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KINEMATIC VERSUS SPECTROSCOPIC RADIAL VELOCITIES FOR THE GAIA RVS

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Abstract. The Gaia spectrometer (RVS) has no built-in calibration device and the RVS will rely on its own observations to carry out the wavelength calibration. A small sample ($\sim$ 1420) of bright RVS F-G-K standard stars will be used for the Radial Velocity Zero Point (RVZP) of the RVS. These standard stars have been observed on the ground with the Sophie, Coralie and Narval spectrometers, and their Spectroscopic Radial Velocities (SRVs) have been published by Soubiran et al. (2013). These SRVs are not Kinematic Radial Velocities (KRVs) which are what we need for studies of galatic dynamics. However in this paper we show that these SRVs are well suited to establish the Radial Velocity Zero Point of the Gaia RVS, provided that CU6 pipelines of the DPAC such as Calibration of the RVS (DU630) and Determination of RVs by cross-correlation with templates (DU650 STA) really use wavelength lines and spectra computed with 3D hydrodynamical model atmospheres, which conveniently treat the convective shifts. Final SRVs given by the Gaia CU6 pipelines and later published in the Gaia final catalogue would then only be corrected from the gravitational shift by the DPAC CU8 in order to become true KRVs.

Keywords: Gaia, RVS, Radial velocities

1 Introduction

Reference stars have been observed on the ground and their RVs will be used to determine the RVZP of the Gaia RVS. This RVZP will also be checked by asteroids, even if bright asteroids ($V < 10$) will not be often observed by the RVS (see Jasniewicz et al. 2011). A lot of ground-based observations of reference stars selected by Crifo et al. (2010) and asteroids have been performed during 5 years at Observatoire de Haute Provence, Pic du Midi and La Silla (Chile). Radial Velocities of these objects have been determined thanks to standard pipelines by Cross-Correlation techniques using stellar masks. The main point of this paper is to give some preliminary results concerning the comparison between observed and computed RVs of asteroids, as they are the only sources for which both RVs are available, and to investigate the best strategy to determine the RVZP for the Gaia RVS.

In the following, the Kinematic Radial Velocity of an object (star or asteroid) is defined as the line-of-sight component of space velocity whereas the Spectroscopic Radial Velocity is deduced from observed spectral-line displacements interpreted as Doppler shifts. Intrinsic stellar spectroscopic effects such as convective motions in the stellar atmosphere and gravitational redshift imply that the measured wavelengths do not correspond to the precise centre-of-mass motion of the star. According to the general theory of relativity, the gravitational redshift is GM/cR. This shift is 636 m.s^{-1} for the Sun, and for a typical white dwarf of 0.6M$_{\rm sun}$ it is between 5 to 13 km.s^{-1}.

If we reduce the solar wavelengths to a system at rest with respect to the solar center of mass, and if we correct the solar wavelengths from the gravitational redshift, then the solar absorption lines generally (not all) appear blueshifted with regard to laboratory wavelengths ; these shifts are connected to convective motions in the

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Table 1. Observed Radial Velocities versus Computed Radial Velocities of asteroids

Spectrometer + Telescope	Number of measurements	$< O - C >$ $m.s^{-1}$	σ $m.s^{-1}$
Coralie + La Silla, Euler swiss telescope	42	19.4	58.6
Sophie + OHP, 193cm	184	37.7	31.1
Narval + OPM, TBL	78	44.5	19.8

atmosphere. Dravins (1982) has shown that typical solar photospheric lines are blueshifted by about 400 $m.s^{-1}$. 1D atmospheric models do not take into account convective shifts. If the estimated errors on RV given by the Gaia RVS are really smaller than $1km.s^{-1}$ for G-stars, it will be possible to test the accuracy of convective shifts included in 3D model atmospheres because the KRV of the nearest stars will also be derived from astrometry. In this paper, we firstly give some results concerning the comparison between Observed and Computed RVs of asteroids by the IMCCE (Institut de Mécanique Céleste et de Calcul des Ephémérides) herefater called $O - C$; secondly we recall some recent results concerning the convective shift in stars ; and finally we discuss the way to transform the RVS SRVs into KRVs.

