The E-ELT instrument roadmap: a status report

S. K. Ramsay, M.M. Casali, J.C.González, N. Hubin
European Southern Observatory, Karl-Schwarzschild-Strasse, 2, Garching bei München, D-85748

ABSTRACT

We present the status of the instrumentation programme for the European Extremely Large Telescope. The instrumentation planning is governed by the E-ELT Instrument Roadmap, which synthesises the scientific, technical and managerial influences on the instrument programme into a staged development plan. Preparations for the start of the design and build phases of the first light instruments and their adaptive optics systems are well underway and are summarised here. In parallel, the process for development of the next three instruments has begun. Recent work on the instrument interface to the telescope is described.

Keywords: instruments: optical, instruments: infrared, instruments: extremely large telescopes

1. INTRODUCTION

The development of the Instrumentation Roadmap for the European Extremely Large Telescope (E-ELT[1]) has been presented by Ramsay et al.[2]. The Roadmap sets out the suite of instruments planned for the telescope and the broad timescales for starting their design and construction. The instrument selection and the assignment of their relative timing arose from discussions between the E-ELT Programme and the E-ELT Science Working Group. The scientific prioritisation was then balanced against managerial and technical concerns leading to the current version of the E-ELT Roadmap, shown in Figure 1.

Seven instruments are selected. At the time of writing, the preparations for the contracts for the first light instruments (ELT-IFU, ELT-CAM) and for the multi-conjugate adaptive system are underway with the consortia that have previously studied these instruments concepts. Further details are given below.

The next three instruments will be a mid-infrared imager and spectrograph (ELT-MIR), a multi-object spectrograph (ELT-MOS) and a high resolution spectrometer (ELT-HIRES). The scientific cases for these instruments and the scientific requirements to fulfill these cases have been studied by the ELT Project Science Team. It is planned that the ELT-MIR instrument will be an evolution of the METIS instrument studied at Phase A. The richness of the science cases for multi-object spectroscopy and high resolution ($R = \lambda/\delta\lambda$ ~>50k) spectroscopy on an E-ELT lead to a broad range of high-level scientific requirements that are unlikely to be met by a single instrument. A call for proposals for ideas for these instruments will be made at which the ESO instrument building community will be invited to propose concepts that meet a subset of these requirements. The science cases and specifications for the selected ideas will then be further developed through ESO-supported Phase A studies for one or more HIRES and MOS instruments during 2015. Finally, a single consortium will be selected for construction of the MOS and HIRES instruments. Ideas for instruments to answer the call for propsoals have been presented at this conference by Hammer et al[3] and Zerbi et al[4].

ELT-6 is a placeholder for an as-yet-undefined instrument. This is a key element to the Roadmap, allowing flexibility for important emerging scientific fields, contributions from future ESO member states or completely new ideas not already studied at Phase A. An instrument that would address the science cases and instrumental functions that cannot be met with the first generation of MOS and HIRES instruments can potentially be reconsidered at this time.

The final selected instrument is a planetary camera and spectrograph, ELT-PCS. Exoplanet detection and characterisation is one of the main science themes for the E-ELT and this specialised instrument has the highest scientific priority. The comparatively late start is for two reasons. The first is the desire to learn from the results anticipated from the Gemini Planet Imager[5], SPHERE[6] and to be able to respond to the rapid developments seen in this particular field, before fully definining the scientific requirements for ELT-PCS. The second is to start work on preparatory studies, including developing the challenging technical components, such as the deformable mirror, and potentially building an on-sky prototype.

Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop TLRs for MOS/HIRES Call for Proposals			Start ETD
2015				Start Phase A			
2016				Consortium Selection for construction		Call for proposals	
2017							
2018							TRL check
2019						Selection	Start when ready
2020							
2021							
2022							
2023							
2024							
	Pre-studies taking the form of phase A or delta-phase A work and/or ESO-funded Enabling Technology Development (ETD)						
	Decision point						
	Development of Technical Specifications, Statement of Work, Agreement, Instrument Start.						

