variations in the IMF has shown to NOT be sufficient to compensate for the missing photons

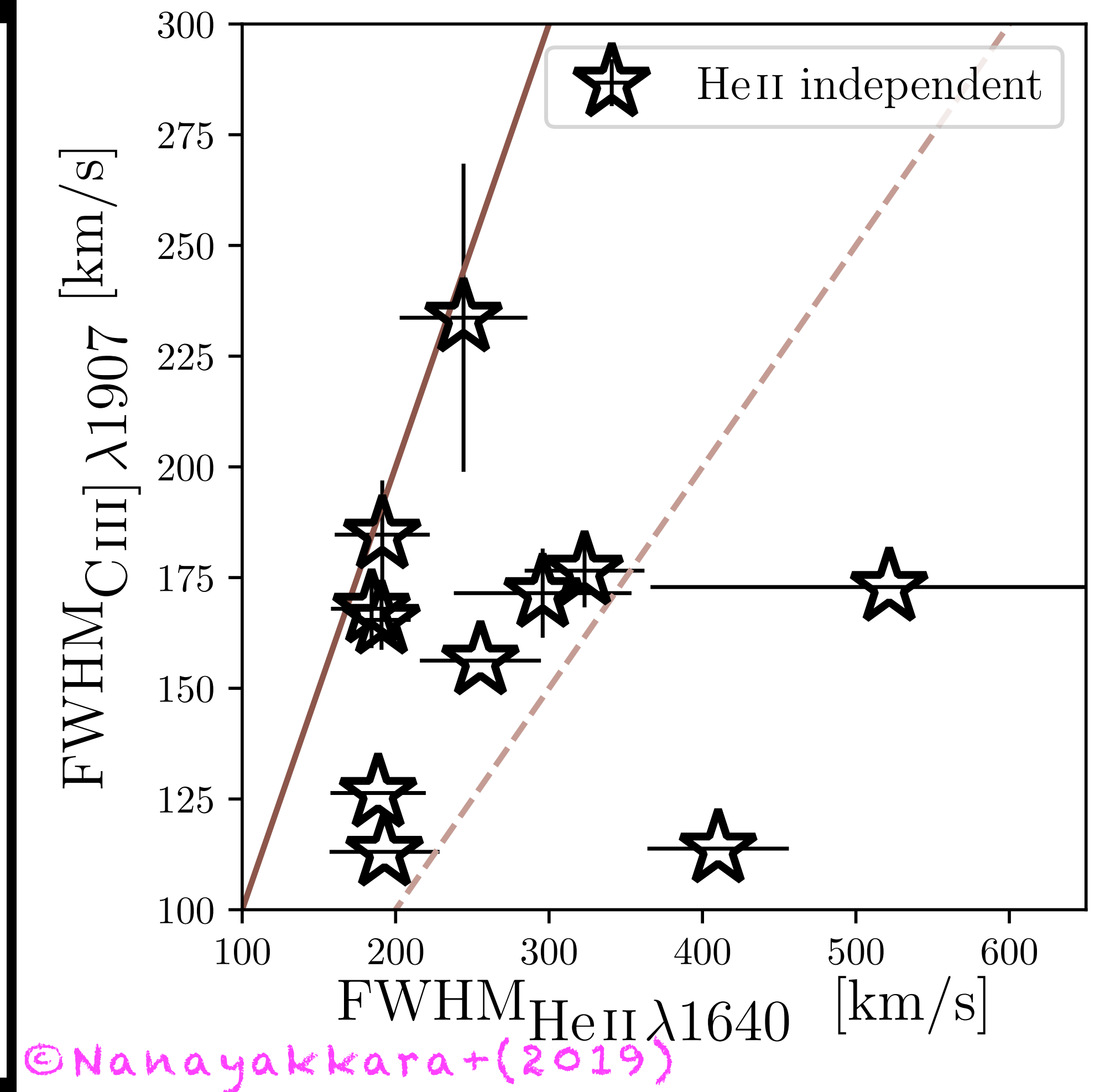
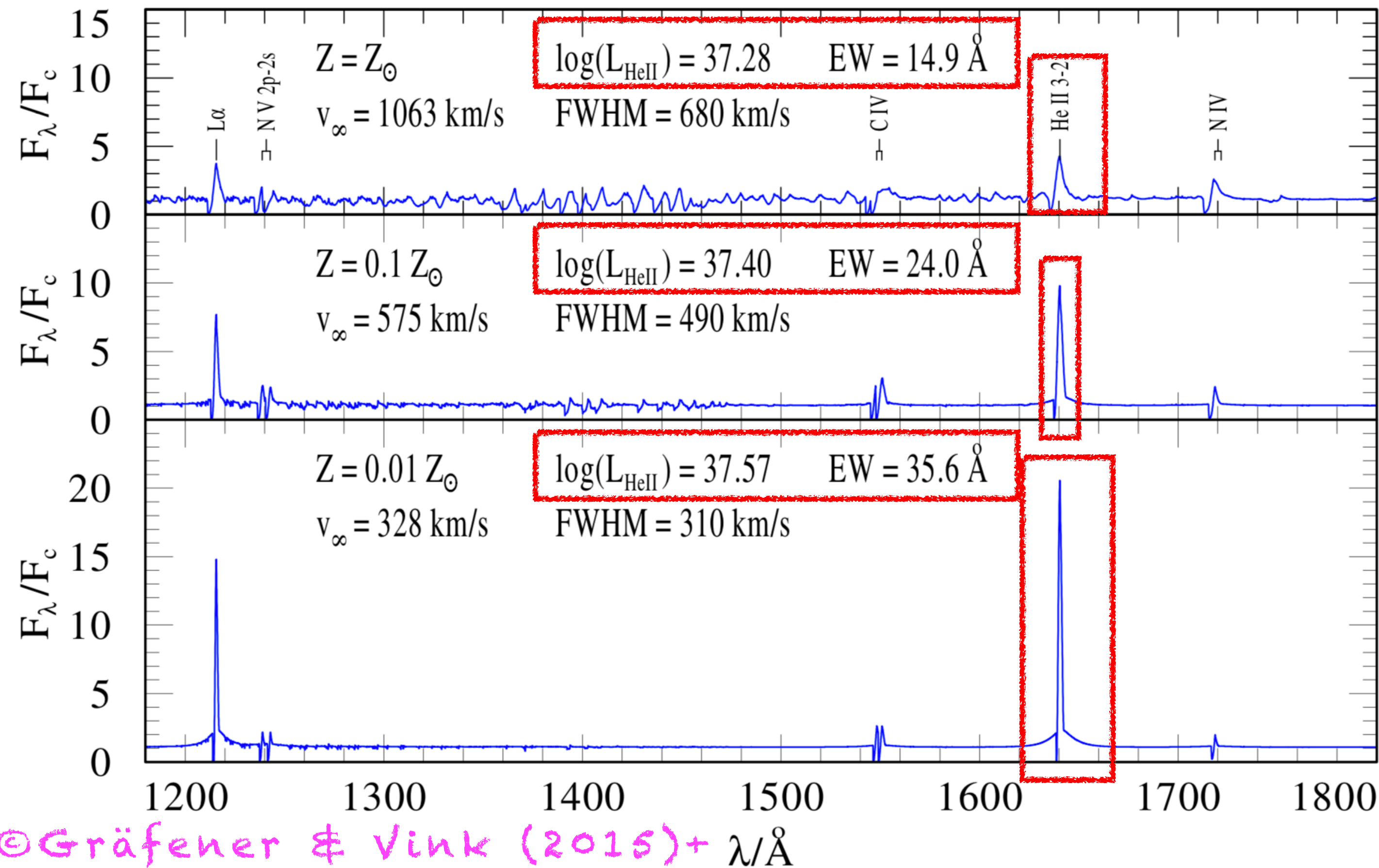
Is it very massive stars at Eddington limit?



