

Structure for the talk

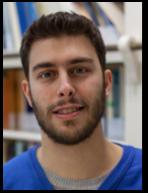
1. What is a stripped star, why are they important
proof of binary interaction, ionising flux
2. How does a stripped star look like? (Kippenhahn+HRD)
including modelling? Compare to OB, WR stars?
3. Composite
WN3/O3 stars, example system
4. Observational techniques
spectral lines, UV excess, ionised bubbles
5. Full population - spectra
stellar lines, cloudy missing, ionising boost, hard spectra, Z dependence? UV boost
(Han+07, van den Ven+, Pellegrini+)
6. Ionizing addition from stripped stars - preliminary
ionising flux with time for a starburst (just to see the delay)



Selma de Mink



José Groh



Emmanouil
Zapartas



Mathieu
Renzo



Nathan
Smith



Maria
Drout



Abel
Schootemeijer



Thomas
Kupfer

Stars stripped in binaries:

characteristics and how to observe them

Acknowledging:
*Pablo Marchant,
Colin Norman,
Hugues Sana,
Douglas Gies &
Alex de Koter*

Ylva Götberg

University of Amsterdam

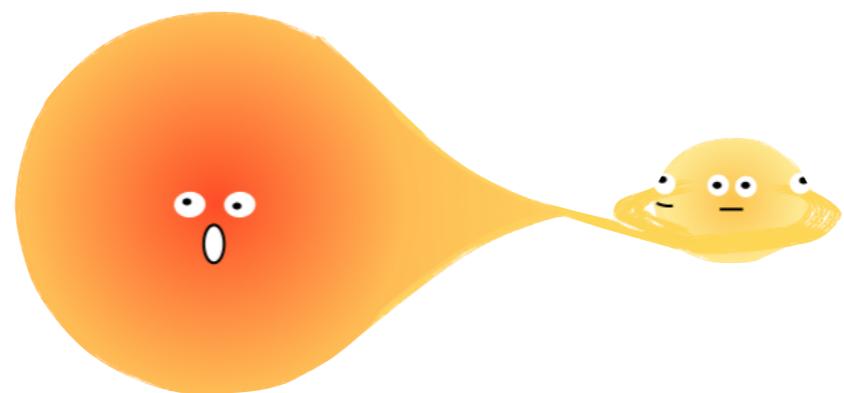
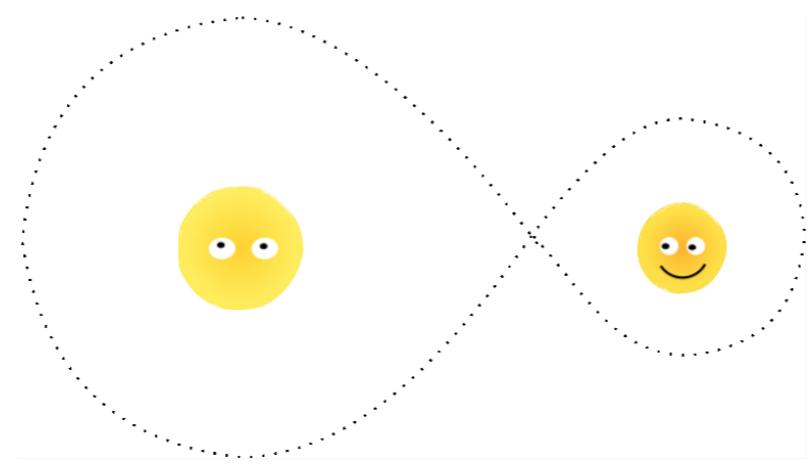


ANTON PANNEKOEK
INSTITUTE

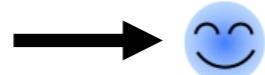
Two stars out orbiting



My focus: stars stripped in binaries



Stripped star



Why stripped stars?

- Proof of binary interaction
- Ionising photons
- Progenitors to SN Ibc

(see e.g. Morton 1960, Smak 1962, Paczyński 1966, Kippenhahn 1969b, Yungel'Son 1973, van der Linden 1987)

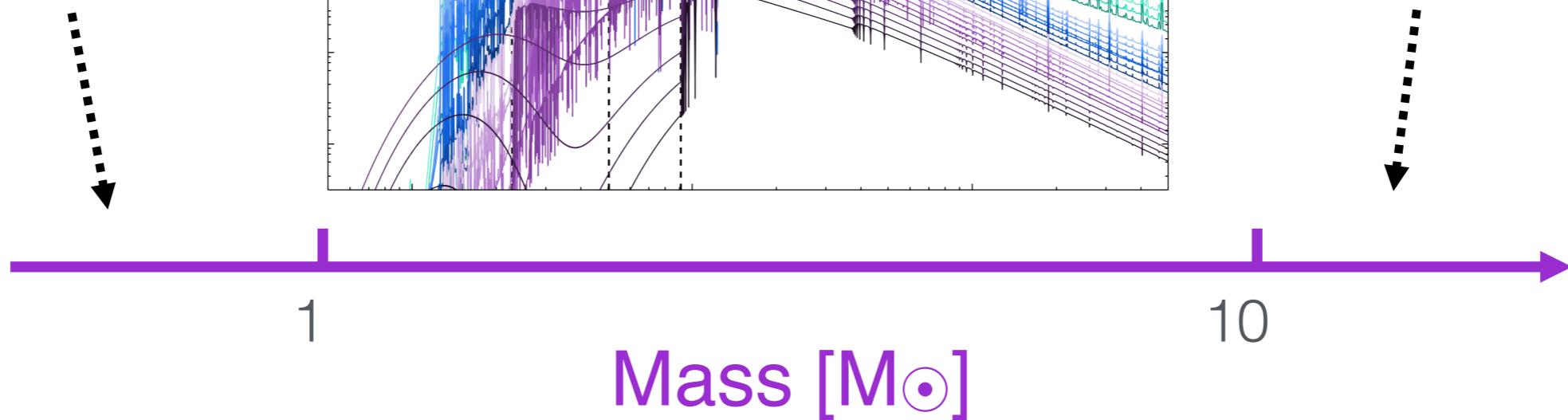
Available atmosphere models

Helium stars

Wolf-Rayet

Subdwarf

ATLAS9 (Kurucz)
(Han et al. 2007)



CMFGEN
(Hillier & Miller 1998)
PoWR
(Gräfener et al. 2002)

(see also Eldridge & Stanway, 2009)

1 How to observe stripped stars?

2 How much can they ionise?

Properties of a stripped star

Modeling stripped stars

(Schaerer et al. 1995, Groh et al. 2014)

1. Structure
and evolution

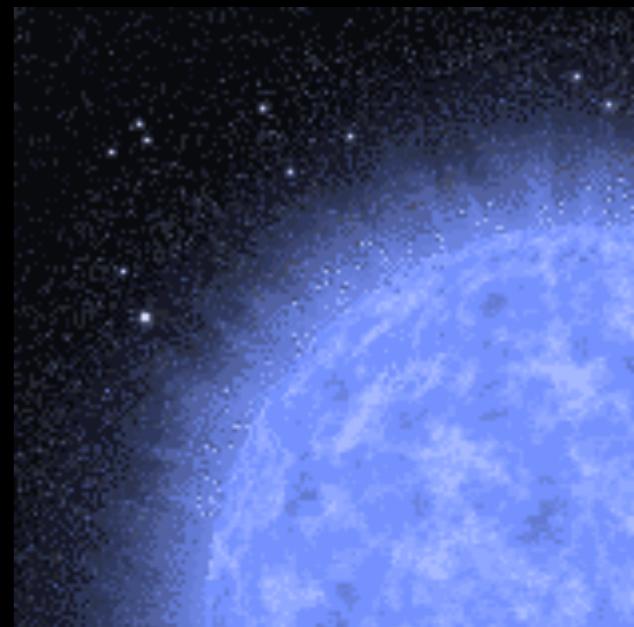
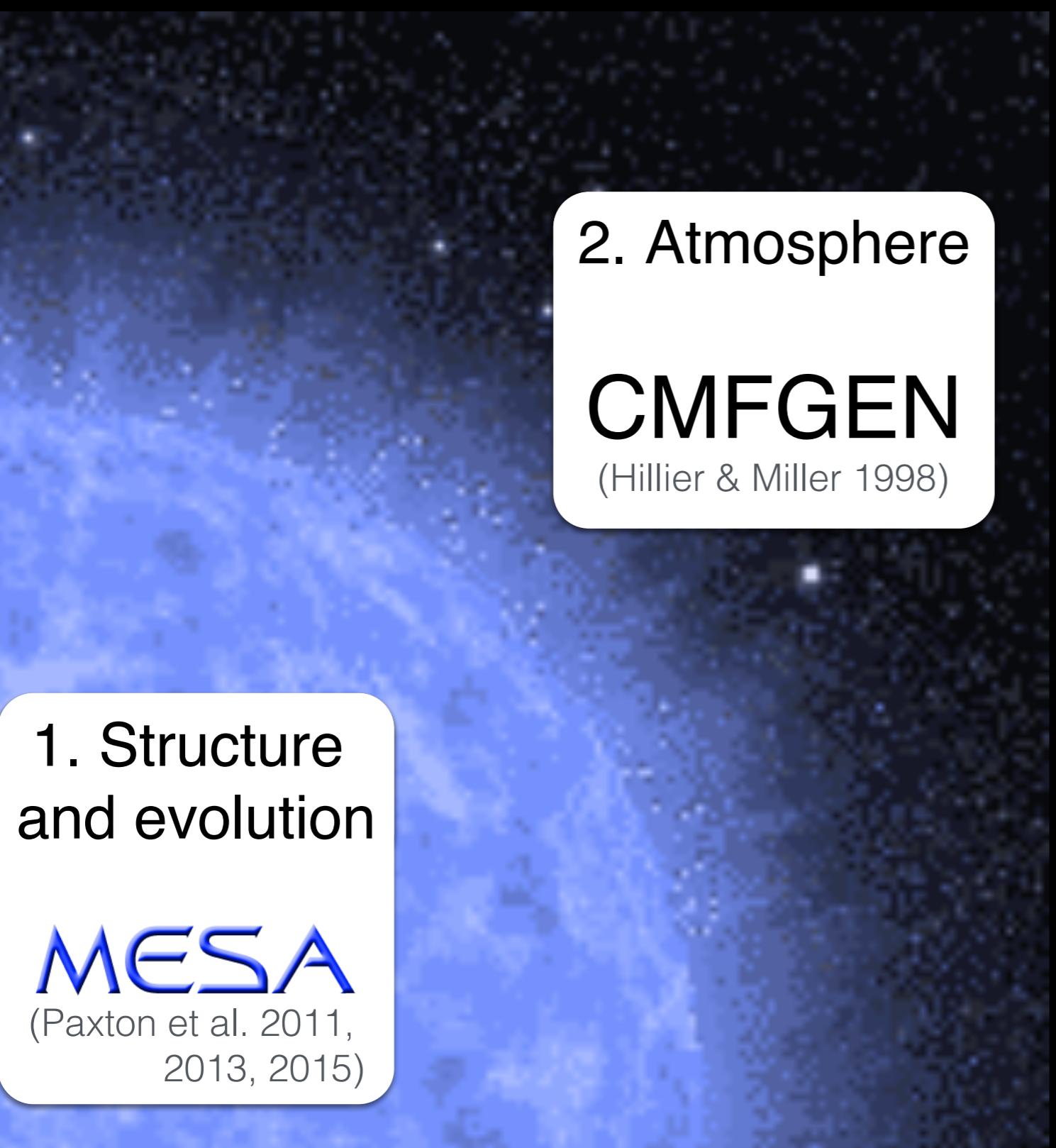
MESA

(Paxton et al. 2011,
2013, 2015)

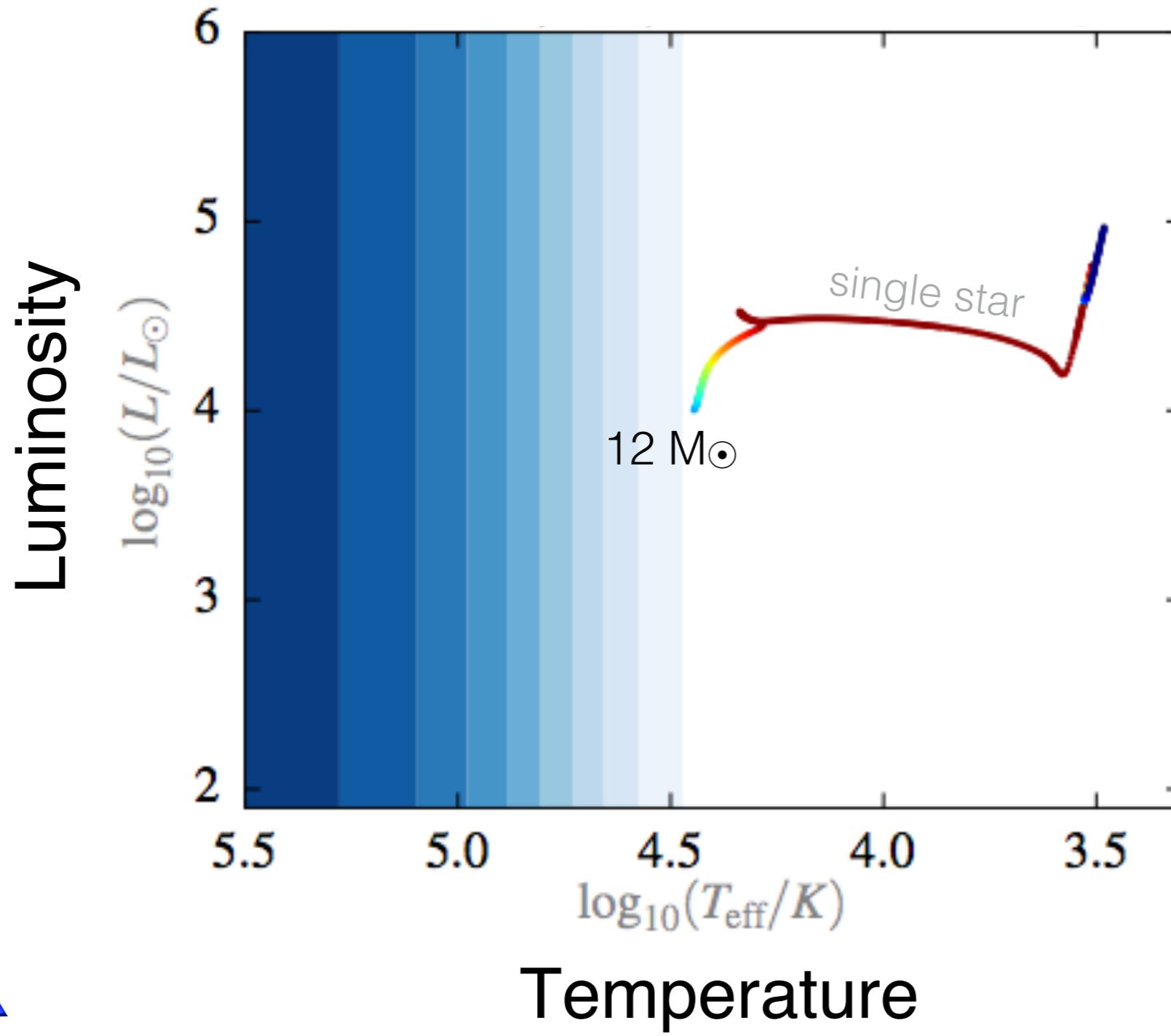
2. Atmosphere

CMFGEN

(Hillier & Miller 1998)

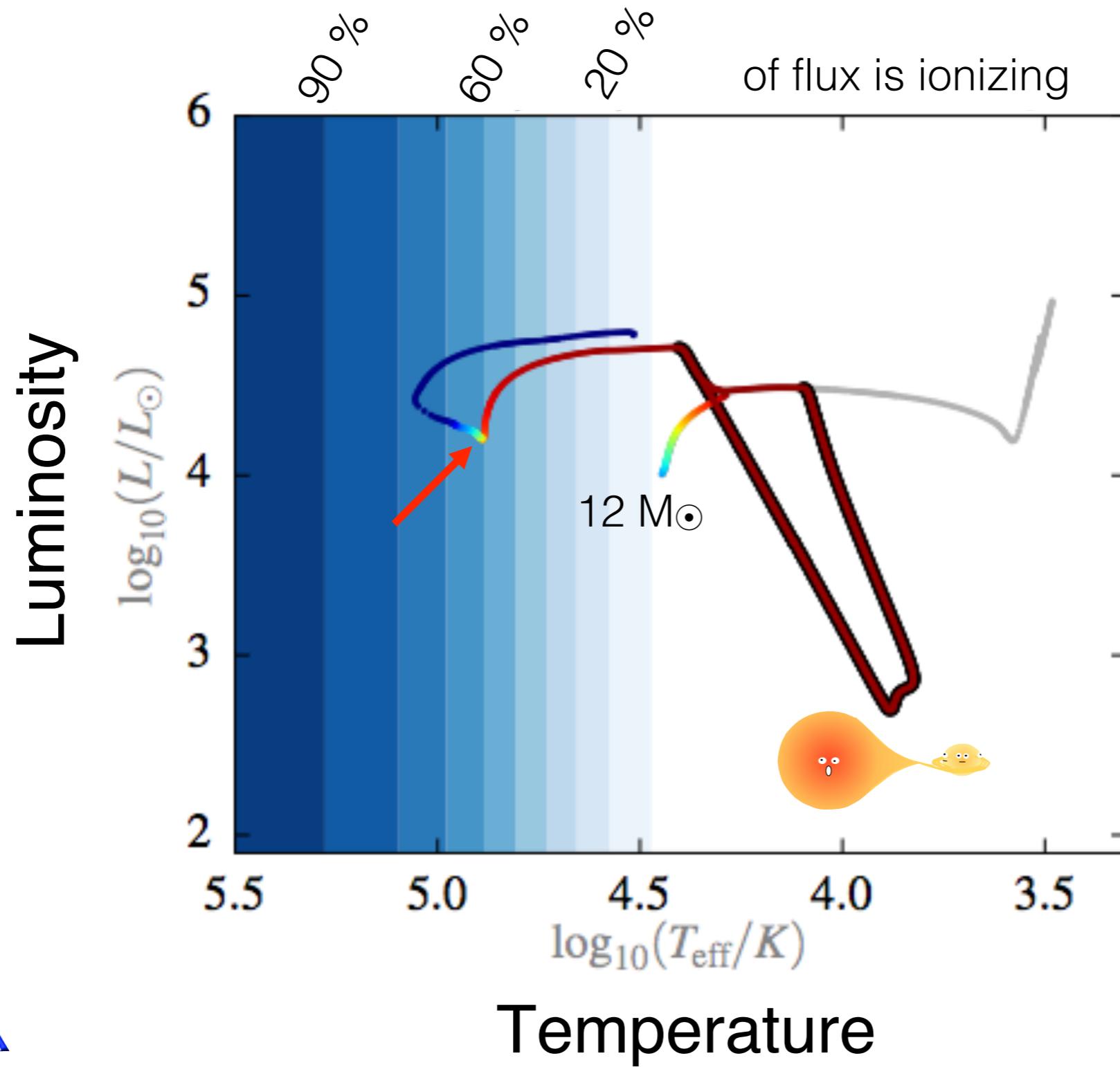


The evolution of a stripped star



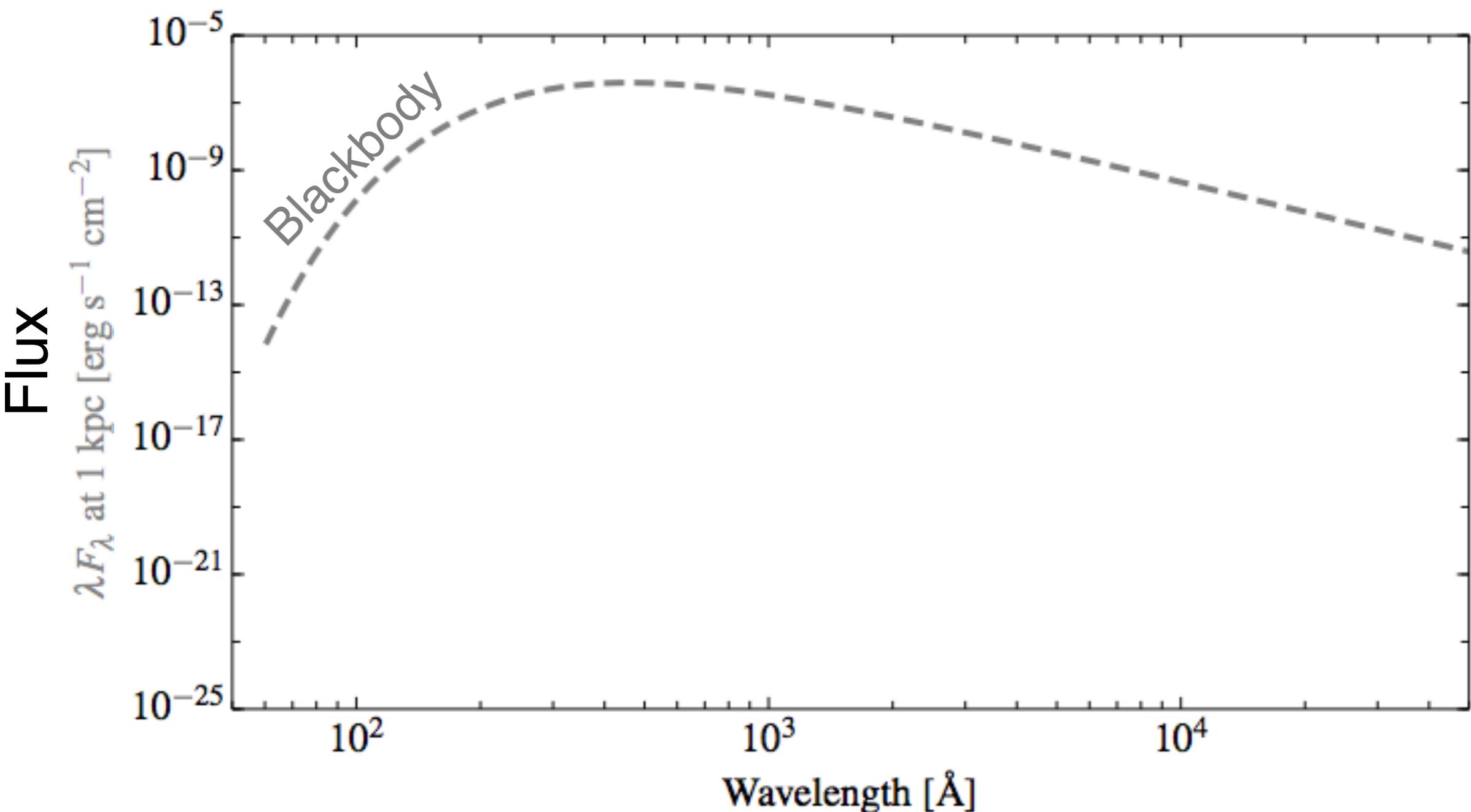
The evolution of a stripped star

Gotberg et al. (2017, arXiv: 1701.07439)



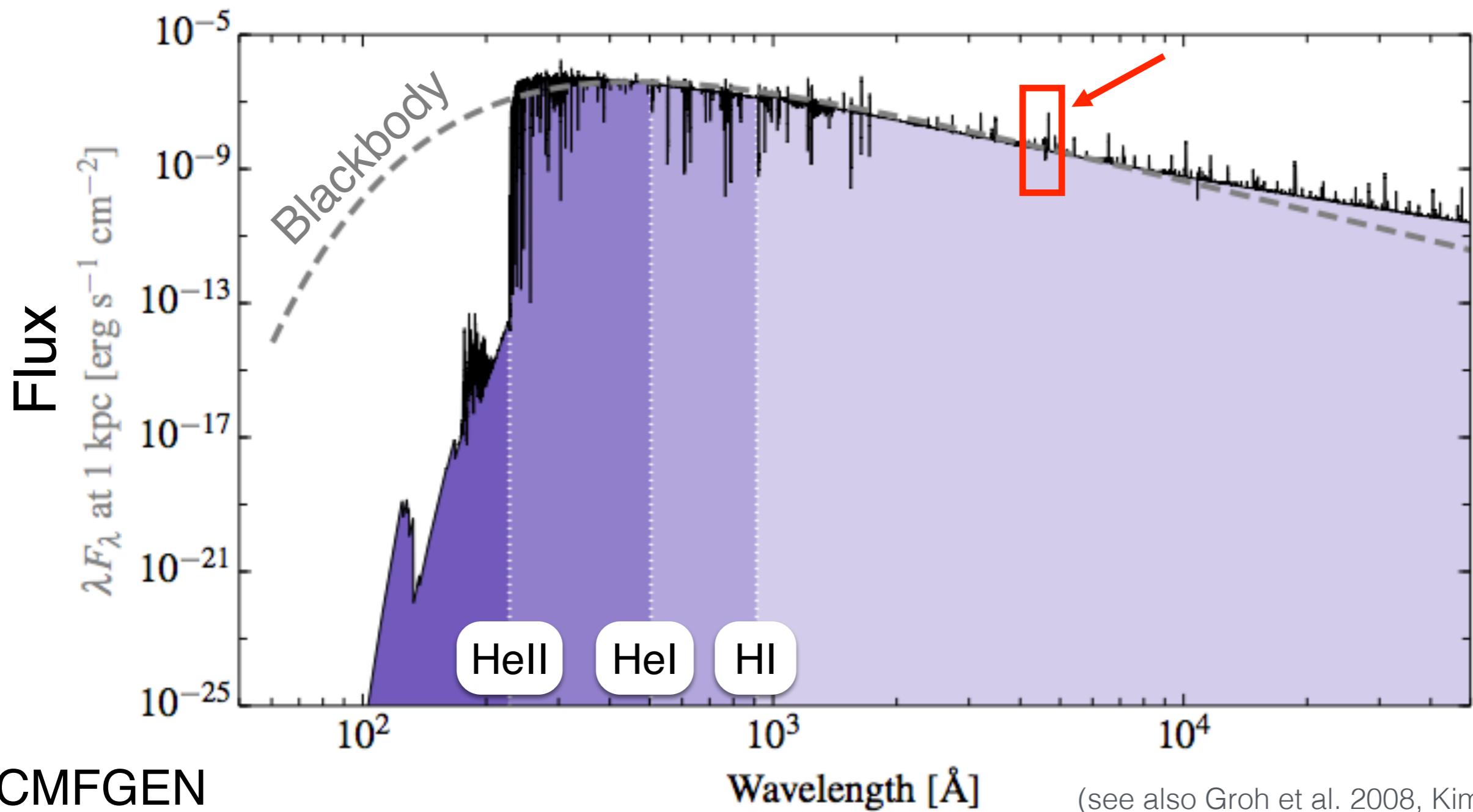
(cf. Kippenhahn & Weigert, 1967,
Podsiadlowski et al. 1992)

Spectrum of a stripped star



Spectrum of a stripped star

Gotberg et al. (2017, arXiv: 1701.07439)



CMFGEN

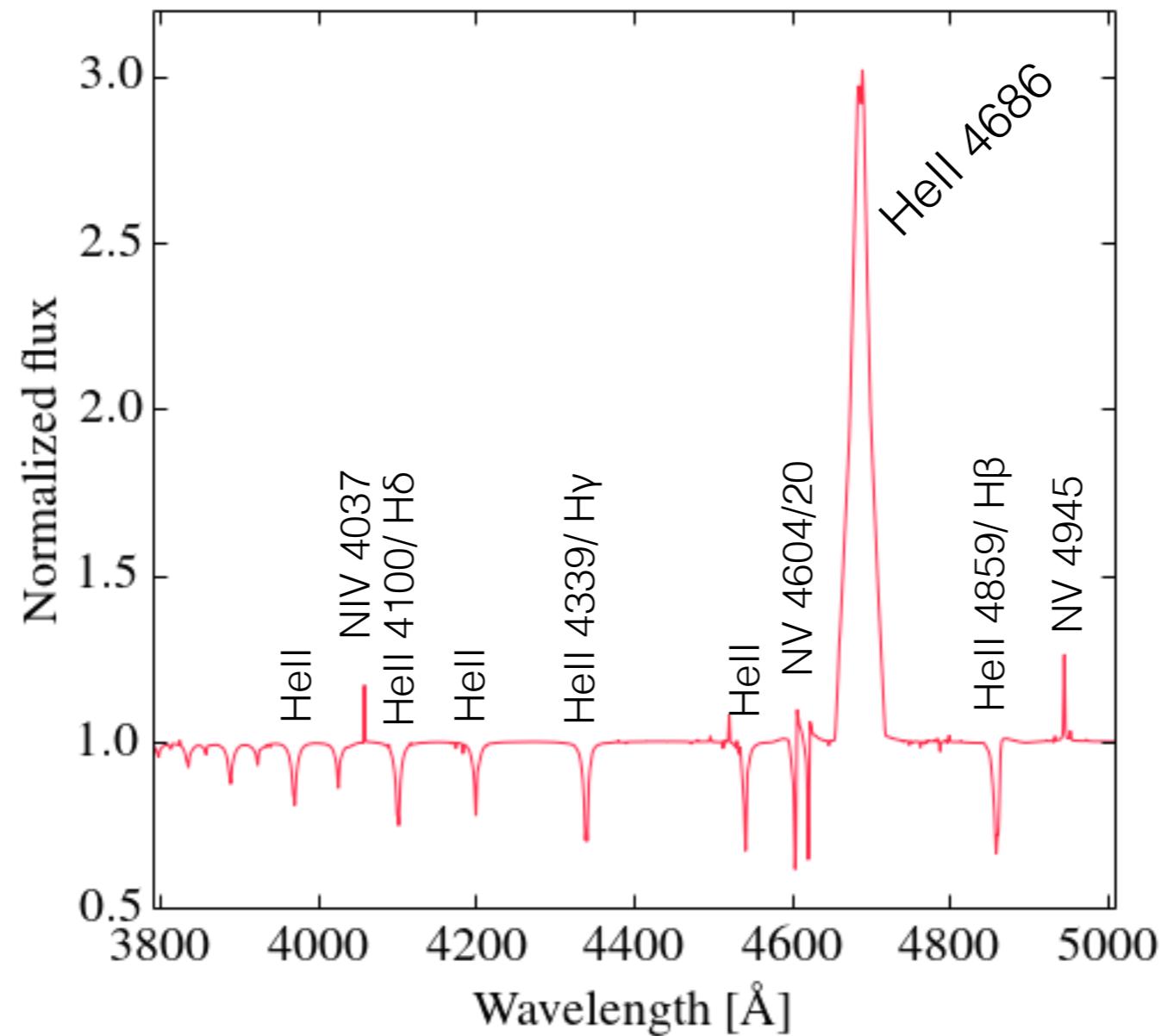
(see also Groh et al. 2008, Kim et al. 2015)

Spectrum of a stripped star

Gotberg et al. (to be subm.)

