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VIMOS Final Design Review

Part J: Chapter 5

Exposure Time Calculator and Image Simulator Design Description

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1. INTRODUCTION

The Visible Multi Object Spectrograph for the VLT (VIMOS) is a wide filed survey spectrograph built by the VIRMOS Consortium and planned for installation at one Nasmyth focus of the third Unit Telescope.

1.1. PURPOSE

This document contains the design description of an ETC/Simulator for VIMOS and is intended to provide all the necessary informations for the implementation and for the preparation of the test procedures.
The design uses as input function specifications given in [4].

1.2. SCOPE

The ETC/Simulator software is part of VIMOS OPS, which consists also of template sequencer scripts. Observation templates are briefly discussed in Sec. 8

1.3. APPLICABLE DOCUMENTS

[1] GEN-SPE-ESO-19400-794, Data Interface Control Document, Issue 1.1, Date 25/11/97.
[2] VLT-SPE-ESO-19600-1217, Data flow system Quality Control Equipment Model API, Issue 1.0 Date 02/10/97.
[3] VLT-PRO-ESO-10000-0228, VLT Software Programming Standards, Issue 1.0, Date 10/03/93.
[4] VLT-TRE-VIRG-14606-0021, VIMOS Preliminary Design - Part G: Software Design, Issue 1.0, Date 23/10/97.
[5] VLT-PLA-ESO-19000-1183, Data Flow System Operations Model for VLT/VLTI Instrumentation, Issue 1.0, Date 9/12/96.
[6]VLT-SPE-ESO-14600-1335, VLT Instrumentation Plan VIRMOS Technical Specifications, Issue 1.0, Date 16/07/97.

1.4. REFERENCE DOCUMENTS

[7] Schroeder D., Astronomical Optics. Ac. Press, 1987

1.5. ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
CCD	Charge Coupled Device
DICB	Data Interface Control Board
DRS	Data Reduction Software
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FITS	Flexible Image Transport System
FWHM	Full Width at Half Maximum
GUI	Graphical User Interface

IDF	Instrument Definition File
IFU	Integral Field Unit
MOS	Multi Object Spectroscopy
OPS	Observation Preparation Software
PAF	Parameter Format File
PSF	Point Spread Function
TBC	To Be Confirmed
TBD	To Be Discussed
VIMOS	Visible Multi Object Spectrograph
VLT	Very Large Telescope

2. OVERVIEW

This section describes the general structure and performances of VIMOS ETC/Simulator.

2.1. INTRODUCTION

The purpose of the VIMOS Exposure Time Calculator and Image Simulator is to simulate the instrument performances in the three main observing modes - direct imaging, MOS spectroscopy both at low and high resolution, and IFU - giving the user the possibility of evaluating exposure times and to plan his/her observations in the most profitable way.
The ETC will be able to simulate observations both of pointlike and extended sources, with different spectral energy distributions.
For each observing mode, the ETC/Simulator can be operated in two different modalities, a generic "scalar" modality and a more sophisticated "two-dimensional" (2-D) modality, that will generate different kinds of outputs and whose performances are detailed in the next sections.

The ETC makes use of an ETC Database as well as of user selected parameters to build the simulated observation. The simulated observation model consists of the following components that contribute to the transmission of the signal: the source, the atmosphere, the telescope, the optics and the detector. The ETC Database contains the instrument calibration tables required for computations and provides also a list of templates for source profiles and spectral energy distributions.

The ETC user interface is based on interactive WEB forms: the description of the GUI is given in Section 6. Once the user has selected the desired modality and observation mode, as well as the values for all the parameters needed to describe the observation, the output of the simulation consists of ASCII data, graphs or simulated images in FITS format.

2.2. SOFTWARE ENVIRONMENT

The ETC software makes use of the Quality Control Equipment Model API library [2] as well as of standard C++ libraries.

2.3. VIMOS ETC/SIMULATOR MODULE STRUCTURE

Due to the differences in the operations performed by the two modalities, the ETC has been divided in two separate subsystems : a scalar one and a 2-D one.

2.3.1. Scalar modality subsystem

The ETC/Simulator scalar subsystem implements all the facilities needed to assists the user in choosing the optimum exposure time required to reach a given S/N level (or viceversa) when observing an astronomical source with VIMOS in one of the possible observing modes.
The modules which have been foreseen to implement these tasks are :

- **vmetcsdi** module for the evaluation of exposure times in direct imaging observing mode ;
- **vmetcsmos** : module for the evaluation of exposure times in MOS observing mode ;
- **vmetcsifu** : module for the evaluation of exposure times in IFU observing mode ;

2.3.2. 2-D modality subsystem

The ETC/Simulator 2-D subsystem implements all the facilities needed to give the user the possibility of simulating the image/spectrum of an astronomical source at a given redshift when observed with VIMOS in one of the possible observing modes.
The modules which have been foreseen to implement these tasks are :

- **vmetc2di** : module for image simulation in direct imaging observing mode ;
- **vmetc2dmos** : module for image simulation in MOS observing mode ;
- **vmetc2difu** : module for image simulation in IFU observing mode ;

2.4. STANDARDS

C++ programming standards are applied in the design and development of the software as well as general rules in VLT Programming Standard [3].

3. ARCHITECTURE

The ETC/Simulator software architecture follows an Object Oriented approach and makes use of classes defined in the Quality Control Equipment Model API Library [2] to build the simulation model and get results.
Each observation model consists of an instrument model, comprehensive of an atmospheric model, a sky model and a source model. In this chapter we first describe how these models are created and then the main operations performed by each ETC software module are discussed. More details on ETC module algorithms are given in Section 5.

NOTE : as VIMOS will be equipped with 4 CCD, we assume that ETC makes use of detector parameters relative to channel A.

3.1. MODELS FOR INSTRUMENT, ATMOSPHERE AND SKY

Instrument, atmosphere and sky models are built following the same procedure, independently of the software module they are used by.

