p3d — A Data Reduction Tool for the Integral-field Modes of VIMOS and FLAMES

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The second release of the data reduction tool p3d now also supports the integral-field modes of the ESO VLT instruments VIMOS and FLAMES. This article describes the general capabilities of p3d and how its different tools can be invoked, with particular reference to its use with data from VIMOS and FLAMES.

p3d is a general and highly automated data reduction tool for fibre-fed integral field unit (IFU) spectrographs. Based on an early proprietary version, p3d was rewritten from scratch to be more versatile, user-friendly, extendable and informative (Sandin et al., 2010). The first release supported four IFUs: the lens array and PPAK of the PMAS spectrograph at the Calar Alto Observatory; SPIRAL at the AAOmega spectrograph at the Australian Astronomical Observatory; and VIRUS-P at the McDonald Observatory. The second release of p3d supports most of the remaining instruments, including the four higher resolution IFU modes of VIMOS (HR-Blue, HR-Orange, HR-Red, and MR), as well as all the setups for the three IFU modes of FLAMES (ARGUS, and the two sets of mini IFUs).

Data reduction features

All the reduction capabilities of p3d, with supporting test studies, are described in detail in Sandin et al. (2010). p3d itself is available at the project website[1]. In Table 1 we outline the available features of p3d and the two ESO pipelines for VIMOS (version 6.2) and FLAMES (i.e. GIRAFFE; version 2.8.7). Cosmic-ray hits in single images, or in images that cannot be combined, are not removed by p3d. Instead, for ESO data, we recommend

Feature	ESO pipelines	p3d
Logging, at different levels of verbosity	x	x
Configuration by a plain text file	x	x
Combination of raw-data images	partly	all recipes
Dark current subtraction	x	–
Spectrum extraction: regular/deconvolution methods	x/–	x/2
Spectrum extraction: subtraction of a scattered-light component	–	x
Fully automatic spectrum tracing	x	x
Creation of a dispersion mask	automatic	interactive
Flat-field normalisation	partly	x
Flux calibration	x	–
Full error propagation	partly	x
Interactive inspection of intermediate and final products	–	x
Reduction using a GUI/scripts	x/x	x/x

Table 1. Comparison between features of p3d and the IFU modes of the ESO VIMOS (version 6.2) and FLAMES (version 2.8.7) pipelines.

using the DCR program (Pych, 2004) first, and thereafter, if required, combining the resulting images in p3d using an average. All extracted images of p3d are accompanied by an error image.

By default p3d shows graphical results of the spectrum tracing, the cross-dispersion profile fits (used later when deconvolving overlapping spectra), the quality of the dispersion solution, and the optimally extracted spectra. Figure 1 shows an example. This makes it easy to check that the outcome is correct and satisfactory; and if it is not these plots will quickly provide important clues for a

solution to the problem. p3d comes with an integrated spectrum viewer that works with any IFU (row-stacked) spectrum image, together with a fibre position table.

The algorithms used in p3d are described in Sandin et al. (2010). With this new release all parts of p3d are now thoroughly documented. The installation procedure is described in the distribution README file, and the various recipes are, together with all the options, described in detail in the headers of the respective files. A more appealing version of the same documentation is available at the project
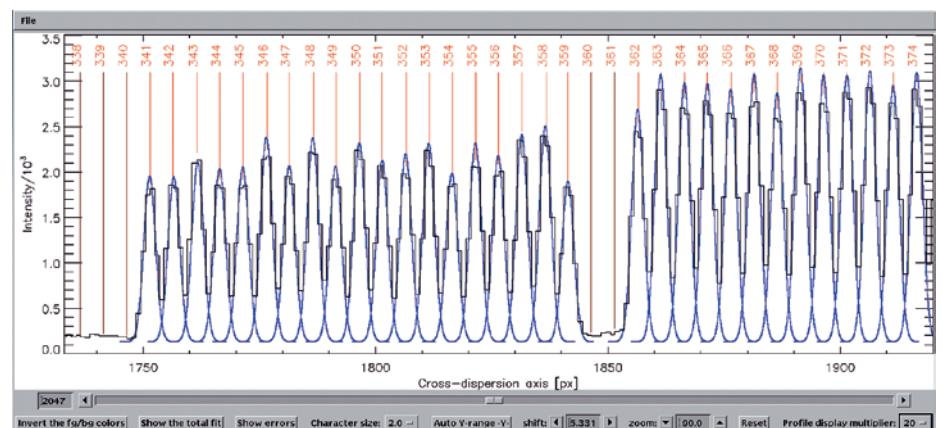

