

An Integral Field Unit for X-shooter

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ABSTRACT

X-shooter is a new high-efficiency integral field spectrograph mainly dedicated to the spectroscopic follow up of the gamma ray bursts. X-shooter will operate at the Cassegrain focus of the VLT with an intermediate spectral resolution of ~ 5000 , and will provide a very wide simultaneous spectral coverage, ranging from 320 to 2500 nm. The instrument consists in a central structure which supports three prism cross-dispersed echelle spectrographs respectively optimized for the UV-blue, Visible and Near-IR wavelength ranges.

X-shooter will offer an image slicer based Integral Field Unit (IFU) designed to analyse a $1.8'' \times 4''$ input field into 3 slices of $0.6'' \times 4''$ and to align them on a 12'' long slit. The principle of the IFU is that the central slice does not include any dioptré, the light is directly transmitted to the spectrographs. Only the two lateral sliced fields are reflected toward the two pairs of spherical mirrors and re-aligned at both ends of the previous slice in order to form the exit slit. We present here the IFU design developed at the Observatoire de Paris.

Keywords: IFU, Image slicer

1. INTRODUCTION

X-shooter will be the first instrument of the second generation available at the ESO Very Large Telescopes: this new spectrograph will be mounted at the Cassegrain focus of one of the VLT UTs, probably during 2007. X-shooter will be dedicated to the study of a wide range of astrophysical phenomena which require the exceptional capabilities of observing faint sources with unknown flux distribution in a single shot and/or in the shortest possible time (see e.g. D'Odorico et al., this conference).

One of the main science drivers for X-shooter will be the use of Gamma-Ray Bursts (GRBs) as high energy laboratories and cosmological probes of their intergalactic medium. Although the still unknown nature of GRBs is currently the subject of an impressively large amount of studies, they represent the most powerful sources in the Universe and thus a unique opportunity to study their galaxy hosts up to very high redshifts. One of the most spectacular characteristic of X-shooter will be its unique capability to provide astronomers with a very large spectral coverage ranging from UV to the K band. This will probably shed a new light on the nature of GRBs, maybe revealing unexpected scenarios on their origin, such as the "run-away star progenitor" hypothesis as proposed by Hammer et al. (2006). Coupled with its fast pointing capability, this will make X-shooter very well suited for studying GRB afterglows, i.e. rapidly fading sources observed soon after the GRB, which are still poorly understood.

X-shooter will propose a single Integral Field Unit mode working at intermediate spectral resolution (~ 5000), especially designed to maximize the detectivity of the instrument. Using the exquisite wide spectral coverage of X-shooter in this IFU mode will also provide a very efficient way to map physical and chemical properties in distant galaxies from their emission lines, such as the spatial distribution of the star formation activity, dust, metallicity or electron density, as pioneered by Puech et al. (2006).

To fulfil these challenging spectral coverage and sensitivity requirements, a new IFU design based on an image slicer has been developed at the Instrumental Division of the GEPI (Observatoire de Paris). We present here this original design, which was successfully reviewed during the recent FDR of the instrument, in February 2006.

2. OPTICAL DESIGN

An Integral Field Unit (IFU) divides the field in three strips (one central and two laterals) and aligns them along a pseudo-slit at the spectrograph entrance.

The used principle was imagined and described by Ruben Mazzoleni, in his PhD thesis (2003, see references) : the central slice doesn't include any dioptré, the light is directly transmitted to the spectrographs. Only the two lateral sliced fields are reflected toward the two pairs of spherical mirrors and re-aligned at both ends of the previous slice in order to form the exit slit.

The gap between the two M1 mirrors defines the central slice of the system. The beam here goes through the IFU without encountering any dioptré. The two other sliced beams, reflected by the two M1 mirrors, are tilted and steered toward two pairs of spherical mirrors M2 and M3 mirrors that recreate on the focal plane two images appended to the central slice. The beams are finally reflected by the pair of plane mirrors M4 towards the spectrograph (Fig. 1).

The IFU is contained within a volume centered on the VLT Cassegrain focus which dimensions are $80 \times 80 \times 80 \text{ mm}^3$. The entrance field size is $1.8 \times 4 \text{ arcsec}^2$ and the exit image is $0.6 \times 12 \text{ arcsec}^2$, which gives $0.950 \times 2.112 \text{ mm}^2$ and $0.317 \times 6.336 \text{ mm}^2$ in the focal plane of the telescope.

