Gaia Status

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Introduction

Gaia is an ESA cornerstone mission to map our Milky Way Galaxy in three dimensions. Gaia will provide a census of 1 billion objects by astrometry, photometry and spectroscopy. The science requirements are compiled to answer fundamental questions concerning the structure and dynamics of the Milky Way. Due to the unbiased surveying of the sky, Gaia will not only detect stars in our Galaxy, but also extragalactic sources and solar system objects which are the topic of this meeting. Gaia capabilities in our solar system is reviewed in this proceedings by Tanga and this paper focuses on the general Gaia capabilities and overall status of the mission.

1. Science capabilities

Gaia is primarily an astrometric mission. The high accuracy astrometry can uniquely be achieved only in space. The mission aims to enter into the new μarcsec domain with errors in bright star parallaxes below 10 μarcsec. In order to achieve such a high accuracy many technical requirements are imposed on the spacecraft. But there are also more 'scientific' requirements needed for astrometry. It is essential to make colour dependent corrections to the astrometric measurements. This can be achieved by measuring the spectral energy distribution of each and every object detected on the focal plane. The colour measurement on board Gaia is achieved with spectrophotometry which can also be used to deduce astrophysical quantities for the detected objects. With the astrometric and photometric limiting magnitude of 20, Gaia is anticipated to observe at least 1 billion objects. The third instrument on board is the radial velocity spectrometer. This is needed to get the sixth dimension of the position velocity phase space in addition to the five parameters gained by astrometric means. The line-of-sight velocity is achieved by Doppler shift of spectral lines in recorded spectra. The brighter magnitude limit for spectroscopy will result to a sample of 150 million objects having their radial velocity determined. For the brightest objects more fundamental astrophysical work can be done with the spectra. In addition to the three instruments a fundamental element of Gaia is the observing strategy which allows to cover homogeneously the whole sky in an unbiased way. This survey approach enables Gaia to be not only precise, but also accurate.

2. Science topics

In addition to the primary science goals concerning the Milky Way structure and dynamics, Gaia is going to address many other fields of astronomy. As already the topic of this SSO–FUN meeting suggests, Gaia is going have a significant impact to solar system studies. However, there is more. Accurate distances to stars allow significant progress to be made in all areas of stellar astrophysics. For binaries and multiple stars the high single epoch spatial resolution allows an unprecedented census. The 4π coverage will give better statistics of rare objects such as brown dwarfs, exoplanets and white dwarfs. Also beyond the Milky Way Gaia will provide measurements. In the Local Group the intrinsically brightest stars can be observed individually and any other point like extragalactic object will be observed just as it would be a star. This will result to some 1 million galaxies and half a million quasars which can at a later stage be used to align the radio reference frame to that of Gaia constructed at optical wavelengths. Last but not least Gaia is going to provide data which can be used for fundamental physics. At μarcsec accuracy level relativistic effects have to be fully accounted for as the photons traveling through our Solar System get bent before reaching the Gaia focal plane. At a later stage when accumulated data has been successfully used to compute an astrometric solution, it is possible to use the enormous redundancy in the Gaia data to test general relativity parameters at the highest possible precision.

3. Gaia vs. Hipparcos

The astrometric Hipparcos mission provided milliarcssec accuracies for more than 100,000 sources. By moving the limiting magnitude from 12 to 20, Gaia achieves the huge increase in the number of measured objects by reaching 1 billion stars. The much higher astrometric accuracy done for a much larger sample will result to a quantum leap to the knowledge of our Galaxy. When recalling the spectroscopic capability of Gaia, it is easy to be convinced that the science potential of the mission is orders of magnitude more than that was for Hipparcos.

4. Technical description

The fundamental property of the Gaia payload is the two fields of view which are combined into a single focal plane. The two primary mirrors have a fixed 106.5° basic angle between them. This angle is kept constant at levels below 10 μarcsec and on top of that monitored at levels below 1 μarcsec by dedicated hardware onboard. This well controlled and monitored basic angle is fundamental to Gaia astrometry in combination with high accuracy transit timing and homogeneous scanning of the sky. The combined fields of view are focused on the 106 CCDs in the focal plane providing the astrometric, photometric and spectroscopic measurements. While astrometry is done with a broad band white light filter optimized to provide as many photons as possible, the spectrophotometry is done with two prisms providing dispersion at wavelength ranges 330–680 and 640–1000 nm. The radial velocity spectrometer is operating in the wavelength range 847–874 nm where 11,500 resolution is achieved with a grating. All payload module elements are attached to so called Torus which is made of Silicone Carbide.

