Protocol for Ground Based Observations of SpectroPhotometric Standard Stars. I. Instrument Familiarization Tests

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approved by: F. van Leeuwen
reference: GAIA-C5-TN-OABO-EP-001
issue: 1
revision: 0
date: 31 Jul 2008
status: Issued

Abstract

When trying to build a large set of ground based SpectroPhotometric Standard Stars (SPSS) for calibrating Gaia BP/RP Spectra and G-Band Images to a few % in absolute flux, it is essential to maintain the maximum homogeneity in data quality, acquisition and treatment. This is especially true when data come from different observing sites around the globe and are obtained and treated by different persons. The Observation Protocols and the Data Reduction Protocols are sets of detailed instructions for observers and collaborators that participate in the large effort required. This first Observation Protocol concerns data and calibrations specifically needed to characterize the performances of each telescope and instrument used, through the Instrument Familiarization Plan.

Contents

1 Introduction

The ground-based observations of Spectro-Photometric Standard Stars (SPSS, see GA-001) for the absolute calibration of the BP/RP spectrophotometers and of the G-Band of Gaia (MBZ-001), represent an enormous observational effort, that must rely on different telescopes and instruments (LF-001). However, we must ensure the maximum homogeneity in the data quality, in the observation procedures and in the data reduction.

As a first step, it is therefore mandatory to test the capabilities of each telescope/instrument combination and to devise methods to keep under control – and eventually correct for – the typical instrumental effects that can affect the high precision required for the Gaia SPSS grid (a few percent in flux at most, relative to Vega).

This document is the first of a series of observation protocols that help observers in the effort of building the Gaia SPSS Grid, and contains instructions to gather the necessary calibration frames and night-time observations, to perform what we call the "Instrument Familiarization Tests". More details on the specific reduction and status of the tests can be found, at the moment, in the form of "Internal Reports" on our local Wiki pages in Bologna (Wiki-Bo, Section 1.1). A detailed description of our "Instrument Familiarization Plan", including the results of all tests, will be presented in a forthcoming document.

1.1 Information and Contact

You will need access to the Wiki-Bo pages (the internal CU5-DU13 Wiki pages maintained in Bologna). If you do not have it already, please contact either Elena Pancino or Giuseppe Altavilla[1]. Sections of the Wiki-Bo that can be particularly useful in this context are:

- The "Documentation Section", in particular:
  - The "Literature" Section, where you can find several useful literature papers on methods and sources of SPSS candidates;
  - The "DU13 Livelink Documents and Drafts", where you can learn about the whole ground-based SPSS observation strategy;
  - The "Internal Reports", where you can find detailed descriptions of the Instrument Familiarization Tests;
- The "Instrument Familiarization Plan" Section, where you can find the progress report of the tests;

For any doubt or problem, or simply to coordinate your observations, do not hesitate to contact us.

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1.2 Observing Checklist

When you go observing, please check the progress status of the "Instrument Familiarization Plan" for your instrument/telescope combination in the Wiki-Bo pages (Section 1.1). If any of the tests listed in Table 1 still needs any good data, please read the detailed descriptions in the indicated Sections and contact us (Section 1.1) to coordinate the observations.

TABLE 1: **Observing Checklist for Instrument Familiarization Tests.**

Test	**Short Description**	**Details**
Dark	1 dark frame with typical t_{exp} and 1 with maximum t_{exp}	Section 2.1
Bad Pixel Mask	Dome Flats with very different count levels	Section 2.2
Lamp Flexures	Series of wave lamps with different instrument positions	Section 2.4
Fringing superflats	Seiris of high S/N night sky dithered exposures	Section 2.5
CCD "Dome" Linearity	For imagers, series of dome flats with diffrent t_{exp}	Section 3.2
CCD "Spectro" Linearity	For spectrographs, series of lamp flats with diffrent t_{exp}	Section 3.3
Shutter Min Time & Delay	A Series of flats starting with very short exposure times	Section 3.1
2^{nd} Order Contamination	Night time observations of very blue and very red stars	Section 4.1
Polarization	Night time observations of polarized and unpolarized stars	Section 4.2

When you have obtained the data, and if you have the permissions to edit Wiki-Bo pages, please update the "Instrument Familiarization Plan" Tables by yourself, otherwise, contact us again (Section 1.1).

2 Calibration Tests

Calibration tests concern the stability and reliability of the calibration frames that we use to remove the instrument signature and to provide the wavelength calibration of our spectra.

2.1 Dark Current

Dark currents are usually irrelevant for the modern generation of nitrogen cooled CCDs, but a one-time check is recommended. Dark calibration frames are exposures taken with the shutter closed and with varying exposure time. When using an instrument/telescope combination for the first time, we recommend to take:

- One dark exposure with the typical, representative exposure time expected during the observing run;
- One dark exposure with the maximum exposure time expected during the run.

