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The GTC Adaptive Optics system: the high spatial resolution Adaptive Optics facility at GTC.

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Abstract

The GTC Adaptive Optics (GTCAO) system is the general Adaptive Optics facility that will provide diffraction limited images in the near-infrared to the GTC telescope. At Day 1 it will consist of a single deformable mirror with 21×21 actuators (373 useful actuators), conjugated to the telescope pupil and a Shack-Hartmann wavefront sensor with 20×20 sub-apertures using a Natural Guide Star (NGS) as a reference source. The GTCAO system is expected to provide a Strehl ratio of 0.65 in the K-band with a bright NGS, and it will be later upgraded to a Sodium Laser Guide Star (LGS) to significantly increase the sky coverage. In this proceeding, we describe the GTCAO and the LGS system, we summarize some of the scientific cases that can be carried out with the GTCAO LGS system and the FRIDA instrument, and we review the planned schedule for the GTCAO system first with the NGS and later with the LGS system.

1 Introduction

The Adaptive Optics (AO) systems allow to correct the atmospheric turbulence and produce images near the diffraction limit [1]. This is fundamental for large diameter telescopes (8–10 m), where the diffraction limit ($\sim$40 mas in the K-band for a 10 m telescope) is ten times smaller than typical good seeing conditions ($\sim$0.6”). The AO systems have two major components: a wavefront corrector, usually based on deformable mirror, and a wavefront sensor,

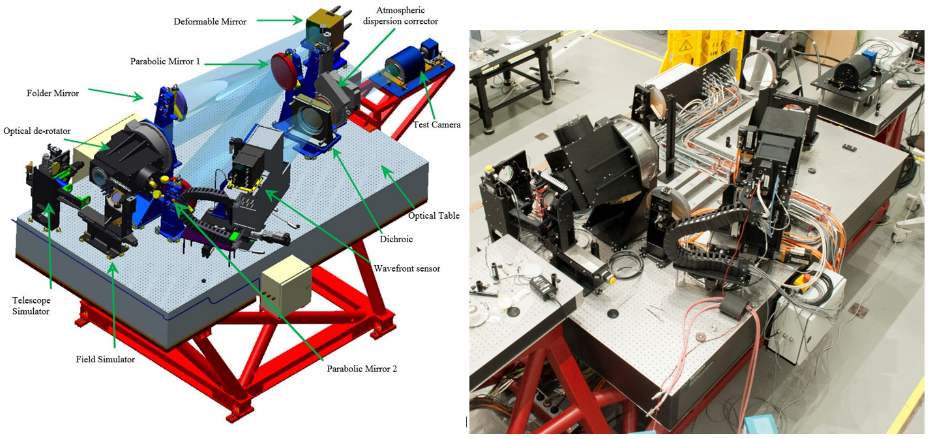

Figure 1: (left) Opto-mechanical design of the GTCAO system. (right) A picture of the fully integrated GTCAO system, currently at the IAC laboratory.

in most cases based on a Shack-Hartmann. A real time control system is also necessary to compute and correct the optical aberrations thousand of times per second.

2 The GTCAO system

The GTC Adaptive Optics (GTCAO) is a post focal AO system that will be installed on the GTC Nasmyth platform B, which corrects the optical beam to feed the scientific instrument placed after it. GTCAO follows the classical collimator-camera design of an AO system with the use of two identical off-axis parabolas (one acting as the collimator and the other as the camera), maintaining the effective focal distance of the telescope (see left panel of Fig 1). On Day 1, the system will provide a single deformable mirror conjugated to the telescope pupil and will use natural stars (NGS) for wavefront sensing. The GTCAO system is expected to provide a corrected beam that will achieve a Strehl Ratio (SR) of 0.65 in K-band with bright guide stars. The size of the transmitted field of view is 1.5 arcmin diameter and the optical layout of the system has been designed to be able to work up to 60 deg of zenithal distance. For the wavefront sensing, the GTCAO has a Shack-Hartmann wavefront sensor with 20x20 subapertures (FOV of 3.5"/subaperture) and an OCAM2 camera with a low noise EMCCD detector CCD220 (240×240 pix, 0.35"/pix). For the wavefront correction, the GTCAO has a CILAS deformable mirror with 21×21 actuators (373 useful actuators), and for tip-tilt correction it uses the GTC secondary mirror (see main characteristics of the system in Fig 2). A more detailed description of the different GTCAO sub-systems can be found in [2]. The GTCAO system is planned to be upgraded in the future by the use of a sodium laser guide star (LGS) for wavefront sensing to significantly increase the sky coverage (see section 4). The first scientific instrument to use GTCAO will be FRIDA (inFRared Imager and Dissector for Adaptive optics), an integral field spectrograph in the near infrared with imaging capability.