The high observing efficiency is gained by integrating on the fly when scanning the sky. In order to maintain the astrometric capabilities this scanning must be in perfect synchronization with the reading of the CCDs. The charge is moved on the CCD chip exactly with the same speed as the satellite is spinning keeping this way the point spread function unsmeared. The spin control is achieved by constant monitoring of the spin speed with on board star detection and speed deduction with attitude corrections done as needed with the micro propulsion system. In addition to the 6 h spin, the spin axis (at 45° with respect to the Sun) is precessing a full circle in 63 days and the spacecraft is located at L2 making a revolution around the Sun in a year. This three movement configuration allows the most homogeneous sky coverage as technically possible. On the average every source is observed 70 times over the 5 year mission. For Solar System studies it is unfortunate that the ecliptic plane is exactly the region where the temporal coverage is in general lower than the average.

5. Science data volume

The hardware technology for Gaia is very demanding, but also the data processing is a challenge. With the sheer volume alone it is easy to be convinced that serious planning is needed to cope with the data. 1 billion objects observed 70 times over 5 years translates to some 40 million objects a day (or some 400 million measurements a day). This requires extremely robust software engineering to cope with all peculiarities that may occur in operations. For spectroscopy due to the brighter limiting magnitude the 150 million objects will be observed 40 times on the average leading to 10 million measurements a day of some 3.3 million stars. These are impressive numbers when comparing with e.g. dedicated ground based spectroscopic surveys which in multi-year campaigns can provide as many spectra as Gaia in a week. In photometry the legacy value of the Gaia data is in the high spatial resolution and simultaneous coverage

