Population III Stars
Ionizing Photon Fluxes and Synthetic Spectra

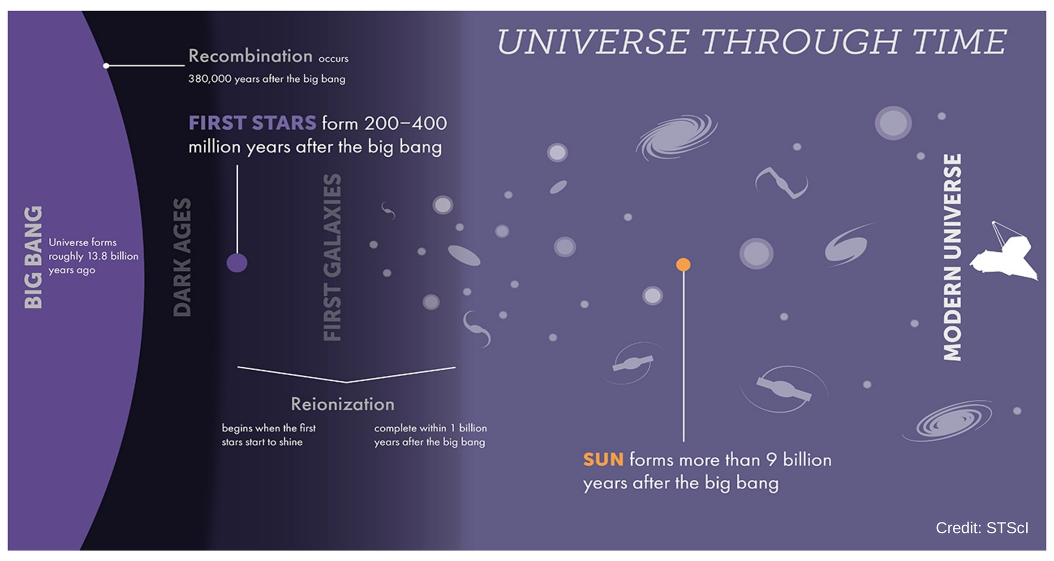
Shrriya Kapoor[1], Andreas A.C. Sander[1], Varsha Ramachandran[1]

[1]Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg

Abstract

Population III (Pop III) stars are theorized to be the first generation of stars formed after the Big Bang and are expected to be main drivers of cosmic reionization. We study these objects using the state-of-the-art stellar atmosphere code PoWR[4], in order to quantify their impact on their surroundings. We model the atmospheres of massive Pop III (zero metallicity, Z = 0), and very low metallicity (Z = 0.0002) stars, to calculate ionizing photon fluxes and provides synthetic spectra. We compare our ionizing photon flux results with blackbody approximation of Pop III stars, as well as plane parallel models, as those are typically used in population studies. We also assess the distinct spectral imprints of the two types of stars.

