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Results of the GTC Adaptive Optics commissioning and prospects for the first science

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Abstract

The GTC Adaptive Optics (GTCAO) system can provide near diffraction-limited capabilities in the near infrared to the GTC telescope using a Natural Guide Star (NGS) brighter than 13–14 mag. In the coming years, it will be upgraded to a Sodium Laser Guide Star (LGS), significantly increasing the sky coverage using a tip-tilt star brighter than 18 mag. The GTCAO system was accepted at the laboratory on April 2023, and successfully transported and integrated in the Nasmyth-B platform on June. The commissioning in the sky started soon after. We will review the main results of the commissioning, and present the current performances of the GTCAO with the TestCam. We will also present future prospects to start scientific observations with GRANCAIN and FRIDA instruments, which will provide imaging and spectroscopic capabilities at the diffraction limit of the GTC telescope (∼40 mas in the K-band).

1 Introduction

The GTC Adaptive Optics (GTCAO) system will provide near diffraction-limited images in the near infrared to the GTC telescope using a Natural Guide Star (NGS) brighter than 14 mag [5, 1]. The system is expected to provide a Strehl Ratio (SR) larger than 65% in the K-band for a bright star. The performances measured in the laboratory indicates a SR of $\sim$80% in the H-band for a bright source and good seeing conditions (<0.5 arcsec) [6]. Since the beginning the system was designed to be upgraded to a Sodium Laser Guide Star (LGS), which can significantly increase the sky coverage using a tip-tilt star brighter than 18 mag. The GTCAO system will be able to provide images with a resolution of $\sim$40 mas in the K-band, $\sim$30 mas in the H-band, and $\sim$25 mas in the J-band. This is more than ten times better than typical good seeing conditions ($\sim$0.5 arcsec) of the best ground-based observatories, and 1.6 times better than the James Webb Space Telescope resolution. Until the arrival of the European Large Telescope (ELT), GTC is the largest optical and near infrared telescope in the world and therefore it will provide the best resolution images.

2 GTCAO commissioning

The GTCAO system was accepted at the IAC laboratory on April 2023, and the system was successfully transported to the observatory on 28^{th} June. Thank to the strong efforts and excellent coordination of both the GTCAO and GTC teams, we were able to fully integrate the system in the Nasmyth-B platform of the GTC telescope in a record time on 30^{th} June (see Figure 1). After the installation in the telescope, we repeated part of the acceptance tests with the calibration system and we checked that the GTCAO system performances were as measured in the IAC laboratory. At the beginning of July we started the optical alignment of the GTCAO and the GTC telescope, and at the end of the month we had the first technical light of the instrument on 24^{th} July . These observations were done under seeing limited conditions and no Adaptive Optics corrections were still done.

The commissioning of the instrument in the sky started soon after these first observations. These tests did not only include the commissioning of the GTCAO system but also the new GTC AO focal station, since many of the telescope operations of acquisition, tracking and guiding with AO were also new for the telescope and have to be done in close communication with GTCAO. During the last year we have been carrying out the commissioning of the GTCAO system during typically 1-2 half nights per month, weather permitting. We have performed these technical night observations during bright time to minimize the effects on the scientific programs. On 7^{th} September 2023, we closed the Adaptive Optics high order loop for the first time on sky, but in these observations no tip-tilt correction were uploaded to the secondary mirror (M2) of GTC. On 29^{th} November 2023, we were able to close all the Adaptive Optics loops, including tip-tilt correction with M2, and we were able to obtain for the first time images close to the diffraction limit of the telescope with the GTCAO and the TestCam, the commissioning camera for AO (see an example in Figure 2).

During the 2024 year, apart from testing most of the GTCAO functionalities, we have also carried out some observations of science verification. We have been able to detect some

