The Gran Telescopio Canarias Adaptive Optics system: getting ready for the sky

Icíar Montilla on behalf of the GTCAO team

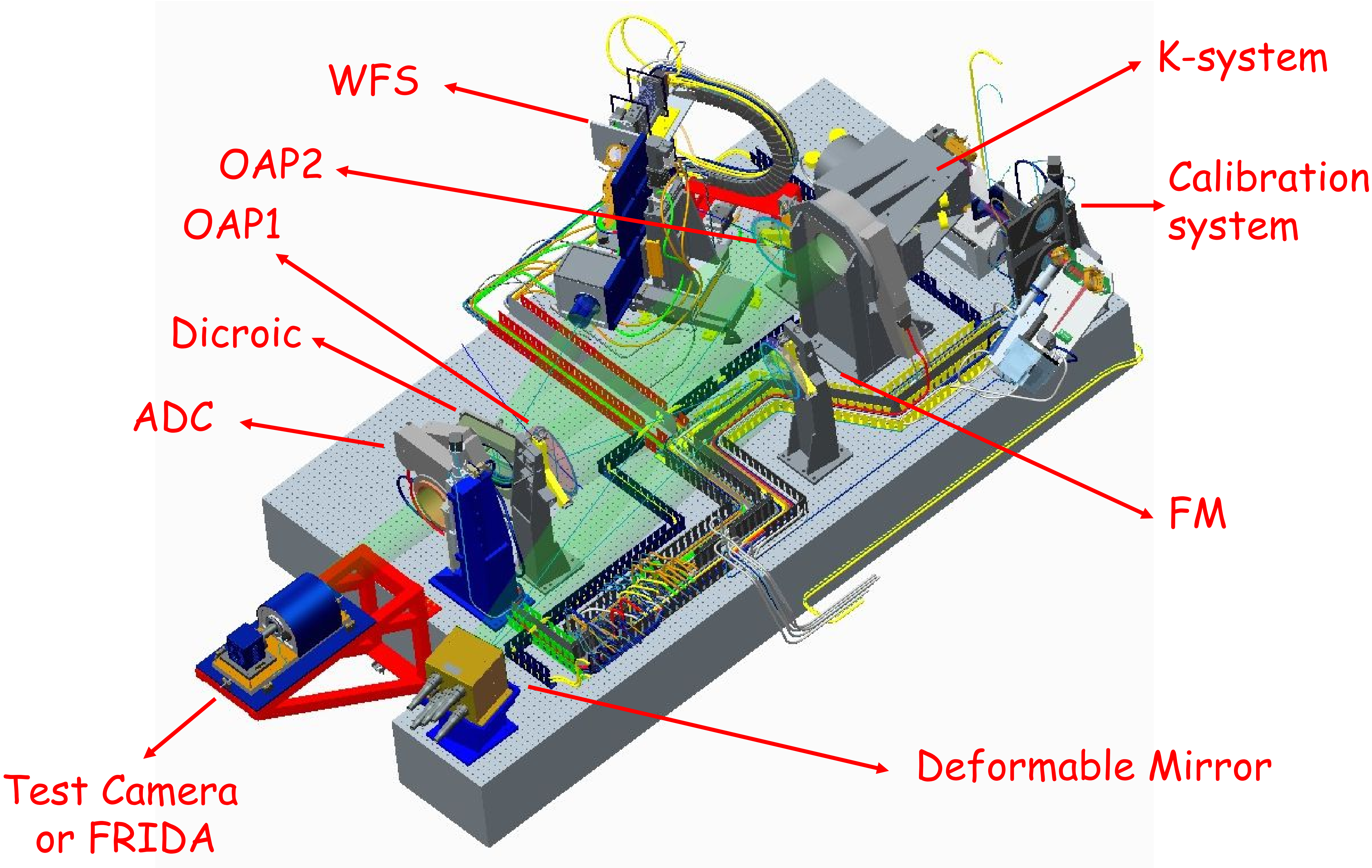
Contents

- GTCAO system overview
- Optical bench calibration system and tools
- Laboratory results
- Ongoing work: calibrations and tests
- GTCAO and LGS schedule

GTC Adaptive Optics System

Mode	Single conjugate correction, NGS (first light) 1 LGS (HOWFS) + NGS tip-tilt (upgrade)
Wavelength range	1.0-2.5µm (goal 0.8-5.0µm)
Strehl ratio (good seeing)	Bright NGS on axis, SR≧0.65 @ 2.2µm (SR≧0.5 @ 2.2µm with LGS)
	NGS m_R=14.5, SR≧0.1 @ 2.2µm (NGS m_R<18, SR≧0.1 @ 2.2µm)
HO Wave-Front Sensor	Shack-Hartmann 20x20 (FOV 3.5" with NGS FOV 5" with LGS), EMCCD (240 x 240pix)
TT Wave-Front Sensor	Shack-Hartmann 2x2 subap, EMCCD (240 x 240pix) (0.47-0.9 µm)
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	at least one hour

