Radial Velocity Standards : update

prepared by: C. Soubiran, F. Crifo, L. Chemin, J.-F. Lecampion
approved by:
reference: GAIA-C6-TN-LAB-CS-015-1
issue: 1
revision: 0
date: 19 March 2015
status: Draft

Abstract

The list of Radial Velocity Standard stars has been extended by mining the archives of the spectrographs ELODIE, SOPHIE, NARVAL and HARPS. New criteria have been defined to classify primary and secondary stars. A quality flag is given to each of them. We present a catalogue of 10 227 stars among which 2 798 are primary standard candidates for the RVS calibration.

Document History

Issue	Revision	Date	Author	Comment
D	1	19-03-2015	CS	Update after the DU640 telecon on 19 Mar. 15
D	1	10-03-2015	CS	Update after the DU640 telecon on 30 Jan. 15
D	0	08-01-2015	CS	Creation

Contents

1 Introduction

The need of additional RV standards (RV-STD) was expressed at the 16^{th} CU6 meeting in December 2013. Since then, DU640 has produced several lists of new primary RV-STD for calibrations and secondary stars for validations. In Soubiran et al. (CS-013), we described the selection of new primary RV-STD and secondary stars in the archives of the high resolution

spectrographs ELODIE and SOPHIE at OHP, and in our GBOG observations of stars at the NEP with the NARVAL spectropolarimeter at Pic du Midi. Here we add the HARPS archive to this previous dataset and we select additional primary RV-STD and secondary stars. Each star is flagged with a quality index depending on the number, time span and standard deviation of the available RV measurements. We apply the same quality classification to the 1420 RV-STD candidates of our initial list (Crifo et al., 2010; Soubiran et al., 2013). One has to keep in mind that the primary RV-STD are only candidates. Their stability at the 300 m s^{-1} level during the Gaia mission has still to be confirmed with new ground-based observations.

2 Summary of available standards

The initial catalogue of RV-STD candidates, released in January 2013, includes 1420 stars among which a number of FGK stars are stable enough *a priori* to be considered as primaries (a.k.a Crifo1). The selection of the 1420 stars is described in Crifo et al. (2010), and the corresponding GBOG measurements in Soubiran et al. (2013). The catalogue is available at CDS.

Mean literature RVs from the XHIP compilation for 7730 selected secondary stars (a.k.a. Crifo2) were released in March 2014. It is described in Crifo & Sartoretti (FCO-002).

A set of additional primary RV-STD candidates from ELODIE-SOPHIE-NARVAL archives (a.k.a. Soubiran1) was released in May 2014, together with secondary stars (a.k.a. Soubiran2). This is described in Soubiran et al. (CS-013).

The selection of 297 318 secondary stars from RAVE (a.k.a. Zwitter1) was released in February 2014. It is described in Zwitter et al. (TZ-002).

Finally, the Unified Montpellier Masterlist (UMM) is in preparation and will include the catalogs of Nordström et al. (2004), Famaey et al. (2005), Nidever et al. (2002) and Chubak et al. (2012).

Here we update the lists Soubiran1 and Soubiran2 by combining the ELODIE-SOPHIE-NARVAL archives to that of HARPS. We also apply new criteria defined by DU640 in two telecons held on January 30th and March 19th 2015, as described in Sect. 3. We also apply the same criteria to the list Crifo1 and we merge all these homogeneous datasets in a common list. These criteria have been defined to help CU6 to choose the appropriate stars when doing the calibration, or comparing ground-based and RVS measurements.

3 Criteria for selecting RV standards

The new primary RV standards are selected to verify :

TABLE 1: Different quality flags (Qflag) of primary RV-STD, secondary and rejected stars. Qflag=9 correspond to binary stars, according to Simbad or XHIP.

