Building sets of reference stars for current and future spectroscopic stellar parameters survey

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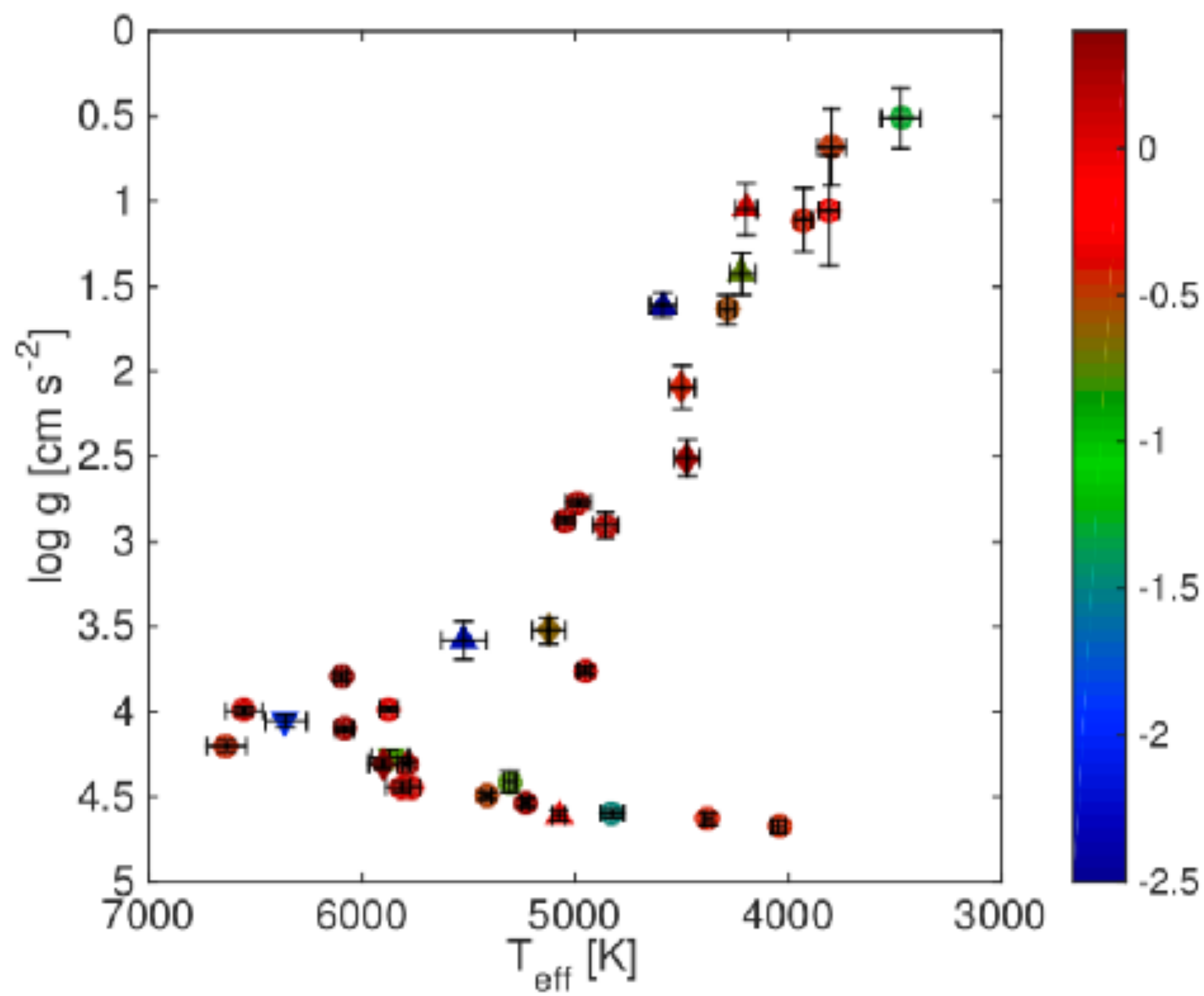
Gaia FGK Benchmark Stars

- Spectroscopy lacked a clearly defined standard stars
- Era of the large stellar surveys
- Calibration of large data sets
- Better understanding of the MW
- Reference sample of stars for X-correlation of different surveys

Name	T_{eff} [K]	$u(T_{eff})$ [K]	$\% u(T_{eff})$	$\log g$	$u(\log g)$ [cm s^{-2}]
F dwarfs					
Procyon	6554	84	1.28	4.00	0.02
HD 84937	6356	97	1.52	4.06	0.04
HD 49933	6635	91	1.38	4.20	0.03
FGK subgiants					
δ Eri	4954	30	0.61	3.76	0.02
HD 140283	[5522]	[105]	[1.91]	3.58	0.11
ϵ For	5123	78	1.53	[3.52]	[0.08]
η Boo	6099	28	0.45	3.79	0.02
β Hyi	5873	45	0.77	3.98	0.02
G dwarfs					
α Cen A	5792	16	0.27	4.31	0.01
HD 22879	5868	89	1.52	4.27	0.04
Sun	5771	1	0.01	4.4380	0.0002
μ Cas	5308	29	0.54	[4.41]	[0.06]
τ Cet	5414	21	0.39	[4.49]	[0.02]
α Cen B	5231	20	0.38	4.53	0.03
18 Sco	5810	80	1.38	4.44	0.03
μ Ara	[5902]	[66]	[1.12]	4.30	0.03
β Vir	6083	41	0.68	4.10	0.02
FGK giants					
Arcturus	4286	35	0.82	[1.64]	[0.09]
HD 122563	4587	60	1.31	1.61	0.07
μ Leo	4474	60	1.34	2.51	0.11
β Gem	4858	60	1.23	2.90	0.08
ϵ Vir	4983	61	1.21	2.77	0.02
ξ Hya	5044	40	0.78	2.87	0.02
HD 107328	4496	59	1.32	2.09	0.13
HD 220009	[4217]	[60]	[1.43]	[1.43]	[0.12]
M giants					
α Tau	3927	40	1.01	1.11	0.19
α Cet	3796	65	1.71	0.68	0.23
β Ara	[4197]	[50]	[1.20]	[1.05]	[0.15]
γ Sge	3807	49	1.28	1.05	0.32
ψ Phe	[3472]	[92]	[2.65]	[0.51]	[0.18]
K dwarfs					
ϵ Eri	5076	30	0.60	4.61	0.03
Gmb 1830	[4827]	[55]	[1.14]	4.60	0.03
61 Cyg A	4374	22	0.49	4.63	0.04
61 Cyg B	4044	32	0.78	4.67	0.04

Gaia FGK Benchmark Stars

- Bright stars of different spectral types, luminosity and metallicities
- Stars previously used as reference, calibration or test objects (eps Vir in Smiljanic+ 2007, Procyon in Porto de Mello+ 2014)
- Stellar parameters and abundances determined in a homogeneous way
- Wide range of temperatures (<4000 to 6500 K). Some M giants were also included
- Temperature and log g determined independently from spectroscopy



