

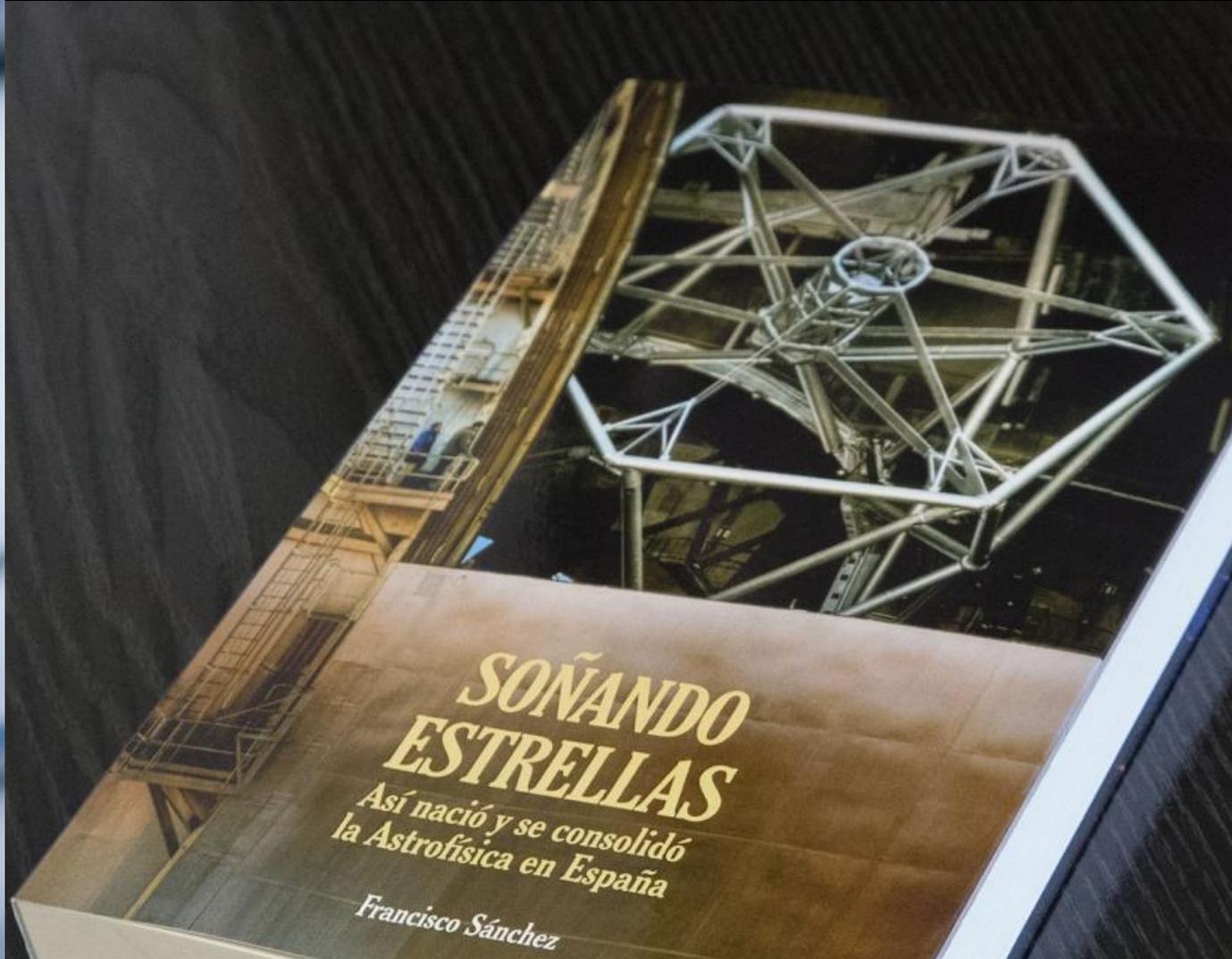
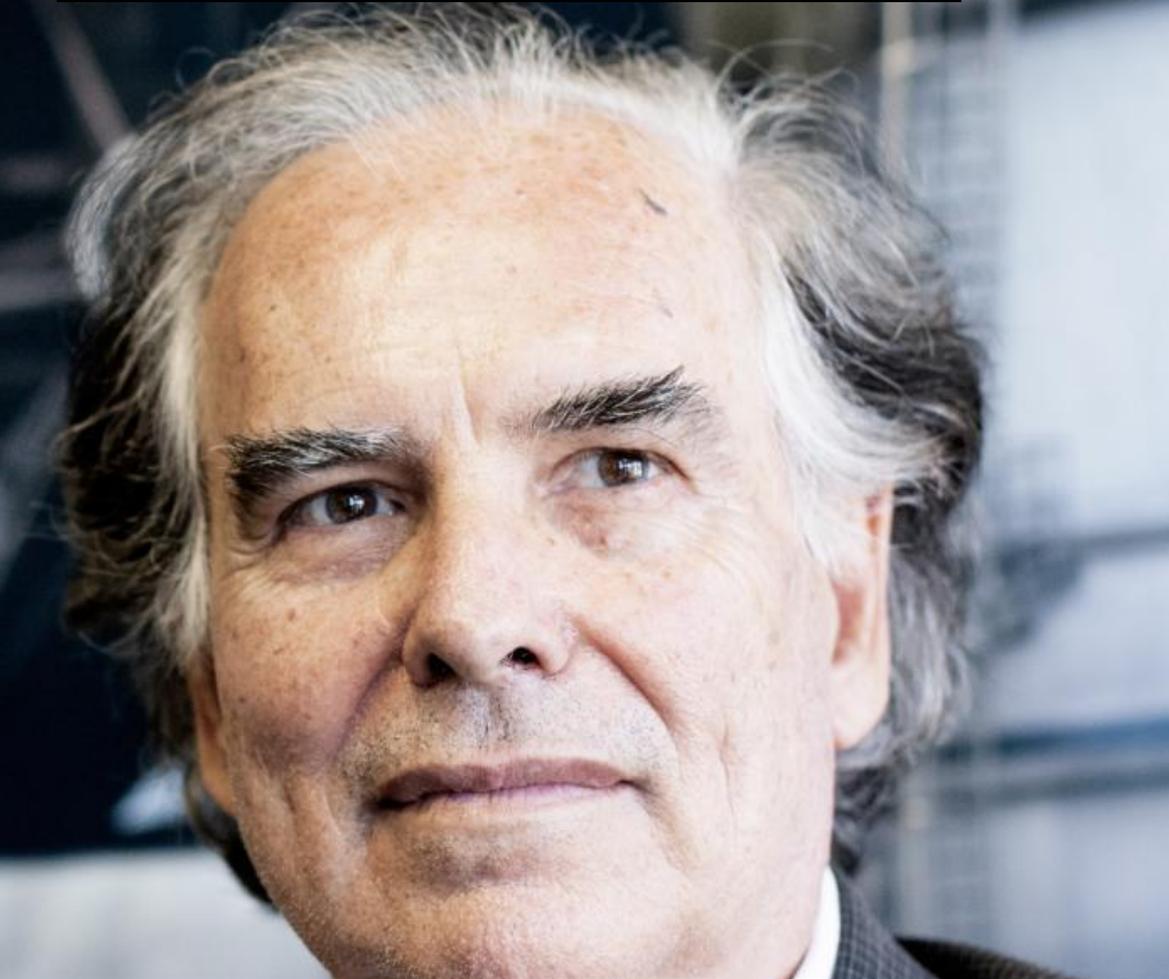
From Keck to GTC

Romano L.M. Corradi

Gran Telescopio Canarias



Francisco Sánchez (1936-2025)



October 1994 (Tenerife): **Francisco Sánchez, Massimo Tarenghi, Jerry Nelson, Masanori Iye & Matt Mountain** recommended to opt for a **segmented** mirror for the GTC project
“Esta reunión había dado carpetazo a los espejos monolíticos”
(This meeting had definitely shelved the monolithic mirrors...)

