Roots of the XMM-Newton Space Observatory:
A blast from the past

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Scientifically the discovery in 1962 of the first extra-solar X-ray source Sco X-1 with a rocket-borne instrument developed by Riccardo Giacconi and his group opened up a fundamentally new horizon in astronomy. The X-ray flux from this object was 1000 times larger than in the optical domain and its intrinsic X-ray luminosity was 1000 times larger than the total luminosity of the Sun over all wavelengths.

A full sky survey in the X-ray domain was started with the launch in 1970 of the scanning satellite UHURU (NASA), leading to the detection of a few hundred celestial X-ray sources (339 in the 4U catalogue of 1978). UHURU discovered that many of these energetic X-ray sources were actually powered by matter accretion onto a degenerate star in compact binary systems. Moreover it showed the presence of vast expanses of million-degree hot gas in rich clusters of galaxies. In Europe initiatives by individual countries in this new field of astrophysics included surveying and monitoring of the X-ray sky by the UK/US Ariel 5 satellite and the first pointed observations of selected cosmic X-ray sources by the Dutch/US 3-axis stabilized ANS satellite, both launched in 1974.

It was clear from the outset that a major leap in angular resolution, and hence dramatically enhancing the limiting sensitivity for source detection, to accurately determine source location and allowing potential identification would require real imaging X-ray optics. Already in 1963, one year after the discovery of the first celestial X-ray source, Giacconi proposed to NASA to build a 1.2 metre aperture, 10 metre focal length, X-ray telescope as a successor to a scanning mission (that became later UHURU). The first proposed concept entailed an extendable Wolter-I telescope, to be launched in stowed configuration on the then available launchers. However, due to severe funding constraints a smaller version of the 1.2 metre telescope, comprising a 60 cm telescope with 4 nested mirror pairs, was approved as the second space mission in the High Energy Astronomy Observatories (HEAO) series. After launch of HEAO-2 in 1978, the operational mission was renamed the Einstein Observatory. Insertion behind a high resolution grazing incidence Wolter-I X-ray telescope of a short period (1μm) transmission grating would allow for high resolution spectroscopy of celestial X-ray sources. Such short period gratings had been

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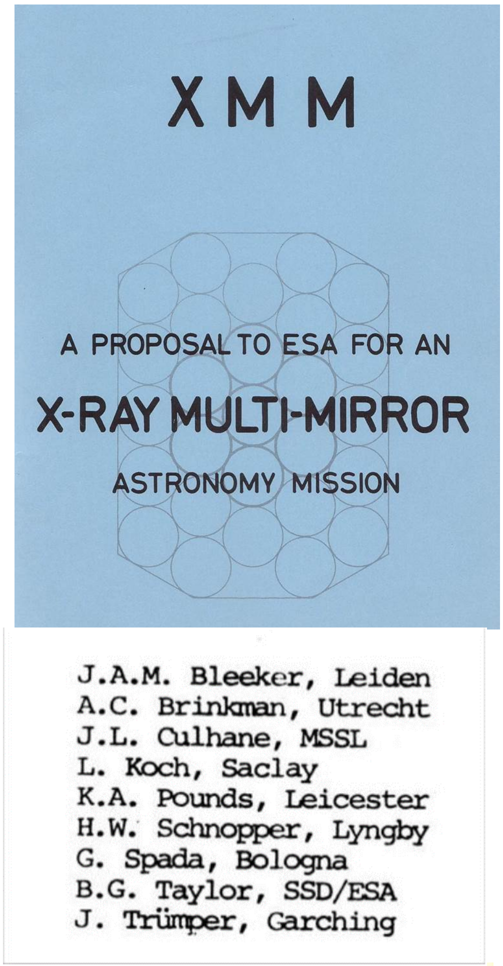
developed by Dutch space research, capitalizing on zone plate technology for solar XUV-research. These gratings were incorporated in the Objective Grating Spectrometer of the Einstein Observatory and covered the soft X-ray domain up to wavelengths of a few tens of Å and led to the first high resolution coronal X-ray spectra ever measured. One could actually consider this as the first 'European' marker on high resolution spectral studies of cosmic X-ray sources. The high quality imaging performance of Einstein (PSF of ~ 4" FWHM and 10" HPW) opened up X-ray astronomy to all types of celestial objects: X-radiating auroras on planets, forming young stars, main sequence and degenerate stars, supernova remnants, normal and active galaxies, clusters of galaxies and the diffuse X-ray background. The number of detected X-ray sources increased from the few hundred in the UHURU era to more than 7000 for which the Einstein telescope established accurate positions and detailed images.

