Massive stars in the metal-poor Universe

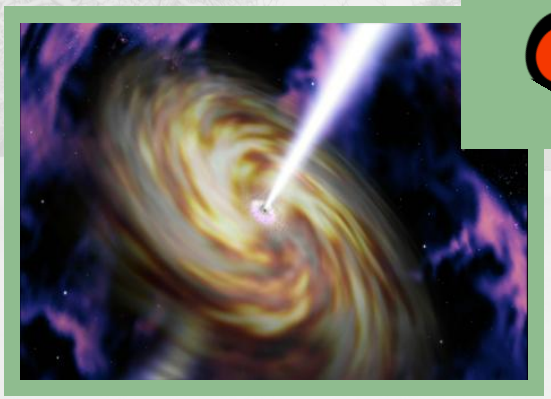
Resarch Experiences and Plans

Dr. Dorottya Szécsi

UNIVERSITY OF BIRMINGHAM

Massive stars with $Z < 0.1\ Z_{\odot}$

Hubble deep field



Cosmic explosions (GRBs, SNe, GW...)

Massive stars with $Z < 0.1\ Z_{\odot}$

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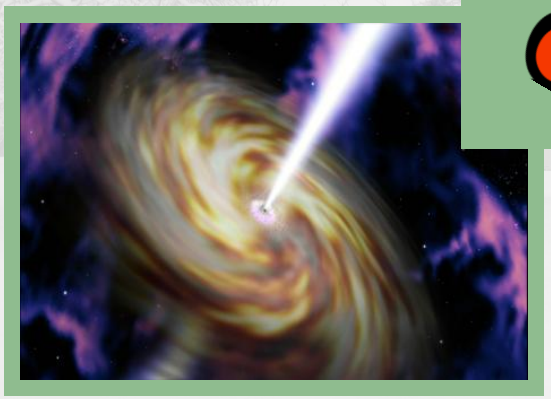
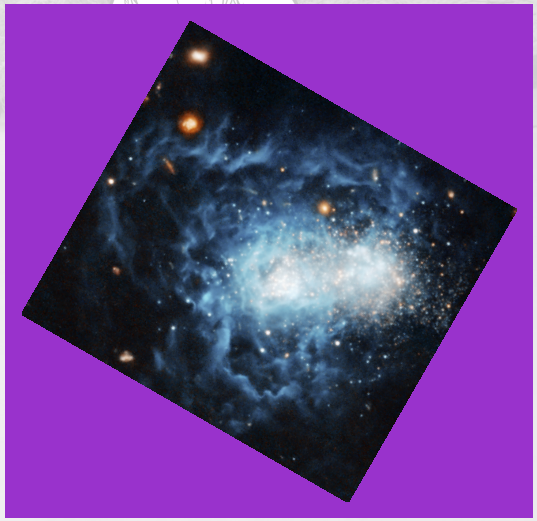


Cosmic explosions (GRBs, SNe, GW...)

In the Milky Way...

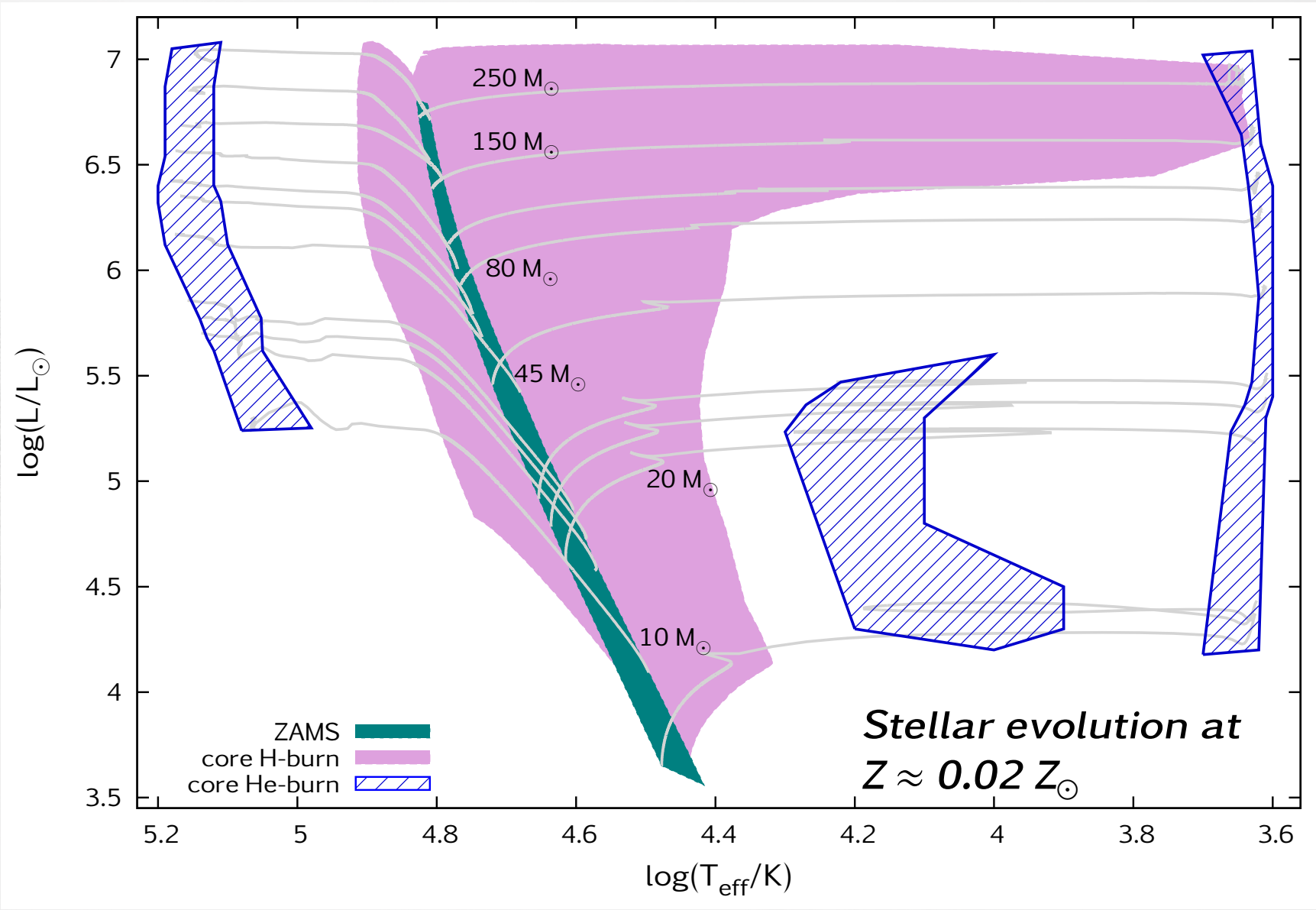
47 Tucanae (Globular Cluster)

Close enough...



I Zwicky 18 (dwarf galaxy)

The theory of the Yeti...



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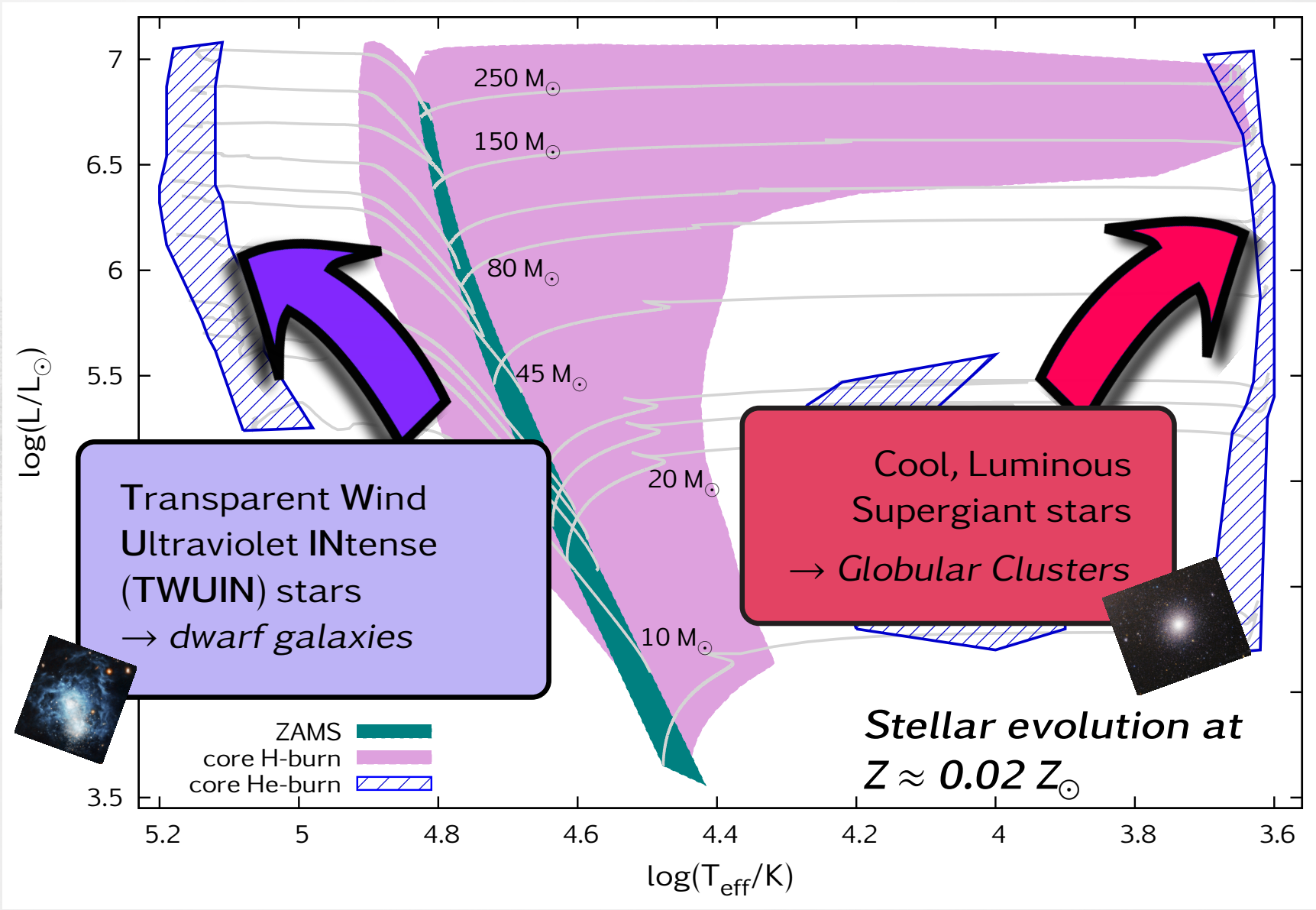
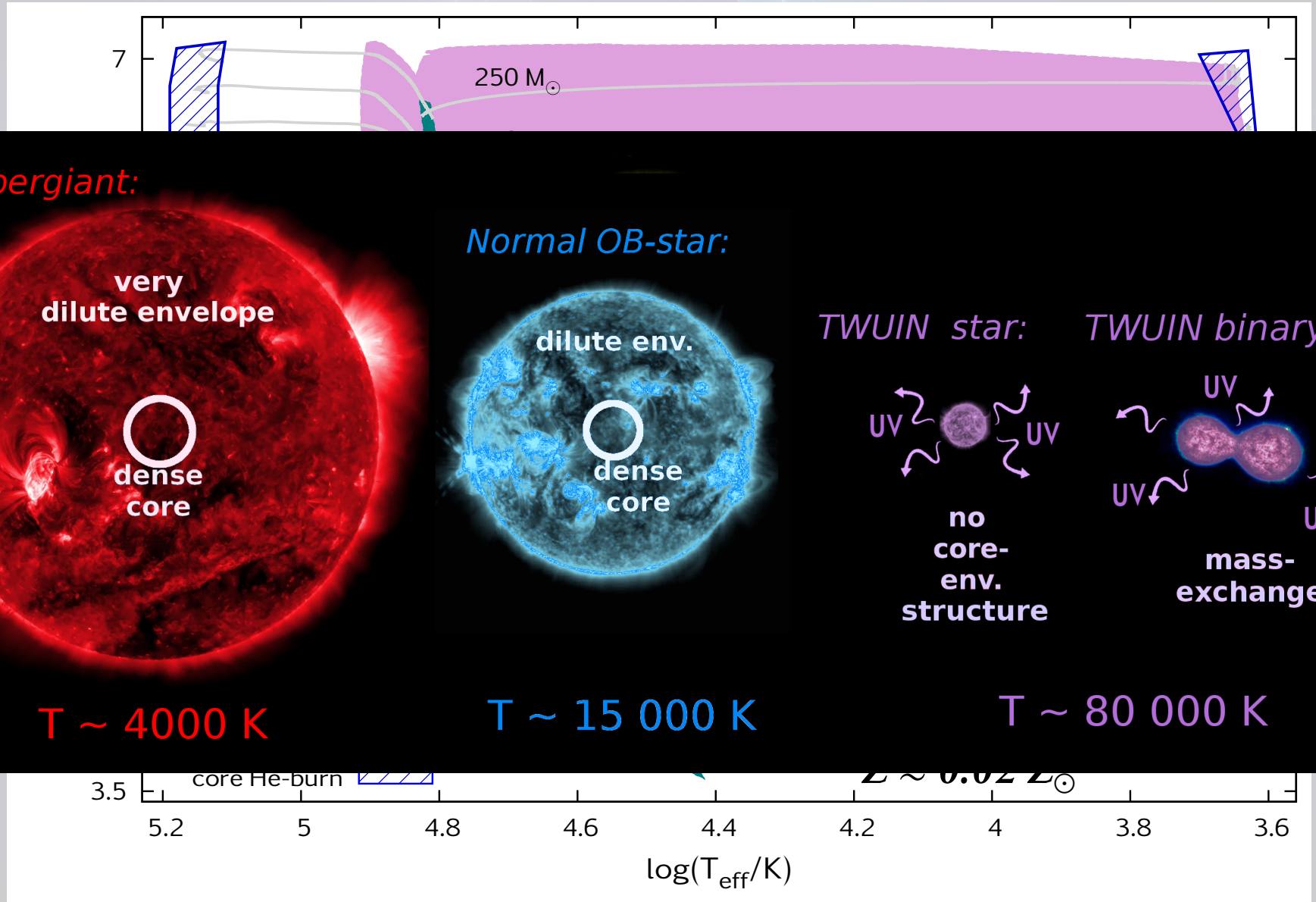


PhD: The evolution of low-Z massive stars



Red supergiant:

very dilute envelope

dense core

T ~ 4000 K

Normal OB-star:

dilute env.

dense core

T ~ 15 000 K

TWUIN star:

UV

UV

no core-env. structure

TWUIN binary:

UV

UV

UV

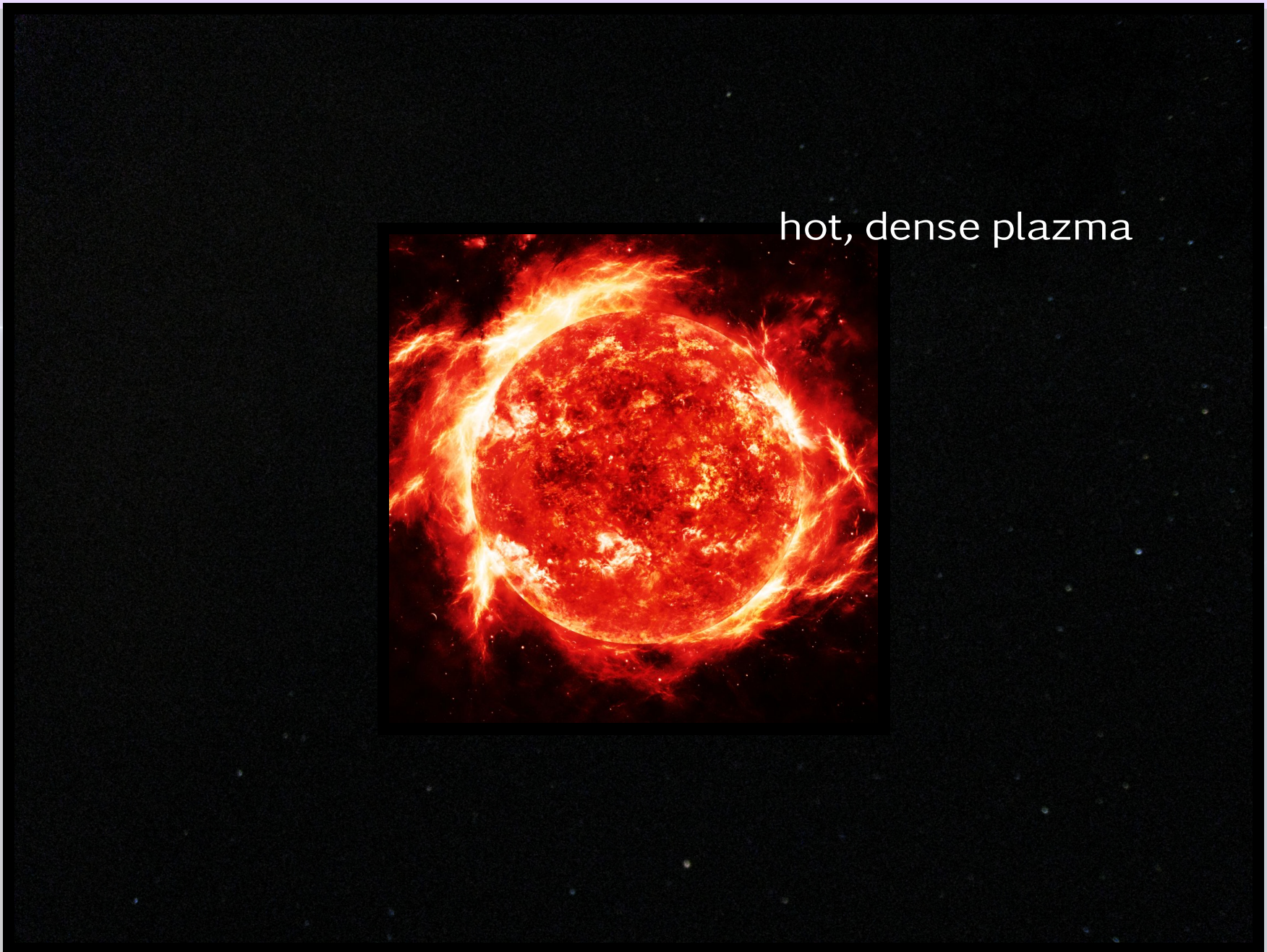
mass-exchange!

T ~ 80 000 K

What is a star?

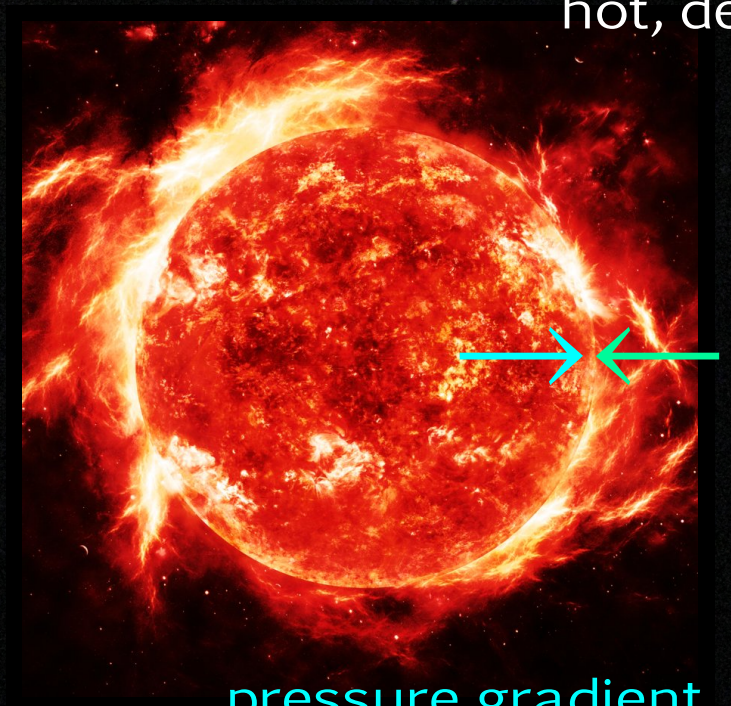
What is a star?

What is a star?



What is a star?

hot, dense plazma



equilibrium: pressure gradient gravity

What is a star?

surface?

