

# Laboratory Acceptance and Telescope Integration of the Gran Telescopio Canarias Adaptive Optics System

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## ABSTRACT

The Adaptive Optics (AO) system of the 10-m class Gran Telescopio Canarias (GTC) has completed the acceptance tests in the laboratory of the Instituto de Astrofísica de Canarias (IAC), and has verified the procedures for the integration in GTC at Roque de Los Muchachos Observatory (ORM), together with critical optics maintenance previous to the shipment. The GTCAO system is based on a single deformable mirror (DM) with 373 actuators, conjugated to the telescope pupil, and a Shack-Hartmann wavefront sensor (WFS) with 312 subapertures, using an OCAM2 camera. The performance required is 65% Strehl Ratio in K-band under average atmospheric conditions and bright NGS.

The instrument will be shipped to the ORM in June, to be installed on the Nasmyth platform B of GTC, to be aligned with the telescope, to be integrated with the telescope control system and to start the technical commissioning. When in operation, the AO system will work as a focal station of the telescope, in charge of providing the commands to M2 for fast guiding and tip tilt correction, and offloading global low order modes to M1 and its segments using the WFS telemetry. Testing these functionalities is part of the initial technical commissioning on telescope. In this paper we focus in the final results of the laboratory acceptance, the integration in telescope and the commissioning plans to get the system ready for science.

**Keywords:** adaptive optics

## 1. INTRODUCTION

The GTCAO system is designed to provide single-conjugate adaptive optics for its scientific instrument, FRIDA. It will use one NGS in first light. The preliminary design was described by Bello et al [1], and its main parameters are shown in Table 1.

GTCAO SYSTEM PARAMETERS	
Diameter	10.4 m
Obscuration	1.4 m
Subapertures/diam	20
WFS Pix/subap	10
Pixel scale	0.35 arcsec/pix
WFS Field stop	3.5"
Frequency	2 KHz
Exposure time	0.5 ms
$t_{\text{delay}}(\text{exp+comm})$	1 ms
WFS ron	0.1 e/pix/frame
Bandwidth	470-900 nm
Wavelength	2.2 $\mu\text{m}$

Table 1: GTCAO system parameters.

The project is now in commissioning phase at ORM. It was shipped to La Palma in June 2023 (Figure 1), and installed at the Nasmyth be platform in July 2023. The integration of the system with the telescope has been conducted during the summer of 2023. In parallel we are working in an upgrade to install a TOPTICA Na laser [2] in the elevation ring



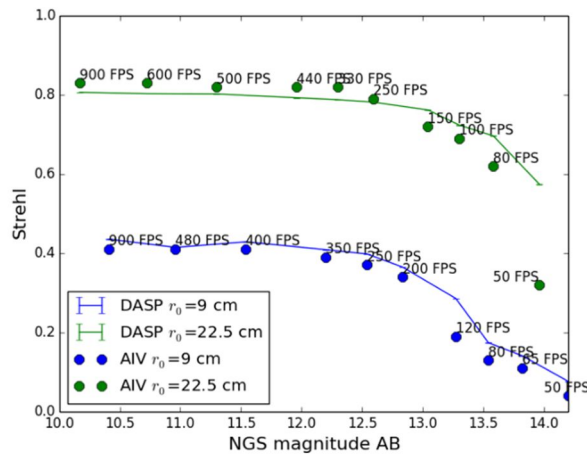
## 2. LABORATORY ACCEPTANCE TESTS

We run several tests to check the performance of the system in order to demonstrate its compliance with the scientific requirements, i.e. to have a 65% Strehl Ratio when operating with a bright NGS in a good seeing night, and to have a minimum of 10% Strehl Ratio when using a faint NGS (14 mag). The system was configured as follows to perform the acceptance tests:

- Laboratory conditions: air-conditioning on, GTC AO without enclosure (local turbulence)
- WFC: No rotation
- Test Camera (science focus): H band filter
- WFS:
  - High order lenslet array (20x20) with mask
  - OCAM2 EMCCD frame rate from 200 Hz to 900 Hz
  - Wide band filter (500 nm to 900 nm)
- Calibration System:
  - Visible NGS and IR source, both on axis
  - Turbulence:  $r_0=22.5$  cm good seeing,  $r_0=9$  cm bad seeing, wind speed=10 m/s
  - GTC hexagonal pupil (no segments)
- RTC:
  - DARC, Regularized Least Squares algorithm
  - Controller: integrator

Close loop gains, sampling frequency and EMCCD gains are adapted to the changing conditions and optimized to obtain the best performance in each case. With the optimum values we create reference lookup tables to be used by the operators or support astronomers during on-sky operation.

