HIGH-ENERGY ASTRONOMY FROM THE INTERNATIONAL SPACE STATION

ARVIND PARMAR
Space Science Department of ESA, ESTEC, 2200 AG Noordwijk, The Netherlands
E-mail: Arvind.Parmar@esa.int

Abstract. The European Space Agency, ESA, is currently studying 3 high-energy astronomy missions that use the International Space Station (ISS). These are Lobster-ISS, an all-sky imaging X-ray monitor, the Extreme Universe Space Observatory (EUSO) which will study the highest energy cosmic rays by using the Earth's atmosphere as a giant detector and XEUS – the X-ray Evolving Universe Spectroscopy Mission, a potential successor to ESA's XMM-Newton X-ray observatory. These first 2 missions will he attached to the external platforms on the Columbus module, while XEUS will visit the ISS to attach additional X-ray mirrors to enlarge the original 4.5 m diameter mirrors to the 10 m diameter required to observed redshifted iron lines from massive black holes in the early Universe.

Keywords: Cosmic rays, Space Station, X-ray astronomy

1. Introduction

The European Space Agency (ESA) has ambitious plans to utilize facilities offered by the International Space Station (ISS) for high-energy astronomy. Currently three such high-energy astronomy missions are being jointly studied by ESA's Manned Spaceflight and Science Directorates. These are Lobster-ISS, an all-sky imaging X-ray monitor, the Extreme Universe Space Observatory (EUSO) which will study the highest energy cosmic rays by using the Earth's atmosphere as a giant detector and XEUS – the X-ray Evolving Universe Spectroscopy Mission, a potential successor to ESA's XMM-Newton X-ray observatory.

A mission is studied before final approval to allow its overall design to be elaborated, the scientific and technical feasibility demonstrated and most importantly the costs evaluated and commitments obtained for all the necessary elements. These activities are normally part of a so-called "Phase A Study" following a successful outcome of which, a project can hopefully move forward into detailed design and build phases as an approved mission. Each of these missions utilizes different aspects of the ISS in order to achieve its scientific goals in a timely and cost effective manner. Each mission is now described emphasizing the characteristics that make it highly suitable for the ISS.

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2. Lobster-ISS

Lobster-ISS in an imaging all-sky monitor which will utilize a novel form of micro-channel plate X-ray optics and thin window microwell anode gas proportional counters to provide a 0.5–3.5 keV sensitivity of 2×10^{-12} erg cm^{-2} s^{-1} in a one day observation. This is an order of magnitude better than previous all-sky monitors. The angular resolution of 4 arc minutes full-width half maximum will allow source location to 1 arc minute to allow the rapid identification of new transient sources. Lobster-ISS will produce a catalog of 200,000 X-ray sources every 2 months which will be made available to the astronomical community via the WWW. As well as providing an alert facility, Lobster-ISS will allow the study of long-term AGN variability, and stellar activity, the discovery of new and the poorly understood X-ray flashes and the observation of X-ray afterglows of Gamma-ray bursts.

The instantaneous FOV of Lobster-ISS is $162 \times 22.5°$ and is synthesized from six identical offset telescope modules each with a $27 \times 22.5°$ FOV. The configuration of the instrument on an Express Pallet Adaptor is shown in Figure 1. It is envisaged that lobster-ISS will be located on the zenith pointing external platform of ESA's Columbus module. Unlike a conventional satellite which orbits the Earth pointing in the same direction, unless commanded otherwise, the ISS orbits rather like an aeroplane, keeping its main axis parallel to the local horizon. This is a great advantage for an all-sky monitor since it means that the FOV will automatically scan most of the sky during every 90 minute ISS orbit. The Lobster-ISS web site is to be found at http://www.src.le.ac.uk/lobster.

