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The ultraviolet telescope UVISS: ion beam figuring and multilayer technology

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Abstract. The recent activity on the optical surface figuring and multilayer technologies for the project UVISS (the italian UV telescope on the ISS) is briefly discussed. According to the studies and the test results, the field correction and the filters for imaging are feasible with the available technologies.

Key words. UV telescopes - multilayer filters

1. Introduction

UVISS (Ultra-Violet Italian Sky Surveyor), a Mission into Hot Phenomena in the Universe, is a small telescope designed for accommodation on the International Space Station (Bernacca et al. 2003). It will use a pointing platform on an Express Pallet Adapter available to the Italian Space Agency (ASI) for more than 4 - 6 months per year after the Station assembly is completed. UVISS is a Ritchey-Chretien telescope of 50 cm aperture, f/3.2, SiC coated. The image spot (80% encircled energy) is better than 1 arcsec on axis, and with a field flattener it is better than 1.3 arcsec in the field of view. Two operating modes are envisaged: 0.3 nm dispersion spectroscopy in the 90 - 320 nm range, or wide field medium bandwidth imaging in the same range but Ly-α and OI 130. The corrected field of view has to be of the order of one square degree with a spatial resolution limited, over the entire field, by the optics quality. The constraints on the spatial resolution of the corrected field of view and on the limiting flux impose an optical de-

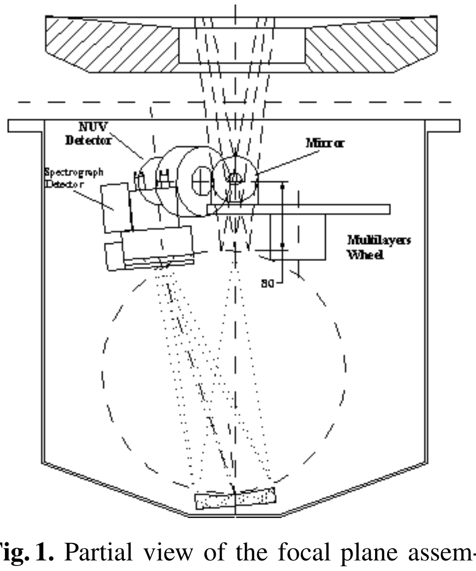

Fig. 1. Partial view of the focal plane assembly of UVISS. The hatched area represents the section of the primary mirror (that has a squared shape). The layout includes the multilayer wheel (with filters and mirrors), one of the imaging detectors (NUV), the spectrogrpah grating (at the bottom) and its detector.

Send offprint requests to: E. Antonello sign based on a minimum number of elements. This will maximize the efficiency of the system while correcting the aberrations introduced by the chosen optical configuration for the telescope. Another important requirement is the rejection of the light emitted in the geocoronal Ly-α line (121.6 nm). These requirements pose serious problems in the development of the wide field imaging camera layout (Scuderi et al. 2000). The camera will consist in any case of two channels, one for imaging below the Ly-α line, the far UV (FUV) channel, and one for imaging above it, the near UV (NUV) channel. The main component of each channel will be a field flattener to correct the telescope aberrations, a series of filters to select several band-passes, and a detector. Here we will report about the experience gained in the developement of the field flattener and the multilayer applications. Fig. 1 shows a partial view of the focal plane assembly of UVISS.

2. Ion beam figuring

The designed Ritchey-Chretien optics, including the tertiary mirror (field corrector), gives a resulting quality of 80% encircled energy of a point source within a diameter of 11 μm, i.e. 1.3 arcsec, over the whole field of view of 1 degree. A careful design of the aspherical profile of the tertiary mirror indicates that it is possible to get the same performance in a larger field of view with a diameter of 2.4 degrees.

The corrected field, however, could be obtained with either a tertiary mirror (e.g. in SiC) or a refraction optical element (in LiF). In both cases, the optical surface is obtained by means of the ion beam figuring (IBF). A facility for the IBF was developed at the Osservatorio Astronomico di Brera (Ghigo et al. 2000) in the framework of a collaboration with Galileo Avionica (Novi et al. 2001); recently, it was successfully applied to the developement of the demonstrative mirrors for the NIRSpec spectrograph of the the JWST. The IBF facility consists externally of a stainless steel vacuum chamber having an height of 1.4 m and diameter of 0.8 m. It is able to figure optics up to 0.5 m diameter. A two stage mechanical pump is used for initial pump-down while the high vacuum is obtained with a cryopump able also to take care of the small volume of Argon gas used in the sputtering process. The 3-cm Kaufman ion source is mounted on two x,y carriages and can be translated with stepper motors. The source is driven by a programmable power supply able to provide current densities up to 10 mA/cm^2. A "bridge" is used to sus-

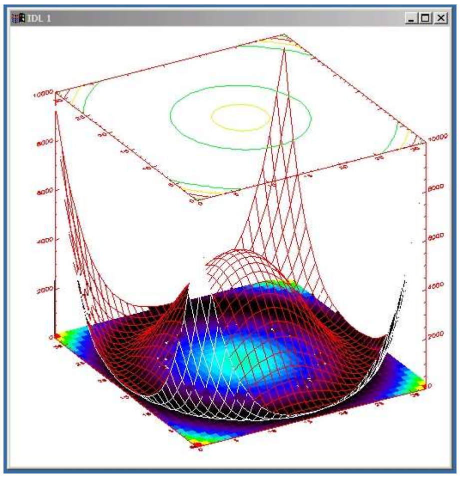

Fig. 2. Ion beam figuring: the material to be removed is represented by the red profile (peak-to-valley: 10 μm)

