The non-single star content of the list of radial velocity standard stars

prepared by: Frédéric Arenou
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Abstract

We analyse the properties of unresolved multiple stars within the full-sky list of radial velocity standard stars, and we estimate that a low remaining fraction would have a radial velocity variation during the mission larger than the requirement. The need for supplementary observations to specifically remove these multiple stars does not appear justified.

Document History

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D	1	2013-02-05	FA	First draft
1	0	2013-02-10	FA	Correction of the RV measurement number and epochs, improvements of the realism of the simulation, statistics for cross-checking.
1	1	2013-02-18	FA	Typos, changed figure B-V to V-I.

Reference Documents

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1 Introduction

The RVS having no wavelength calibration monitoring on-board Gaia, a list of reference standard stars is needed for the radial velocity zero-point calibration (GJ-001). This radial velocity standard star list (noted RVSSL in what follows) which contains 1420 stars has now been built (Crifo et al., 2010).

The radial velocities of the selected stars should obviously be stable, and the main reason for a possible variability is binarity. For this reason, the selection process has tried to discard multiple stars, but a large fraction may remain undetected.

The question has recently been raised by one referee about the fraction of multiple stars which statistically remains in the RVSSL sample and their effect on the constancy of the radial velocities and I have been asked to check this aspect.

2 Simulations

The selection of the stars which have been included in the RVSSL is described in Crifo et al. (2010), to which the reader is referred. In summary, the stars are late-type stars between $V = 6$ and $G_{\rm RVS} = 10$, present in the Hipparcos Catalogue, with no indication of variability or multiplicity and no bright ($\Delta I < 4$) neighbours ($\rho < 80$"). They were initially either official IAU standards or with at least two existing measurements more precise than 300 m.s^{-1} in one among the Nidever et al. (2002, Cat. J/ApJS/141/503), Nordström et al. (2004, Cat. V/117) or Famaey et al. (2005, J/A+A/430/165) Catalogues.

Thus, the exact selection process which allowed a star to be or not present in the RVSSL is clearly very difficult if not impossible to ensure with a simulation. The RVSSL distributions in distance, V magnitude, total proper motion and the colour magnitude diagram is shown Figs.1a-d, which originate from Crifo et al. (2010) and private communications.

What has been adopted is a GaiaSimu simulation (Robin et al., 2012) of F7-M8 stars of the solar neighborhood up to 150 pc and to magnitude 10, to which we applied a random decreasing filter for stars fainter than $V = 8$ or farther than 50 pc. The generated stars may be single, binaries or multiple stars, with probabilities and characteristics consistent with currently known properties, as described in Arenou (2011) or FA-054. We do not describe further both the Galaxy model and multiple star model, but they should be rather representative of the solar neighborhood.

The corresponding figures for the simulated sample are shown Figs. 2. Note that, in order to obtain significant statistics concerning the number of objects[1], the sample has been simulated with 10 times more stars than in the RVSSL. The figures look similar to the RVSSL as far as

[1] In what follows, we call "object" either a single star, a binary or a multiple system as its true nature is unknown.

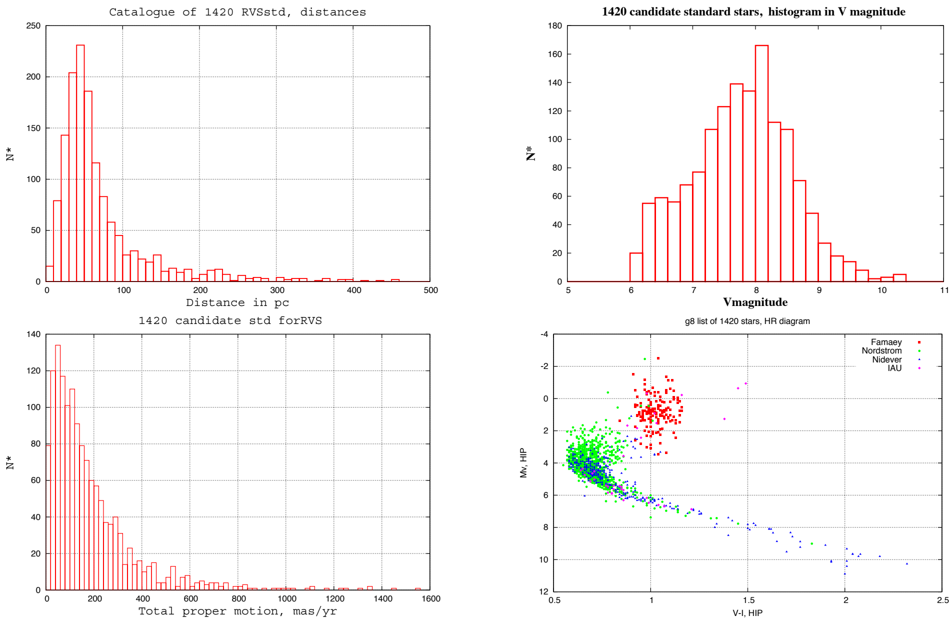

FIGURE 1: The 1420 standard stars: distribution of the number of stars with distance (a), V magnitude (b), total proper motion (c); M_V versus $V - I$ diagram (d). Courtesy F. Crifo.

