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VLT Instrumentation Plan

VISIR

Exposure Time Calculator and Image Simulator Software Design Description

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B. Table of contents

C. Applicable documents

[1] VLT-SPE-VIS-1430-0011 : VISIR Imager Specifications, D. Dubreuil et al.
[2] VLT-SPE-VIS-14321-5004 : VISIR Spectrometer Optical Design and System Specifications, J.W. Pel and A. Schoemaker, part A and B, Isuue 3.1, 31 Jan. 1999
[3] VLT-SPE-ESO-14300-0001 : Technical Specification, Lyraud, C. and Rio, Y., Issue 6.0, 17 Sept. 1996
[4] VLT-SOW-ESO-14300-0307 : Statement of Work, Käufl, H.U., Issue 5.0, 17 Sept. 1996

D. Reference documents

[1] VLT-SPE-ESO-19600-1217, Data Flow System Quality Control Equipment Model API, Issue 1.0, 02/10/97

[2] VLT-PRO-ESO-10000-0228, VLT Programming Standards

[3] Gemini web site : http://140.252.15.172/science/mkmodels

1. Instrument

1.1 Introduction

The VISIR acronym stands for Vlt Imager and Spectrometer for the mid-InfraRed. It is a VLT instrument dedicated to mid-infrared range observations. Its spectral range coverage spans the atmospheric windows N (8-13 µm) and Q (16-28 µm). It includes two sub units : an imager and a spectrometer, each of them offering a large panel of modes quickly described in table 1.

Its installation on VLT unit 3 Cassegrain focus is foreseen for the first semester of 2001 according to the ESO schedule. The scientific domains involved span from planetary and solar system minor bodies sciences, young stellar objects studies, evolved dusty stars, and extragalactic themes like galaxies with star forming regions or Active Galaxy Nuclei.

1.1.1 The Imager part

Imaging in the mid-infrared range is not an easy task since one faces a huge background emission coming from the atmosphere. Therefore, one has, in order to get rid of that, to use specific techniques such as chopping (i.e. fast on-source then off-source observation to remove the atmosphere emission) and nodding (to remove first order residuals due to telescope inhomogeneities). The imager has 3 fields of view : 0.2, 0.127 and 0.075 arcsec/pixel; the expected spatial resolution should be around 0.7" fwhm in N band and 1.4" fwhm in Q band (diffraction limited imaging). It is also equipped with a large panel of narrow and broad-band filters. According to the instrument specifications, the imager should reach a sensitivity around 1 mJy (10 sigma 1 hour) in N band. Several internal features are present in order to calibrate and characterise the imager. The star simulator which will provide a simulated image of a point source through the telescope which will be used for instance to check the Point Spread Function, the field distortion (using a pinhole plate), or the illumination function.

1.1.2 The spectrometer part

The spectrometer sub-unit of VISIR offers high to low spectrometry in N and Q bands. It uses also chopping and nodding techniques. Several slit apertures are available; the smallest spatial resolution corresponds to 0.5"x0.25". The different modes available are the following : long-slit spectroscopy with spectral resolutions of : 350, 3200, and 25000 around 10 µm (N band); 175 (TBC), 1600, and 12500 in Q band. One has the possibility to make spatial scans with the slit along an astronomical object, so that 2-D spectrometry is achieved. In high resolution mode, the expected sensitivity on point sources should be 100 times in N band and 10 times in Q band better than SWS.

The spectrometer has its own calibration units such a Fabry-Perot etalon plate used for relative wavelength calibration, combined with a solid organic sample which absorption spectrum - essentially absorbing lines - is well known. A grating scanning mode is also implemented in order to make a flat-field of the spectrometer detector at the wavelengths of interest.

Imager	- raster imaging with/without chopping/nodding
Spectrometer	- slit imaging with : - low resolution N band - intermediate resolution N band - high resolution N band - low resolution Q band (TBC) - intermediate resolution Q band - high resolution Q band

1.2 Purpose

This document intents to provide the design description of an Exposure Time Calculator for the mid-infrared instrument VISIR mounted on the VLT unit 3 (cassegrain focus). Its purpose is to describe as accurately as possible the necessary modules and their implementation.

