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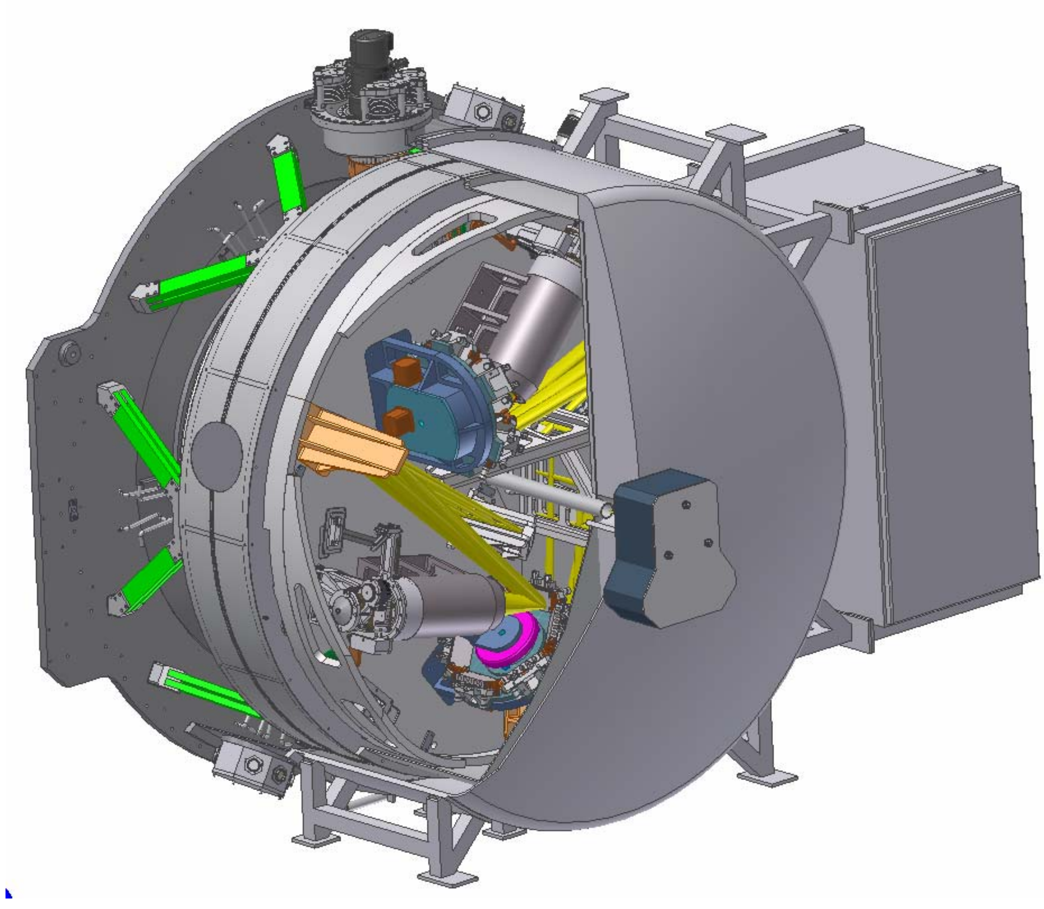
KMOS

A NEAR-INFRARED MULTIPLE-OBJECT INTEGRAL-FIELD SPECTROMETER FOR THE VLT



Change Record

Issue	Date	Section(s) Affected	Description of Change/Change Request Reference/Remarks
1.0	060405	All	First Issue
1.1	311005		Updates for PDR
1.2	241105	Front page and page headers	Updated to PDR template
2.0	200106		PDR internal review Issue
3.0	020406		PDR release
4.0	230807	Sections 1 and 5 altered for FDR	FDR release