The GTC

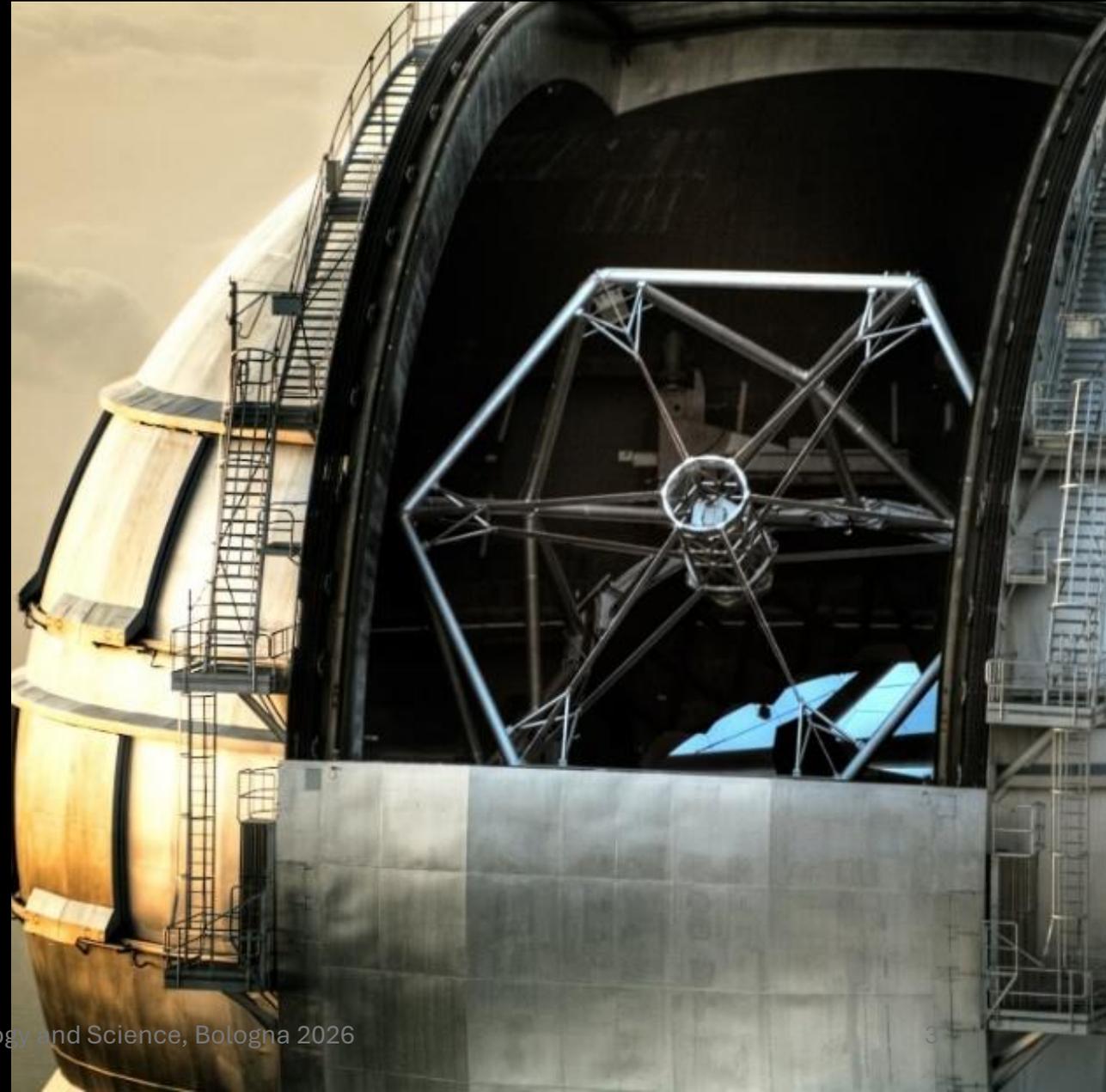
GTC is an initiative of the Instituto de Astrofísica de Canarias
Funded by Spain (90%), México (5%), and the University of
Florida (2.5-5%). China in the process of becoming a new
member

Belongs to the set of Spanish *Unique Scientific & Technical
Infrastructures (ICTS)*

Project office implemented in 1994, construction started in
2000, first light in 2007, science operations since 2009

GRANTECAN is the company that built, operates, maintains
and upgrades GTC. It presently employs 80 people

**Mission: facilitate world-class observations to a wide
scientific community → versatility**



The GTC

Design inspired by Keck

10.4 m alt-az , Ritchey-Chrétien configuration: collecting area 73 m², focal length 169.9 m → plate scale 1.21 arcsec mm⁻¹

- M1: segmented aluminium-coated
- M2: aluminium-coated beryllium/nickel. 5 active degrees of freedom → alignment (hexapode), chopping / AO tip-tilt corrections (chopper). Provides aperture stop.
- M3: aluminium-coated Zerodur flat elliptical

Telescope:

- ~500 electromagnetic axes; moving mass 400 tons

Dome:

