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THE INSTRUMENTAL DESIGN OF ELMER

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RESUMEN

ELMER es un espectrógrafo y cámara en el visible que actualmente está programado para estar en funcionamiento en el GTC en Día Uno. Esta contribución cubre los aspectos de ingeniería del instrumento y resume las cinco contribuciones en póster presentadas en esta reunión. ELMER es un instrumento gestionado directamente por la Oficina del Proyecto GTC, la cual ha desarrollado el diseño preliminar y una gran parte del diseño de detalle. El diseño de detalle, la fabricación y las pruebas de la estructura y mecanismos están siendo llevados a cabo por la asociación de empresas MEDIA-SPASA.

ABSTRACT

ELMER is a visible imager spectrograph currently scheduled to be in operation at the GTC on Day One. This paper covers engineering aspects of the instrument and summarizes five poster contributions presented at this conference. ELMER is an instrument managed directly by the GTC Project Office, which has developed the preliminary design and large part of the detailed design. The detailed design, manufacturing, and testing of the structure and mechanisms is being undertaken by the join venture MEDIA–SPASA.

Key Words: **INSTRUMENTATION:OPTICAL**

1. INTRODUCTION

ELMER is a general-purpose instrument which was requested by the GTC Science Advisory Committee to ensure a science capability at Day One, and so the design has been kept under the control of the GTC Project Office. As ELMER is conceived as an contingency instrument, it will be put in operation only if there are delays in the arrival of the more complex instruments that are being developed by other research institutions. ELMER's design has been driven by the requirements to have a simple, low risk instrument, at a reasonable price but one that will still be very competitive in many areas. The principal scientific requirement is to develop a simple imager and low resolution spectrograph for the visible wavelength range. The instrument should also fill a niche that would be of interest to the community even after the main GTC instruments are commissioned and in operation. Although the field of view (FOV) will not be large in comparison with other instruments, this may allow highly efficient optics and a high throughput. These characteristics, together with a very sensitive detector and the large collecting area of the GTC, will mean that ELMER will be one of the most sensitive instruments in the world. Several managerial and strategic constraints, based on the low budget and low risk instrument concept, were also taken as input for ELMER's design. The expected scientific performance and management plan are described in a different contribution (see Garcia Vargas et al., this volume, p. 9).

ELMER is an optical instrument designed to observe between 370 nm and 1000 nm with a range of observing modes that will suit a wide range of scientific projects to be carried out at the GTC. The scientific observing modes for ELMER on Day One will be (in order of scientific priority): imaging, long slit spectroscopy, fast photometry, fast slit spectroscopy, slitless multiobject spectroscopy, charge shuffling spectroscopy, and mask multiobject spectroscopy. Imaging will be possible with both broad and narrow band filters, over a FOV of 3 arcmin × 3 arcmin on the sky (in fact a 4.2 arcmin diameter FOV is available). ELMER will also provide low resolution spectroscopy capabilities with the use of prisms (for $R = 200$) and grisms (for $R = 1000$ and 1500, with a goal of 2500) for a central long slit 3 arcmin length. Fast photometry, fast slit spectroscopy and charge

