The Gaia Spectrophotometric Standard Stars

C. Jordi[1], J.M. Carrasco[1], E. Pancino[2], G. Altavilla[2], S. Marinoni[2], G. Cocozza[2], F. Figueras[1], H. Voss[1], S. Galleti[2], S. Ragaini[2], W. Schuster[3], C. Fabricius[1], M. Monguió[1], E. Masana[1], M. Bellazzini[2], C. Cacciari[2], A. Bragaglia[2], M. Weiler[1]

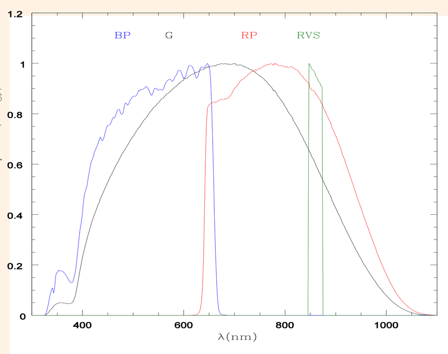
[1]*Universitat de Barcelona – ICC/IEEC, Martí i Franquès 1, 08028 Barcelona, Spain ;* [2]*Osservatorio Astronomico di Bologna, INAF, Via C. Ranzani, 1, I-40127 Bologna, Italy;*
[3]*Observatorio Astronómico Nacional, Universidad Nacional Autónoma de México, Apartado Postal 877, C. P. 22800 Ensenada, B. C., México*

We describe the ongoing observational survey aimed at building a grid of about 200 spectrophotometric standard stars, with an internal precision of 1% and tied to Vega within a few percent, for the absolute flux calibration of *Gaia* photometry. Until to now, more than 400 observing nights were devoted to the project, distributed in several observatories (CAHA in Almería, TNG in La Palma, NTT in La Silla, San Pedro Mártir in México, Loiano in Italy, and many partial nights with robotic REM in La Silla) and for both spectroscopic and photometric campaigns. Additional observations are still needed for finalising the absolute photometric calibrations and for continuing the monitoring of variability (short and long term) in order to discard non optimal candidates.

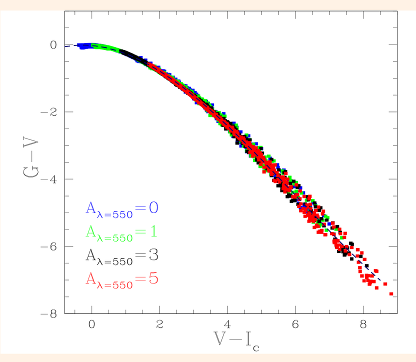
Gaia Photometry and spectrophotometry

G, G_{BP}, G_{RP} and G_{RVS} passbands

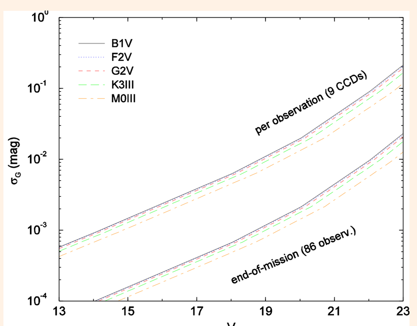
- *Gaia* measures the white light through a very broad band G in the range ~ 350-1000 nm
- Small bolometric correction; G_{lim}~ 20 → V_{lim}~ 20-25
- G_{BP}, G_{RP} and G_{RVS} are the bands corresponding to spectrophotometry and spectroscopy



G, G_{BP}, G_{RP} and G_{RVS}-passbands corresponding to the measurement of white light, BP/RP and RVS fluxes



G-V color as a function of *V-I*$_c$



G magnitude uncertainty

G band

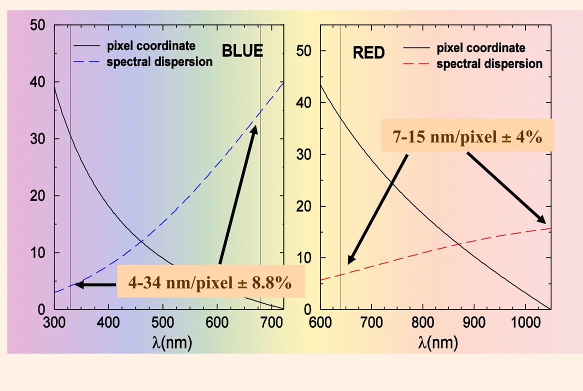
- 9 CCDs per passage (4.42s per CCD)
- 70 observations in average
- σ_{Mv}: σ_G contribution smaller than sp contribution
- It provides the best S/N for variability detection
- G-V is a function of spectral type and reddening
- G_{lim} ~20, V_{lim} ~ 20-25

