Virtual Image Slicer Observations with X-shooter

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1. Abstract

By introducing a controlled amount of astigmatism in the VLT mirror control loop, the target light can be distributed along the X-shooter slits by up to 6". This virtual image slicer mode allows to increase the obtainable signal to noise ratio in a given exposure and to observe bright targets that would otherwise saturate. The basic functionality of this mode was tested for X-shooter. In this technical note we provide instructions on how to perform the observations. We discuss the data reduction using the ESO X-shooter pipeline and compare the reduced spectra with spectra obtained with the standard slit mode.

With the virtual image slicer mode it is possible to increase the exposure times up to 4 times to reach similar counts as with the standard slit mode. However, the gain in signal to noise ratio is only 10-30%. For average sky conditions (seeing in R band at zenith of 0.8”, CLR sky transparency), the bright limiting magnitudes in standard slit mode are about 1 mag for U-Z bands (UVB, VIS detectors) and about 3.5 mag in J-K bands (NIR detector) when using the narrowest slit widths. With the virtual image slicer mode, targets about 1.5 mag brighter in each waveband can be observed.

2. Observing Procedure

The observing procedure for the image slicer mode consists of the following steps:

a) The target acquisition is performed in the same way as for the standard slit observations using the XSHOOTER_slt_acq template.

b) Before the start of the science templates, the M1 mirror has to be deformed from the Telescope Control System to elongate the target. This is done from the Active Optics Control panel, where the “Virtual Slit” can be enabled and an amplitude and angle can be defined. The maximum amplitude for which stable guiding is possible is 6”. For the Cassegrain focus, an angle of 0° (RA-DEC enabled) causes the stellar light to be elongated along the slit for both SKY and ELEV modes.[1] Because the guide star is also elongated, a guiding box of 50 pixels, instead of the nominal 25 pixels, is required for stable guiding.

c) When the star appears elongated along the slit in the acquisition camera (Figure 1), one can start the science observations.

d) The data quality improves significantly when a sky observation at an offset position is obtained. It is therefore recommended to use the XSHOOTER_slt_obs_FixedSkyOffset science template.

[1] SKY: fixed slit position angle; ELEV: slit position angle set to parallactic angle at the start of the acquisition.

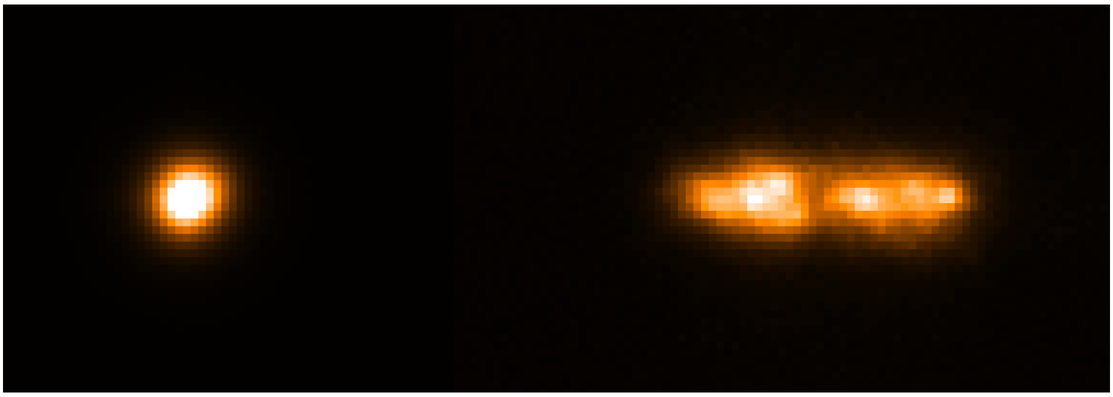

Figure 1: Target appearance in the acquisition camera for standard slit and virtual image slicer modes.