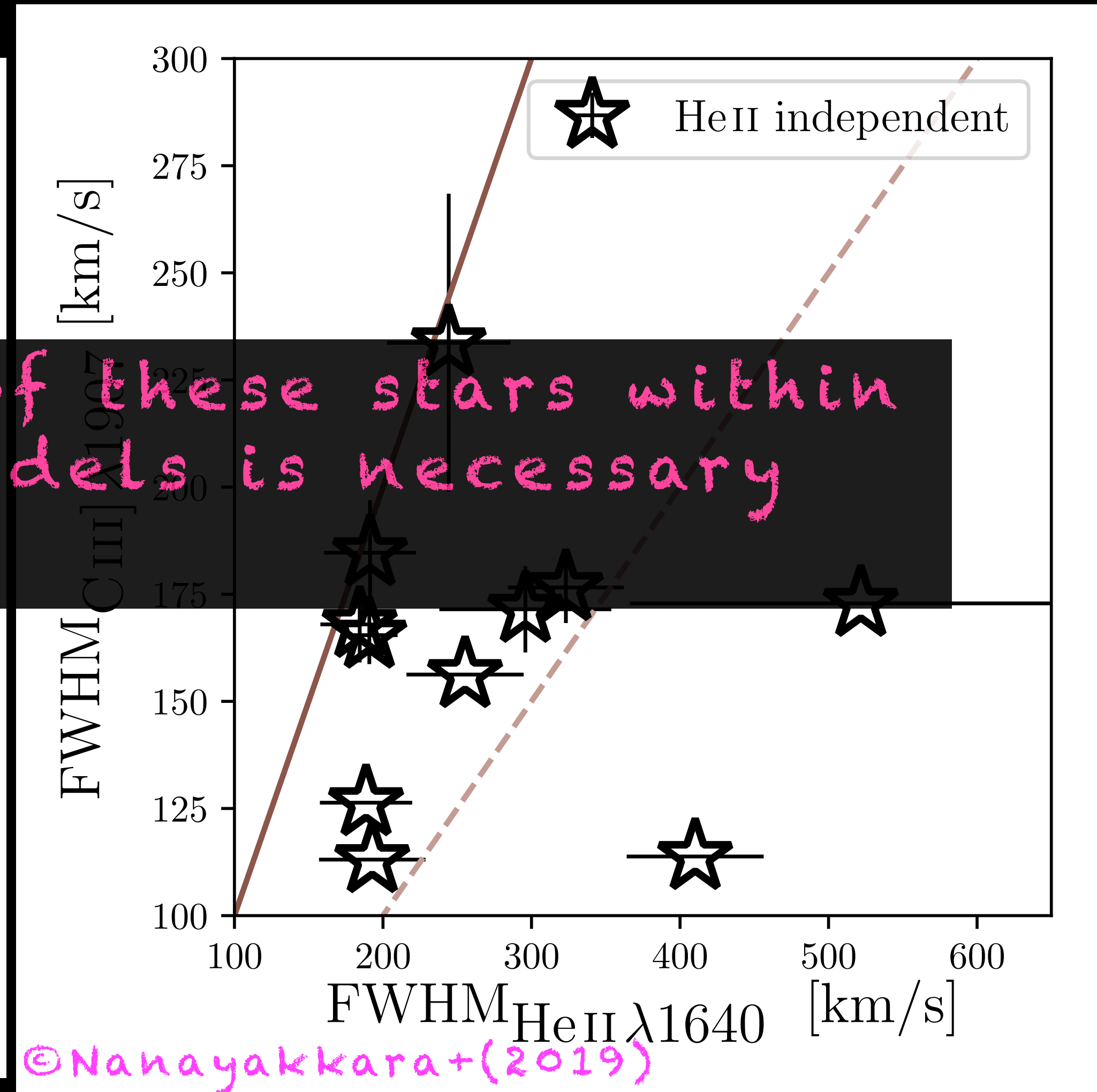
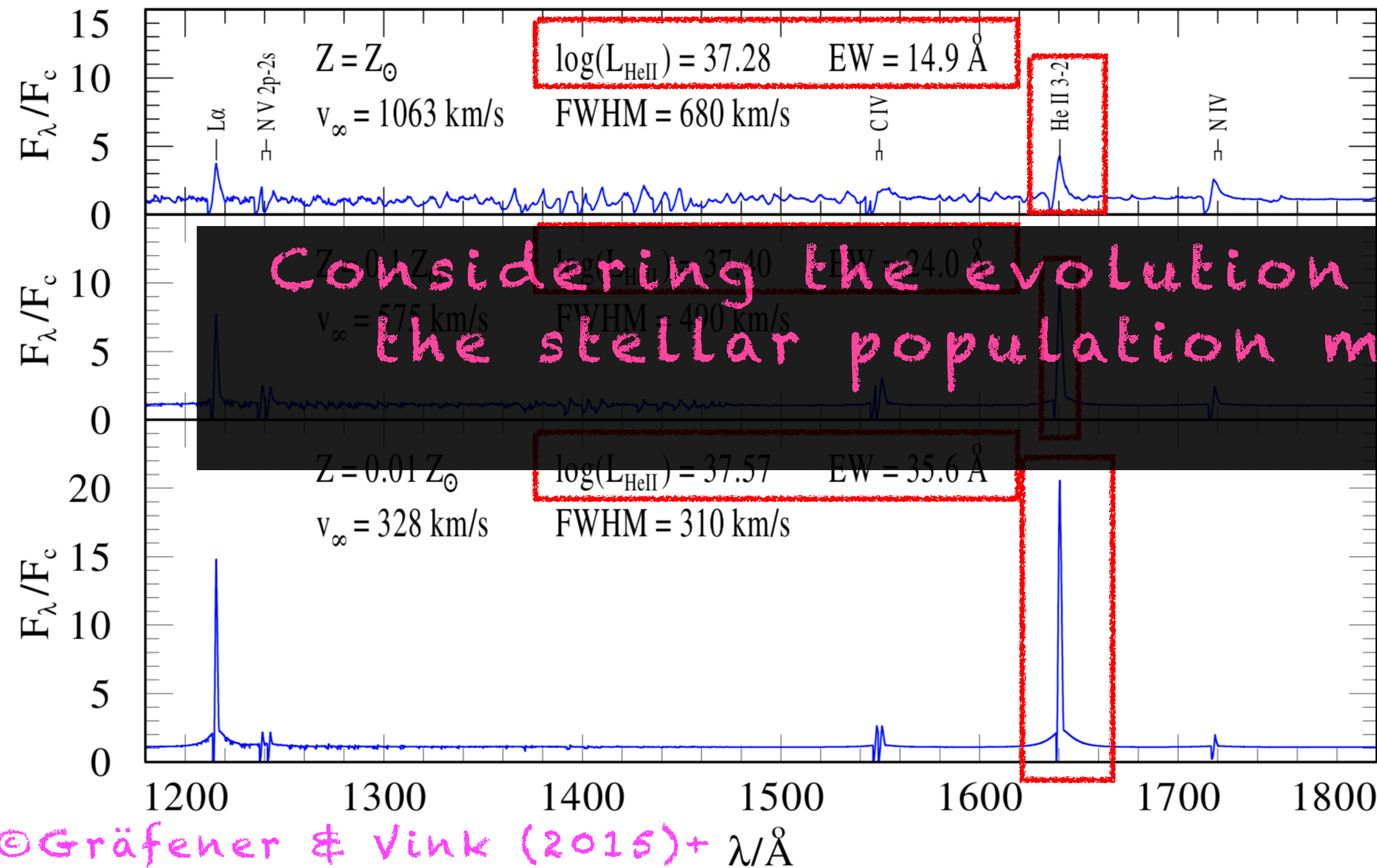
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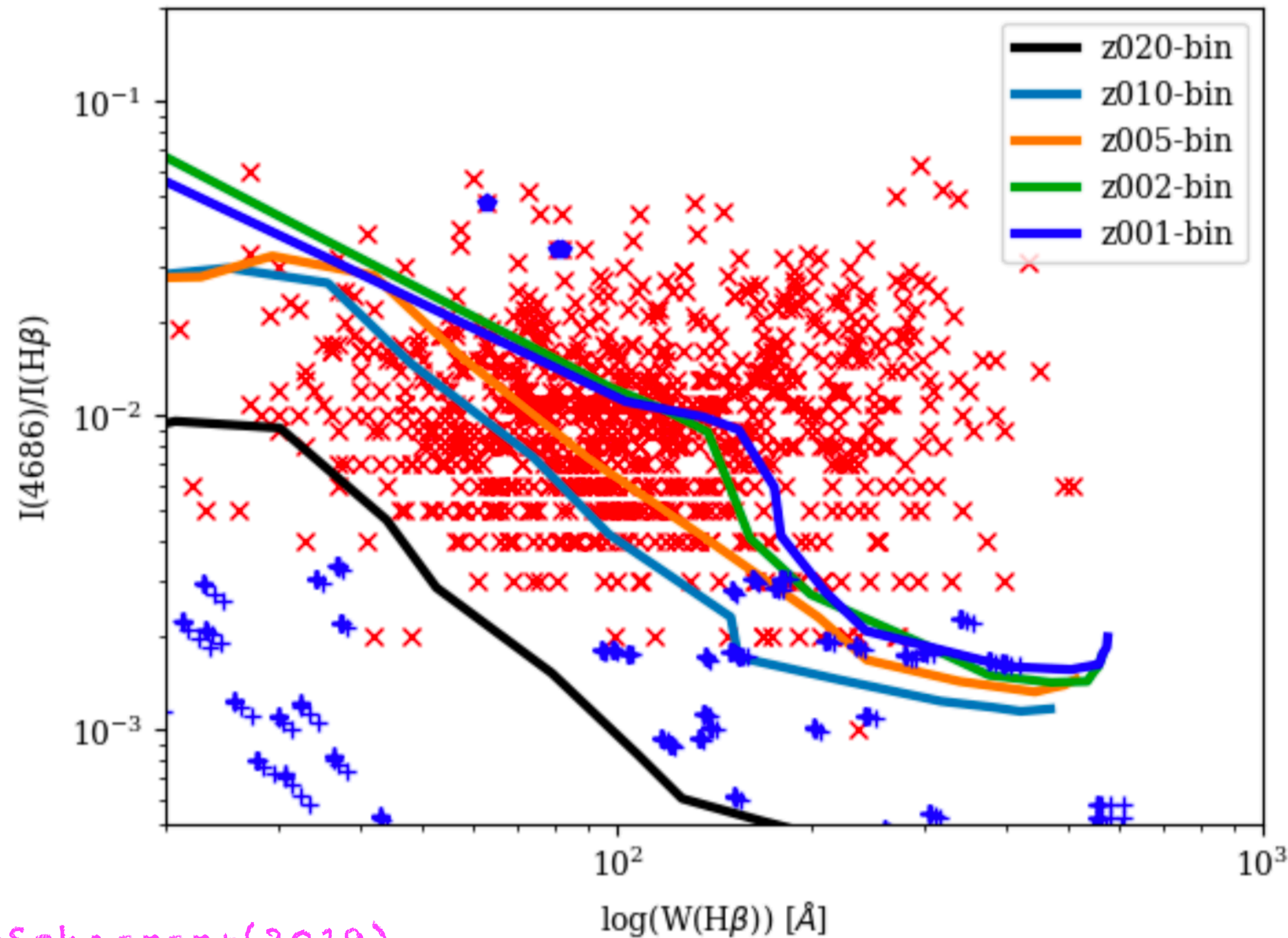
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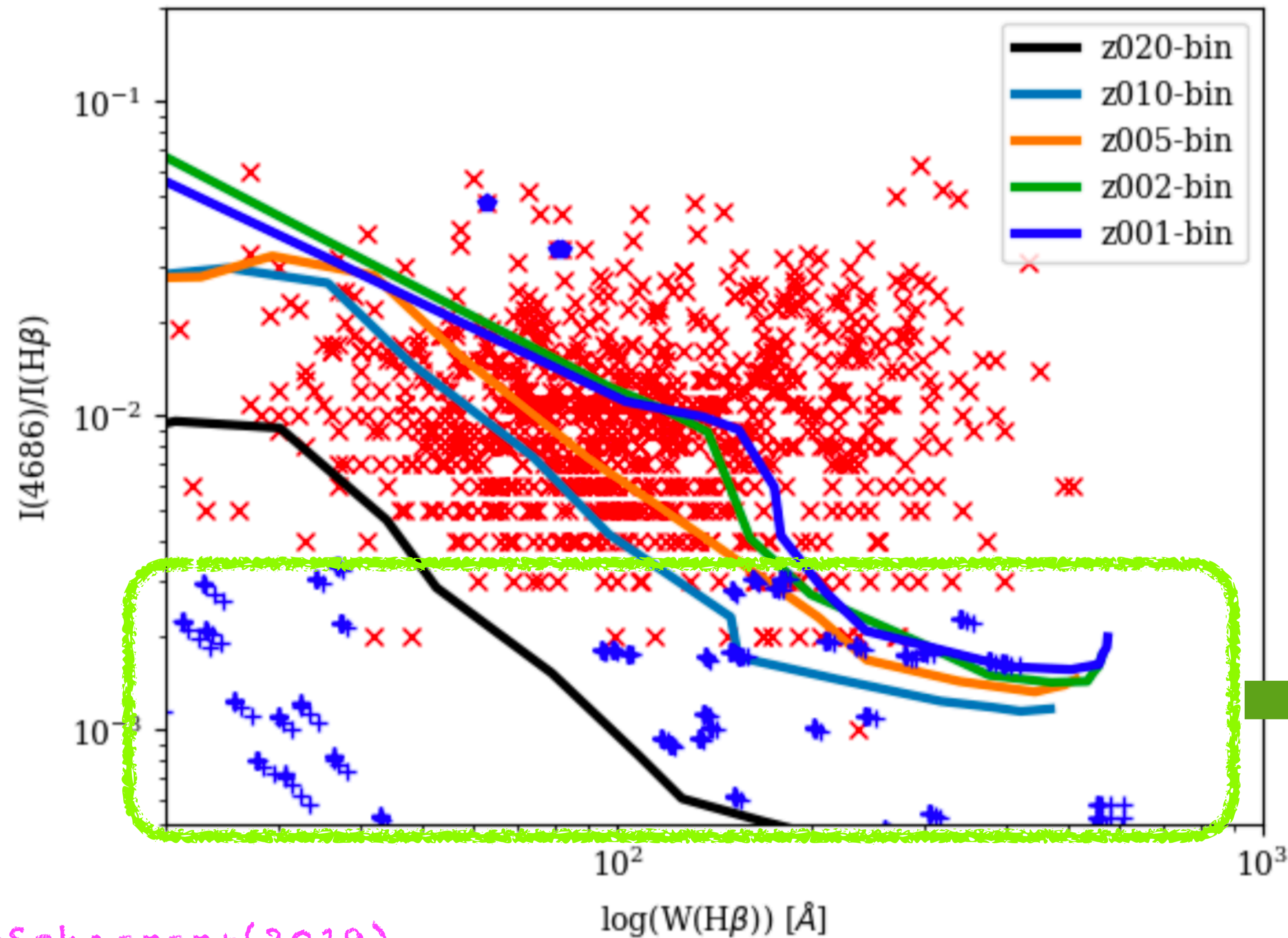
Is it very massive stars at Eddington limit?