1.3 Scope

The ETC is part of the VISIR Observation Preparation Software. It is designed to help the observer to prepare a proposal/observation by computing the necessary exposure time needed to reach a goal defined by the user (usually a given signal to noise ratio). This document describes how to make an estimation of the needed observing time given the observational parameters, and we list also the modules which have to be added to the API library to complete the Exposure Time Calculator Software. As usual, at the time we write this document, it is likely that we have forgotten to mention in it some needed routines or special aspects of input/output parameters; the final ETC product may vary slightly from what is decribed here.

1.4 Abbreviations and acronyms

API	Application Programming Interface
DICB	Data Interface Control Board
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FITS	Flexible Image Transport System
FWHM	Full Width at Half Maximum
GUI	Graphical User Interface
HTML	Hyper Text Meta Langage
IDF	Instrument Definition File
PSF	Point Spread Function
TBC	To Be Confirmed
VISIR	Vlt Imager and Spectrometer for the Infrared

VLT	Very Large Telescope

2. Simulator

2.1 Introduction

The purpose of the VISIR Exposure Time Calculator is to simulate the telescope/instrument performances when observing from a “good observing site” such as Paranal. The two main instrument modes i.e. imagery in N and Q band, and spectroscopy (low/medium/high resolution) will be taken into account, allowing the future observer to evaluate exposure times and the total amount of nights or hours needed to complete a scientific program.

The Exposure Time Calculator will be able to simulate observations both of pointlike objects and extended ones, with different types of spectral energy distributions. It will use of a dedicated database integrated in the existing database system common to all ETCs, based on mSQL, and containing experimental values such as atmospheric transmission as a function of the object airmass, and more generally, contains the instrument calibration tables required for computation of the instrument throughout response.

The user interface will be based on an interactive WEB forms, with a Graphical User Interface whose shape is common to all the VLT instruments. Using this interface through the Internet network, the user will define its observing parameters corresponding to the astronomical object he wants to observe. Then, after selecting the instrument configuration he wants to use, he will launch the computation. In output, the Exposure Time Calculator will provide a curve showing the signal to noise ratio as a function of the observing time. The data curve will be also available in ASCII format and simulated image shall be downloaded in FITS format.

2.2 Environment used

The Exposure Time Calculator make use of the Quality Control Equipment Model API library developed by ESO and which is particularly dedicated to provide a standard package common to all VLT instruments and used to build the corresponding Exposure Time Calculators. For instance, the instruments FORS and ISAAC already make use of this library. In addition, it makes also use of C++ language and associated libraries.

2.3 Standards and platform

The C++ programming standards will be applied in the development of the ETC software, in order to be compliant with the API library. General rules in the VLT Programming Standard are also used as guidelines [2].

At the date of the writing of this document, the type of platform supporting the tools to build an ETC software is the following :

- A Solaris machine with system version 2.5.1
- This machine must equipped as a WEB server with a documentation and cgi-bin area
- This machine must support the GNU C++ gcc compiler version 2.7.2 and GNU tar and zip utilities
- MB of disk space and appropriate read/write protections (~quality account)
- The machine must be equipped with MiniSQL software which is free for non-commercial uses
- The machine must be equipped with the commercial tools h++ Rogues Wave library

3. Architecture

The Exposure Time Calculator and Simulator architecture will follow an object oriented approach i.e. will make use of classes and associated methods following in that the philosophy adopted by the API library. It will use as much as possible the routine already existing in the API library.

4. Models description

In the following, we will describe separately the imager part and the spectrometer part, the tools and models presenting some distinct features.

4.1 The Imager Modelling

4.1.1 Sources models

Each source we will define is characterised by a spectral energy distribution (SED) and a geometry.

The SED can be modelled quite simply using a set of usual physical SEDs such as blackbody emittance or simple mathematical functions such as power-law. In case the source one wishes to observe is atypical with a non-modelizable SED, we plan a possibility for the future VISIR user to give the real SED in an ASCII table which will be loaded into the Exposure Time Calculator for further computing. However, in the first version of the ETC sotware this option will not be offered.

