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

Previous works on heavy elements: Allende Prieto et al. 2004, Reddy et al. 2006, González Hernández et al. 2010, Mishenina et al. 2013, Bensby et al. 2014, Battistini&Bensby 2016, Mikolaitis et al. 2017, poster by G. Guiglion, etc...

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

4400K < T_{eff} < 6800K   -1.40 < [Fe/H] < 0.55

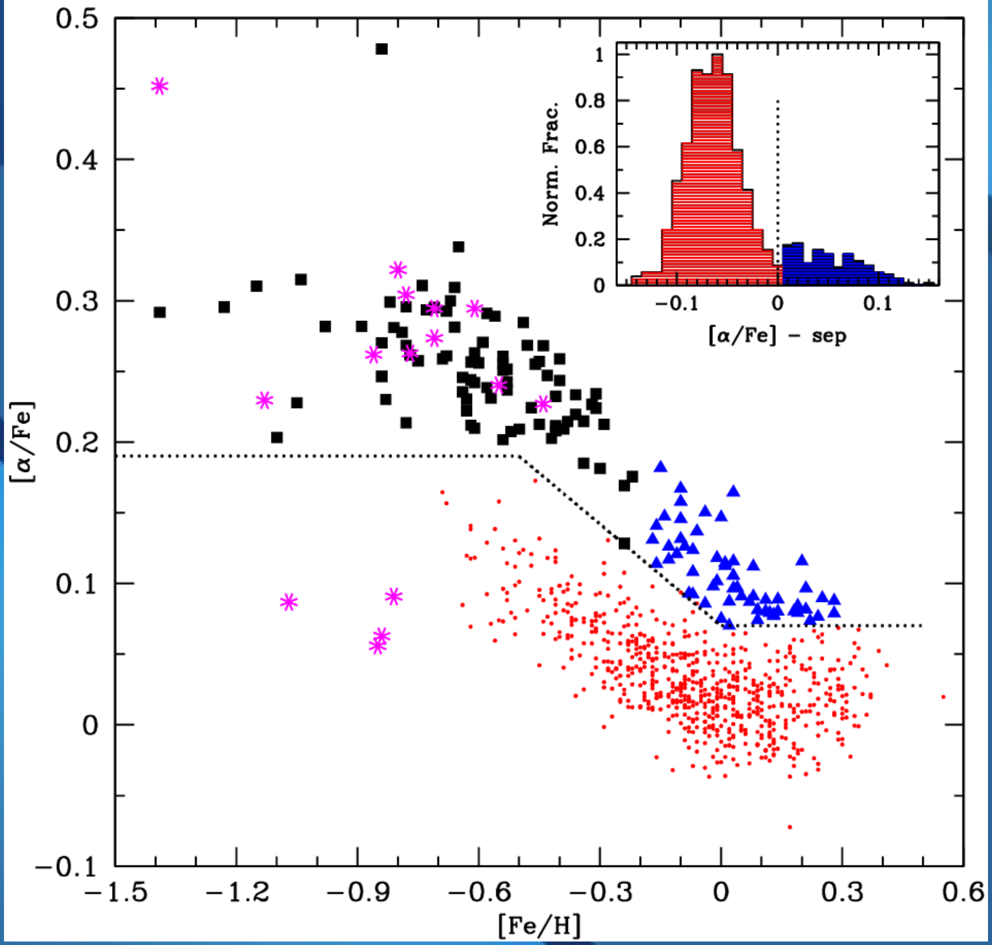
55% spectra S/N > 200

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

Chemical abundances for **α- 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, Kurucz ATLAS model atmospheres and the code MOOG:
Delgado Mena et al. 2017 → soon in astro-ph

Chemical separation



Based on α-elements (Mg, Si and Ti)

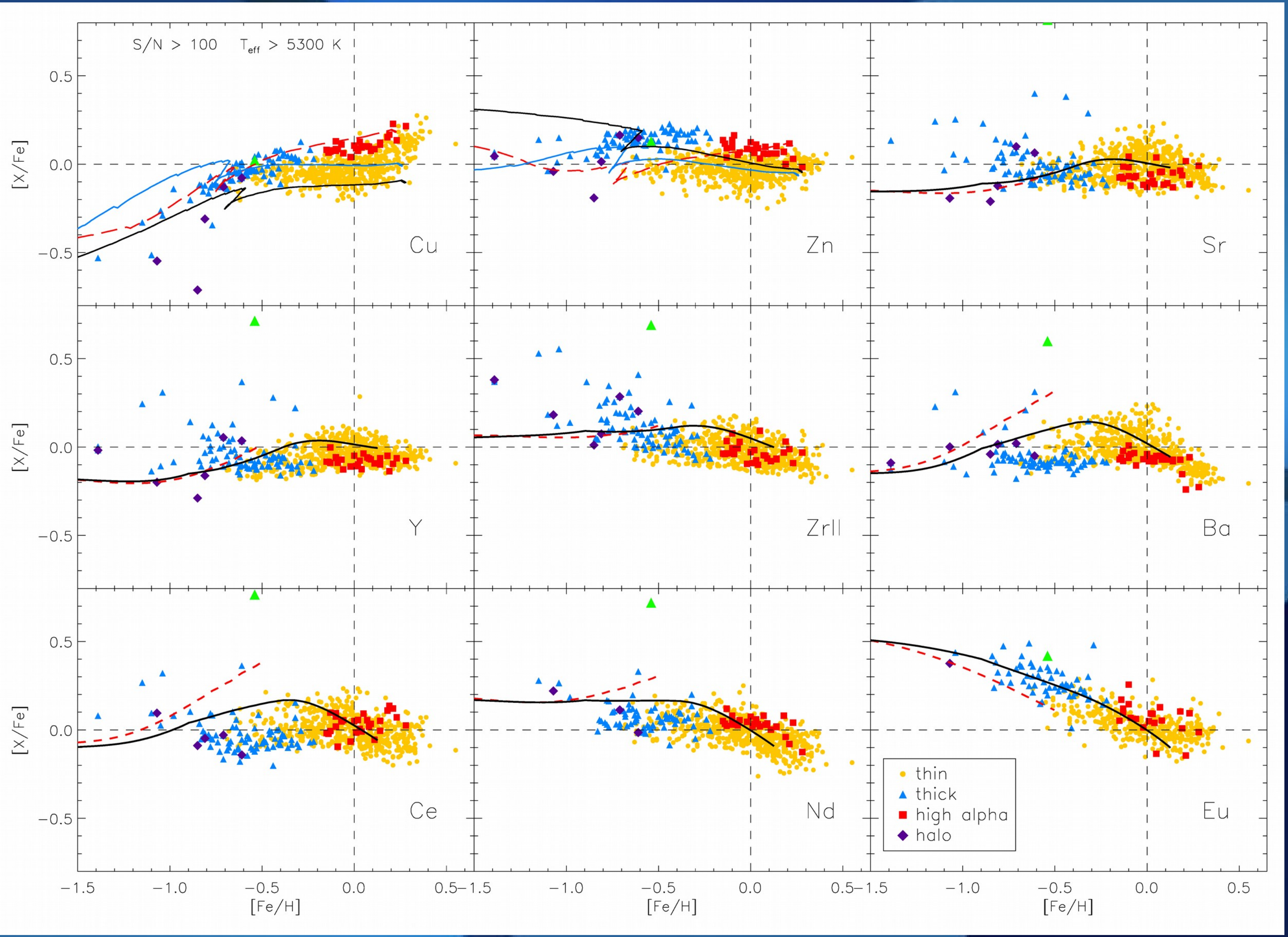
- 882 thin disk stars
- 108 thick disk stars
- 8 halo stars (kinematically selected)
- 60 hαmr stars (older than thin disk stars and with intermediate orbits between the thin and thick disk stars)

→ originated from the inner disk?

