Calar Alto Observatory

Timelapse Dominique Joubert

Strategic plan 2021-2025

- CAHA01. New instrument for the 3.5 telescope.
- CAHA02. Upgrade of the telescope control system
- CAHA03. Energetic island V2.0
- CAHA04. New instrument for the 2.2m
- CAHA05. Upgrade of CARMENES
- CAHA06. Improve of CAFÉ
- CAHA07. Auxiliary telescope system as air compressors, cooling systems etc.
- CAHA08. Improve of the CAHA Archive.

And

- Project MARCOT
- Project CASTLE
- Visitor’s center at CAHA

New instrument for the 3.5m telescope

“Tetra-ARmed Super-Ifu Spectrograph”

A. Gil de Paz (UCM, co-PI), J. Iglesias (IAA, co-PI)

P. Sánchez-Blázquez (UCM), M. Relaño (UGR), J. Oñorbe (US), C. Kehrig (IAA), A. Montaña (INAOE)

TARSIS CONSORTIUM & INSTRUMENT TEAM

CATARSIS SURVEY TEAM

THE CONSORTIUM: Responsibilities

IAA-CSIC

1 co-PI + 1 co-PS

Responsible for the WPs:

- Instrument Control System (ICS)
- Quality Control (QC)
- Acquisition and Guiding and Calibration Unit

Outreach and Communication coordination

In-kind 400 k€ for TARSIS detectors.

CAHA

ERDF – 6,5M€. General administration

1 support engineer

CAB

WP: Instrument simulator

WP: Data storage and dissemination

UCM

1 co-PI + PS

Responsible for the WPs:

- Cryostat and Detectors
- Scientific Software
    - Data Processing
    - Post-processing S/W
- TARSIS System AIV (lab, CAHA)
- Packing and shipping to CAHA.
- Commissioning

FRACTAL

Project Manager

System Engineer

WP: Optics and Mechanics design

INAOE

1 co-PS

WP: Optics manufacturing

UGR

1 co-Project Scientist (co-PS)

WP: Custom S/W tools for CATARSIS

UAL

WP: High Performance Computing

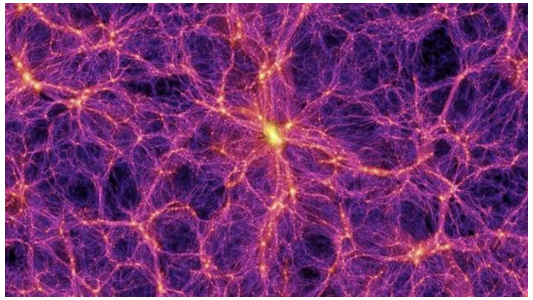
US

1 co-Project Scientist (co-PS)

WP: Site UV characterization

TARSIS – CATARSIS survey

- **Observations**: Spectroscopy of galaxy clusters, at distances between 1900 and 2700 million light years, the time when they accumulated ¼ of their present mass. Spectra of all galaxies in the cluster down to the very small ones and covering the entire cluster down to the filaments that feed it..



Goals:

- To validate the basic predictions of the standard cosmological model :

→ unprecedented cosmological test + measurement of expansion of the universe + measurement of existing biases in large photometric mappings.

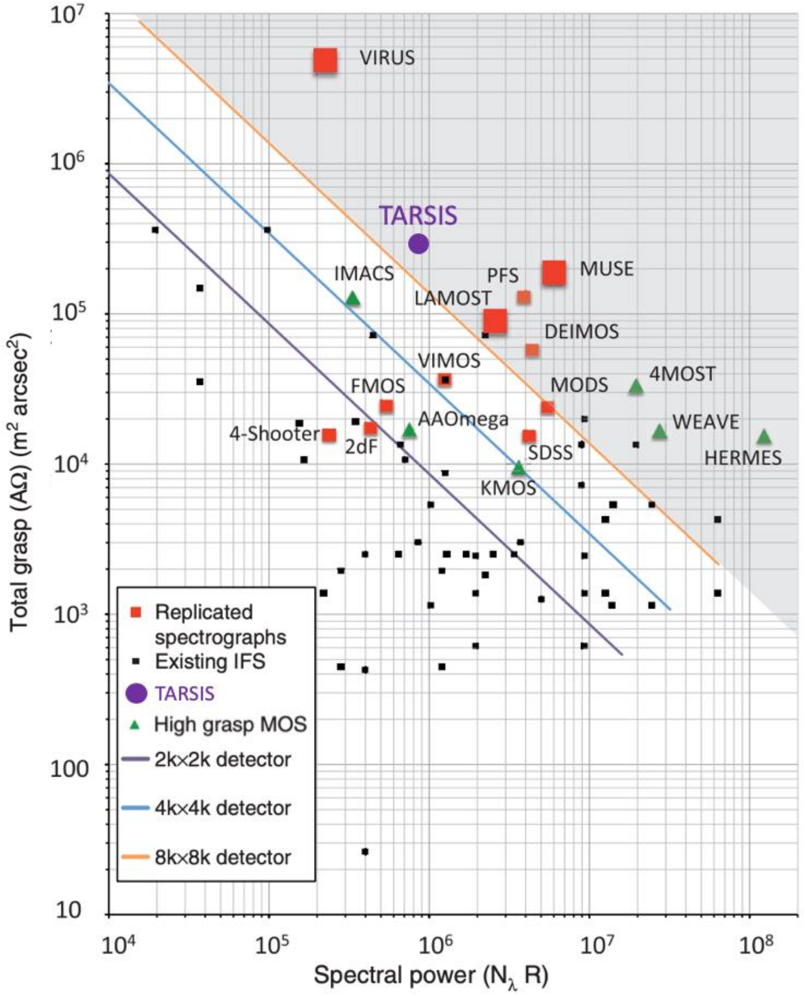
- Study the nature of dark energy and dark matter, and explore new physics **:** by studying alignments between galaxies and filaments, we will be able to determine the degree of interaction of dark matter with itself, shedding light on the nature of dark matter.
- To study the formation of galaxies in relation to their environment : What is really novel is the study of clusters of galaxies that have filaments. The galaxies are altered in the clusters, but it is not known what happens in the filaments.

TARSIS – CATARSIS survey

Why has it not been done before?

Thanks to the combination: large field + sensitivity in the blue + coverage in λ :

- First time that spectroscopy of all galaxies in the cluster is obtained, without prior selection, from the center to the outermost parts, dynamic study of the cluster and its substructure.
- Wavelength coverage makes it possible to determine previously unstudied properties of galaxies.
- Wavelength coverage and the large field make it possible to compete with the world's largest telescopes in the search for distant galaxies and to characterize their properties using those same observations (below).



- Unique combination of large Field of View and spectral coverage (VIRUS provides similar characteristics, but with lower spectral resolution and no red coverage).

Observing plan

- The scientific goals of CATARSIS require reaching galaxies with continuum magnitudes **$m_{AB,r}$~21**, and limiting line fluxes **(1-2)x10^{-17} erg s^{-1} cm^{-2}**.
- The required exposure time per pointing is **28800s (8h) for the Blue range**, and **9600s (2h40m) for the Red range** (see ETC-42 generic Exposure Time Calculator).
- To achieve these requirements, **observations will be carried out during clear dark (or with low Moon illumination) nights** (although not necessarily photometric).
- A required **AIRMASS to be lower than 1.22**, to limit the extinction at the blue end of the TARSIS wavelength range and to fulfill the detection limit requirements.
- CATARSIS will be complete in 6 years.

