# Overview of the Instruments on the 10.4-m Gran Telescopio Canarias (GTC)

**Based on the presentation given by Dr. Antonio L. Cabrera-Lavers at GTC and the GTC website (http://www.gtc.iac.es/instruments/instrumentation.php)**


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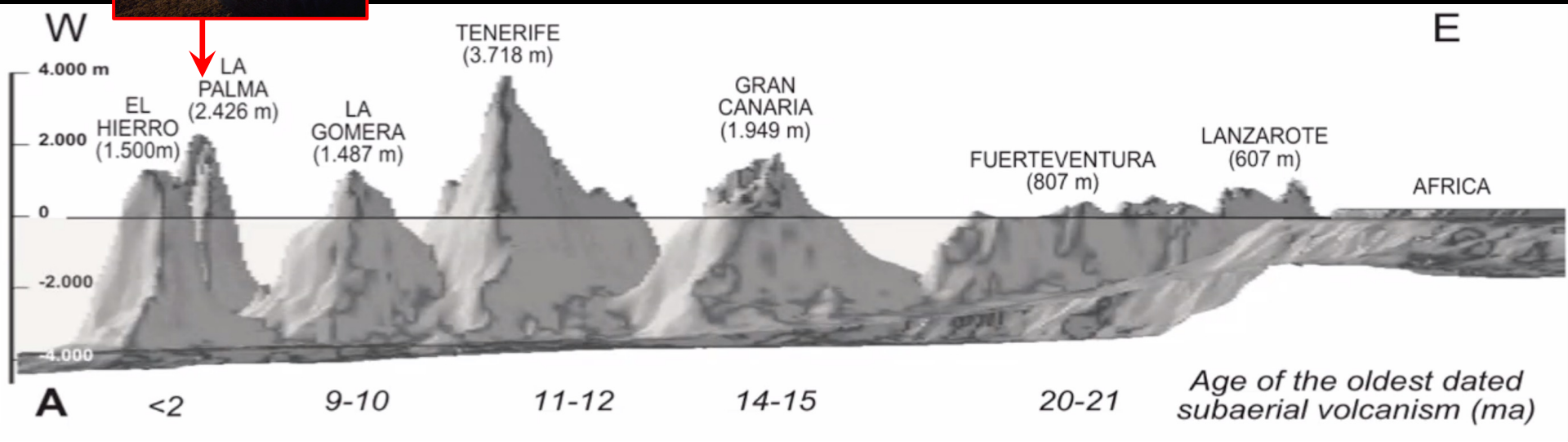
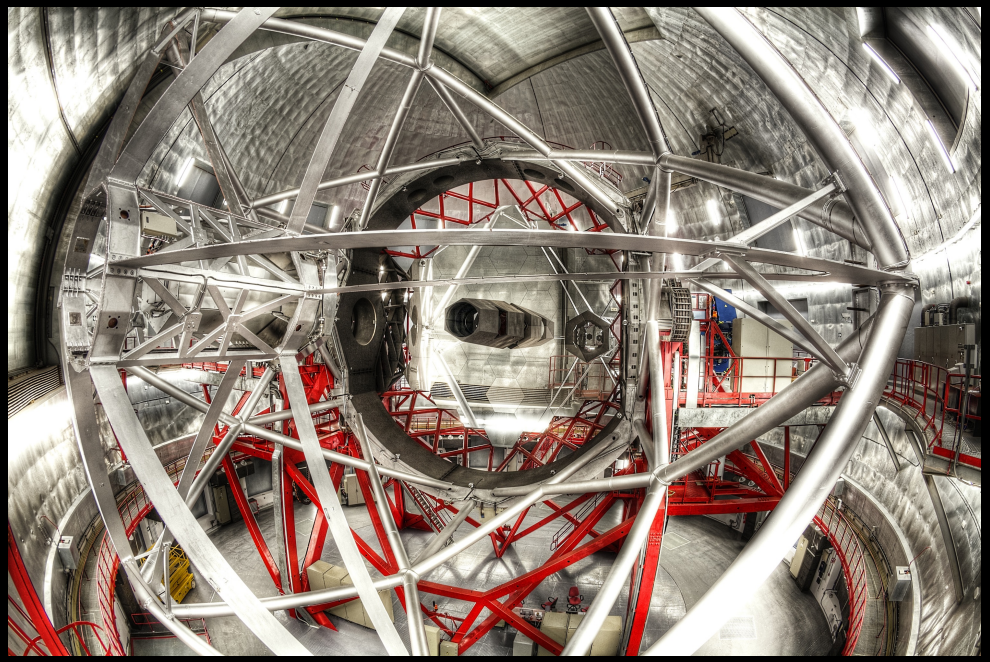
2023年8月31日，山东威海

# Canary Islands of Spain



# Gran Telescopio Canarias (GTC)

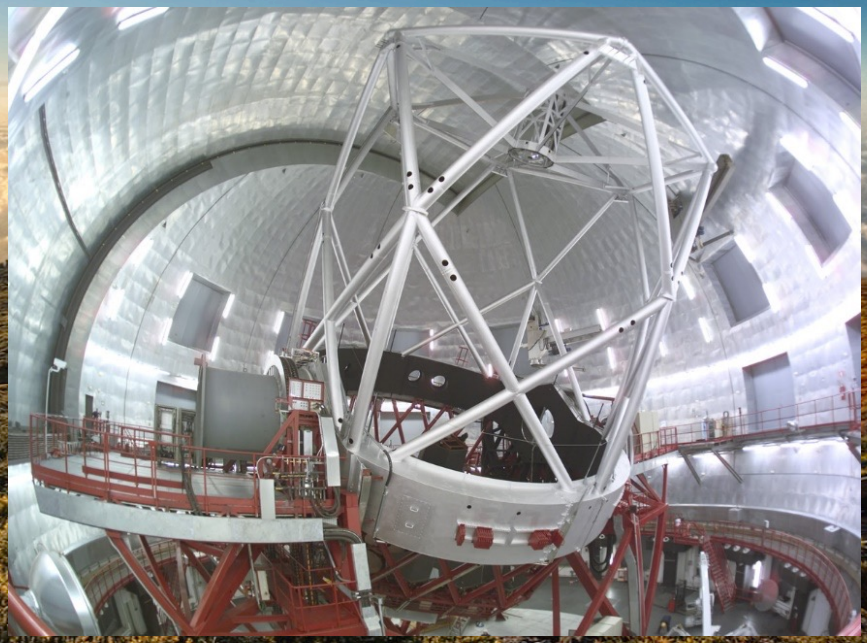
- **GTC** telescope is an initiative of the Instituto de Astrofísica de Canarias (**IAC**)
- Funded by Spain (90%), México (5%), and the University of Florida (2.5-5%)
- GRANTECAN is the company that built, operates, maintains and upgrades GTC
- The GRANTECAN team consists of 78 support astronomers, engineers, technicians and administrative staff: 61 are based on La Palma, and 17 in Tenerife at the IAC headquarters



# The telescope: general information

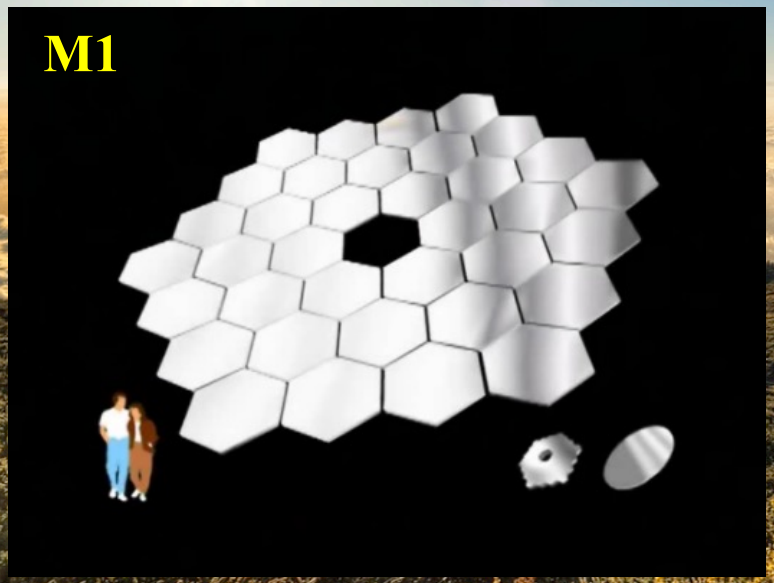
- GTC is located at 2267 m.a.m.s.l. at Observatorio del Roque de los Muchachos (ORM), La Palma, Spain.
- Construction started in 2000, first light in 2007; operations in 2009.
- 10.4m alt-az, Ritchey-Chrétien configuration
- Effective collecting area 73 $m^2$
- Effective focal length 169.9 m → plate scale 1.21 arcsec $mm^{-1}$
- Total telescope moving weight 400 tons

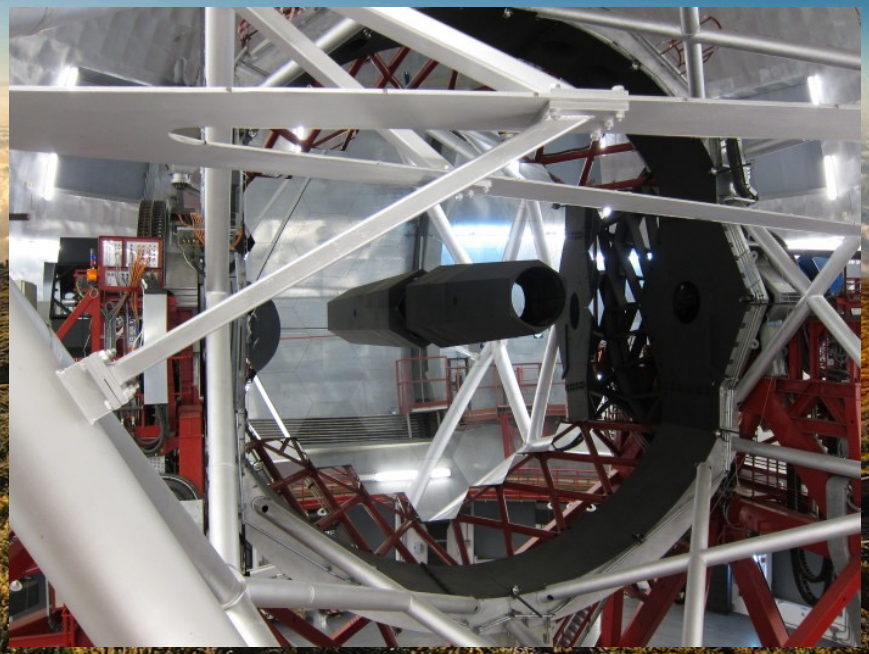
| Focus | Field of view Ø |
|---|---|
| Nasmyth | 20 arcmin (1 m) |
| Cassegrain | 15 arcmin |
| Folded Cass. | 5 arcmin |



# The telescope: the main mirror (M1)

- 36(+6) hexagonal aluminium-coated Zerodur segments, each 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)

