The Gaia Sky

https://doi.org/10.1017/S1743921317005816 Published online by Cambridge University Press

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Alejandra Recio-Blanco opening the IAU symposium 330, as chair of the SOC.

https://doi.org/10.1017/S1743921317005816 Published online by Cambridge University Press

Astronomy and Astrophysics in the Gaia sky
Proceedings IAU Symposium No. 330, 2017
A. Recio-Blanco, P. de Laverny, A.G.A. Brown & T. Prusti, eds.

doi:10.1017/S1743921317005816

The Gaia mission status

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Abstract. Gaia is an ESA cornerstone mission conducting a full sky survey over its 5 year operational period. Gaia performs astrometric, photometric and spectroscopic measurements. The data processing is entrusted to scientists and engineers who have formed the Gaia Data Processing and Analysis Consortium (DPAC). The photometric science alerts started in 2014. The first intermediate data release (Gaia DR1) took place 14 September 2016 and it has been extensively used by the community. Gaia DR2 is scheduled for April 2018. Gaia is expected to be able to continue observations roughly for another 5 years after the nominal phase. The procedure to grant funding for the extension period has been initiated. In case funding is granted, the total operational time of Gaia may be 10 years.

Keywords. space vehicles, catalogs, surveys, astrometry, techniques: photometric, techniques: radial velocities

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1. Introduction

Gaia is an ESA cornerstone mission building on the heritage of the Hipparcos mission as detailed in Gaia Collaboration *et al.* (2016b). Gaia covers the full sky making an astrometric, photometric, and spectroscopic survey. The spacecraft, including its payload, was built by industry with Airbus DS as the prime contractor. ESA has the overall management role as well as the spacecraft operations. The scientific community participation is through the Data Processing and Analysis Consortium (DPAC), which has been selected by ESA to produce the scientific catalogues for the community.

Gaia was launched 19 December 2013 from Kourou with a Soyuz rocket. Its nominal mission includes 5 years of operations and 3 years of post-operations to finalise the catalogues. The photometric science alerts, commenced 2014, were the first products provided to the community. The first intermediate release (Gaia DR1) took place 14 September 2016 (Gaia Collaboration *et al.* 2016a). The Solar system alerts for new asteroids also started 2016. The next data release, Gaia DR2, is planned for April 2018.

2. Operations

After a commissioning period lasting about half a year, Gaia has been conducting routine observations. On average Gaia detects and measures 70 million objects per day. On top days, when the scanning is parallel to the Galactic Plane, the count can exceed 300 million. In total, at the moment of this Symposium (24 April 2017), Gaia has observed 70 billion transits. Overall the Gaia operations are nominal.

Astrometry. By 24 April 2017 Gaia has made 688 billion astrometric measurements. Gaia has an automatic on-board detection to decide whether an object is celestial, point-like and brighter than 20.7 mag. The faint limit is not precise as the on-board magnitude

