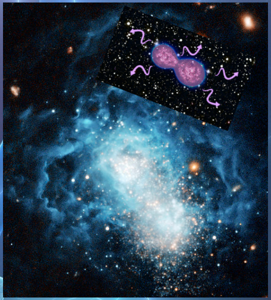
Does I Zwicky 18 harbor GW progenitors?

The story of a dwarf galaxy and what I learned in the past 12 years

Dorottya Szécsi

Nicolaus Copernicus University



Monash University Seminar – Melbourne, Australia
10th Nov 2025

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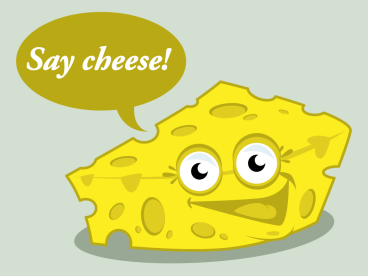

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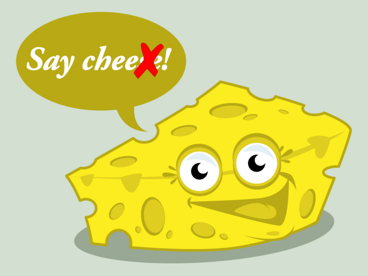

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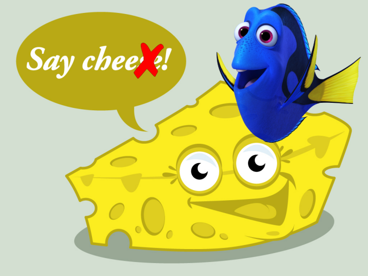


Monash University Seminar – Melbourne, Australia
10th Nov 2025

Formation channels of binary black holes:

Isolated binary evolution

Common envelope phase

e.g.
den Heuvel (1976), Tutukov & Yungelson (1993), Kalogera et al. (2007), Postnov & Yungelson (2014), Belczynski et al. (2016), Mapelli et al. (2017)

Chemically homogeneous evolution

e.g. Maeder (1987), de Mink et al. (2009), Mandel & de Mink (2016), Marchant et al. (2016)

Stable mass transfer

e.g. van den Heuvel et al. (2017), Pavlovskii et al. (2017), Inayoshi et al. (2017)

AGN-disks

e.g. Antonini & Perets (2012), Tagawa et al. (2020)

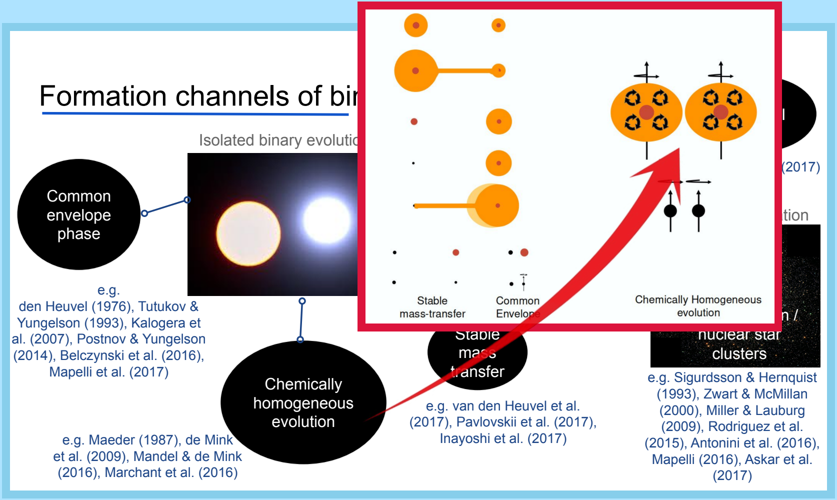
Pop - III

e.g. Inayoshi et al. (2017)

Dynamical formation

e.g. Sigurdsson & Hernquist (1993), Zwart & McMillan (2000), Miller & Lauburg (2009), Rodriguez et al. (2015), Antonini et al. (2016), Mapelli (2016), Askar et al. (2017)

Credit for slides: R. Sarwar



Credit for slides: R. Sarwar

It all started with Sara Heap...

who told Norbert Langer, who told me...

and then Carolina came along:

THE ASTROPHYSICAL JOURNAL LETTERS, 801:L28 (6pp), 2015 March 10 doi:10.1088/2041-8205/801/2/L28

THE EXTENDED He II λ4686-EMITTING REGION IN IZw 18 UNVEILED: CLUES FOR PECULIAR IONIZING SOURCES

C. KEHRIG[1], J. M. VÍLCHEZ[1], E. PÉREZ-MONTERO[1], J. IGLESIAS-PÁRAMO[1,2], J. BRINCHMANN[3], D. KUNTH[4], F. DURRET[4], AND F. M. BAYO[1]

[1] Instituto de Astrofísica de Andalucía (CSIC), Glorieta de la Astronomía s/n, E-18008 Granada, Spain
[2] Estación Experimental de Zonas Aridas (CSIC), Ctra. de Sacramento s/n, La Caada, Almería, Spain
[3] Leiden Observatory, Leiden University, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands
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Received 2014 December 1; accepted 2015 January 20; published 2015 March 12

ABSTRACT

New integral field spectroscopy has been obtained for IZw 18, the nearby lowest-metallicity galaxy considered to be our best local analog of systems forming at high redshift (z). Here we report the spatially resolved spectral map of the nebular He II λ4686 emission in IZw 18, from which we derived for the first time its total He II-ionizing flux. Nebular He II emission implies the existence of a hard radiation field. He II-emitters are observed to be more frequent among high-z galaxies than for local objects. Therefore, investigating the He II-ionizing source(s) in IZw 18 may reveal the ionization processes at high z. He II emission in star-forming galaxies has been suggested to be mainly associated with Wolf–Rayet stars (WRs), but WRs cannot satisfactorily explain the He II-ionization at all times, particularly at the lowest metallicities. Shocks from supernova remnants, or X-ray binaries, have been proposed as additional potential sources of He II-ionizing photons. Our data indicate that conventional He II-ionizing sources (WRs, shocks, X-ray binaries) are not sufficient to explain the observed nebular He II λ4686 emission in IZw 18. We find that the He II-ionizing radiation expected from models for either low-metallicity

He-II ionization in IZw18 (NW region)

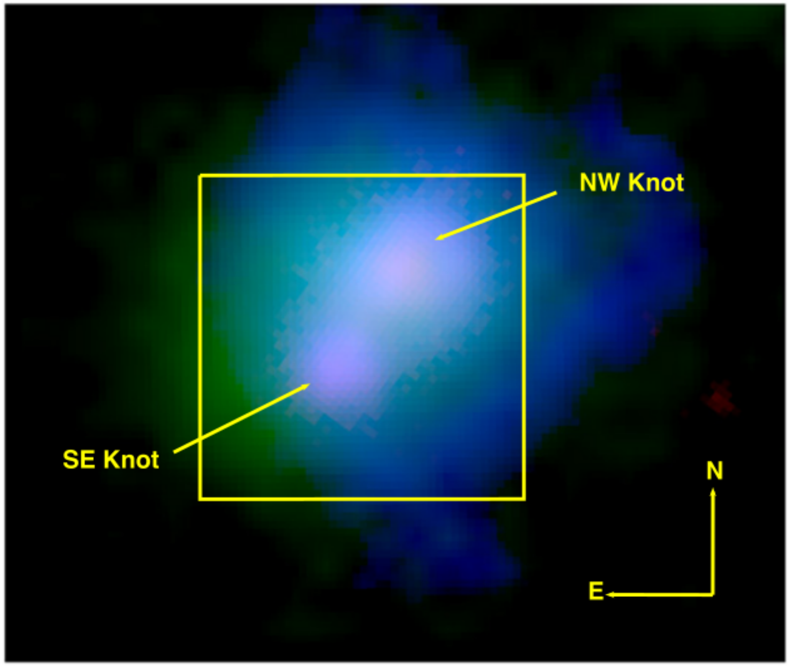
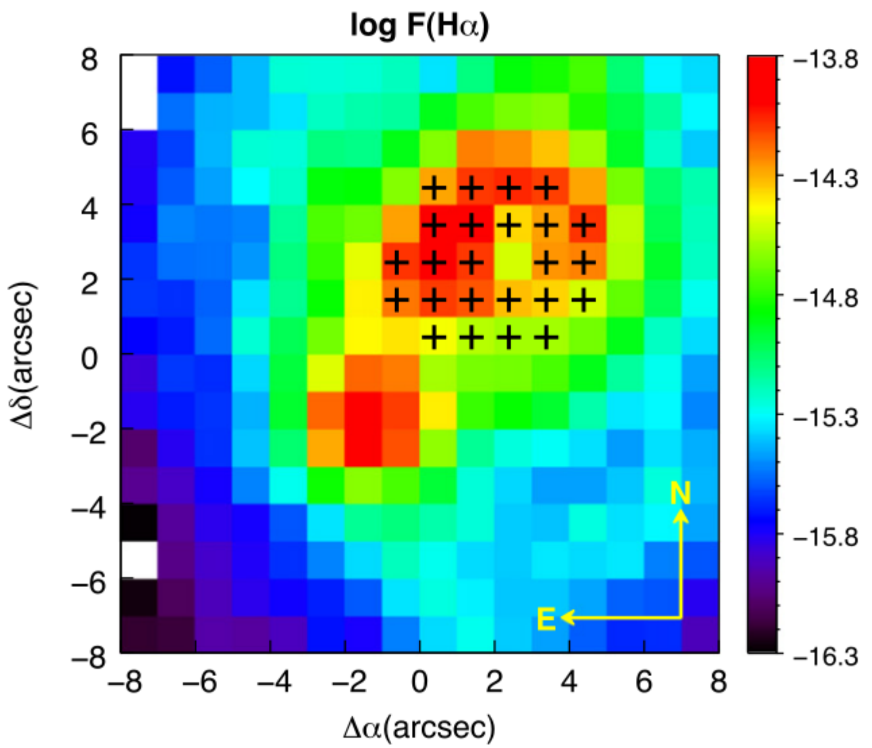


Figure 1. Color-composite image of IZw 18 (blue = Hα from Palomar, green = far-UV/*GALEX*, red = SDSS r'). The box represents the FOV (16"×16") of the PMAS spectrograph over the galaxy main body and the extended Hα halo. The PMAS FOV is centered on the coordinates R.A. (J2000.0) = 09^h:34^m:02^s.2 and decl. (J2000.0) = +55°:14′:25″.



