Lyman radiation production in massive stars

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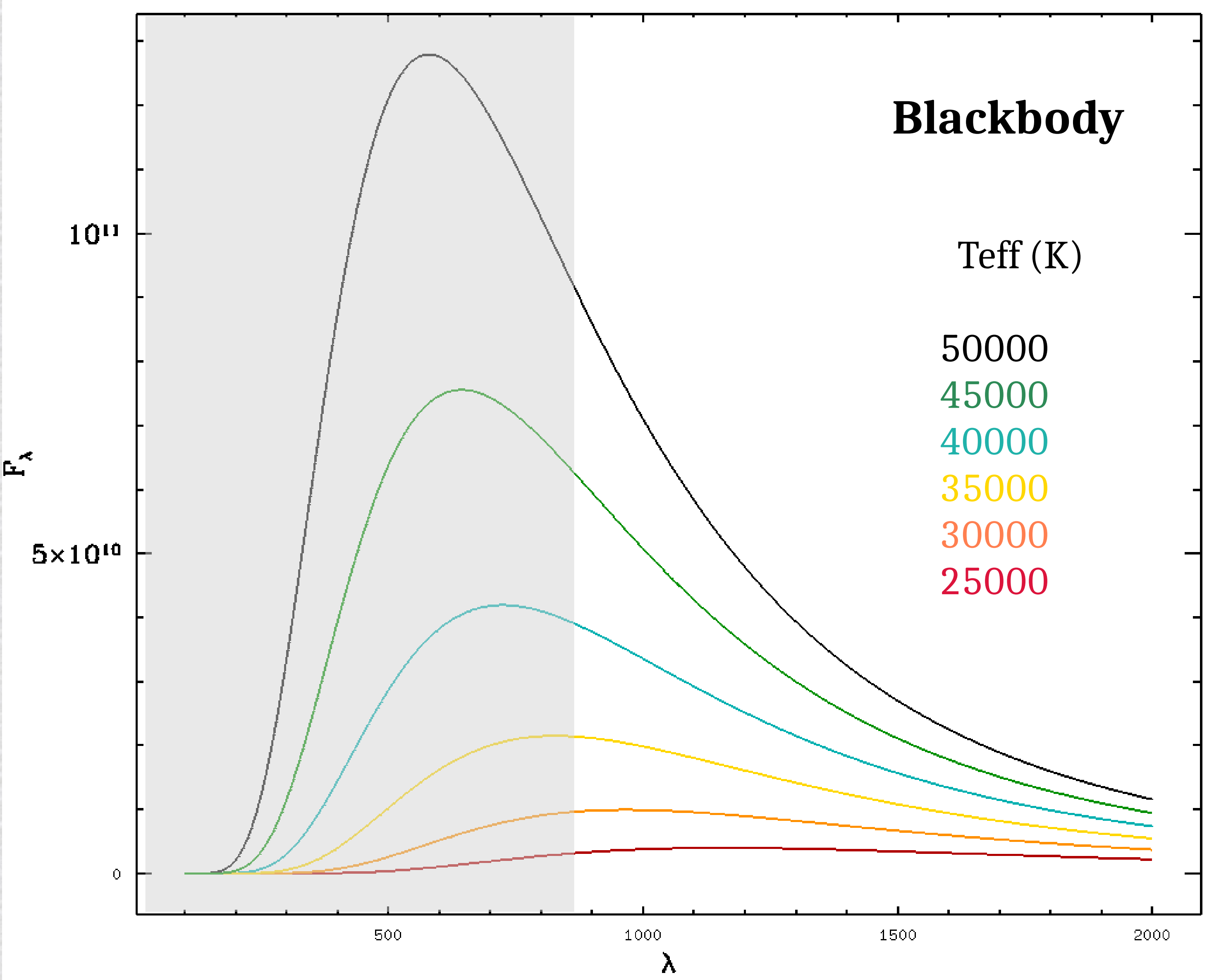
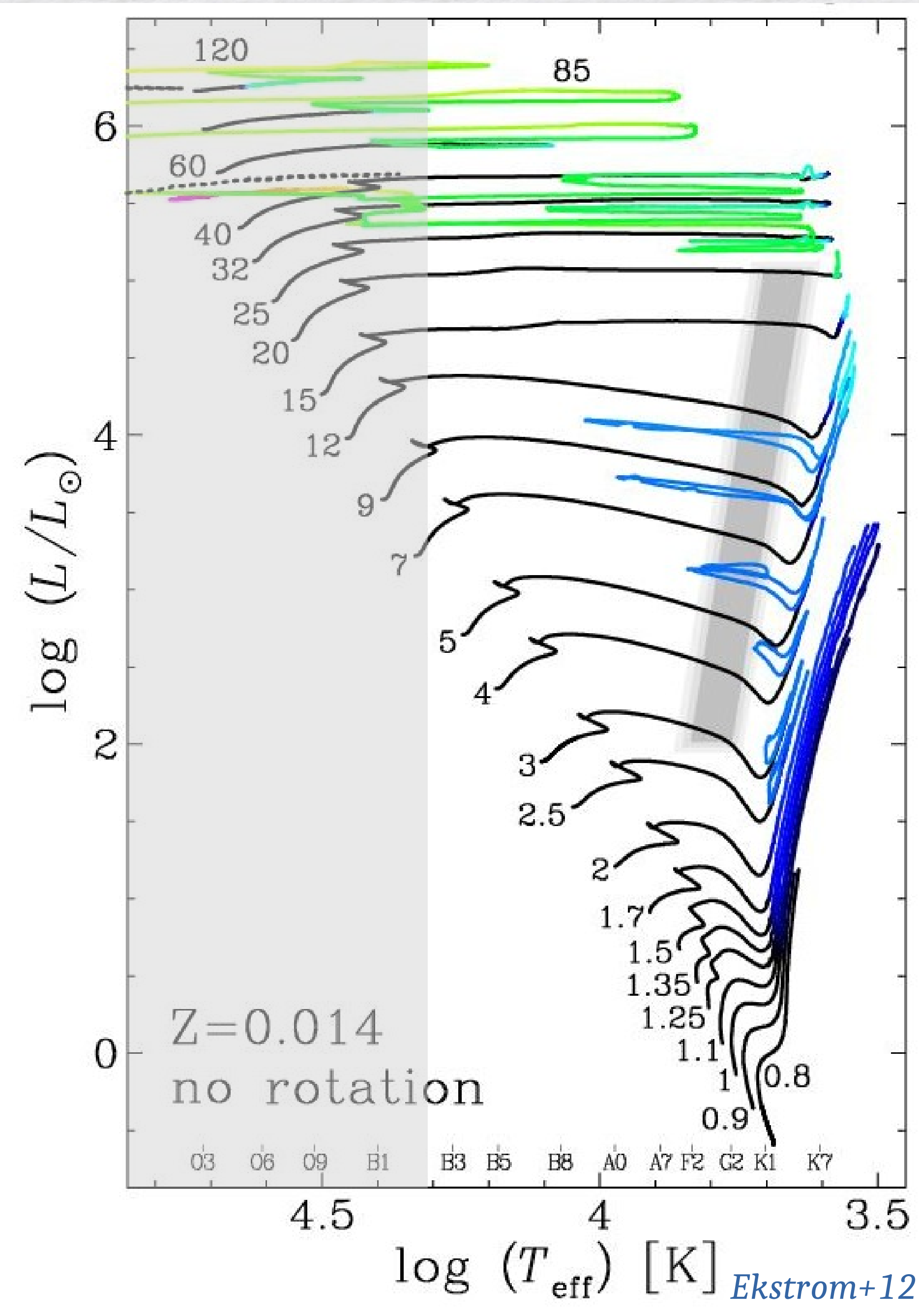
Ionizing photons and effective temperature



Ionizing photons and effective temperature



Ekstrom+12

All stellar objects with Teff $\gtrsim$ 20000 K produce some amount of ionizing photons

- O stars

- B stars < B2

- Wolf-Rayet stars

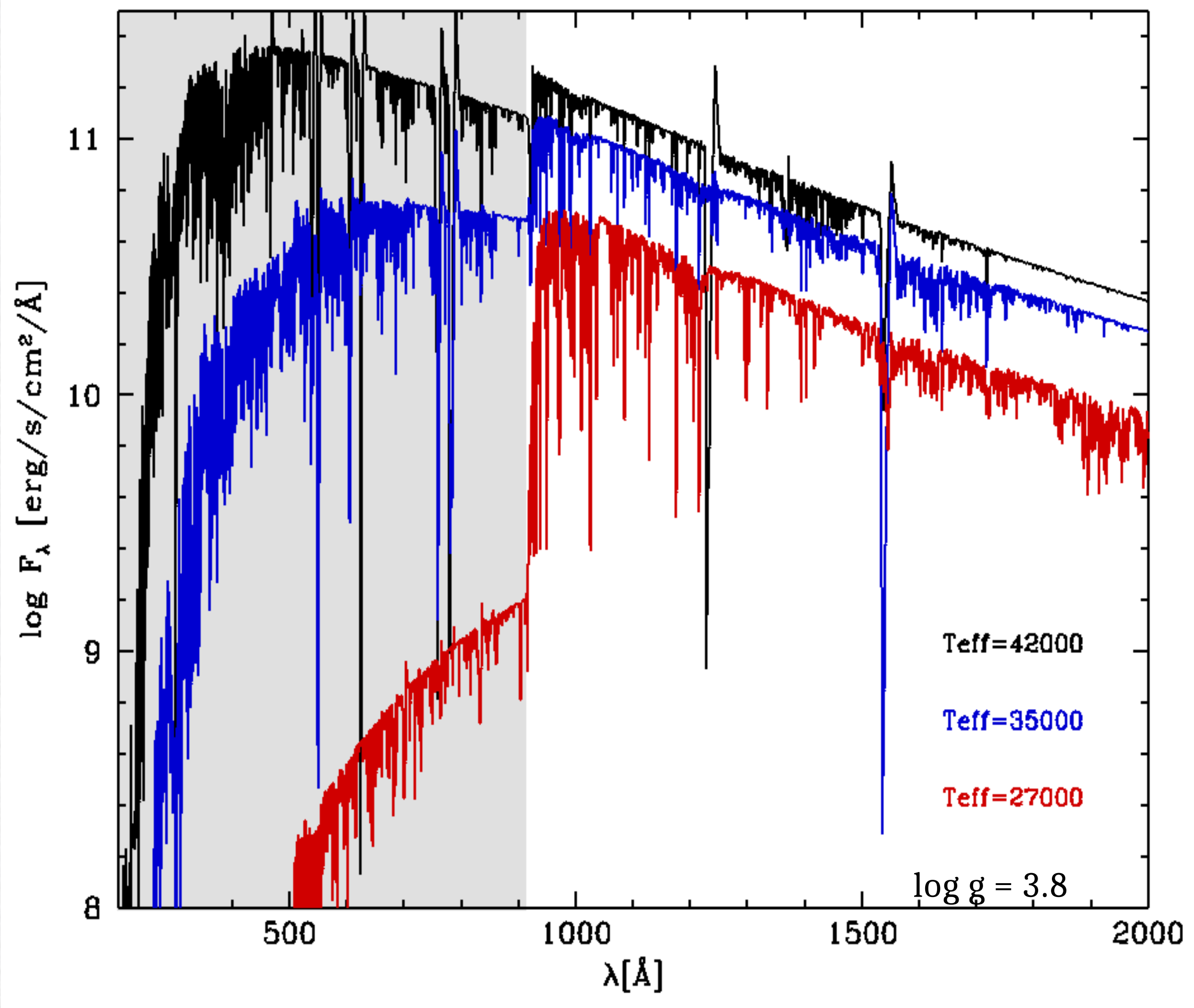
- Very/Super massive stars

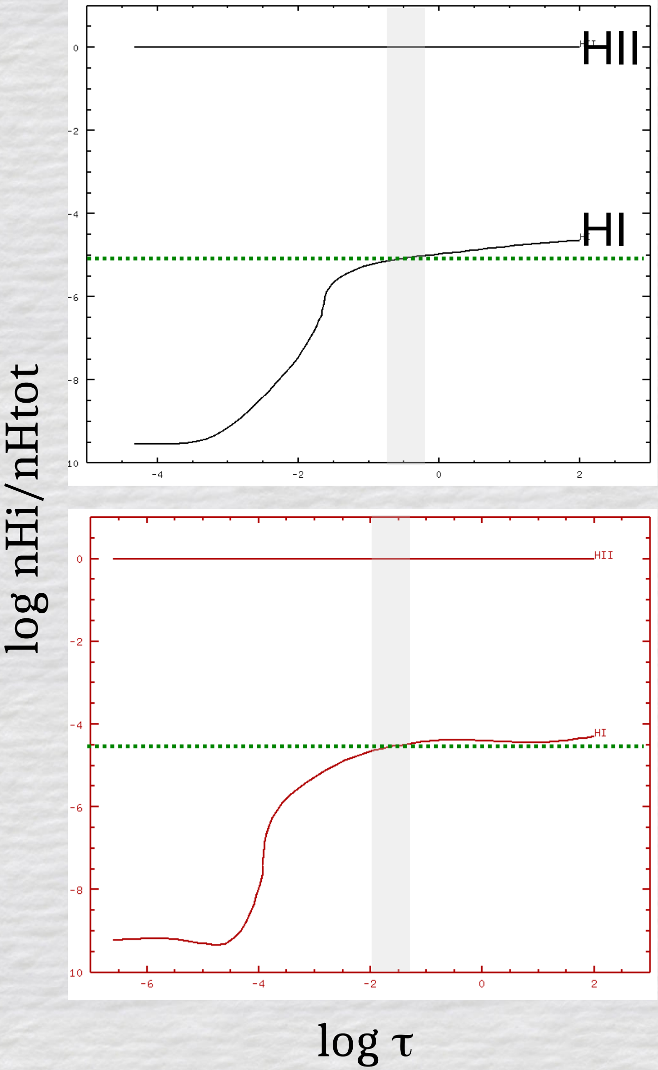
- Stripped stars (sub-dwarfs)

(- White dwarfs)

Ionizing photons and effective temperature

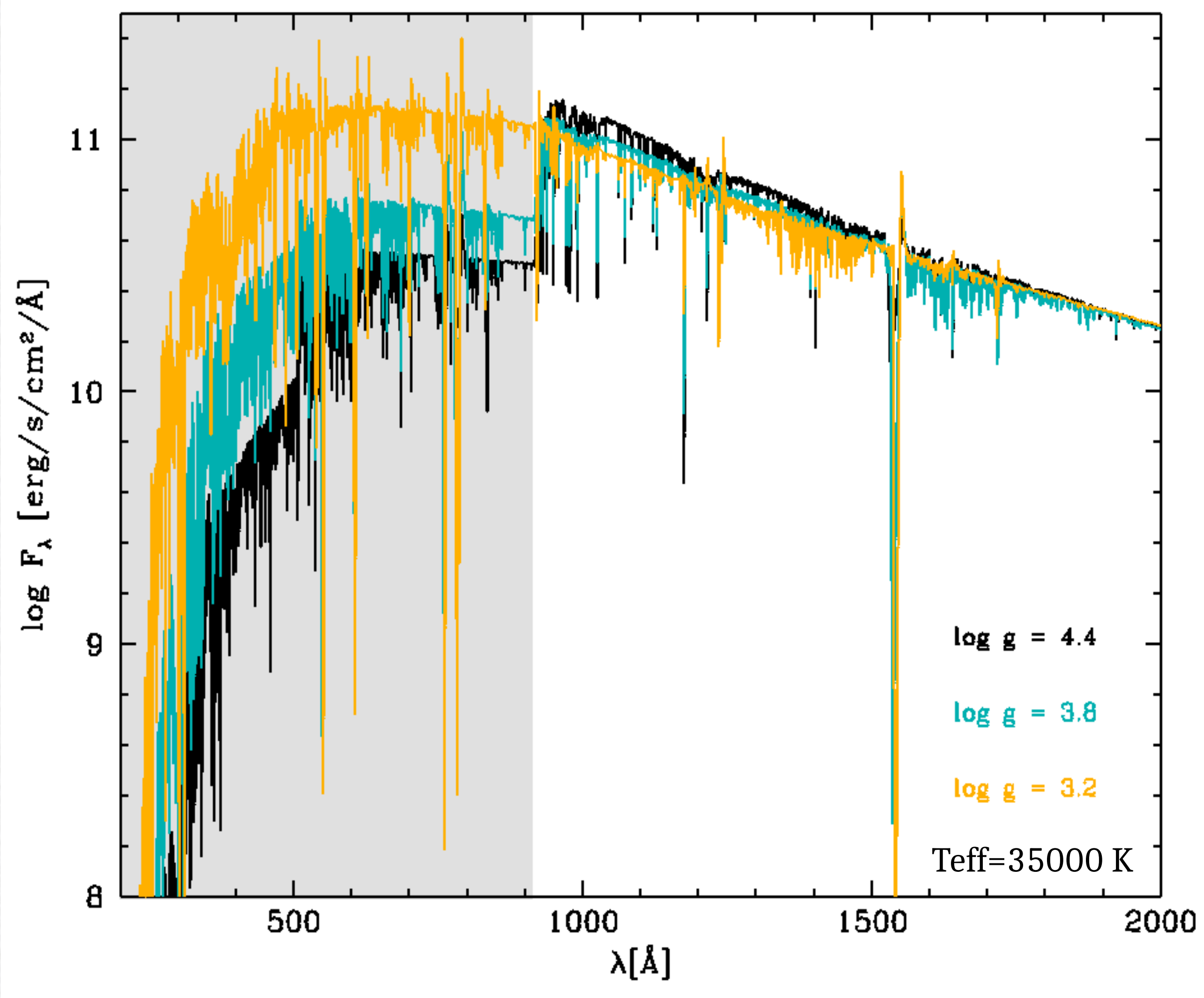
Atmosphere models: CMFGEN (Hillier & Miller 98), PoWR (Hamann+06), TLUSTY (Lanz+03)
WM-BASIC (Pauldrach+03), FASTWIND (Puls+05)

