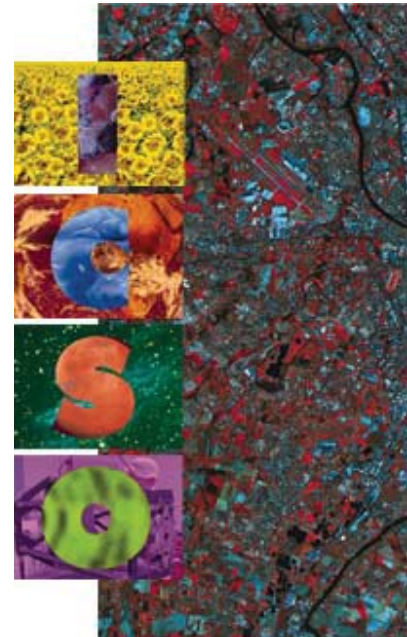


# International Conference on Space Optics—ICSO 2000

Toulouse Labège, France

5–7 December 2000

*Edited by George Otrio*



## *Astronomical space optics development at SAGEM*

*Roland Geyl, Luc Thepaut*



Roland GEYL, Luc THEPAUT

*SAGEM SA  
61, rue Salvador Allende 91751 Nanterre*

## 1 – INTRODUCTION

SAGEM, through its REOSC Products family is presently participating to several aerospace astronomical projects requiring high performance optics. These are :

SOLAR B high resolution sun observation telescope optics fabricated for the Japanese ISAS institute,

NMSD ultra low weight hybrid mirror technological development conducted for NASA NGST project in relation with Composite Optics Inc,

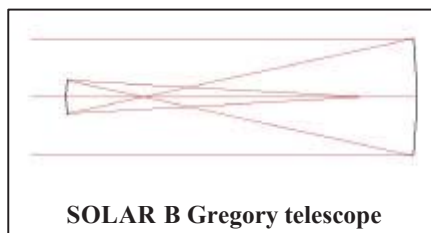
The SOFIA 2.7-m primary mirror assembly developed for NASA-DARA and the Gran Telescopio Canarias using state of the art fabrication and testing technology.

## 2 – SOLAR B

**2.1 The SOLAR B Project :** SOLAR B is a project of the Japanese Institute for Space & Astronomy and Science (ISAS) with the assistance of the National Astronomical Observatory of Japan (NAOJ). The satellite is dedicated to high resolution imagery at various wavelength combined with polarimetry and spectropolarimetry.

SAGEM has been awarded, through Mitsubishi Electric Company (MELCO), for the fabrication of the optical elements for the SOLAR B main optical telescope.

**2.2 Optics specification :** The Solar Optical Telescope (SOT) design is based on a 50 cm aperture, 4500 mm focal length, Gregorian configuration with a concave secondary. This configuration allows to insert a so-called heat dump mirror, also acting as a field stop, at the intermediate focus to reduce the amount of energy reaching the secondary mirror. A collimating lens assembly conjugates the entrance pupil on a real exit pupil behind the primary mirror.



Optical specifications require a Strehl ratio higher than 0.94 at  $\lambda = 0.5 \mu\text{m}$ . We calculated that this correspond approximately to 20 nm RMS wavefront deformation through the whole telescope. This tight requirement will impose matching the M2 mirror on the M1 during a last Ion beam figuring run. In addition, stray light will be controlled with a microroughness level below 1 nm RMS for both mirrors.

Despite these precautions, thermal management of the telescope remains a major concern. Mirror optical surface deformation and defocus under the expected thermal loads should be reduced to the minimum. This led ISAS to select ULE from Corning as the material for the telescope M1 and M2 mirrors because the CTE ( $< 20 \text{ ppb} / ^\circ\text{C}$ ) and CTE uniformity ( $< 5 \text{ ppb} / ^\circ\text{C}$ ) are easily assessed for this material with simple ultrasonic waves velocity measurements.

