MOMSI: science drivers and technical challenges

S Ramsay Howat[1]*, P.Hastings*[1]*, E.Prieto*[2]*, E.Atad*[1]*, R.Haynes*[3]*, C. Norrie*[1]*, C.Cunnigham*[1]*and P.-E.Blanc*[2]

[1]UK ATC, Blackford Hill, Edinburgh EH9 3HJ, UK. E-mail: skr@roe.ac.uk

[2] LAM, Traverse du Siphon, Les trois Lucs, BP8-13376 Marseille, Cedex 12, France.

[3] Anglo-Australian Observatory, PO Box 296, Epping, NSW 1710, Australia.

Abstract: We have developed science requirements for a future ELT instrument that will provide mult-integral field capability over an MCAO corrected field, exploiting the diffraction limit of telescopes of up to 100m diameter. From those requirements, a set of technical requirements for the instrument have been derived, with particular emphasis on the focal plane pick-offs and the integral field units. These requirements are used to drive technology developments in both these areas. In this paper, we outline the science case and requirements and describe the instrument concepts.

Keywords: spectroscopy: multi-object, spectroscopy: integral field, instrumentation: near-infrared, technology: pick-off, technology: deformable mirrors.

1. THE MULTI-OBJECT SPECTROMETER AND IMAGER, MOMSI

MOMSI, is one of five instruments selected for point design studies under the Extremely Large Telescopes (ELT) design study[1] part funded by the European Union under Framework 6. These point designs will explore the impact of the instrument requirements on the telescope design. In developing the framework for a technology development Joint Research Activity in Smart Focal Planes[2,‡], we adopted this instrument concept to explore the technical requirements in this area.

Table 1: Science cases requiring smart focal planes

Example science case	Specification
Assembly of galaxy haloes	FOV minimum 2’, combination of (100) small and (10) large field IFUS
Resolved stellar populations	spectroscopy over >2’ FOV, ~10s of sources per arcmin^2
Galaxies and AGN at the end of reionisation:	<5’x5’ FOV, tens of sources.
Star formation history of the Universe	10s-100 sources, 3’x3’ FOV for imaging

The most challenging case was adopted for the telescope interface[3], namely that of the OWL 100-m ELT. We assumed an f-6 beam and multi-conjugate adaptive optics providing a Strehl ratio >50% at K band over a 2.0’ x 2.0’ FOV (>50% at V band over a 0.5’ x 0.5’ FOV). One clear area for consideration was how to exploit the scientific potential of the near-diffraction limited field of view. To sample the diffraction limit at K-band, 1.8×10^9 pixels are required for imaging, and 2×10^{12} for moderate resolution spectroscopy. Such a detector focal plane presents significant engineering challenges, and so sparse sampling of the objects of scientific interest using a Smart Focal Plane[†] is the natural solution. The likely density of sources arises from the science case for an ELT[4]. Some examples of the science cases and resulting specifications are given in Table 1. From these, a set of science requirements for the MOMSI instrument was derived. These are given

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[†] *Smart Focal Planes are devices that enable the efficient sampling of a telescope’s focal plane to feed spectroscopic and imaging instruments.*

in Table 2. The diffraction limited image quality leads to extremely tight requirements on positioning the pick-offs in the telescope focal plane (repeatability of positioning of 3µm).

Table 2: MOMSI science requirements

Parameter	Requirement
Wavelength range	0.8-2.5µm (0.4-2.5µm goal)
Modes	imaging and IFU spectroscopy
Spatial sampling	2.5mas sampling on sky
Spectral resolution	R~4000
Number of pick-offs	100 (goal 1000) for spectroscopy
	36 (goal 250) for imaging
Pick-off field of view	100mas (goal 200mas)

2. THE MOMSI INSTRUMENT CONCEPT

In the baseline opto-mechanical layout for MOMSI, the telescope focal plane is populated with pick-offs that relay the selected field to beam steering mirrors located around the periphery of the patrol field. Thereafter, each field is reconfigured in an image-slicing integral field unit and the ouput from the IFU presented as the input slit of a unit spectrograph. The principal of the beam steering system is shown in Figure 1.