Light curves: precision at V~20 as Hipparcos at V~9

BP/RP spectrophotometry

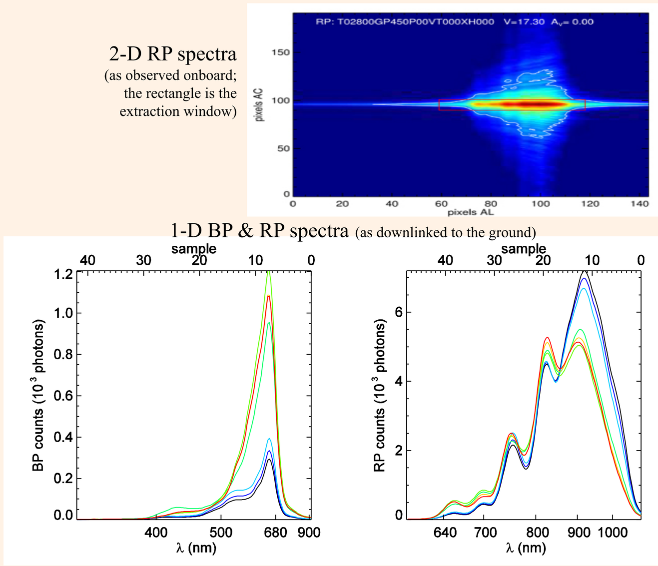
BP/RP spectrometers

- Two fused silica prisms
- Two low-pass and high-pass filters
- Blue and red sensitive CCDs



Dispersion law

Observed spectra



Different colours correspond to different combinations of T_{eff} and logg

(Spectro)photometry calibration

Principles

Gaia photometric calibration is carried out by the Coordination Unit #5 of the Data Processing and Analysis Consortium. The teams involved are those in Cambridge, Barcelona, Bologna and Leiden.

It is not feasible to design a calibration procedure exclusively based on thousands of standard stars with on-ground observations. Instead, calibration will rely on millions of 'internal standard sources' complemented with 'few' (hundreds) of on-ground standard stars.

The process has been thought as two separate tasks:

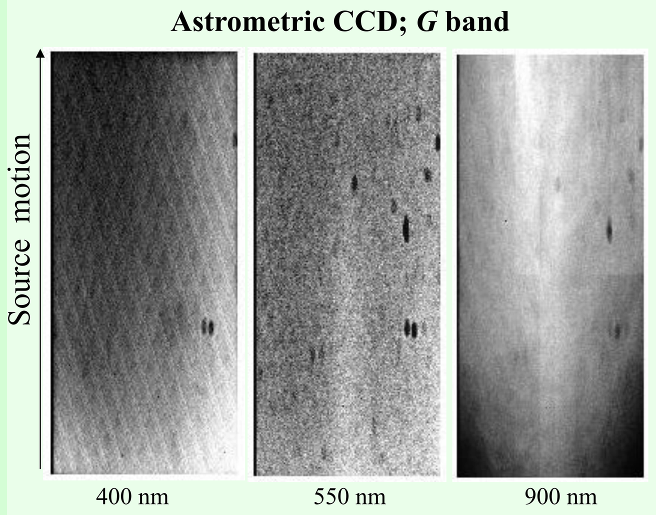
1. **the internal calibration**: to report all the observations to a reference instrument (each wavelength and each position across the focal plane has its own PSF, sensitivity, optical distortion, …), and

2. **the absolute calibration**: to report the relative flux scale to an absolute flux scale in physical units, tied to the calibration of Vega, through a set of standard stars.

Internal calibration

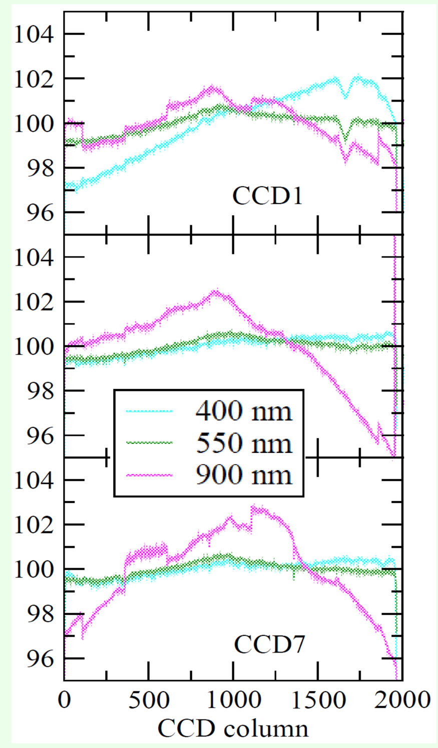
The aim is to define a mean instrumental system and to tie to it all observations in the several CCDs and two FoVs during the entire mission.

