# Building a reference sample using differential spectroscopy

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Lund Reference Star Workshop

# 1. Gaia FGK Benchmark Stars

”Best” and most used reference sample: accuracy and precision

Paula's talk

**"Gaia Benchmark"**

Jofre+2018 and references therein.
See also Jofre, Heiter & Soubiran 2019, ARA&A

They have interferometric radii

$$T_{\rm eff} = \left(\frac{F_{\rm bol}}{\sigma}\right)^{0.25} (0.5\,\theta_{\rm LD})^{-0.5}.$$

To have a zero point for the Temperature.

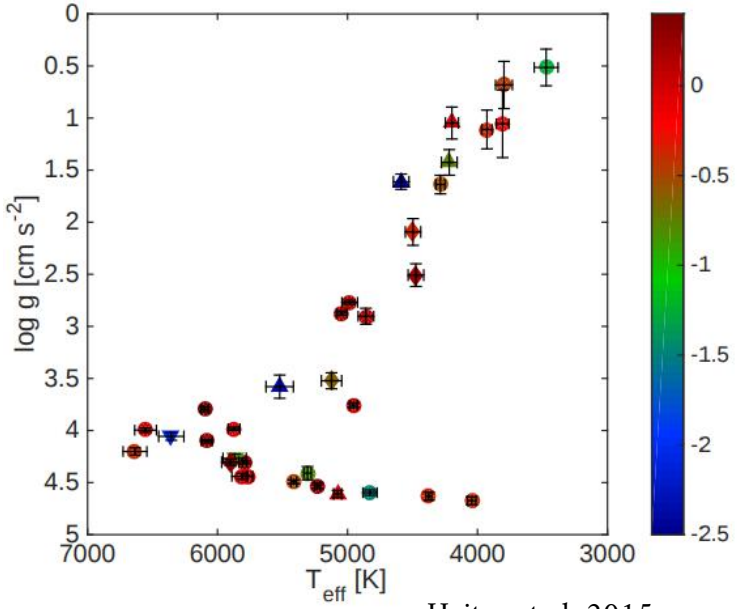
e.g. Accuracy

Sven's talk

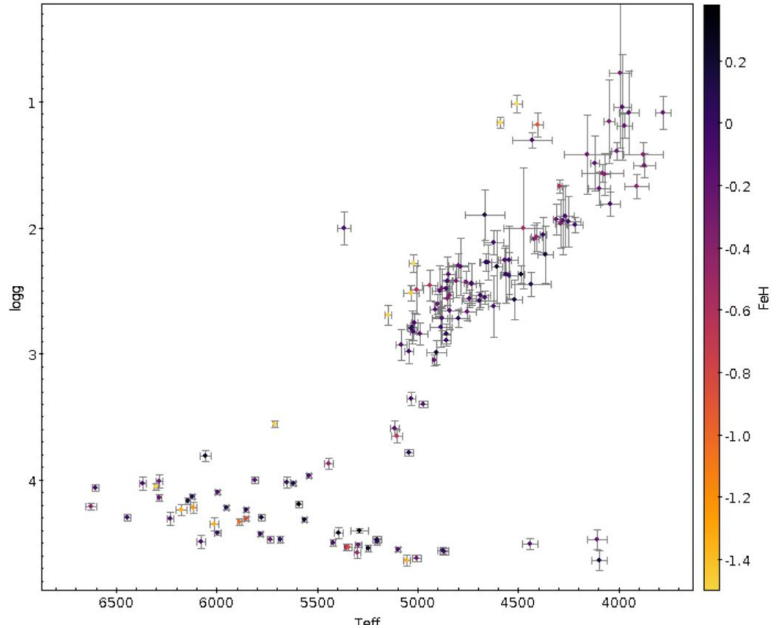
## What References do we lack?

