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Asteroids as wavelength calibration standards for the radial velocity spectrograph of the GAIA mission

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Abstract

Availability of wavelength calibration standards for the GAIA radial velocity spectrograph is briefly reviewed. It turns out that more objects with accurately known radial velocities are desirable and asteroids are proposed as a possible solution. Their advantages include exact knowledge of their radial velocities, suitable spectrum properties and a reasonably large number of these objects. Unfortunately they are not uniformly distributed across the sky and can have smeared spectra due to a rapid transverse motion. It is argued that some observations of sample objects, which are planned for the near future, are urgently needed.

1 Status of stellar radial velocity standards

The Radial Velocity Spectrograph (RVS) of the GAIA mission is a self-calibrated instrument. Spectra collected during the mission are used to calibrate the wavelength scale of the instrument. The spectrograph will operate in a very stable environment; however a significant number of objects with accurately known radial velocities is desirable to assess the zero-point and to map any temporal drift. The choice can be stars with well-known, stable radial velocities, and - as proposed in this report - serendipitious observations of asteroids.

1.1 IAU standard stars

The IAU Commission 30 "Radial Velocities" has defined a list of standard stars, with accurate velocities constant over many years, available on the web site: http://obswww.unige.ch/∼udry/std/std.html

It contains in all 140 stars, 37 of them with an accuracy better than 50 m/s and 70 other better than 300 m/s. All but one are brighter than V=9, and 0.4 ≤B-V ≤ 1.7. They cover both hemispheres, but are more numerous in the North than in the South. As they are not very numerous and probably too bright, it was felt that more reference objects had to be found.

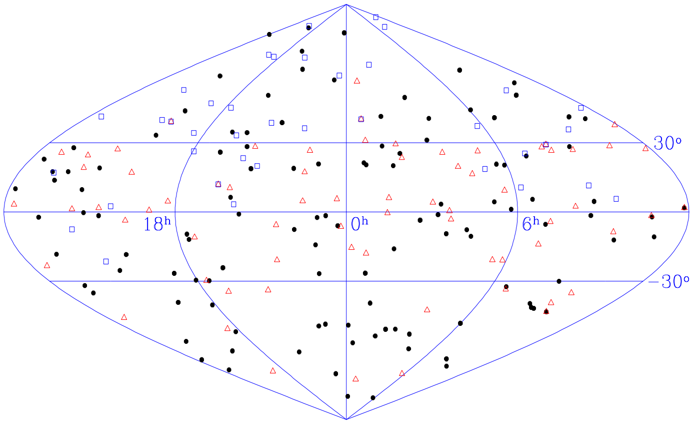


Figure 1.
IAU radial velocity standards with an accuracy better than 50 m s^{-1} (blue squares), those with an error up to 300 m s^{-1} (red triangles), and stars searched for planets (black points) in equatorial coordinates.

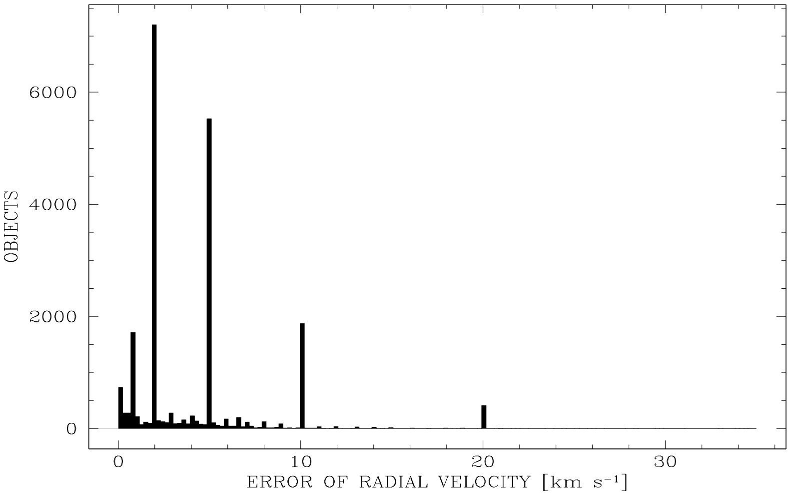


Figure 2.
Histogram of RV errors of Hipparcos stars as reported in the Simbad database. 21 710 objects have velocity errors $\leq$ 20 km s^{-1}, but only 700 within 0.23 km s^{-1}. Note that most errors should have been estimated by eye, demonstrated by large numbers of objects with reported velocity errors of 1, 2, 5, 10, and 20 km s^{-1}. Such rounded errors indicate only a general accuracy class and not the actual error velues.