In 1972, the European Space Research Organisation (ESRO) published an assessment study prepared by a group of European X-ray astronomers (including author JB) to measure with arcsecond accuracy the positions of celestial X-ray sources by employing the method of lunar occultation as opposed to using an imaging telescope: the Highly Eccentric Lunar Occultation Satellite (HELOS). Originally, the model payload included an array of collimated proportional counters covering the energy range 1 – 50 keV and a number of low-energy-X-ray collecting 'light buckets" of the type flown on ANS. Given the fast evolution of the X-ray astronomy field in the 1970s and the upcoming launch of an imaging X-ray telescope on Einstein, it was concluded in 1977 that the focus on occultation should be abandoned. The mission, with its deep orbit allowing for long uninterrupted observation times and real time coverage, was to evolve into the first truly European X-ray Observatory (EXOSAT). Given its excellent attitude measurement and control system, the light buckets were replaced by lightweight X-ray imaging optics. Moreover, since spectroscopy is the 'queen of astronomy', it is evident that any major X-ray observatory should have spectroscopic capability. The presence of two imaging X-ray telescopes on EXOSAT enabled the use of short period X-ray transmission gratings, in this case extending over a much wider waveband than Einstein well into the XUV regime. The development of this lightweight grazing incidence optics resulted in employing the technique of epoxy replication of a gold reflecting surface into thin Be-carrier shells. As Europe's predecessor for XMM-Newton, important lessons could be derived from the EXOSAT technological and operational experience. Among others these included: replication technology, the great value of long uninterrupted looks by virtue of a deep orbit for X-ray variability diagnostics, the potential added value of an on-board optical/UV monitor for transient phenomena, the essential value of proper ground characterisation with a long beam X-ray test facility, consolidation in data archives and of surveys.

With the experience gained and lessons learned from EXOSAT, the European X-ray community contemplated the next generation step in this field in the early eighties. In the US, Giacconi and Tananbaum had again submitted in 1976 an unsolicited proposal to NASA for a 1.2 metre X-ray telescope with ultimate angular resolution of 0.5 arcseconds as a follow-up for the Einstein mission. This initiative was largely based on the successful development of the Einstein mirror, bringing convincing evidence that X-ray optics technology could eventually



XMM

A PROPOSAL TO ESA FOR AN

X-RAY MULTI-MIRROR

ASTRONOMY MISSION

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XMM

X-RAY MULTI-MIRROR

ASSESSMENT STUDY

deliver the performance required by the science drivers. Approval for the 1.2 metre telescope, AXAF, came in 1977 as a result of NASA’s decision to embark on a strategic ‘Great Observatories’ programme.

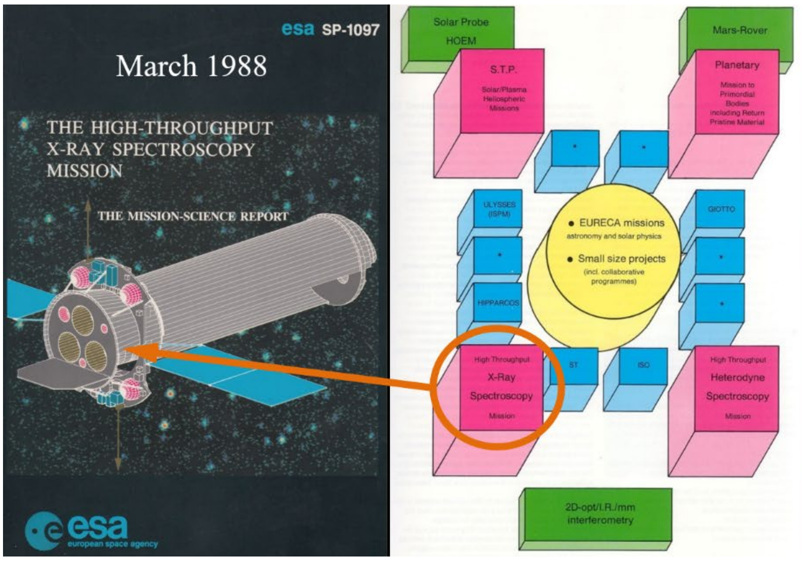
Interalia, on the European front a medium class mission, provisionally called X-80, had undergone a detailed feasibility study and became a contender for the ESA 1983 mission selection, but lost out to the Infrared Space Observatory (ISO). A reincarnation of X-80 came back afterwards on the national level as the Italian/Dutch SAX, after launch in 1996 renamed as BeppoSAX. Another national initiative by Germany at that time resulted in the development of the ROSAT mission during the 1980s (D/UK/US), which entailed a high resolution X-ray sky survey with the aid of an X-ray imaging telescope in the low energy regime.

