SF2A 2007
J. Bouvier, A. Chalabaev, C. Charbonnel (eds)

THE SPECTROSCOPIC GLOBAL ITERATIVE SOLUTION - WAVELENGTH CALIBRATION OF THE SPECTROSCOPIC DATA OF GAIA

A. Guerrier[1], D. Katz[1], C. Turon[1] and F. Crifo[1]

Abstract. The Radial Velocity Spectrometer (RVS) of Gaia will collect spectra for about $100 - 200$ million stars up to magnitude $V \sim 17$ over the wavelength range 847 to 874 nm with a resolving power $R = \frac{\lambda}{\Delta\lambda} = 11\ 500$. Each RVS target will be observed 40 times on average with an extremely stable device, both optically and mechanically. The RVS has no calibration device (such as lamps or absorption cells). It cannot be calibrated with the classical approach based on dedicated calibration exposures. The so-called Spectroscopic Global Iterative Solution (SGIS) provides an efficient alternative to calibrate the RVS instrument. The principle of SGIS is to use a set of well-behaved stars (bright, stable and of a well-suited spectral type) to iteratively derive the radial velocity of the stars and the wavelength scale of the RVS instrument. A prototype of SGIS has been developed in order to study and validate the convergence of the method.

1 Gaia mission and the Radial Velocity Spectrometer (RVS)

The Gaia mission has been designed to decipher the Galaxy, its components, its formation and evolution, and precisely characterise each of the billion observed objects. It will measure with an extreme accuracy, in a survey mode, the astrometric and photometric parameters of all stars brighter than the 20th magnitude. In addition, the spectrometer of Gaia, called Radial Velocity Spectrometer (RVS), will observe $100 - 200$ million brightest stars up to $V \sim 17$ (Perryman et al. 2001). The unbiased and simultaneous acquisition of multi-epoch radial velocities and individual abundances of key elements (for the brightest stars) in parallel to astrometric parameters is an essential clue to the understanding of the formation history of our Galaxy. The Radial Velocity Spectrometer multi-epoch observations are ideally suited for the identification, classification and characterisation of the many types of double, multiple and variable stars (Katz et al. 2004, Wilkinson et al. 2005).

The RVS will continuously and repeatedly scan the sky during the 5 years of the mission and each source will be observed about 40 times on average over the mission. The spectrometer will produce spectra for all stars up to magnitude $V \sim 17$ over the wavelength range 847 to 874 nm with a resolving power $R = \frac{\lambda}{\Delta\lambda} = 11\ 500$. At the end of the mission, the RVS is expected to provide radial velocities with a precision of under 1 $km.s^{-1}$ for the brightest stars (brighter than about $V = 11.5$), degrading to about 15 $km.s^{-1}$ for $V = 16.5$ stars. Rotational velocities, atmospheric parameters and element abundances (for the brightest stars) will also be derived from the spectra.

The satellite will continuously and repeatedly scan the sky and no on-board calibration devices (such as calibration lamp or absorption cells) are integrated on the payload of Gaia. As a consequence, the RVS cannot be calibrated with a classical approach based on dedicated exposures. Following an approach similar to that adopted for the astrometry, the Spectroscopic Global Iterative Solution (SGIS) provides an efficient alternative solution to calibrate the RVS instrument.

The satellite will provide a large volume of raw data: about 50 GB uncompressed scientific data will be collected every day. A consortium of data treatment, named "Data Processing and Analysis Consortium" (DPAC), has been created in june 2006 in order to process the data coming from Gaia satellite. DPAC is a consortium of over 300 scientists and software engineers.

---

[1] Observatoire de Paris, GEPI, CNRS UMR 8111, 92195 Meudon, France

2 The concept of the Spectroscopic Global Iterative Solution

The Spectroscopic Global Iterative Solution (SGIS) is being developed following similar principles as those derived by L. Lindegren for the astrometric Global Iterative Solution (Lindegren 2001). The principle for SGIS is to use bright and stable sources observed by the RVS to self-calibrate the instrument. Each of these bright and stable sources will be observed a large number of times over the mission (about 40 times on average). As these stars are stable, any variation in their measured properties will trace the evolution of the characteristics of the RVS.

Only the wavelength calibration and radial velocity determination are being considered here as example of the SGIS calibrations.

In a ground-based spectrograph, a classical calibration uses reference lines from a calibration lamp. In the case of SGIS, stellar lines of reference stars, characteristic of a given spectral type, are identified in the spectra collected by the RVS, and these will be used in a similar way as calibration lamp reference lines. The wavelength position of the stellar lines used as reference depends upon two parameters: the radial velocity of the sources and the spectral dispersion law of the instrument. The determination of the radial velocities and of the wavelength scale are successively improved during the iterative process, using the stars which are selected as reference stars: (i) an improved calibration of the wavelength scale will allow a more precise determination of the stellar radial velocities; (ii) the improved determination of the radial velocities will be used to obtain a better calibration of the wavelength scale. The process is iterated until a satisfactory level of convergence is reached on the dispersion of the radial velocities for each considered source.

