We present measurements of the soft X-ray background (SXRB) O vii and O viii intensity between $l = 120^\circ$ and $l = 240^\circ$, the first results of a survey of the SXRB using archival XMM-Newton observations. We do not restrict ourselves to blank-sky observations, but instead use as many observations as possible, removing bright or extended sources by hand if necessary. In an attempt to minimize contamination from near-Earth solar wind charge exchange (SWCX) emission, we remove times of high solar wind proton flux from the data. Without this filtering we are able to extract measurements from 586 XMM-Newton observations. With this filtering, $\sim 1/2$ of the observations are rendered unusable, and we are able to extract measurements from 303 observations. The oxygen intensities are typically $\sim 0.5–10$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$ (line units, L.U.) for O vii and $\sim 0–5$ L.U. for O viii. The proton flux filtering does not systematically reduce the oxygen intensities measured from a given observation. However, the filtering does preferentially remove the observations with higher oxygen intensities. Our data set includes 69 directions with multiple observations, whose oxygen intensity variations can be used to constrain SWCX models. One observation exhibits an O vii enhancement of $\sim 25$ L.U. over two other observations of the same direction, although most SWCX enhancements are $\lesssim 4$ L.U. for O vii and $\lesssim 2$ L.U. for O viii. We find no clear tendency for the O vii centroid to shift toward the forbidden line energy in observations with bright SWCX enhancements. There is also no universal association between enhanced SWCX emission and increased solar wind flux or the closeness of the sightline to the sub-solar region of the magnetosheath. After removing observations likely to be contaminated by heliospheric SWCX emission, we use our results to examine the Galactic halo. There is some scatter in the halo intensity about the predictions of a simple plane-parallel model, indicating a patchiness to the halo emission. The O vii/O viii intensity ratio implies a halo temperature of $\sim 2.0–2.5 \times 10^6$ K, in good agreement with previous studies.

Key words: surveys – X-rays: diffuse background – X-rays: ISM

Online-only material: machine-readable tables

1. INTRODUCTION

The soft X-ray background (SXRB) below 1 keV is dominated by line emission from within the Galaxy (e.g., Sanders et al. 2001; McCammon et al. 2002). For many years, this emission was thought to be produced by $\sim$ million-degree gas in the interstellar medium (ISM), including unabsorbed emission from the Local Bubble (LB, a cavity in the local ISM of radius $\sim 100$ pc in which the solar system resides, thought to be filled with $\sim 1 \times 10^6$ K plasma), and emission from $\sim 1–3 \times 10^6$ K plasma in the Galactic halo, which is attenuated by the Galaxy’s H I (e.g., Kuntz & Snowden 2000, and references therein). However, in recent years it has become apparent that X-ray line emission can also originate within the solar system, from charge exchange reactions between highly ionized metals in the solar wind and neutral hydrogen and helium atoms in the heliosphere or in the outer reaches of Earth’s atmosphere (e.g., Cravens 2000; Robertson & Cravens 2003a, 2003b; Koutrompaa et al. 2006). From the point of view of someone interested in studying the Galaxy’s hot ISM, this solar wind charge exchange (SWCX) emission is a time-varying contaminant of the soft X-ray emission.

Our current picture of the Galaxy’s hot ISM is largely derived from maps of the SXRB obtained with rocket-borne and satellite-borne proportional counters (McCammon et al. 1983; Marshall & Clark 1984; Garmire et al. 1992; Snowden et al. 1997), which are presented in a few broad bands between $\sim 0.1$ and a few keV. Higher-resolution spectra of the SXRB have been obtained with the CCD cameras on board Chandra, XMM-Newton, and Suzaku (Snowden et al. 2004; Smith et al. 2005, 2007; Fujimoto et al. 2007; Galeazzi et al. 2007; Henley et al. 2007; Henley & Shelton 2008; Kuntz & Snowden 2008a, 2008b; Masui et al. 2009; Yao et al. 2009; Lei et al. 2009; Yoshino et al. 2009; Gupta et al. 2009). CCD spectrometers can resolve some emission features in the SXRB spectrum, allowing the temperature of the X-ray-emitting plasma to be measured more accurately; it may also be possible to measure the ionization state and relative abundances of the plasma. CCD-resolution spectra help us address questions of the origin and evolution of the hot Galactic gas, such as the possible contributions made by infall and supernova explosions to the hot gas content of the halo (e.g., Lei et al. 2009; Henley & Shelton 2009). We can also measure SWCX emission spectra, for comparison with SWCX models.

Currently, CCD-resolution spectra of the SXRB have been presented for only a few tens of directions. The aim of the current project is to obtain CCD-resolution spectra for a large number ($\sim 1000$) of directions, using archival observations obtained with the EPIC cameras on board XMM-Newton (Jansen et al. 2001). An important innovation is that we do not concentrate only on observations of blank-sky fields. If a target object does not take up too much of the field of view, we can remove the region immediately surrounding the target from the data set and extract an SXRB spectrum from the periphery of the field of view. This technique greatly increases the number of observations that we can use. The ultimate goal of this project is to improve our global picture of the hot gas in the Galaxy, using higher-spectral-resolution data than is available from existing all-sky data sets.
More immediately, our survey includes many directions that have been observed multiple times over spans of time from days to years. Multiple observations of the same direction are useful because the differences between the spectra taken at different times can be used to constrain models of SWCX emission. Such models are essential for obtaining an accurate picture of the hot ISM.

In this paper, we present the first results from this survey. We present intensities of the O\textsuperscript{vii} ISM. Models are essential for obtaining an accurate picture of the hot times can be used to constrain models of SWCX emission. Such because the differences between the spectra taken at different

throughout the heliosphere between solar wind ions and neutral hydrogen and helium atoms that have entered the solar system from the ISM (Cravens 2000).

Enhancements in the geocoronal emission and/or the near-Earth heliospheric emission on a timescale of ∼hours–days have been observed with ROSAT (the so-called “long-term enhancements” in the ROSAT All-Sky Survey; Snowden et al. 1995b), and with XMM-Newton and Suzaku (Snowden et al. 2004; Fujimoto et al. 2007; Carter & Sembay 2008). These bursts of enhanced SWCX emission are often, but not always, associated with times of increased solar wind proton flux (Cravens et al. 2001; Snowden et al. 2004; Fujimoto et al. 2007; Carter & Sembay 2008; Kuntz & Snowden 2008a).

The heliospheric SWCX emission is also expected to vary, but much more slowly, because its variation is due to the 11 year cycle of the Sun from solar minimum to solar maximum back to solar minimum. The variation of the heliospheric SWCX emission with time is particularly strong at high ecliptic latitudes (Robertson & Cravens 2003a; Koutroumpa et al. 2006). This is due to a variation in the ionization state of the solar wind at high latitudes—at solar minimum there are fewer of the O+7 and O+8 ions that produce O\textsuperscript{vii} and O\textsuperscript{viii} SWCX emission than there are at solar maximum. As a result, the heliospheric O\textsuperscript{vii} and O\textsuperscript{viii} emission is fainter at high ecliptic latitudes at solar minimum than at solar maximum.

