The abundances of *s*-process elements:

temporal and spatial trends from observations of open clusters

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With Carlos Viscasillas Vazquez, Giada Casali, Sofia Randich, Lorenzo Spina, Sergio Cristallo, Diego Vescovi, Martina Baratella, Valentina D'Orazi, Gabriele Cescutti, and many others

Perugia, 24/06/2022

The first time I met Maurizio

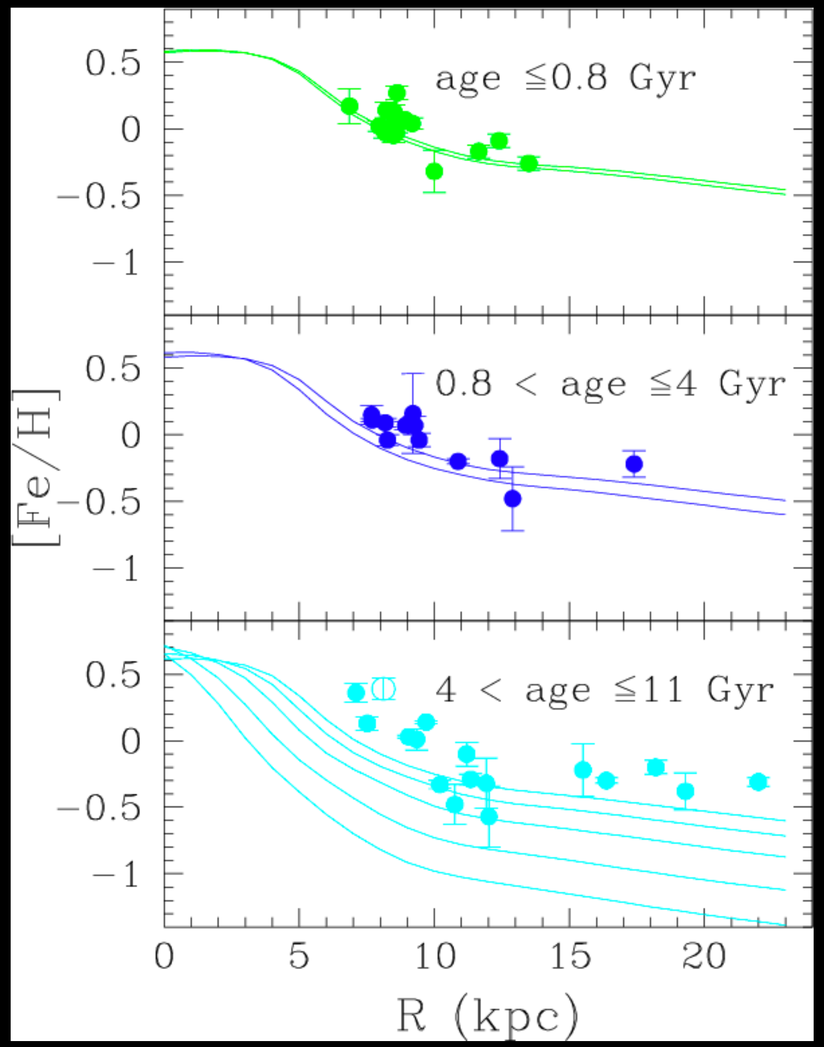
IAU Symposium 234
Planetary Nebulae
2006

Perugia, 24/06/2022

....but yet there were no heavy elements in my life

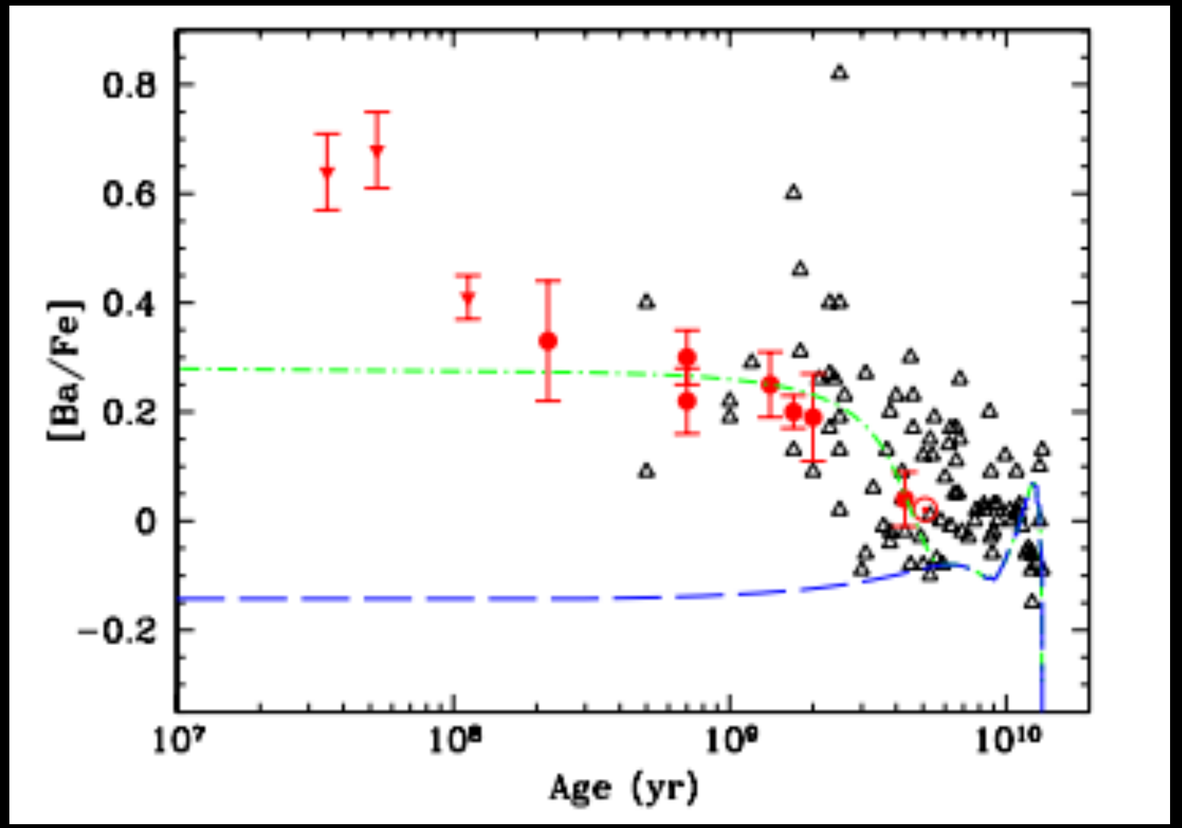
Short story of a long collaboration

....few years later....



Magrini+09

Surprising observational results, missing theoretical interpretation....I remembered that I met Maurizio...