Qflag	σ_{RV} m s^{-1}	N meas.	ΔT days
Primary RV-STD			
1	≤ 100	≥ 4	≥ 730
2	≤ 100	≥ 3	≥ 300
3	≤ 100	≥ 2	≥ 300
Secondary stars			
4	≤ 300	≥ 3	≥ 300
5	≤ 300	≥ 2	-
6	≤ 1000	-	-
7	-	= 1	-
Rejected stars			
8	> 1000	-	-
9	-	-	-

- Vmag ≤ 11 ;
- FGK stars : the spectral types are searched in XHIP and Simbad. We also apply the colour selection 0.35 $\leq$ B-V $\leq$ 1.40. Then we examine individually the bluest and reddest stars to eliminate potential A or M stars. We note that the XHIP and Simbad spectral types are sometimes different for cool stars. To be sure to eliminate as much M dwarfs as possible, we reject all stars with absolute magnitude $M_V > 8$ in XHIP. This is important to avoid M stars among primary RV-STD because of molecular bands in the RVS range which make the RV determination uncertain ;
- no neighbouring star with $\Delta\mathrm{Imag} < 4$ within 20". This is performed with the UCAC4 catalogue. This criterion has been relaxed with respect to the initial one ($\Delta\mathrm{Imag} < 4$ within 80") because the CU6 pipeline is able to reject the transits where a spectrum is polluted by another one ;
- RV stability better than 300 m s^{-1} over 300 days at least. First we eliminate as well as possible the potential binaries, identified as such in Simbad or XHIP. Then we consider the stars showing a standard deviation, σ_{RV}, lower than 100 m s^{-1}(the stability is defined by $3\sigma_{RV}$) ;
- the new stars should not be part of the initial catalogue of 1420 candidates.

The primary RV-STD are labelled with a quality flag (Qflag) from 1 to 3, according to the number of RV measurements available and their time span, as listed in Table 2.

As secondary stars, we selected all the other stars with at least 1 RV measurement. There is no constraint on Vmag and spectral type for the secondary stars, nor inspection of their neighbourhood. Such stars might be stable, but the data available is not sufficient to state about their stability. The secondary stars are labelled with a quality flag (Qflag) from 4 to 7 as listed in Table 2. The sars with $\sigma_{\rm RV}$ larger than 1 km s^{-1} are rejected (Qflag=8) as well as potential binaries according to the information available in XHIP and Simbad (Qflag=9).

4 The HARPS archive

HARPS is a velocimeter mounted on the ESO 3.6m telescope at La Silla, with a resolving power of $R = \lambda/\Delta\lambda \simeq 115\,000$. Contrary to the ELODIE and SOPHIE archives, the HARPS ESO science archive cannot be mined directly with massive queries. We used instead the AMBRE-HARPS catalogue by De Pascale et al. (2014) which provides data for 126 688 scientific spectra including RV measurements from the ESO pipeline for 95% of them.

From this list, only stars which can be identified with a HIP, TYC or 2MASS number were kept. This is to ensure that the cross-match with the IGSL can be done. Observations of signal to noise ratio lower than 10 were rejected, as well as spurious RV measurements, or those not obtained by the ESO pipeline. Large series of observations of a single star within the same night (e.g. for asteroseismology follow-up) were reduced to one observation per night (the one with the highest precision). Finally stars with unknown V magnitude are also rejected. After this cleaning, 32 297 RV measurements remain, for 3 172 different stars.

To be consistent with our previous lists of RV-STD candidates, the RV measurements must be expressed in the SOPHIE scale. In Soubiran et al. (2013), we found an offset of -17 m s^{-1} between SOPHIE and HARPS with a R.M.S. of 33 m s^{-1}, based on 34 FGK stars in common. Here, we have re-evaluated this offset with more stars. Among the 68 stars in common, only stars with at least 2 measurements in good agreement ($\sigma < 0.5$ km s^{-1}) with each instrument were considered. As shown in Fig. 1, there is a significant offset (-379 m s^{-1}, R.M.S. of 186 m s^{-1}) for the reddest stars ($B - V > 1.4$). This trend was previously observed, when SOPHIE measurements were compared to ELODIE ones, and to the catalogues of Chubak et al. (2012) and Nidever et al. (2002), but at a lower degree (Soubiran et al., CS-013; Soubiran et al., 2013). This is likely related to the mask used to analyse M stars. For the other stars, the measured offset between SOPHIE and HARPS is -32 m s^{-1} (R.M.S. 45 m s^{-1}) once 4 outliers at the 3σ level were rejected. Though having a larger amplitude, the new offset remains comparable with the previous determination within the quoted R.M.S. values. The HARPS measurements were transformed into the SOPHIE scale, using this offset of -32 m s^{-1}. One has to keep in mind that M stars, which are not used as primary RV-STD, are affected by larger uncertainties than FGK stars.

