MOSAIC for ELT: development and evolution of the instrument architecture and capabilities

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ABSTRACT

MOSAIC is the multi-object spectrograph (MOS) for the 39-meter Extremely Large Telescope (ELT) of the European Southern Observatory (ESO). We present the evolution of the instrument concept from its initial conception through to the final design concept that will be presented at PDR. The evolution of the design by incorporation of per-target compensation for atmospheric dispersion has provided a route to conformance with tight restrictions on mass and volume, whilst at the same time expanding the overall efficiency of the instrument in terms of functionality and information gathering power.

Keywords: Multi-Object Spectroscopy ; Extremely Large Telescopes ; Fibre-Optics

1. INTRODUCTION

MOSAIC is the multi-object and multi-IFU spectrograph for the ELT covering 0.39–1.8 μm at mid (R~4,000) and high (R~18,000) spectral resolution, with Ground Layer Adaptive Optics (GLAO) correction across a 40 arcmin² field of view. The evolution of the MOSAIC concept from Phase A to the present design was driven by the possibility of applying a local correction for atmospheric dispersion without the need for a large optical reimaging system. This in turn has permitted an optimization of the instrument with reductions in cost, mass, and complexity with arguably better overall performance.

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2. DESIGN CHALLENGES OF A MOS ON THE ELT

The Phase A concept for MOSAIC[1,2] highlighted two key challenges arising from the ELT design that must be addressed by any wide-field instrument aiming to make use of the full science field: Firstly the local non-telecentricity of the telescope focal plane (Focal Surface ROC~9.9m, Telecentricity surface ROC ~97.2m)[1]. We explored (Fig. 1) a number of radically different positioner concepts to address this difference, starting from a motor stack unit built from COTS components (developed because the image scale implied a large pitch between individual positioners), through an extreme hexapod design that would be able to travel substantially outside the platform base (developed for substantially improved closest approach, and reduction to a single motor-type), and culminating in a two-axis SCARA robot with tilted axes to allow full compliance with the telecentricity of the telescope beam. In all designs the fibre pick-off was directly attached to the positioner and placed directly in the telescope focal plane.

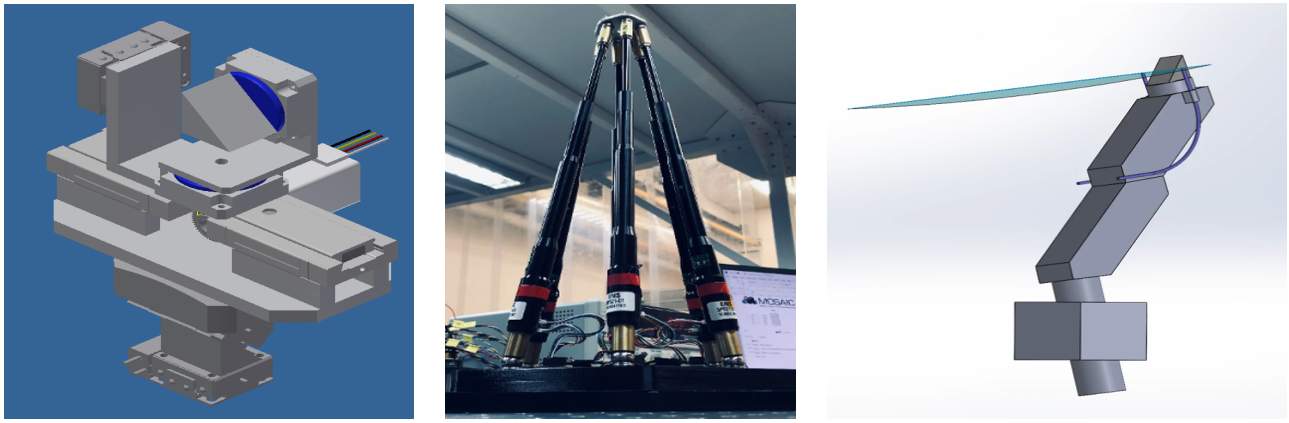

Figure 1. (left) Early design concept of a stack built from COTS components. (centre) Prototype hexapod system. (right) Initial version of the SCARA robot concept with fibre attachment at the end of the upper arm and mIFU pickoff mirror.

