# Software Design Document for CU6 TWP 640 Radial Velocity Zero-point



prepared by: G. Jasniewicz, F. Crifo, D. Katz, A. Siebert, C. Soubiran

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# Abstract

This document concerns with the design of the TWP ”Radial Velocity Zero-point”. The main goal of this TWP is to establish the grid of ground-based reference sources (stars and asteroids) for the radial velocity zero-point of the RVS, to be used by the ”Spectroscopic Global Iterative Solution” software described in the RVS calibration SDD by Huckle et al. (2007). As already mentioned in the associated SRS document, this task is not a real software product under scope of CNES, though it requires the development of a specific database for ground-based observations. The SDD template has been consequently adapted here for reasons of homogeneity between all TWPs of CU6.

# Document History

| Issue | Revision | Date | Author | Comment |
|---|---|---|---|---|
| 1 | 1 | 30-03-2007 | GJ | First draft (cycle 2) |
| 1 | 2 | 05-06-2007 | GJ | Revised document (cycle 2) |

# Contents

# 1 Introduction

## 1.1 Objectives

The RVS having no wavelength calibration device onboard, the Spectroscopic Global Iterative Solution (see RD2) will use a large sample of GAIA-selected reference stars, i.e. qualified as reference based on GAIA observations. These ”well behaved-stars” (bright, RV-stable and of a well-suited spectral type) will allow to iteratively derive the wavelength of the RVS instrument and the RV of the stars in a ”relative” reference frame. The so-called RV-STD stars are stars which have a very stable and accurate RV already known from prior ground-based studies. These RV-STD stars and asteroids (for which celestial mechanics gives a very precise RV) will be used to derive the transformations from SGIS relative reference frame to an absolute reference frame. These transformations are referred to as zero point corrections. Due to a lack of bright asteroids to be observed by RVS, and their peculiar distribution over the sky, the main ground-based reference sources for the RV zero-point will be RV-STD stars. The asteroids however, will be the ultimate references, as the kinematic radial velocity (KRV) can be known with a very high accuracy and in an absolute way, for only these asteroids.
Thus our main objectives are to build a list of ground-based reference stars from existing catalogues of radial velocities and new dedicated ground-based observations, and to check the RV measurements of these RV-STD stars with those of asteroids. An ad-hoc database will also be built for an easy use and verification of the data obtained with different ground-based instruments, as well as for permitting the exchange of data and information through the GAIA community.
A secondary objective is to determine KRV of stars from their SRV taking into account astrophysical corrections (gravitationnal redshift, convective blueshift).

## 1.2 Scope

The list of RV-STD stars (objective of WP-S-640-03000) will evolve with time and its content will be ultimately confirmed only at the end of the mission. Thus the design given here for cycle 2 will be refined in next cycles.
The list of asteroids (objective of WP-S-640-04000) will depend on the date of the launch and ephemeris. Simulation of data and spectroscopic observations of asteroids are in progress.
The software module ”Astrophysical zero-point” (WP-S-640-05000) will be run using all useful information from photometry, spectroscopy (RVS) and astrometry.

Taking into account the scope of this TWP, the present SDD is composed of five main parts:

- list of RV-STD stars (§2)

- ground-based observations (§3)
- database for CU6 & CU8 (§4)
- list for reference sources : asteroids (§5)
- software module : astrophysical zero-point (§6)

## 1.3 Applicable Documents

AD1 : GAIA-C1-SP-CNES–TL-001
Product assurance and engineering provisions for software development

AD2 : GAIA-C6-SP-OPM-DK-003-2
CU6 Software Development Plan

## 1.4 Reference Documents

RD1 : GAIA-C6-SP-UM2-GJ-001-1
Software Requirements Specification, Radial Velocity Zero-point

RD2 : GAIA-C6-TN-OPM-AG-001-01
Prototype of the spectroscopic global iterative solution

RD3 : GAIA-C6-SP-OPM-PS-002-1
Simulation Requirements for spectroscopic processing for cycle 2

## 1.5 Definitions, acronyms, and abbreviations

For all functional requirements used in this document, the constant prefix CU6-WP640-S will be omitted.

AIP :Astrophysikalisches Institut Postdam ASU : Astronomical Server URL (see http://cdsweb.u-strasbg.fr/doc/asu.html)
BVC : Barycentric Velocity Correction
HR : Hertzsprung-Russell KRV : Kinematic Radial Velocity
RV : Spectroscopic Radial velocity (see also SRV)
RVS : Radial Velocity Spectrometer
SGIS : Spectroscopic Global Iterative Solution
SRV : Spectroscopic Radial velocity

STD : Standard
TBD : To Be Defined

# 2 List of RV-STD stars

The selection criteria for the list of RV-STD stars are coming from the functional requirements given in the SRS document (see RD1).

- 1 : RV-STD stars are sufficiently numerous so that the SGIS software converges (FUNC-3000-20)
- 2 : RV-STD stars verify some physical properties from the HIPPARCOS catalogue (FUNC-3000-30)
- 3 : Brightness of RV-STD stars guarantees high S/N for RVS spectra (FUNC-3000-40)
- 4 : RV-STD are RV-stable (FUNC-3000-60)
- 5 : RV Measurements of RV-STD stars are numerous and of good quality (FUNC-3000-50)
- 6 : RV-STD stars cover properly the sky (FUNC-3000-10)
- 7 : Spectra of RV-STD stars are not contaminated by neighbours (FUNC-3000-70)

For the sake of homogeneity, we estimate that the candidate RV-STD stars should belong:

- to only a FEW recent lists of well-observed stars with RV;
- and to a subset of the HIPPARCOS Catalogue, to check properties on photometry, spectral type, variability, some multiplicity, etc.... The present HIP subset is called ”gaia6”.

Up to now, the selected RV lists are:

- ”The Geneva-Copenhagen Survey of Solar neighbourhood”, by Nordstrom et al, 2004, Astron. Astrophys. 419, 989, where the RVs are mainly obtained from the CORAVEL telescopes (N and S);
- ”Radial velocities for 6691 K and M giants” , by Famaey et al, 2005, Astron. Astrophys. 430, 165, where the RVs are all obtained from the Northern CORAVEL;
- ”Radial velocities of 889 late-type stars”, by Nidever et al, 2002, Astrophys. J. Suppl. Ser. 141, 503, where the RVs are obtained from the HIRES echelle spectrometer on the KECK1 telescope, and from the Hamilton echelle spectrometer fed by either the 3m Shane or the 0.6m CAT at Lick.