Is it contributions from X-ray Binaries?

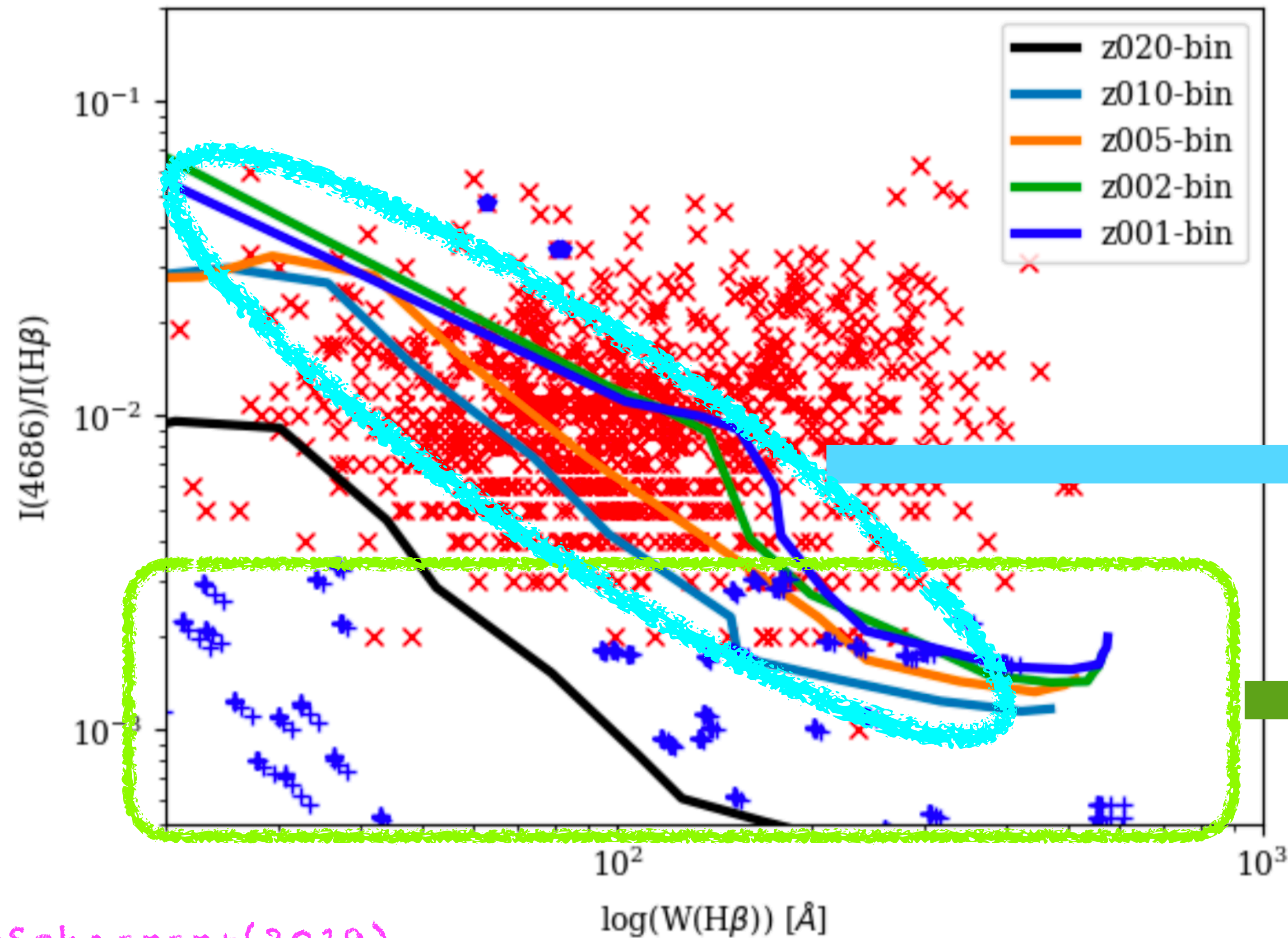


Is it contributions from X-ray Binaries?



