Star Clusters: the Gaia Revolution, 5-7 October 2021, virtual

The chemical composition of very young open clusters in the Solar neighbourhood

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OSSERVATORIO ASTRONOMICO DI PADOVA

The open clusters (OCs) in large surveys

Excellent tracers of the chemical properties of Galactic disc and time evolution!!!

Characteristics:

- **-0.3 < [Fe/H] < 0.4 dex**
- **few Myr** (star forming regions - SFRs) **to several Gyr (high precision)**
- **ubiquitous** in the disc

In large spectroscopic surveys:

1. Programs dedicated to observe OCs
2. Multi-object, high-resolution (R>20000-40000) spectroscopy
3. Thousands of stars in hundreds of OCs
4. Homogeneous data reduction, analysis and characterisation

Clusters ages >1 Gyrs are extensively studied, YOUNG (t<600 Myr) not:

<u>Spectroscopic analysis of young stars is challenging!!!!</u>

Gilmore et al. 2012, Magrini et al. 2017

Casamiquela et al. 2017,2019

de Silva et al. 2015, Spina et al. 2021

Majewski et al. 2015, Donor et al. 2020

OCCAM

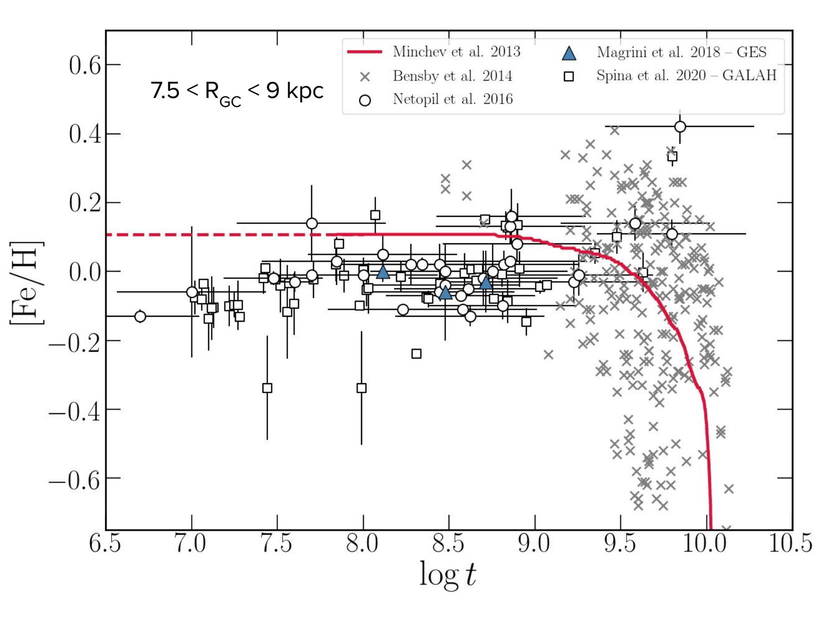
Frinchaboy et al. 2013, Donor et al. 2020

Dalton et al. 2020

de Jong et al. 2019

The issues of the young OCs (YOCs, *t* < 200 Myr): #1

Local anaemia of the interstellar medium (ISM)



