E-ELT PROGRAMME

MICADO Instrument
Development and Management Plan

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ABBREVIATIONS AND ACRONYMS

AO	adaptive optics
CAD	computer aided design
CAE	computer aided engineering
ECSS	European Cooperation for Space Standardization
E-ELT	European Extremely Large Telescope
ESO	European Southern Observatory
FDR	Final Design Review
FTE	Full Time Equivalent (year)
GLAO	ground layer adaptive optics
GMT	Giant Magellan Telescope
JWST	James Web Space Telescope
LESIA	Laboratoire d'Etudes Spatiales et Instrumentations pour l'Astrophysique
LTAO	laser tomography adaptive optics
MAIT	Manufacture, Assembly, Integration, Test
MAORY	Multi-conjugate Adaptive Optics Relay
MCAO	multi-conjugate adaptive optics
MICADO	Multi-adaptive optics Imaging Camera for Deep Observations
MPE	Max-Planck-Institut für extraterrestrische Physik
MPIA	Max-Planck-Institut für Astronomie
NOVA	Nederlandse Onderzoekschool voor Astronomie
OAPD	Osservatorio Astronomico di Padova
PAE	Preliminary Acceptance in Europe
PAO	Preliminary Acceptance at the Observatory
PA/QA	Product Assurance / Quality Assurance
PDR	Preliminary Design Review
PSF	Point Spread Function
RTD	Real Time Display
SCAO	single-conjugate adaptive optics
TMT	Thirty Meter Telescope
USM	Universitäts-Sternwarte München
WP	Workpackage

1 SCOPE

This document describes the management plan for the MICADO instrument, including the design, manufacturing, and integration phases as well as testing and commissioning. It summarises the consortium and its responsibilities. It describes the anticipated management of resources, the schedule of the project, and includes estimates of the workpower and financial resources required. This management plan should be considered provisional, and we emphasize that the workpackage distribution among the partners may need to be revised once ESO publishes the Instrument Roadmap for the E-ELT. Although all partners have resources allocated for E-ELT instrument projects, the decision on how to distribute these among the various projects can only be done once the full roadmap is known.

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

The following applicable documents form a part of the present document to the extent specified herein. In the event of conflict between applicable documents and the content of the present document, the present document shall be taken as superseding.

AD1 Common definitions and acronyms , E-ESO-SPE-313-0066, issue 1

AD2 E-ELT Interfaces for Scientific Instruments, E-TRE-ESO-586-0252, issue 1

AD3 Call for Proposal For a Phase A Study of a High Angular Resolution Camera for the E-ELT, Specifications of the Instrument to be studied, E-ESO-SPE-561-0097, v2.0

AD4 Statement of Work for the Phase A Design of MICADO, E-SOW-ESO-561-0127, v1.0

AD5 Proposal "MICADO: the MCAO Imaging Camera for Deep Observations", 12 Nov 2007, in response to the call CFP/ESO/07/17768/LCO

2.2 Reference Documents

RD1 Standard Procedure for Design Reviews, VLT-INS-ESO-00000-0251, issue 2

RD2 MICADO Phase A Executive Summary, E-TRE-MCD-561-0006, issue v2.0

RD3 MICADO Phase A Science Analysis Report, E-TRE-MCD-561-0007, v2.0

RD4 MICADO Phase A System Overview, E-TRE-MCD-561-0009, v2.0

RD5 MICADO Design Trade-Off and Risk Assessment, E-TRE-MCD-561-0010, v2.0

RD6 Technical Note "Technological options under consideration for the E-ELT Instrument Control Systems", INS-09/03 v1

RD7 MICADO Phase A Opto-Mechanical Design & Analysis, E-TRE-MCD-561-0011, v5.0

3 PROJECT OVERVIEW

MICADO is the Multi-AO Imaging Camera for Deep Observations, which is being designed to work with adaptive optics on the E-ELT. The instrument has been optimised for the multi-conjugate adaptive optics module MAORY; but it is also able to work with other adaptive optics systems, and includes a separate module to provide a single conjugate adaptive optics capability using natural guide stars during the early operational phase.

The instrument is compact and is supported underneath the AO systems so that it rotates in a gravity invariant orientation. It is able to image, through a large number of selected wide and narrow-band near infrared filters, a large 53" field of view at the diffraction limit of the E-ELT. MICADO has two arms. The primary arm is a high throughput imaging camera with a single 3mas pixel scale. This arm is designed with fixed mirrors for superior stability. In addition, MICADO will have an auxiliary arm to provide an increased degree of flexibility. In the current design, this arm provides (i) a finer 1.5mas pixel scale over a smaller field, and (ii) a 4mas pixel scale for a simple, medium resolution, longslit spectroscopic capability. However, in principle the auxiliary arm also opens the door to many other options, including a 'dual imager' based on a Fabry-Perot etalon to image separate emission line and continuum wavelengths simultaneously, or a high time resolution detector.

Early in the project, the consortium highlighted several key capabilities that exemplify the unique features of the E-ELT at which MICADO will excel in comparison to other facilities. These are at the root of the science cases and have driven the design of the camera: sensitivity and resolution, precision astrometry, and high throughput spectroscopy. By both promoting and exploiting these capabilities with a simple and robust design, the consortium believes that MICADO can be considered for an E-ELT first light instrument.

3.1 MICADO Consortium

The MICADO consortium comprises the following six partners:

- MPE: Max-Planck-Institut für extraterrestrische Physik
- MPIA: Max-Planck-Institut für Astronomie
- USM: Universitäts-Sternwarte München
- NOVA: Nederlande Onderzoekschool voor Astronomie:
  Universiteit Leiden, Rijksuniversiteit Groningen,
  NOVA Optical/IR Instrumentaion Group
- OAPD: Istituto Nazionale di Astrofisica:
  L'Osservatorio Astronomico di Padova
- LESIA: L'Observatoire de Paris:
  Laboratoire d'Etudes Spatiales et Instrumentations pour l'Astrophysique

Each partner has one representative on the board of directors, and one responsible person to act as the contact point and coordinator of that partner's administrative and contractual activities in the project. The structural organisation of the project is shown in Figure 1.

The consortium will work together with ESO to design, manufacture, and test the instrument.

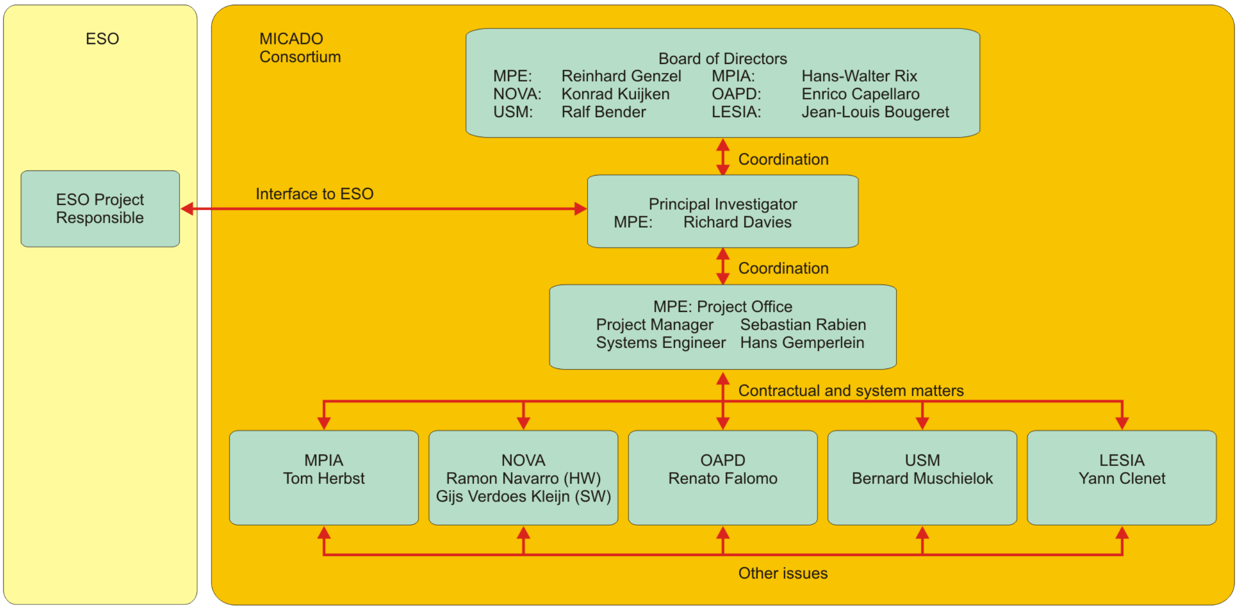

Figure 1: structural organisation of the MICADO project consortium.

