



Role of metal-poor massive stars in galaxies near and far

Dorottya Szécsi

Humboldt Fellow

University of Cologne, Germany

Assistant professor

Nicolaus Copernicus University, Poland

Colloquium at Swinburne University of Technology,
Melbourne, Australia, 28th April 2021

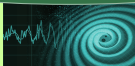


Alexander von Humboldt
Stiftung/Foundation

Dwarf galaxies



Gravitational waves



High-redshift Univ.



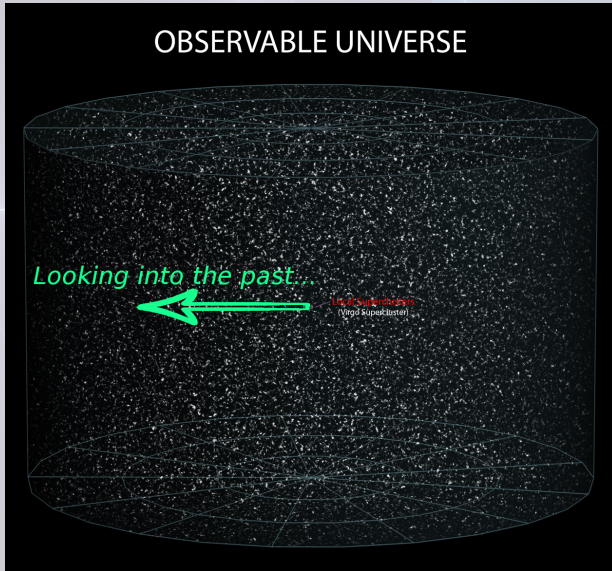
Gamma-ray bursts



Globular clusters



The Universe is pretty large though...



The Universe is pretty large though...

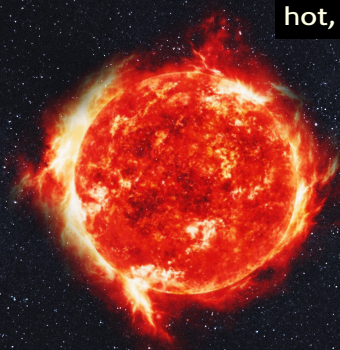


What is a star?

What is a star?

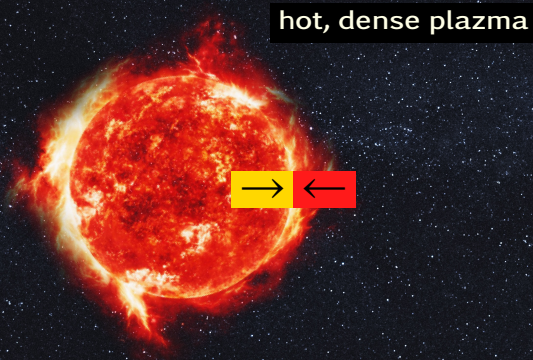


What is a star?



hot, dense plazma

What is a star?



equilibrium:

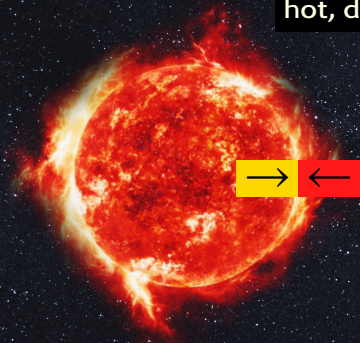
pressure gradient

gravity

What is a star?

surface?

hot, dense plazma



equilibrium:

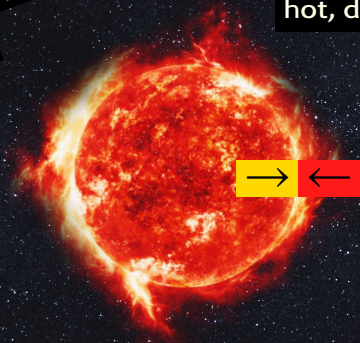
pressure gradient

gravity

What is a star?

surface?
→ photons escape
"photosphere"

hot, dense plazma



equilibrium:

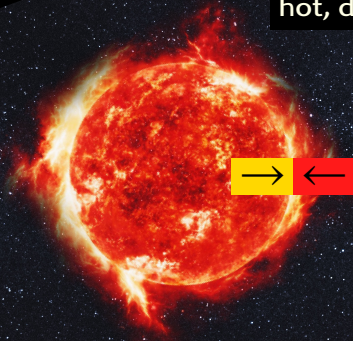
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What is a star?

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equilibrium:

pressure gradient

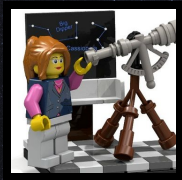
gravity

What is a star?

surface?
→ photons escape
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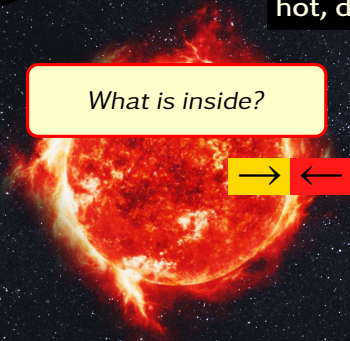
What is inside?



equilibrium:

pressure gradient

gravity



What is a star?

surface?
→ photons escape
"photosphere"

hot, dense plazma

What is inside?



equilibrium:

pressure gradient

gravity

theoretical
modelling
of the stellar
structure

Theoretical modelling of the stellar structure

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

$$\frac{\partial P}{\partial m_r} = -\frac{Gm_r}{4\pi r^4} \quad \text{equation of hydrostatic equilibrium} \quad (2)$$

$$\frac{\partial L_r}{\partial m_r} = \epsilon_{\text{pl}} - T \frac{\partial S}{\partial t} \quad \text{equation of energetic balance} \quad (3)$$

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

Theoretical modelling of the stellar structure

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

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Theoretical modelling of the stellar structure

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Guilera+ 11

composition change due to nuclear burning:

Theoretical modelling of the stellar structure

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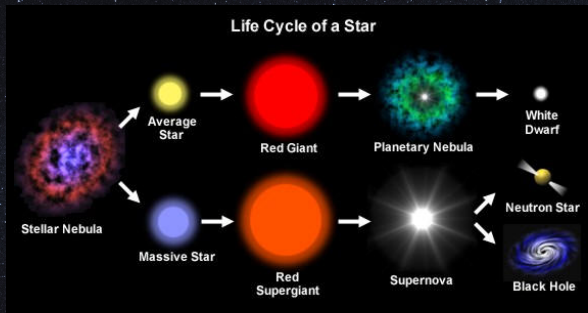
Guilera+ 11

composition change due to nuclear burning:

$$\frac{\partial X_i}{\partial t} = \frac{A_i m_u}{\rho} (-\Sigma_{j,k} r_{i,j,k} + \Sigma_{k,l} r_{k,l,i}) \quad (5)$$