Reliable references for A(X) over the parameter space
-> different lines give different answers for A(X)
-> log gf, 3D NLTE effects, blending

- **Reference stars** for all surveys should be:
  - **Representative**: well balanced selection (**Teff, logg, ages, all/major+rare A(X)**)
  - **Reliable**: Major interest: ***M, R, age, A(X), $v_{rad}$*** best observables: ***F(λ,R)***, $\theta$, $\nu_{max}$, $\delta\nu$
  - **Reachable**: declination, magnitudes, within certain FoV + density
  - **Reusable**: high **S/N** spectra, all ***λ***, high ***R***, (usable by all surveys for acc.+prec.)




Heiter et al. 2015




GBS version2: 30 recommended stars with reliable Teff, logg
GBS upcoming version3: ~150 stars

→ *drawback: these are good numbers, but is it enough for a real(cross)calibration?*

# 2. Differential spectroscopy

*A possible solution*: obtain **atmospheric parameters** and **abundances** spectroscopically BUT differentially with respect to the GBS

**Strictly line-by-line differential abundances** allows us to reach high precision using twin stars. It erases most of the effects that blur typical chemical abundance procedures: unaccounted blends, most of the effects of stellar evolution, and poor atomic line characterization.

*Stellar twin: stars within $\Delta$Teff = 100 K, $\Delta$log g = 0.1 dex, and $\Delta$ [M/H] = 0.1 dex

# 2. Differential spectroscopy

| GBS ref | Results differential | Results absolute (iSpec) |
|---|---|---|
| 5810±80 K | 5820±19 K | 5770±29 K |
| 4.44±0.03 dex | 4.50±0.04 dex | 4.32±0.07 dex |
| 0.03±0.03 dex | 0.034±0.016 dex | 0.056±0.069 dex |

1) For **atmospheric parameters**

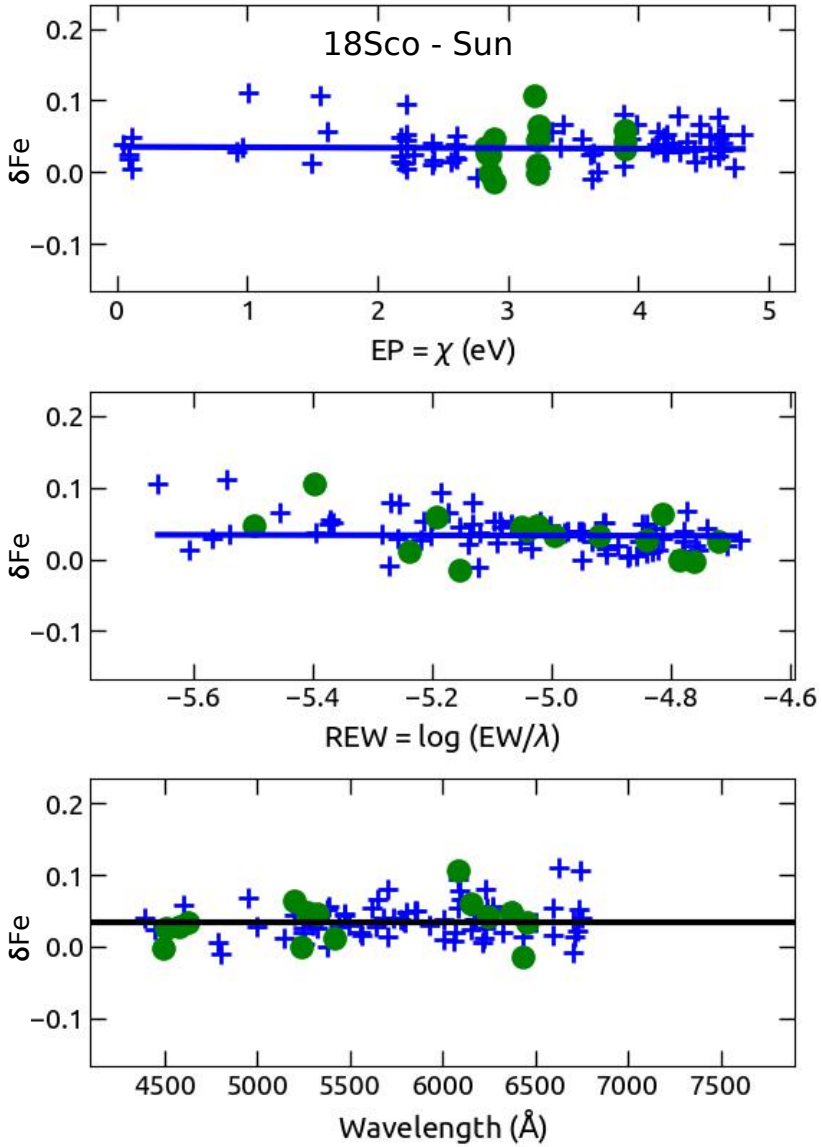
Classical spectroscopic method from EW, imposing excitation/ionisation balance of FeI and FeII abundances.