4.1.1.1 Point-like sources

In this model, we assume that the images are not (yet) affected by image spatial degradation such as seeing or diffraction spreading. The main component of this model is thus the source spectral energy distribution characterised by a set of wavelengths and source intensities.

The source spectral energy distribution (SED) is chosen among a list of predefined templates in the Exposure Time Calculator database. Basically, in order to make it user-friendly, the user will then define the source SED shape and will be asked to enter at least one "well-known" flux in some broad-band filter (preferably in N or Q band, but it can be also in standard UBVRI system; in this later case, the source SED must be known with a very good accuracy !) to produce a model with an absolute flux.

The available spectral templates for the SEDs are :

- blackbody (already defined in API library)
- power-law SED
- single line + flat continuum
- 2 blackbodies with different temperatures and fluxes

4.1.1.2 Extended sources

The modelling of extended sources is very similar to point-like sources. In addition to the SED definition, one has to define the source geometry in order to compute a physical quantity of interest i.e. the object surface brightness.

For simplicity, we assume that the ETC user has to choose among a limited set of geometric models. Simplest geometric models for the **volume brightness (**that must be projected to produce a surface brightness) one can think of are : *spherical model* with radial power-law (in flux), *disc-like structures*. In addition, the user can select also directly a flat extended emission as **surface brightness**.

Thus, an extended source model results from the combination of a SED among :

- blackbody (already defined in API library)
- power-law SED
- single line + flat continuum
- 2 blackbodies with different temperatures and fluxes

and a brightness geometrical distribution chosen among the following possibilities :

- radial power-law
- disc-like structure
- extended flat emission

List of modules concerned already part of API library :

- blackbody SED
- integration on wavelength

List of modules needed :

- power-law SED
- single line + flat continuum SED
- 3-D radial power-law
- 3-D model of disk-like structure
- 3-D model of flat surface brightness
- 3-D to 2-D projection model

4.1.2 Atmosphere model

4.1.2.1 Spectral extinction

When observing or modelling a mid-infrared observation, the atmosphere transmission is a strong constraint. If the N band atmospheric window is relatively "clean" and weakly dependent on atmospheric conditions, when observing in the Q band window (17-26 µm), parameters such as precipitable water content, humidity must be absolutely taken into account.

The atmospheric transmission curve in the mid-infrared range can be calculated via physical models (see e.g. [3]). We will have to make use of similar models for the ETC.

When we can use a first order approximation of the atmospheric transmission in the case of large band imaging, the model must be very accurate in the case of spectroscopy (presence of absorption lines due to water, carbon dioxide, ozone etc ...) .

List of modules concerned already part of API library :

- blackbody SED
- integration on wavelength
- conversion from airmass and atmospheric flux extinction to magnitude extinction

List of modules needed :

- atmospheric mid-infrared extinction/emission

4.1.2.2 Spatial blurring

Due to atmospheric eddies and turbulence, spatial resolution of astronomical images is degraded. The so-called "seeing" effect results in the existence of a low-pass filter applied to the original object and whose cut-off frequency depends, for a fixed set of atmospheric conditions, on the wavelength, and follows approximately a decreasing power law with -6/5 index. This image degradation can be simply modelled by applying a low-pass filter to the initial object.

List of modules concerned already part of API library :

- seeing PSF

4.1.3 Sky brightness model

According to Kirchoff's law on flux conservation, when observing at "opaque" wavelength (e.g. ozone absorption band at 9.7 µm) the atmosphere emits a huge quantity of photons much higher than (almost) any astronomical source. In order to get rid of that "sky brightness" we use specific mid-infrared observation techniques such as chopping and nodding. In principle, the sky flux is totally removed by using these techniques. However imperfect sky removal or uniformity lead to extra noise in the resulting image. In the first version of the ETC we do not plan to include such a level of complexity. Finally, the sky brightness "effect" on the final images can be considered in a first time as simply some photon noise added.