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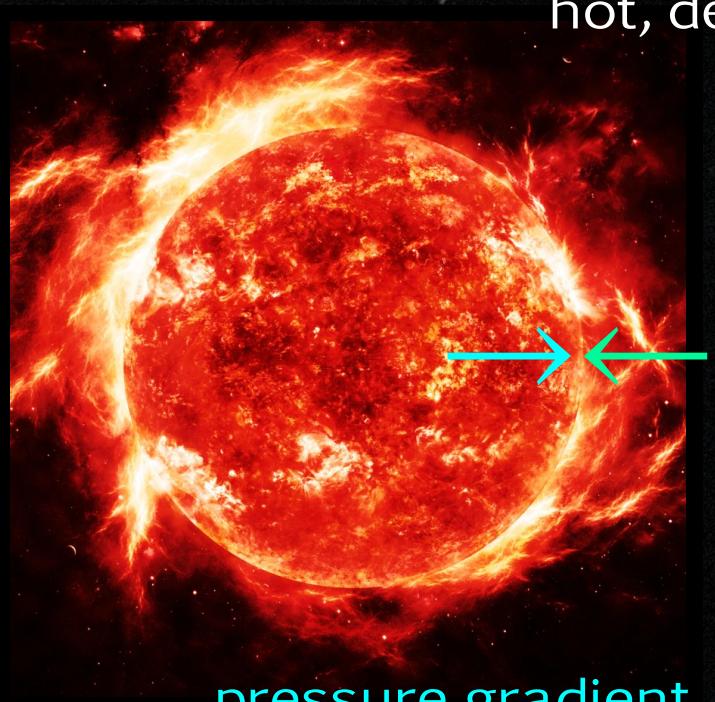

equilibrium: pressure gradient gravity

What is a star?

surface?
→ photons escape
"photosphere"

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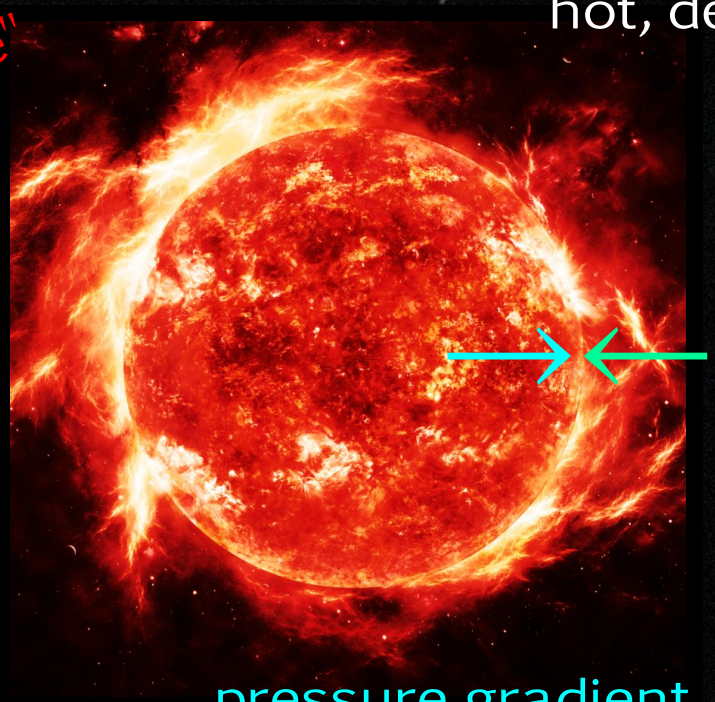

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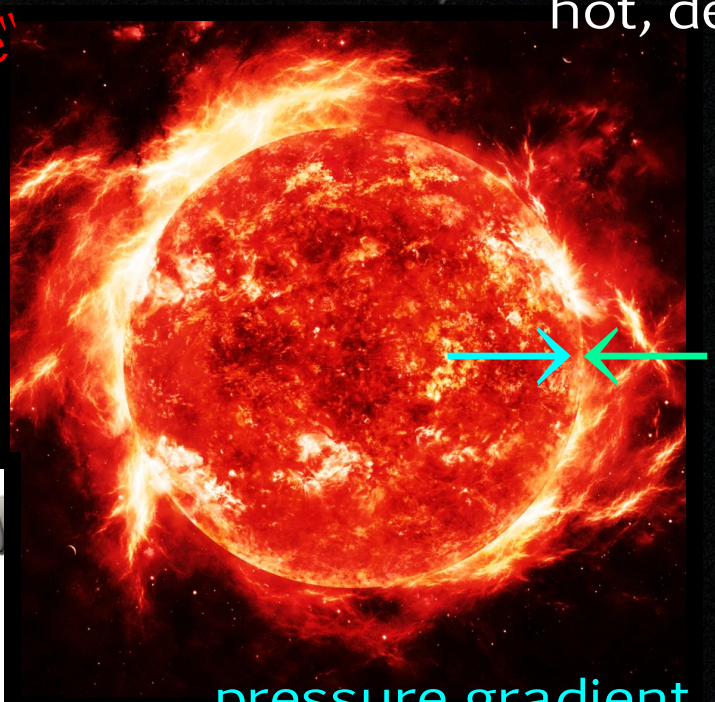

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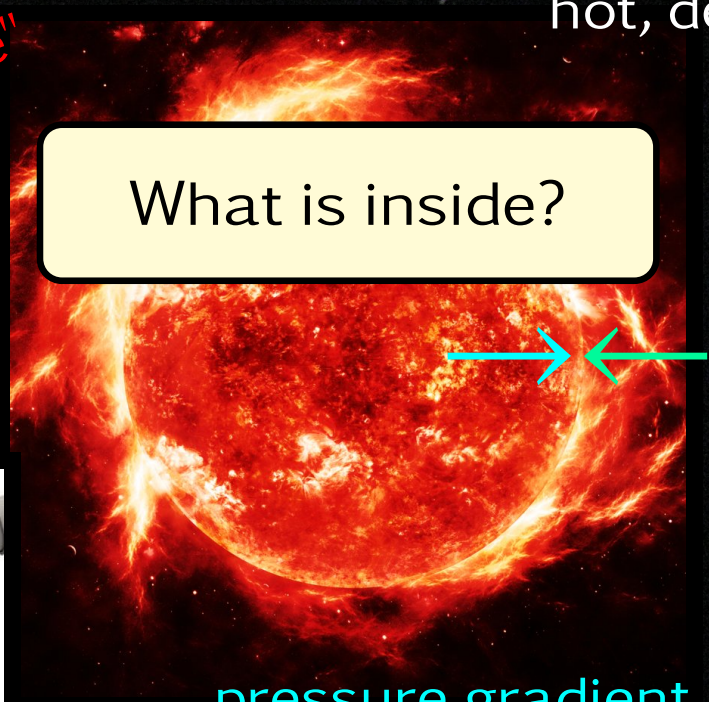
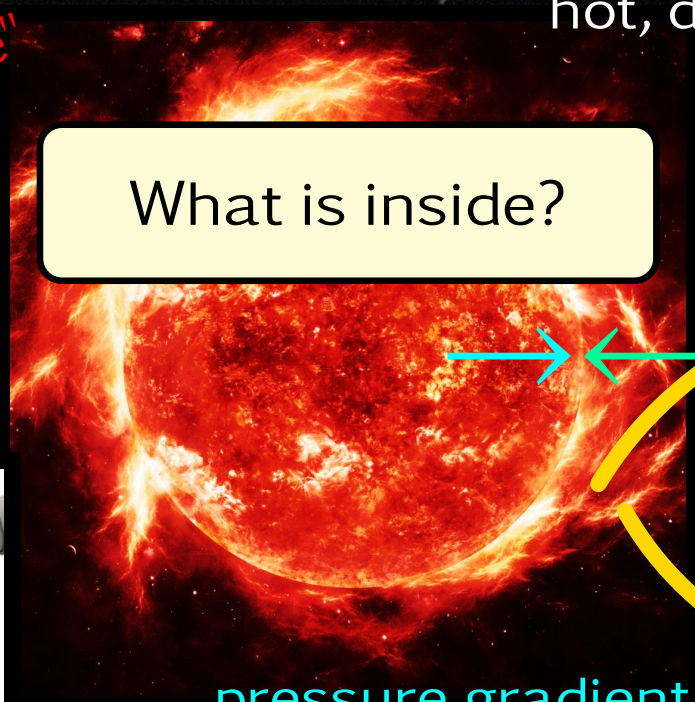


What is inside?

pressure gradient gravity

What is a star?

surface?
→ photons escape
"photosphere"



hot, dense plazma

What is inside?

theoretical modelling of the stellar structure

pressure gradient gravity

Theoretical modelling of the stellar structure

$$\frac{\partial r}{\partial m_r} = \frac{1}{4\pi r^2 \rho} \qquad \text{equation of definition of mass} \qquad (9)$$

$$\frac{\partial P}{\partial m_r} = -\frac{G m_r}{4\pi r^4} \qquad \text{equation of hydrostatic equilibrium} \qquad (10)$$

$$\frac{\partial L_r}{\partial m_r} = \epsilon_{\mathrm{pl}} - T\frac{\partial S}{\partial t} \qquad \text{equation of energetic balance} \qquad (11)$$

$$\frac{\partial T}{\partial m_r} = -\frac{G m_r T}{4\pi r^4 P}\nabla \qquad \text{equation of energy transport,} \qquad (12)$$

Guilera et al. 2011

Theoretical modelling of the stellar structure

$$\frac{\partial r}{\partial m_r} = \frac{1}{4\pi r^2 \rho}$$ ec mass conservation (9)

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transport of energy

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composition change due to nuclear burning ?!

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composition change due to nuclear burning ?!

$$\frac{\partial X_i}{\partial t} = \frac{A_i m_u}{\rho}(-\Sigma_{j,k} r_{i,j,k} + \Sigma_{k,l} r_{k,l,i}) \qquad \text{(13)}$$

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+ Rotation.

Theoretical modelling of the stellar structure

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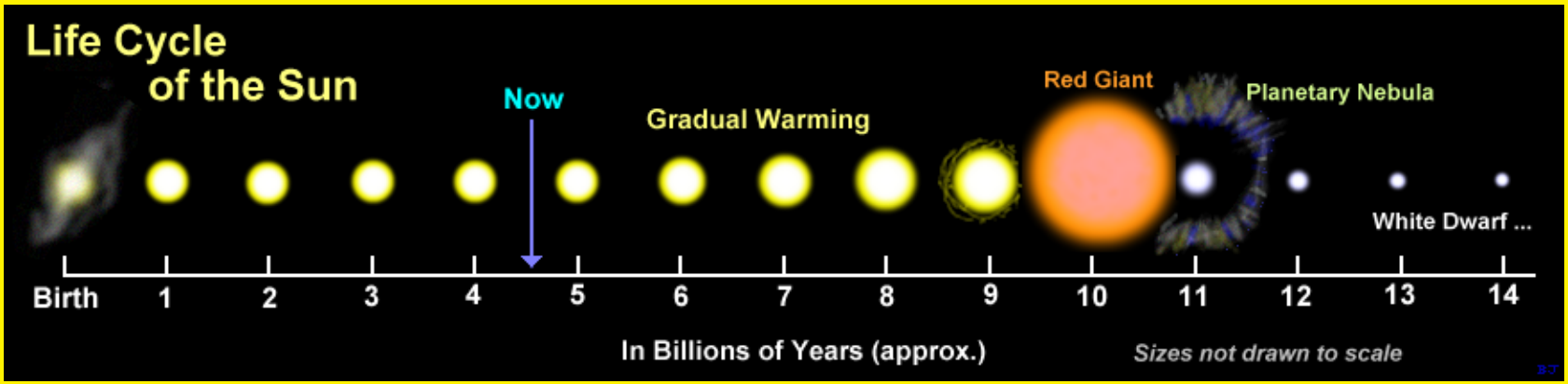
momentum conservation

$$\frac{\partial L}{\partial} \qquad \frac{\partial S}{}$$



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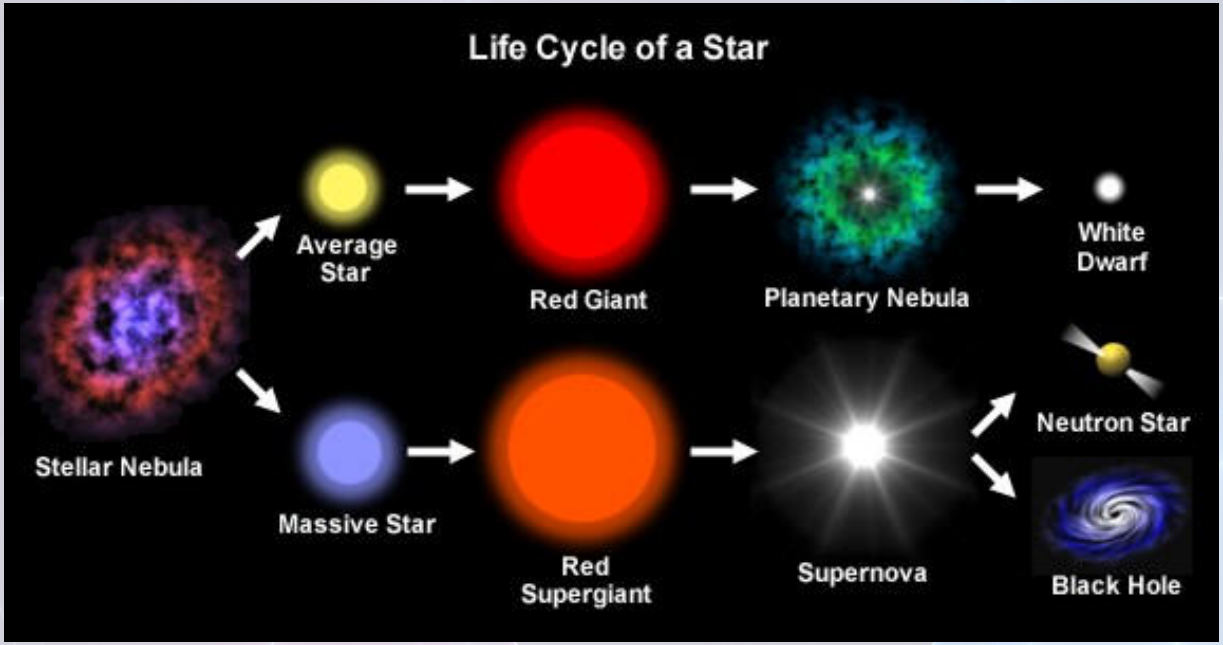
Massive vs. low-mass stars

Massive stars: $\gtrsim 9$ times the Sun ($\gtrsim 9\ M_\odot$)



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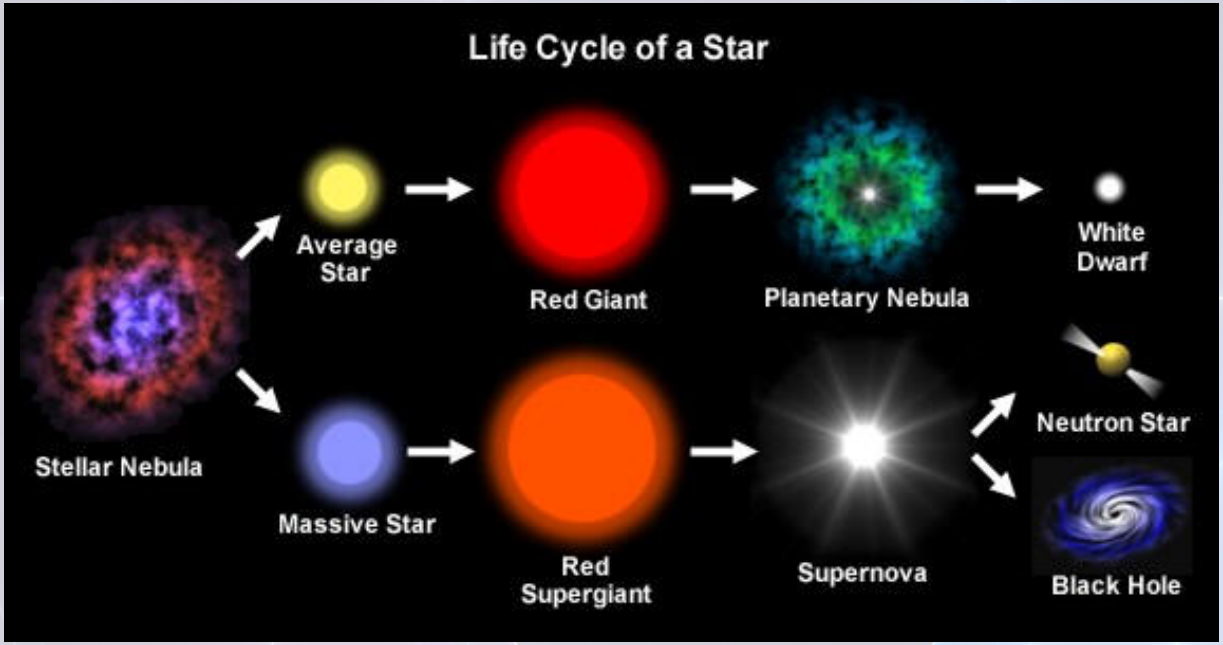

- nuclear reactions, final composition

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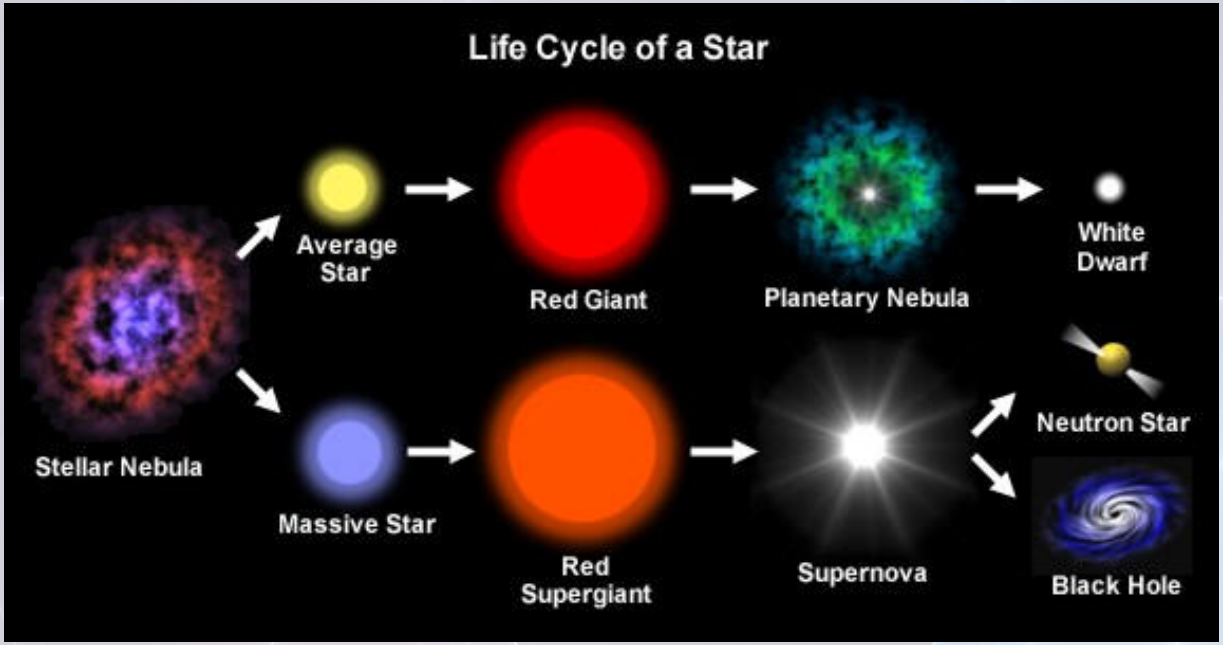

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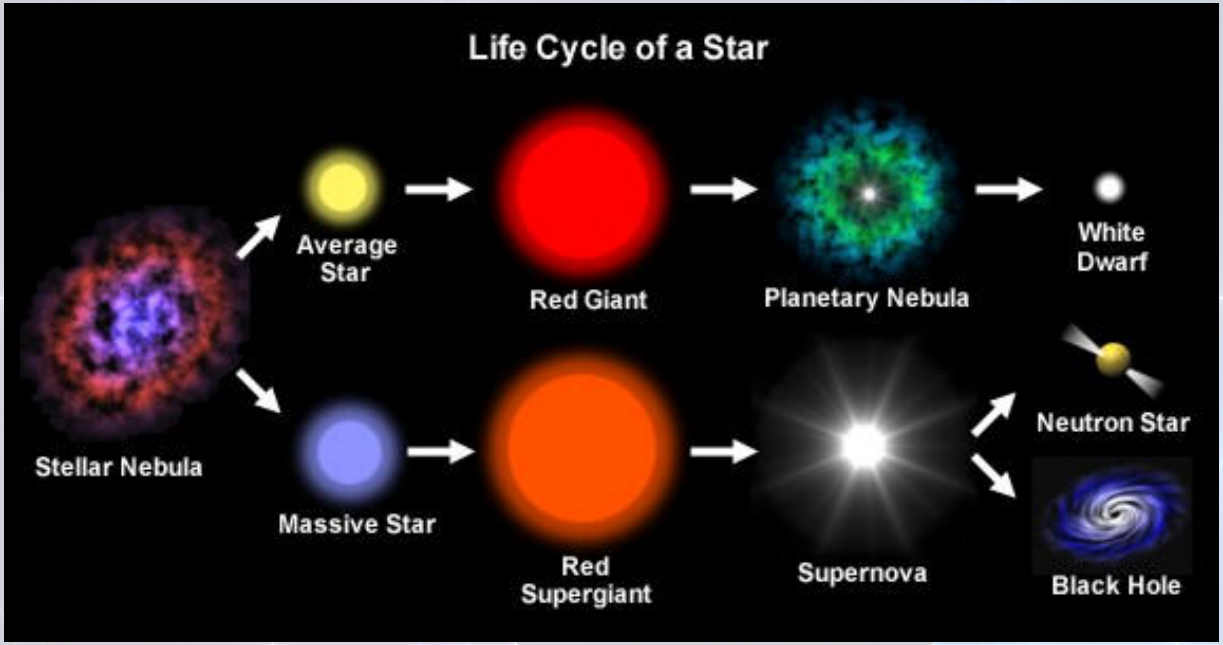