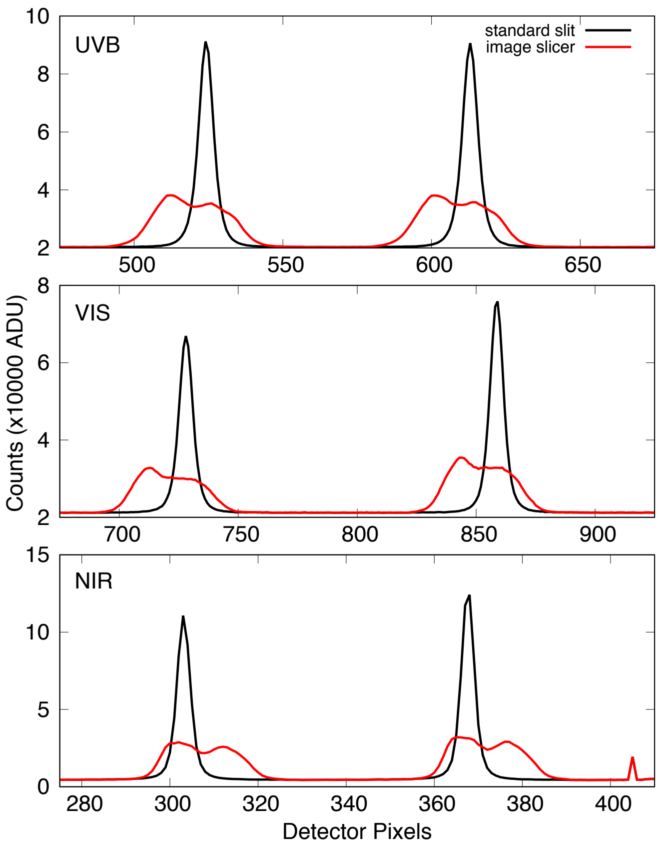

Figure 2: Cut across the raw images showing how the light is distributed along the slit in two echelle orders in the standard slit mode (black line) and the virtual image slicer mode (red line). Observations were conducted with the same exposure times. For the virtual image slicer observations, the target was 6” extended. The peak counts are 2-4 times less in the image slicer mode.

3. Bright limiting magnitudes and exposure times

We observed several bright stars (Table 2) with the narrowest slit widths (UVB=0.5", VIS=0.4", NIR=0.4") to determine the brightest stellar magnitudes that are observable with X-shooter without saturation for both the standard slit mode and the virtual image slicer mode. For the UVB (300-550 nm) and VIS (550-1000 nm) detectors the minimum exposure times are 0.1 s and for the NIR (1000-2500 nm) detector the minimum exposure time is 0.66 s. Under average sky conditions (seeing around 0.8" and CLR sky transparency) the bright limiting magnitudes for the UVB and VIS detectors are 1 mag for all wavebands and for the NIR detector 3.5 mag for all wavebands.

Under average sky conditions one obtains the same maximum count levels in the raw data for the standard slit mode and for the virtual image slicer mode with amplitude of 6" by increasing the exposure times by a factor of about 4 in the latter mode. Thus, for the virtual image slicer mode, the bright limiting magnitudes are about 1.5 mag brighter than for standard slit mode, i.e., -0.5 mag for the UVB and VIS detectors and 2 mag for the NIR detector. One can attempt to observe even brighter stars. A non-saturated spectrum could still be extracted, because the flux distribution along the slit in this mode is not uniform.

4. Pipeline reduction and data quality

The ESO X-shooter pipeline can reduce the virtual image slicer data with only little extra effort compared to the data reduction of standard slit mode observations.

In the virtual image slicer mode the spatial extension is amplitude (max 6") + seeing, which for large amplitudes makes the sky subtraction difficult. It is thus recommended to obtain sky observations at an offset position. For the object localization and extraction of one-dimensional spectra, best results are achieved by using the *localize-method*=MANUAL and by adjusting the central position *localize-slit-position* and the half size *localize-slit-hheight* in accordance with the obtained data set.

Figure 3 compares the reduced two-dimensional frames for the standard slit mode and the virtual image slicer mode. Figure 4 shows reduced spectra obtained with the virtual image slicer mode, with and without sky subtraction. A sky observation at an offset position improves the data quality significantly and increases the signal to noise ratio by 90% or more. We thus recommend to use the XSHOOTER_slt_obs_FixedSkyOffset science template.

Figure 4 also compares reduced UVB, VIS, and NIR spectra for the standard slit mode and the virtual image slicer mode observations. In both modes offset sky observations were obtained. Increasing the exposure times by a factor of 4 in all three arms leads to similar maximum count levels in both modes under average sky conditions. However, the signal to noise ratio increases only by 10-30%. This is because the flux is not distributed with a constant count level across the slit. The resolving power and wavelength calibration do not show any significant changes between the standard slit and the virtual image slicer modes.