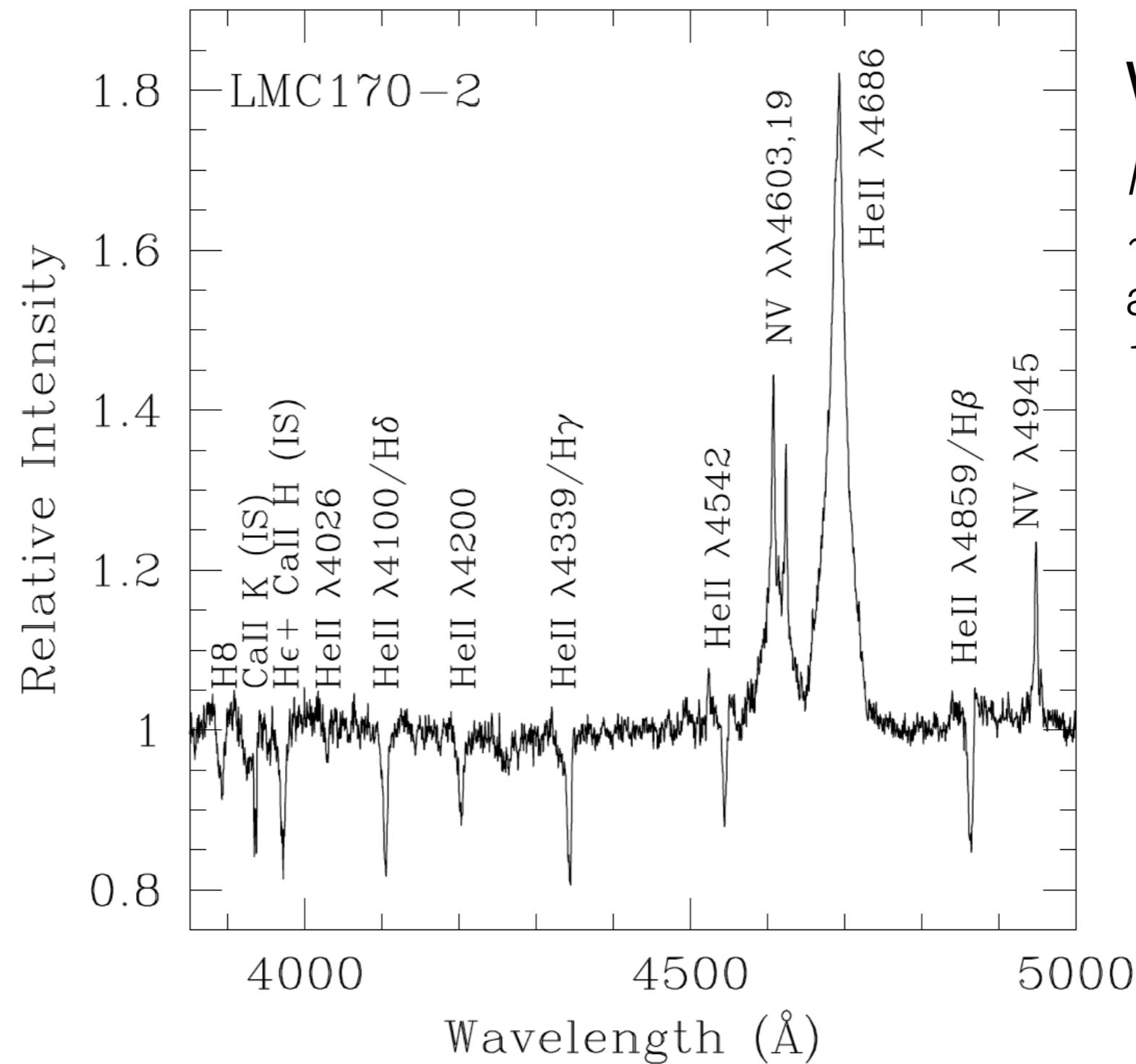
Stripped stars: mix of absorption and emission

$M_{\text{strip}} = 4 M_{\odot}$
 $(M_{\text{init}} = 12 M_{\odot})$
 $T_{\text{eff}} = 76 \text{ kK}$
 $\log g = 5.2$
 $M_{\dot{\text{dot}}} = 2.1 \text{e-}7$



Observational features of stripped stars

WN3/O3 stars – stripped stars in LMC?



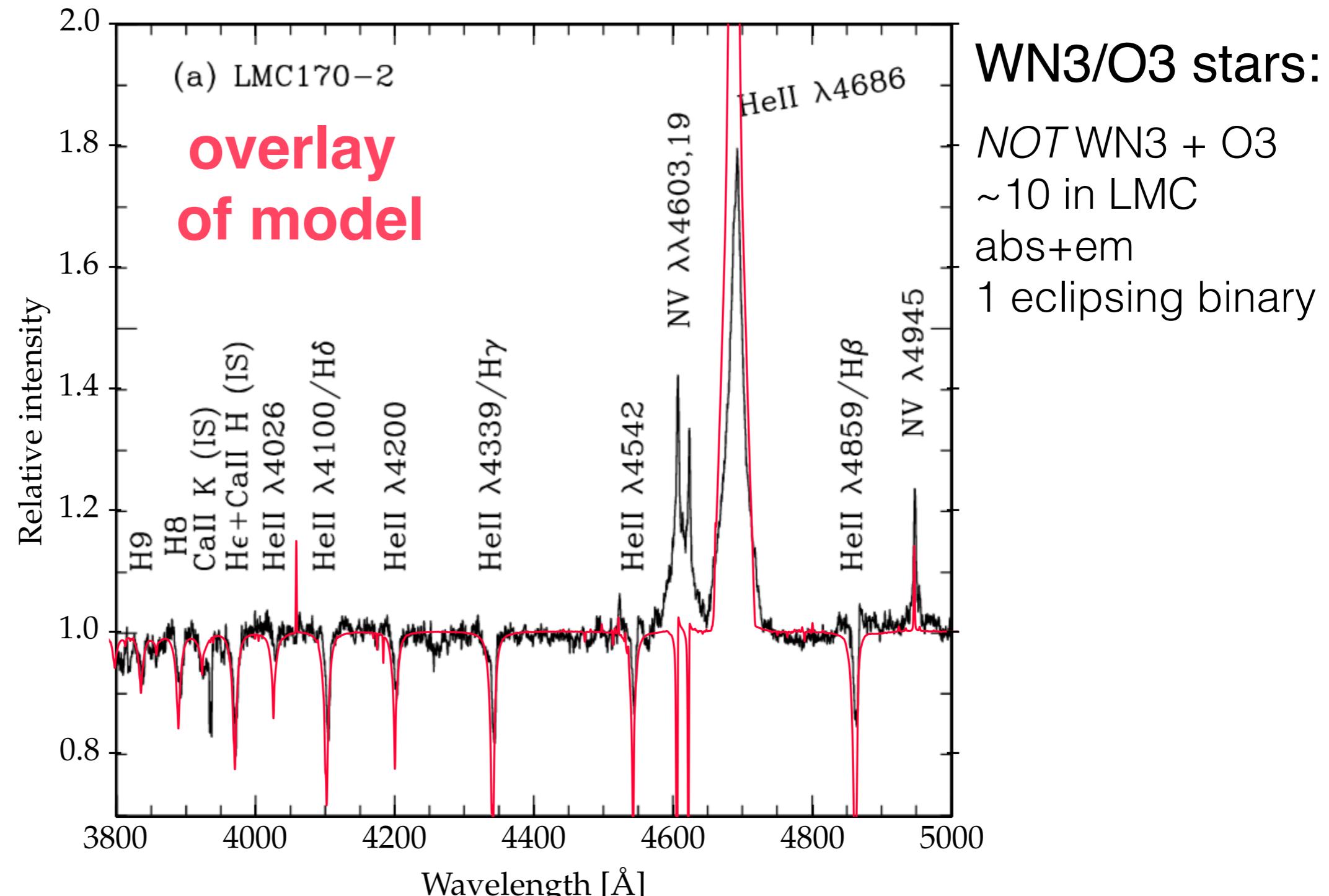
WN3/O3 stars:
NOT WN3 + O3
~10 in LMC
abs+em
1 eclipsing binary

Massey et al. (2014, 2015, 2017), Neugent et al. (2017)

WN3/O3 stars – stripped stars in LMC?

Smith, Gotberg & de Mink (2017, arXiv: 1704.03516)

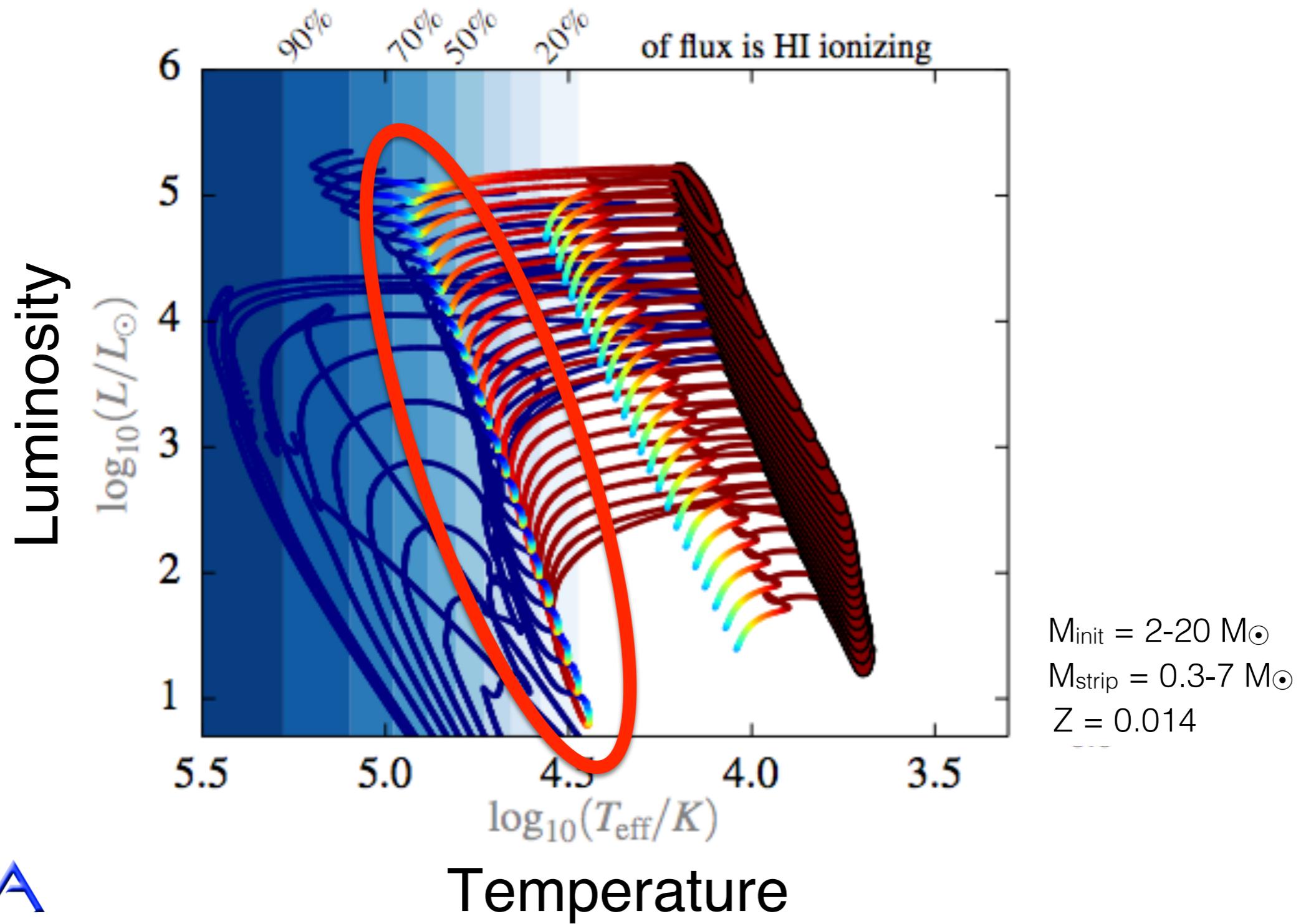
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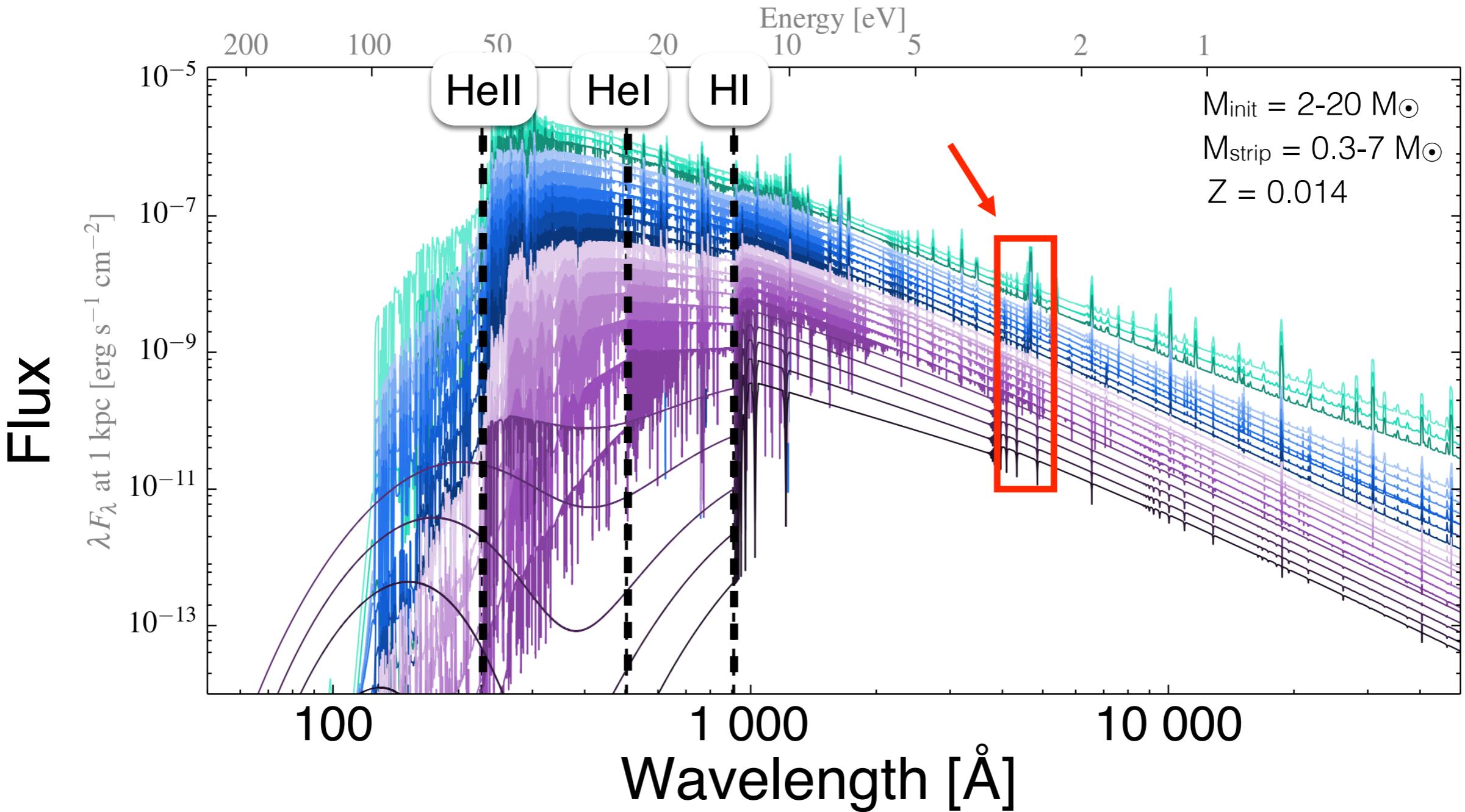
Full mass range of stripped stars

Gotberg et al. (in prep.)



Full mass range of stripped stars

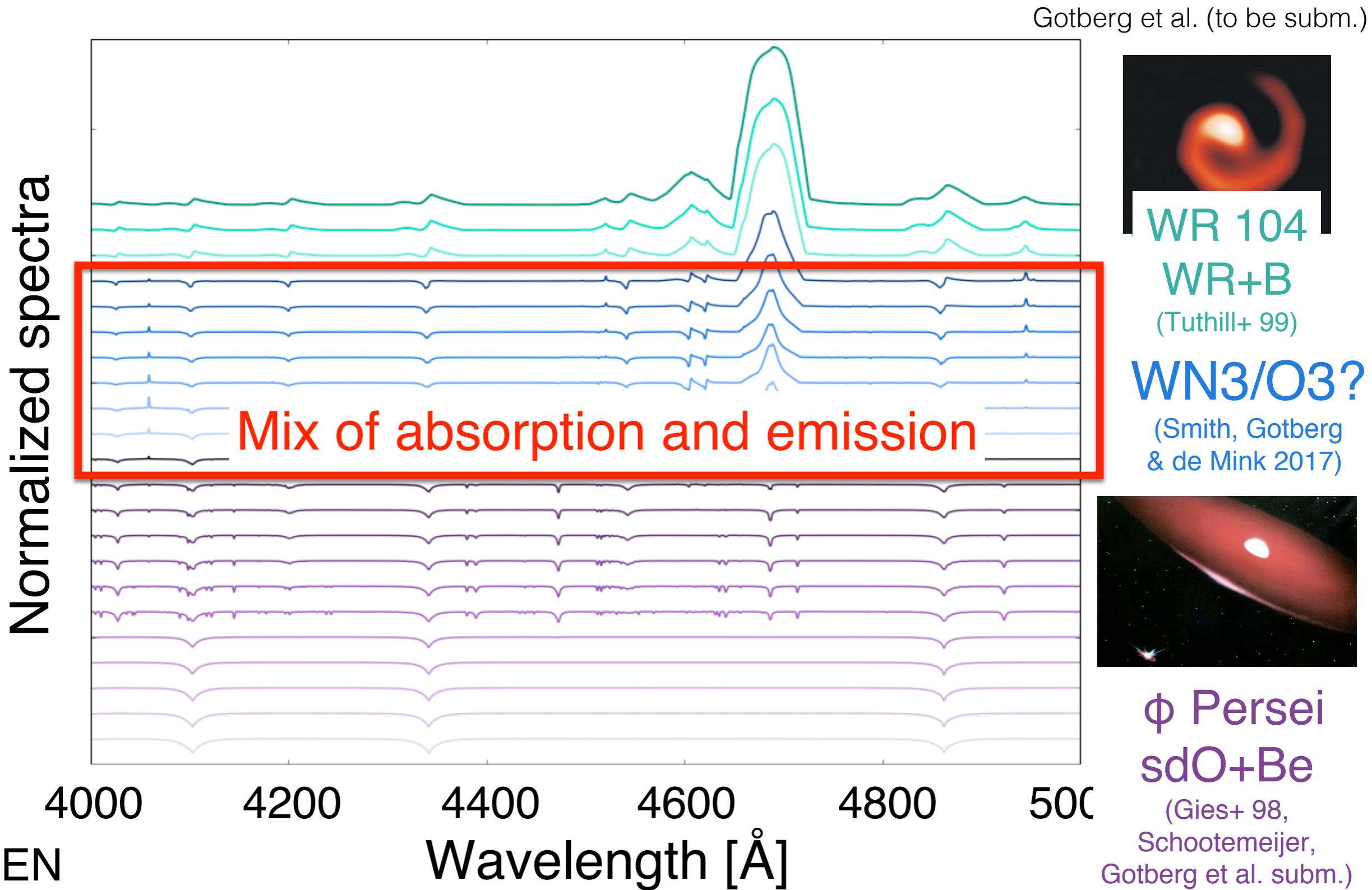
Gotberg et al. (to be subm.)



CMFGEN

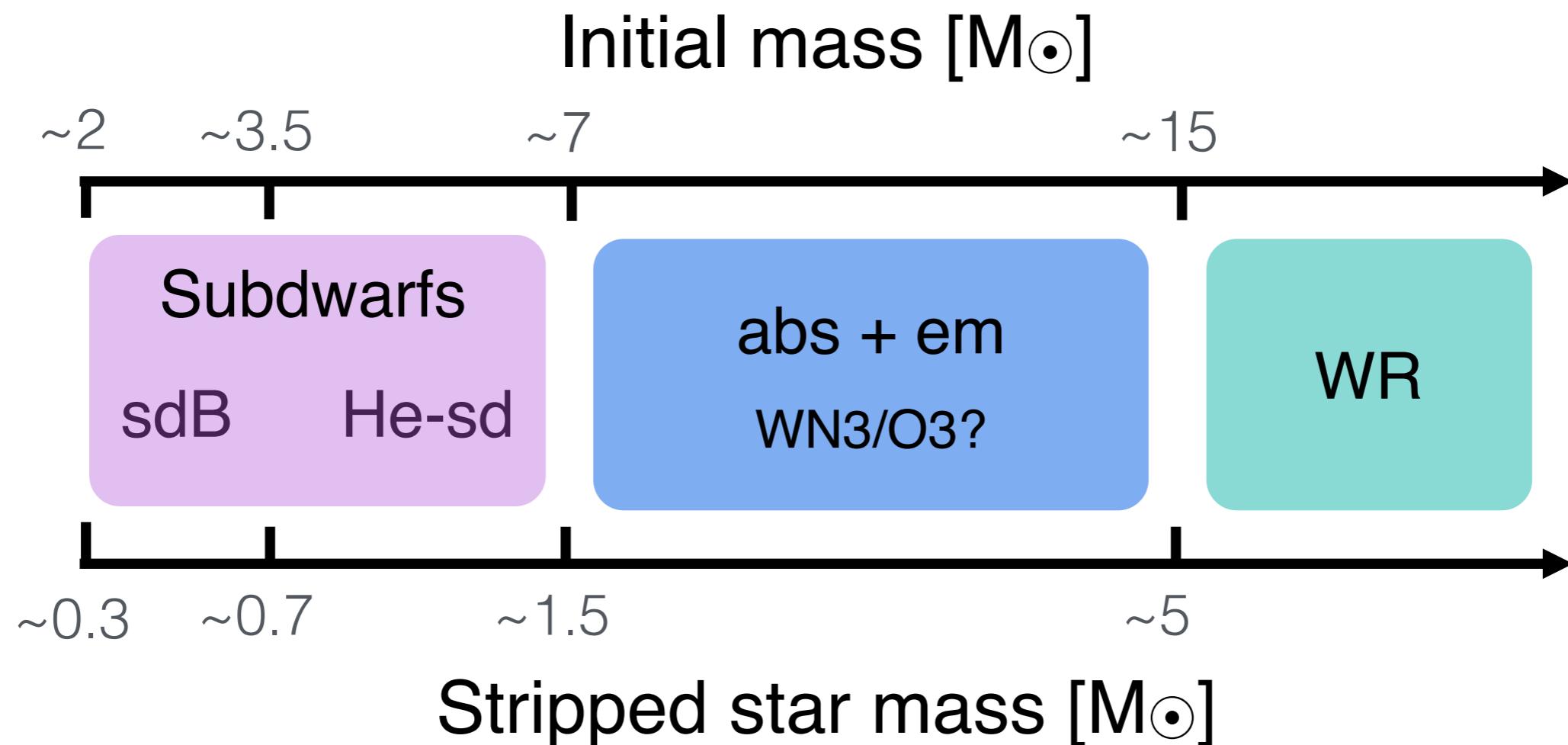
(cf. Han et al. 2007, Groh et al. 2008, Kim et al. 2015)

Spectral characteristics of stripped stars



Spectral characteristics of stripped stars

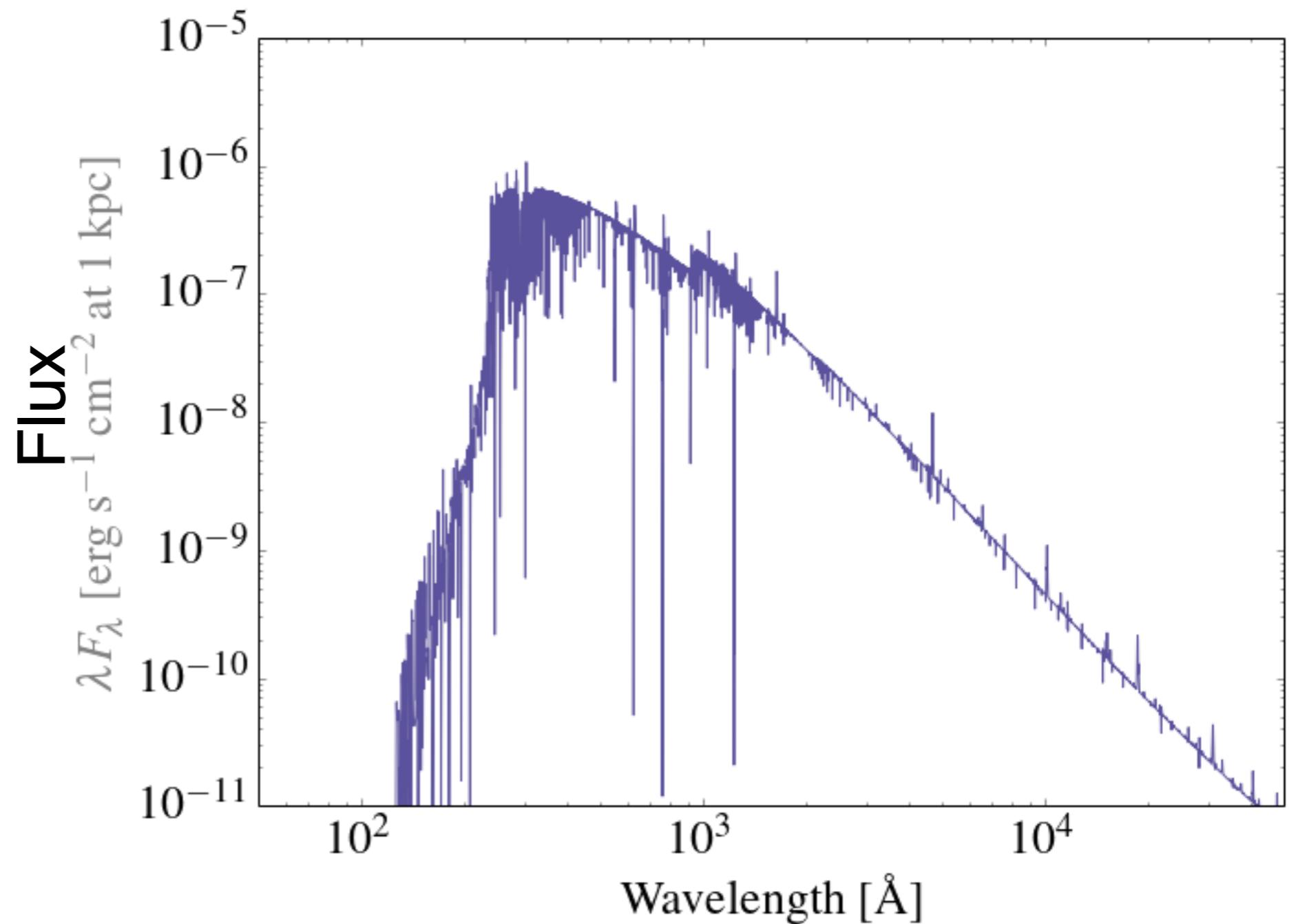
Solar metallicity



Observational features of stripped stars

Stripped star

$M_{\text{strip}} = 4 M_{\odot}$
 $(M_{\text{init}} = 12 M_{\odot})$



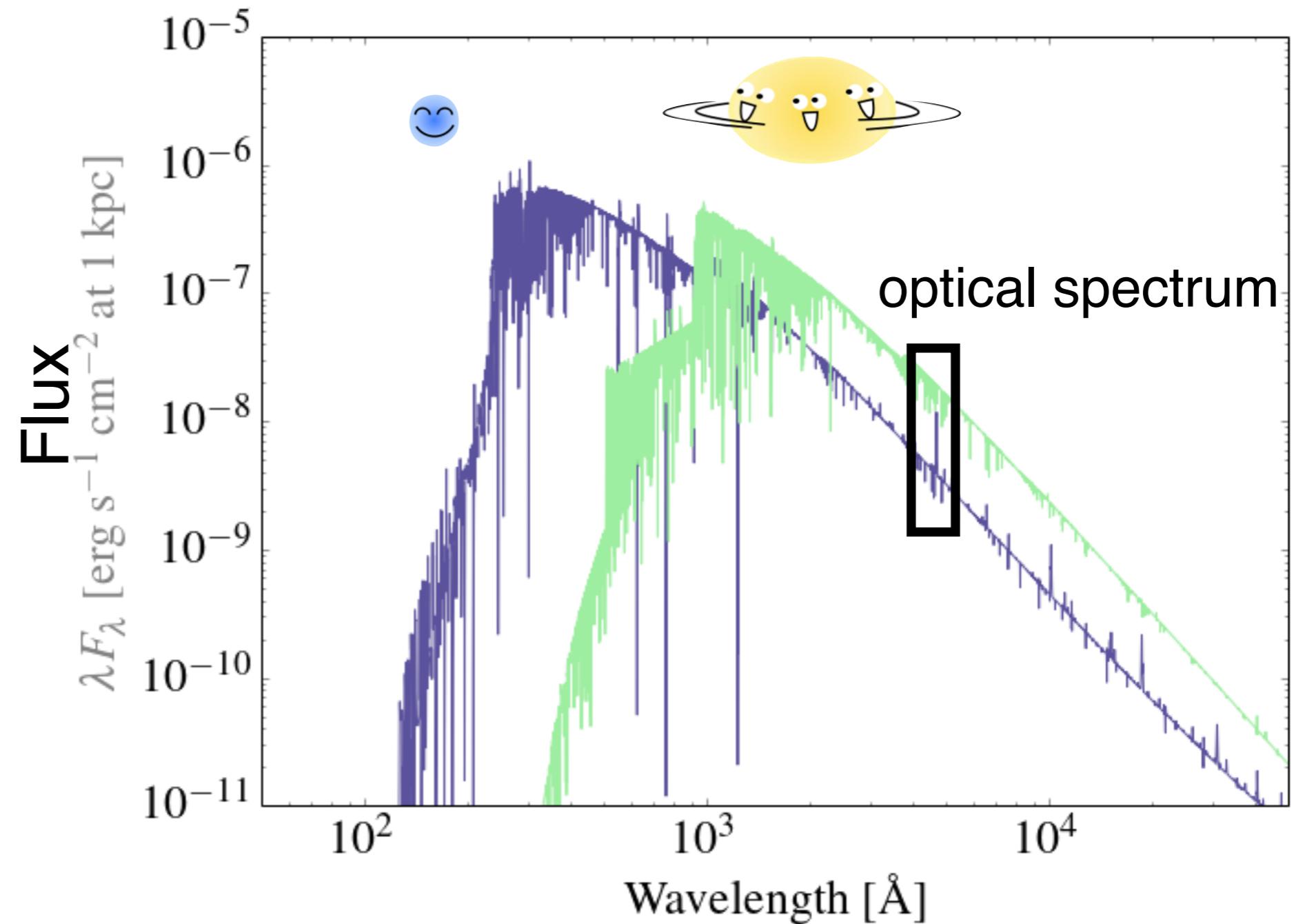
Observational features of stripped stars