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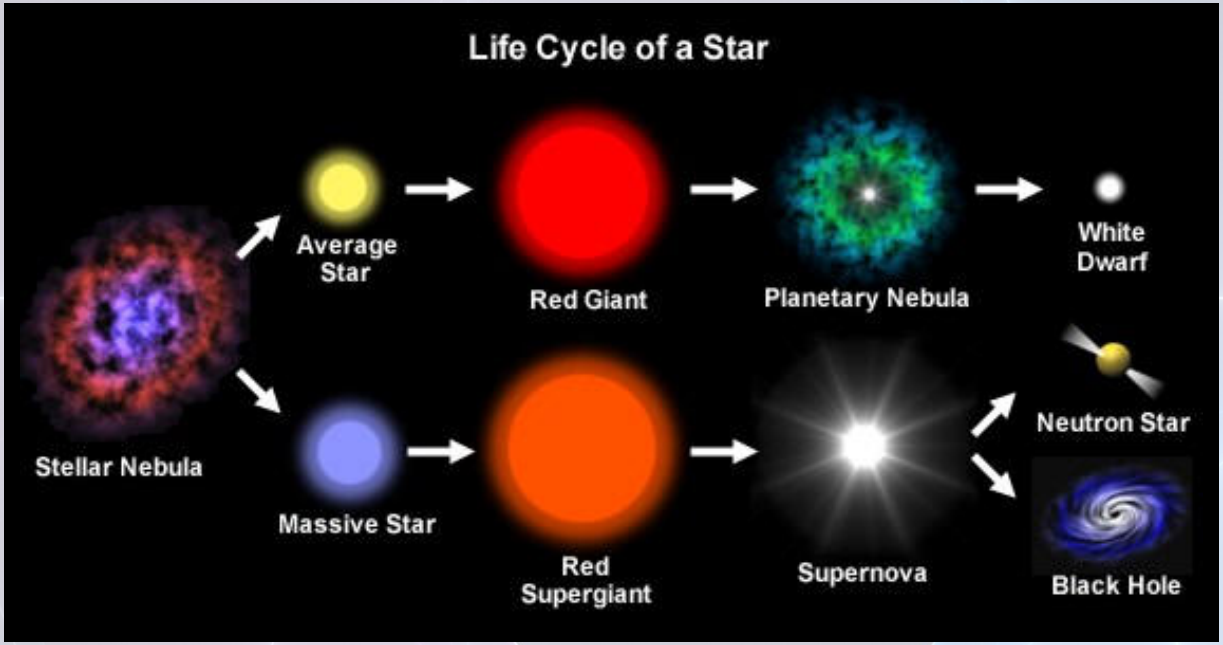

- nuclear reactions, final composition
- number of stars: massive stars are rare
- lifetime: massive stars have shorter lives
- final fate

Matching theory to observations

Surface properties!

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Surface properties! → temperature (i.e. colour) X axis
→ luminosity (i.e. brightness) Y axis

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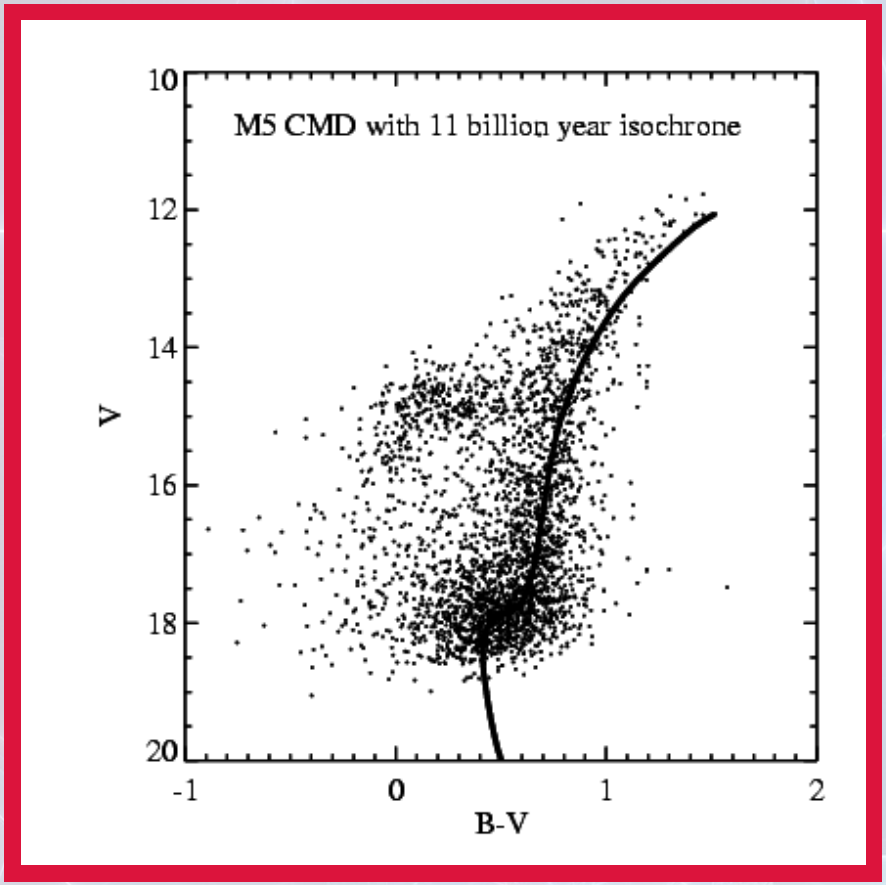
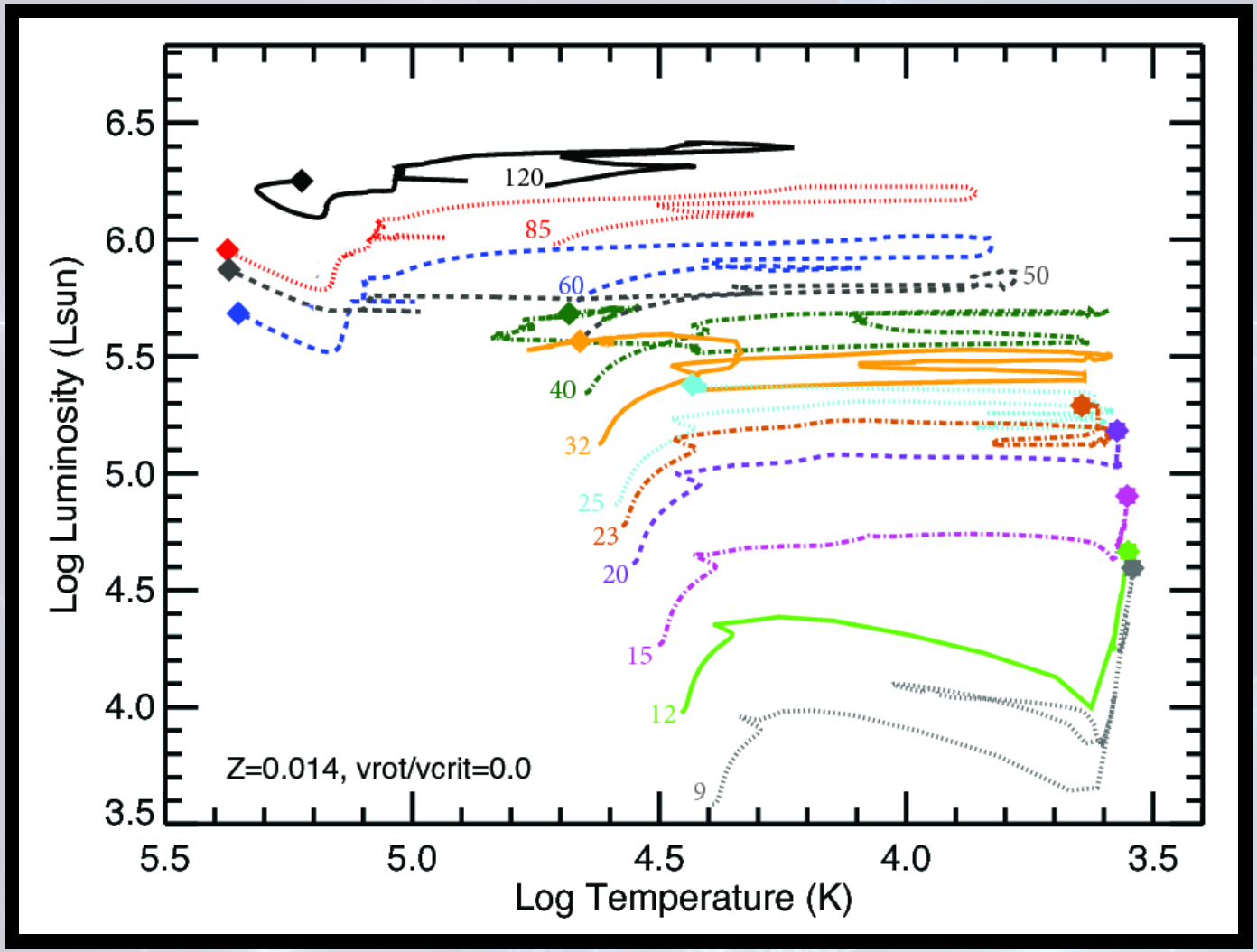


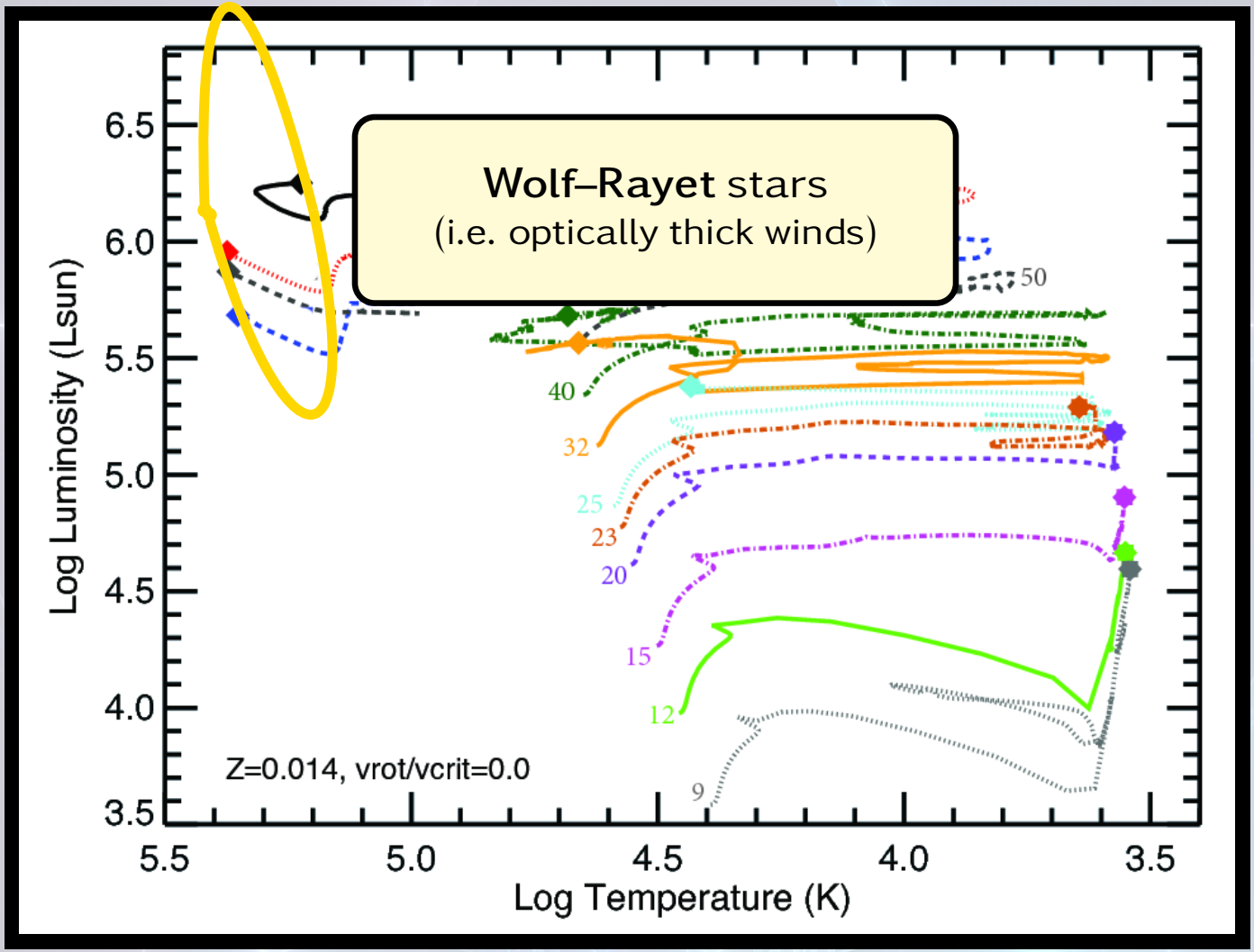
Hertzsprung–Russell diagram (HR diagram)

Hertzsprung–Russell diagram



Groh et al. 2013

Hertzsprung–Russell diagram



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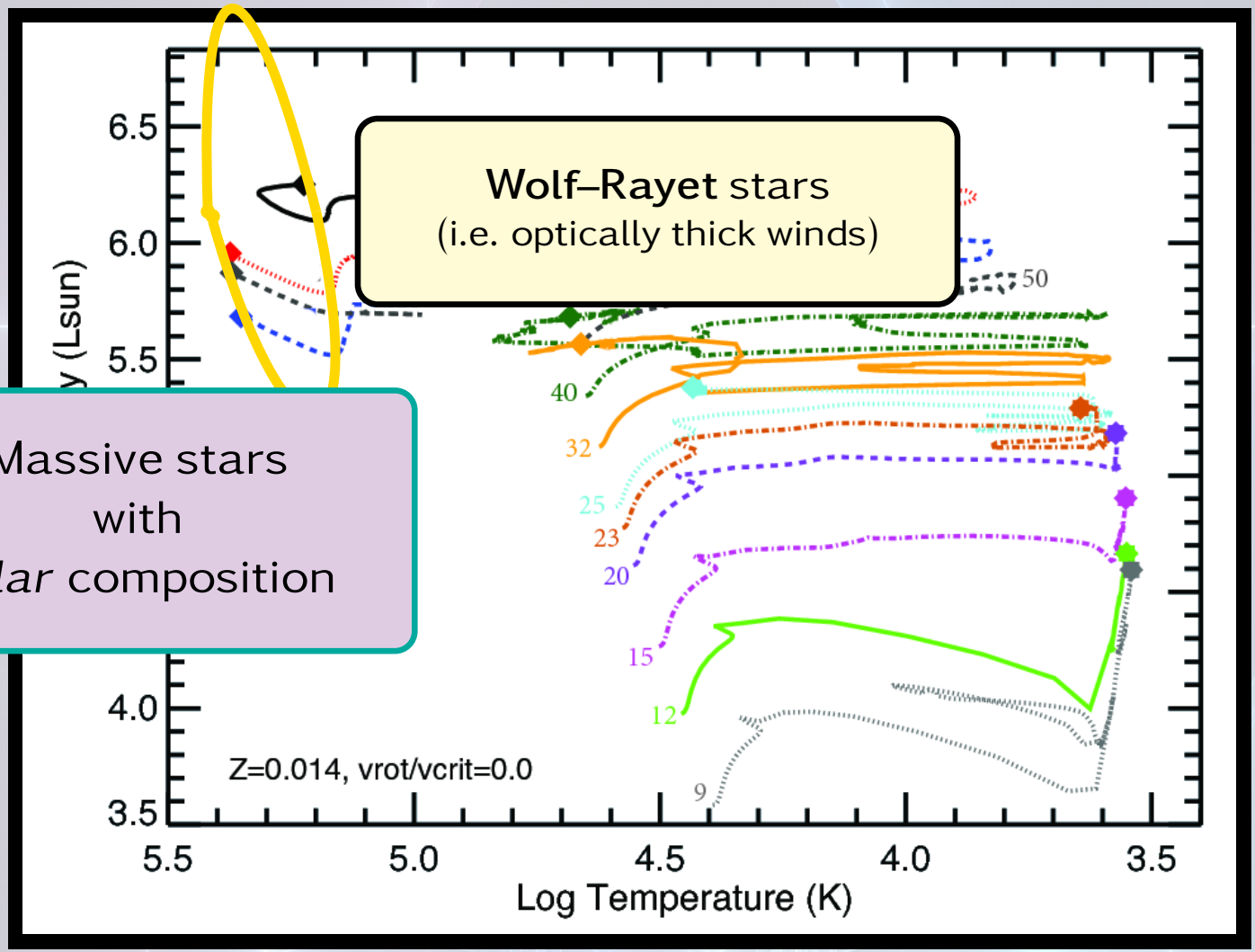

Groh et al. 2013

Low Metallicity Massive Stars

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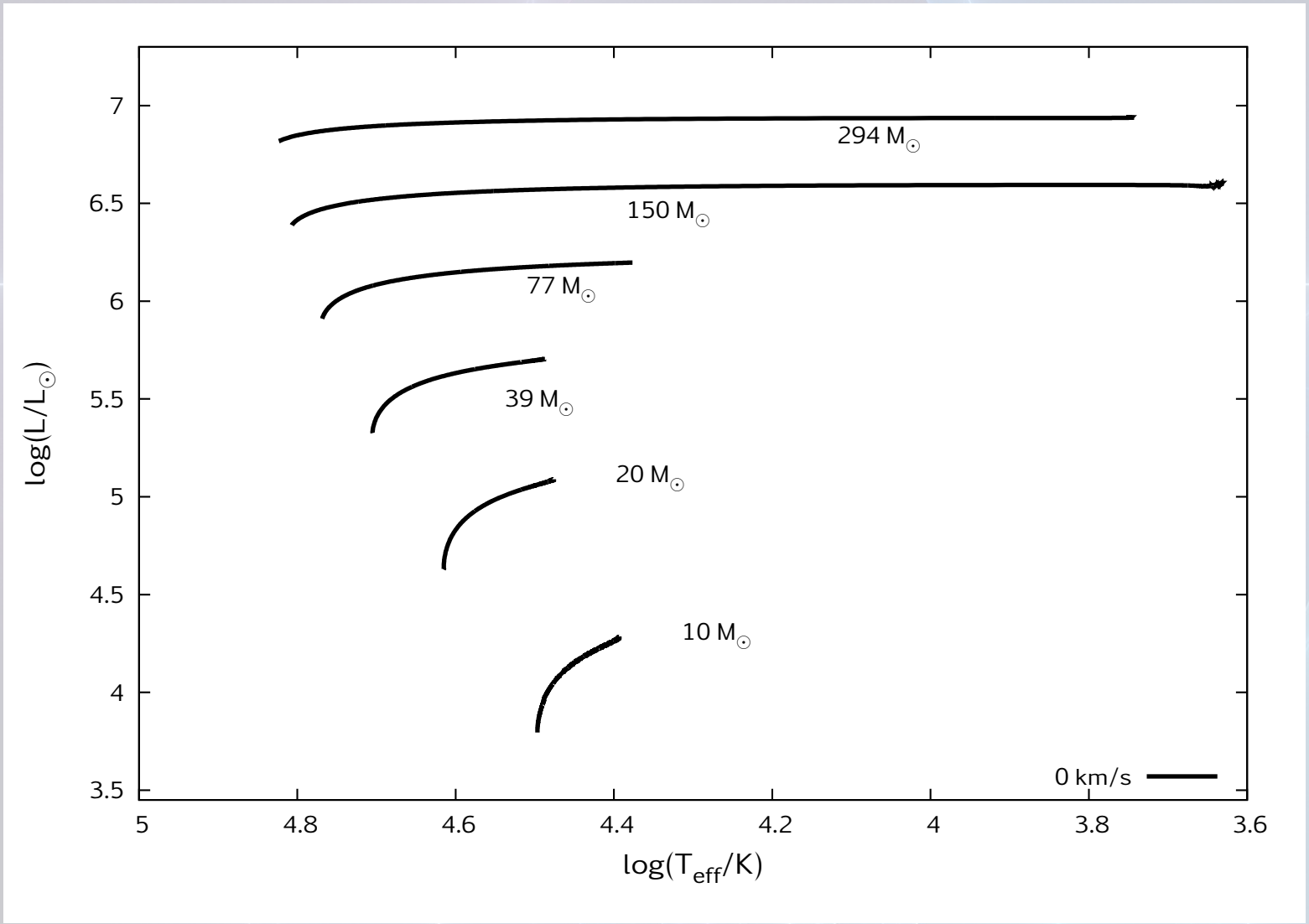
– my thesis ☺

