ELT - MICADO

Phase C

Executive Summary

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Author(s):	R. Davies	4.Aug.2021	
	Name	Date	Signature
WP Manager:	E. Sturm		
	Name	Date	Signature
Proj. Responsible	R. Davies	4.Aug.2021	
	Name	Date	Signature

CHANGE RECORD

ISSUE	DATE	SECTION/PARAGRAPH AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
1.0	25.01.2016	All	Initial issue
2.0	21.09.2018	All	Complete revision for PDR
2.1	16.01.2019	7 (Table 2), 8	PDR RIXs: FKE-12, FKE-13
2.9	19.01.2021	all	For internal use. Small changes to science case; updated design, schedule & cost; added FINCA.
3.0	12.04.2021	7	Updated schedule. FDR release
3.1	11.05.2021	7, 8	Minor text revision for MIC-1082, MIC-714

TABLE OF CONTENTS

1 Scope

The purpose of this document is to provide a top-level non-technical overview of the MICADO project. It emphasizes the scientific role of the instrument; describes the global architecture of the instrument; introduces the consortium partners and their contributions; summarizes the current status of the project in the overall schedule; and indicates the project cost. All statements are subject to possible future change as the project develops.

This release presents an overview of the MICADO instrument as it approaches the Final Design Review.

2 References

2.1 Applicable documents

AD Nr	Doc. Nr	Doc .Title	Issue	Date
AD1	ESO-193104	Top Level Requirements for ELT-CAM	2.0	30.03.2015
AD2	ESO-244537	MICADO (ELT CAM) Technical Specification	2.0	25.11.2020
AD3	ESO-257871	Statement of Work	2.0	10.12.2020
AD4	64364/ESO/15/67002/JSC	Amendment No. 1 to Agreement for the MICADO Instrument		17.12.2020
AD5	MCD-563-MOU-0001	Memorandum of Understanding for the MICADO Collaboration	1.0	22.09.2015
AD6	ELT-MOU-MCD-56300-0095	Amendment No. 1 to MoU	1.0	08.05.2020

2.2 Reference documents

The following reference documents (RD) contain useful information relevant to the subject of the present document.

RD Nr	Doc. Nr	Doc .Title	Issue	Date
RD1	ESO-254311	MAORY (E-ELT MCAO) Technical Specification	1.0	10.11.2015
RD2	ELT-PLA-MCD-56300-0003	MICADO Project Management Plan	3.0	12.04.2021
RD3	ELT-PLA-MCD-56305-0006	MICADO Science Case	2.0	01.03.2019
RD4	ELT-TRE-MCD-56300-0011	MICADO System Overview	2.0	12.04.2021
RD5	ELT-PLA-MCD-56305-0013	MICADO SCAO Science Cases	1.0	16.09.2019

3 Introduction

MICADO is the Multi-AO Imaging Camera for Deep Observations. It will equip the ELT with a first light capability for diffraction limited imaging and long-slit spectroscopy at near-infrared wavelengths. The instrument is optimised to work with a multi-conjugate laser guide star adaptive optics system (MCAO, developed by the MAORY consortium; RD1), and will also make good use of a single-conjugate natural guide star adaptive optics system (SCAO, developed jointly by the MICADO and MAORY consortia). It will interface to the MAORY warm optical relay that re-images the telescope focus. In this configuration, both MCAO and SCAO are available. During an initial phase, MICADO will also be able to operate with just the SCAO system in a ‘stand-alone’ mode, using a simpler optical relay that interfaces directly to the telescope.

MICADO is being designed and built by a consortium of partners in Germany, France, the Netherlands, Austria, Italy, and Finland, together with ESO. The instrument will be delivered to the Observatory at Armazones towards the end of 2025, ready for first light of the ELT.

4 Science Drivers

MICADO has the potential to address a large number of science topics that span the key elements of modern astrophysics. The science drivers (RD3, RD5) focus on five main themes: (i) galaxy evolution at high redshift, (ii) black holes in galaxy centres, including the Galactic Center, (iii) resolved stellar populations, including photometry in galaxy nuclei, the initial mass function in young star clusters, and intermediate mass black holes in globular clusters, (iv) characterisation of exoplanets and circumnuclear disks at small angular scales, and (v) the solar system. To address these, MICADO will exploit its key capabilities of sensitivity and resolution, which are in turn leveraged by its observing modes of imaging, astrometry, coronagraphy, and spectroscopy. With a point-source sensitivity that is comparable to JWST and a resolution about a factor 6 better, MICADO is well suited to numerous science cases. A few of these are highlighted below.