BPASS only

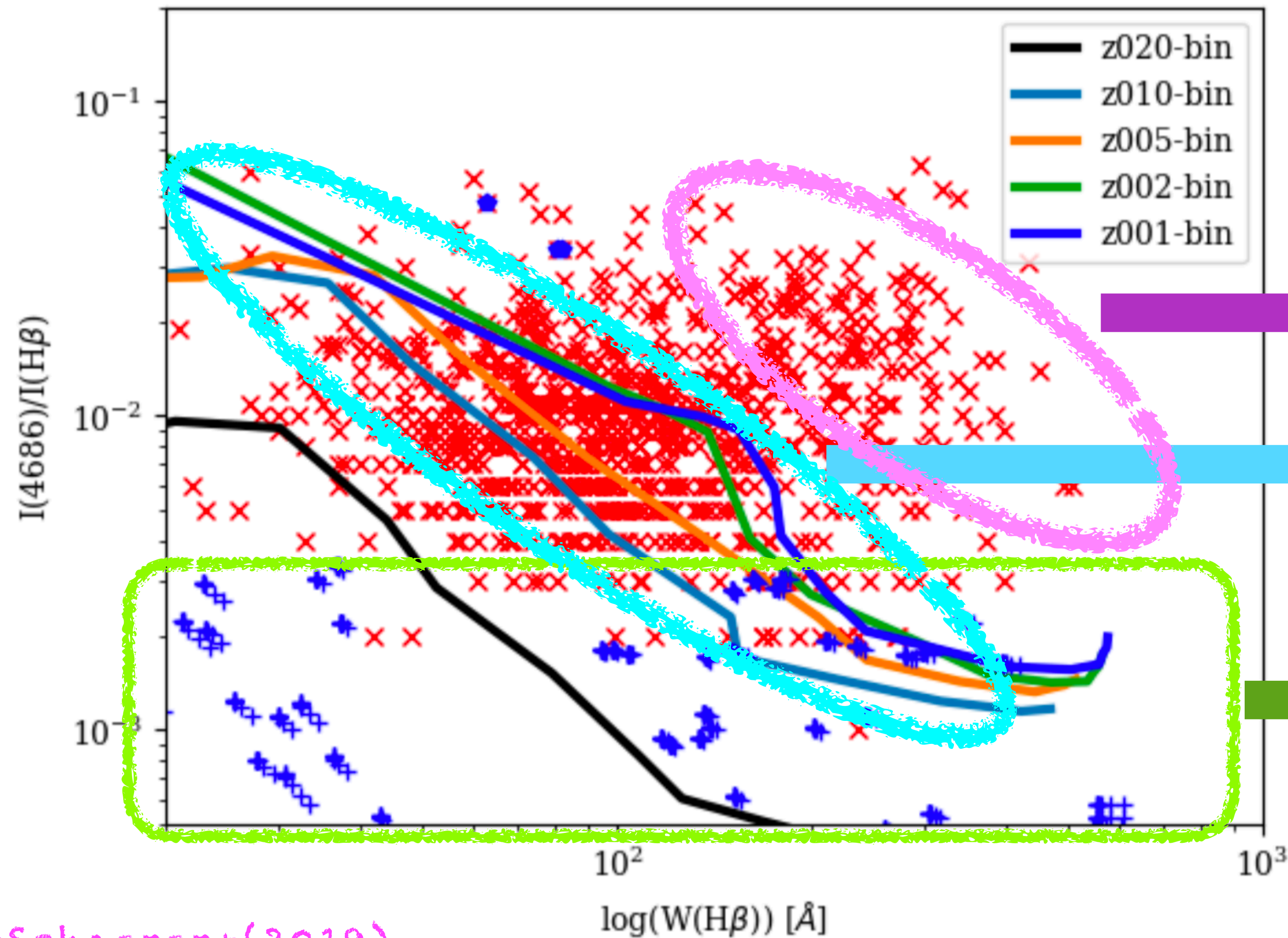
Is it contributions from X-ray Binaries?



BPASS + X-ray
binaries

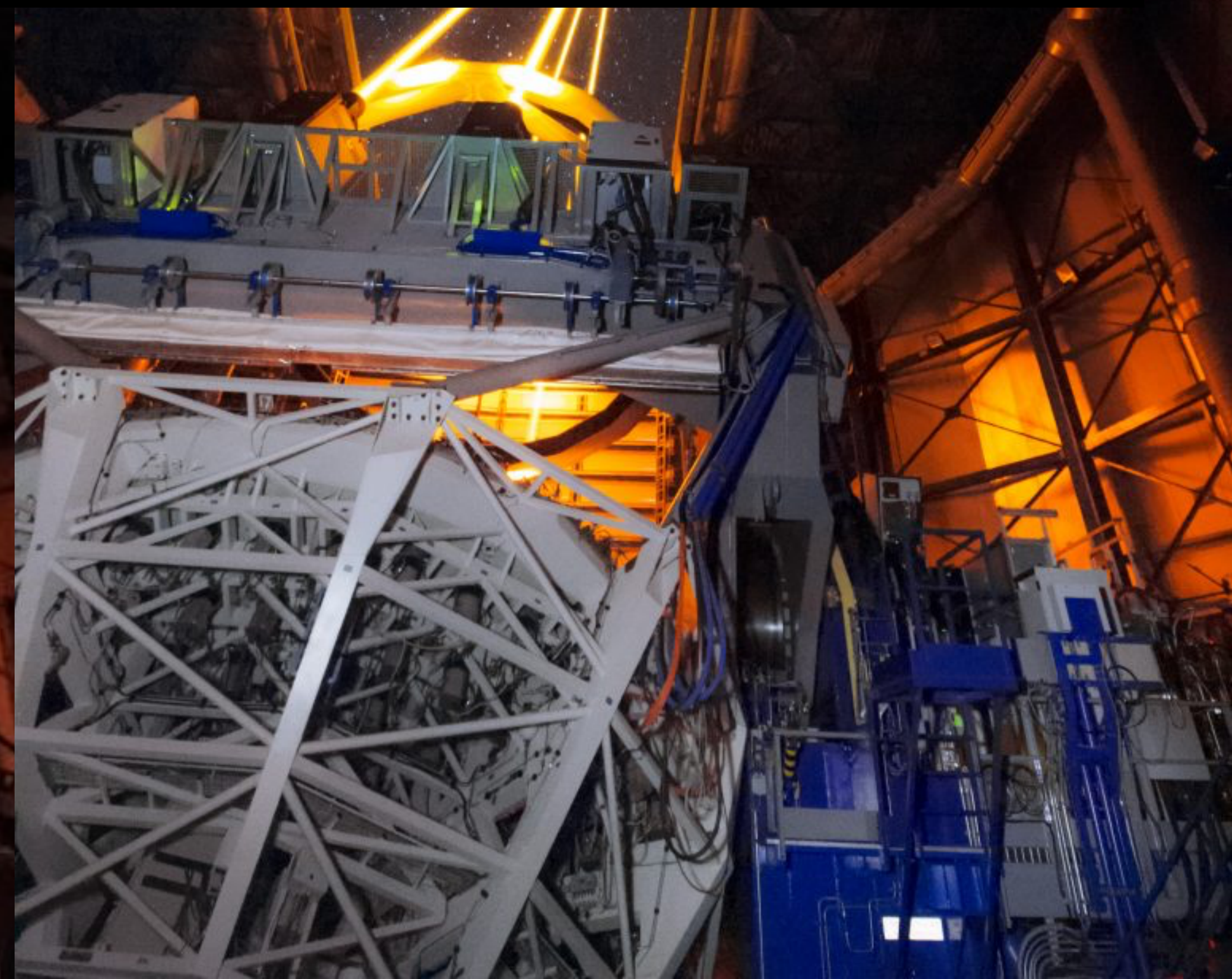
BPASS only

Is it contributions from X-ray Binaries?



How can we provide observational constraints?

Deep high S/N data for simultaneous rest-UV emission and absorption analysis.



