4.5.1 X-ray Evolving Universe Spectroscopy Mission (XEUS)

Introduction

XEUS, the X-ray Evolving Universe Spectroscopy mission, is a potential follow-on to the XMM cornerstone mission currently nearing completion. XEUS was considered as part of the Horizon 2000+ programme within the context of the International Space Station (ISS) utilisation phase. The original mission concept arose from discussions by Europe's scientific community at an international workshop held at Leicester University (UK) in July 1996. At this workshop, the foundations for the 'Next Generation of X-ray Observatories' was laid. With XMM due for launch in the third quarter of 1999 and a mission duration of 5 years, it is not too early for preliminary considerations of the post-XMM era. Two great X-ray observatories will have embarked on their astrophysics programmes at the turn of the century: XMM and NASA's AXAF, to be followed soon after by Japan's Astro-E mission. The requirements of XEUS thus must take account of the key thrusts and potential discoveries of these powerful missions.

The XEUS mission aims to place a permanent X-ray observatory in space with a telescope aperture equivalent to the largest ground-based optical telescope built to date – essentially the equivalent of the Very Large Telescope for X-ray astronomy. By making full use of the ISS facilities in the next century and by ensuring a significant growth and evolution potential in the design, the overall XEUS mission lifetime could be well over a quarter of a century. The power of this observatory will be such that, for the first time, detailed imaging spectroscopic studies of some of the unresolved issues of high energy astrophysics concerning the evolution of the early Universe will be possible.

XEUS design features

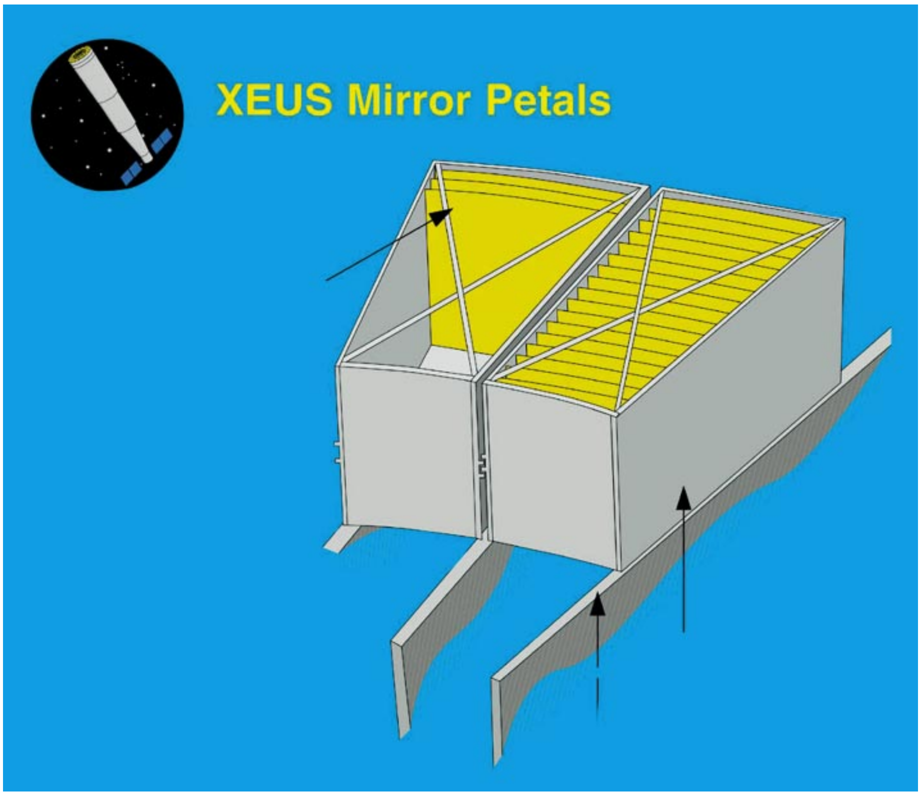
The basic design goals for the XEUS Observatory are summarised in Table 4.5.1.1. It must be stressed that XEUS is in an early phase of study; mission concepts and specifications are therefore preliminary. Clearly, the key characteristic is the large-aperture X-ray mirror. This can be best achieved by capitalising on the successful XMM mirror technology and the industrial foundations that have already been laid in Europe for this programme. The XMM mirror technology has placed European science at the forefront of high-energy astrophysics. Unlike XMM, however, where a heavily nested mirror was fabricated from closed shells, the XEUS mirror aperture of 10 m diameter is divided into annuli, with each annulus subdivided into sectors. The basic mirror unit thus consists of a set of heavily stacked thin mirror plates. This unit is known as a 'mirror petal' and is a complete, free-standing, calibrated part of the