2. SOLAR WIND CHARGE EXCHANGE EMISSION

2.1. Summary of Properties of SWCX

As was noted in Section 1, observations of the diffuse soft X-ray emission from ∼1–3 × 10^6 K gas in the Galaxy can be contaminated by SWCX emission. This emission is from two sources within the solar system. First, geocoronal SWCX reactions occur between solar wind ions and neutral hydrogen atoms in the outer reaches of Earth’s atmosphere. For example, O\textsuperscript{vii} emission is produced by the following charge exchange reaction:

\[ \text{O}^7 + \text{H} \rightarrow \text{O}^6 + \text{H}^+ \]

where the * indicates that the ion is in an excited state. This emission is produced mainly in the magnetosheath, between the magnetopause and the bowshock, and is brightest in the region between the Earth and the Sun (the sub-solar region; Robertson & Cravens 2003b). Second, heliospheric SWCX reactions occur throughout the heliosphere between solar wind ions and neutral hydrogen and helium atoms that have entered the solar system from the ISM (Cravens 2000).

Enhancements in the geocoronal emission and/or the near-Earth heliospheric emission on a timescale of ∼hours–days have been observed with ROSAT (the so-called “long-term enhancements” in the ROSAT All-Sky Survey; Snowden et al. 1995b), and with XMM-Newton and Suzaku (Snowden et al. 2004; Fujimoto et al. 2007; Carter & Sembay 2008). These bursts of enhanced SWCX emission are often, but not always, associated with times of increased solar wind proton flux (Cravens et al. 2001; Snowden et al. 2004; Fujimoto et al. 2007; Carter & Sembay 2008; Kuntz & Snowden 2008a).

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2.2. Reducing SWCX Contamination

Our current knowledge of geocoronal and heliospheric emission, briefly summarized above, suggests methods that can be used to reduce SWCX contamination. The association between bursts of enhanced geocoronal and/or near-Earth heliospheric SWCX emission and increased solar wind proton flux suggests that removing times of high proton flux from one’s X-ray data will help reduce SWCX contamination. As we will describe in Section 3.4 below, we use such filtering in our data reduction. However, it is important to note that this method will only help eliminate enhancements in the SWCX emission produced near the Earth—it will not eliminate the quiescent geocoronal emission, nor will it eliminate heliospheric emission produced away from the Earth.

Carter & Sembay (2008) have suggested using the time variation in the 0.5–0.7 keV band (the “line band,” which is dominated by O\textsuperscript{vii} and O\textsuperscript{viii} emission) relative to the time variation in a continuum band as a way of identifying XMM-Newton observations that are affected by SWCX emission. Short-term variations in the line band that are uncorrelated with continuum-band variations are indicative of SWCX contamination (the degree of correlation between the line band and continuum bands is quantified by two parameters, \( \chi^2 \) and \( R_p \)). However, their method is only sensitive to SWCX emission that varies during the course of an XMM-Newton observation, and so it too only deals with time-varying geocoronal emission and/or near-Earth heliospheric emission. In addition, Carter & Sembay (2008) do not quote thresholds for their \( \chi^2 \) and \( R_p \) parameters for determining whether or not an observation is likely to be contaminated, although they intend to address this issue in a future paper. We have therefore not used their method in the current

\footnote{Note that this is half of the full 22 year solar cycle.}
paper, but we intend to incorporate it into future extensions to this survey.

The above-described methods only help with geocoronal and near-Earth heliospheric emission. To reduce the heliospheric emission as a whole, we make use of its variation with the solar cycle. In particular, we can expect to reduce the heliospheric SWCX contamination by removing observations of low ecliptic latitudes and observations taken during high solar activity. We will do this in Section 5.3, where we use our oxygen line measurements to study the Galactic halo.

3. DATA REDUCTION

3.1. Observation Selection and Initial Data Processing

We began by selecting all XMM-Newton observations between \( l = 120^\circ \) and \( l = 240^\circ \) that were publicly available as of 2008 May 18 and that had at least some exposure with the EPIC-MOS cameras (Turner et al. 2001). This is a total of 1422 observations. The data were downloaded from HEASARC.\(^2\) We processed the data using SAS version 7.0.0\(^3\) and the XMM-Newton Extended Source Analysis Software\(^4\) (XMM-ESAS) version 2.5 (Snowden & Kuntz 2007; Kuntz & Snowden 2008a). We used only the MOS data as the version of XMM-ESAS that we used cannot calculate the particle background for data from the EPIC-pn camera (Strüder et al. 2001). We intend to use EPIC-pn data in future versions of this catalog.

We initially processed and filtered each data set using the XMM-ESAS mos-filter script. This script first runs the SAS emchain script, which produces a calibrated events list for each MOS exposure. These events lists were then further cleaned using the XMM-ESAS clean-rel program, which identifies and removes times affected by soft-proton flaring. For each events list, a 2.5–12 keV light curve was extracted from the whole field of view using 1-s bins, and a histogram of count rates was created. For an observation not badly affected by soft-proton flares, this histogram should have an approximately Gaussian peak at the nominal count rate. A Gaussian was fitted to the peak, and all times whose count rates differed from the mean of this Gaussian by more than 1.5σ were removed from the data. The good time intervals resulting from this light curve analysis were used to produce cleaned events lists.

We inspected the light curve plots produced by mos-filter, in order to determine whether or not each observation was badly contaminated by soft-proton flares. Figure 1 shows examples of the light curves and count-rate histograms. Figure 1(a) illustrates an observation suffering from little or no flaring. The observation shown in Figure 1(b) suffers from a number of bright flares. However, after the removal of such flares, enough good time remains to yield a good quality SXRB spectrum. Figure 1(c) illustrates an observation so badly affected by flaring that it is unusable.

Our basic criterion for accepting an observation was that it had to have at least one MOS1 exposure and one MOS2 exposure each with at least 5 ks of good time. Some observations had multiple exposures from the MOS1 and/or MOS2 cameras—we kept all exposures that had at least 5 ks of good time. For some observations that were badly contaminated by soft protons, the above filtering returned more than 5 ks of good time. Figure 1(c) shows an example of this—mos-filter identified 12 ks of good time for this MOS1 exposure. In most cases, it is clear from a visual inspection of the count-rate histogram that the observation is contaminated, and such observations were rejected. However, for some observations, some soft-proton contamination remained in the spectrum despite our filtering. We dealt with this by including an extra model component in our spectral analysis to model this contamination (see Section 3.6).

We next inspected the cleaned images produced by mos-filter. Example MOS1 sky images are shown in Figure 2. This inspection had several purposes, exemplified by the images in Figure 2:

1. Figure 2(a) shows a simple blank-sky field, which did not require any special treatment in the subsequent processing.
2. For some observations, not all of the CCDs were usable for our purposes. Figure 2(b) shows an example of this—for this observation the central (1) MOS1-1 CCD was operated in partial window mode. This CCD was ignored in the subsequent processing, and an SXRB spectrum was extracted from the surrounding six CCDs. In some observations, a CCD looked significantly brighter than its neighbors. In such cases, the CCD was probably in an “anomalous” state (identified by Kuntz & Snowden 2008a), and it was ignored in the subsequent processing. In other observations, data from some CCDs were missing altogether (for example, from MOS1-6 since its failure in 2005 March), and again these CCDs were ignored in the subsequent processing.
3. Some observations had bright and/or extended sources in the field. Such sources would not be adequately removed by our automated source removal procedure (see Section 3.2, below). Such observations were nevertheless usable for our purposes, as the target sources could be removed by hand (see Section 3.3, below). Figures 2(c) and (d) show examples of observations of an extended source (a cluster of galaxies) and a bright source (a Seyfert galaxy), respectively. The large red circles outline the regions that were removed.
4. In some observations the target source either filled too much of the field of view, or was too bright. Such observations were unusable, and were rejected. Examples are shown in Figures 2(e) and (f). We also rejected a few observations whose fields were crowded with bright point sources.