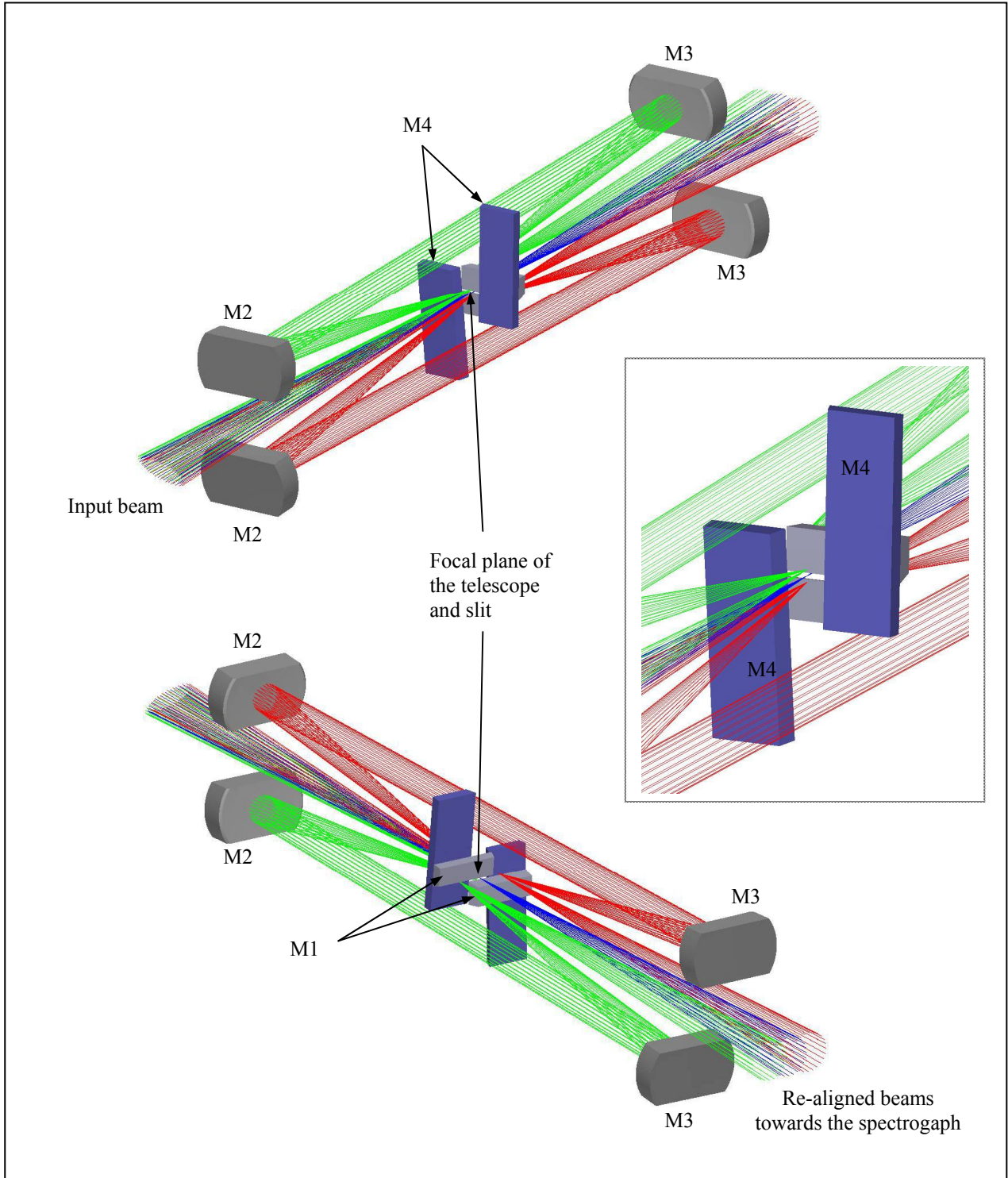


Fig. 1 Optical design of the IFU

3. FIELD STOP IMPLEMENTATION

Due to the quite complex geometry of the optics in focal plane area, the field stopping is done by three items :

1. A diaphragm with a rectangular hole,
2. The chamfers of M4 mirrors that limit the field in the slit direction
3. The chamfers of M1 mirrors that limit the field in the direction perpendicular to the slit.

The diaphragm stops a $3.4 \times 4.5 \text{ arcsec}^2$ field. It is positioned 1.5 mm before the focal plane and is then bigger than IFU input field in order to avoid any vignetting.

The polished chamfers of M1 and M4 mirrors stop the $1.8 \times 4 \text{ arcsec}^2$ field. The light outside this field is refracted and reflected by the polished chamfers of these mirrors. The main part of the light ($\approx 82\%$) is refracted and absorbed inside the mirrors and the other part ($\approx 18\%$) is reflected towards the walls of the mechanical mounting. The M1 and M4 material is Schott NG1 to increase the efficiency of the absorptance.