Galaxy Formation and Evolution

We now have a fairly robust outline of the cosmic evolution of global galaxy properties, and hence the first pieces of evidence about how galaxies assembled and transformed into the present day Hubble sequence. An obvious next step is to resolve the faint distant galaxies on sufficiently small scales to assess their sub-galactic components including disk structures, nascent bulges, clumps, and globular cluster progenitors. The current view is limited by spatial resolution, which corresponds to ~ 1 kpc in the best cases (space-based telescopes or adaptive optics on 8-m class ground-based telescopes). In particular, relatively unexplored regimes include lower mass galaxies, comprising the bulk (by number) of the galaxy population, and galaxies at early cosmic times, when they were building their first stars. Figure 1 illustrates the type of detailed structure within high redshift galaxies that MICADO might be able to detect.

An alternative probe of galaxy evolution is the relic populations in local galaxies, using photometry of individual stars to generate a colour magnitude diagram (CMD). The various features of a CMD relate to stars formed at different cosmic times. In particular, stars on the horizontal branch enable one to trace the star formation history of galaxies to $z > 6$, to the reionization epoch. The ultimate goal for resolved stellar populations is to probe the central regions of elliptical galaxies in the Virgo Cluster. The high surface brightness, due to extreme stellar crowding, makes this very challenging. JWST will only be able to probe the outskirts of these galaxies, while the higher resolution of MICADO will enable it to reach almost to the centre where the bulk of the stars are to be found.

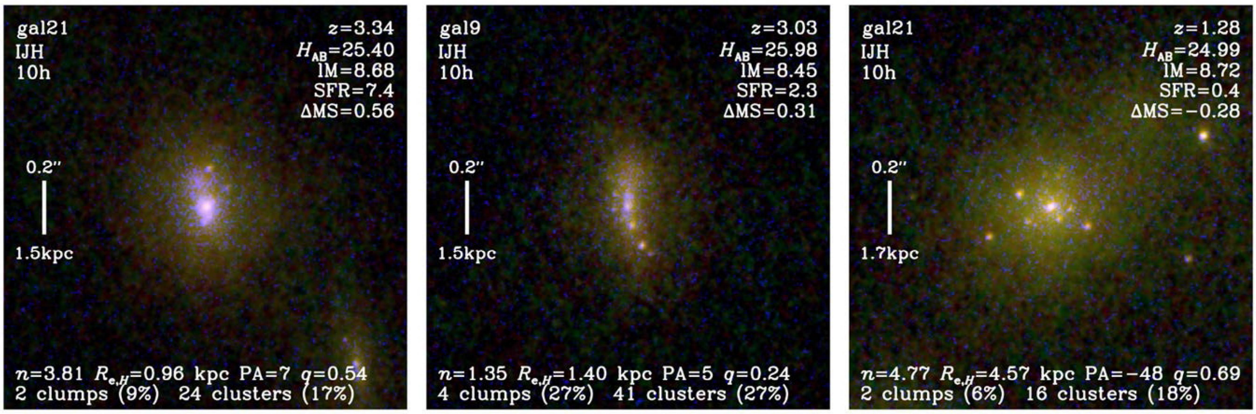

Figure 1: Simulations of galaxies above and below the main sequence at z ~ 2, created with SimCADO. These composite IJH colour maps are based on known galaxies in the Hubble Ultra Deep Field, to which additional inferred structure (in particular particular a star cluster and clump population) has been added. Adapted from the MICADO Science Case (RD3).