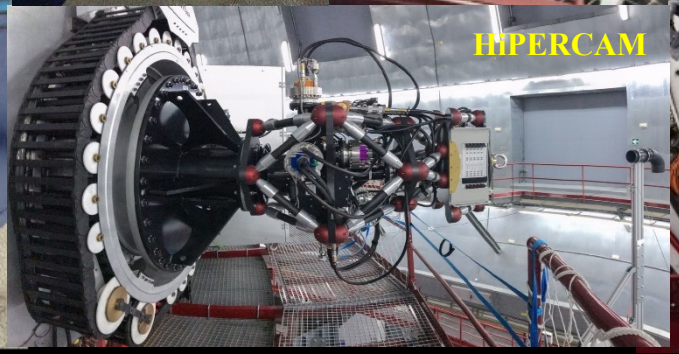


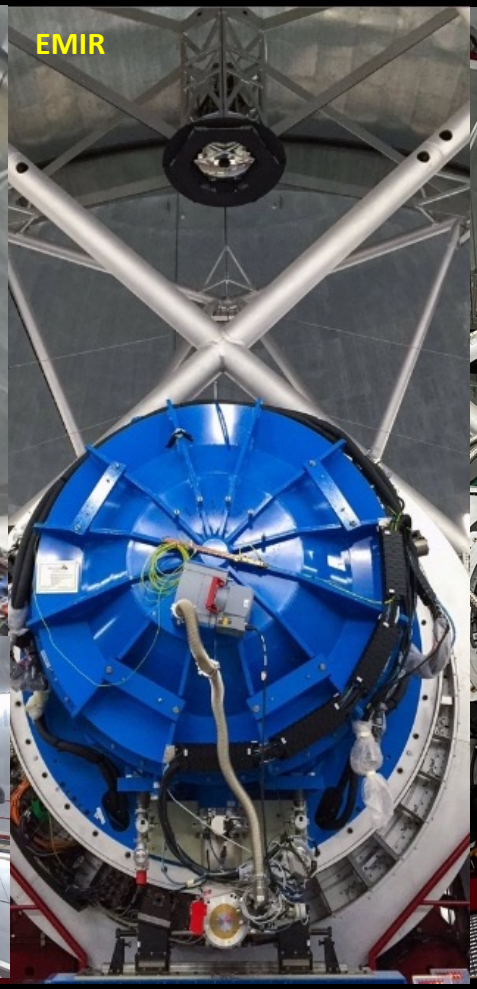



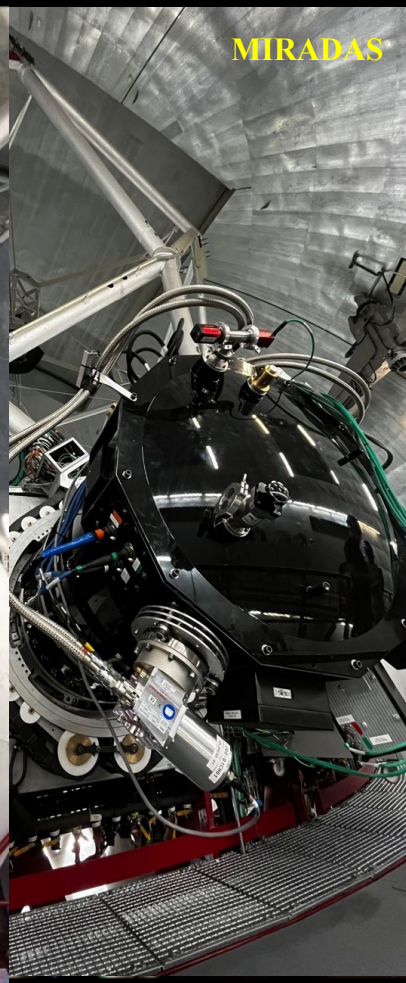
# Current instrumentation status of GTC







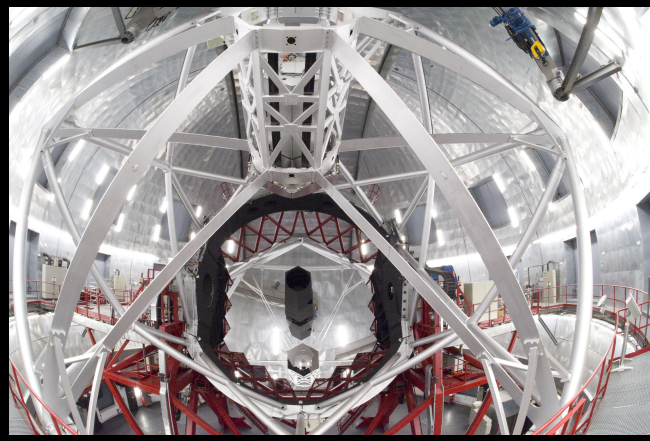



# GTC focal stations

# GTC instruments

**Goals:**

1) a good balance between general-purpose instruments covering a wide spectral range (e.g. OSIRIS/MEGARA + EMIR/MIRADAS) and instruments designed to provide specific capabilities which raise the scientific competitiveness of the GTC
2) Versatility provided by the number of available foci



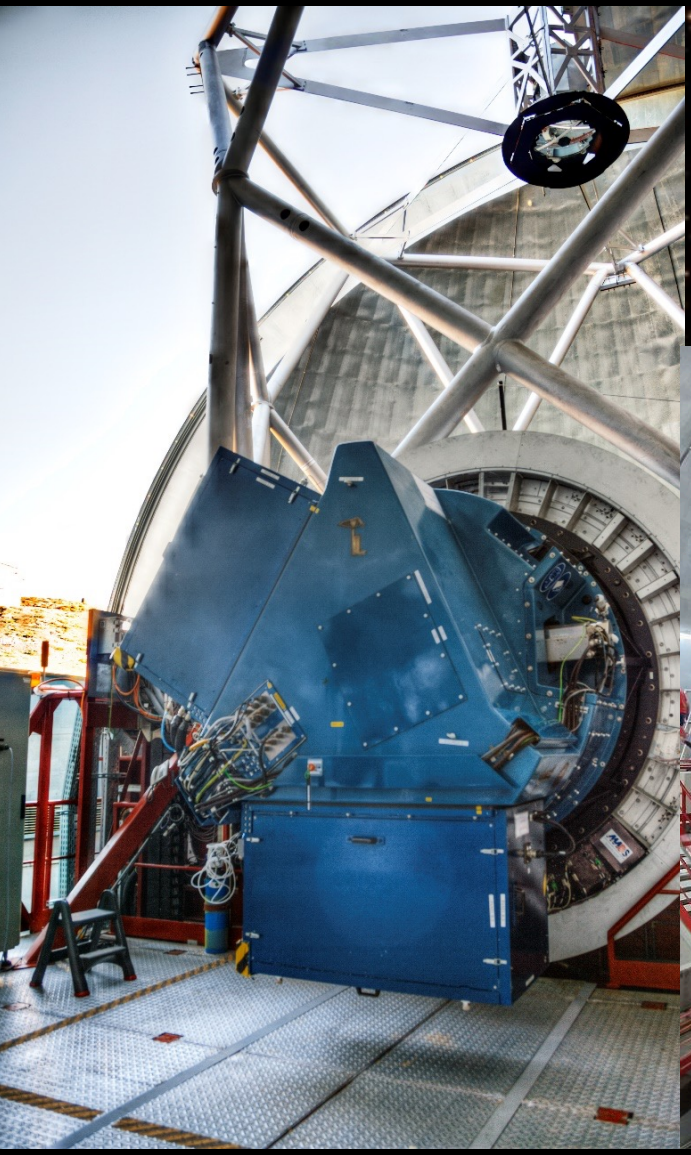
**Distinguished features**:

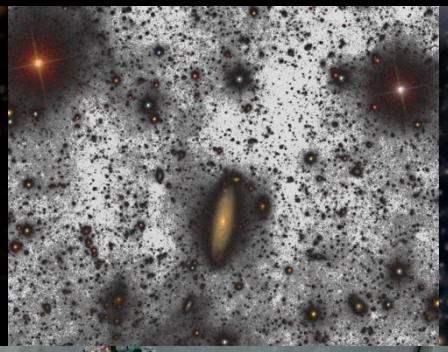
- **Tunable filters** (OSIRIS)
- **Fast imaging** (HiPERCAM)
- **High-resolution ultra-stable spectroscopy** (CHORUS)
- **MOS** (OSIRIS, EMIR, MEGARA, MIRADAS)
- **IFU at low to intermediate spectral resolution** (MAAT, MEGARA, MIRADAS, FRIDA)

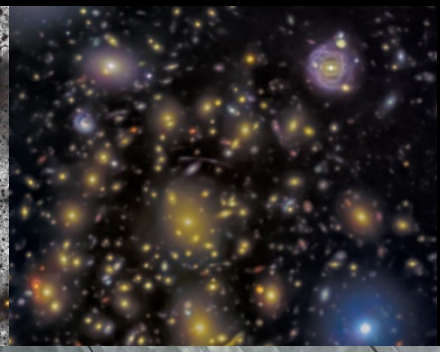
The combination of these features and the large collecting area make them unique instruments, and with higher sensitivity than other similar instruments

# OSIRIS imager and spectrograph

http://www.gtc.iac.es/instruments/osiris/







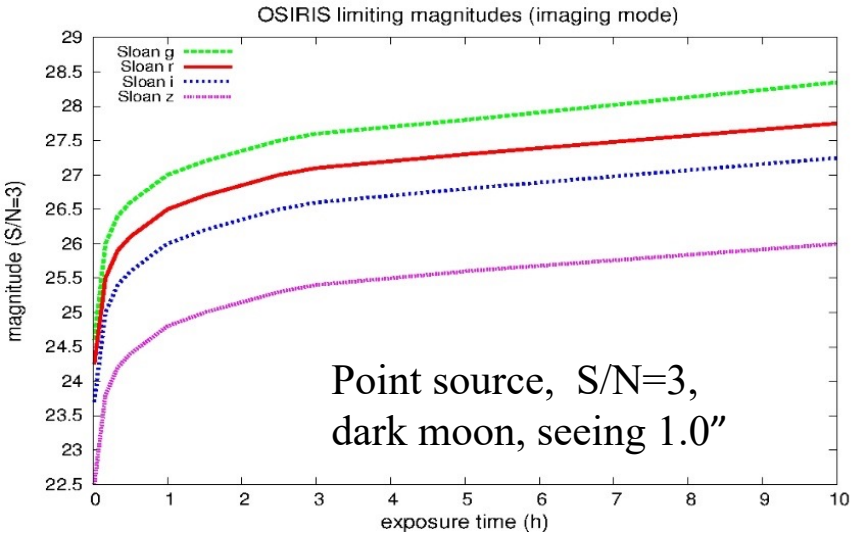
# OSIRIS imager and spectrograph

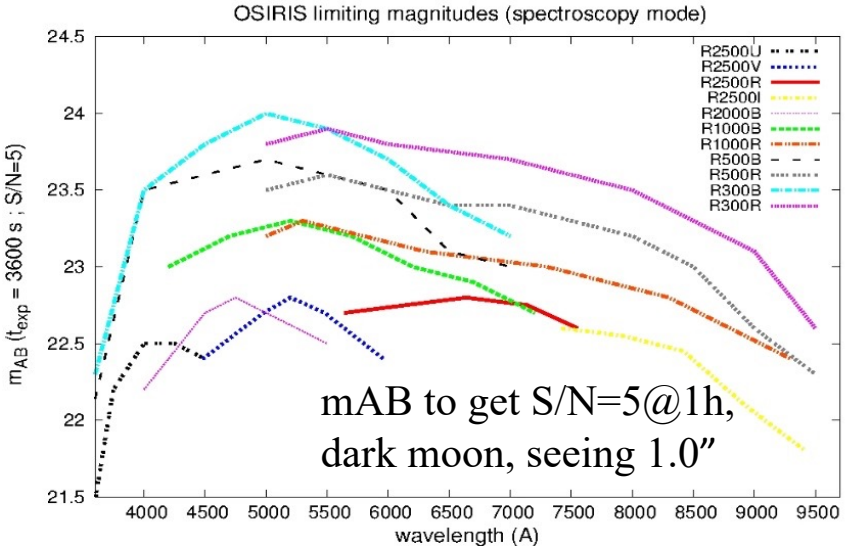
OSIRIS (**O**ptical **S**ystem for **I**maging and low-Intermediate-**R**esolution **I**ntegrated **S**pectroscopy) is a common-user instrument since 2009 (on Nasmyth B), then moved to Cassegrain in 2022, upgraded to a new blue sensitive 4k×4k monolithic CCD in December 2022 (**OSIRIS+**).

https://www.gtc.iac.es/instruments/osiris/

https://www.gtc.iac.es/instruments/osiris+/osiris+.php

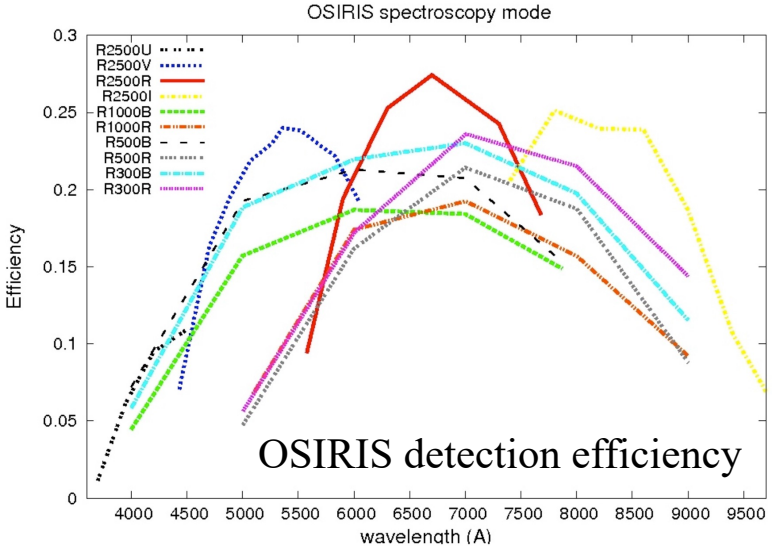
| | |
|---|---|
| *Spectral Range* | 0.36–1.00 μm |
| *Detector* | E2V CCD231-84-1-E74 |
| *Plate Scale* | 0.125 arcsec pix$^{-1}$ |
| *Field of view* | 7.8 × 7.8 arcmin$^2$ |
| *Imaging modes* | Broad-band<br>Medium band<br>Tunable Filters<br>Fast photometry |
| *Spectroscopic modes* | Long-Slit<br>mask MOS |
| *Spectral resolution* | *R* ~300 to 2500 |

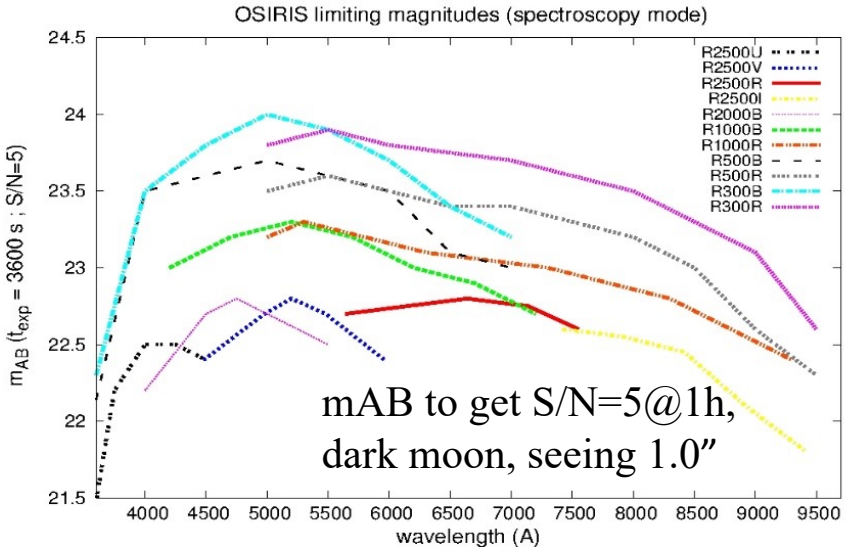


# OSIRIS imager and spectrograph

| ID | $\lambda_c$(A) | λ range (A) | D (A/pix) | Resolution | Peak Efficiency | Type | Efficiency |
|---|---|---|---|---|---|---|---|
| R300B | 4405 | 3600 -7200 | 4.96 | 360 | 70% | Grism | graph |
| R300R | 6635 | 4800 - 10000 | 7.74 | 348 | 70% | Grism | graph |
| R500B | 4745 | 3600 - 7200 | 3.54 | 537 | 68% | Grism | graph |
| R500R | 7165 | 4800 - 10000 | 4.88 | 587 | 67% | Grism | graph |
| R1000B | 5455 | 3630 - 7500 | 2.12 | 1018 | 65% | Grism | graph |
| R1000R | 7430 | 5100 - 10000 | 2.62 | 1122 | 65% | Grism | graph |
| R2000B | 4755 | 3950 - 5700 | 0.86 | 2165 | 87% | VPH | graph |
| R2500U | 3975 | 3440 - 4610 | 0.62 | 2555 | 70% | VPH | graph |
| R2500V | 5185 | 4500 - 6000 | 0.80 | 2515 | 80% | VPH | graph |
| R2500R | 6560 | 5575 - 7685 | 1.04 | 2475 | 80% | VPH | graph |
| R2500I | 8650 | 7330 - 10000 | 1.36 | 2503 | 80% | VPH | graph |