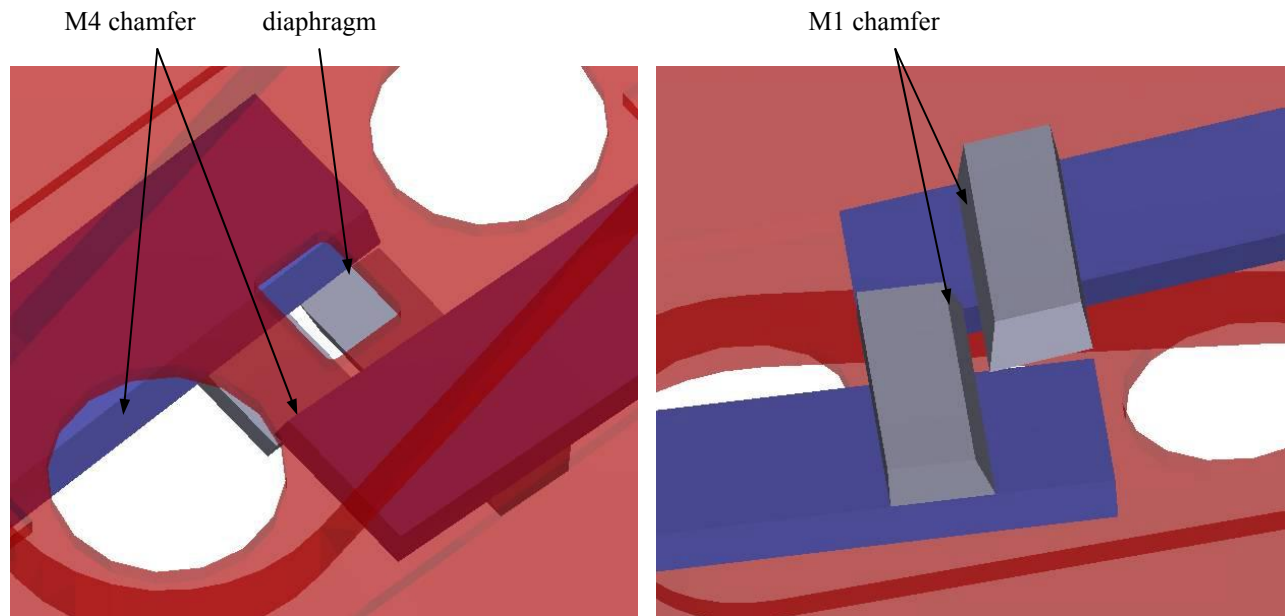


Fig. 2 Field stop implementation

In the following sequence one can see the function of the chamfers and the diaphragm (Fig.3 one M4 mirror is removed).

The $+0.9 \text{ arcsec}$ beam is the boundary of the half-field in the direction perpendicular to the slit and the beam is reflected towards the spectrograph.

The $+1 \text{ arcsec}$ beam is reflected by the chamfer of the M1 mirror towards the walls of the mechanical mounting.

The $+1.4 \text{ arcsec}$ beam is reflected by the M1 mirror and stopped by the below face of the diaphragm.

The $+1.7 \text{ arcsec}$ beam is directly stopped by the diaphragm.

The principle is the same for the slit direction with the M1 mirrors (Fig. 4 one M1 mirror is removed).