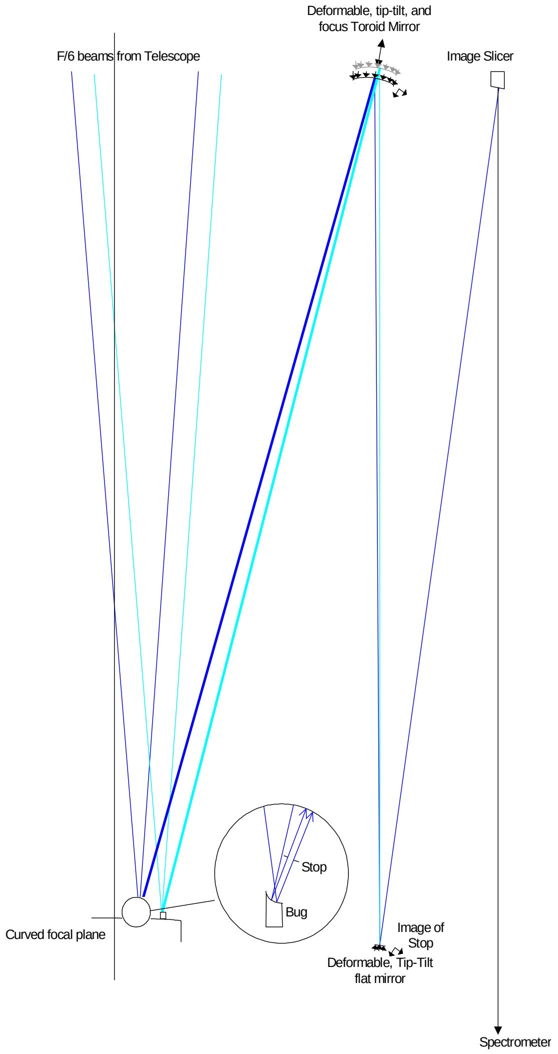

Figure 1: The relay optics in concept.

Four pick-off technologies were considered for the MOMSI concept:

- Pick-off arms as adopted for the VLT KMOS instrument[5]
- Pupil steering mirrors plus static focal plane pick-off mirrors
- Starbugs[6]
- A novel "pick and place" positioner - the planetary positioner.

Overcoming the curvature of the OWL focal plane is a prime requirement for any pick-off technology as the mechanical packaging of the instrument did not permit an optical field flattener to be located close to the focal plane, as required. Solutions were sought that are tolerant of the field curvature, resulting in the Starbugs and planetary positioner being selected for initial studies. Two opto-mechanical concepts are being pursued: one using active Starbugs that patrol the focal plane and the second using passive 'pucks' that are placed using the planetary positioner. The Starbugs are discussed in detail by Haynes et al.[6] and not discussed further here. In concept, either positioning mechanism can be used to place one of two types of optical pick-off considered for the focal plane (Figure 2). Either a single, tilted spherical mirror or a SiO_2/CaF_2 doublet combined with a flat, tilted mirror is used to collimate and relay the beam. to steering mirrors. The implications of pick-off choice for the steering mirrors are discussed below.