Stripped star

$M_{\text{strip}} = 4 M_{\odot}$
($M_{\text{init}} = 12 M_{\odot}$)

Companion star

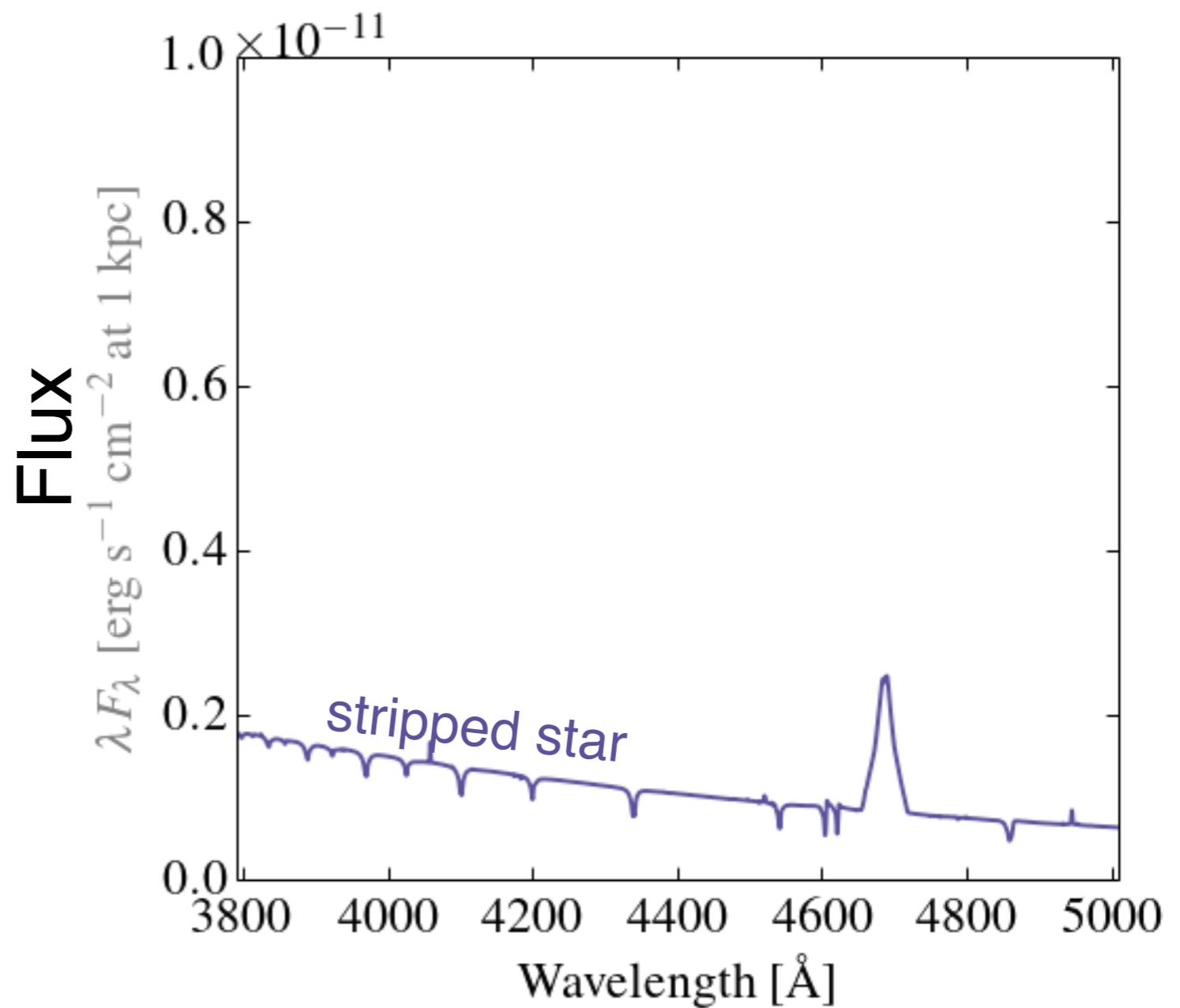
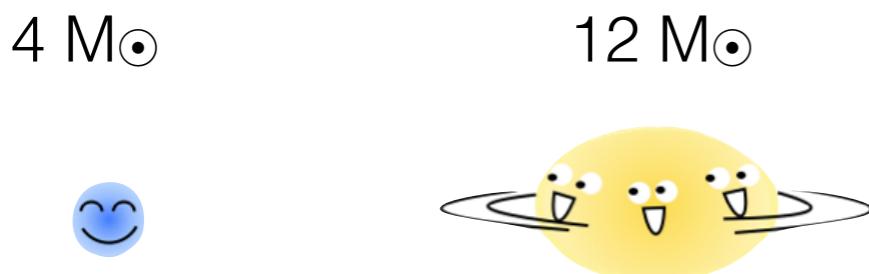
$M_{\text{companion}} = 12 M_{\odot}$
(~B1V)



Normalised spectrum of composite
— show overlay of WN3/O3 observations
 say not meant to fit
 discuss rotation of companion
 mention RV variations possible to see
mention other evolutionary theories of WN3/O3

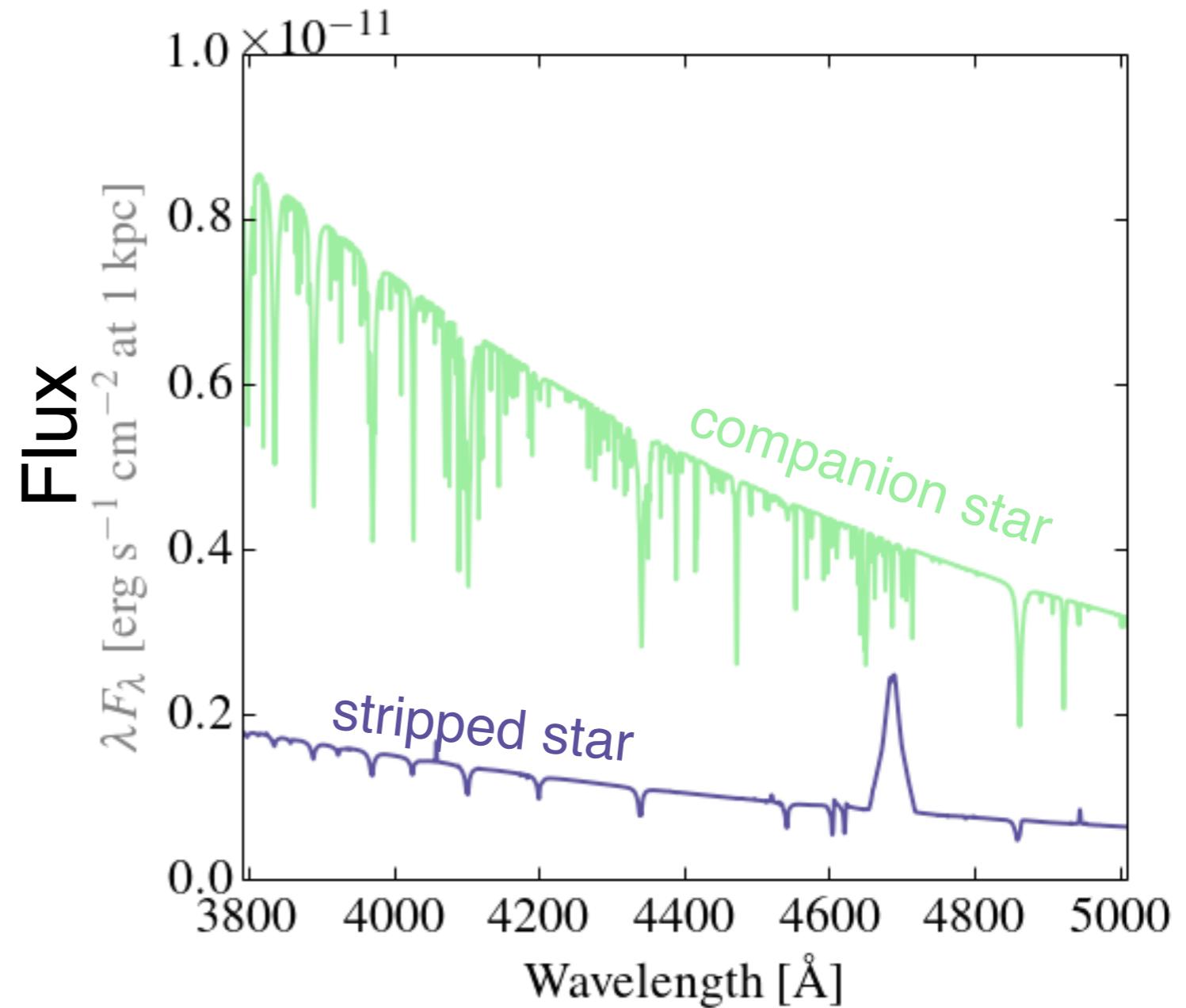
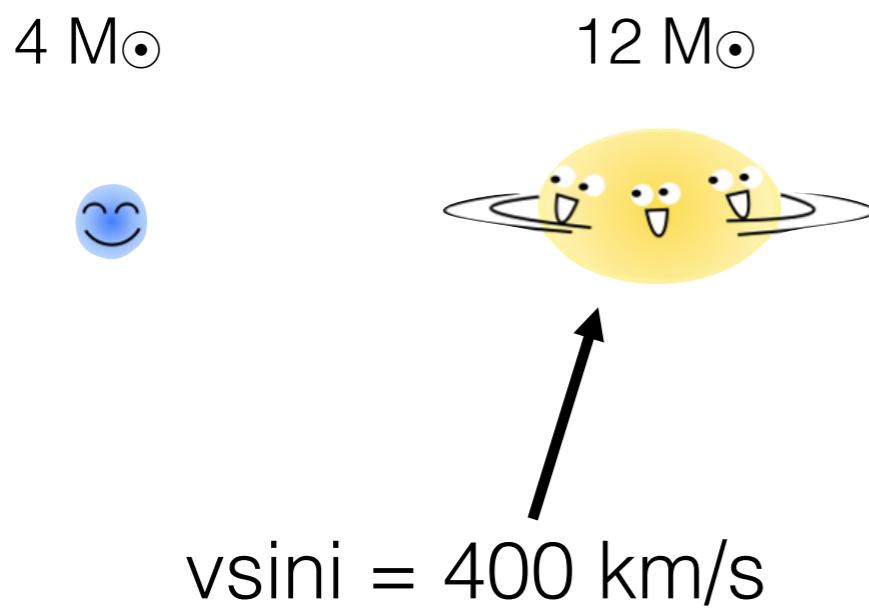
Observational features of stripped stars

Stripped star Companion star



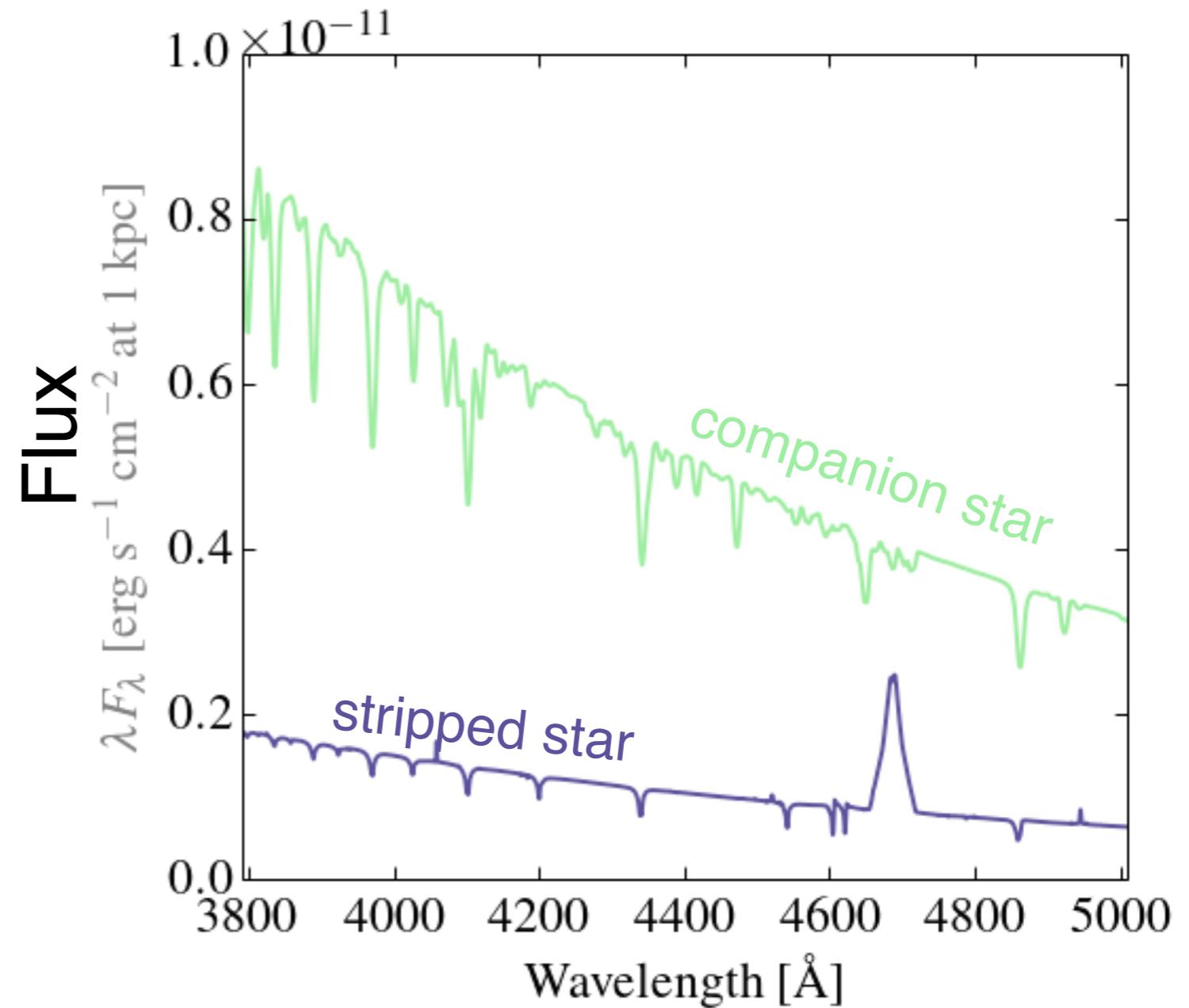
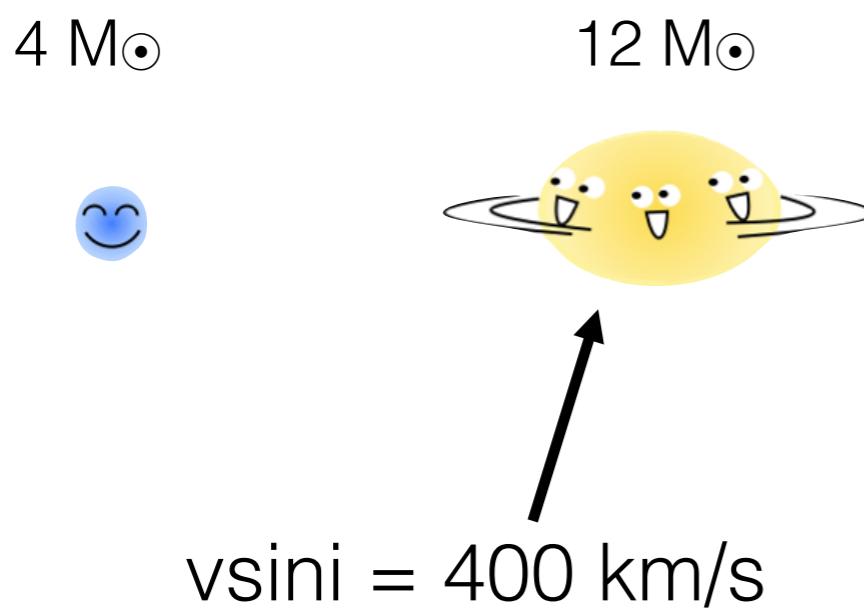
Observational features of stripped stars

Stripped star Companion star



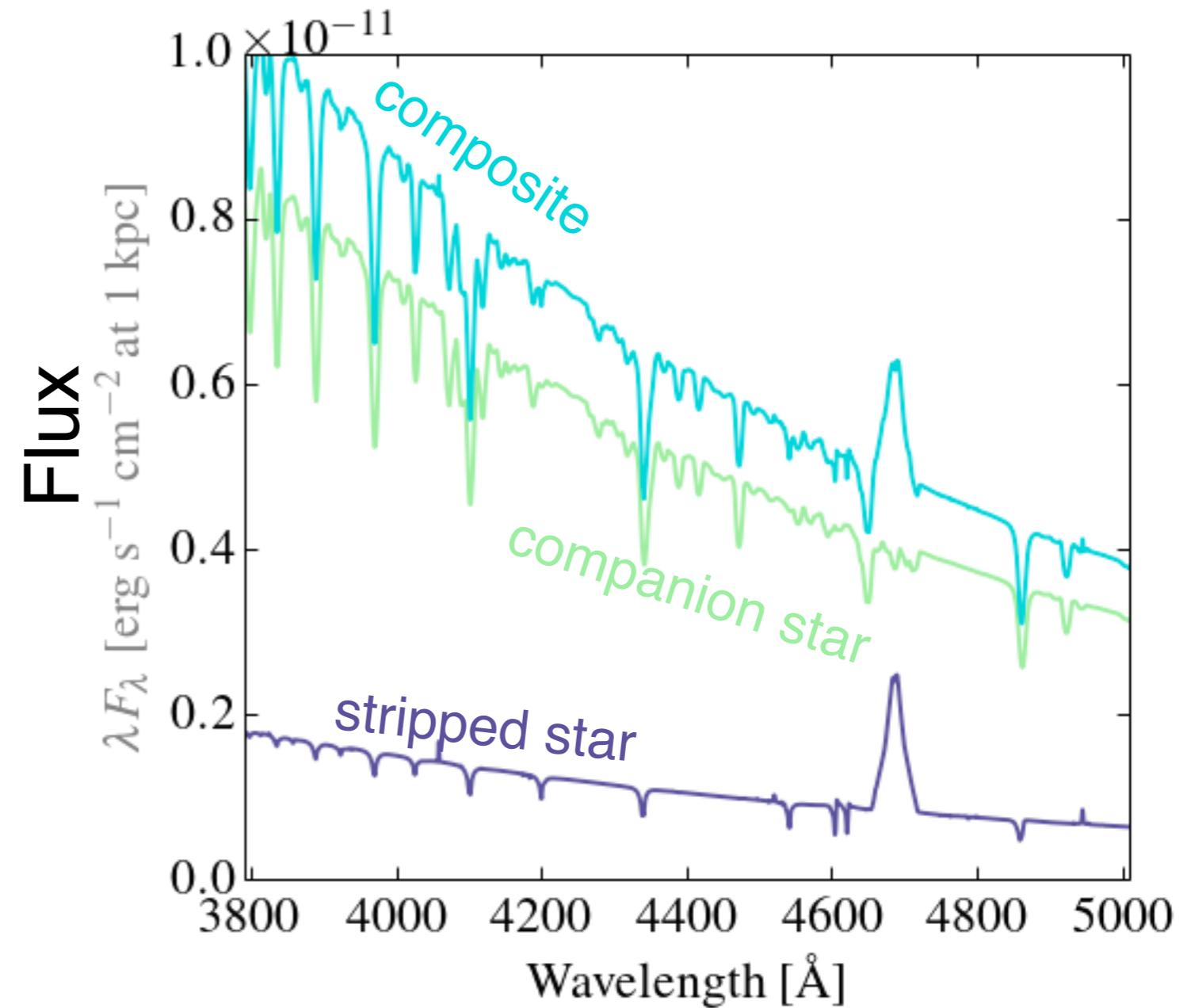
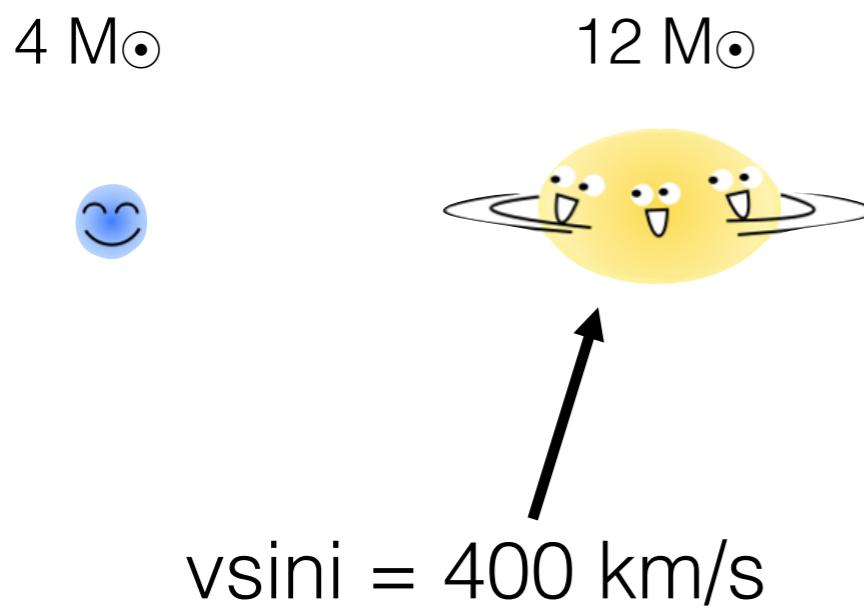
Observational features of stripped stars

Stripped star Companion star



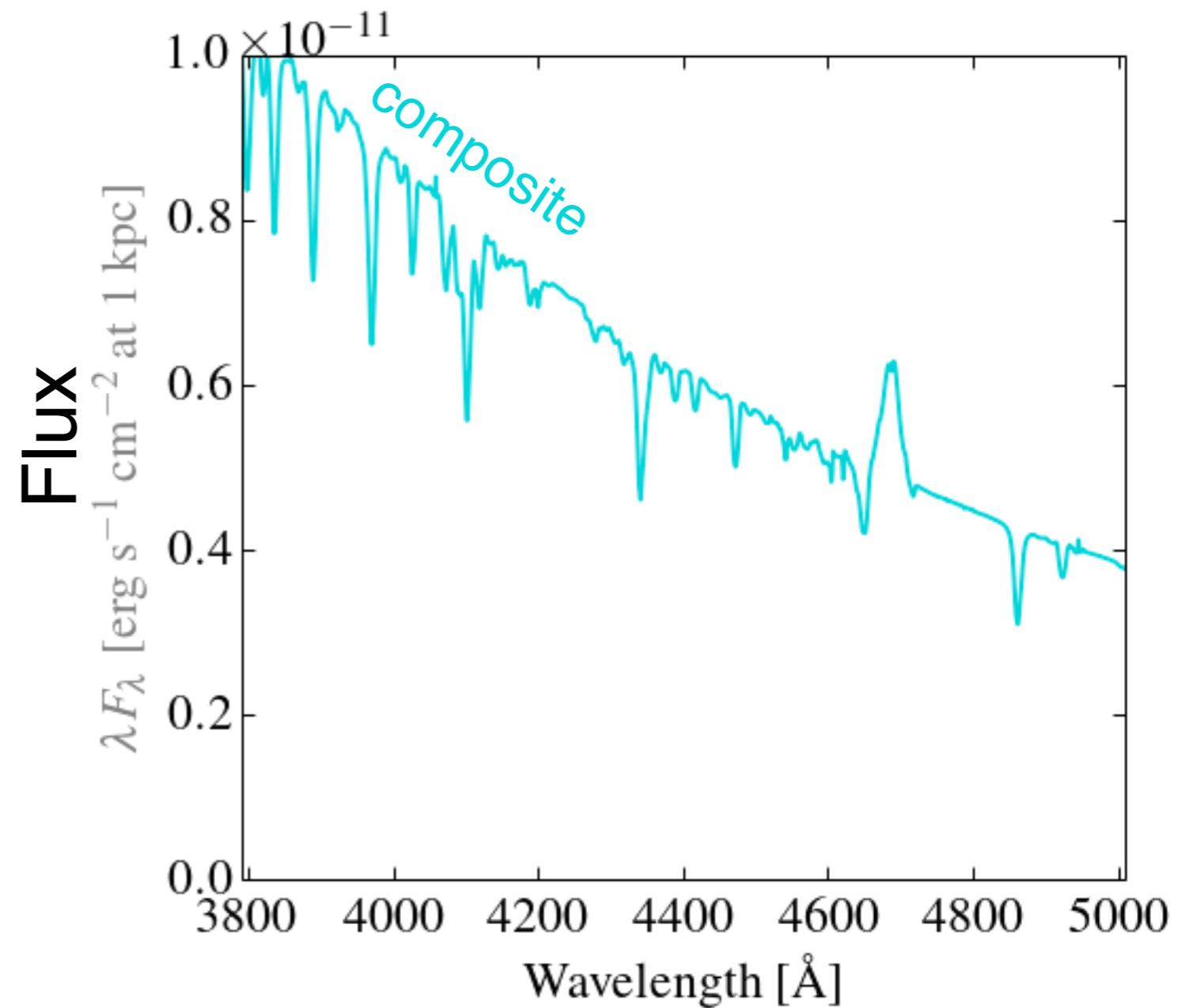
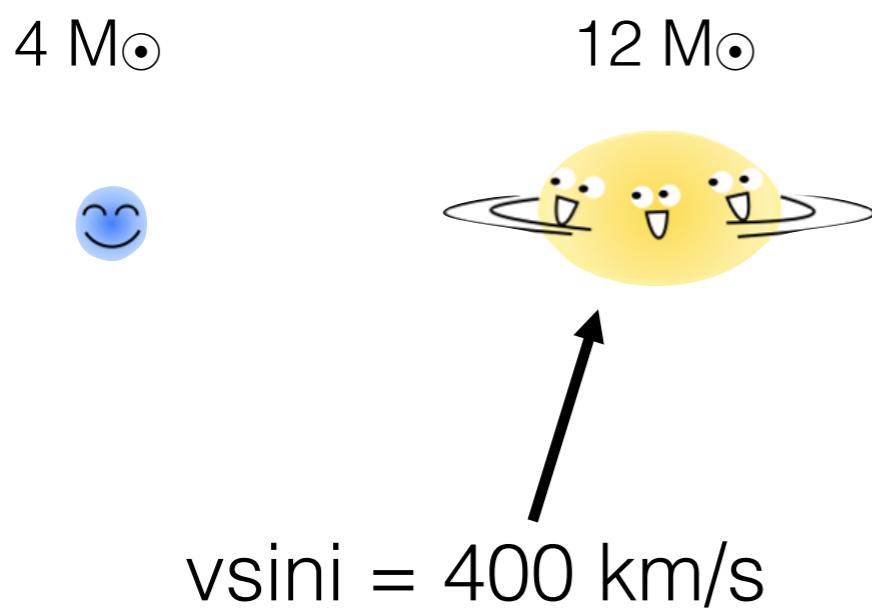
Observational features of stripped stars

