The temporal evolution of the neutron-capture elements in the Galactic disk

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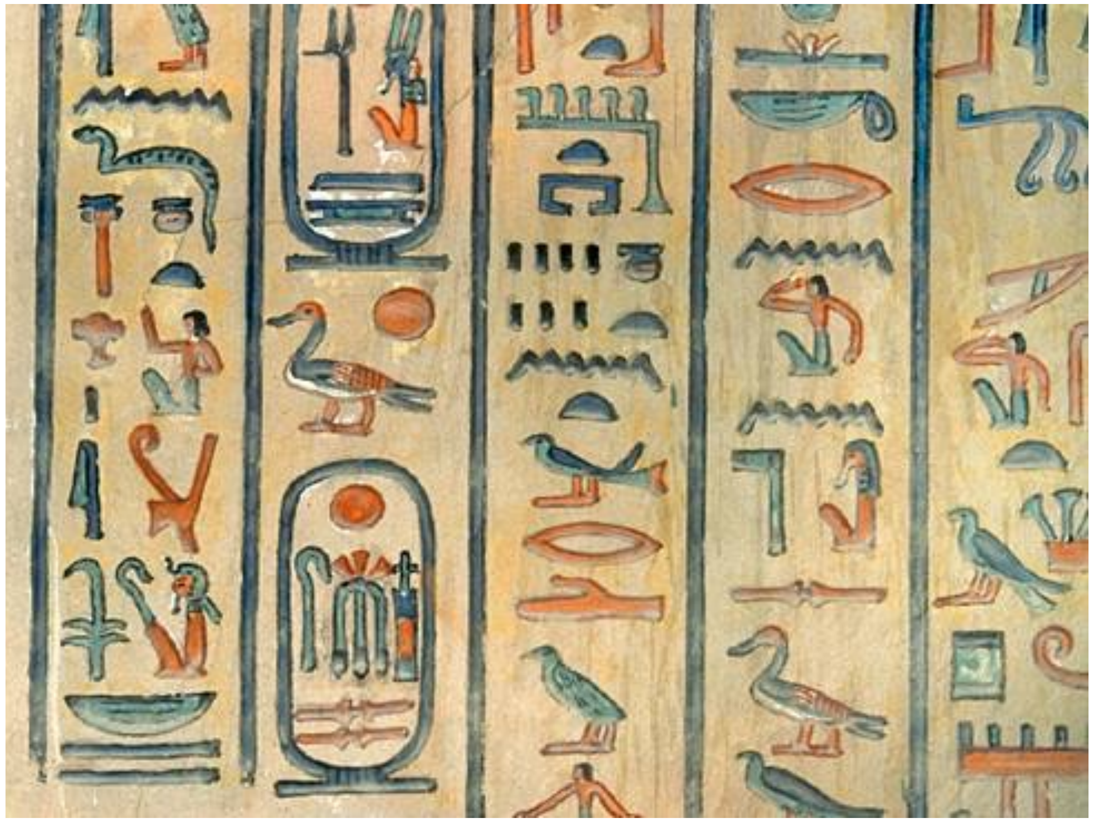
arXiv.org http://arxiv.org/abs/1711.03643

Why chemical abundances?

“*The principal value of abundance determinations from stellar spectra is the clues they give to the nuclear* ***history*** *of stellar matter and, more generally, of the matter in the whole Galaxy.*”

Cayrel & Cayrel de Strobel (1966)



Why solar twins?

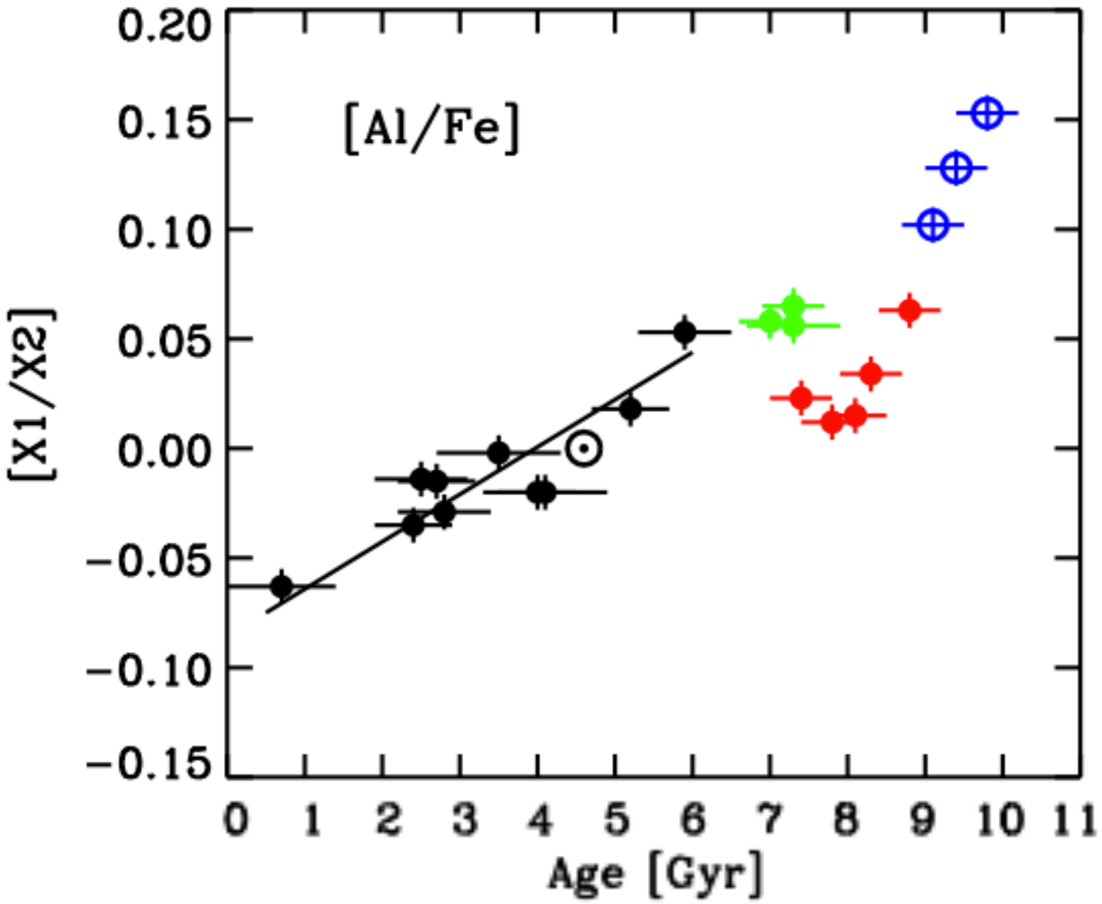
Solar twins, stars with atmospheric parameters very similar to those of the Sun: $T_{\mathrm{eff}\odot}\pm100$ K, $\log g_{\odot}\pm0.1$ dex, $[\mathrm{Fe/H}]_{\odot}\pm0.1$ dex.