The above-described rejections reduced our data set from 1422 observations to 773 (a \( \sim 45\% \) attrition rate). The following subsections describe our subsequent processing of the cleaned events lists, culminating in the extraction of SXRB spectra.

3.2. Point-source Removal

We detected point sources using the standard SAS edetect_chain script. Following the Second XMM-Newton Serendipitous Source Catalogue (2XMM; Watson et al. 2009), we carried out the source detection simultaneously in five bands (0.2–0.5, 0.5–1.0, 1.0–2.0, 2.0–4.5, and 4.5–12.0 keV). For observations with one good MOS1 exposure and one good MOS2 exposure, we used both exposures simultaneously in the source detection. For observations with two or more good exposures from either camera, we carried out the source detection on each exposure individually, as edetect_chain cannot handle more than one exposure from each MOS camera.

Since the extragalactic background is composed of resolved and unresolved point sources, the flux threshold used in the

\(^2\) [ftp://legacy.gsfc.nasa.gov/xmm/data/rev1/]
\(^3\) [http://xmm2.esac.esa.int/sas/7.0.0/]
\(^4\) [http://heasarc.gsfc.nasa.gov/docs/xmm/xmmhp_xmmesas.html]
\(^5\) [http://legacy.gsfc.nasa.gov/xmm/software/xmm-esas/xmm-esas-v2/]
Figure 1. Example MOS1 2.5–12 keV count-rate histograms and light curves, illustrating different levels of contamination by soft protons and the removal of contaminated portions of the data. In the histogram panels, the black points show the data, and the green curve is the Gaussian that was fitted to the peak (between the vertical blue lines). The vertical red lines show the mean of the fitted Gaussian \( \pm 1.5\sigma \). Times with count rates outside that range were rejected. In the light curve panels, the entire light curve is plotted in black, and the light curve for the accepted times is overplotted in green. (a) Obs. 0112650401. This is an example of an observation suffering from little or no flaring. Note that the right vertical red line is obscured by the right vertical blue line. (b) Obs. 0302500101. This is an example of an observation exhibiting several large flares, but which nevertheless yields a usable amount of good data. (c) Obs. 0200730301. This is an example of an observation badly affected by flares—such observations were rejected.

We used the energy conversion factors from the 2XMM Web site\(^6\) (see also Table 4 in Watson et al. 2009) to convert the observed source count rates to fluxes. The region removed for each source was a circle whose radius enclosed 90% of the remaining extragalactic background. We removed point sources with fluxes down to \( 5 \times 10^{-14} \) erg cm\(^{-2} \) s\(^{-1} \) in the 0.5–2.0 keV band, for approximate agreement with Chen et al. (1997), whose model A (fitted to their ROSAT and ASCA data) we use in Section 4.1 to model the extragalactic background.

\(^6\) http://xmmssc-www.star.le.ac.uk/dev/Catalogue/2XMM/UserGuide_xmmcat.html#TabECFs
the same energy band (extracted using a $5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ source removal threshold). More importantly, the summed point-source spectra do not exhibit strong oxygen emission lines. In addition, Gupta & Galeazzi (2009) have examined the summed spectra of sources detected in several deep XMM-Newton observations. The combined spectrum of the sources with $F_X^{0.5-2.0} > 2 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ does not exhibit any excess emission above a power-law spectrum. The combined spectrum of the sources with $F_X^{0.5-2.0} < 2 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ exhibits excess counts below 0.7 keV and could not be fitted with a simple power law. Gupta & Galeazzi (2009) fitted this excess emission with a thermal plasma component. The oxygen emission from this extra thermal component is 0.19 L.U. for O vii and 0.06 L.U. for O viii. These intensities are smaller than the typical errors on our measurements. We therefore think that the faint sources that remain after the point-source removal will not significantly affect our analysis of the Galactic line emission.

3.3. Removal of Bright and Extended Sources

As was mentioned in Section 3.1, we removed extended sources and sources that were too bright to be adequately removed by the above-described automated point-source removal. In all cases we used circular exclusion regions. If the source to be removed was the original observation target, we centered the circle on the target position, which we extracted from the events list header. For other sources, we centered the circle on the source by eye.

The radii of the source exclusion regions were chosen by eye, although for some sources we used radial surface brightness profiles to aid our selection of the source exclusion radius (see Figure 3). We erred on the side of choosing larger source exclusion radii, at the expense of reducing the number of photons from the SXRB. The source exclusion regions that we used typically had radii $r = 1'–4'$. For a few observations we used larger exclusion regions: the largest region that we used had $r = 10'$ (for 1 observation), and we also used exclusion regions with $r = 8'$ for 4 observations and $r = 7'$ for 24 observations.

3.4. Filtering by Solar Wind Proton Flux

As was mentioned in Section 2, we attempted to reduce the near-Earth SWCX contamination of our data set by filtering out the portions of the XMM-Newton data that were taken when the solar wind proton flux was high. The solar wind proton flux data were obtained from OMNIWeb,7 which combines in situ solar wind measurements from several satellites. The OMNIWeb solar wind proton flux data covering the XMM-Newton mission are mainly from the Advanced Composition Explorer (ACE) and Wind—these data are time-shifted to the Earth, based on the relevant spacecraft’s position and the observed solar wind speed (this time-shifting is included in the OMNIWeb data). The OMNIWeb data covering the XMM-Newton mission also include data from IMP-8 and Geotail. These data are not time-shifted. However, the apogee of each satellite (35RE for IMP-8 and 30RE for Geotail,9 where RE is Earth’s radius) divided by a typical solar wind speed of 400 km s$^{-1}$ is < 10 minutes, which is much less than the 1-hr time resolution of the OMNIWeb data. We therefore do not think that the lack of time-shifting in the IMP-8 and Geotail data will significantly affect our results.

7 http://omniweb.gsfc.nasa.gov/
8 http://spdf.gsfc.nasa.gov/imp8/project.html
9 http://www.isas.jaxa.jp/e/enterp/missions/geotail/
In choosing a proton flux threshold for this filtering, we wanted to reduce the potential SWCX contamination as much as possible without discarding too much XMM-Newton data. We chose to remove times when the measured proton flux exceeded $2 \times 10^8$ cm$^{-2}$ s$^{-1}$ from the XMM-Newton data. This threshold was chosen to be somewhat lower than the average proton flux at 1 AU: an average solar wind speed of 400 km s$^{-1}$ was chosen to be somewhat lower than the average proton flux at 1 AU of 7 cm$^{-3}$ (e.g., Wargelin et al. 2004) and an average density at 1 AU of 7 cm$^{-3}$ (e.g., Wargelin et al. 2004) yield an average proton flux of $2.8 \times 10^8$ cm$^{-2}$ s$^{-1}$. We also removed times for which no proton flux data were available from OMNIWeb. This filtering reduced the total amount of usable time over all observations by 55%. For some observations, the good time that remained after this filtering fell below our 5 ks acceptance threshold (see Section 3.1). As a result, filtering on the basis of solar wind proton flux reduced the number of usable observations from 773 to 412. Because of this severe reduction in the number of usable observations, we measured the oxygen line intensities both with and without this solar wind proton flux filtering.