Stripped star Companion star



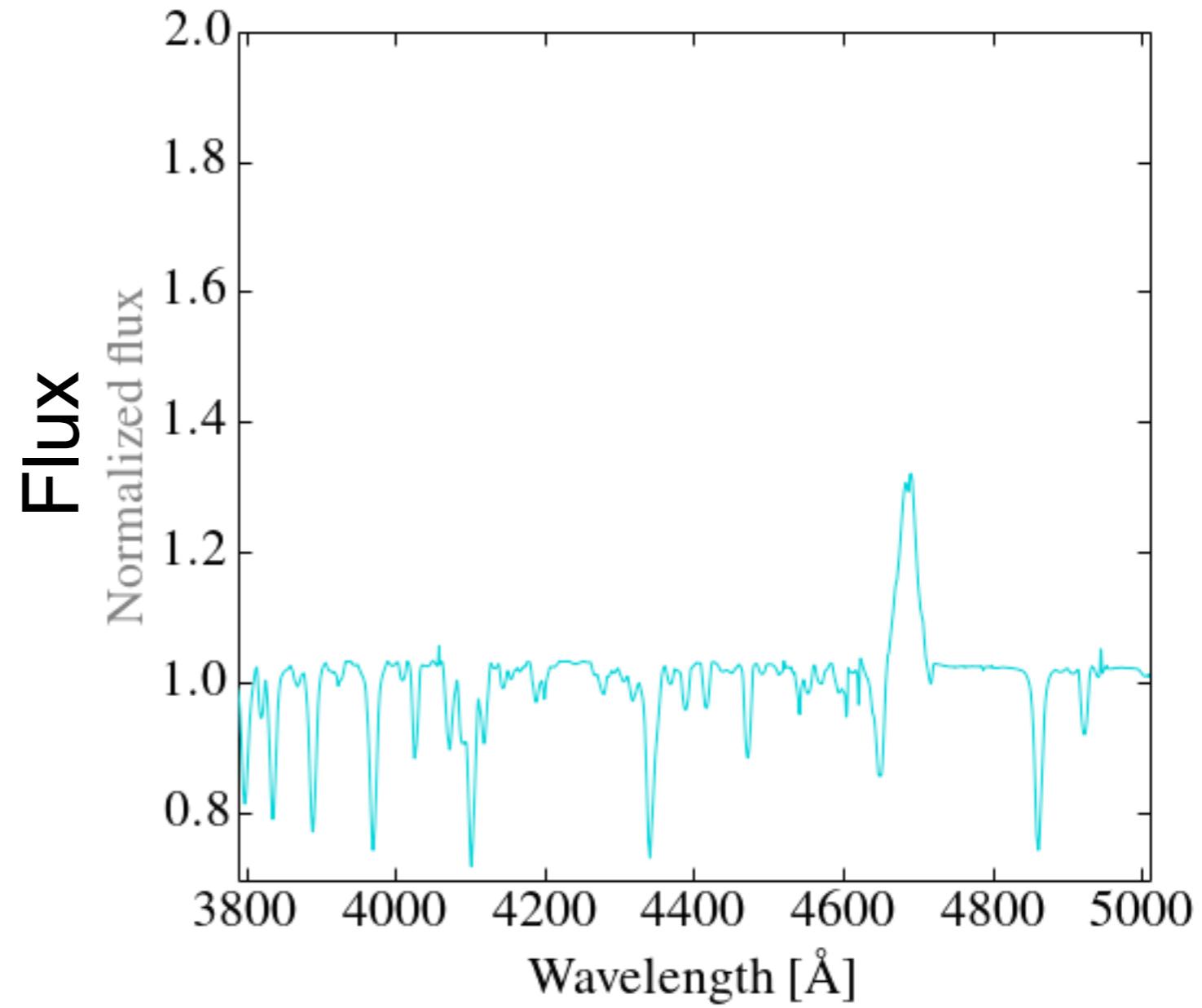
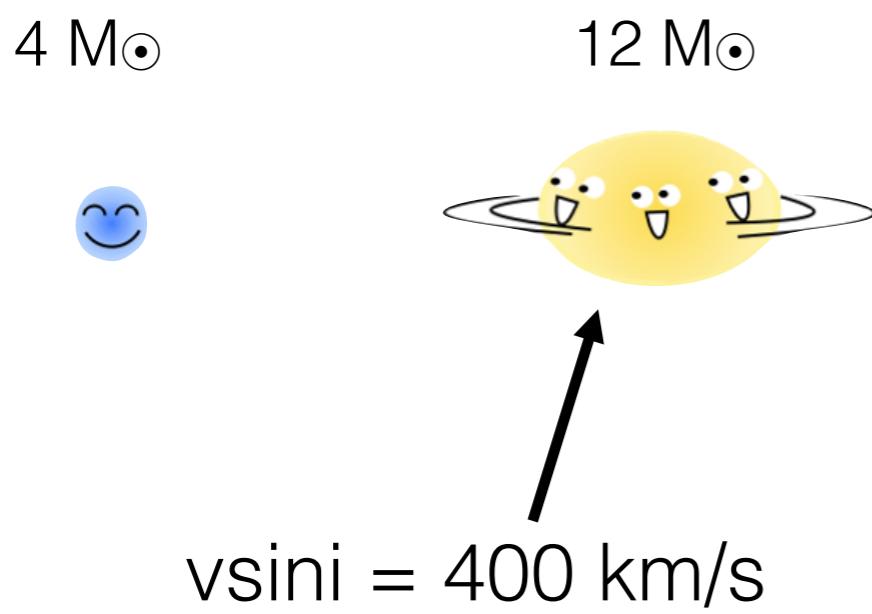
Observational features of stripped stars

Stripped star Companion star



Observational features of stripped stars

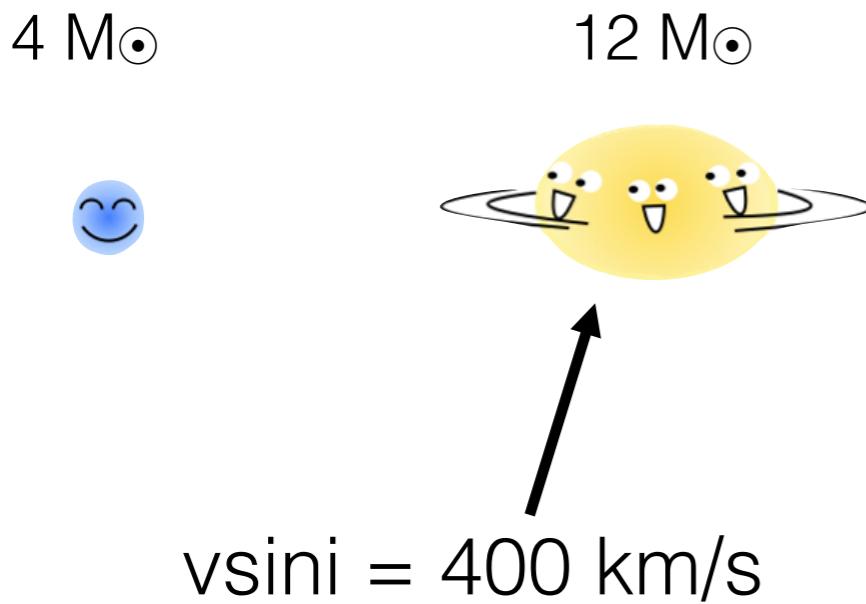
Stripped star Companion star



Observational features of stripped stars

(see Smith, Götberg & de Mink 2017, arXiv 1704.03516)

Stripped star Companion star

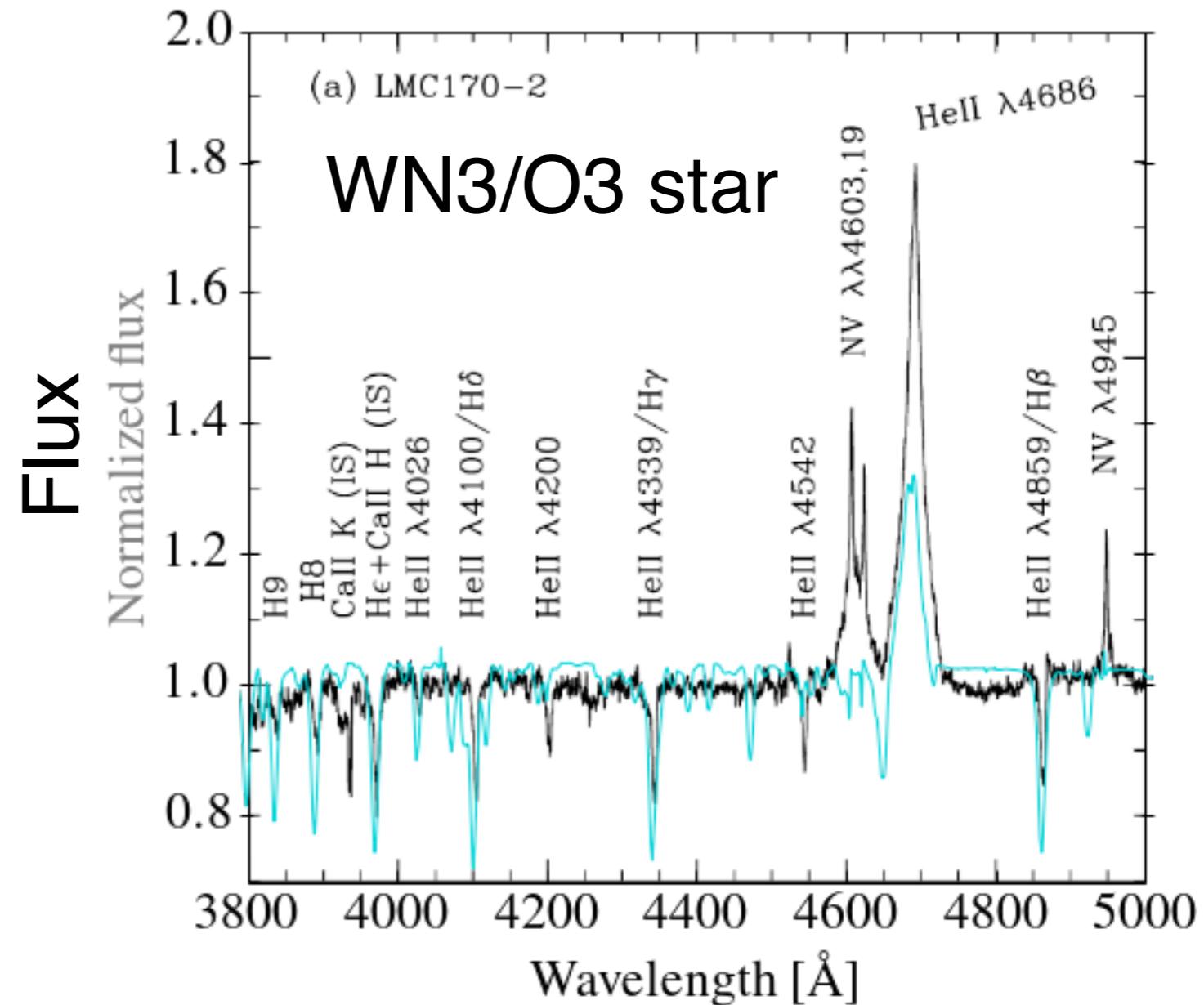


$M_V = -2.2$ mag

$P \sim 100$ days



$\Delta V \sim 60-80$ km/s



WN3/O3 stars: Massey et al. (2014, 2015, 2017), Neugent et al. (2017)

3 examples:

Show SED composites

show normalised composites

examples have to show:

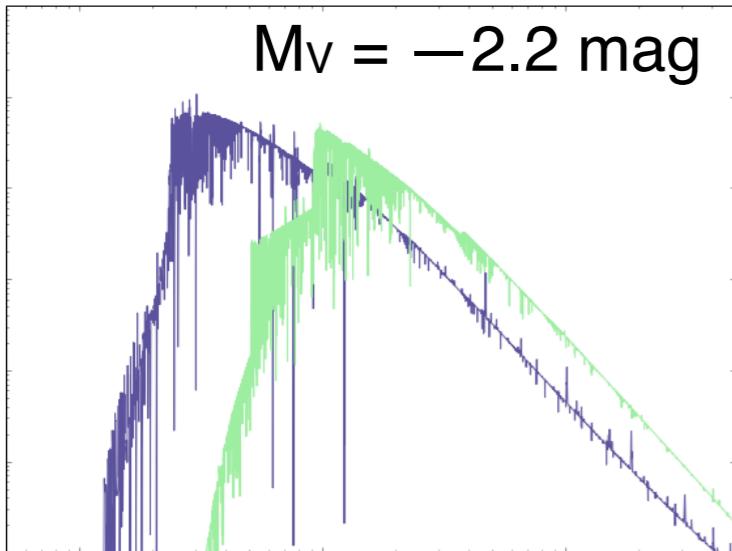
1. no visible stripped star,
2. visible both companion+stripped star
3. visible only stripped star

backup slide on other WN3/O3 stars matching?

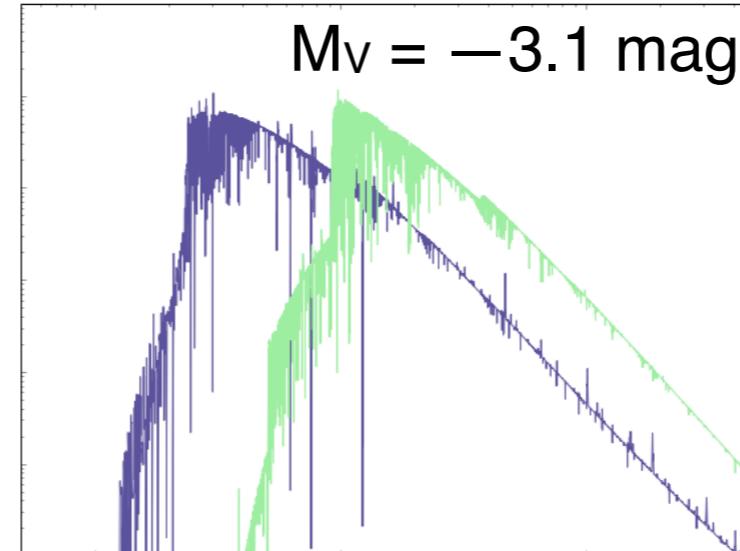
What is needed to confirm stripped star presence?

Observational features of stripped stars

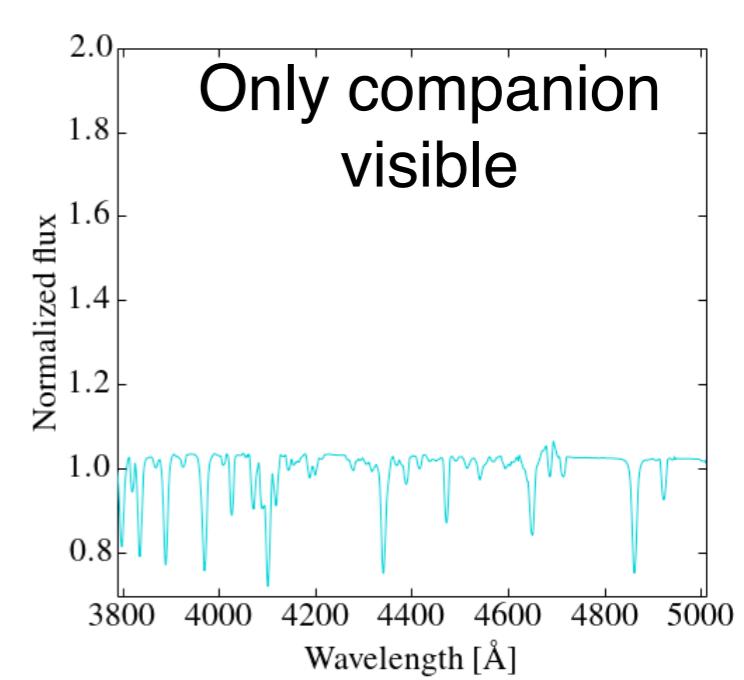
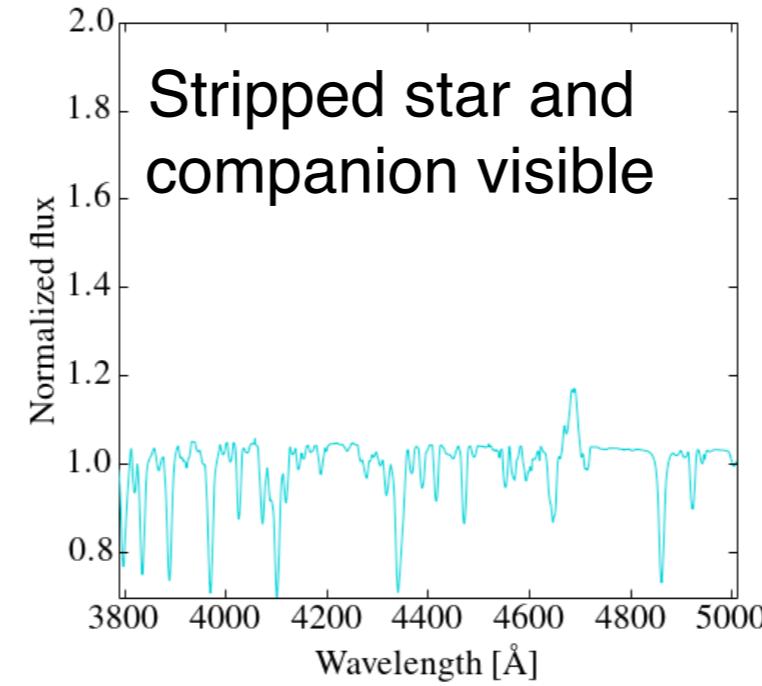
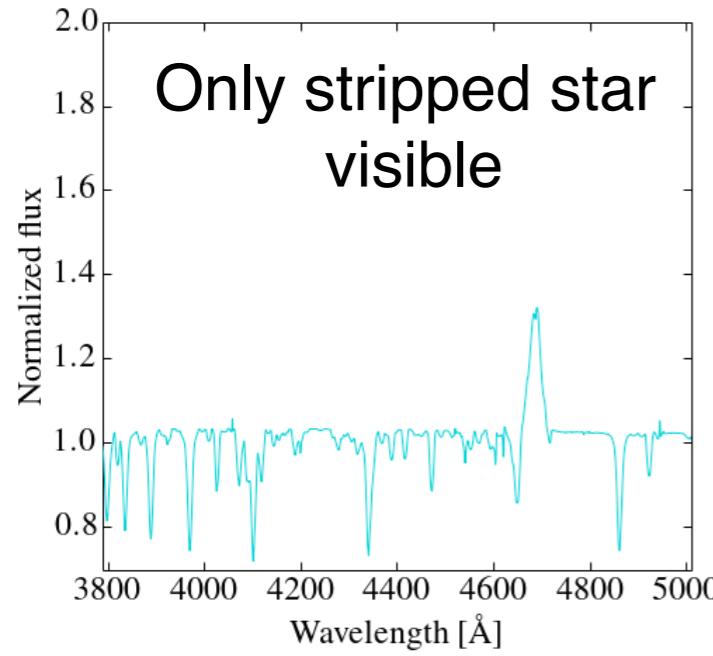
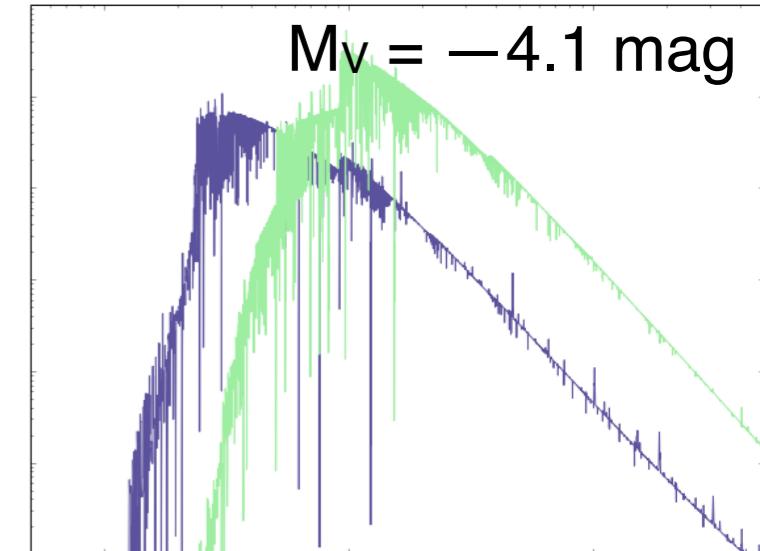
$4+5 M_{\odot}$



$4+12 M_{\odot}$



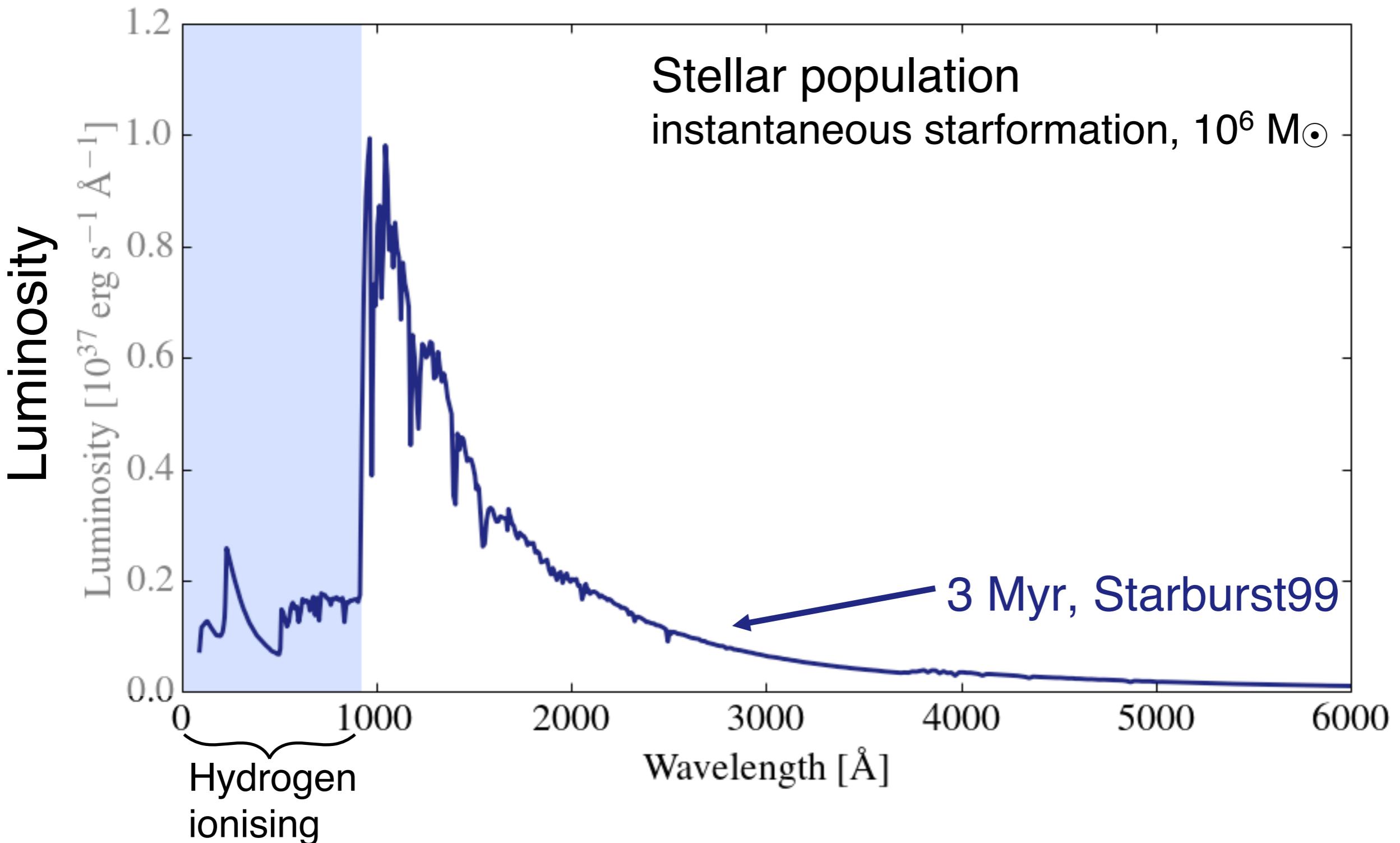
$4+20 M_{\odot}$



Other observational techniques?
UV excess?

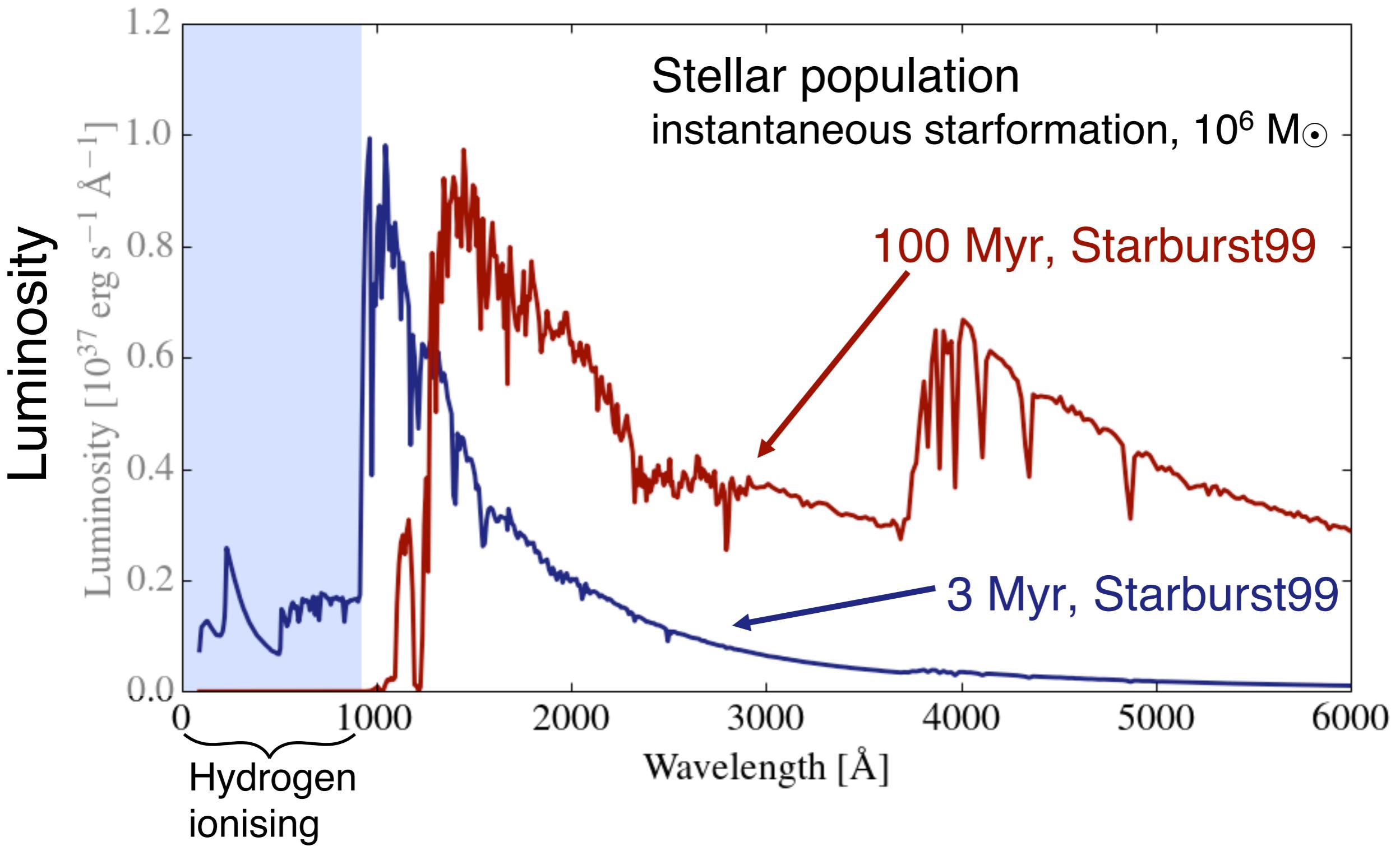
Including stripped stars in stellar populations

Stellar populations – ionising photons



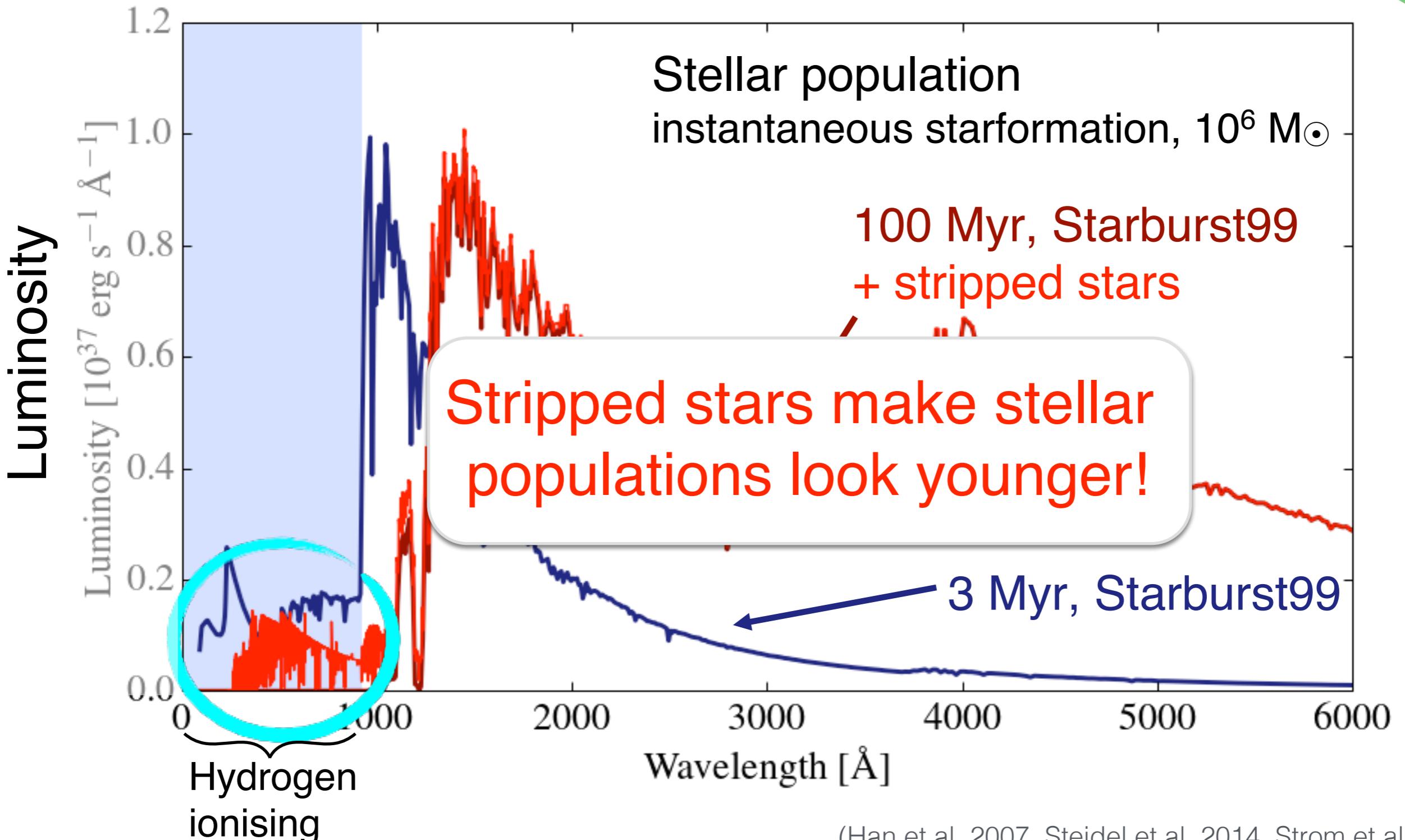
(STARBURST99: Leitherer et al. 1999, see also BPASS, Eldridge & Stanway 2009, 2012)

Stellar populations – ionising photons



(STARBURST99: Leitherer et al. 1999, see also BPASS, Eldridge & Stanway 2009, 2012)