3.2 Approach and Motivation

The partners comprising the MICADO consortium have a strong tradition of working together to design, build, and exploit world-class optical/infrared instrumentation. This includes wide-field and adaptive optics optical and near-IR imagers/spectrometers such as Omega (MPIA), FORS (USM), LBC (OAPD), OmegaCam (NOVA, USM, OAPD), NAOS-CONICA (MPIA, MPE, LESIA), LUCIFER (MPIA, MPE); integral field spectrometers such as 3D (MPE), SPIFFI (MPE, NOVA), KMOS (MPE, USM); laser guide star systems such as ALFA and PARSEC (MPE, MPIA); adaptive optics systems (OAPD, MPIA, LESIA); and more. This experience extends also to handling data. NOVA operates OmegaCEN in Groningen, the data centre that will be used for many of the large VST OmegaCam surveys. In particular the ASTRO-WISE (*ASTRO*nomical *W*ide-field *I*maging *S*ystem for *E*urope) program (NOVA, USM) will provide the software and analysis routines necessary to reduce and mine the vast quantities of data produced by wide-field sky survey cameras.

The combined expertise of the partners covers all the critical requirements for the MICADO instrument. The partners have the appropriate facilities and scientific and engineering expertise available for the project. The consortium will adopt a strong systems-level approach co-ordinated by a single project management team in order to deliver the instrument within budget and on schedule.

3.3 Definition of Terms and Roles

Contract
A contract defines the collaboration between ESO and the consortium institutes for the development of the instrument, and is signed by the directors.

Memorandum of Understanding
A Memorandum of Understanding (MoU) defines the collaboration within the consortium.

Board of Directors
The Board of Directors comprises one member of each institute. The board oversees the collaboration, and ensures that it maintains its goals and momentum. Working on a consensual basis, it provides overall guidance, resolving organisational conflicts and approving major decisions. The board also leads fund-raising activities.

Principal Investigator
The Principal Investigator (PI) is responsible for leading the project. The PI ensures that the instrument will meet its scientific capabilities, sets priorities, and resolves conflicts. The PI represents the collaboration towards ESO and the community. The PI works in close coordination with the Board of Directors and the Project Office.

Project Office
The Project Office comprises the **Project Manager** and **Systems Engineer**, who work at the same Partner institute. They provide overall coordination and management of all aspects of the project, and hence are responsible for delivering the project within time, cost, and specification. They lead the team and ensure that programs are maintained, risk is mitigated, and sufficient effort is in place to deliver the project. They work in close coordination with the Workpackage Managers and Responsible Persons at each of the partner institutes, and report to the PI.

Partner Responsible Persons
The Responsible Persons represent the Partner institutes within the consortium. They work together with the individual project members within their institute, and have full responsibility for the deliverables of their institute. A Partner may have more than one Responsible Person if it comprises several institutes involved in very different roles. The Partner Responsibles work in close coordination with the Project Office.

Workpackage Managers
The Workpackage Managers have local responsibility for all activities within a particular workpackage.

Project Scientist
The Project Scientist has responsibility for leading and coordinating the efforts of the science team.

Instrument Scientist
The Instrument Scientist has responsibility for developing the instrument operational concept, including the calibration and maintenance concepts. The role includes coordination between a number of workpackages: science, instrument software, data processing software, and adaptive optics (both within and beyond the consortium).

Science Team
The Science Team comprise scientists responsible for developing internationally competitive science cases to promote and exploit the key capabilities of the instrument and the E-ELT. These science cases will drive the Top Level Requirements for the instrument, while at the same time being realistic within the predicted instrument performance. The science team is responsible for estimating the instrument performance (based on data for the instrument hardware), and for developing appropriate simulation tools.

3.4 Instrument Overview & Workpackage Definition

The Product Tree shown in Figure 2 outlines all the deliverable hardware and software associated with MICADO (whether from the consortium or from ESO). It includes separate top-level branches for the hardware, software, and SCAO module. It also provides the basis for specifying the individual workpackages. The full list of the workpackages is given in Table 1, together with a summary of their contents. In addition to the deliverable hardware and software shown in the Product Tree, the full workpackage list includes Management (WP1) and Science (WP2), as well as additional non-deliverable hardware or software required to test the instrument.

The full workpackage list can be considered as the sum of the work that has to be done in order to deliver the instrument in compliance with the specification. Contained within it are items concerning management; design, manufacture, assembly and testing of the required hardware; design, scripting, and testing of the necessary software; and verification of the compliance with the top level requirements, and hence also with the scientific goals. Although Table 1 indicates which partner is responsible for each (sub-)workpackage, it does not fully indicate the contributions of each partner to the project. These are therefore summarised in Table 2.

The consortium proposes that ESO should be involved in the instrument project, making use of their vast experience with detectors to be responsible for WP 6.1 which includes detector procurement and characterisation as well as detector control electronics and software.