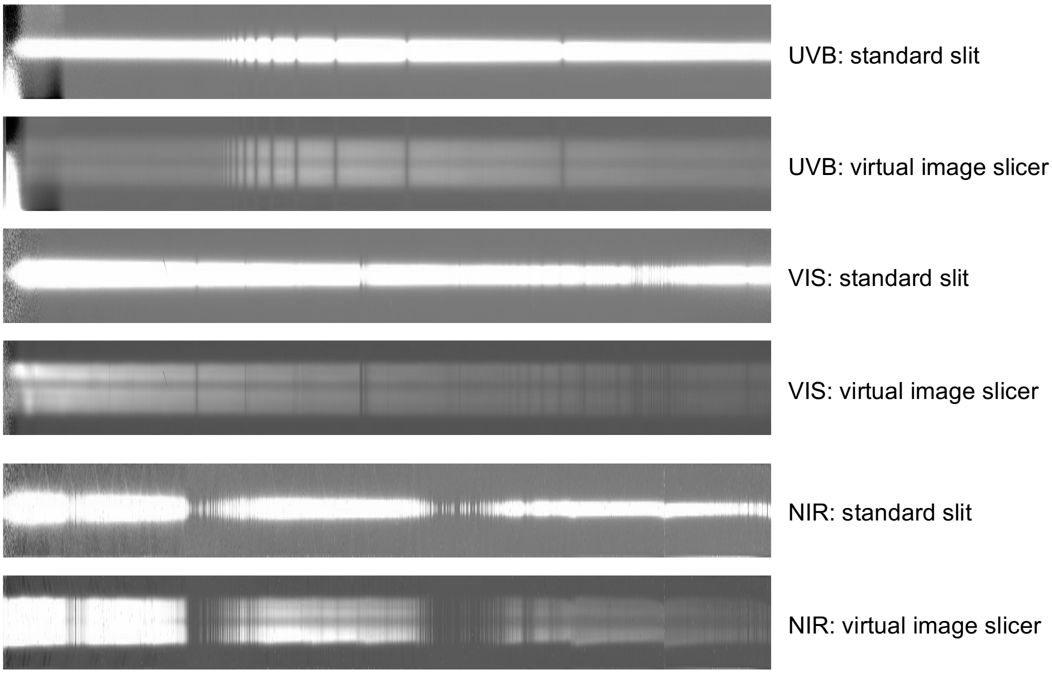

Figure 3: Reduced two-dimensional images for standard slit mode and virtual image slicer mode observations.

5. Summary

The virtual image slicer mode spreads the light of an object over more detector pixels, allowing for higher exposure times by a factor of about 4. However, the increase in signal to noise ratio obtainable in one frame is only 10-30% (measured in reduced spectra). Bright targets, which would otherwise saturate when observed with X-shooter, are observable with the virtual image slicer mode. The bright limiting magnitude at all wavebands is increased by 1.5 mag, i.e., in the UVB and VIS arms from 1 mag to -0.5 mag and in the NIR arm from 3.5 mag to 2 mag.

It is recommended to observe a sky observation at an offset position. The ESO X-shooter data reduction pipeline is able to reduce the data obtained in the virtual image slicer mode with only little extra effort. The resolving power and the wavelength calibration are very stable and without considerable changes compared to the standard slit mode.

A feature to be aware of is that for the virtual image slicer mode the peak counts in consecutive raw frames vary by about 10% for short exposures with the narrowest slit widths. This is due to fluctuations in the flux distribution along the virtual slit, which make the extended stellar light patch appear to flicker. Relative flux measurements are therefore not possible with the virtual slit (or at least significantly less accurate than in standard slit mode).