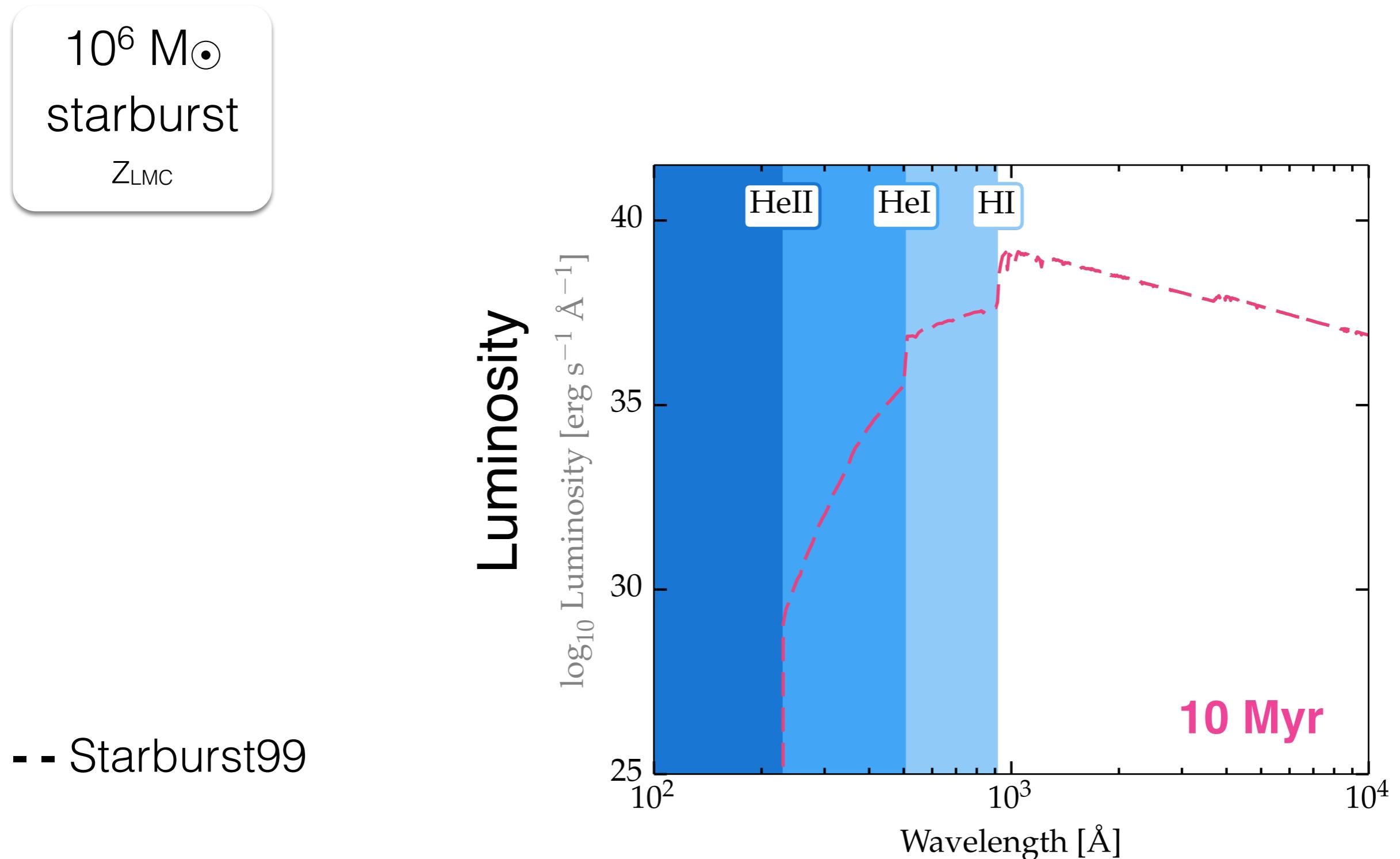
Stellar populations – ionising photons



(Han et al. 2007, Steidel et al. 2014, Strom et al. 2017)

(STARBURST99: Leitherer et al. 1999, see also BPASS: Eldridge & Stanway 2009, 2012)

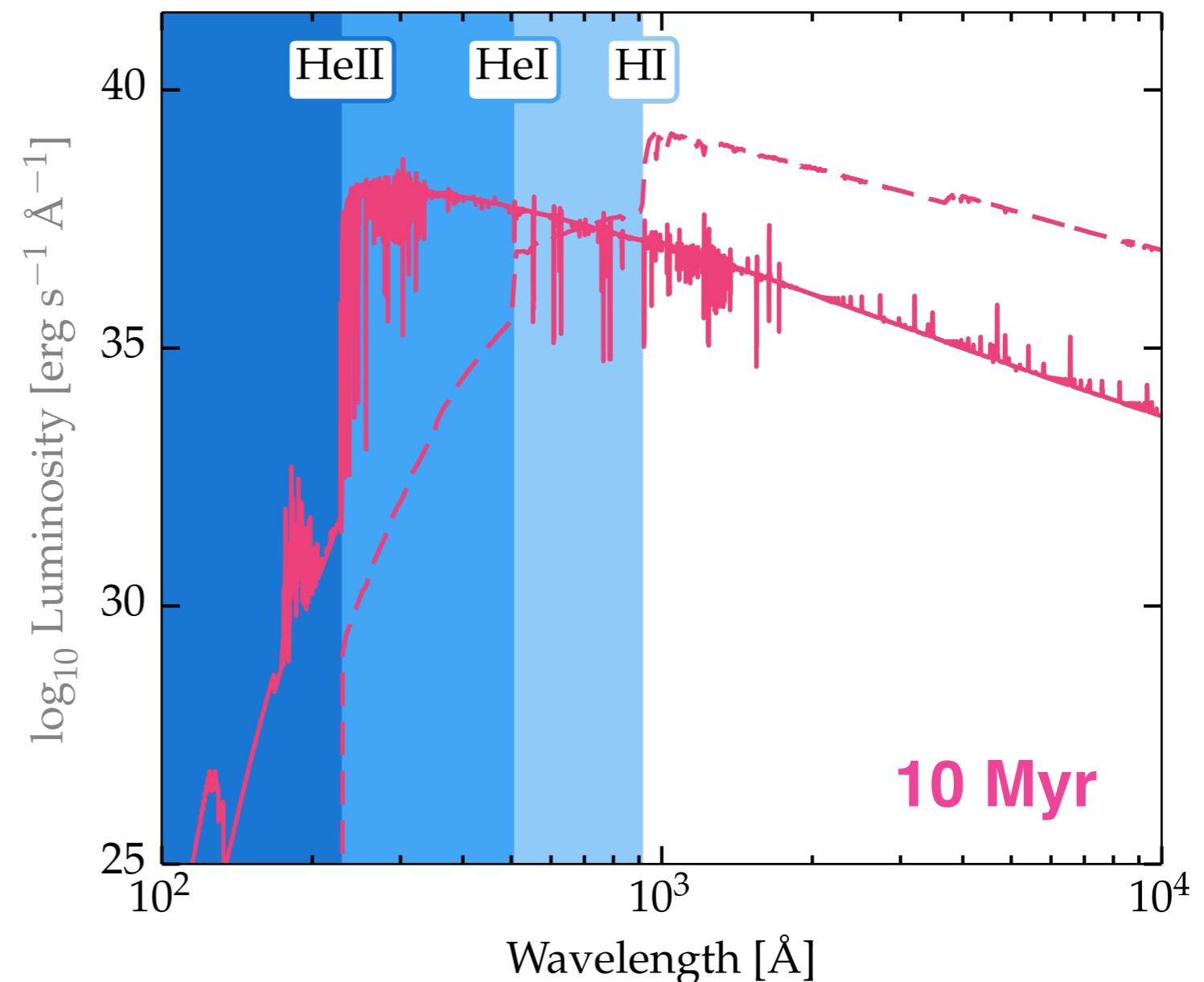
SED addition from stripped stars



SED addition from stripped stars

$10^6 M_{\odot}$
starburst
 Z_{LMC}

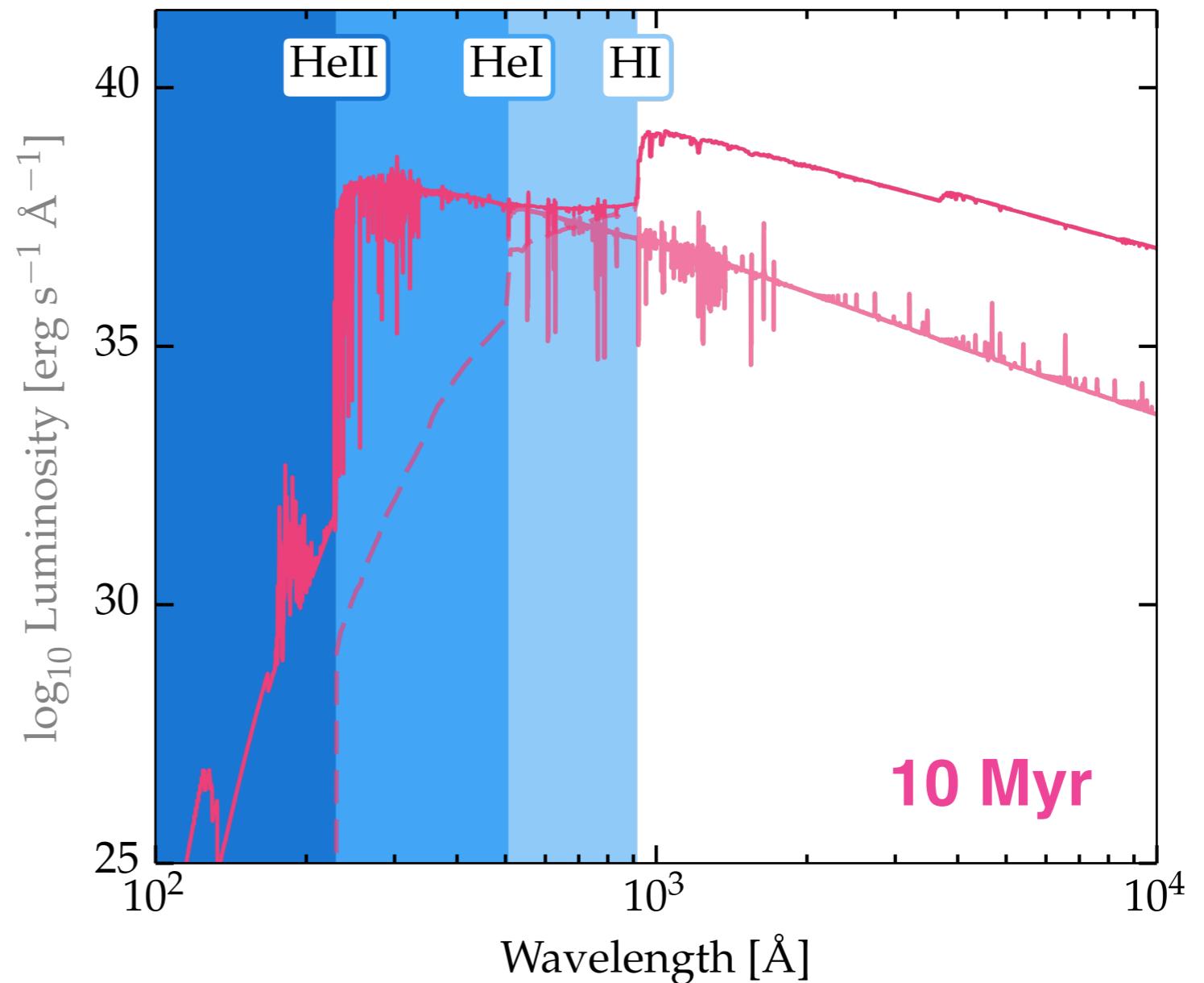
- - Starburst99
- Stripped stars



SED addition from stripped stars

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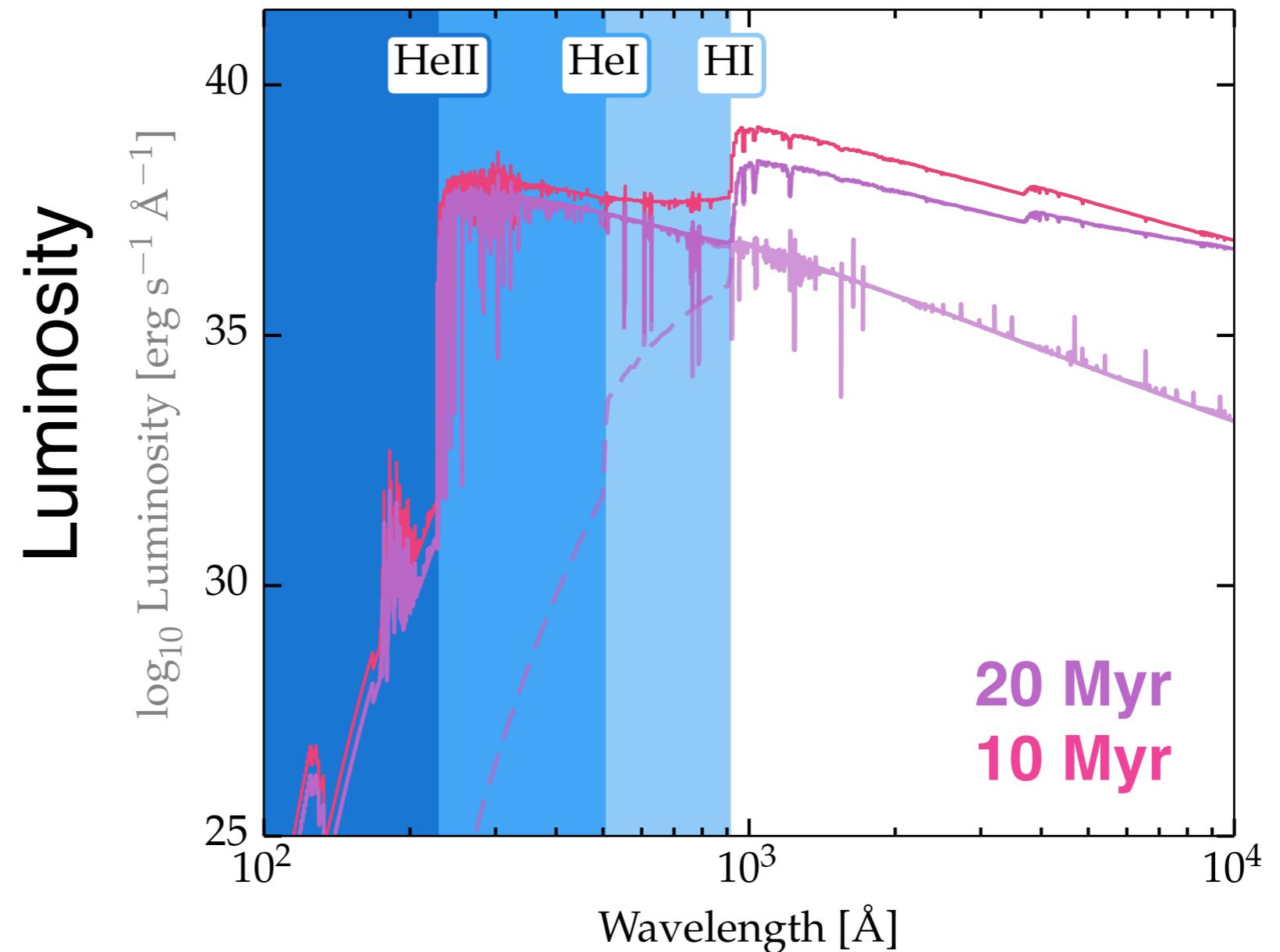
- - Starburst99
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SED addition from stripped stars

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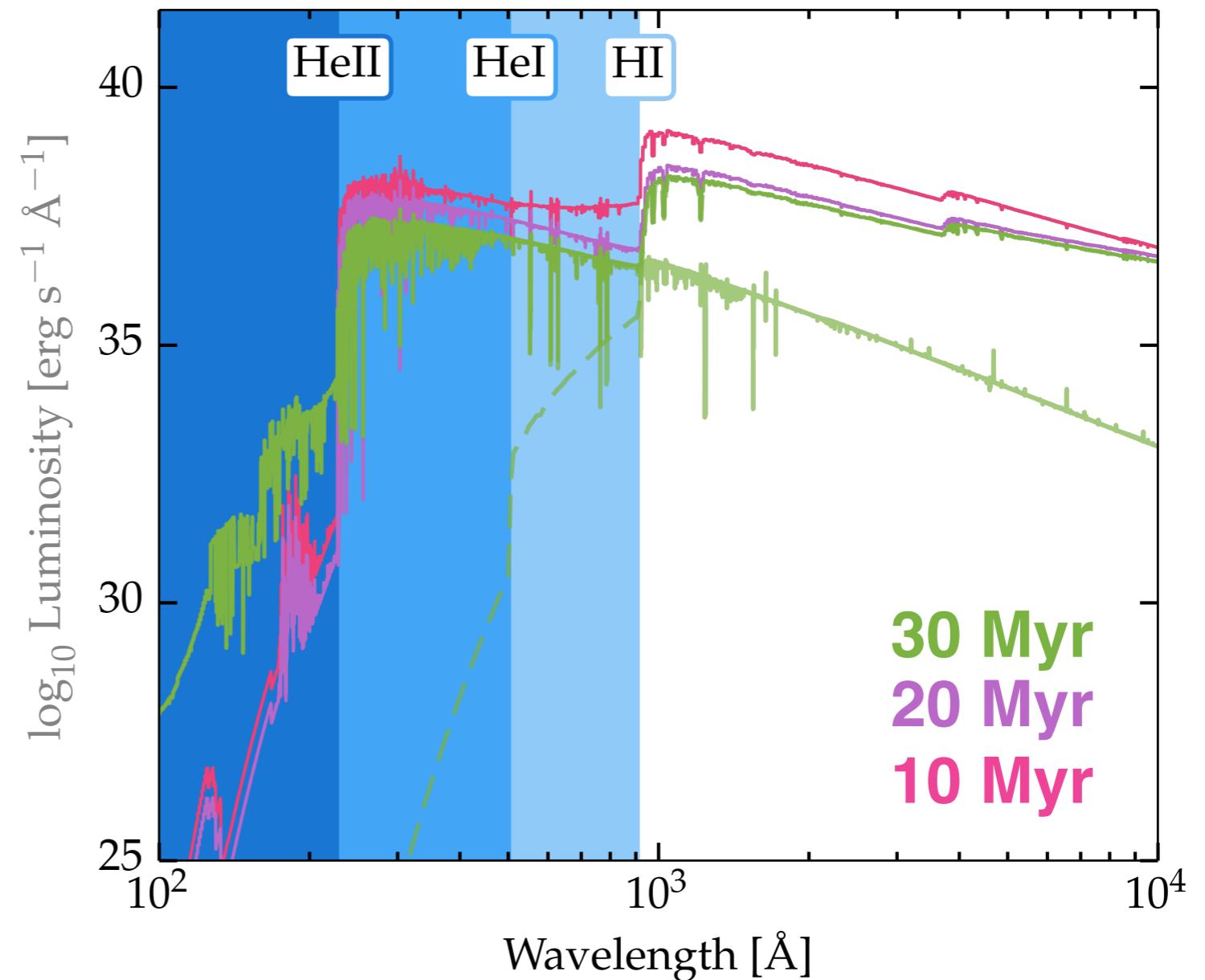


SED addition from stripped stars

Preliminary

$10^6 M_{\odot}$
starburst
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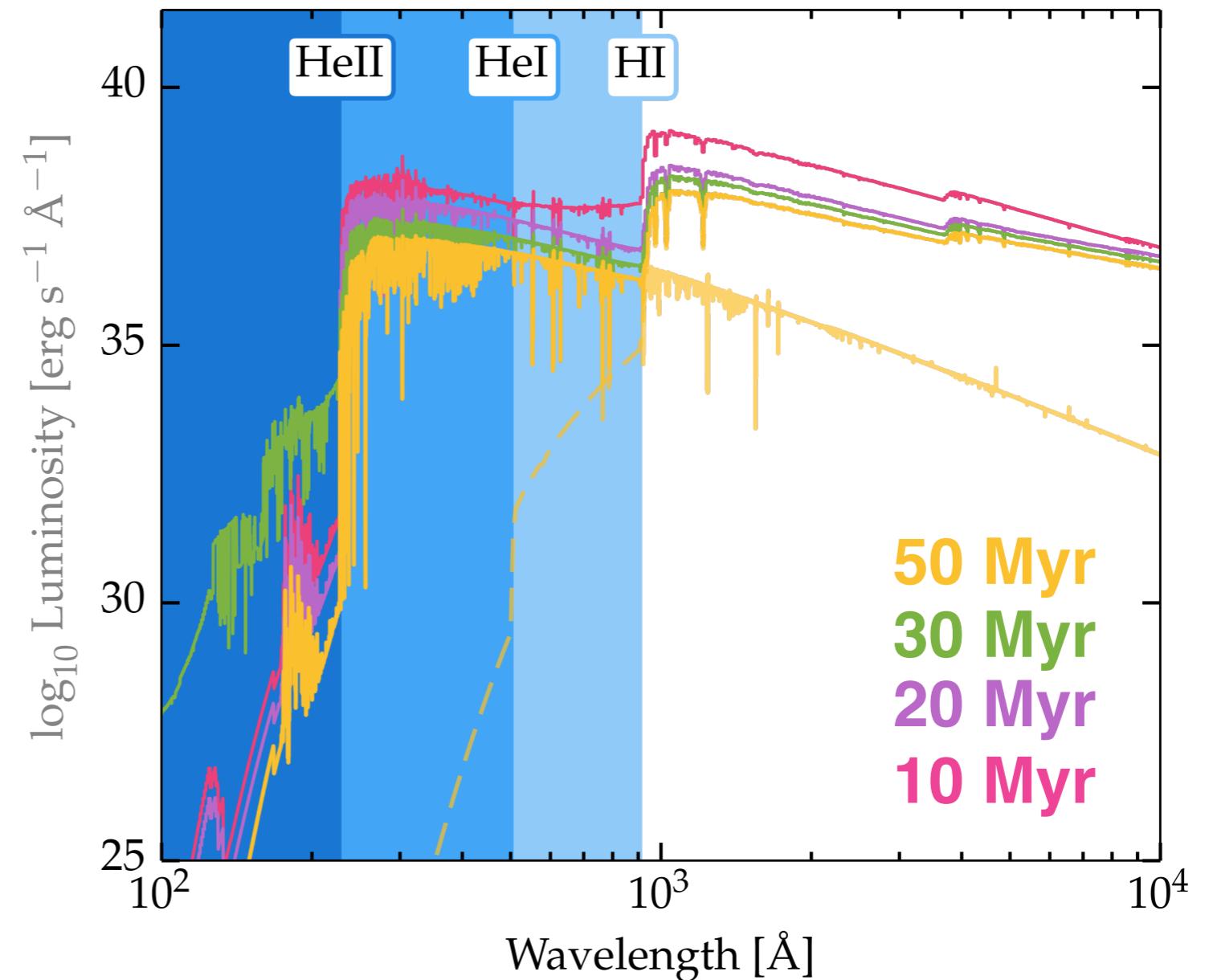


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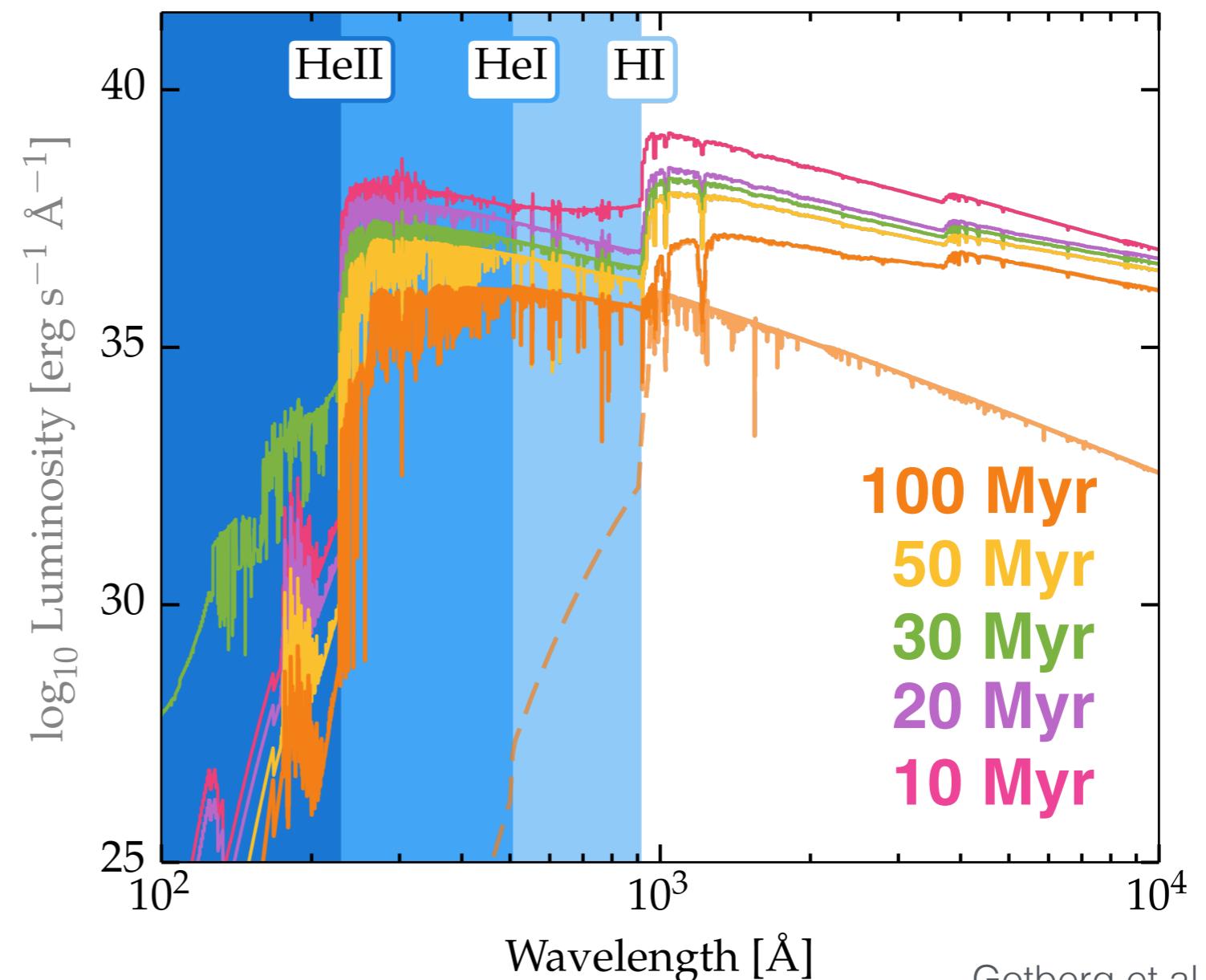


SED addition from stripped stars

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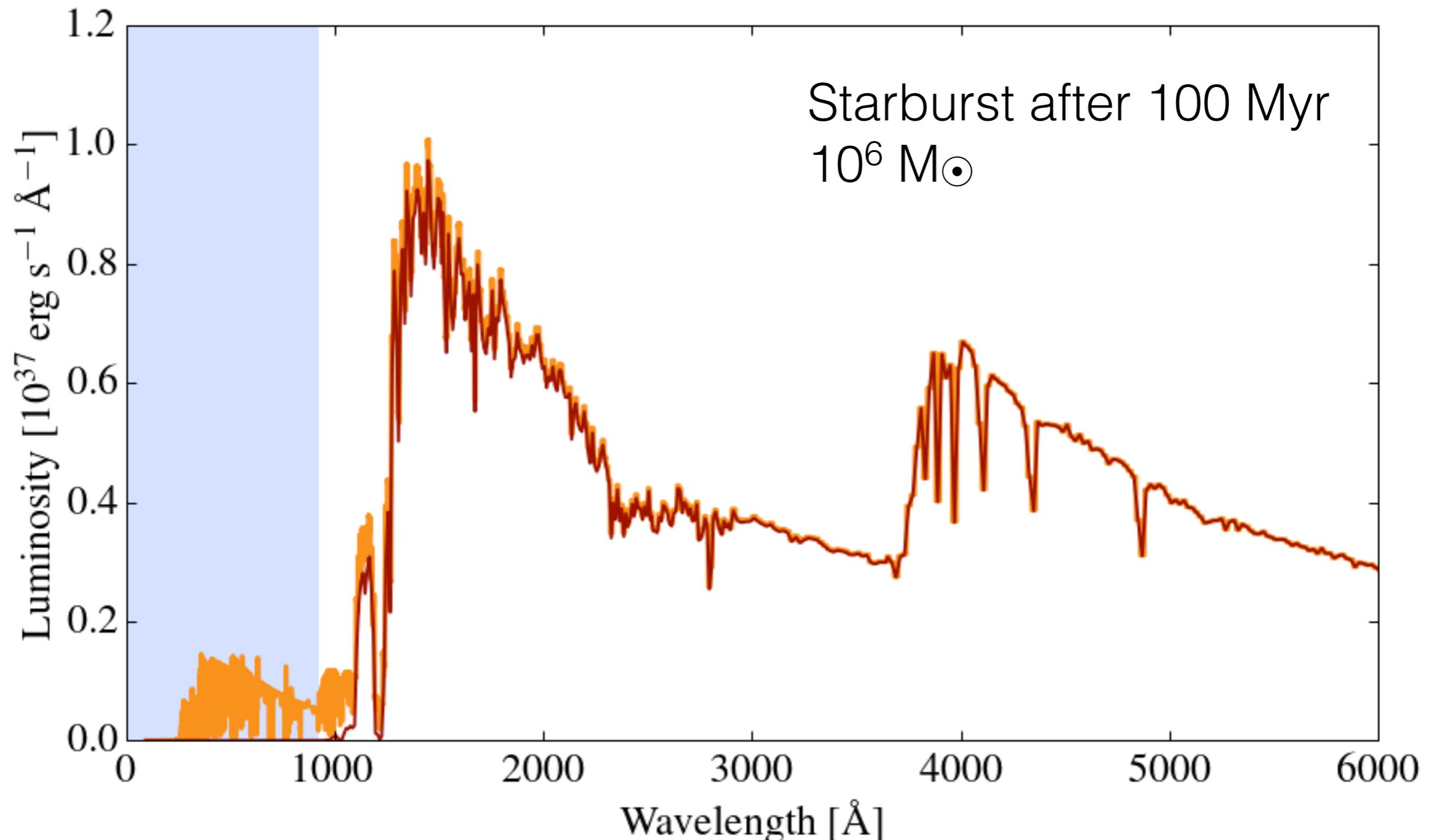
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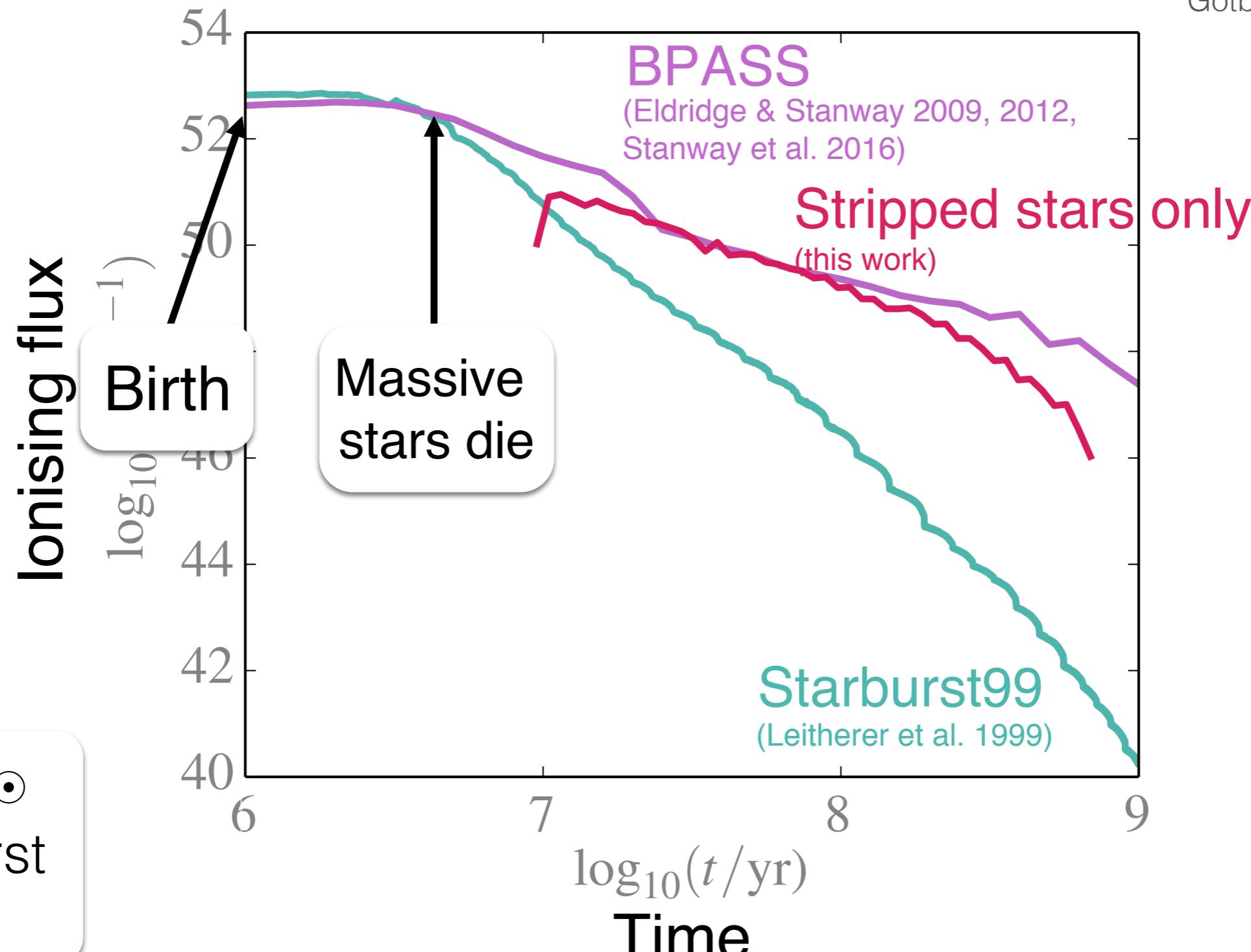
Gotberg et al. (in prep.)

