IACATS. Atmosphere and multiple telescopes simulator

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Abstract

The IACAT (IAC Atmosphere and Telescope) Simulator is an Optical Ground Support equipment which simulates atmospheric turbulence and reproduces the performance of three very different telescopes: GTC and WHT, located at the *Observatorio del Roque de los Muchachos* in La Palma (Canary Islands), and OGS which is located at the *Observatorio del Teide* in Tenerife (Canary Islands). Its mission is to provide scientists with the same measurement conditions as the real telescope but in a friendly laboratory environment. The most important telescope characteristics are simulated, such as the f number, pupil size and position, magnification, central obscuration, etc. Up to 13 stellar objects can be created, individually or as binary stars with specific angular separations down to miliarcseconds. For the atmosphere simulation, it allows the creation of three different turbulence layers concurrently with different altitude and wind speed ranges.

1 Introduction

The development and manufacture of the IACAT Simulator arose from the IAC's (*Instituto de Astrofísica de Canarias*) need for a laboratory tool able to recreate the same conditions as in the real astronomical telescopes. Observation time in science-worthy class telescopes is generally expensive and difficult to obtain. Furthermore, telescope facilities are often uncomfortable for operators working on site for long periods of time. Researchers have expressed the need for a laboratory tool that could provide better and cheaper accessibility than a real telescope, and better characterization than computerized simulations.
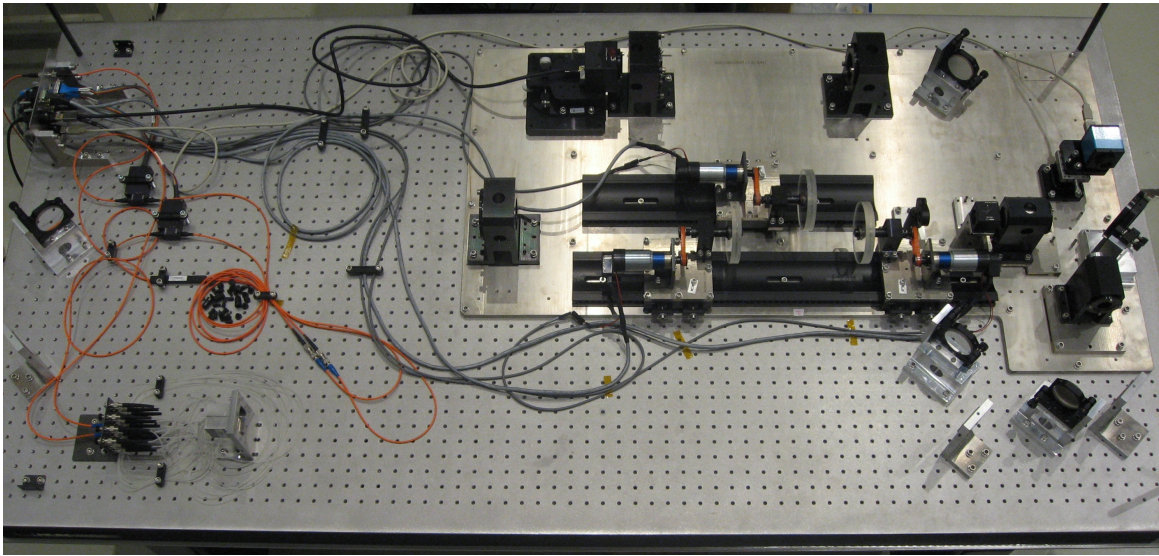
Figure 1: IACAT Simulator.

The IACs laboratory simulations aim to assist in the development of new adaptive optics methods, especially regarding the fast, low-latency and massively parallel control using FPGAs. Main features of the laboratory simulator are:

- Wide, non discrete range of spectral content for the simulated stars; between 0.5 and 1 μm.

- Great variety of simulated turbulence, allowing different combinations of number of layers, altitude, and wind speed.

- Telescope simulation taking into account main variables when working with adaptive optics: f number, aperture size and shape, pupils, central obscuration, etc.

According to the last item, one of the biggest challenges of this project was to simulate and integrate three telescopes of such different sizes (10 m, 4.2 m, and 1 m) and characteristics in a unique simulator. To fulfill all requirements, the simulator is divided into three main subsystems, as follows:

- Stellar objects simulator.

