Characterization of the X-shooter IFU mode

Document Number: ESO-203117

Document Version: 2

Document Type: Report

Released On: 2017-08-29

Document Classification: ESO Public

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Change Record from previous Version

Affected Section(s)	Changes / Reason / Remarks
All	2017-08-29, 1st version

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1. Introduction

1.1 Scope

The X-shooter IFU mode is not scientifically competitive. The main reason seems to be the lack of science-ready data cubes produced by the ESO X-shooter pipeline. There is also not much information regarding the characteristics of this mode. In this report we provide some recommendations on which calibrations need to be taken in order to be able to reconstruct the data cube with the correct spatial information and how to reduce the data as either IFU data (cube reconstruction) or image slicer data (collecting light).

1.2 Definitions, Acronyms and Abbreviations

This document employs several abbreviations and acronyms to refer concisely to an item, after it has been introduced. The following list is aimed to help the reader in recalling the extended meaning of each short expression:

TBC	To Be Clarified
TBD	To Be Defined
IFU	Integral Field Unit
ADC	Atmospheric Dispersion Compensator

2. Related Documents

2.1 Applicable Documents

The following documents, of the exact version shown, form part of this document to the extent specified herein.

AD1 X-shooter User Manual;
VLT-MAN-ESO-14650-4942

AD2 X-shooter Pipeline Manual;
VLT-MAN-ESO-14650-4840

AD3 Reflex X-shooter Tutorial;
VLT-MAN-ESO-19540-5899

3. IFU: reconstruction of the data cube or light bucket?

The X-shooter Integral Field Unit is an image slicer that re-images an input field of 4”x1.8” into a pseudo-slit of 12”x0.6”. The light from the central slice is directly transmitted to the spectrographs. The two lateral sliced fields are reflected toward two pairs of spherical mirrors and realigned at both ends of the central slice in order to form the exit slit. This involves four reflections and thus the throughput of the two lateral fields is reduced with respect to the directly transmitted central one. The measured overall efficiency of the two lateral slit-lets is ~85% of the direct transmission, but drops to ~50% below 400 nm due to reduced coating efficiency in the blue.

3.1 Data cube reconstruction

The X-shooter IFU design makes image reconstruction a very difficult task. The fluxes coming from the two outside slices are rotated and aligned to the central slice before entering the spectrograph slits. When re-constructing the cube, the inverse operation needs to be done. The accuracy of the offsets used to perform the vertical alignment of the external slices to the central one is critical. These offsets have a strong dependency on both the rotator angle and the telescope inclination. In addition, the IFU does not work with the ADCs and thus the data is affected by atmospheric differential refraction. The wavelength dependent spatial location can be properly calculated in the case of a bright stellar source where one can identify the position of the stellar centroid. For extended sources, this is however very complicated. In these cases, in order to retrieve the correct spatial information and reconstruct the data cube, a bright star as close as possible to the position in the sky of the target should be observed immediately before and/or after the scientific observation is concluded.

A very good description of X-shooter IFU observations and data reduction can be found in Flores et al. (2011, AN, 332, 288). The authors describe in detail how to identify the sub-slits, correct for the atmospheric differential refraction, residual deformations, the slit geometry, flux-calibrate the data, and construct the data cubes.

3.2 Efficiency of the IFU as a light bucket

We obtained observations of B-type stars in IFU and in SLT STARE modes at low (~1.0) and high (~1.5) airmass. The SLT observations were obtained with slit widths of UVB=0.5”, VIS=0.7”, NIR=0.6” and UVB=1.0”, VIS=0.9”, NIR=0.9”. The R-band seeing at zenith at the time of the observations was about 1.2-1.3”. The data were reduced with the ESO X-shooter pipeline (v2.9.1). From the IFU data cubes, spectra were extracted with an aperture of 3x5 pixels and also the full cube was collapsed (3x26 and 3x20 pixels). The 3x5 pixel extraction is a fairer comparison to the SLT data and much less noisy than the spectra of the full cube. Figure 1 shows a comparison of SLT and IFU spectra at both high and low airmass. In Table 1 we compare the flux gain in IFU mode compared to SLT mode.

For each arm, the highest gain when using the IFU compared to SLT mode is seen for the narrow slits and at low airmass. The IFU provides the least improvement for the NIR arm since the seeing decreases with larger wavelengths. At high airmass, large flux losses occur in IFU mode since no ADC can be used in this mode.

To use of the X-shooter IFU mode to collect more light, but still maintain high spectral resolving power, is only efficient for a very limited user case. Only in the case a user requires the highest spectral resolving power (R = 8000 in UVB, R = 13000 in VIS), the target is observable at low airmass, and good sky subtraction is not required, we recommend the usage of the IFU mode as a light collector. In case good sky subtraction is required, it is always more efficient for point sources to use the SLT,NODDING mode rather than the IFU,OFFSET mode, where half of the observing time is spend on sky only.

