

Low Metallicity Massive Stars

Dorottya Szécsi

Supervisors: Prof. Dr. Norbert Langer,
Dr. Richard Stancliffe,
Prof. Dr. Claus Kiefer



Gravitation & Relativity Group Seminar
Cologne, 20th October 2015

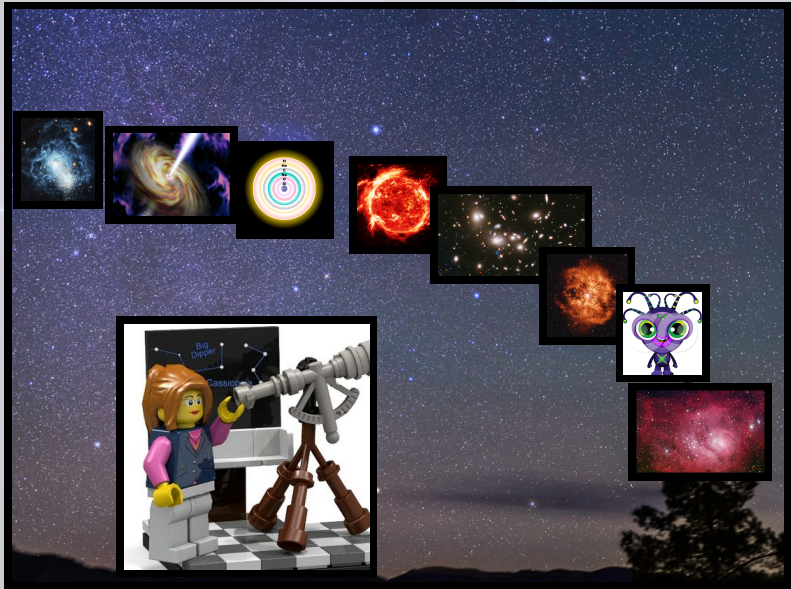
The night-sky and beyond



The night-sky and beyond



The night-sky and beyond



Astronomers and metal

LEGEND

- Non-Metal
- Metal

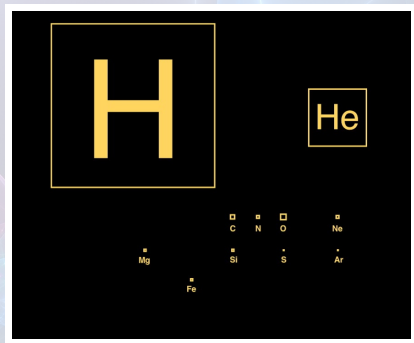
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Unq	Unp	Unh												

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- ☐ : Non-Metal
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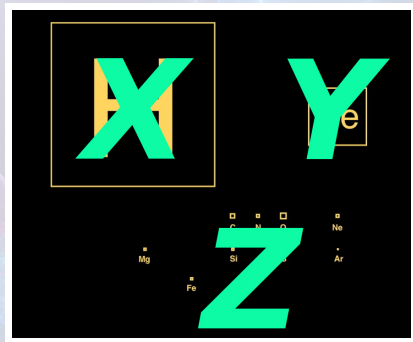


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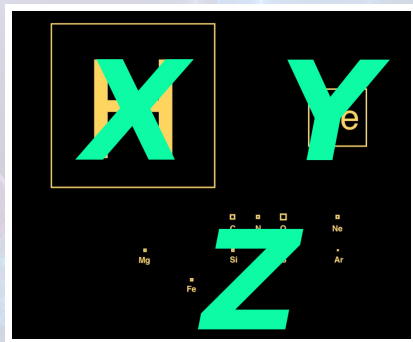
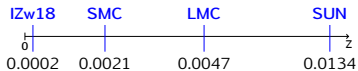


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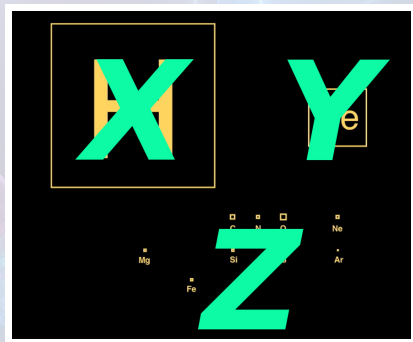
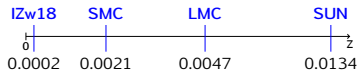
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Fr	Ra	Ac	Unq	Unp	Unh												

"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: $1 M_{\odot}/\text{yr}$
- ionized gas
- low metallicity!



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

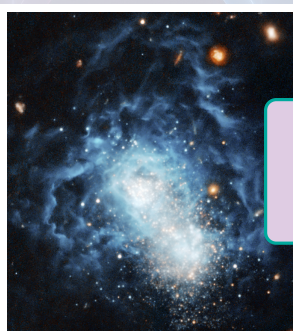
↓

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

Compact Dwarf Galaxies

I Zwicky 18

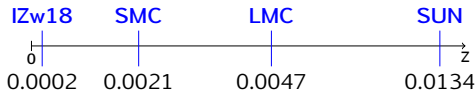
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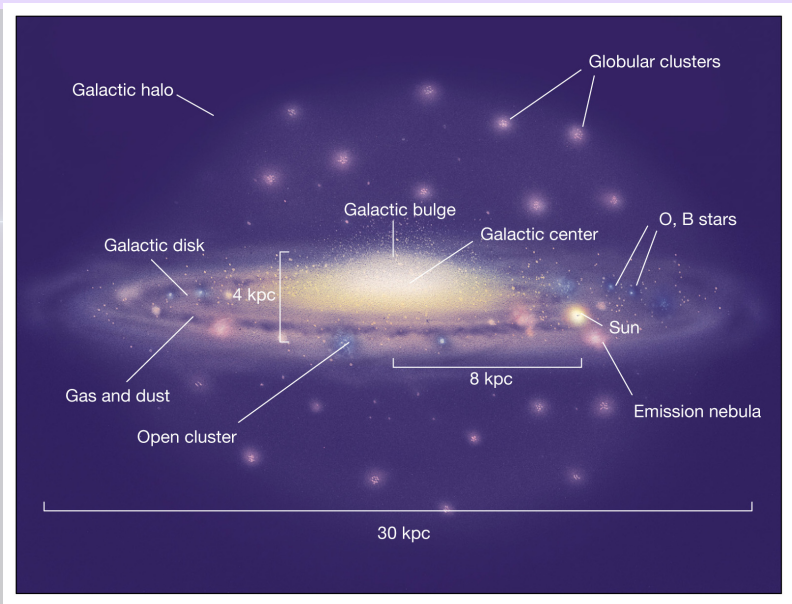
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\downarrow

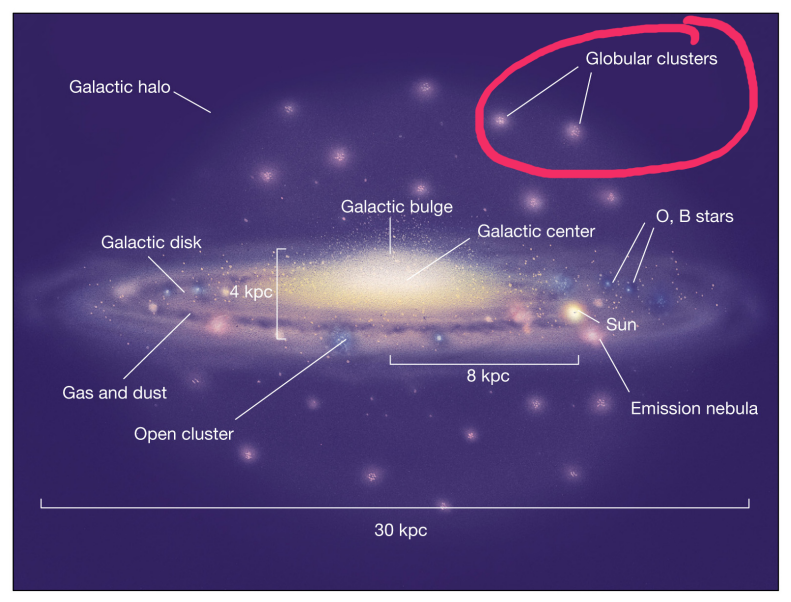
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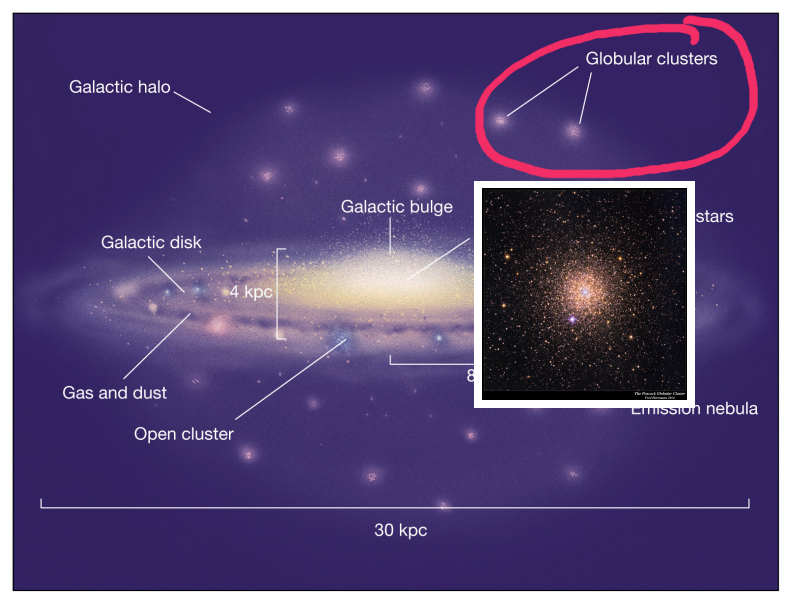
Globular Clusters



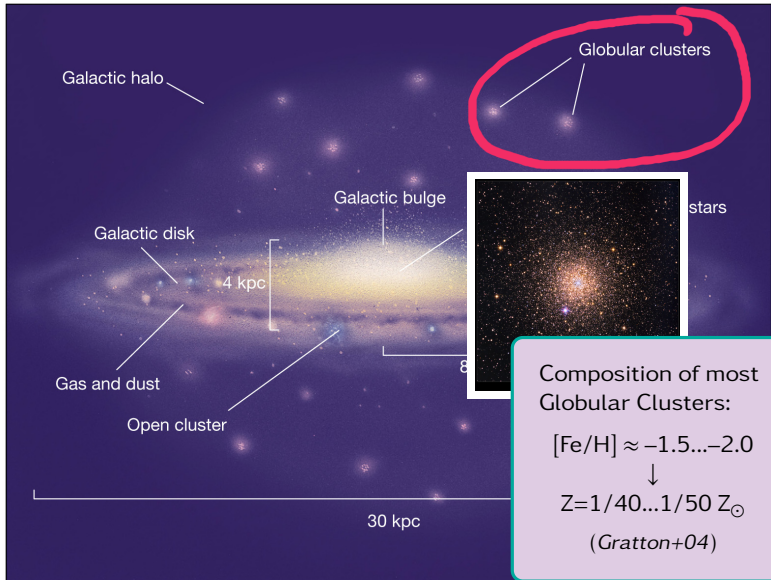
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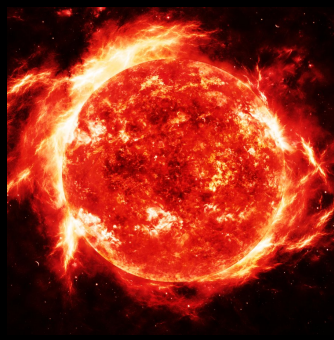
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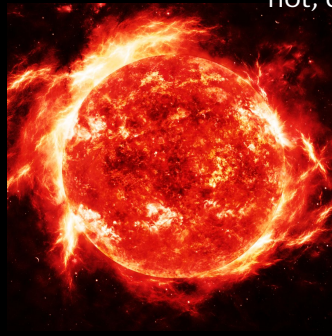
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What is a star?

What is a star?

