Library of empirical spectra covering the RVS range

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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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1	2	27-02-2013	`LCH, CS`	Revision
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1	0	19-12-2012	`CS`	Creation

Acronym List

Acronym	**Description**
AP	Astrophysical Parameters
CU	Coordination Unit (in DPAC)
DPAC	Data Processing and Analysis Consortium
DU	Development Unit
GBOG	Ground-Based Observations for Gaia (DPAC)
MDB	Main DataBase
RV	Radial Velocity
SAMP	Simple Application Messaging Protocol
WG	Working Group

Contents

1 Introduction

DK-015 describes the auxiliary data necessary for the CU6 processing which greatly rely on templates generated from synthetic spectra. But due to uncertainties in spectra modelling, the best templates that could be used for the RV derivation are the spectra of the stars themselves, observed from the ground. High-resolution, high signal-to-noise ratio (S/N) observed spectra are thus required to be used as templates instead of the synthetic ones when possible.

The ground-based spectra can also 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* (LSF) instrumental profile of the RVS.

The observed templates will be especially useful during commissioning. Some observations have been organised to secure observed templates in the vicinity of the ecliptic poles, as these will be the stars observed the most frequently by the RVS during the first two months of the mission.

This TN describes the observational material that will be used to build a vast library of observed spectra in the RVS range. The content of this library will continue to evolve before launch and during the mission.

2 Specifications

According to DK-015 the ground-based spectra should fulfil the following specifications:

- include the RVS wavelength range if possible with some margin to avoid spectrum border effects and differential radial velocity shifts,

- preferably high resolving power $\Re > 50000$ (minimum: $\Re > 30000$),

- high signal to noise, i.e. $S/N = 200$ ratio after re-sampling to the RVS spectral sampling of 0.25 Å/pixel: i.e. $S/N = 100$ if $\Re = 40000$ and $S/N = 70$ if $\Re = 80000$,

- bright stars, preferably $V < 10$, for the stars to be usable as reference for the calibration of the RVS

When available, it would be useful to have the APs for these stars.

The observed spectra will be pre-processed before being delivered to the MDB:

1. Wavelengths: shifted to rest frame, expressed in vacuum (not in the air), re-sampled to a constant step in wavelength.

2. Fluxes: normalised to the continuum, telluric lines removed.

3. Resolving power: constant full width at half-maximum (FWHM) in Å (as high as possible).

3   Spectrographs

We have searched instruments which fulfil the RVS requirements and we found only two of them which have a resolving power $\Re > 30000$ cover the RVS range with no gap, and have a public archive of reduced spectra : **NARVAL** and **ESPADONS**. Both are in the northern hemisphere.

NARVAL is a stellar spectropolarimeter on the 2m Telescope Bernard Lyot (TBL) atop Pic du Midi in southwest France. It provides complete coverage of the optical spectrum (from 370 to 1050 nm) in a single exposure with a resolving power of 78000 on average. The resolving power can vary from ∼65000 to ∼85000 depending of the calibration and wavelength range. The instrumental resolution per order, which can vary from one night to another, is retrieved from the calibration files. The full spectrum spans 40 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. For the GBOG observations we have used the 'star only' mode which gives the highest resolution. We plan to retrieve observations at slightly lower resolution (∼ 60000) obtained in polarimetric mode and available in the **NARVAL** archive. Each exposure is automatically reduced and calibrated on-line by the software Libre-ESpRIT (Donati et al., 1997). Automatic wavelength calibration is achieved, and radial velocity corrections from earth spin and orbit motions are applied to the wavelength scale before storing the final result into two multicolumn ascii files, one in instrumental fluxes, one with fluxes normalised to the continuum. It was found that the automatic normalisation was not satisfactory, so version in instrumental fluxes are used here and the normalisation is performed by us. The peak S/N achieved (per 2.6 km s^{-1} spectral bin) is indicated for all orders.

All reduced spectra obtained with **NARVAL** are public after one year and delivered through an archive with a web interface at : `http://tblegacy.bagn.obs-mip.fr/narval.html`. As of December 2012, the public **NARVAL** archive icludes nearly 38000 spectra of ∼800 different stars.

