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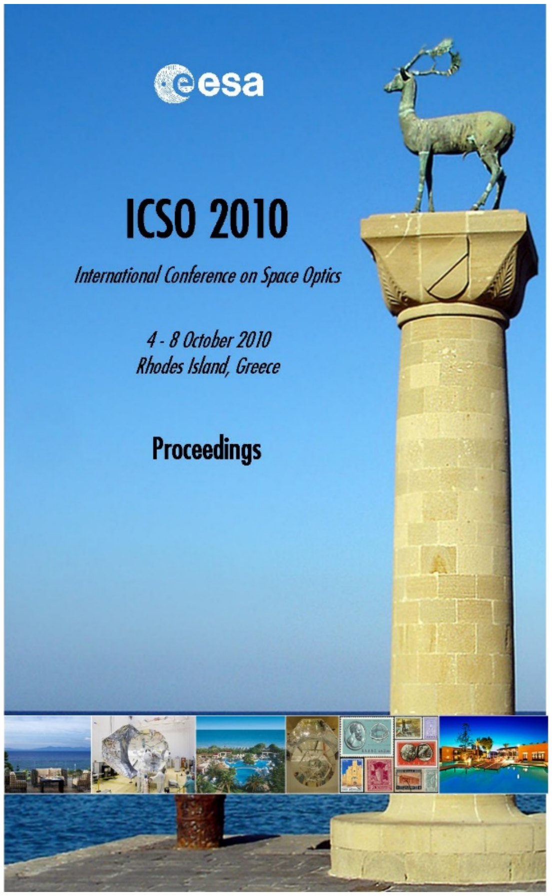

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PHEBUS SPECTROMETER: CHARACTERIZATION OF OPTICAL SUBSYSTEMS PROTOTYPE

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ABSTRACT

The Bepi Colombo mission is a project of European Space Agency (ESA) devoted to Mercury exploration. Probing of Hermean exosphere by ultraviolet spectroscopy (PHEBUS) is a dual Extreme Ultraviolet and Far Ultraviolet (EUV – FUV) spectrometer, that will fly on Bepi Colombo. It will be devoted to spectral analysis of Mercury. A preliminary optical prototype has been assembled by CNRS – LATMOS and the test of optical subsystems (i.e. entrance mirror and gratings) have been performed in the EUV and FUV spectral range at CNR-IFN LUXOR. Experimental results are presented together with proper simulations.

I. INTRODUCTION

The Bepi Colombo mission will explore Mercury. PHEBUS instrument is a dual EUV – FUV spectrometer, that will fly on the Bepi Colombo mission. It is devoted to improve present understanding of Mercury's exosphere by ultraviolet spectroscopy and will provide another clue to the chemical compositions of its surface, including detection of new species, measurements of an average exosphere, and determination of sharp local and temporal variations of the exosphere content at specific times and places of interest. The working range is 55-315 nm with two extra visible lines at 404 nm and 422 nm. It consists on a dual spectrograph in normal incidence configuration, in which two Variable Line Spacing Grating (VLSG) share a common entrance parabolic mirror. A scanning mechanism allows the simultaneous rotation of the baffle and the entrance mirror in order to change the line if sight independently from the spacecraft.

Development, assembling, and testing of PHEBUS spectrometer are led by France and involve Italy, Japan, and Russia [1].

The characterization of prototype optical components is the subject of this paper: testing results of parabola and gratings are presented and compared with simulations. The absolute efficiency of the FUV grating and the parabola have been measured in the total working range of instrument except for 160 – 240 nm range and 404 and 420 nm visible lines, while the EUV grating has been characterized only in EUV region.