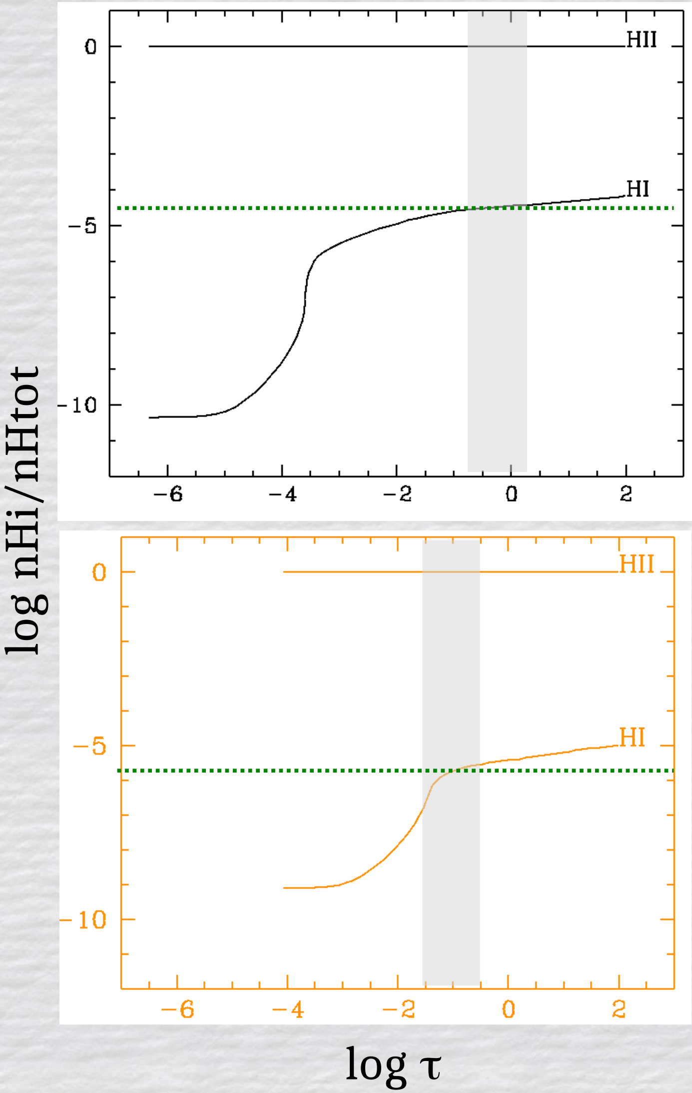




High Teff implies high ionization, and smaller amount of HI
HI ground state less populated → opacity smaller → stronger emission

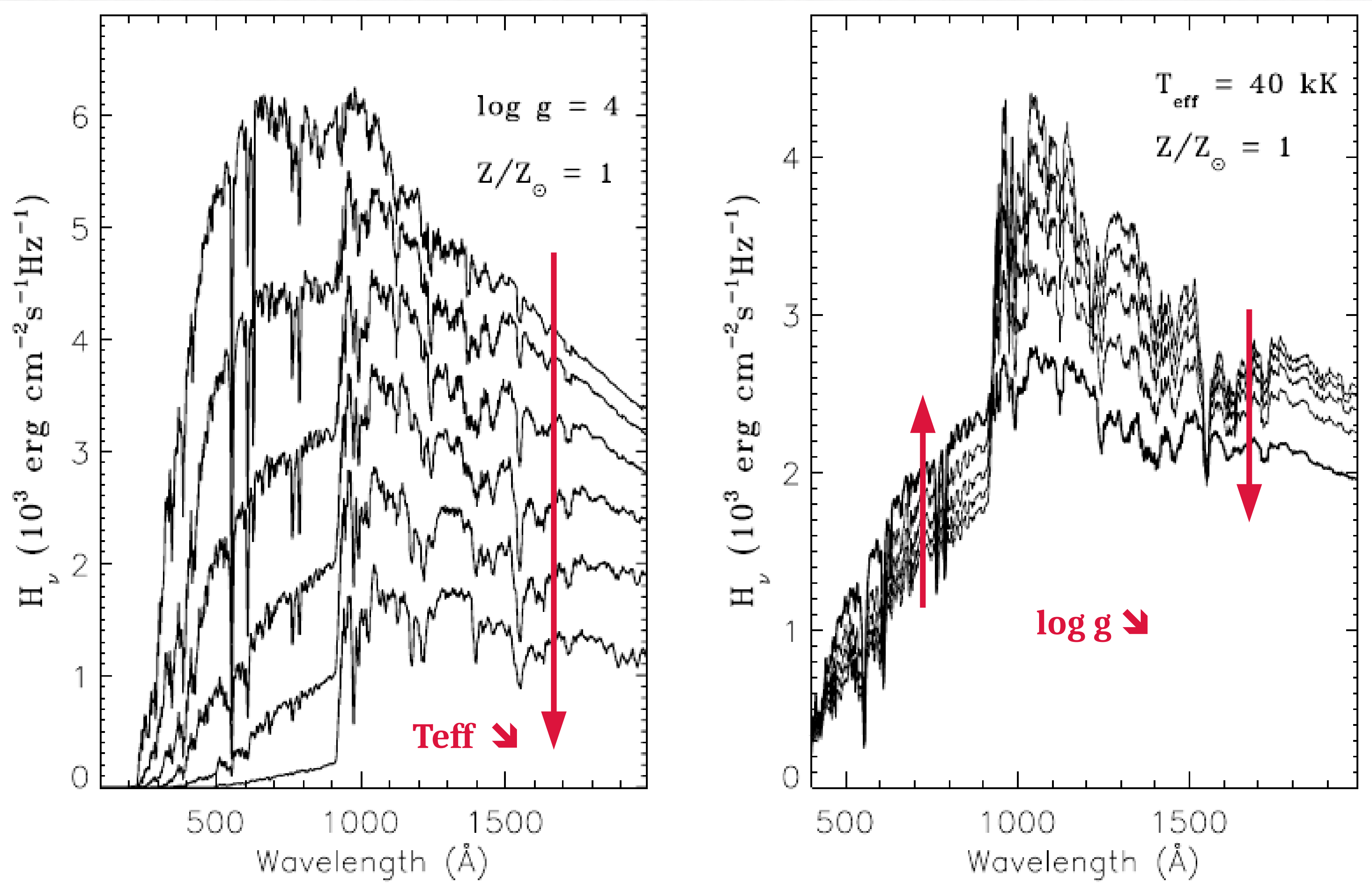
Ionizing photons and surface gravity





Higher gravity → higher density → more recombinations
HI ground state more populated → opacity larger → less emission

