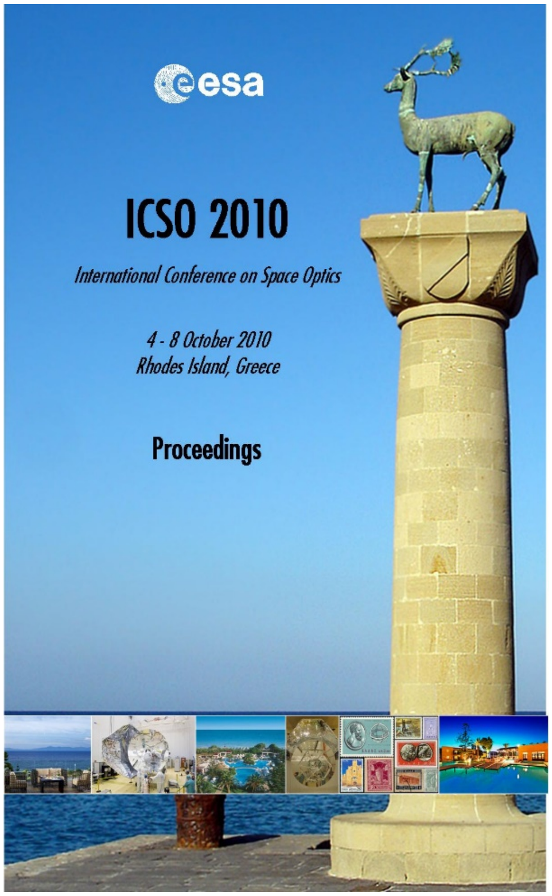

Polishing and figuring of the GAIA M2, M4 and M5 mirrors

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POLISHING AND FIGURING OF THE GAIA M2, M4 AND M5 MIRRORS

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I. INTRODUCTION

As a successor to HIPPARCOS, the GAIA mission will aim at establishing a very accurate three-dimensional map of the objects of our galaxy and at mapping their motion. The GAIA payload module is developed by EADS Astrium and is built from sintered silicon carbide. It includes in particular two three-mirror anastigmatic telescopes (TMA) and a set of flat folding mirrors.
As a subcontractor of EADS Astrium, AMOS is responsible for the polishing and figuring of the secondary mirrors (M2) and of the flat mirrors (M4 and M5).

II. MIRROR CHARACTERISTICS

The mirror blanks are built from sintered silicon carbide (SiC) by BOOSTEC. They are produced to their final geometry, the optical face lying after rectification at a few tens of microns from its wanted shape.

The mirror production steps from the blanks include:

- the deposition of a CVD-SiC cladding on some surfaces of the blank. The cladding operation – chemical vapour deposition - is performed by SCHUNK in an oven at high temperature and silicon carbide is deposited on the free mirror blank surfaces. The surfaces where no further layer is wanted (mounting interfaces, metrology references, mirror back surface) are protected by savings made of refractory material.
- the saving removal
- the mirror blank control with some slight cosmetic repair if necessary
- the mirror surface and interface preparation
- the mirror lapping and CVD layer control
- the 3D metrology
- the mirror polishing
- the interferometric metrology
- the mirror figuring
- the mirror coating
- the final acceptance test

Table 1 herebelow summarises the mirror main characteristics.

Table 1. Mirror main characteristics

Mirror	*Number of items*	*Type*	*Sizes*	*Required quality (in nm RMS on the reflected wavefront)*
M4	2	Flat, rectangular	192 mm x 71 mm	10
M5	2	Flat, rectangular	560 mm x 366 mm	8 (on 90 mm x 40 mm subapertures)
M2	2	Even asphere, convex, off-axis rectangular	345mm x 150 mm	18

