Benchmark stars, benchmark spectrographs!

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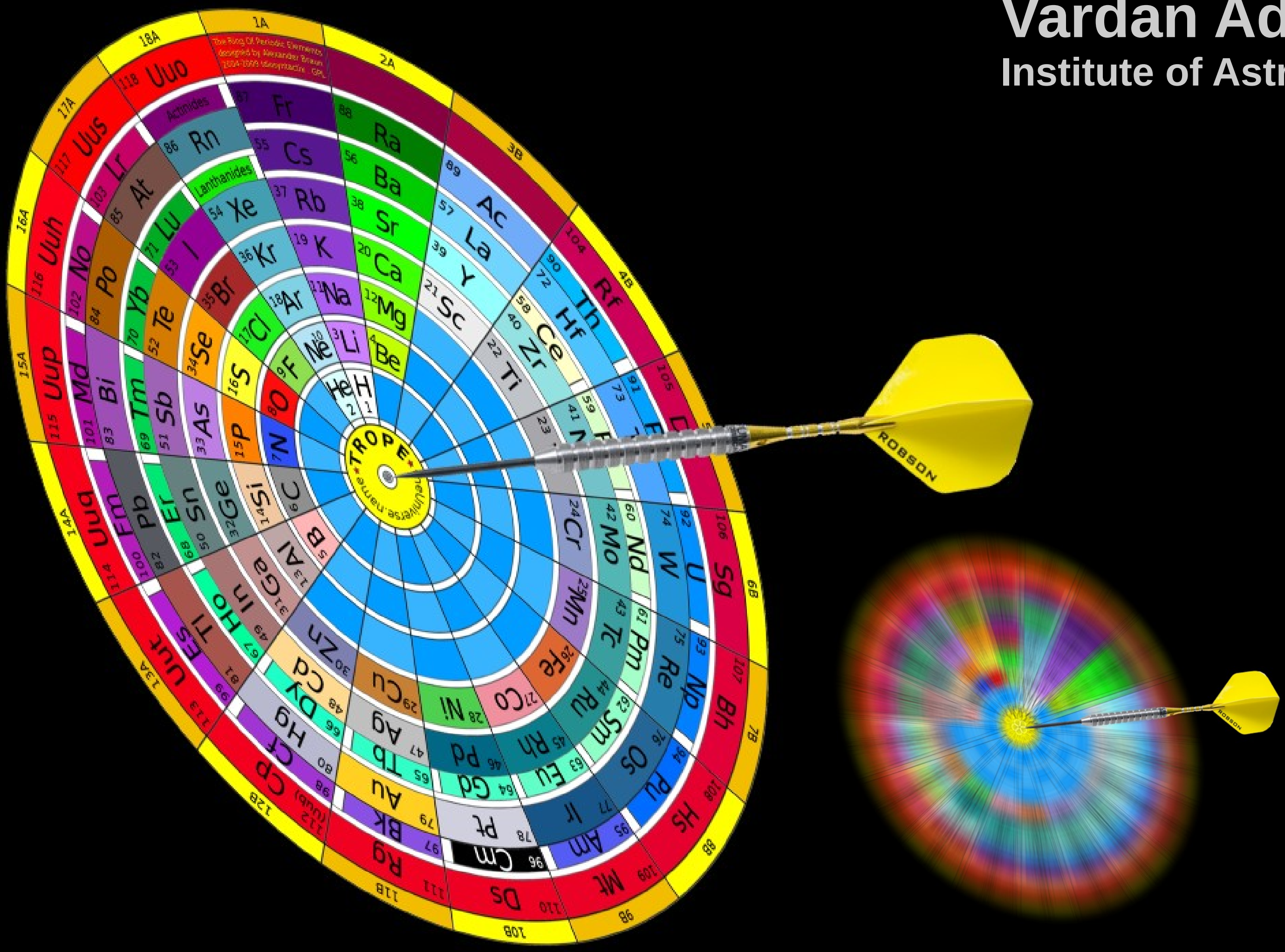


HRMOS Science Workshop

Oct 20, 2021, Firenze, (hybrid), Italy

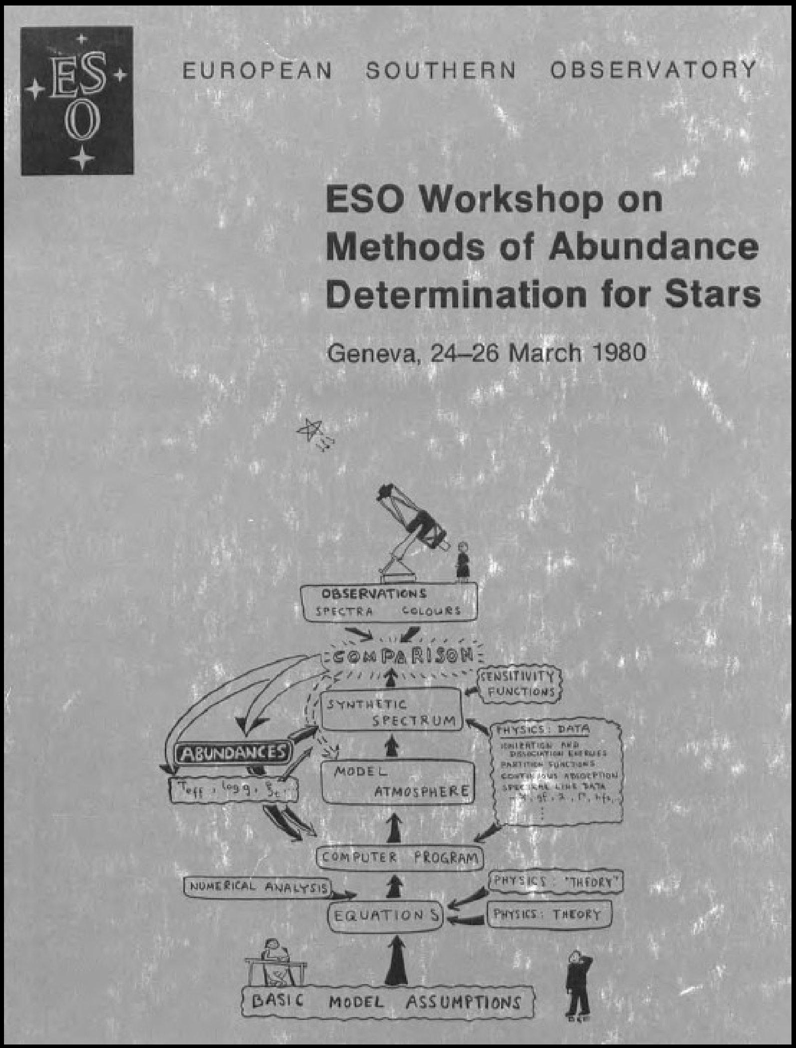
instituto de astrofísica e ciências do espaço

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

Bernard Pagel

Two categories of stellar spectroscopists

The "Ultimate Refiners" and the "Broad Sweepers"