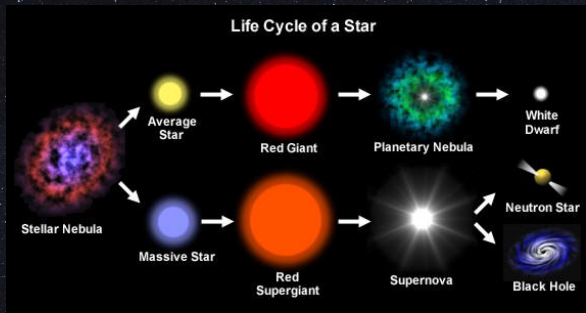
Massive vs. low-mass stars

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

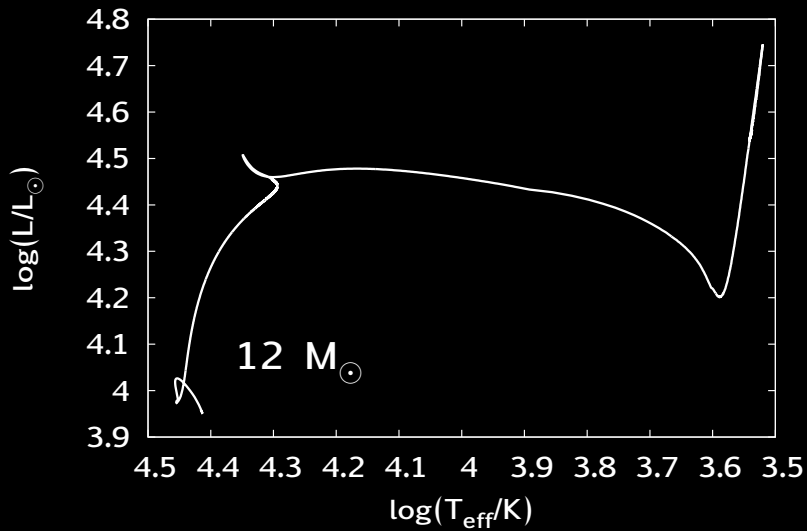


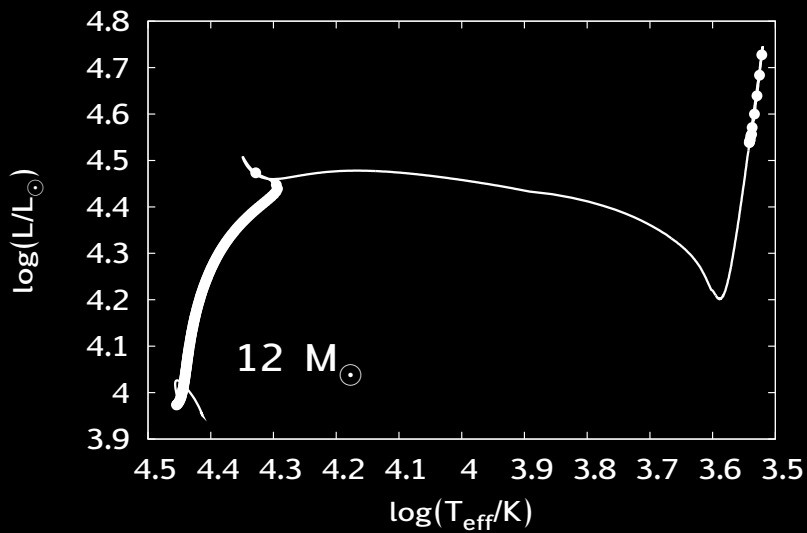
Massive vs. low-mass stars

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



- Metallicity
- Rotation
- Binarity





$1e51 \text{ ph/s}$

$1e50$

$1e49$

$1e48$

Lyman

$\log L/L_{\odot}$

7.0

6.0

5.0

4.0

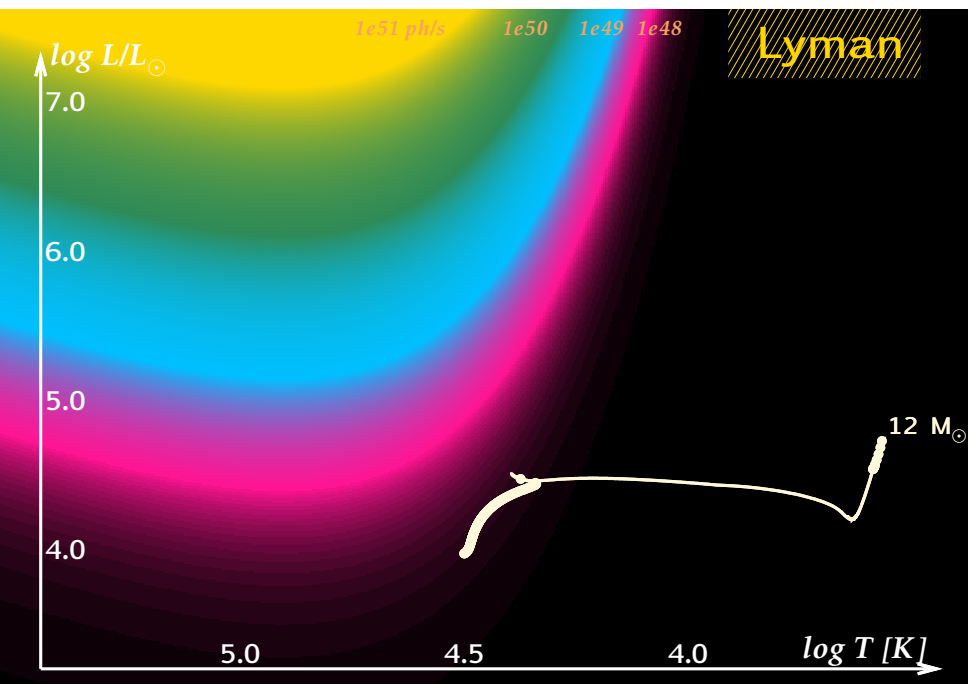
5.0

4.5

4.0

$\log T [\text{K}]$

$12 M_{\odot}$



$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$

Lyman

 $\log L/L_{\odot}$

7.0

6.0

5.0

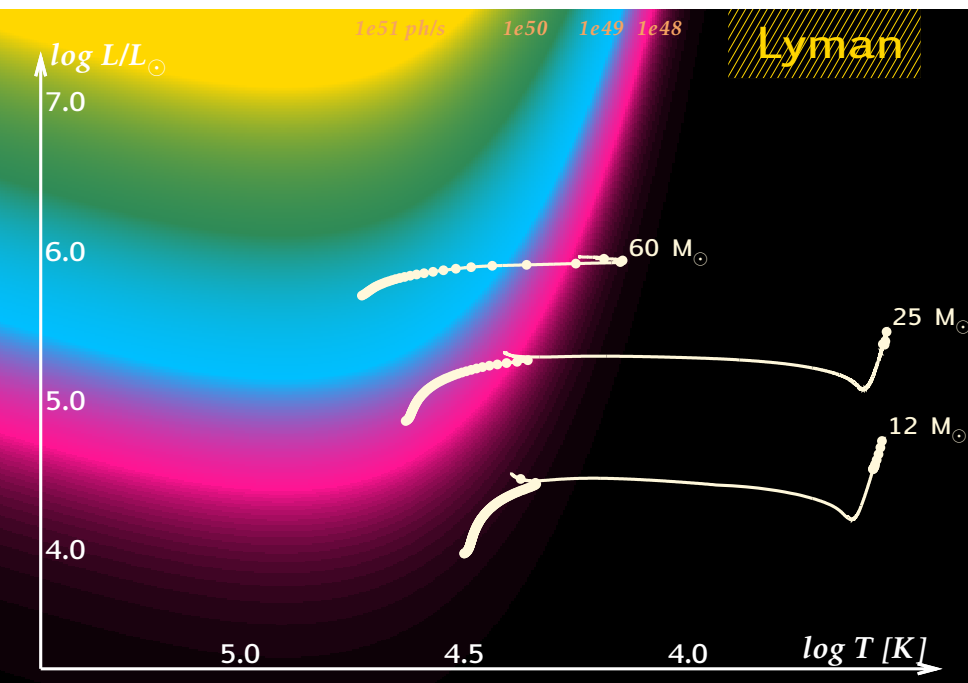
4.0

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$ **Lyman** $\log L/L_{\odot}$