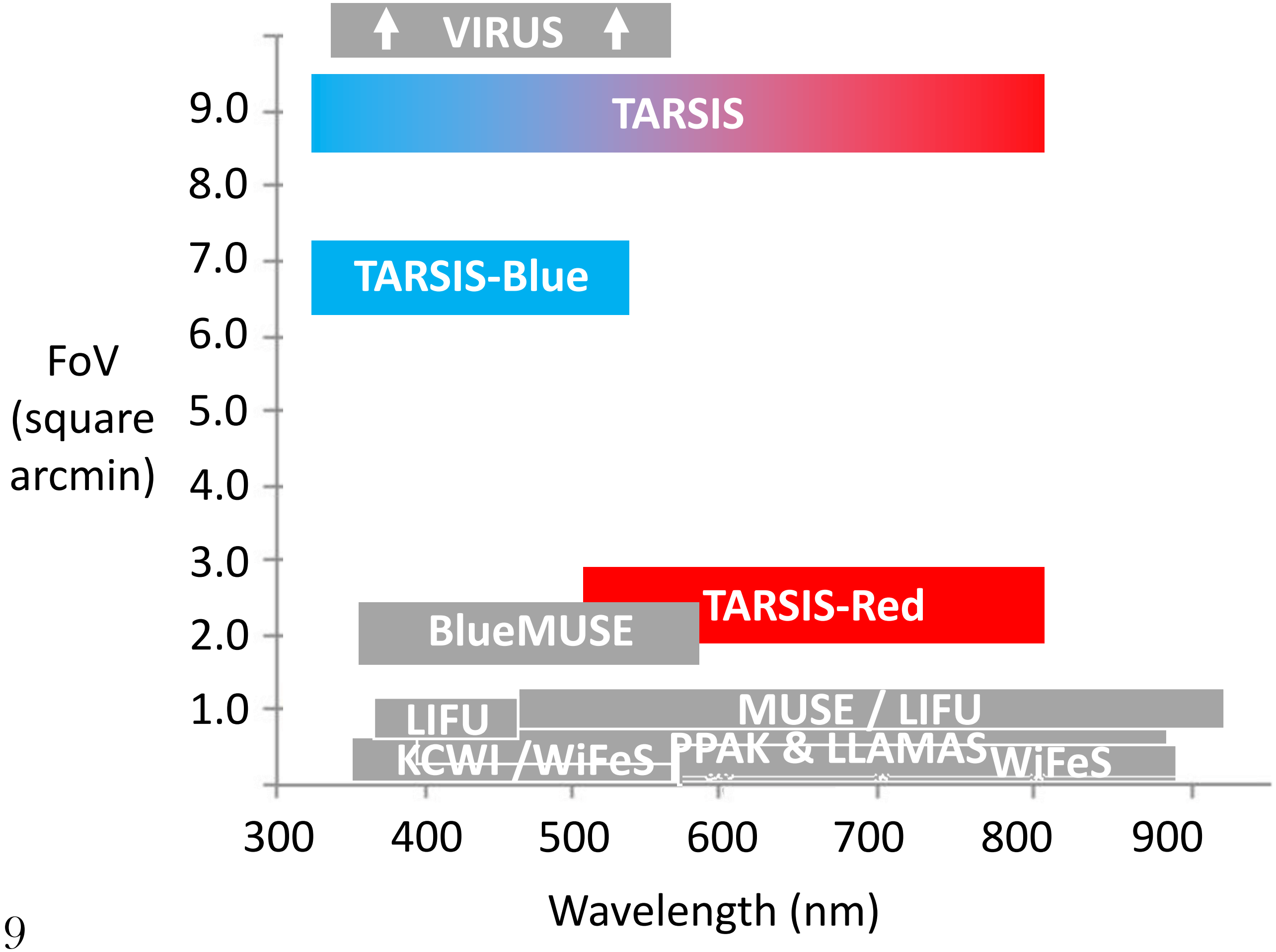
Compatibility with other instrumentation

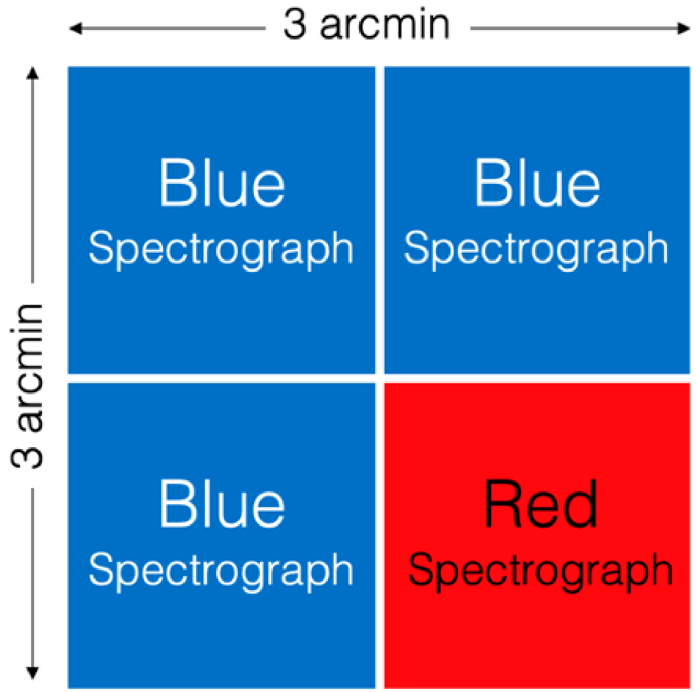
- TARSIS is 100% compatible with the CARMENES Front-End. Thus, both instruments will coexist in the Cassegrain focal station.
- During dark nights, CATARSIS will observe in Staring mode. Since it requires rotating the Cassegrain, the CARMENES fibers will be disconnected.
- During grey nights, CATARSIS will observe in Mapping mode, which does not require rotation, thus allowing to easily change from TARSIS to CARMENES.

(This is currently the situation for CARMENES and PMAS)

TARSIS: THE INSTRUMENT

1. There is a qualitative comparison with other IFUs and surveys, including blueMUSE and HETDEX (1.1.2). Can this comparison be quantified, e.g. in terms of survey speed?





Large FoV, 9 arcmin^2

Spectral resolution R ~1000

Bluest spectral range

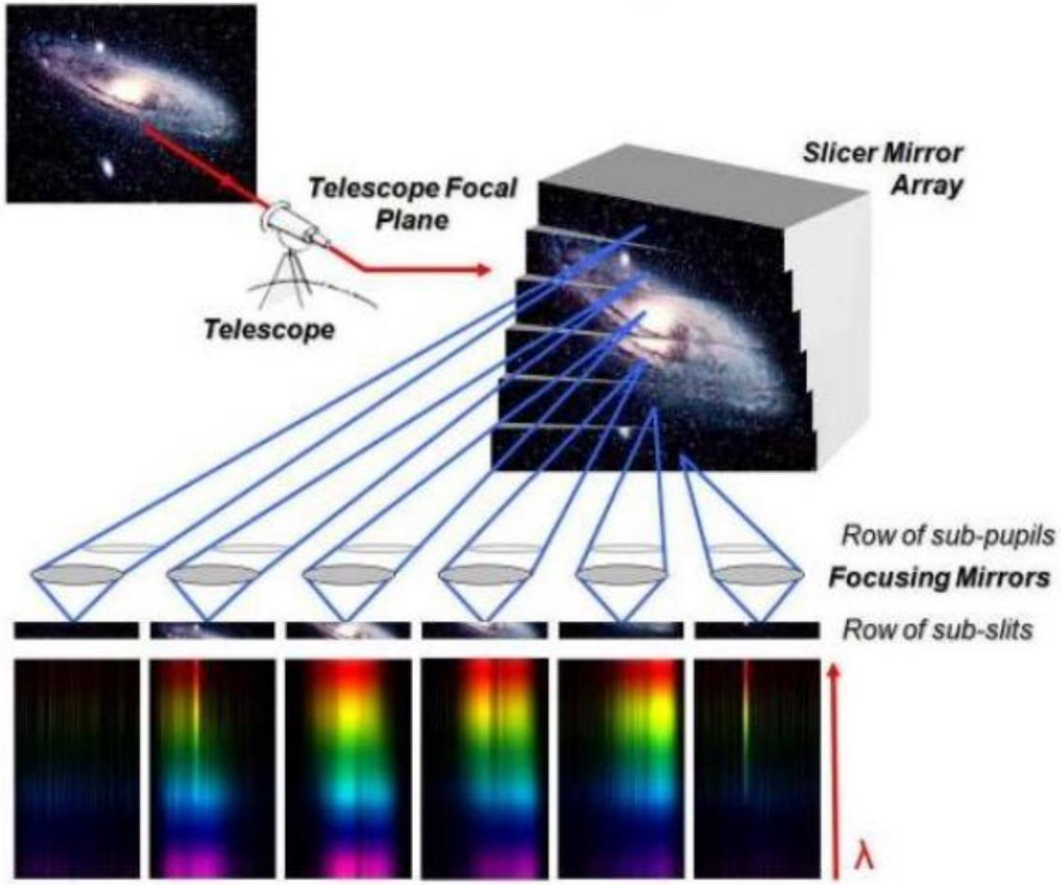
Wide λ coverage

320 to 520 nm

510 to 810 nm

Optical design: Foreoptics

- Image Slicer designed by Winlight
- Requirements include: flat & F/3 output focal plane, 320-810nm coverage, 9 sq.arcm. FoV, ...
- *Backup alternative*: Optical fibers (similar efficiency but half the FoV)



Instrument	FOV	Input F/#	Output F/#
TARSIS	**(x4) 1.5' x 1.5'**	**F/10**	**F/3**
MUSE (1 slicer)	1' x 2.4''	F/(57/115)	F/(4.3/8.6)
KCWI	20" x 34"	F/14	F/14
IRIS	4" x 4" max	F/45	F/15
SOLARNET	-	F/40	F/40

New instrument: TARSIS

- Budget: 7.9M€ (contingency included):

Year	ERDF	Comments
2021	1,5 M€	ICTS2021-MRR
2023	5.0 M€	ERDF Plan 2021-2027
	1.4 M€	TARSIS consortium 1.4M€