A&A 581, A15 (2015)
DOI: 10.1051/0004-6361/201526617

Astronomy & Astrophysics

Low-metallicity massive single stars with rotation

Evolutionary models applicable to I Zwicky 18⋆,⋆⋆

Dorottya Szécsi[1], Norbert Langer[1], Sung-Chul Yoon[2], Debashis Sanyal[1], Selma de Mink[3], Christopher J. Evans[4], and Tyl Dermine[1]

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[2] Department of Physics & Astronomy, Seoul National University, Gwanak-ro 1, Gwanak-gu, 151-742, Seoul, South Korea
[3] Astronomical Institute Anton Pannekoek, University of Amsterdam, 1098 XH Amsterdam, The Netherlands
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Received 27 May 2015 / Accepted 29 June 2015

ABSTRACT

Context. Low-metallicity environments such as the early Universe and compact star-forming dwarf galaxies contain many massive stars. These stars influence their surroundings through intense UV radiation, strong winds and explosive deaths. A good understanding of low-metallicity environments requires a detailed theoretical comprehension of the evolution of their massive stars.
Aims. We aim to investigate the role of metallicity and rotation in shaping the evolutionary paths of massive stars and to provide

A&A 581, A15 (2015)
DOI: 10.1051/0004-6361/201526617

Astronomy & Astrophysics

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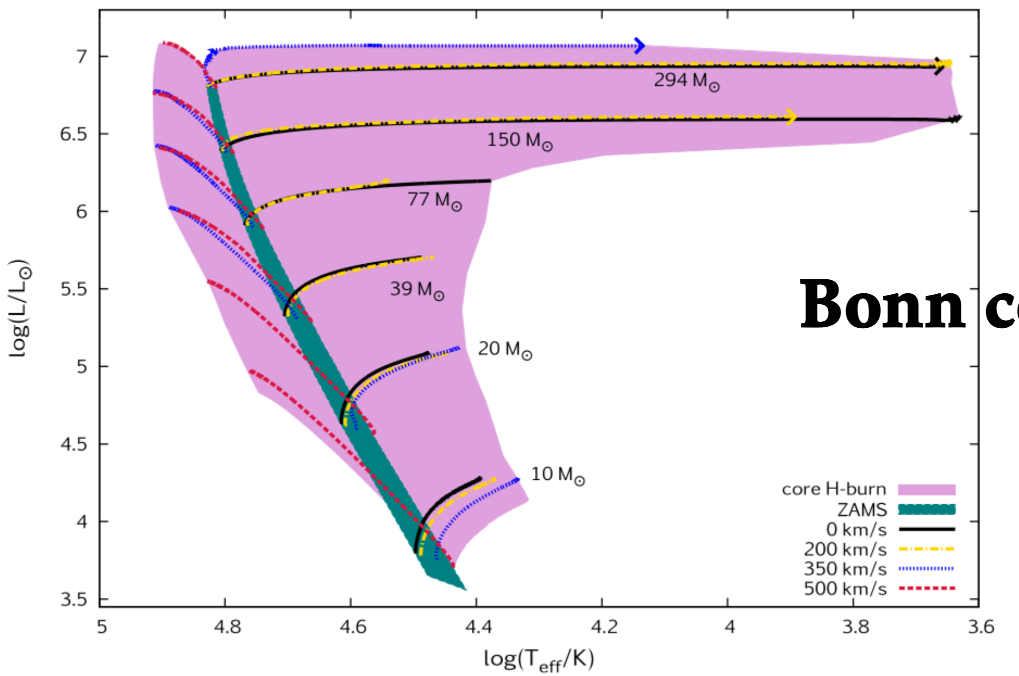

Fig. 5. Evolutionary tracks in the HR diagram during core hydrogen burning for models with initial masses between 9−300 $M_\odot$ (see labels) and initial rotational velocities of 0, 200, 350 and 500 km s^{-1}, with a composition of 1/10 $Z_{\rm SMC}$. The lighter (purple) shading identifies the region in which all models of our grid undergo core hydrogen burning. The darker (green) shading identifies the zero-age main-sequence. An arrow marks the end of the tracks for models that were stopped before the terminal age main-sequence was reached. Core-hydrogen-burning objects are expected to be found on both sides of the ZAMS, inside the purple coloured region.

Bonn code

[1] Argelander-I ...
e-mail: doro ...
[2] Department ... Korea
[3] Astronomica ...
[4] UK Astronor ...

Received 27 M ...

Context. Low- ... many massive stars. These stars influence their surroundings through intense UV radiation, strong winds and explosive deaths. A good understanding of low-metallicity environments requires a detailed theoretical comprehension of the evolution of their massive stars.
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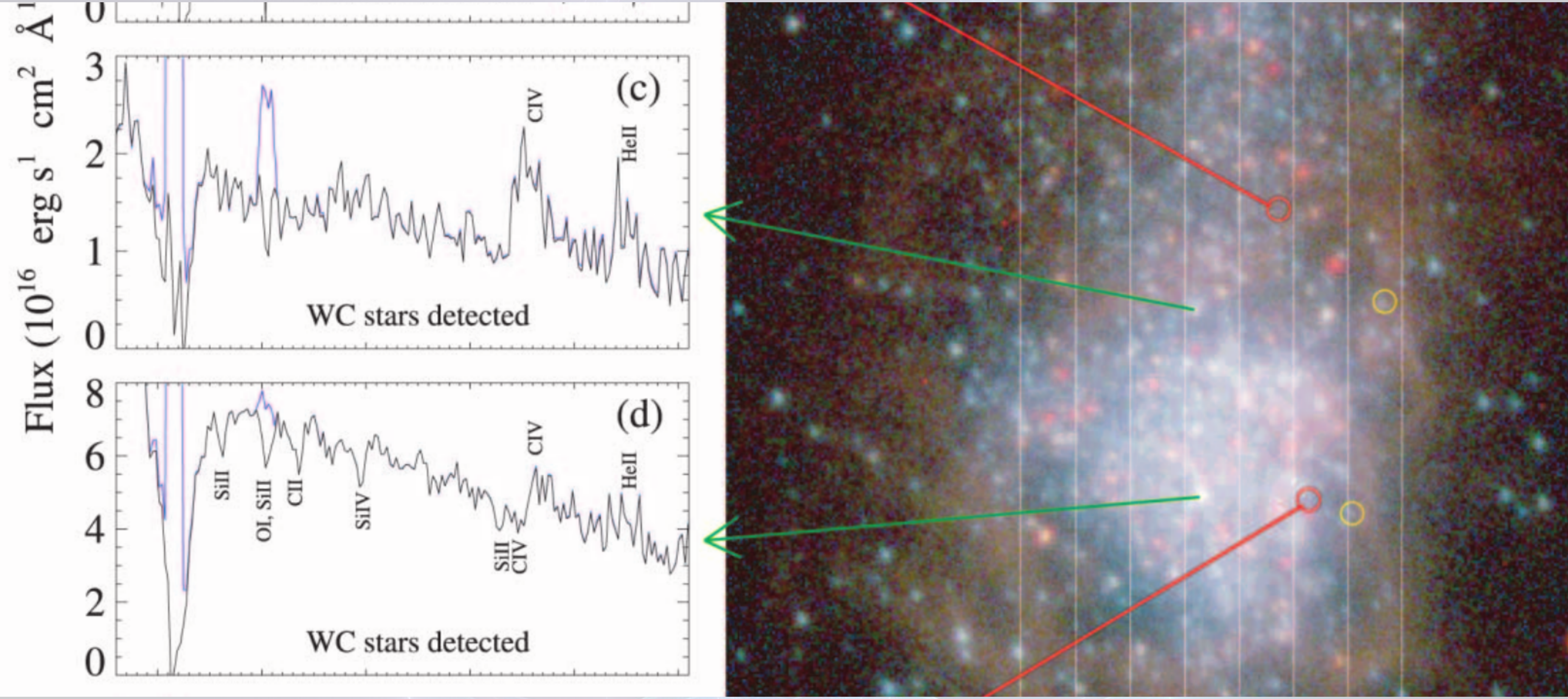
There are ***some*** WCs…



Brown+02

Brankica came along...