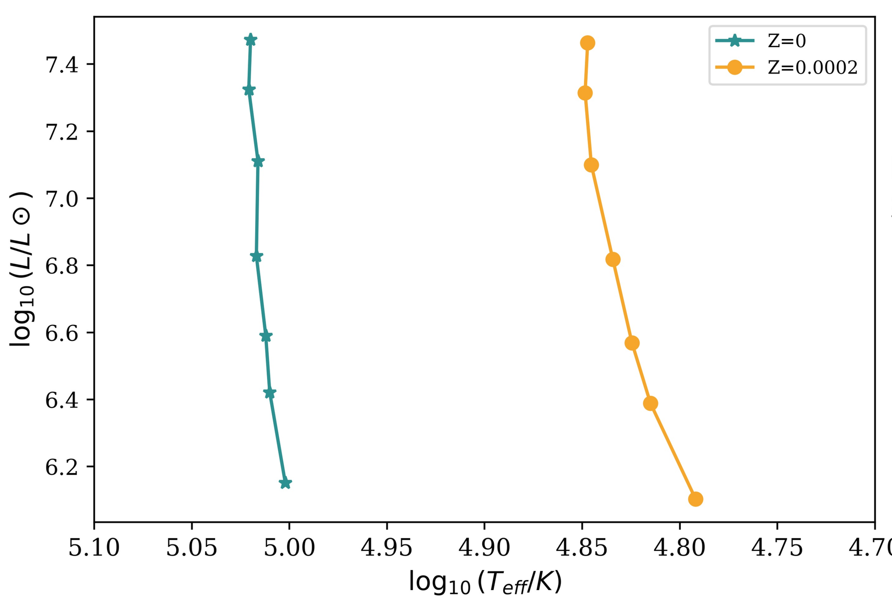
Introduction



- First generation of stars
- Around 100 to 400 million years after the Big Bang
- Virtually zero metals
- Key contributors to Cosmic Reionization

Aim of this work:
- Quantify the impact of Pop III stars via ionizing photon flux
- Comparison with a blackbody, low metallicity star and existing literature.
- Examine distinct synthetic spectral features

Model Specifications



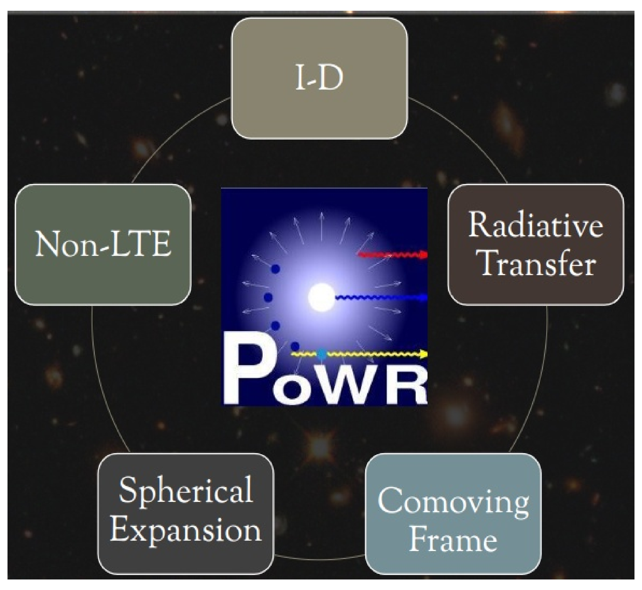
Zero-Age Main Sequence Points from new evolutionary models[1]

Mass Range: 100, 150, 200, 300, 500, 750, 1000$M_\odot$

Chemical Composition
- **Zero metallicity (Z=0) (Population III)**
  - Yp=0.2485[1]
  - X = 0.7514
- **Low metallicity (Z=0.0002)**

G = Ti, Cr, Fe, Ni, Zn

Element	Mass Fraction
C	3.6395e-05
N	9.725e-06
O	8.8232e-05
Ne	2.0238e-05
Mg	8.8583e-06
Na	4.7101e-07
Al	7.632e-07
Si	9.549e-06
S	4.443e-06
Ar	9.616e-07
Ca	8.8002e-07
G	1.9027e-05



[4]

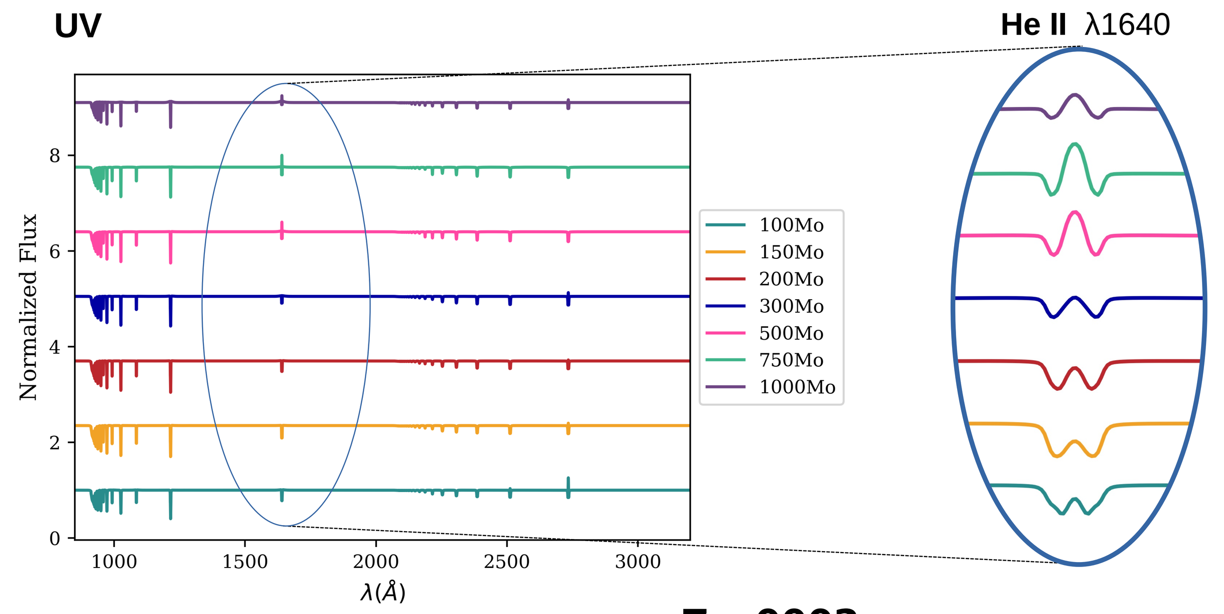
[2]