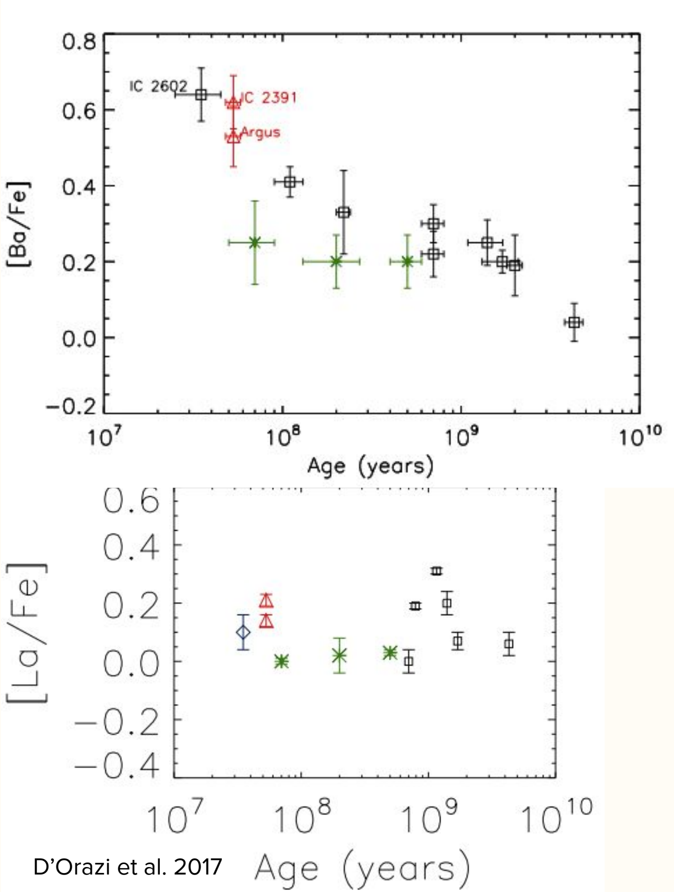
NO METAL-RICH YOCs, star forming regions (SFRs), moving groups or local associations

(e.g., James et al. 2006; Santos et al. 2008; Biazzo et al. 2011; Spina et al. 2014a,b; Spina et al. 2017)

$[Fe/H]_{\star} = \log(Fe)_{\star} - \log(Fe)_{\odot}$ and $\log(Fe)_{\star} = \log(N_{Fe}/N_H) + 12$

The issues of the young OCs (YOCs, *t* < 200 Myr): #2

The behaviour of neutron-capture elements



D'Orazi et al. 2017

Increasing [Ba/Fe] at decreasing ages (values ~+0.6 dex at *t* < 50 Myr) (D'Orazi et al. 2009; Maiorca et al. 2011; D'orazi et al. 2012,2017; Mishenina et al. 2015; Magrini et al. 2018; and others)

For other s-process elements (Y, Zr, La and Ce) = solar or not solar?

Y and Zr = first peak s-process elements (main component)
Ba, La, and Ce = second peak s-process elements (main component)

From nucleosynthesis p.o.v. the most puzzling signature to explain is not the enrichment of Ba
but the **production of Ba DISENTANGLED from La**

$[Ba/Fe] = [Ba/H]_{\star} - [Fe/H]_{\star}$

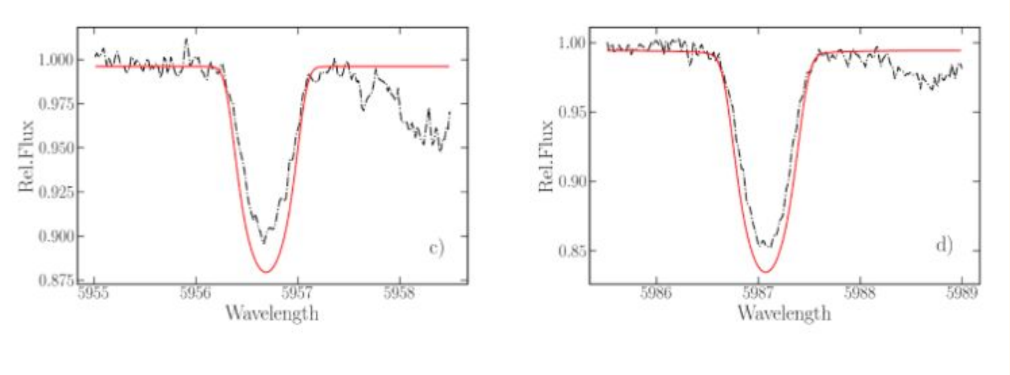
Are these peculiarities real (intrinsic) or not?