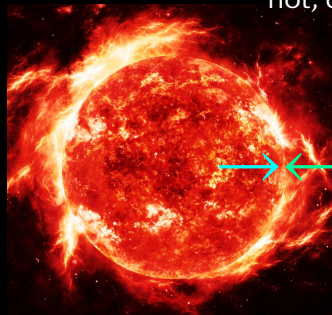


What is a star?



hot, dense plazma

What is a star?



hot, dense plazma

equilibrium:

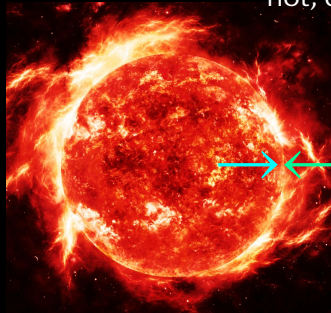
rad.pressure

gravity

What is a star?

surface?

hot, dense plazma



equilibrium:

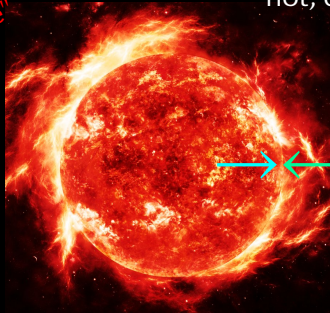
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What is a star?

surface?
→ photons escape
"photosphere"

hot, dense plazma



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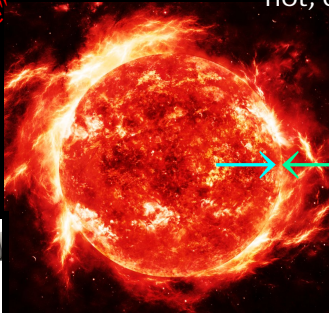
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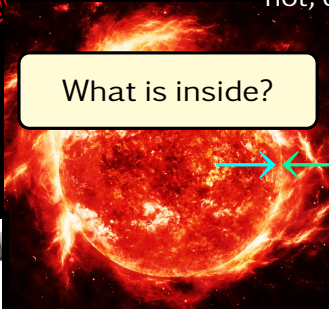
What is a star?

surface?
→ photons escape
"photosphere"

hot, dense plazma

What is inside?

rad.pressure gravity



What is a star?

surface?
→ photons escape
"photosphere"

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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Guilera et al. 2011

composition change due to nuclear burning ?!

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Guilera et al. 2011

composition change due to nuclear burning ?!

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

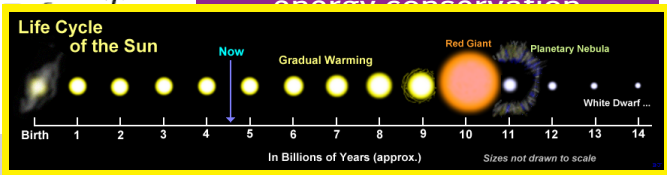
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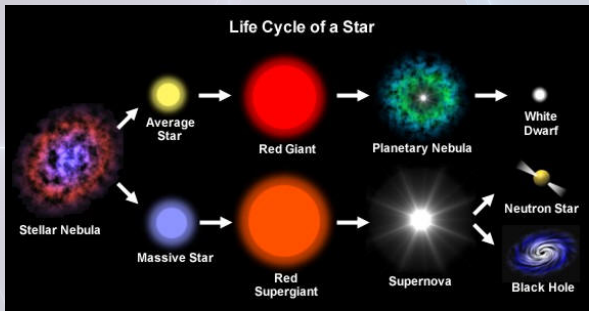


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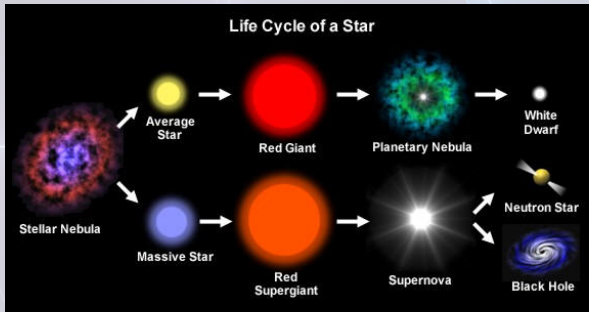
Massive vs. low-mass stars

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



Massive vs. low-mass stars

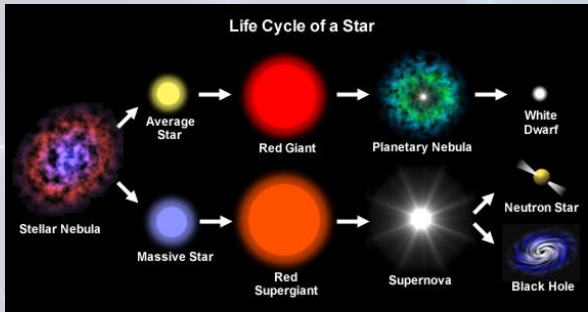
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- nuclear reactions, final composition

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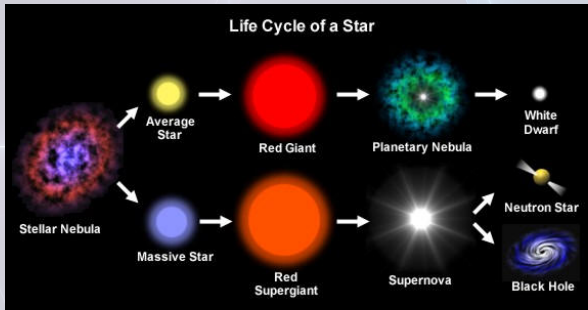
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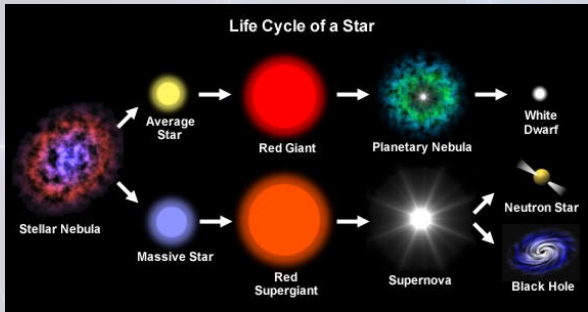
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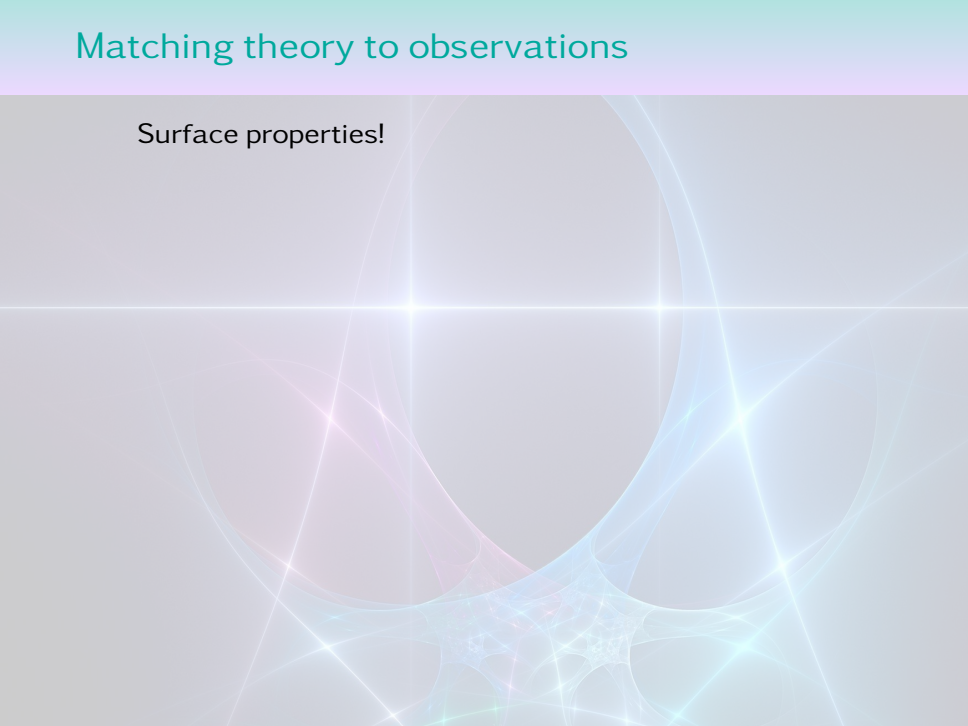
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- final fate

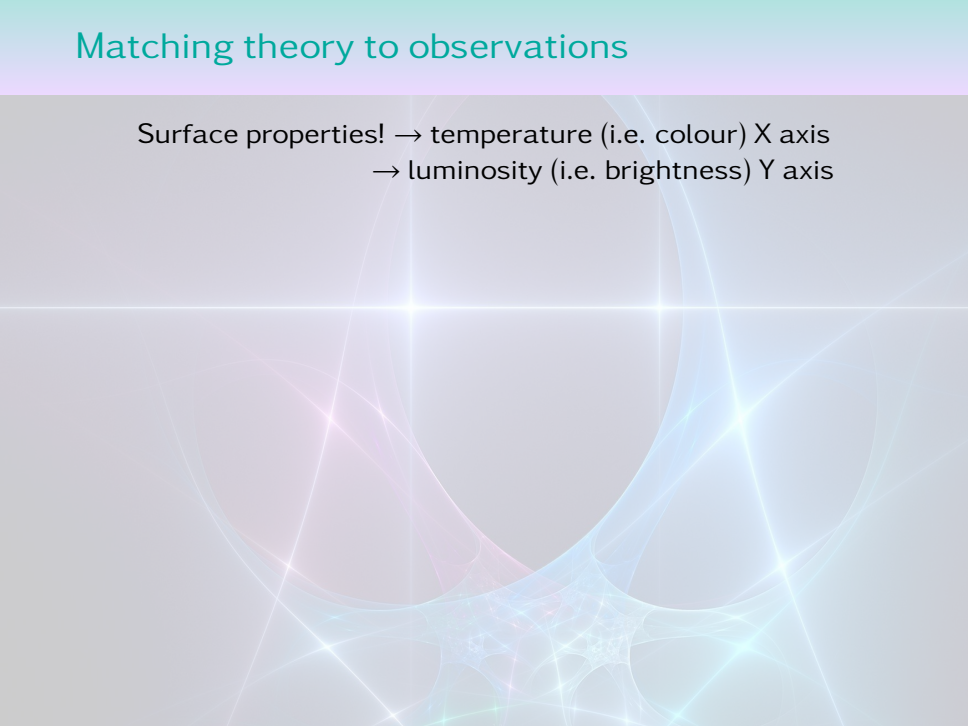
Matching theory to observations

Surface properties!

The background of the slide is a complex, abstract composition. It features a large, semi-transparent sphere in the center, rendered in a light blue-grey color. Overlaid on this sphere and the rest of the frame 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.

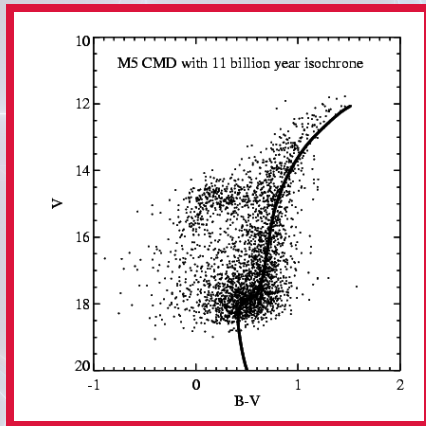
Matching theory to observations

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

The background of the slide features a complex, abstract pattern of glowing, overlapping lines and shapes. A prominent horizontal line of light crosses the center, with a bright, multi-pointed starburst at its intersection with a vertical line. The overall color palette is soft and ethereal, with shades of light blue, pink, and white. The lines appear to be part of a larger, intricate geometric or fractal-like structure.