3. Extreme Universe Space Observatory (EUSO)

EUSO is an ultra-high energy cosmic ray observatory also proposed to fly on the Columbus External Payload Facility on the ISS. EUSO will detect cosmic rays with energies $> 4 \times 10^{19}$ erg by observing the flash of fluorescence light and the reflected Cerenkov light produced when the particles interact with the Earth's atmosphere (Figure 3a). Direct imaging of the light track and its intensity variations will allow the sky position of the event as well as the overall energy to be reconstructed. The origin, nature, method of propagation, and acceleration mechanism of such cosmic rays are all highly uncertain, but almost certainly involve extreme objects such as massive black holes or Gamma-ray bursts, or even more interestingly, imply the presence of new physics.

By looking down from the ISS with a 60° FOV EUSO will detect around 1000 events per year – a factor of around 7 more than the most sensitive planned ground based facility – Auger which is expected to be operational in 2004. Since neutrinos propagate, on average, much deeper into the atmosphere than protons before interacting, EUSO will be able to distinguish between the two types of events by selecting on interaction depth (Figure 3b) opening up the new field of high-energy

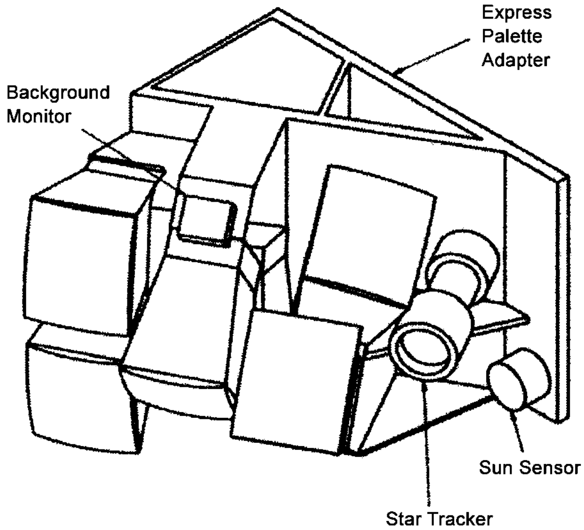

Figure 1. The layout of Lobster-ISS on an Express Pallet Adaptor.

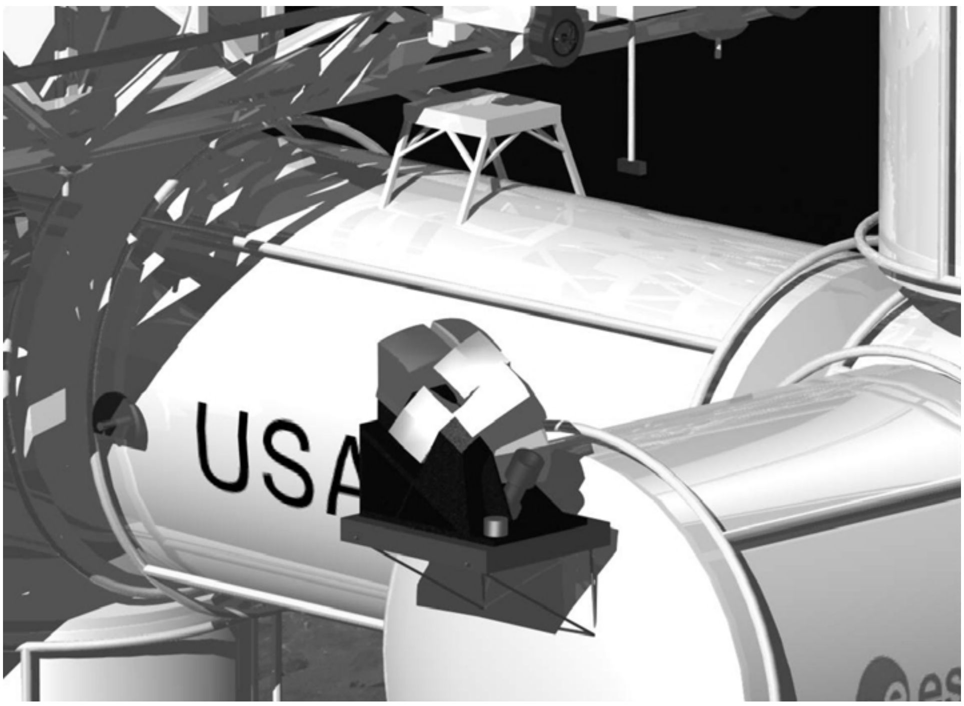

Figure 2. The proposed location of Lobster-ISS on the zenith pointing platform of the Columbus External Payload Facility.