Table 4.5.1.1. The basic design goals of the XEUS Observatory.

Parameter	*Specification (Goal)*
Energy Range (keV)	0.1-20 (0.1-100)
Telescope Focal Length (m)	25-50
Mirror Effective Collecting Area (m^2) @ 1 keV	10 (30)
Mirror Effective Collecting Area (m^2) @ 8 keV	0.8 (3)
Spatial Resolution (arcsec)	5 (1)
Field Of View (arcmin)	10
Energy resolution @ 8 keV (eV)	100 & 10 (wide- & narrow-field detectors)
Energy Resolution @ 1 keV (eV)	40 & 1 (wide- & narrow-field detectors)

For further information, on XEUS, see http://astro.estec.esa.nl/SA-general/Projects/XEUS

Figure 4.5.1.1. A schematic diagram of a pair of XEUS mirror petals before integration into the mirror assembly structure.



overall XEUS optics with a spatial resolution of ~1 arcsec and a broad energy range of 0.1-30 keV. Such a mirror system will provide a dramatic increase in capability over XMM. The required evolution in mirror production technology is being studied. Figure 4.5.1.1 shows the XEUS mirror petal layout.

XEUS mission profile

The XEUS spacecraft consists of the spacecraft bus, focal plane unit, telescope tube and the mirror assembly. Of course, such a large aperture cannot be deployed in a single launch. It is currently envisaged that the ‘zero growth’ XEUS will be launched into a Fellow Traveller Orbit (FTO) to the ISS using an Ariane-5 or similar vehicle. FTO is a low Earth orbit at an altitude of ~350 km and an inclination similar to that of the ISS. The 25-50 m optical bench will be automatically deployed once in orbit. The spacecraft will include an orbital transfer motor that will allow XEUS to be moved to the ISS for expansion and refurbishment work. It must be stressed that XEUS is completely autonomous from the ISS. In its initial launch ‘zero growth’ configuration, XEUS will contain only the two inner annuli of the telescope filled with petals. However, the initial XEUS collecting area is substantial (~5 m^2 at 1 keV), but still has impressive room for growth through use of the ISS. XEUS will, however, be able to start its astrophysics observing programme effectively from day 1 after launch.

It is envisaged that the XEUS optics will be expanded over a period of about a decade by returning to the ISS every 2 years for the insertion of additional mirror petals into the outer annuli of the aperture. This mirror growth phase at the ISS may involve the use of robotics such as the European Robotics Arm for handling petals,