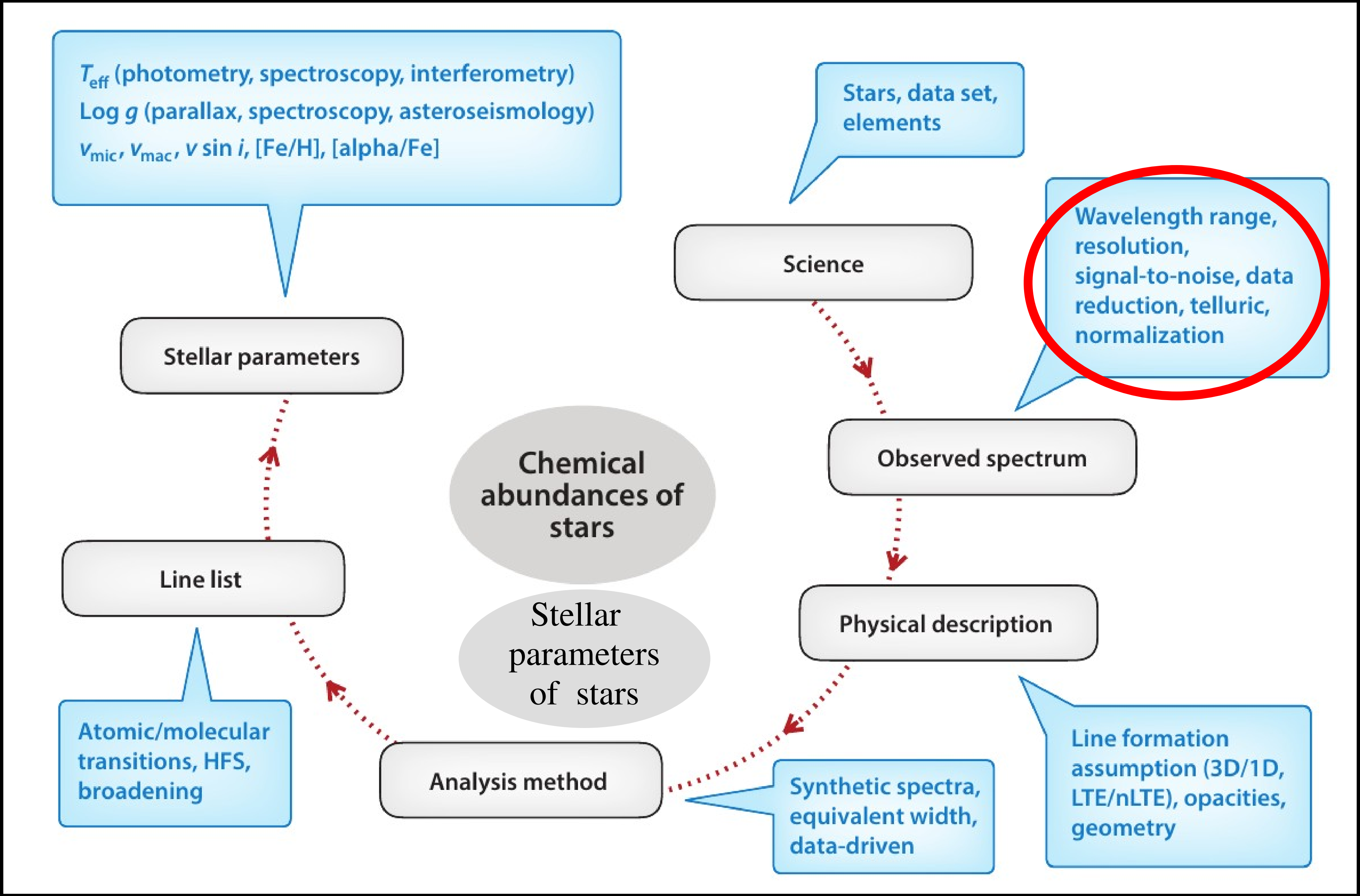


The broad sweepers: satisfied with abundance determinations with uncertainty of **~0.2 dex**. Mostly interested in obtaining a vast amount of data for many stars in order to study problems of nucleosynthesis, stellar and galactic evolution.

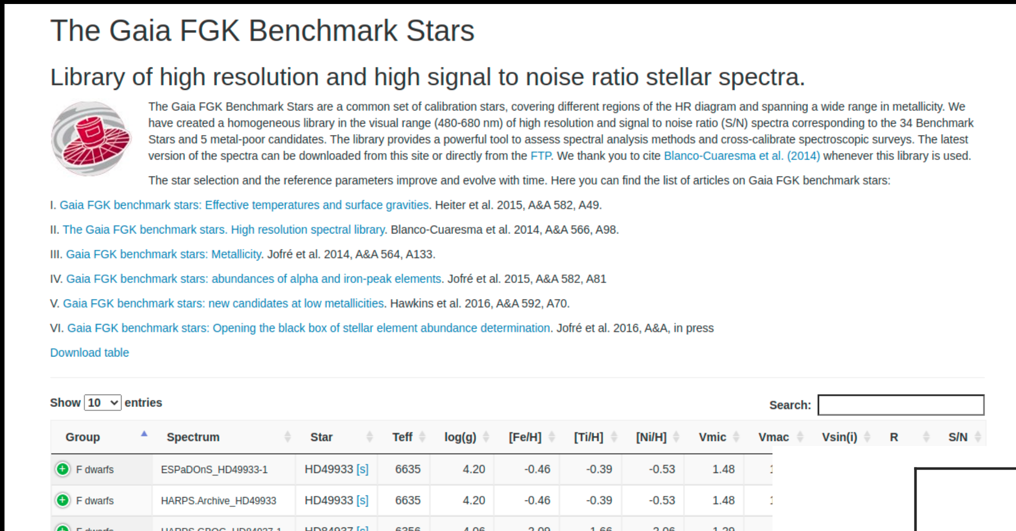
The ultimate refiners: worried about the significant differences between the observed and computed stellar spectra. They try to use these discrepancies to learn more about the stellar atmospheres with the ultimate hope of constructing better models and thus determining more accurate abundances.

Gustafsson (1980)

Spectroscopic stellar parameters and chemical abundances



Courtesy: Jofré et al. (2019)



The Gaia FGK Benchmark Stars

Library of high resolution and high signal to noise ratio stellar spectra.

The Gaia FGK Benchmark Stars are a common set of calibration stars, covering different regions of the HR diagram and spanning a wide range in metallicity. We have created a homogeneous library in the visual range (480-680 nm) of high resolution and signal to noise ratio (S/N) spectra corresponding to the 34 Benchmark Stars and 5 metal-poor candidates. The library provides a powerful tool to assess spectral analysis methods and cross-calibrate spectroscopic surveys. The latest version of the spectra can be downloaded from this site or directly from the FTP. We thank you to cite Blanco-Cuaresma et al. (2014) whenever this library is used.

The star selection and the reference parameters improve and evolve with time. Here you can find the list of articles on Gaia FGK benchmark stars:

I. Gaia FGK benchmark stars: Effective temperatures and surface gravities. Heiter et al. 2015, A&A 582, A49.

II. The Gaia FGK benchmark stars. High resolution spectral library. Blanco-Cuaresma et al. 2014, A&A 566, A98.

III. Gaia FGK benchmark stars: Metallicity. Jofré et al. 2014, A&A 564, A133.

IV. Gaia FGK benchmark stars: abundances of alpha and iron-peak elements. Jofré et al. 2015, A&A 582, A81

V. Gaia FGK benchmark stars: new candidates at low metallicities. Hawkins et al. 2016, A&A 592, A70.

VI. Gaia FGK benchmark stars: Opening the black box of stellar element abundance determination. Jofré et al. 2016, A&A, in press

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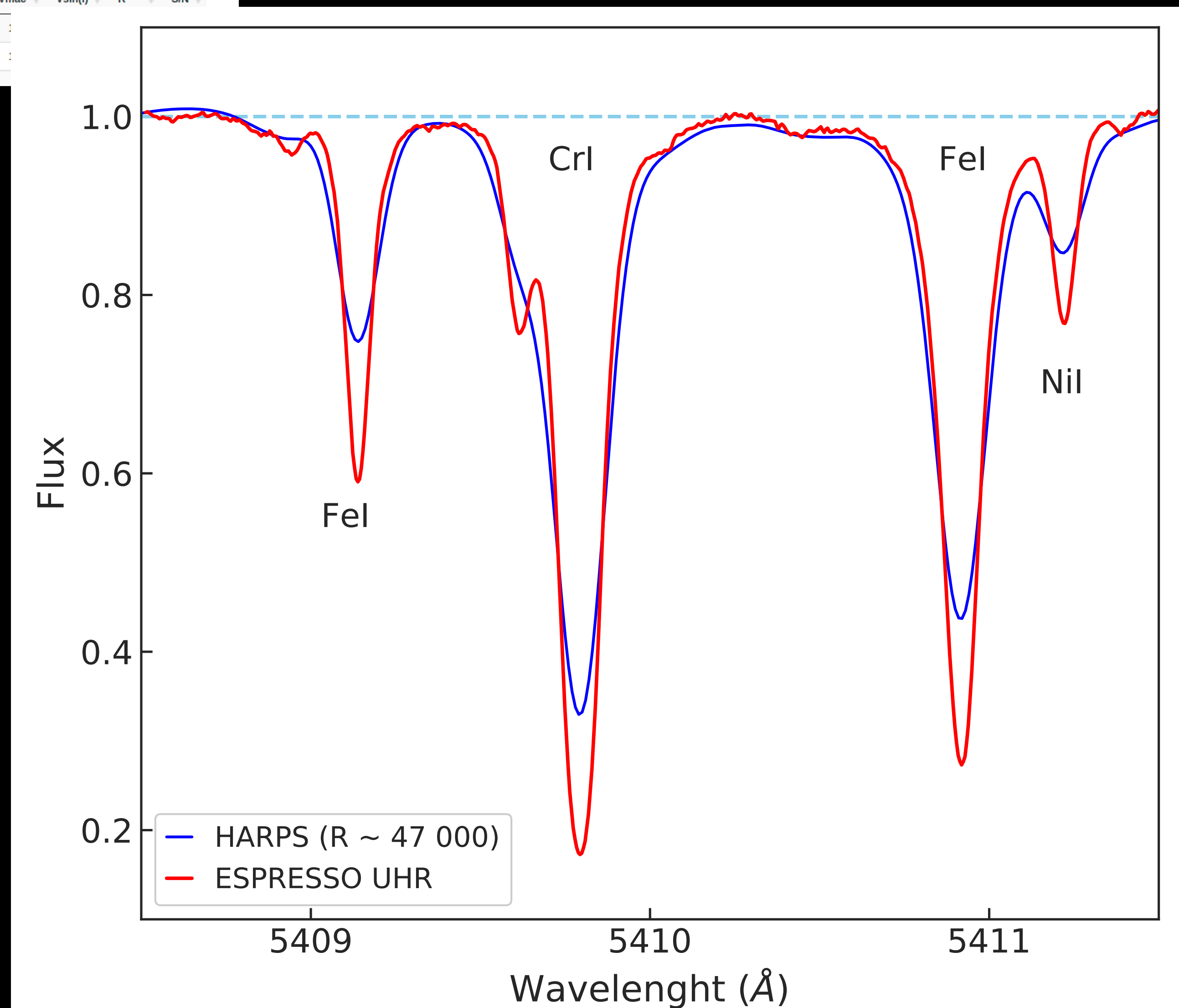
Search:

Group	Spectrum	Star	Teff	log(g)	[Fe/H]	[Ti/H]	[Ni/H]	Vmic	Vmac	Vsin(i)	R	S/N
F dwarfs	ESPaDOnS_HD49933-1	HD49933 [s]	6635	4.20	-0.46	-0.39	-0.53	1.48				
F dwarfs	HARPS.Archive_HD49933	HD49933 [s]	6635	4.20	-0.46	-0.39	-0.53	1.48				
F dwarfs	HARPS.GBOG_HD84937-1	HD84937 [s]	6356	4.06	-2.09	-1.66	-2.06	1.29				

τ Ceti

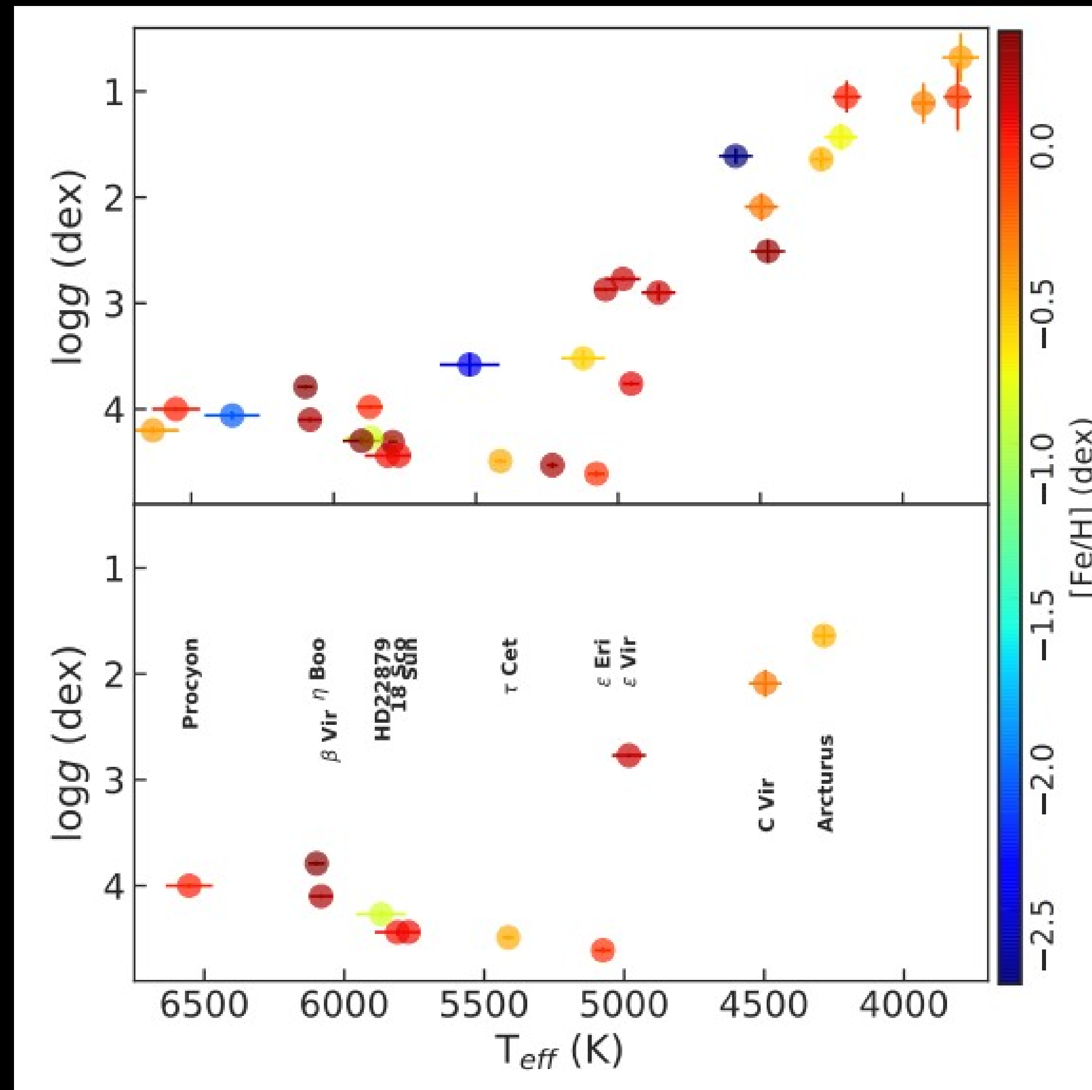


Benchmark stars, benchmark spectrographs

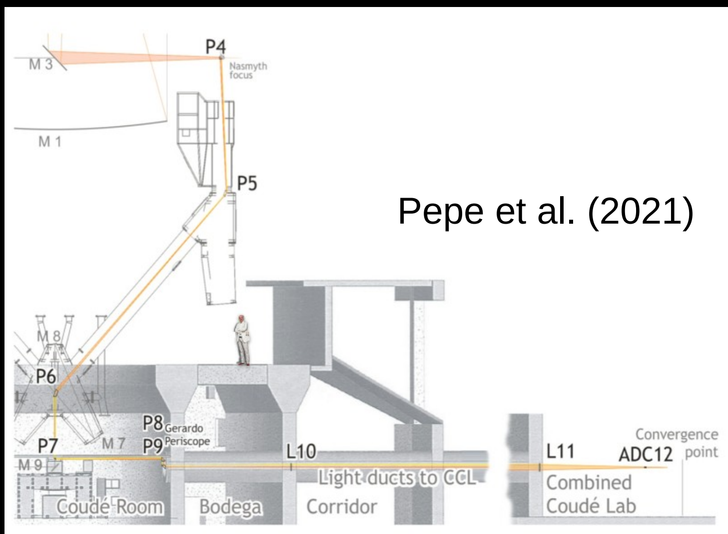
WL: 380-780 nm
R ~ 220'000

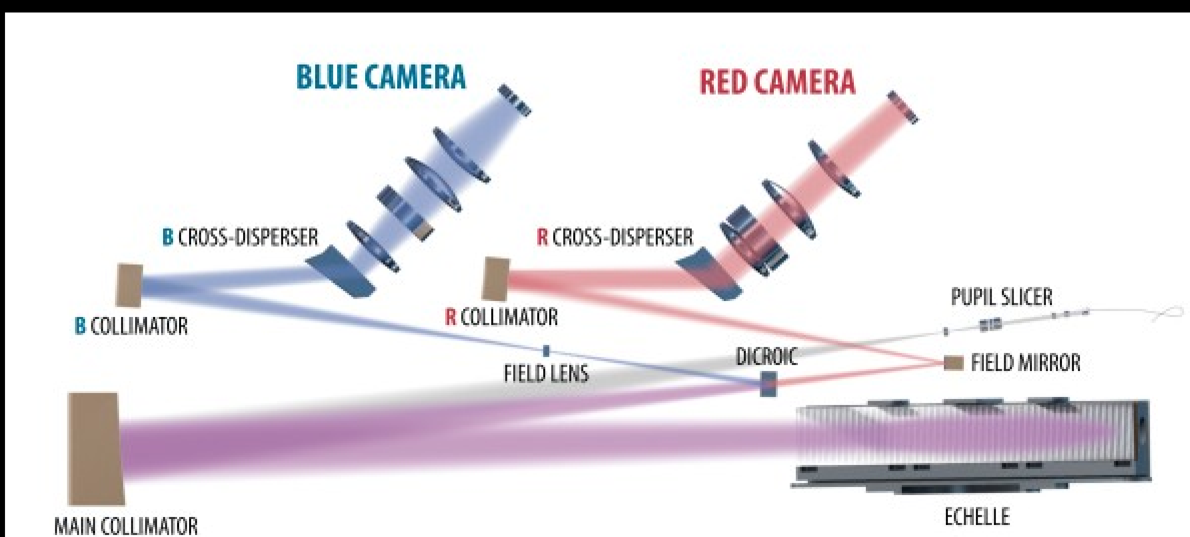
WL: 380–910 nm
R ~ 220'000

WL: 380–690 nm
R ~ 110'000



ESPRESSO spectra: perfect to study effects of ‘spectra reduction’





