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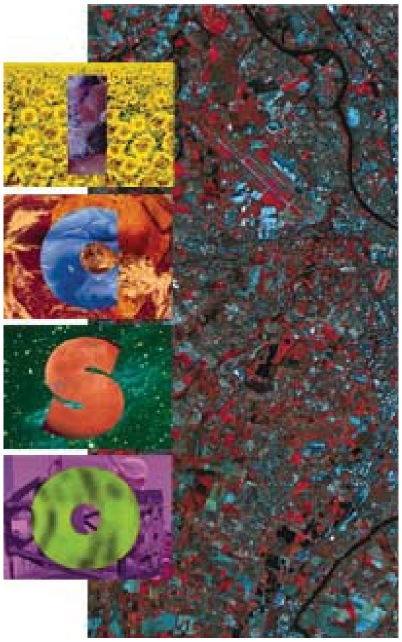

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GALEX UV GRISM FOR SLITLESS SPECTROSCOPY SURVEY

Robert GRANGE[*], **Bruno MILLIARD**[*], **Jean FLAMAND**[**], **Alain PAUGET**[*], **Gabrielle WAULTIER**[*], **Gabriel MOREAUX**[*], **Christelle ROSSIN**[*], **Maurice VITON**[*], **Michel NEVIERE**[***]

** Laboratoire d'Astronomie Spatiale, B.P. 8, 13376 Marseille cedex 12*
*** Jobin Yvon Groupe Horiba, 16-18 rue du canal, 91165 Longjumeau*
**** Laboratoire d'Optique Electromagnétique (URA CNRS 843) Université de Saint-Jérôme, 13397 Marseille cedex 20*

Abstract - The NASA Space Mission Galex is designed to map the history of star formation by performing imaging and spectroscopic surveys in vacuum ultraviolet. The dispersive component for the spectroscopic mode is a CaF2 Grism which can be inserted with loose tolerances in the convergent beam to produce slitless spectra. Grisms are widely used in ground based astronomy in the visible or near infrared bands but the UV cutoff of the resin involved in their manufacturing process prevents their use in the UV range. LAS and Jobin-Yvon developed a proprietary process to imprint the blazed profile into the CaF2 crystal. We will present the measured optical performance of prototypes and flight models delivered this summer to NASA/JPL. We will also present a three bipod flexures mount we designed to minimize the mechanical stress on the optical component. The flight Grism bonded to such a mount has successfully passed the Galex environmental qualification.

1 - INTRODUCTION

The NASA Space Ultraviolet Mission Galex (Galaxy Evolution Explorer) is designed to map the history of star formation by performing imaging and spectroscopic surveys in the wavelength range 130 nm to 300 nm. This mission is under the responsibility of California Institute of Technology with Professor Chris Martin as Principal Investigator. The Laboratoire d'Astronomie Spatiale (LAS) sponsored by the Centre National d'Etudes Spatiales (CNES) is responsible for delivering the optical design and three key optical elements including an UV grism. The Galex instrument is based on a 50 cm diameter Ritchey-Chrétien telescope with a three meter focal length which simultaneously feeds a Near Ultra Violet (NUV) and a Far Ultra Violet (FUV) channels. Both channels have imaging and spectroscopy modes. The dispersive component for the spectroscopic mode is a 75 g/mm CaF2 grism which can be inserted with loose tolerances in the convergent beam to produce slitless spectra. Grisms are widely used in ground based astronomy in the visible and near infrared bands but the UV cutoff of the resin involved in their manufacturing process prevents their use in the UV range. LAS and Jobin-Yvon developed a proprietary process to imprint the blazed profile into the CaF2 crystal. After recalling the specific requirements for Galex, we will present the measured optical performance of flight models delivered this summer to NASA/JPL. We will also present a three bipod flexures mount we designed to minimize the mechanical stress on the optical component. The flight grism bonded to such a mount successfully passed Galex random vibration and thermal cycling tests.

2 - GALEX OPTICAL SCHEME AND GRISM PROPERTIES

Figure 1 shows the Galex optical layout with the grism located behind the primary mirror and the aspheric dichroic which redirects photons onto NUV and FUV detectors. In imagery mode an Imaging Window mounted on an optical wheel replaces the grism giving the same optical thickness to maintain the right focus. In spectroscopic mode the grism feeds the NUV and FUV channels in order 1 and 2 respectively. The narrower bandpass of order 2 compared to order 1 perfectly matches the FUV channel width.