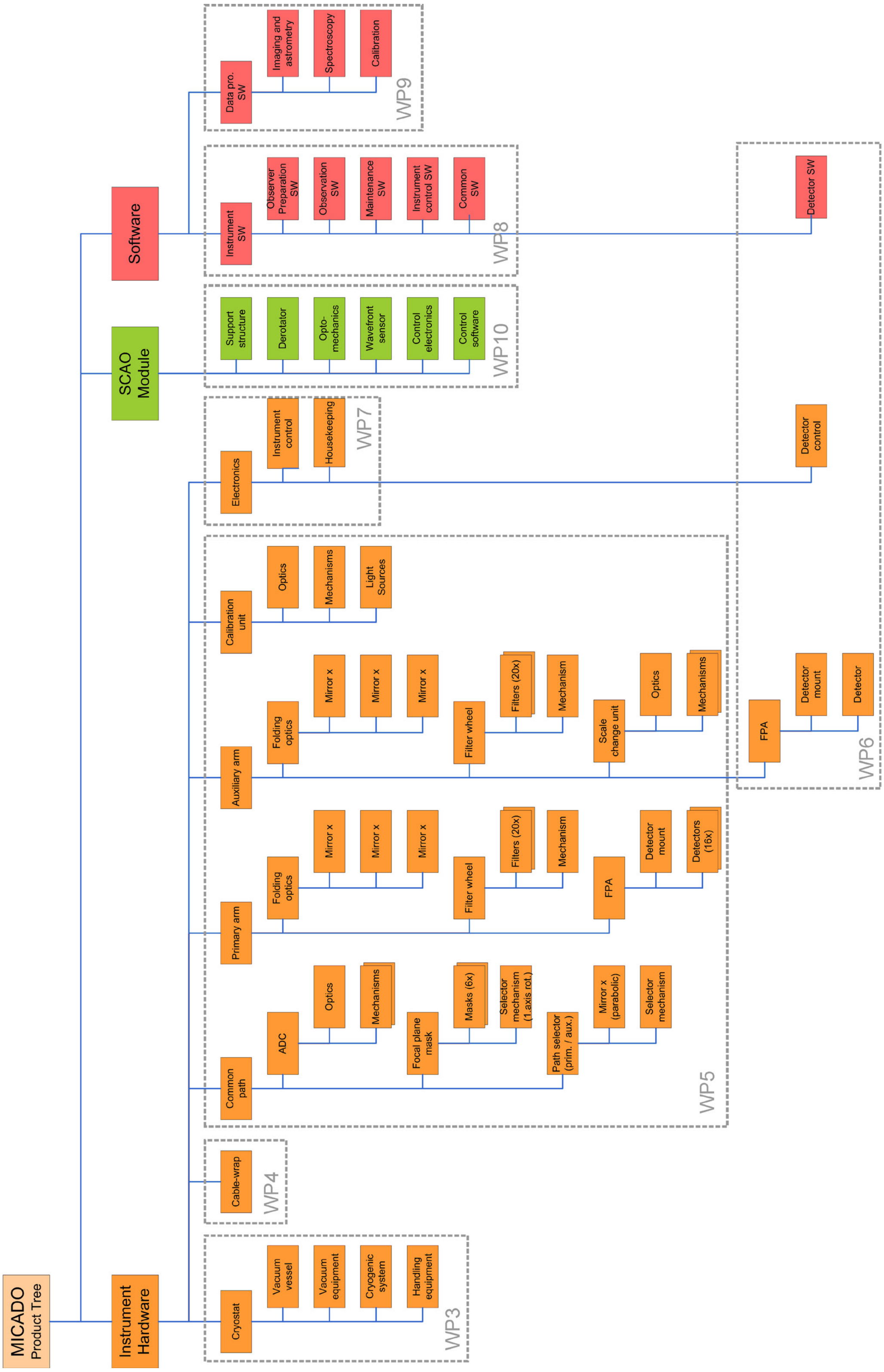

Figure 2: Product Tree for the conceptual design of MICADO at the end of the Phase A study, outlining the breakdown of the *deliverables*: hardware, software, and the SCAO module. The figure also indicates the workpackage to which each item is attributed. Non-deliverable items are not included.

Table 1: List of workpackages and responsible partners

WP #	*WP name*	*Short description*	*responsible partner**
1	**Management**		**MPE**
1.1	Management	Project co-ordination, financial & workpower budgets, schedule	MPE
1.2	Systems Engineering	Global system design, interface management, subsystem specification, error budget, product & quality assurance, coordinate MAIT	MPE
2	**Science**		**OAPD**
2.1	Science	Developing science goals and detailing specific science cases	OAPD (+all)
2.2	OCMD	Deriving top level requirements and specific instrument needs from the science cases; detail operation, calibration, and maintenance plans.	MPIA
3	**Cryostat**		**NOVA**
3.1	Cryostat	cryostat, entrance window, feed-throughs, vacuum equipment, cryogenic system, sensors, cryogenic motors and econders/resolvers qualification	NOVA
3.2	Handling equipment	Equipment required to manoeuvre, to mount/dismount, and to access the instrument	NOVA
3.3	MICADO Test Facility	Equipment required to test the optical and mechanical performance of the instrument as if it were mounted at the observatory; simplified electromechanical motorised testbeds for HW & SW function tests	MPE
4	**Cable-wrap**		**NOVA**
		All hardware associated with cable-wrap	NOVA
5	**Opto-Mechanics**		**MPE**
5.1	Common path	Design, analysis, manufacture, and test of: (i) optics and (ii) mechanics, including mechanisms, associated with the input optical path	(i) OAPD (ii) NOVA
5.2	Primary arm	Design, analysis, manufacture, and test of: (i) optics and (ii) mechanics, including mechanisms, associated with the primary arm	(i) MPE (ii) NOVA
5.3	Auxiliary arm	Design, analysis, manufacture, and test of: (i) optics and (ii) mechanics, including mechanisms, associated with the auxiliary arm	(i) OAPD (ii) NOVA
5.4	Calibration unit	Design, analysis, manufacture, and test of: (i) optics and (ii) mechanics, including mechanisms & lamps, associated with the calibration unit	(i) MPE (ii) NOVA
6	**Detectors**		**MPIA**
6.1	Detectors	Procurement and characterisation of detectors & ASICs; design, manufacture, and test of electronics, software, and cabling associated with operating the detectors	ESO
6.2	FPA	Focal Plane Array	MPIA
7	**Electronics**		**USM**
7.1	Instrument control	Design, manufacture, and test of electronics to control mechanical and calibration functions.	USM
7.2	Housekeeping electronics	Design, manufacture, and test of electronics associated with instrument monitoring and operational health.	USM
8	**Instrument Software**		**USM**

		Design, implementation, and test of SW for observations preparation (OSS), observation execution (OS), instrument control (ICS), and instrument maintenance (MS).	USM
9	**Data Processing**		**NOVA**
		Design, implementation, and test of SW for processing data obtained from calibration and science observations.	NOVA
10	**SCAO**		**LESIA**
10.1	Support structure	Design, analysis, manufacture, and test of: global support structure including the optical bench and derotator (including electronics & control software)	LESIA
10.2	Optical relay	Design, analysis, manufacture, and test of: optics (mirrors, dichroics, etc) and mounts for the optical relay	LESIA
10.3	Wavefront sensing	Design , analysis, manufacture, and test of: WFS, mechanical structure, motion stages, software, RTC, diagnostics, performance metrics	LESIA
10.4	SCAO Test facility	Implementation of optics & mechanics required to test the AO system, with and without MICADO attached	LESIA

* This allocations are provisional and may be revised once the E-ELT Roadmap is announced

Table 2: Provisional task distribution within the consortium and ESO

Partner	*Tasks*	
MPE	1.1 1.2 2.1 3.3 5.2, 5.4	Management Systems Engineering Science Test Facility Optics
MPIA	2.1 2.2 6.2	Science Operations, Calibration, Maintenance Focal Plane Array
USM	2.1 7 8	Science Electronics Instrument Software
NOVA	2.1 3 4 5 9	Science Cryostat, cryogenics, handling Cablewrap Mechanics Data Processing
OAPD	2.1 5.1, 5.3	Science Optics
LESIA	2.1 10	Science SCAO
ESO	6.1	Detectors

4 PROJECT CONTROL

The processes and tasks to be performed within the MICADO project are illustrated in the project flow chart shown in Figure 3. The project structure is divided into two main segments:

- Science: top (blue) segment is under the responsibility of the Science Team, and has the role of defining science cases and top level requirements.
- System Engineering: the lower (yellow) segment is mainly under responsibility of engineers, supported by scientists, and has the role of designing, manufacturing, and testing the instrument.

Both segments are involved to a various degrees in all project phases to ensure that the science cases are realistic for the instrument that will be designed, and that the design is able to deliver the performance needed by the science cases.

The System Engineering segment is sub-divided into (i) System Design, corresponding to the project phases B and C (as well as, to some extent, the preceeding phase A study); and (ii) System Integration during phase D, leading into the commissioning phase E. Throughout these phases, a systems-oriented approach will be adopted. This is possible because several of the partner institutes are regularly involved in leading the design and construction of instruments for large space missions, which has given us the system engineering culture necessary for dealing with expensive, multi-institute projects. This is an important issue, and our experience with large space projects will be directly applicable in this respect.

