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# COMMISSIONING INSTRUMENT FOR THE GTC

S. Cuevas,[1] B. Sánchez,[1] V. Bringas,[2] C. Espejo,[1] R. Flores,[1] O. Chapa,[1] G. Lara,[1] A. Chavoya,[2]
G. Anguiano,[2] S. Arciniega,[2] A. Dorantes,[2] J. L. Gonzalez,[2] J. M. Montoya,[2] R. Toral,[2] H. Hernández,[2]
R. Nava,[2] N. Devaney,[3] J. Castro,[3] and L. Cavaller-Marqués[3]

## RESUMEN

Durante la fase de integración del telescopio GTC el Instrumento de Commissioning (CI) será una herramienta de diagnóstico para la verificación de sus especificaciones. El CI funciona en cuatro modos de operación: imagen, análisis de pupila, medición de frente de onda con curvatura y medición de frente de onda con Shack-Hartmann de alta resolución. Este instrumento ha sido fabricado por el Instituto de Astronomía UNAM y el Centro de Ingeniería y Desarrollo Industrial (CIDESI) bajo contrato de GRANTECAN, después de haber ganado una licitación pública. En este artículo se hace una descripción general del CI y mostramos algunos resultados finales de parámetros medidos durante las pruebas de aceptación en fábrica previos a su transporte a La Palma.

## ABSTRACT

During the GTC integration phase, the Commissioning Instrument (CI) will be a diagnostic tool for performance verification. The CI features four operation modes: imaging, pupil imaging, Curvature WFS, and high resolution Shack-Hartmann WFS. This instrument was built by the Instituto de Astronomía UNAM and the Centro de Ingeniería y Desarrollo Industrial (CIDESI) under GRANTECAN contract after a public bid. In this paper we made a general instrument overview and we show some of the performance final results obtained when the Factory Acceptance tests previous to its transport to La Palma.

*Key Words:* **INSTRUMENTATION: MISCELLANEOUS — TELESCOPES**

## 1. INTRODUCTION

Upon GTC segment integration, the CI will rectify the relative segment alignment and will enhance the telescope overall performance. Obviously, the CI needs a reasonably large field of view to spot objects with the un-calibrated working pointing model (Castro et al. 1998). Likewise, the CI's image quality identifies error sources helping to correct image degradation. Furthermore, the CI needs an accessible pupil image with multi-size stops inserted to measure the background radiation in the visible spectrum range. Basically, the CI is an optical instrument designed to perform three tasks-imaging with individual M1 segments, verifying their surface figure, and segment aligning and co-phasing. Also, the CI performs telescope stray light and background measurements. Neutral and BVRI filters are introduced in the functioning modes. In imaging mode the CI is a focal reducer with an accessible pupil image with multi-size stops inserted to measure background radiation in the visible spectral range. In pupil imaging mode, the detector is placed at the telescope pupil image in order to identify stray light. To verify the M1 surface figure and co-phasing, the CI will perform both Curvature WFS and high resolution Shack-Hartmann WFS methods. High Resolution Shack Hartmann method has been used in the 4 and 8 m class active optics systems(Wilson et al. 1987). Additionally, the relative Piston is estimated by measuring the PSF of the Shack-Hartmann lens-lets placed at the M1 segment interface image. The last is the core of the Gary Chanan (1998) Keck co-phasing algorithms. A modified version of the Keck narrow band algorithm will be used at the GTC (Bello et al 2000; Schumacher et al 2002). Curvature WFS has been used in telescope testing (Roddier et al 1993). M1 segment relative Piston and Tilt can be estimated from the curvature signal has it was shown by Cuevas et al.(2000). Once the GTC commissioning phase is over, the CI could be permanently mounted at a folded Cassegrain focus for either imaging or tuning up telescope imaging. The CI would be an optical bench on an actual segmented telescope for comparing the differences among the co-phasing methods and algorithms for future ELTs (Cuevas et al 2002). Under a con-

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[1] Instituto de Astronomía, UNAM, Ciudad Universitaria, México.