NARVAL is a twin copy of **ESPADONS** available at CFHT since 2005. As **NARVAL**, **ESPADONS** covers from 370 to 1050 nm in a single exposure, with a resolving power of about 68000 (in spectropolarimetric and 'object+sky' spectroscopic mode) and up to 81000 (in 'object only' spectroscopic mode). The reduced **ESPADONS** spectra are available for registered

users at The Canadian Astronomy Data Centre : `http://www.cadc.hia.nrc.gc.ca/AdvancedSearch/`

The echelle spectrograph of the 2.3-m telescope at Siding Springs Observatory (RSAA/ANU) has a mean resolving power of 40 000. The wavelength coverage in a single order at 854.2 nm is 23.6 nm, which is not the whole 27 nm wide window specified for Gaia, but covers the Ca triplet (16.4 nm) without gap.

UVES in slit mode, with a slit width $< 1''$ and grism CD#4 centered on 760 nm seems to cover the entire RVS range. However there is no simple way to query observations in that mode in the ESO archive. The possibility of using spectra UVES will be evaluated.

FEROS has a gap in the RVS range. GIRAFFE HR21 does not cover the entire RVS range and has a too low resolution (< 20000).

4 Observing programs

A Large Program has been underway from 2006 to 2012 on **NARVAL** under the framework of GBOG. It includes the observations of :

- Radial velocity standard stars candidates plus asteroids for the calibration of the radial velocity zero-point by DU-640,

- 63 stars selected around the Northern Ecliptic Pole for the initialization phase,

- benchmark stars and AP reference stars for CU8.

Three nights of observing time at the Siding Spring Observatory 2.3-m telescope have been obtained for this project by Michael S. Bessell (RSAA, College of Mathematical and Physical Sciences, The Australian National University) for the DU640 team. A set of 21 high-resolution and high signal-to-noise ratio spectra of the Southern Ecliptic Pole stars and 7 standards have been collected in November 2012. They are currently being processed by T. Zwitter et al. (Ljubljana University).

5 Spectra processing

The reduced **NARVAL**, and **ESPADONS** ones in a close future, are processed with SVE, the Spectra Visual Editor developed by S. Blanco-Cuaresma in Bordeaux (Blanco-Cuaresma et al., in preparation). SVE is a tool for visual inspection of spectra, determination of radial velocities, estimation of S/N and instrumental resolving power, continuum normalization, resolution

degradation, spectra combination, among other functionalities. SVE is SAMP ready and it can interoperate with other astronomical applications such as TOPCAT, VOSpec and splat facilitating a indirect way to access the Virtual Observatory. The processing of the spectra by SVE can be automatized through a Python script.

- **Radial Velocity correction** Since the spectra should be delivered in the vacuum restframe, their RV must be first determined. This is difficult or not precise for some kind of stars : hot stars with no metallic lines, double lined spectroscopic binaries, fast rotators. Single FGK stars of the sample have been analysed by cross-correlation with a mask and for those the correction was possible. We thus deliver two libraries : one include all types of stars but not shifted onto the restframe (dr0113), another one only including single FGK stars and RV corrected (dr0213).

- **Normalization** As said above, we consider the **NARVAL** spectra not normalized by the Libre-ESPRIT online pipeline in order to control this critical part of the processing. SVE performs the normalization by fitting a number of spline functions to selected points supposed to represent well the continuum. Splines are known to be sensitive to strong lines and a careful verification has to be made around the CaII lines in the RVS range. For the RVS empirical library, the normalisation is performed on the two orders 26 and 27 covering 820.89 - 887.10 nm and including the RVS range. We have noted afterwards that the spectra in emission are not properly normalised, in the sense that the continuum level is too low. This will be corrected in the next versions.

- **Resampling** In the December 2012 version of the RVS empirical library, we consider that the FWHM of the **NARVAL** spectra is constant over the RVS range. This is difficult to verify. According to the calibration files, the instrumental resolving power R measured from the Thorium exposures varies from 71726 to 91430 for the order 26 (852.46 - 887.10 nm), and from 71287 to 92648 for the order 27 (820.89 - 854.25 nm) over the considered 144 nights of observation. The median values are respectively 82200 and 74800 for the orders 26 and 27. Adopting FWHM=λ / R, we get FWHM of 0.0105 to 0.0115 nm at the center of the RVS range $\lambda = 860.5$ nm. It happens that the measured resolving power varies by more than 10000 in the orders 26 and 27 of a same spectrum. The extreme case gives FWHM of 0.0091 to 0.0123 nm at the edges of the RVS range. In case it is necessary, it will be possible to degrade the resolution by convolving the spectra with a gaussian in order to get a constant FWHM.

At the current stage, SVE simply performs a reduction of the wavelength range to 845 - 876 nm, and resamples the spectrum with a constant step of 0.0045 nm using a linear interpolation of the normalized fluxes.