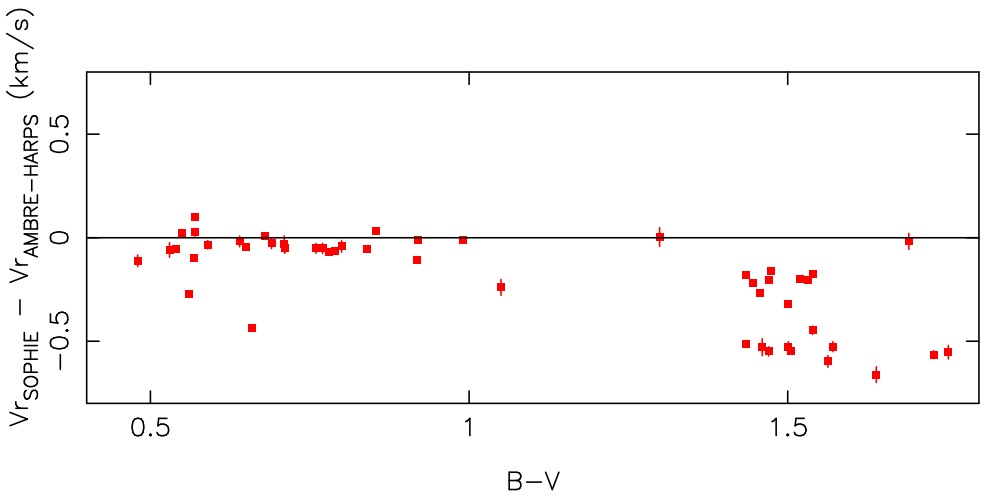

FIGURE 1: Comparison of RV measurements from SOPHIE and HARPS for common stars.

5 The new compilation

Once the individual HARPS RV measurements are corrected to be in the SOPHIE scale, they are merged with those of our previous compilation of ELODIE-SOPHIE-NARVAL measurements described in CS-013. This gives 77 313 RV measurements for 8 807 different stars. The new primary RV-STD and secondary stars are selected from this list. The 1420 stars of the initial catalogue are also considered and classified using the criteria listed in Table 2. The number of stars in each category is given in Table 3, for the 8 807 new stars, and the 1 420 initial ones.

6 Primary RV standards

The 2 798 primary RV-STD candidates are shown on the celestial sphere in Fig. 2 : 1209 are from the initial catalogue, 1589 are new. The initial catalogue of 1420 RV-STD candidates was built to cover the sky at best, on a rather uniform way, leaving no big ”holes”, in order to make sure that calibration stars would be available on all scans, and not concentrated in a few spots. The additional calibration stars did not verify this point, as it was assumed to be already reached.

Figure 3 shows the histograms of the time span between the first and last measurement for the new and previous RV primary standards. One can notice here that the distribution of the time baseline for the new primary candidates peaks at 6 years, which is exactly between the two peaks of the distribution for the Crifo1 primary stars. The peak at ∼12 years in Crifo1 is due to the older measurements of the ELODIE archive. The main peak at ∼3 years in Crifo1 reflects our own GBOG observations on SOPHIE.

TABLE 2: Number of stars per quality category (Qflag), for the 8 807 new stars, and the 1 420 initial ones.

Qflag	N star new	N star initial
Primary RV-STD		
1	1073	629
2	417	201
3	99	379
total	1589	1209
Secondary stars		
4	568	66
5	1251	44
6	242	24
7	2349	5
total	4410	139
Rejected stars		
8	666	7
9	2142	65
total	2808	72
total	8807	1420

Figure 4 shows the two histograms of the RV variations for the new and previous RV primary standards. We take as the measure of the variation 3 times the standard deviation around the mean RV. The new RV-STD stars (red histogram) show a better stability than the initial ones (blue histogram), more than 90% of them having a variation lower than 150 m s^{-1} (i.e. $\sigma_{\rm RV} < 50$ m s^{-1}).

7 Secondary stars

There are 4549 secondary stars. Figure 5 shows the two histograms of the V magnitudes and B-V colours for the secondary stars.

