

Hot massive stars in I Zwicky 18

Dorottya Szécsi

Collaborators:

Norbert Langer (Bonn),
Carolina Kehrig (Granada),
Frank Tramper (Amsterdam),
Takashi Moriya (Tokyo)



Ondrejov

25th May 2016

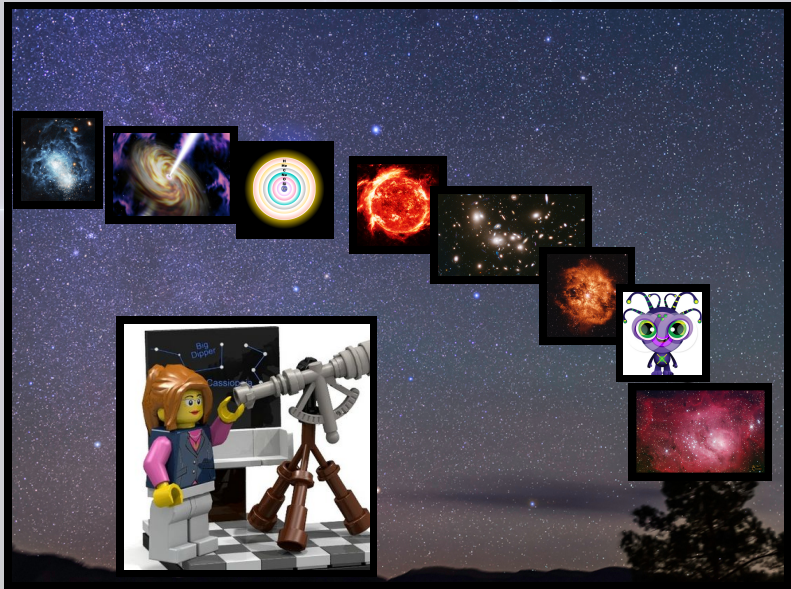
The night-sky and beyond



The night-sky and beyond



The night-sky and beyond



Astronomers and metal

LEGEND

- Non-Metal
- Metal

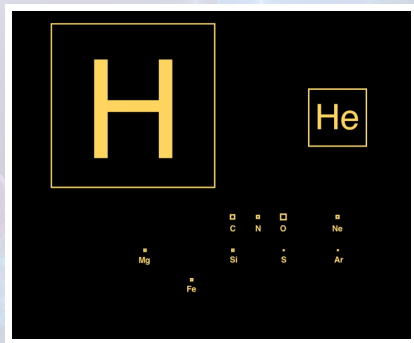
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Unq	Unp	Unh												

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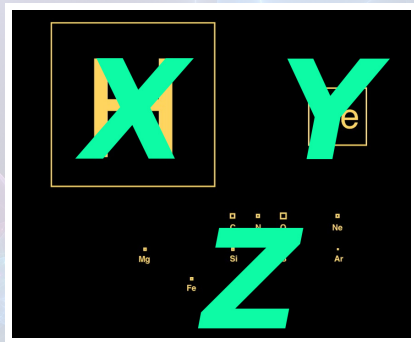


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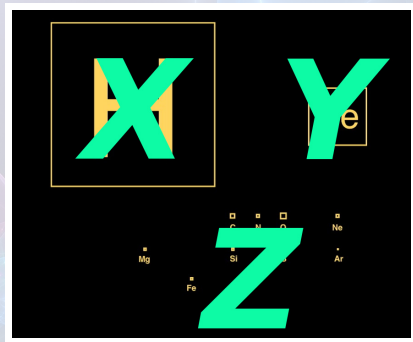
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"Z: metallicity"



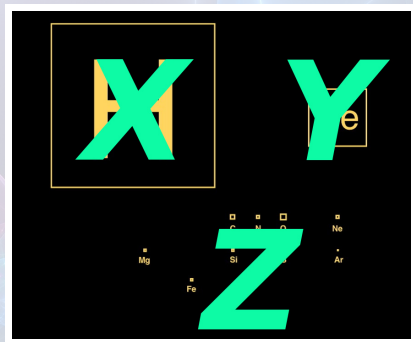
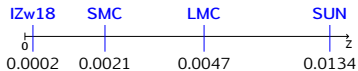
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"Z: metallicity"



The early Universe ($Z \approx 0$)



Credit: hubblesite.org

Compact Dwarf Galaxies



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

Compact Dwarf Galaxies

I Zwicky 18

- Blue Compact Dwarf Galaxy
- 18 Mpc \rightarrow local
- SFR: $0.1 M_{\odot}/\text{yr}$
- ionized gas
- low metallicity!



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$$12 + \log(\text{O}/\text{H}) = 7.17$$

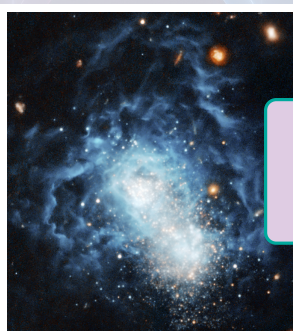
↓

$$Z = 1/50 Z_{\odot} \approx 0.0002$$

Compact Dwarf Galaxies

I Zwicky 18

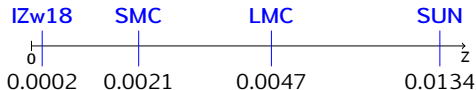
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\downarrow

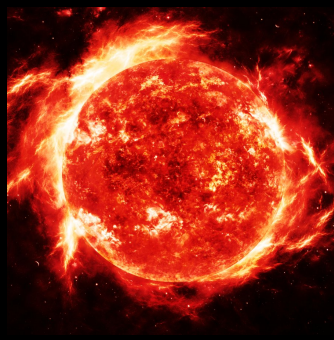
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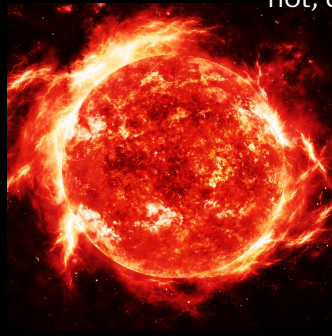
The background features a large, semi-transparent white circle centered in the upper half. Overlaid on this are several thin, glowing lines in shades of cyan, magenta, and white. These lines form a complex, web-like pattern that resembles a fractal or a network of connections. The overall aesthetic is clean, modern, and scientific.

What is a star?

What is a star?

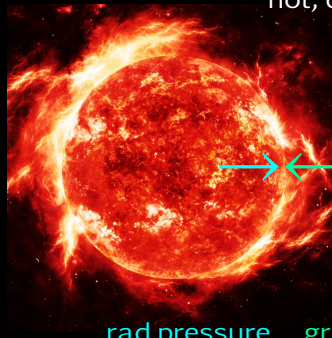


What is a star?



hot, dense plazma

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equilibrium:

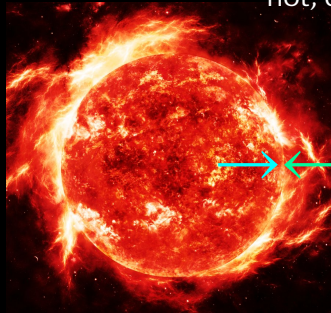
rad.pressure

gravity

What is a star?

surface?

hot, dense plazma



equilibrium:

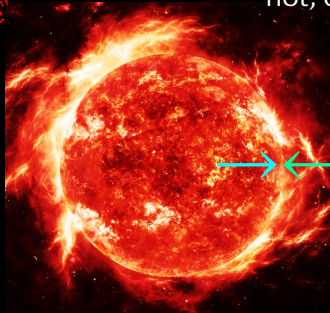
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What is a star?

surface?
→ photons escape
"photosphere"

hot, dense plazma



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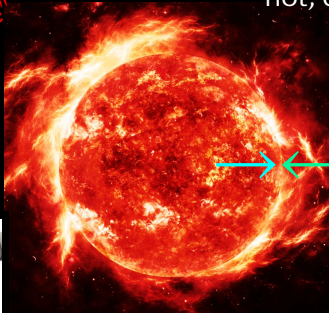
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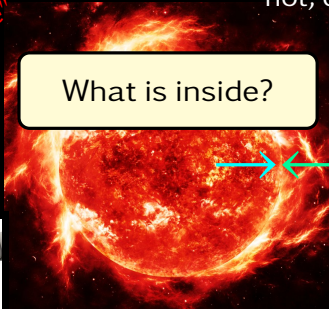
What is a star?

surface?
→ photons escape
"photosphere"

hot, dense plazma

What is inside?

rad.pressure gravity



What is a star?

surface?
→ photons escape
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hot, dense plazma

What is inside?

theoretical
modelling
of the stellar
structure

rad.pressure gravity



Theoretical modelling of the stellar structure

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

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

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

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

Guilera et al. 2011

Theoretical modelling of the stellar structure

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composition change due to nuclear burning ?!

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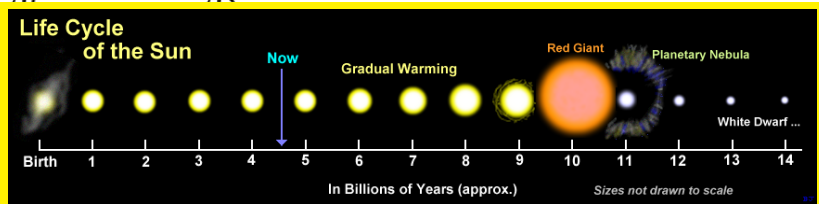
composition change due to nuclear burning ?!

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

Theoretical modelling of the stellar structure

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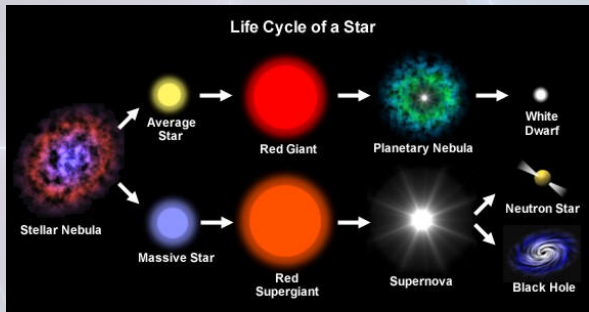


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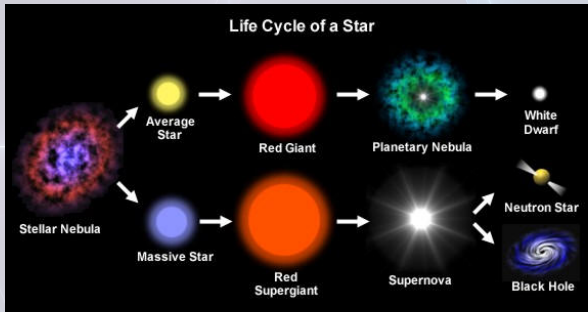
Massive vs. low-mass stars

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



Massive vs. low-mass stars

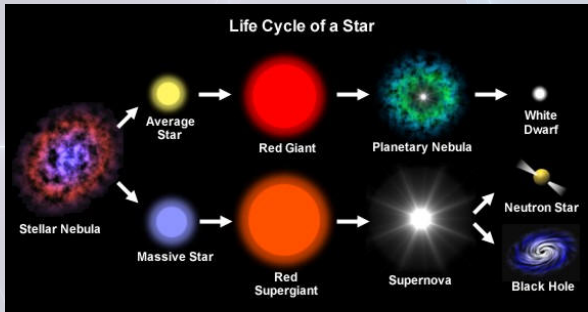
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- nuclear reactions, final composition

