Shadowing of the 0.25-keV extragalactic X-ray background by the disc of NGC 55

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ABSTRACT

ROSAT observations are used to search for a shadow in the 0.25-keV X-ray background cast by the disc of the nearby spiral galaxy NGC 55. Several factors, including the close to edge-on aspect of this galaxy, its extensive H I disc and its location in a direction of relatively low Galactic foreground column density, make NGC 55 an excellent target in which to search for such effects. The ROSAT PSPC image shows a clear deficit of 0.25-keV counts coincident with the outer disc of NGC 55. From the depth of the shadow we obtain an estimate of the total extragalactic background signal at 0.25 keV of 29.4 ± 7.2 keV cm⁻² s⁻¹ sr⁻¹ keV⁻¹. We compare this measurement with other recent estimates of the 0.25-keV background intensity, and briefly discuss the implications of the result in the context of the source populations which may produce the X-ray background radiation.

Key words: diffuse radiation – X-rays: general.

1 INTRODUCTION

Although more than 30 years have passed since the discovery of the cosmic X-ray background (XRB) (Giacconi et al. 1962), the origin of this phenomenon is still keenly debated (see Fabian & Barcons 1992 for a review). The observed isotropy of the background at energies above 3 keV establishes an extragalactic origin for this hard radiation. Current interest centres on identifying the types of discrete X-ray source which may contribute significantly to this background, with the constraint that the integrated spectral properties of the dominant source population (or populations) must match the observed 40-keV thermal-bremsstrahlung spectral form of the hard XRB (Marshall et al. 1980). For example, it has been suggested recently that an evolving population of galaxies having a hidden active nucleus may play a significant role in the synthesis of the XRB spectrum on the basis of the intrinsically hard X-ray spectra of such sources (Madau, Ghisellini & Fabian 1994; Comastri et al. 1995).

In contrast to the situation above 3 keV, at lower energies the XRB exhibits a spatial distribution which is clearly non-isotropic (see the review by McCammon & Sanders 1990). This suggests the emergence of one or more local components of the background with a relatively soft spectral form. In the 0.5–1.0 keV band the average XRB intensity is a factor ∼2 above a simple extrapolation of the power-law form (with an energy index of 0.4) which quite accurately characterizes the XRB spectrum in the 3–10 keV range (Marshall et al. 1980). The excess emission is undoubtedly of Galactic origin and must include a contribution from Galactic dM stars (Schmitt & Snowden 1990) in addition to that from hot (T ∼ 10⁶ K) optically thin plasma (Nousek et al. 1982). In this band much of the observed spatial structure in the XRB can be identified with particular features in our Galaxy (e.g., Loop I, the Vela SNR and the Cygnus Superbubble). In the adjacent 0.1–0.4 keV band the average XRB intensity exceeds the extrapolated hard power law by a factor ≥3, with the Galactic poles being generally brighter than the Galactic plane. There is good evidence that much of the emission is due to a T ∼ 10⁵ K plasma situated within the local low-density cavity in the interstellar medium (ISM) (Snowden et al. 1990). However, based largely on ROSAT observations of shadows cast by discrete clouds in the Galactic ISM, it has been possible, albeit for a limited number of directions, to separate the very local soft X-ray emission from that arising in a much more extensive Galactic component, which in some cases appears to extend into the Galactic halo (Burrows & Mendenhall 1991; Snowden et al. 1991; Wang & Yu 1995).

It has proved extremely difficult to untangle the extragalactic XRB intensity in the spectral range below ∼2 keV from the Galactic signal. For example, there is currently considerable uncertainty as to the normalization and spec-
tral slope of the extragalactic XRB at 1 keV (see Hasinger 1992 and Gendreau et al. 1995). The problem is even more acute in the 0.1–0.4 keV band (in this paper we generally refer to this soft X-ray band as the 0.25-keV band). In this band the extragalactic signal, after allowing for significant absorption by interstellar material along the line of sight, is all but swamped by the Galactic emission. Undoubtedly the best way of sorting out the contributions in the 0.25-keV band of the emission from the local bubble, from more distant Galactic components, and also of extragalactic origin is through shadowing experiments. In particular, if the shadow of an extragalactic object, say the disc of a spiral galaxy, could be detected superimposed on the extragalactic background then, provided the characteristics of the absorbing screen are reasonably well determined, the depth of the shadow provides a direct measurement of the intensity of extragalactic background. This approach is employed in the present paper, leading to a determination of extragalactic XRB intensity at 0.25 keV.

