Hot Stars Survey with the Gaia Space Mission

A.Lobel[1], C.Liu[2] , Y.Frémat[1], C.A.L.Bailer-Jones[2], R.Blomme[1], J.C.Bouret[3], Y. Damerdji[4], C. Delle Luche[5], E.Gosset[4], D.Katz[5], C.Martayan[6,5], Y.Nazé[4], C.Neiner[5], G. Rauw[4], A.Recio-Blanco[7], R.Sordo[8], F.Thévenin[7], A.Vallenari[8], Y.Viala[5], J.Zorec[9]

1. Royal Observatory of Belgium, Brussels, Belgium
2. Max-Planck Institute for Astronomy, Heidelberg, Germany
3. Laboratoire d'Astrophysique de Marseille, Marseille, France
4. Institut d'Astrophysique et de Géophysique, Université de Liège, Liège, Belgium
5. Laboratoire GEPI, Observatoire de Paris Meudon, France
6. European Southern Observatory, Chile
7. Laboratoire Cassiopée, Université de Nice-Sophia-Antinopolis, OCA, Nice, France
8. INAF, Padova Observatory, Padova, Italy
9. Institut d'Astrophysique de Paris, Paris, France

More information on Gaia can be found :
http://sci.esa.int/gaia

1. The Gaia space mission

Gaia is a cornerstone mission of the ESA space program, scheduled for launch in Spring 2012. The satellite will repeatedly survey the whole sky to observe positions, parallaxes, and proper motions to the μas precision level for ~10^9 objects brighter than 20 mag.

In addition to the astrometric instrument, the satellite will have a dispersed photometric instrument aboard (the **B**lue **P**hotometer or BP band: 330–680 nm and the **R**ed **P**hotometer or RP band: 640–1050 nm; Fig. 1) and a medium resolution spectrograph (RVS or **R**adial **V**elocity **S**pectrograph: 847–874 nm). These instruments will provide homogeneous spectrophotometry and astrometry of a large variety of objects for the accurate simultaneous measurement of **R**adial **V**elocities (RVs), as well as the determination of **A**strophysical **P**arameters (APs). Gaia will therefore be a real breakthrough in stellar, galactic and extragalactic astrophysics. Gaia is also a challenge due to the huge amount of data that will have to be processed. The European scientific community has therefore set up the Gaia DPAC (**D**ata **P**rocessing and **A**nalysis **C**onsortium) in 2006, which involves more than 300 scientists in 15 countries with the required expertise that covers different research domains. All the scientists are currently involved in the preparation of Gaia's intermediate and final output catalogs.