Astrometric CCD; *G* band



Examples of flatfield images

Spectrophotometric CCD *G*$_{BP}$ band



Examples of integrated column response non-uniformity

Absolute calibration

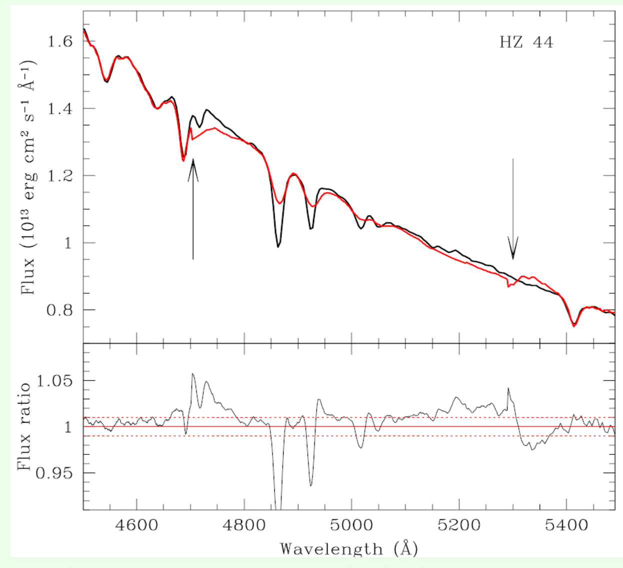
Based on a large set (200-300) of homogeneously calibrated SpectroPhotometric Standard Stars (SPSS), covering a range of spectral types: hot, almost featureless stars such as WD or hot subdwarfs, and also spectra with absorption features, both narrow (atomic lines) or wide (molecular bands), appearing both on the blue and the red side of the spectrum.

Campaigns to acquire the required observations:

- **Spectrophotometry**: to measure the absolute fluxes as a function of wavelength
- **Spectroscopy**: to measure relative fluxes as a function of wavelength
  R~1000 to oversample *Gaia* spec by a factor 4-5
  Wavelength coverage: 330–1050 nm; SNR~100
  Typical uncertainty with respect to the assumed calibration of Vega of ~3%; very homogeneous data treatment and quality, ~1% internal precision

- **Absolute photometry**: to calibrate the relative spectroscopic fluxes
- **Differential photometry**: to monitor the SPSS candidates for short and long-term variability

Photometric stability within ±5 mmag, necessary to ensure the above accuracy and precision.



Top: Our spectrum (black) compared to CALSPEC tabulated spectrum (red) in the region were we found discrepancies (marked by arrows), most probably due to mismatch in CALSPEC spectrum (Bohlin, Dickinson, & Calzetti, 2001).
Bottom: Ratio Ours/CALSPEC spectra and the ±1% margin of internal precision acceptance.

GRID OF *Gaia* SPECTROPHOTOMETRIC STANDARD STARS (SPSS)

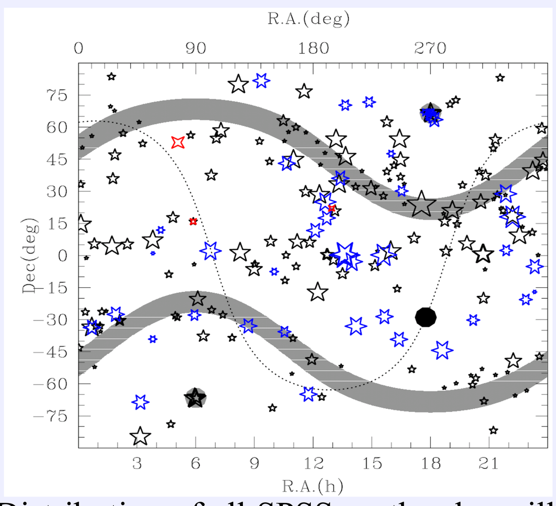
Sample of SPSS

Pillars: G 191-B2B, GD 71, and GD 153, three well known DA white dwarfs widely used as standards [CALSPEC, Bohlin et al. (1995) and Bohlin (1996)].

