CONTRIBUTION OF UNRESOLVED POINT SOURCES TO THE DIFFUSE X-RAY BACKGROUND BELOW 1 keV

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ABSTRACT

We present here the analysis of X-ray point sources detected in several observations available in the XMM-Newton public archive. We focused, in particular, on energies below 1 keV, which are of particular relevance to the understanding of the diffuse X-ray background (DXB). The average field of all the exposures is 0.09 deg$^{-2}$. We reached an average flux sensitivity of $5.8 \times 10^{-16}$ erg s$^{-1}$ cm$^{-2}$ in the soft band (0.5–2.0 keV) and $2.5 \times 10^{-16}$ erg s$^{-1}$ cm$^{-2}$ in the very soft band (0.4–0.6 keV). In this paper, we discuss the log $N$–log $S$ results, the contribution to the integrated X-ray sky flux, and the properties of the cumulative spectrum from all sources. In particular, we found an excess flux at around 0.5 keV in the composite spectrum of faint sources. The excess seems to be a general property of all the fields observed suggesting an additional class of weak sources is contributing to the X-ray emission at these energies. Combining our results with previous investigations, we have also quantified the contribution of the individual components of the DXB in the 3/4 keV band.

Key word: X-rays: diffuse background

1. INTRODUCTION

The existence of a diffuse X-ray background (DXB) was one of the first discoveries of extrasolar X-ray astronomy (Giacconi et al. 1962). In the intervening decades, observations with improving angular and spectral resolution have enhanced our understanding of the components that make up this background. Above 1 keV, the emission is highly isotropic on large angular scales, has extragalactic origin, and can be fully accounted by the superposition of unresolved point sources (Mushotzky et al. 2000). Below 1 keV, the DXB is a mixture of the Galactic diffuse emission from a hot bubble surrounding the solar neighborhood (the Local Bubble, LB), charge exchange from solar wind ions (SWCX), hot gas in the Galactic halo (GH), and an extragalactic flux from point sources and from intercluster warm gas that may contain the bulk of the present-day baryons (Cen et al. 1999; Ursino & Galeazzi 2006; Galeazzi et al. 2009). Analyses of the soft X-ray background (below 1 keV) usually model the LB component as unabsorbed plasma thermal emission, the hotter GH emission as multiple plasma thermal components absorbed by the gas in the Galactic disk, and the unresolved extragalactic sources component (primarily active galactic nuclei, AGNs), with an absorbed power law, which is often an extension of the power-law fit derived at higher energy (Gendreau et al. 1995; McCammon et al. 2002).

Recent investigations have attempted to separate the various components by using shadow experiments and other observational techniques (Galeazzi et al. 2007; Smith et al. 2006; Henley et al. 2008), however such experiments only separate the various components into two major groups, foreground and background, and rely on understanding the spectral properties of the different components to fully separate them. The contribution of unresolved point sources to the DXB dominates above 1 keV and is still significant at lower energies. A good understanding of its properties, beyond the extension of higher energy investigations, is therefore critical for any investigation of the DXB. This, however, is made difficult by the characteristics of current X-ray missions, as high angular resolution missions such as Chandra, designed for good source identification, have a relatively limited response in the energy range of interest, while missions designed for good response in the low-energy range, such as the X-ray quantum calorimeter program (XQC; McCammon et al. 2002), lack the necessary angular resolution. XMM-Newton, while not optimized for such an investigation, is a good compromise of angular resolution and response below 1 keV, and has been used in our investigation.

2. DATA REDUCTION

2.1. Data Preparation

We used the data from 10 observations, corresponding to five different targets available in the XMM-Newton public archive. The choice of the targets was based on several considerations. To limit the effect of absorption from the neutral hydrogen (NH) and contamination from galactic emission, we used targets at least 30° above the galactic plane and with NH densities smaller than $2.0 \times 10^{20}$ cm$^{-2}$. To have significant statistics, we also limited the investigation to targets with at least 80,000 s of good observing time. The targets used and their characteristics are summarized in Table 1.

