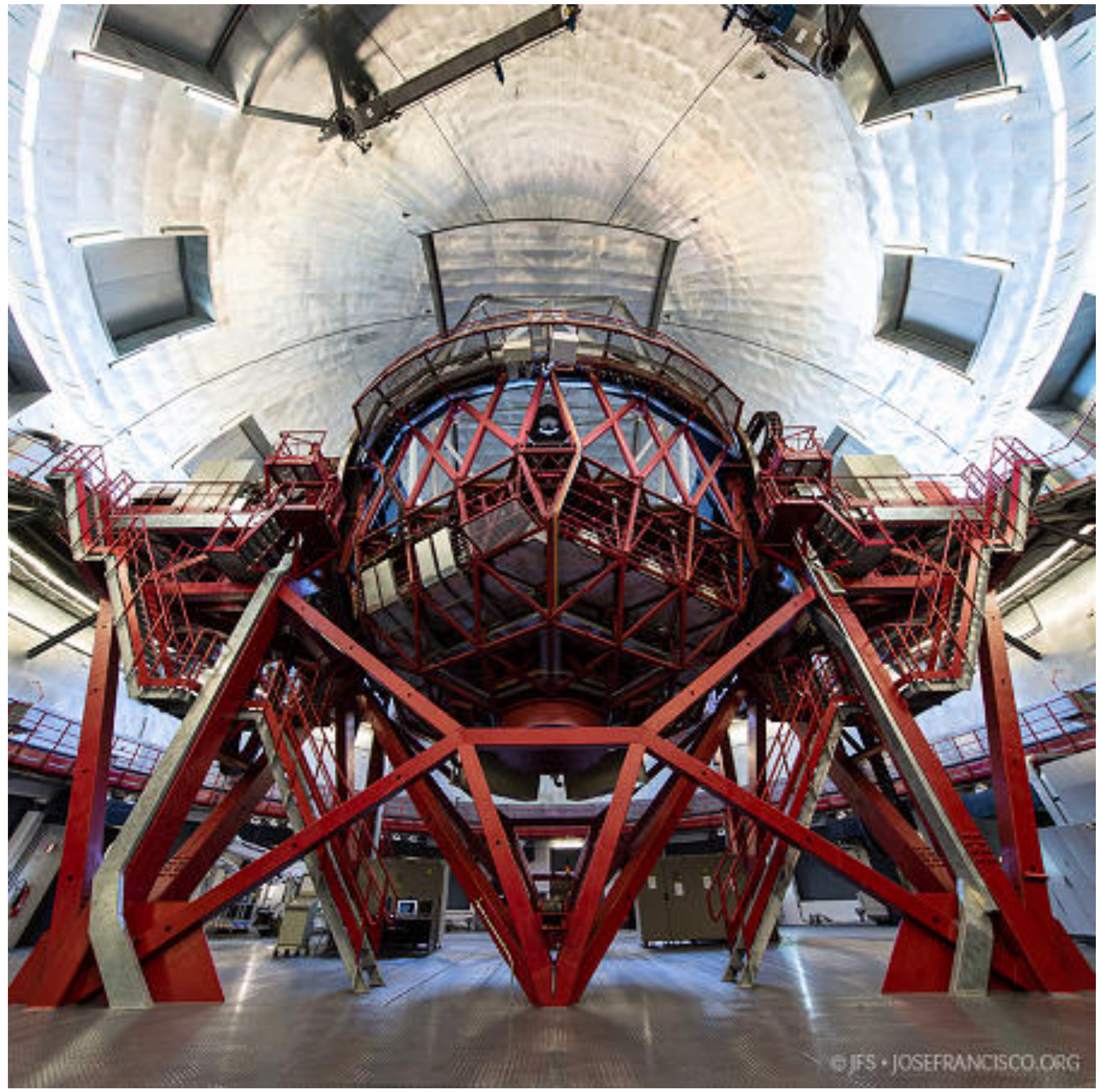
MAAT: A new Integral Field Spectroscopy mode for OSIRIS at GTC

MAAT



Proposal submitted to the GTC Director and Steering Committee

MAAT P.I. Francisco Prada

Workshop MAAT@GTC 5 May 2020

What is MAAT?

Mirror-slicer Array for Astronomical Transients is proposed as a new mirror-slicer optical system that will allow the OSIRIS spectrograph at the 10.4 m GTC the capability to perform Integral-Field Spectroscopy (IFS) over a seeing-limited field of view 14.20'' x 10'' with a slice width of 0.303''.

Parameter	Value
Spectrograph	OSIRIS at GTC-Cass
Module	Integral Field Unit
Field of View[1]	$14.20'' \times 10.00''$
Field aspect ratio	1.42
Slit width	$0.303''$
Spatial sampling[2]	$0.303'' \times 0.127''$
Wavelength range	360 to 1000 nm
Spectral resolution[3]	600 to 4100
Detector[4]	$4k \times 4k$ (15 μm pixel)
CCD plate scale	$0.127''$ per pixel

[1] IFU surface on the sky is 142 arcsec^2, and 141 arcsec^2 without vignetting).

[2] With 1×2 CCD binning$0.303'' \times 0.254''$.

[3] Enhanced 1.6 times resolving power w.r.t. to that of a $0.6''$ long-slit. All OSIRIS grisms and VPHs can be used.

[4] The new OSIRIS detector is a Teledyne-e2v CCD231-84 deep-depleted standard silicon, astro multi-2.

MAAT will enhance the resolution power of OSIRIS by 1.6 times with respect to its 0.6'' wide long-slit. All the eleven OSIRIS grisms and VPHs will be available to provide broad spectral coverage with low / moderate resolution (R=600 up to 4100) in the 3600 - 10000 AA spectral range.

Why MAAT at GTC?

MAAT is devised as a *Visitor* IFS-mode for OSIRIS. Its top-level requirements will broaden its use to the needs of the GTC community for a wide range of outstanding science topics that covers the entire astronomy given its unique observing capabilities, i. e.,

1. MAAT at GTC provides seeing-limited and wide-band Integral-Field Spectroscopy at low / moderate spectral resolution

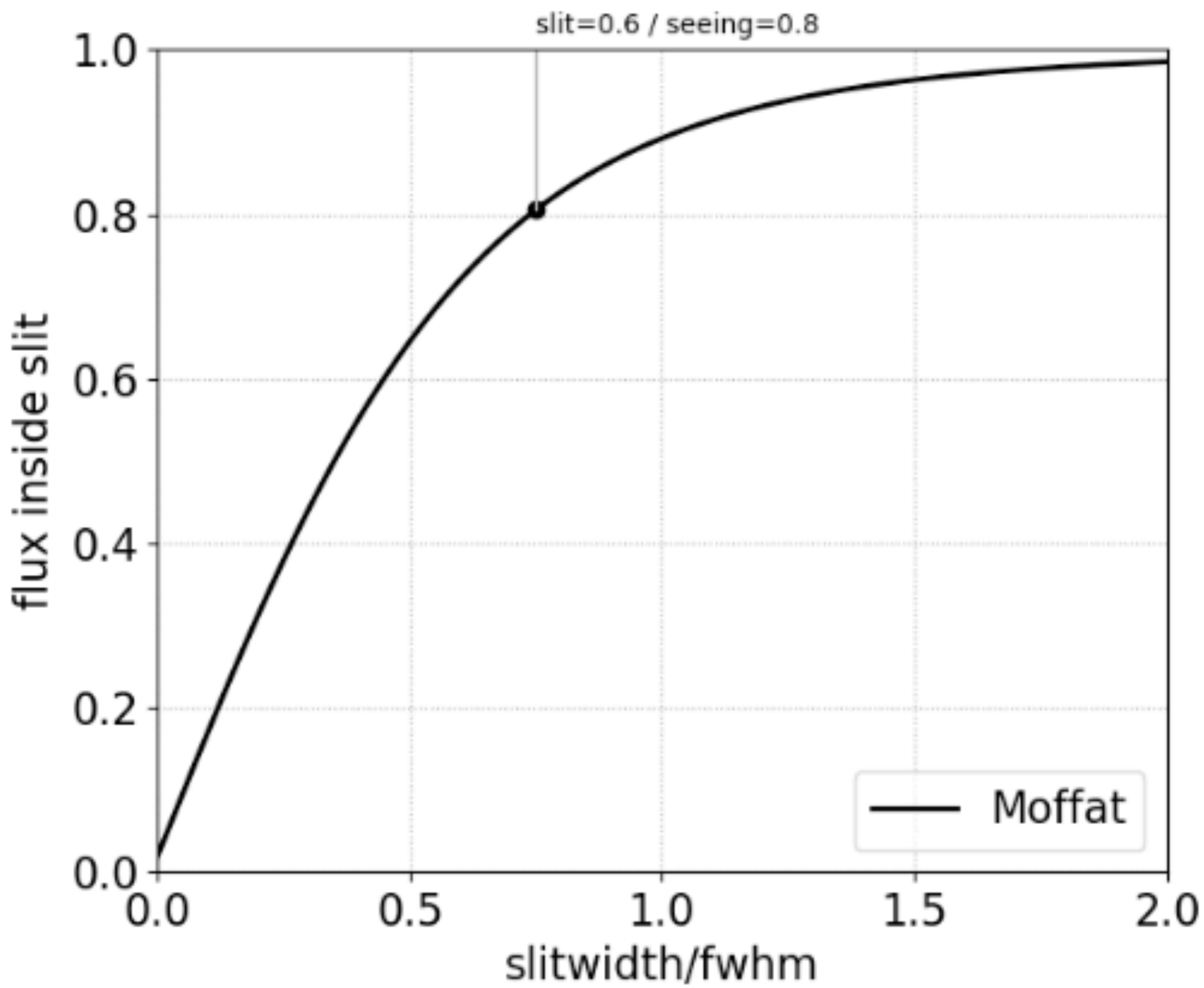
Seeing-limited Integral Field Spectrographs on 10m-class telescopes

Sky	Telescope	Instrument	Spectral range	Resolution	Field of View	Spatial sampling	IFU
Southern	VLT	MUSE	480-930 nm	1770-3590	$59.9'' \times 60.0''$	$0.2'' \times 0.2''$	mirror slicer
Northern	Keck	KCWI	350–560 nm	3000-4000	$8.25'' \times 20.0''$	$0.34'' \times 0.147''$	mirror slicer
N & S	Gemini	GMOS-IFU	360-940 nm	600-4400	$5.0'' \times 7.0''$	$0.2''$	lenslet/fibers
Northern	GTC	OSIRIS+MAAT	360-1000 nm	600-4100	$10.0'' \times 14.20''$	$0.303'' \times 0.127''$	mirror slicer

Why MAAT at GTC?