Instrument model : this model describes the sequence of instrument components that a light ray has to pass through during an observation with VIMOS and consists of some "fixed" pieces (e.g. telescope mirror) and of some user-selected ones (e.g. filter). Once the user has selected the desired instrument set-up for the simulation, the ETC builds this model by parsing the Instrument Definition File ; the IDF contains the description of all instrument components in terms of values (e.g. camera lens focal length,

telescope diameter and obstruction) and paths to retrieve the ETC Database files containing specific informations (e.g. filter transmission curves, detector quantum efficiency curve).
The model of atmosphere is included in the instrument model and describes the effect of atmospheric extinction on the flux emitted by a source observed at a given airmass. The ETC builds this model on the basis of user-selected airmass, retrieving from ETC Database tables the atmospheric extinction coefficient for the selected filter/grism. Atmospheric extinction coefficients are given as a mean value, evaluated by integrating the atmospheric extinction k_λ over the wavelength range of each filter/grism.

Sky model : this model represents the brightness of the night sky ; the ETC retrieves from the ETC Database the mean value of the sky brightness relative to the user-selected filter/grism and moon phase at which the observation is simulated The sky model will undergo the same instrumental transformations as the source model, except airmass correction. For spectroscopic observations in scalar modality, sky is simply approximated as a continuum emission from the atmosphere ; in 2-D modality sky lines will be added to the final 2-D spectrum.

3.2. *SOURCE MODEL*

Each source to be observed is characterized by a spectral energy distribution and a geometry, and is described by an observation model, i.e. an object that contains a set of light rays in a given wavelength band (representative of the spectral energy distribution), characterized by wavelength, direction and intensity.

3.2.1. Source Spectrum

The source spectral energy distribution is chosen among a list of templates in the ETC Database or can be user-defined (see formatting rules in Sec. 4.1). Conversion from source broad band magnitude to flux is done by means of UBVRi system standard calibrators and spectral templates are scaled in order to have such value of the flux at the effective wavelength of the selected filter/grism.
Possibly, also AB magnitude system will be supported.
Provided spectral templates are:

- blackbody
- flat continuum,
- single line (analytic form)
- star and galaxy synthetic templates.

these templates will be generated by means of distributed packages (e.g. Pegase, Gissel).
In the case of a blackbody spectrum, the user must provide the temperature in $^\circ K$. In all cases the magnitude is intended as integrated magnitude in the chosen filter.
For single emission line the input spectrum is simulated with an analytic gaussian for which the user must provide: central wavelength, peak intensity and FWHM. Continuum and single line are used in particular to simulate sky spectrum when doing spectroscopic simulations in 2-D modality.

3.2.2. Source Geometry : SurBright class

As a complement to classes currently available in public versions of the API Library, a new class called SurBright has been foreseen to allow the simulation of different source geometries.
This class builds an observation model characterized by a given spectral energy AND surface brightness distribution for the source.
In order to simulate pointlike sources as well as elliptical and spiral galaxies, provided surface brightness profiles (analytic form) are :

- pointlike sources : Moffat function ;
- extended sources : De Vaucouleur law, exponential law ;

When in scalar modality, the scale factor for extended sources is expected as an angular radius for the major axis (arcseconds). In 2-D modality the scale factor is the usual linear and is transformed to an angular size according to cosmology. Moreover, for extended sources the user can select the minor-to-major axial ratio, so to simulate galaxies with different ellipticities.

The main generic methods available for this class are :

Table 1 : SurBright class methods

Method name	Description
getProfile/setProfile	gets/sets the selected brightness profile
getPparams/setPparams	gets/sets user-selected parameters for the brightness profile
scaleBProfile	apply the brightness scaling of the profile
source2D	apply an elliptical transformation to get the 2-D profile
convProfile	convolute the profile for seeing PSF

Other public methods from classes in [2] shall also be used.

3.3. SCALAR MODALITY

The main task of the ETC when in scalar modality is to evaluate the exposure time required to reach a given Signal to Noise for a given set of source characteristics, atmospheric conditions and instrument configuration. As an option, also the inverse computation can be performed, e.g. given the exposure time the S/N is evaluated.

3.3.1. VIMOS ETC Module for Direct Imaging : VMETCSDI

Purpose: the VMETCSDI software module for direct imaging observations computes the exposure time required to reach a given Signal to Noise ratio when the user wants to make aperture photometry of a source of given geometry, spectral type and magnitude.

Input : source geometry, spectral energy distribution, magnitude (or surface brightness for extended sources) to be detected inside the aperture radius, aperture radius, airmass, seeing, moon phase, readout mode, binning during the readout phase, filter, Signal to Noise to reach over the aperture and range, number of exposures, flat-field accuracy.

Method : the source model is built on the basis of the selected template spectral energy distribution and surface brightness profile ; in order to scale the source template spectrum to the appropriate source flux, a correction from input aperture magnitude to total magnitude is evaluated. For extended sources, this correction is computed after convolution of the profile with seeing PSF. Both source and sky are transformed according to instrument efficiency and correction for telescope effective area is also applied. The resultant models represent the amount of radiation falling onto the CCD from source and sky. Integration over filter wavelength range is done and further integration over the CCD area corresponding to the desired aperture gives the number of electrons s^{-1} from sky and source. The exposure time (or Signal to Noise) is then computed taking into account dark current, readout noise and desired flat-field accuracy as an additional noise term.

3.3.2. VIMOS ETC Module for High and Low Resolution MOS Spectroscopy : VMETCSMOS

Purpose: the VMETCSMOS software module for high and low resolution MOS spectroscopic observations computes the exposure time required to reach a given Signal to Noise ratio at the central grism wavelength when observing a source of given geometry, spectral type and magnitude. It is assumed that source major axis lies along X direction onto the CCD.

Input : source geometry (pointlike or extended), spectral energy distribution, magnitude (expected in mag arcsec $^{-2}$ for extended sources) to be detected, slit, airmass, seeing, moon phase, readout mode, binning during the readout phase, grism, Signal to Noise to reach at the central grism wavelength and range, number of exposures, desired flat-field accuracy.
Pointlike sources: slit losses expressed as the fraction of light falling into the slit.
Extended sources: angular diameter of major axis (it is assumed that major axis for extended sources lies along X direction onto the CCD).

