Spectroscopy at 8-10 m telescopes: the GTC perspective

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GRANTECAN

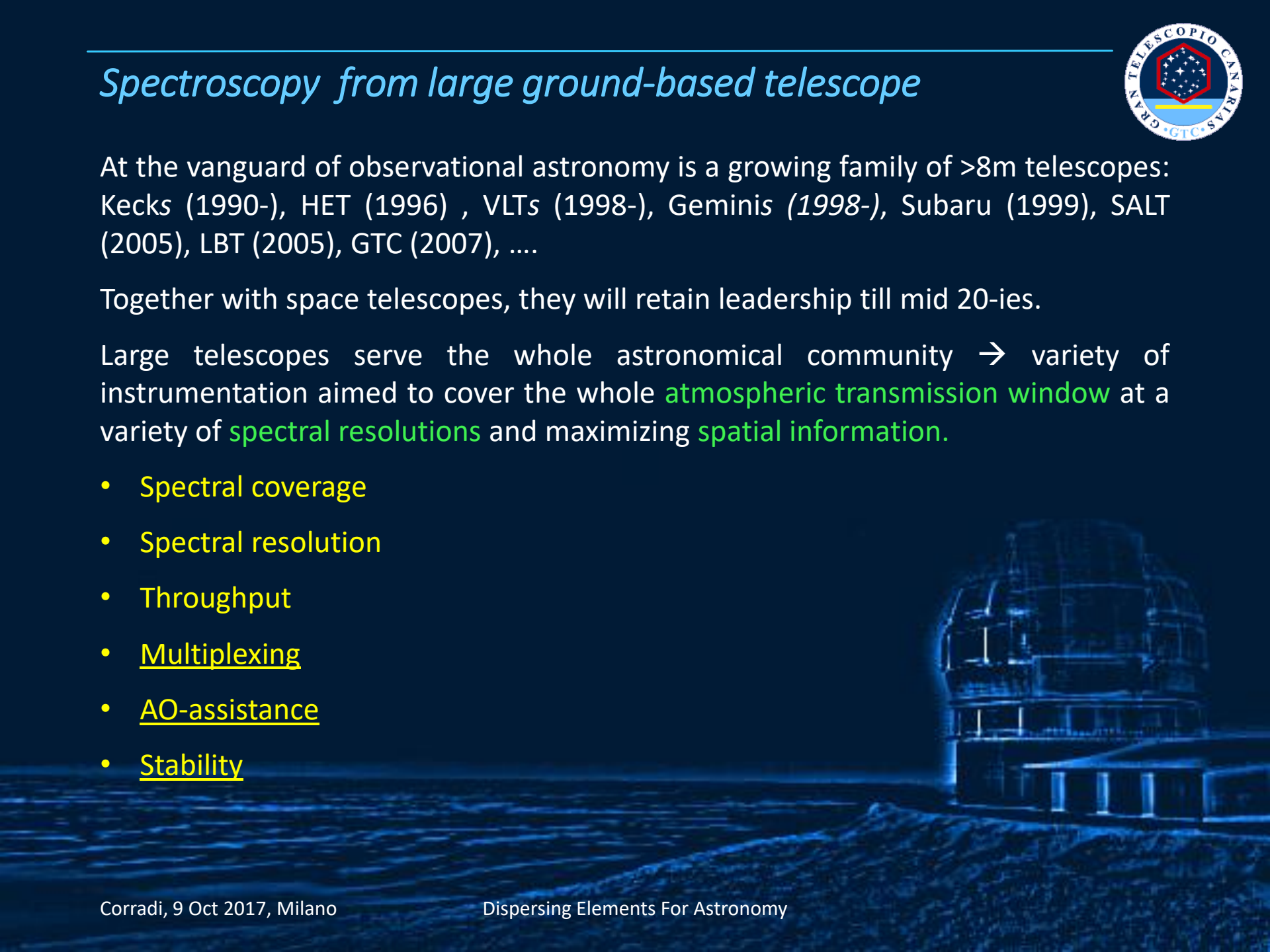
Spectroscopy from large ground-based telescope

At the vanguard of observational astronomy is a growing family of >8m telescopes: Kecks (1990-), HET (1996) , VLTs (1998-), Geminis *(1998-)*, Subaru (1999), SALT (2005), LBT (2005), GTC (2007), ….

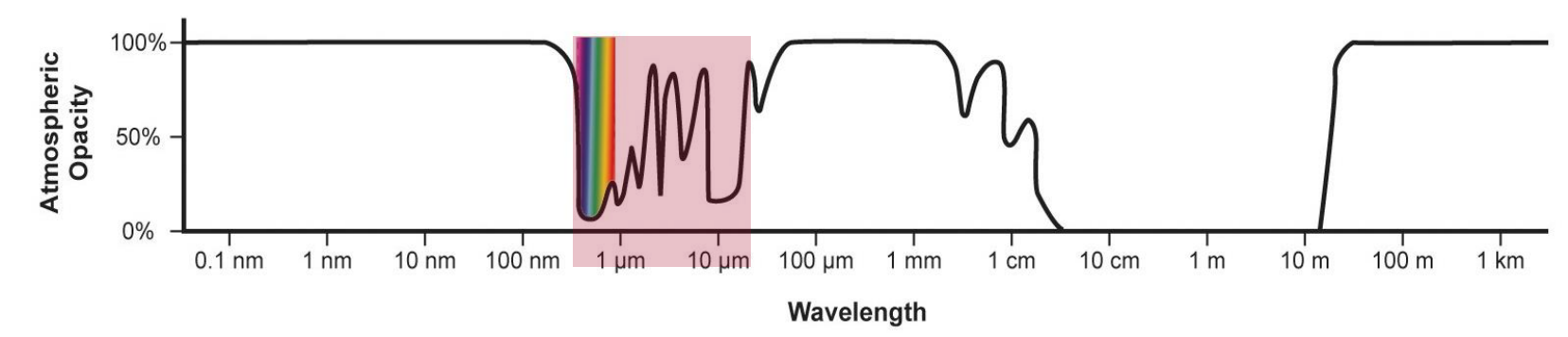
Together with space telescopes, they will retain leadership till mid 20-ies.

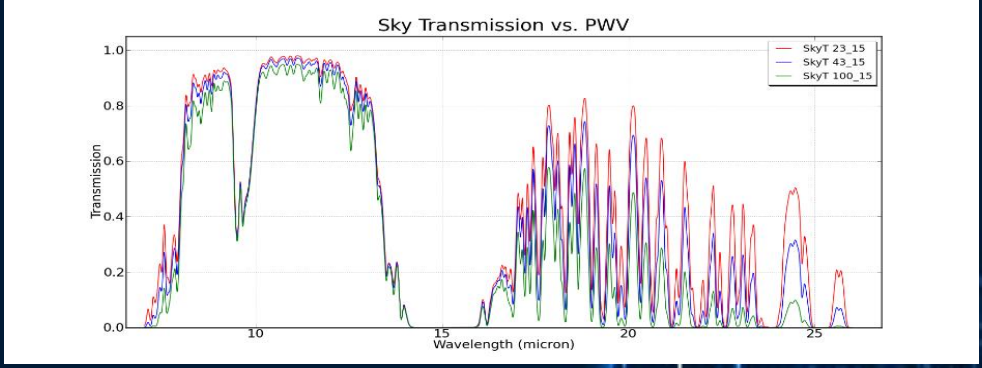
Large telescopes serve the whole astronomical community → variety of instrumentation aimed to cover the whole atmospheric transmission window at a variety of spectral resolutions and maximizing spatial information.

- Spectral coverage
- Spectral resolution
- Throughput
- Multiplexing
- AO-assistance
- Stability



Spectral coverage



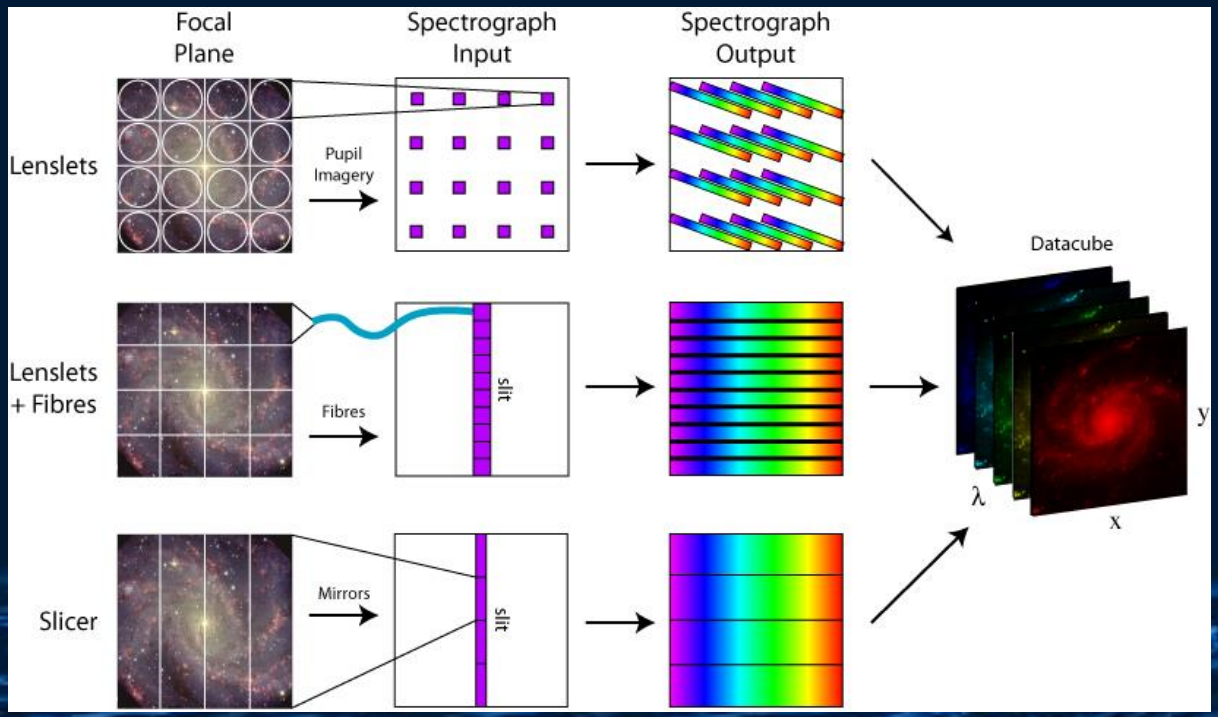


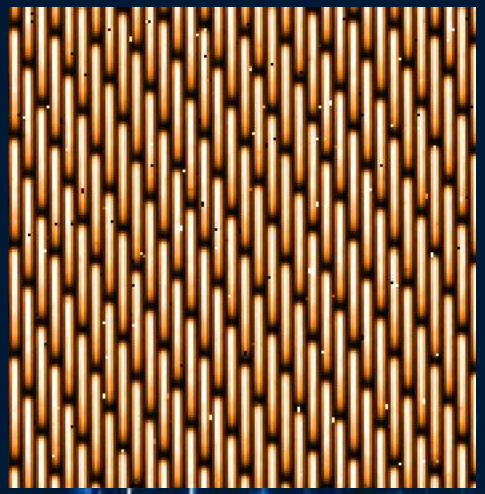
Optics and detectors technology, cooling requirements, as well as observational strategy constraints, mark a division between UV/visible (0.3-1 µm), near-infrared (1-5 µm), and mid-IR (5-25 µm) instrumentation