The "TWUIN collaboration"

A&A 623, A8 (2019)
https://doi.org/10.1051/0004-6361/201834360

Astronomy & Astrophysics

Low-metallicity massive single stars with rotation

II. Predicting spectra and spectral classes of chemically homogeneously evolving stars

B. Kubátová[1], D. Szécsi[1,2], A. A. C. Sander[3,4], J. Kubát[1], F. Tramper[5,9], J. Krtička[6], C. Kehrig[7], W.-R. Hamann[3], R. Hainich[3], and T. Shenar[8]

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[2] School of Physics and Astronomy and Institute of Gravitational Wave Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[3] Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany
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[5] European Space Astronomy Centre (ESA/ESAC), Operations Department, 28692 Villanueva de la Cañada, Madrid, Spain
[6] Ústav teoretické fyziky a astrofyziky, Masarykova univerzita, Kotlářská 267/2, 611 37 Brno, Czech Republic

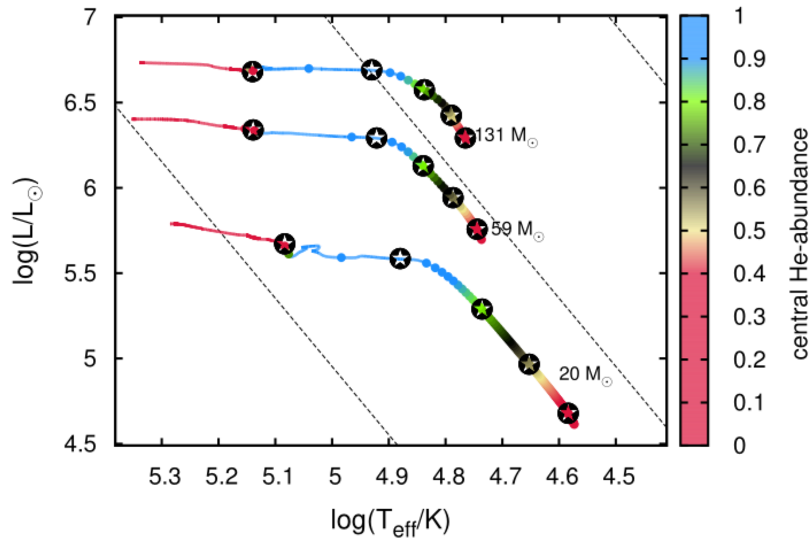


Fig. 1. HR diagram of our models (black symbols) and their corresponding evolutionary sequences. The sequences are taken from Paper I and Szécsi (2016). Initial masses are labeled, showing where the tracks start their evolution, proceeding toward the hot side of the diagram. Colors show the central helium mass fraction, and dots represent every 10^5 years of evolution. Dashed lines mark equiradial lines with 1, 10, and 100 $R_\odot$ from left to right. The black symbols represent the models for which we computed synthetic spectra. From right to left: black symbols correspond to evolutionary phases with surface helium mass fractions of 0.28, 0.5, 0.75, and 0.98, and the fifth symbol on the very left corresponds to a central helium mass fraction of 0.5, i.e., the middle of the CHeB phase.

PoWR code

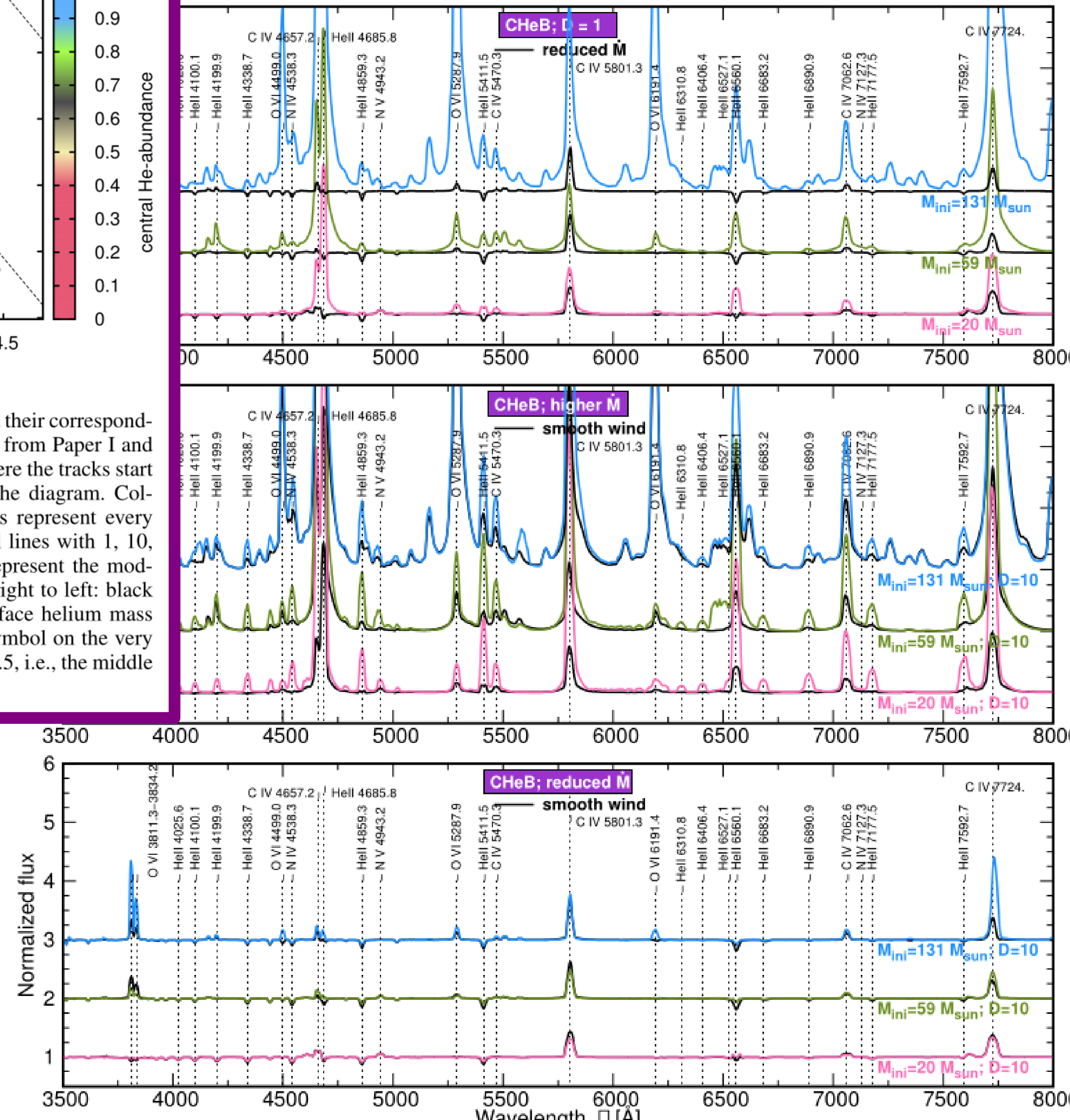
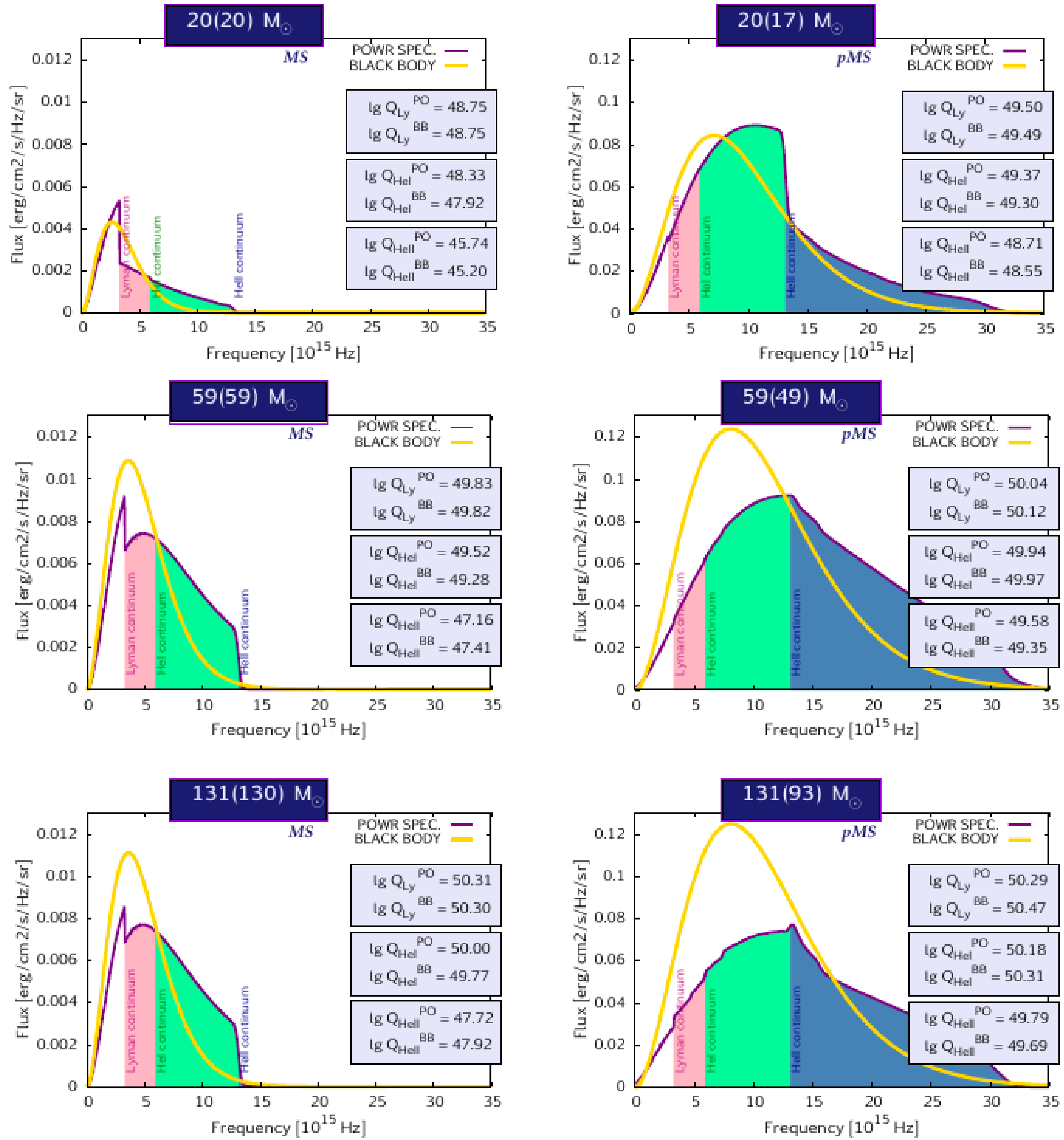
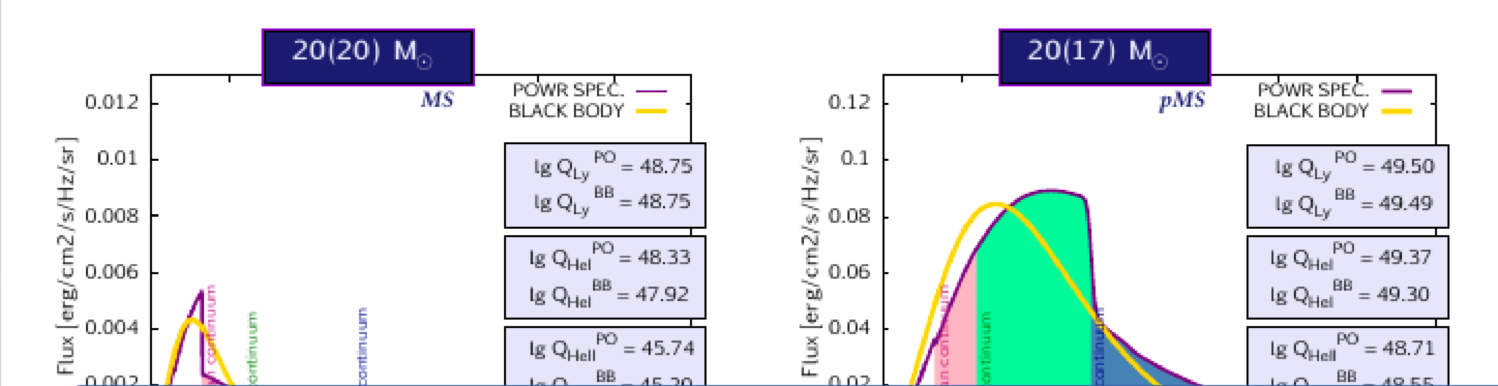


