Mask-mode MOS at the TNG: a flexible approach to multi-object spectroscopy

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ABSTRACT. We describe the implementation of the LRS Mask-Mode multiobject spectroscopy at the Galileo National Telescope. This extended MOS capability will complement the real-time MOS provided by the built-in multislit assembly of LRS, allowing spectroscopy for many tens of objects (usually $\sim 30-40$) simultaneously over a useful field of 6×9.5 arcmin. With the lowest dispersion grism presently available with LRS, or in cases where the needed astrophysical information is contained in a limited wavelength intervals, it will be possible to obtain two rows of spectra on a single mask using an appropriate intermediate band filter. Up to ~ 100 spectra will be obtained with this technique.

The slitlets will have fixed width 1.1 or 1.6 arcsec and user-defined length, with no positional constraints aside from absence of spectrum overlap. We provide observers with a new, user-friendly IDL-based Interactive Mask Design Interface by which aperture masks can be efficiently designed both at La Palma and at home institutions. Up to 7 slit masks, manufactured at the TNG Observatory during daytime and mounted on removable plate holders, will be made available for observation each night using the Slit Exchange Unit of the LRS. We illustrate the mask design and production methods and the observing procedures foreseen for multiobject spectroscopy at the TNG using the mask MOS technique.

1. Scientific motivations

While deep cosmological surveys will be conducted at 10m class telescopes using large-field spectrographs (e.g., VIMOS at the ESO/VLT), MOS facilities at 4m class telescopes offer an appropriate alternative for less extreme targets in fields with size of the order $10'$ in diameter. Among the potential targets for multiobject spectroscopy at the Galileo National Telescope (TNG) we mention stellar populations and kinematics in cluster and field galaxies at intermediate redshift, gravitational lenses, and stars and globular clusters in nearby galaxies. We should also mention the fact that the Galileo telescope will offer us the opportunity to observe targets in the northern sky.

The multislit assembly provided by the Low Resolution Spectrograph (LRS) (19 slits with fixed length of 20 arcsec) will be the standard option for most programs. It has several practical advantages, first of all a real-time slit setup during the observing night, without any intervention of TNG staff, and optimal quality of the slitlets. However, there remain a number of scientific cases where the uniform and fixed (along the spatial axis) coverage by the multislit assembly seriously affects observation efficiency. Based on these consideration, the first author proposed to complement the real-time MOS with a mask mode, a proposal endorsed and supported by the Instrument Definition Team of

LRS (Held, Ramella & Cristiani 1995) and funded by the C.R.A. On similar arguments, an extended (mask) MOS mode was included in FORS2 in December 1997 in response to the recommendations of the Scientific Committee of the instrument. In the Mask-Mode MOS (MM-MOS), the targets will be observed through multislit masks prepared for each target field using a mask manufacturing facility locally available at the TNG. The main advantage of this mode is its flexibility: mask can include a large number of slits with arbitrary position, orientation ans shape, with very little constraints aside from those needed to prevent spectrum overlap. Obviously, masks also have some drawbacks: they must be prepared in advance of the observing night, requiring specialized staff and careful processing.

The reference document in our selection of the hardware for mask manufacturing is the document of specifications issued by the Instrument Definition Team of the LRS. Some requirements originally defined for the multislit assembly, cannot be directly applied to aperture masks, and others had to be somewhat relaxed. We ended up with the following set of specifications:

- Positioning accuracy of the slit centers better than $\pm 10\mu$m, equivalent to ± 0.06 arcsec.
- Parallelism of the slit edges better than $\pm 3\mu$m over the slit length of 20 arcsec.
- Slitlets as narrow as 1 arcsec, yielding a minimum width of 187μm on the focal plane.
- Micro-roughness of the slit edges better than ± 3 μm r.m.s.

In this contribution we present the implementation of the MM-MOS at the TNG, describing all the tools built or procured to this purpose. The experience with MOS instrumentation accumulated in other observatories provided the guidelines for this project (Tanvir 1992; Allington-Smith et al. 1994; Le Fèvre et al. 1994; Oke et al. 1995).

