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New X-ray Missions

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Abstract. Two major technological goals to be achieved in near future in the field of X–ray astronomy are: i) the realization of soft X–ray (0.1 - 10 keV) optics with collecting areas much larger than those permitted for the main current X-ray telescopes (e.g. XMM–Newton and Chandra), and ii) the realization of focusing telescopes based on multilayer coated mirrors for the hard X-ray energy band (10 - 100 keV). In both cases an important parameter to be considered is the angular resolution, that has to be as good as possible in order to avoid problems of source confusion, improve the flux sensitivity and make possible the investigation of details in extended sources. At the Brera Astronomical Observatory – INAF activities devoted to the development of the soft and hard X-ray optics for future missions are presently on-going. In this paper the undertaken technological approaches and some of the main results achieved until now are reviewed.

Key words. X-ray telescopes - X-ray astronomical missions - X-ray optics - Multilayer mirrors

1. Introduction

In the field of optical Astronomy in the last ten years a substantial jump in the performances of the optical telescopes has been achieved. New ideas and creative approaches have permitted the manufacturing of telescopes with diameters in the order of 10 m like, e.g., the Keck telescopes. The idea of building a full mirror telescope joining together many segments has broken the old rules and nowadays many new telescopes are on the drawing boards that will have diameters from 20 up to 100 m. The same is currently going to happen for X-ray telescopes. In this context the XEUS (*X-ray Evolving Universe Spectroscopy* mission) concept (see the exhaustive collection of papers about this mission in Hasinger et al. (1996)) will represent a quantum leap with respect to the state–of–the–art missions (XMM-Newton and Chandra). XEUS will make use of a single Wolter I module having a diameter of 9.9 m (it will be a sort of Keck telescope in X-rays). Since the focal length is 50 m, an innovative approach foresees to employ two distinct spacecrafts, one for the optics and the other for the detectors, that will fly in formation linked by an active laser tracking system. XEUS will provide a permanent space–borne X-ray observatory with an unprecedented collecting mirror area up to 30 m^2 at 1 keV and 3 m^2 at 8 keV. Compared to XMM-Newton the source flux sensitivity and the

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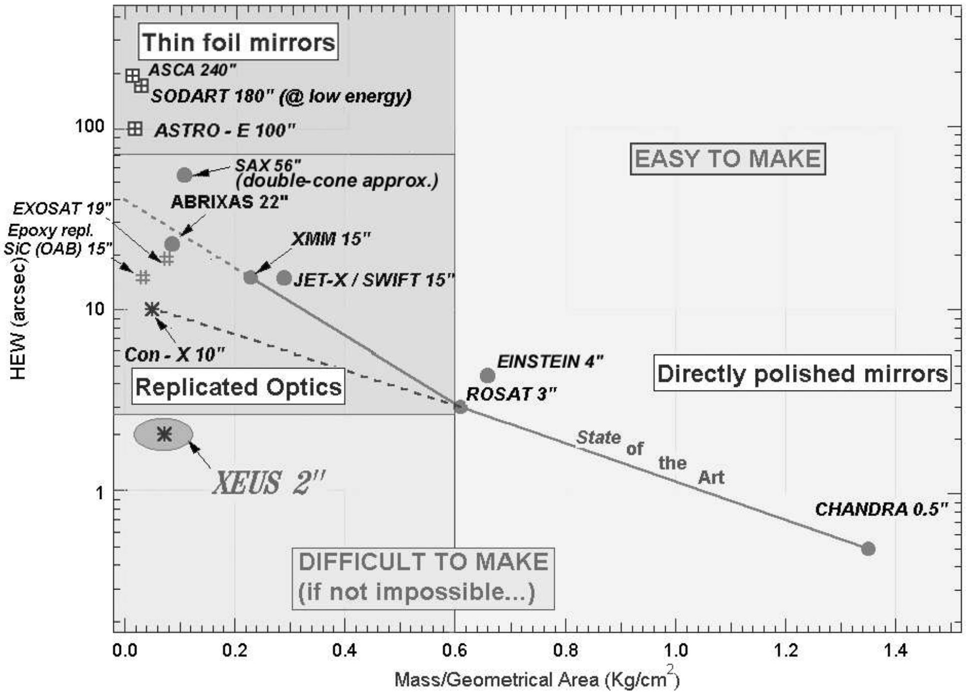