Fig. 4. *Top panel*: same as Fig. 3, but for the CHeB evolutionary phase with Y_s as given in Table 1. *Middle and lowest panels*: same as the top



$20(20)\ M_\odot$
MS
POWR SPEC.
BLACK BODY
$\lg Q_{Ly}^{PO} = 48.75$
$\lg Q_{Ly}^{BB} = 48.75$
$\lg Q_{HeI}^{PO} = 48.33$
$\lg Q_{HeI}^{BB} = 47.92$
$\lg Q_{HeII}^{PO} = 45.74$
$\lg Q_{HeII}^{BB} = 45.20$
$20(17)\ M_\odot$
pMS
POWR SPEC.
BLACK BODY
$\lg Q_{Ly}^{PO} = 49.50$
$\lg Q_{Ly}^{BB} = 49.49$
$\lg Q_{HeI}^{PO} = 49.37$
$\lg Q_{HeI}^{BB} = 49.30$
$\lg Q_{HeII}^{PO} = 48.71$
$\lg Q_{HeII}^{BB} = 48.55$
$59(59)\ M_\odot$
MS
POWR SPEC.
BLACK BODY
$\lg Q_{Ly}^{PO} = 49.83$
$\lg Q_{Ly}^{BB} = 49.82$
$\lg Q_{HeI}^{PO} = 49.52$
$\lg Q_{HeI}^{BB} = 49.28$
$\lg Q_{HeII}^{PO} = 47.16$
$\lg Q_{HeII}^{BB} = 47.41$
$59(49)\ M_\odot$
pMS
POWR SPEC.
BLACK BODY
$\lg Q_{Ly}^{PO} = 50.04$
$\lg Q_{Ly}^{BB} = 50.12$
$\lg Q_{HeI}^{PO} = 49.94$
$\lg Q_{HeI}^{BB} = 49.97$
$\lg Q_{HeII}^{PO} = 49.58$
$\lg Q_{HeII}^{BB} = 49.35$
$131(130)\ M_\odot$
MS
POWR SPEC.
BLACK BODY
$\lg Q_{Ly}^{PO} = 50.31$
$\lg Q_{Ly}^{BB} = 50.30$
$\lg Q_{HeI}^{PO} = 50.00$
$\lg Q_{HeI}^{BB} = 49.77$
$\lg Q_{HeII}^{PO} = 47.72$
$\lg Q_{HeII}^{BB} = 47.92$
$131(93)\ M_\odot$
pMS
POWR SPEC.
BLACK BODY
$\lg Q_{Ly}^{PO} = 50.29$
$\lg Q_{Ly}^{BB} = 50.47$
$\lg Q_{HeI}^{PO} = 50.18$
$\lg Q_{HeI}^{BB} = 50.31$
$\lg Q_{HeII}^{PO} = 49.79$
$\lg Q_{HeII}^{BB} = 49.69$
Lyman continuum
HeI continuum
HeII continuum
Flux [erg/cm2/s/Hz/sr]
Frequency [10^{15} Hz]



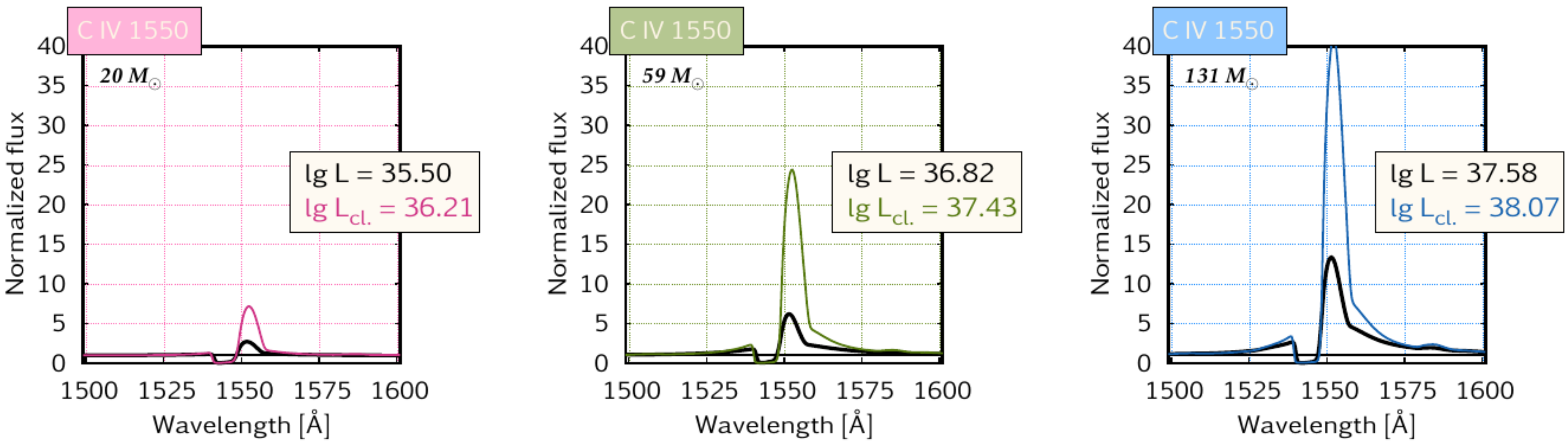
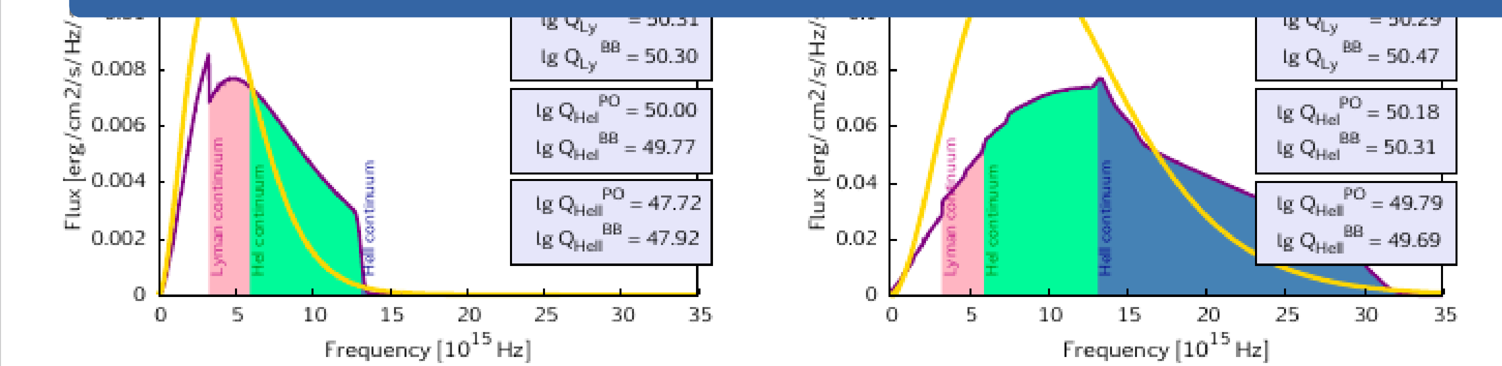