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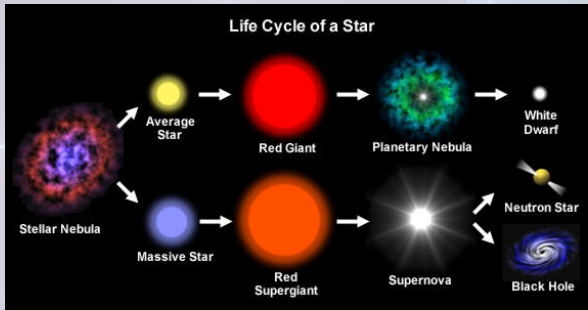
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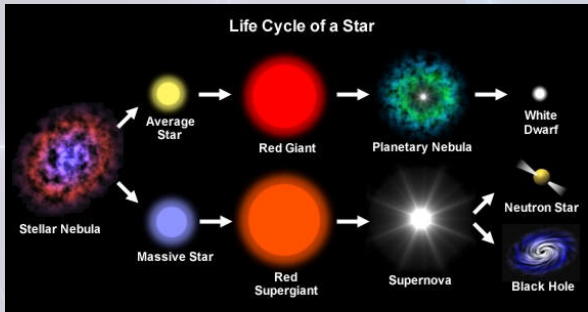
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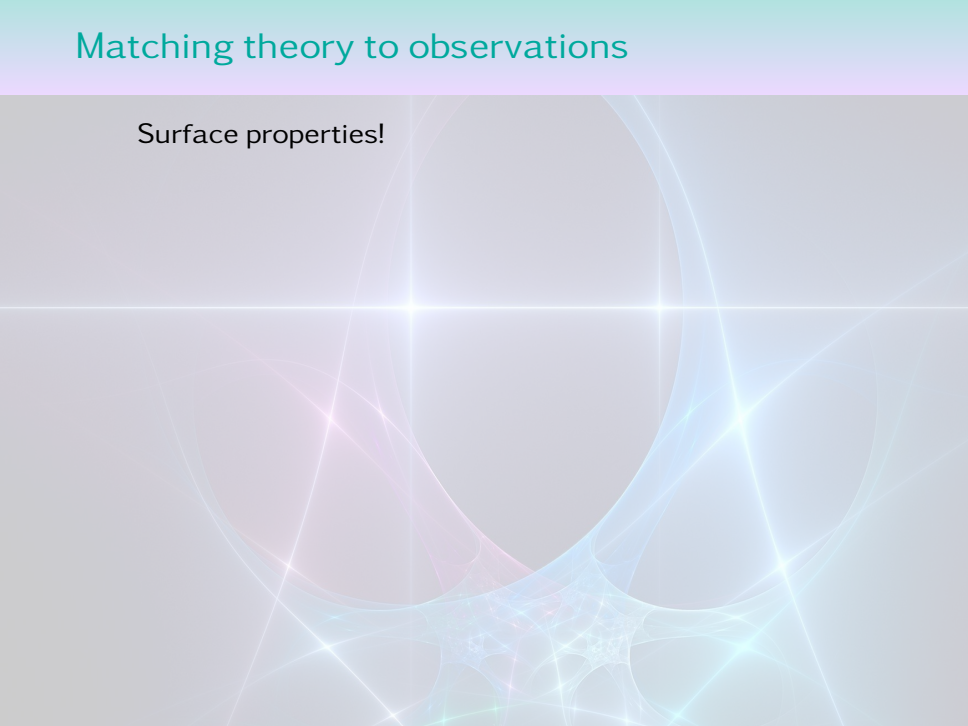
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- final fate

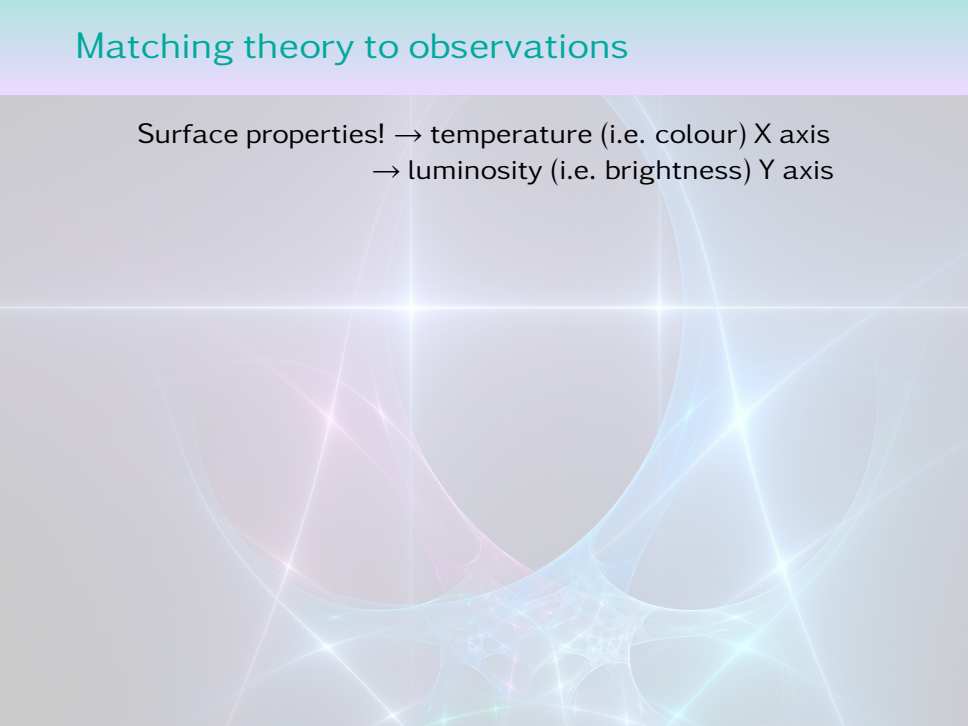
Matching theory to observations

Surface properties!

The background of the slide is a complex, abstract composition. It features a large, semi-transparent sphere in the center, which appears to be a celestial body or a lens. Overlaid on this and the entire background are numerous thin, glowing lines in various colors, including cyan, magenta, and white. These lines intersect and curve, creating a sense of depth and movement. The overall aesthetic is futuristic and scientific, with a focus on light and geometric forms.

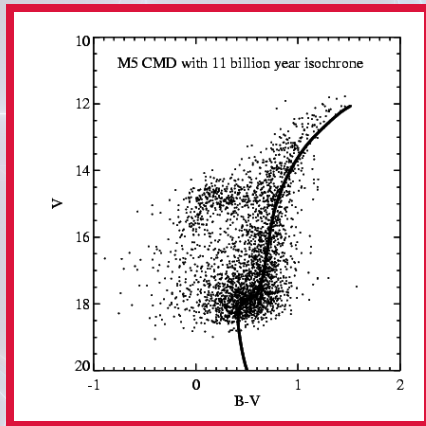
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Surface properties! → temperature (i.e. colour) X axis
→ luminosity (i.e. brightness) Y axis



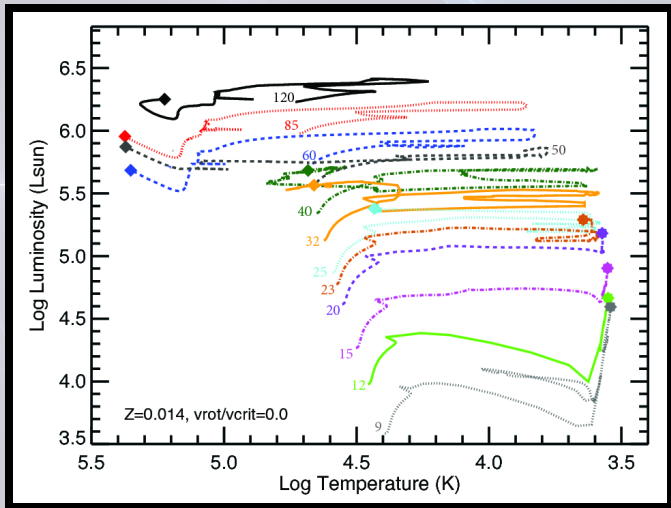
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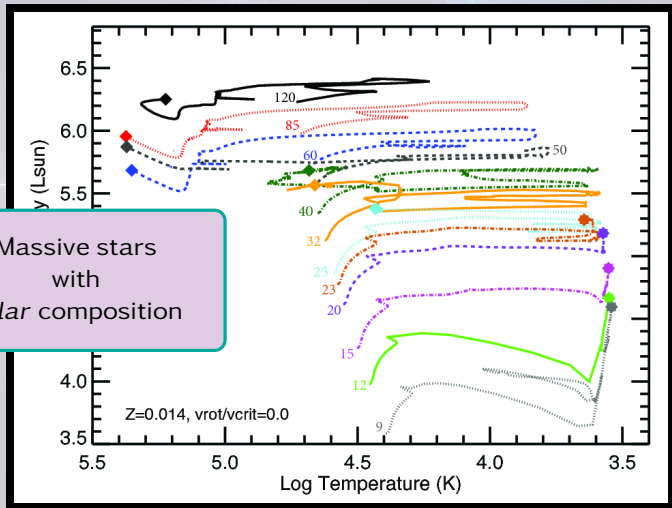


Hertzsprung–Russell diagram (HR diagram)

Hertzprung–Russell diagram



Hertzprung–Russell diagram



The background features a large, semi-transparent circle in the center. Overlaid on this are several thin, glowing lines in shades of blue, cyan, and magenta. These lines form a complex, web-like pattern that resembles a fractal or a network of connections. The overall aesthetic is clean, modern, and scientific.

