The VIMOS upgrade programme

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ABSTRACT

The high multiplex advantage of VIMOS, the VLT visible imager and multi-object/integral-field spectrometer, 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, in 2009 it was decided to upgrade the instrument. This included installing an active flexure compensation system and replacing the detectors with CCDs that have a far better red sensitivity and less fringing. Significant changes have also been made to the hardware, maintenance and operational procedures of the instrument with the aim of improving availability and productivity. Improvements have also been made to the data reduction pipeline. The upgrade will end in 2012 and the results of the program will be presented here.

Keywords: Optical instrumentation, integral field spectroscopy, multi-object spectroscopy, imaging

1. INTRODUCTION

VIMOS (Fig. 1) is a powerful visible (360nm to 1000nm) imager and multi object/ integral field spectrometer mounted on UT3, Melipal. The high multiplex advantage offered makes it ideal for undertaking large scale spectroscopic surveys of faint sources. Following a workshop on spectroscopic surveys and recommendations by ESO's Science and Technology Committee it was decided that the instrument, which entered operation in 2002, should be upgraded to improve data quality, stability, and operational reliability. The first phase of the upgrade included replacing the detectors with CCDs with a far better red sensitivity and less fringing, changing the shutters, installing an active flexure compensation system, , and improving the data reduction pipe lines. Later phases addressed the image quality; the focusing and replacement of the HR-blue grating.

1.1 The Instrument

VIMOS has four identical arms (or quadrants), each with a 7x8 arc minute field of view on the sky and a gap between the quadrants of approximately 2 arc minutes. The instrument offers three main modes

1. U V B R I z- band Imaging in the four quadrants each 7x8 arc-minutes.
2. Slit based multi object spectrometry with spectral resolutions from a few hundred to 2500 in each of the 4 quadrants . As the CCD detector format is 2Kx4K, slits can be placed anywhere within the 2Kx2K imaging field of view.
3. Fibre fed IFU spectroscopy for fields between 13 and 53 arc seconds square.

The four arms are identical focal reducers. Each has correcting optics in front of the focal plane, a focal plane which will accept flat masks, a collimator, a pupil area for the grisms, the camera and a 2kx4k CCD detector.
VIMOS is located on the Nasmyth B focus of UT3 (Melipal). It is mounted on the mechanical de-rotator, and so the whole instrument rotates to correct field rotation. More details on VIMOS can be found in [1] or on the ESO web pages.

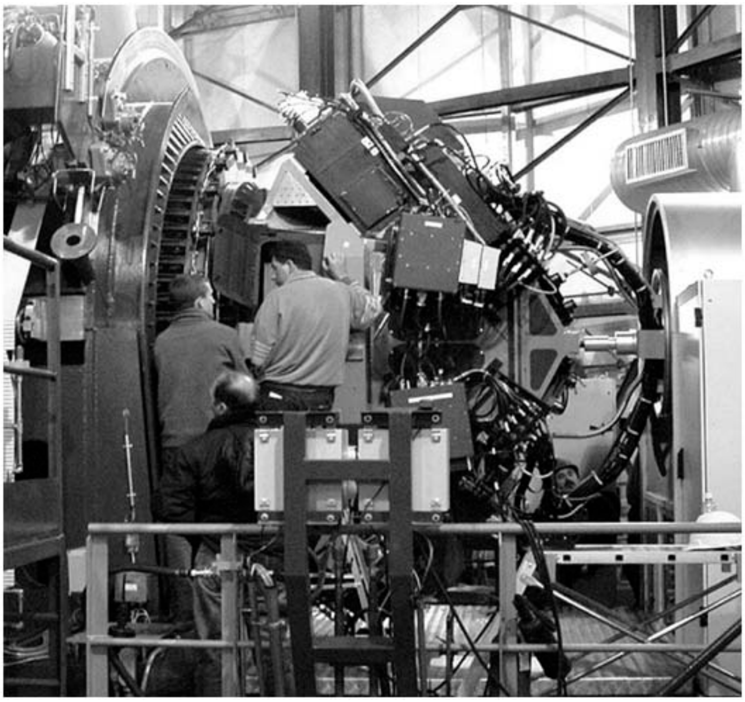


Figure 1 VIMOS being worked on at the Nasmyth B focus of UT3

2. THE UPGRADES

After eight years of operations, and to extend its useful life, it became necessary to upgrade VIMOS in order to address various issues. The upgrade included