$$Q_i = 4\pi R_*^2 q_i = 4\pi R_*^2 \int_{\nu_i}^{\infty} \frac{F_\nu}{h\nu}\,\mathrm{d}\nu$$

Ionization Level	Wavelength (λ) [Å]	Energy [eV]
Lyman edge for H	911.55	13.601
He I	504.3	24.585
He II	227.85	54.415
Ne III	195.49	63.422
Lyman-Werner*	912.26-1107.75	13.591-11.192

Spectral Features

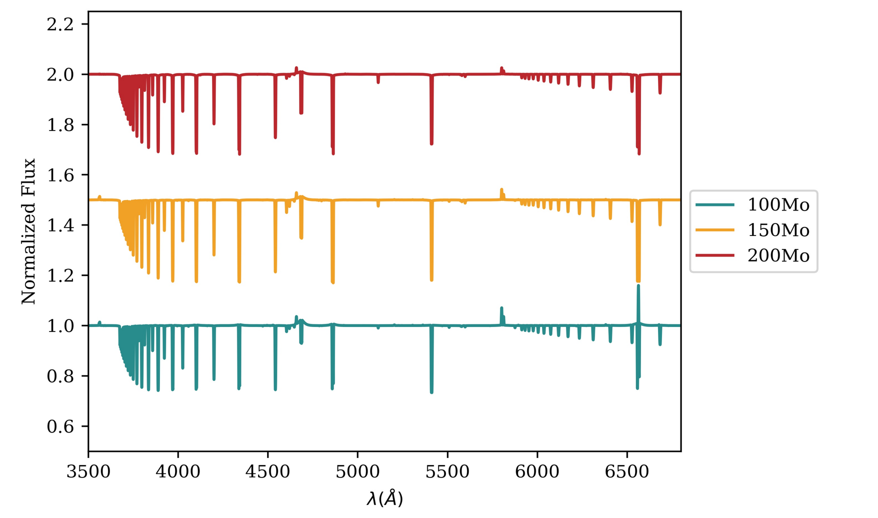
Z=0



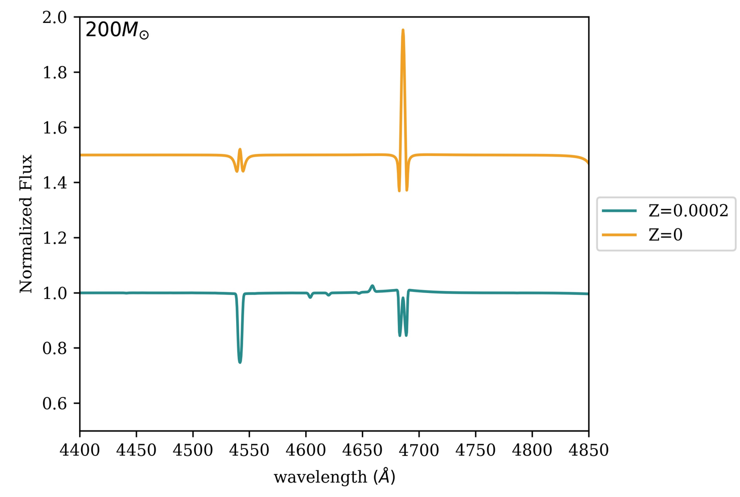
Weak mass-loss rate; No direct imprint of terminal velocity