- **Co-addition of spectra** Combining different spectra of a same star is useful to increase the signal to noise ratio. Thanks to this functionality of SVE, it will be possible to increase the content of the library with fainter stars in the next versions.

- **Telluric and sky line removal** The observed templates to be used for the RVS processing

must be cleaned from contaminating lines, a mixture of airglow emission lines and telluric absorption lines, and possibly the solar spectrum due to scattered moonlight. The positions of contaminating lines are well known but their strengths depend on the observing conditions and on the species.

The removal of telluric and sky lines is not yet implemented in SVE, but a method has been developed by R. Sordo and the Padova group to be applied on UVES and GIRAFFE spectra obtained for the GBOG programme at South Ecliptic Pole. This method could also be applied to the NARVAL spectra but the RVS range is not much affected by telluric absorption, and the real need of performing this correction should be re-evaluated. Figure 2 shows a model spectrum of the Earth atmospheric transmission in the RVS range, and in the spectral range 810-840 nm. Figure 3 shows a spectrum of a telluric standard, a B star with no metallic lines, observed in bad atmospheric conditions. Both cases show that the telluric features are shallow in the RVS range.

6 Format, metadata

To make use of observed spectra for the CU6 processing, a description of the spectra and the targets is provided in content-drMMYY.txt needed (MMYY corresponds to Month and Year of the data release). This file is organized as follows:

- Object identifier (from coordinates)
- Object name (from observer)
- Type of object (STAR only)
- Epoch (2000.0)
- Right ascension (deg)
- Declination (deg)
- Right ascension (hh mm ss.ss)
- Declination (+/-dd mm ss.ss)
- Spectrum file name
- Instrument of observation
- S/N of spectrum at observing order in RVS wavelength range (from observing log file)
- Mean resolving power $\Re$ at observing order
- Number of channels in spectrum
- Minimum/Maximum wavelength of spectrum (nm)
- Size of spectral sampling element (averaged from original spectrum, nm)
- Apparent $V-$band magnitude (from SIMBAD)
- $B-V$ colour index
- $V-K$ colour index
- Spectral type (from SIMBAD, 'Not_provided' if no type if available)
- Miscellaneous properties of object (from SIMBAD, 'Not_provided' if no type is

available, properties are separated by '_')

The catalogues of auxiliary (observed) data will be defined in mdb.cu6.auxiliarydata (DK-015). In each (observed) catalogue, the sources will be identified by a sourceId. Initially, this sourceId will be the same as the one used in the IGSL catalogue. Here we are concerned with auxObsSpe:

auxObsSpe	
long	solutionId
long	sourceId
calibratedSpectrumConstStep	obsSpe

UH-002 defines the Interface Control Document for Gaia observed spectral libraries for CU8. StarObserved is the ICD name for observed spectra of all types of stars. We have to verify if the same ICD can be used for CU6.

Spectra are provided as ascii text files, with wavelengths, fluxes and errors ordered monotonically with increasing in wavelength. A naming convention has been adopted for the files, in the form 'ad-hrs_instrument_coordinates_date-of-data-release'. As an example with the file ad-hrs_nar_121836.18+230712.28_dr0113.dat, "ad" stands for for "Auxiliary Data", "hrs" for "high spectral resolution", "nar" for the **NARVAL** instrument, 121836.18+230712.28 for the (J2000) equatorial coordinates of the star and "dr0113" for Data Release as of 01/2013.

7   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.

The RVS empirical library is stored on the DPAC svn repository, in the directory CU6/AuxiliaryData. The file RVS-LIB.README provides the basic description and the architecture of current releases of the library. There is one directory for each data release of the library. Each directory includes a ReadMe file (drMMYY.README), a detailed file describing the content of the library and basic characteristics of stars (content-drMMYY.txt, see § 6), spectra (ascii files) and a PDF file for a quick view of all spectra.

8   Stellar content and Astrophysical Parameters

The first version of the library (dr0113) includes 406 different stars observed with **NARVAL** and selected to have S/N at order 26 greater than 70. The library offers a large variety of spectral types and object types (retrieved from SIMBAD). Some examples are shown in Fig. 1. Figure 4 shows the distribution of the 406 stars as a function of the $V-$band magnitude and the $B-V$ colour index. Those magnitudes are retrieved from the SIMBAD database.

Another version of the library (dr0213) includes 246 stars for which the RV has been determined by G. Jasniewicz. The spectra have been shifted onto the restframe. Figure 5 shows the distribution of the 246 stars as a function of the $V-$band magnitude and the $B-V$ colour index.

