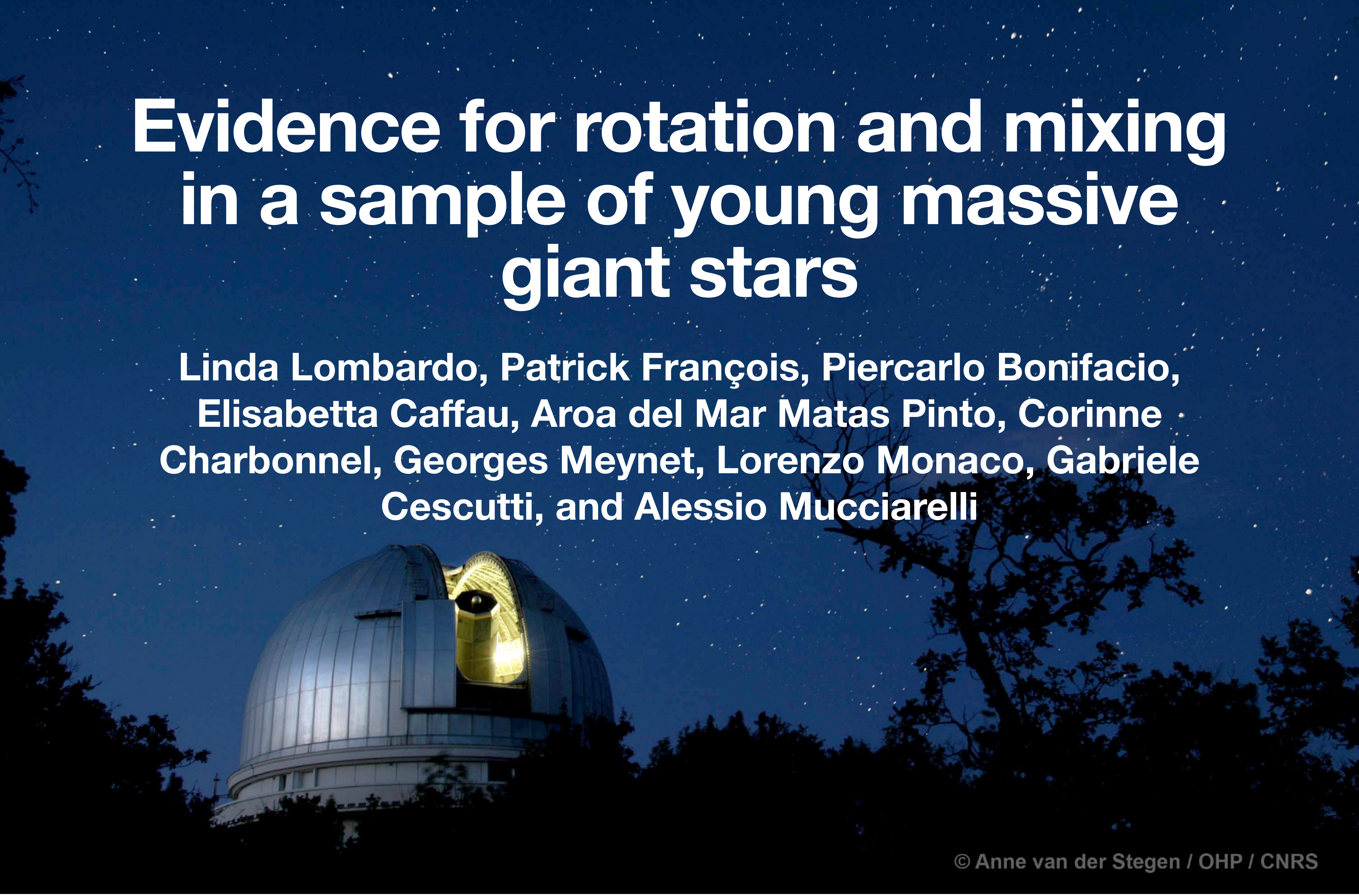


Evidence for rotation and mixing in a sample of young massive giant stars

Linda Lombardo, Patrick François, Piercarlo Bonifacio, Elisabetta Caffau, Aroa del Mar Matas Pinto, Corinne Charbonnel, Georges Meynet, Lorenzo Monaco, Gabriele Cescutti, and Alessio Mucciarelli

PSL UNIVERSITÉ PARIS
l'Observatoire de Paris — GEPI
Galaxies Étoiles Physique et Instrumentation
cnrs dépasser les frontières
anr agence nationale de la recherche

First, some context…

Measuring at Intermediate metallicity Neutron Capture Elements (MINCE) project - PI: Cescutti G.

Abundances of n-capture elements in metal-poor stars: understand the physics of the different n-capture processes as well as the chemical evolution of the Galaxy.

Surprisingly, far less measurements of n-capture elements abundances in metallicity range -2.5< [Fe/H]<-1.5 that at lower metallicities

Goal: determining chemical abundances in about 1000 giant stars in the intermediate metallicity range in the next five years using high quality spectra obtained with several facilities.

