KMOS: Design Overview and Calibration Requirements

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Summary. We present an overview of the KMOS instrument, currently under construction by a consortium of UK and German institutes, which will provide a unique multi-object near-infrared integral field spectroscopic capability on the VLT. We discuss the instrument architecture and the demanding requirements for calibration imposed by multi-object near-infrared integral field data. Details of the specific calibration procedures being developed for KMOS are presented in a companion paper.

1 Introduction

KMOS is a near-infrared multi-object integral-field spectrometer which has been selected by the European Southern Observatory (ESO) as one of a suite of second-generation instruments to be constructed for the Very Large Telescope (VLT) at the Paranal Observatory in Chile. The instrument will be built by a consortium of UK and German institutes working in partnership with ESO and is currently in the preliminary design phase. In this paper we describe the baseline instrument concept derived from the KMOS science case and the particular calibration requirements of this complex multiple-channel IFU instrument.

2 Science Case and Functional Specification

The focus of cosmological studies at the start of the 21^{st} century is rapidly shifting from accurate determinations of the parameters of the world model into investigations of the physical processes which drive galaxy formation and evolution. To achieve this goal requires a capability to map the variations in star formation histories, spatially resolved star-formation properties, merger rates and dynamical masses of well-defined samples of galaxies across a wide range of redshifts and environments. A few of the brightest examples e.g. [1] are now being observed using single integral field unit (IFU) spectrographs on 8-metre telescopes but statistical surveys of these galaxy properties will require a multi-object approach. This is the capability which will be delivered to the VLT with KMOS.

Table 1. Baseline capabilities for the KMOS instrument.

Requirement	Baseline Design
Instrument Throughput	J=20%, H=30%, K=30%
Sensitivity (5σ , 8hrs)	J=21.2, H=21.0, K=19.2
Wavelength coverage	1.0 to 2.5 μm
Spectral Resolution	R=3400,3800,3800 (J,H,K)
Number of IFUs	24
Extent of each IFU	2.8 x 2.8 arcseconds
Spatial Sampling	0.2 x 0.2 arcseconds
Patrol field	7.2 arcmin diameter circle
Close packing of IFUs	$>$ 3 within 1 sq. arcmin
Closest approach of IFUs	edge-to-edge separation of 6 arcsec

For any instrument to address these fundamental questions about how galaxies evolve it should: (1) have a substantial multiplex capability, commensurate with the surface density of accessible targets; (2) have the ability to obtain more than just integrated or one-dimensional information; (3) be able to resolve the relatively small velocity differences observed in rotation curves, velocity dispersions, and in merging galaxy pairs; (4) have the ability to observe several targets concentrated in a small area of sky; (5) have the capability to observe high-redshift galaxies using the well-studied rest-frame optical diagnostic features used at low redshift. These general characteristics imply a near-infrared multi-object spectrograph using deployable integral field units (dIFUs). The specific choices in delivering these capabilities involves a complex trade of cost and scope which is reflected in the baseline capabilities listed in Table 1.

3 Instrument Description

KMOS will mount on the VLT Nasmyth rotator (Fig. 1) and will use the Nasmyth A&G facilities. The top-level requirements are: (i) to support spatially-resolved (3-D) spectroscopy; (ii) to allow multiplexed spectroscopic observations; (iii) to allow observations across the J, H, and K infrared atmospheric windows (extension to shorter wavelengths down to 0.85 μm has been incorporated at lower priority). The baseline design employs 24 configurable arms that position fold mirrors at user-specified locations in the Nasmyth focal plane. The sub-fields thus selected are then anamorphically magnified onto 24 advanced image slicer IFUs that partition each sub-field into 14 identical slices, with 14 spatial pixels along each slice. The anamorphic magnification preserves a rectangular 0.2x0.2 arcsec spatial sampling, whilst having Nyquist sampling of a spectral resolution element. Light from the IFUs is dispersed by three identical cryogenic grating spectrometers which generate 14x14 spectra, each with 1000 spectral resolution elements, for all of the 24 independent sub-fields. The spectrometers each employ a single 2kx2k subsrate-removed HgCdTe detector. The goal is to employ careful design choices and advances in technology to ensure that KMOS achieves a comparable sensitivity to the current generation of single-IFU infrared spectrometers. Fig. 1 shows the overall assembly of the instrument which is partitioned into three layers (Pickoff module, IFU module and Spectrograph module). There is also a natural 3-fold symmetry to many of the opto-mechanical assemblies which has implications for the calibration requirements.