- Atmospheric turbulence simulator.

- Multiple telescopes simulator.

Figure 1 shows a general lay-out of the above subsystems which are described below in detail. The overall size of the simulator is approximately 2000 mm × 1000 mm.
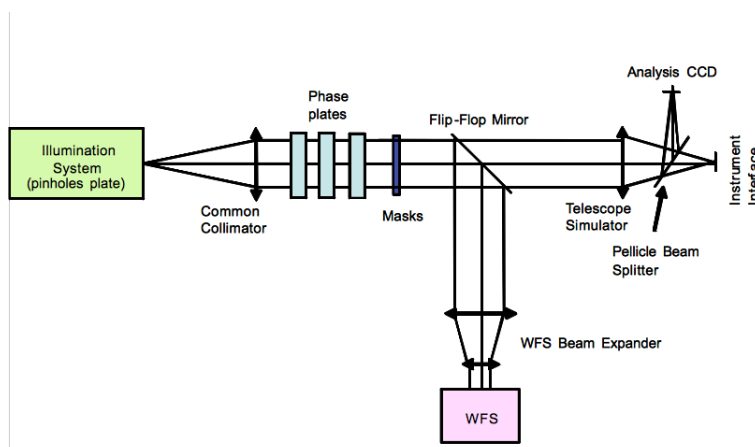
Figure 2: Optical design blocks diagram.

2 Optical design

2.1 Optical layout

The IACAT Simulator optical configuration consists of a Pinhole plate simulating the specified star positions for each telescope, followed by a Common Collimator system, which produces a collimated beam indicating the location of the Phase Screens that simulate the atmospheric turbulence. The optical system stop, or entrance pupil of the telescopes simulator, is located right after the Phase Screens where the telescope simulator masks are placed. A Flip-Flop mirror then redirect the light beam either to a Hartmann-Shack Wave Front Sensor (previously adapted by a Galilean beam expander in order to match the WFS entrance pupil) or to the multiple telescopes simulator. The WFS allows measuring and evaluating the Turbulence created before reaching the telescopes. Figure 2 shows the optical scheme of the simulator.

2.2 Optical parameters

The optical system is refractive; mirrors are only used for folding and packaging. The Common Collimator consists of a cemented doublet while each telescope simulator consists of two cemented doublets. Focal lengths and magnifications are shown in Table 1.

The WFS beam expander is a 1/4× Galilean system and consists of two cemented doublets. Nine mirrors (four of them in the OGS simulator), one flip-flop mirror, and a pellicle beam-splitter are needed for packaging purpose.

The position and size of the real telescope exit pupil are also simulated, in order to properly reproduce the telescope exit beam characteristics.

Other optical parameters of the system are summarized in Table 1.

Table 1: Optical design parameters

	OGS	WHT	GTC	WFS beam expander	Common collimator
Focal length (mm)	779.11	218.768	339.7	Afocal Galilean	3692.87
Magnification	0.211×	0.059×	0.092×	1/4×	NA
Scale	0.02	0.0047	0.002	NA	NA
FOV at the object (X, mm)	2	8.5	27	axis 0°	max 0.42^o @ col. beam
FOV at the object (Y, mm)	−2	8.5	0		
Entrance pupil diameter (mm)	20	20	20	20	20
Exit pupil location (m)[a]	−12.795	−12.794	−20.642	@WFS entr. pupil	NA
Exit pupil diameter (mm)	340.21	1192	1240	4.94	NA
Back focal length (mm)	454.41	248.32	420.26	NA	NA
Image quality WFE rms[b]	-/9	-/9	-/8	-/8	-/15
Length (mm)	1130.26	301.16	566.6	471.15	3702.54

[a]From image plane.
[b]With tolerances and plus collimator.