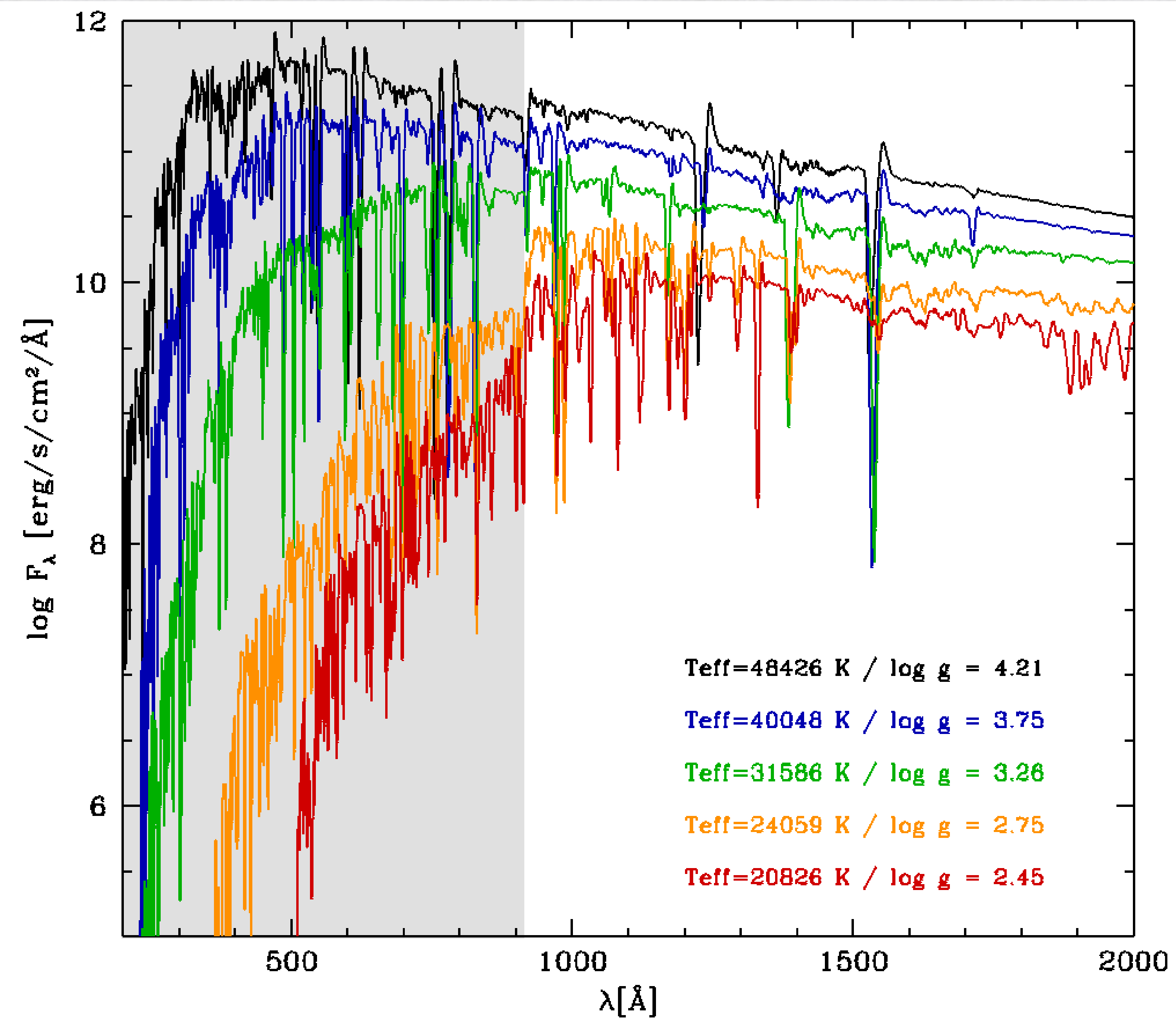
Ionizing photons and stellar parameters

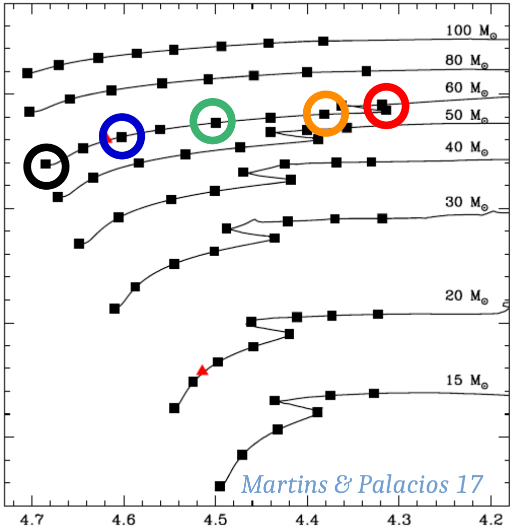


TLUSTY OSTAR2002 – *Lanz+03*

http://tlusty.oca.eu/Tlusty2002/tlusty-frames-OS02.html

Ionizing photons and stellar parameters





Martins & Palacios 17

$L_{<912} / L_{bol}$

0.59

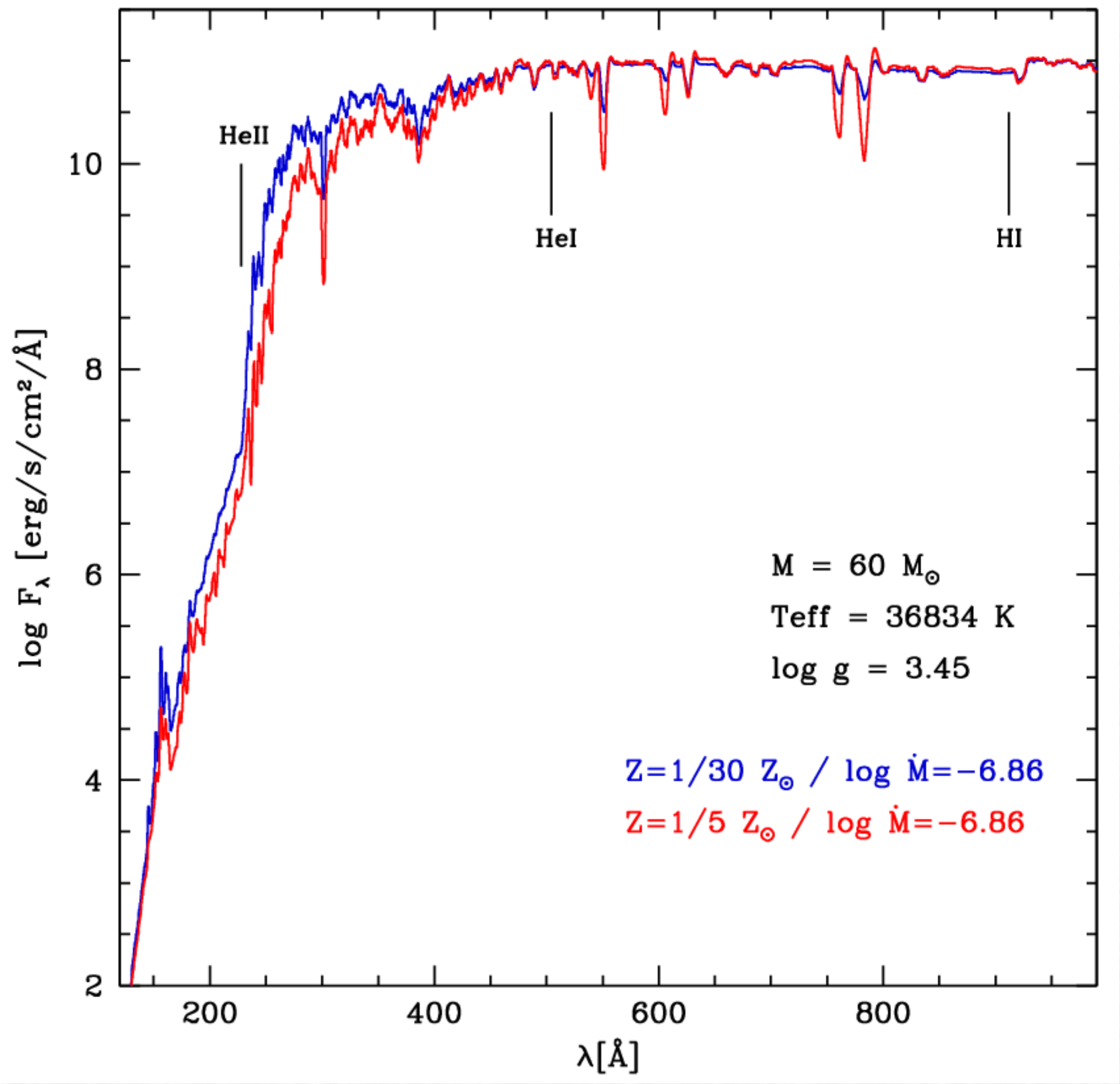
0.44

0.25

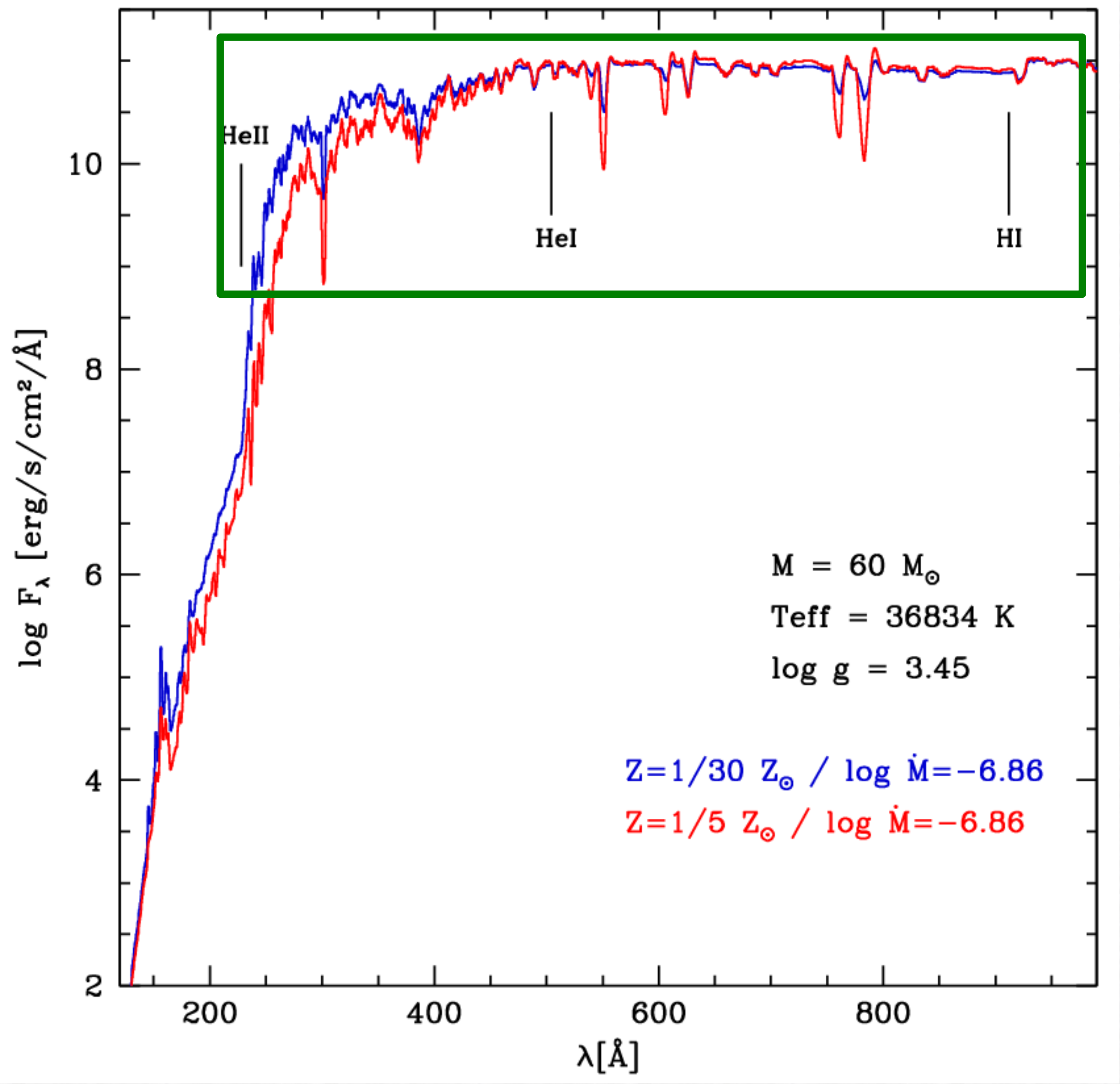
0.04

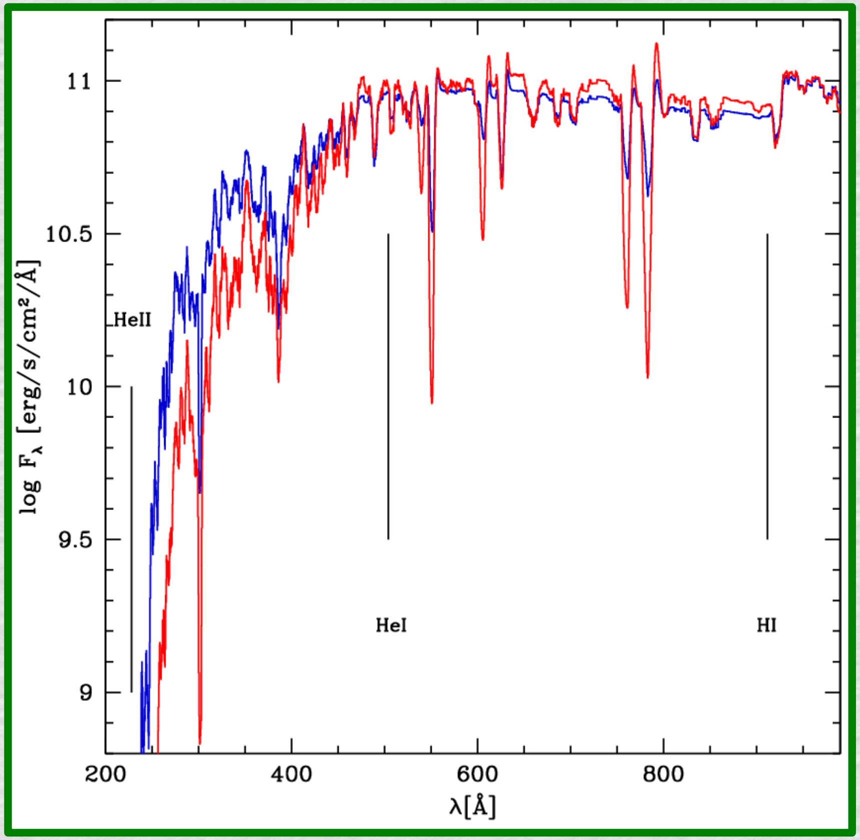
0.02

Ionizing photons and metallicity



Ionizing photons and metallicity

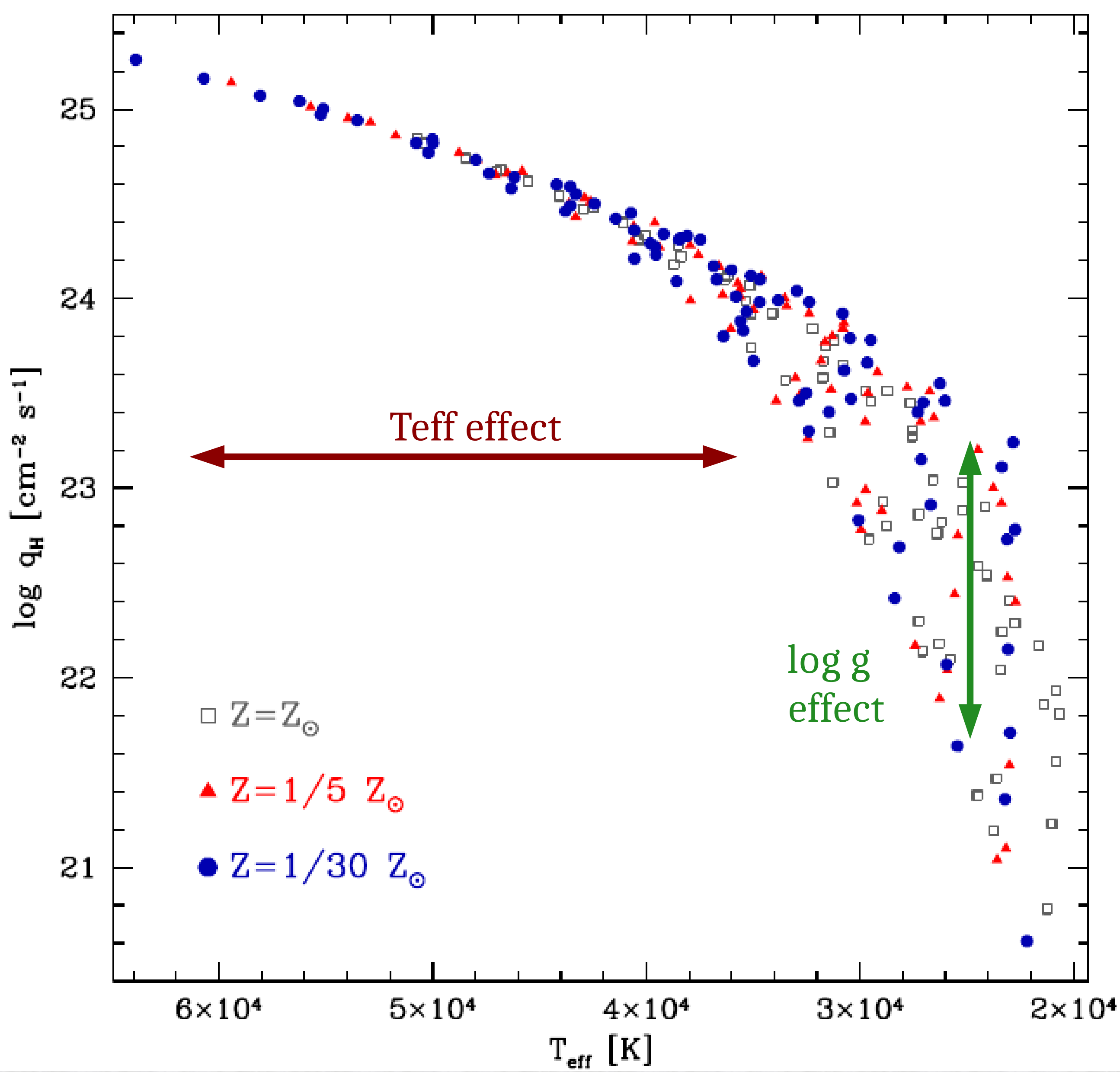




Very limited impact of metallicity on H ionizing fluxes per unit area

Flux redistribution (caused by blanketing) takes place below Lyman break

Ionizing photons and metallicity



Teff effect

log g effect

Martins & Palacios 21

$$qH = \int F_\lambda \, (\lambda/hc) \, d\lambda$$

$$[cm^{-2} / s^{-1}]$$

$\int$ over 0-912 A range

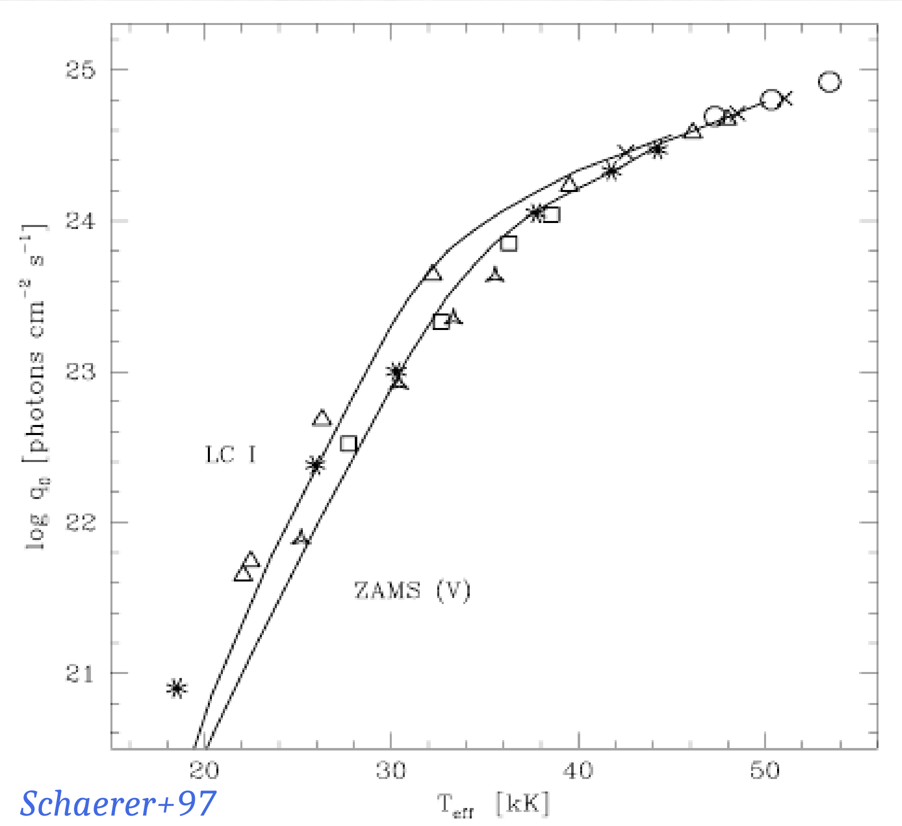