In a previous paper (Barber & Warwick 1994, hereafter BW94) we have shown that the ROSAT Position Sensitive Proportional Counter (PSPC) affords an excellent opportunity to search for the shadowing effects of galactic discs on the extragalactic soft XRB. The constraints on possible shadowing targets are rigorous. The spiral galaxy must not itself be a bright source of soft X-rays, its H\textsc{i} distribution must have been mapped at sufficient angular resolution to match the X-ray data, and the foreground H\textsc{i} column density (in our own Galaxy) must be low. Further, the practical limitations of the ROSAT PSPC and current limits on the extragalactic intensity require that the shadowed region must subtend a significant solid angle (i.e., many tens of square arcmin).

In this paper we report the analysis of a ROSAT PSPC observation of the spiral galaxy NGC 55, which is a member of the nearby Sculptor group of galaxies. NGC 55 is classified as SB(s)m (de Vaucouleurs, de Vaucouleurs & Corwin 1976) and has a close to edge-on configuration. Its extensive H\textsc{i} disc, its location in a direction of relatively low Galactic foreground column density, and its modest X-ray luminosity (see below) make NGC 55 an excellent target for a shadowing study.

2 THE ROSAT PSPC OBSERVATION AND DATA ANALYSIS

A ROSAT PSPC observation of NGC 55 was performed during the period 1991 November 22–24 and gave a total exposure time of 18 993 s. The initial data selection involved the exclusion of periods during which the on-board charged-particle master-vetoing rate exceeded a threshold of 170 count s\(^{-1}\) (allowing the residual charged-particle contribution to be modelled – Snowden et al. 1992; Plucinsky et al. 1993). This constraint leads to a 4.7 per cent loss of data. Fig. 1 shows the central 40 x 40 arcmin\(^2\) region of the 0.25-keV ROSAT PSPC image (corresponding to PI channels 11–41) obtained by binning the data into 15 x 15 arcsec\(^2\) pixels and convolving the resulting image with a two-dimensional Gaussian with full width at half-maximum (FWHM) of 1.5 arcmin. In order to reduce the effects of the telescope vignetting and the possibility of foreground XRB variations, we consider only the central 18-arcmin radius region of the PSPC field of view in the present analysis.

We proceed to remove instrumental effects and non-cosmic contamination from the 0.25-keV band PSPC data by using the scheme of Snowden et al. (1994). This accounts for contamination by solar-scattered X-rays, non-vetoed high-energy charged particles and, as far as is possible, long-term background enhancements. It also corrects for the telescope vignetting function, obscuration of some parts of the detector by window support structures, and the PSPC after-pulsing phenomenon. It should be noted that the process is insensitive to a general baseline shift in the data, so the intensity observed is an upper limit to the true cosmic intensity. The complete analysis of a PSPC observation considers the data in seven ‘R’ bands (R1L to R7) which take nearly full advantage of the PSPC energy resolution. However, for the present work we consider the count rates measured in the combined R1L and R2 band (which extends over the PI channel range of the 0.1–0.4 keV band). Table 1 details the contribution of the various processes in the combined R1L/R2 band as estimated using the Snowden technique. These identified ‘contaminants’ have been projected, with the relevant spatial distributions, into a single count space map, which is then subtracted from the corresponding rate R1L/R2 map. The detector efficiency map is projected on to the sky with the same orientation and wobble as the observation itself, and the resulting exposure map (which accounts for telescopic vignetting and obscuration) is then used to flatten the contamination-free data map, yielding a ‘clean’ 0.25-keV image. Finally, as a check of the validity of the above process, we have subtracted the combined contribution of the contaminants in each band from the observed data as a function of time. The resulting light curves exhibit considerable stability, implying that we have identified all of the sources of contamination which are present (except for a possible baseline shift, as noted earlier).