SAGEM brought to ISAS its experience in lightweight mirror design and iterated on the blank geometry with its customer. Pads will be bond on the mirror periphery to connect them onto the structure through Mirror Fixation Devices.

SAGEM has also been selected for the fabrication of the large, 680 mm diameter, autocollimation flat to be used for ground optical testing and integration verifications. Its optical specification is a reflected wavefront quality below 15 nm RMS.

Photo SAGEM

**2.3 Fabrication status :** Today, the ULE Blanks M1 and M2 blanks of the Mechanical and Thermal Model have been lightweighted and are under polishing. The picture below shows the concave primary mirror during an intermediate inspection.

The flat mirror has been polished without problem. Then, NAOJ people came to integrate the mirror in its structure and a final optical verification has been done, with optical axis vertical, in front of our large 800 mm diameter Fizeau interferometer.



The SOLAR B primary mirror

### 3 – NMSD

**3.1 The NGST requirement and roadmap :** The NASA Next Generation Space Telescope project, with its 8-m aperture and main mirror low areal density of around  $12 \text{ kg / m}^2$  is generating a high amount of effort and technological development on ultra lightweight precision optics. Various NGST concepts are in competition but all will require large off axis aspheric segments with approximately 1.8 m size and 15 meter radius of curvature.

A first technological round is conducted with the NGST Mirror Segment Demonstration (NMSD) program asking to realize such a segment. In this frame, SAGEM participates with the US company Composite Optics Inc (COI) to the project and develops an hybrid mirror concept.

**3.2 The Hybrid COI mirror concept :** COI is working since many years on the fabrication of ultra lightweight panels for telecommunication, IR observation and even visible mirrors. For NGST – NMSD, COI proposed with SAGEM to realize a demonstration mirror segment based on the hybrid technology as follow :

- A lightweight Carbon Fiber Reinforced Plastic (CFRP) rib structure is fabricated and tailored to near zero coefficient of thermal expansion,

- A 3 mm Zerodur sheet is fabricated and polished near the final shape,

- The sheet is bonded to the CFRP structure with a soft, low CTE glue,

- Refine the optical surface quality through Computer Controlled Figuring.

**3.3 Front Sheet fabrication :** The fabrication of a 1.6-m hexagonal Zerodur sheet of only 3 mm thickness is a significant challenge that was accepted by SAGEM. We adopted an approach of ‘thinning after polishing’, the only way to not break such a thin sheet during polishing.

**3.4 Mirror construction :** During the time SAGEM fabricated the Zerodur meniscus, COI fabricated all the CFRP structure elements with the right coefficient of thermal expansion and protected them from moisture effect. The last phase was then to assemble and construct the hybrid sandwich mirror as shown on the pictures below.

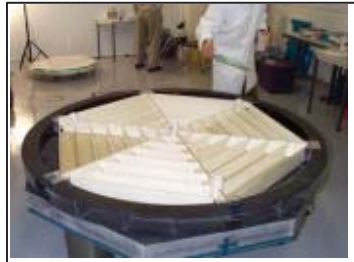
- First the sheet is laid onto the convex gauge within a jig mount

- Second the structure is constructed and, at the same time, bonded onto the sheet

The result is the hybrid, ultra lightweight mirror shown below at right.



The Zerodur sheet



The CFRP structure



The hybrid mirror on 3D machine

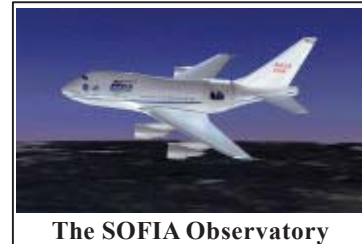
### 3.5 Front surface post polishing

The problem with hybrid mirror is that the bonding operation generates some deformation of the optical surface despite all precautions that can be taken. The two main sources of deformation are the sheet warping while laying onto the convex gauge and the sheet deformation generated by the glue joint polymerization along the CFRP ribs.

