SF2A 2018
P. Di Matteo, F. Billebaud, F. Herpin, N. Lagarde, J.-B. Marquette, A. Robin, O. Venot (eds)

THE BELGIAN REPOSITORY OF FUNDAMENTAL ATOMIC DATA AND STELLAR SPECTRA (BRASS)

T. Merle[1], M. Laverick[2,3], A. Lobel[3], P. Royer[2], M. Van der Swaelmen[1], Y. Frémat[3], S. Sekaran[2], C. Martayan[4], P.A.M. van Hoof[3], M. David[5], H. Hensberge[2] and E. Thienpont[6]

Abstract. BRASS is an international networking project for the development of a new public database providing accurate fundamental atomic data for stellar spectroscopic research. It rose from the fact that astrophysical parameters rely heavily on accuracy of atomic data which are scarcely provided throughout the literature and can suffer from systematic uncertainties. The ambition of the project is to provide carefully assessed atomic data in the range [4200-6800] Å by using high-resolution ($R \sim 80\,000$) and high signal-to-noise-ratio (S/N$\sim$ 1000) spectra of BAFGK benchmark stars from the Mercator-HERMES and ESO-VLT-UVES spectrographs. The validated atomic datasets, combined with the observed and theoretical spectra are interactively offered online at `brass.sdf.org`.

Keywords: stars, solar-type, atomic data, spectroscopic data, line profiles, astronomical databases

1 Introduction

The BRASS project (Lobel et al. 2017) is a unique database, when compared to other stellar spectral libraries, that simultaneously provides high resolution and signal-to-noise ratio spectra (observed and computed), and an assessment of the atomic data for selected clean lines per spectral type. The goal of BRASS is twofold: first, provide spectral atlases of 30 bright BAFGK benchmark stars in the optical range [4000-9000] Å with a resolution of about 80 000 and a signal-to-noise ratio of a thousand using the HERMES spectrograph (Raskin et al. 2011) at the Mercator telescope in the Northern hemisphere and the UVES spectrograph (Dekker et al. 2000) at the VLT in the Southern hemisphere; second, provide the assessment of the wavelengths and oscillator strengths of a selection of unblended lines, per spectral type, in the reduced range [4200-6800] Å to avoid contamination by telluric lines. In addition, BRASS will also make a hundred reference spectra available with a signal-to-noise ratio larger than 300, and the associated synthetic spectra computed with the 1D radiative transfer code Turbospectrum (Plez 2012) using ATLAS9 model atmospheres (Kurucz 1992).

2 How to make an echelle spectrum the right shape?

Using hot and bright stars with well known astrophysical parameters as references to correct for the instrumental response.

The great advantage of cross-dispersed echelle spectrographs is the possibility to have a broad wavelength coverage (thousands of angstroms) at a very large resolving power. Such high resolution spectra allow very detailed spectroscopic analysis of atmospheric parameters and elemental abundances among other things. Nevertheless, the blaze function involves strong variations in the apparent continuum as a function of wavelength. Recovering the overall continuum shape of an echelle spectrum is therefore very challenging. The HERMES

[1] Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Brussels, Belgium
[2] Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Belgium
[3] Royal Observatory of Belgium, Belgium
[4] European Southern Observatory, Chile
[5] Onderzoeksgroep Toegepaste Wiskunde, Universiteit Antwerpen, Antwerp, Belgium
[6] Vereniging voor Sterrenkunde, Leest, Belgium

pipeline reduction* provides reduced spectra that result from flat-field correction of individual orders, a wavelength calibration, cosmics removal, and the merging of the 45 orders.