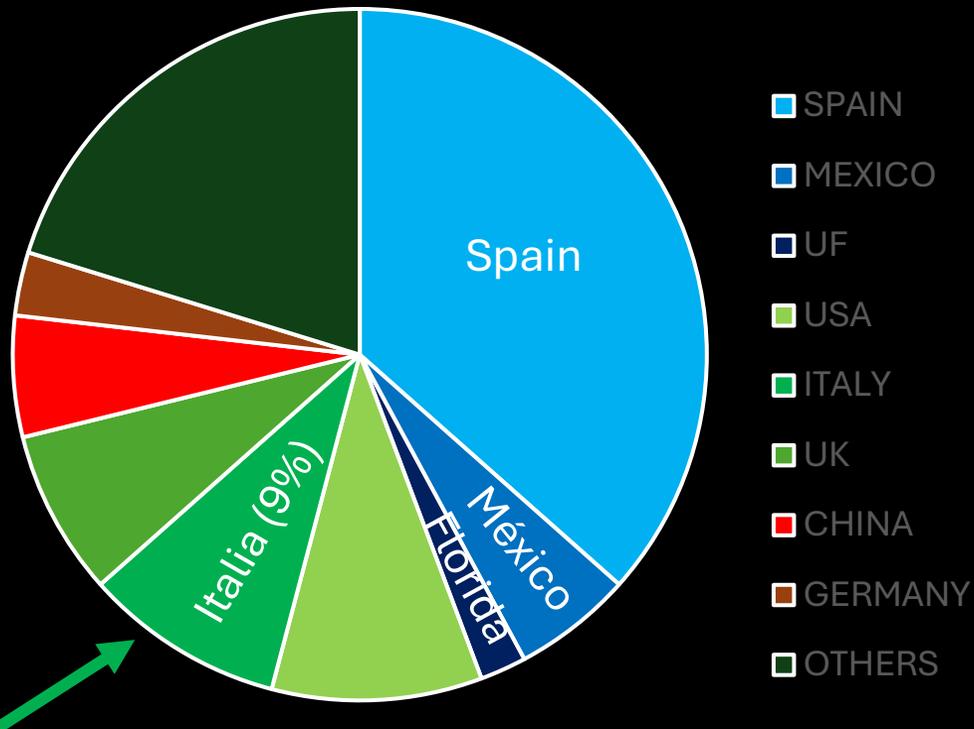
- Ø35m; 13m opening size; 450 tons



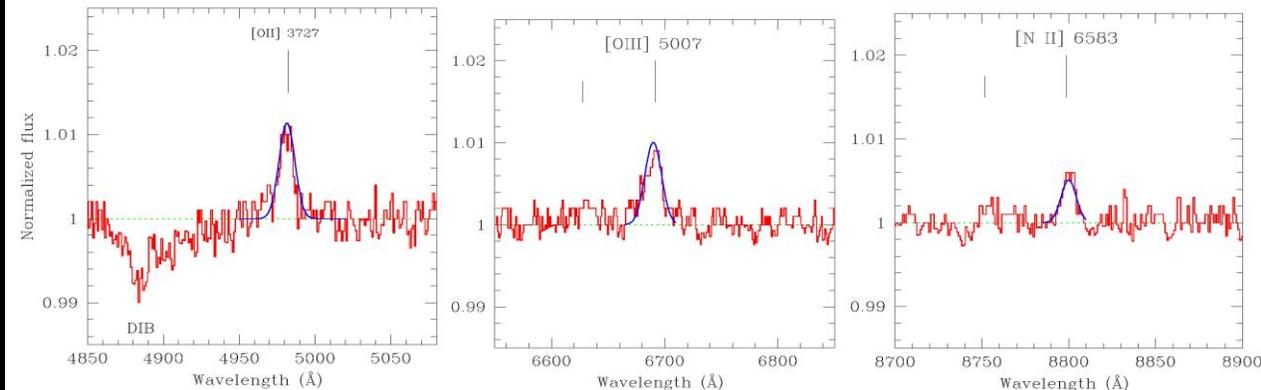
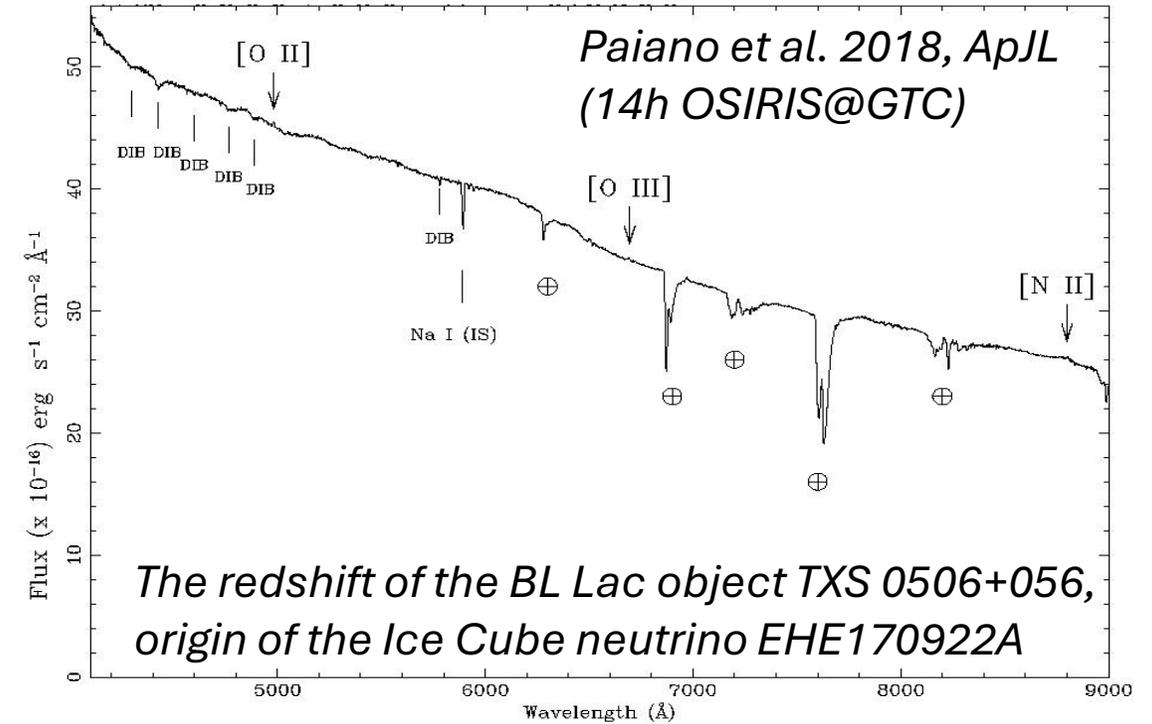
The GTC

Science operations:

- **>95% queue-service mode** → maximum use of available time as it adapts in real-time to weather conditions → ~1800 hours /yr of science observations with as-required quality
- 1113 refereed papers published (123 in 2025), 45 in Nature/Science

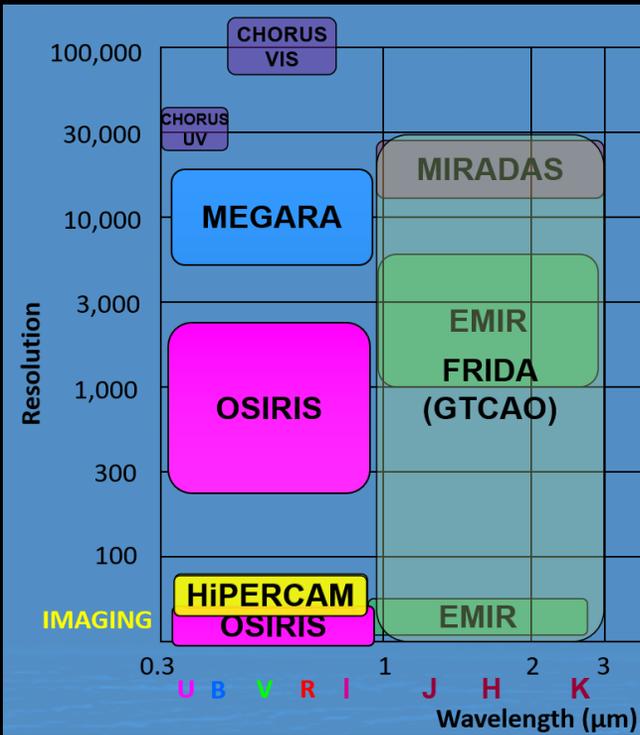


R. Corradi GTC



Mosaic Telescopes Technology and Science, Bologna 2026

GTC instrumentation



COALA (Technical)

GTCAO + 2026 FRIDA (NIR)

ima 40"x40"
 IFU (0.6"x 0.64", 1.2"x 1.28", 2.4"x 2.56")
 R = 1.000-32.000

2027 CHORUS-UV

Single-fibre spectrograph $\phi 1.2''$
 R~30.000 310-420 nm

2026 MIRADAS (NIR)

MOS (x12) + SPECPOL
 12 x (3.7"x1.2")
 R = 20.000

2029 CHORUS-VIS

Single-fibre spectrograph $\phi 1.2''$
 R~110.000 420-780 nm

HiPERCAM (VIS)
Visitor instrument

fast ima ugriz
 (simultaneous)
 2.8' x 1.4'

EMIR+ (NIR)