1. replacement of the detectors by deep-depletion thick devices to improve red sensitivity and reduce fringing,
2. replacement of the shutters, which were worn out, to improve the reliability of the instrument.
3. further reduction of the instrument flexure y replacing the passive flexure compensation mechanisms by active flexure control (AFC)
4. improvement of the focus control to stabilize the image quality
5. replacement the HR-blue grisms with Volume Phase Holographic grisms.
6. improvement of the data reduction pipeline,
7. improvement of instrument reliability and availability.

The main aims were to make the instrument more stable in terms of image quality, to reduce flexure, to enhance red sensitivity, and to improve calibration accuracy.

Following tests on the instrument in November 2009 and February 2010, between May and July 2010 VIMOS was removed from the telescope, 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 optimizing the system, however, then took a few weeks longer. A second intervention was made in May 2011 to reduce the focal plane tilt across the detector. The final interventions were made in 2012 to improve the focus mechanism and to replace the four HR-blue grisms by VPHG-based ones to gain efficiency in the UV-blue.

2.1 The Shutter

The exposure is controlled by dia. 100 mm diameter iris shutters made 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 a science exposure 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. The open/close times are now being monitored so problems are usually detected before a shutter starts to fail. Prototypes have survived lifetime tests of up to 200000 operations without degradation. Four of these new shutters have been mounted and are operating well.

2.2 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 700nm, however, the detectors had bad fringing which meant that near 850nm the quantum efficiency (QE) of the detector could change by up to 40% for changes in wavelength of about ten nanometers, 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 is flexure.

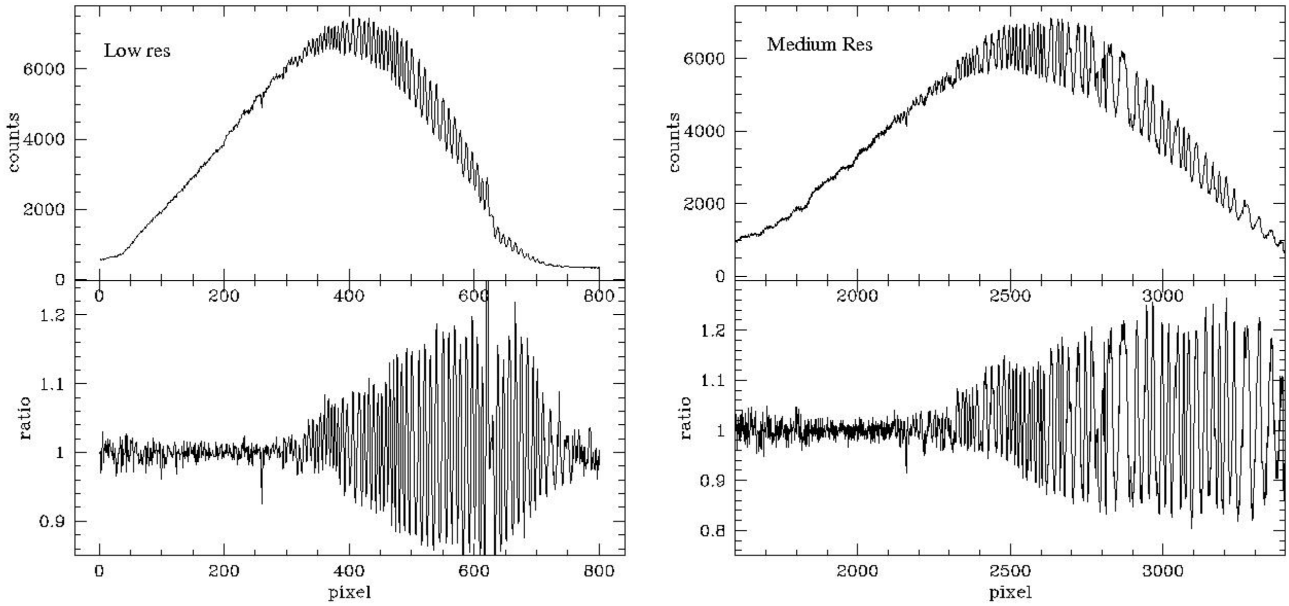


Figure 2. The effect of fringing on the low resolution red and medium resolution gratings with the old detectors. The upper plots show the raw counts and the lower plots the raw counts divided by a smoothed average. The fringing starts at about 750nm and reaches a Peak to Valley variation of about 40% of the signal.