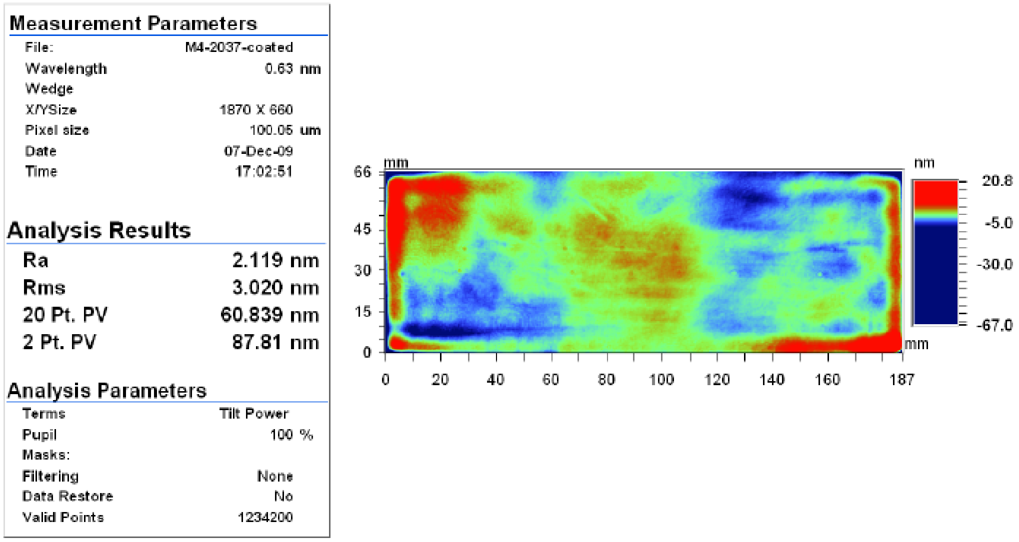
III. M4 MIRRORS

M4 mirrors are relatively small items but require a great accuracy. Their surface figure must be better than 5 nm RMS and their residual radius of curvature has to be higher than 250 km.

For the first operation (CVD-cladding), a baffling device is installed to protect the mirror zones that have to be kept free from CVD-SiC.
A view of this mask is provided in **Fig.1** (Courtesy SCHUNK)**.**

Fig. 1. Baffling of M4 viewed after CVD deposition

The baffles are removed afterwards and the mirror is controlled and cleaned, the CVD layer thickness is measured and the lapping operation begins.
Conventional lapping techniques are used for those mirrors, associated with the continuous control of the CVD layer thickness, which must reach the target of 100 µm ± 50 µm.
There is also a continuous transition from lapping to polishing, the figuring phase being performed under vacuum with an ion beam.
The final step is to deposit onto the mirror an enhanced silver coating, qualified for the GAIA environment.
For all AMOS GAIA mirrors, the coating operation is performed by SAGEM-REOSC.
Fig.2 depicts the final mirror surface figure without power measured after coating under 0-g conditions on M4-2037 mirror (Fizeau test). The last figuring operation lets a small residue of convexity on the mirror to counteract the coating tensile effect. The residual radius after coating stands around 400 km concave.
Fig. 3 shows the mirror at delivery.



Measurement Parameters

File:	M4-2037-coated
Wavelength	0.63 nm
Wedge	
X/YSize	1870 X 660
Pixel size	100.05 um
Date	07-Dec-09
Time	17:02:51

Analysis Results

Ra	2.119 nm
Rms	3.020 nm
20 Pt. PV	60.839 nm
2 Pt. PV	87.81 nm

Analysis Parameters

Terms	Tilt Power
Pupil	100 %
Masks:	
Filtering	None
Data Restore	No
Valid Points	1234200

Fig.2. Mirror M4-2037final surface figure at 3 nm RMS

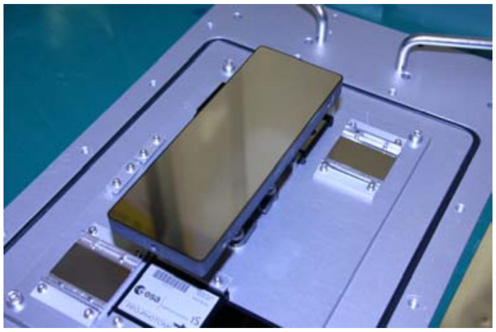


Fig.3. Mirror M4-2037 at delivery

IV. M5 MIRRORS

M5 mirrors are large flat mirrors that follow approximately the same general manufacturing sequence as the M4 mirrors, except that some specific steps are called for, essentially during the lapping phase.
Due to the mirror sizes, the interferometric test involves stitching of diameter 400 mm subapertures maps provided by a flat reference within a Fizeau cavity to reconstruct the full mirror aperture (**Fig. 4**).