Fig. 1. The Half Energy Width (HEW) for a number of past and current X–ray missions as a function of the mirror mass–togeometrical—area ratio. As can be seen, the goal to be achieved for XEUS (just 2 arcsec HEW) is highly challenging due to the small mass/cm^2 allocated.

angular resolution will be 250 times and 7.5 times better, respectively. The angular resolution of the optics is set to be 5 arcsec HEW, with a goal of 2 arcsec. The enormous mirror dimensions and the required angular resolution give rise to a number of problems that need the development of new realization methods and production processes (Citterio et al. (2001)). In our Institute (Osservatorio Astronomico di Brera/INAF, hereafter OAB) we are currently involved in activities addressed to this scope (Citterio et al. (2003)).
On the other hand, in parallel with the activity devoted to XEUS, we are also developing optics for hard X-ray astronomy (10 - 100 keV). It is well accepted that the introduction of concentration techniques in the hard X-ray energy band instead of the only passively collimated direct-view detectors (with or without coded masks) used until now will determine dramatic improvements in terms of flux sensitivity and angular resolution. This could be achieved by using optics based on interferential multilayer-coated mirrors. For this application the manufacturing technique under investigation by our group is based on the Ni electroforming replication process (Citterio et al. (1988)), after an opportune up-grade of the method already successfully used for making the Au coated soft X–ray optics of the Beppo-SAX, Jet-X/SWIFT, and XMM-Newton missions. This approach is able to guarantee good imaging performances, in addition to a high throughput. The main targets for this applications are the HEXIT balloon–born experiment (project supported by ASI) and, in perspective, the Hard X–ray Telescope (HXT) on-

board the NASA mission Constellation-X (Pareschi et al. (2002)).

2. Development of the XEUS segmented mirrors

It is basically impossible to realize the huge mirrors foreseen for the XEUS project assuming closed Wolter I shells, which would benefit from high mechanical stiffness. Instead, the mirrors need to be formed as rectangular segments of 1.0 m $\times$ 0.5 m size, a series of them will be assembled in a petal and the petals assembled in the final telescope optics. The current design foresees a mass-to–geometric–area ratio of 0.08 kg/cm^2, which is very small and much lower compared to other previous missions (see Fig. 1). Finally, the optics will operate in extreme thermal conditions, with the mirror temperature oscillating between –30 and –40 ^{o}C, that tends to exclude the epoxy–replication approach. The mismatch between the Coefficient of Thermal Expansion (CTE) of the substrate and that of the resin would cause prohibitively large deformations of the mirror surface profiles. From these considerations light weight materials with high thermal–mechanical properties such as glass or ceramics become attractive to realize the XEUS mirrors. A technological approach that we are currently envisaging for the large–scale production of the XEUS segments is the use of thin Borofloat^{TM} glass to be thermally formed. This research is being carried out in collaboration with the Max-Planck-Institut fr Extraterrestrische Physik (Garching, Germany). To obtain the correct final profile the thin mirror supports will be directly ground and superpolished. Finally, after the evaporation of a reflecting coating, the segments will be integrated in a mounting structure such that the mirror profile will not be deformed beyond acceptable levels. Up to now we tried a number of slumping processes obtaining very encouraging results. In particular, after just a few iterations, we have realized segments with a size of 20 cm $\times$ 20 cm and a typical thickness of 1.1 mm. The Peak–to–Peak difference when compared to the mold is just 6 μm. This value closely corresponds to the technological requirement to perform the final figuring by automatic polishing.

It should be mentioned that another promising approach is also being investigated at OAB. This is based on the use of ceramic (SiC) carriers, assuming as a baseline the experience already developed for the feasibility studies of the WFXT (Citterio et al. (1999)) and Cosmos SkyMed (Novi et al (2001)) missions.