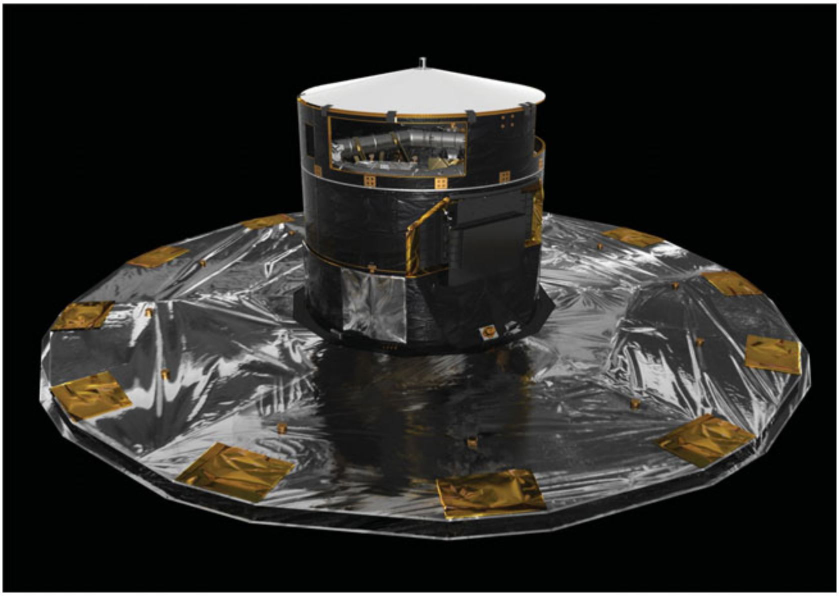

Figure 1. Gaia spacecraft. Copyright ESA

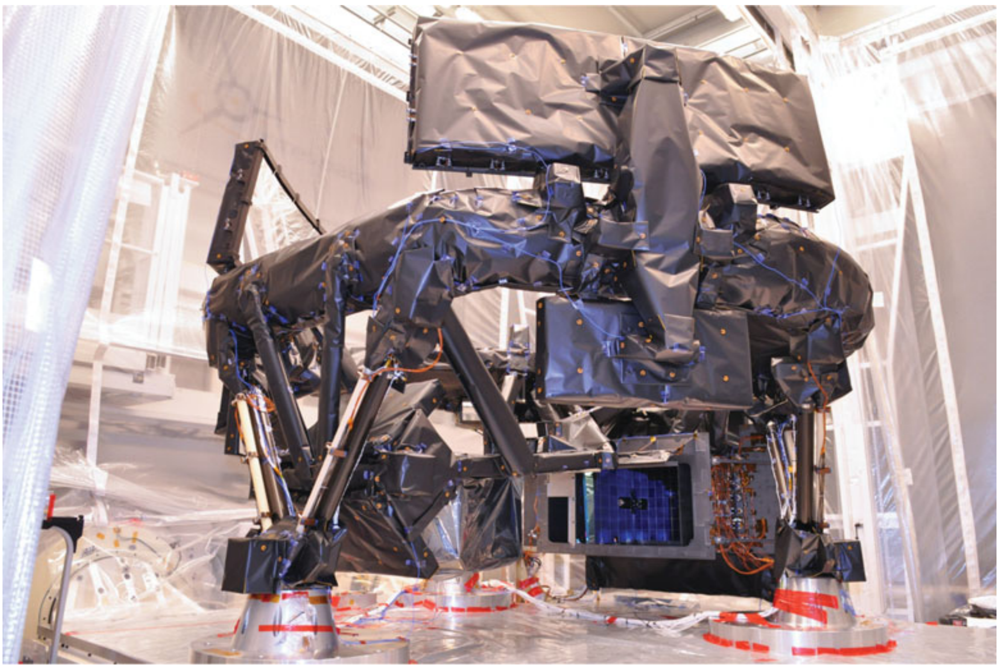

Figure 2. Gaia payload module at the time of vibration testing. Copyright Airbus DS

estimate for the faintest stars is of the order of 0.3 mag. The bright limit of Gaia is between 2 and 3 magnitudes. Brighter objects cause such a large saturation area on the detector, that Gaia cannot anymore determine the object as point like. The bright limit is not fixed as there are sensitivity variations across the CCDs and the brighter stars can be seen if they pass through a less sensitive part of a detector. In order to achieve full completeness, special observation are scheduled for the very brightest stars.

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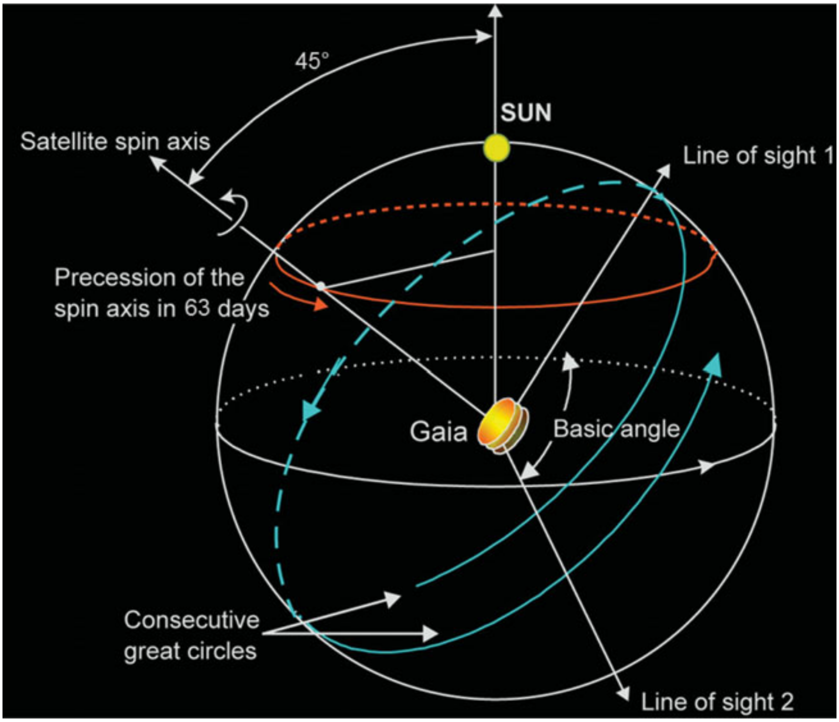

Figure 3. Gaia scanning. Copyright ESA

The ultimate accuracy of those measurements is not yet known, but will be of lower quality than measurements made in the regular way. In addition, selected dense regions are imaged with a special Gaia mode. This is done to compensate for the fact that in the most crowded parts of the sky, the Gaia on-board resources cannot cope with the stellar densities. By producing the images, some astrometric information can be gathered also for the faintest objects in these regions.