1.2 Stars searched for planetary companions

Another source of RV standards could be the results of the RV planetary search programs. All these stars were searched for radial velocity variations at extreme accuracy levels. So even the ones that turned out to have planetary companions are well suited for use as RV standards for the GAIA spectrograph. Schneider (2003, Extrasolar Encyclopedia, http://www.obspm.fr/encycl/encycl.html) lists 121 such stars.

1.3 Other available lists or catalogues of RV

In the SIMBAD data base, about 45000 stars have a radial velocity in the "fundamantal data". But the origins and accuracies are highly heterogeneous; a RV measured once or even twice offers no warranty at all against possible wobbles or long-term trends.

As an example, we performed a Simbad search for RVs for the stars of the HIPPARCOS catalogue (note that the systematic measurements made in the 90's for the Hipparcos stars are still unpublished: about 20 000 stars of typies FGKM, with at least two coherent values separated by at least 1 year, mainly observed at the La Silla with Coravel).

21962 HIP stars have a RV quoted in SIMBAD (as of 8 sept-2003); however, even if the errors quoted are small, they cannot be used as standards, as long as the measurements don't cover a long time-period. A histogram of the errors is given in Fig. 2. Situation is far from a satisfactory one. Most radial velocities are rather uncertain and most errors are just estimates of the general quality class. Only 700 objects have errors smaller than 0.23 km s^{-1}. Figure 3 gives their positions in Galactic coordinates and the breakdown of their spectral types.

The Barbier-Brossat & Figon (2000, A& AS, 142, 217) catalogue of RV available at CDS contains 36145 stars, 12300 of them with an error below 5 km s^{-1} and 5100 below 1 km s^{-1}; 23 800 are fainter than $V = 7$, and 10 800 fainter than $V = 9$; many of these RV's are found in the HIP star list quoted above.

1.4 Importance of the saturation level

Some of the well-measured IAU standard stars may not be accessible to GAIA because of the saturation limit of the spectrograph's ADC converters. If the saturation limit is kept at $V = 7$, as currently planned, 91 IAU standards would be lost and only 35 would remain accessible to observation. Similarly only 52 out of 119 stars that were searched for planets are fainter than $V = 7$.

If the saturation limit comes to $V = 9$, the loss becomes very significant: all IAU standards are lost and all but 5 stars searched for planets would be too bright to observe.

We conclude that even if the still unpublished values for the HIP stars become publicly available, many problems remain. Defining new standard stars requires years of careful observations, taking into account spots, activity, or membership in a binary system.

Therefore we propose asteroids as a possible alternative for wavelength calibration. Their main advantage is that radial velocity information of sufficient accuracy is easily available.