2. Mask design

Figure 1 presents an overview of the steps necessary to prepare the aperture masks, from design of the slit setup to the mounting of mask holders at the telescope. The standard procedure for creating masks will consist in collecting a short exposure image of the astronomical region using the imager mode of LRS, measuring the target positions from the image, setting up the slits, and producing the final drawing necessary to operate the cutting machine. All the necessary steps are performed using a newly created Interactive Mask Design Interface (IMDI), a graphical interface based on IDL widget procedures, conceived to be fully integrated into the LRS User Interface in the telescope/instrument control environment. Previous experience of one of the authors with design of the Galileo Optical Imager user interface ensures compatibility and stylistic compliance with the TNG environment. A standalone version will also be provided to astronomers to design masks at their home institution, using short exposure images taken in advance of the observing run.

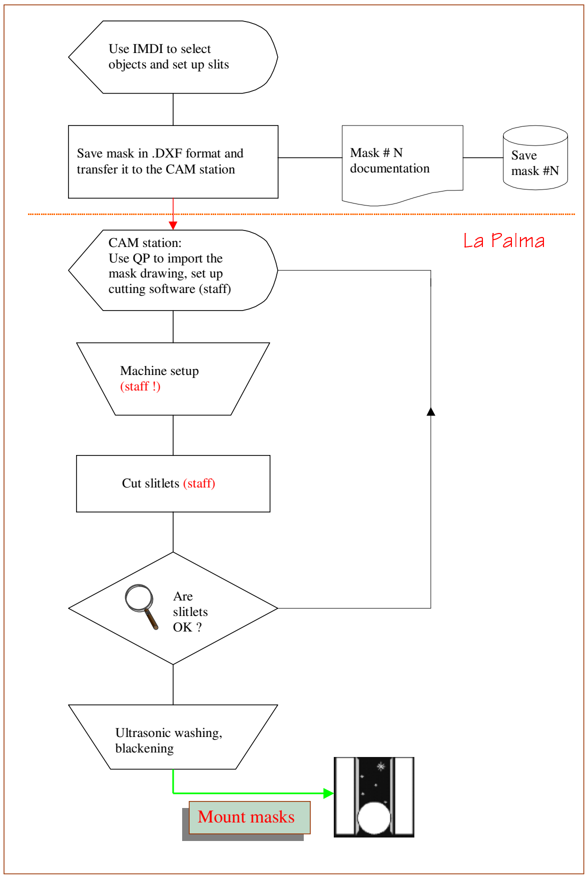

Fig. 1. A flux diagram of the various steps of aperture plate manufacture, from mask design to mounting of masks at the telescope.

The basic setup parameters (wavelength range, spatial scale, etc ...) are directly read from the TNG/LRS database and the image FITS header. The user only needs to select the preferred grism, load the image and start picking up the target objects. A list of object coordinates can also be imported from one of the several existing programs performing automated image analysis and classification (*e.g.,* Sextractor). Each slit is interactively adjusted and can be deleted at any time. The SAVE/RESTORE feature allows users to suspend mask editing and resume it later. A key feature of IMDI is its real-time anti-collision algorithm, warning the user about spectrum overlap during slit editing. To add flexibility to the mask design, acceptance of these warnings is left to the user's responsibility. Only slitlets violating a limited number of severe mechanical constraints are refused. An automatic slit optimizer will not be offered with the first release of IMDI, although this option may become available in upgraded versions. The user is also