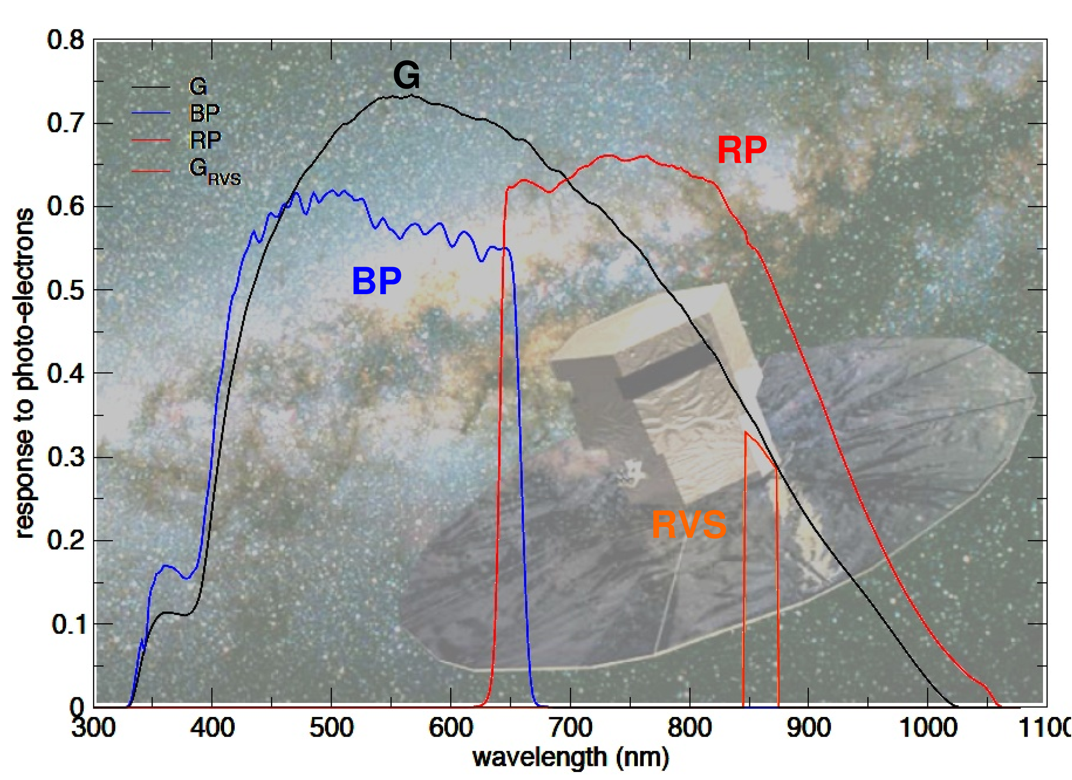

Fig. 1: Response curves of the Gaia passbands C.Jordi (2009, Technical Note)

3. Auxiliary data

Auxiliary data are required to derive the radial velocities using cross-correlation techniques or minimum distance methods. They are also needed during the determination of the astrophysical parameters, where the data is used as a reference or as a learning sample. Finally, a part of it is used to test the whole Gaia pipeline. These auxiliary data are mainly formed by synthetic and observed spectra in the Gaia wavelength range. Currently the observations we use are/were obtained at the Observatoire de Haute Provence (AURELIE and SOPHIE spectrographs), at the Observatoire du Pic du Midi (NARVAL spectrograph), and at ESO (EFOSC).

An important effort is made to compute synthetic data. Currently, our computations for O and B type stars are based on the TLUSTY NLTE atmosphere models computed by Lanz & Hubeny 2003; 2007. However, comparisons (Bouret et al. 2008, *Fig. 2*) were made using different codes (FASTWIND, CMFGEN) in order to check the model assumptions and adopted atomic data. Our conclusion, so far, is that due to the instrument spectral resolution TLUSTY/SYNSPEC spectra are accurate enough to describe O and B type stars.

2. Hot stars

Thanks to Gaia, high accuracy parallaxes will become available for a large sample of hot stars (i.e. O and, mainly, B type stars). According to the Besançon Universe model (Jordi 2007, ASP Conf. Series, 364, 215), about 900,000 OB stars should be observed. About one sixth of these stars (Briot & Robichon 2005, ESASP, 576, 561) are expected to have parallaxes with a relative precision better than 3%. This large number will enable us, for the very first time, to perform unbiased statistical analyses and high accuracy luminosity computations based on a homogeneous dataset. Due to the large number of objects involved, the automation of the classification procedure is an important issue for making the data rapidly usable and advantageously available to the whole astronomical community after completion of the mission. This classification also has its importance during the mission, for the direct measurement of radial velocities, the identification of new objects, to initiate science alerts, etc.

4. Astrophysical parameters

Although different approaches to derive stellar astrophysical parameters (T_{eff}, log(g), A_V) are developed and tested, these methods all have in common that they compare observed and synthetic data (see Box 3). Gaia's **G**eneral **S**tellar **P**arametrizers for BP/RP (GSP-Phot) and RVS (GSP-Spec) data are prepared by teams at the Max Planck Institute for Astronomy in Heidelberg (Germany) and at the **O**bservatoire de la **C**ôte d'**Az**ur in Nice (OCA, France), respectively. They explore different approaches such as the use of supervised learning algorithms (e.g. **S**upport **V**ector **M**achines or SVM, artificial neural network, nearest neighbours, or k-nearest neighbour), or in the case of GSP-Spec the application of the MATISSE algorithm (Recio-Blanco et al. 2006). Additionally, data combination (BP/RP+RVS) is, in particular, explored in an **E**xtended **S**tellar **P**arametrizer (ESP) module using a Simplex least squares procedure, to estimate the APs and the E(B-V) from the study of the DIB at 862.1 nm (Fig. 4). This module is applied on synthetic data, and on observations to test the quality of the theoretical spectra (Fig. 5). By using parallaxes and derived APs, fundamental stellar parameters (e.g. mass, radius, age) will be derived at the end of the procedure with an algorithm named FLAME (Final Luminosity, Age and Mass Estimator), prepared by teams from the University of Rennes and OCA. Currently, the most promising results (Fig. 6) are obtained by the SVM regression algorithm developed in GSP-Phot. For OB stars, the effective temperature and interstellar reddening are highly correlated, but the relative accuracy estimated from the result distributions on these parameters are quite reasonable for massive stars.