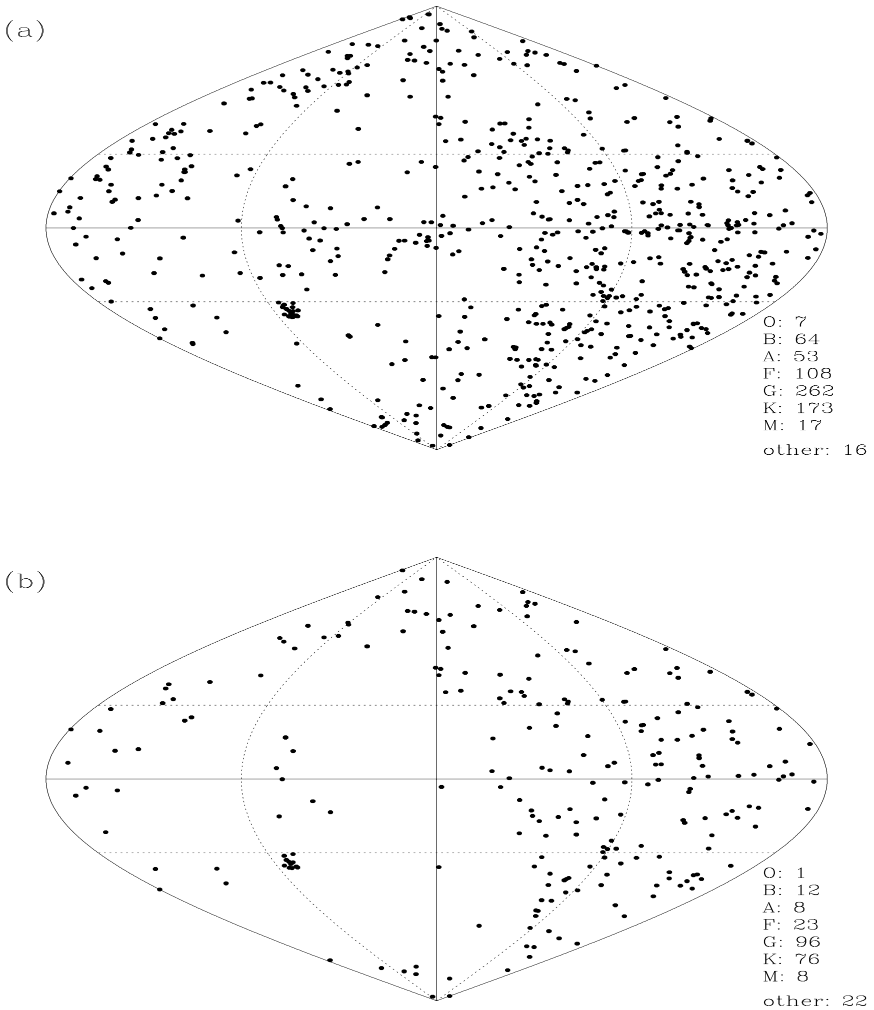


Figure 3.
(*a*) Distribution of the 700 Hipparcos stars that have RV errors smaller than 0.23 km s^{-1} in Galactic coordinates. Numbers of stars with given spectral types are reported at far right. (*b*) As the upper panel, but only 245 stars fainter than $V = 9.0$ are plotted. This demonstrates importance of keeping the saturation limits of the GAIA RVS ADC converters at sufficiently bright levels.

2 General properties of asteroid spectra

Spectra of asteroids are mainly reflected sunlight with some added features intrinsic to a given asteroid. The latter manifest themselves through variation of albedo with wavelength (Fig. 4) and can be variable in time (Fig. 5). They are not thought to contain any sharp spectral lines (D. Hestroffer 2003, private communication). The spectra are quite blue (Fig. 6).

Figure 4.
Representative mineral spectra of asteroids in the near IR domain. There is no evidence of intrinsic sharp lines in the GAIA wavelength domain (848–875 nm). Adapted from the NEAR's NIS fact sheet http://near.jhuapl.edu/ fact_sheets/NIS.pdf

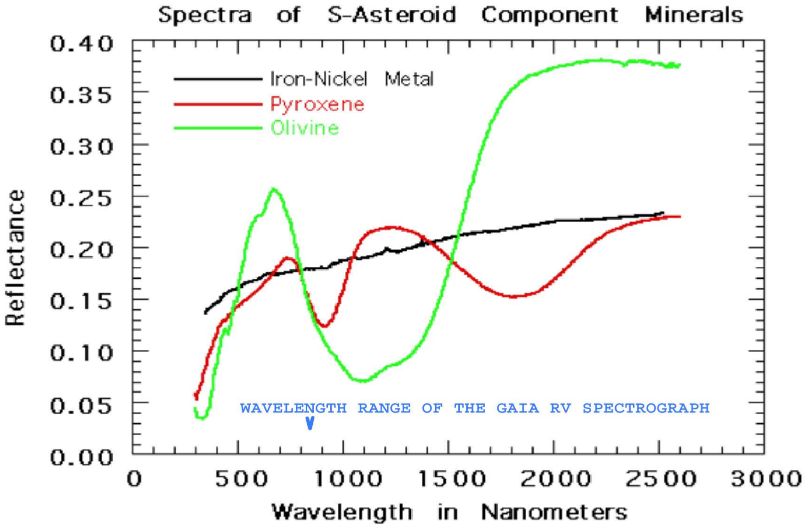
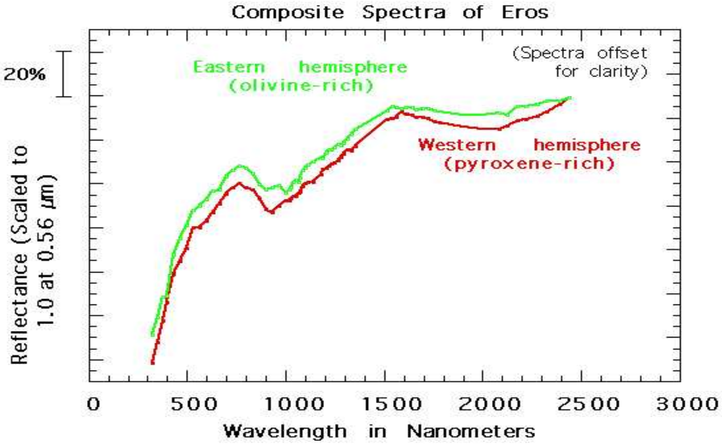