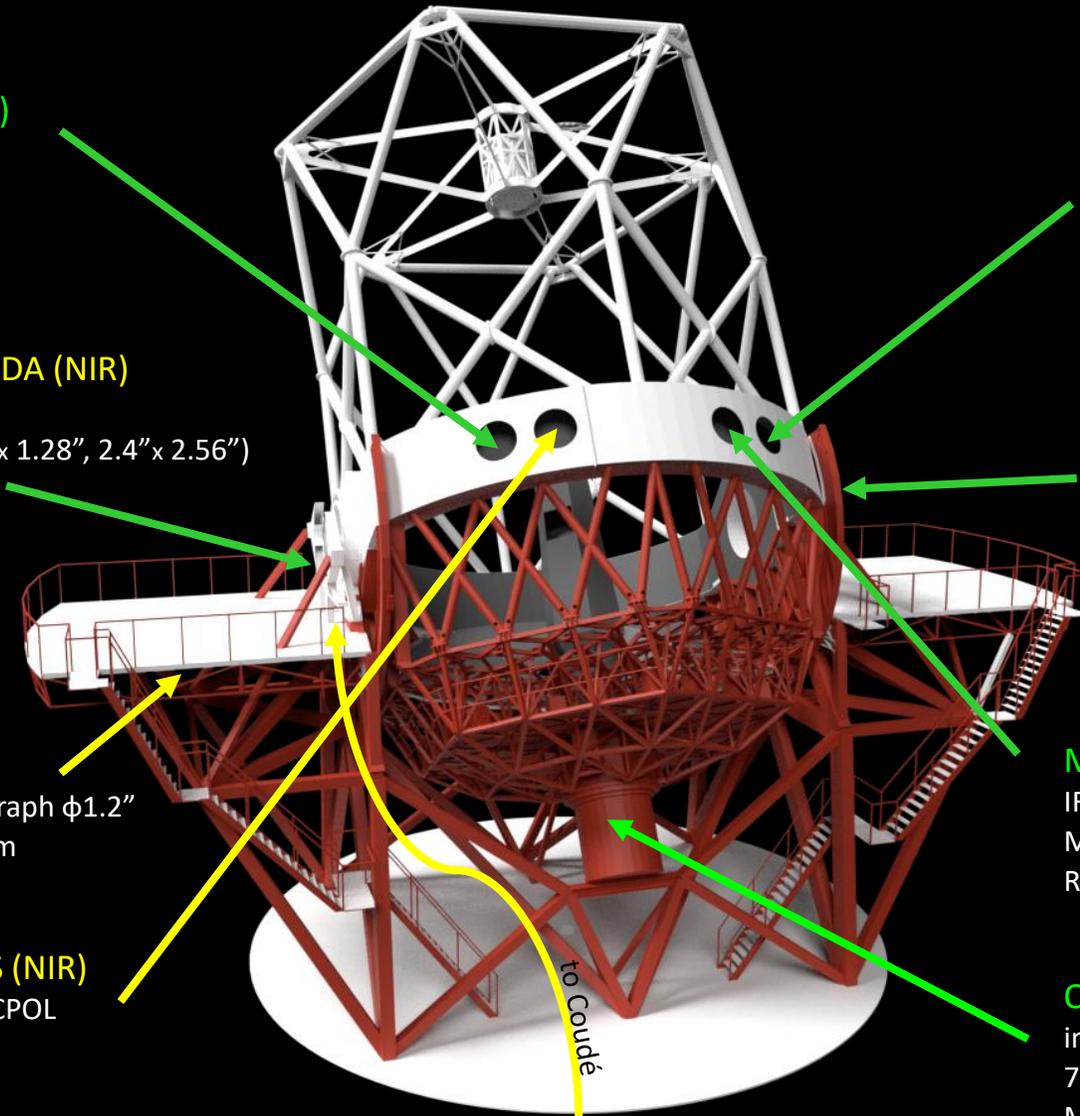
ima + LSS + MOS (x 15-20)
 6.67' x 6.67'
 R=1.000, 4.000, 5.000.

MEGARA (VIS)

IFU (12.5" x 11.3")
 MOS (3.5' x 3.5', x92)
 R=5.500, 10.000, 20.000.

OSIRIS+ (VIS)

ima, LSS, MOS (x 30-40)
 7.8' x 7.8'
 MAAT IFU (10" x 7")
 R=300 - 4.100



Deep

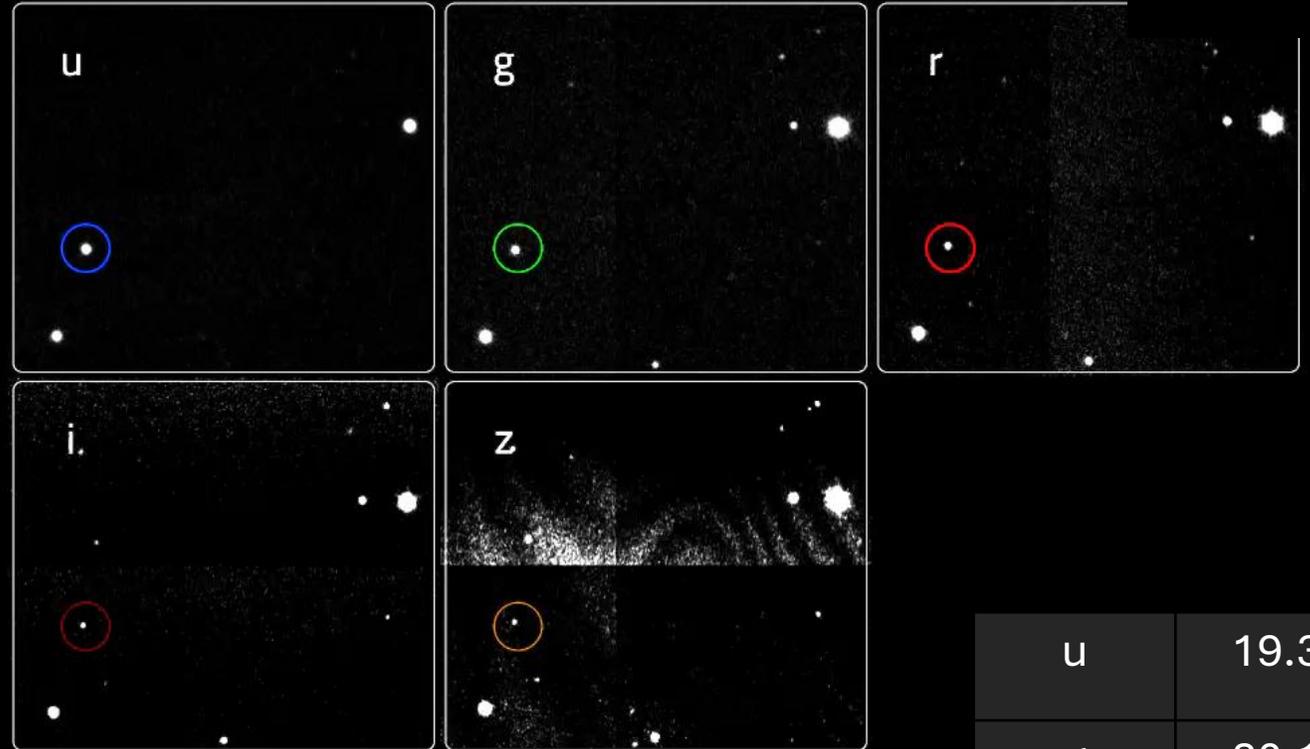
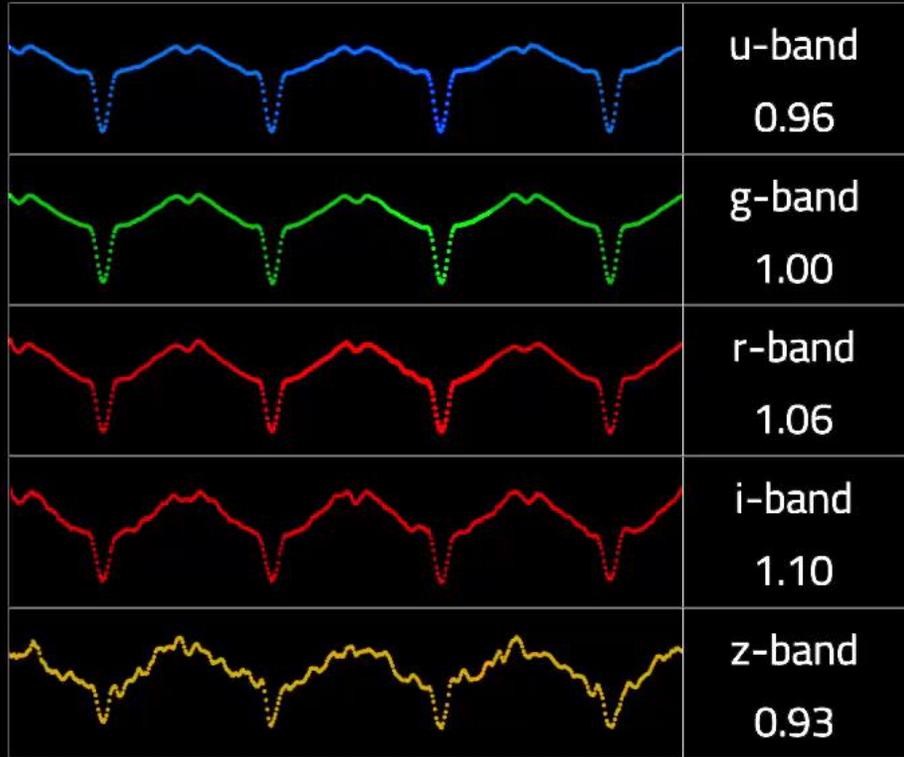
SHARDS (240h OSIRIS narrowband) *P. Pérez González*