Mode	Single conjugate correction, NGS (first light)
Wavelength range	1.0-2.5μm (goal 0.8-5.0μm)
Strehl ratio	Bright NGS on axis, SR≧0.65 @ 2.2μm
	NGS m_R=14.5, SR≧0.1 @ 2.2μm
Wave-Front Sensor	Shack-Hartmann 20x20 (FOV 3.5"), EMCCD (240 x 240pix)
Wave-Front Corrector	Deformable Mirror (21x21, 373 actuators, Fried Geometry)
Throughput	at least 70% in the range 1.0-2.5 μm
Emissivity	less than 20% at 3.8 μm
Seeing	Up to 1.5 arcsec
Science FOV	Up to 1.5 arcmin
Zenith distance	0-60º
Exposure time	at least one hour
Ghost images	Defocused ghosts <1e^{-5} (except dichroic 1e^{-4}) Focused ghosts: <1e^{-3} and located within 0.2 arcsecs)
Tracking	Non-sidereal targets used as NGS
Dithering	offsets of 0.25 arcsecs (goal 1.0 arcsec) with closed-loop

Figure 2: Main characteristics of the GTCAO system.

3 The GTCAO AIV tests

The GTCAO system is currently fully aligned and integrated at the IAC laboratory. The first tests at the system level have been carried out, but possible adjustments are still required during this stage. For this reason, the general enclosure of GTCAO has not been mounted, and the air conditioning system of the clean room introduces a small and slow local turbulence in the optical bench. For these tests, we used TestCam, a near-infrared camera for the characterization of GTCAO performances, and the H-band filter. Two values were used for the OCAM2 camera frame rate, 1000 Hz and 2000 Hz. The telescope and turbulence simulator (GTCsim) of the Calibration System was set to the standard scenario, with r_0=20 cm and wind speed=10 m/s. Under these standard turbulence conditions, we compared the the Point Spread Function (PSF), obtained with the TesCam after closing the loop, with the simulated PSF in H-band, and measured a Strehl Ratio (SR) of 0.66, which has to be compared to the SR of 0.72, as expected from the simulations (see Fig 3).

4 The GTCAO LGS system

AO systems using bright NGS provide wavefront corrections in a limited region of the sky. The AO system using LGS provides a better correction and SR than NGS for natural tip-tilts stars of R>14–15 mag, and a sky coverage of nearly the 100% [3]. The GTCAO LGS system will be based in the commercially available Na laser, built by the company TOPTICA, which delivers a total output power of 20 W. The laser is sent to the atmosphere through a laser launch telescope (LLT), and focused on the mesosphere, at $\sim$90 km distance pointing at zenith, where the Na atoms are stimulated generating the LGS. For the installation of the LLT, the

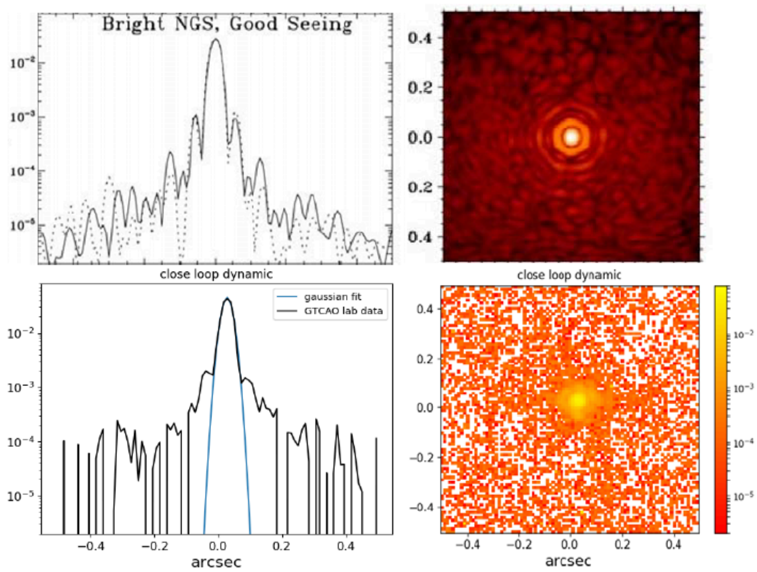

Figure 3: Simulated PSF (top) and real PSF measured with the TestCam (bottom) in the H-band. Left panels show an horizontal cut of the PSF and right panels show the 2-D images of the PSF. A Streh Ratio of 0.72 is predicted from simulations, while 0.66 is measured.