II. EXPERIMENTAL DETAILS

A. Samples

Entrance mirror

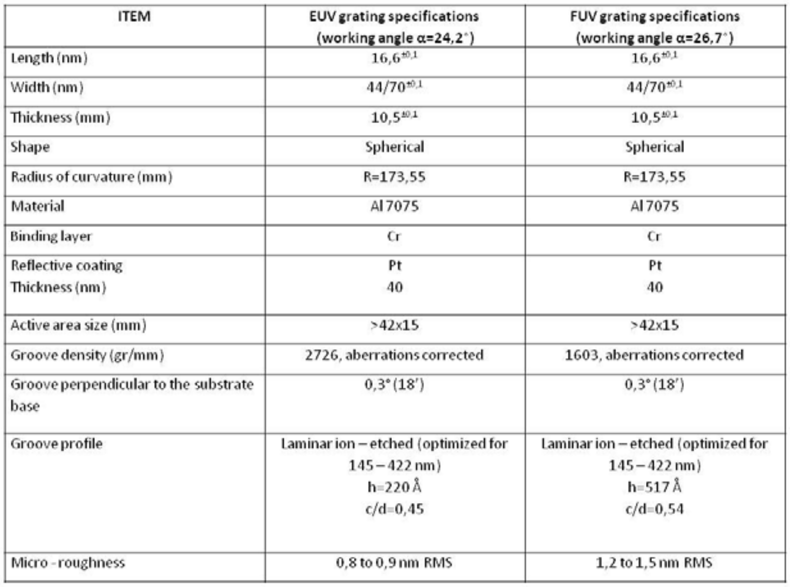
The entrance mirror is an off – axis paraboloid working at 100° angle and with 170 mm focal length, Al substrate coated with 140 nm of Platinum and Cr interlayer. Pt/Al structure offers a homogeneous mirror in terms of material and thermal behavior.

Gratings

The EUV and FUV gratings of PHEBUS prototype have been manufactured by Jobin Yvon SrL. They are spherical shape, aberration corrected holographic gratings and consist of Al substrate coated by Pt reflective layer. Jobin Yvon has performed surfaces characterizations and micro roughness measurements for both components. All specifications are reported in Table 1.

B. Set – up and procedure of measurements

The characterizations of the entrance mirror and the gratings have been performed using the normal incidence reflectometer at LUXOR (CNR – INF, Padova). Experimental chamber is placed with the theta – 2theta plane parallel to the reflection plane of the sample (considering the diffraction plane for gratings) (Fig. 1).



ITEM	EUV grating specifications (working angle α=24,2°)	FUV grating specifications (working angle α=26,7°)
Length (nm)	$16,6^{\pm0,1}$	$16,6^{\pm0,1}$
Width (nm)	$44/70^{\pm0,1}$	$44/70^{\pm0,1}$
Thickness (mm)	$10,5^{\pm0,1}$	$10,5^{\pm0,1}$
Shape	Spherical	Spherical
Radius of curvature (mm)	R=173,55	R=173,55
Material	Al 7075	Al 7075
Binding layer	Cr	Cr
Reflective coating Thickness (nm)	Pt 40	Pt 40
Active area size (mm)	>42x15	>42x15
Groove density (gr/mm)	2726, aberrations corrected	1603, aberrations corrected
Groove perpendicular to the substrate base	0,3° (18′)	0,3° (18′)
Groove profile	Laminar ion – etched (optimized for 145 – 422 nm) h=220 Å c/d=0,45	Laminar ion – etched (optimized for 145 – 422 nm) h=517 Å c/d=0,54
Micro - roughness	0,8 to 0,9 nm RMS	1,2 to 1,5 nm RMS

Table1. EUV and FUV gratings specifications

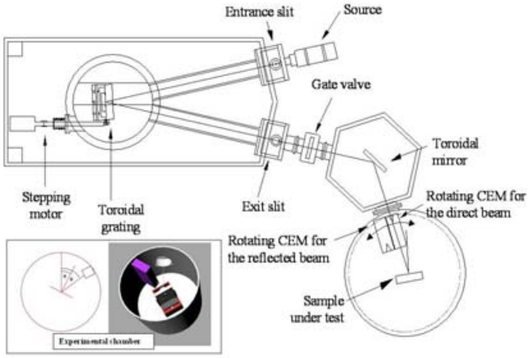


Fig 1. The normal incidence reflectometer at Luxor (CNR – INFN, Padova). Experimental chamber is placed with the theta- 2theta plane parallel to the reflection plane of the sample