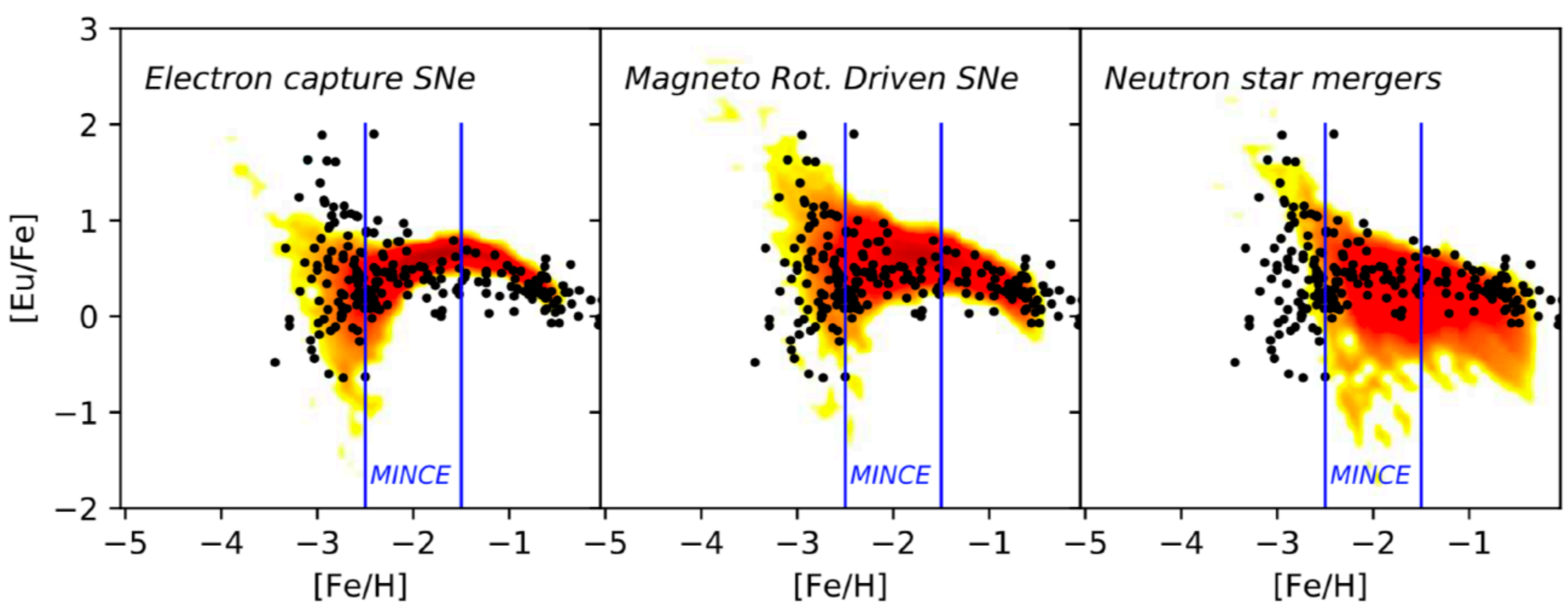


Image adapted from Cescutti & Chiappini 2014

MINCE

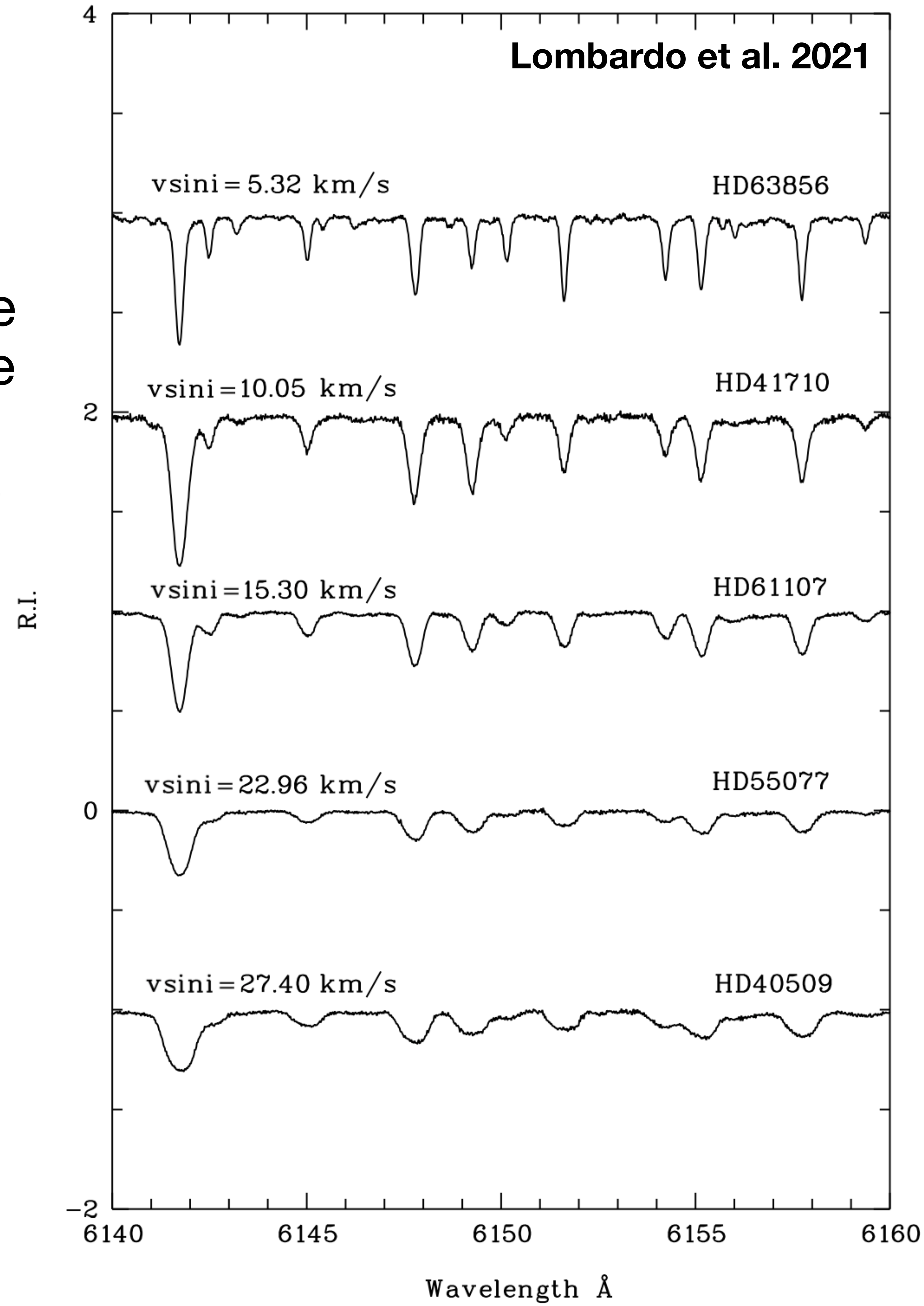
Target selection

Strömgren photometry from the Paunzen (2015) catalogue + the Casagrande et al. (2014) metallicity calibration for giants

16 SOPHIE@OHP spectra
3 ESPADONS@CFHT spectra
7 HARPS-N@TNG spectra

From the spectral analysis: almost solar metallicity and rapidly rotating
(**young and massive**)

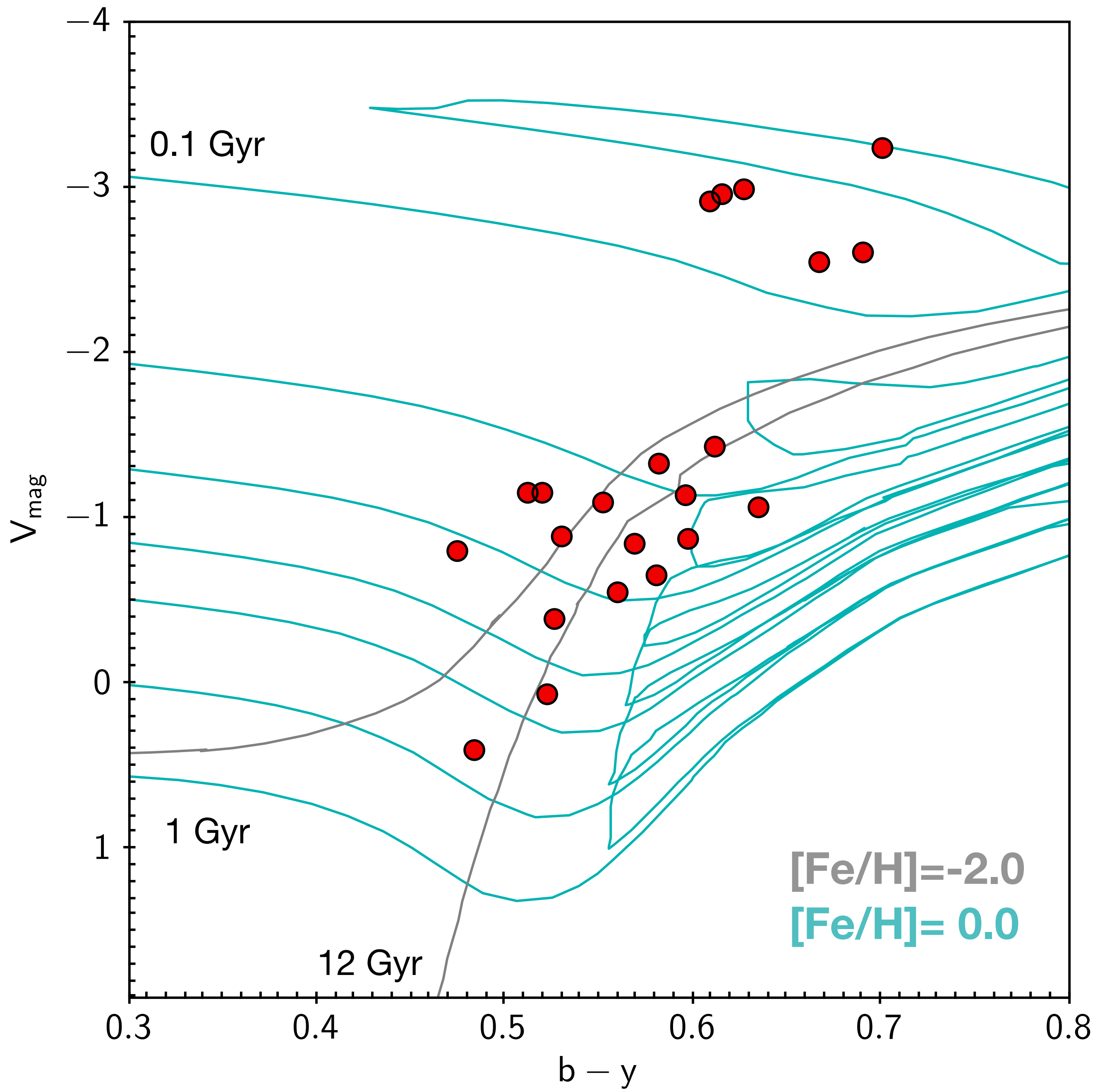
?