Through a line-by-line differential analysis relative to the solar spectrum, we achieve very high precision in **atmospheric parameters** ($\Delta T_{\mathrm{eff}}\leq5$K, $\Delta\log g\leq0.2$, $\Delta[\mathrm{Fe/H}]\leq0.005$ dex), **ages** (≤1.0 Gyr) and **abundances** (≤0.01 dex).

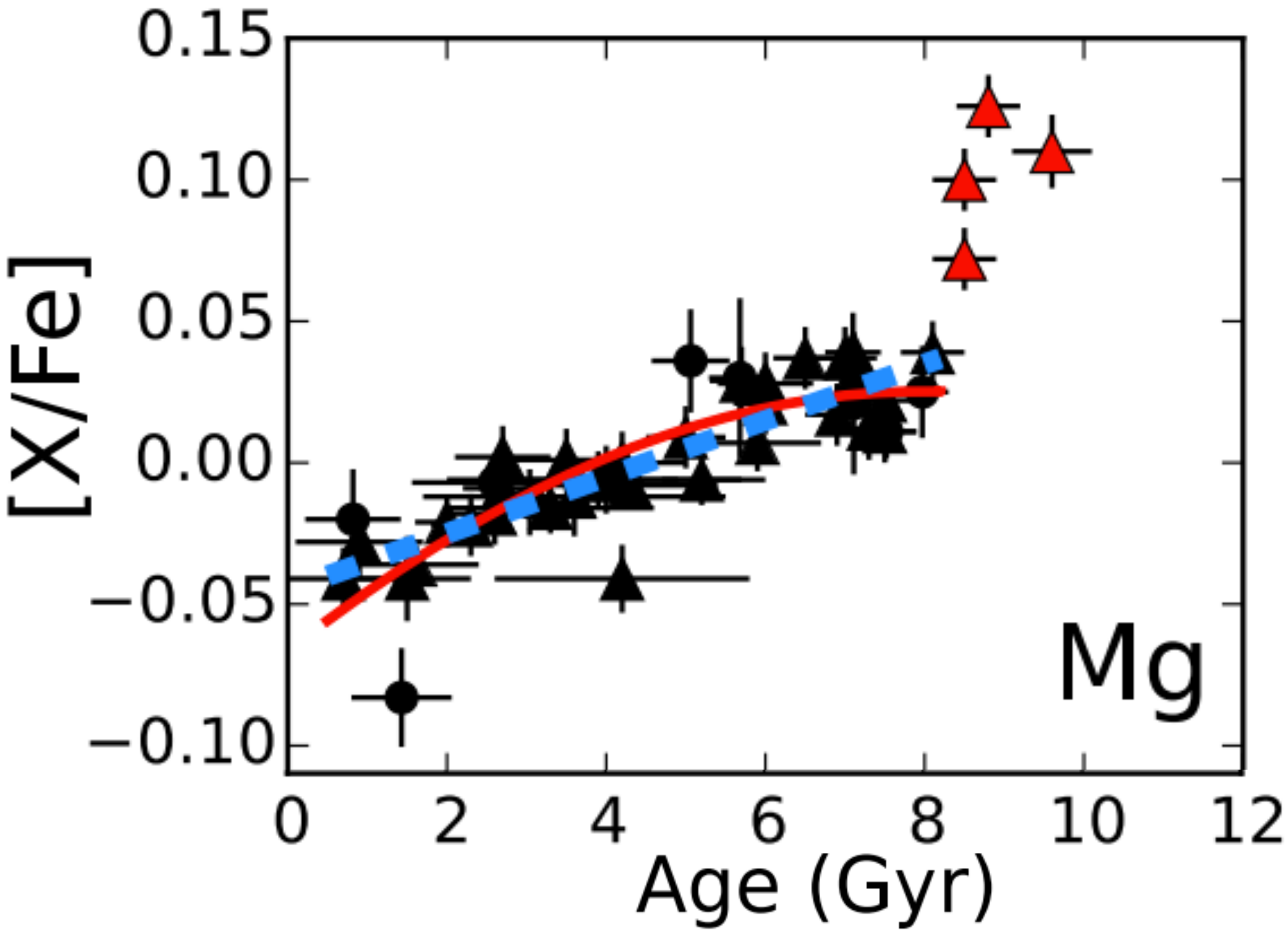
Note: high resolution ($\geq60\,000$) and S/N (≥400) are required!