NOTE : this module does not allow for source surface brightness profile : for extended sources surface brightness is intended as the mean value over the source and the dimension of the resolution element over which the signal will be integrated along spatial direction is set by user-selected source diameter.

Method : source model is generated in a similar way than that of VMETCSDI module and the template spectrum is scaled to the desired magnitude at the central grism wavelength. For pointlike sources, a correction for slit losses is applied. Both source and sky models are transformed according to instrument efficiency and telescope effective area. Wavelength integration of source and sky flux is done on the wavelength range, centered on grism λ_c, defined by binning and angular dispersion at central grism wavelength. For extended sources, signal is integrated over the user-defined length along CCD X axis. Exposure time is evaluated taking into account dark current, readout noise and the desired flat-field accuracy as an additional noise term.

3.3.3. VIMOS ETC Module for IFU Spectroscopy :VMETCSIFU

Purpose : the VMETCSIFU module evaluates the exposure time required to perform : a) bidimensional spectrography of an extended source to the desired level of S/N at central grism wavelength for one fiber; b) integrated spectroscopy summing the signal from a given number of fibers which fall on a pointlike object.

Input : source geometry (pointlike or extended), spectral energy distribution, magnitude of the object at the central grism wavelength (in mag arcsec $^{-2}$ for extended sources), spatial sampling, grism, seeing, airmass and moon phase, required Signal to Noise (or alternatively exposure time) and range, read-out mode, number of exposures, desired flat-field accuracy.
Pointlike sources : number of fibers fully covering the source

NOTE : this module does not allow for source surface brightness profile : we refer to sources for integrated spectroscopy as "pointlike", in the sense that total magnitude is given. For extended sources (i.e. for bidimensional spectrography) surface brightness in intended as the mean value over the source.

Method : the operations performed by this module do not differ substantially from the ones for MOS spectroscopy, except that fiber transmission is also taken into account in the total instrument efficiency. Spatial sampling defines the spatial dimension of the resolution element for integration of signal and noise. For the purpose of bidimensional spectrography, the magnitude is expected in mag arcsec $^{-2}$ and the exposure time requested to reach the given Signal to Noise on a single fiber is evaluated. For the purpose of integrating the signal received on a given number of fibers n_{fib}, it is assumed that an equal amount of light from the object is collected by each fiber, and that flat-field accuracy is the same for each fiber ; flux losses and field losses are taken into account (see Sec. 5.2.3). Under these assumptions, total signal and noise are evaluated in terms of n_{fib}.

3.3.4. Output

The output of each ETC software modules in scalar modality consists of :

- summary of input parameters ;
- exposure time (or Signal to Noise);
- background noise;
- source flux and extension (FWHM) after seeing degradation;

Graphical options for scalar modality are :

- Exposure time vs. hour angle: if this option is set, the user must specify the declination of the source ; degradation of the signal due to atmospheric extinction is evaluated for a set of hour angles ranging from -3 to +3 hours (binning TBD) and the exposure time needed to reach the desired S/N at each HA re-computed.
- Exposure time vs. seeing: the degradation of the PSF of the instrument and the correspondent transmitted signal is evaluated in a user-selected seeing range (binning TBD); the exposure time needed to reach the desired S/N for each seeing value is re-computed.
- Exposure time vs. S/N : the exposure time needed to reach the desired S/N in a user specified range is computed (binning TBD).

3.4. 2-D MODALITY

The main task of the ETC/Simulator in two-dimensional modality is to build a simulated image of a source at a given redshift and with given geometrical and spectral characteristics, when observed at given atmospheric conditions and for a given exposure time with VIMOS in one of the possible observing modes. Spectral templates can be redshifted up to redshift 5.

At present, two different approaches have been identified for direct imaging and spectroscopy: in the first case the underlying hypothesis is that the user wants to know how a source of a given apparent magnitude, spectral energy distribution and geometry would appear when observed with VIMOS in direct imaging for a given exposure time. As an option, the user can provide redshift and absolute magnitude of the source, and cosmological effects will be taken into account.

The spectroscopic case can be interpreted as a second step after having acquired direct imaging of a source (e.g. the apparent magnitude is known), and the user wants to know how the spectrum of this source would appear, when observed for a given exposure time with VIMOS in MOS or IFU observing mode, if the source itself was located at a given redshift and characterized by a given spectral energy distribution and geometry.

Hereafter we will refer to X and Y as the coordinates on the CCD plane, with X axis in the spatial direction and Y axis in the dispersion direction.

3.4.1. Master Frames and FITS files.

In order to reproduce exactly the resultant image of an observation with VIMOS, DRS master frames for bias, dark current and flat-field relative to the selected observing mode, combined and scaled to the required exposure time, will be used.

For direct imaging, the source is supposed to be observed at the center of the upper half of the CCD, and the simulated image will have a fixed dimension (1 arcmin, TBD) in both directions. For MOS and IFU spectroscopy the size along dispersion direction will be set equal to the total useful size of the CCD. Master frames will be considered in the correspondent regions and total counts from source and sky are added at each pixel position.

3.4.2. ETC Module for Direct Imaging : VMETC2DI

Purpose: the VMETC2DI module creates a simulated image of a source of given absolute magnitude in one of the available filters, characterized by a given spectral energy distribution and geometry, when located at a given redshift and observed for a given exposure time with VIMOS in direct imaging.

Input: source magnitude in one of the available filters, source geometry, template spectrum, redshift, exposure time, seeing, airmass and moon phase, readout mode, binning.
Extended sources: scale parameter for the profile and axial ratio.

NOTE: for extended sources the scale parameter is intended relative to the semi-major axis.
If redshift is set to zero the magnitude is the apparent one and scale parameter must be provided in arcseconds. If redshift is not set to zero, the user must provide the absolute magnitude, and the scale parameter must be expressed in kpc.