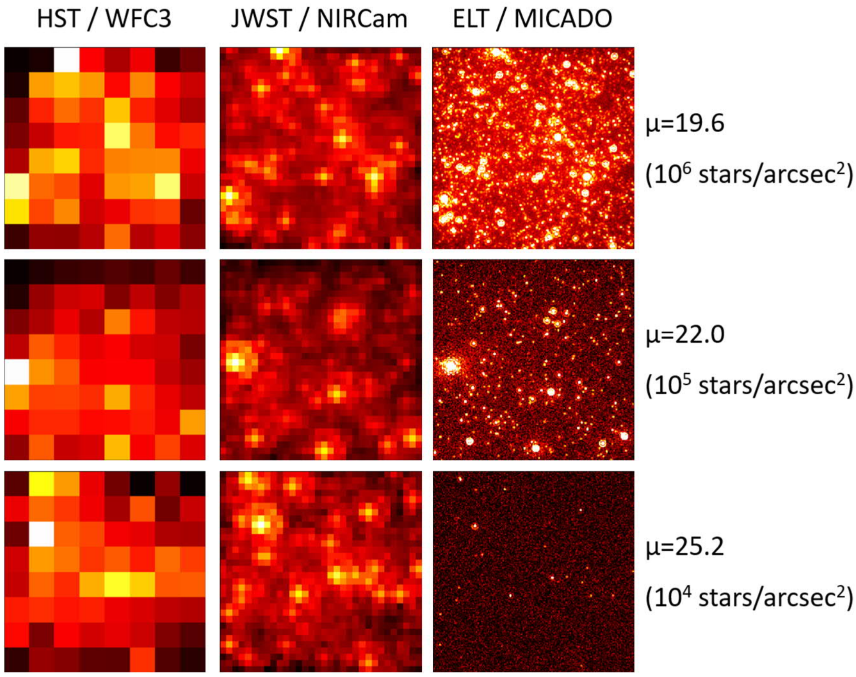

Figure 2: Comparison of how crowded stellar fields might appear if observed by HST (left), JWST (centre), and MICADO (right). The bottom row matches the stellar density at a radius of 4-5 R_{eff} for NGC 4472 in the Virgo Cluster and represents the limit for JWST resolution. The top row corresponds to 2 R_{eff} in the same galaxy and many individual stars can still be measured by MICADO. Each panel is 1” across. These simulations were performed with SimCADO.

Massive Black Holes

One of the obvious rationales for astrometry is using stellar proper motions to probe the existence and masses of black holes in galactic nuclei, stellar clusters, and nearby low mass dwarf galaxies.

The Galactic Centre is a unique laboratory for exploring strong gravity around the closest massive black hole, as recently demonstrated by the remarkable results from GRAVITY. The fundamental goal is to measure the gravitational potential in the relativistic regime very close to the central black hole via stellar motions, using very faint stars that are likely present but cannot be detected nor studied with any other facility prior to the ELT. These motions may also reveal the theoretically predicted extended mass distribution from stellar black holes that should dominate the inner region, as well as test for a distributed component of dark matter. An exciting opportunity is to measure the spin of the black hole, a goal that is more tractable via spectroscopy than astrometry. This can be achieved by tracking a late type star whose complete orbit lies within ~10mas (0.5 light days, about 1/10 of the S2 orbit) so that it is spatially indistinguishable from Sgr A* itself. Spectrally, determining the relative velocity of the star to <1 km/s precision enables one to discern the impact on its orbit of the black hole's quadrupole moment, which according to general relativity is fully determined by the spin. Even though in practice it is difficult to completely stabilize a source in the slit, sufficient precision can be reached via internal referencing between the stellar absorption features and the atmospheric absorption features imprinted into the observed continuum.

An increasing effort to measure the masses of black holes in globular clusters has led to a variety of tantalising results, but without robust detections. One of the key questions concerns the slope of the M_{BH} – σ relation between the mass of the central black hole and the velocity dispersion of the stellar spheroid around it. Initial measurements of black holes in elliptical galaxies and classical bulges of disk galaxies had suggested $M_{BH} \propto \sigma^4$. More recent assessments have argued in favour of a steeper slope of 5.6, which has implications on the physical processes underlying the relation. In contrast, a compilation of black hole limits for globular clusters concludes that the slope for those is closer to 2.3. This rather shallower slope would imply the relation is defined by a process different to that in galaxies, perhaps suggesting that many of these systems are the stripped nuclei of dwarf galaxies.

Currently, this issue is wide open, and is unlikely to be resolved by currently available facilities. The problem is again the extreme crowding, which occurs in the centres of star clusters, exactly where one needs measurements in order to distinguish scenarios with and without black holes. Proper motions, rather than just line-of-sight velocity dispersions, are needed to measure and account for anisotropy, which can have a major impact on the black hole mass derived. Suitable measurements will only become possible with ELTs, when spatial resolution can overcome the crowding.

Exoplanet Characterisation

Now that a large number of exoplanets are known, we are entering a phase driven by the need to characterise these planets, in particular the atmospheres of giant exoplanets. Direct imaging of exoplanets provides an opportunity to do this through the use of intermediate band filters that cover molecular absorption bands, enabling one to distinguish models with different temperatures, surface gravities, and clouds. The large aperture of the ELT offers a multiple gain for such work: the small inner working angle, the increased contrast between the PSF core and the speckles in the halo, and the elongation of the speckles when imaged through a broad or intermediate band (making them easier to distinguish from exoplanets). As such, the focus for MICADO will be in terms of exoplanets at small orbital separations (~ 1 AU) around nearby stars (< 20 pc); exoplanets at larger separations (> 10 AU) around nearby stars as well as more distant stars (> 100 pc), and the circumstellar disks from which they form.