Fig. 3. Normalized flux around the UV-line C IV λ1550 Å in three spectral models with initial masses as indicated in the top left corner of the panels. Line luminosity (computed by integrating the area under the line) is given in the framed boxes in units of log(erg s^{-1}); lg L stands for unclumped (clumping factor D = 1) while lg L_{cl} for clumped (D = 10) wind, see details in Paper II. When creating the synthetic population here (Sect. 2.2 and Sect. 3.1), we always apply the unclumped models' predictions (i.e. black line). Other emission lines are presented in Figs. A.1-A.2.



3rd paper submitted in 2019...

Astronomy & Astrophysics manuscript no. output
April 25, 2019

LETTER TO THE EDITOR

Chemically homogeneously evolving stars as the source of photoionization and C IV emission in dwarf starburst galaxies

Low-metallicity massive single stars with rotation. Part III.

Dorottya Szécsi[1], Brankica Kubátová[2], Andreas A.C. Sander[3,4], Jiří Kubát[2], and Carolina Kehrig[5],

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2 Astronomický ústav, Akademie věd České republiky, Fričova 298, 251 65 Ondřejov, Czech Republic e-mail: brankica.kubatova@asu.cas.cz
3 Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476, Potsdam, Germany
4 Armagh Observatory and Planetarium, College Hill, Armagh, BT61 9DG, Northern Ireland
5 Instituto de Astrofísica de Andalucía (IAA/CSIC), Glorieta de la Astronomía s/n Aptdo. 3004, E-18080 Granada, Spain

Received April 25, 2019; accepted ...

ABSTRACT

Chemically-homogeneously evolving stars have been proposed to account for several exotic phenomena, including gamma-ray bursts, gravitational wave emissions and certain types of supernovae. Nonetheless, their existence has not yet been observationally proven. Here we provide a new piece of evidence that these stars may indeed exist in nature. In a metal-poor dwarf galaxy, I Zwicky 18,

Referee report

- OIV 3818 ??
- CIV 5808 ??
- CIV 7724 ?
- HeII4686 ?

- **UV** OVI 1037
- HeII 1640, OVI 2070, also CIV 1550… ?????

...explain all available observations from the literature

No one knows if CHE stars exist…

- GW (-emitting compact object) progenitors
- lGRB progenitors
- supernova Ib/c
- …

direct observations missing!!

Basically looking for the parent stars of Gravitational Waves…

What to do if you don't know stg?

What to do if you don't know stg?

- ASK FOR HELP

Frank Tramper (CSIC-INTA, Spain / KU Leuven)

Miriam Garcia (CSIC-INTA, Spain)

Brankica Kubátová (ASU CAS, Prague)

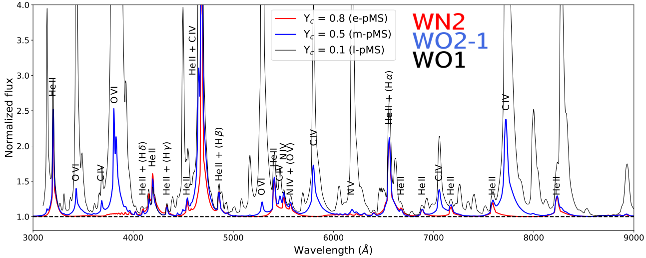
Carolina Kehrig (IAA/CSIC, Spain / MCTIC Brazil)

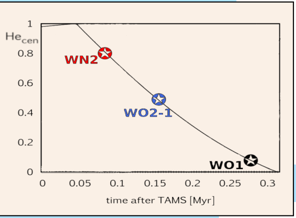
Jiří Kubát (ASU CAS, Prague)

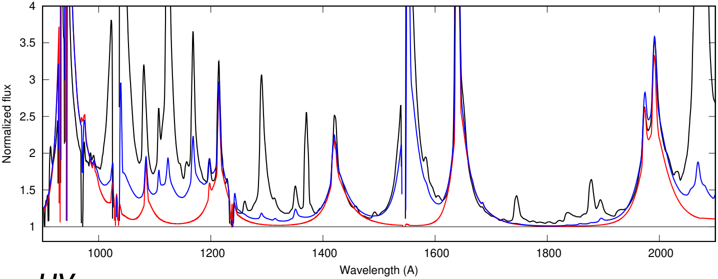
Jiří Krtička (Masaryk Uni, Brno)

Andreas A.C. Sander (Uni Heidelberg, Germany)

optical



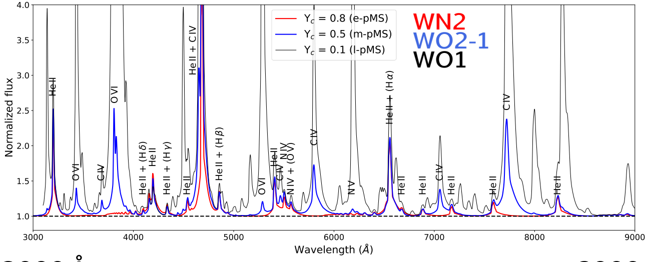




UV

Szécsi+25 (A&A, in press)

optical



3000 Å 9000 Å

Available measurements:

name of dwarf galaxy:

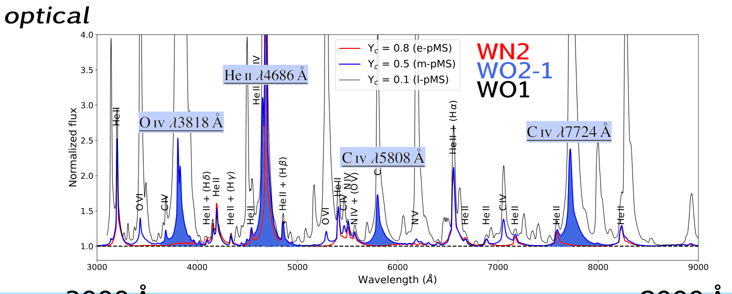
I Zwicky 18

Izotov+97 (MMTO 6.5m) 3700 Å–6800 Å

Kehrig+15 (PMAS 3.5m, *integrated field*) 4440 Å–5200 Å

Thuan+05 (MMTO 6.5m) 3200 Å–5200 Å

Szécsi+25 (A&A, in press)



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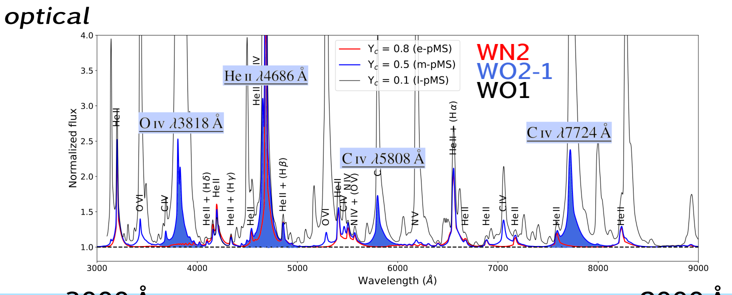
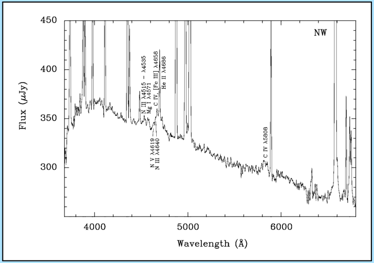


3000 Å

9000 Å

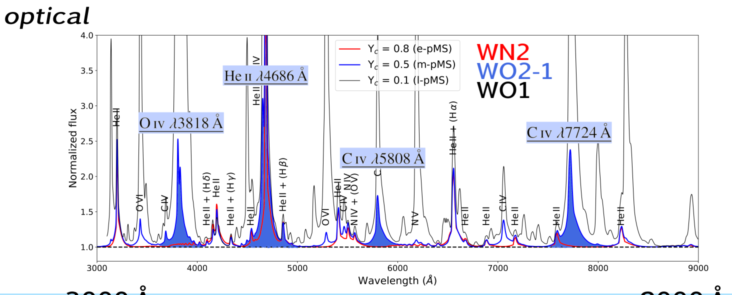


Izotov+97 3700 Å–6800 Å

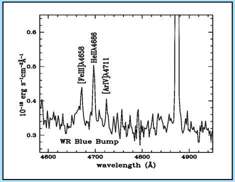
name of dwarf galaxy:

I Zwicky 18

Szécsi+25 (A&A, in press)



3000 Å 9000 Å

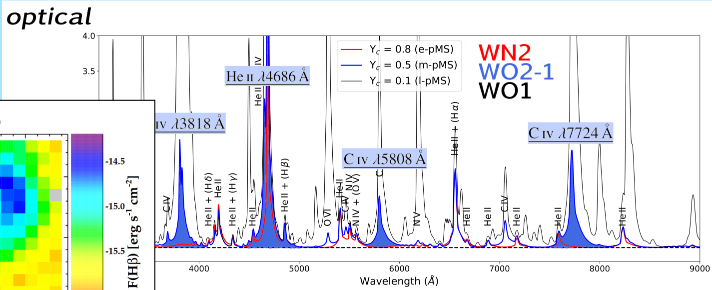


Kehrig+15 4440 Å–5200 Å

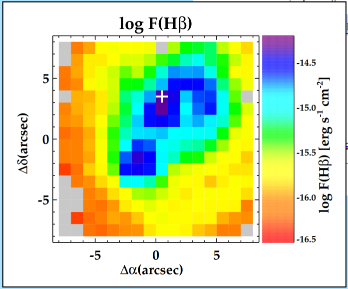
name of dwarf galaxy:

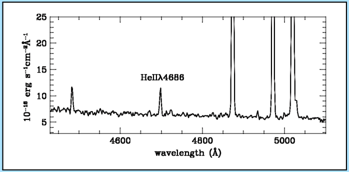
I Zwicky 18

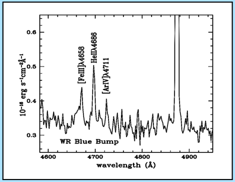
Szécsi+25 (A&A, in press)



9000 Å





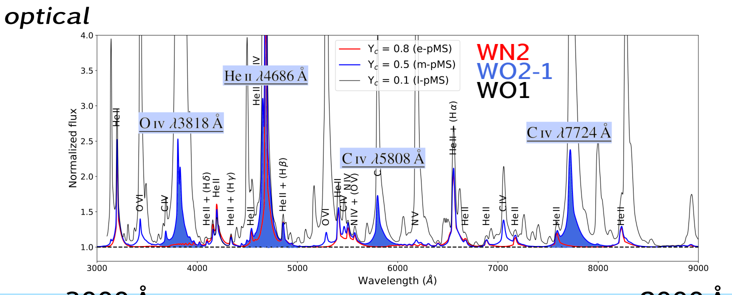


Kehrig+15 4440 Å–5200 Å

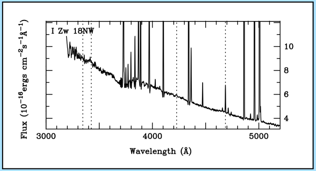
name of dwarf galaxy:

I Zwicky 18

Szécsi+25 (A&A, in press)



3000 Å 9000 Å



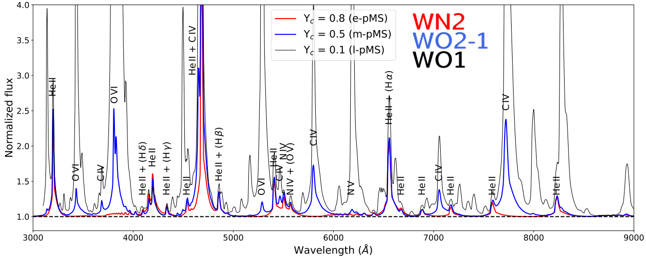
Thuan+05 3200 Å–5200 Å

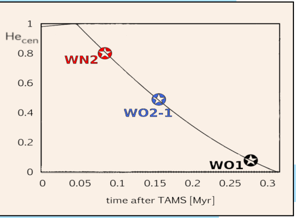
name of dwarf galaxy:

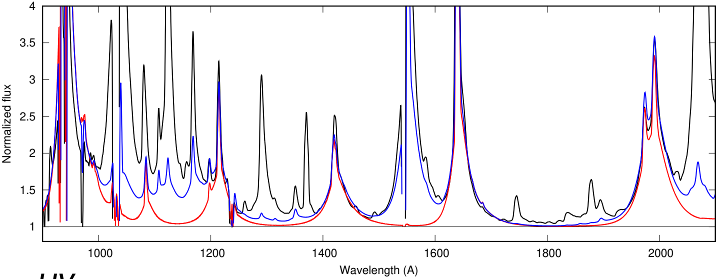
I Zwicky 18

Szécsi+25 (A&A, in press)

optical







UV

Szécsi+25 (A&A, in press)

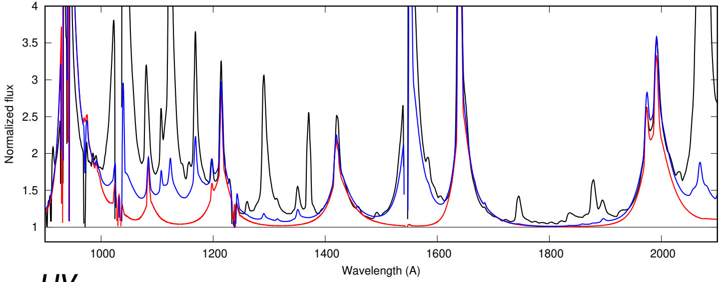
Brown+02 (HST *STIS*)   1160 Å–1710 Å

Lecavelier des Etangs+04 (FUSE) 910 Å–1185 Å

Heap+15/Berg+22 (HST *COS*)   1160 Å–1645 Å

~900 Å

~2100 Å



UV

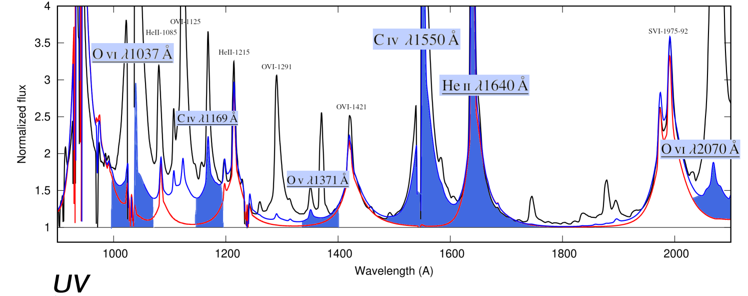
Szécsi+25 (A&A, in press)

Brown+02 (HST *STIS*) 1160 Å–1710 Å

Lecavelier des Etangs+04 (FUSE) 910 Å–1185 Å

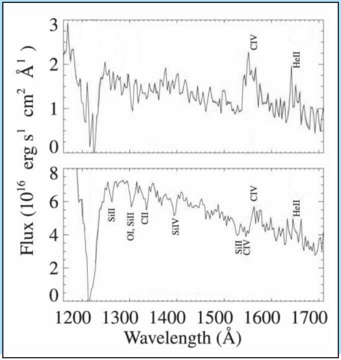
Heap+15/Berg+22 (HST *COS*) 1160 Å–1645 Å

~900 Å ~2100 Å



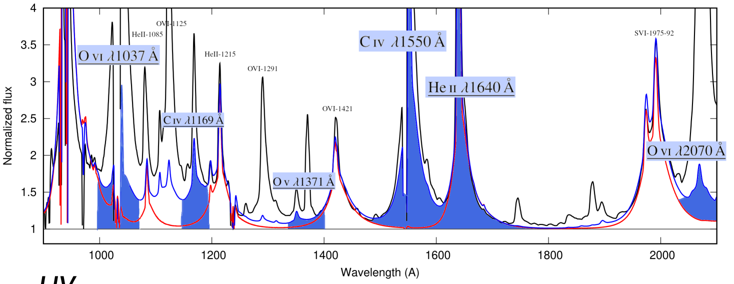
Szécsi+25 (A&A, in press)

Brown+02 1160 Å–1710 Å



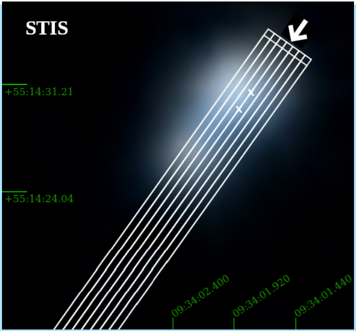
~900 Å

~2100 Å

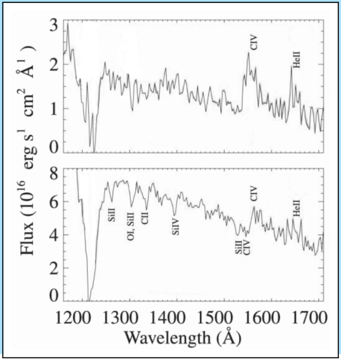


UV

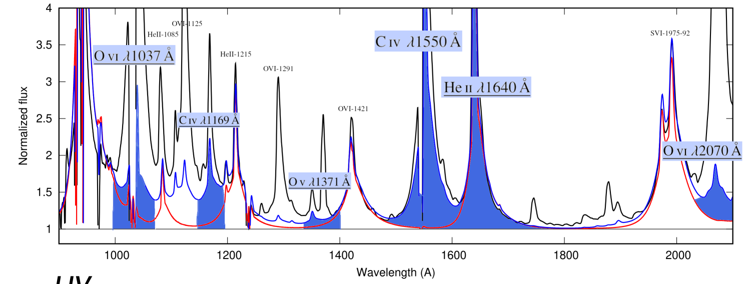
Szécsi+25 (A&A, in press)



