High resolution spectroscopic with sliced pupils gratings

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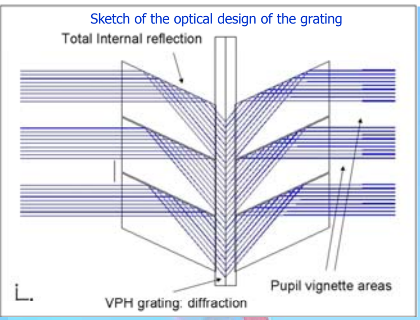
Abstract

FRACTAL and the Extragalactic Astrophysics and Astronomical Instrumentation group at the UCM (GUAIX) have a common R+D project co-funded also by the Comunidad Autónoma de Madrid (Aerospace Program), for the design and development of sliced pupil gratings of intermediate-high spectral resolutions (R = 10.000 to 20.000). We have developed a new concept for sliced pupil gratings that allows an increase of spectral resolution of holographic gratings in Littrow configuration (even with zero incidence angle). This concept can also be applied to instruments of large (8-10m diameter) to very-large (30-42m) telescopes, where the pupils and the incidence angle makes the standard concepts of gratings to be in the limit of the technology and to have very low efficiency. Also, this concept will allow us to design gratings with different resolutions operating in the same instrument and with the same optical configuration. This will be the case of MEGARA, a new instrument lead by UCM that has been proposed for the next generation of instruments of the GTC. Finally, This new concept would allow having a very compact medium-to-high-resolution spectrograph, ideal for small-medium spectrographs placed at 2.5m – 4m telescopes and Space applications, thanks to its compactness. The budget awarded by the CAM will allow us to have a technology demonstrator prototype built by August 2010.

Project Goal: The project has the final goal of designing and manufacturing a prototype of a dispersion unit able to produce high resolution (R > 10.000) in the visible range (650nm) in an already-built instrument (Elmer for the GTC) designed for standard operation at R=2500, in Littrow configuration, and with 0º incidence angle on pupil. The fundamental of this novel design is to "cut" the pupil into different slices and then reconstruct the image on the detector focal plane. The prototype will allow us to test the performance.

Optical Design: The unit is composed of six prisms and a VPH unit. The VPH unit consists on a hologram sandwiched between two windows. The VPH deposition between the windows shall be done by Wasatch Photonics. In order to obtain the high AOI on the grating for the required resolution without changing the geometry, three prisms will slice the beam in three portions. A TIR on the upper faces of these three prisms will supply the required incidence angle on the grating. A gap among the three prisms at either side will be used to avoid tunnel transmission among the prisms. The prisms will seat on the VPH window (gel coupled) in the current design. After diffraction (first order grating with 3400 lin/mm) the beam will be redirected again using TIR on three new prisms to the camera. The unit is placed at the pupil (89mm Ø size) with a clear aperture of 105mm that allows covering all field unvignetted in the edges.

Sketch of the optical design of the grating



Nevertheless, as the pupil is sliced in three pieces to minimize assembly difficulties, some parts of the pupil's flux are lost (producing vignetting). In fact only 62% of the incoming pupil beam passes through the system. The unit is also decentred 4mm to accommodate the beam, going downwards after the TIR reflection the unit. Other designs optimized together with the main instrument has allowed us to get vignetting as low as 18%.

Nominal performance: In a perfect prism manufacturing and assembly there are no stacking errors and the three images are coincident.

Prism assembly: We plan to manufacture the large prisms with tight wedges between the top and bottom surfaces. Nevertheless as the spatial axis is referenced in the piling of the prisms, shims might have to be used with the aid of an alignment telescope in order to guarantee the stacking of the images.