Another difficulty appear with the 39K deep cryogenic operational temperature of NGST. Computations have shown that about 6  $\mu\text{m}$  quilting are expected to appear at this temperature. Therefore a negative quilting has been introduced on the surface, after bonding, by computer controlled figuring. A first cryo optical test has been performed last June at Marshall Space Flight Center (MSFC) in a 5-m diameter, 15-m length cryogenic chamber and showed that the pre-polish was not sufficient. Two more  $\mu\text{m}$  have to be introduced at room temperature to reach a smooth shape at low temperature. A second Computer Controlled Polishing run is now in progress up to the next cryogenic test scheduled for begin 2001.

## 4 – SOFIA

**4.1 The SOFIA project :** The Stratospheric Observatory For Infrared Astronomy is a 2.7-m astronomical telescope installed aboard a 747 SP Boeing aircraft. SOFIA will fly at an altitude of 12 to 15 km in order to stay above the water vapor of the atmosphere and catch the spectral range of 0.3-1600 micrometers. This flying infrared observatory will be 10 to 1000 times more powerful than its predecessor the Kuipper Airborne Observatory (KAO) of 0.9-m aperture only.



The SOFIA Observatory

Credit NASA

This program has been conceived by NASA in cooperation with the German Space Agency (DARA). NASA will supply the 747 SP specifically modified Boeing aircraft and DARA is responsible for the telescope. The German Consortium Kayser Threde / MAN Technologies has been selected by DARA as prime contractor for the telescope design and manufacture. REOSC, now merged within SAGEM Defense and Security Division, has been awarded in 1997 for designing and manufacturing the 2.7-m parabolic primary mirror.

**4.2 Primary mirror specification :** As shown on the picture, observation will be done through a large door opened laterally during flight. This implies severe environmental conditions with a low operating temperature of  $-63^{\circ}\text{C}$ , vibrations and turbulence. The main optical specifications are :

Spectral range	300 nm -1600 $\mu\text{m}$ .	Focal length	3200 mm
Outer diameter	2690 mm.	F number	1.19

Operational Optical quality at 633 nm : 80% of light within 1.0 arcsec

The primary mirror main mechanical specifications are :

Elevation	15 – 70 deg	Mirror assembly stiffness	> 120 Hz
Mass	< 850 kg	Thermal time constant	< 2 hours



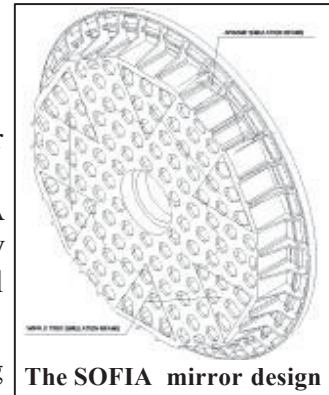
### 4.3 The mirror design

Low expansion Zerodur from Schott has been selected for SOFIA.

The lightweight structure is obtained by machining pockets from the rear side as done by the company for many space optical telescopes elements. A honeycomb structure is made with 185 mm size hexagonal pockets. A large edge bevel of about 45 cm size is cut around the mirror periphery and contributes to further mass reduction without sacrifice on its overall stiffness. Radial ribs ensure maximum optical surface stiffness.

Axially, the mirror is supported by an 18 point waffle tree system leaving gravity sag residuals of about 80% light within 0.5 arcsec at 45° elevation. A final computer controlled polishing run will compensate most of this amount.

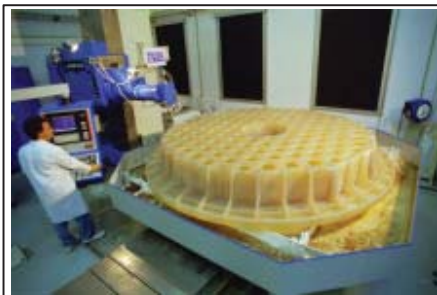
Laterally, the mirror is attached through strong bipods filtering perturbations induced by the cell.



