Library of empirical spectra in the RVS range for Northern stars

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Abstract

This TN describes the on-going compilation of high resolution spectra in the RVS range to be used as templates by the CU6 processing.

Document History

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Acronym List

Acronym	**Description**
CU	Coordination Unit (in DPAC)
DPAC	Data Processing and Analysis Consortium
DU	Development Unit
GBOG	Ground-Based Observations for Gaia (DPAC)
RV	Radial Velocity

Contents

1 Abstract

We present a library of 1238 ground-based, high-resolution spectra in the RVS range to be used for RVS data commissioning, validation or reduction processing. This technical note supersedes the former note LC-001.

2 Initial specifications

DK-015 describes the auxiliary data necessary for the CU6 processing, which greatly relies on templates generated from synthetic spectra. The ground-based spectra can be used a posteriori to check the quality of the processing: e.g. background modelling and subtraction, de-blending and calibration of the wavelength dispersion law and of the Line Spread Function instrumental profile of the RVS. Observed templates of stars are also used for validation of data obtained during the commissioning.

Requirements of DK-015 stipulate that spectra must:

- include the RVS wavelength range, preferentially with no gaps,
- have a minimum resolving power $\Re > 30000$,
- have a high signal-to-noise ratio. A $\mathrm{S/N} = 200$ is expected after re-sampling to the RVS spectral sampling of 0.25 Å/pixel. For instance, it implies $\mathrm{S/N} = 100$ for $\Re = 40000$, and $\mathrm{S/N} = 70$ if $\Re = 80000$,

3 Spectrographs

Two instruments were found to match perfectly the specifications: **NARVAL** and **ESPADONS**. **ESPADONS** and **NARVAL** are twin spectro-polarimeters. **ESPADONS** is mounted on the 3.6-m CFHT since 2005. **NARVAL** is installed on the 2-m Telescope Bernard Lyot (TBL) at Pic du Midi (South-West France) since 2006. They cover a large spectral range (370-1050 nm) in a single exposure, with an average resolving power of $\Re$ =78000. The resolving power can vary from $\Re$ ∼65000 to ∼85000, depending of the calibration and wavelength range, and the observing mode (spectroscopy or polarimetry). The full spectrum spans fourty grating orders (from order 61 in the blue to order 22 in the red). The RVS range is covered by the orders 26 and 27. Each exposure is automatically reduced and calibrated on-line by the software Libre-ESpRIT (Donati et al., 1997). The peak S/N (per 2.6 km s^{-1} spectral bin) is given for all orders. **NARVAL** and **ESPADONS** are available in the PolarBase `http://magics.bagn.obs-mip.fr/Espadons_Narval/` (Petit et al., 2014). **NARVAL** spectra are also available in a archive at `http://tblegacy.bagn.obs-mip.fr/narval.html`.

4 Selection of stars

Following the above-mentioned specifications, we have retrieved spectra with $\mathrm{S/N} > 70$ (except for faint stars at North Ecliptic Pole, NEP, see below), and $\mathrm{S/N} < 1200$. This upper limit is set to avoid potential saturation problems for high-flux observations. Due to the large volume of data, spectra were kindly provided by T. Louge (IRAP), upon request. Among ~ 1950 uploaded spectra, we have selected those either observed with the spectroscopy mode of the instruments, or with the polarimetry mode. In that later case, only data with total intensity have been kept (Stokes parameter 'I'). Those spectra have a resolving power of 65000. The data cover 8 years for **ESPADONS** (2005-2012) and **NARVAL** (2006-2013). In case stars have been observed several times during those periods, and by both instruments, we kept the spectrum of highest S/N for them. We have chosen only spectra whose continuum has not been normalized by the automatic data reduction pipeline of the instruments.

