GAIA STATUS AND EARLY MISSION

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ABSTRACT.

After about 15 years of design and manufacturing the Gaia spacecraft was launched at the end of 2013. A nearly 6-month long in-orbit qualification and verification phase followed which formally ended in July 2014. This marked also the real start of the scientific mission with the regular observation taking. I report on this early mission phase and on the major findings made during the commissioning, allowing to give more realistic figures for the expected science performances.

1. GAIA LAUNCH AND EARLY OPERATIONS

The long awaited ESA space astrometry mission was successfully launched on 19 December 2013 at 09:12:18 UTC from the Europe's Spaceport in Kourou. Gaia was brought to space by a Soyuz ST-B launch vehicle equipped with a Fregat-MT upperstage. This Soyuz is the most recent version of this highly reliable rocket crowned with more than 1700 successful launches. It is, and by an enormous margin, the most used launcher since the beginning of the space era in 1957.

On January 7 the flight dynamic group at ESOC in Darmstadt sent a command to fire five of the eight thrusters attached to the chemical propulsion system to bring naturally Gaia onto its planned orbit around L2. This took place at 18:58 UTC and the burn lasted about two hours. The operation was very successful and completed as expected, with even a lower consumption of chemical due the accurate launch from Kourou. One week later a very small correction was applied to complete the insertion. From this day Gaia was on a pathway leading the spacecraft to reach its Lissajous orbit about L2 without further action. Later on, orbit manoeuvres are planned about every month to maintain the orbit within about 7000 km of this predicted path. The orbit reconstruction itself will reach a staggering accuracy of 100 m in position and 2.5mm/s in speed with the combination of the radio and optical tracking of Gaia.

During the few days after launch, several critical operations and tests have been completed:

- launch on 19th December 2013 from Kourou
- Sunshield successfully deployed within 90 mn of lift-off
- first reliable target orbit released by ESOC on 30 December
- focal plane video switched on on January 3, 2014 with all the 103 CCDs responding
- first image acquisition with a very bright star (α Aquarii)
- early scan in test mode starting on January 8, 2014
- injection to L2 done on 7 and 14 January, 2014 to near perfection
- service module in-flight test completed by mid-January without incident

The orbit, including the cruise phase to L2 is plotted in Fig. 1 for the whole 2014. The following years the same set of loops around L2 will repeat.

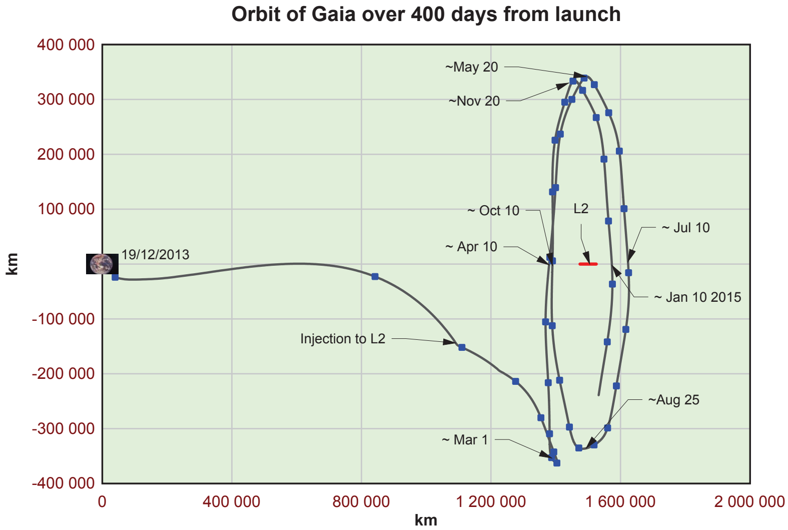

Figure 1: The orbit of Gaia in 2014. The orbit is plotted in a rotating frame and is referred to the Earth barycenter. The L2 point is not fixed in this frame, as the result of the elliptical orbit of the Earth-Moon barycenter about the Sun. The cruise phase is well visible on the left part of the plot.

The on-flight payload commissioning started early January after the completion of the Service Module qualification. All Gaia subsystems were tested during commissioning and can now be used in the routine phase of the mission. In particular:

- all 106 CCDs and associated electronics modules are working and are collecting data
- the data collection hardware is fully operational and the software has been tuned to match the in-orbit performances
- the science data from the CCDs is correctly transferred into the mass memory with an assigned priority
- the priority scheme on board is working correctly with low-priority data being overwritten in case of mass-memory overflow and high-priority data getting precedence in the downlink
- the telescopes have been aligned and focused for the full focal plane
- the attitude feed-back loop with the actuation of the micropropulsion system is operating normally
- the spacecraft spin rate has been matched to the clocking speed of the CCDs
- the phased-array antenna has a good link margin allowing high throughput of data to ground
- the power budget on board is very healthy
- the launch and all orbit corrections have been very accurate and efficient leaving a good margin of chemical propellant for all future orbit manoeuvres
- the science-mode attitude control is working very well, including the determination of the spin rate from the stars observed with the payload and the continuous adjustment of the spin rate with the micro-propulsion system
- the rubidium atomic clock on-board and the time-correlation procedure on ground provide the necessary accuracy for Gaia's science

2. UNEXPECTED PROBLEMS

While the overall functioning of all Gaia units is truly satisfactory, three significant departures from nominal were detected during the commissioning phase and are still under investigation.