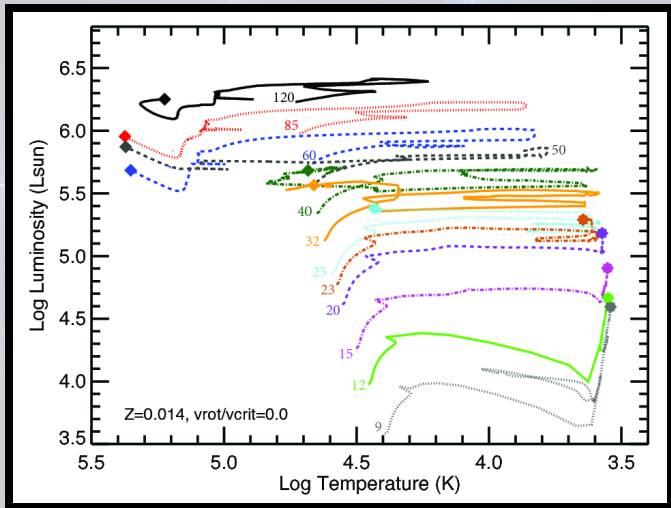
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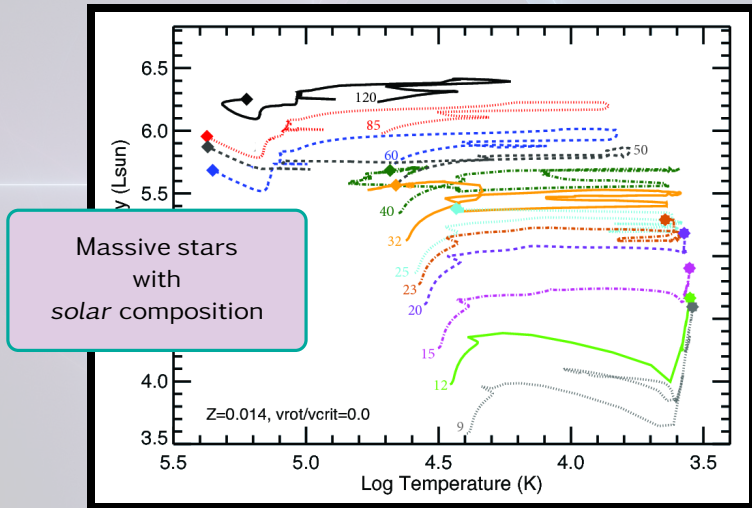


Hertzsprung–Russell diagram (HR diagram)

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.

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– my thesis 😊

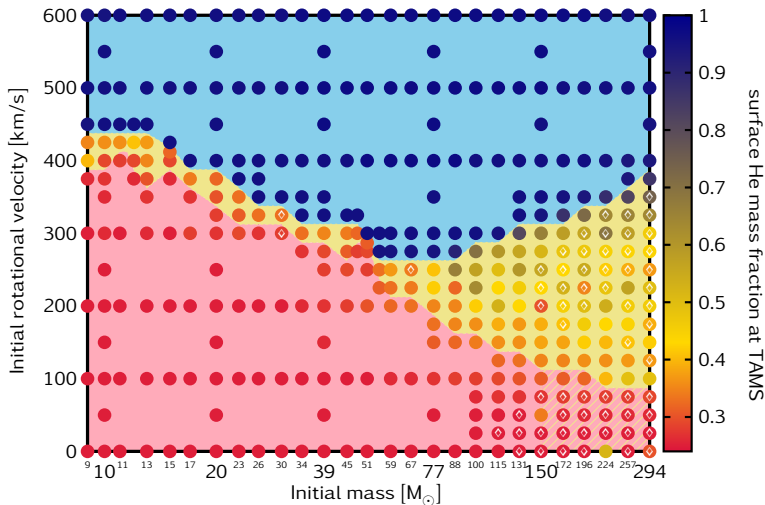
Low Metallicity Massive Stars

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



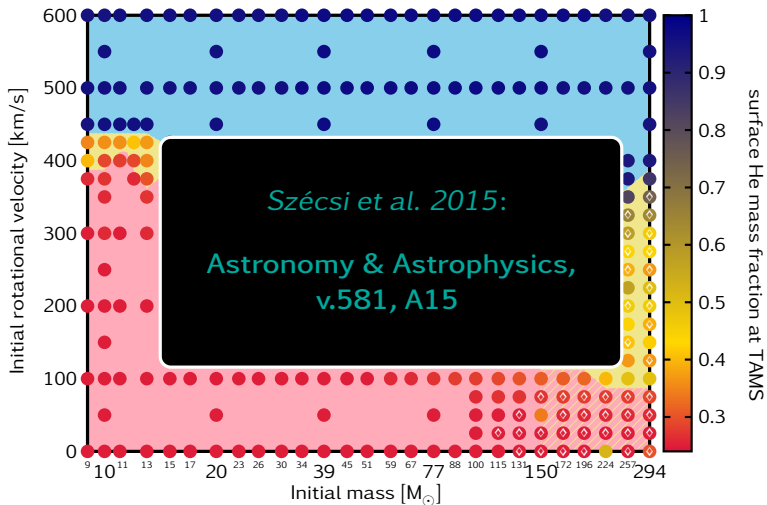
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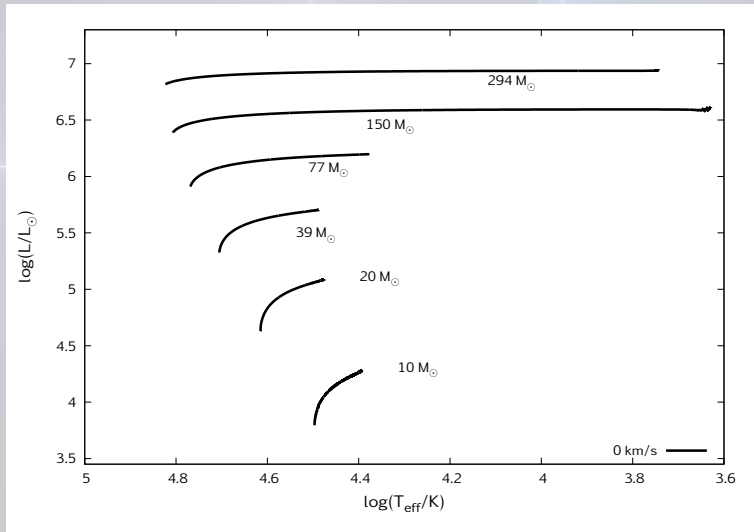
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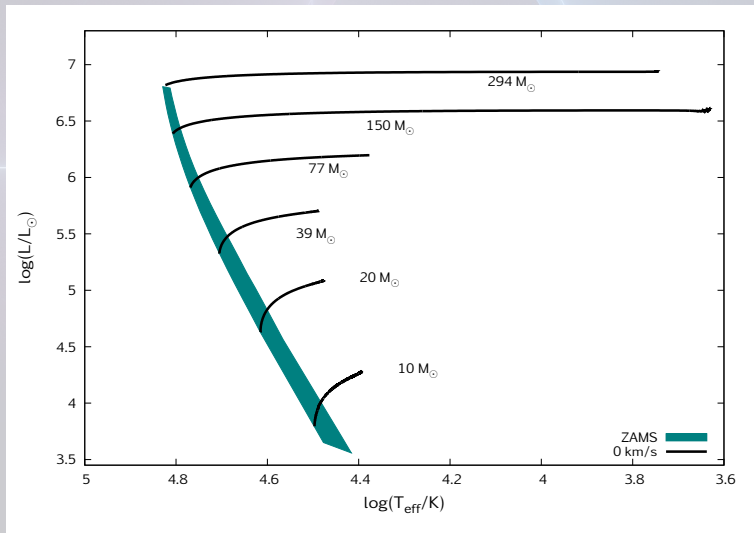
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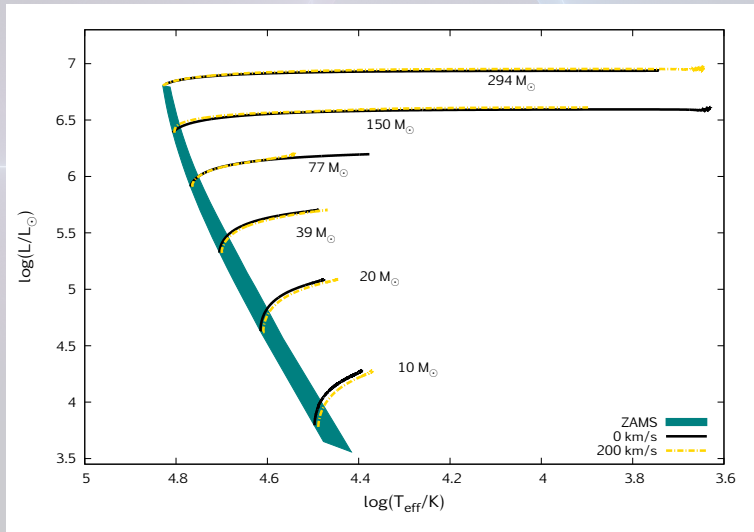
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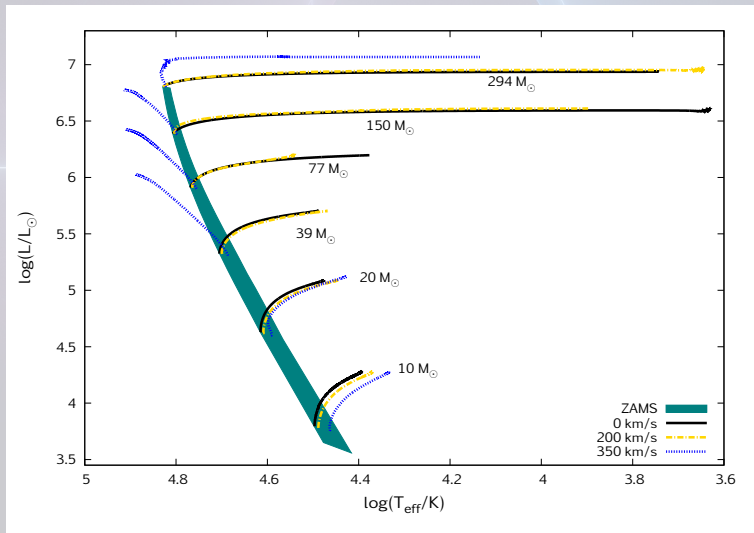
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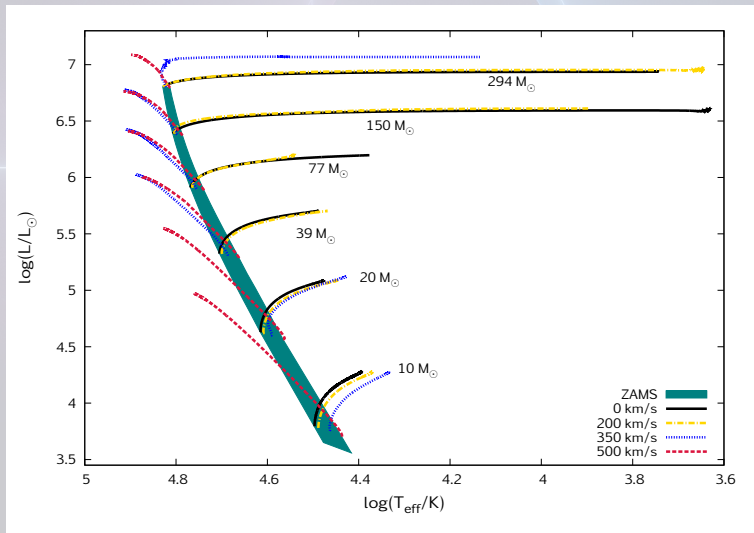
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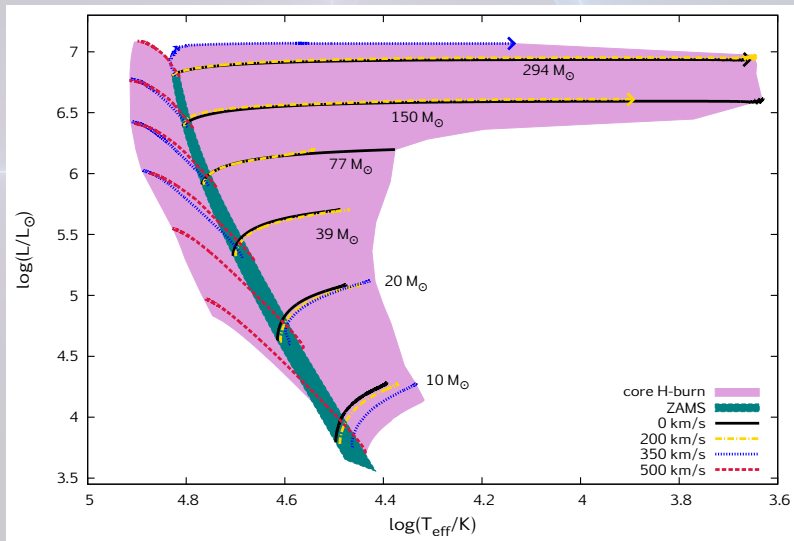
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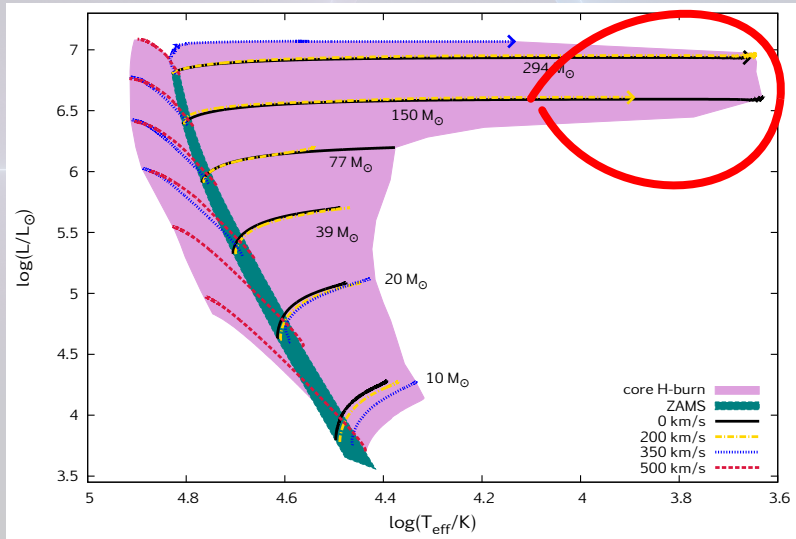
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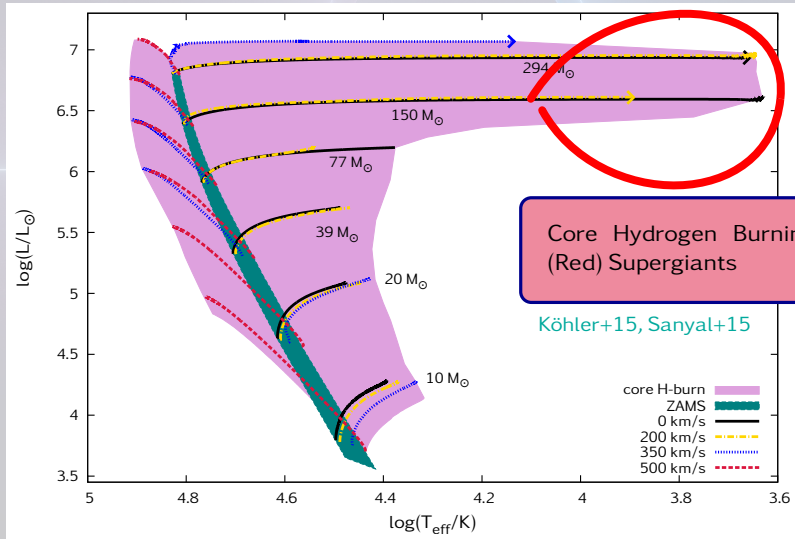
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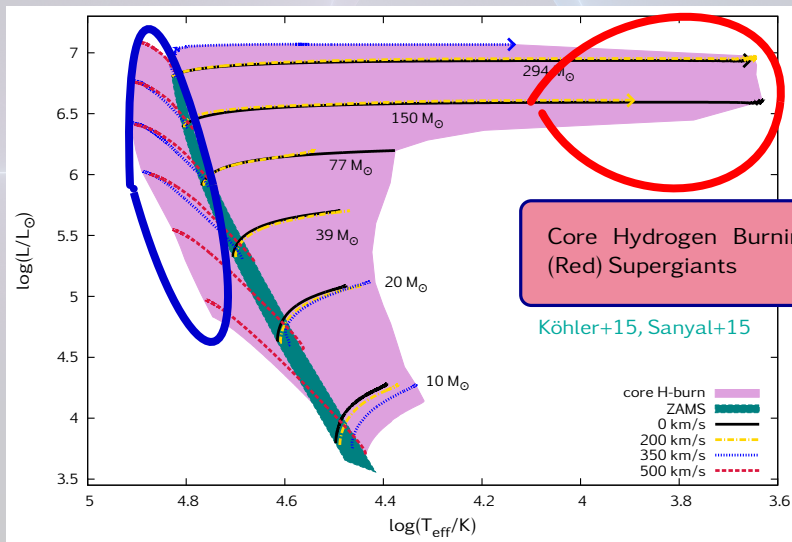
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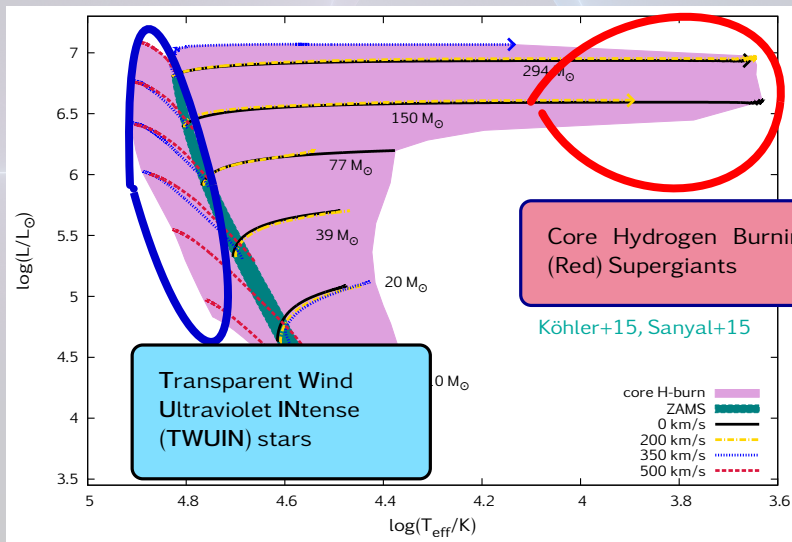
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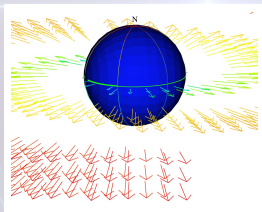
Transparent Wind
Ultraviolet Intense stars
(TWUIN stars)

