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# TESTING THE OPTICS OF THE INSTRUMENT ELMER

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RESUMEN

Elmer es un espectrógrafo y cámara de imagen para el GTC en el intervalo visible del espectro. La óptica de Elmer ha sido exhaustivamente probada en las diferentes etapas, desde los substratos hasta los conjuntos finales ensamblados, para garantizar que cumple con las prestaciones requeridas. En esta contribución describimos las pruebas realizadas a los diferentes subsistemas ópticos hasta la fecha. Hemos llevado a cabo la verificación de los substratos, la calidad de imagen (WFE en las superficies) y la transmisión en la mayoría de los componentes, así como pruebas de conjunto del sistema óptico integrado en la estructura del instrumento.

ABSTRACT

Elmer is a visible imager and spectrograph for the GTC. Elmer Optics has been exhaustively tested at different steps, from the blanks to the final assemblies in order to guarantee the fulfillment with the required performance. In this contribution, we describe the tests done to the different optical components until now. Blank testing, WFE Image quality and Transmission tests have been carried out in most of the components, as well as some tests of the complete optical system integrated on the instrument structure.

*Key Words:* **INSTRUMENTATION: MISCELLANEOUS — INSTRUMENTATION: SPECTROSCOPY**



## 1. INTRODUCTION

The Elmer optical system consists on a field lens, a collimator, and a camera, plus two folder mirrors to package the instrument into the small Folded-Cassegrain envelope. Elmer Optics is completed with the pupil elements: 4 broad band and 8 narrow band filters for Imaging and 2 prisms, 2 grisms and 6 VPHs for Spectroscopy, to cover the whole wavelength range at resolving powers of 250, 1000 and 2500 respectively. A composition of different pictures of the optical parts is shown in Figure 1. Elmer was extensively presented to the GTC community in different contributions in this conference (García-Vargas et al., Kohley, Kohley et al., Martín-Fleitas et al., Maldonado et al. and Gómez-Alvarez & García-Dabó). In this paper we concentrate the description in the optical tests carried out until now. The results obtained and the foreseen tests are allowing us to follow an acceptance plan for the individual elements as well as to predict the final performance of the integrated assembly on the basis of as-built results. Many companies have participated in Elmer Optics (Schott glass, Schott Lithotec, OHARA, OMEGA Optical, SESO, INAOE, Richardson RGL and Wasatch Photonics). Some of the delivered items were out of specifications. Our tests have proved fundamental to reject some of the finished pieces due to defects or, in the case of keeping the elements, we identified the possible effects on the final assembly, and we made the corrective actions on non-manufactured elements to compensate the final system. Due to the low budget for Elmer, which is a contingency instrument planned to be delivered in a short time and with a low budget, the test assemblies were designed and mounted with existing material in the GTC Project Office (PO) that was recycled from test to test. The test plan carried out to date (May 2004) is, chronologically, the following:

- Blank testing: bulk defects, dimensional and birefringence.
- Filter testing: current wavefront error (WFE) in 90mm apertures.
- SESO factory acceptance of the main optics.
- Lens curvature testing for a back-up field lens.
- Flatness surface testing for the coated folder mirrors.
- Flatness surface testing for prisms and windows (they will become part of the final pupil elements assemblies: prisms, grisms and VPHs).
- Test of the camera for studying the impact of cosmetic defects on the last lens.
- Transmission of the camera.

