Abundance ratios & ages of stellar populations in the HARPS-GTO sample

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The importance of heavy elements

Elements heavier than iron would require energy to be created by stellar fusion → neutron captures, which can be slow or rapid, followed by β decay:

- **s-process**: long timescales between consecutive captures, low density of neutrons: produce most of elements with \( A < 150 \)
- **r-process**: short timescales, high density of neutrons: produce elements like Eu
- **\( p \)-process**: proton rich nuclei, marginal contribution

Production sites:
- **Weak s**-component, \( 60 < A < 90 \) : produced during He-core and C-shell burning in massive stars
- **Main s**-component, \( 90 < A < 204 \): produced in between thermal pulses in AGB stars (mainly low mass)
- **r-process**: probably associated to explosive conditions in supernovae
The importance of heavy elements

The contribution from each process varies among different elements and change with age/metallicity → constrains to models of GCE

Estimations of s-process contribution for the Solar System composition by several authors (Cameron 1973, Arlandini et al. 1999, Bisterzo et al. 2016, etc…)

- Light-s elements: Sr (67%), Y (70%), Zr (64%)
- Heavy-s elements: Ba (83%), Ce (81%), Nd (56%)
- Eu (7%) → considered as pure r-process element

Stellar spectra and abundances

1111 stars in the HARPS GTO sample (R ~ 115000):

Volume limited sample (within 60pc, no selection based on kinematics), $V < 12$, slow rotators, no binaries, no very active stars

136 stars with planets, 975 stars without planets

$4400\text{K} < T_{\text{eff}} < 6800\text{K}$  \hspace{1cm} -1.40 < [Fe/H] < 0.55

55% spectra S/N > 200

Stellar parameters from Sousa et al. (2008, 2011) corrected for cool stars using linelist from Tsantaki et al. (2013)

Chemical abundances for $\alpha$- and iron peak elements in Adibekyan et al. (2012), lithium in Delgado Mena et al. (2014,2015), oxygen in Bertran de Lis (2015) and carbon in Suarez-Andres et al. (2016)

Abundances of Cu, Zn, Sr, Y, Zr, Ba, Ce, Nd and Eu using EWs, HFS, Kurucz ATLAS model atmospheres and the LTE code MOOG:
Delgado Mena et al. 2017, accepted by A&A  \rightarrow  arXiv:1705.04349
Chemical separation

Based on $\alpha$-elements (Mg, Si and Ti)

- 882 thin disk stars
- 108 thick disk stars
- 8 halo stars (kinematically selected)
- 60 h$\alpha$m$\rho$ stars (older than thin disk stars and with intermediate orbits between the thin and thick disk stars)

→ originated from the inner disk?

Definition based in chemistry, separation both in [$\alpha$/Fe] and [Fe/H]

Adibekyan et al. (2011, 2013)
[X/Fe] vs [Fe/H] trends

Cu and Zn models by Romano et al. (2010), rest from Bisterzo et al. 2017
$[\text{X/Fe}]$ vs $[\text{Fe/H}]$ trends for 'solar $T_{\text{eff}}$' stars

Thin disk-thick disk $[\text{Fe/H}] < -0.2$ separation for Zn, Zr, Ba and Eu

Thin disk-håmå $[\text{Fe/H}] > -0.2$ separation for Cu, Zn, Y, Ba, Nd and Eu
[X/Fe] vs [Fe/H] trends for 'solar T$_{eff}$' stars

Thin disk-thick disk ([Fe/H] < -0.2) differences for Zn, Zr, Ba and Eu
Thin disk-hαmr ([Fe/H] > -0.2) differences for Cu, Zn, Y, Ba, Nd and Eu
Different contributions at different $[\text{Fe/H}]$

- r-process: SNII of 8-10 M$\odot$
- oxygen: SNII of 15 M$\odot$ Travaglio et al. (1999)
- s-process: low mass AGB (at higher metallicities)
- Different r-process contributions to Ba (<20%), Ce (<20%), Nd (~45%) Arlandini et al. (1999) Bisterzo et al. (2016)
Stellar ages


- Parallaxes from Gaia DR1 and Hipparcos → V magnitudes, Teff and [Fe/H] with PARSEC isochrones (Bressan et al. 2012) using PARAM interface