The SGIS process is divided into 5 main phases:

1. **Initialization:** it initializes the radial velocity values and the wavelength calibration parameters of the RVS. It is the starting point of the iterative process.
2. **Source updating:** it is the first phase of the iterative process. It estimates the radial velocity of each observation of the stars, using the last wavelength calibration of the instrument.
3. **Reference selection:** it selects bright and stable stars which will be used to calibrate the wavelength scale of the spectroscopic data of Gaia.
4. **Calibration updating:** it is the last phase of the iterative process. It calibrates the wavelength scale of the instrument, using the last estimates of the radial velocity of the stars. The principle of the wavelength calibration of the RVS is to associate a mean wavelength λ to a couple (η, ζ) of field of view coordinates, using a second order polynomial:

$$\lambda = \sum_{m=0}^{2} \sum_{n=0}^{2} C_{mn} \eta^m \zeta^n$$

   where C_{mn} are the unknown calibration coefficients estimated during this phase.
5. **Zero point correction:** it uses ground-based standard stars to fix the zero point of the radial velocity of the sources in order to express the radial velocity of all stars in an absolute reference frame. At the end of this phase, a new wavelength calibration is computed according this absolute reference frame.

All of these phases are illustrated in Fig 1 (Guerrier et al. 2006).

3 The convergence of SGIS

A prototype of SGIS has been developed in Java, programming language adopted by the Gaia DPAC for all the software developments. The prototype is implemented by 36 Java classes grouped into 12 Java packages. For the sake of simplicity, the reference selection and the zero point phases have not been developped.

To test the implemented prototype, a simple database, containing about 12 000 spectra, has been created from simulated input data:

- Kurucz spectra ($R = 250\ 000$) degraded to the RVS resolution (R=11 500);
- synthetic spectrum of a G5V star with $T_{eff} = 5\ 500K$, $[Fe/H] = 0.0$ and $Logg = 4.00$;

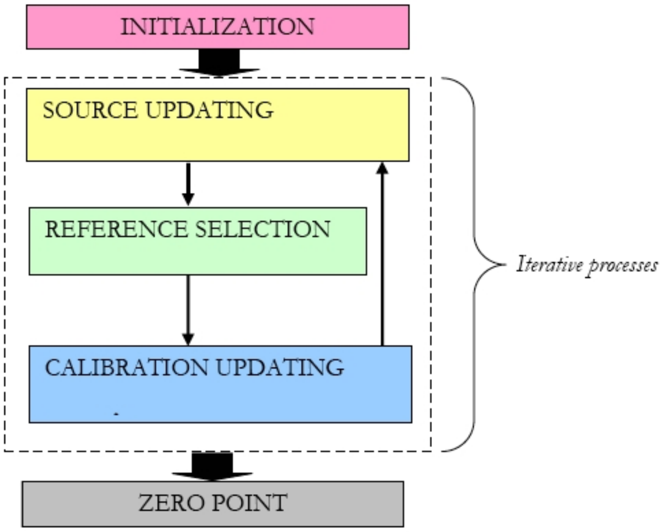

Fig. 1. Schematic view of the Spectroscopic Global Iterative Solution

- observation times of 2 000 stars simulated for 700 days of mission, according the scanning law of the satellite;

- 700 pixels along the scanning direction (old design of the RVS, 2004).

Two campaigns of tests have been performed on the simple database with the prototype of the SGIS calibration. The difference between the two campaigns is the initialization procedure. In the first one, the prototype is initialized with the true calibration parameters of the RVS and the true radial velocities. The aim of this campaign is to prove the non-divergence of the prototype. In the second one, the prototype is initialized with noisy calibration parameters. This second campaign had to prove the convergence of the prototype of SGIS.

During a first campaign of tests, the implemented prototype has been tested starting from the true spectral dispersion law. The results of this campaign (c.f. Fig 2 - *red curve*) has proved a good behaviour of the prototype: the empirical dispersion of the estimated radial velocities stabilizes at about 0.09 $km.s^{-1}$.

During a second campaign of tests, the prototype has been tested starting from noisy spectral dispersion laws:

- the calibration data have been initialized with a noisy spectral dispersion law, which introduces a dispersion of the radial velocity errors about 5.0 $km.s^{-1}$ on average (c.f. the results presented in Fig 2 - *blue curve*) at the beginning of the iterative process;

- the calibration data have been initialized with a noisy spectral dispersion law, which introduces a dispersion of the radial velocity errors about 50.0 $km.s^{-1}$ on average(c.f. the results presented in Fig 2 - *green curve*) at the beginning of the iterative process;

The behaviour of the prototype in these two cases (i.e. noise about 5.0 $km.s^{-1}$ and 50.0 $km.s^{-1}$) shows a convergence effect: the solution converges slowly to the non-divergence evolution of the prototype (i.e. the numerical solution of the prototype). A satisfactory level of convergence is reached after about 10 iterations (each iteration takes about 30 minutes).