The GTC ultra-Deep imaging legacy archive (S. Guerra Arencibia , in prep)

32 mag arcsec⁻² (g', 4h)

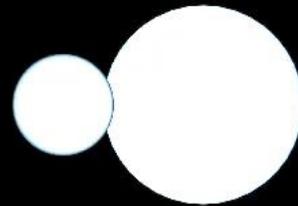
*UGC7321 (OSIRIS+, g+r, 4+4 h)
courtesy Javier Román & Sergio Guerra Arencibia
IAC Low Surface Brightness Science Group (PI: Ignacio Trujillo)*

$P_{orb} = 7$ min eclipsing white dwarf binary



u	19.3
g	20.1
r	20.5
i	20.8

HiPERCAM v. Dhillon



00 m : 03 s

Primary mirror M1

36 hexagonal segments (+6 spares):

- 8 cm thick made of Zerodur™ (Schott), and polished by SAGEM/REOSC with surface error roughness $\leq 15\text{nm rms}$
- Vertex-vertex distance $\sim 1.9\text{m}$
- Gap between segments $< 3\text{mm}$
- Weight $\sim 470\text{ kg/each}$ \rightarrow M1 total weight $\sim 17\text{ ton}$



M1 maintenance

Maintaining a 10.4m segmented mirror is a highly challenging task (frequent & dangerous for people/machine).

- M1 target reflectivity 86%
- M1+M2+M3 target reflectivity 67%
- Periodic CO2 cleaning removes (dry) dust
- Keeping the reflectivity targets requires that each segment is substituted once a year → 3 segments/ month recoated using in-house facility