Spectral coverage vs. resolution vs. multiplex

$$\sum_{\text{pixels}} \times f \geq \sum_{\text{spectra}} \times \sum_{\text{spectral elements}}$$

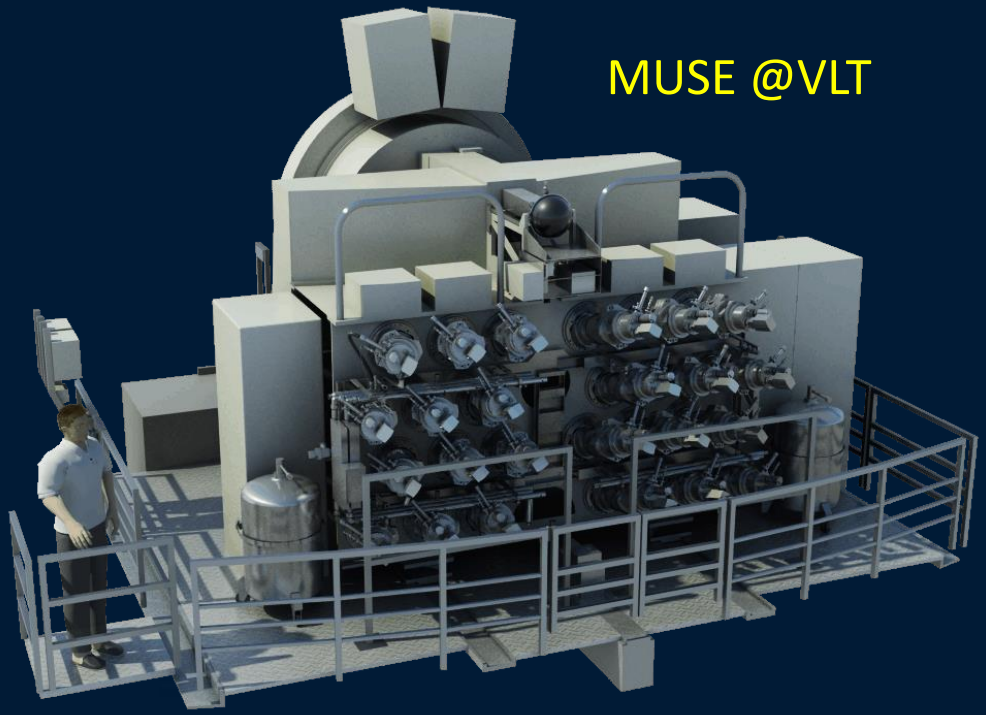
Emphasis on multi-object and integral-field spectrographs: slit masks, configurable slits, (bare) fibers, lensets, lenslets+fibers, image slicers, Fabry-Peror interferometry, Fourier transform spectroscopy