Definition based in chemistry, separation both in [α/Fe] and [Fe/H]

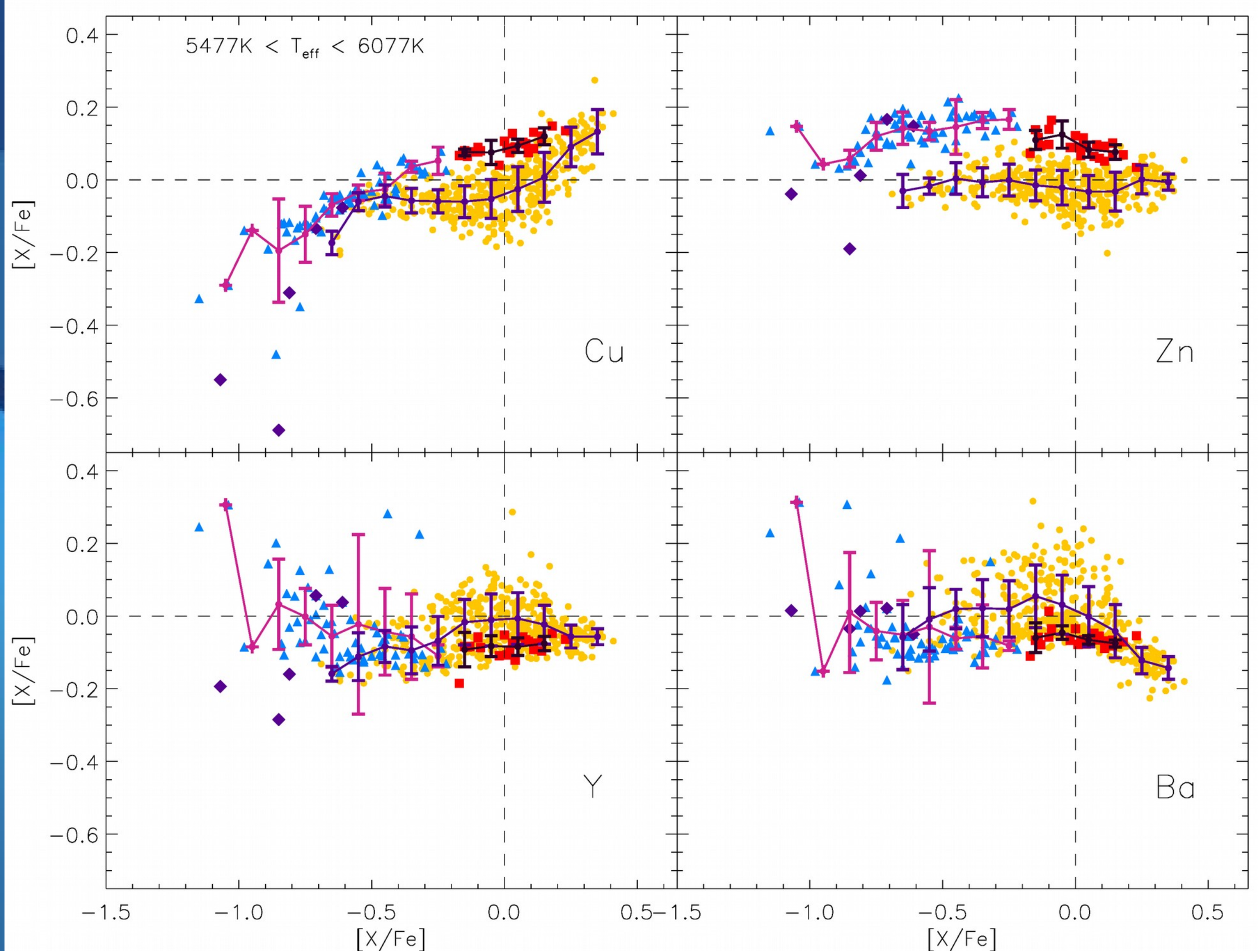
Adibekyan et al. (2011, 2013)

[X/Fe] vs [Fe/H] trends



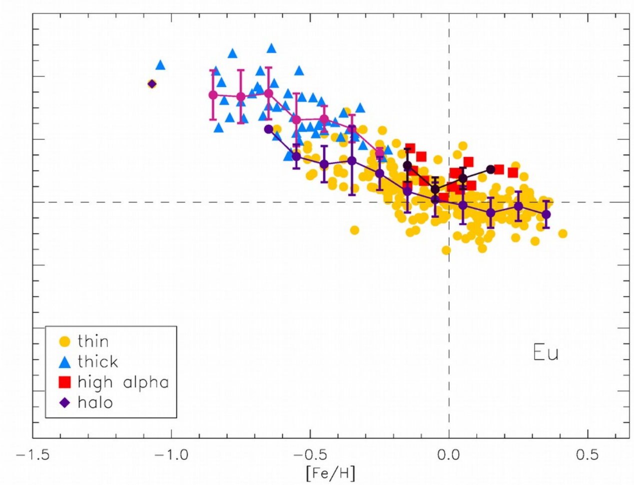
Cu and Zn models by Romano et al. (2010), rest from Bisterzo et al. 2017

[X/Fe] vs [Fe/H] trends for 'solar T_{eff}' stars



Thin disk-thick disk
[Fe/H] < -0.2
separation for Zn, Zr, Ba and Eu

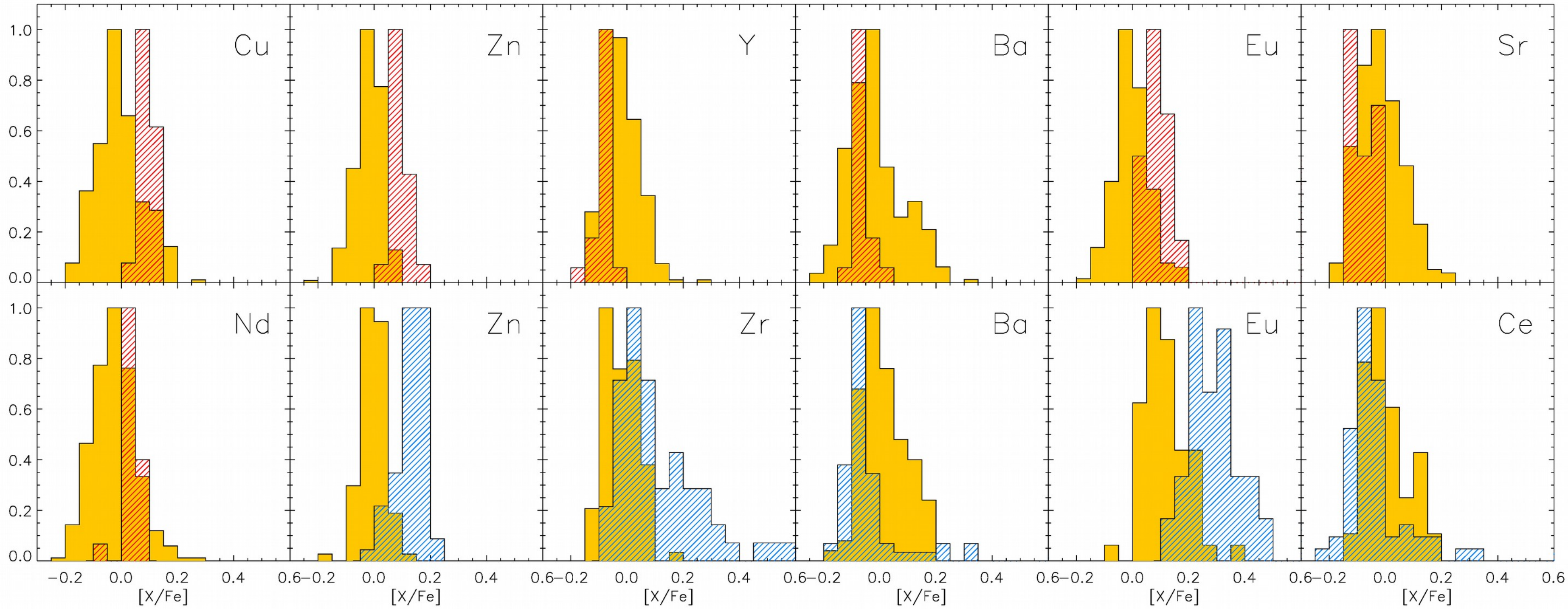
Thin disk-hαmr
[Fe/H] > -0.2
separation for Cu, Zn, Y, Ba, Nd and Eu



