A Method to Deal with the Fringe-like Pattern in VIMOS-IFU Data

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Many observers using spectrographs will be familiar with the fringes normally appearing at longer wavelengths (λ ≥ 7000 Å). In spectra obtained with the VIMOS integral field unit such a fringe-like pattern is also observed in the optical wavelength range. This fringe-like pattern affects the shape of the continuum and will, if not corrected, have consequences for derived parameters such as recession velocity, stellar velocity dispersion and line strengths. We describe an empirical method to correct for these fringe-like patterns and briefly describe the improved results.

Integrated field units (IFUs) are now common at all major observatories, where they offer an efficient means of obtaining spectra and imaging information at the same time. Due to the complex design of the IFU instruments and the large amount of information, there are often challenges for the data reduction pipelines. In the case of the VLT visible image and multi-object/integral field spectrometer (VIMOS), data from its IFU mode require additional reduction steps beyond the standard pipeline in order to handle some issues not resolved by the pipeline. The VIMOS-IFU contains 6400 microlenses coupled to fibres covering the wavelength range 4000–10150 Å with a set of six grisms (Le Fèvre et al., 2003). With the medium and high resolution grisms only a square of 40 × 40 fibres is used, yielding either a field-of-view (FoV) of 27 by 27 arcseconds at 0.67 arcseconds per fibre or a FoV of 13 by 13 arcseconds at 0.33 arcseconds per fibre. The light is fed to four different spectrographs dividing the FoV into four quadrants, which are processed separately and combined into a datacube as a final data reduction step.

For the data reduction the ESO pipeline can be used with the standard settings given in the pipeline manual. After the data reduction, the datacubes still feature some problems that need to be attended to before any scientific analysis can begin. Firstly, there are large-scale intensity differences between the four quadrants and also differences between individual spectra visible as stripes in the reconstructed image; the details of which are described in Lagerholm et al. (2012). In this article, we will focus on the more severe problem of fringe-like features visible in the spectral domain even at optical wavelengths.

The fringe-like pattern

It has been known for several years (e.g., Jullo et al. 2008; VLT VIMOS manual) that VIMOS-IFU spectra acquired with the HR-Blue and HR-Orange grisms exhibit spectral features that are visually similar to fringes. Fringes normally arise from the interference in the charge-coupled device (CCD) detection layer between the incident light and the light reflected from the interfaces of the CCD layer. Due to the typical thickness of this layer, fringes are observed at red wavelengths (> 7000 Å). The features seen in the VIMOS-IFU spectra resemble fringes but are present over the whole wavelength range (see Figure 1), suggesting that they are caused by a different mechanism. The most likely origin of the fringe-like patterns is a “pseudo-etalon” — approximately 3–10 μm thick — created by imperfect fixing of the fibre to the output prism (Hans Dekker, private communication; Lagerholm et al., 2012). The fringe-like patterns are present in the science data and in the flat field; they are also present in the raw data, and thus cannot be an artefact created by the data reduction process.

The fringe-like pattern affects more than half of the spectra in a VIMOS-IFU data cube. The amplitude and frequency of the fringe-like pattern is not randomly distributed between fibres but shows a clear connection to specific fibre modules. In quadrant 2 almost all spectra are affected, while the other quadrants exhibit regions with negligible or no fringe-like patterns (Figure 2). What is important to note is that the fringe-like pattern varies with time as indicated in Figure 1, where we plot the fringe-like pattern in the same spatial element separated in time. An explanation for this can be the change in the instrument rotator angle and associated flexure in the instrument, which changes the properties of the pseudo-etalon. In the most affected spectra, the pattern accounts for around 13% difference in intensity, peak-to-valley (PTV), while the mean value of the effect is about 6%.

The empirical correction method

We have devised an empirical method for removing the fringe-like patterns

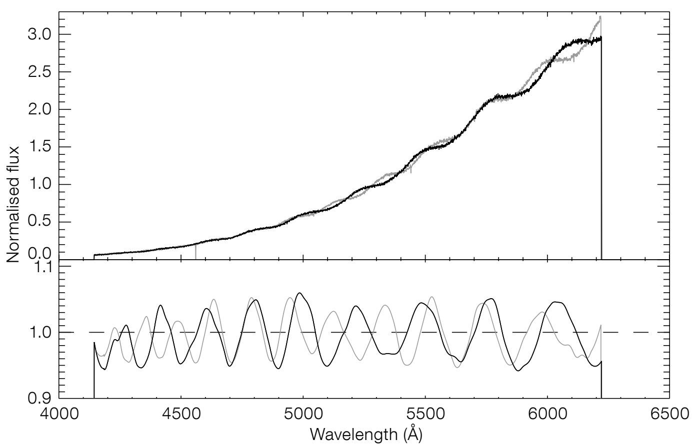


Figure 1. The fringe-like pattern in the VIMOS-IFU used with the HR Blue grism. Upper panel: Flat-field spectrum from a single spatial element (fibre) clearly showing the effects of the fringe-like pattern (black). Lower panel: the corresponding, normalised correction function for this fibre (black). In grey the flat-field spectrum and correction function are shown from the same spatial element but observed on a different night.