Low Metallicity Massive Stars

Low Metallicity Massive Stars

– my thesis 😊

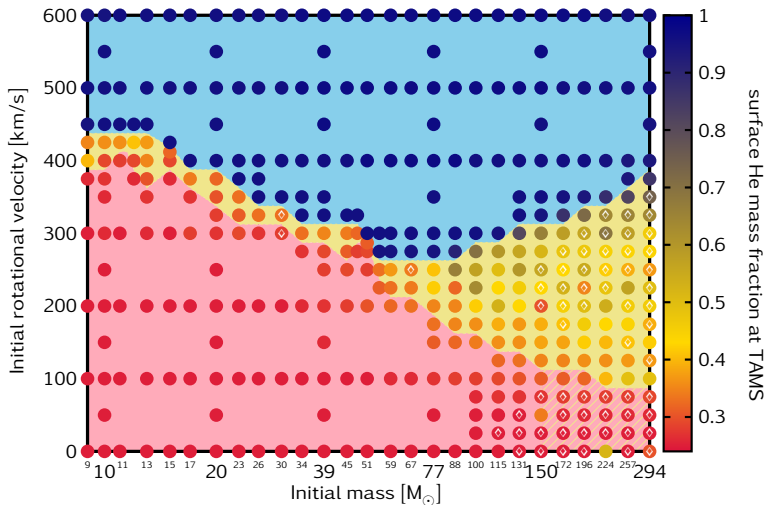
Low Metallicity Massive Stars

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



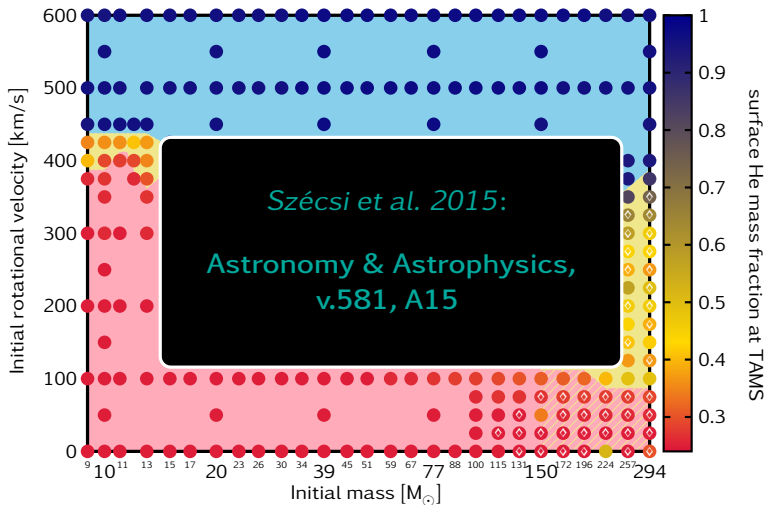
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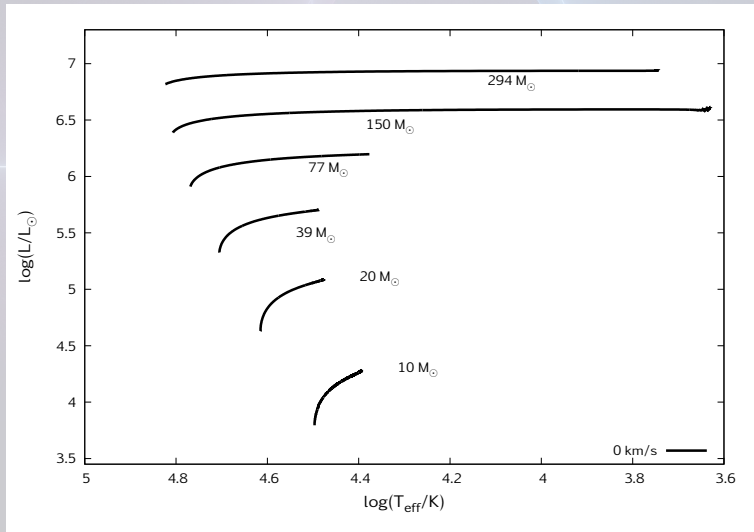
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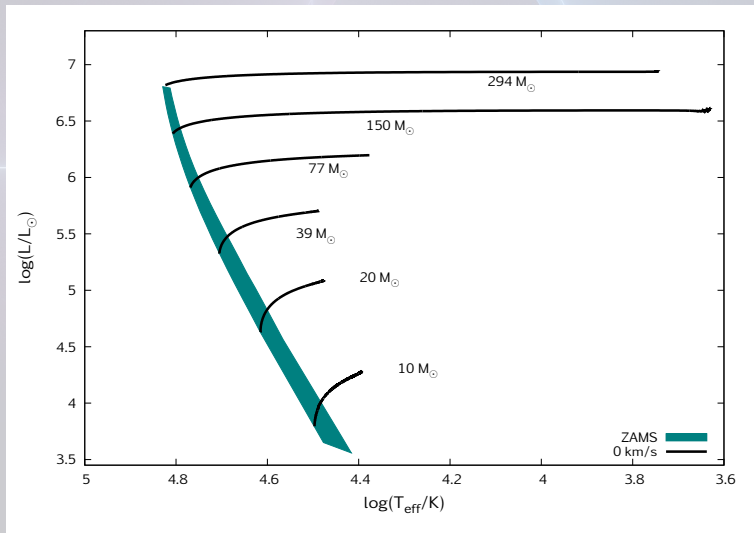
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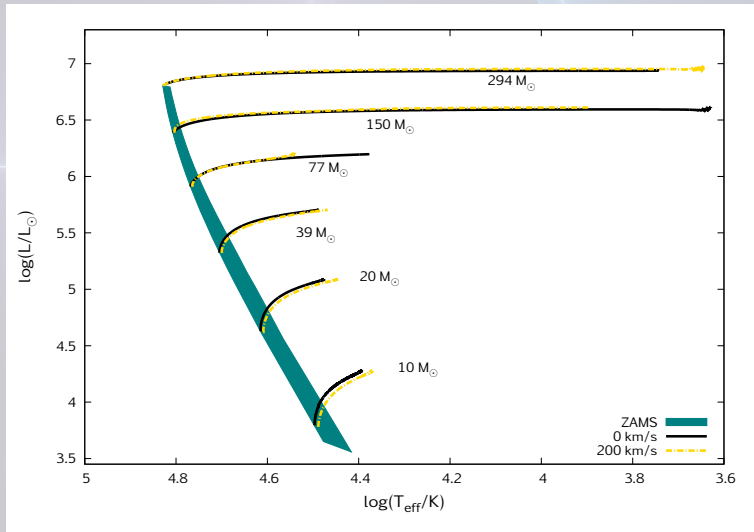
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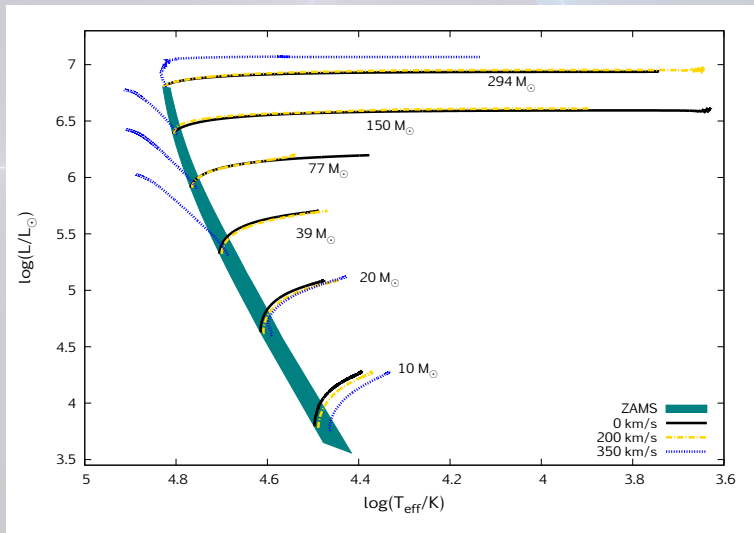
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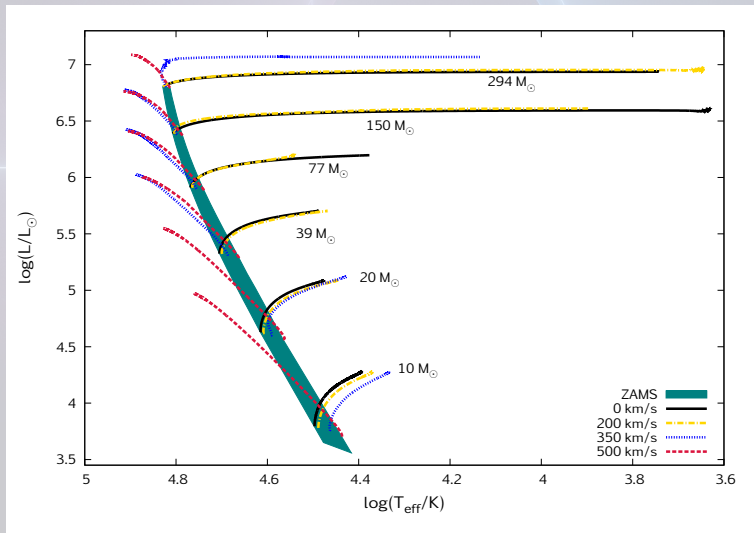
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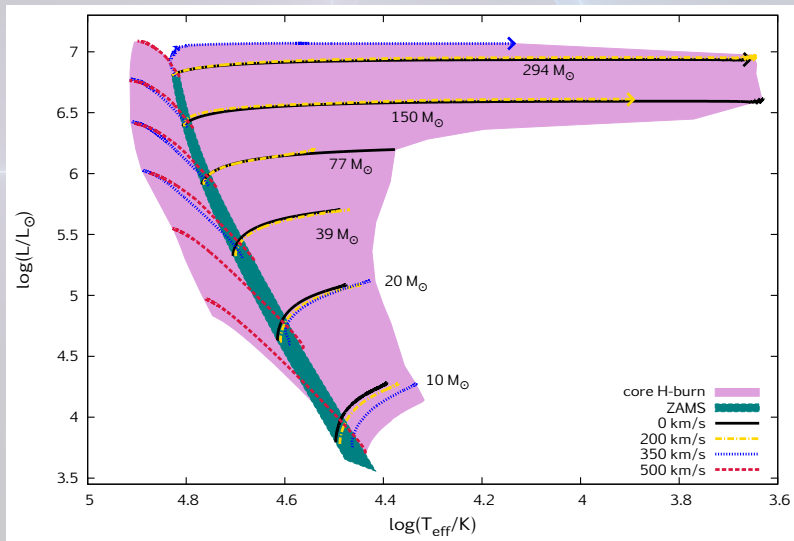
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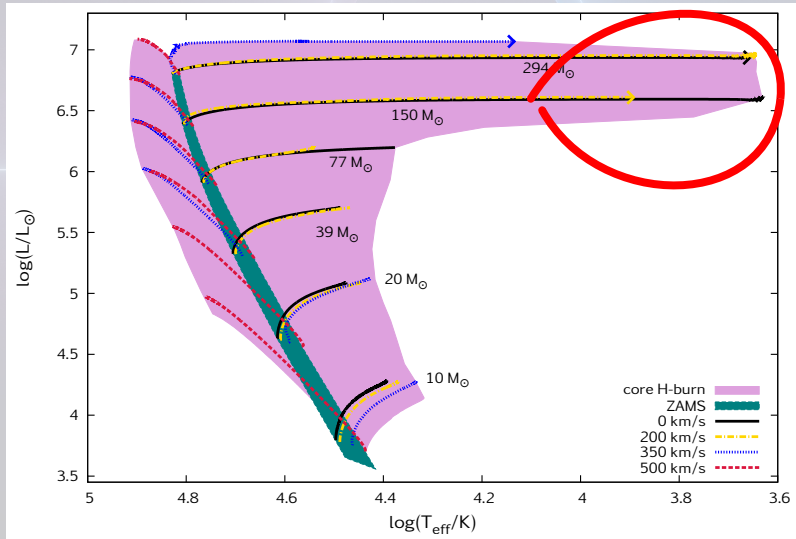
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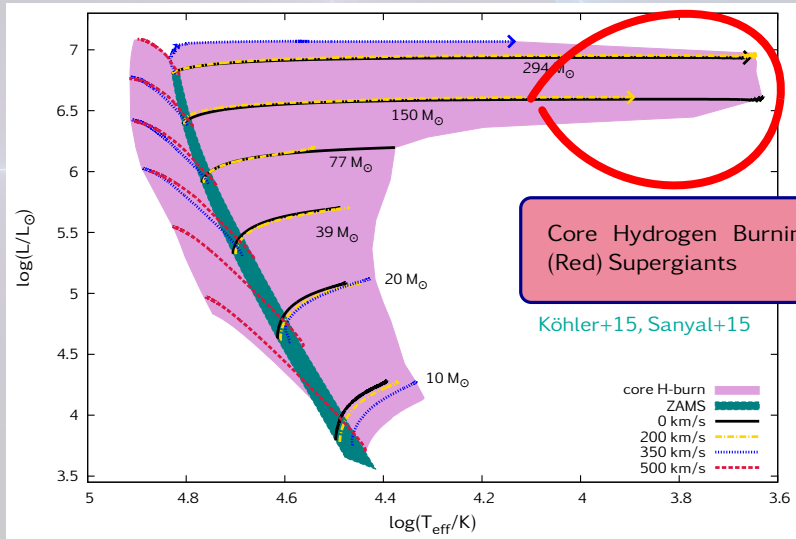
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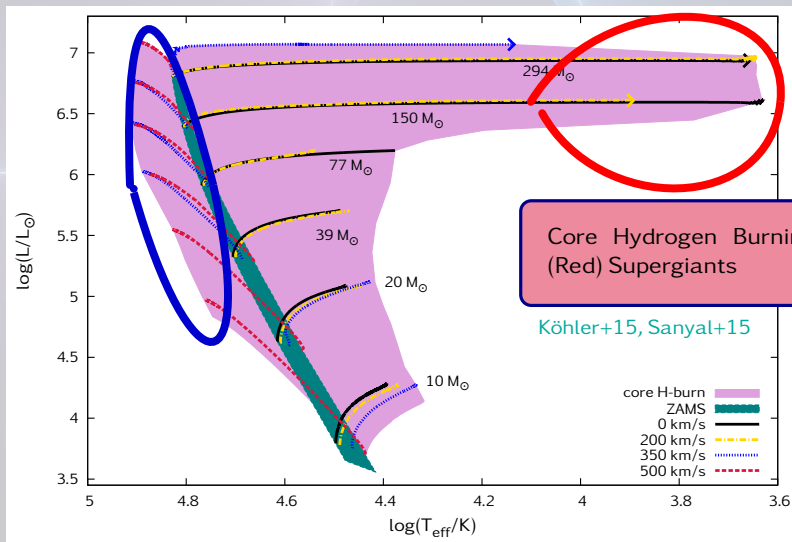
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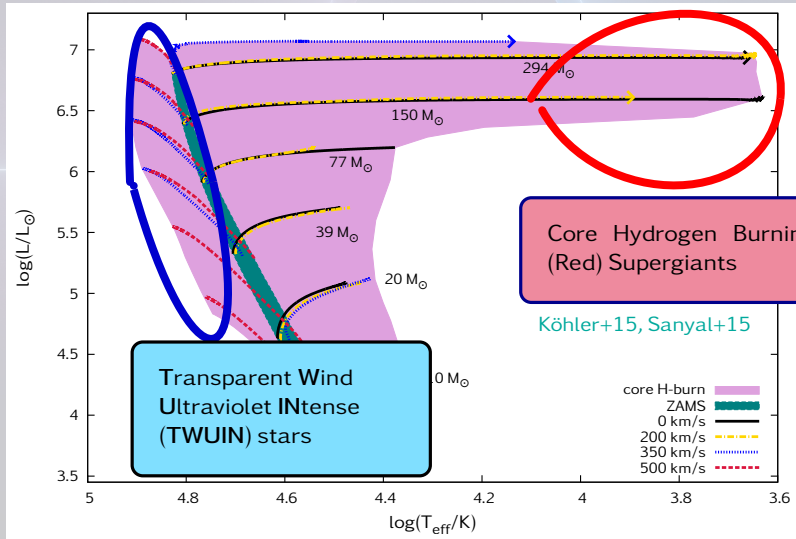
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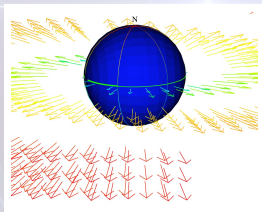
Transparent Wind
Ultraviolet Intense stars
(TWUIN stars)