One of the basic joint tasks for Science and System Design is to translate scientific top level requirements into technical system and subsystem level requirements. Management of these system and subsystem requirements is an iterative process and includes:

- Control of requirements definition and evolution,
- Control of compliance with requirements
- Assessment of the impact of changes on project performance and schedule

The baseline system functions are derived from the functional requirements via a functional analysis. It is then possible to define the functional interfaces and sub-functions. The next step is to introduce a system-level error budget and analyse the impact of errors at the level of the sub-functions. Together, these allow one to form the logical architecture, by separating the instrument into subsystems. Following this, internal and external interfaces are defined, and subsystem requirements are allocated to responsible working groups or contractors as a starting point for the detailed design phase. Management of the internal and external interfaces is a continuous process, connecting System Design with System Integration.

Within phases B and C, changes to both the system architecture and internal interfaces, as well as, to some extent, even the requirements, are possible. However, the further the system design evolves, the more the respective costs and impact on other subsystems increase.

A major part of the project control and management is associated with system engineering, and these aspects are described in detail in the following section.

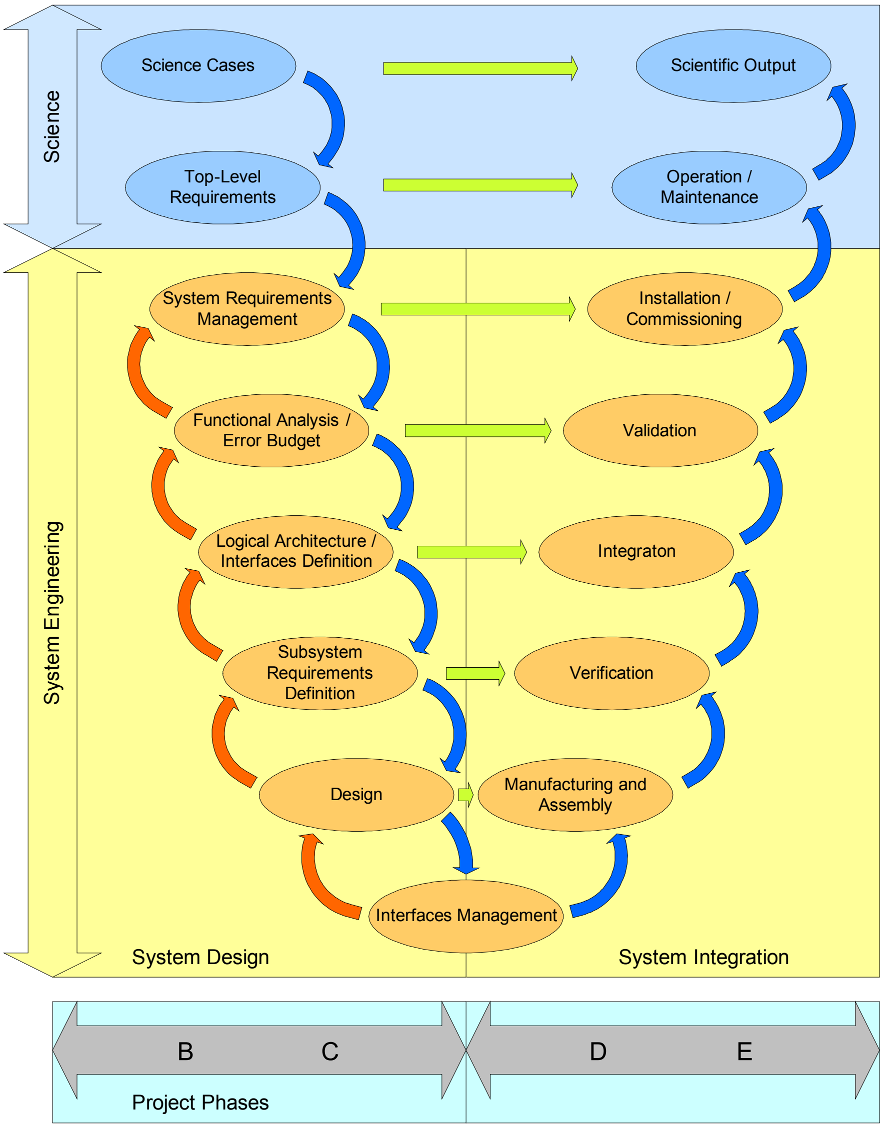

Figure 3: MICADO Instrument Project Flow Chart. This is a model that has been used successfully for many instruments that have been managed by MPE.

5 SYSTEM ENGINEERING MANAGEMENT

5.1 System Engineering Tasks

As illustrated above in the project flow chart (Figure 3), system engineering includes the following tasks:

- System requirements management
- Functional analysis / error budget
- Logical architecture and interfaces definition

- Definition of subsystem requirements
- Definition of the system design with regard to functional performance, and the ability to manufacture, integrate and maintain the instrument
- Scope of the design with regard to the applicable requirements and the allocated financial and workpower budgets, as well as performance and safety
- Definition of a program for manufacture, assembly, integration, and test (MAIT) and supervision of the activities
- Definition and implementation of the installation and commissioning activities

The entire engineering work is sub-divided into workpackages (see Section 3.4). System Engineer plays a key role here, and is responsible for:

- Coordination between design, analysis, manufacturing and test phases
- Negotiation and management of internal and external interfaces
- Specification of the design and procurement items
- Compilation of parts, materials and process list
- Allocation, compilation and control of budgets
- Identification of baseline configuration
- Definition of verification approach

The development activities are divided into three disciplines, namely optical engineering, mechanical/cryogenic engineering, and electronics/software engineering. The necessary input to the system engineering tasks is:

- Top-level requirements
- Functional, performance and budget requirements
- Requirements from the telescope infrastructure
- Subsystem designs
- Subsystem performances and budgets
- Subsystem CAD models

Output from the system engineering activity is:

- System configuration (integrated CAD models, drawings)
- Interfaces to the telescope & AO systems, and subsystem interfaces
- System performances and budgets
- Subsystem specifications

State of the art CAE tools will be used for design and analyses.

5.2 Design and Development Approach

The design and development process for the MICADO will follow the ECSS guidelines (including project phasing, technical guidelines and PA guidelines) as far as is applicable and meaningful. The project will be performed in phases as outlined in Section 6.1. Within each phase, work will be divided into system level and subsystem level activities. Reviews at the subsystem level will be performed prior to the corresponding system level reviews, to ensure that the various subsystems are compatible and fulfil the functional needs associated with the entire system. Design and development will be based, as appropriate, on

- Computer aided design techniques
- Numerical analyses and computer simulations
- Material tests for determination and validation of material characteristics
- Breadboarding on component level for functional characterisation
- Development tests of components or subsystems for validation of simulations and analysis assumptions

Based on the initial specifications, conceptual design and analyses have already been performed with the following aims:

- Verification of the feasibility
- Trade-off and selection of lower level solutions
- Allocation of system and subsystem level budgets
- Definition of specific technical requirements
- General definition of interface requirements

The results will be subject to the Phase A review. Together with any updates to the specifications following the definition of the E-ELT Instrument Roadmap, this work will form the basis for the preliminary design phase with the purpose of

- Establish a preliminary design (engineering drawings)
- Selection of parts, materials and processes
- Dimensioning of components
- Identification of manufacturing, assembly, and test processes
- Definition of interfaces
- Characterisation of materials

The documented design will be subject to a preliminary design review (PDR). The budgets and system level interfaces will be communicated to, and negotiated with, the instrument Project Office. Subsequently the design will be finalised including

- Preparation of manufacturing drawings, procurement specifications, assembly drawings
- Justification of the design by detailed analyses, breadboarding and development tests
- Preparation of test plans/procedures
- Update of budget reports and interface drawings

The documented design will be subject to a final design review (FDR) performed on subsystem and system level. The final and compliant subsystem/system design will be released for manufacturing. Further design activities may be needed for updates after qualification tests or upon failures or non-conformances or for improvements with respect to manufacturing.