Galactic chemical evolution with solar twins

Nissen (2016): 21 solar twins



Spina et al. (2016): 45 solar twins



Our data set and analysis

- **79 solar-twins** observed with HARPS@3.6m (R ~ 110 000; SNR ~ 1000)**.**
- **Differential line-by-line analysis** of the stellar spectra relative to the Sun (see Bedell et al. 2014).
- Abundance determinations for **12 n-capture elements** in addition iron (Sr, Y, Zr, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, and Dy).
- **Stellar ages** have been determined through isochrones.

Why the neutron-capture elements?

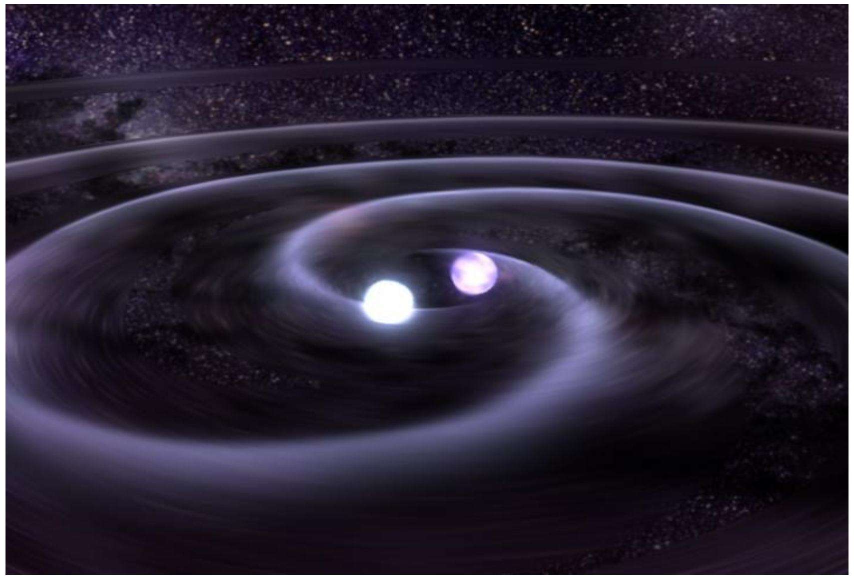
These species are produced via neutron capture of isotopes heavier than iron. This process can occur through two channels:

Slow-process

- Low- and intermediate-mass stars (0.5-8 M) during their AGB phase.
- Y, Ba, etc…

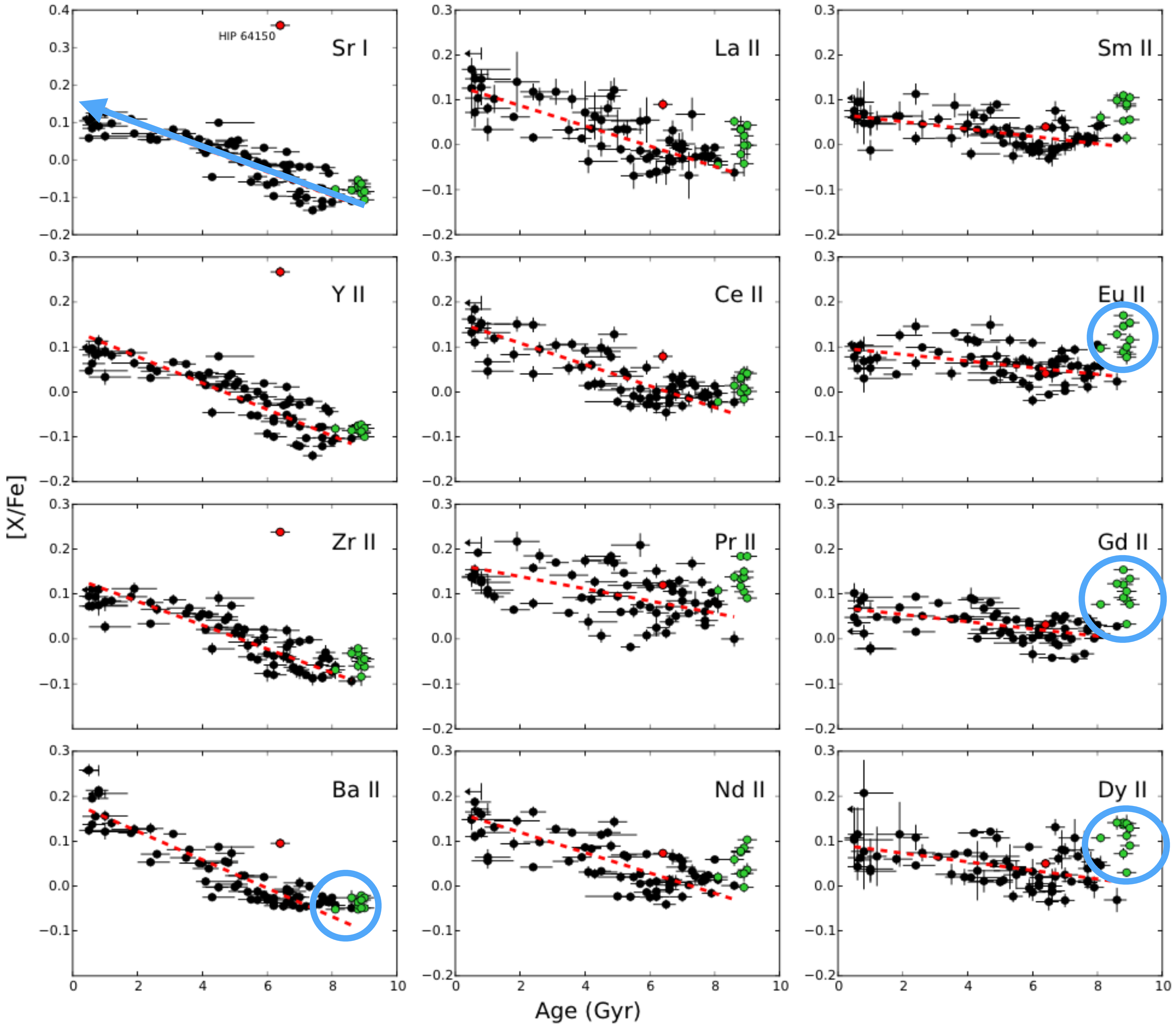
Rapid-process

- The production sites are not very well known: merging of massive compact objects, Type II SNe (?)
- Eu, Gd, Dy, etc…