There are 31 secondary stars which were selected as primary RV-STD, but rejected because of their absolute magnitude $M_V > 8$ despite they have a K spectral type. This was a conservative rejection to avoid misclassified M dwarfs. However such stars could move back to the primary list if it is demonstrated that their RVS spectrum is not affected by molecular bands.

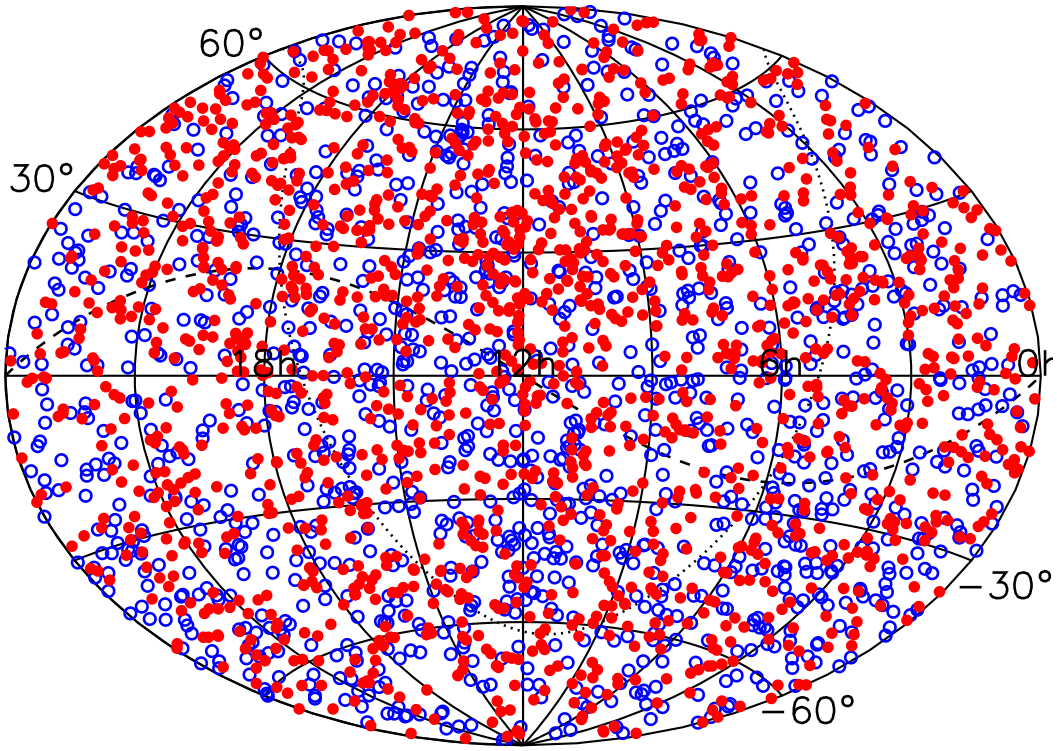

FIGURE 2: Distribution of the primary RV-STD candidates on the celestial sphere in equatorial coordinates : blue open circles for the initial catalogue, red dots for the new ones. The dashed line indicates the projection of the Ecliptic plane, the dotted line that of the Galactic plane.

8 Format and distribution

The new list of 10 227 stars described in this TN, is stored on the ESAC disk space created for the GBOG WG : gbogcom at ssh.esac.esa.int, /gbog/cu6/RV-STANDARDS (password gbog4dpce). It can be retrieved by sftp. The ascii file, described in a ReadMe file, includes the HIP, TYC or 2MASS identifier, the quality flag Qflag, J2000 equatorial coordinates, Vmag, B-V (99.999 when not defined), spectral type (when known from Simbad or XHIP), mean RV in SOPHIE scale, internal error of RV, standard deviation, uncertainty , maximum deviation, time baseline of observations, mean julian day of observations, julian day of last observation, number of RV measurements.