Low Metallicity Massive Stars

Szécsi et al. 2015 (Astronomy & Astrophysics, v.581, A15)



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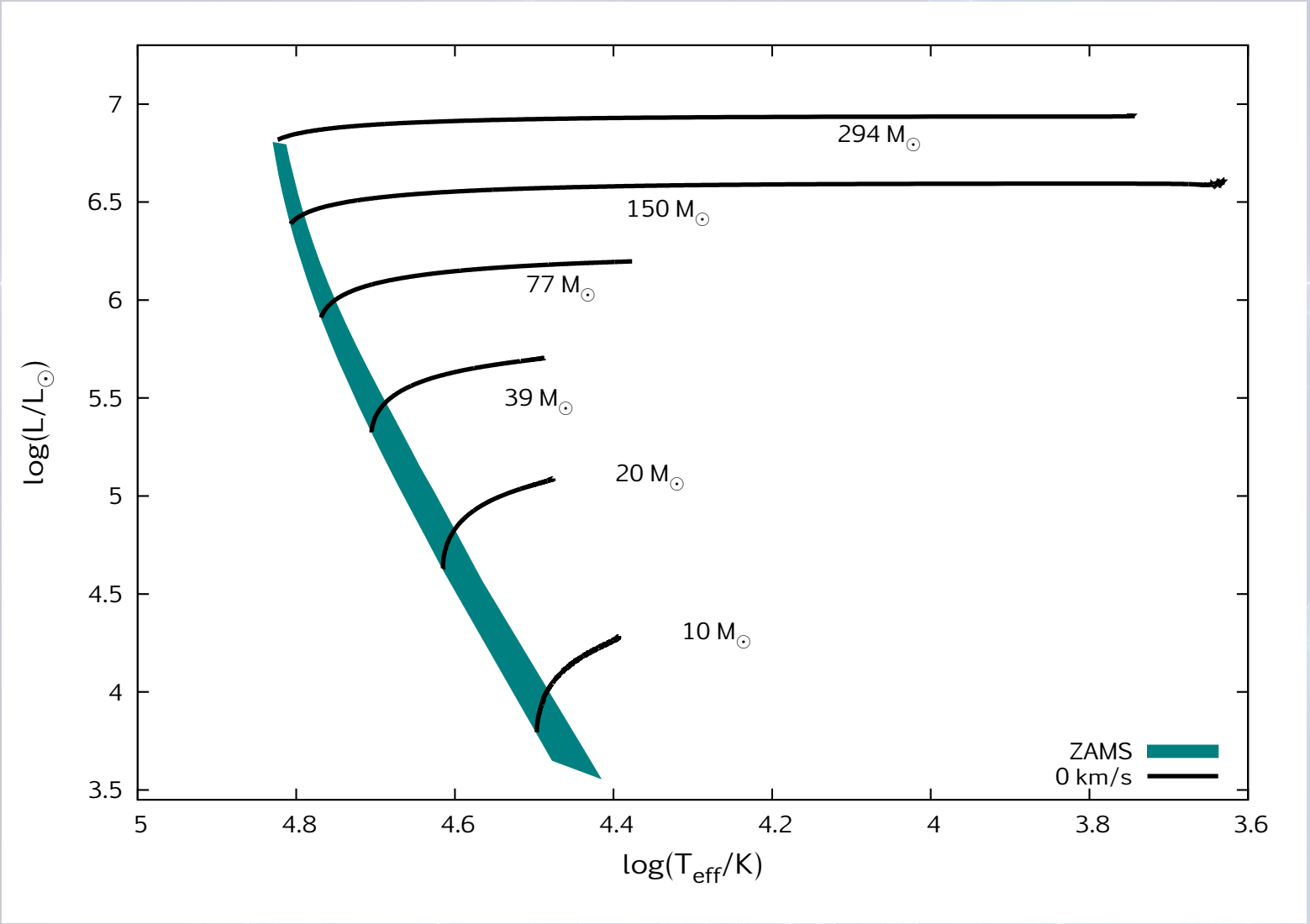

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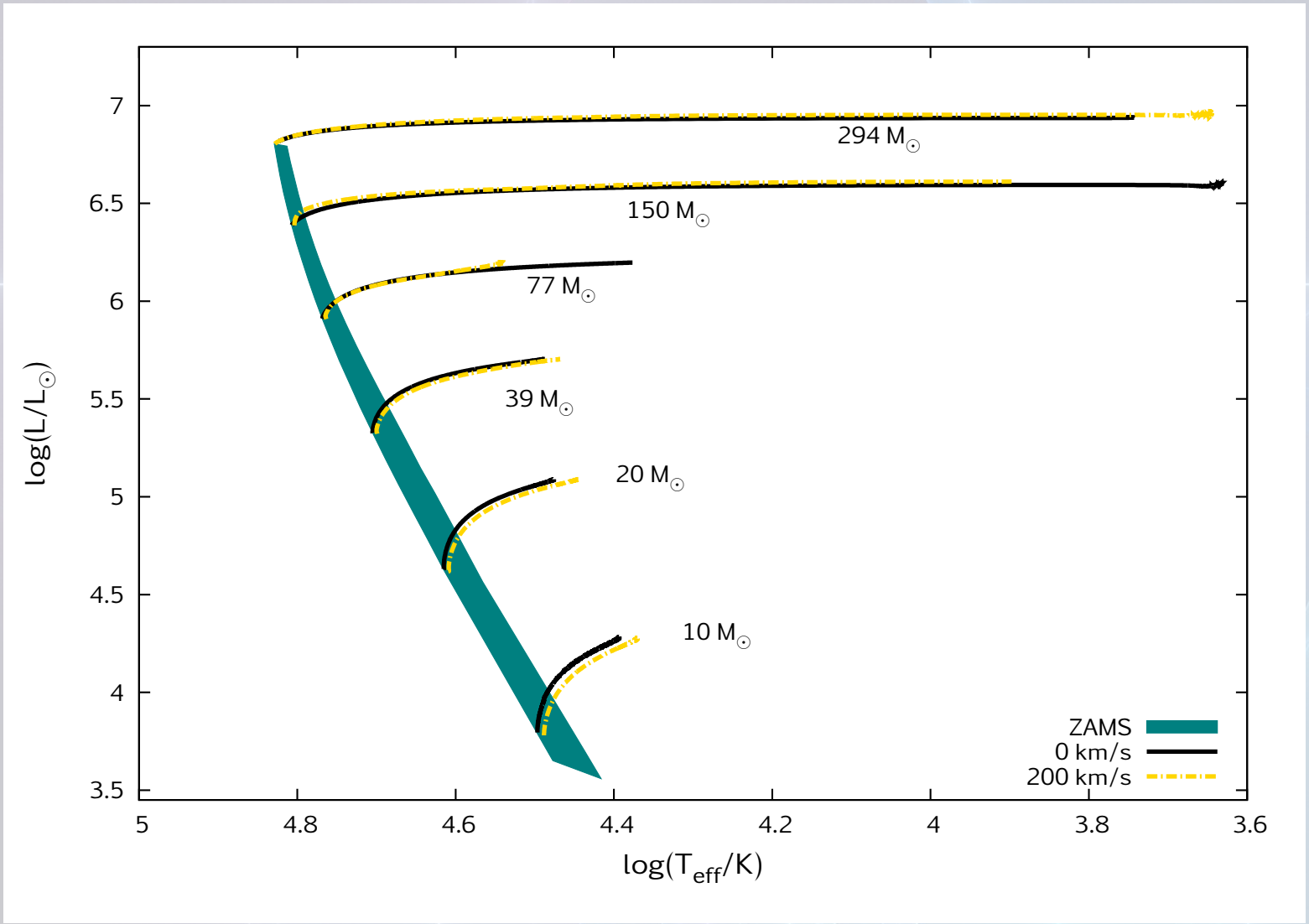

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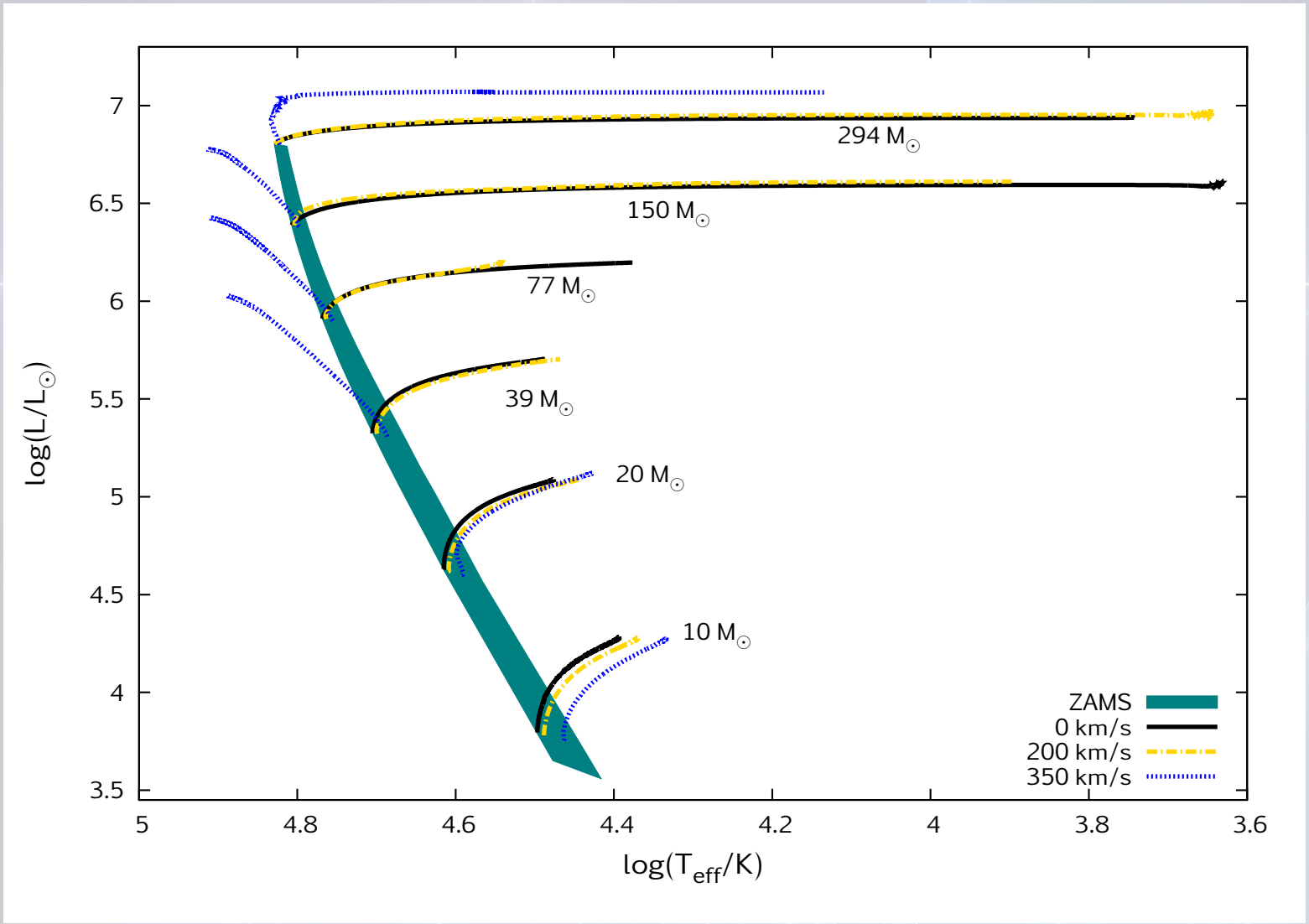

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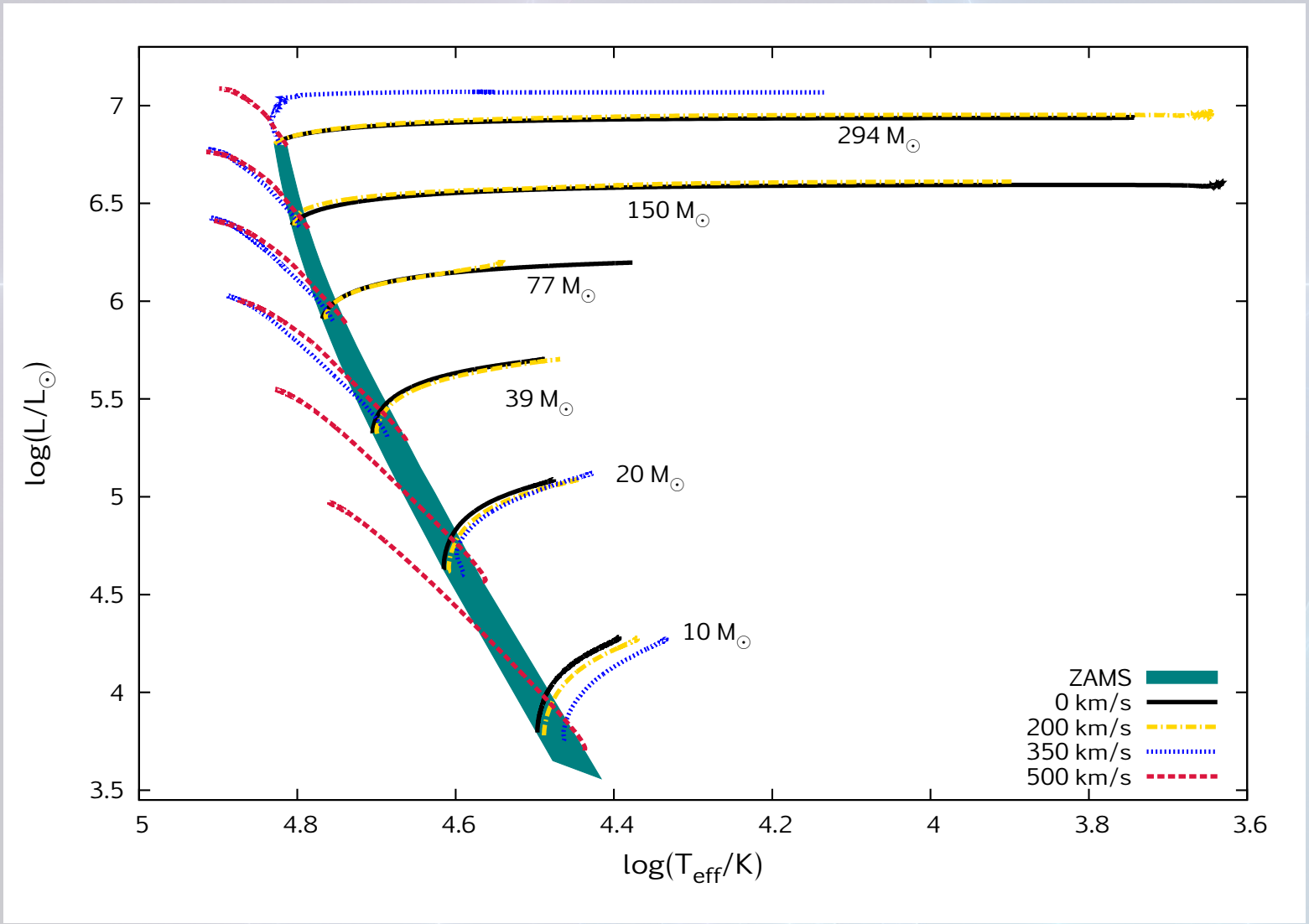

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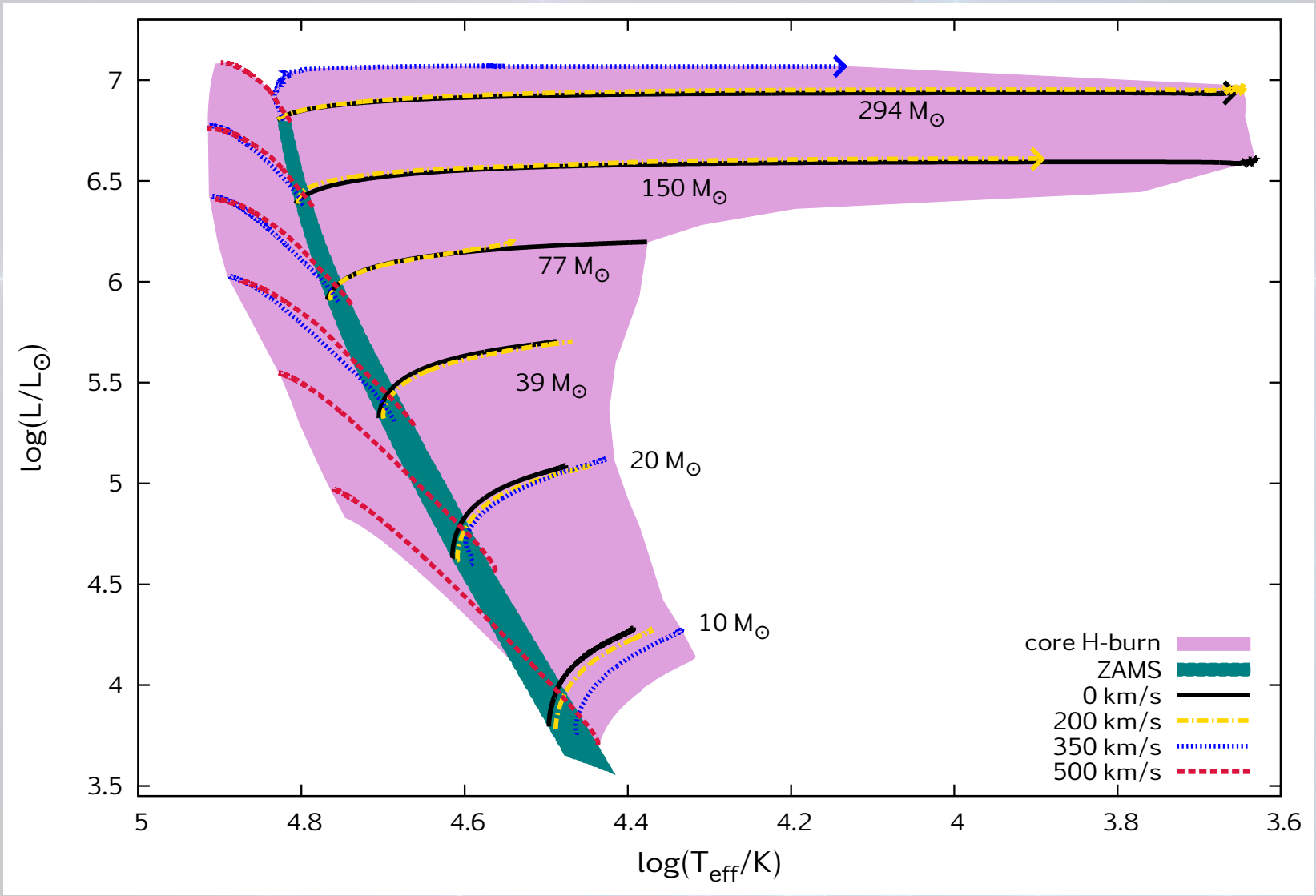