3   Stellar objects simulator

The main objective of this subsystem is to create stellar objects that are as similar as possible to the stars that could be observed by a real astronomical telescope. In this sense, the philosophy shown in Fig. 3 has been followed.
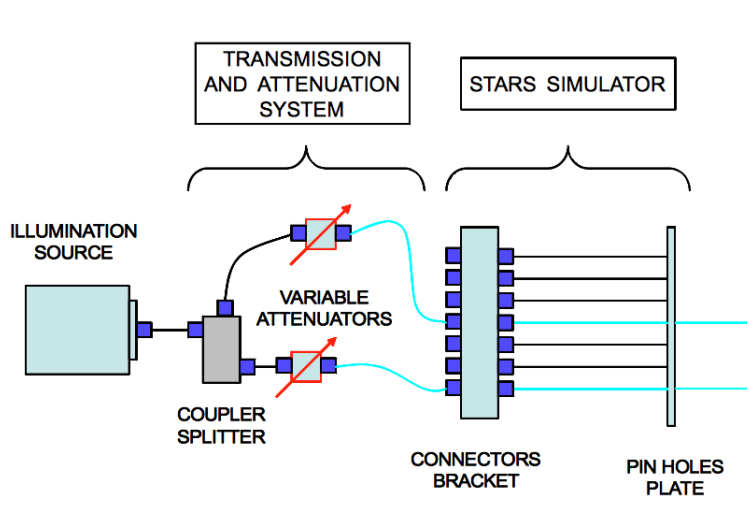

Figure 3: Stellar object simulator scheme.

Single and binary stars are simulated by means of a highly customized light source and optical fibers. In order to obtain a spectral content that is as real as possible, several super-bright LEDs from green to NIR wavelengths are combined to provide a single light beam which is introduced into an optical fiber. A fiber splitter is in charge of providing two illumination channels which are located at different positions of the object plane (pin holes plate). This is intended to simulate up to 12 double stars with angular separations from 0.025
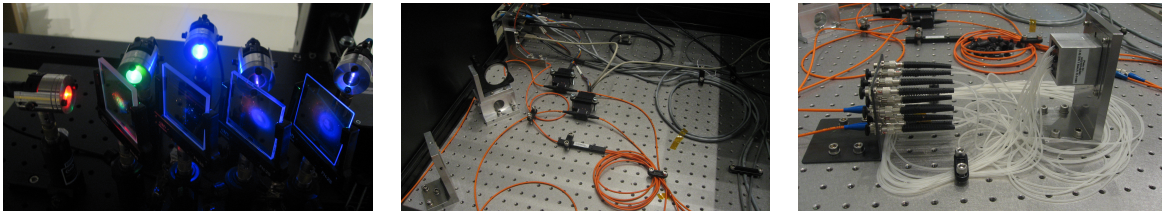
Figure 4: Stellar objects simulator. *Left*: Customized light source. *Middle*: Fiber splitter and variable attenuators. *Right*: Connectors bracket and pin holes plate.

to 3 arcsec, depending on the telescope. Selection of the desired binary or single star is easily carried out interchanging the fibers in the Connector Bracket. Additionally, the luminous intensity of each of the double stars can be independently regulated by means of an electronic variable attenuator on each channel. Figure 4 shows the main elements of this subsystem.

4 Atmospheric turbulence simulator

This is one of the most important subsystems in the simulator, since it provides the atmospheric turbulence which affects the image taken by the telescope. Three different turbulence layers are simulated and the following parameters are controlled:

- Turbulence level: simulated by pseudo-random phase plates with specific r_0 values.

- Turbulence wind speed: each one of the phase plates corresponding to a turbulence layer is mounted on its own customized rotation mechanism, which provides a controlled rotation rate to simulate wind speed.

- Turbulence layer altitude: dependent upon the distance of the phase layer to the entrance pupil of the simulators.

4.1 Phase plates

Simulation of atmospheric turbulence is obtained by using pseudo-random phase plates from LEXITEK working in transmission mode. Five different phase plates are provided with r_0 values from Table 2. Figure 5 displays two turbulence masks.

Table 2: Values of r_0

Phase plate	1	2	3	4	5
r_0 (mm)	0.38	0.97	1.36	2.32	3.24

Up to three turbulence layers can be simulated at the same time, allowing altitude regulation along different ranges depending on the selected telescope as indicated in Table 3. Figure 6 shows the turbulence layers disposition.
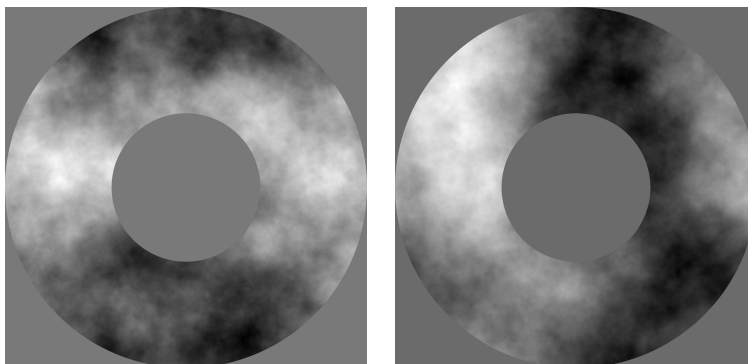
Figure 5: 0.97 mm and 2.32 mm turbulence masks.