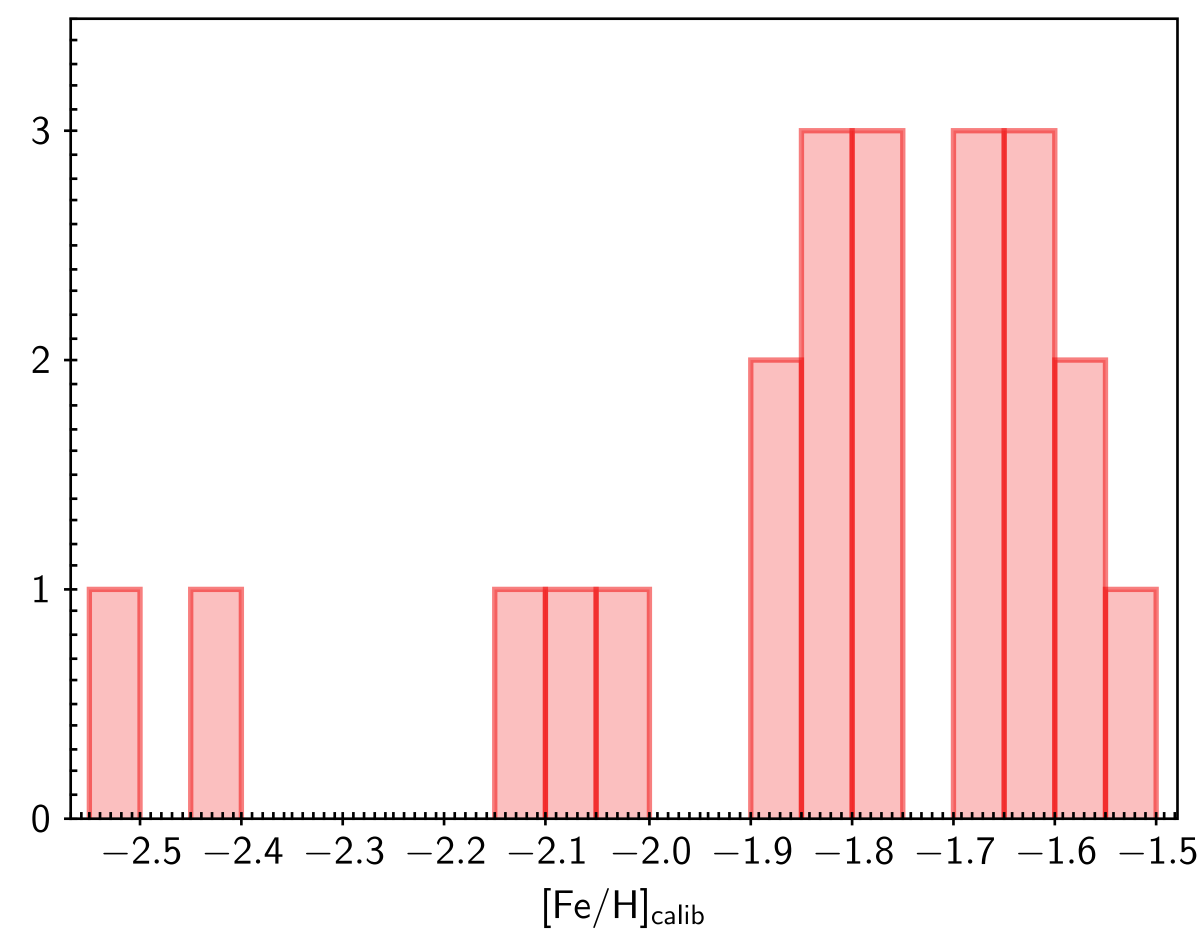
MINCE

Target selection

Strömgren photometry from the Paunzen (2015) catalogue + the Casagrande et al. (2014) metallicity calibration for giants



Age-metallicity degeneracy



Young giants of intermediate mass

Sample of 26 evolved A-B type stars with solar metallicity and high rotational velocities

Interesting and poorly studied stars:

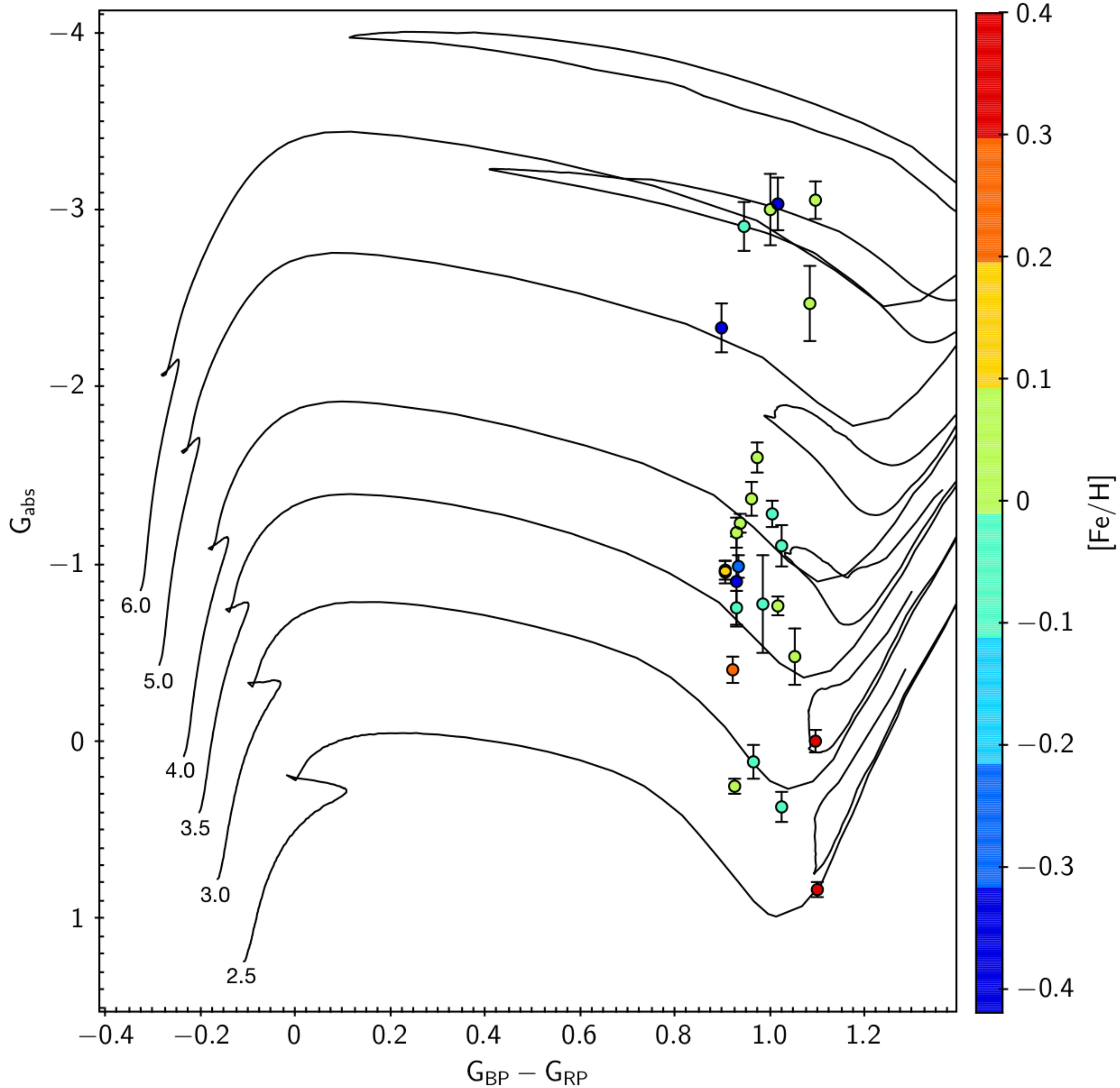
- Information on evolution of post MS stellar rotation
- Information on stellar mixing due to rotation

Stellar masses deduced from Ekström et al. (2012) evolutionary tracks without rotation at solar metallicity provided by the SYCLIST code (Georgy et al. 2014)

0.1 Gyr < Age < 1 Gyr

$2.5\,M_\odot$ < Mass < $6\,M_\odot$

Lombardo et al. 2021



Young giants of intermediate mass

Stellar parameters

Teff and logg from Gaia EDR3 photometry and parallaxes.