Spoiler ….. Maybe NOT!

The effects of stellar activity

Increased levels of activity could alter the line formation, especially of those lines forming up in the photosphere

(confirmed independently by Flores et al.2016, Yana-Galarza et al. 2019, Spina et al. 2020, Baratella et al. 2020a)



Young **dwarf** stars (t < 200 Myr): ξ values are overestimated (2.0-2.5 km/s wrt the typical values of 1.0 km/s, e.g., James et al 2006, Santos et al. 2008)

Result = poor fit of the observed lines

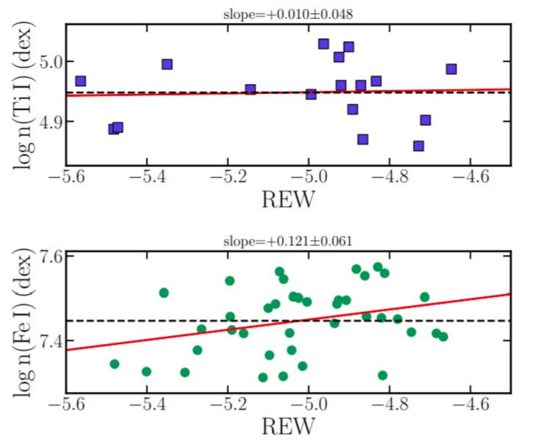
ARTIFICIALLY LOW VALUES OF [Fe/H] and [X/Fe] rescaling accordingly

(for solar-like dwarf stars in OCs we expect solar [X/Fe]**)**

The *new* spectroscopic approach: Ti(+Fe) lines

Titanium lines (form deeper in the photosphere and very precise atomic data from laboratory measurements - Lawler et al. 2013)

- **T_{eff} from Ti + Fe** (larger coverage of E.P.)
- **log *g* from TiI and TiII**
- **ξ from TiI ONLY**



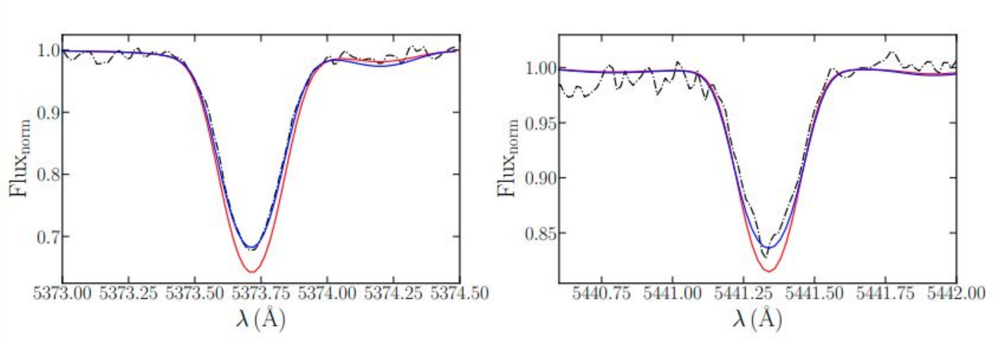
ξ=0.85±0.10 km/s

ξ_{exp}=0.70±0.05 km/s

ξ (from FeI) = 1.75 km/s

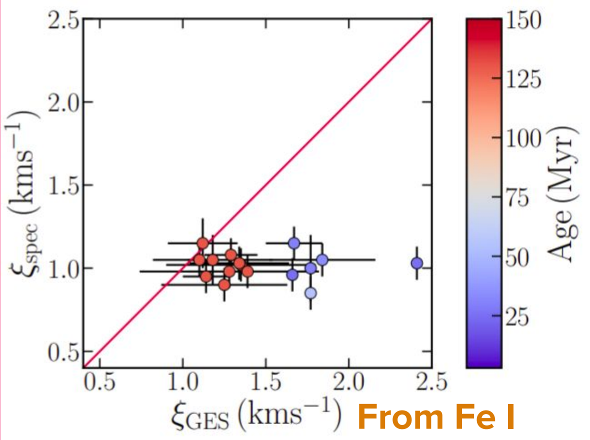
With new ξ, synthetic profiles reproduce well the observed lines