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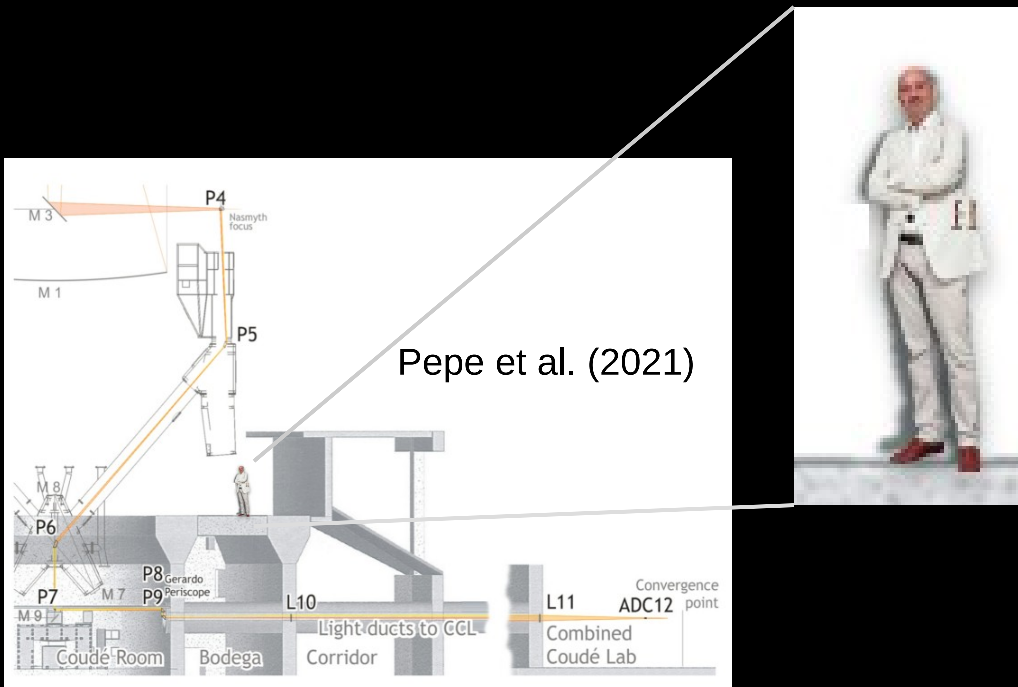