Secondly, there is no provision within the ELT itself for correction of atmospheric dispersion[3], and so the original MOSAIC concept was restricted to observations confined to a single waveband, requiring three separate settings in VIS/NIR to cover the full visible/NIR ranges of 390nm<λ<770nm and 770nm< λ<1800nm originally forseen. The project revisited this question after Phase A, considering both monolithic fore-optics and a novel approach to a local ADC (Fig. 2), originally rejected in Phase A due to insufficient scope for correction. The monolithic concept is easily rejected on grounds of cost, but would also provide further challenges for optical fibres due to telecentricity issues. The local concept[4] requires triplet prisms to achieve sufficient dispersion, but the optical components are small. This concept also provides the significant advantage that the fibres can be relocated from the moving part of the positioner and fixed at the base (the 'positioner' is now really a 'target selector').

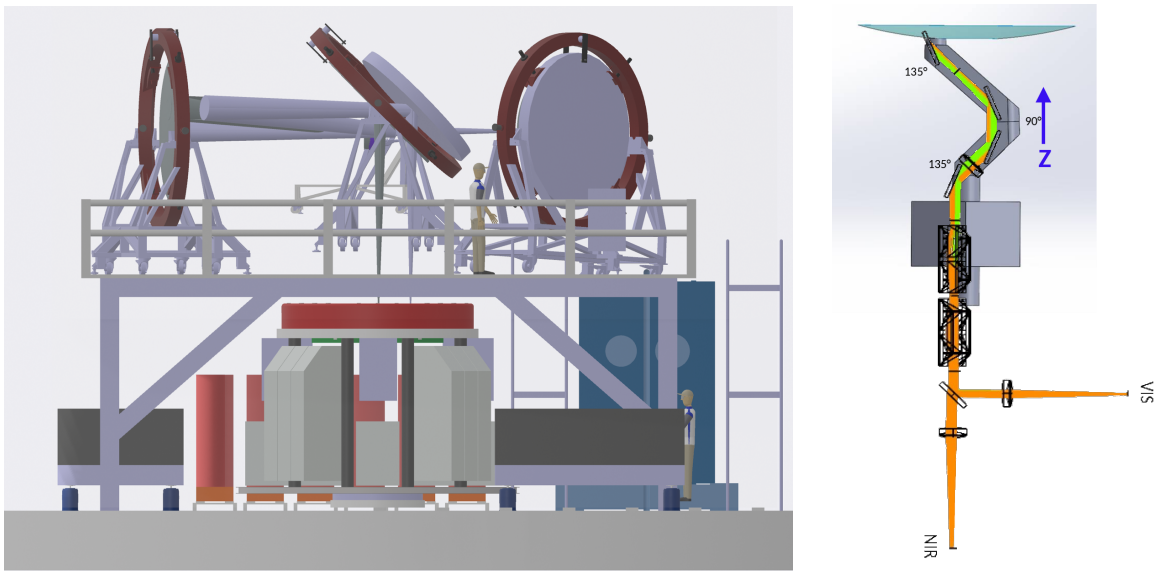

Figure 2. Options Considered for ADC correction: (left): Monolithic ADC optical relay system (for scale, the large mirrors are 3m diameter). (right): Early design of the optical relay within the structure of the SCARA positioner from Fig 1. (for scale the beam diameter is 25mm). In a later concept the beam splitter between VIS and NIR has been removed in favour of a side-by-side arrangement with a slightly larger field of view and the pick-offs separated by 3 arcseconds.

3. FIBRE PUPIL FILLING-FACTORS

To achieve stability of the LSFs, and to allow a single telescope PSF to be sampled by means of microlens arrays injecting a pupil image into each fibre core. Mis-alignment and movement between the image and the core implies that the LSF is only stable if the pupil either completely overfills the core, or is completely contained within the core (Fig. 3). The choice of core size directly impacts size and feasibility of the spectrographs.