The central 18-arcmin radius region of the ‘clean’ 0.25-keV image was finally rebinned into a total of 256 pixels of size 2 x 2 arcmin\(^2\). The average intensity was ~690 x 10\(^{-6}\) count s\(^{-1}\) arcmin\(^{-2}\), with a typical statistical error of ~15 per cent.

Next, we attempt to minimize the effect of the bright discrete sources evident in Fig. 1. As a preliminary step we employed the point-source search algorithm PSS (which is part of the UK Starlink \textsc{asterix} software package; Allen 1992) to search for point-like enhancements above the local background in the original (15 x 15 arcsec\(^2\) pixel) 0.25-keV image. PSS found six such sources with a significance of more than 4.5\sigma within the central 18-arcmin radius field; details of these sources are given in Table 2. Assuming a power-law source spectrum with an energy index \(\alpha = 1\), and absorption by a Galactic column density \(N_H = 1.55 \times 10^{20}\) cm\(^{-2}\) (Stark et al. 1992), the minimum 0.25-keV count rate of 2.0 x 10\(^{-3}\) count s\(^{-1}\) corresponds to a 0.5–2.0 keV band count rate of 2.1 x 10\(^{-5}\) count s\(^{-1}\) and a flux of 2.6 x 10\(^{-14}\) erg cm\(^{-2}\) s\(^{-1}\) (0.5–2.0 keV). In the present paper we use this ‘standard’ spectral conversion on a number of occasions. The influence of the discrete soft sources identified in Table 2 was removed using the scheme adopted by BW94. Thus 2 x 2 arcmin\(^2\) pixels in the background map were excluded if
the pixel centres were within a radius of 3 arcmin of a
discrete source containing greater than 100 counts in the
0.25-keV image. Similarly, the exclusion radius was 1.5 arc-
min for sources with less than 100 soft counts. On this basis,
24 of the $2 \times 2$ arcmin$^2$ pixels were excluded from the
analysis.

As a further check on the effect of bright discrete sources,
we have analysed the 0.5–2.0 keV ROSAT image. This
resulted in 43 source detections at a significance greater
than 4.5$\sigma$ (within the central 18-arcmin radius field), six of
which have count rates greater than $2.1 \times 10^{-3}$ count s$^{-1}$
(the equivalent 0.5–2.0 keV count rate threshold noted

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**Figure 1.** The central region of the 0.25-keV ROSAT PSPC image. The ring is drawn at a radius of 18 arcmin. The data have been smoothed with a two-dimensional Gaussian with a FWHM of 1.5 arcmin but not (at this stage) exposure- or background-corrected. The grey-scale has units of count pixel$^{-1}$. 


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Table 1. Contribution of contaminants in the 0.25-keV PSPC image.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Raw Counts</th>
<th>Percentage of total counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long term enhancement</td>
<td>7007</td>
<td>7.4</td>
</tr>
<tr>
<td>Detector afterpulses</td>
<td>1180</td>
<td>1.2</td>
</tr>
<tr>
<td>Solar contamination</td>
<td>1388</td>
<td>1.5</td>
</tr>
<tr>
<td>Residual Charged Particles</td>
<td>340</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 2. Bright point sources detected in the ROSAT PSPC images.

<table>
<thead>
<tr>
<th>RA (2000)</th>
<th>Dec(2000)</th>
<th>0.1–0.4 keV count s⁻¹</th>
<th>0.5–2.0 keV count s⁻¹</th>
<th>Coincident with NGC55?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>soft sources</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 14 02.7</td>
<td>-39 23 06</td>
<td>2.5 × 10⁻³</td>
<td>2.9 × 10⁻³</td>
<td>N</td>
<td>Foreground Star</td>
</tr>
<tr>
<td>00 14 45.8</td>
<td>-39 14 34</td>
<td>1.6 × 10⁻²</td>
<td>2.7 × 10⁻²</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>00 14 51.5</td>
<td>-39 24 17</td>
<td>3.4 × 10⁻³</td>
<td>1.9 × 10⁻³</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>00 15 29.0</td>
<td>-39 13 27</td>
<td>3.9 × 10⁻³</td>
<td>1.7 × 10⁻¹</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>00 15 38.2</td>
<td>-39 26 30</td>
<td>2.0 × 10⁻³</td>
<td>1.1 × 10⁻³</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>00 16 01.3</td>
<td>-39 14 40</td>
<td>9.5 × 10⁻³</td>
<td>-</td>
<td>Y</td>
<td>Supersoft Source</td>
</tr>
</tbody>
</table>