3.5. Source Spectra and Response Files

The SXRB source spectra and the spectral response files were created using the XMM-ESAS mos-spectra script. The SXRB spectra were extracted from the cleaned and filtered event lists using the whole field of view, minus any CCDs that were ignored or missing and any sources that were automatically removed (Section 3.2) or removed by hand (Section 3.3). The spectra were binned so that each bin contained at least 25 counts. Redistribution matrix files (RMFs) and ancillary response files (ARFs) were created with the SAS rmfgen and arfgen programs.

3.6. The MOS Particle Background

The MOS particle background has two main components (e.g., Read & Ponman 2003; Kuntz & Snowden 2008a). Soft-proton flares are caused by protons with $E \sim$ few $\times$ 100 keV interacting directly with the detector. These flares are largely removed by the light curve analysis described in Section 3.1. However, even after this cleaning, some soft-proton contamination may remain in the data. We modeled this residual contamination by adding a broken power-law component to our spectral analysis model. This broken power law was not convolved with the instrumental response, and its break was fixed at 3.2 keV. Such a model is a good description of the mean shape of the soft-proton contamination (Kuntz & Snowden 2008a).

The second particle background component is the so-called quiescent particle background (QPB). This is produced by cosmic rays either interacting directly with the detector, or producing fluorescent X-rays from the detector’s surroundings. As the QPB varies with time, as well as across the detector, its spectrum has to be calculated for each observation. We used the XMM-ESAS xmm-back program to calculate QPB spectra for our observations. For each exposure from a given observation, the QPB spectrum is constructed from a database of filter-wheel-closed data, scaled using data from the unexposed corner pixels outside the field of view (see Figure 2). This scaling is energy dependent, and is based on the 0.3–10.0 keV count rate and the (2.5–5.0 keV)/(0.4–0.8 keV) hardness ratio from the unexposed corner pixels. For more details of the modeling of the QPB spectrum, see Kuntz & Snowden (2008a). The QPB spectra were subtracted from the corresponding source spectra before we carried out our spectral analysis.

The QPB includes two bright fluorescent instrumental lines at 1.49 and 1.74 keV, produced within the telescope by aluminum and silicon, respectively. These lines cannot be adequately removed by the above-described procedure, because small variations in the gain and the line strengths between the source and background spectra can lead to large residuals in the spectral fitting (Kuntz & Snowden 2008a). Instead, the continuum QPB spectrum was interpolated across the 1.2–1.9 keV energy range, and we modeled these instrumental lines by adding two Gaussians to our spectral analysis model.

Kuntz & Snowden (2008a) identified several periods in which certain MOS CCDs were in an “anomalous” state, characterized by a low hardness ratio and a high background count rate in the unexposed corner pixels. Because such data should not be used, after processing each observation we inspected plots of the (2.5–5.0 keV)/(0.4–0.8 keV) hardness ratio against the 0.3–10.0 keV count rate for the corner pixels. If any CCDs were found to have the hardness ratio and count rate that characterize the anomalous state, we excluded those CCDs, and then re-ran the spectral extraction and QPB calculation for that observation.

4. OXYGEN LINE INTENSITIES

4.1. Method

In order to measure the diffuse O vii and O viii intensities, we fitted a multicomponent spectral model to the cleaned and QPB-subtracted MOS spectra extracted from each XMM-Newton observation. The model that we used is similar to that described
in Henley & Shelton (2008), and consisted of Galactic ISM, extragalactic, and instrumental components.

The Galactic ISM emission was modeled using a single-temperature APEC thermal plasma model (Smith et al. 2001), except for the O vii and O viii Kα lines, which were modeled separately using two δ functions.\(^{10}\) In Henley & Shelton (2008), we disabled the oxygen emission from the APEC component by simply setting its oxygen abundance to zero. The disadvantage of this method is that higher transitions (e.g., the Kβ lines) and continuum emission (due to two-photon processes and radiative recombination) from oxygen are also removed from the model. Here, we followed Lei et al. (2009), and removed only the O vii and O viii Kα lines (and their satellite lines) from the APEC model. We did this by setting these lines’ emissivities to zero in the APEC line emissivity data file (apec_v1.3.1_line.fits).

As the thermal diffuse emission in the XMM-Newton band mainly originates in the Galactic halo, beyond the majority of the Galaxy’s H I, the APEC component was attenuated by absorption. For each observation, we fixed the column density \(N_\text{H}\) at the appropriate H I column density from the LAB survey (Kalberla et al. 2005). The oxygen lines were not subject to this absorption, so the intensities that we report in Section 4.2 below are observed intensities, not intrinsic, deabsorbed intensities. As we are reporting the observed oxygen intensities, the fact that our absorption model neglects the effects of molecular hydrogen and dust should not significantly affect our intensity measurements.

The extragalactic background was modeled using a power law. Because of possible residual contamination from soft protons (see Section 3.6), we could not independently constrain the extragalactic background spectrum. We therefore fixed the extragalactic background spectrum at 10.5\(\times\)\((E/1\ \text{keV})^{–4.46}\) photons \(\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{keV}^{-1}\) (Chen et al. 1997). The extragalactic component was assumed to be attenuated to the same extent as the APEC component.

As described in Section 3.6, we included components to model parts of the instrumental particle background. We used two Gaussians to model the aluminum and silicon instrumental lines at 1.49 and 1.74 keV, respectively, and a broken power law to model any residual soft-proton contamination that may have remained after the cleaning described in Section 3.1.

We carried out our spectral analysis using XSPEC\(^{11}\) version 12.5.0. For each observation, we fitted the above-described model simultaneously to all the usable exposures (normally this was one MOS1 exposure and one MOS2 exposure, but some observations had more). The δ functions used to model the oxygen lines were XSPEC gauss models with the widths fixed at 0. The energy of the O vii Kα feature was a free parameter, but that of the O viii Lyα line was fixed at 0.6536 keV (from APEC). The temperature and normalization of the APEC component were both free parameters. We used the XSPEC phabs absorption model (Bahcicinska-Church & McCammon 1992, with an updated He cross section from Yan et al. 1998) to attenuate the APEC and extragalactic components. We used Wilms et al. (2000) interstellar abundances for the APEC and phabs models. The parameters of the particle background components (the Gaussian instrumental lines and the soft-proton broken power law) were independent for each exposure.

\(^{10}\) Note that the O vii Kα “line” is actually a forbidden–intercombination–resonance triplet. However, as the energy resolution of the MOS cameras (\(\sim 30\ \text{eV}\)) is much larger than the splitting of the triplet (\(\sim 10\ \text{eV}\)), using a single δ function to model the O vii emission is a reasonable approximation.