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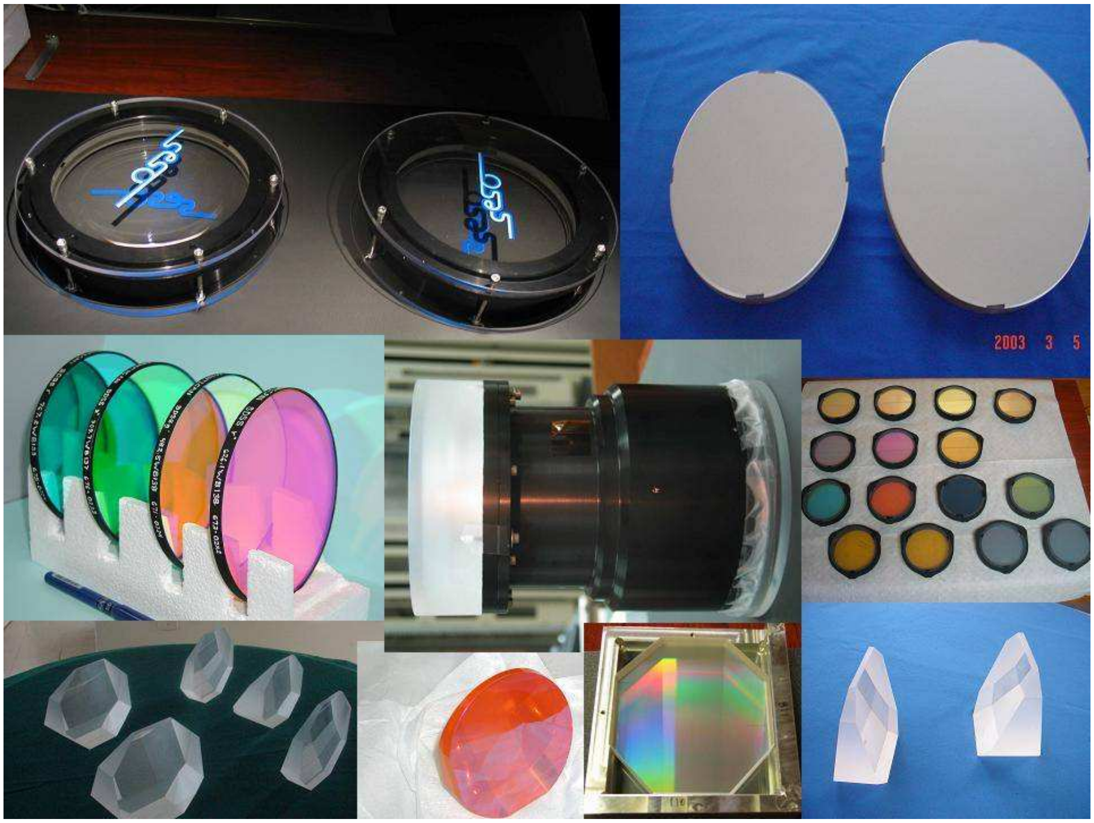


Fig. 1. Different as-built optical elements of Elmer. Only the VPHs are missing, since they will be delivered in October 04.

- Transmission of the field lens and collimator.
- Reflectance of the folders mirrors.
- Camera ghost tests.
- Tests for gratings acceptance.
- WFE and cosmetic tests of the cementing glue to be used in the grisms and the prisms.
- Whole system integration.
  - Folders alignment and collimator position
  - Encircled Energy. Image quality tests.
  - System back focal length.

## 2. BLANK TESTING

We have tested forty-five pieces of glass or crystal in the PO. Schott Lithotec AG supplied the $CaF_2$ blanks and OHARA and Schott Glass all the glasses (S-LAL18 for the lenses and other materials for the blanks for prisms, grisms and VPHs). In the case of the Elmer main optics (Field lens, Collimator and Camera) only two materials for lenses (S-LAL18 and $CaF_2$ ) were used in order to optimize the coatings. The tests done were:

1. Inspection bulk tests, to look for bulk defects: absorption, inclusion, impurities, striae, and fracture. For the bulk tests, we used different oils to match blank index to allow inspection within the volume. We returned one blank to Schott Lit. due to its colored appearance.

2. Dimensional tests, to measure the thickness and the diameter of the lens blanks and the thickness and the face parallelism and perpendicularity of the prismatic blanks. Relaxed and standard dimensional tolerances were designed from the beginning to lower the blanks cost. This implied an exhaustive testing of blanks for feeding back the design and the manufacturing specifications, in order to keep the overall performance. The dimensional testing allowed us to identify the best faces of the blanks to be cut and polished. Therefore, we could select the best orientation of the blank. Some pieces were out of the dimensional specifications, but we asked the pol-