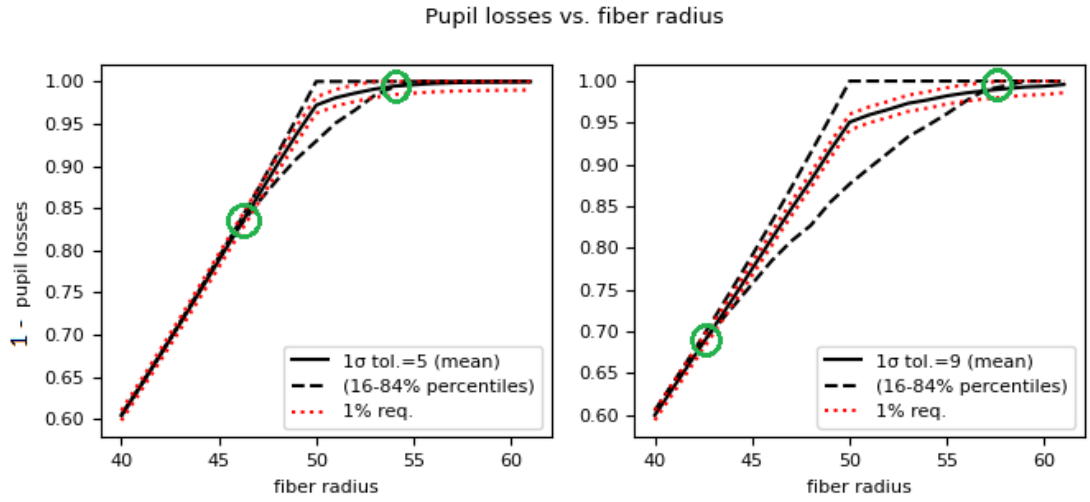

Figure 3. Illustration of the effect of 8% (left) and 15% (right) pupil wander at the fibre entrance on the effective light losses for fibre core radii shown as fractional pupil diameters (i.e. for radius < 50 the fibre is smaller than the input pupil. Between the green circles in each case, we have variable losses (and a consequent variation of the line spread functions within the spectrographs. When the pupil+wander is completely contained within the fibre core the loss is zero. If the fibre core is sufficiently undersized there is a light-loss penalty, but the effects are stable.

4. VISIBLE SPECTROGRAPH

The full evolution of the VIS spectrograph design is covered in more detail elsewhere in this conference[5], but summarized here. At the end of Phase A, the design (Fig. 4) assumed 5 VIS spectrographs, each with a single camera hosting a 6kx6k CCD231-C6 detector in an articulated camera and 6 gratings to provide 3 low-resolution and 3 high-resolution bands. A slit exchanger was included to account for separate low- and high-resolution fibre slits (The HR mode being realized by the utilization of separate, smaller fibre cores in a 19- rather than 7-fibre pick-off bundle).

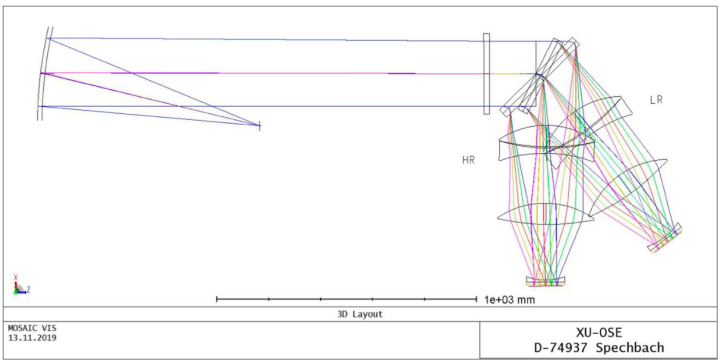

Figure 4. Optical layout of the visible channel spectrograph at Phase A with exchangeable gratings, a single articulated camera, and a slit-exchange mechanism to switch between HR and LR mode fibres. The detector is a single 6kx6k CCD and the optics are broad-band coated from 390–770nm.