M1 maintenance

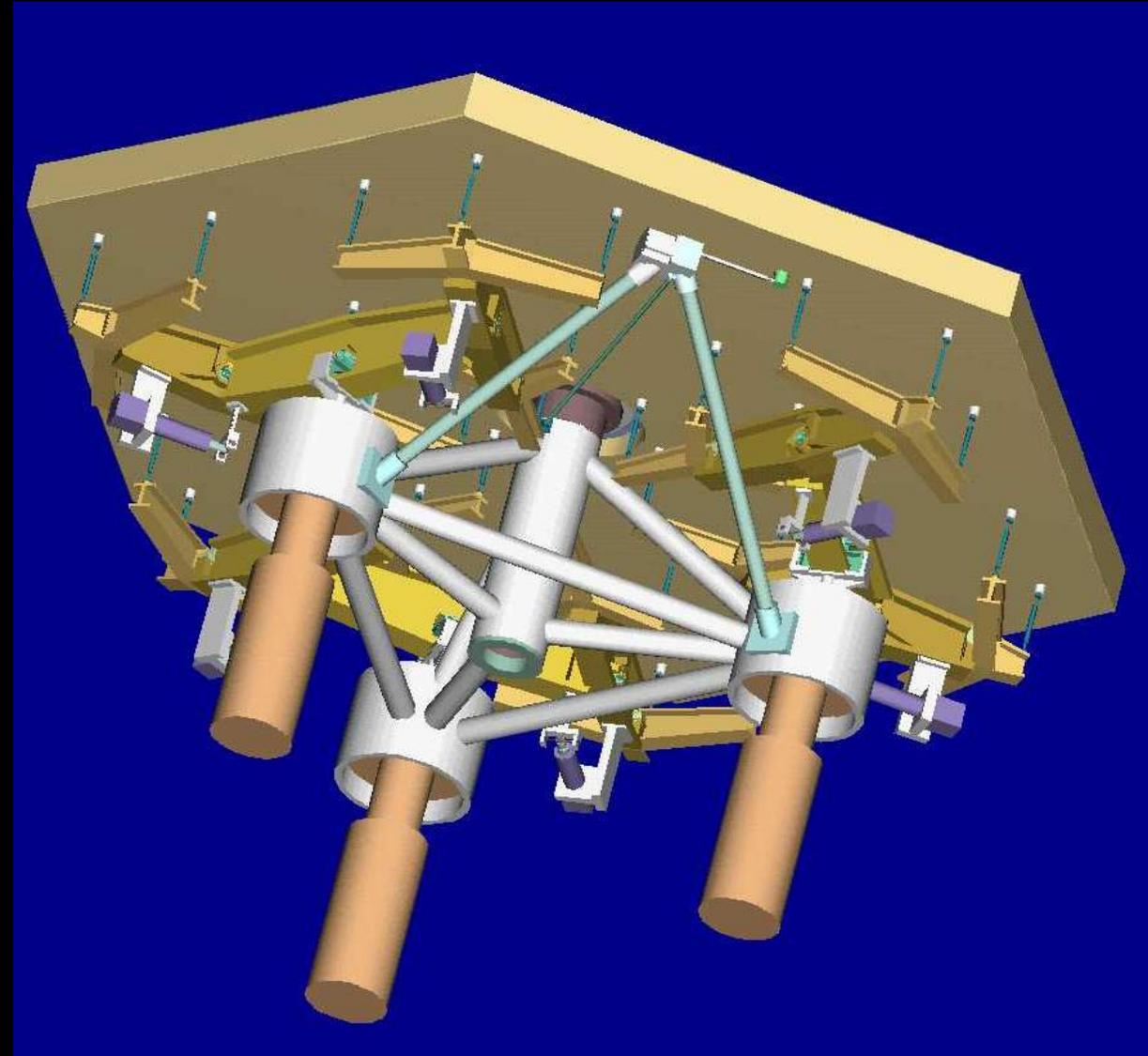


M1 image quality

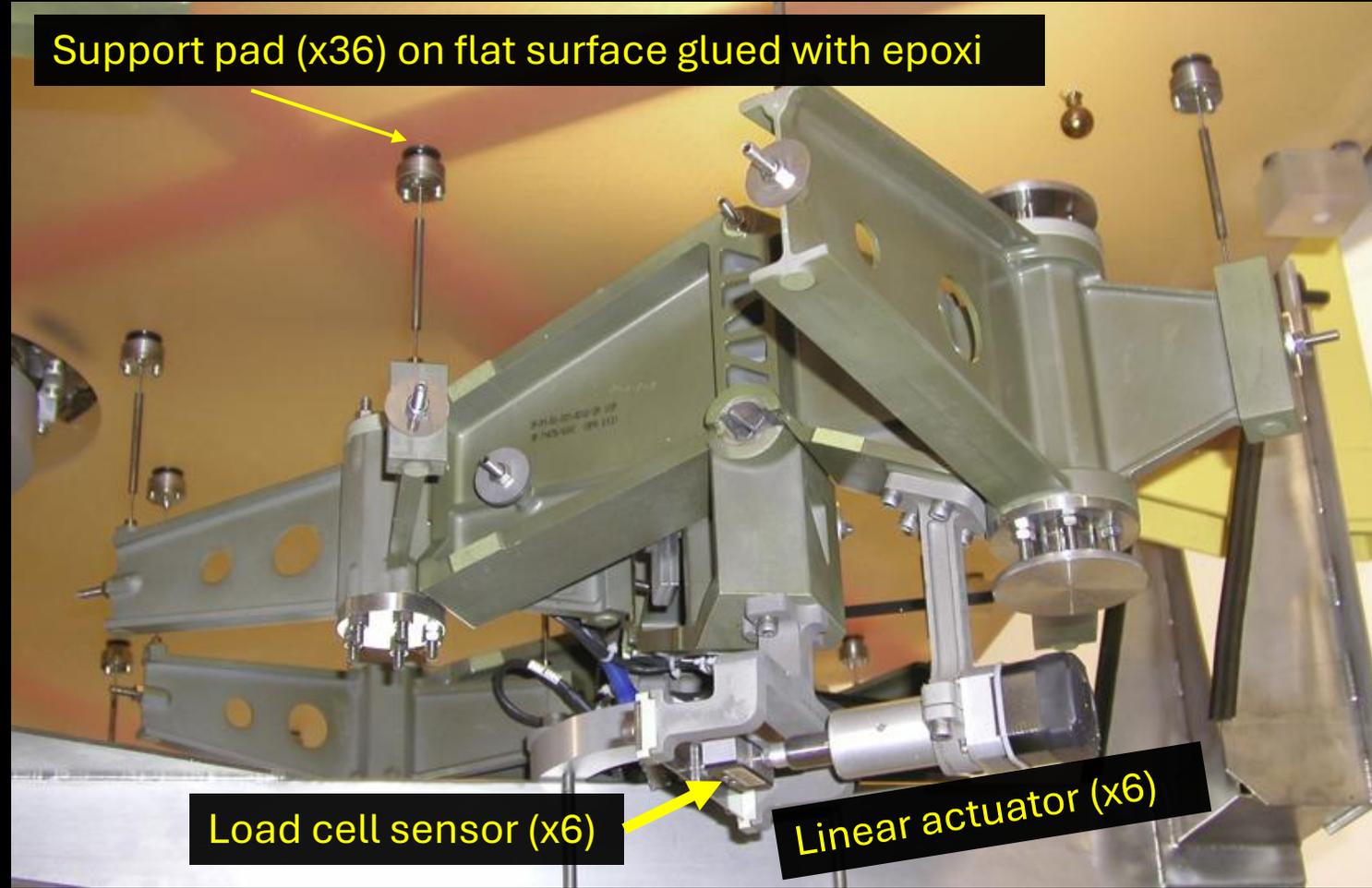
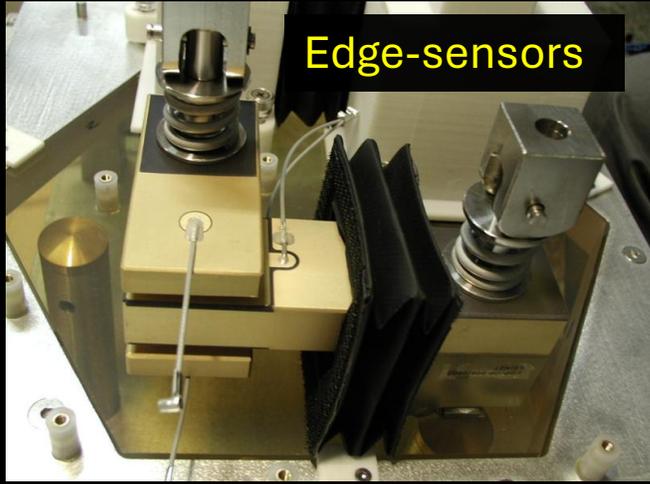
Reaching the nominal image quality of a 10.4m aperture is the other most challenging task for a segmented mirror.

It requires **aligning the 36 segments with $\sim 50\text{nm}$ rms accuracy**

- **324 degrees of freedom** with mechanical actuators :
 - 108 for M1 figure (stacking and phasing) with 3x36 positioners
 - 216 for segment figure correction with 6x36 linear actuators in whiffletree
- 168 capacitive gold-coated edge sensors at 20Hz (35nm r.m.s. accuracy)
- 216 torque load-cell sensors



Segmented M1: hardware

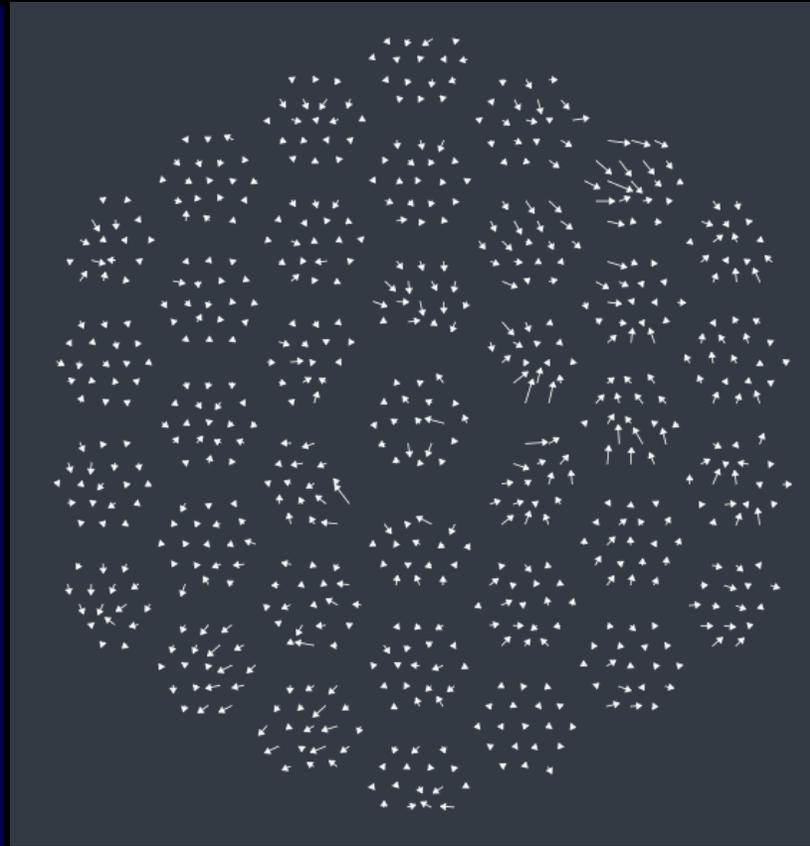
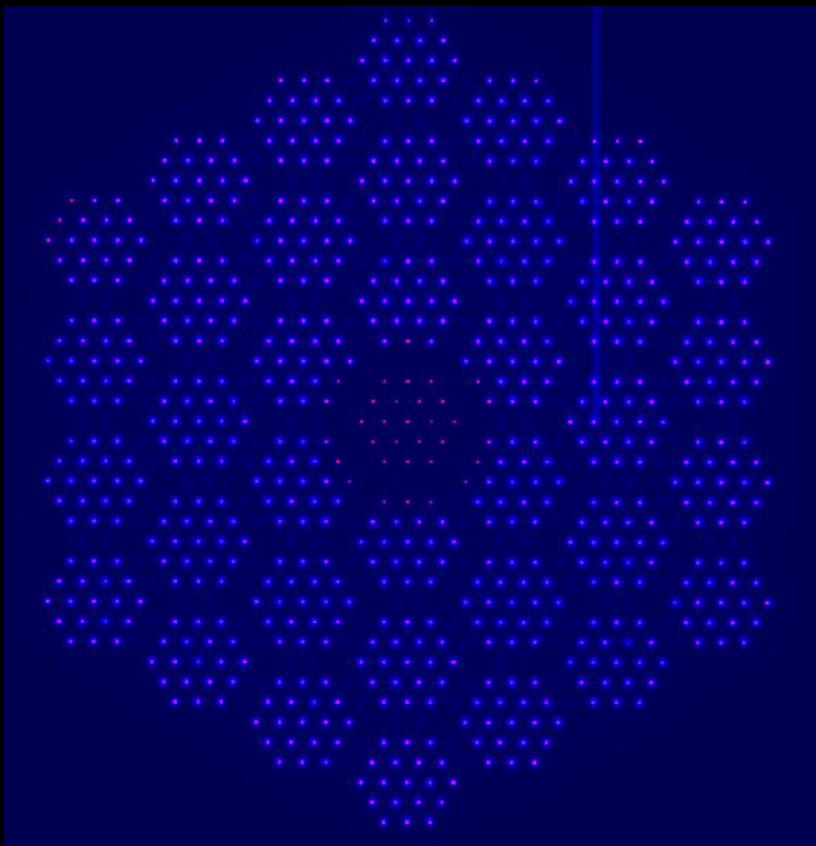