– in the
starburst galaxy | Zwicky 18

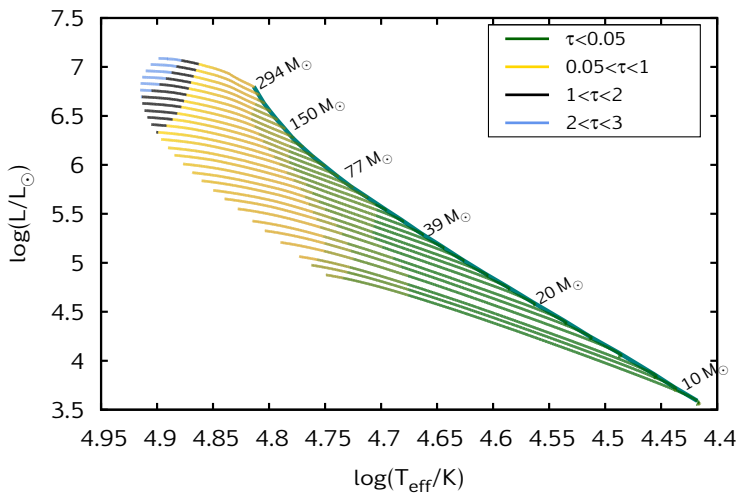
TWUIN stars and their stellar winds



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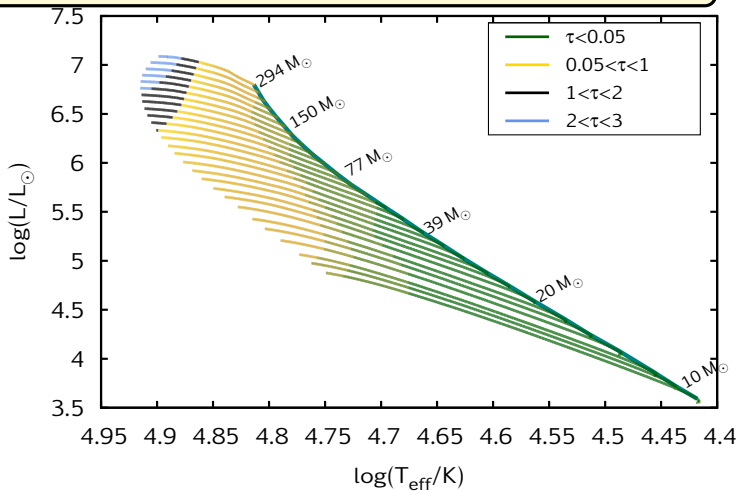


TWUIN stars and their stellar winds



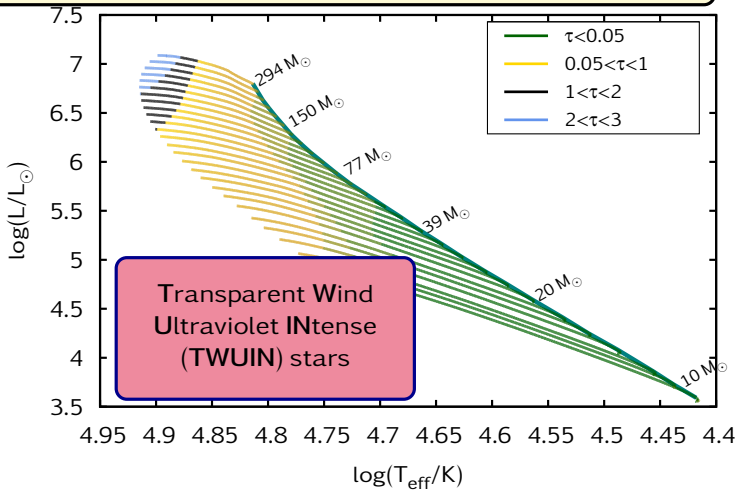
TWUIN stars and their stellar winds

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



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Back to I Zw 18

I Zwicky 18

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

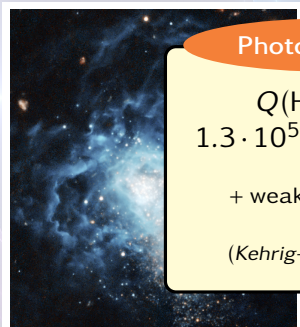


Legrand+07, Aloisi+09, Annibali+13, Kehrig+13, Leboutteiller+13

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Photoionization

$$Q(\text{HeII})^{obs} = 1.3 \cdot 10^{50} \text{ photons s}^{-1}$$

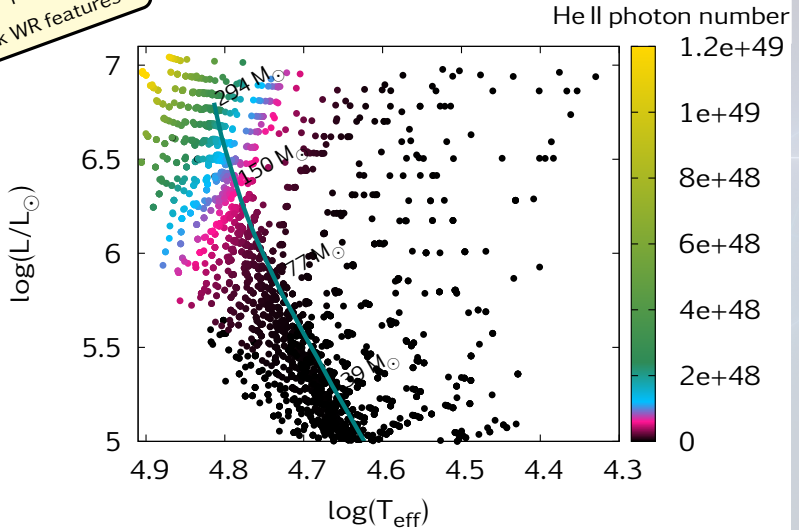
+ weak WR features

(Kehrig+15, Crowther+06)