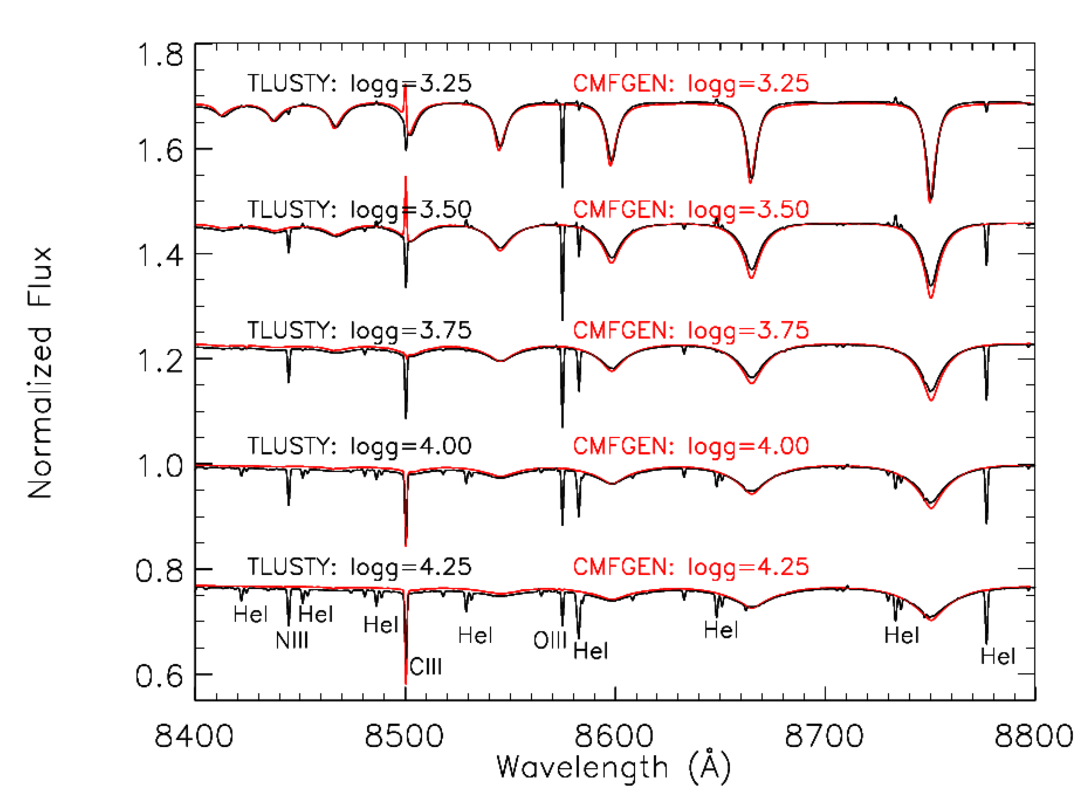

*Fig. 2: Comparison between synthetic spectra computed with CMFGEN (**red**) and TLUSTY (**black**). The most significant differences are due to the lack of atomic data in CMFGEN.*

