Helium-rich stars in globular clusters

Constraints for self-enrichment by massive stars

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Abundance anomalies in GCs

In any individual Globular Clusters

- Low scatter and same trends as field stars (heavy elements)

$\Longrightarrow$ Heavy metals come from pre-enrichment of the galactic halo (i.e., are not produced in situ) Harris & Pudritz (1994)

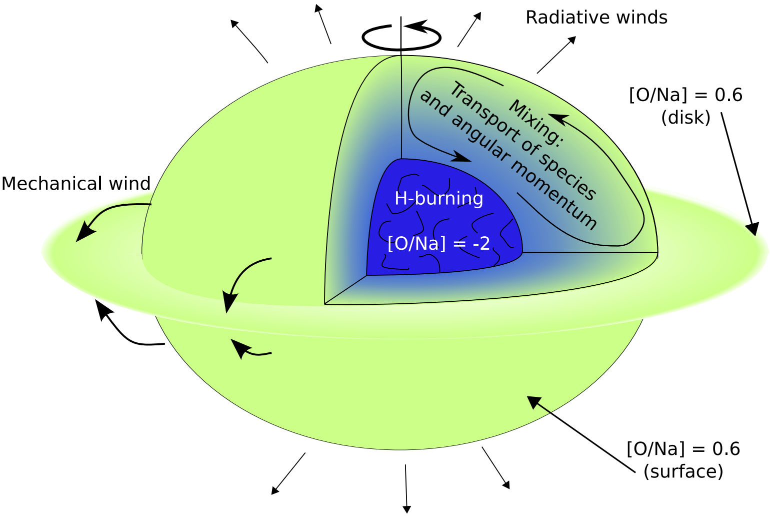
- Complex patterns and strong differences with field stars
  - C-N, O-Na, Mg-Al and Li-Na anticorrelations
  - C+N+O nearly constant
  - both in unevolved and giants stars Gratton et al (2004)

$\Longrightarrow$ Abundance anomalies come from self-enrichment of GC

- multiple main sequence (ω Cen, NGC 2808) and extended HB (Bedin et al 2004, Piotto et al 2008, D'Antona & Caloi 2004...)
  - Due to increase in He

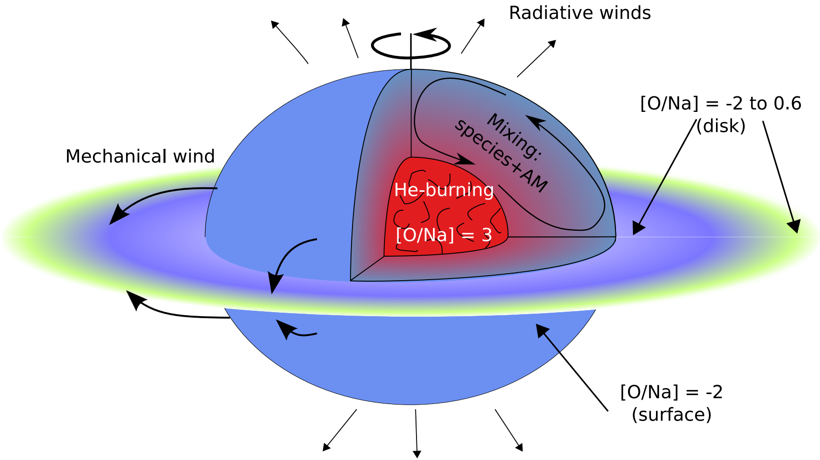
$\Longrightarrow$ abundance anomalies and He enrichment:
due to H-burning nucleosynthesis at high temperature