5 Spectral processing

The spectra have been processed with the iSpec software (Blanco-Cuaresma et al., 2013). For each spectrum, we applied the following processing (in that order):

• **Determination of the radial velocity (RV)**. For the FGKM standard stars from Soubiran et al. (2013), the reference values of RV were used. For all other stars, cross-correlation of spectra with A0, F0, G2, K0, and K5 masks, and with an observed template has been done. The cross-correlation has been performed using the whole **NARVAL/ESPADONS** spectral range, divided into orders. The template was a solar spectrum observed with the **NARVAL** instrument. A conservative derivation procedure has then been applied to yield a correct final RV. First, for each star and for each mask/template, a radial velocity has been determined at each grating order. We then got rid of all values for which the derived error was larger than 400 m s^{-1} for the A0 mask, and 300 m s^{-1} for all other masks or solar template. Then, a 2σ clipping has been applied to get rid of outlier orders. A radial velocity (and its associated error) has then been derived as the average (1σ standard deviation, respectively) of those orders. Note that if less than ten orders remained, then we decided that no realistic RV could be derived for the associated mask/template. Then, we have adopted as the final RV the value for which the 1σ standard deviation was the smallest between all masks/template. If the procedure could not make the derivation of a RV possible, then a not-a-number (NaN) has been provided for the associated star;

• **Selection of channels** . All spectral channels between $\lambda = 835$ nm and $\lambda = 880$ nm have been selected. This range is chosen slightly larger than the RVS range for further processing (commissioning, etc.). In the range where the two orders overlap, we have chosen the channel for which the associated flux error is the lowest;