# OSIRIS upgrade (OSIRIS+)

https://www.gtc.iac.es/instruments/osiris+/osiris+.php

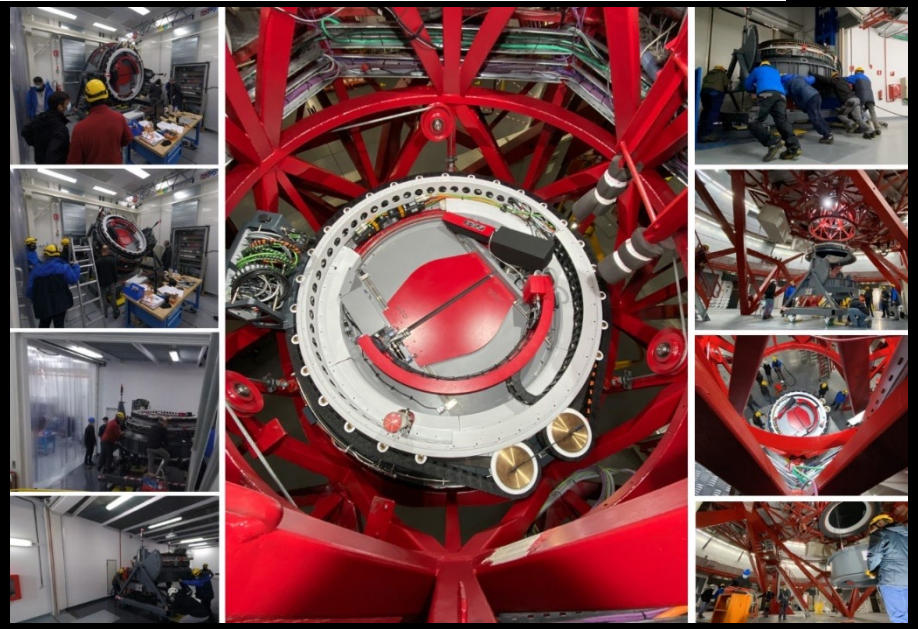
OSIRIS+ stands for the complete upgrade of OSIRIS instrument carried out along 2022, with the installation of OSIRIS at Cassegrain focal station first, and with the use of a new blue sensitive monolithic detector later. In this manner, **from January 1st 2023 all the science observations with OSIRIS are obtained with this new OSIRIS+ configuration**, with the need of adapting all the related information (data reduction, data format, etc..) accordingly.

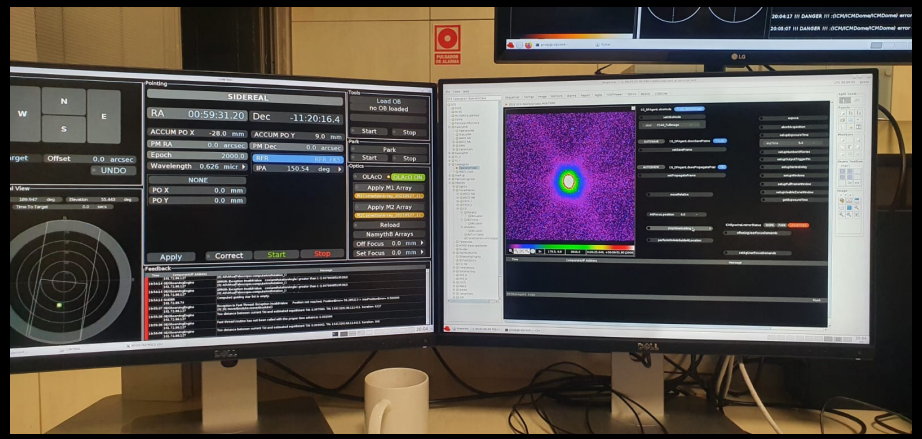
New focal station (Cassegrain) installed in December 2020, operative in November 2021, and on sky commissioning completed in February 2022.

OSIRIS was installed at the new focal station (Cassegrain) in February 2022.

First science observations obtained on late April 2022 (without ICM), and routinely observations began in July 2022.

OSIRIS new monolithic CCD was installed and commissioned at the instrument in December 2022, **included in the scientific operations in late 2022B/2023A**



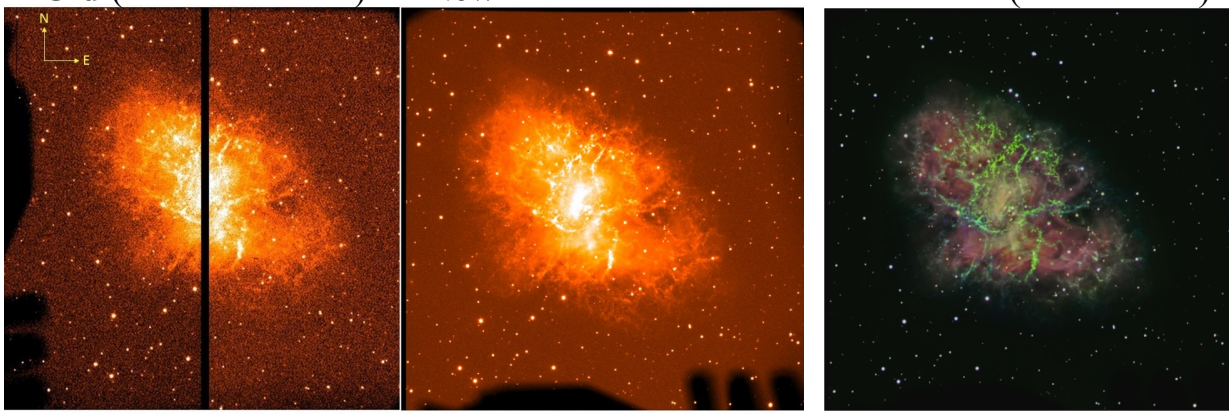


# OSIRIS upgrade (new CCD)

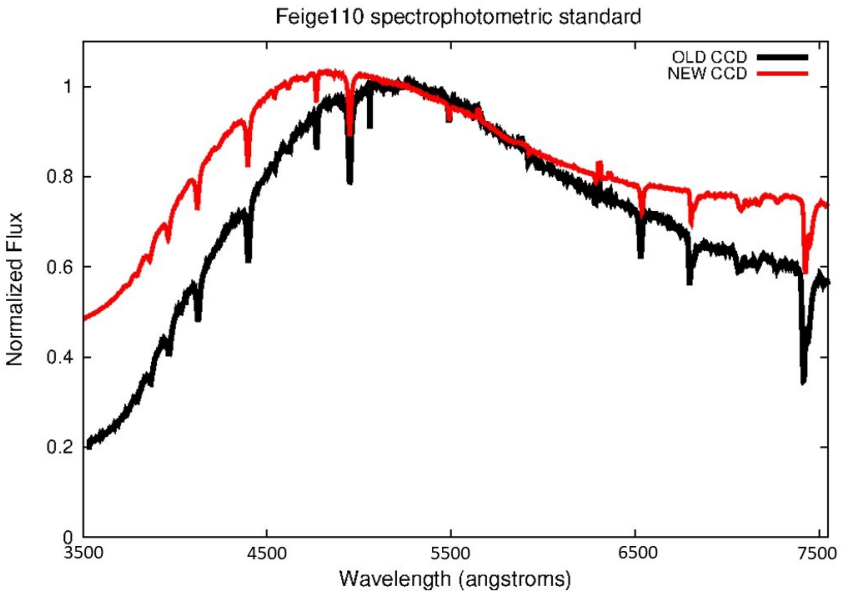
**Notable sensitivity gain** at blue wavelengths (0.5–1.2 mag); also improvement in the red

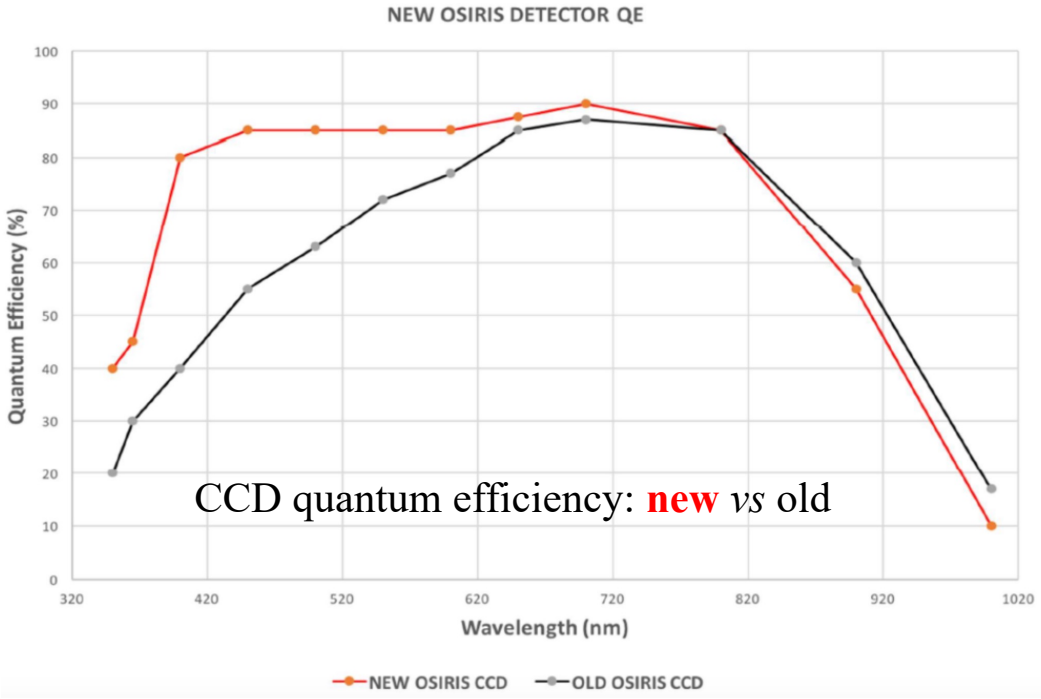
| *ZPs* | OSIRIS | OSIRIS+ * |
|---|---|---|
| *u'* | 25.7 | 26.9 |
| *g'* | 28.85 | 29.3 |
| *r'* | 29.3 | 29.4 |
| *i'* | 28.85 | 29.0 |
| *z'* | 28.15 | 28.3 |

**Old** (CCD1 + CCD2) **New** monolithic CCD New CCD (color-coded)




* Converted to 'old' CCD gain (equivalent ZPs in ADU/s are 0.7 mags lower).




CCD quantum efficiency: **new** *vs* old

# OSIRIS upgrade (new CCD)

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* Converted to 'old' CCD gain (equivalent ZPs in ADU/s are 0.7 mags lower).

| Filter | Surface mag limits ($3\sigma$; 10″×10″ boxes) mag/arsec$^2$ (1.5h on source) | Limiting magnitude ($5\sigma$; r=1″) mag (1.5h on source) |
|---|---|---|
| **Sloan *u*** | 30.3 | 26.0 |
| **Sloan *g*** | 31.5 | 27.3 |
| **Sloan *r*** | 31.0 | 26.6 |

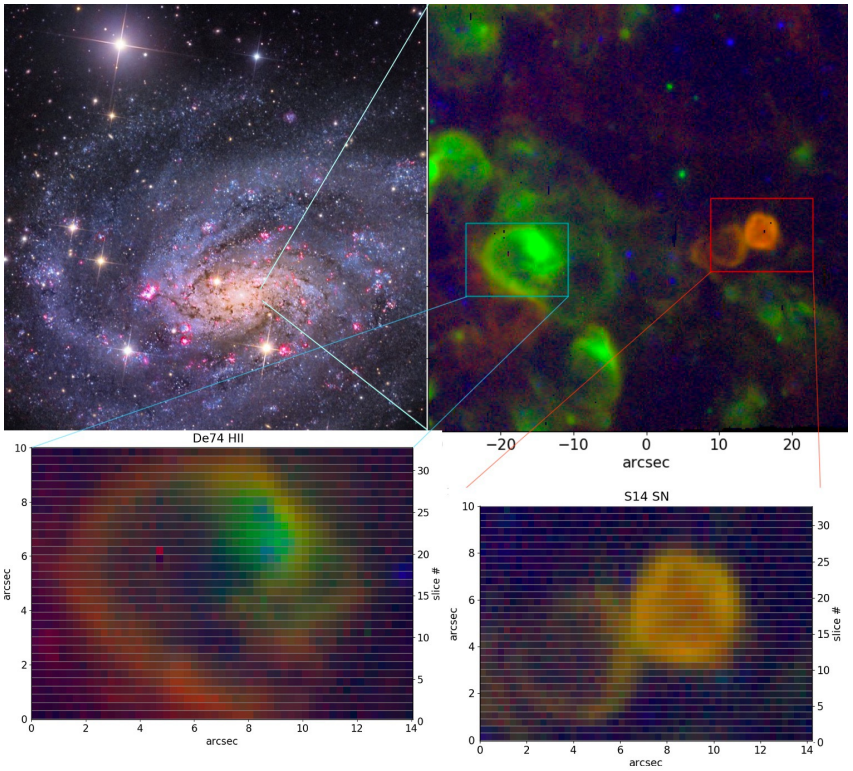
# MAAT@OSIRIS https://maat.iaa.es/

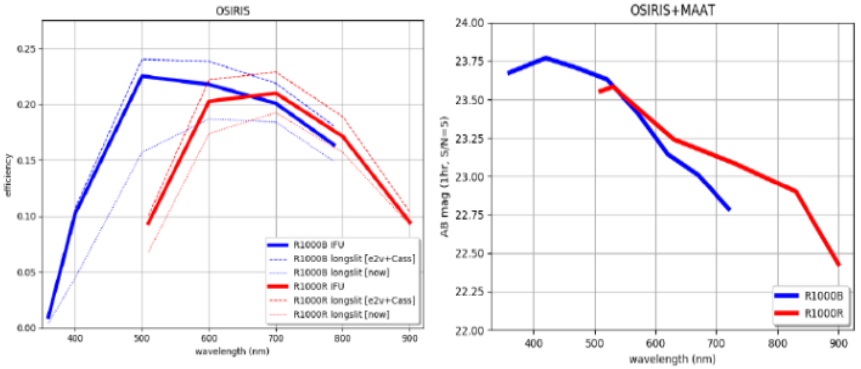
MAAT (Mirror-slicer Array for Astronomical Transients) is a mirror-slicer optical system that will allow the OSIRIS spectrograph the capability to perform Integral-Field Spectroscopy (IFS).

