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POSTCARD FROM GAIA

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Abstract. Nineteenth of December 2013 9h12 UTC, Gaia is launched from Kourou on a Soyouz-Frégat. Fourteenth of January 2014, Gaia is inserted on its orbit around the second Sun-Earth Lagrange point, 1.5 million kilometres beyond the Earth. The first months of the mission have been devoted to the commissioning of the satellite and its instruments and, since July, Gaia has entered the nominal mission phase. This presentation summarises the Gaia activities over the last months and presents the status of the mission at the beginning of the nominal phase.

Keywords: Surveys: Gaia.

1 Introduction

Gaia has been launched from Kourou on the 19^{th} of December 2013 at 9h12 UTC, by a Soyouz-Frégat. This success is the results of about 20 years of work during which several hundreds of people have been committed to the preparation of the Gaia mission. The ideas for a successor to Hipparcos have emerged in the first half of the 90s. In 2000, the Gaia mission was selected by the European Space Agency (ESA) as a cornerstone of its Horizon 2000+ space program. The next 13 years have been devoted to the definition of the technical design, then of the detailed technical design, building, assembly and ground-testing of the satellite. In 2006, and in parallel to the work on the spacecraft, a consortium has been charged by ESA to prepare and later operate the ground segment for the processing of the Gaia data. The Gaia Data Processing and Analysis Consortium (DPAC), today counts about 450 members from 25 different countries. The following pages present a tiny fraction of the work of the Gaia and DPAC people.

Gaia is orbiting around the second Lagrange point (L2) of the Sun-Earth system, about 1.5 million kilometres beyond the Earth. It has taken a little bit less than a month for Gaia to journey to L2. The insertion manoeuvre on the L2 orbit has been finalised on the 14^{th} of January 2014. Gaia is now repeatedly surveying the full celestial sphere for the 5 years of nominal mission and maybe for one or a few more years, if the fuel supply permits (which is currently the case). At the moment of the "Journées de la SF2A", June 2014, Gaia is at L2 since 5 months. These "Journées" offer an opportunity for a reminder of the Gaia science case and design (Sect. 2), for a presentation of the first news from the satellite (Sect. 3) and for an overview of the on-going ground-based activities connected to Gaia (Sect. 4).

2 Gaia in a few words

Gaia (Perryman et al. 2001; Lindegren 2010) is a full-sky survey mission. It is continuously and repeatedly observing the sky down to magnitude 20. This represents more than a billion sources. The bulk of them are stars from the Milky-Way, i.e. of the order of 1% of the total stellar content of our galaxy. In 5 years, Gaia will observe on average each source about 70 times (40 times for the RVS) with its 3 instruments: an astrometric instrument, a spectro-photometer and a medium resolution near infra-red spectrograph, the Radial Velocity Spectrometer or RVS. As successor of Hipparcos, Gaia will measure the position, trigonometric distances and proper motions of this billion sources. The spectrograph and spectro-photometer will complement the astrometric information with astrophysical parameters, e.g. radial velocities and stellar atmospheric parameters.

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2.1 Science case

Gaia will make a complete census of the celestial sources brighter than magnitude 20. This represents a large variety of objects and as a consequence the Gaia science case is very broad. The first science driver of Gaia is the study of our Galaxy, the Milky-Way: map its spatial, kinematical and chemical structure, reconstruct the history of the assembly of the stellar populations (inner and outer halo, thick and thin disk, bulge and bar), constrain the physical processes that drives the evolution of large spiral galaxies (turbulence, accretion, stellar mixing, dynamical resonances, etc...). Gaia is expected to provide distances with precisions better or equal to 10% for 150 millions stars (e.g. in zero extinction area, 10% precision on the parallax should be achieved for a 12 magnitude star located at 10 kpc).

Another important field of research for Gaia, is stellar physics. The direct measure of the distance will provide the absolute magnitude of the stars, which is a key parameter in stellar modelling. As a consequence, there will be a strong synergy between Gaia and the asteroseismology missions like, Kepler, Corot or the recently selected Plato mission. With 70 observations per source on average distributed over 5 years, Gaia will allow to study the time domain: variable stars, eruptive and cataclysmic variables, double and multiple stars (including the determination of stellar masses with precisions up to 1%). Gaia will provide information on the interstellar medium, in particular via a Diffuse Interstellar Band (DIB) located at 8620 Å and included in the RVS wavelength range. Gaia should detect extra-solar planets by spotting the (astrometric) reflex motion of the star due to the planetary companion(s). It should provide a census of Jupiter-like planets around bright stars within 200 parsecs, as well as masses for 2 000 to 5 000 planets with periods in the range 2 to 10 years.

