THE X-RAY BACKGROUND

G. HASINGER
Astrophysikalisches Institut Potsdam
An der Sternwarte 16, 14482 Potsdam, Germany
& Universität Potsdam
Am Neuen Palais 10, 14469 Potsdam, Germany

Abstract.
The recent progress in the measurement and understanding of the X-ray background is reviewd here. Particular emphasis is put on a discussion of the partially discrepant measurement of the X-ray background spectrum in the 0.5-3 keV range. New and important constraints on large scale structure are obtained from measurements of the smoothness of the XRB. Recently the first discovery of a signal in the angular correlation function of the XRB could be announced. Finally, various X-ray surveys and their identification content is summarized. The role of optically inactive galaxies as a major contributor to the faint X-ray source population which might produce a substantial fraction of the XRB is clarified.

1. Introduction

The X-ray background (XRB), discovered as the first cosmic background radiation (Giacconi et al., 1962) well in advance of the Cosmic Microwave Background (CMB), presented one of the long-standing puzzles of modern astrophysics. At higher energies and on scales larger than about 10 degrees its celestial distribution is very isotropic, apart from a weak dipole anisotropy (Shafer & Fabian, 1987), indicating its cosmological origin. Major steps have been taken in the past few years towards an understanding of its nature. Originally the XRB spectrum in the range 3-40 keV, which resembles very closely a thermal bremsstrahlung model with a temperature of $\sim 40\ keV$ (Marshall et al., 1980) led the way to an interpretation in terms of a hot, diffuse intergalactic medium. Such a truly diffuse hot

M. Kafatos and Y. Kondo (eds.), Examining the Big Bang and Diffuse Background Radiations, 245–262.

plasma would, however, produce a severe Compton distortion on the CMB spectrum, which has not been observed by the COBE satellite (Mather et al., 1990). This puts stringent constraints on the fraction of the XRB originating from hot gas and leaves the alternative interpretation of the XRB in terms of discrete sources the only feasible one. Nevertheless, the existence of cooler and/or significantly clumped hot plasma has not been ruled out by the COBE measurements.

At higher X-ray and soft gamma-ray energies (above 4 keV) measurements until recently have been performed only using collimated X-ray detectors with relatively coarse angular resolution (degrees). Consequently, while these measurements yielded very reliable estimates of the intensity and shape of the **total** X-ray background, they were only able to resolve a small fraction ($\sim$ 3%) of the XRB into discrete sources. The situation in the soft X-ray band (0.1-3 keV), where grazing incidence focussing optics can be used, is diametrically opposite. Due to the high sensitivity and angular resolution (below 1 arcmin) a substantial fraction of the X-ray background could already be resolved into discrete sources here. Deep surveys with the ROSAT satellite were able to resolve about 60% of the 1-2 keV background into discrete sources amounting to a surface density of $> 400\ deg^{-2}$ at a flux of $2.5 \cdot 10^{-15}\ erg\ cm^{-2}\ s^{-1}$ (Hasinger et al., 1993). Direct optical follow-up studies could identify a substantial fraction of these objects as active galactic nuclei (QSOs and Seyfert galaxies, see e.g. Georgantopoulos et al., 1995 and references therein). However, for several reasons the total extragalactic X-ray background in this energy range is very hard to measure, so that its detailed shape and intensity are still a matter of debate (see below).

While the explanation of the X-ray background in terms of the summed X-ray emission of discrete objects (e.g. AGN), integrated in Olber's sense over cosmic distance and time, is a very attractive one (see eg. Setti & Woltjer, 1989), there were two puzzles in recent years which made this interpretation questionable, in particular in the hard X-ray band: the first one is the "spectral paradox", i.e. the fact that no single class of objects known so far has a spectrum resembling that of the XRB (e.g. Boldt, 1987). The second one is the "logN-logS" paradox, i.e. the fact that fluctuation analyses in the "hard" (2-10 keV) band indicate a surface density of objects a factor of 2-3 higher than that in the "soft" (0.5-2 keV) band (e.g. Mushotzky 1992). Another complication is, that the number counts of the faintest objects in the ROSAT deep surveys exceed the predictions from the most recent determination of the AGN X-ray luminosity function (Boyle et al., 1993) by about a factor of two (Hasinger et al., 1993), so that the possibility of a "new class of sources" had to be invoked.

However, a better understanding of the various classes of active galactic nuclei in terms of the "Unified Model", where differences between the classes are mainly due to orientation effects (e.g. Antonucci 1993) has shed new light on these questions. Recent detailed spectral observations of bright, nearby AGN in the X-ray and soft gamma-ray band, as well as ROSAT deep surveys have now obtained new ingredients that led the way to a solution of the two puzzles above in a complete and self-consistent way, assuming only known objects with measured properties (see e.g. Matt, 1994; Comastri et al, 1995; Setti, this volume)

In this *review* I summarize the most recent observations of the X-ray background and what we know about its constituents. I start with a discussion of the spectrum and angular correlation function of the XRB, then I summarize the major soft X-ray surveys and follow-up optical identifications. Finally I shortly discuss the new theoretical models for the X-ray background (this is the topic of the accompanying paper by Setti) and the role of galaxies which seem to become more and more important at fainter X-ray fluxes. At this location I want to thank my collaborators in quite a number of projects for the fruitful cooperation over many years and the permission to show some new material in advance of publication (representative for many more): R. Bower, R. Burg, R. Ellis, R. Giacconi, K. Mason, R. McMahon, M. Schmidt, A. Soltan, J. Trümper, G. Zamorani.