5.3 MAIT Philosophy

Following the work breakdown structure, manufacturing, assembly, integration, test and verification activities will be carried out at three different levels:

- Subsystem level: under responsibility of the subsystem / workpackage manager; in most cases the activities will take place at the premises of the supplier.
- Instrument level: instrument integration, test, and verification at MPE, coordinated by the Project Office and supported by the subsystem suppliers.
- System level: integration, test, and commissioning of MICADO at the E-ELT in close cooperation with the E-ELT staff

5.3.1 Manufacturing, Assembly and Integration

The manufacturing, assembly and integration of the MICADO subsystems and all test and handling equipment required on subsystem level will be performed under responsibility of the subsystem supplier (whether consortium partner or contractor), adopting the PA/QA and configuration control policy agreed within the consortium. As far as is possible, all subsystems will be integrated into the instrument, which will then be mounted to a telescope simulator (i.e. mechanical mounting flange equivalent to the one MICADO will be attached to at the observatory). At this point, a full instrument-level hardware and software test will be performed. The instrument integration will take place at the MPE integration facility. In addition, a test facility for the SCAO system will be set up by LESIA. Once the instrument and AO system have been tested separately, they will be tested together.

The instrument level testing activities will be planned and coordinated by the System Engineer. Technical staff from MPE will be available during this phase, and the integration of the subsystems will typically be performed by experts from the responsible partner together with MPE technicians.

Following the instrument-level verification, MICADO and the SCAO system will be partly dismantled and packed for shipment to the E-ELT. Most of the steps to be performed at the E-ELT will be similar to the first integration at the test bed. However the constraints due to space and operations at the observatory mean that a thorough integration planning will be required, closely coordinated with the observatory staff.

5.3.2 Verification and Commissioning

To provide evidence of compliance with the system design and performance requirements a complement of reviews, analyses, inspections and tests on different levels will be performed to demonstrate:

- Compliance with functional and performance requirements
- Compliance with budget and interface requirements
- Design margins for all modes of operation and environmental conditions

The starting point of the verification activities will be the system specification and the verification matrix. The verification matrix is the basis of the verification process. It defines the qualification method, acceptance method and the associated levels, from which the analytical and test programs are developed. An assessment of the verification requirements will lead to a set of analysis reports as well as test procedures and reports, which will be used as input for the formal approval of the verification evidence. This will be performed as follows:

- Verification of the design will be performed by review of design, justification analyses and/or development tests.
- Qualification/acceptance will be demonstrated by means of tests on a representative model. The performance tests, functional tests and environmental tests shall be performed at the maximum levels predicted during the service life.

Verification will be performed by one of the following methods, as appropriate with regard to schedule, effort and credibility:

- Verification by review of design
- Verification by similarity assessment
- Verification by analysis
- Verification by inspection or test

Verification of the structural/thermal design is typically a combination of analyses and tests, where the test boundary conditions will be verified by analysis and in return the tests will be used to verify the structural and thermal mathematical models. Testing will be limited to those items which cannot be verified by similarity or analysis, or where a formal demonstration of compliance is required. Prior to any testing, an assessment or analysis will be made in order to make sure that the item to be verified is understood, and to verify that the test conditions are representative and safe. Verification by similarity is acceptable when it can be shown that the design and application of the reference item is at least as strict as that of the item to be verified. Verification by review of design is limited to those items where compliance can be shown by comparison of design documentation (e.g. dimensions on drawings) with the corresponding design requirements.

Verification will be performed at different levels of the product tree (see Figure 2). The baseline for the test and verification philosophy is that all delivered units should be qualified and verified on subsystem level, under responsibility of the supplier, prior to delivery of the unit to the instrument integration site. The requirements to be verified are defined in the verification matrix, and all tests will be documented in test reports. Prior to acceptance and integration an incoming inspection and a limited functional test shall be performed with all subsystems and/or components.

The instrument-level test programme will be carried out at MPE, after integration of all components in MICADO, and cover all tests which can not be performed on component level:

- functional verification tests
- verification of top-level requirements

The final system level verification of the instrument will be carried out during the commissioning phase, after integration at the E-ELT.

5.4 PA/QA and Safety

A PA/QA and Safety management system will be implemented and practiced for the MICADO project. It will include clear strategies for defining requirements, achievement of goals, error prevention, acquiring feedback from all involved entities, and for continual improvement.

5.4.1 PA/QA

A PA/QA Manager will be nominated at the beginning of Phase B. The initial task for this person will be to prepare a Product Assurance Plan based on international guidelines (ECSS, DIN EN ISO 9004:2000). The PA/QA approach will be tailored appropriately to the specific objectives and boundary conditions of the MICADO project. The PA Plan will be an applicable document to all entities involved in the design, development, manufacture, and AIT of the instrument. The PA/QA management system covers the following activities:

- Document and design control
- Materials, mechanical parts and processes
- Electrical, electronic and electromechanical components
- Procurement Product Assurance
- Manufacturing and assembly control
- Inspection, verification, validation
- Non-conformance control
- Configuration Management
- Reliability, Availability, Maintainability, Safety
- Software Product Assurance

5.4.2 Hazard Analysis

The whole consortium will jointly identify hazards for the Preliminary Hazard List during the Preliminary Design Phase of the project. The workpackage managers, supported as necessary, will conduct the Subsystem Hazard Analysis. The Consortium PA/QA manager will be responsible for approval of the Subsystems Hazard Analysis. The tasks involved include:

- Definition of the Preliminary Hazard List
- System & Subsystem Hazard Analysis
- Risk Estimation

The hazard analysis is used as input to the safety analysis and assessment (Section 5.4.4).

5.4.3 Risk Management

The objective of the risk management process is to improve the probability of project success by anticipating possible problems, identifying opportunities and by taking cost effective actions to improve the current situation, margins and working efficiency. The key activities in the risk management process are to

- identify critical items (hardware or software) to ensure they are given sufficient attention, and to mitigate further impact

- identify long-lead items, so that an appropriate procurement strategy can be implemented well in advance

Regular iterative updating of these lists ensures that evolving circumstances are taken into account. The initial risks and trade-offs that have been identified and assessed during the Phase A study for MICADO are described and listed in the Trade-Off and Risk Assessment (RD6).

5.4.4 Health and Safety Assurance

Health and safety are a key requirement for any scientific instrument, and the hazard analysis will form a key input to the safety assessment. This section is intended as an overview of the health and safety assurance approach to be adopted within the MICADO project. Detailed requirements from the E-ELT and from national law will be applicable to any activity that is occurring in the MICADO project. The following activities will be part of the health and safety assurance program:

- Safety Verification
- Safety Compliance Assessment

The Consortium Project Manager will be responsible for ensuring that the health and safety requirements are fulfilled. However each workpackage manager must be familiar with the health and safety assurance policy.

6 SCHEDULE & MILESTONES

The schedule for MICADO has been developed under the following three assumptions:

- The E-ELT Roadmap, which will list the first light instruments, will be made public around September 2010 (as suggested by S. D'Odorico in a presentation at the 'E-ELT Instrumentation at Phase A Mid-term' workshop help during February 2009).
- That MICADO is selected as one of the first light instruments, at which time it will operate with a SCAO module.
- After some time, MICADO will be moved to operate with other post-focal AO systems, with its final location on an MCAO system.

The current baseline is that MICADO should be used initially with a SCAO module, since this is the simplest and most robust form of adaptive optics; and that after a number of years, MICADO will be moved to its final location under MAORY. However, depending on the E-ELT roadmap, there could be an opportunity to use MICADO for several years with other post-focal AO systems such as LTAO. In this respect, it is noted that the optical relay and support structure could in principle be used as the interface between MICADO and ATLAS.