2. MAAT at GTC can perform spectrophotometry

- All photons are collected



A clear advantage of IFS as compared to long-slit is the fact that all the flux of the object (point sources or extended features inside the IFU F.o.V.) can be collected allowing to perform absolute spectrophotometry.

- Larger efficiency, thus enhancing the measured S/N

Why MAAT at GTC?

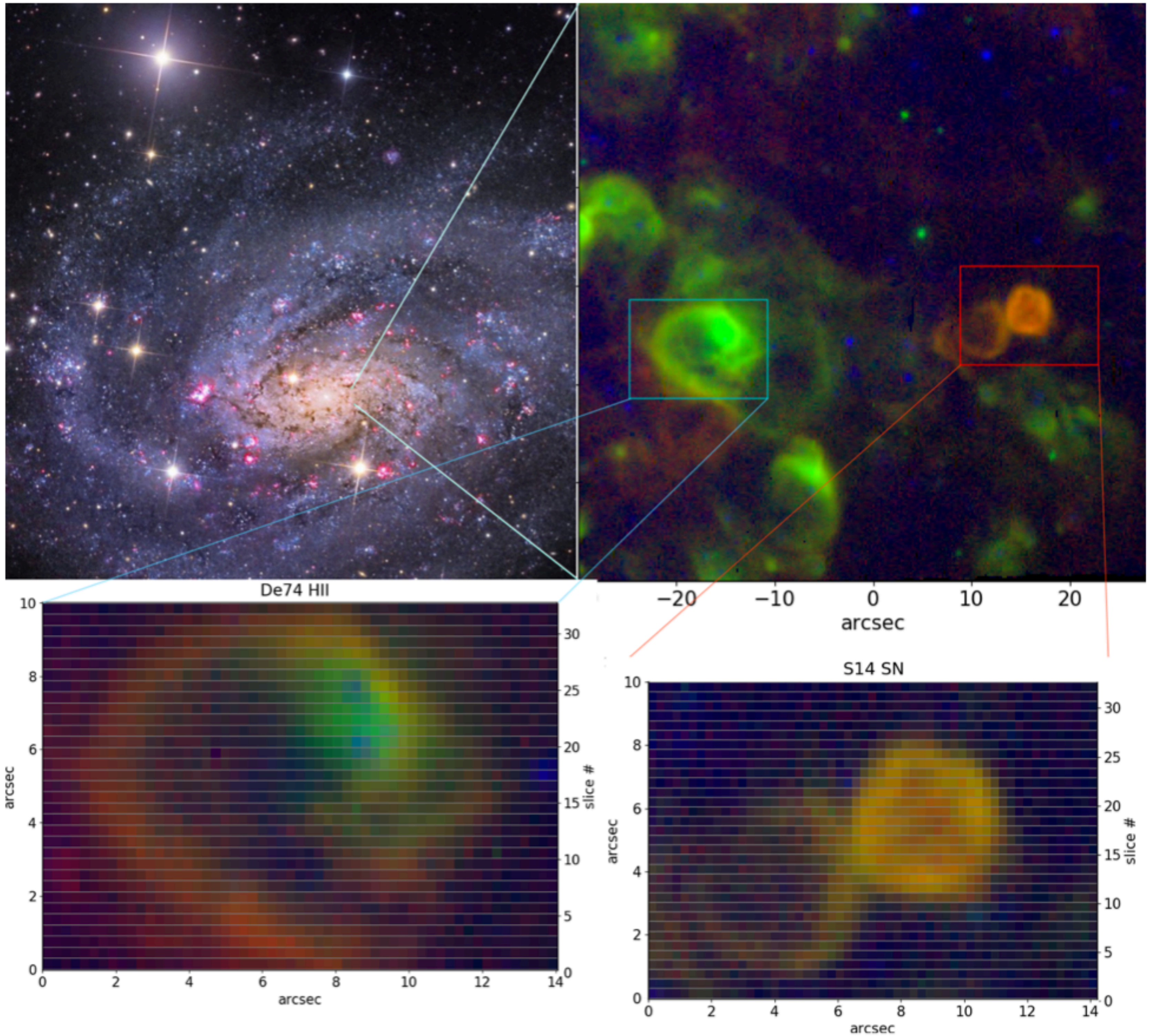
3. Advantage on bad (any) seeing conditions

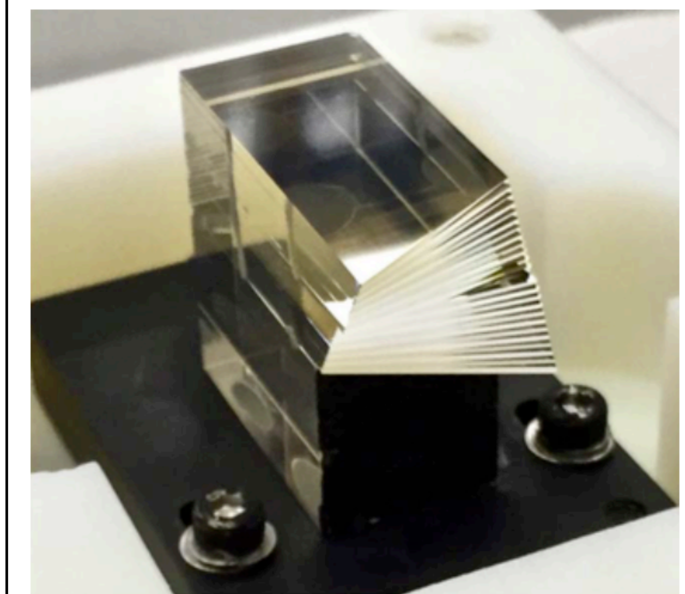
MAAT keeps its nominal spectral resolution regardless the seeing conditions. This is a big advantage w.r.t. to the OSIRIS long-slit mode.

4. Prompt to Targets of Opportunity

Note that the main advantage of MAAT is that a broad-band image of the entire 14.2” × 10” field could be generated from the 3D data cube, which will confirm the correct target acquisition, but at the same time will guarantee observations of targets whose position is known within an accuracy of few arcsec. This represents another advantage to use MAAT, in particular for transient astrophysics.

MAAT “eyes”