These elements trace yields of a broad range of sites of nucleosynthesis with very different timescales.

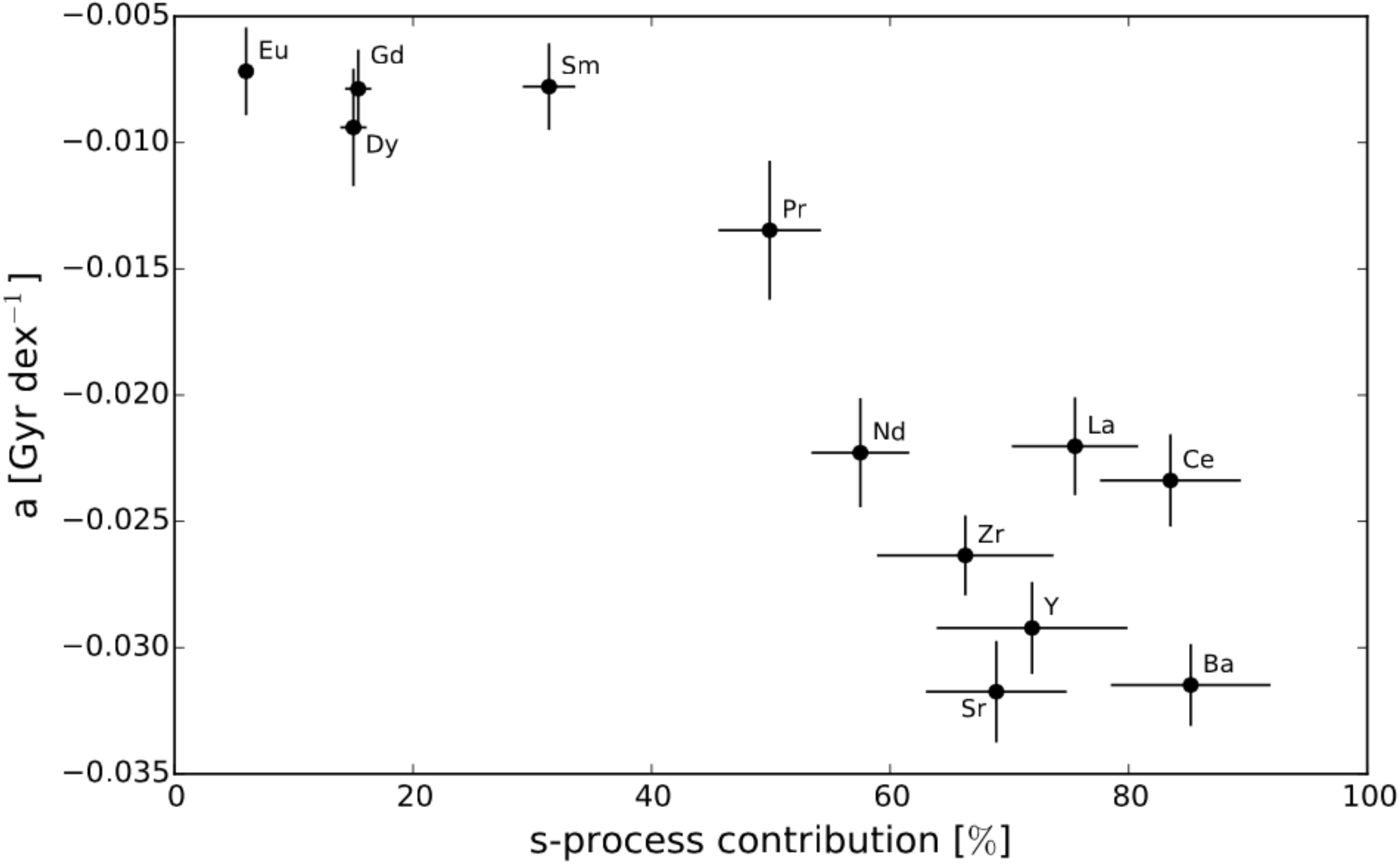
The evolution of the n-capture elements in the disk(s)



Chemically anomalous stars

Contribution over time to the Galaxy evolution

The contribution of AGB stars during the thin disk phase



The s-process elements have steeper slopes. ⟷ The enrichment in n-capture elements is mainly operated by AGB stars.