2 Observed versus Computed Radial velocities of asteroids

Computed Kinematic Barycentric Radial Velocities of asteroids are given by :
$KBRV = KGRV + KRV_{sun} - BERV$
where:
KGRV is the Geocentric Radial Velocity of the asteroid
KRV_{sun} is the component due to the asteroid's radial motion toward the Sun
BERV is the Barycentric Earth´s Radial Velocity

In the following, we write $O - C = SRV_{(observed)} - KBRV_{(computed)}$

Asteroids reflect the solar light, thus their spectra include the gravitational and convective solar shifts. At first we assume that the G2 masks built for Sophie/Coralie/Harps are wavelength-calibrated with 1D synthetic spectra of the Sun ; since the observed solar spectrum is blueshifted by $0.4\,km.s^{-1}$ with regard to these masks (see Sect. 1), the RV of an asteroid determined by cross-correlation with such a mask should be corrected from the convective and gravitational shifts of the Sun (see Sect. 1): -0.4 + 0.6 $km.s^{-1}$, that is about $0.2\,km.s^{-1}$. But the average $< O - C >$ of asteroids given in Table 1 are much smaller for each ground-based instrument. Residuals O-C are also plotted for each asteroid in Fig. 1 as a function of phase. Here we have chosen the phase on the abcissa, only because there is no obvious correlation between phase and O-C. The very small values for O-C mean that there is somewhere in the software pipelines and/or the building of the masks a compensation of the solar gravitational redshift and convective shifts. This point is still under investigation for details.

3 Observed Radial velocities versus Kinematic Radial velocities of stars

Realistic modelling of stellar atmospheres is crucial for a better interpretation of future Gaia data and, in this context, three-dimensional (3D) Radiative-HydroDynamical (RHD) models such as these developed by Magic et al. (2013) are needed for a quantitative correction of the radial velocities (few hundreds $m.s^{-1}$) for all the stars observed and, in evolved stars, for the determination of the photocenter positions. According to Chiavassa et al. (2011) the convective lineshift is stronger for high excitation lines and it ranges, in average, from -0.22 $km.s^{-1}$ (K giant with [Fe/H]=-3.0) to -0.75 $km.s^{-1}$ (F star).The amplitude of the shift increases when going from K giants to the F star, as a consequence of the more vigorous convective motions. Moreover, the Ca II triplet lines are *redshifted* because these lines are formed in the upper part of the photosphere where the granulation pattern is reversed. Red supergiant stars (RSGs) show a completely different behavior with strong redshifted Fe I up to $2.80km.s^{-1}$ and blueshifted Ca II up to $8km.s^{-1}$ In conclusion, velocity shifts of F and K giant stars are of the order of RVS accuracy ($1km.s^{-1}$), and they are even larger for RSG stars.
If the stellar masks used for ground-based observations of stars are wavelength-calibrated from observed spectra (see also Sect.2), then RVs determined by Cross-Correlation are true KRVs for all stars whose spectra are very

close to these masks. We can expect some residuals between SRVs and KRVs for all other stars in the CU6 catalogue of standard stars by Soubiran et al. (2013).