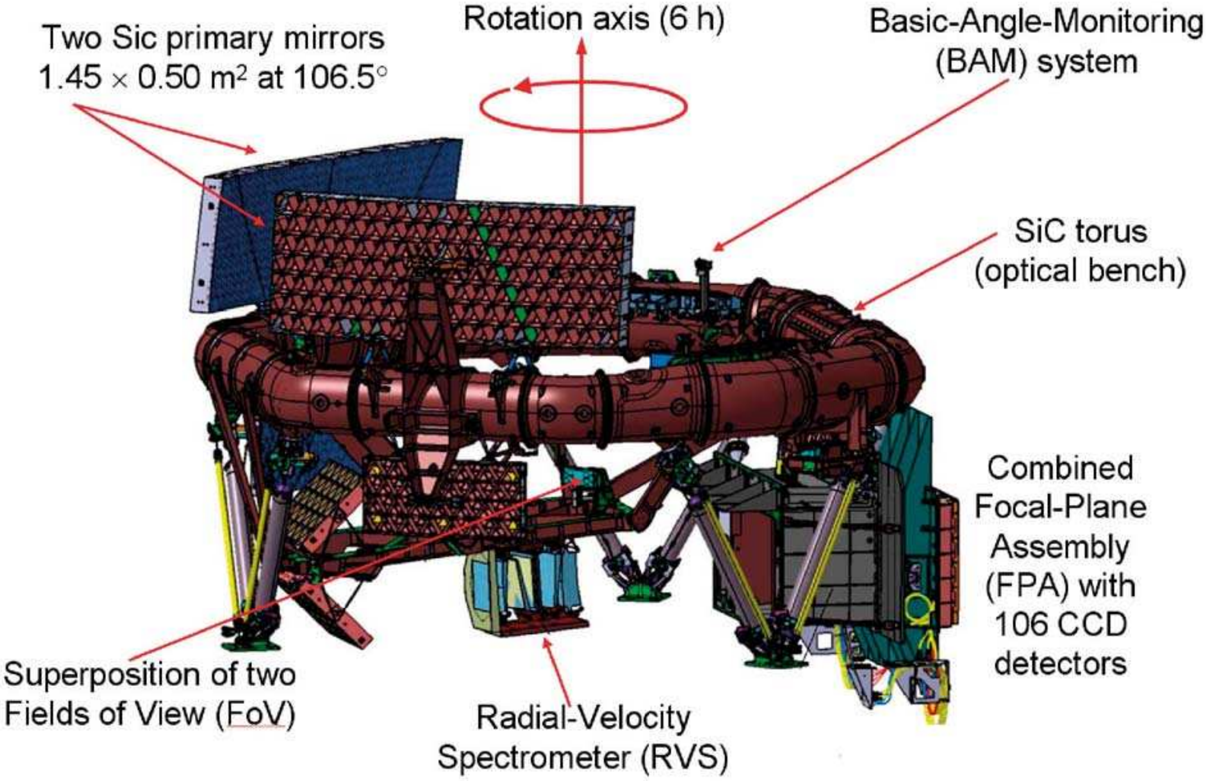

Figure 1: Schematic picture of the Gaia Torus with mirrors, radial velocity spectrometer and focal-plane assembly. Copyright EADS Astrium

