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GAIA PAYLOAD MODULE DESCRIPTION

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1. ABSTRACT

The European Space Agency has approved Gaia, the sixth cornerstone mission of its Scientific Programme, and awarded the satellite development contract to EADS Astrium SAS at beginning of 2006 for its Implementation Phase.

The Gaia mission will provide unprecedented stellar position and radial velocity measurements. This will be used to produce a three-dimensional map of about one billion stars in our Galaxy and beyond. The most prominent feature of the Gaia satellite is the high precision payload, which is fully developed by EADS Astrium SAS. The paper is devoted to the payload description.

1. OBSERVATION PRINCIPLE

Gaia uses the global astrometry concept successfully demonstrated by Hipparcos. This measurement principle relies on the systematic and repeating observation of the star positions in two fields of view.

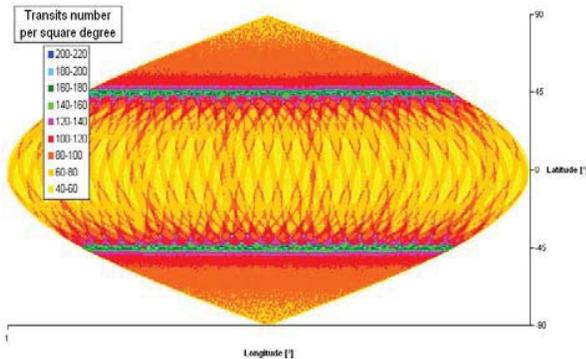


Fig. 1. Repeated observations of sky regions

For this purpose, the spacecraft is slowly rotating at a constant angular rate of 1deg/min around a spin axis perpendicular to both fields of view, which thus describe a great circle on the sky in 6 hours. With a basic angle of 106.5° separating the astrometric fields of view, sky objects transit in the second field of view 106.5 min after crossing the first one.

The spacecraft rotation axis makes an angle of 45° with the Sun direction; this represents the optimal point

between astrometry performances, calling for a large angle, and implementation constraints, such as sunshield sizing and solar array efficiency. A slow precession around the Sun-to-Earth direction, with a 63.12 days period, enables to repeat the observation of sky objects with 86 transits on average over 5 years.

In some regions of the sky, like the Baade's window or globular clusters, the star density is so high that it exceeds the detection capability of the fields of view. In these cases, a modified scanning law may temporarily be followed, in order to increase the number of successive transits in these regions.

2. PAYLOAD CONFIGURATION

The payload is split in three major functions: the Astrometric Instrument (Astro) devoted to the star angular position measurements, the Photometric Instrument providing continuous star spectra on 66 pixels for astrophysics in the band 330-1000 nm and the Astro chromaticity calibration, the Spectrometric Instrument, also named Radial Velocity Spectrometer (RVS) providing radial velocity and high resolution spectral data in the narrow band 847-874 nm.

The astrometric accuracy relies on the very high stability of the Basic Angle between both lines of sight (LOS) of the telescopes, which is achieved thanks to the full Silicon Carbide optical bench and optics. The large focal length enables to operate in dense sky areas up to 3 million stars/deg².

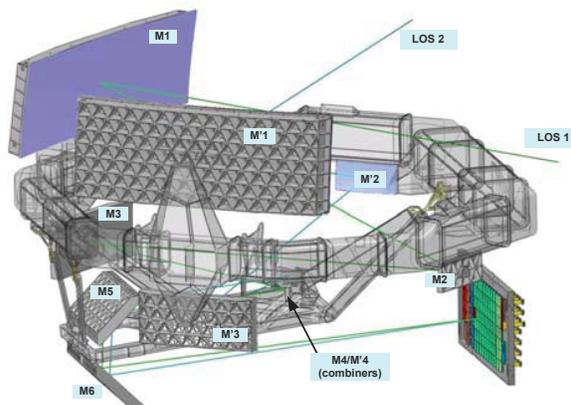


Fig. 2. Combination of the two fields of view

The Photometer and RVS are merged with the principal instrument, thus using the same large collecting apertures: dedicated dispersive elements are placed in the main optical path and image the Photometers and RVS spectra on dedicated detectors in the same focal plane than Astro: two prisms are placed near the focal plane for Blue and Red Photometry ; the more complex RVS dispersive optics are placed on the Folding Optics Structure in the middle of the optical bench.