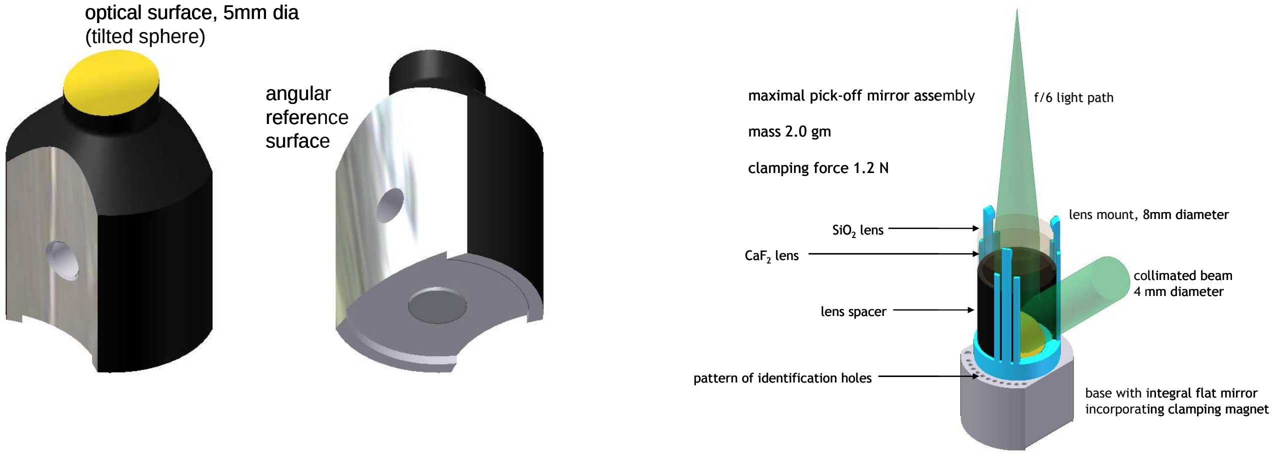

Figure 2: Options for the optics at the focal plane.

2.1. The planetary positioner system (PPS)

The PPS is illustrated in Figure 3. It places the pick-off mirrors in locations which match those of the astronomical target fields. Each mirror has a magnet in its base which holds it to the curved focal plate from which they are lifted by a gripper mechanism. This has two jaws which are actuated electro-magnetically through a parallel-action linkage. A second electro-magnet is used to lift the jaws and mirror away from the plate along the Z-axis.

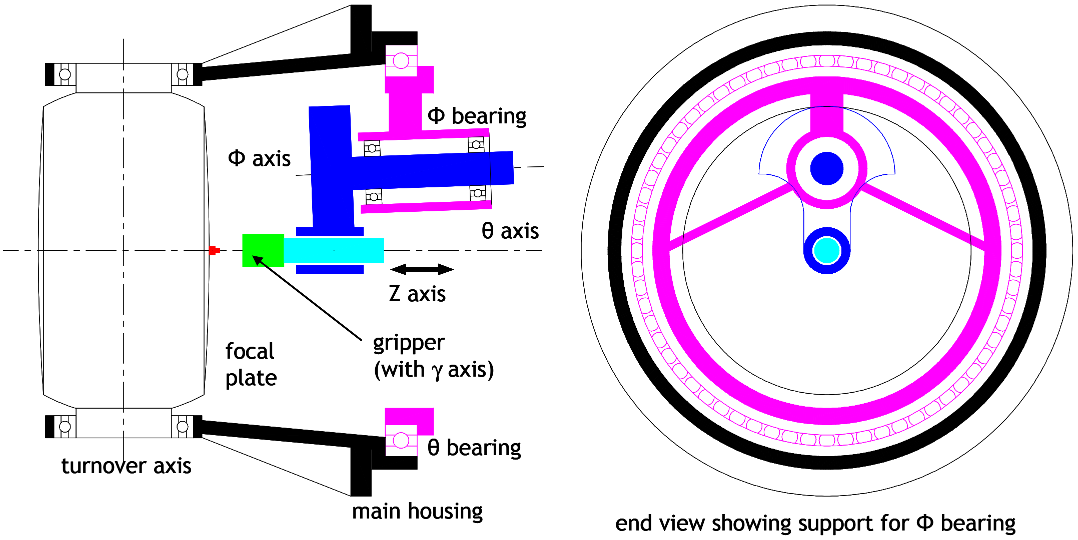

Figure 3: The planetary positioner.

The gripper can be rotated about the Z-axis to align the output beam from the mirror with its appropriate beam-steering mirror (see Section 2.2).The gripper can be positioned anywhere across the surface of the focal plate by a combination of two rotations. Rotation of the gripper about the phi-axis moves it in an arc from the centre of the plate to the edge. Rotation of the whole unit about the theta-axis sweeps the arc around the whole of the plate – giving complete coverage. The phi-axis is not parallel to the theta-axis but passes through the centre of curvature of the focal plate. This ensures that, irrespective of the location of the gripper, movements along the z-axis are normal to the plate's surface. Positioning a large number of mirrors will take some time and so two focal plates are provided and positioned back-to-back. As one is illuminated and taking an observation, the other is being re-configured for the next observation. At the end of an observation the gripper is swung completely clear of the focal plate and the plates are turned over, allowing a new observation and re-configuration sequence to start.

