GAPS: Using the information of the HARPS-N exposure-meter to improve the precision of RV measurements

Prepared by :	*Signature*
Name: F. Borsa, M. Rainer, E. Poretti *Institute:* *INAF-OABrera* *Date :* 01/07/2013	
Approved by :	*Signature*
Name: *Institute:* NA *Date :*	
Released by :	*Signature*
Name: F. Borsa, M. Rainer, E. Poretti *Institute:* *INAF-OABrera* *Date :* 01/07/2013	

Change Record

Issue	Rev.	Paragr.	Page	Date	Observations
0	1	All		01/07/2013	First release
0	2	4-5		03/07/2013	Added confidence test for expmeter centroid info

Table of contents

List of Tables

List of Figures

1. GENERAL ASPECTS

1.1 Scope of the document

While taking a spectrum, if the flux received from the detector is not equally time-distributed while the shutter is open, the Radial Velocity (RV) information we receive can't be exactly referred to the middle of the exposure. That's why last generation spectrographs use the information of an exposure-meter to measure the centroid of the flux received vs. time, to correct the time information in case of a change in the seeing conditions during the exposure.
The HARPS-N reduction pipeline does not take into account, up to now, the exposure-meter information, using by default the mid-exposure time as the reference value for each exposure.
If the information of the exposure-meter centroid in the fits files of HARPS-N (keyword 'HIERARC EXP_METER_A EXP CENTROID') is reliable and trustworthy, it's not difficult to include it in the analysis of the radial velocities (even if it's not always present). The problem is to correct for the Barycentric Earth Radial Velocity (BERV) at the relative time, in a homogeneous way to the HARPS-N pipeline.

With the correction of the BERV at the right time, we can insert the information of the exposure-meter centroid in the RVs estimation of the pipeline, where available.

1.2 Applicable Documents

no.	document name	document number, Iss./Rev.
AD1		

1.3 Reference Documents

no.	document name	document number, Iss./Rev.
RD1	GAPS Project Management Plan	GAPS-MAN-PLN-0001, Issue 1.4, 23 Mar 2013
RD2		

1.4 Acronyms

BERV	Barycentric Earth Radial Velocity
BJD	Barycentric Julian Date
HARPS-N	High Accuracy Radial velocity Planetary Search - North
INAF	Istituto Nazionale di Astrofisica
JD	Julian Date
MJD	Modified Julian Date
N/A	Not Available
RD	Reference Document
RV	Radial Velocity
TNG	Telescopio Nazionale Galileo

2. BERV CALCULATION FOR THE SUM FILES OF AST01

We observed AST01 by means of 30 consecutive exposures of 60-sec each. For each string of 60-sec exposures we computed a co-added spectrum by summing all the spectra by means of the script SUMFITS. The co-added spectrum is then processed offline by the HARPS-N pipeline to supply the RV value not affected by any short term variation (e.g., pulsations) of the RVs of AST01. In such a way we get the set of the RVs obtained from the 60-sec exposures and the RV of the sum file. By comparing these values, we found the average RVs of the single files to be distant more than 10 m/s from the RV of the co-added spectrum. We realized that the information of the exposure-meter was not taken into account by the pipeline, that seems to consider the value MJD+0.5+exptime/2 as the JD time of the exposure in any condition. In the specific case of the co-added files, the discrepancies are due to the overheads between the exposures, which are not considered by the pipeline, that simply takes into account the time of the start of the integration and its total duration. One way to trick the pipeline is to include the overheads in the total integration time. However, this method still fails when the overheads are not regularly spaced (e.g., due to a system/guiding problem delaying the acquisition).
We then decided to use as the time of reference for the co-added spectrum the mean of the times of the single spectra, weighted for the relative signal-to-noise ratios. To have the relative RV, we had to modify the BERV value, subtracting the one calculated by the pipeline and adding a new one calculated at the new time.
Once developed this tool, we were able to modify the information of the BERV for each exposure where the information of the exposure-meter centroid was available.

To correct for both time and RVs, we developed a tool that modifies the time of the exposure using the information of the exposure-meter included (even if not always) in the fits files, and consequently corrects for the relative BERV.

2.1 Verification of uniformity with the pipeline in the BERV calculation

As a first step, we tried to verify that the BERV calculated from the pipeline and from our tool were comparable. In fact, uniformity with the pipeline is essential, in order to have a homogeneous set of RVs and to be able to apply the exposure-meter information to different targets. To do this, we estimated the BERV at the mid-exposure time of each image (the same as the pipeline does). The BERV velocities calculated by our tool for AST01, with respect to the pipeline, have differences of less than 3 cm/s for each measurement (Fig. 1).