The star's iron abundances are measured wrt the reference abundance in a strictly line-by-line basis.

*q*2 code (Ramirez et al. 2014)

Example: the very well known solar twin 18 Sco

$$\delta X = \frac{1}{N_{lines}} \sum_{i=1}^{N_{lines}} (A_{X_i} - A_{X_i,REF})$$



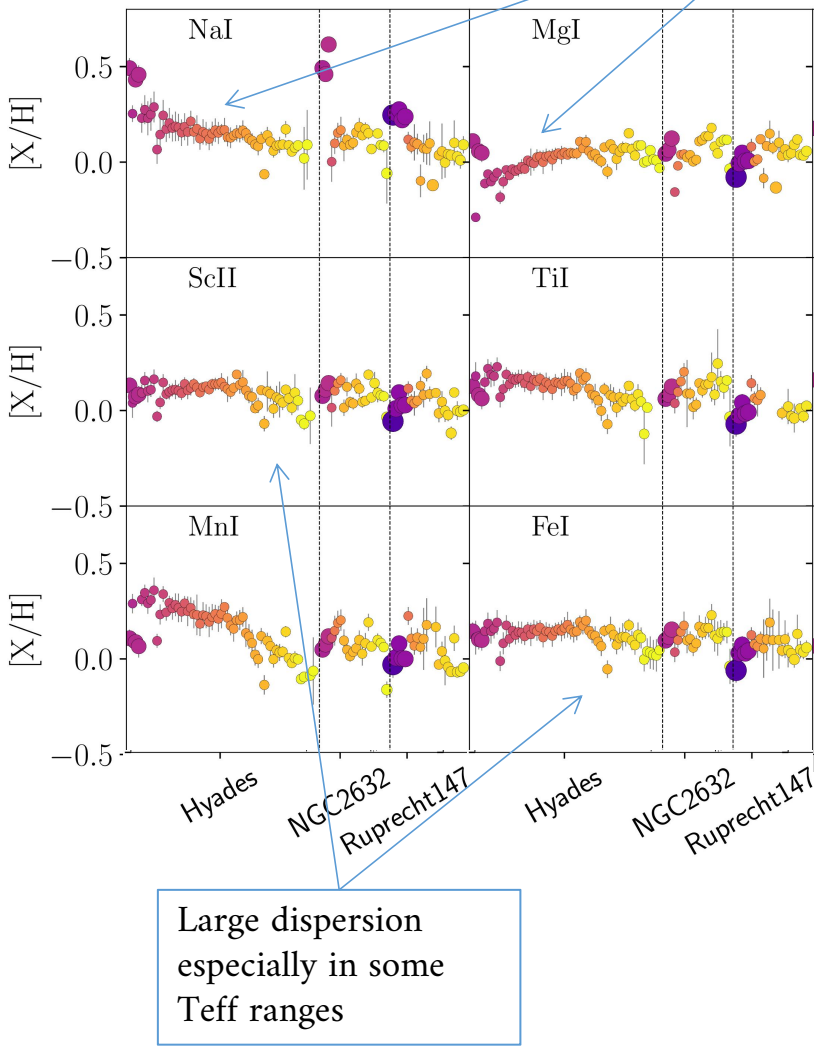
# 2. Differential spectroscopy

2) For **abundances**

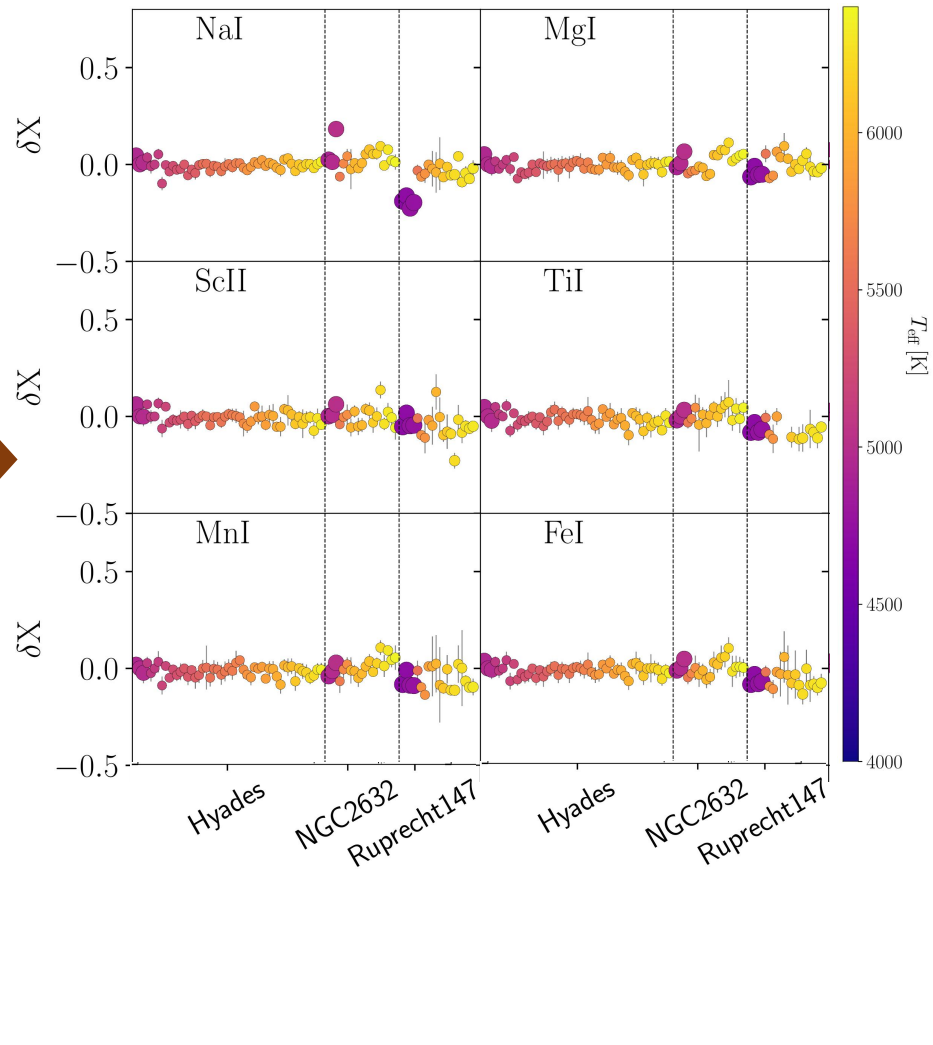
Tests with open clusters
Casamiquela et al. 2020

Bias due to difference in spectral type

Generally solved with a differential analysis wrt twin stars in the Hyades




Large dispersion especially in some Teff ranges



# 3. Applying differential spectroscopy to the GBS

We need: good quality (HR and high S/N) spectra of rv stable stars, so low probability of spectroscopic binaries