- **Teff** from the Mucciarelli et al. (2021) InfraRed Flux Method (IRFM) colour-Teff calibration for giants stars based on Gaia EDR3 data

- **Logg** from Stefan–Boltzmann equation

$$\log g = \log (M/M_\odot) + 4\log (T_{eff}/T_\odot) + 0.4(G_0 + BC) + 2\log p + \log L_\odot + \log g_\odot$$

- Microturbulent velocities (**ξ**) were estimated using the Dutra-Ferreira et al. (2016) calibration

M: stellar mass
G0: dereddened apparent G magnitude
BC: bolometric correction
p: Gaia parallax

Young giants of intermediate mass

Chemical abundance measurements

- **[Fe/H]** from measured EWs using ATLAS9 + WIDTH, GALA code as a wrapper (Mucciarelli et al. 2013). EWs measurement performed with FITLINE code by P. François (Lemasle et al. 2007)

For stars with vsini > 15 km s^{-1} : Gaussian + rotational profile

WARNING: stellar rotation allow us to detect only the strongest lines

- O, Mg, Al, Ca abundances from measured EW

- C, N, Sr, Y, Ba, La, Ce, Pr, Nd, Sm, Eu abundances from spectrum synthesis technique

Young giants of intermediate mass

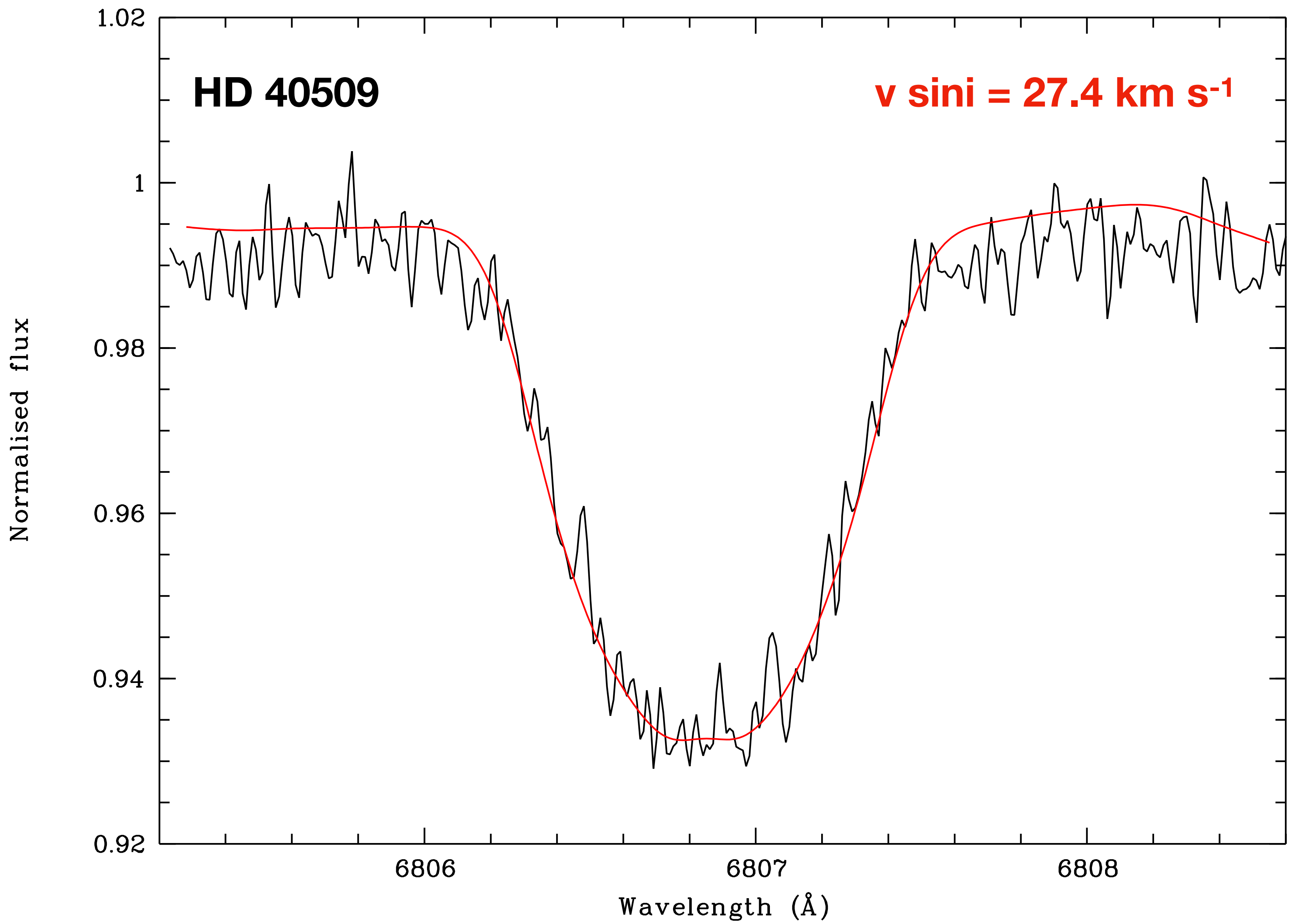
Rotational velocities

Set of FeI lines to be fitted.

$\chi 2$ minimisation fit on observed line profile using three synthetic spectra with different rotational velocities.

[Fe/H] of synthetic spectra fixed at the value derived from the EW of the single line.