\(^{11}\) http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/
extensions to this survey may use this variability to identify detailed examination of the oxygen line variability within each

12 All the statistical analysis in this paper was carried out using the R software package (R Development Core Team 2008).

time removed by the proton flux filtering and that yield measurable oxygen line intensities after the filtering, the median difference between the O\text{vii} intensity obtained without proton flux filtering and the intensity obtained with proton flux filtering is 0.04 L.U. (90% bootstrap confidence interval: –0.05 to 0.14 L.U.). The corresponding value for O\text{viii} is 0.0 L.U. (–0.03 to 0.02 L.U.). Again, these results show that proton flux filtering does not cause a systematic shift to lower oxygen intensities.

Proton flux filtering does, however, preferentially remove the observations with higher oxygen intensities (meaning that, during such observations, the solar wind proton flux tended to be above the filtering threshold of 2 × 10^8 cm^{-2} s^{-1}). For example, 31 observations in Table 1 have \( I_{\text{O} \text{vii}} > 10\) L.U., obtained without the proton flux filtering. Among those 31 observations, only five yield usable data after the proton flux filtering. Similarly, among the nine observations with \( I_{\text{O} \text{vii}} > 15\) L.U. without proton flux filtering, only one yields usable data after the proton flux filtering. Among the O\text{vii} measurements, nine observations have \( I_{\text{O} \text{vii}} > 5\) L.U. without proton flux filtering, but only two of those yield usable data after the proton flux filtering.

| Obs. ID     | Start l | b      | MOS1 Exp. (ks) \( \Omega \) (arcmin^2) | MOS2 Exp. (ks) \( \Omega \) (arcmin^2) | \( I_{\text{O} \text{vii}} \) (L.U.) | \( \Delta I_{\text{O} \text{vii}} \) (L.U.) | \( E_{\text{O} \text{vii}} \) (keV) | \( I_{\text{O} \text{viii}} \) (L.U.) | \( \Delta I_{\text{O} \text{viii}} \) (L.U.) | \( \langle f_{\text{sw}} \rangle \) \((10^8\text{ cm}^{-2}\text{ s}^{-1})\) | \( \frac{P_{\text{L.U.}}}{P_{\text{exgal}}} \) | Affected Data |
|------------|---------|--------|----------------------------------------|--------------------------------------|-------------------------------|----------------------------------|-----------------|-------------------------------|----------------------------------|---------------------------------|---------------------------------|-----------------|
| 0153030101 | 2003 Jul 4 | 120.057 | 37.320 | 6.0 | 473 | 6.4 | 478 | 6.44 | (5.30, 7.66) | 0.5625 | 1.90 | (1.32, 2.45) | 1.40 | 1.86 | Y |
| 0308090101 | 2005 Jun 15 | 120.236 | 56.654 | 28.1 | 487 | 30.4 | 582 | 7.15 | (6.49, 7.48) | 0.5675 | 1.67 | (1.43, 1.95) | 1.71 | 1.70 | Y |
| 0402560701 | 2006 Jul 23 | 120.404 | 22.166 | 26.2 | 498 | 30.3 | 584 | 7.53 | (5.48, 5.55) | 0.5725 | 1.63 | (1.29, 1.96) | 3.32 | 1.63 | N |
| 0402560901 | 2006 Jul 20 | 120.554 | 21.822 | 53.9 | 378 | 55.0 | 498 | 6.90 | (5.52, 6.31) | 0.5675 | 1.28 | (1.10, 1.56) | 3.13 | 1.89 | N |
| 0304570101 | 2006 Apr 20 | 120.580 | 58.034 | 10.6 | 469 | 10.5 | 484 | 6.91 | (6.26, 7.73) | 0.5575 | 0.67 | (0.37, 1.07) | 2.94 | 1.07 | N |
| 0402560801 | 2006 Dec 25 | 120.591 | 22.424 | 48.2 | 404 | 47.9 | 577 | 5.58 | (5.14, 6.23) | 0.5625 | 1.45 | (1.28, 1.74) | 0.95 | 1.50 | Y |
| 0112570301 | 2002 Jan 24 | 120.595 | 22.245 | 25.9 | 564 | 26.6 | 575 | 8.96 | (8.27, 9.22) | 0.5725 | 1.29 | (2.02, 2.73) | 2.62 | 1.99 | N |
| 0402560601 | 2006 Jul 28 | 120.742 | 22.461 | 31.2 | 474 | 32.0 | 505 | 5.86 | (5.40, 6.32) | 0.5675 | 1.42 | (1.16, 1.86) | 0.84 | 1.18 | Y |
| 0402560301 | 2006 Jul 1 | 120.784 | 21.514 | 46.4 | 410 | 47.6 | 512 | 5.00 | (4.64, 5.46) | 0.5675 | 1.95 | (1.73, 2.20) | 1.52 | 1.75 | Y |
| 0410582001 | 2007 Jul 25 | 120.820 | 21.565 | 14.6 | 338 | 14.9 | 566 | 5.21 | (4.28, 5.68) | 0.5675 | 1.52 | (1.25, 2.03) | 2.85 | 1.63 | N |
**Table 3**

Ranges and Quartiles of the Oxygen Intensities

| Line | Proton Flux Filtering? | Range (L.U.) | Lower Quartile (L.U.) | Median (L.U.) | Upper Quartile (L.U.) |
|------|------------------------|--------------|-----------------------|---------------|------------------------|
| O vii | N                      | 0.5–31.2     | 3.79 (3.63,3.93)     | 5.22 (4.99,5.39) | 6.72 (6.51,7.02)      |
| O vii | Y                      | 0.5–17.6     | 3.62 (3.46,3.77)     | 4.89 (4.62,5.14) | 6.24 (5.96,6.50)      |
| O viii | N                      | 0.0–11.3     | 0.64 (0.58,0.71)     | 1.06 (1.01,1.16) | 1.75 (1.68,1.90)      |
| O viii | Y                      | 0.0–6.0      | 0.60 (0.49,0.69)     | 1.01 (0.94,1.06) | 1.62 (1.49,1.73)      |

*Notes.* The numbers in parentheses are the 90% confidence intervals, calculated by bootstrapping.

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Figure 5 shows the measured oxygen intensities plotted against Galactic latitude. We have looked for correlations between the measured intensities and Galactic latitude using Kendall’s τ (e.g., Press et al. 1992). The results are summarized in Table 4. In the northern Galactic hemisphere, the O vii intensity is significantly correlated with Galactic latitude (i.e., the intensity tends to increase from the Galactic plane to the north Galactic pole). This correlation exists with or without the proton flux filtering, and whether or not we exclude data from low Galactic latitudes. No such correlation exists for O viii in the north. In the south, if we exclude the observations from low Galactic latitudes, we find that both the O vii and O viii intensities are significantly correlated with latitude—here the correlation implies a decrease from the Galactic plane to the south Galactic pole.

Figure 6 compares the oxygen intensities, averaged over $10^\circ$ bins, for the two hemispheres. For each latitude bin, we compared the mean intensities from the two hemispheres using the $t$ test—mean intensities that are significantly brighter (at the 1% level) than their counterparts from the opposite hemisphere are marked with solid circles. At high latitudes, the northern hemisphere appears somewhat brighter in O vii than the southern hemisphere, whereas for O viii there is in general no difference between the hemispheres.