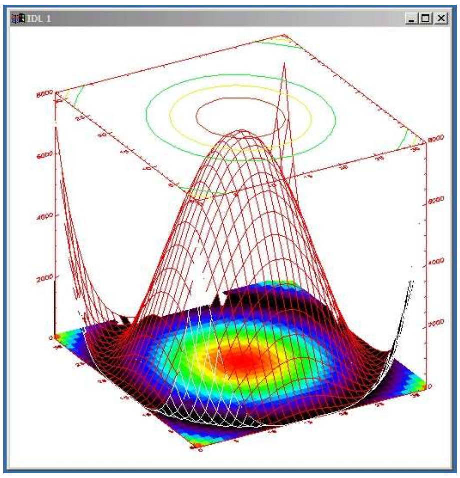

Fig. 3. Ion beam figuring: the resulting profile after six (the ordinatae scale is changed with respect to that of Fig. 2)

Table 1. UVISS filters

λ (nm)	FWHM (nm)	Reflection multilayer	Transmission multilayer	Substrate window
105	100	8 Y_2O_3/LiF	-	-
145	90	76 MgF_2/BaF_2	62 MgF_2/BaF_2	BaF_2
155	90	48 MgF_2/BaF_2	64 MgF_2/BaF_2	SiO_2
195	160	44 MgF_2/BaF_2	32 MgF_2/BaF_2	SiO_2
220	130	20 SiO_2/Y_2O_3	20 SiO_2/Y_2O_3	Al_2O_3
250	180	20 SiO_2/Y_2O_3	27 SiO_2/Y_2O_3	Al_2O_3

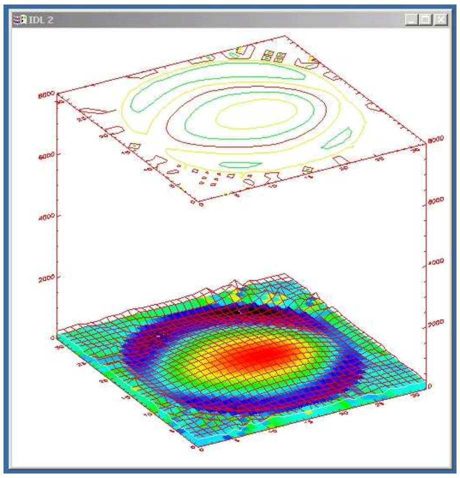

Fig. 4. Ion beam figuring: the expected final result after about 60 hours; the optics quality is 5 μm r.m.s. (to be compared with the specific value of 11 μm)

pend the optics above the source. The system is controlled by a computer and it has been built to be autonomous and self-monitoring during the figuring, using a process control software written specifically for the purpose. This software uses a time matrix map indicating the dwell times required for each pixel of the optical surface. This time matrix is computed from another program that uses the starting surface map, the removal function of the ion source and the final target surface, to compute the times and the path necessary to correct for the errors. The Fig. 2 shows the starting profile of the surface to be figured, which corresponds to a thickness of 10 μm (peak-to-valley). Fig. 3 shows an intermediate state of the process, with the profile of the remaining material to be removed, and Fig. 4 shows the final expected result after a certain number of working hours. The technique should be able to give an optical quality (5 μm) much better than that required (11 μm).

3. Multilayer filters

The wide field imaging mode will be based on interferential multilayer mirror filters. Multilayer mirrors consist of alternating layers of materials with different refraction indices. If the d-spacing (i.e. the bi-layer thickness) is kept constant along the stack, for a given monochromatic collimated beam impinging on the mirror surface we will get peaks of reflectivity at angles of incidence defined by the Bragg law (2d sin θ = n λ). Going from small incidence angles to greater ones, the central wavelength moves to longer wavelengths, while the reflectivity peak is reduced and the bandwidth increased. If used in reflection configuration, the main advantage in using a single multilayer mirror is given by its high efficiency, while the major drawback is the presence of not negligible off-band reflectivity peaks. Usually this problem is solved by keeping the d-spacing not constant, changing its value in a suitable way along the stack, in order to create a reflectivity profile specifically tailored for the application requirements. In addition, to minimize the secondary peaks, in general one exploits the reflection in sequence from two or more multilayer mirrors. It should be noted that multilayers can be also used as transmission filters; in this case the minimum transmission of the beam will occur in correspondence of the first Bragg peak. Obviously, for this configuration the substrate onto which the film is deposited has to be transparent in the maximum transmission band of the filter. The selection of materials for making multilayer filters in the relatively far UV band is difficult because of the limited number of materials which are transmitting. Despite such a difficulty, filters based on multilayer coatings for this band have been already used for space astronomy/geophysics applications. In the UVISS case, six filters are currently foreseen, centred respectively at 105, 145, 155, 195, 220 and 250 nm wavelengths. Each filter will be formed by two separate optical components mounted according to the following sequence. 1) A reflecting multilayer is directly deposited onto the surface of the aspheric mirror acting as field flattener, which is inclined at 45 deg with respect to the telescope optical axis. The mirror substrate will be made of fused silica, a material well known for the production of optical components due to its optimal thermal mechanical parameters and particularly well suitable for surface superpolishing. 2) A transmission (flat) filter, which for the 105 nm window will be based on a single layer of Indium, for all the other windows will be given by a multilayer film deposited on both sides of the substrate. The substrate is not always the same, but it has been chosen in order to have a large transparency at each specific wavelength band. The main characteristics of the filters are reported in Table 1. The tests performed up to now on multilayer samples show a fair agreement between theory and measurements (Conconi et al. 2003).

4. Conclusion

The studies and the tests performed show that it is possible to: a) get the field corrector for UVISS by means of the IBF, and b) develop the required NUV and FUV filters by means of the multilayer technology.

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