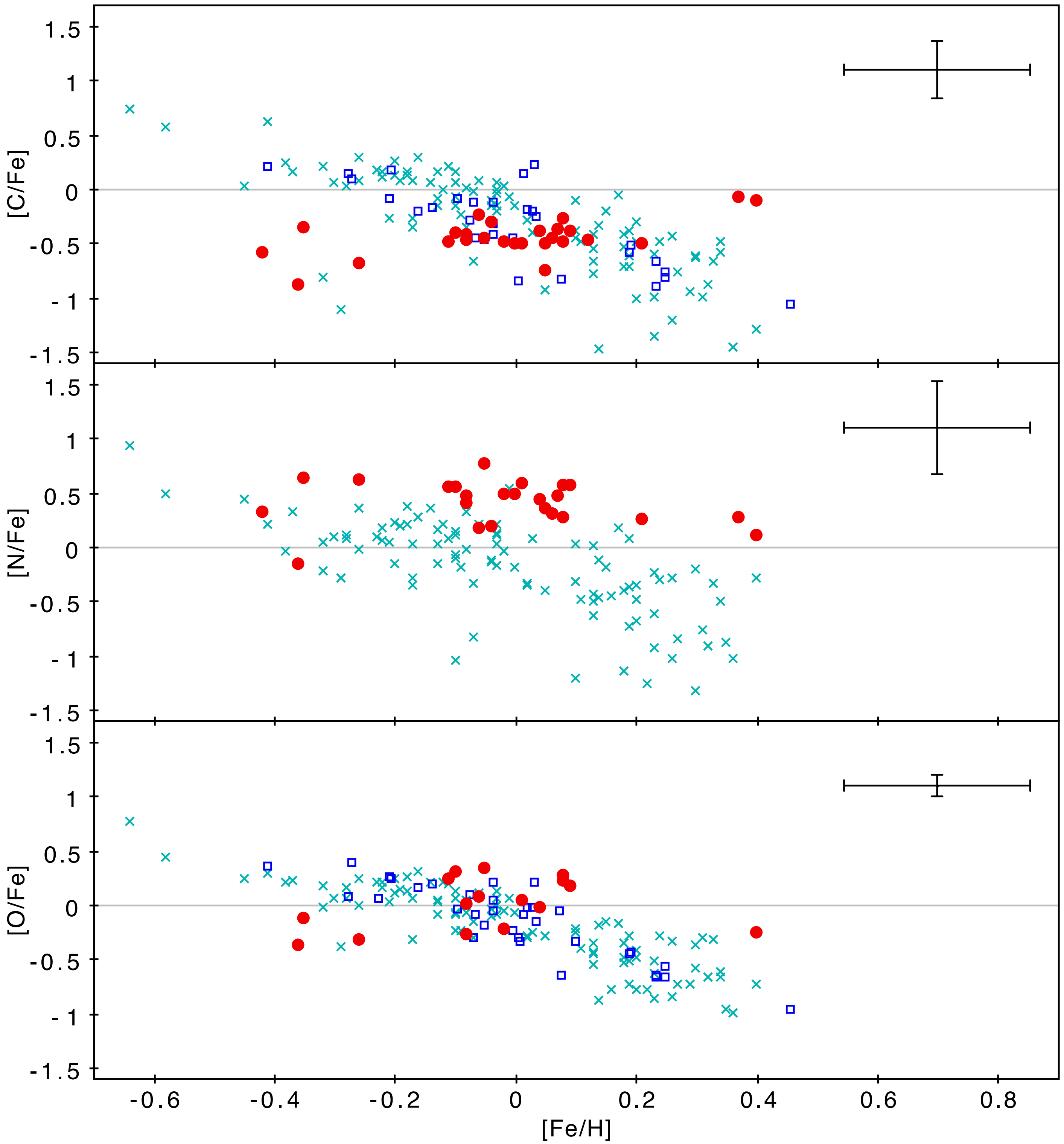
4.0 < v sini < 27.4 km s^{-1}

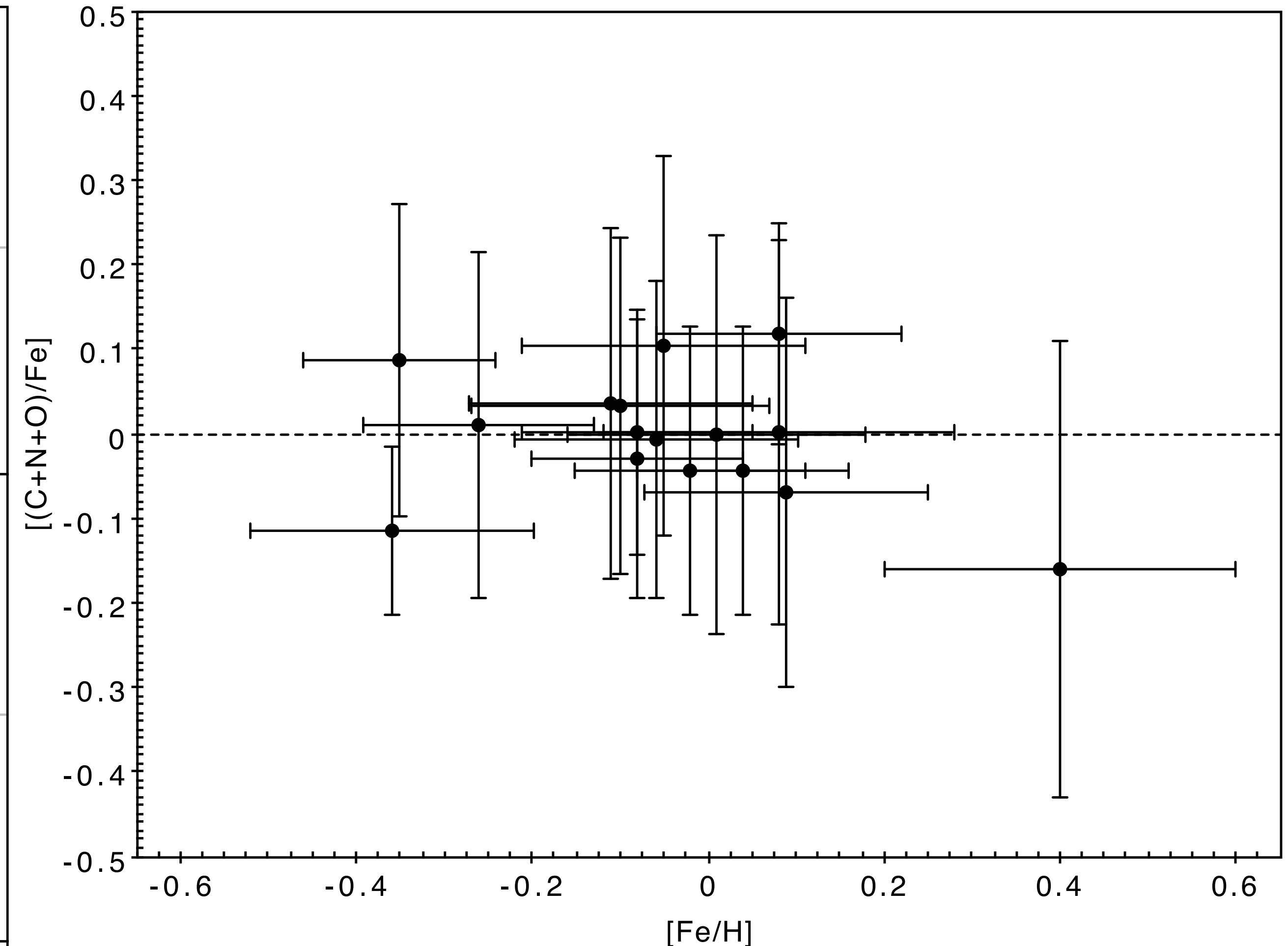


Young giants of intermediate mass

Chemical composition: C,N,O

Lombardo et al. 2021





Takeda et al. 2018 : A type MS stars

Royer et al. 2014 : A type MS stars

Almost all stars show sub-solar [C/Fe] and super-solar [N/Fe] -> the material in the photosphere is mixed with the products of CNO cycle

Young giants of intermediate mass

Chemical composition: Mg, Al, Ca

Lombardo et al. 2021

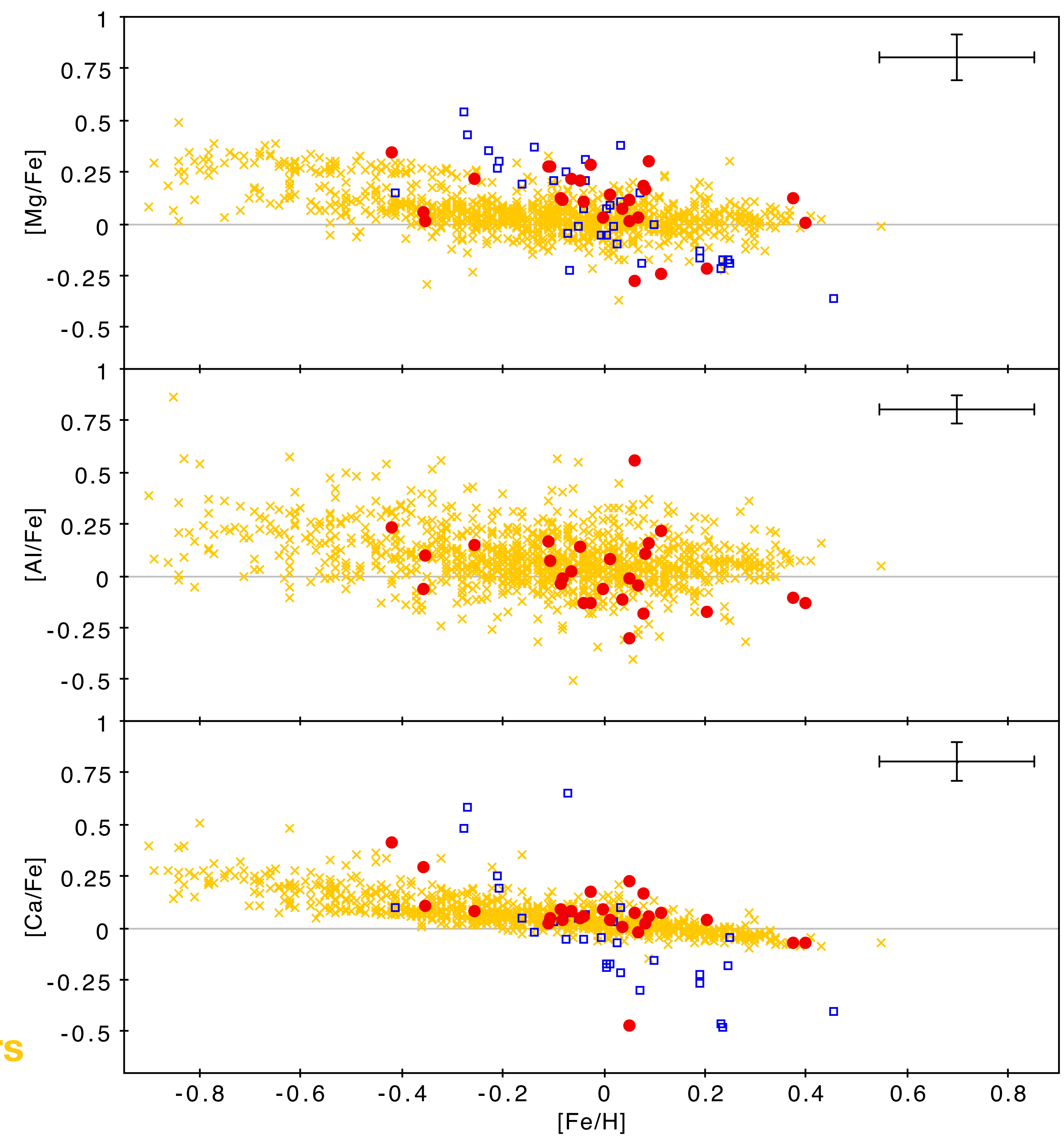
Good agreement with previous studies

HD278:
[Al/Fe] = 0.55 ± 0.24 dex

HD21269:
[Mg/Fe]= 0.11 ± 0.36 dex
[Al/Fe] = –0.30 ± 0.11 dex
[Ca/Fe]= –0.47 ± 0.26 dex

