The evolution of low-metallicity massive stars

Dorottya Szécsi

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Jíři Kubát (Ondřejov, Czech Rep.)

AKADEMIE VĚD
ČESKÉ REPUBLIKY

Astronomický
ústav
AV ČR

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The night-sky and beyond

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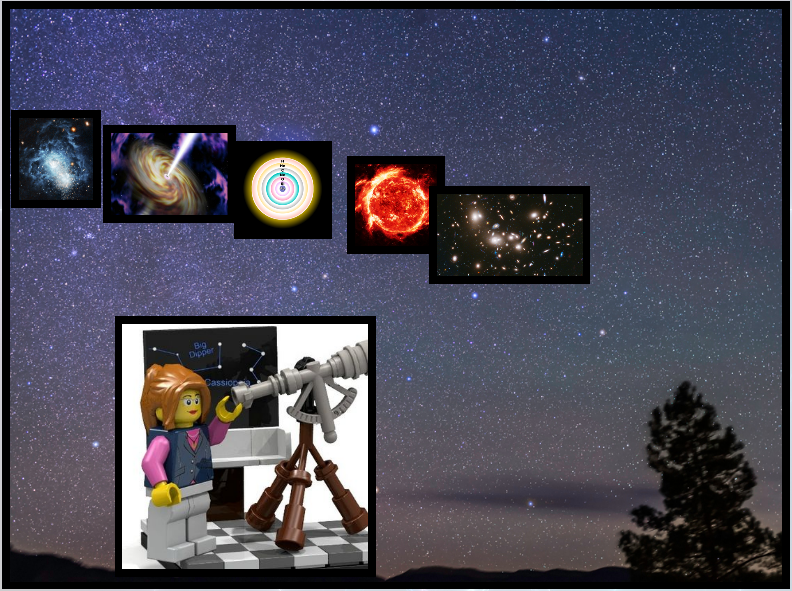

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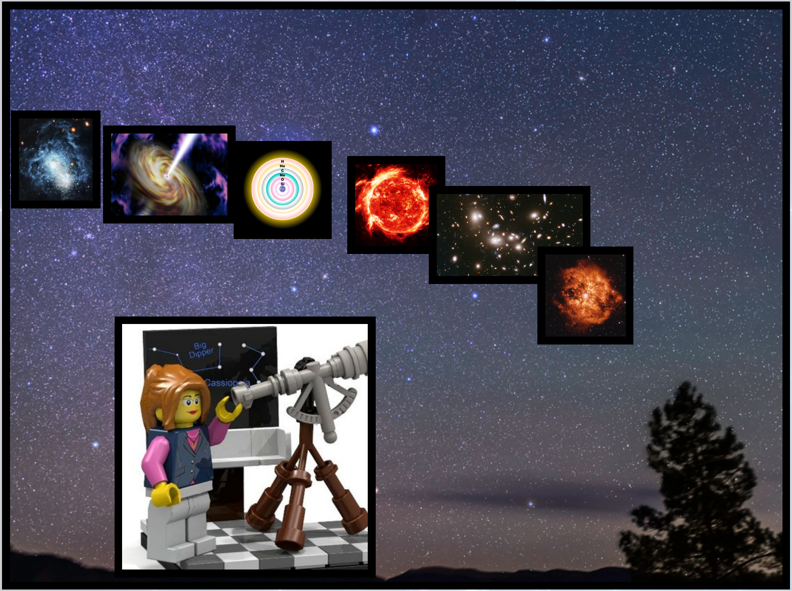

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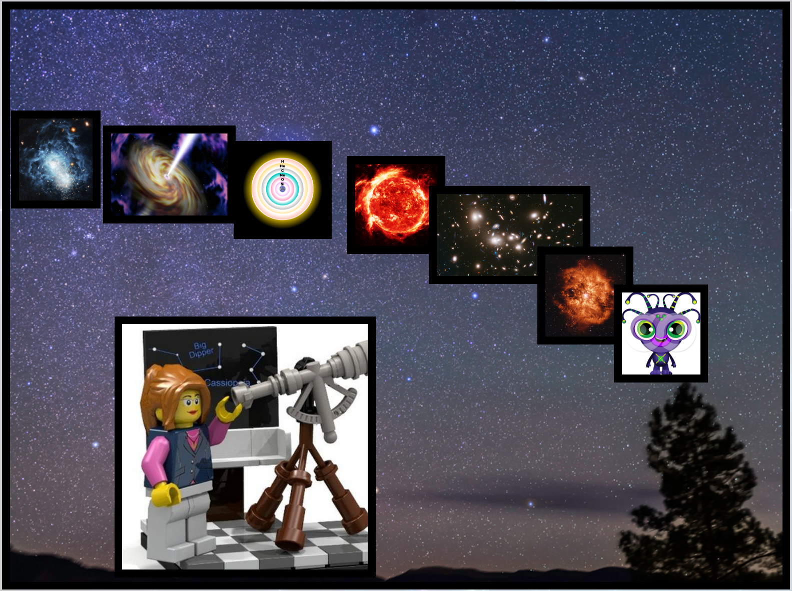

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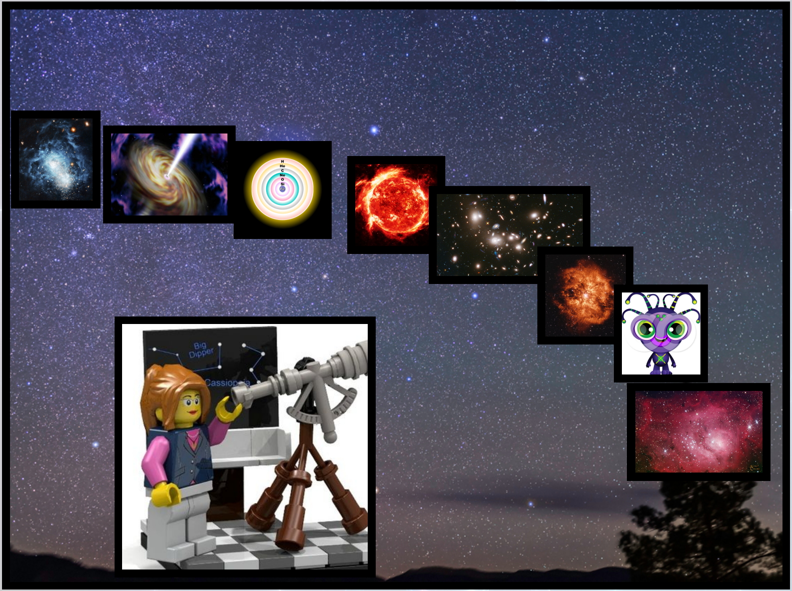
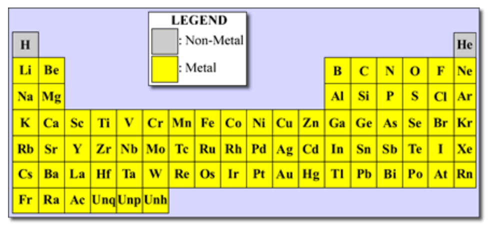


Astronomers and metal



LEGEND

▨ : Non-Metal

🟨 : Metal

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
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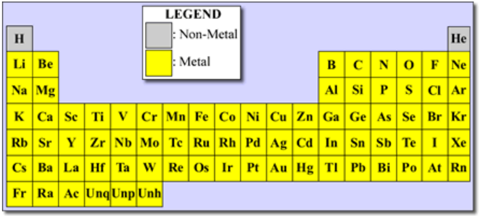

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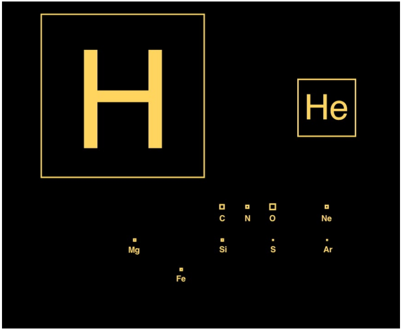

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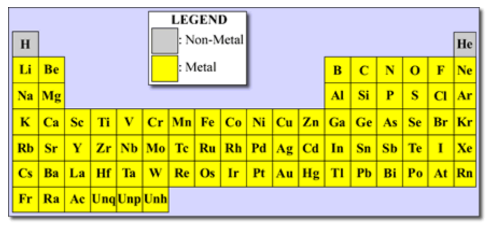

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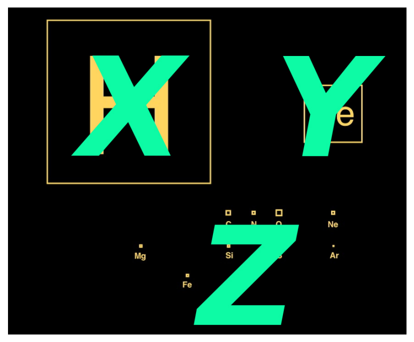

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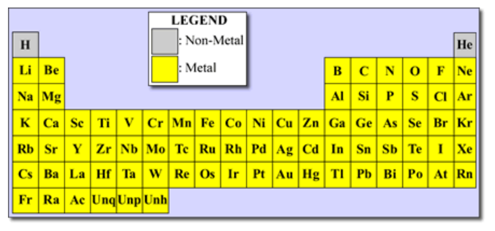

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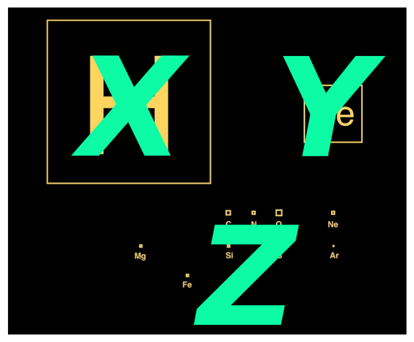

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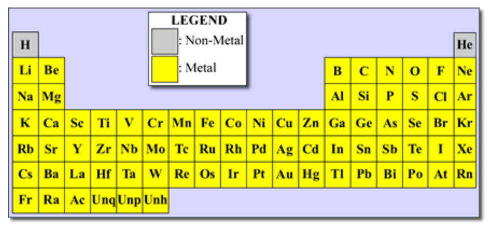

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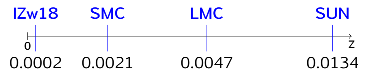
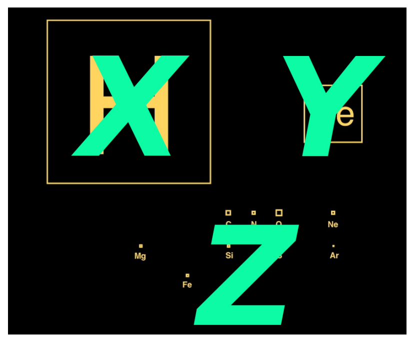
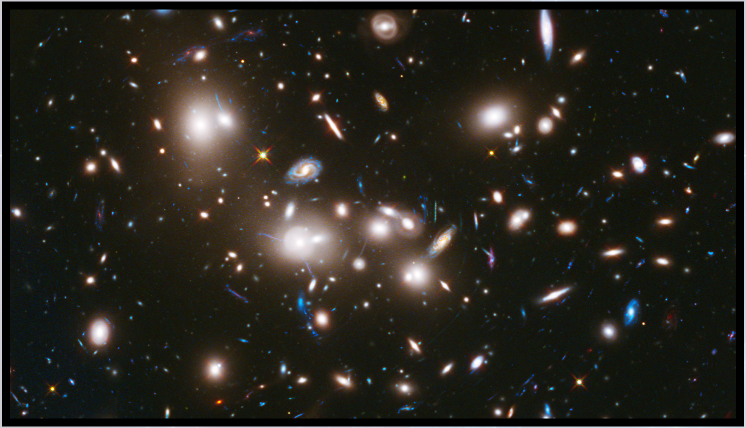




The early Universe ($Z \approx 0$)



Credit: hubblesite.org

Compact Dwarf Galaxies

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

Compact Dwarf Galaxies

I Zwicky 18

- Blue Compact Dwarf Galaxy
- 60 million lightyears → local
- star formation rate: 0.1 $M_\odot/\mathrm{yr}$
- ionized gas
- low metallicity!