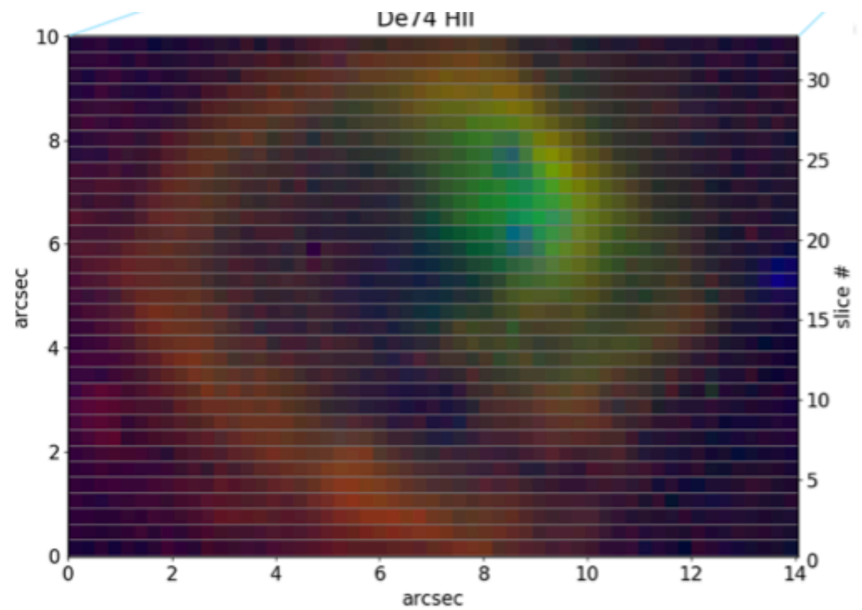


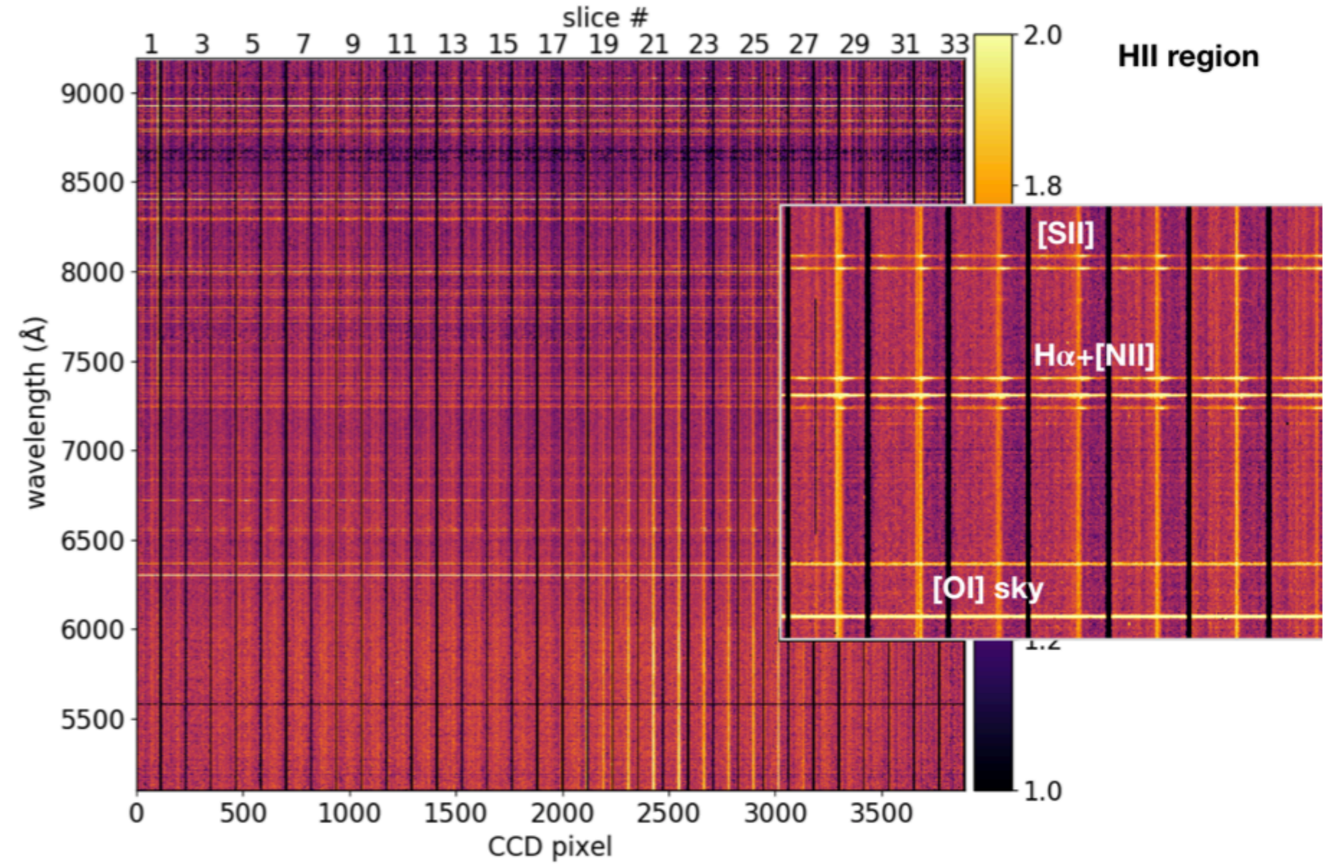


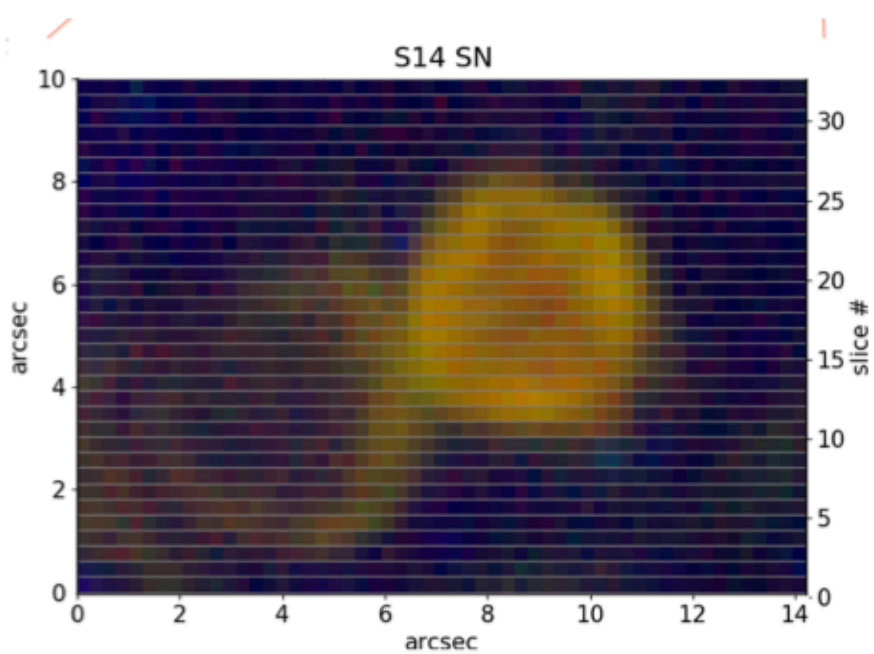
A close-up view of the KCWI slicer built at Winligth. The MAAT slicing mirror stack will be very similar but with 33 slicers each 0.8 mm thick (0.303” on the sky).

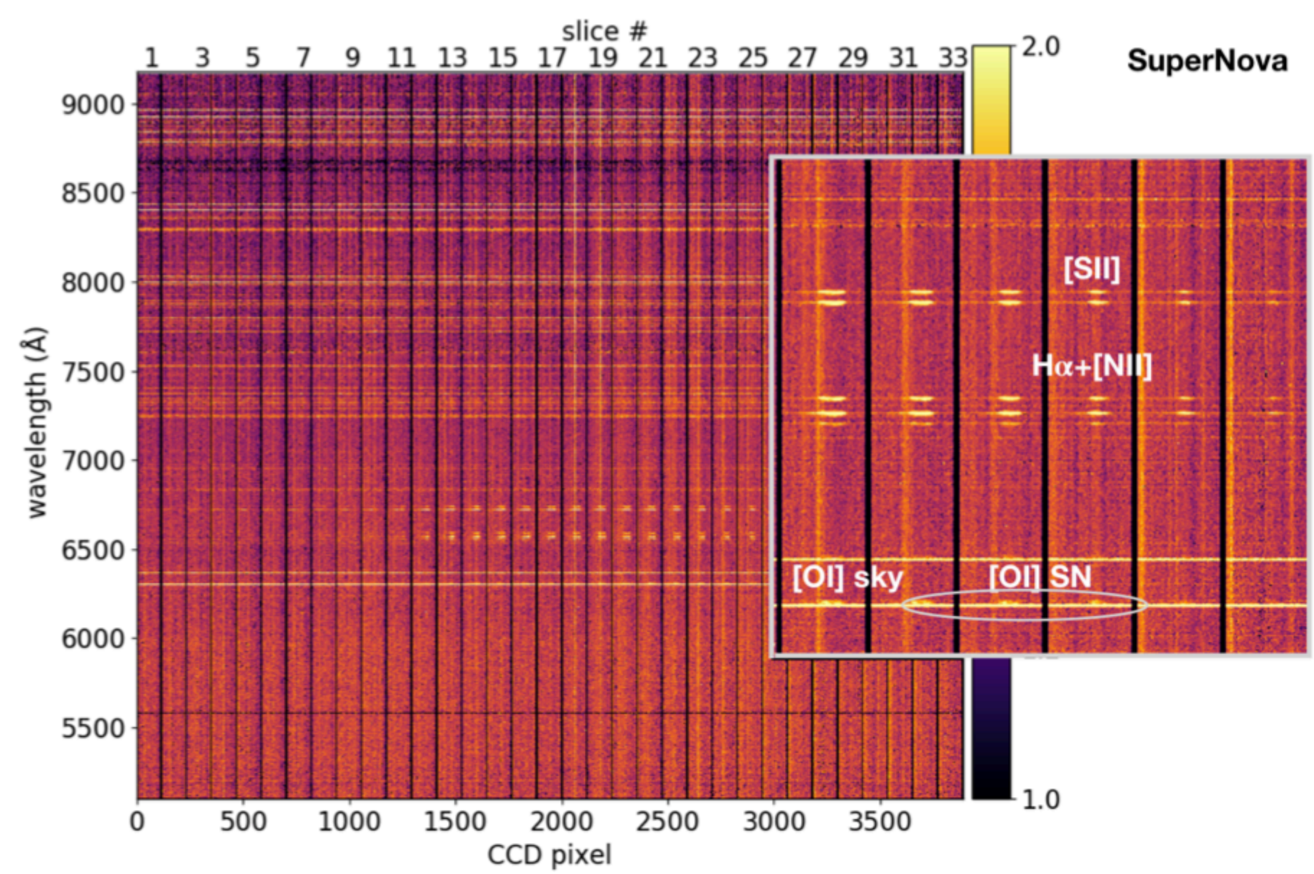
MAAT simulation of two nebular objects in the spiral galaxy NGC300: the HII region De74 (left) and the SN remnant S14 (right). The two bottom images is how the slicer sees each of the objects that are then dispersed onto the CCD to obtain the frames as shown in the next slide.