In the solar system, Gaia should bring a factor 30 improvements on the orbits of small bodies, masses for about a hundred binary objects and shapes and dimensions for thousands of asteroids. By measuring the deflection of the light caused by the gravitational field of massive objects in the solar system (e.g. Jupiter), Gaia will provide tests of the theory of the general relativity. Gaia should also observe more than a million galaxies and 500 000 quasars. These later observations, performed in the optics, will allow for a direct link between Gaia's reference frame and the International Celestial Reference Frame (ICRF) defined in the radio domain. Gaia will spot some transient phenomenons which deserve a rapid ground-based follow-up and are interesting to observe without waiting for the publication of the catalogues. To allow for a rapid ground-based reaction, the DPAC will issue public science alerts. A typical case of science alerts are the super-novae. About 6 000 super-novae alerts are expected in 5 years, with 85% of SNe Ia and 30% discovered, and therefore observable, before maximum light.

2.2 Design

Gaia continuously surveys the sky with 2 telescopes. Their pupil areas are rectangular: 1.45×0.5 m. The 2 lines of sight are separated by 106.5 deg (hereafter referred to as the *basic angle*). The two fields of view, of 0.39×0.22 deg^2 each, are imaged on a single focal plane. It is made of 106 CCD detectors, for a total of about 1 billion pixels. The spatial resolution of a pixel is 59 mas by 177 mas.

Gaia payload's is made of 3 instruments. The astrometric instrument images the sky in a broad band G: [330, 1000] nm. Table 1 summarises the expected precisions (updated in July 2014 after the conclusion of the commissioning) on the end-of-mission parallaxes. This table is extracted from the Gaia *science performance* web page on the ESA Cosmos site, where a full detailed discussion of Gaia performances can be found: `http://www.cosmos.esa.int/web/gaia/science-performance`.

Table 1. Expected precision, as of July 2014, on the end-of-mission parallaxes. *"Bright stars"* corresponds to the V magnitude ranges 3 to 12 for B1V and G2V spectral types and 5 to 14 for M6V stars.

V	B1V	G2V	M6V
Bright stars	5-14 μas	5-14 μas	5-14 μas
15	26 μas	24 μas	9 μas
20	600 μas	540 μas	130 μas

The spectro-photometer (Jordi et al. 2010) is made of two prisms to disperse the light of the sources in two low resolution spectra, a blue spectrum [330, 680] nm and a red spectrum [640, 1050] nm. The spectral dispersion varies from 3 nm.pixel^{-1} at 330 nm to 27 nm.pixel^{-1} at 680 nm (for the blue channel) and from 7 nm.pixel^{-1} at 640 nm to 15 nm.pixel^{-1} at 1050 nm (for the red channel). The spectro-photometer provides the spectral energy distribution of the sources. For the stars, this allows to derive in particular their atmospheric parameters (effective temperature, surface gravity, metallicity) and mean alpha elements over iron ratio as well as to constrain the interstellar reddening.

The Radial Velocity Spectrometer (Katz et al. 2004; Katz 2009; Cropper & Katz 2011) is a medium resolution ($R = \lambda/\Delta\lambda = 11\ 500$) integral field near infra-red ([845, 872] nm) spectrograph. The RVS will record 40 epochs, on average, per source during the 5 years of the mission. The first objective of the spectrograph is the measure of the radial velocities down to about V=16 magnitude (for the redder stars). At the limiting magnitude, the end-of-mission precision on the mean radial velocity will be of the order of 15 km.s^{-1}. On the bright side (down to V=12-13), the expected end-of-mission precision is of the order of 1 km.s^{-1}. In addition to the radial velocity, the RVS will provide information on the stellar atmospheric parameters, on the abundance of the chemical species contained in its wavelength range (e.g. Si, Ti, Mg, N, S, Ne, C depending on the spectral type), on the interstellar reddening or on the rotational velocity.

In nominal observing mode, all the pixels are not transmitted to the ground, because this would largely exceed the antenna capabilities. Instead, "windows" around objects brighter than the limiting magnitude, are readout from the CCDs and telemetred to the Earth.