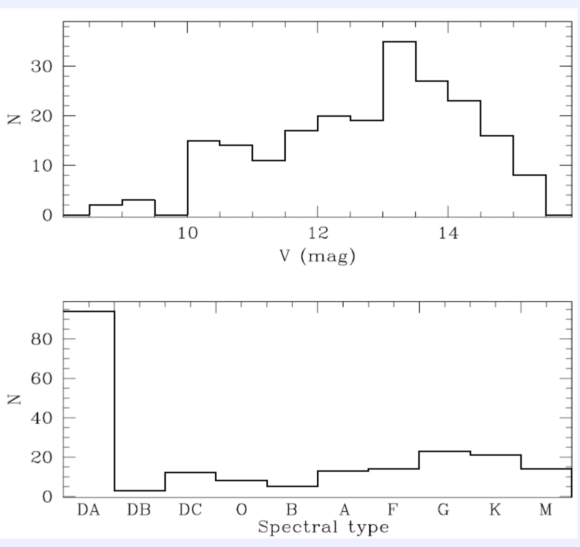
Primary SPSS candidates: 44 bright (9<V<14) well known spectrophotometric standards with spectra in the CALSPEC flux scale, or which can be easily tied to that scale with dedicated ground-based observations.
The *Primary* SPSS are calibrated using the *Pillars*, and constitute our grid of groundbased calibrators for the *Secondary* SPSS.

Secondary SPSS candidates: 162 stars from:
–*"Catalog of Spectroscopically Identified White Dwarfs"* (McCook & Sion, 1999)
–*"A Catalog of Spectroscopically Confirmed White Dwarfs from the Sloan Digital Sky Survey Data Release 4"* (Eisenstein et al., 2006)
– list of 121 DA white dwarfs for which there are FUSE13 data (Barstow 2010, private communication)
– metal poor stars from *"A survey of proper motion stars. 12: an expanded sample"* (Carney et al., 1994)
– *"The HST/STIS Next Generation Spectral Library"* (Gregg et al., 2004)
– *"The M dwarf planet search programmeat the ESO VLT + UVES. A search for terrestrial planets in the habitable zone of M dwarfs"* (Zechmeister et al., 2009) and from *"Rotational Velocities for M Dwarfs"* (Jenkins et al., 2009)
– *"Medium-resolution Isaac Newton Telescope Library of Empirical Spectra (MILES)"*15 (Sánchez-Blázquez et al., 2006)
– *"SEGUE: A Spectroscopic Survey of 240,000 Stars with g=14–20"* (Yanny et al., 2009),
– *"The Ecliptic Poles Catalogue Version 1.1"* (Altman & Bastian, 2009),
– *The WD online catalogue* maintained by A. Kawka, and information from Kawka et al. (2007)
– *A provisional list of targets for the ACCESS mission* (Kaiser et al., 2007; Kaiser, 2010)

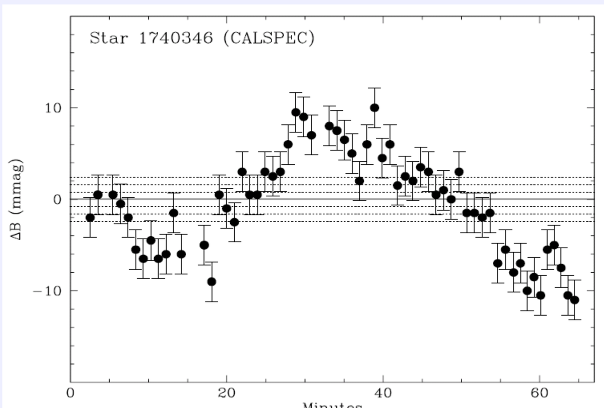
The full list of SPSS is available in Pancino et al (2012): A&A submitted



Distribution of all SPSS on the sky: pillars (red), primary (blue), secondary (black). Grey circles are ecliptic poles. Black circle is Galactic center. The grey strips are at ±45 deg from the Ecliptic poles and are scanned more often.



Distribution of all SPSS in magnitude and spectral type.