Figure 3 compares SPHERE observations of the planetary system around HR 8799 to simulations for MICADO, provides a glimpse of what it may be possible to achieve. The central panel shows a coronagraphic simulation of how this system might appear with MICADO after adding 30 s of exposures. The elongated central region is the effect of the wind on the residual halo close around the suppressed PSF core. The cleaned control region is clearly visible, as is its hexagonal boundary.

Even in this raw image, the inner 2 planets are already visible. The right panel shows that, after basic processing, one is in principle able to see fainter planets closer in. Two giant planets have been added, at 10 AU and 5 AU. By imaging these through various intermediate band filters, one can estimate their temperature (700 K and 1300 K respectively) due to their different molecular absorption properties. This opens the exciting potential that MICADO will be able to directly image planets for which a mass estimation is available from Gaia.

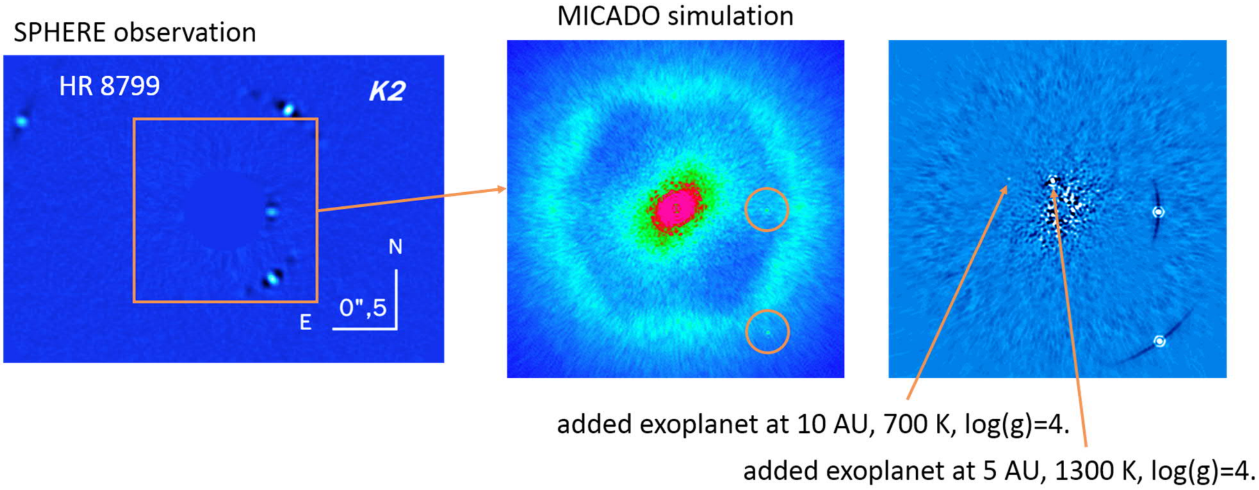

Figure 3: Left: SPHERE image of HR 8799 showing the four known planets. Centre: simulation of 30 s integration with MICADO already reveals the two inner planets. The structure in the image arises from the optical configuration of the telescope and AO system, and its wavefront correction. Right: with basic processing of a series of ADI exposures, one is in principle able to detect other fainter and cooler planets at smaller radii.

5 Baseline Requirements and Design

The design of MICADO is based around five fundamental requirements given in the Technical Specification (AD2):

- MICADO shall offer the following observing modes: standard imaging, astrometric imaging, coronagraphic imaging, and spectroscopy.
- Where conflicts arise between the requirements of the MICADO spectroscopic mode and the MICADO imaging mode, the requirements of the imaging mode shall be given priority.
- MICADO shall be able to work with the MAORY multi-conjugate adaptive optics system.
- MICADO shall work with a single conjugate adaptive optics capability
- MICADO shall be able to work in a stand-alone mode, using its SCAO capability, without MAORY.

The global architecture of MICADO is illustrated in Figure 4. The main hardware sub-systems indicated there are complemented by the instrument control and pipeline software, and also the electronics sub-system – which can be considered respectively the instruments brain and nervous system. In addition, there is a data simulator called ScopeSim, which is publically available at https://scopesim.readthedocs.io/ (developed from the original SimCADO which is still available at https://simcado.readthedocs.io/). Further information about all of these can be found in the System Overview (RD4).