7.0

6.0

5.0

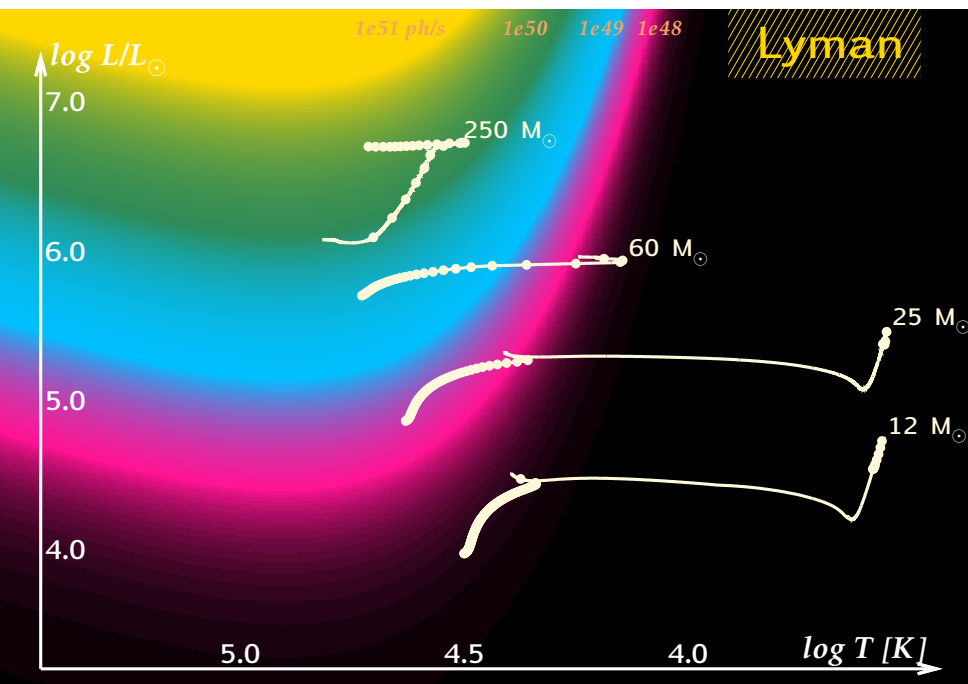
4.0

250 $M_{\odot}$ 60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$

Lyman

 $\log L/L_{\odot}$

7.0

6.0

5.0

4.0

250 $M_{\odot}$

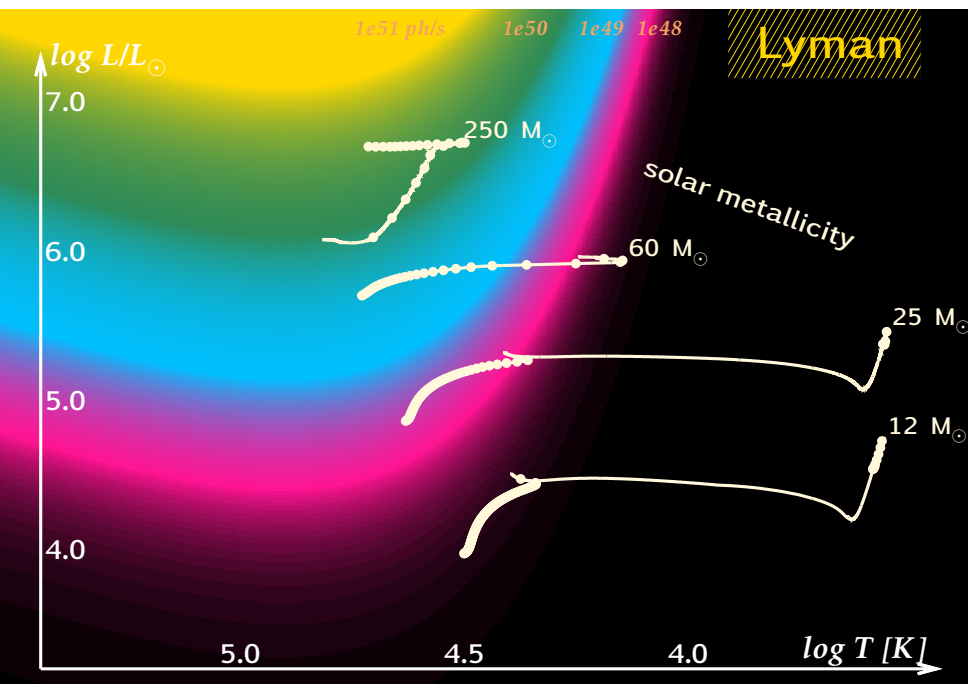
solar metallicity

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

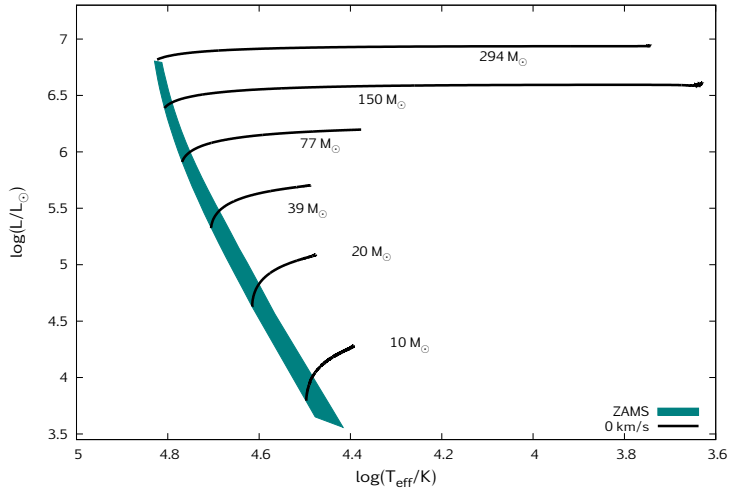
 $\log T [\text{K}]$ 

Low Metallicity Massive Stars



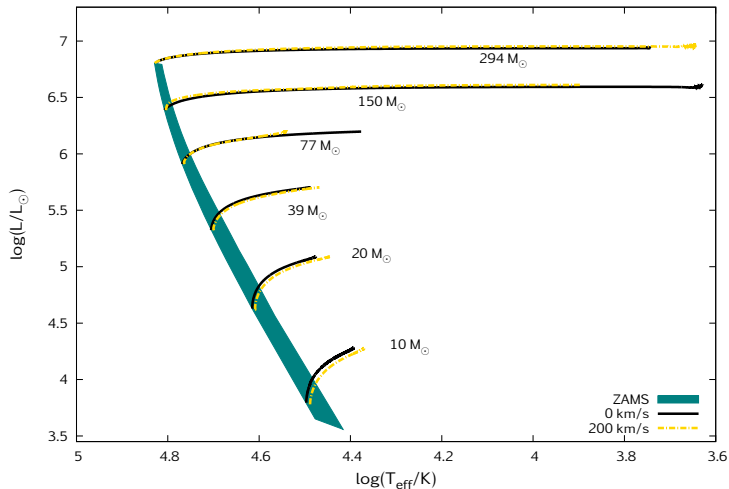
Low Metallicity Massive Stars

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



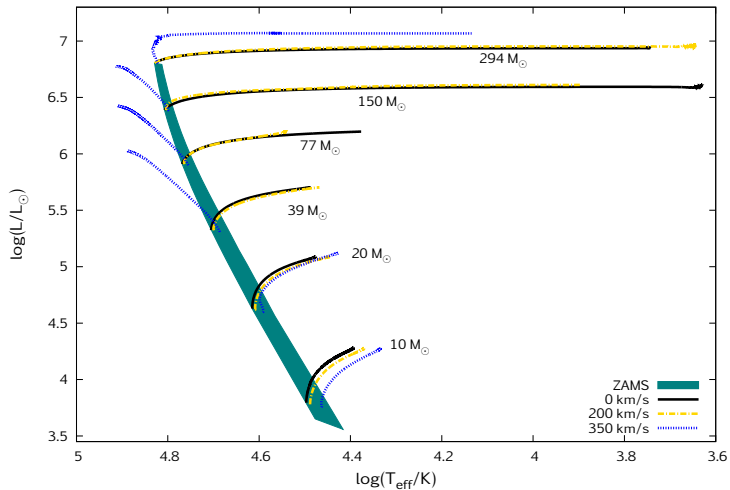
Low Metallicity Massive Stars

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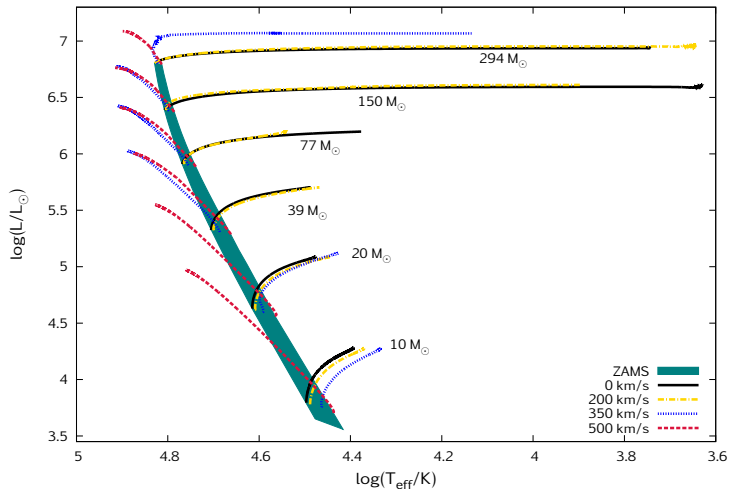
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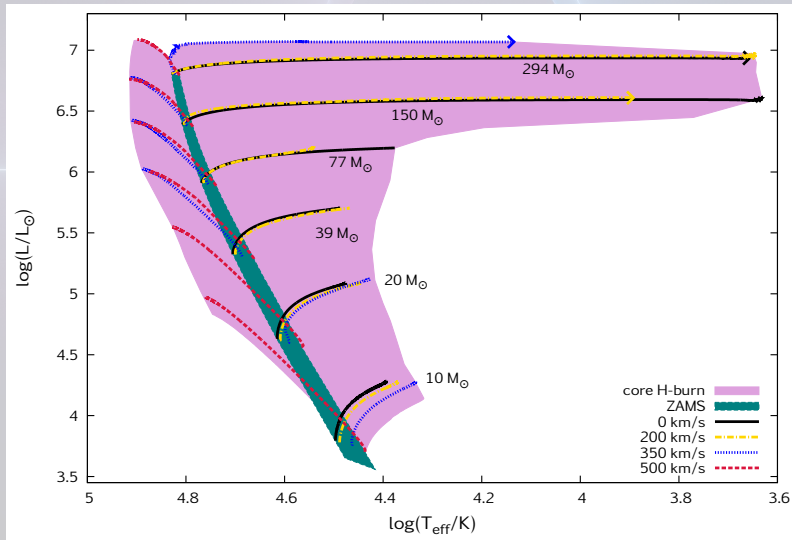
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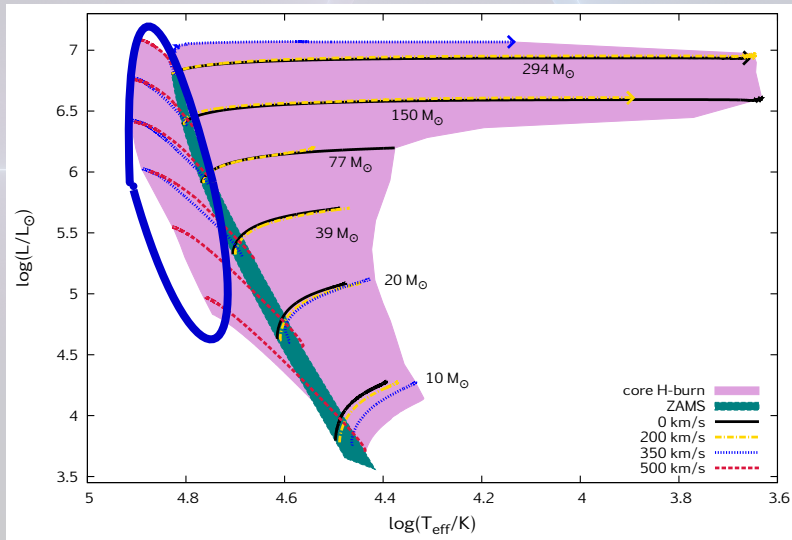
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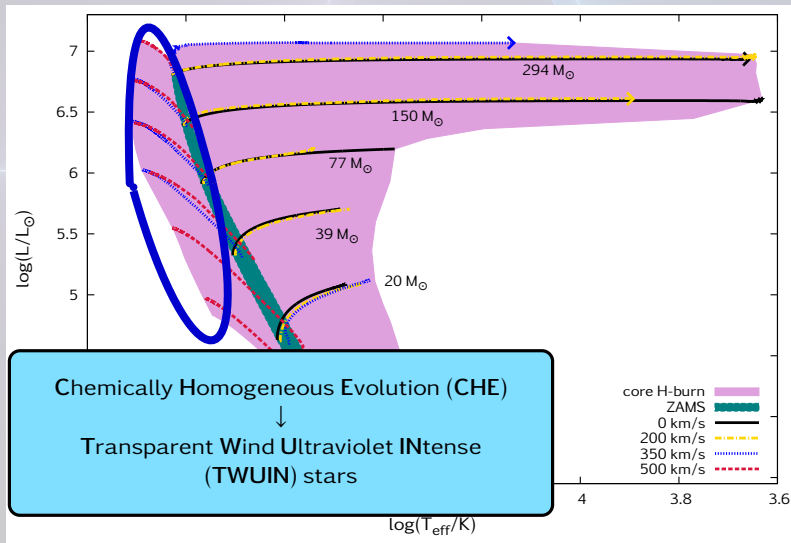
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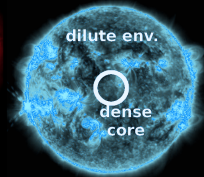


Red supergiant:



$T \sim 4000 \text{ K}$

Normal OB-star:

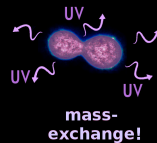


$T \sim 15\,000 \text{ K}$

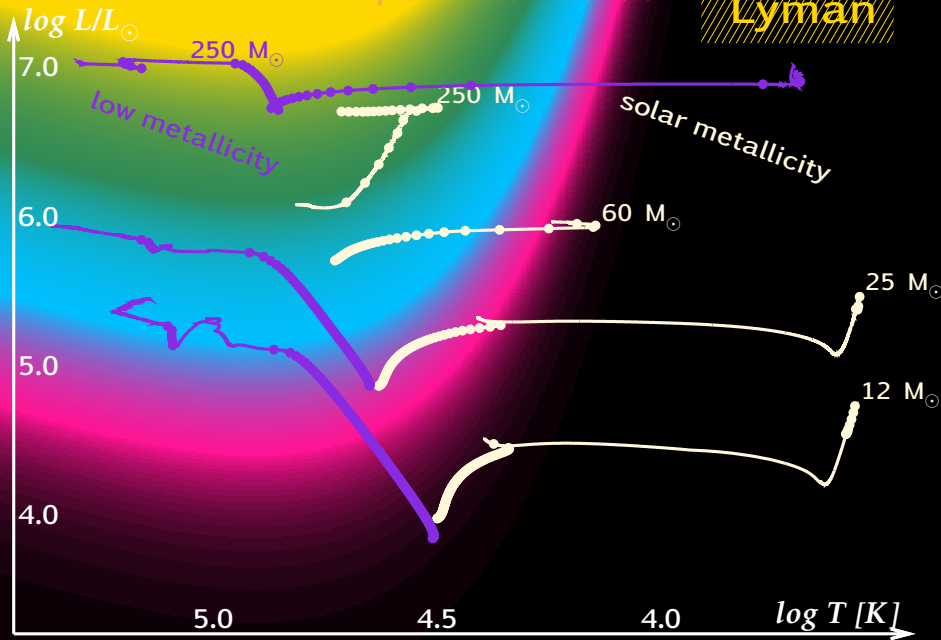
TWUIN star:



TWUIN binary:



$T \sim 80\,000 \text{ K}$

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$ **Lyman**

Metallicity



Dorottya Szécsi:

The BoOST project

Bonn Optimized Stellar Tracks

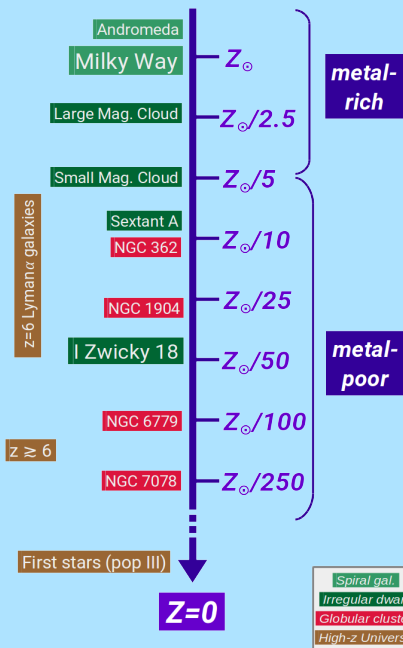
Metallicity



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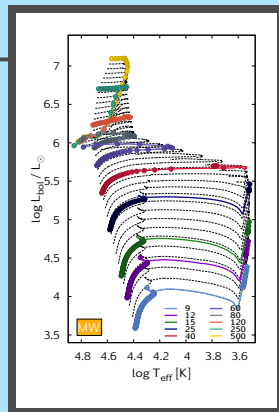
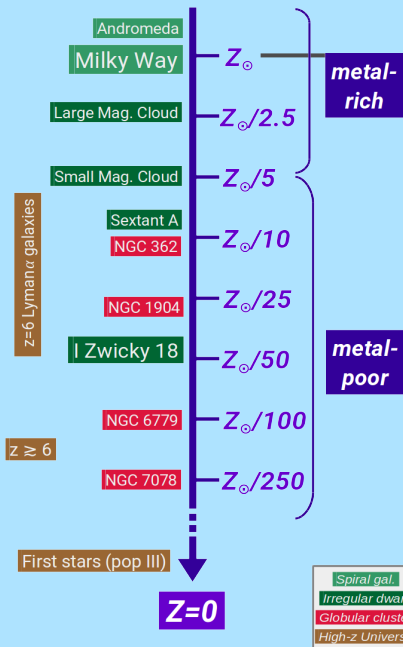
Bonn Optimized Stellar Tracks