D'Orazi+09

Short story of a long collaboration

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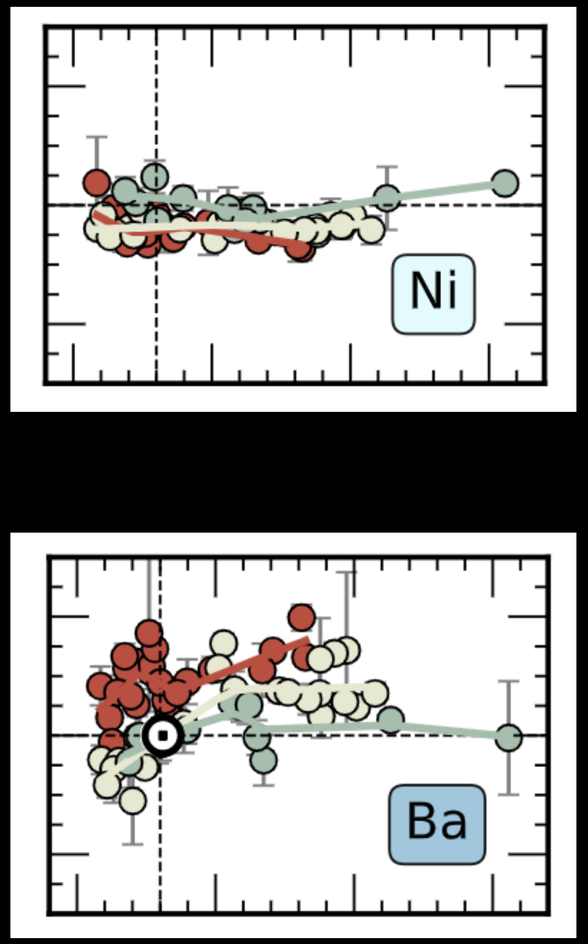
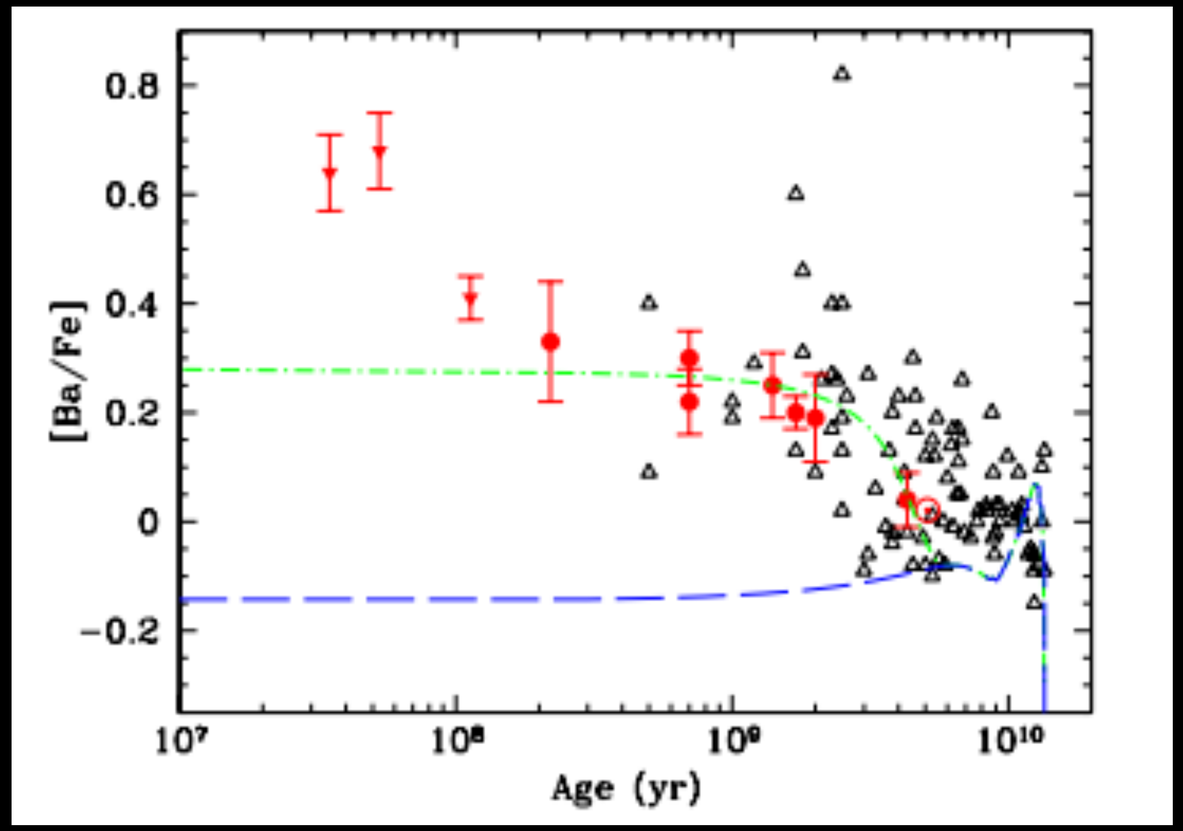


Magrini+22

Surprising observational results, missing theoretical interpretation....I remembered that I met Maurizio...



D'Orazi+09

See Martina's talk for the observed overabundance of Ba

Short story of a long collaboration

☆ **Maurizio Busso** Tutti i...grini@inaf.it 3 December 2008 at 11:14 Details

Paper on Ba enrichment and much more.....

To: Daniele Galli, Cc: Sofia Randich, Valentina D'Orazi, Laura Magrini

MB

Cari amici,

chiedo scusa per il tempo impiegato, e per la lunghezza di questo messaggio, ma in questi giorni ho fatto moltissimi test in quanto, come al solito, le cose si sono rivelate diverse del previsto. Per anticipare le conclusioni, mi e' ormai chiaro che io avevo torto e voi ragione, e soprattutto credo di avere capito il perche'. Non solo moltiplicare per un fattore notevole lo yield del Ba in piccole masse e' possibile, ma forse e' anche logico e necessario per motivi piu' generali.