Results of the laboratory performance tests are shown in Figure 4 compared with the simulations done with the Durham AO Simulation Platform (DASP) [3]. DASP is the simulation tool used as reference to compare the experimental results. The performance obtained in the test at H band was 80% Strehl with a bright NGS in good seeing, 30% Strehl with a faint NGS (14 mag) in good seeing, and 5% Strehl with a faint NGS (14.2 mag) in a bad seeing scenario. The conclusion is that the system complies with the scientific requirements both in good and bad seeing scenarios.



**Figure 4:** Strehl ratio vs magnitude for good and bad seeing conditions. The dots are results obtained with the GTC AO bench, the lines are the DASP simulations.

## 3. TELESCOPE INTEGRATION

For the GTC AO system the most concerning of the differences between the laboratory tests and on-sky tests is the fact that in the former case the tip-tilt correction with the GTC M2 mirror is not accessible, and that GTC AO has to communicate and be integrated with the Observing Engine (OE). Hence it was expected that a significant part of the time during integration would be spent on this aspect, which has been the case. Diagnostic tools have been implemented to evaluate the performance on-line (during on-sky tests) and off-line, with the possibility to store WFS data streams in open loop and close loop, at full WFS speed.

GTCAO works as a focal station, which means that when in operation it will guide the telescope. The OE will guide all the mechanisms that depend on telescope pointing:

- ADC,
- derotator,
- pupil positioner,
- WFS position update due to the differential TT due to the atmospheric refraction difference between the science wavelength and the WFS wavelength.

All these mechanisms are being tested and verified during the integration phase.

#### **4. ON-SKY OPERATION**

The steps to close the GTCAO loop on-sky are the following:

1. Guide with the telescope Fast Acquisition & Guiding Camera, which compensates with M2. The AO loops are open in GTCAO. Capture the science object in the GTCAO Test Camera and evaluate the performance, as a reference of tip-tilt compensation performance. Stop guiding with the telescope.
2. Transfer from the telescope A&G system to GTCAO focal station.
3. Capture the NGS in the GTCAO WFS, and close the GTCAO tip-tilt loop with the telescope M2, only using the tip-tilt information. From this moment, the telescope fast guiding camera is the WFS. This is the essential point of the tests which cannot be checked in the laboratory. Evaluate the result on the GTCAO Test Camera, and compare the performance with the telescope Fast Acquisition & Guiding Camera.
4. Close the GTCAO high order loop with the DM, and the tip-tilt loop also with the DM. From this moment, the tip-tilt starts to be compensated at high frequency by the DM, while simultaneously the tip-tilt is being offloaded to M2 and compensated at low frequency by M2 to avoid saturation of the DM, while improving the tip-tilt compensation performance. Evaluate the performance improvement in the GTCAO Test Camera.
5. Offloading static errors onto M1 and M2 at low frequency. It is planned to offload any static errors that appear in the DM onto M1 and M2 at low frequency. Basically GTCAO will provide information on the global measured wavefront, focus and coma will be offloaded to M2, and segments low order modes will be offloaded to M1.
6. Performance will be evaluated on-line and off-line, WFS data streams will be stored at full WFS speed.

#### **5. ON-SKY COMMISSIONING TASKS**

During commissioning the loop will be optimized for different NGS magnitudes and atmospheric conditions (at the lab the Calibration System has only 2 phase screens) to create lookup tables including WFS frame rates, WFS EMCCD gains and control loop gains to be used by the telescope operator.

Most near IR observations will use sky subtraction and this will require multiple pointings probably on time scales of 30 seconds to, at most, a few minutes. Also acquisition will require very precise offsetting. In the laboratory only small dithering has been tested in close loop due to the range limitation of the DM. The scientific offsets for the dithering cannot be tested in the lab and will have to be demonstrated during commissioning. Nodding and dithering over 10 arcsec will also be part of the on-sky commissioning. An appropriate task sequence will be defined in order to verify the GTCAO offsetting, multiple pointing and acquisition capabilities. It has to be decided whether to keep the loop closed when nodding over a few arcseconds, since this requires moving the WFS and telescope at the same time.