3 Postcard from L2

Gaia is orbiting around the second Lagrange point (L2) of the Sun-Earth system since the 14th of January 2014. Mid-January, Gaia has started to record and transmit astrophysical data to the Earth. The data are received by the ESA Deep Space antenna in Cebreros (Spain), New Norcia (Australia) and Malargue (Argentina). They are then transmitted to the ESA and DPAC processing centers which have been successfully activated and process daily the incoming data. From January to June 2014, Gaia has collected a little bit more than 2 billion astrometric and spectro-photometric observations (representing respectively about 20 billion astrometric and 4 billion of spectro-photometric measures) and 500 million of spectroscopic observations (1.5 billion of RVS spectra)*. The volume of the raw scientific data is about 2.6 TB, while the processed data represent about 10 times more data, i.e. 25 TB.

The first months of the mission, December to July, have been devoted to the commissioning of the satellite and its instrument. This includes the adjustment of the satellite spin rate and the in-flight calibration of the micro propulsion system, the fine-tuning of the on-board software adjustable parameters, the focus of the telescope using mechanisms moving the M2 mirrors (Mora et al. 2014), the calibration of the CCDs, image quality, wavelength scale, instrument response and many other activities. Gaia has few calibration devices. The instruments are for a large part self-calibrated, i.e. calibrated using their own observations. For example, the RVS wavelength scale is calibrated from RVS spectra, measuring the location of reference lines in reference stars.

Figure 1 (top) shows an example of an RVS spectra of the star HIP86564. The "wings" on the left and right side, are produced by a filter which restrict the RVS wavelength range to [845, 872] nm (in order to limit the superposition of spectra, in particular in dense stellar areas). HIP86564 is a K star and its RVS spectrum is dominated by the strong lines of the Ca II triplet. Many other weaker lines are present in the spectrum. Four Fe and one Ti lines have been identified on the figure. HIP86564 is one of the reference stars, which has been used to calibrate the resolving power of the RVS by comparison to a library of ground-based spectra (assembled by DPAC members before launch in prevision of this task) convolved to a range of resolving power. This and other techniques†, have been used to find the best focus of the telescopes and optimise the image quality and the resolving power. Figure 1 (bottom) shows a spectrum of HIP86564 observed with the Narval@Pic-du-midi spectrograph. The Narval spectrum has been convolved to the nominal resolving power of the RVS, R = 11 500.

*One observation is made of 9 astrometric measures, 1blue and 1 red spectro-photometric measure and 3 RVS spectra

†e.g. the RVS resolving power has also been assessed by measure of the width of the cross-correlation function between RVS spectra and a mask. Dedicated methods have been used for the astrometric and spectro-photometric instrument.