Figure 1: The European Extremely Large Telescope Instrument Roadmap

2. THE FIRST LIGHT INSTRUMENTS

2.1 ELT-CAM: MICADO plus the MAORY adaptive optics module

MICADO (Davies et al.[7]*)* is a near-infrared camera designed to exploit the diffraction limit of the 39-m telescope. Many of the features of the instrument design is driven by desire to deliver exquisite astrometry (<40uas) as a facility available to all users. The standard mode of operation is for the instrument to be located at one port of the multi-conjugate adaptive optics facility, MAORY. The MICADO field of view will be ~1arcminute in diameter with 6-10mas angular resolution and with uniform PSFs over that field delivered by MAORY. A second scale, for even higher precision astrometry, will have 1-1.5mas per pixel over a smaller field. MICADO has been revised since the Phase A design, in which the two plate scales were delivered by different channels in the instrument with separate focal planes. In the current concept, these two modes use the same detector focal plane, with the finer plate scale achieved by the insertion of zoom optics into the fixed path of the principal plate scale. A long-slit spectroscopic option is provided by inserting diffraction gratings into the optical path. By virtue of this design, the primary mode remains stable enough to deliver the required astrometric accuracy. A trade-off of the parameters (resolving power, slit length, wavelength coverage) of the spectroscopic mode is currently underway.

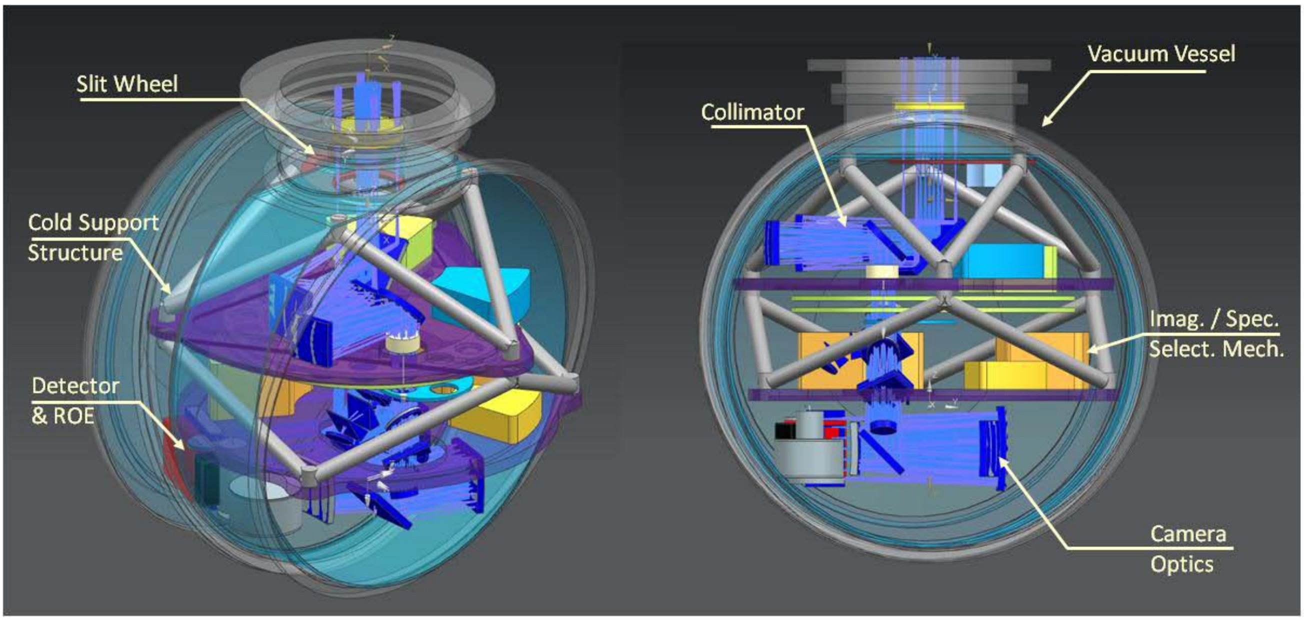

Figure 2: One of the current conceptual layouts of the MICADO[7] camera being considered as the design progresses. (Image courtesy of the MICADO consortium.)