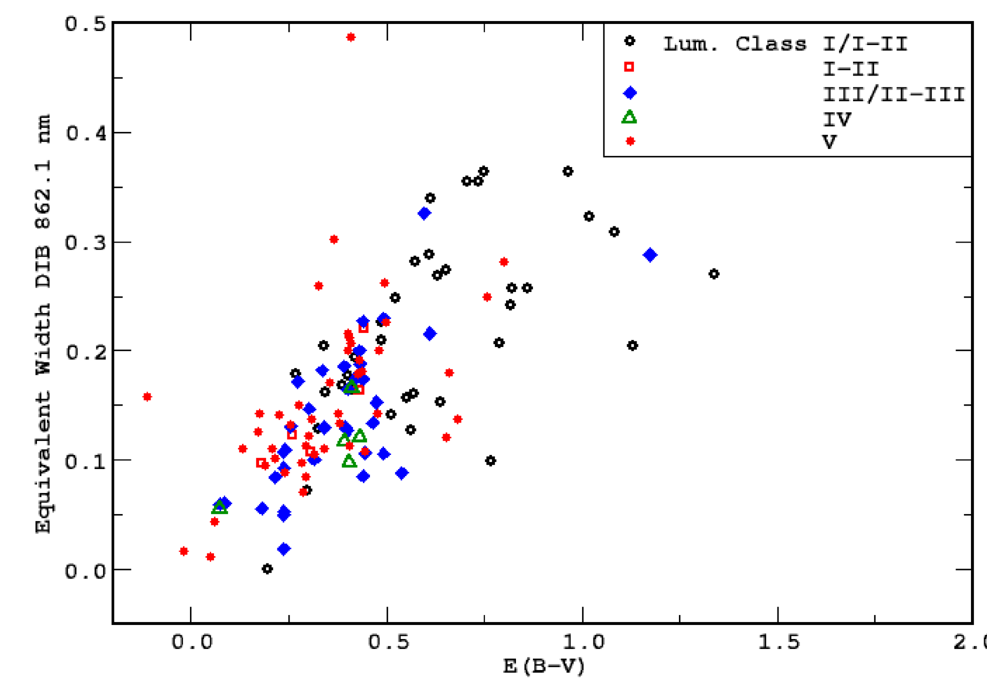

*Fig. 4: Plot of the equivalent width of the **D**iffuse **I**nterstellar **B**and (DIB) at 862.1 nm as a function of E(B-V) for several hot stars observed in the framework of Gaia. This DIB indeed has been shown to be a good E(B-V) indicator (e.g. Munari et al. 2008, A&A, 488, 969) with a behavior that depends on the line of sight and the environment (Wallerstein et al. 2007, PASP, 119, 1268). We are searching for the best way to use and implement it in the pipeline.*