**In the Final Design Phase; first light by late-2024**

| | |
|---|---|
| *Spectral Range* | 0.36–1.00 μm |
| *Detector* | E2V 4k × 4k |
| *Plate Scale* | 0.127″ pix$^{-1}$ |
| *Field of view* | 12″ × 8.5″ |
| *Module* | Integral Field Unit |
| *Spatial Sampling* | 0.303″ × 0.127″ |
| *Spectral resolution* | *R* ~600–4100 |

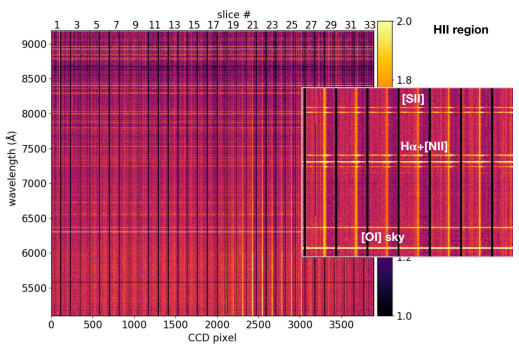
**MAAT simulation of two nebulae in NGC300:**

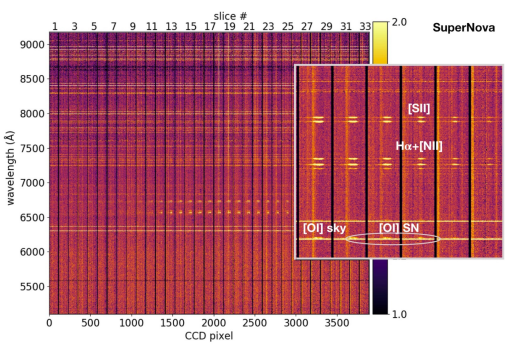








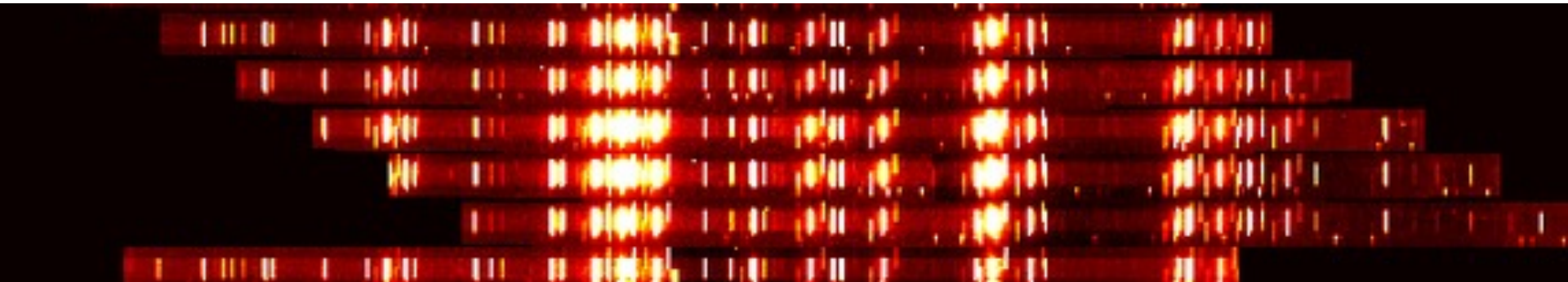



# **EMIR** NIR imager and multi-object spectrograph

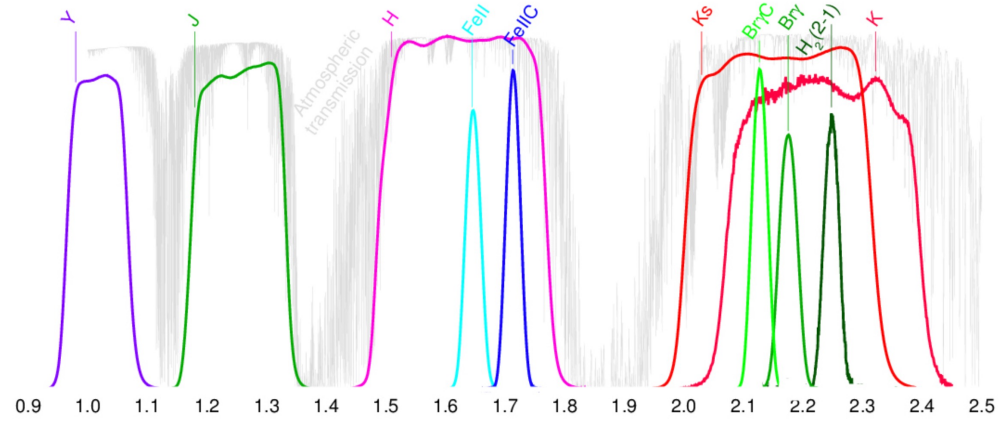
Common-user instrument since 2017 at Nasmyth-A

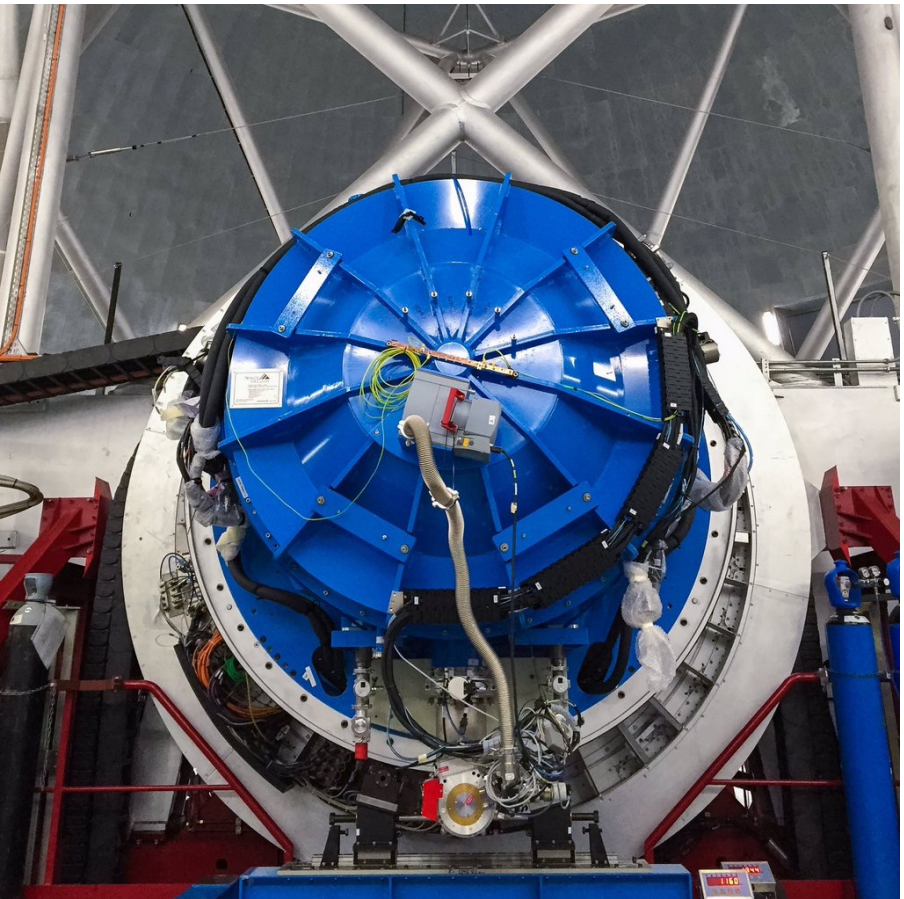
http://www.gtc.iac.es/instruments/emir/emir.php

| | | | |
|---|---|---|---|
| *Spectral Range* | 0.9–2.5μm [1.1–2.5μm] | *MOS mode* | |
| *Detector* | HAWAI2 2048 × 2048 | *FoV* | 4 × 6.67 arcmin$^2$ (55 slitlets) |
| *Spectral resolution* | 1000 (*YJ*, *HK*)<br>5000, 4250, 4000 (*JHK*) | *Sensitivity* | **<u>*K*~20.1 in 2h @ S/N=5 (continuum)</u>** |
| *Spectral coverage* | 1 single window/exp. | | 1.4 × 10$^{-18}$ erg/s/cm$^2$/Å @S/N=6 (line) |
| *Imaging modes* | broad/narrow band | *Imaging mode* | |
| *Plate Scale* | 0.1945 arcsec pix$^{-1}$ | *FoV* | 6.7 × 6.7 arcmin$^2$ |
| *Image quality* | $\theta_{80}$ < 0.3 arcsec | *Sensitivity* | **<u>*K*~22.0 in 1h, for S/N=3 & 0.6 arcsec aperture</u>** |
| *Limiting magnitudes* | *Y*=26.0, *J*=25.0, *H*=23.5, *K*=22.0 for S/N=3 ($t_{exp}$ = 1 h) | | |