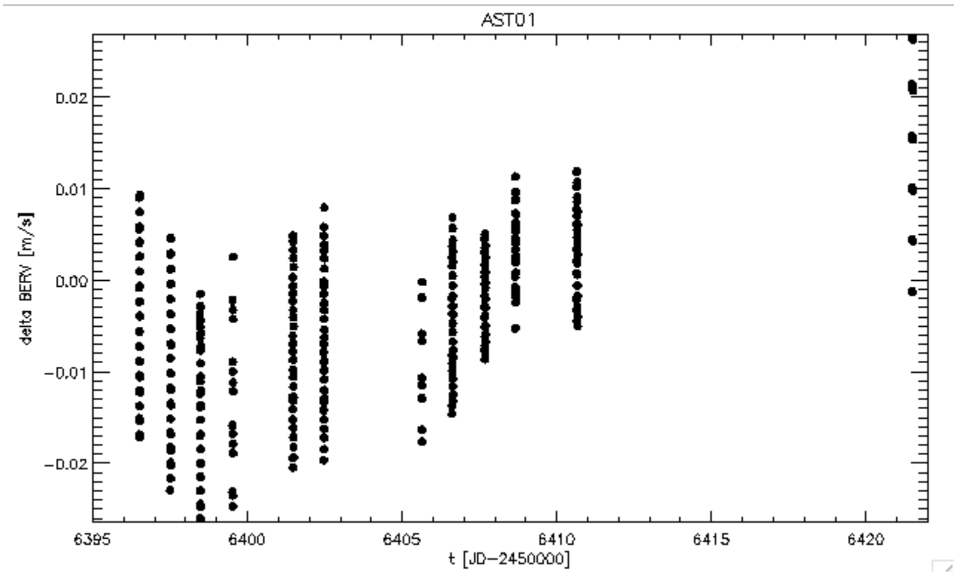

Figure 1 – BERV differences for the mid-exposure time between the pipeline and our tool

Despite the fact that this difference is negligible with respect to the instrumental uncertainty in the RVs of HARPS-N, we noted a strange behaviour happening each night in Fig. 1. Zooming one night, we found a quite regular pattern in the differences between our BERV correction and the HARPS-N pipeline BERV correction (Fig. 2, left panel). This pattern is present for each night of Fig. 1.

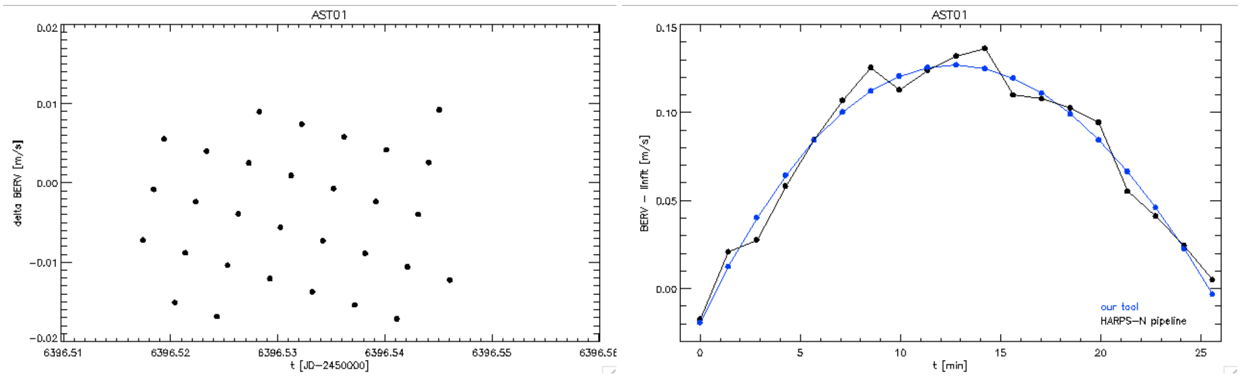

Figure 2 – BERV differences between the pipeline and our tool at short cadence

Analysing independently the BERVs calculated by the pipeline and by our tool, we noted that there seems to be a strange behaviour in the BERV estimation by the pipeline, with some parameter that seems to be updated/rounded every ~6 minutes (Fig. 2, right panel; a linear fit was subtracted for graphic clarity).