3.1 Pickoff Module

One of the key KMOS elements is the pickoff module which relays the light from 24 selected regions distributed within the patrol field to an intermediate focus position at the entrance to the integral field unit module(Fig. 2). The method adopted for selecting these subfields uses robotic pickoff arms whose pivot points are distributed in a circle around the periphery of the patrol field and which can be driven in radial and angular motions by two stepper motors which position the pickoff mirrors with a repeatable accuracy of < 0.2 arcsec. The arms patrol in one of two layers positioned either side of the Nasmyth focal plane. The changing path length within the arm is compensated via an optical trombone which uses the same lead screw, but with a different pitch, as for the main radial motion. The pickoff module also contains a central integrating sphere which relays the light from the external flatfield and wavelength calibration lamps into the pickoff arms, and a filter wheel which acts as a focus compensation device between the different bands. The cold stop for the instrument is at the base of the arm, after which the intermediate image is formed by a K-mirror assembly which also acts to orientate the pickoff fields so that their edges are parallel on the sky.

3.2 Integral Field Unit Module

The IFU subsystem contains optics that collect the output beams from each of the 24 pickoffs and reimages them with appropriate anamorphic magnification onto the image slicers. The slices from groups of 8 sub-fields are aligned and reformatted into a single slit for each of the three spectrographs.

The optical design of the IFU sub-systems is based on the Advanced Image Slicer concept [2] and draws heavily on experience developed in building the GNIRS integral-field unit for Gemini South [3]. Three off-axis aspheres are used in the fore-optics to facilitate a production method based on diamond-turning, rather than raster fly-cutting, in order to improve the surface roughness. Important considerations in developing the design for 24 optical trains,

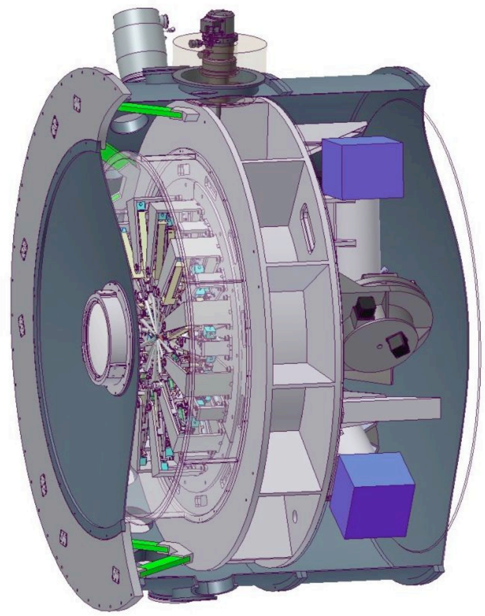

Fig. 1. Cutaway view of the main KMOS cryostat showing the entrance window and the pickoff arm module at the front, the IFU module in the middle and the spectrograph module at the rear. The cryostat will be an aluminium/stainless steel hybrid to reduce weight.

have been the need to incorporate manufacturability into the optimisation process, and a desire to use monolithic optical components wherever possible. In the current design the slicer mirrors are all spherical with the same radius of curvature, and so are the pupil mirrors. The slit mirrors are toroidal with the same radius of curvature in the spectral direction, but different radii of curvature in the spatial direction. This configuration was chosen because it is well adapted to the available methods of machining. Each IFU sub-module produces a 256mm long slit containing 112 separate slices from 8 subfields.

The mechanical design of the whole pickoff-IFU module is shown in Fig. 2 which emphasises the three-fold symmetry of the KMOS system and the advantages from a mechanical perspective of positioning common components in a single plane.

3.3 Spectrograph Module

The three identical spectrographs use a single off-axis toroidal mirror to collimate the incoming light, which is then dispersed via a reflection grating and refocussed using a 6-element transmissive achromatic camera. The grat-

