Improving the Multiplexing of VIMOS MOS Observations for Future Spectroscopic Surveys

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The need to reduce the negative effects of fringing on VIMOS spectra has led astronomers to use observing techniques that significantly limit the multiplexing of VIMOS observations in multi-object spectroscopy mode. In this paper we propose a new observing strategy which, coupled with a new data reduction technique, has the potential to double VIMOS multiplexing while producing spectra of a quality comparable to that obtained in the major surveys performed so far.

Modern spectroscopic surveys are generally based on multi-object observations, where many tens to hundreds of objects are observed simultaneously during each telescope pointing, to speed up the completion of projects that collect the spectra of many thousands of objects. As it is often the case with astronomical instrumentation, the practical requirements to achieve this high degree of multiplexing are quite at odds with those necessary to obtain high quality spectra for each of the surveyed objects. In this paper we describe an observing strategy and a specific data reduction procedure for the ESO Very Large Telescope (VLT) VIsible Multi-Object Spectrograph (VIMOS), designed to increase the multiplexing of MOS observations, without significantly affecting the quality of the spectra thus produced. In the optimal case of a deep survey with a large set of potential targets for the spectroscopic observations, it will be possible to double the multiplexing of the MOS observations with VIMOS using this new strategy.

VIMOS fringing problems

The most important characteristic of the VIMOS spectrograph (Le Fèvre et al., 2002) is its high degree of multiplexing, conceived specifically to speed up the execution of spectroscopic surveys significantly. Unfortunately, the VIMOS CCDs installed when the instrument was commissioned are thinned E2V detectors from early 2000 technology, and they are affected by significant fringing redwards of approximately 800 nm, as shown in Figure 1. Without proper corrections the spectra obtained with VIMOS red grisms (including the LR_red, MR, HR_orange and HR_red grisms) for faint extragalactic sources are very difficult to use above this wavelength. The effects of fringing need to be counteracted to obtain spectra that can take full advantage of the wavelength coverage provided by these grisms (reaching approximately 950 nm), and in order to extend the wavelength and the redshift coverage of the redshift surveys as much as possible. This is why the data for the two main surveys carried out so far with this instrument in MOS mode, the VLT VIMOS Deep Survey (VVDS; Le Fèvre et al., 2005), and the zCOSMOS survey (Lilly, 2008), and the data for many other smaller VIMOS programmes, have all been obtained starting from observations carried out in jitter mode. The total exposure time for each instrument pointing is subdivided into separate shorter exposures, and the telescope is offset by a small amount after each exposure (typically 1 or 2 arcseconds), making sure that the objects are kept inside the MOS mask slits. As a result of the offsets, the object spectra fall on different pixels on the CCD in different exposures, and it is possible to obtain a relatively accurate and complete reconstruction of the fringing pattern by median-combining all the available exposures.

Figure 1. Fringing pattern in VIMOS MOS red data. A small portion of a flat-field exposure obtained with the LR_red grism is shown, including spectra from six different MOS slits. The red end of the spectra is towards the top.

The cost of implementing this observing technique is a reduced multiplexing for MOS observations. To make sure the target objects remain visible inside the slits after the offsets, the slits must be designed and cut longer than they would otherwise need to be (in practice, one has to specify a larger sky region inside the VIMOS mask preparation software [VMMPS]). In stare mode, with a typical faint object size of 2 arcseconds (the average apparent diameter of a high redshift galaxy in ground seeing conditions), and a minimum sky region on each side of the object of 2 arcseconds to allow for an accurate sky subtraction, slits would typically be 6 arcseconds long (i.e., 30 VIMOS CCD pixels). In jitter mode, to accommodate a pattern with five jitter positions (like those used for VVDS and zCOSMOS observations), we must add another 2 to 3 arcseconds on each side of the object, for a total slit length of 10 to 12 arcseconds (i.e., 50 to 60 VIMOS CCD pixels). This approximate doubling of the typical slit length directly translates into a reduction of 50% of the VIMOS multiplexing, which is precisely what has happened for both the VVDS and zCOSMOS projects.