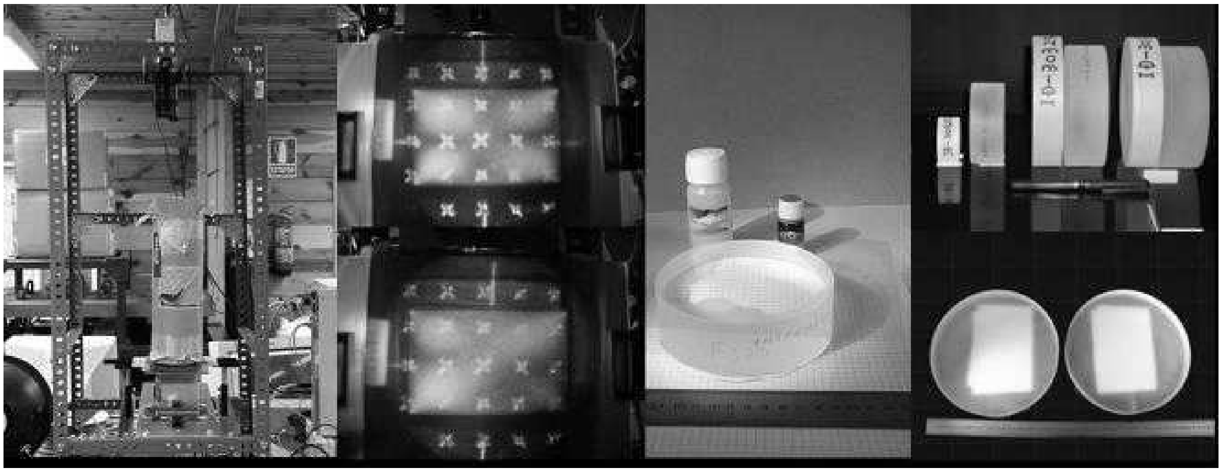

Fig. 2. Picture on the left shows the full assembly for the birefringence test. In the middle, some raw images of a FSL5 120x120x90 mm blank. Picture on the right shows a $CaF_2$ blank while is being inspected using glycerin and the blanks of the camera (top right), collimator and field lens (bottom right).

ishers about their restrictions and we modified the mounts, avoiding the blanks to be returned to OHARA and saving time.

3. Birefringence tests. For this test, we used a small instrument including a homemade large $\lambda/4$ plate for compensation was assembled between two polarizers and a pattern structure. All blanks turned to be in specification.

## 3. MAIN OPTICS ACCEPTANCE TESTS

The refractive main optics of Elmer was awarded to SESO (France) who was in charge of the polishing, coating and assembly of the lenses as well as the mechanical barrel design. Optical detailed design was done at the PO under SESO assessment. The optical assemblies (field lens, collimator and camera) were contracted together with acceptance tests to check the fulfillment of both, optical and mechanical specifications. The main tests done at SESO were:

- WFE quality: Peak to Valley (P-V) and RMS for (a) the field lens plus the collimator together and (b) the camera. The central field, and four other marginal fields were measured within a circle equivalent to 4.2 arcminutes on sky.

- Fresnel losses, which were estimated from the measurements of the witness samples of each coating run.

- Camera back focal length measurement. In addition, we also measured the camera chromatism and we got a qualitative view of the image quality.

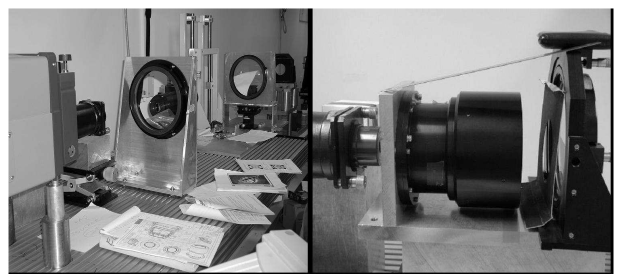

Fig. 3. Interferometric assemblies of field lens/collimator (left) and the camera (right) in SESO. All the WFE results were in specifications.

In the PO different tests regarding the main optics were done: (a) Transmission test for the Camera and for the Field lens and Collimator assembly, (b) The fused silica field lens was tested regarding curvature, (c) a ghost test and a cosmetic effect test regarding the last lens of the camera, which allowed us to send back the camera to SESO for L6 substitution. Final figures for transmission are given in García-Vargas et al. (this conference).

## 4. FILTER TESTING

Elmer contains an initial set of 16 filters (4 SDSS broad band, 8 narrow band, two neutral density and two order sorting filters for spectroscopy). Filter testing at PO was needed in order to verify dimensions for mounts and specially to check for WFE, as the documentation from the supplier did not cover the required full aperture (the pupil is 87mm). All the filters were analyzed with a Hartmann test specifically mounted for this purpose. After testing

Fig. 4. Transmission assemblies: Left: for the camera, Center: The field lens and collimator, Right: Assembly and optical path for one of the folders.

