Calibration of the KMOS multi-field imaging spectrometer

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1 An introduction to KMOS

The K-band multi-field spectrograph (KMOS[4]) is a near-infrared (0.8–2.5μm) spectrometer for 3D observations of 24 fields of 2.8" x 2.8" distributed over a 7' patrol field. The instrument will be located on the Nasmyth platform of the VLT and is due for delivery to the telescope in 2010. Details of the instrument are presented by Sharples (*these proceedings*,[1]). Objects are selected using pick-off mirrors mounted on arms that patrol the field. The arms are located on two planes, one above and one below the focal plane of the telescope and are positioned using two stepper motors. Each arm relays one pick-off field into an integral field unit (IFU). The output of eight IFUs is formed into a long slit that is the input to a grating spectrometer. There are three identical spectrometer modules.A single channel of KMOS (pick-off+IFU+spectrometer) is a very similar system to the single IFU spectrographs already used in the near-infrared (e.g. SINFONI, UIST, GNIRS). The calibration issues are the same to first order and are increasingly well understood as use of these instruments is becoming standard on large telescopes ([2],[3]). In this paper, we discuss the unique calibration issues encountered in observing with KMOS, the first facility class multi-field NIR spectrometer. We present this in the context of the users experience of KMOS, showing how the principal KMOS observing modes set the calibration requirements and define the pipeline reduction requirements. Finally, we present the unique design of the KMOS calibration system and it's expected performance.

2 Planning KMOS observations

KMOS observers will employ a custom-built add on to the ESO Phase 2 Proposal Preparation Tool (called KARMA) to allocate arms to objects in a given

[4]The KMOS consortium members are Max Planck Institut für Extraterrestriche Physik, Universitäts-Sternwarte München, ESO, Oxford University, Durham University and UKATC

field (Figure 1). Users provide an input catalogue of coordinates for their science target and reference stars which must all be on the same astrometric reference frame. The arms are then allocated to those positionsusing an automatic alogorithm which handles target priorities. The automatic allocation may be overidden by the user. The translation of input target coordinates (RA, dec on the sky) to arm motor steps for two motors per arm for 24 arms requires a number of calibration stages, the last of which is to be carried out during the on-sky commissioning of the instrument. These are described in the sections that follow.

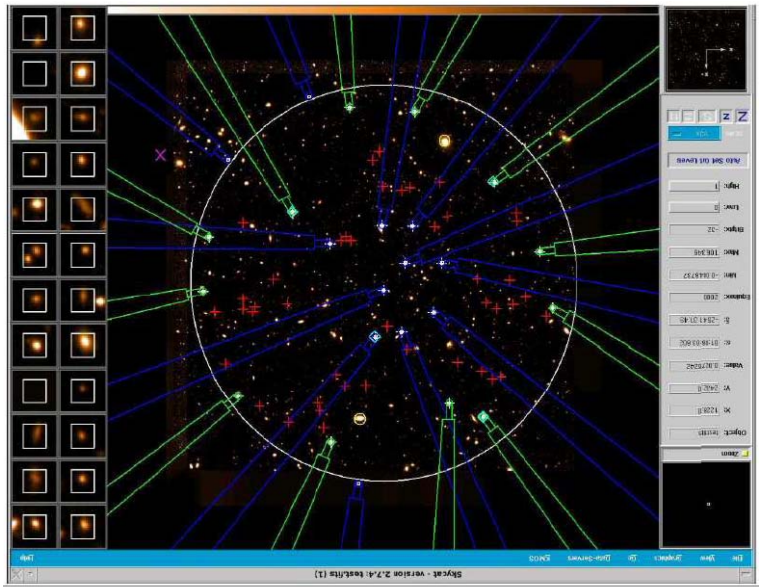

Fig. 1. The KARMA tool for allocation of arms to targets under development at the Universitäts-Sternwarte München.

2.1 Calibration of motor steps to arm positions

Individual arms move in radius (R) and angle (θ) driven by one stepper motor for each axis. Once the range of travel and initial calibration of steps to (R, θ) is obtained for each arm, the arms are assembled into the cryostat. The laboratory calibration of the arm position is then carried out using a reference source that projects an f-15 beam to the position of the focal plane, forming a point source. The arm is driven to acquire the source the offset from the optical axis at the output of the arm is determined. The f-15 source is then translated on an accurate (x,y) stage and the arm steps to (x,y) on the focal plane is mapped out for the entire patrol field of each arm. The VLT focal plane is curved and therefore the KMOS foreoptics (a powered window and field lens) flatten the field and render the input beam telecentric. Rather than attempt to simulate the telescope field curvature, these calibrations will be carried out using a flat window and the correction for the residual field distortion calibrated at a later stage. This procedure calibrates any repeatable non-linearities of the arm motion, such as would be introduced by e.g. eccentricity of the motor shaft.