Method: if redshift is not set to zero, the input template spectrum is scaled to the absolute flux emitted by the source and the observed flux in the selected filter is computed according to cosmology. The observed radial surface brightness profile is described by the observed angular size of the source, set equal to seeing for pointlike sources and computed according to luminosity distance for extended ones. If redshift is set to zero, the scaling of template spectrum is performed as done for VMETCSDI module.
Transformation for instrument efficiency and telescope collecting area is applied. The observed profile is then mapped in two dimensions by an elliptical transformation, and for extended sources correction for seeing PSF is applied. For each pixel in the source image, the analytic profile is integrated over the size of the image pixels. Pixel subsampling will be allowed in order to get the best approximation of the flux associated to each pixel. The source image is at this level represented by a two-dimensional matrix.
Sky brightness relative to the selected filter and moon phase is corrected for instrument and detector efficiency (except atmospheric correction) ; both source and sky total counts are transformed in ADU pixel^{-1} and added to bias, dark current and flat-field master frames, scaled to the desired exposure time.

3.4.3. ETC Module for High and Low Resolution MOS Spectroscopy : VMETC2DMOS

Purpose: the VMETC2DMOS module simulates the two dimensional spectrum of a source of given apparent magnitude, described by a geometry and template spectral energy distribution, located at a given redshift and observed with VIMOS in high or low resolution MOS for a given exposure time, airmass and seeing.

Input: source apparent magnitude in one of the available filters, redshift, spectral energy distribution, source geometry, exposure time, seeing, airmass and moon phase, grism, slit length, readout mode, binning, fraction of light into the slit.
Extended sources: scale parameter (kpc) for the selected brightness profile (semi-major axis).

NOTE: it is assumed that the slit is positioned at the center of the CCD and that the slit itself is centered on the source, whose major axis (for extended objects) lies along the X direction. No tilting of the spectrum along the dispersion direction is taken into account. A default 1 arcsecond slit width is assumed.

Method: magnitude in a given filter, corrected for slit losses, is used to scale the template spectrum to the absolute flux emitted by the source (this will take into account cosmological effects, see Sec. 5.3). The observed spectral energy distribution is computed by taking into account redshifting of the rest frame spectrum, and is then corrected by telescope collecting area and instrument efficiency (excluding grism); the dispersion solution is applied to the spectrum, which is then corrected by grism efficiency tabulated values, and conversion to ADU is performed.
The transformation to two dimensional spectrum is done in three steps: the analytic radial surface brightness distribution of the source is scaled according to the angular size, as done for the VMETC2DI module, and represents the normalized profile of the source in the spatial direction on the CCD. The mean flux at each pixel along the dispersion direction is evaluated by integrating the one-dimensional spectrum over pixel size, and is used to scale the intensity of the spatial profile. For each pixel along Y, a second integration over pixel size is done across the spatial direction to get the flux associated at each (X,Y) pixel in the two dimensional spectral image. Pixel subsampling is applied both in X and in Y directions.
Sky spectrum is approximated by a continuum, whose intensity is set by the selected grism and moon phase, with sky lines superimposed as a series of single-line spectra. The FWHM of sky lines is set by grism spectral resolution. Sky spectrum undergoes the same transformations as the source one, except for atmospheric correction, and its intensity along spatial X direction is assumed constant over the slit length (TBD a more refined approximation for sky spectral profile along the slit). Total sky counts for each pixel are then computed in ADU. Master frames for bias, dark current and flat-field, scaled to the desired exposure time, are combined and source and sky counts are added.

3.4.4. ETC Module for IFU Spectroscopy : VMETC2DIFU

Purpose: the VMETC2DIFU module builds the simulated spectrum of a source of given magnitude and spectral energy distribution, observed at a given redshift with VIMOS in IFU observing mode at a given airmass and seeing, and for a given exposure time.

Input: source geometry (pointlike or extended), magnitude in one of the available filters, redshift, spectral energy distribution, exposure time, seeing, airmass and moon phase, grism, spatial sampling, readout mode, binning.
Pointlike sources : number of fibers fully covering the source.

NOTE: this module does not consider surface brightness profiles ; sources can be pointlike or extended and in this last case magnitude (expected in mag arcsec^{-2}) represents a mean value over the source. The module builds the simulated spectrum of a single fiber.

Method: as for scalar modality, also in 2-D the basic operations performed by IFU module do not differ substantially from those of the MOS one, except that now also fiber transmission is taken into account when correcting for instrument efficiency. For pointlike sources, in addition, a correction for flux losses and field losses (see Sec. 5.2.3) due to IFU geometry and to the presence of the pseudo-slit is applied. The spatial profile both of source and sky is now approximated by the convolution of the pseudo-slit profile with PSF.

3.4.5. Output

The output for each ETC module in 2-D modality consists of:
- summary of input parameters;
- simulated image/spectrum in FITS format;

FITS files can be retrieved via the WEB and their headers contain information about simulation parameters, and all the keywords necessary to further analysis with VIMOS DRS or with other astronomical data reduction packages.

4. DATA DESCRIPTION

To build the observation model, VIMOS ETC/Simulator needs to access an ETC Database which contains :

- calibration files; they list all the necessary informations on the instrument equipment (filter and grism transmission curves, mirrors reflectivity, optical elements response curves), on the sky and atmosphere (mean atmospheric extinction coefficients and sky brightness vs. moon phase for each available filter), and on detector (dark current, detector response curve, readout noise).

- template files for surface brightness profile and spectral energy distribution of a source. Provided spectral templates are: blackbody, continuum, single line (analytic form), star and galaxy synthetic spectra. Available surface brightness templates are: Moffat function for pointlike sources, De Vaucouleur law and exponential disk for extended sources.

- DRS master files for flat-field, bias and dark current for each observing mode, to be used in 2-D simulation.

- VIMOS Instrument Definition File.

The ETC will handle the following data, that are automatically lost each time the user logs off or starts with a new simulation :

- observation-related, such as user-defined configuration of the instrument and characteristics of the observation to be simulated. These data are stored in a temporary file and summarized in output. They are also used to write the FITS header when a simulated image/spectrum is required by the user (2-D modality).