– in the
starburst galaxy | Zwicky 18

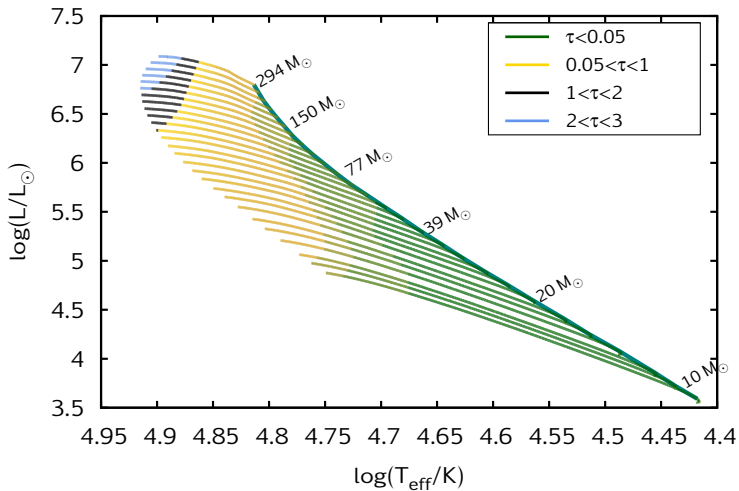
TWUIN stars and their stellar winds



TWUIN stars and their stellar winds

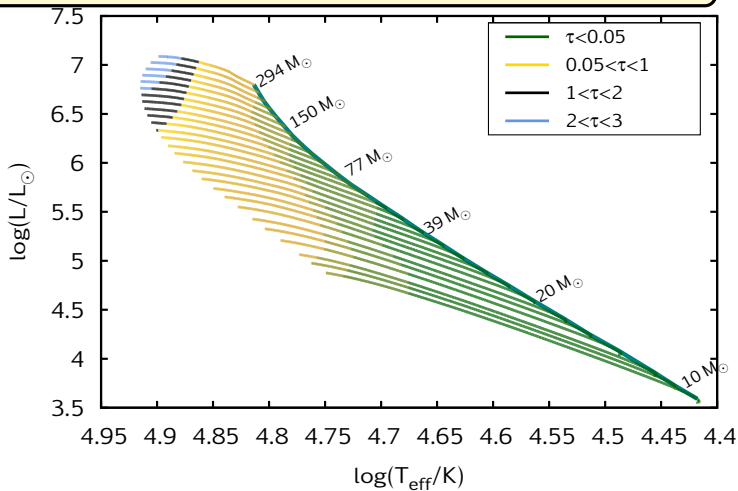


TWUIN stars and their stellar winds



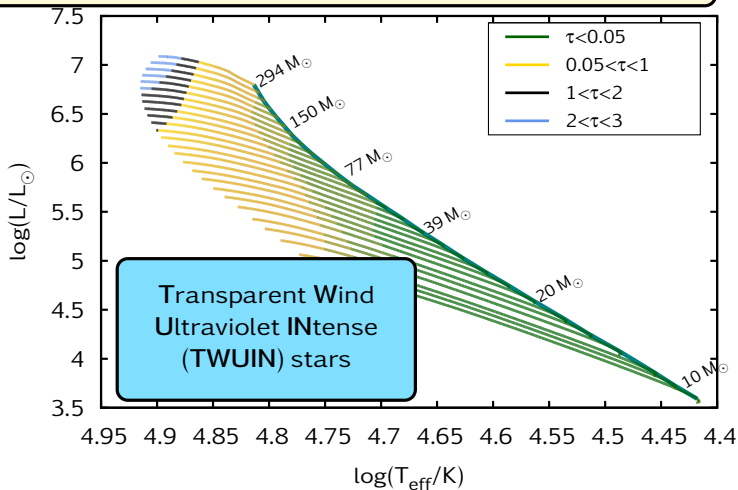
TWUIN stars and their stellar winds

Main sequence lifetime: wind optical depth is $\tau \lesssim 1$



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Back to I Zw 18

I Zwicky 18

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- 18 Mpc \rightarrow local
- SFR: $0.1-1 M_{\odot}/\text{yr}$
- ionized gas
- low metallicity:
 $12+\log(\text{O}/\text{H})=7.17$
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 $Z=1/50 Z_{\odot} \approx 0.0002$

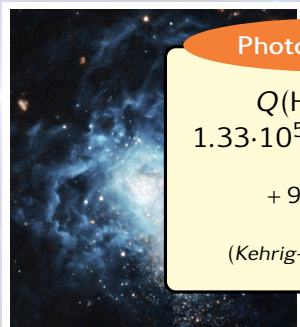


Legrand+07, Aloisi+09, Annibali+13, Kehrig+13, Leboutteiller+13

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Photoionization

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

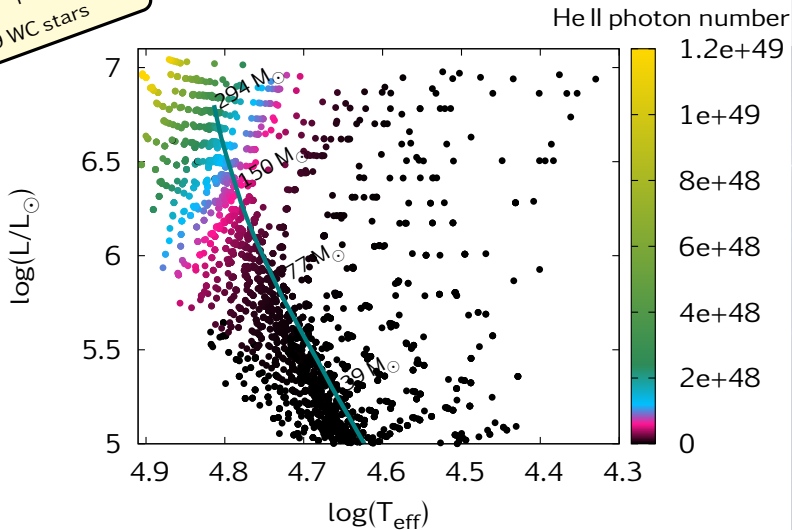
+ 9 WC stars

(Kehrig+15, Crowther+06)