A pdf file also provides plots of individual measurements for each of the new primary RV-STD, an excerpt of it being shown in Fig. 6 and Fig. 7. In Fig. 6, HIP010306, HIP017378, HIP082750, and TYC4212-01106-1 are typical examples of very stable stars found in the combined archives. Fig. 7 on the contrary shows the 15 stars visually identified as exhibiting some variations, either periodic or in form of a long term trend, but within the 300 m s^{-1} stability limit. For instance

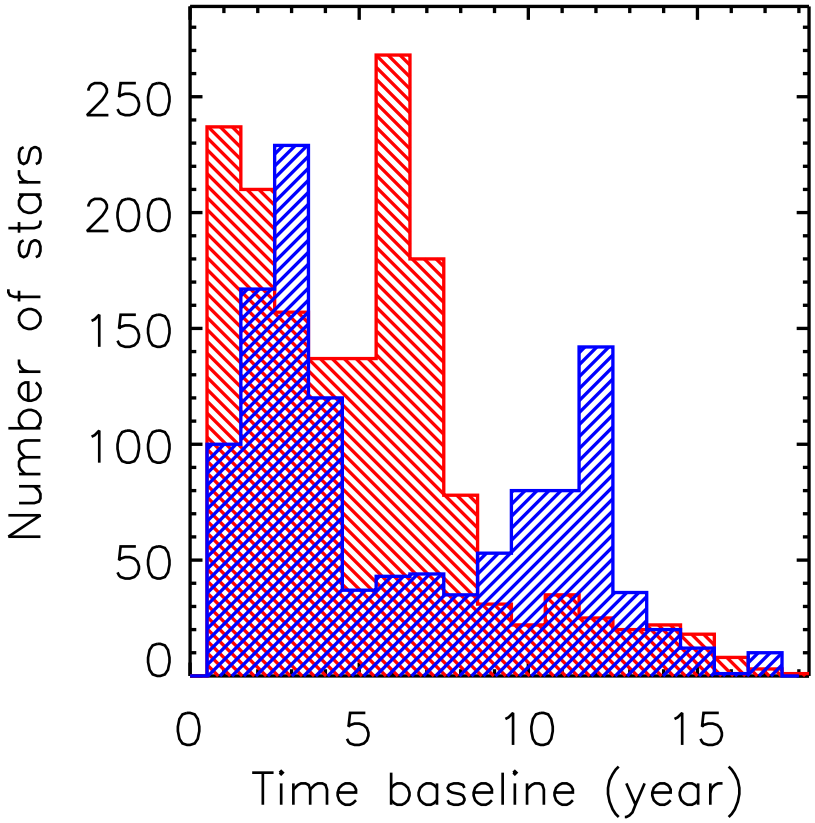

FIGURE 3: Distribution of time baselines of observations for the new (red) and previous (blue) primary RV-STD candidates.

HIP113834 shows a periodic variation of its RV due to substellar companion of mass $13M_J$ with a period of 1319 days according to the Extrasolar Planets Encyclopaedia. Similarly HIP042723 has 3 exoplanets. In these 15 cases, the amplitude of the variation is still compatible with the RVS criteria for the RV-STD.

9 Next steps

Within the coming year we will :

- search for the most recent public observations of the RV-STD in the archives of SOPHIE and HARPS. As said above, the AMBRE-HARPS catalogue only covers the period 2003-2010, so we expect that some of the very well followed-up stars that we selected are still observed after 2010. Similarly, we searched the SOPHIE archive more than one year ago and new measurements can be available now ;