2. The Spectrum of the X-ray Background

2.1. THE HARD X-RAY BACKGROUND

The spectrum of the XRB actually extends over an energy range of more than 4 decades, from soft X-rays to low-energy gamma rays as can be seen in figure 1. In the 3-10 keV band it is largely isotropic, indicating an extragalactic origin. Above 3 keV, the large (and sometimes quite discrepant) variety of "historical" balloon- and satellite-based measurements with collimated proportional counters and scintillators as well as Compton telescopes has been summarized by Gruber (1992) by fitting a simple analytical form to the best available data. In the 2-10 keV band (HEAO-1 A2 data) this spectrum can be well approximated by a power law with an energy index of -0.4 and a normalization of 8 $keV\ cm^{-2}\ s^{-1}\ sr^{-1}\ kev^{-1}$ (Marshall et al, 1980). I would, however, like to caution that an independent measurement of the 2-6 keV background by the Wisconsin group yields a normalization which is almost 40% higher (11 in the above units; McCammon & Sanders 1990).

2.2. THE SOFT X-RAY BACKGROUND

In soft X-rays the situation is much more complex. Here the first reliable measurements of the celestial distribution, intensity and spectral shape of

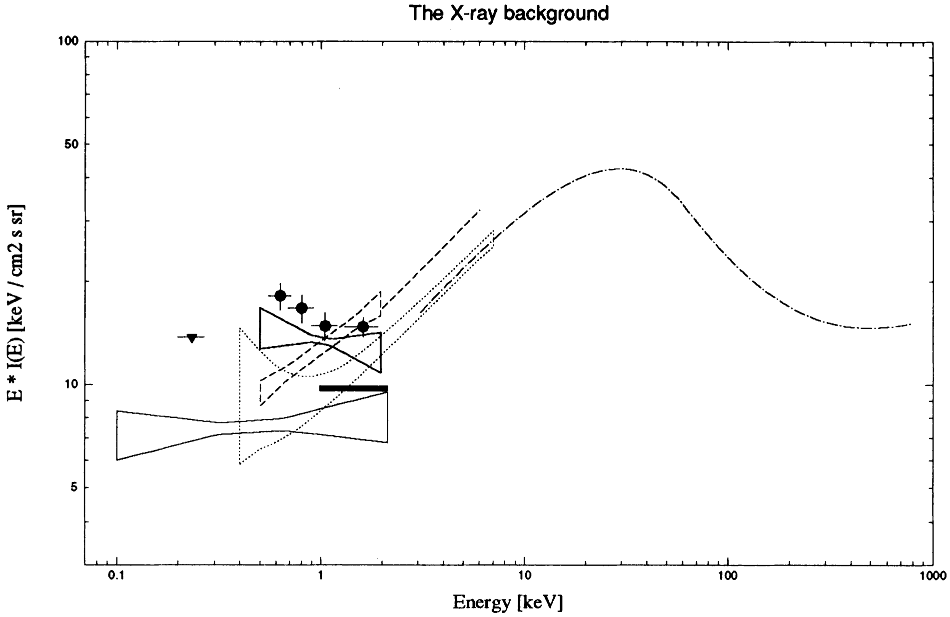

Figure 1. Measurements of the X-ray background spectrum in the energy range 0.1 keV to 1 MeV. The dash-dotted line at high energies gives the analytical representation by Gruber (1992). The trumpet-shaped dotted region refers to the ASCA measurement (Gendreau et al., 1994). The solid and dashed bow-tie shapes in the range 0.5-2 keV represent the ROSAT total background measurements (extragalactic power law component only) by Hasinger (1992) and Georgantopoulos et al. (1994). Filled symbols and the dashed line are from the Wisconsin data (McCammon & Sanders 1990 (see text). The long bow-tie shape in the 0.1-2 keV band is the spectrum of the resolved sources in the deepest ROSAT field; the thick solid line refers to the minimum resolved flux including fluctuations (Hasinger et al., 1993)

the X-ray background have been obtained by the University of Wisconsin in a series of sounding rocket flights using scanning collimated proportional counters (see McCammon & Sanders 1990). The Wisconsin results have been basically confirmed by the ROSAT all-sky survey both in celestial distribution and intensity (to about 10%), however, at dramatically improved angular resolution (Snowden et al., 1994). In all-sky maps below 2 keV there is a substantial variation in galactic coordinates with several discrete diffuse emission features clearly visible (mostly supernova remnants, including the dominant emission from Loop-I). Interstellar hydrogen absorption is also very important in this band, so that the combination of galactic emission and absorption severely complicates the determination of a true extragalactic XRB spectrum. Figure 1 shows a comparison of various X-ray background measurements.

2.2.1. *The C-band background: a "soft thermal component"*

The softest X-ray energy band, the "C-band" below the carbon edge at 0.28 keV, shows the emission of the million-degree hot local bubble (most likely the remnant of the supernova explosion from which the Geminga pulsar originated, see Gehrels & Chen, 1993). This "soft thermal" component is completely dominating the extragalactic light, which is in addition severely attenuated by interstellar absorption. The only chance to get a handle on the extragalactic XRB is by shadowing experiments using extragalactic absorbers. Shadow experiments have been performed by the Wisconsin group using the Small Magellanic Clouds (McCammon & Sanders 1990) and with ROSAT by Barber & Warwick (1994), using other nearby galaxies. The upper limits on the extragalactic background light derived from a lack of any detectable shadow are consistent between the two groups (see upper limit in fig. 1). On the other hand, a substantial fraction of the C-band background ($\sim$ 12%) has already been resolved into - mainly extragalactic - discrete sources, so that a firm lower limit for the extragalactic background can be established (see Hasinger et al., 1993, Snowden et al., 1994, fig. 1).

2.2.2. *The 0.5–2 keV background: a "hard thermal component"*

Between 0.5 and 2 keV, at galactic latitudes above 20^o and outside major diffuse and point-like emission features, the XRB is largely isotropic. The "error bars" for the Wisconsin data above 0.5 keV (see figure 1) show the extremely small variation with galactic latitude (of order 10%), indicating that this background might be dominated by extragalactic emission.