The correlations noted above could ultimately be due to variations in the SWCX intensity (although this is unlikely to be correlated with Galactic latitude), LB intensity, observed halo intensity (which in turn could be due to variations in intrinsic intensity or absorbing column), or any combination thereof. The different correlations in the two hemispheres, and the results shown in Figure 6, suggest at least some differences between the two hemispheres, and also possible differences between the distributions of O vii and O viii emission. Without an accurate model for the SWCX emission in each observation, we cannot use the above-noted trends to draw conclusions about the hot ISM. However, in Section 5.3 we apply various filters to our data set to remove observations likely to be contaminated by SWCX emission, in order to study the Galactic halo emission. Such filtering greatly reduces the number of usable observations, but those that remain should give a more accurate picture of the halo than if we were to use the whole, unfiltered data set.

4.3. Measurements for Directions with Multiple Observations

Many directions have been observed multiple times by XMM-Newton. The separations in time between observations of the same direction range from $\sim 1$ day to several years. The contributions to the SXRB from the LB and the Galactic halo are not expected to vary on such a short timescale. For example, if the LB is filled with $10^6$ K plasma, then the sound-crossing time for crossing XMM-Newton’s field of view ($\sim 0.5$) at a distance of
Table 4
Correlation Coefficients for Intensity Against Latitude

| Line  | Proton Flux | North \( b > 0^\circ \) | North \( b > 20^\circ \) | South \( b < 0^\circ \) | South \( b < -20^\circ \) |
|-------|-------------|-------------------------|-------------------------|-------------------------|-------------------------|
| O\textsc{vii} | N           | 0.21 (2.9 \times 10^{-7}) | 0.14 (7.4 \times 10^{-4}) | \ldots | 0.18 (3.8 \times 10^{-5}) |
| O\textsc{vii} | Y           | 0.23 (3.5 \times 10^{-5}) | 0.20 (6.7 \times 10^{-4}) | \ldots | 0.19 (1.1 \times 10^{-3}) |
| O\textsc{viii} | N           | \ldots | \ldots | \ldots | 0.17 (9.0 \times 10^{-2}) |
| O\textsc{viii} | Y           | \ldots | \ldots | \ldots | 0.17 (4.5 \times 10^{-3}) |

Notes. Correlation coefficients are Kendall’s \( \tau \) for the relevant intensity against \( b \). Values in parentheses are \( p \)-values (i.e., the probabilities of obtaining correlation coefficients at least as large as the observed values, assuming that the null hypothesis is true). Only correlations that are significant at the 5% level are included.

Figure 5. Variation of the observed oxygen line intensities with Galactic latitude. Panel (a) shows the O\textsc{vii} intensities obtained without the solar wind proton flux filtering described in Section 3.4, and panel (b) shows the O\textsc{vii} intensities obtained with this filtering. Panels (c) and (d) show the corresponding O\textsc{viii} intensities.

Figure 6. Variation of the observed oxygen line intensities with Galactic latitude, grouped in 10\(^\circ\) bins. The vertical error bars indicate the errors on the means. Panel (a) shows the O\textsc{vii} intensities obtained without the solar wind proton flux filtering described in Section 3.4, and panel (b) shows the O\textsc{vii} intensities obtained with this filtering. Panels (c) and (d) show the corresponding O\textsc{viii} intensities. Data points marked with a solid circle are significantly brighter (at the 1% level) than the corresponding data point from the other hemisphere.

The oxygen line intensities from directions with multiple observations are shown in Table 5. Column 1 contains a unique number (1–69) which identifies each set of observations of nearby directions. Column 2 contains the number of observations in each set. Column 3 contains the XMM-Newton observation IDs of these observations. Columns 4 and 5 contain the Galactic coordinates \( (l,b) \) of the pointing direction. Columns 6 through 9 contain the O\textsc{vii} intensity, the 68% confidence interval on the O\textsc{vii} intensity, the O\textsc{viii} intensity, and the 68%
Table 5
Oxygen Line Intensities from Directions with Multiple Observations

| Data Set | N_{obs} | Obs. ID     | l (deg) | b (deg) | \(I_{O\text{vii}}\) (L.U.) | \(\Delta I_{O\text{vii}}\) (L.U.) | \(I_{O\text{viii}}\) (L.U.) | \(\Delta I_{O\text{viii}}\) (L.U.) | \(I_{O\text{vii}}\) (L.U.) | \(\Delta I_{O\text{vii}}\) (L.U.) | \(I_{O\text{viii}}\) (L.U.) | \(\Delta I_{O\text{viii}}\) (L.U.) |
|----------|---------|-------------|---------|---------|---------------------------|-----------------------------|--------------------------|-----------------------------|--------------------------|-----------------------------|--------------------------|-----------------------------|
|          |         |             | (1)     | (2)     | (3)                       | (4)                        | (5)                       | (6)                        | (7)                       | (8)                        | (9)                       | (10)                       | (11)                       | (12)                       | (13)                       |
| 1        | 2       | 0112570301  | 120.59  | -22.245 | 8.96 (8.27, 9.22)         | 2.39 (2.20, 2.73)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 2        | 2       | 0402560301  | 120.820 | -21.565 | 5.21 (4.28, 5.68)         | 1.52 (1.25, 2.03)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 3        | 2       | 0402562001  | 120.784 | -21.514 | 5.09 (4.64, 5.46)         | 1.95 (1.73, 2.20)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 4        | 2       | 0405306001  | 121.707 | -20.938 | 9.04 (8.56, 9.50)         | 2.73 (2.48, 2.97)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 5        | 2       | 0109270301  | 121.703 | -20.934 | 5.04 (4.65, 5.43)         | 2.18 (1.95, 2.41)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 6        | 2       | 0402560801  | 121.807 | -21.183 | 6.79 (5.65, 7.93)         | 2.66 (2.04, 3.29)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 7        | 2       | 0109271001  | 122.774 | -22.470 | 7.34 (6.94, 7.74)         | 2.11 (1.90, 2.33)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |
| 8        | 2       | 0100640101  | 122.774 | -22.471 | 9.57 (9.15, 9.86)         | 3.52 (3.38, 3.77)          | ...                       | ...                        | ...                       | ...                        | ...                       | ...                        | ...                        | ...                        |

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Confidence interval on the \(O\text{viii}\) intensity, all obtained without the proton flux filtering described in Section 3.4. Columns 10 through 13 contain the corresponding values obtained with the proton flux filtering. Missing values in Columns 10 through 13 indicate observations that were unusable after the proton flux filtering.

For each of the 69 sets of observations in Table 5, we find the minimum intensity, \(\text{min}(I_{O\text{vii}})\) or \(\text{min}(I_{O\text{viii}})\). Then, for each observation in Table 5, we calculate \(I_{O\text{vii}} - \text{min}(I_{O\text{vii}})\) and \(I_{O\text{viii}} - \text{min}(I_{O\text{viii}})\), where \(\text{min}(I_{O\text{vii}})\) or \(\text{min}(I_{O\text{viii}})\) is the minimum measured intensity for that direction. The difference \(I - \text{min}(I)\) can be attributed to SWCX. This SWCX intensity is actually a lower limit, because SWCX may have contributed photons to the dimmest measurements, as well as to the brighter observations.