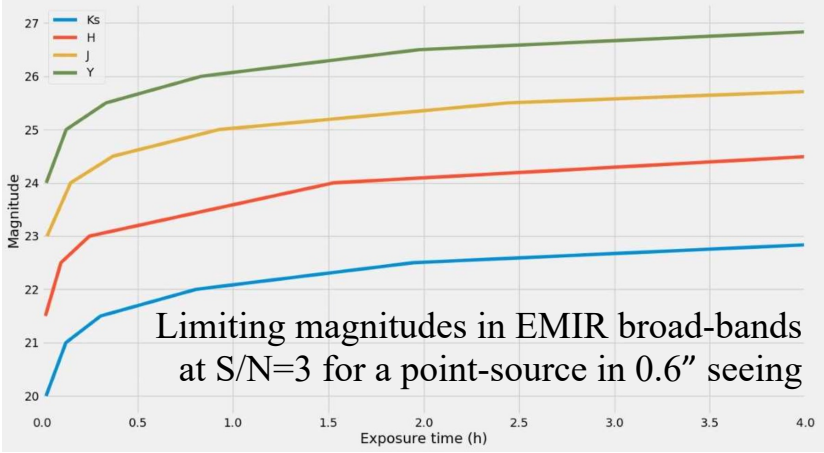


# EMIR NIR imager and multi-object spectrograph

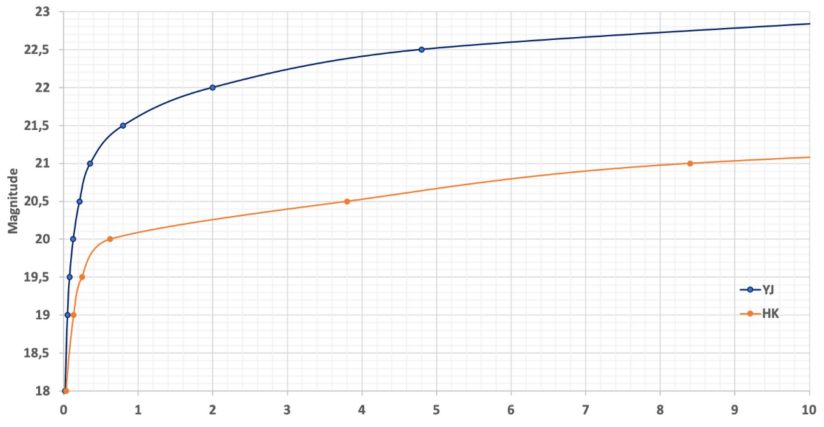


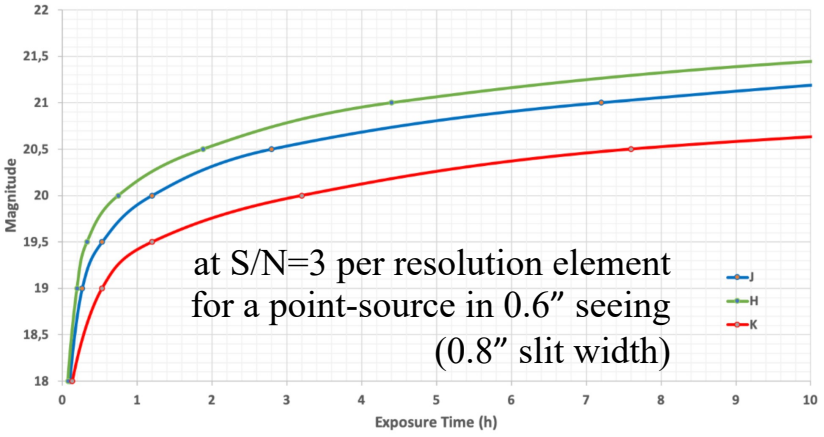



Broad-band imaging




Long-slit Spectroscopy



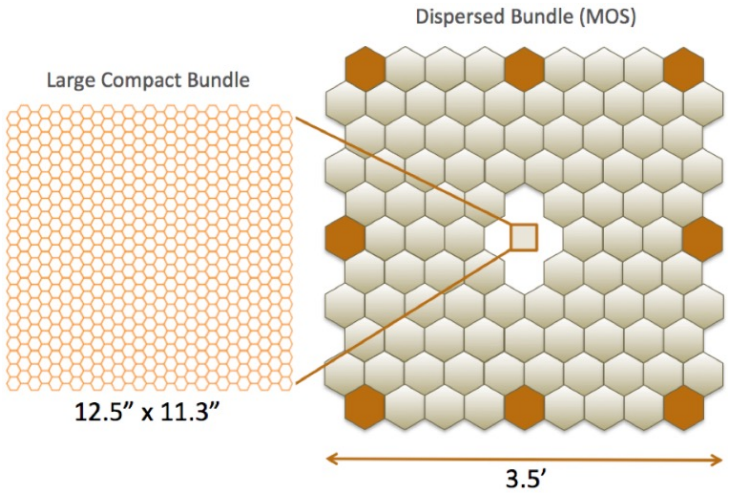



# MEGARA optical medium-resolution multi-object spectrograph

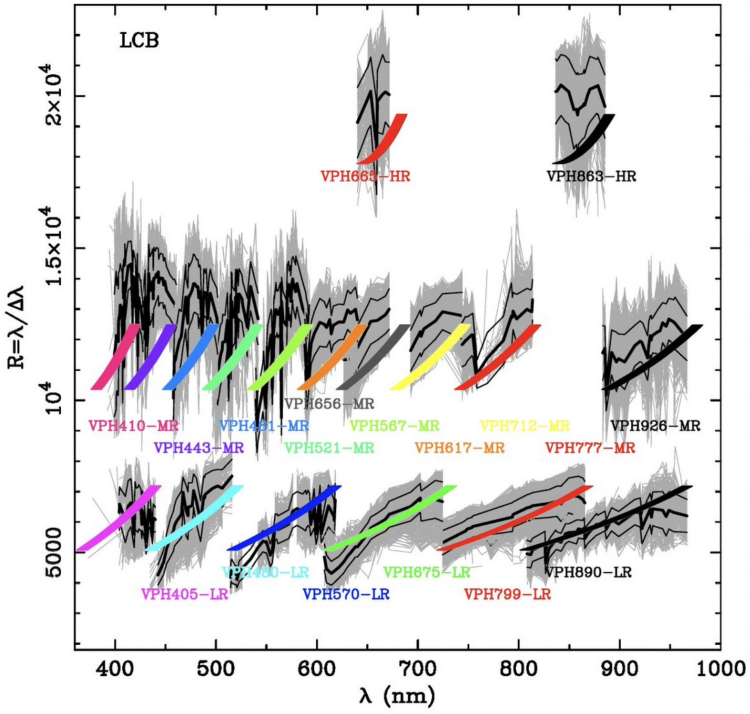
| | |
|---|---|
| *Spectral range* | 0.365–1.000 μm |
| *Detector* | 4k × 4k (15μm pixel$^{-1}$)<br>E2V CCD231-84-1-E74 |
| *IFU field of view* | 12.5 × 11.3 arcsec$^2$ |
| *IFU spaxel size* | 0.62 arcsec |
| *MOS mode* | 92 × 7-fiber mini-IFUs * |
| *MOS field of view* | 3.5 × 3.5 arcmin$^2$ |
| *Spectral resolution* | *R* ~6000–20000 |
| *No. of spectra* | 650 |

* Currently not available

http://www.gtc.iac.es/instruments/megara/megara.php

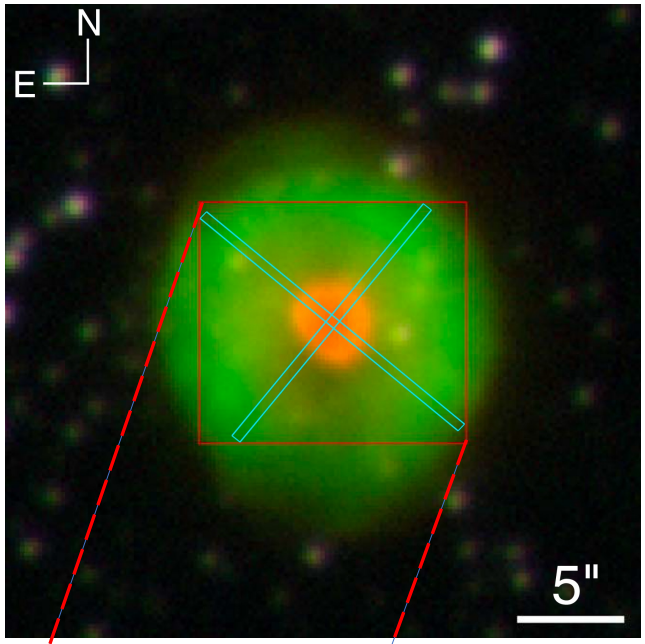


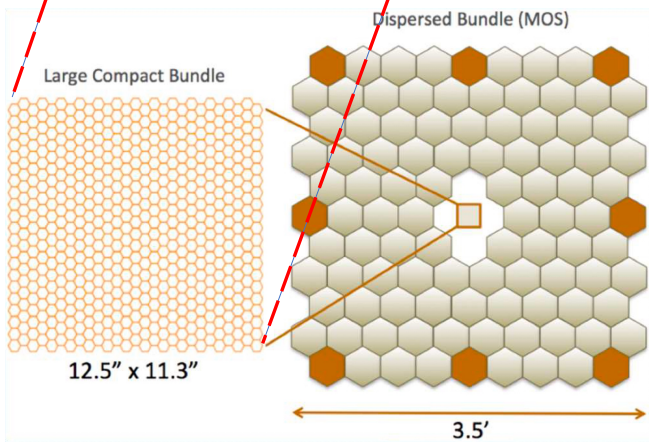

| VPH ID | Setup | $R_{FWHM}$ | $\lambda_1$-$\lambda_2$ (Å) | $\lambda_C$ (Å) | $\Delta\lambda(@\lambda_C)$ (Å) | lin res (Å/pix) |
|---|---|---|---|---|---|---|
| VPH405-LR | LR-U | 5750 | 3654.32-4391.88 | 4025.90 | 0.700 | 0.176 |
| VPH480-LR | LR-B | 5000 | 4332.05-5199.96 | 4785.32 | 0.957 | 0.207 |
| VPH570-LR | LR-V | 5850 | 5143.74-6168.19 | 5687.63 | 0.971 | 0.244 |
| VPH675-LR | LR-R | 5900 | 6096.54-7303.21 | 6729.61 | 1.141 | 0.287 |
| VPH799-LR | LR-I | 5750 | 7224.11-8640.37 | 7976.31 | 1.387 | 0.337 |
| VPH890-LR | LR-Z | 5800 | 8042.74-9634.92 | 8873.16 | 1.530 | 0.379 |
| VPH410-MR | MR-U | 13100 | 3919.81-4282.17 | 4102.87 | 0.313 | 0.086 |
| VPH443-MR | MR-UB | 13050 | 4226.38-4625.79 | 4429.44 | 0.339 | 0.095 |
| VPH481-MR | MR-B | 13200 | 4585.66-5025.07 | 4809.46 | 0.364 | 0.105 |
| VPH521-MR | MR-G | 12000 | 4963.22-5445.00 | 5208.79 | 0.434 | 0.115 |
| VPH567-MR | MR-V | 12600 | 5413.11-5923.90 | 5664.96 | 0.450 | 0.122 |
| VPH617-MR | MR-VR | 12100 | 5894.23-6448.26 | 6165.79 | 0.510 | 0.132 |
| VPH656-MR | MR-R | 12150 | 6243.10-6865.26 | 6560.33 | 0.540 | 0.148 |
| VPH712-MR | MR-RI | 12200 | 6764.58-7440.85 | 7109.81 | 0.583 | 0.161 |
| VPH777-MR | MR-I | 8600 | 7386.53-8127.95 | 7766.14 | 0.903 | 0.177 |
| VPH926-MR | MR-Z | 11600 | 8810.52-9698.97 | 9274.84 | 0.800 | 0.212 |
| VPH665-HR | HR-R | 20050 | 6405.61-6797.14 | 6602.59 | 0.329 | 0.093 |
| VPH863-HR | HR-I | 20500 | 8380.20-8882.38 | 8626.01 | 0.421 | 0.120 |



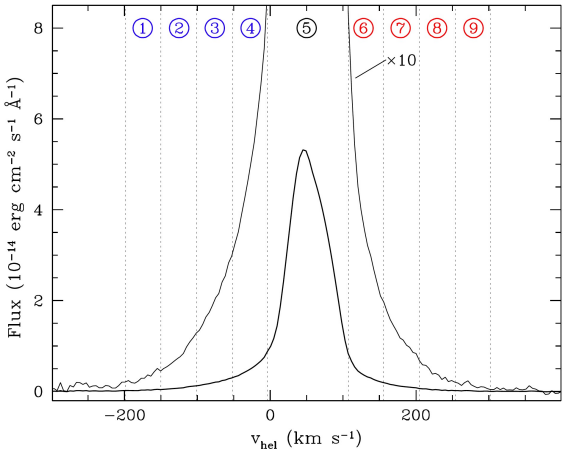
# MEGARA optical medium-resolution multi-object spectrograph

Example: GTC/MEGARA IFU observations of Galactic PN HuBi 1



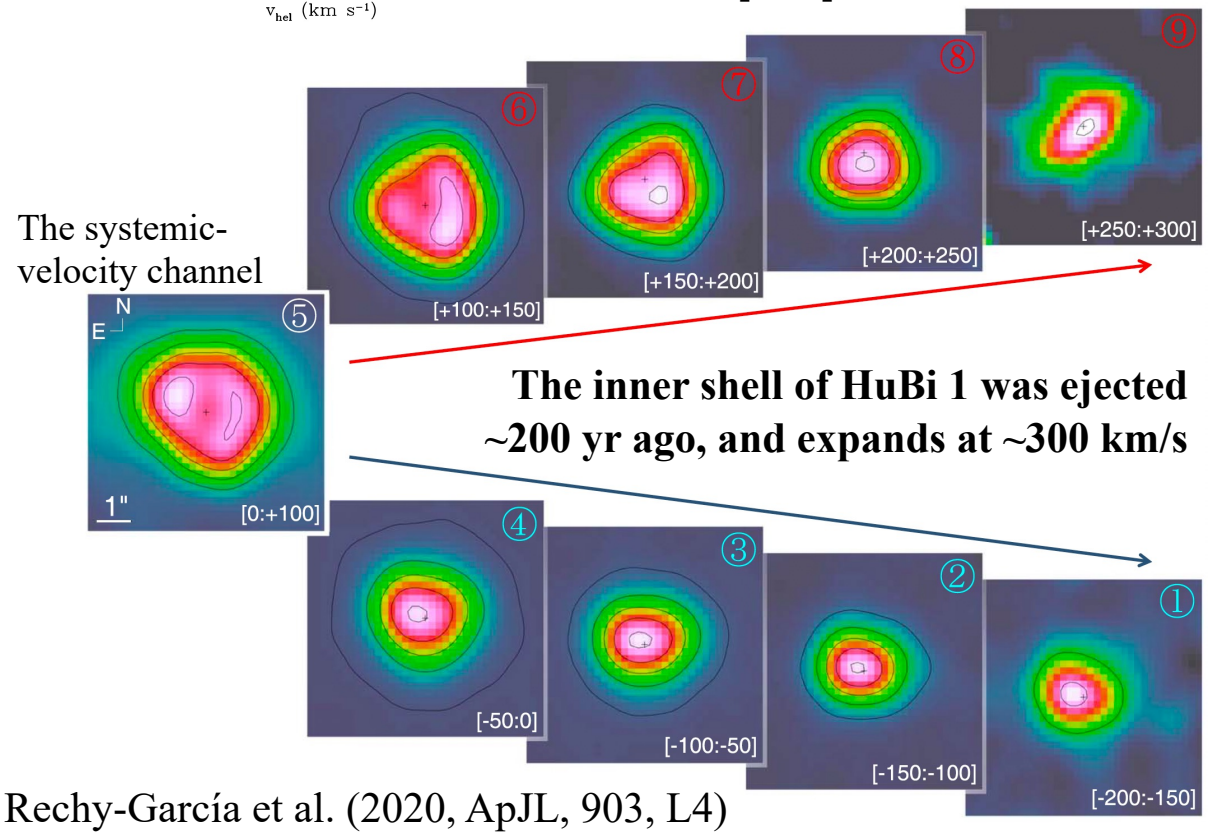




*R*~18700 ($\Delta V$ = 16 km/s)
Spaxel diameter 0.62″
VPH665-HR (6405–6797 Å)