Single Slice Wavefront Error Budget

ITEM	S (waves at 656.3 nm)	Verification
Nominal performance: Telescope+Instrument+Disperser	0.77	Zemax: Nominal design
Prism glass homogeneity	0.26	Analytical model
Prism error: Surface quality	0.62	Analytical model
VPH fabrication	0.31	Analytical model
TOTAL	1.06	

Prism error surface quality

	Surface error (λ)	OPD (P-V)	OPD (rms)
Front Surface	0.5	0.25	0.071
Back Surface	0.5	0.25	0.071
Top Surface (TIR)	0.5	1.51	0.43
TOTAL 1 prism			0.44
TOTAL 2 prisms			**0.62**

Prism Glass Homogeneity: Index errors are not important in this budget as the incidence angle is obtained from reflection. Standard index tolerances are valid for this purpose ($\pm 1 \times 10^{-4}$). Large optical paths are done in the prism glass. Homogeneity has to be specified in order to avoid large phase delays. The total length within the prism glass is 120mm.The contribution of the index homogeneity of each optical component to the OPD is computed as: OPD= Optical Thickness x Index Homogeneity. For a homogeneity group with $\pm 5 \times 10^{-6}$ ppm (Schott H2 or Ohara A5) the OPD P-V = ± 0.6 μm (so 0.91 waves at 656.3nm). The average rms is estimated as PV/3.5, thus $\sigma = 0.26$. No compensation can be foreseen for this error.

VPH WFE and specification to the manufacturer

Aberration type	Spec (PV) to manufacturer	Effect in the budget	rms (PV/3.5)
Focus	Max of 10 waves	Completely removed	
Spherical	1	Compensated 0.5	0.14
Irregularity	1	1	0.28
TOTAL (rms)			**0.31**

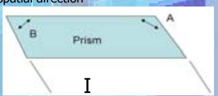
In order to complete the specification we will set an error in the line number of ± 3 lines/mm (that are within manufacture capabilities in previous works) and a wedge on the VPH after assembly of 2 arcmin. Both effects will introduce a small shift of the spectrum in the detector without image degradation.

Stacking Error Budget

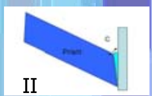
ITEM	Image centroid (spatial) x-axis , μm	Image centroid (spectral) y-axis, μm	Verification
Nominal performance: Telescope+Instrument+Disperser	0	0	Nominal per design
Prism manuf: angles & parallel.	-	0	Analytical + Zemax
Prism assembly	< 21	<5 gel stacking residuals	
VPH fabrication	0	0	
TOTAL	< 21	< 5	Residuals

Prism manufacturing: The manufacturing differences in the angles among the three prisms at either side of the VPH introduce an error in the image stacking. Figure I shows the angles that produces this error.

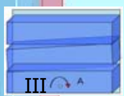
Assembly tolerance: Two mounting tolerances are important when assembling. These are shown in Figure II and Figure III. Figure II shows the wedge error (c) introduced if the prism were optically coupled with error to the VPH. This affects the spectral direction. Figure III shows the mounting error (tilt in A) one prisms are mounted stacked on top of the next one, affecting the spatial direction



I



II



III

VPH fabrication: Each group of three prisms is extremely sensitive (few arcsec) to differences in angle. We will manufacture two large single prisms and cut three pieces from them in order to not generate any error in the stacking spectral direction.

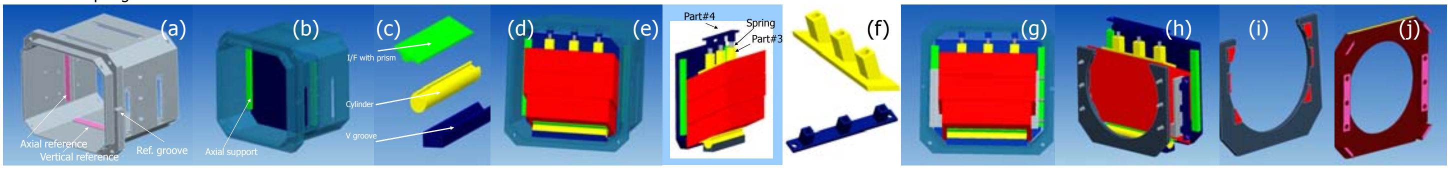
Opto-mechanical mount

The mount has a total of 23 parts, 23 screws and 24 compression springs. Up to 21 parts are manufactured on aluminum alloy (Al-Mg-Si) 7075-T6 or similar. They are given a matte black-anodized surface treatment to provide a protective layer against corrosion and prevented stray light within the mount. They all can be manufactured with standard mechanical workshop machines. All screws and springs are made of stainless steel. The screws are socket head DIN7991, of different lengths. The main mount body is shown on (a). It is made of 7075-T6 aluminum alloy. It is the biggest part of the mount and provides the interface with the instrument wheel with a tolerated hole and groove that fit on correspondent alignment pins.