A selection within these RV lists, and intersection with ”gaia6”, produces the provisional list ”faninor4”, used for plotting Figures 1, 2 and 3.

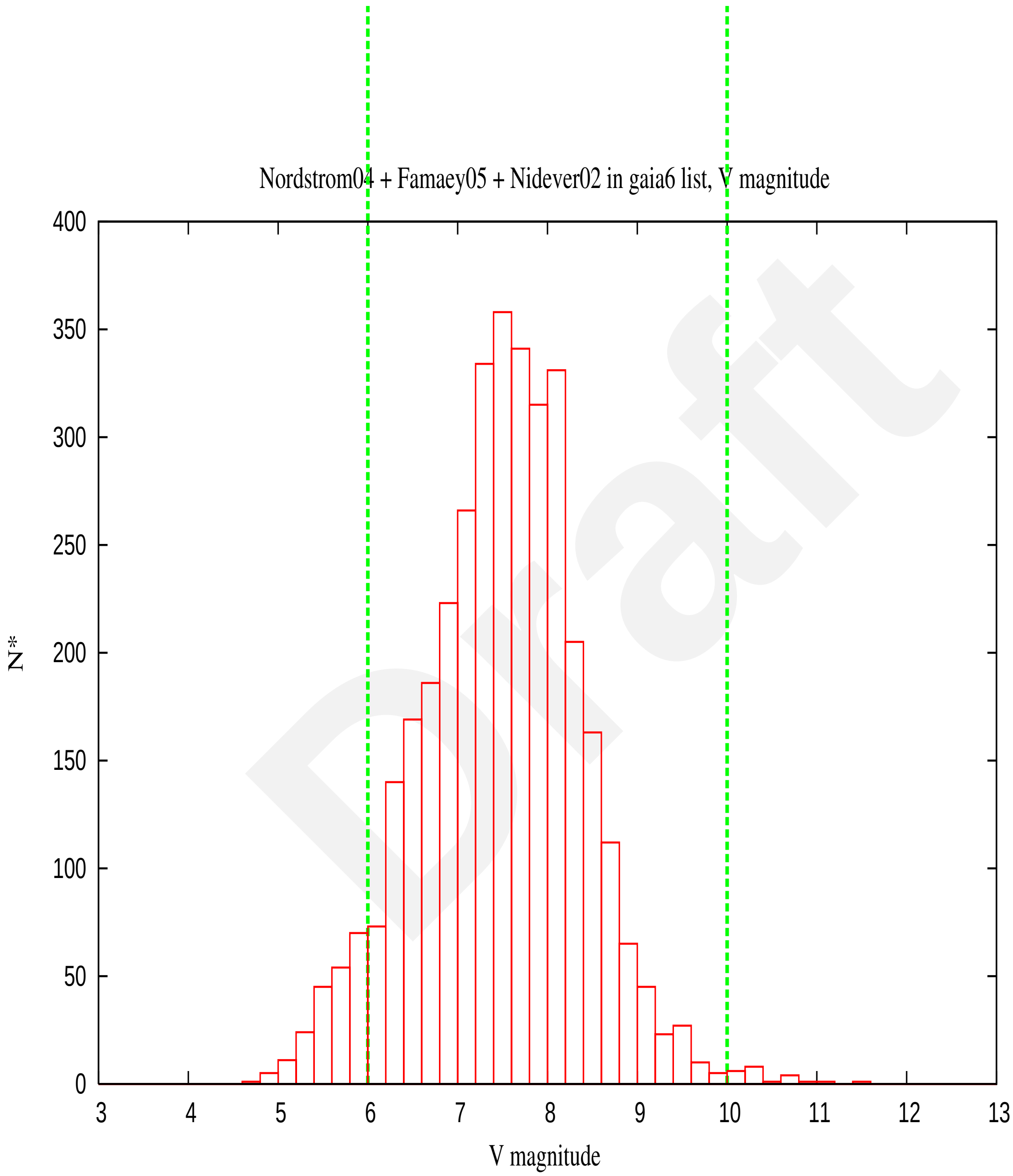


Figure 1: Histogram according to magnitude of the faninor4 sample.