The positive results of these two campaigns have validated the SGIS concept for the calibration of the spectral dispersion law of the RVS.

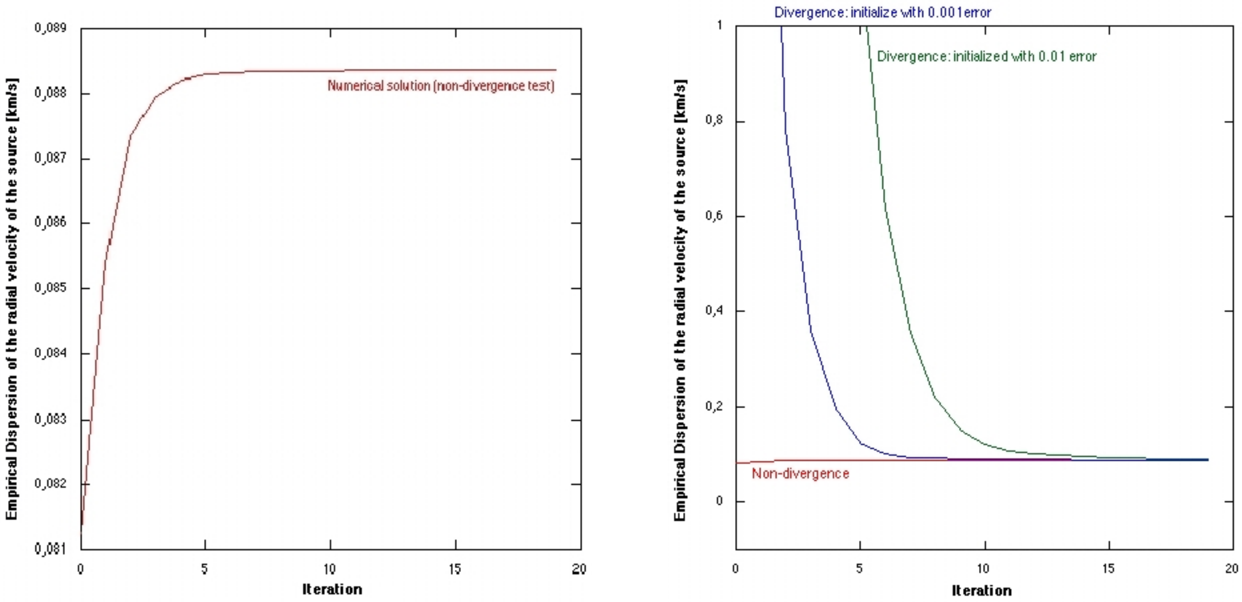

Fig. 2. Evolution of the empirical dispersion of the radial velocity of the stars: *left* - the result of the non-divergence test (initialization of the calibration data with true values) ; *right* - the results of the convergence tests (initialization of the calibration data with noisy values, blue and green curves) in comparison with the result of the non-divergence test (red curve)

4 Conclusions

The concept of the Spectroscopic Global Iterative Solution has been studied for a few years at GEPI in collaboration with the Gaia team of the Mullard Space Science Laboratory (UK). This study has provided several prototypes in Java language. The implemented prototypes have allowed to prove the convergence of the iterative process and to validate the SGIS approach for the wavelength calibration of the spectroscopic data of Gaia. A first prototype has been provided to CNES (Toulouse), the spectroscopic data processing center of Gaia, in march 2007. A more realistic version will be provided in october 2007.

The performances of the prototype are statisfactory: the dispersion of the radial velocities converges under 100 $m.s^{-1}$ for $V = 8$. However, the convergence effect is slow: the calibration takes about 1 second per spectrum on bi-processor Xeon 2.20 GHz with 2 Go RAM. The daily data representing 50 000 spectra, the current version of the prototype processes one day of data in more 13 hours on that computer. In order to accelerate the convergence, the SGIS could use ground-based standard stars. These standards stars also could be used to correct the zero point of the radial velocity (i.e. last phase in the SGIS processus). More details on the set of radial velocity standards can be found in the paper by Crifo et al. 2007.

5 The bibliography

References

Crifo, F. and al., 2007, this issue
Guerrier, A. et al., 2006, ESA report , GAIA-C6-TN-OPM-AG-001
Katz, D. et al., 2004, MNRAS, 354, 1223
Lindegren, L. ,2001, ESA report, GAIA-LL-34
Perryman, M. A. C. et al., 2001, A&A, 369
Wilkinson, M. I. et al., 2005, MNRAS, 359, 1306