UNIÓN EUROPEA

Fondo Europeo de Desarrollo Regional
"Una manera de hacer Europa"

Up to now…but before end of 2023

CAHA

ICTS2021-06917 (1.47M€)

ERDF	Comments
	Optical design until PDR
	Mechanical optical design PDR
	Management and system engineering

UNIÓN EUROPEA
NextGenerationEU
Mecanismo de Recuperación y Resiliencia

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Fondo Europeo de Desarrollo Regional
"Una manera de hacer Europa"

More info about TARSIS?

https://tarsis.caha.es

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MARCOT: A new Approach to a large aperture telescope with a novel multimode photonic lantern

Jesús Aceituno (PI) (CAHA-IAA), Stefan Cikota (CAHA), José L. Ortiz, Pedro Amado, Fran Pozuelos, Rafael Luque, Nicolas Morales (IAA)
Martin M. Roth, Kalaga Madhav, John Davenport (AIP), Tim Birks (Univ. Bath), Faustino Organero, Leo Ana, Fernando Fonseca (AstroHita)

MARCOT Pathfinder at Calar Alto progress report", Proc. SPIE 12182, (2022); https://doi.org/10.1117/12.2629901

Science Case & Motivation

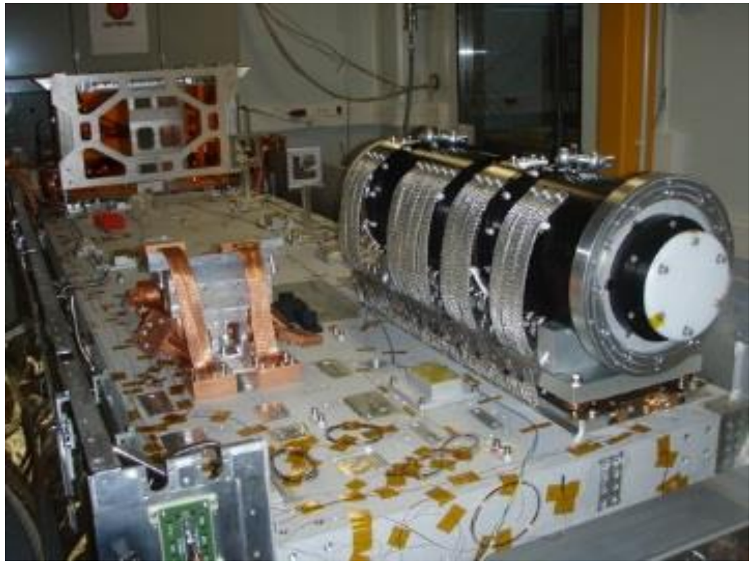
CARMENES at CAHA 3.5m Telescope

(Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs)

- **in operation since 2016. https://www.caha.es**

SpType	J mag	Texp	SNR NIR	SNR Vis
M1.0	6.7	568 s	200	169
M1.5	5.2	116 s	140	159
M3.5	8.5	1800 s	137	88
M7.0	9.8	1800 s	82	31

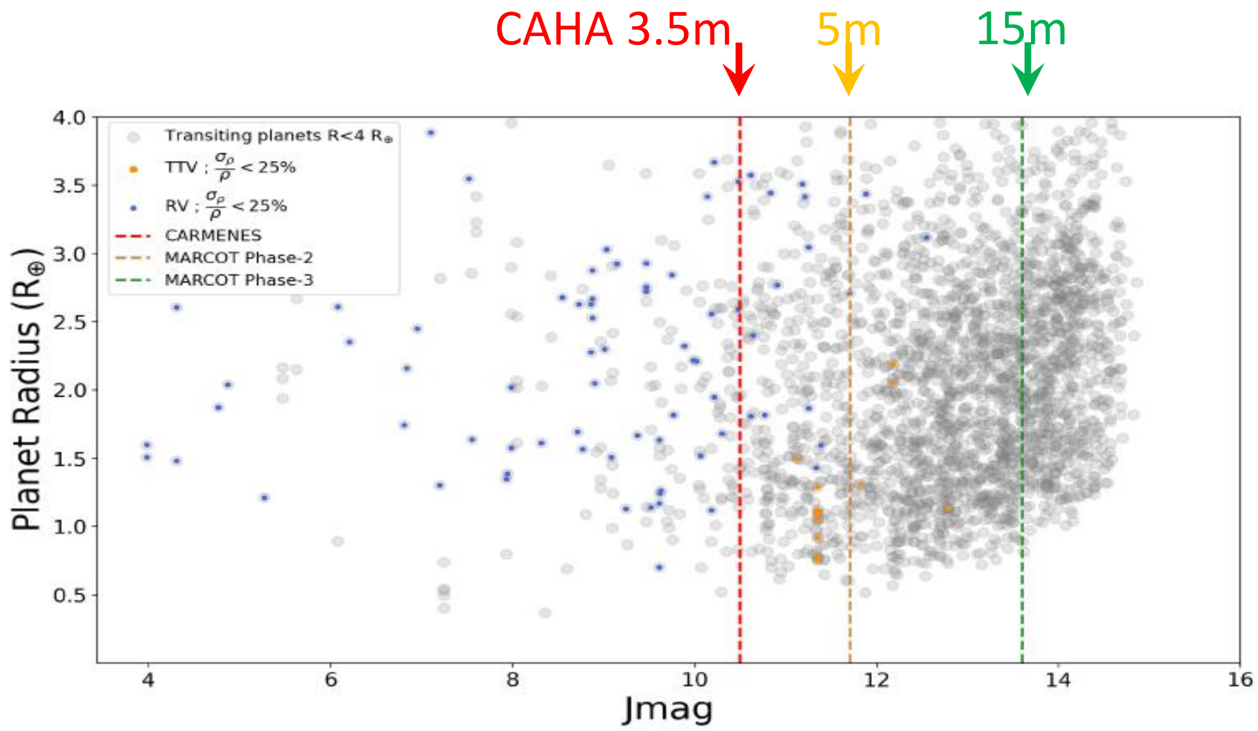
	VIS channel	NIR channel
Wavelength coverage	**520-960 nm** ([*V*]*RIZ*)	**960-1710 nm** (*YJH*)
Detector	1 x e2v CCD231-84	2 x Hawaii-2RG (2.5 μm cutoff)
Wavelength calibration	Th-Ne lamps & Fabry-Pérot etalon	U-Ne lamps & Fabry-Perot etalon
Working temperature	285.000 ± 0.005 K	140.000 ± 0.005 K
Spectral resolution	**94,600**	**80,400**
Mean sampling	2.8 pixels	2.8 pixels
Mean inter-fibre spacing	7.0 pixels	7.0 pixels
Cross disperser	Grism, LF5 glass	Grism, infrasil
No. of orders	55	28
Échelle grating	2 x Richardson Gratings R4 (31.6 mm^{-1})	2 x Richardson Gratings R4 (31.6 mm^{-1})
projected fiber diameter	1.5 arcsec	1.5 arcsec
A&G field of view	3 arcmin	3 arcmin



MARCOT: Science Case & Motivation

CARMENES Science Case:
populating the Mass-Radius Diagram

5060 Exoplanets (as of July 17, 2022)
https://exoplanets.nasa.gov/



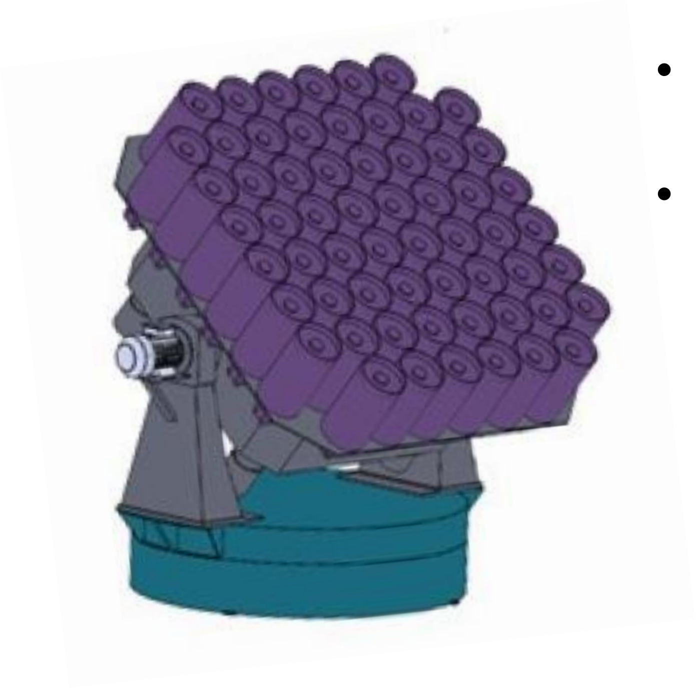
30…. 100 RV samples per exoplanet needed