Photoionization in I Zw 18

Photoionization

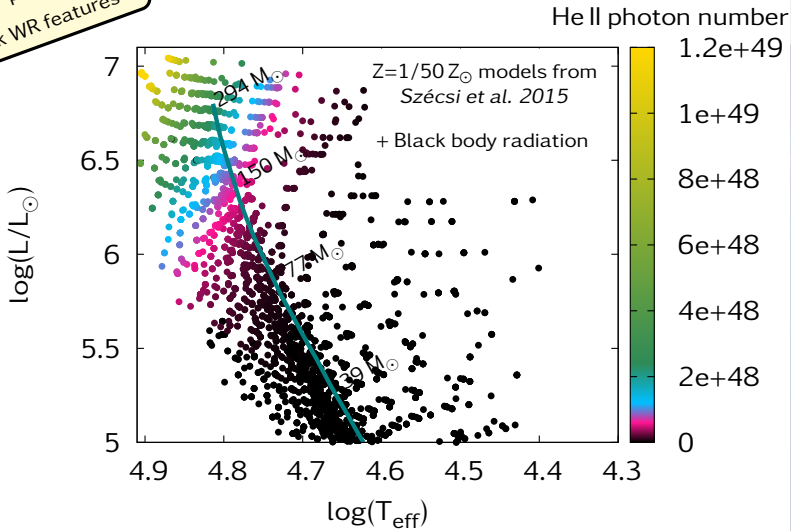
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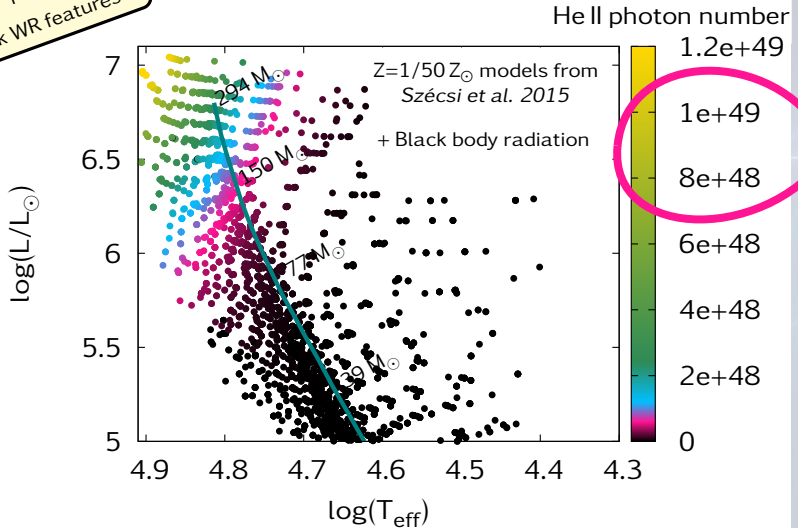
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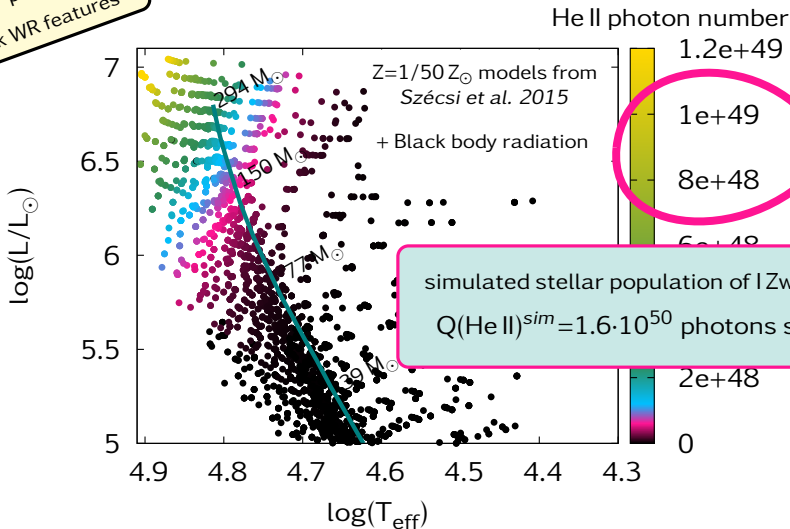


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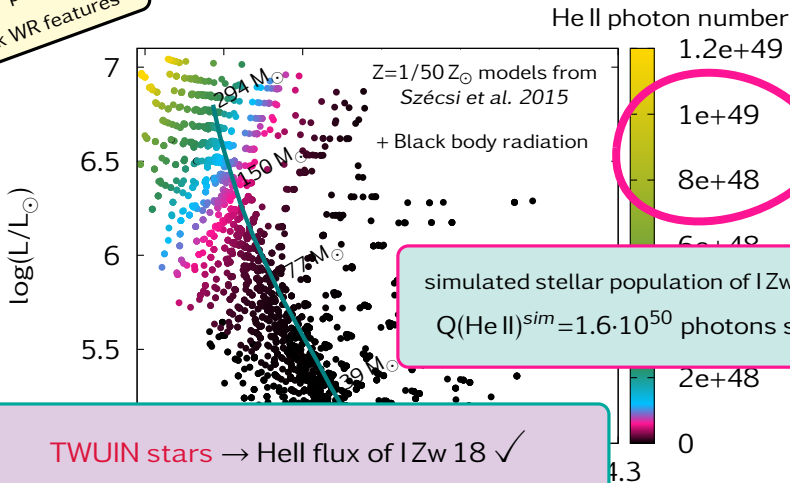


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simulated stellar population of I Zw 18:

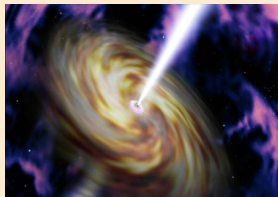
$Q(\text{He II})^{\text{sim}} = 1.6 \cdot 10^{50}$ photons s^{-1}

TWUIN stars → HeII flux of I Zw 18 ✓

Transparent Wind Ultraviolet Intense

Life and Death of Massive Stars

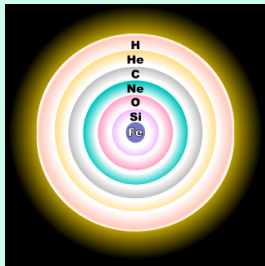
Collapsar \rightarrow IGRB



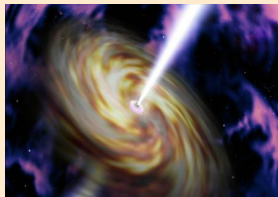
Yoon&Langer'05; Woosley&Heger'06; Yoon+06; Yoon+12

Life and Death of Massive Stars

Massive stars



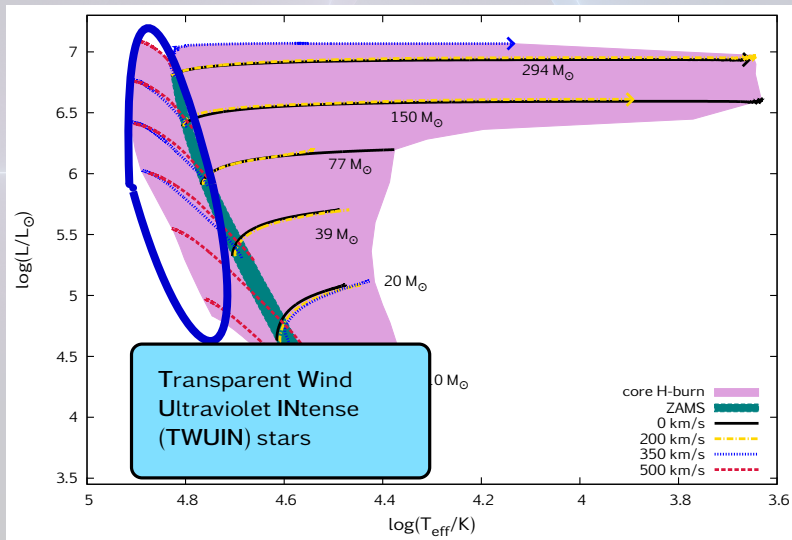
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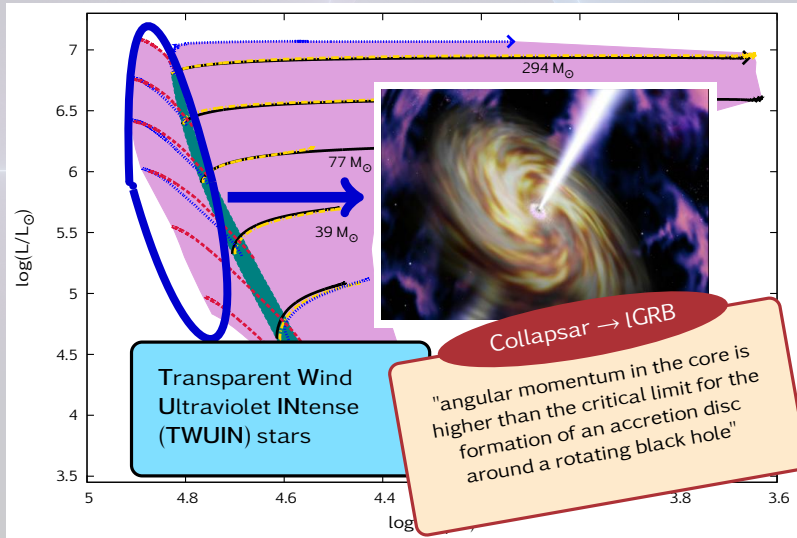
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Life and Death of Massive Stars

Life of Massive Stars

He II photons
(*Shirazi+12, Kehrig+15*)



Death of Massive Stars

IGRBs
(*Levesque'10, Niino'11*)



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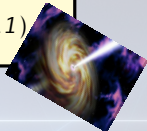
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Explanation

Hot stars with weak winds



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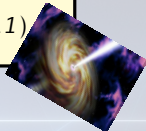
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Chemically Homogeneous Evolution