- run-time files ; they contain a variety of parameters like intermediate-step results of the simulation.

- simulation results : the output is stored in one (or more, in case of multiple output request) temporary file that can be retrieved by the user.

4.1. ETC DATABASE

Specific reference units and file formats have been defined for ETC Database files, as detailed here.

Units

The chosen reference units are: nm for wavelength and erg $s^{-1} cm^{-2} nm^{-1}$ for monochromatic flux. Transmission values range from 0 to 1, 1 corresponding to 100 percent transmission.

Sky brightness is given for each available filter as mean surface brightness in mag arcsec $^{-2}$ vs. days from the last dark moon (TBD binning in days).
Atmospheric extinction coefficients are given as the instrumental response (telescope + filter/grism + detector) to the extinction curve integrated over each filter/grism wavelength band ; they are eventually re-computed to account for changes in the equipment or update of extinction curves.

File format
All the files contained in the ETC Database are written in a standard format:

- calibration files are stored as ASCII files and consist of two comment lines explaining briefly the piece of instrumentation described by the file, a third line giving the number of rows of data value to follow, and the data values listed on two columns (e.g. for a filter in the first column the wavelength and in the second the transmission). Sampling in wavelength will be set according to the maximum spectral resolution achievable with VIMOS. They will be taken from the Instrument Calibration Database, changing the format if needed.
- the IDF is written using DICB keywords in a PAF according to [1] ;
- source spectral template files are stored as ASCII files and list monochromatic flux in the wavelength range from 900 to 1000 nm (TBC).
- source brightness profiles are given in analytic form and normalized to unit total intensity.
- Master files are stored as FITS files.

5. FEATURES

In this section we give the detailed description of the algorithms used by the ETC/Simulator.

5.1. GLOSSARY OF PARAMETERS

S_e	Source counts (e s $^{-1}$)
B_e	Sky counts (e s $^{-1}$)
ff	Flat-field accuracy
N_λ^{obj}	Monochromatic flux from source (erg cm $^{-2}$ sec $^{-1}$ nm $^{-1}$)
N_{DC}	Noise due to dark current per resolution element (e s $^{-1}$)
t	Exposure time (s)
S/N	Signal to Noise Ratio
RON	Noise due to readout per resolution element (e s $^{-1}$)
τ_λ	Transmission telescope-detector (no slit losses, no telescope obstruction)
δ	Resolution element area (arcsec ^{2})
θ	Source diameter along the slit (arcsec)
$\Delta\lambda$	Wavelength bin (nm)
E	Mean atmospheric transmission at given airmass

Q_λ	Detector quantum efficiency
k_i	Total to aperture area ratio
arc_pix	Plate scale (arcsec pixel $^{-1}$)
A_pix	Dispersion (Angstrom pixel $^{-1}$)
n_{fib}	Number of fibers on the source
d_{fib}	Fiber diameter projected onto the CCD (arcsec)
m^{obj}	Source total magnitude (mag or mag arcsec $^{-2}$)
m_r^{obj}	Source aperture magnitude (mag or mag arcsec $^{-2}$)
r	Aperture radius (arcsec)
A_{aper}	Aperture area (arcsec ^{2})
n_{bin}	Binning during readout phase
R,O	Mirror and central obstruction radii (cm)
$M(\lambda_o, t_o)$	Source absolute magnitude
$K(z)$	K correction (mag)
$l(\lambda_o)$	Observed spectral flux (erg s $^{-1}$ cm $^{-2}$ nm $^{-1}$)
$F(\lambda_o)$	Emitted spectral flux (erg s $^{-1}$ nm $^{-1}$)
D_L	Luminosity distance (Mpc)
z	Redshift
$\Delta\theta$	Observed angular size (arcseconds)
r_c	Scale parameter of source brightness profile (kpc)

5.2. *SCALAR MODALITY*

The starting point is the classical equation for the evaluation of exposure time given the Signal to Noise Ratio S/N for a single exposure:

$$S/N = \frac{S_e t}{\sqrt{S_e t + B_e t + ff^2 (B_e + S_e)^2 t + t N_{DC}^2 + RON^2}}$$

and the one for the exposure time if S/N is given :

$$t = \frac{(S/N)^2 (S_e + B_e + F + N_{DC}^2) + \sqrt{(S/N)^4 (S_e + B_e + F + N_{DC}^2)^2 + 4 S_e^2 (S/N)^2 RON^2}}{2 S_e^2}$$

where:

$F = ff^2 (B_e + S_e)^2$

S_e = count rate from the object (e^- / s);

B_e = count rate from the sky (e^- / s);

ff = flat-field accuracy.

N_{DC} = detector noise due to dark current (e^- / s);

RON = readout noise in e^- ;

t = exposure time in seconds ;

The ETC takes into account the desired flat-field accuracy as an additional noise term. If the multiple exposure option is selected, the S/N for n added exposures of equal length t is computed scaling the S/N for a single long exposure by the factor $\sqrt{n}$. In the next sections the expression of the various terms in the above formula for the different observing modes will be derived. We assume:
speed of light in vacuum $c = 2.9979 \cdot 10^{10}$ cm s^{-1}
Plank constant $h = 6.62620 \cdot 10^{-27}$ erg s;
Boltzman constant $k = 1.380662 \cdot 10^{-16}$ erg K^{-1}