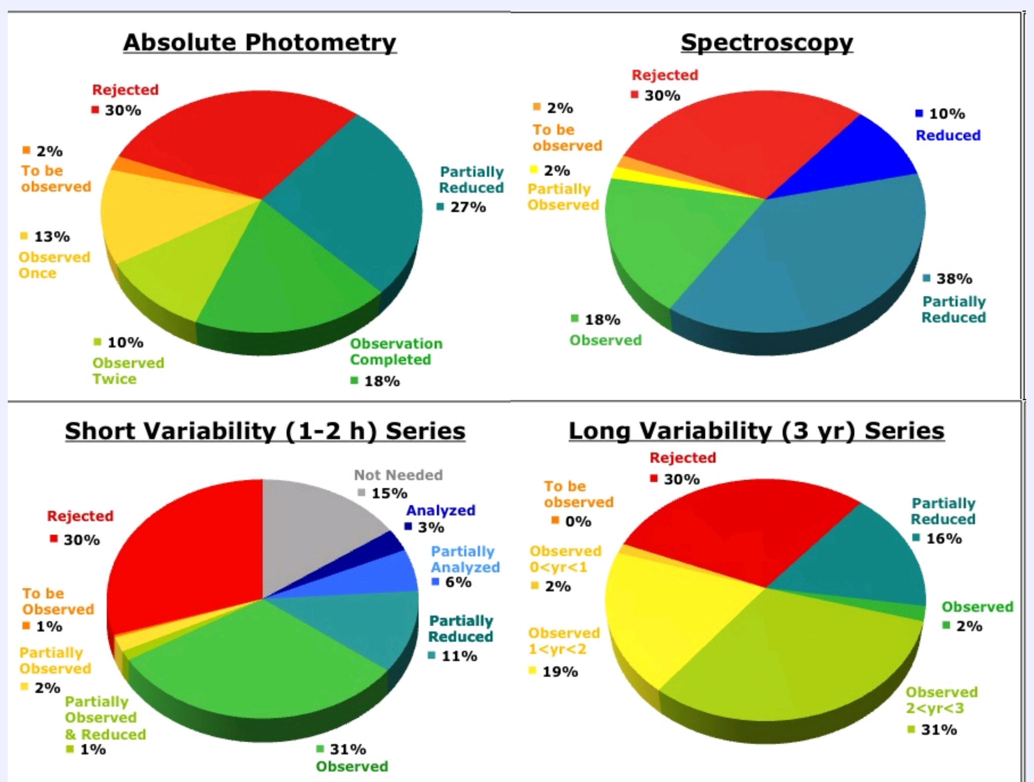


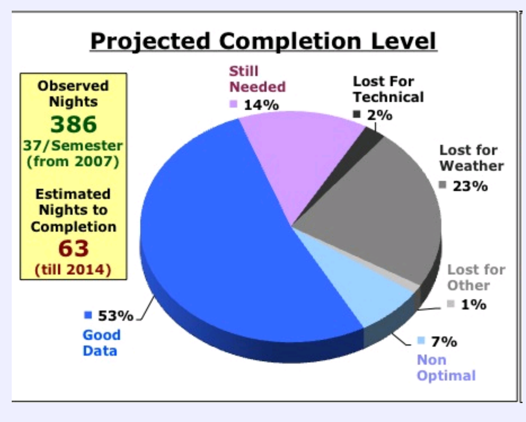
The CALSPEC standard 1740346 was found to vary with an amplitude of ~10 mmag; most probably of δ-Scuti type.

Observational facilities used for the project

– EFOSC2@NTT at the ESO La Silla Observatory, Chile, our Southern facility for spectroscopy and absolute photometry, and for some constancy monitoring; 31 nights
– CAFOS@2.2m at the Calar Alto Observatory, Spain, one of our Northern spectrographs and imagers, for absolute and relative (spectro)photometry; 88 nights
– DOLoRES@TNG at the Roque de Los Muchachos in La Palma, Spain, one of our Northern spectrographs and imagers, for absolute and relative (spectro)photometry; 54.5 nights
– BFOSC@Cassini in Loiano, Italy, providing a few spectra and more relative photometry in the Northern hemisphere; 85 nights
– LaRuca@1.5m at the San Pedro Mártir Observatory, Mexico, our Northern source of absolute and relative photometry; 119 nights
– ROSS@REM at the ESO La Silla Observatory, Chile, our Southern facility for relative photometry; ~400 partial nights in robotic mode

Status of the project





- The main campaign (spectroscopy) should be completed within 2012, with the last ESO run assigned in July 2012 for the South and the last Calar Alto run in May 2012 for the North.
- The short-term variability monitoring is 85% complete
- The long-term monitoring will probably be completed around 2013–2014.

Data products will be made public together with each Gaia data release. At the moment the accumulated data and literature information are stored locally and can be accessed upon request.

More information in Wiki-Bo *Gaia* website http://yoda.bo.astro.it/wiki/index.php/Main_Page (username and password provided upon request)

For more information please contact C. Jordi (carme@am.ub.es)