Figure 5.
Time variability of the spectrum of Eros. Adapted from the NEAR's NIS fact sheet http://near.jhuapl.edu/ fact_sheets/NIS.pdf



Reflected sunlight in the GAIA spectrograph wavelength domain is rich in spectral lines. The most prominent are the lines of Ca II triplet and numerous Fe lines (see Fig. 3 in Munari 1999, Balt. A. 8, 73). These reflected lines are Doppler shifted due to relative motions of the asteroid, Sun and the GAIA satellite. But these motions are accurately known. Most asteroids have been observed during many (~ 30) oppositions so that their positions are known to within 1 arcsec for several years in advance. Assuming a typical space motion of ~ 30 arcsec hour^{-1} this corresponds to a time error of only 120 sec. The radial velocity of an asteroid changes by ~ 30 km s^{-1} in 3 months or 0.5 m s^{-1} in 120 s. So we may conclude that Doppler motion corrections are known to within 1 m s^{-1}. Rotation of an asteroid coupled with a changing surface brightness could change the measured radial velocity. But this effect is negligible because asteroids with a size of a few km and with a rotational period of a few hours have rotational velocities at an 1 m s^{-1} level. We conclude that radial motions of asteroids are known with an adequate accuracy for wavelength calibration purposes.

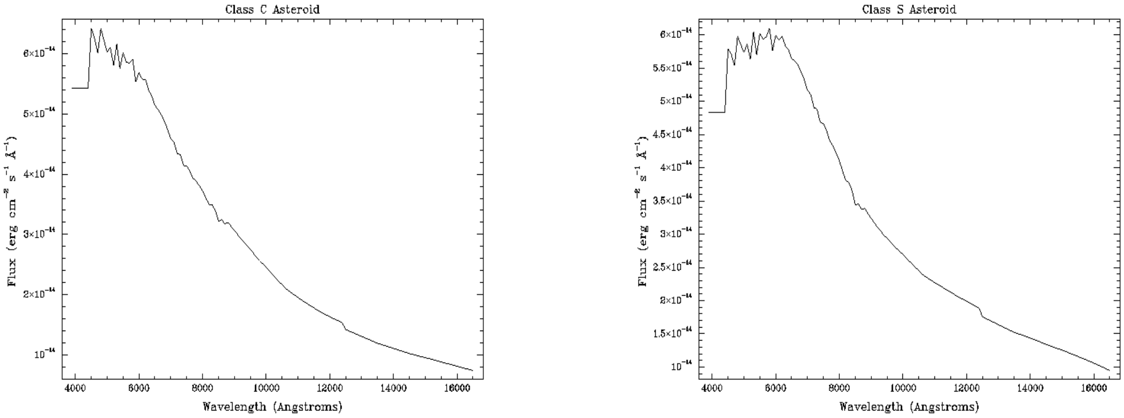


Figure 6.
Spectra of C and S type asteroids. Note their blue colour. From the HST WFC3 exposure time calculator documentation (http://www.stsci.edu/instruments/wfc3/wfc3_etc_models.html) .

3 Number of asteroids suitable for wavelength calibration

We used the JPL's DASTCOM database (http://ssd.jpl.nasa.gov/cgi-bin/sb_search) to assess the number of suitable asteroids. Figure 7 plots all asteroids brighter than $V = 15$ for 19 September 2003. The plot is in ecliptic coordinates centered on the anti-Sun direction. The spectrograph sweeps a grand circle on the sky every rotation period which equals 6 hours. One can see that the number of observed asteroids does not depend critically on spatial orientation of the satellite's axis. The spectrograph will typically observe $\sim$ 8 asteroids brighter than V=15 in a 6-hour rotation period. A quarter of them (see Fig. 8), i.e. $\sim$ 2 asteroids every 6-hours, will be brighter than magnitude $V = 12.5$, so giving a spectrum with a high signal to noise ratio.

4 Conclusions

IAU radial velocity standards can be used to accurately calibrate the zero point offset of the spectrograph's wavelength scale. These stars are however not numerous enough to map the optical distortions of the spectrograph and to look for any changes during the mission lifetime. Other bright stars with known radial velocity can be used to map those. However one may reasonably expect that some of these stars have not been measured accurately or that they will show unexpected radial velocity changes due to surface outbursts or magnetic activity. The comparative advantage of the use of asteroids is that there cannot be any doubt about the accuracy of their radial velocity. On the other hand a typical proper motion of 30 arcsec per hour implies a spatial smearing of 0.8 arcsec during 100 seconds of integration time of the spectrograph. This smearing can be accurately calculated in advance. Still it marginally widens the spectral tracing (if it is perpendicular to the dispersion direction) or decreases the resolution (if it is along the dispersion direction). Those asteroids with sufficiently small proper motion will manifest themselves as point-like sources in the RVS focal plane, as the RVS spatial resolution is much lower than that of the astro instrument (which will resolve many large bodies). All asteroids (save for some NEARs) will be detected as point sources in the star mapper instrument.