APPLICABLE DOCUMENTS

Ref	Document Title	Document Number
AD1	KMOS Technical Specification	VLT-SPE-ESO-14660-3190
AD2	N/a	N/a
AD3	Pickoff Arms Design and Analysis	VLT-TRE-KMO-146607-001
AD4	Pickoff Module Design and Analysis	VLT-TRE-KMO-146607-002
AD5	IFU Design and Analysis	VLT-TRE-KMO-146608-001
AD6	Spectrograph Design and Analysis	VLT-TRE-KMO-146609-001
AD7	Detector Design and Analysis	VLT-TRE-KMO-146610-002
AD8	Infrastructure I Design and Analysis	VLT-TRE-KMO-146605-002
AD9	Infrastructure II Design and Analysis	VLT-TRE-KMO-146605-003
AD10	Infrastructure I MAIT Plan	VLT-PLA-KMO-146605-001
AD11	Infrastructure II MAIT Plan	VLT-PLA-KMO-146605-002
AD12	Pickoff Module & IFU MAIT Plan	VLT-PLA-KMO-146607-001
AD13	Spectrograph MAIT Plan	VLT-PLA-KMO-146609-001
AD14	Detector & Detector Mount MAIT Plan	VLT-PLA-KMO-146610-001
AD15	System Design & Analysis	VLT-TRE-KMO-146602-012
AD16	System MAIT Plan	VLT-PLA-KMO-146602-002
AD17	Configuration Item Data List	VLT-LIS-KMO-146604-001
AD18	KMOS Risk Register and Analysis	VLT-TRE-KMO-146601-003

REFERENCE DOCUMENTS

Reference	Document Title	Issue & Date
RD1	KMOS Phase A Science Case	1.0 29/08/2003

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1. Introduction

This Executive Summary forms part of the packages submitted for the Preliminary Design Review (PDR) and the Final Design Review (FDR) of the KMOS instrument. KMOS is a near-infrared multi-object integral-field spectrometer which has been selected by the European Southern Observatory 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 is being built by a consortium of UK and German institutes with the UK providing the Principal Investigator.

2. Science Objectives

Within the next few years it is likely that photometric redshifts, allied with deep wide-angle optical-IR surveys and the generation of wide-field instruments currently being built for large telescopes (e.g. FLAMINGOS-2, EMIR, FMOS), will provide distances to unprecedented numbers of young galaxies in the range $1<z<5$. These large redshift surveys will be capable of determining the global properties of the galaxy population such as its luminosity evolution and the three-dimensional clustering. The next logical steps will be to investigate the physical processes which drive galaxy formation and evolution over this redshift range and to differentiate between the intrinsic and environmental processes acting on galaxies.

To achieve these goals 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 environments - stretching from the cores of the richest, highest density clusters out to the low density field - at a series of progressively earlier epochs. A few of the brightest examples are now being observed using single IFUs on 8-metre telescopes but a statistical survey of these galaxy properties will require a multi-object approach. This is the unique capability which will be delivered to the VLT with KMOS.

The KMOS Science Case outlines a number of detailed observational programmes which exploit the unique capabilities of KMOS to study star and galaxy formation processes at both high and low redshift. A list of these science cases is given in Table 1 and outlined in more detail in RD1.

Science Case	Scientific Area
Cluster/group formation and the morphology-density relation	Extragalactic Astronomy
The masses and growth of galaxies	Extragalactic Astronomy
Extremely high-redshift galaxies and re-ionisation	Cosmology
The connection between galaxy formation and active galactic nuclei	Cosmology
Age-dating at z = 2 to 3	Cosmology
Stellar populations in nearby galaxies	Extragalactic Astronomy
High-mass star formation	Galactic Astronomy
A complete survey of star-forming molecular clouds	Galactic Astronomy

Table 1: List of detailed science cases that KMOS will address

3. Baseline Requirements

One of the most important instrumental characteristics which can be extracted from the detailed science cases is the need for a significant multiplex capability. It is this feature which makes KMOS unique amongst any currently proposed second-generation instrument on 8-metre class telescopes. KMOS is a multi-IFU spectrograph designed for operation on the VLT in the J, H and K near-infrared bands. The instrument will mount on the Nasmyth rotator. The top-level requirements are therefore: (i) to support spatially-resolved (3-D) spectroscopy; (ii) to allow multiplexed spectroscopic observations; (iii) to allow observations in any of the J, H and K infrared atmospheric windows. A more detailed set of design specifications derived from the science requirements are contained in the KMOS Technical Specification (AD1); these are summarized in the following table:

Requirement	Baseline Specification
Optical Throughput	J>20%, H>30%, K>30%
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 sq. arc seconds
Spatial Sampling	0.2 arc seconds
Patrol field	7.2 arcmin diameter circle
Close packing of IFUs	≥3 within 1 sq arcmin
Closest approach of IFUs	≥2 pairs of IFUs separated by 6 arcsec