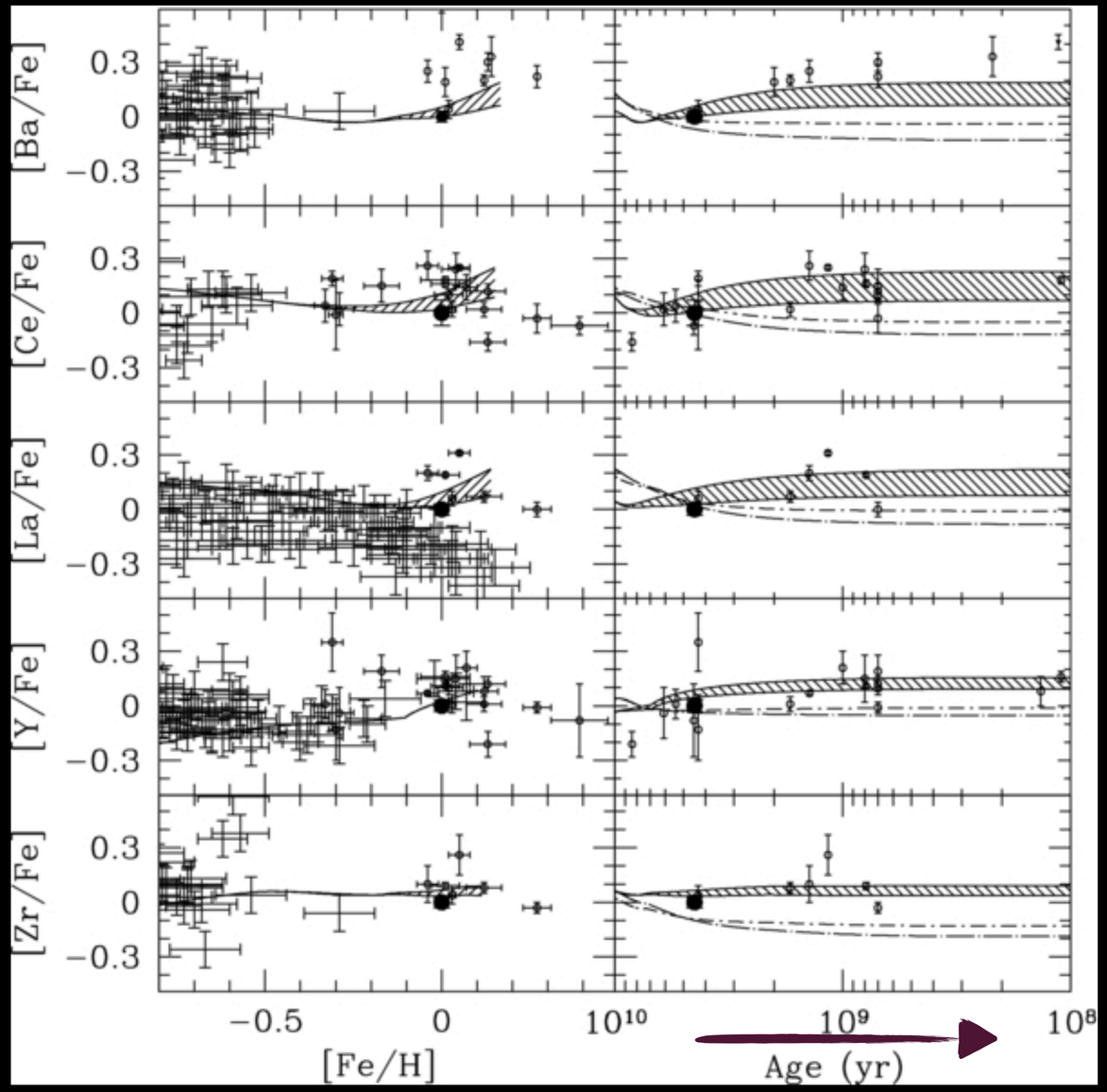
3 December 2008

Maurizio's fundamental insight and contribution, the role of low-mass AGB stars is discussed for the first time

BINGO! un fattore 3 di maggiore efficienza nel produrre 13C vuol dire un fattore 5-6 nel produrre il Ba.

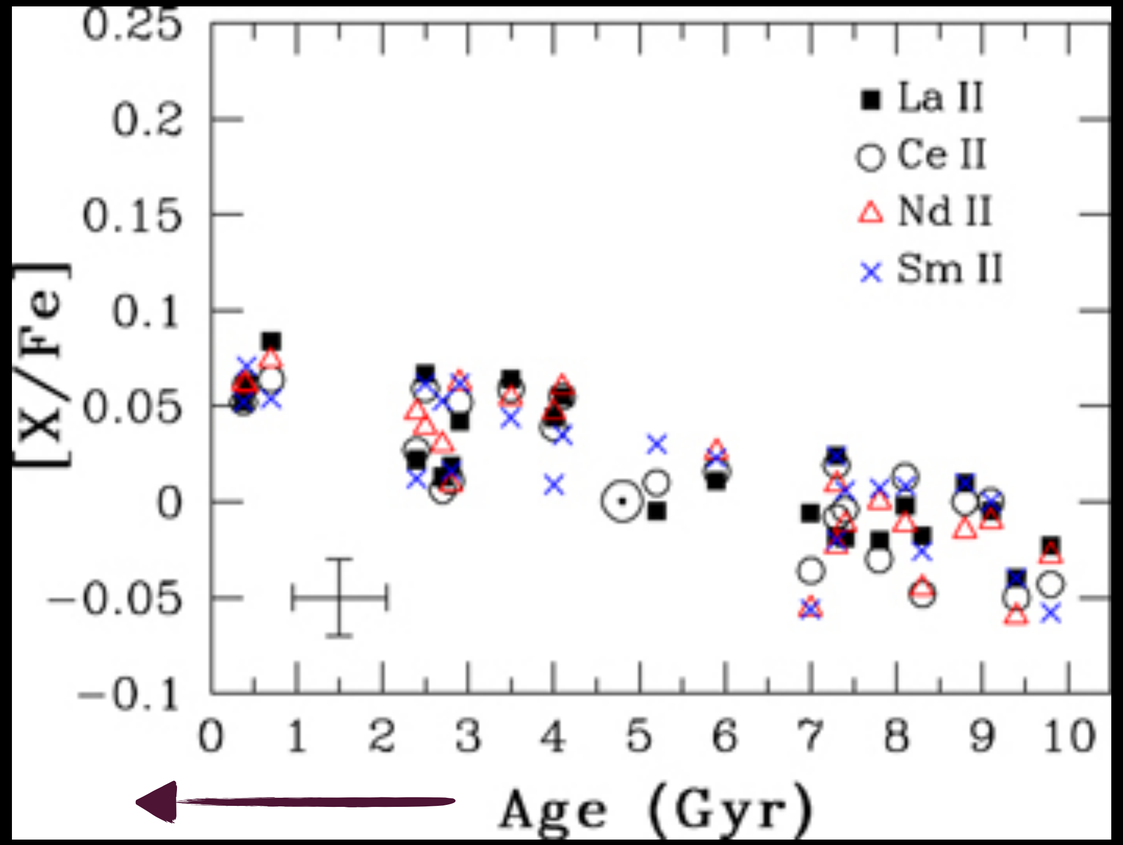
Vi piace? E' sufficiente a farmi perdonare i miei errori? Vorrebbe dire che le stelle, diciamo, di 3 Mo producono poco 13C, quelle di M=1.2 -1.5 molto di piu', con una media che deve essere quella di Busso et al 2001 (ST/1.5).