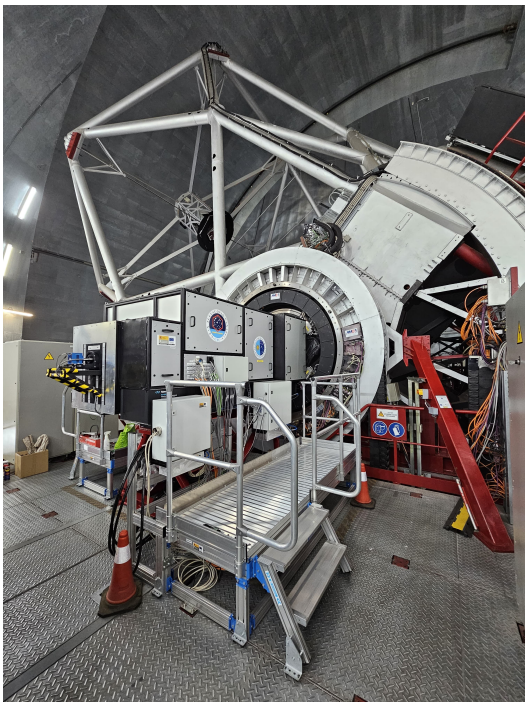

Figure 1: GTCAO system integrated in the Nasmyth-B platform of the GTC

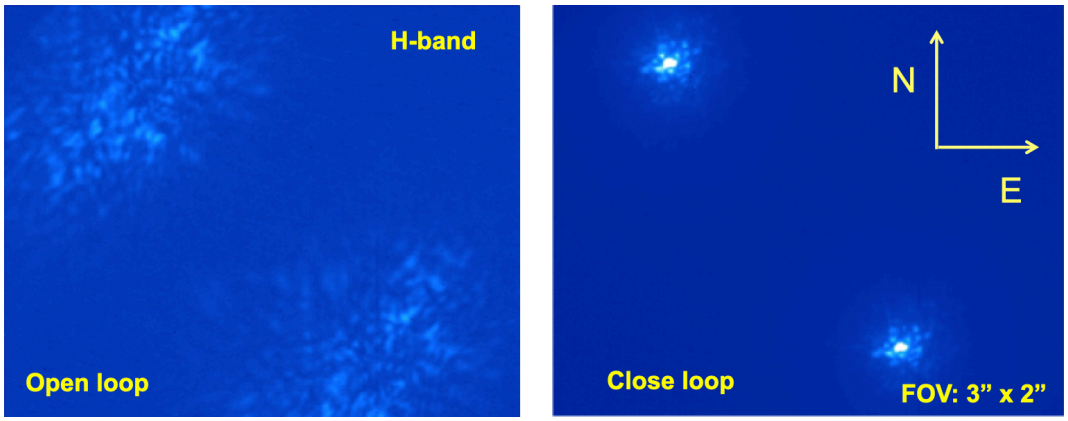

Figure 2: TestCam images of the ξ UMa binary in open loop (left) and close loop (right).

substellar companions such as G196-3B [4] and resolve some close binaries. On February 2024 we observed the very close young M dwarf binary DG CVn, previously resolved by TCS/FastCam in 2012 at a separation of 190 mas, but unresolved in 2015 [2]. We resolved the system at a separation of $\sim$70 mas with GTCAO/TestCam (see Figure 3). On April 2024, we also confirmed a previously known companion around the metal poor star Wolf 834, separated by $\sim$0.80 arcsec, and measured the orbital motion of GJ 3919 binary.

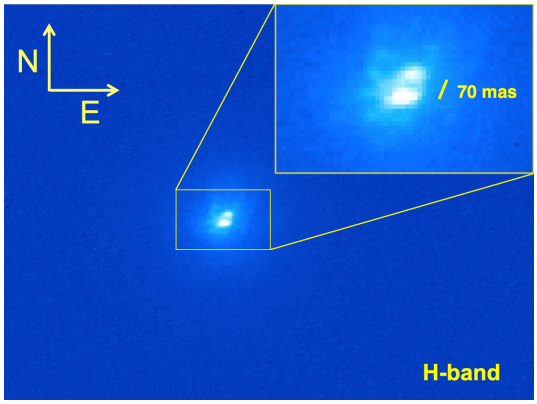

Figure 3: TestCam images of DG CVn M dwarf binary.

3 The Laser Guide System (LGS)

The LGS is an upgrade of the GTCAO system based on the generation of an artificial laser star using a high-power (20W) Na laser from TOPTICA, and a tip-tilt natural star brighter than 18 mag, which will allow obtaining nearly diffraction limited images covering almost the whole sky. The optical and mechanical design of the Laser Wavefront Sensor (LWS) have been finished and most of the optical components, except for the dichroic, have already been received. The TOPTICA laser was accepted in 2020, and it is regularly operated at the IAC laboratory. The optical design of the Laser Transfer System (LTS), the system that transfer the laser to the launch telescope, is finished and most of the components are already ordered. The opto-mechanical design of the LTS is close to completion, but still some of the components are pending. The optical components of Laser Launch Telescope (LLT) provided by TNO have already been received, but the mechanical design provided by our primer contractor was not complete and we are still pending its finalization. We are also currently designing the support structure of the LGS in the elevation ring of the GTC telescope. All these remaining tasks put the operation of the LGS on the telescope in 2027. The detailed schedule of GRANCAIN and LGS is indicated in Table1.

4 GRANCAIN

GRANCAIN (GRAN Telescopio Canarias CAmara INfrarroja) is the first near-infrared scientific camera that will operate with the GTCAO system. The instrument with a plate scale of 10.89 mas/pixel will provide diffraction limited images and with an adequate spatial resolution sampling (Nyquist sample) in J, H and K band, providing a field of view in image mode of 22 arcsec $\times$ 22 arcsec (diffraction limited within the isoplanatic angle). The main characteristics of the GRANCAIN are indicated in Figure 4. The instrument would consist of a conventional cryostat with a closed helium cycle that would cool down the 2K$\times$2K pixel Hawaii-2 PACE detector from Teledyne to 77 K. The detector and the control software of the instrument would be replicated from EMIR instrument including its high-level operation.

