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STATUS OF THE GAIA SPACECRAFT DEVELOPMENT

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Abstract.
Gaia, ESA's ambitious astrometric mission due for launch in spring 2012, will provide multi-epoch, micro-arcsecond astrometric and milli-magnitude photometric data for the brightest one billion objects in the sky, down to at least magnitude 20. Spectroscopic data will simultaneously be collected for the subset of the brightest 100 million stars, down to about magnitude 17. This massive data volume will allow astronomers to reconstruct the structure, evolution, and formation history of our galaxy, the Milky Way. It will also revolutionise studies of the solar system and stellar physics and will contribute to diverse research areas, from extra-solar planets to general relativity.

Underlying Gaia's scientific harvest will lie a catalogue, built on the space-based measurements. During the 5-year nominal operational lifetime, Gaia's payload, with at its heart a CCD mosaic containing nearly 1 billion pixels, will autonomously detect all objects of interest and observe them throughout their passage of the focal plane. This contribution addresses the summer-2009 development status of the Gaia spacecraft, with particular emphasis on the torus and the deployable sunshield assembly. These two sub-systems reached important milestones on the day this presentation was orally delivered to the SF2A, namely 29 June 2009. On this day, the qualification model of the sunshield arrived at the ESTEC test facilities for thermal tests inside the Large Space Simulator. On the same day, the torus brazing was successfully concluded.

1 The Deployable Sunshield Assembly

Gaia will perform micro-arcsecond astrometry of over 1 billion objects in our Galaxy and beyond. In order to achieve the required measurement precision, the spacecraft and payload must be shielded from direct sunlight and maintained at a stable, low temperature: any thermal instability at the level of a few tens of micro-Kelvins or more can affect the final accuracy of the measurements that will be made.

The thermal stability of the Gaia spacecraft will be largely determined by a sunshield, with a diameter of 10.2 m when fully deployed and covering a surface of $\sim$75 m^2, the sun-facing area of which has to remain flat within a few millimeters deviation over the entire spacecraft lifetime. The sunshield assembly is composed of 12 rigid, rectangular panels and 12 foldable, triangular sections. In order to fit inside the launcher fairing, the assembly must be folded against the sides of the Gaia spacecraft during launch. After launch, the sunshield will deploy to form a flat structure at the base of the spacecraft, supporting two parallel blankets of multi-layer insulation (MLI) which will act as thermal shields so that the solar flux is damped by a factor of $\sim$280. In addition, the sunshield has to provide structural support for 8 deployable solar panels. All this has to be achieved with a mass of 125 kg. The large size and foldable MLI sections make this a unique sunshield design.

The qualification model (QM) of Gaia's deployable sunshield assembly (DSA) is functionally representative of the flight model and comprises three rigid panels plus the two sections of foldable MLI between them. Thermal vacuum and thermal balance (TV/TB) testing of this model is part of a comprehensive qualification test campaign designed to verify the compliance of the sunshield with design and operational specifications. The qualification test campaign includes functional testing (deployment), vibrational testing (launch conditions), environmental testing (including the TV/TB test), and life-cycle testing (ensuring its endurance with multiple deployment tests).

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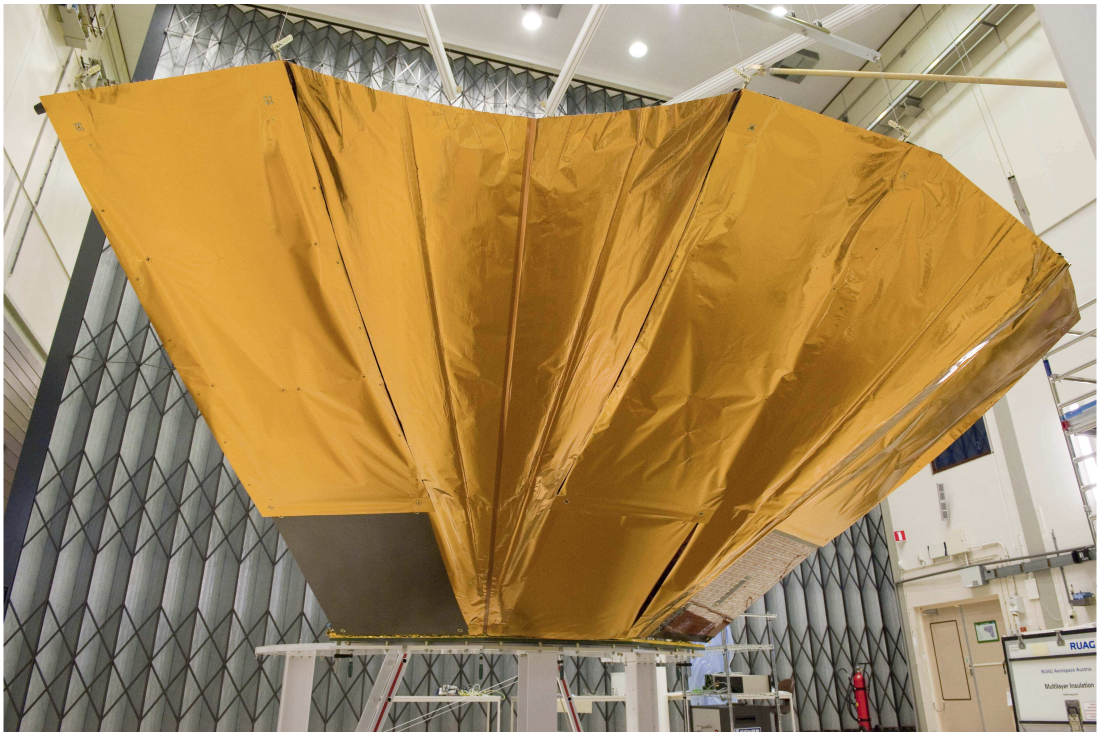