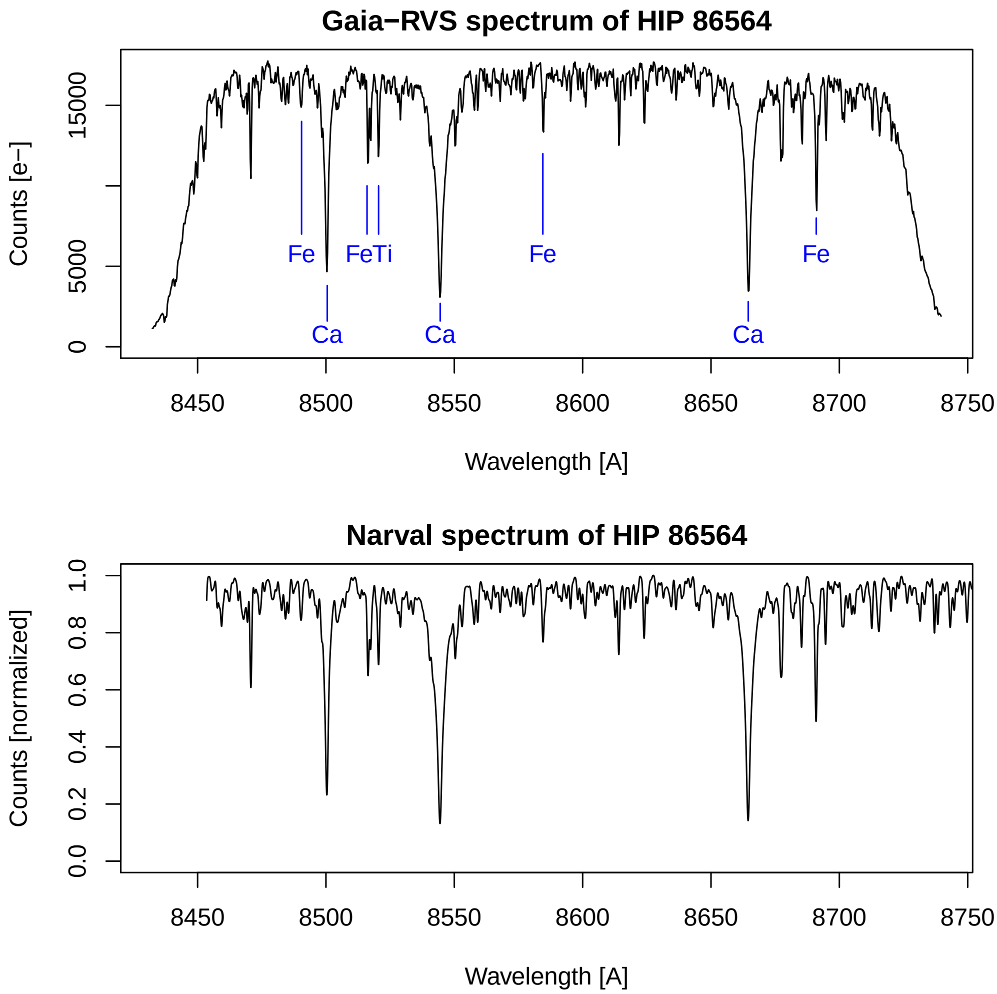

Fig. 1. Spectra of the star HIP86564, observed by the Gaia-RVS (top) and with the Narval spectrograph (bottom). The Narval spectrum has been convolved to the RVS nominal resolving power R = 11 500. Credits: ESA/Gaia/DPAC/Airbus DS/David Katz, Olivier Marchal and Caroline Soubiran.

At the start of the nominal mission phase, July 2014, Gaia works nominally, except for 3 issues that were identified during the commissioning:

- The level of straylight is higher than expected. This has a limited impact on the bright sources which remain much brighter than the underlying background. Faint sources, and in particular the faintest RVS targets, are more significantly impacted. To mitigate this problem, the on-board software and the RVS operating mode are revised. Since July, the RVS is operated in un-binned mode[‡]. It is also envisaged to reduce the surface of the windows read around each object in order to minimise the amount of background light recorded.

- The transmission of the mirror is slowly diminishing with time. This is caused by a small amount of water, trapped in the satellite, which deposits slowly, in particular, on some optical surfaces. The solution to recover the transmission is to briefly warm-up some mirrors and the focal plane which are equipped with heaters. This solution has been applied successfully during commissioning and could be repeated during the mission if needed.

[‡] The RVS used to be operated in 2 modes: an un-binned mode, called high resolution (HR), for the stars brighter than about V=11 and a binned mode, called low resolution (LR), in which the pixels were hardware-binned by samples of 3 pixels to minimise the total readout noise for the faint stars.

- The basic angle (i.e. the angle between the two lines of sight) is showing larger periodic variations than expected. Work is on-going to model and calibrate the effect.

4 Ground-based activities

4.1 Ground-based processing

The DPAC consortium includes several data processing centres (DPCs) in charge of different aspects of the processing[§]. In France, the Centre National d'Etudes Spatiales (CNES), is in charge of the processing of the spectroscopic data, of the asteroids, multiple systems, extra-galactic sources and of the classification and parameterisation of the sources. In particular the daily *routine* processing of the spectroscopic data should start soon. Figure 2 shows 3 spectra of the stars HIP117279 (K5 giant) recorded by 3 RVS CCDs during the same transit and processed at the CNES Toulouse centre. The spectroscopic pipeline (Katz et al. 2011) calibrates the RVS instrument, pre-processes, extracts, cleans and calibrates the spectra and derives their radial velocities (David et al. 2014). For HIP117279 the pipeline has derived a radial velocity of -49.1 km.s^{-1} (after barycentric correction), in good agreement (at this early stage) with the bibliographic radial velocity -50.1 km.s^{-1}.