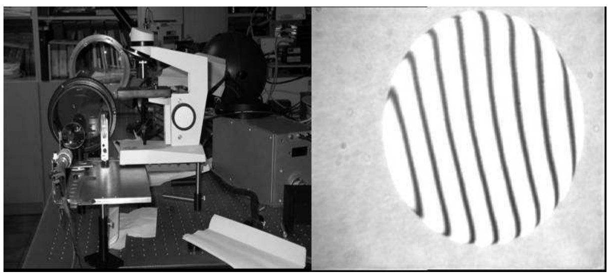

Fig. 5. Left, the assembly to measure the curvatures of the fused silica lens. On the right the interferogram supplied by INAOE for the concave surface.

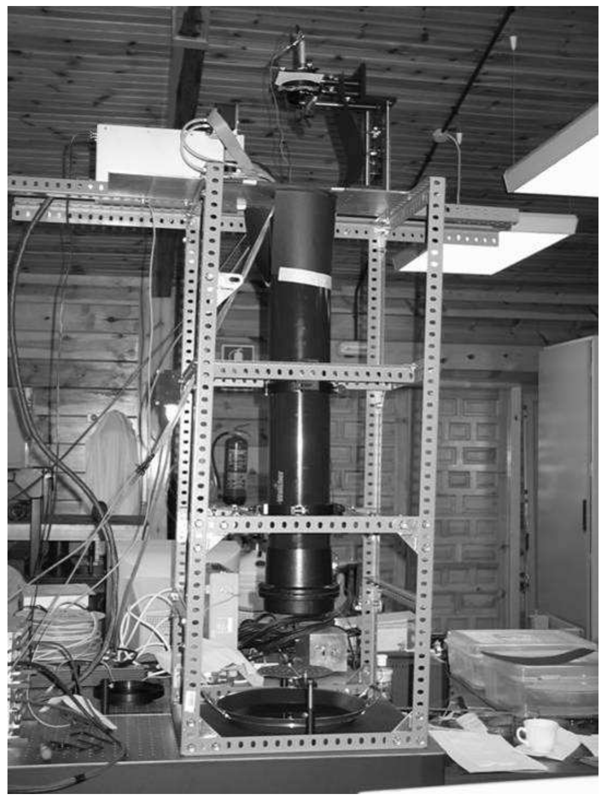

Fig. 6. Left, Hartmann assembly. The Hartmann had a beam of 150mm diameter and was placed vertically to have an oil surface at the bottom.

the filters we really could know the overall performance of each filter. Dominant aberration is focus (correctable thanks to the focusing mechanism on the collimator stage) and, after that, astigmatism and spherical aberrations (depending on the filter) dominates the errors. Some of the filters consumed more image quality budget than expected. Nevertheless the top requirements will be met since other elements are better than specified.

## 5. SURFACE FOLDER MIRRORS TESTING

Four type of tests have been done to the folder mirrors: blank tests, reflectance tests, coating degradation monitoring and surface quality testing. The blanks (in Zerodur) were ordered from Schott Glass, verified at the PO and sent to INAOE, who made the polishing and coating. The flatness documentation of the folder mirrors was not supplied for the required aperture but for smaller ones. To verify the fulfillment of the specification, a Hartmann test was setup at the PO by using oil as a flat reference. Two composed images were taken for each analysis: one for the oil reference and one for the mirror. The oil reference was done as the average of 100 images to avoid surface stability effects. Each mirror image was obtained as the average of 10 images with the real mirror we wanted to characterize. A software was developed for the analysis and reconstruction of the mirror surface. The mirrors turned out to be out of specifications. However, the overall performance will be met by compensation of the error budget with other subsystems, whose performance were better than specified.