## *Gaia* Data Release 2

### The catalogue of radial velocity standard stars ⋆ ⋆⋆

C. Soubiran[1], G. Jasniewicz[2], L. Chemin[3], C. Zurbach[2], N. Brouillet[1], P. Panuzzo[4], P. Sartoretti[4], D. Katz[4], J.-F. Le Campion[1], O. Marchal[4], D. Hestroffer[5], F. Thévenin[6], F. Crifo[4], S. Udry[7], M. Cropper[8], G. Seabroke[8], Y. Viala[4], K. Benson[8], R. Blomme[9], A. Jean-Antoine[10], H. Huckle[8], M. Smith[8], S. G. Baker[8], Y. Damerdji[11,12], C. Dolding[8], Y. Frémat[9], E. Gosset[12,13], A. Guerrier[14], L.P. Guy[15], R. Haigron[4], K. Janßen[16], G. Plum[4], C. Fabre[17], Y. Lasne[14], F. Pailler[10], C. Panem[10], F. Riclet[10], F. Royer[4], G. Tauran[14], T. Zwitter[18], A. Gueguen[4,19], and C. Turon[4]

*(Affiliations can be found after the references)*

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**ABSTRACT**

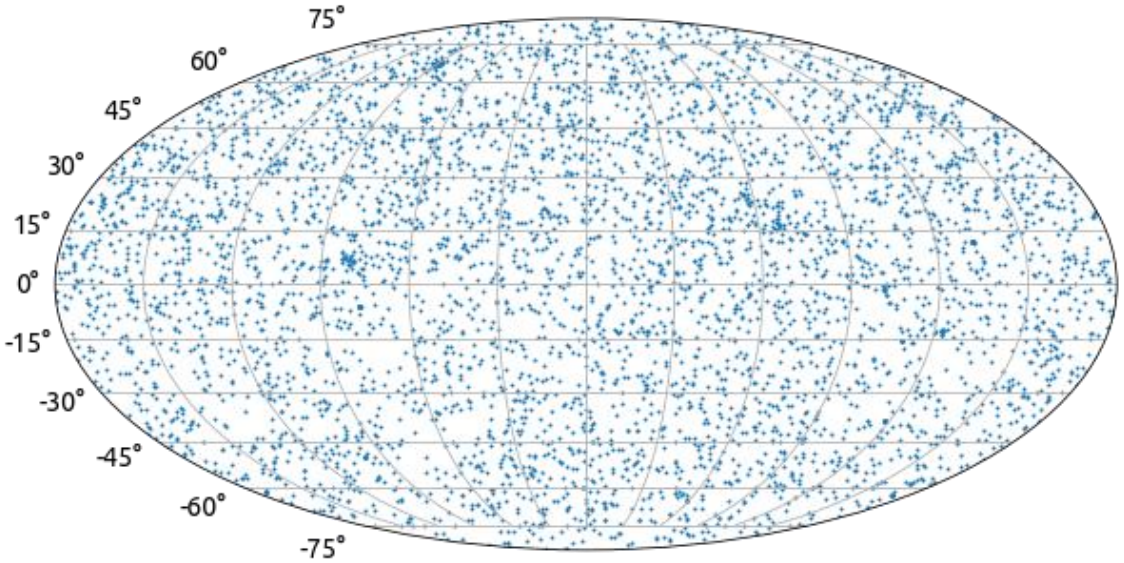
*Aims.* The Radial Velocity Spectrometer (RVS) on board the ESA satellite mission *Gaia* has no calibration device. Therefore, the radial velocity zero point needs to be calibrated with stars that are proved to be stable at a level of 300 m $s^{-1}$ during the *Gaia* observations.