This behaviour is still under investigation, but due to its negligibility (2-3 cm/s) we continue our comparison with respect to the pipeline on other targets.

3. BERV CALCULATION FOR OTHER TARGETS

We tried to verify that the agreement on the BERV calculation between our tool and the pipeline was valid not only for the target AST01, but also for other targets, with observations spacing a longer time interval than the ~20 days of AST01. Using as example the data for M56 and KP32 (random choice of targets), the difference between the BERV calculated by the pipeline and that of our tool is less than 2 cm/s during all the period of observations (Fig. 3-4).

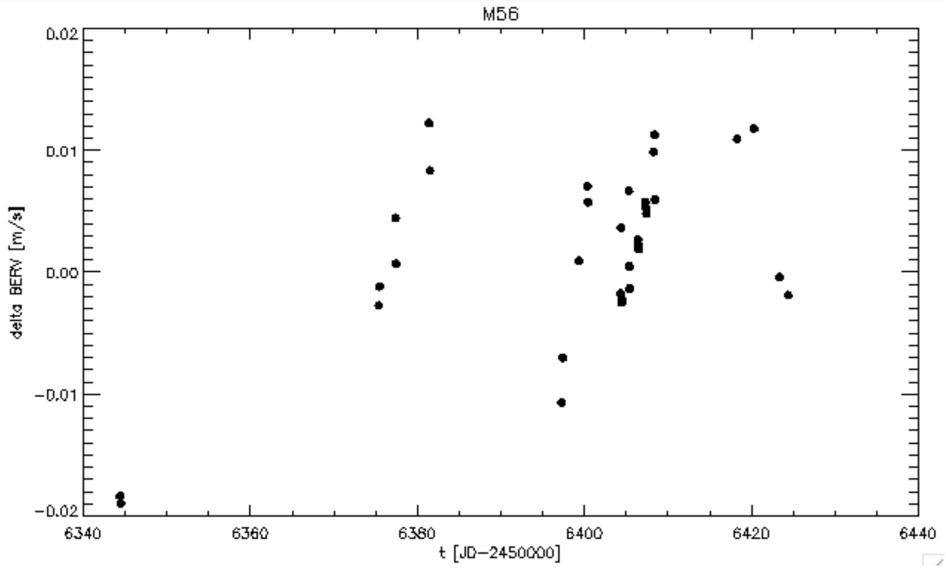

Figure 3 – BERV differences for the mid-exposure time between the pipeline and our tool for M56

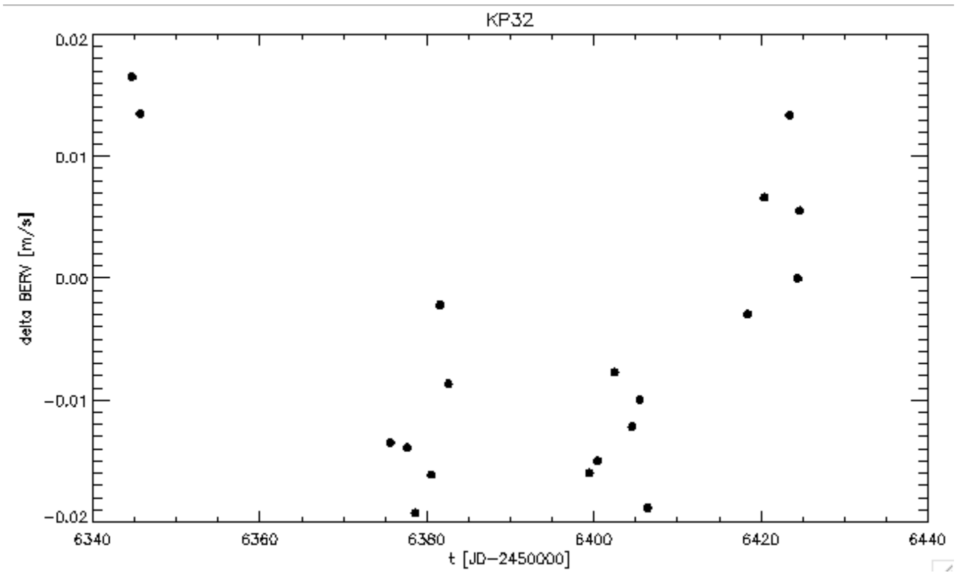

Figure 4 – BERV differences for the mid-exposure time between the pipeline and our tool for KP32

An error of 2-3 cm/s is negligible with respect to the instrumental error, so we are confident that our correction is valid even for different targets and different epochs.