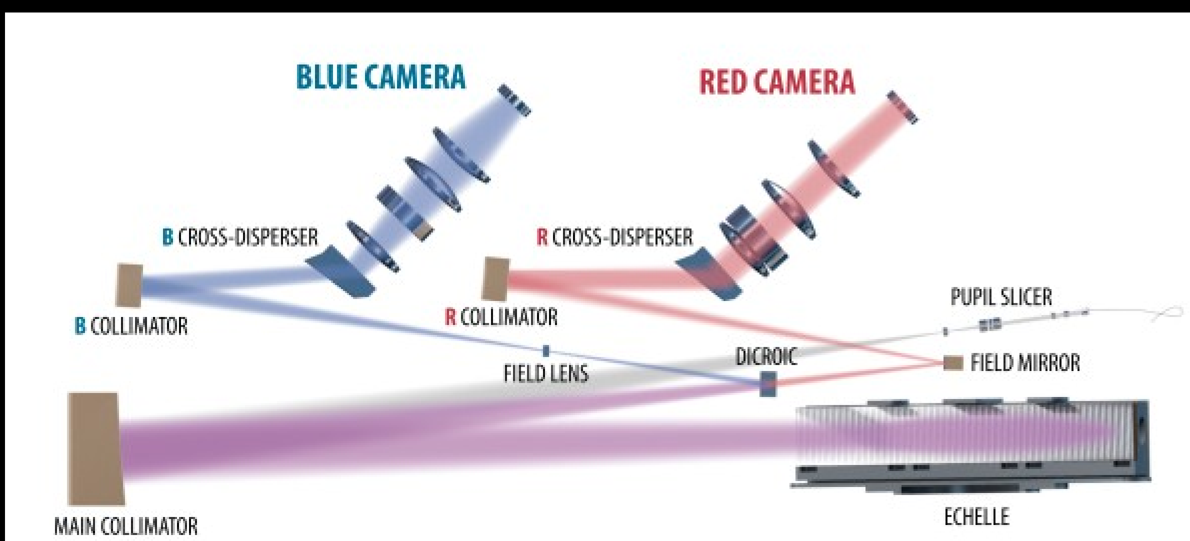

ESPRESSO spectra:
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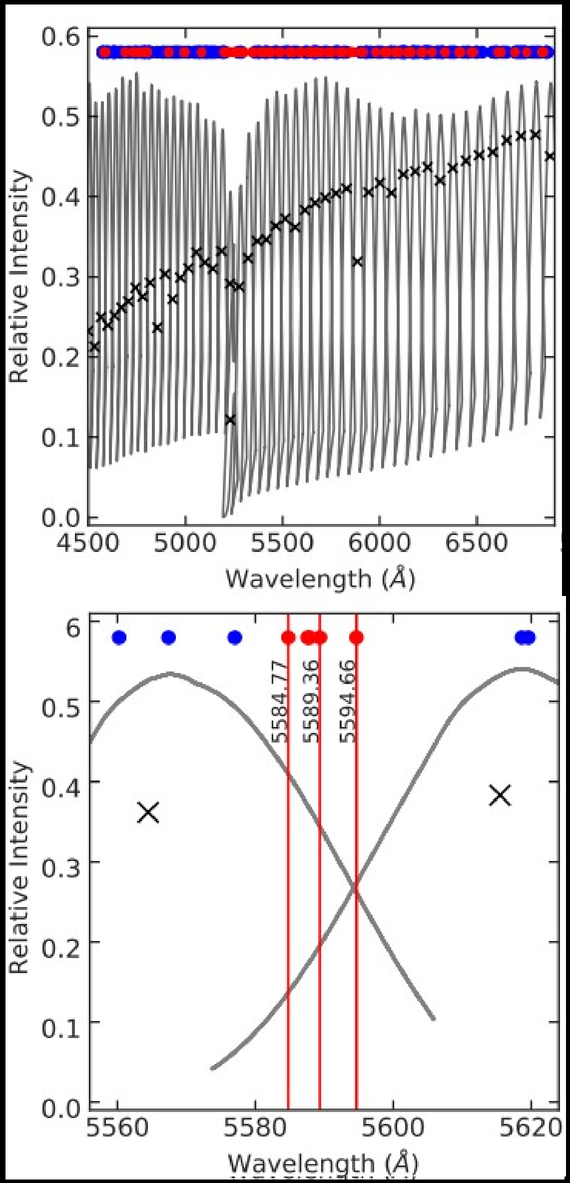
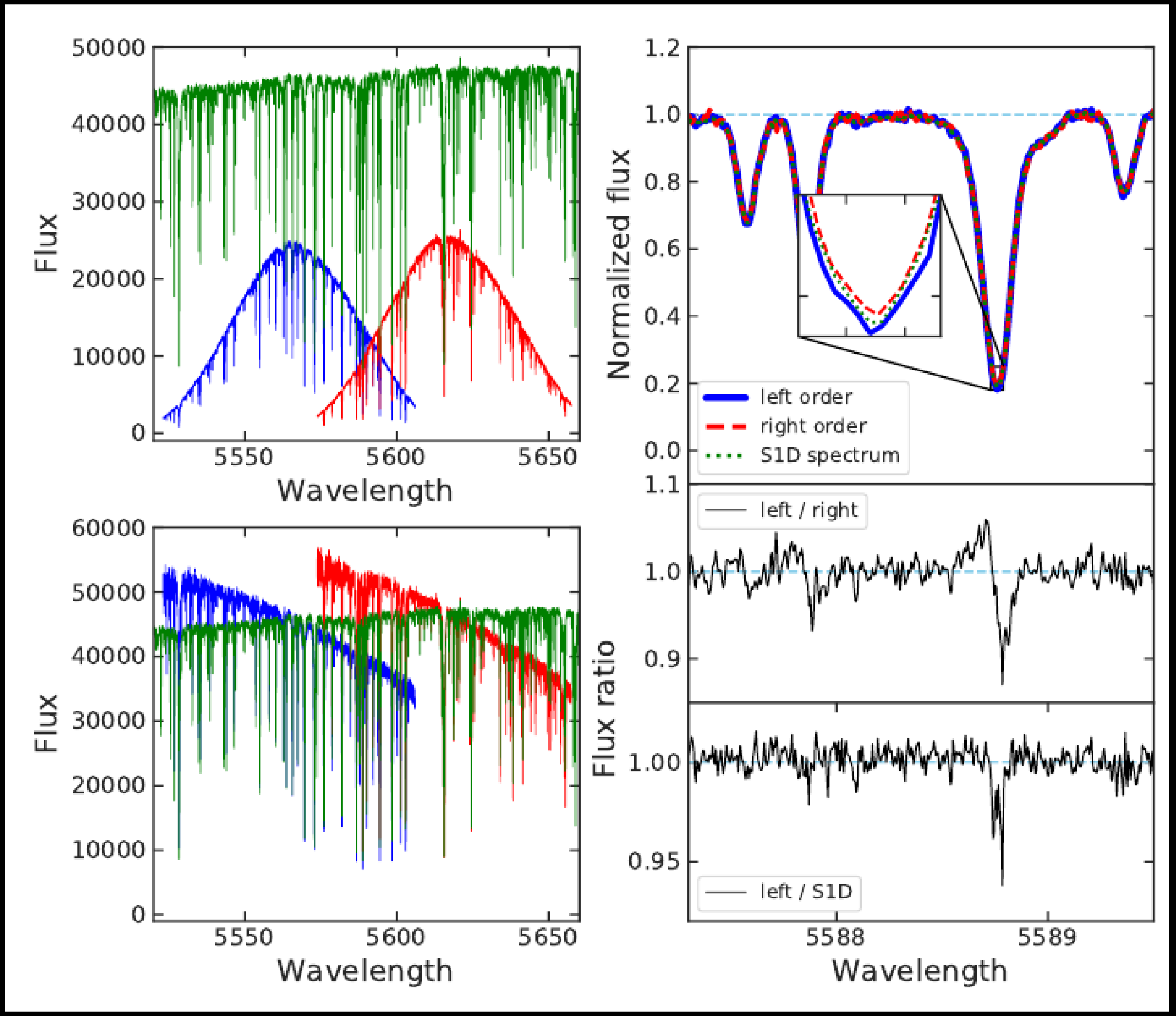
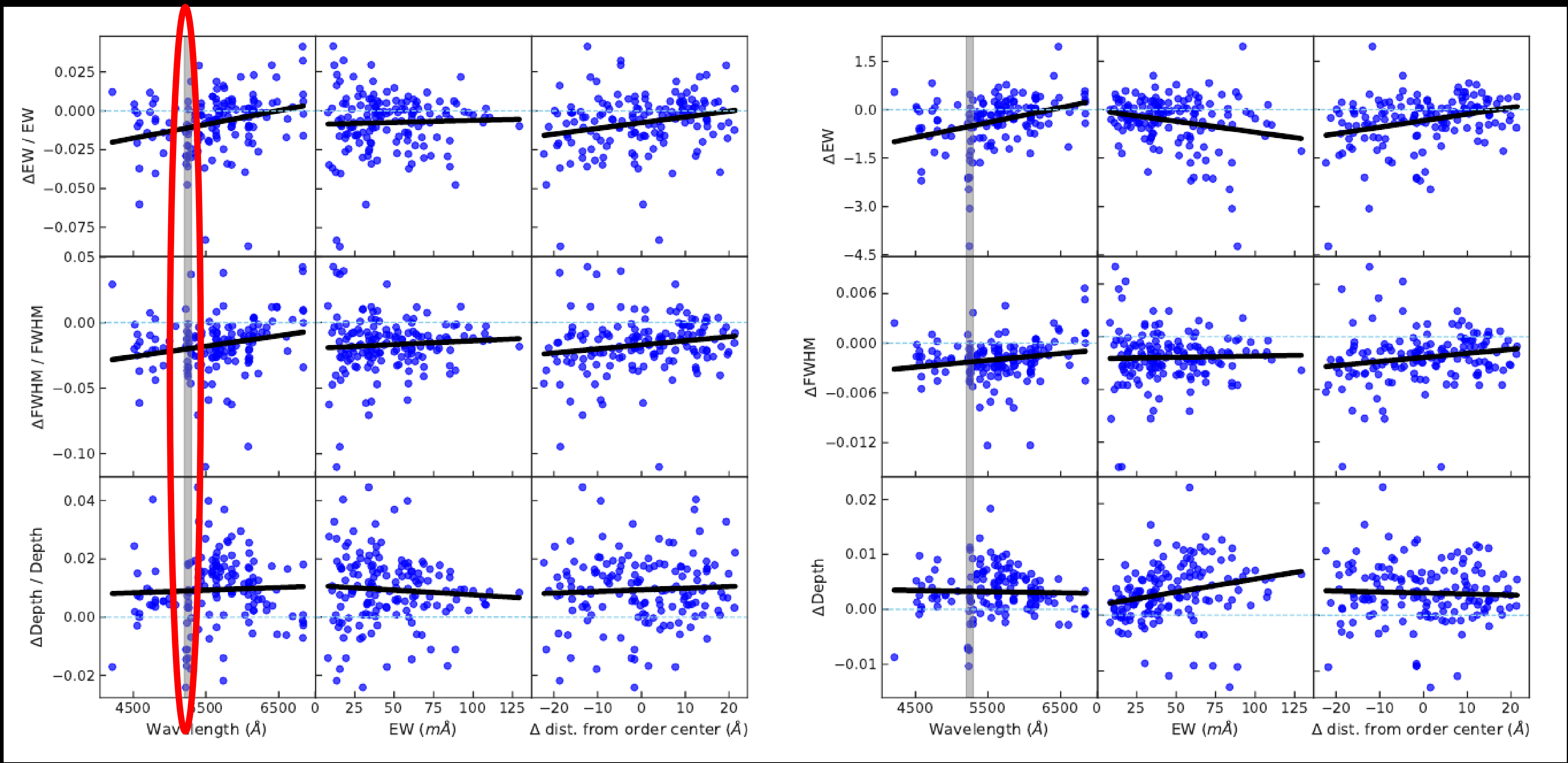




Spectral response (blaze function) for the
ESPRESSO echelle orders for a solar spectrum.