The replacement 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 two percent in the HR-red grating and cannot be seen at all with the LR-red grating or in imaging. Fig. 3 shows two raw stellar spectra near 850 nm taken with the old (upper plot) and new (lower plot) 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 [2]. The raw spectrum taken with the replacement detector, however, is almost good enough to use as it is, so simplifying the reduction and improving the quality of the results, especially on faint red objects. In a test, the number of reliable redshifts that were obtained when observing identical fields with the new detectors increased by up to 40% using the same slit masks. With the better calibration accuracy, optimized masks with shorter slits might be used, which would lead to a further efficiency increase.

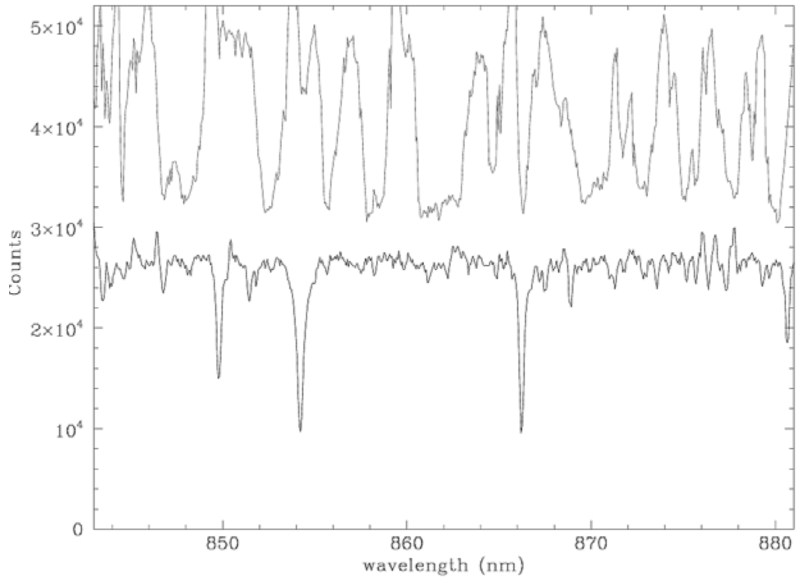
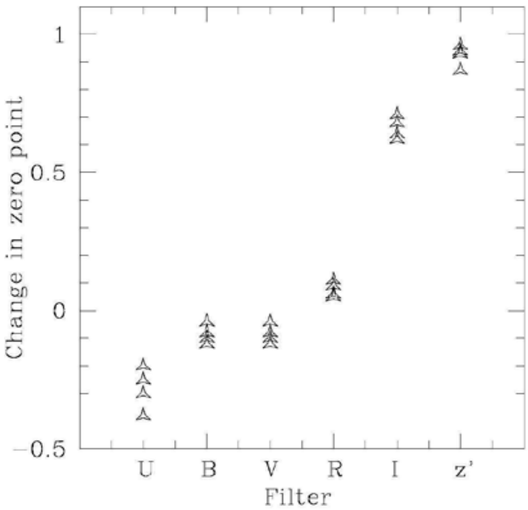


Figure 3. Raw stellar spectra taken with the old (upper) and new (lower) detectors using the HR–Red grism. The star observed with the old detector was over a magnitude brighter that the star observed with the new detector. The "noise" in the upper spectrum is caused by the fringing which makes the detector response vary rapidly with wavelength. This fringing has almost disappeared with the replacement detector so that the absorption features, such as the CaII triplet lines, can be easily seen.

Figure 4 shows the change in zero point between the old and replacement detectors in imaging. 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 a further 0.05 to 0.1 magnitudes.