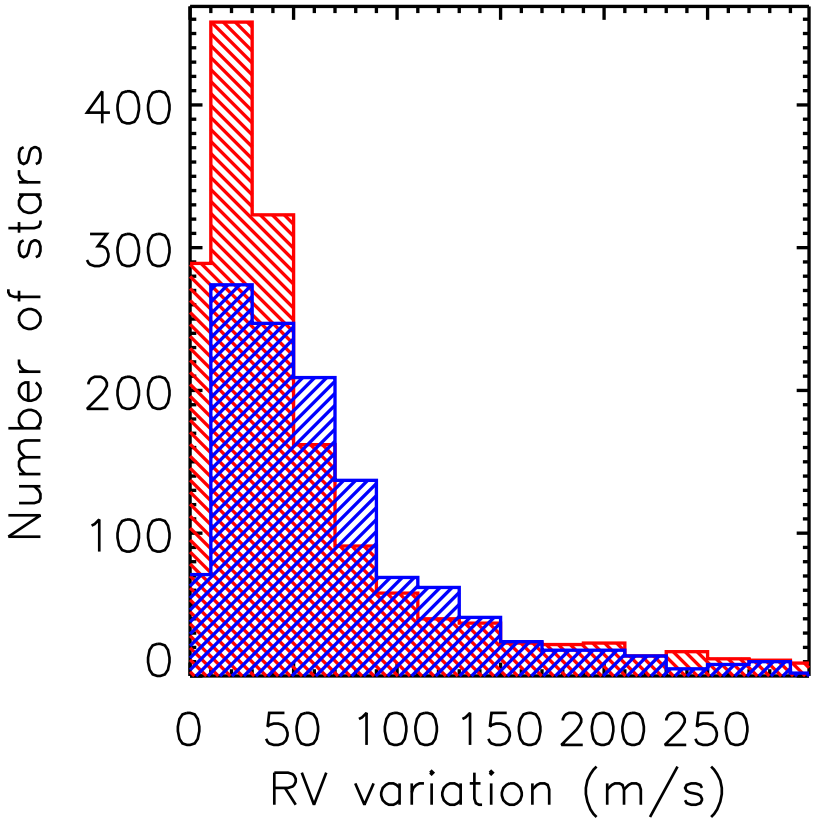

FIGURE 4: Distribution of RV variations of the new (red) and previous (blue) primary RV-STD candidates.

.

- search for the most recent measurements of the RV-STD in the CORALIE database ;
- start the follow-up of the majority of the RV-STD with CORALIE and SOPHIE depending upon the attribution of telescope time.

References

Chubak, C., Marcy, G., Fischer, D.A., et al., 2012, ArXiv e-prints, ADS Link

[FCO-002], Crifo, F., Sartoretti, P., 2014, *RVS secondary standards*, GAIA-C6-TN-OPM-FCO-002, URL http://www.rssd.esa.int/cs/livelink/open/3254264

Crifo, F., Jasniewicz, G., Soubiran, C., et al., 2010, A&A, 524, A10, ADS Link

De Pascale, M., Worley, C.C., de Laverny, P., et al., 2014, A&A, 570, A68, ADS Link

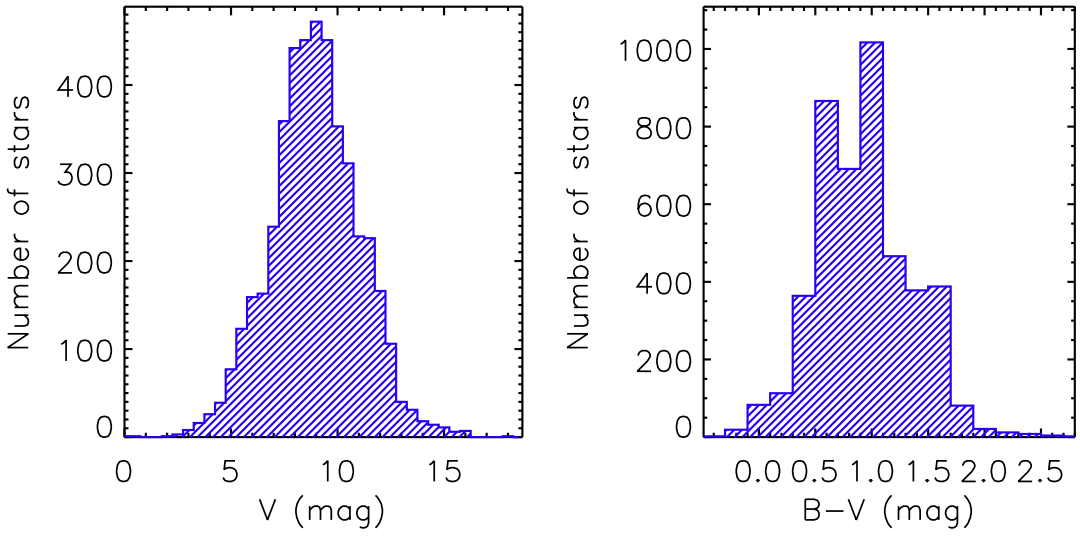

FIGURE 5: Histograms of the V magnitudes and B-V colours for the secondary stars.