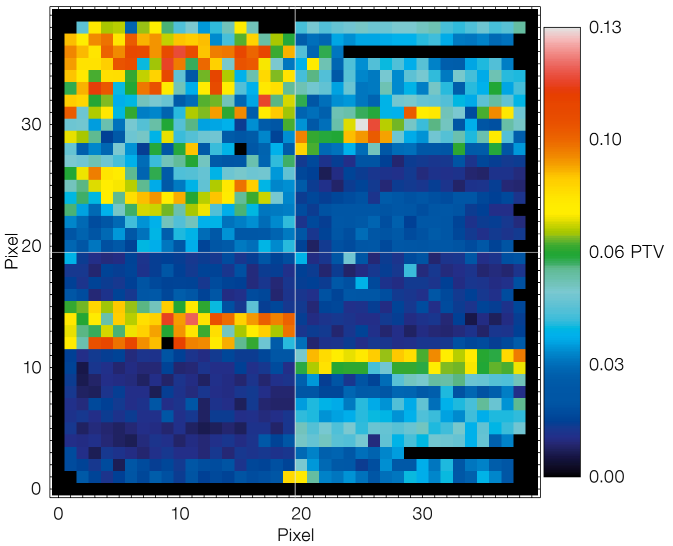
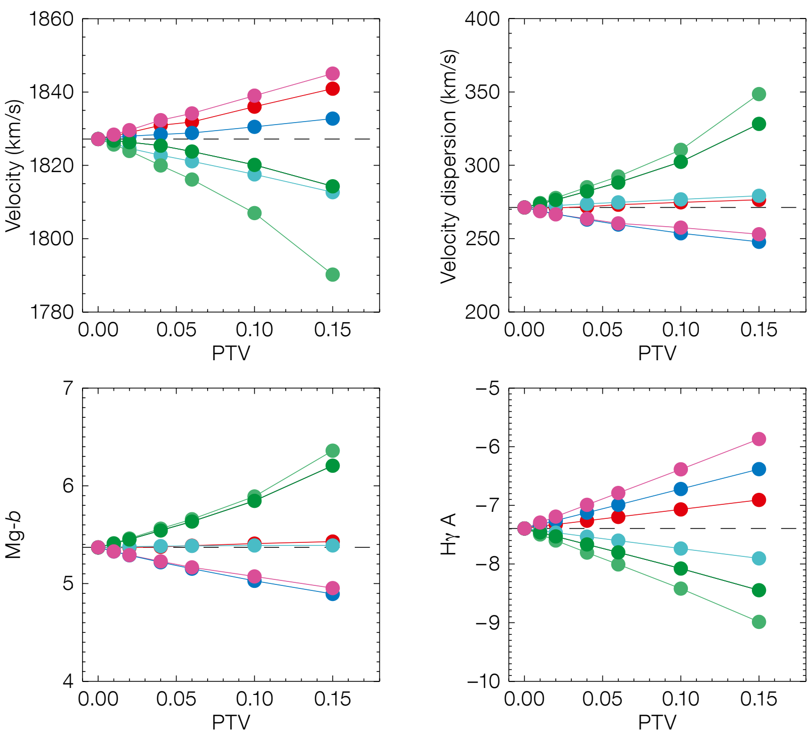


Figure 2. Spatial map of the maximum variations (PTV) in the correction spectra is shown as derived from a flat-field and the wavelength range 5188–5620 Å. Regions with a strong fringe-like pattern are clearly visible and related to distinct fibre modules. The white solid lines indicate the borders of the quadrants. Quadrant 1 is located at the top right, with quadrant numbers increasing counterclockwise.



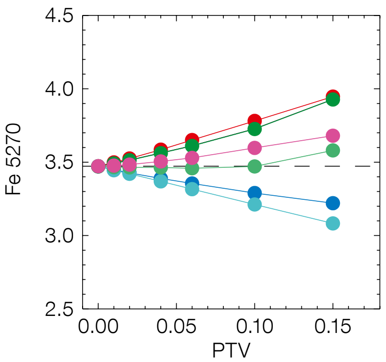


Figure 3. Simulations of the effects of the fringe-like pattern are shown. Changes in recession velocity, velocity dispersion and the line strength indices Mg-*b*, Hγ A and Fe 5270 are shown as function of the amplitude (peak-to-valley, PTV) of the fringe-like pattern here approximated by a sinusoid. Different colours indicate different phase shifts of the sinusoid, equally separated between 0 and 2 π. The shift in colour goes from dark green, red, magenta, blue, light blue, light green, back to dark green. The black dashed lines indicate the correct values given by the fringe-free galaxy spectrum.

from VIMOS-IFU data. Our method is constructed to work on data without strong intensity differences, such as early-type galaxies, which have a smooth surface brightness profile. The method was developed and tested on HR-Blue grism data (coverage 4015 –6200 Å) with the 27 by 27 arcsecond FoV.