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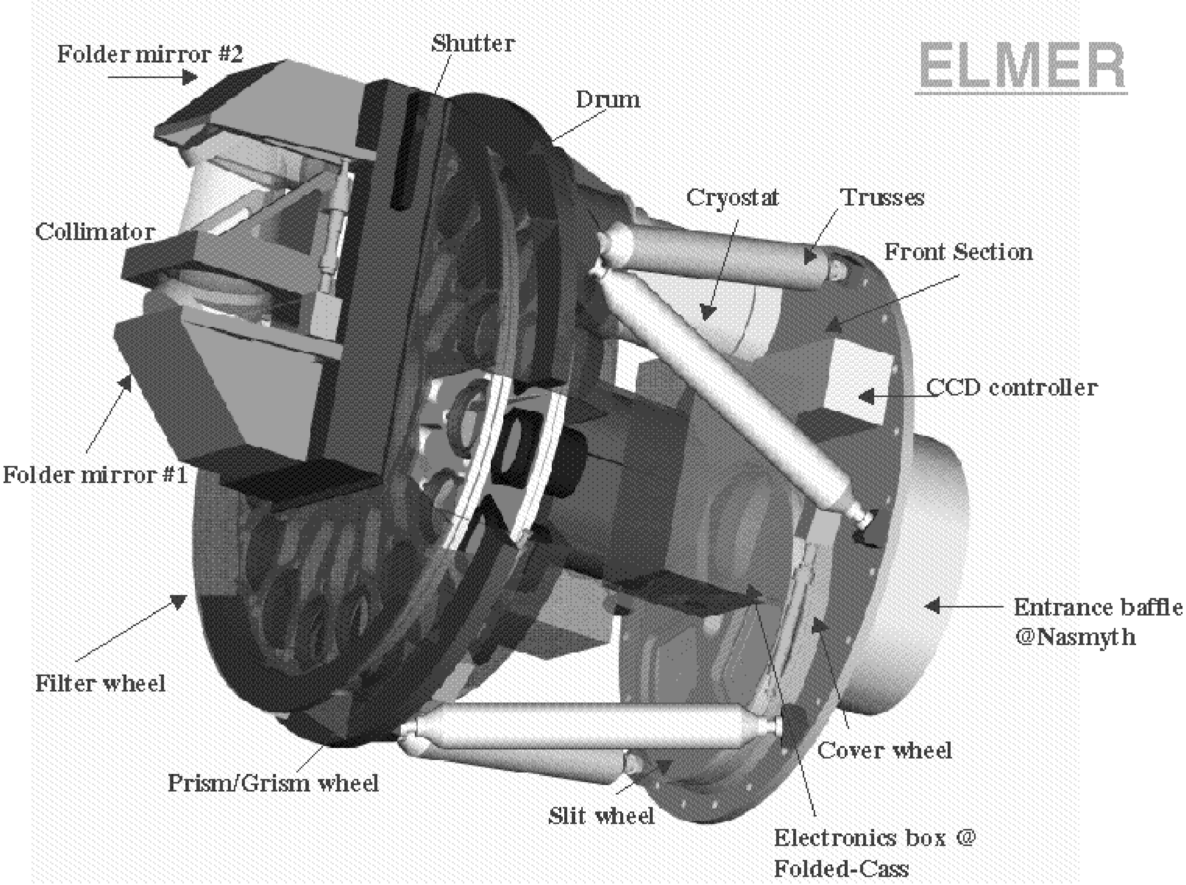

Fig. 1. A 3D view of ELMER 3D from the Preliminary Design. The instrument is viewed from the inner side of the attachment structure to the rotator.

shuffling spectroscopy will be also possible thanks to the frame transfer and charge shuffling capabilities of the detector and controller. The two final observing modes to be implemented will be slitless multiobject spectroscopy and mask multiobject spectroscopy in a FOV of 3 arcmin × 3 arcmin. A final plate scale of 0.195″/pix has been fixed in all observing modes.

The detector is a CCD44-82 Marconi 2k × 4k, with a 15 μm pixel size. It is fully used in the 2k direction for spectroscopy and in the 4k direction to move the charge and store subimages in the modes with charge shuffling and frame transfer requirements.

2. INSTRUMENT DESCRIPTION

ELMER is functionally divided into several subsystems: The support structure, the slit unit, the field lens, the collimator unit, the fold mirrors, the shutter, the wavelength selection subsystem (filter and prism/grism wheels at pupil), the camera, the cryostat and the control system. Figure 1 shows a general view of ELMER.

2.1. *The support structure subsystem*

The support structure (SS) subsystem supports the other components and so is the main structural part of the instrument. The SS has two main areas.

The "attachment section" is the structure that will couple ELMER to the telescope rotator at the corresponding focal station. This attachment structure will be different for the Nasmyth and for the folded Cassegrain focal stations. At Nasmyth, the attachment section will support the cabinets that will rotate with the instrument. At folded Cass, these cabinets will be non-rotating and directly attached to the elevation ring.

The structural support to different elements subsystems,will be provided by:

- The front section (supporting the slit unit and

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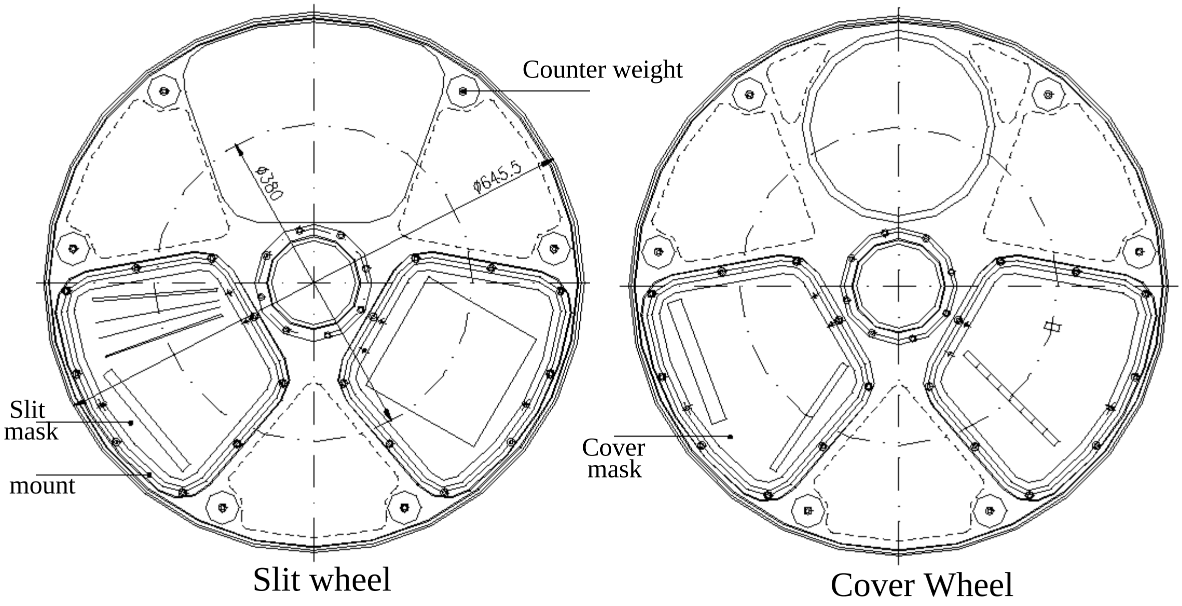

Fig. 2. Slit and cover wheel mechanism. Combining different wheels positions provides the required focal plane configurations.

the CCD controller)

- The trusses (to join the front section and the drum)
- The drum supports the field lens and the cryostat support (through the CCD head) and on the other side the collimator, the two fold mirrors and the shutter. The drum also contains the two pupil-element wheels.
- Covers to protect the optical components and avoid unwanted light in the instrument.

2.2. *The slit unit*

This has two wheels: the cover wheel (in front of the focal plane) and slit wheel (in the telescope focal plane). Each of these two wheels has one open position (open) and two positions for masks. These two positions will support different covers (at the cover wheel) or slits (at the slit wheel). Combining the cover wheel and slit wheel will provide the required focal plane configurations for the different observing modes (see Figure 2).

2.3. *Optics*

Field lens: A single lens placed after the telescope focal plane.

Collimator: This consists of the optics (two lenses) and a stage mechanism, which allows the collimator to be moved to focus the different instrument configurations.

Folder mirror: Two flat mirrors (either side of the collimator) whose purpose is to bend the optical path in order to minimize the size of the instrument.

Camera: This is a four-element camera (six lenses in total) and produces the image on the detector. The last lens is also the cryostat window, but it will be be mounted together with the other camera lenses in the camera barrel.

2.4. *Near the pupil*

Shutter: This is a commercial slit shutter device customized to the required dimensions of the optical path. The position of the shutter will allow easy access for maintenance operations.

Pupil wheels: The pupil elements are located in two wheels which intercept the collimated beam after the second fold mirror and located inside the drum. The first wheel houses the broad band and narrow band filters, as well as the