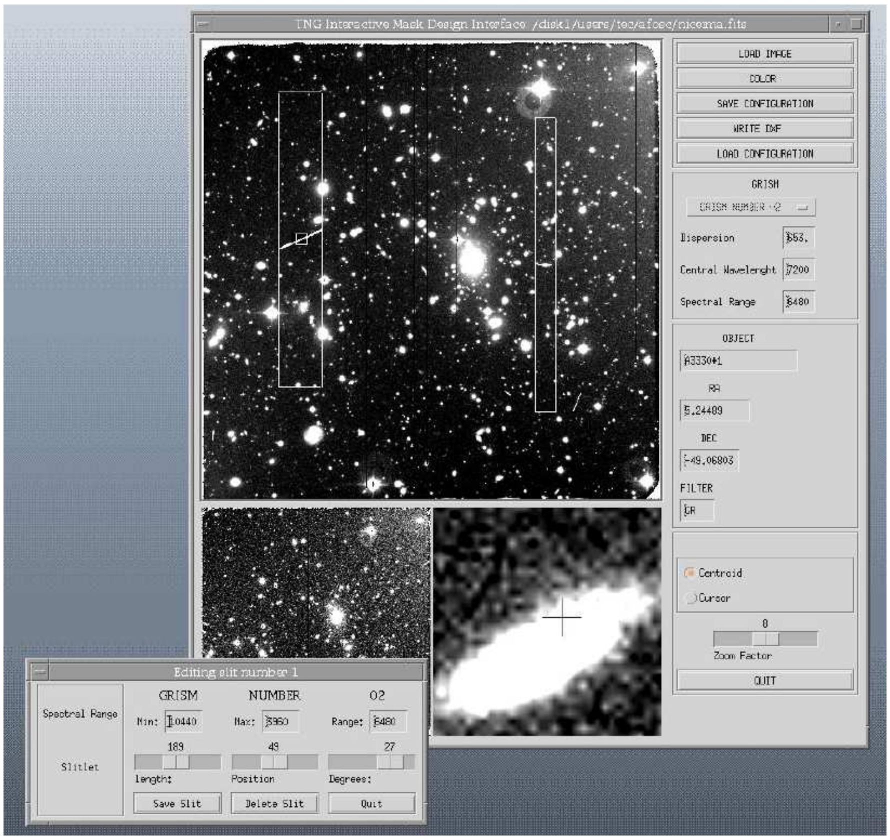

Fig. 2. A working prototype of our Interactive Mask Design Interface, including most features needed to design the masks. The rectangles represent the location of the expected spectra, calculated from the instrument database. The centering, as well as the length and position angle of the slits, are interactively set by the astronomer under control of an anti-overlap algorithm. Objects can be centered anywhere in the slitlets to optimize the number of targets. Most operations are executed by cursor, buttons and sliders in a self-explaining sequence.

required to mark three reference stars for subsequent mask alignment.

Figure 2 shows a example of the use of IMDI, illustrating its great flexibility in defining not only the centers and length of the slits, but also their position angle. This may be useful to optimize the signal-to-noise of spectra of elongated objects (*e.g.,* gravitationally lensed distant galaxies). Another useful feature allowed by the mask design software (and by Mask-Mode MOS observations) is stacking of two rows of spectra. This technique, finding its classical application in surveys of distant galaxies, uses a low-dispersion grism in combination with a bandpass filter to reduce the spectrum length, so as to accommodate more than one spectrum along the dispersion direction. The TNG MM-MOS will allow to have up to ~ 100 spectra in a mask, provided that an appropriate grism/filter

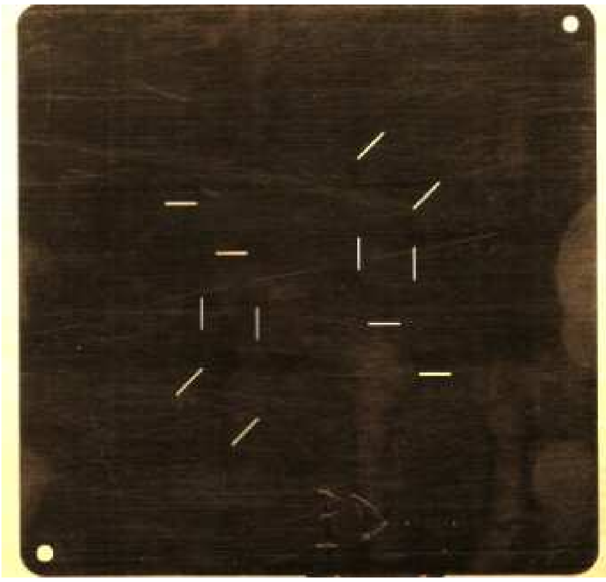

Fig. 3. An actual mask produced during tests of different materials and tools. Two reference holes ensure accurate repositioning of the mask in the plate holder. A third pinhole made during mask cutting (not shown here) will ensure correct mounting. The useful field for MOS with the foreseen 2048×2048 CCD will be about $6' \times 9.5'$.

combination is available.