MAORY (Diolaiti et al.[8]) uses the telescope adaptive M4 and two post-focal deformable mirrors (conjugated to 12.7km and 4km) to correct a field of view of up to 2arcminutes. The predicted Strehl ratio is about 0.5 at $\lambda = 2.16$ µm, averaged over the MICADO FoV, over about 50% of the sky at the Galactic Pole[8]. Two instruments can be fed by this module. MICADO will be located under MAORY, in an upward looking, gravity invariant configuration. A second side looking port with the identical optical configuration is selected with a fold mirror. Significant work on the optical design of the instrument has been carried out as the preparations for the kick-off of the construction phase. This work is motivated by a number of aims: to reduce thermal background contributed by the instrument by reducing the number of optical surfaces; to accommodate alternative deformable mirror technologies and to provide a suitable pupil for locating an atmospheric dispersion corrector to serve MICADO. MAORY will also offer a single conjugate adaptive optics mode that will be developed jointly with the MICADO consortium. This mode is required to deliver the highest Strehl, highest contrast performance demanded by the camera science case.

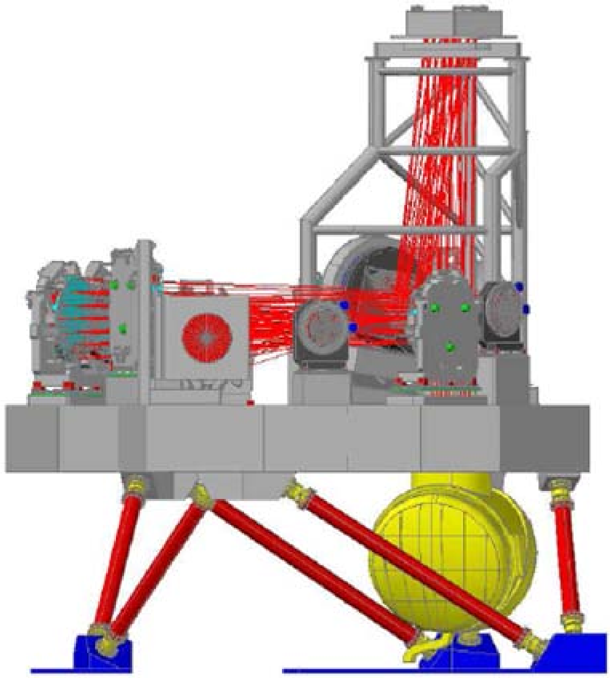

Figure 3: The Phase A concept of the MAORY[8] MCAO module, showing the MICADO camera mounted below (courtesy of the MAORY consortium).

2.2 ELT-IFU: HARMONI and LTAO

The integral field spectrograph, HARMONI[9], offers a broad range of capabilities consistent with its role as a workhorse spectrograph for first light. It provides visible-NIR coverage and can be used with deliver image quality from natural seeing, ground-layer corrected image quality through to the diffraction limited image quality that will be delivered by laser conjugate AO and highest Strehl single conjugate AO. Four spaxel scales in the range 4mas to 60mas deliver corresponding fields from view 0.6arcsec x 0.8 arcsec to from 6.4arcsec x9.1arcsec. Four spectral resolving powers are available: R of 500, 3500, 8000, 20 000. Full coverage of the useable atmospheric windows in the 0.47-2.45um range are provided in all modes expect R=20 000. Four gratings will be provided in this mode; their exact wavelength ranges are to be decided as the science case is developed in the preliminary design phase. Simultaneous coverage over the full HARMONI wavelength range in the R~500 mode will be available. HARMONI will also develop concepts for providing high-contrast spectral imaging for exo-planet science case in the PDR phase. During the instrument Phase A studies, the ATLAS facility adaptive optics module was used with HARMONI and the baseline plan for delivering the adaptive optics requirements for this instrument remains that it is used in combination with an LTAO module. In Section 5 we describe the work that has been carried out recently in this area.