Significant line emission by ionized oxygen (OVII at 0.574 keV and OVIII at 0.650 keV), indicating the existence of 2-3 million degree plasma even outside the region of Loop-I has been inferred from early rocket flights (Inoue et al., 1980, Rocchia et al., 1984). This "hard thermal" component on top of any reasonable extrapolation of the high-energy extragalactic power law (see above) has been confirmed by the analysis of many high-latitude ROSAT PSPC pointings across the sky (Hasinger 1992, Wang & McCray 1993, Georgantopoulos et al., 1995). Fitting an optically thin Raymond and Smith spectral model to the ROSAT data, the temperature of this component can be determined surprisingly accurately to 0.15-0.20 keV, despite the relatively coarse PSPC energy resolution and despite known systematic uncertainties of ±3% in the wavelength calibration of the PSPC. (However, one has to carefully select time intervals which are not contaminated by the monochromatic geocoronal oxygen emission line at 0.54 keV on the dayside of the satellite orbit!).

This hard thermal component may represent the hot intracluster gas in the local group of galaxies (Wang & McCray, 1993), similar to the intrgalactic medium that has been detected using ROSAT in several other nearby groups of galaxies, e.g. NGC 2300 (Mulchaey et al., 1993) or HCG 62 (Ponman et al., 1993). Recent ASCA SIS observations of the XRB with high energy resolution confirm the presence and the temperature of the hard thermal component (Gendreau et al., 1994). Unfortunately the dominant oxygen emission lines are not directly visible in the data, otherwise constraints could be put on the redshift of this plasma.

2.2.3. *The 0.5–2 keV background: the power law component"*

Folding the hard thermal component through the ROSAT PSPC response matrix one finds, that it becomes negligible compared to the extrapolation of the high-energy power law for pulseheight channels above $\sim 0.9keV$. This means that at 1 keV, where the effective area of ROSAT is highest, the flux of the extragalactic power law component can be determined quite accurately (within the systematic error of the absolute normalization of $\sim$ 15%). This is confirmed by a direct comparison with the Wisconsin data (see figure 1).

At the highest energies accessible to ROSAT ($\sim 2.5keV$), on the other hand, the quality of the PSPC spectra becomes comparatively poor, due to statistical and systematic errors. Because of the exponentially diminishing mirror reflectivity at higher energies the sky spectrum drops radically above 1.5 keV and the particle background becomes important. Systematic uncertainties in the subtraction of the particle background (Plucinsky et al., 1993) and in the wavelength calibration transform into a flux error of about 30% (a rough estimate) at 2 keV. Because of the very small spectral lever arm (0.9-2 keV), the slope of the extragalactic power law component cannot be determined to better than 0.2. Early estimates of the extragalactic soft X-ray background spectrum using the IPC aboard the Einstein observatory (Wu et al., 1991), with much higher particle background and less energy resolution, which did not take the galactic forground into account, have therefore to be taken with scepticism.

The slope of the extragalactic power law component underlying the hard thermal component in the 0.5-2 keV band has been determined by various authors using ROSAT data (Hasinger 1992, Wang & Mc Cray 1993, Georgantopoulos et al., 1995); the energy index typically lies between -0.5 and -1.1 (see figure 1), a spread which is expected from the large systematic error.

The spectrum of the resolved sources, on the other hand, does not suffer from uncertainties due to the subtraction of diffuse galactic and instrumental backgrounds, because for the discrete sources any diffuse background component can be easily subtracted from source-free regions. The slope of the average source spectrum is therefore usually determined quite accurately, in particular in directions with low interstellar absorption, because of the very long spectral lever arm from 0.1-2 keV (see figure 1). It lies in the range -0.9 to -1.3, depending on the survey depth. Figure 1 shows the resolved source spectrum measured in the deepest ROSAT pointing on the Lockman Hole in the 0.1-2 keV band (Hasinger et al., 1993). Also indicated is the minimum flux due to discrete sources in the 1-2 keV band, which is estimated from a fluctuation analysis in the Lockman Hole (Hasinger et al., 1993).

2.2.4. *The contribution of bright sources*

An important systematic error in background measurements originates from the treatment of bright sources. When comparing background fluxes quoted by different authors which are obtained by measurements with different angular resolution one has to carefully take into account the contribution by resolved sources brighter than the upper flux threshold in a particular observation (see Hasinger et al., 1993, Snowden et al., 1994). While e.g. the $\sim 10^o$ beam used for the Wisconsin observations averages the contribution of all but the brightest extragalactic sources into a "true total background" measurement, some investigators of imaging X-ray observations quote only results for a "residual background", i.e. after removal of all detected discrete sources (e.g. Wang & McCray 1993), which clearly depends on the depth of the survey. Even if "total background" measurements are given, i.e. the sum of all observed photons in a particular sky region (e.g. Georgantopoulos et al., 1995; Gendreau et al., 1994) there is a bias in the resulting flux (roughly 10% for typical ROSAT PSPC fields, maybe more for ASCA fields), because obviously background measurements are taken far away from known bright X-ray sources, which nevertheless contribute to the "true total background" (after all, a large fraction of the background is made of sources). To avoid the poisson error due to the statistical presence or absence of individual bright sources in the field it is therefore advisable to remove all sources brighter than a fixed threshold and to later add their contribution to the results, e.g. estimated from a known logN-logS function (see e.g. Hasinger et al., 1993), in order to predict the "true total background". An estimated contribution of 10% due to brighter sources has therefore been added in figure 1 to the bow-tie shaped 90%-confidence contours for the average extragalactic power law determined by Georgantopoulos et al., 1995. Their average energy slope from 5 medium-deep PSPC fields is -0.56 ± 0.12 (without systematic errors) and the average normalization corrected for brighter sources is $12.8 \pm 0.6\ keV\ cm^{-2}\ s^{-1}\ sr^{-1}\ keV^{-1}$

at 1 keV. The currently best estimate from my own analysis of night-sky data averaged from 3 deep PSPC pointings yields an energy slope of -1.12 ± 0.12 and a normalization 13.0 ± 0.2 in the above units (Hasinger 1993). The systematic error on the slope determination is 0.2 and has been assumed in figure 1. Again, at 1 keV the two independent flux determinations are consistent with each other and with the Wisconsin data, while the slopes are consistent within the systematic errors. An estimate of the background flux at 1 keV from the combined ROSAT and Wisconsin data is $13.7 \pm 0.6\ keV\ cm^{-2}\ s^{-1}\ sr^{-1}\ keV^{-1}$. Comparing this with the extrapolation of the HEAO-1 background spectrum from higher energies ($8 \cdot E^{-0.4}$), one would have to conclude that the background spectrum has to steepen somewhere between 2 and 3 keV.