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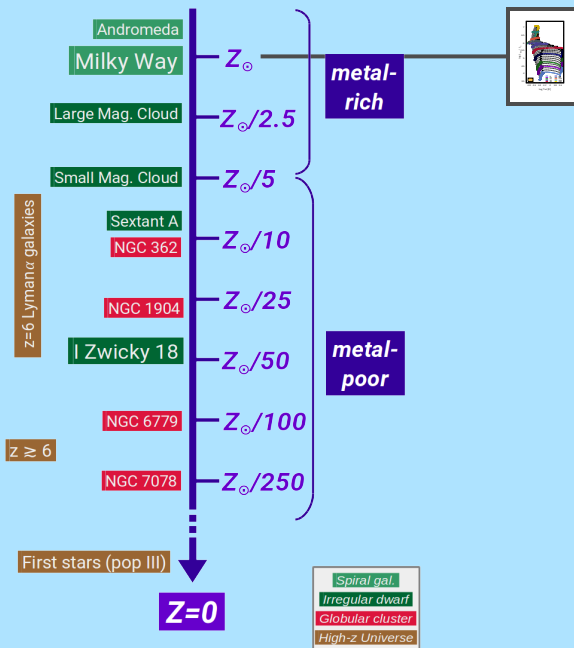
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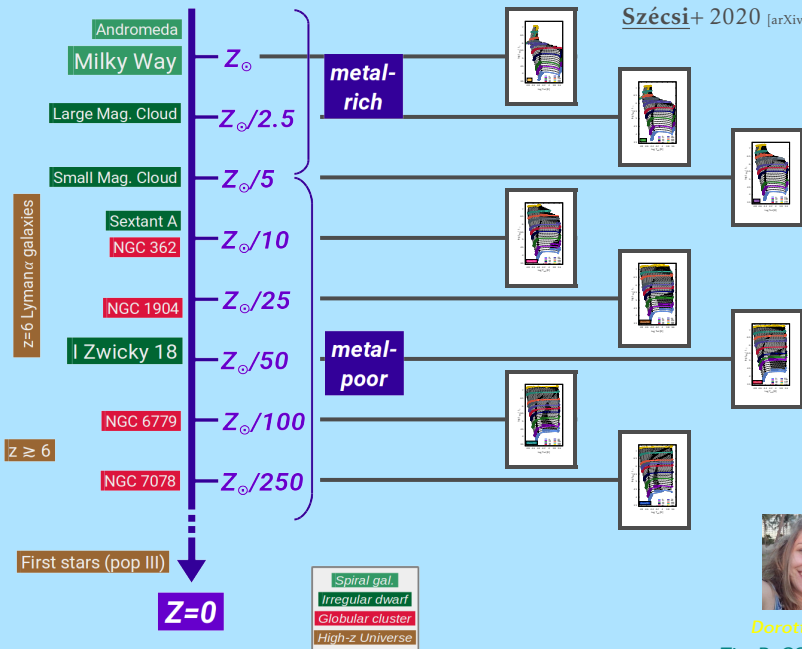
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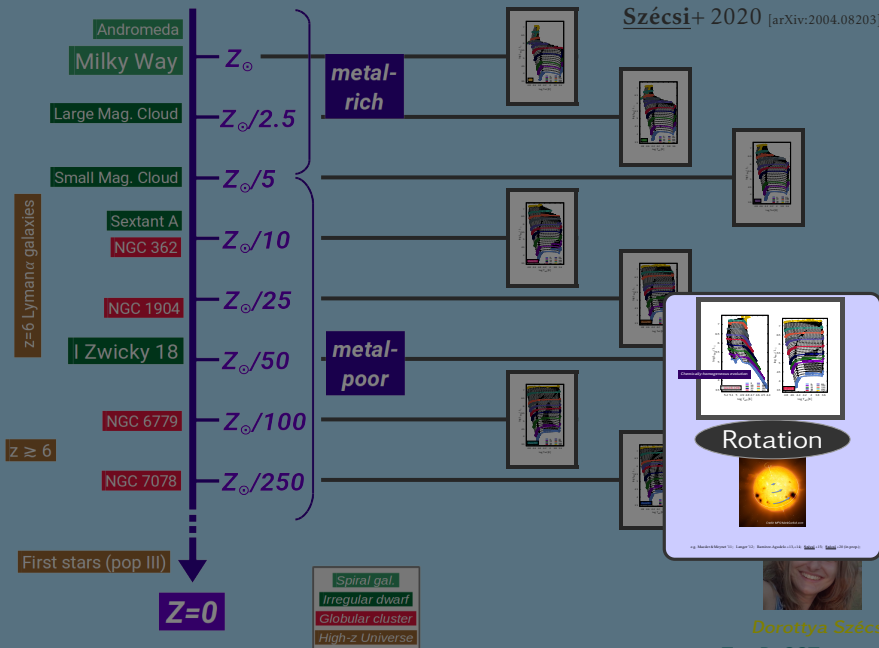
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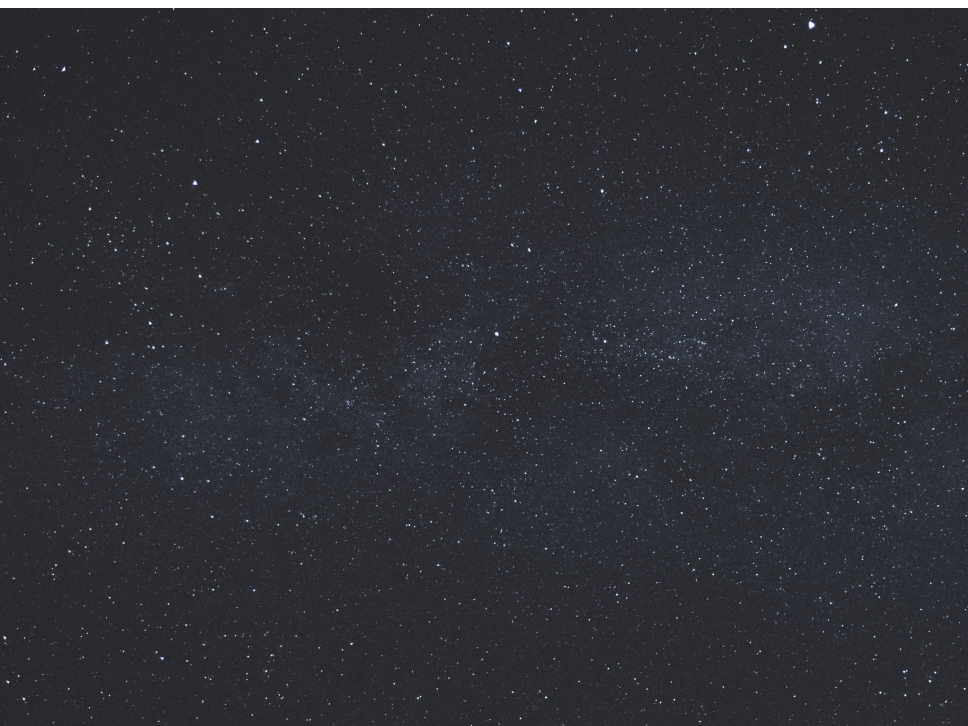
Bonn Optimized Stellar Tracks



Dorottya Szécsi:

The BoOST project

Bonn Optimized Stellar Tracks



Dwarf galaxies

low metallicity ($Z \sim 10^{-3} - 10^{-2}$)
 active star formation → massive stars
 (that often explode)

• PHD computed metallicity evolution
 (10% per Myr)
 • increasing bursts
 releasing star formation
 metallicity

• current models
 (10% per Myr)
 are consistent of
 observations of
 galaxies
 (e.g. dwarf galaxies
 in the Local Group)

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 (10% per Myr)
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 in the Local Group)

e.g. [Seargent et al. \(2015\)](#), [Seargent et al. \(2015\)](#), [Kobayashi et al. \(2015\)](#), [Seargent et al. \(2015\)](#)

Gravitational waves

mass loss + metallicity
 very massive black holes in LIGO

• general idea in
 binary systems
 (e.g. LIGO)
 • LIGO waves are
 produced by
 compact objects

• current models
 (10% per Myr)
 are consistent of
 observations of
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 (e.g. dwarf galaxies
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e.g. [Merritt et al. \(2015\)](#), [Kobayashi et al. \(2015\)](#), [Seargent et al. \(2015\)](#), [Seargent et al. \(2015\)](#)

High-redshift Univ.



Metal-poor massive stars

Gamma-ray bursts

PHD
 general idea in
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Globular clusters

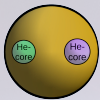
metal-poor
 low-mass stars
 general idea in
 binary systems
 (e.g. LIGO)
 • LIGO waves are
 produced by
 compact objects

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GRB progenitors

Dorottya Szécsi:
New vision
for *THESEUS*



Common
envelope
in a binary



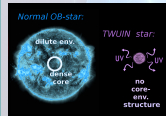
Chemically-
homogeneous
evolution
in a binary



