First Light for the KMOS Multi-Object Integral-Field Spectrometer

Ray Sharples[1]
Ralf Bender[2, 5]
Alex Agudo Berbel[2]
Naidu Bezawada[3]
Roberto Castillo[4]
Michele Cirasuolo[3]
George Davidson[3]
Richard Davies[2]
Marc Dubbeldam[1]
Alasdair Fairley[3]
Gert Finger[4]
Natascha Förster Schreiber[2]
Frederic Gonte[4]
Achim Hess[5]
Ives Jung[4]
Ian Lewis[6]
Jean-Louis Lizon[4]
Bernard Muschielok[5]
Luca Pasquini[4]
Jeff Pirard[4]
Dan Popovic[4]
Suzanne Ramsay[4]
Phil Rees[3]
Josef Richter[5]
Miguel Riquelme[4]
Myriam Rodrigues[4]
Ivo Saviane[4]
Joerg Schlichter[5]
Linda Schmidtobreick[4]
Alex Segovia[4]
Alain Smette[4]
Thomas Szeifert[4]
Arno van Kesteren[4]
Michael Wegner[5]
Erich Wiezorrek[2]

[1] Department of Physics, University of Durham, United Kingdom
[2] Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
[3] UK Astronomy Technology Centre, Royal Observatory, Edinburgh, United Kingdom
[4] ESO
[5] Universitätssternwarte München, Germany
[6] Sub-Department of Astrophysics, University of Oxford, United Kingdom

The KMOS near-infrared multi-object integral-field spectrometer was transported to Chile in the middle of 2012 and achieved its first views of the Paranal skies in November 2012. We describe the delivery and re-integration of KMOS and present the first results from the two on-sky commissioning runs.

Figure 1. The KMOS CACOR leaving the UK Astronomy Technology Centre (left), and installed in its open-top container ready for the sea journey to Paranal (right).

KMOS is one of a suite of second generation VLT instruments which, along with MUSE (Bacon et al., 2012) and SPHERE (Kasper et al., 2012), will bring exciting new capabilities to the Paranal Observatory in next few years. KMOS is a unique design of near-infrared multi-object spectrograph that uses deployable integral field units to obtain spatially resolved spectra for up to 24 target objects selected from within an extended 7.2-arcminute diameter field of view (Sharples et al., 2010).

In mid-2012, KMOS reached its Provisional Acceptance Europe milestone (Ramsay, 2012) and then began its long journey to the summit of Cerro Paranal via a combination of road, sea and air transport. Whilst the main cryostat could be shipped in a Boeing 747 cargo hold, the auxiliary CACOR unit, which carries the KMOS electronics cabinets in a large co-rotating structure, was too large to fit into any available air-freight carrier. This large item was therefore securely packed and made the slightly more perilous, but more leisurely, journey on the open deck of a container ship (Figure 1). Fortunately both cargoes arrived without damage, more or less at the same time, at the port in Antofagasta. KMOS then made the final leg of the journey by road to the new integration hall at the Paranal Observatory.

KMOS was fully re-assembled and recalibrated in the integration hall over an eight-week period in September–November 2012 by a dedicated team of technical experts from the UK and German consortium partners, working closely with ESO personnel. After an extensive set of verification tests, the instrument was then taken up the final stretch of the mountain road at walking pace (Figure 2, left), before being installed on the Nasmyth platform of VLT Unit Telescope 1 (Antu). Because of the size of the CACOR (about four metres high), this item had to be lifted directly

Figure 2. KMOS cryostat on the road from the integration hall to the summit (left); the CACOR being hoisted into the dome of UT1 (right).

Figure 3. Some of the commissioning team in the VLTI control room during the first night of observations with KMOS.

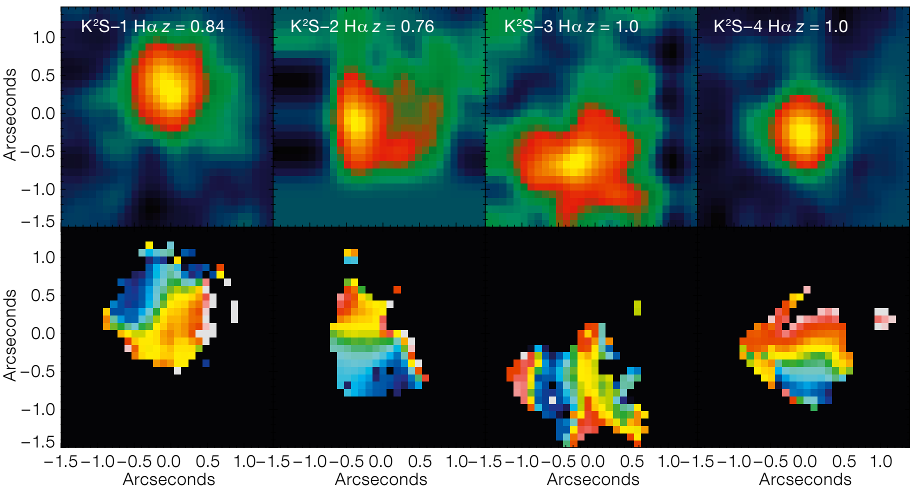

Figure 4. (Top) Hα emission line maps (top) and derived velocity fields (bottom) for a sample of faint $z \sim 1$ emission-line galaxies in the GOOD-South field. The brightest targets have an observed integrated Hα flux of 1.0×10^{-16} ergs cm^{-2} s^{-1}. These data were obtained with only 30 minutes of on-source exposure using KMOS and demonstrate the power of this facility instrument for such surveys. Reductions courtesy of Mark Swinbank.

