An XMM EPIC Slew Survey: feasibility & science goals

L.R. Jones
Birmingham University

D. Lumb
ESTEC

ABSTRACT

An XMM EPIC slew survey would detect several thousand AGN and clusters of galaxies, including absorbed AGN and extreme or rare objects (e.g. blazars & high redshift objects), as well as absorbed Galactic sources. The flux & sky area combination would be very different from XMM pointed observation serendipitous surveys, probing a complementary range of source luminosities and redshifts.

1. Motivation

AXAF and XMM deep and serendipitous surveys will give an unprecedented coverage of faint source populations, reaching eg. QSOs up to redshifts of z=4-6 and with a sufficiently broad bandpass to include absorbed sources (eg. type II QSOs) for the first time. However, there is a severe danger that in 2-3 years time we will understand the faint source populations better than the bright source populations, especially in the relatively unexplored 2-10 keV band, where only the brightest few hundred sources over the whole sky were detected by early surveys (eg. Ariel V, Uhuru). An XMM slew survey would provide the coverage of thousands of fainter (but still moderately bright) sources necessary to understand the evolution of the source populations as a whole, over many decades of luminosity and probing the majority of the history of the Universe. The XMM slew survey would cover a large fraction of the sky, with excellent sensitivity a factor $\sim$10 better than the ROSAT all-sky survey, and at energies up to 10 keV. Possible studies include:

- X-ray evolution of those clusters of galaxies most sensitive to cosmological model parameters: high X-ray luminosity clusters at very high redshift ($z\approx1$).
- X-ray QSO/AGN evolution, including absorbed and unabsorbed AGN, and their contribution to the X-ray background.
- Definition of a large, unbiased and complete sample of AGN from which to measure evolution of source spectra and intrinsic absorption with follow-up XMM & AXAF observations.
- Discovery of bright absorbed and rare sources for multi-wavelength follow up observations.
- Galactic sources eg. transients, absorbed X-ray binaries & SNRs

2. Predicted flux limits

For a point source at a typical off-axis angle of 7.5 arcmin, the EPIC exposure time will be ≈80 s, and the vignetting factor compared to on-axis will be ≈0.7. Combining the 3 EPIC cameras, a source of flux 2x10^{-13} erg cm^{-2} s^{-1} (0.5-2 keV) will give 16 counts (0.5-2 keV) compared with 2 total background counts (0.5-2 keV) in a cell of radius 1 arcmin. A background of 3.4 ct/s (0.5-2 keV) in the pn camera and a source spectrum of a power law of photon index 2 and N_H=3x10^{20} cm^{-2} has been assumed.

In the 2-10 keV band, a source with the same spectrum and a flux of 1.5x10^{-12} erg cm^{-2} s^{-1} (2-10 keV) will give 16 counts (2-10 keV) compared with 1 total background count (2-10 keV) in a cell of radius 1 arcmin.

3. Predicted source numbers

The precise rate at which the sky will be surveyed is somewhat uncertain. Assuming that 10% of the observatory time is spent slewing, 830 hours of slew observations will be made per year, covering 8300 deg^2 (less if slews overlap). An alternative calculation assumes a mean pointed exposure length of 20 ksec and 70% observing efficiency, giving ≈1000 observations per year. If the average slew length between observations is 20 deg, then 10,000 deg^2 will be covered per year (the EPIC field of view diameter is 0.5 deg). An alternative estimate can be made from the parameters of the *Einstein* Observatory slew survey (Elvis et al 1992). The *Einstein* slew survey covered 35,000 deg^2 using 2800 slews and a total slew exposure time of 10^6 s during the satellite lifetime of ≈3 years, or 11,600 deg^2 per year. The *Einstein* IPC had a field of view twice the size of the XMM EPIC camera, so if XMM follows the same observing pattern as *Einstein*, ≈6000 deg^2 will be covered per year.