Adding pieces to the intricate puzzle: collaboration between Arcetri and Perugia



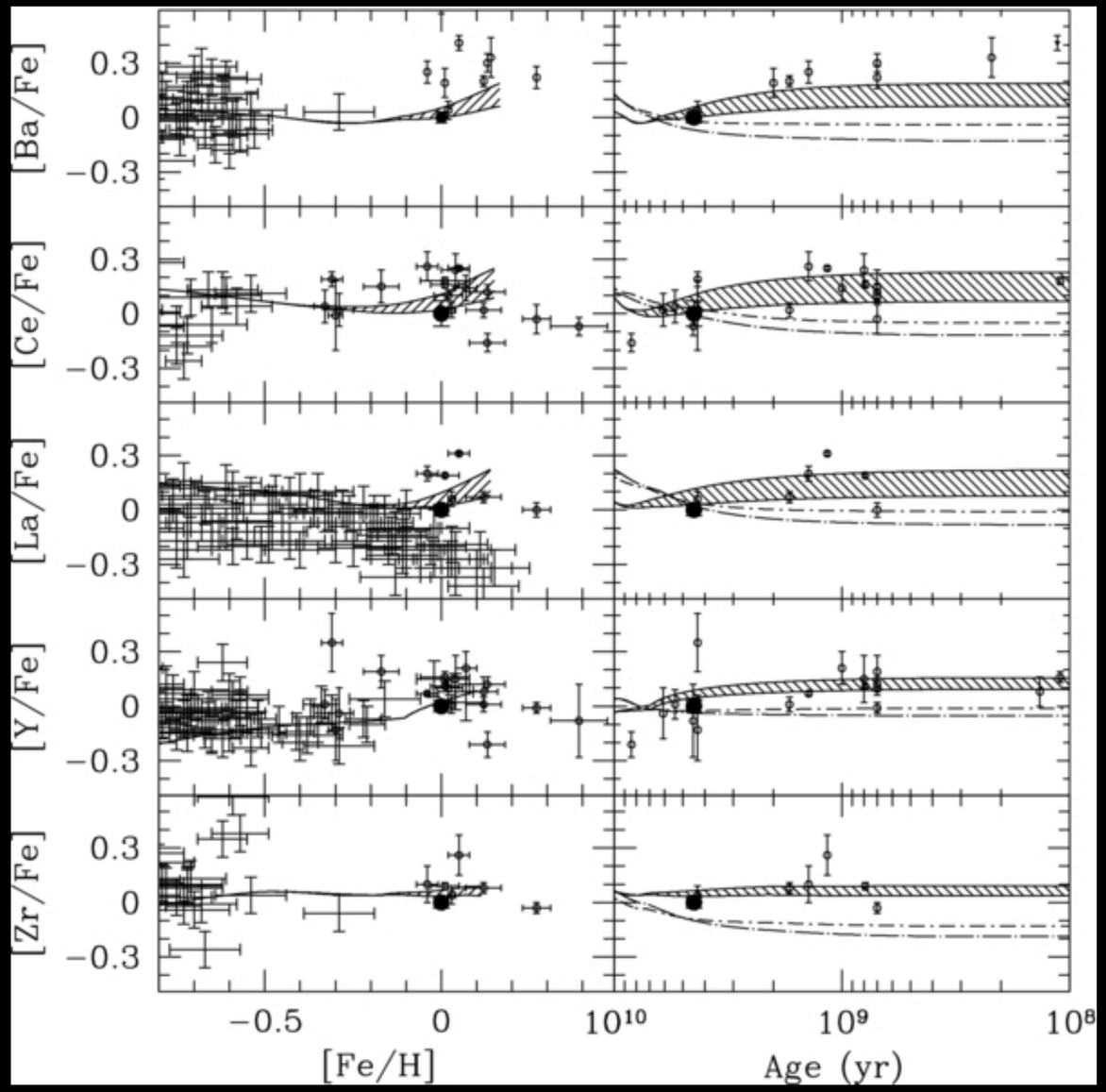
Maiorca+12

Not only Barium, but all the s-process element abundances increase with time



Lambert&Reddy17

Adding pieces to the intricate puzzle



Maiorca+12

Adding more elements and confirming the trend

Consequences:

- Constraints on the ^{13}C pocket and on the mixing episodes in evolved stars of a mass below 1.5 M⊙.
- Similar requirements were already inferred from very different constraints (Palmerini et al. 2011) to explain the isotopic admixture of oxygen in presolar oxide grains (many other results on this trend, see Palmerini et al. 2021).
- On the composition of the youngest stars, possible application of the s-process abundances as age tracers.

Enlarging the sample of open clusters:
Best tracers of time evolution of abundances

We were limited to a small statistics and to few stars with an age measurement

Ages are among the most difficult quantities to be measured

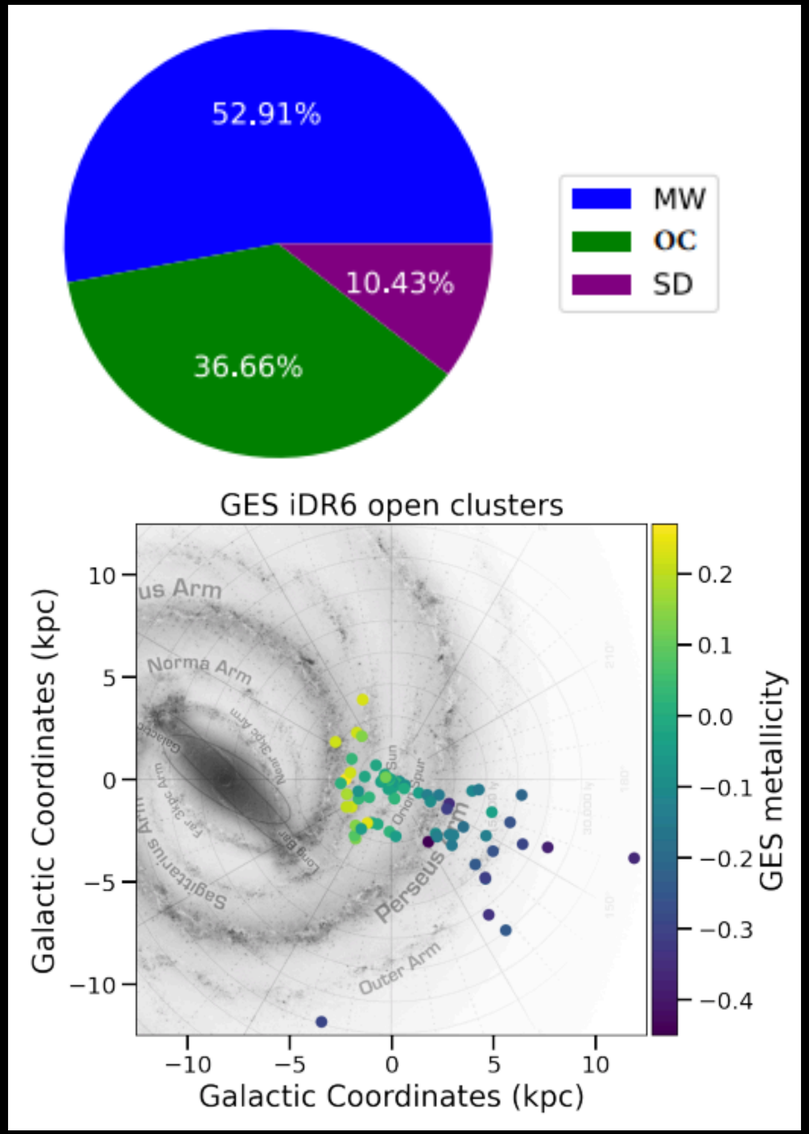
Need of large spectroscopic surveys and reliable ages