Table 2: Summary of baseline technical requirements for the KMOS instrument

4. Instrument Design

The instrument design employs 24 configurable arms that position pickoff mirrors at user-specified locations in the Nasmyth focal plane. The arms are now based on a new R-θ design which gives improved opto-mechanical performance and better failsafe recovery than the design presented at Phase A. The sub-fields thus selected are then fed to 24 advanced image slicer integral-field units (IFUs) that partition each sub-field into 14 identical slices, with 14 spatial pixels along each slice. The IFUs will be manufactured using precision diamond-machining of monolithic metal optics to simplify optical alignment/test and minimize thermal effects. Light from the IFUs is dispersed by three cryogenic grating spectrometers which generate 14x14 spectra with ~1000 Nyquist-sampled spectral resolution elements for each of the 24 independent sub-fields. The spectrometers each utilize a single 2kx2k HgCdTe detector and use a reflective collimator with a 6-element achromatic camera. Our goal throughout has been to employ careful design choices and advances in technology to ensure that KMOS achieves at least as good a sensitivity as the current generation of single-IFU infrared spectrometers.

The patrol field of the pickoffs is 7.2 arcmin in diameter, which is the diameter of the unvignetted field at the VLT Nasmyth focus, thus minimising the thermal background in the K-band. Each IFU has a square field of view of 2.8x2.8 arcsec; anamorphic magnification in the IFU foreoptics ensures uniform spatial sampling of 0.2x0.2 arcsec whilst maintaining Nyquist sampling of the spectral resolution element at the detector. The field of view for each IFU is large enough to allow local sky-subtraction for compact high-redshift targets, doubling the effective multiplex gain over systems which require beam-switching. A crossed beam-switching mode is also possible for more extended sources or for critical applications which require minimal systematic effects.

The use of focal-plane pickoffs allows considerable flexibility in selecting targets and in particular the important capacity to deal with strongly clustered or close-paired sources. In addition to observing multiple individual sources, KMOS has the capability for integral field mapping of contiguous areas (~1.0 sq. arcmin) in a 24-point dither pattern. This mode would be useful for very extended sources or blank-field surveys for emission-line sources (e.g. Ly α at z>7). The spectral resolution of R~3500 provides velocity resolution for studies of low-mass objects and is optimal for OH-avoidance in the J & H bands. Lower resolution modes are also possible and would allow simultaneous coverage of two adjacent bands. Since we cannot predict all science applications in the future, our goal has been to make KMOS as versatile as possible without compromising reliability or significantly increasing complexity. Investigations have been made into the as-delivered throughput and image quality shortward of 1 μm and have demonstrated that KMOS can deliver scientifically useful performance down to 0.8 μm.

From a hardware perspective the instrument partitions into the following key subsystems which are covered in more detail in the associated design and analysis documents:

- Pickoff subsystem (see AD3 & AD4)
- IFU subsystem (see AD5)
- Spectrograph subsystem (see AD6)
- Detector subsystem (see AD7)
- Infrastructure subsystem (see AD8 & AD9)

5. KMOS Design Reviews

5.1 Preliminary Design Review Status

The design presented for PDR has been developed with the key success criteria of producing an instrument that (1) fulfils the science case, (2) that is viable technically and minimizes technical risk, (3) that can be constructed within the budgetary and schedule constraints of the project and (4) that can be maintained and operated on the VLT at Paranal under the existing operational paradigm. Due consideration has also been given to the safety considerations of those maintaining and using the instrument, and the quality procedures required to ensure a successful project.

The KMOS Technical Specification (AD1) contains the top level instrument requirements that have been agreed with ESO. These flow down into individual requirements documents for each subsystem. The subsystem design and analysis documents describe how these requirements are realized and the proposed implementation plan is detailed in the subsystem Manufacture, Assembly, Integration and Test (MAIT) documents (see AD10, AD11, AD12, AD13 & AD14). The system level design and analysis (AD15) and MAIT (AD16) documents draw all of the design considerations together and provide a convenient starting point for review of the instrument. The Configuration Item Data List (AD17) contains the full list of applicable documents that are submitted for this review.