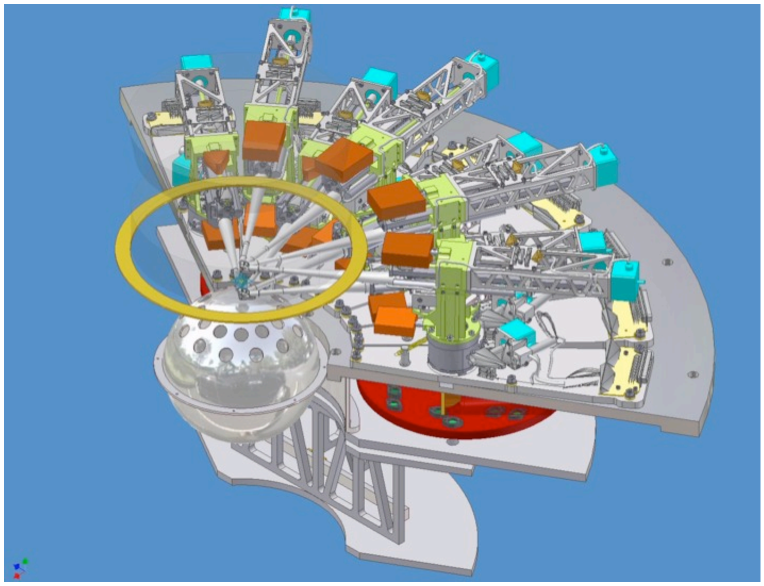

Fig. 2. One of the three integrated pickoff and IFU sub-modules showing the three mounting plates for the pickoff arms, the filter wheels and the IFU optics. Each sub-module is attached to the main cryogenic optical bench within the cryostat. At the centre of the unit is shown the integrating sphere of the calibration unit and the ring mirror which reflects light from the calibration sources in to the pickoff arms.

ings are mounted on a 5-position turret which allows optimized gratings to be used for the individual J,H,K bands together with two lower resolution gratings and the option of a z-band grating to enhance versatility [4]. Each spectrograph contains a 2048x2048 HgCdTe array which is mounted on a three-axis translation stage in order that focus can be adjusted and, if required, some components of flexure can be compensated. All three spectrographs are mounted in a plane perpendicular to the Nasmyth rotation axis for maximum stability.

4 Calibration Requirements

KMOS will require all of the standard calibration templates used by single integral field unit instruments such as SINFONI. These include bias frames, dark current/thermal background frames, bad pixel masks, wavelength calibration frames, flat-field frames, atmospheric telluric calibration and flux calibration. In addition there will be specialised engineering calibration routines needed to check the metrology of the positioning mechanisms and to

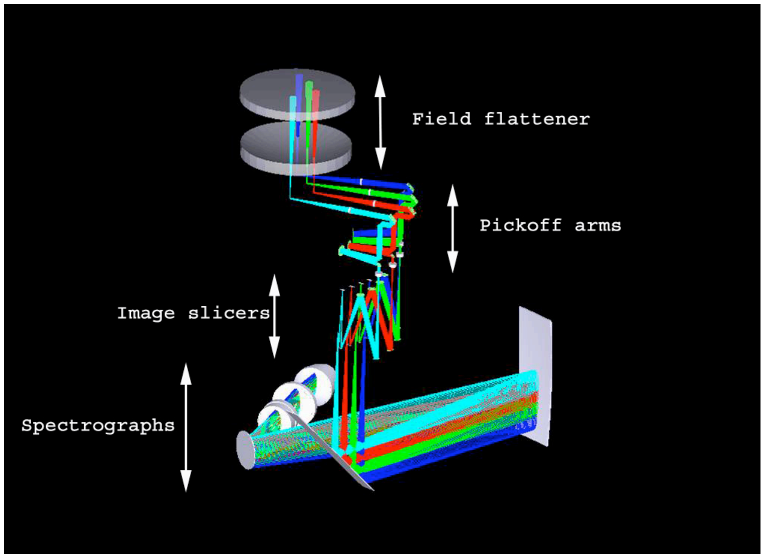

Fig. 3. Optical raytrace through four pickoff arms, their associated IFUs and one of the spectrometers. Light exiting the pickoff arms is brought to an intermediate focus using a 3-element K-mirror, which aligns the edges of all 24 IFU fields on the sky so that they can be put into a compact sparse array configuration for bllnd surveys of contiguous areas on the sky.

map out the geometrical distortions of the spatial/spectral dimensions of the data cubes. These are discussed in more detail in a companion paper [5]. Because of the complex optical layout (Fig. 3) each of the 24x14x14 spatial channels of KMOS will have subtly different response characteristics. Calibrating these differences using a combination of internal lamps and blank sky exposures will be crucial in removing systematic effects in the wavelength and flatfield response functions, which will be essential if KMOS is to achieve its full scientific potential.

References

1. R. Genzel, R. Hofmann, D. Tomono, N. Thatte, F. Eisenhauer, M. Lehnert, M., Tecza & R. Bender: In *Proceedings of ESO Workshop on Scientific Drivers for ESO Future VLT/VLTI Instrumentation (2002)* (astro-ph/0108318).
2. R. Content: Proc. SPIE **2871**, 1295 (1997).
3. M. Dubbeldam, R. Content, J.R. Allington-Smith, S. Pokrovsky & D.J. Robertson: Proc. SPIE **4008**, 1181 (2000).
4. I.J. Lewis, J. Lynn, W. Lau, S. Yang & M. Wells: Proc. SPIE **5492**, 1395 (2004).
5. S.K.Ramsay Howat, S. Rolt, R. Sharples & R. Davies: These proceedings.