- Exoplanet discovery and characterization
- Refining the architecture of the most nearby stars and brown dwarfs
- Exoplanet atmospheres

Rather than going on an extensive 'blind RV search' (survey) for planets, the optimal approach for MARCOT is to target systems with already known transiting candidate planets for which planetary radii have already been estimated from ground- and space-based observations

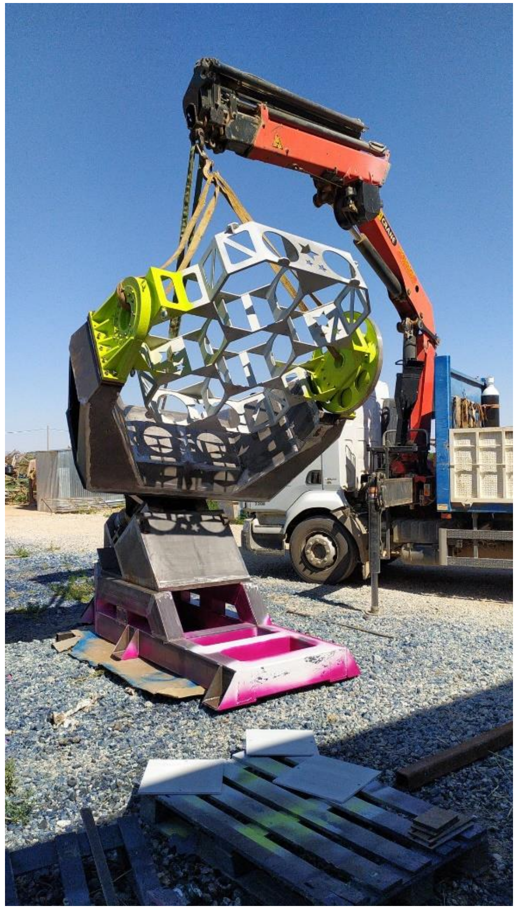
MARCOT: Concept

MARCOT: Multi Array of Combined Telescopes



60 OTAs ⇔ 3m monolithic

- All OTAs point the same target on the same mount.
- Two operational modes:
  - Imaging --- Each OTA is equipped with an acquisition and guiding system. Specific algorithm get the resulting image frame. Large Fov, very high dynamic range, f#< 1.0 for large apertures, simple high AO corrections available.
  - Spectroscopy --- a fiber optic feed one spectrograph. Light is combined optically through optical fibers, by using a novel Multi-Mode Photonic Lantern (MM-PL)



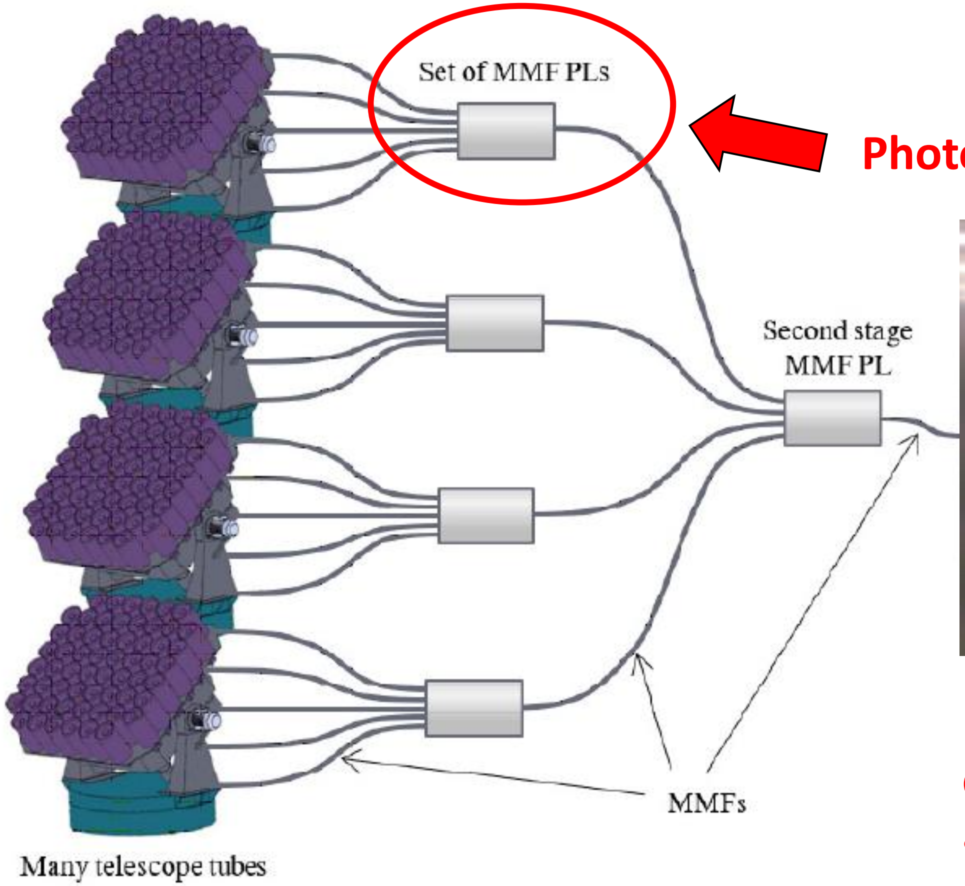
MARCOT Pathfinder mount

MARCOT: Concept

The light collected by the modules through the individual optical fiber feed of each OTA is optically injected into a novel multi-mode photonic lantern (MM-PL), which can either directly feed the astronomical instrument attached to the telescope or, feed a second stage MM-PL that can combine the light from a cascade of several MARCOT modules.

9× 5m

Equivalent to 15m



Photonic Lantern

Carmenes

Goals:

- Modules of about 5m
- Infraestrucure of about15m

MARCOT: Concept

CALAR ALTO Observatory

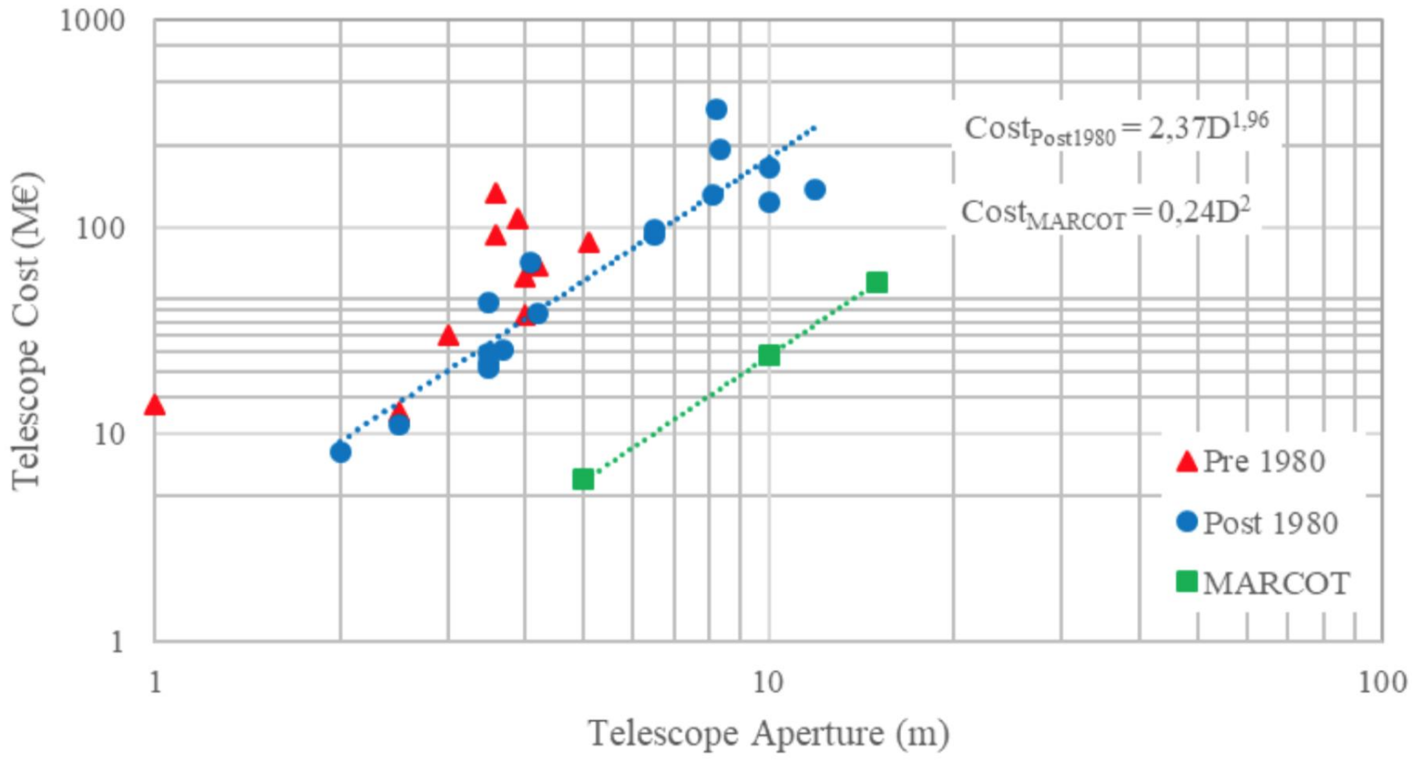
MARCOT

Multi **A**rray
of **CO**mbined
Telescopes

MARCOT: Concept

Cost estimates

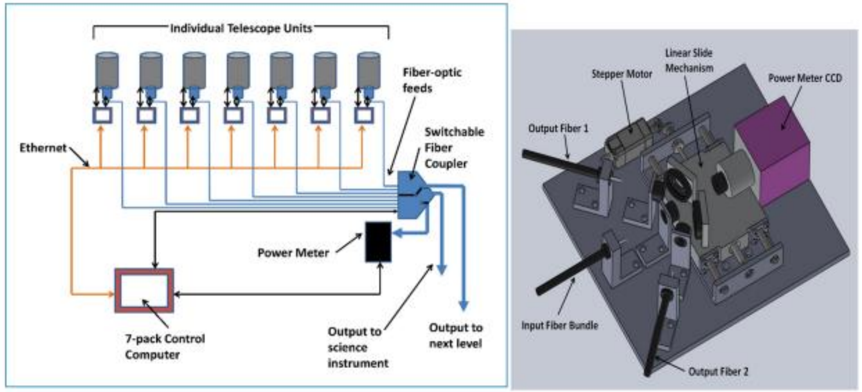
Consists of multiple identical low-cost telescopes, at a fraction of the cost of building extremely large telescopes



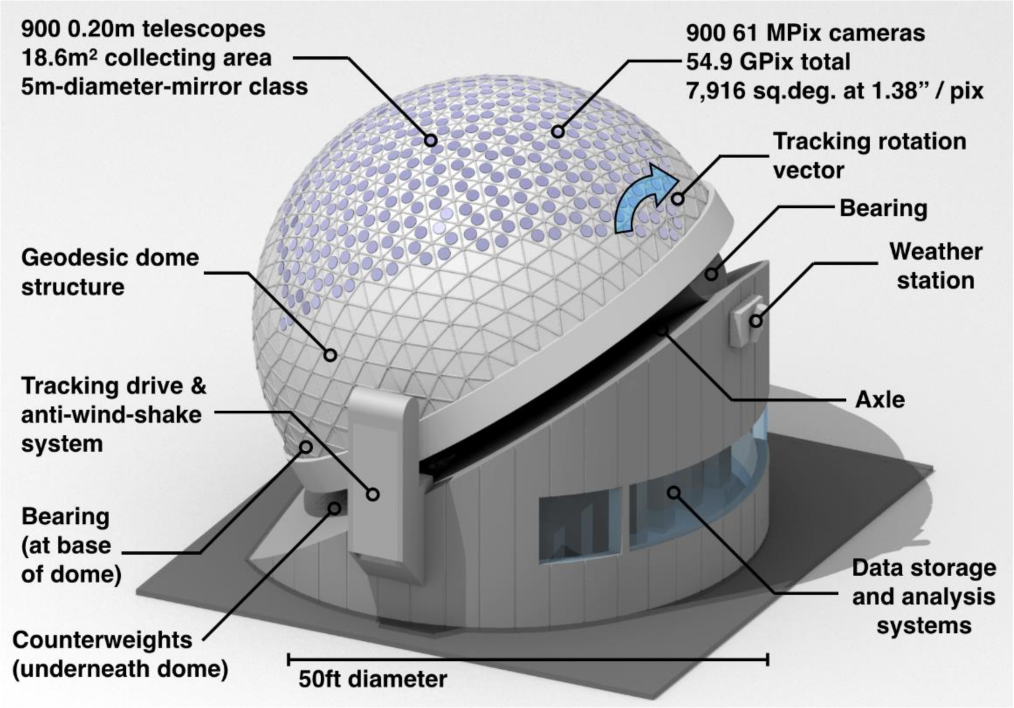
adapted from: van Belle, G. T., Meinel, A. B. & Meinel, M. P. 2004 SPIE 5489, 563

MARCOT: Concept

Dragonfly Telescope (Abraham & van Dokkum, 2014), being developed to image extended structures down to surface brightness levels as low as B = 32 mag arcsec.



PolyOculus (Moraitis et al., 2021), which, proposes to link commercial-of-the-shelf telescopes through a single-mode fiber photonic lantern.



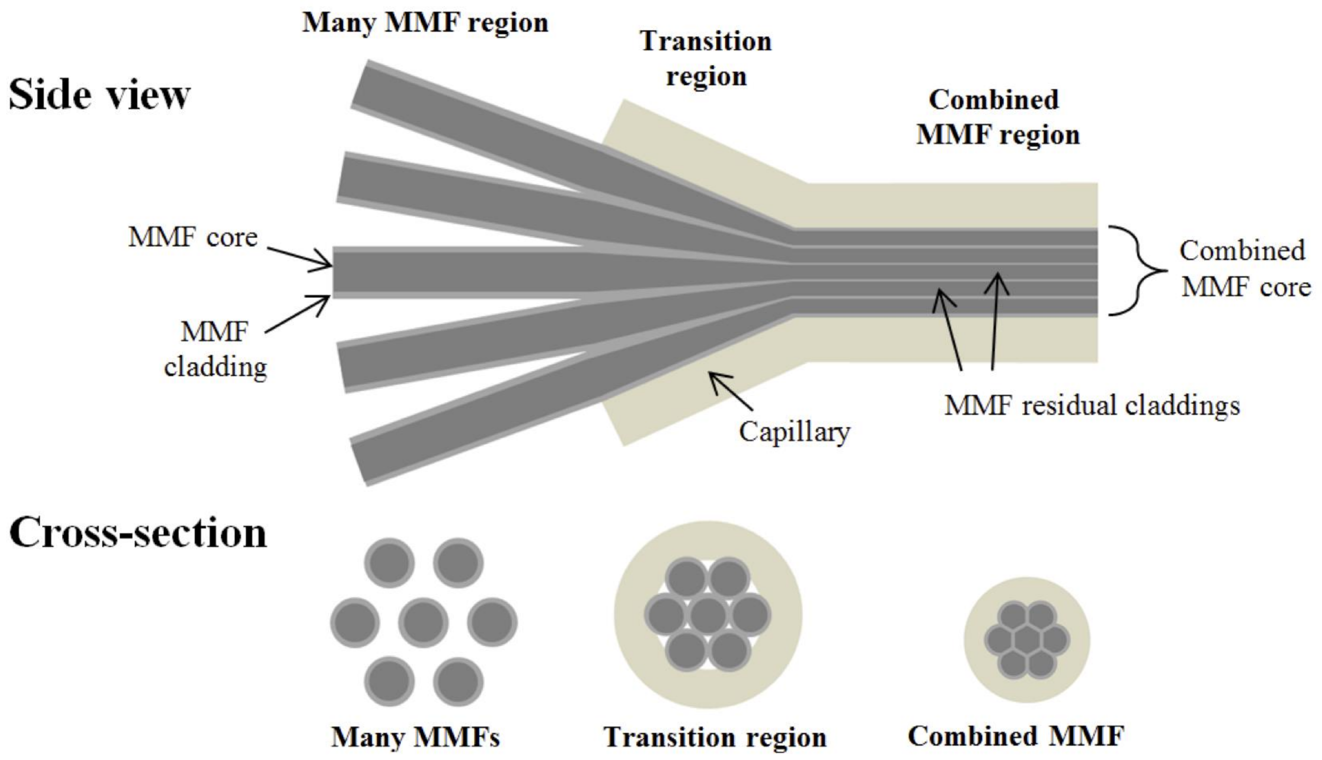
Argus concept is a large all-sky telescope consisting of 900 moderate-aperture (5m aperture-equivalent), of-the-shelf telescopes multiplexed into a common hemispherical dome to observe each part of the sky for nine minutes at high cadence each night.

Concept. The photonic lantern

- The classical PL is essentially a mode converter that fuses several input single mode fibers (SMF) into a tapered output MMF.
- The plate scale of large telescopes normally precludes fiber links with SMFs because the core diameter of order 10 μ m would be far too small for the image of a star. A simple demagnification with a lens does not help since the invariance of etendue of the demagnified beam would overfill the numerical aperture (NA) of the SMF
- MARCOT OTAs (Φ=405 mm, FL=f 3250 mm, PS= 63.5 "/mm => SMF core diameter for 1" FWHM seeing,
- Fiber core diameter envisaged of 0.047mm, => the light from the wings of the stellar point-spread-function, and to reduce the sensitivity to pointing and guiding errors
- Traditionally, a common method for producing PLs is to stack a bundle of single-mode fibers (SMFs) inside a capillary, and taper them down to fuse into a single MMF. The capillary becomes the cladding of the MMF, while the claddings of the SMFs fuse to become into the core of the MMF.
- The cores of the SMFs reduce to the point that they can no longer contain light. MMFs cannot be drawn into photonic lanterns in the traditional way as their larger cores are still able to couple light even after tapering.
- This has traditionally meant that PLs could only be used to combine light from near diffraction limited systems such as extreme AO corrected telescopes, which is unsuitable for MARCOT.