2011: First observations of Gaia-ESO

2013: Launch of Gaia

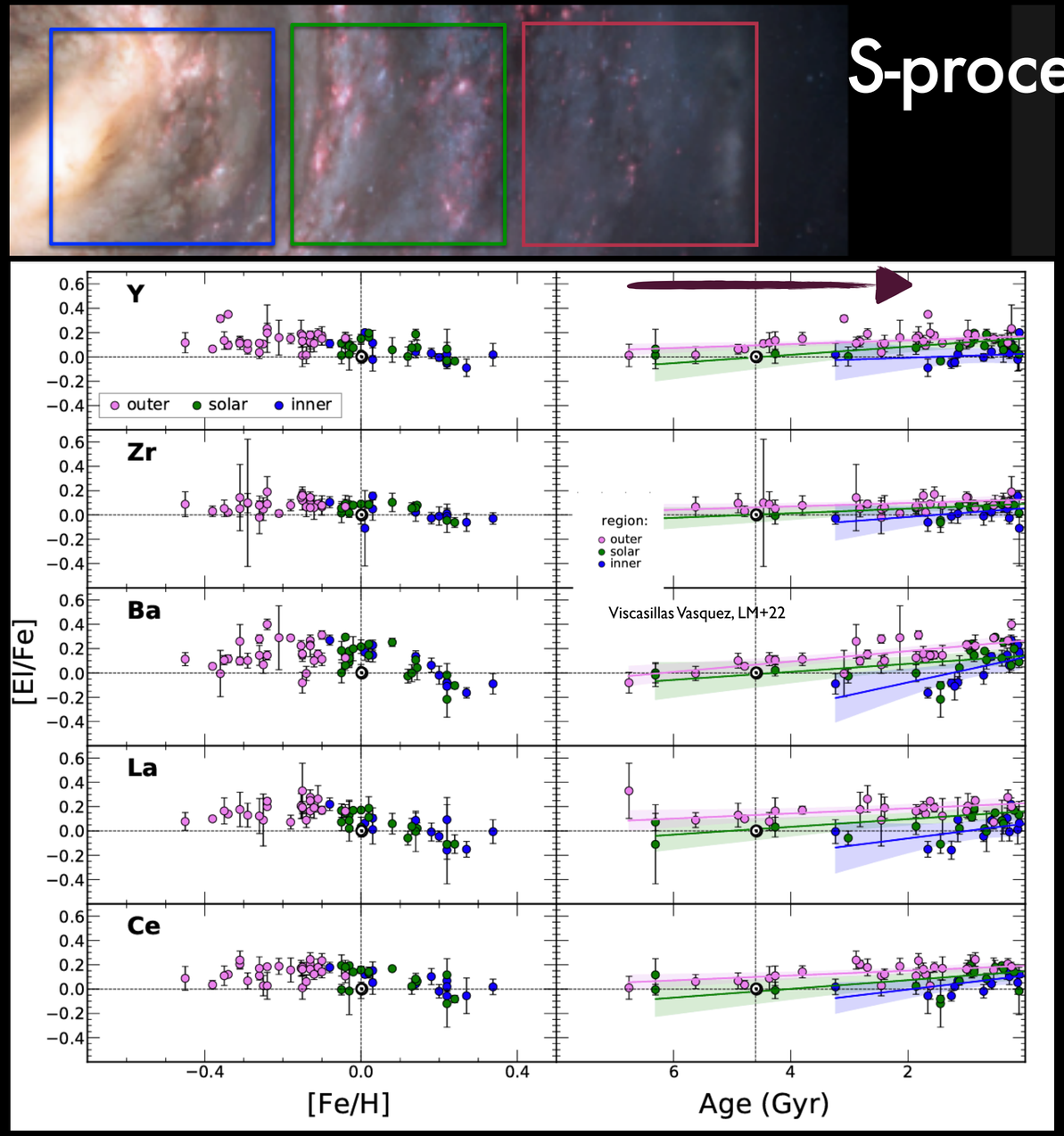
Gaia-ESO: Technical Details

Observations at VLT (8 m)
Duration: 2011-2018 for 340 nights
Spectral Resolution: R=47000 with UVES
Final release (June 2022): 10^4 UVES stars
Abundance Precision: 0.05-0.1 dex for 30 species (UVES)
Neutron capture elements: Y, Zr, La, Ce, Ba, Eu, Nd, Mo, Pr



Randich+22

S-process evolution with Gaia-ESO



Viscasillas Vasquez, LM+22

Confirmation of the previous finding of a recent increase of the abundances of all s-process elements

Differences in the time growth in different Galactocentric regions

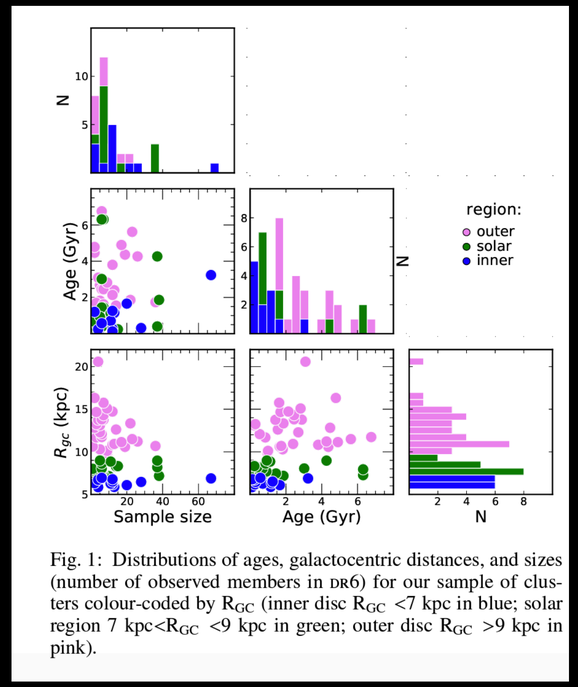
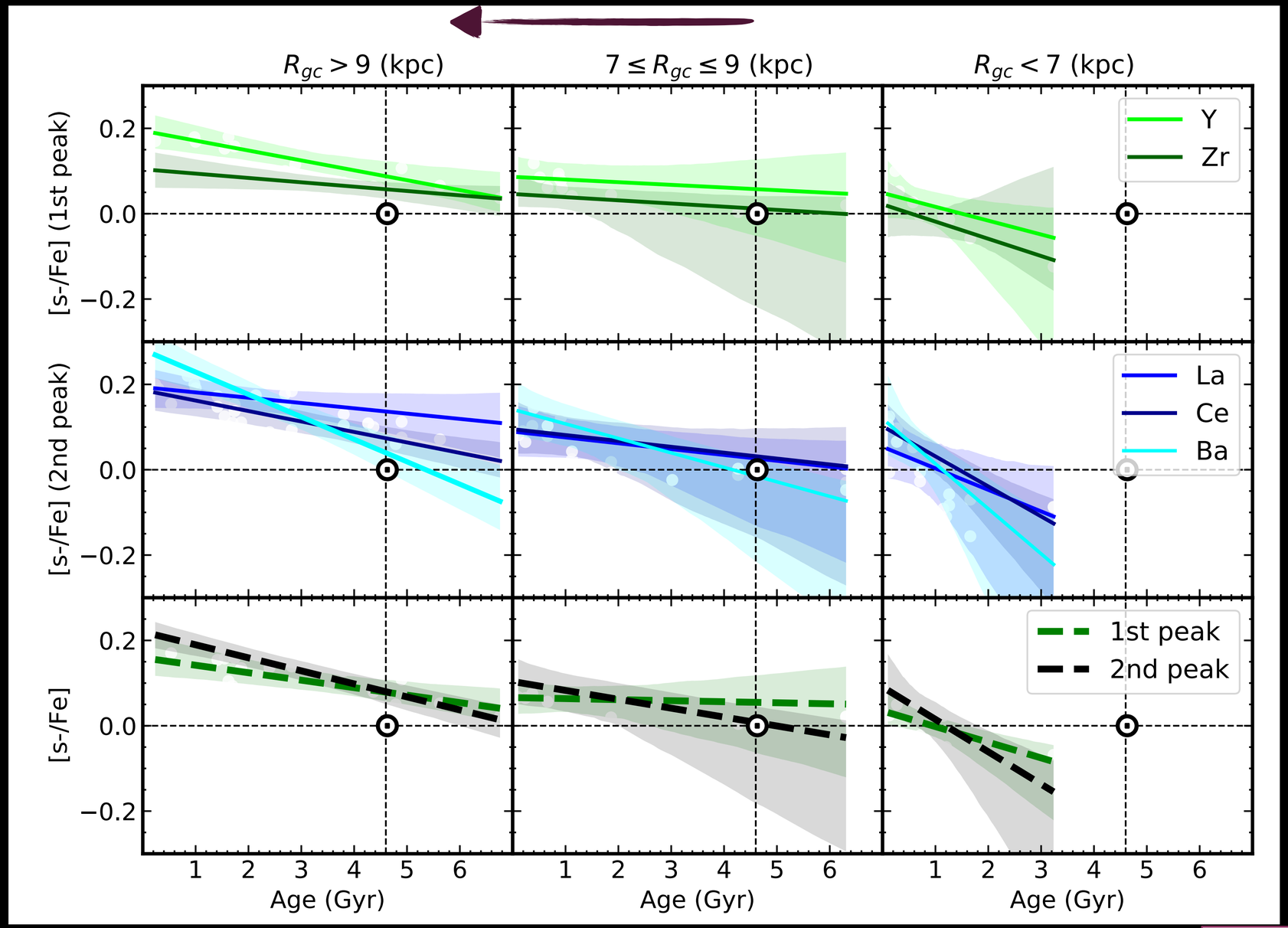


Fig. 1: Distributions of ages, galactocentric distances, and sizes (number of observed members in DR6) for our sample of clusters colour-coded by R_{GC} (inner disc R_{GC} <7 kpc in blue; solar region 7 kpc<R_{GC} <9 kpc in green; outer disc R_{GC} >9 kpc in pink).