Figure 1. The fitted cross-dispersion line profiles for a set of the spectra in the VIMOS fourth quadrant (with grism HR-orange). The different lines are: intensity (in raw counts) at the middle column of the bias-subtracted continuum image (black line); the fitted Gaussian profiles (blue lines); the initial position of each spectrum (vertical red lines); and the vignetted spectra, which were not fitted (vertical blue lines).

```
<ob900000.sh>
#!/bin/bash

cpath=`pwd`
path="/data/user/VLT-P87/C/2011-04-27"
cd $path

name="ngc1-hr-blue-T1-1a"
parfile="${p3d_path}/data/instruments/vimos/nvimos_hr.prm"
userparfile="../p3dred/user_p3d.prm"
opath="../p3dred/odata/$name"
mkdir -p $opath

df1="\
VIMOS_IFU_OBS117_0001_B.1.fits.gz,\
VIMOS_IFU_OBS117_0002_B.1.fits.gz,\
VIMOS_IFU_OBS117_0003_B.1.fits.gz,\
VIMOS_IFU_OBS117_0004_B.1.fits.gz"
group=1,1,1,2 # Files 1-3 are combined, file 4 is used single

# Extracting the object spectra for quadrant 1:
logfile="../p3dred/logs/dred_${name}_objx_q1.log"
masterbias="../p3dred/odata/VIMOS_SPEC_BIAS118_0001_B_mbias1.fits.gz"
tracemask="${opath}/VIMOS_IFU_LAMP118_0001_B_imcmb1_trace1.fits.gz"
 dispmask="${opath}/VIMOS_IFU_WAVE118_0001_B.1_dmask1.fits.gz"
flatfield="${opath}/VIMOS_IFU_LAMP118_0001_B_imcmb1_flatf1.fits.gz"
${p3d_path}/vm/p3d_cobjex_vm.sh $df1 $parfile masterbias=$masterbias \
 tracemask=$tracemask dispmask=$dispmask flatfield=$flatfield \
 userparfile=$userparfile opath=$opath detector=0 \
 logfile=$logfile loglevel=2 group=$group & \
# Click away the popup window (for a 1600x1200 screen):
sleep 1 && xdotool mousemove 800 600 && xdotool click 1
```

```
<ob900000.pro>

cd,cur=cpath
path='/data/user/VLT-P87/C/2011-04-27'
cd,cpath

name='ngc1-hr-blue-T1-1a'
parfile=!p3d_path+'/data/instruments/vimos/nvimos_hr.prm'
userparfile='../p3dred/user_p3d.prm'
opath='../p3dred/odata/'+name
file_mkdir,opath

df1=[, $
 'VIMOS_IFU_OBS117_0001_B.1.fits.gz', $
 'VIMOS_IFU_OBS117_0002_B.1.fits.gz', $
 'VIMOS_IFU_OBS117_0003_B.1.fits.gz', $
 'VIMOS_IFU_OBS117_0004_B.1.fits.gz']
group=[1,1,1,2] ; Files 1-3 are combined, file 4 is used single

; Extracting the object spectra for quadrant 1:
logfile='../p3dred/logs/dred_'+name+'_objx_q1.log'
masterbias='../p3dred/odata/VIMOS_SPEC_BIAS118_0001_B_mbias1.fits.gz'
tracemask=opath+'/VIMOS_IFU_LAMP118_0001_B_imcmb1_trace1.fits.gz'
 dispmask=opath+'/VIMOS_IFU_WAVE118_0001_B.1_dmask1.fits.gz'
flatfield=opath+'/VIMOS_IFU_LAMP118_0001_B_imcmb1_flatf1.fits.gz'
p3d_cobjex,df1,parfile,masterbias=masterbias, $
 tracemask=tracemask,dispmask=dispmask,flatfield=flatfield, $
 userparfile=userparfile,opath=opath,detector=0, $
 logfile=logfile,loglevel=2,group=group
```

