Multi-Object Spectroscopy

With the Nordic Optical Telescope
Spectroscopy

- Slit
  - Width of the slit determines the amount of signal that can pass through
- Diffraction grating
  - Determines the energy range dispersed over the detector
- Detector
  - Determines the number and size of discreet points in which the spectrum can be digitized

All three determine the spectral resolution:

$$\partial \lambda \sim \frac{\text{spectral range} \times \text{slit width}}{\text{total pixels}}$$
What is MOS?

- MOS (Multi-object spectroscopy) is exactly that, spectroscopy with more than a single slit on the mask.
- Important for observations of clusters of targets or sky surveys
- Advanced preparations must be done because of the uniqueness of each observation
  - Usually mask designs need to be submitted as little as a month before observations will be made in order to be fabricated on time
  - In many cases, pre-imaging is needed as well even further in advance in order to create the mask designs.
  - Rare cases where masks can be designed from catalogue data and fabricated on site the day before observing
- Other MOS methods
  - Fiber fed spectrograph (requires plates or robot)
  - IFU
  - Slit-less spectroscopy
Pre-imaging

This is a filter-less image taken with ALFOSC about 3 months before the scheduled observing run. No filters are used when taking spectra for this run, so any field distortion will be consistent. Only a short exposure is usually needed, in this case 1 minute. From this image, the relative positions of the stars and galaxies can be used to design an accurate slit mask.
Mask design

It is up to you to prioritize your target list in anyway you see fit to achieve your science goals. In this case we are looking for galaxies most likely bound to the same massive halo, so the prioritization can be based on color, distance from the optical center, and magnitude. From there we add targets to the design based on this prioritized list, rejecting targets that overlap with previous slits. Ideally we can get ~20 objects, while making room for the guide stars needed for aligning the telescope.
Spectral range

The y-axis position of the target is important because it determines the spectral range visible across the detector. Objects at high y values will cut off blue (smaller) wavelengths, objects at low y values will cut off red (larger) wavelengths. You must have some idea of where the spectral features you want to observe will most likely fall on the detector when designing a mask.
Design file

An example of the format that must be used to upload designs to the NOT. It lists the proposal details, target position, set-up, and slit positions in pixel coordinates.
Preparation before the night
Observing set-up

• Florence (data is available here to work with)
  • Login using ssh, the night observer will give you the relevant info you need to do this
  • Open a ds9 window: “ds9 &”
  • Open an X terminal: “\xgterm –sb –sl 1000 &”
  • Open IRAF in xgterm: “ecl”
  • Start the ALFOSC package: “alfosc”

• Telescope
  • Point the telescope the same way you would for imaging
  • Must use the same rotation angle as the pre-imaging (check header)
    • $\ tcs.field-rotation\ value
Field image

Image the field in order to make a reference to where the stars are located on the detector. For this image, the only requirements are there are no filters and the guide stars are visible. An exposure somewhere between 5-10 seconds is usually sufficient.
Mask image

A mask image is needed next in order to make a reference to where the fiducial holes are located on the detector. A 5 second exposure is good enough to get enough background photons through the holes. At this point, you can not have any objects appearing through the holes or else finding their centers will be impossible. In this rare instance, you will have to move the telescope slightly and start over from the last step.
IRAF task: mosstrong

- The task mosstrong will calculate how much the telescope must move/rotate to align the mask.
- In IRAF:
- You will now use ds9 to manipulate the images.
Mark fiducial holes

In ds9, hover over a fiducial hole and type “a” to find the center. It will display a circle around the hole. If you are satisfied with the position, type “q”. Repeat these steps for each hole. When done, type an additional “q” to move on to the next step. Example: in this image, the command sequence would be a,q,a,q,a,q,a,q,q.
Mark star locations

The first hole will be marked on this field image. It should be near to where the actual star is located. The fiducial hole can be associated to a star by hovering over the star with the cursor and type “a,q”, just as you did in the previous step. Repeat for the rest of the holes as prompted. Example: in this image, the command sequence would be a,q,a,q,a,q,a,q,a,q.
First attempt to align

• mosstrong will print out the required x,y shift and rotation to align.

• In IRAF, type “mosmove”, to apply this correction.
  • If this is the first time during the run that an IRAF command moves the telescope, you will first be prompted to input the TCS password (usually written on the board)

• After the move, the guide star will need to be found manually. This can only be done by someone sitting in the observatory, so the night astronomer will do this for you. (There might actually be a new command to do this automatically now. I will look into this.)

• Once the guide star is reacquired, restart autoguiding with the command:
  • $ tcs.ag-relaxed-on

• Go ahead and make another image through the MOS mask to check the alignment.
What will likely happen is that the alignment will be close, but not perfect. We can make one more adjustment using same mosstrong procedure now using this new mask image as the field image, because the stars are now visible in the fiducial holes.
Second attempt to align

• In IRAF:
• Follow the same procedure as before
• This time we will use the output from mosstrong directly. Rotation at this point should be near zero, and the x and y shift should be small numbers in arc seconds. Remember! Positive shift for alignment is a negative move for the telescope and vice versa.
• Input into the sequencer: $ teloffset X Y
• Follow the same procedure again to recover auto guiding and image the mask one more time.
You should now be able to see the galaxies in the slits. If not, you will have to reposition the telescope and try again. Usually this is due to a bad fiducial hole. You can try to identify which one and not use it in the aligning routine.
Calibration

• After aligning, it is an opportune time to calibrate your mask. If time is limited, this step can be done at any time during the same day/night the mask is mounted on the telescope.
  • It is very rare for the mask to shift inside the instrument, but it has happened!
• For this case, calibration is just as you would do for long-slit spectroscopy.
• For the NOT school, I will copy over my calibration script for your use.
Resulting halogen flat
One of three.
Resulting calibration lamp

Make sure lines are visible over the entire y-axis range. In the past there has been some trouble with the He lamp taking time to warm up. An exposure of 10 seconds is enough to get good He line strengths and not saturate the bright Ne lines.
Set exposure

Finally, set the exposure time, then sit back and relax. We typically expose for a total of 45 to 60 minutes, with the total exposure divided into 3 parts. The image is just one of those parts.

Example: \$ \text{exp} \ 1200 \ ; \ \text{exp} \ 1200 \ ; \ \text{exp} \ 1200 \ ; \ \text{playphone}

(It’s a good idea to add a noise at the end of a long sequence in case you doze off or lose track of time.)

Remember! \$ \text{alfosc.object target\_name}

Use this command after setting the exposure, always!
Full exposure result
A combined image of all three exposures. You get the full signal-to-noise without any of the cosmic rays potentially contaminating any of the spectra. Note how faint the spectra tracks look compared to the long-slit spectra at the beginning. This will change the way we analyze this data.