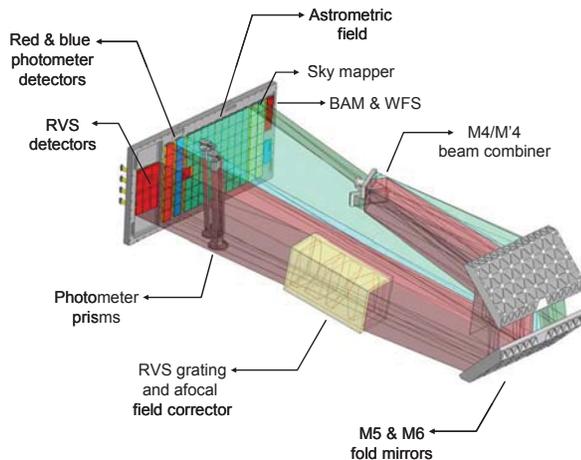


Fig. 3. Three instruments sharing the same focal plane

This concept takes benefit of the large focal length of the main telescopes for observing dense sky area, enables to optimise the Focal Plane Assembly design and to share the video processing with Astro.

3. OPTICS

3.1 The telescopes and beam combiner

The Gaia instrument input consists of two identical telescopes, pointing in two directions separated by the 106.5 ° basic angle, and merged into a common path at the exit pupil.

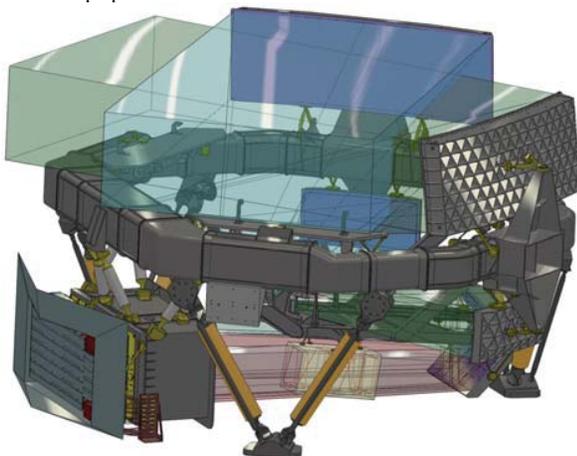


Fig. 4. View of the Payload Module

Each telescope is based on a three-mirror anastigmat (TMA) design, with an intermediate image.

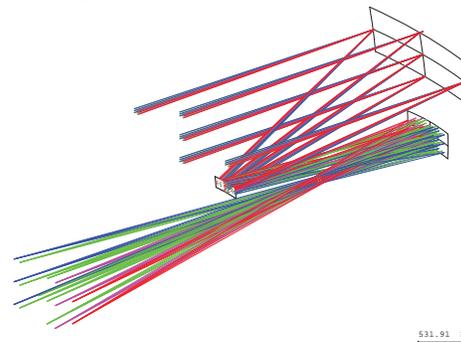


Fig. 5. Telescope TMA in unfolded configuration

The two sets of mirrors M1, M2, M3 and M'1, M'2, M'3 are mounted on the same optical bench. The small beam combiner M4, M'4 is located in the exit pupil region on the Folding Optics Structure: the following folding mirrors M5, M6 and the focal plane are then common to both telescopes.

3.2 The discrimination of field of view

In each telescope intermediate image a mask is placed across scan. All stars from telescope 1 cross this mask and are not imaged on the corresponding Star Mapper (SM2) detector strip of the focal plane: they are detected by the adjacent SM1 detectors. Conversely the stars from telescope 2 are detected by SM2 detectors and are not imaged on SM1. This design enables to discriminate the star origin without ambiguity.

3.3 Photometer and spectrometer optics

For the photometric and RVS instruments, the star light is dispersed along scan prior detection. Red and blue photometry (RP&BP) uses fused silica prisms for dispersing the star light along scan. The Radial Velocity Spectrometer (RVS) uses a grating plate and afocal field corrector lens located close to the focal plane. The lens is made of four prismatic spherical lenses in fused silica material, which is insensitive to radiations.

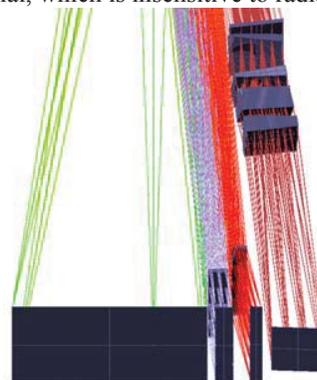


Fig. 6. BP, RP, RVS optics in front of the focal plane

4. FOCAL PLANE ASSEMBLY

4.1 Detector lay-out and operations

The detection uses a large focal plane of 0.5 m x 1 m with 106 CCD featuring almost one Giga-pixel. Key focal plane technologies, including the Astro Field (AF) detectors, are backed by a past Technology Development Activity (TDA) led by EADS Astrium.