Star:
T_{eff}=5215±100 K;
log g =4.35±0.10 dex;
age=50 Myr



Baratella et al. 2020a

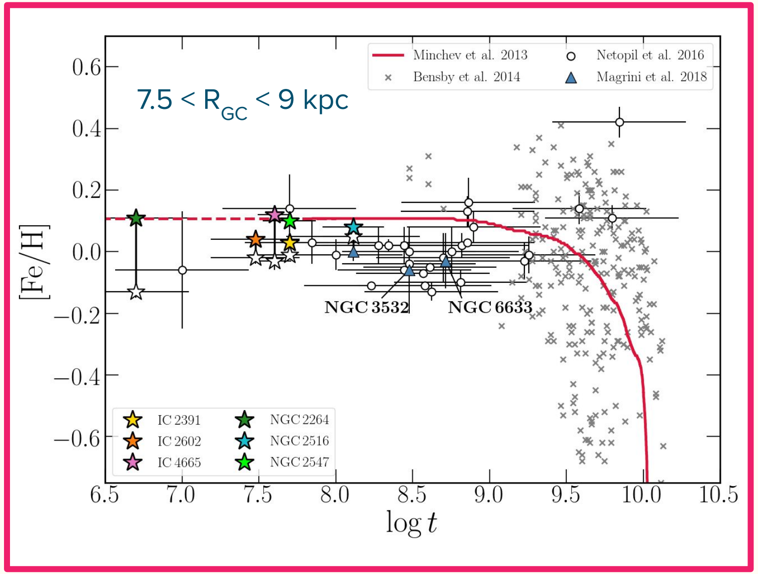
The *new* spectroscopic approach: results



Clusters *t* < 100 Myr: $\Delta(\xi_{Ti}-\xi_{Fe, GES})$ = **-0.85±0.27** kms^{-1}

Clusters *t* ~150 Myr (NGC 2516): $\Delta(\xi_{Ti}-\xi_{Fe, GES})$ = **-0.23±0.13** kms^{-1}

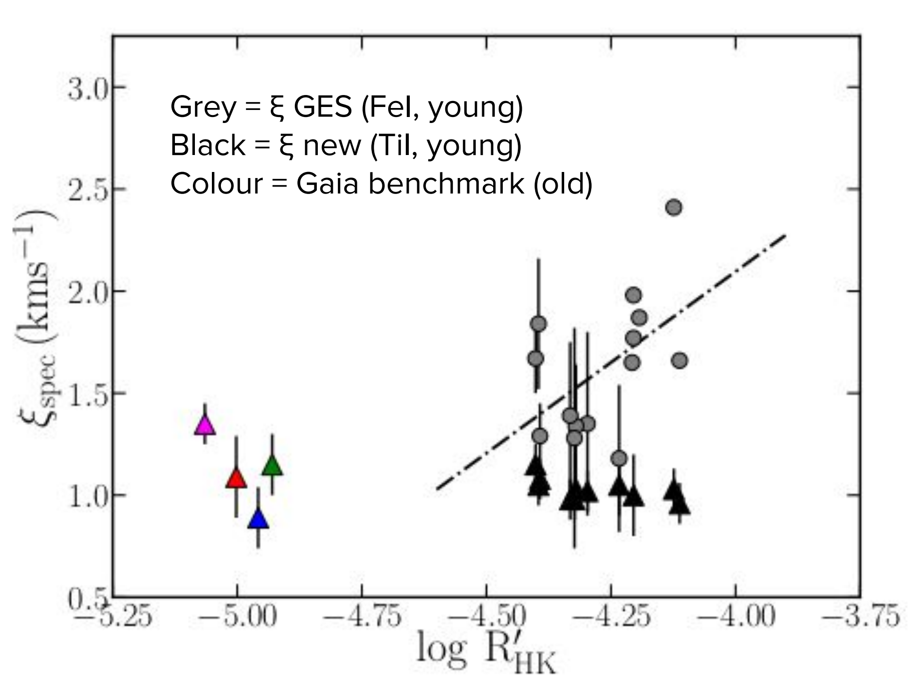
No sub-solar [Fe/H] at all ages !!!