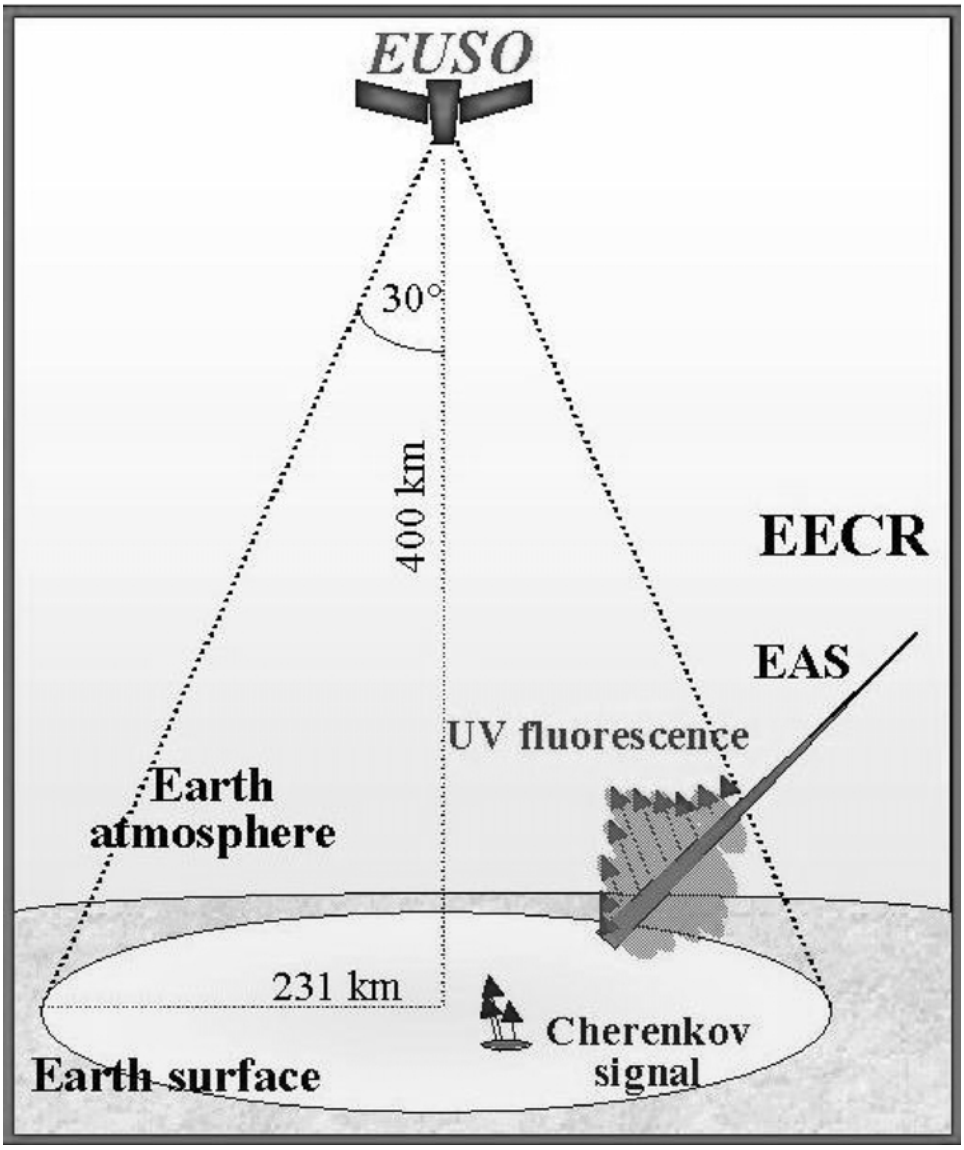

Figure 3a. The method of operation of EUSO. EUSO will look down from the ISS with a 60° FOV and detect the fluorescent and reflected Cerenkov radiation produced when an Extreme Energy Cosmic Ray (EECR) interacts with the Earth's atmosphere.

