Upgrading VIMOS

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The high multiplex of the VLT visible imager and multi-object/integral-field spectrometer, VIMOS, makes it a powerful instrument for large-scale spectroscopic surveys of faint sources. Following community input and recommendations by ESO's Science and Technology Committee, it was decided to upgrade the instrument in phases. The first phase of the upgrade is described and included changing the shutters, installing an active flexure compensation system, replacing the detectors with CCDs with a far better red sensitivity and less fringing, and improving the data reduction pipeline.

VIMOS (Figure 1) is a powerful visible (360 nm to 1000 nm) imager and mult-object/integral-field spectrometer mounted on VLT Unit Telescope 3 (Melipal). Following a workshop on spectroscopic surveys[1] and recommendations by the ESO Science and Technology Committee, it was decided that the instrument, which entered operation in 2002, should be upgraded. In order to miminise downtime, it was decided to complete the upgrade in phases. This article describes the activities of the first upgrade and the resulting improvement in performance.

The instrument and upgrades

VIMOS has four identical arms, each with a 7 × 8 arcminute field of view on the sky with a gap between the fields of 2 arcminutes. The instrument offers three main observing modes:
- *U*-, *V*-, *B*-, *R*-, *I*- and *z*-band imaging covering four fields each 7 × 8 arcminutes in size.
- Slit-based multi-object spectroscopy with spectral resolutions from a few hundred to 2500 in each of the four imaging fields.
- Integral-field unit (IFU) spectroscopy with fields of view between 13 × 13 and 54 × 54 arcseconds.

After eight years of operations, and to extend its useful life, it became necessary to upgrade the instrument in order to address various issues. The first upgrade included:
1) replacing the shutters, which were worn out, and improving the reliability of the instrument;
2) replacing the CCD detectors;
3) reducing the instrument flexure;
4) improving the data reduction pipeline.

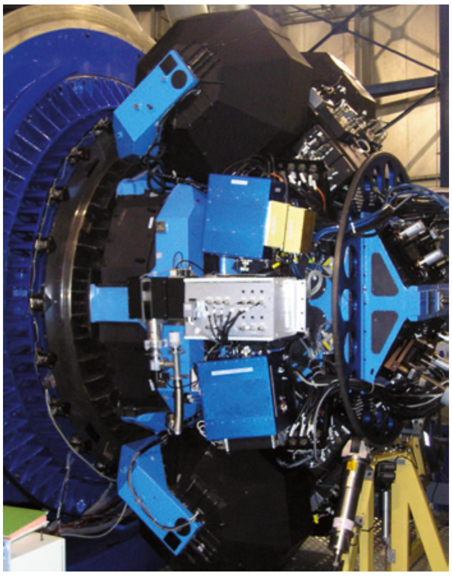

Figure 1. VIMOS is shown on the Nasmyth platform of VLT UT3.

Following tests on the instrument in November 2009 and February 2010, VIMOS was removed from the telescope between May and July 2010, so that the first stage of the upgrades could be made. The instrument was re-commissioned at the end of July. Making fine adjustments and optimising the system, then took a few more weeks.

New shutters and other measures to improve reliability

The exposure is controlled by 100 mm iris shutters manufactured by the Prontor company. Due to the size and speed requirements, these shutters are subject to considerable wear that has led to occasional failures. A failure occurring at the end of science integration is especially frustrating because it means that the exposure is lost and must be counted as technical downtime. Analysis of night reports from the last two years shows that the technical downtime due to shutter or detector controller failures has been 0.9 % on average, a non-negligible fraction of the total VIMOS downtime which varied between 6 % (Q4/2009) and 10 % (Q4/2008).

Since this type of shutter is no longer commercially available, ESO has reverse-engineered the Prontor shutters and built ten copies. A new shutter controller was also designed, which has no dissipation in the open or closed condition and has an electromagnetic braking function to reduce the mechanical loads. Prototypes have survived lifetime tests of up to 200 000 operations without degradation. Four of these new shutters have been mounted and no technical downtime due to shutter failures has been experienced since then.