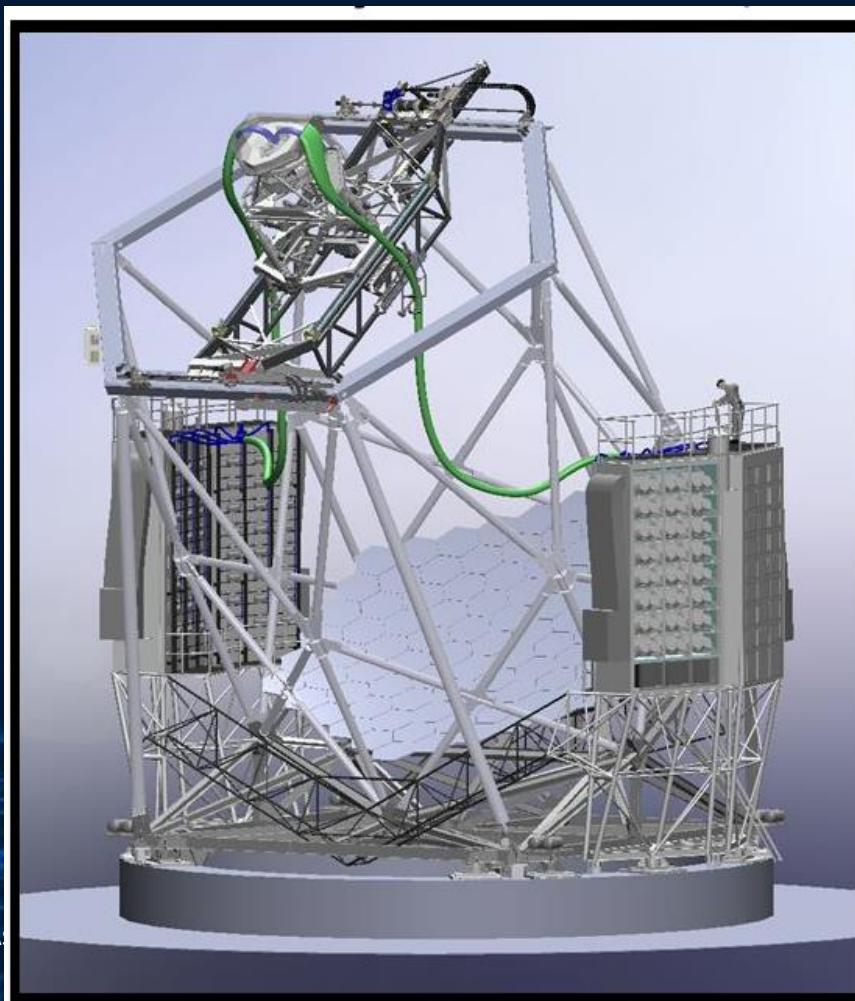


Multiplex: modular solutions

MUSE @VLT

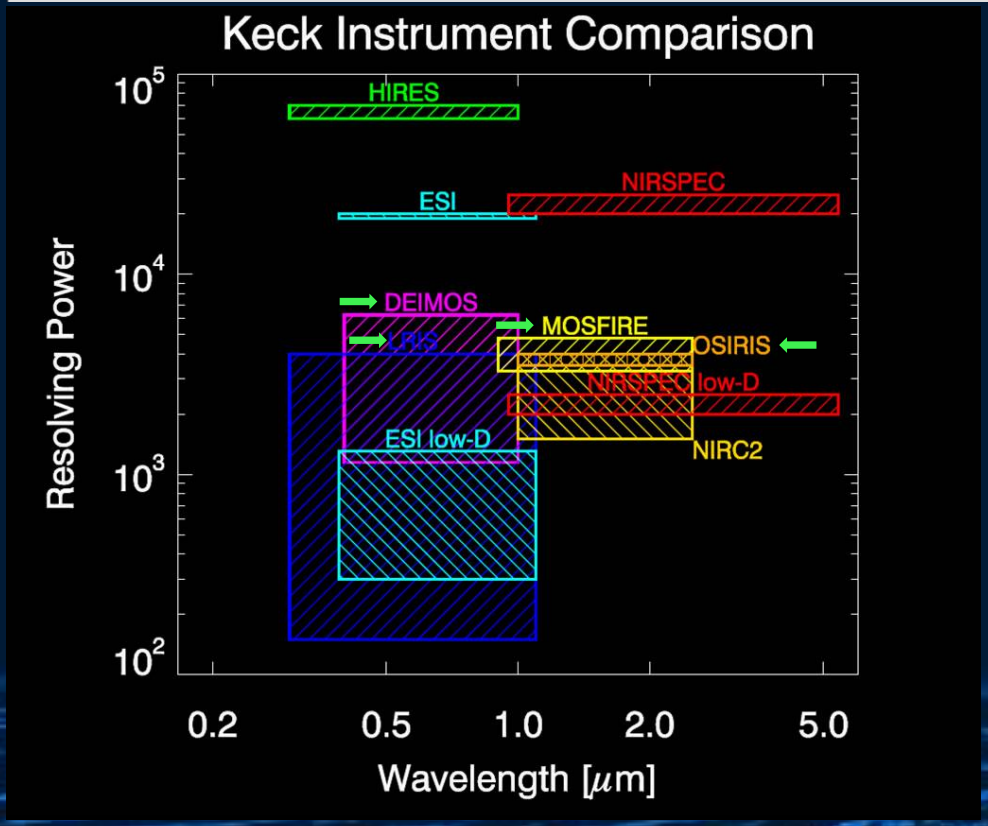


VIRUS @HET



Spectroscopic instrumentation suites: Keck telescopes

Keck I	Keck II
HIRES	DEIMOS
LRIS	ESI
MOSFIRE	KCWI
OSIRIS	NIRES
	NIRC2
	NIRSPEC



VLTs

	range		resolution	multiplex/IFU		
FORS2	optical 330 - 1100 nm	imaging (incl. configurable occulting bars), long slit and multi-object spectroscopy, spectropolarimetry, imaging polarimetry	260 - 2600	yes	Spectroscopy with ~7' long slit, ~20" multi-slit, and laser-cut slit masks; high time resolution imaging; high time resolution modes spectroscopy and multiple object spectroscopy in visitor mode only; RRM	VLT UT1
KMOS	near-IR 0.8 - 2.5 µm	multi-object integral field spectroscopy (24 arms)	1800 - 4000	yes	24-arms Integral Field Spectroscopy; 2.8x2.8", 0.2" sampling IFU over a 7.2' field;	VLT UT1
FLAMES	optical 370 - 950 nm	multi-fibre echelle,integral field spectroscopy	6000 - 47000	yes	132 Medusa fibres; 15 deployable IFUs, one large IFU; GIRAFFE: single echelle order; 8 fibres to UVES	VLT UT2
X-SHOOTER	UV-optical-NIR 300 - 2500 nm	echelle, slit and integral field spectroscopy	~5000-17000	no	full spectral coverage with one pointing; slit + IFU; RRM	VLT UT2
UVES	optical 300 - 1100 nm	echelle, image slicer, slit spectroscopy	up to 80,000 (blue arm) / 110,000 (red arm)	no	long slit capability in single order; iodine cell; RRM	VLT UT2
SPHERE	optical: 500 - 900 nm near-IR: 0.95 - 2.32 µm	high-contrast imaging, dual-band imaging, integral field spectroscopy, differential-polarimetric imaging with or without classical, apodized pupil Lyot or four-quadrant phase mask coronagraphs	~30, 50, 400	no	extreme AO with optical wave-front sensor.	VLT UT3
VISIR	mid-IR: 8 - 21 µm	N and Q band imaging; coronography (Angular Groove Phase Mask); N band low resolution long slit spectroscopy; high-resolution long slit and cross-dispersed spectroscopy	~400, 20000	no	pixel size of 0.045 arcsec in imaging and 0.076 arcsec in spectroscopy	VLT UT3
VIMOS	optical 360 - 1000 nm	imaging, multi-object spectroscopy, integral field spectroscopy	200-3000	yes	IFU size on sky from 13"x13" to 54"x54"; multi-object spectroscopy (MOS) with 4 laser-cut slit masks; Imaging and MOS field of view 4 times 7'x8'.	VLT UT3
SINFONI	near-IR 1.1 - 2.45 µm	integral field spectroscopy	1500-4000	no	AO with natural and laser guide star; no AO; RRM	VLT UT4
MUSE	optical 465 - 930 nm	integral field spectroscopy	1770 @ 480nm 3590 @ 930nm	no	IFU size on sky 60"x60", spaxel size 0.2"	VLT UT4
AMBER	near-IR 1.5 - 2.5 µm	spectro - interferometry	R~30, 1500 or 12000	no	3 beam combiner - measures also closure phase; spatial resolution up to 3 mas at 2 µm	VLTI - ATs VLTI - UTs

IFU (image slicer)

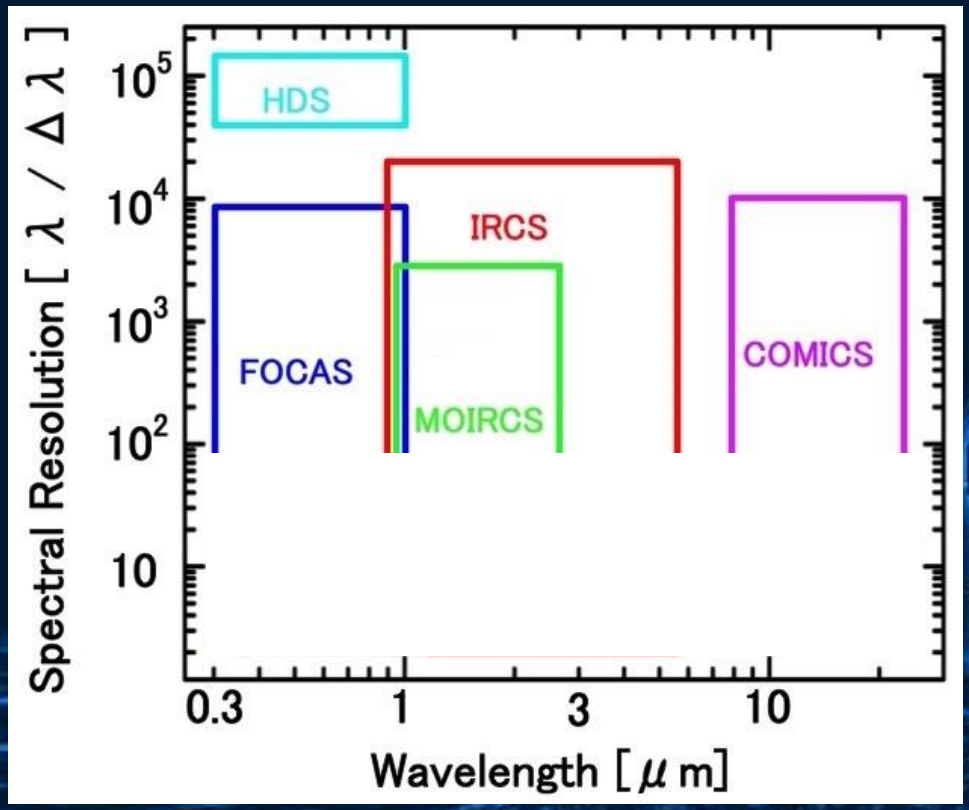
IFU (lenslets)

IFU (image slicer)

IFU

Subaru

Instrument	Resolution (slit width)	Slit length	Pixel scale
COMICS	250-10000 (0.33")	40"	0.165"
FOCAS	250-7500 (0.4")	6', MOS (masks)	0.1"
HDS	32000 (1") - 160000 (0.2")	10", 60"	0.138"
IRCS (grism)	50 (0.9") - 1400 (0.1")	6.5-20"	0.020", 0.052"
IRCS (echelle)	5000 (0.54") - 20000 (0.14")	3.47-9.37"	0.055"
MOIRCS	463-3180 (0.5")	MOS (masks)	0.116"



Gemini

VISIBLE	NEAR-IR	MID-IR
Facility Instruments		
GMOS (multi-object, long-slit and IFU spectrograph and imager) R 210-8800		
	NIFS (1.0-2.5μm integral field spectrograph) R 5000	
	GNIRS (1-5μm long-slit and 0.9-2.5μm cross-dispersed spectrograph; formerly at Gemini South) R 1200-18000	
Visiting Instruments		
GRACES (0.4-1.0μm high resolution spectrograph) R 210-67000		TEXES*(10-20μm high resolution spectrograph) R 4000-100000

VISIBLE	NEAR-IR	MID-IR
Facility Instruments		
GMOS (multi-object, long-slit and IFU spectrograph and imager)		
	GPI (adaptive-optics imaging polarimeter/integral-field spectrometer) R 40	
	FLAMINGOS-2 (long-slit spectrograph and imager) R 1000-3000	
Visiting Instruments		
	IGRINS** (high-resolution spectrograph, R 45000	

HET, SALT, LBT

HET

- LRS2: 12”x6“ IFU, R=1000-2000, 0.37-1 mu /4 arms
- VIRUS: being integrated (150 spectrographs for 34,000 bare fibres)

SALT

- HRS: Dual-beam (370-550 nm & 550-890 nm) single-object fibre-fed echelle spectrograph, VPH gratings as cross dispersers. R ~14,000 to 65,000.
- RSS: 320 to 900 nm VPHs → R up to 9000, MOS (masks), Fabry-Perot, 430–860 nm, R = 320 to 9000

LBT

- MODS1/MODS2: pair of spectrographs, each two arms, 320-1100nm R=500 to 2000, MOS
- LUCI1 /LUCI2: 0.9 to 2.44 microns. MOS R~2000 to 8500
- PEPSI : single-target fibre-fed spectrograph and polarimeter (383 to 907 nm). R= 43,000 to 270,000. 2 monolithic 10.3kx10.3k CCDs

The 10.4m Gran Telescopio Canarias (GTC)

Funded by Spain (90%), México (5%), and the University of Florida (2.5-5%)

Located at 2267 m.a.m.s.l. at Observatorio del Roque de los Muchachos, La Palma

Construction started in 2000, first light in 2007, and operations in 2009

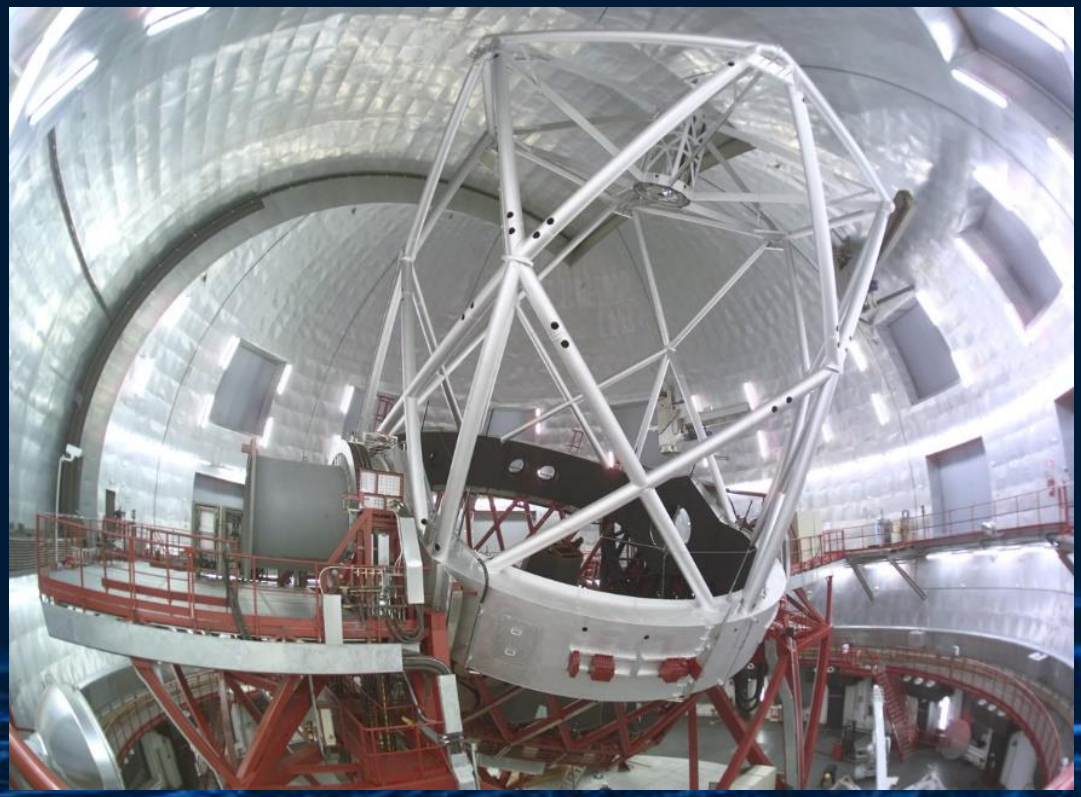
10.4 m alt-az , Ritchey-Chrétien configuration