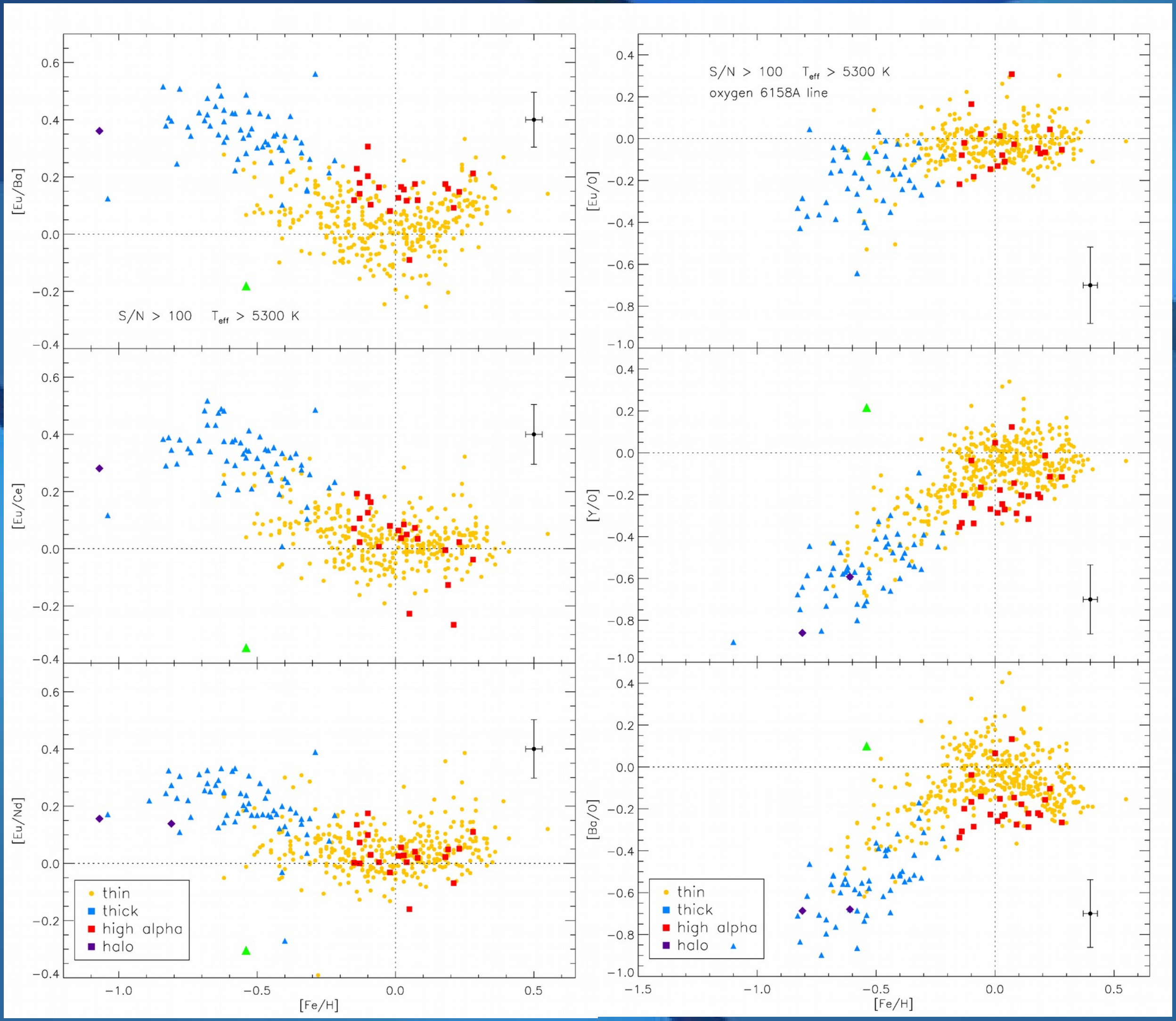
[X/Fe] vs [Fe/H] trends for 'solar T_{eff}' stars

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 [Fe/H]



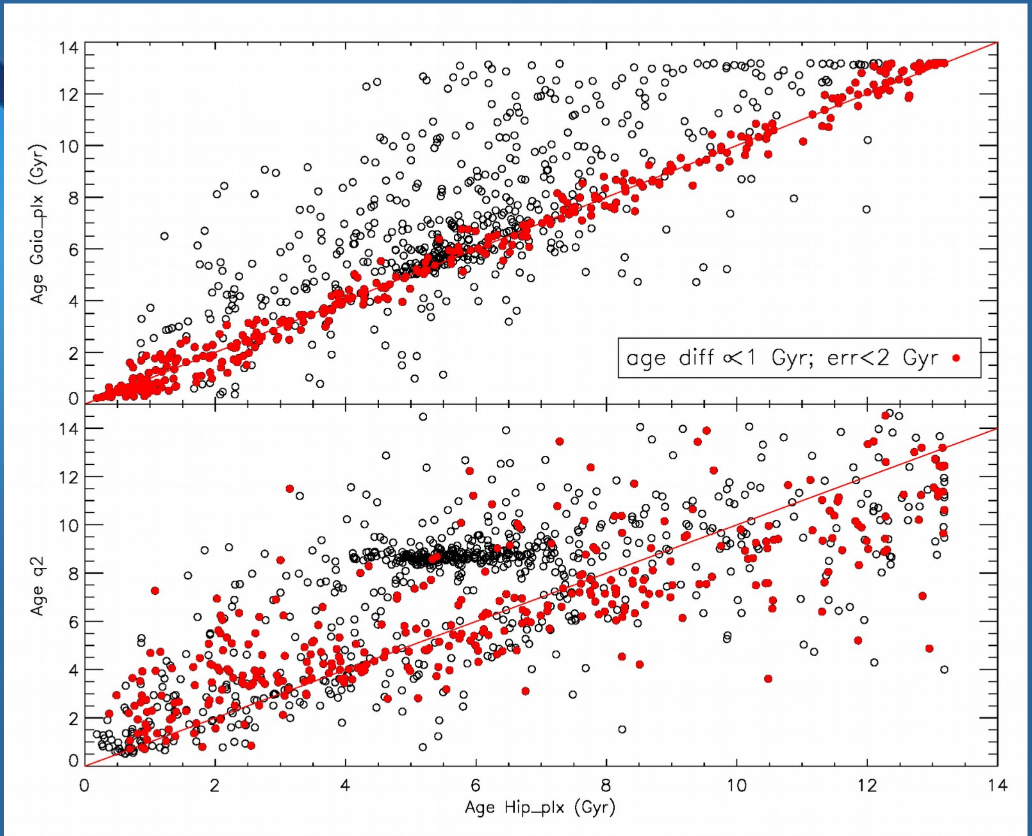
- r-process: SNII of 8-10 M⊙
- oxygen: SNII of 15 M⊙ Travaglio et al. (1999)
- s-process: low mass AGB (at higher metallicities)
- Different r-process contributions to Ba (<20%), Ce (<20%), Nd (~45%) Arlandini et al. (1999) Bisterzo et al. (2016)

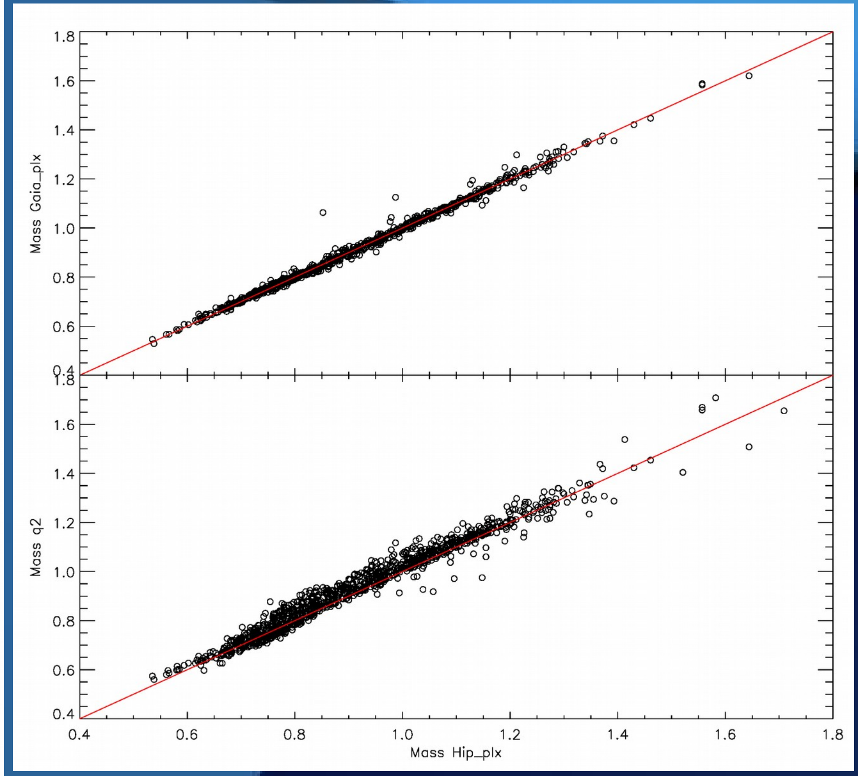
Stellar ages

Can we obtain ages from different abundance ratios? Solar twins/analogues in Da Silva et al. 2012, Nissen et al. 2015, Spina et al. 2016 but see Feltzing et al. 2016

- **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.)