**4.4 Mirror lightweighting :** This huge, one year lasting, glass machining operation, unique through the word, has been achieved on our large 3-m capacity CNC milling machine. Careful validations and process control were essential for the success. HF acid etch has been applied to remove residual stresses.

All pads interfacing with axial and lateral supports have been glued to the structure after extensive gluing validations.

The next operation was critical again and consisted in flipping over the component in order make its concave surface looking up for optical polishing. The two minutes required several months preparation for success.



End of the SOFIA mirror machining

The steep concave parabolic surface was then generated on the CNC milling machine within 17  $\mu\text{m}$  accuracy and lapped to remove subsurface damages, further improve its figure and refine its texture prior the polishing operations.

This last task, aiming to bring the mirror down to 20 nm RMS figure error is now close to be finished. Latest results will be presented at the time of the conference.

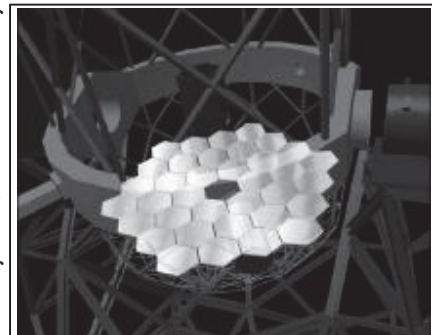
Photo SAGEM

## 5 – Gran Telescopio Canarias

We take the opportunity of the symposium to briefly present to the space astronomy community our work for the Gran Telescopio Canarias (GTC) ground astronomical telescope. The technology developed for this project will surely find application for space astronomy.

**5.1 The project :** GTC is a project of the Institute of Astrophysics of Canarias (IAC) managed by GRANTECAN S.A., a company set up for the project. The telescope is to be erected on top of La Palma island at an altitude of 2300 m. Its main feature is an 11-m large segmented primary mirror inspired from the Keck telescopes design. SAGEM has been selected by GRANTECAN S.A. for the polishing of the 36 (+ 6 spare) 1.8-m off axis hexagonal segments. First light with a first set of segments is scheduled for 2003.

Credit Grantecan



The GTC primary mirror

**5.2 The segments :** Each segment is a 75 mm meniscus of Zerodur with an hexagonal contour inscribed in a circle of 1.8-m. The vertex radius is  $R = 33.000$  mm and the conic constant  $\varepsilon = -1.00225$ . A critical requirement is the radius matching between all the segment within 0.2 mm.

Credit Grantecan



The optical surface polishing specification is expressed in Central Intensity Ratio, a Strehl Ratio taking into account air effect. The specification of  $CIR > 0.887$  is equivalent to a 20 nm RMS reflected wavefront error. GTC pays a great attention to the edge effects on the polished surface. This has to remain below  $\lambda/4$  over no more than a couple of millimeters around the segment contour.

Each segment is resting on a 36 points waffle tree support system. 6 actuators allows to remove a small amount of low order aberrations.

**5.3 Work progress :** Since the begin of this year, all the efforts are spent on the facility modification, machinery definition and procurement, optical process improvements.

Several large equipment have been designed and are now under procurement. These are : large lapping machines, a large aspheric generator, a 2.5-m ion beam figuring machine and several computer controlled figuring robots.

Photo SAGEM

In the same manner, the test set up is defined with a large Offner type null lens and a versatile test bench at the top of our present 29-m test tower in our Saint Pierre du Perray plant. A large bidimensionnal spherometer with sub micrometer accuracy over the 3 m<sup>2</sup> area of each segment.

Production of the 42 segments is beginning with the fabrication of a master segment and first acid etching, pad bonding and lapping operations on the first segments.



## 6 - CONCLUSION

Space astronomical optics is a demanding field of space optics pushing more and more the technology towards new limits. But ground and airborne astronomy are doing the same and all these fields of activity can greatly benefit, at SAGEM within its REOSC product family, from the development conducted in their counterparts.

SAGEM takes this opportunity to thank its customers for placing their confidence in the company.