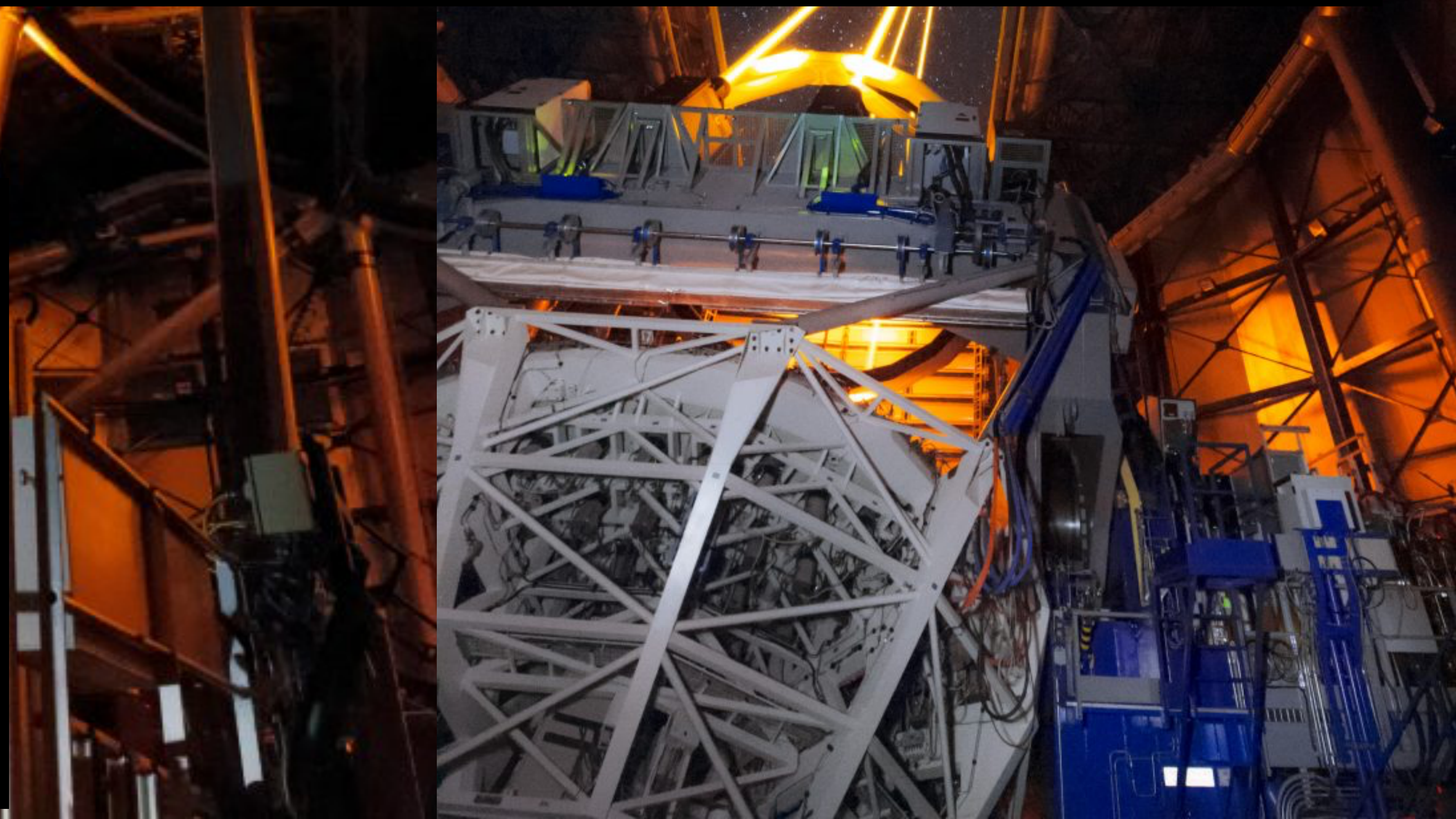
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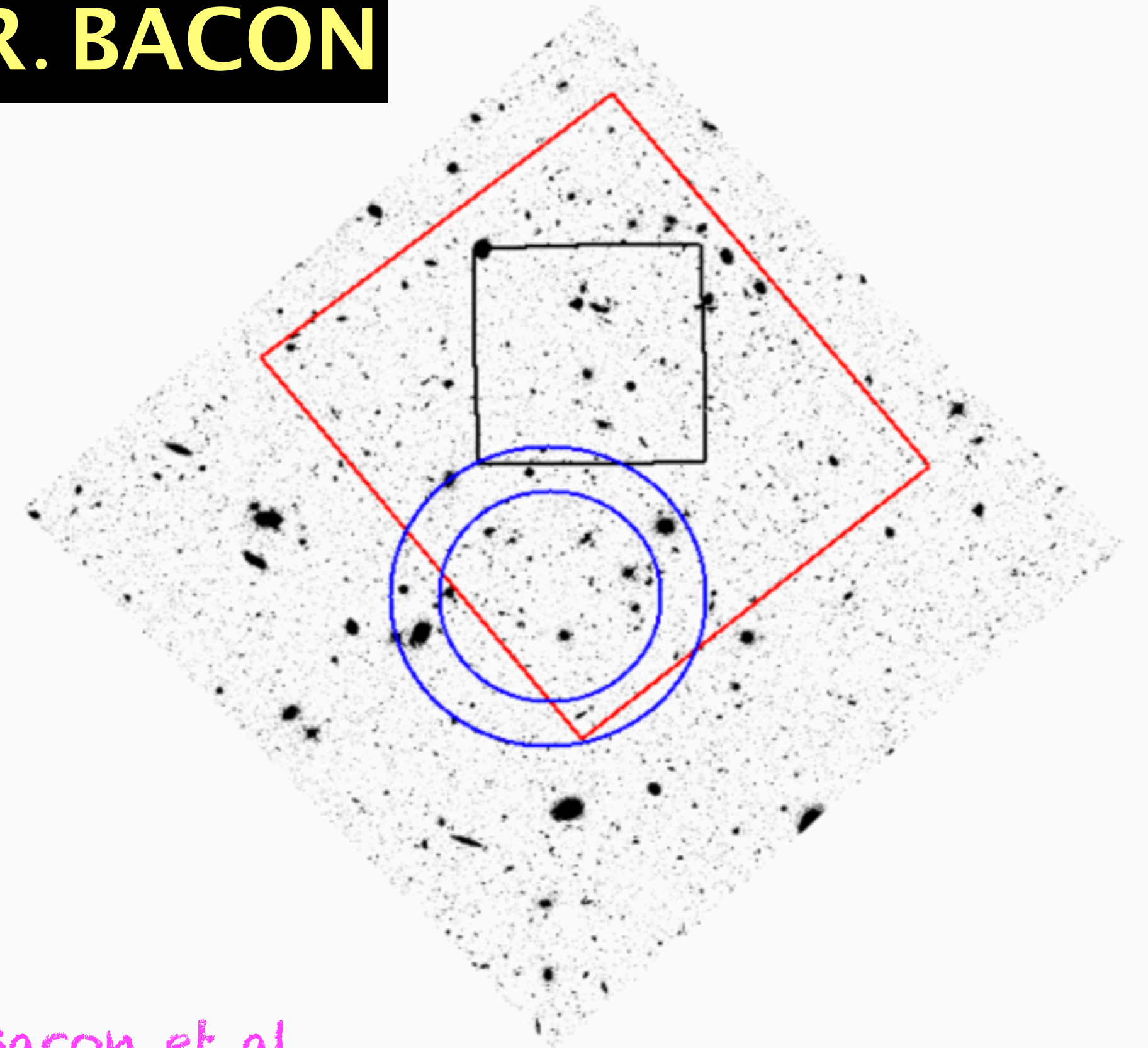
Deep MUSE pointings:

- MXDF ~ 160h single UDF pointing
- HFF parallels



MUSE XDF program

PI R. BACON



©Bacon et al.,

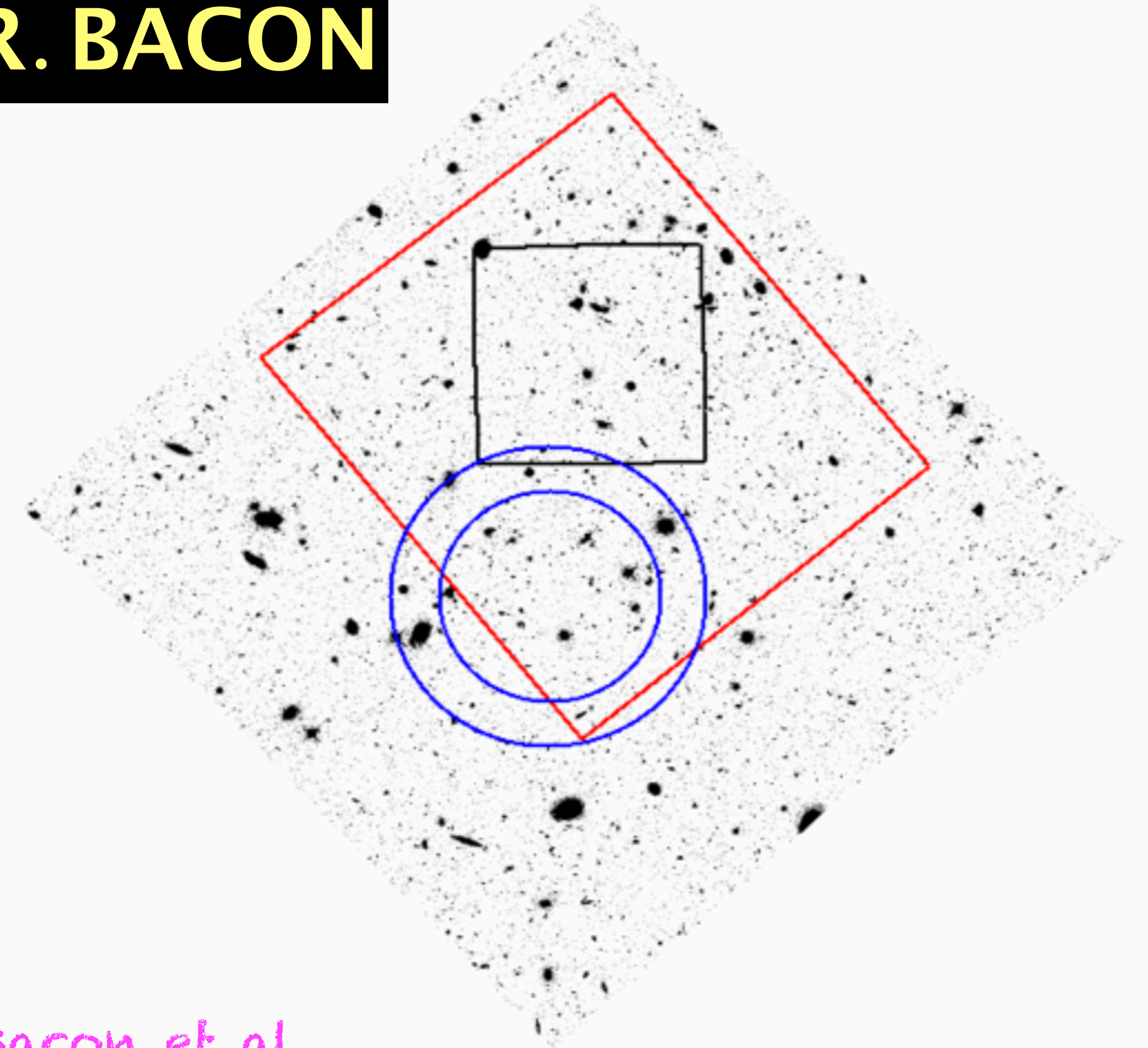
MUSE XDF program

160h 1'x1' single pointing in UDF

Complemented by MUSE UDF program:

- Deep: 1'x1' 30h pointing
- Shallow: 9'x9' 10h pointings

PI R. BACON



©Bacon et al.,

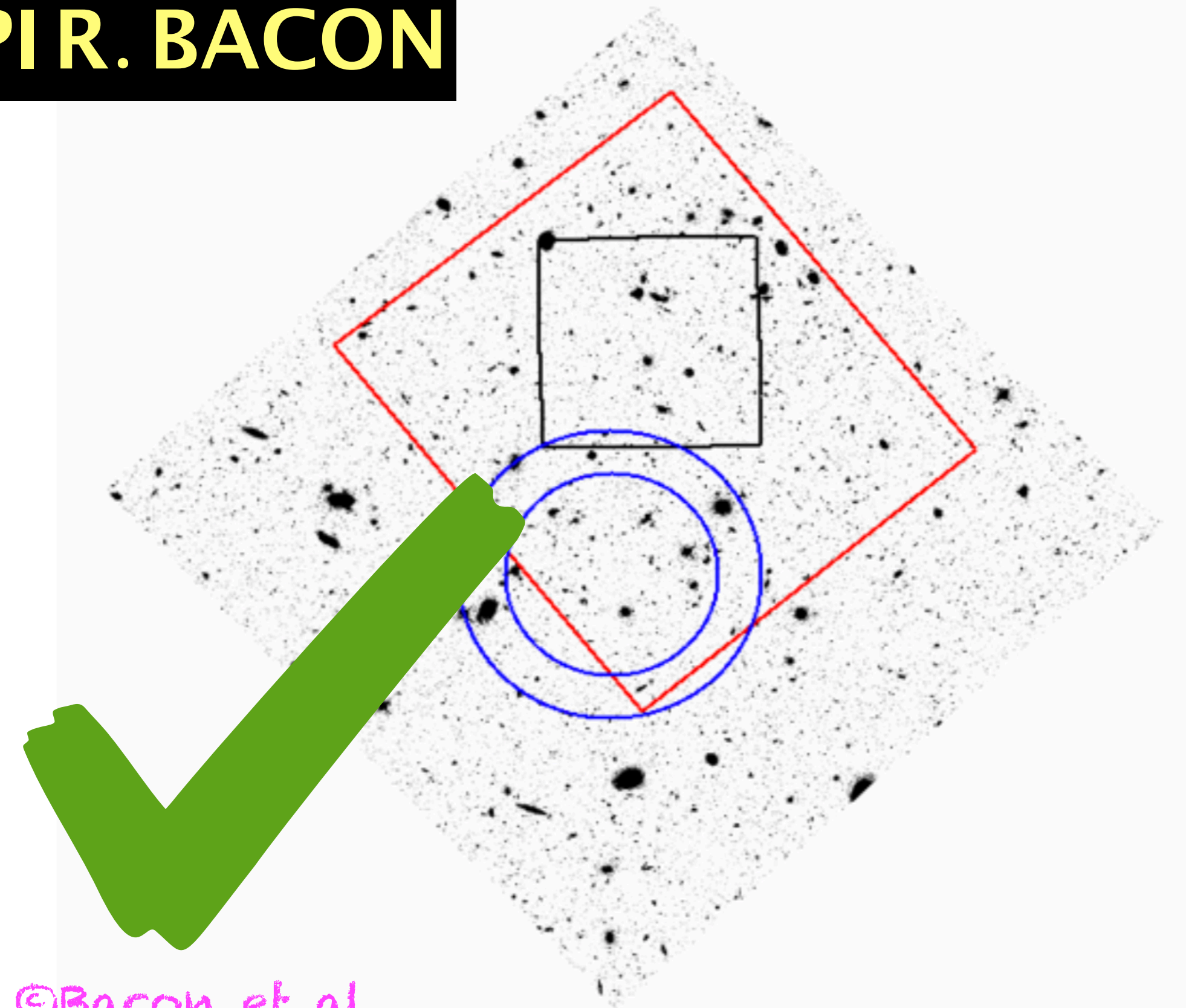
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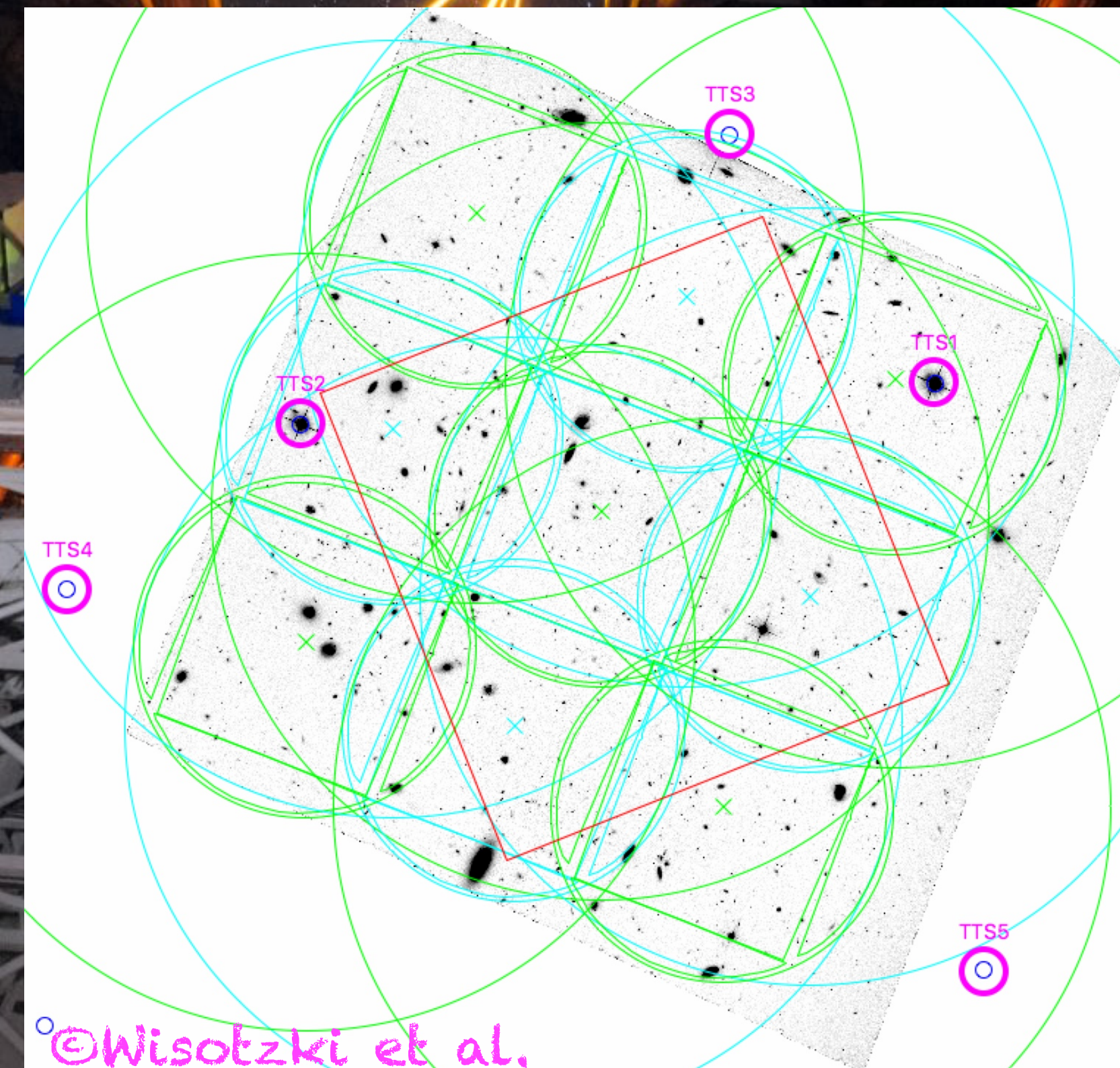
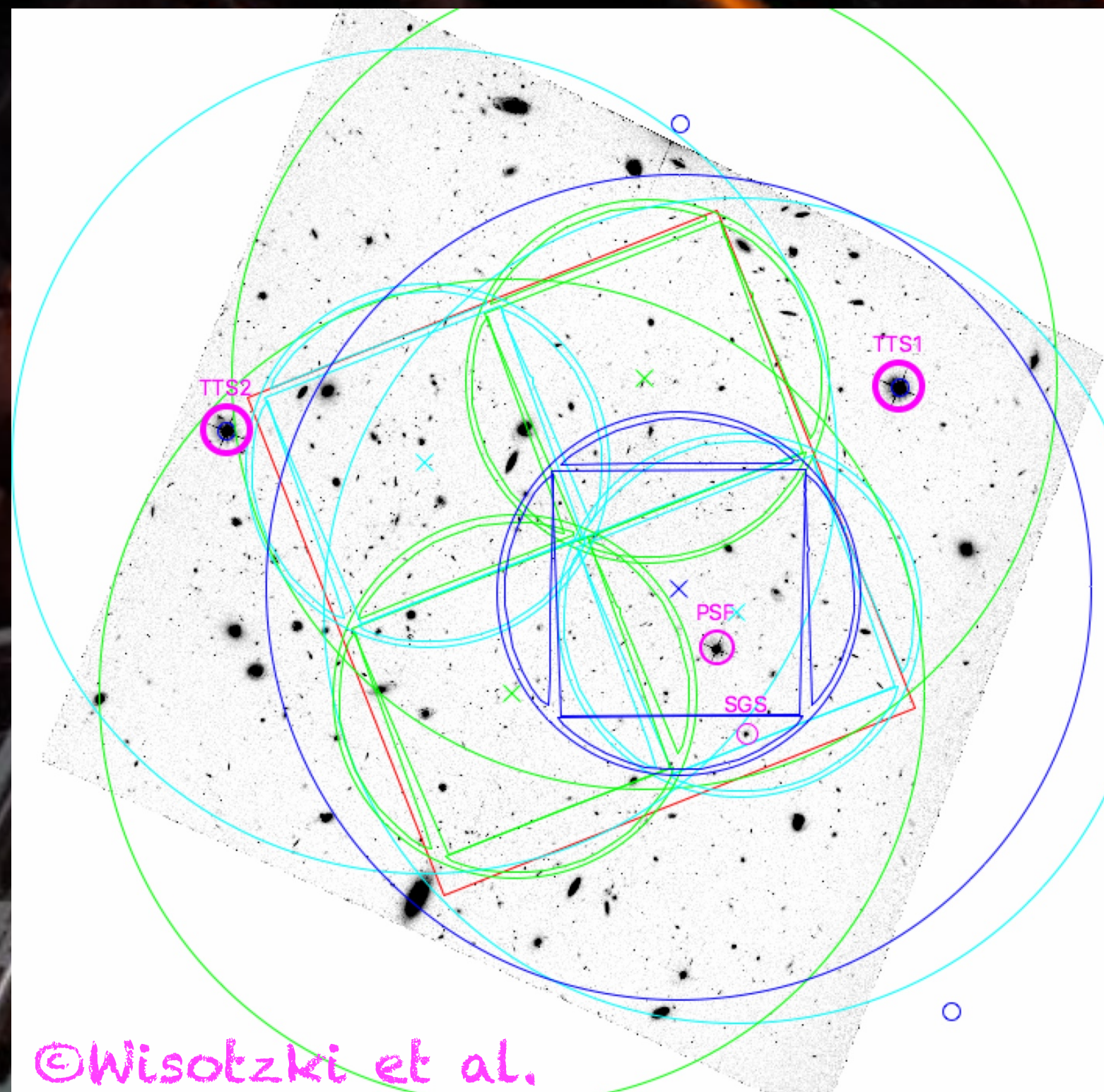
PI R. BACON