2.2.5. *The ASCA data*

The Japanese X-ray satellite ASCA carries the first imaging X-ray telescope which is sensitive between 0.5 and 10 keV and therefore the first to cover the transition region in the 1-3 keV band with one instrument continuously. It also carries the first X-ray CCD detector with a very high energy resolution compared to proportional counters. Initial results on the X-ray background spectrum have been presented by Gendreau et al. (1994). At higher energies the measurd spectrum agrees very well with the previous observations. Surprisingly however, the ASCA spectrum does not show any trace of the expected steepening in the 2-3 keV band. On the contrary, it remains compatible with the HEAO-1 extrapolation down to energies as low as 1 keV (see figure 1). At lower energies the ASCA data confirm the existence of the hard thermal component (see above), but cannot distinguish between an additional steep power law component and/or non-solar abundances in the hot plasma, so that the estimate of the true extragalactic contribution becomes quite uncertain.

The new measurement disagrees significantly with previous data in the absolute flux level at 1 keV, where ASCA gets a value of 8.9 ± 0.4 versus the above 13.7 ± 0.6 (in the usual units). If one would take the ASCA estimate at face value one would have to conclude that the deepest ROSAT observations have already resolved a much larger fraction of the extragalactic XRB at 1 keV than previously assumed. Including the results of the ROSAT fluctuation analysis we have the paradoxical situation that practically all or even more of the ASCA background at 1 keV have been resolved. What are the possibilities to understand and "cure" this discrepancy?

(1) Might there be a general mismatch of about 50% between the ROSAT/Wisconsin and ASCA absolute calibrations? Although both ASCA and ROSAT/PSPC teams are still in the process of understanding the subtleties in the systematics of their respective calibrations, this seems for-

tunately not to be the case. On the contrary, a flux agreement to better than 10% between the two instruments is generally found when comparing near-simultaneous observations or observations of putatively constant targets with simple spectra (P. Serlemitsos, B. Warwick, N. White, priv. comm., 1994 November).

(2) Could the discrepancy be due to the different energy resolution of the instruments? ASCA is the first X-ray instrument with appreciable spectroscopic capacities and it is clear that it can handle complex spectra much better than the proportional counters with only moderate energy resolution (ROSAT PSPC and Wisconsin). One would therefore tend to believe better in the ASCA results, in particular with respect to the spectral shape. On the other hand, ASCA and ROSAT agree in the existence and the temperature of the hard thermal component and it can be demonstrated that this has a negligible influence for PSPC pulseheight spectra at and above 1 keV. Also, the average spectrum of the resolved sources in PSPC fields is simple and featureless, so that the discrepancy that ASCA finds too little background compared to the resolved sources still remains.

(3) Are there special problems of diffuse background measurements? I have discussed above a number of systematic errors in the treatment of the diffuse XRB. A specific of absolute background measurements is the relatively complicated calculation of the effective area × solid angle product. In the case of ASCA this is particularly complex, because a large and energy-dependent fraction of the diffuse background photons in the field-of-view actually originates from directions outside the field-of-view due to single reflections on one of the two X-ray mirror sections. (For the ROSAT telescope this is not a problem due to a complex system of baffles and field stops, which is not possible for highly nested mirror systems.) However, Gendreau et al. have demonstrated convincingly that they have corrected for this effect using ray tracing simulations. Another, more likely systmatic difference is the bright source bias, as discussed above. According to my understanding the authors of the ASCA paper have not corrected for this effect. For the total 1-10 keV band the correction procedure might actually be quite complicated, because the logN-logS functions are apparently different in the 0.5-2 keV and the 2-10 keV band, and are much less well known in the latter. A rough estimate of the correction that has to be applied to the ASCA 1-2 keV data can be derived as follows: The brightest sources that ASCA is expected to find in its 20×20 $arcmin$ field-of-view has a flux corresponding to a source density $N(> S) = 9\ deg^{-2}$ (i.e. one source per FOV). Checking with the soft X-ray logN-logS function (Hasinger et al., 1993,1994) this yields a source flux of $5 \cdot 10^{-14}\ erg\ cm^{-2}\ s^{-1}$ $(0.5 - 2\ keV)$. Integrating the logN-logS function above this flux to infinity yields a background intensity of 2.65 $kev\ cm^{-2}\ s^{-1}\ sr^{-1}$ from sources brighter than

the upper flux threshold. Assuming a power law spectrum with an energy slope of −1 in the 0.5-2 keV band for the brighter sources, the spectrum of their contribution to the "true total background" has a normalization of 1.9 $keV\ cm^{-2}\ s^{-1}\ keV^{-1}\ sr^{-1}$ at 1 keV, which has to be added to the spectrum given by Gendreau et al., (1994), such that the total normalization has a value of 10.8. Surprisingly this value is consistent with the Wisconsin data (norm 11) and approaches the ROSAT data. While the estimate of the bright source correction to the soft X-ray background (∼ 21%) is relatively straightforward, the best guess for the correction factor in the 2-10 keV band depends on the relatively uncertain logN-logS function and the average bright source spectrum in this band and could be in the range 10 – 30%. The bright-source contribution might therefore resolve the apparent discrepancies in the observations at 1 keV at the expense of the nice match between ASCA and HEAO-1. The conclusion would then be, that indeed the background spectrum remains flat down to 1 keV with a normalization of 11 (like McCammon & Sanders have told us all along) and that the steepening observed by ROSAT occurs only below 1 keV. A formal fit to the combined ASCA/ROSAT data, after applying the same corrections for bright sources might give the definitive answer.