Including stripped stars in stellar population



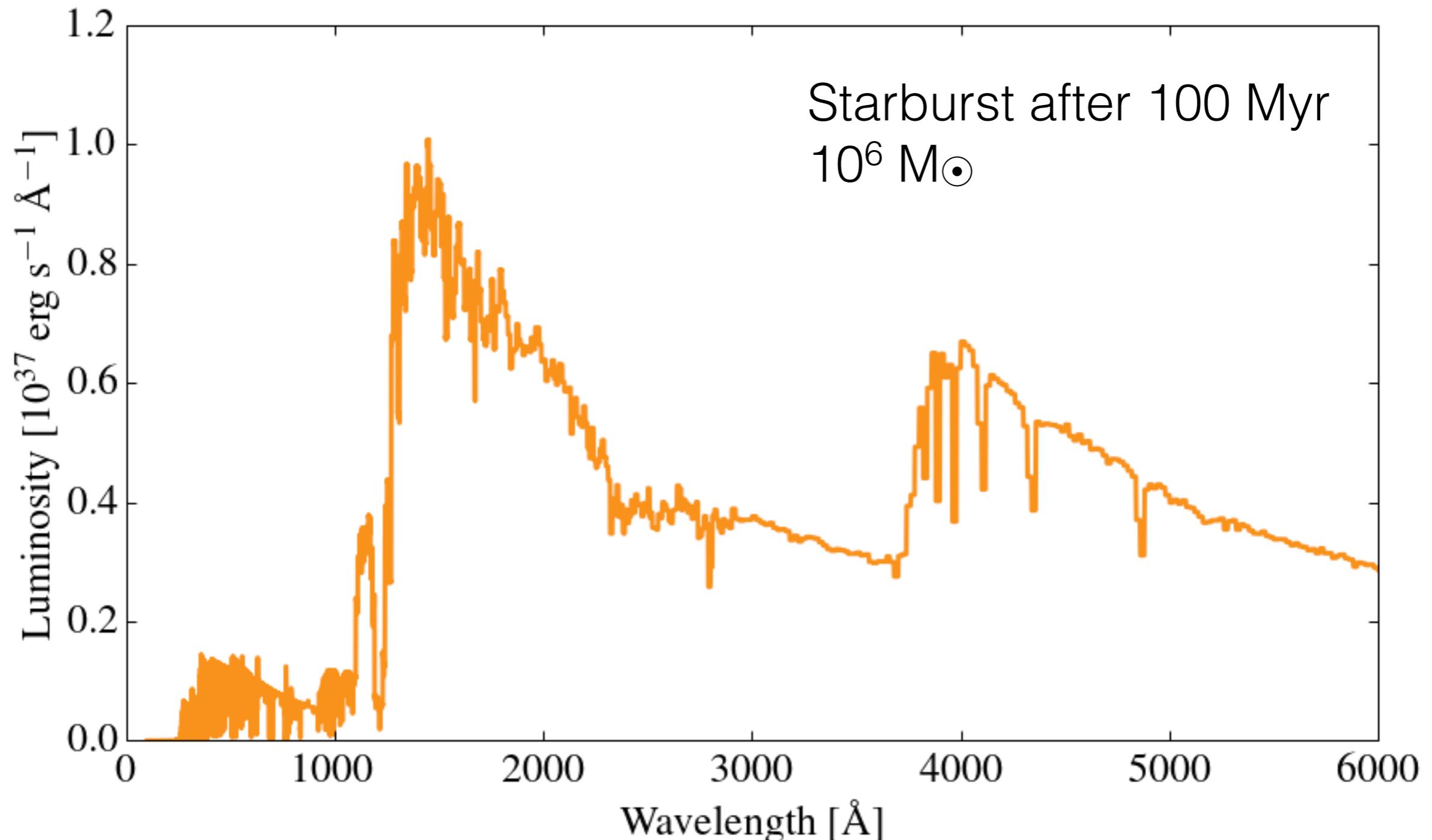
Ionising contribution from stripped stars

Gotberg et al. (in prep.)

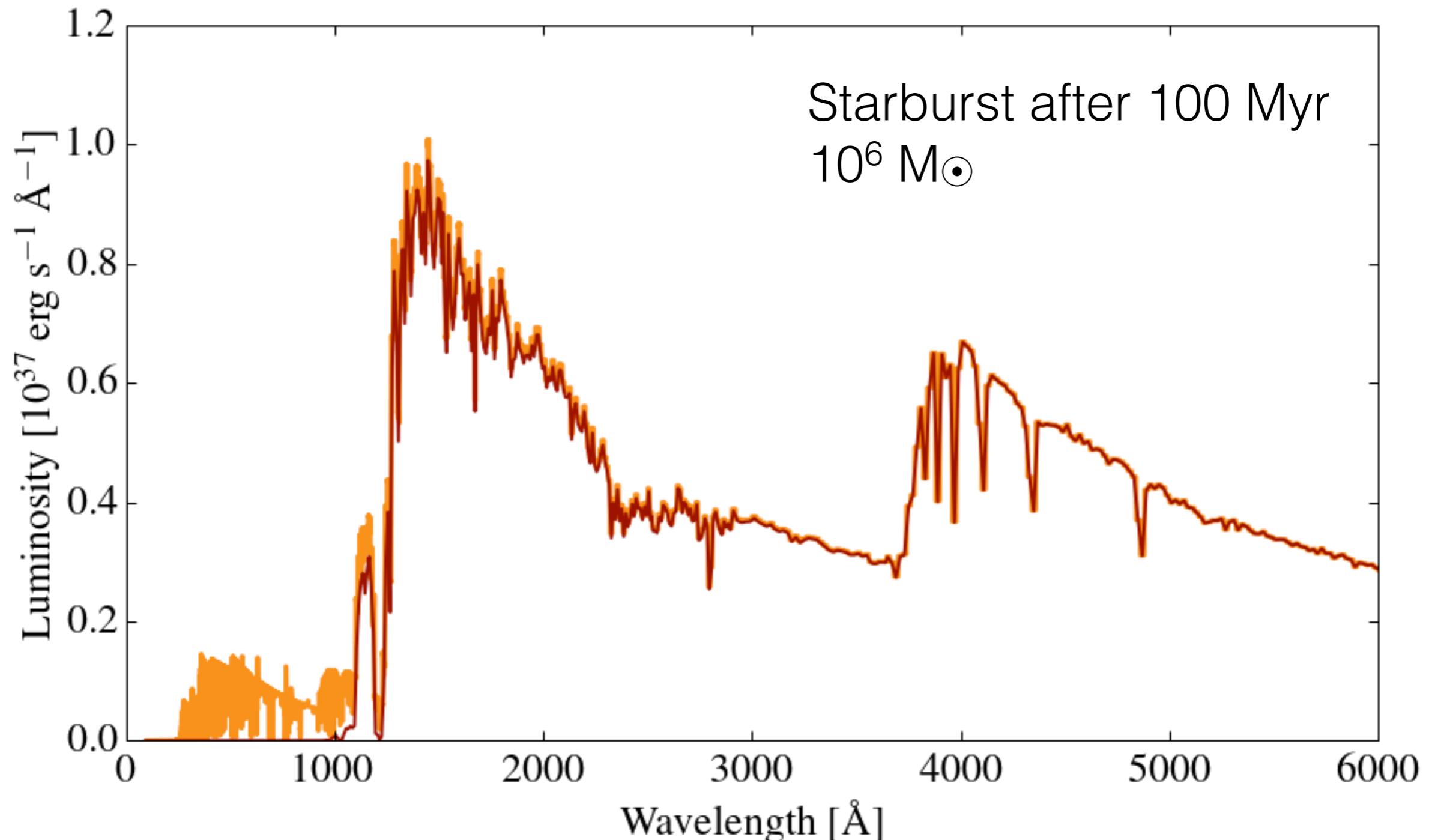


(see also Han et al. 2007, Van Bever et al. 1998, Van Bever & Vanbeveren 2003)

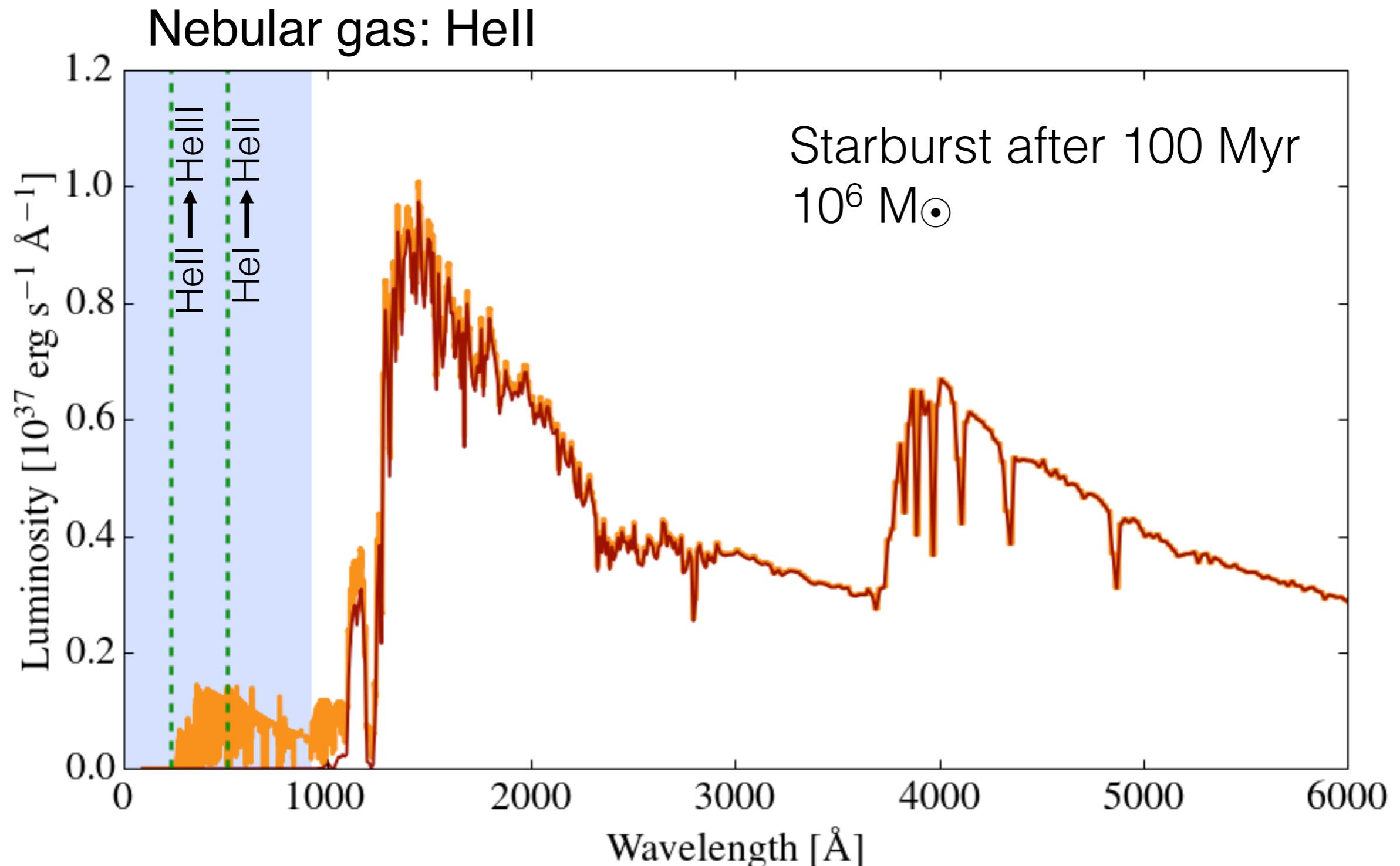
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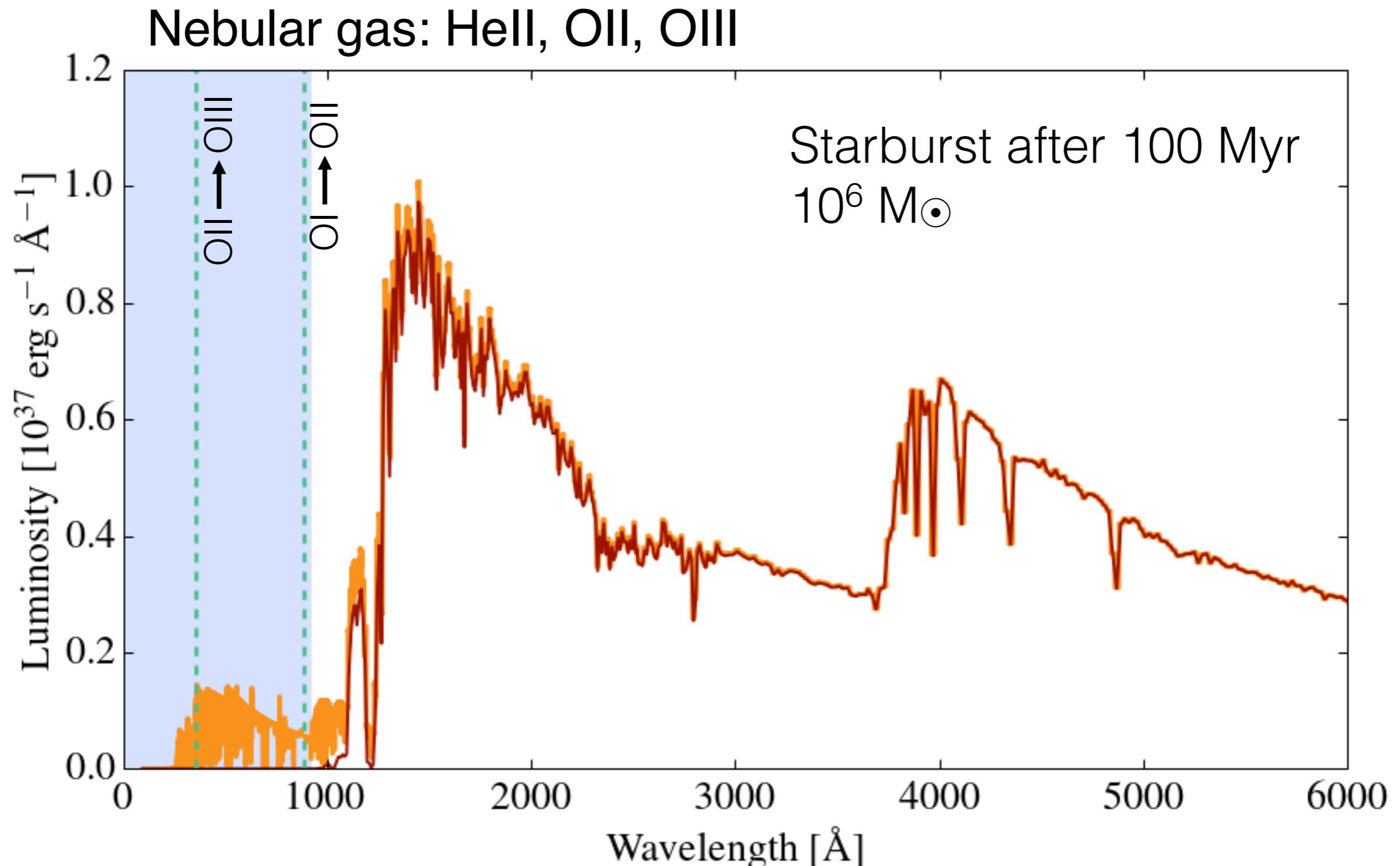
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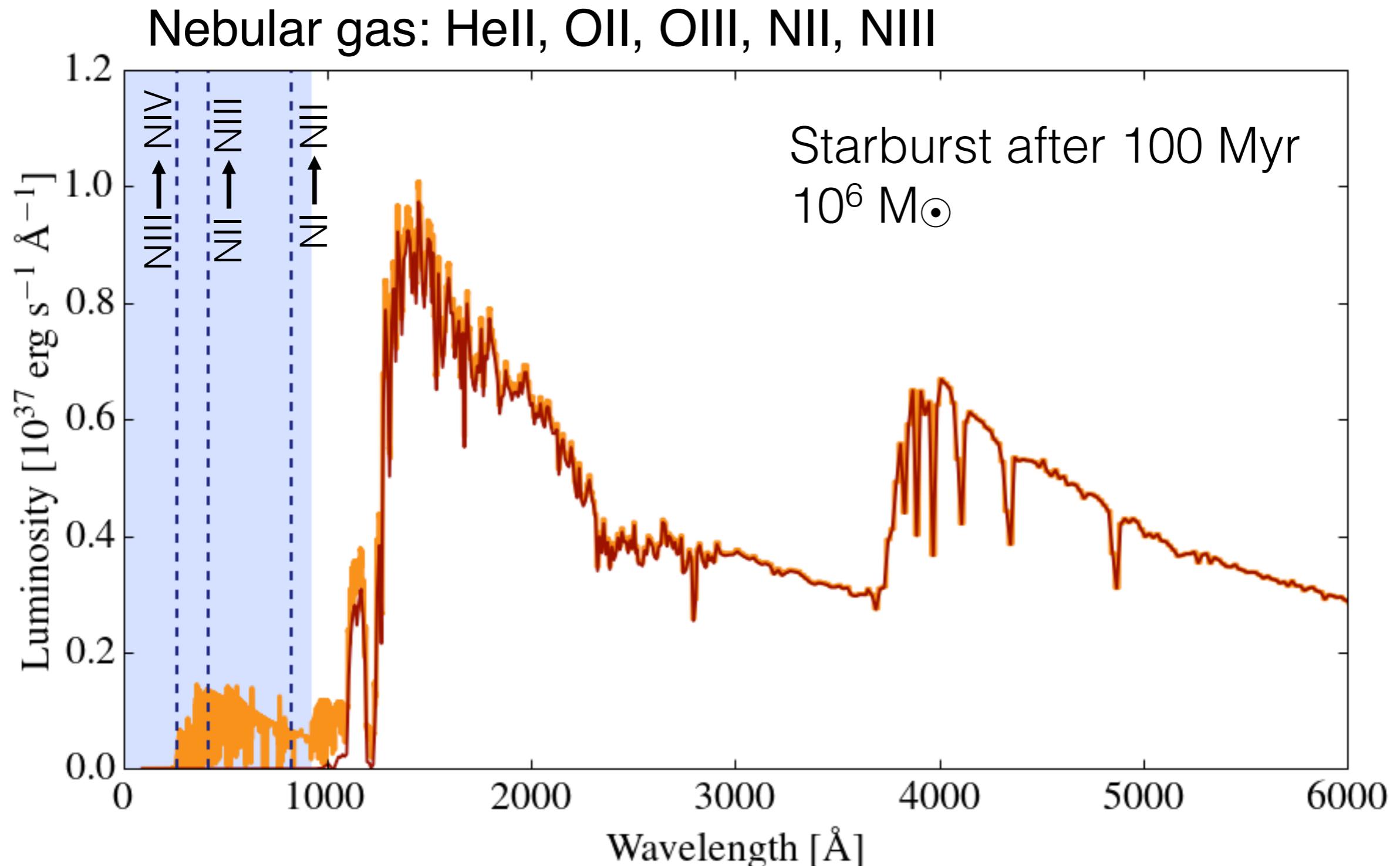
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Including stripped stars in stellar population