$$QH = qH \times 4 \pi R^2$$

$$[s^{-1}]$$

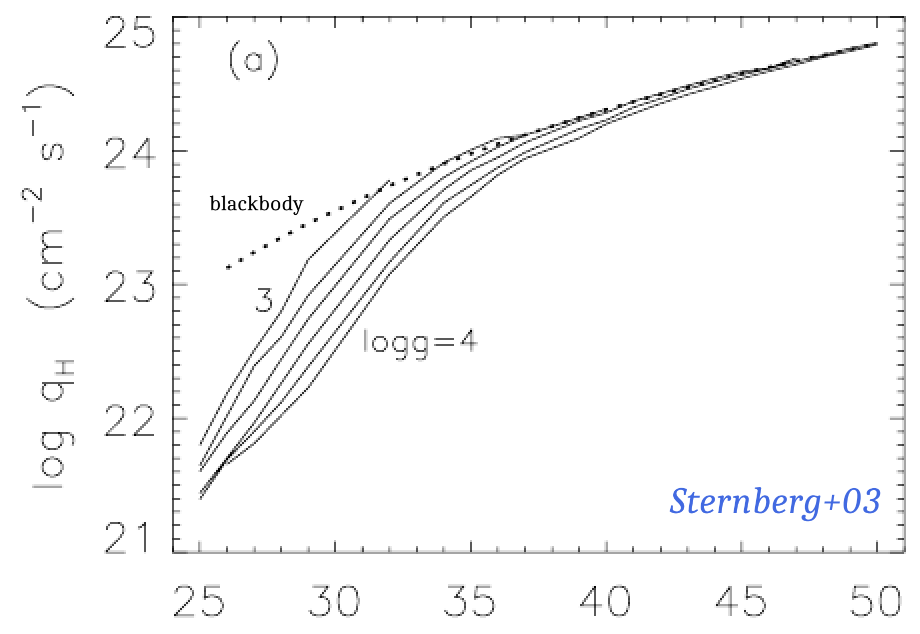
qH depends mainly on Teff, log g

Metallicity has almost no effect on qH

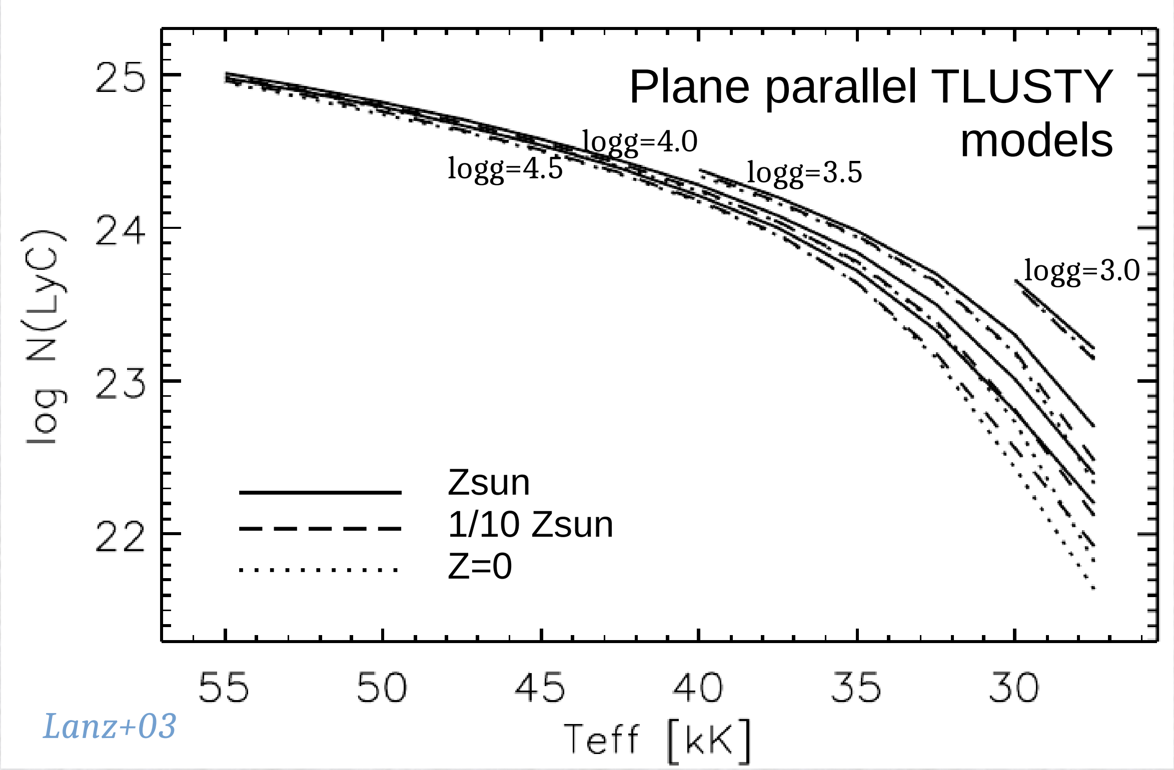
Ionizing photons and metallicity



Schaerer+97



Sternberg+03



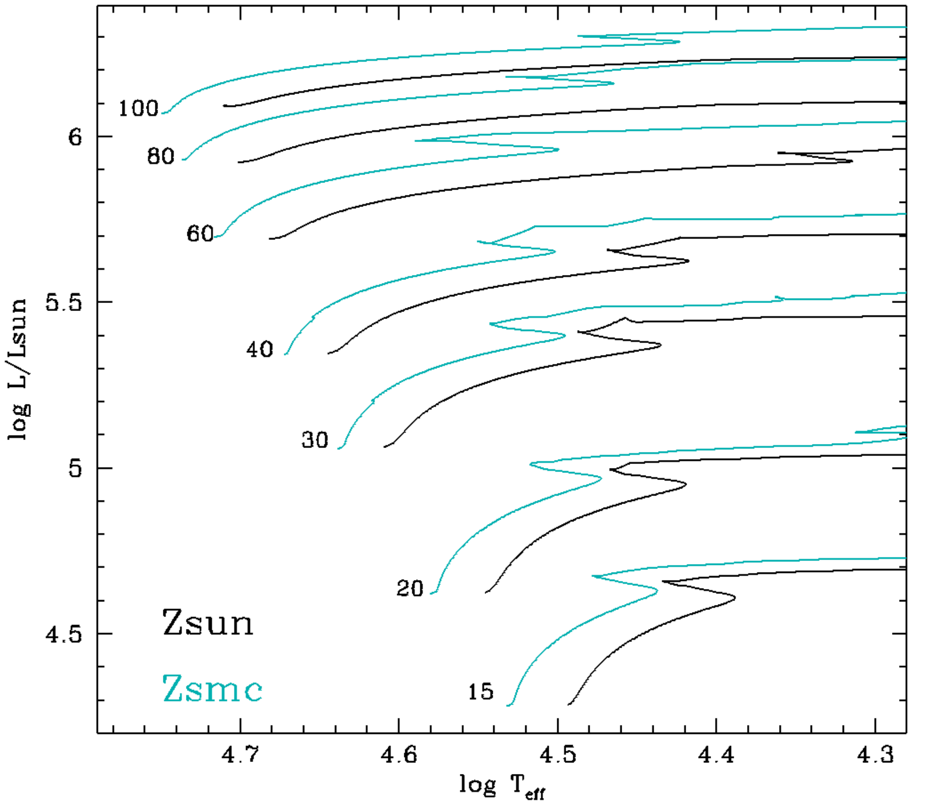
Lanz+03

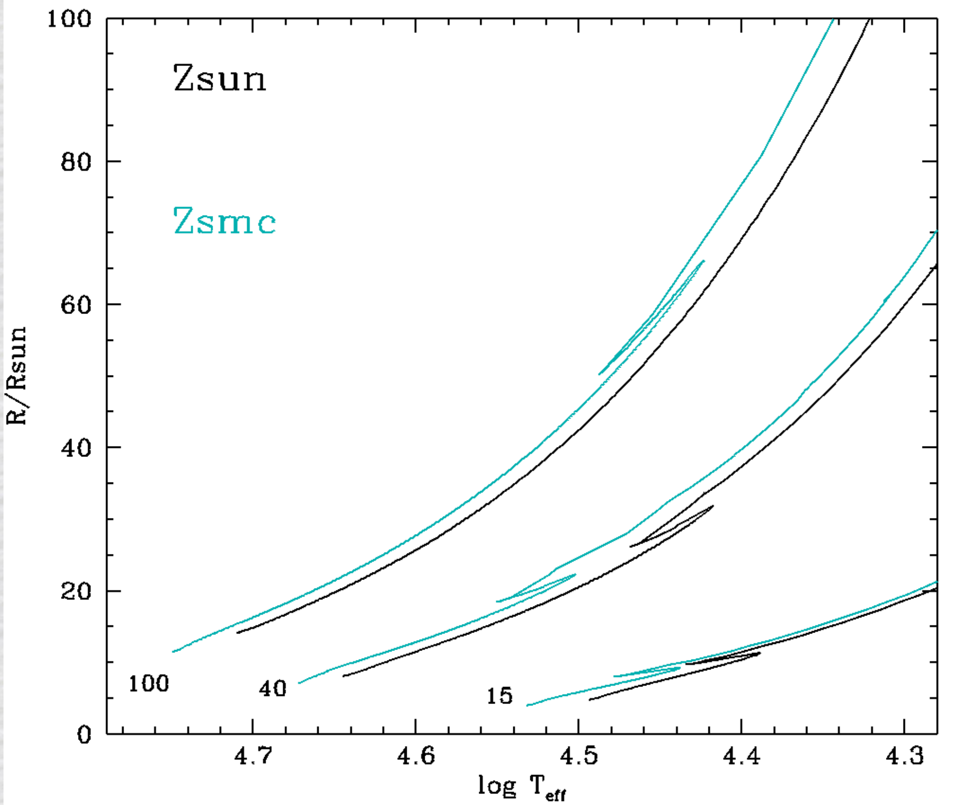
Surface gravity and metallicity

have similar effects

Ionizing photons and metallicity

the role of stellar evolution





At lower Z:

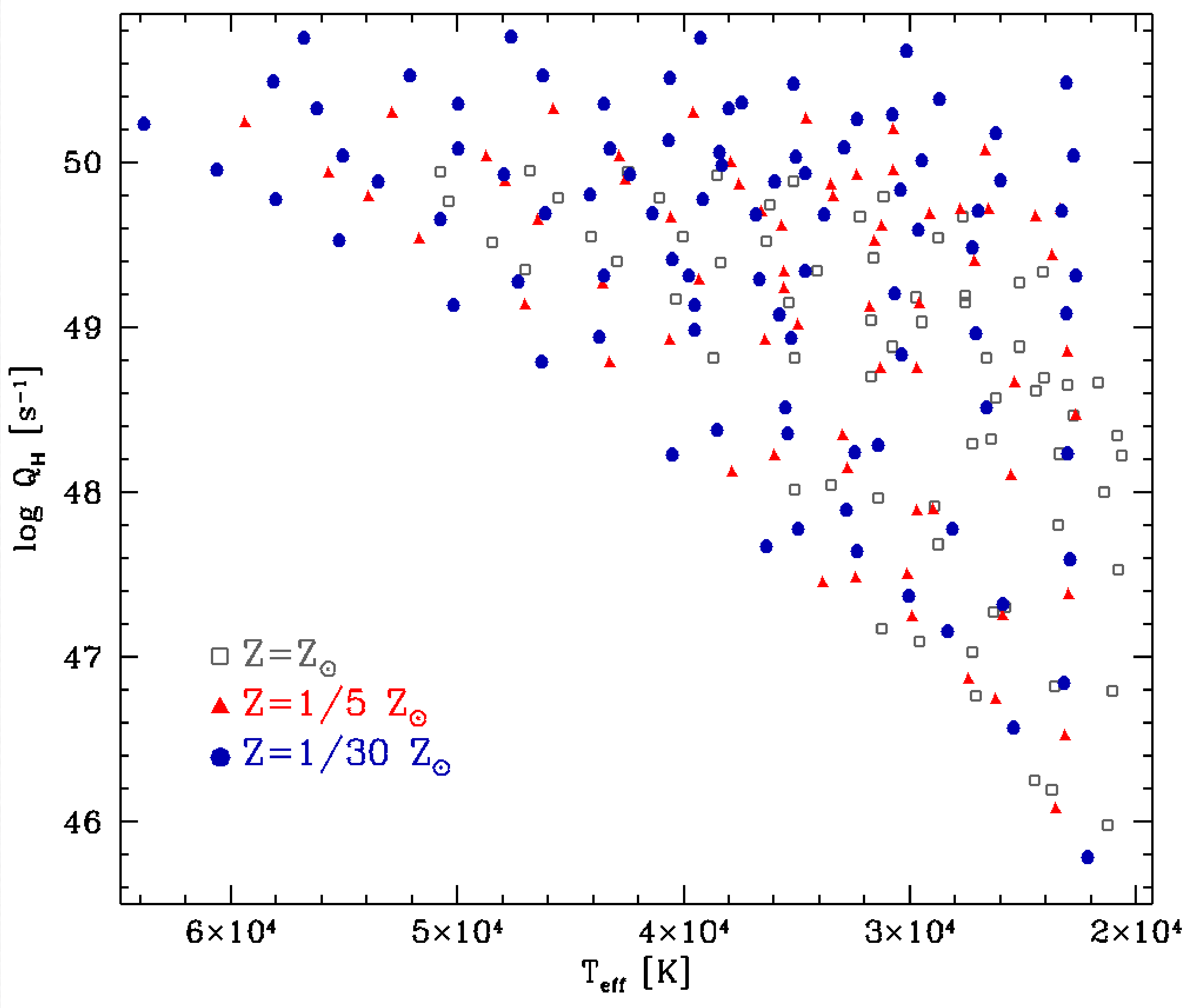
For a given Teff radius is larger → Q is larger

Stars reach higher Teff → Q is larger

$$QH = qH \times 4\pi R^2$$

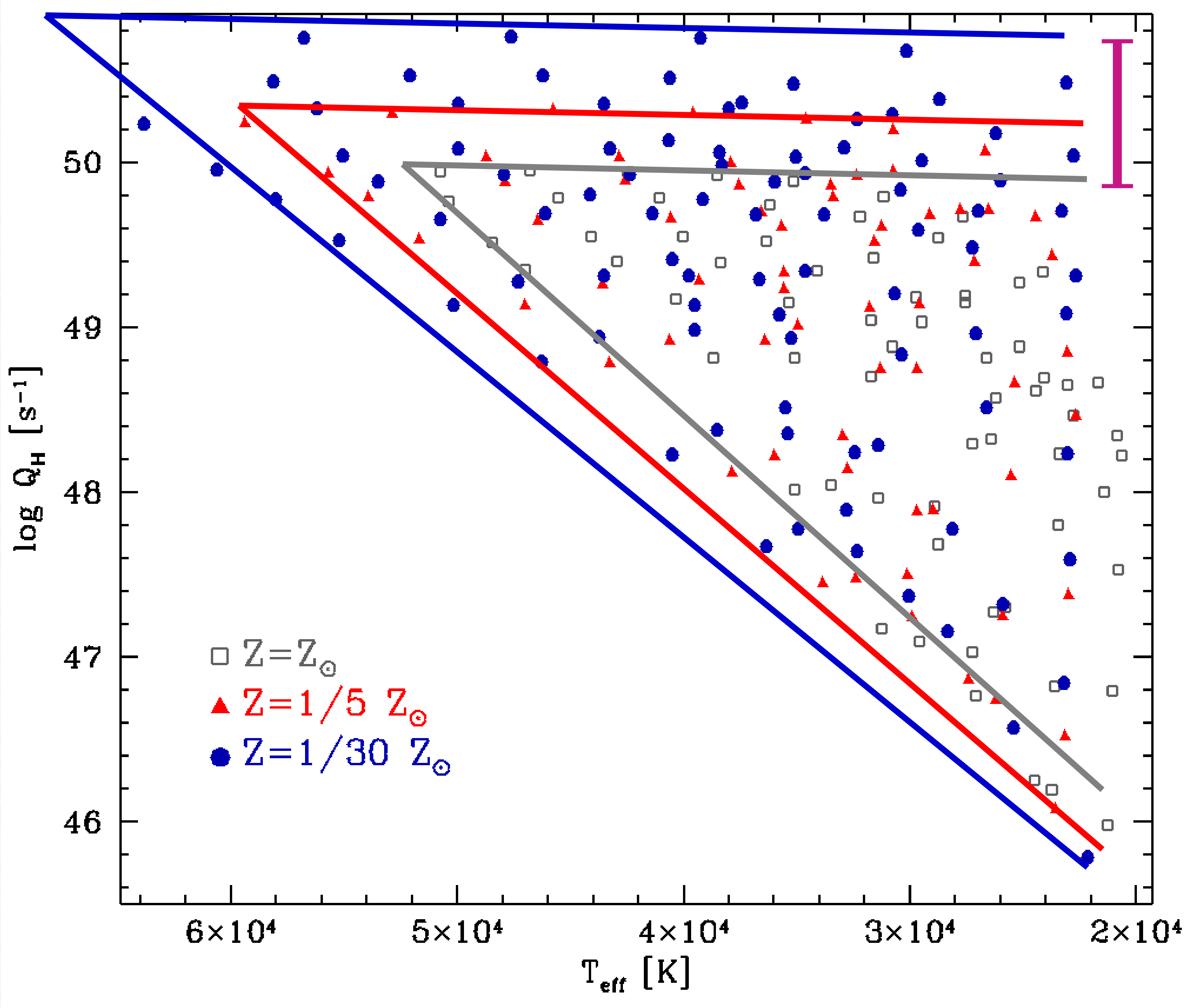
$$L = 4\pi R^2 \sigma T_{eff}^4$$

Ionizing photons and metallicity



Models from Martins & Palacios 2017, 2021

Ionizing photons and metallicity

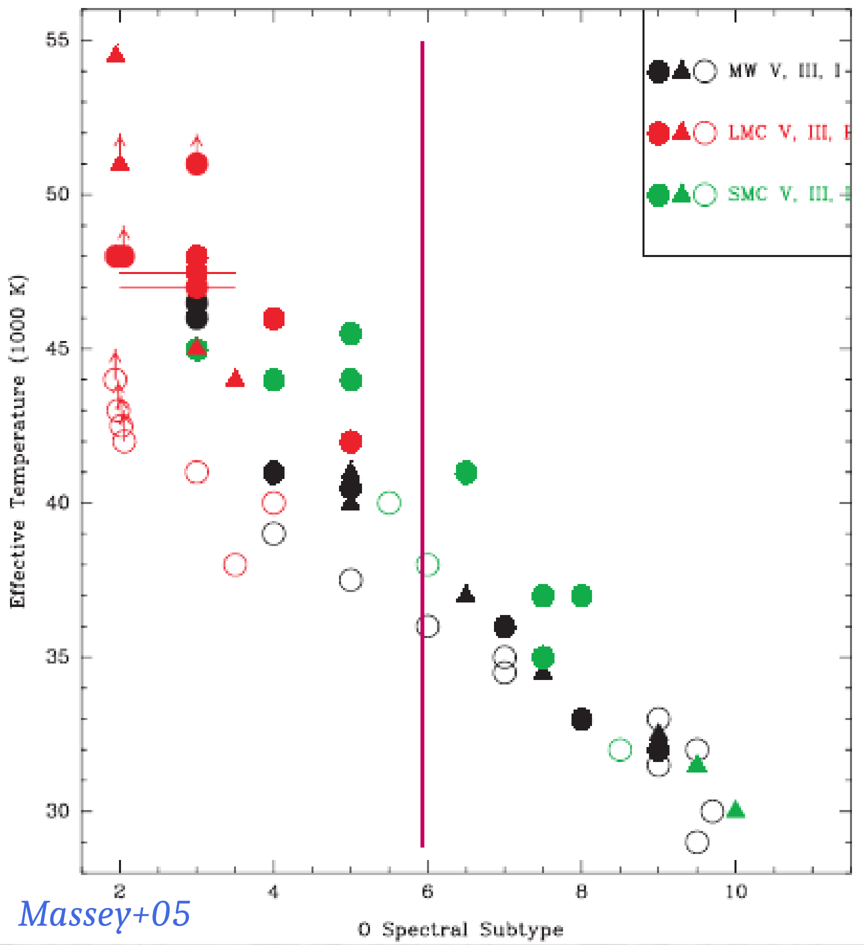


~1dex

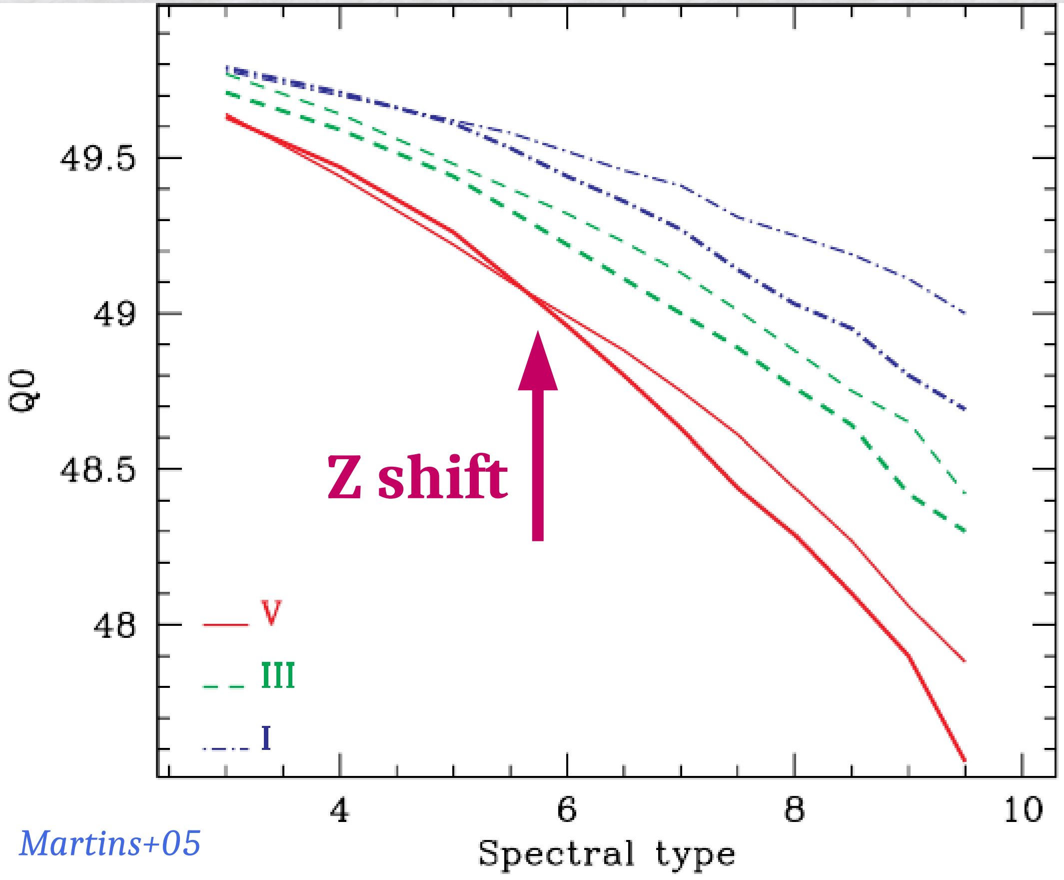
Models from Martins & Palacios 2017, 2021