In the framework of BRASS, we aim at going a step further by recovering the true shape of the spectral continuum emission. For this, we use spectra of B and A bright stars, taken as reference, that are less crowded than late-type stars to estimate the flat-field and the instrumental response (spectrograph, fiber and detector). Figure 1 shows the different steps for correcting the flat-field continuum and the intrumental response. The top panel shows the scientific (cyan) and the reference (black) spectra resulting from the standard HERMES pipeline reduction. The second panel show the detailed smoothed flat-field response for each order (in black). By taking the maximum on each order, we fit the flat-field continuum (blue curve) and multiply by the scientific (cyan) and reference (black) spectra of top panel and show the results in the third panel, after correcting for the atmospheric extinction. Then, we use a synthetic model of the reference star, here with a spectral type of A2V (in red in the 5th panel), and select continuum wavelengths to sample each order (vertical black lines, excluding the ones near strong lines, vertical dashed grey lines, and the ones falling among the tellurics, vertical dashed red lines) to estimate the instrumental response (green line in the 4th panel). The science (cyan) spectrum, from a F5V star, corrected from the instrumental response is displayed in the 6th panel. As a check the reference spectrum corrected for the instrumental response (black line in 5th panel) is compared to the synthetic template used (red spectrum).

3 Why should we quantitatively assess atomic data?

Because the precision of the stellar parameters heavily relies on them.

The Sun as a star should be modeled with a high degree of accuracy since the best spectra with the highest resolution and highest signal-to-noise ratio are obtained for it. And indeed, for the vast majority of the lines, the differences between theoretical and observed wavelengths is lower than 0.01 Å and the differences in the oscillator strength is of the order of 0.2 dex. Nevertheless, even in the Sun, numerous discrepancies remain:

- wavelength discrepancies larger than 0.02 Å (*e.g.* the Si II line at 6371.35 Å)
- oscillator strength discrepancies as large as several dex
- observed lines without theoretical atomic data (the *missing* lines)
- spurious theoretical lines without observation counterpart (the *unobserved* lines)

All of these cases are extensively analyzed and discussed in Laverick et al. (2018a) with numerous illustrative examples showing that the origin of such discrepancies cannot be due to the determination of atmospheric parameters, but instead are due to the discrepancies in the input atomic data.

4 How can we quantitatively assess atomic data?

By comparing theoretical equivalent widths and line profiles of well selected unblended lines with their occurrences in observations of a series of benchmark stars of different surface temperature.

We present here the steps of the procedure to assess the precision of the input atomic data. First, we need to collect as much atomic data as possible in the range [4200-6800] Å from theoretical and experimental atomic databases. Second, we perform a careful selection of clean lines defined as being stronger than the noise at the normalized continuum level and having an equivalent width barely contaminated by other lines. Thirdly, for several main-sequence stars with similar spectral type for which the atmospheric parameters are well constrained, we fit the wavelengths and the oscillator strengths ($\log gf$) on the high resolution and high signal-to-noise ratio normalized spectra. Two complementary methods are used: one based on the fits of the equivalent widths, and another one based on the fits of line profiles.

As an illustrative example, we show in Fig. 2 the fits of the oscillator strength of an Fe I line profile at 4574.2 Å in seven G-type stars. The top left panel shows the best fit (blue crosses) and the mean (blue line) $\log gf$ as a function of the effective temperature of the G stars and how they compare with the most recent published value of $\log gf = -2.38$ (Den Hartog et al. 2014). The other panels of Fig. 2 show the comparison between the observed profiles and the theoretical ones with the mean (blue line) and the (Den Hartog et al.