Effective collecting area 73 m^2

Effective focal length 169.9 m →

plate scale 1.21 arcsec mm^{-1}

Focus	Field of view Ø
Nasmyth	20 arcmin (1 m)
Cassegrain	15 arcmin
Folded Cass.	5 arcmin



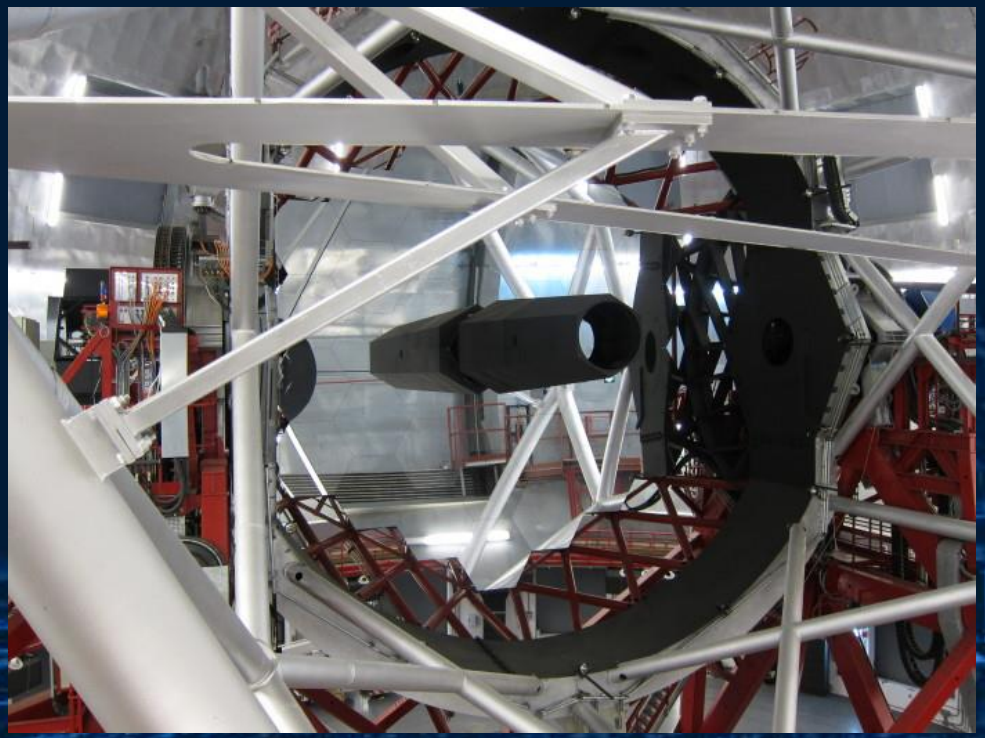
Total tel. moving weight 400 t

M1

36(+6) hexagonal aluminium-coated Zerodur segments 1.9m wide, 8cm thick, of 6 different types

Total weight = 17 tonnes

Open/closed-loop active-optics control is provided by 108 positioners (piston and tip-tilt), 216 moment actuators, and 168 position sensors (capacitive edge-sensors) → 324 active degrees of freedom (72 for stacking, 36 for phasing, and 216 for change of segment figure)



M2

Aluminium-coated beryllium, 118 cm wide, 13 cm thick, 35 kg weight.

M2 provides GTC aperture stop.

5 active degrees of freedom → alignment, chopping, image-motion corrections

Hexapode maintains optical alignment in presence of predictable thermal and gravity effects. Chopper allows tip-tilt image-motion correction (20-50 Hz), as well as IR chopping (2Hz)

The focal stations

M3 (flat elliptical 1.5x 1.1 m) selects focal station in <5 min.

Available foci:

2 Nasmyth

1 Cassegrain

4 folded Cass.

[Coudé]

[prime]

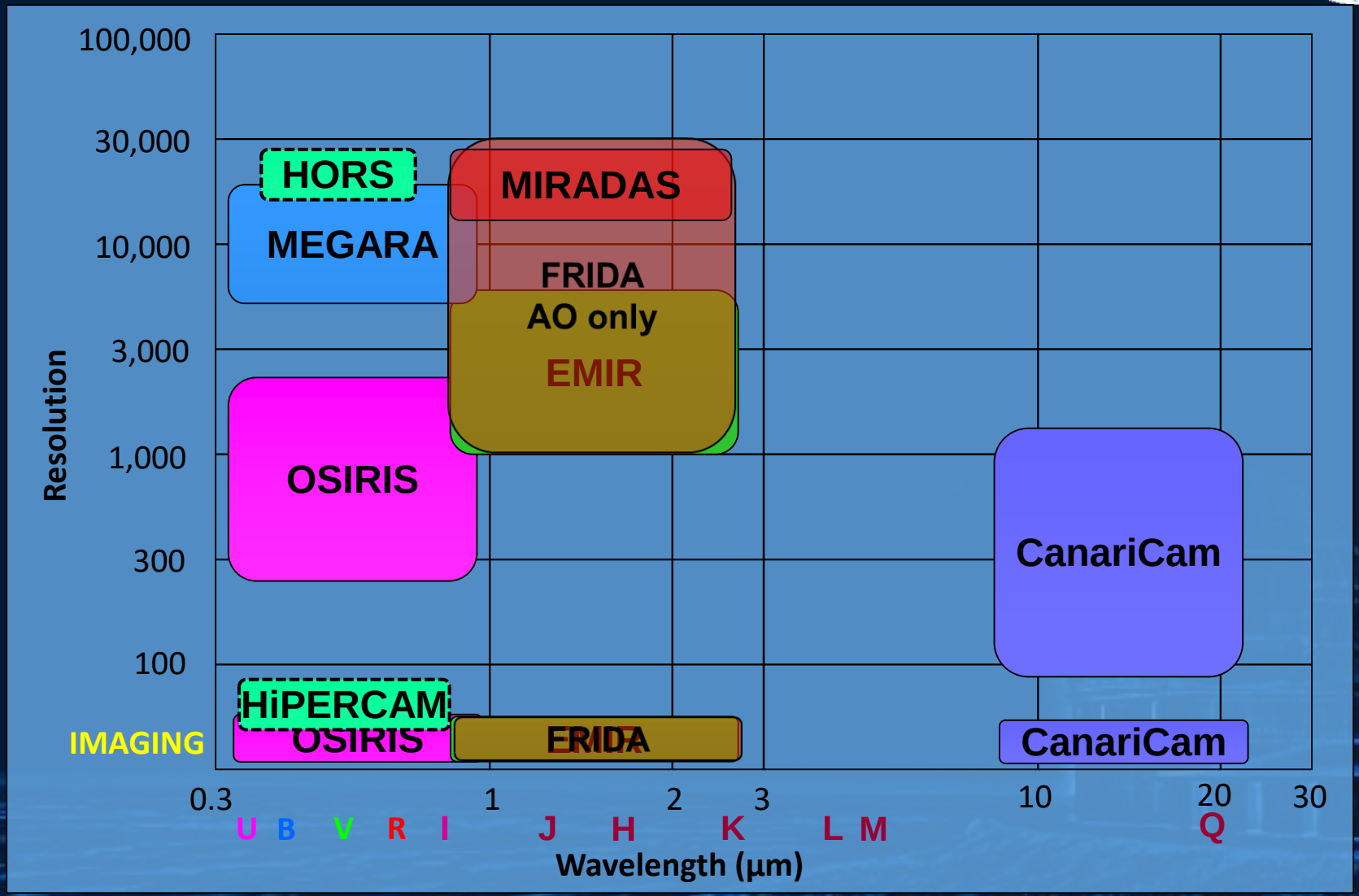
The instruments

Goal is good balance between general-purpose instruments covering a wide spectral range (e.g. OSIRIS + EMIR + CanariCam) and instruments designed to provide specific capabilities. Versatility allowed by the number of available foci.

Distinguished features are:

- Tunable filters (OSIRIS),
- MOS (OSIRIS, EMIR, MEGARA, MIRADAS)
- IFU (Megara, MIRADAS, FRIDA)
- at low to intermediate spectral resolution (MEGARA, MIRADAS, FRIDA)
- IR polarimetry (CIRCE, CanariCam)
- AO assisted (FRIDA, 2019)