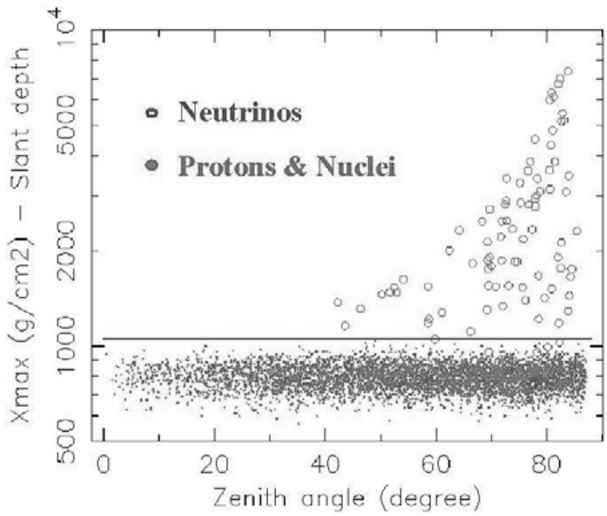

Figure 3b. Cosmic ray shower depth simulations showing how particle and neutrino induced events can be distinguished.

neutrino astronomy. Unlike Lobster-ISS which fits neatly into the ISS standard external accommodation package called an Express Pallet Adaptor which basically provides for about a cubic meter of volume, EUSO is substantially bigger with a 2.5 m diameter cylinder necessary to enclose the double fresnel lens optics and photo-multiplier focal plane. The accommodation of such a large payload on the ISS is currently being studied. A view of what EUSO might look like attached to ESA's Columbus module is shown in Figure 4. More information on EUSO is available on http://www.ifcai.pa.cnr.it/∼EUSO.

4. X-Ray Evolving Universe Spectroscopy Mission (XEUS)

The third high-energy mission under study by ESA that utilizes the ISS is the X-ray Evolving Universe Spectroscopy mission, or XEUS. This mission is under study as part of ESA's long-term Horizon 2000+ science programme. The aim is to place a long lived X-ray observatory in space with a sensitivity comparable to the next generation of ground and space based observatories such as ALMA and NGST (Figure 5). By making full use of the facilities available at the ISS and by ensuring in the design a significant growth and evolution potential, the overall mission lifetime of XEUS could be as long as 25 years.

A key goal of this mission is nothing less than the study of the hot baryons and dark matter at high redshift through spectroscopic investigations of some of the first massive black holes. These are believed to form at redshifts of 10–20 and have X-ray luminosities of around 10^{44} erg s^{-1}. In order to have sufficient sensitivity to derive their masses, spins and redshifts through studies of intensity variability and