Figure 2. An example of a script that can be used to extract object spectra in VIMOS data. The script on the left-hand (right-hand) side is used from the shell (IDL command line).

website[1]; these web pages are updated with each new release.

p3d is based on the Interactive Data Language (IDL)[2], which must be installed on the system. All computing platforms supported by IDL can be used with p3d. There are three ways to invoke p3d. The first is through the graphical user interface (GUI), which can be started either from the IDL command line or using the shell script provided. This approach corresponds to the ESO tool Gasgano. The second is to run the individual recipes from the command line, and the third is to use the shell scripts provided; this last approach most closely corresponds to the ESO tool Esorex. The shell scripts use the IDL Virtual Machine together with the compiled binary files that are provided, with or without an IDL license. The shell scripts work on all platforms with a bash shell.

The GUI method is an easy entry point for the new user. By comparison, the two script methods allow the more experienced user to save time, since she or he can simply execute the scripts anew,

after any change to the procedure or the code. Figure 2 shows an example of a simple script, using both methods, which can be used to reduce VIMOS data.

Details regarding VIMOS and FLAMES

When p3d is used with FLAMES and VIMOS some care is required in the configuration procedure to produce the most accurate outcome possible. We emphasise that the required modifications are small when comparing data that were extracted either before or after the respective refurbishments (cf. Hammersley et al., 2010; Melo et al., 2007). Here we note the details of each instrument separately, beginning with VIMOS.

VIMOS

With VIMOS data the reduction is done for each of the four quadrants individually. The data from the four quadrants are combined in a final step — after the data have been flux calibrated — to produce a datacube image with all 1600 spectra. Data from quadrants one, two and four,

are all traced well, without any required user interaction. The third quadrant sometimes requires a manual parameter adjustment to trace all the spectra properly; this is caused by the spectrum pattern, which is less well defined than in the other quadrants. The tracing plots show that the tracing procedure sometimes misses one spectrum in the last group of spectra. With pre-refurbishment data, a similar problem is only found in data from the fourth quadrant. The scattered-light subtraction should be used in all spectrum extraction procedures to set the zero background level properly; we recommend a zeroth-order polynomial fit.