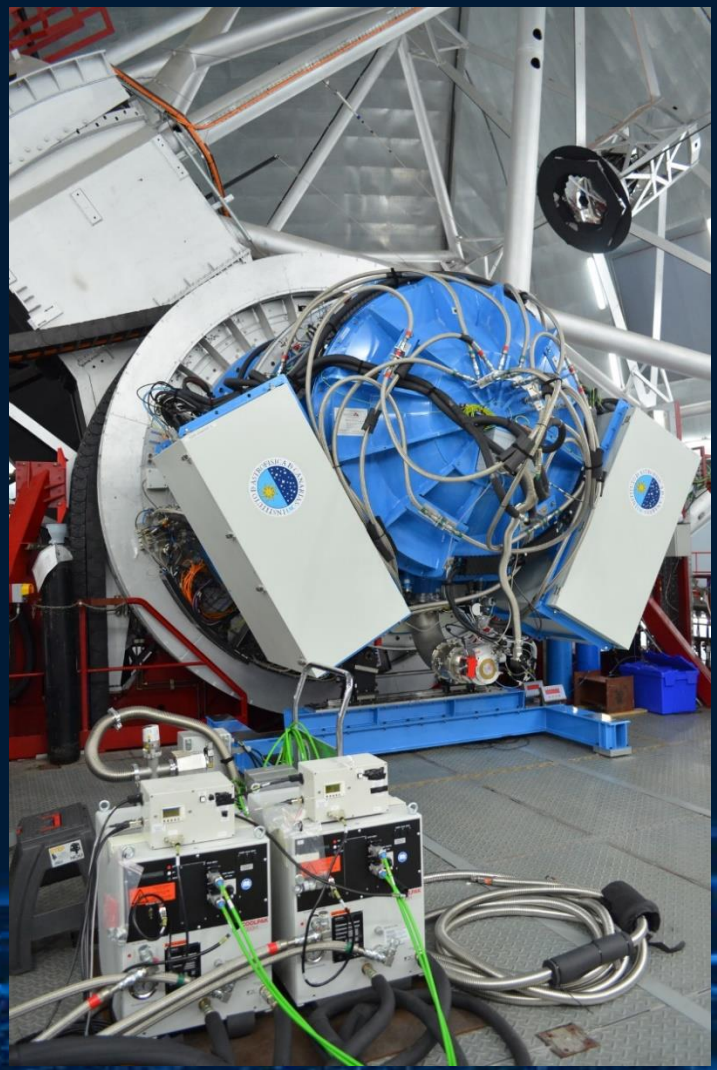
GTC instrumentation 2017-2019



EMIR NIR imager and multi-object spectrograph

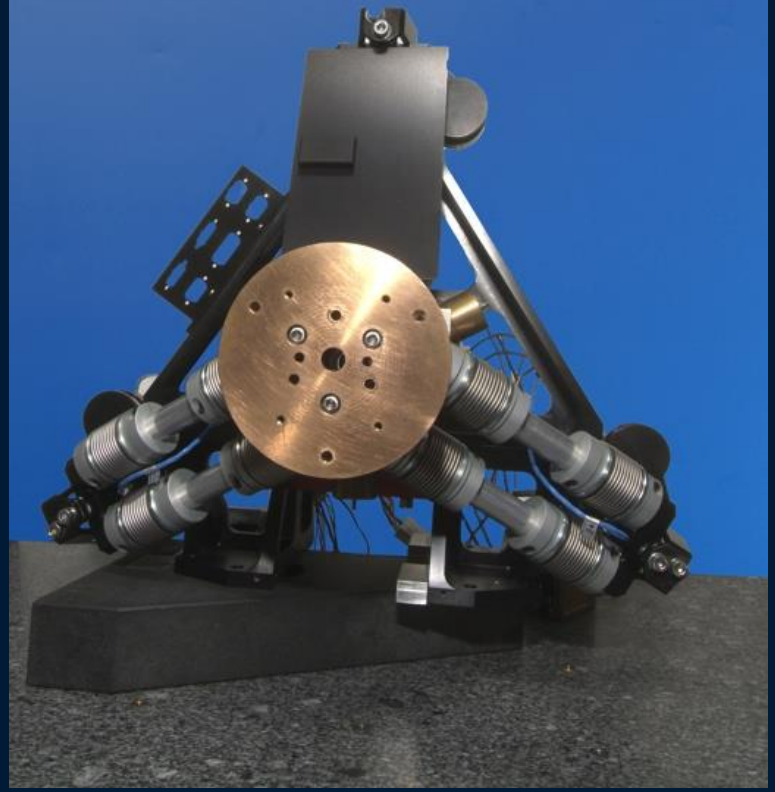
Commissioned on June 2016.

Spectral Range	0.9-2.5μm[1.1-2.5μm]	*MOS mode*	
Detector	HAWAI2 2048^2	*F.O.V.*	6.7 x 4 $arcmin^2$ (55 slitlets)
Spectral resolution	1000 (YJ, HK) 5000,4250,4000 (JHK)	*Sensitivity*	K~20.1 in 2h @ S/N=5 (continuum)
Spectral coverage	1 single window/exp.		$1.4x10^{-18}$ $erg/s/cm^2/Å$ @ S/N=6 (line)
Imaging modes	Broad/narrow band	*Imaging mode*	
Plate Scale	0.2 arcsec pix^{-1}	*F.O.V.*	6.7 x 6.7 $arcmin^2$
Image quality	θ_{80} < 0.3 arcsec	Sensitivity	K~22.8 in 1h, for S/N=5 & 0.6 arcsec aperture