Fig. 1. This picture shows the Gaia deployable sunshield assembly (DSA) qualification model (QM) during deployment tests in the cleanroom at ESTEC, Noordwijk, The Netherlands. This model arrived at the ESTEC test facilities on 29 June 2009 for thermal tests inside the Large Space Simulator (LSS). Before the tests inside the LSS, several deployment tests of the sunshield were performed in the cleanroom at ambient conditions. This view shows the qualification-model sunshield during this deployment. The gold-coloured blanket of multi-layer insulation (MLI) is the sun-side blanket of the sunshield. Like the parallel-installed, shadow-side blanket behind it, it is made up of fixed sections attached to the three rectangular frames, and two foldable sections between the frames which are rolled in stowed configuration and unroll during deployment. The dark-coloured squares at the left and right bottom of the sunshield are solar panels. Copyright: ESA.

On 29 June 2009, the qualification-model sunshield arrived at ESA's ESTEC space centre in Noordwijk, the Netherlands, after transport from the SENER[1] premises in Spain. After arrival, the sunshield was unpacked and prepared for a deployment test at ambient conditions inside the ESTEC cleanroom. The MLI blankets were attached to the sunshield, and a zero-gravity kit – three masts with pulleys and counterweights used to simulate weightlessness – was installed. The deployment test involved the sunshield opening from its stowed configuration to its fully deployed configuration and was successfully completed on 3 July 2009 (Figure 1).

On 11 July 2009, the sunshield was transfered to the Large Space Simulator (LSS) for the TV/TB test. The LSS, with its 9.5-metre-diameter main chamber, is the only facility in Europe where tests of the Gaia sunshield can be performed in deployed configuration under simulated space conditions. The rectangular panels of the sunshield each measure about 0.8 m $\times$ 3.2 m and, once deployed, the qualification-model sunshield measures roughly 6.0 m $\times$ 4.0 m.

The main objective of the TV/TB test is to verify the deployment performance in simulated orbit conditions, the alignment and planarity (flatness) of the sunshield once it is deployed and exposed to the Sun, and the thermal performance of the sunshield. Inside the LSS chamber, the environmental conditions are regulated to simulate conditions encountered during operations in space. Shrouds with liquid nitrogen flowing through them cool the chamber to below 100 K. The chamber is vacuum pumped to a pressure of less than 10^{-8} bar.

During the tests, the planarity of the deployed sunshield was tested with videogrammetry measurements.

[1]SENER is developing the Gaia sunshield. The company is subcontractor to EADS Astrium, responsible for the overall design and development of the spacecraft. The frames and the blankets of the sunshield are supplied to SENER by RUAG, Austria.

Fig. 2. This picture shows the Gaia flight-model torus at the BOOSTEC premises at Bazet, near Tarbes, France. Pictured are members of the BOOSTEC and EADS Astrium SAS team just after the torus removal from the brazing furnace. The 3-metre-diameter, quasi-octagonal torus, which will support the two Gaia telescopes and the focal-plane assembly (FPA), is composed of 17 individual, custom-built, Silicon-Carbide (SiC) segments, all of which were constructed by BOOSTEC under contract to the Gaia prime contractor, EADS Astrium SAS. Starting on 28 April 2009, the 17 elements were assembled and aligned into the form of the torus. The torus brazing took place from 24–29 June 2009. Following the successful completion of the brazing, the torus has been delivered to EADS Astrium SAS in Toulouse for assembly of the bipod and release mechanisms (BRMs). Copyright: ESA.

This technique uses video observations of reflectors placed at specific points on the sunshield to accurately determine the relative positions of these points during the test. Deviations from the desired flat shape of the sunshield in its deployed configuration can be identified this way.

The thermal performance was monitored by 150+ temperature sensors attached to the sunshield and by temperature-map measurements of the sun-exposed surface of the deployed sunshield using an infrared camera. During the TB/TV test, the solar illumination was simulated at different intensity levels with special lamps generating up to 1400 W m^{-2} (just over 1 solar constant). The collimated light beam from these lamps was horizontal so the sunshield was deployed from horizontal to vertical position while inside the LSS. A mask in the form of a large foil shield, with a window exactly matching the shape of the deployed sunshield, stood in front of the opening where the collimated beam entered the main chamber. This mask allowed light to impinge directly only onto the sun-exposed side of the sunshield and blocked light that would otherwise pass the sunshield and reflect inside the vacuum chamber back onto the shadow side of the sunshield. Weightlessness conditions were simulated using the zero-gravity kit.