Radial and temporal evolution of ls and hs elements



- Growth with time of [El/Fe]
- The changes of the relations in the different radial bins (with different metallicities) indicates a metallicity-dependent yields for s-process elements
- Differences between ls (first peak) and hs (second peak) elements

Magrini+22

A possible explanation

To produce the "less" s-process elements at high metallicity, acting in a different way for light and heavy elements:

- mechanisms able to depress their production; FRUITY (opacity-induced overshoot) and FRUITY magnetic (with magnetic-buoyancy induced mixing) yields
- At low metallicities: neutron fluxes are sufficiently high to robustly produce Y but not to saturate the first s-process peak and move to the second peak, so efficiently producing Ba.
- At higher metallicities: the net Y production of magnetic models drops faster than standard FRUITY models. The decrease is less evident for the Ba yields

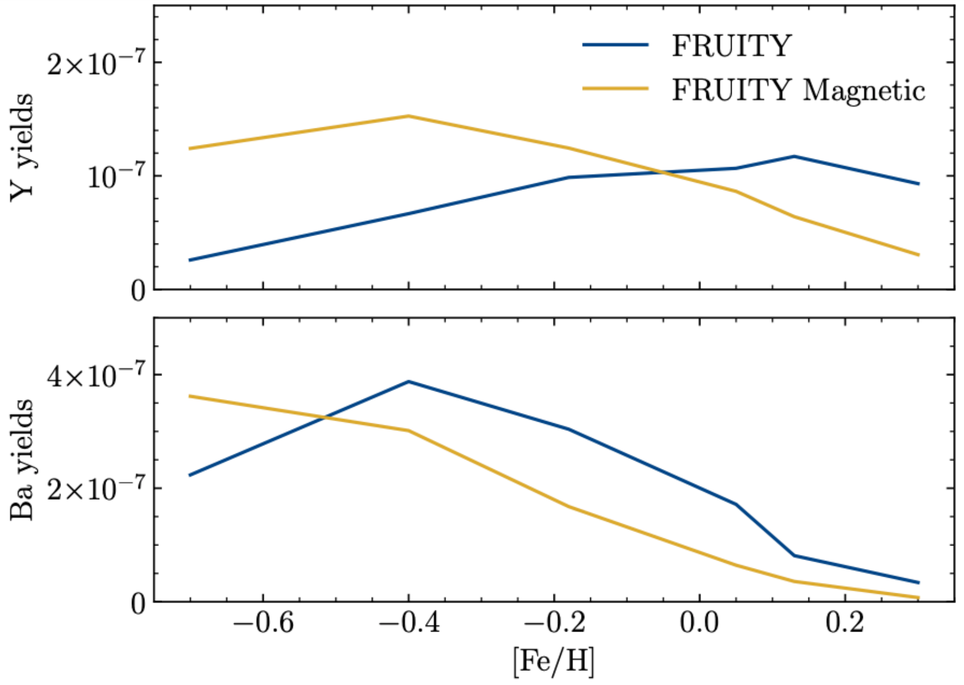
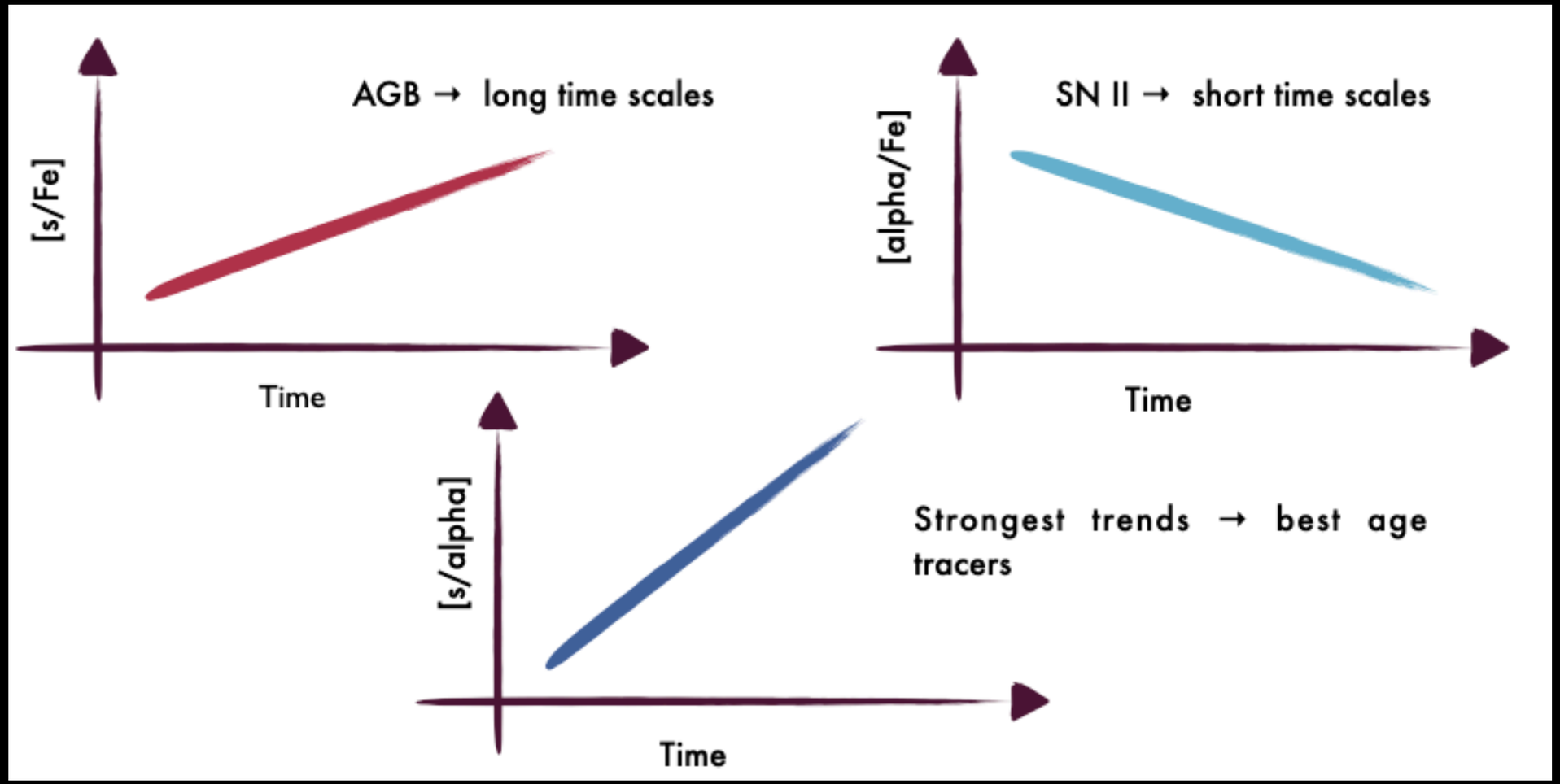


Figure 4. Net yttrium (top panel) and net barium (bottom panel) yields as a function of [Fe/H] for a 2 $M_\odot$ AGB star as predicted by FRUITY and FRUITY Magnetic models.