Searching for alternatives

In preparation for future spectroscopic surveys, we have recently studied the possibility of adopting a different observing strategy to increase the multiplexing of VIMOS observations in MOS mode, without significantly affecting the data quality and the measurement reliability of redshifts. As a first step we started using real VIMOS MOS data, originally obtained in jitter mode with long slits as part of the VVDS and zCOSMOS surveys, to simulate a number of different observing strategies, and to evaluate their capability of providing a reliable sky subtraction and an accurate fringing pattern removal. The main indication of this work is that a data quality comparable to that of VVDS and zCOSMOS data can be obtained with observations carried out in stare mode, with relatively small slits. The necessary fringing corrections for the red spectra can be derived from a flat-field exposure, provided that such an exposure is obtained as part of the night-time calibrations, immediately before or after the wavelength calibration lamp observation that is normally executed at the end of each set of exposures in an Observing Block.

This flat-field exposure is affected by fringing, much like the scientific exposures, except for the precise positioning of the fringing pattern on the CCD pixels which, because of flexure inside the instrument, can shift by a few pixels between any two exposures. We have seen that it is possible to compensate for these offsets by allowing a search for the best-matching fringing pattern between the flat-field and the scientific exposure over a range of a few pixels (comparable to the known extent of the image shift resulting from the flexure). This technique is schematically described in Figure 2: for each row of pixels in the image of a two-dimensional spectrum produced by a MOS slit during a science exposure, we search in the corresponding image produced by a flat-field exposure for the row that best reproduces the count variations created by the fringing pattern, extending this search over a few rows (typically five) of the flat-field image.

Technically, we normalise the flat-field row counts to have the same median counts as in the science exposure row data, and then we compute a very simple χ^2 statistic adding together, pixel by pixel, the squared values of the difference between normalised flat-field and science exposure. The flat-field row that minimises the total χ^2 value is considered the best-matching one. Once such a row has been identified, we scale the total counts in this row to match those measured in the science exposure, and we subtract the scaled flat-field row values from the science exposure row values, effectively producing both a sky subtraction and a fringing pattern removal in a single step. Any region of the CCD where a significant contribution from the spectrum of an object is present on top of the general sky background in the science