GTCAO Opto-mechanical design

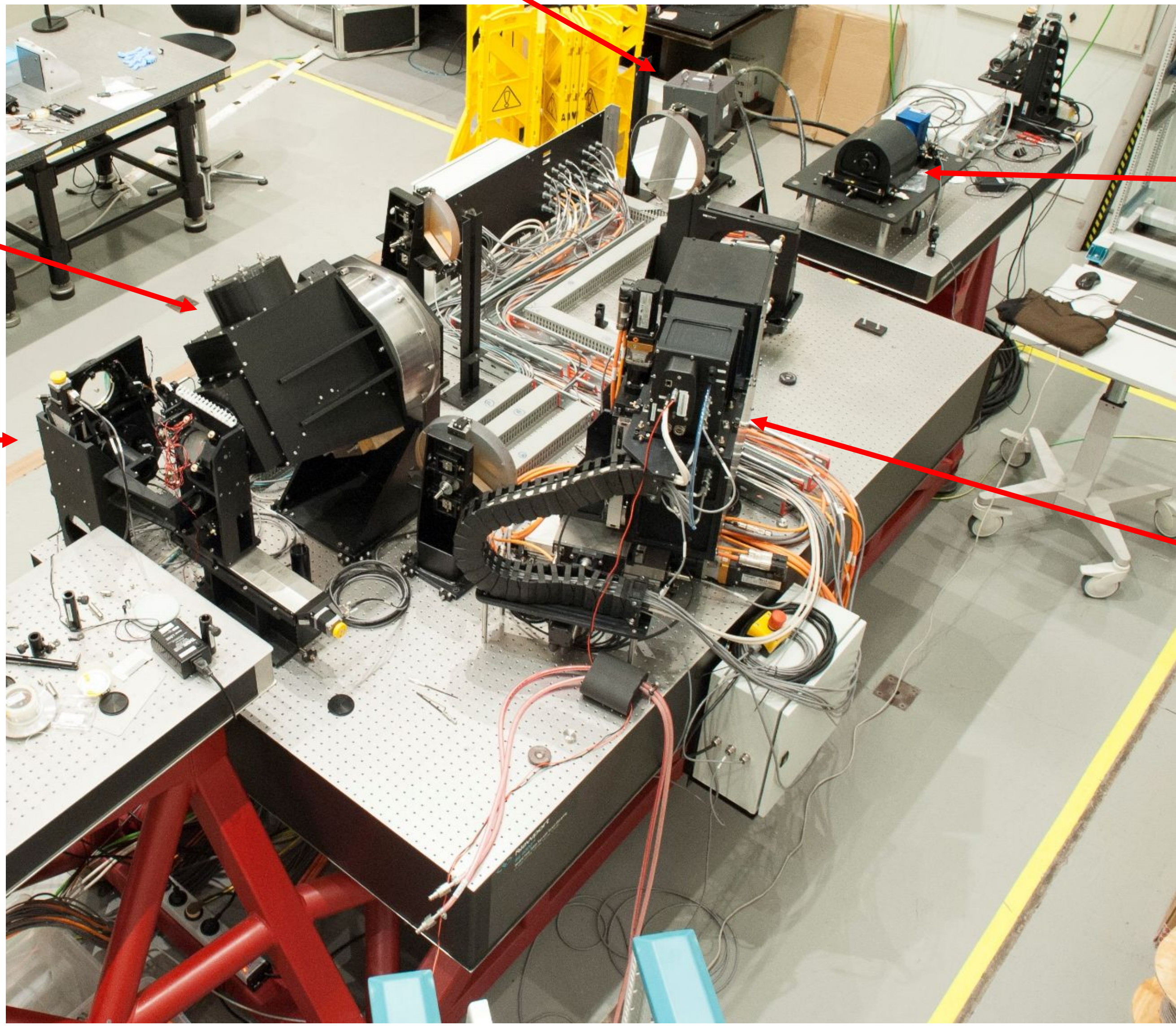


GTCAO Opto-mechanical design

Deformable Mirror

K-system

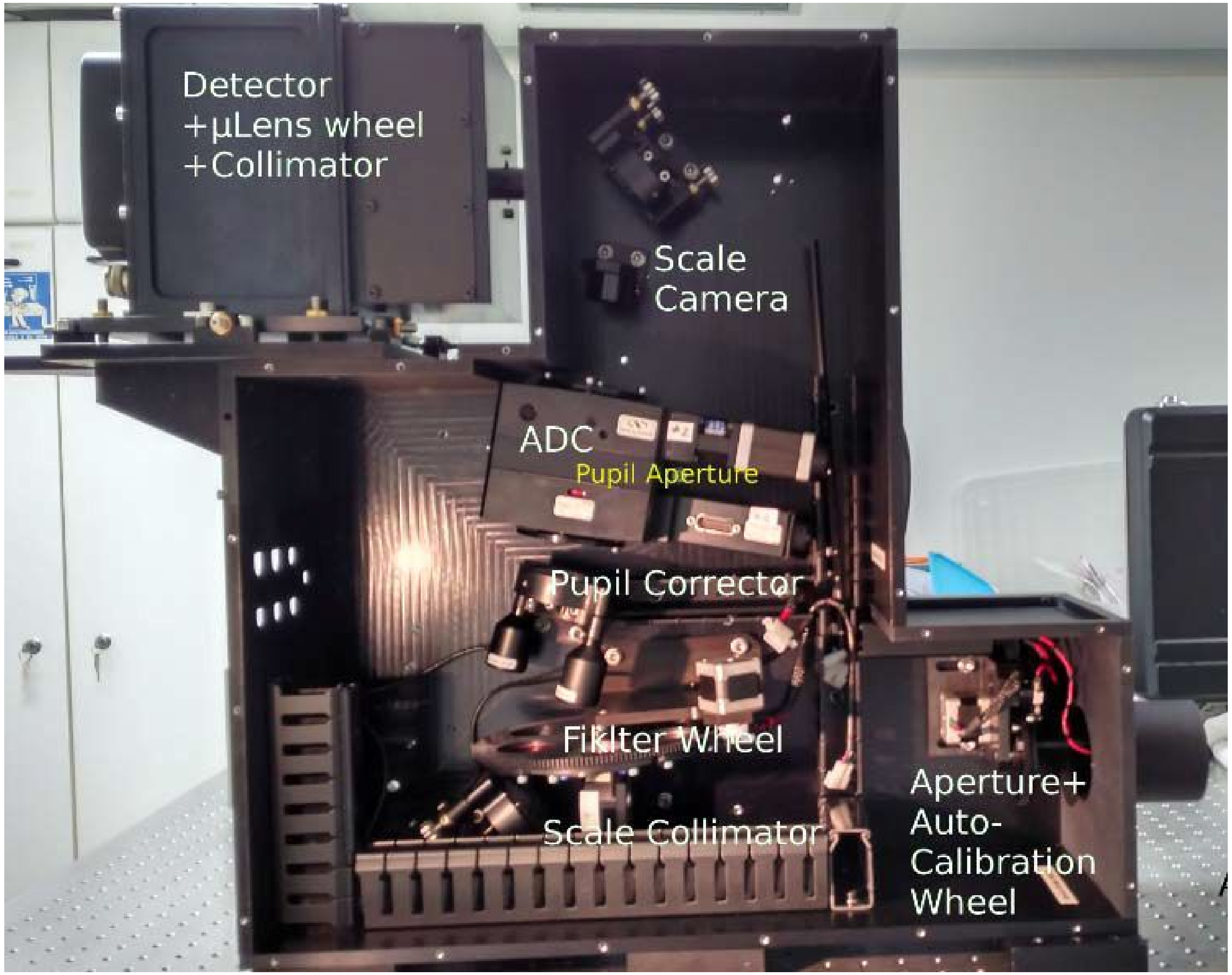
Calibration system



Test Camera

WFS

GTCAO WaveFront Sensor



Shack-Hartmann WFS visible (0.47-1 µm)

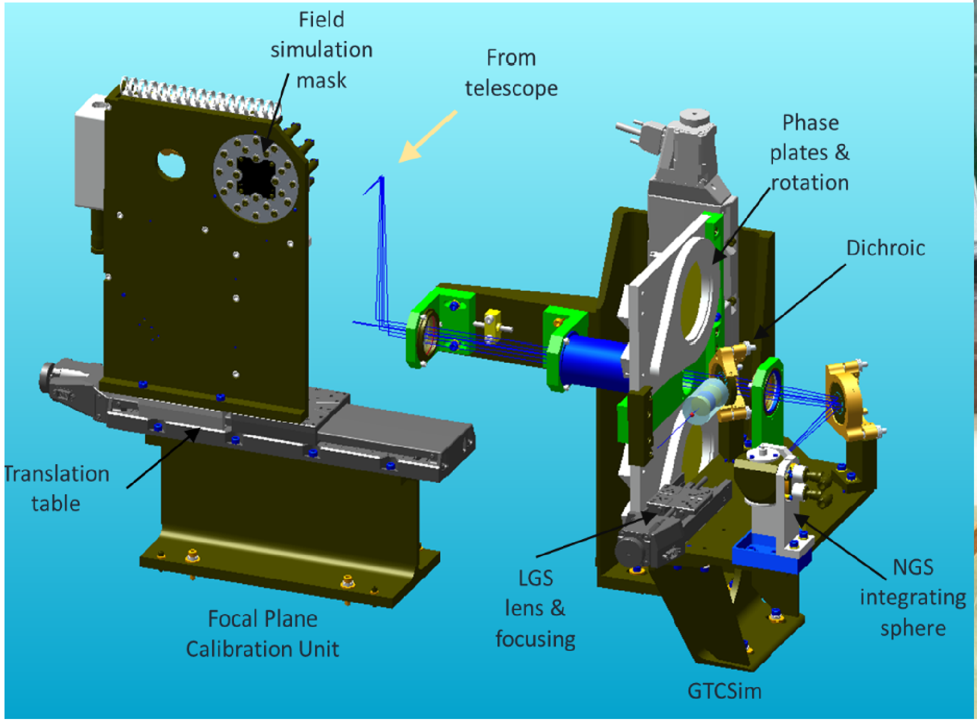
- High order 20 x 20 subap, 3.5” FOV
- Low order 2 x 2 subap for LGS system

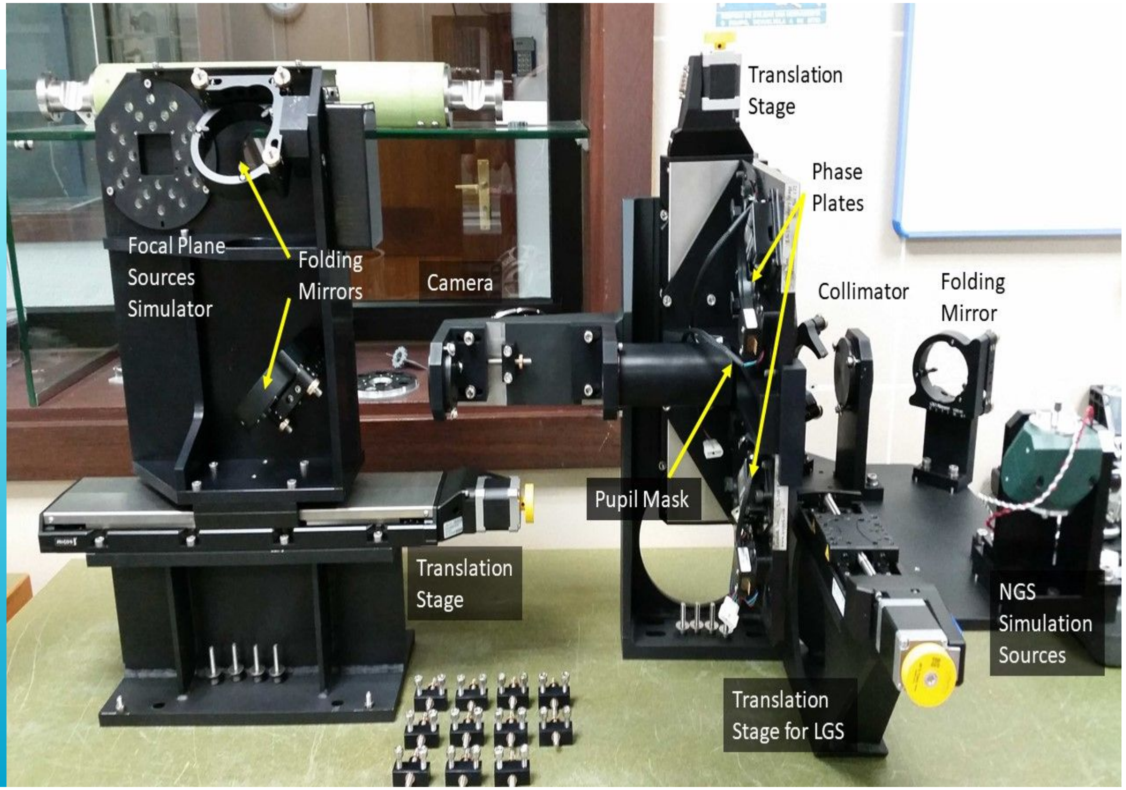
FOV of 2 arcmin (XYZ-translator table)

OCAM camera: e2v CCD220, EMCCD detector 240x240 pix (0.35”/pix)