The production of *light* and *heavy* s-process elements

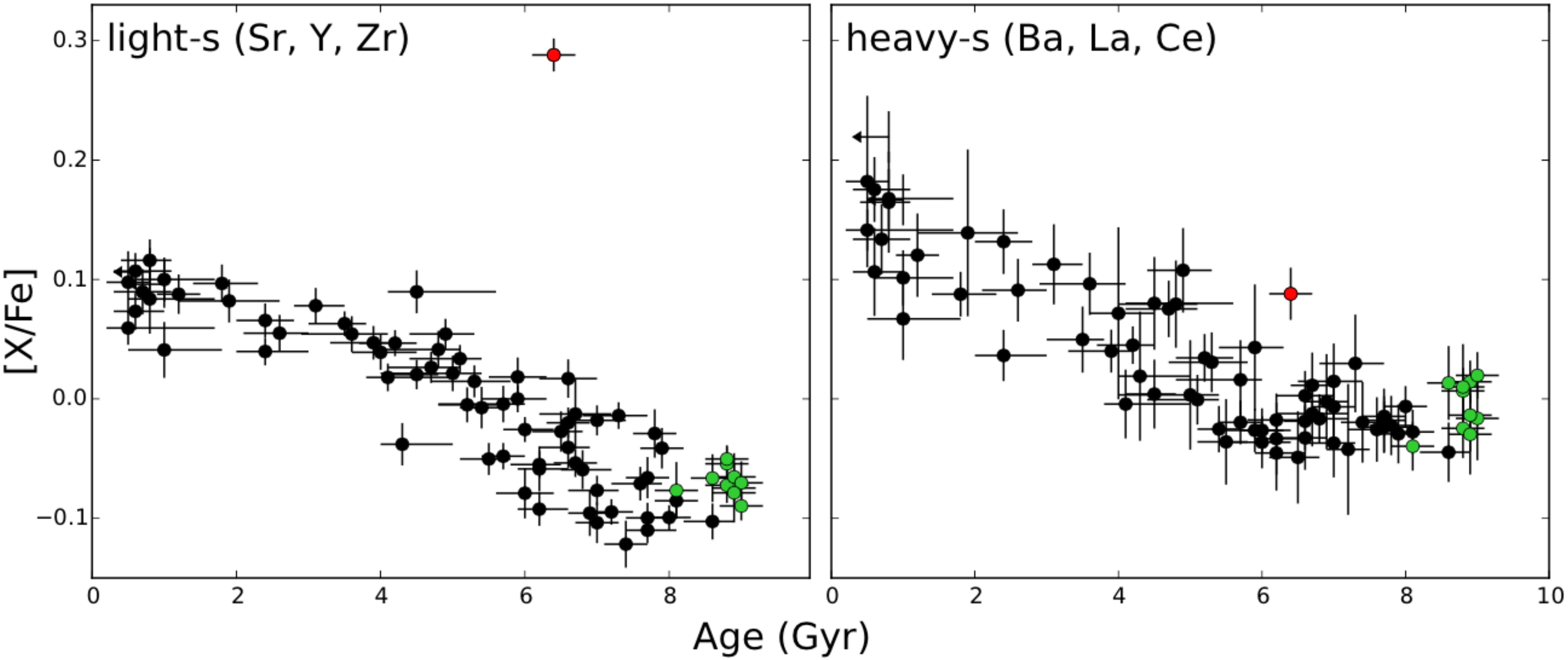
^{22}Ne neutron source

- At solar metallicity is the main source in intermediate-mass stars (5-8 M).
- Lower flux of free neutrons.

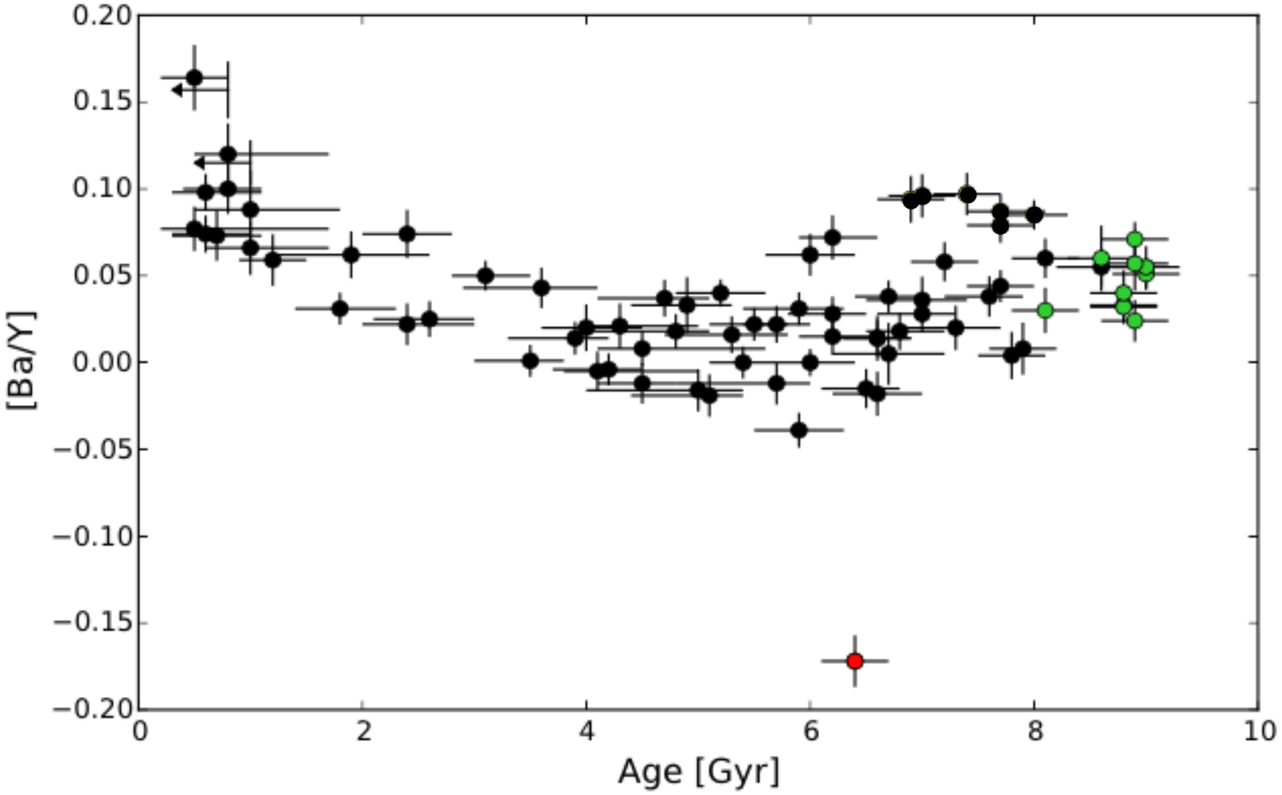
^{13}C neutron source

- At solar metallicity is the prominent source in low-mass stars (≤3 M).
- Higher flux of free neutrons.