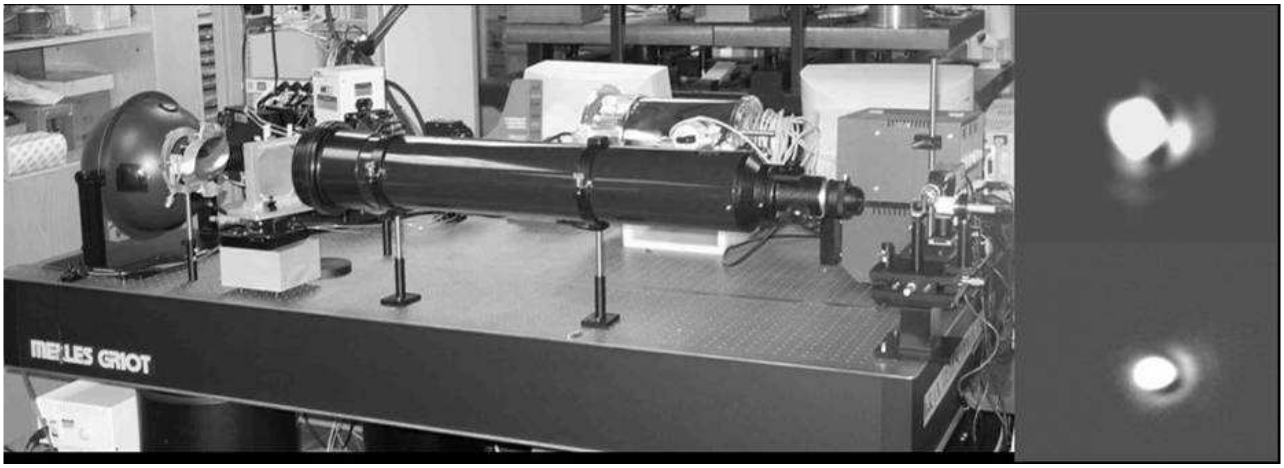

Fig. 7. Star test in double pass to measure the PSF degradation. The light goes from right to left, and is returned back by a flat mirror just next to the integrating sphere (not used in this test). On the right of the telescope a splitter cube feeds the light (diode laser beam with a spatial filter) and sends the returned beam to a microscope with a CCD. Right: PSF images before grating (down) and with the grating (up).

## 6. GRATING TESTING

Two gratings were purchased to form part of the grisms (red and blue), once glued to the corresponding prisms. The PO supplied the windows of different sizes (previously polished and coated by INAOE) to the grating company (Richardson, RGL) to proceed with the replica. The acceptance tests regarding the gratings were: (a) verification of the number of lines/mm and the blaze angle, (b) the visual inspection of the replica for cosmetic defects detection and (c) the estimation of the transmitted WFE quality (by measuring indirectly the PSF with a microscope). The gratings were returned twice to the manufacturer. First time due to a replica in the wrong substrate and second time due to strong surface defects on the replica.

## 7. PRISMS AND WINDOWS SURFACE TESTING

Prisms, grisms and VPHs have been designed at the PO. Blanks were bought, tested and sent to the polishers (INAOE, JANOS and SESO). Surprisingly for us some of the surfaces were nominally out of specifications although still valid using the best faces to air (once coupled). A simple Fizeau interferometer was assembled to verify surface quality, which sometimes was not provided by the manufacturers.

The real information about the surfaces permit the use of many of the surfaces nominally out of specifications without major degradation. This analysis also allowed us to understand the difficulties of the polishers with certain soft materials with high CTE.

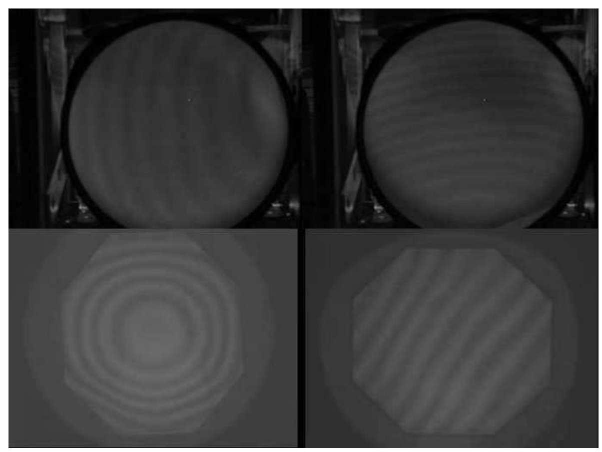

Fig. 8. Top, ZnSe prism with severe turned down edge that is nominally out of specification. Bottom, window interferogram. The flat surface (around $\lambda$ /8) was used to place the replica grating while the other side was cemented. This second surface was out of specification.