GTCAO calibration system: GTCSim and FieldSim

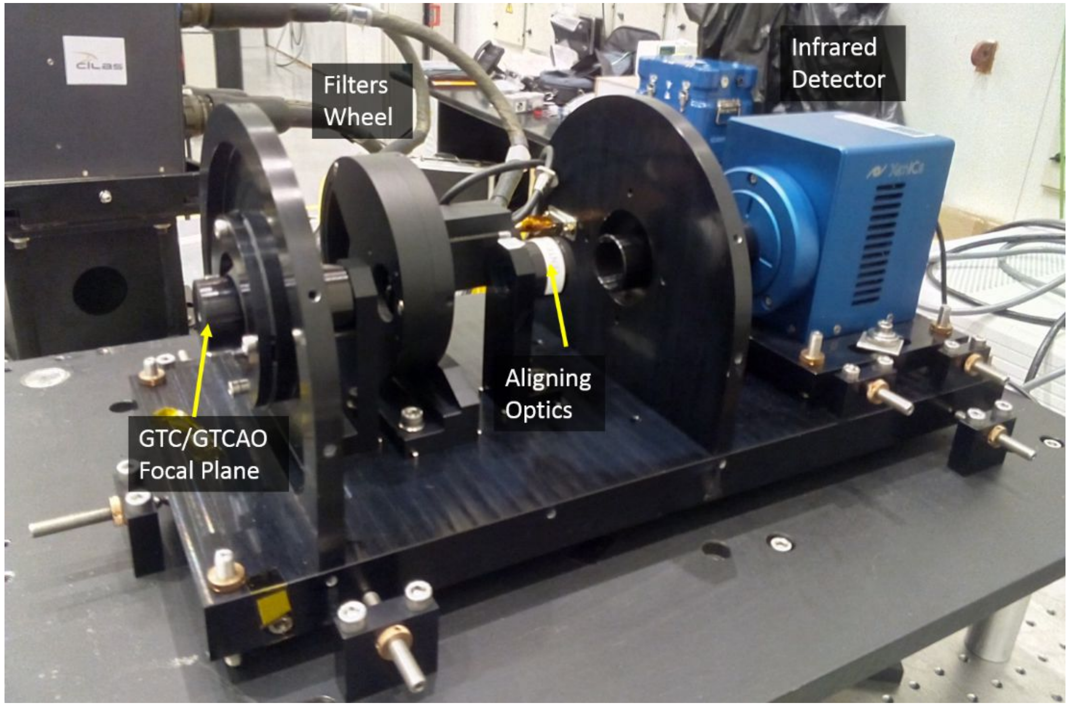
- GTC and Turbulence Simulator
  - NGS Simulator (VIS and IR)
  - LGS Simulator
  - Phase Screen
  - Aperture Simulator
- Focal Plane Unit
  - Selects Telescope or Simulator beam
  - Field Simulator
  - IR and VIS sources across the 2’ FOV
  - Insertion Mirrors for Simulator



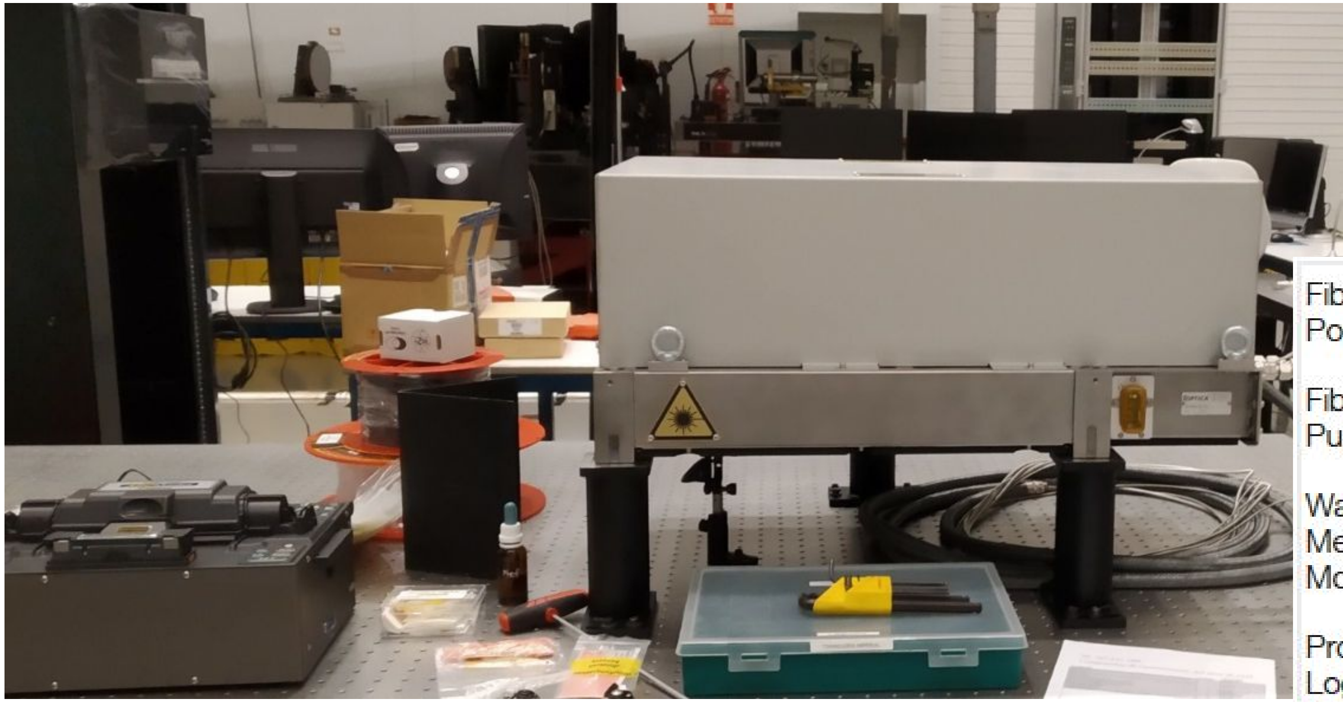


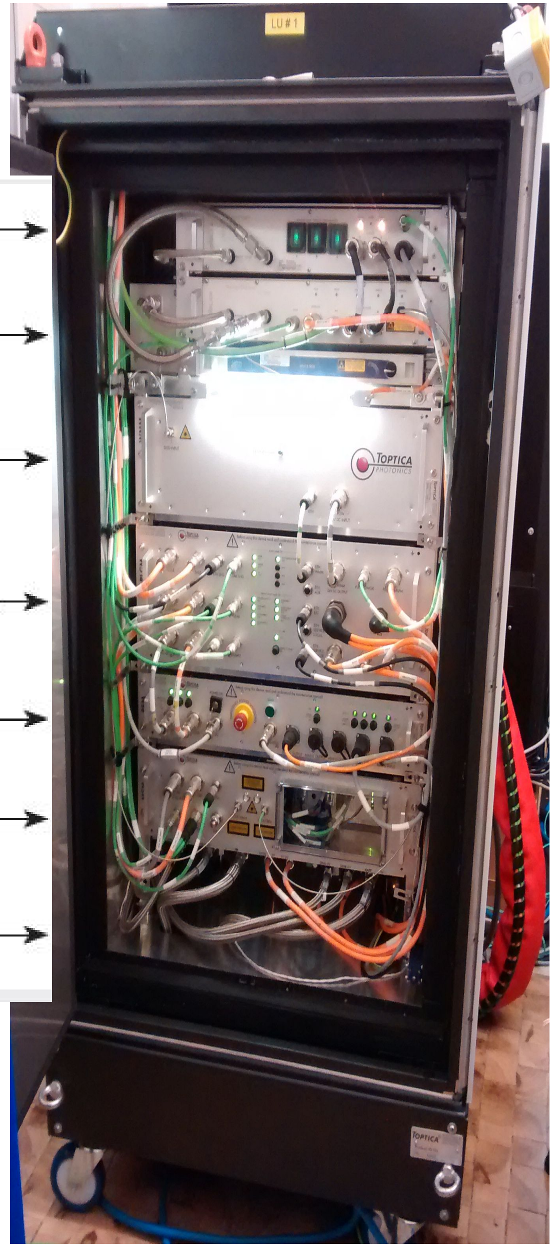
GTCAO calibration system: TestCam

- Test Camera based on a commercial InGaAs Xenics camera
- 320x256 pixels, 30 mm/pixel
- Plate scale 0.011 arcsec/pixel