Table 3: Altitude ranges

Telescope	Turbulence altitude range (km)
GTC	2–110
WHT	0.3–19.4
OGS	0.02–1.1

4.2 Phase plates rotation system

Turbulence wind simulation is achieved rotating each phase plate about its axis at different speeds. For this purpose, a customized rotation system based on a belt-pulley system is provided for each plate, which is managed under computer control. These devices allow the simulation of wind speeds from 0 to 50 m s^{-1} in both spin directions. All these features (including up to three turbulence layers at the same time, five different phase plates, wind speed and altitude regulations) provide a huge number of possible combinations in the generated turbulence. The phase plate rotation system is shown in Fig. 7.

4.3 Wave front sensor assembly

It is worth pointing out that in addition to creating turbulence, the simulator makes it possible to check the wave front distortion being produced in the light beam before introducing it into each simulated telescope. A Hartmann-Shack Wave Front Sensor (from Imagine Optic) allows the measurement of optical aberrations in the light beam in real time. An additional optical system (Galilean expander) is provided to adapt the light beam aperture to the WFS analysis pupil size. A general view of both turbulence and measurement paths is shown in Fig. 8.

Figure 9 shows two images of the aberrated wave front from the Hartmann-Shack WFS.
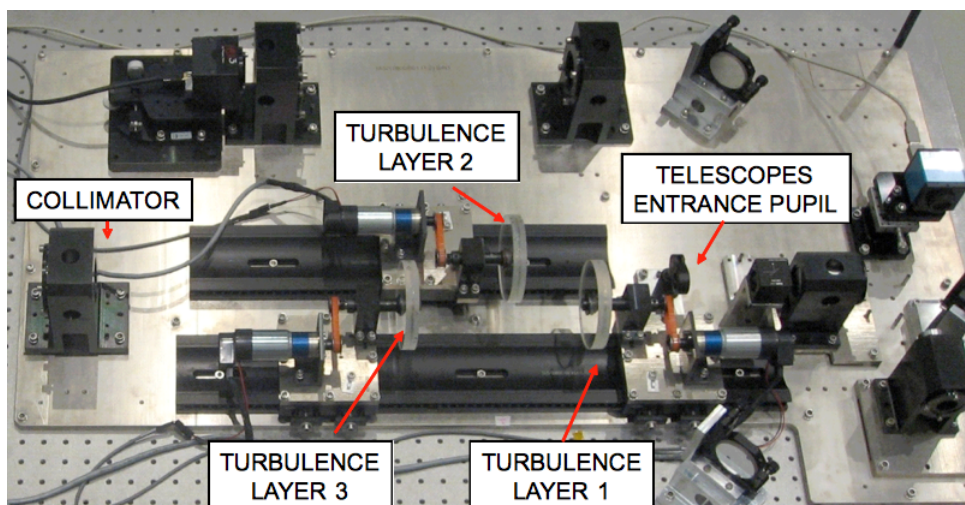
Figure 6: Turbulence layers.

5 Multiple telescopes simulator

Three very different telescopes are simulated in the same optical bench: GTC, WHT and OGS. Their optical parameters are faithfully reproduced by means of cemented doublets, providing the same features as the real telescopes. Every set of lenses is accommodated in a lens barrel which is later placed in a specific bracket, supported by an individual baseplate. This concept, together with a dowel pins positioning system, allows interchanging the different telescopes assemblies without the need for new alignment tasks, and always meeting the optical tolerancing requirements.

The telescopes are optically designed so their respective entrance pupils are coincident; therefore, three different image plane positions will be obtained, where a CCD camera is placed to obtain the image of the stars simulated. A pellicle beam-splitter is located between the telescopes and the CCD camera assemblies to provide two identical focal planes, one for the image monitoring and the other for the instrument to be tested.