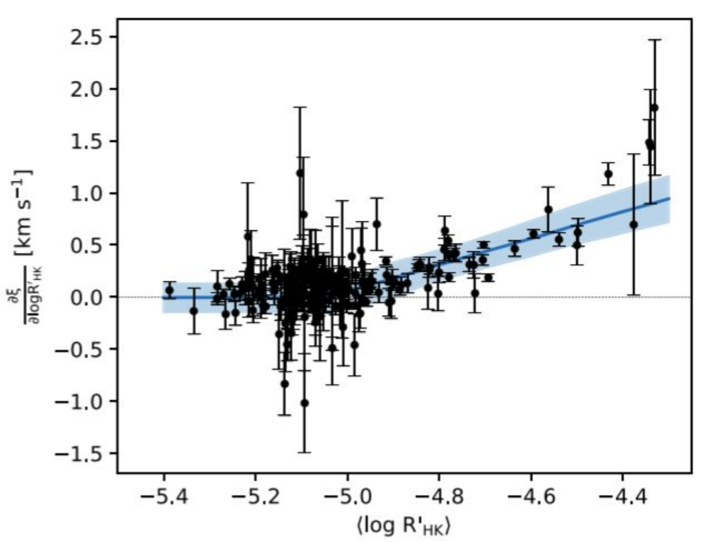


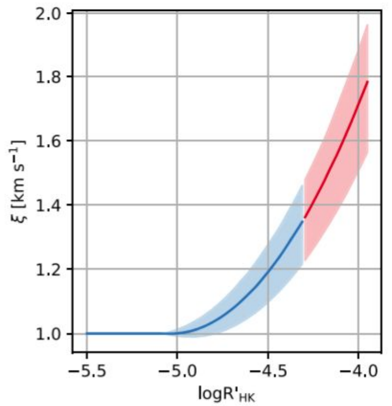
FGK stars (5200<T_{eff} <6000 K) in the cluster sample:

- IC2391 (~50 Myr)
- IC2602 (~30 Myr)
- IC4665 (~40 Myr)
- NGC2264 (~5 Myr)
- NGC2516 (~130 Myr)
- NGC2547 (~50 Myr)

Is the slight metal-poor nature of nearby YOCs and SFRs real or not?