5.2.1. *VMETCSDI Module*

The scaling of spectral template to the total source flux requires first the correction from the given magnitude m_r^{obj}, to be detected inside the aperture of radius r (arcsec), to the total magnitude m^{obj} for the selected brightness profile :

$$m_r^{obj} - m^{obj} = \Delta m = 2.5 Log\left[\frac{\int_{-\infty}^{+\infty} profile_\alpha}{\int_{-r}^{+r} profile_\alpha}\right] = 2.5 Log(k_i)$$

where $profile_\alpha$ is the normalized surface brightness distribution (convoluted with seeing for extended sources) ; the integral over the total profile is equal to 1 for pointlike sources. The input spectrum is then scaled to the source magnitude as:

$$N_\lambda^{obj} = N_\lambda^0 \cdot 10^{0.4(m_{obj}+\Delta m)}$$

where N_λ^0 (erg cm^{-2} s^{-1} nm^{-1}) is the flux in the selected filter of the zero-magnitude star used for calibration. The scaling is applied at the filter effective wavelength. Transformation to photons cm^{-2} s^{-1} nm^{-1} is accomplished through the factor λ/hc. The expression for S_e and B_e in electrons s^{-1} are then written as:

$$S_e = k_i^{-1}\pi(R^2 - O^2)E\int N_\lambda^{obj}\tau_\lambda d\lambda$$ pointlike sources (m^{obj} in mag)

$$S_e = A_{aper}\pi(R^2 - O^2)E\int N_\lambda^{obj}\tau_\lambda d\lambda$$ extended sources (m^{obj} in mag arcsec^{-2})

$$B_e = A_{aper}\pi(R^2 - O^2)\int N_\lambda^{sky}\tau_\lambda d\lambda$$

where $A_{aper} = \pi r^2$ in square arcseconds is the aperture area, $\pi(R^2 - O^2)$ represent the effective mirror area (R and O are the radius of telescope mirror and central obstruction in cm). E and τ_λ are respectively the mean atmospheric transmission at the given airmass for the selected filter, and the transmission from the telescope to the detector (including filter and detector quantum efficiency, Q_λ). The integral is performed over the filter wavelength range.
N_λ^{sky} is the number of photons cm^{-2} s^{-1} nm^{-1} arcsec^{-2} received from the sky for the selected filter and moon phase.

Noise terms in e s $^{-1}$ due to the dark current DC (e s $^{-1}$ pix $^{-1}$) and readout noise R_n (e pix $^{-1}$) are :

$$N_{DC} = \sqrt{DC \cdot A_{aper}(arc\_pix)^2} \quad ; \quad RON = R_n \sqrt{\frac{A_{aper}(arc\_pix)^2}{n_{bin}^2}}$$

where the aperture area has been transformed to pixels using the pixel scale arc_pix (arcsec pix $^{-1}$) and n_{bin} is the binning referred to the pixel summation (readout mode).

5.2.2. VMETCSMOS Module

The Signal to Noise ratio is assumed to be computed in the spectral continuum at the central grism wavelength, and summed over n_{bin} pixels along the dispersion direction, where n_{bin} is the binning. The input spectral template is scaled to the user-selected magnitude at the central grism wavelength according to the formula in VMETCSDI module.
The expression for S_e and B_e (e s $^{-1}$) can be written as :

$$S_e = k_s \pi (R^2 - O^2) N_\lambda^{obj} E \tau_\lambda \Delta\lambda$$ pointlike sources (m^{obj} in mag)

$$S_e = \delta \pi (R^2 - O^2) N_\lambda^{obj} E \tau_\lambda \Delta\lambda$$ extended sources (m^{obj} in mag arcsec $^{-2}$)

$$B_e = \delta' \pi \left(R^2 - O^2\right) N_\lambda^{sky} \tau_\lambda \Delta\lambda$$

where the wavelength bin for integration, $\Delta\lambda$ (nm), correspond to the dimension of the resolution element in the dispersion direction: $\Delta\lambda = n_{bin} \cdot A\_pix$, and A_pix (nm pix $^{-1}$) is the angular dispersion at central grism wavelength.
N_λ^{obj} (ph cm $^{-2}$ s $^{-1}$ nm $^{-1}$, or ph cm $^{-2}$ s $^{-1}$ nm $^{-1}$ arcsec $^{-2}$ for extended sources) is the number of photons from the source at the central grism wavelength; the term τ_λ now takes into account the transmission from the telescope to the detector including grism. N_λ^{sky} is the number of photons cm $^{-2}$ s $^{-1}$ nm $^{-1}$ arcsec $^{-2}$ from the sky for the selected grism and moon phase.
Pointlike sources : k_s represent the user-selected fraction of light falling into the slit and the area δ' over which sky count rate is computed is set to $(2\alpha / arc\_pix) \cdot n_{bin}$ (i.e. we are assuming that the total light from the source falls in a circle of radius 2α).
Extended sources : $\delta = \delta' = \theta(arc\_pix \cdot n_{bin})$ is the CCD area (square arcsecs) used to integrate the signal both from source and sky, set by slit width and user-selected source diameter θ (arcseconds).
Noise terms in e s $^{-1}$ due to dark current DC (e s $^{-1}$ pix $^{-1}$) and read out noise R_n (e pix $^{-1}$) are :

$$N_{DC} = \sqrt{DC \cdot \delta' / (arc\_pix)^2} \quad ; \quad RON = R_n \sqrt{\frac{\delta' / (arc\_pix)^2}{n_{bin}^2}}$$

where binning during the readout phase has been taken into account.

5.2.3. VMETCSIFU Module

The operations performed by this module do not differ substantially by those of VMETCSMOS one except that the factor τ_λ now takes into account also fiber transmission. As it is not a priori known which fiber (or set of fibers) fall on the image, the ETC uses a mean fiber transmission.
User-selected spatial sampling defines the fiber diameter projected onto the CCD, d_{fib} (arcsecs).
For the purpose of bidimensional spectrography of an extended source (e.g. during data reduction the signal will not be summed over all the fibers covering the source) what is of interest is the exposure time needed to reach the given S/N on a single fiber. Given a mean surface brightness of the source in mag arcsec $^{-2}$ at the central wavelength of the selected grism, the signal is :

$$S_e = \delta N_\lambda^{obj} E \tau_\lambda \pi (R-O)^2 \Delta\lambda$$

The wavelength bin is as for VMETCSMOS module, and the resolution element dimension in the spatial direction is now set by the projected fiber diameter, so that $\delta = d_{fib}(n_{bin} \cdot arc\_pix)$.
Noise contributions due to sky background, dark current and readout noise are computed using the formulas given for the VMETCSMOS module, with $\delta' = \delta$.