Ionizing photons and metallicity

Relation with spectral type



Massey+05



Martins+05

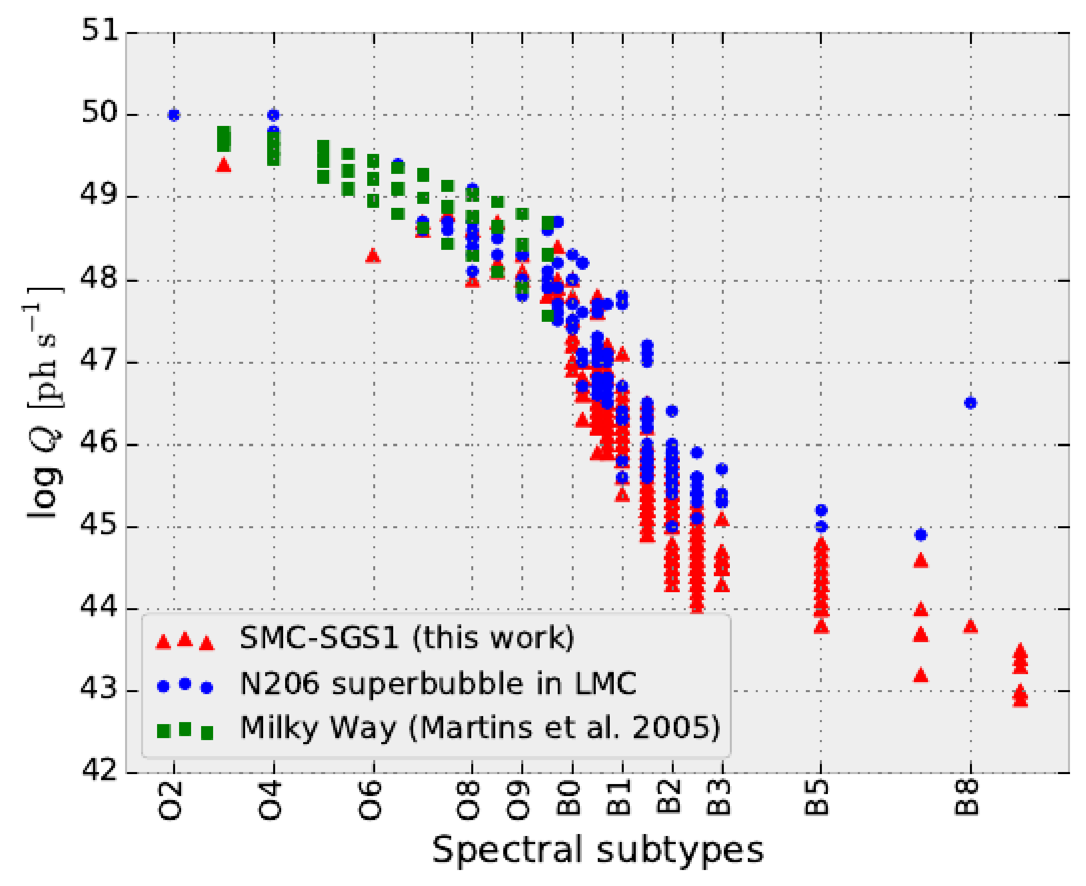
see Gull+22 for Z<1/5 Zsun

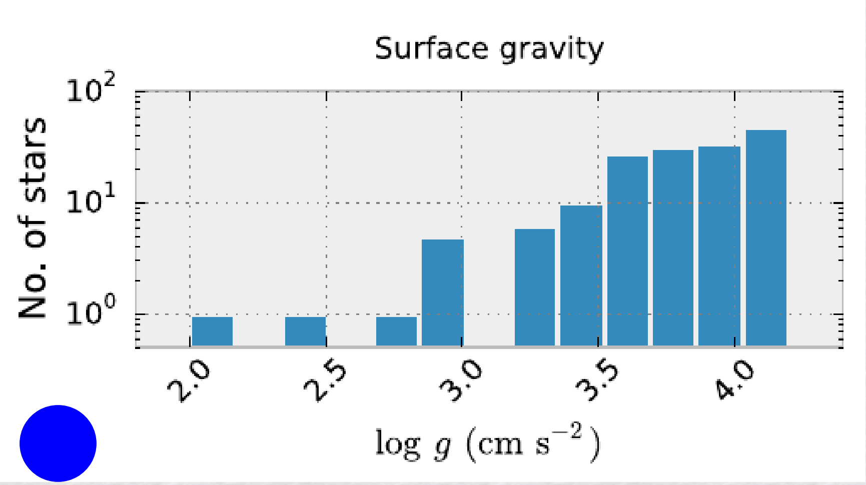
Effective temperature scale (relation Teff - spectral type) depends on Z (and log g):

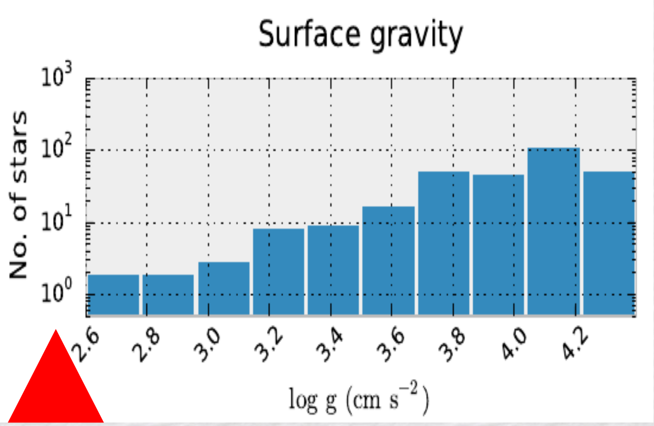
for a given spectral type, stars are hotter at lower Z (and have more QH)

Ionizing photons and metallicity

Constraints from observations







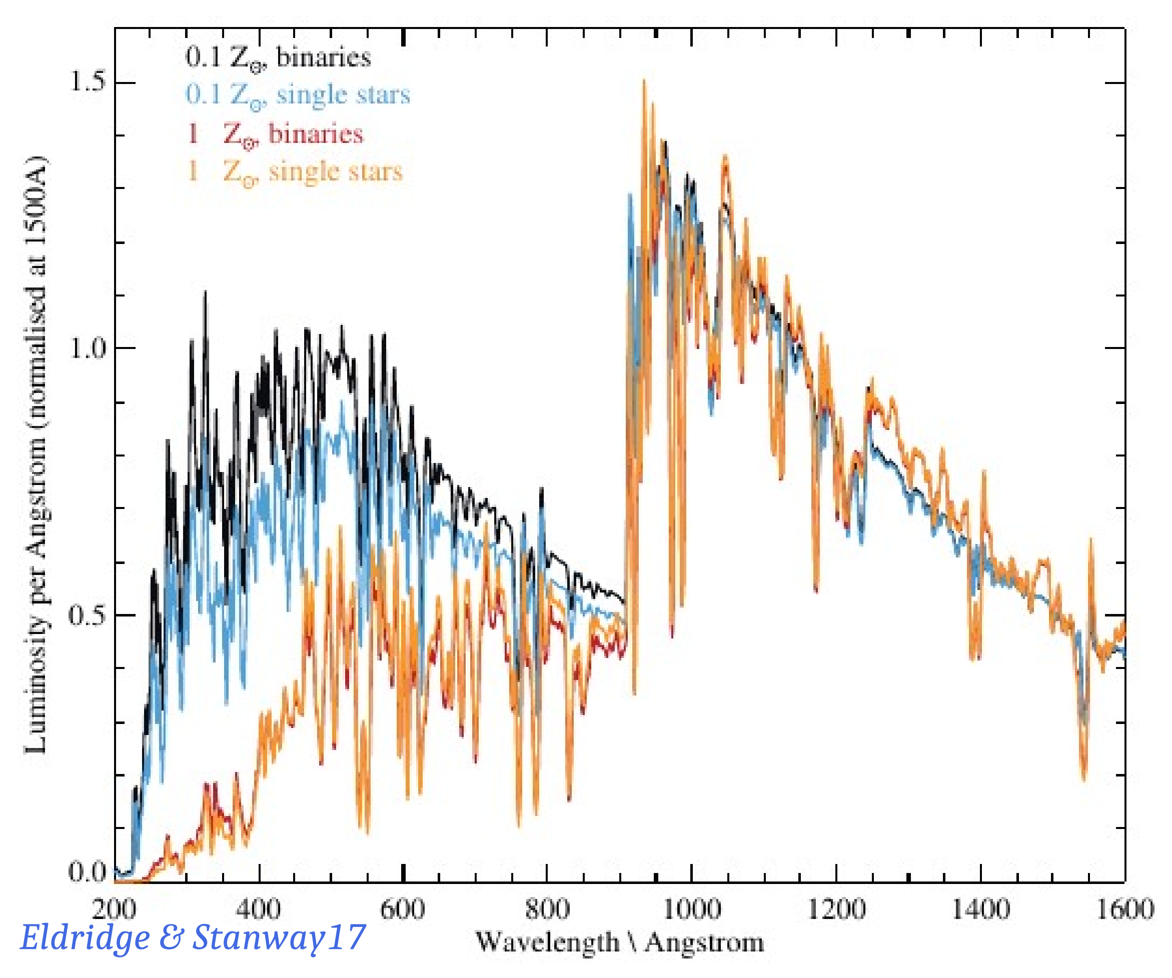
Ramachandran+18,19

Effects of Z and log g on QH- SpT difficult to separate

Ionizing photons and metallicity

Stellar populations: stellar evolution + atmospheres

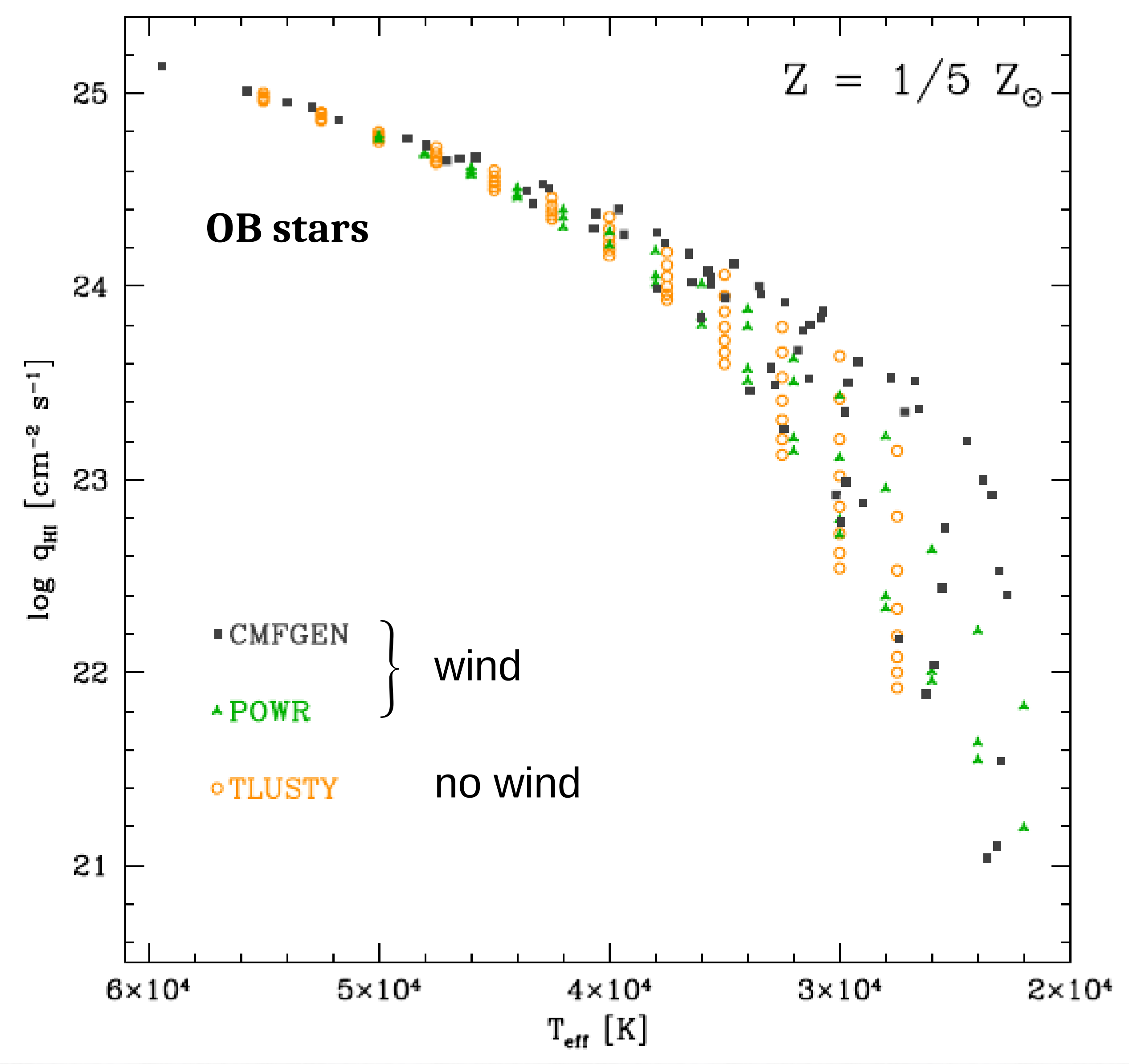
Most Z effects

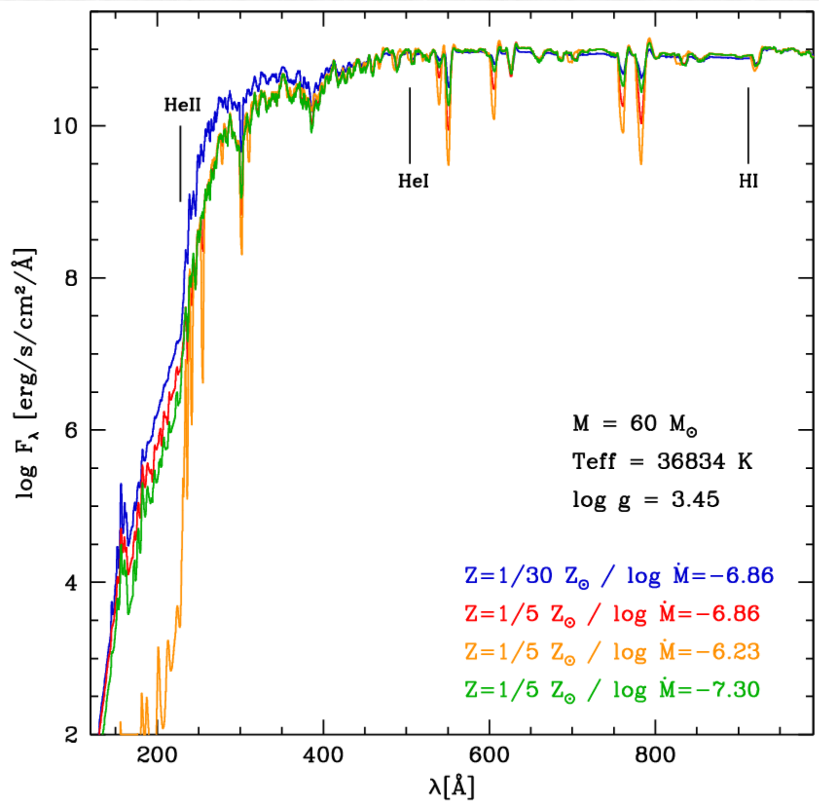


Eldridge & Stanway17

Stellar populations at lower Z produce more ionizing photons because stars tend to be hotter