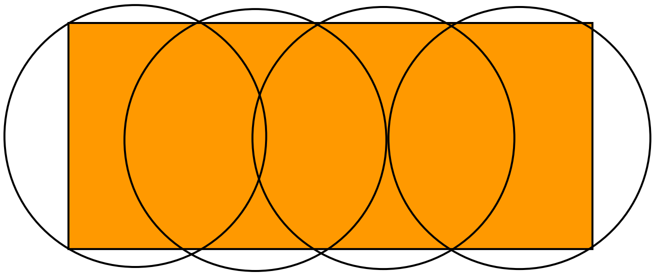
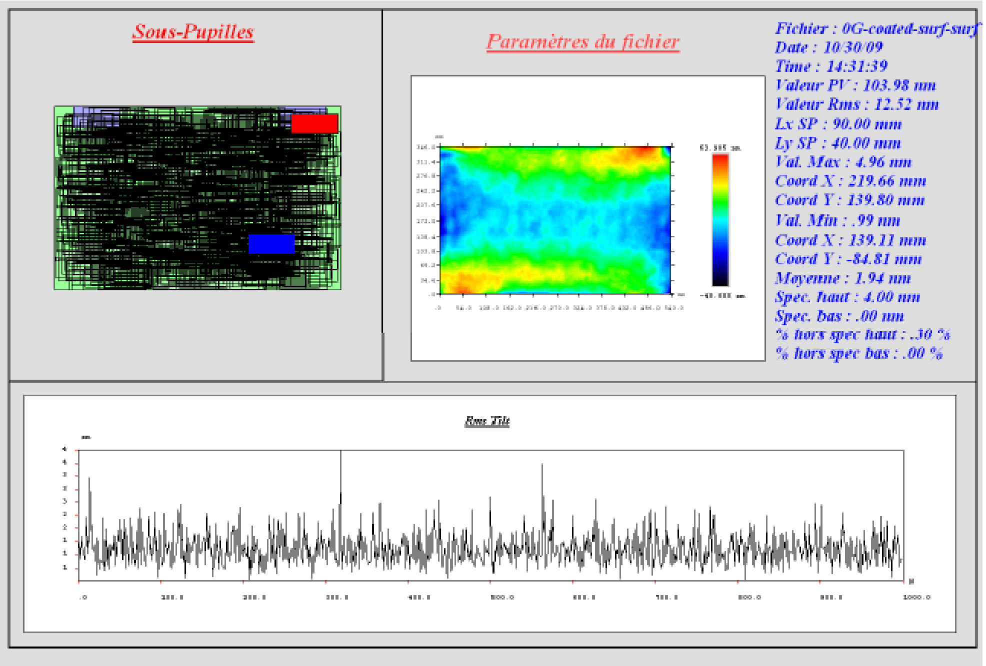


Fig.4. Subaperture stitching principle for M5 mirror testing

The main quality requirement involves subapertures of 90 mm by 40 mm on which the surface figure must be better than 4 nm RMS and the local tilt vary less than 0.04 µrad RMS on a 18 mm shift along the long mirror size. **Fig. 5** shows the surface figure values measured after coating in 0-g conditions on a Monte Carlo selection of subapertures.



Fichier : 0G-coated-surf-surf
Date : 10/30/09
Time : 14:31:39
Valeur PV : 103.98 nm
Valeur Rms : 12.52 nm
Lx SP : 90.00 mm
Ly SP : 40.00 mm
Val. Max : 4.96 nm
Coord X : 219.66 mm
Coord Y : 139.80 mm
Val. Min : .99 nm
Coord X : 139.11 mm
Coord Y : -84.81 mm
Moyenne : 1.94 nm
Spec. haut : 4.00 nm
Spec. bas : .00 nm
% hors spec haut : .30 %
% hors spec bas : .00 %

Fig.5. Surface figure values on a set of M5-2285 subapertures (mean 1.9 nm RMS)

Fig.6 shows the mirror at delivery.