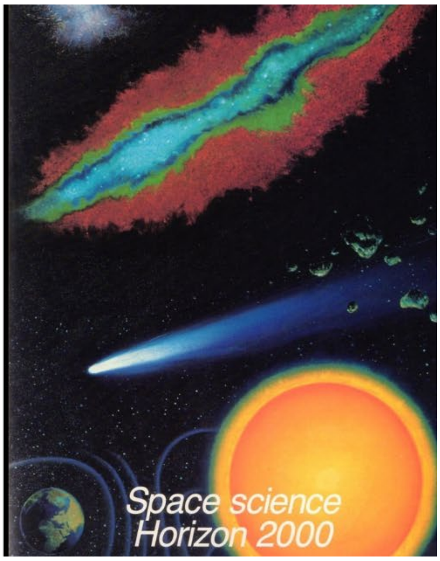
Given these developments, a group of X-ray astronomers in Europe concluded that, on the European level, there existed a need for a multi-purpose high throughput X-ray facility completely complementary to AXAF. The high costs and other limitations of the AXAF single focus system argued in favour of an array of telescopes with some compromise in angular resolution but with a substantially larger X-ray spectral collecting area to accommodate high resolution spectral studies that were not ‘photon starved’. Hence, they responded to a ‘call for ideas” issued by ESA with a proposal1) for an ‘X-ray Multi Mirror Astronomy Mission’ in November 1982, that could also benefit from the experience gained during the development of EXOSAT (still to be launched in May 1983). The cover of this proposal symbolizes the original presence of 27 telescopes: a cluster of 20 low-energy telescopes (up to 3keV) with 10” HPW (at 1keV) and 1m^2 effective area, and 7 high-energy telescopes going out to 10 keV with 30” HPW (at 7 keV) and 0.5 m^2 area, i.e. a true broad band X-ray mission optimized for high collecting power to accommodate maximum spectral sensitivity. In the proposed instrument complement, the replica technique pioneered for EXOSAT was adopted as the baseline enabling technology for the 20 low-energy mirrors, the number of nested shells per telescope was assumed to be around 10 to benefit optimally from repeated usage of the high quality mandrels. The technology for the high-energy mirrors assumed the deployment of thin metal (e.g. Al) foils in conical surfaces of revolution to meet the half arcminute resolution design goal. Every conceivable form of focal plane detector could be considered, along with gratings and crystal spectrometers as dispersive spectral elements. The size of the optics tentatively dictated a shuttle launch in low earth orbit. During 1983, some of the XMM proposers supported by ESA staff conducted an assessment study[2], that was issued in September 1983. The proposed payload had then be scoped to fit within an Ariane 4 envelope by lowering the number of low-energy mirrors to 12 and by the inclusion of an extendable optical bench to accommodate the 8 meter focal length required for the high-energy optics resident in the central part of the telescope.