hard sources

<table>
<thead>
<tr>
<th>RA (2000)</th>
<th>Dec(2000)</th>
<th>0.1–0.4 keV count s⁻¹</th>
<th>0.5–2.0 keV count s⁻¹</th>
<th>Coincident with NGC55?</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 14 20.1</td>
<td>-39 11 16</td>
<td>-</td>
<td>6.9 × 10⁻³</td>
<td>Y</td>
</tr>
<tr>
<td>00 14 37.1</td>
<td>-38 59 14</td>
<td>-</td>
<td>2.6 × 10⁻³</td>
<td>N</td>
</tr>
<tr>
<td>00 14 52.4</td>
<td>-39 10 50</td>
<td>-</td>
<td>2.6 × 10⁻²</td>
<td>Y</td>
</tr>
</tbody>
</table>

above). Three of these detections, the 'hard sources' in Table 2, have no soft-band counterpart and therefore exhibit significantly harder spectra than our standard spectral form. Although undetected in the soft band, we have chosen to remove the possible contribution of these three sources by treating them as <100 count soft-band detections. This leads to the loss of a further five pixels. Fig. 2 shows a grey-scale representation of the remaining array of 0.25-keV intensity measurements.

3 EVIDENCE FOR A SHADOW

To determine the expected depth of a shadowed extragalactic signal, we use the H I map of Puche, Carigan & Wainscoat (1991). The resolution of the H I map, ~80 × 80 arcsec², facilitates comparison with the 2 × 2 arcmin² pixel size of the X-ray data. Fig. 2 shows the H I contours from Puche et al. (1991) overlaid on to the 0.25-keV background intensity measurements. A total of 69 pixels overlap with the measured H I distribution of NGC 55 (i.e., the pixel centre is encompassed by the minimum contour in Fig. 2), leaving the remaining 158 pixels as a 'control' sample.

An important assumption of shadowing experiments is that the region casting the shadow is not sufficiently X-ray bright as to compromise the absorption measurements. In order to investigate the possible masking of shadowing effects by soft diffuse emission associated with NGC 55, we have divided the 69 'on-source' pixels into two subsamples. Thus pixels from regions within a 7.5-arcmin radius of the centre of NGC 55 (taken to be the centroid of the disc component; see Hummel, Dettmar & Wielebinski 1986) form an 'inner-disc' sample, and those outside of this radius give an 'outer-disc' sample. The frequency distributions of the pixel intensities in the control and on-source samples are shown in Fig. 3, and the corresponding mean and standard error value are given in Table 3. These data suggest the presence of a shadow cast by the outer-disc regions of NGC 55, but with no counterpart for the inner-disc region.

In Fig. 4 we plot the average background intensities measured in both the inner- and the outer-disc regions of NGC 55 for three ranges of the H I column density within the NGC 55 disc. For the outer-disc data the observed profile is fully consistent, within the limits of the statistics, with the presence of a shadowing effect. However, there is no evidence for a similar feature for the inner-disc region. The most likely interpretation of the latter result is in terms of in-filling of the putative shadow by either diffuse emission or unresolved point sources located within ~3.5 kpc of the centre of NGC 55 (assuming that the galaxy is at a distance of 1.6 Mpc – see Puche & Carigan 1988). We find that if the radius of the inner-disc region is decreased, the apparent enhancement in the 0.25-keV emission of the inner disc increases somewhat, whereas the converse is true if this radius is increased, consistent with the excess emission having a central concentration. Based on the level of outer-disc emission for $N_H > 10^{21}$ cm⁻² (Fig. 4), the peak surface brightness of the in-filling emission in the inner-disc range.