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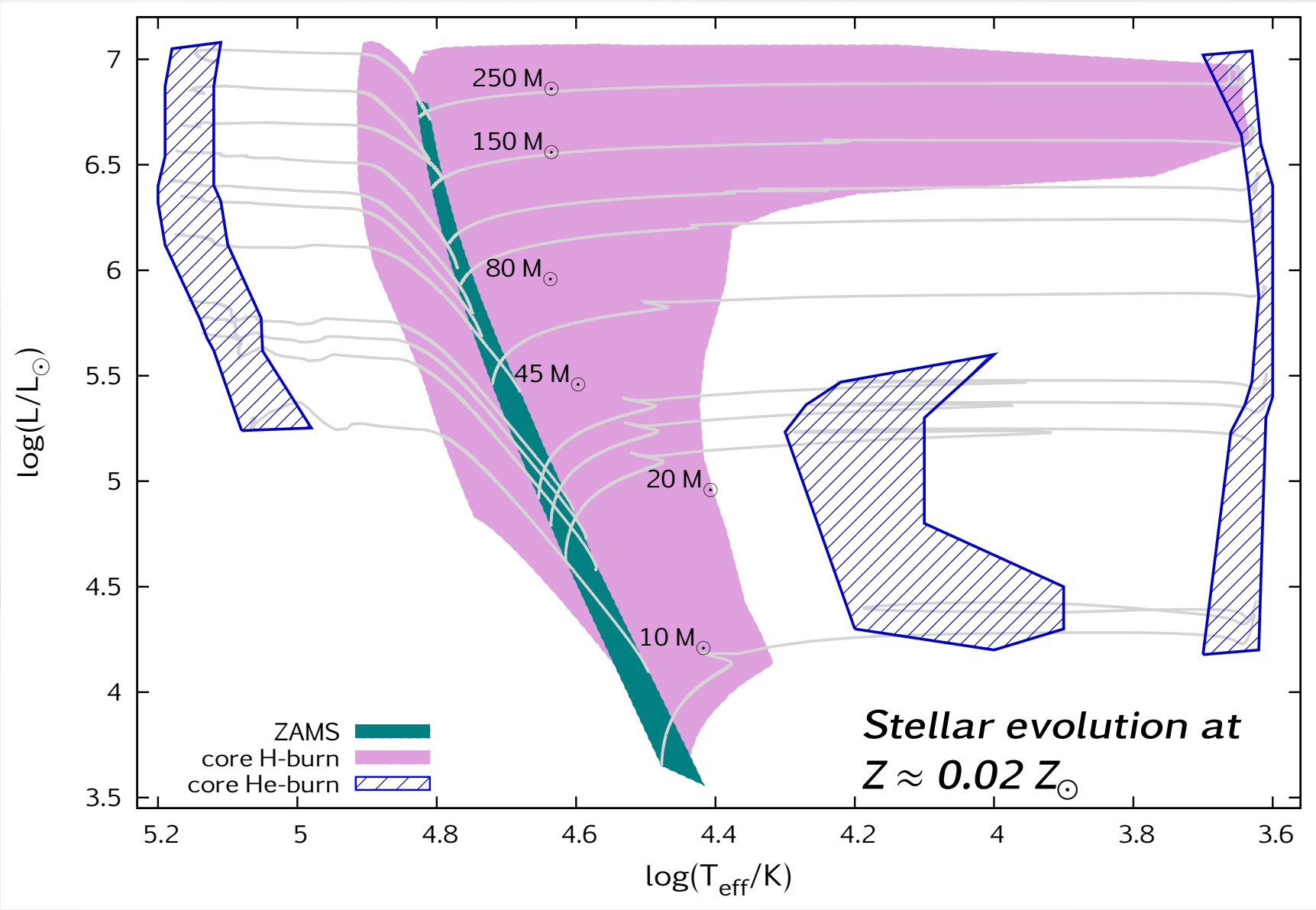

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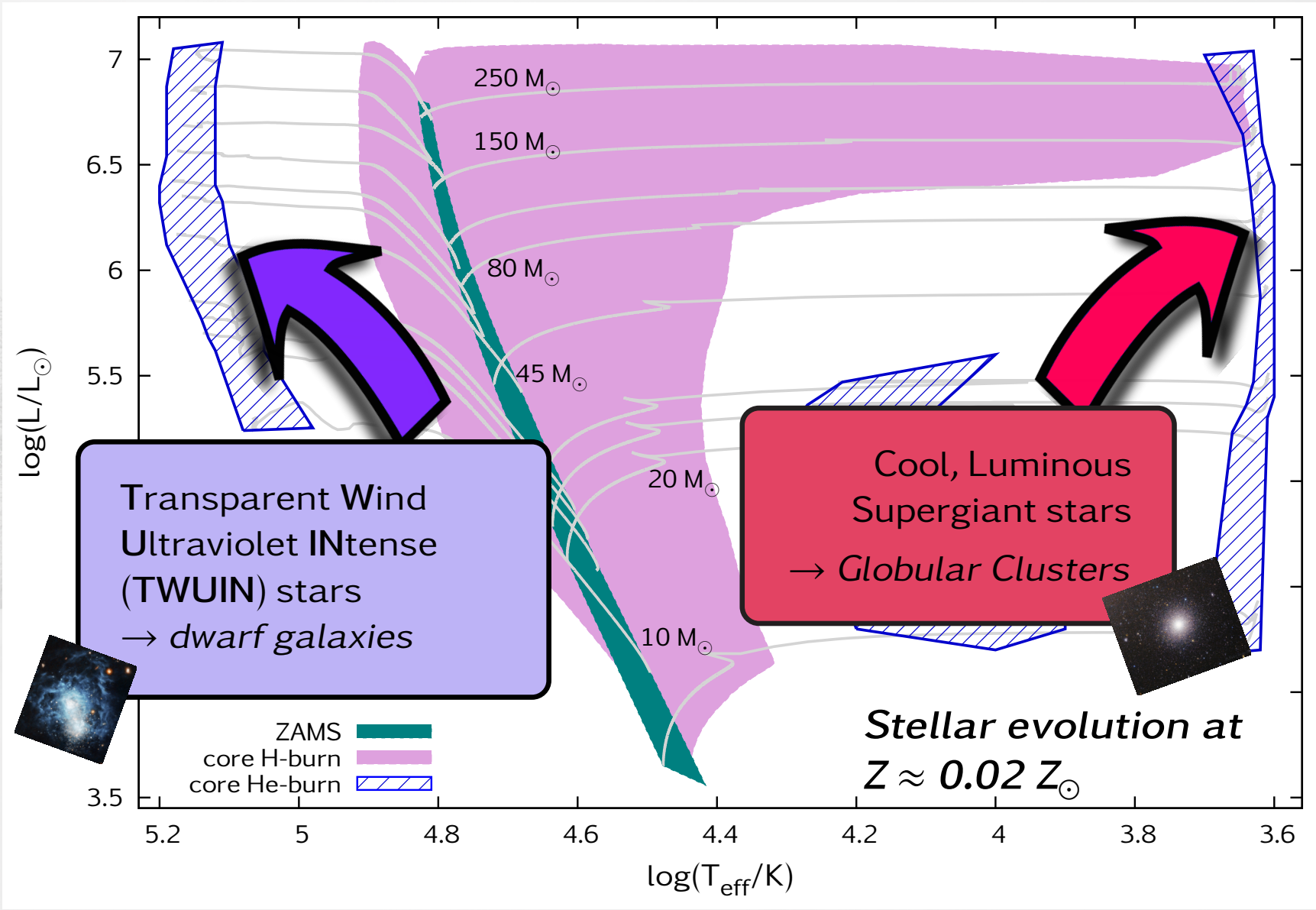

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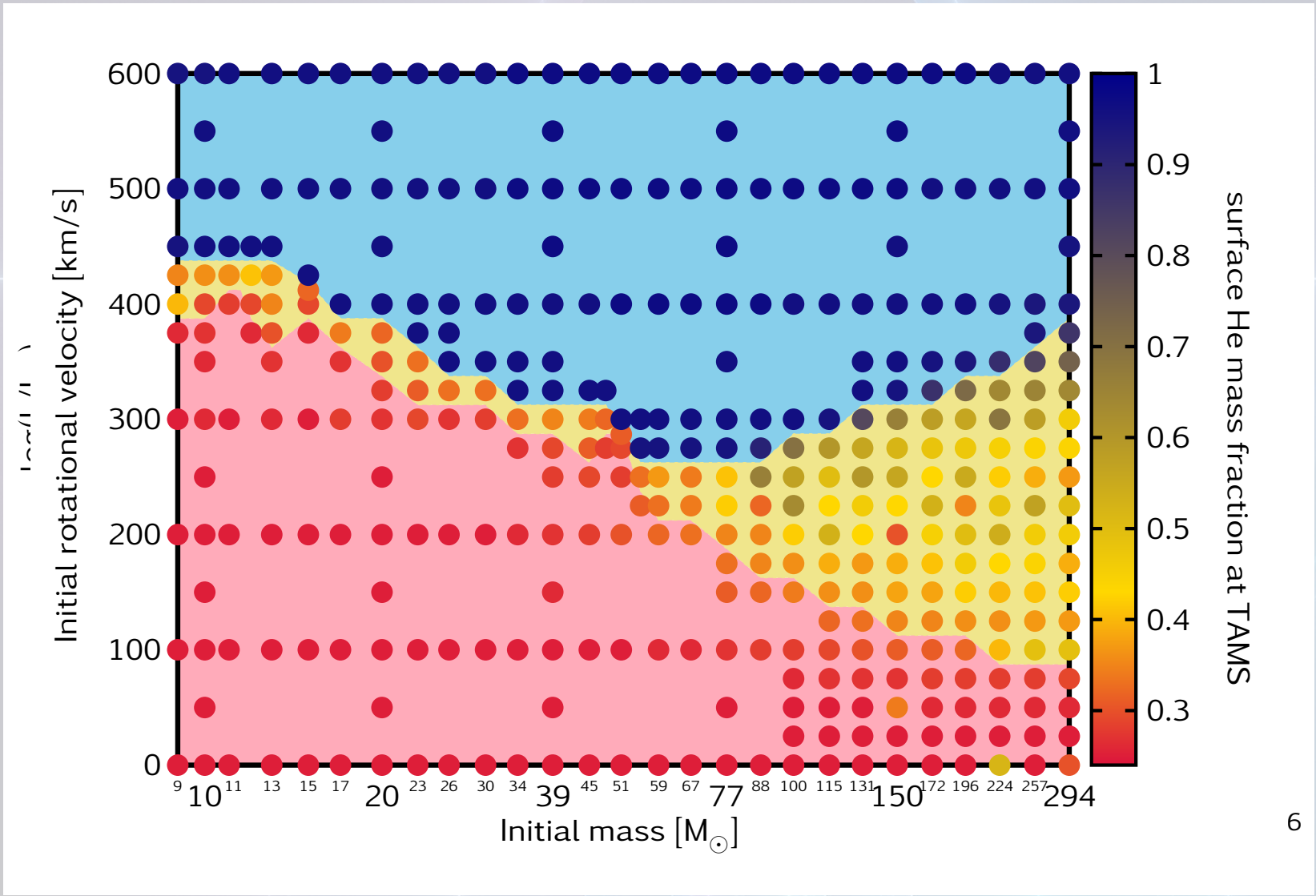

Back to I Zw 18

I Zwicky 18

- Blue Compact Dwarf Galaxy
- 60 million lightyears $\rightarrow$ local
- star formation rate: 0.1 $M_\odot$/yr
- ionized gas
- low metallicity: Z=1/50 $Z_\odot$

Legrand+07, Aloisi+09, Annibali+13, Kehrig+13, Lebouteiller+13

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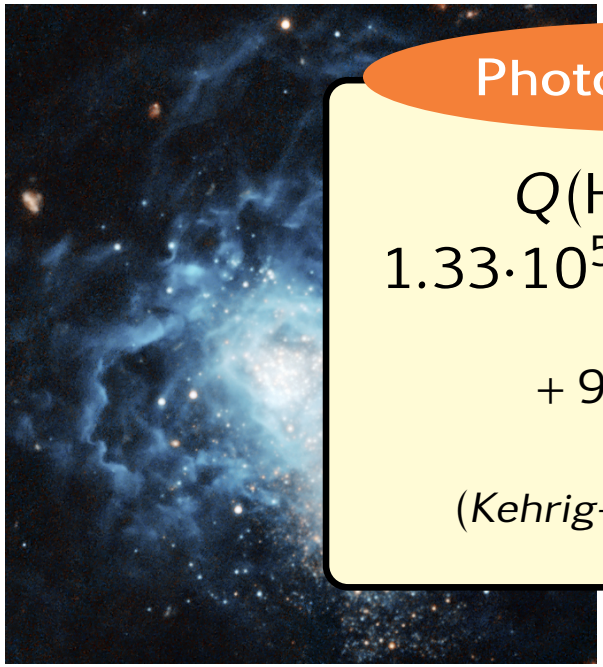

Photoionization

$Q(\mathrm{HeII})^{obs} = 1.33 \cdot 10^{50}$ photons s^{-1}

+ 9 WC stars

(*Kehrig+15, Crowther+06*)

Legrand+07, Aloisi+09, Annibali+13, Kehrig+13, Lebouteiller+13

Photoionization in I Zw 18

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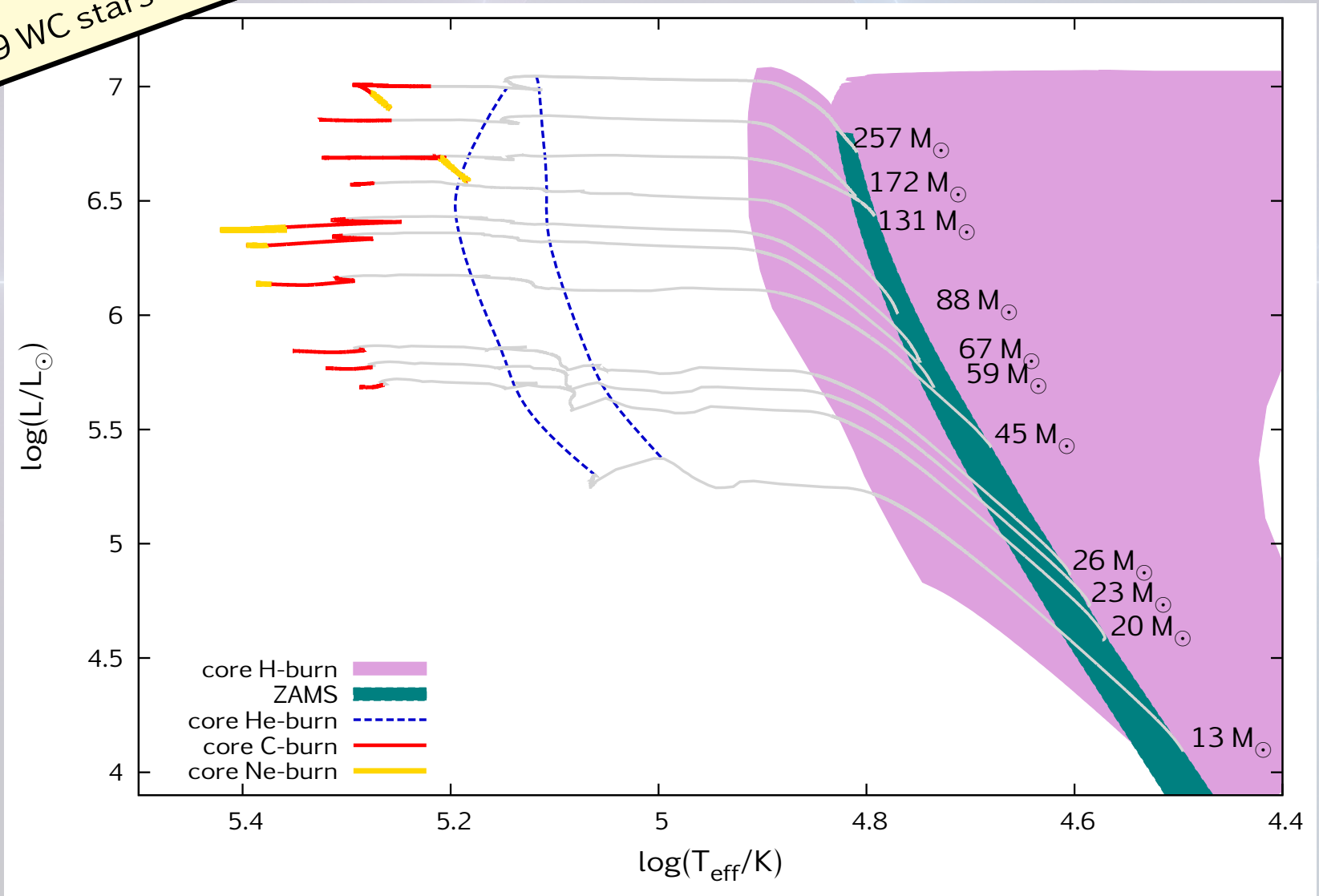

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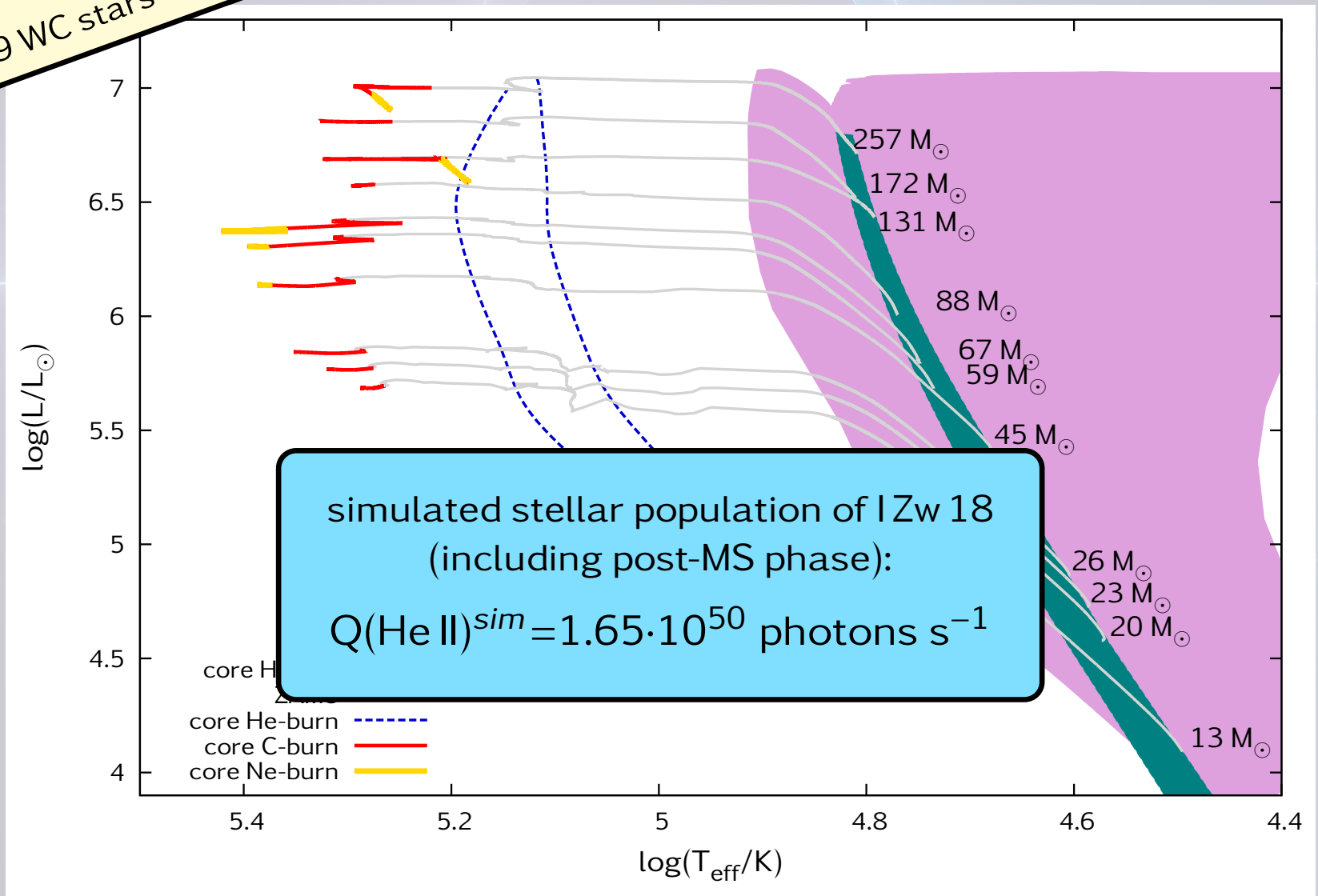

simulated stellar population of I Zw 18
(including post-MS phase):