Ionizing photons and stellar winds

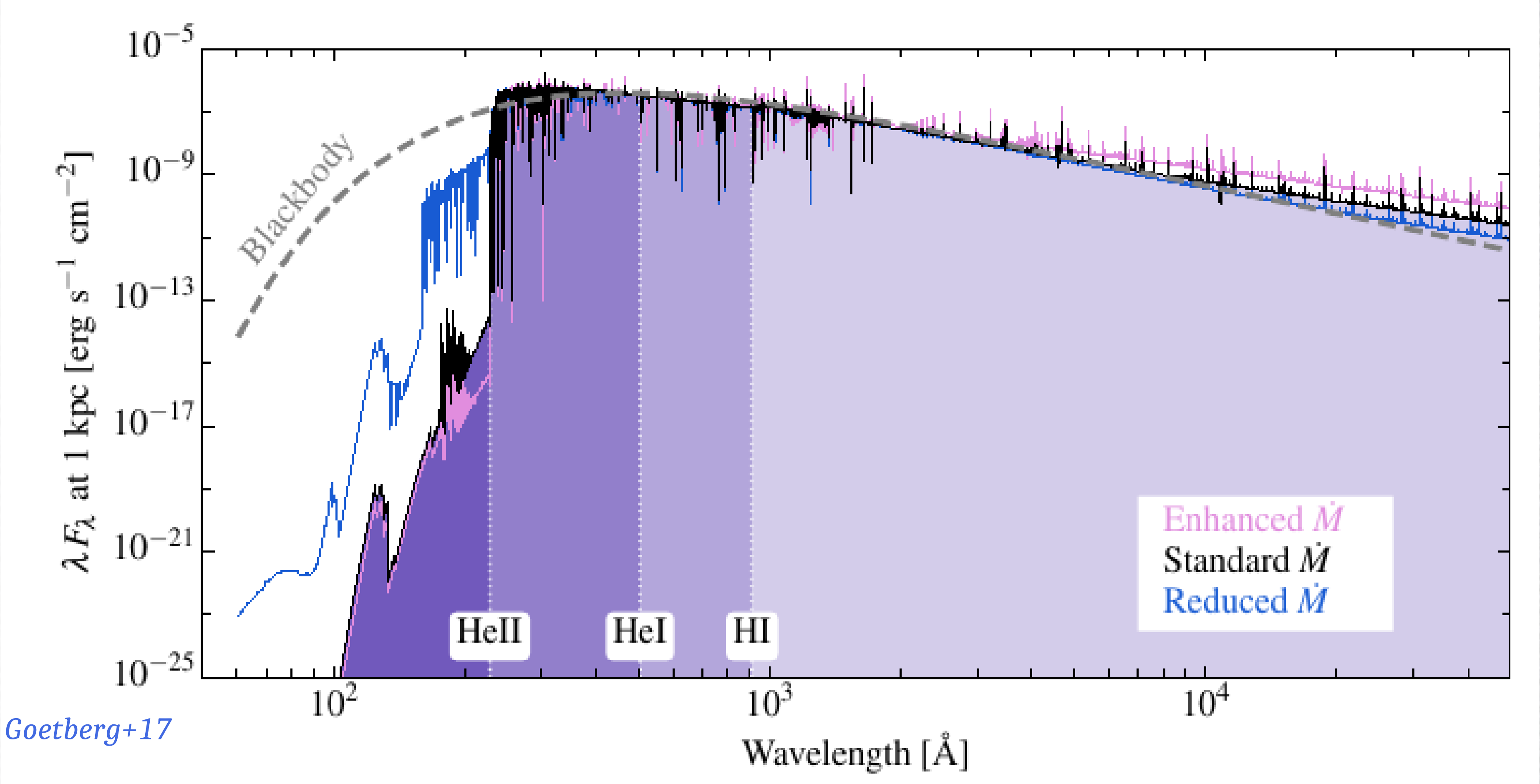




Martins & Palacios 21, see also Gabler+89, Schaerer & de Koter 97, Kudritzki 02

Winds have little effect on QH
(but impact QHeII)

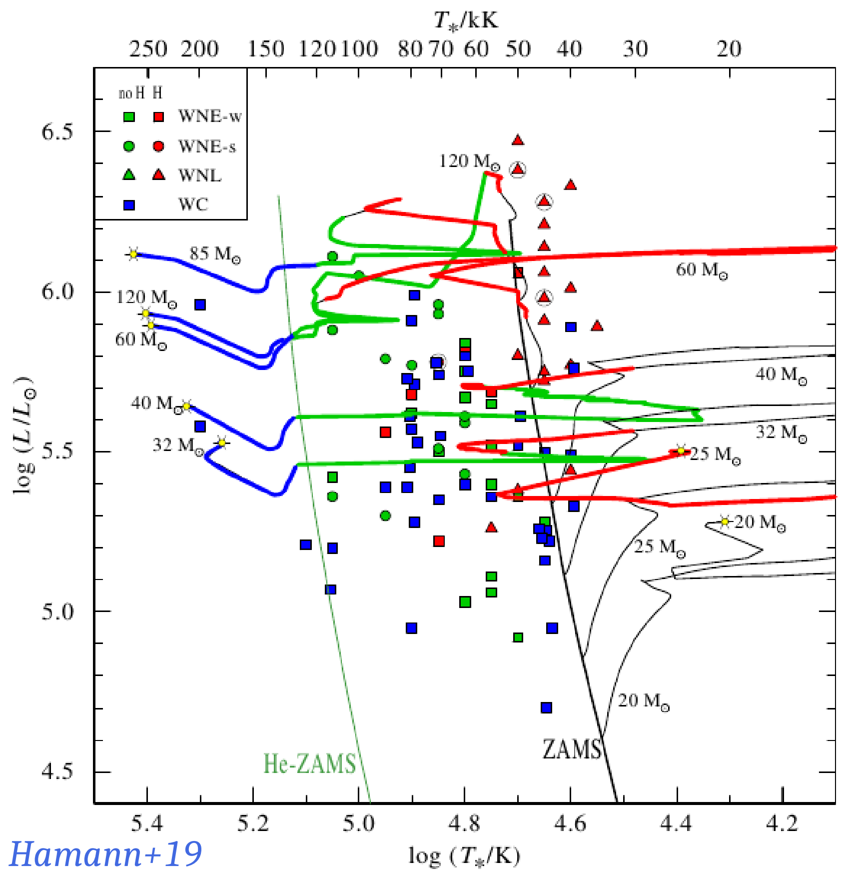
Ionizing photons and stellar winds



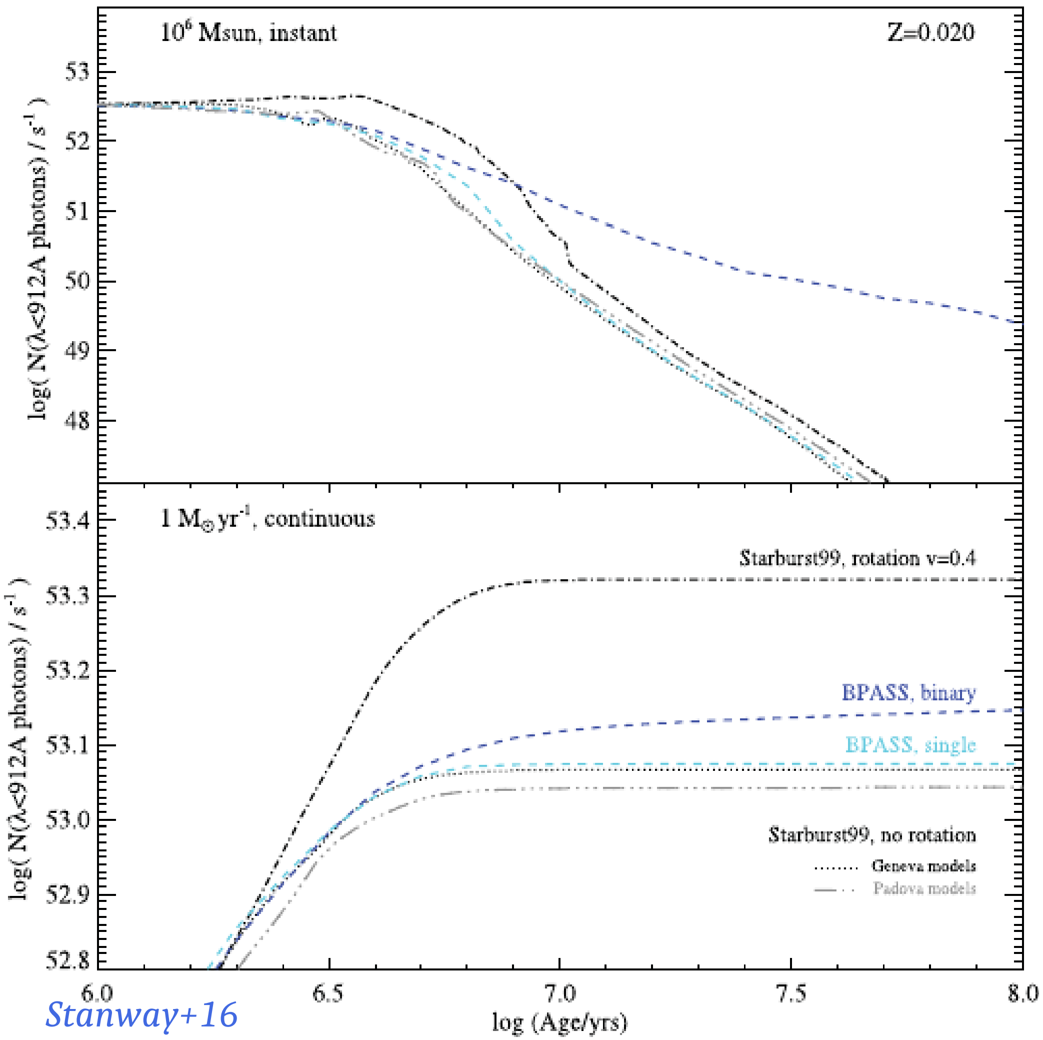
Goetberg+17

Stripped stars: effect of mass loss rate on SED

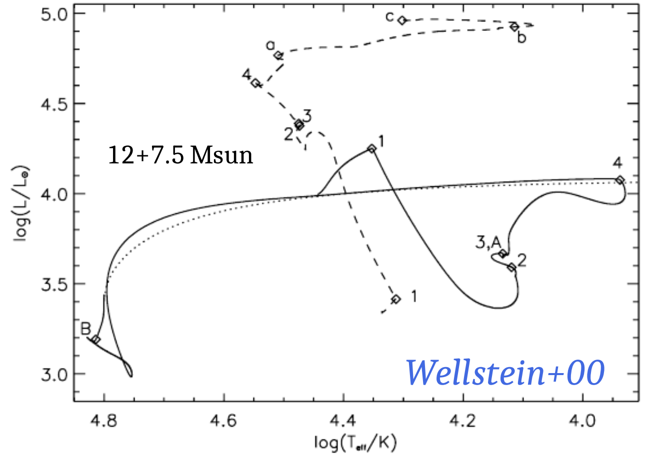
The role of binaries



Hamann+19



Stanway+16

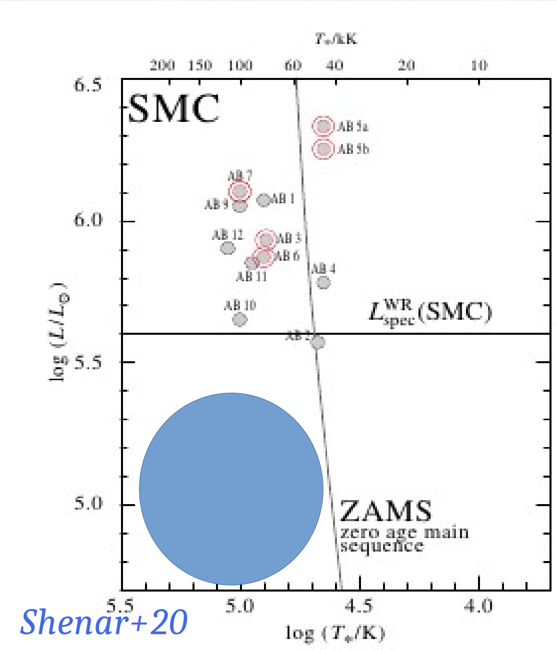


Wellstein+00

Envelope stripping in binary systems can produce WR stars for objects with masses below the threshold mass for WR formation through wind stripping

→ WR stars present at later stages in stellar populations

Stripped stars



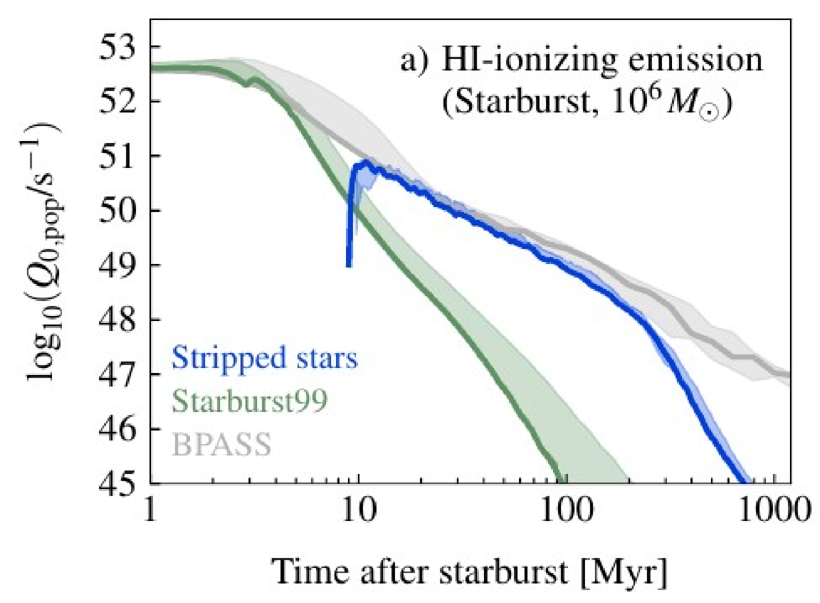
Shenar+20

Counterparts of WR binary products at low masses (sdO objects)