Brown+02 1160 Å–1710 Å



~900 Å ~2100 Å

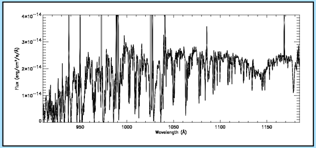


UV

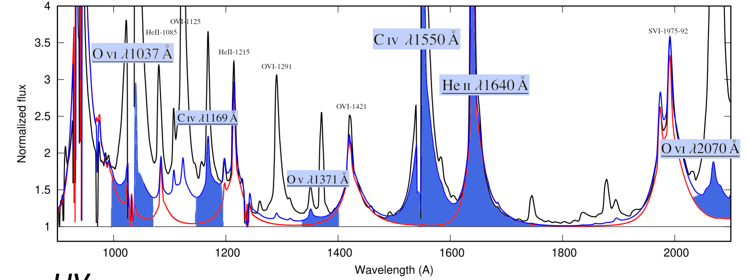
Szécsi+25 (A&A, in press)

Lecavelier des Etangs+04

910 Å–1185 Å



~900 Å ~2100 Å

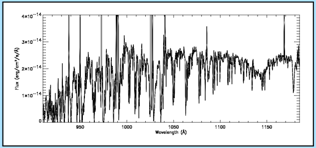


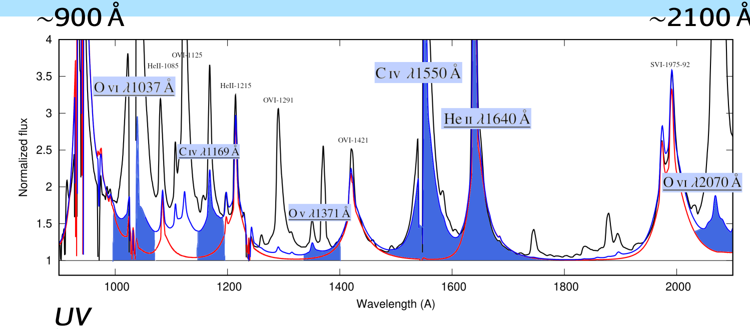
UV

Szécsi+25 (A&A, in press)

Lecavelier des Etangs+04

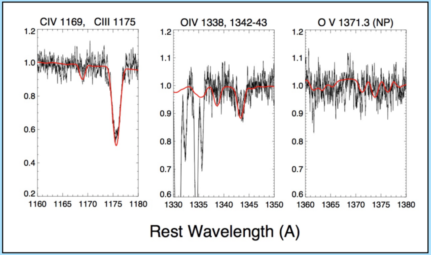
910 Å–1185 Å



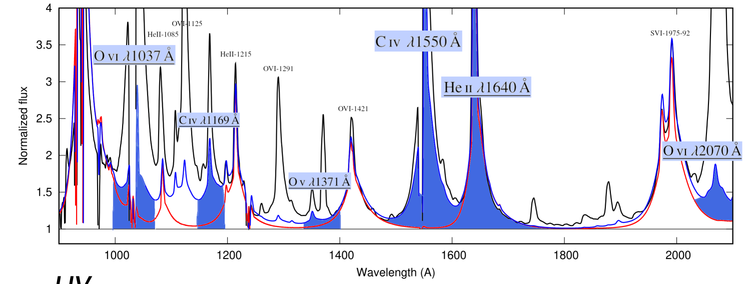


Szécsi+25 (A&A, in press)

Heap+15/Berg+22   1160 Å–1645 Å



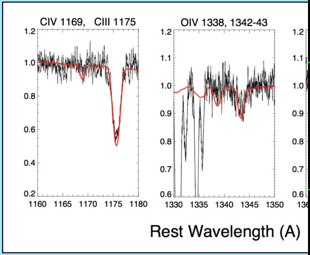
~900 Å   ~2100 Å

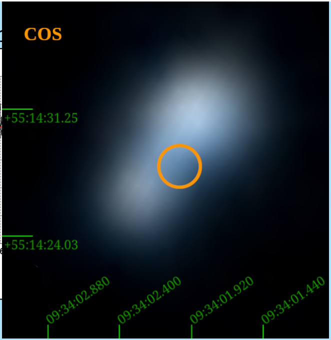


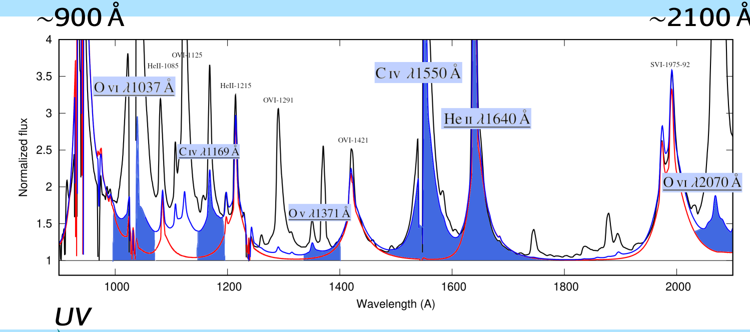
UV

Szécsi+25 (A&A, in press)

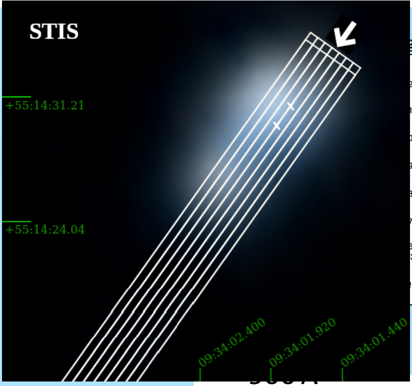
Heap+15/Berg+22 1160 Å–

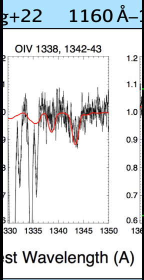


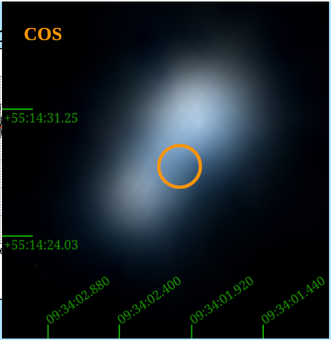




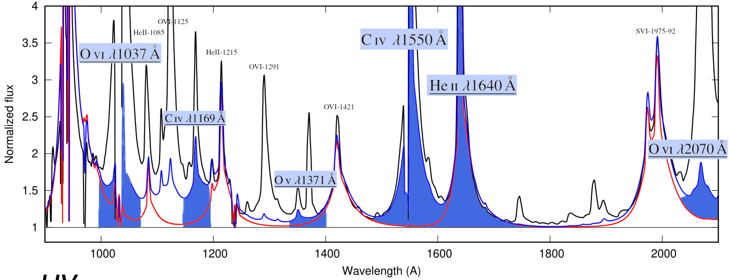
Szécsi+25 (A&A, in press)