Dynamics in
dense
clusters

S-GRBs

Metal-poor massive stars



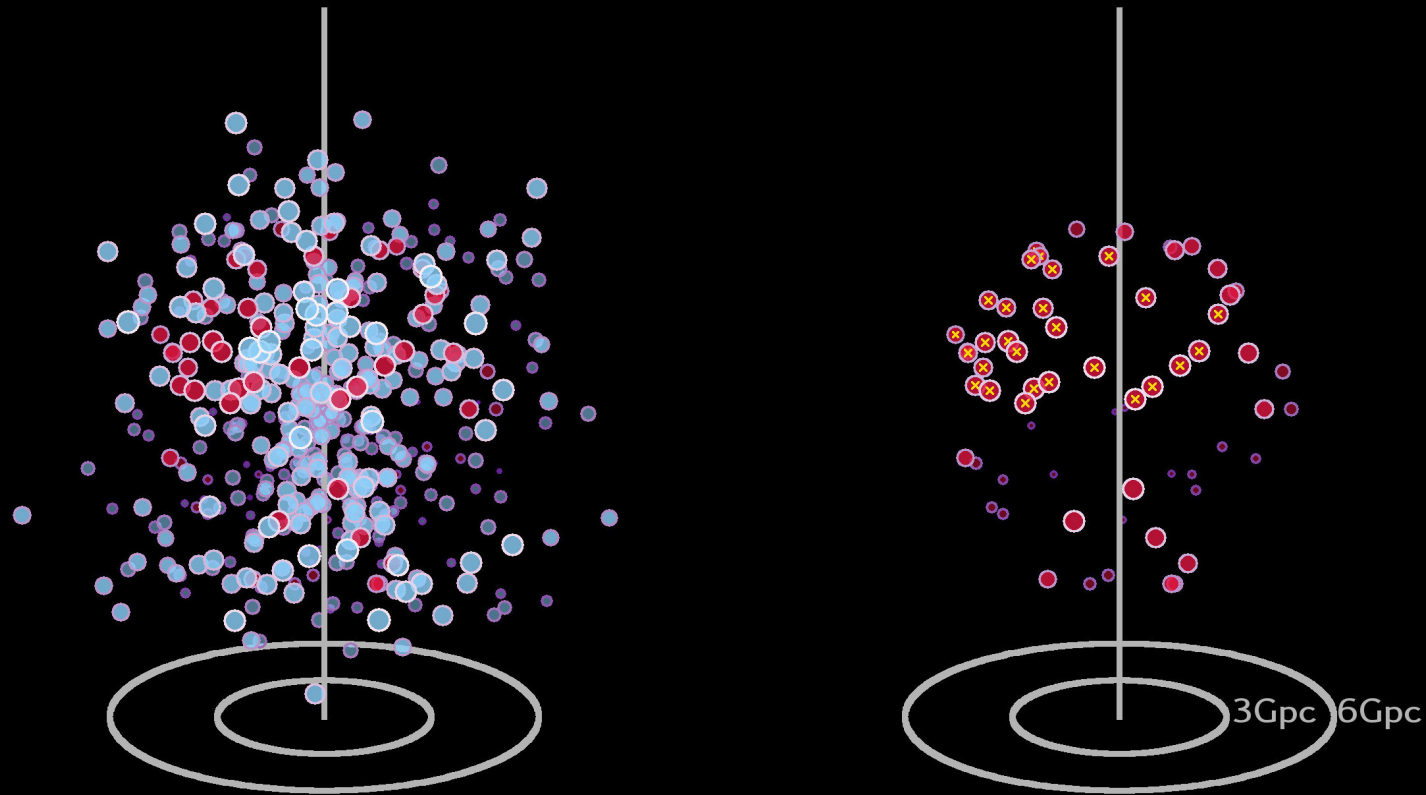
Chem.-hom.
evolution
as single star



Chem.-hom.
evolution
in a binary

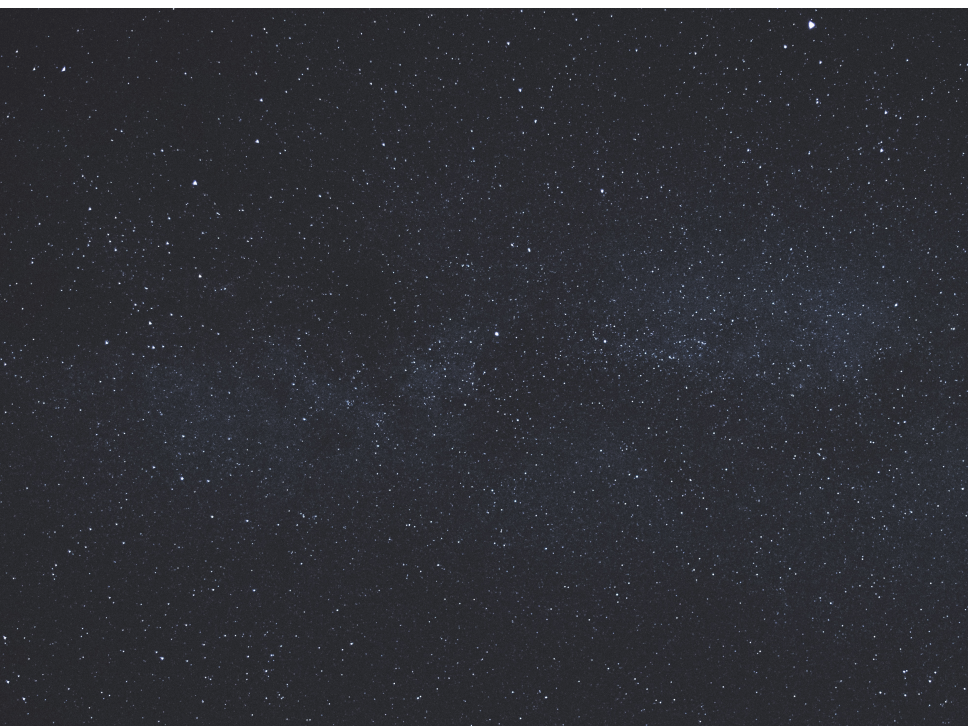
L-GRBs

The 3D Universe seen in GRBs:



“Hercules–Corona Borealis Great Wall”: 2–3 Gpc

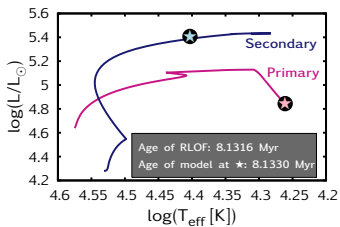
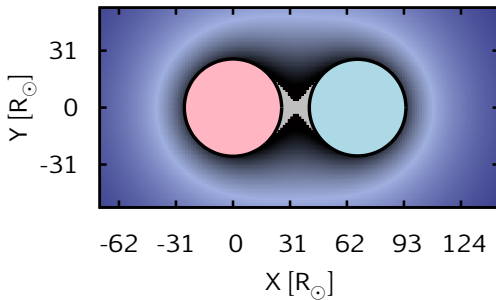
Horvath, [Szécsi](#), ..., [Szabó](#), ... et al. (2020, MNRAS)



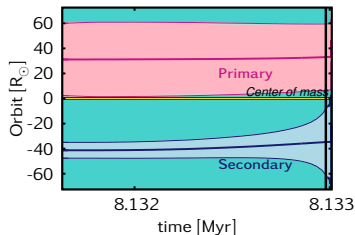
Binary stars...

System: $20 M_{\odot} + 15 M_{\odot} + 12 \text{ d}$

Age: 8.1330 Myr

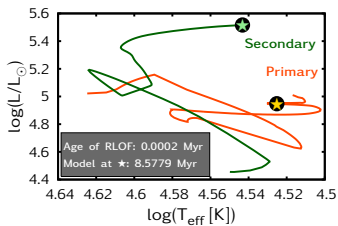
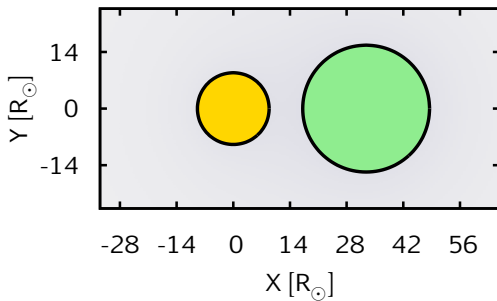


de Mink +09, [Szécsi +14](#)

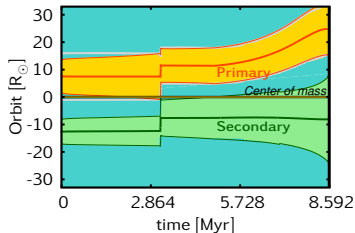


System: $29 M_{\odot} + 17 M_{\odot} + 1.5 \text{ d}$

Age: 8.5779 Myr

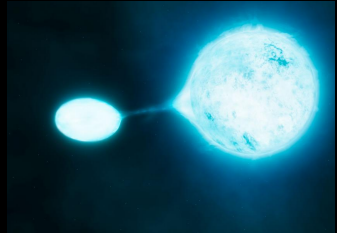
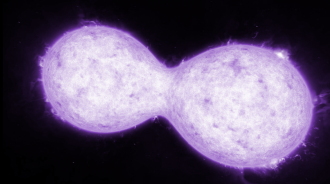


Menon & Szécsi +20 (in prep.)



Binary stars!

(Sana+12)



$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$ **Lyman** $\log L/L_{\odot}$

7.0

6.0

5.0

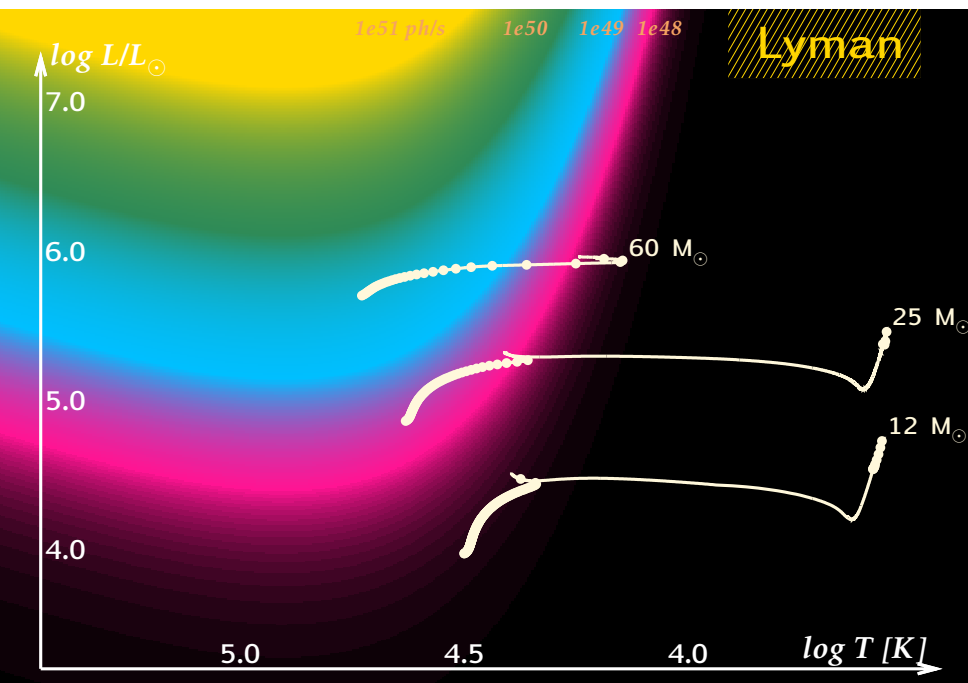
4.0

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$

Lyman

 $\log L/L_{\odot}$

7.0

6.0

5.0

4.0

60 $M_{\odot}$

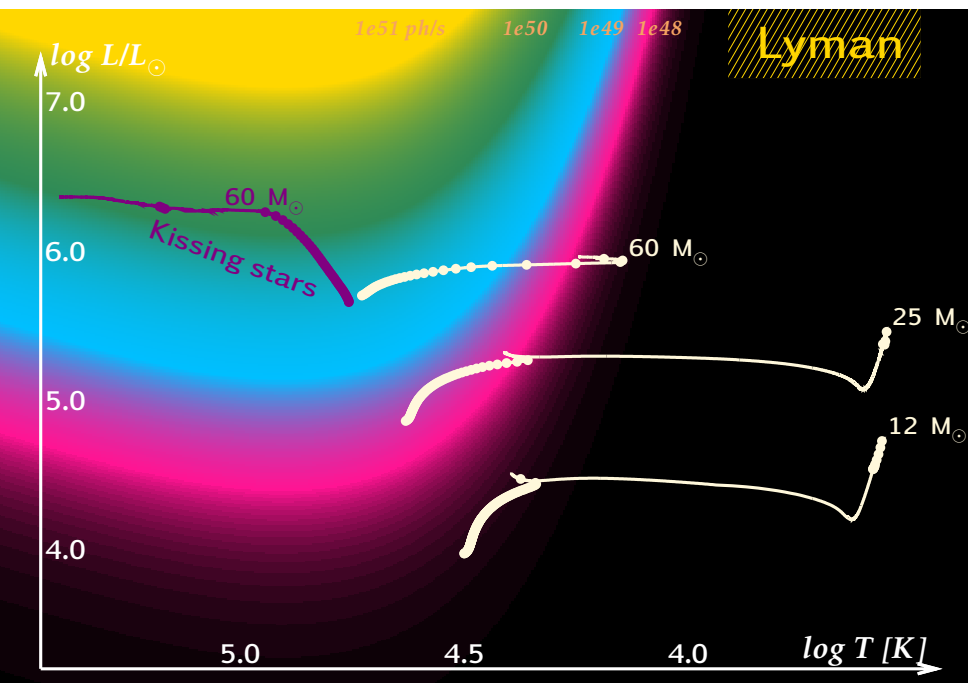
Kissing stars

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$

Lyman

 $\log L/L_{\odot}$

7.0

6.0

5.0

4.0

60 $M_{\odot}$

Kissing stars

↓
gravitational
waves!