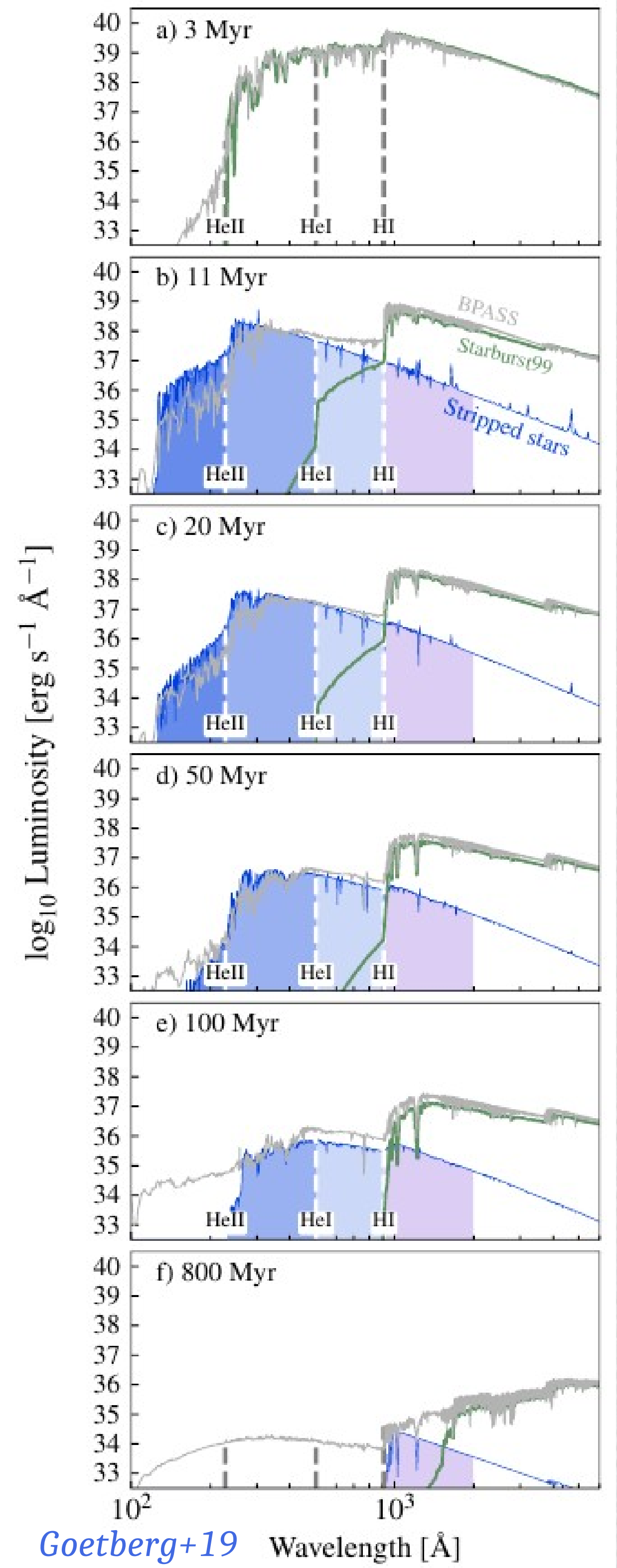
Appear after 10 Myr

Increase significantly QH

Individual objects to be identified

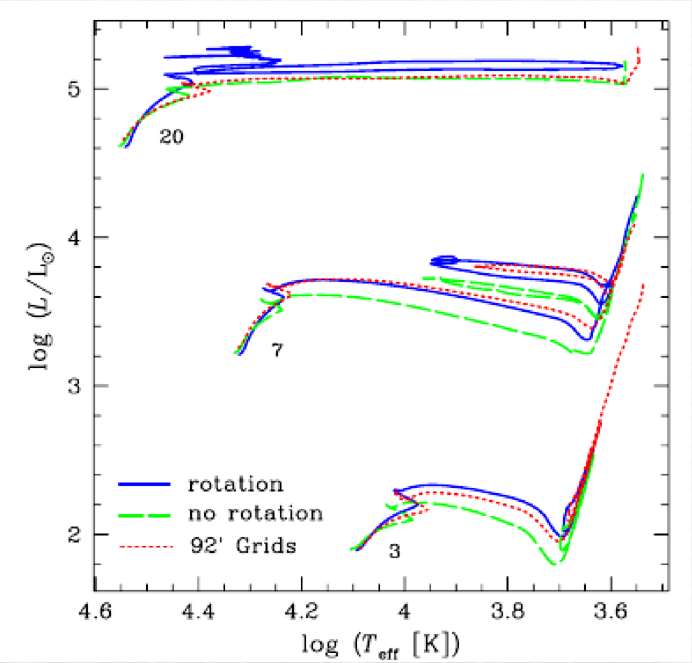


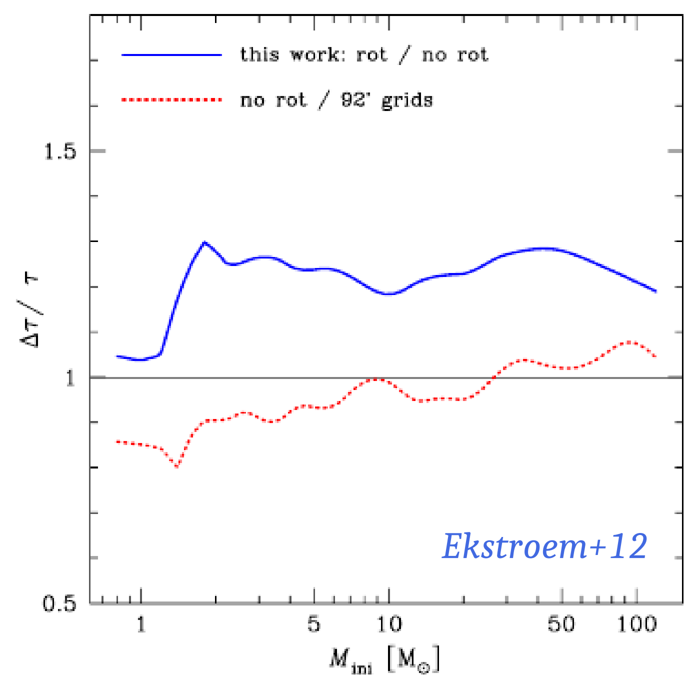
Goetberg+17,18,19,20



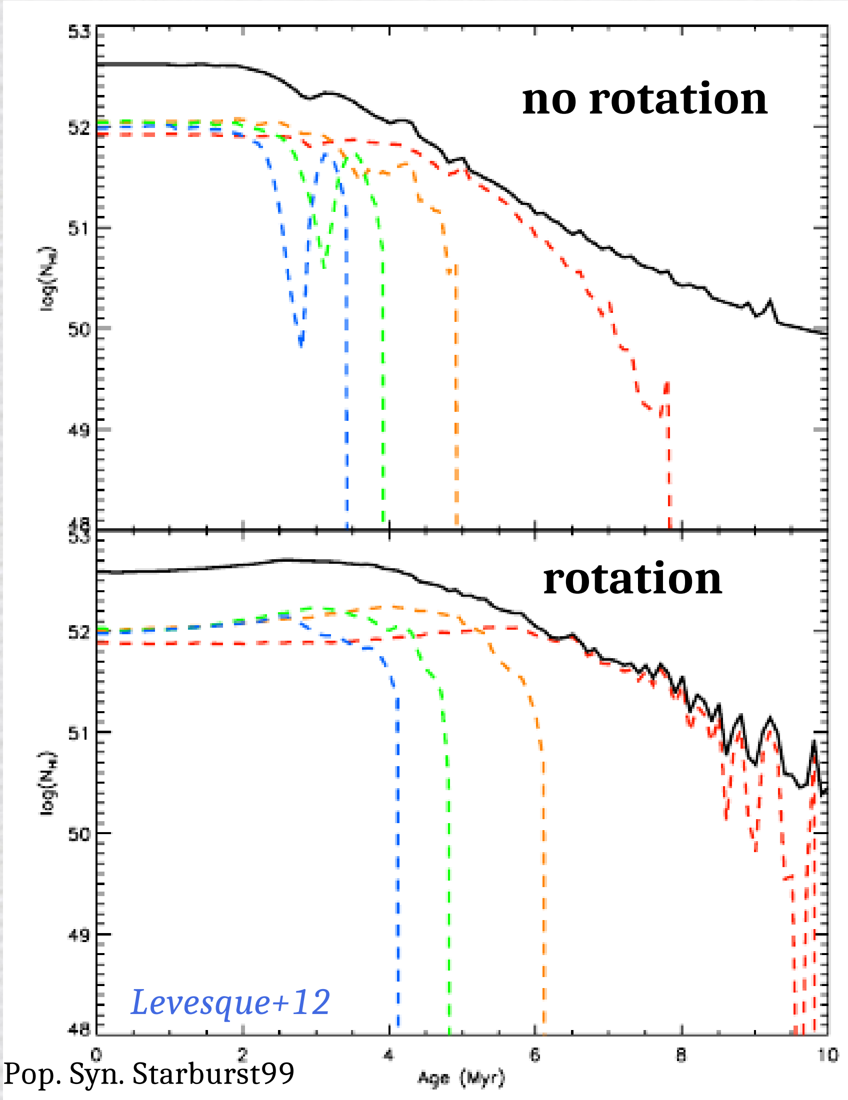
Goetberg+19

Ionizing photons and stellar rotation





Ekstroem+12



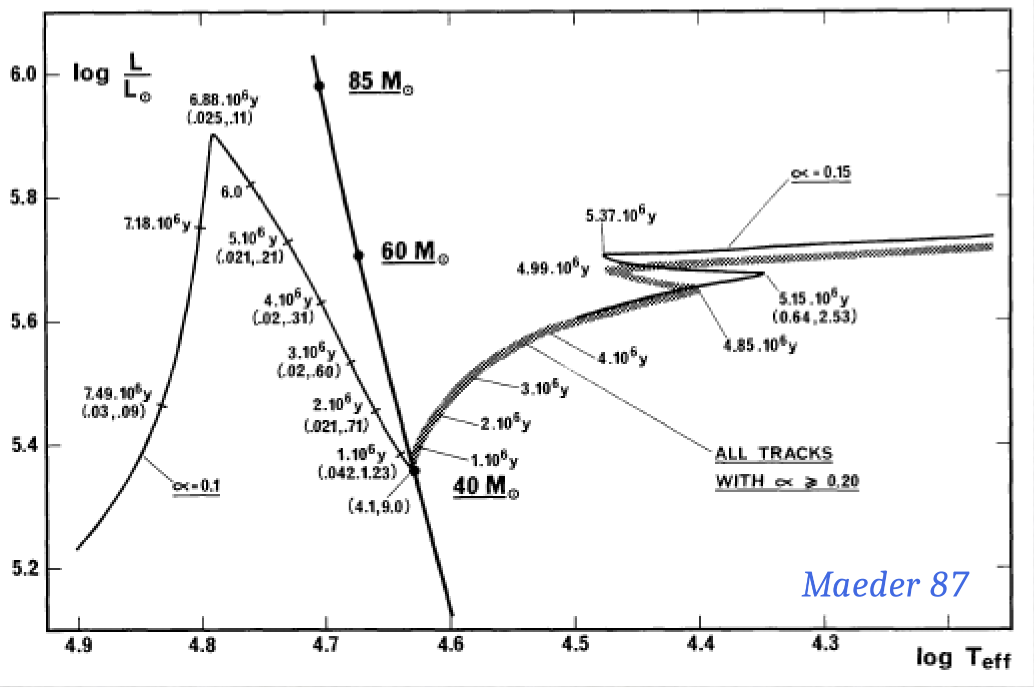
Levesque+12

Pop. Syn. Starburst99

Rotation increases main sequence lifetime

→ more ionizing photons

Chemically homogeneous evolution

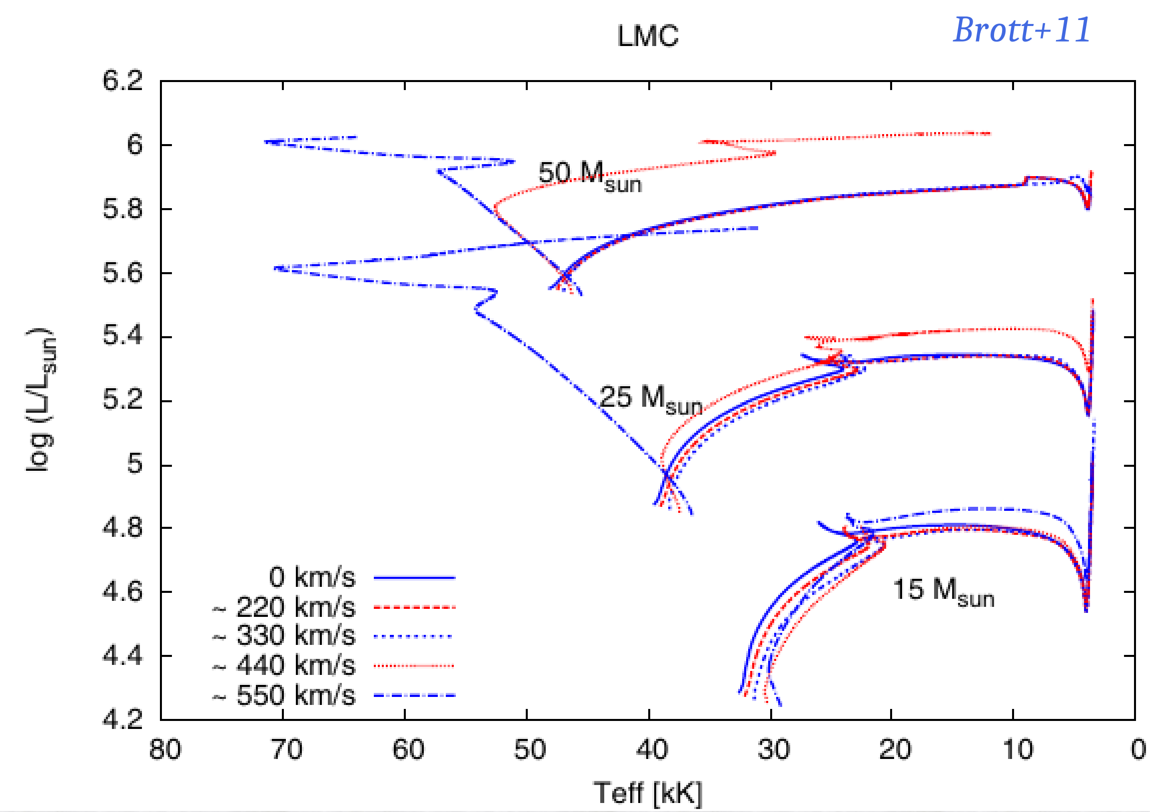


Maeder 87

mixing timescale < nuclear timescale

Star almost immediately mixed, with surface composition similar to central composition

Surface opacity reduced → Teff increases



Brott+11

Blueward evolution

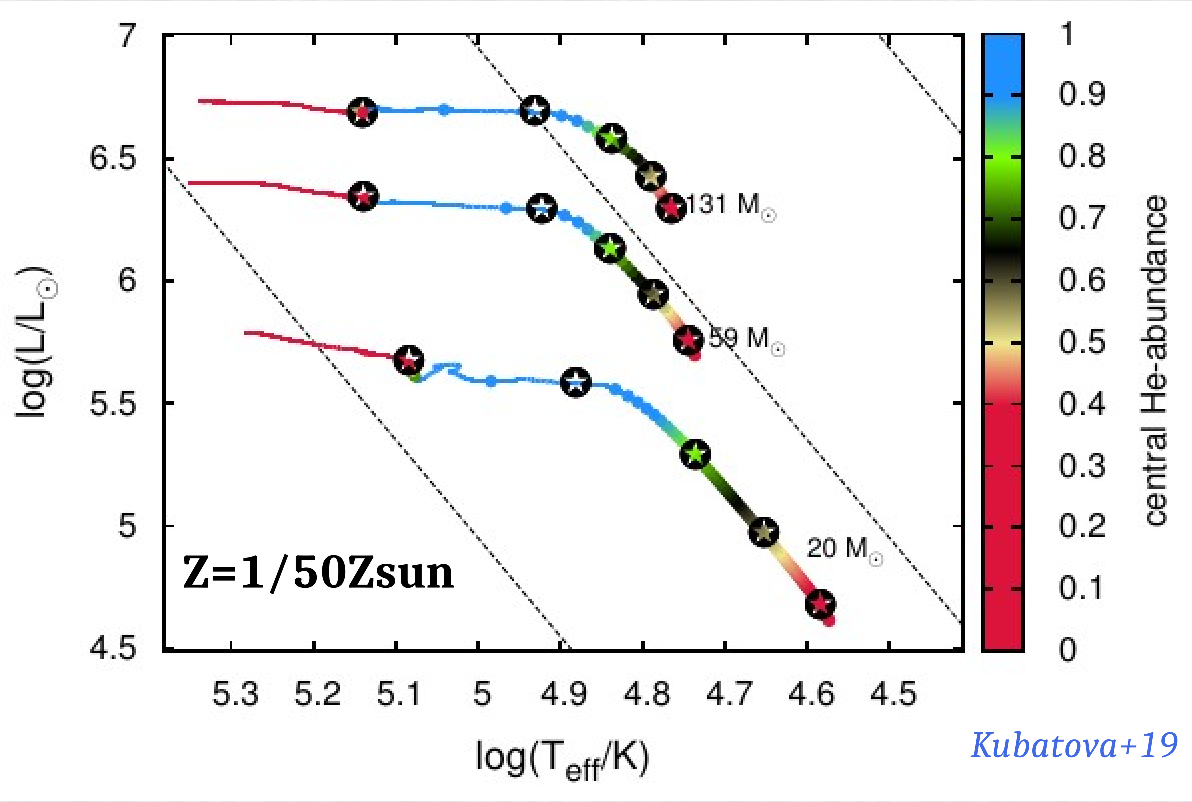
Maeder 87, Langer 92, Yoon+06, Mandel & de Mink 16, de Mink & Mandel 16, Marchant+16, Cui+18

Favoured at lower Z (reduced angular momentum loss because of weaker winds)

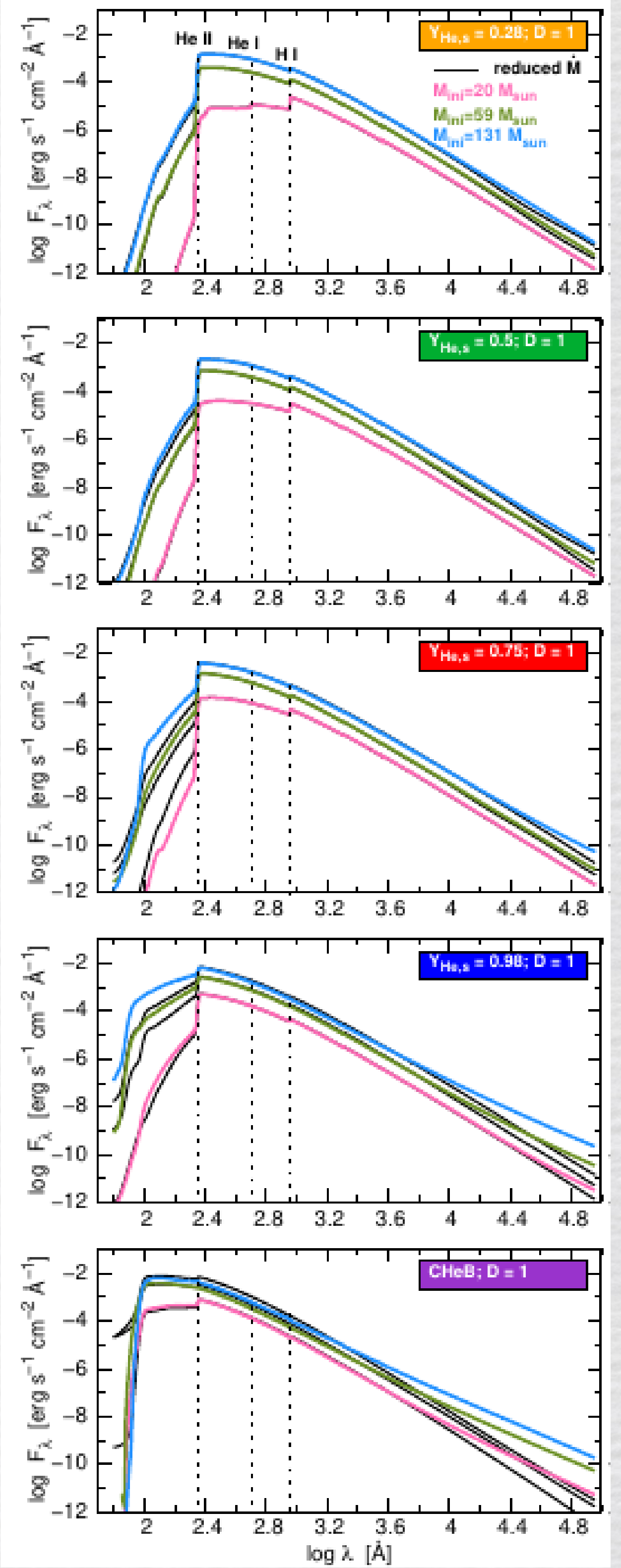
Can explain the properties of peculiar O and WR stars