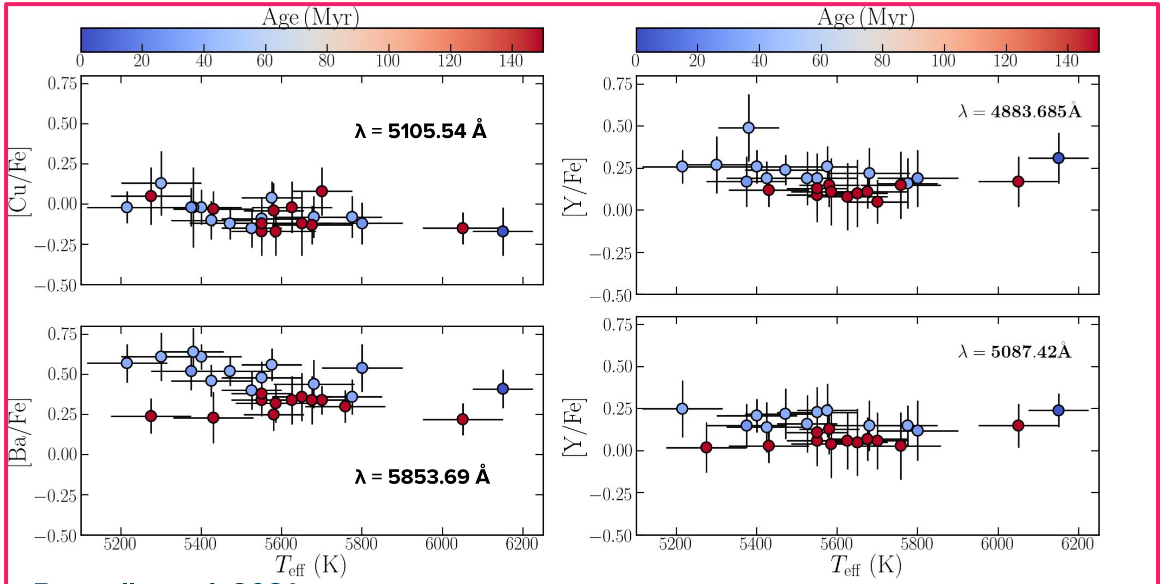






Link of standard ξ and stellar activity Baratella et al. 2020
(variation increases with increasing activity, Spina et al. 2020)

Abundances of n-capture elements (Cu, Sr, Y, Zr, Ba, La and Ce)



Baratella et al. 2021

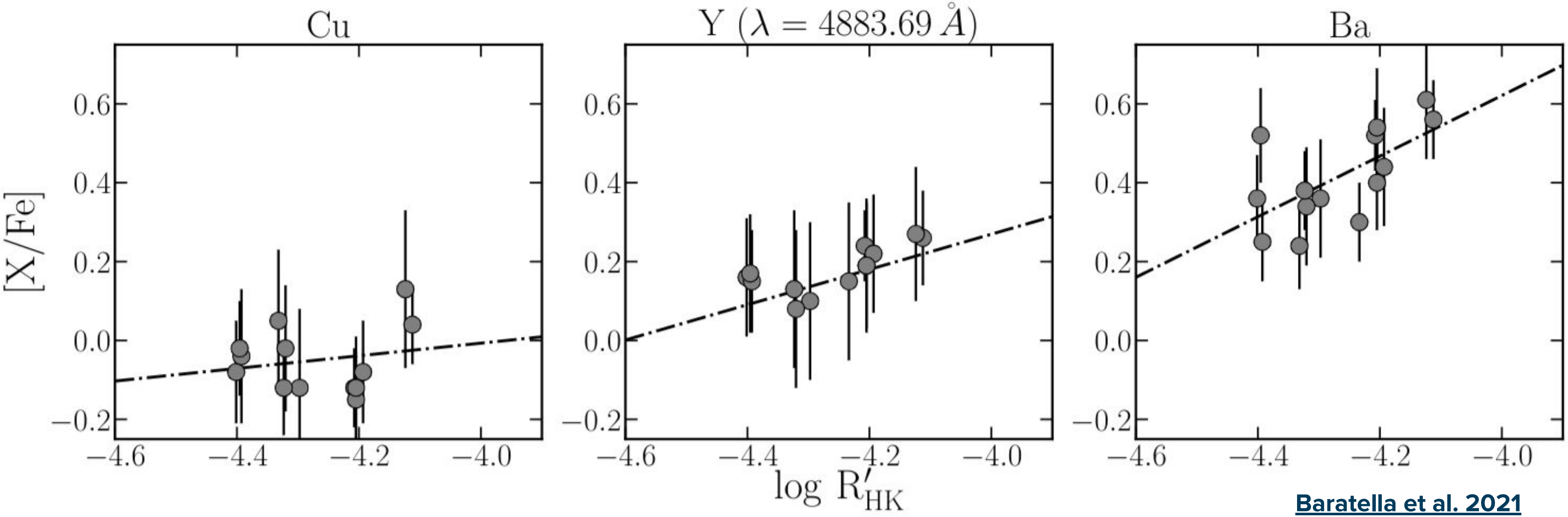
- Sharp separation with age for Ba and Y (homogeneous for Cu)
- [Cu/Fe] ~ SOLAR
- [Ba/Fe] between +0.25 and +0.65 dex
- [Y/Fe] between 0 and +0.30 dex