$Q(\mathrm{He\,II})^{sim} = 1.65 \cdot 10^{50}$ photons s^{-1}

Photoionization in I Zw 18

Photoionization

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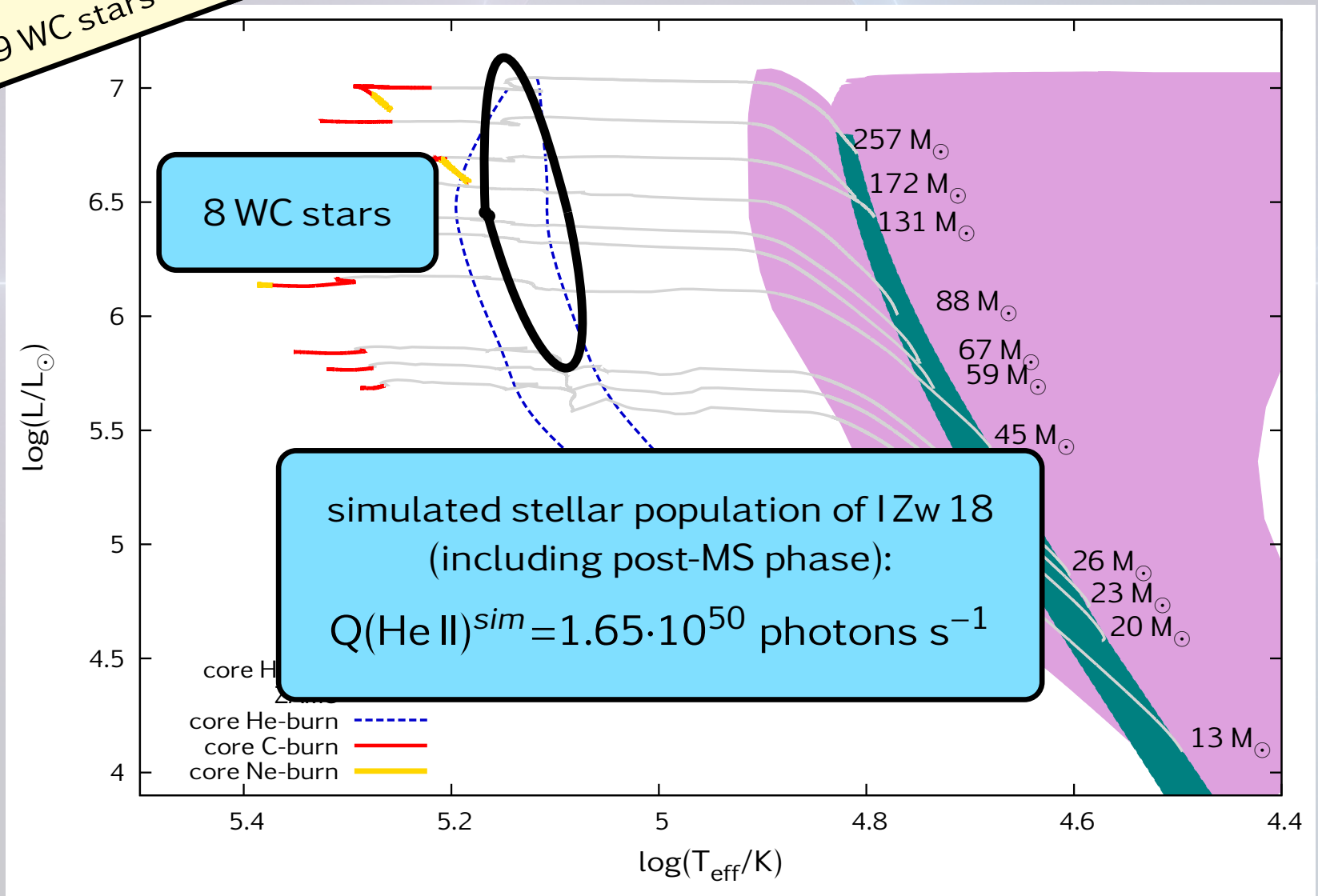
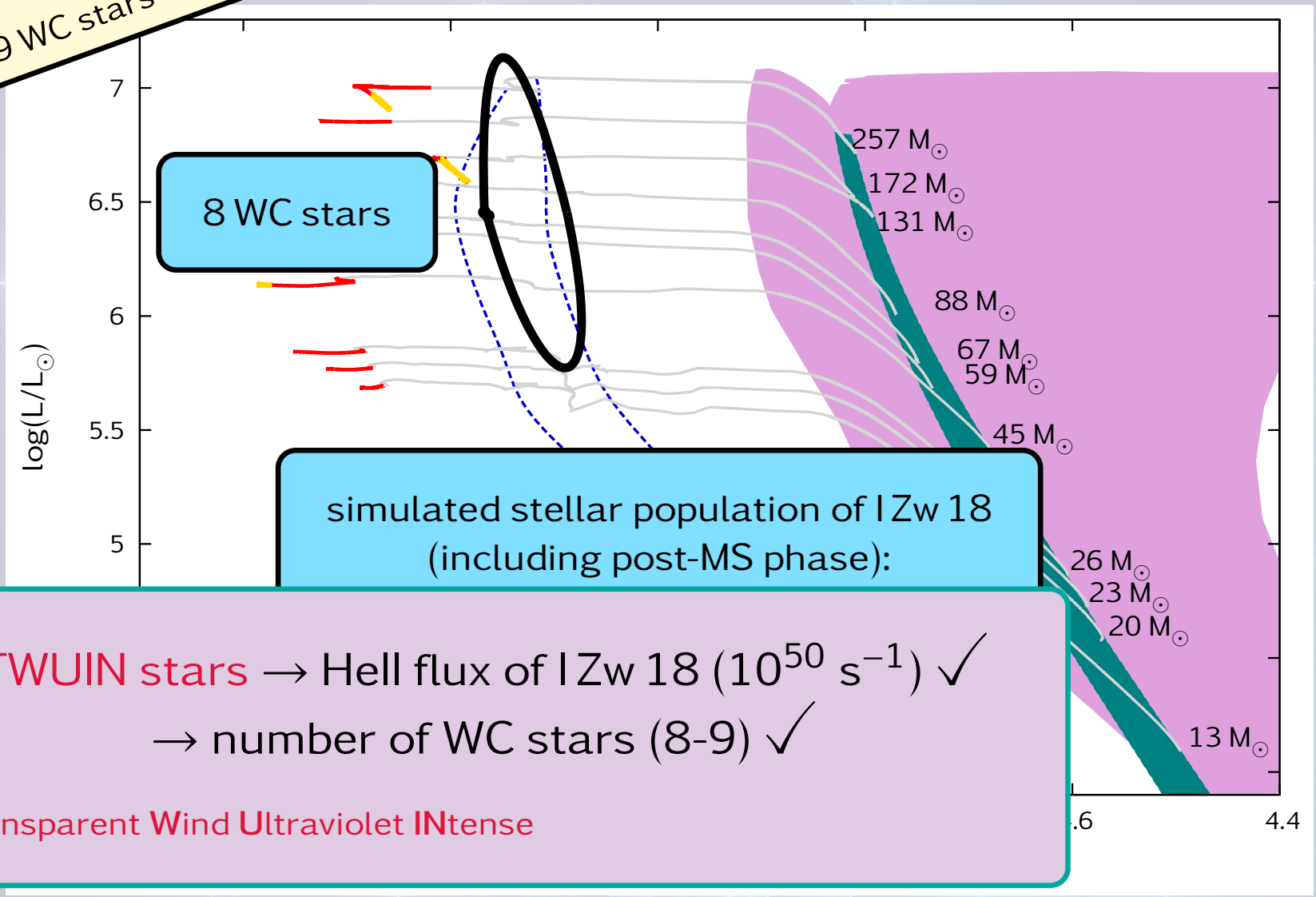


Photoionization in I Zw 18

Photoionization

$Q(\mathrm{HeII})^{obs} = 1.33 \cdot 10^{50}$ photons s^{-1}

+ 9 WC stars



TWUIN stars → HeII flux of I Zw 18 (10^{50} s^{-1}) ✓

→ number of WC stars (8-9) ✓

Transparent **W**ind **U**ltraviolet **IN**tense

Photoionization in I Zw 18

Photoionization

$Q(\mathrm{HeII})^{obs} = 1.33 \cdot 10^{50}$ photons s^{-1}

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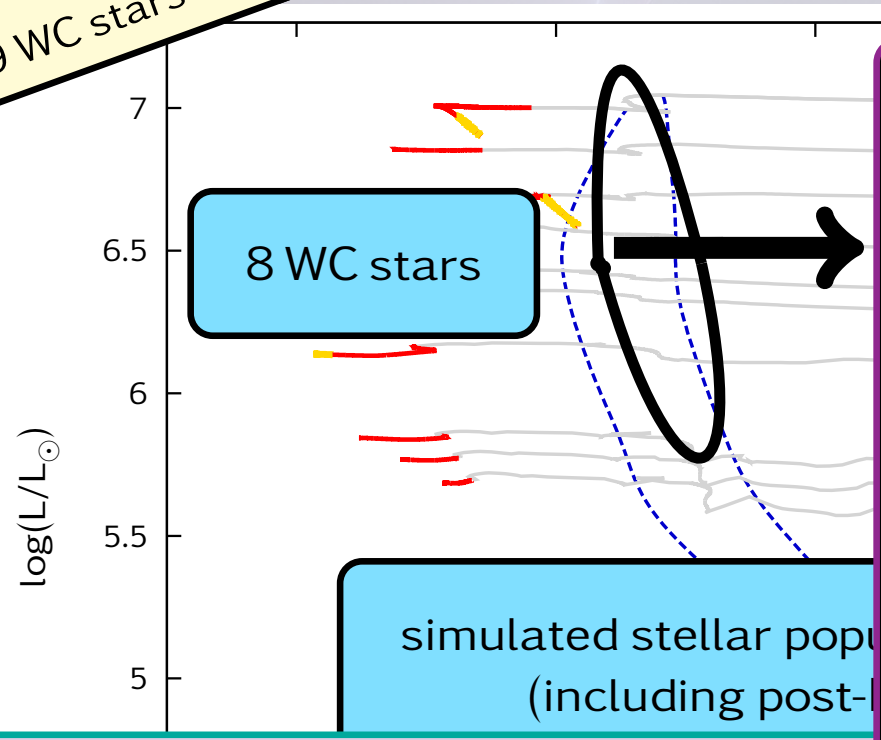


TWUIN stars → HeII flux of I Zw 18

→ number of WC stars (8-

Transparent Wind Ultraviolet INtense

Collapsar → lGRB

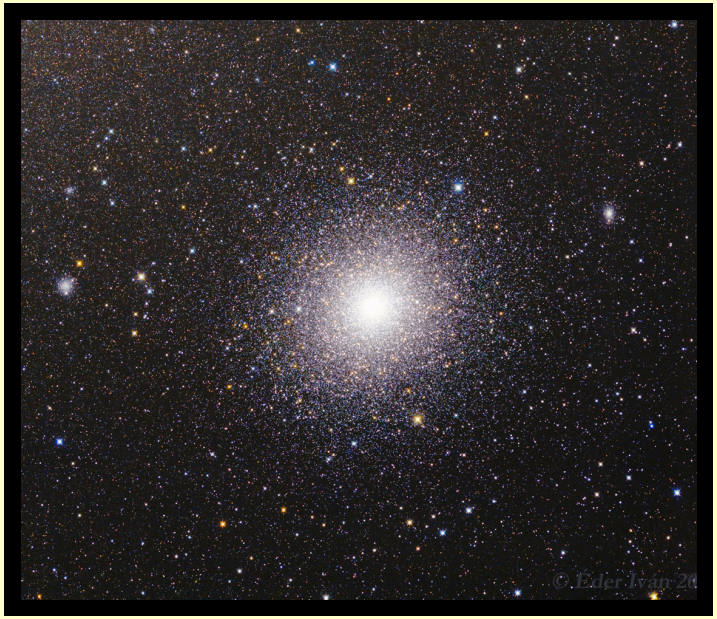
long-duration Gamma-Ray Burst (lGRB)

"angular momentum in the core is higher than the critical limit for the formation of an accretion disc around a rotating black hole"

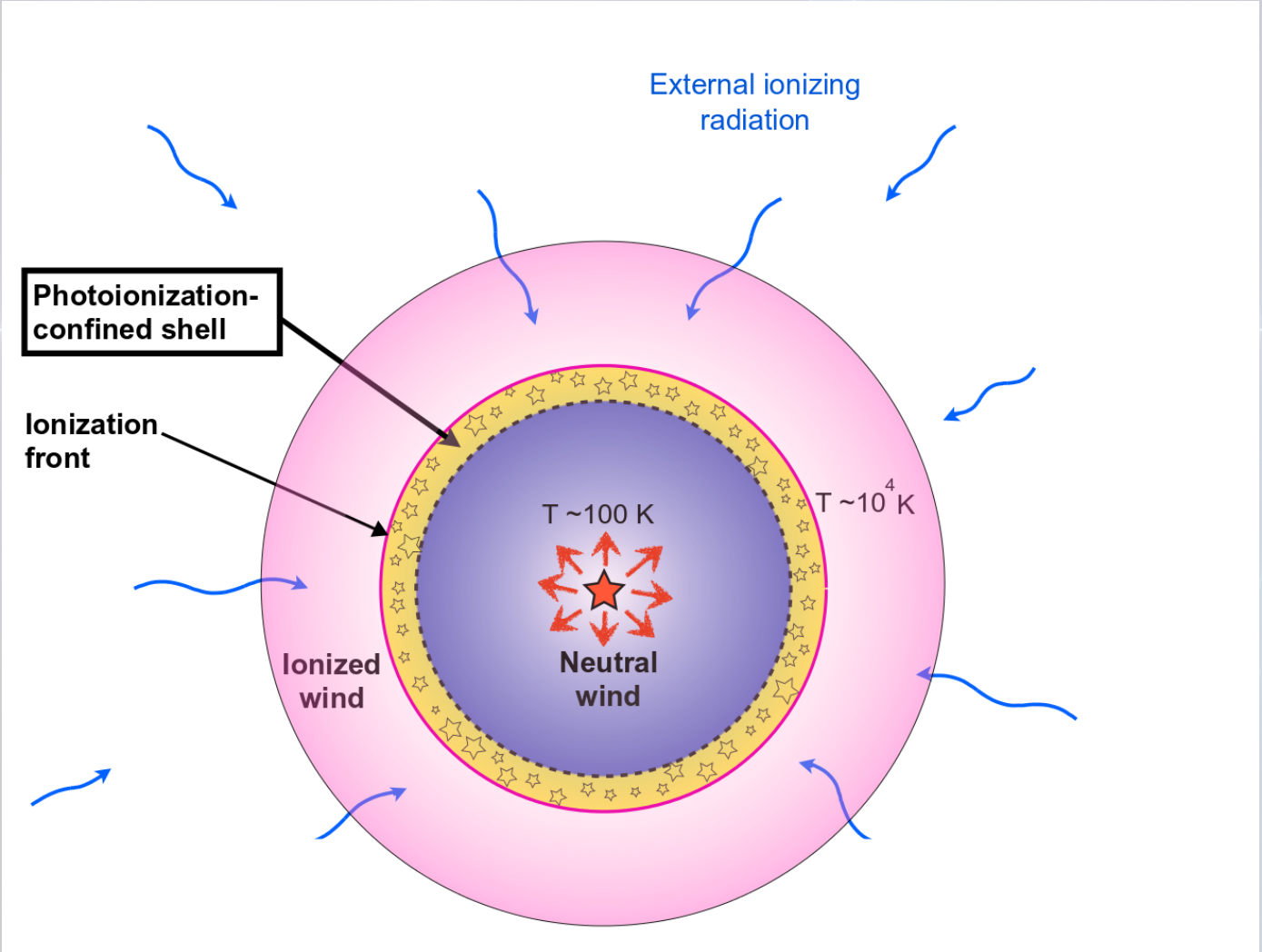
Supergiants and globular clusters

Globular clusters:

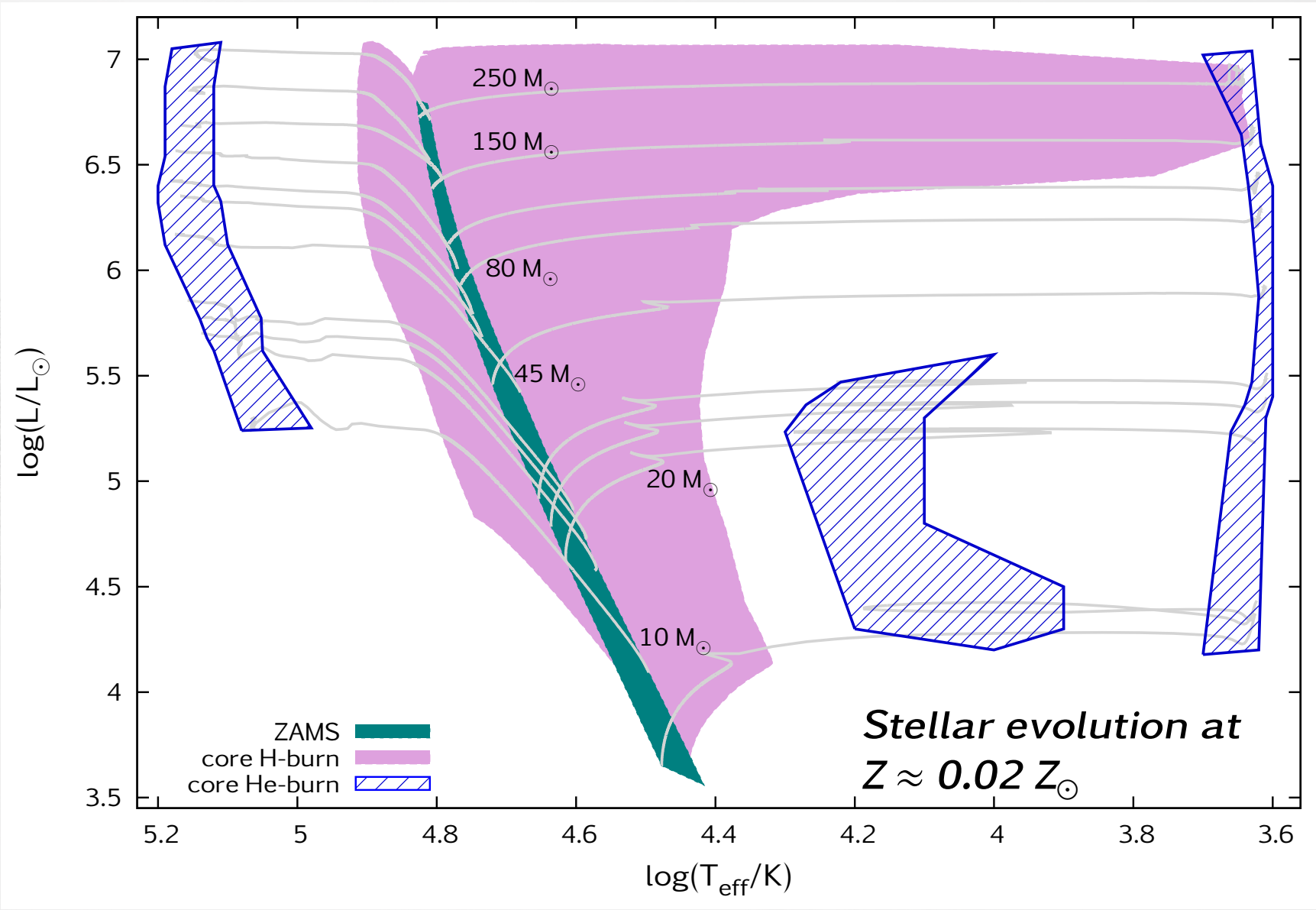
multiple stellar populations observed



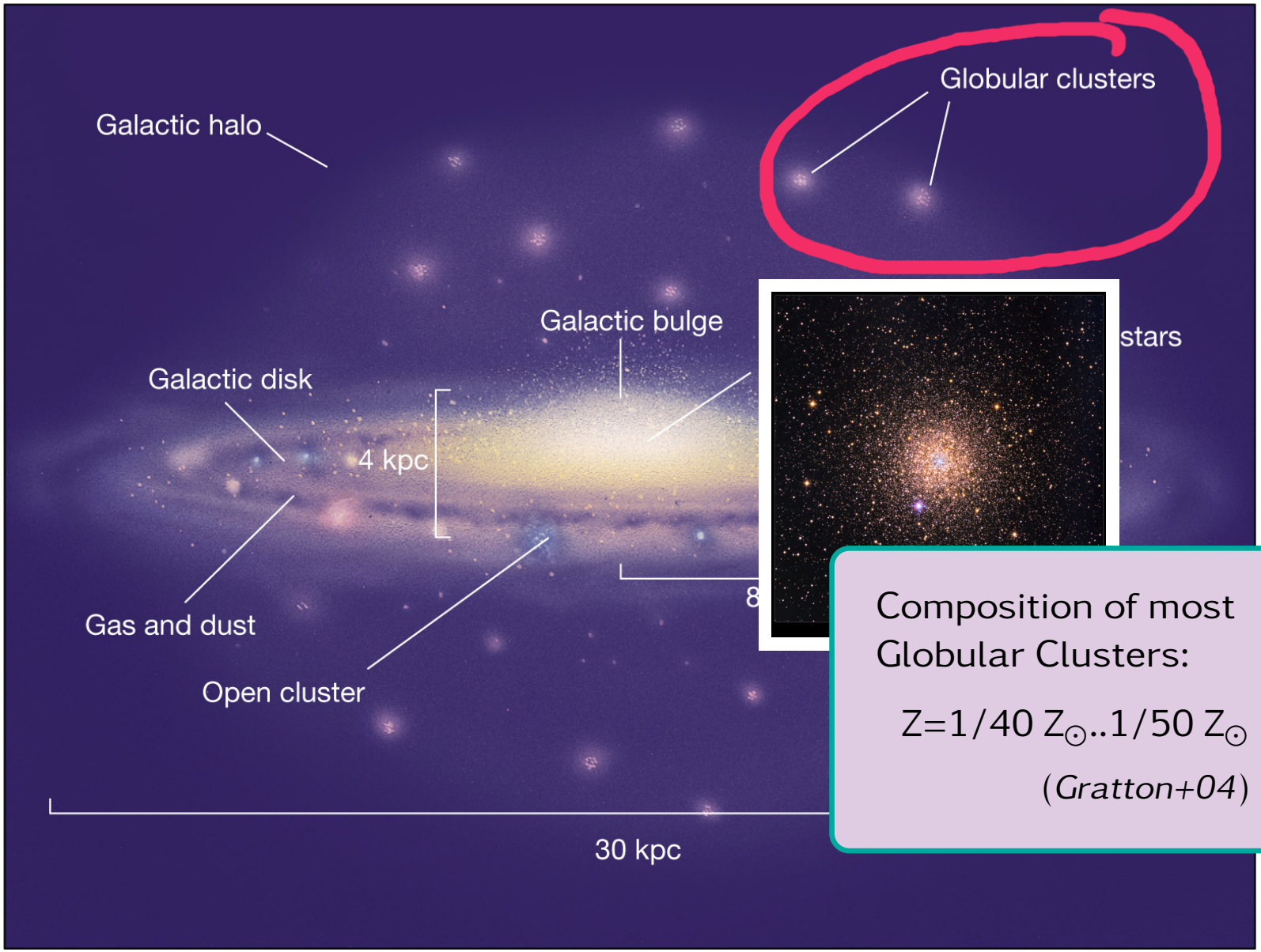
Supergiants and globular clusters



The theory of the Yeti...