As source, an hollow cathode filled with different gas and a deuterium lamp have been used for EUV range (55 – 155 nm), while a Hg spectral lamp (OSRAM Hg/100) for FUV range. The hollow cathode and Hg spectral lamps emissions are characterized by quasi – monochromatic sharp lines typical of the gas used, while measurements with deuterium source have been performed with an incidence beam having a finite spectral bandwidth related to resolution of the system. In order to select the wavelength a monochromator facility has been used for the EUV range and 10,0 nm bandwidth interferential filters (Melles Griot) for the FUV range (see Table 2).

SOURCE	Wavelength (nm)
Hollow – cathode (Ne)	46,1
Hollow – cathode (He)	58,4
Hollow – cathode (Ne)	74,4
Hollow – cathode (Ar)	91,9
Deuterium lamp	121,6
Deuterium lamp	145
Deuterium lamp	160
Hg – lamp & FIU111 filter	238
Hg – lamp & FIM016 filter	254
Hg – lamp & FIM018 filter	265,4
Hg – lamp & FIM 024 and > 300 nm filters	312,57

Table 2: Wavelengths of measurements

The polarization degree of the incident light was not determined at all wavelengths [2], then the measurements have been done in two different positions of the test chamber rotated 90° to each other: the mean value of them at each wavelength corresponds to the throughput for un – polarized light. The detectors used are a channel electron multiplier (CEM AMPTEK MD501) for EUV range and a photomultiplier (PM Hamamtsu R1414) for FUV range.

The alignment of the samples and the detector has been performed by using visible light. The reflected (diffracted for gratings) and incident beams have been used to determine the plane of incidence and check the proper positioning of the detector. The samples have been fixed at the working angle, that was determined relatively to the 0° incidence angle by looking at the back reflected. The throughputs have been calculated according to (1) depending on the detector:

$$\varepsilon = \frac{Counts / Current(reflected / order)}{Counts / Current(directbeam)}(CEM, PM) \tag{1}$$

III. RESULTS

A. Entrance mirror

The results of the reflectivity measurements performed on the Aluminium/Platinum entrance mirror have been done at wavelengths reported in Table 2. The maximum uncertainty associate to the experimental data is 10% in EUV range, and 15% in FUV. These values take into account all contributions like source stability, detector sensitivity, mechanical limitations of the facility and reproducibility.

Fig. 2 shows the experimental results and theoretical trends simulated by IMD [3]. The input parameters were selected considering the manufacturing characteristics of the sample: the mirror model is 140 nm Pt layer onto Al substrate with 4nm Cr layer interposed. Let's to note that the surfaces roughness plays a fundamental role in the performances of the mirror, then this parameter has been varied in the simulations. The experimental data have been compared with two theoretical trends with different roughness (σ) of the layers. The gray line refers to σ=4 nm for Pt and Al and σ=2 nm for Cr, while the black line to σ=0,5 nm for Pt, Al and Cr. The two theoretical curves highlight that the roughness of the surfaces affects significantly the reflectivity at shorter wavelengths: the reflectivity goes down of 45% at 60 nm wavelength, 20% at 74 nm. The experimental data are in better agreement with the high roughness surface profile and follow quite well the theoretical trend.