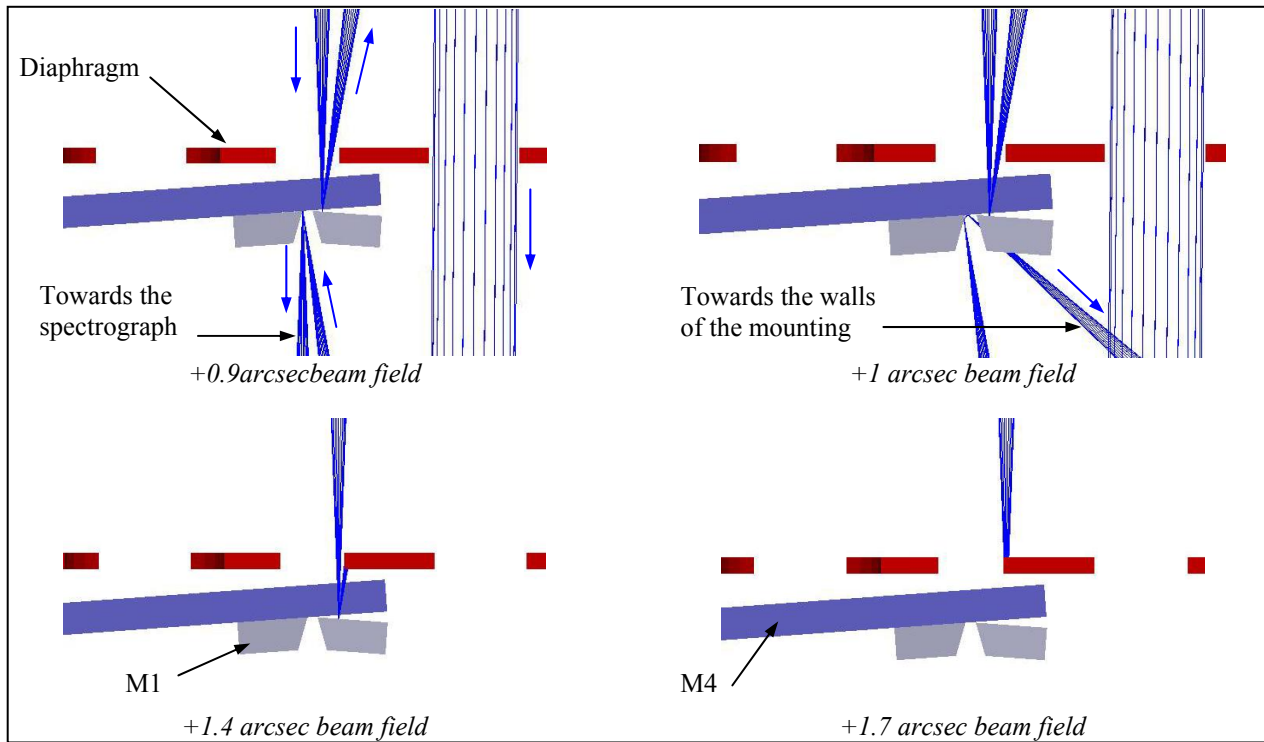


Fig. 3 Function of the diaphragm and the chamfers of the M1 mirrors

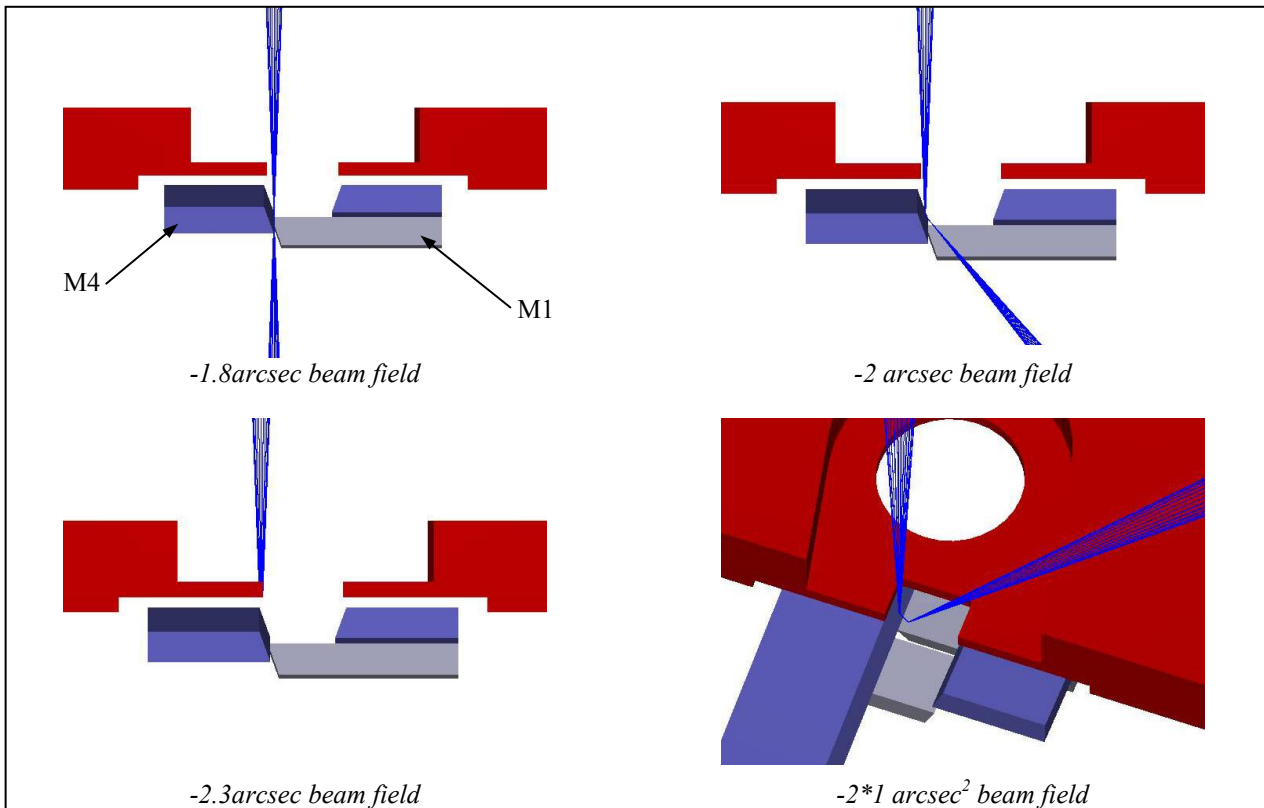


Fig. 4 Function of the diaphragm and the chamfers of the M4 mirrors

4. IMAGE QUALITY

Fig.5 shows the spot diagrams of 11 object points covering 4arcsec distributed along 3 lines parallel to the slit at 0arcsec, +0.6arcsec and -0.6arcsec at the focal plane of the telescope.

The distortion is computed for 11 object points covering 4arcsec distributed along 3 lines parallel to the slit at -0.6arcsec, 0arcsec and +0.6arcsec at the focal plane of the telescope. The slit image shows a S-shape distortion. To decrease the peak to valley distortion the IFU is rotated. The best fit line angle versus the slit-axis is 0.18°.