- Undesired stray-light falling on the focal plane was detected early January and fully characterised the weeks after. It shows up as a periodic illumination of about 50% of the CCDs, with a period of 6h, equal to Gaia revolution period, and a phase indicating without ambiguity a geometry related to the direction of the Sun. The effect is smaller when the FOVs are at the largest angular distance from the Sun (135 deg) and increases gradually when the Sun is the closest (45 deg). The amount of light is large compared to the requirements, but still small in the absolute sense. The consequences are negligible for the bright stars, but the impact increases toward the smaller fluxes. The Radial Velocity instrument is the most affected by the effect and this will lead to a revision of the observation procedure to optimise the science return. There are apparently two distinct sources of parasitic light: one due the diffraction of the sunlight at the edge of the sunshield and the other from the Milky Way average brightness. Internal and hard to model reflections within the payload lead a small fraction of this light onto the focal plane.

- The angle between the two pointing directions of Gaia must be very stable over the spin period of 6h. For longer periods this is less critical and the angle is calibrated by the astrometric solution [1]. Given the importance of this issue, stringent design and manufacturing requirements were set by ESA to the Gaia industry main contractor. To control this stability Gaia is fitted with a metrological instrument (BAM: the Basic Angle Monitoring) to monitor passively the slightest high-frequency variations of this angle with few μas accuracy. It was expected that the natural variations would be below 10μas at the spin period thanks to a good thermal insulation. However the actual variations are much larger and close to 1 mas at the 6h-period. There is not yet a satisfactory explanation, but it has been demonstrated now that the BAM system does measure real variations. Its performance are good enough to calibrate the Basic Angle close to the required accuracy. A possible remaining calibration bias would affect the zero-point of the parallax and astronomical sources will be used at the mission end to assess and possibly correct this bias.

- The third anomaly seen during commissioning deals with the contamination of the mirror surfaces by water ice. Some water vapour has probably been stored into the Service Module during handling and is now released, enters the payload module before condensing on the cold surfaces. This impacts the overall optical throughput at a rate of a 10% efficiency loss per 50 to 100 days. The optical efficiency is regularly monitored and the contamination is removed by a periodic heating of optical parts. This is not a major inconvenient except for the increase of dead time, since after each heating one must wait the return to thermal stability at nominal temperature before collecting meaningful observations.

3. EXPECTED ASTROMETRIC PERFORMANCES

The astrometric standard-error is evaluated with the parallax according to general principles described in [2]. Calculation includes all known instrumental effects, including the straylight levels as measured during the commissioning phase. For instrument-related residual calibration errors at ground-processing level, an appropriate calibration error is included. So-called residual "scientific calibration errors" (e.g., mismatch of the model point spread function, sky-background estimation errors, etc.), all of which result from the on-ground data processing, are not included. These latter errors are assumed to be covered by a 20% margin. The post-commissioning values are given in Table 1. Compared to the pre-launch estimates, the degradation is limited to the faint stars, starting at about $V = 16$ in astrometry and is really significant for the mission faintest sources, which are also the most numerous. One must also notice that more bright stars will be eventually observable, since the conservative pre-launch detection limit was set at $V = 5.7$ instead of $V = 3$ for the current level. Even with this faint-end degradation, Gaia remains an unrivaled astrometry mission with its intrinsic performance and its survey mode with a single instrument. Nothing better can be envisioned at the moment at least for two decades. For solar system objects, only the single-observation astrometric accuracy makes sense, but due to the scanning mode used by Gaia this accuracy is essentially 1-dimensional. Applying a typical degradation by a factor between 4 and 5 from the performances, one has a good measure of the individual epoch astrometry applicable to asteroids. This will be further degraded for planets with large apparent diameters (say above 100 mas) and fast moving (typically the NEOs with displacement > 100 mas/s). The vast majority of the asteroids are outside these ranges.

Table 1: Expected science performance after commissioning given as end-of-mission parallax standard errors averaged over the sky with uniform distribution.

	B1V μas	G2V μas	M6V μas
Bright stars	$3 < V < 12$ 5–14	$3 < V < 12$ 5–14	$5 < V < 14$ 5–14
V = 15	26	24	9
V = 20	600	540	130

4. CONCLUSION

On July 18, 2014 the commissioning phase was formally terminated and the Gaia in-orbit commissioning review (IOCR) took place. The IOCR board has endorsed all the recommended actions to mitigate the problems detected during the qualification. The mission has been formally handed from the ESA Project Manager (G. Sarri) to the ESA Mission Manager (W. O'Mullane). The nominal science mission has then started with about four weeks on an ecliptic pole scanning mode, before drifting continuously to the nominal scanning mode in September 2014. The scanning parameters will be selected and fixed for the next five years. During the commissioning phase nearly 30 billion astrometric images has been collected together with 2 billion spectra by the RVS instrument. The first public data release is now planned for mid-2016, nine months later than the pre-launch schedule. This is due partly to the much longer commissioning phase and to the need for the data processing to cope with a more difficult instrument calibration than foreseen during the preparatory phase.

References

[1] Lindegren, L., Lammers, U. et al., 2012, The astrometric core solution for the Gaia mission. Overview of models, algorithms, and software implementation, A&A vol. 538.

[2] De Bruijne, J. et al., 2005, Gaia astrometric,photometric,and radial-velocity performance assessment methodologies, Gaia Tecnical Note, Gaia-JDB-022.