Data from the full XMM-Newton field of view were used in the analysis. The raw data were processed using the Standard Analysis Software (SAS). Events spread at most in two contiguous pixels for the PN (i.e., pattern = 0–4) and in four contiguous pixels for the MOS (i.e., pattern = 0–12) have been selected. Event files were cleaned of bad pixels (hot pixels, events out of the field of view, etc.) and soft proton flares. The soft proton flares are due to protons with energies less than a few hundred keV. The flares can produce a count rate up to a factor of 100 greater than the mean stationary background count rate. They are variable during an observation and from observation to observation, and do not have a predictable spectral shape or spatial distribution on the detector (Read & Ponman 2003). In order to remove periods of unwanted high background levels, we rejected the times with a 0.5–10 keV count rate higher than 8 counts s$^{-1}$ for the PN and 3 counts s$^{-1}$ for each of the two MOS cameras. Multiple observations of the same XMM-Newton targets were added using SAS task merge.

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1 http://cxc.harvard.edu/cdo/about_chandra/overview_cxo.html

2 http://xmm.vilspa.esa.es/sas/
Table 1
Targets Used in this Investigation

| Target            | \(l\)   | \(b\)  | \(NH\left(10^{20}\text{ cm}^{-2}\right)\) |
|-------------------|---------|--------|------------------------------------------|
| Lockman Hole      | \(149\ 16\ 48.1\) | \(53\ 08\ 45.9\) | \(0.7\)                     |
| Hubble Deep Field N | \(125\ 53\ 31.3\) | \(54\ 48\ 52.4\) | \(1.4\)                     |
| Deep Field 1334+37 | \(85\ 37\ 22.5\) | \(75\ 55\ 16.4\) | \(0.8\)                     |
| Eridanus Hole     | \(213\ 25\ 17.9\) | \(-39\ 04\ 25.6\) | \(0.86\)                    |
| AXAF Ultra deep F | \(223\ 34\ 36\) | \(-54\ 26\ 33.3\) | \(1.0\)                     |

2.2. Source Detection

The clean event files were used to generate MOS1, MOS2, and PN images in the 0.4–0.6 keV and 0.5–2.0 keV bands. A corresponding set of exposure maps was generated to account for spatial quantum efficiency, mirror vignetting, and field of view of each instrument by running XMM-SAS task \texttt{eexpmap}. This task evaluates the above quantities assuming an event energy that corresponds to the mean of the energy band boundaries.

The excellent relative astrometry between the three cameras (within \(1\arcsec\), well under the FWHM of the point-spread function, PSF) allowed us to merge together the MOS and PN images in order to increase the signal-to-noise ratio of the sources and reach fainter X-ray fluxes; the corresponding exposure maps were merged as well. The source detection and characterization procedure applied to the image sets involved the creation of a background map for each energy band. As a first step, the XMM-SAS sliding cell detection algorithm \texttt{eboxdetect} was run in local detection mode. In this procedure, source counts were collected in the cells of \(5 \times 5\) pixels adopting a low threshold in the detection likelihood to produce a source list. The XMM-SAS task \texttt{esplinemap} removed from the original merged image within a radius of 1.5 times the FWHM of the PSF all the sources in the list and creates the so-called “cheesed” image and a mask image with value unity in each pixel outside the source circles and zero within. We then flat-fielded the cheesed images by dividing them by the exposure maps and smoothed them with a Gaussian of 5\arcsec FWHM using SAS task \texttt{asmooth}. The masked images were also smoothed with the same Gaussian as the actual image data. Finally, background maps were calculated by dividing the smoothed cheese images by the smoothed mask images. The result was multiplied by the exposure maps. An example of background map of the Lockman Hole is shown in Figure 1.

Using the calculated background maps, \texttt{eboxdetect} was run in map detection mode to identify point sources. In map detection mode, the background is taken from the background maps, resulting in improved detection sensitivity as compared to the local detection step. The source list produced by \texttt{eboxdetect} was then used as input for \texttt{emldetect}. For all the sources detected with the sliding cell method, this task performs a maximum likelihood PSF fit. In this way, refined positions and fluxes for the sources were determined. As likelihood threshold for the detection, we adopted the value \(\text{det}_{ml} = 6\) (about 3\(\sigma\)). Source detection summaries for each pointing in both the

Figure 1. Background map derived as described in the text for the Lockman Hole target.
0.5–2.0 keV and 0.4–0.6 keV bands are listed in Tables 2 and 3, respectively.