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$$12+\log(\mathrm{O/H})=7.17$$
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$$Z=1/50\ Z_\odot \approx 0.0002$$

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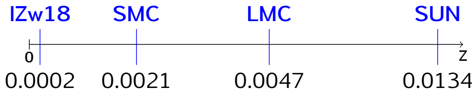
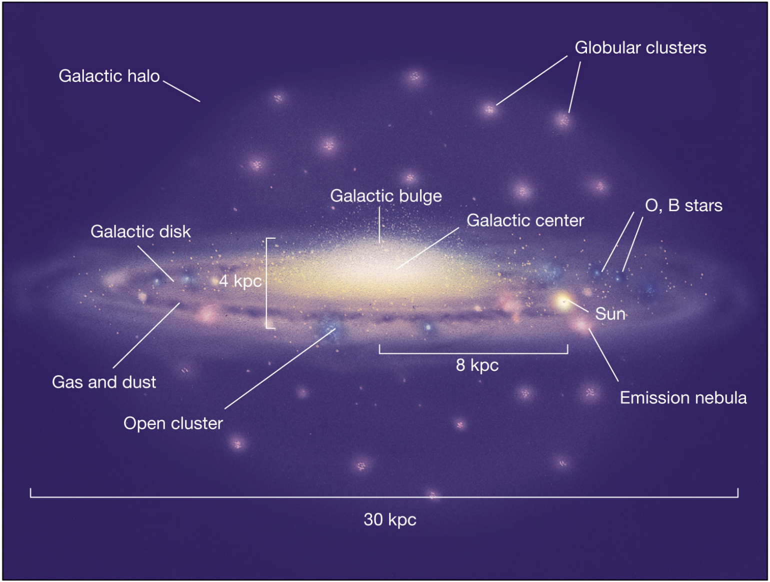


Legrand+07, Aloisi+09, Annibali+13, Kehrig+13, Lebouteiller+13

Globular Clusters



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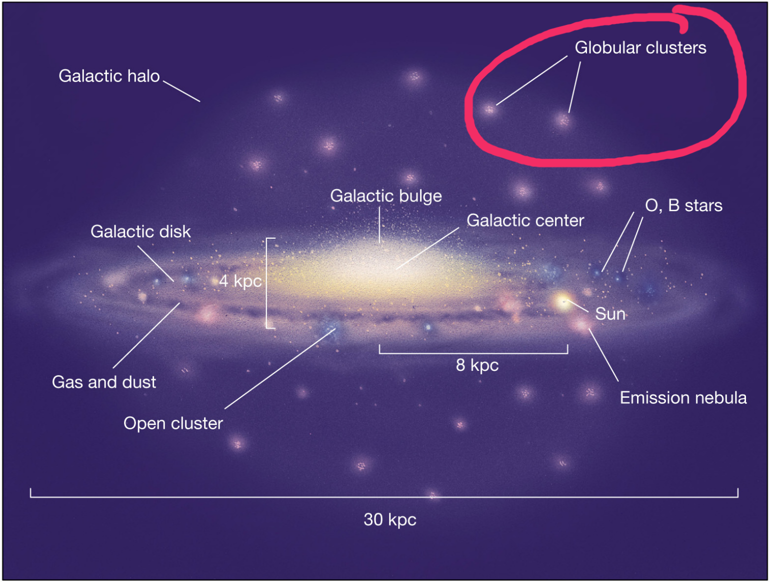

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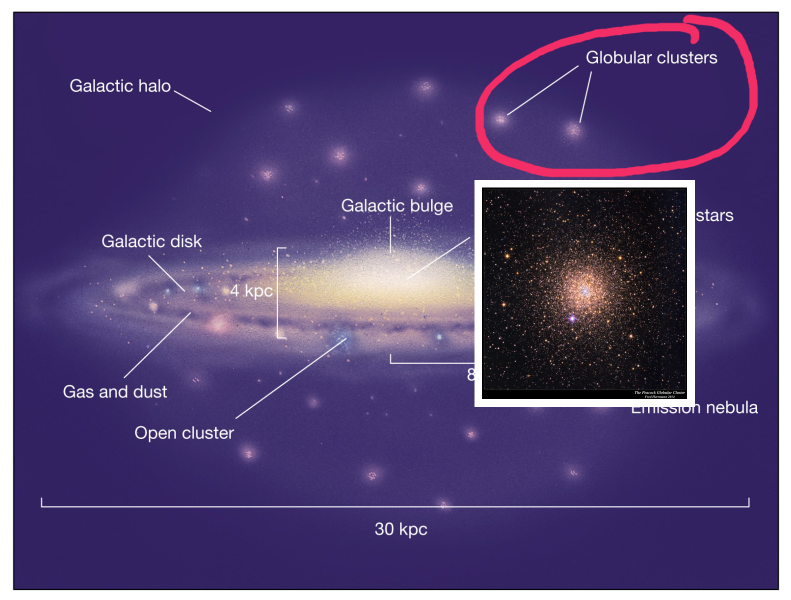

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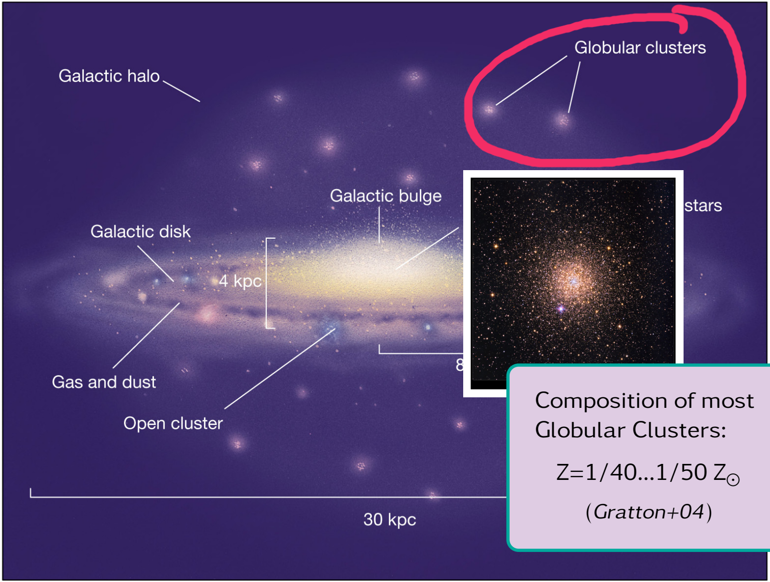

Composition of most Globular Clusters:

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

(*Gratton+04*)

What is a star?

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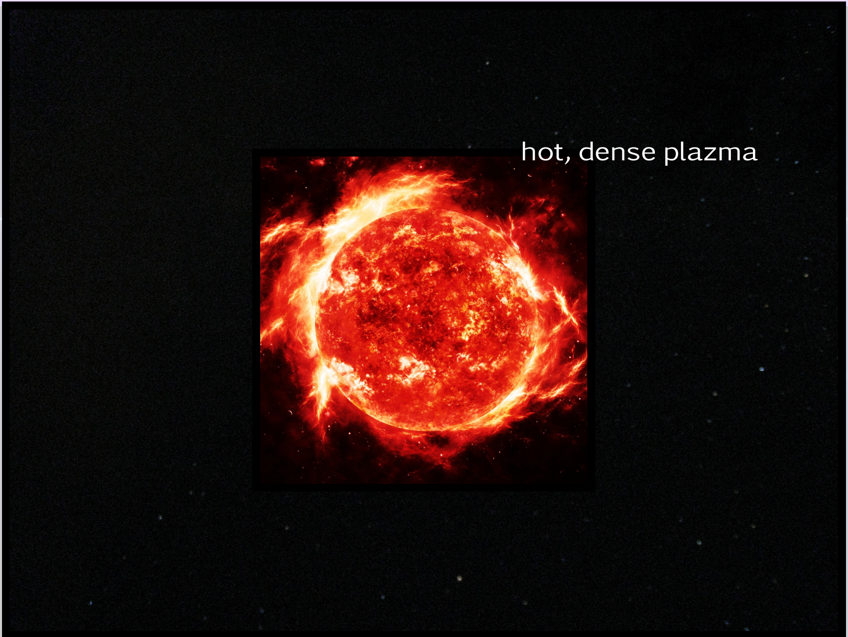

hot, dense plazma

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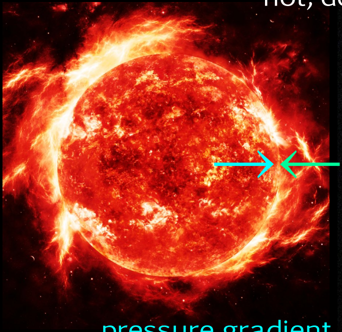

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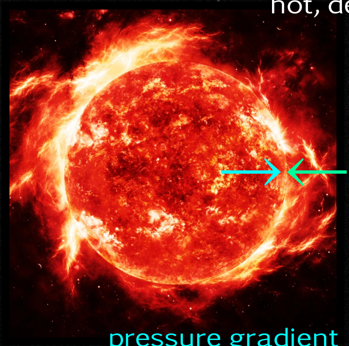
equilibrium: pressure gradient gravity

What is a star?

surface?

hot, dense plazma



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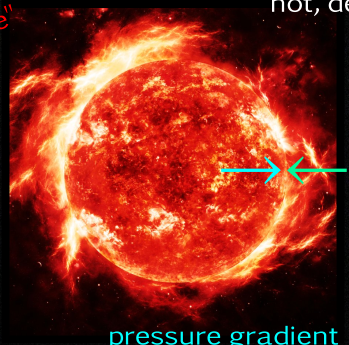

surface?

→ photons escape

"photosphere"

hot, dense plazma

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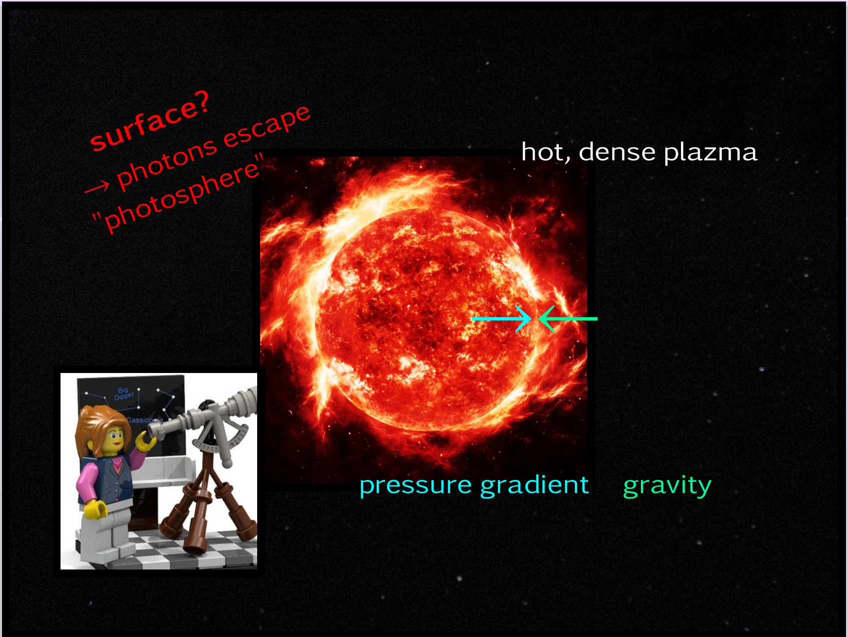

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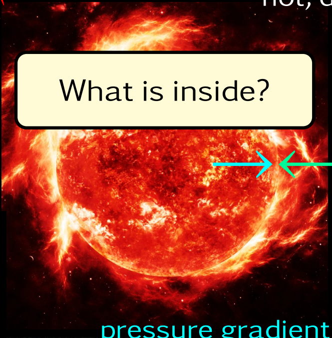


What is inside?

pressure gradient

gravity

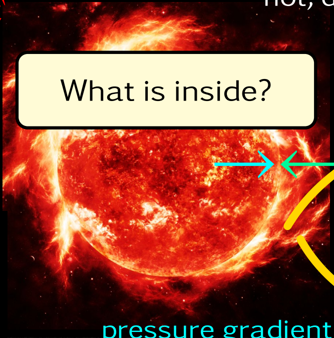
What is a star?

surface?

→ photons escape

"photosphere"

hot, dense plazma



What is inside?

pressure gradient → ← gravity

theoretical modelling of the stellar structure

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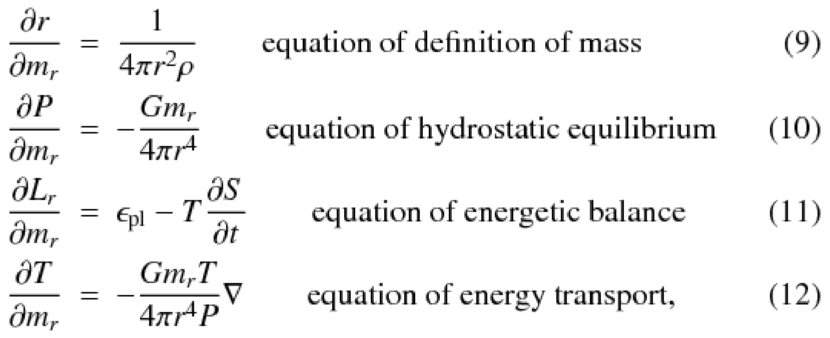

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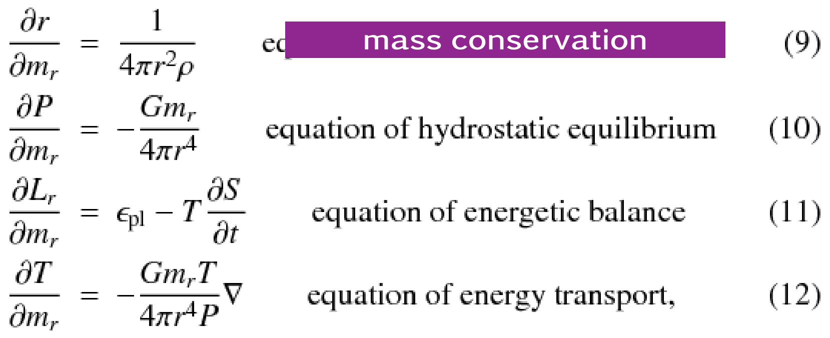
$$\frac{\partial P}{\partial m_r} = -\frac{G m_r}{4\pi r^4} \quad \text{equation of hydrostatic equilibrium} \tag{10}$$

$$\frac{\partial L_r}{\partial m_r} = \epsilon_{\rm pl} - T\frac{\partial S}{\partial t} \quad \text{equation of energetic balance} \tag{11}$$

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

Guilera et al. 2011

Theoretical modelling of the stellar structure



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eq

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equation of energy transport,

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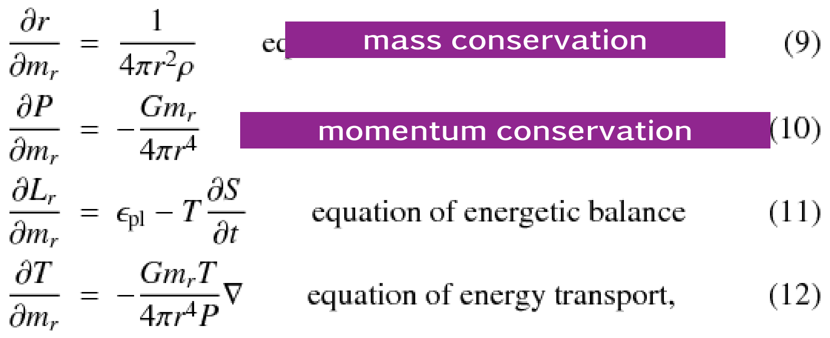