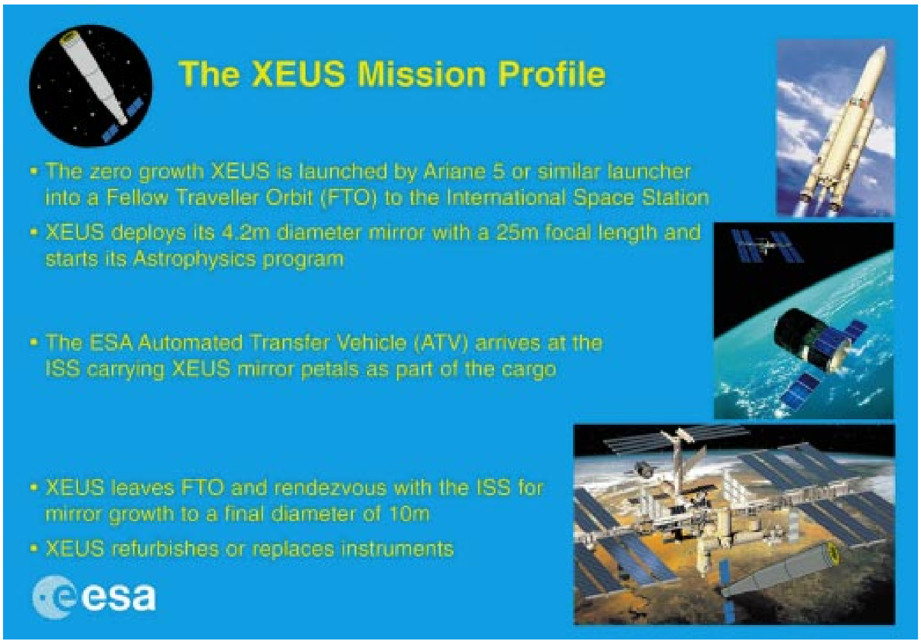


Figure 4.5.1.2. The key facts associated with the XEUS mission profile.

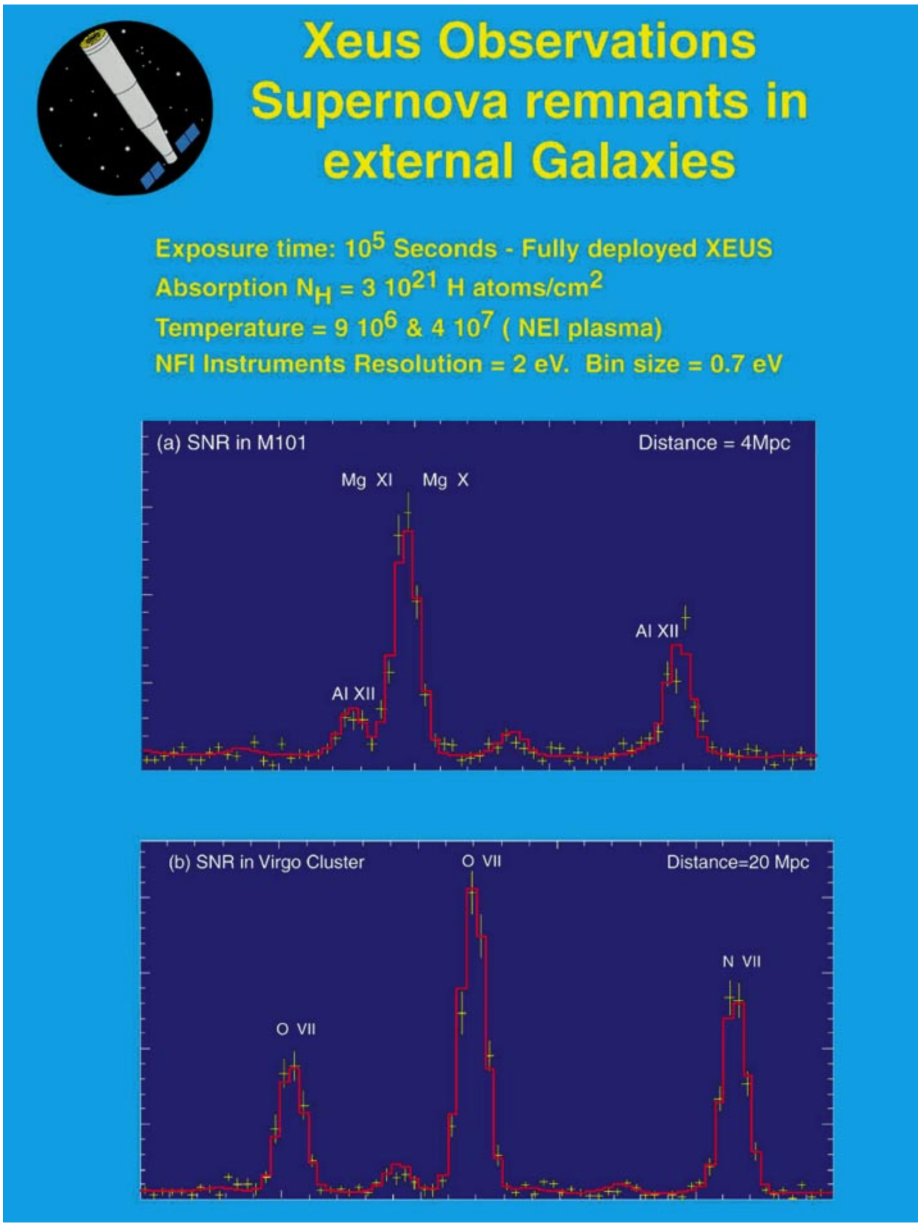
and a limited amount of EVA. Petals will be delivered to the ISS as part of regular cargo, possibly using ESA's Automated Transfer Vehicle (ATV) and stored externally until XEUS leaves FTO for rendezvous with the ISS. At this time, consumables for the focal plane instruments will also be replenished. Instrument replacements are envisaged every 5 years, while the complete spacecraft bus will be designed to be replaced every 7-10 years. After each upgrade, or growing season, at the ISS XEUS will return to FTO where it will continue its astrophysics programme, but each time with an enhanced capability. In this way, high energy astrophysics can achieve a permanent, yet evolving, presence in space deep into the next century. This strategy allows us to take advantage of the key attributes of the ISS as well as ensuring that improved new technology for future mirror petals and focal plane instruments can be incorporated into XEUS. The key features of the mission profile are shown in Figure 4.5.1.2.