©Bacon et al.,

MUSE HFF program

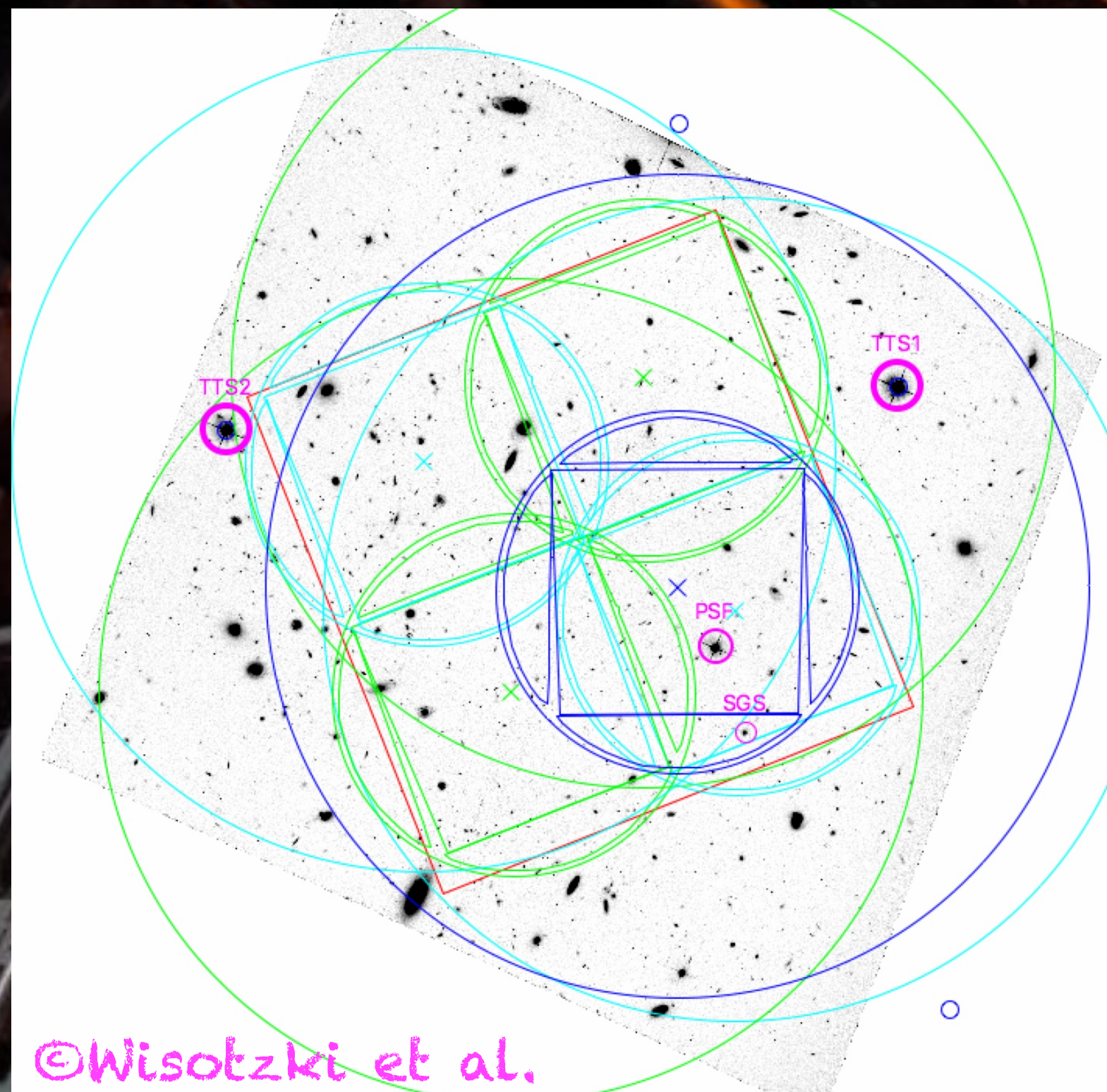
PI L. WISOTZKI



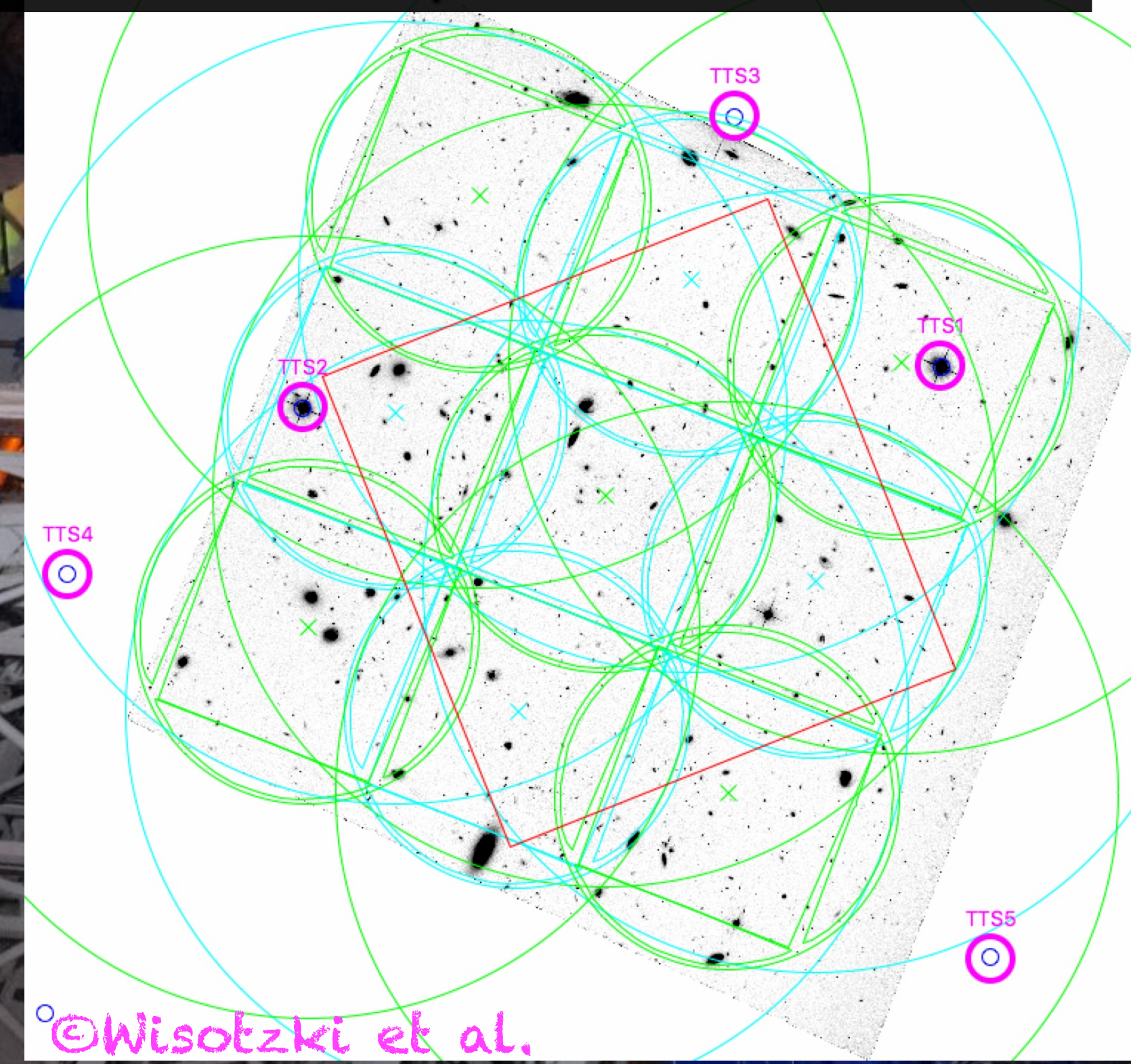
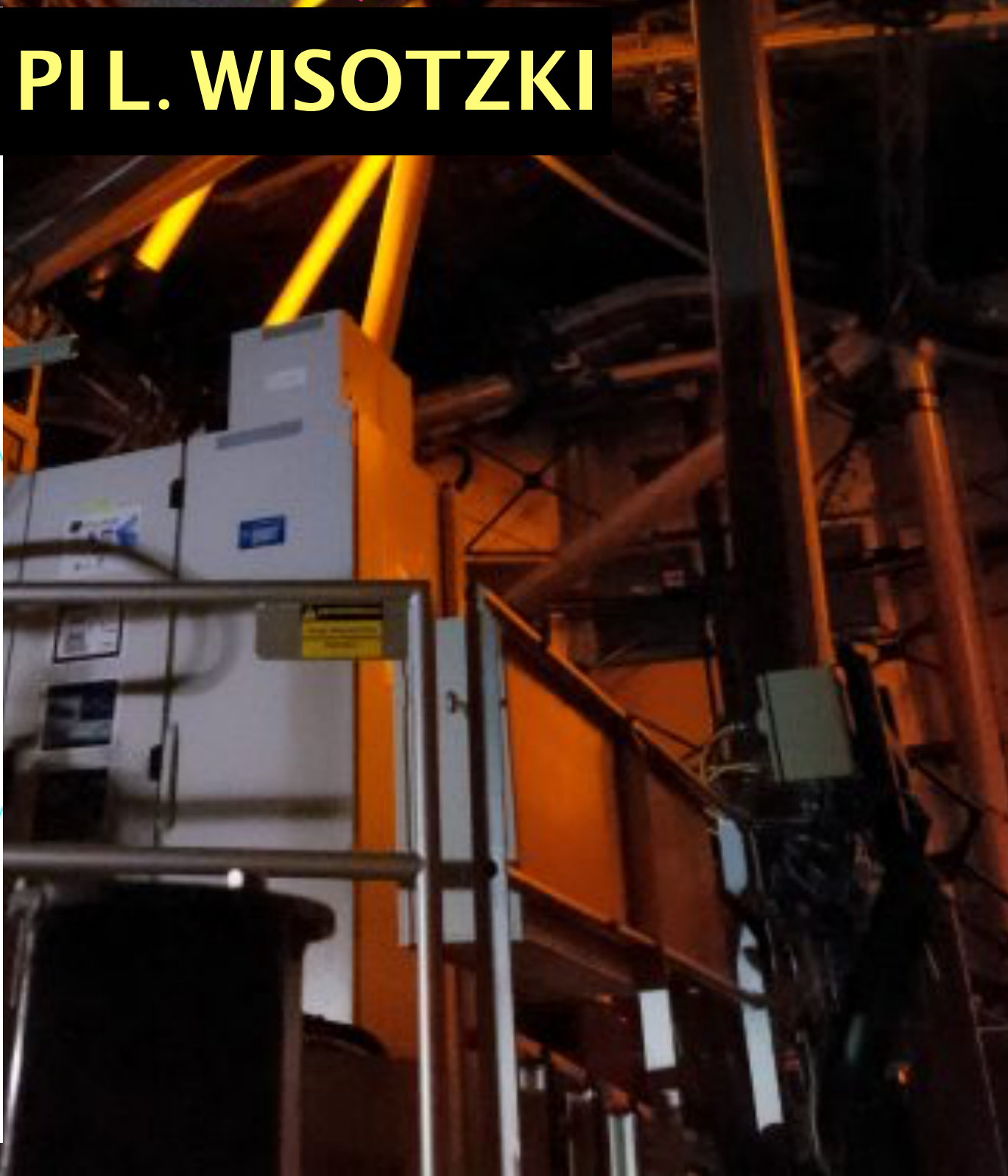
MUSE HFF program

200h program with 4 HFF parallel fields.
Each field:

- Deep: $1' \times 1'$ 25h pointing
- Medium: $2' \times 2'$ 5h pointings
- shallow: $3' \times 3'$ 1.7h pointings



PI L. WISOTZKI



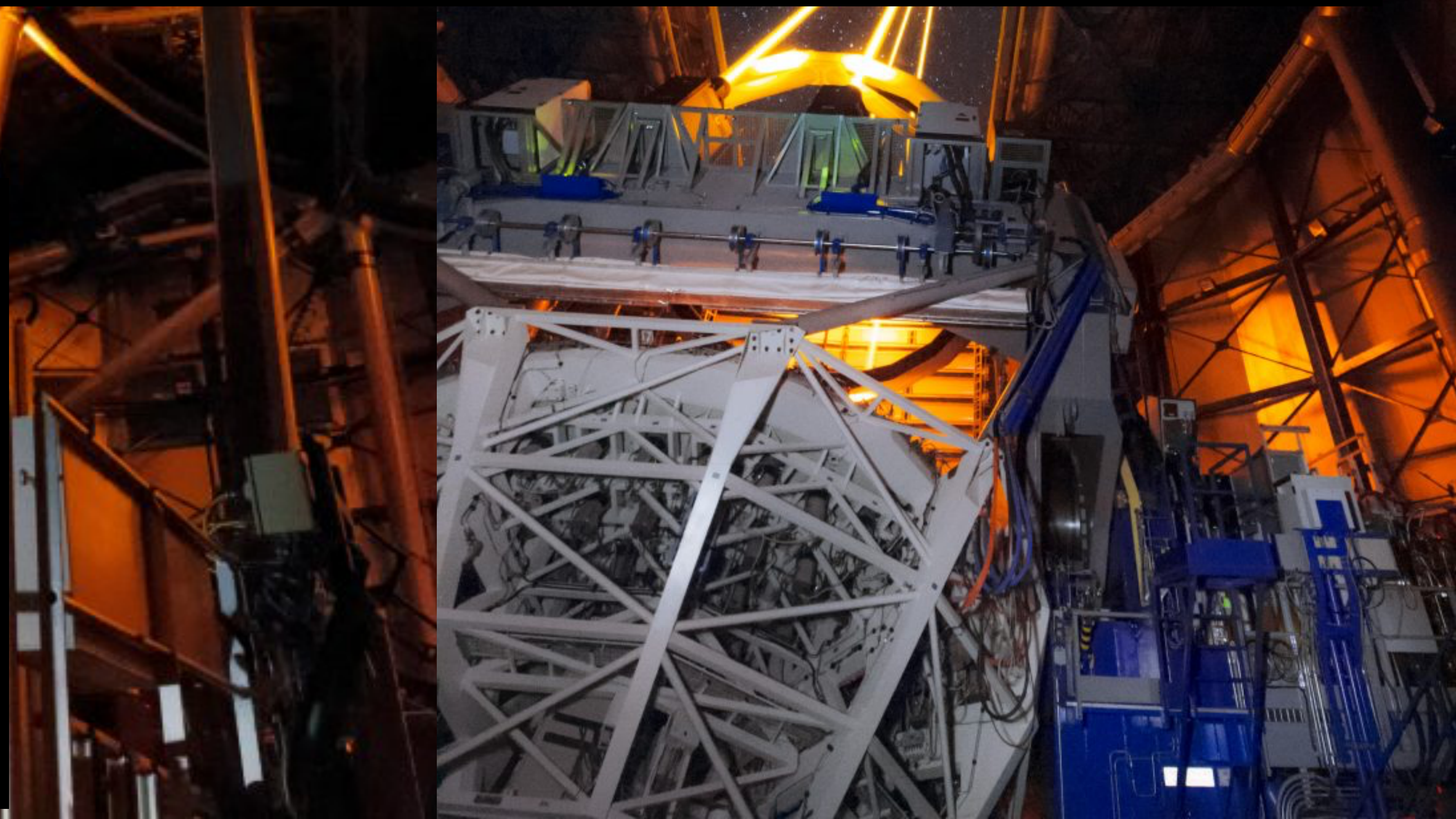
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How can we provide observational constraints?

Deep high S/N data for simultaneous rest-UV emission and absorption analysis



Deep MUSE pointings:

- MXDF ~ 160h single UDF pointing
- HFF parallels



Stacking MUSE UDF (30h) + MUSE WIDE (10h*9) + several ~10 other GTO pointings

Testing stellar population models

Include X-ray binary spectra, VMS evolution models in SSPs and investigate observed correlations with galaxy properties

Investigate the variations in the IMF along with other changes

Include realistic dust models and investigate how extra ionising photons effects observed emission line ratios

CONCLUSIONS

arXiv:1902.05960

- We compose a catalogue with ≈ 13 HeII_{1640} detections from MUSE (and ≈ 20 tentative detections from other public surveys).
- Using Gutkin et al., (2016) models we show our observed emission line ratios can be reproduced via high-U sub-solar Z models.
- Including effects of binaries from Xiao et al., (2018) models makes the model parameters degenerate.
- We show even BPASS models are unable to reproduce the observed $\text{HeII}\lambda_{1640}$ and $\text{OIII}\lambda_{1666}$ equivalent widths.
- We show that matching $\text{HeII}\lambda_{1640}$ luminosities with BPASS models require $\sim 1/200 Z_{\odot}$ models which are in tension with gas phase metallicities inferred via line-ratio diagnostics.
- IMFs with larger fractions of high mass stars (top heavy) or exotic stellar population mechanisms such as XRBs or very massive WNh stars that can produce photons at wavelength $> 275 \text{ \AA}$ with relatively low wind effects are required to match our observed data with models.