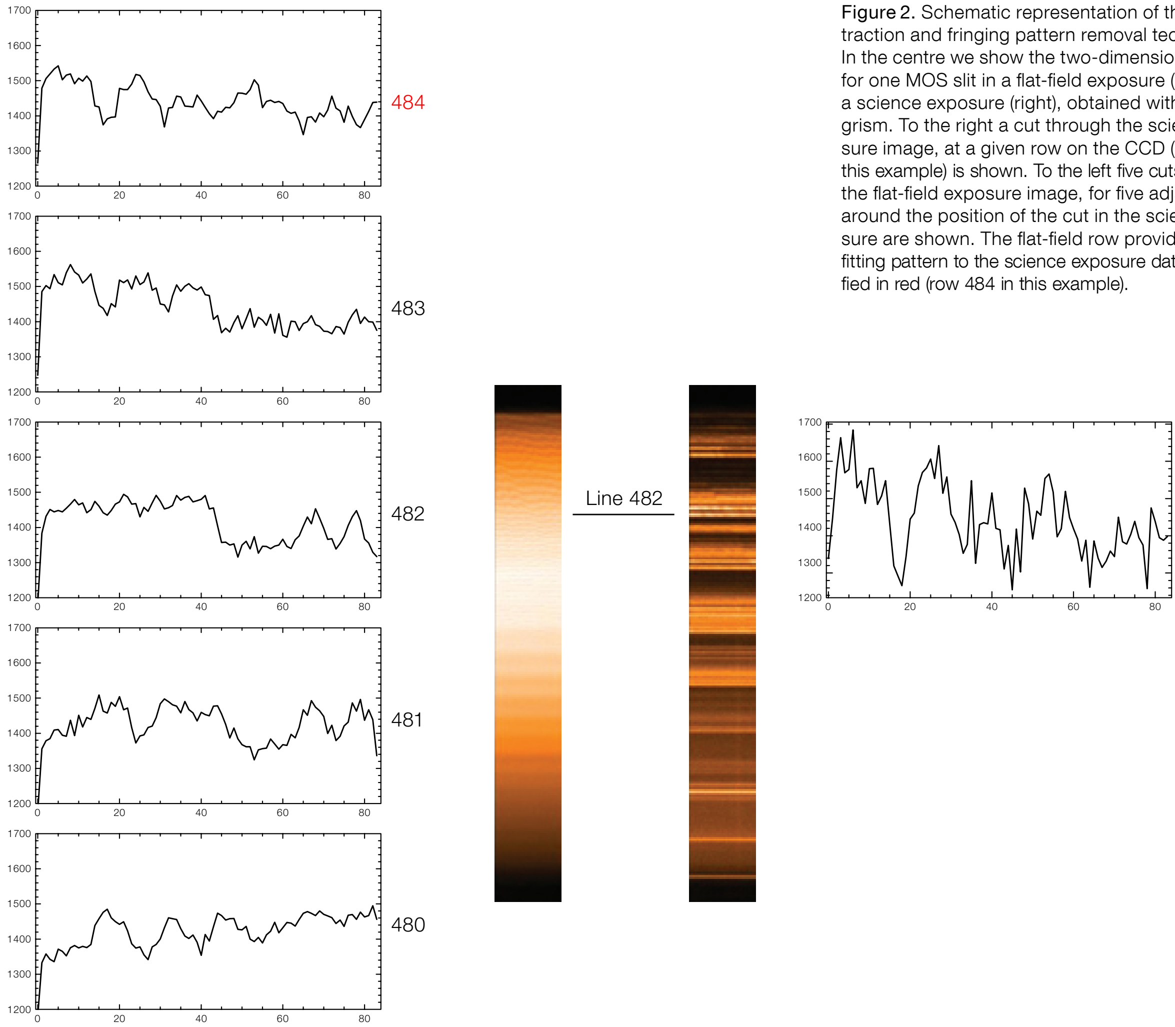

Figure 2. Schematic representation of the sky subtraction and fringing pattern removal technique. In the centre we show the two-dimensional spectrum for one MOS slit in a flat-field exposure (left) and in a science exposure (right), obtained with the LR_red grism. To the right a cut through the science exposure image, at a given row on the CCD (row 482 in this example) is shown. To the left five cuts through the flat-field exposure image, for five adjacent rows around the position of the cut in the science exposure are shown. The flat-field row providing the best fitting pattern to the science exposure data is identified in red (row 484 in this example).

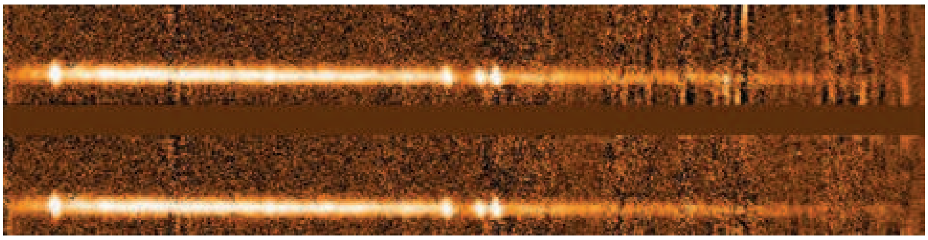

Figure 3. A comparison of results obtained using the traditional jitter sequence observation and the standard VIMOS data reduction pipeline *v.* the new stare mode observation and fringing removal technique. The same two-dimensional sky-subtracted spectrum of a galaxy observed with the LR_red grism as part of the VVDS is shown: the result of the traditional data reduction method (upper); the result of the simulated stare mode observation coupled with the newly proposed reduction technique (lower). In this example the new reduction method produces better removal of the fringing pattern than the traditional one.

exposure image is excluded from the matching pattern search and from the rescaling computation.

An example of a sky- and fringing-subtracted spectrum is shown in Figure 3, where we compare the results of the traditional jitter sequence data reduction with the results of the new technique proposed here, applied to a simulated short slit stare mode observation derived from a VVDS observation obtained with the VIMOS LR_red grism.

Validation of new method

The simulation results briefly discussed above indicate that it should be possible to obtain good quality spectra for faint astronomical targets from VIMOS spectroscopic observations in MOS mode carried out using a stare mode observing technique. The main advantage of using stare mode observations would be the possibility of using MOS slits that have, on average, half the length of the slits used in traditional jitter mode observations. Using short slits in this way would immediately translate into an approximate doubling either of the efficiency or of the total yield for a spectroscopic survey carried out with VIMOS, in comparison with the efficiency or yield obtained so far with the VVDS and zCOSMOS surveys. This result would of course be achievable only for a deep survey, where the number of potential targets is at least twice as large as the number of slits that could potentially be placed on a MOS mask. Given the very significant impact that this result could have on future spectroscopic surveys, we decided to propose a direct on-sky verification of our results.