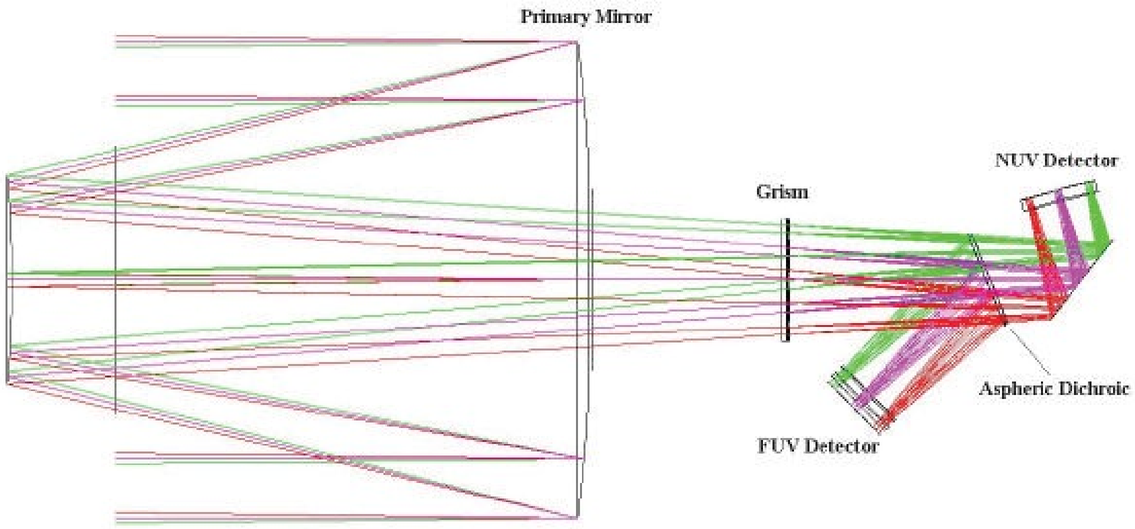

Fig. 1: Galex Optical Layout

A grism, also known as a Carpentier prism, is a prism with its hypotenuse ruled to form a transmissive grating. A simple prism used in the ultraviolet region where glass refractive index change rapidly with wavelength would have a strongly non linear dispersion. In contrast a grism whose dispersion relies mostly on diffraction effect exhibits quasi-linear dispersion. Moreover, in a grism the dispersion of the prism and the diffraction of the grating combine to leave the direction of the beam unchanged at the blaze wavelength. These combined properties make the grism a perfect component for an instrument designed to perform both imaging and slitless spectroscopy with a minimum change from one mode to the other.

When the grism is inserted in a parallel beam, it does not add aberrations to the instrument. Unfortunately the 50 cm aperture diameter of the Galex telescope prevents the use of a single grism located in the incoming parallel beam. An array of smaller grisms would be an alternative at the expense of sub arc second alignment extremely difficult to achieve. An efficient solution was to place the grism in the F/6 convergent beam behind the primary mirror. However any dispersive or diffractive element in a convergent beam introduces significant aberrations among them the most prominent is third order coma. The last but not the least advantage of a grism is to be able to correct for the coma at the blaze wavelength by a judicious choice of the prism angle and the pitch of the grating [Bowe 73]. It turns out that this choice is close to the zero deviation case of great interest for switching from imagery to spectroscopy.

For the Galex wavelength range the only available transmissive materials are MgF2 or CaF2 crystals. The 175 mm required diameter of the Galex grism blank prevents the use of MgF2 which is presently grown up to 125 mm only. Unfortunately, the CaF2 crystal is well known to be a soft material difficult to polish, sensitive to thermal gradient and cleavable. We selected the best monocrystalline CaF2 ingot from Sorem company on criteria of deep UV transmission and low phosphorescence. With the help of the Commissariat à l'Energie Atomique (CEA) in Saclay we irradiated with a Ci Sr^{90} $-Y^{90}$ source several samples and measured the phosphorescence decay in the NUV over several weeks with a photon counting imaging detector from Quantar [Vito 00].