Segmented M1: optical quality

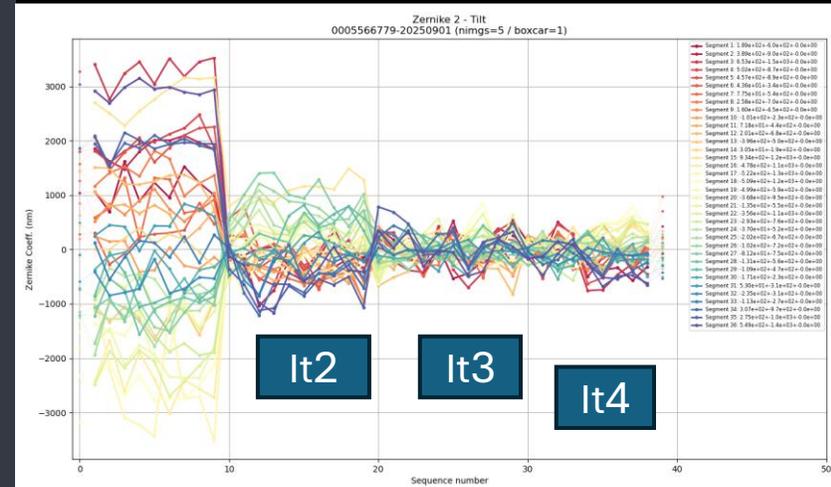
Coarse stacking by direct image to within the seeing-limited PSF

Fine stacking (daily) with Shack-Hartmann WFS – residual tip-tilt error ≤ 0.05 arcsec rms on-sky

This guarantees seeing-limited observations in visible and near-infrared.



iterative process

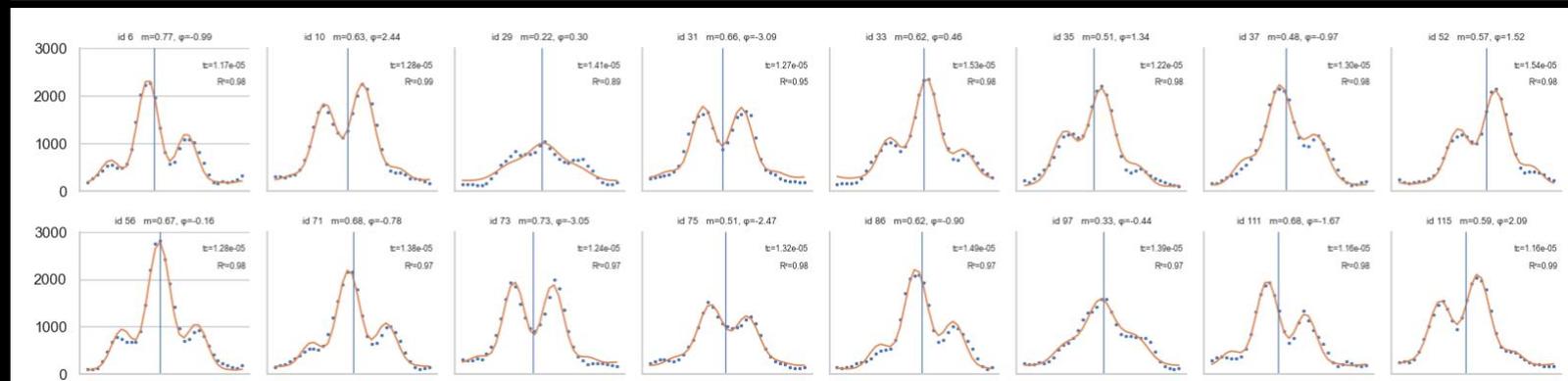
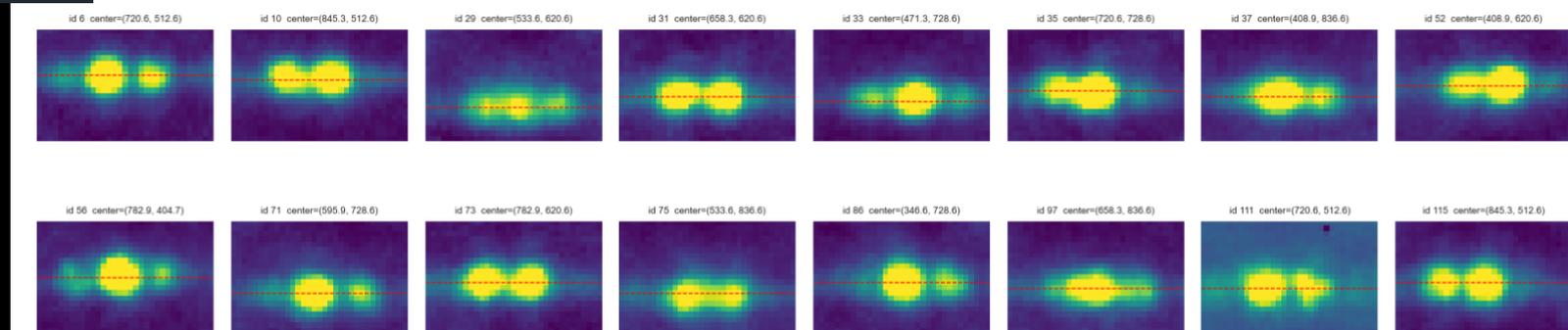
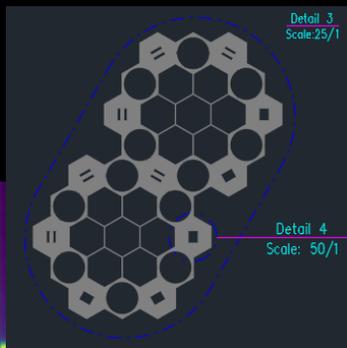


Segmented M1: optical quality



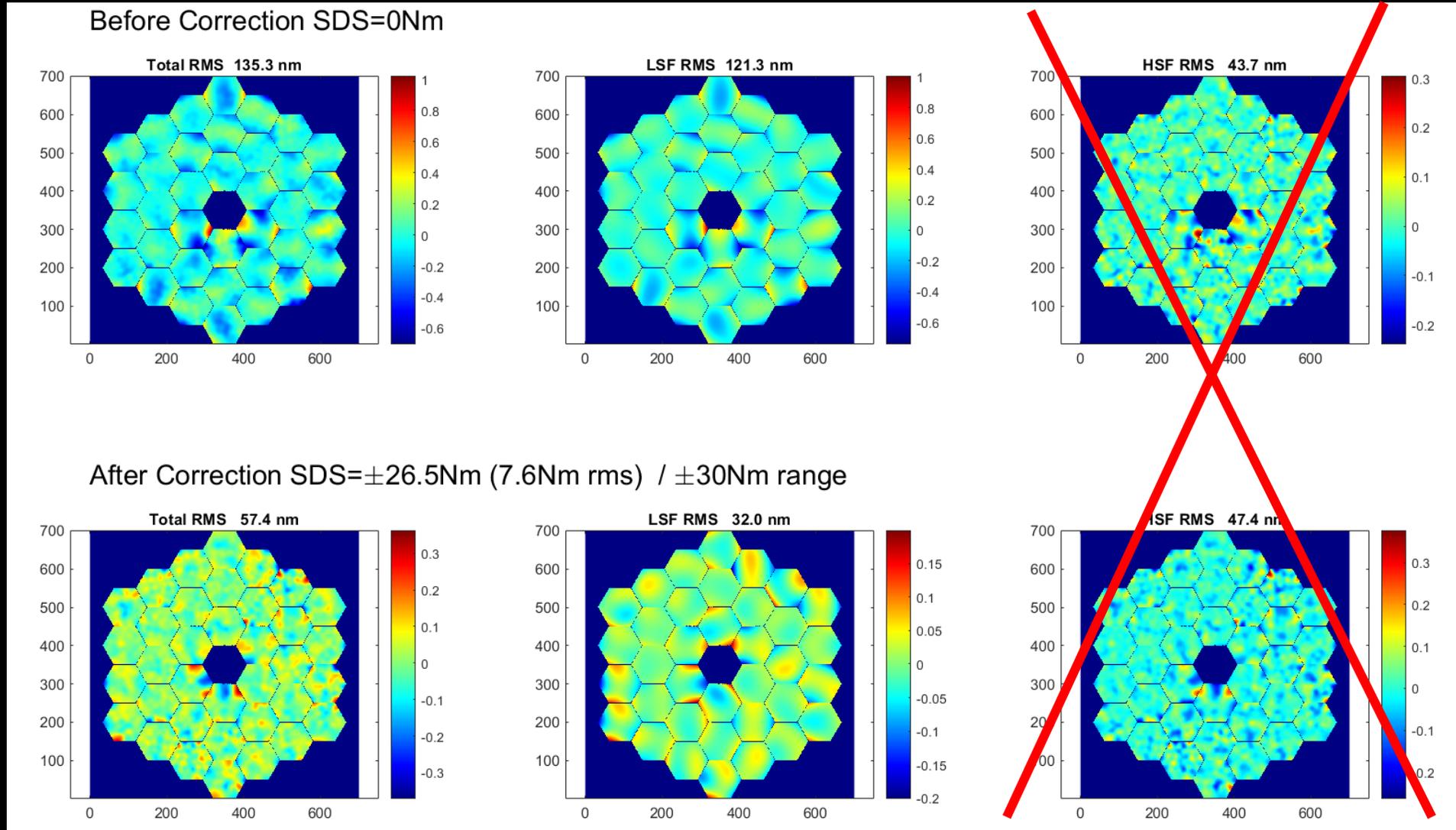
Phasing \rightarrow residual piston errors, presently $\sim 80\text{-}100\text{ nm}$ (AO target $\leq 50\text{ nm}$)