In reality there will be considerable overlap between slews because the satellite rotates along lines of constant ecliptic longitude, keeping the solar panels pointed toward the sun. Thus the ecliptic poles will receive extra exposure, as will the areas near calibration sources. There will be a distribution of areas with differing flux limits; for our purposes we take a conservative estimate of 4000 deg^2 per year at 2x10^{-13} erg cm^{-2} s^{-1}.

For this sky area of 8000 deg^2 in the first 2 years of the mission, the total number of sources above 4σ significance in the 0.5-2 keV band is given in the table below, including the influence of the effective psf size.

PSF size $\sigma_{eff}(arcsec)$	f_{lim} (0.5-2 keV)	No. sources	No. unrelated optical counterparts per error circle (R<21 mag)
10	2x10^{-13}	7200	0.16
20	2x10^{-13}	7200	0.64
60	2x10^{-13}	7200	5.8
120	2.8x10^{-13}	4000	23
300	3.9x10^{-13}	2400	140

Since the cosmic & particle backgrounds are expected to be negligible, the limiting source flux is nearly independent of the effective psf size for σ_{eff} <2 arcmin.

There are, however, at least two crucial arguments in favour of minimizing the effective psf below 2 arcmin:

a) In order to resolve distant clusters of galaxies, a FWHM < 40 arcsec (or σ_{eff} <17 arcsec) is required (from experience with ROSAT PSPC surveys). Since optical spectral identification of all slew survey sources is unlikely, given restrictions on optical telescope time, the ability to distinguish clusters via their X-ray extent is crucial.

b) In order to optically identify *any* of the slew survey sources reliably and quickly, an error circle containing <3 possible optical counterparts of R<21 mag (e.g. on POSS-II/UKST plates) is required. This requirement gives σ_{eff} <30 arcsec for extragalactic error circles, as listed above, and a smaller value will be required for the more crowded Galactic error circles. The limit of R<21 arises because although most AGN are predicted to have counterparts of 17<R<20 (eg. Maccacaro et al 1988), distant clusters at z>0.4 will have R>20.

4. Numbers of different source classes

Of the 7200 sources in total, the number of AGN predicted is 3600 (using the LogN-LogS relation of Page et al 1997) and the number of clusters of galaxies is 2500 (using the LogN-LogS relation of Jones et al 1998). The number of clusters of galaxies with measurable source extensions will be less than this (∼1900) if, in practice, a 6σ significance source detection is required to detect source extension rather than the 4σ significance required to measure a source flux.

For clusters, a vital regime (the only one where evolution of the cluster X-ray luminosity function has been observed) is moderate to high redshifts (z$\gtrsim$0.35) and high luminosities L_X > 5x10^{44} erg s^{-1} (Henry et al 1992). This cosmologically important observation remains unconfirmed because no other survey has had the necessary combination of survey area and depth to provide a test. Of the 1900 slew survey clusters, 400 are predicted to lie at z>0.3, 110 at z>0.5, and 36 at z>0.7 (using the local luminosity function of Ebeling et al 1997 and assuming