Heiter+2015

Temperature

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

- Where F_{bol} is the bolometric flux and θ_{LD} the limb darkened angular diameter
- Most values for F_{bol} and θ_{LD} from literature (Ex: Pasinetti Fracassini et al. 2001, Blackwell & Lynas-Gray 1998)
- Additional values for θ_{LD} from indirect calibrations (Claret 2000 and Claret et al. 1995)

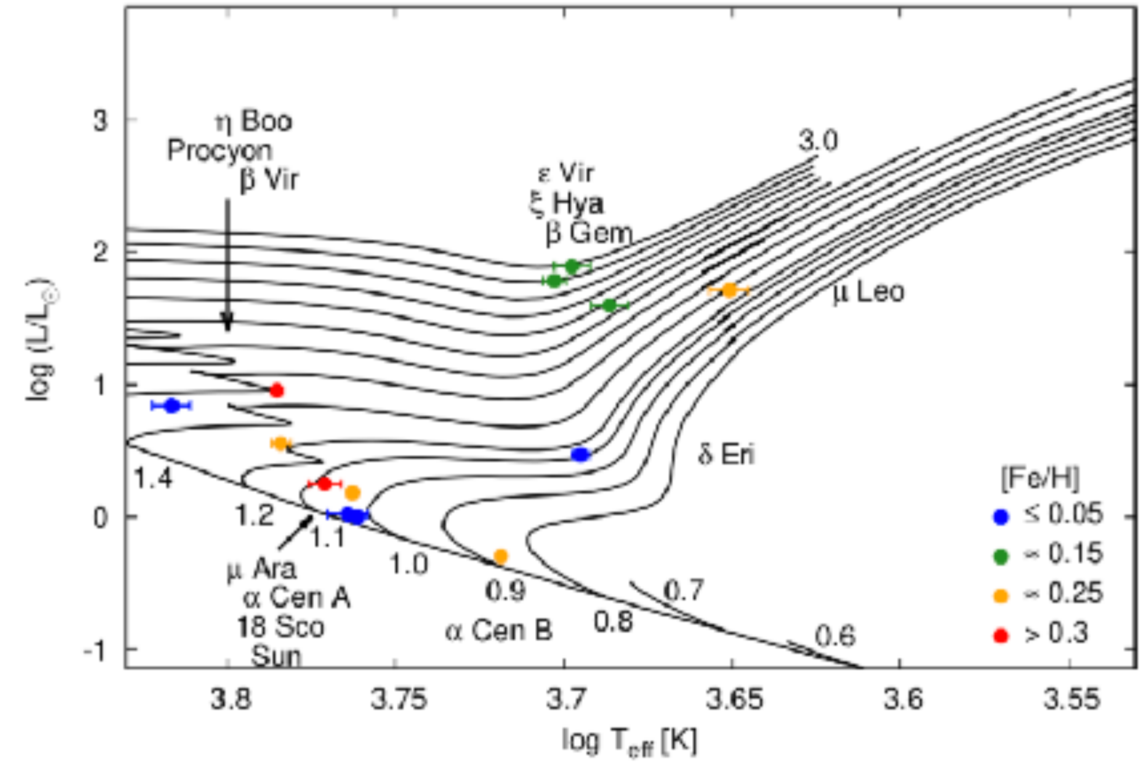
Gravity

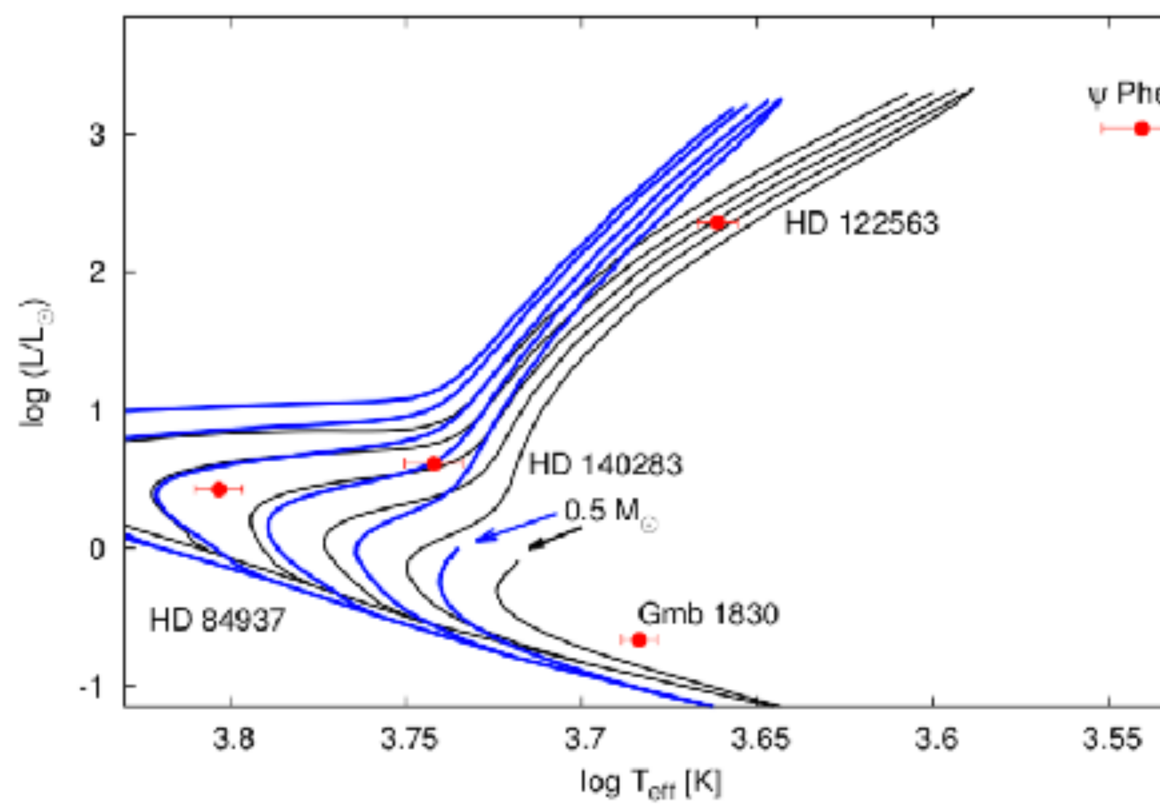
$$g = GM/R^2$$

R from angular diameter and parallax; complementation from asteroseismology when available

M from evolutionary tracks (Padova and Y2) with Teff, L and [Fe/H] (Jofré+2014) as constraints

Visual or eclipsing binaries





Heiter + 2015

GBS 2.1

- Abundances of Mg, Si, Ca, Sc, Ti, V, Cr, Mn, Co and Ni
- Updated stellar parameters: some objects were excluded and metal-poor added, making a total of 36 stars
- GBS light elements (Li, C, N, O, Na, Al) *available next year
- Refine parameters with parallaxes from Gaia
- GBS 3.0 (work in progress)