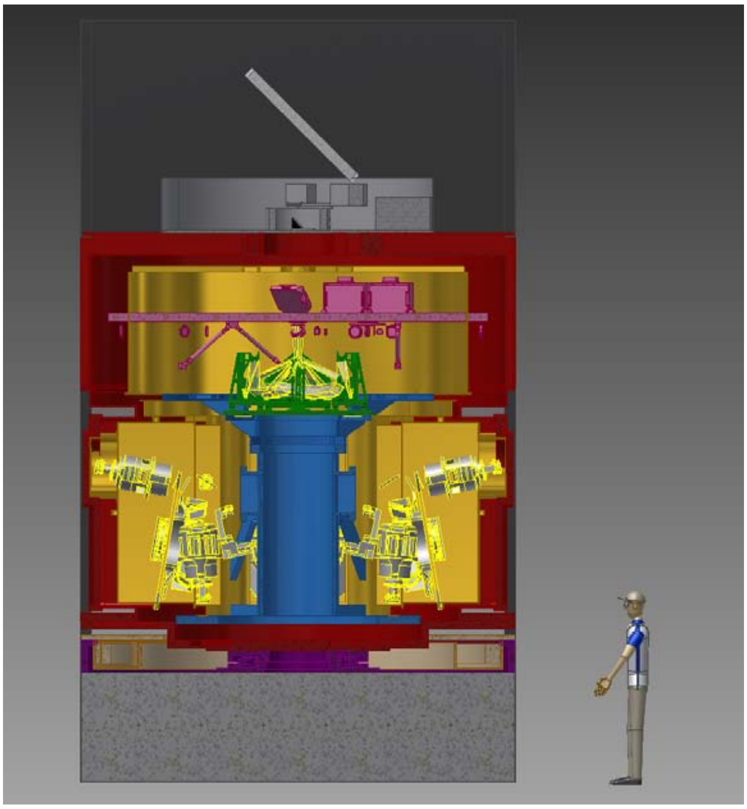

Figure 4: A recent rendering of the HARMONI[9] concept (courtesy of the HARMONI consortium).

3. ELT-MIR/ELT-HIRES/ELT-MOS

3.1 ELT-MIR/METIS

The kick-off for the mid-infrared instrument, ELT-MIR, is also planned for 2015. The top level requirements for this instrument are for imaging in the LMN bands over a field of view of ~20-30arcsecs and both low (R~few 1000) long slit and high (R~100 000) IFU spectroscopic modes over these bands. ESO is working with the team that produced the METIS Phase A study towards an agreement for the construction of ELT-MIR. This work includes a study of extending METIS to the Q band in the high spectral resolution mode. An update of this instrument is presented in these proceedings by Brandl et al.[10].

3.2 ELT-HIRES

The Phase A studies for the E-ELT included two very different high resolution spectrographs. The CODEX[11] concept was for an ultra-stable seeing limited, fibre-fed optical spectrograph to be located at the coude focus of the telescope. SIMPLE[12] was a high spectral resolution AO-fed NIR spectrograph fed by either of the facility AO systems (LTAO and MCAO). Both spectrographs were designed for single or compact objects and with spectral resolving power of R~100 000. The principal science requirements for the ELT-HIRES instrument are:

- 0.37-2.5um wavelength range
- 100 000 < R< 200 000
- Diffraction limited resolution >1um
- Also seeing limited performance

3.3 ELT-MOS

Three different concepts for MOS spectrographs, each tailored to different scientific cases, we presented during the E-ELT Phase A design studies (see LeFevre et al.[13], Hammer et al.[14], Cuby et al.[15],). The concepts range from a low-resolution imaging spectrometer (OPTIMOS DIORAMAS[13]) to a high resolution fibre-fed optical-H-band spectrograph (OPTIMOS-EVE[14]) and included a multi-field AO corrected IFU spectrograph (EAGLE[15]). The main requirements on the future ELT-MOS are now

- 0.4-2.45um wavelength range
- 1 000 < R< 15 000
- Multiplex ~>400 and 2-100 (with AO)
- Seeing limited or MOAO-type resolution

4. THE EAGLE DELTA-PHASE A DESIGN

The EAGLE[15] spectrograph was studied at Phase A as one of the three possible options for multi-object spectroscopy. It is a multi-IFU, multi-object AO assisted spectrometer operating at NIR wavelength ranges. EAGLE has been discussed in previous SPIE meetings, most recently by Morris et al. 2012[16]. This spectrometer was designed to be located at the gravity invariant focus of the telescope that was removed from the design at the time that the new telescope baseline was set. In order to understand whether the EAGLE science case could be delivered by an instrument mounted on the Nasmyth platform, an extension to the Phase A study was made by the EAGLE consortium. This 15 month study considered a revised opto-mechanical design, including the simplification of reducing to a single spectral resolving power R~8000 and the impact on the science case. New AO modeling of the expected performance was also part of the work. The study concluded in March 2014. FEA analysis of the new structure suggested that the scientific requirements could still be met with such an instrument. An image of the rotating EAGLE is shown in Figure 4.