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Intense
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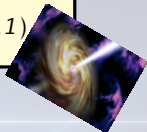
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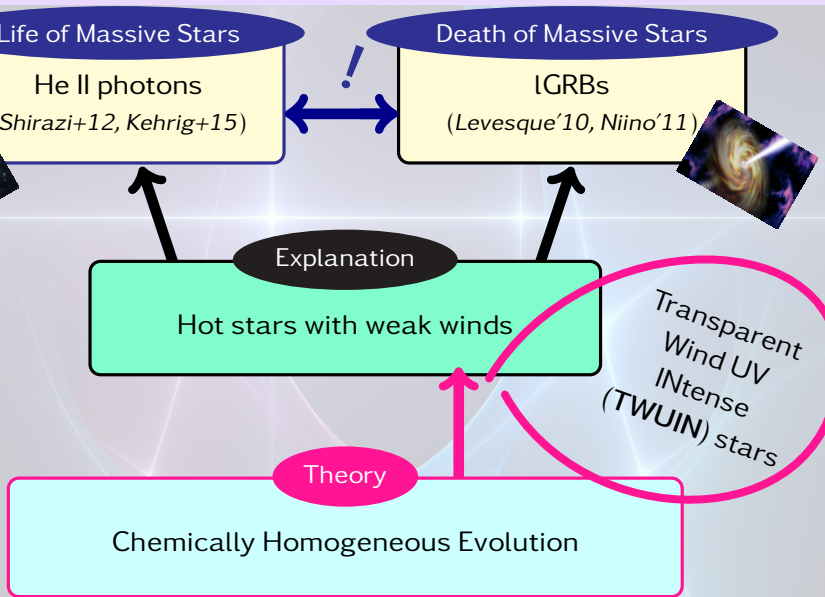
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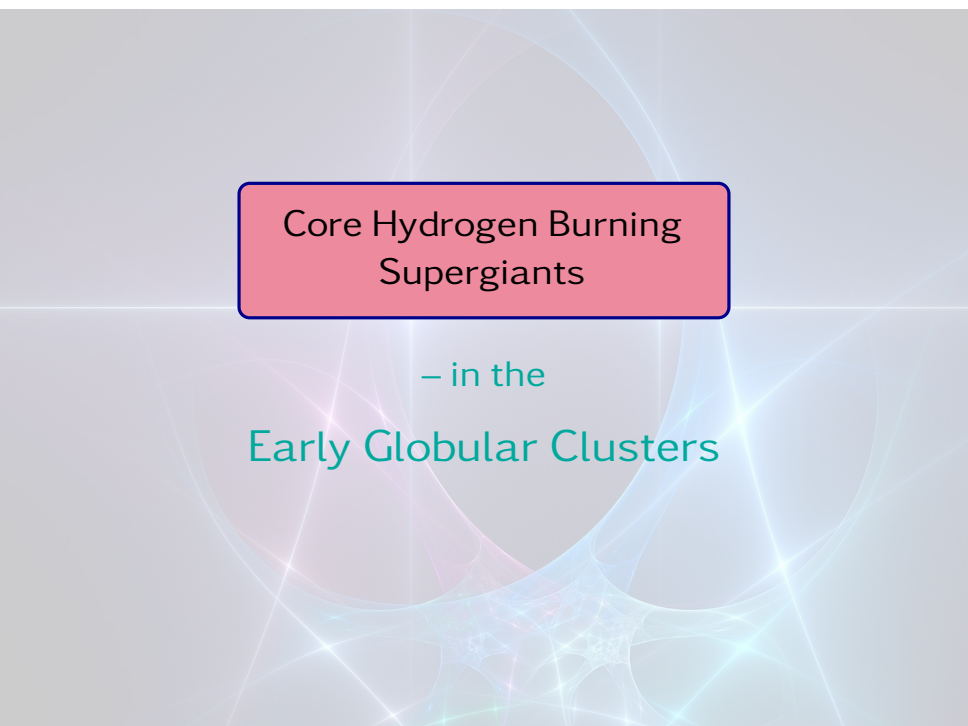
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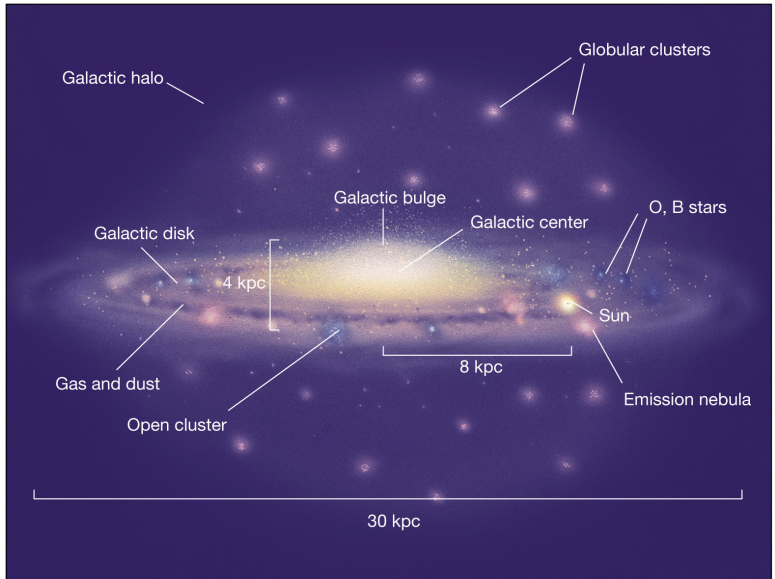




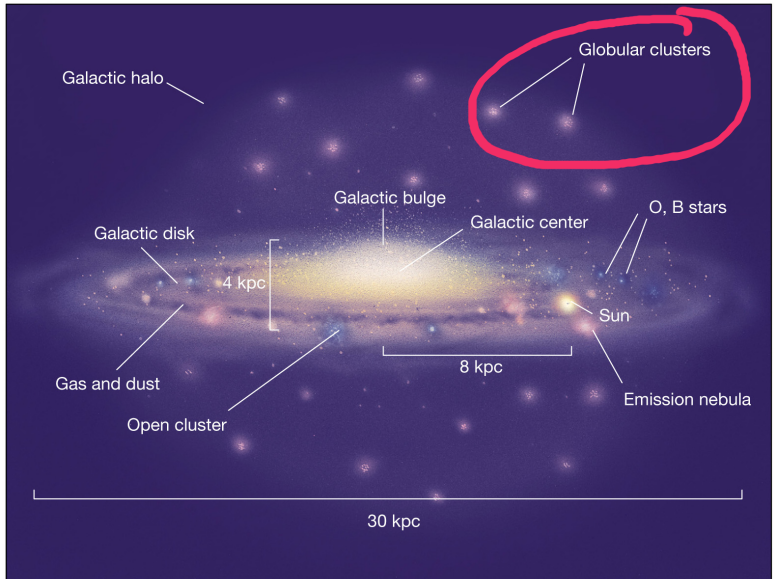
Core Hydrogen Burning
Supergiants

– in the
Early Globular Clusters

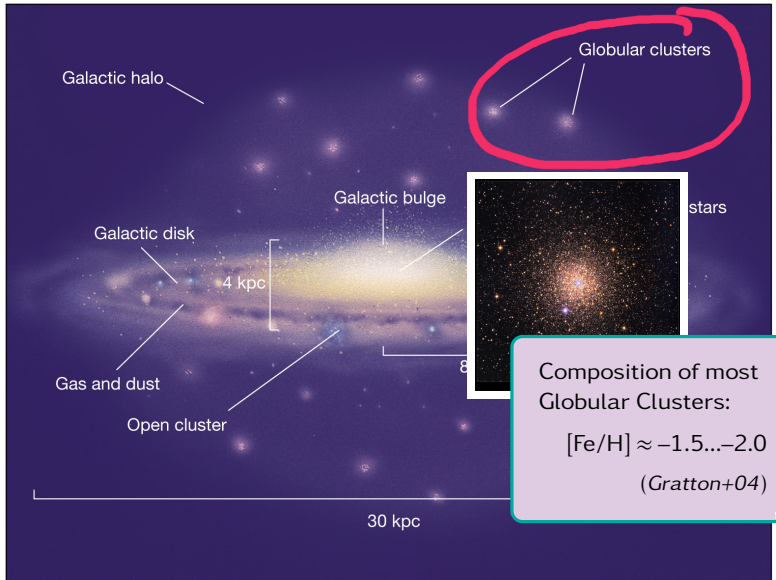
Globular Clusters & Abundance Anomalies



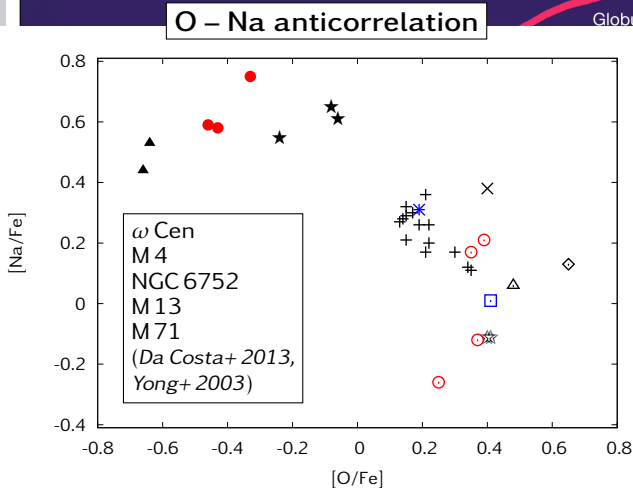
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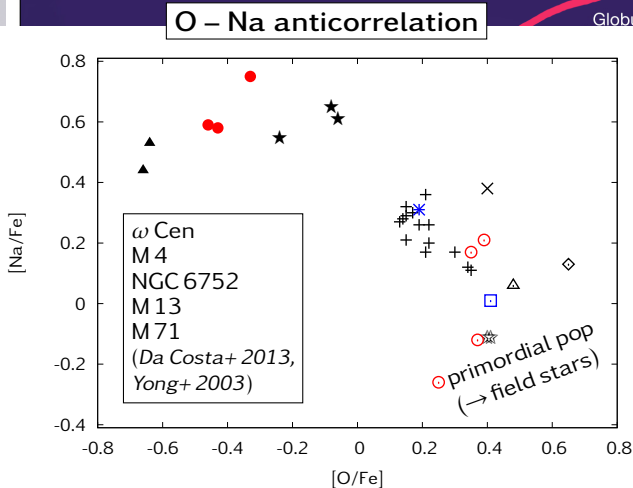
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ion of most
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-1.5...-2.0
(Gratton+04)



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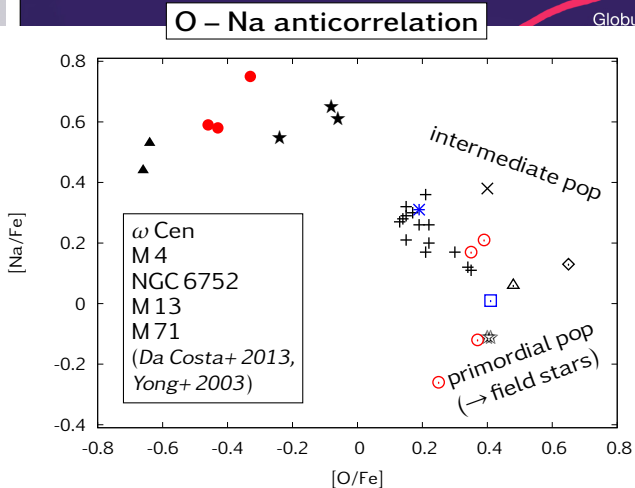
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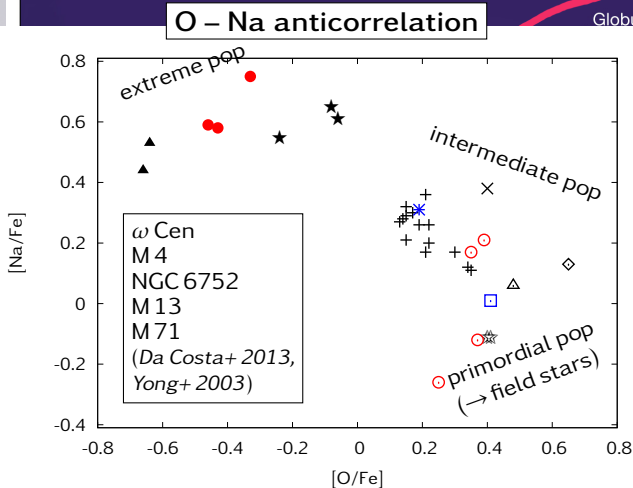


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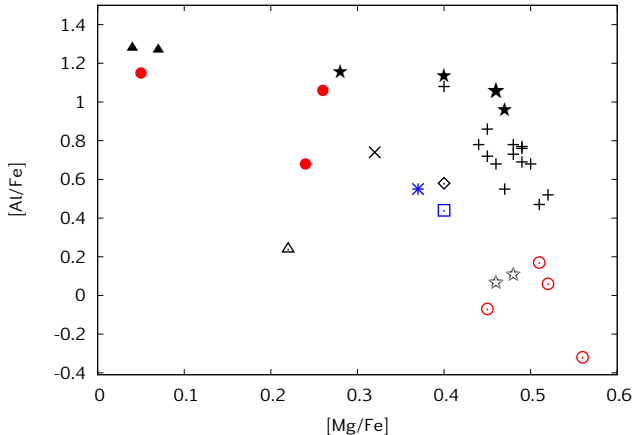


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Globular Clusters & Abundance Anomalies