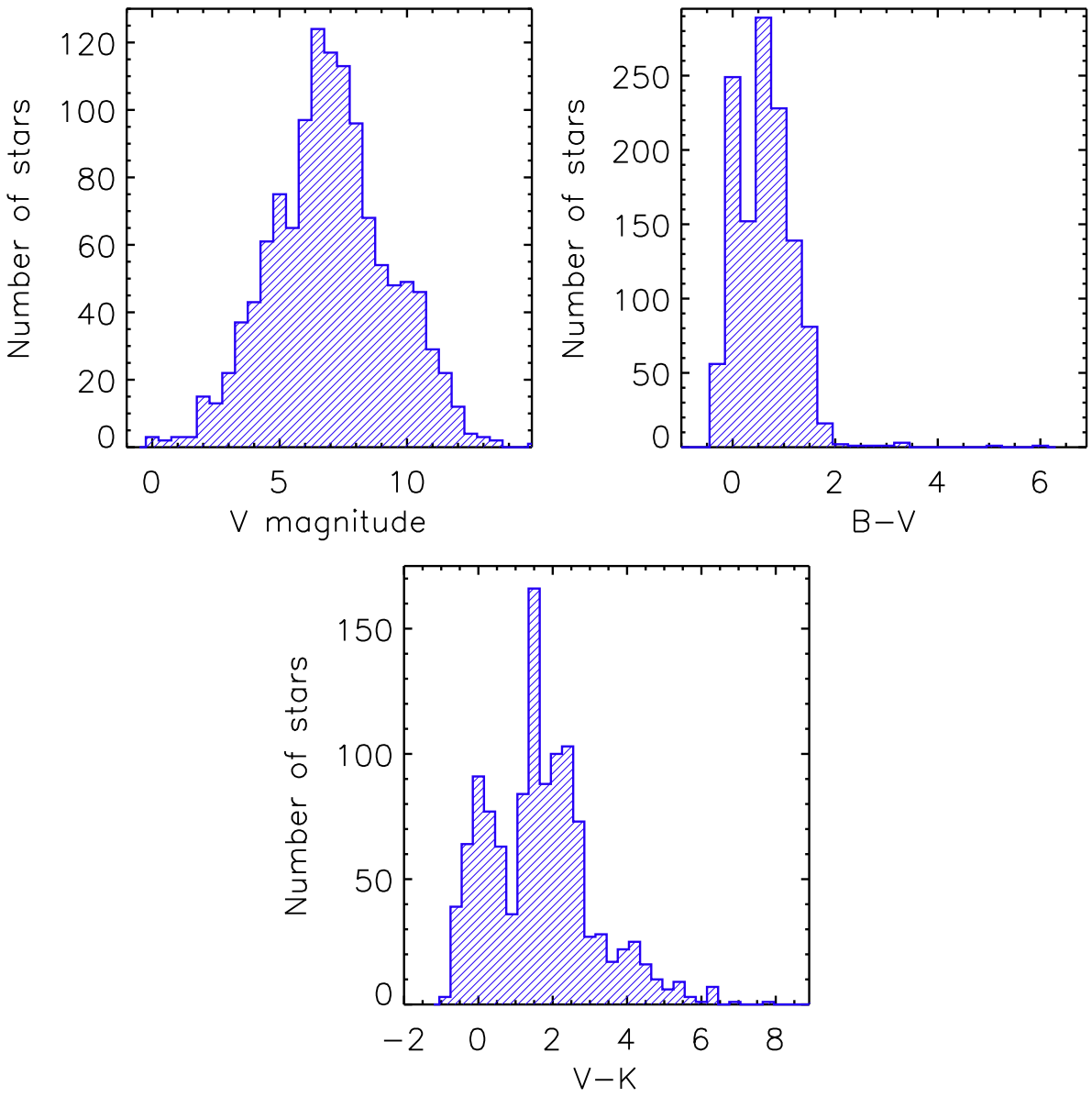

FIGURE 1: Distribution of the 1238 stars of the dr0514 library as a function of V, $B-V$ and $V-K$.

• **Removal of narrow peaks** Narrow peaks are removed. They correspond to noisy features caused e.g. by residuals from cosmic ray hits. In general, such peaks are well detected and removed by iSpec. However, it happens that small residuals remain in the spectra;

• **Normalization** iSpec normalizes spectra by fitting a number of spline functions to selected points supposed to represent well the continuum around expected absorption lines. Note that this normalization procedure is very appropriate for spectra with well identified continuum

regions, but not so much for emission-line or variable stars;

• **Radial Velocity correction** Each star with a derived RV has its spectrum shifted to RV = 0 km s^{-1}. No shift was performed for the other stars. A flag indicates whether the spectrum has been corrected from the radial velocity ('1' for correction, '0' for no correction) in the metadata file described below;

• **Air-to-vacuum correction** The spectra are shifted to the vacuum rest-frame;

• **Resampling** For sake of homogeneity, a uniform step of 0.0067 nm is used for spectral resampling, irrespective of the spectral resolution.

No subtraction of telluric lines has been performed.

6 The empirical library dr0514

The present library dr0514 we have built contains 1238 spectra, among which 925 come from the **NARVAL** database, and 313 from the **ESPADONS** archive. Many of the retrieved spectra in the **NARVAL** archive come from the Large Program for GBOG (CU6-CU8) that we led since 2007. In particular, there are standard FGKM stars observed for RVS calibrations (Soubiran et al., 2013), and NEP stars for Gaia commissioning. Most of spectra for NEP stars have $S/N < 70$, as caused by faint stars. Though this value does not fulfill the specifications, we kept them because NEP observations are crucial for commissioning. Other spectra from the archives are either for variable, earlier-type, or emission-line stars. This is expected because the spectro-polarimeters are very appropriate to study the magnetic field activity of such stars.

The provided spectra are ascii text files, with wavelengths, fluxes and errors ordered monotonically with increasing in wavelength. The metadata file named 'content-dr0514.txt' contains all useful spectral informations, and basic characteristics of the stars. This file is organized as follows:

- **Col. 1:** Object name. In decreasing order of priority, the name is the HIPPARCOS id., or the TYCHO id, or 2MASS id., or another id. from SIMBAD if none of the HIP/TYC/2MASS names exist
- **Col. 2-3:** Right ascension and Declination (deg)
- **Cols. 4-9:** Right ascension (hh mm ss.ss) and Declination (+/-dd mm ss.ss)
- **Col. 10:** Flag indicating whether the star is in the catalogue of RVS standard stars of Soubiran et al. (2013) ('1' for Yes, '0' for No)
- **Col. 11:** Spectrum file name
- **Col. 12:** Instrument of observation (NAR for **NARVAL**, ESP for **ESPADONS**)
- **Col. 13:** S/N of spectrum in RVS wavelength range (from observing log file)