3. The angular correlation function

Since the X-ray background is made up largely from discrete sources one would expect some variance in the background due to those sources. A signal in the angular correlation function (ACF) can give strong constraints on the clustering properties of the sources contributing to the X-ray background. However, the XRB is remarkably smooth. Until recently no signal could be detected in the XRB ACF neither at soft X-ray nor at hard X-ray energies (see Fabian & Barcons, 1992 for a review and figure 2). A first signal could be found in a 1-2 keV analysis of 50 deep ROSAT pointed observations in about 10% of the fields (Soltan & Hasinger, 1994). This signal could be clearly associated with a few extended, very-low X-ray surface brightness clusters or groups of galaxies at moderate redshift. These objects are now termed "blotches" (Hasinger et al., 1991). In trying to obtain an upper limit on structure in the background due to the clustering of sources producing the bulk of the emission, Soltan & Hasinger excluded the fields with significant cluster emission. Indeed, once those fields were excluded, only upper limits for the ACF could be obtained, however, those limits strongly constrain the nature and clustering properties of the sources contributing to the residual X-ray background. According to this analysis, less than 35% of the residual background can be due to objects with clustering properties similar to QSOs. The objects which make up the remainder of

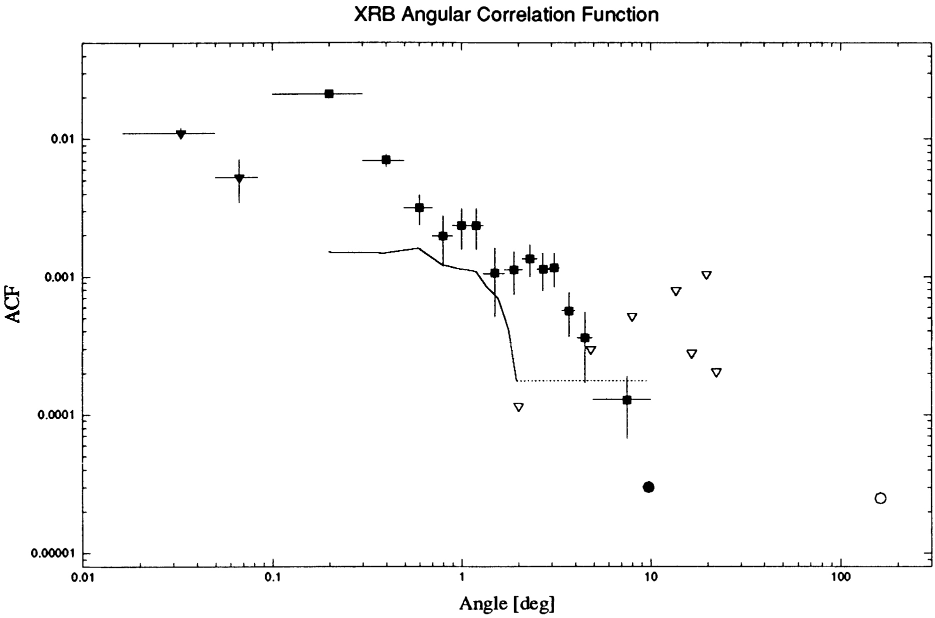

Figure 2. Measurements of the angular correlation function of the X-ray background from different instruments (after Fabian & Barcons, 1992). The open circle corresponds to the measurement of the XRB dipole moment (Shafer & Fabian 1983). The filled circle refers to the upper limit for large-scale surface brightness variations measured by the HEAO-1 A2 experiment (Jahoda 1993). The open triangles are upper limits from the Ginga pointed observations (Carrera et al., 1991). The continuous line shows the 2-sigma upper limits obtained from Ginga scan data (Carrera et al., 1993). The filled squares refer to the first detection of a significant signal in the ACF of the XRB in the ROSAT all-sky survey (Soltan et al., 1994). The filled triangles are upper limits to the ACF obtained by summing up about 50 ROSAT pointed observations (Soltan & Hasinger 1994).

the background must have a clustering length smaller than normal galaxies and/or show very strong cosmologic evolution of their clustering (Soltan & Hasinger, 1994).

In figure 2 the angular correlation function at 2 and 4 arcmin is shown, determined from the average of all 50 ROSAT pointings, i.e. including the "blotchy" fields. A significant signal is detected there. In a recent analysis of the 0.9-1.3 keV background from a "clean" region of 1 sr in the ROSAT all-sky survey, Soltan et al. (1995) detected a very significant signal in the ACF of the X-ray background, extending out to about 10^o (see figure 2). The angular resolution of this measurement is 12'. At angles of $0.5 - 5^o$ this signal corresponds to roughly 3% fluctuations of the X-ray background. The authors could show convincingly that a large fraction of this signal must be extragalactic, actually galactic contributions to the fluctuations could be largely removed using the angular correlation function in a softer energy band (0.7-0.9 keV). Therefore this measurement represents the first discovery of the long-sought signal in the extragalactic X-ray background flux. Soltan et al. correlated the X-ray background fluctuations with the Abell catalogue of clusters of galaxies and find a significant crosscorrelation signal, not only with the direct cluster emission (within 20') but also an extended component reaching out to $\sim 5^o$. The magnitude of this effect, which corresponds roughly to one third of the total background fluctuations, excludes the possibility that this signal is due to the cluster-cluster or the galaxy-cluster correlation and the tentative assumption put forward by the authors is, that typical Abell clusters are surrounded by large ($\sim 10\ Mpc$) haloes of diffuse hot gas with an average luminosity of $\sim 10^{43.4}\ erg\ s^{-1}$. This could be the first detection of hot diffuse supercluster gas emission.

Similarly, the ROSAT data are being correlated to catalogues of other object classes (e.g. nearby groups of galaxies), work which will presented elsewhere. A crosscorrelation between the ROSAT all-sky survey map and the 2nd-year COBE DMR map (Smoot et al., 1992) is in progress, but the results are still inconclusive.