We found that the first-guess dispersion solution of p3d allows the emission lines that are required to create an accurate dispersion mask to be easily identified for all grism setups and quadrants. For our data from P86 (PI: Lundqvist), the maximum residual (for HR-blue and HR-orange) between the true wavelength and the fitted wavelength of any arc line was 0.002–0.007 nm for a fifth-order polynomial. Larger residuals are found in
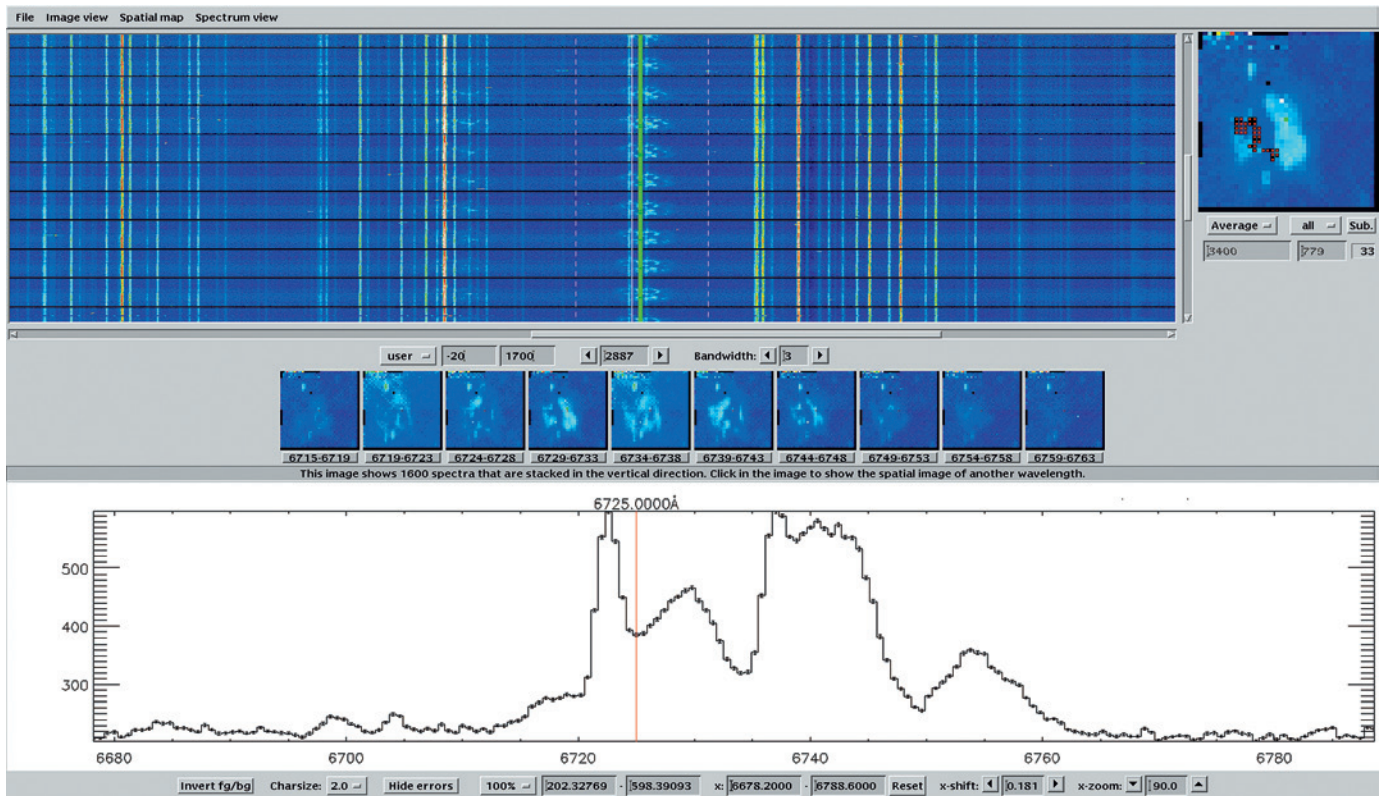
Figure 3. The p3d spectrum viewer showing an extracted datacube, where all four quadrants of VIMOS have been combined. The four different panels show: the spectrum image (upper left); the spatial map at a selected wavelength (upper right; north is up and east left); ten stored spatial maps of different wavelengths (middle panels); the selected spectrum, in this case the average of the 33 spectra that are marked in the spatial map (bottom panel).

low-transmission spectra. We also found that the highest accuracy level can be achieved in more spectra if cosmic-ray hits are removed in the arc image before creating the dispersion mask.

Noise reduction is a good reason to replace an extracted flat-field image with a smoothed version. Such a replacement proved impossible with VIMOS, due to the strong fringing at red wavelengths. With the new data the fringing effects are smaller, but still present. The default is therefore to avoid any smoothing of the flat-field image. Moreover, if twilight flat-field images are available, it is possible to use their transmission correction and correct the data further. In Figure 3 we show the spectrum viewer display for an extracted and combined dataset of a supernova remnant (using HR-orange).

The data were not flux-calibrated, but the data from the separate quadrants were re-normalised using the mean flat-field spectrum of each quadrant.

FLAMES

The three different IFU modes of FLAMES use the same instrument configuration file. Since there is only one detector, all spectra are reduced at once. We have found that the tracing works well in all cases, although the last sky fibre is always outside the CCD. The calibration fibres are reduced along with the other fibres, but are never used by p3d. Furthermore, p3d provides a linear first-guess dispersion solution for the same set of arc lines that is used by the GIRAFFE pipeline. However, in order to enable easy identification of all the arc lines to be used, it is advisable to re-

strict the set of arc lines to the brightest before the reduction is begun. In our data from P83 (programme ID 083.B-0279, PI: Neumayer), the maximum residual, between the true wavelength and the fitted wavelength of any arc line, is constant at about 0.005–0.006 nm, for a fourth-order polynomial using about 20 lines and the LR02 setup. While the fringing effects in the red wavelength range are lower with the refurbished instrument than previously, one should still not smooth the flat-field data to remove the fringes more completely.