2.2 Bad Pixel Mask

To construct a Bad Pixel Mask, you will need:

- At least three dome flat fields with high counts (≃20000–30000 ADU);
- Al least three dome flat fields with low counts (≃500–1000 ADU)

The exact broadband filter used is irrelevant. Incidentally, the dome flat series described in Section 3.2 already contain the above images, therefore taking a dome series for the CCD linearity test automatically ensures that we have good flats for building the Bad Pixel Mask. However, unlike the CCD linearity, the Bad Pixel Mask should be repeated approximately once per year for each instrument. More information about bad pixel masks can be found in *"Instrumental Pattern and CCD Cosmetic. Part 1: Bad-Pixel Mask"* by Silvia Marinoni, which can be found in the "Internal Reports" Section of the Wiki-Bo.

2.3 Bias and Flat stability

These tests do not require any addional observation, since they can be performed using the regular daytime and twilight time calibration frames that are normally obtained. Therefore, they are not listed in Table 1, but we mention them here for sake of completeness.

2.4 Wavelength Lamp Flexures

Low resolution spectrographs are usually attached to the telescope or to the telescope derotator, and they move during observations. At each different position, the varying projection of the gravitational force leads to mechanical distortions, either negligible or important. These mechanical distortions are seen on the wavelength calibration frames, where they produce shifts of the lamp emission lines, either linear or non linear in wavelength.

To evaluate the mechanical distortions, lamps must be taken at different positions of the telescope. Depending on the instrument/telescope combination, the position can be parametrized with a single angle (the derotator angle), if the instrument is attached to a fixed derotator (as at a Nasmyth focus), or with two different angles, if the instrument is attached to the telescope. In the complex case of two parameters, it is safer to assume that flexures are relevant, and to take night wavelenght calibration lamps close to each observed object. Otherwise, lamp flexures ca be measured with:

- One full circle of the derotator angles should be observed, by moving both in the clockwise and anti-clockwise directions, with respect to a reference position, for an ideal total of ∼50–100 exposures (steps of ∼5 deg);

The choice of the lamp depends on the expected kind of distortion. One lamp with a relatively good wavelength coverage is sufficient if only linear distortions are expected. If, after a first set of measurements, non-linear distortions are suspected, measurements could be repeated with at least two different lamps, to evenly sample the whole spectral range covered by Gaia ($\simeq$350–1050 nm). However, if the measurements are too time consuming, it could be better to assume that flexures are relevant, and to take night wavelenght calibration lamps close to each observed object.

More details on the lamp flexures problem can be found in *"Evaluation of mechanical distortions in DoLoRes@TNG"* by Silvia Marinoni, which can be found in the "Internal Reports" Section of the Wiki-Bo.

2.5 Fringe Nightflats

Fringe nightflats are series of at least 5 images of empty areas of the sky, taken with a relatively long exposure time and dithered (i.e., each offset by a few arcseconds to allow for star removal). Only passbands redder than V may need fringe correction (in our case, R or I). No fringe nightflats are needed for instruments that are only used in spectroscopic mode.

More details on the imaging fringing correction can be found in *"Instrumental Pattern and CCD Cosmetic. Part 2: Fringing Mask"* by Silvia Marinoni, which can be found in the "Internal Reports" Section of the Wiki-Bo.

3 CCD Performance Tests

Most telescope staffs measure regularly their CCD performances, but we need to do very high precision photometry and spectroscopy, therefore we must know the Instrument Shutter characteristics and the CCD Linearity with a very good precision.

3.1 Shutter Minimum Exposure Time & Delay Time

There are two effects of the shutter finite closing time that we need to measure accurately. The first is the shutter minimum exposure time and the second is the shutter delay time. Exposures taken with too short exposure times can incur into vignetting, due to subsequent projection of the shutter's shade on the CCD surface. We need therefore to know the minimum exposure time that avoids vignetting. Also, short exposures must be corrected for the so called "Shutter Delay Time" to know their exact *effective* exposure time. This is especially important when a high precision is required, for example in the CCD Linearity measurements mentioned in Sections 3.2 and 3.3.

Both measurements require the same set of frames, although they are then used in different ways. Dome flats need to be taken with a wide band filter with good transmissivity (e.g. not U), to grant a good S/N, in the following sequence:

- Wait until the flat lamp is hot and stable;
- Take three subsequent flats of at least a few seconds but without saturating; this is the *lamp monitoring triplet*, to keep an eye on the lamp stability;
- Start the *flats sequence* taking flat triplets, each triplet with a different exposure time, starting from the minimum exposure time allowed (can be 0.1 sec or even 0.05 sec, depending on the instrument) and raising up to a few tens of seconds, without saturating;
- After each triplet of the *flat sequence*, repeat the *lamp monitoring triplet*, always with the same exposure time that you used at the beginning.

