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THE CATALOGUE OF RADIAL VELOCITY STANDARD STARS FOR GAIA

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Abstract. The Radial Velocity Spectrograph (RVS) on board of Gaia needs to be calibrated using stable reference stars known in advance. A catalogue has being built for that purpose, including 1420 radial velocity standard star candidates selected on strict criteria in order to fulfill the Gaia-RVS requirements. We have undertaken a large programme of ground based observations in 2006 to monitor these stars and verify their stability which has to be better than 300 m s^{-1} over several years. We report 6536 radial velocity measurements for the 1420 stars. For a mean time baseline of 5.9 years, nearly 95% of the candidates (1394 stars) fulfill the stability criterion of 300 m s^{-1}. 80.4% have a stability better than 100 m s^{-1}. We compared our measurements to other sources.

Keywords: Catalogs, Radial Velocities, Stars: kinematics and dynamics

1 Introduction

The Radial Velocity Spectrograph (RVS) on board of Gaia will provide radial velocities (RV) of about 150 million stars up to 17$^{\text{th}}$ magnitude with precisions ranging from 15 km s^{-1} at the faint end to 1 km s^{-1} or better at the bright end (Katz et al. 2004; Katz 2009). RV combined with astrometry will give access to the 6D phase space for kinematical studies. The RVS will also provide rotational velocities and atmospheric parameters for about 5 million stars up to 13$^{\text{th}}$ magnitude and abundances for about 2 million stars up to 12$^{\text{th}}$ magnitude. Such a large spectroscopic survey will have a tremendous impact on many science cases, such as the chemistry and dynamics of the Milky Way, the detection and characterisation of multiple systems and variable stars. The expected science yield from the RVS is described in Wilkinson et al. (2005).

The RVS has a resolution of 11500 and covers the spectral range 847-874 nm. It is an integral field spectrograph with no entrance slit and no on-board wavelength calibration source. The wavelength scale and RV zero-point will be derived from already known reference stars carefully selected for that purpose (Crifo et al. 2010). The RV standard stars used to calibrate the RVS have to be stable in radial velocity at the 300 m s^{-1} level, to be in adequation the 1 km s^{-1} precision expected from their future RVS measurements, with no drift until the end of the mission in 2019. To be qualified as a reference star, each candidate has to be observed at least twice before launch and another time during the mission in order to verify its long term stability. We describe the RV measurements available to date and the status of this new catalogue of RV standard stars in its pre-launch version.

2 RV measurements

The catalogue consists of 1420 standard star candidates whose criteria of selection are fully described in Crifo et al. (2010). The candidates have been selected in three catalogues : ”Radial velocities of 889 late-type stars” (Nidever et al. 2002), ”Radial velocities for 6691 K and M giants” (Famaey et al. 2005), ”The Geneva-Copenhagen Survey of Solar neighbourhood” (Nordström et al. 2004), complemented by IAU standards. In the three RV

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catalogues, we selected the stars which have the best observational history in terms of number of consistent radial velocity measurements over several years. The observations of all these stars have been conducted on the echelle spectrographs ELODIE and SOPHIE on the 1.93 m telescope at Observatoire de Haute-Provence (OHP), NARVAL on the Télescope Bernard Lyot at Observatoire du Pic du Midi and CORALIE on the Euler-Swiss telescope at La Silla. We also used RV measurements retrieved from the public archives of SOPHIE and ELODIE at OHP (Moultaka et al. 2004), and of HARPS at the ESO Advanced Data Products database. Considering that the candidates have already a good observational history, our strategy is to have at least 2 measurements per star before launch, and then one more during Gaia operations. We have obtained nearly 100 observing nights since 2006 for this long term programme.

SOPHIE, CORALIE, ELODIE and HARPS have respectively resolving powers of $R=\lambda/\Delta\lambda \approx 75\,000$, 50 000, 42 000 and 120 000. They all have similar automatic on-line data reduction softwares to derive the barycentric RV by cross-correlation of the spectra with a numerical mask (Baranne et al. 1996). The spectral type of the numerical mask is chosen to be the closest to the star observed. It can be G2, K5, M4, M5 for SOPHIE, G2, K5, M2 for HARPS and CORALIE, F0, K0 for ELODIE.

NARVAL has a resolving powers of $R=\lambda/\Delta\lambda \approx 78\,000$. As this intrument has not been built for RV measurements, but for polarimetry, the on-line reduction software does not include the RV determination. We measured it by cross-correlating the observed spectra with the SOPHIE G2 mask. Our main interest in observing with NARVAL is that its spectral coverage includes the RVS range, 847-874 nm, allowing us to investigate the systematic difference occuring when measuring the RV in the full visible range and in that narrow NIR spectral range.