We therefore submitted a small Director's Discretionary Time (DDT) proposal to ESO to perform one spectroscopic survey-like observation with VIMOS using short-slit masks and stare mode exposures. This was approved as programme 281.A-5044 (A), and executed on 26 September 2008. Figures 4 and 5 show the results obtained by reducing these data with both the traditional data reduction technique (Figure 4) and the newly proposed method (Figure 5). It is quite clear from a comparison of the two images that the new fringing subtraction technique is quite efficient. In order to quantify the impact of the technique better, we have systematically compared the root mean square (rms) variations in the residual background level (after sky subtraction) of the two-dimensional spectra between the red spectral region (affected by fringing) and the blue region (free of fringing). For the data shown in Figure 4, which effectively still contain the whole fringing pattern, the rms variations in the red part of the background are six to eight times as large as those in the blue part. For the data shown in Figure 5, reduced with the new fringing removal technique, the rms variations in the red part of the background are only two to four times as large as those in the blue. To visualise the impact that these residuals

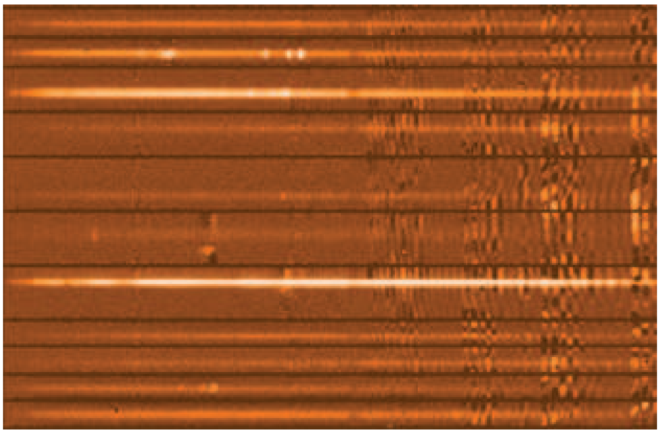

Figure 4. Two-dimensional sky-subtracted spectra for a number of slits, produced using a mask with short slits and stare mode observations as part of our DDT programme. The blue end of the spectra is to the left. The data have been reduced with the traditional method, appropriate for jitter mode observations. The fringing pattern residuals are clearly visible in the right half of the image.

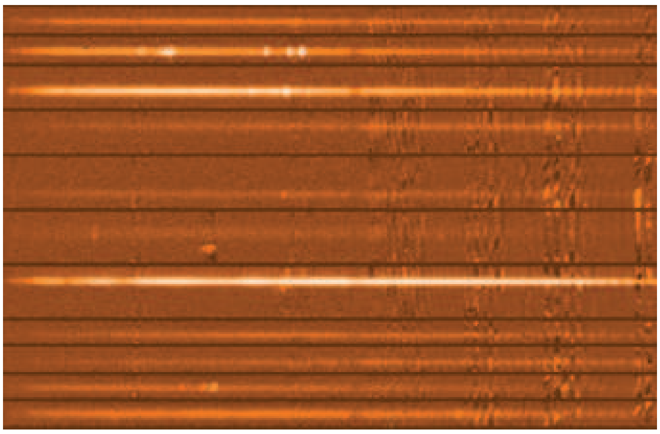

Figure 5. Same data as in Figure 4, but this time the newly proposed data reduction method has been used. The image colour cuts are identical to those in the previous figure. The significant removal of the fringing pattern, although not perfect, can be easily appreciated by comparing the two images.