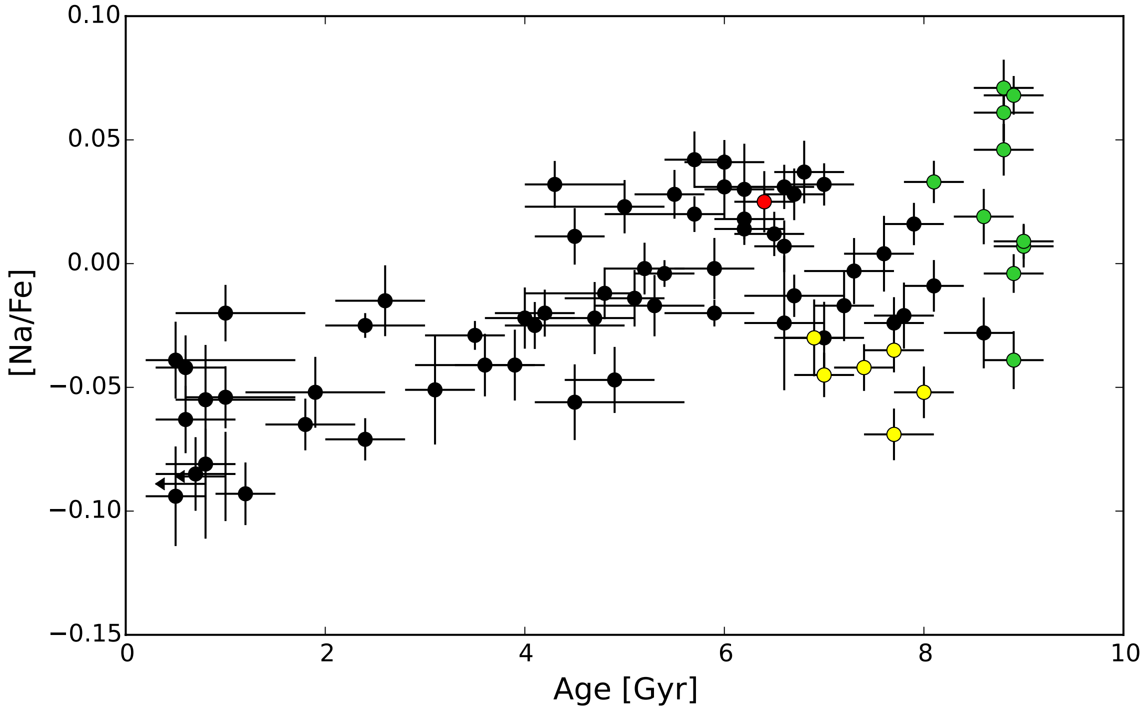
The ^{13}C neutron source favour a higher production of *heavy* s-process elements (Ba, La, Ce) at the expenses of the *light* s-process elements (Sr, Y, Zr).