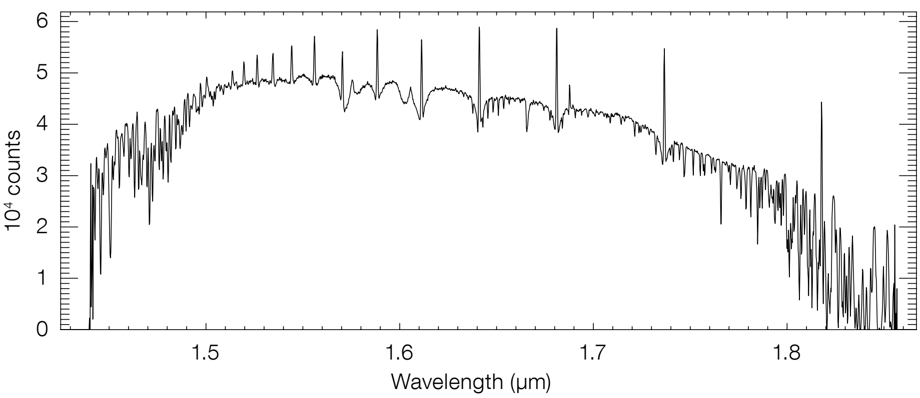

Figure 5. KMOS *H*-band spectrum of the B8 III emission line star Hip 022112 (HD 30123).

in through the dome aperture using an external crane (Figure 2, right).

Commissioning-1

First light with KMOS occurred on 21 November 2012. After a slightly cloudy start, the dome opened at 21:30 and the first targets were acquired. Initially this involved pointing the telescope at a relatively bright star and taking short exposures with one arm at a time placed at the centre of the field. Every single star appeared within the integral field unit (IFU) field of view of 2.8 × 2.8 arcseconds, much to the relief of the commissioning team (Figure 3)! Even this relatively simple observation required a large number of systems to be working together, such as the real-time display, which shows the positions of the target objects in the reconstructed datacubes. This acquisition sequence is a key feature of KMOS and allows the telescope pointing to be refined by placing a subset of the pickoff arms onto bright targets, which are then centred automatically using a shift and rotation of the telescope field of view (in much the same way that bright reference stars are used to align the slit masks in the FORS2 spectrograph). Once the field is aligned, these arms can then be redeployed to science targets.

One of the first issues to address therefore was the astrometric positioning of the arms; this included both the overall plate scale, and any radial variation at the arm focal plane(s), and also the local corrections (lookup tables) which are used to take out the individual variations in the movement of each arm. The latter stage was particularly troublesome, as it required an astrometric calibration procedure to be set up on sky using densely populated star fields in open or globular star clusters. The final calibration was not achieved until Commissioning-2, but now demonstrates that the arms have a final 1σ positioning accuracy of 0.1 arcseconds. The rest of the first commissioning run was taken up with exercising all the KMOS modes, including its unique capabilities to produce large mosaic patterns covering up to 60 by 40 arcseconds on the sky, and in obtaining calibration and performance data to complete the verification tests (e.g., Figure 4).

Commissioning-2

The second commissioning run took place in the latter half of January 2013 and, whilst not blessed with the same level of clear skies as the first run, enabled the commissioning team to complete a number of outstanding tests and improve the integration with the VLT control system. A further focus of the second run was to obtain some deep-sky observations with KMOS to evaluate the different modes of sky subtraction, and to fully test the KMOS data reduction pipeline SPARK (Davies et al., 2012). Calibration arc and flatfield exposures were taken automatically during the daytime at position angles close to those of the night's observations; this step minimises the effects of instrument flexure on the wavelength accuracy. After calibration using the daytime arc exposures, the remaining shifts of the night-sky OH lines have a root mean square residual < 20 km/s; this can be reduced to < 5 km/s by application of a simple model of the flexure. Figure 5 shows a typical example spectrum of a bright emission-line star processed at the telescope using the default pipeline.