Globular Clusters & Abundance Anomalies

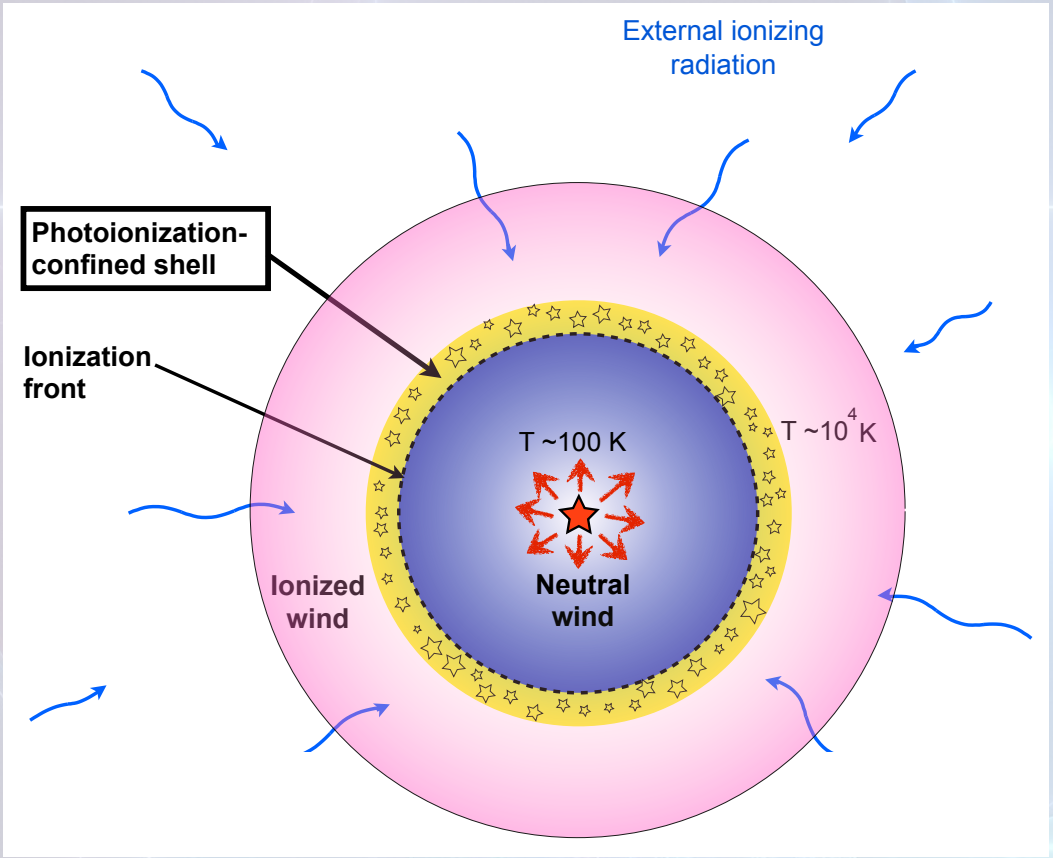


Composition of most Globular Clusters:

$Z=1/40\ Z_{\odot}..1/50\ Z_{\odot}$

(*Gratton+04*)

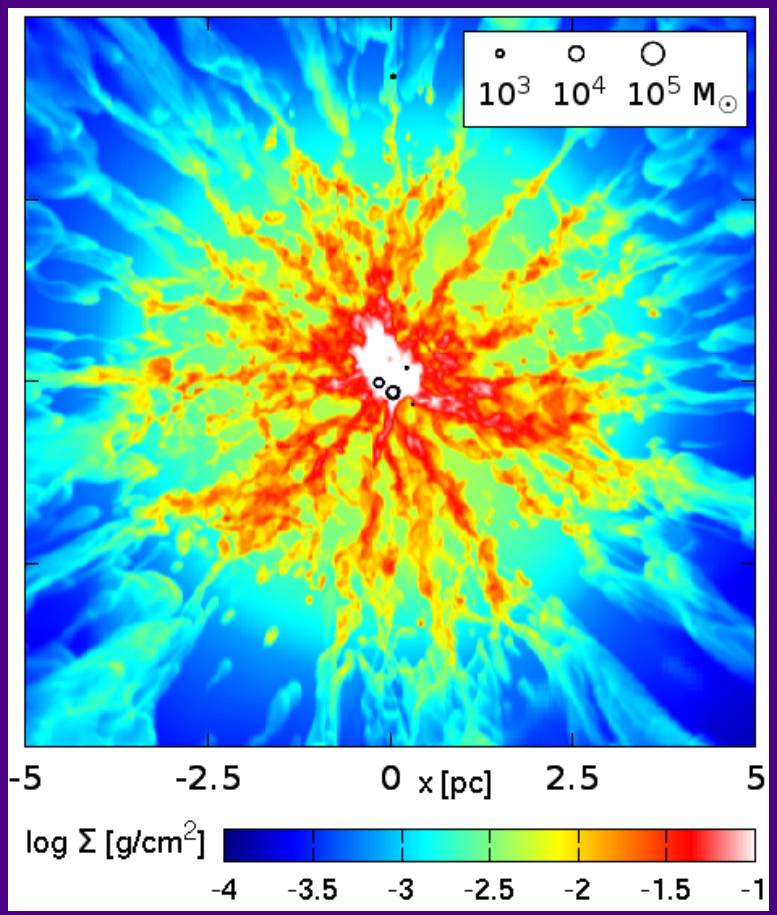
New scenario:
Starforming Supergiant Shells

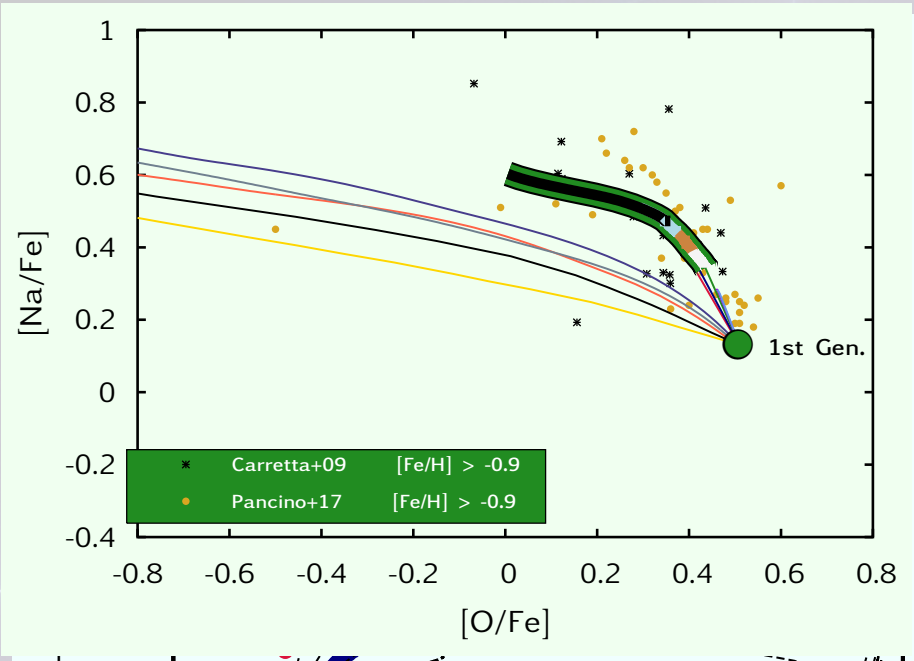


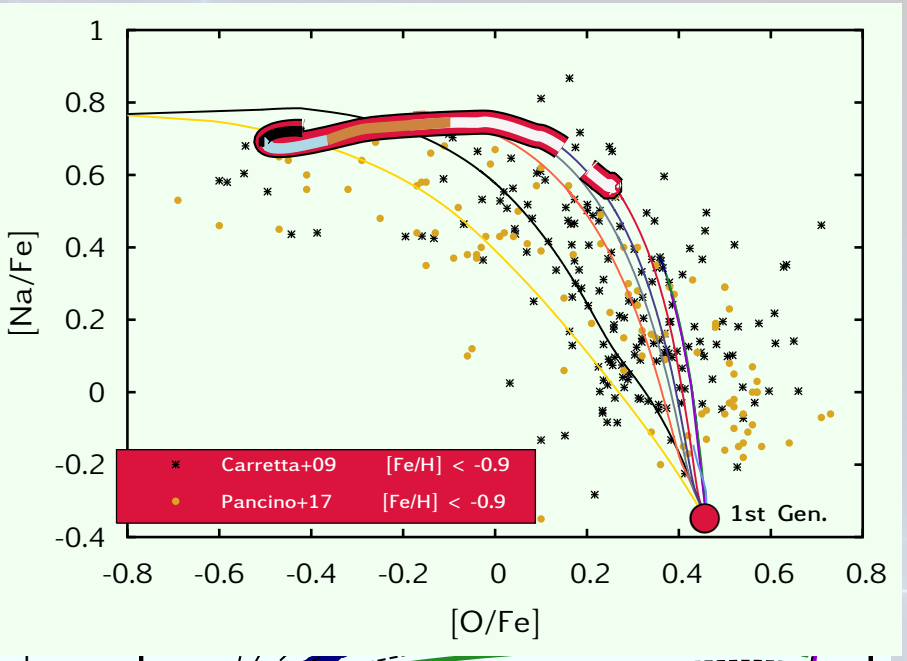
PICO shell: *Mackey+ 2014 (Nature)*

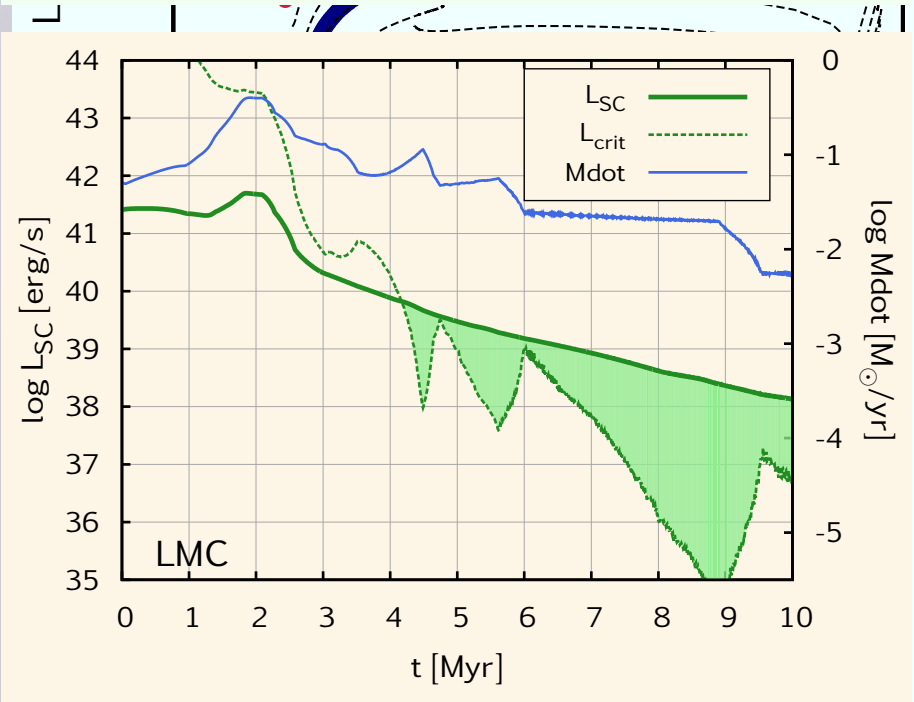
So I went to do my 1st postdoc in Prague...

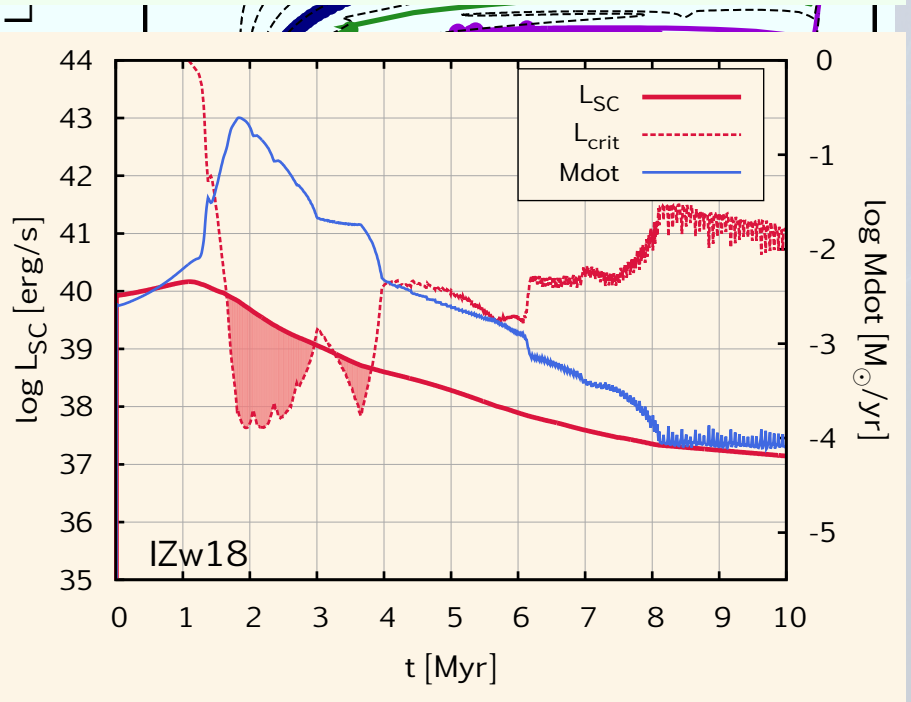
Rapidly cooling shocked stellar winds model




[Na/Fe]
[O/Fe]
1st Gen.
Carretta+09 [Fe/H] > -0.9
Pancino+17 [Fe/H] > -0.9

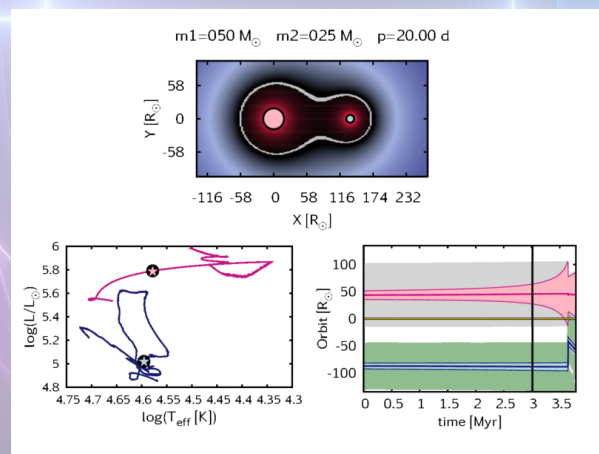

[Na/Fe]
[O/Fe]
1st Gen.
Carretta+09 [Fe/H] < -0.9
Pancino+17 [Fe/H] < -0.9


log L_SC [erg/s]
log Mdot [M⊙/yr]
t [Myr]
L_SC
L_crit
Mdot
LMC


log L_SC [erg/s]
log Mdot [M⊙/yr]
t [Myr]
L_SC
L_crit
Mdot
IZw18

The BEC interface

Dorottya Szécsi
Argelander-Institut für Astronomie



June 12, 2014

The BEC interface: `beci`

BEC = Binary Evolutionary Code

- single and binary stellar systems
- with or without rotation
- developed since the 1970s in Fortran
- very powerful!
- ...but difficult to use

`beci` = the interface for BEC

- automatized + documented
- easy to learn and use
- transferable, extensible
- and more...

Basic commands 1.

Run a new single stellar evolutionary model

```
WORKDIR/BEC$ ./beci -single 20 0.8 50 lmc -run
```

M_{ini}=20 $M_{\odot}$ Z=0.8*Z_{LMC} v_{ini}=50 km/s

Check its status

```
./beci -single 20 0.8 50 lmc -v1
```

Create a HRD

```
./beci -single 20 0.8 50 lmc -visualize -HRD
```

Create a Kippenhahn diagram

```
./beci -single 20 0.8 50 lmc -visualize -kippenhahn
```

Basic commands 2.

Get help any time

```
./beci -help
./beci -help -run
```

Modify the `m.dat` from the command line

```
./beci -single 20 0.8 50 lmc -mdat IOUT=20 DTMIN_1=1.0d0
```

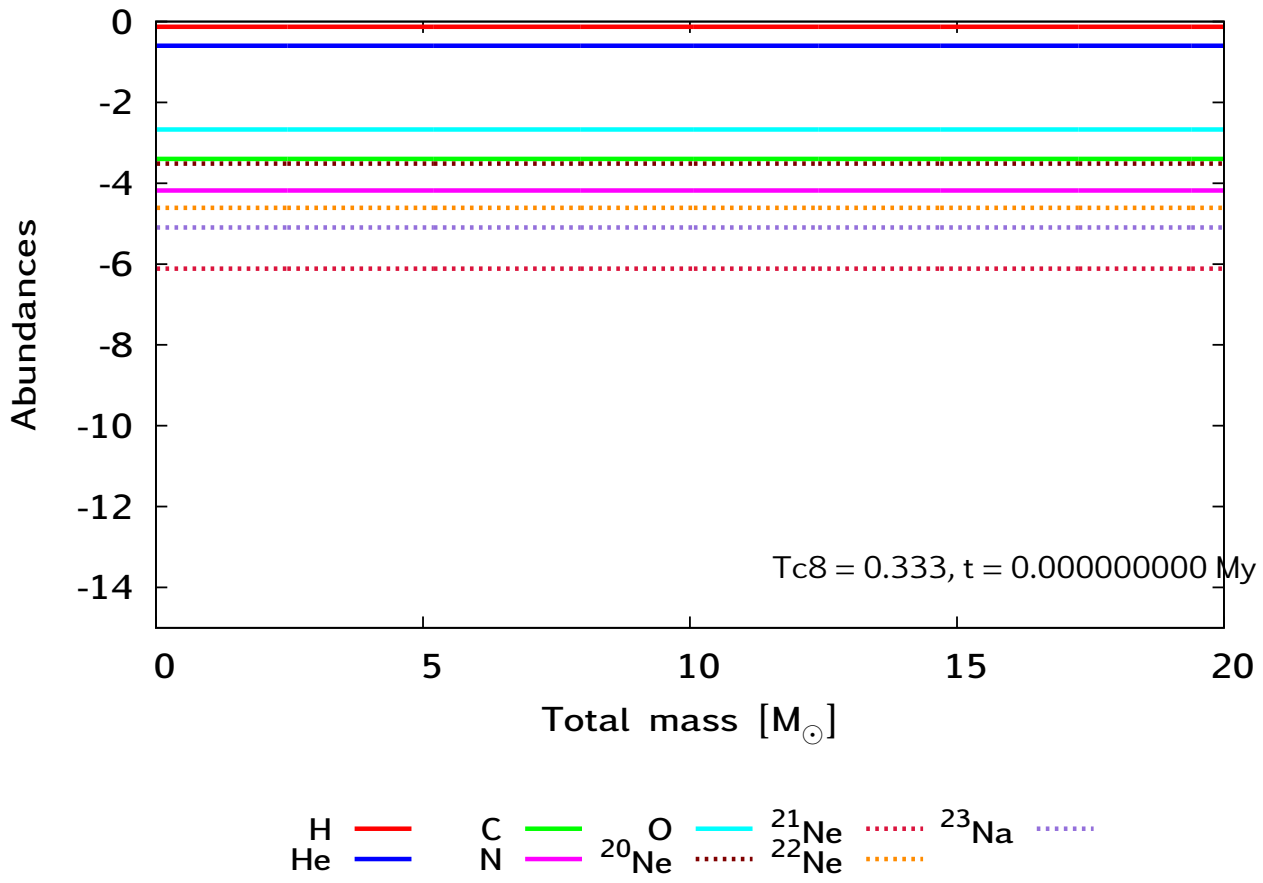
Continue a stopped calculation

```
./beci -single 20 0.8 50 lmc -continue
```

