Scientific Requirements for Extremely Large Telescopes
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Requirements on ELTs from X-ray astronomy

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Abstract. The requirements on ELTs from the perspective of X-ray astronomy are explored. These requirements will be driven largely by deep X-ray surveys, like those conducted with XMM-Newton and the Chandra X-ray Observatory. Up to the present time, ground-based telescopes have largely kept abreast of the needs arising from deep X-ray surveys, i.e. the current generation of 10m-class telescopes is able to (barely) match the required spectroscopic needs for optical identifications in most cases (up to 70%). There are two X-ray astronomy facilities currently proposed and under study: the European-led X-ray Early Universe Spectroscopic mission (XEUS) and the NASA proposal Constellation-X. The emphasis of both these missions, like XMM-Newton, is X-ray spectroscopy, but they will both perform deep surveys which will need optical follow-up spectroscopy towards the middle or end of the next decade.

Keywords. X-rays: galaxies, diffuse background, identifications; Galaxies: active

1. Introduction

Although ELTs will be needed for a host of follow-up studies to observations made with the next generation of X-ray telescopes, the most extreme requirements are those arising from the need to make full spectroscopic identifications of the sources which will be detected in the deep surveys.

Deep surveys in X-ray astronomy had the initial goal of solving the problem of the origin of the extragalactic X-ray background (XRB), and these surveys and their optical follow-up have now shown that the soft XRB (0.5-6 keV) is largely comprised of the evolving populations of AGN, some heavily absorbed (Hasinger *et al.* (2006)). This success has come from the optical spectroscopy performed using the current generation of 10-m class telescopes, in particular the Keck telescopes and the VLT, albeit with a success rate between about 50% and 70% (Brandt & Hasinger (2005)). With the next generation of major X-ray observatories, the scientific emphasis will be on X-ray spectroscopy, targeting all known classes of sources, but there will also be a need for infrared and optical spectroscopy of the sources detected in the deep surveys, where these deep surveys will cover smaller areas than those performed using XMM-Newton and the CXO.

The deep surveys with the Chandra X-ray Observatory (CXO) have shown that normal galaxies are detected in large numbers, in addition to AGN. The survey of the Hubble Deep Field (HDF) North demonstrated that, at flux levels approaching 10^{-16} erg cm^{-2} s^{-1} (0.5 - 2.0 keV), about a third of the X-ray sources were identified with galaxies (Hornschemeier *et al.* (2002), Bauer *et al.* (2004)).

2. The next generation of X-ray observatories

Led by the European Space Agency and in collaboration with the Japanese, the X-ray Early Universe Spectroscopy mission (XEUS) has been studied for several years and has

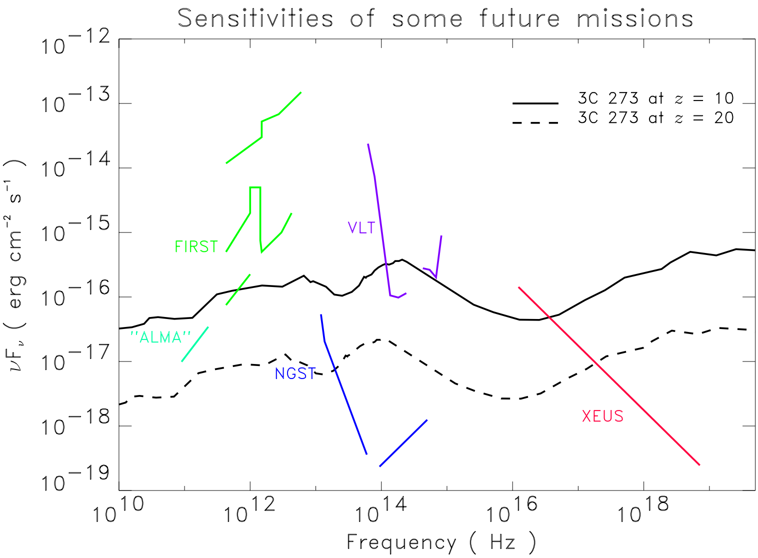

Figure 1. Sensitivities of future facilities, plotted as $\nu f(\nu)$ - from Parmar *et al.* (2004).

already undergone major changes in its proposed configuration. For a summary of the mission as currently proposed, see Bavdaz *et al.* (2005). Studies for this mission have led to a breakthrough in lightweight X-ray optics, using high-precision pore optics developed in the semiconductor industry (Bavdaz *et al.* (2005)). The effective mass per unit area of mirror is a factor of ten lighter than XMM, and a factor of nearly 100 lighter than CXO. The requirement on angular resolution for XEUS will be 5 arcsec (half-power diameter), with a goal of 2 arcsec. The difference between the 'requirement' and the 'goal' on angular resolution will be crucial for the deep surveys, since the uniqueness of optical counterparts will need the goal of 2 arcsec (at $I \sim 30$ there is one object per 3 arcsec^2). Test optics have already reached 5.5 arcsec half-energy width, with a FWHM of 3.1 arcsec. The overall spacecraft configuration for XEUS is a formation-flying mission, with a mirror spacecraft and a detector spacecraft separated by the focal length of 50m. The requirement on effective area is 10m^2 at 1 keV, 2m^2 at 6 keV and 0.3m^2 at 40 keV, with a sensitivity of 4×10^{-18} erg cm^{-2} s^{-1}(0.2 - 10 keV) and a field of view of 7×7 arcmin.