Based on experience with other projects, we foresee a period of about 9 months at the end of the preparatory phase, between announcement of the Roadmap and commencement of Phase B (the official instrument 'Kick-off') in order to revise this Management and Development Plan. Specifically, this time will be used by the consortium partners to finalise both the work distribution as well as financial and workpower issues. This time will also be used to revise the project schedule according to how the AO system deployment is foreseen in the E-ELT Roadmap.

If the roadmap is announced in September 2010, we expect to have the formal Kick-Off in June 2011. The overall design, manufacturing, assembly, and testing time for MICADO amounts to 6 years, and thus Preliminary Acceptance in Europe is anticipated for mid-2017. This leaves sufficient time for shipping and re-integration so that MICADO can be ready and available for use at the E-ELT first light in 2018. We will continually update and adjust the MICADO schedule to match that of the E-ELT. Potential changes in the E-ELT schedule will be taken into account in the mid- and long-term staff planning of the MICADO consortium partners.

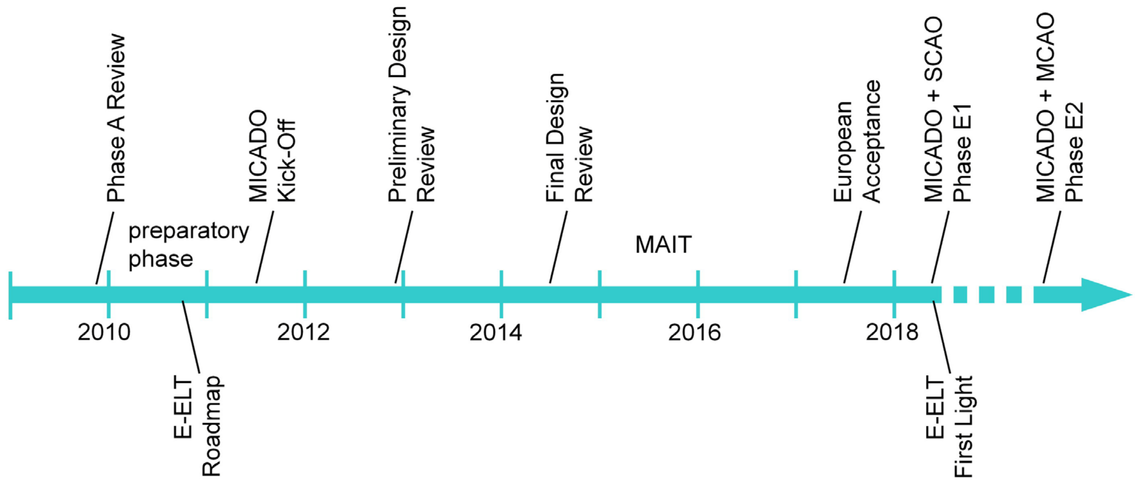

Figure 4: Illustration of the MICADO instrument schedule from the end of Phase A, through Kick-Off in 2011 to European Acceptance in 2017 and a first light matching that of the E-ELT to avoid delay in the start of science operations. A more detailed schedule is given in the Appendix (Figure 5).

6.1 Project Phases

The MICADO project schedule consists of five phases.

- ***Phase A*** lasts from Phase A kick-off, which took place in Feb 2008, to the Phase A review meeting, scheduled for Nov/Dec 2009. During Phase A, using the specifications given in the Call for Proposals as a basis, the instrument requirements were derived from the science cases. An advanced conceptual instrument design was then developed. This includes, as far as is possible, electronics architecture, instrument SW requirements, interfaces to the AO module MAORY. Following the midterm review, development of a SCAO module for use during initial science operations was included.
- The ***preparatory phase*** commences at the end of Phase A. It is the period during which preparatory work or technological developments are pursued. In particular, the following topics will be addressed:

- Involvement in definition of electronics and software standards and frameworks for the E-ELT, so that we are fully conversant with these at the beginning of Phase B.
- Advancing the status of the observation simulations and data analysis; this will assist with design choices during Phase B.
- Development of high throughput broadband filters and of OH suppressing filters (research contract with Laser Zentrum Hannover); see RD7.
- Investigation of options for the Auxiliary Arm, specifically (i) dual imager based on a tunable Fabry Perot (with FRACTAL, Spain), and (ii) high time resolution detectors (with the National University of Ireland, Galway); see RD3 and RD4.

The preparatory phase will also include a time during which the work distribution within the consortium is finalised, once the E-ELT Roadmap is announced by ESO. This period will conclude with the instrument Kick-Off at the start of Phase B.

- ***Phase B and C*** of the MICADO project are assigned to the design of the instrument, and are each expected to last 1.5 years. They comprise the confirmation of the scientific requirements, the final derivation of the top level specifications, conclusion of the technical specifications and confirmation of the work package distribution amongst the consortium members. The design of the instrument takes place in two phases: from beginning of Phase B to the Preliminary Design Review (PDR); and in Phase C from acceptance of the preliminary design to the Final Design Review (FDR).
- ***Phase D*** is assigned to manufacturing, assembly, integration and testing (MAIT) and is expected to last 3 years. The progress of Phase D will be monitored and maintained by reference to a series of mini-milestones. These milestones will be decided during Phase B and C of the project. Phase D ends with the Preliminary Acceptance in Europe (PAE). Following completion of this phase, the instrument will be shipped to the observatory.
- ***Phase E*** is devoted to re-installation, verification, commissioning and operation of the instrument at the E-ELT. The first major milestone will be the Preliminary Acceptance at the Observatory (PAO), after which science operations can begin. This phase will end with Final Acceptance, after which the observatory staff will take over full responsibility for operating and maintaining the instrument. Since MICADO is foreseen to operate with at least 2 different AO systems, this phase will comprise several sub-phases:
  - Phase E1: integration and commissioning with the SCAO module, and science verification. In this sub-phase, the full instrument functionality is tested and science operations begin. Both preliminary and final acceptance will be related to this sub-phase.
  - Phase E2: integration and commissioning of additional detectors; and commissioning of interface functionality with MCAO; science verification.

The sub-phases within phase E are dependent on the final decision (based on the E-ELT roadmap) about which AO systems MICADO should operate with. The current baseline plan is for SCAO and MCAO; however, between these two, there could be a time-span during which (using the support structure and optical relay from the SCAO module), MICADO could also operate successfully with LTAO.

The Appendix shows the planned schedule down to the level that can be drawn today.

6.2 Design and Test Reviews

Following the formal start of the instrument project at its Kick-Off, the major milestones of the project are the design reviews and the acceptance tests. The preliminary and final design reviews (PDR and FDR) will be held at the conclusion of their respective design phases. Test reviews will be held prior to shipping the instrument (preliminary acceptance in Europe: PAE), and again once the instrument has been installed at the observatory and commissioned (preliminary acceptance at the observatory: PAO). We envisage an additional shorter test review each time the instrument is moved to a different AO system. Initially, we anticipate that the instrument will be commissioned with its own SCAO module.

The reviews listed in Table 3 will follow the standard procedures as established by ESO. In the following schedule, milestones up to and including Preliminary Acceptance at the observatory (with the SCAO module), are foreseen:

Table 3: summary of MICADO reviews and dates

Instrument Kick-Off	June 2011
PDR	December 2012
FDR	June 2014
PAE	June 2017
PAO	2018, matching first/early light at the E-ELT

6.3 Progress Meetings & Communication

The PI is the formal point of contact to the ESO nominated responsible. In addition, informal day-to-day contact between the Consortium and ESO will be via the members of the engineering management team with responsibility for the particular area of work and the appropriate ESO personnel.