Our method is applied on individual, fully reduced datacubes. The underlying assumption is that, to first order, the fringe-like patterns are localised, i.e. they are different between spectra that are spatially neighbouring on the sky. This is a reasonable assumption if the fringe-like pattern is caused by a pseudo-etalon associated with the fibre output prism. If all spectra have different fringe-like patterns, a median spectrum of eight spectra surrounding each spectrum (central spectrum) would be, to first order, free from the fringe-like pattern. This median spectrum can be used as an approximation of the underlying “true” spectrum, since the spectral properties of our targets vary relatively slowly as a function of spatial position and the signal in the spatially neighbouring spectra is correlated due to seeing. The ratio of the median spectrum to that of the central spectrum will provide an estimate of the fringe-like pattern, i.e. a correction spectrum that by construction has a mean of about one.

The correction spectrum is typically limited in signal-to-noise (S/N), and, since we are only interested in the overall shape of the correction spectrum, we smooth the spectrum using the *lowess* smoothing function within IDL, which is part of the IDL astronomy user’s library (Landsman, 1993). Taking into account the typical frequency of the pattern, we smooth the correction spectrum using a second order polynomial for each step of 150 pixels. For each spectrum in the datacube, a smoothed correction spectrum is constructed, except in the outermost corners and spectra neighbouring more than three dead fibres. We remove the fringe-like pattern from the datacube by dividing each spectrum by the corresponding smoothed correction spectrum. The end product is a datacube corrected for the fringe-like pattern.

Science impact

If the fringe-like pattern is not corrected, it can adversely affect the science derived from the data. The fringe-like pattern changes the continuum level in the spectra and will thus affect, for example, line-strength measurements. In the Lick/IDS system (Trager et al., 1998), absorption line strengths are measured by indices, where a central feature bandpass is flanked to the blue and red sides by pseudo-continuum bandpasses. The mean level of the two pseudo-continuum regions is determined independently on each side of the feature bandpass and a straight line is drawn through the midpoint of each one. The difference in flux between this line and the observed spectrum within the feature bandpass determines the index. If the continuum level is changed due to the fringe-like pattern across the range of the blue and red bandpasses, the derived values for the indices will be wrong. Furthermore, velocity and velocity dispersion measurements can also be affected, although to a lesser extent since these measurements are typically obtained from a larger wavelength range covering several periods of the fringe-like pattern.

In order to evaluate the effects of the fringe-like pattern on typical measurements, we constructed simple simulations obtained from IFU data of nearby early-type galaxies. In these simulations we approximated the fringe-like pattern with a sinusoidal function with varying phase and amplitude to illustrate how the differences will affect derived recession velocities, velocity dispersions and line strengths. In our simulations we changed the amplitude (PTV between 0% and 15%) and phase (between 0 and 2 π). We multiplied these different simulated fringe-like patterns into a galaxy spectrum free from the fringe-like pattern and measured the corresponding velocities, velocity dispersions and line strengths. The results are summarised in Figure 3. As expected, the exact location of the fringe-like pattern determines whether a given quantity is changed in a positive or negative direction. Even for large amplitudes, a negligible change is possible when the effects of the fringe-like pattern cancel out. For a typical amplitude of 5% (PTV = 10), the velocity measurement can be affected by up to ± 20 km/s, the velocity dispersion up to ± 40 km/s, the Mg-*b* line strength index by up to ± 0.5 Å, the Hγ A index up to ± 1 Å, and the Fe 5270 index up to ± 0.3 Å. We therefore conclude that for these typical amplitudes of the fringe-like pattern, there is a significant influence on the scientific analysis. However, while these above numbers are representative for individual exposures and single fibres, the combination of several dithered exposures or fibres will significantly mitigate the problem.

As mentioned earlier, our empirical method was constructed and tested on data with slowly varying spectral properties. For other types of data, such as with strongly varying background or low intensities (the fringe-like pattern scales with the intensity), a different approach should be preferred. In these cases it may be better to rely on the combination of several exposures; we would recommend the combination of about eight exposures thus mimicking the averaging effect used in our method.

References

Jullo, E. et al. 2008, in 2007 ESO Instrument Calibration Workshop, eds. Kaufer, A. & Kerber, F., 343
Lagerholm, C. et al. 2012, A&A, 541, 82
Landsman, W. 1993, in ASP Conf. 52, ADASS II, eds. Hanisch, R. J., Brissenden, R. J. V. & Barnes, J., 246
Le Fèvre, O. et al. 2003, Proc. SPIE, 4841, 1670
Trager, S. et al. 1998, ApJS, 116, 1

A colour image of the grand design Sc spiral galaxy NGC 6118 taken with VIMOS. Three images in *B*-, *V*- and *R*-bands were combined and the image size is 6.5 by 5.2 arcminutes. NGC 6118 hosted a recent core collapse supernova of Type Ib, SN 2004dk. See Picture of the Week potw1022 for more details.