Realistic wavelength correction for RVS with 3D hydrodynamical simulations of surface convection.

Purpose of the visit

The main goal of the Gaia mission (Perryman et al. 2001, A&A, 369; Lindegren et al. 2008, IAU Symp. 248, 217) is to determine high-precision astrometric parameters (i.e., positions, parallaxes, and proper motions) for one billion objects with apparent magnitudes in the range $5.6 \leq V \leq 20$ and kinematic velocities of about 100 millions of stars with a precision of ~1 km.s^{-1} up to $V \leq 13$.

These data along with multi-band and multi-epoch photometric data will allow to reconstruct the formation history, structure, and evolution of the Galaxy. Convection plays a crucial role in the formation of spectral lines and deeply influences the shape, shift, and asymmetries of lines in late type stars, which will represent most of the objects that will be observed by Gaia. In addition to this, granulation-related variability that is considered as ”noise” must be quantified in order to better characterize any resulting systematic error on the parallax and photometric determinations.

Realistic modelling of stellar atmospheres is therefore crucial for a better interpretation of future Gaia data and, in this context, three-dimensional (3D) radiative-hydrodynamical (RHD) models are needed for a quantitative correction of the radial velocities for all the stars observed and, in evolved stars, for the determination of the photocenter positions. These corrections may be up to 1-1.5 km.s^{-1}, same order of the expected precision of Gaia spectrometer (see figure and the end of the document).

The purpose of my visit to the Observatoire de la Côte d’Azur (OCA) was to exploit the 3D RHD simulations, covering the stellar parameters corresponding to spectral types from F to M, to extract high-resolution spectra within the range of RVS and BPRP.

I worked with Dr. Frederic Thévenin and Dr. Lionel Bigot (OCA) from the 3rd of February to the 15th of February 2012.

Description of the work, main results and future collaborations

A convenient and usual way to estimate kinematic radial velocity of a star is commonly made from a measurement of its spectroscopic radial velocity. Gaia is provided with a dedicated radial velocity spectrometer (RVS, Katz et al. 2004, MNRAS, 354, 1223), with a resolving power at best of 11500 centered on Ca II triplet in the spectral band from 8480 to 8750 Å.

The Gaia/RVS algorithms need the computation of synthetic spectra and tables of corrected wavelength of the lines detectable in the spectra, based on atomic and molecular lines with wavelengths in the laboratory frame given in atomic databases such as VALD[1] or NIST[2]. These spectra can be produced either with one-dimensional (1D) hydrostatic codes of stellar atmospheres or with three-dimensional (3D) hydrodynamic codes. 1D codes are unable to reproduce any convective shifts because, being hydrostatic, the spectral lines produced have the same input laboratory wavelength. On the other hand, realistic RHD simulations coupled to radiative transfer are mandatory to correct the wavelengths and radial velocities because they take into account the convective motions. The resulting spectra are Doppler shifted with respect to the nominal laboratory values can reproduce very well the shapes of the absorption lines (depth, shifts and asymmetries). Moreover, the great advantages of such approach is also that it is no longer needed to include adjustable 1D parameters (micro- or macro- turbulence) in the diagnostics. Thus, the resulting radial velocities and spectral lines is more correct.

My stay at OCA allowed us to discuss the possibility to compute 3D spectra in RVS domain using the new RHD simulation grid (Collet, Magic, Asplund, Journal of Physics: Conference Series, 328, 012003). This grid covers uniformly and largely the H-R diagram as well as different metallicities ranging from [Fe/H] = 0.0 to [Fe/H] = -3.0 with step of 1.0 dex.

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[1] http://vald.astro.univie.ac.at/~vald/php/vald.php
[2] http://physics.nist.gov/PhysRefData/ASD/lines_form.html

We started with an accurate selection of the most representative 3D models across the diagram:

Effective temperature [K]	Surface gravity	[Fe/H]	Type
5777	4.44	0.0	Sun
5777	4.44	-1.0	Main sequence
6500	4.00	0.0	Sub giant
6500	4.00	-1.0	Sub giant
6500	4.00	-2.0	Sub giant
5000	3.00	0.0	Turnoff
5000	3.00	-1.0	Turnoff
4500	2.00	0.0	Giant
4500	2.00	-1.0	Giant
4500	2.00	-2.0	Giant
5000	5.00	0.0	Dwarf
5000	5.00	-1.0	Dwarf
5000	5.00	-2.0	Dwarf

We started the computation of high-resolution (R=300000) synthetic spectra in RVS domain and in BPRP domain (Thévenin 2008, Phys. Scripta T, 133, 014010) using the radiative transfert code Optim3D (Chiavassa et al. 2009, A&A, 506, 1351) for all the models reported in Table above. The spectra are computed along rays of four μ−angles [0.88,0.65,0.55,0.34] and four φ−angles [0, 90, 180, 270] degrees, after

which we I perform disk integration and temporal average over all selected snapshots. It is important that the total time covered by the simulations is such that there are no trends in the lineshift if a subset of snapshots is used for the calculations. Due to the three dimensional approach, the CPU time necessary to make such a computation is quite large. I will provide the final spectra in the next couple of months to the Gaia/RVS community.
The spectra in RVS range will be then delivered to DU630 to ensure the calibration stage and to DU650 for the analysis and determination of radial velocities. The spectra in BPRP range will be delivered to CU8 for the determination of the stellar parameters. I will then increase the number of computed spectra to the rest of the 130 models of the RHD grid. However, it is clear that this number is far too limited to cover all the stellar parameters that will be observed with Gaia. New models will be computed in the future only for peculiar stars that falls in between the stellar parameters of the 3D grid. We will then compute the estimations of 1D - 3D convective corrections for the available stellar parameters of the grid and then correct all the stars using interpolations in these convective shifts 1D - 3D correction table.

This collaboration with OCA researchers will continue in the future on regular exchanges (2 times per year) between Nice and Bruxelles. The theoretical radial velocities will be compared to standard observed stars and the results will be published on a referred journal.

References:

Chiavassa, Bigot, Thévenin et al., Journal of Physics: Conference Series, 328, 012012

Thévenin, Jasniewicz, Chiavassa, Bigot, Gaia technical note, GAIA-C6-TN-OCA-FT-003-1

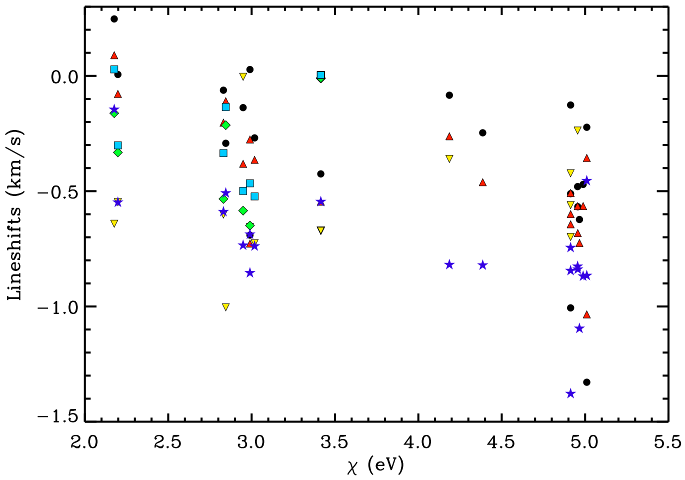

Fig. 1: Predicted convective lineshits of 20 Fe I lines as a function of excitation potential for different 3D simulations of giants and sub giants stars (Chiavassa, Bigot, Thévenin et al., Journal of Physics: Conference Series, 328, 012012).