Concept. The photonic lantern

Multi-Mode Photonic Lantern



Schematic of an MM-PL made from 7 MMFs. MMFs with high core-to-cladding ratios (left) are tapered down to form a single MM core (right) as the claddings can no longer efficiently confine light. The capillary now forms the cladding of the new combined MMF.

In MM-PL the new core is formed from the original cores instead of the claddings of the individual MMFs.

This was done by using reduced-clad MMFs with high core-to-cladding ratios which are then tapered to a point where they are too thin to confine light.

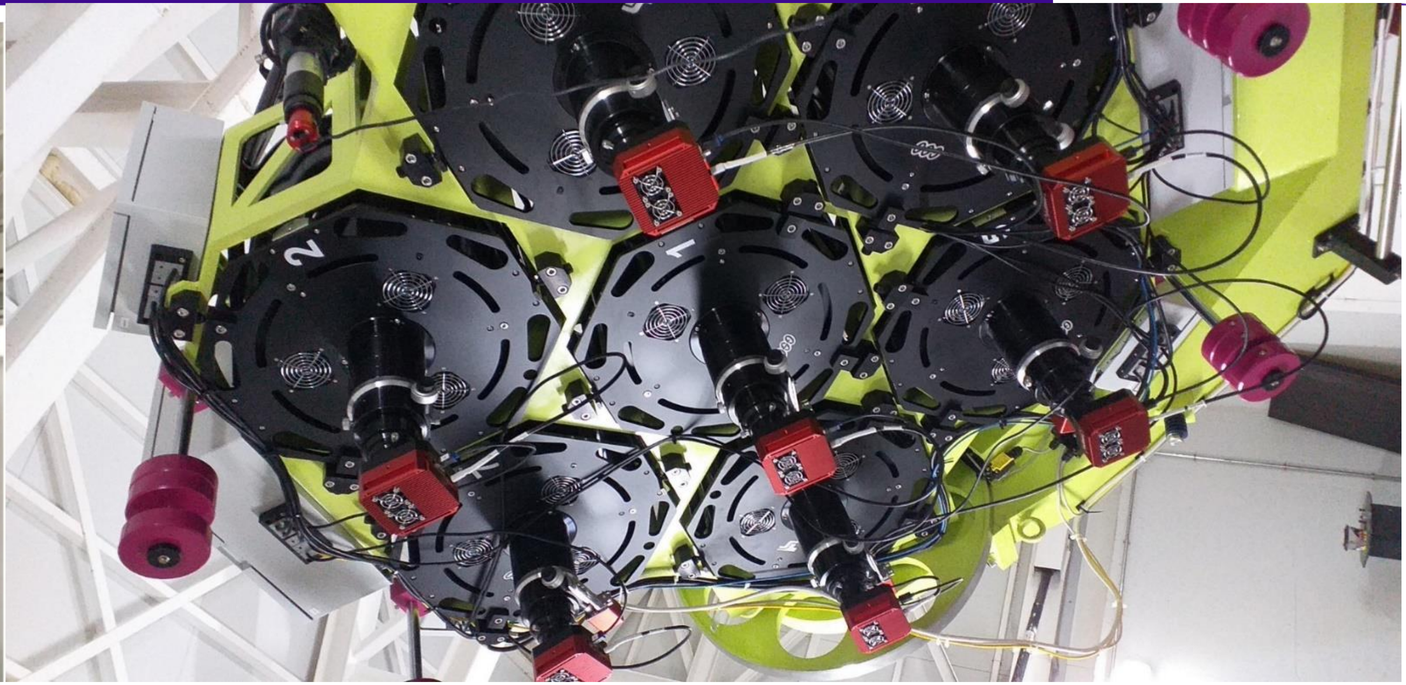
A capillary with a refractive index lower than an individual MMF's cladding is used to ensure a regular arrangement of the MMFs during the tapering process.

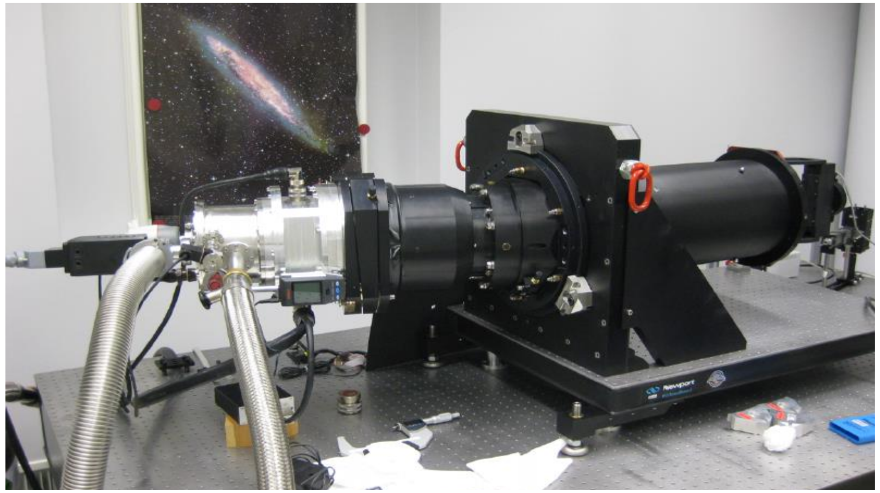
After tapering, the capillary becomes the new cladding of the resultant combined MMF, and the residual claddings of individual MMFs are now too thin to contain light, working as a single large diameter core.

Pathfinder Telescope

SOMM17_5208_IAA

Pathfinder Telescope





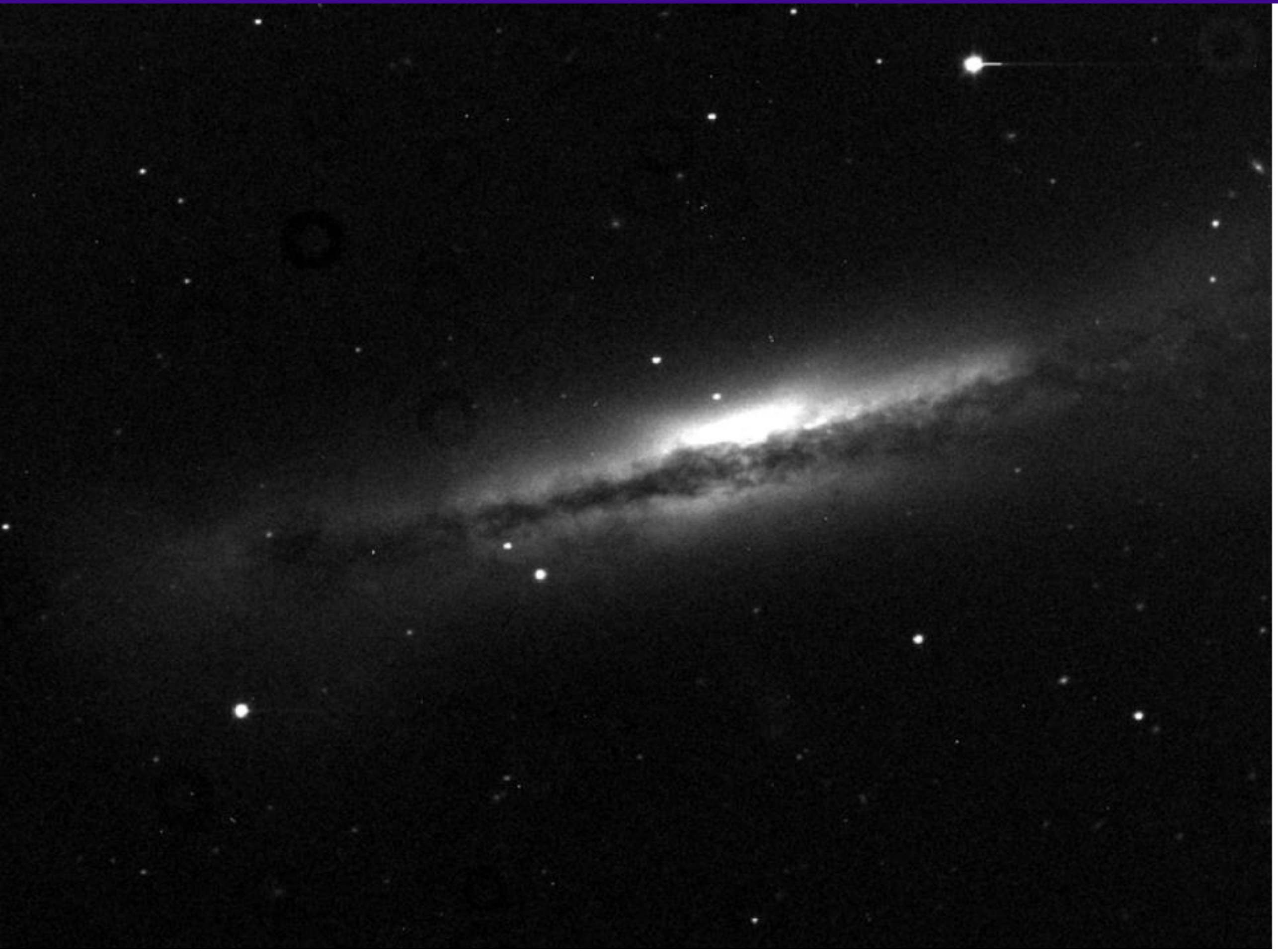
MARCOT Pathfinder at Calar Alto progress report", Proc. SPIE 12182, Ground-based and Airborne Telescopes IX, 121820M (2022); https://doi.org/10.1117/12.2629901