B. FUV grating

The FUV grating has been characterized in EUV and FUV spectral region for the order *m*=1 according to (2):

$$\sin\alpha + \sin\beta = m\frac{\lambda}{d} \tag{2}$$

where α and β are the incidence and diffracted angles respectively, λ the wavelength and *d* the groove density (gr/mm). Jobin Yvon characterized the theoretical troughputs for 130 – 430 nm, no references have been done at lower wavelengths. Moreover, the theoretical behavior of the grating (gray line in Fig. 3) has been simulated by using a demo version of PCGrate program [4] and considering the Jobin Yvon specifications (Table 1) as input parameters. The experimental data reported in Fig. 3 refer to the efficiencies measured at the center of the grating covering 1 mm^2 of area. Taking into account all contributions, the uncertainty associated to measurements is 15% in EUV, and 20% FUV. As we can see on the graph (Fig.3), the FUV experimental data are higher than the expected values, while they are very close to the nominal trend for lower wavelengths.

C. EUV grating

The absolute efficiency of EUV grating have been measured in the EUV region for *m*=1. It was not possible to perform measurements in FUV range because of the mechanical constraints. The beam on the sample was of 1 mm^2 of area, the uncertainty of measurements 15%. The experimental data and the PCGrate simulations have been reported in Fig. 4: the experimental efficiencies are lower than expected.

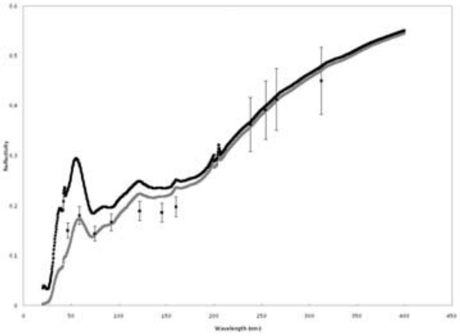


Fig 2. Reflectivity measurements of the entrance mirror
Gray line: simulation by IMD considering 140 nm Pt layer (σ=4nm) onto Al substrate (σ=4nm) with 4 nm Cr layer (σ=2nm) interposed;
Black line: simulation by IMD considering 140 nm Pt layer (σ=0,5nm) onto Al substrate (σ=0,5nm) with 4 nm Cr layer (σ=0,5nm) interposed

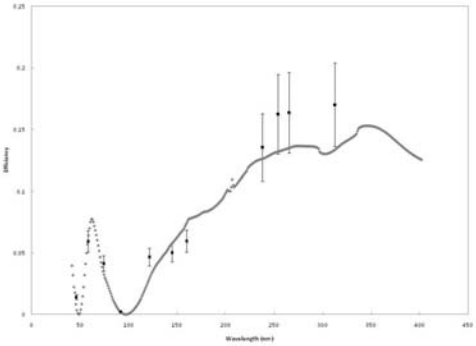


Fig 3)

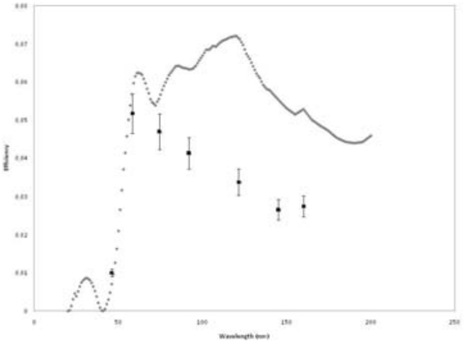


Fig 4)

Fig 3. The absolute efficiency of the FUV grating (m=1) Black squares: EUV and FUV experimental data Gray line: simulation by PCGrate
Fig 4. The absolute efficiency of the EUV grating (m=1) Black square: EUV experimental data Gray line: simulation by PCGrate

IV. CONCLUSIONS

Experimental measurements of Phebus prototype's components have been shown in this paper: this is the first step towards the optimization of a method that will be used to characterize the optical subsystems of the flight model. The experimental performances of the entrance mirror and the gratings have been analyzed and compared with the simulated trends. It is worth to be noticed that the uncertainty associated to FUV measurements are significant. Then, one of our purpose for the next future is to reduce this uncertainty.

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