[2] Centro de Ingeniería y Desarrollo Industrial, Querétaro, México.

[3] GRANTECAN, La Laguna, Tenerife, Spain.

tract with the GRANTECAN, the Commissioning Instrument (CI) is a project developed by a team of Mexican scientists and engineers from the Instrumentation Department of the Astronomy Institute at the UNAM and the Centro de Ingenieria y Desarrollo Industrial (CIDESI)in Querétaro, Qro. Some optical components have been manufactured at the Centro de Investigaciones en Optica (CIO) in León, Gto. The big mechanical parts have been manufactured in Morelia, Mich. Some machined parts and fabrication have been made in small companies in the Querétaro area and Mexico City. In this paper we made a general CI instrument description and report some of the performances.

## 2. INSTRUMENT DESCRIPTION

### 2.1. *General Description*

The CI has a modular design comprising a positioner (CIP) and an instrument box (IB). The positioner consists of a main structure and a support structure, both linked by a turntable. The box is mounted on a focusing stage, which is fixed to the instrument positioner (Figure 1). Linked to the instrument box, there are a CCD controller, and an electronic cabinet (allocating the control electronics (Flores et al. 2003). The latter is attached to the main structure to purposely avoid the faulty bending of the turntable frame's default flexures (Farah et al. 2003). The CCD controller is fixed to the instrument box's support structure. The complete CI was designed for high reliability and maintainability. The MTBF exceeds 900 hours and the MTTR is lower than 4 hours. Operation temperatures are -6°to 30°C (-15 to +35°C is the survival limit). Other specifications are described by Espejo et al. (2003).

### 2.2. *Instrument Positioner*

The CIP features a turntable, a main structure, and a focusing stage. The IP positions the IB at any point of the telescope field (20′) simultaneously maintaining the IB aligned to the M2 center. The positioner design was the result of a FEA analysis performed to obtain the best design choice using matrix decision technique with customised performance indicators (Farah et al. 2003). The measured performance of the CIP for gravity flexions and thermal comportement was in agree with the FEA analysis. Furthermore, the measured repeatibility of the turntable controlled by the instrument electronics is 0.005″projected on the sky, well in the performance requierements.

### 2.3. *Instrument Box*

The aluminum-made IB features a light-weighted plate forming an optical bench with an aluminium cover bolted to the IB frame (Figure 2). As for the inside, along the optical path, the system consists of a shutter and a glass window followed by a collimator, a pupil positioner, and two filter wheels. Next, there is a wheel featuring two pupil stops and a micro-lens array. A removable camera and a CCD detector complete the optical system. The CCD is mounted on a translation stage. Besides, a removable optical fiber is mounted on a wheel at the telescope focus for calibration. The optical fiber wheel features two aperture stops: one (6″×6″) for WFS and pupil imaging and another one (1′× 1′) for imaging. The measured insertion repeatibility of the fiber wheel is 0.01″.

## 3. OPTICS

The CI optics can therefore be divided in four units. The collimator unit comprises the collimator lens, the input window, the pupil positioner, and the neutral and color filters. The collimator unit provides a high-quality diffraction limited pupil image. The camera unit takes the collimated beam after the pupil image to form an image on the detector. Finally, the lens array unit is used for the S-H WFS. The same CCD detector is used in all CI modes. This CCD is a 13$\mu$m pixel, 1k × 1k array Marconi, EEV CCD 47-20 thinned and back illuminated.

### 3.1. *Collimator Unit*

#### 3.1.1. *Input Window*

An input window protects the instrument from dust (specially when the Saharan dust storms blows over the Canary Islands). Window optical aberrations must be taken into account when the instrument is calibrated in the Shack-Hartmann mode. A 3 mm-thick BK7 glass plate multi-layer coated window is placed along the optical path, after the calibration wheel.