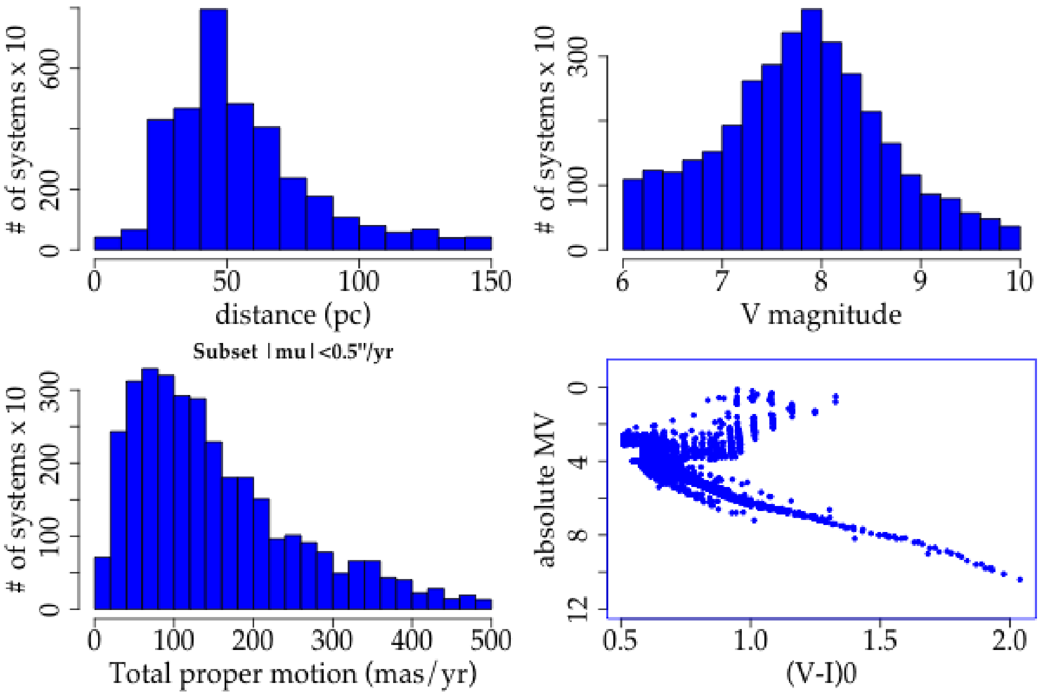

FIGURE 2: Simulated sample, see legend of Figs.1. In order to get meaningful statistics, 10× more stars than the original sample have been generated.

magnitude, distance, proper motion and H-R diagram are concerned. Although it is likely that other possible underlying RVSSL censorships have not been reproduced, there is no obvious reason why this would specifically bias the binary fraction or orbital properties.

3 Non-single star content

To discuss the final content of the simulation in terms of multiple systems, we first have to mention how we attempted to reproduce the rejection of binaries, as inferred from Crifo et al. (2010). We rejected the following systems:

- all couples separated by $\rho > 80$" and companion brighter than 20^m,
- 30"$< \rho <$80" and $\Delta I < 4$,
- $0.1 + 0.04\Delta V < \rho < 30$" and $\Delta V < 3.5$ in order to represent the resolved double star detection capabilities of Hipparcos (Lindegren et al., 1997, sect. 3.2)[2]
- Objects with an astrometric acceleration larger in module than 3 mas/yr^2 to take the DMSA/G (more or less) into account.

It should be noted that we also applied these criteria to ternary systems, the rejection of a detected third component thus possibly helping to remove systems with a secondary more threatening in terms of radial velocity change.

Actually, the most efficient selection was the one using the constancy of the radial velocity. The ground-based radial velocity measurements have been obtained at two different observational "epochs":

- A large observation program has been undertaken since 2006, what we will call a second "epoch" centered around 2009: to simplify, we consider that this can be simulated as one measurement followed by another observation between one and three years later;
- older measurements were also then found in the SOPHIE, ELODIE, etc. archives. To simplify, we simulate these observations as a central "epoch" around 2001 with an amplitude of four years.