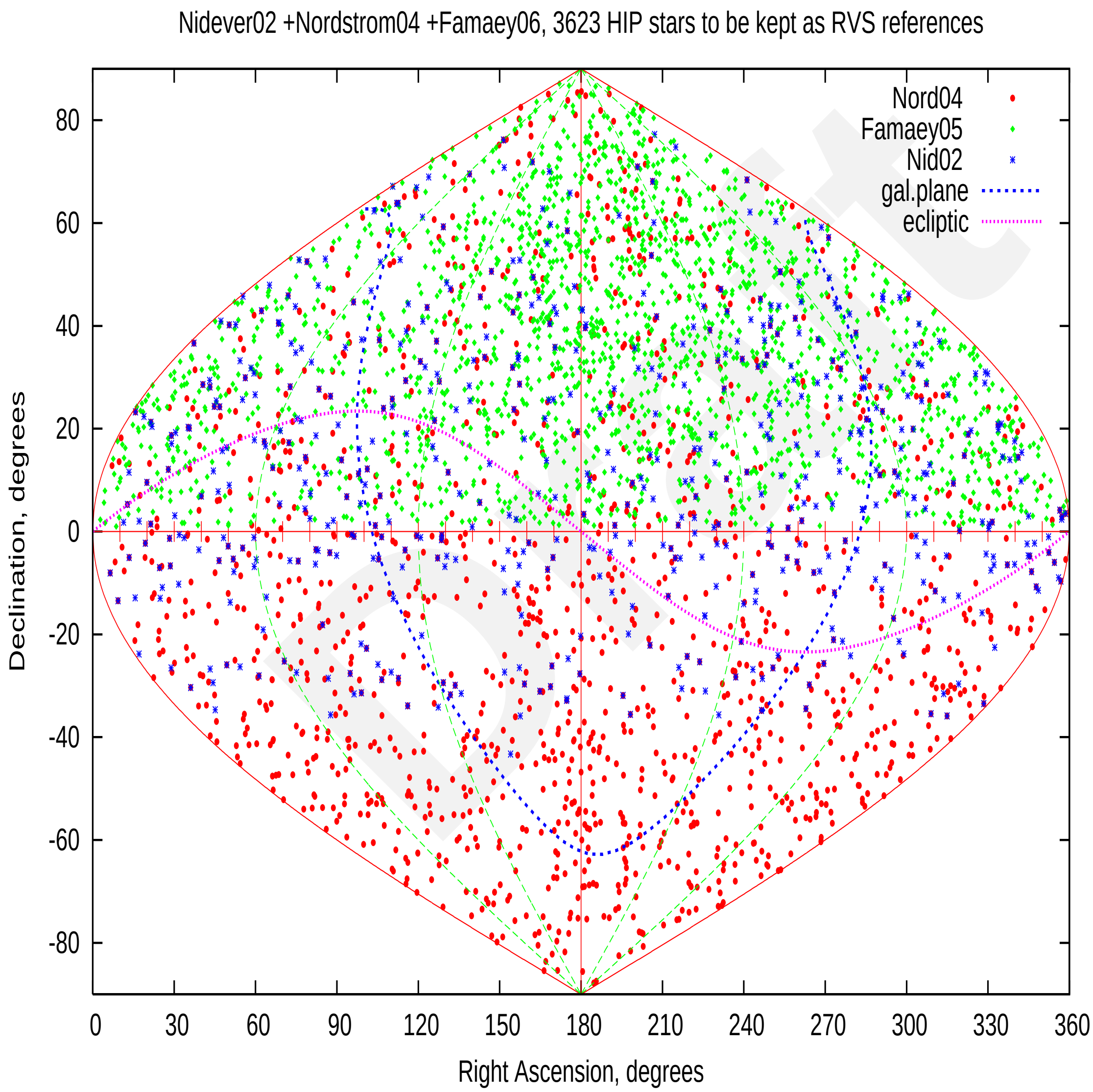


Figure 2: Coverage of the sky by the faninor4 sample.

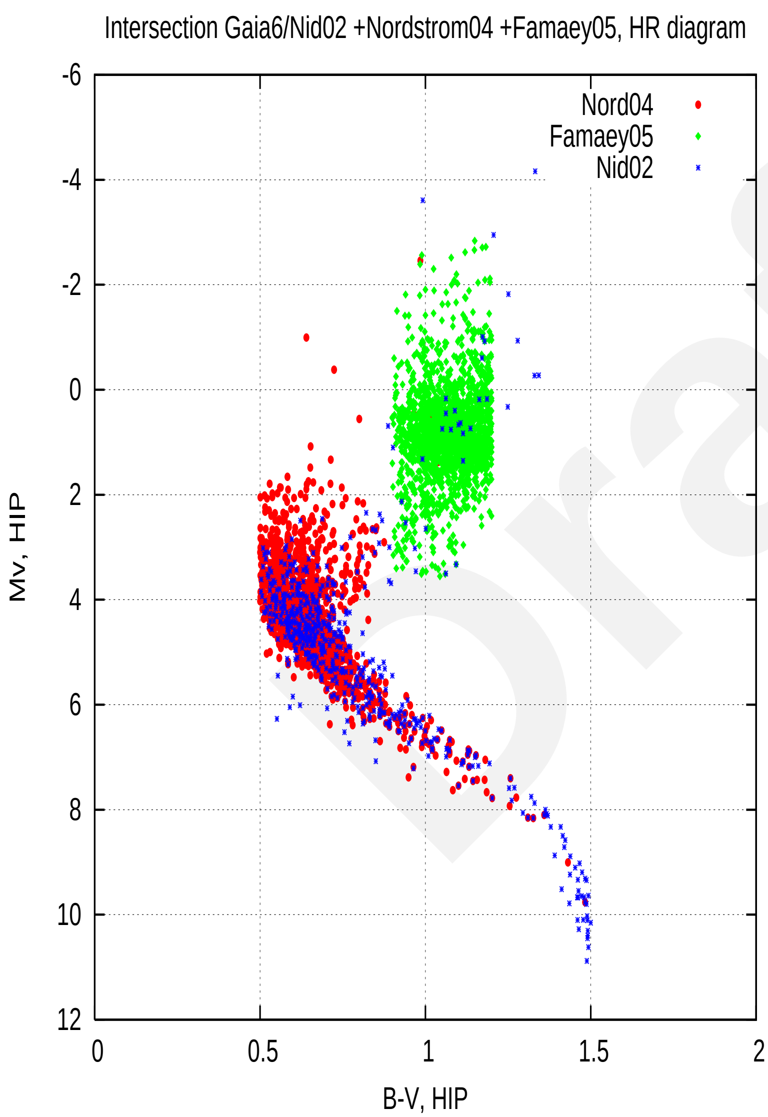


Figure 3: The HR diagram for the faninor4 sample.

## 2.1 Design to requirement traceability

FUNC-3000-10 : PC ; see §2.7
FUNC-3000-20 : PC ; see §2.2
FUNC-3000-30 : C ; see §2.3
FUNC-3000-40 : PC ; see §2.4
FUNC-3000-50 : PC ; see §2.6
FUNC-3000-60 : PC ; see §2.5
FUNC-3000-70 : PC ; see §2.8

## 2.2 Number of stars

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-20 | PC | Density of the reference stars in the sky coverage: TBD (thus total number of reference stars : TBD) |

In order to ensure the convergence of the SGIS software, there must be a nominal number of RV-STD stars. This number will be derived later from simulations carried out within CU6 ; it is presently estimated to be about 1000.
Some RV-STD candidate stars could prove to be RV-variable with time. We have estimated that the worst percentage of reject would be 50% in the initial list. Therefore, the provisional list should contain about 2000 RV-STD stars, or 1000 per hemisphere, before final selection through new observations.

## 2.3 Physical properties

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-30 | C | The reference stars belong to the HIPPARCOS catalogue ; they have a late-type spectral type and are not known as photometric variables nor as binaries. |

The selected HIPPARCOS stars (provisional "gaia6" list) verify the following properties :

- Spectral type F5-G-K (HIP field H76), in order to select only stars with a lot of lines in the RVS wavelength range. Among them giant stars with $0.9 < \mathrm{B} - \mathrm{V} < 1.2$ (corresponding to G8III-K2III stars in the giant clump) are especially interesting due to the RV-stability criteria by Bizyaev et al. (2006, AJ131,1784) and Hekker et

al. (2006, A&A 454,943).
M dwarfs have also been selected, though molecular bands could alterate the precision of their SRV.

- No variability (due to pulsation, rotating spots, etc): constant or microvariable in HIP (HIP field H52); and error on magnitude $\leq 0.1$.
- Not double/multiple (HIP fields H2, H43, H58, H64).