This sequence can be extended to exposure times that include the CCD saturation limit and in this case it can also be used to measure the CCD linearity with the usual dome flat method (Section 3.2).

More details on the shutter times can be found in *"Notes on the shutter delay"* and *"Notes on the minimum shutter time"* by Giuseppe Altavilla, which can be found in the "Internal Reports" Section of the Wiki-Bo.

3.2 CCD Linearity with usual Dome Flats method

For this kind of test, the needed images are very similar to the ones described in Section 3.1. The only difference is in the exposure times: they should range from the shutter minimum time (to avoid vignetting), up to the full CCD saturation limit.

Therefore, covering the whole range from the minimum allowed shutter time to the CCD saturation limit, ensures completion of both the shutter tests and the CCD linearity test with the usual dome flats method. Incidentally, these kind of dome flat series are also ideal to create bad pixel masks (Section 2.2).

3.3 CCD Linearity with the "Stello" method

If the instrument has spectroscopic capabilities, the CCD linearity can also be measured with a much higher degree of precision (Section 3.2). The method is described in Stello et al. (2006).

A grism or grating with a very steep – and as monotone as possible – response curve should be employed, to allow the widest sampling of the CCD dynamical range. The slit width is unimportant, but it would be better to avoid too narrow slits.

The spectroscopic lamp flats sequence is similar to the dome flat sequence described in Section 3.1. In principle, two flat triplets are sufficient, but we suggest to take three (max five) triplets: one with a very short exposure time (but avoiding vignetting), one or two with intermediate exposure times, and the last one very close to saturation. One *lamp monitoring triplet* should always be taken before starting the sequence and after each triplet of the series.

More details on this linearity method, and its comparison with the usual method, can be found in *"Notes about the linearity of the definitive CCD at TNG"* by Giuseppe Altavilla and Silvia Marinoni, which can be found in the "Internal Reports" Section of Wiki-Bo.

4 Instrument Tests

These more sophisticated tests are only required for instrument with spectroscopic capabilities.

4.1 Second Order Light Contamination

Some spectrographs can present this problem (e.g. DoLoRes@TNG, and probably also EFOSC2 @ESO). Light coming from the second order of the grism falls into the same region of the CCD where the first order falls, i.e., the one we are interested in. In the case of TNG, for example, light from the blue side of the spectrum (approx U, B and V bands) falls on top of the red side (around ∼950 nm). The more flux is present on the blue side of the spectrum, the higher the resulting contamination. Hot stars have therefore more contamination than red stars, and most of our candidate SPSS are hot stars.

To correct for the second order contamination, spectra of two very well known candidate SPSS, a blue one and a red one, must be obtained. Literature flux tables with good quality must exist for these stars (i.e., from CALSPEC). Anyway, uncontaminated spectra of the same two SPSS should also be obtained, by putting an appropriate filter on top of the grism or grating. Two good candidates for the test can be:

- SPSS 014 (HZ44) as the blue star;
- SPSS 120 (G146-76) as the red star;

The following exposures are needed:

- Observe each of the two SPSS with5" slits (plus 2" slit and wavelength lamp), with the red (contaminated) grism;

- Observe each of the two SPSS with the same slits and grisms as above, but adding a wide band filter to suppress the second order contamination (e.g. z' or I, depending on the instrument);
- Observe also the night's calibrator (Pillar or Primary) in the same conditions, both with and without the optical filter;

More details on the second order contamination issue can be found in *"E2V4240 CCD second order contamination test (DOLORES@TNG)"* by Giuseppe Altavilla and Silvia Marinoni, in the "Interanl Reports" Section of the Wiki-Bo pages.

4.2 Polarization

The issue of polarization has been raised by the TNG Time Allocation Committee. They asked us to prove that the polarization added by the plane mirrors inside DoLoRes do not alter the outcoming flux of our candidate SPSS spectra enough to compromise the required precision (a few percent). This effect is of course more important if the observed SPSS have some intrinsic polarization.

To test the effect of polarization, two stars with very different levels of polarization should be chosen, e.g., from Turnshek et al. (1990). Both stars should be observed at half a dozen different position angles, from 0 to 180 deg, using a wide slit (5-6 time the seeing, to gather all incoming flux). The last exposure of each sequence should also be taken with a narrow slit (1" to 2") and a wavelength calibration lamp.

More information on the polarization issue can be found in *"Preliminary Notes on the possible effect of polarization on ground-based DU13 spectrophotometric observations of Gaia SPSS"* by Michele Bellazzini, which can be found in the "Internal Reports" Section of the Wiki-Bo.

5 Reference Documents

Altavilla, G., Bellazzini, M., Pancino, E., et al., 2007, *The Primary standards for the establishment of the GAIA Grid of SPSS. Selection criteria and a list of candidates.*, `GAIA-C5-TN-OABO-GA-001`, URL `http://www.rssd.esa.int/llink/livelink/open/2736914`

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