Line parameters in different echelle orders

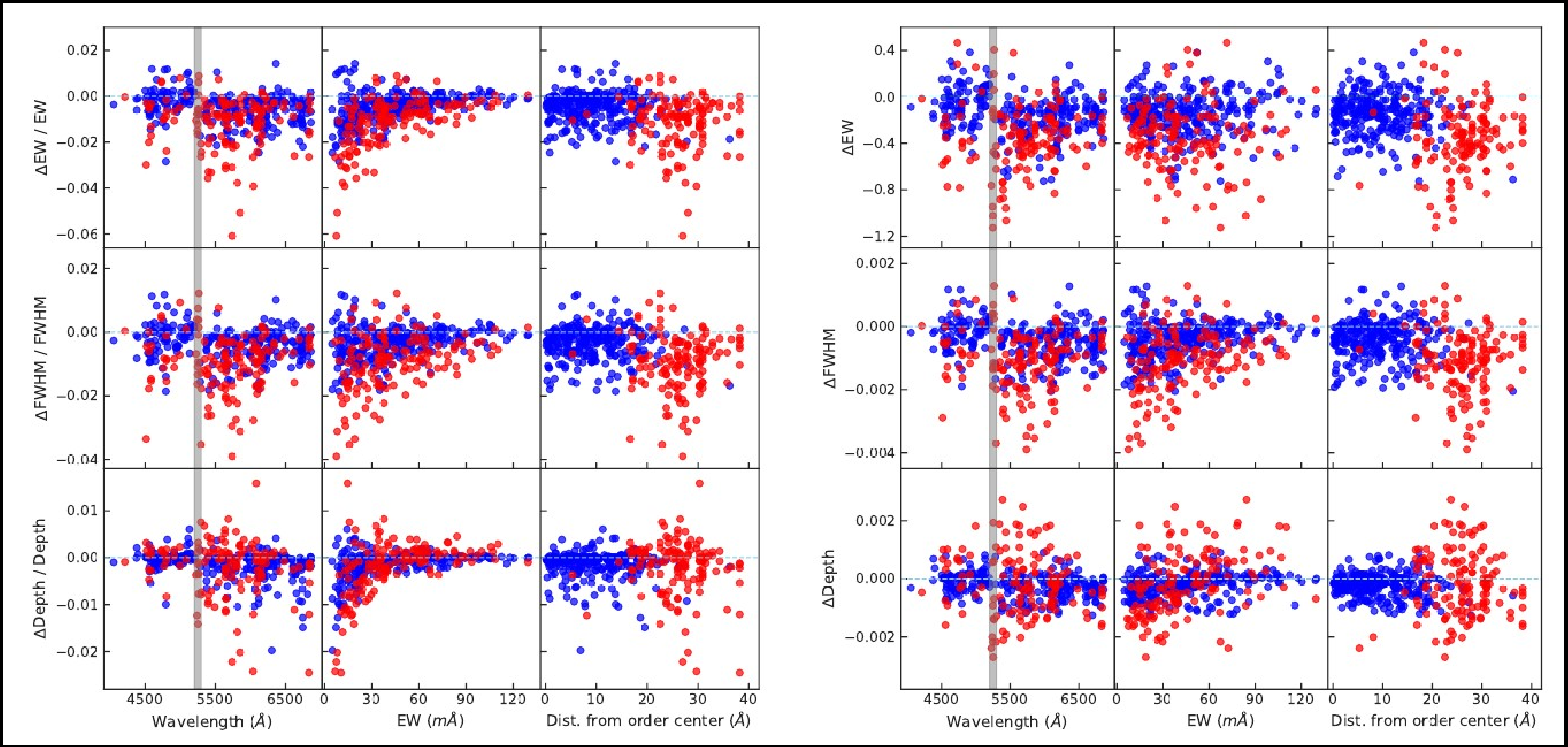
Line parameters measured automatically with ARES (Sosua et al. 2015)



Relatively good agreement between the line parameter measurements. Some trends, mostly related to the line measurement technique.

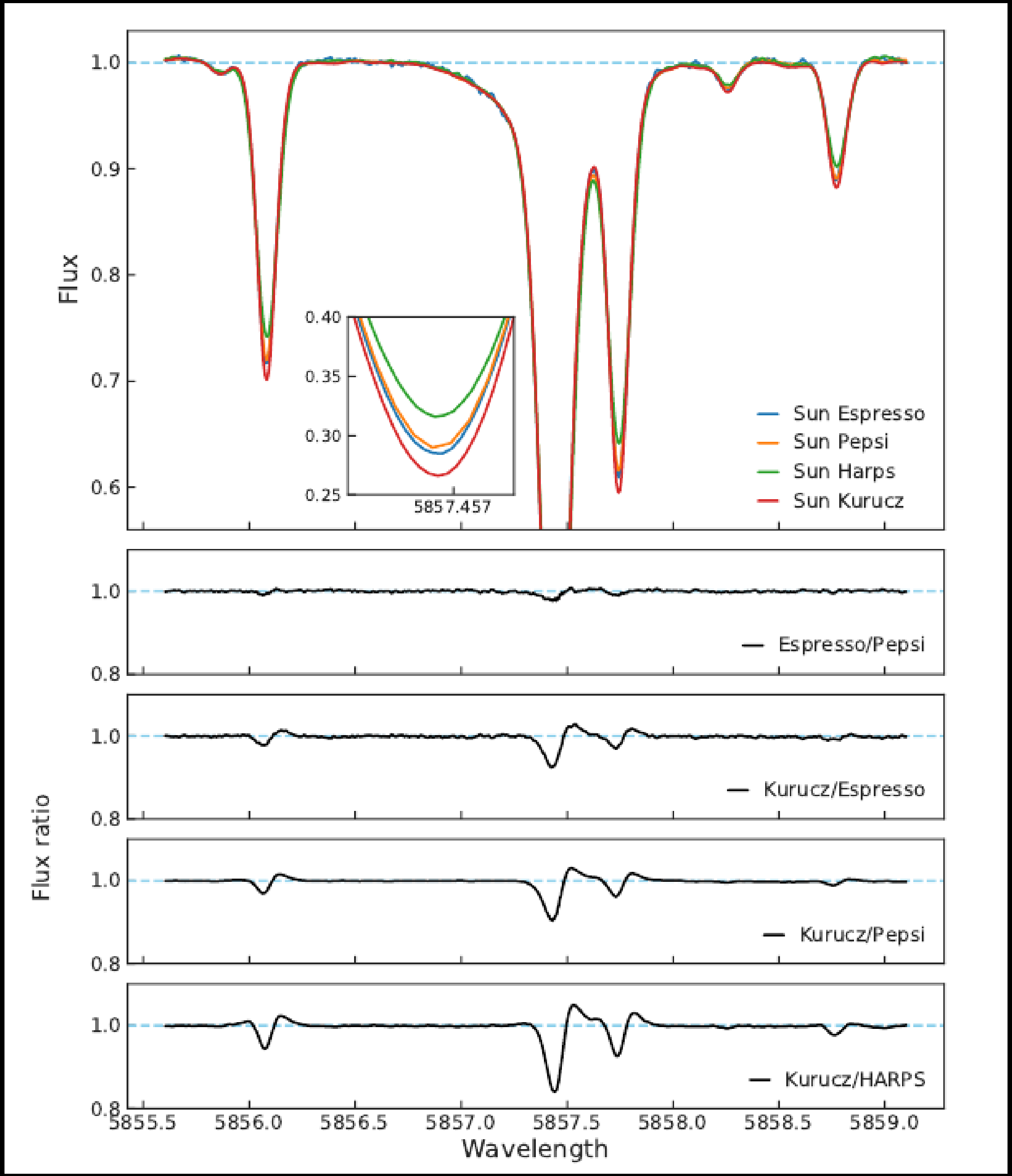
Line parameters in S1D vs S2D spectra

Line parameters measured automatically with ARES (Sosua et al. 2015)