Z=.0002

OPTICAL

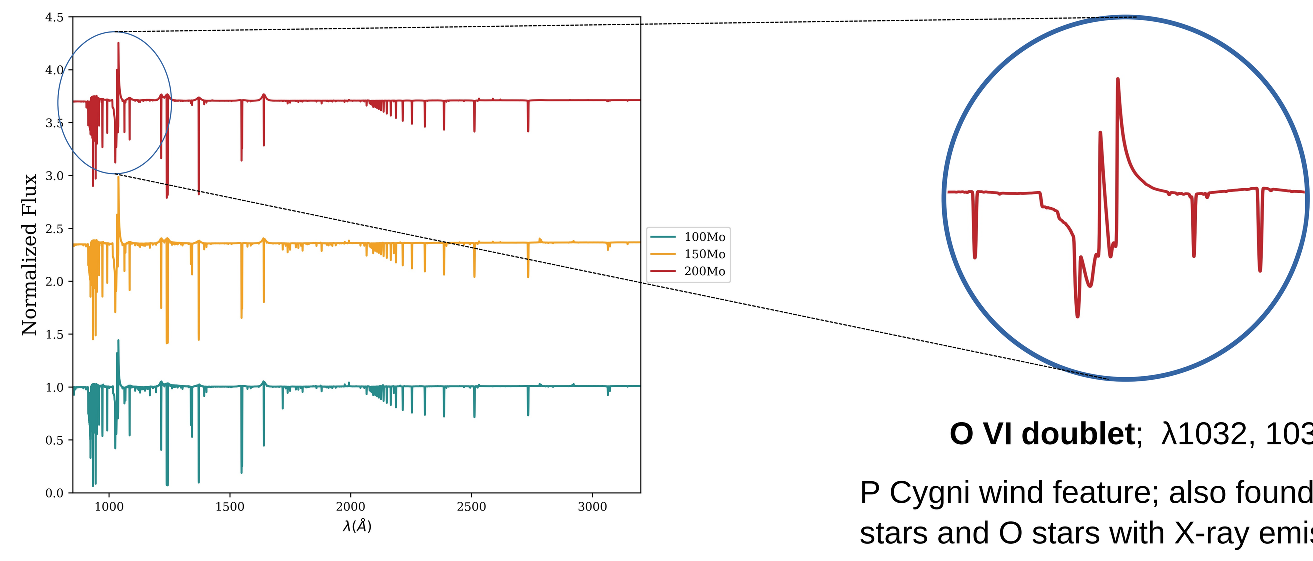


Comparing **He II** λ4686 – Z=0 vs. Z=0.0002



Strong He II λ4686 emission for Z=0 model

UV



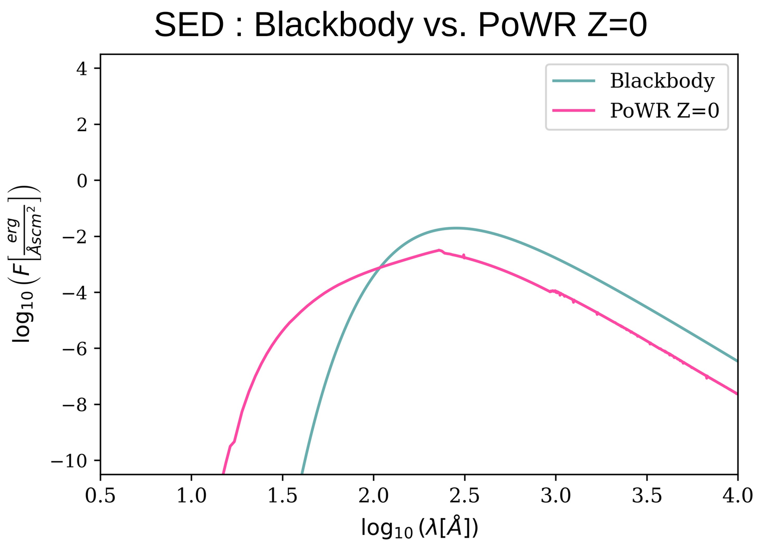
O VI doublet; λ1032, 1038