Create an animation of the composition change

```
./beci -single 20 0.8 50 lmc -visualize -composition
```

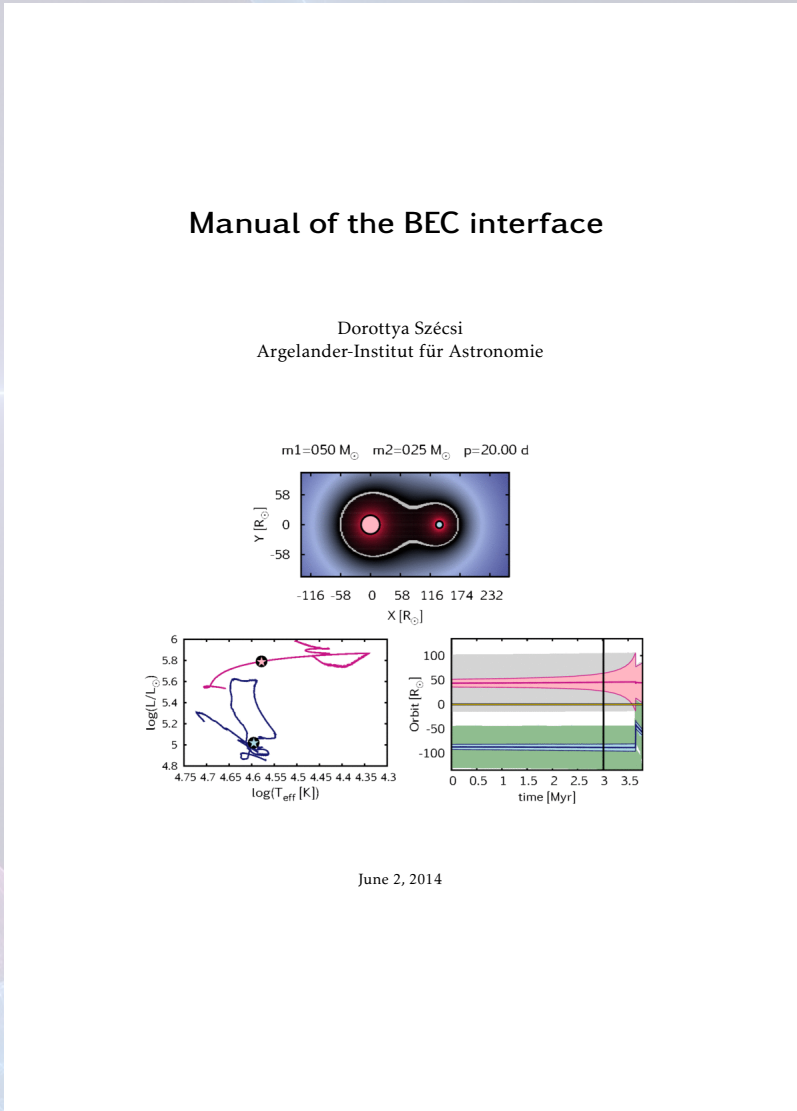
Basic commands: -composition



More options for single stars in the Manual

- `-normal`
- `-extended`
- `-savetozams`
- `-comeclean`
- `-obsHRD`
- `-recipes`
- `-structure`
- `-elements`
- `-YcYs`
- `-yield`
- `-angmom`
- `-PISN`

Also see the `-help` command!



Manual of the BEC interface

Dorottya Szécsi
Argelander-Institut für Astronomie

June 2, 2014

So what about binaries?

Run a new binary stellar evolutionary model

```
./beci -binary 050 025 1.0 20.00 smc -run
```

M^{P}_{ini}=50 $M_{\odot}$ M^{S}_{ini}=25 $M_{\odot}$ Z=1.0*Z_{SMC} p_{ini}=20 days

Check their status

```
./beci -binary 050 025 1.0 20.00 smc -v1 -v2 -v3
```

Visualize them on the HRD and Orbit diagram

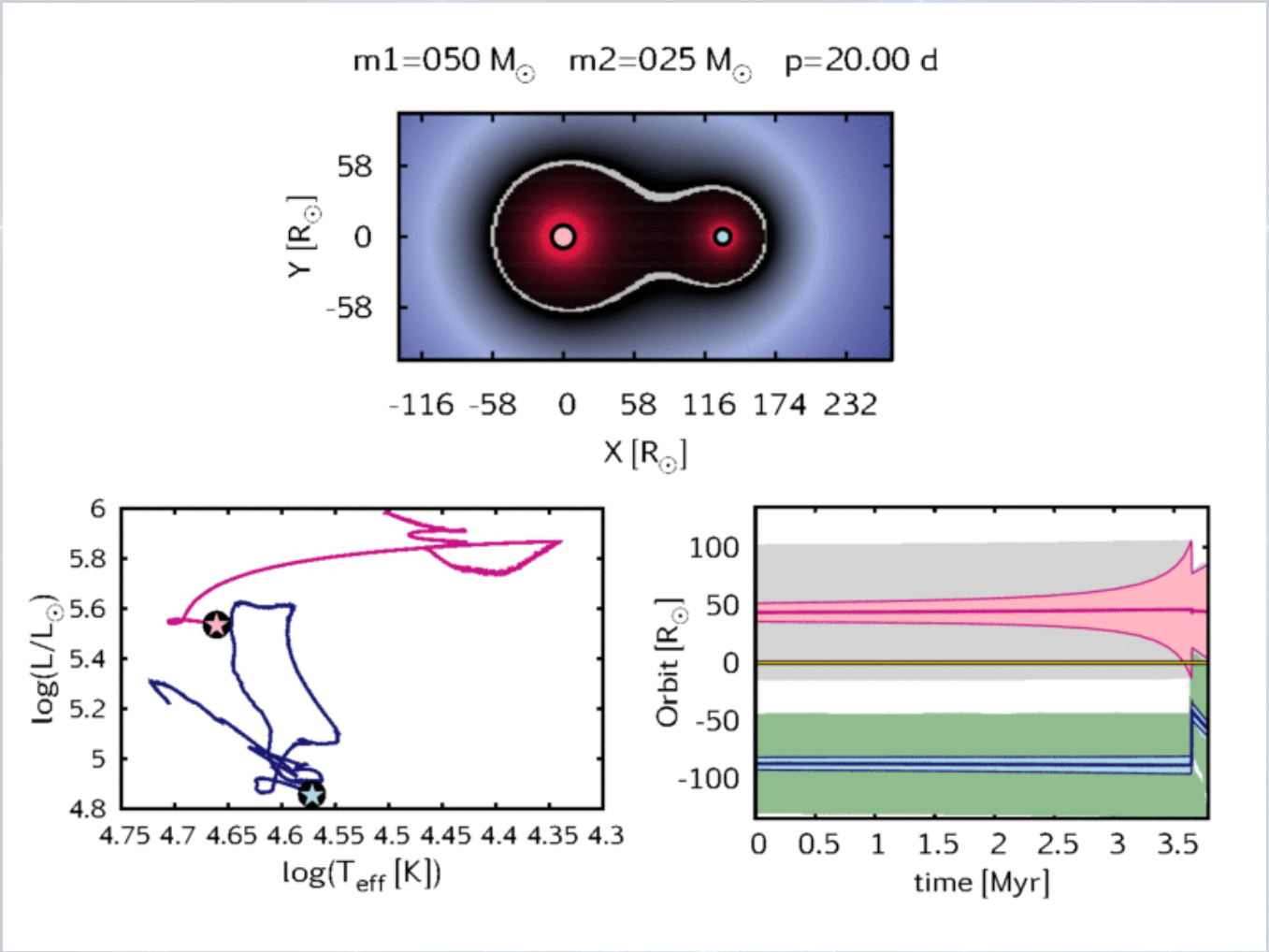
```
./beci -binary 050 025 1.0 20.00 smc -visualize
```

More options for binary stars in the Manual:

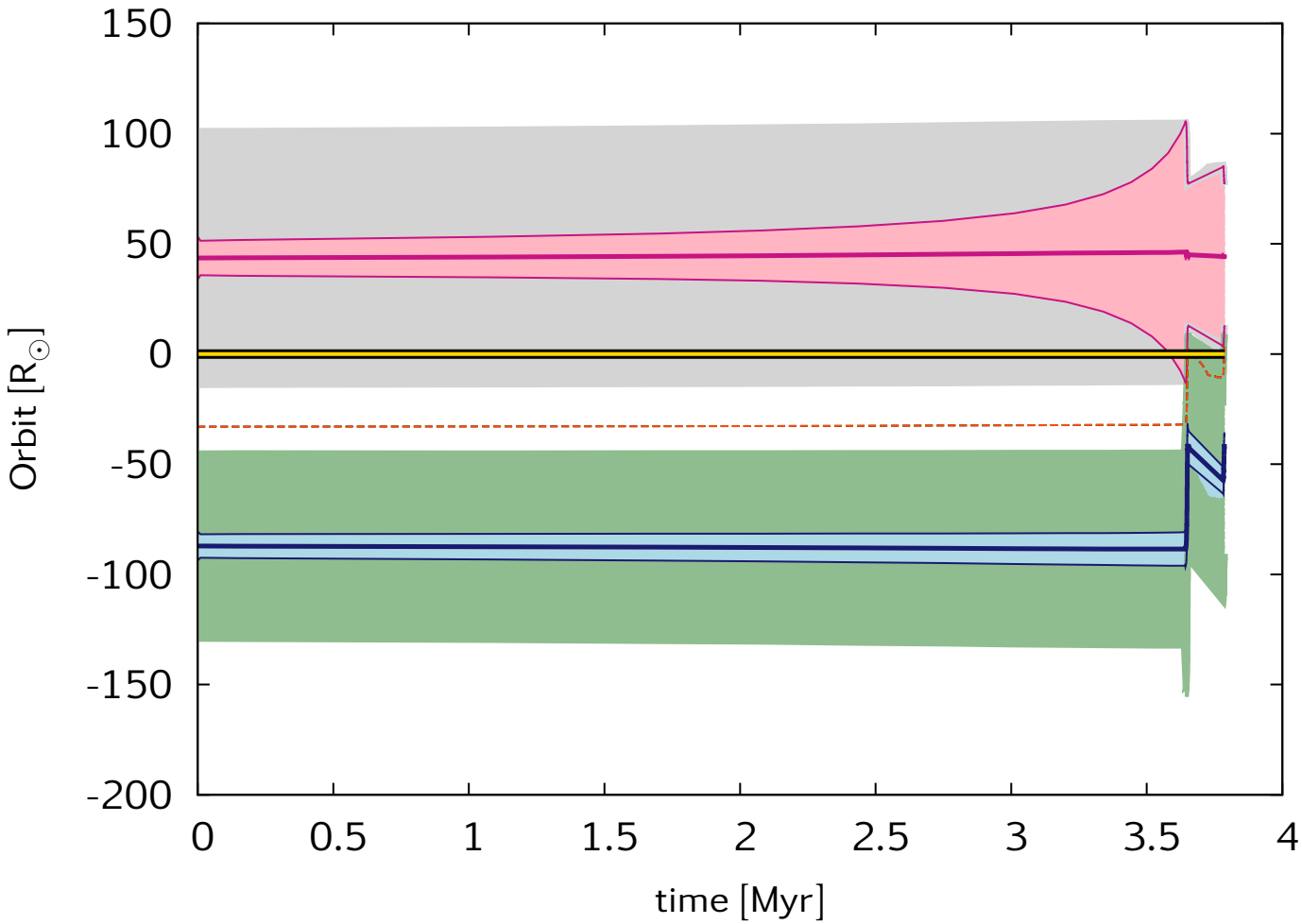
- `-mdat -continue -normal -kippenhahn -composition -recipes -structure -help`

...and more

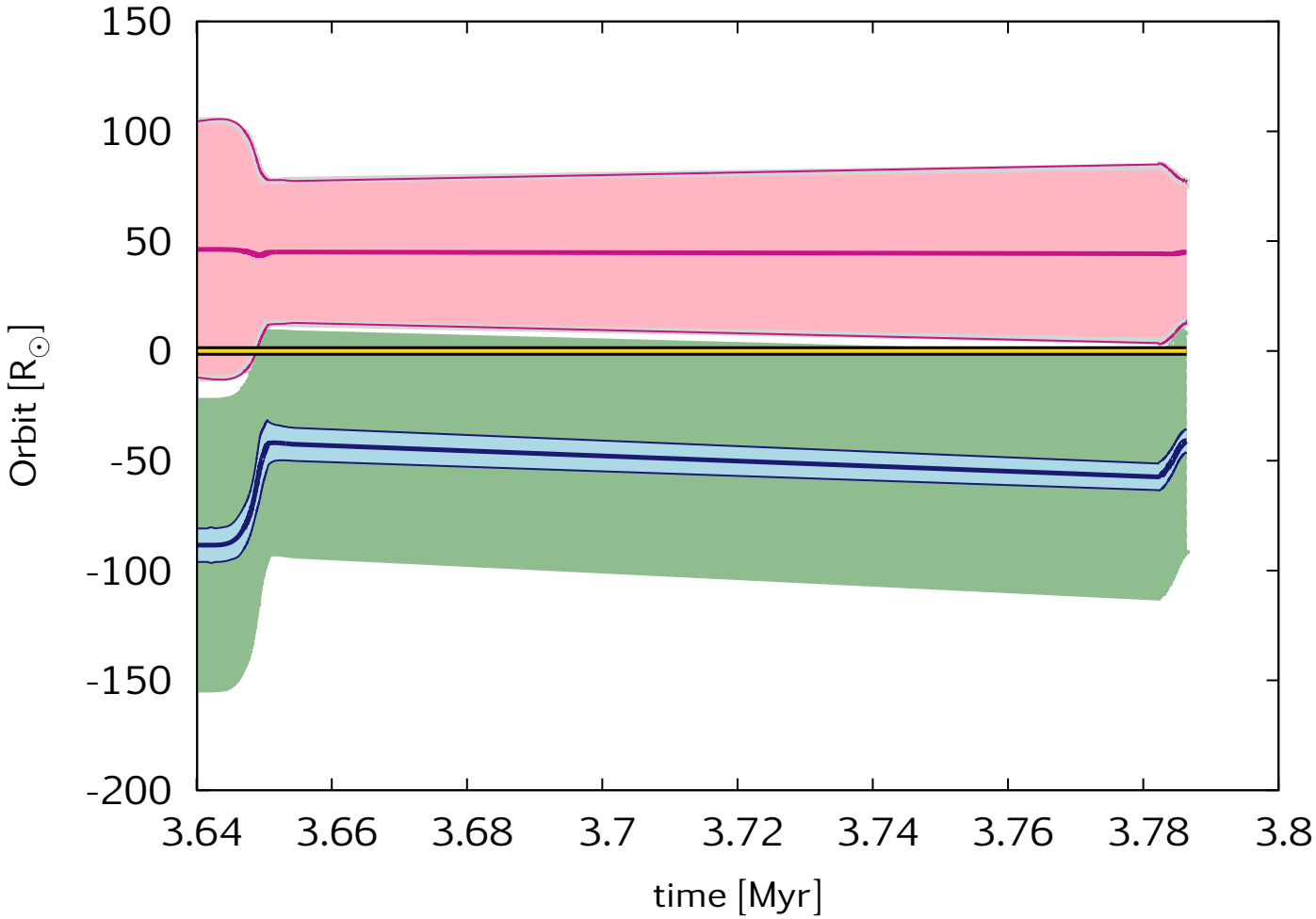
```
./beci -binary 050 025 1.0 20.00 smc -visualize -anim
```



The 'Orbit' diagram



The 'Orbit' diagram - after RLOF



Handling large grids of stars

Grids created by BEC:

- Yoon et al. 2006, 2012 (low Z, Pop.III)
- Brott et al. 2011 (MW, LMC, SMC)
- Köhler et al. 2014 (LMC)
- Szécsi et al. 2014 (IZw18)

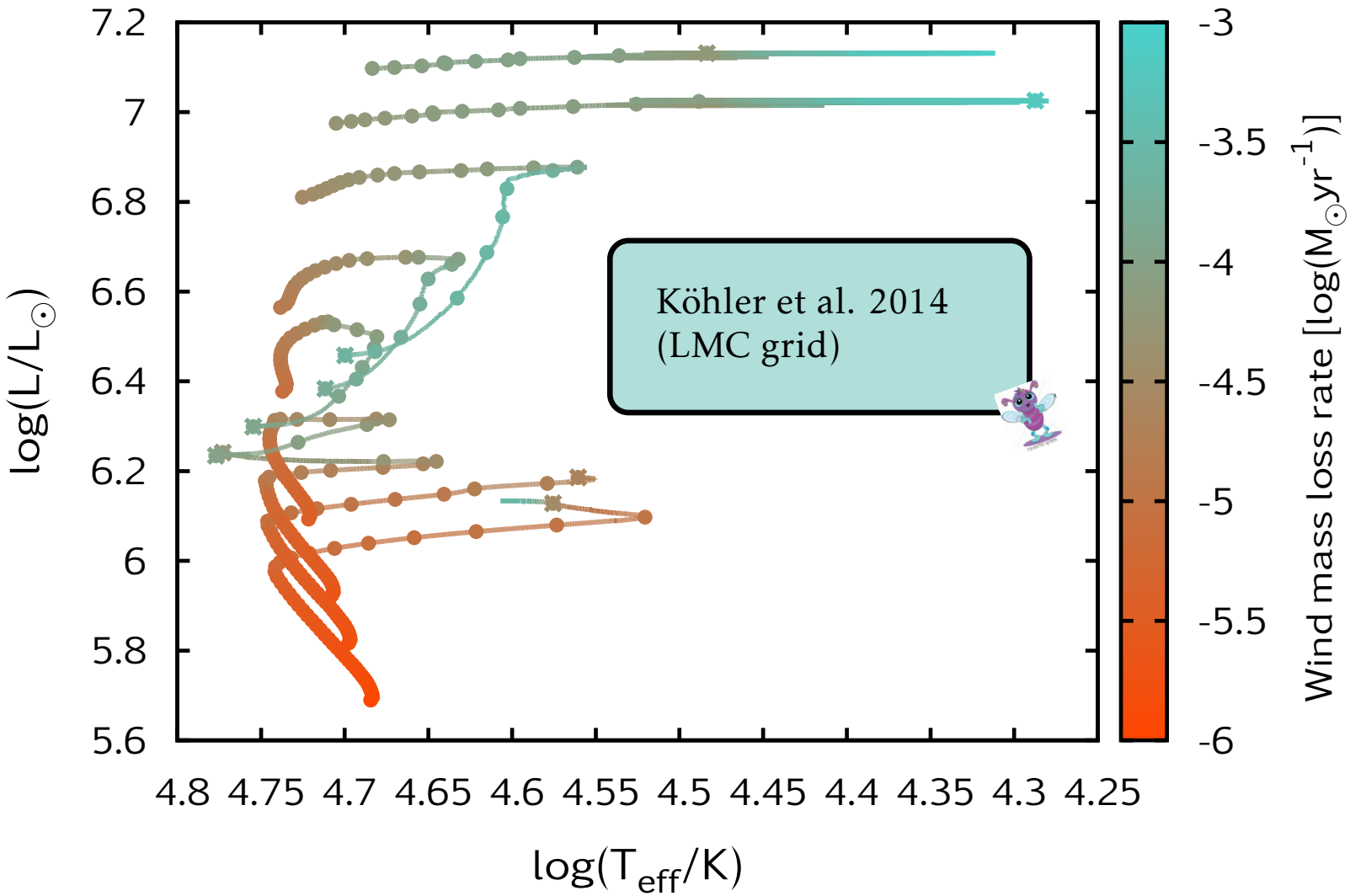
Common HRD of all stars in the grid

```
./beci -grid NameOfGrid -gridHRD
```

More grid commands are available, see the Manual or call

```
./beci -help -grid
```

Handling large grids of stars: -gridHRD



Write your own script!

```
./beci -single 20 0.8 50 lmc -myscript -coolscript Dori
```

```
##coolscript.sh
echo "Hi dear friend $1!"
echo "You are working with the star
M=$m Msun - z=$z x Z_$g - v=$v km/s in $path_BEC/bin"
endMS=`cat ./m$m-z$z-v$v.$g/$m-$z.plot1 | sed 's/D/E/g' | awk '
BEGIN{max=0}{if($3>max){max=$3;tmax=$1}} END{print tmax}'`
endMSMyr=`echo $endMS | awk '{printf "%1.3f", $1/1000000 }'`
echo "Main sequence lifetime:  $endMSMyr Myr"
echo "Bye!  :)"
```

Result

```
Hi dear friend Dori!
You are working with the star
M=20 Msun - z=0.8 x Z_lmc - v=50 km/s in $WORKDIR/BEC/bin
Main sequence lifetime:  7.886 Myr
Bye!  :)
```

Thank you for your attention!

Program files are available here:

`/vol/cstorage/raid18/dorottya/BECinterface`

Copy the files in your $WORKDIR and call

```
./beci -setup
```

Please try it and find bugs!