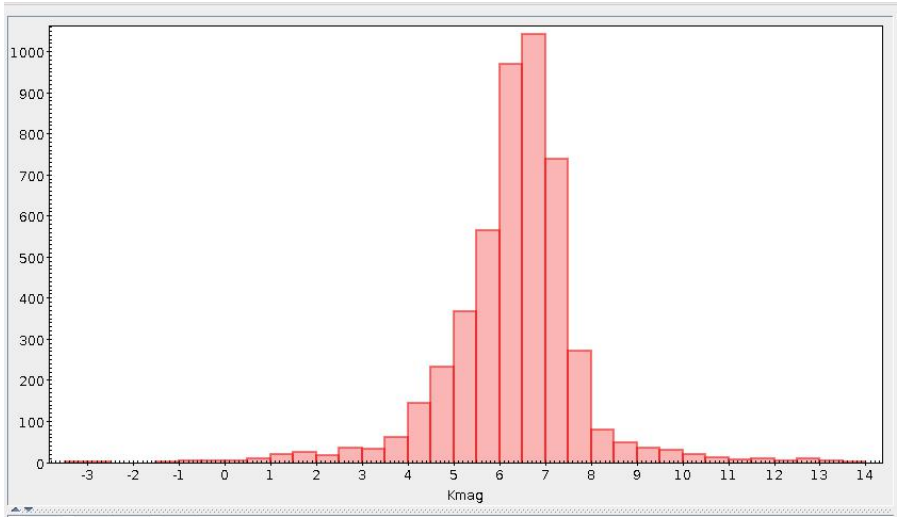
*Methods.* We compiled a dataset of ~71 000 radial velocity measurements from five high-resolution spectrographs. A catalogue of 4 813 stars was built by combining these individual measurements. The zero point was established using asteroids.

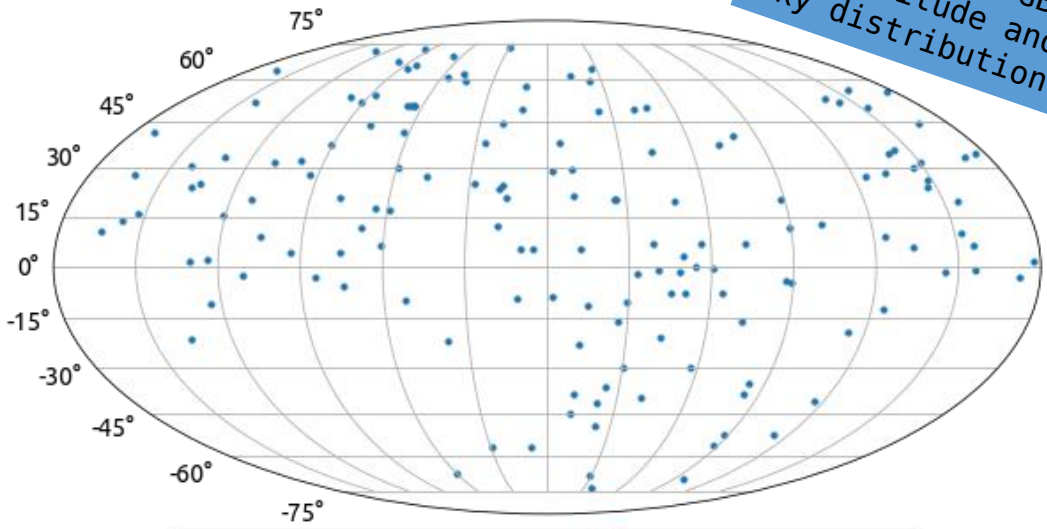
*Results.* The resulting catalogue has seven observations per star on average on a typical time baseline of six years, with a median standard deviation of 15 m $s^{-1}$. A subset of the most stable stars fulfilling the *RVS* requirements was used to establish the radial velocity zero point provided in *Gaia* Data Release 2. The stars that were not used for calibration are used to validate the *RVS* data.

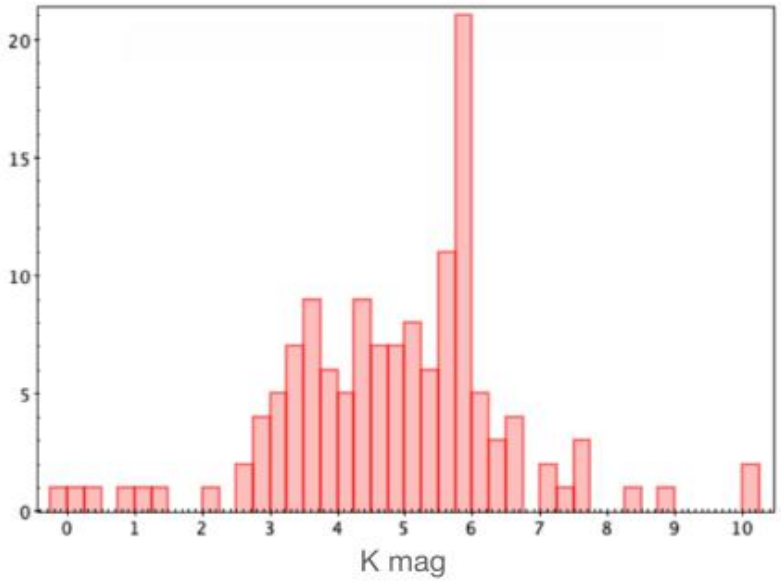
# 3. Applying differential spectroscopy to the GBS