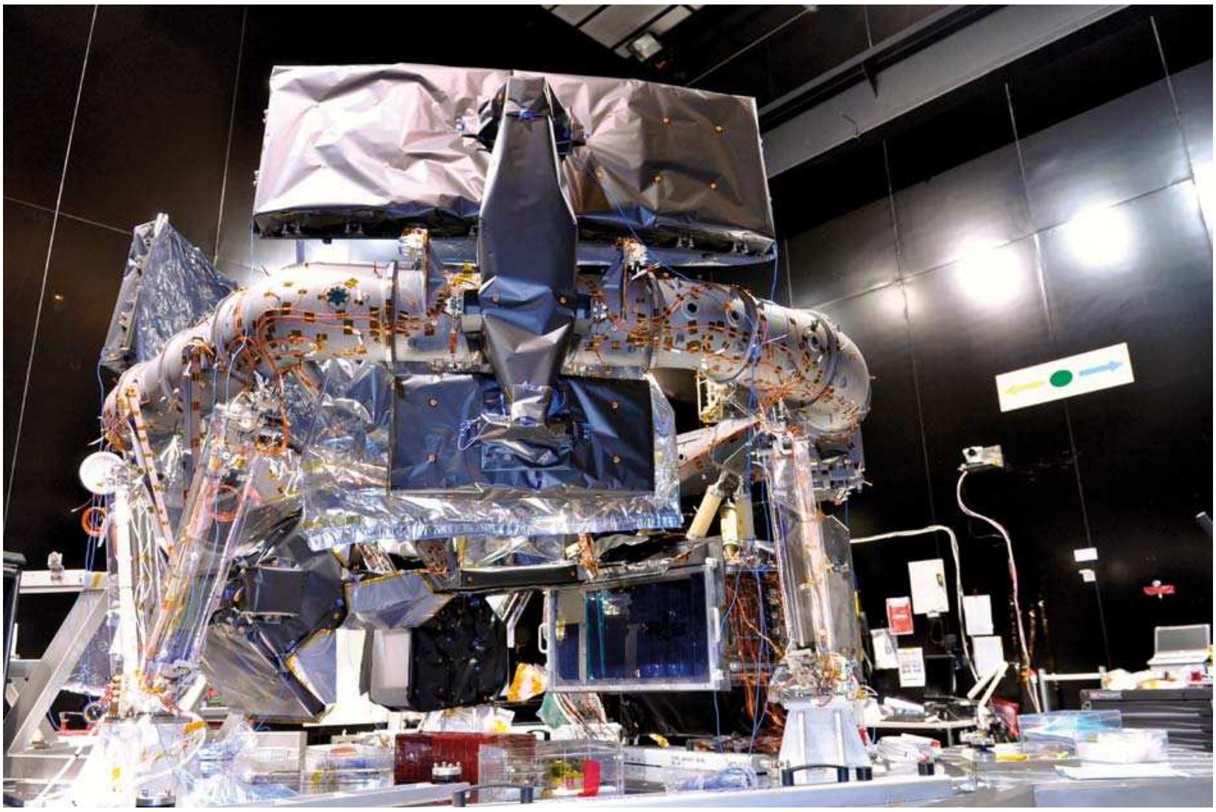

Figure 2: Current status of the Payload Module. Copyright EADS Astrium

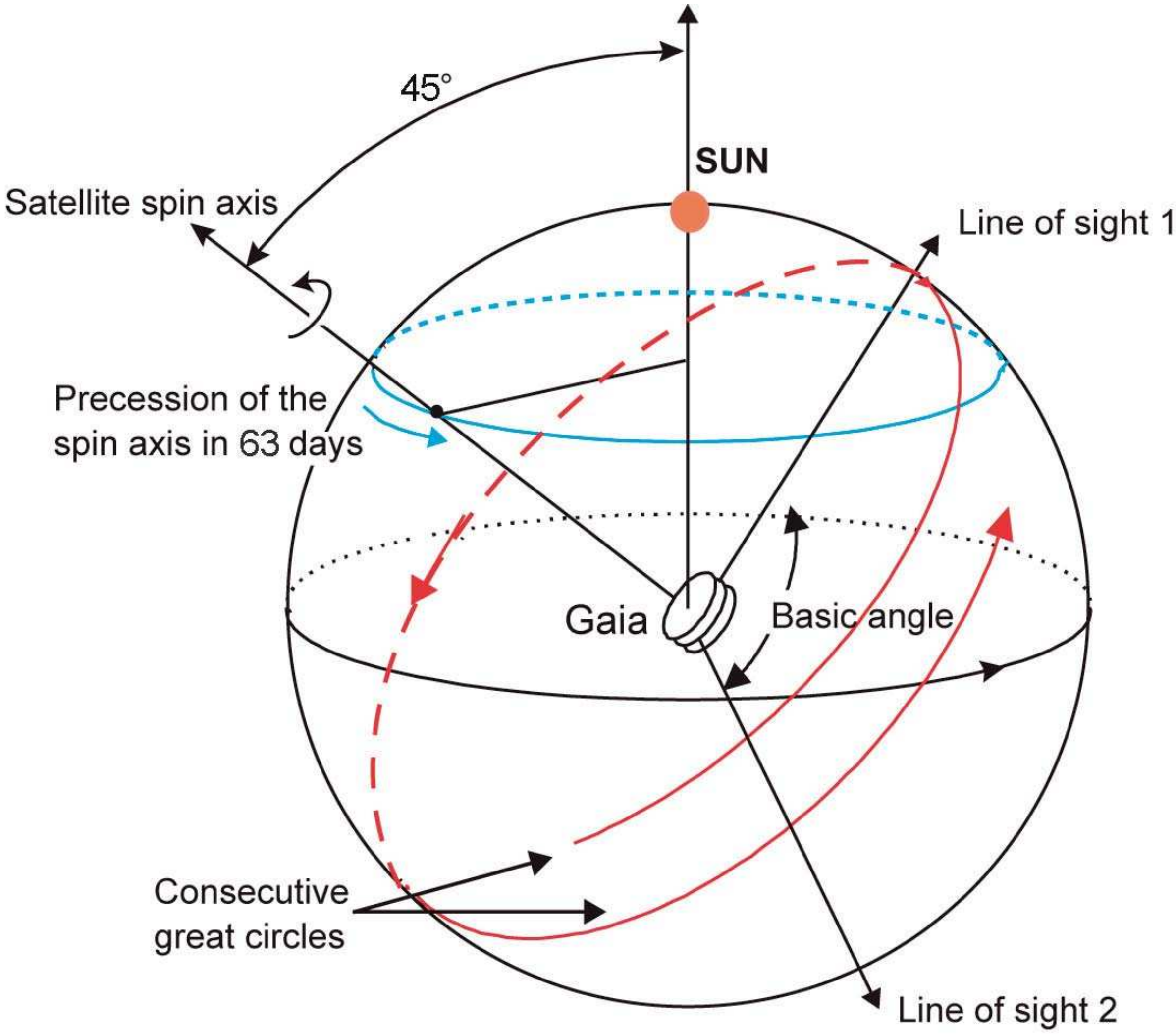

Figure 3: The scanning law.