Some of the more visually impressive capabilities of KMOS are the spectral images which can be produced using the mosaic mode in which the IFUs are packed into a regular grid pattern, with gaps which are then filled by offset pointings of the telescope. Two modes are available: either using all 24 arms (16 pointings) or a reduced mosaic of eight arms (nine pointings) if a faster coverage of a smaller area is required. All of the offsetting and combining of the cubes is handled automatically by the templates and data pipeline. Figure 6 shows one of the early results obtained (using non-sidereal tracking) of an *H*-band mosaic of Jupiter. Although the full information content of this observation (75 000 spectra in total) cannot be gleaned from a simple two-dimensional picture, the colour scheme has been tuned to reveal the spectral differences (mainly methane bands) in the equatorial zones and the polar caps of the planet. Another example is shown in Figure 7 for observations of 30 Doradus in the Large Magellanic Cloud, where the cube has been sliced to show the continuum in the *K*-band,

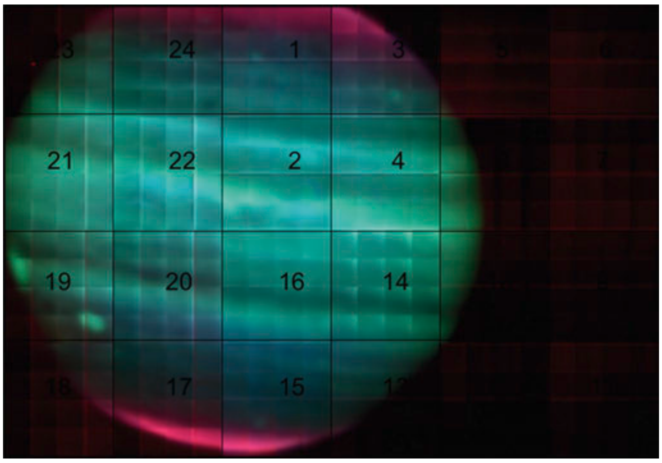

Figure 6. Reconstructed spectral image of Jupiter (pseudo colours refer to narrow bands extracted from the spectrum to highlight various features). This image was created using the 24-arm mapping template with non-sidereal tracking and comprises nearly 75 000 spectra. The numbers refer to zones covered by specific IFUs during the dithered pointings.

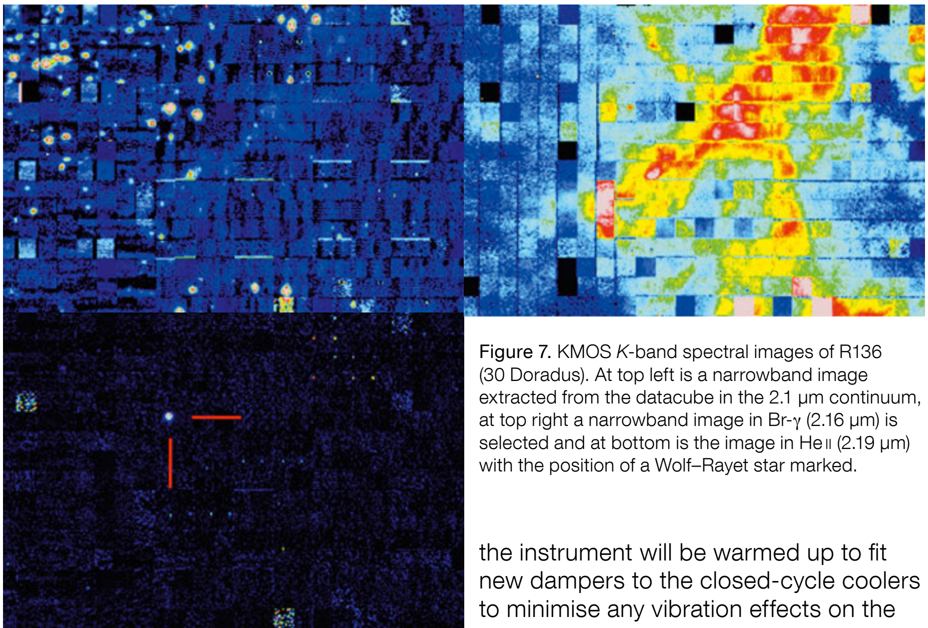

Figure 7. KMOS *K*-band spectral images of R136 (30 Doradus). At top left is a narrowband image extracted from the datacube in the 2.1 μm continuum, at top right a narrowband image in Br-γ (2.16 μm) is selected and at bottom is the image in He II (2.19 μm) with the position of a Wolf–Rayet star marked.

regions of Brackett-γ emission and the He II emission characteristic of massive Wolf–Rayet stars. The data for these commissioning observations are available for download[1].

Current status

The data from the first two commissioning runs are currently being fully reduced and analysed. During both observing campaigns, the instrument has performed nearly flawlessly and it is offered to the ESO community in the Call for Proposals for Period 92 (October 2013–March 2014). A final "Paranalisation" run is scheduled for March 2013, after which the instrument will be warmed up to fit new dampers to the closed-cycle coolers to minimise any vibration effects on the VLTI. Assuming this is successful, the first community Science Verification observations may take place in summer 2013. We look forward to much exciting new science from KMOS in the next few years.

References

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Davies, R. et al. 2010, Proc. SPIE, 7735, 77356V
Kasper, M. et al. 2012, The Messenger, 149, 17
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Sharples, R. et al. 2010, The Messenger, 139, 24

Links

[1] Access to presented KMOS commissioning data: http://www.eso.org/sci/activities/vltcomm/kmos.html