2.2. The beam steering mirrors

Using a tilted spherical mirror for the bug rather than the lenses has advantages in terms of simplicity of the bug (Figure 2). However, the aberrations introduced must be corrected and this correction is dependent on field position. This solution requires the introduction of active deformable mirrors at the pupil. For the refractive pick-off, non-deformable steering mirrors may be used. The active steering mirror corrects aberrations due to the beam angle on the beam steering mirror and reimages the pupil on the cold stop. The technology for the active mirrors (Figure 4) is being developed by LAM[7]. A metrology technique also under development at LAM allows the precise alignment of high quality images of the science target onto the image slicer.

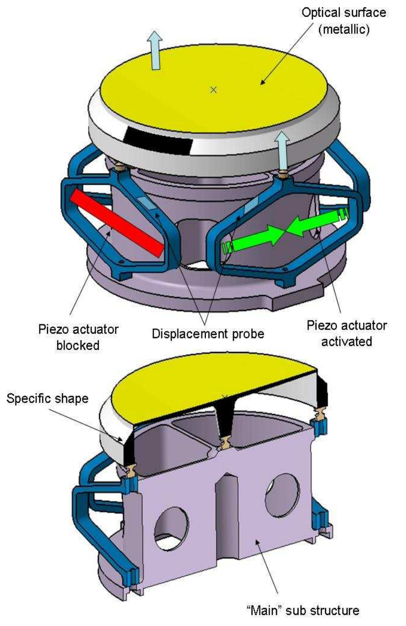

Figure 4: The deformable BSM.

2.3. The image slicers

The requirements for the MOMSI instrument were also used to drive the image slicer technology development programme. The science requirements do not constrain the slicer mirror in a direct way. Rather, a concept for the overall instrument was developed and the requirements for the integral field unit derived from these and, additionally, from understanding the current state-of-the-art and probably next steps. The opto-mechanical design for MOMSI was based around coupling a simple, modular, unit spectrometer to each pick-off. The spectrometer (shown in Figure 5) has a 1:1 magnification from the slit plane to the detector focal plane. The camera and collimator sections are identical (the same doublet lens is used for each) and are balanced around a grism and filter wheel. A 40mm pupil on the grism can meet the requirements for R~4000 using standard low refractive index materials such as fused silica.

Table 3: MOMSI image slicer requirements

Parameter	Requirement
Wavelength range	0.8µm to 2.5µm
No. of slicer elements	40
Slice width on the sky	2.5mas
Thickness of slicers (mm)	0.3
Surface roughness (nm rms)	5
Fill factor	>90%
Throughput of IFU	>80%

A single 2048x2048 detector provides the final focal plane for the spectrometer. The input slit is 41mm long (assuming 1:1 magnification of the detector's 2048 x 20µm pixels). For a 100mas field of view with 2.5mas sampling, the slicer must have 40slices of ~1mm length at the input to the spectrometer. This implies slices of width 25microns, which is ~20-40 times narrower than slices in existing spectrometers and not thought practicable to manufacture and align. With a moderate magnification in the IFU, the requirement of 300µm for the slicer width was selected. The complete set of image slicer requirements is given in Table 3. See Schmoll et al.[8] for a report on the slicer technology development.

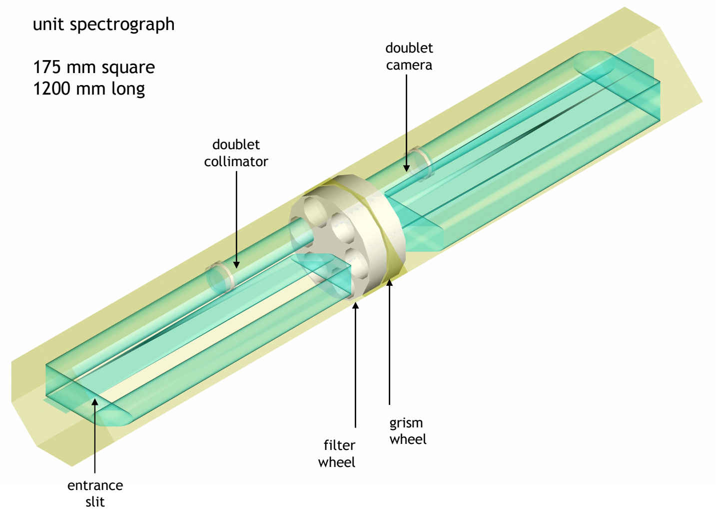

Figure 5: The unit spectrograph.