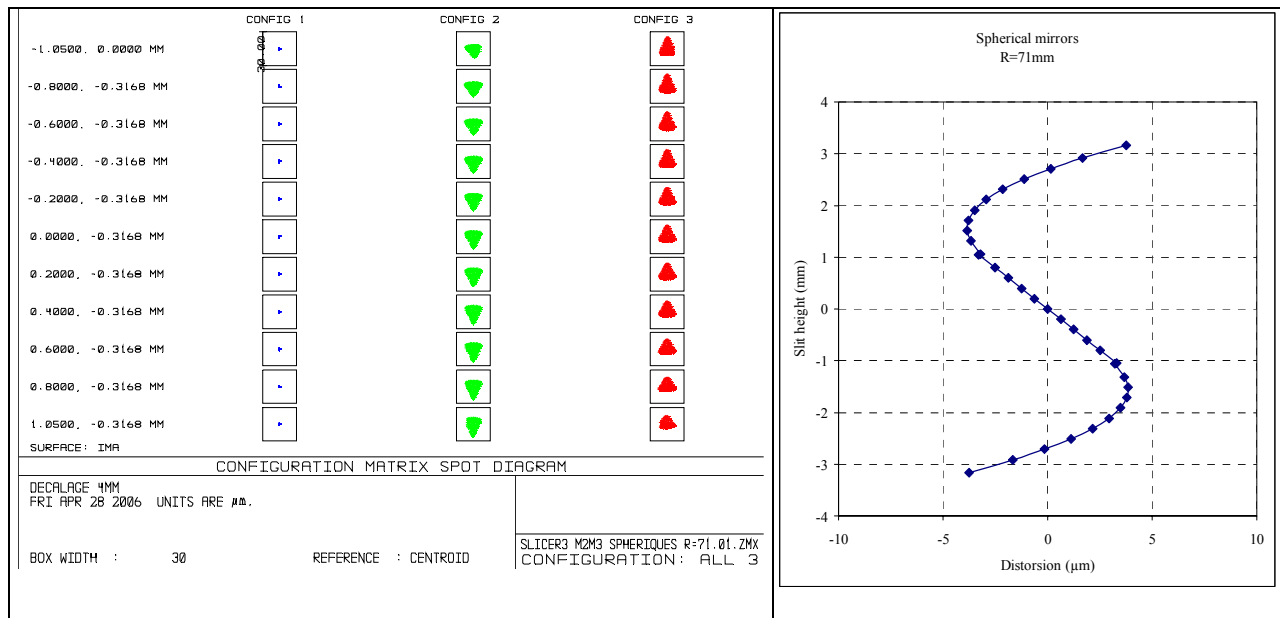


Fig. 5 Spot diagram and distortion curve

5. PROTOTYPE

A prototype has been build to validate the concept. Only the central slice and one lateral slice have been mounted, the third slice being symmetrical to the second one.

The pictures (Fig. 6) show the images seen by the spectrograph of a 0.9arcsec disk sliced by the IFU for different positions in the field. The rear side of the M1 and M4 mirrors have been lit so that it is easier to see them. One can see on the last picture that there is no appreciable dead zone between the different sliced fields.

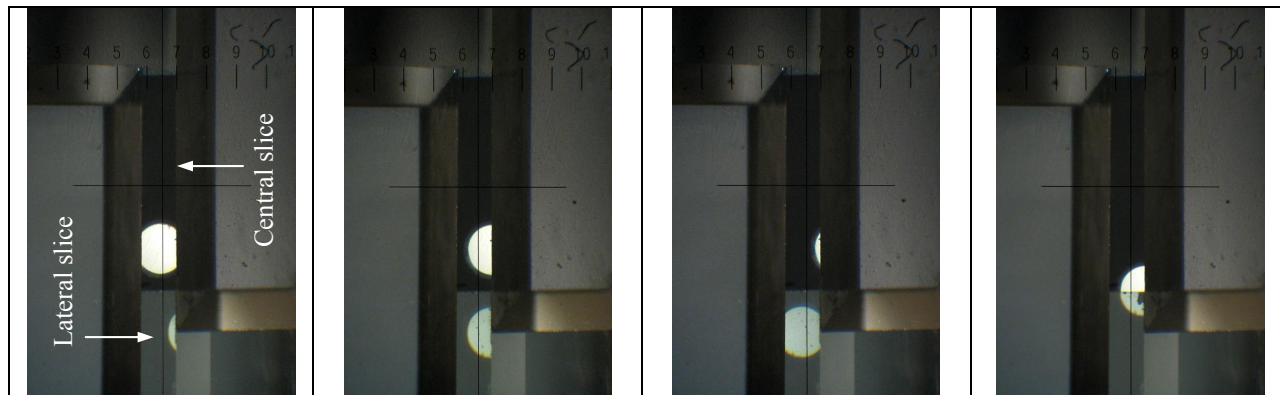


Fig. 6: 0.9arcsec object

6. MECHANICAL DESIGN

Aim and problem

The mechanical design is set by the optical properties of the needed IFU. The IFU could be changed by a spare one without losing the slit position. So the mechanical of the IFU manages the problem of locating and the problem of the stability of all optical components. The place allowed to the IFU is a cube of 80mm edge. The optic is composed of four spherical and four plane mirrors. Each spherical mirror must be set in TX, TY, TZ, RX and RY. Each plane mirror must be set in position in order to form a perfect central slit (TX TY) and angled (RX) in order to carry the light to the spherical mirror. X is the axe of the slit length, Y is the axe of the slit width and Z is the axe of the telescope.