Moralejo, B., Roth, M. M., Godefroy, P., Fechner, T., Bauer, S. M., Schmälzlin, E., Kelz, A., Haynes, R. 2016. *The Potsdam MRS spectrograph: heritage of MUSE* SPIE 9912, 991222

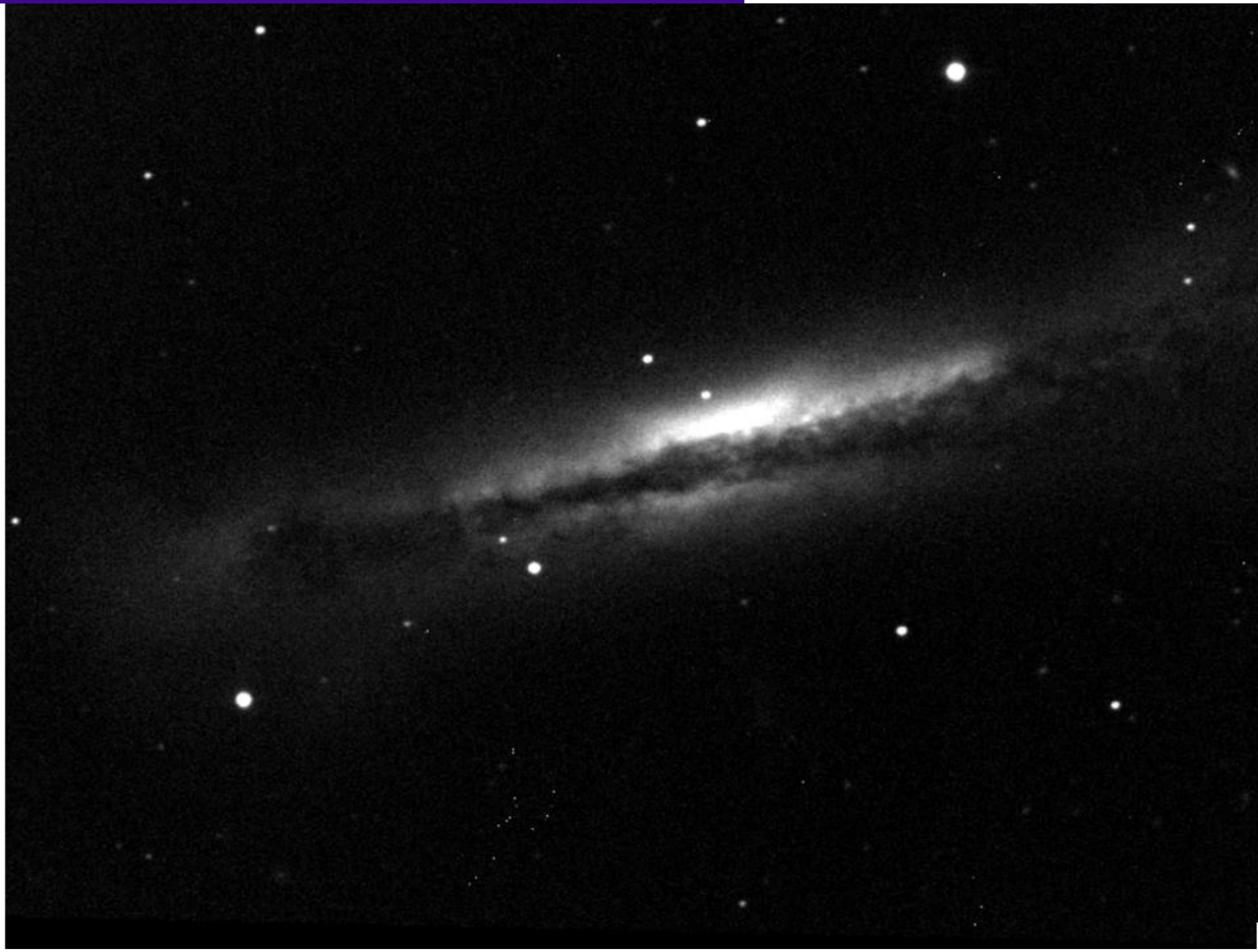
Pathfinder Status

Dome:	in operation
Telescope mount:	in operation
Unit telescopes:	installed + functional replacement of instable mirror mounts in progress
Spectrograph:	shipment and installation completed 08/2022
Commissioning:	beginning 09/2022 (Conclusions to come very soon!!!)
MMPL development:	3 year project, to be launched in 01/2023

Comparison MARCOT PF1.08 VS CAHA1.23m



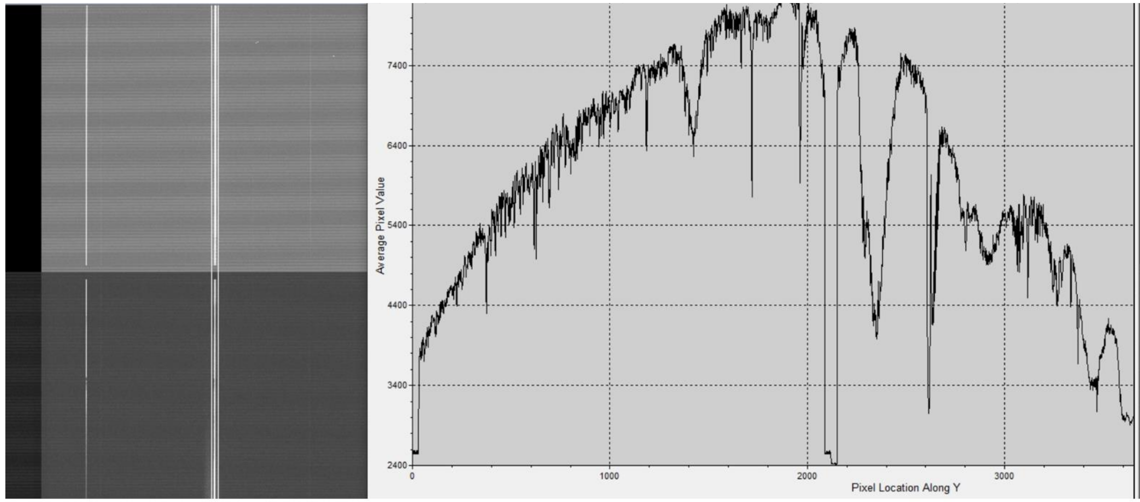
PATHFINDER (1.08m)



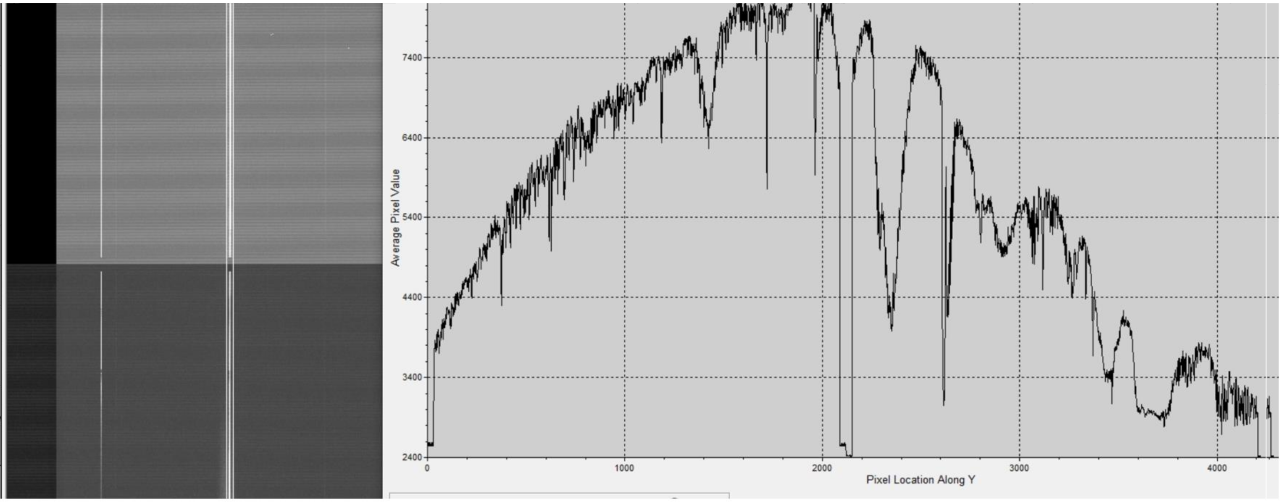
1.23m CAHA Telescope

NGC 3628 (900s).The effective integration time of the combined images on MARCOT is comparable to those of the 1.23-m telescope. Both images show a similar limiting magnitude, of ~21.5 mag.