## 2.4 Brightness

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-40 | PC | $6 \leq V; G_{\mathrm{RVS}} \leq 10$ |

The histogram concerning the distribution of magnitudes in faninor4 is given in Fig.1. Criterion on brightness could be modified if necessary in next cycles (for the red stars for instance).

The calculation of $G_{\mathrm{RVS}}$ is made by the transformation formulae given in the GAIA Parameter Database using the HIP values of V and V-I, although it has been shown by Platais et al. (2003, A&A 397,997) that the HIP values of V-I are slightly wrong.

## 2.5 RV-stability

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-60 | PC | RV-stability : $\sigma(\mathrm{RV}) < 300\,\mathrm{ms}^{-1}$ (no high RV-variations due to binarity, pulsation, etc...) ; $\sigma$ being the standard deviation of measurements. |

Expected accuracy for the RV to be obtained with the RVS should be at the best $1\,\mathrm{kms}^{-1}$ (see RVS WG, Katz & Crifo, etc...). Taking into account the new value of the number of RV-STD candidates (see §2.3), this criterion could become more severe (say $\sigma(\mathrm{RV}) < 100\,\mathrm{ms}^{-1}$) for some stars in cycle 3.
The number of measurements should be at least 2.

## 2.6 Observational history

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-50 | PC | ”Good” observationnal history (spectra with a high S/N, high number of measurements, time span of observations of several years). |

The presently selected RV-STD candidates have all been observed already at least twice before 2004. This is however not enough for insuring good stability and no drift until the end of mission (2017). In particular, high-eccentricity or long-period binaries may not have been fully detected and eliminated. Consequently, new additional ground-based observations have to be performed in order to statistically avoid such binaries. According to S. Udry (private communication), each candidate star must have before launch at least 3 observations spanning over a time interval of at least 10 years.

## 2.7 Coverage of the sky

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-10 | PC | Sky coverage of the reference stars : as uniform as possible, and with no ”holes”. |

Stars belonging to the provisional file ”faninor4” are plotted in Fig.2 (sky distribution) and Fig.3 (HR-diagram per list). The northern hemisphere is better covered by ”faninor4” than the southern one. According to §2.3 a list of 1000 RV-STD candidates is desirable for each hemisphere. The ”faninor4” list having 1016 stars in the south, and some 2600 in the north, further selection is allowed in the north. However, as the southern hemisphere lacks of good giants, some more southern star lists should be examined (the Famaey stars are all in the northern hemisphere).
Fig.2 exhibits a ”hole”, near coordinates ($\alpha = 140, \delta = -20$): is it a problem ? (this question will be put to concerned colleagues at the CU6 Workshop 3, London, 21-23 May 2007).

## 2.8 Overlap of spectra

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-70 | PC | For each RV-STD star : absence of neighbours ($\Delta m \leq 5$) within a 70” radius in the sky (their spectra could contaminate the reference source spectrum). |

Due to the windowing of the RVS CCDs and to the extension of the spectra in the AL direction, some spectra may overlap. RV-STD spectra should not be contaminated by neighbours, whatever the orientation of the scan can be (Here we don't try to estimate the pertubation produced by the stars belonging to the conjugate field, which should be more randomly distributed.)
The acceptable magnitude difference and angular distance of neighbours relative to each RV-STD are under study and should be available in cycle 3. Present work (cycle 2) is concerned with :

- Systematic search for disturbing neighbours around the faninor4 stars (magnitude difference presently taken at $\Delta m \leq 5$) within a 70" radius on the sky using the USNO-B1 catalogue (a spectrum is 62 arc-sec long).
- Study of composite spectra in combining two synthetic spectra with different spectral types, relative fluxes and S/N ratios.

# 3 Ground-based observations

## 3.1 Design to requirement traceability

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-80 | C | Ground-based observations have to be made before the launch and during the mission in order to guarantee the RV-stability (see FUNC-3000-60) of the reference stars. |

## 3.2 Instruments

The aim of the ground-based observations is to qualify as RV-STD the candidates selected following the seven criteria described in §2. New measurements of their RV, with high resolution echelle spectrographs, make it possible to verify their long term stability. Four instruments are forseen : SOPHIE at OHP, NARVAL at Pic du Midi, CORALIE Swiss facility at La Silla Observatory, FEROS at ESO La Silla.

The echelle spectrographs NARVAL and FEROS have been selected because they include in their spectral range the RVS interval 847-874 nm from which we will study possible systematic effects between the radial velocity measured from the full optical range and the RVS range. These 2 echelle spectrographs are the only ones which fullfil our requirements :

- easy access for the european community
- 2-meter class telescopes (our candidates are bright, V $\leq$ 10, and do not require larger telescopes)
- suitable for accurate RV measurements
- include the RVS range
- one in the North, one in the South to achieve the sky coverage

However FEROS is in question because of a gap in its wavelength range (853.4nm to 854.1nm) on Ca line of the RVS range which compromises the forseen tests.

The proposal on NARVAL for the first 2007 semester has failed, but a new proposal will be applied for semester 2007B.

Nine nights on SOPHIE have been obtained. On average 40-50 RV measurements can be realized per clear night.

A Memory Of Understanding is being negotiated with the Geneva Observatory (M. Mayor & S. Udry) to obtain 3 nights per semester on CORALIE.

Several asteroids and IAU standards are systematically observed with the candidates to check the consistency between the different instruments and to set the zero-point scale. In order to obtain a final grid of 1000 RV-STD, a larger number of candidates has to be observed. The exact number depends on the rate of rejection that we will have to face. We start with candidates that have already an observational history. The constitution of the ”faninor4” list, as explained above (§2.1), is aimed at providing the best observing list. We estimate that at least 2000 stars should be followed-up to obtain a reliable grid of 1250 stars before launch and a final number of 1000 stable stars at the end of the mission. Frederic Arenou is making simulations to estimate the rate of undetected binaries in our list of candidates.

Depending on the observational history of the candidates, one or several observations should be done.

## 3.3 Status of observations

A first run on ELODIE took place in Febuary 2006, but with very poor weather conditions that did not allow us to obtain a sufficient number of spectra with good S/N ratio. The lesson learned from this run is that we need a S/N (at 550 nm) of at least 20 to measure precise RV.

Our first run on SOPHIE took place in November 2006 for 5 nights. The weather was good for about half of the time and we could obtain 122 spectra :
- 11 IAU standards
- 24 asteroids
- 89 reference star candidates (29 from the Nidever's list, 60 from the Famaey's list).