The count rate-to-flux conversion factors for individual cameras were calculated using XSPEC and the EPIC response matrices generated by XMM-SAS tasks *rmfgen* and *arfgen*. The spectral model used was an intrinsic power law $\Gamma = 1.52$ affected by Galactic NH. The individual conversion factors are listed in Table 4. The total conversion factor (CF) was calculated using the exposure times for MOS1, MOS2, and PN, and the conversion factors for the three instruments, CFMOS1, CFMOS2, and CFPN following the formula

$$\frac{T_{\text{TOT}}}{\text{CF}} = \frac{T_{\text{MOS1}}}{\text{CFMOS1}} + \frac{T_{\text{MOS2}}}{\text{CFMOS2}} + \frac{T_{\text{PN}}}{\text{CFPN}},$$

(1)

where $T_{\text{TOT}} = (T_{\text{MOS1}} + T_{\text{MOS2}} + T_{\text{PN}})$. The source flux is then straightforward:

$$F_X = \text{CF} \times \text{CR}. $$

We generated sensitivity maps for each X-ray field and energy band, which contains the faintest flux at which a source can be detected at the assumed level of significance above the local background. The “sky coverage” defines the area of the sky covered down to a given flux limit, as a function of the flux. Due to the telescope vignetting and the increase in the size of the PSF in the outer regions of the detector, the sensitivity decreases toward the outer detector region. The sky coverage at a given flux was then obtained by adding up the contribution of all detector regions with a given flux limits. Figure 2 shows the average sky coverage for all pointing in the 0.5–2.0 keV and 0.4–0.6 keV bands.

### Table 2

| Target                  | Exposure Time\(^a\) (s) | Minimum Flux (erg s\(^{-1}\) cm\(^{-2}\)) | Total Faint\(^b\) | Bright\(^c\) |
|-------------------------|--------------------------|------------------------------------------|--------------------|-------------|
| Lockman Hole            | 628,945                  | $2.34 \times 10^{-16}$                   | 291                | 185         |
| Hubble Deep Field       | 131,751                  | $7.18 \times 10^{-16}$                   | 144                | 57          |
| Deep Field 1334+37      | 165,989                  | $6.45 \times 10^{-16}$                   | 159                | 60          |
| Eridanus Hole           | 50,230                   | $9.96 \times 10^{-16}$                   | 110                | 38          |
| AXAF Ultra deep F       | 431,618                  | $3.19 \times 10^{-16}$                   | 225                | 149         |

Notes.

\(^a\) Total exposure time from all available observations of the same target.
\(^b\) Sources with flux $\leq 2 \times 10^{-15}$ erg s\(^{-1}\) cm\(^{-2}\).
\(^c\) Sources with flux $\geq 2 \times 10^{-15}$ erg s\(^{-1}\) cm\(^{-2}\).

### Table 3

| Target                  | Minimum Detected Flux (erg s\(^{-1}\) cm\(^{-2}\)) | Total | Faint\(^b\) | Bright\(^c\) |
|-------------------------|---------------------------------------------------|-------|-------------|-------------|
| Lockman Hole            | $1.67 \times 10^{-17}$                           | 143   | 99          | 44          |
| Hubble Deep Field       | $4.02 \times 10^{-16}$                           | 50    | 13          | 37          |
| Deep Field 1334+37      | $3.84 \times 10^{-16}$                           | 75    | 28          | 47          |
| Eridanus Hole           | $4.48 \times 10^{-16}$                           | 47    | 15          | 32          |
| AXAF Ultra deep F       | $1.6 \times 10^{-17}$                            | 108   | 78          | 30          |

Notes.

\(^b\) Sources with flux $\leq 10^{-15}$ erg s\(^{-1}\) cm\(^{-2}\).
\(^c\) Sources with flux $\geq 10^{-15}$ erg s\(^{-1}\) cm\(^{-2}\).