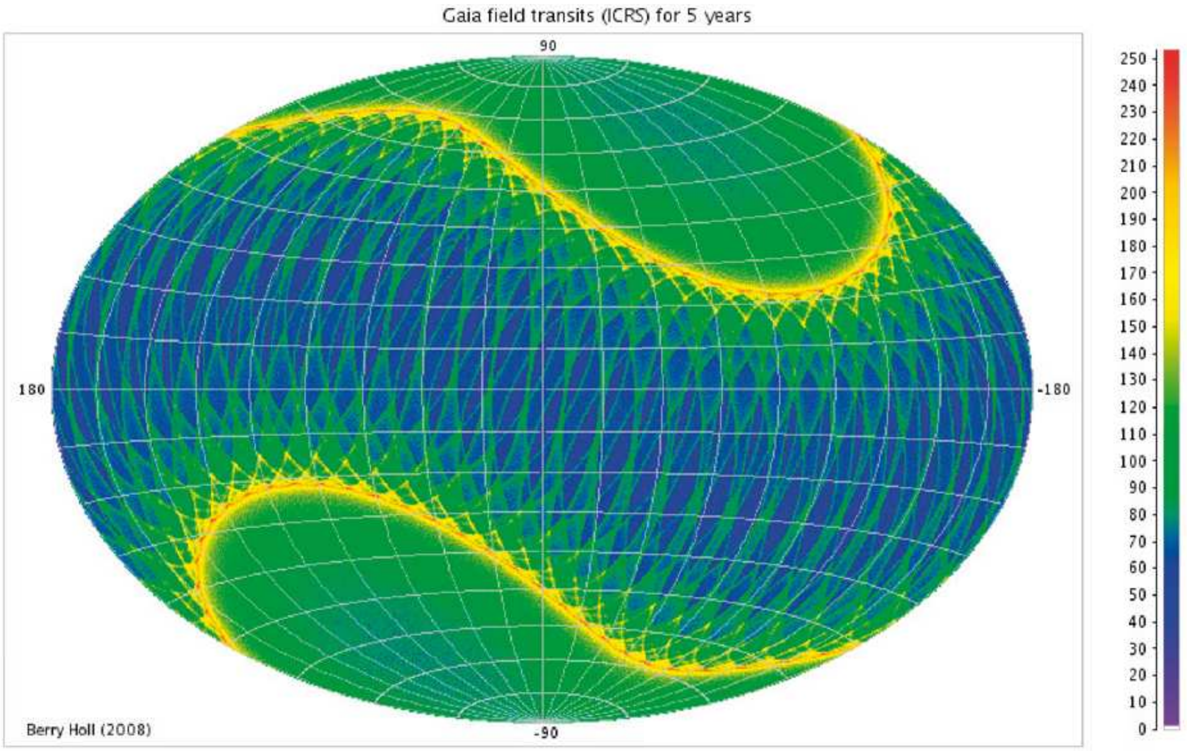

Figure 4: The sky coverage by Gaia after 5 years of nominal operations. Copyright Berry Holl

of the whole wavelength range at 70 epochs. While spectroscopy and photometry remain feasible from the ground and any single Gaia measurement can be repeated and improved if needed, the astrometric part of the Gaia mission remains unique far into the future.

6. Scientific performance

The design of Gaia is based on requirements set at the beginning of the project. As hardware is being built and various subsystems are integrated, it is possible to base part of the scientific performance estimates to real measurements from various tests although a major part of the calculation is still by analysis. A satellite project managed by ESA is subject to a series of reviews which offer occasions to summarize the scientific performance estimates. The last major review was concluded in October 2010 when Gaia successfully passed the Critical Design Review. This review provided the current science performance estimates which have not changes ever since.

Photometry can be summarized with millimagnitude precision for the magnitude range 6–13 and thereafter factor of ten worse at 17 and another factor of ten worse at 20 magnitude. For astrometric white light these precisions can be achieved at single epoch with one CCD (and there are 9 astrometric CCD measurements per transit which allows higher precision for transit photometry) while for the spectrophotometry these precisions are for the end of mission for the full two wavelength ranges. Accordingly epoch photometry, especially when limited to fractions of the spectral ranges, has a lower precision.

The spectroscopic requirements are defined as end of mission radial velocity accuracies. For the bright stars 1 km/s is achieved while for the very faintest ones values between 8 and 13 km/s are reached depending on the stellar spectral type. This performance allows the original aim to do additionally astrophysical parameters from spectra to a rough limiting magnitude of 12.