2.2 Transformation of (RA, Dec) to focal plane (x,y) position

Once the procedure above is complete, the arms can address any (x,y) on the focal plane accurately and repeatably. A transformation from sky coordinates to focal plane (x,y) is required to link this to the user's input catalogue. This transformation may be estimated for the perfect telescope+KMOS system, as follows.

- Mean (RA, dec) for the observations transformed to apparent (RA, dec) using an atmospheric model of the differential refraction.
- Using the field centre, apparent (RA, dec) are transformed to positions on the tangent plane (ξ, η)
- The coordinates in the tangent plane are corrected to perfect (x,y,) in the telescope focal plane using the plate scale and the rotation of the field relative to the instrument focal plane.
- The perfect (x,y) position above must be corrected to the real (x,y) by correcting for predictable residuals in the field distortion from the telescope after correction by the field corrector. These values are obtained from Zemax and are less than 3 pixels at the detector focal plane (0.3").

These steps are calculated in the instrument control software and may be estimated before use of KMOS at the telescope. During the on-sky commissioning, a final confirmation that these calibrations are correct will be made using observations of globular clusters. Stars with H magnitudes between 13 and 11 are ideal for obtaining good centroids in a reasonable time. Globular clusters containing source densities of stars meeting this criterion and that are visible from Paranal throughout the year have been identified and include 47Tuc, M22 and M5. On the telescopes, stars are acquired on to pick-offs using the nominal calibration and The arms will be allocated to stars and the offset of the star relative to the centre of the IFU field calculated and used to correct a look-up table of arm positions. This final calibration step confirms that the optical model of the KMOS field corrector does indeed provide the small residual field distortions predicted by the Zemax model. The procedure will be carried out whenever KMOS is remounted on the telescope.

3 Calibration of spatial and spectral distortions

To reconstruct a datacube of an astronomical target, every detector pixel must be mapped onto the correct spatial and wavelength position. The spatial and spectral distortions introduced in the instrument must therefore be calibrated.

These distortions arise in the IFU (the build up of manufacturing tolerances in the optics of the integral field unit introducing small offsets of the field) and in the spectrometer offsets (which introduce slit curvature and curvature of the spectrum). For KMOS, these offsets are tightly controlled, particularly within the IFU as the optics (slicing mirror, pupil mirror and slit mirror) are all manufactured as monolithic pieces ([4]). To measure this mapping, the f-15 source used for arm calibration will also project an image of three slits that run parallel to the dispersion direction. These slits will be sliced by the IFU and dispersed by the spectrograph. The offsets required to reconstruct the slitmask image will be determined and applied in a single transformation in the data pipeline, maximising the data quality from KMOS by minimising the number of times the data are resampled.

4 KMOS sky subtraction modes

The KMOS operational concept includes two sky distinct sky subtraction methods. In the first, the telescope is offset and the sky frame measured in through the same optical path as the source frame. For the second, a sky measurement is obtained from an arm which is not deployed on an object, from an area on the field of the IFU that does not have sky signal or from a combination of both. The first of these methods does not place strong requirements on flatfielding, as the sky signal is measured along the same optical path and with the same pixels as the source+sky. The flatfield should be accurate to 1%. However, this method is inefficient in observing time. The second method requires the measure sky signal to be corrected for any changes in vignetting or pixel gain between the pixels on which the sky is measured and that on which the source+sky is measured. Thus the calibration and reduction requirements depend on the mode chosen. In this case, the sky subtraction accuracy must be 0.1%. This will be achieved through a combination of flat-fielding accuracy and application of data reduction techniques developed for SINFONI ([3]). This second mode is expected to be the standard mode of observing for KMOS.

5 Calibration unit design and performance

To measure accurate flatfields and arc spectra efficiently, KMOS has a built-in calibration system. Figure 2 shows a top view of the internal modules of the instrument with calibration unit running up the centre of the structure. At the top of the calunit, an integrating sphere with 24 ports provides the illumination from either a flat field source (Halogen lamp) or from one of two arc lamps (argon or krypton). Light emitted from the ports is reflected from small mirrors mounted around the field lens. To obtain calibration frames, the arms are moved to a calibration position outside the field where they intercept the reflected beam. A schematic of this is shown in Figure 3. The