The locating of the IFU on the carriage plate is also achieved in XY by three g5 (-9 μ) rods inserted in three H5 (+5 μ) grooves, so the mislocating in XY of the middle of the slit is a square of 14*14 microns (+/-7 μ). In Z axis, the IFU is spring loaded with 90N force (weight of the IFU 3kg), so the misfocus is done only by the dust and would be less than 10 microns.

Slits mirrors are glued on a slit support. This part is precisely milled in order to set the 4° angle of the slits mirrors. The slit support is screwed on an interface flange, all screw have three free diameter long between head and screwed part in order to allow elastic elongation by the screwing torque for a perfect assembling. As the interface flange allow a RZ managed by a H5/g5 fitting (+15 μ /-27 μ) and the locating of the interface flange in the slit support is done by a two g5 rods (-11 μ) in (four) H5 holes (+6 μ) the maximum error in XY of the position of the center of the slit is less than 79 microns (27+15+11+6+6+9+5) in fact +32/-47 μ . So the optical spec X axis position stability (+/-50 μ) is set. The Y axis spec (+/-100 μ) is done to.

In order to reduce the "S" distortion of the slit, all the IFU can be set and lock with a tilt angle along the Z axe. The sensitivity of this setting is less than 5 arcmin.

Central slit

The central slit is done by the edges of the tow M1 and the tow M4 mirrors. One M1 and one M4 are glued together at 90° under microscope. Each assembly will be glued in position on slit support.

Slit support

As previously described, the two pairs of M1 & M4 mirrors are separately glued under a microscope. These 2 assemblies are then glued on a mechanical support that defines the internal mechanical reference of the IFU. This support, shown on picture below, is manufactured in a material which thermal expansion coefficient matches approximately the one of silica: the "Dilver-P" for example. The slit support is the mechanical reference for optical parts. It also includes on its back the fixation of adjustments of the two mirrors M3, as we will see later

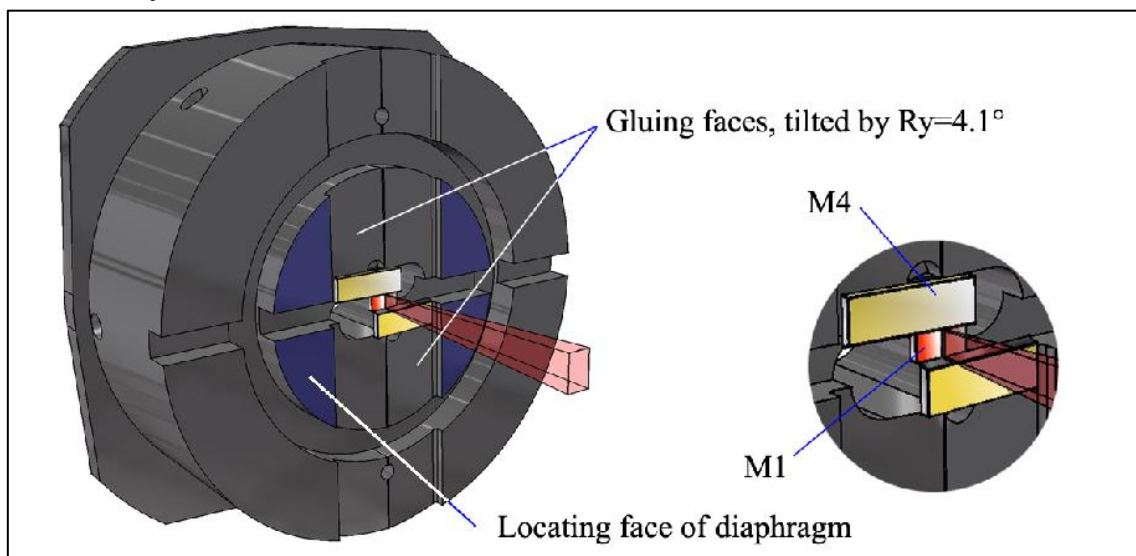


Figure 7 Slit mirror support.

M2 support & IFU body

The previous part is covered by the M2 support. It mainly includes the fixation of M2 adjusting systems and a locating system on slit support. The last gathered with this M2 support makes the IFU#2 body as shown in the following figure.