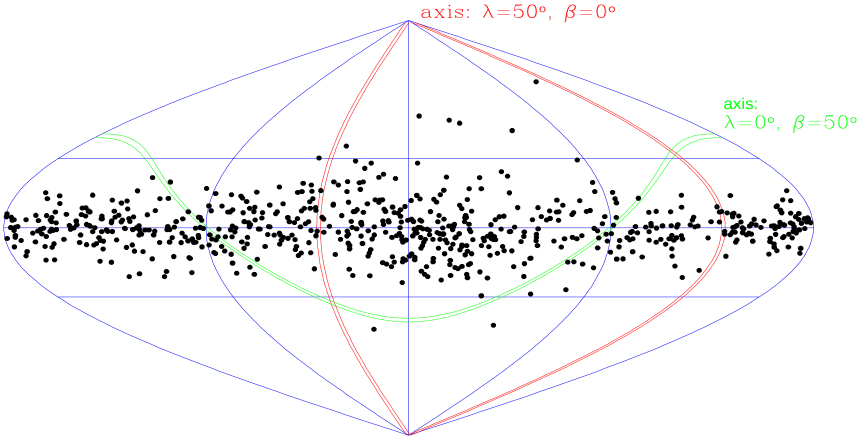


Figure 7.
Asteroids (and comets) brighter than V=15 on 19-sep-2003 at 13h GMT. Plot is in ecliptic coordinates centered on the anti-Sun direction. Coloured lines mark the area covered in one 6-hour rotation of the satellite around its axis. Two extreme cases are plotted: when the satellite axis lies in the ecliptic plane (red) and when it is at the greatest elongation from it (green).

Figure 8.
Magnitude distribution of asteroids and comets brighter than V=15. Only a quarter of the objects are brighter than V=12.5.

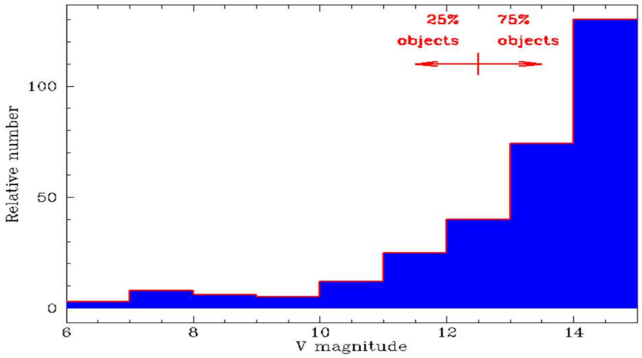


Table 1. Possible sources of wavelength calibration for the GAIA radial velocity spectrograph.

Type of wavelength calibrator	RV error [km s^{-1}]	Adopted magnitude constraint	Number of objects
IAU RV standard stars	≤ 0.3		107
IAU RV standard stars	≤ 0.3	$7.0 < V$	35
Stars searched for planets	≤ 0.05		119
Stars searched for planets	≤ 0.05	$7.0 < V$	52
Asteroids	~ 0.001	$7.0 < V < 15.0$ (a)	~ 600
Asteroids	~ 0.001	$7.0 < V < 12.5$ (a)	~ 150

(a) on a given date.

There appears to be a similar number of suitable asteroids and radial velocity standard stars (Table 1). The advantage of using asteroids lies in our perfect knowledge of their radial velocity, but their spatial motion is a nuisance which degrades the results. So we conclude that both types of objects will need to be observed in order to obtain optimal results.

GAIA covers 1.4% of the whole sky during each 6-hr rotation. So it will typical observe 1 standard star and 2 bright ($V < 12.5$) asteroids each 6 hours.

It appears (D. Hestroffer 2003, private communication) that high resolution observations of asteroids in the GAIA wavelength domain are rare if existing at all. Most observations were obtained in low resolution, studying variations of reflectance in the far red and infrared domains (see Figs. 3 and 4). So we argue that observations of a few sample asteroids in the wavelength range of the GAIA spectrograph are urgently needed to verify the above concepts. Echelle spectrograph of the Asiago observatory is very suitable for this task. We plan to submit a corresponding observing proposal in the near future.