APs will be provided later. They will be determined by us from the spectra, when possible, or from the literature compilation which is in preparation. Note that some carbon stars are included in the library. Such stars are very difficult to model and their APs difficult to estimate.

9   Future works

- Measure the RV of all the spectra and put them in the vacuum rest frame
- Refine the normalization of emission spectra
- Convolve all the spectra to a common resolution if needed
- Co-add multiple spectra of a same star to include lower S/N spectra and thus fainter stars
- Provide a spectral library for the Ecliptic Pole stars
- Remove telluric absorption lines and sky emission lines if needed
- Include more stars from the **NARVAL** archive
- Include stars from the **ESPADONS** archive
- Compile APs from the literature
- Measure APs from the spectra

References

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GAIA-C8-SP-UAO-UH-002,
URL http://www.rssd.esa.int/llink/livelink/open/2906426

[DK-015], Katz, D., Soubiran, C., Chemin, L., et al., 2012, *Auxiliary data in CU6 processing*,

GAIA-C6-TN-OPM-DK-015,
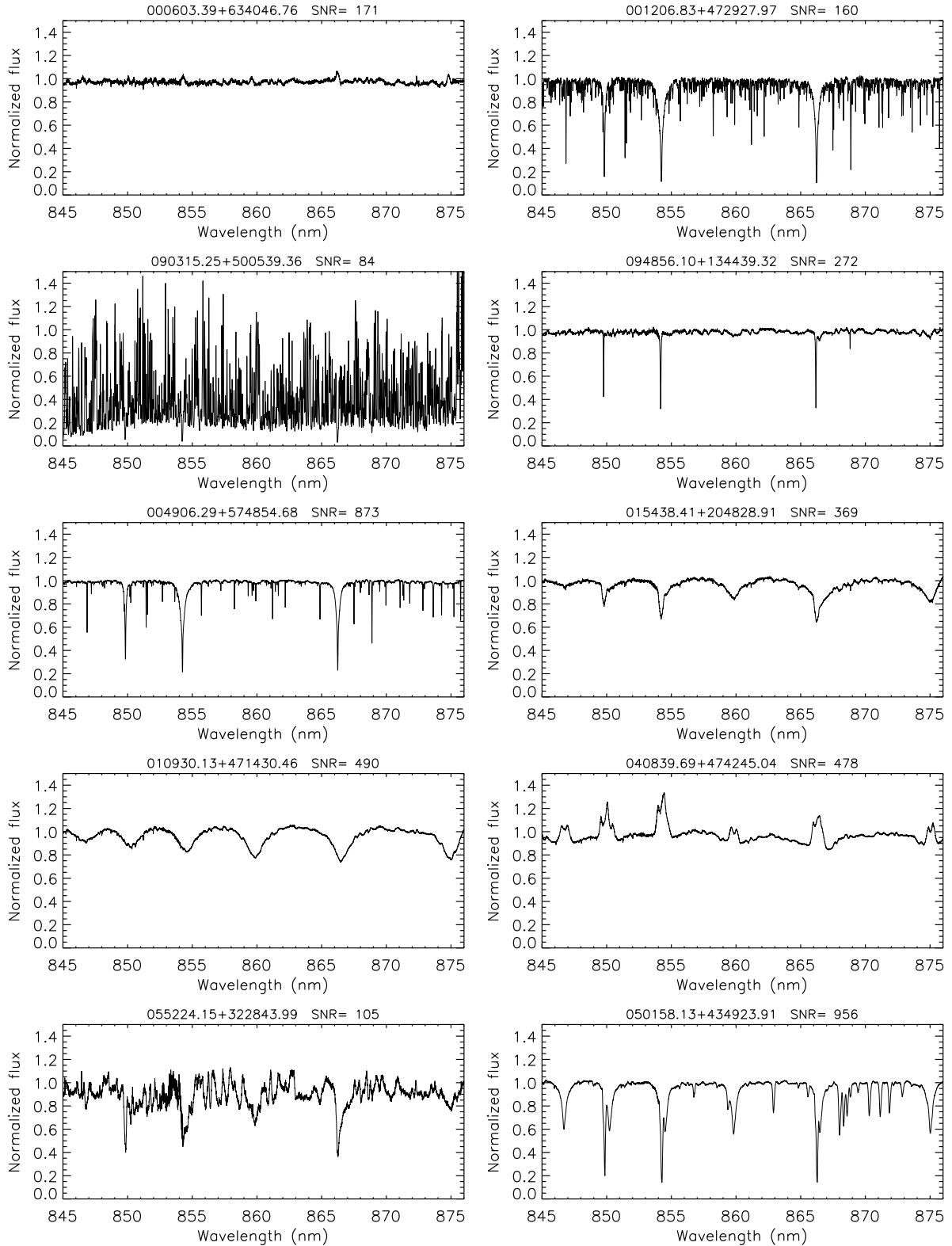URL http://www.rssd.esa.int/llink/livelink/open/3149104