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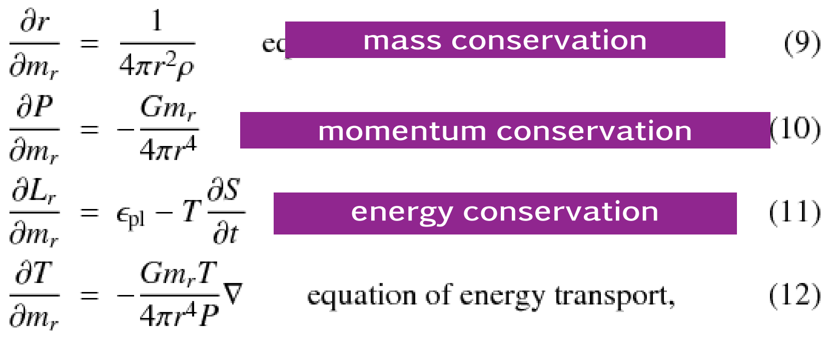

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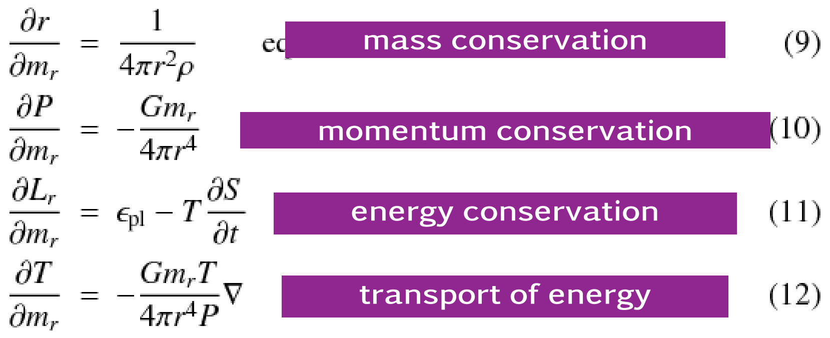

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transport of energy

Guilera et al. 2011

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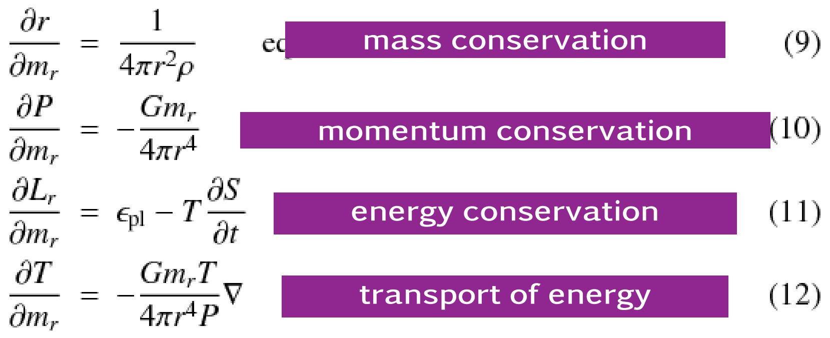

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Guilera et al. 2011

composition change due to nuclear burning ?!

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

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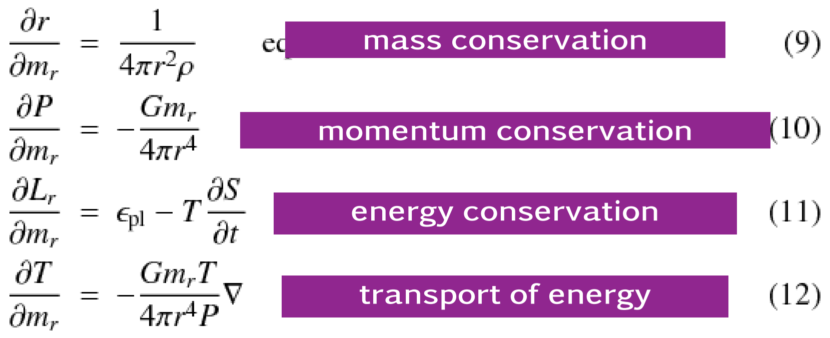

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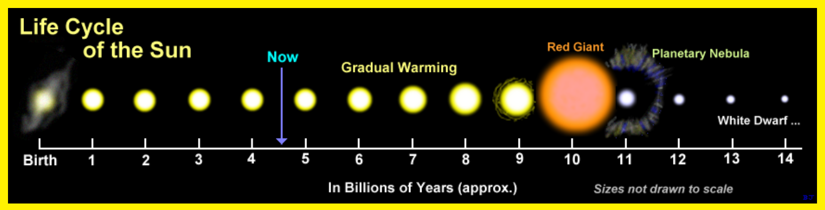

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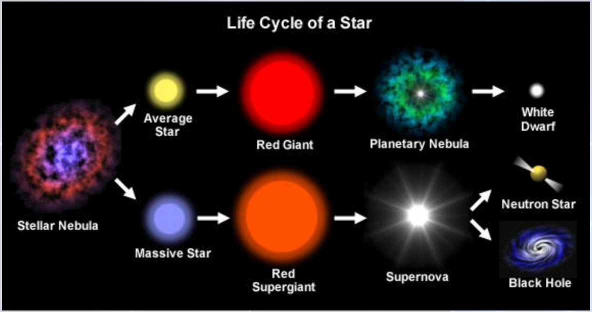
Massive vs. low-mass stars

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



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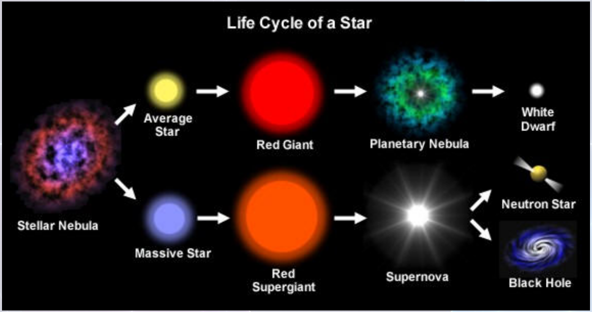

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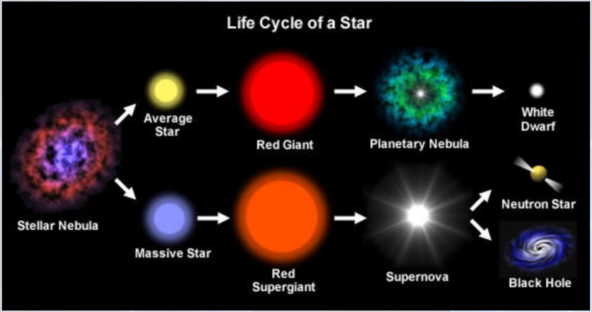

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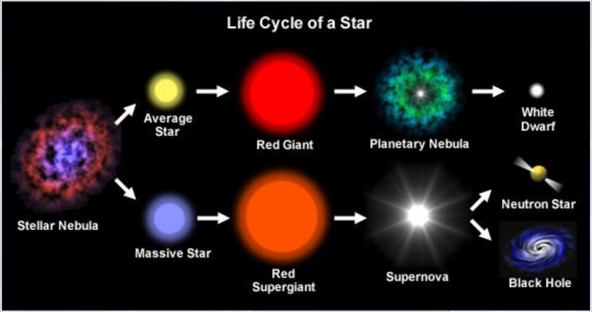
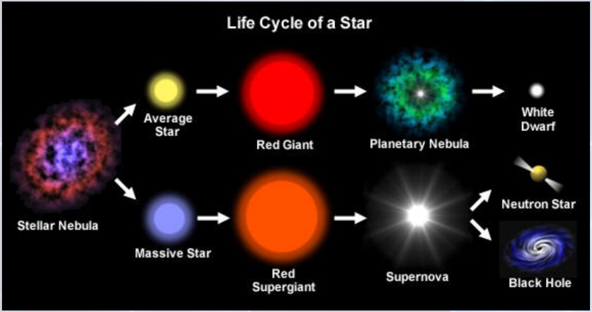


- nuclear reactions, final composition
- number of stars: massive stars are rare
- lifetime: massive stars have shorter lives

Massive vs. low-mass stars

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



- 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!

Matching theory to observations

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

Matching theory to observations

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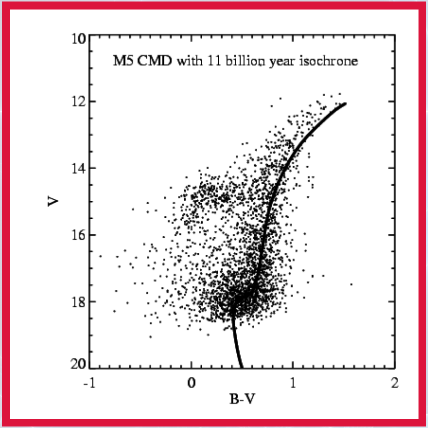
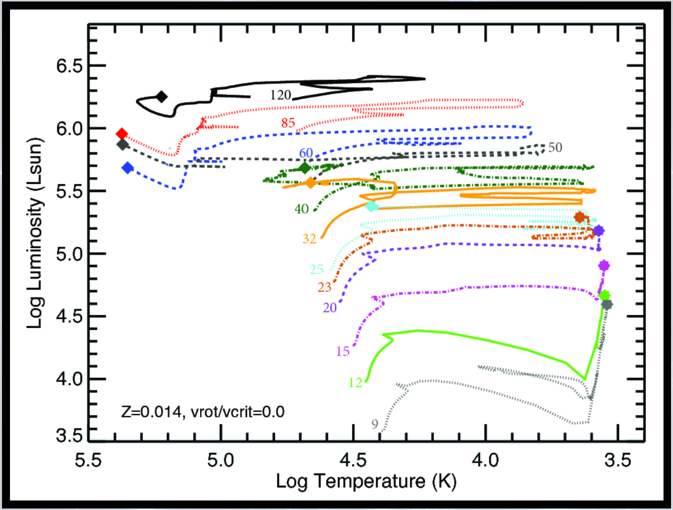


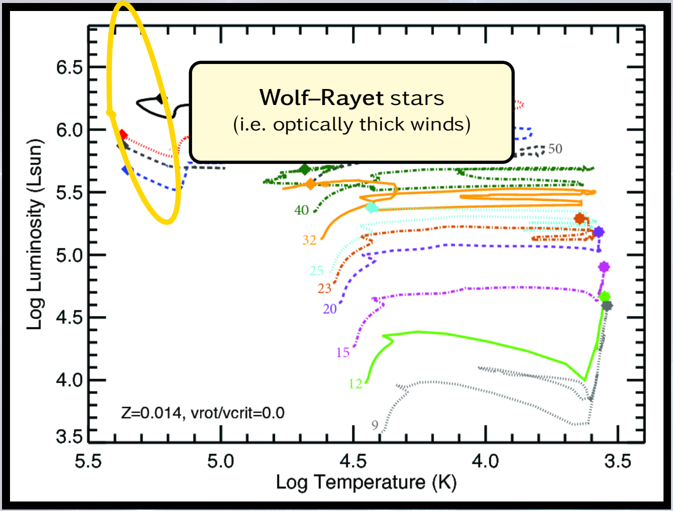
Hertzsprung–Russell diagram (HR diagram)

Hertzsprung–Russell diagram



Groh et al. 2013

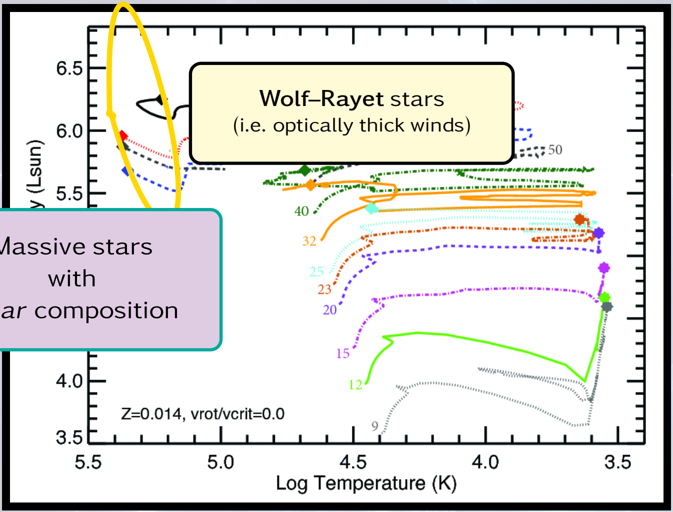
Hertzsprung–Russell diagram



Wolf–Rayet stars
(i.e. optically thick winds)

Groh et al. 2013

Hertzsprung–Russell diagram



Wolf–Rayet stars
(i.e. optically thick winds)

Massive stars
with
solar composition

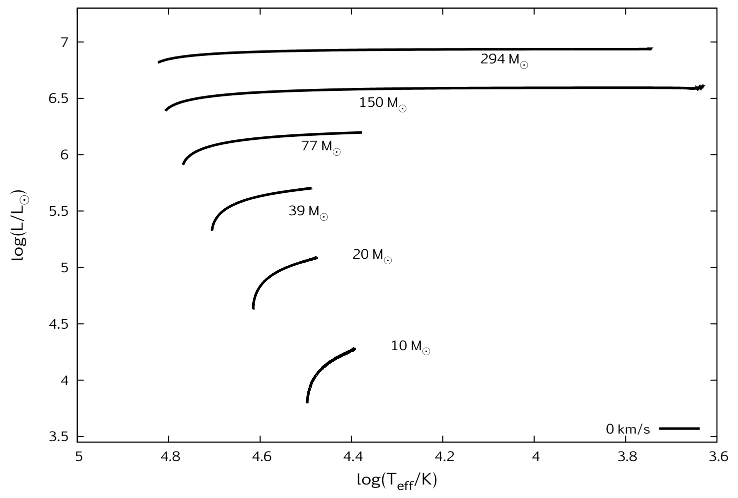
Groh et al. 2013

Low Metallicity Massive Stars

Low Metallicity Massive Stars

Low Metallicity Massive Stars

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



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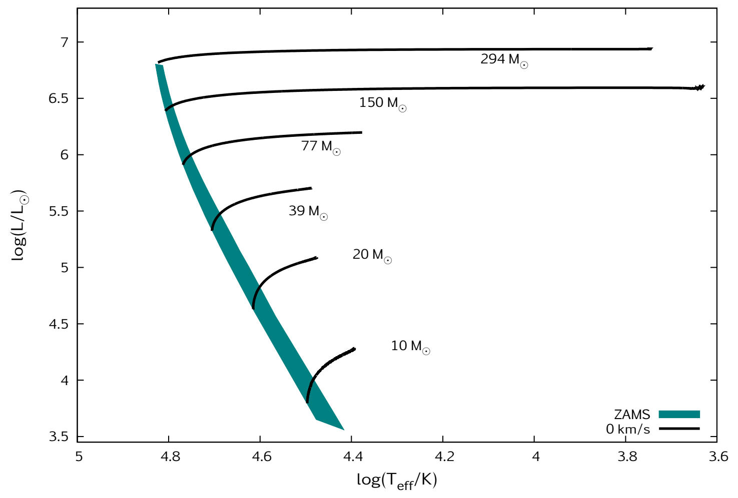