The 106 detectors are distributed in strips as following:

- 14 AF detectors for SM1 and SM2 strips, made of 7 detectors each. The first strip SM1 is illuminated only by telescope 1, and SM2 by telescope 2,
- 62 AF detectors for Astro Field, made of 9 strips,
- 14 detectors for photometric field, made of two strips of blue enhanced and red enhanced AF CCDs,
- 12 red enhanced AF CCDs for Radial Velocity Spectrometer, made of 3 strips of 4 detectors each,
- 4 AF detectors for metrology purpose.

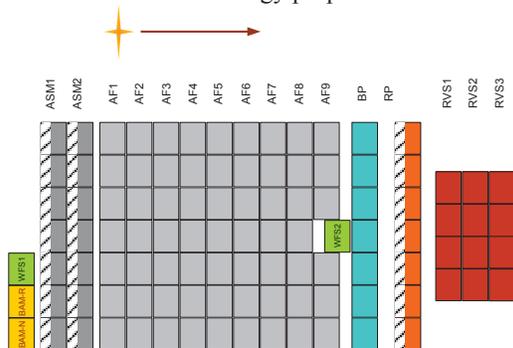


Fig. 7. Detector lay out in the focal plane

During science observations, the satellite is controlled for meeting the scan law and the derived attitude stability requirements. The sky objects follow a regular motion along scan that is along a row of detectors. Stars cross the entire focal plane in about 1.5 minute. The focal plane is operated as following:

- All CCDs have the same format and are derived from e2v Technologies design demonstrated within the FPA & CCD Demonstrators TDA. They are operated in Time Delayed Integration,
- Every object crossing the focal plane is first either detected by SM1 or by SM2, which are operated in full read out mode, corresponding to 1966 pixels across scan. A window is then allocated to the object and is propagated through the following CCDs of the row.
- The object is confirmed by AF1 for eliminating false detections due to cosmic events.
- The accurate attitude control provides the star position versus time along the row : AF1-9, BP, RP and RVS CCDs are then operated in windowing mode for reducing the readout noise to a few electrons.
- The nominal integration time per CCD is 4.42 s and corresponds to 4500 pixels along scan. For bright saturating stars, the integration time in AF1-9, BP and

RP is reduced by activating electronic TDI gates in the detector over a short period corresponding to the bright star window. The purpose of the TDI gates is to lower the effective number of pixels along scan. Twelve gates are available in the detector and allow optimising the signal collection for bright stars at minimum expense for faint stars. A gate is systematically used in SM in order to minimize the false detections due to cosmic events.

4.2 FPA architecture

The detectors in the focal plane are passively cooled to 170 K for reducing their sensitivity to radiations. A large box-shaped radiator provides the necessary radiative surface with the colder internal payload cavity at about 120 K. This radiator shields also the CCD against radiations and supports the Photometer prisms.

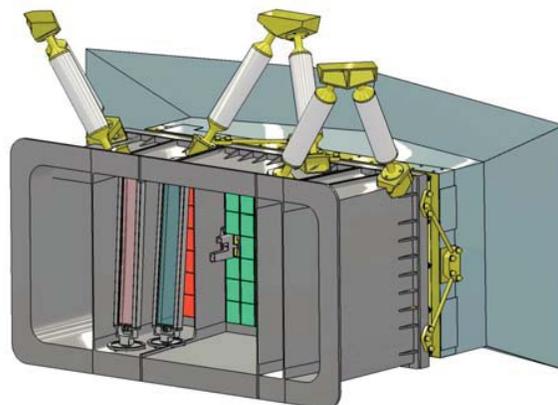


Fig. 8. Front view of the Focal Plane Assembly

The proximity electronics are located just behind the CCD detectors and are operated at room temperature. Their thermal control is ensured passively by the mean of an external radiator. The temperature gradient between the detectors and the proximity electronics is achieved through very efficient thermal shields that have been demonstrated in the FPA Technology Development contract.

The overall FPA is mounted isostatically under the optical bench. This ensures also a high thermal decoupling between the dissipative electronics and the stable optical bench.