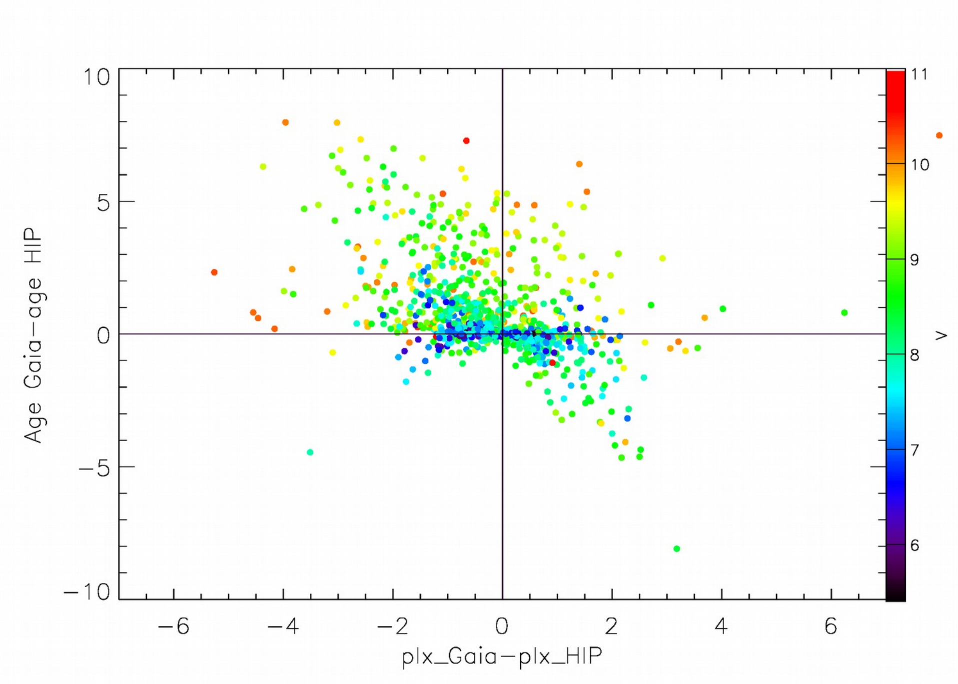
Stellar ages

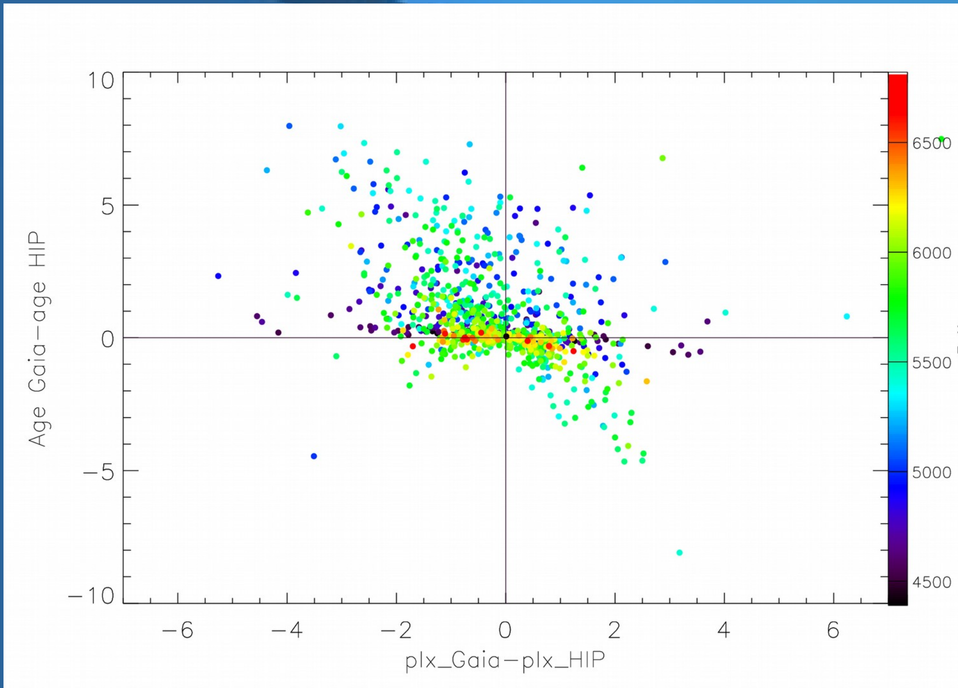
Gaia parallaxes are smaller on average than Hipparcos for our sample

- 923 stars with Gaia parallaxes, 1051 stars with Hipparcos parallaxes

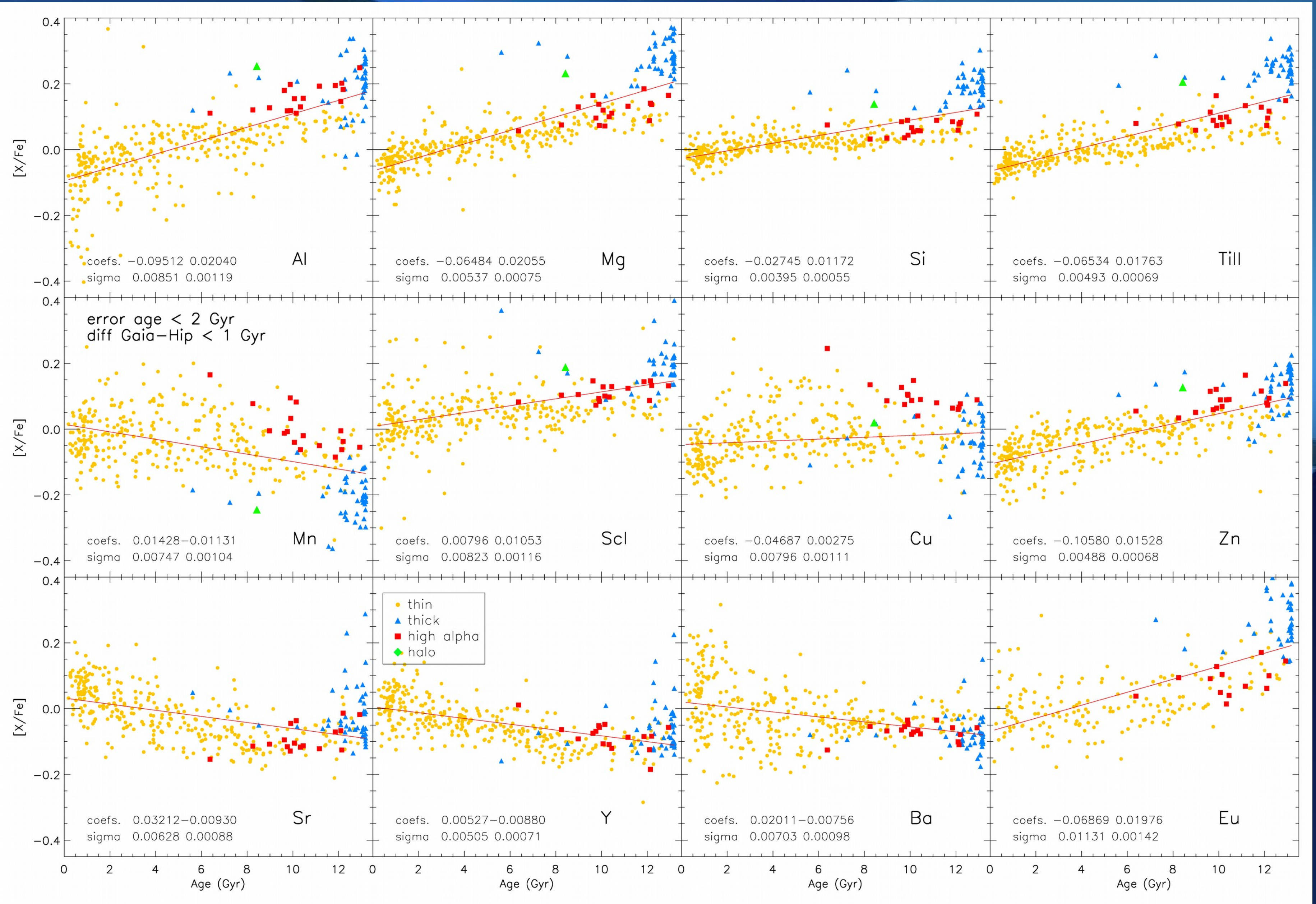
- 455 stars with errors in HIP ages less than 2 Gyr