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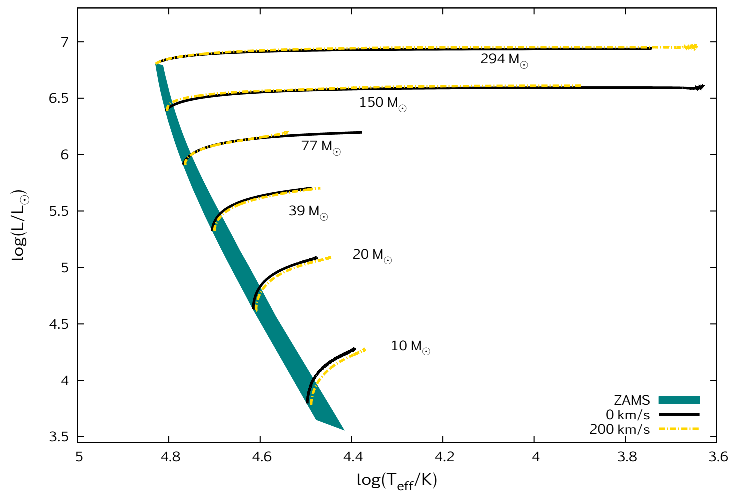

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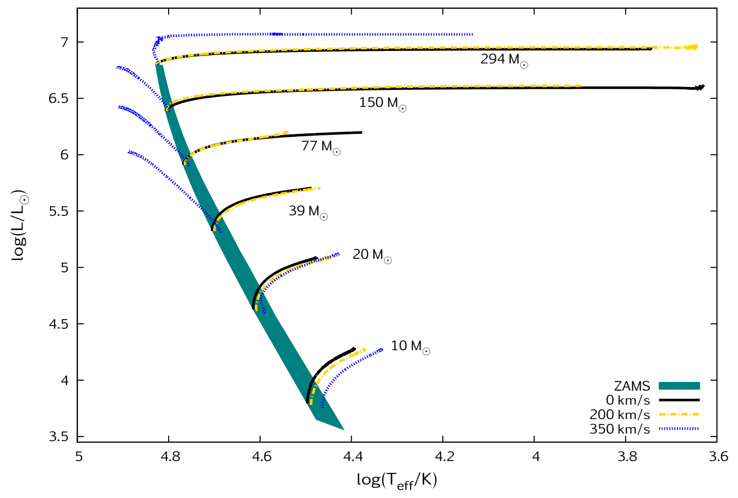

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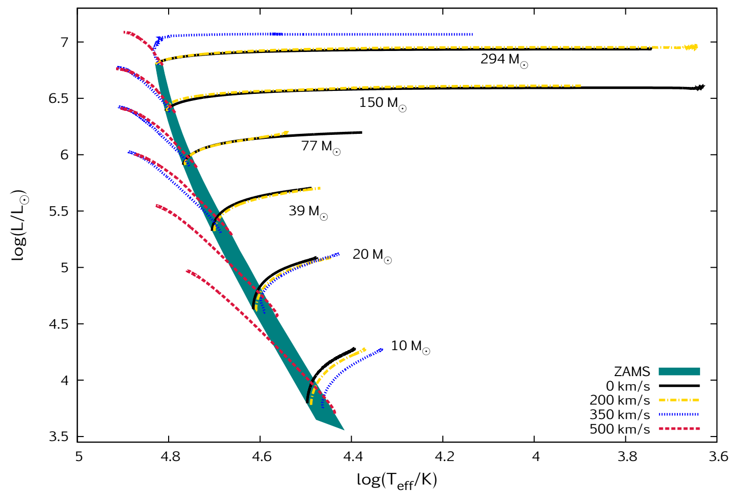

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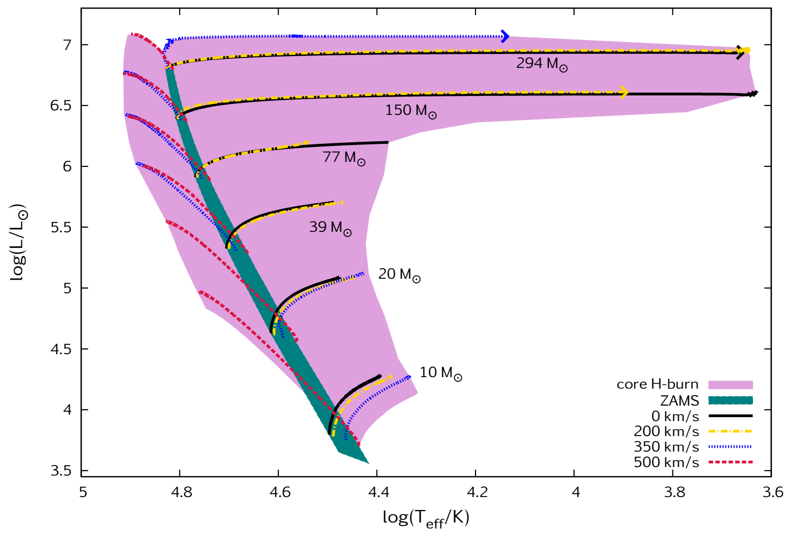

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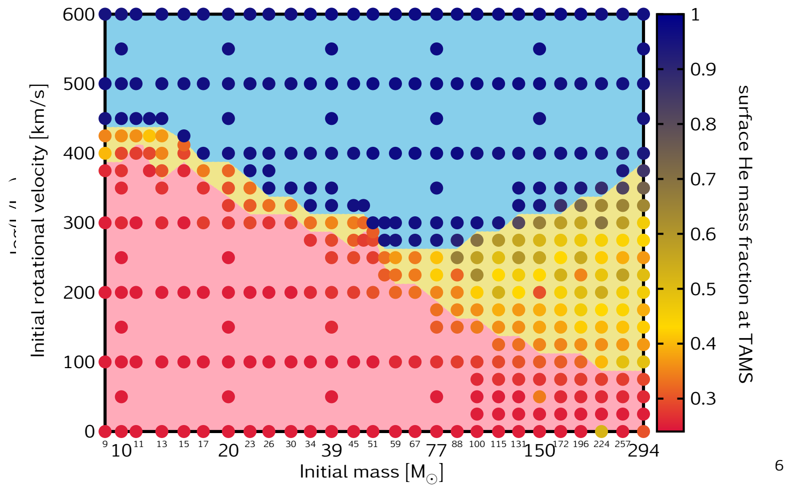

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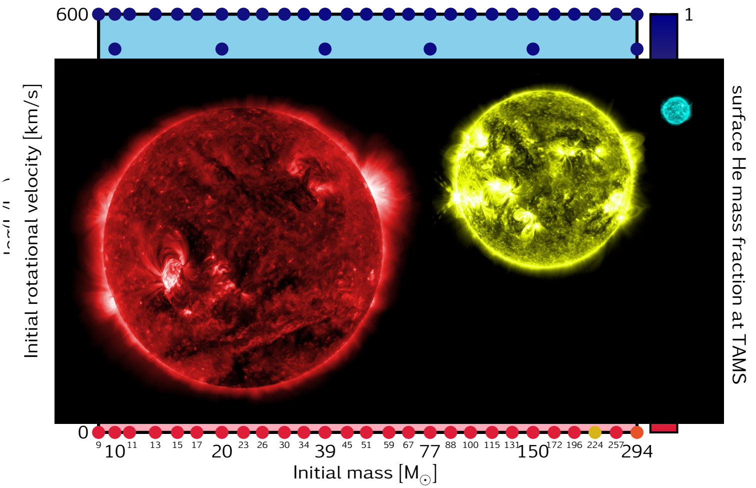

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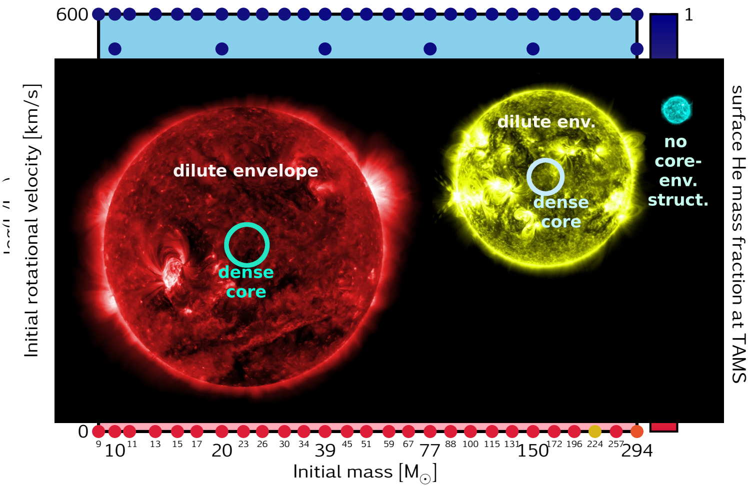

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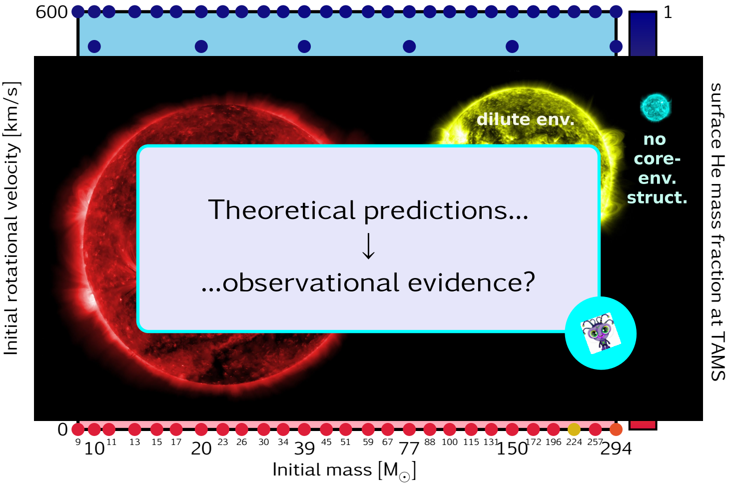

Theoretical predictions…

↓

…observational evidence?

Low Metallicity Massive Stars

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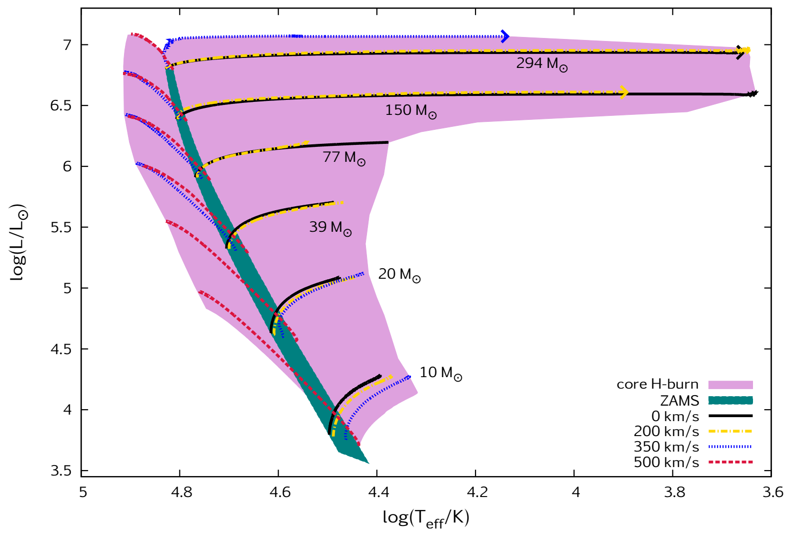

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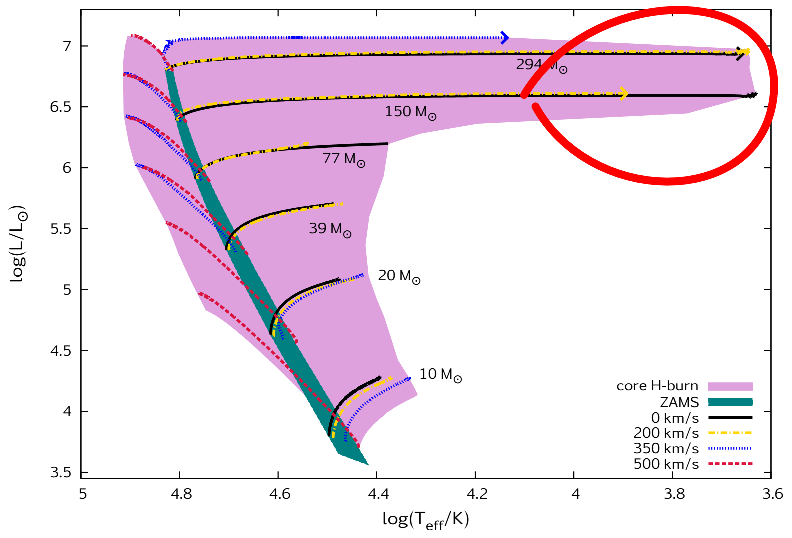