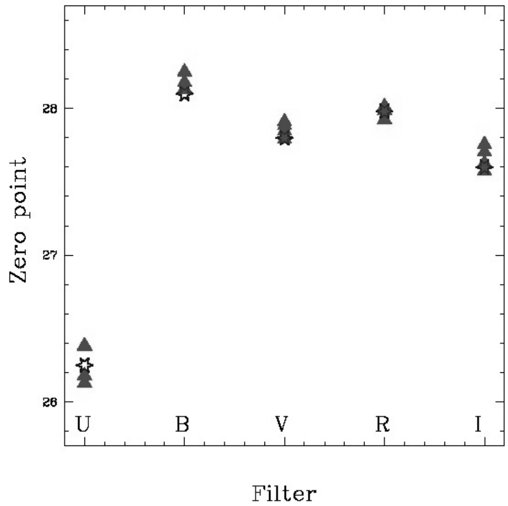


Figure 4. The change in imaging zero point (in magnitudes) between the old and new detectors. The results for each of the 4 quadrants are shown. The right hand plot shows the measured (triangle) and predicted (stars) zero points

2.3 Correcting the detector tilt

After the initial exchange of the detectors it was found that one detector was very tilted so that when the centre of the detector was in focus, the edge was badly out of focus. The detector mount was examined and it was found the detector had not seated properly and this was fixed. Even then, however there was still a significant change in optimal focus across the detectors on all quadrants. The optical system of VIMOS becomes very astigmatic towards the edge of the field, and the defocus was sufficient to make the images in the corners of the field highly elliptical. Fortunately, the optical design of VIMOS allows the focus tilt to be controlled by laterally moving the field lens of the camera. In May 2011 the focus tilts were corrected and now the image quality is uniform across the detector with only the corners showing some ellipticity in very good seeing.

2.4 The focusing mechanism

The original focusing mechanism was based on a stepper motor, which over time lost steps and has on occasion led to the camera being slightly out of focus, until the focus was re-initialized. Furthermore the software only allowed correction for temperature and filter, whilst tests showed that due to flexure in the focus mechanism there is a significant focus error with changing rotator angle. It was also noted that the grisms, particularly the high resolution ones, require a significantly different focus setting, since they introduce some optical power. In March 2012 the focus mechanism was changed to a direct drive motor with an encoder directly attached to the moving optical component. At the same time the software was modified to allow focus correction based on filter, grism, temperature, and rotator angle. Initial tests show highly consistent and stable focus behaviour, with a focus error that is nearly a factor of ten smaller than it used to be, due the improvements in the focusing software.

2.5 The active flexure compensation

VIMOS is a large instrument, weighing three tons, and when the instrument is rotated to follow the field rotation, it suffers from 12 – 20 pixels P-V of flexure between the focal plane and the detector. 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 P-V, but the system is not easy to maintain or adjust, and in 2009 some channels exhibited flexures of nearly six pixels P-V when the instrument rotated. These flexures had a major impact on operations as well as on the quality of the observations. 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 compensation system. Two motors were placed on the fold mirror of each arm, which allow the 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 0.3 pixel accuracy, while the registration between science and calibration observations is approximately 1 pixel, the latter degraded by hysteresis.