Photometry. All astrometric measurements of Gaia are also photometrically calibrated. Therefore for every astrometric measurements there is a corresponding photometric measurement. In addition Gaia has dedicated prisms and CCDs to record spectrophotometry of all objects detected by Gaia. The spectrophotometry is split into two ranges. BP covers wavelengths from 330 to 680 nm and RP from 640 to 1050 nm. The number of spectrophotometric measurements by 24 April 2017 is 147 billion. While the dispersed spectra can be used as narrow-band photometry, the BP and RP channels can also be integrated to provide more precise magnitudes for the wavelength ranges covered. Although every astrometric measurement has accompanying spectrophotometric measurement, it is important to note that in crowded regions, where the spectra overlap, deblending methods are needed to disentangle close-by sources from each other. In very crowded regions this leads to lower quality spectrophotometry than in nominal source density areas.

Spectroscopy. The spectrometer on-board Gaia is called Radial Velocity Spectrometer (RVS). The main task is to enable deducing radial velocities. The spectra cover wavelength range from 845 to 872 nm with resolution of the order of 11,000. In the on-board detection algorithm the limiting magnitude for gathering RVS spectrum is set to 16.2 in the RVS wavelength range. By 24 April 2017 about 13.7 billion spectra have been collected. For most of the objects the only astrophysical quantity that can be deduced is the radial velocity. However, for stars brighter than about 11 to 14 magnitudes also

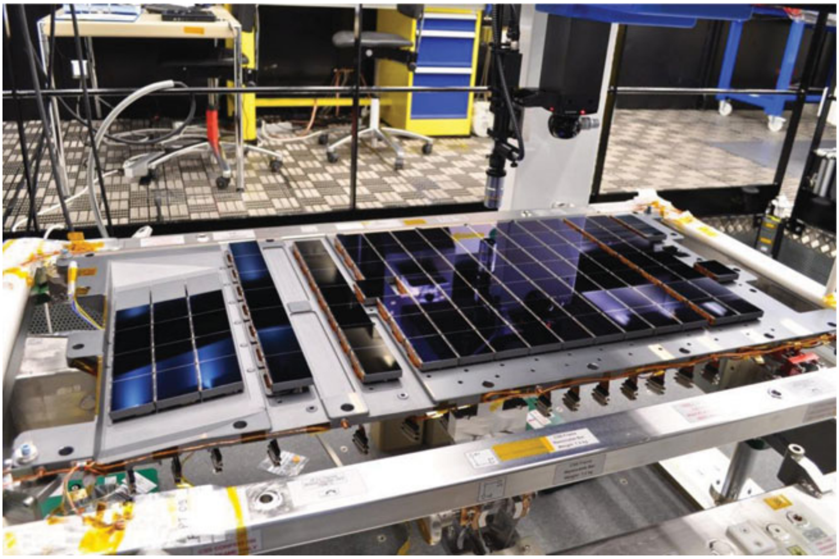

Figure 4. Gaia focal plane assembly. Groups from left to right: 12 RVS CCDs, 7 RP CCDs, 7 BP CCDs, 62 astrometric CCDs and 14 sky mapper CCDs. The two most extreme CCDs in the corner are for the Basic Angle Monitor and the one out of the row of astrometric CCDs together with the one most to the right in the middle of the focal plane are for wavefront censors (the wavefront censor is missing still in this picture). Copyright Airbus DS

spectroscopy can be done (the brighter the star, the better the signal to noise and the more spectroscopic analyses are possible).

3. Intermediate data releases

Gaia DR1 took place 14 September 2016. The number of publications went very quickly up and many of the published (or close to publication) results can be found from these proceedings.

Gaia DR2 is scheduled for April 2018. The expected contents and precisions are detailed to some level in these proceedings and especially the scientific expectations are listed in many contributions.

4. Mission extension

The nominal Gaia mission will be completed by mid-2019. At that moment Gaia has been scanning the sky for 5 years. The operations are smooth and can continue beyond the nominal life time. If nothing unexpected happens, then the Gaia mission life time will be limited by the consumable, cold gas, for the micro propulsion system. The cold gas is used to keep the spin matching exactly the readout speed of the CCDs. The consumption is very regular, but with an expectation, that the consumption will increase as the satellite surfaces age and the Solar wind causes more torque on Gaia. The current best estimate of cold gas exhaustion is mid-2024. After cold gas exhaustion the spin control is not anymore sufficient for precision astrometry work.