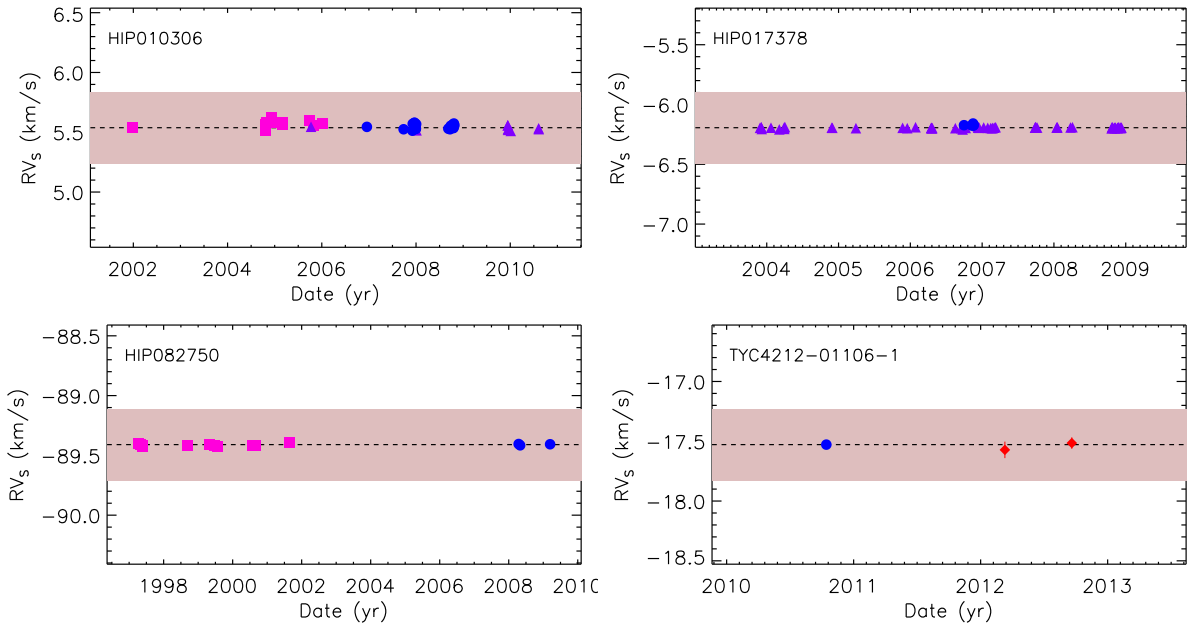

FIGURE 6: RV measurements for some of the new primary RV-STD candidates. The pink squares, blue dots, red diamonds and purple triangles are respectively ELODIE, SOPHIE, NARVAL and HARPS measurements. The RV axis is centered on $\overline{\mathrm{RV_S}}$ and spans 2 km s^{-1}. The shaded area represents the 300 m s^{-1} stability limit ($3\sigma_{\mathrm{RV}}$).