The S/N ratios are very good (50 on average) and according to the typical exposure times needed for our targets, we know now that we can count on 50 spectra at least per (good) night.

We made various comparisons of RV obtained from SOPHIE, ELODIE (archive) and those published in the reference catalogues : IAU standards, Nordstrom and Famaey catalogues (CORAVEL), Nidever catalogue. We found an offset between the RV system of SOPHIE and ELODIE (120 m/s) which has to be modeled. We also learned that CORAVEL measurements have a precision of several 100 m/s. Consequently, the IAU standards that we use to set the zero-point from one run to another have to be selected in the ELODIE list, not in the CORAVEL one. Moreover, our reference star candidates from Nordstrom and Famaey catalogues have to be carefully selected regarding to their observational history and dispersion of CORAVEL RV.

# 4 Database for CU6 & CU8

Data associated with the ground-based reference stars, either from the literature or from our dedicated ground-based observations, will be integrated in a dynamical database according to criteria of RV-stability. Required for both CU6 & CU8, the database is aimed at storing both the astrophysical parameters (CU8) and the radial velocities (CU6) from ground-based observations for a large number of reference stars that will be observed during the mission. Stars with the requested properties (stability over several years for RV-STD stars) will thus be easily selected from the database and used for calibration purposes. The database consists of a set of four tables which can be accessed and updated via a web interface, plus a local disk storage (functional requirements are those given in the SRS document, see AD1):

- Basic Data Table : stores external information, i.e not linked to CU6 or CU8 observations, on the objects (FUNC-3000-100).
- RV measurements Table : stores radial velocities and associated quantities/description to assess the radial velocity stability (FUNC-3000-400).
- Stellar parameters measurement Table : stores measured stellar parameters for a given observation (FUNC-3000-500).
- Observation Table : contains a full description of the observation and associated spectra (FUNC-3000-300).
- Calibrated ground-based spectra will be stored in a local disk storage (FUNC-3000-200)
- The database can be accessed using a web-application (FUNC-3000-600)

See Fig. 4.

## 4.1 Design to requirement traceability

FUNC-3000-100 : PC ; see §4.2
FUNC-3000-200 : NC ; see §4.6
FUNC-3000-300 : NC ; see §4.5
FUNC-3000-400 : NC ; see §4.3
FUNC-3000-500 : NC ; see §4.4
FUNC-3000-600 : C ; see §4.7

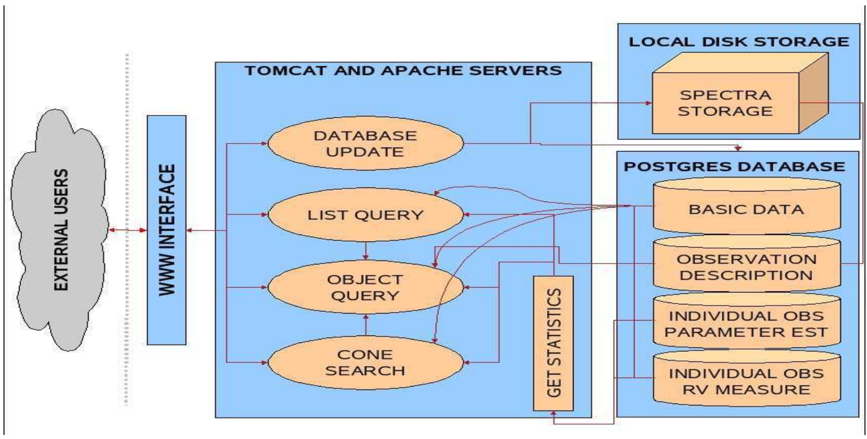


Figure 4: Structure of the CU6 & CU8 external database and interface. The database consists of four tables containing the description of the objects, radial velocity measurements, stellar parameters measurements and description of the observation. A web interface hosted at the AIP enables to query and update the database.

## 4.2 Basic data

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-100 | PC | The database will store basic data for stars extracted from literature and other databases. |

These basic data are well defined (see below), but not yet stored for each RV-STD candidate.

The *Basic Data* Table stores the following data (1 line per object):

- Identifiers : Hipparcos, 2MASS, HD, UCAC2 (primary identifiers) BD, CPD, Tycho-2 (secondary identifiers)
- Photometry : B, V, I from Hipparcos (but other sources can be used for updates) J, H, K from 2MASS with associated errors and photometric flag, $G_{RVS}$ (TBD).
- Astrometry : proper motions (J2000), associated errors and source parallaxe from Hipparcos or other sources, position (RA, DE) in degrees J2000
- Spectral classification
- Variability

## 4.3 RV measurements

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-400 | NC | The external database will store RV measurements (old and new) and associated quantities for CU6. |

The *RV measurements* Table, not yet implemented, will store the following data (1 line per measurement):

- Identifiers (both primary and secondary, see above)
- radial velocity (km/s)

- associated error (km/s)
- method used (to select from a drop down-list in the web interface)
- observation date (Julian date)
- instrument used
- resolution of the instrument when indicated.

(The last three columns are used to define uniquely an observation).

## 4.4 Stellar parameters measurements

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-500 | NC | The database will store stellar parameters measurements for CU8. |

This work is in progress within CU8. The *Stellar parameters measurement* Table will store (1 line per measurement):

- measured stellar parameters for a given observation.
- Identifiers (both primary and secondary)
- Stellar parameters : $T_{\rm eff}$, $\log g$, [M/H], [alpha/Fe], V$\sin i$ (km/s)
- associated errors
- method used to calculate the parameter (one per parameter from a drop-down list)
- observation date (Julian date)
- instrument used
- resolution of the instrument.

(The last three columns of the table are used to describe uniquely an observation. As stellar parameters can also be obtained from pure photometric methods, those fields can be empty for a given measurement.)

## 4.5 Observations

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-300 | NC | The external database will store full description of observations and associated spectra. |

The *Observation* table will be implemented in cycle 3. It will contain a full description of the observation and associated spectra (1 line per observation).

## 4.6 Spectra storage

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-200 | NC | The database will store spectra from dedicated ground-based observations for CU6 & CU8, before and during the GAIA mission. |

Spectra are not yet stored. There will be calibrated ground-based spectra in the database, but also raw spectra with associated calibration files and useful data (name and version of software used for processing spectra).