Photoionization in I Zw 18

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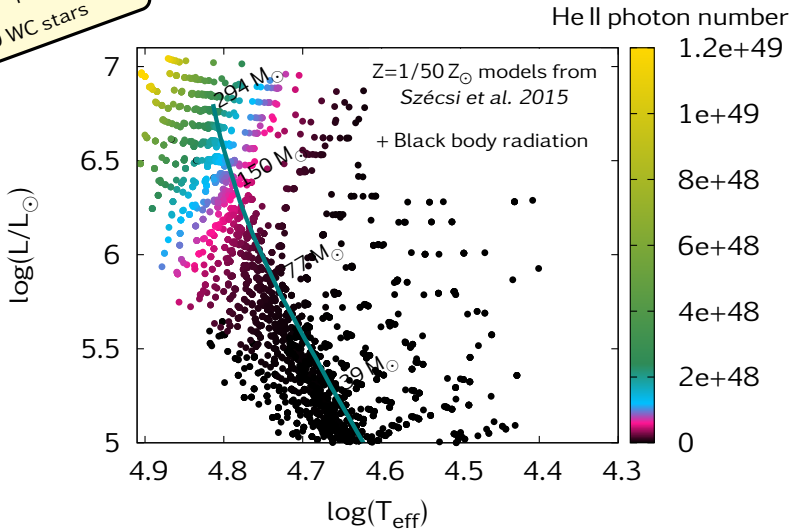
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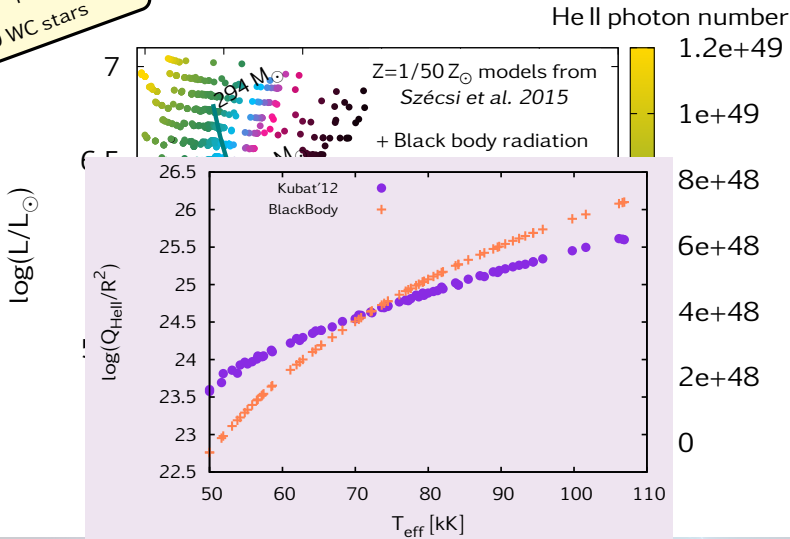
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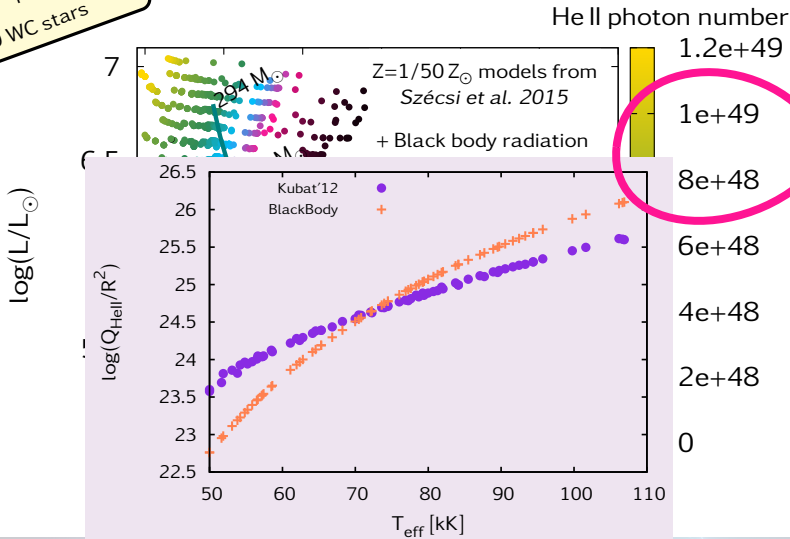
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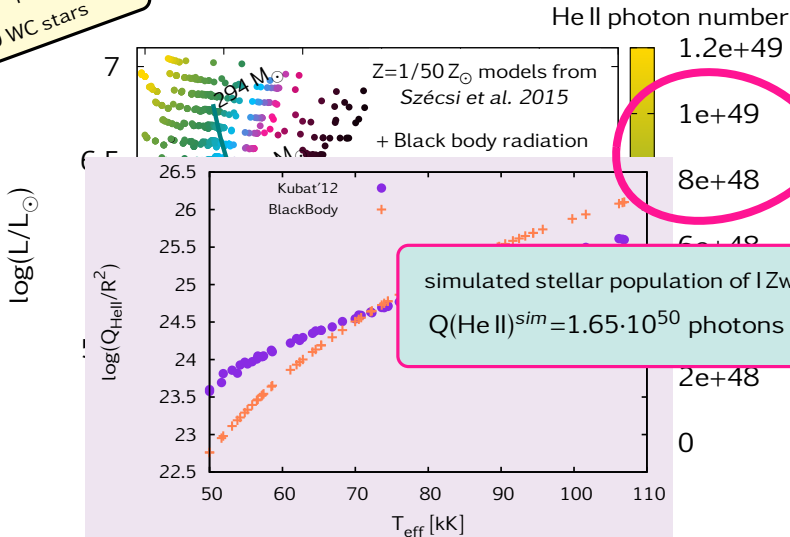
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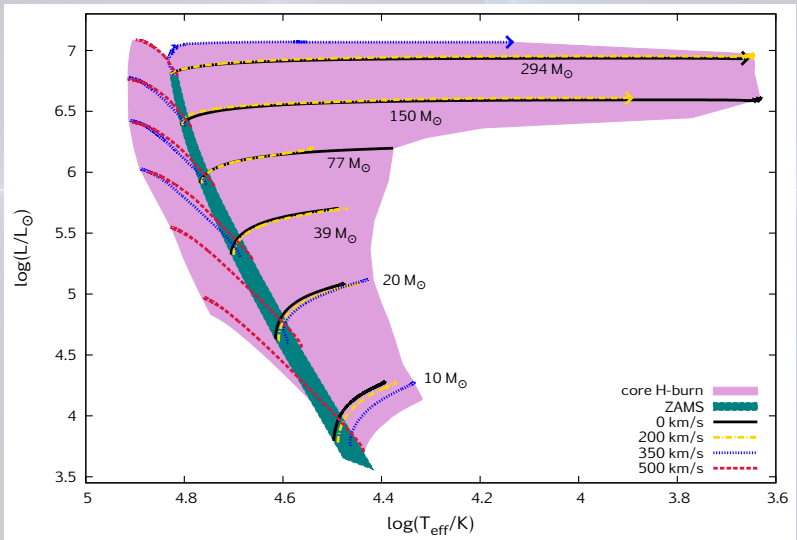
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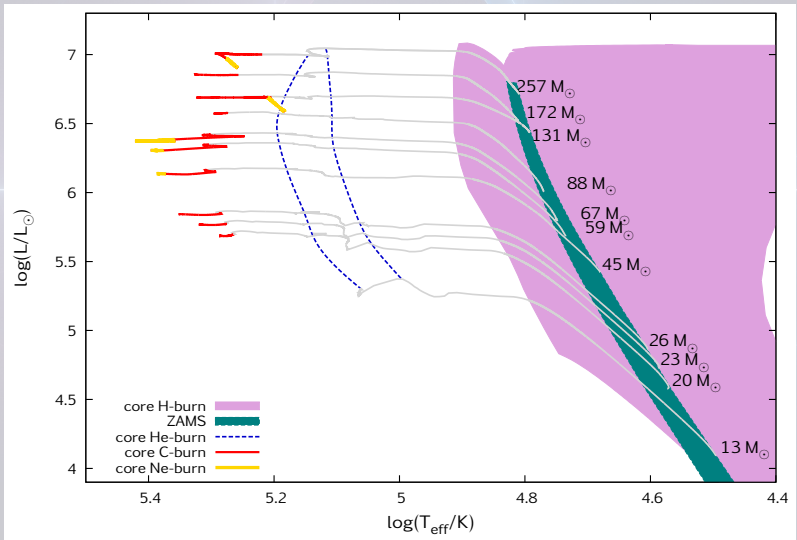
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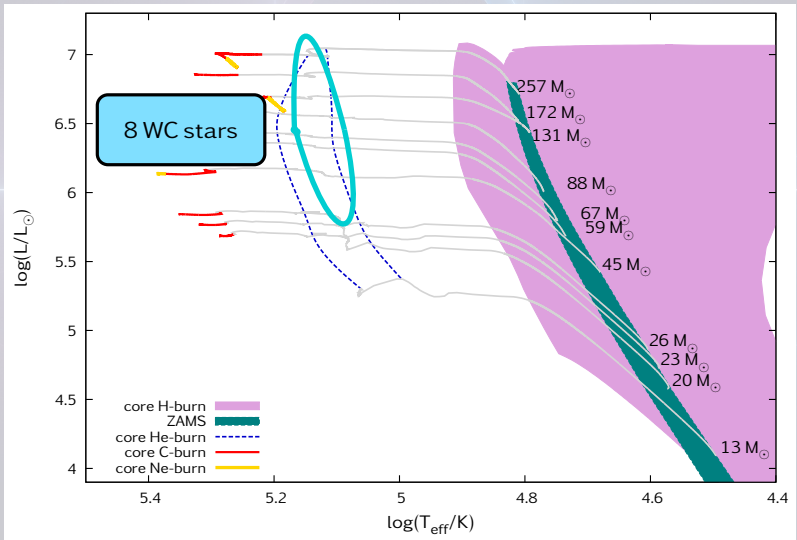
WC stars? Post-main-sequence!



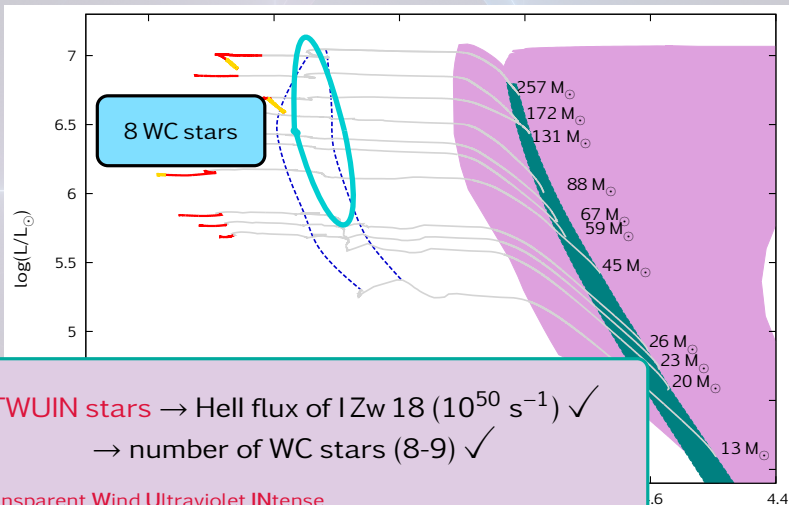
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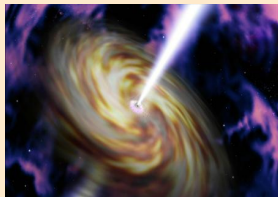


TWUIN stars → Hell flux of I Zw 18 (10^{50} s^{-1}) ✓
→ number of WC stars (8-9) ✓

Transparent Wind Ultraviolet INTense

Final Fate of Hot Massive Stars at Low Z

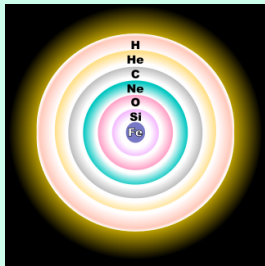
Collapsar \rightarrow IGRB



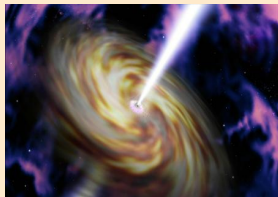
Yoon&Langer'05; Woosley&Heger'06; Yoon+06; Yoon+12

Final Fate of Hot Massive Stars at Low Z

Massive stars



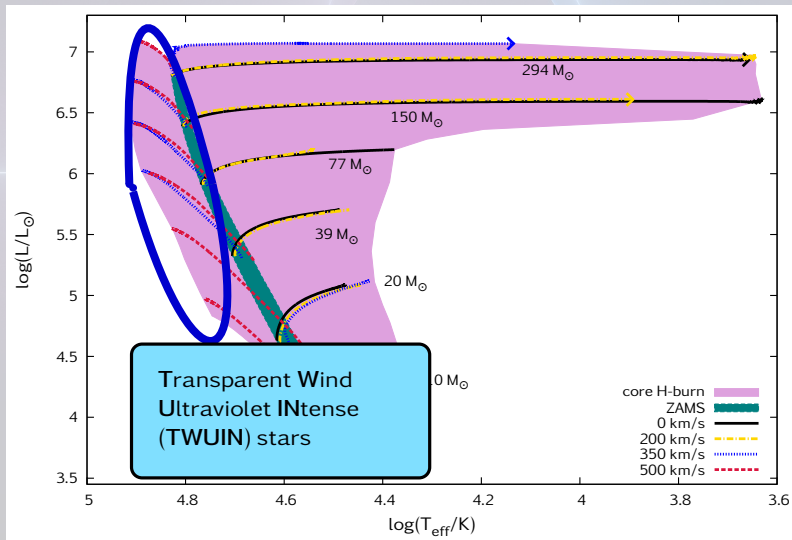
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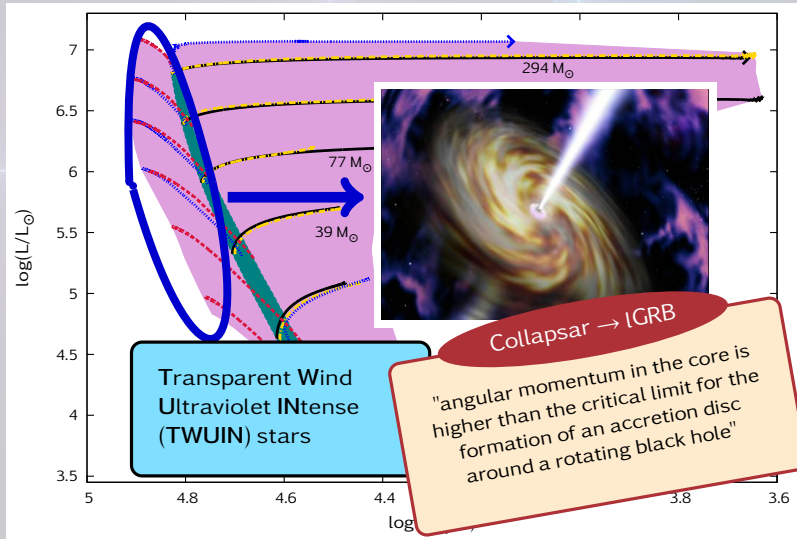
Hertzprung–Russell diagram

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



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Life and Death of Massive Stars

Life of Massive Stars

He II photons

(*Shirazi+12, Kehrig+15*)



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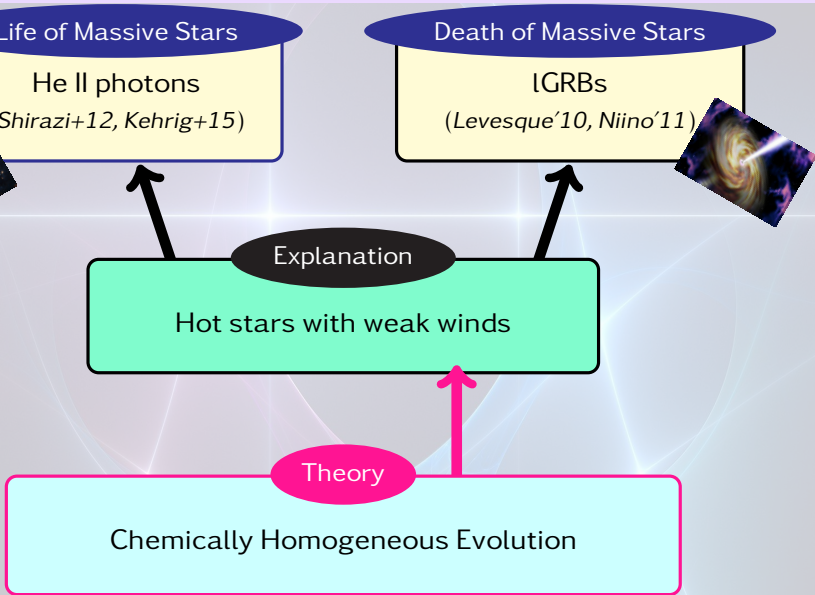