4. X-ray surveys

X-ray surveys are important for our understanding of the object classes contributing to the X-ray background as well as their cosmological evolution. Because of the requirement to obtain optical spectroscopic identifications for large, statistically complete samples of X-ray selected objects, X-ray survey work is quite tedious and time consuming. For many years the two X-ray surveys from HEAO-1 (Picinnotti et al., 1982) and the Einstein observatory Extended Medium Sensitivity Survey (EMSS; Gioia et al., 1990) were the only available workhorses. With the advent of the ROSAT X-ray observatory substantial progress has been made both in depth and in coverage of X-ray surveys. The optical follow-up work is, however, still a problem. This is illustrated in figure 3, where various completed and on-going surveys are compared. The filled symbols indicate surveys which are already largely optically complete (typically less than 10% incompleteness), including the EMSS and the Piccinnotti Sample. Open circles refer to ROSAT X-ray sorce catalogues with largely incomplete optical identifications (the all-sky survey, the ROSAT ecliptic pole survey and the deepest ROSAT PSPC survey in the Lockman Hole).

Filled circles indicate a number of independent, relatively complete

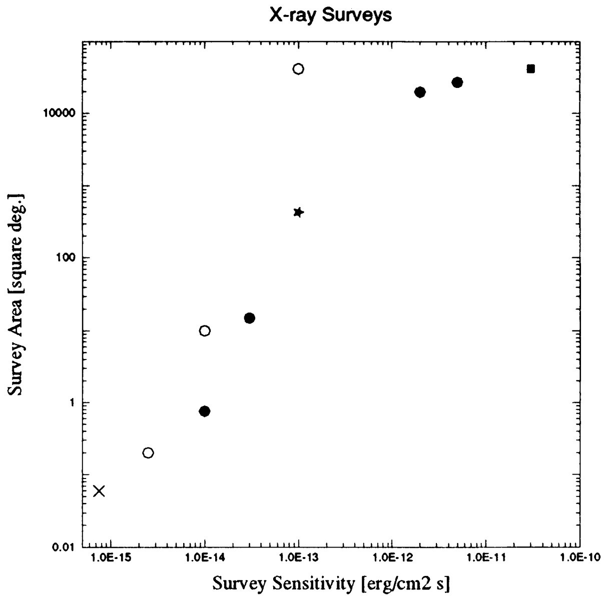

Figure 3. Graphical display of the solid angle versus limiting sensitivity for various X-ray surveys. Filled symbols correspond to surveys which are largely spectroscopically identified, square: HEAO-1 survey (Piccinnotti et al., 1982), star: EMSS (Gioia et al., 1990), circles: ROSAT surveys (see text). The cross corresponds to the ROSAT Ultradeep HRI Survey, which is currently in progress.

ROSAT high galactic latitude survey projects, which contain typically between 100 and 1000 sources. There are two almost complete ROSAT surveys substantially fainter than the EMSS, which contribute most to our understanding of the sources of the XRB: the RIXOS project and the ROSAT Deep Survey project. RIXOS, the ROSAT International X-ray Optical Survey is large program to completely optically identify serendipitous sources from PSPC pointings longer than 8 ksec down to a flux limit of $3 \cdot 10^{-14}$ $erg\ cm^{-2}\ s^{-1}$. For the purpose of optical identifiations 1.5 years of the CCI international time on the Canary Island telescopes was awarded to a large consortium (PI Keith Mason) in the years 1993-1994. In a solid angle of $\sim$ 10 deg^2 (40 fields) the identifications are 100% complete, the remaining $\sim$ 40 fields should be completed by the end of 1994.

A small number of PSPC pointings reach sensitivities substantially below 10^{-14} $erg\ cm^{-2}\ s^{-1}$, the so called ROSAT deep surveys. Optical counterparts in these pointings typically have magnitudes in the range $m_R = 19 - 24$, so that optical identifications become very time consuming. In this review data from a total of 5 ROSAT PSPC fields with optical identifications largely complete down to an X-ray flux of $10^{-14}\ erg\ cm^{-2}\ s^{-1}$ have been combined (see also Branduardi-Raymont et al., 1994): the Lockman Hole (Hasinger et al., 1993; deRuiter et al., 1995), the Marano Field (Zamorani et al., 1995), the North-ecliptic pole field (Henry et al., 1994; Bower et al., 1995) and the QSF3 and GSP4 fields (Shanks et al., 1991; Boyle et al., 1993).

At fainter X-ray fluxes the typical magnitude of optical counterparts increases correspondingly and the surface density of faint galaxies rises dramatically. While ROSAT PSPC position errors can be as small as 2-3" for brighter sources, the X-ray error boxes at detection threshold are still quite large (10-15" radius), so that the likelihood of spurious associations of faint galaxies with faint X-ray sources increases substantially. In order to overcome these difficulties and to be able to push the limit for secure optical identifications an order of magnitude deeper we have started observations for an Ultradeep ROSAT HRI survey inside the PSPC survey of the Lockman Hole. A total of 1Msec of HRI observations and a new "X-ray speckle" technique to correct for aspect errors are forseen to obtain arcsecond positions for about 70 objects down to a flux limit of $7 \cdot 10^{-16}\ erg\ cm^{-2}\ s^{-1}$. At the extremely faint optical magnitudes expected, probably only new telescopes of the 8-10m class with multislit spectroscopy capabilities over a large field can achieve completeness in a reasonable exposure time. Nevertheless this is the only possibility to obtain secure information about the role of faint galaxies and clusters for the X-ray background (see below).

TABLE 1. Summary of X-ray Surveys

Survey	S_{lim} $[erg/cm^2 s]$	Area $[deg^2]$	Total [%]	Unid. [%]	AGN [%]	Gal. [%]	Clus. [%]	Stars
EMSS	10^{-13}	430	835	4	55	2	13	26
RIXOS	$3 \cdot 10^{-13}$	14.9	285	14	51	4	11	20
DEEP	10^{-14}	0.76	61	8	62	7	5	15
ULTRA	$7 \cdot 10^{-16}$	0.06	70?					