A simplification of the design was proposed to incorporate a separate collimator for the high-resolution fibre slit, removing both the camera articulation and slit exchange mechanisms, but at the cost of a substantially increased space envelope. With the possibility of an ADC, we explored increasing the simultaneous wavelength coverage of the spectrograph by increasing the camera spectral FOV to reduce the number of gratings required from 6 to 5. This has a natural consequence of also increasing the spatial field, and hence the available slit length, allowing a single spectrograph to accommodate 140 VIS LR targets.

The next step was to consider the possibility of a WEAVE-like[6] dual beam spectrograph, allowing full wavelength coverage of the visible arm in a single exposure at low resolution. Building on the concept for a dual collimator, this approach also represents only a modest further increase in the spectrograph's physical footprint[5]. The final adjustment was to consider stretching the full wavelength coverage at the red end to ~950nm in order to achieve a rebalancing with the NIR channel in terms of the overall size and cost of the MOSAIC instrument.

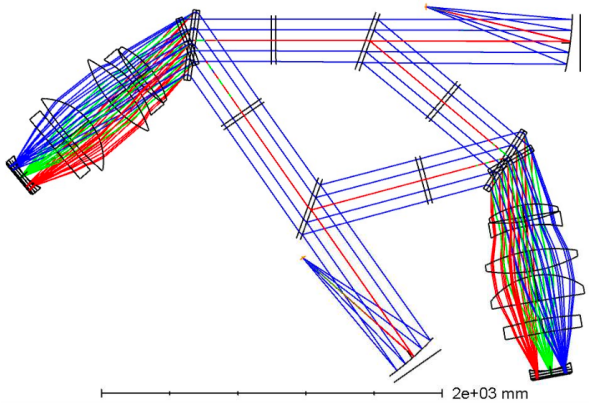

Figure 5. Optical layout of the visible channel spectrograph at the end of Phase B1: with exchangeable gratings, two fixed (red and blue) cameras, and a separate collimator path for the high-resolution fibre slit, avoiding the need for both a slit exchange mechanism and articulated cameras. The detectors are now mosaics of 4x9kx9k CCDs and the optical coatings are optimised for 390–625nm and 595–952nm, respectively[5].

5. NEAR-INFRARED SPECTROGRAPH

The impact of no ADC correction on the NIR spectrograph was quite marginal[7], and so an early stage of the NIR spectrograph evolution was to move from a single transmissive camera[2] (Fig. 6) to a 3-arm (YJH) design similar to MOONS[8] (although with higher resolution) with 4kx4k HgCdTe detectors and a fast catadioptric design that would accommodate 180 NIR MOSAIC targets with two spectrographs. A full description of the NIR spectrograph design is presented elsewhere in this conference[9].

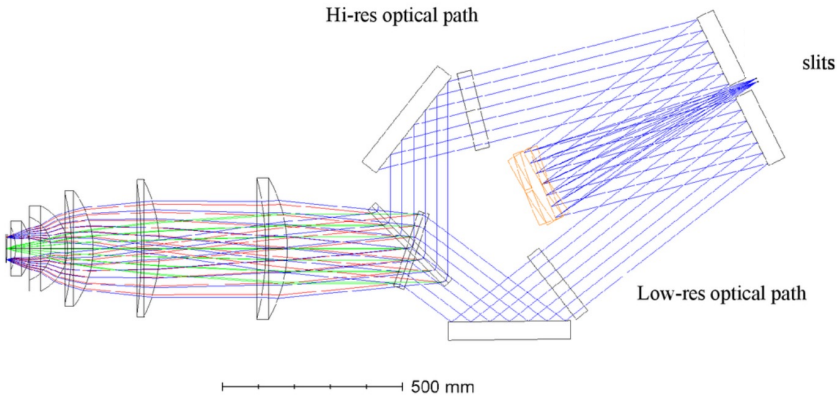

Figure 6. Optical layout of the near-infrared channel spectrograph at the end of Phase A:

The possibility of extending the VIS channel to 950nm described above allows for a simplification of the 3-arm design by removal of the bluest camera. An interim concept which retained a third camera solely for the high-resolution H-band mode was also considered, but rejected on grounds of cost and mass once a workable 2-arm design had been achieved. The current design (Fig. 7) maintains both J and H cameras fixed with the high-resolution H-band path corrected using a large pair of Silicon prisms[9].