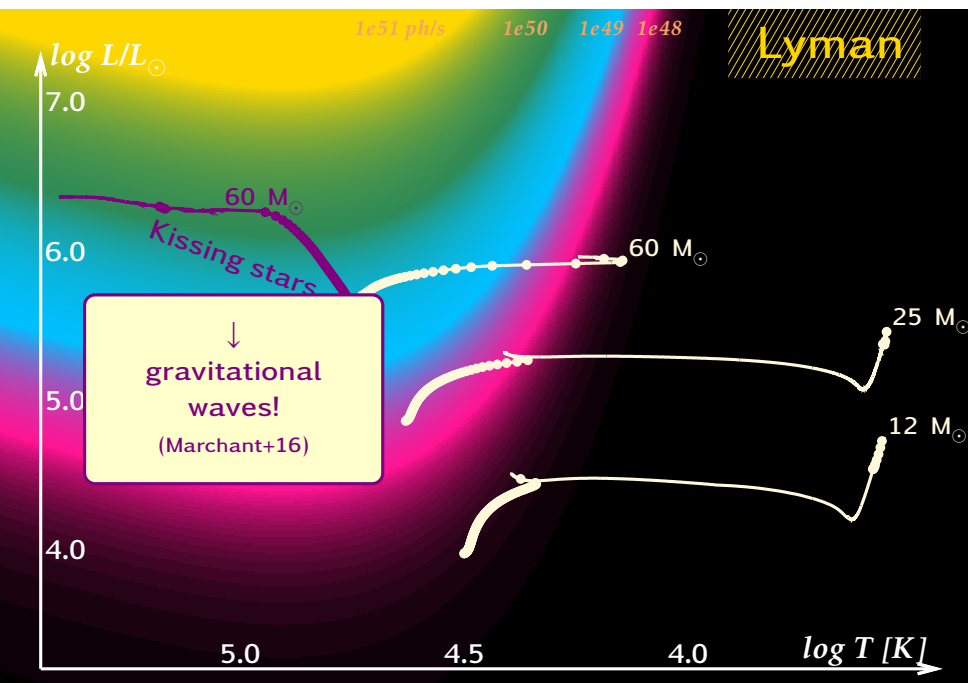
(Marchant+16)

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$ **Lyman** $\log L/L_{\odot}$

7.0

6.0

5.0

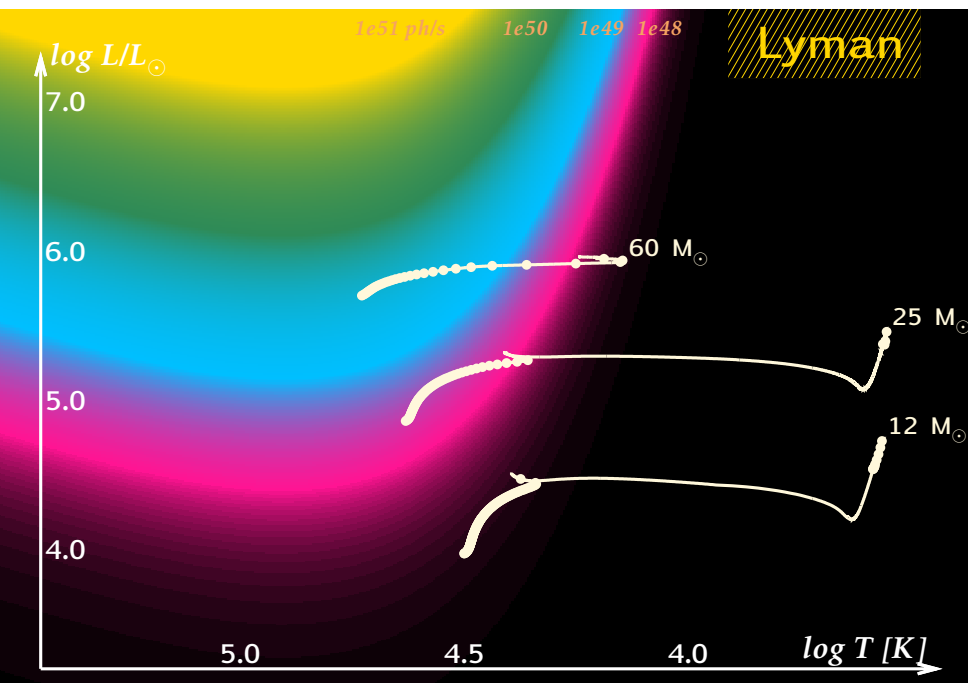
4.0

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$

Lyman

 $\log L/L_{\odot}$

7.0

6.0

5.0

4.0

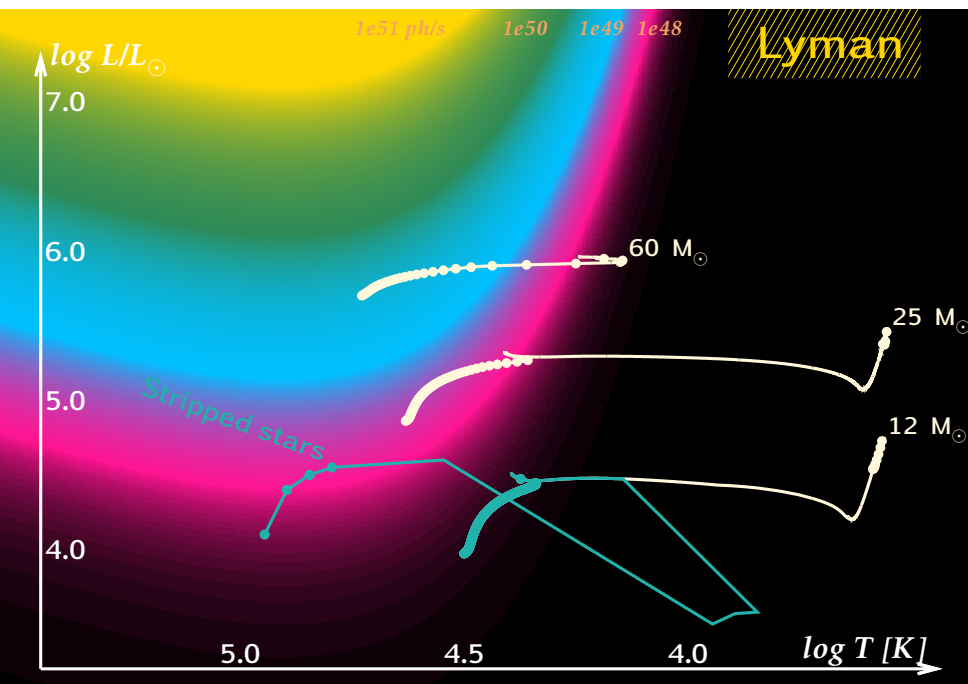
Stripped stars

60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

5.0

4.5

4.0

 $\log T [\text{K}]$ 

$1e51 \text{ ph/s}$ $1e50$ $1e49$ $1e48$

Lyman

 $\log L/L_{\odot}$

7.0

6.0

5.0

4.0

X-ray binaries!

(Götberg+17)

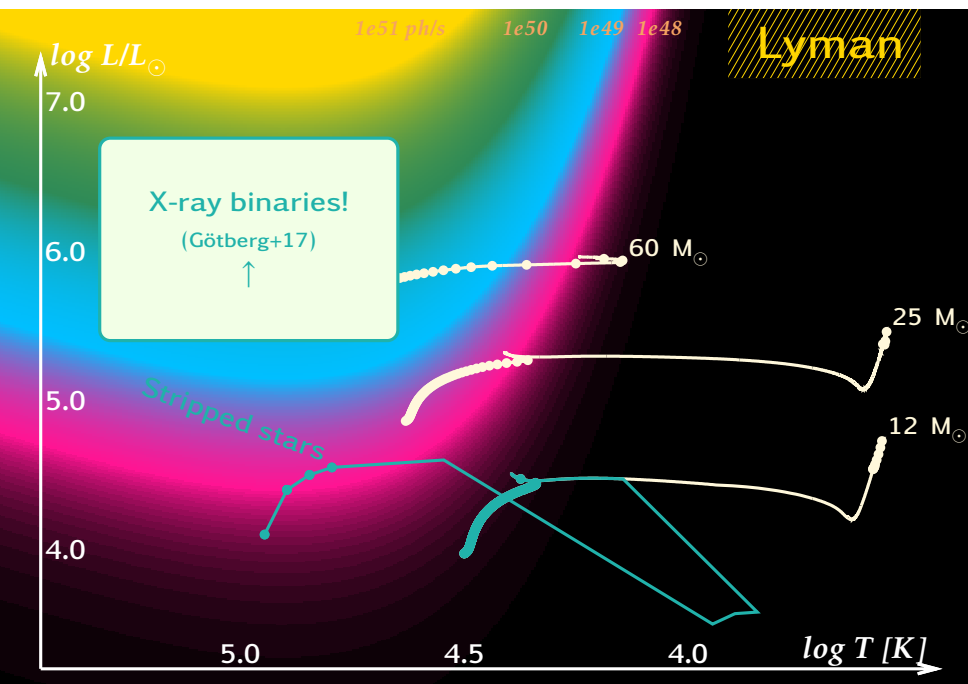
60 $M_{\odot}$ 25 $M_{\odot}$ 12 $M_{\odot}$

Stripped stars

5.0

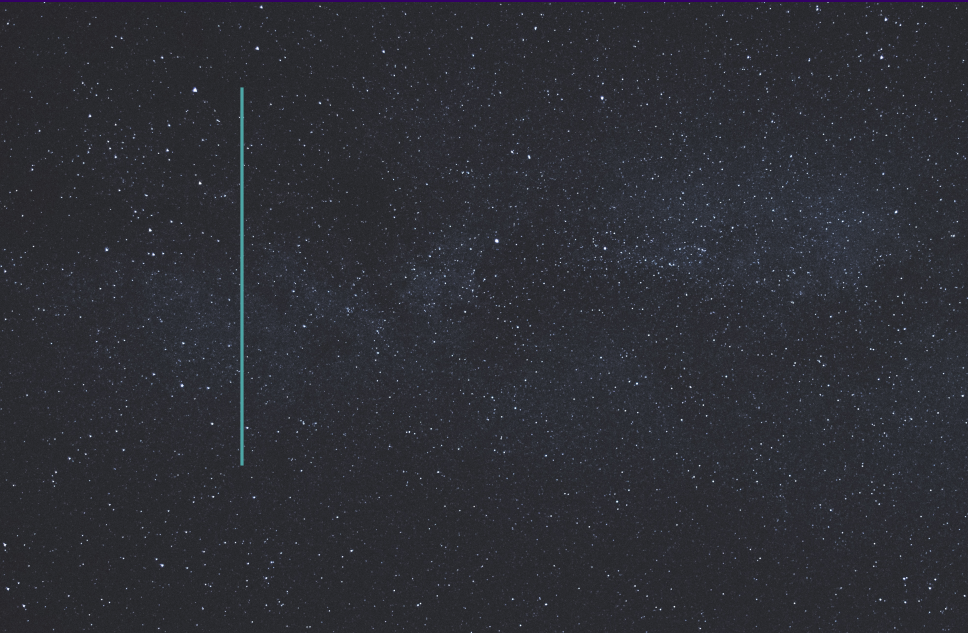
4.5

4.0

 $\log T [\text{K}]$ 

Future plans

How well do we understand metal-poor massive stars?