Overview: fast rotating massive stars evolution



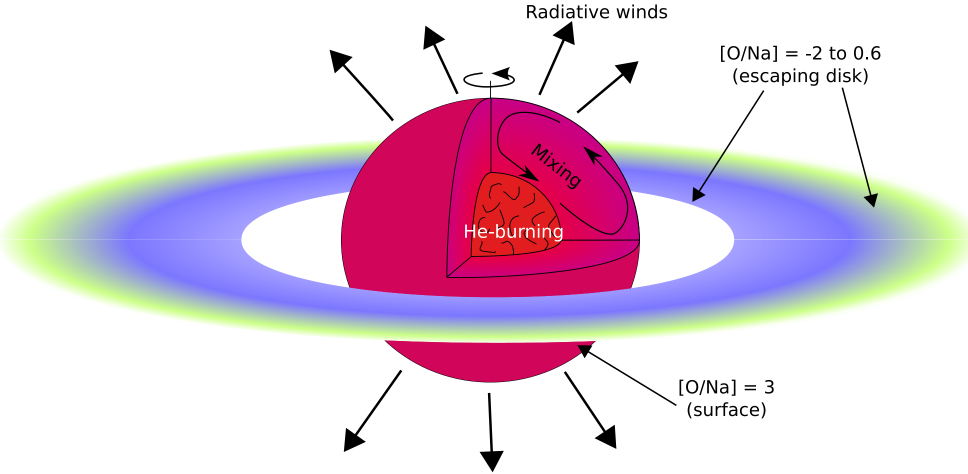
Decressin et al. 2007

Overview: fast rotating massive stars evolution



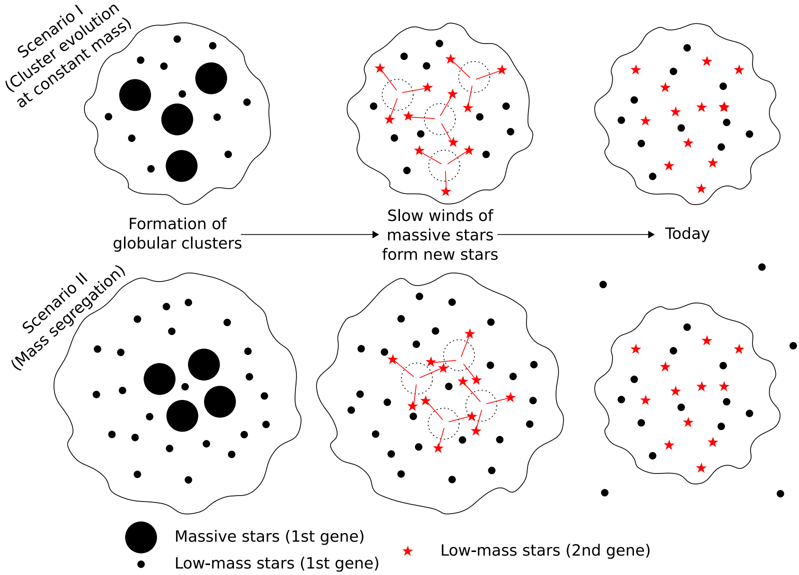
Decressin et al. 2007

Overview: fast rotating massive stars evolution



Decressin et al. 2007

GC evolution

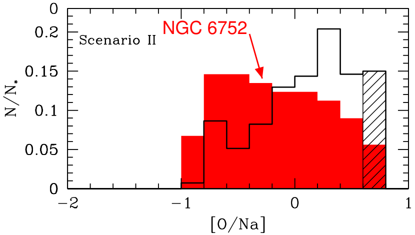


Decressin, Charbonnel & Meynet (2007)

He content of long-lived stars

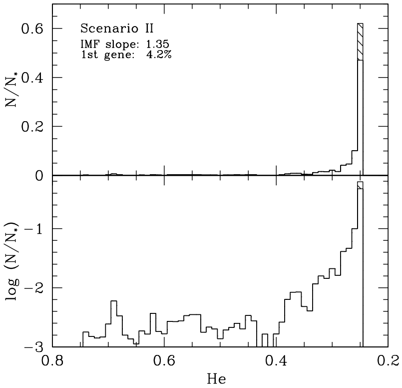
Assumption: local dilution between slow winds and ISM

Reproduce range of [O/Na] distribution in NGC 6752



Decressin et al. (2007)