FIGURE 1: Some examples of the spectra included in the RVS empirical library
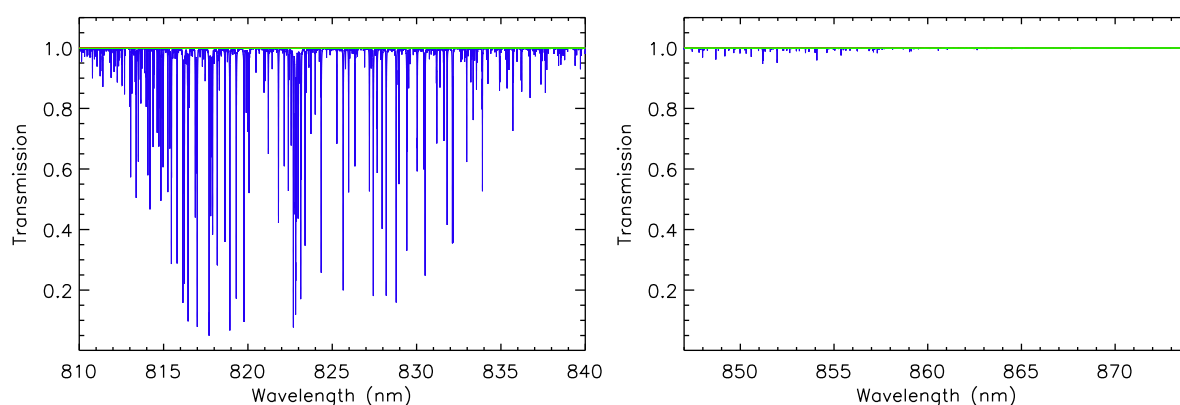
FIGURE 2: Model spectrum of the Earth transmission in the RVS range (right panel) and next to the RVS range (left panel). The dominating molecule is H2O in blue, O2 and O3 appear in red and green respectively.
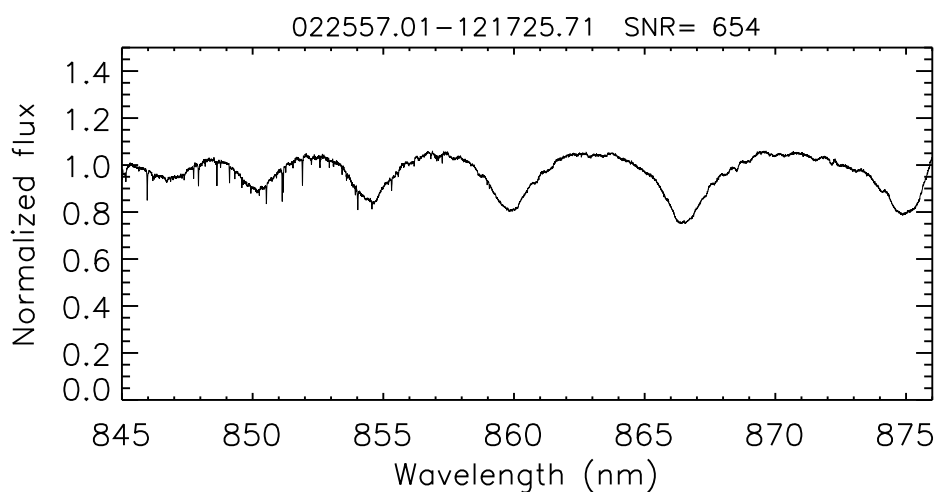