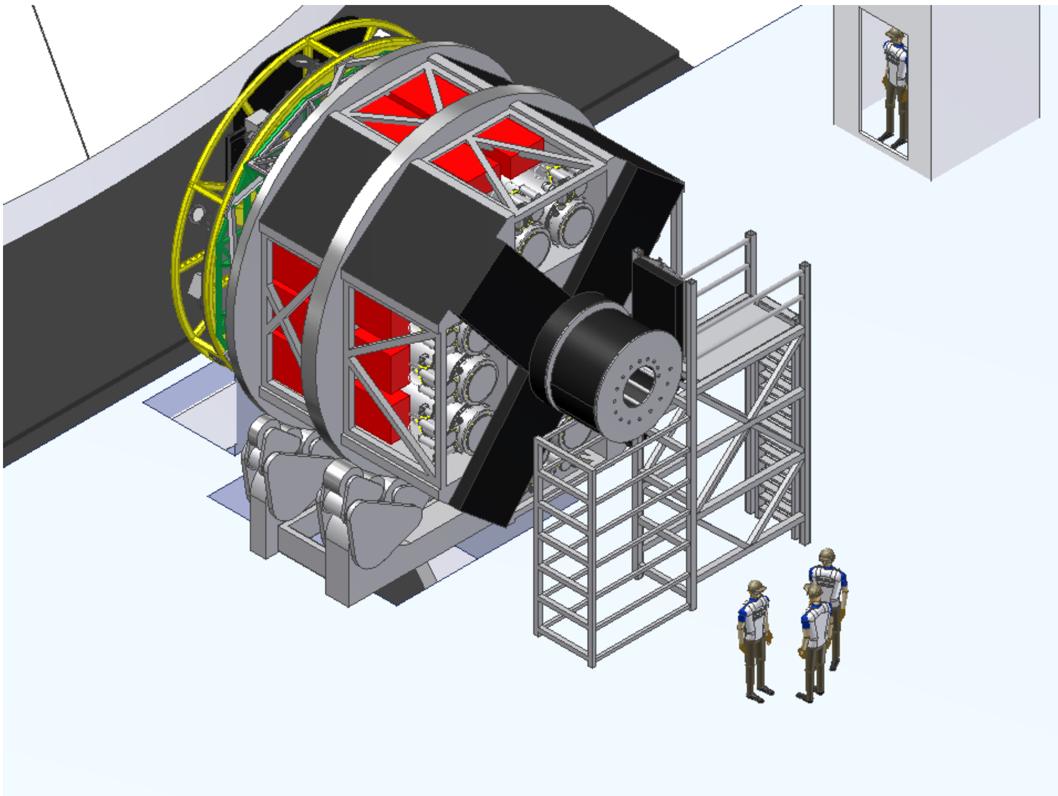

Figure 5: EAGLE[15] on the E-ELT Nasmyth platform (Image courtesy of the EAGLE consortium).

5. THE NASMYTH PLATFORM ARCHITECTURE

A key requirement for the ELT is to have simultaneous access for at least three instruments per Nasmyth platform and that those instruments are available for use on short timescales (<10 minutes). In the original design, a “pre-focal station” module (PFS) hosted the telescope wavefront sensors (natural guide star and laser guide star), provided a mechanical rotator for light instruments and provided an M6 mirror that directed the telescope beam to each of three ports. Two side-looking instrument ports are delivered a 5arcminute field by the flat M6 mirror. The straight-through port has access to the full 5arcminute field of view and the area of the peripheral field that is not vignetted by the telescope wavefront sensors that are mounted on a rotating ring at the location of the focal plane. (In the EAGLE concept described above, this wide-field MOS actually takes over the responsibility for providing the telescope wavefront sensing to maximise their survey area.) This concept formed the instrument interface at the time of the Phase A conceptual designs. Since then, the requirements on this module have been reviewed, removing both the built-in instrument rotator (not used by the instruments studied at Phase A) and the laser wavefront sensors for ground layer adaptive optics. In the past year, a study into this interface and the instrument architecture on the Nasmyth platform has been carried out.