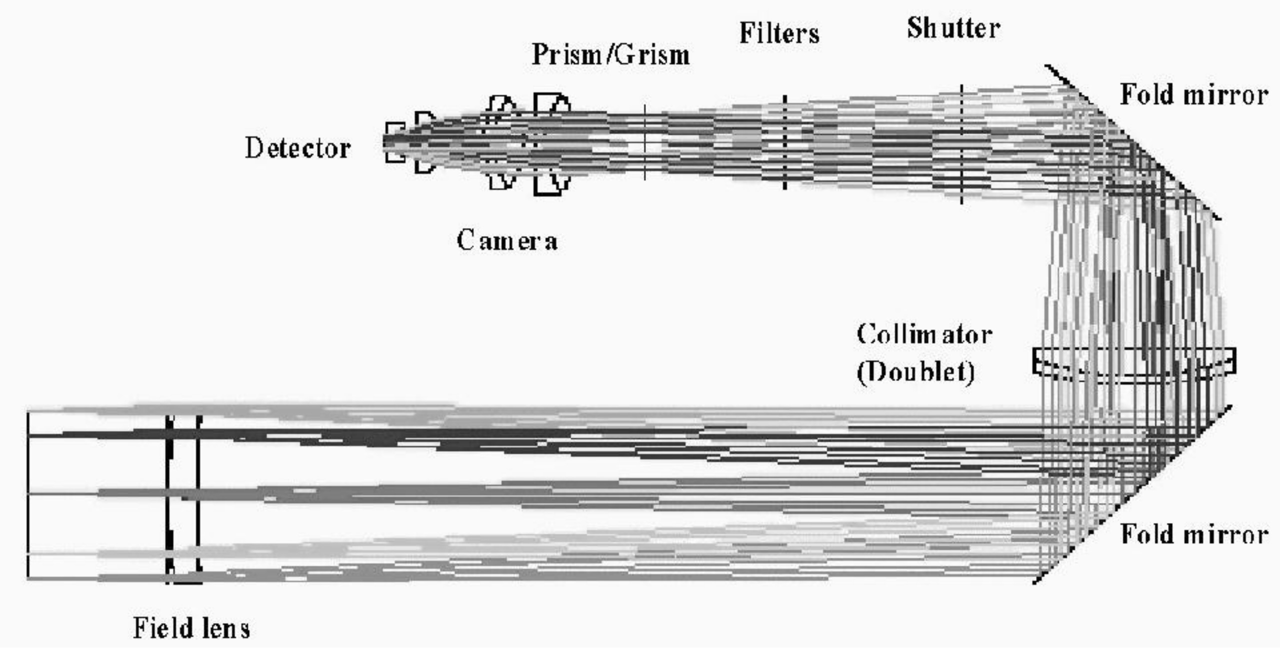

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Fig. 3. Layout of the optical System.

order-sorting filters for spectroscopy. The second wheel, which is in pupil, contains the dispersive elements (prisms and grisms), as well as density filters and an OH suppression filter.

2.5. *Cryostat*

The cryostat is made up of the CCD head and a commercial LN_2 dewar back. The cryostat contains the optical detector. The last lens of the camera is so close to the detector that it has to be use as the entrance window of the dewar. Therefore, it is proposed to attach the camera to the front plate of the CCD head to avoid displacements among the different lenses of the camera.

2.6. *Control system*

The ELMER control system (ELCS) encompasses the hardware and software necessary to control the different electro-mechanical devices in ELMER (e.g., slit unit wheels, pupil element wheels, collimator stage, and shutter) and monitor the different sensors. These sensors monitor temperature and pressure inside the cryostat and the temperature of the support structure. The ELCS also includes the data acquisition system that interacts directly with the CCD controller and obtains the raw scientific data. The GTC data factory processes these data. The ELCS is integrated with the rest of the GTC control system, which coordinates and synchronizes the ELCS with the rest of the telescope subsystems.

3. OPTICAL DESIGN

The ELMER optical system consists of a field lens, a collimator, and a camera. Figure 3 shows a simplified layout of the optics. Light passes through the slit or the open position at the telescope focal plane, the field lens, a fold mirror, the collimator and the second fold mirror. It then passes through the shutter aperture and the two pupil wheels (filter wheel and prism/grism wheel). Finally, a four-element camera (two doublets and two single lens) produces the image on the detector (see Figure 4 with the camera layout).

A detailed analysis of the optical system was performed during the design phase. This analysis includes

- The athermalization study of the system.
- The ghost analysis.
- The stray light to provide a baffle design.
- The camera barrel opto-mechanics design.
- The image quality error budget.
- The image stability error budget.

The last two items were studied in great detail, with the image stability being probably the most difficult specification to fulfill (better than half a pixel for

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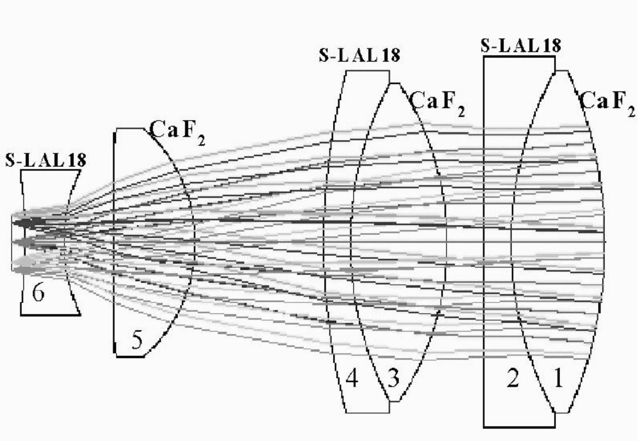

Fig. 4. Camera detail: The design has a four-element camera (two doublets and two individual lens).

a complete instrument rotation). A detailed FEM model was developed to study flexure under gravity loads and thermal gradients, and the results were then fed into a Zemax model to analyze the impact on image stability.