When the mask slit setup is deemed satisfactory, it is saved in its final form. The end products of IMDI include: (i) the mask-cutting drawing in the standard Drawing Interchange File Format (DXF); (ii) a full documentation, specifying the LRS and telescope setup associated to the mask, including information from the image header and a listing of the slits in plain ASCII format; (iii) an include file to be transferred to the telescope database, conveying all information on a specific mask to be written in the FITS header of the MOS spectra.

A copy of all files will be sent to the TNG team (via ftp upload into a dedicated area) for mask production under the responsibility of mechanics staff. In special cases it will be possible to make masks directly at the telescope with a short lead time.

3. Mask manufacturing

Cutting the masks (an example of which is shown in Fig. 3) is quite easy, although its execution will be reserved to specialized TNG staff. Before further describing mask production, we summarize here the characteristics of the mask cutting system.

The milling machine, heart of the system, is a high-precision commercial CNC cutting plotter by Scripta s.r.l. which was chosen since it is heavy and stiff enough to ensure compliance with the required positioning accuracy (0.01 mm). The blank mask, a thin $\sim 10 \times 10$ cm square plate of brass, is securely clamped to the bed of the machine

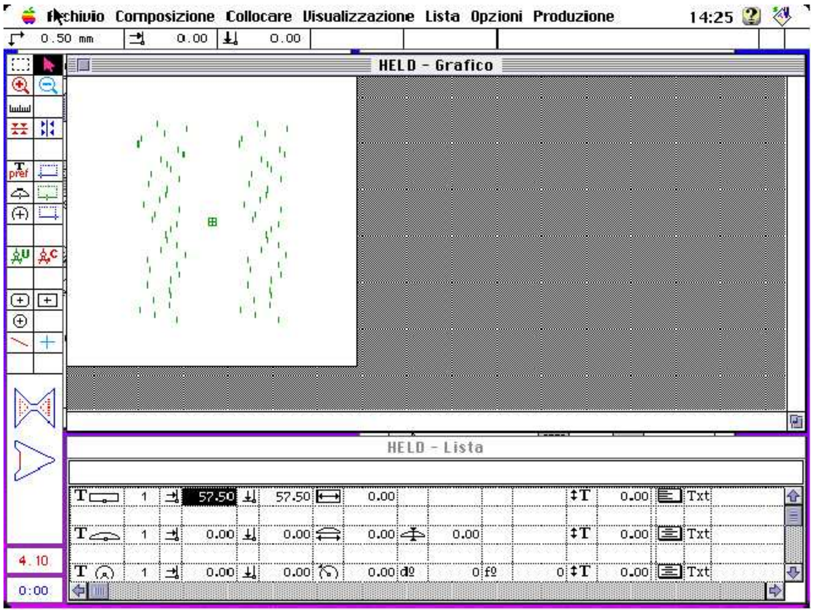

Fig. 4. A window of the mask production CAM software. In this example the QP program has just imported a drawing with a double series of slitlets, used to test mask design for faint galaxy observations. This facility may be directly employed to cut non-standard curved slits if required by special programs.

by a mask holder custom-made by Cinel s.r.l. The cutting tools are special cylindrical micro-mills with diameter 0.2 and 0.3 mm, corresponding to about 1.1 and 1.6 arcsec slits at the TNG. Using cylindrical rather than conical tools (the defocusing of the inner side of the plate is negligible) greatly improves the quality of the slits, in particular for the parallelism of the edges. A major problem with conical tools is the fact that any change in the cut depth (e.g., caused by a tool not perfectly sharpened or slight bending of the plate) affects the local slit width in an unpredictable way. By using cylindrical micro-mills, the quality of the cut remains good until the tool breaks down at the end of its operating life (which usually happens after cutting about a hundred slitlets). The small diameter of the cutting tools and the high quality of the final result require a fast rotating mandrel. Our cutting machine is equipped with a high-speed electrospindle reaching 90000 r.p.m., that we have chosen to operate at 80000 r.p.m. to prevent overheating and ensure a longer operating life. A spare of the spindle, which is the most critical component of the system, will be stocked with the system at La Palma.