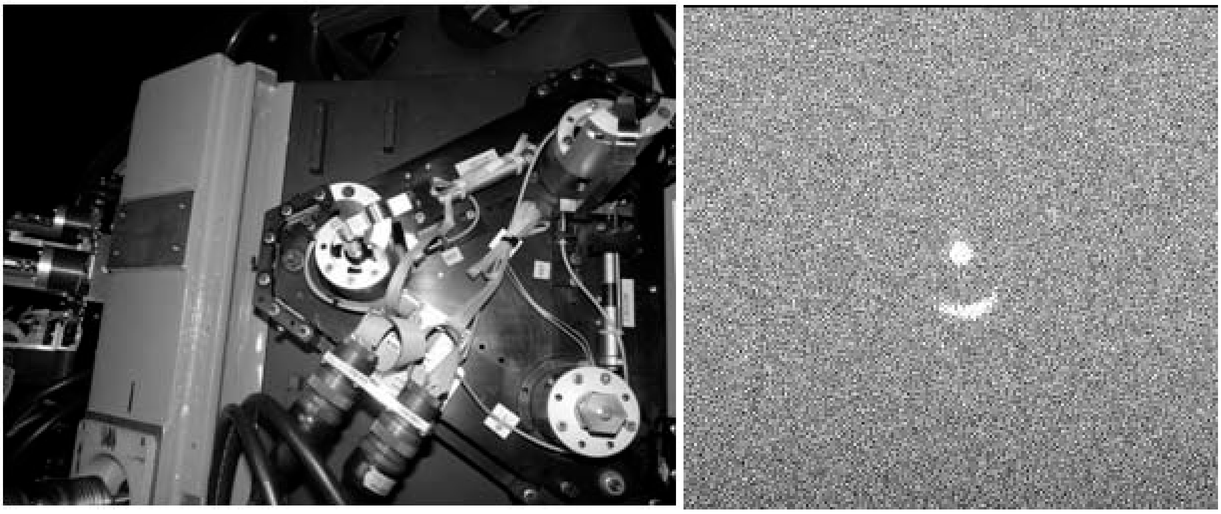


Figure 5. A close up of the AFC motors left and, right, an image of the illuminated fibre. The arc is a faint glint on the fiber mounting; it does not affect the centroiding.

2.6 The HR-Blue grating

The original HR-blue grating was a normal grism which produced a dispersion of 0.6 Å per pixel but with a moderate efficiency. It was therefore decided to change this to a VPH grism with a slightly lower dispersion of 0.71Å per pixel but a significantly higher efficiency, particularly near 400nm.

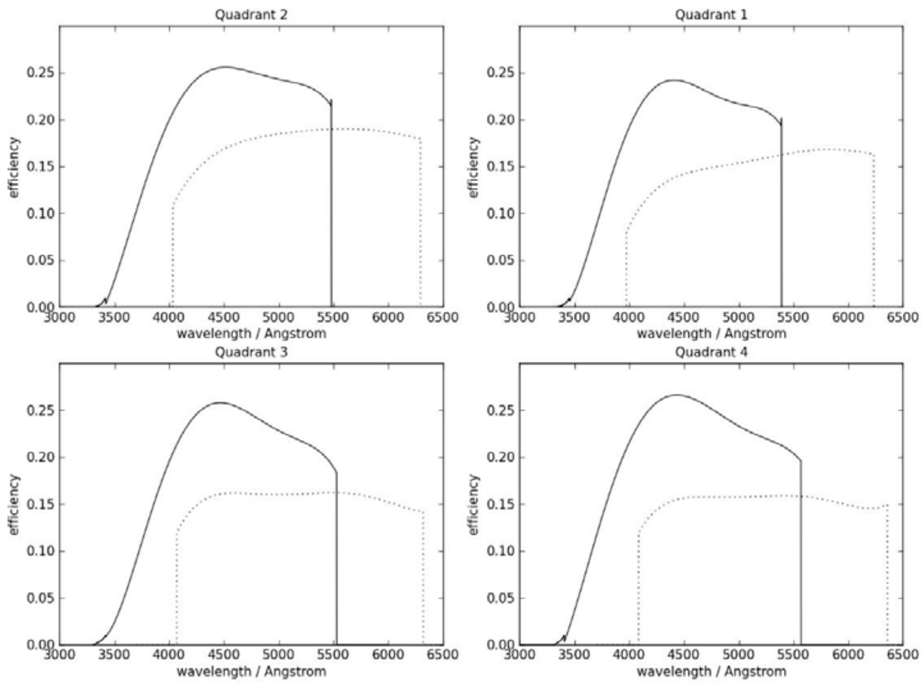


Figure 6 The efficiency of the old (dotted) and new (solid) HR-Blue gratings The new grating has a higher efficiency and goes further into the UV, although at a slightly lower spectral resolution. The measurements were taken immediately before and after exchanging the grisms.

3. MAINTENANCE

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. At the beginning of the upgrade project, about half of the total unplanned technical downtime of VIMOS was due to MEU failures. This was initially addressed by increasing the level of preventive maintenance and changes in operational procedures. In Eerly 2010, new mask cabinets were installed with differently placed magnets to better hold the masks in place, and we also began performing daytime dry runs with the MEU whenever new masks were mounted. The idea is to detect possible failures during daytime, when they can still be corrected, and so minimize night time interventions. As shown in Fig. 7, at the start of the upgrade programme, unplanned technical down time of VIMOS was close to 10% whereas by the end of 2011 it was reduced to 2.5%.