- **Col. 14:** Mean resolving power of spectrum (nb: resolving power is 65000 for all **ESPADONS** spectra)
- **Col. 15:** Number of channels in spectrum
- **Cols. 16-17:** Minimum/Maximum wavelength of spectrum (nm)
- **Col. 18:** Size of spectral sampling element (0.0067 nm)
- **Col. 19:** Apparent $V-$band magnitude (from SIMBAD, 'NaN' if no colour is available)
- **Col. 20:** $B-V$ colour index (from SIMBAD, 'NaN' if no colour is available)
- **Col. 21:** $V-K$ colour index (from SIMBAD, 'NaN' if no colour is available)
- **Col. 22:** Spectral type (from SIMBAD, 'NaN' if no type is available)
- **Col. 23:** Flag indicating whether the spectrum has been corrected for the star radial velocity ('1' for Yes, '0' for No)
- **Cols. 24-25:** Radial velocity and radial velocity error (km s^{-1}). 'NaN' if no velocity could be derived
- **Cols. 26-27:** Effective temperature, and its error (K). 'NaN' if not available. From CS-011
- **Cols. 28-29:** Log(gravity), and its error. 'NaN' if not available. From CS-011
- **Cols. 30-31:** [Fe/H], and its error. 'NaN' if not available. From CS-011

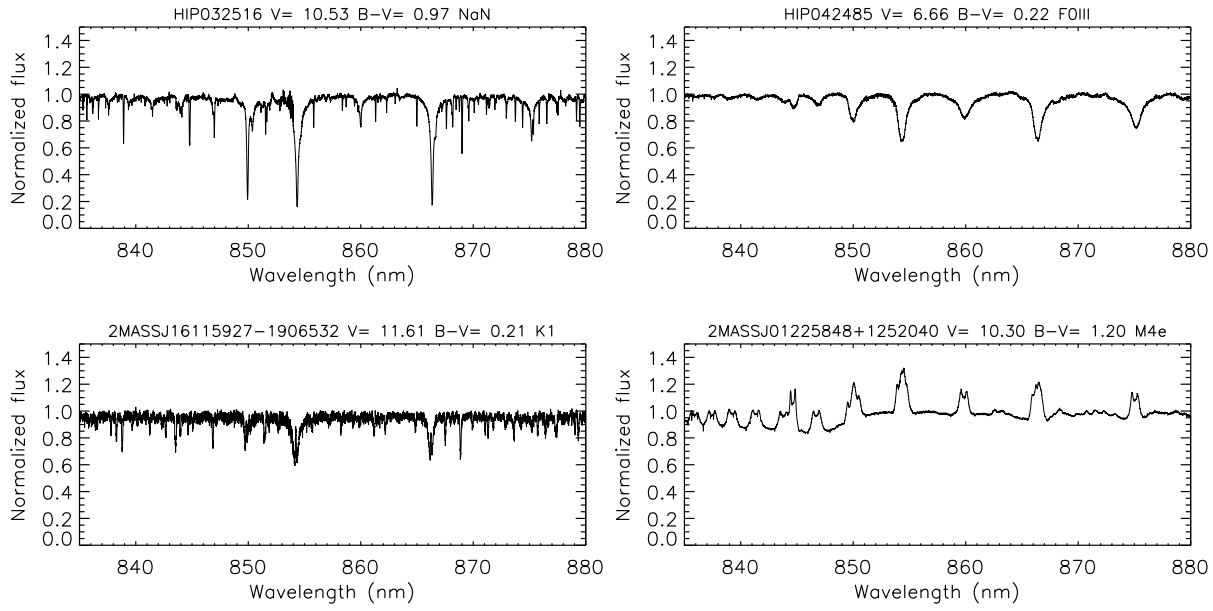

FIGURE 2: Examples of spectra from the new empirical library. Name, V magintude, $B-V$ colour and spectral type are indicated for each star.

7 Improvement with respect to former libraries

The current library dr0514 supersedes all former versions of libraries dr0713, nep-dr0513, dr0213, dr0113. The evolution with respect to those libraries are: larger number of stars, improved processing of spectra, different procedure to derive radial velocities (expect for the published RVs for standard stars in Soubiran et al. (2013) and the NEP stars), different organization of the content file. The library sep-dr0813 of medium resolution spectra for South Ecliptic Poles SEP is still valid.

8 Storage

The RVS empirical library is stored on the ESAC disk space created for the GBOG WG : gbogcom at ssh.esac.esa.int, /gbog/cu6/RVS-LIB. Password is given upon request. A RVS-LIB.README file provides the basic description and the architecture of the current release of the library. The current library dr0514 is stored in the dr0514 directory. This directory includes a ReadMe file (dr0514.README), the detailed file describing the content of the library and basic characteristics of stars (content-dr0514.txt), the spectra (ascii files) and a PDF file fig-hrs.pdf for a quick view of all spectra.

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