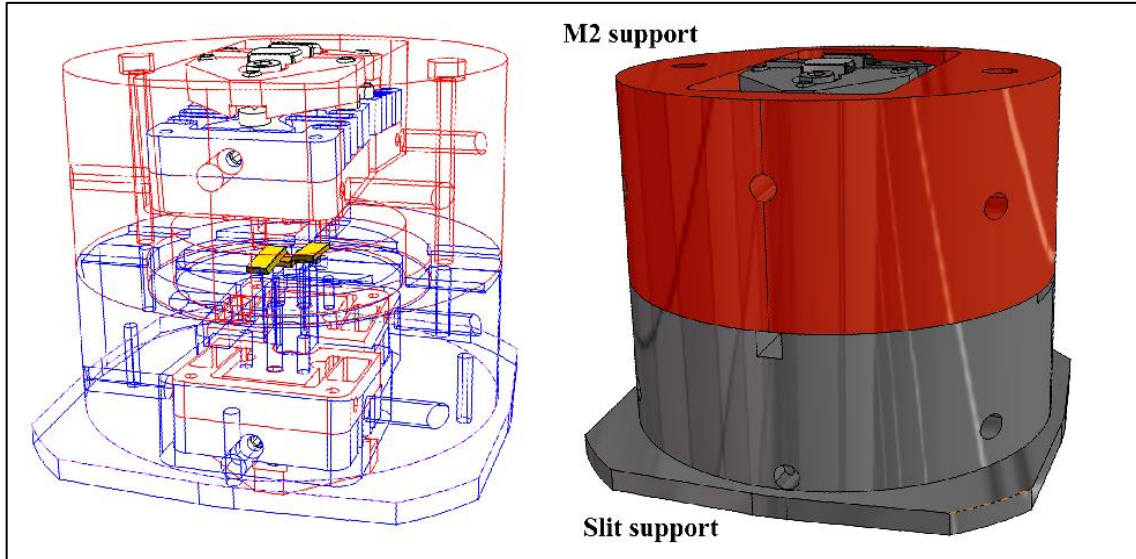


Figure 8 M2 support & IFU#2 body.

Spherical mirrors adjustments

The four spherical mirrors are adjustable along 5 DOF. Only RZ, the rotation along the mirror axis, is not implemented. RX, RY and TZ are adjustable with a "trait-point-plan" system. This system is fixed on a deformable titanium part that allows the TY translation. All the previous is then fixed on a second deformable titanium part for TX translation.

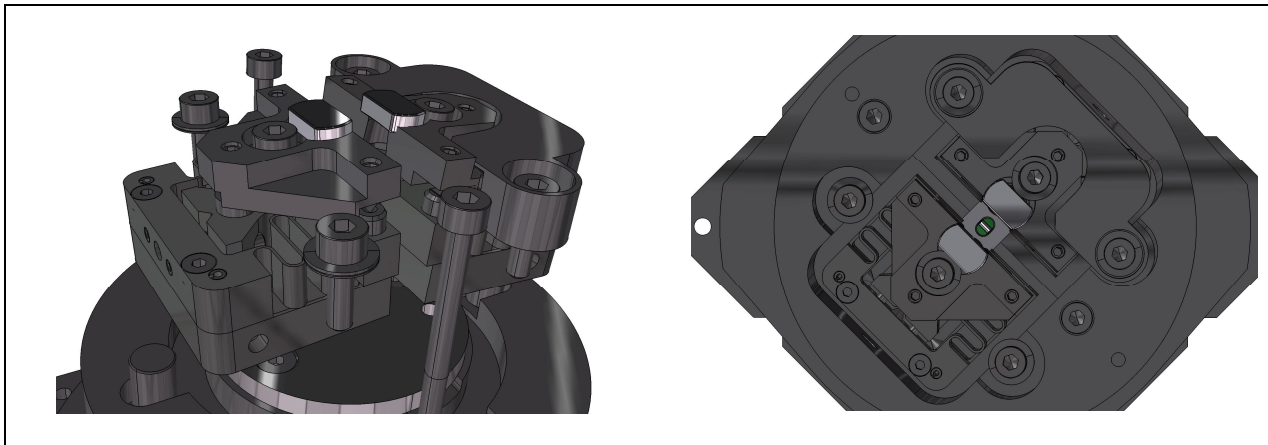


Figure 9 Spherical mirror adjustment systems.

The 2 deformable titanium pieces are designed in order to make it possible an adjustment range of about 1 mm with an acceptable stress in material. We obtain here for the 2 parts a Von Mises mean stress of about 300 MPa where the yield limit of titanium is 900 MPa. The TX deformable part provides a good guiding along the X direction because it includes 4 blades in the plane YZ that fixes the 5 other DOFs. On contrary the TY deformable part keeps some compliance along the 5 DOF (the rotation around Z axis notably) that should be stiffened. Rods have been added in order to reduce this problem by guiding together the tow moving parts of the TX. This possible defect of the system could be corrected by gluing the part after the adjustment. A spring loaded part is added in order to prevent up to 3g movement.

IFU interface flange

The flange includes an RZ adjustment capability via a set of four (green) pin moved by tow opposite screws. The choice of four systems is to allow a perfect looking of the RZ when set and to virtually vanish the big error introduced by the H5/g5 assembly of the outer part (violet) and the inner part (bleu sky). Red rods shown are the locating system of the slit support on the flange. The rose part is a 2.5mm spacer used for the setting of the all IFU, a spare part made with calibrated multilayer steel will be provided in order to set a spacer from 2mm to 3mm with a step of 0.025mm. Overall dimensions of interface flange are square 80mm.