### Table 4

| EPIC Camera | 0.5–2.0 keV | 0.4–0.6 keV |
|-------------|-------------|-------------|
| PN          | $1.85 \times 10^{-12}$ | $1.48 \times 10^{-12}$ |
| MOS         | $5.9 \times 10^{-12}$   | $6.18 \times 10^{-12}$   |

Notes. Count-rate-to-flux conversion factors for the individual EPIC cameras and energy bands, stated in units of erg s\(^{-1}\) cm\(^{-2}\) for a rate of 1 counts s\(^{-1}\). A photon-index power law of $\Gamma = 1.52$ affected by Galactic absorption of $1.0 \times 10^{20}$ cm\(^{-2}\) was assumed. Both MOS cameras were assumed to be identical.

![Figure 2](image)

**Figure 2.** Average sky coverage for all pointing in the 0.5–2.0 keV and 0.4–0.6 keV bands.

### 3. RESULTS

#### 3.1. log $N$–log $S$ and Total Flux from Discrete Sources

The cumulative log $N$–log $S$ distribution (shown in Figure 3) for all the observations has been computed by summing up the contribution of each source, weighted by the area in which the source could have been detected, following the formula

$$N(> S) = \sum_{i=1}^{N_i} \left( \frac{1}{\Omega_i} \right) \text{deg}^{-2},$$

(3)

where $N_i$ is the total number of detected sources in the field with flux greater than $S$ and $\Omega_i$ is the sky coverage associated with the flux of the $i$th source. The variance of the source number counts is then defined as

$$\sigma_i^2 = \sum_{i=1}^{N_i} \left( \frac{1}{\Omega_i} \right)^2.$$  

(4)

Our result in the 0.5–2.0 keV energy band is qualitatively similar to other surveys (e.g., in Figure 3 we show the fits of Giacconi et al. 2001, Mateos et al. 2008, Hasinger et al. 1998, and Mushotzky et al. 2000), however our sample seems consistently richer in faint sources. When we fit the data with a power law in the flux range $9.0 \times 10^{-16}$ to $1.0 \times 10^{-13}$ erg s\(^{-1}\) cm\(^{-2}\), the resulting best fit to the log $N$–log $S$ is

$$N(> S) = (119 \pm 10) S^{-1.17 \pm 0.08},$$

(5)

where $S$ is the flux in units of $10^{-14}$ erg s\(^{-1}\) cm\(^{-2}\).
The lines represent the best fits from Giacconi et al. (2001), Mateos et al. (2008), curves represent the power-law fit to the two experimental data sets, respectively. The black and gray bands for all targets used in this investigation. The black and gray circles) bands for all targets used in this investigation. The black and gray bands for all targets used in this investigation. The black and gray circles) bands for all targets used in this investigation.

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Figure 3. Average log N–log S in the 0.5–2 keV (full circles) and 0.4–0.6 keV (empty circles) bands for all targets used in this investigation. The black and gray curves represent the power-law fit to the two experimental data sets, respectively. The lines represent the best fits from Giacconi et al. (2001), Mateos et al. (2008), Hasinger et al. (1998), and Mushotzky et al. (2000).

To quantitatively compare our result with previous investigations, we looked at the number of detected sources at the faint end, bright end, and middle point of the flux range covered by our investigation. We compared our results both with the previous Chandra surveys by Mushotzky et al. (2000) and Mushotzky et al. (2000) and Giacconi et al. (2001) and the XMM-Newton results by Baldi et al. (2002). At the faint end of our log N–log S plot, the number of sources detected by our investigation is 42% higher than the estimates of Mushotzky et al. (2000) and Giacconi et al. (2001) and 35% higher than the results of Baldi et al. (2002). At brighter fluxes our results are consistent, within the errors, with both Chandra data and the XMM-Newton survey. At the middle of the log N–log S (S = 10^{-14} cgs), the number of detected sources is 20% higher than the Chandra results and 26% higher than XMM-Newton results. This discrepancy could arise from cosmic variation and/or by the different sample investigated. Baldi et al. (2002) used a single, large area of the sky, while in most other investigations, e.g., Mushotzky et al. (2000) and Hasinger et al. (1998), the sources were identified and the log N–log S plot was limited to AGNs. While AGNs are expected to be the biggest contribution to X-ray point sources, our result, as confirmed by our spectral analysis reported in the next section, indicates that there is a significant component of non-AGN faint sources.