The Mask Exchange Unit (MEU) of each of the four VIMOS arms consists of four mechanisms (mask selector/gripper/translator/blocker) that must be precisely aligned for reliable operation. About half of the total technical downtime of VIMOS is due to MEU failures. In the first quarter of 2010 we began performing daytime dry runs with the MEU whenever new masks were mounted. The idea was to detect possible failures during daytime, when they can still be corrected.

Apart from the extra manpower to perform the daytime tests, the experience with dry runs is encouraging, although more statistics are needed.

The new detectors

The original VIMOS detectors were thinned back-illuminated CCDs made by e2v. These were cosmetically very clean and gave a good performance in the blue and visible wavelength ranges. At wavelengths longer than about 700 nm, however, the detectors had strong fringing, which meant that near 850 nm the quantum efficiency (QE) of the detector could change by up to 40 % for changes in wavlength of about ten nanometres, or a movement across the detector of a few pixels. This made obtaining high quality spectroscopy very difficult in this wavelength range, particularly when there was flexure present.

The new detectors are also e2v devices. These are the same format as the original but the silicon is more than twice as thick. This has dramatically reduced the fringing so that now the maximum change in QE is at most 2 % and cannot be seen at all with the LR-Red grating or in imaging. Figure 2 shows two raw stellar spectra near 850 nm taken with the old (red) and new (black) detectors using the HR-Red grating. With the old detector the fringing is so large that none of the stellar features can be recognised, and so careful reduction is required to produce usable results (Scodeggio et al., 2009). The raw spectrum taken with the new detector, however, is almost good enough to use, so simplifying the reduction and improving the quality of the results, especially on faint red objects.

Figure 3 shows the change in imaging zero points between the old and new detectors. The significant improvement in the *R*-, *I*- and *z*-bands can be clearly seen, however there is a slight decrease in sensitivity in the *U*-band. The data used for calculating the zero point with the new detectors were taken just before the primary mirror of Melipal was recoated, which has improved the zero points by 0.05 to 0.1 magnitudes.

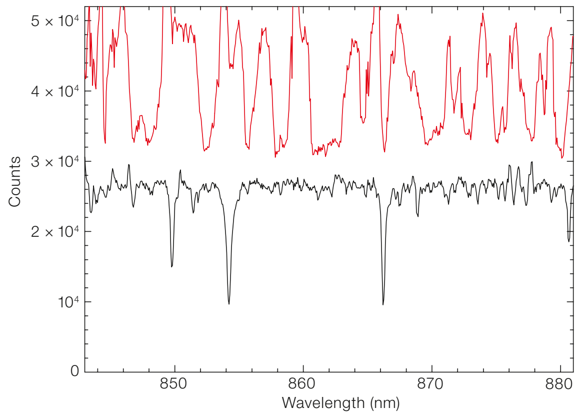

Figure 2. Raw stellar spectra taken with the old (red) and new (black) detectors using the HR–red grism. The star observed with the old detector was over a magnitude brighter that the star observed with the new detector. The "noise" in the red spectrum is caused by the fringing which makes the detector response vary rapidly with wavelength. This fringing has almost disappeared with the new detector so that the absorption features, such as the Ca II triplet lines, can be easily seen.

The active flexure compensation

VIMOS is a large instrument, weighing three tonnes, and suffers from 12–20 pixels of flexure between the focal plane and the detector, when the instrument is rotated to follow the field rotation. This flexure causes the image to smear during long exposures, makes calibration more difficult, and reduces the accuracy of object position measurements taken in the imaging mode, necessary for MOS mask production. The instrument was delivered with a passive (mechanical) flexure compensation system. Its performance was improved by ESO to about four pixels, but the system is not easy to maintain or adjust, and in 2009 some arms exhibited flexures of nearly six pixels when the instrument rotated. These flexures had a major impact on operations. The spectroscopic flat and arc calibrations had to be taken immediately after the science observations to ensure that the flexures affecting science and calibrations were as similar as possible. Furthermore, the relative pointing of the four arms between pre-image and spectroscopic observation could change, thus offsetting the sources in the slit. This was particularly annoying, as observers could never optimally position the targets in all four quadrants at the same time.