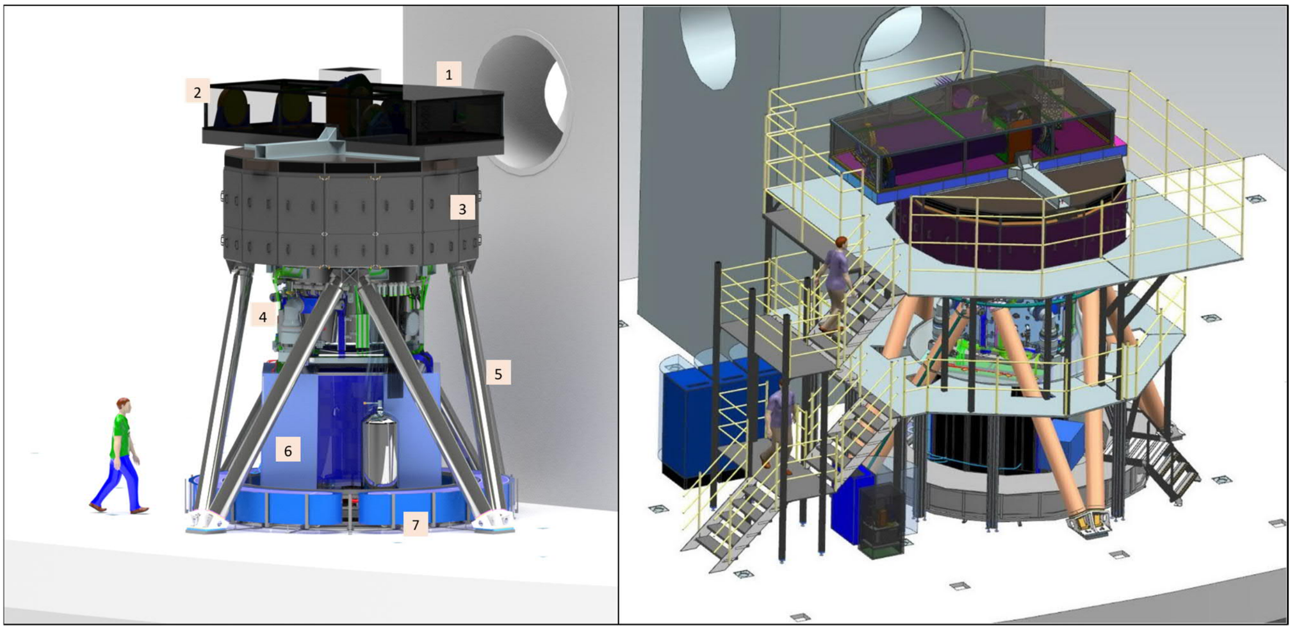

Figure 4: Global MICADO architecture in 'stand-alone' mode, left showing the various hardware sub-systems, and right with the maintenance platform. (1) Calibration assembly, mounted next to relay optics, replicates ELT focal plane (later moves to MAORY bench); (2) Relay optics to transfer ELT focal plane downwards into MICADO (later exchanged for last MAORY mirror); (3) NGS WFS module, which rotates under the fixed cover, containing SCAO on a top bench & the MAORY NGS WFS on a lower bench; (4) derotator and cryostat, surrounded by peripheral devices; (5) Support structure, for rotating mass (cryostat & NGS WFS module) as well as fixed upper platform; (6) Co-rotating platform with electronics cabinets (due to cable length limitations); (7) Cable wrap for connection to external cabinets and services.

The instrument provides the observing modes listed in the requirements, as well as a capability for pupil imaging.

Standard imaging is designed to obtain images with a diffraction limited resolution at wavelengths in the range 0.8 – 2.4 µm, given that the MCAO will deliver Strehl ratios of 30 – 50 % (K-band) across the field, and that with bright stars SCAO will provide ~65 % Strehl ratio in K-band on axis. Going beyond this, astrometric imaging is one of the most challenging requirements for MICADO. The aim of the astrometric imaging mode is to reach signal-to-noise limited astrometric precision over the full field, better than 50 µas and with a goal of 10 µas for bright sources. To fulfil this would be a remarkable achievement, since it is a factor 5 – 10 better than ground-based 8-m class telescopes with current MCAO systems or space telescopes such as HST, and is similar to that reachable with GRAVITY or dedicated astrometry space missions such as Gaia. To understand what the requirement means, we must distinguish between absolute and relative astrometry. Absolute astrometry is needed when comparing the position of objects observed with different instruments, often in different wavebands. Because it relies on an external reference frame, which is dependent on the target field, it can only be done on a best effort basis. Instead, the MICADO instrument requirement refers to relative (or differential) astrometry, which is about changes in position between epochs and focusses on proper motion rather than position. To achieve this requires a global plate scale precision of 10^{-4} to 10^{-5}, which corresponds ~30 µas over local arcsec scales. Stability and calibration are more important than solely minimising the geometric distortion, which is <0.4% and <1.2% for the low and high resolution imager respectively. And it is necessary to distinguish between linear distortions over the full field, low order distortions that affect ~10” scales, and high order distortions which dominate at <1” scales. These are handled in different ways most appropriate for each case, whether via instrument design (minimizing mechanical and thermal flexure), operational scenario (use of calibration masks, and if needed, observational constraints), or post-processing (correcting low-order drifts between individual frames).