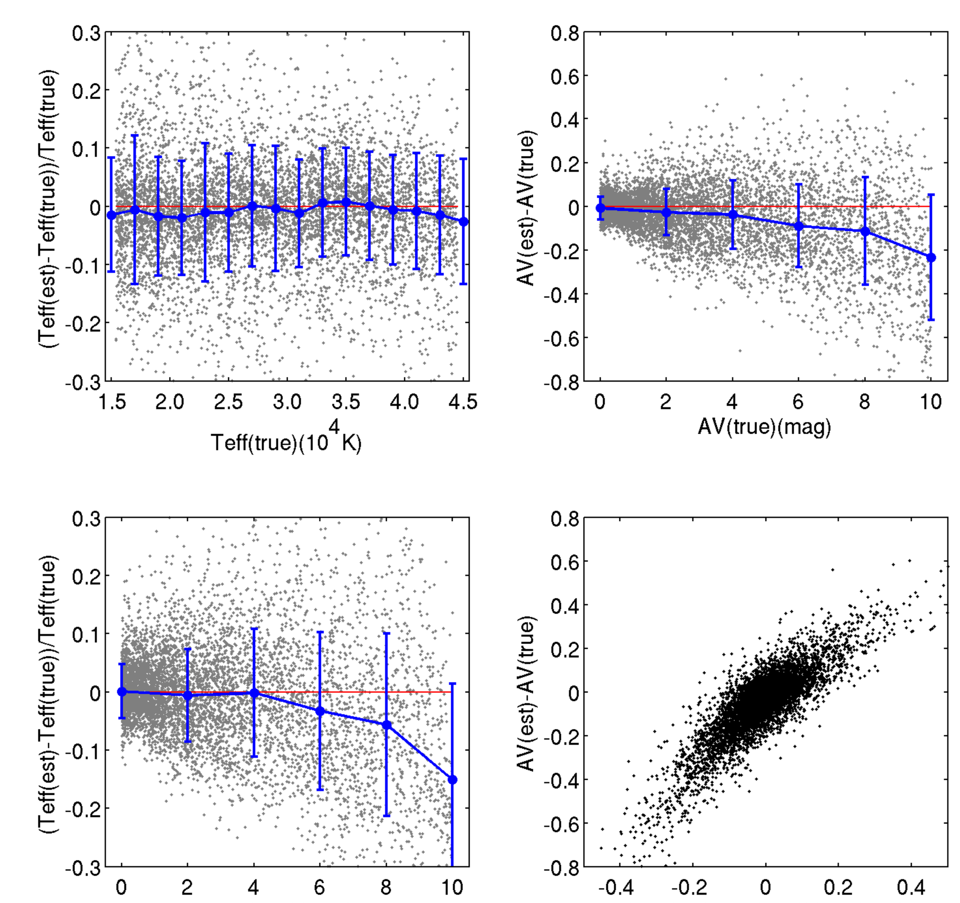

Fig. 6: Results obtained from the BP/RP data. The grey dots in top-left panel show the relative error of Teff estimated by GSP-Phot against the true values of Teff for OB stars. The filled blue cycles are median values of the errors at various temperatures, while the error bars show the standard deviations. The top-right and bottom-left panels show the errors of Av and Teff against true values of Av, respectively. The bottom-right panel exhibits the high correlation between the errors of Teff and those of Av.

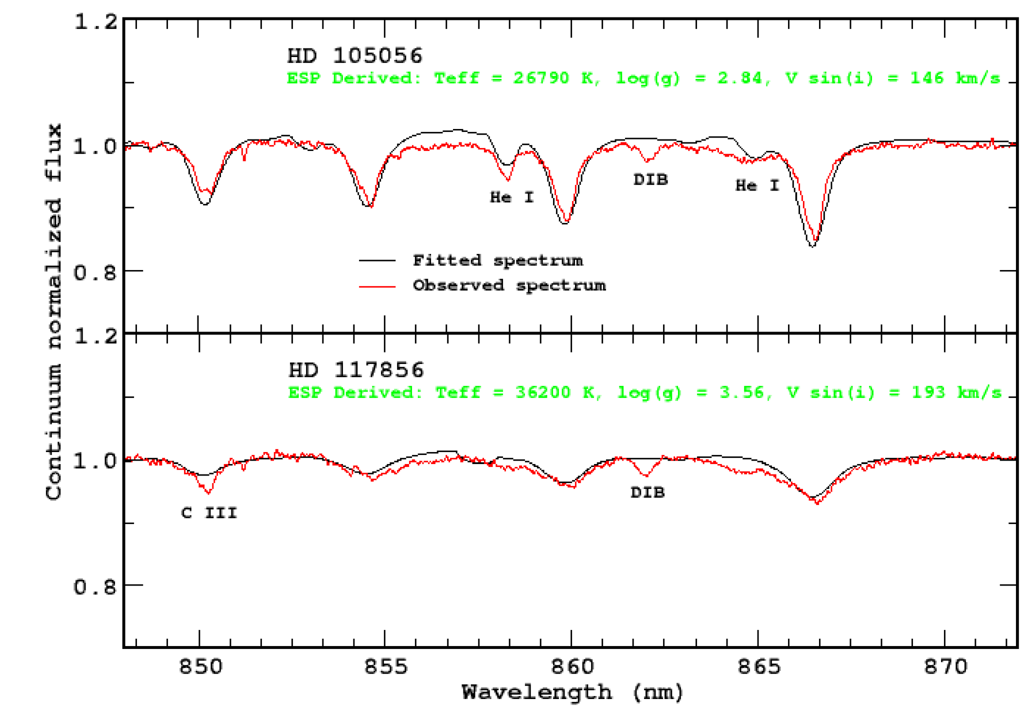

Fig. 5: Observations were fitted using the simplex least squares algorithm in order to derive the APs (see results in green text). Although the agreement between the spectra is not yet completely perfect, the obtained parameters are generally consistent with published values except for V sin(i). For HD 105056, Lefever et al. (2007, A&A, 463, 1093) found a Teff = 27,000 K and a log(g) = 2.70, while for HD 117856, Gulati et al. (1989, A&A, 80, 73) derived a Teff = 35,600 K.