Mg - Al anticorrelation



Globular clusters

stars

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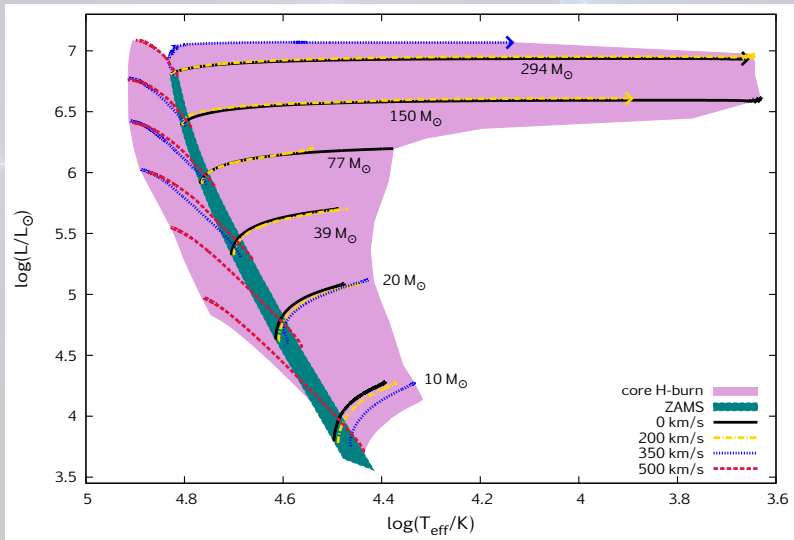
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→ **New scenario...**

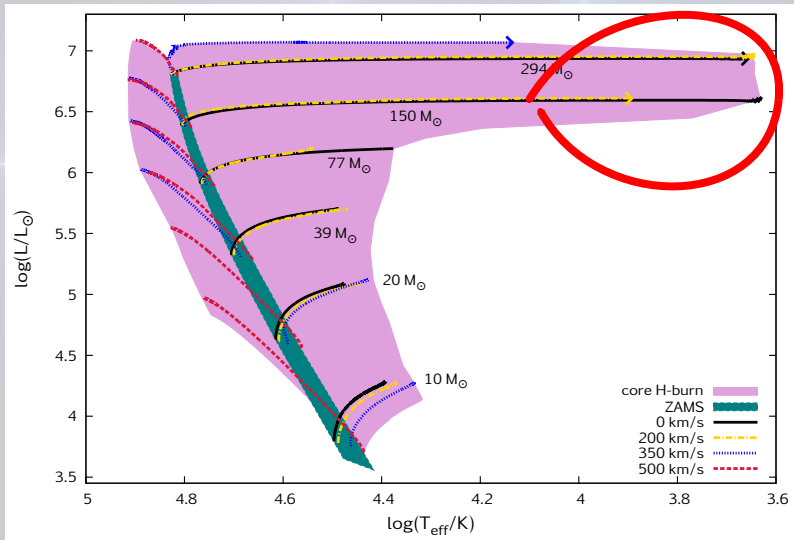
Evolution of low metallicity massive stars

Szécsi et al. 2015 (A&A)



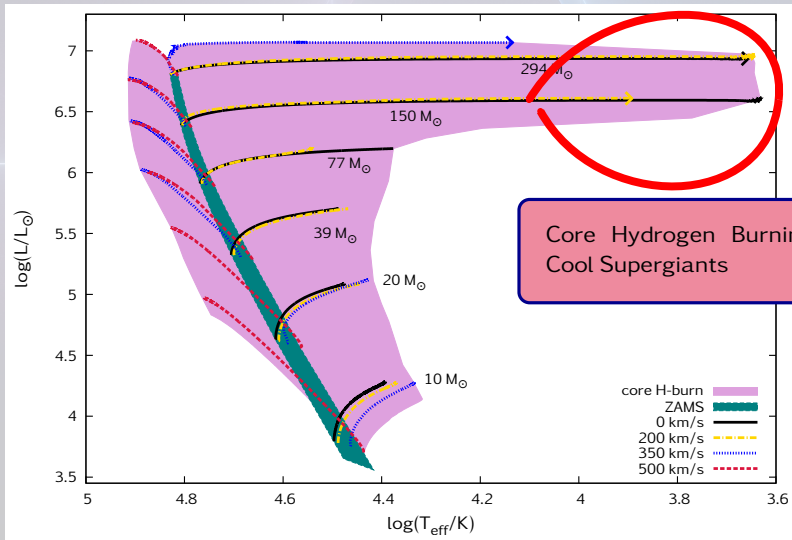
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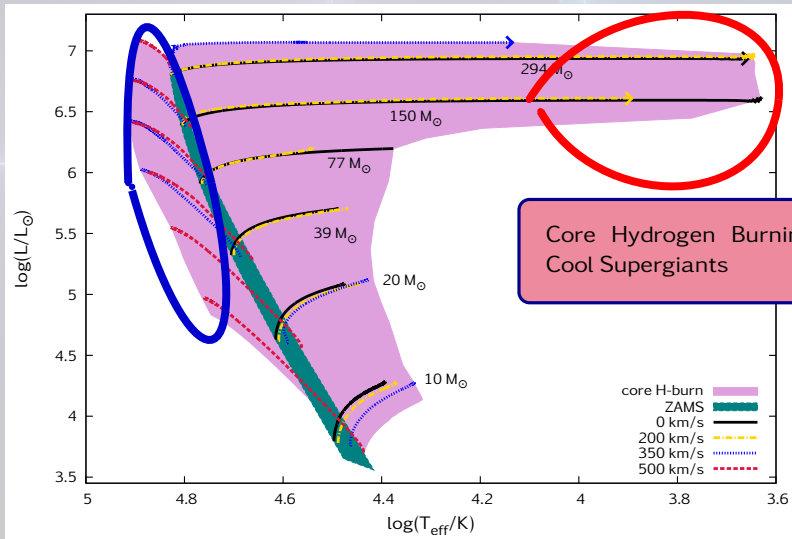
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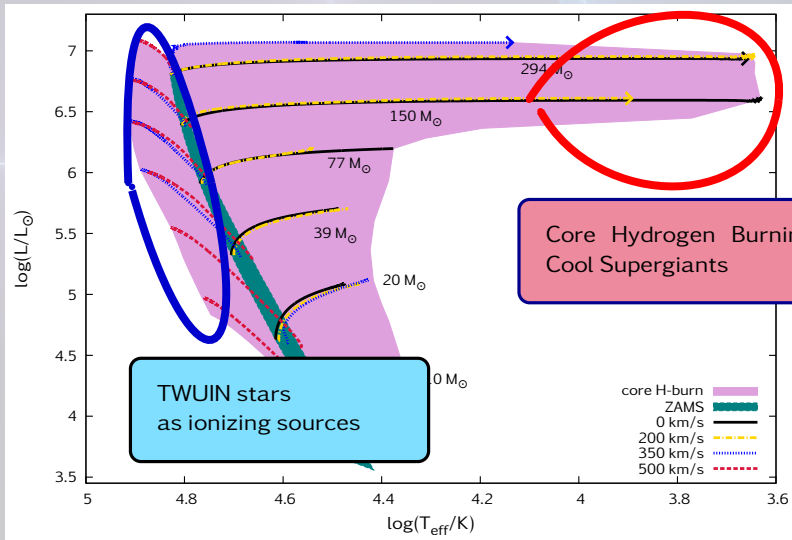
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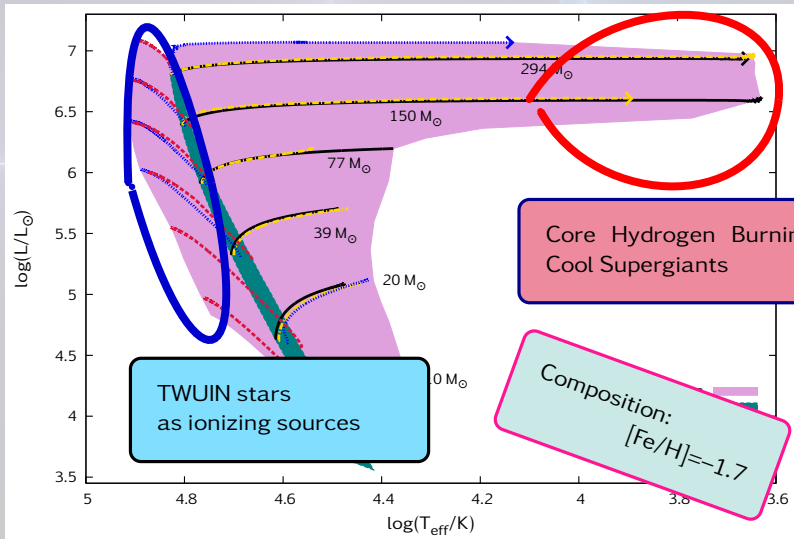
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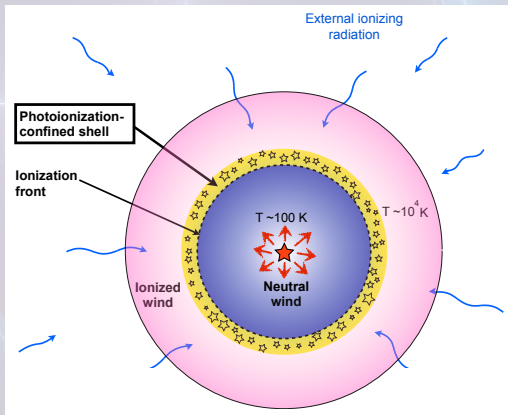
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The background features a large, semi-transparent sphere in the upper center. A network of glowing, multi-colored lines (pink, blue, green, and white) crisscrosses the scene, creating a complex, web-like pattern. A prominent horizontal white line with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

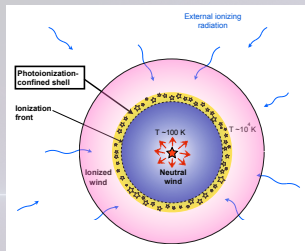
New scenario:
Starforming Supergiant Shells

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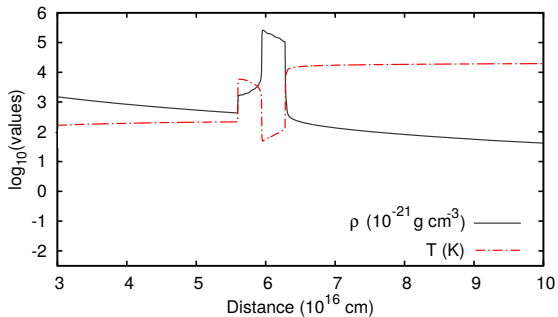
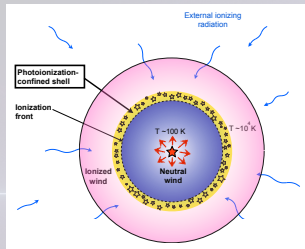


PICO shell: Mackey+ 2014 (*Nature*)

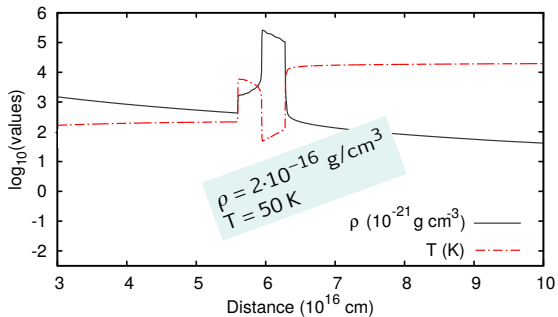
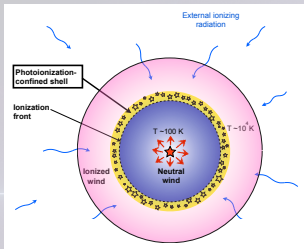
Simulating the PICO shell