To enable these two modes, the instrument is supported above the Nasmyth platform in a gravity invariant orientation to minimize flexure, includes an optical path comprising entirely of fixed mirrors, uses a state-of-the-art atmospheric dispersion corrector, and has a dedicated astrometric calibration plan and data pipeline. The array of detectors at the focal plane provides imaging of a small field of about 19” with a fine 1.5 mas pixel sampling that is especially useful in very crowded fields or at short wavelengths; or a large field, which is 50.5” across, with a coarser 4 mas pixel scale that still fully samples the H- and K-band diffraction limit. In either case, a wide selection of broad and narrow band filters are available.

The study of planets around other stars is one of the fundamental science drivers for the ELT. The two top level goals for MICADO in this respect are to exploit the large aperture of the ELT in order to achieve a meaningful contrast at very small inner working angles, and to learn about how to perform high contrast imaging on ELTs as a pathfinder for future dedicated instrumentation. While MICADO itself is not primarily a high contrast imager, this mode will be implemented to the limits possible without compromising the standard and astrometric imaging modes. It is enabled via a classical configuration of coronagraph and Lyot stop, as well as focal and pupil plane phase masks; and is envisaged to make use of angular differential imaging techniques.

The main rationale for spectroscopy in MICADO is to provide coverage of a wide wavelength range simultaneously at a resolution R ~ 20000, on faint compact or unresolved objects. In this sense it aims to emulate the success of X-shooter, while addressing a complementary role to the spatial resolution afforded by the integral field spectroscopic capabilities of HARMONI. The implementation of spectroscopy in MICADO must not compromise the imaging modes. This has constrained the design choices available, but still led to a powerful capability. There are two main settings, covering either 1.48 – 2.46 µm or 0.84 – 1.48 µm simultaneously. A narrow slit, width 16 – 20 mas, is optimised for point sources while a wider slit, width 48 mas, will be available for resolved but compact sources. For the longer wavelength bandpass, a 15” slit length will allow very good simultaneous sky measurements; for the shorter wavelength bandpass the slit length is limited to 3”, still easily sufficient for simultaneous sky measurement with point sources.

6 Consortium Partners

The consortium comprises nine partners together with ESO (an associate partner), as summarized in Table 1 together with their primary contribution. Several partners are split into further nodes, but provide local management so that the consortium has a single interface to each. These are: NOVA, which includes the University of Leiden, the University of Groningen, and the NOVA optical/IR instrumentation group; LESIA, which represents also GEPI and IPAG; A*, which, for MICADO, comprises the University of Vienna, the University of Innsbruck, and the University of Linz; INAF, which is represented by Osservatorio Astronomico di Padova; and FINCA, which is represented by Tuorla Observatory at the University of Turku.

Table 1: Summary of the partners and their main roles

Country	*Partner*	*Primary Roles*
Germany	MPE	PI & project management, science, systems engineering (including optics, mechanics, and electronics), cryostat, cold optics, focal plane masks & wheel, de-rotator, operational concept, imaging/astrometry pipeline (post-FDR), AIT equipment, system integration.
	MPIA	Instrument scientist, science, astrometry analysis & calibration/operation concept, relay optics for stand-alone mode including electronics, instrument calibration units including electronics.
	USM	Science, main selection mechanism, spectrograph, pupil imager, electronics, control software including software system engineering, preparation & observing software.
	IAG	Science, support structure, co-rotating platform, cable wrap, handling/maintenance equipment.
Netherlands	NOVA	Project scientist, science, ADC, filters & wheels, pupil masks & wheel, imaging/astrometry pipeline (pre-FDR), pipeline management, calibration plan.
Italy	INAF	Science, PSF reconstruction.
France	LESIA	Science, coronagraphs, SCAO with dichroic, field selector, WFS, RTC, SCAO calibration unit, and including SCAO electronics & control SW.
Austria	A*	Science, data simulator (SimCADO), spectroscopic pipeline, PSF reconstruction algorithms.
Finland	FINCA	Science, contribution to PSF reconstruction.
Europe	ESO	Detector procurement & characterisation, detector control electronics & software, focal plane mosaic.

7 Project Development and Status

The project phases of MICADO follow the definitions as set out in the Statement of Work (AD3) and summarised in Table 2, with the aim of meeting a delivery date to the ELT in 2025.