How well do we understand metal-poor massive stars?

Theory

Metal-*rich*
massive stars



“assumptions”



Metal-poor
massive stars

How well do we understand metal-poor massive stars?

Theory

Metal-rich
massive stars



“assumptions”



Metal-poor
massive stars

Observations

spectroscopy
(good resolution,
large samples)

How well do we understand metal-poor massive stars?

Theory



Observations

Metal-rich
massive stars



"assumptions"



Metal-poor
massive stars

spectroscopy

(good resolution,
large samples)

How well do we understand metal-poor massive stars?

Theory ↔ Observations

Metal-rich
massive stars

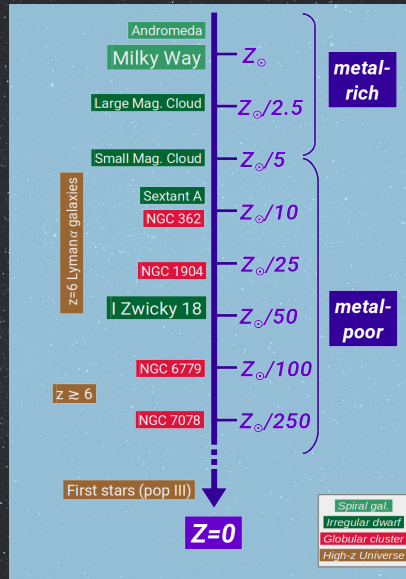


“assumptions”



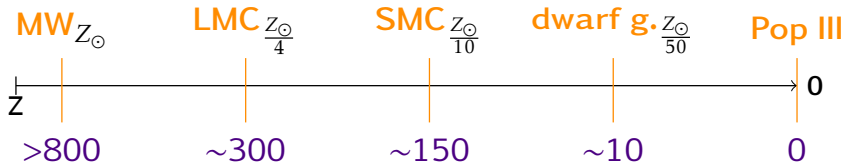
Metal-poor
massive stars

spectroscopy
(good resolution,
large samples)



Are they observed?

Dorottya Szécsi:
New vision
for THESEUS

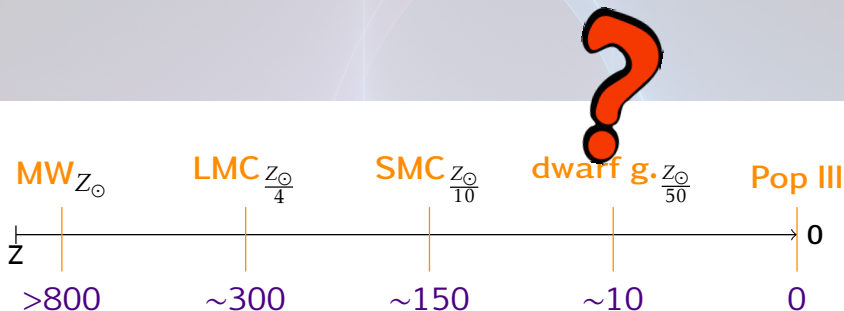


spectroscopy
(i.e. direct evidence)

e.g. Castro+14,+18, Ramírez-Agudelo+17, Kubátová&[Szécsi](#)+18

Are they observed?

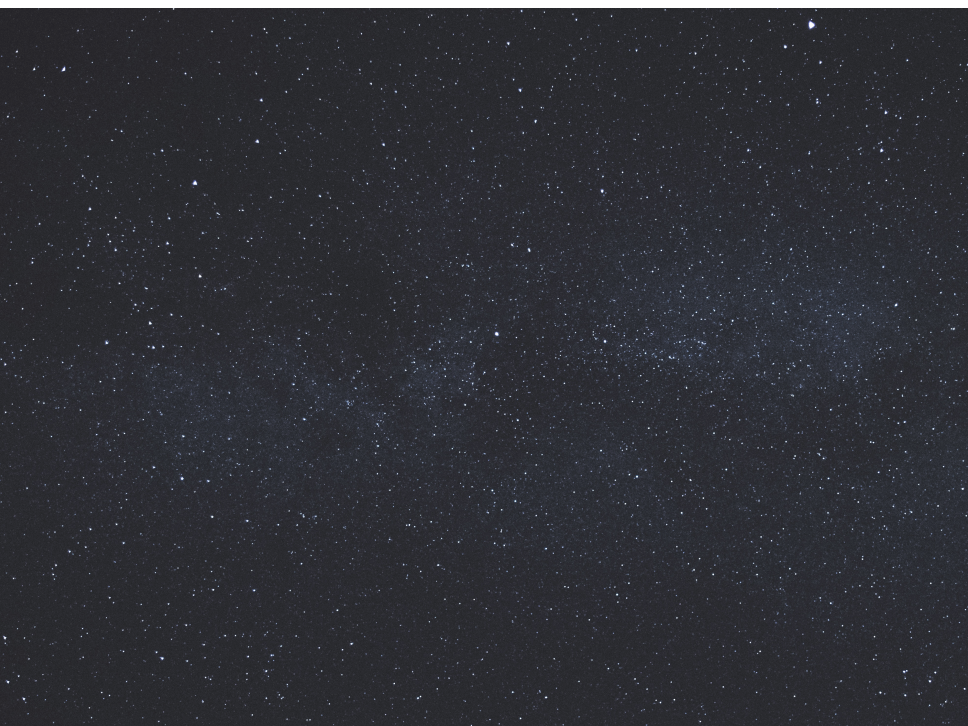
Dorottya Szécsi:
New vision
for THESEUS



spectroscopy
(i.e. direct evidence)

GRB-progenitors theories...

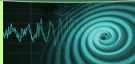
e.g. Castro+14,+18, Ramírez-Agudelo+17, Kubátová&Szécsi+18



Dwarf galaxies



Gravitational waves



High-redshift Univ.



Metal-poor
massive stars

Gamma-ray bursts



Globular clusters



Dwarf galaxies

PhD

Gravitational waves

Post-doc

High-redshift Univ.

Post-doc



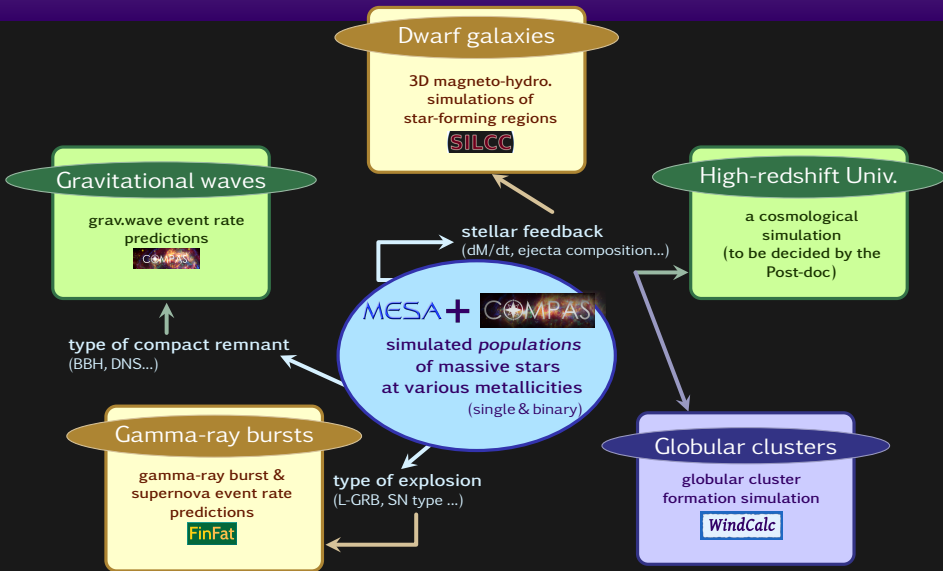
Gamma-ray bursts

PhD

Globular clusters

Me
(group leader)

Technical details...



Technical details...



Gravitational waves

grav.wave event rate predictions



type of compact remnant
(BBH, DNS...)

Gamma-ray bursts

gamma-ray burst & supernova event rate predictions



Dwarf galaxies

3D magneto-hydro. simulations of star-forming regions



stellar feedback
(dM/dt , ejecta composition...)

MESA+ COMPAS

simulated *populations* of massive stars at various metallicities (single & binary)

type of explosion
(L-GRB, SN type ...)

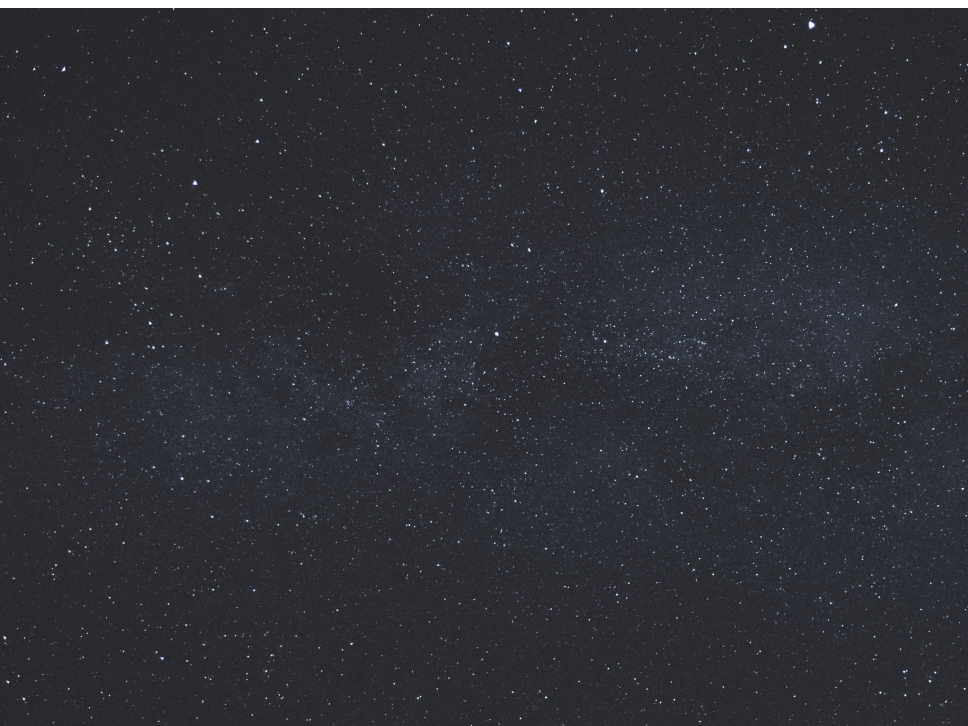
High-redshift Univ.

a cosmological simulation
(to be decided by the Post-doc)

Globular clusters

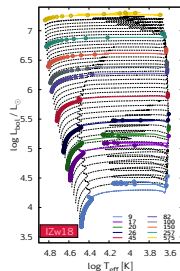
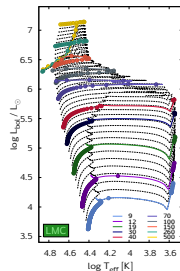
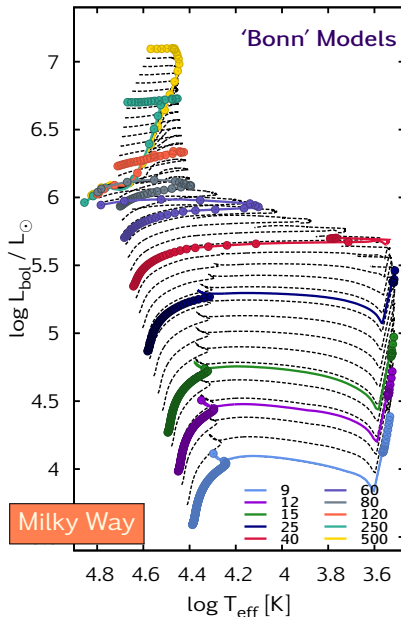
globular cluster formation simulation