The electrical architecture of the FPA is organised by rows along scan: all detectors are connected to corresponding Proximity Electronics Modules which get their power supply and clock distribution from one Interconnexion Module. This parallel architecture guarantees a safe redundancy scheme. The focal plane design and integration concept is thus very modular. In particular, should a failure happen during integration, a single detector and its proximity electronics can be replaced without disassembling the entire focal plane.

5. VIDEO PROCESSING AND STORAGE

The Payload Data Handling System (PDHS) is implemented as a set of 7 parallel Video Processing Units (VPU) feeding a common solid state mass memory. The processing part of the PDHS presents a modular architecture which follows the FPA architecture. The PDHS units are integrated in the Service Module, outside the very stable payload cavity.

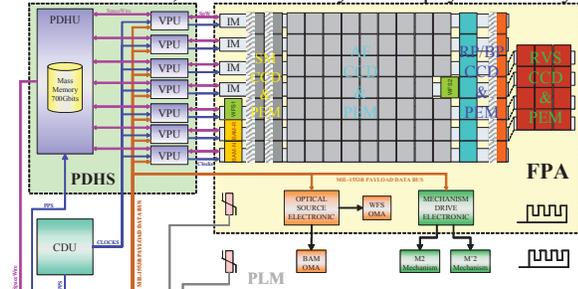


Fig. 9. Payload electrical architecture

The VPU are in charge of the star detection, discrimination from cosmic events, window allocation and propagation, confirmation, constitution of star packets and compression. A precise centroiding of bright stars is made in SM and AF1 CCDs, in order to determine the star velocities for monitoring the attitude control.

To evaluate the performances of the detection algorithm, a wide range of data has been processed that contains various densities of sky with faint and bright stars, multiple objects but also cosmic rays and ripples.

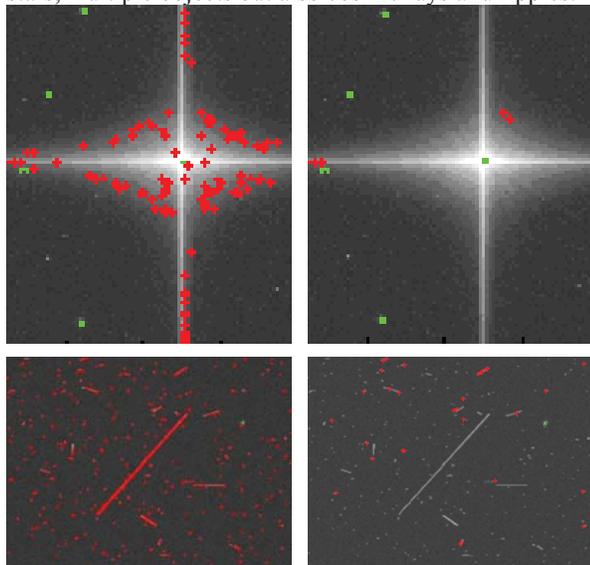


Fig. 10. Effect of discrimination on bright star (top) with ripples and cosmic rays (bottom)

In green: detected real objects, in red: false detections

On most cases the star flux is estimated with a standard error of about 0.1 magnitude.

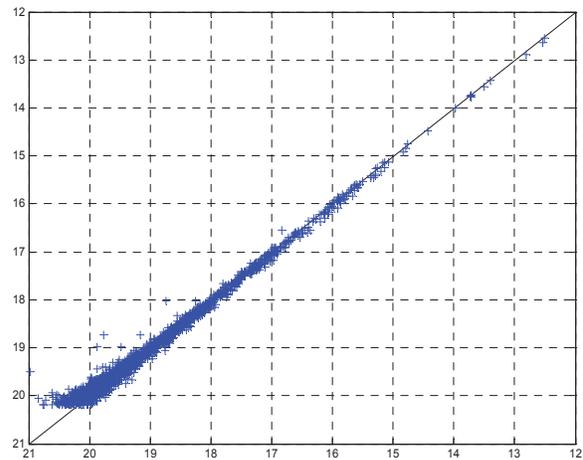


Fig. 11. Estimated magnitude vs. magnitude of simulated objects

The on-board data processing algorithms allow performing computations in the flow, with reduced data buffering. The baseline hardware-software share offers full flexibility, and object-based algorithms may be modified in flight following first in-orbit results. The proposed approach is compatible with very dense areas up to 3 million stars/deg², where a modified scan law can be used for increasing the number of transits.