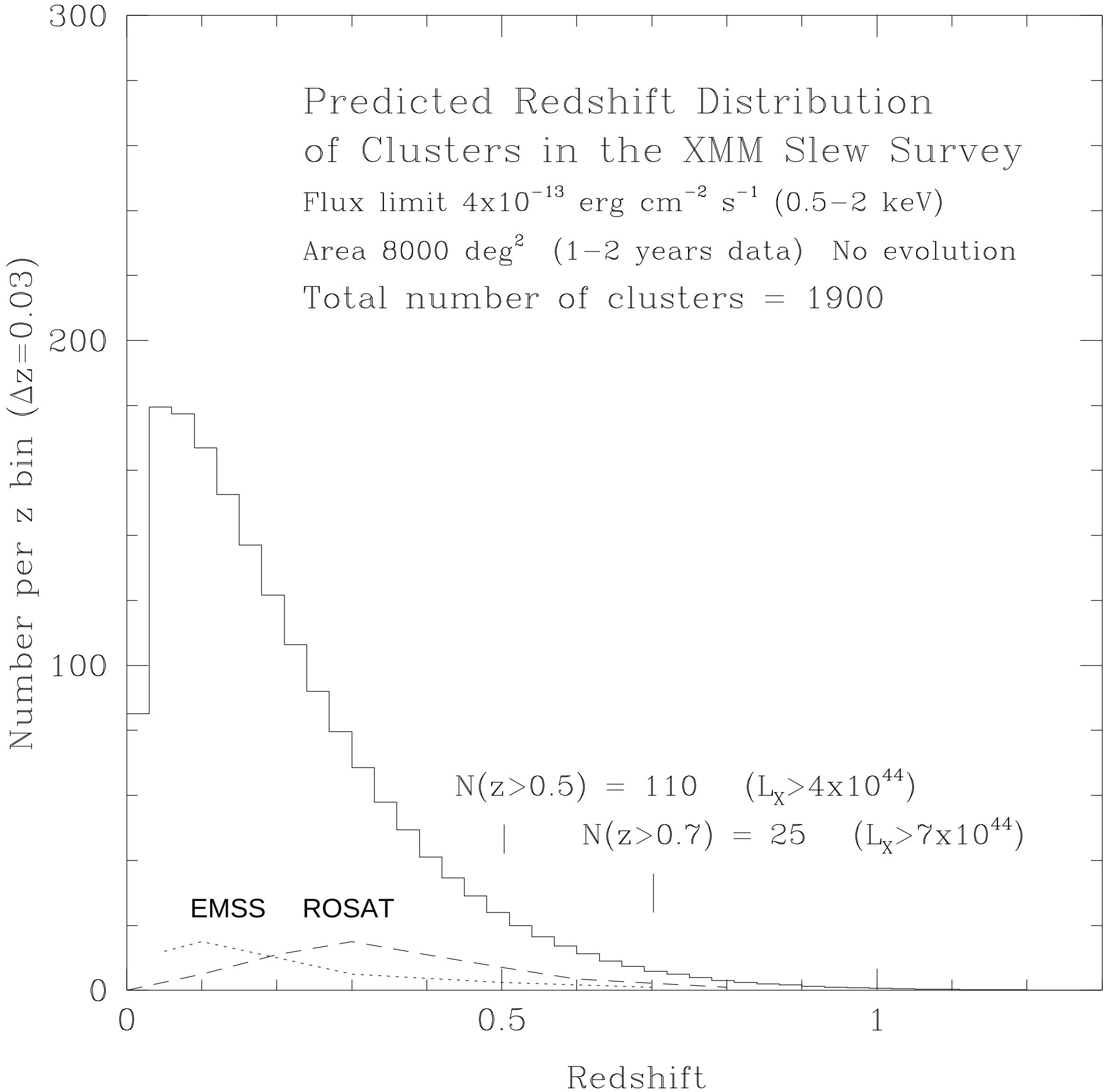

Fig. 1.— Predicted redshift distribution of EPIC Slew Survey clusters of galaxies. All the clusters at high redshifts will be (by design) of high luminosity & will therefore produce strong cosmological constraints. Approximations to the Einstein EMSS and current deep ROSAT cluster surveys are also shown

no evolution). All the clusters at z>0.7 will have high luminosity (L_X >7x10^{44} erg s^{-1}). For comparison, the current number of X-ray selected clusters (and therefore suitable for statistical studies) at z>0.7, is <10, and only 2-3 are of high luminosity.

In the 2-10 keV band, the total number of slew sources predicted is 2000, assuming the 2-10 keV LogN-LogS relation has an amplitude twice that of the scaled 0.5-2 keV LogN-LogS relation (where the scaling assumes unabsorbed sources). This assumption is consistent with recent ASCA deep survey results. The breakdown into source classes is unknown, but many of the sources detected in the 2-10 keV band will be absorbed AGN (e.g. Sy2s with $N_H \gtrsim 10^{23}$ cm^{-2}) which are undetectable at softer energies.

