Atomic Diffusion in NGC 6752

A EuroGENESIS FirstStars project

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Overview

• Setting the stage
• Atomic diffusion and AddMix:
  – What?
  – How to observe?
  – Why?
• Results NGC 6752
• Conclusions
Nucleosynthetic fingerprints of the first stars

• No 1\textsuperscript{st} generation stars ever observed
  ➞ Nucleosynthetic fingerprints of the first stars are imprinted in 2\textsuperscript{nd} generation stars

Globular Clusters

• Dense stellar conglomerates
• Oldest (>10 Gyr) stellar aggregates in MW
Atomic Diffusion (AD)

- Atoms/ions are subjected to number of forces in stellar atmospheres:
  - Gravity (\(\downarrow\), gravitational settling)
  - Gas pressure gradient (\(\uparrow\))
  - Macroscopic flows: primarily convection (inhibiting)
  - Thermal gradient (\(\downarrow\))
  - Radiative acceleration (\(\uparrow\), levitation)
  - Chemical gradient (restoring force)
  - Rotation, e-m forces, waves, shocks, …

“Atomic diffusion”: the net effect of all processes

- Convection + small diffusion constants \(\Rightarrow\) long timescales are required to produce sizable effects in warm metal-poor stars in GCs
Atomic diffusion throughout the HR-diagram

Atomic diffusion is a **slow** process which is efficiently counteracted by macroscopic mass flows, e.g. convection.

On the hot side of the HRD, time scales are generally short and other effects dominate, e.g. rotation.

On the cool side of the HRD, the convective envelopes are deep inhibiting diffusion.

Big effects in Ap/Bp, Am/Fm, Hg/Mn stars

Small but significant effects?
• Stellar structure models including only AD lead to a too large depletion of metals
  → Include *additional mixing* (AddMix)

\[
D_T = 400 D_{\text{He}}(T_0) \left[ \frac{\rho}{\rho(T_0)} \right]^3
\]

• Additional mixing = turbulent transport of unknown physical origin below the outer convection zone
  → It hinders the downward diffusion of elements
How to observe?

compare abundances in TOP stars to those in stars at the base of the RGB, all drawn from a single population

GCs are ideal objects for this purpose

\[ T_{\text{eff}} \sim 1000 \text{ K} \]
\[ \log g \sim 0.7 \text{ dex} \]

Neutral species:

\[ \delta T_{\text{eff}} = 100 \text{ K} \rightarrow \delta \log \varepsilon = 0.07 \text{ dex} \]

Ionised species:

\[ \delta \log g = 0.05 \rightarrow \delta \log \varepsilon = 0.02 \text{ dex} \]
NGC 6752: Observations

- **FLAMES-UVES:**
  - 2000Å (4800-6800Å)
  - R = 47,000
  - Variable S/N over λ-range

- **Typical exposure times:**
  - 6 RGB: 2h (14.5 m)
    - $S/N_{\text{ind}} \sim 60$
    - $S/N_{\text{comb}} \sim 150$
  - 5 TOP: 30h (17 m)
    - $S/N_{\text{ind}} \sim 35$
    - $S/N_{\text{comb}} \sim 60$

➡️ Observing at the limit
Aim

Constrain the existence and size of atomic-diffusion vs mixing effects at a second metallicity point.
### Stellar Parameters

- **b-y photometry:**
- $[\text{Fe/H}] \approx -1.6$
- **Errors:**
  - $\delta T_{\text{eff}} = 100 \text{K}$
  - $\delta \log g = 0.01$
  - $\delta \log \varepsilon \ll 0.01$

- **Fe, Ti and Sc (and Mg and Ca)**
- NLTE

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<th>$T_{\text{eff}}$ (K)</th>
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Grundahl, priv. comm.
Results

- At [Fe/H] = -1.6, atomic diffusion *may* be at work at the level predicted by current models including efficient additional mixing (T6.2)

\[ \Delta \log \varepsilon(\text{Fe})_{\text{RGB-TOP}} = 0.08 \pm 0.06 \]

\[ \Delta \log \varepsilon(\text{Mg})_{\text{RGB-TOP}} = 0.11 \pm 0.08 \]

- other elements (Sc, Ti & Ca) show shallower (insignificant) trends, as predicted by the models

- 3D LTE corrections do not change the results in a sizeable measure
Results (cont’d)

- Average Trend:
  \[
  \chi^2 = \sum_{i=1}^{4} \frac{(y_i - \overline{M})^2}{\sigma_i^2} \approx 7.06
  \]

- 7% probability that the points are randomly scattered around the weighted mean

- Trends best fitted by efficient extra mixing (T6.2)
Results: Lithium

Within mutual error bars agreement with CMB+BBN predictions:

\[ \log \varepsilon(\text{Li})_{\text{NGC6752}} = 2.58 \pm 0.1 \]

\[ \log \varepsilon(\text{Li})_{\text{CMB+BBN}} = 2.71 \pm 0.06 \]
Constraining AddMix

- Determine Addmix parameter in Globular Clusters:
  - \([\text{Fe/H}] = -2.1\)
    - \(\text{NGC6397: } \log T_0 = 6.0\)
      - (Korn et al. (2007), Lind et al. (2009), Nordlander et al. (2012))
  - \([\text{Fe/H}] = -1.6\)
    - \(\text{NGC6752: } \log T_0 = 6.2\)
      - (Gruyters et al. 2013)
  - \([\text{Fe/H}] = -1.1\)
    - \(\text{M4: } \log T_0 = 6.3\)
      - (Mucciarelli et al. 2011)
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\[\log \frac{N_{\text{Li}}}{N_{\text{H}}} + 12\]

\(12.5\) Gyr; “100s”

- \(\log \varepsilon(\text{Li})_{\text{init}} = 2.57 \pm 0.1\)

Nordlander et al. (2012)
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\[ \log \varepsilon(\text{Li})_{\text{M4}} = 2.35 \pm 0.30 \]
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Conclusions

- We identified abundance trends for Mg, Ca, Sc, Ti, and Fe with evolutionary phase in the GC NGC 6752 at [Fe/H] = -1.6. Though the significance is weak, they seem to indicate that AD is operational along the evolutionary sequence of NGC 6752.

- We have shown how AD with AddMix can help to solve the primordial Li problem for NGC 6752.

- The results tend to indicate more efficient mixing at this metallicity compared to NGC 6397 at [Fe/H] = -2.1. This adds a non-trivial data point to the dependence of extra mixing on metallicity which calls for further investigation of globular clusters at different metallicities such as M92 and M30.