List of modules concerned already part of API library :

- simulated additive noise

4.1.4 Telescope model

In mid-infrared, the telescope itself produces a huge background which must be taken into account. The application of nodding technique (beam switching) allows to subtract this background but with a remnant photon noise due to stochastic fluctuations of the associated flux.

The second effect of the telescope is to degrade the spatial resolution. Indeed, when observing at wavelength of 10 and 20 µm, the corresponding diffraction effects due to a 8.2 m telescope lead to a spatial resolution of 0.35" and 0.7" (fwhm) respectively. Considering the quality of Paranal site in terms of seeing, we have mostly to take the telescope diffraction into account to model the image blurring. In addition, a central obscuration by the M2 mirror has also to be considered to compute the diffraction pattern. However, in case an observer would like to compute the effects of the seeing on spatial resolution, the ETC models can take it into account in the computing (see section 4.1.2)

List of modules concerned already part of API library :

- Additive noise generation
- Diffraction blurring taking into account the secondary mirror obscuration

4.1.5 Instrument model

Once the user has selected the proper instrument/configuration combination among a list of available items, the ETC builds an instrument model using a pre-defined parameters file. This file, called Instrument Definition File (IDF) and whose format is identical for all VLT instruments, contains the description of needed physical values (which can be also tables obtained through the calibration database) corresponding to all the instrument components. For instance a detector-specific element that must considered is the location of bad pixels which define "blind" zones in the array.

The VISIR instrument modelling is relatively straightforward compared to visible/near-infrared instruments. The relatively small field of view allows to not take into account any field image distortion and thus no ray-tracing has to be modelled. We will have to use simple classes such as *filter class*. To model the instrument sensitivity, we take only into account the instrument overall transmission which depends on optics transmission and detector quantum efficiency.

In addition to spatial noise due to atmospheric photon noise, to modelling of the instrument includes also an internal background noise produced by the instrument structure itself (at a temperature of 35 K)

List of modules concerned already part of API library :

According to [], all needed modules are present in the API library.

4.2 The Spectrometer modelling

4.2.1 Sources models

Each source we will define is characterised by a spectral energy distribution (SED), and more explicitly, for simplicity sake, a continuum plus some added lines, and a geometry (because of long-slit spectroscopy).

As in the case of image modelling, the SED can be modelled quite simply using a set of usual physical SEDs such as blackbody emittance or simple mathematical functions such as power-law. We plan also to include the possibility for the observer to give table in input of the ETC.

4.2.1.1 Point-like sources

In this model, we assume that the images are not (yet) affected by image spatial degradation such as seeing or diffraction spreading. The main component of this model is thus the source spectral energy distribution characterised by wavelength, direction and intensity.

The source spectral energy distribution (SED) is chosen among a list of predefined templates in the Exposure Time Calculator database. Basically, in order to make it user-friendly, the user will then define the source SED shape and will be asked to enter at least one "well-known" flux (used for absolute calibration) in some broad-band filter (preferably in N or Q band, but it can be also in standard UBVRI system; in this later case, the source SED must be known with a very good accuracy !).

The available spectral templates for the SEDs are :

- blackbody (already defined in API library)
- power-law SED
- single line + continuum
- 2 blackbodies with different temperatures and fluxes

4.2.1.2 Extended sources

The modelling of extended sources is very similar to point-like sources. In addition to the SED definition, one has to define the source geometry in order to compute a physical quantity of interest i.e. the object surface brightness and then simulate its profile through a slit of variable width.

Source geometry : as in the case of imagery, we will consider the following cases : spherical model with radial power-law (in flux) volumic emission, disc-like structures, flat extended emission (already projected).

