Tracing Small-Scale Fluctuations in the Soft X-ray Background

R. Warwick[1], I. Hutchinson[1], R. Willingale[1], K. Kuntz[2], and S. Snowden[3]

[1] Department of Physics and Astronomy, University of Leicester, Leicester, UK
[2] University of Maryland, College Park, MD 20742, USA
[3] NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA

Abstract. An overlapping set of *ROSAT* PSPC observations made in a region of very low Galactic foreground column density, has been used to investigate variations in the soft X-ray background on angular scales of $15' - 5°$. In the 1/4 keV band there is a clear inverse correlation of the count-rate with the line-of-sight hydrogen column density. However, after correcting for this absorption effect, strong residual fluctuations remain in the data, with an amplitude which is significantly larger than that due to the counting statistics or the confusion of unresolved discrete sources. In contrast a similar analysis for the 3/4 and 1.5 keV *ROSAT* bands shows no evidence for an excess signal. The most likely origin of the 1/4 keV fluctuations would seem to be in a patchy distribution of $\sim 10^6$ K gas in the Galactic halo.

1 Introduction

A major achievement of the *ROSAT* mission has been the detailed mapping of the spatial structure in the soft X-ray background (SXRB) both on an all-sky basis and in pointed observations. This observational progress has, in turn, led to considerable new insight into the nature and origin of the background radiation, particularly in the softest accessible band at 1/4 keV. The observed diffuse flux in the 1/4 keV band is now known to be comprised of at least three components, emission from 10^6 K plasma residing in the Local Bubble, thermal emission at a similar temperature associated with the Galactic Halo and extragalactic flux of uncertain spectral form, representing the summed emission from discrete sources including broad-line QSOs. Numerous attempts (e.g. Burrows & Mendenhall 1991; Snowden et al. 1991; Wang & Yu 1995; Snowden 1997) have been made to separate the foreground emission (produced in the Local Bubble typically within ~ 100 pc of the Sun) from the halo/extragalactic flux via the shadows cast on the latter by cold interstellar clouds (a gas column density of $N_H \sim 10^{20}$ cm^{-2} gives an optical depth of unity at 1/4 keV). One such study (Snowden et al. 1994) considered the diffuse 1/4 keV emission observed in the primary Lockman Hole region (an area of ~ 300 deg^2 centred on $l \approx 147°, b \approx 54°$) where the Galactic line-of-sight column density, N_H, falls to a global minimum value. It was found that, although the observed 1/4 keV intensity shows a clear anticorrelation with N_H, there is very considerable scatter in the correlation plot. Here we

https://doi.org/10.1017/S0252921100071189 Published online by Cambridge University Press

focus on the origin of this scatter. A preliminary version of this work has been reported earlier by Barber, Warwick & Snowden (1996).

2 Data Reduction and Analysis

The present investigation is based on a set of nine overlapping *ROSAT* PSPC observations targeted at a region near $l \approx 161°, b \approx 51°$, in the south-west corner of the primary Lockman Hole. The $N_{\rm H}$ in the surveyed region is relatively uniform ($6 - 10 \times 10^{19}$ cm^{-2}) except in one or two localized areas where it increases to a maximum of 14.0×10^{19} cm^{-2}.

The data from each observation were reduced using standard background subtraction, exposure correction and flat-fielding procedures (Snowden 1995). After correcting for field-to-field baseline variations, the 1/4 keV PSPC images were mosaiced together, smoothed with a $4'$ radius circular top-hat function and bright sources removed. The observed 1/4 keV background intensity was then correlated with N_H (we use the same N_H data as Snowden et al. 1994). As in the earlier study of Snowden et al. (which encompasses a much larger sky area but with significantly lower exposure) these parameters show a clear inverse correlation consistent with the progressive absorption of halo/extragalactic flux with increasing N_H. In order to investigate the residual scatter in the correlation plot we corrected the original PSPC images for the effects of absorption (by adding back signal in accord with the best-fitting absorption model) and then heavily smoothed the source-excluded image with a $15'$ radius top-hat function. The resulting map is shown in Fig. 1.