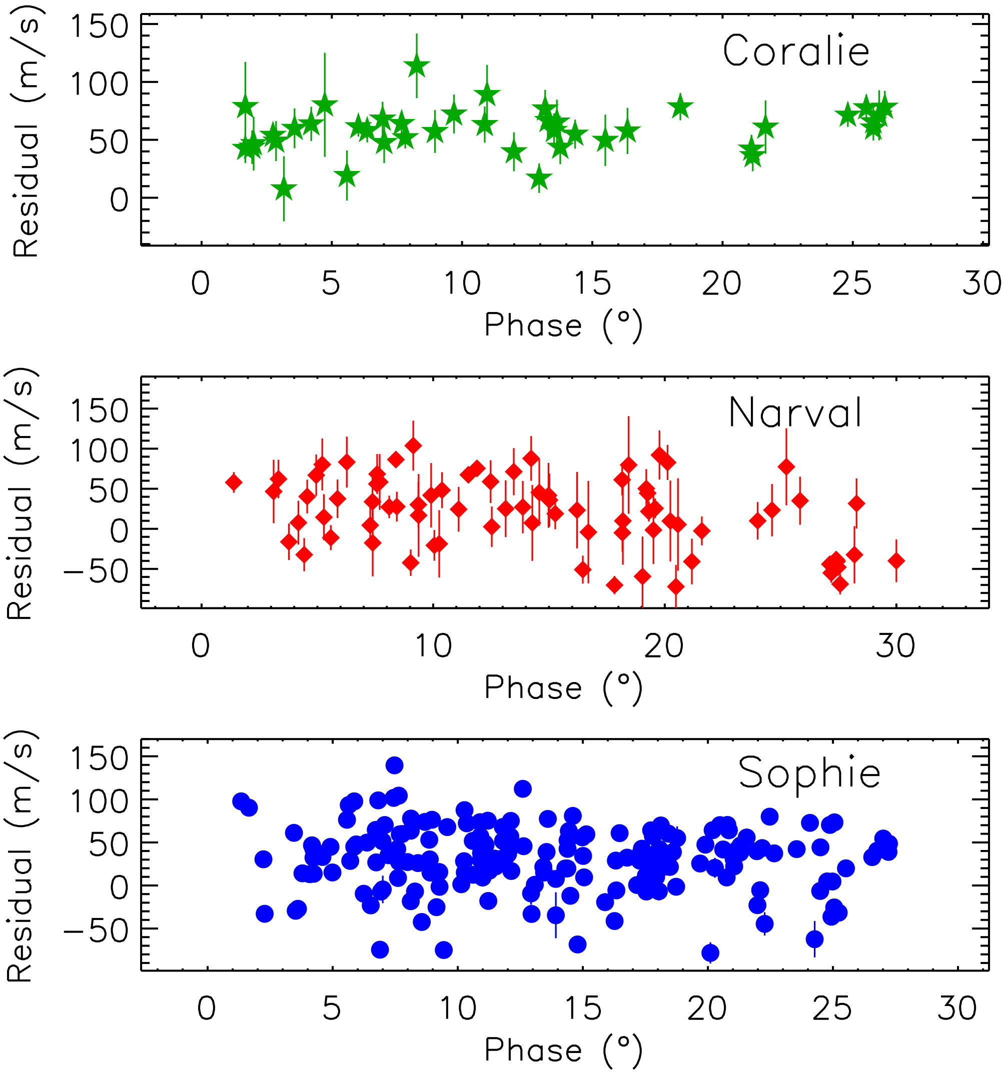

Fig. 1. Residual O(bserved) - C(omputed) Radial Velocities of asteroids versus the phase. Observed Coralie, Narval and Sophie RVs have been determined by Cross-Correlation with G2 masks. Computed RVs come from the IMCCE.

4 Conclusions

In the CU6 Gaia context, we have called Astrophysical Zero Point (AZP) the corrections to be made on the RVS Spectroscopic Radial Velocities (SRVs) in order to get Kinematic Radial Velocities. According to this poster and the Technical Note (TN) GAIA-C6-TN-FT-001-1 by Thévenin et al. (2011)at the ESA livelink, we strongly recommend the use of 3D RHD atmosphere models for both CU6 and CU8. The critical points are the following :

- SRVs of the RVS STD stars published by the DU640 team (Soubiran et al. 2013), seem to be rather well corrected from the convective shift (see Sect. 3), and rigorously corrected from the convective and gravitational shifts for stars the spectrum of which is very near of a mask used in the ground-based pipelines (Sophie, Coralie, Harps, etc). Thus these published RVs which will be used for the RV Zero Point (RVZP) of the RVS, are KRVs.
- The 3D RHD models take into account the convective shift. As a consequence, the RVS CU6 pipelines such as Calibration (DU630) and STA (DU650) should use them, and would be consequently compatible with the DU640 Catalogue of RVs.

- AZP software will only correct the RVS RVs from the gravitational redshift thanks to the APs determined by CU6 and CU8.

Abbreviations used in the text
AP : Astrophysical Parameter
AZP : Astrophysical Zero Point
CC : Cross- Correlation
DU : Development Unit
KBRV : Kinematic Barycentric Radial Velocity
KRV : Kinematic radial velocity
O-C : O(bserved)-C(omputed) radial velocities
RHD : Radiative HydroDynamical
RV : Radial Velocity
RVZP : Radial Velocity Zero Point
SRV : Spectroscopic Radial Velocity
RVS : Gaia Radial Velocity Spectrometer
TN : Technical Note
WP: Work Package

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