Thus, an extended source model results from the combination of a SED among :

- blackbody (already defined in API library)
- power-law SED
- single line + continuum
- 2 blackbodies with different temperatures and fluxes

and a brightness geometrical distribution chosen among the following possibilities :

- radial power-law
- disc-like structure
- extended flat emission

List of modules concerned already part of API library :

- blackbody SED
- integration on wavelength

List of modules needed :

- power-law SED
- single line + continuum SED
- 3-D radial power-law
- 3-D model of disk-like structure
- 3-D model of flat surface brightness
- 3-D to 2-D projection model

4.2.2 Atmosphere model

4.2.2.1 Spectral extinction

When observing in spectroscopy through the atmosphere, one has to deal with high absorption and emission from various molecules composing the atmosphere. The model must be accurate enough to model accurately the absorption and emission lines produces by species such as water, carbon dioxide, ozone. Low and medium resolution spectroscopic modes will follow the same observing techniques as in the imagery modes, while the high resolution mode will use nodding-only correction. Perturbing effects such as photon noise, dark current noise and internal background noise must be modelled accurately.

List of modules concerned already part of API library :

- blackbody SED
- integration on wavelength
- conversion from airmass and atmospheric flux extinction to magnitude extinction

List of modules needed :

- atmospheric mid-infrared extinction/emission
- dark current noise
- internal background noise

4.2.2.2 Spatial blurring

Spatial blurring by seeing must also be taken into account because it degrades the final spectral resolution.

List of modules concerned already part of API library :

- seeing PSF

4.2.3 Telescope model

In mid-infrared, the telescope itself produces a huge background which must be taken into account. The application of nodding technique (beam switching) allows to subtract this background but with a remnant photon noise due to stochastic fluctuations of the associated flux.

The second effect of the telescope is to degrade the spatial resolution. Indeed, when observing at wavelength of 10 and 20 μm, the corresponding diffraction effects due to a 8.2 m telescope lead to a spatial resolution of 0.35" and 0.7" (fwhm) respectively. In addition, a central obscuration by the M2 mirror can be also considered to compute the diffraction pattern. All these spatial degradations have an effect to the final spectral resolution. In addition, when using the smallest slits widths, one has to deal with diffraction effects which degrade the spatial resolution.

List of modules concerned already part of API library :

- Additive noise generation
- Diffraction blurring taking into account the secondary mirror obscuration

List of modules needed :

- diffraction degradation by a slit

4.2.4 Instrument model

The spectroscopic instrument model adds to the imagery mode, the presence of the slit, the spectral dispersion by gratings. The grating dispersion is already modelled in the API library. The only specific element that must considered is the location of bad pixels which define "blind" zones in the array.

List of modules concerned already part of API library :

In addition to the imager case, we will use the following modules :

- slit setting
- grating object (grating class and associated methods)

5. Data description

5.1 Database

5.1.1 Description

In order to build the observation model, the VISIR ETC/image simulator has to access to an ETC database. This database contains the following objects :

- VISIR instrument Definition file (IDF)
- Calibration files containing the filters characteristics (transmission curves), optics characteristics (available magnification modes and associated transmission), atmospheric transmission sampled with a very fine resolution (R>50000), gratings characteristics, experimental flat-field obtained in the laboratory and later, from "on-telescope" measurements, dark current values

5.1.2 Units and file formats

Units : since most of the astronomer are familiar with cgs international units, we will try to follow this standard as close as possible, with some slight adaptations to infrared convenient units. However, we plan also to propose an option allowing to stick to SI units, following the recommendations of the 11th CGPM (Conférence générale des Poids et Mesures) in 1960.

- Wavelength : µm
- Monochromatic flux : erg/cm^2/µm
- Transmission ranging from 0 to 1, 0 corresponding to the case of totally opaque material/surface, 1 corresponding to a perfect transmission.
- Dark current in ADU/s
- Object projected extension in arcsec

File Format

- The following standard formats will be used :
- Instrument Definition File : ASCII format, with DICB standard keywords.

- Calibration files : we will use as much as possible FITS format
- sources spectral templates are stored in ASCII files, the spectral resolution must be around 50000. Letting that the possible wavelength coverage goes from 6 to 28 µm, a spectrum model should, in principle, cover this range. However, keeping the whole wavelength coverage would lead to files of 100000 lines. Thus, the spectral coverage will be matched to the selected spectral resolution and recalculated each time.
- Sources geometric definitions are defined analytically in an ASCII file
- Output/result files are written in FITS format

5.2 Miscellaneous

Apart from Database data, several miscellaneous data will be handled by the ETC. These are generally temporary files erased once the user logs off.