The peak-to-peak signal in the residual fluctuations apparent in Fig.1 on a scale of $\sim 15' - 30'$ amounts to $\sim 15\%$ of the average surface brightness. In principle such fluctuations could arise from counting statistics, from the confusion effects of discrete sources just below the source exclusion threshold or from variations attributable to the diffuse SXRB. The magnitude of the first effect can be determined from the typical exposure time of ~ 10 ksec whereas the confusion noise can be estimated from the source counts measured in the 0.5–2.0 keV *ROSAT* band (e.g. Hasinger et al. (1993)), assuming a standard spectral conversion to the 1/4 keV band (in fact we use a power-law spectrum with an energy index $\alpha = 1.0$). In practice we have used Monte Carlo simulations of the mosaiced image in Fig.1 to determine the expected level of scatter and find that the observed fluctuations are very significant (i.e. $> 4\sigma$) with an amplitude roughly a factor two greater than the estimates based solely on counting statistics and confusion noise.

As a check the analysis was repeated for the 3/4 keV and 1.5 keV ROSAT bands (where the effects of Galactic absorption are negligible). In this case the Monte Carlo simulations showed that the level of the observed fluctuations were consistent with the predicted scatter. This would seem to rule out the clustering of discrete sources as a source of the 1/4 keV excess fluctuations (see also Soltan et al. 1996; Carrera, Fabian & Barcons 1997).