A study contract has been placed through ESA's Directorate of Manned Spaceflight and Microgravity to study the feasibility of using the ISS in this role for XEUS, together with the technological problems associated with mirror petal production. The outcome of this study will be a clear demonstration of the use of the ISS to support the building of large-scale structures in space, together with its capability for refurbishing and replenishing large science spacecraft to extend their usefulness well beyond conventional design lives.

XEUS science goals

The XEUS mission will build upon the European leadership in X-ray astronomy that XMM will provide by supplying unique opportunities for studying the distant Universe, hot plasmas, material under extremes of density, temperature and pressure and subjected to the effects of strong gravity. These studies will have implications for the life cycles of matter, the formation and evolution of galaxies and clusters, the evolution of massive black holes in active galactic nuclei (AGN), as well as providing direct tests of general relatively in the strong gravity limit.

Figure 4.5.1.3. Simulations showing XEUS spectra of supernova remnants in the nearby galaxy M101 and in the Virgo cluster. Only small parts of the entire spectra are shown in order to highlight the diagnositic capabilities for the astrophysically important elements Al and Mg (M101) and O and N (Virgo).



Currently, X-ray astronomy can detect only the most luminous of AGN, quasars, to a redshift of about 4. With comparable energy resolution, the sensitivity of XEUS will be dramatically better than provided by the AXAF and XMM dispersive spectrometers. As well as allowing the detection of much more distant objects, XEUS will pioneer the field of detailed X-ray spectroscopy of these distant AGN. As an example, the presence of the ‘double horned’iron line caused by general relativistic effects and Doppler broadening near a massive black hole in a 10^{44} erg/s AGN at a redshift of 3 can be easily detected. Several of these objects are expected in a 100 ks observation and will provide a powerful means of studying the number of massive black holes to redshifts of 3 and beyond.

The XEUS narrow field detectors with their 1-10 eV resolution, 0.1-20 keV energy range and high effective area will revolutionise cosmic high-energy spectroscopy. The X-ray spectrum in this energy range is rich in plasma diagnostics that can provide electron density and temperature and abundance determinations. The ~1 eV energy resolution of the XEUS narrow field detectors below 2 keV will be essential for unravelling the effects of line blending. When this spectral capability is combined with the excellent spatial resolution, the real power of XEUS becomes apparent. Sources as faint as 10^{35} erg/s can be studied in M31, while Doppler variations (~100 km/s) of the Fe line in X-ray binaries will allow masses to be directly measured. Further away, the abundances of elements such as Al and Mg can be measured from observations of supernova remnants (SNRs) in Local Group galaxies. Even at the distance of the Virgo cluster, spatially-resolved spectra of galaxies will allow the temperature and chemical composition of the Interstellar Medium and SNR to be studied.