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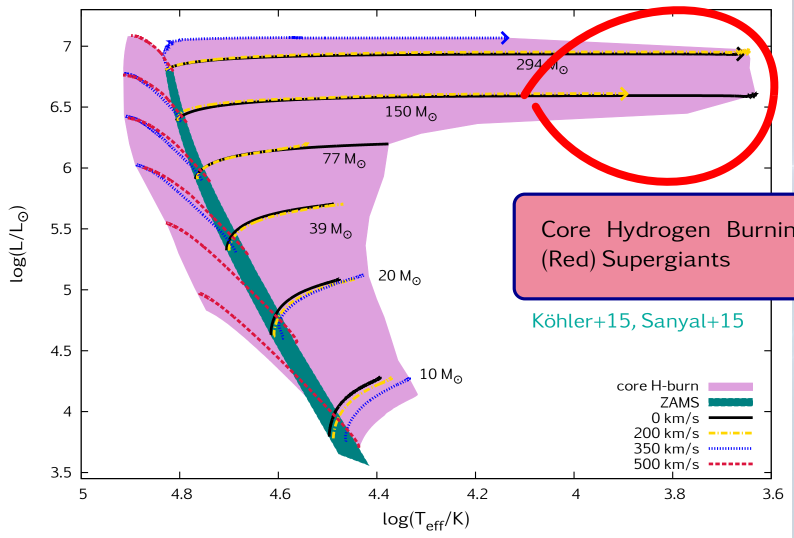

Core Hydrogen Burning (Red) Supergiants

Köhler+15, Sanyal+15

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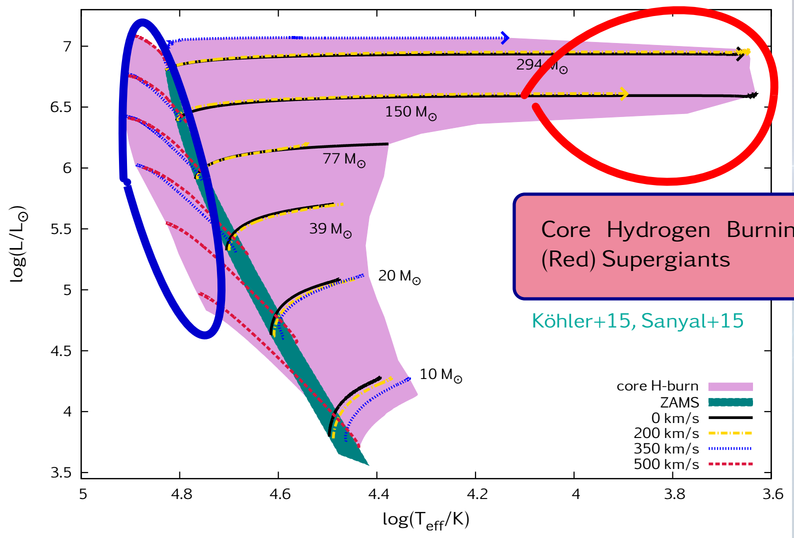

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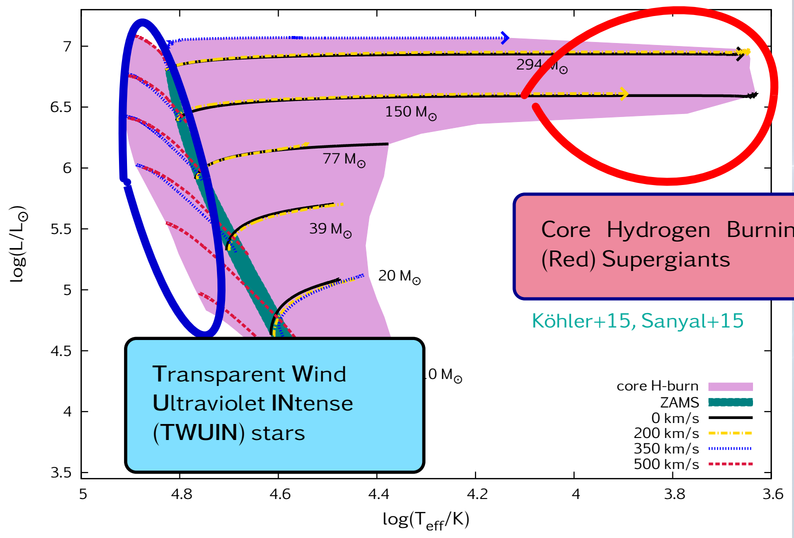


Transparent **W**ind
Ultraviolet **IN**tense
(**TWUIN**) stars

Core Hydrogen Burning
(Red) Supergiants

Köhler+15, Sanyal+15

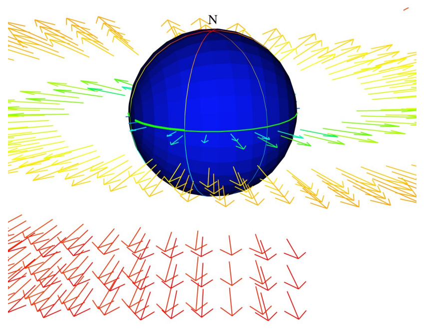
Transparent Wind Ultraviolet INtense stars (TWUIN stars)

– in the

starburst galaxy I Zwicky 18

Stellar winds

- stellar 'wind': accelerated particle flow
- hot stars at solar Z: **Wolf–Rayet** (WR) stars
    - opaque wind → strong emission lines
- hot stars at low Z?



Hot stars at low Z: transparent wind!

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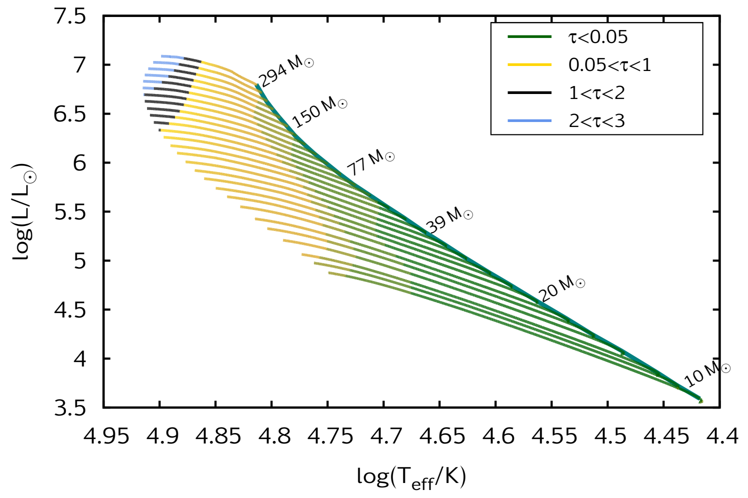

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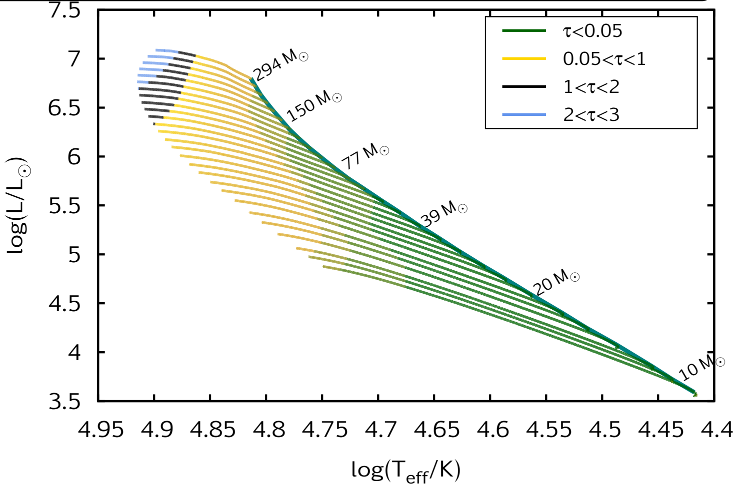
Core-H-burning lifetime: wind optical depth is $\tau \lesssim 1$



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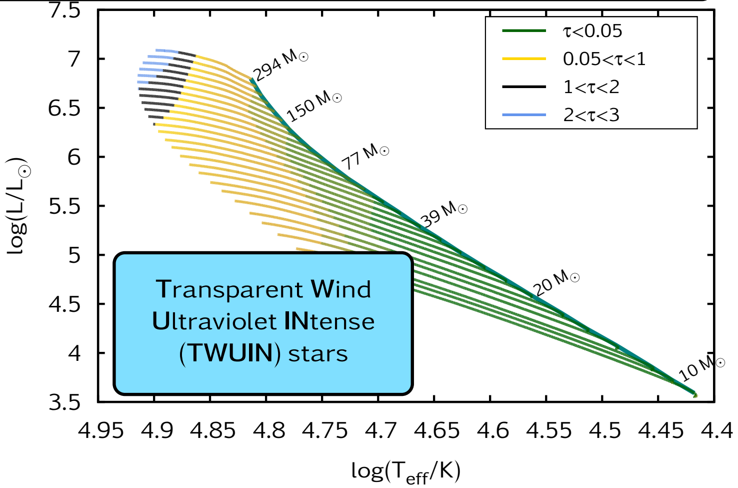

Transparent **W**ind
Ultraviolet **IN**tense
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Back to I Zw 18

I Zwicky 18

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

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

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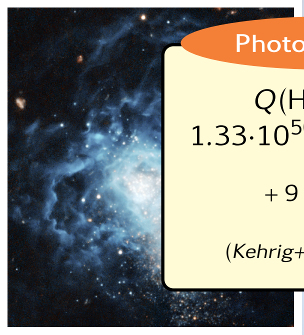

Photoionization

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

+ 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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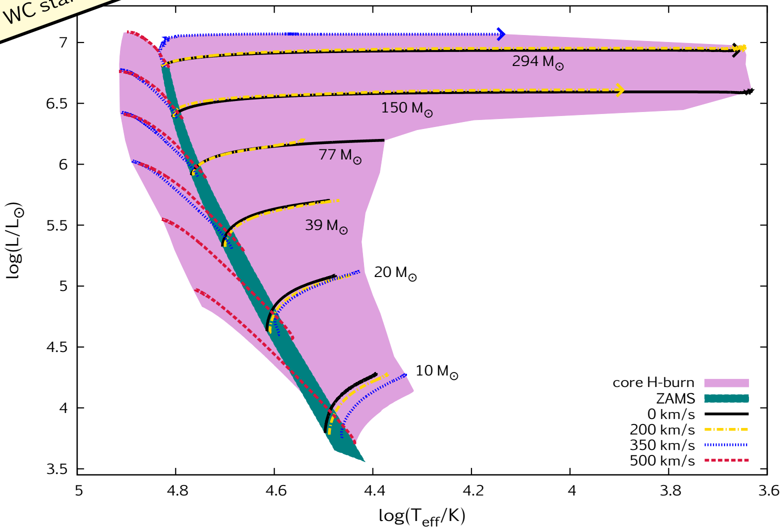

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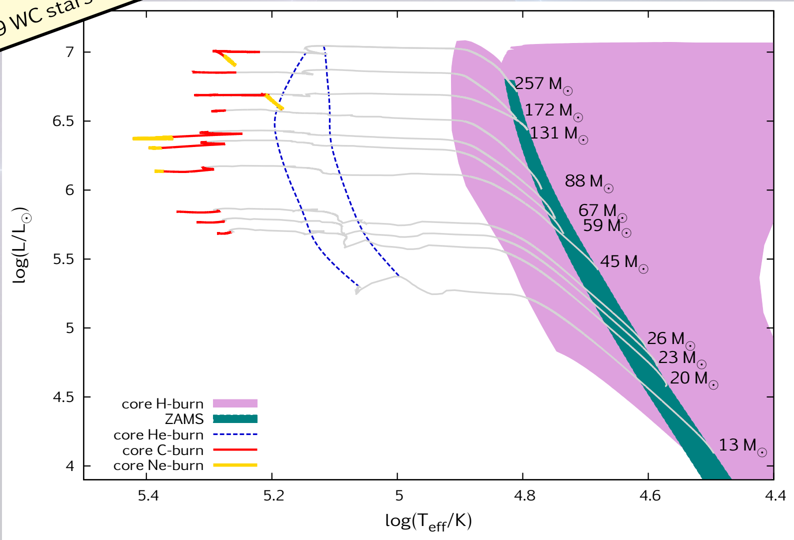

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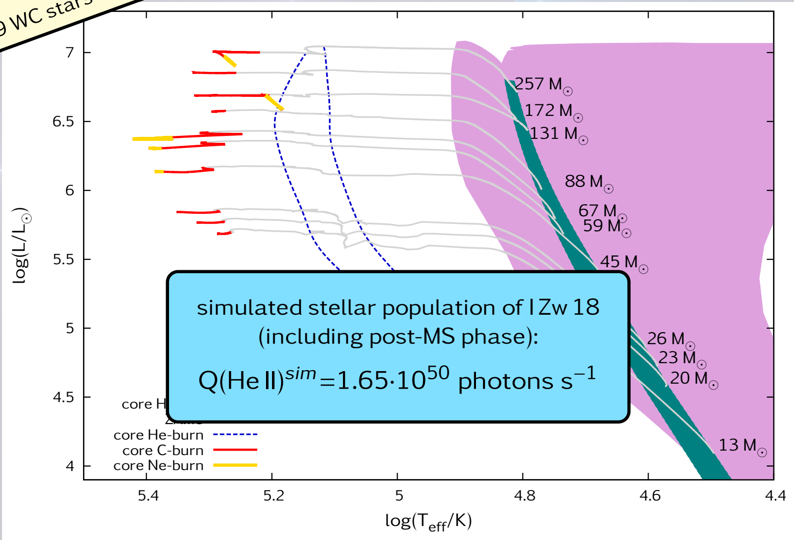

simulated stellar population of I Zw 18
(including post-MS phase):

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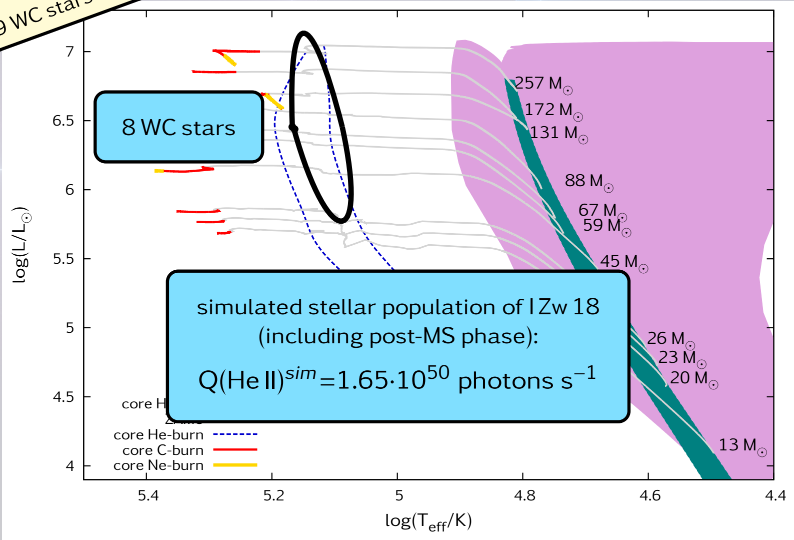

