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The VIMOS Mask Preparation Software

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Abstract. The main scientific characteristic of VIMOS (VIsible Multi Object Spectrograph, to be placed on ESO Very Large Telescope) is its high multiplexing capability, allowing astronomers to obtain up to 800 spectra per exposure. To fully exploit such a potential a dedicated tool, the VIMOS Mask Preparation Software (MPS), has been designed. The MPS provides the astronomer with tools for the selection of the objects to be spectroscopically observed, including interactive object selection, handling of curved slits, and an algorithm for automatic slit positioning that derives the most effective solution in terms of the number of objects selected per field. The slit positioning algorithm must take into account both the initial list of preferred objects, and the constraints imposed either by the instrument characteristics or by the requirement of having easily reduceable data. The number of possible slit combinations in a field is in any case very high (10^{73}), and the task of slits maximization cannot be solved through a purely combinatorial approach. We have introduced an innovative approach, based on the analysis of the function (Number of slits)/(slit length) vs. (slit length). The algorithm has been fully tested with good results, and it will be distributed to the astronomical community for the observation preparation phase.

1. Introduction

The VIRMOS (Visible and Infrared Multi-Object Spectrograph) project consists of two spectrographs with enhanced survey capabilities to be installed on two unit telescopes of ESO Very Large Telescope (Chile): VIMOS (0.37–1 μm) and NIRMOS (0.9–1.85 μm), each one having a large field of view ($\sim 14' \times 16'$) split into four quadrants and a high multiplexing factor (up to approximately 800 spectra per exposure).

To exploit such potential, a dedicated tool, the VIRMOS Mask Preparation Software (MPS), has been implemented. It provides the astronomer with tools for selecting objects to be observed spectroscopically, and for automatic slit

[1]On behalf of the VIRMOS Consortium

positioning. The output of MPS is used to build the slit masks to be mounted in the instrument for the spectroscopic observations.

2. Requirements

At a limiting magnitude$_I < 24$, the density of objects in the sky is such that more than 1000 galaxies are visible in a VIMOS quadrant. Of course, not all these objects can be observed spectroscopically, as some requirements imposed by data quality have to be taken into account when placing slits: the minimum slit length will depend on the object size, since the slit must contain some area of "pure sky" to allow for a reliable sky subtraction; spectra must not overlap either along the dispersion or the spatial direction; as each first order spectrum is coupled with a second order spectrum which will contaminate the first order spectrum of the slit above, a good sky subtraction can be performed only if slits are aligned in columns (same spatial coordinate) and, within the same column, have the same length. All these factors lead to a theoretical maximum number of spectra per quadrant of approximately 200.

Another requirement for MPS is set by the very good VLT seeing which allows the use of slits widths of $0\farcs3$–$0\farcs4$. Such narrow slits imply an extremely precise slit positioning, with maximum uncertainties of order $0\farcs1$. Thus the need for some (1–2 per quadrant) manually selected reference objects (possibly bright and point-like) to be used for mask alignment. Moreover, the user must have the possibility to choose manually some particularly interesting sources to be included (Compulsory objects) and some others to be excluded (Forbidden objects) from the spectroscopic sample. A tool for manual definition of curved or tilted slits, to better follow the shape of particularly interesting objects, must also be provided.

The MPS starts from a VIMOS image, to which a catalogue of objects is associated. The catalogue can be derived from the image itself or from some other astronomical dataset. In this second case, a way to correlate the celestial coordinates of the objects in the catalogue with image coordinates is to be provided. Some catalog handling capabilities, to allow for the selection of classes of sources among which to operate the choice of spectroscopic targets, some image display and catalogue overlay capabilities have to be provided by the package.

3. MPS Graphical User's Interface

As MPS will be distributed to the astronomical community, it should be based on some already known package (Not Yet Another System). It was therefore decided to base the MPS GUI on the SKYCAT[1] tool distributed by ESO. This tool allows astronomers to couple VIMOS images and catalogues on which to operate selections of objects over which to place slits.

[1] `http://archive.eso.org:8080/skycat/`

A new panel for catalogue display and object selection (Reference, Compulsory, Forbidden object) has been implemented. For each type of catalogued object, a different overlay symbol has been defined.

3.1. Curved/Tilted Slits Definition

A dedicated zoom panel allows the definition of curved/tilted slits. Curved slits are defined by fitting a Bezier curve to a set of points chosen by clicking on the zoom display. The fitted curve is then automatically plotted. The slit width is chosen through a scale widget.