Double-slits between any pair of segments produce interferometric fringes if light is coherent between the two (segments phased within a small fraction of λ)



Segmented M1: optical quality

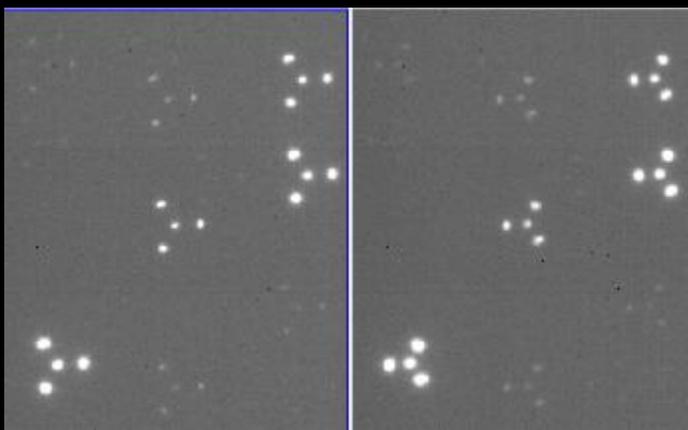
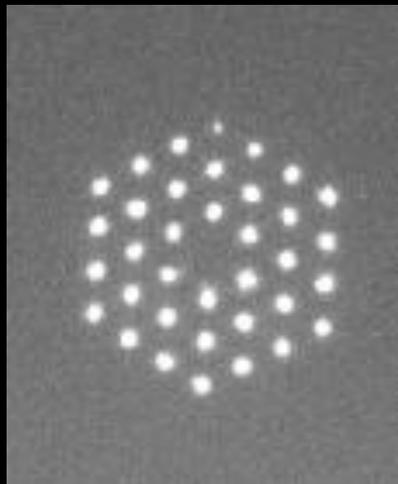
Segments' figure corrections implemented in 2025 → WFE ~50-60 nm r.m.s. across M1 (design target is 30nm)



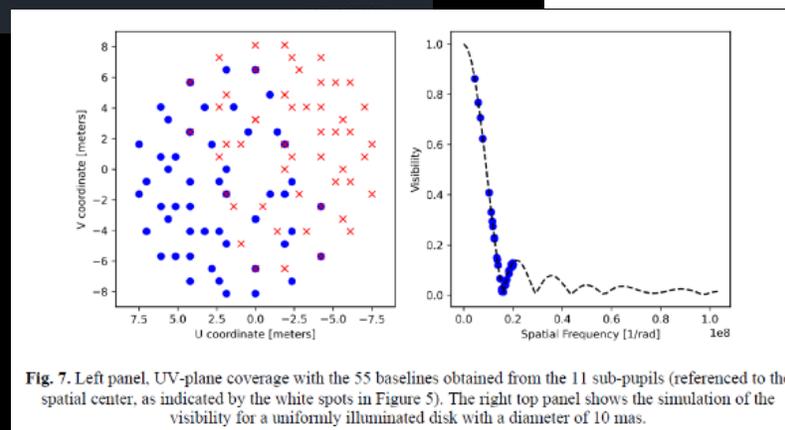
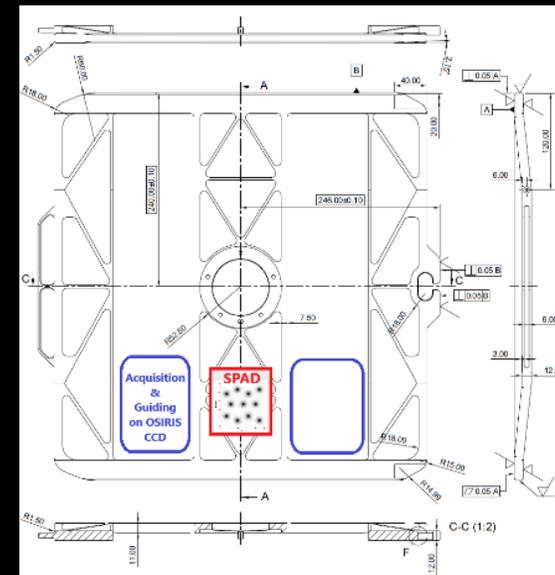
Segmented M1: Special Use-Cases

Segments can be arbitrarily de-stacked for...

... engineering tests (optical alignment, fine focus adjustment...)



... and experiments like **intensity interferometry** (LPQI project)



The future

- 2026: Reach the M1 nominal performance and complete **GTC-AO** commissioning with its instrument **FRIDA**
- 2027: **laser guide star**
- 2027-2029: **high-resolution ultra-stable spectrograph CHORUS**
- 2032: Single-conjugated AO → **MGTCAO** (3 laser stars with 1 laser). Contract awarded to IAC.
- 2032: **VIS+NIR imager and spectrograph**. Tender process to be launched asap.

Foster collaborations within La Palma Observatory.

Opportunities:

- **time-domain astronomy** (CCI working group)
- **intensity interferometry** (LPQI: GTC, TNG, NOT, +...)
- **exoplanets** (TNG+HARPS-N, INT+HARPS3, GTC+CHORUS,..)
- ...?...

GTCAO+ FRIDA		
Resolution		46 mas at 2 μ m
Spectral range		0.9-2.5 μ m
Imaging	mode	broad & narrow-band
	f.o.v (scale)	20''x20'' (0.01 arcsec pix ⁻¹) 40''x40'' (0.02 & 0.04 arcsec pix ⁻¹)
Spectroscopic mode		IFU 0.6x0.6, 1.2x1.2 & 2.4x2.4 arcsec ²
Spectral resolution		1000 (ZJ, HK), 4,000 (Z,J,H,K), 30,000 (H,K)

CHORUS		
Subsystems	UV band Spectrograph (UVS)	Visible band Spectrograph (VIS)
Location	Below Nasmyth Platform B	Coudé room
Fiber configuration	Φ 1.2" aperture on the sky	Φ 1.2" aperture on the sky
Spectral resolution	R\geq25,000	R\geq110,000
Wavelength coverage	310-420 nm	420-780 nm
Wavelength calibration precision		\sim 10cm/s with LFC
Calibration	Single fiber calibration	Sim.-Calibration, Sky subtraction
Instrument daily stability		Inside Vacuum Chamber at \sim 16°C (\pm 2°C) \pm 0.001°C /night Oper. pressure in IVC \leq 0.001 mbar
efficiency (input fiber \rightarrow detector front)	\geq 17% at peak, \geq 5% at minimum	\geq 17% at peak, \geq 8% at minimum



Thank you for you attention

(and for the help of the GTC senior astronomer Sergio Fernández