MAAT simulated CCD frames of the giant HII region De74 (top) and the SN remnant S14 (bottom) in the galaxy NGC300

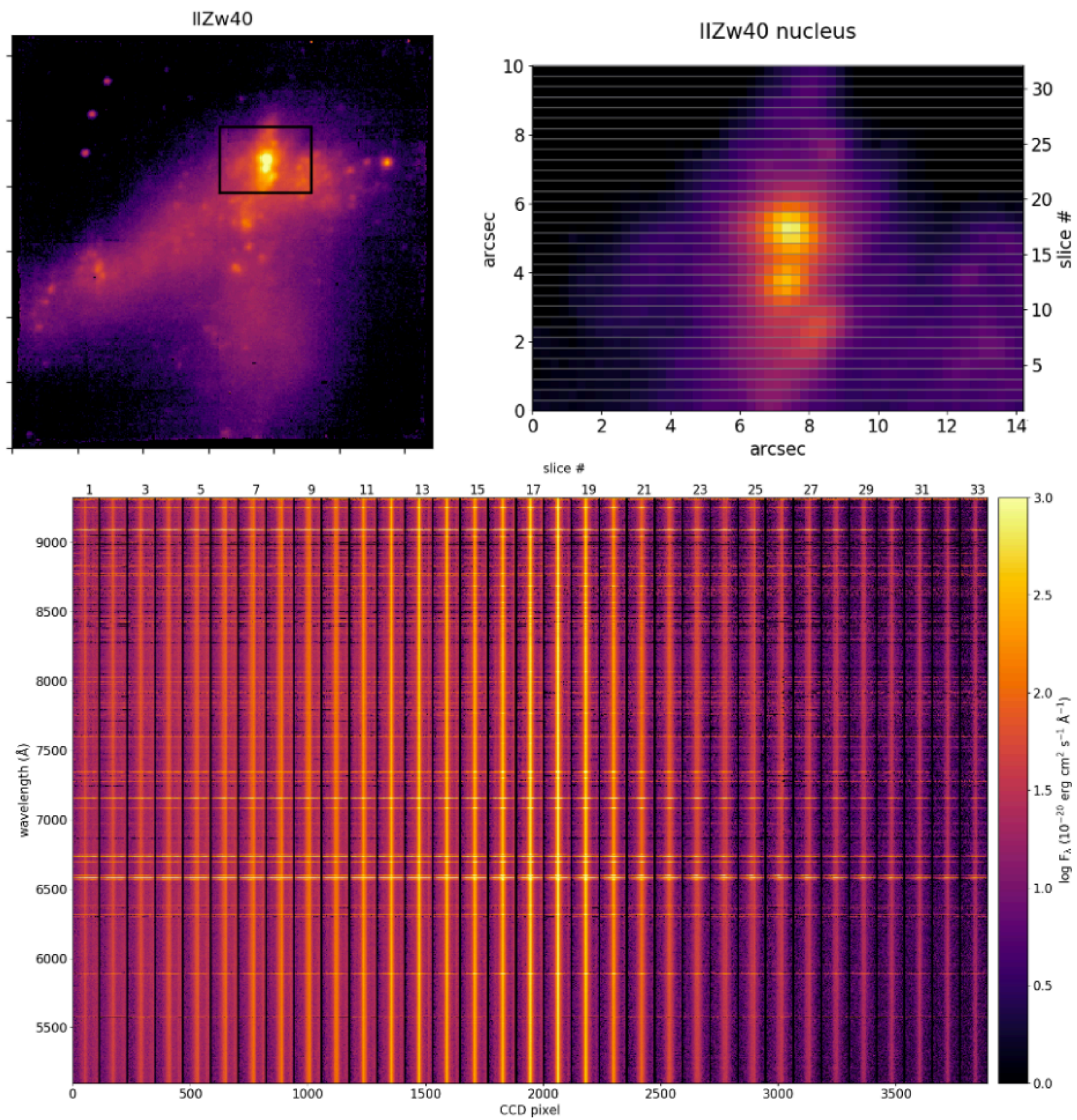




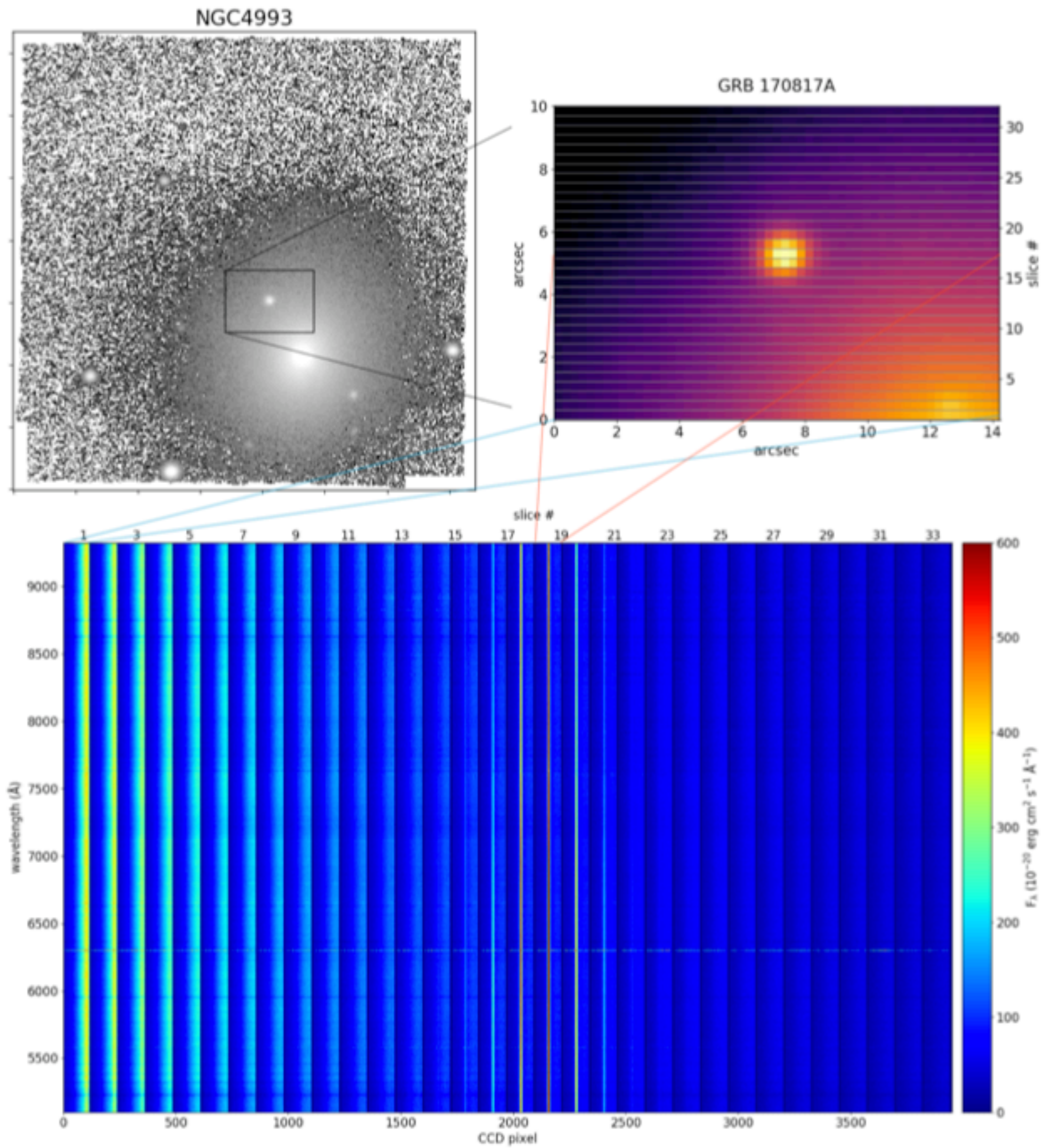




MAAT simulation of the circumnuclear region of the metal poor dwarf galaxy IIZw40