3. Development of multilayer coated mirrors for hard (10 – 100 keV) X-ray astronomy

For the development of the hard X-ray multilayer optics manufacturing we are pursuing two different approaches. Both of them are derived from the original replication technique by Ni electroforming used for the Au–coated soft X-ray mirrors of past missions. As usual, one has to produce a low–roughness mandrel having the negative profile (Wolter I geometry or a linear approximation to it) of the mirror to be fabricated. The mandrel is made of Al and electrochemically coated by a thin layer (100 μm) of Kanigen, a material particularly well suitable to sustain a superpolishing process by lapping. The first method (see Fig. 2 - left panel) foresees the direct deposition (by Ion Beam Sputtering or another vacuum deposition technique) of the multilayer film onto the superpolished mandrel surface and the successive deposition by electroforming of the Ni external substrate. The mirror is then separated from the mandrel by cooling it, exploiting the large difference in CTEs between the Al of the mandrel and the Ni walls of the shell. The second approach (see Fig. 2 - right panel) is based on the growth by a linear vacuum deposition source of the multilayer film onto an Au-coated Ni substrate, previously produced by replication. Until now both approaches have been

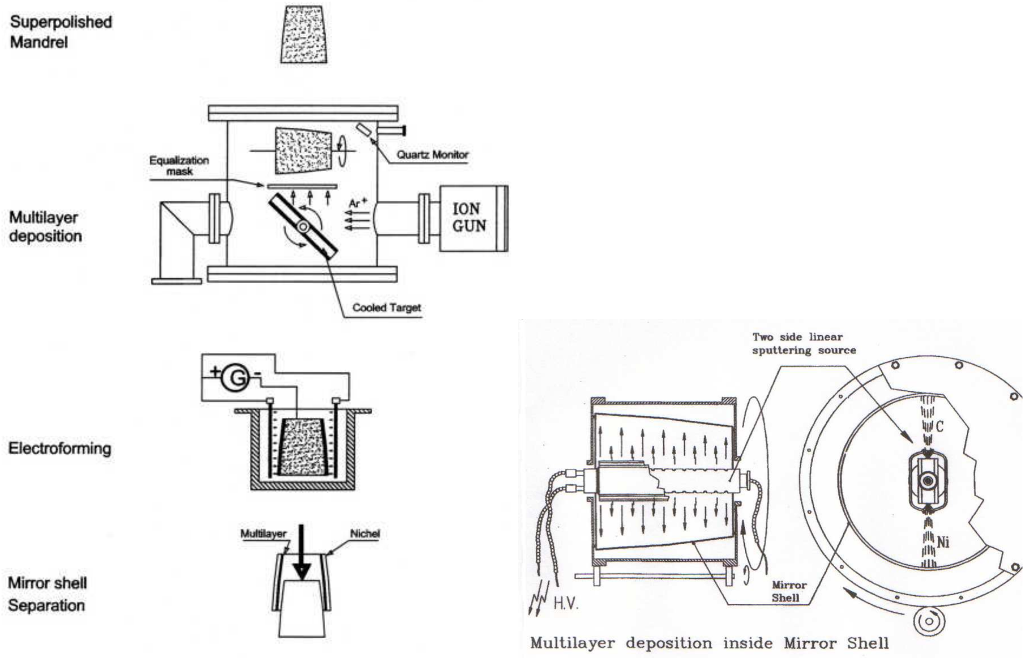

Fig. 2. Left panel: direct deposition of the multilayer film onto the surface of a superpolished mandrel and successive replication by Ni electroforming. Right panel: application of the multilayer film onto the surface of a previously Ni replicated Au-coated substrate by a magnetron sputtering linear source.

followed in parallel, and important results proving their feasibility were obtained.

4. Conclusions

The on-going activities currently being carried out at OAB for the developments of optics for future X-ray missions have been reviewed. The results achieved until now by means of prototypes are very promising.

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