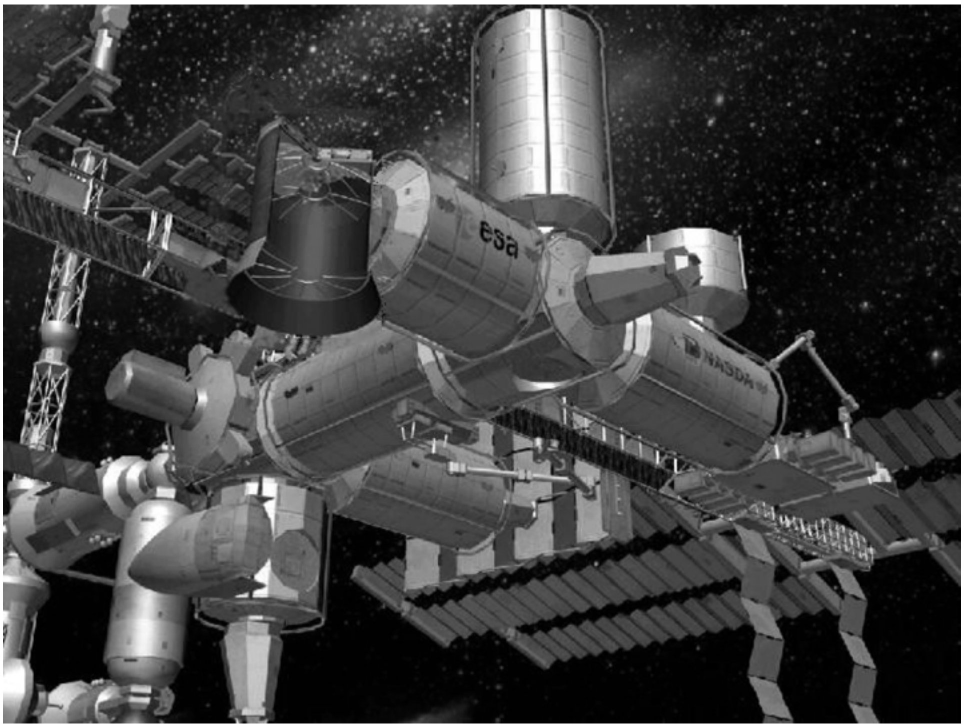

Figure 4. A cut-away of EUSO attached to the Columbus External Payload Facility and viewing towards the ISS nadir.

Fe-K lines broadened by strong gravity effects, XEUS will need a 10 m diameter X-ray mirror with a spatial resolution of 2 to 5 arc second half-energy width. This will provide a limiting 0.1–2.5 keV sensitivity of around 4×10^{-18} erg cm^{-2} s^{-1}.

Other key science goals include (1) the study of the formation of the first gravitationally bound, dark matter dominated, systems, i.e., small groups of galaxies and tracing of their evolution into today's massive clusters. (2) The study of the evolution of metal synthesis down to the present epoch, using in particular, observations of the hot intra-cluster gas and (3) the characterization of the mass, temperature, and density of the intergalactic medium, much of which may be in hot filamentary structures, using absorption line spectroscopy. High redshift luminous quasars and X-ray afterglows of gamma-ray bursts may be used as background sources.

XEUS will be a long-term X-ray observatory consisting of separate detector and mirror spacecraft flying in formation and separated by the 50 m focal length of the optics (Figure 6). XEUS will be launched by an Ariane V and have an initial mirror diameter of 4.5 m, limited by the launch shroud of the rocket. The mirror will be divided into segments, or "petals". Each petal will be individually calibrated and aligned in orbit. Narrow and Wide field imagers will provide FOVs of $1'$ and $5'$, and energy resolutions of 1–2 eV and 50 eV at 1 keV. It is likely that the narrow field imager will be a cryogenic detector such as an array of bolometers or super-

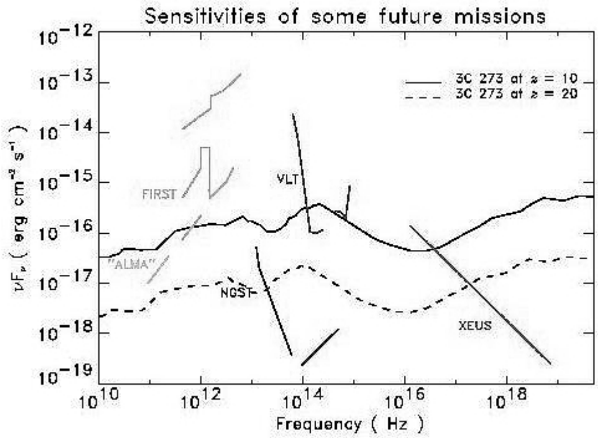

Figure 5. Comparison of the sensitivities of future missions in different wavebands. A horizontal line corresponds to equal power output per decade of frequency. For ALMA an 8 hr integration was assumed, for FIRST a 5σ detection in 1 hr, For NGST a 5σ detection in 10 ks, and for XEUS a 100 ks exposure.