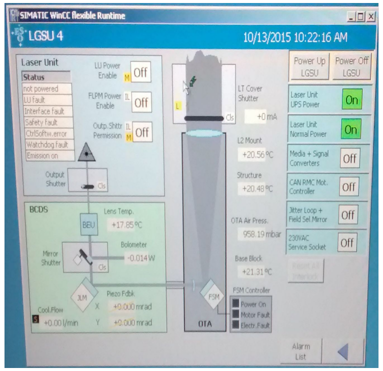


GTCAO Toptica laser in the lab





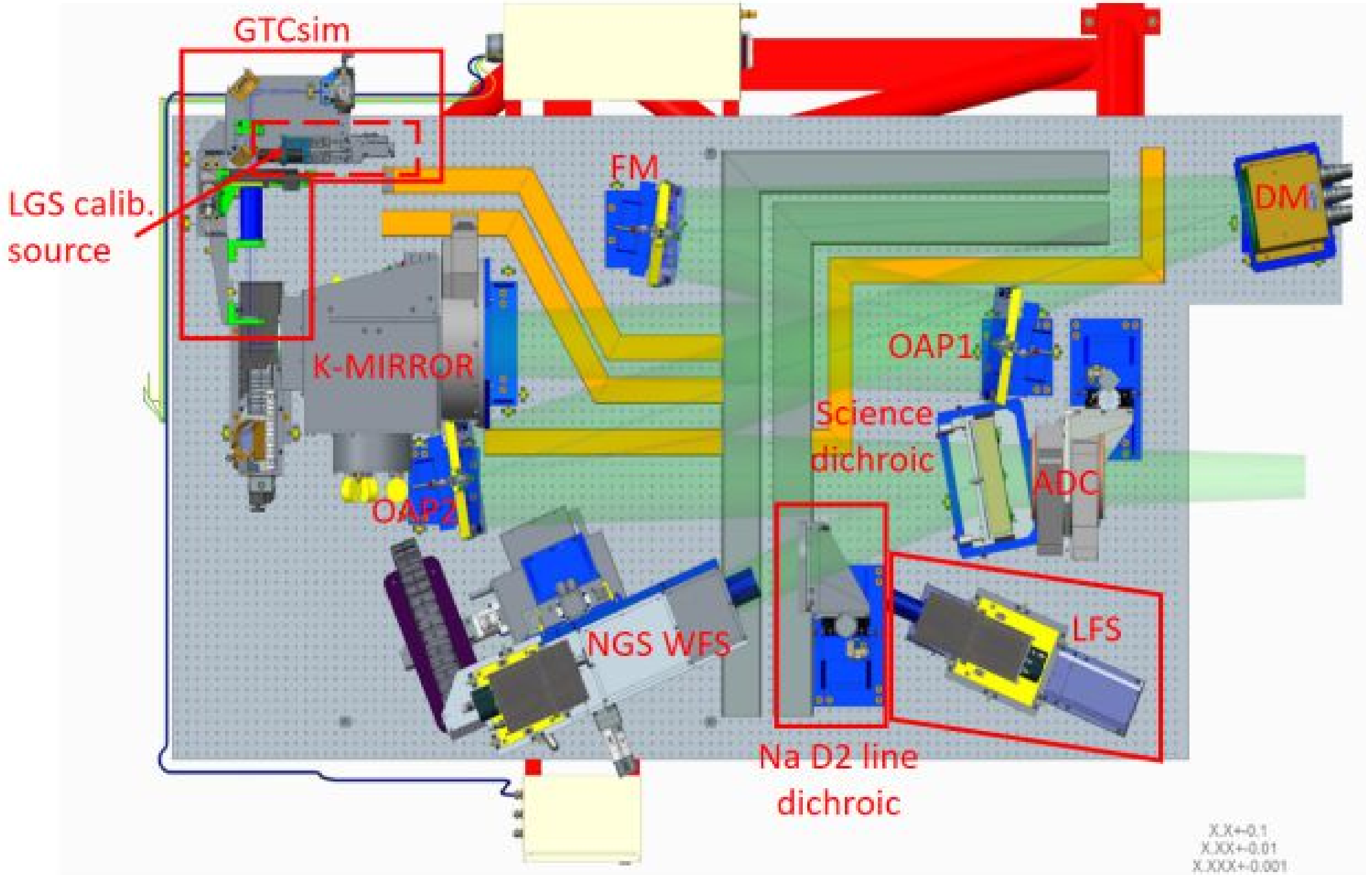
- Fiber Laser Power Supply
- Fiber Laser Pump Module
- Wavelength Measurement Module
- Programmable Logic Controller Module
- Power Entry Module
- Main / Seed Laser Module
- Hydraulic Module



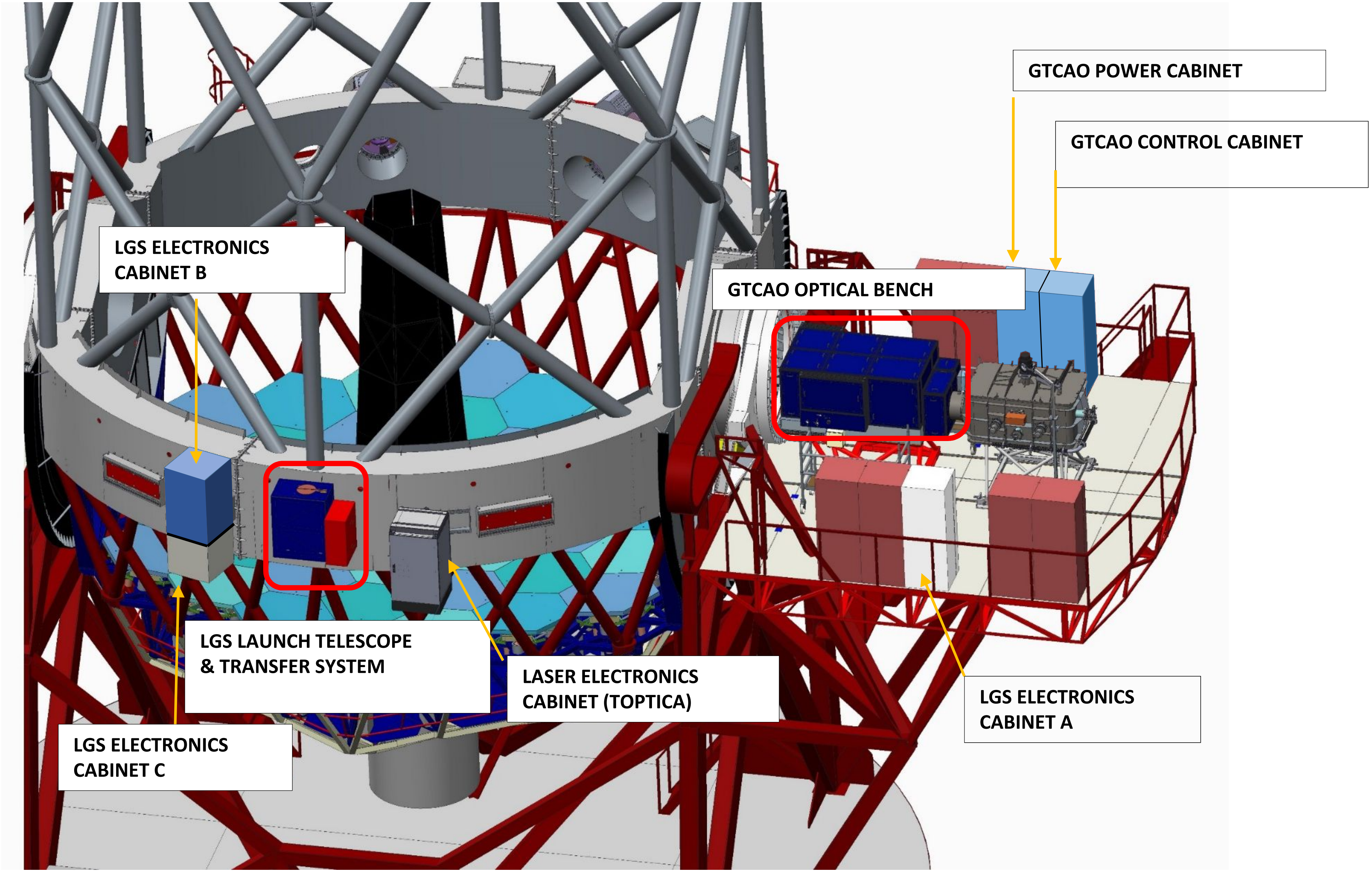
Toptica Laser SW

GTCAO Laser Guide Star WFS

- Shack Hartmann WFS in Fried geometry (20x20 subapertures)
- Focus range: 80-200 km
- Plate scale: 0.6”/pix (FOV 7.2”)
- OCAM2 camera 240x240 pix
- LWS dichroic in reflection: Na D2 (589±6nm)



GTCAO-LGS system location at GTC



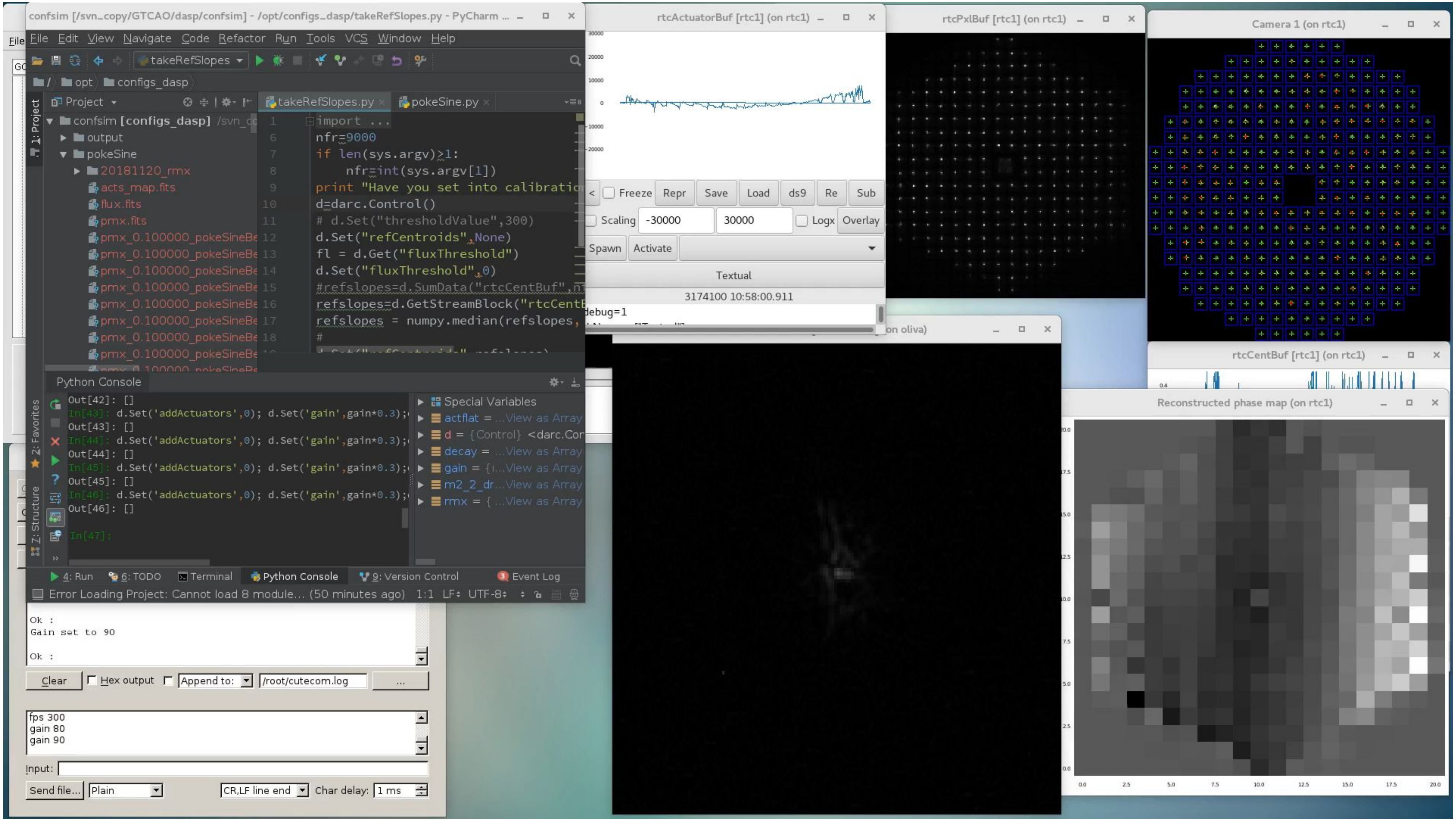
Closing the loop in the lab

Tests Configuration:

- Laboratory: air-conditioning on, GTCAO without enclosure (local turbulence)
- WFC: No rotation
- Test Camera (science focus): H band filter
- WFS:
  - High order lenslet array (20x20) with mask
  - OCAM2 frame rate from 200 Hz to 1000 Hz
  - Wide band filter (500 nm to 900 nm)
- Calibration System:
  - Visible and IR NGS in "bright star" configuration, on axis
  - Turbulence: r_0=20 cm good seeing, r_0=7 cm bad seeing, wind speed= 10 m/s)
  - GTC Pupil
- RTC:
  - DARC, Regularized Least Squares algorithm
  - Controller: simple integrator

GTCAO & LGS

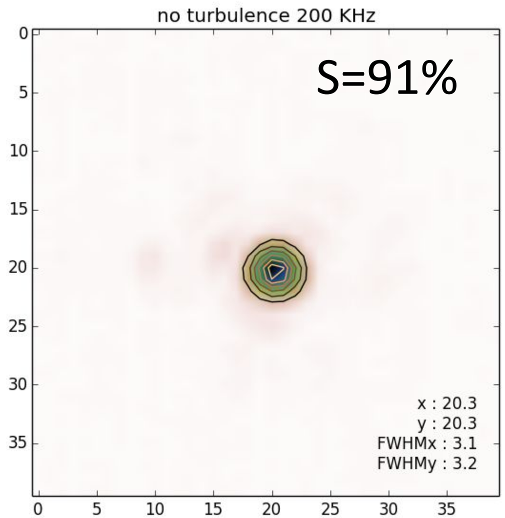
Closing the loop in the lab



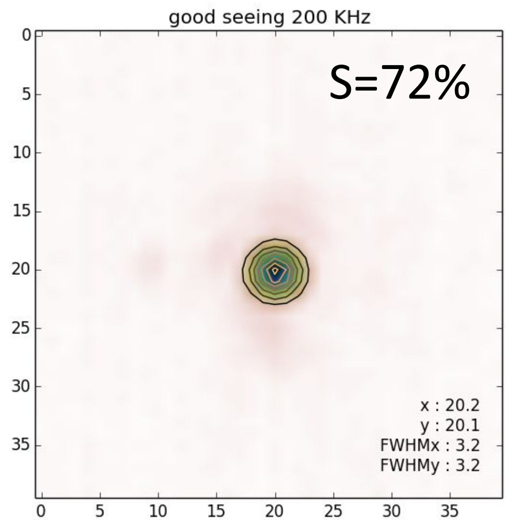
Closing the loop in the lab: measured Strehl

1. compute normalized theoretical diffraction-limited PSF with hexagonal pupil. Find maximum
2. subtract lab image background
3. normalize lab measured PSF
4. find maximum of normalized measured PSF (Gaussian fitting)
5. divide maximum of normalized lab PSF by maximum of normalized theoretical diffraction-limited PSF

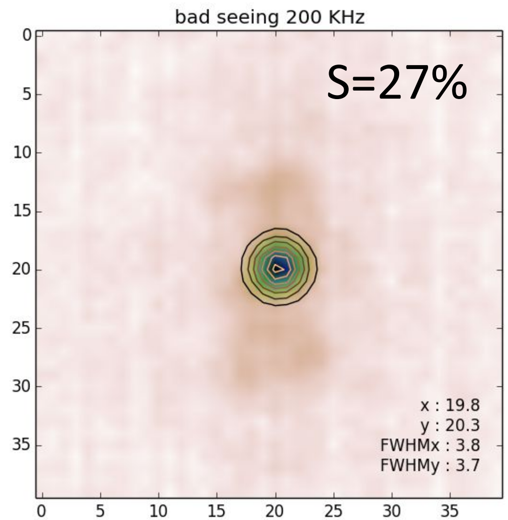
No seeing



Good seeing

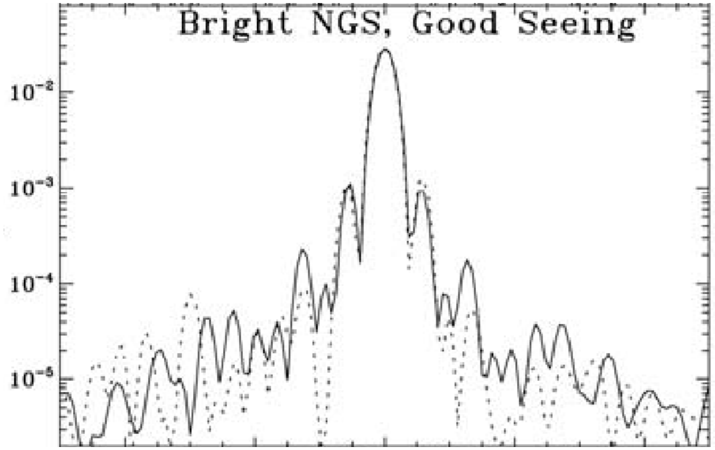


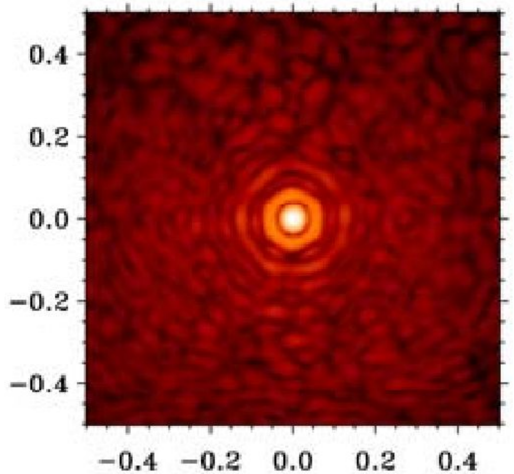
Bad seeing



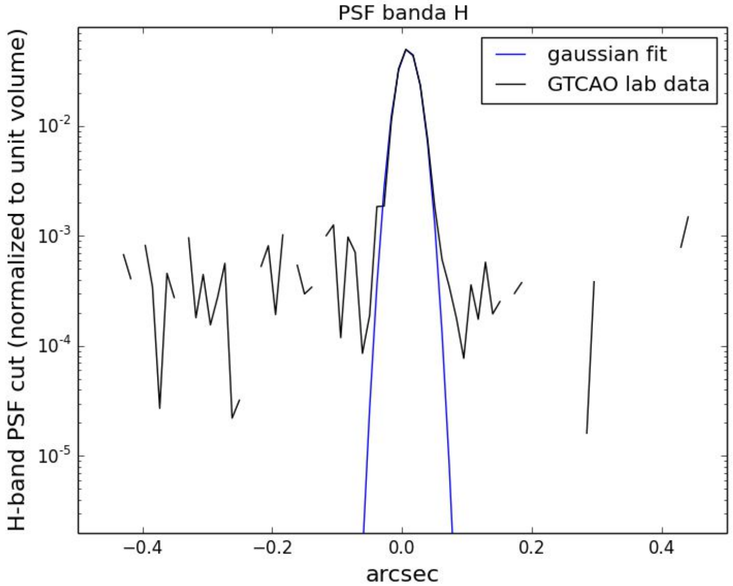
Closing the loop in the lab: measured PSF