4. MID-EXPOSURE VS EXPOSURE-METER CENTROID

Once we verified the agreement between the HARPS-N pipeline and our tool in the calculation of the BERV, we could apply the information of the exposure-meter centroid to each observation where it is available, replacing the BERV value with the one calculated at the corrected JD. We then verified for some targets how much the mid-exposure time is different from the exposure-meter centroid, and the relative difference in the RV values.

We considered the information of the exposure-meter centroid trustworthy where the maximum number of counts of the exposure-meter (keyword 'HIERARCH EXP_METER_A COUNTS MAX') did not exceed the expected mean counts (keyword 'HIERARCH EXP_METER_A EXPECTED MEAN') by a factor 10. Sometimes, in fact, the number of maximum counts reported by the exposure-meter reaches unreliable/saturation values ('9.91E37'), and this can probably affect the estimation of the centroid. In case of not passing this confidence test, we impose the centroid to be at the mid-exposure, as the pipeline does.

As an example, we take the case of KP32, since we saw that the error we introduce in estimating the BERV independently for this target is less than 2 cm/s (see Fig. 4).

Table 1 – BJD and RV differences for mid-exposure vs centroid for KP32

Exptime	Exp_meter_info	Exp_meter_centroid	Time diff (sec)	RV diff (m/s)
900.000	N/A	0.500 Imp	-0.020	0.016
900.000	N/A	0.500 Imp	-0.020	0.013
900.000	N/A	0.500 Imp	-0.011	-0.014
900.000	Spurious counts	0.500 Imp	-0.010	-0.014
900.000		0.467	29.780	-0.729
900.000	Spurious counts	0.500 Imp	-0.010	-0.016
900.000	Spurious counts	0.500 Imp	-0.010	-0.002
900.000		0.512	-11.260	0.232
82.211		0.290	17.109	-0.266
1200.000		0.507	-8.890	0.135
900.000	N/A	0.500 Imp	-0.010	-0.008
900.000	Spurious counts	0.500 Imp	-0.009	-0.012
900.000		0.522	-19.721	0.434
900.000		0.553	-47.712	0.901
900.000		0.554	-49.061	0.873
600.000		0.495	2.930	-0.051
900.000		0.503	-2.442	0.069
900.000		0.520	-17.833	0.335
900.000	Spurious counts	0.500 Imp	-0.003	0.005

In Table 1, "Imp" stands for Imposed: when the information of the exposure-meter centroid is not available/trustworthy in the fits files, we impose it to be equal to the mid-exposure value.

We found that in 5 out of 15 exposures of KP32 where the information of the centroid is available, this is not trustworthy due to some unreliable level of counts in the exposure-meter; this 30% of probability of implausible counts is maybe the reason why the pipeline does not take into account this information up to now.

The differences found in both time and radial velocities between mid-exposure and exposure-meter centroid are, in some cases, important.

For the observations where the information of the exposure-meter centroid is available and trustworthy in the fits files, we are able to insert it in the analysis, for a more precise estimation of the RVs of the target.

4.1 Influence of the proper motion of stars in the BERV calculation

Given the fact that, for the target AST01, the information of the proper motion of the star was not always inserted in the Observing Blocks, we also noted a discrepancy in the RVs between these cases and the data where this information was correctly used. The discrepancy in the BERV estimation for this target, with/without the information of proper motion, is of about 80-90 cm/s. It is then important, in order to have a homogeneous set of data, to always use a correct information of the proper motion of stars in the Observing Blocks, because this value is used for the estimation of the BERV and can have a significative influence on the RV measurements, especially for high proper motion stars.

5. CONCLUSIONS

Studying the co-added spectra of the target AST01, we noted that the HARPS-N pipeline takes as the time of reference for each spectrum the mid-exposure time. We then developed a tool that can take into account the information of the exposure-meter centroid present in the fits files (after passing a confidence test), correcting by consequence for the BERV relative to the new time of reference of each exposure.
Comparing our tool with the pipeline, we noted a strange behaviour of the BERV calculation by the pipeline, with small jumps of about 2-3 cm/s every ~6 minutes, that at the moment has an unknown reason and is still under investigation.
The corrections that can derive by the use of the exposure-meter centroid information can be in some cases important: we showed that the difference in RV between the mid-exposure time and the exposure-meter centroid time can be up to 90 cm/s.