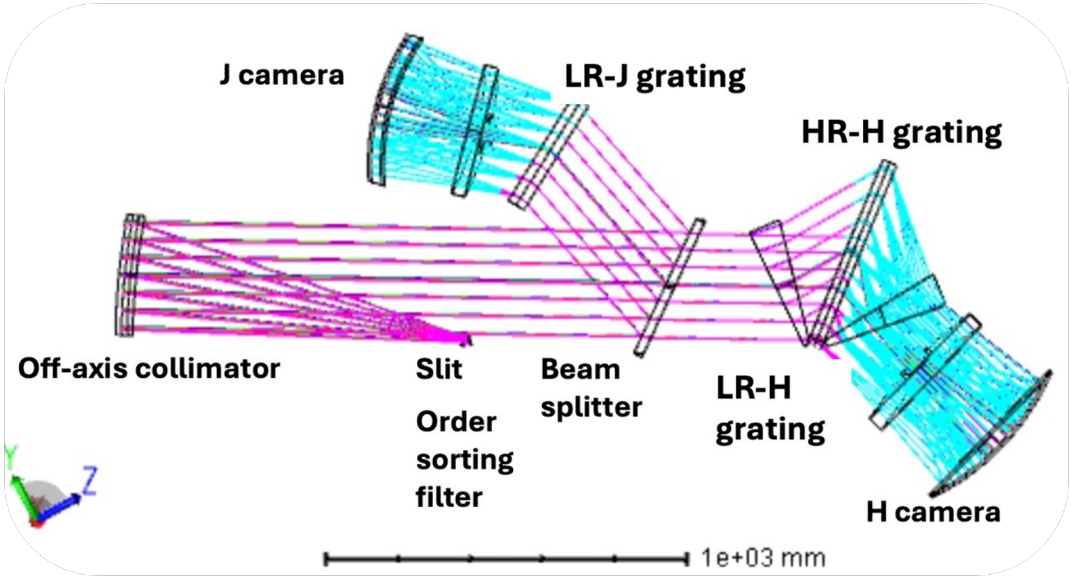

Figure 7. Optical layout of the near-infrared channel spectrograph at the end of Phase B1:

6. PARALLEL MODE CAPABILITIES

The ADC implementation provide a positive impact for the spectrograph design optimization, and allow a realization of MOSAIC that reduces the overall instrument costs, and can now fit within its allocated mass and space envelopes.

Parameter	Phase A	Phase B
N VIS spectrographs	5	1
VIS multiplex	200	140
Nexp (FullVIS coverage)	3	1
Parallel VIS/NIR	No	Yes
N NIR sprectrographs	5	2
NIR multiplex	200	180
Nexp (Full NIR coverage)	3	1
Nexp (Full VIS+NIR)	6	2

Table 1. Evolution of the basic parameters of MOSAIC from Phase A to PDR.

The ADC implementation provide a positive impact for the spectrograph design optimization, and allow a realization of MOSAIC that reduces the overall instrument costs, and can now fit within its allocated mass and space envelopes. However, these choices also allow modes of operation where both the NIR and VIS spectrographs can be utilized in a single observation block, allowing full use of the MOSAIC focal plane and spectrographs. We envisage the following maximal parallel modes are possible:

Case	VIS multiplex	NIR Mutiplex	NIR mIFUs
1	140 LR	100 LR/HR	0
2	140 LR	0	8
3	60 HR/LR	180 LR/HR	0
4	60 HR	0	8

Table 2. Outline of parallel mode capabilities for MOSAIC.

In these cases, we note that the local ADC settings will be different for VIS and NIR[4], but also that the NIR channel may implement beam-switching modes at the level of individual positioners, leaving the VIS integrations and the AO field stabilization unaffected.

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