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Galactic foreground absorption and extends over an area of \( \sim 50 \) arcmin\(^2\), then the corresponding X-ray luminosity in the 0.25-keV band is \( \sim 10^{37} \) erg s\(^{-1}\). Interestingly, of the point sources listed in Table 2, only the supersoft source, with \( L_X \approx 4 \times 10^{37} \) erg s\(^{-1}\), has a higher apparent 0.25-keV
Table 3. The mean 0.25-keV count rates for the three regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>No. pixels</th>
<th>Mean count rate (count s$^{-1}$ arcmin$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>158</td>
<td>$690 \pm 11 \times 10^{-6}$</td>
</tr>
<tr>
<td>Inner disk</td>
<td>23</td>
<td>$691 \pm 18 \times 10^{-6}$</td>
</tr>
<tr>
<td>Outer disk</td>
<td>46</td>
<td>$643 \pm 15 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

band luminosity. Thus NGC 55 is far from being a luminous source of soft X-rays.

However, an important question which still needs to be addressed is whether the shadow of the outer disc might also be partially masked by unresolved 0.25-keV emission from NGC 55. In this context it is useful to make a comparison with the face-on Sc supergiant spiral M101. In a recent study, Snowden & Pietsch (1995) have shown that this galaxy is a bright and extended soft X-ray source, and have...
derives the radial profile of its 0.25-keV emission over an angular scale of 0–20 arcmin. Although the distance of M101 is a factor ~4.5 greater than that of NGC 55, the corrected $D_L$, diameter of the two galaxies is almost the same (23.8 and 24.2 arcmin for M101 and NGC 55 respectively – Tully 1988). From the 0.25-keV radial profile of M101, the ratio of the average (area-weighted) surface brightness within a radius of 7.5 arcmin to that in the annulus between radii of 7.5–17.5 arcmin is ~4. Although in going from a face-on to an edge-on aspect a number of unknown geometrical (e.g., emission scaleheight) and absorption corrections will apply, this does support the possibility of a significant fall-off in the intensity of diffuse/unresolved component between the inner- and outer-disc regions in NGC 55. The fact that the lowest $N_{\text{H}_2}$ bin for the outer disc in Fig. 4 lies below the control level is also consistent with the hypothesis that any masking of the shadow in this region of the disc is slight. In the present paper we take the view that the depth of shadow observed in the outer-disc region of NGC 55 (beyond a radius of 7.5 arcmin) provides an effective measure of the intensity of the 0.25-keV extragalactic background rather than simply giving a lower limit value.

4 THE 0.25-keV EXTRAGALACTIC XRB INTENSITY

We have applied a statistical weighting technique similar to that described in BW94 to the 46 intensity measurements for the outer-disc region of NGC 55, in order to obtain a best estimate of the 0.25-keV extragalactic background intensity, $C_{\text{ext}}$. Specifically, $C_{\text{ext}}$ is the extragalactic XRB intensity, corrected for all line-of-sight absorption, after excluding point sources to a particular 0.25-keV sensitivity threshold. One problem is that this threshold (when expressed in terms of the intrinsic source flux in, say, the 0.5–2 keV band) actually varies between the control region, where the absorption is due only to the foreground Galactic H i, and the on-source regions, where there is significant additional absorption due to the H i in the disc of NGC 55. In effect, the source-exclusion process is less effective in removing sources for the on-source regions, since the extra absorption reduces the 0.25-keV count rate of discrete sources behind NGC 55. In Appendix A the method of BW94 is reformulated to account for this varying threshold. The result is a correction term which should be incorporated in equation (4) of BW94; however, in practice this correction amounts to only a ~5 per cent effect, which is small compared with the statistical errors.

Using the method described in Appendix A, we derive a weighted mean value $C_{\text{ext}} = (228 \pm 90) \times 10^{-8}$ count s$^{-1}$ arcmin$^{-2}$. This is a 2.5$\sigma$ positive detection of the unresolved extragalactic background. Allowing for a transmission of only 29 per cent through the foreground Galactic H i column ($N_{\text{H}_2} = 1.55 \times 10^{20}$ cm$^{-2}$), the observed $C_{\text{ext}}$ signal is thus $66 \times 10^{-8}$ count s$^{-1}$ arcmin$^{-2}$, or ~10 per cent of the total observed 0.25-keV band background signal. Assuming that the spectrum of the extragalactic emission can be reasonably represented by a power law of energy index $\alpha = 1$ (the in-band conversion is not very sensitive to the assumed spectral form), the derived count rate corre-
5 DISCUSSION