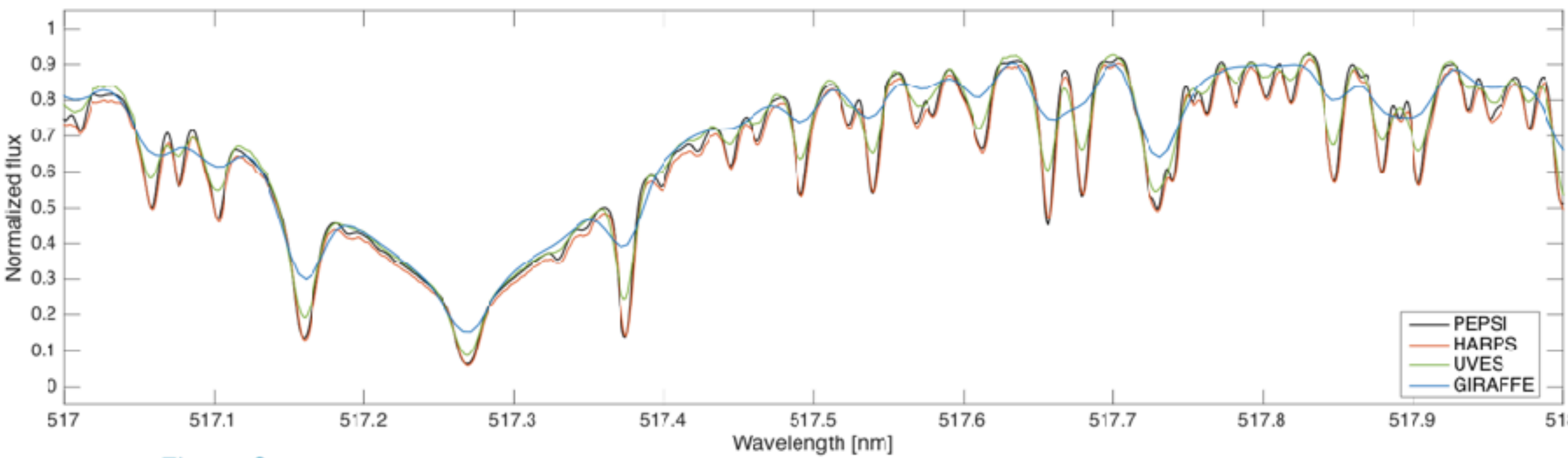
Uncertainties

- Combining abundances from different surveys is non-trivial due to the uncertainty arising from different data analysis and different error treatment