A dedicated PowerPC computer (Mac 7100), equipped with a network interface card and TCP/IP communication software, runs proprietary CAM software (QP) to control the machine. The drawing files are copied from the storage area, converted to internal binary format, and used to drive the milling machine. Figure 4 shows an example of a mask drawing ready for plate production.

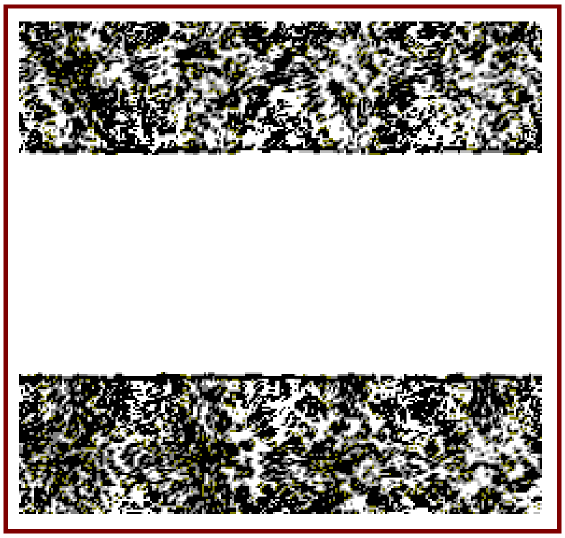

Fig. 5. Microphotograph of a 200 μm slitlet after ultrasonic cleaning. This enhanced contrast image allows assessing the degree of micro-roughness of the slit edges. Both the r.m.s of the slit edges and their parallelism over a $20''$ length are better than 3 μm.

The mechanical part is the only one that really requires specialized staff. After setting a number of technical software parameters, the operator will get the machine itself ready for cutting. While finding the x, y origin on the mask plane is not a problem, given the good positioning accuracy of the table, setting the zero point for the z axis (i.e., the axis perpendicular to the plate) definitely calls for a skilled operator. About 15-40 min. are necessary to cut one mask, depending on the number and length of the slits. After cutting, the masks are not yet usable since metal powder and chips dirty the slit edges. These are effectively cleaned by ultrasonic washing. We have used a commercial ultrasonic washing machine allowing cleaning of 10 plates together. After a 30 min washing all masks are routinely checked to detect possible flaws. The most common cause for discarding a mask is the breakdown of the tool during processing. Finally, after inspection at the microscope, the plates are painted with an antireflection coating and mounted on the holding frames. Any residual dust shall be carefully swept away using compressed air before mounting the frame in the slide assembly of the spectrograph.

An example of a multislit mask where several slits were cut using two different tools (200 and 300 μm in diameter) has been shown in Figure 3. This plate was cut from a 0.2 mm thick bronze sheet. Note the semicircular ends of the slits, leading to the loss of a small part of the slit at each end. After testing the cut quality with different metals, such as aluminium and several brass and bronze alloys, we concluded that bronze gives the cleanest slits. Our trials also included testing of cylindrical mills of two different lengths, produced by two different US firms. Figure 5 shows an example of the good quality of the edges. Microphotographs of many slits obtained with different tools/materials/cleaning were taken with a small CCD camera attached at a microscope. The micro-roughness and parallelism were measured using standard image processing packages. We also measured the parallelism of the edges and the relative positions of the slits using a PDS microdensitometer in manual mode (1 μm precision). These tests led to the following conclusions:

- The relative positions are accurate to within a few μm. Differential temperature effects between day time, when the masks are prepared, and night time when observations are executed shall be carefully evaluated during MM-MOS commissioning. Preliminary considerations suggest a 0.02% change in plate scale for a temperature variation of 10 °C. The parallelism of the slit edges is better than ± 3 μm over the entire slit length of 20 arcsec, excluding the semicircular ends.

- The minimum slit width is about 210 μm, equivalent to $\sim$ 1.1 arcsec, slightly larger than originally specified.

- Good micro-roughness of the slit edges – r.m.s. <3 μm – can be routinely achieved with appropriate ultrasonic cleaning. The plates must be stored in a clean place because the slits have a tendency to collect dust due to the relative roughness and finite thickness of the cut edges.