Finally, central obscuration and spider of the real secondary mirrors support structures are also recreated with three different interchangeable masks, which are carefully manufactured by means of wire EDM. They are located at the telescopes entrance pupil position. Figure 10 shows these elements.

6 Mechanical design

6.1 General

The mechanical design of the IACAT Simulator focuses on the following objectives:

- To provide an adequate support system for the multiple optical elements, guarantying
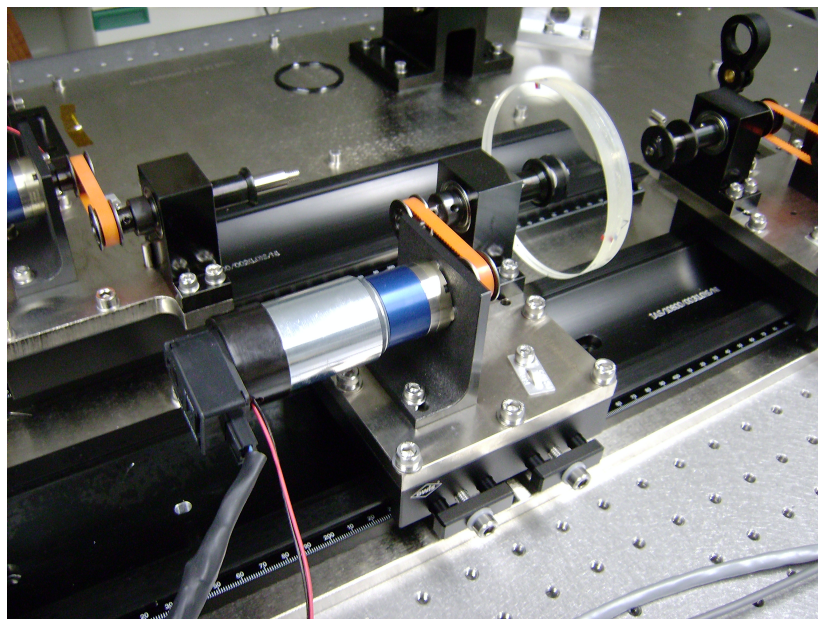
Figure 7: Phase plate rotation system.

their nominal positions according to the optical tolerancing, as well as great repeatability during simulators operation.

- To assemble the necessary elements to integrate three different telescopes simulators.

- To provide mechanical solutions to meet performance requirements of the simulator (e.g., rotation mechanisms, optical compensators, height regulation, etc.).

In addition, position of the interchangeable elements (Flip-flop and telescopes) must be highly repeatable to guarantee the correct installation within tolerances to be made by a non-specialist operator and without realignment tasks. To this end, a dowel pins based positioning system is provided in all parts of the simulator which must have either a very specific position or high position repeatability:

- Collimator assembly.

- Atmospheric turbulence simulator: rails, phase plates assembly.

- Wavefront sensing system: mirror cube assembly (Flip-Flop), beam expander, WFS assembly telescopes simulators.