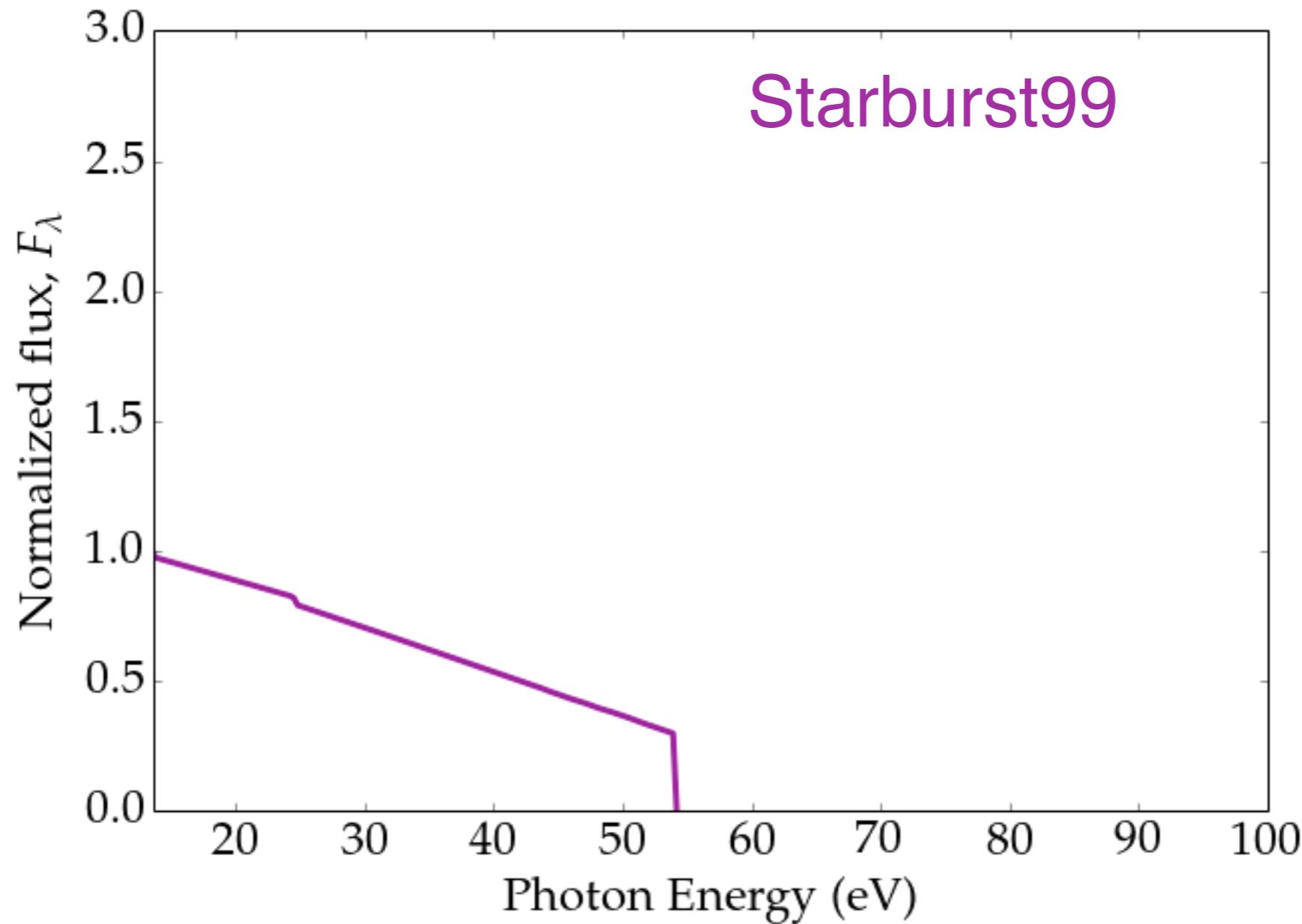


Including stripped stars in stellar population



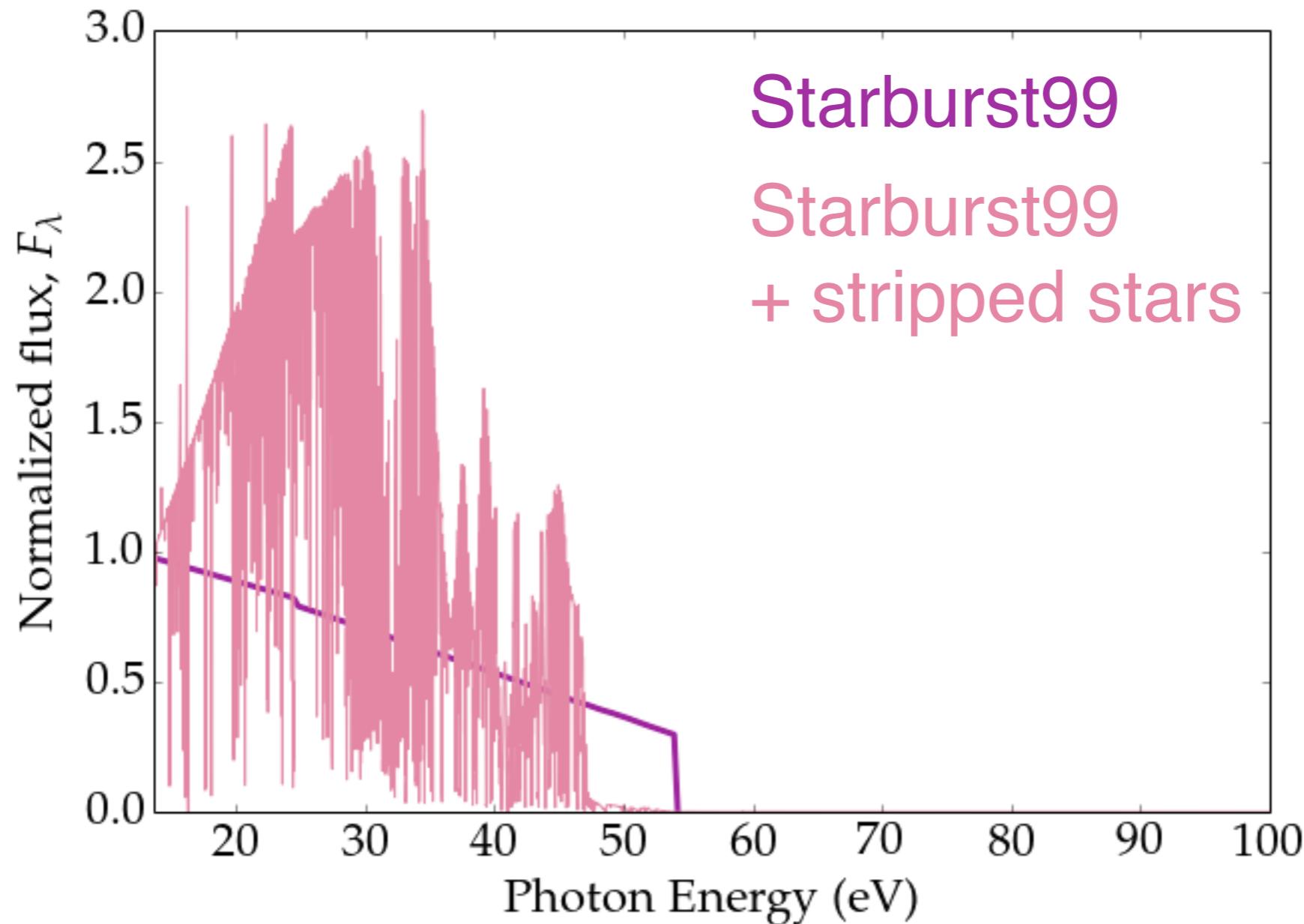
Nebular features

100 Myr starburst
 $Z \sim Z_{\odot}$



Nebular features

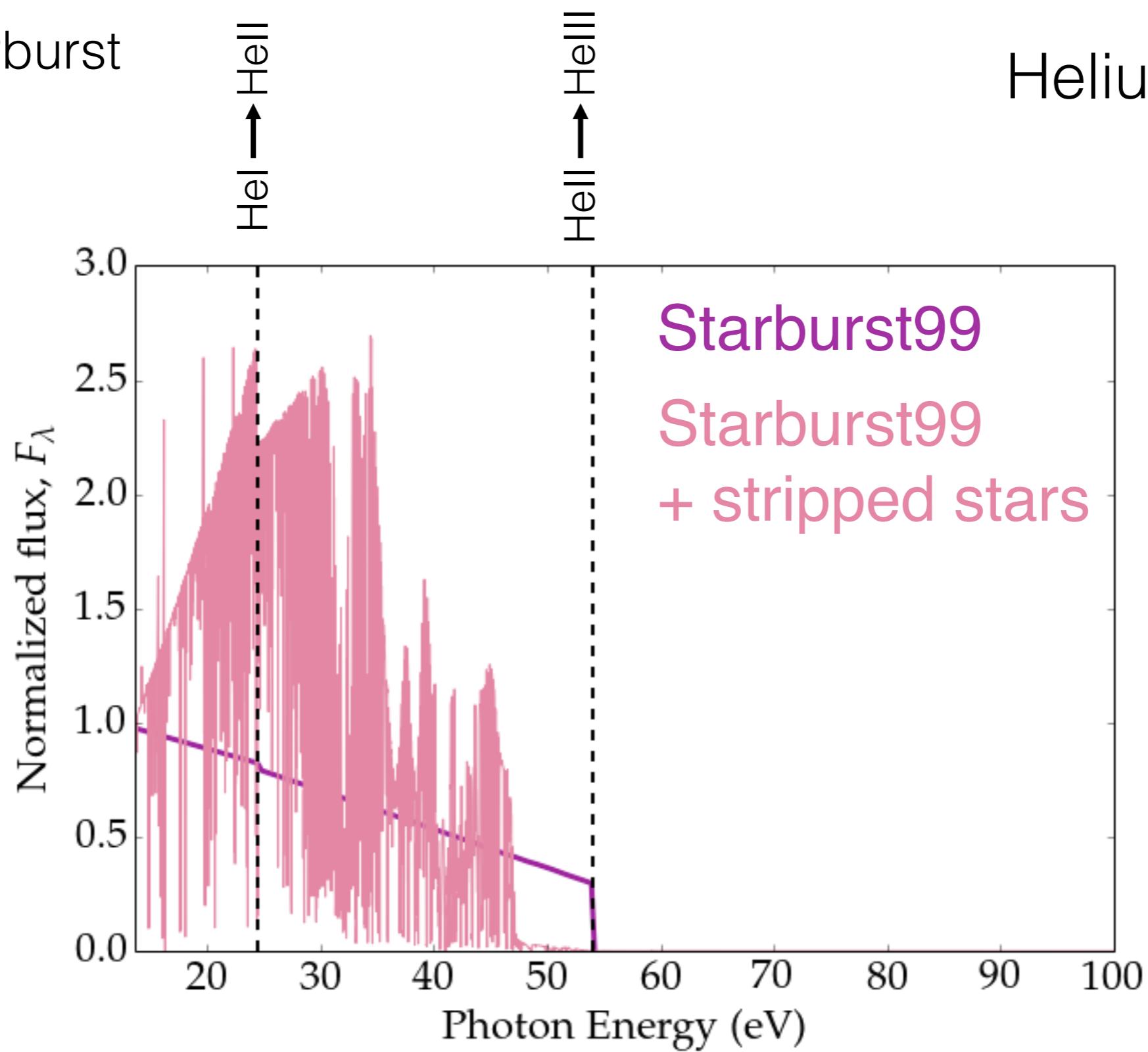
100 Myr starburst
 $Z \sim Z_{\odot}$



Nebular features – Helium

100 Myr starburst
 $Z \sim Z_{\odot}$

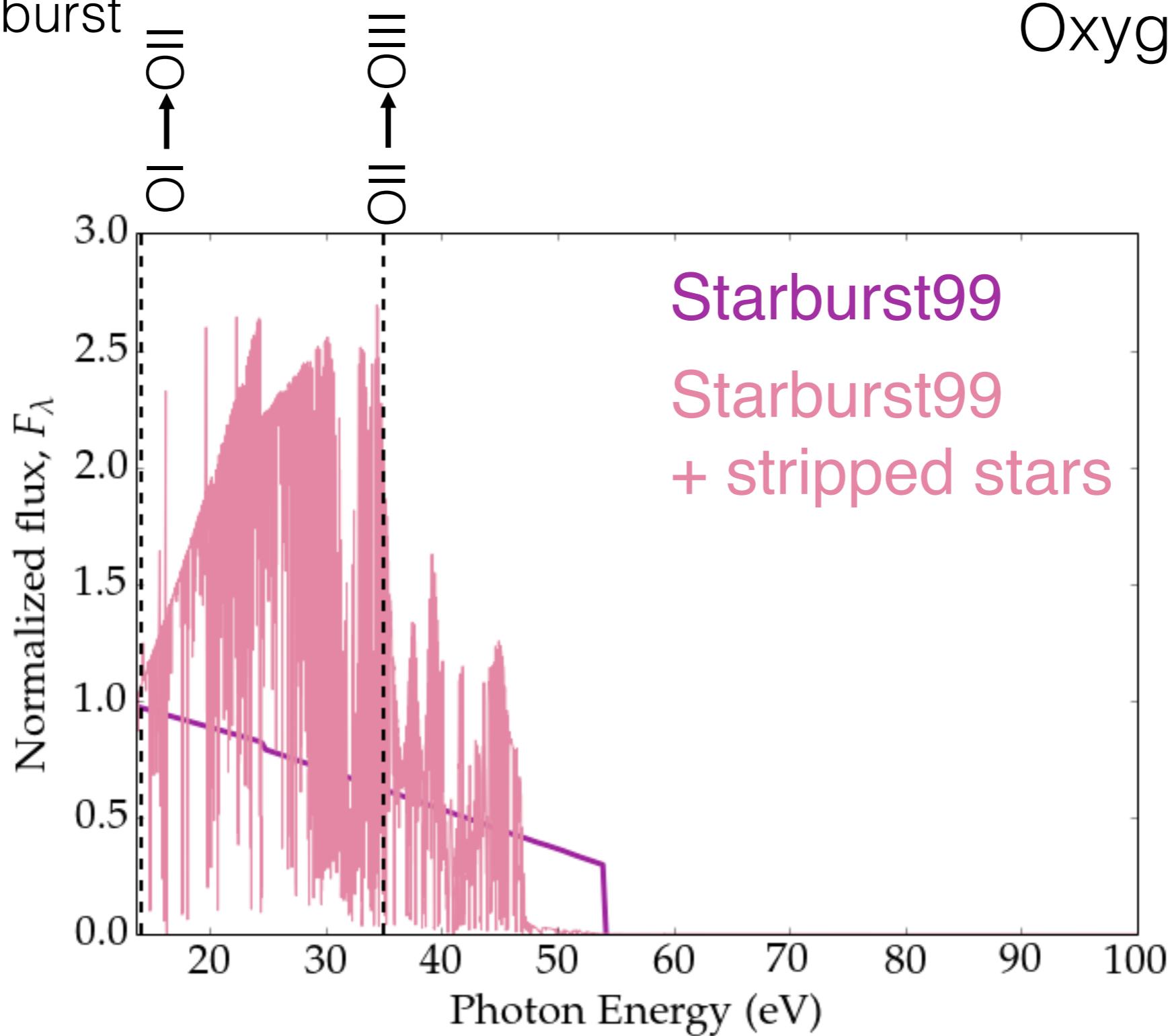
Helium in Hell?



Nebular features – Oxygen

100 Myr starburst
 $Z \sim Z_{\odot}$

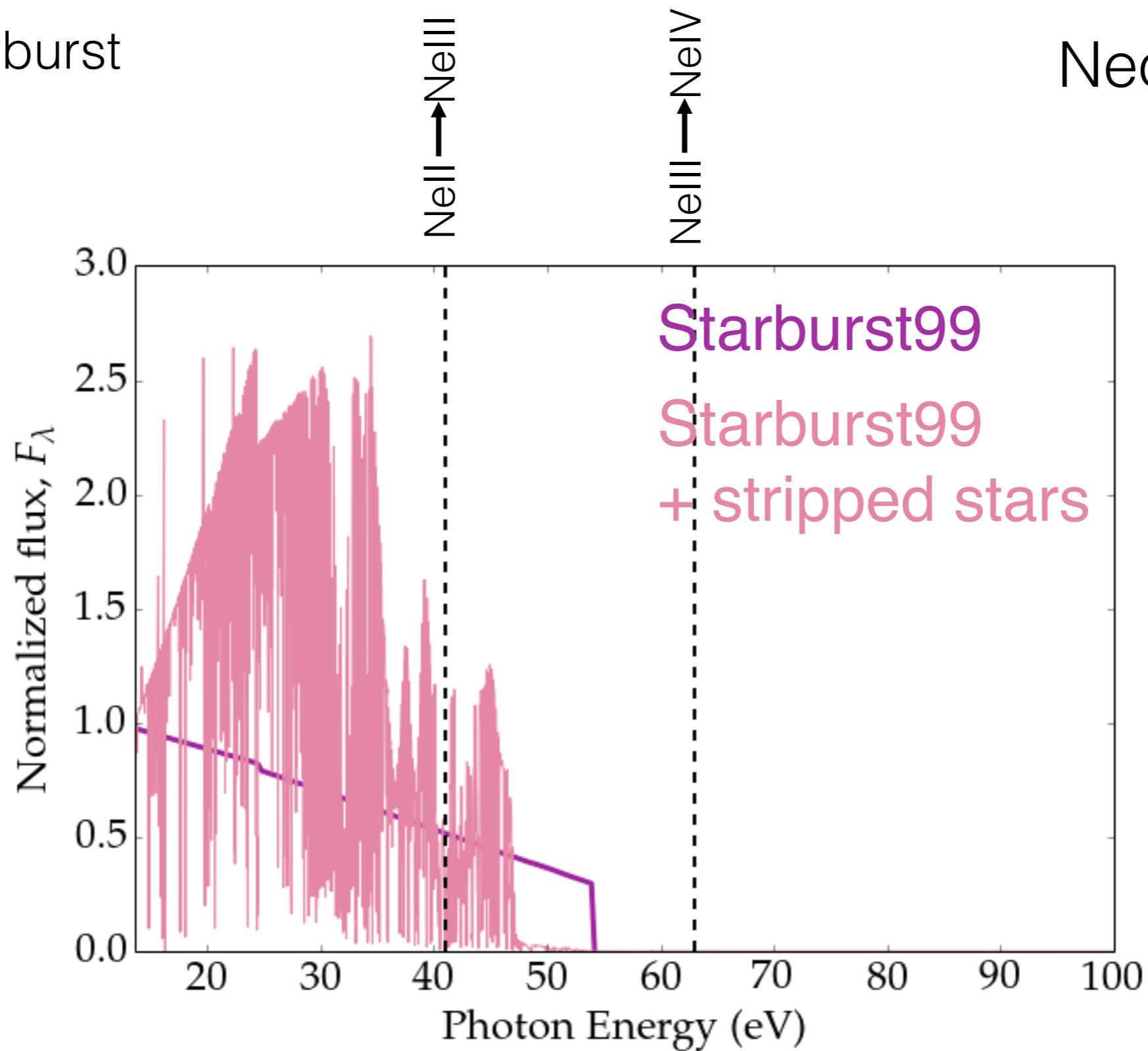
Oxygen in OIII?



Nebular features – Neon

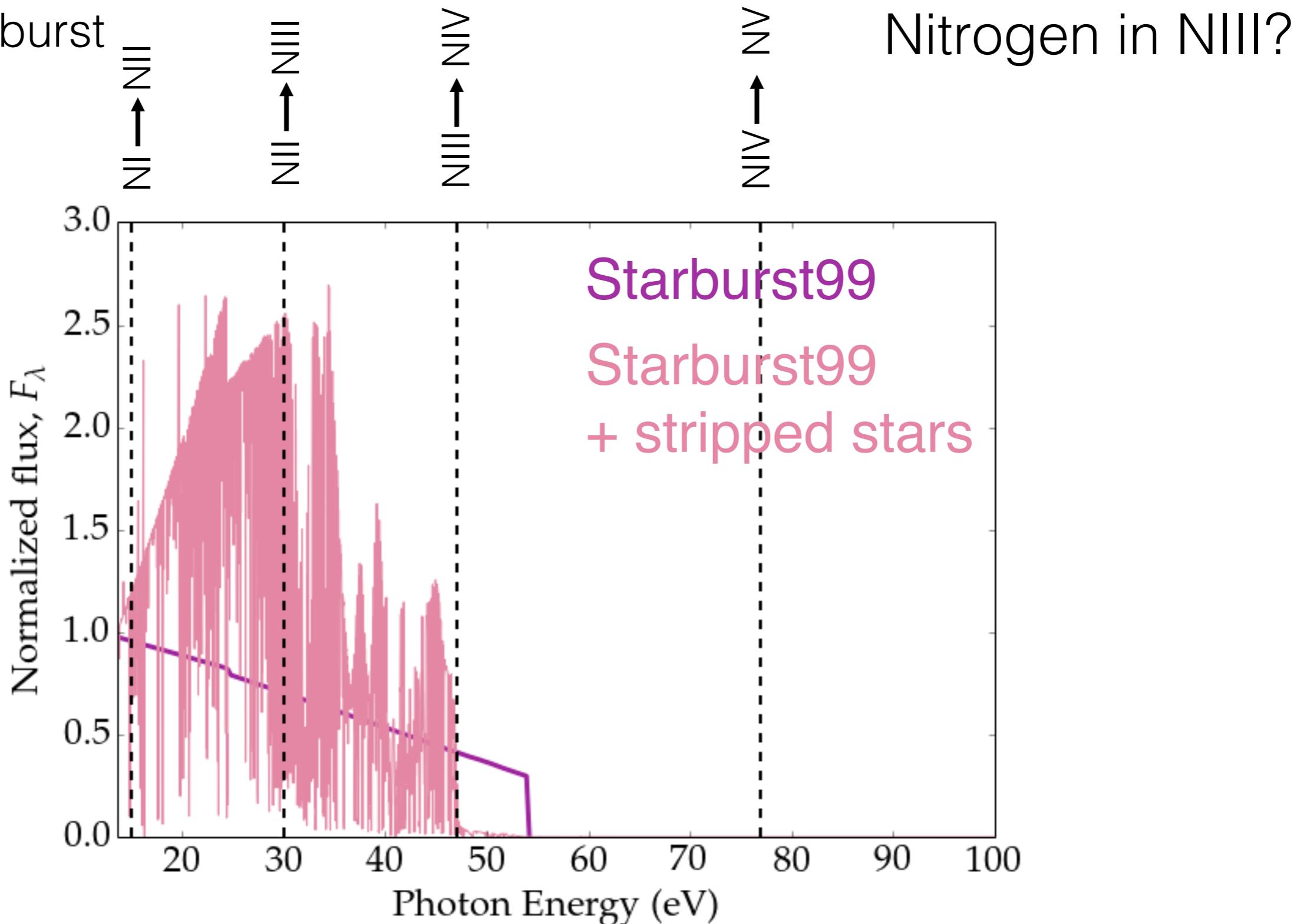
100 Myr starburst
 $Z \sim Z_{\odot}$

Neon in NeII?



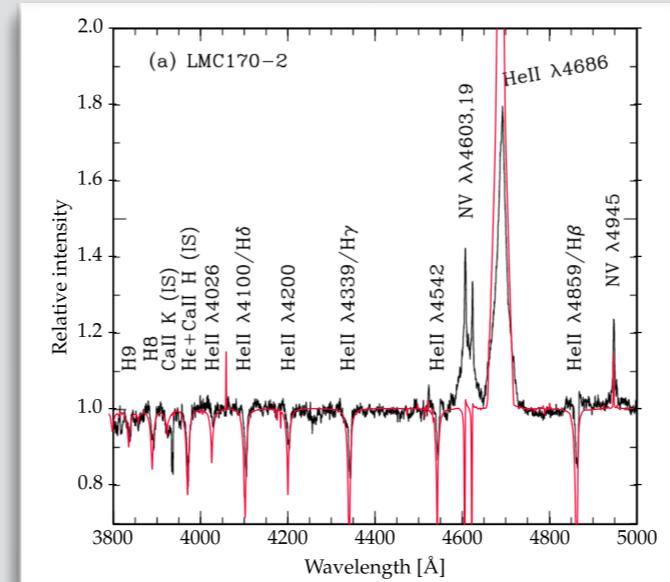
Nebular features – Nitrogen

100 Myr starburst
 $Z \sim Z_{\odot}$



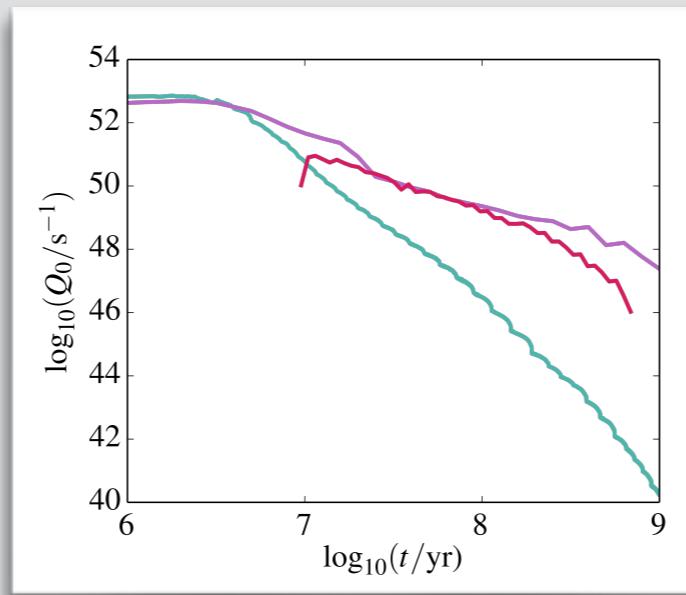
1

How to observe stripped stars?



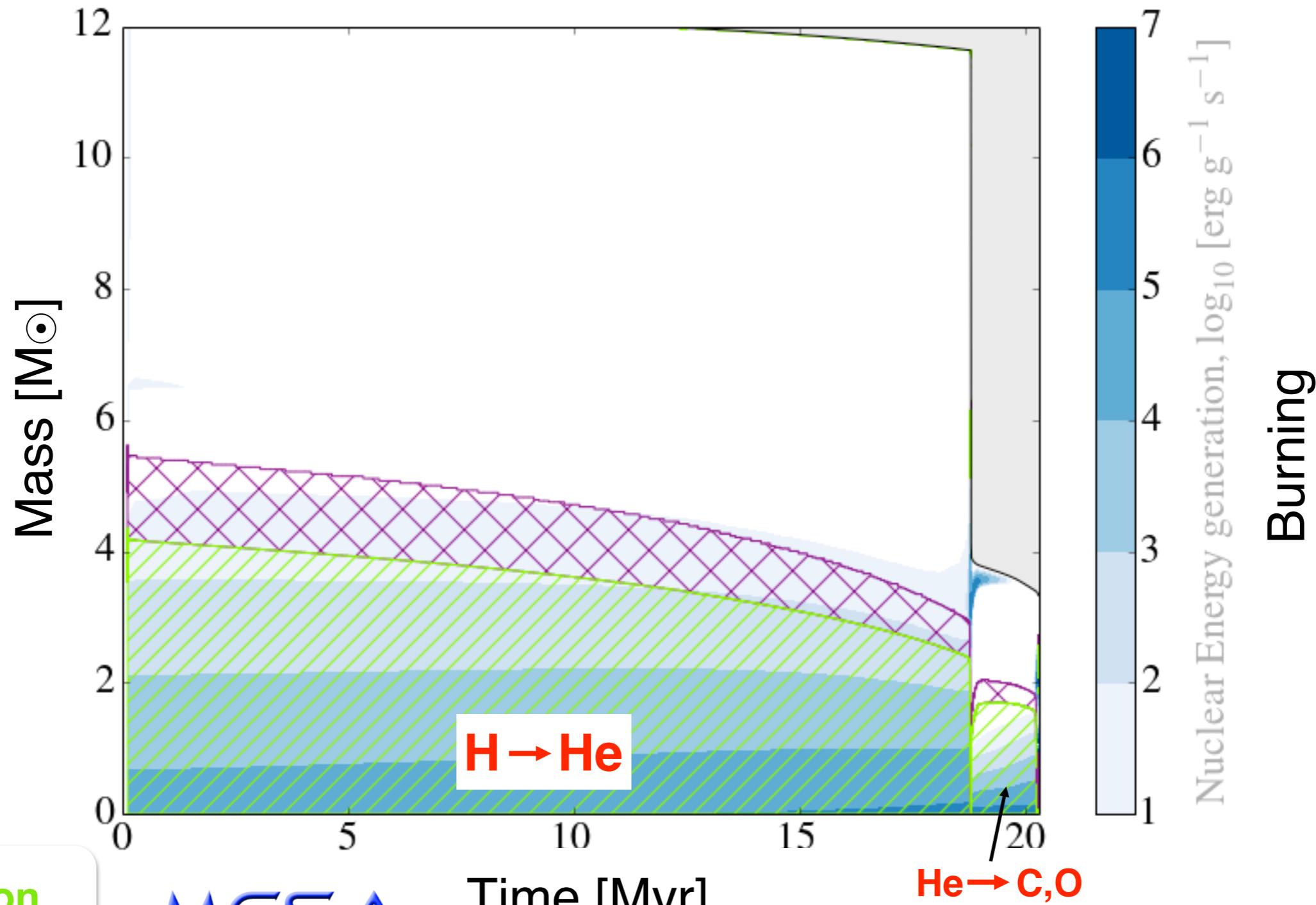
2

Enough ionising flux from stripped stars to affect the surrounding?



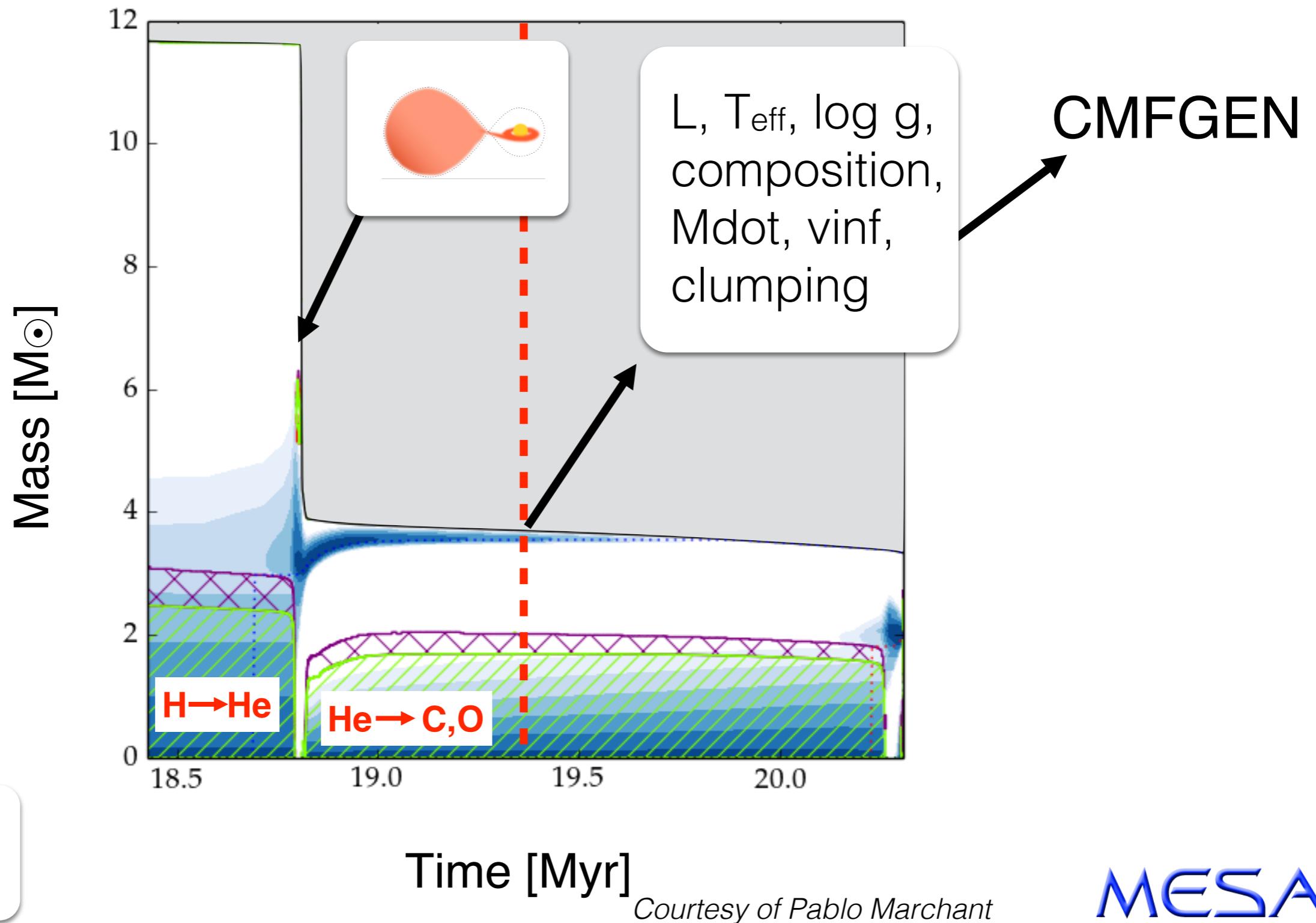
Backup slides

The interior structure of a stripped star

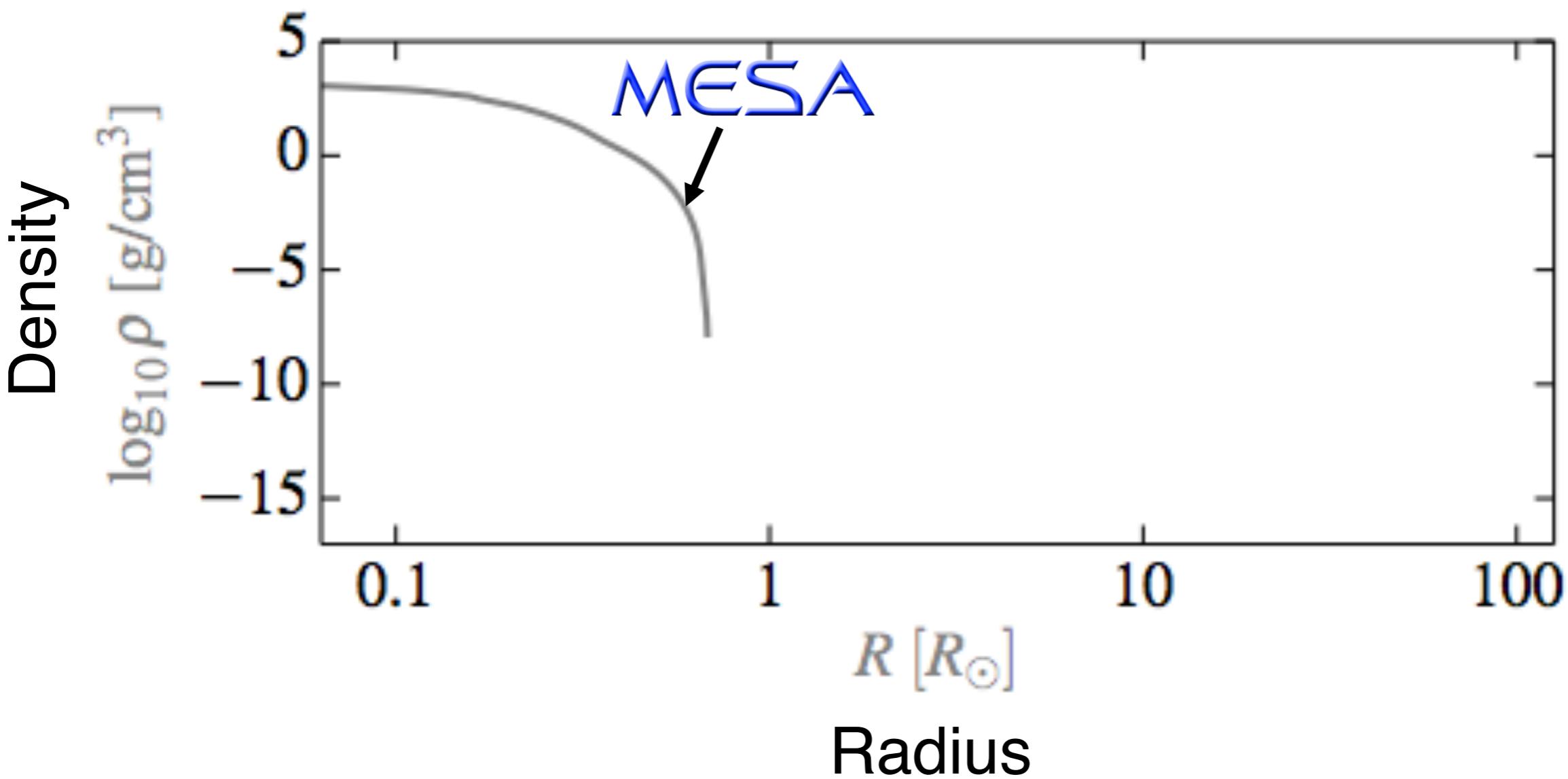


(Kippenhahn & Weigert, 1967)