- 377 stars which also show differences between Gaia and HIP less than 2 Gyr

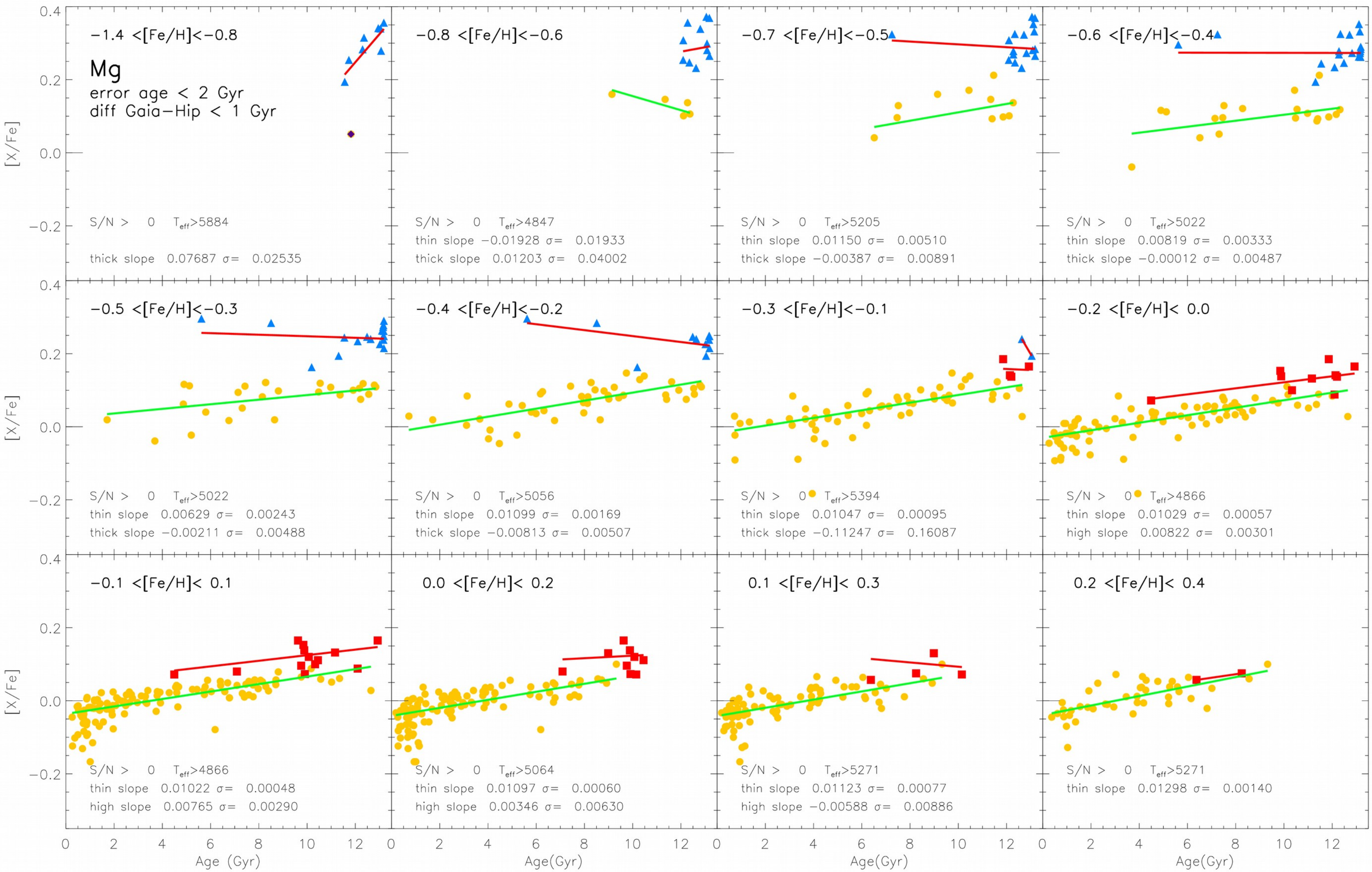




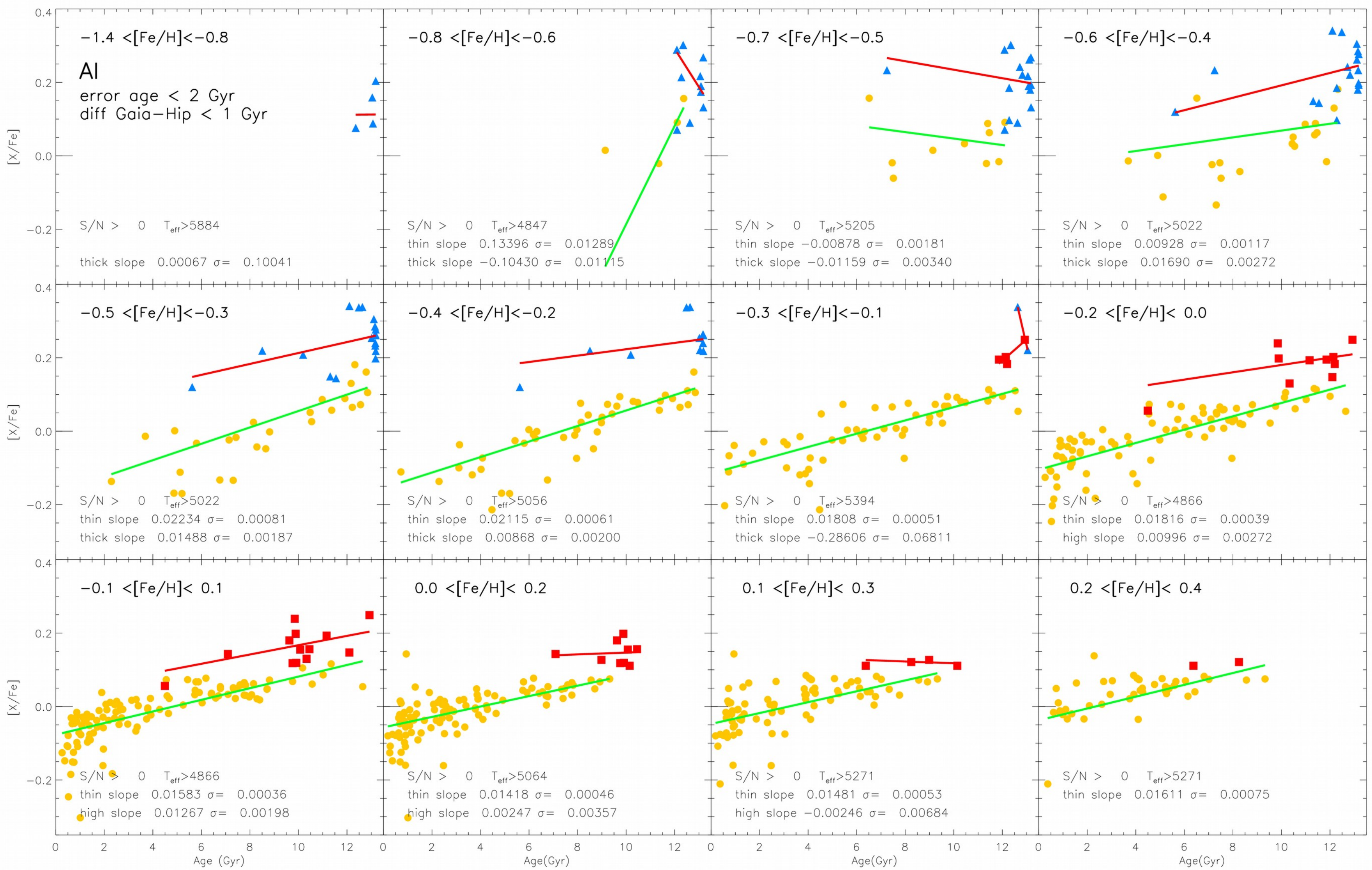
General [X/Fe]-age trends



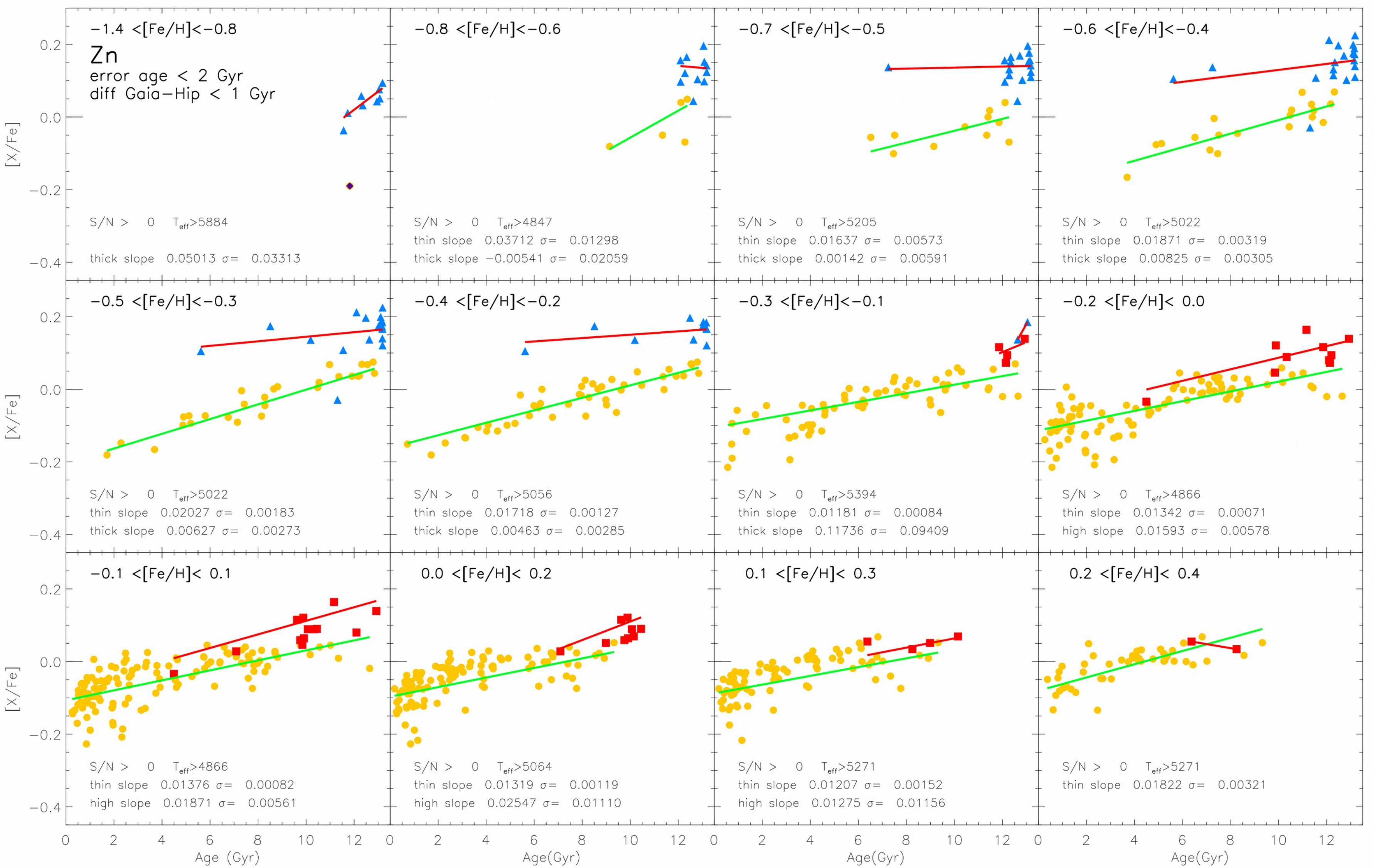