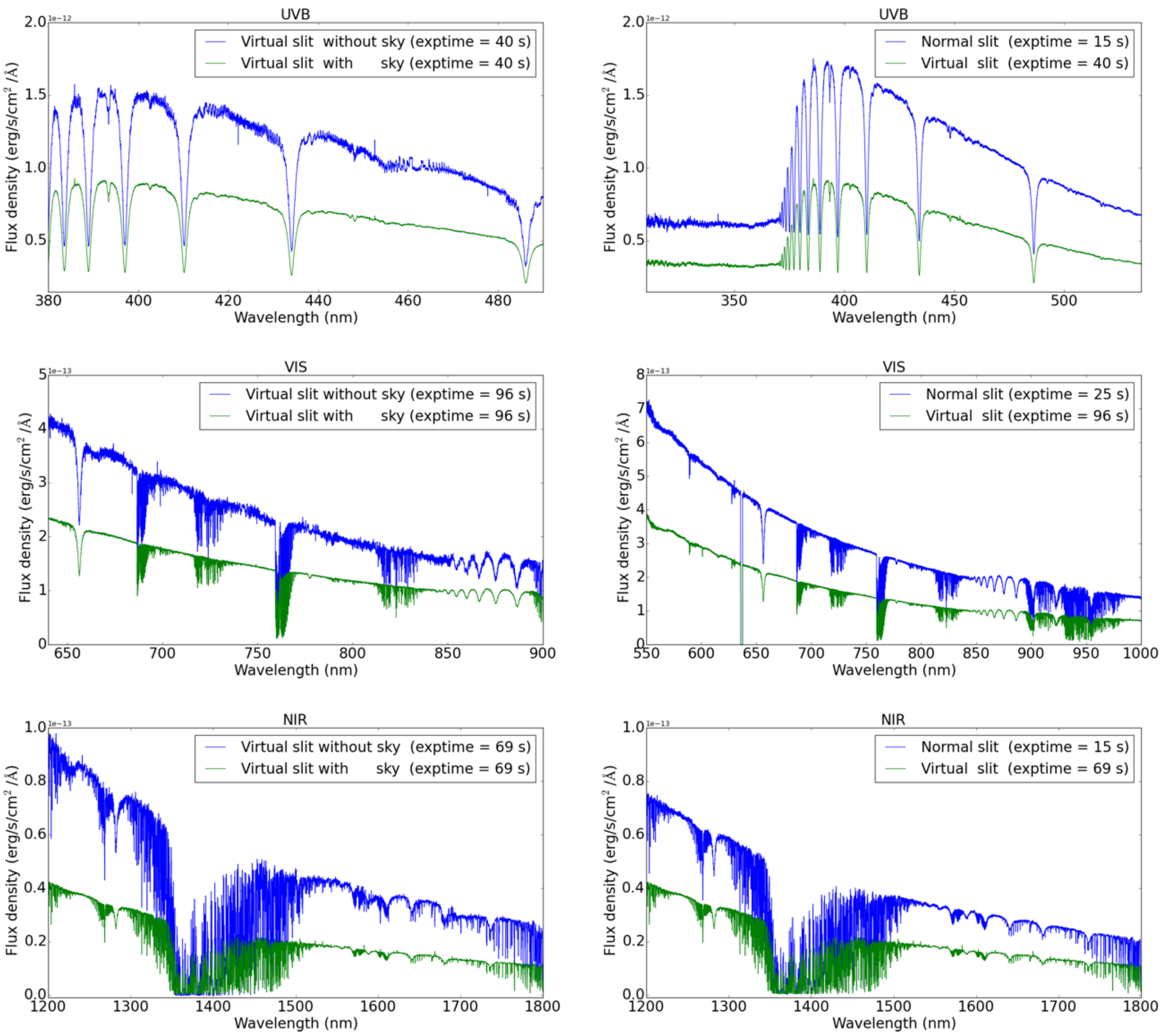

Figure 4 Left: Comparison of reduced UVB, VIS, and NIR spectra obtained with the virtual image slicer mode, with and without an offset sky observation. Sky subtraction with an offset sky position is increasing the signal to noise ratio significantly: at 400 nm by 90%, at 665 nm by 140%, and at 1625 nm by 110%. Right: Comparison of the reduced UVB, VIS, and NIR spectra for standard slit mode and virtual image slicer mode observations (both with offset sky observation). The same count levels are reached for both modes with virtual slit exposure times 4 times as long as for the standard slit mode. The increase in signal to noise ratio is only 10-30%.

Table 1: Observing log of HD 27528 on 2016 January 14. The seeing in R band at zenith was about 0.7” and the sky was CLR. The smallest slit widths were used (UVB=0.5”, VIS=0.4”, NIR=0.4”). The star has a spectral type of B9V and magnitudes are about 6.8 mag in the B, V, J, H, K bands. The signal to noise ratio was determined at 405 nm (UVB), 665 nm (VIS), 162.5 nm (NIR).