We also computed the resolved intensity of the detected sources by summing over the flux of each source divided by the inverse area over which the source would have been detected. The total intensity of the sources in all the pointings, in the flux range 7×10^{-16} to 10^{-14} erg s^{-1} cm^{-2} for the 0.5–2.0 keV band is 4.4±0.4×10^{-12} erg s^{-1} cm^{-2} deg^{-2} which corresponds to ~36% of the total DXB in the same band.

Figure 3 also shows the log N–log S distribution for sources in the 0.4–0.6 keV band, extending to a flux limit of 5.6×10^{-12} erg s^{-1} cm^{-2}. Again, we fit the data with a power law in the flux range of 5.6×10^{-16} to 2.0×10^{-14} erg s^{-1} cm^{-2}. The resulting best fit to the log N–log S is

\[ N(>S) = (21.7 \pm 4.9)S^{-1.16 \pm 0.15}. \tag{6} \]

The total intensity of the sources in all the pointings, in the flux range 2.0×10^{-16} to 2.0×10^{-14} erg s^{-1} cm^{-2} in the 0.4–0.6 keV band is 1.07±0.12×10^{-12} erg s^{-1} cm^{-2} deg^{-2} which corresponds to ~25% of the total DXB in that energy band. We note that all the sources identified in the 0.4–0.6 keV band are also identified in the 0.5–2.0 keV band.

3 http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/manual/manual.html

3.2. Energy Spectra

We measured the average stacked spectrum of all the sources detected in the 0.5–2.0 keV and 0.4–0.6 keV bands. For this purpose, we use only PN data. The background spectrum was obtained using the event file of the total field of the same exposure, after removing the detected sources. The background was scaled by the ratio of the total exposure maps of the sources and the background. The SAS tasks rmfgen and arfgen were used to produce EPIC response matrices. We used XSPEC3 to compute the slope of a power-law spectrum with average NH = 1×10^{-20} cm^{-2}. The fit was over the energy range 0.5–7.5 keV (the PN spectrum shows a strong Cu–K line at 8.1 keV that should be avoided). We obtained a photon index of 1.75±0.07 with normalization 7.24±0.07 photons keV^{-1} s^{-1} cm^{-2} sr^{-1} and 1.93±0.08 with normalization of 5.87±0.06 photons keV^{-1} s^{-1} cm^{-2} sr^{-1} for all the sources detected in the 0.5–2.0 keV and 0.4–0.6 keV band, respectively. Errors refer to 90% confidence levels. Both spectra with the best-fit power law are shown in Figure 4. We note that, as it may be expected, the spectrum of the sources identified in the 0.4–0.6 keV energy band is softer than that for the sources identified in the 0.5–2 keV band. The spectrum of the sources identified in the 0.5–2.0 keV band shows an excess of counts around 1 keV at the 3σ level (\(\chi^2 = 26.7, n = 9\)). The excess is well fitted with a zero-redshift thermal component with temperature T = 0.92 keV, and emission measure \(EM = 9 \times 10^{-5} \text{ cm}^{-6} \text{ pc}\), corresponding to a flux of 6.5×10^{-14} erg s^{-1} cm^{-2} deg^{-2}. We attribute this thermal component to the contribution of stars in the Milky Way (Kashyap et al. 1992).

We also investigated the dependence of the spectral shape on the source brightness. This is particularly important as in

Figure 4. Average spectra of all the sources detected in the 0.5–2.0 keV (full black circles) and 0.4–0.6 keV (empty gray circles) bands. The dark gray and gray curves represent the power-law fit in energy range 0.5–7.5 keV, for the two bands, respectively.
most studies of the DXB only bright sources are detected and their properties are extended to faint ones. For this purpose, we divided the detected sources into two groups, bright and faint, based on their flux. The threshold between the two groups was set to \(2.0 \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}\). The spectrum of bright sources detected in the 0.5–2.0 keV band was well fitted in the energy range 0.5–7.5 keV with a power law of photon index 1.87 ± 0.07 and normalization 0.70 ± 0.02 photons keV\(^{-1}\) s\(^{-1}\) cm\(^{-2}\) sr\(^{-1}\). Note that the spectrum of faint sources does not show any significant thermal component around 1 keV.