Table 1 gives the number of RV measurements available and the number of different stars oberved per instrument. Fig. 1 represents the distribution of the 1420 stars on the celestial sphere, with a color code indicating the number of measurements available.

To verify the stability of the stars, we need to combine their RV obtained with different instruments, having different zero-points. The zero-point is related to the instrument itself, its spectral range, resolution and calibration procedure and to the method used to measure the RV. In our case the same algorithm of cross-correlation with a numerical mask has been used which minimizes the offsets between instruments. We took care to have a sufficient number of stars observed in common with the different instruments to measure the offsets between them. We adopted the SOPHIE scale as our reference and we applied a correction to the measurements of the other instruments in order to put them in that common scale. Then for each star, we computed its mean RV, standard deviation, amplitude of the RV variation and time baseline. In this process each individual measurement is weighted according to its uncertainty.

Table 1. Number of RV measurements per instrument and number of stars

	SOPHIE	CORALIE	NARVAL	ELODIE	HARPS
number of RV meas.	2198	2421	209	1053	655
number of stars	727	775	157	292	113

Fig. 2 shows the histogram of variability of the 1420 candidates, measured by the maximum difference of individual measurements in the SOPHIE scale. We find that 94.7% of the stars have a stability better than 300 m s^{-1} which is the threshold defined for the calibration of the RVS instruments. The mean time baseline is 5.9 years. 80.4% of the stars have a stability better than 100 m s^{-1}.

3 Comparison with other catalogues

We have selected a fraction of the 1420 candidates in the catalog of Nidever et al. (2002), so we have a good intersection with it, namely 336 stars. Note that we selected only the stars from Nidever et al's table 1 which lists those with variations supposedly lower than 100 m s^{-1}. We also have a good intersection of 354 stars with the recent catalog by Chubak et al. (2012). We compare our RV in the SOPHIE scale with those of Nidever et al. and with those of Chubak et al. in Fig. 3 as a function of colour. We measure respectively offsets of 73 and 62 m s^{-1} with RMS of 40 and 98 m s^{-1} up to B$-$V= 1.3, after removing iteratively the 3σ outliers. The RMS of 40 m s^{-1} obtained when comparing Nidever et al. and us is an indication that the mean error of the two catalogs is lower than that value. It also confirms that the vast majority of these stars are stable. The outliers reveal the intrinsic variable stars as well as systematics due to methodology. In the range of M stars,

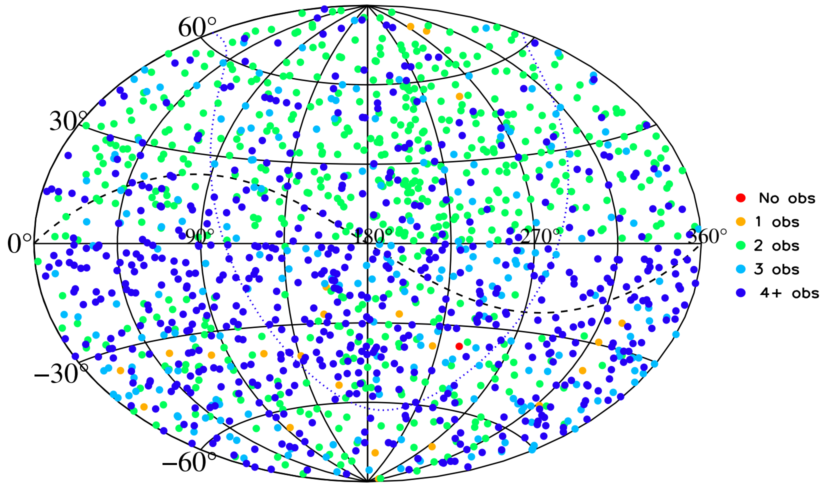

Fig. 1. Distribution of the 1420 candidate stars on the celestial sphere in equatorial coordinates, with a color code indicating the number of measurements available.