## 4.7 WEB interface

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-3000-600 | C | The external database will be reachable through a Web interface. |

The database can be accessed using a web-application hosted by the *Astrophysical Institute Postdam*. Its URL is : http://gaia.aip.de/cu6a8
The access is password protected for security as database update features are available in the web-application ; it is presently restricted to four people : F. Crifo, G. Jasniewicz, A. Siebert & C. Soubiran.

Fig. 4 presents the main feature of the web interface which belongs to two categories : query procedures and update procedures.

- Query procedures

  So far the query procedure allows to query from a standard Vizier-like interface the basic data catalogue (QUERY DATABASE interface) ; see Fig. 5. Query can be performed using identifiers, position, parallaxes or magnitudes. The constraints must comply to the ASU syntax (apropriate link is provided from the web interface). The interface returns a list of objects matching the given criteria. This list contains the basic parameters and simple statistics on the measured quantities (mean radial velocity, standard deviation etc.).

From the result page, access to the full description of a given object is provided. This page, generated on the fly, contains the current status of the database and presents a summary of all the measurements for the given object. Tables are provided for each separate quantity (radial velocity, effective temperature, gravity, metallicity, rotational velocity and alpha enhancement). Graphics presenting the evolution with time and/or method for each quantity are also provided.

- Update procedures

  Two type of update facilities are provided by the web interface. Security measures to avoid duplicates in the tables are incorporated but the user is advised to verify the existence of an object prior to the updates

  First a standard update interface (UPDATE DATABASE) enables the users to modify or complement the basic data for a given object, and it also enables the user to add new measurements (either radial velocities or stellar parameters) ; see Fig. 6. This procedure requires the object to exist in the database (test on the primary identifiers).

  A second interface (ADD NEW DATA) allows to add new objects to the basic data table. The current version of the catalogue contains data from the gaia6 catalogue described above (§4, criterion 2) as well as the cross-identification of this catalogue with other sources (see description of the basic data table). The final list of possible reference stars is not yet stabilized and it will evolve from the current catalogue hence this facility (for example to include giants).

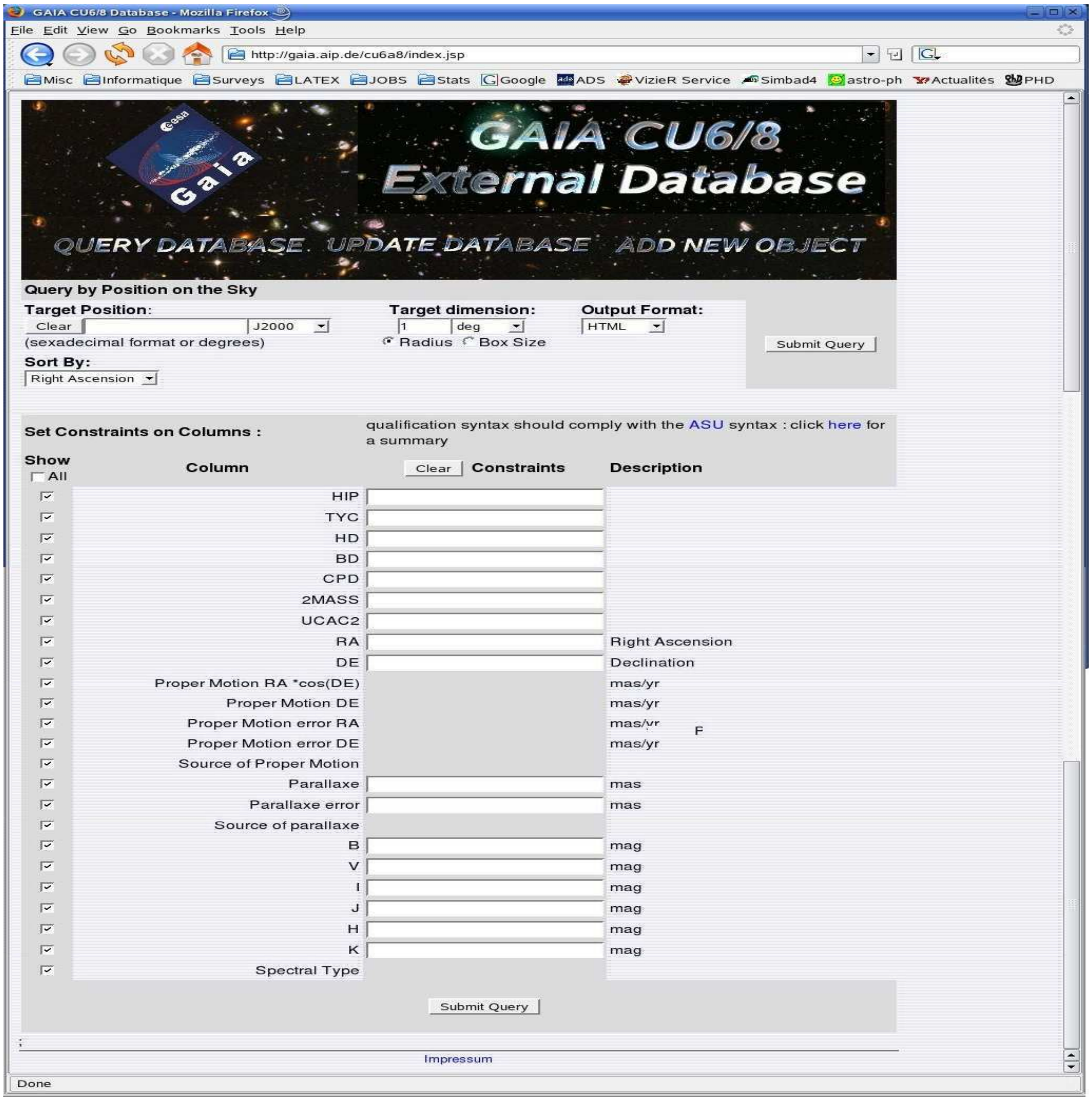

Figure 5: Query form of the CU6 & CU8 external database.