Prior to ROSAT, the best estimate of the intensity of the total extragalactic XRB at 0.25 keV had been obtained from wide-beam measurements of the shadowing of the soft XRB by neutral gas in the SMC (McCammon et al. 1976). McCammon & Sanders (1990) quote an up-dated result from this study, namely that the 95 per cent confidence upper limit for flux originating from beyond the SMC is 30 keV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\). McCammon & Sanders (1990) also point out that their upper limit will need to be revised upperwards by a significant factor (i.e., \(\approx 1.5\)) if there is substantial additional soft X-ray opacity in our Galaxy due to He\(^{+}\) and/or He\(^{++}\) associated with the ionized component of the ISM. Of course, this important caveat also applies to other shadowing studies, including the present work (see Section 4).

More recently, a number of shadowing studies have been reported which make full use of the high spatial resolution of the ROSAT telescope and the low intrinsic background of the ROSAT PSPC. BW94 obtained a 95 per cent upper limit of 40 keV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\) based on a search for shadow cast by the H\(^{+}\) associated with the galaxy pair NGC 4725/4747. Snowden & Pietsch (1995) in their analysis of the ROSAT observations of M101 note a depression in the 0.25-keV surface brightness which correlates with a galactic spiral arm, and from which they derive an estimate of the extragalactic XRB intensity at 0.25 keV of 28 ± 10 keV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\). Also, Cui et al. (1996) quote a 95 per cent lower limit of 28 ± 10 keV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\) based on an analysis of the properties of a sample of face-on galaxies.

In the present paper we detect the shadow cast by the outer H\(^{+}\) disc of NGC 55, and use this to determine the intensity of extragalactic XRB at 0.25 keV to be 29.4 ± 7.2 keV cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\). Thus there is evidence for a convergence of recent measurements.

The spectrum of the extragalactic XRB in the soft X-ray band can, in principle, be obtained by combining our present measurements at 0.25 keV with recent estimates of the normalization of the extragalactic spectrum at 1 keV. Since shadowing measurements are not practical at this higher energy, these latter estimates rely on spectral model-

<table>
<thead>
<tr>
<th>(N_{H}) (10(^{20}) cm(^{-2}))</th>
<th>(C_{\text{ext}}) (count s(^{-1}) arcmin(^{-2}))</th>
<th>Total 0.25 keV XRB intensity (keV cm(^{-2}) s(^{-1}) sr(^{-1}) keV(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.55</td>
<td>228 ± 90 \times 10^{-6}</td>
<td>29.4 ± 7.2</td>
</tr>
<tr>
<td>upper limits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.85</td>
<td>273 ± 113 \times 10^{-6}</td>
<td>33.0 ± 9.0</td>
</tr>
<tr>
<td>2.05</td>
<td>307 ± 128 \times 10^{-6}</td>
<td>35.7 ± 10.2</td>
</tr>
<tr>
<td>lower limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.45</td>
<td>216 ± 87 \times 10^{-6}</td>
<td>28.5 ± 6.7</td>
</tr>
</tbody>
</table>

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α = 1 (and no measurable intrinsic absorption within the 0.1–0.4 keV band), then the residual extragalactic XRB spectrum from 0.25 to 1 keV has a spectral index α ≈ 0.6. At the other extreme, if the resolved fraction is ~ 60 per cent and QSO spectra are more typically characterized by α ≈ 1.2, then we have already accounted for the whole of the 0.25-keV extragalactic XRB. Fig. 5 provides a schematic summary of the available constraints on the spectral form of the extragalactic XRB and the integrated QSO contribution as noted above.

6 CONCLUSIONS

We have used ROSAT observations of the shadow cast by the disc of the nearby spiral galaxy NGC 55 to derive a new measurement of the total extragalactic background signal at 0.25 keV. We obtain $29.4 \pm 7.2$ keV cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$ for the extragalactic XRB intensity at 0.25 keV, which is in excellent agreement with earlier constraints and estimates of this quantity. The spectrum of the extragalactic XRB in the soft X-ray (0.25–1 keV) band is now fairly well constrained, some 15 years after the definitive HEAO-1 measurements covering the 3–50 keV energy range were published. It is somewhat perverse that the most recent part of the XRB spectrum to be measured may turn out to be the first to be fully explained in terms of the integrated emission of known populations of sources.