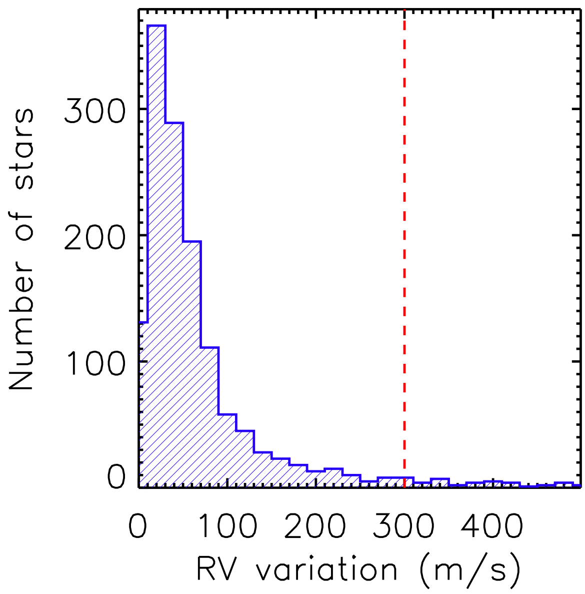

Fig. 2. Distribution of RV variations of the candidate standard stars having at least two RV measurements separated by 100 days or more. A dashed line shows the adopted 300 m s^{-1} stability threshold.

for B−V> 1.3, there is a clear systematic effect. We interpret this disagreement by the fact that both Nidever et al and Chubak et al use real templates for the CCF, while we use numerical masks computed from synthetic spectra.

4 Next steps

As explained in Lindegreen & Dravins (2003), there are many limitations to measuring accurate spectroscopic RV. The convective shift due to motions in the stellar atmosphere depends on stellar lines and Astrophysical

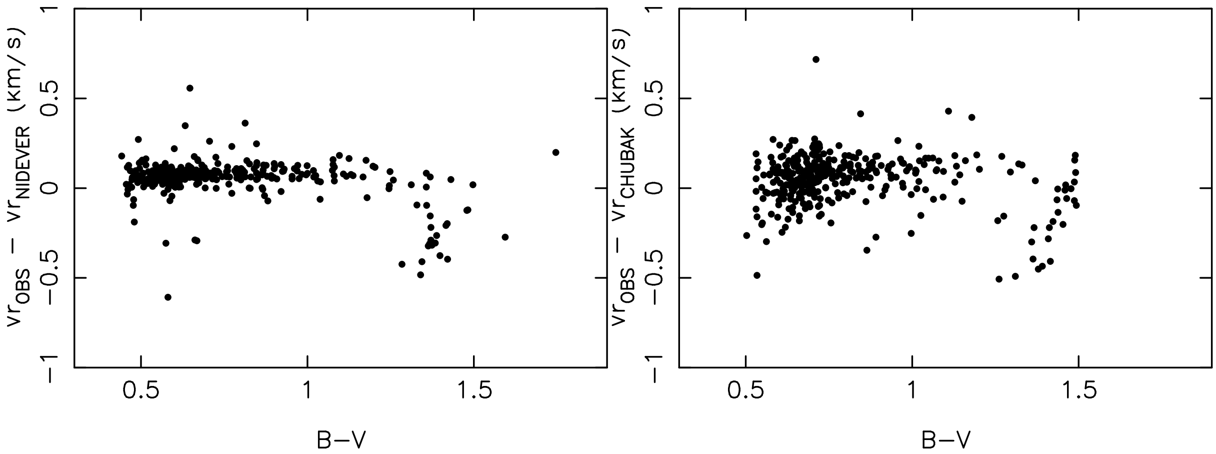

Fig. 3. RV difference between Nidever et al. (2002) and us (left panel) and between Chubak et al. (2012) and us (right panel) as a function of B-V colour.

Parameters (APs); it can reach +3 km s^{-1} for a CaII line in a F dwarf and −0.4 km s^{-1} for a FeI line in a K giant (Chiavassa et al. 2011). Other astrophysical effects may affect the RV of a star, such as rotation, activity, granulation as well as the presence of small-mass companions. Our on-going project is to estimate gravitational redshift (from APs) and compute convective shifts corrections in the RVS spectral interval from 3D hydrodynamical model atmospheres, in order to get the kinematic RV of each star. We will also define the RV zero-point of the catalog thanks to RV measurements and theoretical kinematic RV of asteroids. Finally our long-term plan is to re-observe the 1420 stars in 2016-2018 in order to check their long term stability.

5 Conclusion

We have presented the pre-launch version of the catalogue of RV standard stars for Gaia, assembled thanks to a long-term observing program started in 2006 on several spectrographs. Among the 1420 selected candidates, 1394 are found to be stable at the 300 m s^{-1} level, which make them suitable for the calibration of the RVS instrument. Their long-term stability will have to be confirmed with new ground-based observations during Gaia operations. We find a good agreement for FGK stars with two other catalogues, but systematic offsets for M stars.

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