Tilted slits can be defined as curved slits and then straightened. If the astronomer wants to have slits of a width different from the one chosen for the automatic slit placements, he can define them as tilted slits and then align them to the other automatically placed slits.

4. Slit Positioning Optimization Code

The core of Mask Preparation Software is the Slit Positioning Optimization Code (SPOC). Given a catalog of objects, SPOC maximizes the number of observable objects in a single exposure and computes the corresponding slit positions.

SPOC places slits on the field of view taking into account: special objects (reference, compulsory, forbidden), special slits (curved, tilted or user's dimension defined), spectral first order superposition, spectral higher order superposition and sky region parameter (the minimum amount of sky to be added to an object size when defining a slit).

4.1. The Optimization

The issue to be solved is a combinatorial computational problem. Because of the constraint of slits aligned in the dispersion direction, the problem can be simplified slightly: the quadrant area can be considered as a sum of strips which are not necessarily of the same width in the spatial direction. Slits within the same strip have the same length and the alignment of orders is fully ensured. The problem is thus reduced to be one dimension. It is easy to show that the number of combination is roughly given by: $N_{combination} = (N_{possible\ strip\ widths})^{(average\ number\ of\ strips)}$. The slit length (or strip width) can vary from a minimum of 4 arcsec (20 pixels, i.e., twice the minimum sky region required for the sky subtraction) to a maximum of 30 arcsec (150 pixels, limit imposed by the slit laser cutting machine). The average number of strips can be estimated as the spatial direction size of the FOV divided by the most probable slit length: assuming the latter to be 50 pixels (10 arcsec), we would have $2048/50 = 41$ strips. The number of combinations would then be: $N_{combinations} = 130^{41} \simeq 4.7 \times 10^{86}$. Computing these many combinations would correspond to 10^{60} years of CPU work! The problem is similar to the well known traveling salesman problem: in the standard approach, this is solved by randomly extracting a "reasonable" number of combinations and maximizing over this subsample. In our case, due to computational time, the "reasonable" number of combinations cannot be higher than $10^8 - 10^9$, so small with respect to the total number of combination that the result is not guaranteed to be near the real maximum. Our approach has been to consider only the most "probable" combinations, i.e., the ones that have the highest probability of maximizing the solution.

Step 1: For each spatial coordinate, we can vary the strip width from the given minimum to the given maximum, count how many objects we can place in the strip, and build the diagram of the number of slits in a strip divided by the strip width as a function of the strip width. For each spatial coordinate, only the strip widths corresponding to peaks in this histogram are worth considering, as they correspond to local maxima of the number of slits per strip. The exact positioning of the peaks varies for each spatial coordinate, but the shape of the function remains the same. The position of the peaks can be easily found in no more than 6–7 trials (using a partition exchange method).

Step 2: For each spatial coordinate we have K (where K is the number of peaks) possible strips, each with its own length and number of slits. Although the number of combinations to be tested is decreased, it is still too big in terms of computational time.

Step 3: A further reduction can be obtained if, instead of considering all the strips simultaneously, we sequentially consider M subsets of N consecutive strips, which together cover the whole FOV. At this point, we should vary N (and consequently M) to find the best solution. In practice, when N is higher than 8–10, nothing changes in terms of number of observable objects. For N=10, thus M=4 (i.e., $2048/(4 \times 50)$), the number of combinations is reduced to only $4 \times 4^{10} - 4 \times 10^6$, which means a few seconds of CPU work. Unfortunately, as a consequence of the optimization process, small size objects are favored against the big ones.

4.2. An Alternative Optimization

A second, less optimized algorithm has been implemented within SPOC. This alternative algorithm does not optimize all strips simultaneously but builds the $N_{Slit}/Strip$ function strip by strip without considering object sizes, and takes only the maximum of the distribution. Then it enlarges each strip width by taking into account object sizes. In this way the number of placed slits decreases by a few percent but the object dimension bias disappears.

5. SPOC Graphical User Interface

A dedicated panel for SPOC setup has been implemented within SKYCAT. Through this panel, users can select the grism, the slit width, the sky region parameter, the number of masks to be obtained for the given field, and the type of SPOC maximization.

The number of input slits and placed slits for all kinds of objects (Reference, Compulsory, etc...) is printed in a text box.

The slit catalogue produced by SPOC can be loaded as a normal SKYCAT catalog with overlay symbols defined for all kinds of objects, and it is also possible to plot the slit and spectrum overlay for all SPOC catalog objects.