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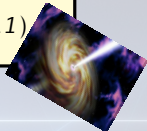
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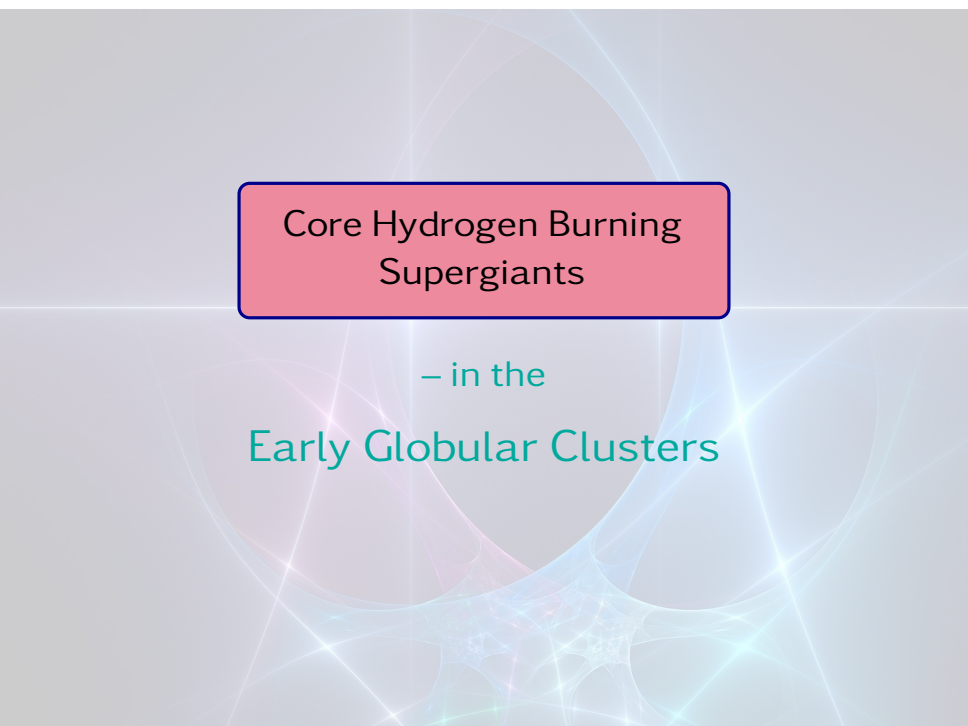
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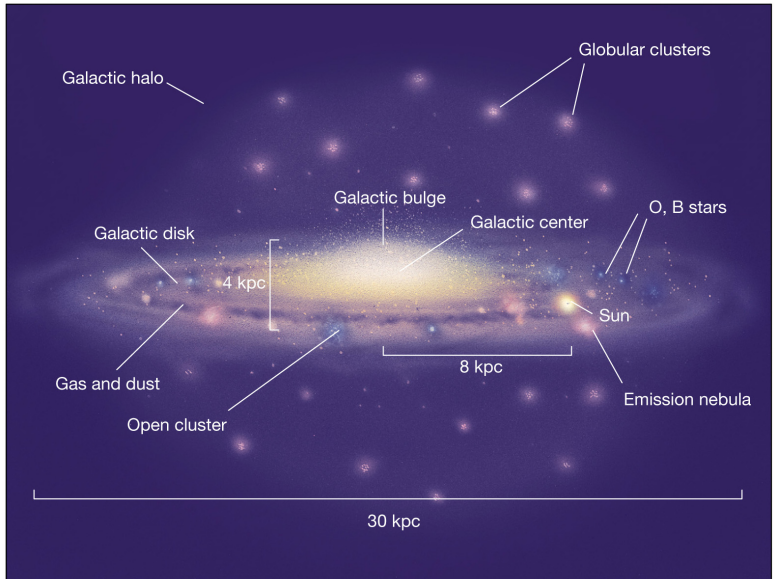
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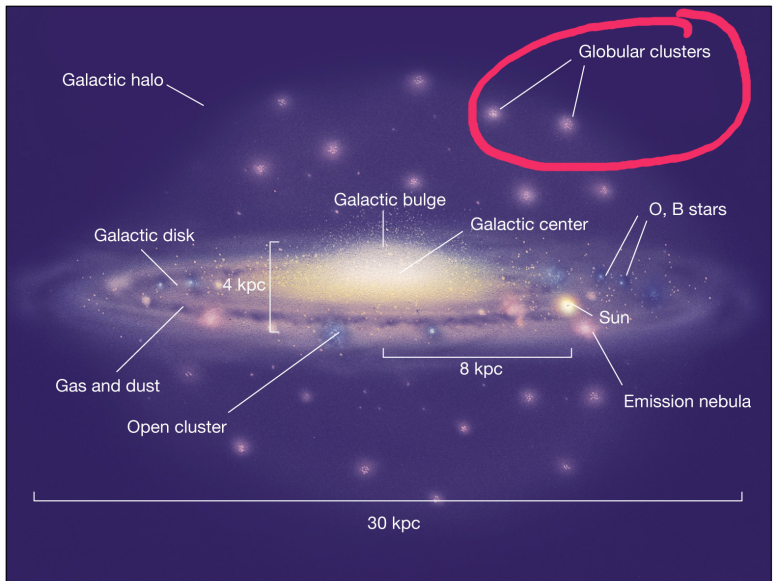
Core Hydrogen Burning
Supergiants

– in the
Early Globular Clusters

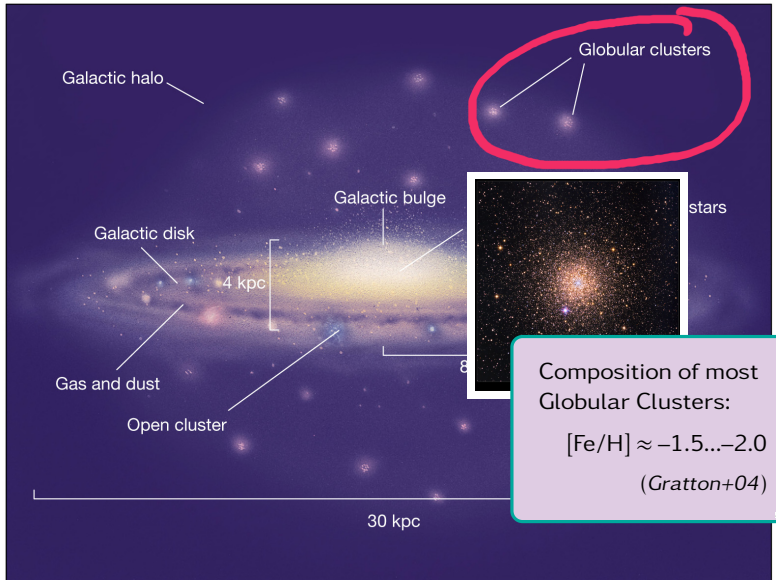
Globular Clusters & Abundance Anomalies



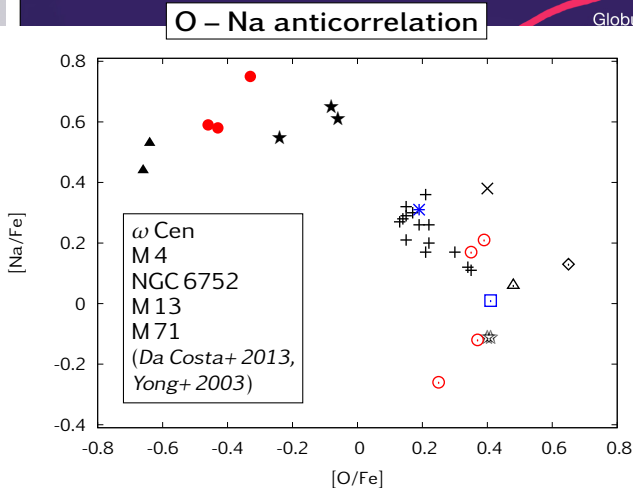
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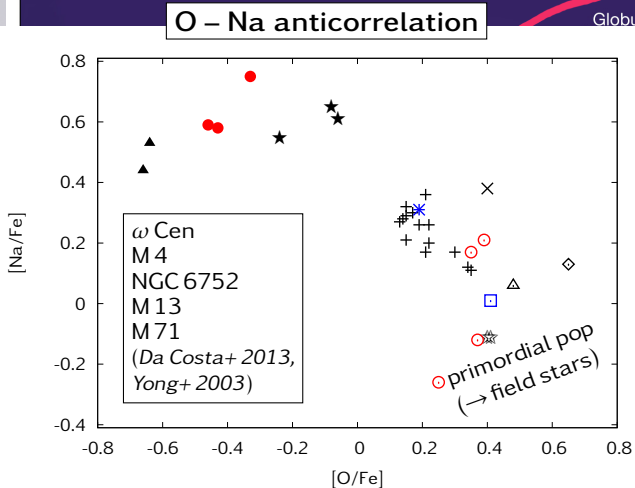
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-1.5...-2.0
(Gratton+04)



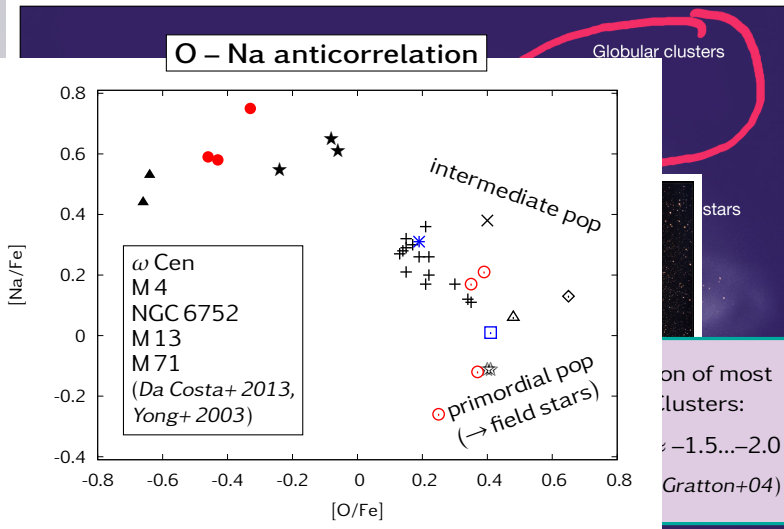
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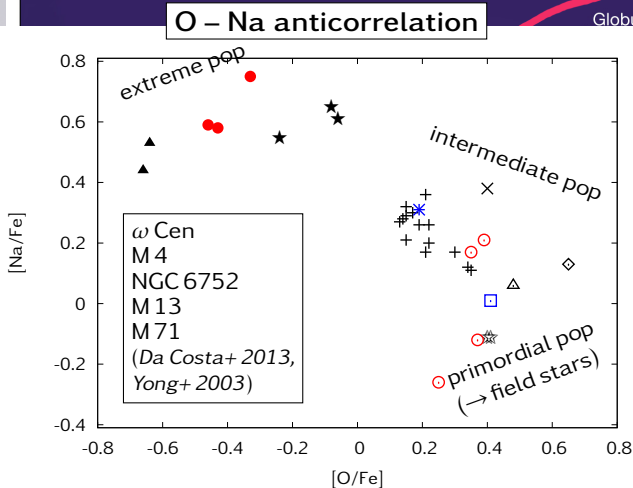
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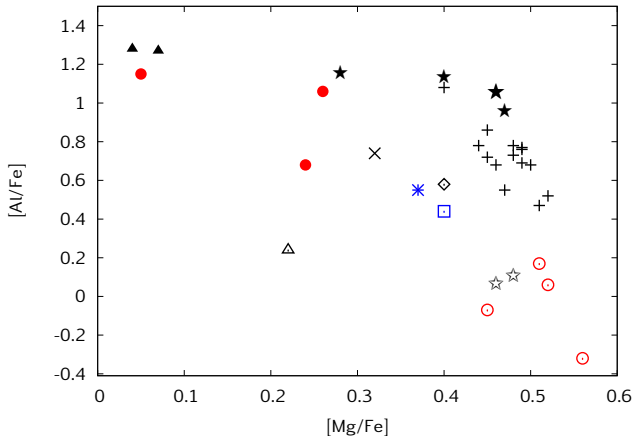


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Globular Clusters & Abundance Anomalies