An outstanding issue from the instruments Phase A was to resolve a volume conflict between the HARMONI spectrograph and the ATLAS laser tomographic adaptive optics model that was to provide the AO corrected beam to HARMONI. An additional significant development has been in the modelling of the performance of the adaptive optics systems as the diameter of the LGS asterism increases. As the asterism diameter increases, the tomographic error increases resulting a reduction in the theoretically achievable Strehl ratio. The Phase A ATLAS design selected a laser asterism diameter of 4.2arcmins. This small compromise in Strehl allowed for a simplified opto-mechanical design of non-overlapping laser spots (selectable by pick-off mirrors and obviating the need for a large dichroic) in which a 60 arcsec science beam could be delivered to the instrument with no additional optical surfaces between the instrument and the telescope. Modelling of the AO performance carried out since Phase A and reported in LeLouarn et al[17] showed that the impact of the tomographic error was more severe than previously thought, resulting in an unacceptable degredation in Strehl for the 4.2arcmin diameter asterism. The optimum asterism is now at approx. 2arcmin diameter. A new concept for the LTAO module was therefore required to reconsider the problem of separating the science and laser light and to resolve the volume conflict around the focal plane.

A possible layout for the instruments on the Roadmap is shown in Figure 6. The revised Nasmyth architecture is an evolution from the original design. The major changes are a reduction in the volume available for the PFS, to move the location of the focal plane on the Nasmyth platform by ~1m to free up space around the focal plane and also to lower the Nasmyth platform, increasing the height of the optical axis relative to the platform to 6m. This latter step allows the redesign of HARMONI into the orientation shown above (Figure 4). With HARMONI in this configuration, light from the laser guide stars is transmitted over the top of HARMONI to an LTAO module at the laser focus. A schematic of this module is shown in Figure 7 with a cartoon showing the approximate space envelopes required for the instruments and light paths. A large (~1.4m diameter) dichroic mounted above HARMONI allows the laser light to pass through and reflects the science beam from a central mirrored patch into the upward looking instrument. An outer annulus of the reflected field is used by the natural guide star wavefront sensors that provide low-order and tip-tilt correction for the LTAO mode. A similar configuration for METIS is shown in Figure 6, though the additional stringent requirements on emissivity for the mid-infrared instrument mean that we are also exploring the option for removing additional mirrors from the beam. The arrangement of the other instruments – MICADO, MAORY, ELT-MOS (represented by the EAGLE instrument volume), ELT-HIRES and ELT-PCS (represented by the EPICS[18] instrument volume) – are the same as at Phase A. Further design work is currently underway to develop this modified baseline and to consider procurement of the dichroic.