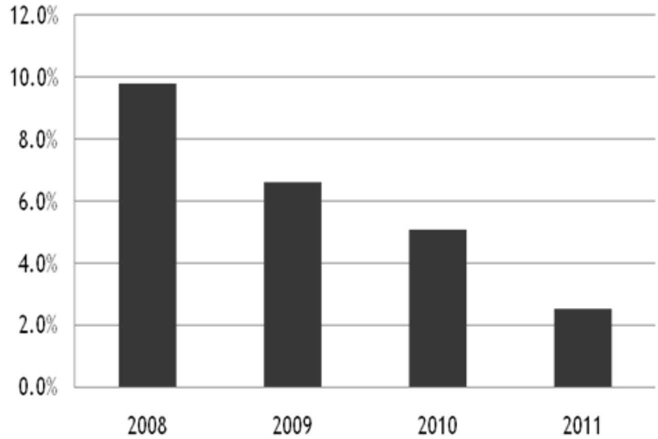


Fig. 7 Evolution of unplanned technical downtime of VIMOS during the upgrade project

4. PILMOS

Originally, VIMOS foresaw the possibility of creating MOS masks directly from astrometric catalogues, but a pre-imaging capability was included due to the need to provide accurate astrometry in cases where no catalogue was available. However, once in operation, it was concluded that pre-imaging would be mandatory to ensure that uncertainties in the mapping of celestial co-ordinates on to detector and then from the detector to the focal plane would not lead to incorrectly placed slits, particularly with the large instrumental flexure. This need for pre-imaging means that the total time for a MOS observation is increased by up to 15%. Therefore a study was made to determine whether following the upgrades, VIMOS was now sufficiently stable that Pre-ImageLess MOS (PILMOS) would now be feasible.

There are two prerequisites for the PILMOS to work effectively:

1. A tool to allow the user catalogues to be converted into masks. It was decided that producing a virtual image from the catalogue with exactly the same header information as a normal pre image, and entering this into the VMMPS, the VIMOS mask preparation tool, would be the simplest approach. The production of the virtual image has been included as an extension of the existing Guidecam tool.
2. A demonstration that that the accuracy of the slit placement was as good with PILMOS as it would have been using a pre- image. To this end a series of tests were made first compareing the virtual images with pre-images, then producing slit masks for fields of bright point sources, and finally masks for typical science fields from but

the catalogue and pre-images. . Furthermore a significant amount of work was done examining the stability of the astrometric solution. The test showed that ,assuming the input coordinates are good, the results are comparable to those produced using pre-imaging.

Currently the PILMOS option is in preparation to be offered to the users later this year.

5. THE NEW MOS PIPELINE

In the new release of the pipeline data reduction software (version 2.5.0, delivered to the users on 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 of arc lamp lines, which was already applied successfully to the FORS1/2 and EFOSC2 pipelines [3]. 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 4 quadrants and 6 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, the optimal extraction of the detected objects, and the sky fringing correction.

6. CONCLUSIONS

The VIMOS upgrade programme is now drawing to a close and although there are still some details to be optimized, it is expected that the project will finish by the end of 2012. The new detector has far lower fringing, and a significantly higher quantum efficiency in the red. Modifications to the instrument and to maintenance and operational procedures have reduced the technical downtime to a few percent. The upgrades have significantly improved the stability and calibration accuracy of the instrument, allowing (for programs where this is appropriate) higher multiplex gains through the use of shorter slits. PILMOS will make the overall observations more efficient. The result is that VIMOS will continue to deliver high quality science for many years to come, at a significantly increased productivity and improved data quality.

REFERENCES

[1] Le Fèvre O. et al, “Commissioning and performances of the VLT-VIMOS instrument,” SPIE.4841, 1670 (2003)

[2] Scodeggio M., Franzetti P., Garilli B.,Le Fèvre, O. and Guzzo, L., „Improving the Multiplexing of VIMOS MOS Observations for Future Spectroscopic Surveys” , Messenger 135 , 13 (2009)

[3] Izzo C., Jung Y., and Ballester P., “A Bottom-Up Approach to Spectroscopic Data Reduction” in " The ESO Instrument Calibration Workshop", 191 (2007)