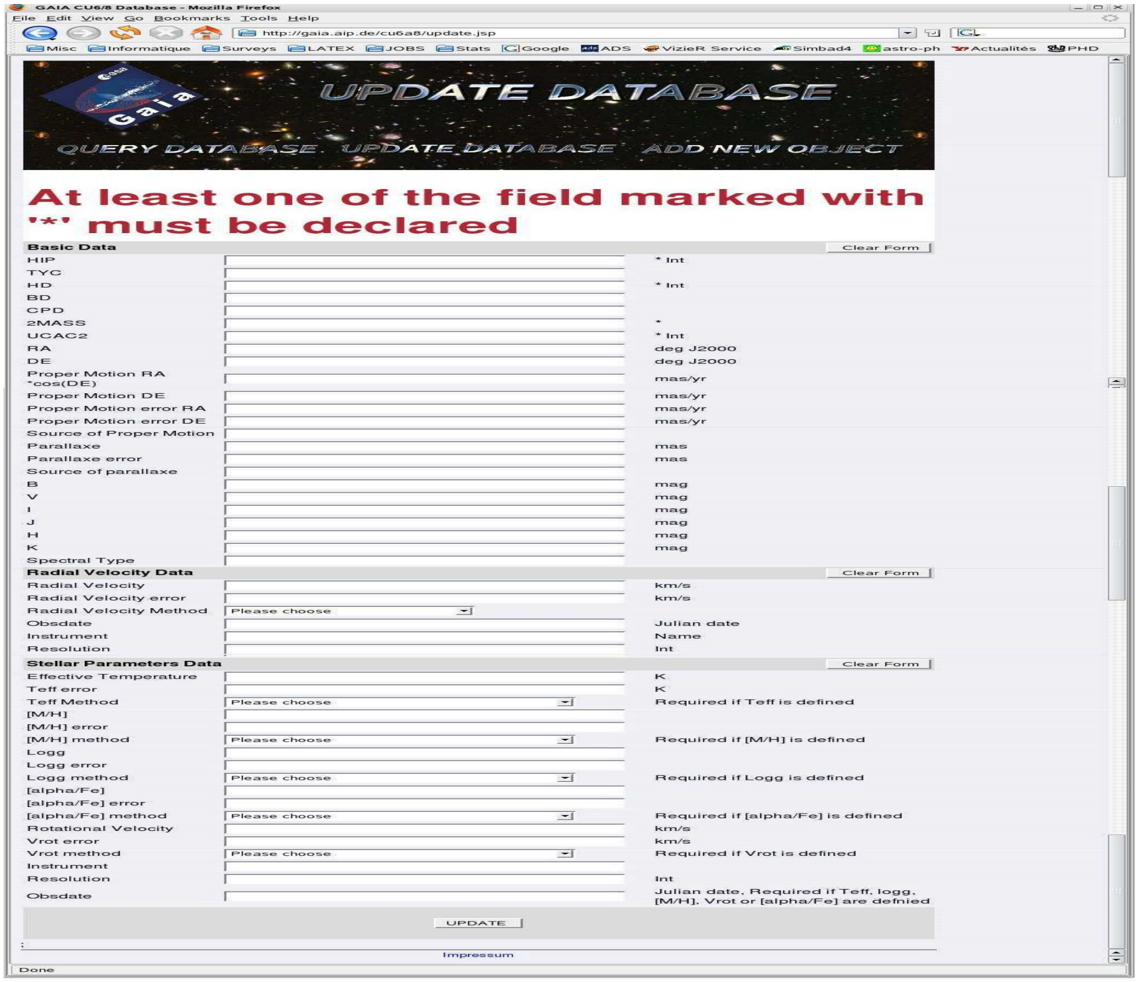


Figure 6: Update form of the CU6 & CU8 external database.

# 5 List of reference sources : asteroids

This task will be described in cycle 3.

# 6 Software module : Astrophysical zero-point

## 6.1 Static description : Decomposition into algorithms

Accordingly to the SRS document (see RD1, §1.4), the *Astrophysical zero-point* software module

- selects only the sources which are qualified as stars (S-FUNC-5000-20)
- computes the gravitationnal redshift (S-FUNC-5000-30)
- retrieves auxilary data from stellar atmospheric models, and computes blueshifts (S-FUNC-5000-40)
- computes radial velocity corrections in order to get KRV from SRV and BVC (S-FUNC-5000-10)

## 6.2 Dynamic description

The three algorithms are executed one after the other, following the order given in the static description. The third one uses results of 1st and 2nd ones as inputs.

## 6.3 Interfaces

| Name | Description | Type | In/out | Values |
|---|---|---|---|---|
| Object | Type of the object | byte | C | |
| Teff | Effective temperature | double | C | |
| TeffErr | Error on Teff | double | C | |
| Logg | Surface gravity | double | C | |
| LoggErr | Error on logg | double | C | |
| Metal | Metallicity [M/H] | double | C | |
| MetalErr | Error on Metal | double | C | |
| Parallax | Parallax of the star | double | C | |
| ParallaxErr | Error on Parallax | double | C | |
| BP | BP magnitude of the star | double | C | |
| BPErr | Error on BP | double | C | |
| RP | RP magnitude of the star | double | C | |
| RPErr | Error on RP | double | C | |
| Extinct | Interstellar extinction | double | C | |
| ExtinctErr | Error on Extinct | double | C | |
| RVSpeBar | Barycentric Spectroscopic Radial Velocity of the star | double | I | |
| RVSpeBarErr | Error on RVSpeBar | double | I | |
| RVCorBlue | RV correction due to blueshifts | double | O | negative |
| RVCorBlueErr | Error on RVCorBlue | double | O | |
| RVCorGrav | RV correction due to gravitational redshift | double | O | positive |
| RVCorGravErr | Error on RVCorGrav | double | O | |
| RVKinBar | Barycentric Kinematic Radial Velocity | double | O | |
| RVKinBarErr | Error on RVKinBar | double | O | |

RVCorBlue is a function of Logg, Teff & Metal.

## 6.4 Design to requirement traceability

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-5000-10 | PC | The ”Astrophysical zero-point” software module computes radial velocity corrections (redshifts and blueshifts of spectral lines) in order to get KRV from SRV and BVC. |

This requirement is partially compliant because S-FUNC-5000-40 is not yet compliant.

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-5000-20 | C | The ”Astrophysical zero-point” software module applies only to stars. |

The criterion *Object*=Star will be fullfiled by means of to the *Discrete Source Classifier* (WP-S-821) delivered by CU8.