[Sr/Fe], [Zr/Fe], [La/Fe] and [Ce/Fe] = SOLAR

Δ_{NLTE}(Cu) = +0.02dex
Δ_{NLTE}(Ba) ~ -0.10 dex

Not sufficient to explain the observed enhancements!

Indication of dependency on activity

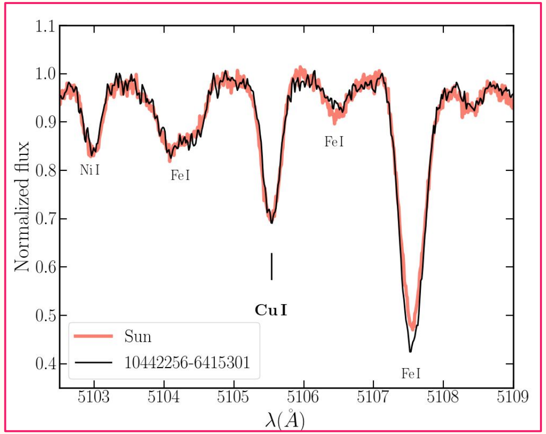


Baratella et al. 2021

Indication of a possible correlation with activity index log R'_{HK}

Behaviour of spectral lines: comparison of Sun and a 30 Myr solar-analog (IC 2602)

Fe-peak + weak/main s-process

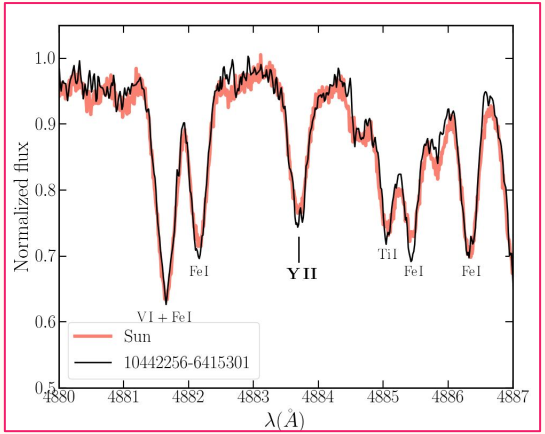


[Cu/Fe]= -0.08±0.13

log τ (Cu_{5105}) = -3.4 g_L=1.10

FIP=7.72 eV **Neutral**

First-peak main s-process

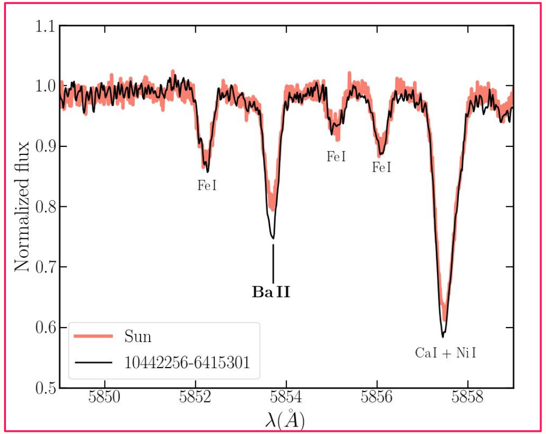


[Y/Fe]= +0.16±0.15

log τ (Y_{4883}) = -2.6 g_L=1.13

FIP=6.38 eV **Ionised**

Second-peak main s-process



[Ba/Fe]= +0.36±0.11

log τ (Ba_{5853}) = -3.2 g_L=1.07

FIP=5.21 eV **Ionised**

Overionization effect (e.g. Tsantaki et al.2019)