The IFU data can be reduced using the IFU recipes of the ESO X-shooter pipeline. This will produce data cubes from which spectra can be extracted. For a better reduction, however, we recommend to reduce each of the three slices separately with the SLT mode recipes and with a manual localization of source and sky. Sky subtraction is difficult, because there is only about 1” of sky around the target trace.

4. Recommendations

1. The IFU cube reconstruction with precise spatial information is very difficult. The ESO X-shooter pipeline does not provide science-ready data cube products. For observations of extended or faint sources, a bright star not further than 2-3 degrees from the main target should be observed before and/or after the main science target and with the same rotator angle. This will allow to re-construct the IFU geometry. A detailed description of X-shooter IFU observations and data reduction can be found in Flores et al. (2011, AN, 332, 288). Alternative instruments such as MUSE and SINFONI should be considered.

2. The user cases where the IFU as a light bucket, i.e., to collect more light than in SLT mode at high spectral resolving power, provides a gain are very limited. Only for STARE observations at low airmass and poorer than average seeing conditions leads the usage of the IFU mode to a gain in terms of flux compared to the SLT mode.

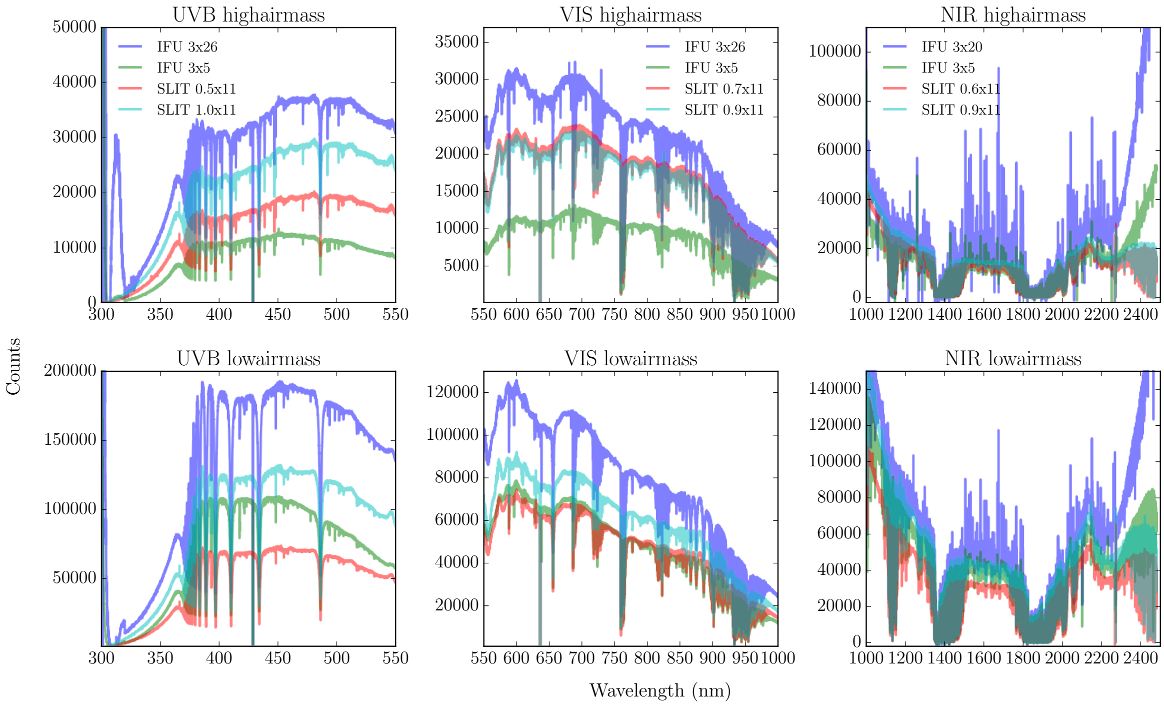

Figure 1 Comparison of SLT and IFU spectra at both high and low airmass.

Arm	Conditions	Slit Width	Median flux gain using the IFU (3x5 pixel extraction)	Median flux gain using the IFU (3x26 pixel extraction)
UVB (350-500nm)	Low air mass	0.5x11	1.5	2.7
		1.0x11	0.8	1.5
	High air mass	0.5x11	0.6	1.9
		1.0x11	0.4	1.3
VIS (550-1000nm)	Low air mass	0.7x11	1.0	1.6
		0.9x11	0.8	1.3
	High air mass	0.7x11	0.5	1.3
		0.9x11	0.6	1.3
NIR (1000-2200nm)	Low air mass	0.6x11	1.3	1.5
		0.9x11	0.9	1.1
	High air mass	0.6x11	0.9	1.3
		0.9x11	0.8	1.1

Table 1: Gain in flux when using IFU compared to SLT mode.

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