- Random (input data) and systematic (methodology) errors

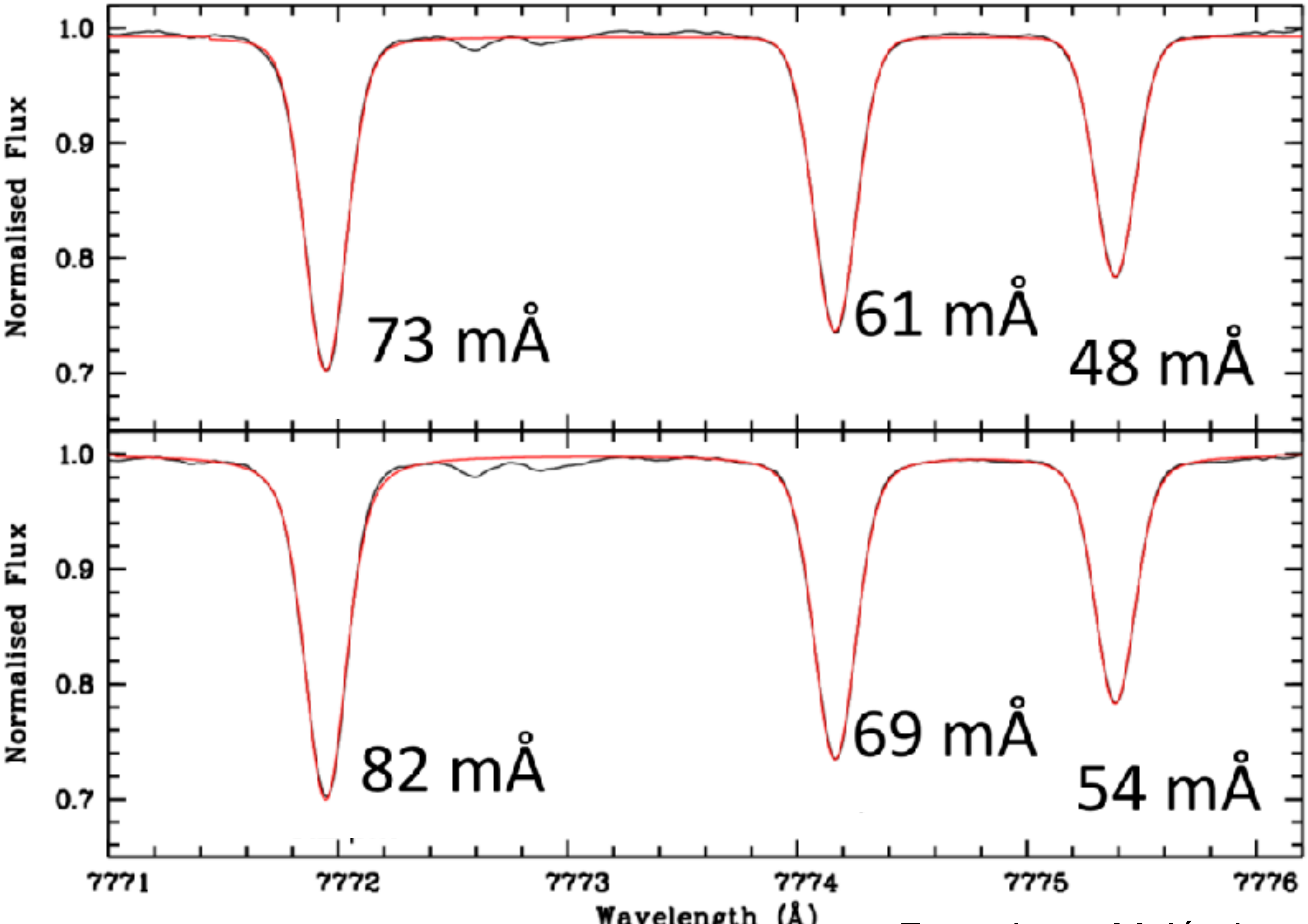
Instrumental error

Blends cannot be identified depending on the R and S/N



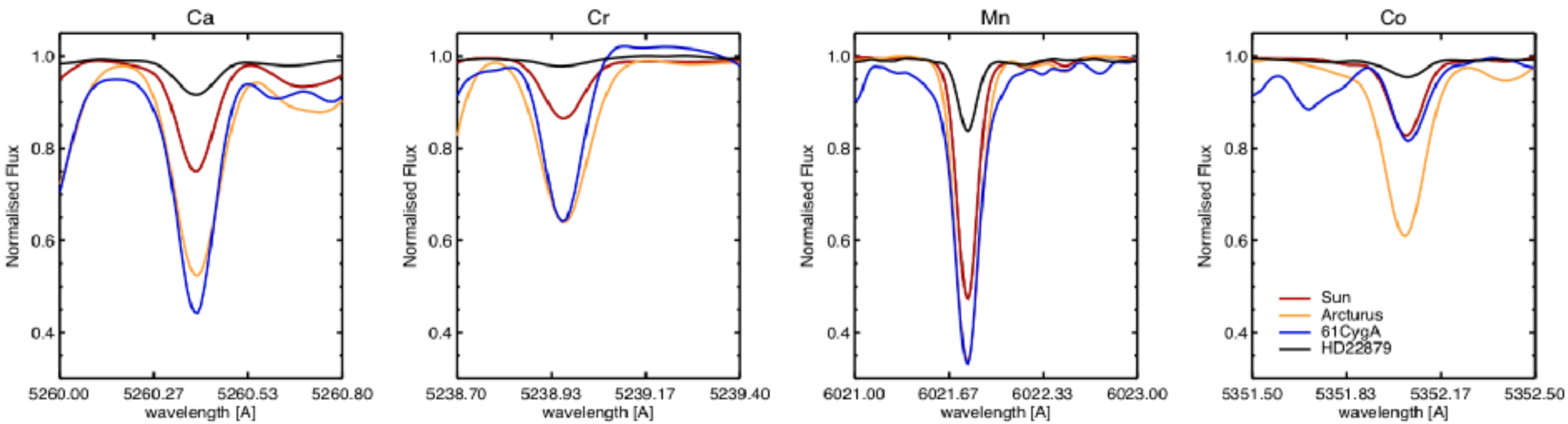
Jofré + 2018

Normalization process and continuum placement



From Jorge Meléndez

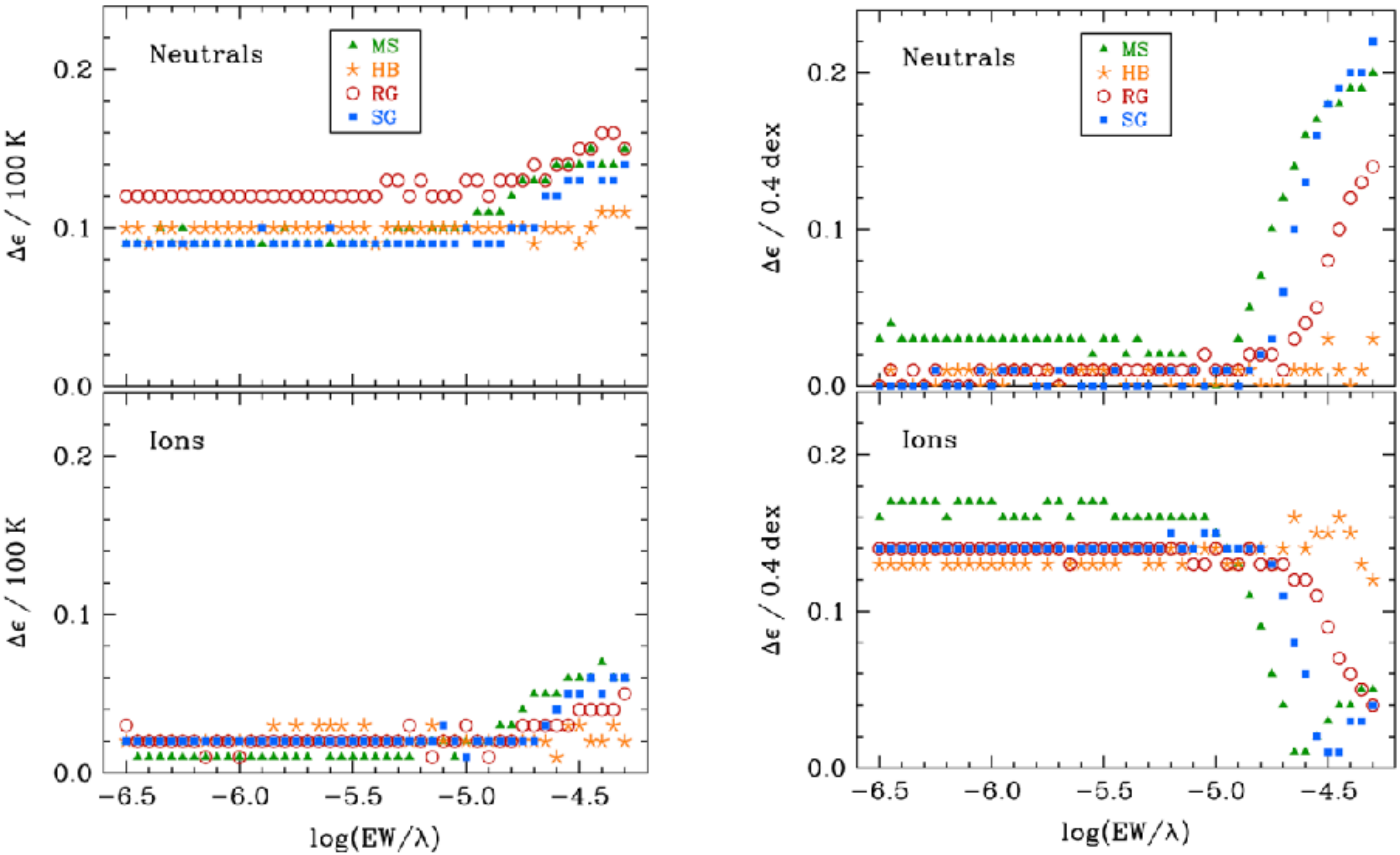
Line list



Jofre + 2016

- Quality is better than quantity
- Saturated, blended, too weak, poor atomic data, poor HFS treatment, telluric contamination and etc. may only add noise to your analysis