The science goals of Con-X and XEUS are quite similar, with XEUS currently pushing towards higher angular resolution than Con-X. Many of these goals are overlapping or complementary to the primary goals of ELTs as described elsewhere in this volume. The XEUS mission science goals include the following:

Large Scale Structure and Nucleosynthesis

Formation, dynamical and chemical evolution of groups and clusters of galaxies - groups and clusters at high redshift will need spectroscopic confirmation from ELTs (galaxies with $I \sim 25 - 30$).

Baryonic composition of the IGM

Enrichment dynamics: inflow, outflow and mergers

Coeval Growth of Galaxies and Massive Black Holes

Birth and growth of supermassive black holes (SMBH); Galaxy evolution induced by SMBH

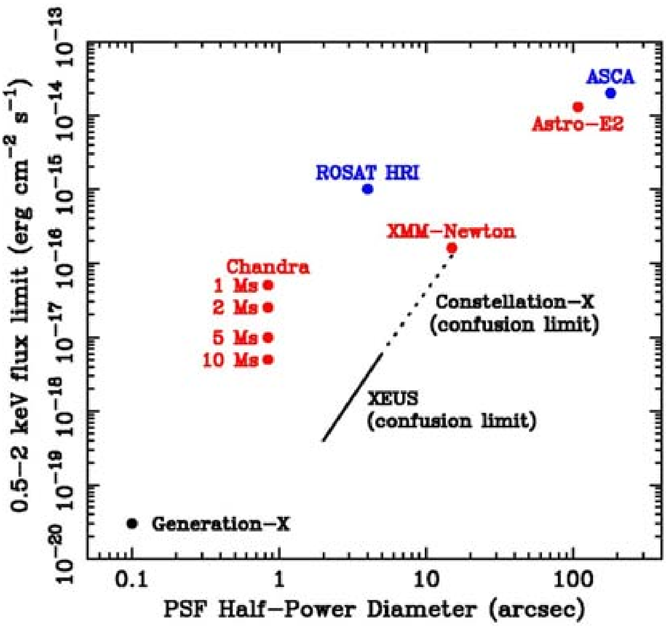

Figure 2. Sensitivities of past, present and future X-ray astronomy facilities, as a function of X-ray mirror HPD, from Brandt & Hasinger (2005).

Matter under extreme conditions:
Gravity in the strong field limit; Equations of state; Acceleration phenomena.

3. Future deep surveys, source counts and optical identifications

What will be the likely identification content and optical magnitudes of the sources that will be detected with the next generation of X-ray facilities? We can obtain a guide to the answer by looking at the identification content of the current deepest X-ray surveys, and extrapolating the results based on our best estimates of the luminosity functions of the source populations (AGN and galaxies) and how they are likely to evolve with redshift.

The X-ray number counts in the HDF-N have been measured by Miyaji & Griffiths (2002), and extended to fluxes below 10^{-17} erg cm^{-2} s^{-1} in the soft band (0.5 - 2 keV) and to 10^{-16} erg cm^{-2} s^{-1} in the hard band (2 - 10 keV) by analysis of the fluctuations which remain after removal of the individual discrete source detections. Below this limit, the fluctuation analysis shows that the number counts continue to rise, as shown in Fig. 3, with a slope consistent with that between 10^{-15} and 10^{-16} erg cm^{-2} s^{-1}. This continued rise in the number counts cannot be due to AGN, and is much more likely due to galaxies. The current best models for the AGN contribution to the number counts fall well below the fluctuations, which show that the number counts are approximately 20 000 – 40 000 per sq. deg. at X-ray fluxes of 10^{-17} erg cm^{-2} s^{-1}. Such number counts match those of the optical counts of galaxies at $B \sim 24$.