The RVSSL sample contains 6 stars having one measurement only[3], 455 stars with 2, 221 with 3, 280 with 4 measurements, and 458 with 5 measurements or more and 92.8% of the objects had a variation below 300 m.s^{-1} (F. Crifo, private comm.).

[2] We used the ΔV criteria, not having the ΔH_p Hipparcos magnitude difference at hand.
[3] We assumed that a second measurement will be obtained and count these stars as having two.

The simulated radial velocity measurements[4] were simulated following this recipe. To the RV, a 0.017 km.s^{-1} gaussian measurement error, larger than the average formal errors in the RVSSL, was added. The average and dispersion $\sigma_{\rm RV}$ between all measurements of each star was then computed. If the $3\sigma_{\rm RV}$ radial velocity variation was larger than 300 m.s^{-1}, the object was rejected. We thus simulated a sample of size 1420×92.8%=1317 objects expected to be similar to the RVSSL after elimination of objects with large velocity variations.

The final content of the simulated sample is shown Table 2 and we concentrate for the moment on its first line which represents the current situation in terms of available observations. The third and fourth column which total amounts to the 1317-sample describe respectively the content in single stars and in unresolved objects (among which about 6% are more than binary). The second column represents the number of objects which have been rejected by the efficient binary selection described above, about 3/4 of the initial content in terms of multiple systems.

It should be noted that most of the astrometric selection above (no neighbours, no indication of multiplicity in Hipparcos), although it has a very large impact on the number of detected objects (half of them), concerns the long period ones only. The radial velocity measurements were much mode efficient (63% vs 27%) for the detection of the multiple stars and obviously more adapted for selecting constant radial velocities. It is obvious that two *precise* radial velocity measurements separated by more than one year have a much more important impact: for intermediate periods, this is due to the long baseline; for short periods this is because the "random" sampling on a large amplitude curve has a large probability to detect a variation with two values only.

TABLE 2: Average multiplicity property and number of problem objects, depending on whether one supplementary measurement is done in 2015. Number of rejected systems (i.e. no more in the list), remaining single and multiple systems with variation below 300 m.s^{-1}. Among them, the final columns are those for which the variation of radial velocity at the end of mission will be respectively larger than 300 and 100 m.s^{-1}.

Measurement in 2015 ?	Rejected systems	Single stars	Unresolved systems	ΔRV > 300	ΔRV > 100
No measurement	971	968	349	22	64
Another measurement for all	1037	999	318	1	23
A third measurement only	1019	1003	314	2	26

The properties of the remaining unresolved systems is shown Fig. 3. The magnitude difference between the components is Fig. 3a, while Fig. 3b represent the K_1 radial velocity semi-amplitude of the primary versus orbital period. Longer period are still present mostly because of the stringent $\Delta H_p < 3.5$ constraint of the astrometric selection, leaving faint M-type (and

[4]The binary simulation includes of course the computation of the binary (multiple) system motion with time, so the relative radial velocity variation with time of the system primary is available.

sometimes white dwarf) companions undetected. But, unfortunately, as is known since Bessel, even invisible companions may have a large influence on the system motion.

So the interesting question is of course the radial velocity variation which is expected for the reflex motion of the primary for the ≈ 350 undetected systems. We computed for each star the difference between the radial velocity in 2018.0 and the average velocity as estimated by the existing measurements, and this variation is shown Fig. 3c and d.