It should be borne in mind that because MICADO is designed to interface to MAORY, ideally their schedules should be synchronised. In reality this is not the case, but detailed definition of interfaces (including the control software, the NGS module, the Calibration Unit, and a General Interface) means that the project schedules are largely independent. This is important for ESO and the MICADO consortium, to reduce programmatic risk and to ensure that a diffraction limited imaging capability with SCAO will be available at first light. In this respect, while SCAO is formally a joint development, it follows the MICADO schedule and is reviewed at an appropriate level as part of the MICADO project.

Table 2: summary of MICADO Project Phases as given in the SoW.

Phase	*Short Description*	*Concluding Review*
Phase A: Conceptual Design	This was formally begun in Feb 2008 and successfully completed with a review in Dec 2009. Note that the concept has changed significantly since this time.	Phase A Review
Phase B: Preliminary Design	The purpose of this phase is to develop and consolidate the design of the instrument and subsystems, as well as its various interfaces. Appropriate technical solutions will have been identification and explored with the aim of meeting the specified requirements. Mitigation activities (such as breadboarding) will have been performed for critical items so that they reach TRL≥4.	Preliminary Design Review
Phase C: Final Design	In this phase MICADO shall be designed down to the level of components, and technical solutions shall have TRL≥6. The design shall be sufficiently advanced to begin the manufacturing of hardware and software. A plan for operations and maintenance is prepared.	Final Design Review
Phase D: Manufacturing, Assembly, Integration, and Testing	Materials and commercial components will be procured; the parts for MICADO will be manufactured, and integrated in the laboratory. All required sub-system tests shall be performed. Full instrument testing will be conducted.	Preliminary Acceptance Europe
Transport Phase	The instrument will be packed and transported to the observatory in Chile. On arrival, parts and equipment will be unpacked and inspected. The consortium will provide ESO with an inspection report.	
Installation and Commissioning	MICADO will be assembled at the observatory. After successful completion of the tests which do not require light from the telescope, commissioning will start. Following the Statement of Work (AD3), this will be first with SCAO and then MCAO.	Provisional Acceptance Chile with SCAO Provisional Acceptance Chile with MCAO
Guarantee Period	This begins with the declaration by ESO of Provisional Acceptance with SCAO and will last for 24 months, as stated in	Final Acceptance

	the Agreement. During this time, the Consortium shall be responsible for repairs, adjustments and/or modifications of the delivered instrument unless otherwise agreed with ESO.	

An overview of the main milestones in the MICADO project, including the reviews marking the conclusion of each phase as well as intermediate meetings and review, is given in Table 3. The dates are based on the master schedule.

As stated in the SoW (AD3), commissioning will occur first with SCAO so that science observations can begin at the earliest opportunity. Commissioning with MCAO will occur at a later date, and is expected to be a more lengthy process due to the use multiple LGS and NGS.

Table 3: summary of main milestones that occur during the MICADO project

Actual Date		*Phase*	*Milestone (Meeting/Review)*	*Original Date*
2015	Oct	B	Kick-Off	2015 Oct
2017	Apr	B	Systems Requirements Internal Review (baseline consolidation)	2017 Apr
2018	Nov	B	Preliminary Design Review	2018 Oct
2018	Dec	B	Cost Review	–
2021 2021 2021	May Oct Dec	C	Final Design Review(s)	2020 Oct
Planned Date				
2023	Sep	D	MAIT mid-term Meeting*	
2024	Oct	D	Move from MPE X4 to ESO Garching Integration Hall	
2025	Apr	D	PAE Document Review (Test Readiness Review, start of PAE process)	
2025	Nov	D	Preliminary Acceptance Europe	
2026	Nov	P1	Provisional Acceptance Chile with SCAO	
2029	Jun	P2	Provisional Acceptance Chile with MCAO (see MAORY schedule)	
2029	Nov		Final Acceptance	

*aim is to have this after first test of the cold optics in the cryostat with partially populated focal plane array, and in anticipation of delivery of central wheel & main selection mechanisms.

8 Project Cost

Work Effort

Making comparable estimates of the work effort contributed by each partner is very difficult. Although FTE estimates made by each partner have been used as a proxy in many previous projects, this is considered unrealistic because of the great variation in the assumptions and methods adopted by each partner to do so. Instead, these estimates have been combined with a top-level approach in which coarse global estimates were made by a number of people through the consortium. The contributions of INAF and FINCA were added *post facto*. The process has led to the distribution of staff effort given in Table 4. ESO's contribution has been omitted from this table, but is ~2 %.

As assessment of the total FTEs required, including some contingency at the sub-system level, has been made by the Project Office. This is based on scaling to the detailed bottom-up estimate made for MPE's contribution, and is an attempt to put all the FTE contributions from the partners on an equal and directly comparable basis. Excluding ESO's contribution to the consortium workpackages, it yields 534-645 work years, a range that represents an uncertainty of +/-10%. This total is consistent with top-level global estimates mentioned above, between which there was general agreement on the total FTEs required.