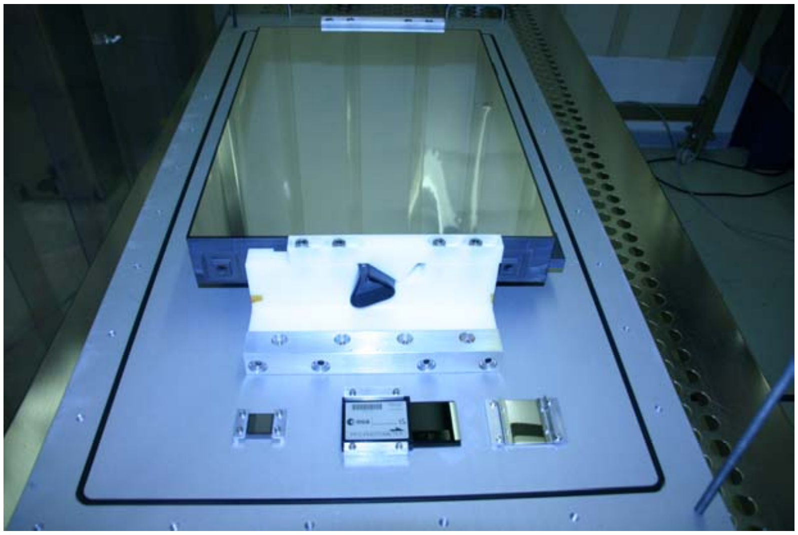


Fig.6. Mirror M5-2285 at delivery

V. M2 MIRRORS

The M2 mirrors are the most challenging to face in the AMOS set.
Being convex and off-axis, they are inherently difficult to test and present in addition a high departure to the best fit sphere and an aspheric slope of some 8 mrad.

The principle of the interferometric test is to realize a null configuration in double pass on the mirror, using a computer-generated hologram (CGH) and a return sphere as auxiliary devices.
The test scheme is illustrated in **Fig. 7**.
The CGH null e-beam master on a fused silica photomask substrate is located in a diverging spherical test wavefront from the interferometer equipped with a f/3.3 reference sphere. The M2 vertex is decentered 50 mm from the CGH axis.
The minimum grating spacing within the critical null aperture is about 108 lp/mm.
The CGH null incorporates one retro-reflective (accuracy in axial positioning of about 3 microns), one autocollimation (parallel to M2 asphere axis) and one focused spot (concentric with return sphere) alignment features.