Therefore, it was decided to install an active flexure compensation system (AFC). Two motors were placed on the fold mirror of each arm, allowing the

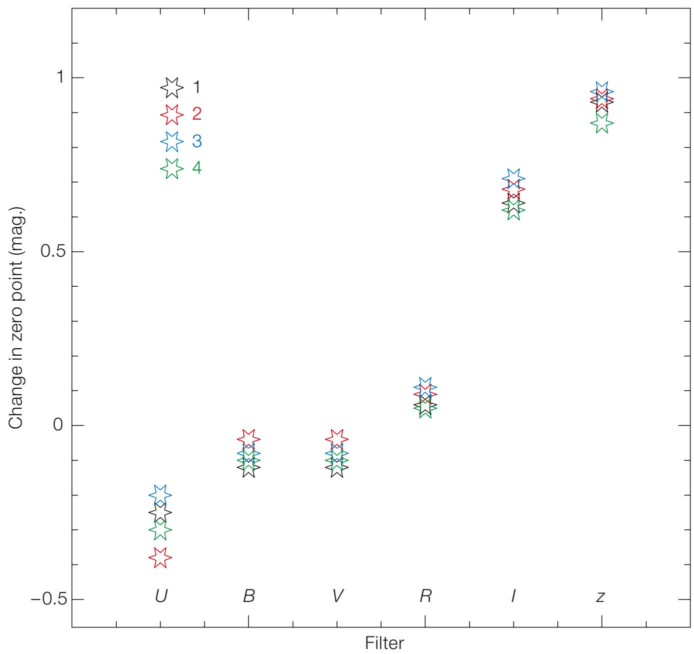

Figure 3. The change in imaging zero point (in magnitudes) between the old and new detectors is shown. The results for each of the four arms (indicated 1-4) are shown by separate points.

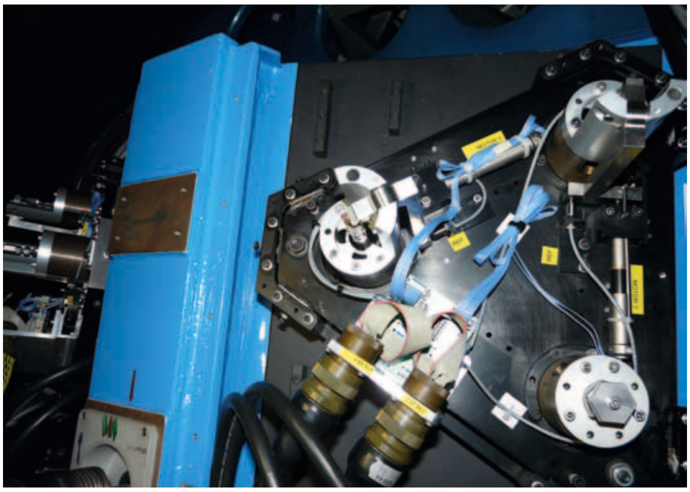

Figure 4. A close-up of the motors of the active compensation system.

image of the focal plane to be displaced in X and Y on the detector. A fibre in the focal plane, but just outside the nominal imaging field, then acts as a reference source and so before an observation is started the image of the focal plane can be correctly positioned on the detector. Any flexure during an observation is corrected by driving the motors using a look-up table. With the current system the target positioning can be done with approximately one pixel accuracy, while the registration between science and calibration observations is approximately two pixels, thelatter degraded by hysteresis. Duringthe commissioning it was gratifying to be able to see all targets centred in all quadrants at the same time!

The new MOS pipeline

In the new release of the pipeline data reduction software (version 2.5.0, delivered to the users in October 2010) two new MOS recipes have been added; one for processing the calibration frames, and another for reducing the scientific exposures. Using the new recipes is mandatory for reducing data obtained after the VIMOS CCD upgrade, and they can also be used for reducing older data. This new software, developed at ESO, is intended to replace the original set of five MOS recipes.

The new calibration recipe uses a calibration approach, based on pattern recognition, which was already applied successfully to the FORS1/2 and EFOSC2 pipelines (Izzo et al., 2007). This greatly reduces the software maintenance workload as it no longer requires any preliminary optical and spectral modeling of the instrument. This approach has been adopted in order to cope with the mechanical instabilities affecting any real-world instrument, a problem which was especially felt with VIMOS. Supporting the new VIMOS mosaic commissioning would have been impossible using the old MOS pipeline. VIMOS, with its four quadrants and six grisms, required the manual recomputation of at least 72 spectral distortion models at each major instrument intervention. With the new recipes, this is no longer necessary.