3.1. *Lens blanks*

Only two materials are used for lens blanks (S-LAL18 from Ohara and CaF$_2$ from Schott Lithotec AG) in ELMER in order to optimize the coatings.

All the blanks were ordered after the preliminary design and are now at the PO. Figure 5 shows the camera blanks. The S-LAL18 blanks have a detailed qualification from the provider. However, the manufacture of CaF$_2$ blanks seems to be very repeatable and no tests are offered by the provider. For example, no index measurement is offered for the material although a very high homogeneity tolerance can be specified.

The CaF$_2$ blanks were specified as UV quality (high deep UV transmission) except one VIS-quality grade. All of them were delivered with UV-quality grade. All of the small blanks were specified to be monocristaline. The large blanks were allowed to have the outer 1/3 of the diameter with grain boundaries. Optically, CaF$_2$ is isotropic regardless of the crystal orientation. Nevertheless, grain interfaces are regions of stress that, via the elasto-optical coefficient, create birefringence and—more importantly—could eventually fracture.

A series of tests were done at the Project Office to verify the CaF$_2$ blanks specifications. These were:

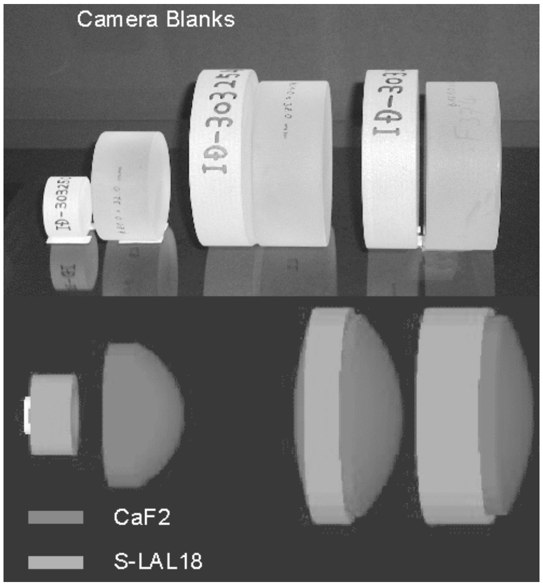

Fig. 5. Camera blanks compared to the future manufactured lenses. CaF$_2$ and S-LAL18 blanks are already at the Project Office.

- Inspection tests, to verified for bulk defects: absorption, inclusion, striae, and fracture. One or both surfaces (ground finished) were covered with a matching index oil (glycerine ND = 1.473, CaF$_2$ ND = 1.433) to allow visual inspection in the bulk of the material illuminated by a 100 mm exit port of an integrating sphere.

- Dimensional verification: Dimensions and tolerances for the thickness and diameter of the cylinders.

- Birefringence: The birefringence gives a measure of the internal stress of the blank. An optical assembly was mounted at the exit port of the integrating sphere. Two crossed linear polarizers were mounted with a $\lambda/4$ plate in between. The measurements were done at 500 nm with a test beam of 67 mm in diameter. The $\lambda/4$ plate was used as a compensator of the change of phase induced by the blank. This plate was rotated until the no-flux condition was recovered. At this point, the introduced phase is measured. The small (monocrystaline) blanks did not show any measurable variation. The large ones did show birefringence areas at the edge (where polycrystals were allowed) while the central part had no measurable birefringence.

The blanks met all specifications.

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3.2. *Optics detailed design*

The optics detailed design is being developed at the PO while the polishing, coating, and opto-mechanical barrel final design and manufacturing have been contracted to the optical company SESO. The main tasks during this phase have been fitting the radii of curvature of the lenses to the test plates, the updating the design using the final blanks parameters (refraction indices, CTE, etc.), revising the tolerance and error budget, and a new detailed thermal analysis. Two decisions have been taken: a) not to cement the collimator (to avoid risks from thermal changes and to allow a better degree of collimation, which would allow us in future to upgrade the instrument to three times the current spectral resolution) and b) to design and build in parallel an alternative field lens to mitigate the potential risk of breakage during manufacture, or even at the telescope with such a large CaF_2 lens. After a trade-off analysis of the different material a fused silica lens was chosen.

Filters (broad band, narrow band, and neutral density) have already been ordered from OMEGA Optical. The detailed design of the prisms and grisms has not started yet, but blanks should be ordered before 2002 June. The fold mirrors have been designed and specified and shall be ordered before 2002 May. The detail of the project schedule can be seen in García-Vargas et al. (this volume, p. 9).