5.2 Final Design Review Status

5.2.1 Science Case

The Science Case for KMOS (RD1) has been thoroughly reviewed by the Instrument Science Team since PDR as part of the work undertaken during the final selection of the 5th spectrograph grating. However, it is still focused on investigations of the physical processes which drive galaxy formation and evolution over the redshift range z=1 to z=5 and the search for first light objects which reionized the Universe at z>7. With a multi-object near-infrared integral field capability out to the end of the K-band at 2.5μm, KMOS will be a unique facility on any 8-10 metre class telescope. Although not designed to compete directly with multi-slit instruments, which have somewhat higher multiplex capability but cannot deal with objects having complex spatial morphology, it is worth noting that two of the main instruments under development with this capability have been the subject of long schedule delays. Commissioning of Flamingos-2 (6'x2' FoV) on Gemini-S is now planned for 2008A (from 2005B). Commissioning of EMIR 6'x4' FoV) on GTC is now planned for 2009A (from 2006A). Furthermore, the original (ambitious) KIRMOS instrument for Keck has been cancelled and has been replaced by a more modest capability (MOSFIRE) with 6'x3' FoV due in 2009A. In summary, the Science Case for KMOS at FDR remains as compelling as it was at PDR.

5.2.2 Design Status

The design of the instrument is as per PDR but with the following changes:-

- Introduction of a 5th grating with consequential changes to some of the instrument wavebands.
- Stiffening of the pick-off arm design and use of more powerful motors.
- Addition of a bespoke Cable Co-Rotator (CACOR) between KMOS and the Nasmyth Platform.
- Repositioning of the instrument electronic cabinets from the cryostat chassis to the CACOR.
- Detector design construction (from a 4-leg to 3-leg package with substrate removed).
- Introduction of a de-fogging system on the cryostat window.
- Adoption of a 2-compressor/ 3-cold head cooling system.

Furthermore, the following non-compliances against the KMOS Technical Specification (AD1) have been identified:

- Wavebands (as a consequence of 5th grating selection)
- Image Quality
- Spectral Stability
- Dismounting/Remounting of assemblies
- Ghosting
- SCP Interface
- Array Cosmetic Quality

All of these non-compliances are detailed within the submission documentation for FDR.

5.2.3 FDR Process

The FDR process adopted for KMOS is different to the standard ESO process and arose as a result of a recommendation made at PDR. It involves a series of sub-assembly design reviews which concentrate on specific parts of the overall instrument, with the normal design and analysis documentation/RIX response/review action and minutes/reports produced for each. The actual FDR meeting is then left to concentrate on system level issues, based on the associated new document submissions (see BSCW 'KMOS//FDR Meeting Documents' directory), and any outstanding actions arising from the previous sub-assembly meetings, without need to re-review any of the sub-assembly review material (see BSCW 'KMOS//Sub-System Reviews' directory) other than to verify that all the closed actions are indeed closed as indicated in the project master action register. The sub-assembly review status is as follows:

Review	Scope	Status
Cryostat	Design and analysis of the KMOS cryostat and all associated equipment.	Completed 13/12/2006
Optics	All optical systems aspects of the instrument. The long lead time optical components can be ordered following this review given ESO approval.	Completed 25/04/2007
Electronics, Detector and Software	All elements of the instrument control electronics, detector and software including the data reduction software.	Completed 14/06/2007
Pickoff and IFU	All parts of the three internal front segments of KMOS plus the Calibration Unit.	Completed 31/05/2007
Spectrograph	All parts of the three internal back segments of KMOS.	Completed 01/06/2007
Handling and CACOR	Instrument and sub-system handling and CACOR concept design.	13/09/2007
System FDR	Systems overview, instrument MAIT plan, OCMD, prototype test reports and action/issue review.	25/09/2007

Notes

- Following the optics review ESO agreed that the procurement process for the diffraction gratings could be started by Oxford in advance of the System FDR.

- At the Pick-off & IFU review ESO agreed that the procurement process for the two pre-production pickoff arms could be started in advance of the System FDR.

- The System FDR date was originally July 2007 but was changed to September 2007 due to delays in prototype testing. However, to negate any impact on the project delivery date ESO gave permission to initiate the cryostat manufacturing contract in advance of FDR given its critical path status with caveat that the money spent did not exceed what ESO had released up to PDR.