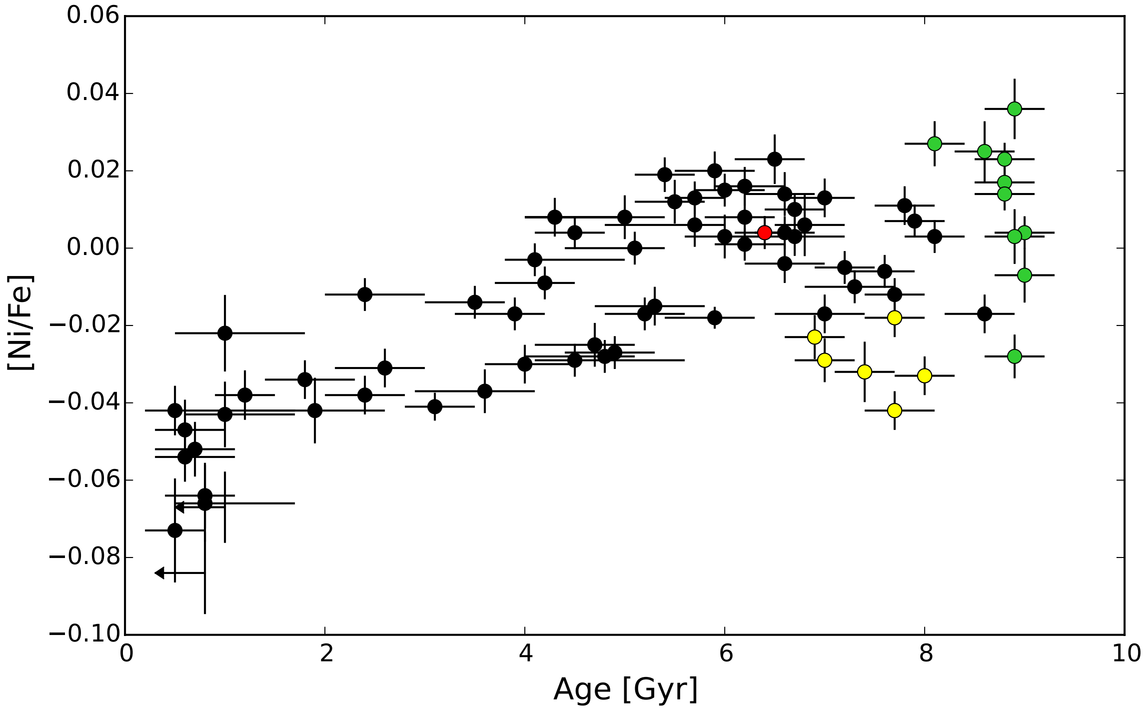


The production of *light* and *heavy* s-process elements



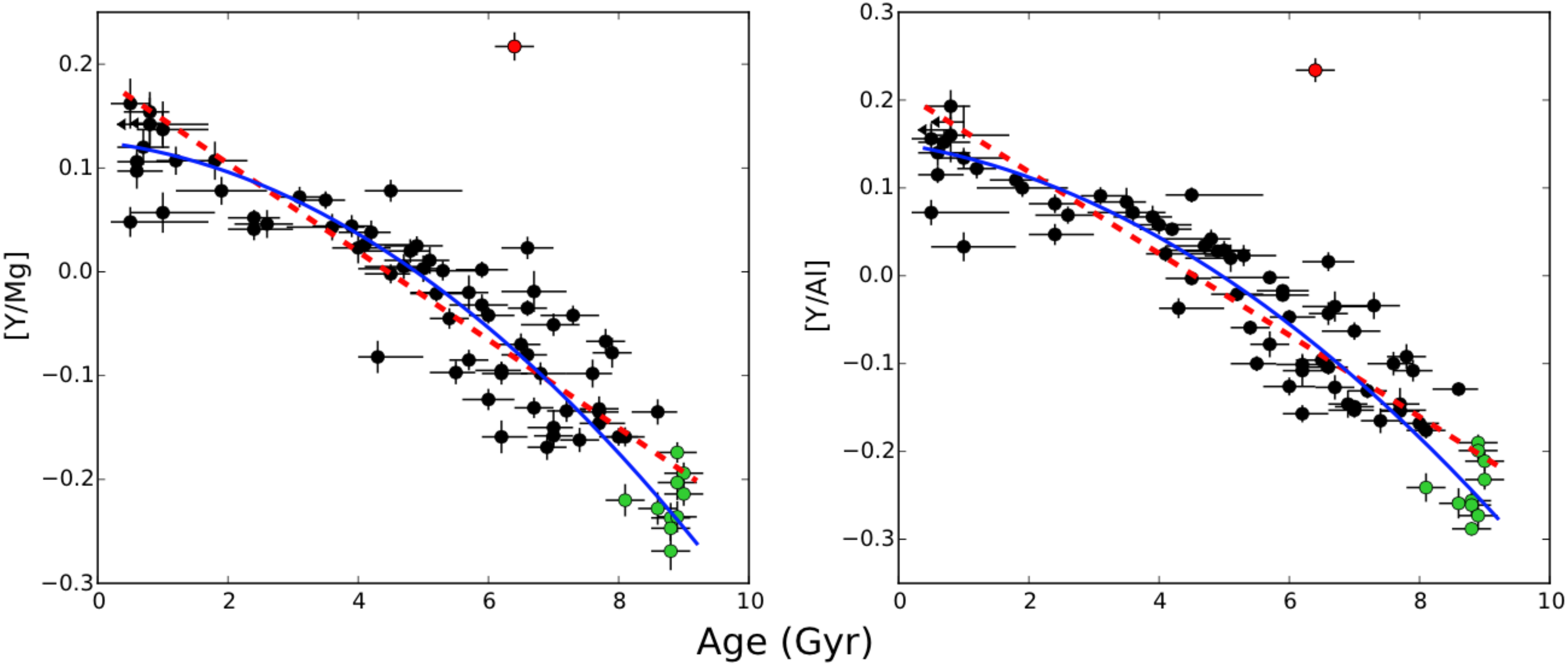
- **1-5 Gyr**: [Ba/Y] increases as time goes on. Low-mass AGB stars of solar and sub-solar metallicity yield more Ba than Y.
- **5-6 Gyr**: inversion of the trend?
- **6-8 Gyr**: bunch of old thin disk stars with high [Ba/Y] ratios. The production of heavy s-process elements is more favourable at lower Z (e.g., Busso 2001). Stars formed by gas polluted by metal-poor AGB stars?





The production of Na and Ni in core-collapse SNe is controlled by the neutron excess (Venn et al. 2004; Kobayashi et al. 2006).

Chemical clocks



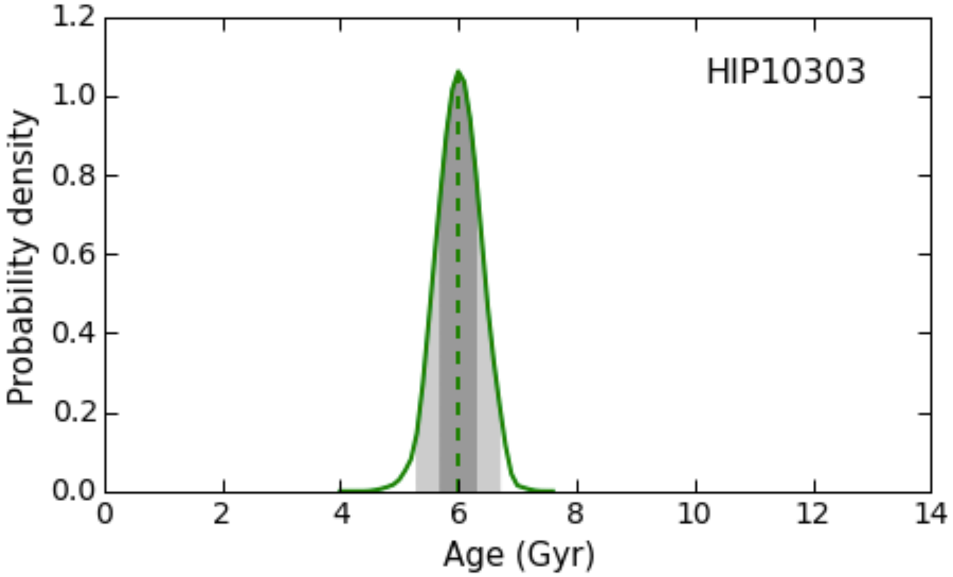
[Y/Mg] and [Y/Al] have a very tight and steep dependence on time (see also da Silva et al. 2012; Nissen 2015).