2.4. The opto-mechanical layout

A schematic of the opto-mechanical layout of the MOMSI instrument is shown in Figure 6. A total of 140 pick-offs are coupled to 140 integral-field spectrometers. The production of such an instrument is close to an industrial scale process and a new departure from the production methods current used in ground based astronomy. With a diameter of 2.7m and height of 3.1m the instrument is compliant with the space envelope and expected to fit within the maximum mass budget of 17tonnes defined in the OWL interface document. Whether the stringent flexure requirements implied by the desire to exploit the telescope diffraction limit can be met in the changing gravity vector that will be experienced by instruments mounted in the OWL instrument enclosure will be the subject of future study, but it is undoubtedly the case that a gravity stable platform would greatly simplify the MOMSI mechanical design.

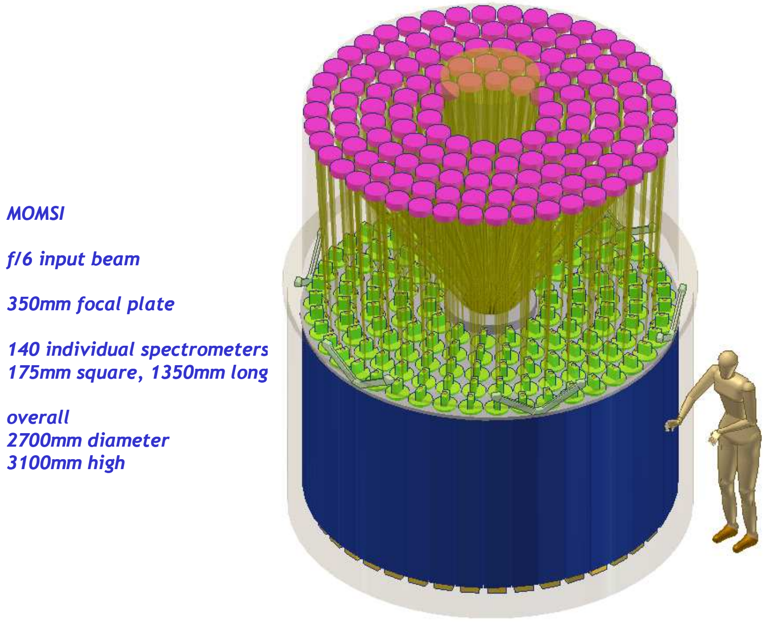

Figure 6: The schematic of MOMSI.

REFERENCES

1. Russell, A.P.G. et al. 2004, 'Instruments for a European Extremely Large Telescope: the challenges of designing instruments for 30- to 100-m telescopes' in Proc SPIE 5492, 1796, ed. Moorwood & Iye.
2. Cunnigham , C.R. et al. 2006, 'Smart Focal Plane Technology for ELT Instrument', *these proceedings.*
3. Monnet, G. 2004 'OWL Telescope-Instruments Interface Control Document', ESO-ICD-OWL-00000-0139.
4. 'The science case for the European Extremely Large Telescope', 2005, ed. I. Hook.
5. Sharples, R.M. et al. 2004, 'KMOS: an infrared multiple-object integral field spectrograph for the ESO VLT', in Proc. SPIE Vol. 5492, 1179, ed. Moorwood & Iye.
6. Haynes, R. et al. 2006, 'Smart Focal Plane and Photonics Technologies for ELTs', *these proceedings.*
7. Cuby, J.-G. et al. 2006 'MOMFIS : The multi-object IR spectrograph for OWL', *these proceedings.*
8. Schmoll, J et al. 2006, 'Optical Replication Techniques for Image Slicers' astroph/0509684.