Mode	ARCFILE	SEQ.ARM	Exptime (s)	Max. counts	Max. counts per sec	S/N
slit	XSHOO.2016-01-14T00:37:19.537.fits	NIR	15	10000	667	234
slit	XSHOO.2016-01-14T00:37:11.459.fits	UVB	15	12000	800	150
slit	XSHOO.2016-01-14T00:37:16.670.fits	VIS	25	12000	480	274
slit (with sky)	XSHOO.2016-01-14T00:56:25.837.fits	NIR	15	2000	133	221
slit (with sky)	XSHOO.2016-01-14T00:56:17.842.fits	UVB	15	3700	247	141
slit (with sky)	XSHOO.2016-01-14T00:56:23.013.fits	VIS	25	3600	144	183
virtual slit	XSHOO.2016-01-14T00:41:47.323.fits	NIR	69	10000	145	71
virtual slit	XSHOO.2016-01-14T00:46:32.537.fits	NIR	86	10000	116	87
virtual slit	XSHOO.2016-01-14T00:50:02.117.fits	NIR	86	10000	116	67
virtual slit	XSHOO.2016-01-14T00:41:38.873.fits	UVB	40	8000	200	69
virtual slit	XSHOO.2016-01-14T00:46:24.089.fits	UVB	63	11000	174	88
virtual slit	XSHOO.2016-01-14T00:49:53.998.fits	UVB	63	11000	174	84
virtual slit	XSHOO.2016-01-14T00:41:44.034.fits	VIS	96	9400	98	101
virtual slit	XSHOO.2016-01-14T00:46:29.299.fits	VIS	115	9500	83	98
virtual slit	XSHOO.2016-01-14T00:49:59.198.fits	VIS	115	8300	72	95
virtual slit (with sky)	XSHOO.2016-01-14T01:03:22.241.fits	NIR	69	4000	58	186
virtual slit (with sky)	XSHOO.2016-01-14T01:03:14.409.fits	UVB	40	4000	100	128
virtual slit (with sky)	XSHOO.2016-01-14T01:03:19.589.fits	VIS	96	4600	48	243

Table 2: Other targets used for testing during the nights of 9-15 January 2016. Seeing conditions varied between 0.7" and 2". The observations were used to determine the bright limiting magnitude in all bands for standard SLT mode and virtual image slicer mode. All observations were conducted with minimum integration times, i.e., 0.1 s for UVB and VIS arm and 0.66 s for NIR arm, and the narrowest slit widths (UVB=0.5", VIS=0.4", NIR=0.4"). The data are not public.

Target	Spectral Type	Magnitudes (mag)
HD 13709 (mu. For)	B9V	BVIJHK ~ 5.3
HD 12438 (pi. For)	G5III	B=6.2, V=5.4, J=3.7, H=3.3, K=3.2
HD 20720 (tau04 Eri)	M3/M4III	U=7.1, B=5.3, V=3.7, R=2.1, I=0.7, J=-0.0, H=-0.8, K=-1.1
HD 29291 (ups02 Eri)	G8+III	U=5.5, B=4.8, V=3.8, R=3.1, I=2.6, J=2.3, H=1.8, K=1.7
HD 19349	M3III	B=6.9, V=5.3, J=1.6, H=0.7, K=0.4
HD 25025 (gam Eri)	M0III-IIIb	U=6.5, B=4.5, V=2.9, R=1.7, I=0.7, J=0.1, H=-0.7, K=-0.9
HD 10144 (alf Eri)	B6Vpe	U=-0.4, B=0.3, V=0.5, R=0.5, I=0.6, J=0.8, H=0.9, K=0.9
HD 35468 (gam Ori)	B2V	U=0.5, B=1.4, V=1.6, R=1.7, I=2.0, J=2.2, H=2.2, K=2.3
HD 48915 (alf CMa, SIRIUS)	A1V+DA	U=-1.5, B=-1.5, V=-1.5, R=-1.5, I=-1.4, J=-1.4, H=-1.3, K=-1.4
HD 45348 (alf Car)	A9II	U=-0.5, B=-0.6, V=-0.7, R=-1.0, I=-1.1, J=-1.2, H=-1.3, K=-1.4
HD 17824 (tau02 Eri)	K0III	U=6.3, B=5.7, V=4.8, R=4.1, I=3.6, J=3.2, H=2.8, K=2.7
HD 16212 (80 Cet)	M0III	B=7.2, V=5.5, J=2.2, H=1.4, K=1.2
HD 12274 (ups Cet)	K7III	U=7.5, B=5.6, V=4.0, R=2.8, I=1.7, J=1.1, H=0.3, K=0.1
HD 34085 (bet Ori)	B8Iae	U=-0.6, B=0.1, V=0.1, R=0.1, I=0.2, J=0.2, H=0.2, K=0.2