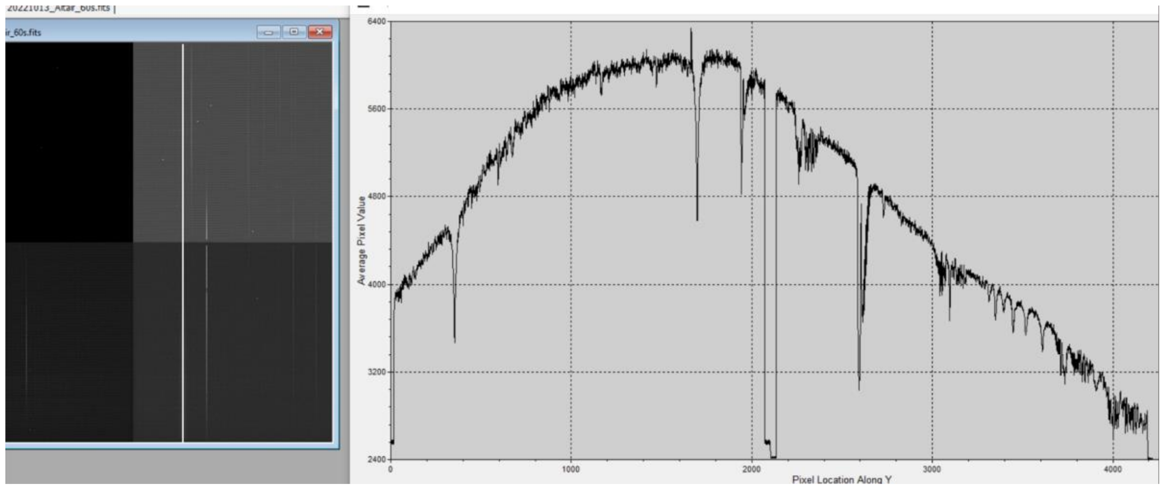
Very first spectra with MARCOT PF1.08m



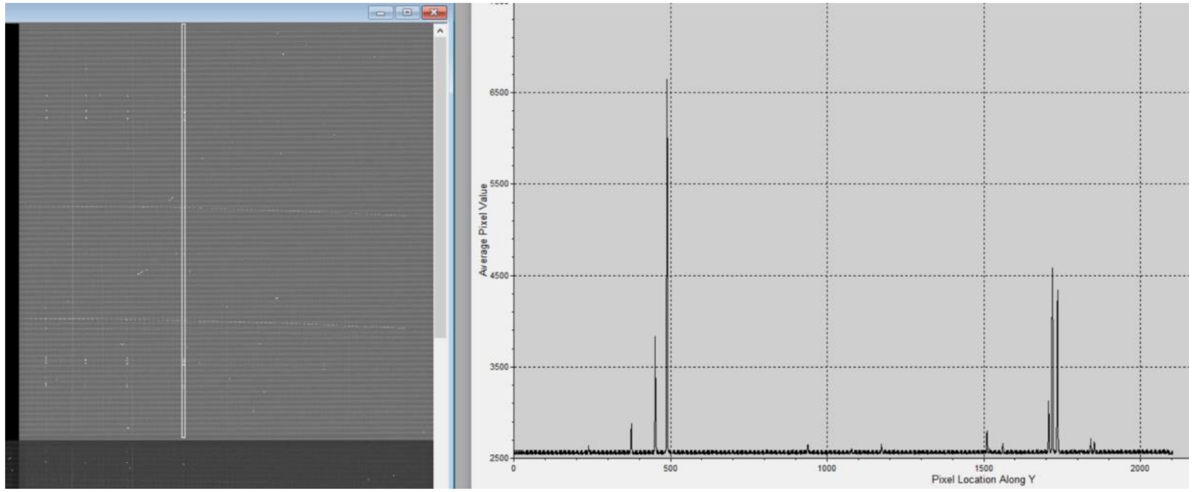
M31 300s



Saturn 300s

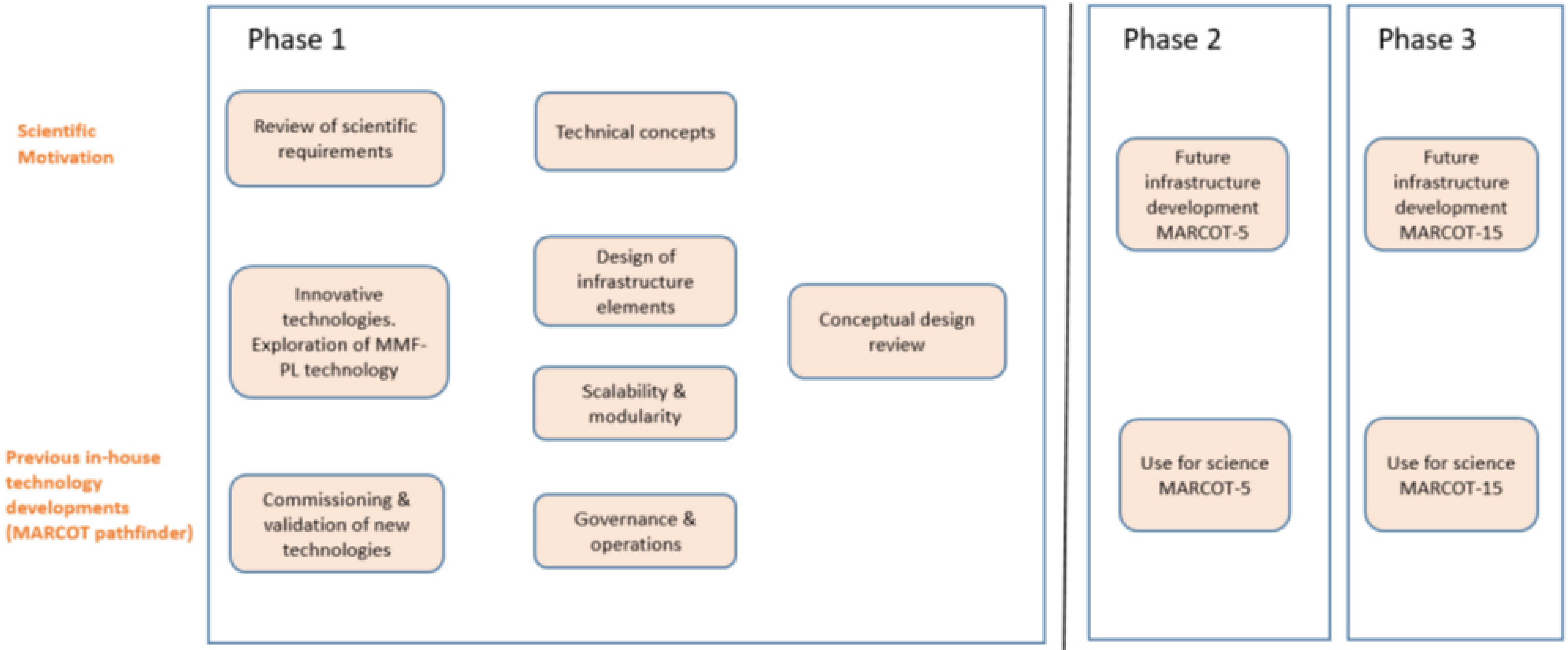


Altair 300s



M57 300s

MARCOT: Status. Roadmap



Now	Design study up to FDR	Marcot-5m	Marcot15m
0.2M€	2.5M€	5-8M€	9xphase2
1yr	2yr	3yr	5yr

Fund raising: **ongoing, new partners welcome!!!**

MARCOT

https://marcot.caha.es

aceitun@caha.es

SUMMARY

- TARSIS https://tarsis.caha.es
- MARCOT https://marcot.caha.es

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