Famaey, B., Jorissen, A., Luri, X., et al., 2005, A&A, 430, 165, ADS Link

Jordi, C., Gebran, M., Carrasco, J.M., et al., 2010, A&A, 523, A48, ADS Link

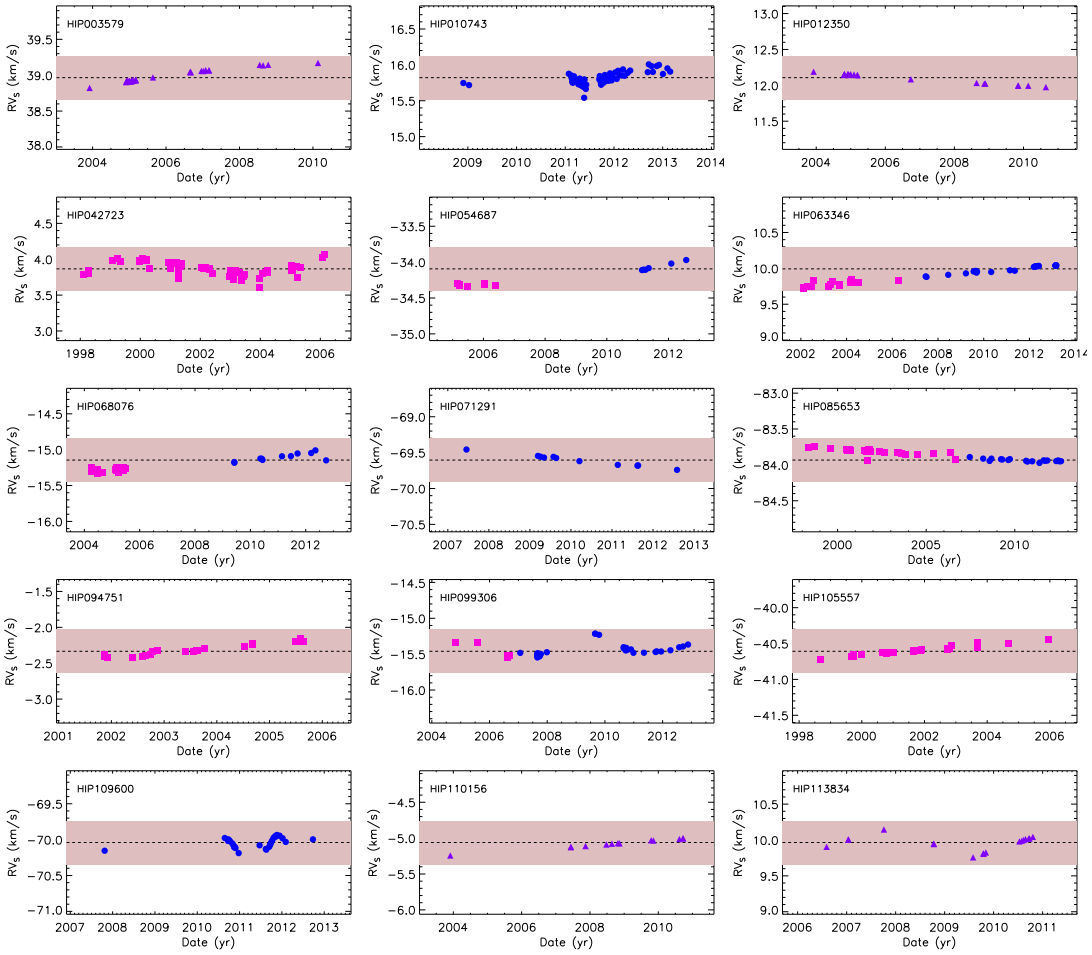

FIGURE 7: Same as Fig. 6 for the 15 new primary RV-STD candidates showing variations in RV within the 300 m s^{-1} stability limit.

Nidever, D.L., Marcy, G.W., Butler, R.P., Fischer, D.A., Vogt, S.S., 2002, ApJS, 141, 503, ADS Link

Nordström, B., Mayor, M., Andersen, J., et al., 2004, A&A, 418, 989, ADS Link

Soubiran, C., Jasniewicz, G., Chemin, L., et al., 2013, A&A, 552, A64, ADS Link

[CS-013], Soubiran, C., Chemin, L., Lecampion, J.F., 2014, *New Radial Velocity Standards for the RVS*,
GAIA-C6-TN-LAB-CS-013,
URL http://www.rssd.esa.int/cs/livelink/open/3259915

[TZ-002], Zwitter, T., Kos, J., Zerjal, M., 2014, *Contribution of RAVE radial velocity measurements to the list of RVS radial velocity standards*,

GAIA-C6-TN-LU-TZ-002,
URL http://www.rssd.esa.int/cs/livelink/open/3252514

Acronym List

The following table has been generated from the on-line Gaia acronym list:

Acronym	Description
2MASS	Two-Micron All Sky Survey
CDS	Centre de Données astronomiques de Strasbourg
EPC	Ecliptic Pole Catalogue
ESAC	European Space Astronomy Centre (VilSpa)
ESO	European Southern Observatory
GBOG	Ground-Based Observations for Gaia (DPAC)
IGSL	Initial Gaia Source List
NEP	North Ecliptic Pole
OHP	Observatoire de Haute Provence (France)
RV	Radial Velocity
RVS	Radial Velocity Spectrometer
RV-STD	Radial Velocity Standard Star
TBL	Telescope Bernard Lyot (Pic du Midi, France)
TN	Technical Note
WG	Working Group