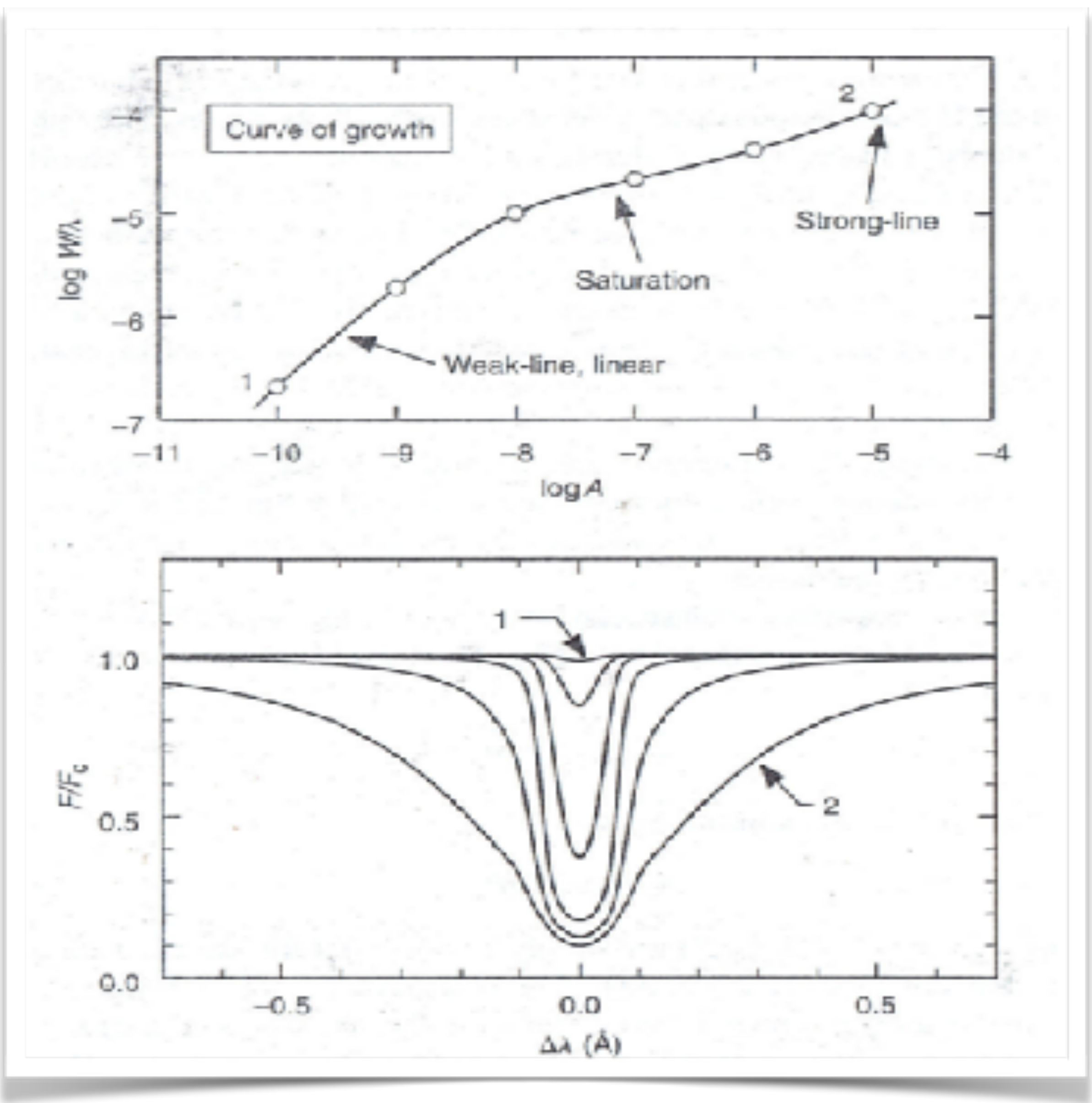
Stellar Parameters



Roederer + 2014

Improving the Precision

Differential Analysis



$$\log\left(\frac{W}{\lambda}\right) = B + A_X + \log gf + \log\lambda - \theta_{\chi_{exc}} - \log\kappa_{cont}.$$

$$\log\left(\frac{W_{1,i}}{W_{2,i}}\right) = A^1_{X,i} - A^2_{X,i} - (\theta^1 - \theta^2)_{\chi_{exc}} - \log\left(\frac{\kappa^1_{cont}}{\kappa^2_{cont}}\right).$$

$$\delta A_{X,i} \sim \log(W_i / W_i^{\odot}) + (\theta - \theta^{\odot})_{\chi_{exc}}$$

Errors on the differential method between very similar stars are mostly due to errors in the EW measurement

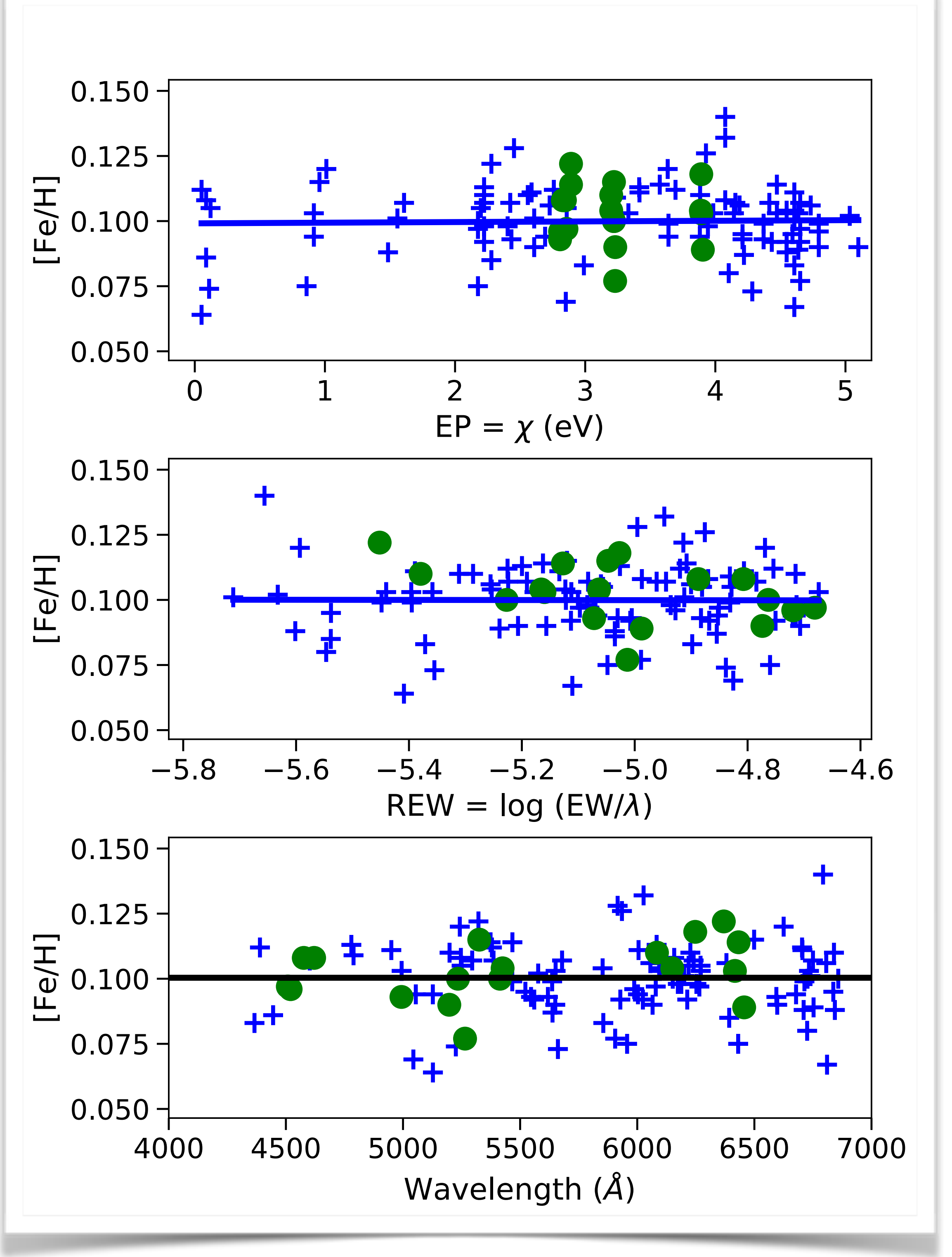
Solar Twins

Stellar Parameters

Excitation equilibrium (Temperature)