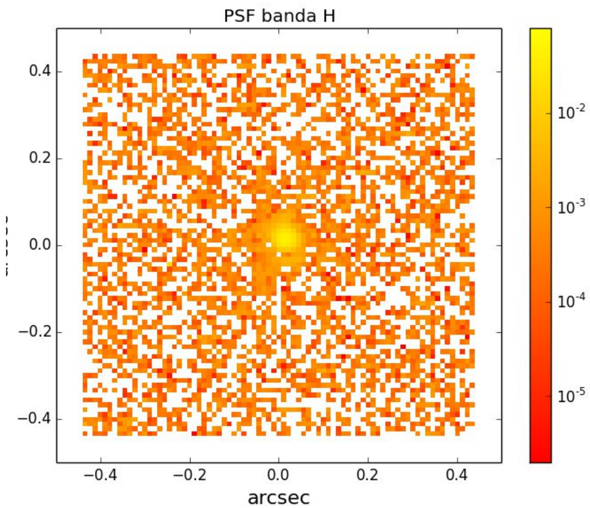
Bright star, r_0=20 cm, close loop, H band





simulated PSF

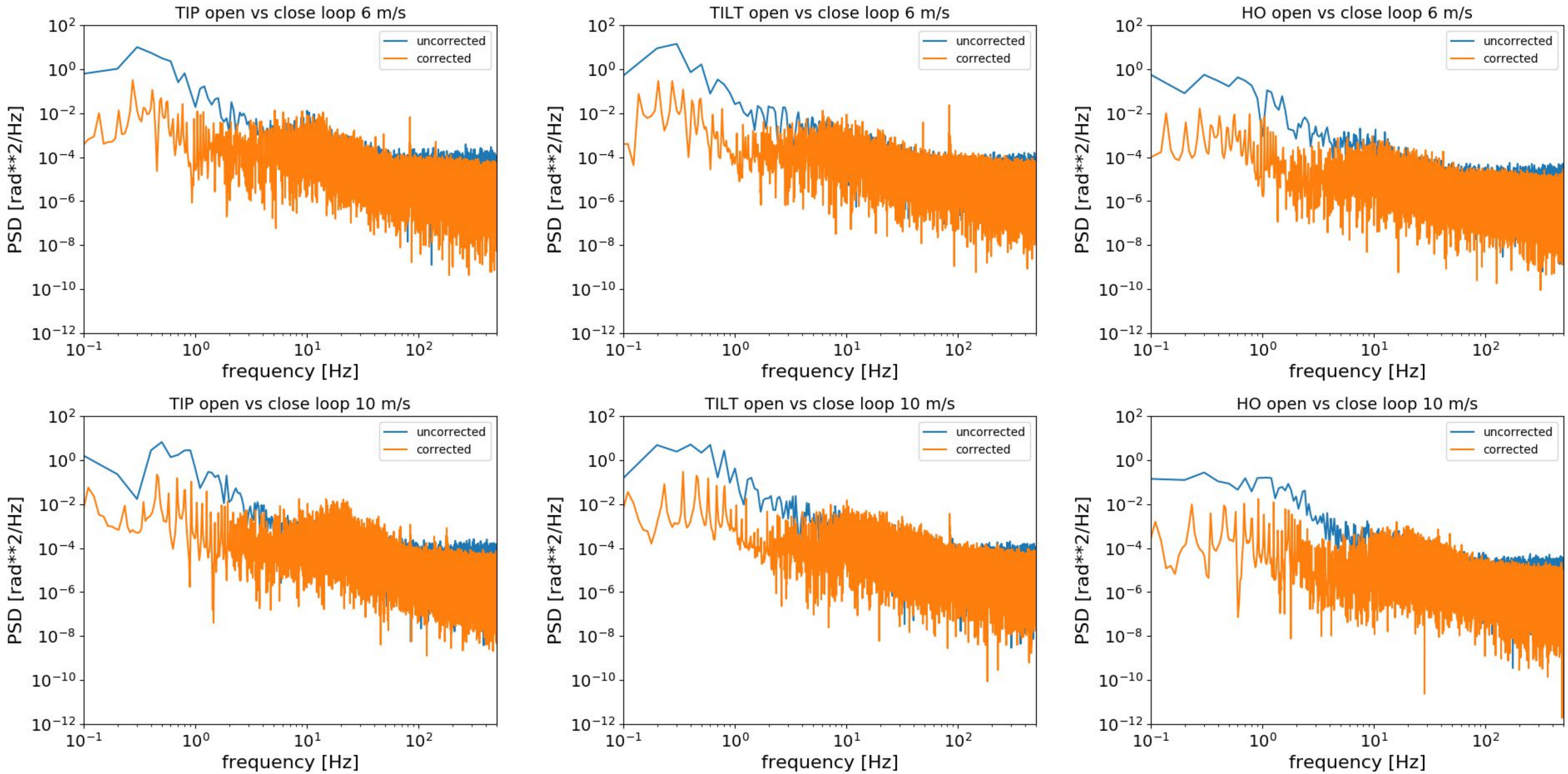




GTCAO TestCam PSF

Closing the loop in the lab: PSD

- bright star, r_0=20 cm, 1000fps
- Power Spectral Density of the Tip, the Tilt and the higher Zernike modes till mode 40
- rejection of 2 orders of magnitude of the Tip and Tilt, and 3 orders of magnitude of the higher Zernike modes



But the lab is not the sky….

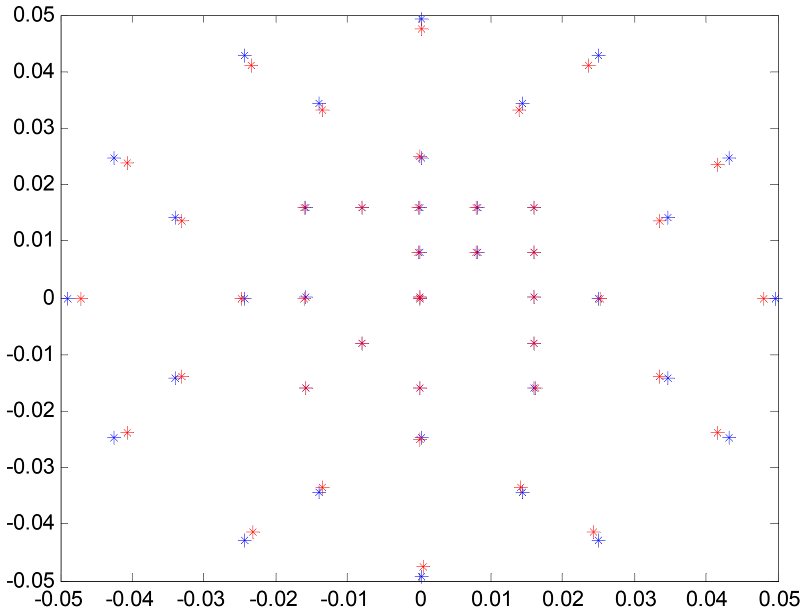
… "unfortunately", the Earth rotates. When tracking a science object a lot of mechanisms in an AO system have to move following the rotation of the Earth. We need to characterize and calibrate them to avoid NCPAs.

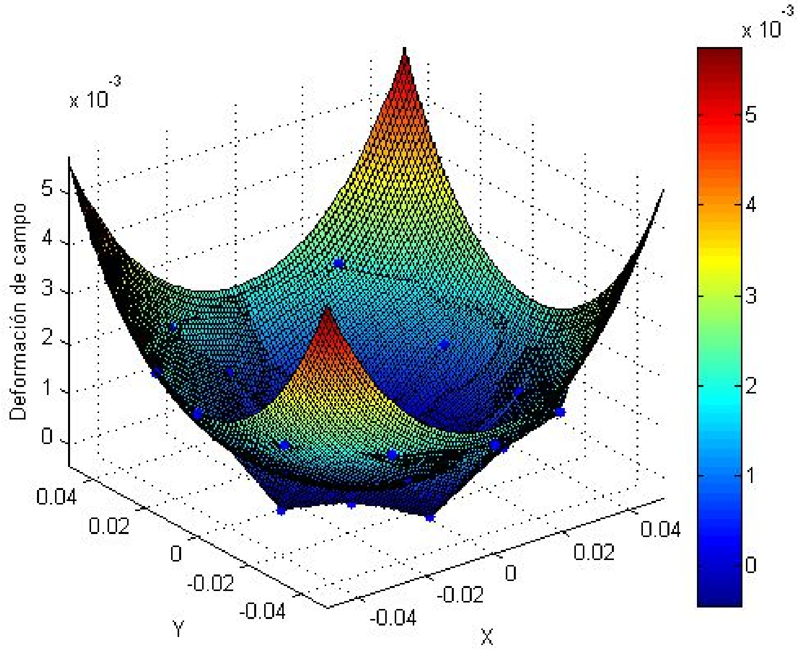
- FOV-related issues (field distortion, pupil displacement): calibration of the WFS pupil positioner
- Characterization and calibration of the XYZ WFS table
- Pupil rotation and characterization of the K-system
- Chromatic aberrations: system calibration for different filters and characterization of the ADC of the WFS
- NCPAs

FOV calibrations

The system suffers the classical barrel distortion: if not calibrated it would add a NCP TT to the science arm