→

These ratios can be used as chemical clocks: average precisions of 0.5-0.8 Gyr.

Only for solar-twin stars! at lower metallicities the [Y/Mg] and [Y/Al] vs age relations flatten (Feltzing et al. 2017)

Take home messages



Differential analysis of solar-twin stars relative to the solar spectrum allows to achieve an incredibly high precision in abundances (<0.01 dex) and stellar ages (~0.5 Gyr).

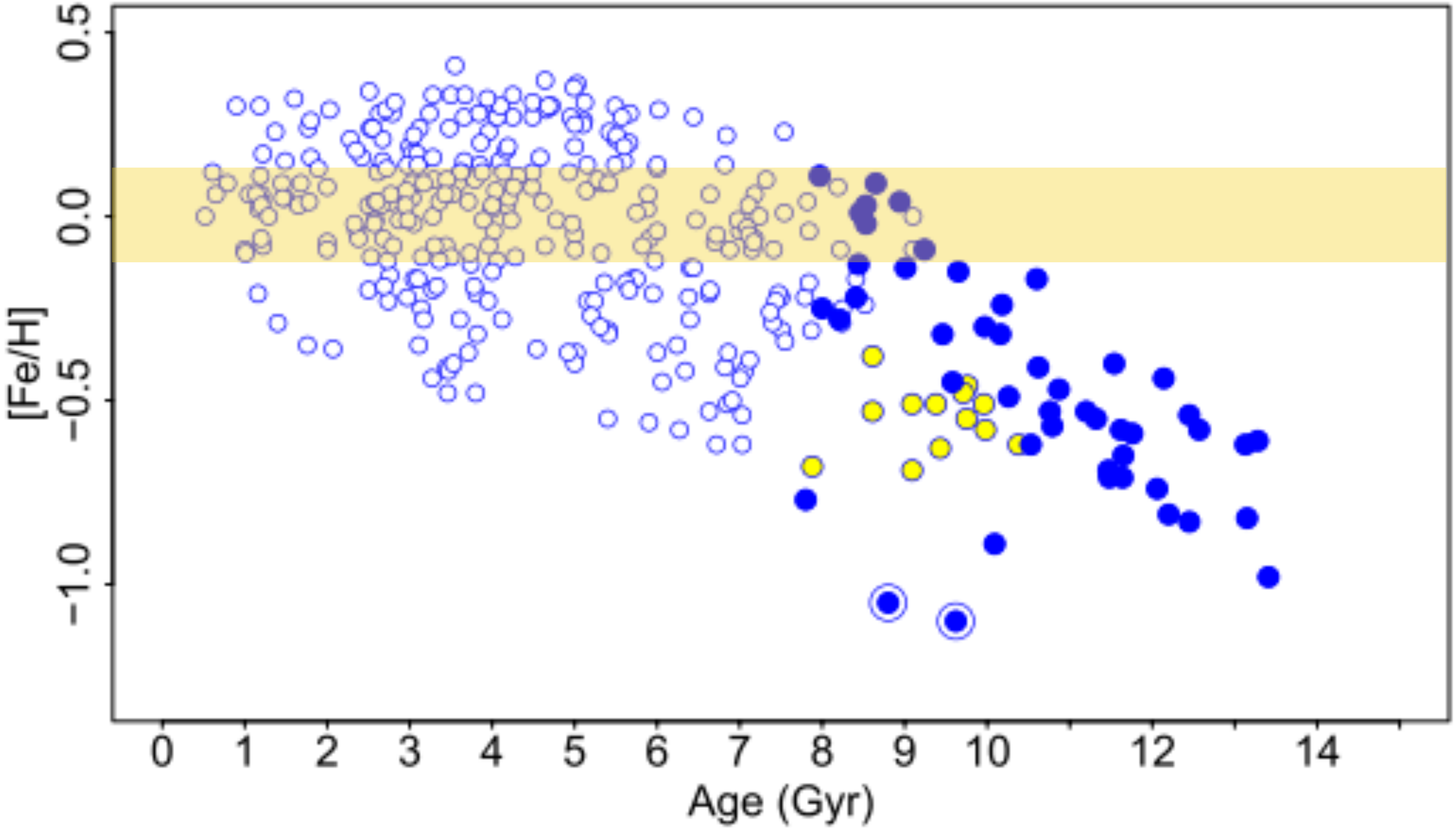
Knowledge of the [X/ Fe]-age relations is a gold mine from which we can achieve a great understanding about the processes that governed the formation and evolution of the Galactic disk.

arXiv.org **http://arxiv.org/abs/1711.03643**

Next challenges

Develop models of Galactic chemical evolution that can reproduce the [X/Y]-age relations.

Study the [X/Y]-age diagrams for stars with different metallicities. Large spectroscopic surveys will allow us to identify the best targets.



Haywood et al. (2013)