Mg - Al anticorrelation



Globular clusters

stars

most
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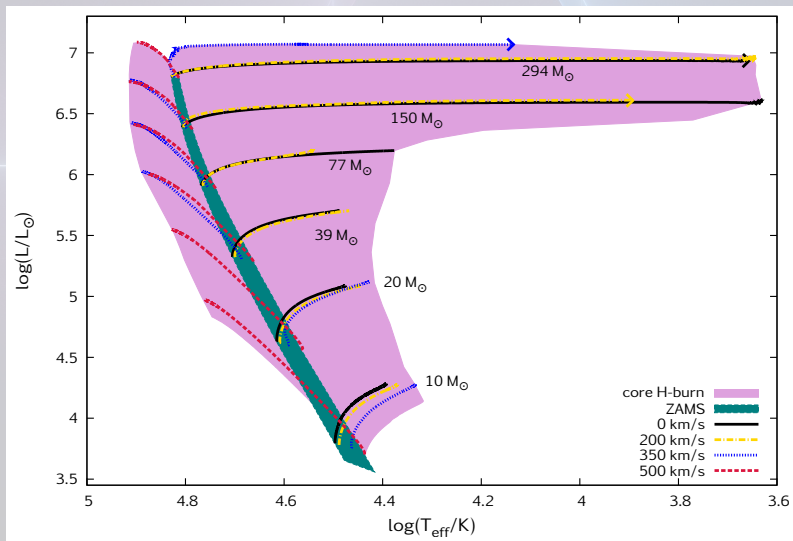
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→ **New scenario...**

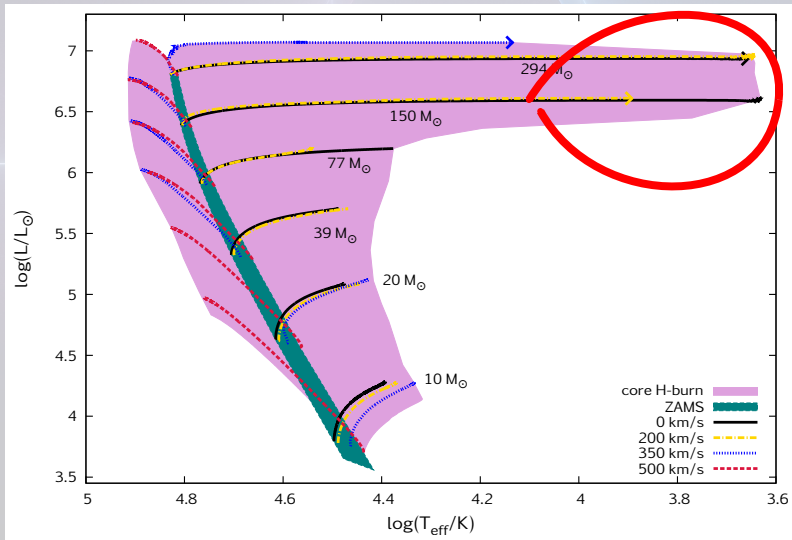
Evolution of low metallicity massive stars

Szécsi et al. 2015 (A&A)



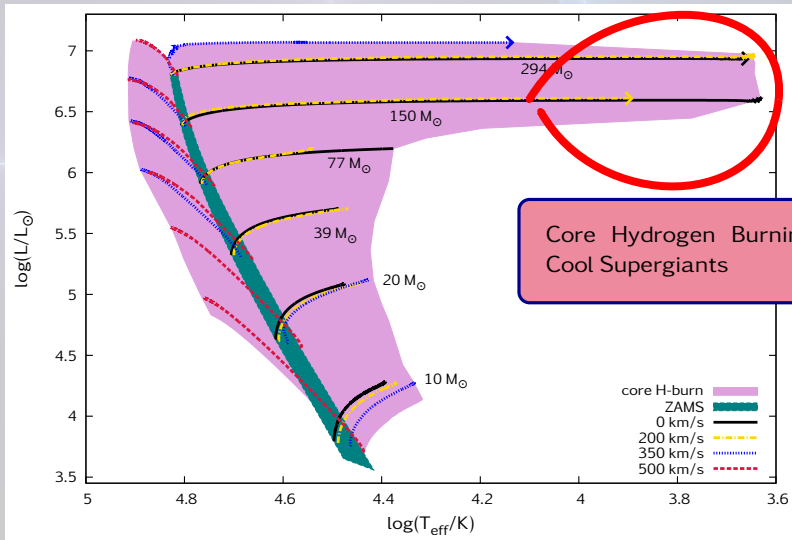
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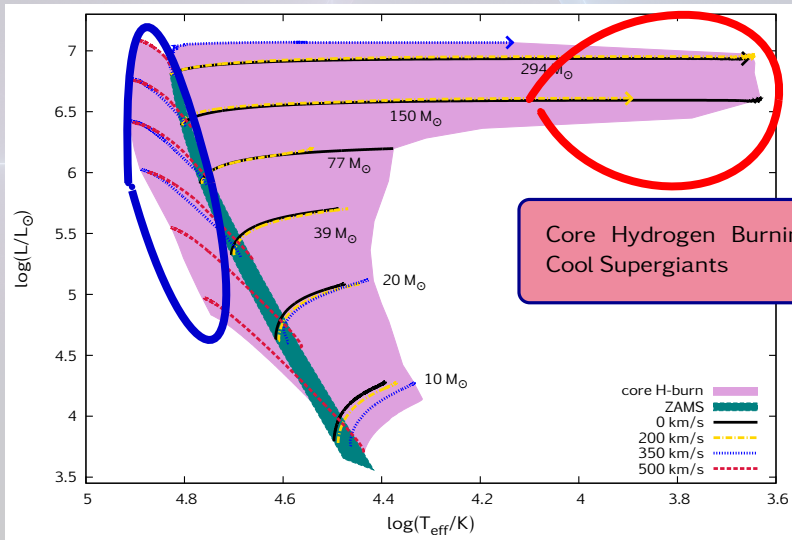
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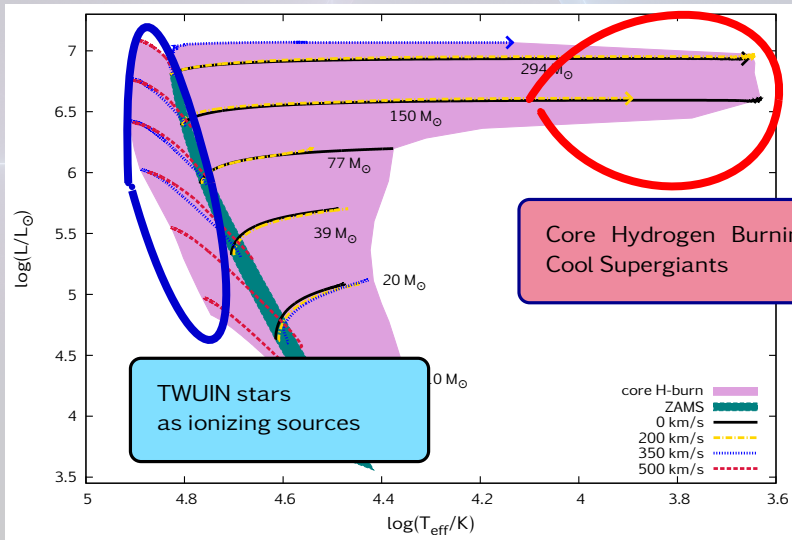
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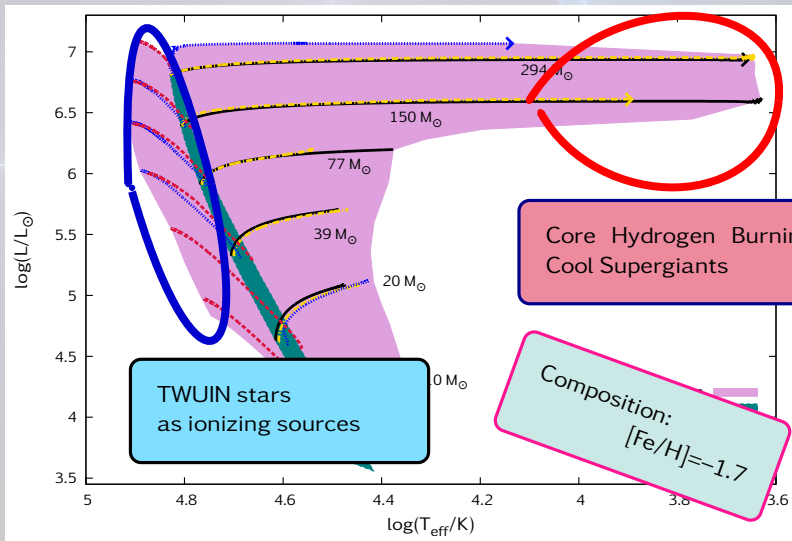
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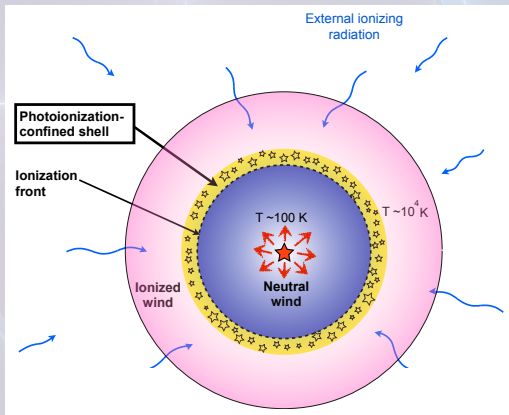
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The background features a large, semi-transparent sphere in the upper center. A network of glowing, multi-colored lines (pink, blue, green, and white) crisscrosses the scene, creating a complex, web-like structure. A prominent horizontal white line with a bright starburst at its center intersects the sphere and the network of lines. The overall aesthetic is futuristic and scientific.

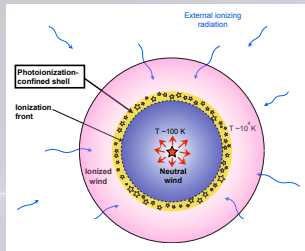
New scenario:
Starforming Supergiant Shells

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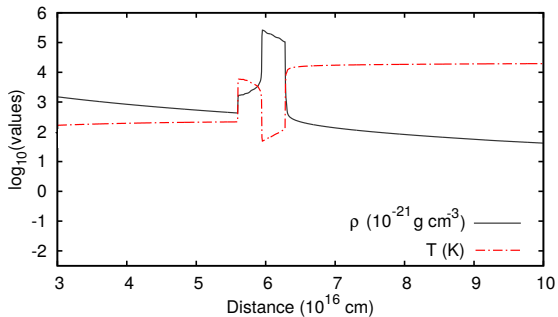
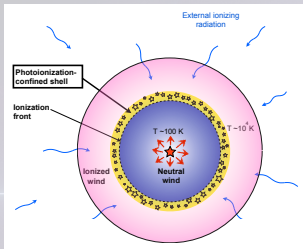


PICO shell: Mackey+ 2014 (*Nature*)