MAAT simulation of the kilonova in NGC4992



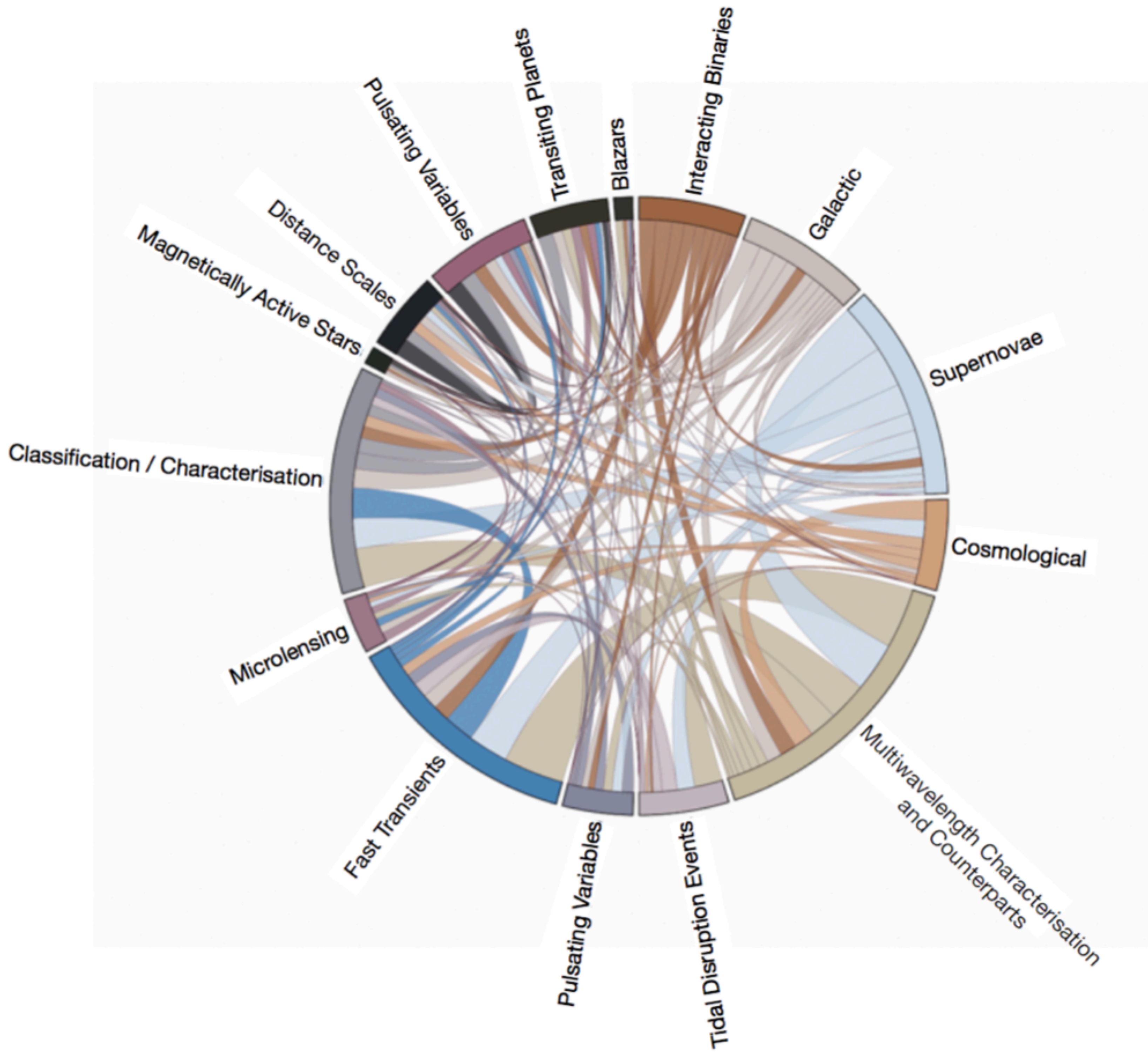
Science with MAAT at GTC

While the science potential of MAAT is essentially unlimited, this workshop will highlight the focus on a selected set of outstanding science topics enabled by the proposed instrument in different areas of expertise. These include,

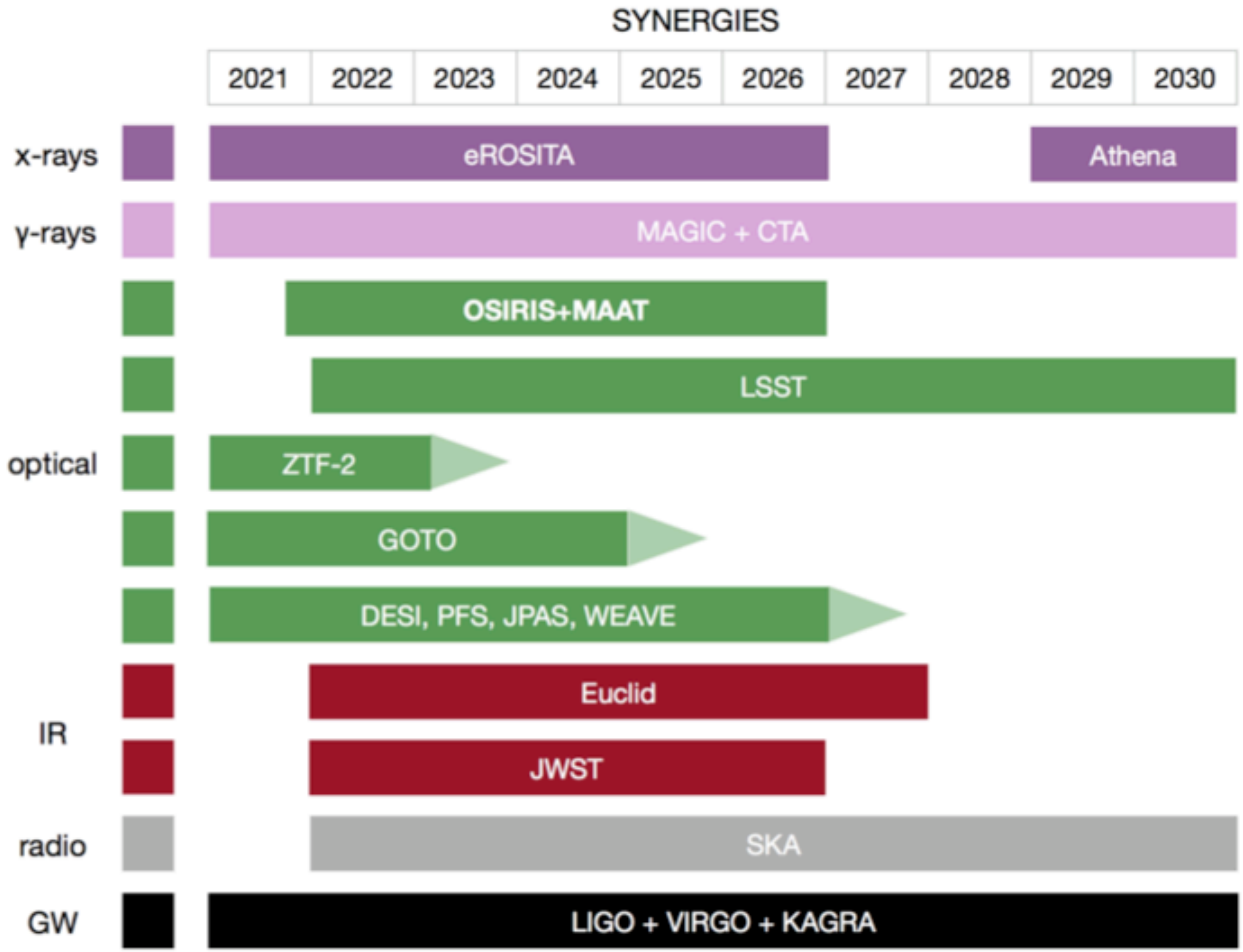
- Characterisation of the diffuse universe: the intergalactic and circumgalactic mediums
- Strong galaxy lensing studies,
- Black holes in QSOs and stellar remnants,
- ANGs and the origin of relativistic jets,
- Cosmology with time-domain probes: identification and characterisation of EM-GW counterparts; time-delay measurements of strongly lensed supernovae and quasars,
- Exploration of the host galaxy environment of Type Ia SN, GRBs, Kilonova and other remnants,
- Brown dwarfs and planetary-mass objects,
- Synergies with the JWST in galaxy evolution studies,
- Potential discovery and characterisation of the transient sky.

GTC in the era of time-domain astrophysics

While imaging surveys are essential for the discovery of rare transients, timely identification of the nature and evolution of transients and their host galaxy environments requires spectroscopic screening in a telescope with great light collection power.



Chord diagram showing the structure of the LSST Transients and Variable Stars Collaboration Working Groups. It shows at glance the potential discovery and characterization of the transient sky. (Credit: LSST Collaboration.)



The GTC equipped with OSIRIS+MAAT will play a fundamental role in synergy with other facilities operating in La Palma, opening a new era for transient studies at the Observatory of the Roque de Los Muchachos. Furthermore, the MAAT top-level requirements allow to broaden its use to the needs of the GTC community for a wide range of competitive science topics given its unique observing capabilities well beyond time-domain astronomy.

The MAAT Proposal

The MAAT proposal has been developed through a fruitful collaboration of a group of scientists and engineers in Spain, Australia, Denmark, and Sweden:

Francisco Prada (P. I.), IAA-CSIC, Spain
Robert Content, AAO, Australia
Enrique Pérez, IAA-CSIC, Spain
Luca Izzo, DARK, Denmark
Ariel Goobar, Stockholm University, Sweden

We also acknowledge the contribution from Ernesto Sánchez Blanco (OpticsDevelopment) and Winlight Systems.

The work presented in the MAAT proposal would have not been possible without the technical support and help of the GTC staff Manuela Abril (Optical Scientist and Contact person for MAAT), Kilian Henríquez Hernández (Mechanical Engineer), Andreas Gerarts (Mechanical Engineer), Luis A. Rodríguez García (Head of Engineering), Antonio Cabrera (Head of Astronomy), and Romano Corradi (Director).

GTC has provided a detailed 3D space envelope study for MAAT and all the relevant documentation on the optics and mechanics of OSIRIS. We are grateful to Manuela Abril for their very efficient and instantaneous feedback over the last four months after our many requests and questions. Furthermore, their effort included 3D printed relevant pieces to test the envelope of MAAT inside OSIRIS. Proper credit to their work has been recognised, see figure captions.