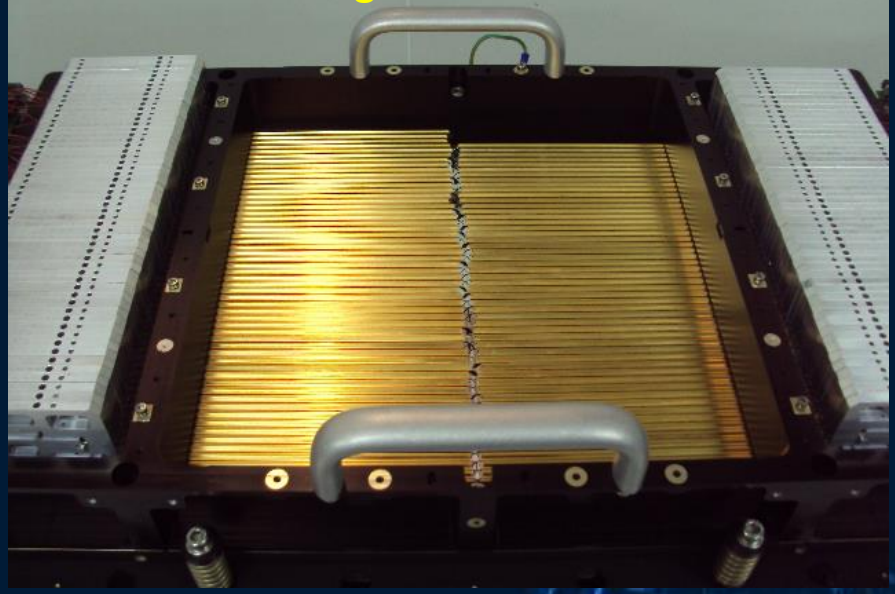


EMIR NIR imager and multi-object spectrograph

Detector Translation Unit

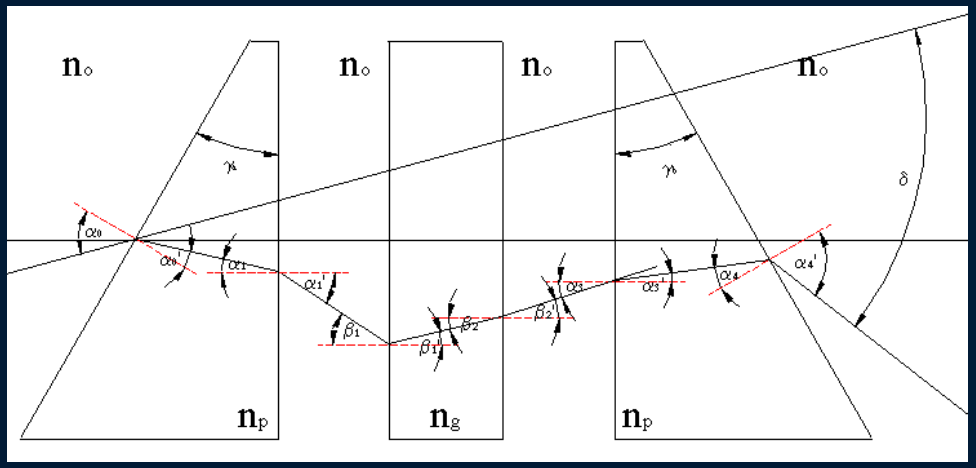


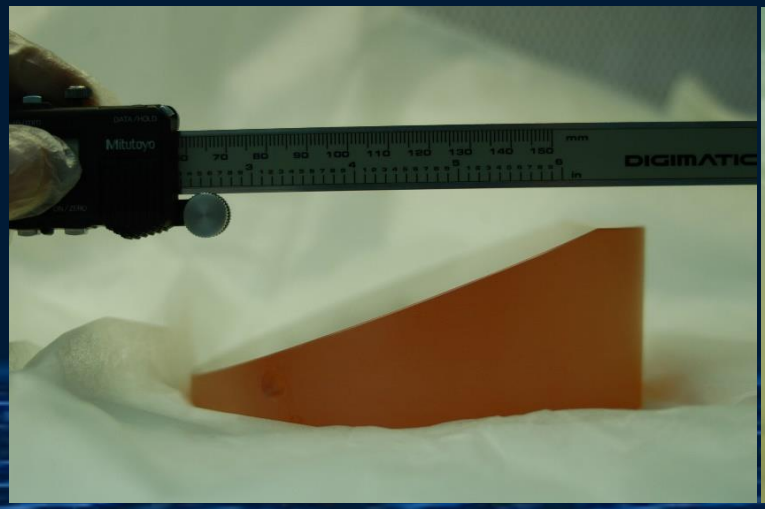
Configurable Slit Unit

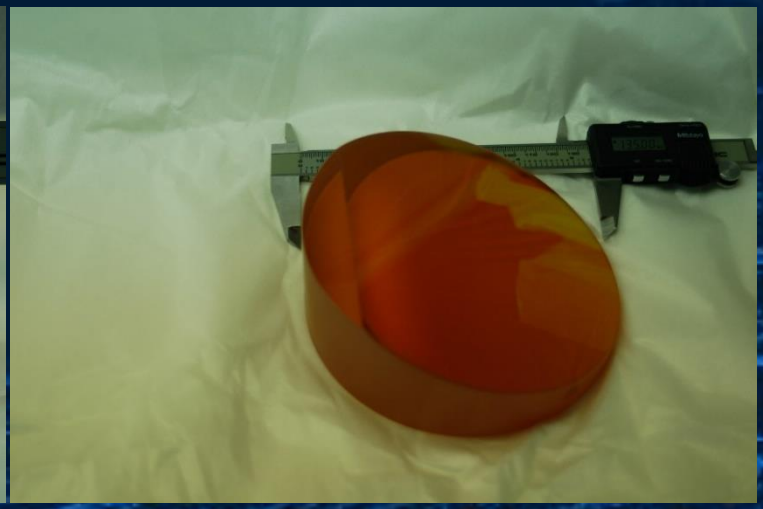


EMIR NIR imager and multi-object spectrograph

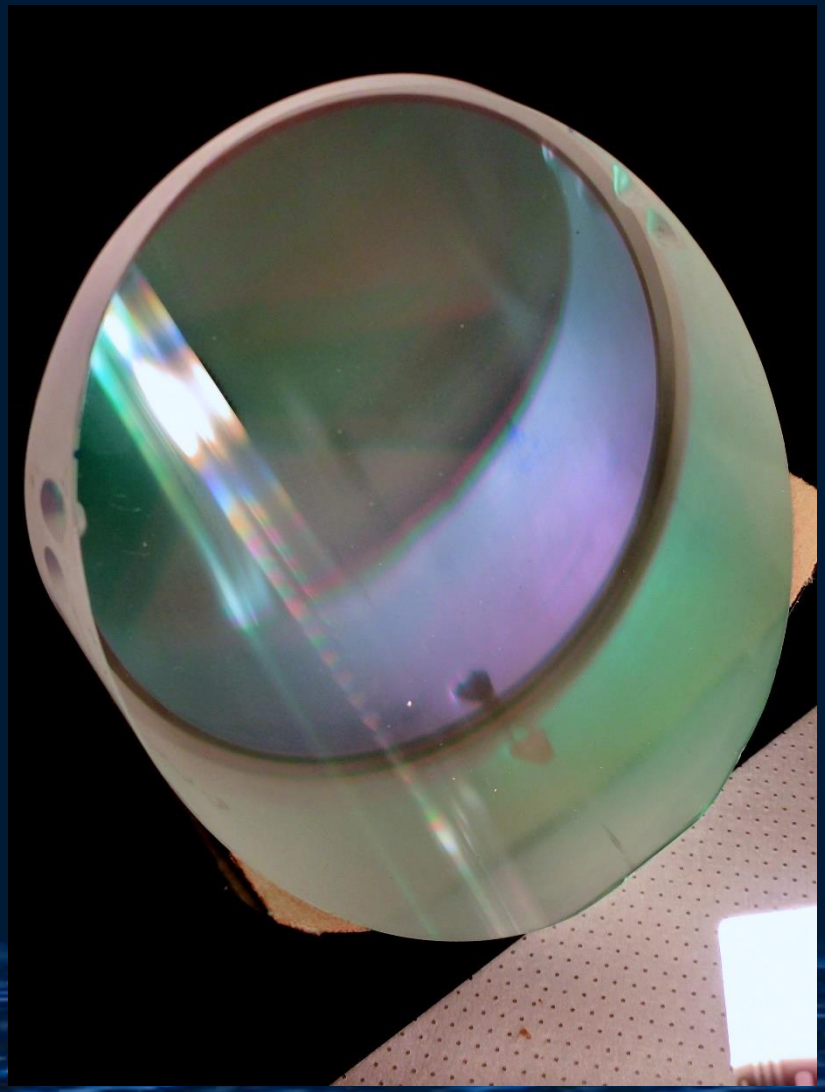
Dispersive element: pseudo-grism





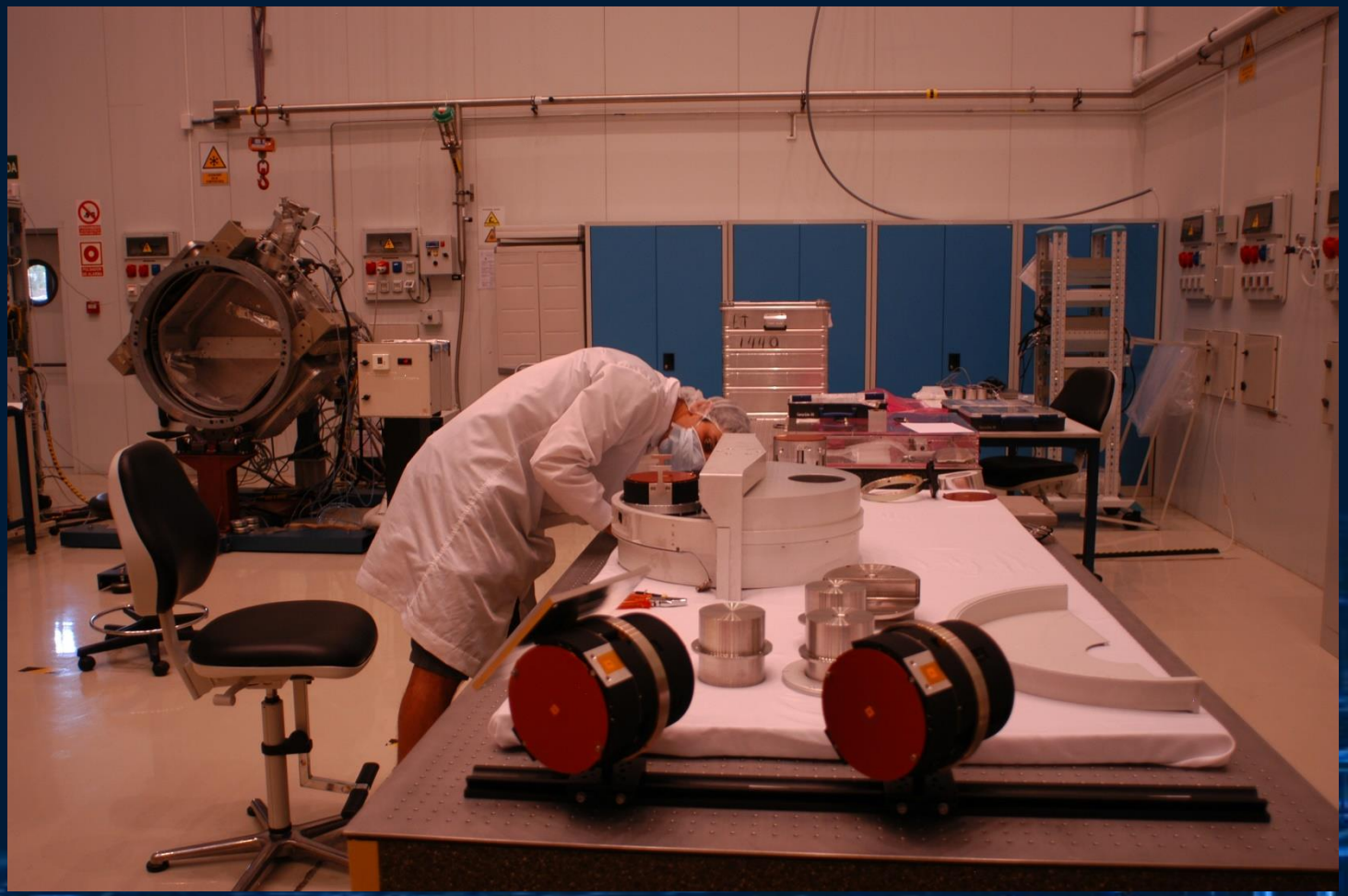


EMIR NIR imager and multi-object spectrograph

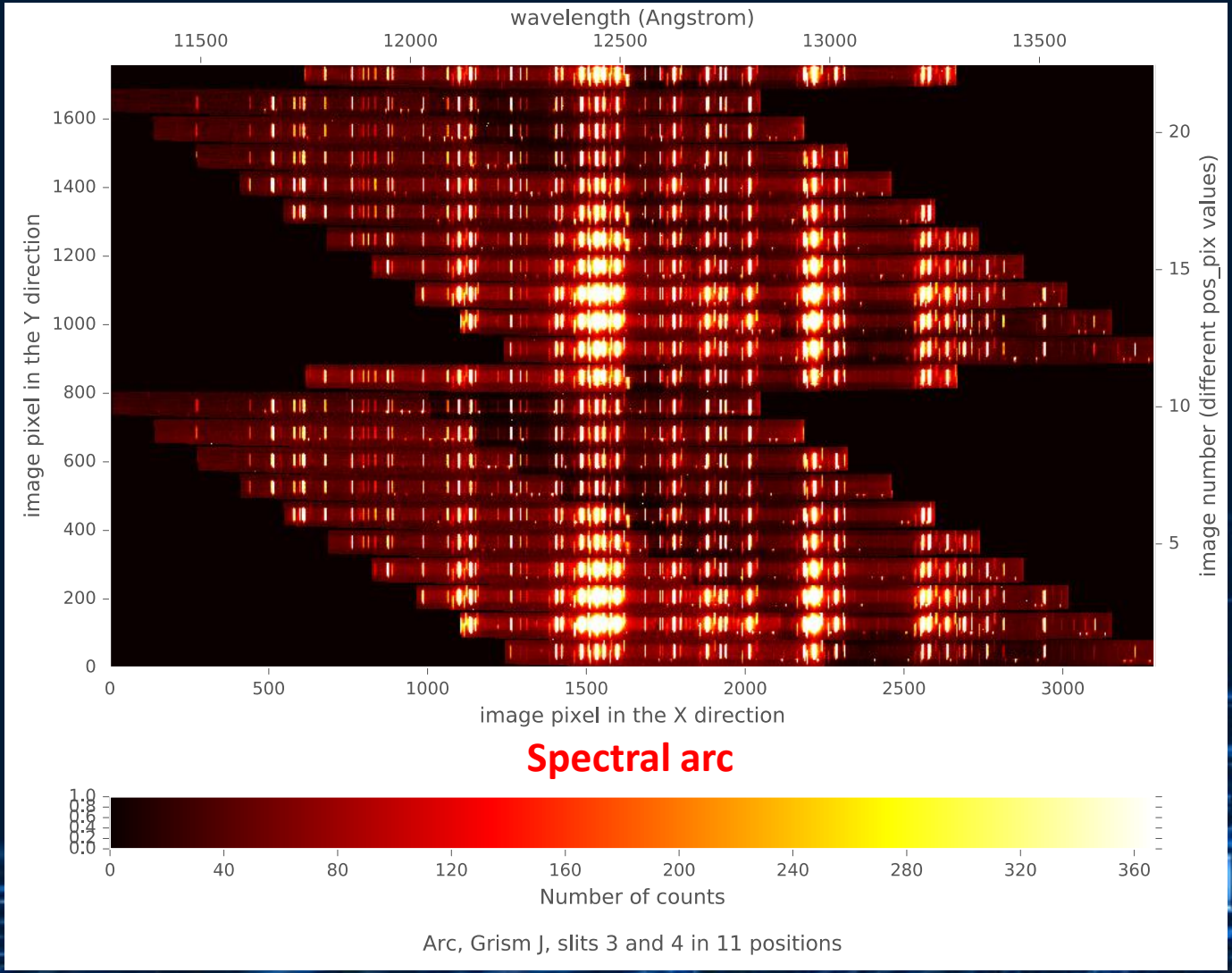


LR grism
HK 1st order
YJ: 2nd order

EMIR NIR imager and multi-object spectrograph



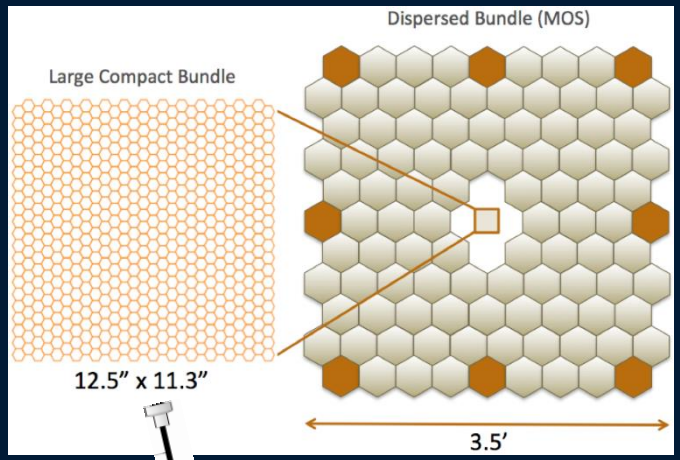
EMIR NIR imager and multi-object spectrograph