In astrometry the bright star parallax error is below 10 μarcsec and 25 μarcsec for 15 magnitude stars. At magnitude 20 blue star (B1V spectral type) have parallax error of 330 μarcsec, G2V type star of 290 μarcsec and M6V star of 100 μarcsec. For the solar system targets single epoch astrometry is more

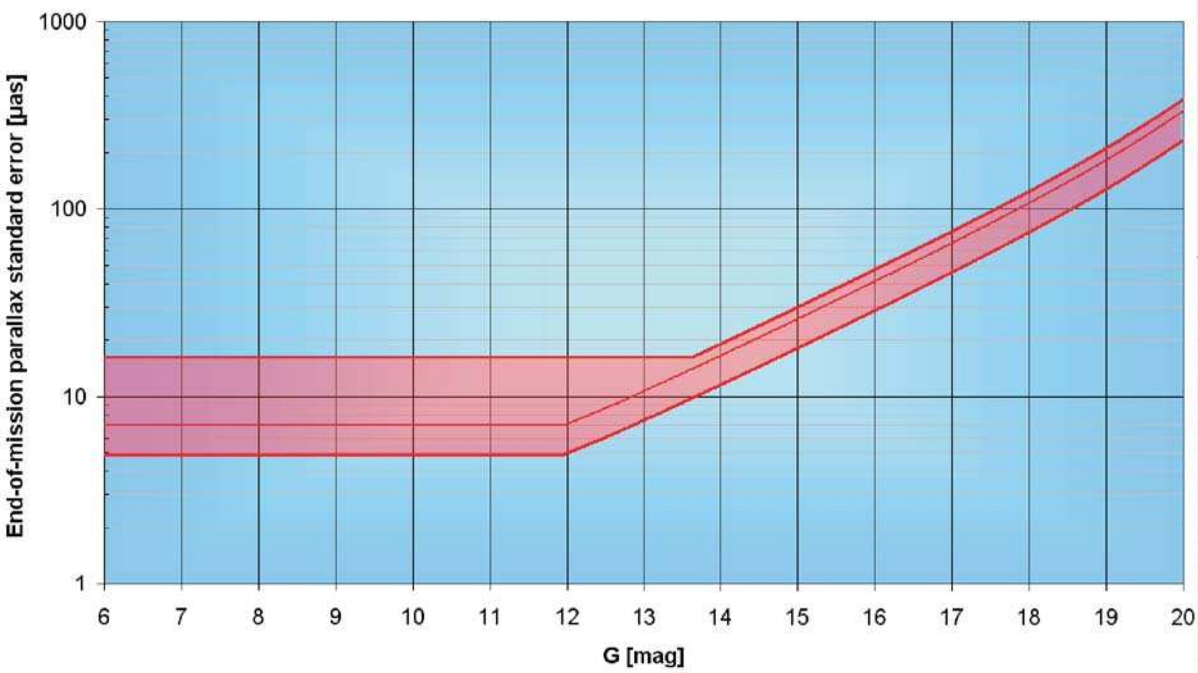

Figure 5: The end of mission astrometric performance estimate expressed in terms of parallax standard error against magnitude. The end of mission parallax standard error gives roughly the single epoch astrometric accuracy in scanning direction (i.e. in one dimension only) when the y-axis values are multiplied by factor of 4.3. For Solar System objects this is a maximum performance as their apparent movement against stars deteriorates the position determination. The faster the movement the worse the precision.

relevant and can be 20 μarcsec at best for the brightest objects in the scanning direction. Naturally the movement of solar system objects with respect to the stars will smear the image on the focal plane making the position determination less precise. All in all Gaia science performance estimates are close to the original requirements allowing the anticipated science topics to be addressed.

7. Schedule

The current schedule for Gaia has the launch date in October 2013. The Service Module has passed all tests and few retrofits of subsystems with changed components is on-going. The Payload Module is at the moment of writing this contribution under thermal balance and thermal vacuum test. These tests will give the best on-ground verification of the in-orbit performances. After completion of the thermal tests the Payload Module and Service Module will be integrated early 2013. The launcher for Gaia, Soyuz-013, is already being manufactured.

Conclusion

Gaia is a cornerstone mission with a tremendous science potential. The current schedule and the scientific performance estimates predict that the first Gaia intermediate releases can be expected 2015. This is noted by the astronomical community. The expectations are high and at the moment all signs are positive that Gaia will indeed change the astronomy just in few years time.