The new recipes also significantly improve the accuracy of the wavelength calibration, the quality of the sky subtraction,

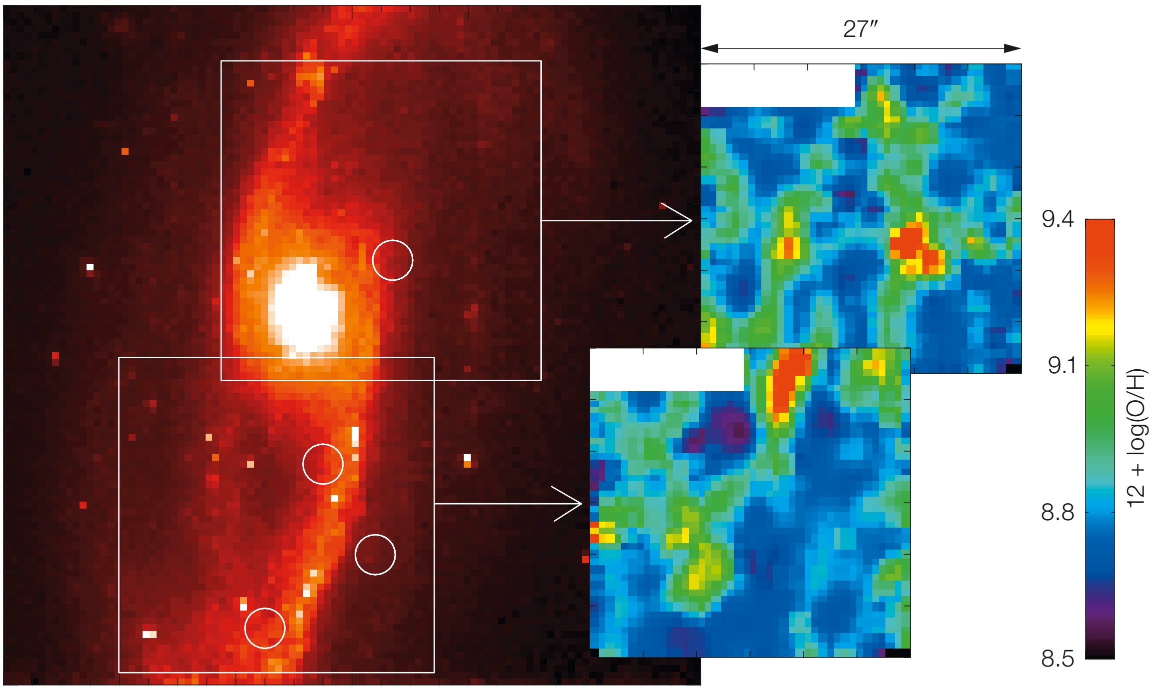

Figure 5. The image shows the galaxy NGC 6754 observed with the HST/NICMOS in the *J*-band. From the two IFU pointings the oxygen abundance was determined in the regions corresponding to where four SNe exploded (shown as open circles).

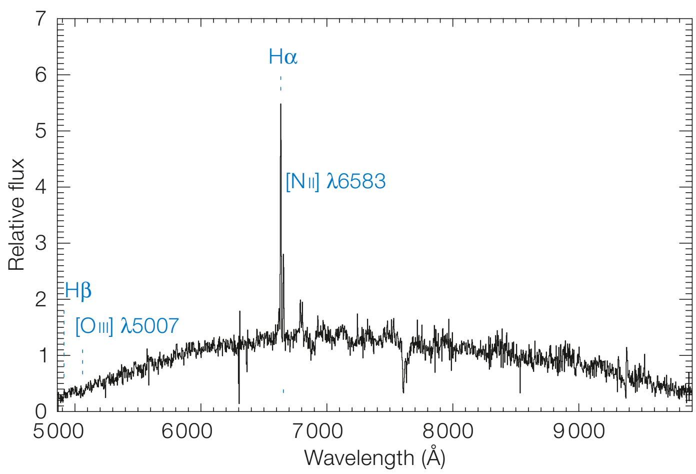

Figure 6. The VIMOS spectrum of one single spaxel of the IFU observation of NGC 6754.

the optimal extraction of the detected objects, and the sky fringing correction. The new pipeline and the manual can be downloaded[2].