In summary, the quality of our mechanically cut slitlets basically meets the specifications and is similar to the current standards at ESO/NTT. Higher (VLT) standards, such as those attainable with last-generation cutting lasers (*cf.* Conti et al. 1999), are obviously desirable and will be considered if high demand by the Italian community justifies an order-of-magnitude larger investment.

4. Observing with the MOS slit masks

The flux diagram in Fig. 6 outlines the telescope pointing and target acquisition procedures. Once the masks have been mounted in the LRS slide assembly using their appropriate plate holders, it should be possible to reposition them in and out the optical beam with high accuracy. A short direct image of the target field will be taken without the mask, using the Pointing Window of IMDI as part of the LRS User Interface. The coordinates of three reference stars will be measured and memorized. Then, a direct image will be taken through the mask back-illuminated by a flat-field lamp. The coordinates of the reference stars will be measured (possibly in an automatic way), and PW-IMDI will calculate the offset (and possibly rotation) that should be applied to map the targets onto the centers of the slits. During this move, the autoguider will be locked on the guide stars to avoid the possibility of a telescope drift. This operation should be repeated during long observations to check pointing. These operations will be tested and all open issues investigated during MOS commissioning.

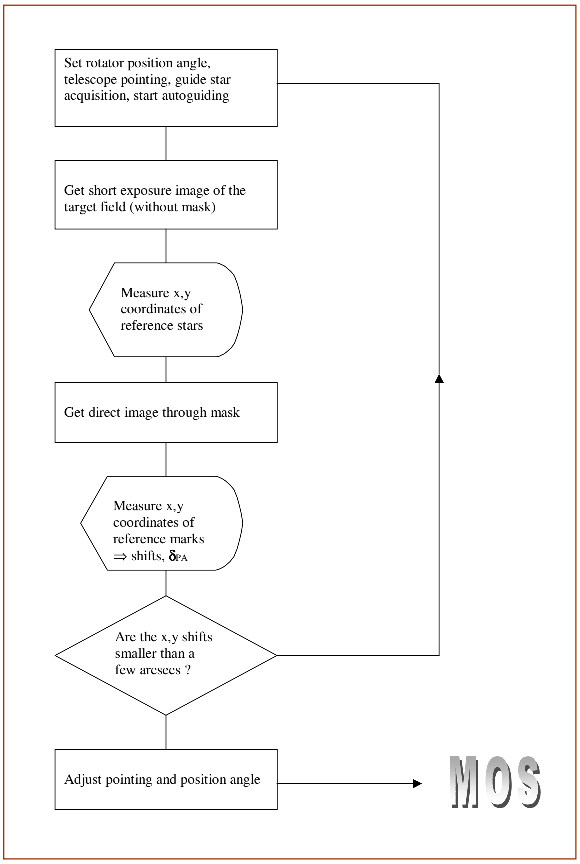

Fig. 6. The sequence of operations needed for target acquisition and MOS observations.

5. Conclusions

The Mask-MOS facility offers to the Italian community a highly flexible tool for multiobject spectroscopy, with a quality standard comparable to that of MOS facilities presently available at 4m class telescopes, at a very affordable cost (<40000 Euro) and with reasonable equipment size. The features made possible by the Mask-Mode MOS, such as a portable mask design software, its interface with automated photometry programs, the possibility of inclined or curved slits and slit stacking, represent a development of great potential interest for astrophysics.

Acknowledgements

It is a pleasure to thank R. Merighi for his invaluable help at many stages of this project. Drs. M. Breare (INT Group), K. Szeto (Gemini Project), N. Tanvir (Cambridge, UK), and P. Kiergaard (Copenhagen Obs.) are warmly thanked for helpful discussions about aperture mask manufacturing and design. We are indebted with Ing. Mattaini (IFC/CNR Milan) for generously sharing the results of his mask cutting experiments for VIRMOS. We also thank Dr. M. Ramella for his contribution of scientific and technical motivations in support of this project. Several tests of hardware and software for this project have been done at the Stazione Astronomica L. Rosino of the Padova Astronomical Observatory with the collaboration of R. Claudi and L. Traverso.

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