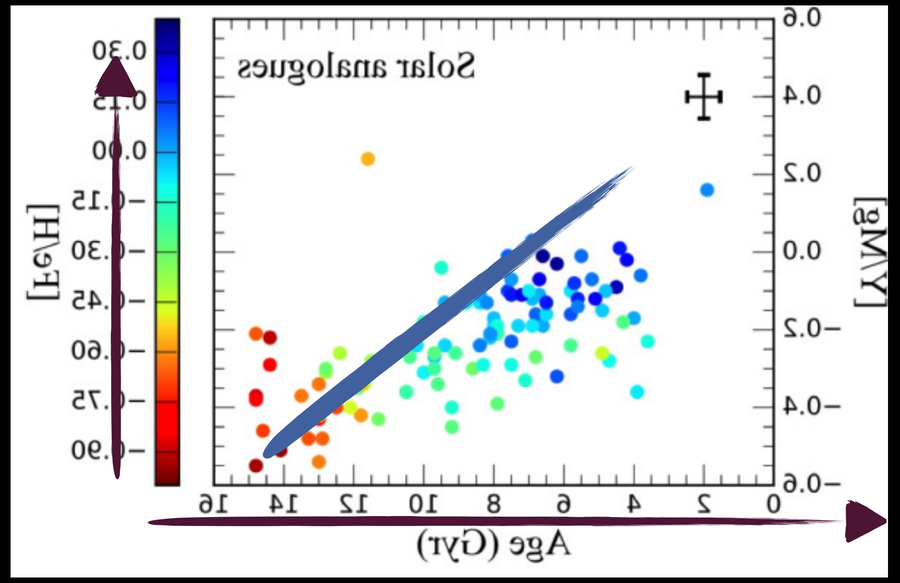
Magrini+21, Vescovi 22

Measuring ages using abundance ratios

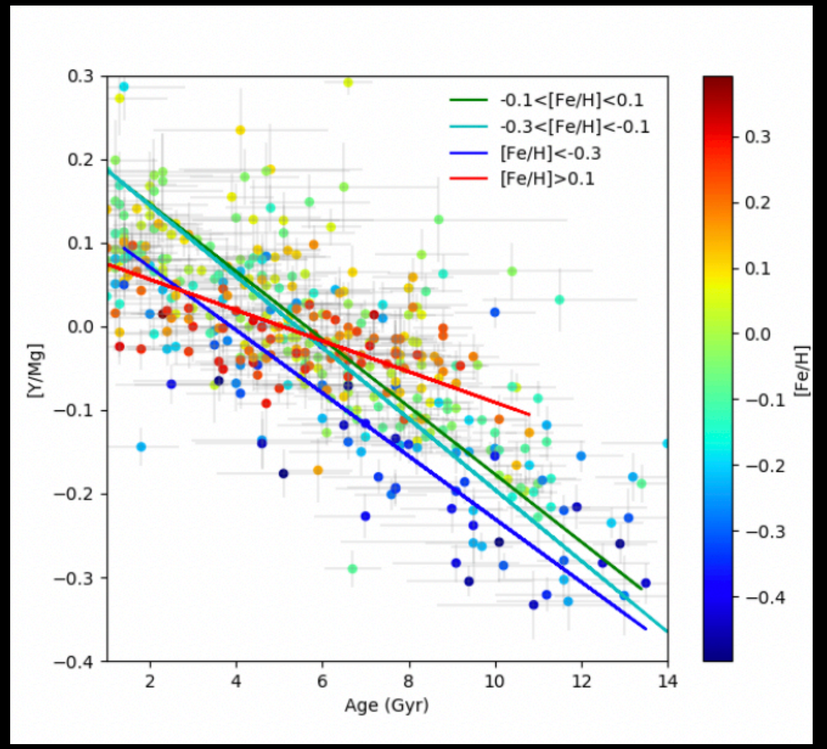


Measuring ages using abundance ratios

[s/alpha]



Time



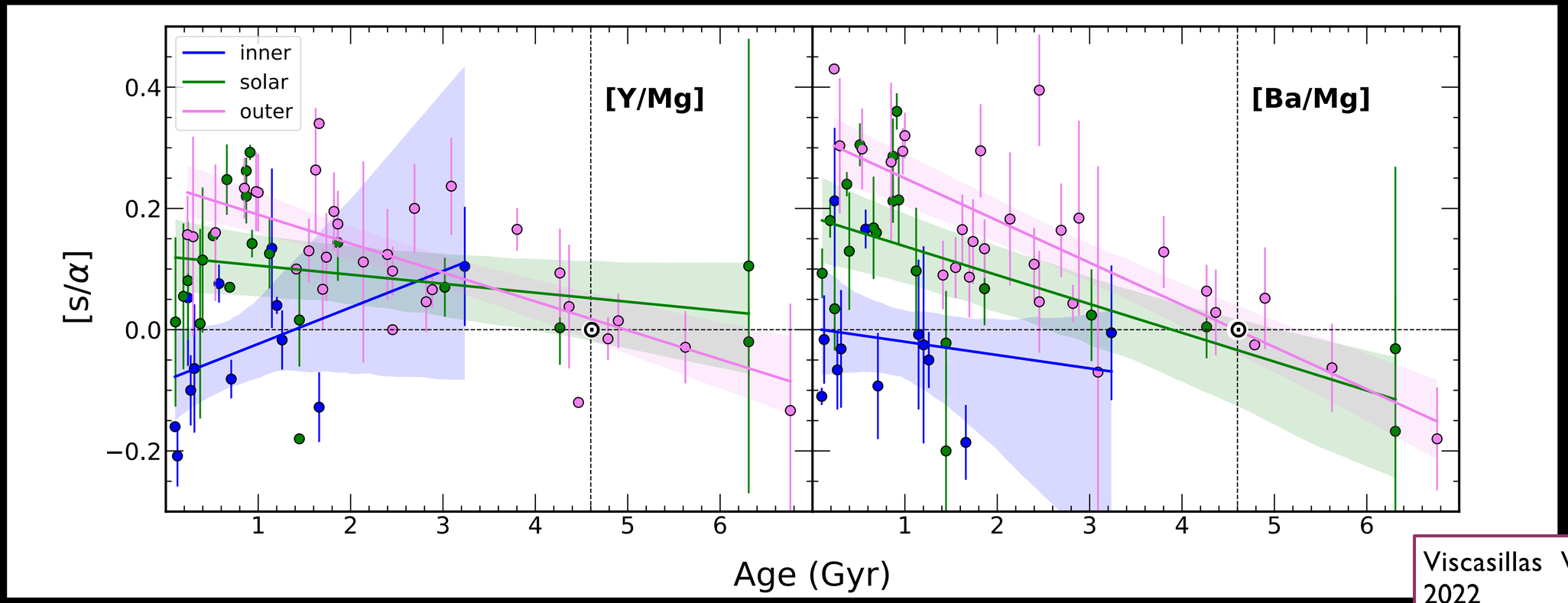
Casali et al. (2020)

- Good relation, but still some scatter
- Related to secondary effects, like metallicity

- [Y/Mg] to infer (statistically) stellar ages

- **Caveat:** this relation was initially built with a sample of solar twins stars located in the solar neighbourhood.