The commissioning tasks, to be performed during autumn 2023, are the following:

- Confirm alignment of the GTCAO with the telescope, this has been already done in summer 2023
- Commissioning of WFS ADC
- Closing the GTCAO loops with on-axis bright NGS:
  - at different airmass
  - at different seeing range
  - using a small dithering pattern
- Closing the GTCAO loops with on-axis faint NGS
- Closing the GTCAO loops with off-axis bright NGS
- Characterizing and Optimizing the GTCAO loop with on-axis bright NGS

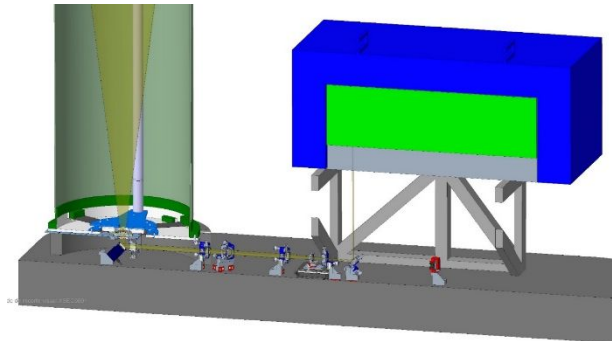
- Characterizing NCPAs with close loop on-axis bright NGS
- Closing the GTCAO loops with:
  - NGSs of different spectral types
  - extended sources as NGS
  - a non-sidereal target as NGS
- Checking the differential atmospheric dispersion between WFS and TestCam

## 6. LASER GUIDE STAR SYSTEM

GTCAO was designed from its beginning to be upgraded to do the high-order modes sensing with a Laser Guide Star. The LGS chosen was a Na LGS, the high power 20 W commercialized by TOPTICA. After conducting a study on the effects of side-launching on the system performance, we decided to launch off-axis because it reduces the overall risks, maintenance and costs of the system. The requirements of the LGS facility are shown in Table 2. The laser is now installed in a clean room in the AIV hall at the IAC. The Launch Telescope and the Beam Transfer Optics are in its Final Design Phase, and procurement of the subsystems is in progress.

<b>Strehl ratio (good seeing)</b>	Bright NGS on axis, $SR \geq 0.5$ @ $2.2\mu\text{m}$ with LGS
	NGS $m_R < 18$ , $SR \geq 0.1$ @ $2.2\mu\text{m}$ -> <b>ALMOST 100% SKY COVERAGE</b>
<b>High Order LGS WFS</b>	Shack-Hartmann 20x20, FOV 7", 0.6"/pix, EMCCD
<b>Tip-Tilt NGS WFS</b>	Shack-Hartmann 2x2, EMCCD (0.47-0.9 $\mu\text{m}$ )
<b>Same seeing range, Science FOV, zenith angle, exposure time...</b>	

**Table 2: LGS Facility requirements**



**Figure 5: left, Toptica laser in the clean room of the AIV hall; right, optomechanical design of the Beam Transfer and Launch Telescope.**

## 7. GTCAO FUTURE PLANS

The system was shipped to ORM in June 2023 and during the summer the efforts were focused on installing the system in Nasmyth B platform and fully integrate the GTCAO control system with the GTC OE. During the autumn of 2023 the commissioning of the system will be accomplished. Meanwhile, we are procuring all the hardware necessary for building GRANCAIN, the first science instrument that will be installed at the exit focus of GTCAO while FRIDA arrives. The factory acceptance of GRANCAIN will be done in spring 2024 and it will be shipped to La Palma and commissioned at GTC in autumn 2024. The LGS system will follow one year later, in 2025.

MILESTONE	DATE
GTCAO AIV in laboratory completed – Factory Acceptance	T1 2023
GTCAO Transport and AIV in Telescope	T2 2023
GTCAO commissioning in GTC	T3 2023
GRANCAIN subsystems procurement	T4 2023
GRANCAIN AIV in laboratory completed – Factory Acceptance	T2 2024
GRANCAIN AIV in Telescope and Commissioning	T3 2024
LGS subsystems procurement	T2 2024
LGS AIV in laboratory completed – Factory Acceptance	T2 2025
LGS AIV en Telescope	T3 2025

**Table 3: timeline of GTCAO.**

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