Formal monitoring of the progress and reporting to ESO will take place throughout Phases B-D, up to PAE. This will take the form of submitted reports and regular progress meetings, which will be held every 4 months.

Internal consortium meetings will be held more frequently, to monitor the progress and address issues that arise, on a weekly basis. These will be conducted as face-to-face meetings, videocons, or telecons, as appropriate.

In addition, ad-hoc ‘event driven’ internal consortium meetings will be set-up and conducted as the need arises.

7 COST AND WORKPOWER

The resources required for MICADO have been estimated under the following assumptions:

- That there will be a limited E-ELT instrument software framework (providing the communication software, detector control software and image archive, but not including real time display, broker for observation blocks, SW alarm system, logging system, and so on.
- That there will only be a limited E-ELT data processing framework, and that ESO will provide sufficient computing facilities to run the software
- That electronics standards and technologies similar to those being evaluated by ESO (see RD7) will be adopted
- That for commissioning, the consortium will cover the cost of travel to the observatory, but that ESO will cover the cost of board and lodging at the observatory.

For these reasons, the cost and workpower estimates for electronics hardware and for software are greater than for an equivalent VLT instrument. These estimates may change significantly once the E-ELT Electronics Standards and the E-ELT Software Frameworks are defined in more detail.

7.1 Resources Required

The cost and workpower estimates and summaries shown in Table 4 to Table 7 are based on the estimates made during the Phase A study. For each workpackage, these estimates are the result of a detailed calculation or based on experience from similar involvement in other instrument projects. Since the members of the consortium do have long experience, we expect the calculation to be fairly realistic – although we note that some of the estimates may need to be revised as indicated above. We note that the Management workpackage includes only global project management and systems engineering; local management of workpackages is included in their individual cost and workpower estimations.

Table 4: cost and workpower estimates without contingency, organized by project phase and workpackage

WP #	WP name	Phase B 18 months		Phase C 18months		Phase D 36 months		Phase E1 6months		Phase E2 6months (some time later)	
		cost k€	FTE	cost k€	FTE	cost k€	FTE	cost k€	FTE	cost k€	FTE
1	Management										
1.1	Management	6	0.90	6	1.05	12	1.80	4	0.35	4	0.35
1.2	Systems Engineering	6	1.50	6	1.50	12	3.00	4	0.50	4	0.50
2	Science										
2.1	science	15	1.90	10	1.40	10	1.00	5	0.50	5	0.40
2.2	OCMD	4	0.55	4	0.55	8	1.00	4	0.45	4	0.45
3	Cryostat										
3.1	cryostat	2	1.97	2	3.51	318	2.94	2	0.30	1	0.10
3.2	handling equipment	2	0.22	2	0.31	54	0.46	2	0.17	1	0.10
3.3	MICADO test facility	2	0.49	12	1.00	134	0.98	6	0.23	6	0.10
4	Cable-Wrap										
		2	0.92	2	1.44	154	1.23	2	0.26	1	0.10
5	Opto-Mechanics										
5.1	common path	2	2.78	2	5.61	923	4.11	2	0.49	1	0.10
5.2	primary arm	2	0.87	2	1.68	42	1.89	2	0.13	1	0.10
5.3	auxiliary arm	2	1.35	2	2.02	52	1.80	2	0.13	1	0.10
5.4	calibration unit	2	0.25	2	0.25	94	0.50	2	0.12	1	0.12
6	Detectors										
6.1	detectors	2	0.20	7	0.20	2154	0.80	2	0.20	5016	0.45
6.2	FPA	2	0.40	12	0.40	224	0.70	2	0.20	7	0.35
7	Electronics										
		45	6.90	79	7.05	322	15.05	26	1.00	18	0.50
8	Instrument Software										
		67	5.62	66	5.63	118	14.25	12	1.13	6	0.62
9	Data Processing										
		16	2.25	16	2.25	14	9.00	14	1.50	14	1.50
10	SCAO										
10.1	support structure	8	1.10	4	1.27	87	1.18	5	0.17	0	0.00
10.2	optical relay	3	0.85	3	1.15	87	0.70	3	0.15	0	0.00
10.3	wavefront sensing	5	2.35	5	2.75	299	2.55	7	0.45	0	0.00
10.4	AO test facility	1	0.35	1	0.65	56	3.10	0	0.00	0	0.00

Shipping costs are not included in this table. The reason is that customs duty will be a non-negligible fraction of the overall cost, and if MPE ships the instrument out of Germany it must pay these costs. Instead MPE notes its intention of negotiating a waiver for the shipment with ESO (so that the consortium delivers to ESO, and ESO ships to the observatory). The outcome of this request will be included in the revised Management Plan.

Table 5: summary of the cost and workpower estimates without contingency, given by Workpackage

WP #	WP name	total for initial phase		upgrade for MCAO	
		cost k€	FTE	cost k€	FTE
1	Management	56	10.60	8	0.85
2	Science	60	7.35	9	0.85
3	Cryostat	538	12.58	8	0.30
4	Cable-Wrap	160	3.85	1	0.10
5	Opto-Mechanics	1135	23.98	4	0.42
6	Detectors	2405	3.10	5023	0.80
7	Electronics	471	30.00	18	0.50
8	Instrument Software	264	26.63	6	0.62
9	Data Processing	60	15.00	14	1.50
10	SCAO module	574	18.77		

Table 6: summary of the cost and workpower estimates without contingency, given by Project Phase

	Phase B 18 months		Phase C 18months		Phase D 36 months		Phase E1 6months		Phase E2 6months	
	cost k€	FTE	cost k€	FTE	cost k€	FTE	cost k€	FTE	cost k€	FTE
MICADO	179	29.07	232	35.85	4645	60.51	93	7.66	5091	5.94
SCAO module	17	4.65	13	5.82	529	7.53	15	0.77	0	0.00

Table 7: total cost & workpower, both without and with 20% contingency

	without contingency		**with 20% contingency**	
	cost k€	FTE	cost k€	FTE
MICADO	5149	133.09	6178	159.71
SCAO module	574	18.77	689	22.52
upgrade for MCAO	5091	5.94	6109	7.13
grand total	10814	157.80	12976	189.36

Looking at individual work packages in detail, the main cost driver can easily be identified as the detectors. This is inevitable, and should be expected, for an imaging camera. In the case of MICADO, the detector workpackage comprises approximately 50% of the cost for the initial phase, and approximately 70% of the total cost.

Although the large number of detectors (16 in the primary arm, and 1 in the auxiliary arm) brings the total cost of 13.0M€, over the specification of 10M€, the consortium is convinced that the best imaging science requires this large number. The reasons for this are outlined in the Science Analysis (RD4) and the Trade-Off (RD6) documents.

The phrased approach that the consortium has as its baseline mitigates this cost to some extent. As a result, the initial cost (including MICADO with 4+1 detectors and the SCAO module) is 6.8M€, within the cost specification. The additional 6.1M€ would be required only later when the MCAO module is implemented.

7.1.1 Costs of Auxiliary Arm & Spectroscopic Option

During the Phase A study, there was a request from ESO to provide a separate estimate of the cost of the Auxiliary Arm alone. This is provided in Table 8. It has been estimated by summing the respective partial costs associated with the common path (e.g. selection mechanism, filters and filter wheel), the detector workpackage (1 HAWAII-4RG with controller), the opto-mechanics for the arm itself, as well as a fraction of the electronics and software costs. The overall cost is dominated by the detector and the filters.