- We can extend it to different radial regions with open clusters



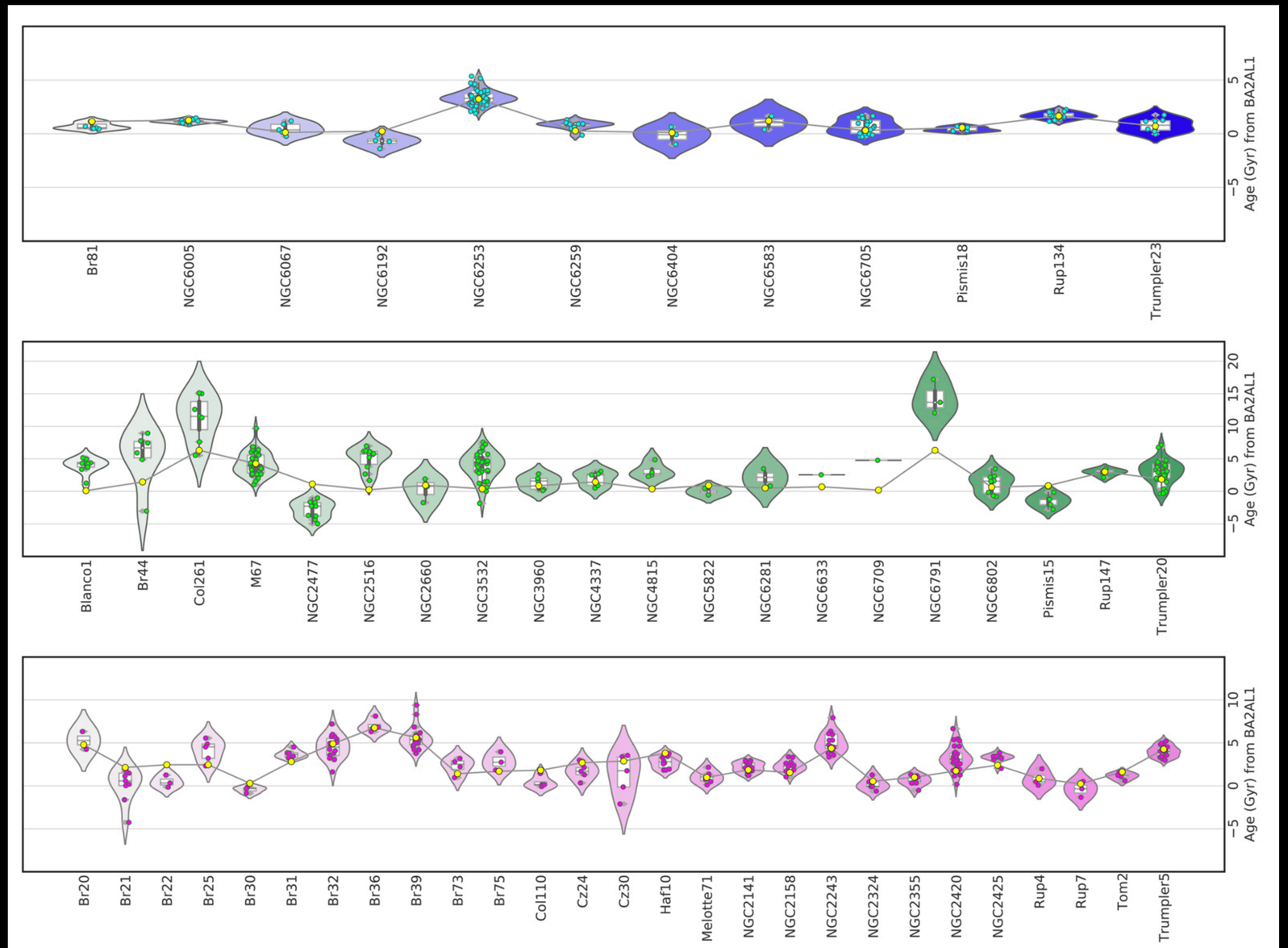
Viscasillas Vasquez et al. 2022

Can we apply it to the whole Galactic disc?

Open clusters indicate a change in the [Y/Mg] and [Ba/Mg] behaviour in the inner galactic regions

Limited by clusters' age ⇢ see Giada's talk for the use of ages from asteroseismology

Recovering the cluster ages: using multi-parametric relationships



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Implications for the study of our Galaxy

Ages derived for the [s/alpha] abundances ⇢ considering the radial variation of the relations

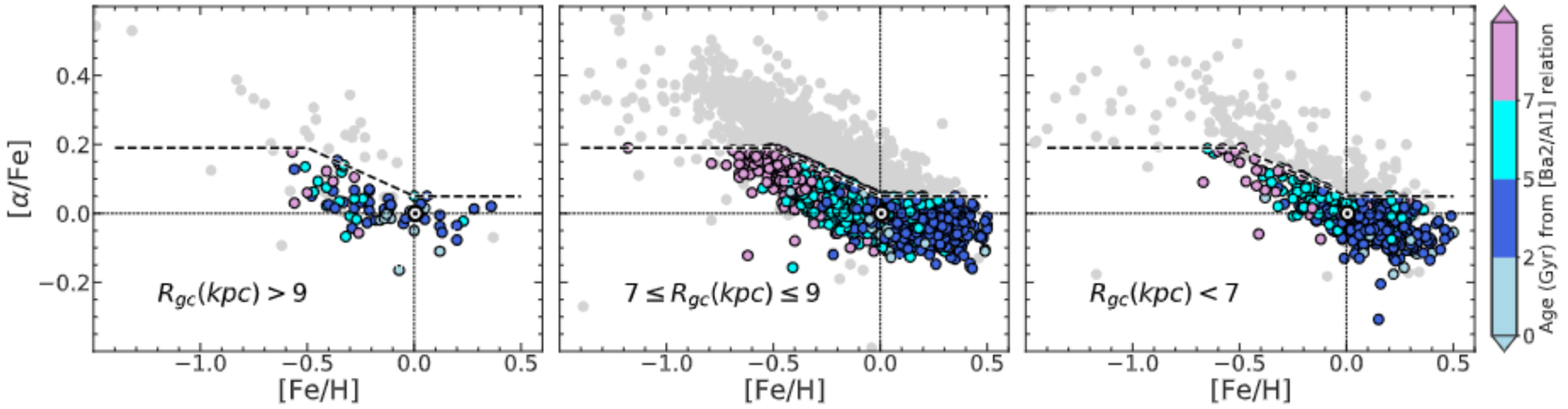

Fig. 10: [Fe/H] versus [α/Fe] for field stars in the three radial regions coloured with the inferred ages using the [Ba/Al] relations computed for each radial region.The dashed black line is the dividing line given by Adibekyan et al. (2012). In the background (gray color) the field stars excluded from our selection, presumably thick disc and halo stars.

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The potential of s-process Neutron capture elements for stellar physics and Galactic archaeology

- Understanding the physics of low and intermediate mass stars
- The role of magnetic field in the mixing process in the AGB phase
- Tools to measure the ages of stars

meeting point of the different souls of astrophysics: observations, nucleosynthesis and stellar evolution, Galactic chemical evolution

Thanks for you attention

Thanks Maurizio!