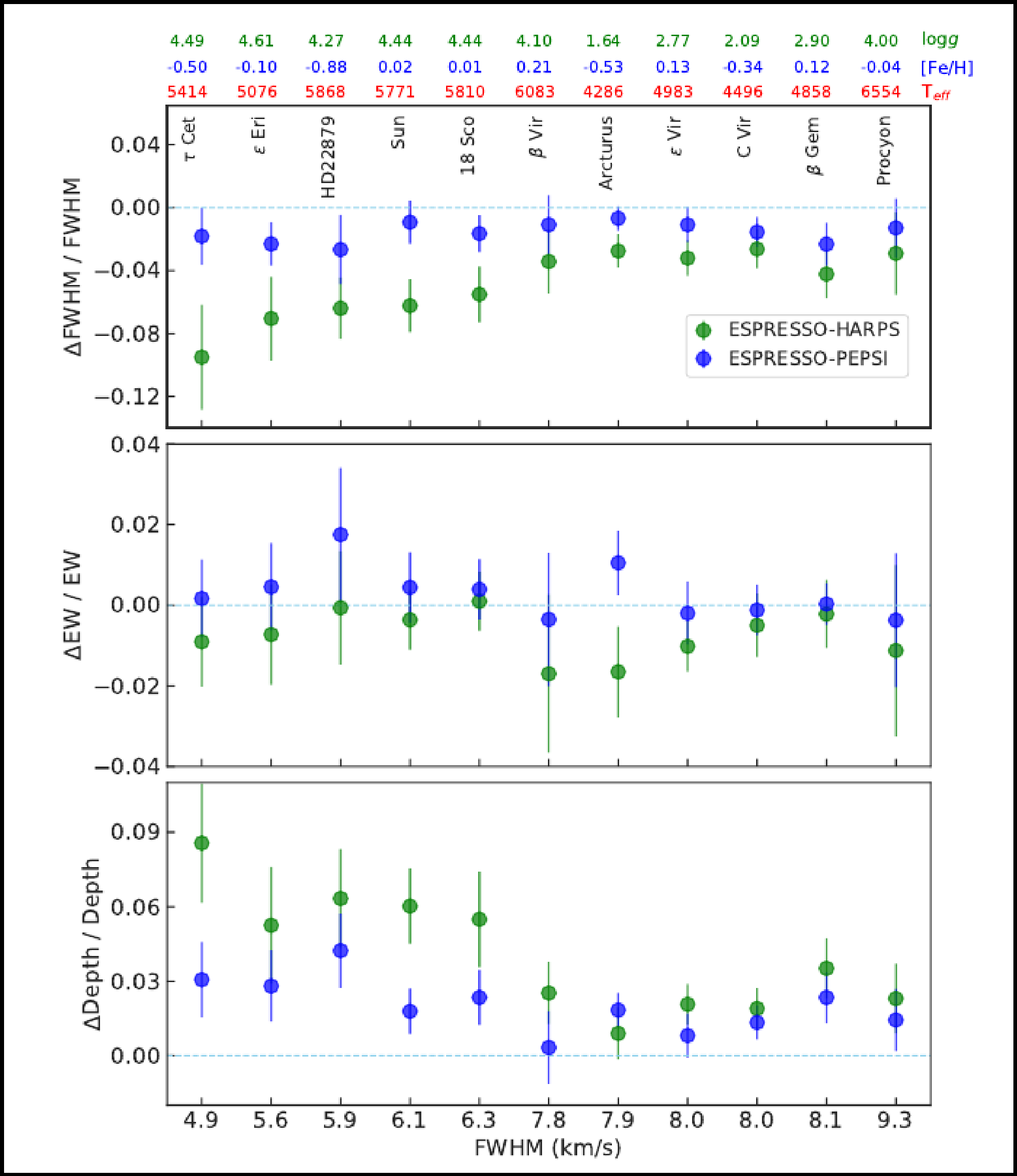


Relatively good agreement between the line parameter measurements. Some trends, mostly related to the line measurement technique.

Solar spectra



Comparing the line parameters

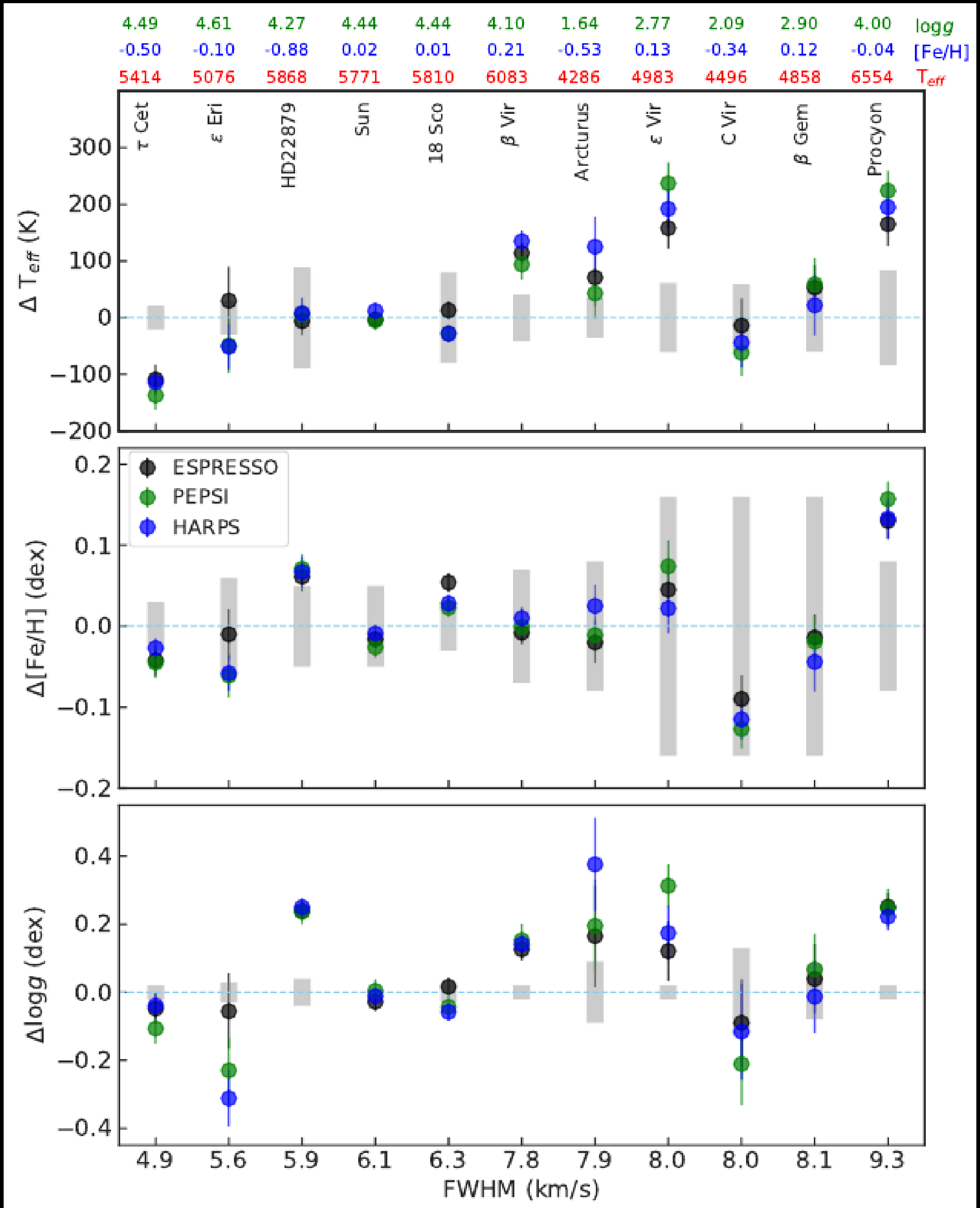


FWHM as measured on each spectrograph is expected to scale with resolution.

Where the difference between PEPSI and ESPRESSO comes from?

- spectral sampling
- resolution changes within the order and with wavelength

Stellar parameters



The three spectrographs give consistent results, but sometimes very different from the reference values.

Summary of conclusions

- **Spectral lines observed in multiple echelle orders.** Our results suggest that on average, the EWs of spectral lines measured from different spectral orders agree well. However, we found an offset between the FWHM and depths of the spectral lines as measured in adjacent orders. We interpret this as a consequence of the variation in spectral resolution with wavelength for each echelle order.
- **Spectral lines measured from the S1D and S2D spectra.** By measuring the EWs of spectral lines from the 1D and 2D spectra, we found an average difference of ~0.6% with a scatter that is slightly larger than the offset. The observed offset is larger for spectral lines that were observed in multiple orders (these lines are usually located farther from the center of the spectral order) than for lines that are located in only a single order. Our comparison of these measurements with the manual EW measurements of Sousa et al. (2008) based on the solar Kurucz atlas suggests a better agreement for the 1D spectra. This result may mean that a single measurement of spectral lines from combined (after combining the echelle orders and two slices) 1D spectra is preferable to simply averaging multiple measurements of spectral lines from different orders and slices in 2D spectra.
- **Spectrum-to-spectrum scatter.** We compared the line parameters measured from five individual 1D spectra and found that the measurements agreed very well. The average scatter in EW is 0.35±0.15 mÅ, which is very close to the average statistical photometric error for EWs estimated (Cayrel 1988) for the quality of the used spectra.
- **Solar atmospheric parameters and chemical abundances.** Using the EW measurements of the lines from the five S1D spectra, we determined the stellar parameters and chemical abundances of a few refractory elements. Our results show an excellent agreement between the parameter and abundance determinations. A scatter of only 9 K for $T_{\rm eff}$, 0.01 dex for $\log g$, and 0.005 dex for [Fe/H] is measured. The ob-

- **Individual versus combined spectra.** Our comparison of the solar atmospheric parameters and chemical abundances determined from the combined and individual S1D ESPRESSO spectra showed very consistent results. We also note that the uncertainties in the parameters and abundances (for the elements with several available spectral lines) do not decrease for the combined ESPRESSO spectrum when compared with those based on the individual, lower S/N ESPRESSO spectra. This result suggests that below given values, the precision is mostly dominated by the uncertainties in the atomic data of spectral lines, uncertainties in the model of atmospheres, our assumption of a Gaussian profile for the spectral lines, and/or the process of combining the individual spectra. However, it is important to note that for elements with only one or two weak lines, the increase in S/N is very important (see, e.g., Adibekyan et al. 2016, for the case of oxygen lines).