4. MECHANICS

4.1. *Structure and mechanisms*

The joint venture UTE MEDIA–SPASA is the contractor for the procurement of the ELMER structure and mechanisms. MEDIA is responsible for the global management as well as the detailed mechanical design of the instrument while SPASA will manufacture, assemble, and test the structure and the mechanisms. Starting from the preliminary design developed by GRANTECAN, the UTE is developing the detailed design to be ready for manufacturing in 2002 July.

4.2. *The structure*

The ELMER structure basically consists of a hexapod, in which two platforms (the front section and the drum) are rigidly joined through six trusses with flexible ends. The opto-mechanics is mounted on the two platforms: the slit and cover wheels on the front section (see Figure 6) and the field lens, fold mirrors, collimator mechanism, shutter, filter wheel, prism/grism wheel, camera, and cryostat on the drum.

The geometry of the hexapod has been optimized to maximize the stiffness and to minimize the ratio between the lateral displacement of the drum and its rotation. This factor contributes to the reduction of the image motion owing to gravitational deflections by moving the point of rotation of the optics closer to to the telescope focal plane, located 75 mm above the attachment flange of the instrument. The flexibility in the hexapod trusses allows the drum to be to decouple the front section thermally and avoids deformation of these platforms due to the manufacturing tolerances. The flexible ends are made by the narrowing of the trusses at their ends (the body diameter is 67 mm while the extremes are only 24 mm in diameter). However, this narrowing reduces the axial stiffness of the trusses, which affects the global stiffness of the hexapod. Therefore, the design of the trusses is a trade-off between the sensitivity to temperature variations and manufacturing tolerances and the stiffness of the hexapod.

The front section supports the slit unit (slit and cover wheels) and provides the external interface with the telescope. In the case of the installation at the Nasmyth focus, an interface structure is required to attach the instrument to the rotator, whose diameter is far larger than that of the instrument. The front section design follows the philosophy of adding radial and circular ribs to provide sufficient stiffness where the opto-mechanics is attached.

The design of the drum has taken into account the opto-mechanics to be installed on it, providing structural elements (such as ribs) at the regions where the strain density energy is maximum. An external stiff ring provides the interface with the hexapod trusses. The drum is formed by three parts: the main body, to which the hexapod trusses are attached; the central shaft, on which the filter and prism/grism wheels are assembled, and the top cover, also reinforced with radial ribs, on which the box assembly is supported.

The box assembly is composed of the box (structure) and the support for the fold mirrors, the collimator mechanism, and the shutter. The structural design of the box has been made to provide sufficient stiffness to support the opto-mechanics.

4.3. *The mechanisms*

There are in total four wheels, two in the slit subsystem (cover and slit wheels) and two in the wavelength selection subsystem (filter and prism/grism wheel). Their design has been driven by the gravity deflection and dynamic requirements. Also, an accurate representation of the structural behavior of the

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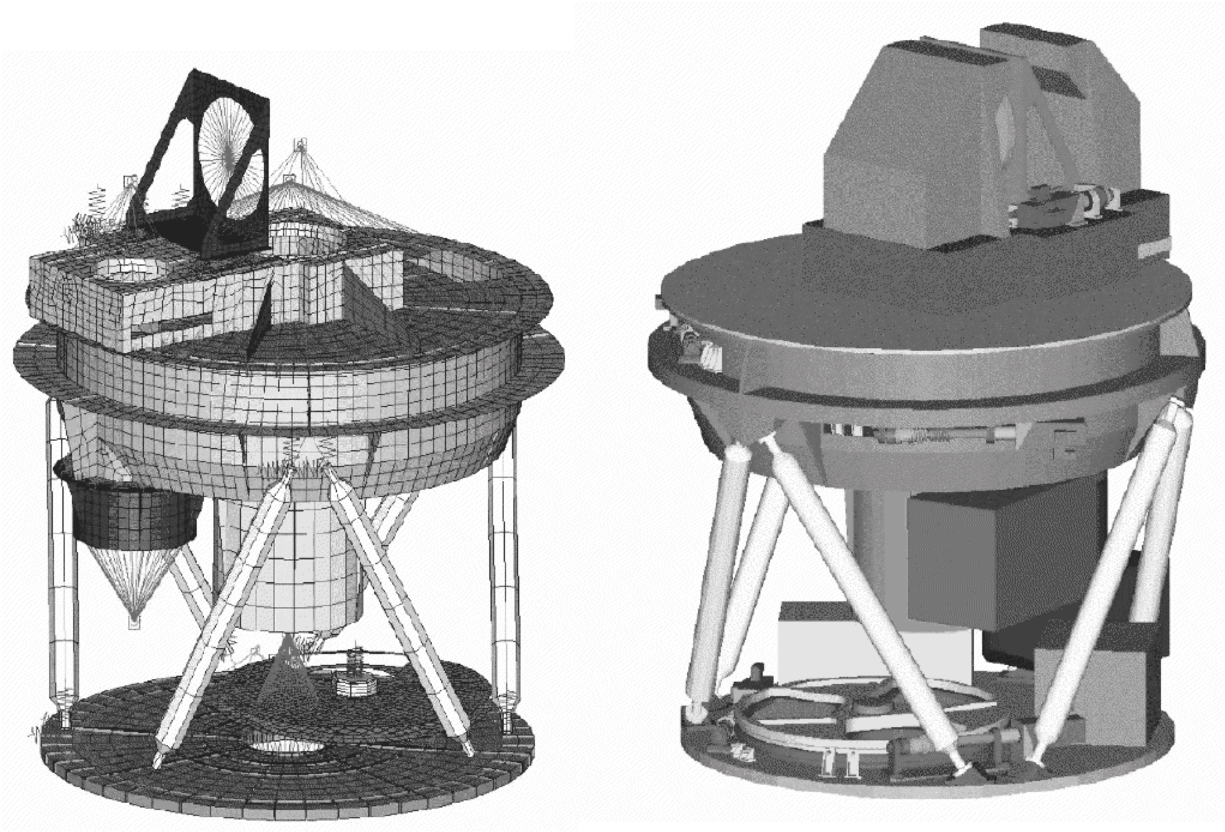