From October 1983 to July 1984 a 'Survey Committee' (chair, author JB) of European scientists developed the strategy behind the 'Horizon 2000' long term plan for the ESA Scientific Programme[3]. The stimulus was to achieve a ~50% increase in the annual Science budget over the following five years or so. Central to this plan was the concept of four 'cornerstones', large scale missions whose scientific objectives were preordained so as to allow the requisite technological, industrial and programmatic developments prior to their correctly timed implementation, together with a flexible element, the so-called medium and small missions which were to be selected in competition. In this plan, the second cornerstone was to be a 'High Throughput X-ray Spectroscopy' mission - XMM by another name. The Survey Committee said:

"A High Throughput X-Ray Mission for Spectroscopic Studies between 0.1-20keV

The observatory, comprising multiple telescopes, provides the required sensitivity to perform detailed spectral diagnostics of many classes of objects with low (surface) brightness. This is particularly important for studying the evolution of the large and small-scale structures of the universe. It further allows simultaneous observations of several aspects of astronomical targets which considerably enhance its unambiguous physical interpretation. It is an ideal complement to the AXAF (NASA) mission, which pursues ultimate imaging capabilities with primary emphasis on deep surveys."





A scientific meeting was held in Lynby[5] in 1985 to give the scientific community the opportunity to express its view on the science of XMM and to identify the drivers in the payload development. Serious work on XMM started in 1985 with the establishment of a number of XMM working groups and the conduct of a 'Phase A' industrial study with Dornier Systems.

Following the scientific requirements, as confirmed by the Lyngby Workshop[4)], the XMM Telescope Working Group carried out design studies[5)] for three types of telescope, i.e. for conical, Wolter-1 and Kirkpatrick-Baez designs, and recommended the use of seven Wolter-1 telescopes, each with a focal length of 8 meters and an aperture diameter of 70 cm. These Wolter-1 telescopes would have to be manufactured by replication techniques similar to those used successfully for EXOSAT. An effective collecting area of $1m^2$ at 2keV with a spatial resolution better than 30" HPW was deemed feasible.

The overall configuration developed by March 1987, looked very much like XMM as we know it today. XMM was to be placed in a 48hr period orbit using the Ariane 4 launcher, fully reaping the benefits of long uninterrupted observation periods for variable X-ray sources that had proven to be a major observational asset during the EXOSAT operation. The payload now featured only four X-ray mirror systems. However, a very important feature had been added, the Optical Monitor Instrument, to allow simultaneous observation of the (majority of the) field of the X-ray telescopes in the UV and visible bands, again highlighting a lesson learned from the operation and exploitation of EXOSAT.

In November 1987, the XMM Instrument Working group produced its report[6)] which, constrained by the 4 mirror systems, concluded that each system should be equipped with a CCD camera and a GSPC, complemented with 2 reflection gratings and 2 Bragg crystal spectrometers.

In March 1988, the XMM Mission Science report was issued[7)]. Within the constraints given by an Ariane 4 and now placed in a 24hr period orbit, the 'model' payload comprised three mirror modules which, using replication technology, was specified to yield a total area of $6000cm^2$ at 2keV and $3000cm^2$ at 7keV with a spatial resolution of <30" HPW. Each mirror module was to be equipped with a CCD camera and two were to be equipped with reflection gratings. The X-ray telescopes were to be complemented by the Optical Monitor. ESA's Scientific Programme Committee (SPC) approved the mission in this form in June 1988 and the AO for the instruments was released the same month.

One year later, in 1989, ESA's SPC approved the selection of the EPIC axial instruments (PI Giovanni Bignami, succeeded by Martin Turner in 1997), the RGS instruments (PI Bert Brinkman) and the Optical Monitor (PI Keith Mason). So, the long, hard haul of the hardware development programme began.

During the course of the XMM development programme a number of issues arose, perhaps typical of any such endeavour but it was determined that the replication technique using lightweight carbon fibre carriers for the mirrors would not yield the performance required due to 'print through' of the carrier onto the X-ray reflecting layer. Ultimately, nickel carriers, with commensurate mass penalty, were utilized. This lead to the replacement of Ariane 4 by Ariane 5 which allowed XMM to be placed in the deeper, 48hr eccentric orbit, as originally conceived.

To complete the XMM (preparatory) picture, the Survey Science Centre (PI Mike Watson) was selected by ESA in 1995, the tasks being to develop the pipeline processing for the XMM science data, to marry the serendipitous fields of the X-ray cameras and the Optical Monitor and to initiate ground-based follow up.

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