5. Optical identifications and the role of galaxies

Table 1 gives a summary of the survey papameters and optical identification content for the EMSS, RIXOS and ROSAT Deep Surveys, which span

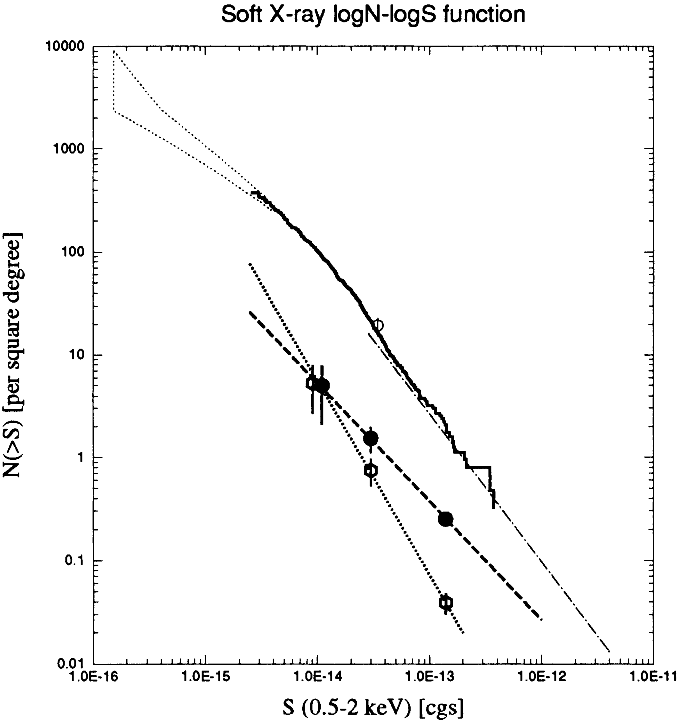

Figure 4. Integral soft X-ray source counts (from Hasinger et al., 1993). The filled circles give the contribution of spectroscopically identified clusters of galaxies, the open hexagons that of single galaxies. For clarity, galaxies and clusters for the ROSAT deep surveys are plotted with a small shift in flux.

roughly a decade in limiting flux. Active galactic nuclei, mainly QSOs, represent the majority in all three surveys and are expected to contribute a large fraction of the X-ray background. Foreground stars, galaxy clusters and apparently normal or weak emission line galaxies contribute only 5 – 25% each. Of particular interest is the relative behaviour of galaxy clusters on one hand and apparently normal or weak emission line galaxies on the other hand. Figure 4 shows the source counts for clusters and galaxies in the three samples, compared to the total logN-logS function in the soft X-ray band (from Hasinger et al., 1994). The sub-Euclidean slope for clusters of galaxies found in the Einstein Medium Survey (Gioia et al., 1984) seems to continue to much fainter X-ray fluxes: for the three samples discussed here a power law slope of -1.1 is found for the integral source counts. This is consistent with the strong negative evolution found for the

X-ray luminosity of galaxy clusters (Edge et al., 1990; Henry et al., 1992). An independent estimate of the cluster evolution could be obtained from the RIXOS sample (Castander et al., 1994).

Galaxies, on the other hand, seem to have a much steeper logN-logS function than clusters. A slope of -1.9, steeper than Euclidean, has been determined for the cumulative source counts of galaxies in the three samples, indicating a strong positive evolution for this population, which eventually could become the dominant contributor to the X-ray background at the faintest X-ray fluxes. One has to be careful with this interpretation, however, for several reasons: First, as discussed above, the number of spurious identifications of galaxies with faint X-ray sources increases sharply, both because the galaxy number counts and because the increasing X-ray error boxes with decreasing flux. Some fraction of the galaxies in the ROSAT deep surveys could be spurious. Secondly, there may be some distant clusters of galaxies misidentified as single galaxies, e.g. objects which are dominated by a single CD-galaxy in the optical and which are too faint to measure an X-ray extent. Finally a number of galaxies, in particular those with faint emission lines might actually host hidden AGN and might therefore be misclassified. A number of these objects has been detected through a ROSAT/IRAS correlation (Boller et al., 1992; see also Moran et al., 1994). In one particular case an object classified as a normal HII galaxy showed strong and fast time variability (Boller et al., 1993). Interesting is also one of Boller's IRAS/ROSAT correlations which turned out to be a narrow line (type-II) QSO (Elizalde & Steiner, 1994). According to the new unified AGN-background models which can give a satisfactory fit to the background spectrum and many other observational constraints (Comastri et al., 1995; Matt, 1994) we would actually expect type-II AGN, i.e. low-luminosity absorbed Seyfert galaxies and type-II QSOs as one of the major contributors to the X-ray background. This fits well with the fact that the faintest X-ray sources in the Lockman Hole seem to have a substantially hard, intrinsically absorbed spectrum.

References

Antonucci R.R. *Ann. Rev. Astr. Astrophys. Astrophys.*, **31**, 473 (1993).

Barber C.R. & Warwick R.S. *Mon. Not. R. astr. Soc.*, **267**, 270 (1994).

Barcons X. & Fabian A.C., *Mon. Not. R. astr. Soc.*, **243**, 366 (1990).

Boldt E. *Phys. Rep.*, **146**, 215 (1987).

Boller T., Meurs E.J.A., Brinkmann W., Fink H., Zimmermann U. & Adorf H.M. *Astr. Astroph.*, **261**, 57 (1992).

Boller T., Trümper J., Molendi S., Fink H., Schaeidt S., Caulet A. & Dennefeld M. *Astr. Astroph.*, **279**, 53 (1993).

Branduardi-Raymont G., Mason K.O., Warwick R.S. et al. *Mon. Not. R. astr. Soc.*, **270**, 947 (1994).

Bower R. et al. (in preparation) (1994).

Boyle B.J., Griffiths R.E., Shanks T., Stewart G.C. & Georgantopoulos I., *Mon. Not. R. astr. Soc.,* **260**, 49 (1993).

Carrera F.J., Barcons X., Butcher J., Fabian A.C., Stewart G.C., Warwick R.S., Hayashida K. & Kii T. *Mon. Not. R. astr. Soc.,* **249**, 698 (1991).