#### 3.1.2. *Collimator*

The collimator is the main optical part. It is F96 mm EFL=185 mm triplet lens (FK51, CaF2 and LLF1 glasses) fully achromatic and diffraction limited for a 6″field and 12 mm pupil. Accordingly, glasses are of Schott H3/NVS quality. Also, lenses are MgF2 coated. The CI Collimator images the GTC output pupil (M2) scaled down 947.3 times. This scaling is carried out with a distortion lower than 0.5% for all the wavelengths inside the operation temperature range. The collimator design compensates any window aberrations. The FK51 and

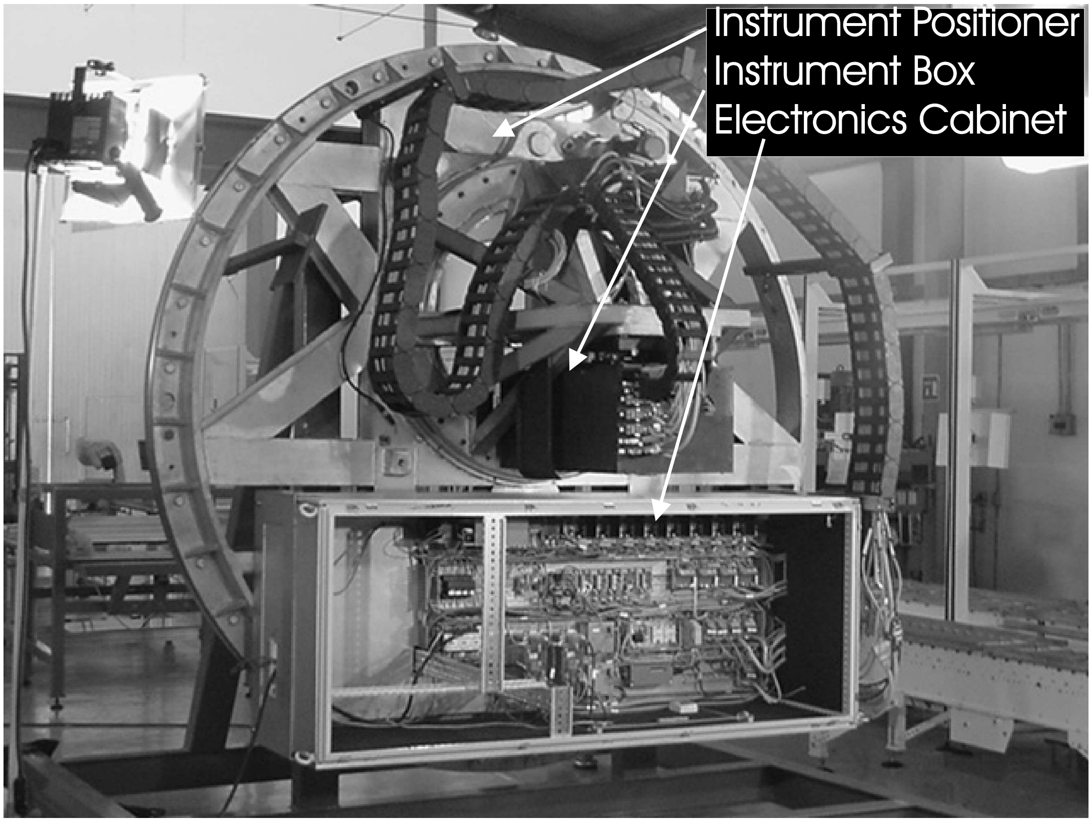

Fig. 1. Commissioning Instrument. The instrument positioner attachs and positions the Instrument Box inside a 20′diameter field.The Instrument Box contains the optics and mechanisms for the four operation modes. Note the electronics Cabinet and the Cable Wrap from this to the Instrument Box

CaF2 lenses were polished at the IAUNAM workshops. The LLF1 lens was polished at CIO in Mexico. Lenses were coated by ZC&R Collimator barrel mechanical design compensates the differences in thermal expansion among the barrel separators and glass lenses. Furthermore,the barrels are filled with dry Nitrogen to eliminate internal condensation.