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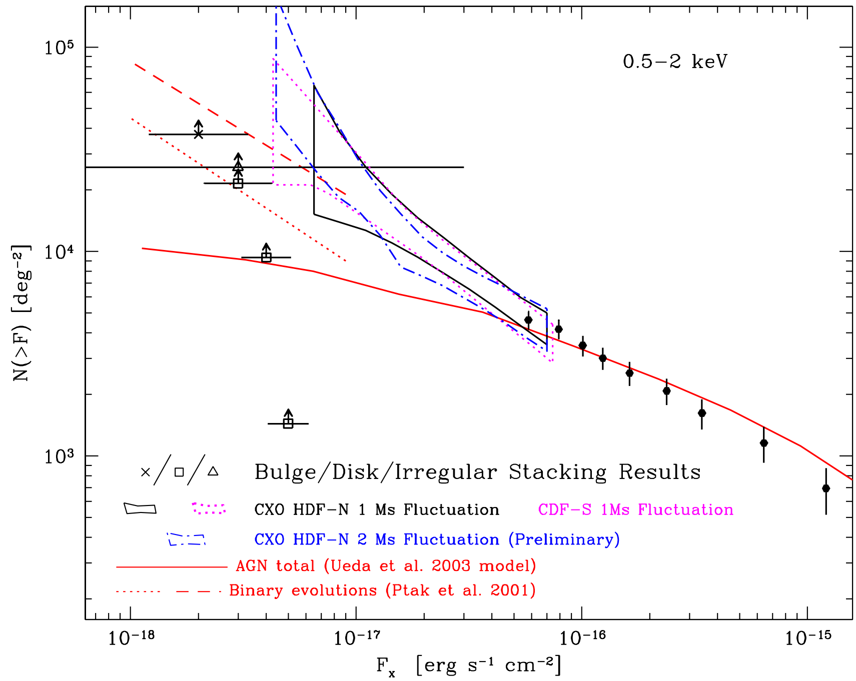

Figure 3. X-ray Number Counts from the Hubble/Chandra Deep Field North. The 1 Ms "fish–tail" fluctuation limits are from Miyaji & Griffiths (2002), and similar results were found from the HDF-S. Fluctuation limits from the 2Ms CDF-N are preliminary and possibly contaminated by cosmic-ray background events. Points showing stacked galaxies of different morphological types are all lower limits - stacking was done on optical galaxies in the HDF-N and the data points represent the average fluxes of the stacked galaxies. For any given morphological type, it is unlikely, however, that the number counts due to them are much higher than those shown here, unless contaminated by AGN. The prediction of AGN number counts is from Ueda *et al.* (2003). An estimate of the number counts from X-ray binary populations in normal galaxies was made by Ptak *et al.* (2001).

4. Conclusions

Based on the optical identification content of the CXO and XMM deep surveys, we are in a good position to extrapolate to the projected optical identifications in the deep surveys with the next generation of X-ray telescopes. Approaching X-ray fluxes of 10^{-18} erg $cm^{-2}\,s^{-1}$, these counterparts will be in the range $I \sim 28-30$. The angular resolution of the XEUS observatory will need to achieve the goal of 2 arcsec. in order to reduce the ambiguity in these identifications. The requirement on the ELTs will then be the moderate-resolution spectroscopy of the optical candidates at $I \sim 25-30$.

5. Acknowledgements

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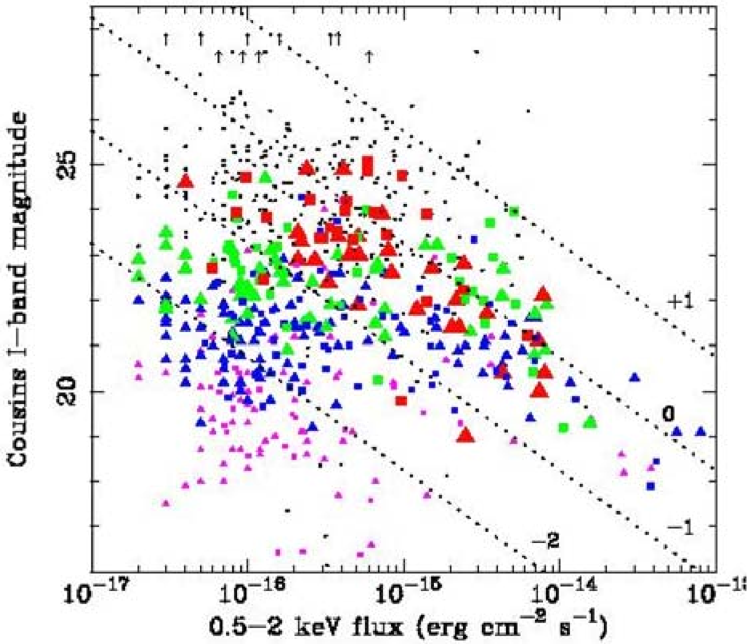

Figure 4. Optical identifications of X-ray sources in deep surveys, from Brandt & Hasinger (2005). f_x/f_{opt} for these sources is noted in the diagonal lines, with sources of extreme X-ray brightness at the top of the figure, normal galaxies at the bottom, and AGN in between. Colour coding is in broad redshift bands from 0-0.5 (violet, lower) through 0.5-1.0 (blue), 1.0-2.0 (green) and 2-6 (red). Spectroscopy is still lacking for the black points at the top.

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6. Discussion

Bergeron: An angular resolution of 5 arcsec will result in multiple optical counterparts to the sources in deep surveys

Griffiths: It will be crucial to reach the *goal* on angular resolution of 2", rather than the basic requirement of 5". Accuracy of centroid determination will be several times smaller than the HPD. Optical IDs. will be further aided by multiple-object spectroscopy.

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