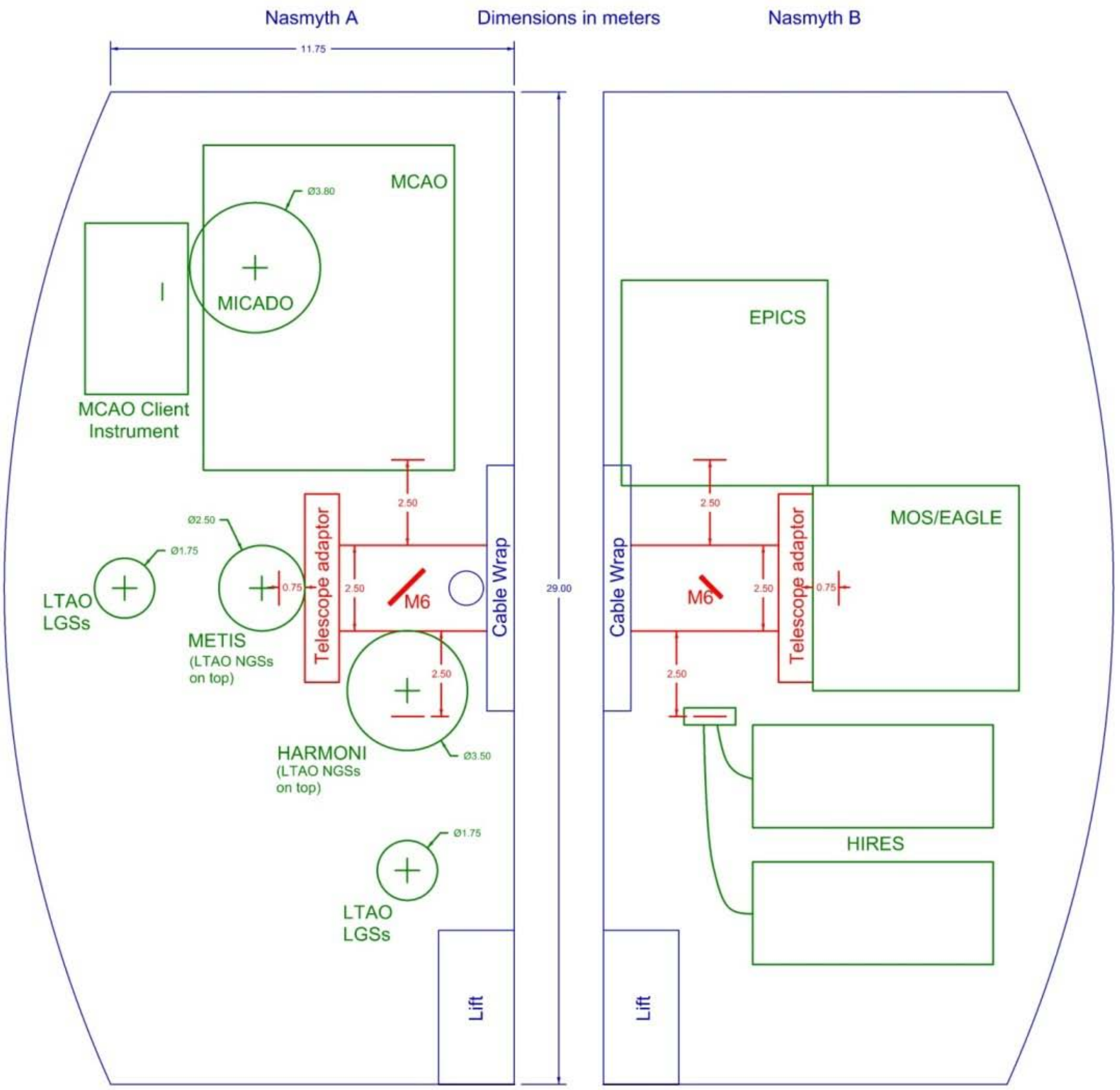

Figure 6 A possible layout of the instruments on the Nasmyth. In practice, the first light instruments would not all occupy a single platform.

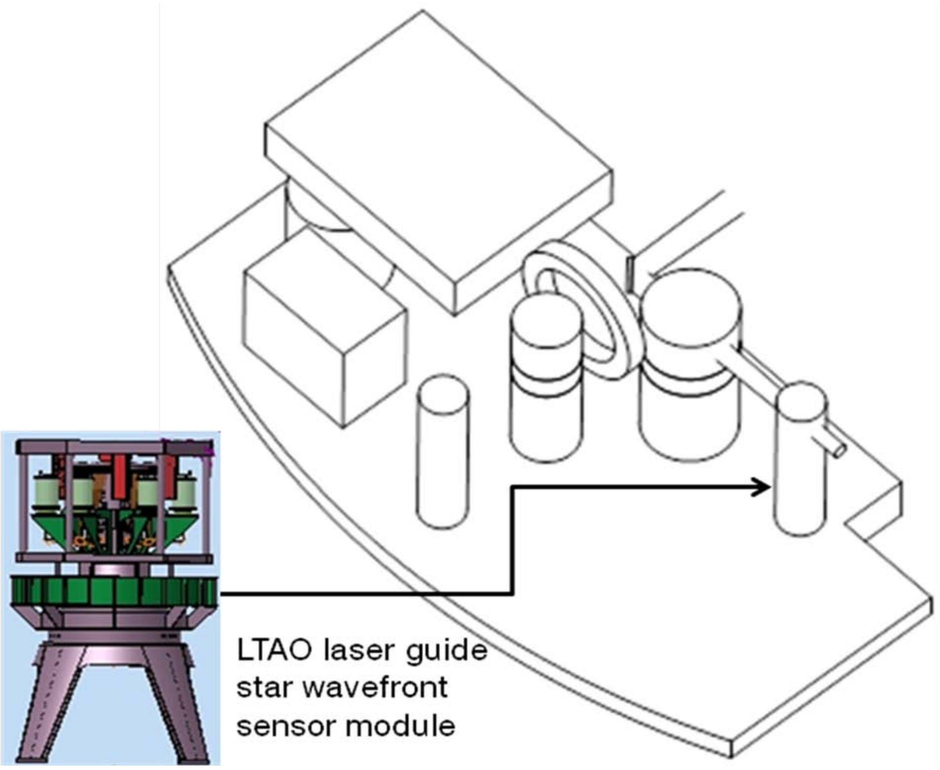

Figure 7: Concept of the upward looking LTAO module.

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