- Spectroscopic logg, Teff and [Fe/H] → Yonsei-Yale isochrones (Yi et al 2001) and the python package q2 (Ramirez et al.)
Stellar ages

Gaia parallaxes are smaller on average than Hipparcos for our sample
- 923 stars with Gaia parallaxes, 1051 stars with Hipparcos parallaxes
- 454 stars with errors in HIP ages less than 2 Gyr
- 384 stars which also show differences between Gaia and HIP less than 1 Gyr
General $[\text{X/Fe}]$-age trends

- **Al**: coefs. $0.09545, 0.02068$
  - sigma $0.00848, 0.00118$
- **Mg**: coefs. $-0.06408, 0.02036$
  - sigma $0.00534, 0.00074$
- **Si**: coefs. $-0.02753, 0.01183$
  - sigma $0.00394, 0.00055$
- **Till**: coefs. $-0.06488, 0.01765$
  - sigma $0.00496, 0.00069$

**Error age < 2 Gyr**

- **Mn**: coefs. $0.01426, -0.01089$
  - sigma $0.00759, 0.00105$
- **Scl**: coefs. $0.00872, 0.01024$
  - sigma $0.00816, 0.00114$
- **Cu**: coefs. $-0.04697, 0.00310$
  - sigma $0.00799, 0.00110$
- **Zn**: coefs. $-0.10592, 0.01534$
  - sigma $0.00486, 0.00067$

**Diff Gaia-Hip < 1 Gyr**

- **Sr**: coefs. $0.03051, -0.00873$
  - sigma $0.00636, 0.00088$
- **Y**: coefs. $0.0579, -0.00878$
  - sigma $0.00503, 0.00070$
- **Ba**: coefs. $0.01999, -0.00754$
  - sigma $0.00694, 0.00096$
- **Eu**: coefs. $-0.06944, 0.02012$
  - sigma $0.01123, 0.00139$
Mg: constant slopes of ~0.010 dex/Gyr at [Fe/H] > -0.7 for thin disk stars
Al: slopes decrease for higher [Fe/H]. 0.018–0.022 dex/Gyr at $-0.05 < [\text{Fe/H}] < 0$ for thin disk stars, $\sim 0.015$ dex/Gyr at $[\text{Fe/H}] > 0$. 
Zn: slopes decrease for higher [Fe/H]. 0.016-0.020 dex/Gyr at [Fe/H] < -0.2 for thin disk stars, ~0.013 dex/Gyr at [Fe/H] > -0.2. Similar slopes for hαmr stars.
Y: change of slope around 8 Gyr for thin disk stars. Slopes $[-0.012, -0.020]$ dex/Gyr for $-0.3 < [\text{Fe/H}] < 0.3$ for thin disk stars. Different slopes for thick disk and hømr stars at some [Fe/H] bins.
Sr: change of slope around 8 Gyr for thin disk stars. Quite constant slope of -0.021 dex/Gyr for thin disk stars in most metallicity bins. Different slopes for thick disk and h\(\alpha\)mr stars at some [Fe/H] bins.
[Y/Mg-Zn-Al] and [Sr/Mg-Zn-Al]
[Y/Mg-Zn-Al] and [Sr/Mg-Zn-Al]
Summary

• Heavy element abundances are necessary to constrain models of GCE and to understand the yields of both massive and low-mass stars → need of high quality data to analyze these elements.

• The distinction of the thin and thick disk (based on α elements) is also observed for Zn, Zr, Ba and Eu.

• hαmr stars show enhanced abundances of Cu, Zn, Nd and Eu when compared to the thin disk at the same metallicity. They also show lower abundances on average of Y and Ba.

• The [X/Fe] ratios of thick disk stars show little correlation with age (but we have a small sample). Thin disk stars show clear correlations with age for some elements but the slopes can change at different [Fe/H] regimes. → steeper trends for Sr ratios than for Y ratios, valid at lower metallicities.

• Looking forward for future GAIA releases: more precise ages will allow to increase our sample and evaluate how the different elements behave in smaller ranges of $T_{\text{eff}}$ and [Fe/H]
Thanks