- The total number of actions raised at the sub-assembly review held to date plus all the actions from PDR etc is 348, with <100 open at the time of issue of this document.

5.2.4 Prototypes Test Status

At PDR it was agreed that certain high risk elements of the KMOS instrument design should be prototyped and tested as a de-risk activity, with test plans submitted to ESO for approval. The exact requirement related to the IFU and grating exchange mechanism of the Spectrograph but also included the testing of the pick-off arm with the design changes incorporated as actioned at PDR to improve its flexure performance. The test reports form part of the submission material for FDR with interim reports by the FDR document submission date and final reports by the FDR meeting.

5.2.5 Project Management Status

The current project schedule predicts the following major milestone dates:

Major Milestone	Baseline	Scheduled	Actual
Kick-Off	July 2004	July 2004	July 2004
Contract Signature	June 2005	July 2005	Oct 2005
PDR	Mar 2006	May 2006	May 2006
FDR	Mar 2007	Sep 2007	
PAE	Mar 2010	Aug 2010	
PAC	Sept 2010	Jan 2011	
Final Acceptance	Sept 2012	Jan 2013	

Notes

- FDR has slipped due to delays associated with the prototype testing caused by the necessary prioritization of work towards the sub-assembly reviews which required much more effort than anticipated. However the effect of a later than planned FDR on all subsequent milestones has been minimized by ESO allowing the early procurement of optics, pre-production pick-off arms and the instrument cryostat prior to FDR which has kept the FDR date off the Critical Path.

- The Critical Path of the project is defined by the Cryostat Manufacturing time as only limited AIV/T testing is possible without an operational cryostat due to the size and volume requirements of the instrument sub-assemblies.

- The FDR date is off the Critical Path by only 6 weeks albeit the actual impact of any delay beyond 6 weeks could be minimized through the use of some of the prototype hardware developed pre-FDR.

- Analysis of the project risk register (AD18) shows that there is a 10 month uncertainty (was 16 months at PDR) on the delivery date as currently predicted against a worst case risk scenario.

6. Consortium Partners

The following consortium partners will be responsible for the stated work packages:-

University of Durham: Project Science (PI), Pick-off module, Integral Field Units.

University of Oxford: Spectrographs.

UK Astronomy Technology Centre (UK ATC): Project Management, Systems Engineering, AIT/V, Instrument Scientist, Quality Assurance, Cryostat, Pick-off Arm design, Active Detector Mount.

Universitats-Sternwarte Muenchen (USM): Project Science (CoPI), instrument electronics & software.

Max-Planck-Institut fuer Extraterrestrische Physik (MPE): Project Scientist, Data Analysis software.

European Southern Observatory (ESO): Detectors.

7. Project Development

The project phases will follow the definitions as set out in the ESO Statement of Work, with the aim of meeting a delivery date to the VLT in the second quarter of 2010.

The project phases can be summarised as follows:-

Phase 1: Preliminary Design Phase: The purpose of this phase is to consolidate the design of the instrument and sub-systems as presented in the Phase A study. Appropriate technical solutions are to be identified and explored with the aim of meeting the specified requirements. A prototype Pick-off Arm will be produced and the manufacturing capability for the IFU optics confirmed.

Phase 2: Development and Final Design Phase: During this period KMOS shall be designed down to component level.

Phase 3: Manufacture, Assembly, Integration and Test Phase: Materials and commercial components will be procured; the parts for KMOS will be manufactured, and integrated in the laboratory. All required sub-system tests shall be performed. Full instrument testing will be conducted. Based on the results of these tests, *Preliminary Acceptance in Europe* will be granted by ESO.

Phase 4: Transport to the VLT-Observatory: The instrument will be packed and transported to Paranal Observatory Chile. On arrival at Paranal, a survival of transport inspection will be carried out.

Phase 5: Installation on the Telescope & Commissioning: KMOS will be assembled in the Paranal Observatory. After successful completion of the tests, which do not require light from the telescope, commissioning will start. Based on the results of all test ESO will declare *Provisional Acceptance in Chile.*

Phase 6: Guarantee Period: The guarantee period starts with the declaration of *Provisional Acceptance in Chile*. The responsibilities of the KMOS consortium during this period are set out in the ESO / Consortium Agreement.

End of Document