The grism CaF2 blank which is a prism with a wedge angle of 1.3 deg was polished by Stigma company. A difficult task was to figure the entrance face with a large radius of 26 meters with an accurate control of the thickness at the center to match the thickness of the imaging window and then to guarantee the focus of the telescope.

But the main difficulty was to produce a grism working in the Far Ultraviolet region which has never been done before. The classical technique of embossing a resin layer with a ruled master does not work since the remaining resin is not transparent in the vacuum ultraviolet. With the help of a series of smaller prototypes, we developed a proprietary process to directly rule onto the CaF2 crystal. Using electromagnetic theory [Nevi 91], a rigorous computation of the theoretical efficiency has been performed. It showed that polarization is negligible with this coarse grism. After cross-checking with rigorous results, a simpler scalar computation of the efficiency has been used throughout the development process.

Scanning Tunelling Microscopy (STM) was a helpful technique to measure the blaze angle and the roughness of groove facet which are key parameters to obtain a high throughput within the required bandpass. Fig 2 shows a STM image of the phase B prototype which has been coated with gold for STM measurement; the step height is 0.5 micrometer.

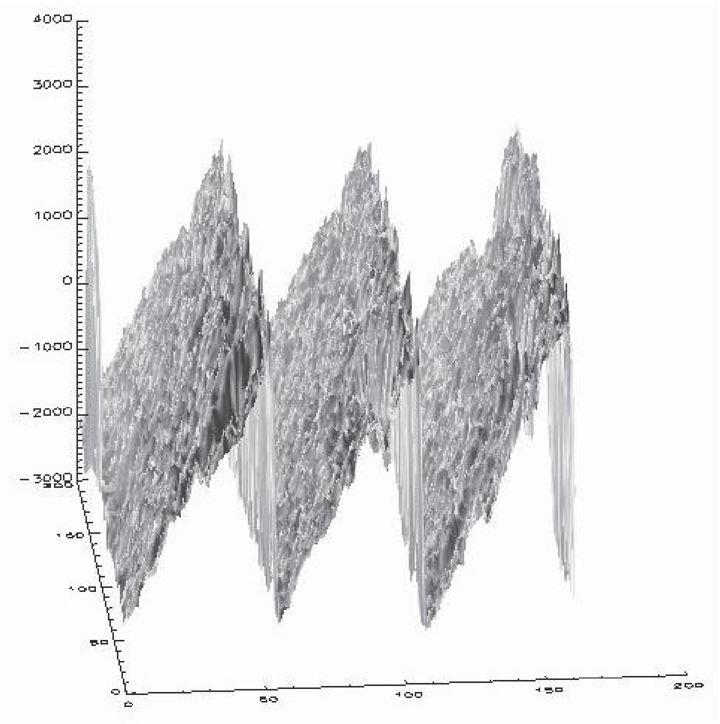

Fig. 2: STM image of the Phase B prototype

3 - FLIGHT GRISM EFFICIENCY AND IMAGES

To test the flight grism in the FUV channel, we adapted the vacuum setup developed for the FUSE grating calibration. The flight grism illumination (F/6 convergent beam) is reproduced in a 6m3 vacuum tank. The beam focuses onto a 65*10 mm photon counting detector with a delay line readout. The FWHM of the detector PSF in the spectral direction is 25 micrometers well adapted to the expected image quality. In high resolution mode the pixel is 5.3 micrometers wide. For efficiency measurements we defocused the image and compared at several wavelength the integrated photon counts with and without the grism in the convergent beam. Thus we obtained the absolute efficiency which is the product of the groove efficiency times the substrate transmission.

In the NUV channel the sensitivity of the FUSE detector equipped with bare microchannel plate is extremely low. The solution we adopted was to place the grism in front of the pupil of the 40 cm FOCA telescope which is designed to perform imagery around the 200 nm window reachable from stratospheric balloon flights. In a 7m3 vacuum tank, the FOCA telescope stands in front of a 8 meters focal length collimator and the grism is placed in the parallel beam right between the two instruments.