We investigated the nature of the excess counts below 0.7 keV and here is a summary of our conclusions.

1. The excess has a statistical significance of several sigmas \((\chi^2 = 217, n = 39)\) and cannot be simply explained by statistical fluctuations.
2. The excess was present in all pointings and is not due to a single anomalous source or target.
3. We tried to fit the spectrum of faint sources with two power laws, one dominating above 1 keV, the other below 1 keV, but we could not improve the fit significantly.
4. We also tried to fit the spectrum with a power law plus a thermal component (Figure 6) and the fit was greatly improved. Note that, since the spectrum is the sum of the contribution from several sources, a fit with a single thermal component has, per se, limited significance. However, the goodness of the fit is a strong indication that the excess flux may be thermal in nature. The best-fit parameters for the thermal component are \(T = 2.1 \times 10^6\) K, redshift \(z = 0.02\), and emission measure \(EM = 0.00014\) cm\(^{-6}\) pc, for a total flux of the excess component equal to \(8.5 \times 10^{-14}\) erg s\(^{-1}\) cm\(^{-2}\) deg\(^{-2}\). The corresponding power law has photon index \(\alpha = (1.03 \pm 0.02)\) and normalization \(0.55 \pm 0.02\) photons keV\(^{-1}\) s\(^{-1}\) cm\(^{-2}\) sr\(^{-1}\). At this temperature, the thermal component is expected to have a significant emission in O vii and O viii, at a redshift that is practically indistinguishable from zero with the resolution of current satellites. The estimated emission from the excess thermal component is 0.19 LU (photons s\(^{-1}\) cm\(^{-2}\) sr\(^{-1}\)) and 0.06 LU for the O vii and O viii, respectively.
5. We investigated the possibility that the excess is due to the contribution of Milky Way stellar sources. Kashyap et al. (1992) estimated the contribution to the diffuse soft X-ray background flux from Galactic stars at various energies ranging from 0.1 to ~5 keV. They found that stellar contribution at high Galactic latitudes is less than 3% for photon energies less than 0.3 keV, 3%–17% in the medium energy (~0.4 to ~0.9 keV) and 10%–30% in the high-energy band (~0.8–2.0 keV). Stars mainly have two temperature thermal spectra, since stellar corona emission is composed of two components namely a hot active component at nominal temperature \(kT_a \sim 1\) keV (\(1.1 \times 10^7\) K) and a somewhat cooler quiescent component \(kT_q \sim 0.3\) keV (\(3.5 \times 10^6\) K). In some stars only one thermal component is present, with a mean coronal temperature \(kT\) in the range [0.5, 0.8 keV] (5.8–9.3) \times 10^6\) K; see, e.g., Kashyap et al. 1992; Dell’Oro et al., 2004; Lopez-Santiago et al., 2007). We have already discussed the excess thermal emission at \(T = 0.92\) keV which we attribute to the stellar hot active component and we investigated the possibility that this lower temperature excess could be due to the cooler quiescent component. We fitted the excess with a thermal component at redshift zero and obtained a good fit with temperature \(kT = 0.15\) keV (\(1.7 \times 10^6\) K) and emission measure \(EM = 0.00016\) cm\(^{-6}\) pc. The total flux of the excess thermal component is compatible with what expected for stellar contribution, however, the best-fit temperature is significantly smaller than the temperature range predicted by Kashyap et al. (1992). We also tried to fit the excess emission constraining the temperature values to the ranges described by Kashyap et al. (1992), using both one- and two-temperature models, but we were unable to obtain a good fit.

In conclusion, we believe that, when we look at faint sources in addition to the typical AGN contribution, there is also a
significant contribution from a different class of sources with primarily thermal emission. Although the total flux of this contribution is consistent with stellar origin, its temperature is too low compared to typical stellar emission. This class of sources may also be explained by unresolved faint galaxies, galaxy clusters, and/or groups, and must be taken into account in the DXB budget.