conducting tunneling junctions and the wide field device will be based on more conventional semi-conductor technology. The detector spacecraft will have a sophisticated attitude and orbit control system, maneuvering itself to remain at the focus of the optics. After using most of its fuel the detector spacecraft will dock with the mirror spacecraft and the mated pair will transfer to the same orbit as the ISS. The mirror spacecraft then docks with the ISS and additional mirror segments that have been previously transported to the ISS, are attached around the outside of the spacecraft (Figure 7). This increases the mirror diameter to 10 m and the effective area at 1 keV from 6 m^2 to 30 m^2 (Figure 8). The huge increase in sensitivity that is associated with this expansion at the ISS means that once the mirror spacecraft has left the ISS to be joined by a new detector spacecraft, complete with the latest generation of detectors, the study of the early X-ray Universe can begin in earnest.

Following an initial feasibility study, the many new and challenging technologies that are needed for XEUS are being studied within Europe and Japan. The XEUS web site is at http://astro.esa.int/XEUS. There is great excitement at the prospect of a mission with a sensitivity some 200 times better than that of XMM-Newton, ESA's current X-ray observatory, which is already producing many exciting new results.

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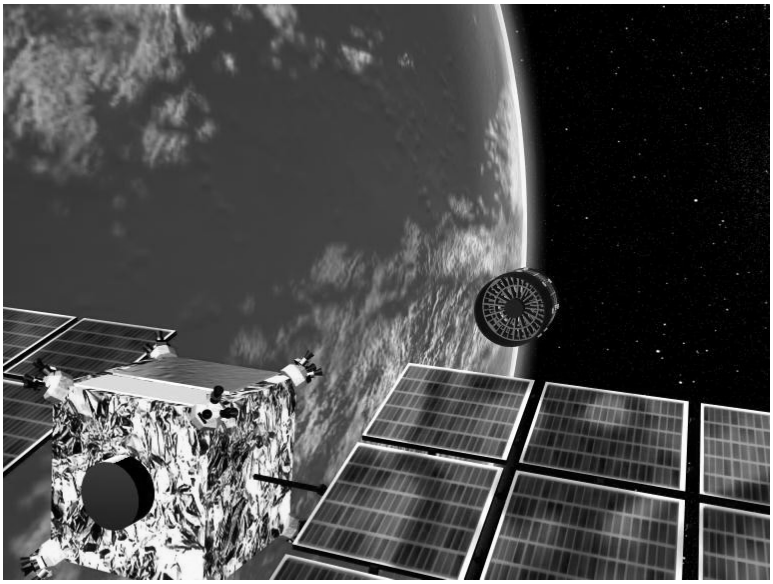

Figure 6. XEUS in its operational configuration. The detector spacecraft (foreground) maintains its position at the focus of the X-ray mirrors 50 m away to within ± 1 mm.

