ESRF	**Experiment title:** Hard X-ray tests of integral multilayer Wolter I shell prototypes for astronomy realized by Nickel electroforming replication	**Experiment number**: MI-486
Beamline: BM05	**Date of experiment**: from: 02 June 2001 to: 10 June 2001	**Date of report**: 31 Aug 2001
Shifts: 21	**Local contact(s)**: E. Ziegler – M. Sanchez del Rio	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

*Giovanni Pareschi – Osservatorio Astronomico di Brera – Italy
*Franco Mazzoleni - Osservatorio Astronomico di Brera – Italy
*Donato Garegnani - Osservatorio Astronomico di Brera – Italy
Oberto Citterio - Osservatorio Astronomico di Brera – Italy
Mauro Ghigo - Osservatorio Astronomico di Brera – Italy
Paul Gorenstein – Harvard Smithsonian Center for Astrophysics – USA
Suzanne Romaine - Harvard Smithsonian Center for Astrophysics – USA
Adrian Ivan - Harvard Smithsonian Center for Astrophysics – USA

Report: The beam time allocarted for the MI-486 experiment has been exploited to carry out hard X-ray reflectivity tests of two different mirror shells based on multilayers:

- **a first single-cone multilayer optics with the following characteristics:**

Ø = 121 mm ***height*** **= 15 cm** ***taper angle*** **= 0.465 deg**
Coating: **Ni/C multilayer (11 bi-layers) with constant d-spacing (4.6 nm)**
The mirror shell was realized using the so called "*direct Ni electroforming replication method*": i) a mandrel having the negative profile of the mirror to be produced is fabricated (the mandrel is made of Aluminum but its external surface is superpolished electroless Nickel); ii) the mandrel is mounted onto a rotational stage at the interior of a vacuum chamber and the multilayer is deposited onto its external surface by ion-beam sputtering; iii) the mandrel is then put into an electrolytic bath, where a layer of Ni is electroformed around it to give a mechanical stiffness to the mirror shell to be realized; iv) the mirror shell is then separated from the mandrel by cooling it, exploiting the fact that the thermal expansion coefficients of the Aluminum of the mandrel is about 2 times larger than the Ni electroformed walls.
This mirror shell has been in particular produced by exploiting a mandrel with an average roughness level of ~7 Å (rms) in the 3-660 µm window of spatial wavelengths as measured by a WYKO profilometer.
The X-ray tests at the BM05 facility of the ESRF have been done at the photon energy of 17 keV, exploring the mirror shell at several azimuthal positions by means of a pencil beam. The multilayer reflectivity and the first Bragg peack is 11 %, with the whole profile that can be fitted by a model involving a Debye-Waller roughness of 7 Angstroms (i.e. very similar to the starting roughness level of the mandrel, which in this case acts as a substrate). It should be noted that, before the ESRF MI-428 experiment here described, the on-axis effective area of the optics was previously been measured at several energies between 8 and 20 keV at the PANTER X-ray facility (Neuried, Germany, operated by the Max Planck Institute for Astronomy). In this case the optics pupil was fully illuminated by means of a isotropic point-like source located very far (130 m). The results of the two measurements are in good agreement each-other.

➢ **a second single-cone multilayer optics with the following characteristics:**

Ø = 280 mm *height* = 15 cm *taper angle* = 0.2 deg

***Coating:* W/Si multilayer supermirror (250 bi-layers)**

Min d_{spac} = 2 nm – Max d_{spac} =7.8 nm

The second mirror shell was realized in a different way from the first case: a gold-coated mirror shell was realized by Ni electroforming replication, i.e. using the same approach exploited for making the soft X-ray mirrors with single-layer Au coating of the ESA mission XMM-Newton. Afterwards the internal gold surface of the shell was used as a substrate for the deposition of the multilayer coating. Concerning this aspect, a DC magnetron sputtering source located at the interior of the cone was used (the sputtering source was developed for this specific application at the *Harvard-Smithsonian Center for Astrophysics*, Cambridge, Ma, USA). It should be noted that the mandrel utilized for the substrate shell replication was superpolished at the Brera Astronomical Observatory by means of a special lapping machine able to give an average roughness level of 3 Å (rms) in the window of spatial wavelengths between 3 and 660 µm.

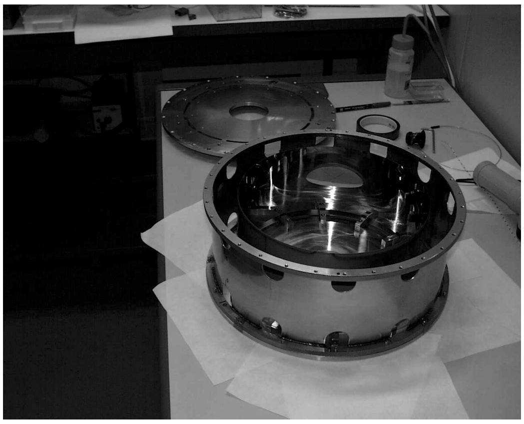

Fig. 1 The multilayer mirror shell during the Integration into the mechanical case.

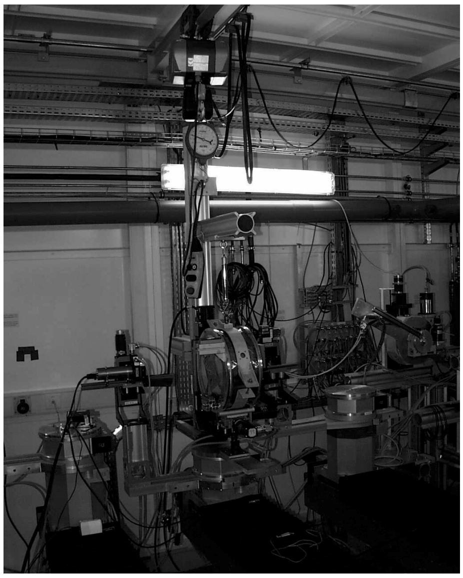

Fig. 2 The case containing the multilayer optics mounted on the goniometer of BM05.

During the measurement at ESRF the mirror shell was integrated into a mechanical case able to simulate the true system that would have been used for a real X-ray telescope (Fig.1) and then mounted on the goniometer of the BM05 beamline (Fig. 2). Due to the large dimensions of the case (Ø = 340 mm) and its large mass (about 20 Kg), special large-stroke translational motors were used to move the sample, in addition to a systems of counterweigths to get a better sample equiilibrium during the optics rotation. Exploiting the 2-crystals monocromator of the BM05 facility it has been possible to measure the mirror reflectivity at several positions at the photon energy of 17 keV and 40 keV (see Fig. 3). These data are currently being analyzed.

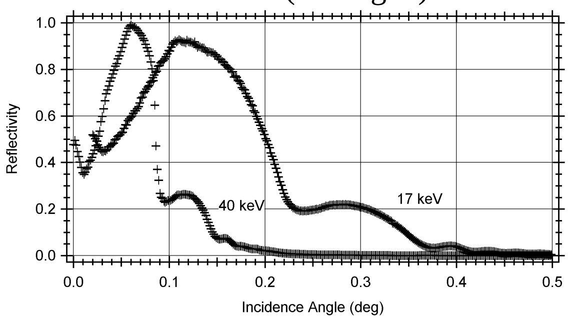

Fig. 3 Reflectivity profiles of the mirror shell at 17 and 40 keV.