The MAAT basic parameters

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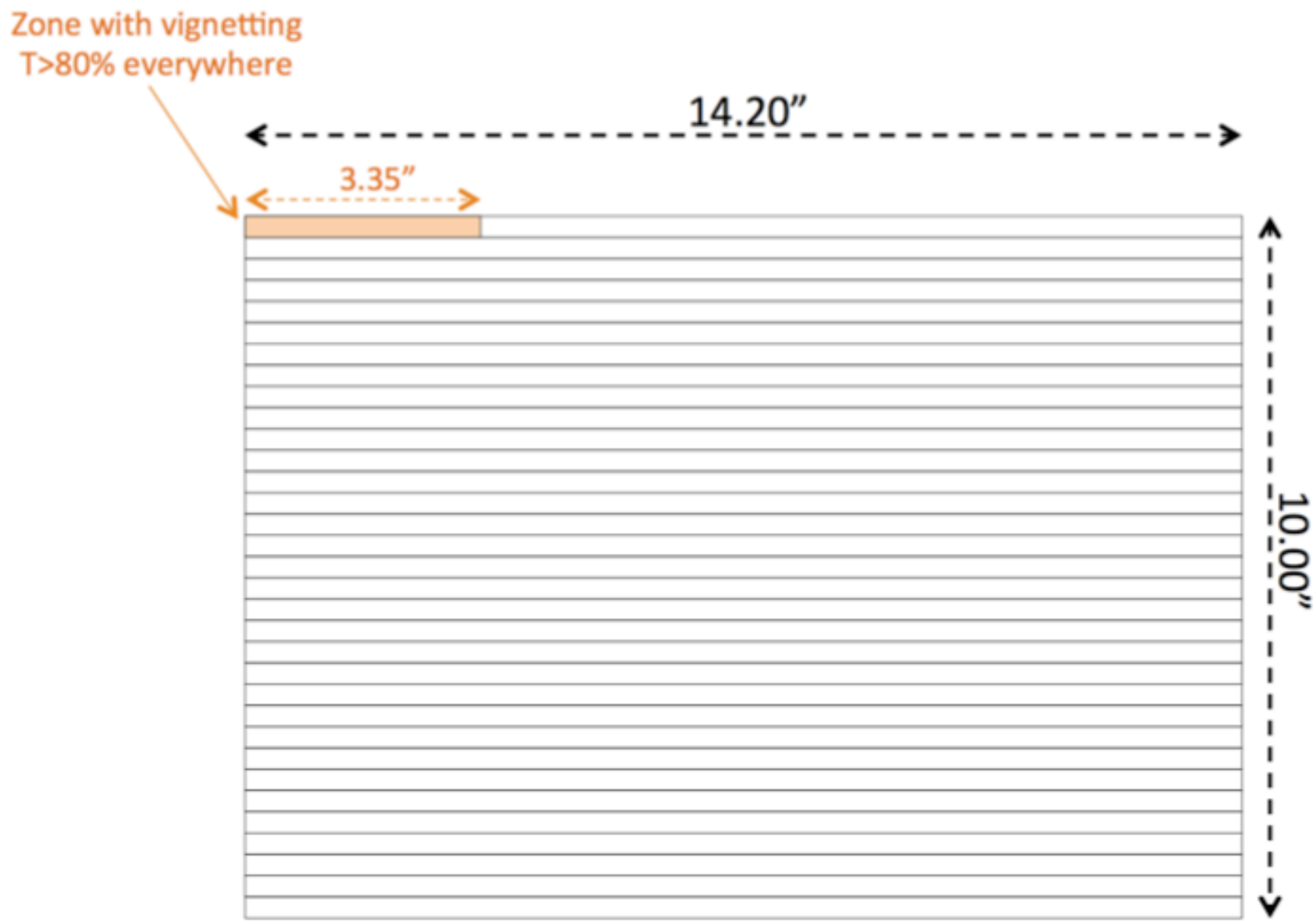

Sky footprint of the MAAT mirror-slicer IFU

Table 1. The MAAT basic parameters

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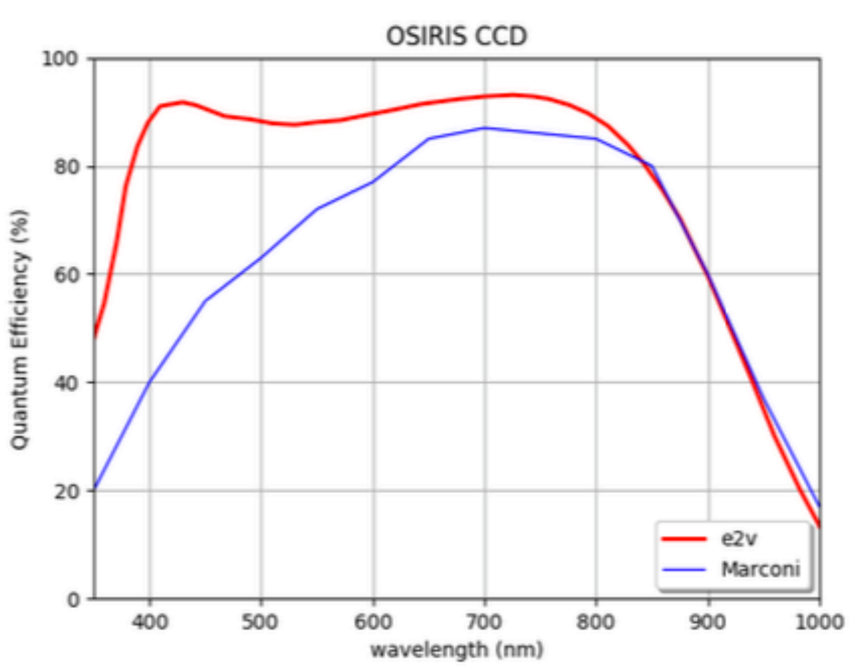
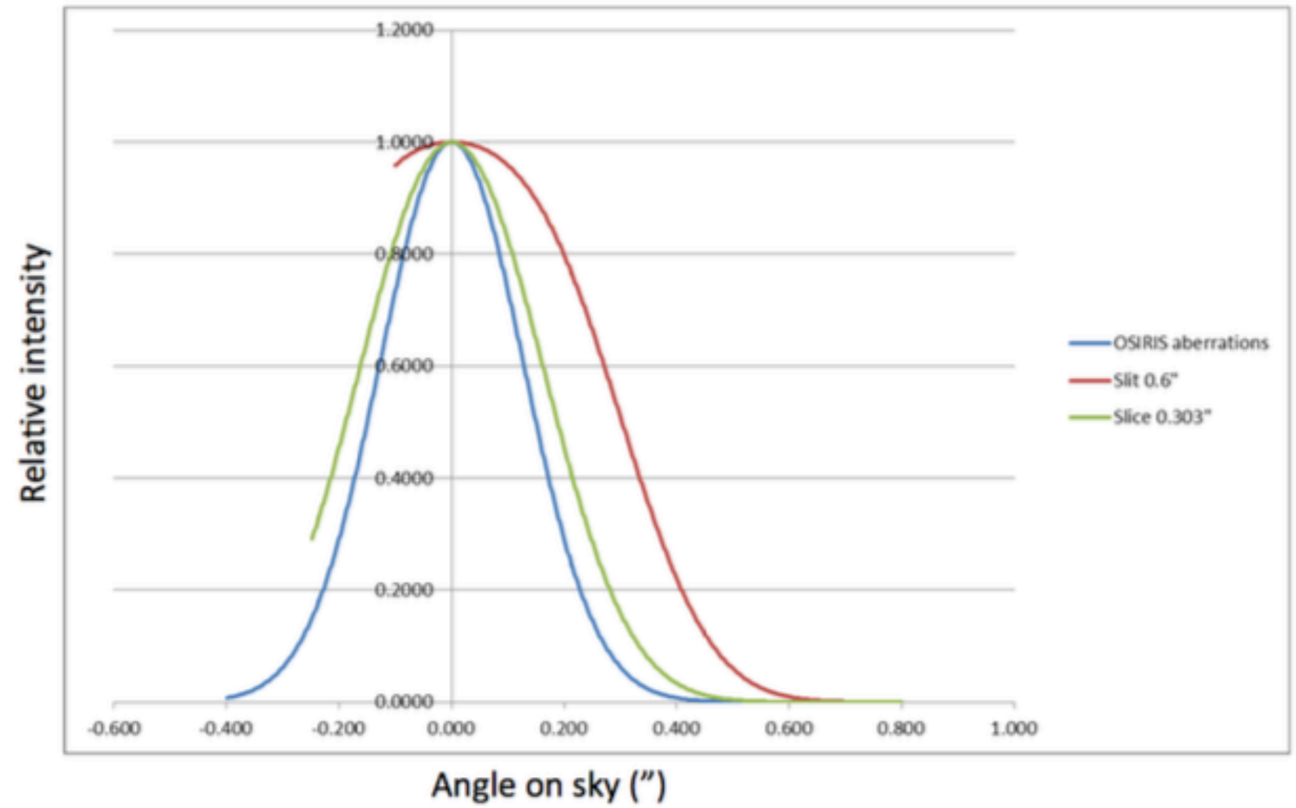


PSF of OSIRIS for the MAAT slicer width of 0.303” as compared with the 0.6” wide long-slit.