Paula's talk GBS v3 magnitude and sky distribution



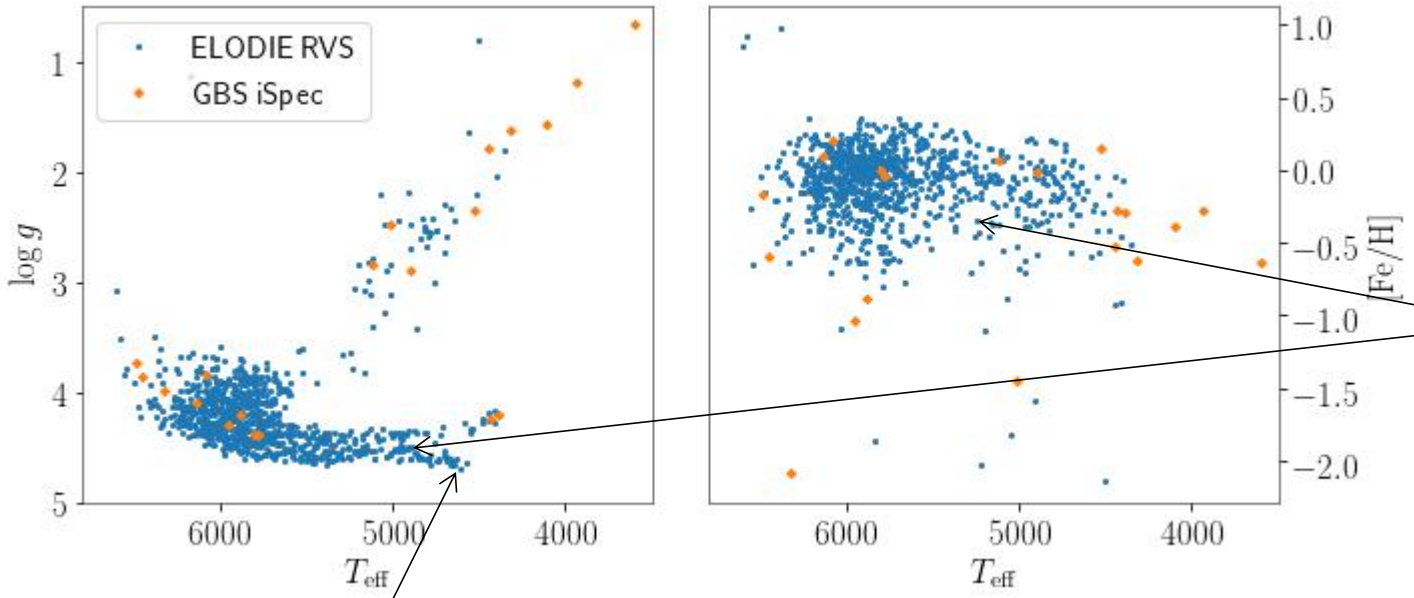



# 3. Applying differential spectroscopy to the GBS

(Very) preliminary test: the ELODIE subsample of the radial velocity standards catalog (940 stars)

Spectroscopic (absolute) analysis of the GBSv2 and the ELODIE subsample of reference stars