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-5000-30 | C | The ”Astrophysical zero-point” software module derives mass and radius from parallax, BP & RP (photometry), extinction and atmospheric parameters, and then computes gravitational redshift. |

This requirement will be completed thanks to the *FLAME* software module developed by CU8 (WP-S-825). This software derives mass and radius, and thus it is easy to add one programming line computing the gravitational redshift (see §6.5.4).

| Requirement | Compliance | Description |
|---|---|---|
| [CU6-WP640] S-FUNC-5000-40 | NC | The ”Astrophysical zero-point” software module derives blueshifts (especially convective blueshift) from atmospheric parameters and stellar atmospheric models. |

This requirement is very difficult to complete in the near future. Theoretical developments on convective blueshifts and other subtle effects (rising shocks in the atmosphere, etc...) are in progress within CU6 (Ludwig et al., Bigot et al.). A table giving these corrections as a function of effective temperature, gravity and metallicity will be delivered for some stars in the HR diagram. Estimates of convective velocities from mixing-length theory (scaled with the sun), will be a first step for next cycles. It is worth to note that deriving synthetic spectra from 3D stellar atmospheric models and using them as templates for the RV derivation of all stars in the HR diagram is probably unrealizable during the GAIA project.

## 6.5 Algorithm *gravitationnal redshift*

### 6.5.1 Static description : Decomposition into methods

- get the atmospheric parameters (temperature $T_{\rm eff}$[K], gravity $\log g$, metallicity [M/H]) of the star (and associated errors)
- get the parallax $\pi$ of the star [microarcsec] (and associated error)
- get the BP & RP magnitudes, and extinction $A_{BP}$ (and associated errors)
- compute bolometric correction, bolometric magnitude, mass, radius and gravitationnal redshift (and associated errors)

Except for the gravitational redshit, all items above are collected by the CU8 FLAME software (GWP-S-825):
http://gaia.esac.esa.int/dpacsvn/DPAC/CU8/software/FLAME/src/gaia/cu8/flame/
Thus, we suggest that the gravitational redshift (derived from mass and radius ; see §6.5.4) is also delivered by CU8.

### 6.5.2 Dynamic description

### 6.5.3 Internal interfaces

| Name | Description | Type | In/out | Values |
|---|---|---|---|---|
| Object | Type of the object | byte | I | |
| Teff | Effective temperature | double | I | |
| TeffErr | Error on Teff | double | I | |
| Logg | Surface gravity | double | I | |
| LoggErr | Error on logg | double | I | |
| Metal | Metallicity [M/H] | double | I | |
| MetalErr | Error on Metal | double | I | |
| Parallax | Parallax of the star | double | I | |
| ParallaxErr | Error on Parallax | double | I | |
| BP | BP magnitude of the star | double | I | |
| BPErr | Error on BP | double | I | |
| RP | RP magnitude of the star | double | I | |
| RPErr | Error on RP | double | I | |
| Extinct | Interstellar extinction | double | I | |
| ExtinctErr | Error on Extinct | double | I | |
| RVCorGrav | RV correction due to gravitationnal redshift | double | O | positive |
| RVCorGravErr | Error on RVCorGrav | double | O | |

### 6.5.4 Scientific concepts used for the algorithm implementation

- $\log g$ is given by RVS and/or photometry
- the bolometric correction BC is determined from log g, Teff and [M/H] from a data grid of stellar atmospheric models
- $\mathrm{M_{bol}}$ = ($\mathrm{m_{BP}}$ - $\mathrm{A_{BP}} + 5\log\pi - 1)$ + BC
From the classical definitions of the luminosity and the gravity, we deduce the mass M and radius R of the star:
$\log\left(\mathrm{M/M_{sun}}\right) = -0.4\mathrm{M_{bol}} + \log \mathrm{g} - 4\log \mathrm{T_{eff}}$ + B ; B : constant
$\log\left(\mathrm{R/R_{sun}}\right) = -0.2\mathrm{M_{bol}} - 2\log \mathrm{T_{eff}}$ + C ; C : constant
- the gravitationnal redshift is given by : $\mathrm{V_{grav}} = \frac{\mathrm{GM}}{\mathrm{cR}}$ where G and c are respectively the gravitationnal constant and the speed velocity.

## 6.6 Algorithm *Blue redshift*

### 6.6.1 Static description : Decomposition into methods

- get the atmospheric parameters (temperature $\mathrm{T_{eff}}$, gravity $\log g$, metallicity [M/H]) of the star (and associated errors) ; same as above for the algorithm *Gravitationnal redshift*
- retrieve the blueshift (and associated error) from a grid a stellar atmospheric models

### 6.6.2 Dynamic description

### 6.6.3 Internal interfaces

| Name | Description | Type | In/out | Values |
|---|---|---|---|---|
| Object | Type of the object | byte | I | |
| Teff | Effective temperature | double | I | |
| TeffErr | Error on Teff | double | I | |
| logg | Surface gravity | double | I | |
| loggErr | Error on logg | double | I | |
| Metal | Metallicity [M/H] | double | I | |
| MetalErr | Error on Metal | double | I | |
| RVCorBlue | RV correction due to blueshifts (convective, etc...) | double | O | negative |
| RVCorBlueErr | Errors on ConvectiveShift | double | O | |

### 6.6.4 Scientific concepts used for the algorithm implementation

Wavelength blueshifts in convective stars and rapidly rotating stars have been detected (Dravins et al., 2004 astro-ph/0409212). Theoretical predictions are in progress within the CU6 (Ludwig et al., Bigot et al.). A grid of intrinsic spectral blueshifts $V_{blue}$ for stars in the H-R diagram should be available in the next cycles.

## 6.7 Algorithm *Computation of the KRV-SRV correction*

### 6.7.1 Static description : Decomposition into methods

- get the Barycentric SRV i.e the SRV corrected by the BVC (this BVC is given by CU3)
- get the wavelength spectral redshift and blueshift, and compute the Barycentric KRV.

### 6.7.2 Dynamic description

### 6.7.3 Internal interfaces

| Name | Description | Type | In/out | Values |
|---|---|---|---|---|
| Object | Type of the object | byte | I | |
| RVSpeBar | Barycentric Spectroscopic Radial Velocity of the star | double | I | |
| RVSpeBarErr | Error on RVSpeBar | double | I | |
| RVCorBlue | RV correction due to blueshifts | double | I | negative |
| RVCorBlueErr | Error on RVCorBlue | double | I | |
| RVCorGrav | RV correction due to gravitational redshift | double | I | positive |
| RVCorGravErr | Error on RVCorGrav | double | I | |
| RVKinBar | Barycentric Kinematic Radial Velocity | double | O | |
| RVKinBarErr | Error on RVKinBar | double | O | |

### 6.7.4 Scientific concepts used for the algorithm implementation

For each star the kinematic radial velocity RVKinBar is deduced from the spectroscopic radial velocity RVSpeBar by : RVKinBar = RVSpeBar - RVCorGrav - RVCorBlue