Figure 3 shows the efficiency curve we obtained with both setups. The doted line is the theoretical model adjusted in the Y axis direction to fit the data. We can see that absolute efficiency measurements reach 82% in the NUV and 61% in the FUV.

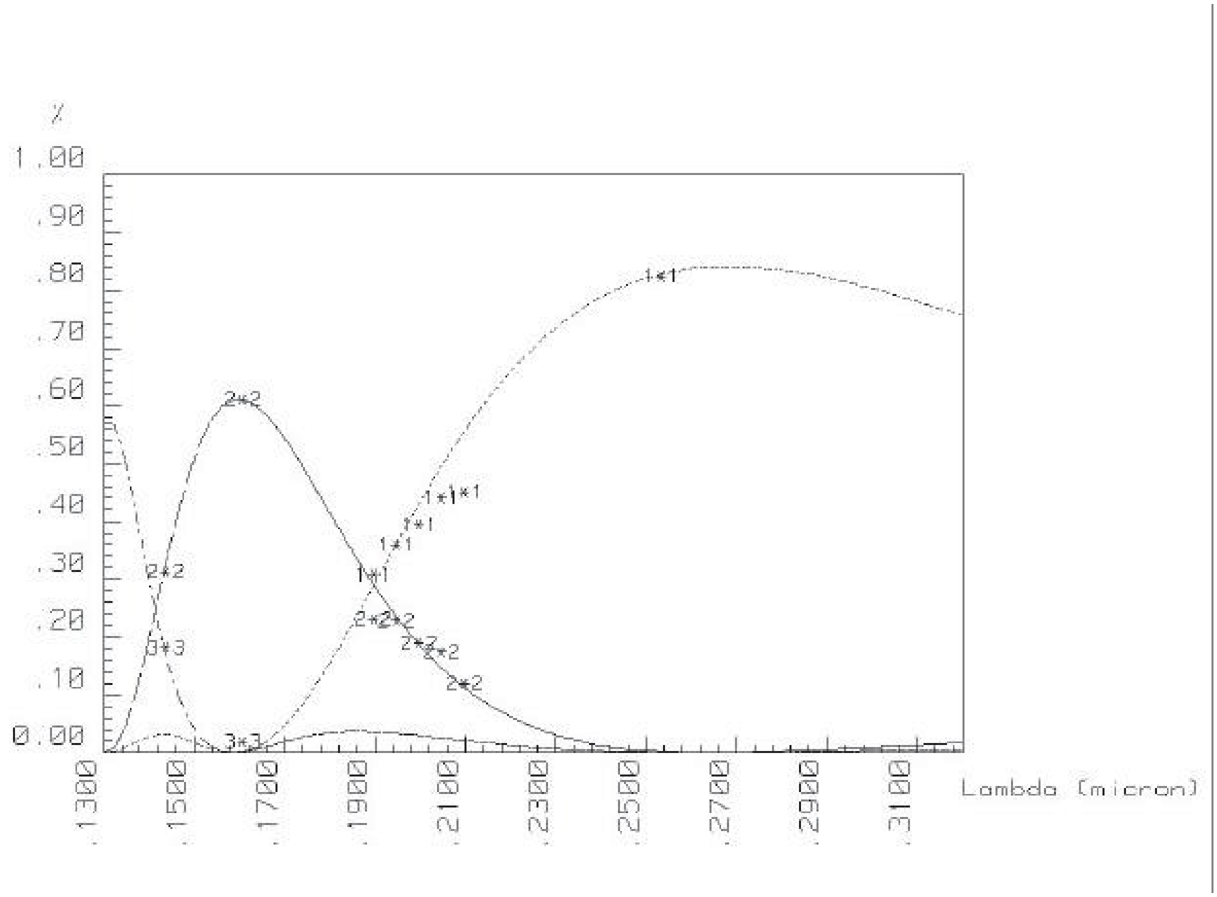

Fig. 3: Flight Grism G2 Efficiency Curve

To check the imagery performance of the grism, we basically used the same setup as for FUV efficiency measurement. However the bandpass selected by the monochromator slit was dispersed by the grism and prevents a good measurement of the spatial PSF. Two strong narrow lines (185 nm and 253.7 nm) of a Mercury lamp allow us to give up the monochromator and feed directly the setup at the previous location of the monochromator exit slit.