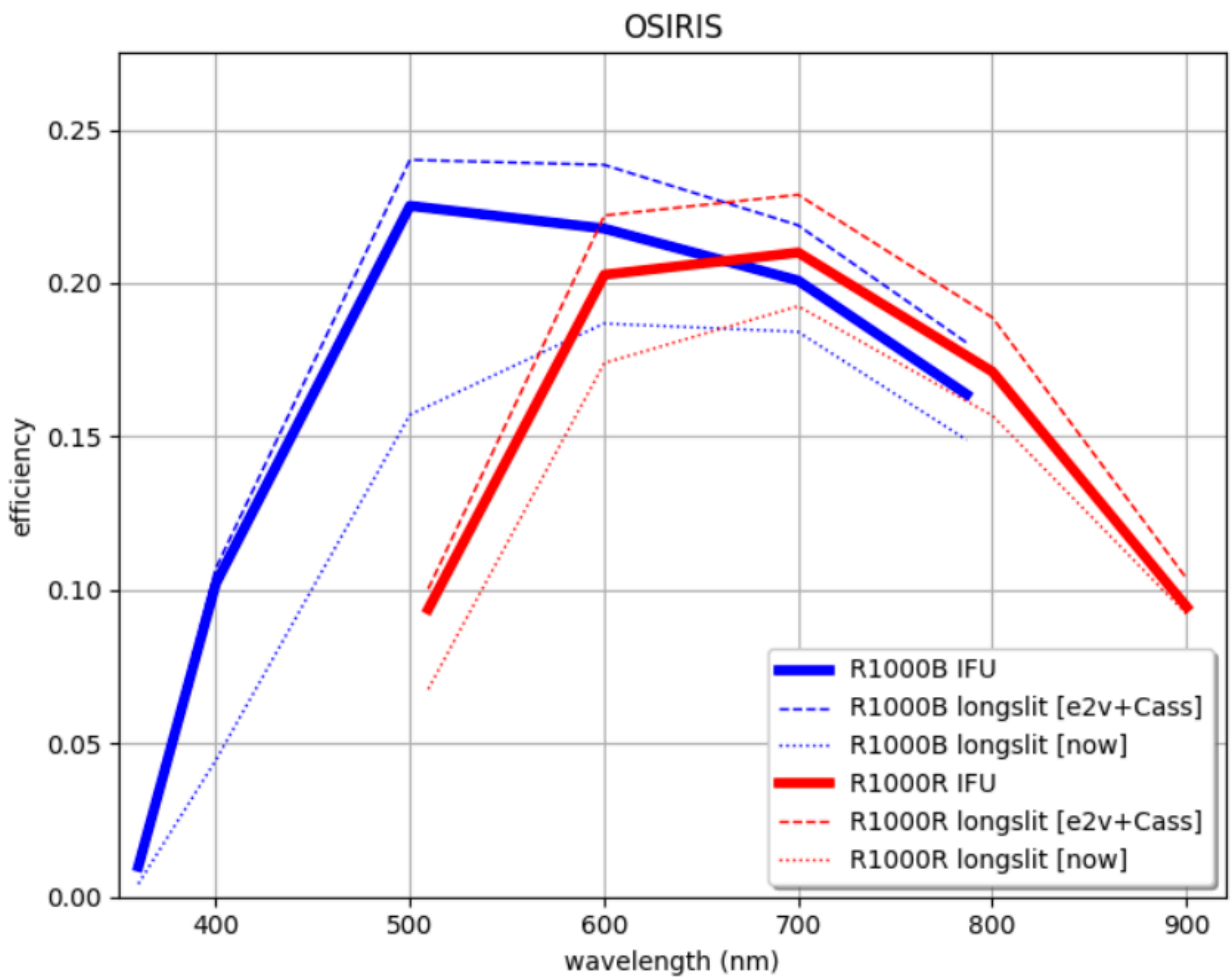


Resolutions and spectral ranges with OSIRIS+MAAT for all available Grisms and VPHs

ID	λ_c (Å)	$\Delta\lambda$ (Å)	D (Å/pix)	R (LS[1])	Peak Efficiency	Type
R300B	4405	3600-7200	2.60	575 (360)	70%	Grism
R300R	6635	4800-10000	4.02	560 (348)	70%	Grism
R500B	4745	3600-7200	1.87	860 (537)	68%	Grism
R500R	7165	4800-10000	2.58	940 (587)	67%	Grism
R1000B	5455	3630-7500	1.13	1630 (1018)	65%	Grism
R1000R	7430	5100-10000	1.40	1795 (1122)	65%	Grism
R2000B	4755	3950-5700	0.46	3465 (2165)	87%	VPH
R2500U	3975	3440-4610	0.33	4090 (2555)	70%	VPH
R2500V	5185	4500-6000	0.44	4025 (2515)	80%	VPH
R2500R	6560	5575-7685	1.56	3960 (2475)	80%	VPH
R2500I	8650	7330-10000	1.73	4005 (2503)	80%	VPH

[1] Resolving power for the OSIRIS 0.6″ long-slit (LS) mode.