- Simulation results : in FITS format as much as possible
- Run-time files : they contain intermediate results and parameters. ASCII files format.
- User-defined configuration(s) of the instrument and characteristics of the observation to be simulated. These informations are also put in the FITS output file (simulation results) header.

6. Interfaces

6.1 Graphical User Interface (GUI)

As it is the case for all the other VLT instruments, the ETC software will reside in Garching on a dedicated host computer. The ETC software will be accessible through the WEB via an HTML/CGI interface whose format is common (but adapted to particularities of each instrument) to all VLT instruments. In a first WEB page/CGI interface, the user defines the observing mode and the source/atmospheric parameters. An observation data file is then created which is used an input of the ETC software which is activated and whose called modules depend on the user selection.

The output WEB page contains all relevant informations i.e. a summary of the entered observing parameters, the results of the simulation in form or both numbers (tables) and graphs usually plotting the signal to noise ratio as a function of the total observing time.

Annex 1. Description of modules

Module Name : power_law_SED

Purpose : Simulate a SED with a power-law distribution

Method : Simple analytic form : $F_\lambda=F_0(\lambda/\lambda_0)^\alpha$ where F_0 and λ_0 are the reference flux and corresponding wavelength, α is the spectral index.

Inputs : F_0 and λ_0 the reference flux and corresponding wavelength, α the spectral index

Output : F_λ the SED in Watt/m^2/µm or converted to a F_ν in Jy

Sub-modules used : None

Module Name : Line_and_continuum_SED

Purpose : Simulate a single line superimposed to a continuum SED

Method : Assimilate the line to a gaussian function around the central wavelength, and add a continuum function chosen among : blackbody, power-law

Inputs :

- The line(s) central wavelength(s)
- The gaussian fwhm(s)
- The lines peak intensitie(s)

Output : The simulated SED in Watt/m^2/µm or converted to a F_ν in Jy

Sub-modules used :

- Gaussian distribution generation
- Blackbody function
- power_law_SED

Module Name : 3D_radial_powlaw

Purpose : create a 3-D radial structure of the brightness

Method : Compute the radial 1-D brightness distribution, then replicate it on a 3-D grid

Inputs :

- The spectral index of the power-law distribution
- The outer and inner limit radii
- The integrated flux at a given wavelength

Output : the 3-D brightness grid

Sub-modules used : None

Module Name : 3D_disc

Purpose : create a 3-D structure of the brightness of a disc

Method : Compute the 2-D structure of an axisymmetric disc, then replicate it to form a 3-D structure (disc thickness)

Inputs :

- The spectral index of the radial power-law distribution in intensity at a given wavelength
- The outer and inner limit radii
- The integrated flux at a given wavelength
- The disk thickness
- The disk inclination with respect to the line of sight direction

Output : the 3-D brightness grid

Sub-modules used : None

Module Name : 3D_to_2D_projection

Purpose : Project a 3D structure created by former modules on a 2D grid corresponding to the observation plane

Method : Projection usual formulae (Radon transform)

Input : the angle-of-view tilt between the line of sight and a 3D reference axis of the 3D grid.

Output : The scaled (in flux) 2D surface brightness distribution

Sub-modules used : None

Module Name : MIR_atmos_ext

Purpose : Compute the atmosphere extinction in the mid-infrared range

Method : An atmosphere model, probably in form of an accurate table, with a vapour content as an input supplementary parameter. Check of any line saturation.

Input : the wavelength range on which the atmospheric extinction must be computed

Output : the atmospheric extinction as a function of the wavelength.

Sub-modules used :

Module Name : dark_current_comp

Purpose : Compute the dark current in ADU

Method : following the detector manufacturer data sheets (TBD once the detector is chosen)

Input : the integration time

Output : the dark current value in ADU

Sub-modules used : None

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