**Left:** GTC MEGARA profile of [N II] **λ**6583 of the inner shell of HuBi 1 integrated within a circular region 2.5″ in radius

**Bottom:** MEGARA tomography of the inner shell of HuBi 1 in the [N II] **λ**6583 emission line



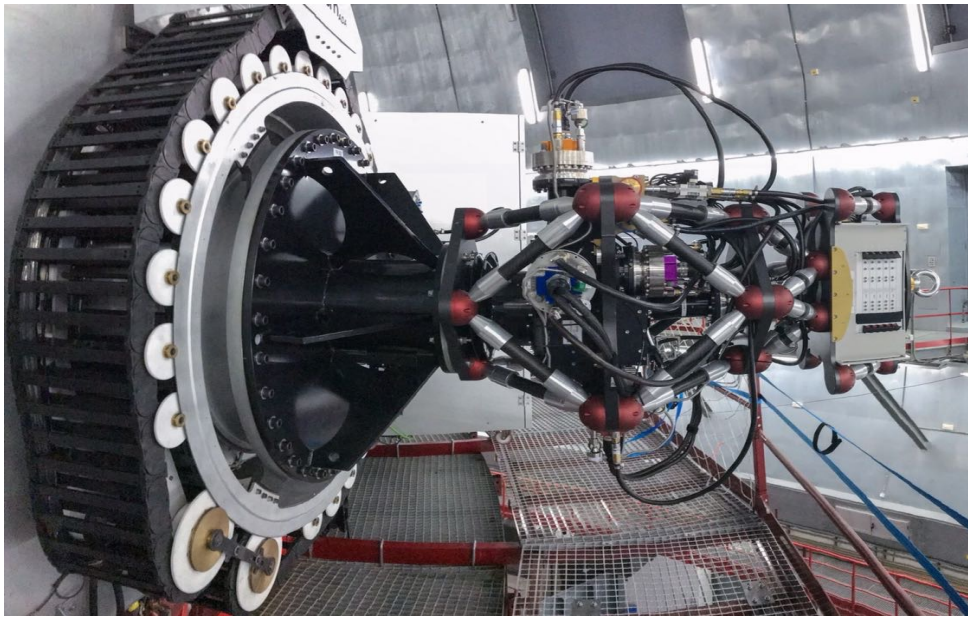

**The inner shell of HuBi 1 was ejected ~200 yr ago, and expands at ~300 km/s**

Rechy-García et al. (2020, ApJL, 903, L4)

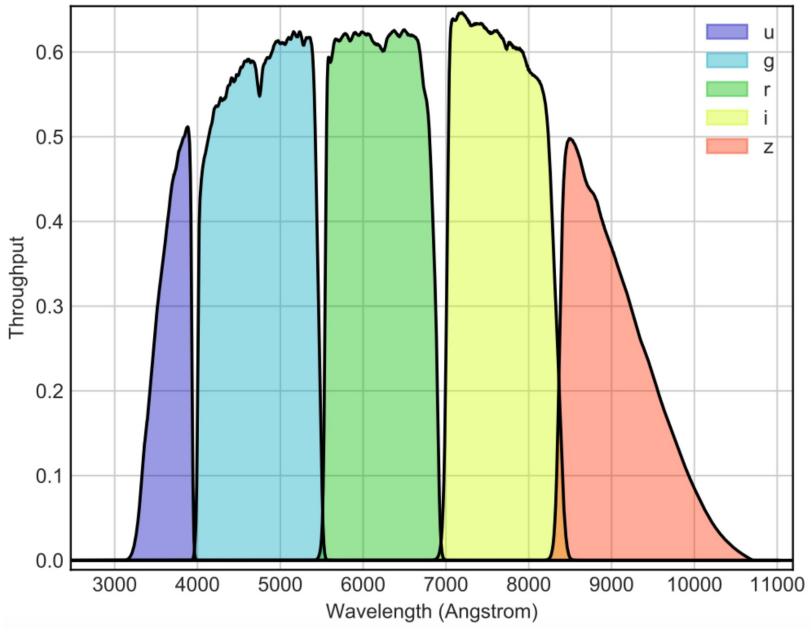
# HiPERCAM high-speed multi-band imager on GTC

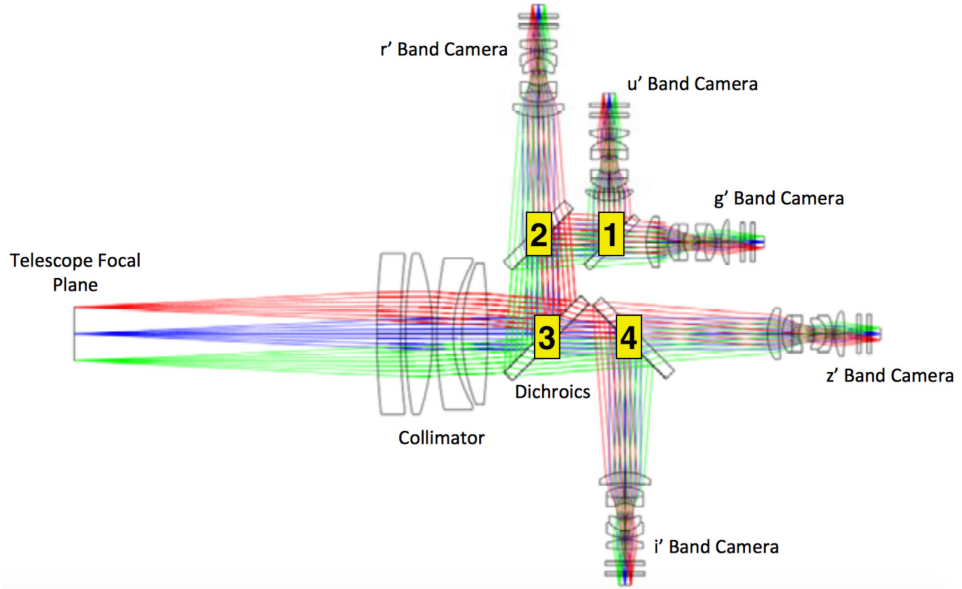
A quintuple-beam imager that saw first light as a Visitor Instrument in Feb. 2018

| | |
|---|---|
| *Spectral Range* | 0.36–1.00 μm |
| *Detector* | 5 × E2V 47-20 frame-transfer devices |
| *Detector format* | 4k × 4k; 15 μm pixel$^{-1}$ |
| *Plate Scale* | 0.081 arcsec pix$^{-1}$ |
| *Field of view* | 2.8 × 1.4 arcmin$^2$ |
| *Imaging modes* | Fast photometry with broad band filters (***u' g' r' i' z'***) simultaneously |



https://www.gtc.iac.es/instruments/hipercam/hipercam.php



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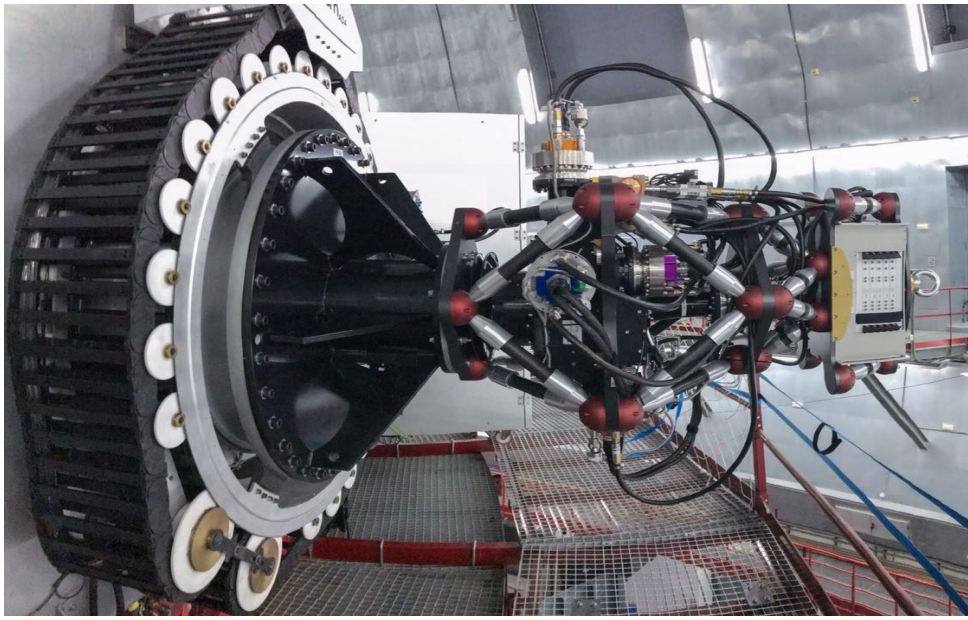
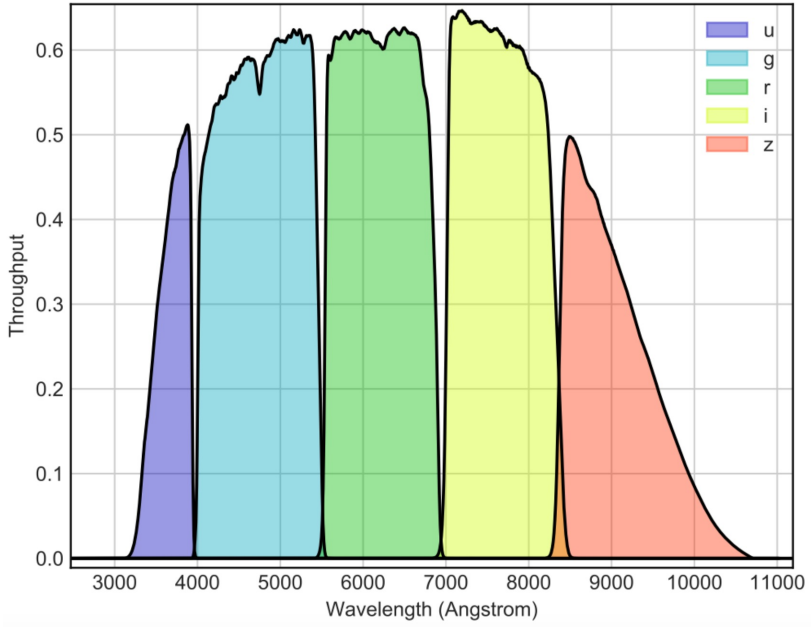
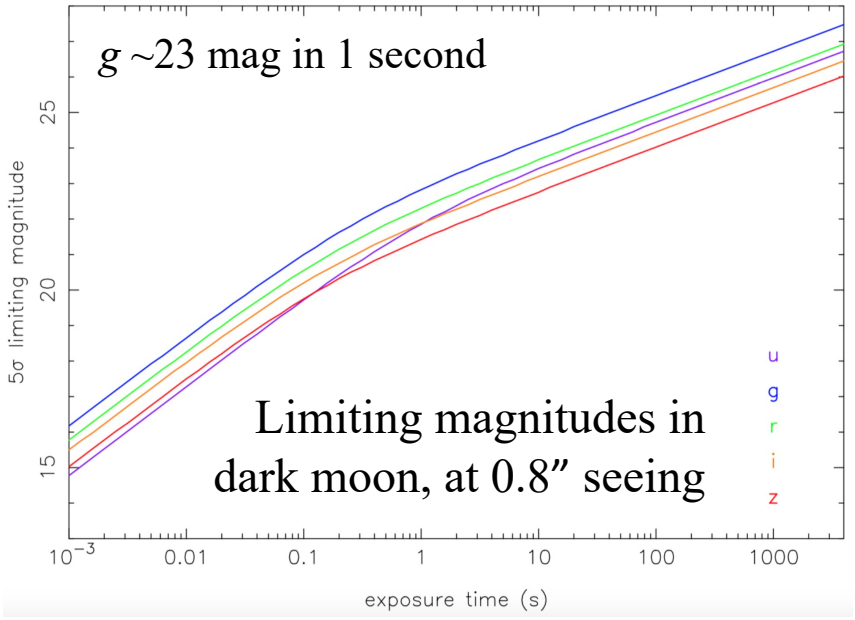
http://www.vikdhillon.staff.shef.ac.uk/hipercam/