On 11 July 2009, the sunshield was lowered into the LSS chamber using an overhead crane. In the following days leading up to the TV/TB test, the set-up and the sunshield were prepared inside the LSS chamber. A dry run of the deployment inside the LSS was performed on 17 July 2009 under normal cleanroom conditions with the chamber still open. After bringing the sunshield back to its stowed configuration, the chamber door was closed on 20 July 2009, signalling the start of the TV/TB test in simulated space conditions. This test lasted 7 days. After completion of the TV/TB test, the sunshield was removed from the LSS and moved back to the cleanroom, where the life cycle deployment testing in ambient conditions was completed.

At the time of writing, the sunshield is waiting for a second slot of LSS tests to be performed in October

2009. After these tests, the qualification model will be delivered to the Gaia prime contractor, EADS Astrium SAS. Upon successful completion of this test campaign, the manufacturing of Gaia's flight-model sunshield will commence, incorporating all results from the qualification-model test campaign in the definitive design and assembly of the flight-model sunshield.

2 The torus

On 29 June 2009, the Gaia spacecraft development passed an important milestone when the 17 individual segments of the torus, a key structural element of the payload, were brazed into one coherent structure at the BOOSTEC premises at Bazet near Tarbes, France. The results of this process were successfully concluded after a mandatory inspection point (MIP) of the torus on Monday 20 July 2009.

The 3-metre-diameter, quasi-octagonal torus, which will support the two Gaia telescopes as well as the focal-plane assembly (FPA), is composed of 17 individual, custom-built segments. The scientific requirements of the mission translate to a requirement for a payload that is mechanically and thermally ultra stable, reaching micro-Kelvin and pico-meter levels. For these reasons, all elements of the torus are constructed from Silicon Carbide (SiC), a ceramic material with very special physical characteristics: it is very light-weight and the low thermal expansion coefficient and high thermal conductivity of SiC mean that it is a very stable material which can quickly dissipate thermal gradients. In addition, SiC is twice as stiff as steel.

Construction of the individual torus segments began more than one year ago at BOOSTEC. The process started with a 'green body' SiC powder and an organic binder material that was compressed with hydrostatic forces in a high-pressure facility. The resulting chalk-like material is easy to mill, although very abrasive in nature. Each of the 17 segments of the torus was milled from a green body. The segments were then sintered in a furnace to produce a solid, hard body. The segment interface surfaces were subsequently lapped to create an extremely flat surface so that there was a tight interface between segments during the brazing process. After lapping, the individual segments were subject to static-proof tests in which forces exceeding the range and magnitude of those experienced during launch were applied. Silicon Carbide, like most ceramics, is a hard material which is subject to fracturing due to microscopic flaws in the structure. The likelihood of fracturing is statistical in nature. The best way to ensure that the segments that are used in the construction of the flight model of the torus will not crack when in space is to verify their integrity by means of static-proof tests. Segments which passed these tests were validated for launch conditions and have been used to construct the torus.

Starting on 28 April 2009, the torus began to take shape as the individual elements were assembled together and precision-aligned using laser trackers and reference points on the torus segments. A special braze paste was applied to the interface points between each of the segments. When heated above 1000 degrees, this paste melts and seals the joints by capillary action: the torus then becomes one complete unit.

The completed torus was placed in the brazing furnace[2] at BOOSTEC on Wednesday 24 June 2009 and remained there until the morning of Monday 29 June 2009. After a cooling-down period, the torus was removed from the furnace and moved to the laboratories for post-brazing quality control (Figure 2). This included a thorough visual inspection of external and internal surfaces – the latter by means of borescopes – and ultrasonic inspection to confirm the integrity of the structure. On 20 July 2009, the torus was formally declared flight ready, marking a major milestone of the spacecraft development.

In August 2009, the torus was delivered to EADS Astrium SAS, the Gaia prime contractor, in Toulouse, France. At the time of writing, the assembly of the payload module, including the torus and mirrors, is being prepared. The first elements in line to be integrated are the folding optics structure (FOS) – supporting the M4/M'4 mirrors and the RVS optics module – and the bipod and release mechanisms (BRMs).

The oral presentation associated to this contribution was delivered on 29 June 2009, the day that the torus brazing cycle ended and the qualification model of the sunshield arrived at the ESTEC test centre. This proceedings contribution is heavily based on web articles which appeared on ESA's Science and Technology Gaia webpages. We gratefully acknowledge the contribution of Karen O'Flaherty and Guido Kosters of the Programme Management Support Office of the European Space Agency in the preparation of these web articles. High-quality versions of Figures 1 and 2, as well as other images, can be downloaded from http://sci.esa.int/gaia.

[2]The furnace at BOOSTEC was built for brazing the Herschel 3.5-metre-diameter primary mirror, and has also been used for the optical bench of the JWST NIRSPEC instrument.