The commissioning

The commissioning of an instrument as complex as VIMOS needs to be carefully planned. There are many modes, and the tree of dependencies has become even more complex with the introduction of the AFC system. The AFC reference source is at the edge of the field and so focusing is now even more critical if defocus is not to cause the centroids to move. The conversion from pixel coordinates to millimetres at the mask plane, is now tied to the coordinates of the AFC reference pixel. Any change to the reference pixel means that the mask-to-CCD matrix must be re-determined.

VIMOS has three reference systems which must be aligned to a few pixels in 4000; the detector *xy* in pixels, the focal plane *XY* in mm and the spectral dispersion direction. This last alignment is particularly important for multiplexed observations with the low resolution grisms, as the reduction pipelines assume that the contaminating zero or second orders are well aligned with the first order spectrum (we thank Luigi Guzzo, Bianca Garilli, and Marco Scodeggio for strongly insisting on this point). There are four arms, and six grisms per arm, each of which needs to be aligned, and so realignment of all grisms is a lengthy process. The re-characterisation of the instrument after any intervention that causes a displacement of the image of the focal plane on the detector, takes a minimum of a week. During the commissioning, which was also a time to become familiar with the newly installed hardware, we had to repeat this re-characterisation a few times. Although this led to a loss of efficiency during the first two months of service observing, the stability achieved in the coefficients of the mask-to-CCD matrix are now outstanding, with daily positioning variations well below a pixel.

Performance validation

As part of the commissioning, performance validation observations were made to help characterise the MOS and IFU modes and provide a taste of the performance after the upgrade. Figures 5 and 6 show the results from the IFU observations. Figure 5 shows the HST/NICMOS *J*-band image of NGC 6754 where four supernovae were observed between 1998 and 2005. Two belonged to massive stars that exploded in core collapse events (Type II SNe) and the other two to white dwarf star explosions (Type Ia SNe). NGC 6754 is dominated by numerous H II regions and widespread star formation over the face of the galaxy. The strong optical emission lines in the spectra at the two VIMOS–IFU pointings allows the oxygen abundance in the regions where the SNe exploded to be derived, as well as in other regions of the galaxy. The oxygen abundance was calculated from the Hα/[N II] ratio using the calibration of Pettini & Pagel (2004). The colour maps on the right-hand side of Figure 5 illustrate this abundance, where the dark blue colour corresponds to solar metallicities, green and red to super-solar metallicities, and violet and black to sub-solar metallicities. Figure 6 shows an extracted spectrum from a single spaxel identifying the lines used, but also demonstrating fewer systematic sky subtraction residuals beyond 700 nm, thanks to the absence of detector fringes. The signal-to-noise ratio for continuum emission is 50 % higher, while in the region of strong sky emission lines the improvement is a factor of two, relative to the old detectors.

Next steps

The first stage of the upgrade has significantly improved the performance of VIMOS in the red and reduced the amount of flexure to values close to the initial specifications of the instrument. Even so, further improvements are being planned for 2011 and 2012:

1. Replace the high resolution blue grism by a volume phase holographic grating with almost double the efficiency.
2. Improve the reliability and accuracy of the grism placement, mask insertion and focus mechanisms.
3. Increase the speed of the grism exchange unit (expected increase in overall operational efficiency is 2 %).
4. Eliminate the need to perform pre-imaging with VIMOS before masks can be made. Potentially this could increase operational efficiency by 10 to 15 %.

After these changes we expect to have an instrument with a much improved stability, reliability, and efficiency that will permit more ambitious science to be attempted.

References

Izzo, C., Jung, Y. & Ballester, P. 2007, in *The 2007 ESO Instrument Calibration Workshop*, 191
Pettini, M. & Pagel, B. E. J. 2004, MNRAS, 348, 59
Scodeggio, M. et al. 2009, Messenger, 135, 13

Links

[1] Conference web page including presentations: www.eso.org/sci/meetings/ssw2009/
[2] VIMOS reduction pipeline available at: http://www.eso.org/pipelines