The science cases have indicated that there are some situations where the ability to change pixel scales is a key requirement. In the MICADO design, this has been implemented in the Auxiliary Arm in order to keep the Primary Arm as stable as possible (i.e. no large movable optics). In this case, one can consider the Auxiliary Arm (including the primary/auxiliary selection mechanism and additional filter wheel and detector) to be required for MICADO independently of the spectroscopic option. The cost of the spectroscopic option within the Auxiliary Arm is given in Table 9. This cost includes the mechanism to change the pixel scale as well as the grisms; as well as, for that arm, approximately half of the design and MAIT work, and one third of the electronics and software.

Table 8: total cost of Auxiliary Arm

	cost k€	FTE
common path	285	1.40
opto-mechanics	59	5.40
detector	510	0.20
electronics	47	3.00
instrument software	0	2.66
data processing	0	1.50
total	901	14.16

Table 9: cost of spectroscopic option within the Auxiliary Arm

	cost k€	FTE
common path	0	0.00
opto-mechanics	25	2.57
electronics	14	0.90
instrument software	0	0.80
data processing	0	0.45
total	39	4.27

7.2 Key Personnel

The key personnel involved in the project are listed in Table 10. All other workpower will be provided by permanent or hired staff and scientists or students, as appropriate.

Table 10: Key MICADO personnel involved at a level >10%

Partner	*Person*	*Experience*	*Role*
MPE	Richard Davies	PARSEC, KMOS, ARGOS	Principle Investigator
MPE	Sebastian Rabien	PARSEC, ARGOS	Project Manager
MPE	Hans Gemperlein	ARGOS	WP 5 manager, Systems Engineer
MPE	Markus Thiel	EQUATOR-S, ROSETTA, PACS/Herschel, GRAVITY	systems
MPE	Frank Eisenhauer	3D, SINFONI, LUCIFER, GRAVITY	systems/optics
MPE	Stefan Kellner	PARSEC, GRAVITY	systems/electronics
MPE	Markus Haug	GRAVITY	systems/mechanics
OAPD	Alvio Renzini	MICADO Phase A	WP 2 manager, Project Scientist
OAPD	Renato Falomo	MICADO Phase A	OAPD Responsible
OAPD	Roberto Ragazzoni	TNG, MAD, LINC-NIRVANA, LBTC	Optics
MPIA	Tom Herbst	Cornell near-IR FP, MAX mid-IR camera, LINC-NIRVANA	Instrument Scientist, MPIA Responsible

NOVA	Ramon Navarro	Manager of NOVA optical/IR lab at ASTRON	WP 3 manager, WP 4 manager, NOVA HW Responsible
NOVA	Niels Tromp	GLAS-BLT, WYFFOS, SPIFFI, JWST MIRI, XShooter	mechanical engineer
NOVA	Marco Drost	VISIR, MIDI, SPIFFI, JWST MIRI	mechanical engineer
NOVA	Gijs Verdoes Kleijn	Astro-WISE, Euro-VO, Target	WP 9 manager, NOVA SW responsible
NOVA	Edwin Valentijn	Astro-WISE, OmegaCEN, KIDS, VIKING, VESUVIO	data processing, astrometry
USM	Hans-Joachim Hess	FORS, OmegaCam, KMOS	WP 7 manager
USM	Bernard Muschielok	FORS, OmegaCam, KMOS	WP 8 manager, USM Responsible
USM	Michael Wegner	KMOS	WP 8 deputy
LESIA	Yann Clenet	GriF, GRAVITY	WP 10 manager, LESIA responsible
LESIA	Pernelle Bernadi	COROT	AO, optics
LESIA	Frederic Chapron	SPHERE, Canary	AO, mechanics
LESIA	Eric Gendron	ADONIS, NAOS, GRAVITY	AO
LESIA	Zoltan Hubert	Canary	AO, engineering

8 APPENDIX

8.1 Detailed Schedule

Figure 5 lays out the master schedule of MICADO to the level of detail that can be given at the current time.

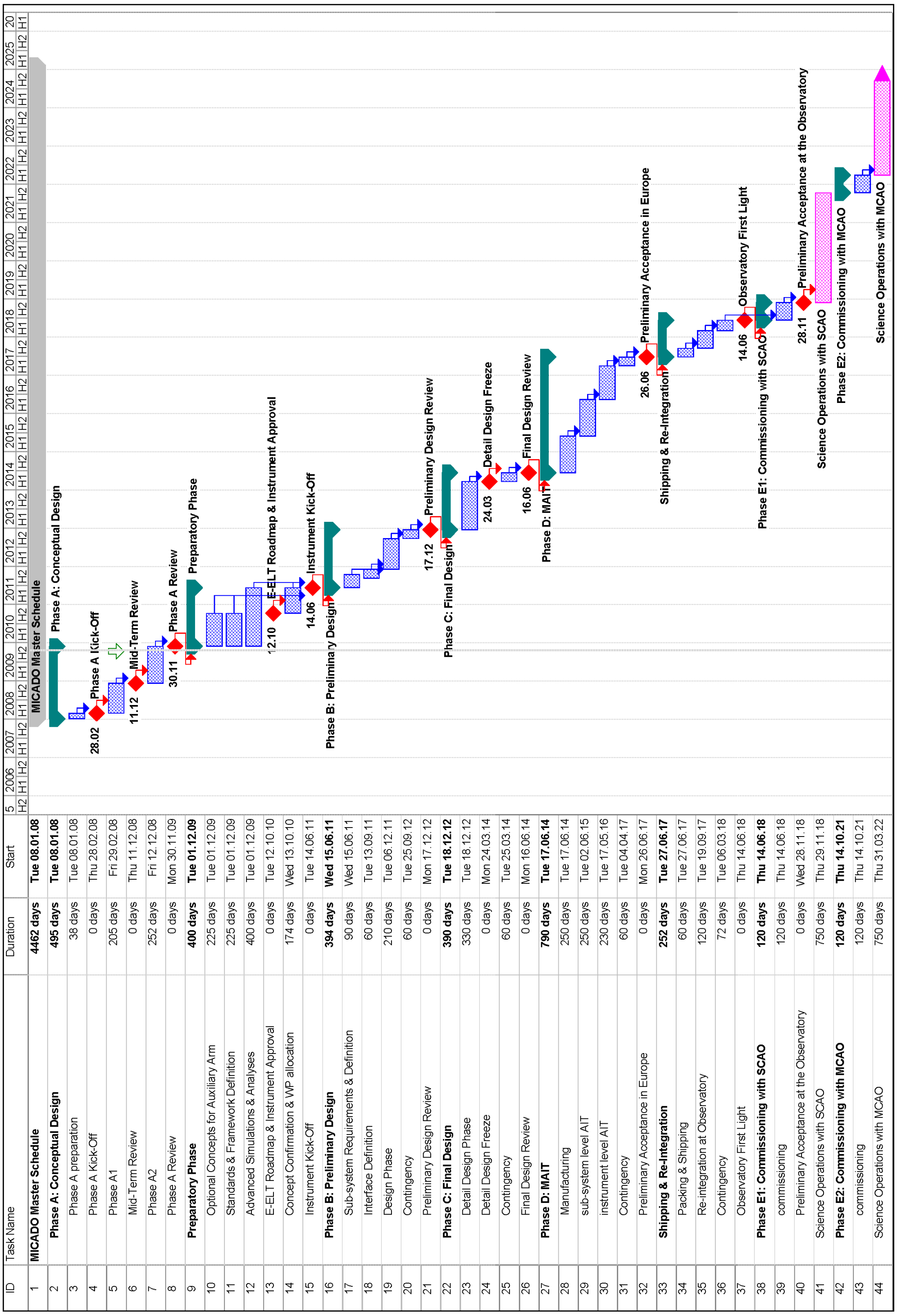

Figure 5: MICADO master schedule, shown to the level of detail that can be given at the current time.

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