Consequences for He:



Main peak: He 0.245–0.4

Super-He-rich stars ($\sim$ 12%) tail extends to 0.75

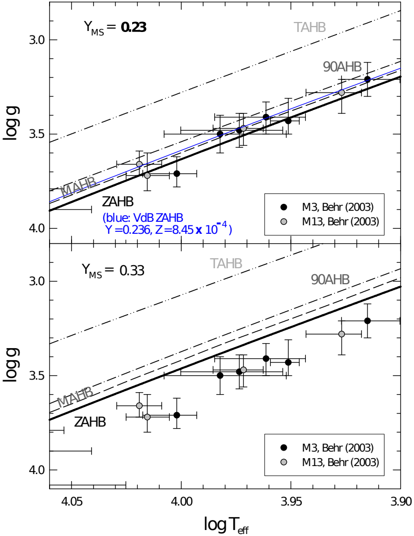
Low mass stellar models

Grid of models for low-mass stars

- Mass: 0.2—0.9 $M_{\odot}$
- Initial He: 0.245—0.72 (mass fraction)
- Z=0.0005 ([Fe/H]$\sim$-1.6, similar to NGC 6752)
- Standard models (no extra mixing)
- From PMS to end of He-burning

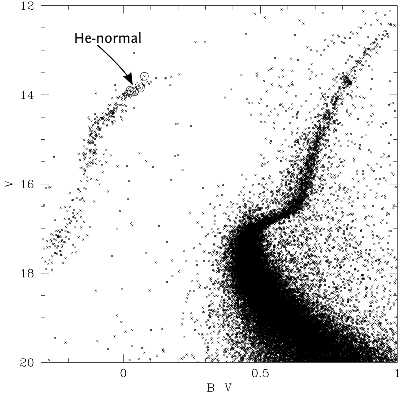
Calibration for mass loss on RGB

M3 and M13



Catelan et al. 2009

NGC 6752

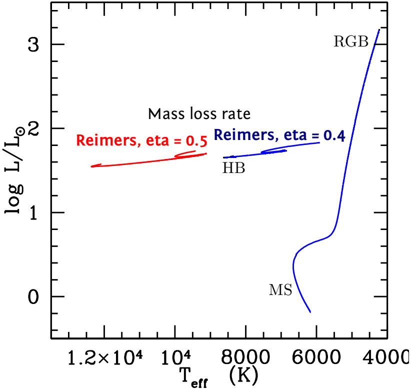


Villanova, Piotto & Gratton, 2009

$\Rightarrow$ $T_{\mathrm{eff}} \leq 10000$ K: He-normal

Mass loss on RGB

$M_{\rm ini} = 0.86\ M_{\odot},\ t_{\rm TO} = 13$ Gyr



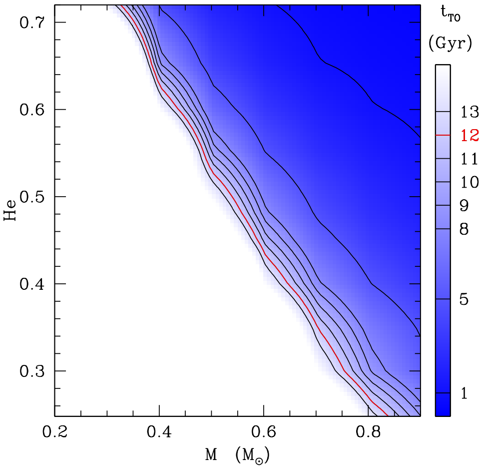
Calibration for mass-loss:

- $T_{\rm eff} \leq 10000$ K: He-normal stars on HB

$\Rightarrow$ Reimers mass loss rate with $\eta_R = 0.4$

- He-rich stars on hotter HB

Lifetime of He-rich stars



Decressin Meynet & Charbonnel (in preparation)