For the purpose of integrating the signal received from a source of magnitude m^{obj} (mag) at central grism wavelength, fully covered by a given number of fibers n_{fib}, the desired Signal to Noise is intended as relative to the summed spectra.
Before scaling the spectrum, the total source flux must be corrected by the mean fraction of source area which is lost by each fiber due to IFU fibers geometrical configuration, and by the mean fraction of flux lost by each fiber due to the pseudo-slit.
We make the simplifying assumption that an equal amount of flux falls on each fiber and flat-field accuracy is the same for each fiber ; under these conditions the integrated signal is:

$$S_e = N_\lambda^{obj} E \tau_\lambda \pi (R^2 - O^2) \Delta\lambda$$

Noise contributions from sky background, dark current and readout noise are computed as above and multiplied by the total number of fibers, n_{fib}.

5.3. *2-D MODALITY*

The starting points for the operations performed in 2-D modality are the expressions describing changes of received flux and angular dimension of a source when observed at different redshifts.
Given a source at redshifts z, which emits $F(\lambda)$ erg s $^{-1}$ nm $^{-1}$ at a given wavelength λ and time t_e in its rest frame, the observed flux at t_o at the wavelength λ_o is given by:

$$f(\lambda_o) = \frac{F(\lambda_o / 1+z)}{4\pi D_L^2 (1+z)} \qquad (1)$$

with D_L the luminosity distance:

$$D_L = \left(\frac{c}{H_0}\right) \frac{1}{q_0^2} \left[q_0 z + (q_0 - 1)(\sqrt{1+2zq_0} - 1) \right]$$

The observed flux (erg s^{-1} cm^{-2}) integrated over a band with *effective wavelength* λ_o is:

$$l(\lambda_o) = \frac{\int F(\lambda,t_o)\tau_\lambda d\lambda}{4\pi D^2} \cdot \frac{\int F(\lambda/1+z,t_o)\tau_\lambda d\lambda}{(1+z)\int F(\lambda,t_o)\tau_\lambda d\lambda} \qquad (2)$$

where τ_λ is the instrumental efficiency (including DQE), and the second term on the right side is relative to the K correction. The same formula can be expressed in magnitudes as:

$$m(\lambda_o) = M(\lambda_o,t_o) + 5\log D_L + K(z) + 25 \qquad (3)$$

with $M(\lambda_o,t_o)$ the absolute magnitude in the same band and the K correction (mag) is:

$$K(z) = 2.5\log(1+z) + 2.5\log\left(\int_0^\infty F(\lambda,t_o)\tau_\lambda d\lambda \Big/ \int_0^\infty F(\lambda/1+z,t_o)\tau_\lambda d\lambda\right) \qquad (4)$$

The angular size subtended by a source of given linear size d and redshift z varies with redshift and luminosity distance as :

$$\Delta\theta = d(1+z)^2 / D_L \qquad (5)$$

The observed surface brightness of a source is related by the emitted one by: $i_o = i_e / (1+z)^4$.
In the following we will assume H_0=50 km s^{-1} Mpc^{-1} and q_0=0.5 and will not take into account evolutionary corrections.

5.3.1. VMETC2DI Module

One dimension : if redshift is set to zero, the apparent magnitude is used to scale the spectral template as done for VMETCSDI module. If $z \neq 0$, the total emitted flux for the source is derived from its absolute magnitude and used to scale the spectral template ; the observed flux for unit collecting area of the telescope over the filter wavelength band is given by equation (2).
Conversion to photons cm^{-2} s^{-1} nm^{-1} is done through the factor λ/hc and the total counts in electrons on the detector for the exposure time t are:

$$S_e \cdot t = \pi(R^2 - O^2)E \cdot l(\lambda_o) \cdot t$$

where again E is the mean atmospheric transmission at the given airmass.
Mean sky brightness for the selected filter and airmass is transformed as usual to get sky counts in t (electrons). Transformation from electrons to ADU is done by multiplying for detector gain.

Transformation to two-dimension : if $z \neq 0$, the observed angular size $\Delta\theta_e$ corresponding to the linear scale parameter of the profile is set equal to seeing radius for pointlike sources, while for extended sources it is obtained by transforming the scale parameter r_e of the profile according to equation (5). The normalized radial profile is scaled to the total number of ADU from the source and transformed into two dimensions by applying an elliptical transformation:

$$dX = x - x_0 \ ; \ dY = (y - y_0)/ar \ ; \ dR = \sqrt{dX^2 + dY^2}$$

where (x_0, y_0) are the coordinates of the source center, (x, y) the image coordinates relative to the center, ar the axial ratio (minor to major, equal to 1 for pointlike sources) and dR is the circular radius of the profile. As the profiles of the analytic functions extend to infinity, a cutoff is imposed in terms of dynamical range.
For extended sources, the two dimensional profile is then convoluted with seeing PSF (also transformed with the elliptical transformation).
To associate the best approximation of total counts to each pixel in the resultant CCD image, the source analytic model is integrated over pixel size by applying pixel subsampling. Pixel subsampling and dynamical range for the cutoff are crucial values for optimizing computational time, so these values will be defined during the implementation phase.
FITS files containing master frames for bias, dark current and flat-field are combined after scaling for exposure time; finally, counts from the source, sky and noise due to readout are added.

5.3.2. VMETC2DMOS Module

One-dimension : from apparent source magnitude, the total emitted flux is computed by means of the formula (3), where K correction is evaluated from the template spectrum with equation (4), and scaled to account for the fraction of light actually falling onto the slit. The observed spectral energy distribution is obtained by applying equation (1) at the rest frame spectrum and transforming for instrument efficiency (excluding grism), telescope effective area and exposure time to get the number of electrons received per unit wavelength across the dispersion direction :

$$S_e(\lambda) \cdot t = \pi(R^2 - O^2)E \cdot f(\lambda) \cdot t$$

The normalized efficiency of each grism in the various orders along the CCD Y coordinate (pixels) has been computed: tabulated values are fitted with a spline function in each order, interpolating values between orders so to produce a smooth function. Before applying grism efficiency, the object spectrum is thus transformed by means of the dispersion solution, computed with the well known formulas for prisms and gratings. The spectrum is then corrected for grism efficiency and transformed to ADU by multiplying for detector gain.