5. Radial velocities

Data from the Gaia RVS instrument will give us radial velocities of the observed stars. Radial velocity determinations form the basis for detecting binaries and determining their stellar parameters. The data will also be used for detecting runaway stars and determining if clusters of hot stars are gravitationally bound. RVS data are therefore highly relevant for the subjects of star formation and stellar evolution. Combined with other Gaia data, the RVS velocities will lead to a full 6-dimensional knowledge of stellar positions and velocities needed to understand the formation process of the Galaxy.

The radial velocities are determined by comparing the RVS spectra to theoretical templates (Fig. 7). A number of techniques are available to derive the radial velocity from these comparisons. To make sure we can use the advantages of all these techniques, we determine the radial velocities in three independent ways: **(1)** by cross correlation in direct space, **(2)** by cross correlation in Fourier space, and **(3)** by the minimum distance method. In addition, the **TodCor** (i.e. 2-D cross-correlation) technique is applied to search for possible binaries and to determine the velocities of both components, if detected.

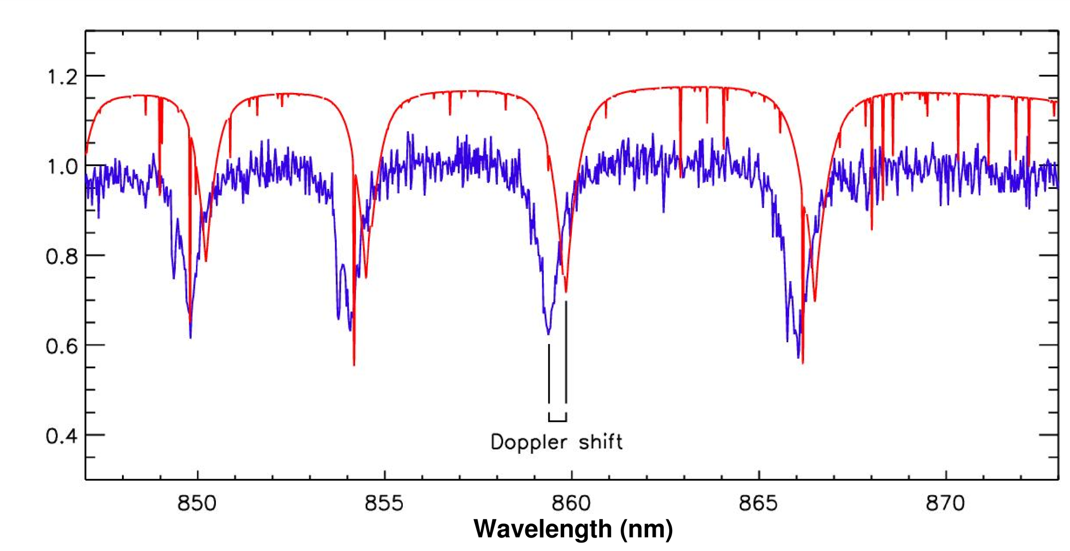

Fig. 7 : Radial velocity determination

6. Future perspectives

Gaia is an ambitious and challenging mission that will provide in the next decade parallaxes with a precision 100 times better and for 1000 times more objects than HIPPARCOS. The prior classification of stars will be an asset in the overall Gaia process and also for the query of the output catalogue. The final output catalogue is expected for 2020, but releases of intermediate versions are planned some years after launch. Much hope is placed further in the detection and the identification of science alerts (e.g. detection of supernovae, of huge mass loss events, …) that will be immediately communicated to the entire scientific community. Thanks to Gaia, accurate bolometric magnitudes for a large fraction of the known hot stars will be available, radial velocities up to magnitude 12 will be obtained at about 40 epochs (permitting the detection and/or study of binaries). Detection of variability and classification will also be performed based on the BP/RP and on the RVS, 3D dynamical maps of their position in the Galaxy will be available, etc. For all these reasons, Gaia will be a real breakthrough in the study of the physics and evolution of hot stars.

This work is partially funded by the ESA/Belgian Federal Science Policy in the framework of the PRODEX program (C90290).