8 WC stars

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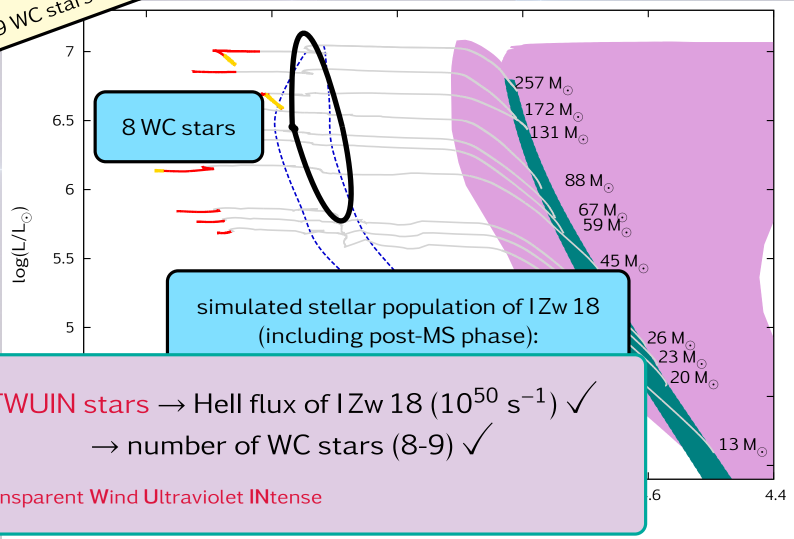

8 WC stars

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

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

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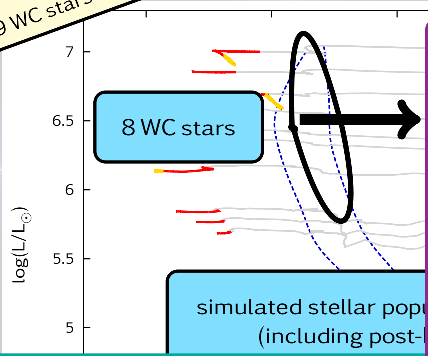

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Transparent Wind Ultraviolet INtense

Collapsar → lGRB

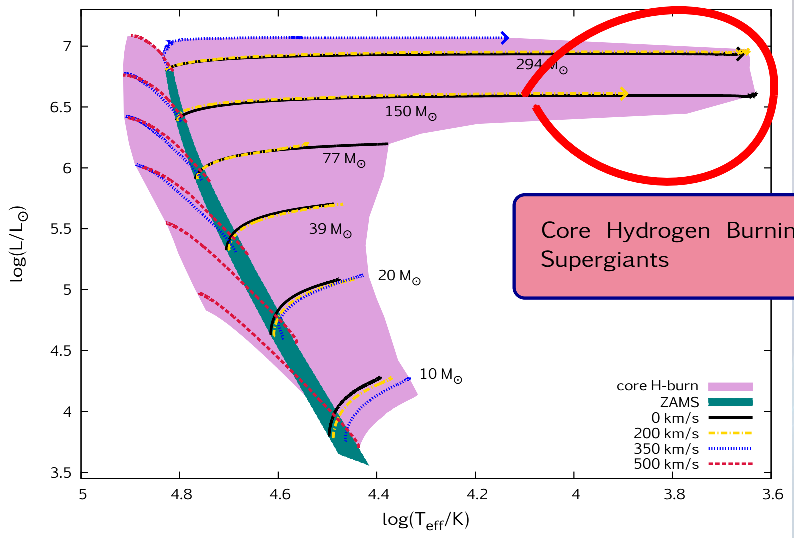
long-duration Gamma-Ray Burst
(lGRB)

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

Core Hydrogen Burning Supergiants

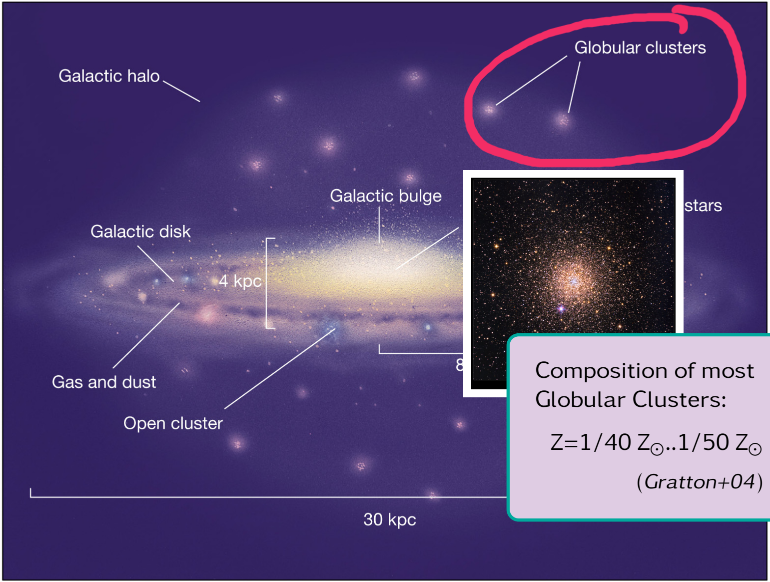
– in the

Early Globular Clusters



Core Hydrogen Burning Supergiants

Globular Clusters & Abundance Anomalies

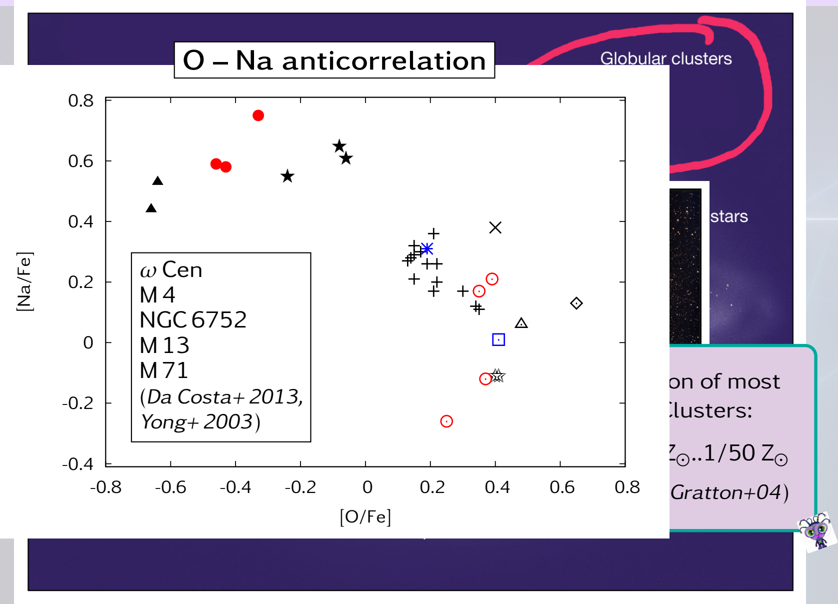


Composition of most Globular Clusters:

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

(*Gratton+04*)

Globular Clusters & Abundance Anomalies

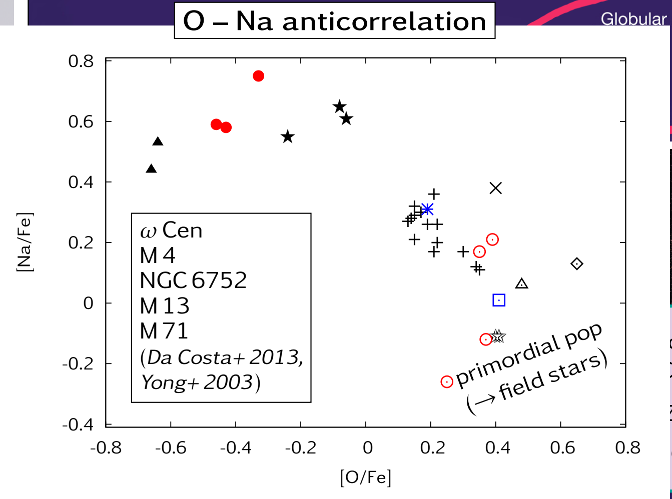


O – Na anticorrelation

(*Da Costa+ 2013, Yong+ 2003*)

Globular Clusters & Abundance Anomalies

Globular clusters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stars

on of most
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Gratton+04)

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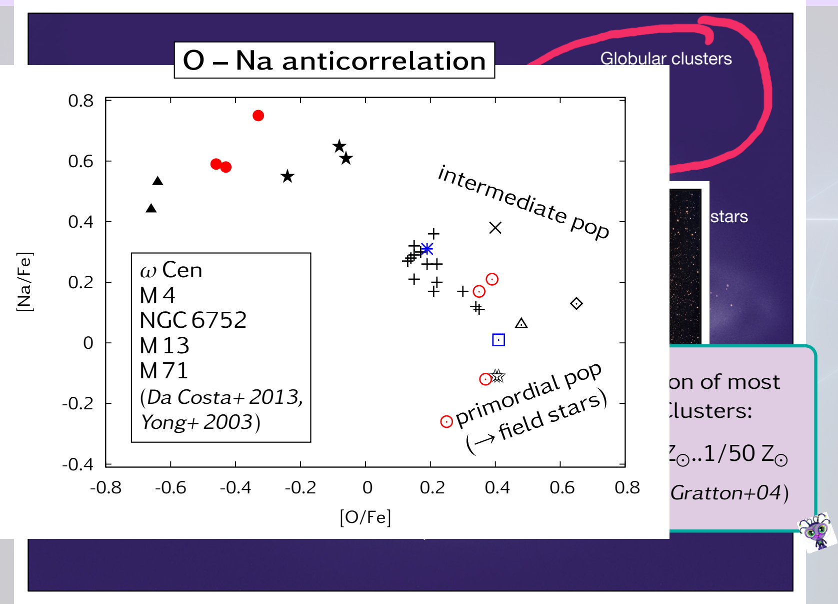

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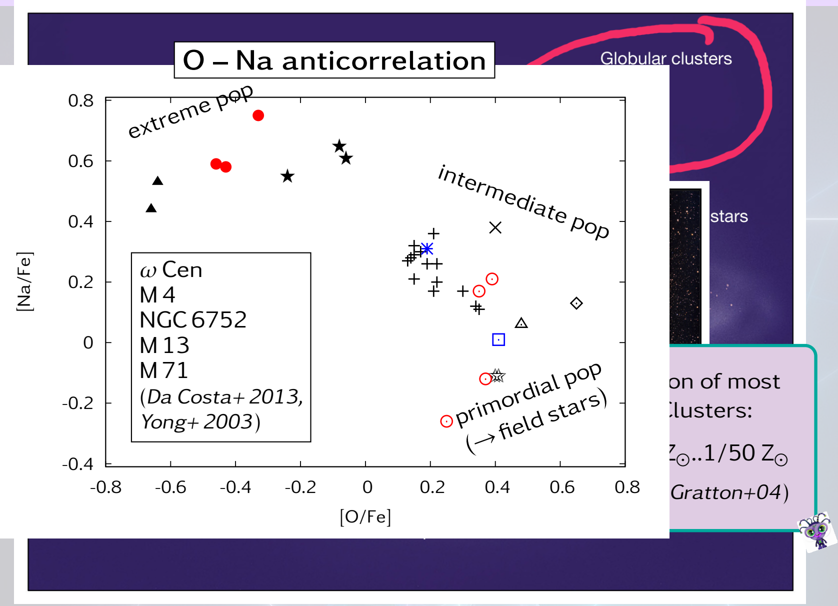

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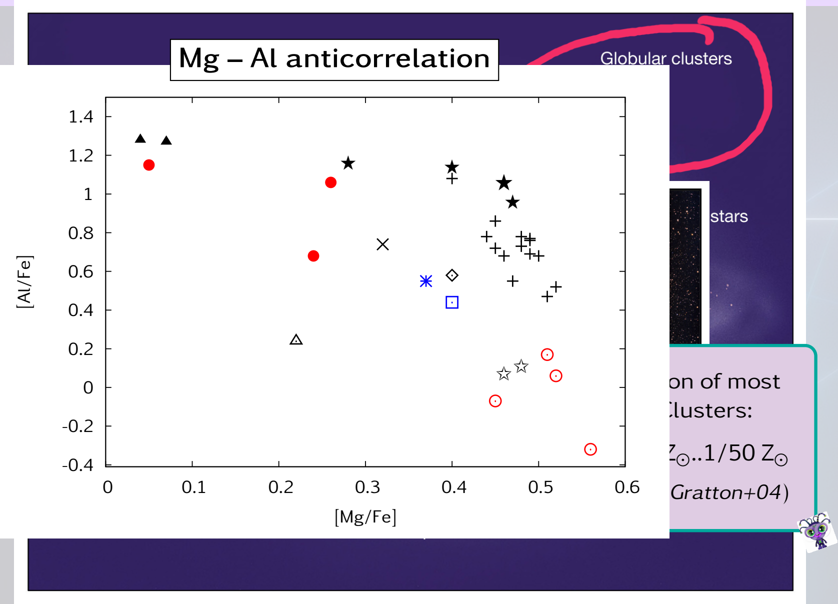