5. Comparison with previous & future surveys

The Einstein EMSS survey is the most closely related to the XMM slew survey. The EMSS covered 780 deg^2 at bright fluxes >2x10^{-12} erg cm^{-2} s^{-1} (converting to the 0.5-2 keV band), and covered 300 deg^2 at the XMM slew survey flux limit of 2x10^{-13} erg cm^{-2} s^{-1}. The EMSS contains 427 AGN and 100 clusters, but only 5 of the clusters are at z>0.5. The EMSS had no sensitivity at energies >4 keV.

The XMM slew survey will reach a limiting flux a factor of ≈10 fainter than the ROSAT All-Sky Survey. In addition XMM probes to higher energies, detecting absorbed sources, with improved spatial resolution.

The XMM slew survey limiting flux is very similar to that expected with ABRIXAS (launch 1999). Despite the survey area being less here, since ABRIXAS will perform an all-sky survey, an XMM slew survey is competitive with ABRIXAS since many of the science goals do not require all-sky coverage.

6. Issues affecting the effective point spread function

The intrinsic psf will be smeared by the satellite slew during CCD readout and by the accuracy of the attitude reconstruction from star tracker data.

1.) The CCD readout time is 70ms for the pn CCDs, so the image smearing can be ignored. For the MOS CCDs, the readout time is 2.5s, corresponding to 50 arcsec end-to-end displacement (or ≈11 arcsec one sigma radius). Thus for maximum spatial resolution, at the expense of sensitivity, the pn CCD data could be used alone.

2.) The accuracy of the attitude reconstruction from star tracker data during slews is expected to be between 10 arcsec and 1 arcmin. The effect of different attitude accuracy values is discussed above. The star tracker field of view is 3.1^ox4.1^o, enough so that a star brighter than the limit of

V=8.5 mag is always present. The XMM star tracker system is very similar to that used on eg. ISO and is designed (and has been sucessfully tested) to provide (a) $\approx$2 arcsec accuracy during pointed observations and (b) <10 arcsec accuracy for stars of V=8.5 mag moving through the field of view at rates faster than the expected XMM slew rate. The star tracker CCD integration time of 0.5s implies movement of 10 arcsec during the integration; given the pixel size of 40 arcsec and a 3x3 pixel star window, the the star centroiding will be degraded by <5 arcsec. The limiting magnitude during slews will also be largely unaffected.

7. The *Einstein* Slew Survey

Although successfully used to detect rare sources (e.g. BLLacs), the *Einstein* slew survey has not produced, for example, large numbers of luminosity functions. Any future slew survey needs to learn from this experience. The major problems encountered in the *Einstein* slew survey were: Eddington bias in the flux measurements due to the small number of photons ($\approx$8) contributing to each source detection (requiring Monte-Carlo simulations to define the source detection criteria); a highly non-uniform exposure map due to the IPC rib support shadows, vignetting and high satellite acceleration at the ends of slews; and finding an accurate satellite attitude solution from gyro data.

Eddington bias can be avoided by only using source detections with >16 photon detections for statistical studies of source populations. XMM has a lower slew rate than *Einstein* and EPIC has no obstructions in its field of view, so the exposure map will be more uniform. Finally, use of star tracker data will give an accurate attitude solution.

8. Acknowledgements

Technical help from Anders Elfving (ESTEC) & M. Watson (Leicester).

9. References

Elvis, M. et al 1992 ApJS, 80, 257.
Hasinger, G. & Brunner H., 1996, SSC-AIP-TN-0002.
Maccacaro, T. et al 1998, ApJ 326, 680.
Page, M., et al 1997, MNRAS 291, 324.
Jones et al 1998, ApJ 495, 100..