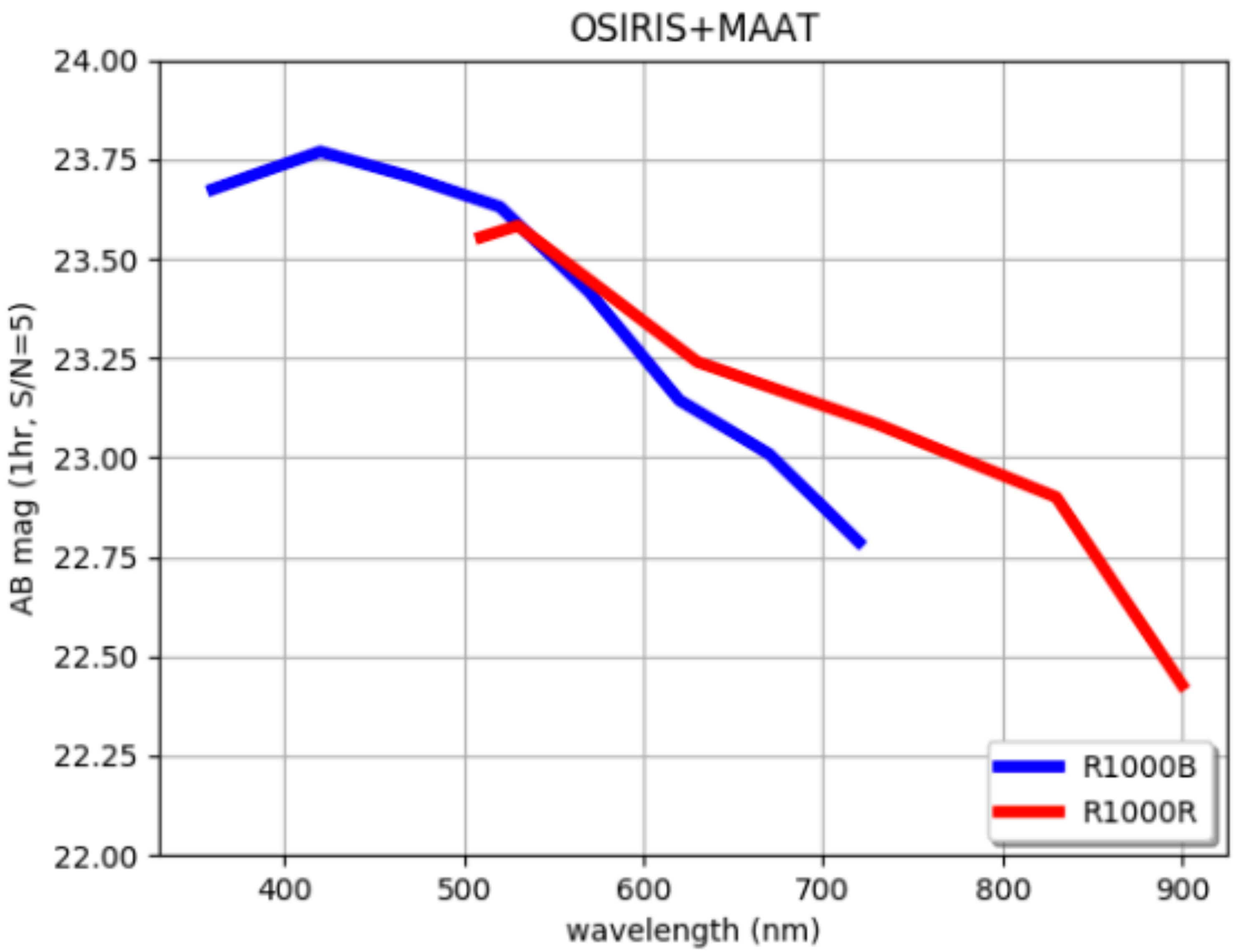
OSIRIS+MAAT Efficiency



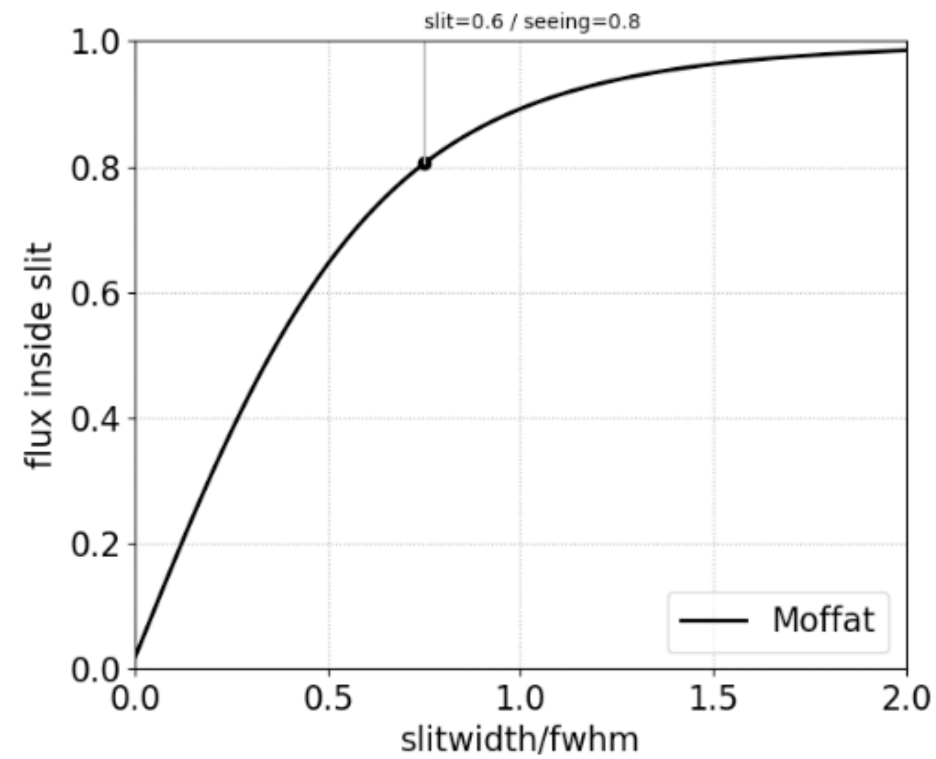
Total throughput (atmosphere, telescope, and instrument) of the OSIRIS long-slit and IFU mode as currently mounted on the Nasmyth focus and as it will be on the Cassegrain, which will result in a significant gain in efficiency derived from the new e2v detector and the absence of M3. The curves are shown for the broadband R1000B and R1000R Grisms.

OSIRIS+MAAT limiting magnitudes and fluxes

(Note that these estimates can be obtained for any of the OSIRIS Grisms and VPHs)



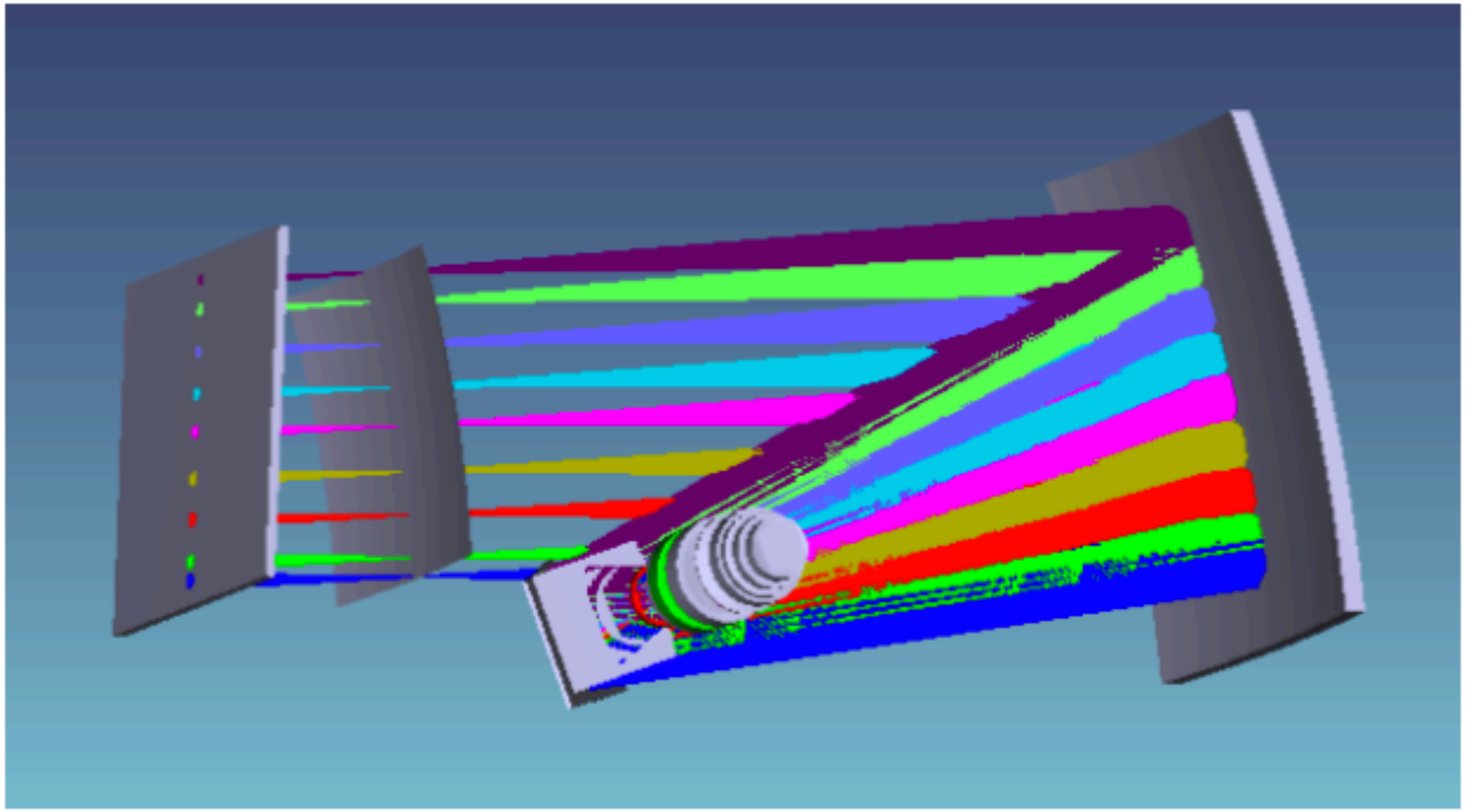
OSIRIS+MAAT limiting magnitudes for the broadband R1000B and R1000R Grisms.



A clear advantage of IFS as compared to long-slit is the fact that all the flux of the object (point sources or extended features inside the IFU F.o.V.) can be collected, thus enhancing the measured S/N and allowing to perform absolute spectrophotometry.

In order to estimate the MAAT limiting flux we have used the MUSE@VLT exposure time calculator with the following assumptions to achieve a S/N = 5 with 30 exposures of 1800s each: an extended Lyα emitting galaxy with a Sersic profile at redshift 4, a peak emission line flux of 3e-18 erg/s/cm^2 arcsec^2 (Wisotzki et al. 2018), a line width of 600 km/s, spatial binning of 3 × 3 and integrated over the spectral line profile, seeing of 0.8”, dark moon, and PWV=5 mmH2O.

MAAT Instrument Overview



OSIRIS optical layout in spectroscopy mode

MAAT Optical Study
by Robert Content

MAAT Envelope
by GTC

MAAT Manufacturing
by Winlight System

MAAT Pipeline
by Rubén GB

Observing with OSIRIS+MAAT

- We propose that the MAAT module be permanently mounted on the OSIRIS Cartridge from late 2021 onwards, thereby enabling immediate response to transient targets and the execution of standard programs at any given time. Yet, it can be removed from the Cartridge as any other OSIRIS mask if necessary since it uses the same mask-frame interface.

- MAAT can be easily used by the GTC Support Astronomers via the OSIRIS control software by selecting the appropriate mask position of the Cartridge where it is inserted. MAAT does not require from GTC staff any daily nor night technical engineering support or specific telescope operation.

- Overall, the observation procedure with MAAT is simple. To ensure accurate acquisition and centering the telescope must be pointed to the center of the IFU pick-off mirror. This position is accurately known with respect to both the OSIRIS and the telescope optical-axis positions. The 1″ r.m.s. pointing error of GTC guarantees that the target will be placed right at the very center of the IFU F.o.V. The same acquisition procedure applied for MEGARA and EMIR MOS can be applied to MAAT, which will guarantee a target positioning better than 0.303" (a spaxel).

- Note that the main advantage of MAAT is that a broad-band image of the entire 10″ × 14.2″ field could be generated from the 3D data cube, which will confirm the correct target acquisition, but at the same time will guarantee observations of targets whose position is known within an accuracy of few arcsec. This represents another advantage to use MAAT, in particular for transient astrophysics.

- The Instrument Calibration Module at GTC with the three different calibration lamps (HgAr, Ne, and Xe) will be used to obtain the arc lines for the selected OSIRIS Grisms and VPHs.

- The MAAT team will provide an on-line user-manual with detailed observing and calibration procedures, and guidelines for the public available data reduction pipeline. A quick-look pipeline will also be provided to assist the Support Astronomers during the observing runs, which will include acquisition and focusing scripts.

Concluding Remarks

The scientific and technical work presented in the MAAT proposal suggest that we will be in the position to formally start the project as soon as we have the approval of the GTC Office. The design and construction phase will take in total 20 months.

This plan should fit well with the GTC plans of having OSIRIS installed and ready for operation at the Cassegrain focus (with the new e2v detector) by the end of 2021.

This MAAT@GTC Workshop aims to collect the interest from the community and form a consortium for its construction and science exploitation. Anyone is welcome to join!

We will submit a report to the GTC Steering Committee in response to their additional information request for their review by their July meeting.

MAAT

MAAT *refers to the ancient Egyptian concepts of truth, balance, order, harmony, law, morality, justice, and cosmic order.*

Thanks!