## 8. CEMENTING TESTS

A set of tests on samples was done previous to glue the gratings to the prisms and the prism units. The process was (a) to find the optimal cavity thickness using gages, (b) to carry out tests to avoid and to control bubbles and (c) to test the substrate reactivity and WFE deformation. For the WFE tests, we setup a Fizeau interferometer and developed specific software for basic wavefront map reduction.

## 9. SYSTEM TESTS

In May 2004, we integrated Elmer Optics on the main structure (Fig. 10). We aligned the optics with

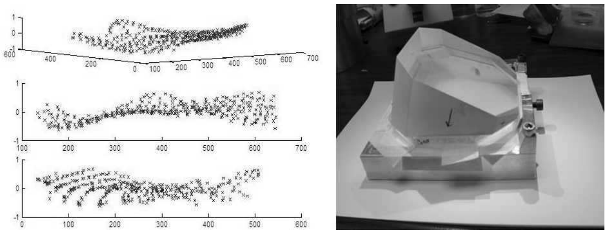

Fig. 9. On the left the wavefront surfaces in three views for some of the glue samples.The difference between the blue and the red surfaces are due to the glue.Tilt and focus were removed for both of them. Vertical scale is in waves units. The difference between the wavefront surfaces (one in red and the other one in blue)is not only due to the silicone but to the index mismatch and fringe positioning. In this sample the difference is under 30nm rms. On the right, the prism glued over the grating (replicated on a window, which is placed below the prism).

the passive screws in the folder mirrors and following a detailed procedure that allowed us a precise diagnostics of the Optics. We located the nominal focus position of the collimator with the use of a home-made lateral shearing interferometer. In addition, we had a first value of the EER80 on a webcam (not on the real detector) of better than 14$\mu$m, which allows us to predict even a better value (9$\mu$m) on the real detector (the requirement is 15$\mu$m). Preliminary results of the back focal length are 0.13mm under the expected value, so the detector position will be shimmed accordingly. Although the alignment of the instrument was done successfully, a tuning may be necessary with the real detector, when we will be able to inspect simultaneously the central and edge fields (what was not possible with the webcam used for the first alignment). The complete characterization of Elmer will be carried out along this year.

## 10. CONCLUSIONS

An exhaustive series of tests were planned for Elmer. We have used the results to (a) accept or reject the components, (b) make corrective actions on non-built components at the time of accepting some of the delivered ones with non-conformances and (c) update the optical design and the error budgets, by building a semi-empirical optical model, as similar as possible to our final system. To do that, we have been taken as input for the feed- back both, the optics design and the test results from the as-built elements. As it can be deduced from the pictures shown in this paper, we have maximized the imagination and the first principles and minimized the resources (human effort, money and time). As resulting from the tests, we have spotted and returned some elements, when they were major offenders for the system performance. In other cases we have developed strategies to minimize the effects while keeping the global specifications within our available error budget. In these later cases, we took the corresponding corrective actions to keep the elements and notified the manufacturer about the defects. The tests carried out and the methods for mounting the experiments and reducing the data were also fully presented in the Instrumentation workshop that took place after the Science conference. All the tests are reported and are accessible in the GTC database under request.

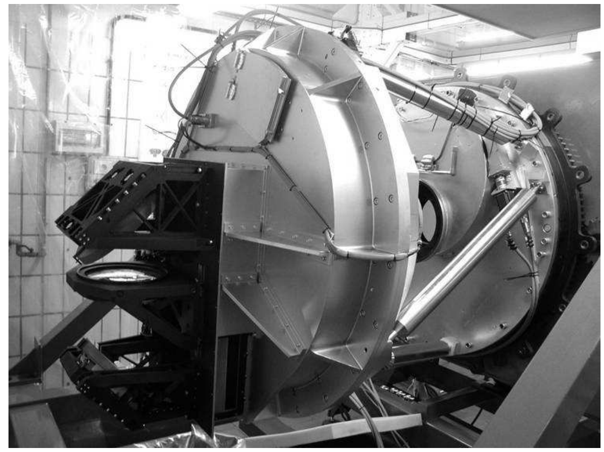

Fig. 10. Elmer with the Optics assembled and aligned.

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## REFERENCES

Information at http://www.gtc.iac.es, where all the documents and drawings are available under request

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