We repeated the same investigation for sources detected in the energy band 0.4–0.6 keV. The spectrum of bright (flux $\geq 10^{-15}$ erg s$^{-1}$ cm$^{-2}$) sources detected in the 0.4–0.6 keV band is well described with a power-law fit of photon indexes 2.05 ± 0.02 with normalization of 4.74 ± 0.04 photons keV$^{-1}$ s$^{-1}$ cm$^{-2}$ sr$^{-1}$ (Figure 7). The spectrum of faint sources has a 3σ statistical significance for the thermal excess below 0.7 keV and could not be fitted with a simple power law in that range (Figure 7). We performed the power-law fit over the energy range 0.7–7.5 keV, obtaining a photon index $\Gamma = 1.69 \pm 0.02$ with normalization of 1.02 ± 0.03 photons keV$^{-1}$ s$^{-1}$ cm$^{-2}$ sr$^{-1}$. In Figure 8, we show the spectrum of faint sources with overlapped the power law plus thermal component model. For the thermal component, we used the same parameters as for the fit of faint sources identified in the soft band. The result of the spectral analysis in both bands is summarized in Tables 5 and 6.

4. THE DIFFUSE X-RAY BACKGROUND

We combined our result with previous results to create a global picture of the DXB emission below 1 keV. As discussed before, in this energy range, the DXB is a mixture of the Galactic LB emission, solar wind charge exchange (SWCX), hot gas in the GH, and extragalactic flux from point sources and from intergalactic warm–hot gas (WHIM). The ROSAT All Sky Survey (RASS) represents the most extensive study of the X-ray diffuse emission below 1 keV. Analysis of RASS data and subsequent observations has shown that there is a significant spatial and temporal variation in the DXB emission (Snowden et al. 2000). The temporal variation is mostly attributable to the SWCX, while the spatial variation seems mostly due to LB and GH emission. An average over the whole sky indicates that the total diffuse X-ray emission in the 0.4–2 keV energy band is $3.04 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$ (Kuntz et al. 2001). More recent work using XMM-Newton, Chandra, and Suzaku produces similar results. In particular, combining observations performed by Smith et al. (2005, 2006), Galeazzi et al. (2007), Henley et al. (2007, 2008), and A. Gupta et al. (2009, in preparation), we obtained a total flux in O vii plus O viii lines of $(3.1 \pm 0.8) \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$ (12.5 ± 3.6 LU). Considering that the 3/4 keV band is dominated by these lines, the two results are in good agreement.

Moreover, the observations by Smith et al. (2005, 2006), Galeazzi et al. (2007), Henley et al. (2007, 2008), and A. Gupta et al. (2009, in preparation) are shadow experiments and can be used to separate the DXB emission into two components, a foreground component consisting of LB and SWCX emission, and a background component consisting of GH, point sources, and WHIM. A typical shadow experiment consists of two observations, one in the direction of a high NH density cloud at a distance of 50–200 pc, the other in the direction of a low NH column density region as close as possible to the

Table 5

| Sample | Objects | $\Gamma$ | Flux$^a$ | Norm$^c$ | Reduced $\chi^2$ |
|--------|---------|---------|---------|---------|----------------|
| Total  | 929     | 1.77 + 0.01 | 4.8 $\times$ 10$^{-12}$ | 7.24 $\pm$ 0.07 | 1.3 |
| Faint  | 489     | 1.05 + 0.03 | 3.8 $\times$ 10$^{-13}$ | 0.70 $\pm$ 0.02 | 1.9 |
| Bright | 440     | 1.37 + 0.01 | 4.8 $\times$ 10$^{-12}$ | 6.39 $\pm$ 0.06 | 1.1 |

Notes.

$^a$ Power-law index of photon spectrum fit in the energy range of 0.5–7.5 keV.

$^b$ Flux of the sources in the energy range of 0.5–2.0 keV in units of erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$.

$^c$ Normalization of power-law fit in units of photons keV$^{-1}$ s$^{-1}$ cm$^{-2}$ sr$^{-1}$.

Table 6

| Sample | Objects | $\Gamma$ | Flux$^a$ | Norm | Reduced $\chi^2$ |
|--------|---------|---------|---------|------|----------------|
| Total  | 423     | 1.93 + 0.01 | 1.1 $\times$ 10$^{-12}$ | 5.87 $\pm$ 0.06 | 1.1 |
| Faint  | 233     | 1.69 + 0.04 | 1.5 $\times$ 10$^{-13}$ | 1.02 $\pm$ 0.03 | 0.89 |
| Bright | 190     | 2.05 + 0.02 | 8.6 $\times$ 10$^{-13}$ | 4.74 $\pm$ 0.04 | 0.94 |

Note. $^a$ Flux of the sources in the energy range of 0.4–0.6 keV in units of erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$.