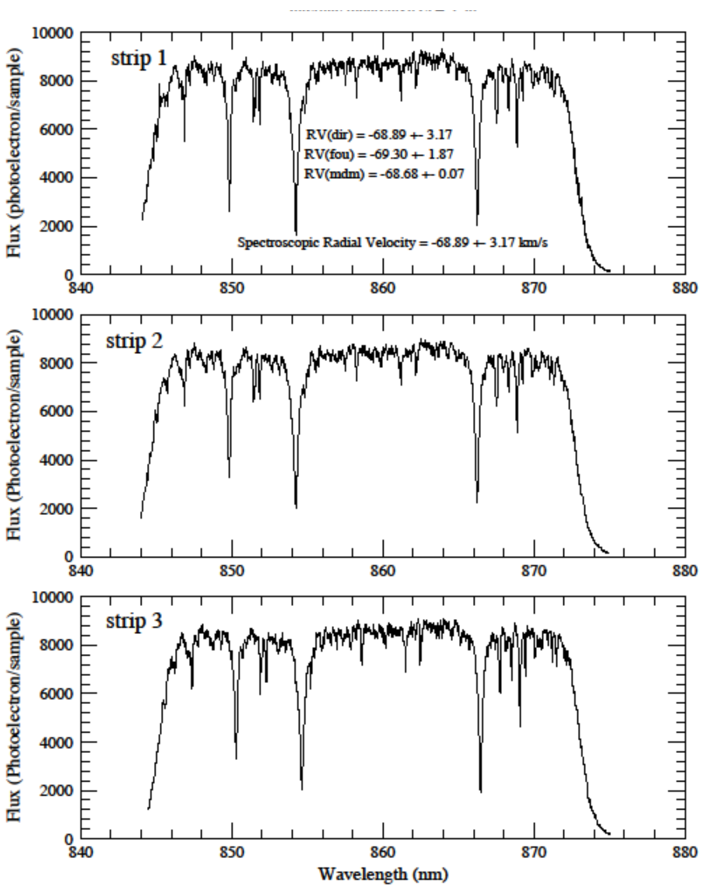

Fig. 2. Three RVS spectra of the star HIP 117279 processed at the CNES centre of Toulouse in September 2014. Credits: ESA/Gaia/DPAC/CNES/Yves Viala and Francoise Crifo.

The commissioning is completed and the nominal mission has started in July. The next important milestone will be the publication of the first intermediate catalogue, scheduled for the summer 2016. It should contain, the positions (α, δ) and G-magnitude for single stars as well as the proper motions and radial velocities for the Hipparcos stars. The second intermediate catalogue, scheduled early 2017, should contain the 5 astrometric parameters for single stars, integrated spectro-photometric bands and mean radial velocities for single stars. The

[§]for example: core and astrometric processing in ESAC (Spain), photometric processing in Cambridge (UK).

following intermediate catalogues will gradually provide more and more elaborated information with improved precision and accuracy until the final release currently scheduled in 2022. Detailed information can be found on the ESA Cosmos web site: `http://www.cosmos.esa.int/web/gaia/release`.

4.2 Ground-based observations

Several ground-based observing program are on-going in synergy with Gaia. They could be divided in two broad categories:

- The observations used for the calibration of Gaia and the processing of the data. Fall in this category, e.g. the observation of Gaia itself (the Ground-Based Optical Tracking - GBOT) necessary to achieve the best astrometric performance or the identification and characterisation of ground-based stable radial velocity standard stars (Crifo et al. 2010; Soubiran et al. 2013).

- The observations which will complement Gaia and maximise its scientific return: follow-up of Gaia detection of asteroids or of super-novae alerts, complementary spectroscopic surveys providing detailed chemical composition of bright stars and/or radial velocities beyond the RVS limiting magnitude. The Gaia-ESO Survey - GES (Randich et al. 2013), is a 300 nights survey on the VLT, aiming to collect about 100 000 Giraffe spectra and a few thousands UVES spectra.

Several projects of spectrograph with high multi-plexing will also provide ideal complement to Gaia. For the present/near future one can site: HERMES (Sheinis et al. 2014), MOONS (Cirasuolo et al. 2014), WEAVE (Dalton et al. 2014) or 4MOST (de Jong et al. 2014). For the next decade, the Maunakea Spectroscopic Explorer - MSE (Simons et al. 2014) is a very promising project. The concept is to upgrade the Canada-France-Hawaii telescope from the current 3.6 m telescope, to a 10 m telescope, to equip it with a wide field very large multiplexing low and high resolution spectrograph and to dedicate large fraction of the nights to spectroscopic surveys.

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