Fig. 6. FEM and the 3D Model of ELMER, produced in the detailed design.

support bearings has been included in the finite element model. The starting point for wheel rotation mechanisms is to use worm gear drives rotated by stepper motors. These are compact transmissions (large reduction ratio in only one stage) although the efficiency is low (60% or less). In spite of this, the expected resistant torque on the wheels are low enough as to ensure that the low efficiency will not be a limitation for the design. The feasibility of transforming a double enveloping worm gear, which provides contact in several teeth of the worm gear, into a preloaded gear has been studied. This basically consists of dividing the worm in two halves; the master and the slave. The slave will preload the wheel against the master worm (directly driven by the motor), avoiding the backlash in the transmission (see Figure 7) . This solution eliminates the necessity of additional blocking devices for the wheels. To simplify the manufacturing of the worms, the master half will be a straight whereas the slave half will be conical .

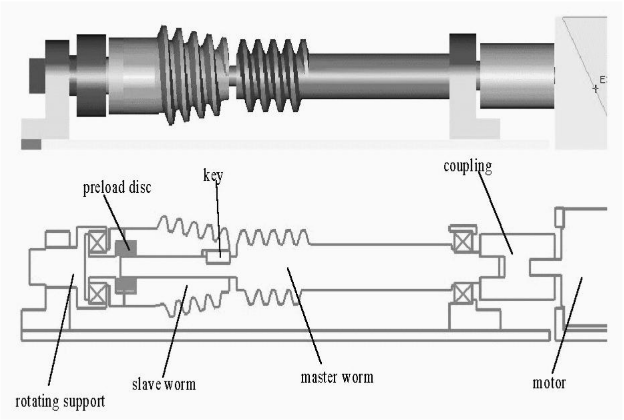

Fig. 7. Preload system scheme for driving the wheels.

The collimator mechanism consists of a custom-made linear stage formed by two linear guides, a ball screw and a motor with brake to maintain the po-

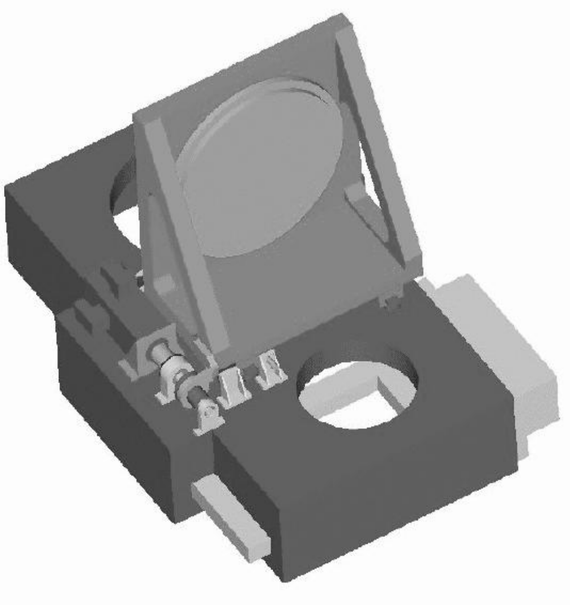

Fig. 8. Collimator mechanism.

sition. The blocks of the guides and the ballscrew are preloaded to eliminate backlash and increase the stiffness (see Figure 8).