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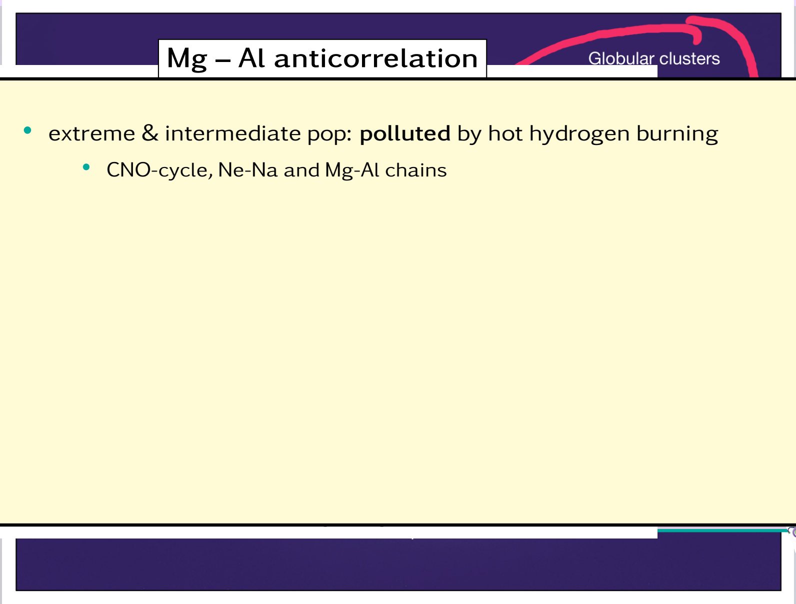

Mg – Al anticorrelation

- extreme & intermediate pop: **polluted** by hot hydrogen burning
    - CNO-cycle, Ne-Na and Mg-Al chains

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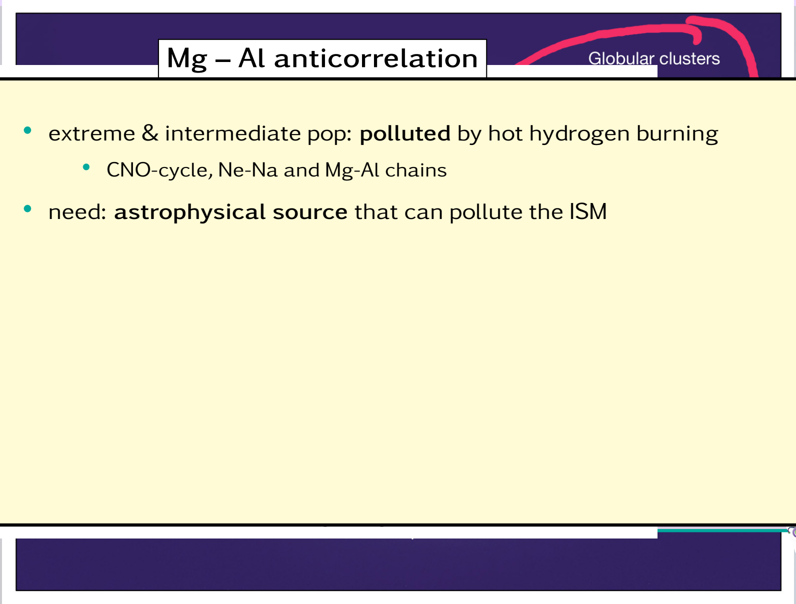

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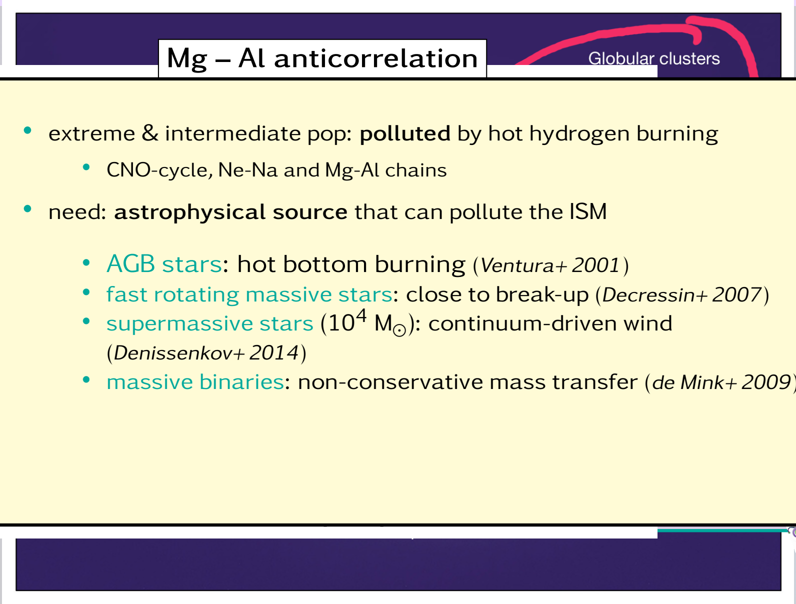

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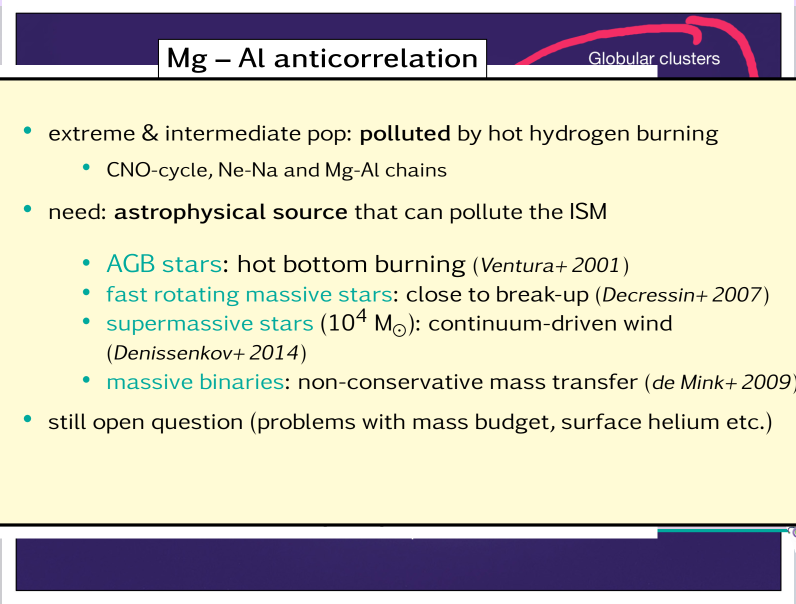

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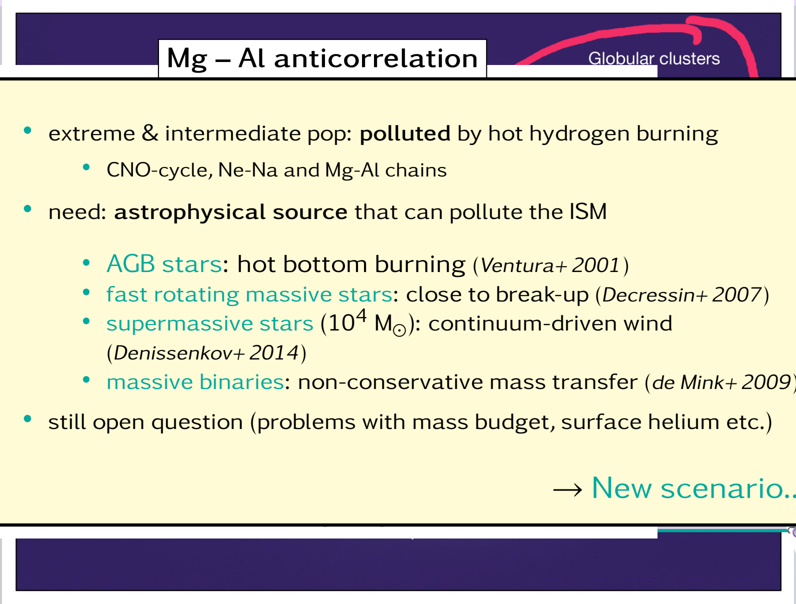

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→ New scenario...

New scenario:

Starforming Supergiant Shells

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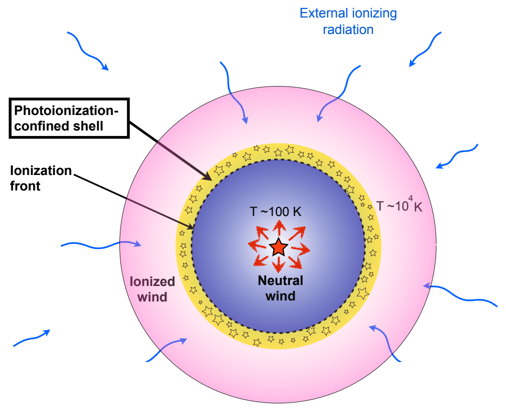
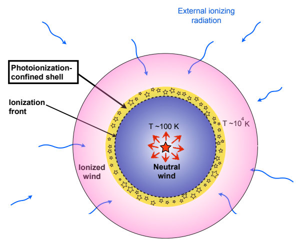
Starforming Supergiant Shells



PICO shell: *Mackey+ 2014 (Nature)*

Simulating the PICO shell



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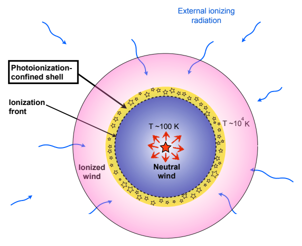
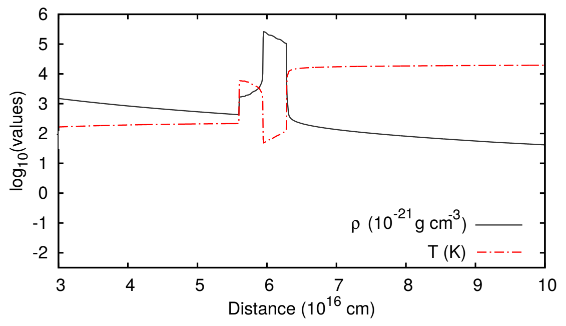
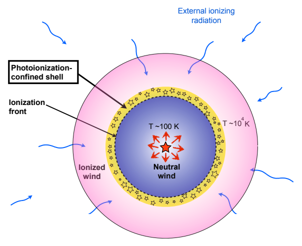
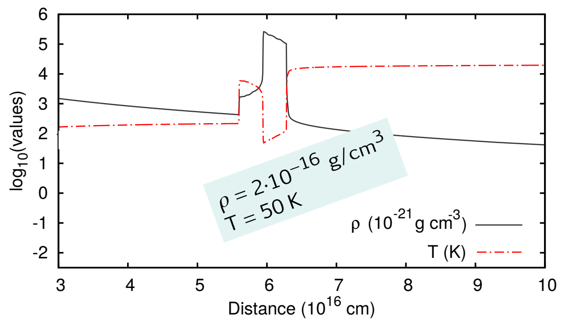




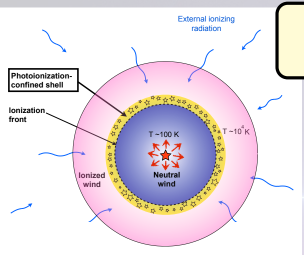
Simulating the PICO shell



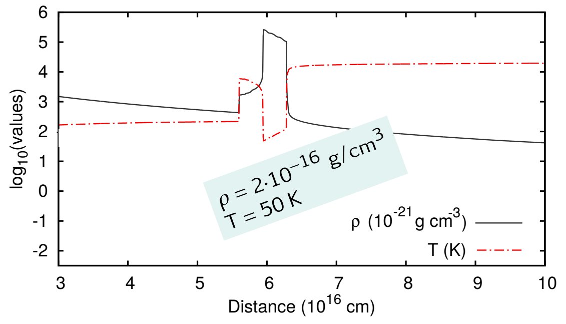


$\rho = 2{\cdot}10^{-16}$ g/cm^3
T = 50 K

Simulating the PICO shell



Mass of the photoionization-confined (PICO) shell: ~14 $M_\odot$



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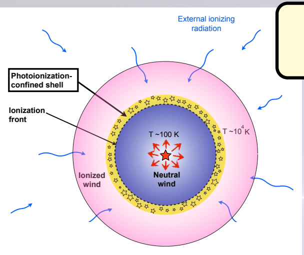

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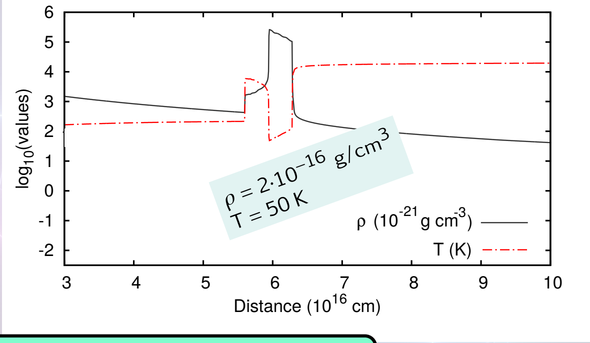
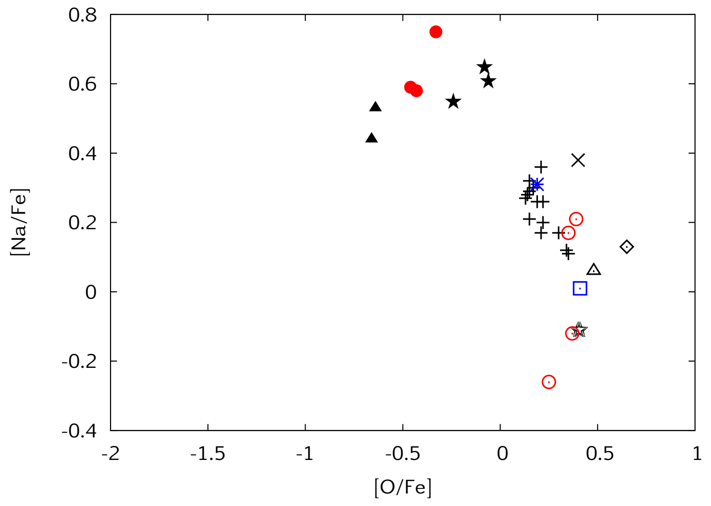


$\rho = 2{\cdot}10^{-16}$ g/cm^3
T = 50 K

Lifetime of the shell: ~10^5 yr
>>
Growth timescale of grav. unstable perturbations: ~10^4 yr

Compared to observations: O – Na anticorr.