Mg: constant slopes of ~0.010 dex/Gyr at [Fe/H] > -0.7 for thin disk stars



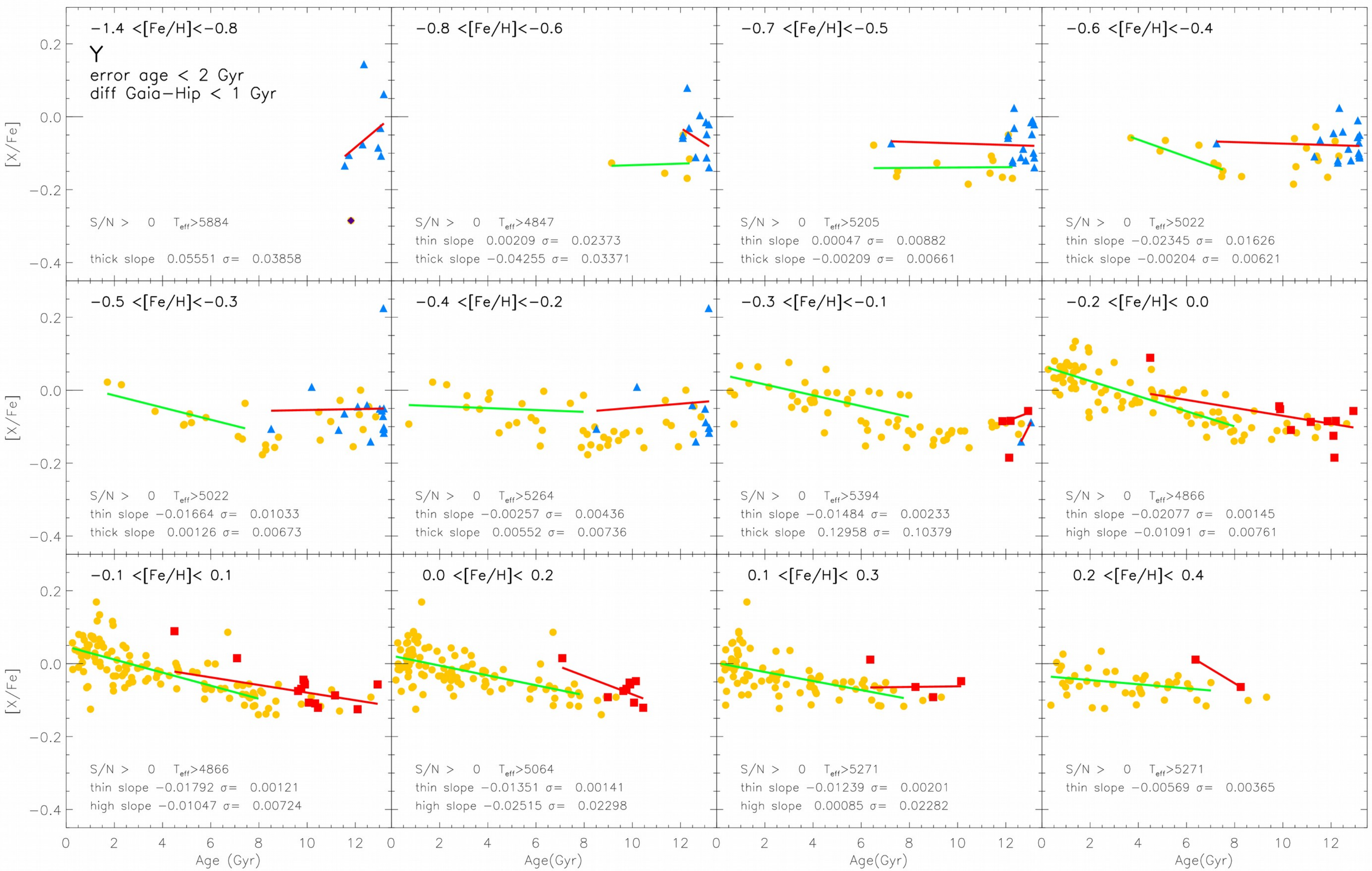
Al: slopes decrease for higher [Fe/H]. 0.018-0.022 dex/Gyr at -0.05<[Fe/H] < 0 for thin disk stars, ~0.015 dex/Gyr at [Fe/H] > 0.