$\Longrightarrow$ He-rich stars evolve faster

$\Longrightarrow$ Spread in He $\Leftrightarrow$ Spread in mass at TO

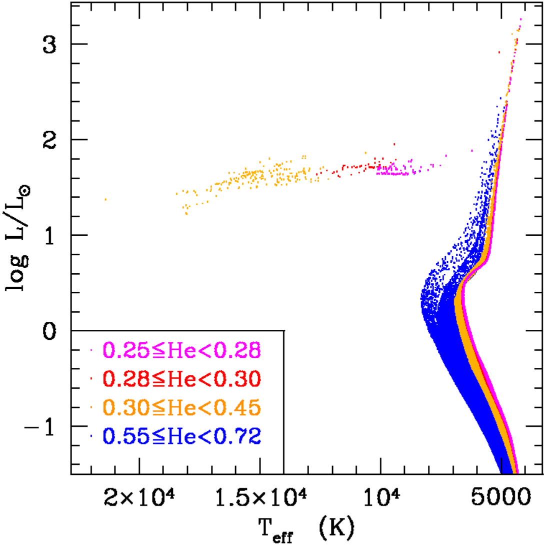
He-rich stars in CMD

He-spread: 0.25-0.72
t: 13 Gyr

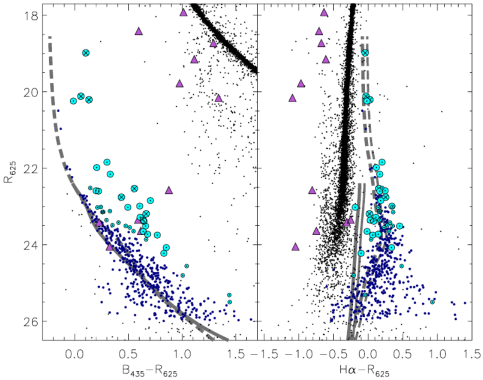
TO:
Higher T_{eff}
Small decreases of L

RGB:
Smaller spread in T_{eff}

HB:
Extended HB
No super-He-rich stars



He-WD in NGC 6397



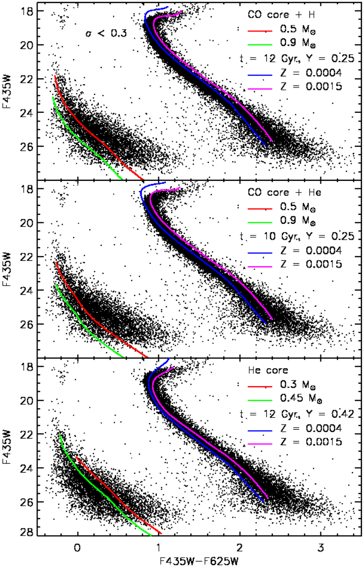
Strickler et al. 2009

NGC 6397

- weak abundance anomalies
- no split of MS or RGB

About 24 He-WD detected
Members of binary systems

He-WD in ω Cen



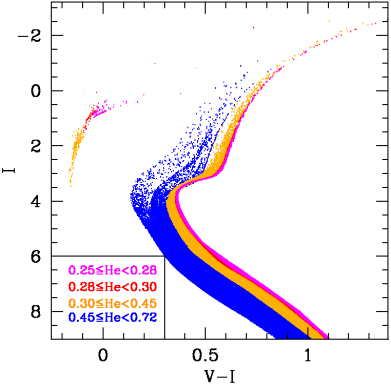
Calamida et al. 2009

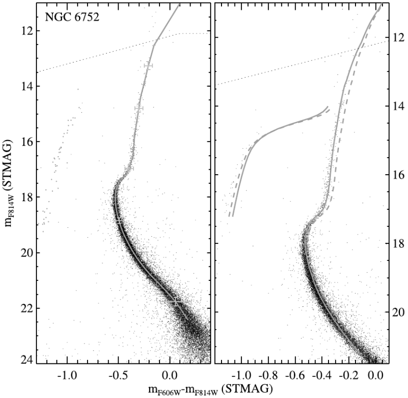
ω Cen

- Blue MS with Y $\sim$ 0.42
  Piotto et al., 2005
- Display abundance anomalies

6500 WD detected
Some can be He-WD

Comparison with NGC 6752



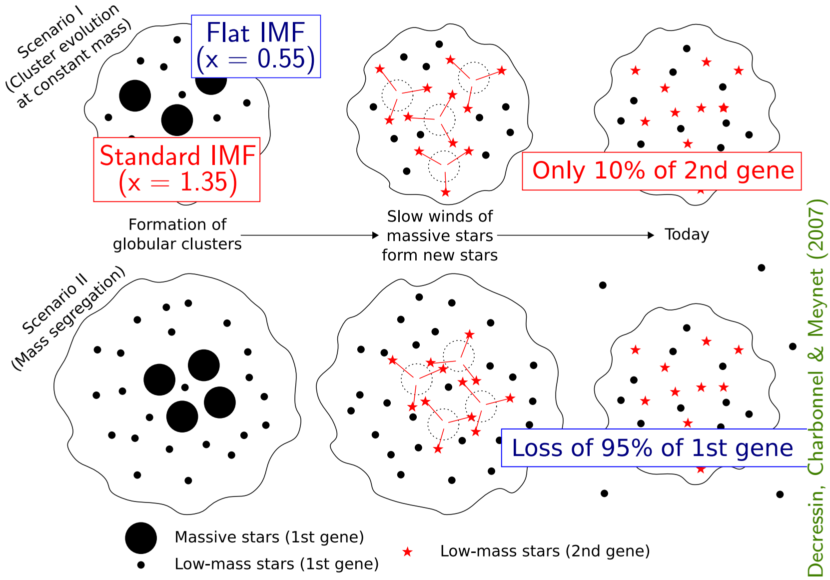


from Brown et al. (2005)

In NGC 6752: too broad MS and RGB and agreement with HB