6.2   Support structure, enclosure and height regulation

All subsystems of the IACAT Simulator are accommodated on an optical breadboard which provides support and stiffness to the whole system. The optical breadboard is supported by
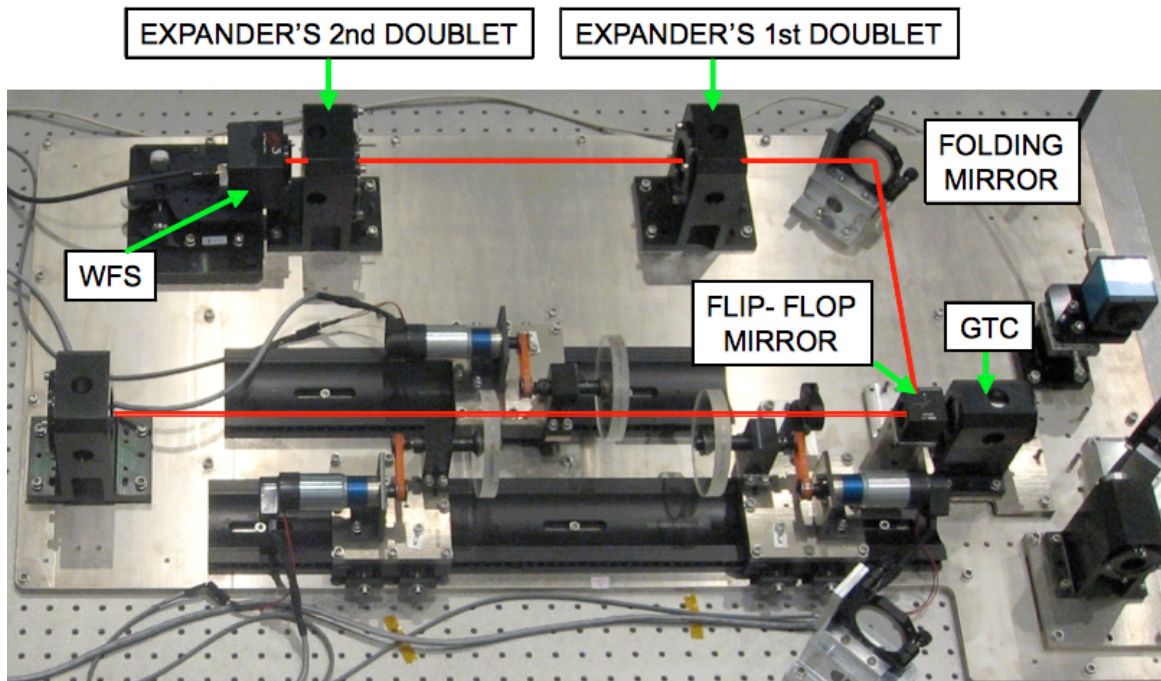
Figure 8: Atmospheric turbulence simulator.

a rigid frame with rubber mounts which is provided with a set of casters to allow an easy transportation. A protective cover is also provided to avoid damage to the simulator and to keep undesired external light and dust out of the system. Finally, three screw jacks are provided to allow height regulation of ± 200 mm of the whole equipment. A general view of this subsystem is shown in Fig. 11.

7   Control system

The IACAT Simulator control system is in charge of controlling the following elements:

- Stellar objects irradiance.

- Turbulence layers wind speed.

- Wavefront sensor.

- CCD image monitoring

Both the WFS and the CCD camera provide their own proprietary software, while attenuation of binary stars and wind speeds are controlled by means of LabVIEW code, where both functionalities are managed jointly to simplify the control tasks.
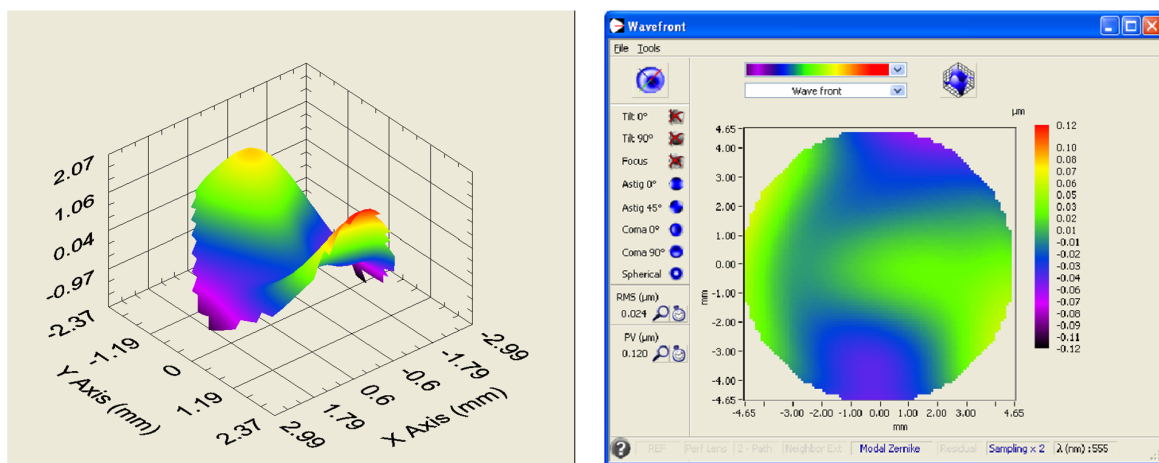
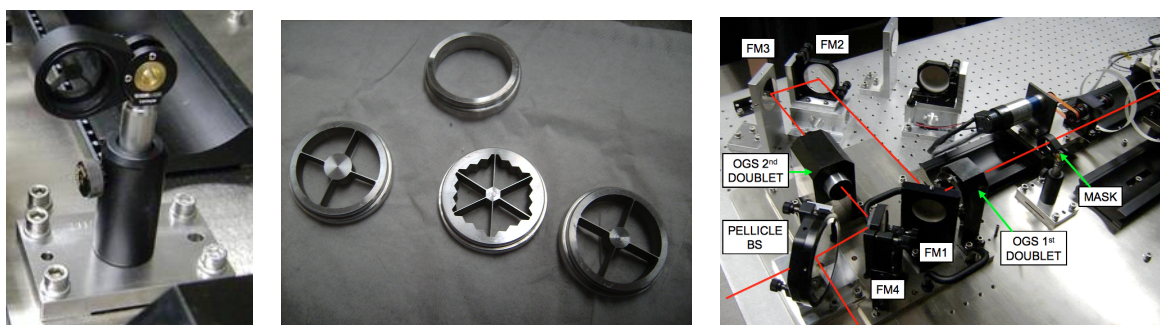Figure 9:   Wave front images from the WFS.