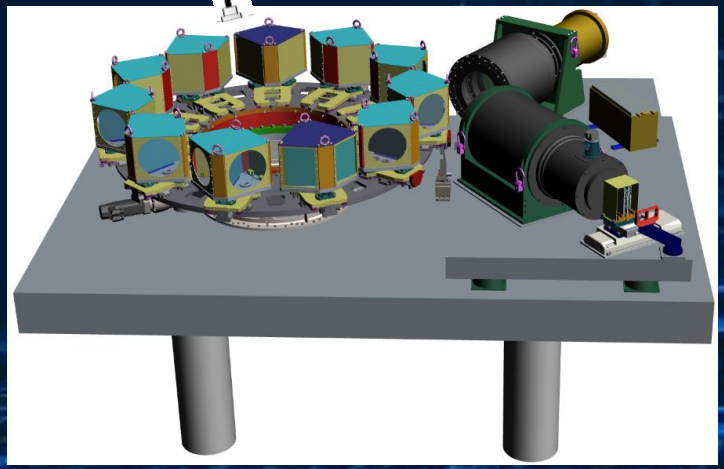


MEGARA optical medium-res multi-object spectrograph

Developed by the UCM (Spain). Commissioned on summer 2017.

Spectral range	0.365-1.000 µm
Detector	E2V CCD231-84-1-E74
IFU field of view	12.5 x 11.3 arcsec^2
IFU spaxel size	0.62 arcsec
MOS	100 x 7-fibre mini-IFUs
MOS field of view	3.5 x 3.5 arcmin^2
Spectral resolution	6000 to 18700
# of spectra	650

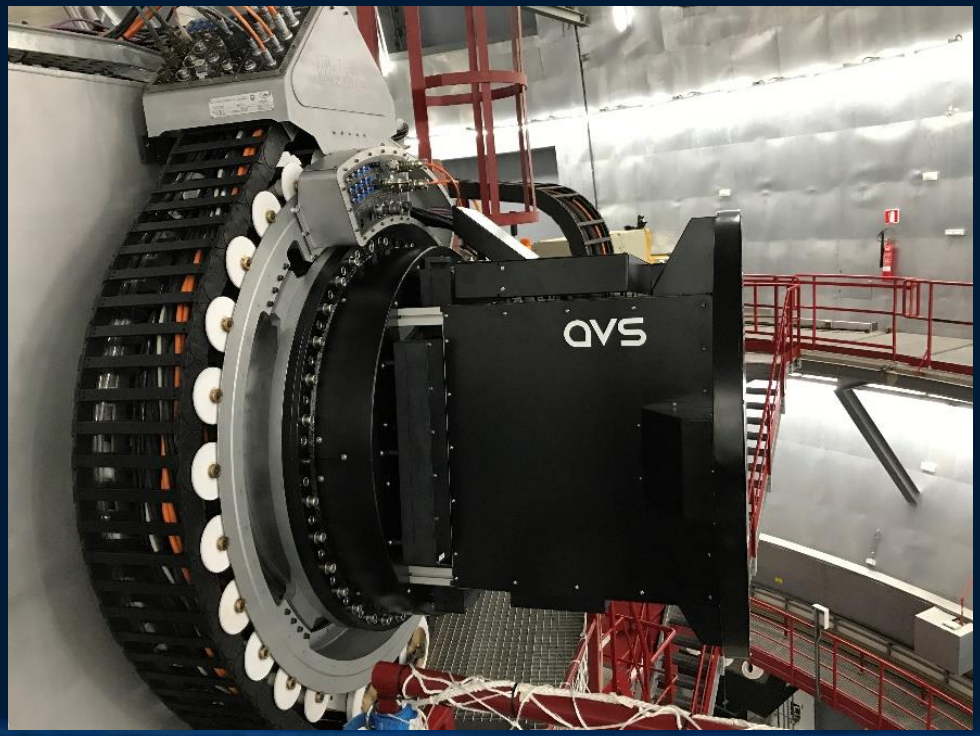


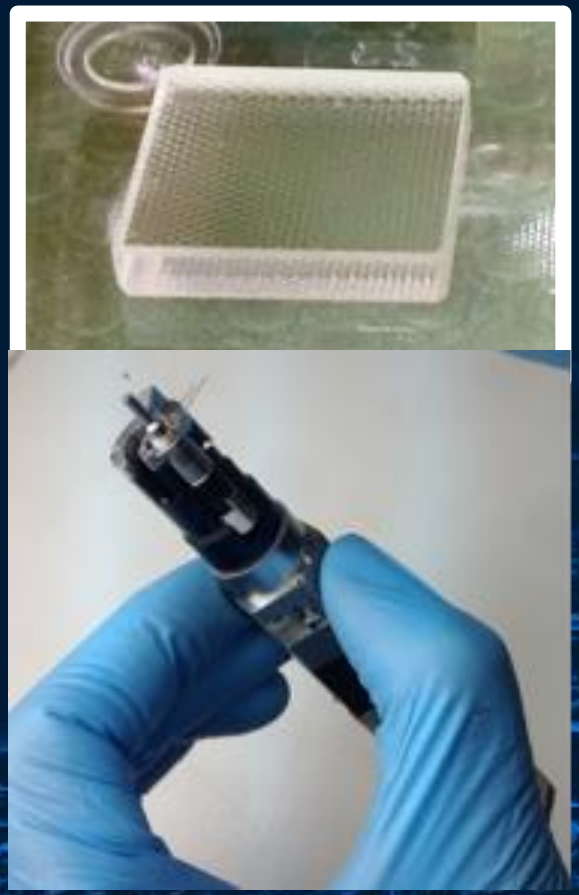


MEGARA optical medium-res multi-object spectrograph

Developed by consortium led by the UCM Spain. Commissioned on summer 2017.

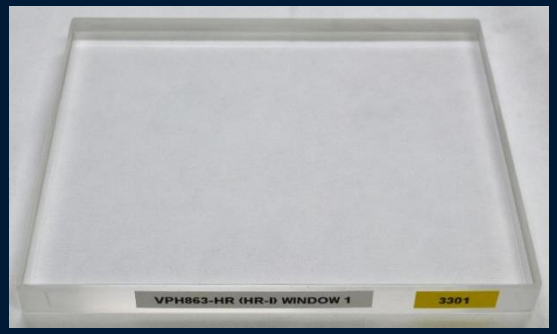
IFU microlens array →
focal ratio from f/17 to f/3

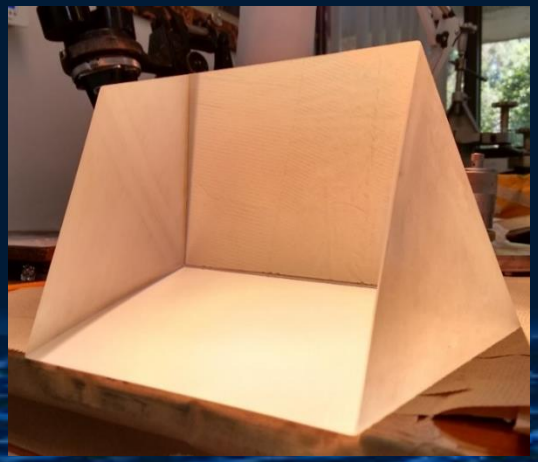


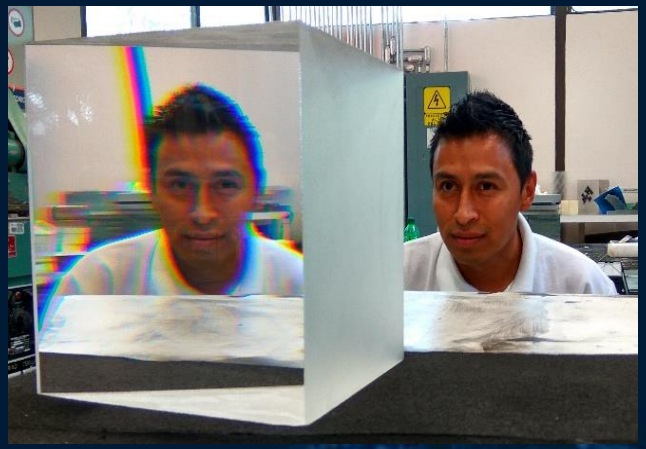


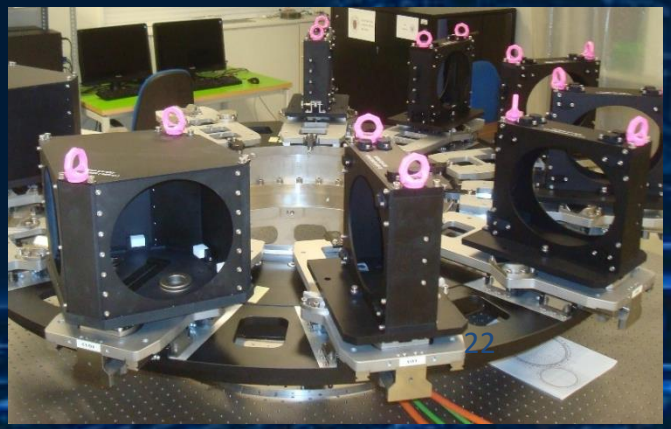
MEGARA spectral elements

(INAOE+Wasatch photonics) Volume phase holographic gratings sandwiched between two flat Fused Silica windows, in combination with prisms to keep collimator & camera angle fixed.