Walborn+04, Martins+09,13, Hainich+15

Chemically homogeneous evolution



Kubatova+19



Stars reach Teff ~ 100 000 K

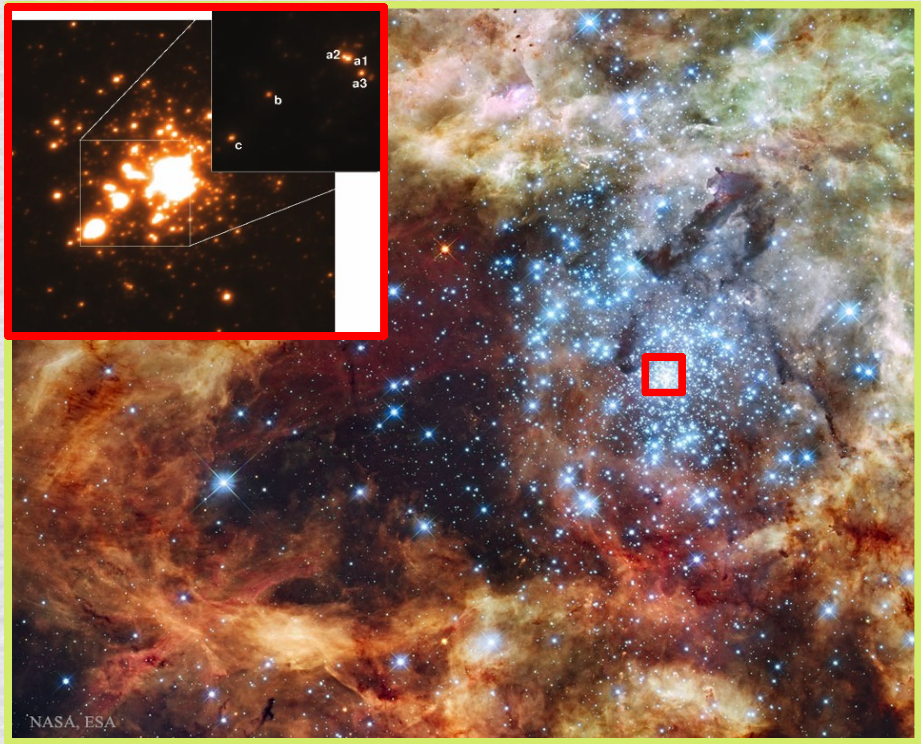
Powerful sources of ionizing photons

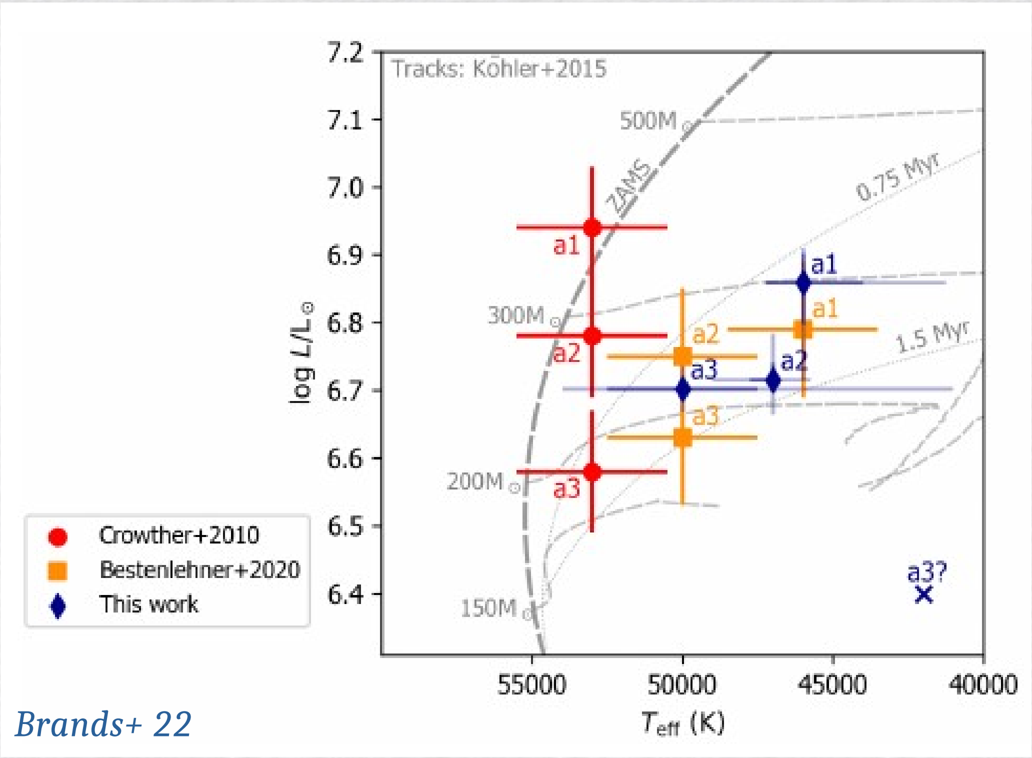
VMS and ionizing photons

Very Massive Stars are defined by M>100 Msun

A dozen individual objects known in the MW + MCs

R136 in the LMC hosts the most massive stars

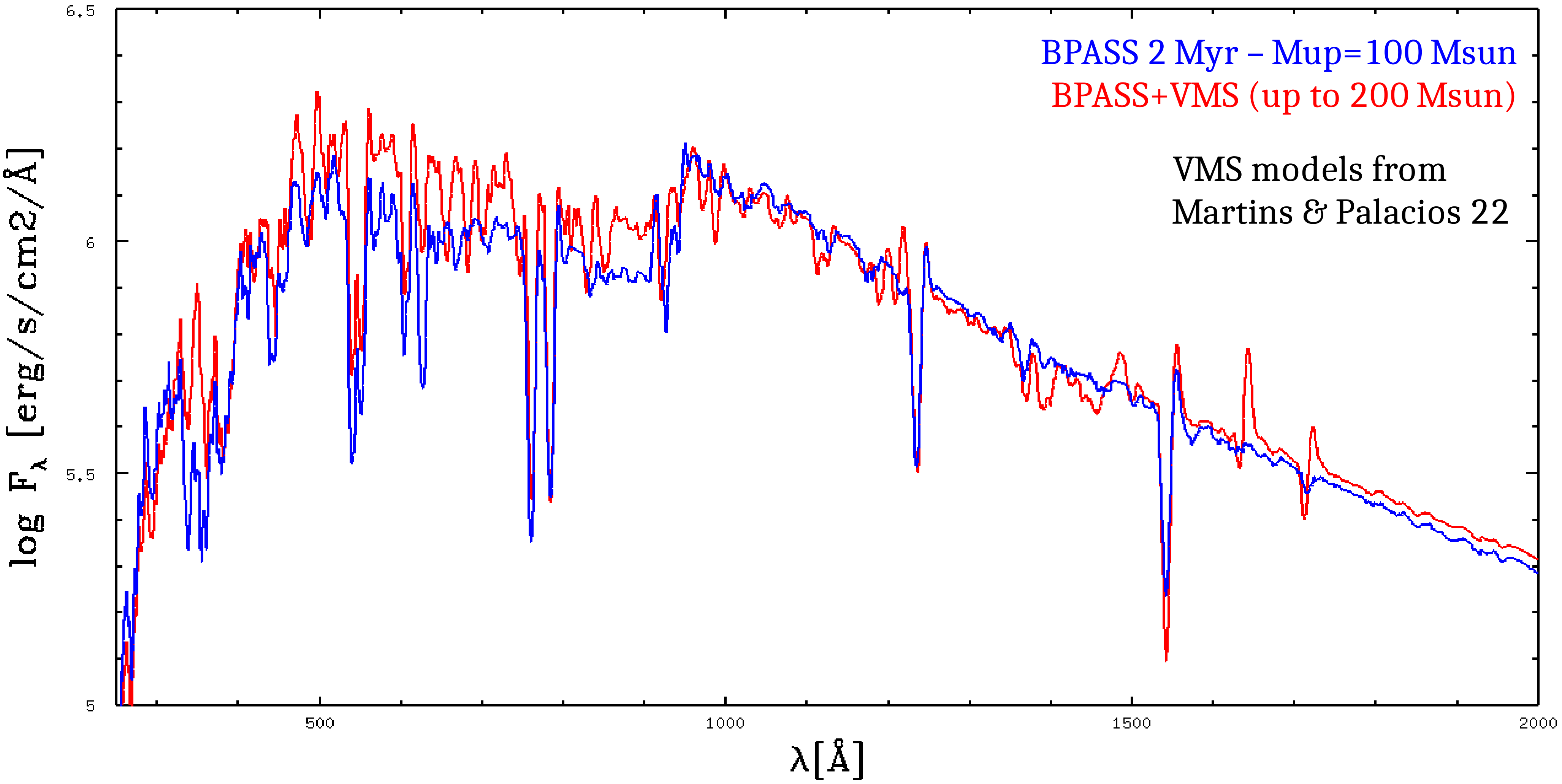




Brands+ 22

Hot and very luminous
→ large number of ionizing photons

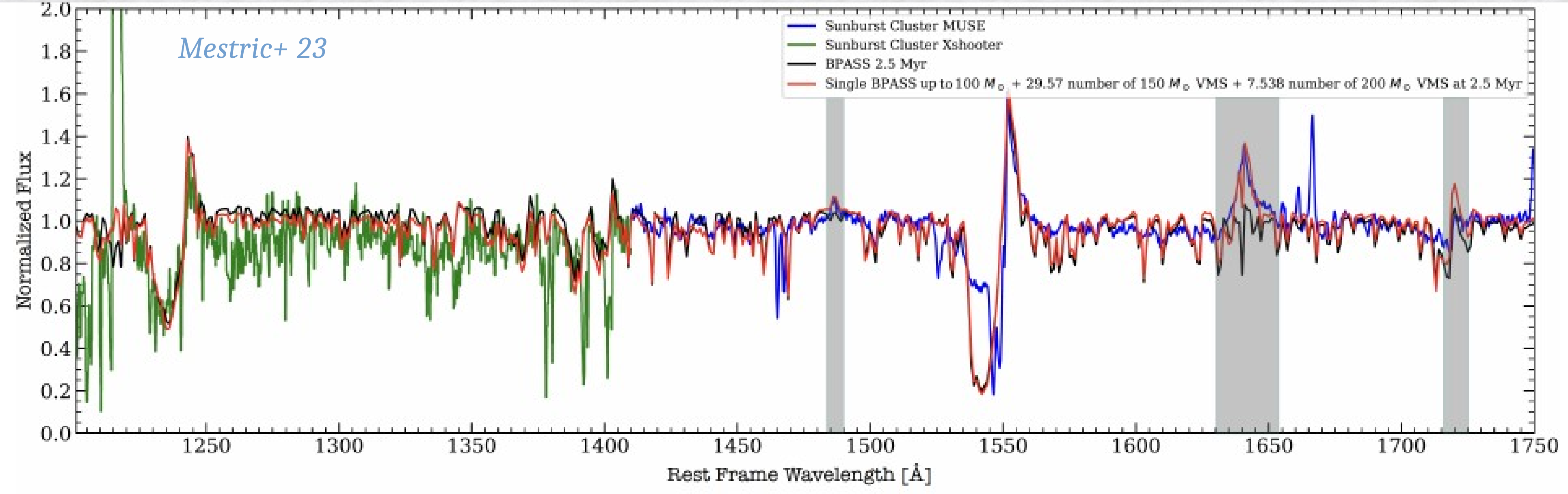
VMS and ionizing photons

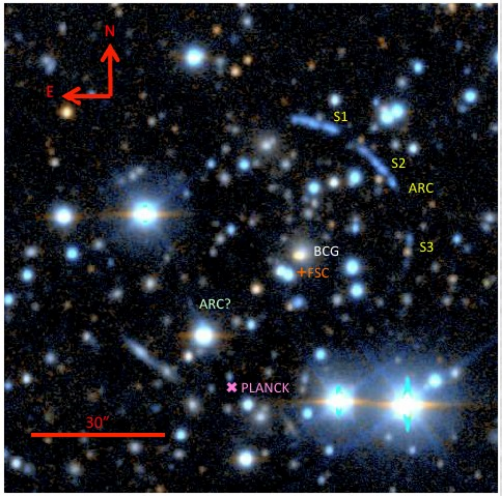


For simple extrapolation of IMF, VMS contribute an additional 50% of ionizing photons

ξ_{ion} is increased

VMS and ionizing photons





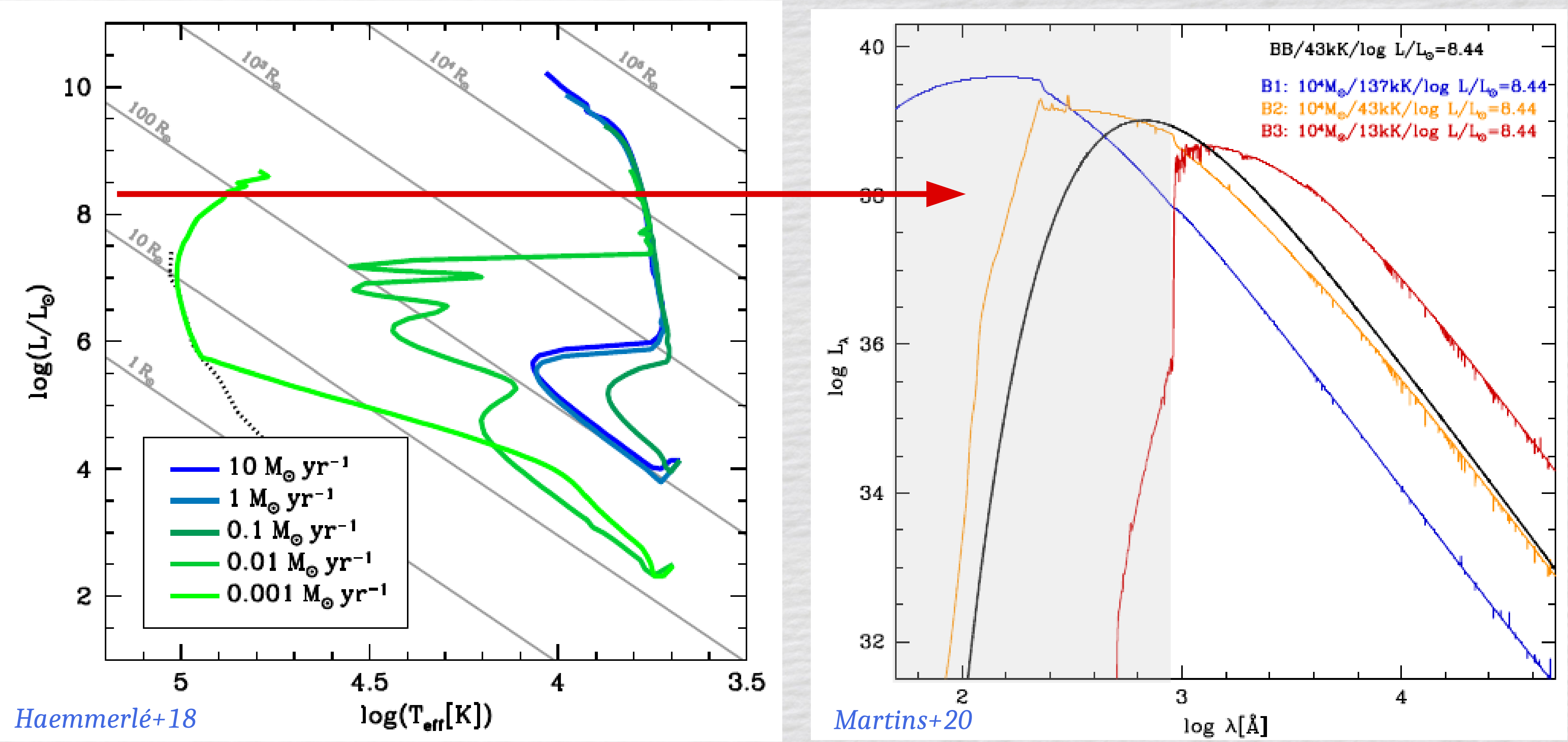
Sunburst: VMS contribute an additional 15% of ionizing photons

In spite of a small number of VMS relative to IMF extrapolation

VMS likely have a role in the early phases of the Universe

See talk by U. Mestric

Supermassive stars



Haemmerlé+18

Martins+20

Hypothetical objects, potential seeds of supermassive black holes
May explain multiple populations in globular clusters (*Denissenkov+14, Gieles+18*)

Preferentially “cool” objects, but may have very hot phases → lots of H ionizing photons

Conclusion

- All stellar objects with Teff > 20000 K emit H ionizing photons
- qH (per unit surface) depends on the ionization strucutre and the HI ground level opacity. This is mainly controlled by Teff and log g
- qH depends weakly on metallicity, since flux redistribution caused by change of opacity takes place below the Lyman break
- QH depends on stellar radius and thus on stellar evolution and metallicity
- Calibration of QH vs spectral type depends on the effective temperature scale, which is Z sensitive
- Stellar winds affect relatively little the Lyman continuum (but impact the HeII continuum)
- Besides OB and WR stars (single or binaries), VMS do emit Lyman radiation. Stripped stars and supermassive stars are additional candidates