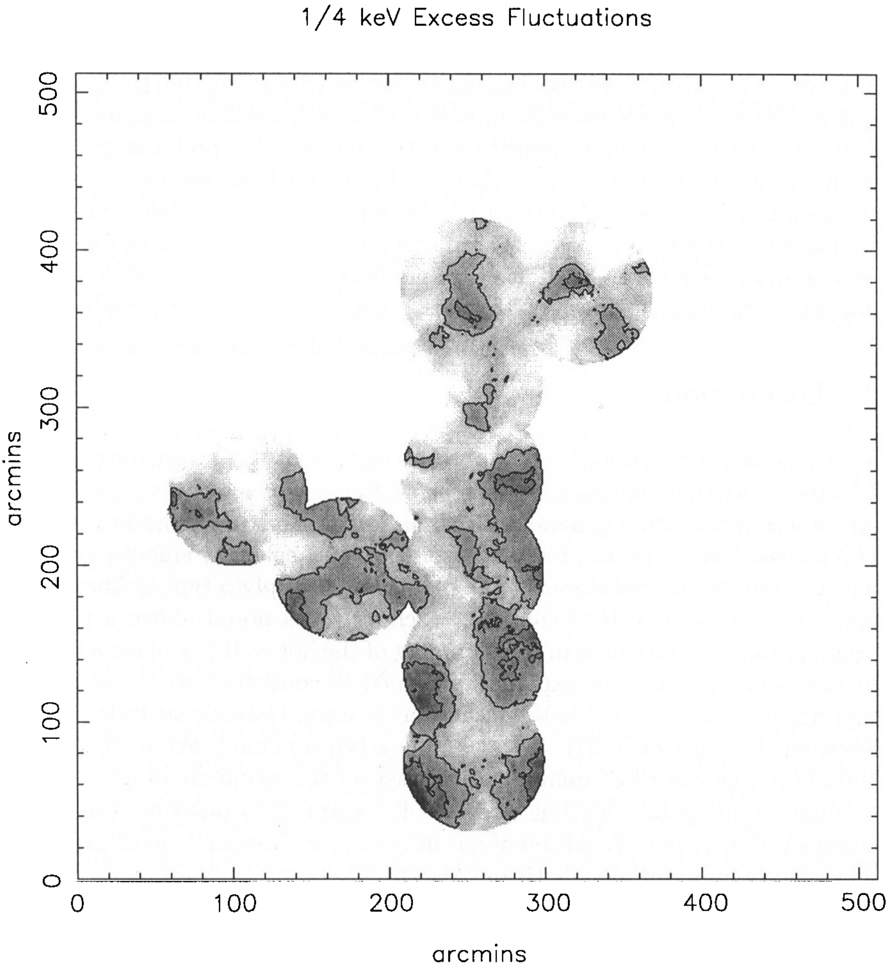

Fig. 1. The *ROSAT* PSPC image of the residual 1/4 keV fluctuations after correcting for the best-fitting absorption model. The grey scale encompasses surface brightnesses from $1050 - 1350 \times 10^{-6}$ count s^{-1} $arcmin^{-2}$ (white to black). The contours correspond to surface brightnesses of 1150 and 1200×10^{-6} count s^{-1} $arcmin^{-2}$ and accentuate the bright fluctuations.

3 Spectral Signature of the 1/4 keV Fluctuations

The spectral characteristics of the fluctuations may provide a further clue as to their origin. Based on the 1/4 keV background image shown in Fig. 1 we have extracted PSPC spectra for the high-, mid- and low-intensity regions. The spectrum corresponding to the mid-intensity regions was then fitted with a model including spectral components representative of the ex-

https://doi.org/10.1017/S0252921100071189 Published online by Cambridge University Press

tragalactic flux, the Galactic halo and the Local Bubble emission. The latter two components provided the major contribution in the 1/4 keV band on the basis of an assumed $\sim 10^6$ K thermal spectrum (Snowden 1997). The PSPC spectra from the high- and low-intensity regions were then examined in relation to the best-fit mid-intensity spectral model. The preliminary results from the spectral study suggest that the bright fluctuations are most likely the result of an increased emission measure in the Galactic halo component compared to the field average. There was also marginal evidence for an excess of absorption over and above that predicted by the measured N_H in the low-intensity regions. However, this latter point needs further investigation.

4 Discussion

This analysis has revealed an important feature of the morphology of the 1/4 keV SXRB, namely the existence of fluctuations on a scale of $15' - 30'$ superimposed on a general anticorrelation of the surface brightness with N_H (of the form expected for the absorption of a spatially smooth Galactic halo/extragalactic component). The observations imply a typical fluctuation amplitude of $\sim 50 \times 10^{-6}$ count s^{-1} arcmin^{-2}. As noted above a possible origin of the fluctuations is in the clumping of the hot $\sim 10^6$ K plasma located in the Galactic halo, an explanation which is consistent with the lack of significant small-scale 1/4 keV fluctuations at lower Galactic latitude (Kuntz, Snowden & Warwick 1997). If we assume a typical clump extent of $20'$, the clump lifetime can be estimated on the basis of the sound crossing time; this calculation suggests a lifetime of $10^5 - 10^6$ years. It is plausible that these clumps relate to the circulation of gas in the lower Galactic halo as predicted by Galactic fountain models (Kahn 1997).

References

Barber C.R., Warwick R.S., Snowden, S.L. (1996): MPE Report 263, 319
Burrows D.N., Mendenhall, J.A. (1991): Nature, 351, 629
Carrera F.J., Fabian A.C., Barcons, X. (1997): MNRAS, 285, 820
Hasinger, G., et al. (1993): A&A, 275, 1
Kahn, F.D. (1997): these proceedings
Kuntz K.D., Snowden S.L., Warwick R.S. (1997): these proceedings
Snowden S.L. et al. (1991): Science, 252, 1529
Snowden, S.L. et al. (1994): ApJ, 430, 601
Snowden S.L. (1995): Cookbook for Analysis Procdures for *ROSAT* XRT/PSPC Observations of Extended Objects and the Diffuse Background
Snowden, S.L. (1997): these proceedings
Soltan A., Hasinger G., Egger R., Snowden S., & Trümper J. (1996): A&A, 305, 17
Wang Q.D., Yu K.C. (1995): AJ, 109, 698