*http://hermes-as.oma.be/manuals/cookbook5.0.pdf

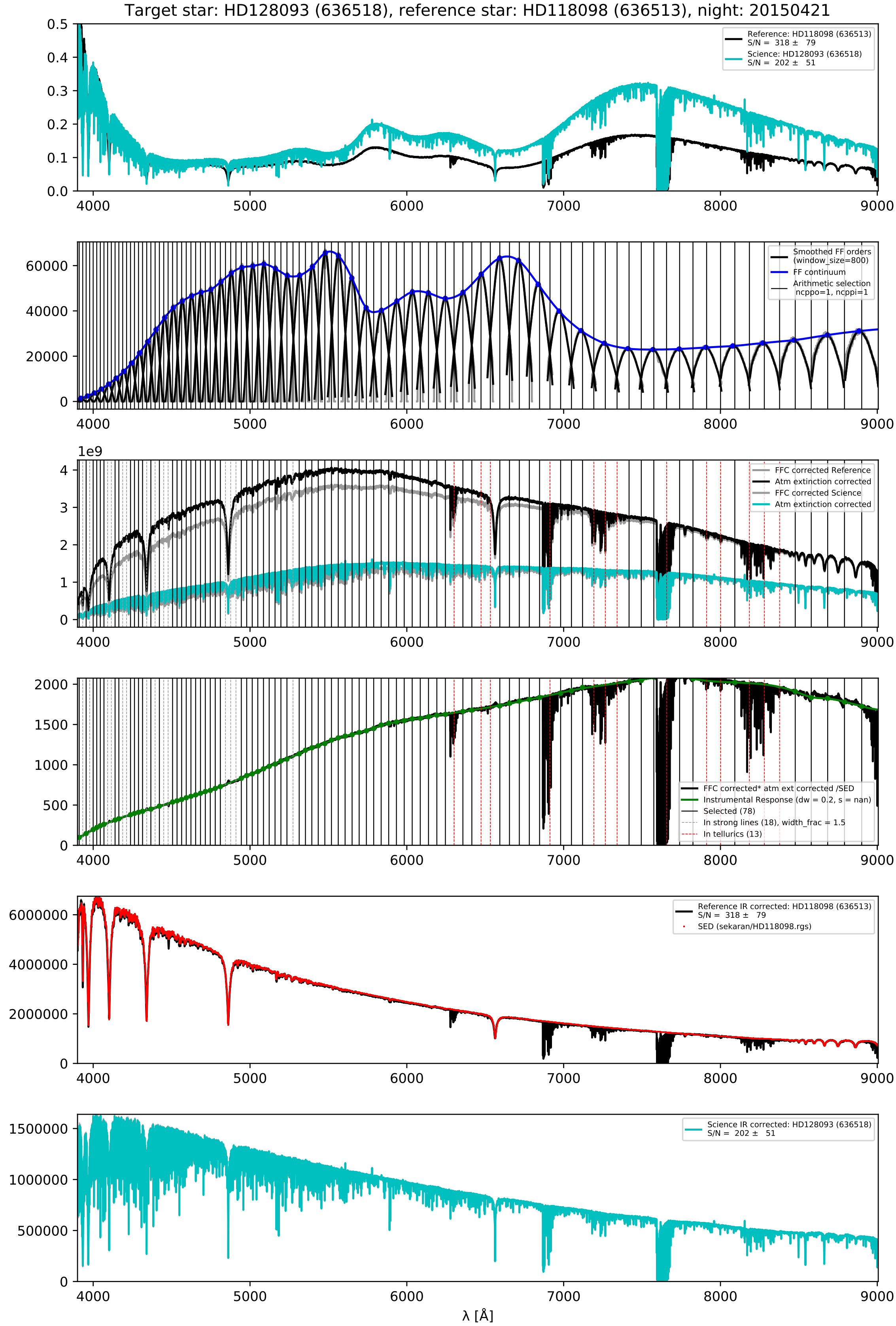

Fig. 1. Steps to remove the residuals of the instrumental response function in HERMES spectra. The science target spectrum is in cyan (F5V) whereas the reference spectrum for the night is in black (A2V). See text for detailed explanations.