side (off-axis) laser launch configuration from the GTC elevation ring has been chosen as the concept baseline. The GTCAO LGS system will provide single-conjugate correction in the near-infrared using a LGS to perform high-order wavefront corrections and a tip-tilt NGS to provide tip-tilt and defocus corrections. The LGS system will be able to operate under similar conditions as the GTCAO system using a tip-tilt guide star of magnitude $R<18$ mag located at an angular separation up to 60 arcsec from the center. The main characteristics and the top level requirements of the LGS are indicated in Fig 4.

5 Science with the GTCAO LGS system

Most of the science cases proposed for NGS can also be done with the GTCAO LGS facility. In these cases the advantage of the use of LGS and a relatively faint tip-tilt guide star is that the sky coverage increases from about 10% with GTCAO NGS to about 60-100% with GTCAO LGS for average and good seeing conditions, and hence the number of accessible targets increase substantially.

The upgrade of the GTCAO system to the LGS facility will also allow GTC community to carry out some science cases that are not feasible with NGS, because there is no star bright enough in the FOV to perform the AO corrections. Some references science cases are mentioned here:

Mode	Single conjugate correction, 1 LGS (HOWFS) + NGS tip-tilt
Science focus Wavelength range	1.0-2.5μm
Strehl ratio	Bright tip-tilt NGS on axis, SR≥0.5 @ 2.2μm
	NGS m_R<18, SR≥0.1 @ 2.2μm
NGS Wave-Front Sensor	Shack-Hartmann 2x2 subap, EMCCD (240 x 240pix) (0.47-0.9 μm)
LGS Wave-Front Sensor	Shack-Hartmann 20x20 (FOV 5"), EMCCD (240 x 240pix)
Wave-Front Corrector	Deformable Mirror (21x21, 373 actuators, Fried Geometry)
Seeing	Up to 1.5 arcsec
Science FOV	Up to 1.5 arcmin
Zenith distance	0-60º
Exposure time	maximum one hour

Figure 4: Main characteristics of the GTCAO LGS system.

- AO observations of the nearest galaxies: The GTCAO with LGS will allow us mapping the full body of the nearest galaxies at unprecedented sub parsec scales, almost twice the resolution achievable with JWST. Because of the brightness and extension of nearby galaxies, very often the nucleus itself is the only suitable source for NGS AO correction. Subsequently, AO studies of galaxies are mostly restricted to the active galactic nuclei class. GTCAO with LGS is thus a must if we are to extend current studies to representative members of different galaxy types, across the Hubble sequence.

- AO observations of high-redshift galaxies: The Laser capability of GTCAO will be instrumental to sample z>4 at kpc scales. Dynamical studies at z>2 with the IFU will yield first determinations of galaxy virial masses at those z. The angular resolution and sensitivity of FRIDA in imaging mode will represent a step further in our quest to unveil the morphology of galaxies at higher z: mergers, discs and/or spheroids.

- Dynamical masses of very-low mass stars and brown dwarfs: Brown dwarf binaries offer a unique opportunity to determine their physical properties and test theoretical evolutionary models. The GTCAO LGS system will allow us to investigate the multiplicity and to determine the dynamical masses of the least massive brown dwarfs and planetary-mass objects.

- Multiplicity and dynamical masses of young brown dwarfs: Since the physical properties of substellar objects evolve with time, it is fundamental to find brown dwarfs and planets at different ages to investigate their evolution and test theoretical models. The GTCAO LGS system will allow us to study the multiplicity and to determine dynamical masses of brown dwarf binaries belonging to Young Moving Groups of the solar vicinity.

6 The GTCAO and LGS system schedule

The GTCAO sytem is fully integrated and we are currently performing tests at the system level at the IAC laboratory. The LGS system is in the Preliminary Design Phase, which is based on the side launch baseline. The expected schedule of the GTCAO and LGS systems are:

- GTCAO Acceptance Tests at IAC laboratory: September 2019.
- Preliminary Design of LGS: March 2019.
- Laser Acceptance at the IAC: September 2019.
- Detailed Design of LGS: end of 2019.
- AIV of the LGS subsystems: mid 2021.
- LGS Acceptance Tests at IAC laboratory: early/mid 2022.

Acknowledgments

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