Table 4: Distribution of staff effort by partner & country as listed in the MoU Amendment (AD6).

Partner	*Relative FTE Contribution (%)*	*Expected FTE range*
MPE	29.6	158-191
MPIA	12.8	68-82
USM	15.3	81-99
IAG	8.2	44-53
NOVA	8.2	43-52
INAF	2.7	14-17
LESIA	15.8	84-102
A*	7.4	39-47
FINCA†	0	0

Country	*Relative FTE Contribution (%)*
Germany	65.9
Netherlands	8.2
Italy	2.7
France	15.8
Austria	7.4
Finland	0

† FINCA contributes some FTEs, but it was agreed that because the number is small the GTO distributions should not be adjusted; and so it is listed as zero. FINCA does receive GTO through its cash contribution.

Cash Contribution

The initial cost estimate was made based on an uncertain design with uncertain interfaces. Towards the end of the preliminary design phase, a new estimate of the cost was prepared. This indicated a cost increase, the majority of which was attributable to relatively few major items: (i) the price of the science detectors was higher than foreseen; (ii) inclusion of stand-alone relay optics that previously were risk mitigation only; (iii) high quality mirrors, mounted in pre-aligned units, for the cold optics instrument; (iv) the need for a SCAO calibration unit; (v) proto-typing and bread-boarding to meet

ESO's TRL requirements. The additional cost of the project, as well as the additional GTO that could be granted for the consortium's contribution to that cost, were agreed between ESO and MPE in a series of meetings during 2019.

The Amendment No. 1 to the Agreement (AD3) states that the total cash cost for MICADO is estimated to be 23.96 MEuro (excluding contingency); and that ESO will provide 13.4MEuro, while the consortium will provide 10.56 MEuro for which ESO will grant a total of 28.6[1] nights of observing (in addition to the 65 nights granted for the FTEs).

The MAORY project schedule is such that MAORY is expected to complete its AIV and perform its PAE tests while MICADO is in operation at the ELT. The MICADO consortium is willing to support the MAORY AIV in Europe, but the cost of such effort – for either FTEs or hardware (e.g. a duplicate SCAO system) – is explicitly not included in the MICADO cost estimate. If such support is required, the issue of the associated cost would need to be revisited at that time.

Table 5: Agreed funding for MICADO[†]

Partner	*Cash contribution (M Euro)*	*Note*
MPE	7.66	2.73 MEuro were confirmed at Kick-Off; the other 4.93 MEuro were approved on signing of the Amendment No.1 to the Agreement.
MPIA	0.64	0.50 MEuro were confirmed at Kick-Off; the remainder at the cost review.
USM	0.70	Pending successful grant applications.
IAG	0.17	Confirmed at Kick-Off.
NOVA	–	
INAF	0.30	Confirmed in Feb 2016 in a letter from the INAF science director; re-confirmed in Sep 2018.
INSU	0.77	0.68 MEuro were confirmed at Kick-Off; the remainder at the cost review. Additional funding (amount TBC) is expected early 2021.
A*	–	
Finland	0.30	Pending successful grant applications.
ESO	13.40	11.70 MEuro confirmed in the Agreement; the other 1.70 MEuro were confirmed in the Amendment No. 1 to the Agreement.

[†] if additional funds become available, they are handled in the context of contingency together with additional costs.

[1] Only eligible extra costs were awarded additional GTO by ESO; however the Project Office decided that within the consortium, the extra nights would be allocated uniformly across all extra funds provided.

Total Cost

The total instrument cost is 99.0 MEuro. This is found from summing the value of the FTEs (using a mid-range value of 589, and adding in an additional 11 for ESO) and the cash cost. The conversion from FTE to cost is based on ESO Council resolutions for the VLT (that 1 FTE is worth 1.5 nights, and that 1 night on the VLT is valued at 83kEuro), and is approximately 125 kEuro per FTE. This estimate excludes contingency.

Taking into account the cost of the hardware, the staff effort involved, and the value of the GTO awarded, leads to the conclusion that ESO and the consortium contribute roughly equally to the project.

This emphasizes that ESO is not just procuring an instrument that meets a set requirements as given by the Agreement, but the consortium itself is making a substantial investment in the instrument. Indeed, the consortium is delivering an instrument that its members want to use themselves. The contributions made by both ESO and the consortium underline that successfully developing an instrument in parallel to the ELT, and ensuring it will deliver the best science with the ELT, is a collaborative effort.

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