The Galex spare policy was to deliver two flight grisms. When the first flight grism became available for imagery check, the spare was still in the manufacturing process. This component was so critical in the Galex project that it was decided to keep it in a safe location without any further test until the spare was available. The dispersed image of Mercury lines shown in figure 4 comes from the Flight Spare G5. It is worth noting that for generating the F/6 beam we used a spherical mirror working close to its center instead of an ellipsoid which would be difficult to figure with low stray light. The astigmatism of the spherical mirror gives elongated images in the Y axis but does not affect the measurement in the spectral direction.

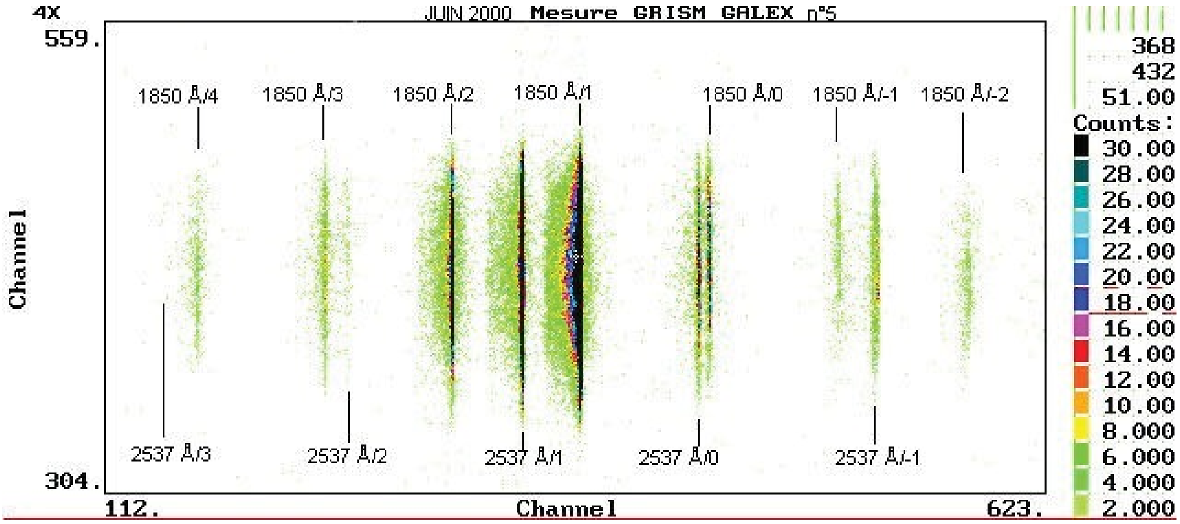

Fig. 4: Two Mercury lines dispersed by the Flight Spare Grism

4 - THREE BIPOD FLEXURES MOUNT

Galex will be launched by a Pegasus rocket which has severe environmental requirements. For qualification the random vibration level for the grism is set to 15 g RMS in the range 20-2000 Hertz and the thermal cycling ranges from –25°C to +45 °C. Since the grism is made of CaF2 well known to be a highly brittle crystal, we studied a mount design to isolate as much as possible the optical element from mechanical and thermal strain.

Bipod flexures mount [Hog 1975, Vuko 1988] rapidly appeared to us as a clever solution to provide both the required stiffness to maintain alignment and the compliance to avoid grism deformation from the mount. The compliance is based on flexure hinges which are free of stick-slip and friction effects compared to rolling or sliding mechanisms. The two axis flexure at each end of the legs consists of two single axis flexures at right angles to each other (see Fig.5). This hinge geometry provide higher compliance and better strength than the more intuitive universal circular flexure. In the bipod design we adjusted the angle between legs to have the same strength in the three axis. Furthermore, the intersection point of legs which correspond to the instantaneous pivot was designed to be in the plane containing the center of gravity of the grism.

For bipod and ring manufacturing, we choose Titanium primarily because of its high yield strength and its low young modulus. Its resistance to corrosion, medium density and nonmagnetic property are added interested features. We bonded the grism at the three heads of bipods with a 100 micrometers layer of 3M 2216 epoxy.