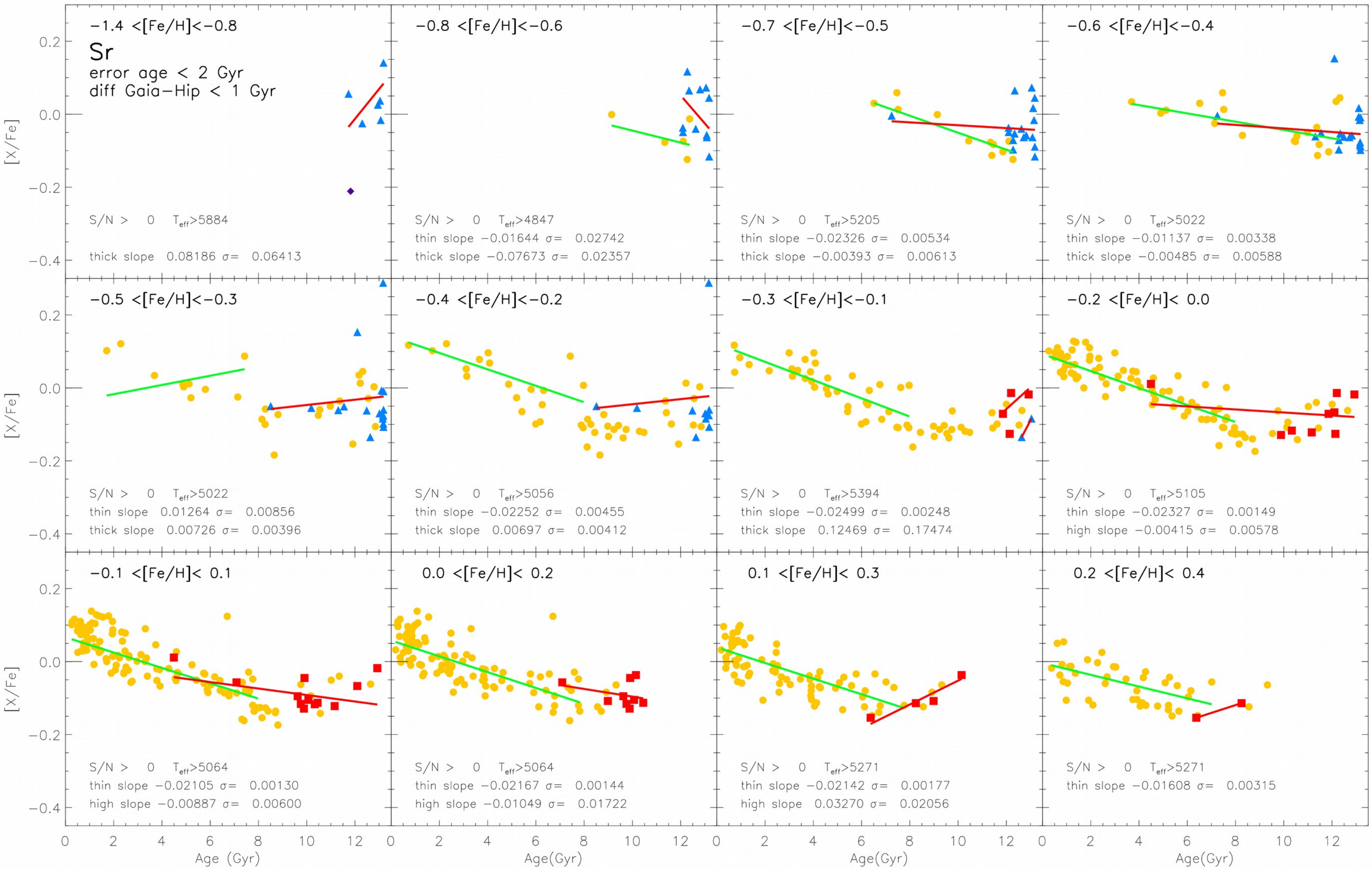
Zn: slopes decrease for higher [Fe/H]. 0.016-0.020 dex/Gyr at [Fe/H] < -0.2 for thin disk stars, ~0.013 dex/Gyr at [Fe/H] > -0.2. Similar slopes for hαmr stars.



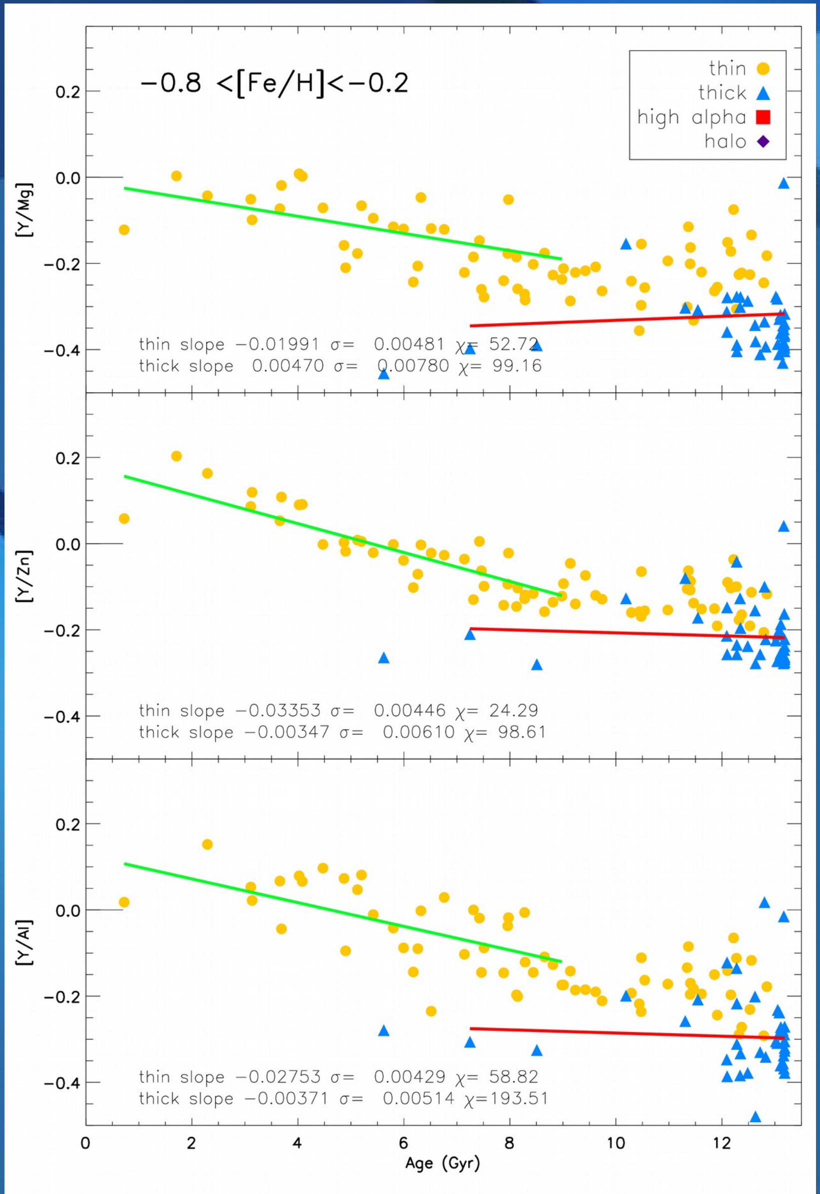
Y: change of slope around 8 Gyr for thin disk stars. Slopes [-0.012,-0.020] dex/Gyr for -0.3 < [Fe/H] < 0.3 for thin disk stars. Different slopes for thick disk and hαmr stars at some [Fe/H] bins