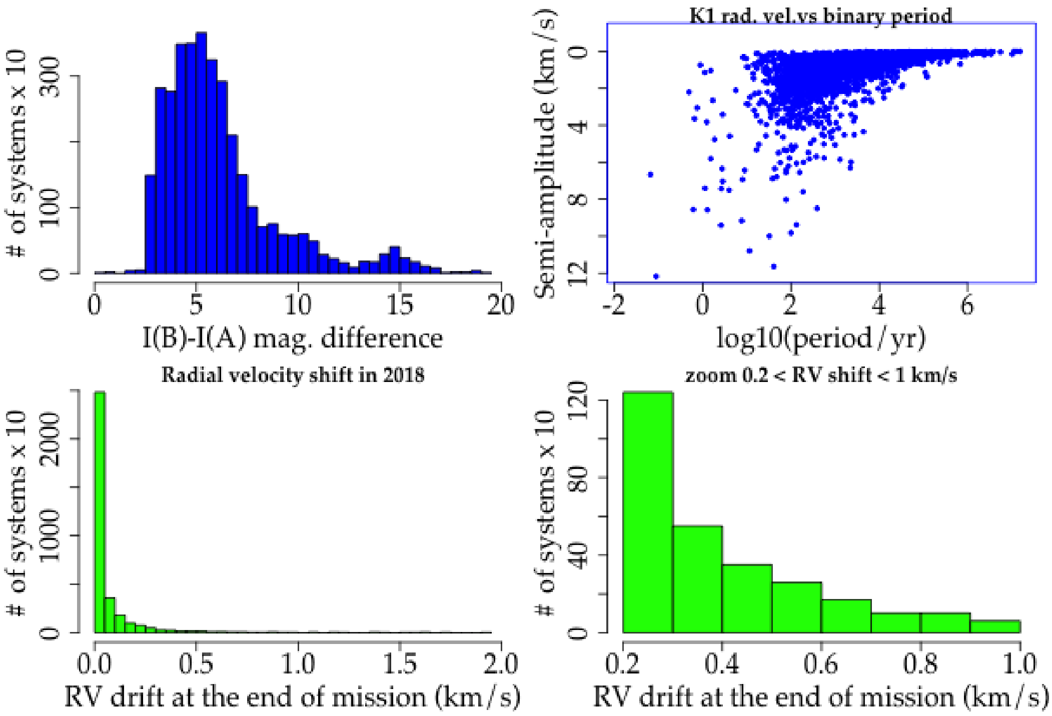

FIGURE 3: For the undetected multiple stars: I-band magnitude difference between components (a), semi-amplitude of the binary vs log of period (b), expected variation of radial velocity at the end of mission (2018) (c), and zoom on this latter distribution into the 0.2-1 km.s^{-1} interval (d), assuming that no supplementary measurement will be done in 2015. Here also 10×1317 objects have been simulated.

The number of objects having an absolute difference larger than 300 m.s^{-1} or larger than 100 m.s^{-1} is also indicated in the two last columns of Table 2. Because it is anticipated to undertake supplementary ground-based observations during the mission to check the stability of the RVSSL, the second line of Table 2 represents the situation if a new measurement was made for all stars during the year 2015, and the last line if a measurement was made for the stars with currently two observations only, i.e. one third of the objects only.

The uncertainty on the indicated numbers is not fully obvious to establish. As far as the random sampling errors are concerned, this amounts to a few units only. Systematic errors may originate on one hand from the inadequacy to represent the unknown stellar properties of RVSSL with the Galaxy model, and from the multiple star model on the other hand, so of course Gaia only will show the truth. With respect to this latter point, it may be however noted that, during the course of the Gaia simulations, many statistics are being computed and they all well agree to the known observational properties of binaries, cf. Arenou (2011, Table 1).

Under the assumption that the extended tail of the σ_{RV} distribution is due to the unrecognized multiplicity, one test which can be done is the ratio of less "stable" objects, $30 < \sigma_{\mathrm{RV}} < 100$ m.s^{-1} over the total of selected objects with $\sigma_{\mathrm{RV}} < 100$ m.s^{-1}. It amounts to about $23 \pm 1\%$ in the RVSSL but $11 \pm 1\%$ only are found in the simulation here. This may indicate that either the measurement errors have been underestimated (in which case there may be no real instability) or the instability may be due to other reasons than multiplicity. This goes beyond this technical note but this should be studied.

4 Conclusions

It is useful to remind that the initial need for RVS calibrations was 1000 standard stars only, and the list was extended to ≈ 1400 precisely to cope with binarity (Crifo et al., 2010). Currently, the stability, as far as multiplicity is concerned, looks already ensured for 98% of the objects, thus well above the initial requirement.

It has been advocated that supplementary measurements should be acquired during the mission in order to remove long period binaries. This has of course practical and funding implications and this note may help to clarify the need. The above analysis shows that one quarter of the sample is still made of unresolved binaries, but most do not need to be detected, so that adding a third measurement (instead of remeasuring all stars) would be enough to remove those with a significant variation, and would require observing one third of the RVSSL objects only.

One could still question whether the two dozens only of long period binaries remaining on the average would require half a thousand new observations[5], but the (negative) answer in this respect could have been anticipated much earlier for a simple reason: all these remaining binaries will already be detected by CU4 as astrometric binaries – and their predicted radial velocity variations estimated – well before the end of mission thanks to the large orbital signal[6] compared to the astrometric precision of Gaia.

[5]On the other hand, if the measured "instability" originates from other reasons than multiplicity, in particular transient phenomena, it is however unclear how one new measurement could *prove* the stability during *all* the mission. The spectroscopic data reduction itself may be much more useful in this respect and will have to cope anyway with a small number of unwanted but also unavailable outlying measurements.

[6]One may remember that we expect to detect Jupiter-like companions at this distance, so stellar companions should not really be a problem. More quantitatively, in the worst case, a variation of 300 m.s^{-1} over 9 years represents an acceleration of about 50 μas.yr^{-2} at 150 pc, well above noise for these very bright stars.