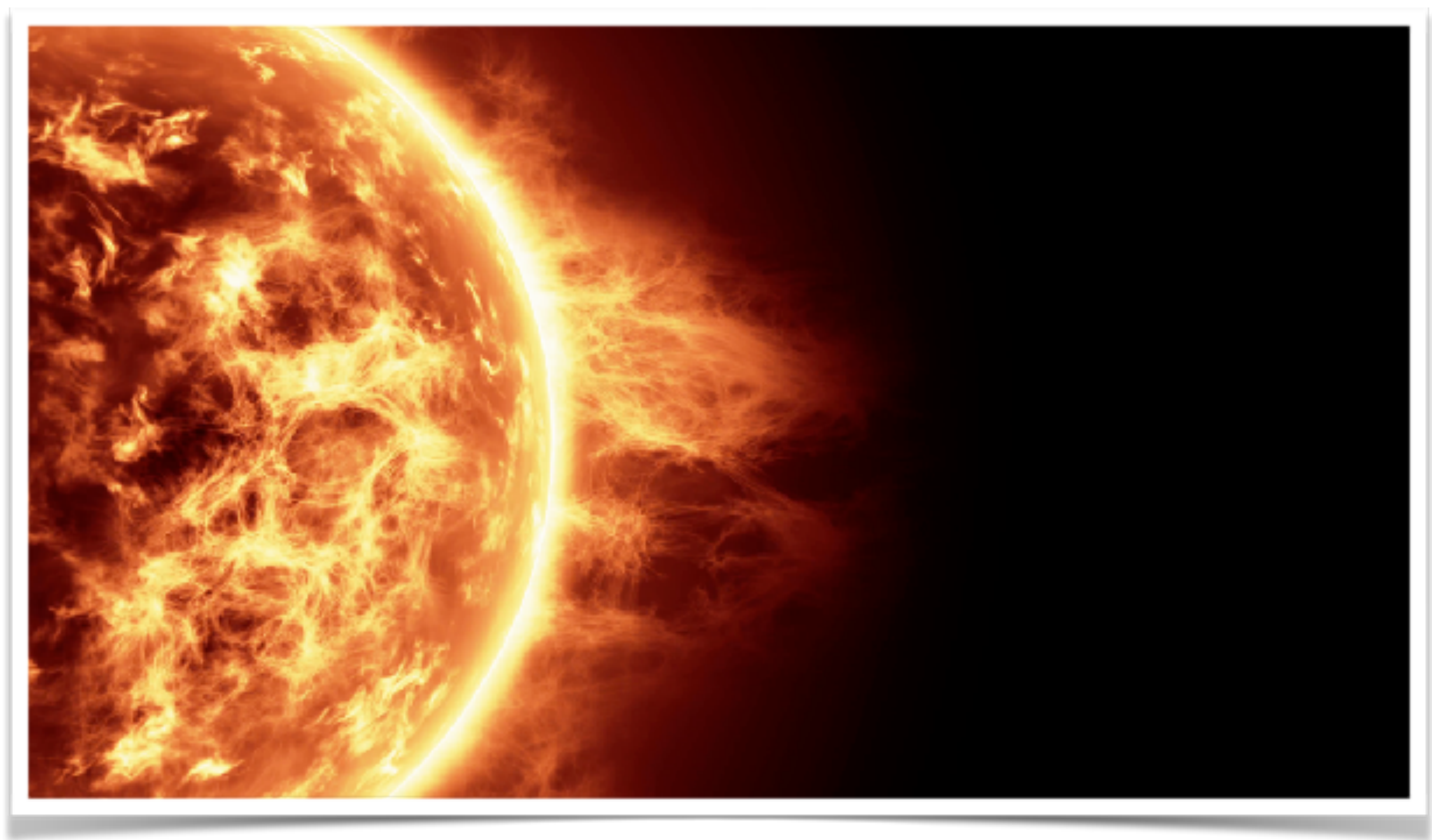
Ionization equilibrium (Gravity)