Figure 7. Average spectra of bright (full black circles) and faint (empty gray circles) sources detected in the 0.4–0.6 keV band. The dark gray and gray curves represent the power-law fits for the bright and faint sources, respectively.

Figure 8. Average spectrum of faint sources identified in the 0.4–0.6 keV energy band, fitted with an absorbed power law plus thermal component.
cloud. As the cloud absorbs most of the background X-ray emission, the comparison of the two observations allows a clean separation between foreground and background. For example, emission, the comparison of the two observations allows a clean cloud. As the cloud absorbs most of the background X-ray emission, the comparison of the two observations allows a clean separation between foreground and background. For example, emission, the comparison of the two observations allows a clean range. Similarly, Smith et al. (2005, 2006) performed shadow observations in the direction of the cloud MBM12, and Henley et al. (2007, 2008) in the direction of a filament in the southern galactic hemisphere. Combining all shadow investigations to account for spatial and temporal variations in the total diffuse flux, we found that 30% ± 12% (or 3.75 ± 1.3 LU in oxygen lines) of the diffuse emission is due to foreground sources, while 70% ± 12% (or 8.75 ± 1.3 LU in oxygen lines) is due to background sources.

Using the point sources identified in this investigation, we can also set a lower limit to the diffuse emission due to usually unidentified point sources. Scaled to the 3/4 keV band, the cumulative flux of all point sources identified in this investigation corresponds to 35% ± 11% of the total DXB emission. We recently also performed an investigation of the WHIM emission using a statistical approach on the same targets used in this investigation (Galeazzi et al. 2009). In our investigation, we found clear evidence of the emission from the WHIM and we quantified it as 12% ± 5% of the total DXB in the energy band 0.4–0.6 keV. A summary of the results with the contribution from each component is shown in Table 7.

### 5. CONCLUSIONS

We investigated the properties of point sources using data from the *XMM-Newton* public archive, focusing, in particular, on the properties below 1 keV and the contribution to the DXB. We looked at sources identified in two separate energy bands, a typical soft band 0.5–2 keV and a very soft one 0.4–0.6 keV. In the soft band, the sources detected in all the pointings at fluxes from $7.0 \times 10^{-16}$ erg s$^{-1}$ cm$^{-2}$ to $1.0 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ contribute a total flux of (4.4 ± 0.4) × 10$^{-12}$ erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$, which corresponds to ~36% of the total DXB. The flux resolved in the very soft band from $2 \times 10^{-16}$ to $2 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ contributes a flux of (1.07 ± 0.12) × 10$^{-12}$ erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$ corresponding to ~25% of the total DXB.

We obtained the cumulative spectra of all the sources identified in the two energy bands and also classified our sources using different flux thresholds. The threshold between the two groups was set to $2.0 \times 10^{-15}$ and $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ in the soft band and very soft band, respectively. A power-law fit of the spectrum from bright sources in the range 0.5–7.5 keV using the average Galactic value of NH = $1 \times 10^{20}$ cm$^{-2}$ yields photon indexes of $1.77 \pm 0.01$ and $2.05 \pm 0.02$ for the sources detected in the soft band and very soft band, respectively. When looking at faint sources, we found an excess flux around 0.5 keV in both bands that seems to be thermal in nature. We attribute the excess to a class of sources different from the typical AGN component, possibly unresolved galaxy clusters and/or groups, or coronal emission from stars in the Milky Way.

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| Table 7 Components of the Total Diffuse X-ray Emission in the 3/4 keV Energy Band |
|-----------------------------------------------|
| Foreground, 30% ± 12% | SWCX |
| Background, 70% ± 12% | Galactic halo |
| | WHIM |
| | Point sources |
| | Local Bubble |
| | 12% ± 5% |
| | 35% ± 11% |

Total Luminosity = 6.25 keV s$^{-1}$ cm$^{-2}$ sr$^{-1}$