In order to continue operations beyond the nominal end of mission to the real, functional end of the mission, additional funding is required for the 5 years from mid-2019 till mid-2024. As mission extensions are not unusual for ESA spacecrafts, there is a procedure that is followed up within the science programme. Every two years there is a decision made whether to continue or to stop. In addition a forward look is done for years 3 and 4 ahead. As Gaia is in the nominal phase till mid-2019, at this stage only the issue of forward look to the second half of 2019 and 2020 has been on the table. Extension decision for the second half of 2019 and 2020 will take place toward the end of 2018 in combination with a forward look to 2021 and 2022.

The nominal 5 year mission life time is has played a fundamental role in Gaia design. Various technical and operational aspects are tuned for completing a homogeneous survey in 5 years. After mid-2019, the end of the nominal mission, the estimated end of life in mid-2024 results to another 5 year operational period. Given the technical and operational characteristics of Gaia, the anticipated 5 year extended life time and the survey nature of the mission, it was decided to prepare a science case for an extra 5 year period although administratively the extensions to missions are funded in the above mentioned two year cycles.

It is clear that more Gaia data, 10 years in total instead of the nominal 5 years, will give better science. However, in some fields the gain is more impressive than in others. In all Gaia areas, astrometry, photometry and spectroscopy, the basic performance for bright objects is limited by calibration accuracy, while for the faint objects signal to noise increase will improve the deduced astronomical parameters. As most Gaia sources are faint (due to faint sources outnumbering the bright ones), the gain from an extension affects the majority of Gaia detected objects. For bright stars the gains are in more complex systems. In astrometry these are related to kinematics and dynamics while in photometry and spectroscopy variable objects will benefit.

In this contribution two case studies with significant science improvement due to Gaia extension are presented. These examples concern exoplanets and reference frames.

Exoplanets. Gaia is able to detect exoplanets both by photometry and astrometry. It is specifically the astrometric method, which is of special interest as Gaia is more or less the only facility able to provide this complementary information. Perryman *et al.* (2014) estimated that based on data from the nominal mission, Gaia will detect about 20,000 exoplanets. By extending the operational period to 10 years will result to 70,000 exoplanet detections. The method is the same as for unresolved double stars where a wobble of the stellar light centroid around its joint, with the exoplanet, barycentre can be detected on top of the system parallax and proper motion. Clearly this is easier for massive planet detection as the wobble is larger and Gaia is mostly detecting 'Jupiters'. Nevertheless, the huge advantage is that with astrometry also the inclination of the system may be determined. This allows exoplanet mass determination without the sin(inclination) ambiguity. A longer Gaia life time not only allows more exoplanets to be detected, but specifically Jupiter mass objects further away from their host star in orbits longer than 5 years. If we believe that a giant planet in distant orbit is useful in 'guarding' possible exoplanets closer by a star, then Gaia is the way to find these systems.

Reference frame. One of the important results from Gaia will be the establishment of an accurate and dense optical reference frame. This can also be aligned with the radio reference frame based on quasars as Gaia is able to detect a sufficient number of quasars. The advantage of a dense optical reference frame is that practically all astronomical images contain Gaia objects in the field, allowing good derivation of the astrometry in that field. However, the density of objects is achieved with stars and stars have proper motions with errors assigned to this quantity. This means that in the course of time the optical reference frame will degrade. The strength of Gaia is that the proper motion errors are typically very small and therefore the Gaia defined optical reference frame will be sufficiently accurate for decades. Nevertheless, the evolution in e.g. ground based facilities continues with the extremely large telescopes. For some instruments on the future giant telescopes the field of view can be extremely small. Therefore a very accurate optical reference frame is a necessity. Gaia with a 10 year operational period can provide this, as the proper motion errors scale with time to exponent 1.5 giving a factor of 2.8 better astrometry with respect to 5 year nominal mission. With a 10 year Gaia all extremely large telescopes can count on having a sufficiently accurate optical reference frame at least till 2050.

5. Conclusions

Gaia mission operations are nominal and on average 70 million transits are recorded daily. Gaia DR1 has triggered studies in many areas of astronomy and raised the expectations toward Gaia DR2. We can conclude that Gaia is well on its way to fulfil 'The Promise of Gaia'. The best way to enjoy that and to get ready for Gaia DR2 is — to use Gaia DR1.

Acknowledgement

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

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