σTeff ~ 10 K
σlog g < 0.02 dex
σ[X/H] ~ 0.01 dex



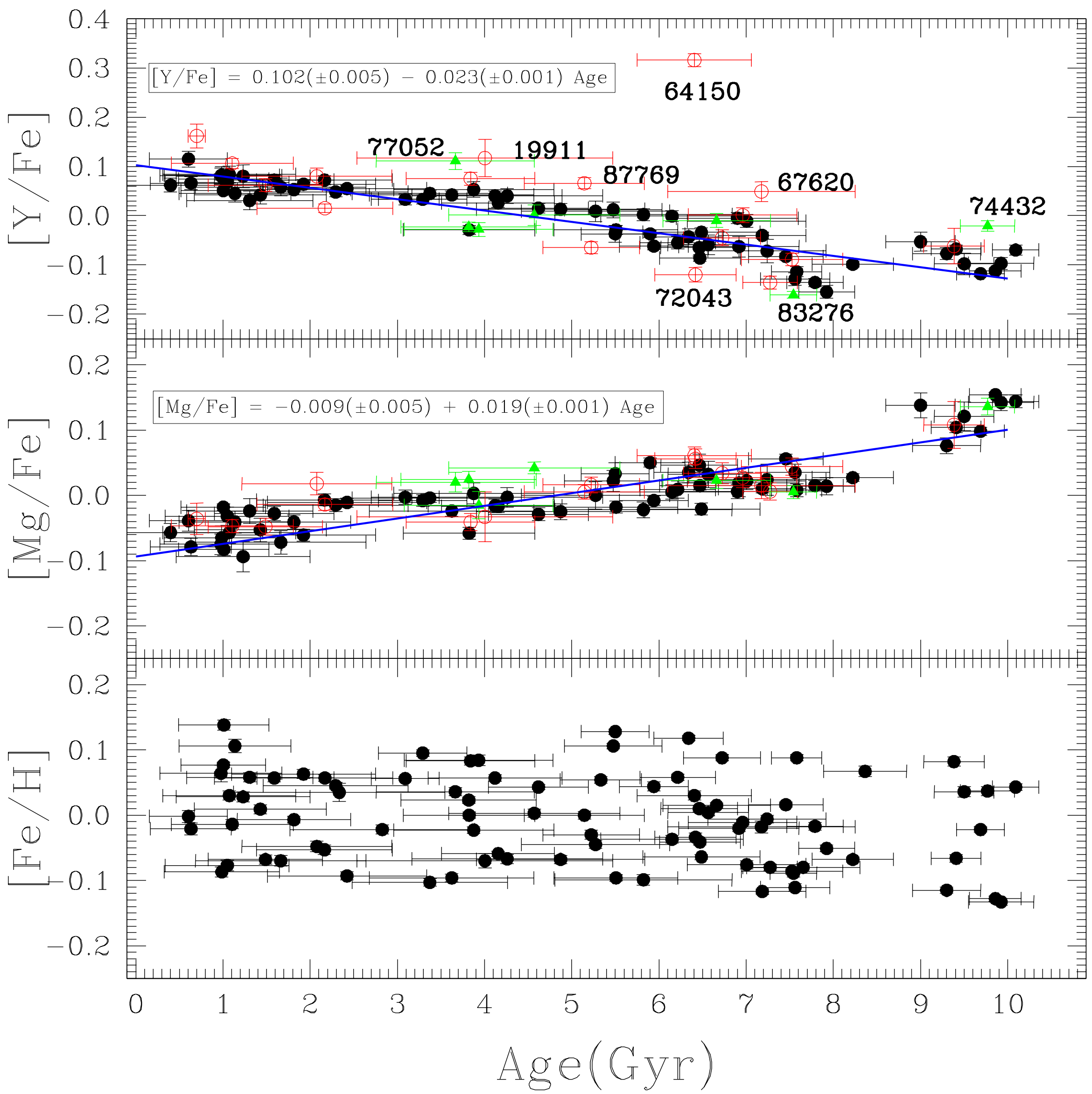
Solar Twins

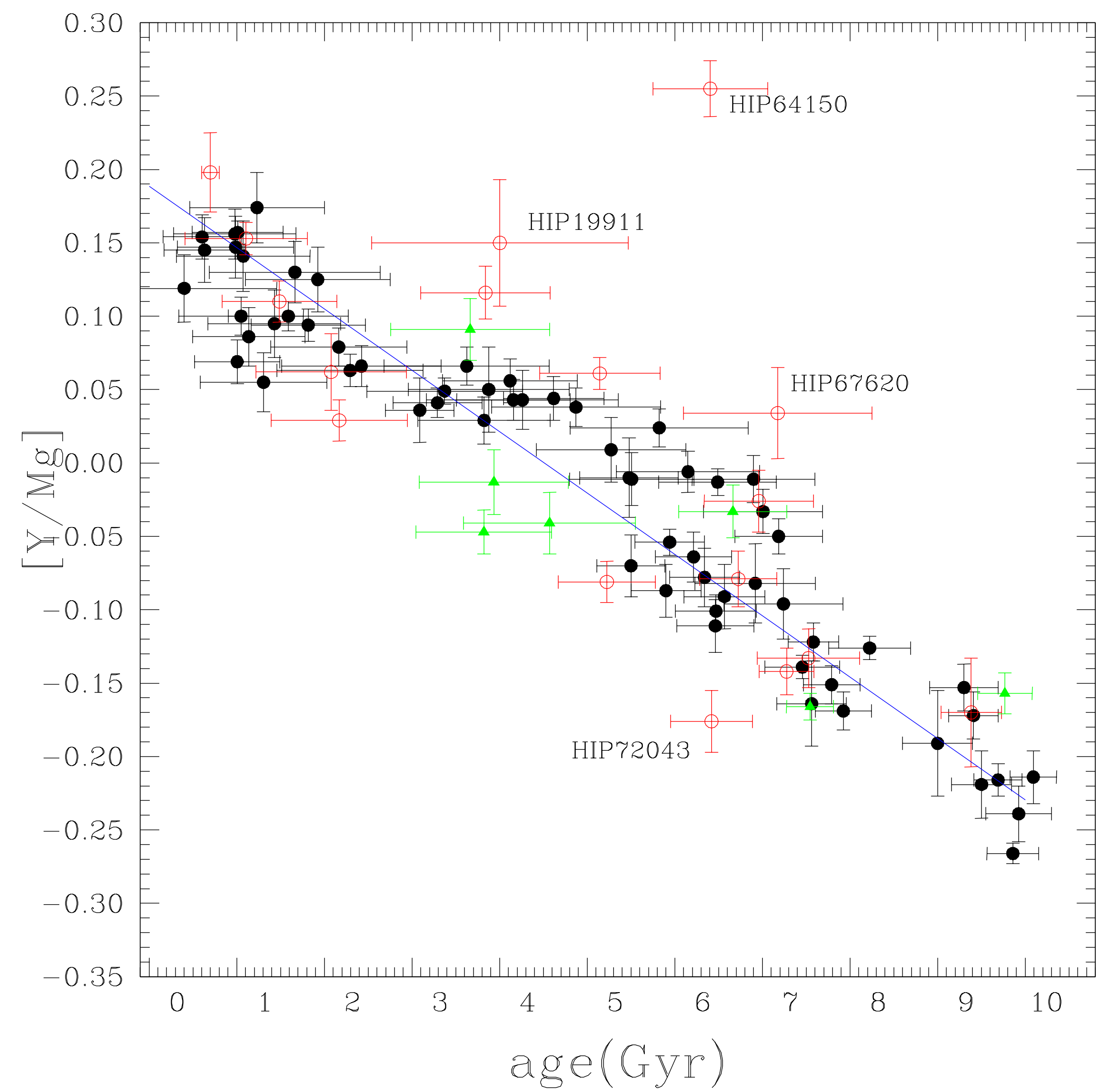
- Stars very similar to the Sun
- Temperatures 5777 ± 100K, gravity 4.44 ± 0.10 dex, [Fe/H] 0.0 ± 0.1 dex
- Very similar spectra