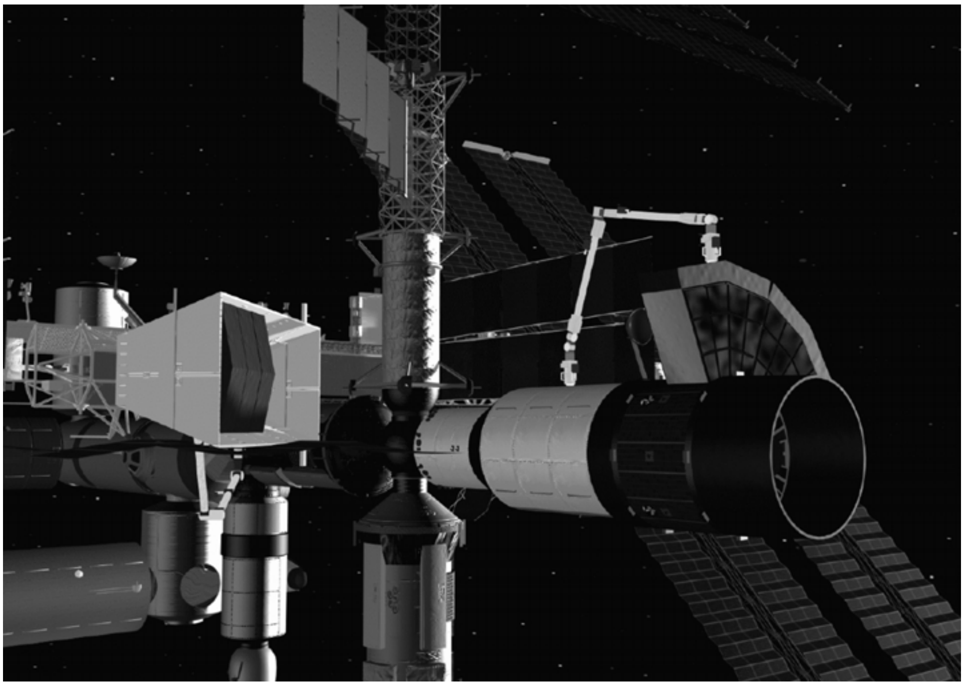

Figure 7. Using the European Robotic Arm, additional mirror segments are added to the XEUS mirror spacecraft. The ISS is the perfect platform, offering the in-orbit infrastructure required to build the world's most powerful X-ray telescope.

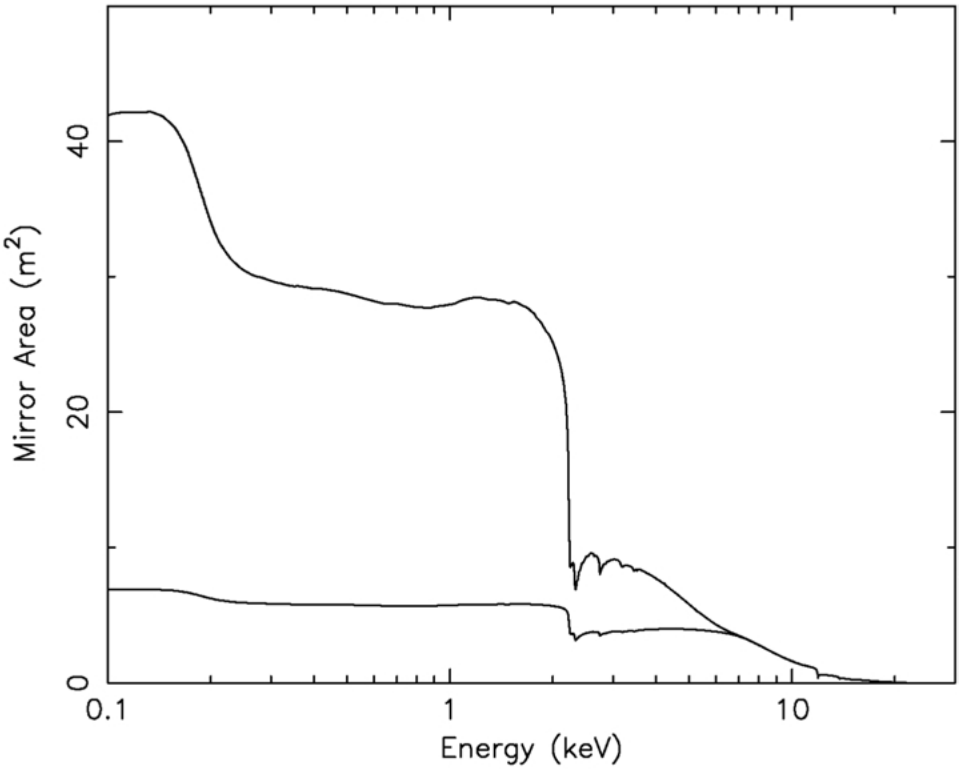

Figure 8. The lower curve shows the initial XEUS mirror area while the upper curve shows the area after growth at the ISS.

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