### 3.1.3. *Pupil Positioner*

The Pupil Positioner (PP) is a 19 mm-thickness BBAR coated BK7 glass plate (polished by CIO and coated by ZC&R), mounted on a motorized tip-tilt stage. The plate inclination causes a $\mp 400\ \mu$m displacing of the GTC pupil on the lens array. The plate is placed on the collimated light beam so no aberrations occurs. The repeatibility of the GTC pupil positioning on the lens array is better than 4 $\mu$m .

### 3.1.4. *Filters*

The neutral and color filters are inclined 5°with respect to the optics beam, to reduce both ghosts and stray light. The filters are placed on two wheels. The filter wheels allows to place 7 neutral and 7 color filters: four Johnson BVRI filters and two 100 nm

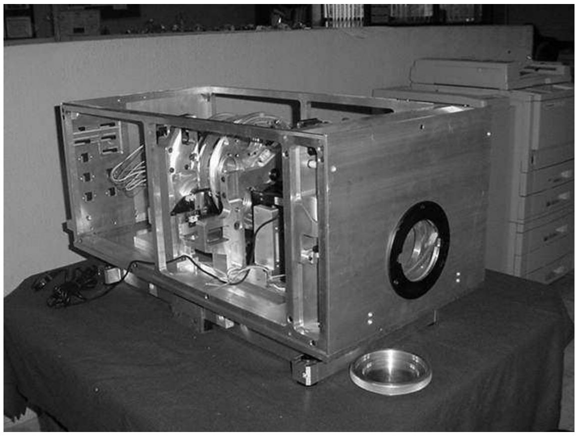

Fig. 2. Instrument Box before to be blackened by anodyzing

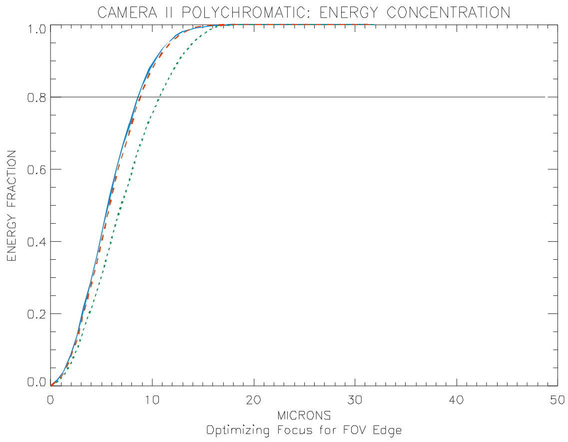

Fig. 3. CI Image quality energy concentration $r_{80}$ inside the $1'\times1'$FoV. The focus position was optimized for FoV edge. Continuous line FoV edge, $r_{80} = 9\mu m$. Pointed line : center of the FoV $r_{80} = 11\mu m$ Dotted line: $r_{80} = 9\mu m.(r_{80} = 0,1''$ corresponds to $r_{80} = 22\mu m)$. Image quality is better than $d_{80} = 0,2''$

wideband filters centered in 700 and 800 nm. No aberrations occur in both the pupil and the image plane.

### 3.2. *Camera Unit*

The camera unit is EFL=32 mm f/4.04 four lens objective (CaF2, F2, BaK5 and LLF1 NH2 class glasses). This objective is nearly achromatic for 370 nm< $\lambda$ <1060 nm. The CaF2 lens was polished at the IAUNAM workshops. The rest were polished at the CIO. Coatings were made by ZC&R. As the Collimator unit barrel the Camera is thermal compensated and filled with dry Nitrogen. Both combined, the collimator and the camera work as a 1/4 focal reducer. The measured optics quality is $d_{80}$ better than $0.2''$inside a $1'\times 1'$ field for white light and $0.17''$for the B filter (Figure 3). The camera is mounted on a motorized wheel. The measured insertion repeatability is $0.05''$.