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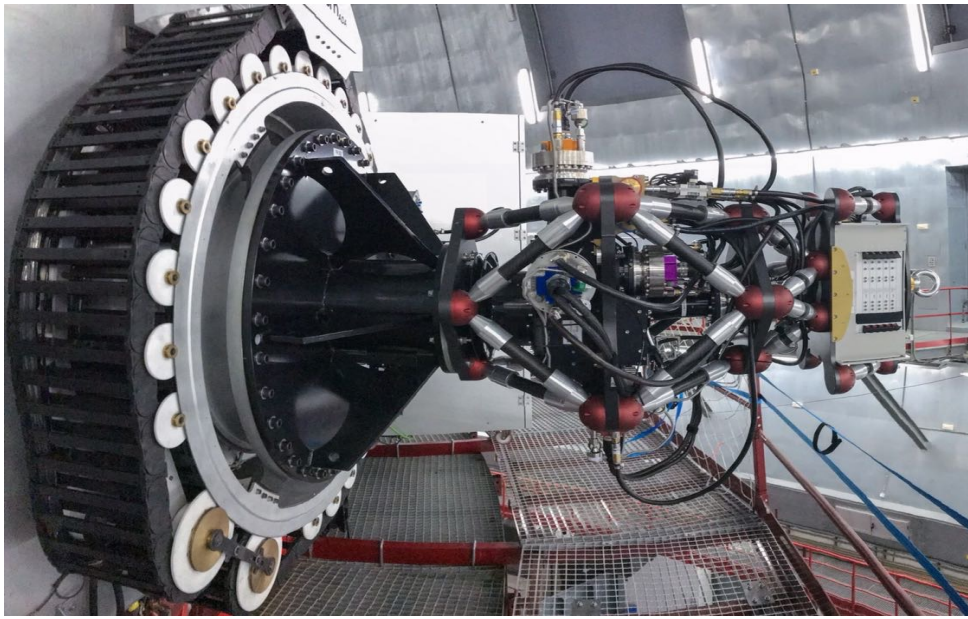
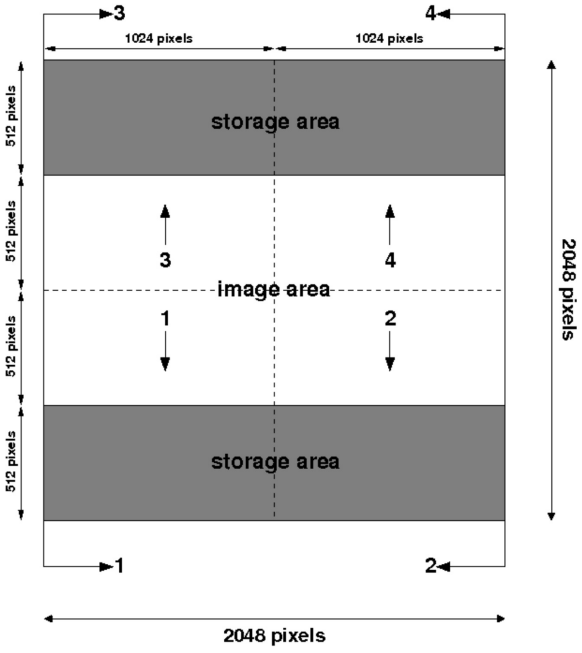
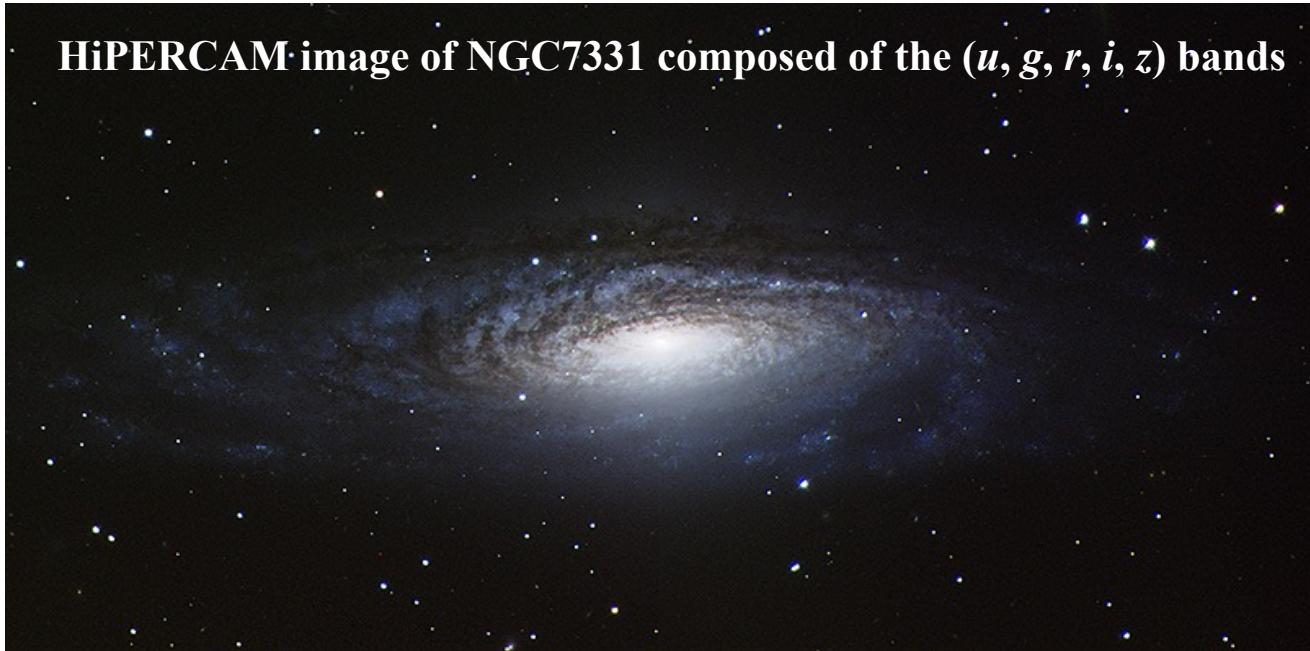
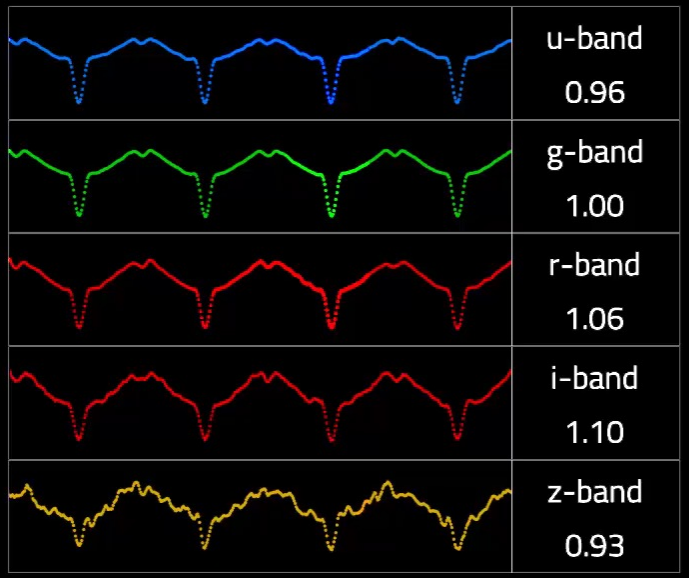
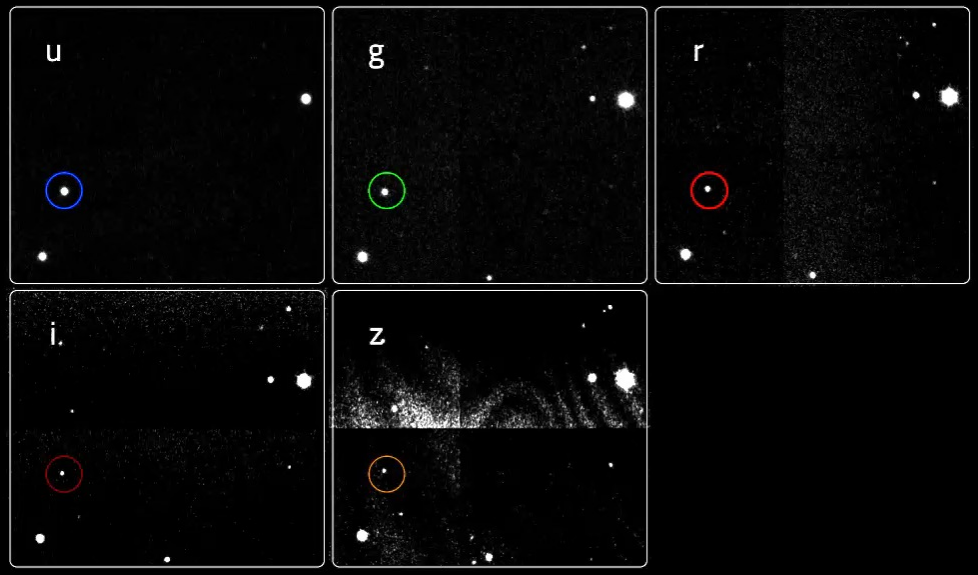


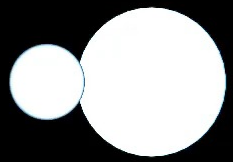


# HiPERCAM high-speed multi-band imager on GTC



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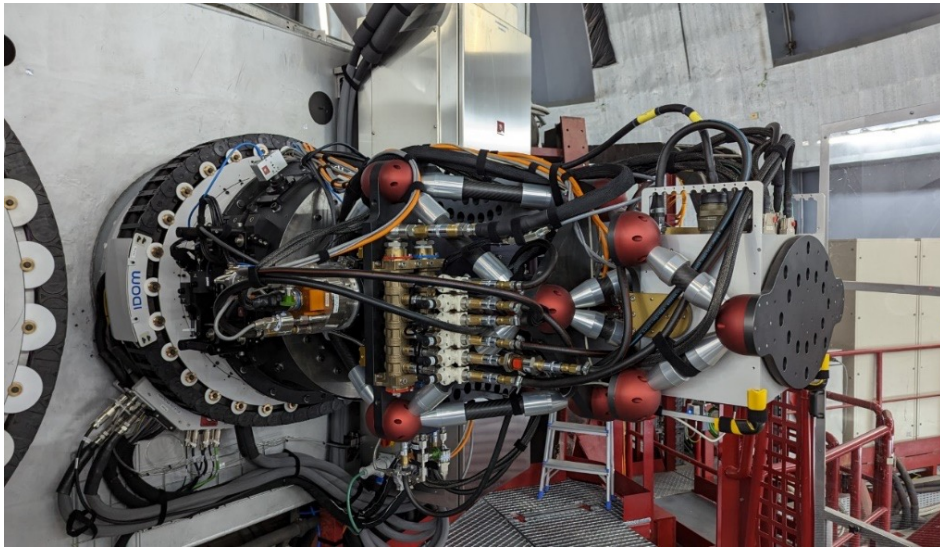
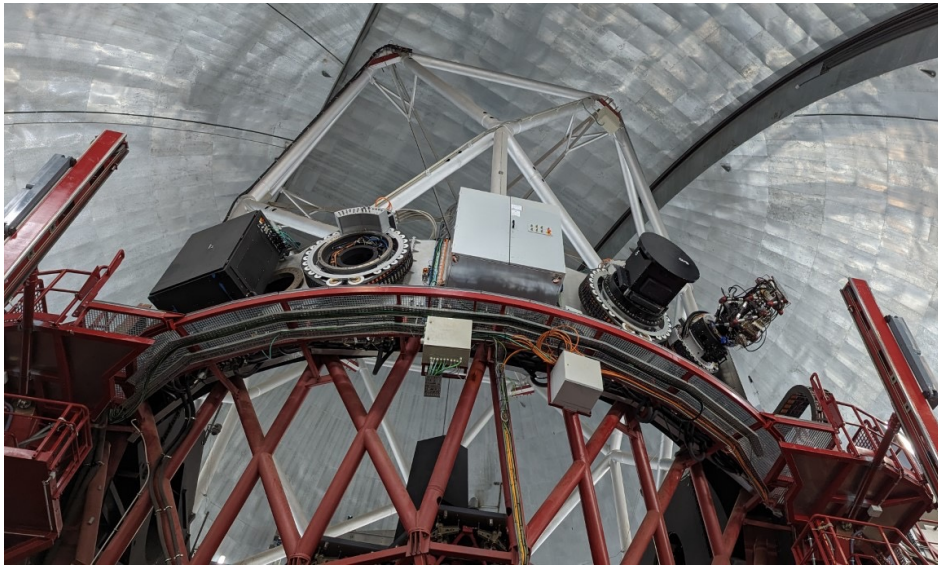
# HiPERCAM high-speed multi-band imager on GTC

- FCass G rotator for HiPERCAM installed and tested in April 17-23 2023, as well as a custom cabinet for the HiPERCAM electronics that will fit in the (tight) space envelope.
- COMPO collar (including autoguider) also installed in 17-23 April 2023.
- HiPERCAM instrument finally mounted in April 20, 2023.
- First on-sky tests with HiPERCAM completed successfully in May 14, 2023.
- On-sky tests for COMPO/HiPERCAM commissioning completed in May 24-26, 2023.
- **HiPERCAM was offered on June 12 in a special call for proposals for S23B**, to observe from July 2023 to February 2024.