FIGURE 3: Spectrum of the telluric standard HR708, a B star with no metallic lines, observed in bad atmospheric conditions.
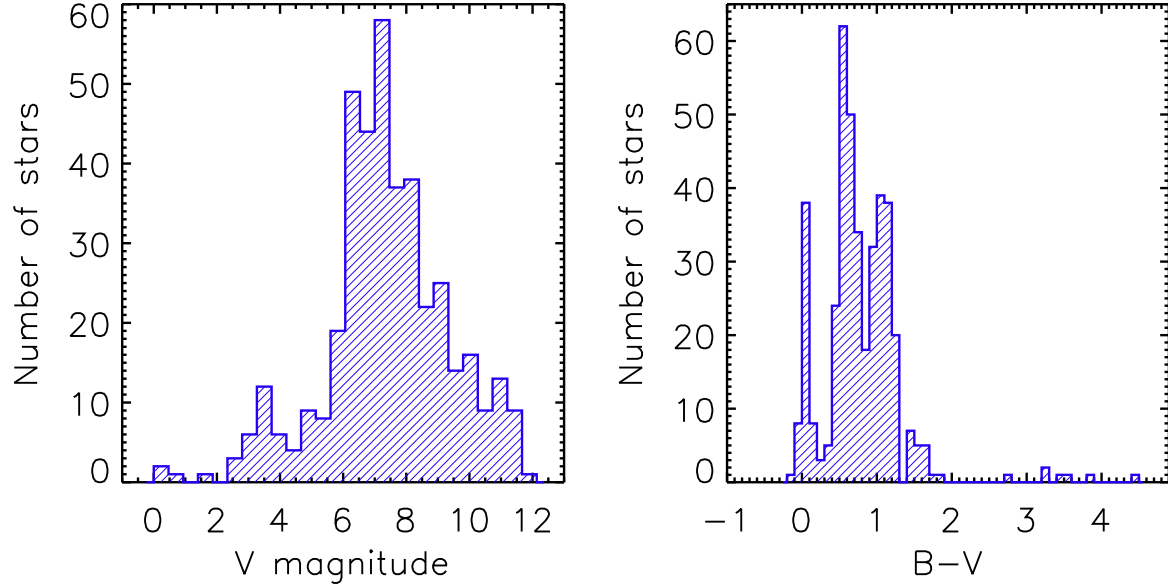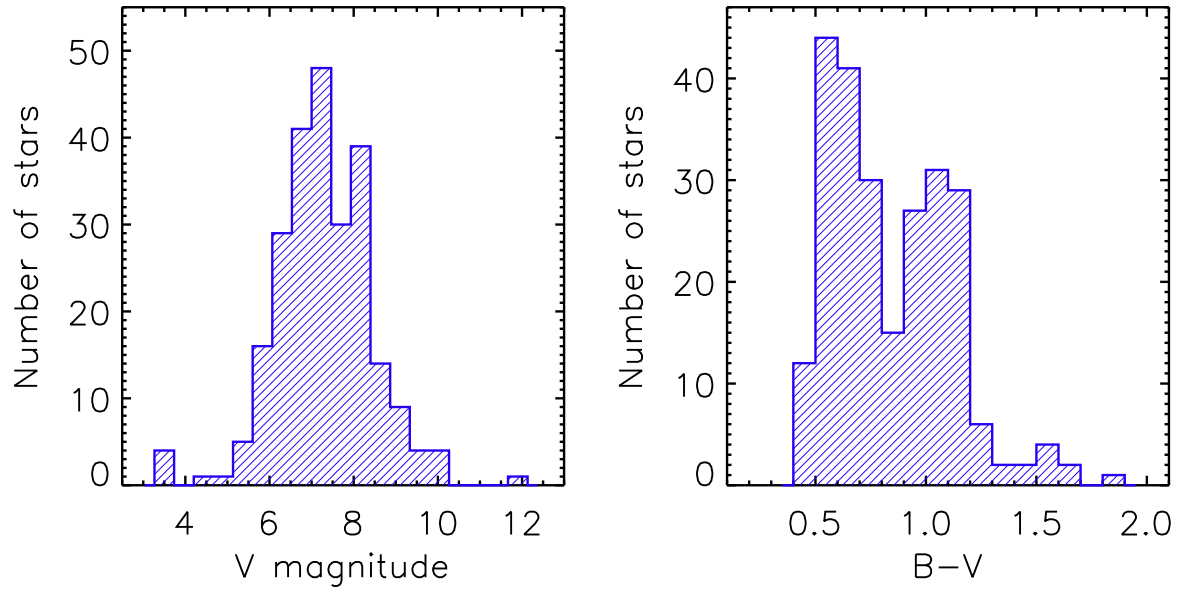
FIGURE 4: Histograms of the 406 stars of the dr0113 library as a function of V and $B - V$.

FIGURE 5: Same as 4 for the 246 spectra of the dr0213 library.