BUT
vsin i ~ 22 km s^{-1} for HD 278
vsin i ~ 16 km s^{-1} for HD 21269

Rotation affect the estimate of the abundance of the lines →large uncertainty

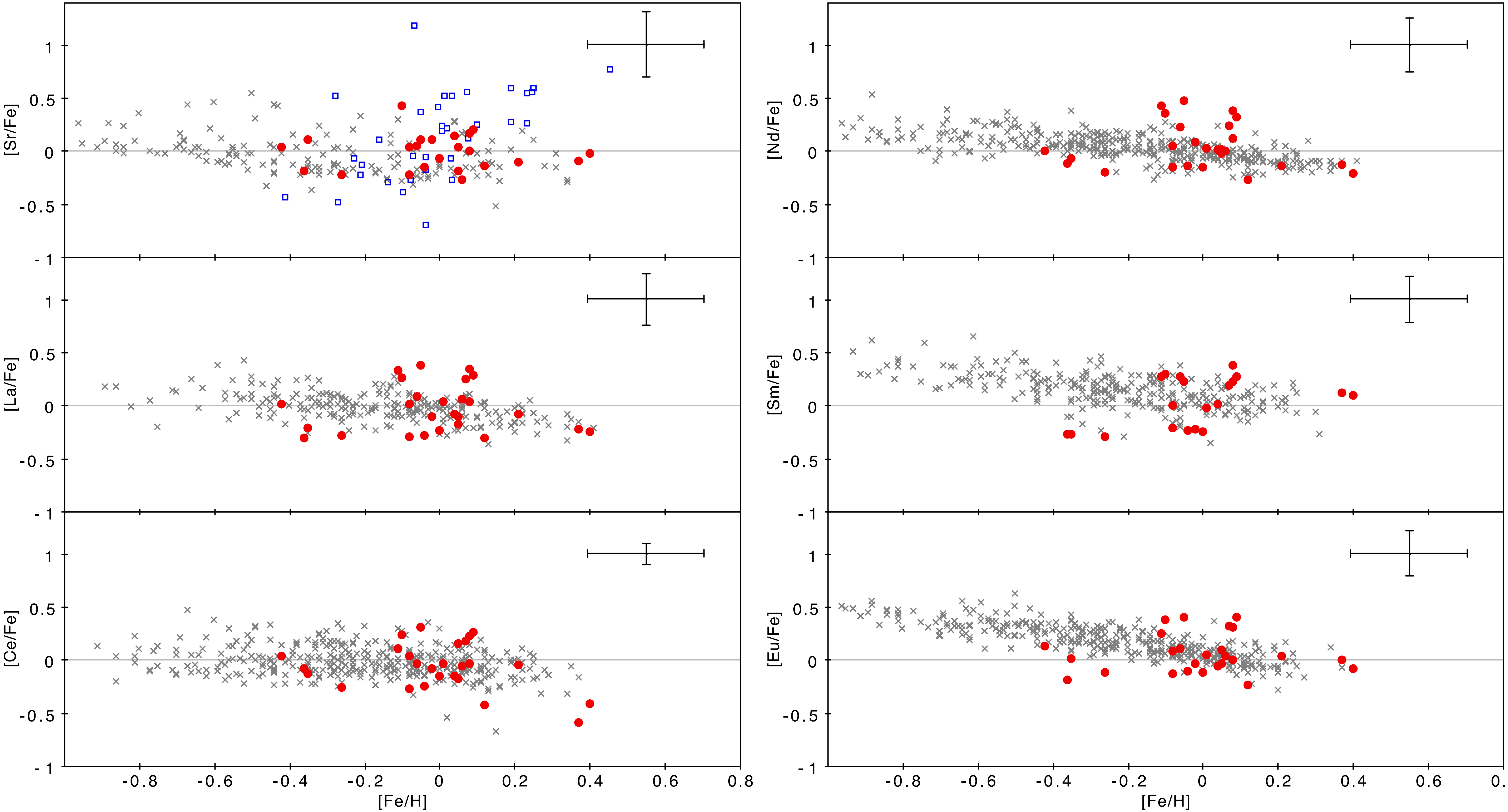


Adibekyan et al. 2012: F, G, K dwarf stars
Royer et al. 2014 : A type MS stars

Young giants of intermediate mass

Chemical composition: n-capture elements

Lombardo et al. 2021



Battistini & Bensby 2016: F and G dwarf and subgiant stars

Royer et al. 2014 : A type MS stars

Young giants of intermediate mass

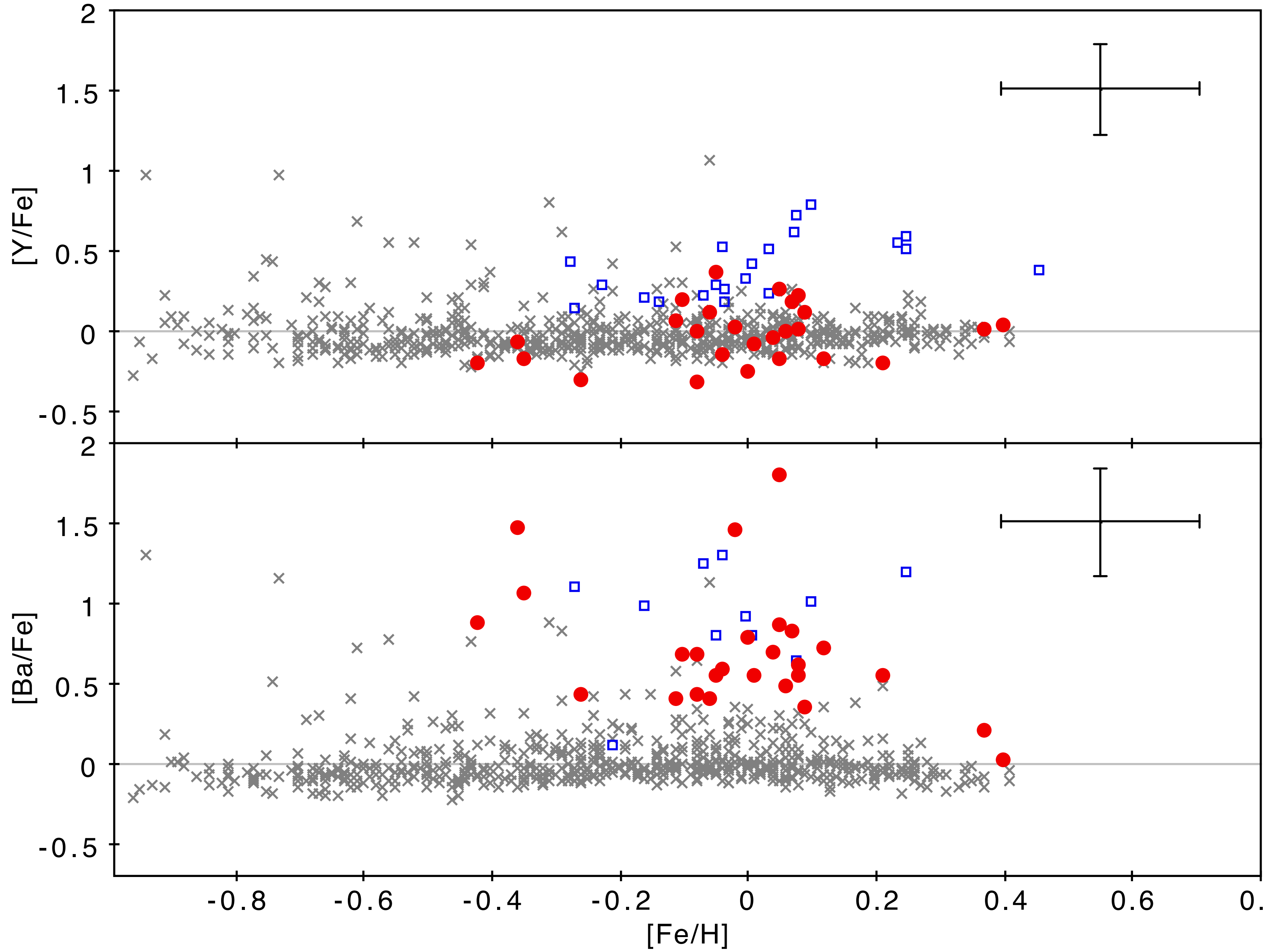
Chemical composition: Ba enhancement

Lombardo et al. 2021

Ba enhancement in all stars:

-NLTE?
NLTE correction for Ba lines provided by Korotin et al. (2015) decrease the Ba abundances by 0.1 dex
→not sufficient

-microturbulent velocity?
An increase in microturbulence of 0.6 kms^{-1} decreases Ba abundance by 0.6 dex for star HD55077
(ξ = 1.54 km s^{-1})
→no observation that supports such a high micro-turbulence



Bensby et al. 2014 : F and G dwarf and subgiant stars
Royer et al. 2014 : A type MS stars

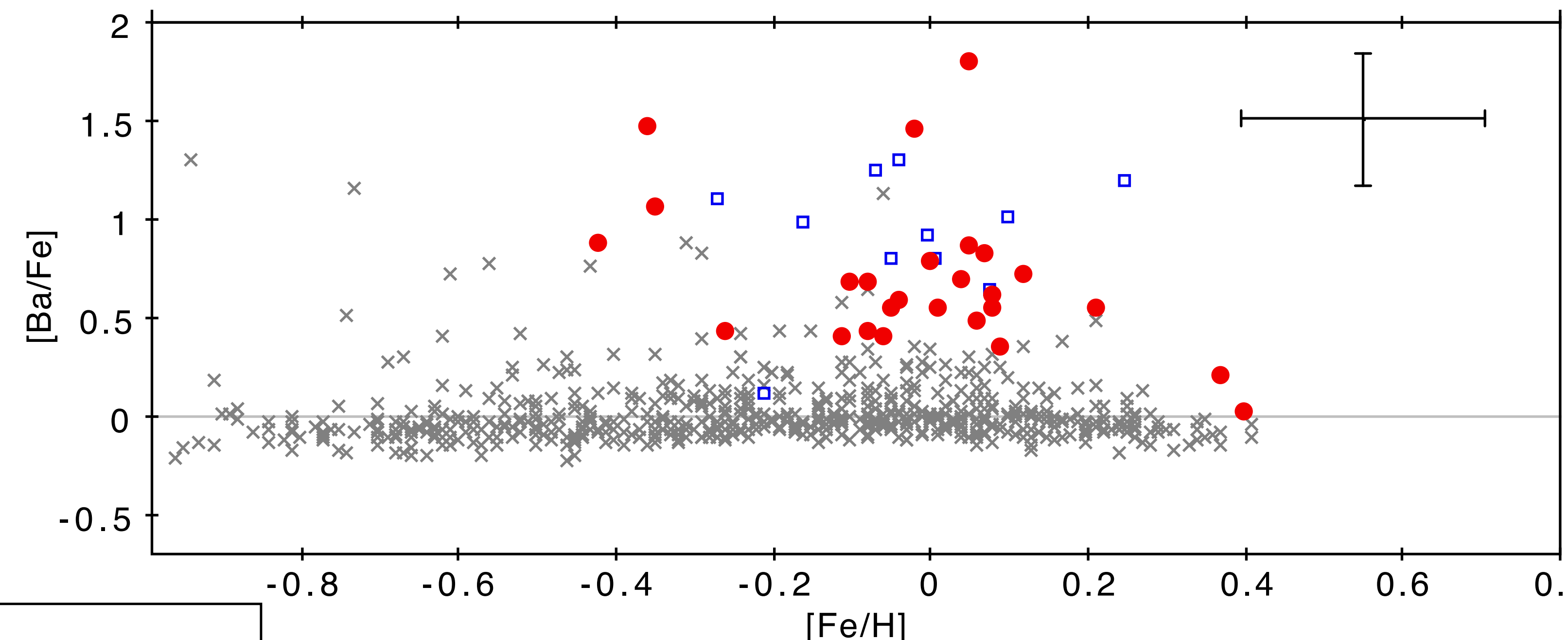
Young giants of intermediate mass

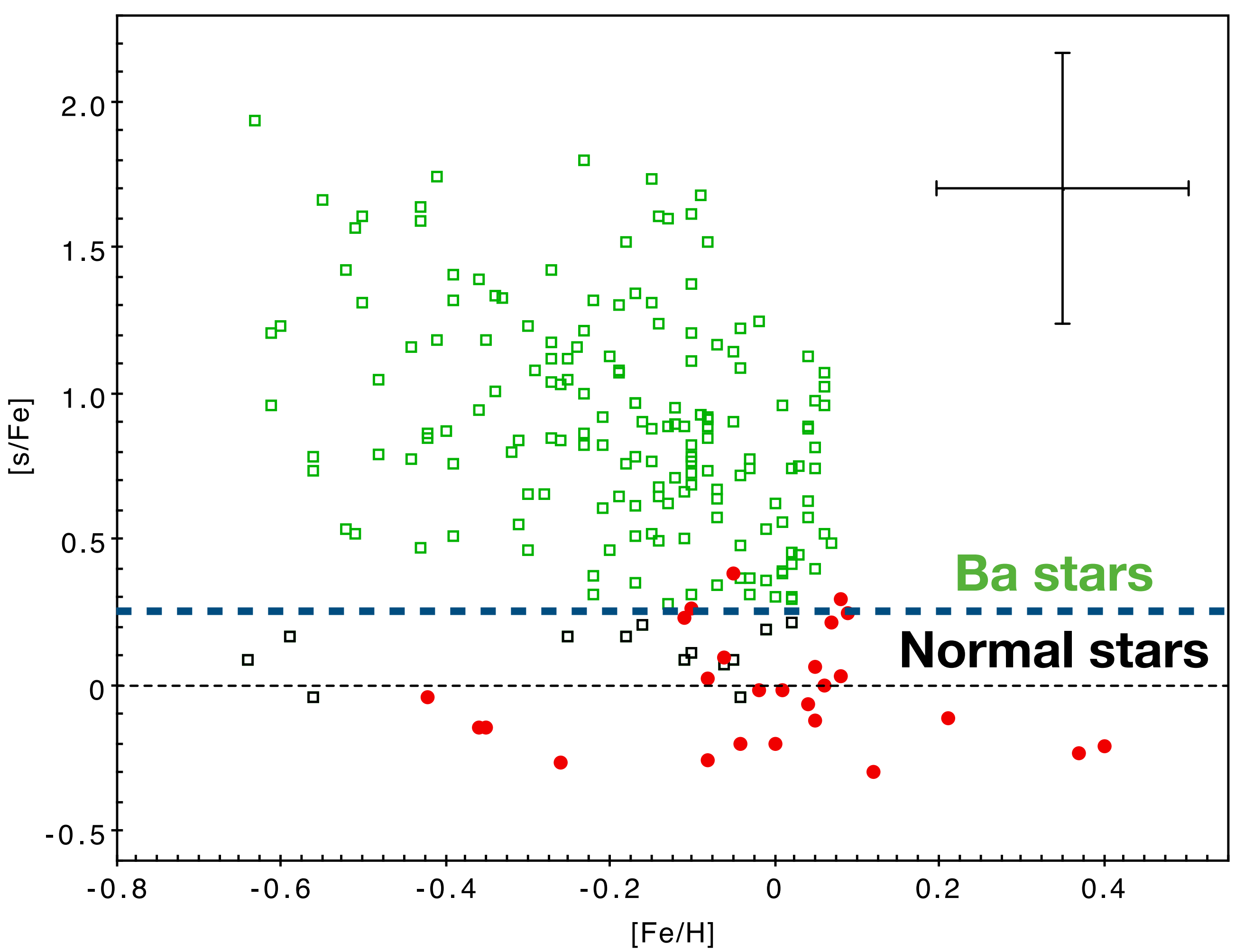
Chemical composition: Ba enhancement

Lombardo et al. 2021

Ba enhancement in all stars:

-NLTE?
-micro-turbulent velocity?
-Mild Ba stars?
3 stars have [s/Fe] > 0.25 dex
only HD 63856 has [s/Fe]=0.38 dex





Bensby et al. 2014 : F and G dwarfs and subgiants
Royer et al. 2014 : A type MS stars
De Castro et al. 2016: Ba stars
De Castro et al. 2016: normal stars

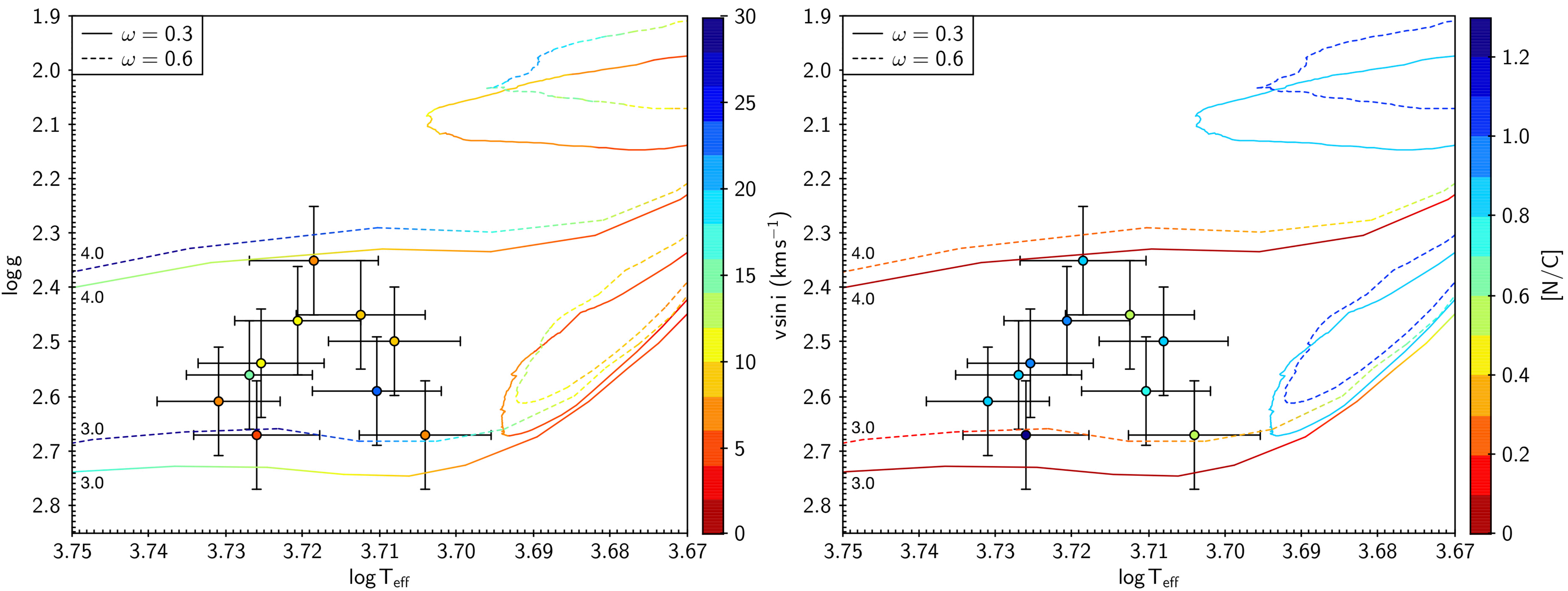
[s/Fe] = [Y/Fe]+[La/Fe]+[Ce/Fe]+[Nd/Fe]

High [Ba/Fe] ratios puzzling and unexplained

Young giants of intermediate mass

Comparison with stellar models

Lombardo et al. 2021



Stellar evolution models with rotation by Georgy et al. 2013 with [Fe/H]=0.0 dex

vsini compatible with rotational velocities predicted by models with 0.3<ω<0.6

[N/C] abundance ratios for the majority of stars are consistent with the values predicted for clump stars in the Georgy et al. models

-0.1 < [Fe/H] < 0.1
5 < vsini < 22 km s^{-1}
3.5 < Mass < 4 M$_\odot$

Clump (or blue loop): region of the CMD where stars are located when they undergo central He-burning.
ω = Ωinitial/Ωcrit , where Ω is the angular velocity

Summary:

- Photometric metallicity calibrations may be affected by the age-metallicity degeneracy

- Stellar masses between 2.5 $M_\odot$ and 6.0 $M_\odot$ suggest that the sample is composed of evolved A- to B-type stars. This hypothesis is supported by their chemistry, which is similar to that of A- and B-type stars in other studies.

- Low [C/Fe] and high [N/Fe] suggest that stars have undergone mixing. This is in line with the predictions from stellar evolution models.

- The derived vsini agree with the theoretical values that have been predicted for these stars by stellar evolution models with rotation.

- The stars show Ba enhancement but low [s/Fe] ratio. This makes them similar to mild Ba stars.

Thanks for your attention

PSL UNIVERSITÉ PARIS

l'Observatoire de Paris — GEPI

Galaxies Étoiles Physique et Instrumentation

cnrs dépasser les frontières

anr agence nationale de la recherche

Young giants of intermediate mass

Potential binary stars

HD 195375 : consistent parallax -> physical binary system

HD 278 : different parallax -> visual double system

Kervella et al. 2019 : identification of probable binary stars from proper motion anomalies

✻: The Washington Double Star Catalog
● : Gaia DR2 radial velocity errors > 1 km/s
○ : Gaia DR2 radial velocity ≠ observed radial velocity
★ : Stars in Kervella et al. 2019

HD 192045 and HD 213036 are likely binary stars

Star	$v_{radGDR2}$ km s^{-1}	v_{rad} km s^{-1}	flag
HD 192045	-43.846 ± 2.253	-4.834 ± 0.077	● ○ ★
HD 191066	-5.911 ± 3.451	-9.349 ± 0.001	● ★
HD 205732	-3.150 ± 0.147	-3.971 ± 0.001	○
HD 213036	-4.369 ± 1.662	-40.890 ± 0.128	● ○ ★
HD 217089	-7.441 ± 0.150	-7.684 ± 0.001	
HD 9637	-1.879 ± 0.169	-2.361 ± 0.002	
HD 21269	-15.676 ± 0.262	-12.602 ± 0.002	○
HD 19267	3.387 ± 0.153	2.697 ± 0.001	★
HD 13882	-28.545 ± 0.170	-29.038 ± 0.001	
HD 189879	-10.391 ± 4.430	-29.532 ± 0.001	● ★
HD 195375 ∗	-9.352 ± 0.154	-10.276 ± 0.001	○
HD 221232	-29.894 ± 0.158	-30.649 ± 0.001	
HD 219925	-14.596 ± 2.837	-22.916 ± 0.001	● ★
HD 278 ∗	-26.143 ± 7.736	-60.526 ± 0.003	●
HD 11519	-10.625 ± 0.177	-11.260 ± 0.001	
TYC 2813-1979-1	-16.201 ± 0.338	-17.170 ± 0.002	
BD+42 3220	-18.523 ± 0.219	-19.298 ± 0.053	
BD+44 3114	-17.302 ± 0.170	-15.216 ± 0.055	○
TYC 3136-878-1	0.922 ± 0.985	1.034 ± 0.053	
HD 40509	-1.223 ± 0.310	-1.656 ± 0.005	
HD 41710	-6.812 ± 0.269	-7.917 ± 0.002	
HD 40655		7.332 ± 0.001	
HD 45879	5.902 ± 0.224	7.047 ± 0.001	○ ★
HD 55077	-25.729 ± 0.514	-25.499 ± 0.003	★
HD 61107	12.126 ± 0.738	10.476 ± 0.001	★
HD 63856	22.402 ± 0.206	19.755 ± 0.001	○ ★