Dorottya Szécsi:
The BoOST project
Bonn Optimized Stellar Tracks

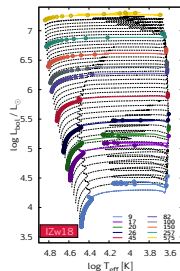
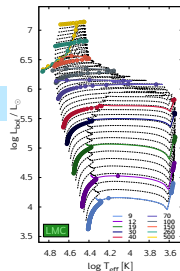
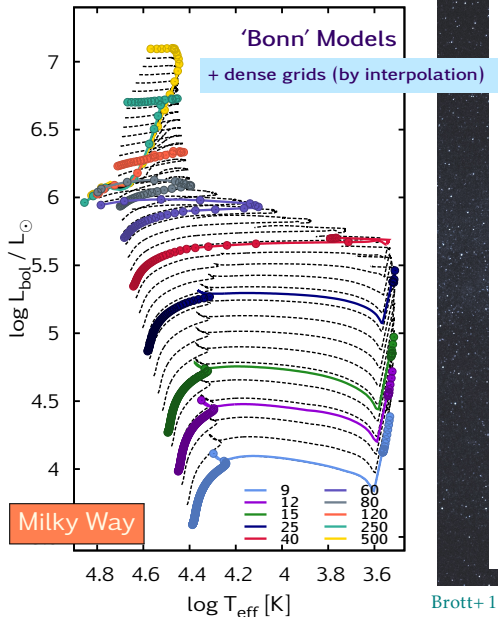


Brott+11 ($< 60 M_{\odot}$), Köhler+15

Szécsi+15,20 ($> 60 M_{\odot}$ & interp



Dorottya Szécsi:
The BoOST project
Bonn Optimized Stellar Tracks

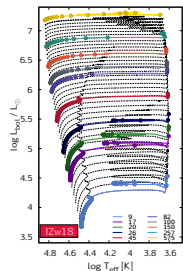
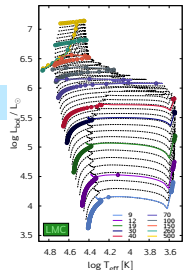
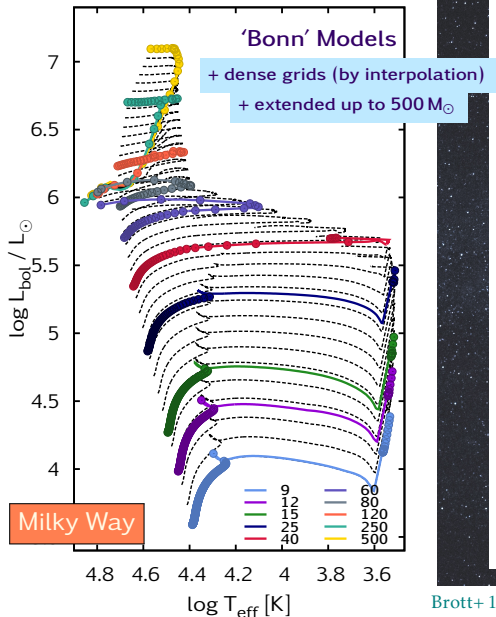


Brott+11 ($< 60 M_{\odot}$), Köhler+15

Szécsi+15,20 ($> 60 M_{\odot}$ & interp



Dorottya Szécsi:
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Bonn Optimized Stellar Tracks

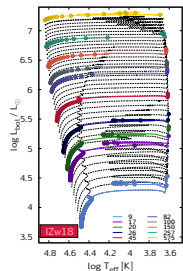
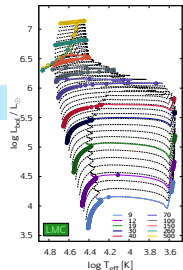
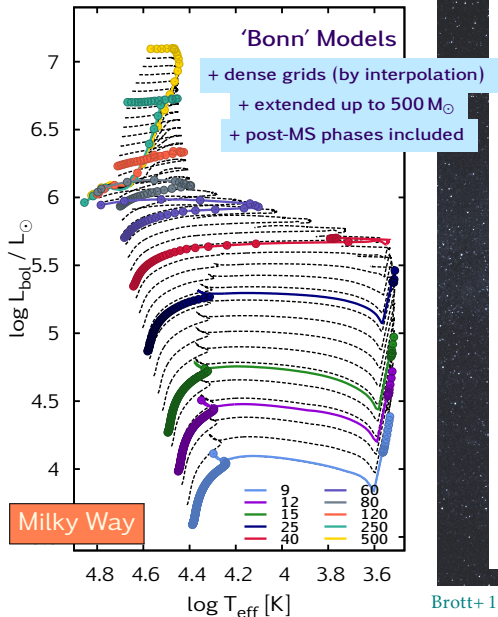


Brott+11 ($< 60 M_{\odot}$), Köhler+15

Szécsi+15,20 ($> 60 M_{\odot}$ & interp)



Dorottya Szécsi:
The BoOST project
Bonn Optimized Stellar Tracks



Brott+11 ($< 60 M_{\odot}$), Köhler+15

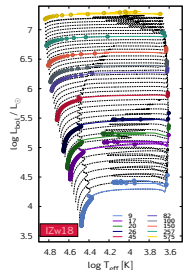
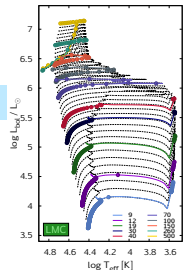
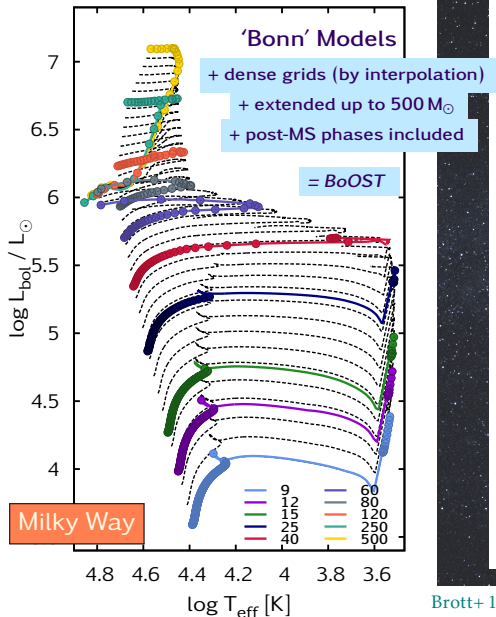
Szécsi+15,20 ($> 60 M_{\odot}$ & interp



Dorottya Szécsi:

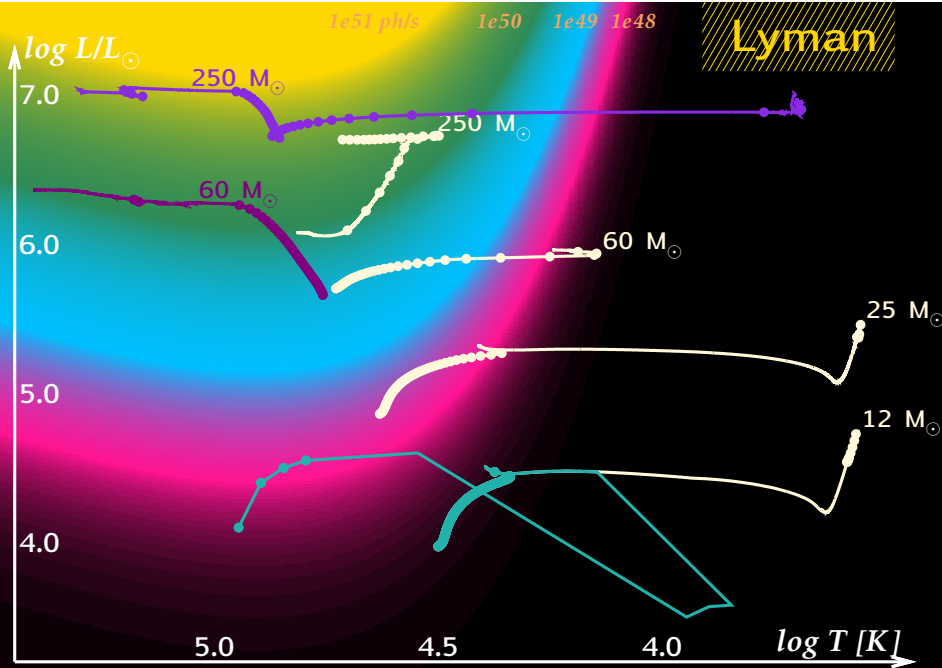
The BoOST project

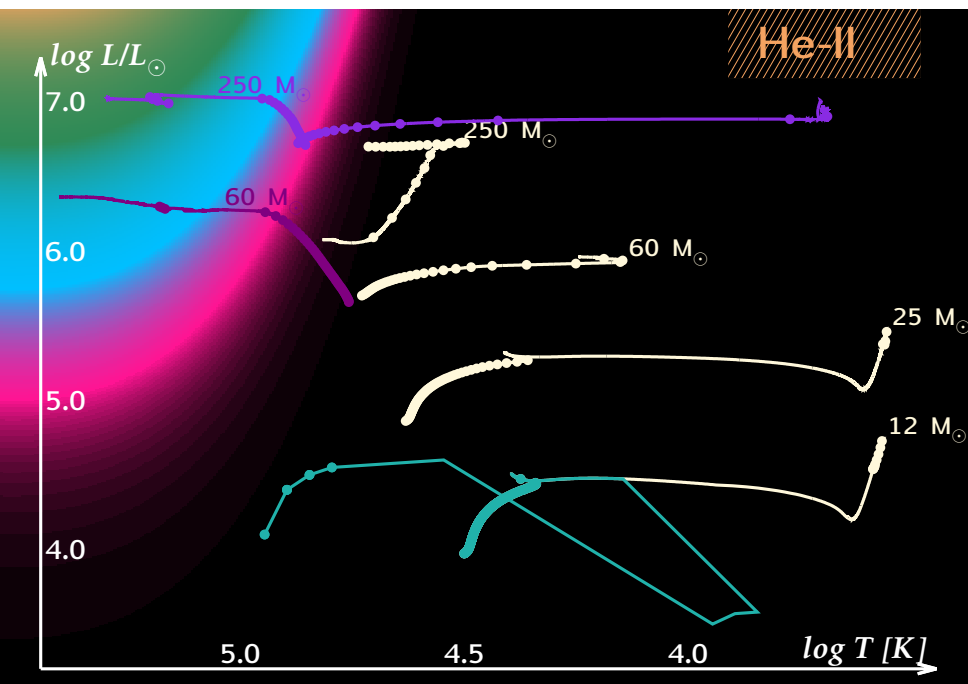
Bonn Optimized Stellar Tracks



Brott+11 ($< 60 M_{\odot}$), Köhler+15

Szécsi+15,20 ($> 60 M_{\odot}$ & interp)





He-II