4.4. *Other mechanics detailed design tasks*

Several subsystems are under detailed design by the PO and will be ordered directly from manufacturers. This is the case for the folder mirrors, the electronic cabinets, and the mounts for filters, prisms, and grisms.

5. ELECTRONICS AND CONTROL SYSTEM

The ELMER mechanism control system and the data acquisition system are being developed at the Project Office. Most of the components have been already purchased and delivery is well under way in order to start integration and tests in 2002 October. The instrument control electronics is based on two CPUs in VME crates, one for the data acquisition system and the other for the mechanism control system. The data acquisition system is composed of: a) a Marconi CCD44-82, 2k × 4k, 15 μm pixel CCD detector housed in a commercial LN_2 cryostat with a detachable and customized CCD head (the detector has frame-transfer architecture and is built on high resistivity silicon to increase the red response and reduce interference fringing); b) A closed-loop CCD temperature control and permanent monitor of the cryostat vacuum; c) an Astronomical Research Cameras CCD controller (SDSU-II) to operate the detector at 1 Mpix s^{-1} over two output ports. Figure 9 shows the Marconi CCD44-82 detector for ELMER and Figure 10 the quantum efficiency of the detector.

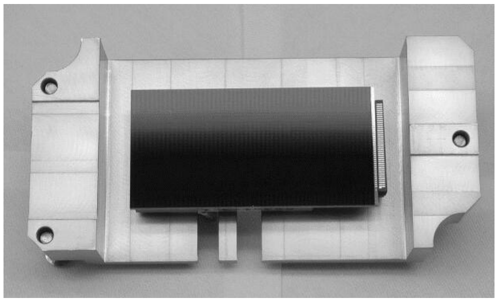

Fig. 9. ELMER detector Marconi CCD44-82 (already at the Project Office).

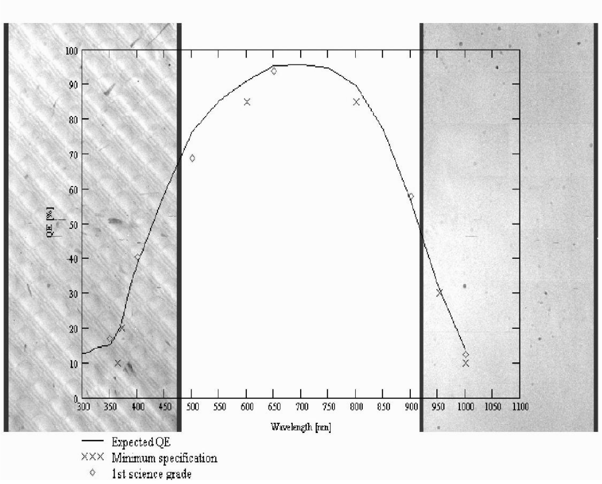

Fig. 10. Quantum efficiency curve for the detector.

The mechanism control system is composed of:

- Local positioning controllers, which drive all stepper motors and check the final position of the different mechanisms. Communication is based on the CAN bus.
- Focus control to compensate any changes in temperature.
- An instrument safety and interlock system.

The electronics will be housed in two cabinets to avoid heat dissipation into the telescope chamber.

5.1. *Conclusions*

The ELMER instrument is being developed by GRANTECAN to have a simple imager and low resolution spectrograph ready for early scientific exploitation of the GTC. The optics is being designed at the Project Office. The blanks have been characterized and are ready to be sent to SESO, the

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company in charge of the polishing and coating of the lenses, as well as for the final design and manufacturing of the barrels. Filters have been ordered from Omega Optical. The prism and grism design is under way. Regarding the mechanics, the Spanish joint venture MEDIA–SPASA was awarded the detailed design, manufacture, assembly, and tests of the structure and mechanisms. Other mechanics tasks, such as the fold mirrors, cabinets, and pupil-element mounts, will be ordered for manufacture soon. Regarding the data acquisition system, most of the components (including the detector and the controller) are already at the PO and cryogenic testing will start in 2002 October. Finally, the electronics and control system is being developed according to plan. It is expected that all the components will be at the Project office by the end of 2003 April (previous assembly and testing at the level of subsystems) to start the integration and tests at system level in La Laguna in 2003 May. The instrument will be transported to the Observatorio del Roque de los Muchachos as soon as the telescope is ready.

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