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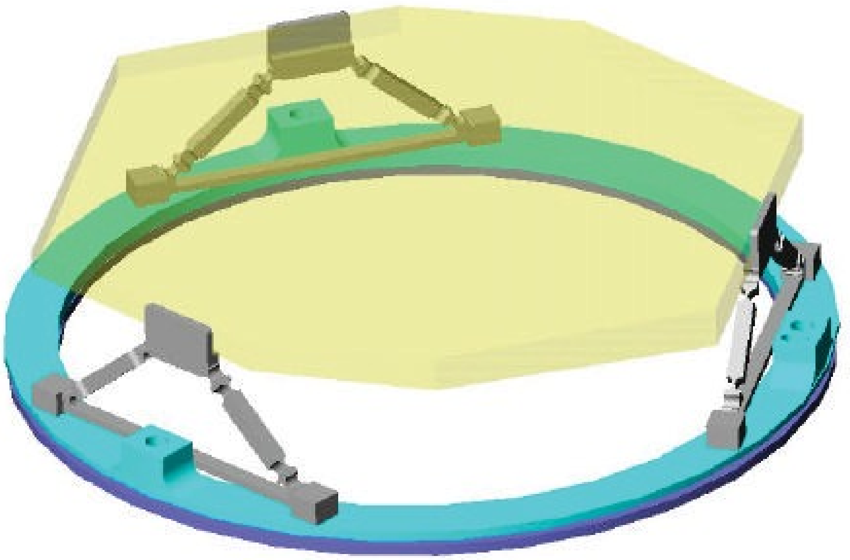

Fig. 5 : Grism mount using three bipod flexures

We first design the flexure hinge by an analytic approach [Paros 1965] and then made extensive use of Finite Element Modeling (FEM) with Cosmos/M to analyse the dynamical behaviour of the stress in the CaF2 crystal. Figure 6 shows the fundamental mode which dominates the stress distribution.

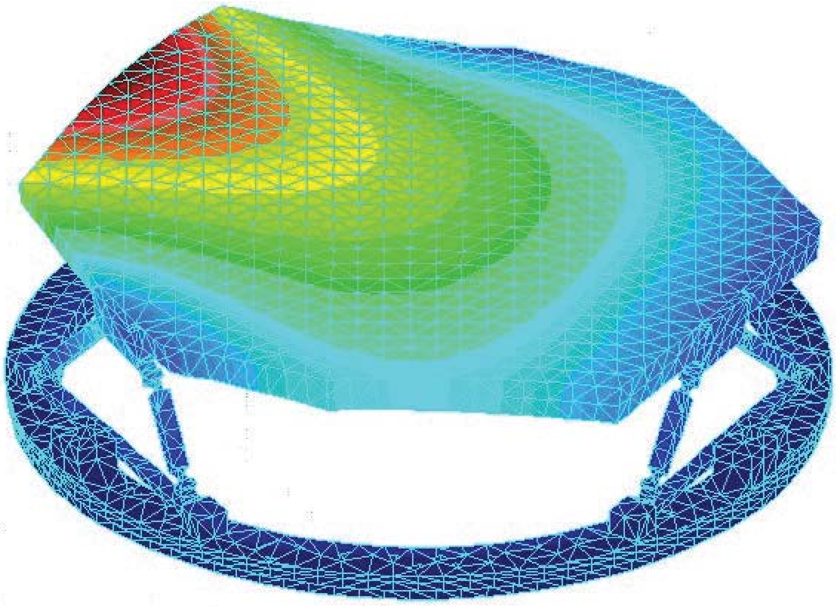

Fig. 6 : Deshape in the fundamental mode

4 – CONCLUSION

In the context of the Galex NASA mission, LAS and Jobin-Yvon developed for the first time a grism working in deep ultraviolet down to 130 nm. Through a series of prototypes we gradually improved the absolute efficiency and we finally reach values up to 61% in the FUV and 82% in the NUV. This grism working in a F/6 convergent beam is corrected for third order coma. To hold this highly brittle CaF2 crystal, we designed a three bipod flexures mount to isolate the optical element from mechanical and thermal stress. This mount proved to be a successful design since it passed both the thermal cycling and random vibration Pegasus qualification test. This development has promising applications in future UV space missions.

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