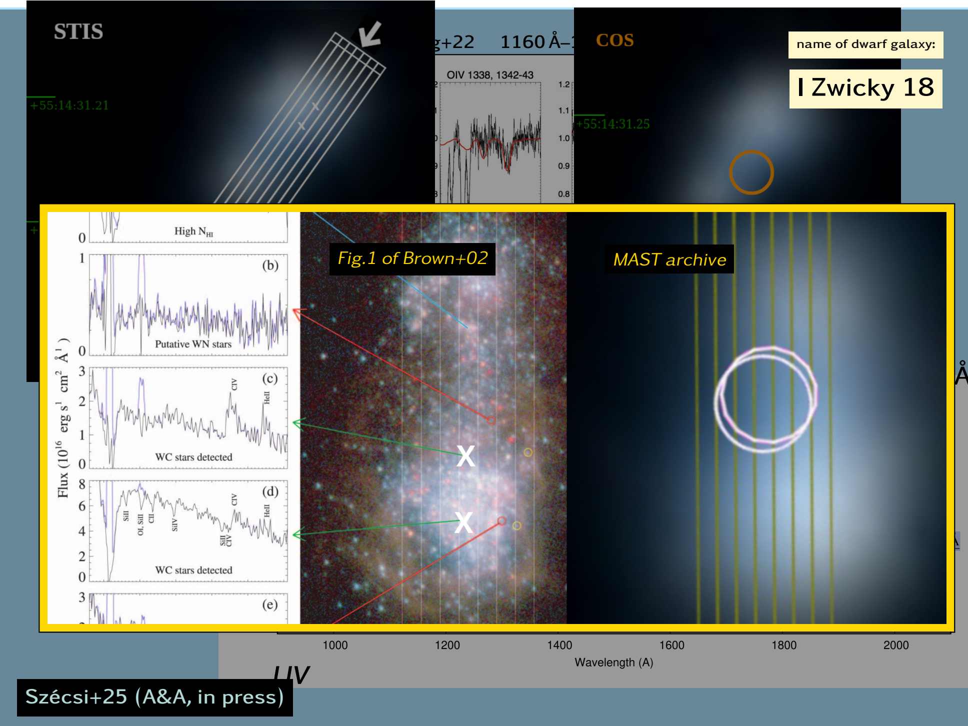


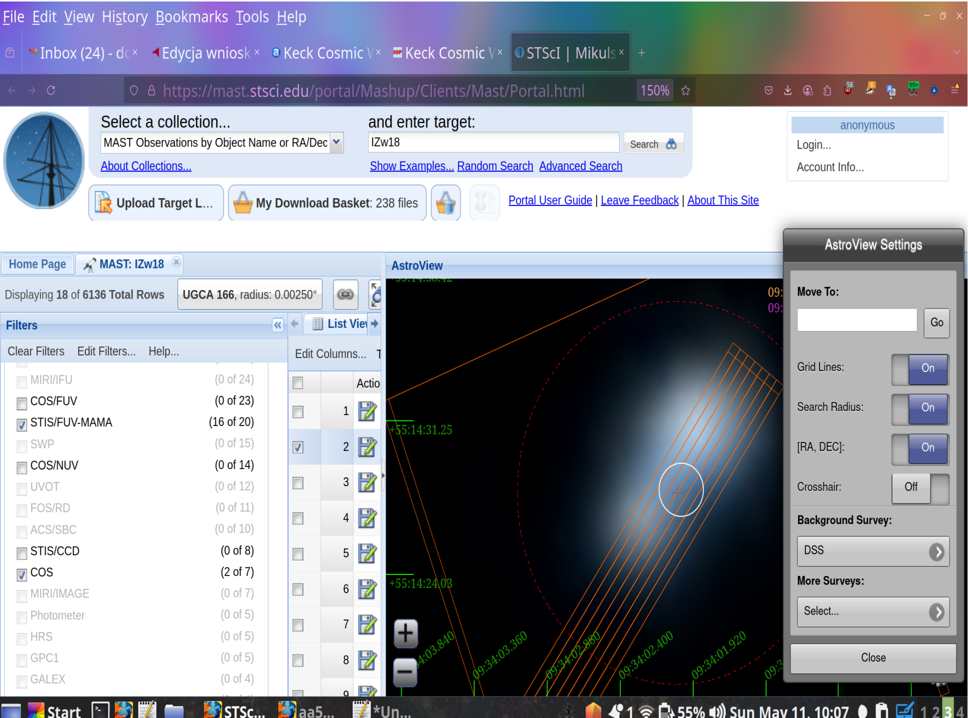
~2100 Å



UV

Szécsi+25 (A&A, in press)


STIS
+55:14:31.21
g+22 1160 Å–1
OIV 1338, 1342-43
COS
+55:14:31.25
name of dwarf galaxy:
I Zwicky 18
Fig.1 of Brown+02
MAST archive
High N_HI
(b)
Putative WN stars
(c)
CIV
HeII
WC stars detected
(d)
SiII
OI, SiII
CII
SiIV
SiII CIV
WC stars detected
(e)
Flux (10^16 erg s^-1 cm^2 Å^-1)
1000
1200
1400
1600
1800
2000
Wavelength (A)
UV
Szécsi+25 (A&A, in press)



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STIS/FUV-MAMA (16 of 20)
SWP (0 of 15)
COS/NUV (0 of 14)
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COS (2 of 7)
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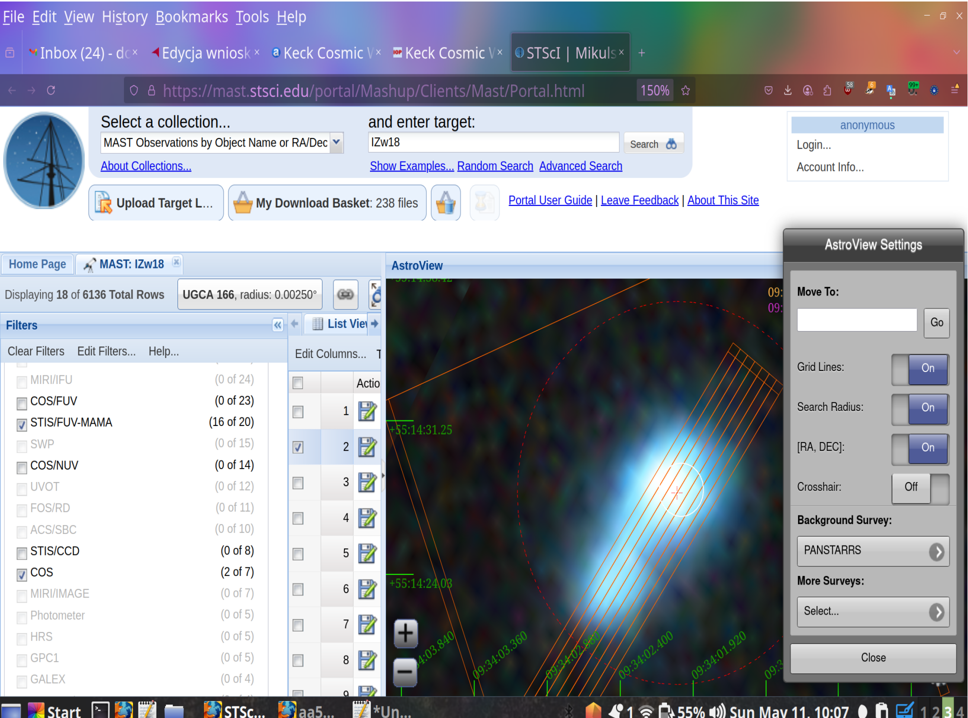
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MAST: IZw18
Displaying 18 of 6136 Total Rows
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MIRI/IFU (0 of 24)
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AstroView Settings
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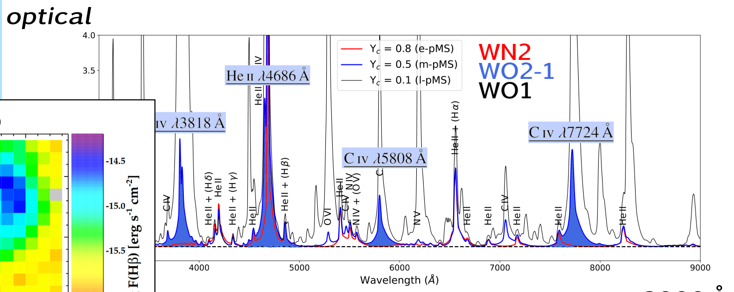
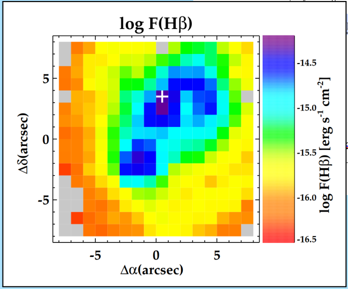
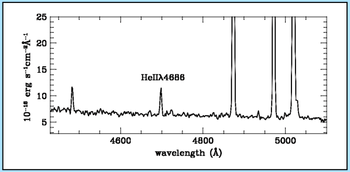
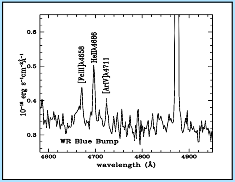


9000 Å





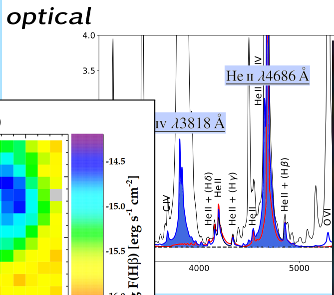


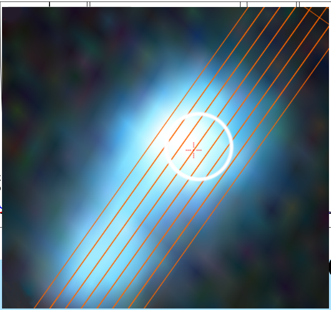
Kehrig+15 4440 Å–5200 Å

name of dwarf galaxy:

I Zwicky 18

Szécsi+25 (A&A, in press)





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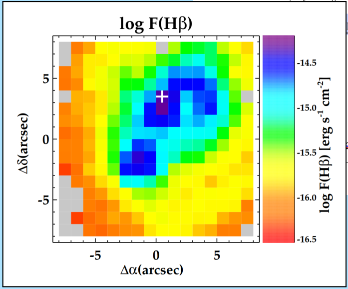

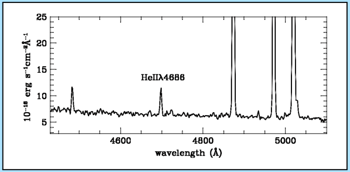

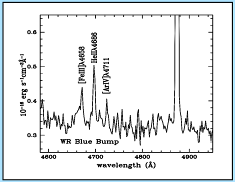

Kehrig+15 4440 Å–5200 Å

name of dwarf galaxy:

I Zwicky 18

Szécsi+25 (A&A, in press)

Conclusions...

- Available observations ***cannot exclude***
  chem.hom. GW progenitors in I Zw 18 !
- ***Proving them*** though?
  - I Zw 18 is in Ursa Major... Northern Hemisphere! → ~~MUSE~~
  - OVI-3818 could be a sign-post (of WO stars, confirming our theory) → **KECK!**
- do the same for other starburst/dwarf galaxies ...
- do the same for high-z galaxies (JWST) ...

Szécsi+25, A&A (in press), arXiv:2506.21442