Sky spectrum is described by a continuum plus sky lines: these are superimposed, at the proper wavelength and intensity, as gaussian profiles whose FWHM in the dispersion direction is set according to the spectral resolution. Sky spectrum undergoes the same instrumental transformations than the source (except for atmospheric correction).

Transformation to two-dimensions : subsampling of pixels along Y is performed on the one-dimensional spectrum, to associate the best flux approximation at each Y position. The profile of the spectrum in the spatial direction across the slit is set by source geometry, evaluating the angular radius of surface brightness radial profile as done for the VMETC2DI module. The total intensity of this profile is scaled to the one-dimensional spectral flux, and subsampling across the X direction is performed to evaluate the flux at each (X,Y) coordinate.
One-dimensional sky spectrum is sampled in a similar way along Y, and its intensity along the spatial direction is assumed to be constant (TBD the possibility of approximating the shape with a "slit" spatial profile which takes into account the rapid decrease of sky light at the slit edges).
FITS files containing master frames for bias, dark current and spectroscopic flat-field are combined after scaling for exposure time ; finally, counts from the source, sky and noise due to readout are added at each pixel position in the source spectrum.

5.3.3. VMETC2DIFU Module

One dimension : corrections for cosmology are performed in a similar way than in VMETC2DMOS module. For pointlike sources, the apparent magnitude is corrected for field losses and flux losses, as described in VMETCSIFU module, before scaling the spectral template.
As in scalar modality, for pointlike sources we assume an equal fraction of light falling on each fiber. The number of photons received per unit wavelength along the dispersion direction on each fiber is then :

$S_e(\lambda)\cdot t = n_{fib}^{-1}\pi(R^2 - O^2)E\cdot f(\lambda)\cdot t$ pointlike sources (i.e. m^{obj} in mag)

$S_e(\lambda)\cdot t = a_{fib}\pi(R^2 - O^2)E\cdot f(\lambda)\cdot t$ extended sources (i.e. m^{obj} in mag arcsec $^{-2}$)

where a_{fib} (square arcsecs) is the projected fiber area corrected by pseudo-slit image.

Transformation to two-dimensions : the transformation is similar to the one done by the VMETC2DMOS module, taking into account that now the spatial profile of the resultant spectrum (both for source and sky) is set by the convolution of the pseudo-slit profile with the PSF.

6. INTERFACES

6.1. GUI INTERFACE

The ETC/Simulator will reside in Garching and the user interface is constituted by a HTML based GUI panel in the form of WEB pages. The GUI panel is developed according to already existent ETC at ESO.
A first WEB form defines the ETC/Simulator modality and desired observing mode: depending on these choices, the correspondent software module is activated and the user is prompted with the main form, in which all the relevant observing parameters must be specified. The input parameters are grouped as source-related, atmosphere and sky-related, instrument-related, output-related.
The output WEB page contains a summary of input parameters and the results of the simulation in form both of numbers and graphs/files, that can be retrieved via the WEB.

6.2. CALIBRATION DATABASE INTERFACE

Instrument parameter files as well as master calibration files which are stored in the ETC Database are retrieved from the general VIMOS Calibration Database. The ETC Database shall thus access the most updated version of Calibration Database to take into account changes in instrument equipment.

7. FUNCTION TRACEABILITY MATRIX

Reference	Description	Design Reference
[4] VI.1.1.1	ETC scalar modality for direct imaging	2.3.1 and 4.1.1
[4] VI.1.2.1	ETC scalar modality for MOS spectroscopy	2.3.2 and 4.1.2
[4] VI.1.3.1	ETC scalar modality for IFU spectroscopy	2.3.3 and 4.1.3
[4] VI.1.1.2	ETC 2-D modality for direct imaging	2.4.1 and 4.2.1
[4] VI.1.2.2	ETC 2-D modality for MOS spectroscopy	2.4.2 and 4.2.2
[4] VI.1.3.2	ETC 2-D modality for IFU spectroscopy	2.4.3 and 4.2.3
[6] 3.2.3.16.1	Validation Sets	8
[6] 3.2.3.16.3	Observation Templates	9

8. VALIDATION SETS

For each ETC module described in this document, a validation dataset of tables/FITS images, input data parameters, intermediate results and final results will be given as specified in [5] and [6].

9. OBSERVATION TEMPLATES

Observation sequences are described by template sequencer scripts, i.e. Tcl-Tk scripts which will be inputs for BOB. Template scripts use the parameters from the template signatures and build up sequences of commands to be sent to OS. They will handle also pre-defined sequences of observations (e.g. MOS scientific exposure, associated flat-field and calibration arcs). As template scripts are tools used in connection with P2PP and BOB, their design and syntax will strictly follow ESO recommendations. For complex observing techniques, involving sequence of exposures, adequate template scripts will be provided, which will follow a modular approach, i.e. will be built up of more simple scripts. There will be dedicated scripts for each supported observing mode and for each calibration procedure. Building VIMOS templates we will make use as far as possible of already existing templates for other VLT instruments.

10. DEVELOPMENT PLAN

The tools provided by the ETC/Simulator will be developed according to the following schedule :

- ETC Scalar modality - software modules plus testing and documentation : end November 1998.
- ETC 2-D modality - software modules plus testing and documentation : end March 1999.
- OPS Observation Templates : end April 1999.

11. APPENDIX A - PROGRAMS

This section will be filled during the implementation phase.

12. APPENDIX B - ROUTINES

This section will be filled during the implementation phase.

13. APPENDIX C - INCLUDE FILES

This section will be filled during the implementation phase.

14. APPENDIX D - ERROR DEFINITION

This section will be filled during the implementation phase.

15. APPENDIX E - COMMAND DEFINITION

This section will be filled during the implementation phase.