- **ESPRESSO – PEPSI – HARPS: spectral line measurements.** The comparison of the EW measurements based on the spectra of these three spectrographs showed a good agreement. The average relative difference in EW varied from 0.03±0.5% (for β Gem, between ESPRESSO and PEPSI) to 1.7±1.7% (for HD22879 between ESPRESSO and PEPSI). While the EWs seems to be conserved when line parameter measurements are made, our results show that the lines appear deeper in ESPRESSO spectra than in PEPSI and HARPS. The largest difference in line depth between ESPRESSO and PEPSI is about 3% and about 9% when ESPRESSO is compared with HARPS. The largest differences, as expected, are observed for the stars with intrinsically narrow spectral lines where the effect of the spectral resolution is more apparent. While the observed difference between ESPRESSO and HARPS is expected because of the difference in spectral resolutions, the discrepancy between ESPRESSO and PEPSI results is still to be understood.
- **ESPRESSO – PEPSI – HARPS: stellar parameters.** The good agreement in EW measurements between the different spectra resulted in consistent stellar parameters. The differences range from 2 to 82 K in $T_{\rm eff}$, from 0.002 to 0.256 dex in $\log g$, and from 0.004 to 0.052 dex in [Fe/H].

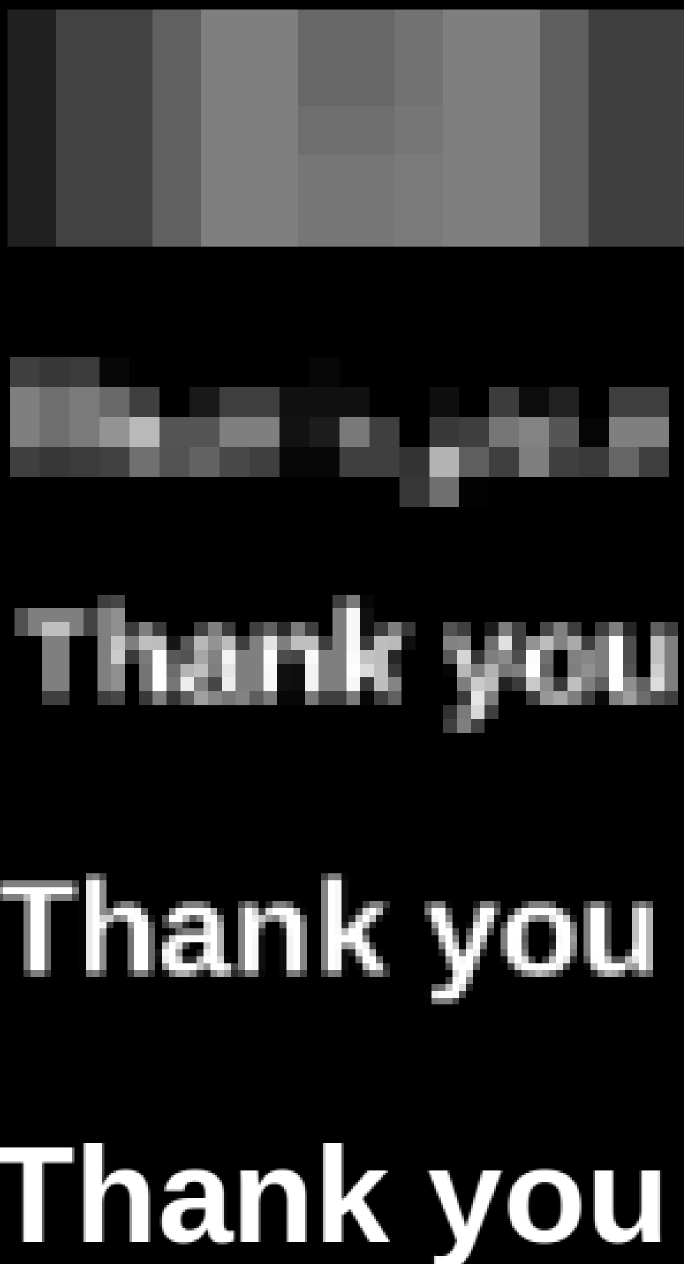
- **The three spectrographs can deliver results that are sufficiently consistent for most of the science cases in stellar spectroscopy**

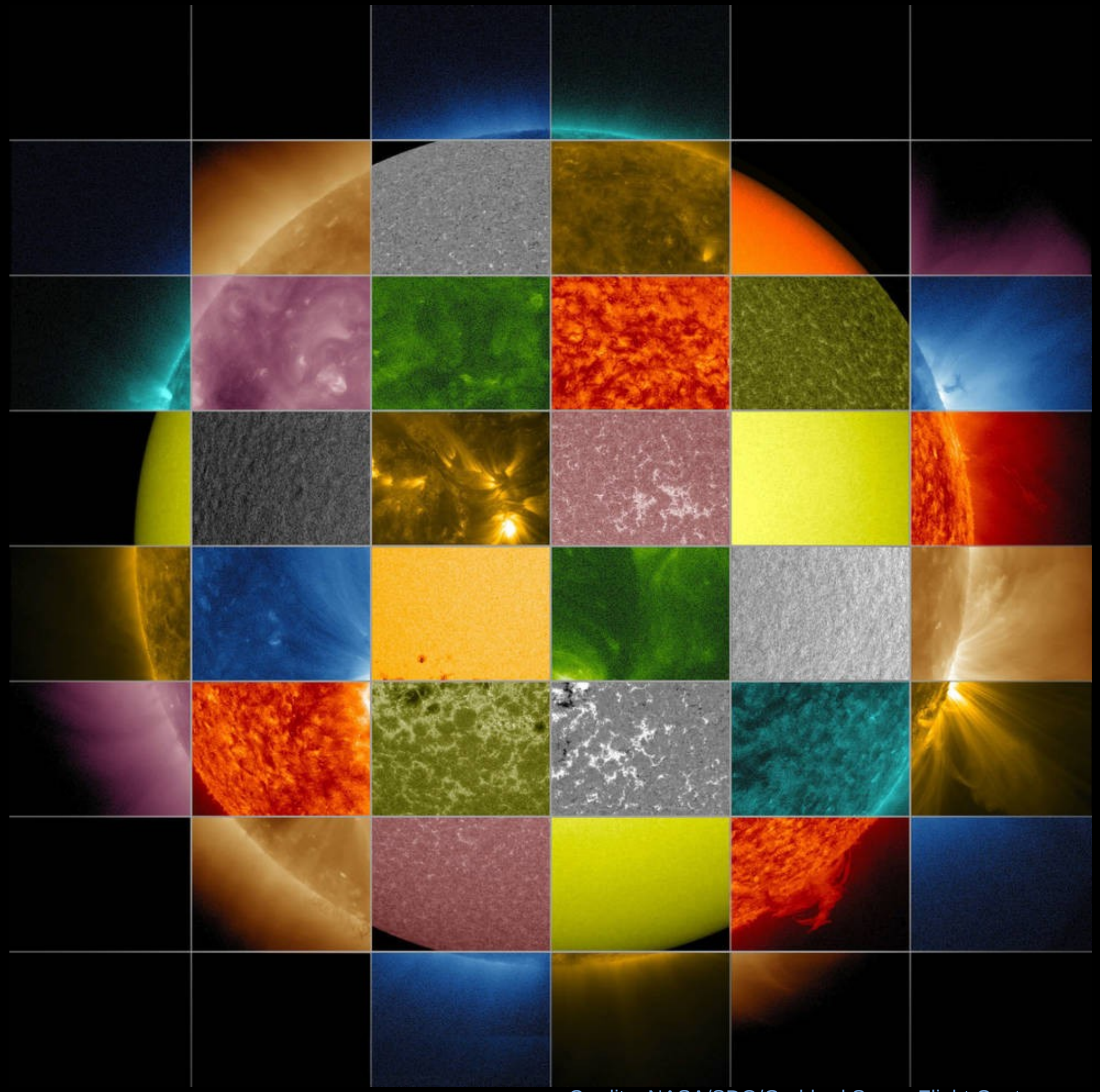
- **There are small but important differences in the performance of these three spectrographs that can be crucial for specific science cases**

http://www.astro.up.pt/~vadibekyan/benchmark-espresso.htm

ESPRESSO ultra-high resolution (R ~ 220'000) 1D spectra for the Gaia Benchmark stars (Adibekyan et al. 2020)

Resolution and wavelength matters!





Credits: NASA/SDO/Goddard Space Flight Center