### 3.3. *CCD Unit*

The CCD is a 13 microns pixel 1k´1k array Marconi EEV CCD 47-20 thinned and back illuminated. The CCD head and controller were provided by GRANTECAN and are similar to the CCD unit for the GTC A&G system (Devaney et al. 2000). The CCD head is mounted on a translation stage thus allowing for the displacement of the CCD along the optical axis in the operating modes described below.

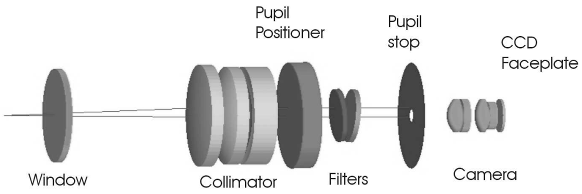

Fig. 4. CI in Imaging Mode. The Camera is placed in the optical axis.

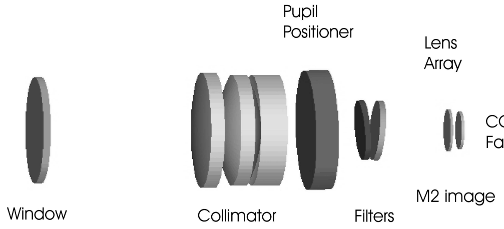

Fig. 5. CI in Shack Hartmann Wave front sensing mode. The Camera is out, the lens array is placed in the optical stream and the CCD is placed at the Lens Array focal plane

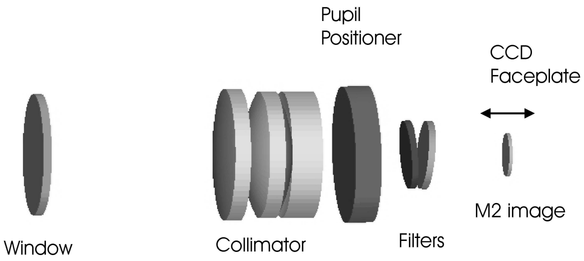

Fig. 6. CI in the Pupil analysis and Curvature Mode. The Camera, the Lens array and the pupil stop are missed out of the optical stream. The CCD can ve placed at the instrument focal plane for stray light analysis or for Curvature sensing mode geting shots of defocused pupils.

### 3.4. *Lens Array*

A lens array for high resolution Shack-Hartmann WFS can be placed on the optics beam. The lens array is mounted on a motorized wheel. The wheel also features two pupil stops. The lens-lets have 9 mm EFL and 100 $\mu$m diameter each.

## 4. OPERATING MODES

The operating modes are illustrated in Figures 4, 5 and 6.

## 5. INSTRUMENT STATUS

The CI project started in December 2000. The critical design phase was reviewed in April 2002. The factory acceptance tests were made in August and November 2003. When this conference was held the instrument was ready to be sent to La Palma. The CI was accepted at the GTC Site in April 2004.

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O. Chapa, S. Cuevas, C. Espejo, R. Flores, G. Lara and B. Sánchez: Instituto de Astronomía, Universidad Nacional Autónoma de México, Ciudad Universitaria, Apartado Postal 70-264, 04510 México, D.F., México (chavoc@astroscu.unam.mx).

G. Anguiano, S. Arciniega, V. Bringas, A. Chavoya, A. Dorantes, J. L. González, H. Hernández, J. M. Montoya, R. Nava and R. Toral: Centro de Ingeniería y Desarrollo Industrial, Playa Pie de la Cuesta No. 702 Desarrollo Habitacional San Pablo 76100 Querétaro, Qro., México.(vbringas@cidesi.mx).

J. Castro, L. Cavaller-Marqués and N. Devaney: GRANTECAN, S.A., c/Via Láctea s/n, 38200 La Laguna S/C. de Tenerife España (Nicholas.Devaney@iac.es).