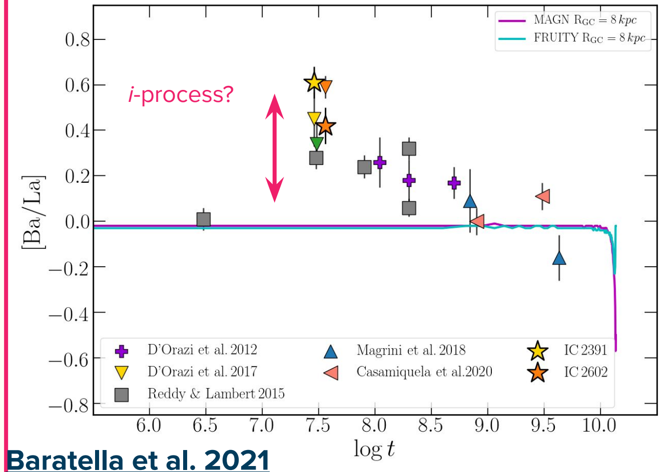
Ba and Sr = similar physical and chemical properties, however **[Sr/Fe]=solar** (Y and Sr = 1° peak, but Y is enhanced)

Y and La = both ionised, same depth, nucleosynthesis channel, however **[La/Fe]=solar**

Ba and La produced in the same way, but Ba is enhanced while La is solar: WHY?

Baratella et al. 2021

The Galactic chemical evolution at young ages



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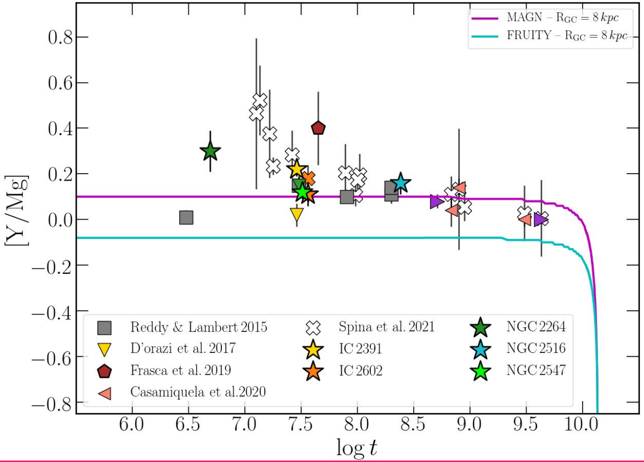

FRUITY (Cristallo et al. 2009)
MAGN (Magrini et al. 2021) = recent FRUITY with mixing by magnetic fields

Ba and Y enhancements at young ages: NOT PREDICTED by models!

Ba and La produced in the same way = FAIL at reproducing [Ba/La]

***i*-process** (Cowan & Rose 1977, Mishenina et al. 2015) =
ADDITIONAL source of Ba (La untouched),
but site of production ??

Mild enrichment of Y wrt Sr and Zr = mainly observational issues, but large variety of processes could contribute

Extreme caution with chemical clocks (e.g., [Y/Mg] or [Ba/Mg]) at ages < 200 Myr !!!

Summary and conclusions

1. **Standard analysis fails** = new spectroscopic approach (Galactic [Fe/H] vs. age in solar vicinity is restored)
2. **n-capture elements** = La (Ce and Zr) are better tracers of the Galactic time evolution of *s*-process
3. Strong lines (forming up in the photosphere) = more affected
4. (for now) overcome such issues with strategic choices of spectral lines

5. Mechanism(s) behind alteration of spectral lines = still unknown
6. Possible solutions, both from spectral and from nucleosynthesis p.o.v., are still under investigation
7. Future high-resolution, multi-objects instrument (e.g., HRMOS and WEAVE) big contributions

Now is the time to revise the classical chemical abundance analysis techniques applied to young stars!