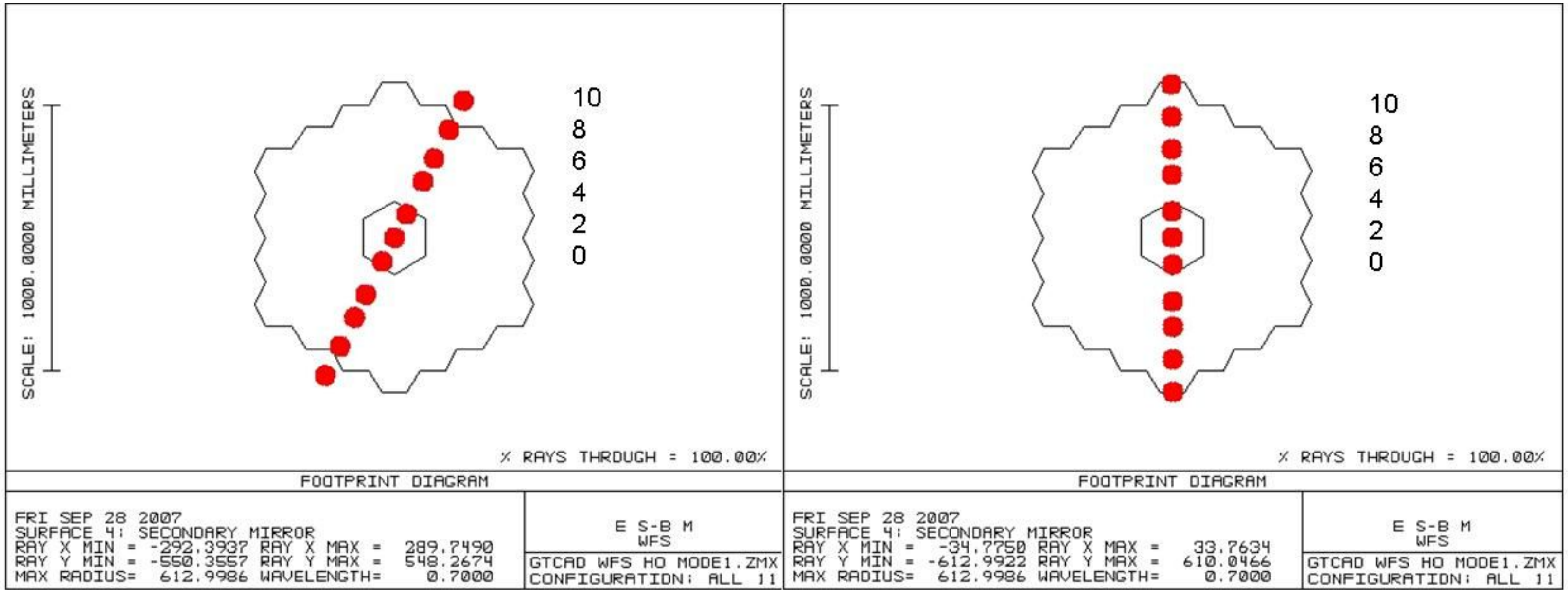
- the distortion is characterized using the field LEDs of the FPU
- WFS-X and WFS-Y have to be adjusted when NGS is off-axis





Pupil rotation and characterization of the K-system

The serrated shape of the secondary mirror rotates on the lenslet array that samples the pupil. This introduces partial vignetting of some apertures in the HOWFS, or light variations in the illumination area of the LOWFS.



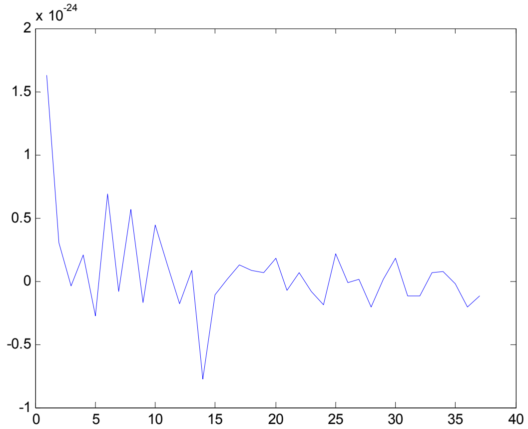
Thanks to the central pinhole at the FPU, we have computed the rmx of the complete circular pupil. A threshold is set and the subapertures that are illuminated below it are discarded.

Chromatic aberrations

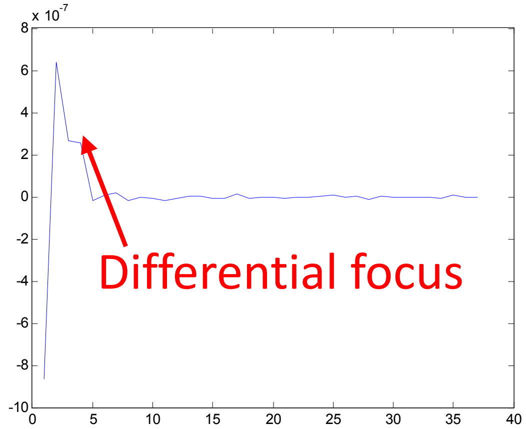
"Achromaticity is fiction"

We check the behavior of the system for different wavelengths with different filters.

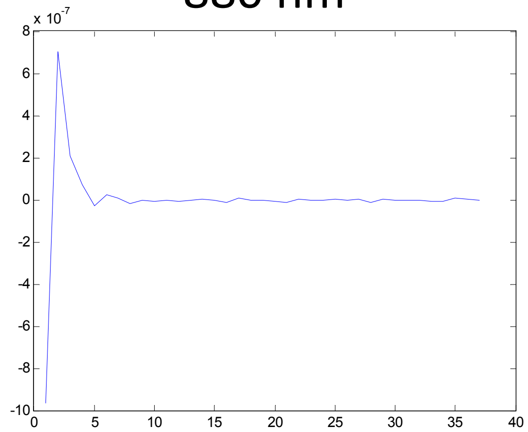
window
400-900 nm



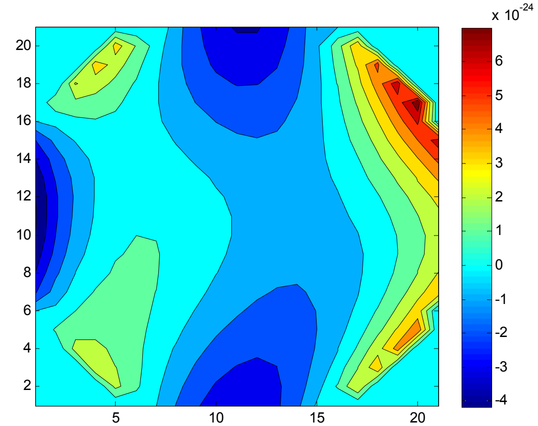
Filter
480 nm



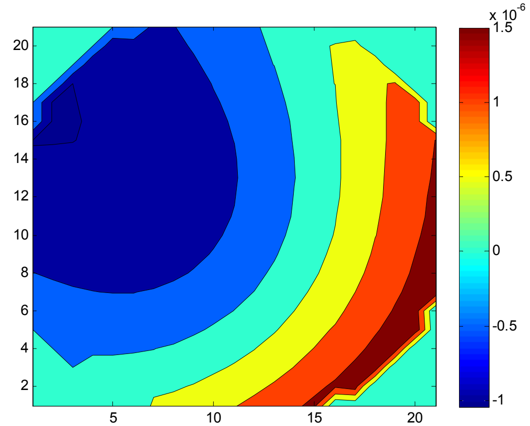
Filter
880 nm



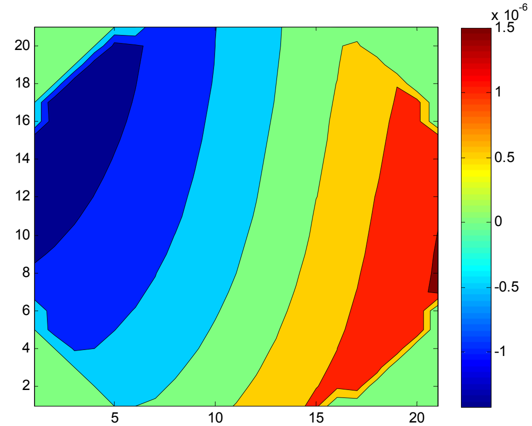
Zernike modes



Zernike modes



Zernike modes



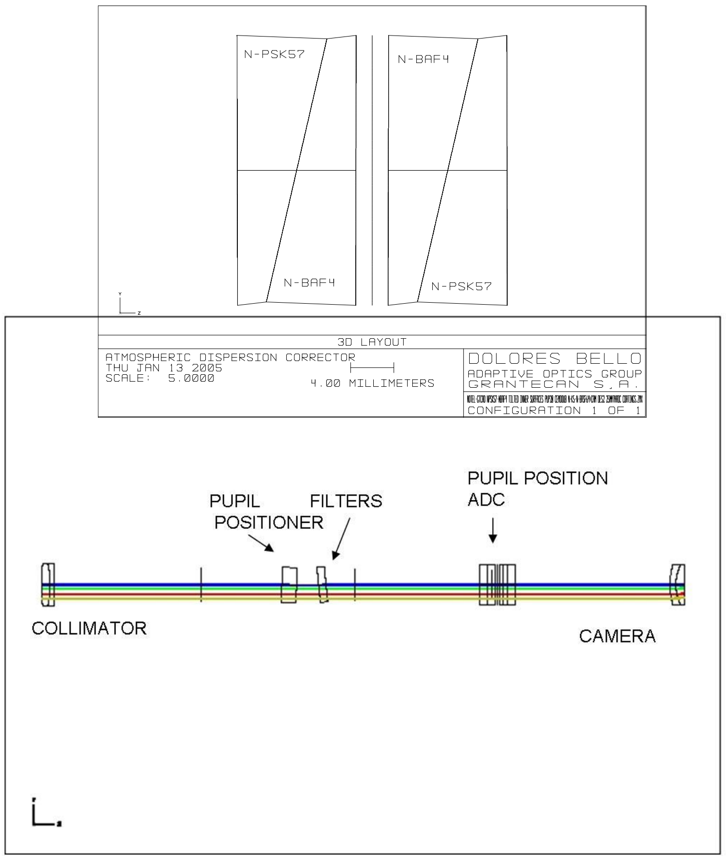
WFS Atmospheric Dispersion Corrector

From the GTCAO WFS Optical Design doc:

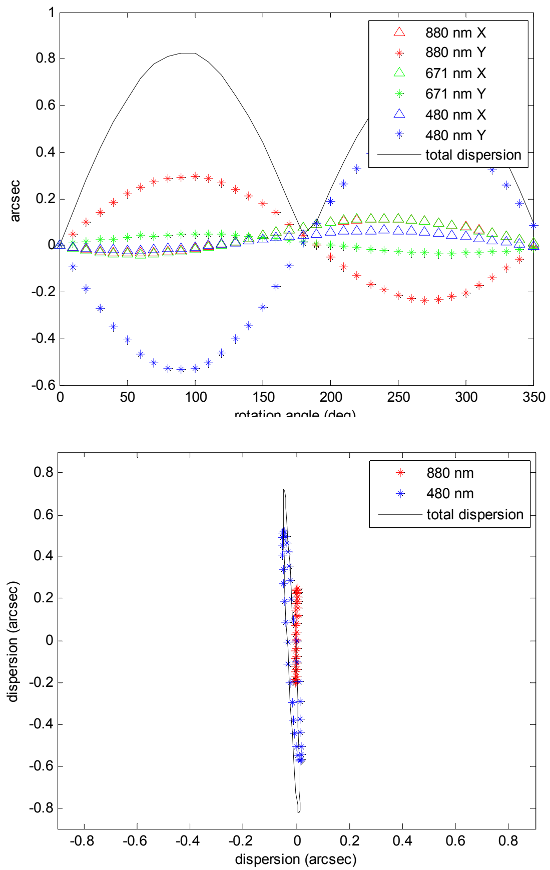
"The ADC is designed to correct for the atmospheric dispersion between 470 and 900 nm and to give null angular deviation at 665 nm. It will not introduce significant chromatic aberrations at the pupil. The ADC is in the collimated beam and ensures that it will not introduce aberrations."

never trust this kind of statement !!!

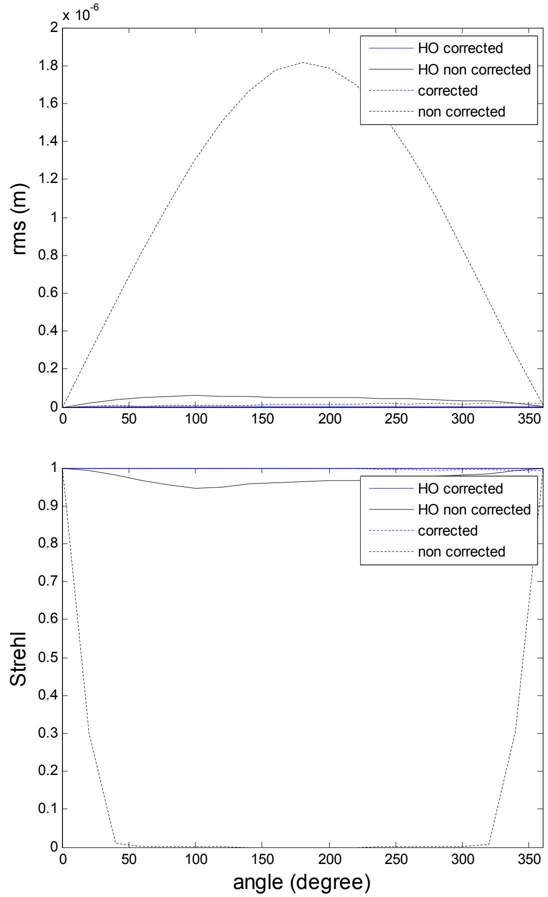
ADC optical layout



ADC dispersion calibration



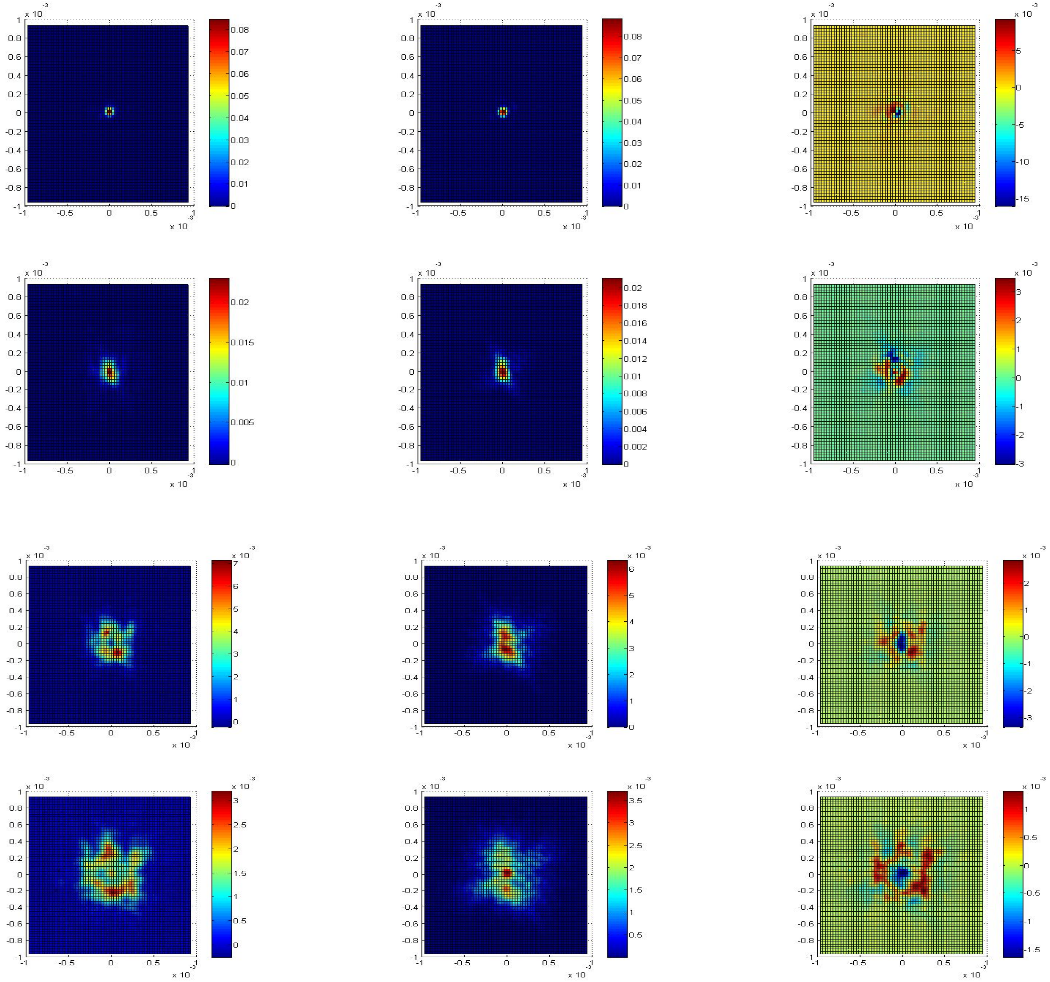
ADC aberrations characterization

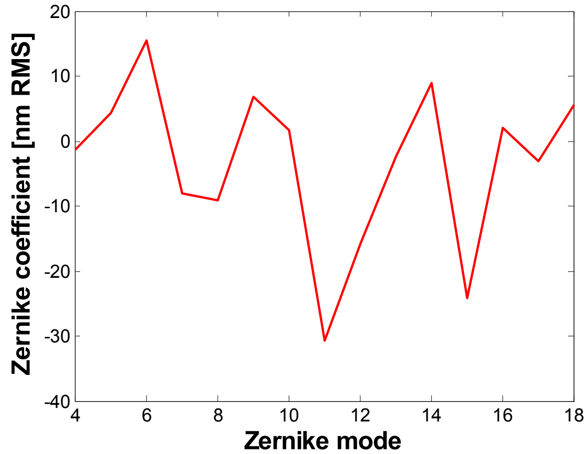


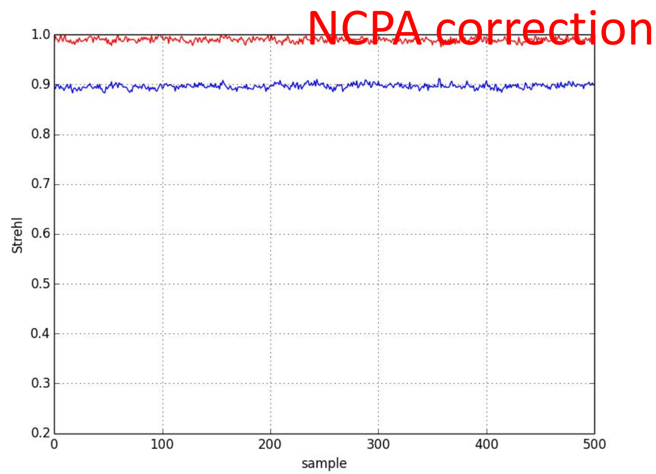
NCPAs

Diversity images commanding defocus in the DM
CL Strehl changed from 0.88 to 0.98 @ 1.6 micron.
Retrieved Zernike coefficients result in 49.8 nm wavefront rms.

TC Reconstructed Difference







GTCAO and LGS schedule

MILESTONE	DATE
GTCAO AIV completed in lab – Acceptance tests	November 2021 (TBC with GRANTECAN)
GTCAO commisioning at GTC	S1 2022 (TBC with GRANTECAN)
Preliminary Design LGS	PDR May 2019
Laser system acceptance at IAC	December 2019
Detailed Design Laser Launch Telescope	April 2021
Detailed Design LGS system	T1 2022
Laser Launch Telescope acceptance at IAC	S1 2022
LGS Subsystems integration in laboratory	S2 2022
LGS AIV completed in lab – Acceptance tests	S1 2023
LGS commisioning at GTC	S2 2023

RISK: re-coating of the mirrors (at least OAPs) is strongly recommended before going to telescope. This may cause a delay of up to 4 months

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