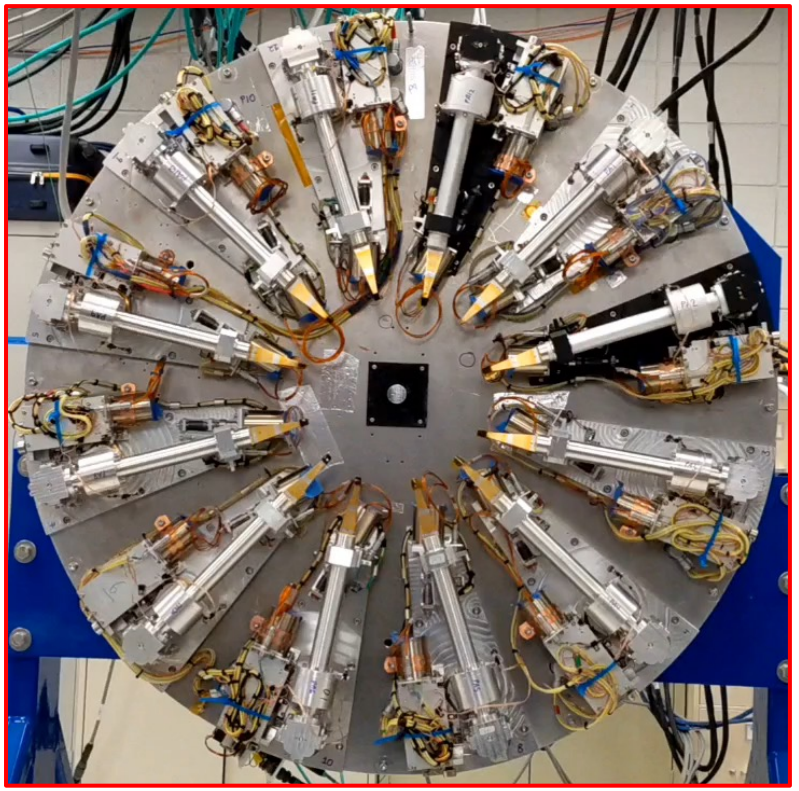
# MIRADAS NIR multi-object echelle spectrograph

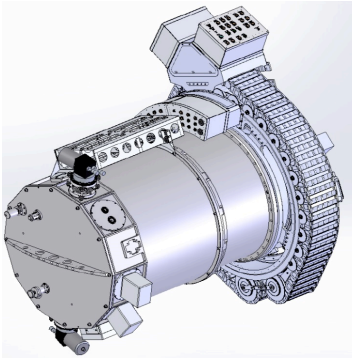
Common-user instrument (folded-Cassegrain focal station E), in operation in late 2023

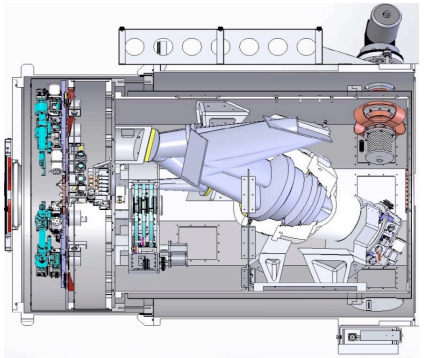
**http://www.gtc.iac.es/instruments/miradas/miradas.php**

**https://astro.ufl.edu/miradas-consortium/**

| Parameter | Value | Comment |
|---|---|---|
| *Spectral Range* | 1–2.5 μm | |
| *Target field of view* | 5 arcmin diameter | Each probe arm patrols a 2D workspace within a circular field |
| *Individual target field of view* | 3.7″×1.2″ | Slit slicers: 3 slices of 3.7″×0.4″ each |
| *Spectroscopic mode* | MOS up to **12 deployable probe arms** | |
| *Detector focal plane* | 4096×2048 pixels | Mosaic of 2Kx2K HAWAII-2RG |
| *Spectral resolution* | *R* ~20000 | |
| *Continuum sensitivity* | J=18.0 mag<br>H=17.7 mag<br>K=16.7 mag | S/N=10 for 1-hour on-source exposure |
| Emission line sensitivity | $5x10^{-18}$ ergs/cm$^2$/s (point)<br>$8x10^{-18}$ ergs/cm$^2$/s (resolved) | S/N=10 for 1-hour on-source exposure; resolved source assumes 1 square arcsecond detect cell |
| *Spetropolarimetry* | | WP in single-object mode |







# MIRADAS NIR multi-object echelle spectrograph

Common-user instrument (folded-Cassegrain focal station E), in operation in late 2023

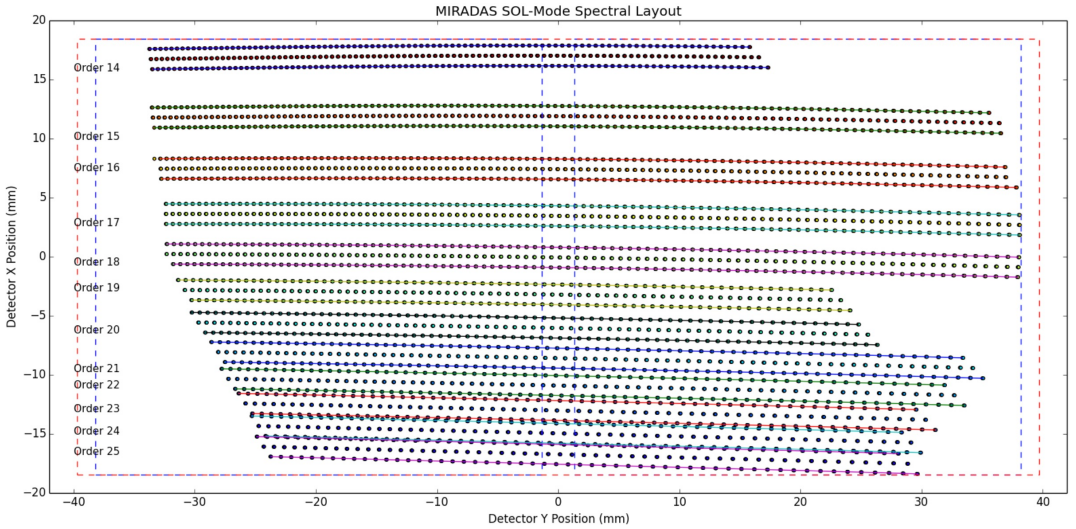
## Offered Multiplex Configurations (MXS)

| Configuration | MXS Targets | Instantaneous Bandpass |
|---|---|---|
| ***SO-Short Mode*** | 1 | 1.04–1.78 µm |
| ***SO-Long Mode*** | 1 | 1.34–2.50 µm |
| ***Maximum-multiplex Mode (MMX)*** | 12 | Any SINGLE order from the Table below |

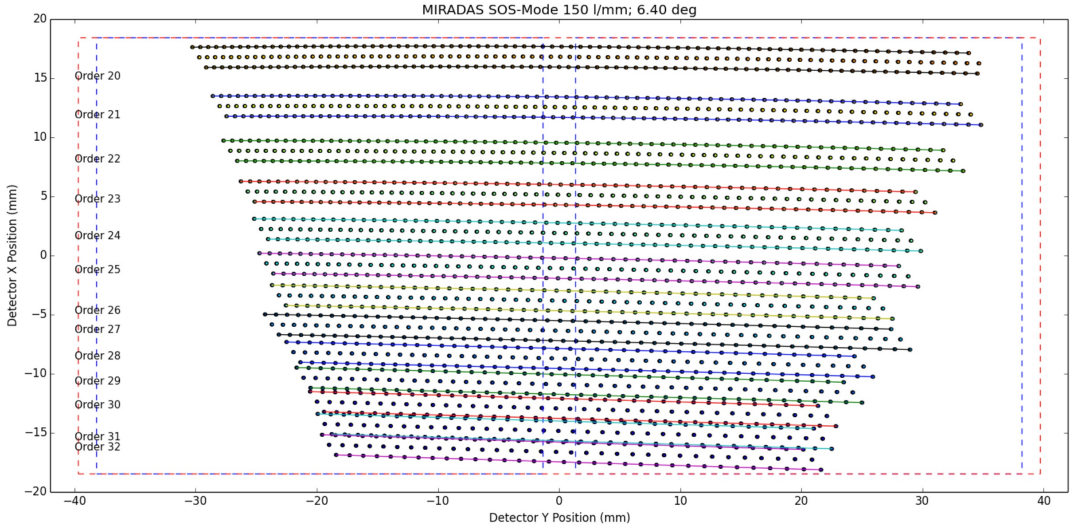
## MIRADAS Echelle Orders

| Order | Wavelength (µm) | Band | Order | Wavelength (µm) | Band |
|---|---|---|---|---|---|
| **14** | 2.3700-2.5000 | K | **24** | 1.4132-1.4718 | Atm. |
| **15** | 2.2220-2.3820 | K | **25** | 1.3555-1.4095 | Atm. |
| **16** | 2.0885-2.2245 | K | **26** | 1.3107-1.3493 | J |
| **17** | 1.9360-2.0860 | K | **27** | 1.2602-1.2988 | J |
| **18** | 1.8700-1.9700 | Atm. | **28** | 1.2170-1.2531 | J |
| **19** | 1.7869-1.8534 | H | **29** | 1.1750-1.2100 | J |
| **20** | 1.6943-1.7608 | H | **30** | 1.1365-1.1703 | Atm. |
| **21** | 1.6144-1.6809 | H | **31** | 1.1009-1.1291 | J-Io |
| **22** | 1.5409-1.6044 | H | **32** | 1.0664-1.0937 | J-Io |
| **23** | 1.4746-1.5355 | H | **33** | 1.0343-1.0607 | J-Io |
| | | | **34** | 1.0048-1.0303 | J-Io |

Single-object Long-wavelength mode (SO-Long), orders 14–25




Single-object Short-wavelength mode (SO-Short), orders 12–32



# GTCAO + FRIDA NIR imager and IFU spectrograph

FRIDA (inFRared Imager and Dissector for Adaptive optics) is an Integral Field Spectrograph with imaging capability, making use of the GTC Adaptive Optics (GTCAO) system. Natural guide-star AO is being developed at IAC; FRIDA is being developed at UNAM

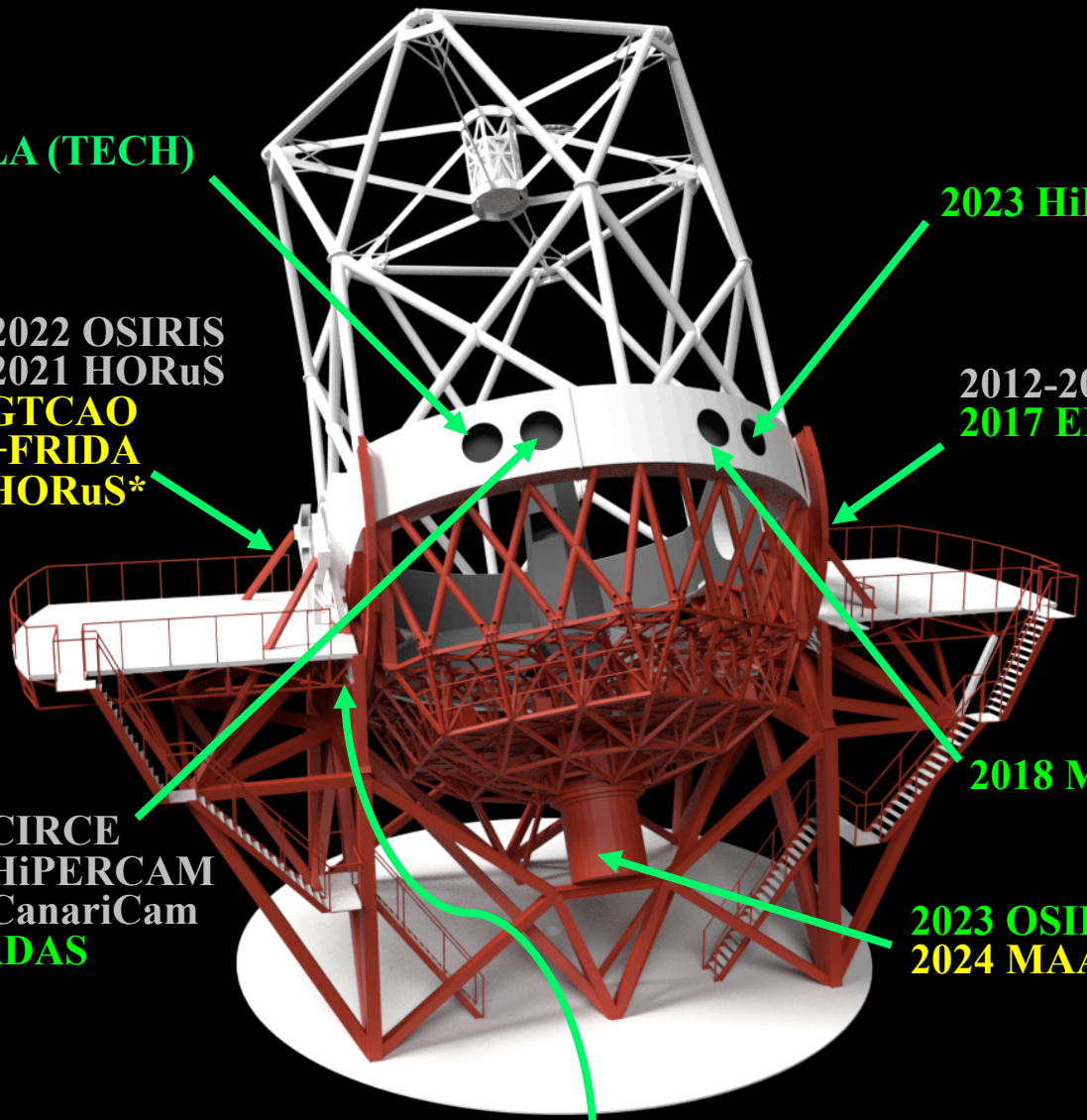
Both expected in 2023–2024

| **GTCAO** | |
|---|---|
| *Spectral range* | 0.9–2.5 μm |
| *Correction* | Shack-Hartmann wfs in visible light |
| *Corrected FOV* | 1.5 arcmin |
| *On-axis SR* | >0.65 at 2.2 μm |
| | |
| | |
| | |
| | |

| **FRIDA** | | |
|---|---|---|
| *Spectral range* | | 0.9–2.5 μm |
| *Detector* | | HAWAII2RG 2048×2048 |
| *Imaging* | *Mode* | diffraction limited broad/narrow-band |
| | *FOV + plate scale* | 20″×20″ (0.01″ pixel$^{-1}$)<br>40″×40″ (0.02″ & 0.04″ pixel$^{-1}$) |
| *Spectroscopic mode* (IFU) | | 0.60″×0.64″, 1.20″×1.28″ & 2.40″×2.56″ |
| *Spectral resolution* | | 1000 (ZJ, HK), 4000 (Z,J,H,K), 25000–32000 (H,K) |

https://www.gtc.iac.es/instruments/frida/frida.php

# GTC instruments (2009–2027)



2023 COALA (TECH)

2023 HiPERCAM

2009-2022 OSIRIS
2019-2021 HORuS
2023 GTCAO
2024 +FRIDA
2023 HORuS*

2012-2016 CanariCam
2017 EMIR

2018 MEGARA

2015-2017 CIRCE
2018-2021 HiPERCAM
2019-2020 CanariCam
2023 MIRADAS

2023 OSIRIS+
2024 MAAT @OSIRIS

2027 CHORUS (UV+Optical)


中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES
CHINESE ACADEMY OF SCIENCES

2023年8月31日，山东威海