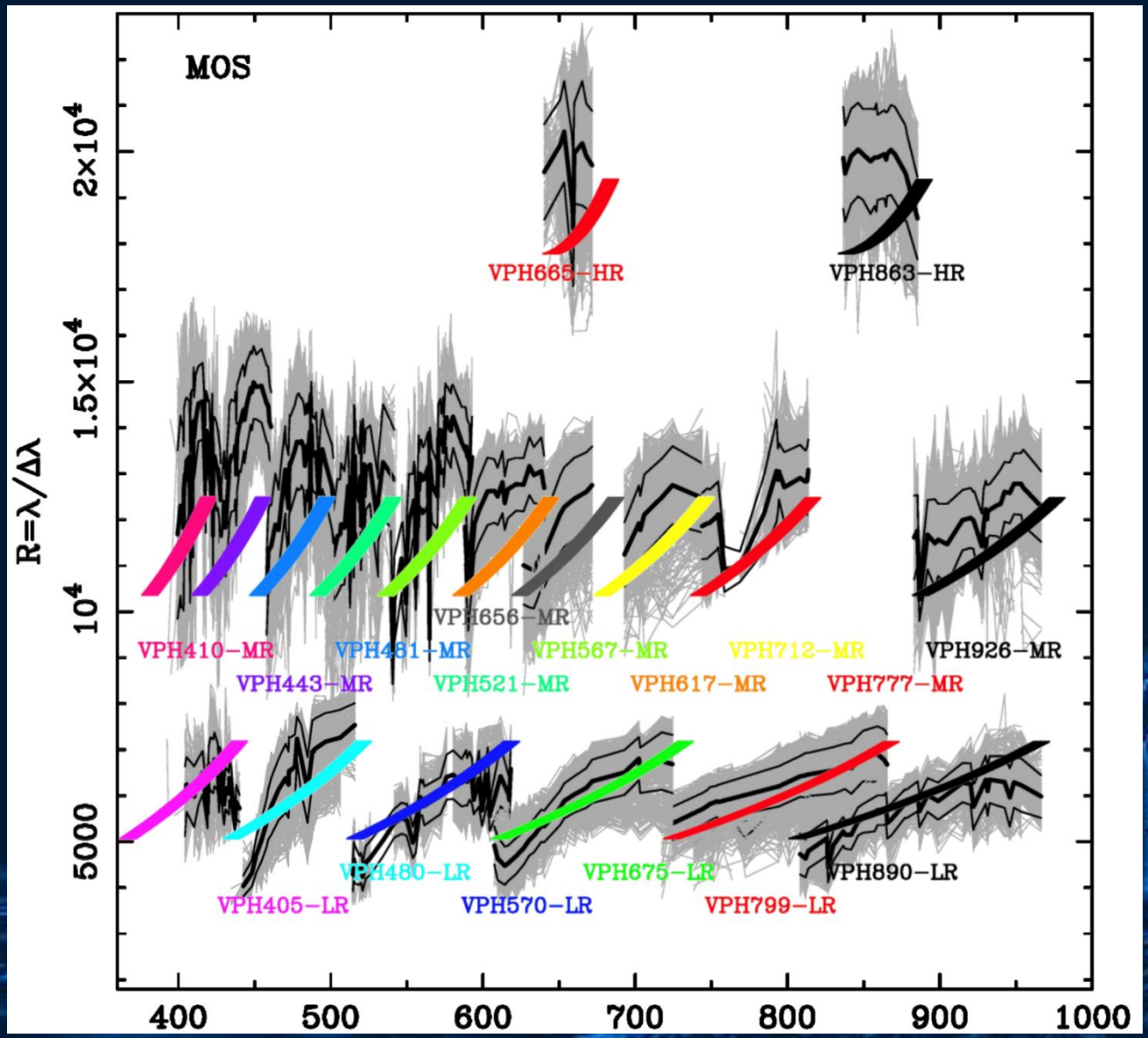




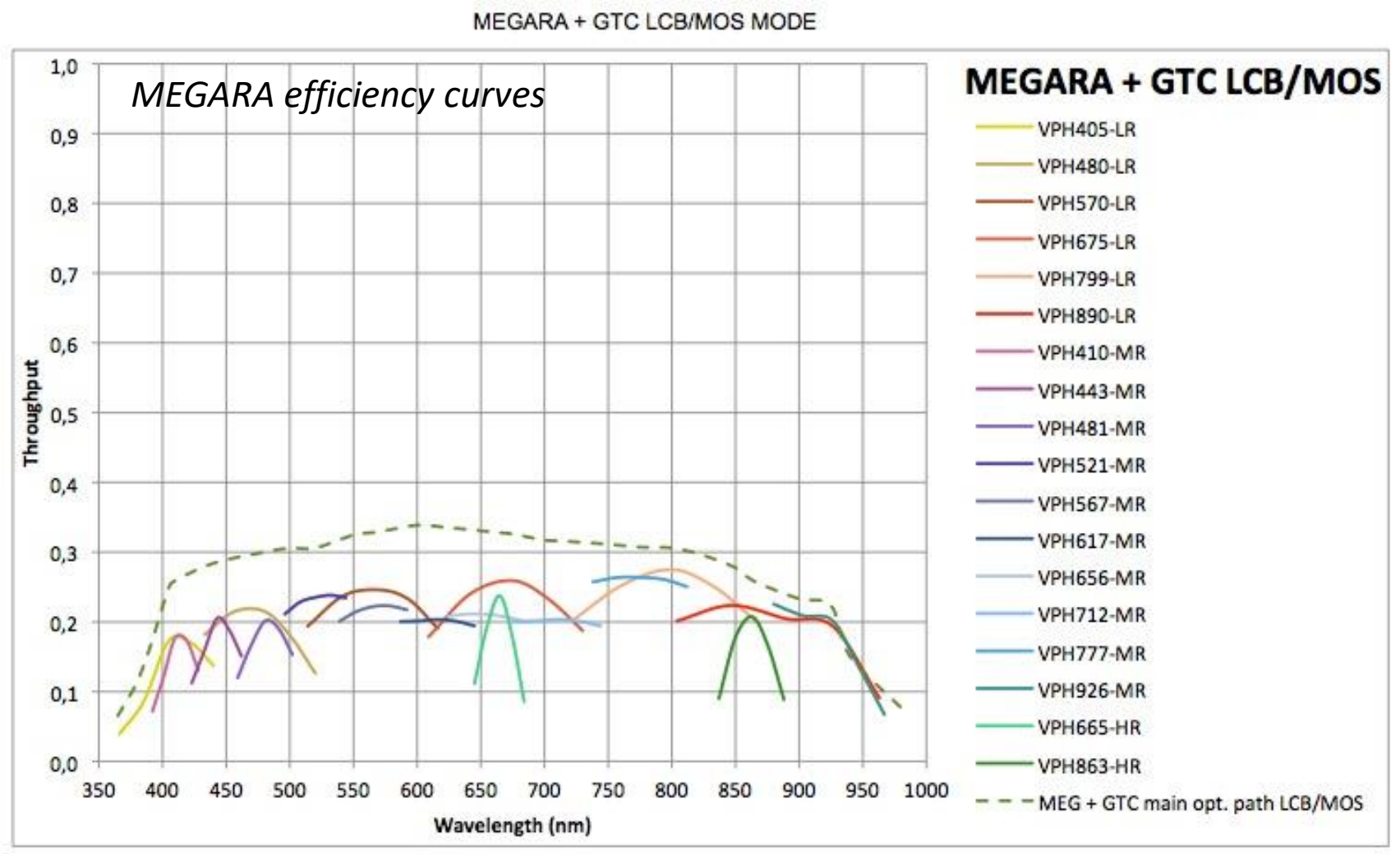




MEGARA performance



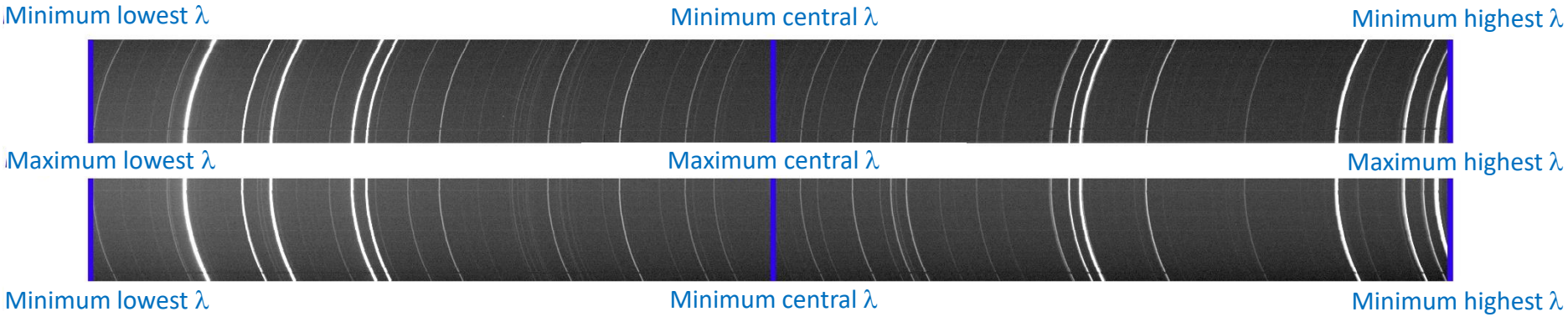
MEGARA performance



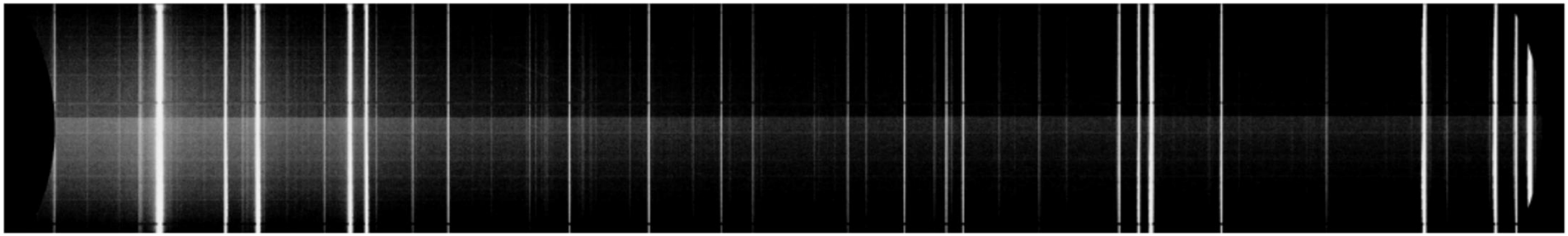
MEGARA Performance

Example (Reduced) images

Reduced image (not yet λ calibrated)



Reduced image (λ calibrated) → Online product



Beyond 2020

A formal open discussion for instrumentation plan from 2020-on will be started soon

The contribution of the community is essential

This is also an opportunity for new parties interested to join GTC