ACKNOWLEDGMENTS

We thank Steve Snowden for providing software relating to the ROSAT PSPC background and detector efficiency map. CRB and TPR acknowledge financial support from PPARC. The ROSAT data used in this project were obtained from the Leicester Database and Archive Service (LEDAS).

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APPENDIX A: SHADOWING MEASUREMENTS – THE EFFECT OF A VARYING SOURCE EXCLUSION THRESHOLD

In BW94 the 0.25-keV extragalactic XRB intensity was calculated for each pixel in the shadowed region via the expression

\[ C_{\text{ext}} = \frac{\bar{C} - C_{\text{obs},i}}{T_{\text{gal}} - T_{\text{tot},i}}. \]  

(A1)

Here \( C_{\text{ext}} \) is the value of the 0.25-keV extragalactic XRB intensity, fully corrected for absorption, as derived from the count rate \( C_{\text{obs},i} \), measured in the \( i \)th pixel. \( \bar{C} \) is the mean intensity in the control sample, \( T_{\text{gal}} \) is the transmission factor for an extragalactic signal in the control region (based solely on the foreground Galactic H I column density), and \( T_{\text{tot},i} \) is the equivalent transmission factor for the \( i \)th pixel (including the absorption in the H I disc of the shadowing galaxy).

An error was assigned to each measurement, assuming that the \( C_{\text{obs},i} \) values originate from a Gaussian distribution with the same standard deviation as the control sample. The weighted mean of the \( C_{\text{ext}} \) values over the set of ‘on-source’ pixels is then taken as the best estimate of the extragalactic XRB intensity.

This approach must be modified in the situation where the flux threshold for the exclusion of bright discrete sources varies due to the additional absorption in the shadowing target. The average intensity measured in the control region can be equated to the sum of the local foreground emission \( C_{\text{tot}} \) plus the transmitted fraction of the unresolved extragalactic signal:

\[ \bar{C} = C_{\text{tot}} + T_{\text{gal}} C_{\text{ext}} \]  

(A2)

The equivalent expression for a pixel in the shadowed region is

\[ C_{\text{obs},i} = C_{\text{tot}} + T_{\text{tot},i} (C_{\text{ext}} + \Delta C_{\text{ext},i}). \]  

(A3)

The \( \Delta C_{\text{ext},i} \) term reflects the fact that the intensity of the unresolved extragalactic XRB is somewhat higher for a pixel in the shadowed region since \( T_{\text{tot},i} < T_{\text{gal}} \), and thus there is a higher source exclusion threshold in terms of intrinsic source flux. Note that if we set \( \Delta C_{\text{ext},i} = 0 \), then the elimination of \( C_{\text{obs}} \) from equations (A2) and (A3) takes us back to equation (A1).

The correct expression for \( C_{\text{ext}} \) is then

\[ C_{\text{ext}} = \frac{\bar{C} - C_{\text{obs},i}}{T_{\text{gal}} - T_{\text{tot},i}} + \frac{\Delta C_{\text{ext},i} T_{\text{tot},i}}{T_{\text{gal}} - T_{\text{tot},i}}. \]  

(A4)

In practice, the values of \( \Delta C_{\text{ext},i} \) are calculated as:

\[ \Delta C_{\text{ext},i} = AF \int_{S_{\text{low}}}^{S_{\text{high}}} N(S) S \, dS, \]  

(A5)

where \( N(S) \) is the differential form of the 0.5–2.0 keV source counts (e.g. Hasinger et al. 1993), \( F \) is the conversion factor from a 0.5–2.0 keV band flux \( (S) \) to a 0.25-keV band count rate \( (C) \) (assuming a particular continuum form but no absorption), and \( A \) represents the relevant solid angle conversions. The limits of the integration are \( S_{\text{high}} = C_{\text{min}} / FT_{\text{tot},i} \) and \( S_{\text{low}} = C_{\text{min}} / FT_{\text{gal}} \), where \( C_{\text{min}} \) is the 0.25-keV source detection threshold.