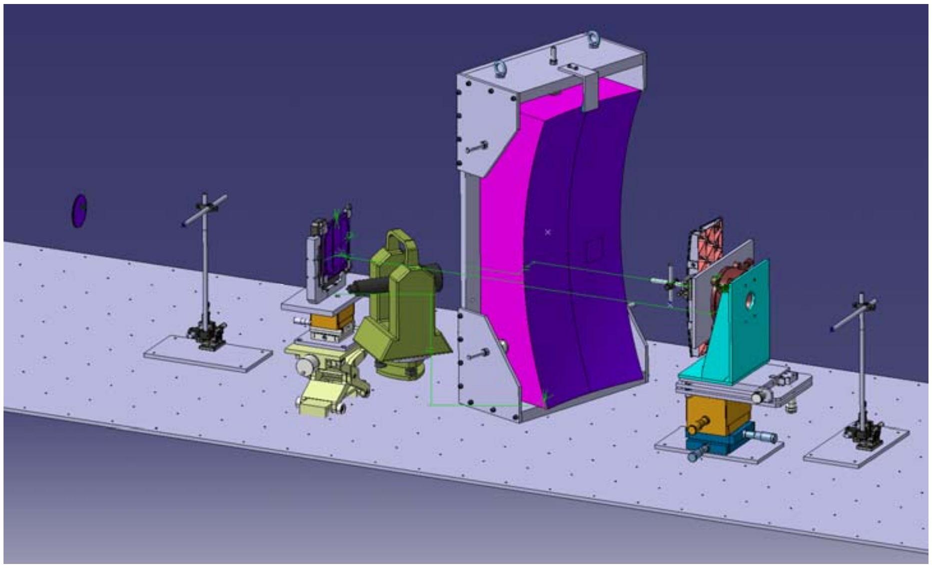


Fig.7. Interferometric test lay-out for M2

The return sphere has a radius of curvature of 1000mm. Its dimensions are 800x350mm.
The sphere is mounted in a dedicated cell that minimizes its deformation under gravity.

The test bench is aligned through a dedicated procedure in accordance with the following error budget **(Table 2).**

Table 2. M2 test error budget

Contribution	Surface figure error (nm RMS)
Interferometer	2.5
CGH alignment	0.2
CGH encoding and digitisation	2.5
CGH E-Beam registration	3.9
CGH transmission wavefront distorsion after patterning	1.5
Hindle sphere (half contribution)	2.5
Hindle sphere location	0.2
Hindle sphere : tolerances on RoC	0.2
Mirror vertex localisation and tilt knowledge	0.4
Mirror : tolerances on RoC	0.6
0g residuals	1
Ag coating effect	1
Measurement (figuring criterion)	6.5
TOTAL	**9**

The measured phase map is corrected for distortion according to a dedicated software.
In order to take into account the uncertainty brought by the test set up, the figuring criterion is set at a value such that if added to this uncertainty in a root-sum-square sense, the obtained value remains at the specification.
A picture of the mirror under test is given in **Fig.8**. The last manufacturing step on the mirror is performed by ion beam figuring (IBF).

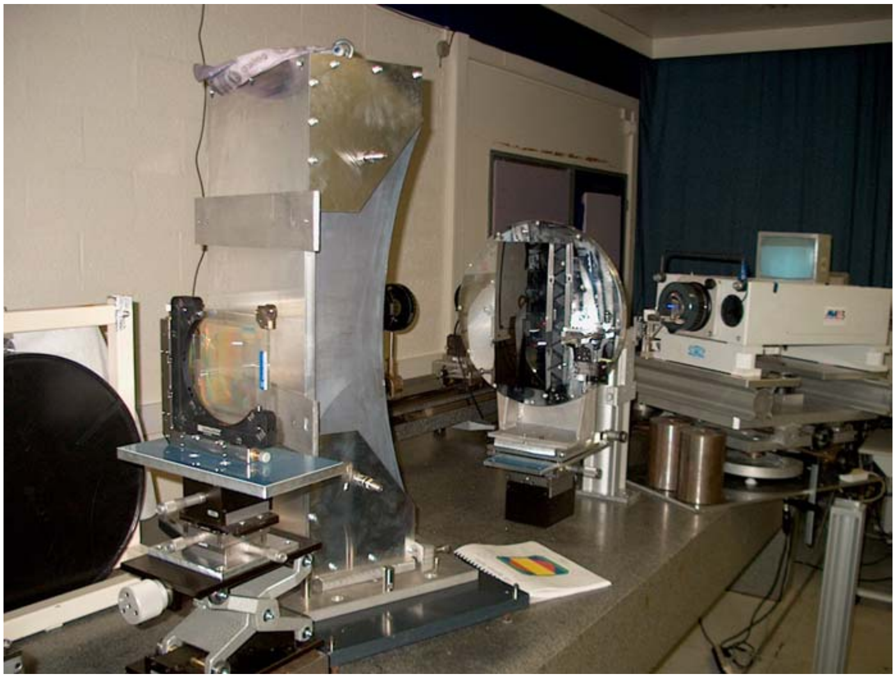


Fig. 8. M2 test set under test

VI. SUMMARY

The steps performed by AMOS for manufacturing SiC mirrors for GAIA were here briefly described and commented.