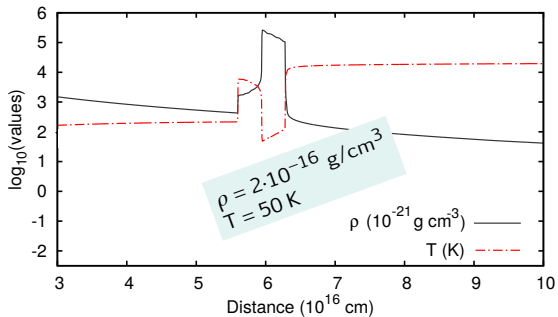
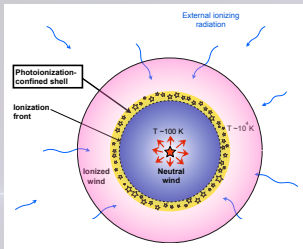
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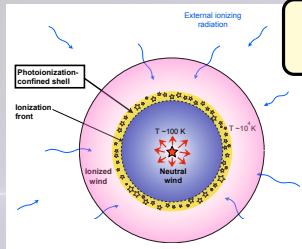
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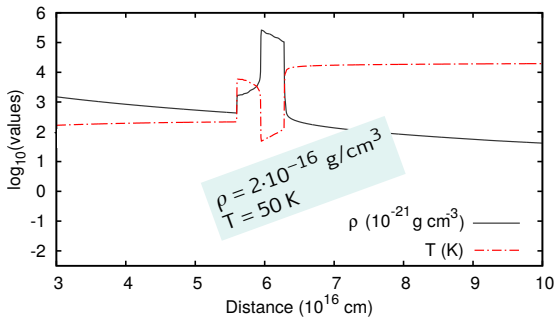
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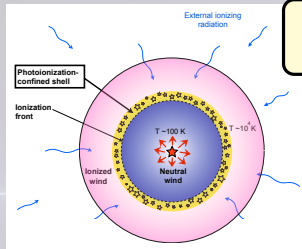
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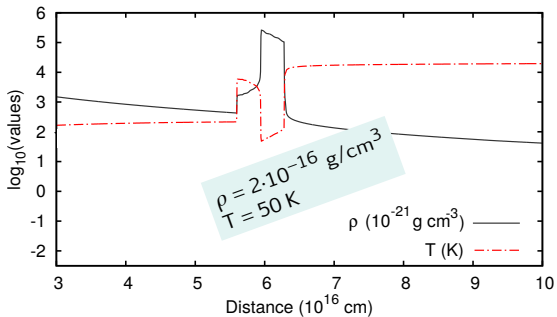
Mass of the photoionization-confined (PICO) shell: $\sim 14 M_{\odot}$



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Lifetime of the shell: $\sim 10^5 \text{ yr}$

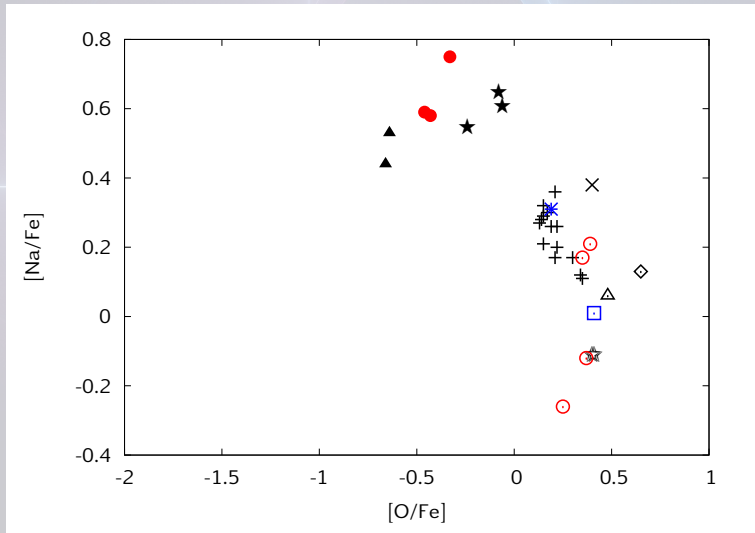
\gg

Growth timescale of grav. unstable perturbations: $\sim 10^4 \text{ yr}$

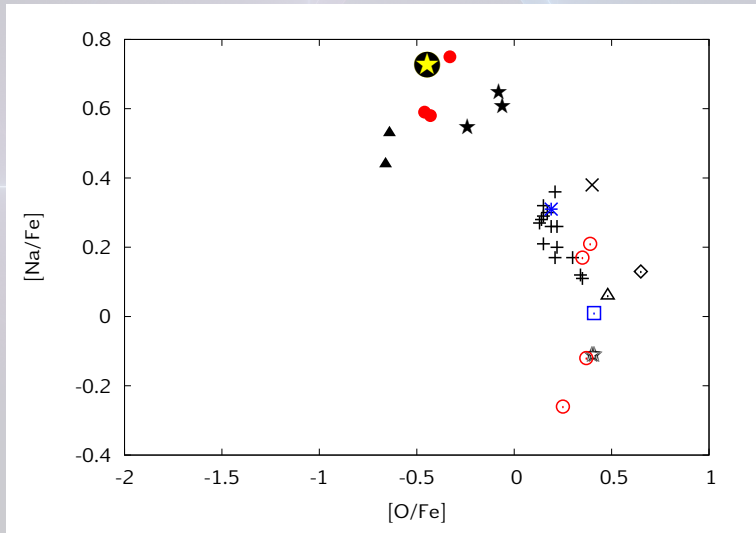
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Compared to observations:
O – Na anticorrelation

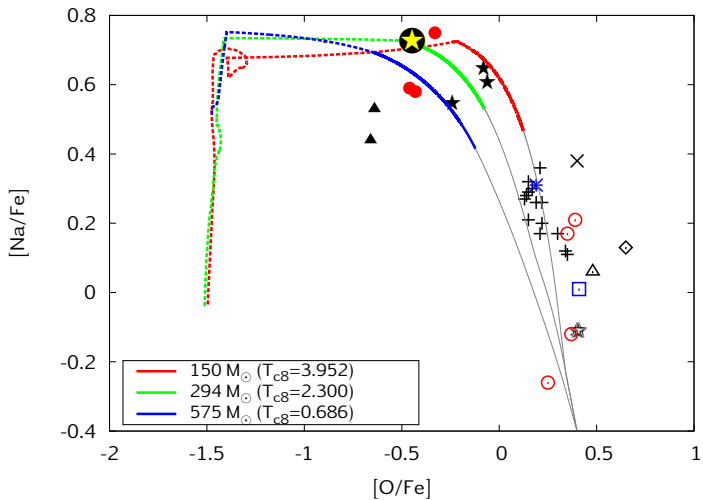
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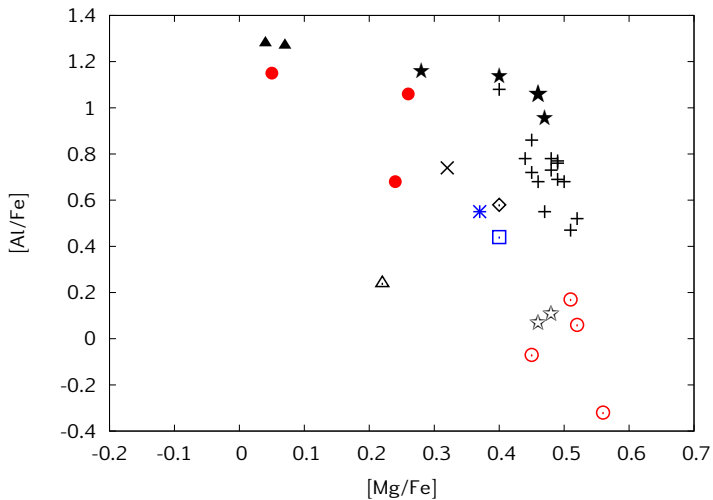
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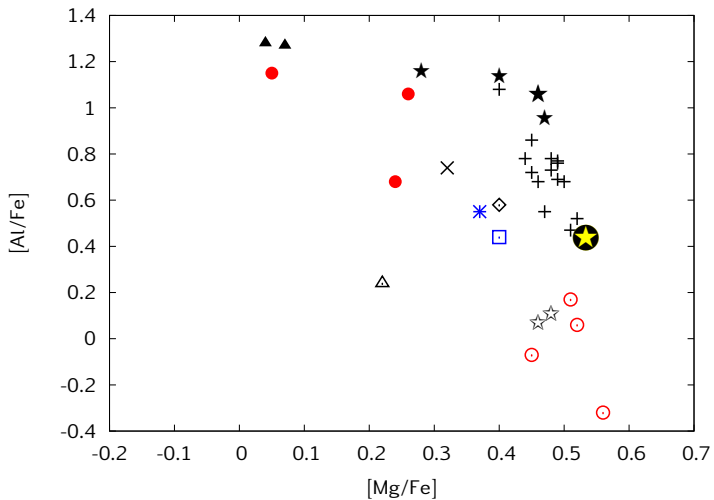
The background features a large, semi-transparent white circle centered on the page. Overlaid on this are several glowing, ethereal lines in shades of light blue and pink. These lines form a complex, web-like pattern that resembles a fractal or a network of connections. The lines are thin and have a soft, glowing aura around them, creating a futuristic and abstract aesthetic. The overall color palette is light and airy, with the glowing lines providing a subtle contrast against the white and light gray background.

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Mg – Al anticorrelation

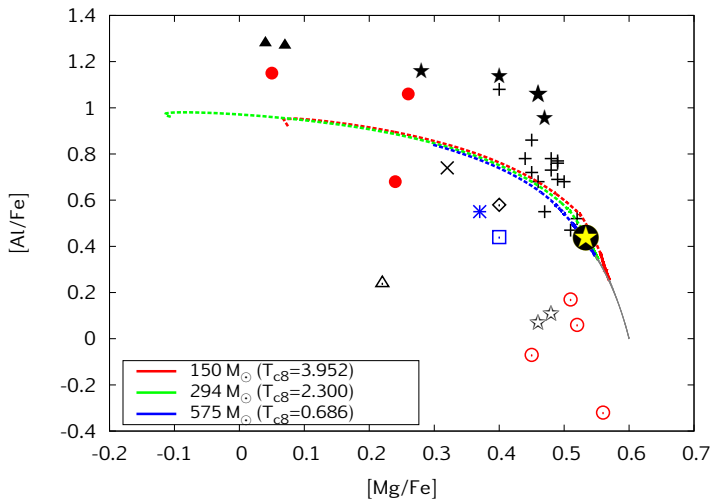
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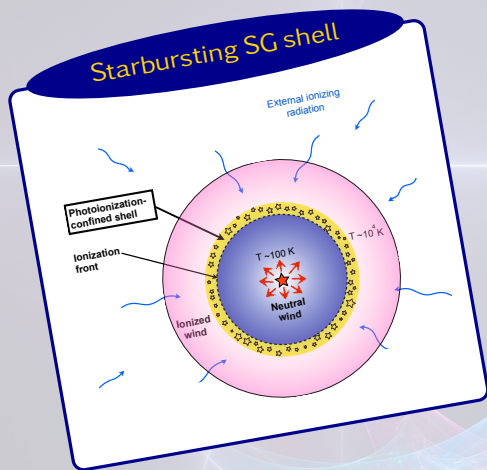
RSGs as polluters

- at low-Z, core-H burning RSGs
- even without PICO shell: contributing to the general pollution of the GC!

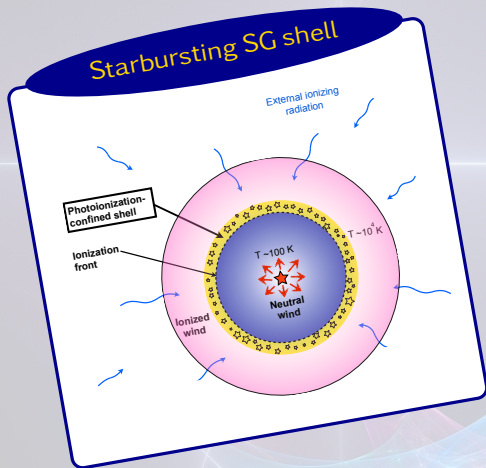
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Core-H-burning Supergiants in the Early GCs

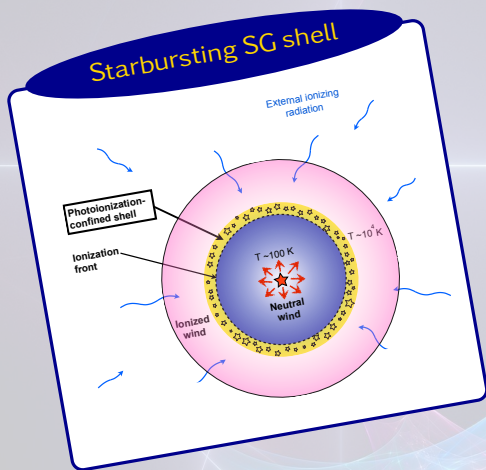


Core-H-burning Supergiants in the Early GCs



- early globular clusters
- PICO shell around core-H burning cool/red supergiants
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Core-H-burning Supergiants in the Early GCs



Szécsi et al. 2015
(A&A, vol. 581, A15)

Szécsi & Mackey & Langer 2016
(in preparation)

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Beyond the night-sky: Low-Z Massive Stars



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