Figure 7 shows histograms of \(I_{O\text{vii}} - \text{min}(I_{O\text{vii}})\) and \(I_{O\text{viii}} - \text{min}(I_{O\text{viii}})\), obtained with and without the solar wind proton flux filtering described in Section 3.4. For each of the 69 sets of observations in Table 5 there is, by definition, an observation with \(I - \text{min}(I) = 0\). These observations are omitted from the histograms in Figure 7.

The histograms in Figure 7 show that the measured enhancements due to SWCX are typically \(\lesssim 4\) L.U. for \(O\text{vii}\) and \(\lesssim 2\) L.U. for \(O\text{viii}\). However, there are more extreme enhancements. The largest measured enhancement for \(O\text{vii}\) is 26 L.U., and there are two other observations with enhancements that exceed 10 L.U. These observations are from data sets 12, 16, and 26 in Table 5. The spectra from these sets of observations are shown in Figures 8(a)–(f), and the brightest and faintest \(O\text{vii}\) intensities for these directions are shown in the first three rows of Table 6. The brightest \(O\text{viii}\) enhancement is 8 L.U., for data set 49. This is the only \(O\text{viii}\) enhancement in our survey that exceeds 5 L.U. The spectra are shown in Figures 8(g)–(h), and the intensities are in the final row of Table 6. It should be noted that these extreme enhancements are only seen when we do not apply the proton flux filtering described in Section 3.4. When this filtering is applied, we find \(I_{O\text{vii}} - \text{min}(I_{O\text{vii}}) < 4\) L.U. and \(I_{O\text{viii}} - \text{min}(I_{O\text{viii}}) < 2.5\) L.U.

The extreme \(O\text{vii}\) enhancements shown in Figure 8 and Table 6 are particularly noteworthy, as they are much larger than most previously reported \(O\text{vii}\) SWCX enhancements (~3–7 L.U.; Snowden et al. 2004; Fujimoto et al. 2007; Henley & Shelton 2008). Koutroumpa et al. (2007) have reported \(O\text{vii}\) SWCX enhancements of up to 10 L.U. for some observations of the Lockman Hole. However, we do not present results for the three observations of the Lockman Hole exhibiting the brightest \(O\text{vii}\) enhancements, because we find that these observations are badly contaminated by soft protons. In particular, for obs. 0147510901 the XMM-ESAS software yielded no good time at all for the MOS1 exposure, and obs. 0147511001 and 0147511101 failed our \(F_{\text{total}}^2 / F_{\text{exgal}}^2 \leq 2\) requirement (see Section 4.2).

5. DISCUSSION

The main purpose of this paper is to present the first measurements from our XMM-Newton survey of the SXRB. In Section 5.1, we discuss possible systematic errors which could be affecting these measurements. We also discuss some of the implications of our results. In Section 5.2, we discuss the results obtained from directions with multiple observations, and the implications of these results for SWCX. In Section 5.3, we look at the oxygen emission from the Galactic halo. We apply various filters to our measurements in an attempt to minimize the SWCX contamination. However, because more sophisticated methods for removing SWCX contamination are unavailable, and because we only have data for one third of the sky, the results for the halo must be considered preliminary.

5.1. Possible Systematic Errors

In this section, we discuss possible systematic errors which could bias our intensity measurements. In particular, in Section 5.1.1 we investigate possible contamination of our SXRB spectra by photons in the wings of the point spread functions of bright sources. In Section 5.1.2, we investigate if the residual soft-proton contamination has a systematic effect on our measurements. Because of this soft-proton contamination, we had to fix the normalization of the extragalactic background in our spectral analysis. In Section 5.1.3, we investigate if the value we used for this normalization (10.5 photons cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\) at 1 keV) significantly affects our results.

5.1.1. Contamination from Bright Sources

Although bright sources were removed from the XMM-Newton observations, and although we tended to err on the side of choosing larger source exclusion radii, it is possible that photons in the wings of the XMM-Newton point spread function could be contaminating our spectra of the SXRB. Bright
sources with non-thermal spectra should not be a problem. However, bright sources with thermal spectra, such as stars, could contribute line emission photons to our SXRB spectra, potentially biasing our SXRB line intensity measurements.

To investigate if thermal emission from bright sources affects our SXRB measurements, we selected observations of stars for which the central source had been removed by hand (we chose only observations for which the central source was the only object removed by hand). For these observations, we increased the radius of the source exclusion region from its original value, and measured the oxygen intensities as a function of the source exclusion radius. If contamination from the central source were a problem, we would expect the SXRB intensities to decrease with increasing source exclusion radius.

The results of this experiment are shown in Figure 9. Although there is some variation in the SXRB oxygen intensities as we increase the source exclusion radii, the intensities do not systematically decrease as the source exclusion radii are increased. For each observation, and for each of the two lines, we have used $\chi^2$ to test if the measured intensities as a function of source exclusion radius are consistent with no variation from the intensity measured with the original source exclusion radius. At the 5\% level, only the O vii intensity from obs. 0200370101 shows significant variation with source exclusion radius. However, as can be seen in Figure 9(a), the variation is non-monotonic, which is not what we would expect if the central source were contaminating the SXRB spectrum. Furthermore, for this particular observation the central source is not bright. We therefore conclude that our SXRB spectra are not significantly contaminated by thermal emission from bright sources.

5.1.2. Soft-proton Contamination

Despite the cleaning of the data described in Section 3.1, some soft-proton contamination may remain in the spectra. We modeled this residual contamination as a broken power law in our spectral analysis. Here we wish to examine whether or not this contamination significantly affects our intensity measurements.

To investigate the extent to which the soft-proton contamination affects our measurements, we used the results from directions with multiple observations. For a given direction, the variation in the intensity is expected to be due to SWCX. However, if the presence of soft-proton contamination biases the intensity measurements, we would expect correlations between measures of the soft-proton contamination and $I - \text{min}(I)$, where $\text{min}(I)$ is the minimum intensity measured in the same direction as the $I$ measurement (see Section 4.4).

Figure 10 shows $I_{\text{O vii}} - \text{min}(I_{\text{O vii}})$ and $I_{\text{O viii}} - \text{min}(I_{\text{O viii}})$ against $F_{\text{total}}^2 / F_{\text{exgal}}^2$, which is a measure of the soft-proton contamination (see Section 4.2). Using Kendall’s $\tau$ (e.g., Press et al. 1992) we find there is no significant correlation between the oxygen intensity and the amount of soft-proton contamination. This statement is also true if we use other measures of the soft-proton contamination, such as the normalization of the broken power law (at 1 keV), or its spectral index below the break at 3.2 keV. Therefore, soft-proton contamination does not seem to have a systematic effect on our intensity measurements.

5.1.3. The Normalization of the Extragalactic Background

As mentioned in Section 4.1, we were unable to independently constrain the normalization of the extragalactic background, because of the broken power law that we used to model the residual soft-proton contamination. We therefore had to assume a normalization—we used 10.5 photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$ at 1 keV (Chen et al. 1997). Chen et al. (1997) obtained this value after removing a few bright sources with $F_X^{0.5-2.0} > 5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$, and so we too removed sources down to this flux level.