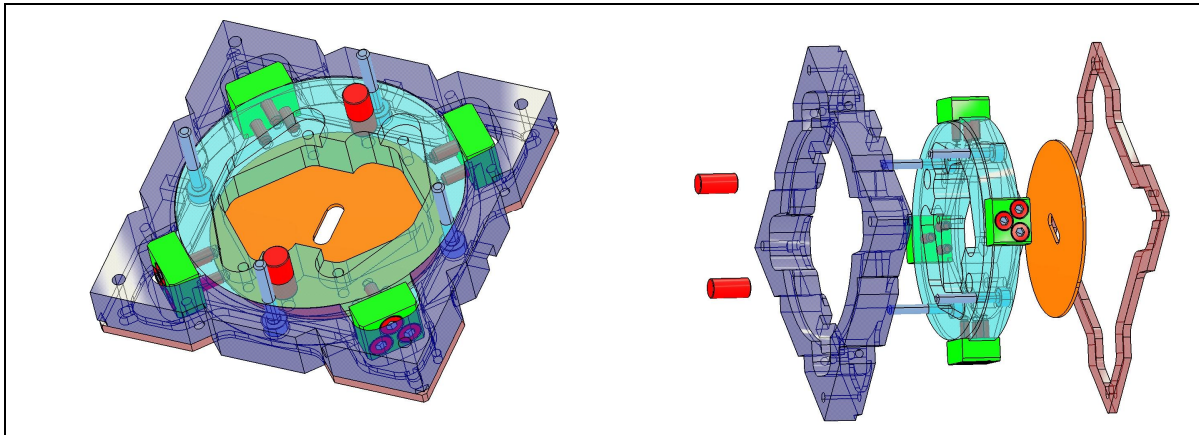


Figure 10 Interface flange

Clamp

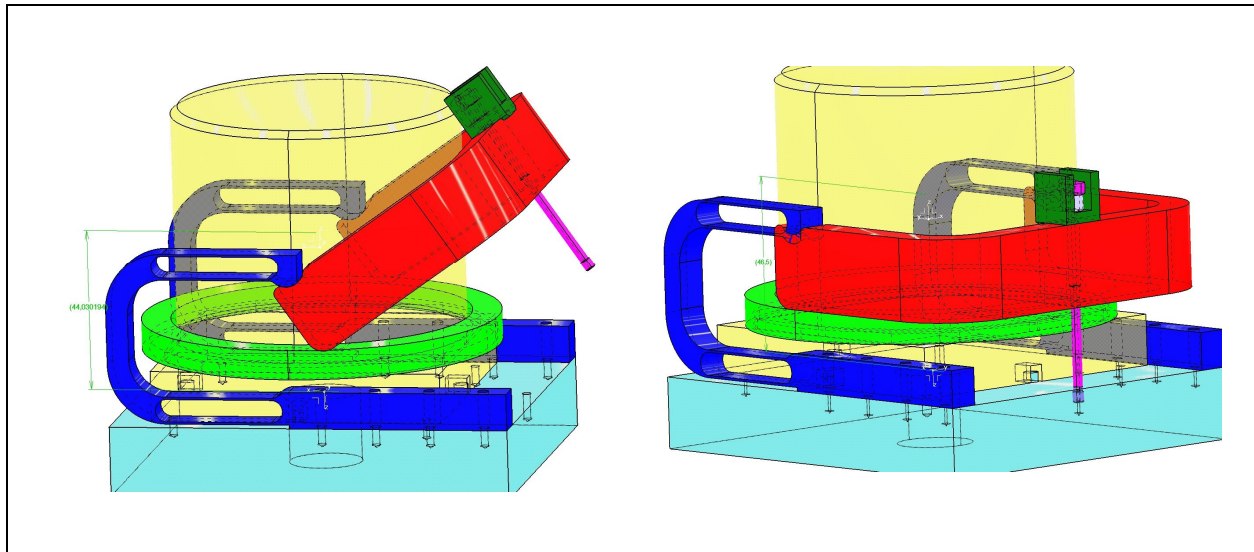


Figure 11 Opened / Closed clamp

The purple screw, manipulated by the green piece, settles down the clear blue piece. Dark bleu piece are made in spring steel. The red piece cocks the spring and transmits the load to the green annulus in order to have as possible the same load on each corner of the flange. The spring is drawn with two parallelograms in order to have a perfect Z axe load on all the system.

7. CONCLUSION

We have described here the design of the IFU of X-shooter. At the time of writing, we have got all the optical and mechanical pieces. The Schott NG1 mirrors have to be coated with a broadband high-efficiency coating. The procedures of gluing and testing have already been successfully completed. We hope we will integrate the IFU by autumn 2006.

This small IFU covering an area of 4×1.8 arcsec on the sky can be inserted in the focal plane and reformats this field as a 0.6×12 arcsec slit. This option can be used in time of poor seeing, for spectroscopy of slightly extended objects or for quick pointing of targets with coordinates known with 1 arcsec rms accuracy.

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