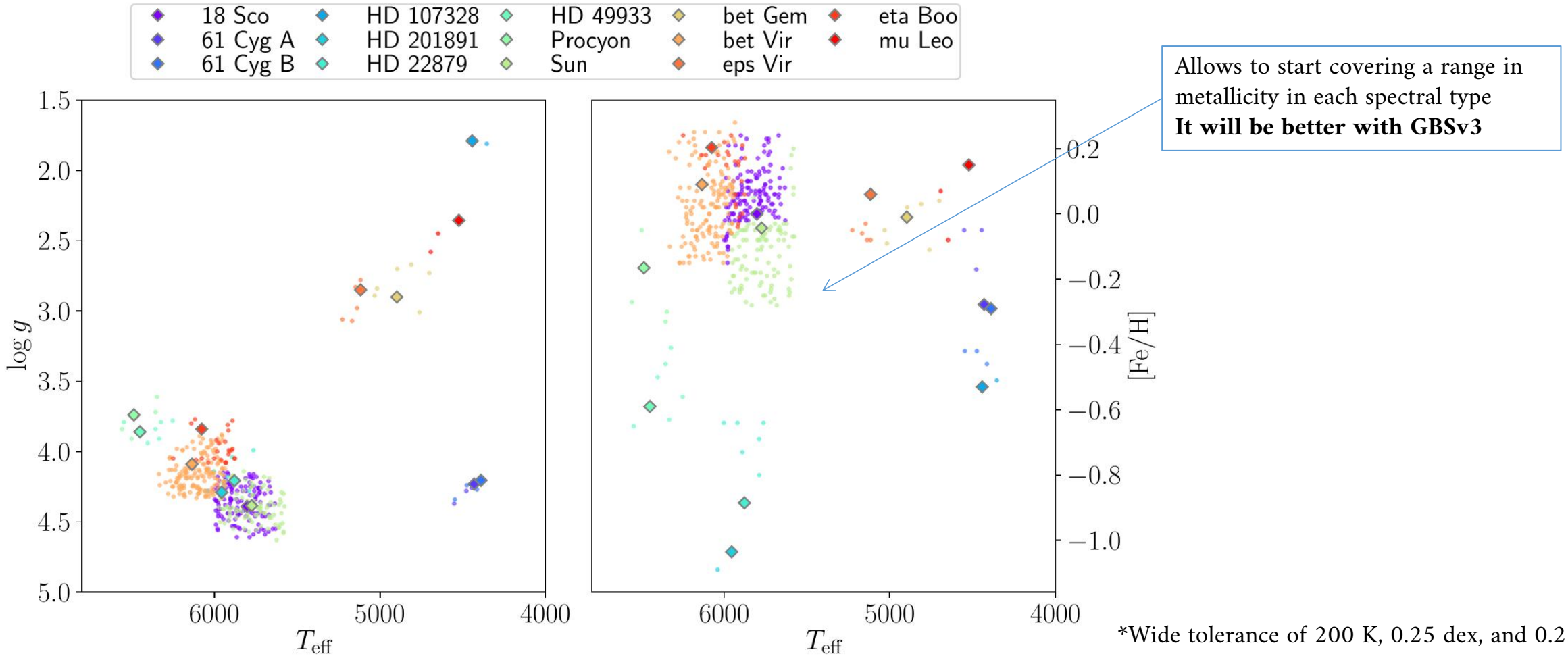



Eventually will help to fill some gaps in the metal-poor side and in the main sequence stars:
1. doing the **differential analysis iteratively**
2. once using the **full sample** or RV standards & GBSv3

But the absolute spectroscopic analysis introduces some known biases in logg

# 3. Applying differential spectroscopy to the GBS

Preliminary test: groups of twin stars in the ($T_{eff}$, log g, [Fe/H]) space wrt GBSv2: 440 stars




*Wide tolerance of 200 K, 0.25 dex, and 0.25 dex

# Conclusions

- We need more “GBS”: but we are limited in statistics, spectral types, metallicity, magnitude and declinations
- Differential spectroscopy can help if we find a sample of good spectra that better covers the parameter space: to build a *silver GBS sample*
- The *Gaia* radial velocity standard stars are a good option (4813 stars)
  - Even other samples of stars with good spectra could be added
- Promising tests with 1/4 of the full sample (ELODIE, 940 stars)
- Looking forward to GBS version3