Figure 10:   *Left*: Masks assembly. *Middle*: Masks before anodizing. *Right*: OGS simulator.

8   Conclusions

The following conclusions can be established:

- A telescope and atmospheric turbulence simulator has been developed for the IAC in response to their needs to study new adaptive optics methods.

- The simulator recreates and simulates the most important characteristics of the astronomical ground telescopes observation process, this is, from the stellar objects simulation through a wide range of atmospheric turbulence, and up to the telescopes optical features.

- A highly customizable laboratory tool has been developed, being easily adaptable to any astronomical telescope and to the needs of the scientific community.
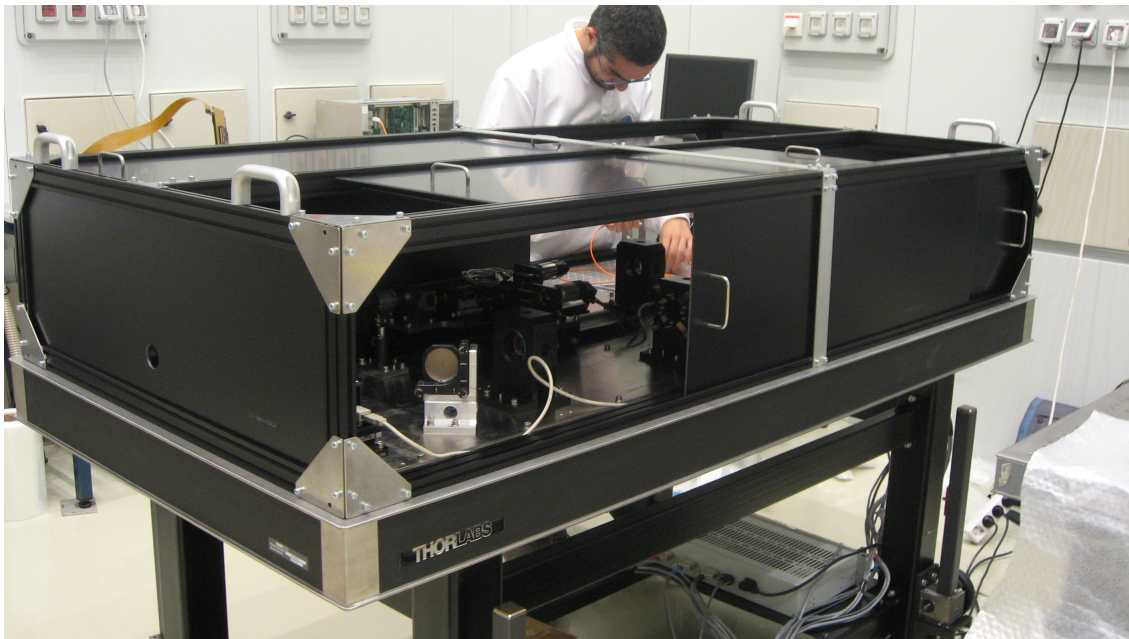
Figure 11: IACATS protective and support structure.

Acknowledgments