Our reduced data of the nuclear region of the galaxy NGC 3621 were fitted with stellar population models and are shown in Figure 4; specifically we used the pixel-fitting code PARADISE (Walcher et al., 2009), as well as a preliminary version of
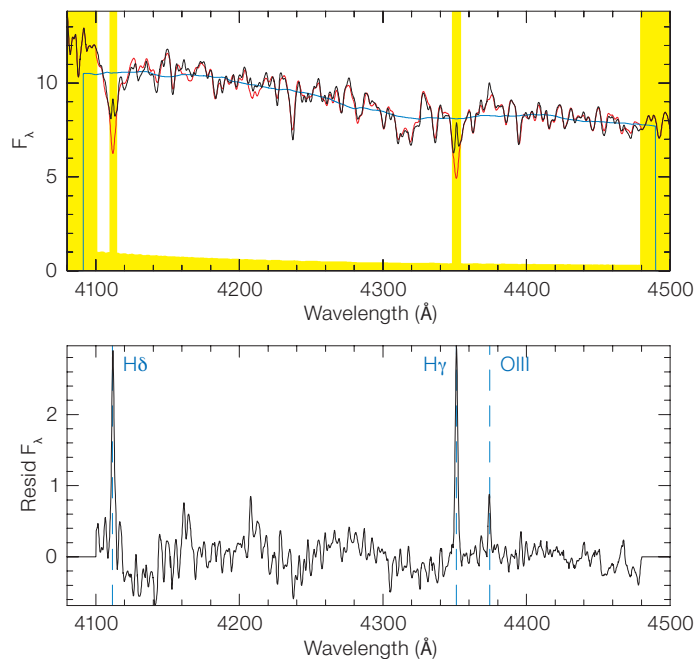
Figure 4. A spectrum of the circum-nuclear disc of the galaxy NGC 3621. The data (black line) are fitted with a stellar population model (red line). The blue line is the continuum used to normalise the data. Yellow areas mark wavelengths masked from the fit. The lower panel shows the fit residuals.

VIMOS–IFU (Monreal-Ibero et al., 2005). While the new version of p3d already contains a high level of functionality, there are many features that could still be included. For example, flux calibration, automated dispersion-mask creation, and an integrated line-fitting tool. With sufficient interest from the community we would consider adding full support also for the two remaining fibre-fed IFUs, *viz.* IMACS (Magellan) and Integral (WHT).

References

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Walcher, C. J. et al. 2009, MNRAS, 398, 44

the Charlot & Bruzual (in prep.) stellar population model (see Gonzalez et al., 2010). The lower panel shows the residuals of the fit, i.e. a pure emission line spectrum. Note the presence of [O III] at 436.3 nm and of Wolf–Rayet features at 415–422 nm. This plot demonstrates the excellent quality of the data and of the reduction procedure, allowing even the faintest features to be identified reliably.

Both VIMOS and FLAMES benefit from optimal extraction. The associated profile-fitting stage in p3d makes use of modern multi-core workstations for improved processing speed. Instrument-specific guidelines on how to tailor the extraction are provided on the p3d Wiki[3].

Outlook

The old version of p3d has already been used successfully to reduce and publish data from various instruments (Roth et al., 2004) — including first data from the

Links

[1] p3d project website: http://p3d.sourceforge.net.
[2] IDL can be downloaded free from: http://www.ittvis.com.
[3] p3d Wiki: http://sourceforge.net/apps/mediawiki/p3d/index.php?title=Main_Page

MPG/ESO 2.2-metre telescope image of the spiral galaxy NGC 3621 taken with the Wide Field Imager (WFI). NGC 3621 is a nearby Sd galaxy with a high inclination, situated at a distance of 6.2 Mpc. The centre hosts a Seyfert 2 active galactic nucleus and a nuclear star cluster. The colour image was formed from broad-band (*B*, *V* and *R*) and narrowband ([O III] and Hα) images selected from the ESO archive by Joe DePasquale as part of the *Hidden Treasures* competition (Hainaut et al. 2011, *The Messenger*, 143, 57). See image eso1104a for more details.