The file-organised mass memory is implemented as a standard stand-alone unit. The memory management is organised in files classified by objects of similar scientific priority, e.g. by magnitude.

6. METROLOGY AND ALIGNMENT

6.1 The Wave Front Sensors

Two Wave Front Sensors are installed in the focal plane using two dedicated CCDs of the same AF-type.

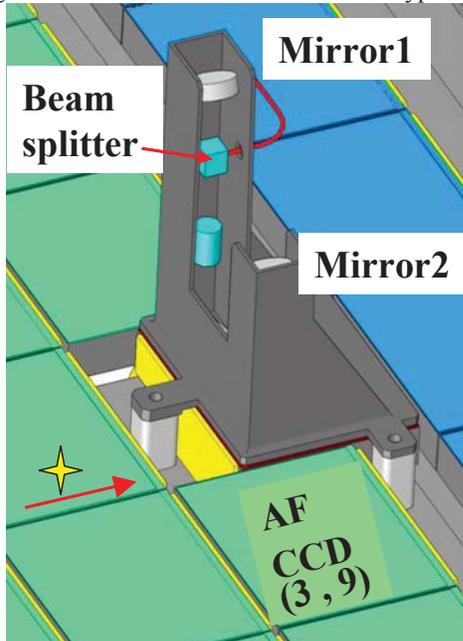


Fig. 12. Wavefront Sensor opto-mechanical assembly

The signal is formed by the signal of bright stars when they cross their fields of view. The WFS data are analysed on ground.

6.2 Mirror Alignment Mechanisms

Two five degree of freedom static mechanisms are implemented behind the secondary mirrors of the TMA telescopes for securing the optical performance in orbit and for cancelling static residual errors on mirrors due to micro-settings after launch, room to operational temperature effect and gravity release. The development of this mechanism has been secured through Technology Development. It is actuated thanks to the WFS measurements in an iterative manner.

6.3 Basic Angle Monitoring

The Basic Angle Monitoring secures the mission performance in case of failure leading to basic angle fluctuations higher than expected and is also useful for data reduction on ground.

The basic angle monitoring system consists of a Fizeau interferometer continuously measuring basic angle fluctuations, with accuracy intrinsically compatible with Gaia performance. The measurement concept was originally created by EADS Astrium in 1998 and subject to technological demonstration in 1999-2000.

The point source generates two laser beams which are sent towards telescope 1 and produce a fringe pattern in the focal plane of this telescope. The same point source also sends a beam towards bar 2, whose optics deflect and split the beam so as to produce two other parallel beams, which are sent towards telescope 2 and produce another fringe pattern in the second focal plane. The fringe motion with respect to the detector frame provides the line-of-sight of the telescopes along scan, and therefore the basic angle variations.

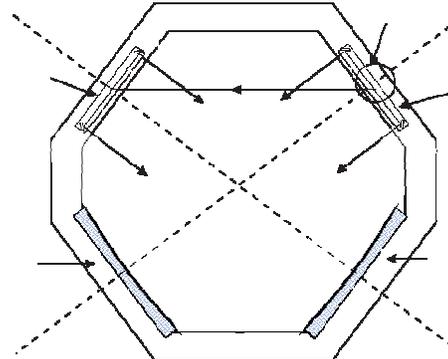


Fig. 13. Measurement principle by using interferometry

7. CONCLUSION

The proposed design for the Gaia payload features several key advantages with respect to previous configurations.

The large common focal plane is now shared by all instruments and is active for both telescopes, except in dedicated areas, on Star Mapper detectors, which are devoted to object detection and field of view discrimination.

The photometric and spectroscopic functions use a fraction of the available field of view common to both telescopes. Afocal elements are placed in front of the detectors for dispersing the star spectrum along scan. Therefore, the Photometers and Radial Velocity Spectrometer are conceptually similar, the major difference being the dispersion power (or spectral resolution).

Aside from obvious cost and mass aspects, the advantages of this configuration are numerous:

- All CCDs have the same format,
- Production of a continuous photometric spectrum spread over 66 pixels and significantly improving science information,
- Use of two large collecting apertures for RVS, enabling satisfactory performance with standard red enhanced AF CCD,
- Use of Astro large focal length (35 m) for the photometer and for the spectrometer, enabling to operate in sky dense areas,
- Use of a common video processing for the three instruments.