[Y/Mg] Chemical clock

Tucci Maia et al. 2016

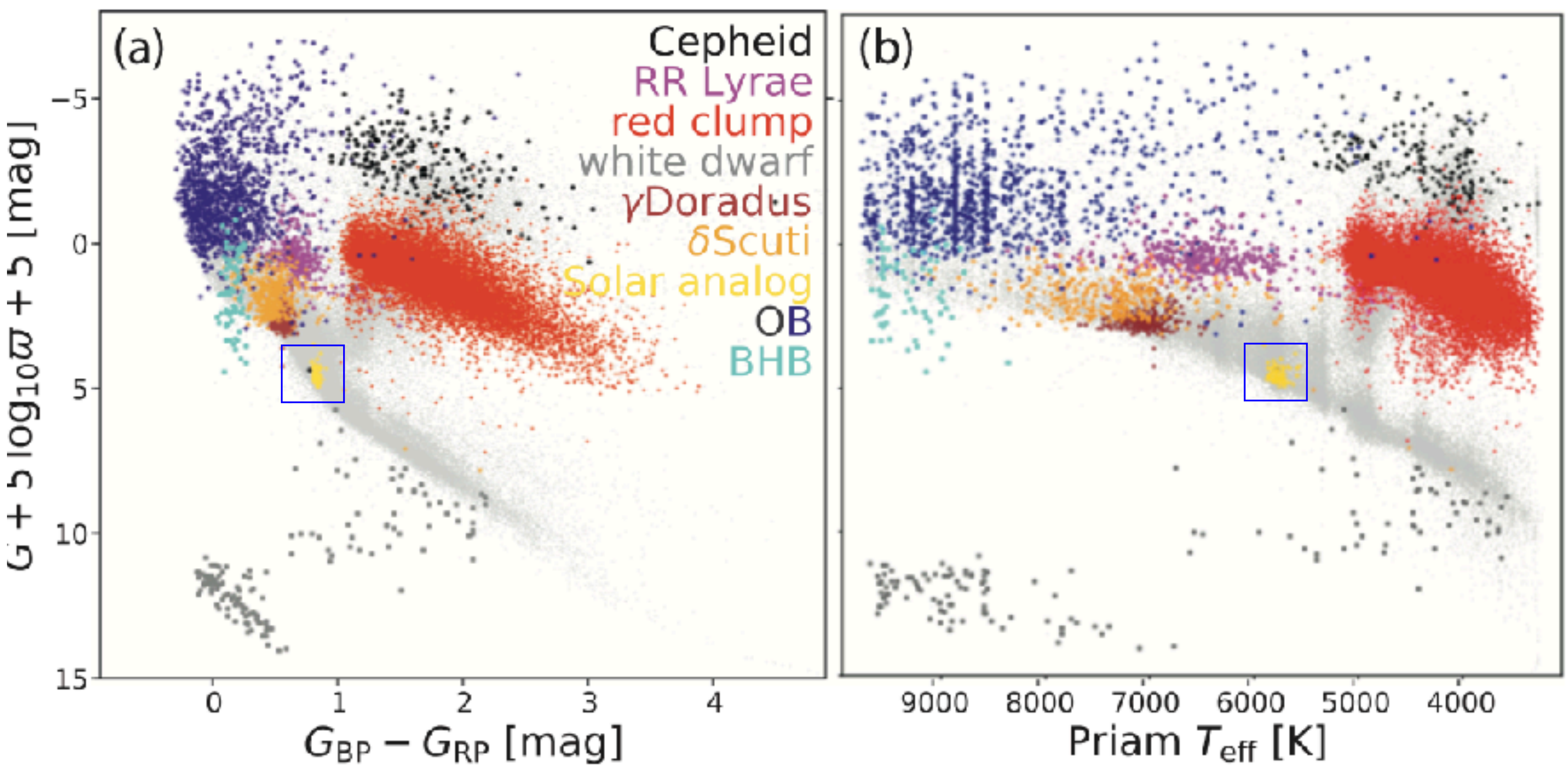




Apsis

Gaia pipeline calibration

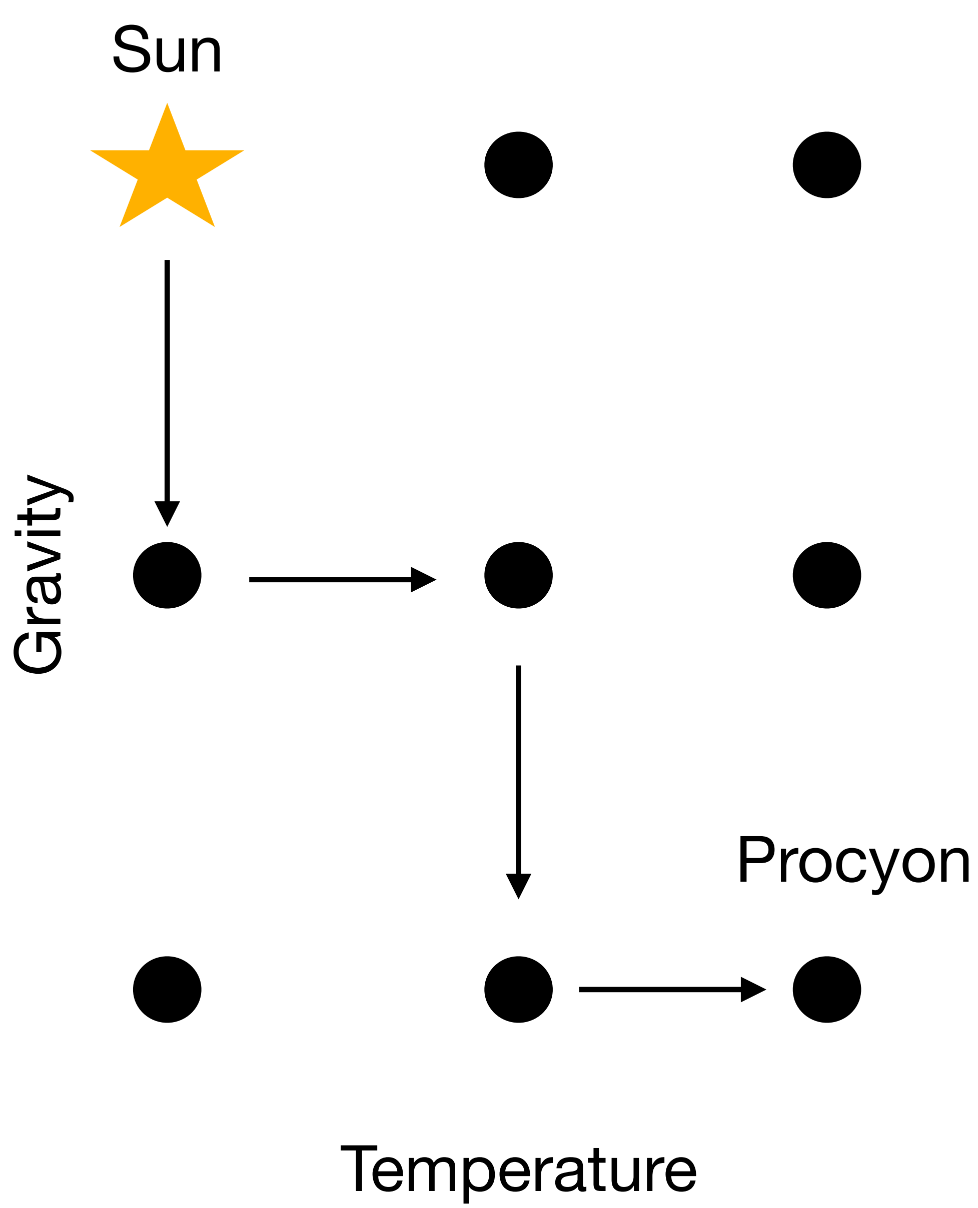
GBS and solar twins Tucci Maia+ 2016



Andrae+ 2018

GBS 3.0

- Apply similar method as the solar twins
- Spectroscopic standard stars so we can fill the stellar parameter space to differentially access stars of various spectral type
- Determination of its parameters using the same approach of the previous benchmark stars together with the differential analysis
- Take into account different stellar ages



Summary

- It is necessary a “universal” set of reference star for X-correlation between different surveys
- Uncertainties can be improved by differential analysis
- Determination of stellar parameters using the same approach as the other benchmark stars together with differential methods
- More benchmark stars to fill the gaps on the stellar parameter space to access with high precision stars with different spectral types (GBS 3.0)