Optical Design of MAAT
an IFU for the GTC OSIRIS Spectrograph

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Published in:
Proceedings of SPIE

DOI:
10.1117/12.2630717

Publication date:
2022

Document version
Publisher's PDF, also known as Version of record

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Citation for published version (APA):
MAAT: an Integral Field Unit on GTC that does spectrograph aberration corrections

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The Mirror-slicer Array for Astronomical Transients (MAAT) is an IFU for the OSIRIS spectrograph on the Gran Telescopio Canarias (GTC), spectrograph that has recently been upgraded with a new detector. We present the nearly final design. Funds has been secured to build MAAT. The spectrograph can be used for multi-objects spectroscopy using masks that are in a cartridge. The IFU will be in a box that will take the place of a few masks. It is based on the Advanced Image Slicer concept as for MUSE and KMOS on the VLT and many others. The field of view is 10” x 7” with spaxels of 0.254” x 0.305” and the wavelength range 360 nm to 1000 nm. The curvature and tilt of the slit, and the limited weight that the mask cartridge can support, created additional challenges. The resolution is about 1.6 times larger than with a standard slit of 0.6” because of the smaller size of the slices. Two out-of-focus masks with pinholes along the slit have been manufactured and used to measure out-of-focus images of the pinholes. These are under analysis to calculate the spectrograph aberrations that will be corrected in part by the IFU.

The layout above shows the slicer system with 7 of the 23 slices; top and side views are shown. The fore-optics are shown separately for clarity. The fold bends the light at 90° toward the fore-optics which magnify the field to get 0.9 mm slices. Toroidal shapes of the fore-optics give a magnification a bit larger in the spectral direction (see bottom-right paragraph). The intermediate pupil then suffers from astigmatism but a stop there is very useful. Two baffles that we call pseudo-stops are used to solve the problem. One is in the vertical focus, the other the horizontal. The slices form a unique sphere when moved of the correct distance along their length to make it possible to polish all of them simultaneously.

The OSIRIS spectrograph was designed for a 0.6” slit. With 0.3” slices, the aberrations of the spectrograph will reduce the improvement in resolution from the nominal value of 2. We proceeded to measure the wavefront of these aberrations from the images of 2 out-of-focus masks with pinholes along the slit, one 30 mm before the focal plane, the other after. Analysis is in progress. The pinholes are 200 µm wide at 6 mm from each other. Modifications to the reimaging mirrors will then be introduced to reduce these aberrations. The main aberrations that we want to measure are those introduced by misalignment of the optics, namely focus, coma, astigmatism and spherical aberration. Focus and astigmatism can easily be corrected because the reimaging mirrors need to be toroidal so we only need to change some values given to the manufacturer. Coma and spherical aberration corrections would make the mirrors more complex so increase the cost.

The IFU starts with a fold followed by fore-optics that make an image of the telescope field on a slicing mirror array made of 23 thin mirrors 0.305” x 10” called slice mirrors. They send the light in different directions to be re-imaged side by side on the slit by another mirror array. Binned pixels are 0.127” x 0.254” so the spaxels are 0.305” x 0.254”. In the version on the left, there is a line of reimaging mirrors each sending the light to a slit mirror that reimage the pupil in the spectrograph. Different versions were studied. In the focal plane, there were 3 options:

1) A third and last mirror array that reimage the pupil at the right place in the spectrograph. This version makes it easier for the manufacturer to do the alignments and is well adapted to the very curved slit of the spectrograph but an array of 23 slit mirrors is necessary.
2) 2 flat rectangular mirrors on the slit. This version of the Advanced Image Slicer was developed at the then Edinburg Observatory. It has the disadvantages of giving a worse image quality in the focal and pupil planes and of delivering a "staggered" slit which slightly reduces the spectral length, and can cause important cross-contamination between slice spectra where bright lines as background OH lines contaminate faint object lines.
3) A new innovative considerably cheaper last mirror array. Instead of a staggered slit, it is the 2 flat mirrors that are staggered. The cost is then not too much higher than for 2 rectangular flat mirrors but the slit is now back to be linear.

Option 1 was chosen to help reduces the difficulties to do alignments and to reduce field and pupil aberrations by having an additional optics. Different challenged had to be addressed:

- A large maximum incident angle on the reimaging mirrors. This can generate large aberrations. Toroidal reimaging mirrors are necessary.
- A curved slit. The centre of the slit mirrors were placed along the curved slit but they are tilted with respect to the spectrograph input focal plane. The position of the reimaging mirrors with respect to the slit mirrors was optimized to reduce slice image edge defocus.
- A tilted slit. The slit mirror had to be tilted more than usual.
- A very large incident angle on the slit mirrors. They usually are toroidal but due to budget limitation only the few edge mirrors on the slit, which gives the worst aberrations, are toroidal; the others are spherical.
- IPF weight. This happened to be the biggest challenge, the mask holder not being designed to support an IFU. Our first concept of 14.2” x 10” was fastly abandoned for a 12” x 8.5” after a preliminary look at the mechanical design but this field was also abandoned after a full mechanical design. We had to settle for 10” x 7” and a 5 kg weight. Even so, the mask holder will be reinforced.

Images of the same pinholes from the 2 out-of-focus masks (left and middle). The large difference in size shows that the main aberration is defocus. Out-of-focus image of spectra from a calibration lamp (right). Unresolved lines give us out-of-focus PSF all over the detector.

Simulation of out-of-focus images with no aberrations (740 nm)

The primary and secondary of GTC have a complex shape, roughly an hexagon with a broken edge. Since the derotator rotates that pupil, the PSF changes slightly with the derotator angle complicating optical design. To simplify, an average pupil was calculated. It is circular with a variable transmission along its radius.

The IFU output pupil has large aberrations. The black circle shows what a perfect pupil should be. Apertures are quite large except for the most used grating which is very tight in the spectral direction. This can give systematic errors by variable vignetting due to the hexagonal pupil rotation with the derotator. To solve the problem, the magnification was increased by 1.125 in the spectral direction (horizontal) which reduces the pupil size by conservation of the A.Omega product. This would in principle reduce the resolution but the spectrograph was designed for a 0.6” slit so the aberrations dominate the resolution with 0.305” slices. The reduction of pupil size reduces the spectrograph PSF size. The combination of larger slice images and smaller PSFs leaves an average resolution almost identical.