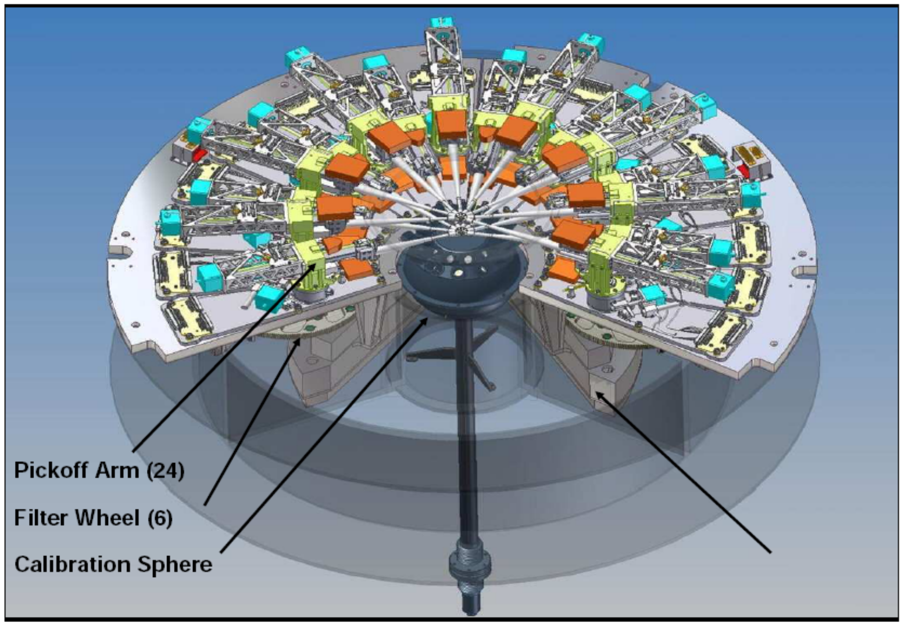

Fig. 2. An internal view of the KMOS cryostat showing the pickoff arms and the calibration unit fed through from the rear of the cryostat.

uniformity of illumination from this system has been calculated for an integrating sphere of this geometry and using the characteristics of the Spectralon diffuse relfectance coating for the NIR. We find better than 0.01% variability across the individual ports and better than 0.1% from port to port. A high throughput for the system is also a key requirement. As for other ESO instruments, the KMOS calibration plan is to take calibration frames during daylight hours. Nevertheless, maintaining the option for efficient nighttime calibrations is desirable. The light pipes running the length of the KMOS cryostat are gold coated light pipes from Epner. A flux concentrator at the input to the cryostat also boosts the throughput. The predicted throughput of this system is better than 12% for IJH and 12% reducing to 6% over the K band (1.9–2.5μm). The photon flux from the flatfield lamp in this case is

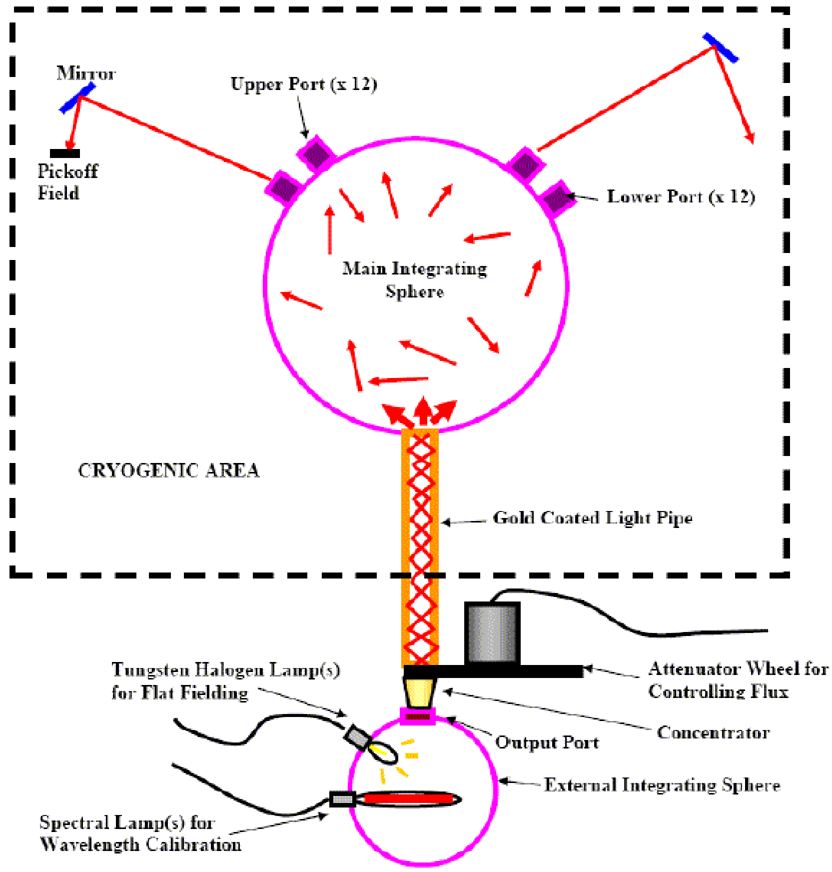

Fig. 3. This schematic of the calibration unit shows key features of the operation and design. Lamps are fed into the cryostat from an external integrating sphere. The light is reflected from mirrors mounted around the field lens into arms located at the calibration position.

ample. For the pencil beam arc lamps (Ar,Kr), exposure times of 150s will provide e.g. 15 lines with more than 500photons in the K band.

References

1. Sharples, R., et al., 2006, SPIE, Vol.6269, p44.
2. Davies, R.I., 2007, MNRAS, 375, p1099.
3. Ramsay Howat, S.K., et al., 2004, SPIE, Vol. 5492, p1160.
4. Dubbeldam, C.M., et al., 2006, SPIE, Vol.6273, p105.