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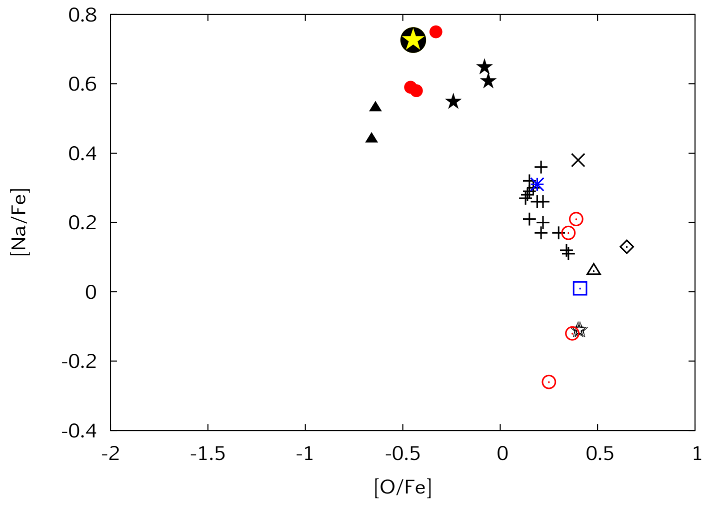

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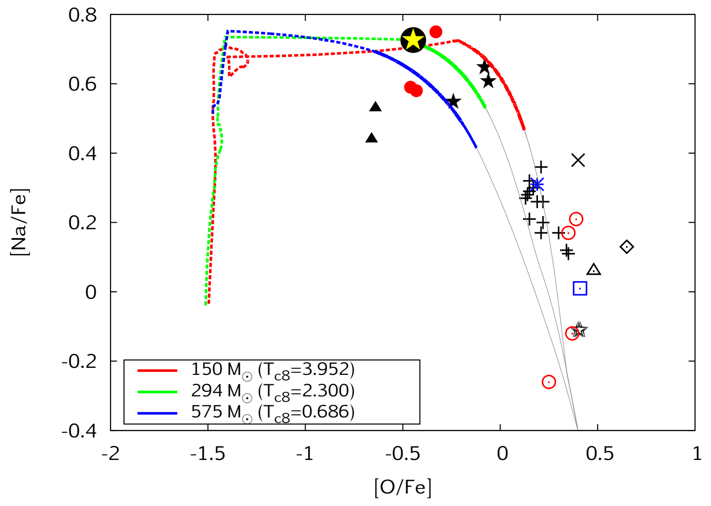
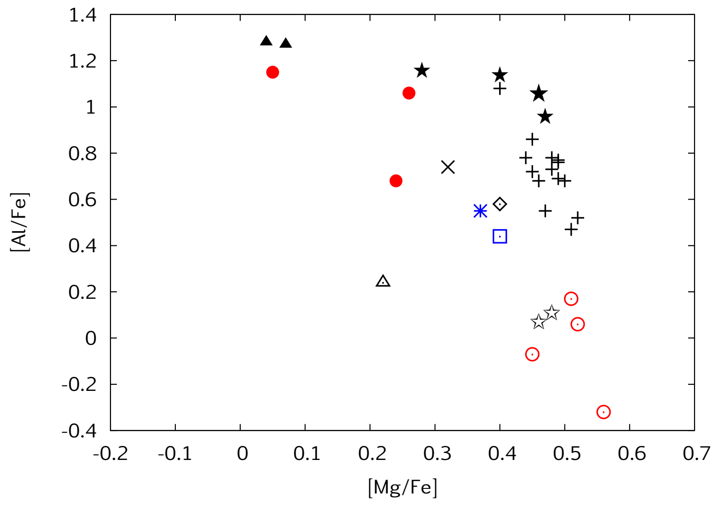


Compared to observations: Mg – Al anticorr.



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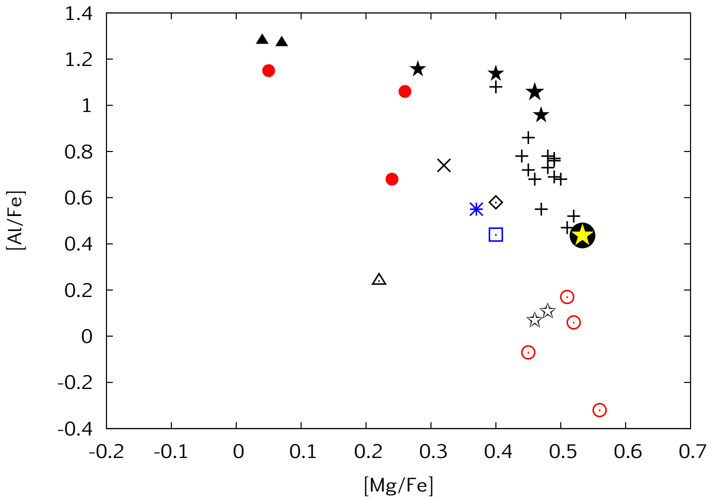

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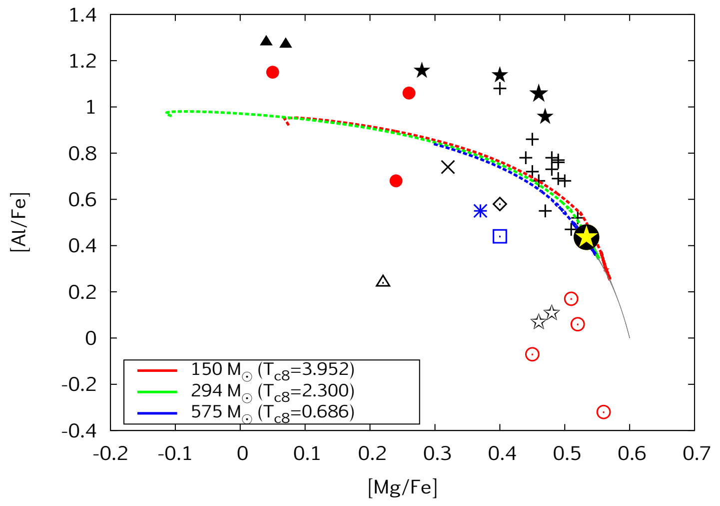

Future plans in Prague/Ondrejov

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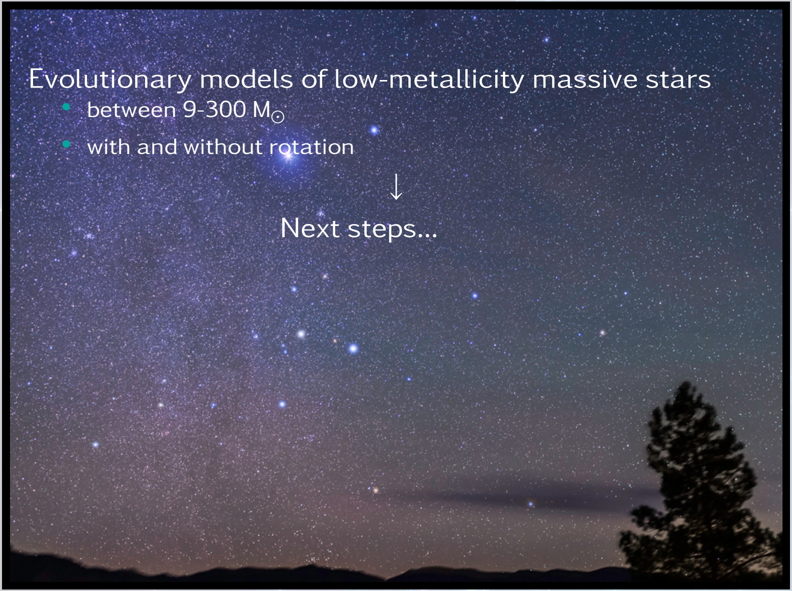


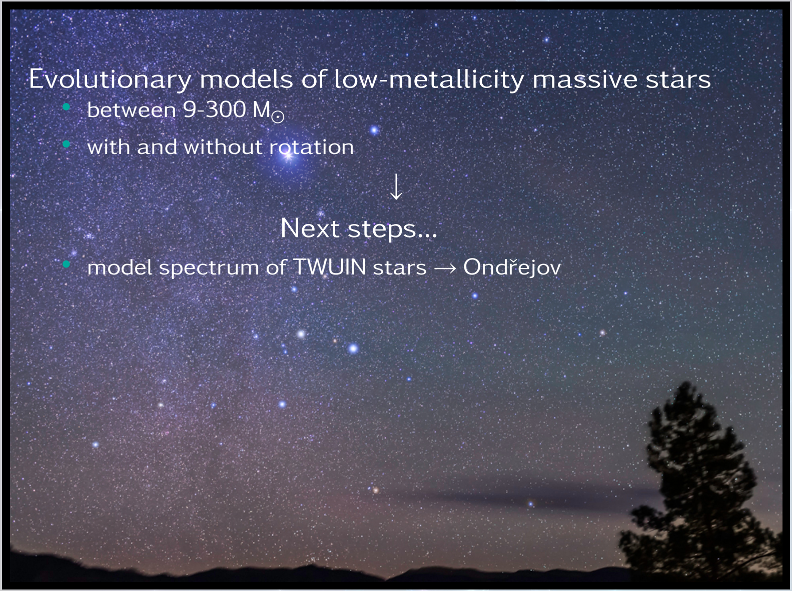
Evolutionary models of low-metallicity massive stars

- between 9-300 $M_\odot$
- with and without rotation

↓

Next steps...

Future plans in Prague/Ondrejov



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Next steps...

- model spectrum of TWUIN stars → Ondřejov

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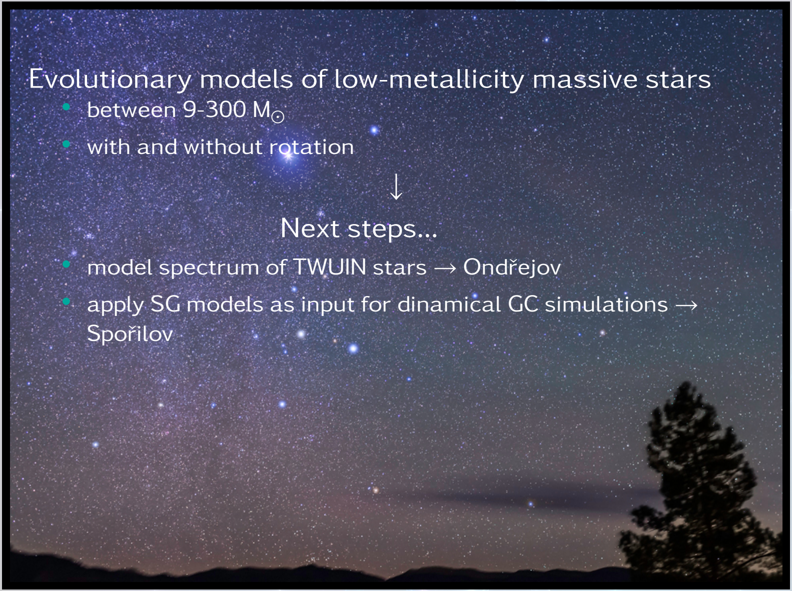

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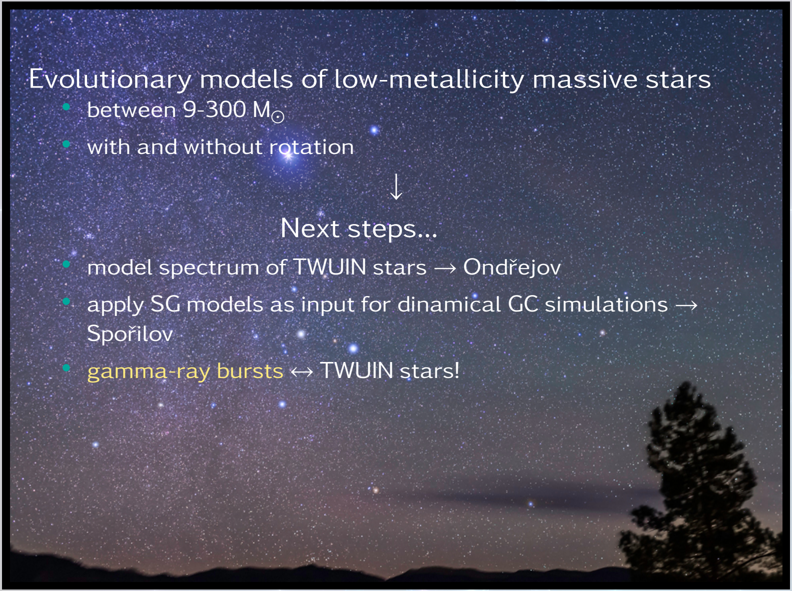

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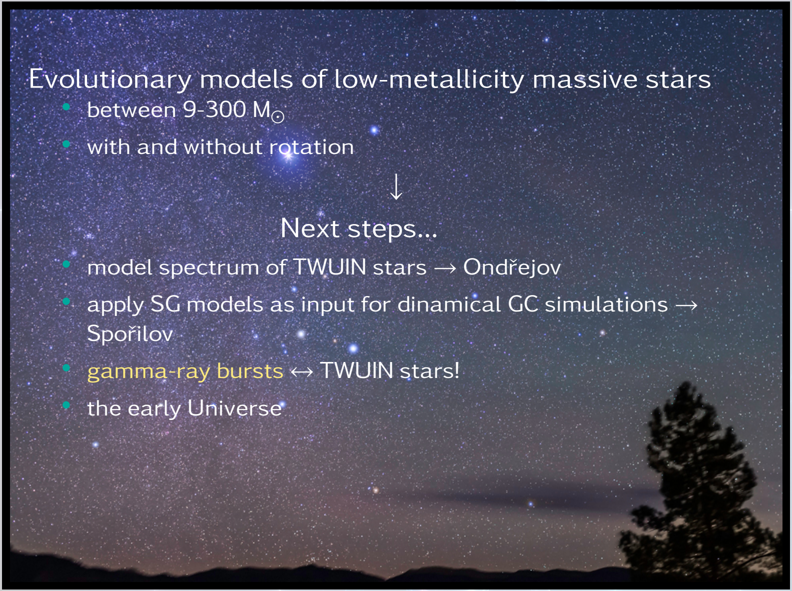
Future plans in Prague/Ondrejov



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Thank you for your attention!