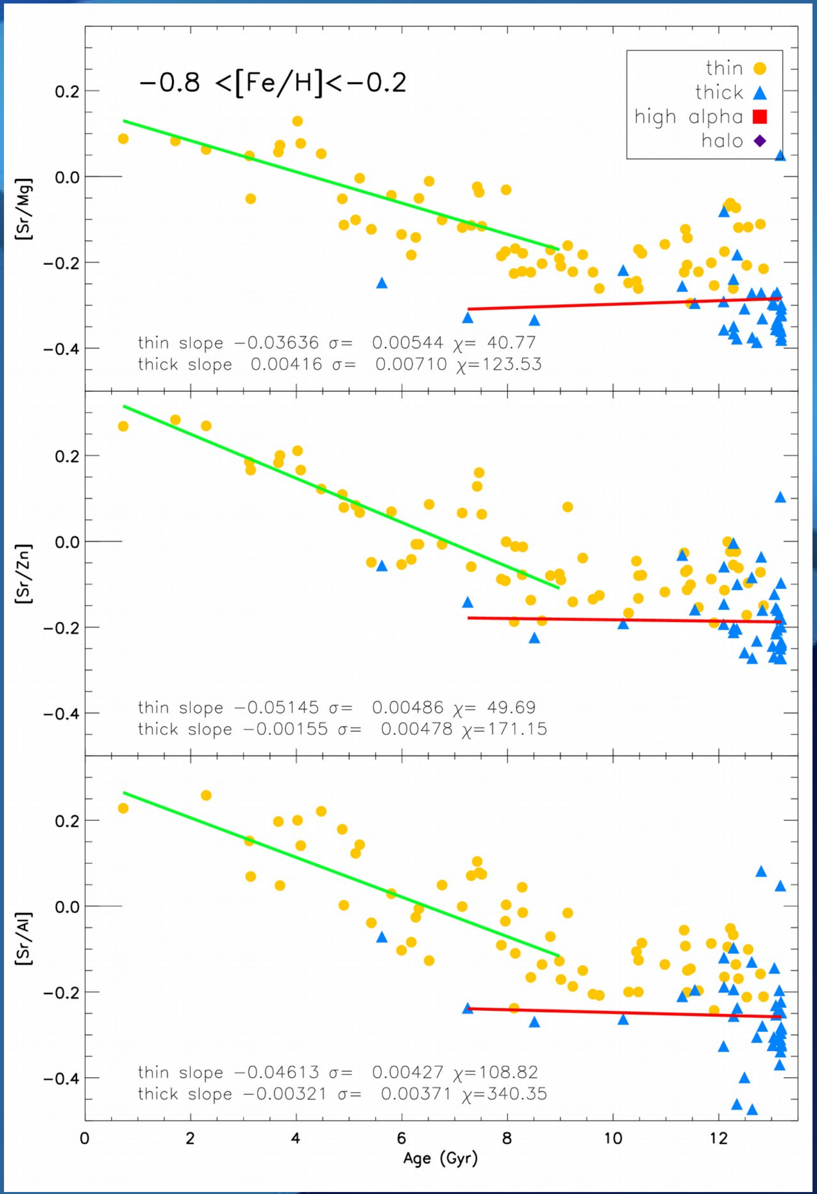


Sr: change of slope around 8 Gyr for thin disk stars. Quite constant slope of -0.021 dex/Gyr for thin disk stars in most metallicity bins. Different slopes for thick disk and hαmr stars at some [Fe/H] bins

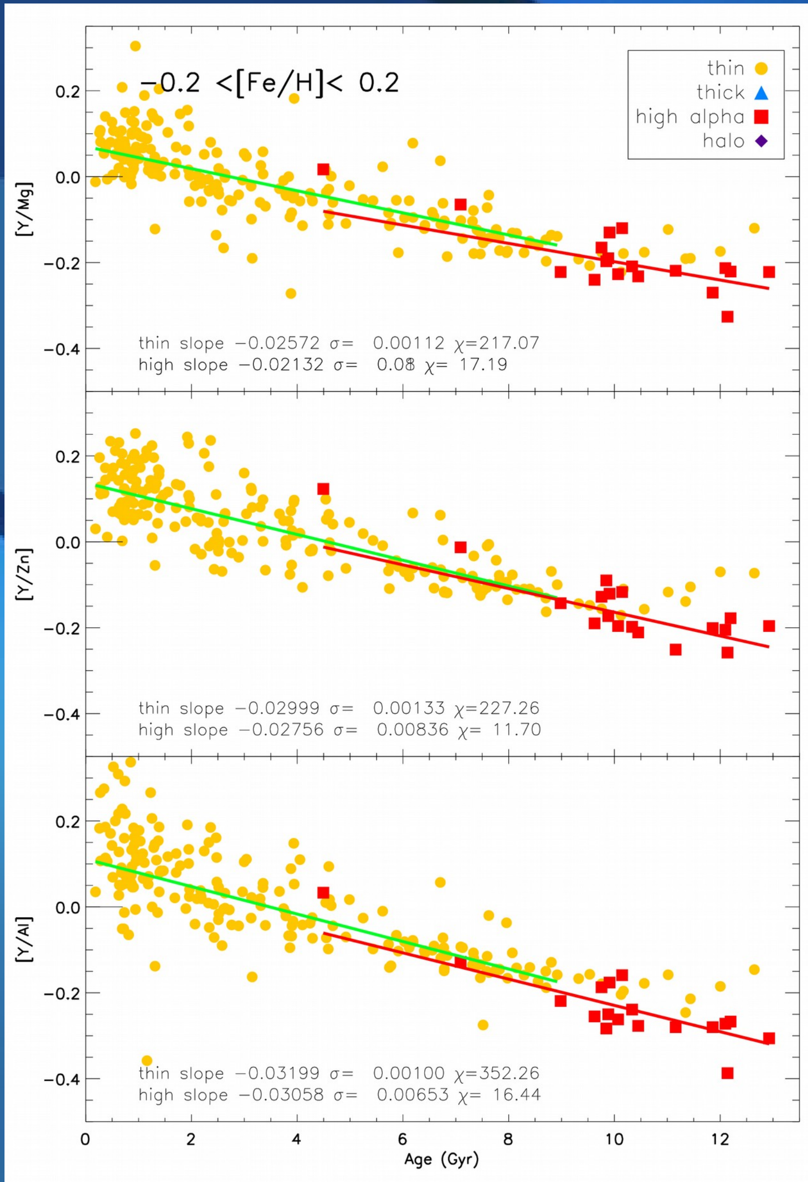


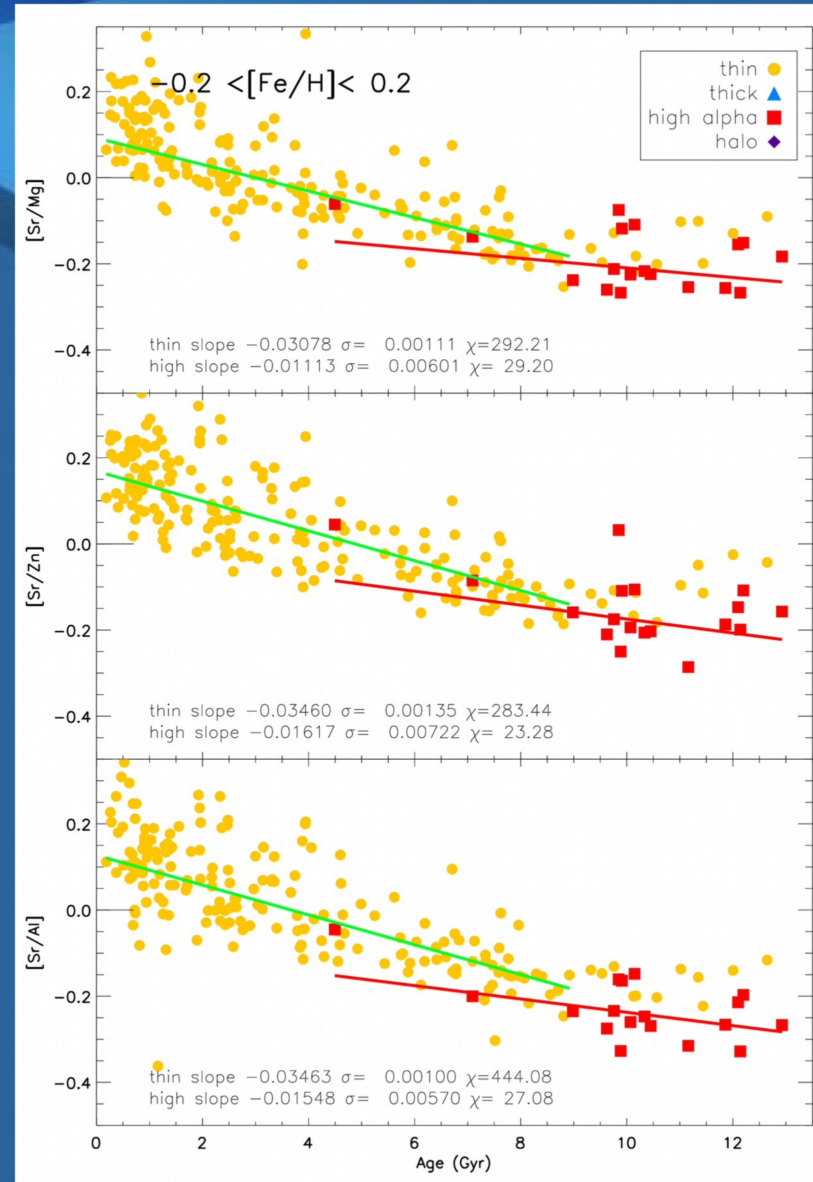
[Y/Mg-Zn-Al] and [Sr/Mg-Zn-Al]





[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.

- Looking forward for GAIA DR2: more precise ages will allow to increase our sample and evaluate how the different elements behave in smaller ranges of T_{eff} and [Fe/H]


Thanks