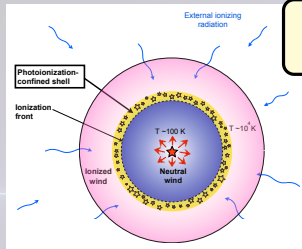
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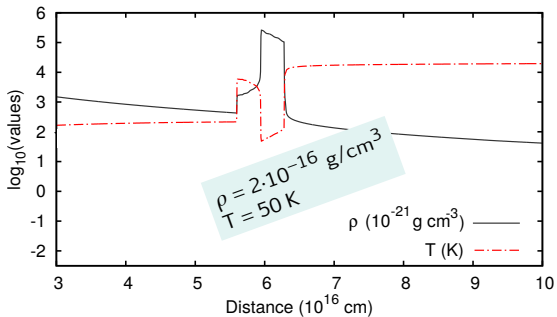
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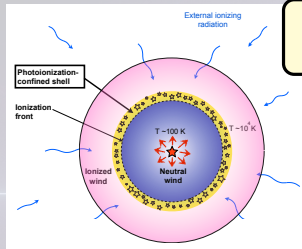
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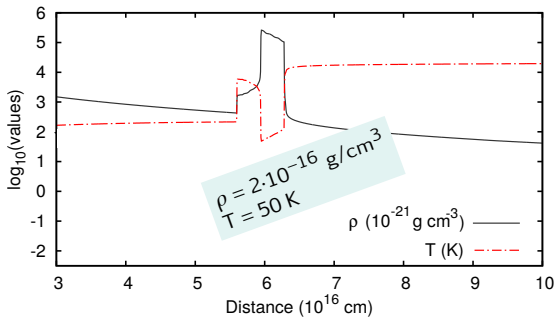
Mass of the photoionization-confined (PICO) shell: $\sim 14 M_{\odot}$



Simulating the PICO shell



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

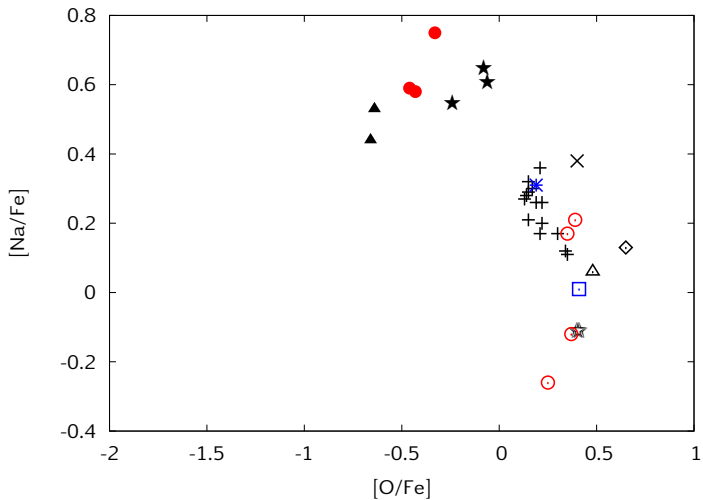
\gg

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

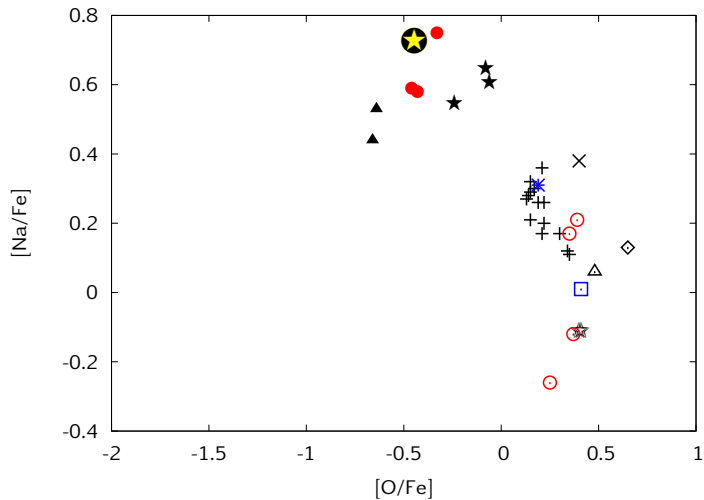
The background features a large, semi-transparent circle in the center. Overlaid on this are several thin, glowing lines in shades of blue, cyan, and magenta that intersect to form a complex, web-like pattern. The overall aesthetic is futuristic and scientific.

Compared to observations:
O – Na anticorrelation

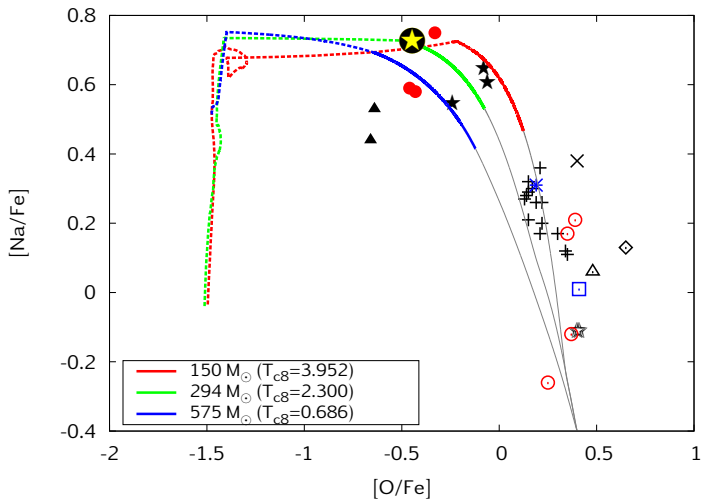
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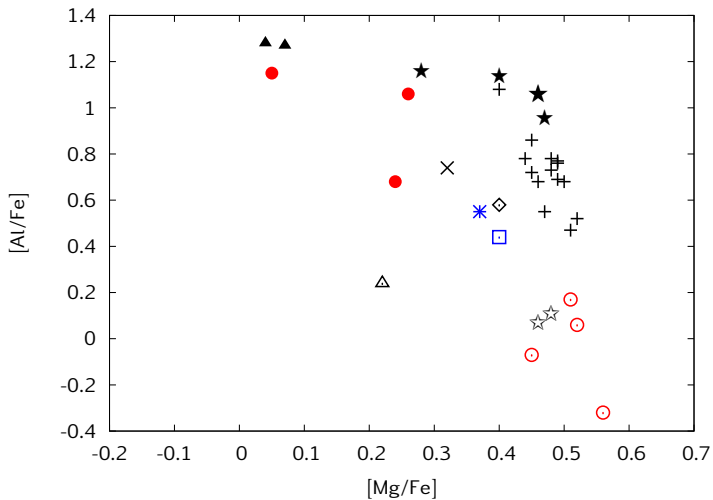
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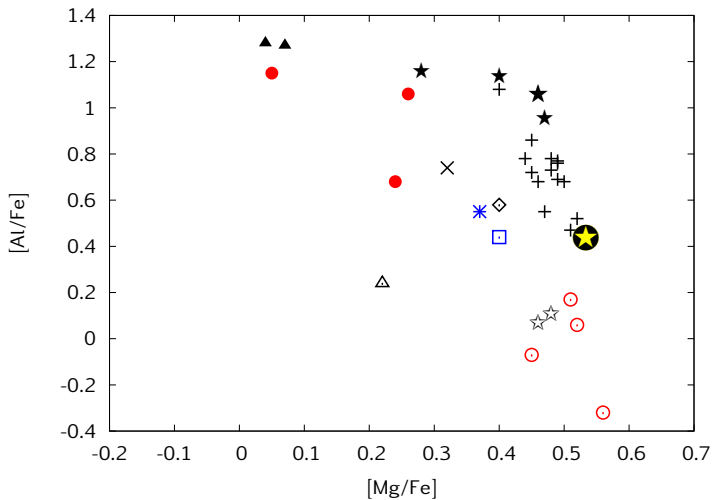
The background features a large, semi-transparent white circle centered in the upper half. Overlaid on this are several glowing, ethereal lines in shades of light blue and pink. These lines form a complex, web-like pattern that resembles a fractal or a network of connections. The lines are semi-transparent and have a soft, glowing aura around them. The overall aesthetic is clean, modern, and scientific.

Compared to observations:
Mg – Al anticorrelation

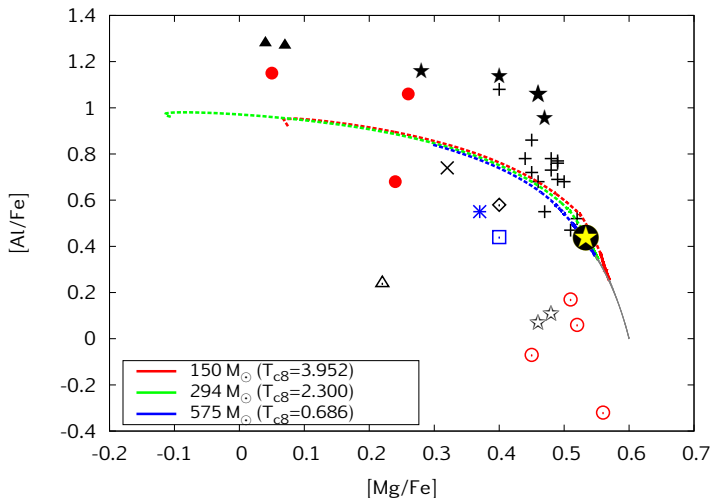
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Details

Mass budget

- second generation IMF only contains low-mass stars!

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He-spread

- some GCs (but not all): $Y \sim 0.4$ observed
- shell-stars are predicted to have $Y_{\text{sh}} = 0.48$
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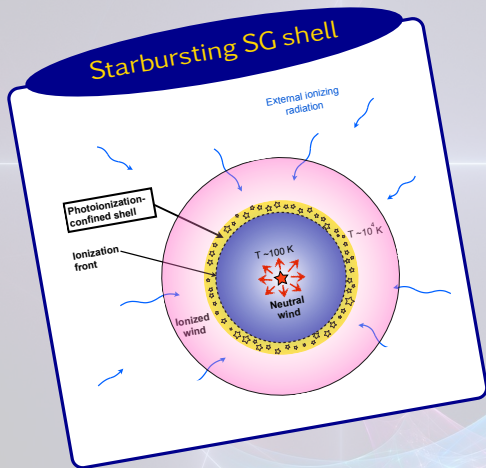
RSGs as polluters

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

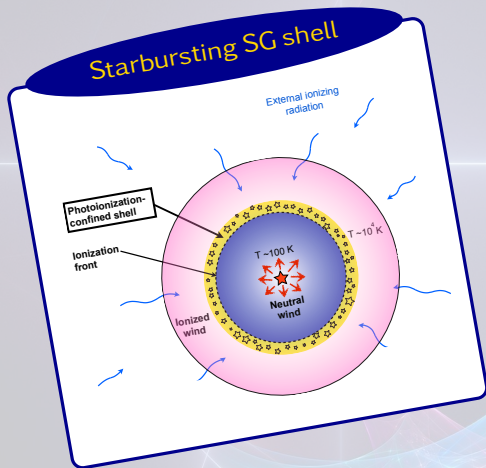
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Core-H-burning Supergiants in the Early GCs

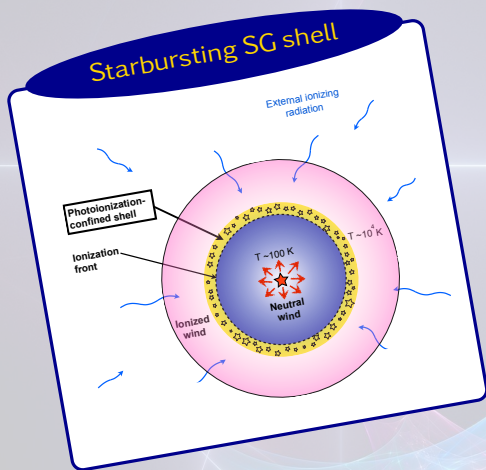


Core-H-burning Supergiants in the Early GCs



- early globular clusters
- PICO shell around core-H burning cool/red supergiants
- grav. unstable \rightarrow low-mass starformation
- simulated composition fits the 2nd generation stars
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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



Beyond the night-sky: Low-Z Massive Stars



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Beyond the night-sky: Low-Z Massive Stars