P Cygni wind feature; also found in hot WR stars and O stars with X-ray emission

Ionizing Photon Fluxes

Z=0 vs. Blackbody

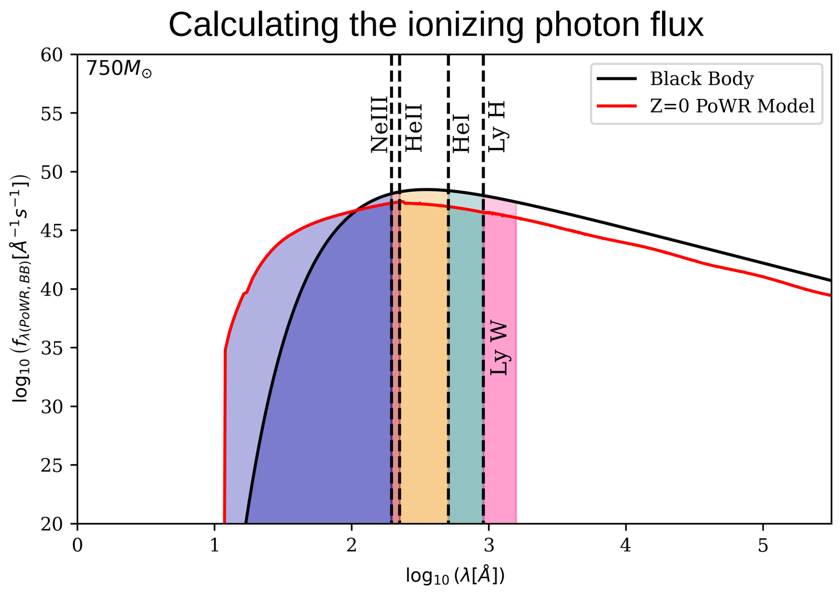
SED : Blackbody vs. PoWR Z=0



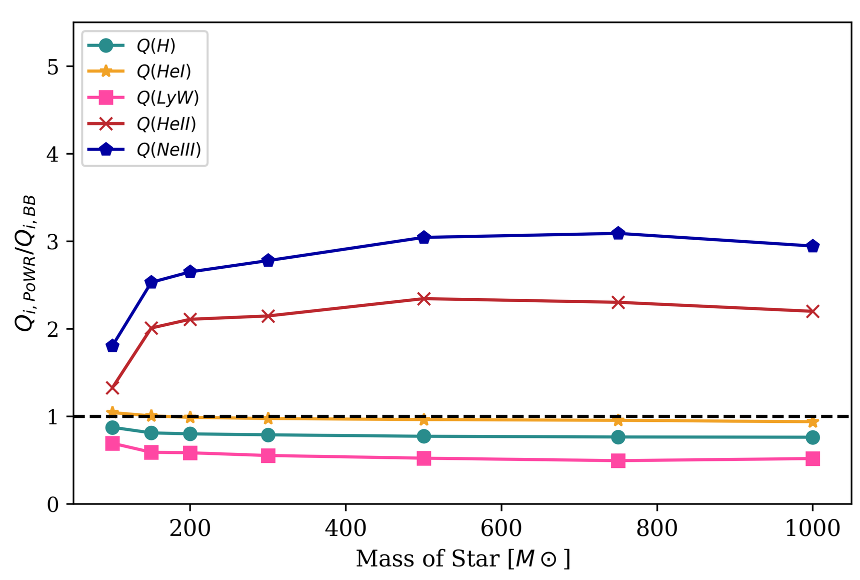
Parameters for PoWR Z=0 model:

Stellar Mass[$M_\odot$]	log $L/L_\odot$	log T_{eff} [K]	V_∞ [Km/s]	$\log_{10}\dot{M}[M_\odot/yr]$
100	6.1515	5.0021	7153.25	-13.6253
150	6.4217	5.01007	7639.84	-13.0627
200	6.5903	5.0121	8044.68	-12.7877
300	6.8284	5.0169	8687.73	-12.4575
500	7.111	5.0161	9515.84	-11.489
750	7.3249	5.0208	10417.2	-9.8229
1000	7.4726	5.0199	11025.9	-8.74505

Calculating the ionizing photon flux



Ionizing photon flux yields for PoWR Z=0 model compared to a blackbody:



$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

$$4\pi^2 R_*^2 \int B_\lambda \frac{\lambda}{hc}\mathrm{d}\lambda = 4\pi d^2 \int F_\lambda \frac{\lambda}{hc}\mathrm{d}\lambda$$

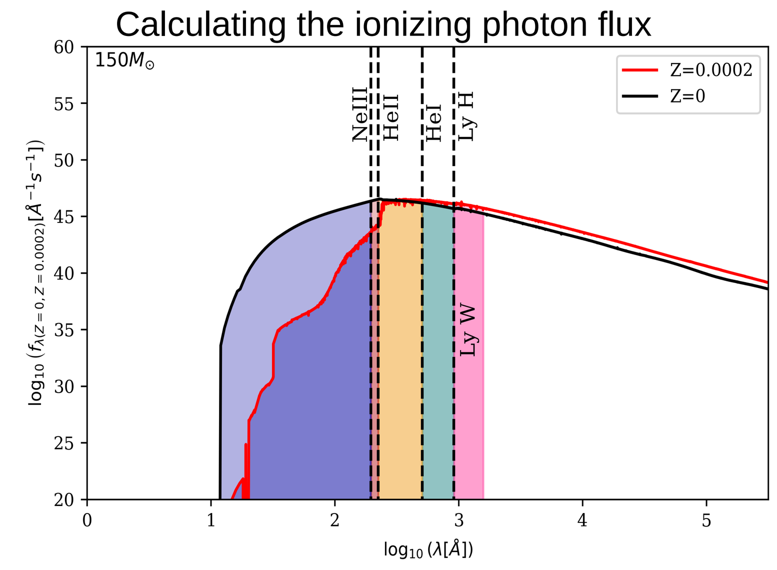
Q(H) → 20% lower
Q(Ly-W) → 40-50% lower
Q(He I) → Comparable
Q(He II) → Factor of 2 higher
Q(Ne III) → Factor of 3 higher

Z=0 vs. Z=0.0002

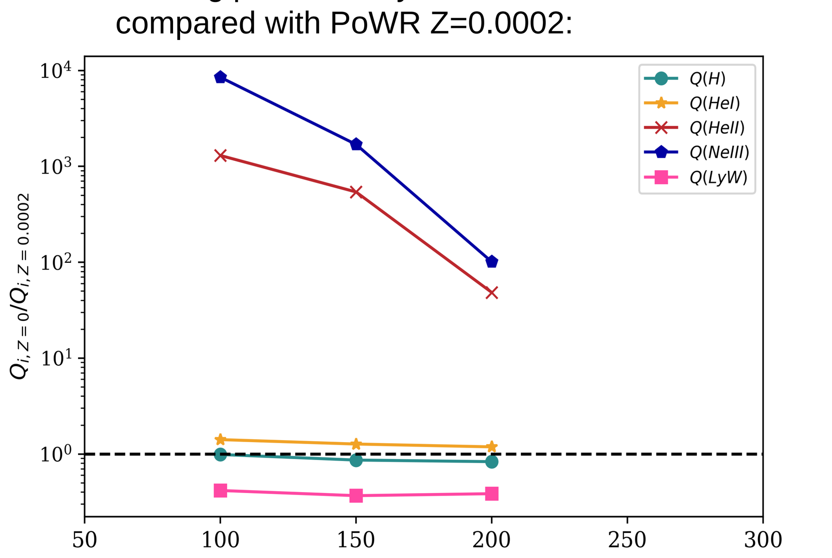
Parameters for PoWR Z=0.0002 model:

Stellar Mass[$M_\odot$]	log $L/L_\odot$	log T_{eff} [K]	T_{eff} [K]	V_∞ [Km/s]	$\log_{10}\dot{M}[M_\odot/yr]$
100	6.103	4.7919	61929.8	4533.92	-7.26628
150	6.3883	4.815	65313.1	4970.35	-7.01239
200	6.5688	4.8245	66757.5	5288.05	-6.8501

Calculating the ionizing photon flux

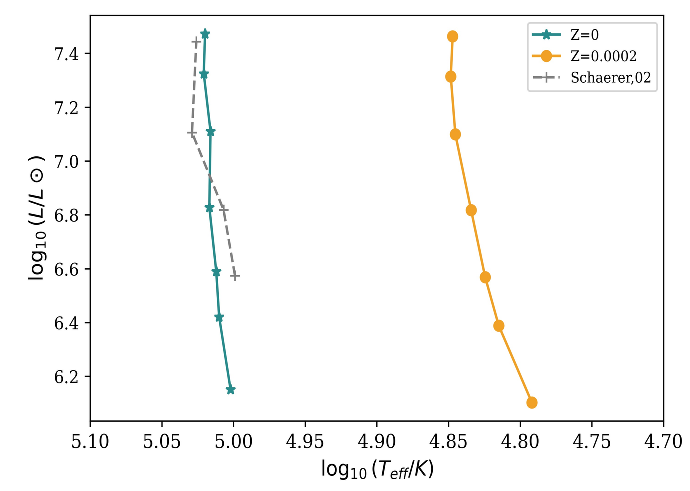


Ionizing photon flux yields for PoWR Z=0 compared with PoWR Z=0.0002:



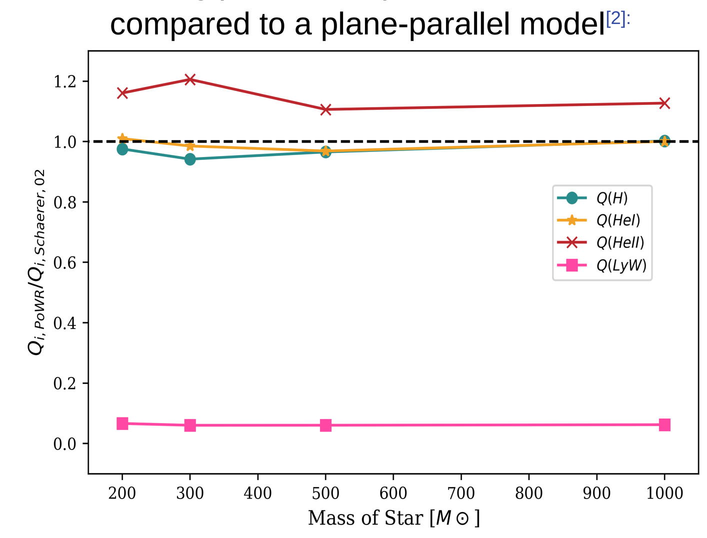
Q(H, Ly-W, He I) → relatively comparable
Q(He II, Ne III) → 3, 4 orders of magnitude higher

Z=0 vs. Existing Literature



*Grey points represent ZAMS points from Schaerer, D., 2002[2]

Ionizing photon flux yields for PoWR Z=0 compared to a plane-parallel model[2]



Q(H, He I) → in agreement
Q(Ly-W) → significantly lower (about 90%)
Q(He II) → 15-20% higher

- Different assumption in mass-loss rate for plane-parallel models
- Choice of tracks

Further Work/ Open Questions

- Investigating the nature of He II emission feature in high redshift galaxies: stellar or nebular
- Effect of metallicity variation on ionizing photon fluxes
- Comparison with available observed spectra

References

[1] Volpato, G. et al. 2023, ApJ, 944, 40
[2] Schaerer, D. 2002, A&A 382, 28-42
[3] Gräfener, G., Koesterke, L., & Hamann, W.-R. 2002, A&A, 387, 244

Contact and Group information

- shriya.kapoor@stud.uni-heidelberg.de
- Emmy Noether Research Group on Stellar Atmosphere and Mass Loss