On its inner surface there will be mechanized two axial reference surfaces that provide a precise location with respect to the instrument I/F. There will also be a vertical reference that also provides restriction on rotation around the optical axis. This is critical due to the alignment of the lines of the grating.

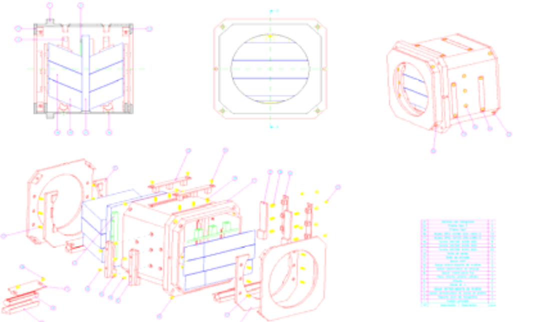
In order to place the optical elements in their exact position within the instrument optical path, they must be inserted on a mount that interfaces with the instrument wheel. This mount allows placing the different optical elements in its exact position relative to each other as well as locating the whole grating with precision onto the optical path, both defined by the optical design. The mount has been designed to absorb the differential thermal dilatations of the optics with respect to the aluminum mount, maintaining its performance, and preventing surface stresses that may affect the transmission. In (b) we can see the flat sandwiched window with the hologram located into the mount. It is secured on its position with two axial support pieces, screwed to the mount, so it can be handled to locate the following optical and mechanical elements on the VPH grating. This support piece also gives certain lateral fixation to the hologram window. Then, the prisms have to be located on the mount. Its mounting reference surface is the hologram window itself. The vertical support is a pivot device that does not disturb the perfect coupling between the prisms surfaces and the hologram surface. Also for this reason, there will be a very small and thin shim between each two prisms. The pivot device (c) is comprised of three parts: a part that interfaces with the prism, joined with screws to a cylinder that rolls on a V-groove. These are of different materials to have lower friction: the V-groove is made of stainless steel and the cylinder is made of aluminum. The prisms are pressed against the pivot support with another part, located on the opposite side of the mount, which holds three springs. The elongation of the spring is determined by the depth of the holes of both parts #3 and # 4, see (d) and (e). The later is screwed to the outer side of the Main Body while passing through a hole provided for it. These rectangular holes are clearly visible on (a) for example. The location of the springs coincides with the lines of centers of gravity of the prisms. Figure (f) shows the part that leans against the prism. It's made of aluminum, like the part #4, which keeps the spring load. All the surfaces that make contact with the prisms shall be covered with tape to prevent direct metal-glass contact.

On the lateral direction, the mount also has an elastic support. As seen on Figure (g) , there is one fixed part on one side (to the left, in this view) and on the opposite side, another part that presses with three springs against the first one. On the axial direction, the whole system (hologram + prisms) is fixed by another spring-loaded part. It can be seen on Figure (h). To obtain a more stable position, instead of pretending to establish a full-surface contact, there will be mechanized 6 protrusions that push on the prisms as near as possible to their centers of gravity (i). The last elements to introduce in the mount are the baffles (j). We have two, one on each side of the mount. Each baffle is joined to the mount with 4 screws, which are placed on the corners because there is no room enough to place them on the front. The baffles are quite similar, being the only difference a small rectangular protrusion made on the entrance baffle to allows using the same springs on both sides.



Mounting Sequence

1.- Place the hologram on the reference surfaces of the main body, being this vertical
2.- Place the axial fixation parts on the hologram sides, pushing a little with the fingers. Screw
3.- Screw the fixed lateral support to the main body.
4.- Screw the V-groove of the pivot support on the main body. Join the cylinder and screw it to the interface piece.
5.- Place the 3 prisms of one side, lean on the hologram and take as reference the lateral and the pivot supports.
6.- Place the vertical support part (ref #3). Introduce the springs and fix them with the spring-support part (ref #4), then screw it to the main body. Maintain the prisms pressed against the hologram window.
7.- Place the other part of the lateral support, with the springs.
8.- Locate the axial support on the back of the prisms. Introduce the springs and close with the baffle.
9.- Screw the baffle to the main body.
10.- Repeat steps 3-9 for the other prisms.



This project is being funded by FRACTAL, CAM [22/2009 for Aero-spatial Innovation] and UCM