The optical design is telecentric and based on a collimator-camera with a 2:1 magnification. The optical system consists of two lenses, a cold stop which removes all the thermal background and two filter wheels inside of the cryostat with three (J, H and K_s) broad band filters and three narrow filters (Pa_β, Fe II, and H_2). The details of the optical and mechanical design are described in [3]. GRANCAIN is currently in the last stages of assembly and integration at the IAC laboratory. After several cool downs, the optical system is fully aligned and the scientific detector will be mounted one of the next cool downs. Only the filter wheels are still pending for integration. The control system including the software fo the sensors, mechanisms and detector is well advanced. A picture of current status of GRANCAIN in the IAC laboratory can be seen in Figure 5. We expect the instrument to be available at the GTC telescope in the first semester of 2025 (see detailed schedule in Table1).

Mode	Imaging mode + NGS GTCAO
Wavelength range	1.0-2.5μm
Detector	Hawaii-2 PACE Teledyne (2k x 2k pix) – old FRIDA detector
Pixel scale	10.89 mas/pix (Nyquist sample at J,K-band)
FOV	22"x22" (covering isoplanatic angle: 10-20")
Filters	J, H, K broad and narrow filters in each band (Paβ, FeII, H_2)
Throughput/Sensitivity	GTC+GTCAO+GRANCAIN: 60% / TBC: K_{lim}~ 20 in 20 min
Resolution	~40 mas in K-band
Strehl ratio	Bright NGS on axis, SR≅0.65 @ 2.2μm
	NGS m_R=14.5, SR≅0.1 @ 2.2μm

Figure 4: Main characteristics of GRANCAIN near-infrared AO camera.

Table 1: LGS and GRANCAIN schedule

Milestone	Date
GRANCAIN subsystems integration	T4 (4^{th} quarter) 2024
GRANCAIN AIV completed in laboratory	T1 (first quarter) 2025
GRANCAIN AIV in GTC	T2 (second quarter) 2025
Detailed Design LGS closed	T1 (first quarter) 2025
LGS Subsystems integration	T1 (first quarter) 2026
LGS AIV completed in laboratory	T1 (first quarter) 2027
LGS AIV en GTC	T2 (second quarter) 2027

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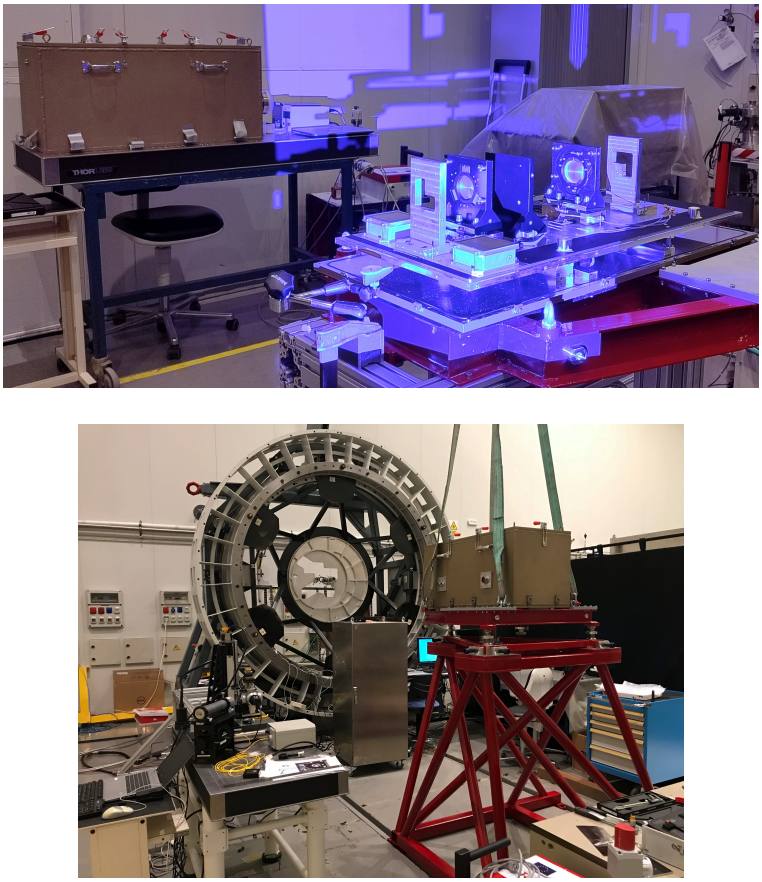

Figure 5: Current status of GRANCAIN at the IAC laboratory.

and ERDF/EU. Based on observations made with the Gran Telescopio Canarias (GTC), installed at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofsica de Canarias, on the island of La Palma.

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