The interior structure of a stripped star

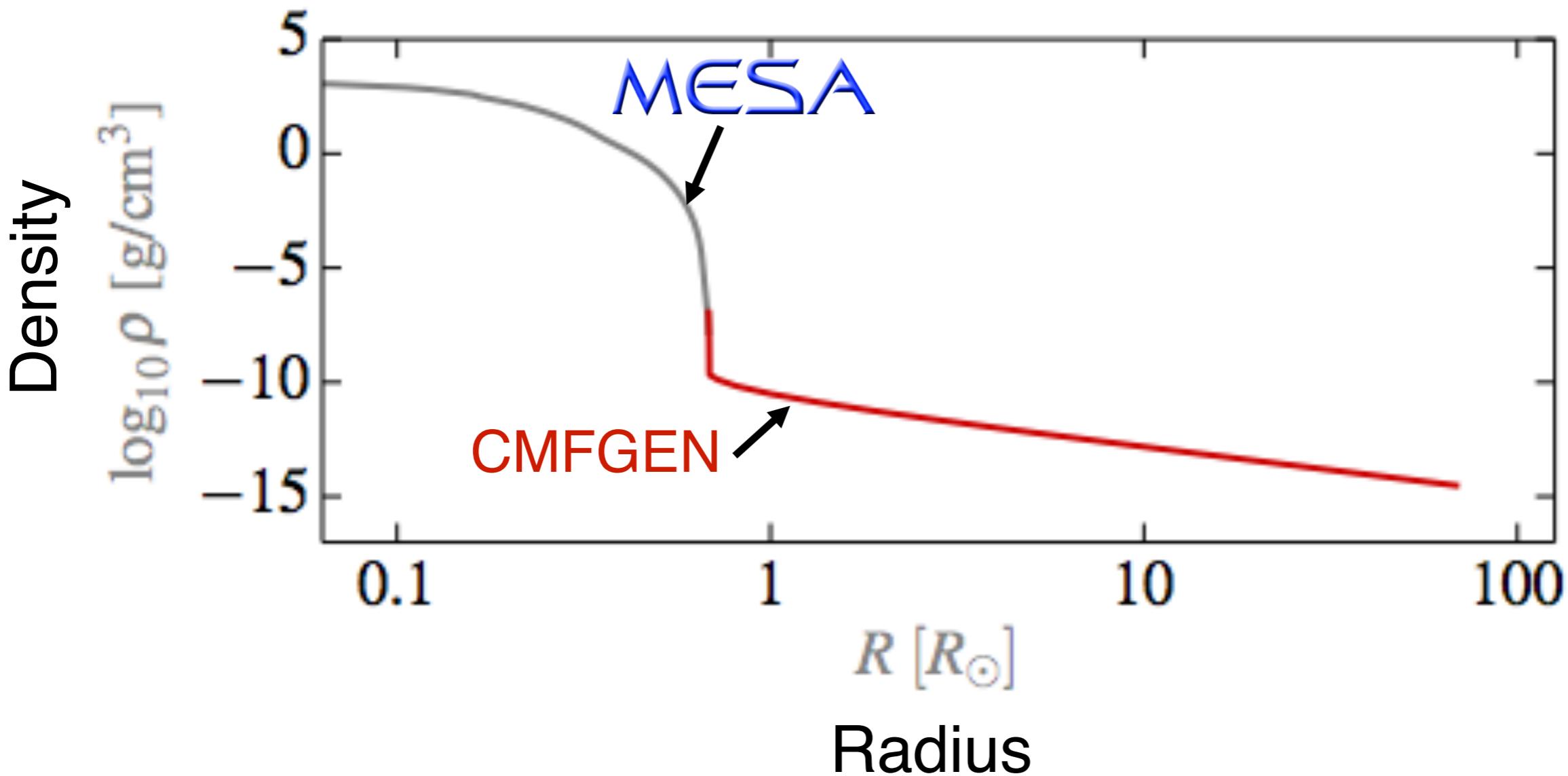


Modeling the atmosphere



Modeling the atmosphere

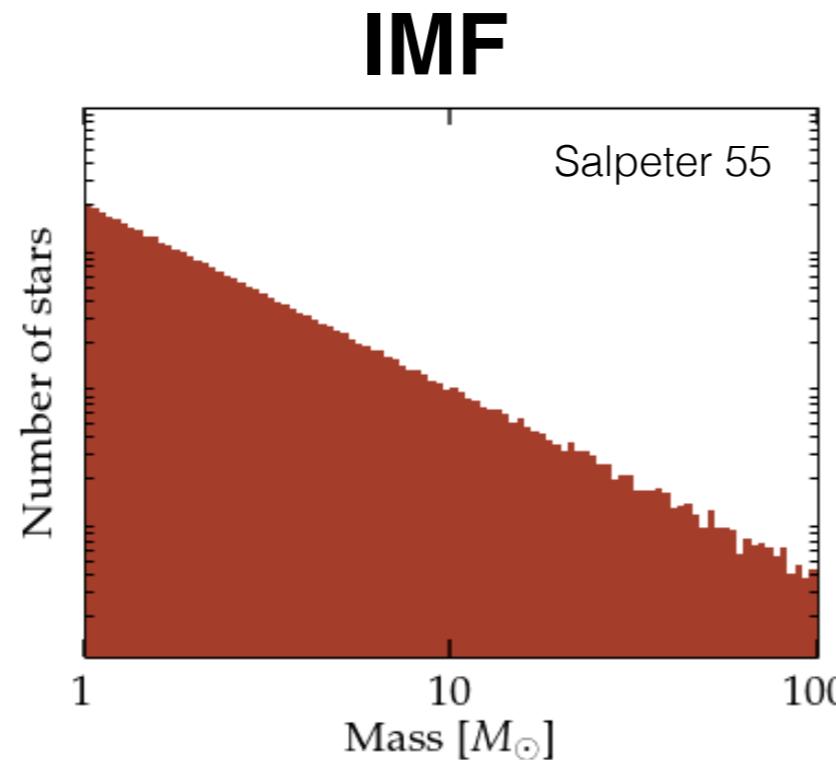
Gotberg et al. (arXiv: 1701.07439)



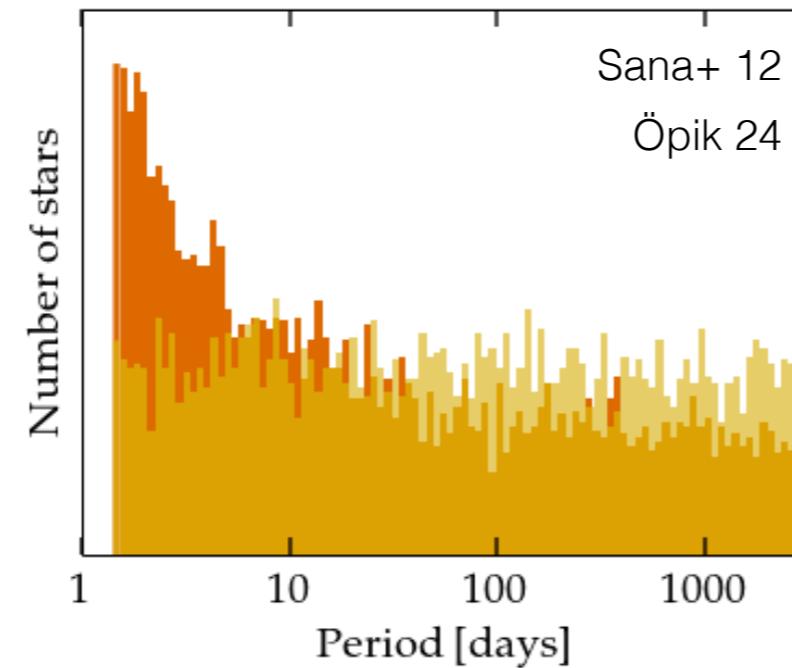
(Groh et al. 2014)

A population with binaries: initial distributions

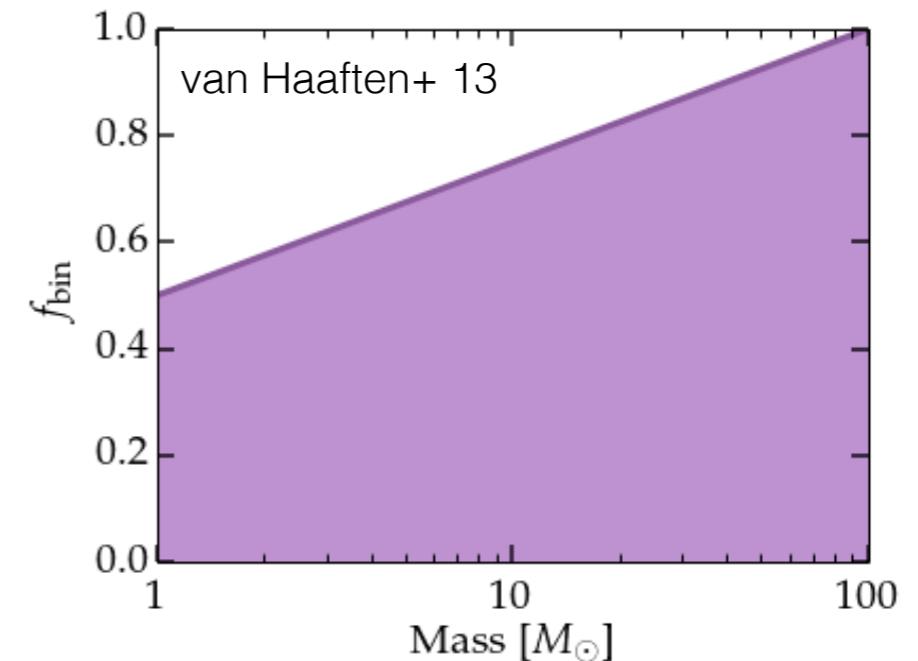
$10^6 M_{\odot}$
starburst
 Z_{LMC}



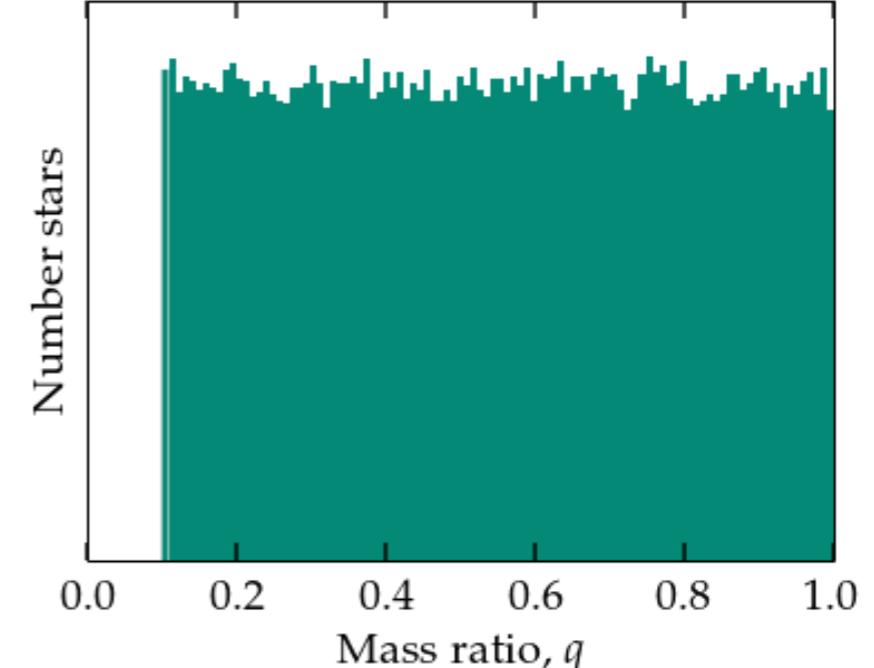
Period distribution



Binary fraction

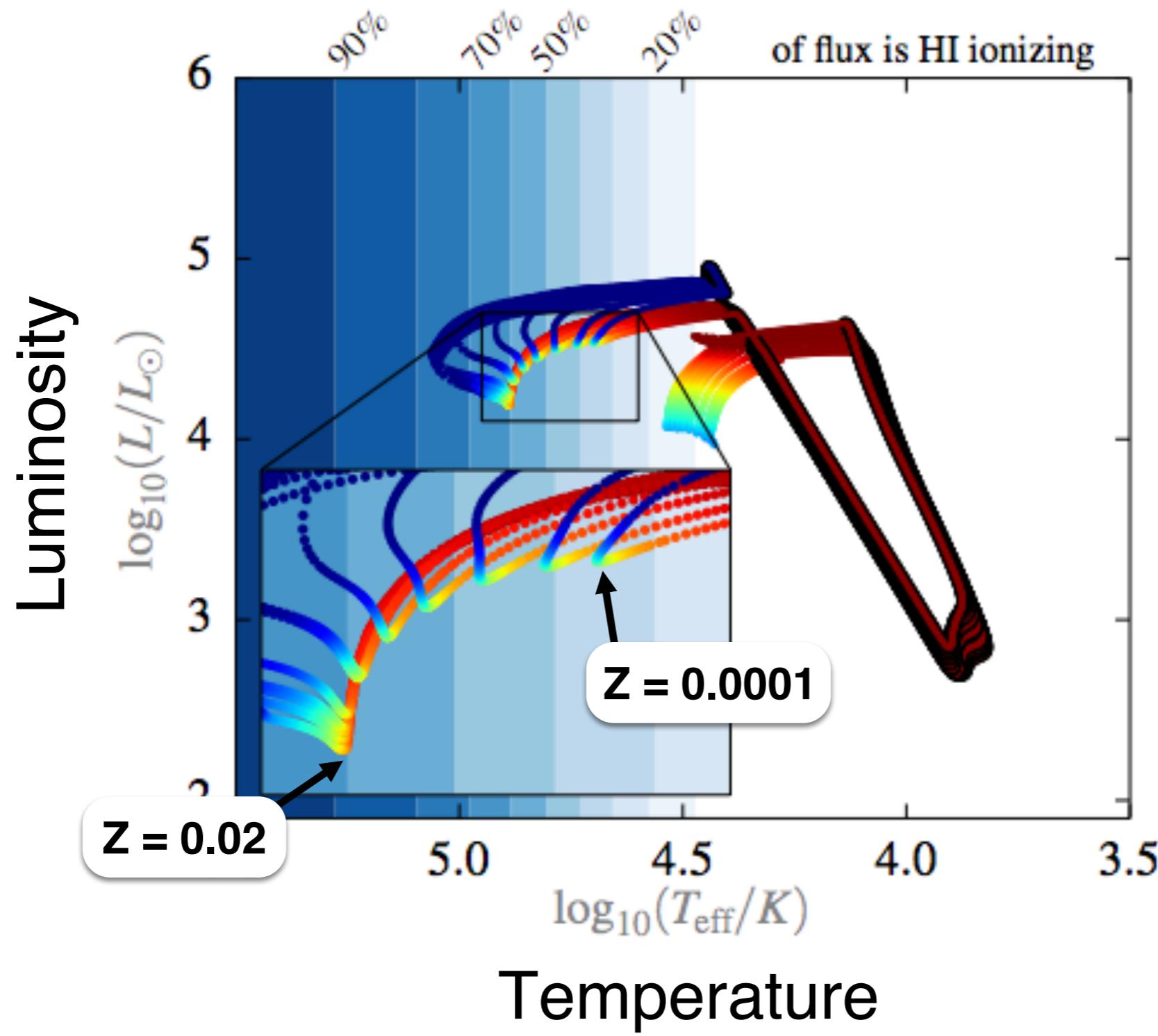


Mass ratio distribution



Metallicity dependence

Gotberg et al. (arXiv: 1701.07439)

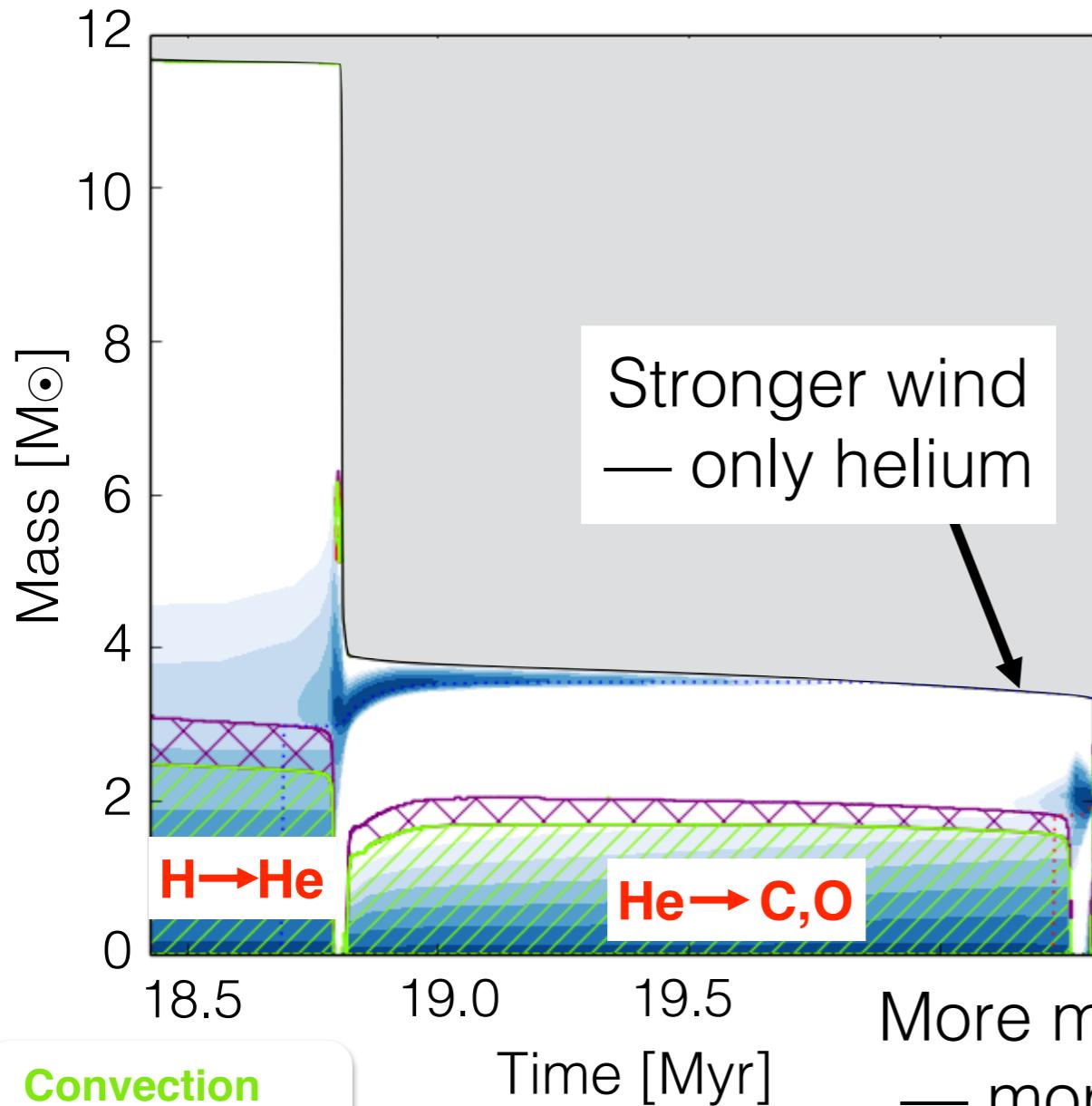


MESA

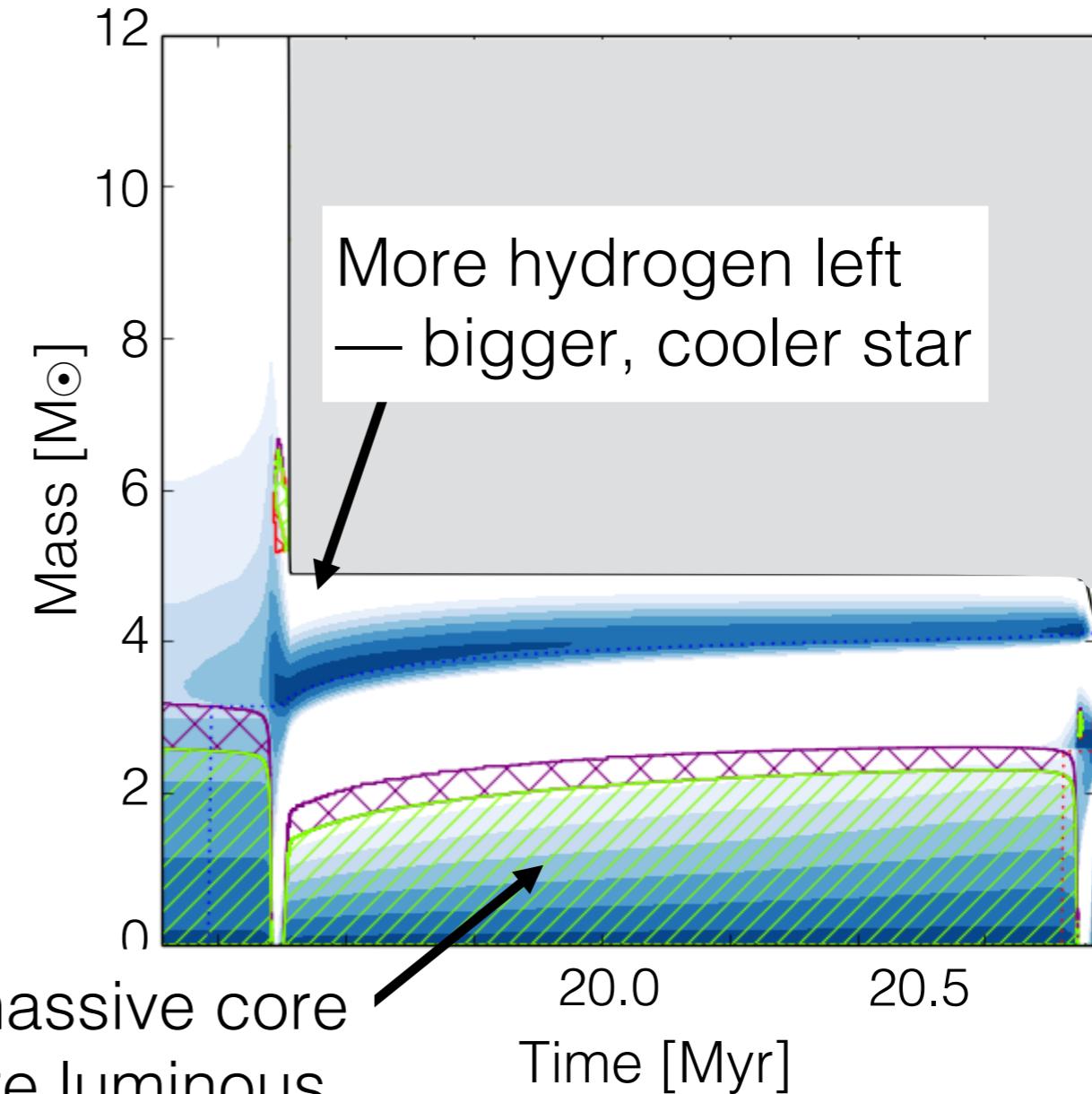
Low metallicity strips less

Gotberg et al. (arXiv: 1701.07439)

High metallicity



Low metallicity

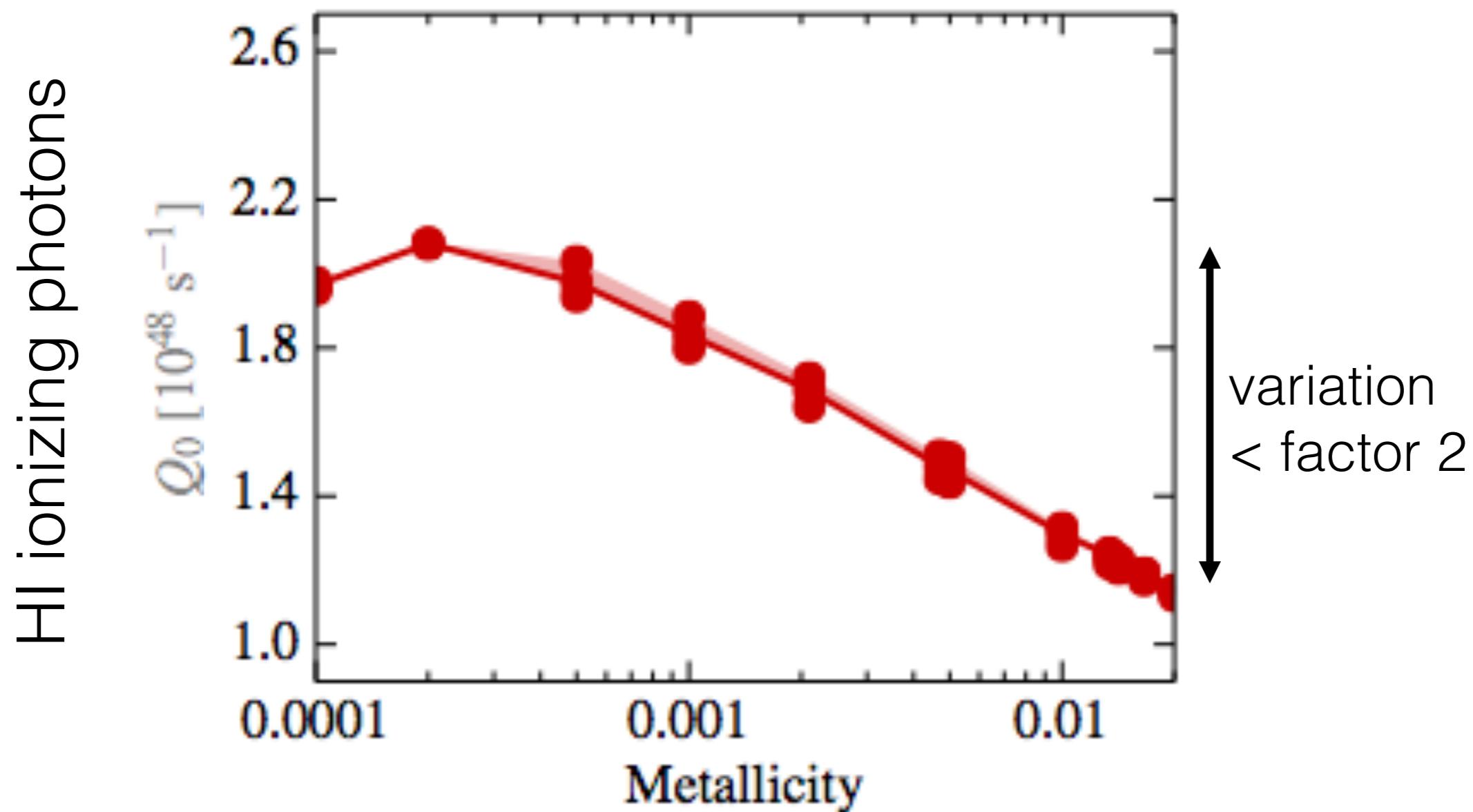


Courtesy of Pablo Marchant

MESA

Ionizing photons

Gotberg et al. (arXiv: 1701.07439)

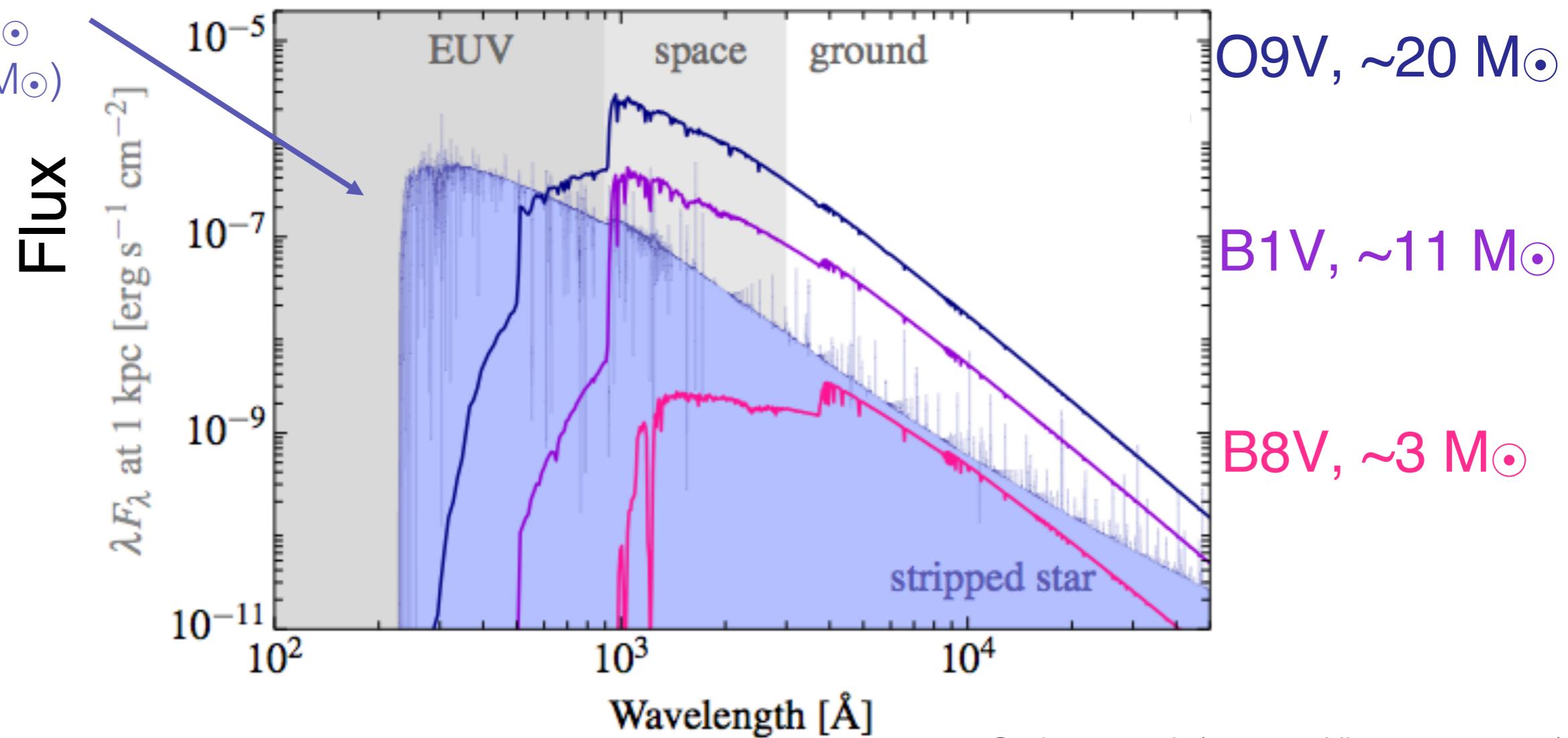


$M_{\text{init}} = 12 M_{\odot}$

Composite spectra

stripped star

$M_{\text{strip}} = 4 M_{\odot}$
($M_{\text{init}} = 12 M_{\odot}$)



Gotberg et al. (2017, arXiv: 1701.07439)