Carrera F.J., Barcons X., Butcher J.A., Fabian A.C., Stewart G.C., Toffolatti L., Warwick R.S., Hayashida K., Inoue H. & Kondo H. *Mon. Not. R. astr. Soc.,* **260**, 376 (1993).

Castander F.J., Bower R.G., Ellis R.S., Aragon-Salamanca A., Mason K.O., Hasinger G., McMahon R.G., Carerra F.J., Mittaz J.P.D., Perez-Fournon I. & Barcons X. *Nature,* (subm.) (1994).

Comastri A., Setti G., Zamorani G. & Hasinger G. *Astr. Astroph.,* (in press) (1995).

Edge A.C., Stewart G.C., Fabian A.C. & Arnaud K.A. *Mon. Not. R. astr. Soc.,* **245**, 559 (1990).

Elizalde F. & Steiner J.E. *Mon. Not. R. astr. Soc.,* **268**, L47 (1994).

Fabian A.C. & Barcons X. *Ann. Rev. Astr. Astrophys. Astrophys.,* **30**, 429 (1992).

Giacconi R., Gursky H., Paolini F.R. & Rossi B.B., *Phys.Rev.Letters,* **9**, 439 (1962).

Gehrels N. & Chen W. *Nature,* **361**, 706 (1993).

Gendreau K. et al. (preprint) (1994).

Georgantopoulos I., Stewart G.C., Shanks T., Boyle B.J. & Griffiths R.E. *Mon. Not. R. astr. Soc.,* (submitted) (1994).

Gioia I.M., Maccacaro T., Schild R.E., Stocke J.T., Liebert J.W., Danziger I.J., Kunth D. & Lub J. *Astrophys. J.,* **283**, 495 (1984).

Gioia I.M., Maccacaro T., Schild R.E., et al., *Astrophys. J. Suppl.,* **72**, 567 (1990).

Gruber D.E., in *The X-ray Background* X. Barcons & A.C. Fabian eds, (Cambridge University Press), p.45 (1992).

Hasinger G., Schmidt M. & Trümper *Astr. Astroph.,* **246**, L2 (1991).

Hasinger G., in *The X-ray Background* X. Barcons & A.C. Fabian eds, (Cambridge University Press), p.229 (1992).

Hasinger G., Burg R., Giacconi R., Hartner G., Schmidt M., Trümper J. & Zamorani G., *Astr. Astroph.,* **275**, 1 (1993).

Hasinger G. in: *Observational Cosmology,* G.Chincarini, A.Iovino, T.Maccacaro, D.Maccagni, eds., A.S.P. Conf. Ser. Vol. 51, p.439 (1993).

Hasinger G., Burg R., Giacconi R., Hartner G., Schmidt M., Trümper J. & Zamorani G., *Astr. Astroph.,* **291**, 348 (1994).

Henry J.P., Gioia I.M., Maccacaro T., Morris S.L., Stocke J.T. & Wolter A. *Astrophys. J.,* **386**, 408 (1992).

Henry J.P., Gioia I.M., Boehringer H., Bower R.G., Briel U.G., Hasinger G., Aragon-Salamanca A., Castander F.J., Ellis R.S., Huchra J.P., Burg R. & McLean B. *Astron. J.,* **107**, 1270 (1994).

Inoue H. et al. *Astrophys. J.,* **238**, 886 (1980).

Jahoda K. *Adv. Space. Res.* **Vol. 13, No. 12**, p.(12)231 (1993).

Marshall F.E. et al., *Astrophys. J.,* **235**, 4 (1980).

Mather J. et al. *Astrophys. J. (Letters),* **354**, L37 (1990).

Matt G. (preprint), (1994).

McCammon D. & Sanders W.T., *Ann. Rev. Astr. Astrophys. Astrophys.,* **28**, 657 (1990).

Moran E.C., Halpern J.P. & Helfand D.J. *Astrophys. J.,* **433**, L65 (1994).

Mulchaey J.S., Mushotzky R.F. & Weaver K.A. *Astrophys. J.,* **390**, L69 (1992).

Mushotzky R. in: *Frontiers of X-ray Astronomy,* Y.Tanaka, K.Koyama, eds., Universal Academy Press:Tokyo, p.657 (1992).

Piccinnotti G., Mushotzky R.F., Boldt E.A., et al. *Astrophys. J.,* **253**, 485 (1982).

Plucinsky P.P., Snowden S.L., Briel U.G., Hasinger G & Pfeffermann E. *Astrophys. J.,* **418**, 519 (1993).

Ponman T.J. & Bertram D. *Nature,* **363**, 51 (1993)

Rocchia R. et al., *Astr. Astroph.,* **130**, 53 (1984).

deRuiter H. (in preparation) (1994).

Setti G. & Woltjer L., *Astr. Astroph.,* **224**, L21 (1989).

Shafer R.A. & Fabian A.C. in: *Early Evolution of the Universe and its Present Structure*, G.O. Abell, G. Chincarini, eds., Reidel:Dordrecht, p.333 (1983).

Shanks T., Georgantopoulos I., Stewart G.C., Pounds K.A., Boyle B.J. & Griffiths R.E. *Nature,* **353**, 315 (1991).

Smoot G.F. et al. *Astrophys. J.,* **396**, L1 (1992).

Snowden S.L., Hasinger G., Jahoda K., Lockman F.J. McCammon D. & Sanders W.T. *Astrophys. J.,* **430**, 601 (1994).

Snowden S.L. et al. (in preparation) 1995

Soltan A. & Hasinger G. *Astr. Astroph.,* **288**, 77 (1994).

Soltan A., Hasinger G., Egger R., Snowden S. & Trümper J. *Astr. Astroph.,* (submitted) (1994).

Wang Q.D. & McCray R. *Astrophys. J.,* **409**, L37 (1993).

Wu X., Hamilton T.T., Helfand D.J. & Wang Q. *Astrophys. J.,* **379**, 564 (1991).

Zamorani G. et al., (in preparation) (1994).