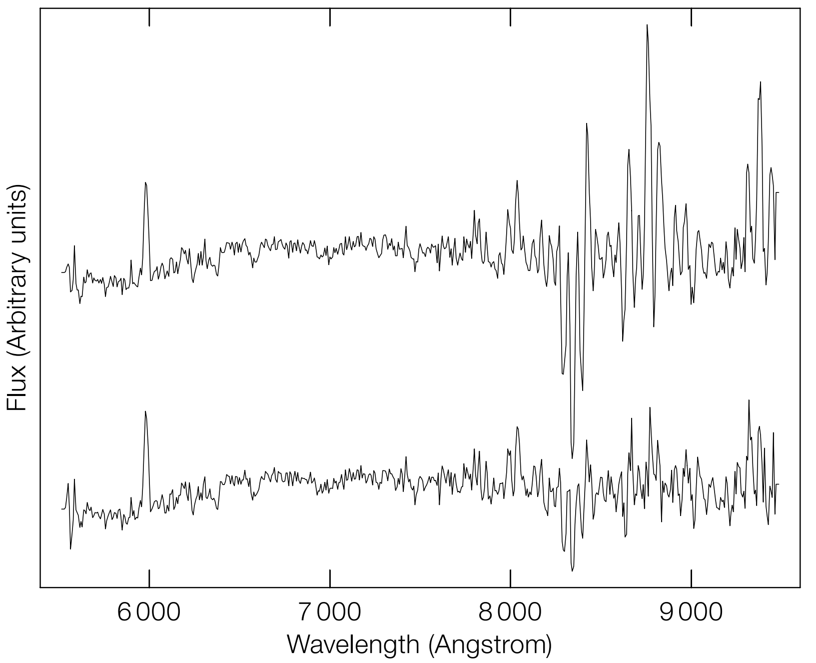

Figure 6. Comparison of one-dimensional spectra for one galaxy observed during our DDT run. The top spectrum is extracted from the data shown in Figure 4, and clearly shows the noise introduced by the strong fringing residuals. The bottom spectrum is extracted from the data shown in Figure 5, and shows a more uniform noise pattern in the blue and red half of the wavelength range.

can have on the final one-dimensional spectra extracted from these data, we show in Figure 6 a comparison of the extracted one-dimensional spectra for the same object, obtained by starting from the data shown in Figures 4 and 5. It is quite clear from this figure that the noise in the red part of the final spectra is significantly reduced by our new data reduction technique. The new data reduction technique is implemented as part of the VIMOS Interactive Pipeline Graphical Interface (VIPGI) data reduction pipeline[1] (Scodeggio et al., 2005), and will be available to the whole astronomical community with VIPGI public release 1.4.

Future prospects

The results discussed here show that it is possible to obtain spectroscopic data with a quality comparable to that of VVDS and zCOSMOS data, which in turn translates into a success rate for redshift measurement of approximately 90% for the targeted galaxies, using MOS masks with short slits coupled with stare mode observations, irrespective of the wavelength range covered by the spectra. Using MOS slits that are on average only half as long as those used for jittered observations would translate into the option to place twice as many slits on any VIMOS MOS mask. To take full advantage of this option it is necessary to have a relatively densely populated starting sample for the spectroscopic observations: our experience with VVDS and zCOSMOS indicates that MOS masks are populated with their maximum slit capacity only when the starting sample of potential targets includes at least twice as many objects per VIMOS quadrant as this maximum number of slits. This is generally the case in relatively deep extragalactic spectroscopic surveys: both the VVDS and zCOSMOS, in their Wide and Deep samples, have a density of potential targets which is two to three times as large as the potential maximum number of short slits one could accommodate on VIMOS masks.

The first project to take advantage of this new observing strategy and data reduction method is already under way: the VIPERS survey (ESO Large Programme 182.A-0886 with PI L. Guzzo). From the set of MOS masks that were designed for the first semester of observations, we can estimate that this survey should be able to observe spectroscopically 60% of the parent galaxy sample defined from the complete photometric catalogue. In contrast, with a mask design typical of jittered observations, and with the same allocation of telescope time, it would have been possible to sample only some 32% of the galaxies. This increase in efficiency has a very significant impact not only on the final survey sample, but also on the science results expected from this project.

Finally, the general capability of the ESO community to carry out very large spectroscopic surveys in an efficient manner will receive a further boost by the planned substitution of the VIMOS CCDs, which should produce spectra with much reduced fringing residuals in the red part of the spectrum with respect to the currently installed CCDs. Using the data produced by these new CCDs as input, our new reduction technique is expected to produce final one-dimensional spectra that have uniform noise levels over the whole wavelength range covered by the VIMOS grisms. This result, coupled with the higher quantum efficiency in the red part of the spectrum provided by the new CCDs, is expected to increase the overall efficiency of a VIMOS-based redshift survey for faint astronomical targets by a factor of two to three.

References

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Notes

[1] http://cosmos.iasf-milano.inaf.it/pandora/vipgi.html