⟹ assumption on local dilution to be changed

GC evolution



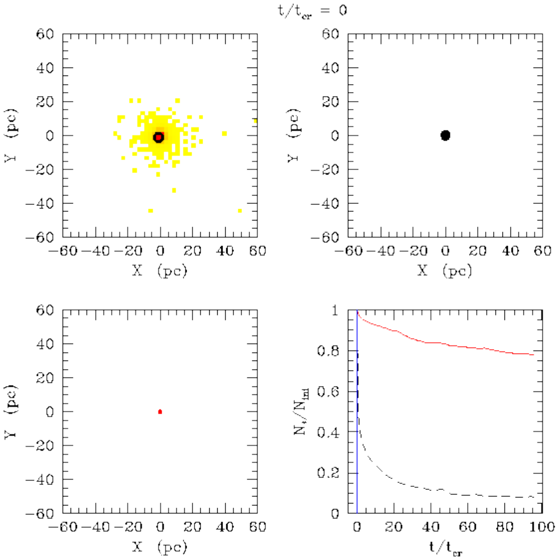
Models of Baumgardt & Kroupa (2007)

- 20 000 stars (1 $M_\odot$)
- gas treated with additional potential
- time dependent

Physical input parameters

- SFE (ϵ) $\Longrightarrow$ amount of gas left
- r_h/r_t $\Longrightarrow$ concentrated cluster and strength of tidal field
- $\tau_{gas}/t_{\mathrm{cr}}$ $\Longrightarrow$ speed of gas expulsion vs internal dynamics

Case: $\epsilon = 0.3$, $r_h/r_t = 0.06$, $\tau_{GE}/t_{cr} = 0.33$



Conclusions

Chemical consequences of early pollution by massive stars in GCs

- 2nd gene of low-mass stars: enriched in H-burning material
- increase of He content
  $\Rightarrow$ no super-He rich detected in GC
  Dilution of slow winds on larger scales

Dynamical consequences

- proto-GCs need to be up to 20 times more massive at birth
- primordial gas expulsion in early times seems to be the main responsible to lose 1st generation stars