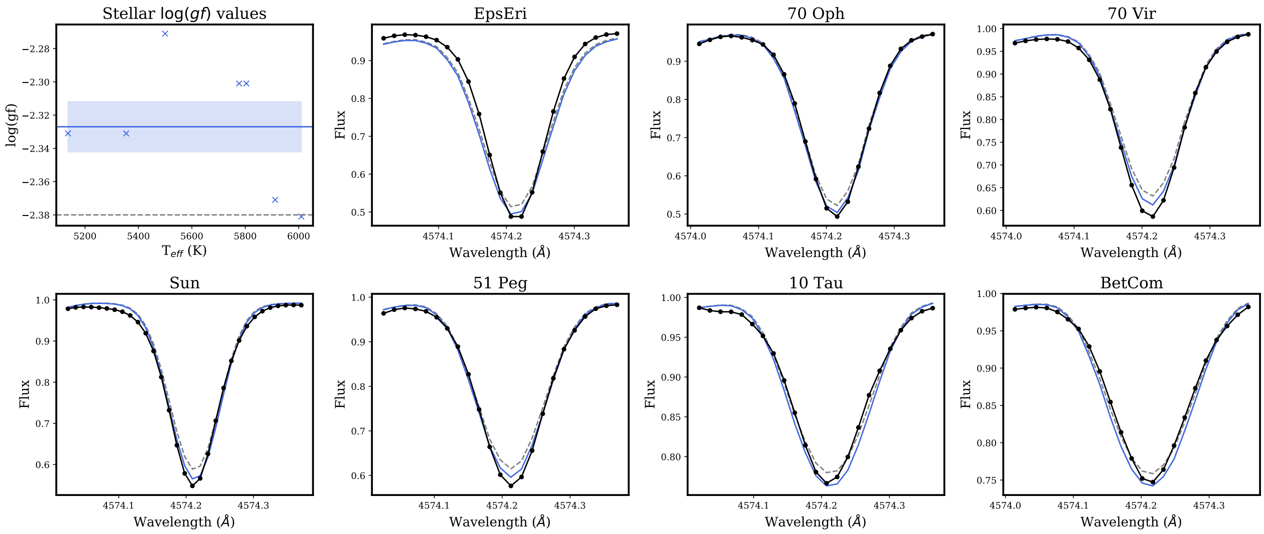

Fig. 2. Fitting of the Fe I 4572.2 Å $\log gf$ value. Top left panel: fitted (blue crosses) and mean (blue line) $\log gf$ values as a function of effective temperature of the seven G-type stars. Remaining panels: observed (in black) and synthetic with the mean $\log gf$ (in blue) line profiles. The synthetic gray dashed line is computed with the most recent $\log gf = -2.38$ value from Den Hartog et al. (2014)

2014) $\log gf$ values (gray dashed line). The mean $\log gf$ is the value that best reproduce the *ensemble* of the seven line profiles. We consider the dispersion of the individual best fit $\log gf$ values (blue shaded area in the top left panel of Fig. 2) as a measurement of the uncertainty of the $\log gf$ that takes into account the effect of the uncertainties in the atmospheric parameters for the seven G-type stars. Further illustrations can be found in Laverick et al. (2018b) and in Laverick *et al.* (in prep.).

5 Conclusions

The BRASS project is, to our knowledge, a unique attempt to publicly provide high quality spectra and assessed atomic data *together*. In these proceedings, we have presented the on-going effort to improve the reduction of HERMES echelle spectra by recovering the true shape of spectral continuum emission thanks to the use of bright hot stars as references to correct the shape from the flat-field continuum and the instrumental response. Including this step will simplify the normalization of the spectra. We have also presented the guiding ideas of why and how we should quantitatively assess atomic data. The spectra and assessed atomic data can be found at `brass.sdf.org`.

References

Dekker, H., D'Odorico, S., Kaufer, A., Delabre, B., & Kotzlowski, H. 2000, in Proc. SPIE, Vol. 4008, Optical and IR Telescope Instrumentation and Detectors, ed. M. Iye & A. F. Moorwood, 534–545

Den Hartog, E. A., Ruffoni, M. P., Lawler, J. E., et al. 2014, ApJS, 215, 23

Kurucz, R. L. 1992, Rev. Mexicana Astron. Astrofis., 23

Laverick, M., Lobel, A., Merle, T., et al. 2018a, A&A, 612, A60

Laverick, M., Lobel, A., Royer, P., et al. 2018b, Galaxies, 6, 78

Lobel, A., Royer, P., Martayan, C., et al. 2017, Can. J. Phys., 95, 833

Plez, B. 2012, Turbospectrum: Code for spectral synthesis, Astrophysics Source Code Library

Raskin, G., van Winckel, H., Hensberge, H., et al. 2011, A&A, 526, A69