Moretti et al. (2003) present X-ray source counts in the 0.5–2.0 keV band obtained from shallow wide-field and deep pencil-beam surveys carried out with ROSAT, Chandra, and XMM-Newton. Using their results for the source flux distribution, we find that sources with $F_X^{0.5-2.0} < 5 \times$...
Figure 8. MOS1 (left) and MOS2 (right) spectra from our survey that exhibit the strongest SWCX emission. The spectra were extracted without the solar wind proton flux filtering described in Section 3.4 (the observations exhibiting the brightest SWCX emission were unusable after this filtering). The data set number refers to the data set numbers in Table 5. In each panel, the black spectrum exhibits the brightest O\textsc{vii} (a)–(f) or O\textsc{viii} (g)–(h) emission, and the red spectrum the faintest O\textsc{vii} or O\textsc{viii} emission. The blue and green spectra, where plotted, are intermediate. The O\textsc{vii} and O\textsc{viii} lines are at \(\sim 0.57\) and \(\sim 0.65\) keV. The bright lines at 1.49 and 1.75 keV are the Al and Si instrumental lines.

\[10^{-14}\ \text{erg cm}^{-2} \text{s}^{-1}\] contribute a total 0.5–2.0 keV flux of \(5.46 \times 10^{-12}\ \text{erg cm}^{-2} \text{s}^{-1} \text{deg}^{-2}\). Assuming a power-law index of 1.46 (Chen et al. 1997), this corresponds to a normalization of 7.9 photons cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\) at 1 keV, in contrast to the value of 10.5 photons cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\) that we used.

We examined the effect of our assumed extragalactic background normalization on our results by repeating the measurements described in Section 4.1, but this time using an extragalactic background normalization of 7.9 photons cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) keV\(^{-1}\). The results obtained with the two different extragalactic background normalizations are compared in Figure 11.

In general, using the lower normalization for the extragalactic background results in slightly lower oxygen intensities. Lowering the extragalactic background normalization increases the normalization of the soft-proton broken power law, which in turn tends to decrease the intensities of the thermal emission components, including those of the oxygen lines. However, it should be noted that the differences are generally not significant.
Figure 9. (a) O vii and (b) O viii intensities as a function of the radius used to exclude the central source. For each observation, the intensities are plotted as the differences from the intensity measured using the original source exclusion radius. The curves have been shifted upward by 0, 2, 4,...L.U. for clarity.

Table 6
Directions with the Brightest SWCX Emission

| Data Set\(^a\) | Line   | Faintest | Brightest | Difference |
|--------------|--------|----------|-----------|------------|
|              | Obs. ID | \(I\) (L.U.) | Obs. ID | \(I\) (L.U.) | \(\Delta I\) (L.U.) |
| 12           | O vii  | 0400560301 4.11 +0.30 | 0059140901 14.83 +0.91 | 10.72 +0.99 |
| 16           | O vii  | 0112520901 5.14 +0.86 | 0112520601 31.29 +1.31 | 26.15 +1.52 |
| 26           | O vii  | 0143150301 3.26 +0.74 | 0143150601 21.47 +0.63 | 18.21 +0.99 |
| 49           | O viii | 0302352201 0.58 +0.40 | 0203362201 8.78 +0.34 | 8.20 +0.56 |

Note. \(^a\) The data set number from Table 5.

within the error bars. In addition, our general conclusions are not affected by these differences.

5.2. Directions with Multiple Observations: Implications for Solar Wind Charge Exchange

Multiple observations of individual directions are useful because they allow us to study the variation in SWCX X-ray intensity. Such observed variations can be used to constrain models of SWCX emission. As was noted in Section 4.3, the measured O vii and O viii enhancements due to SWCX are typically \(\lesssim 4\) and \(\lesssim 2\) L.U., respectively, (see Figure 7) although some observations exhibit much larger intensity enhancements (see Figure 8). In this section, we discuss the variations in the oxygen intensities seen in directions that have been observed multiple times, and the implications of these variations for SWCX.

In a collisionally excited plasma, the brightest component of the Kα emission from an He-like ion is the resonance 1s2p \(^1P_1\) \(\rightarrow\) 1s\(^2\) \(^1S_0\) line. However, if the Kα emission is produced by charge exchange, the lower-energy forbidden 1s2s \(^3S_1\) \(\rightarrow\) 1s\(^2\) \(^1S_0\) line dominates (e.g., Wargelin et al. 2008). For example, in a plasma in collisional ionization equilibrium with \(T\) \(\sim\) few \(\times 10^6\) K, the O vii forbidden line is roughly half as bright as the resonance line (using line emissivity data from APEC), whereas the O vii forbidden line yield from charge exchange between O vii and He is \(\sim 5\) times the resonance line yield (Krasnopolsky et al. 2004). (Note that a recombining interstellar plasma would also produce a bright forbidden line; e.g., see Figure 26 in Shelton 1999.) As the splitting between the O vii resonance and forbidden lines is 12.8 eV (from APEC) and the energy bin size in the XMM-Newton RMF is 5 eV, we might expect to see a shift in the O vii centroid toward lower energies in observations with brighter SWCX emission. Such a shift could potentially be used as a diagnostic of SWCX contamination.

Figure 12 shows histograms of the centroid energy of the O vii emission, \(E_{\text{O vii}}\), for different ranges of \(I_{\text{O vii}} - \min(I_{\text{O vii}})\) (i.e., for different levels of enhanced SWCX emission). We take the instrumental gain shift between observations to have unobservably small effects on the apparent line centroids,
because we find no measurable variation in the O\textsc{viii} line centroid energy in a sample of observations (probably partly due to the insensitivity of our analysis to line shifts small than a few eV; see below). There appears to be a shift in $E_{\text{O\textsc{vii}}}$ toward the energy of the forbidden line for 4 L.U. $< I_{\text{O\textsc{vii}}} - \min(I_{\text{O\textsc{vii}}}) \lesssim 8$ L.U., but not for $I_{\text{O\textsc{vii}}} - \min(I_{\text{O\textsc{vii}}}) > 8$ L.U. Therefore, enhancements in the O\textsc{vii} intensity are not clearly associated with shifts in the centroid energy toward that of the forbidden line, at least not to the extent that $E_{\text{O\textsc{vii}}}$ could be used as a diagnostic of SWCX contamination. In fact, $\chi^2$ tests show that all the histograms in Figure 12, except for the $I_{\text{O\textsc{vii}}} - \min(I_{\text{O\textsc{vii}}}) = 0$ L.U. histogram, are consistent with a Gaussian distribution centered on $E_{\text{O\textsc{vii}}} = 0.5675$ keV (roughly midway between the energies of the forbidden and resonance lines) with a standard deviation of 5 eV.

The lack of an observable shift toward the forbidden line energy in observations with enhanced O\textsc{vii} emission is most likely due to the uncertainty in $E_{\text{O\textsc{vii}}}$. Because we used a $\delta$ function for the O\textsc{vii} emission, the fit statistic ($\chi^2$) is insensitive to changes in $E_{\text{O\textsc{vii}}}$ within an RMF energy bin (each of which is 5 eV wide); i.e., the model intensity integrated between, say, $E_1 = 0.565$ keV and $E_2 = 0.570$ keV, and hence the corresponding model count spectrum, will be the same no matter where $E_{\text{O\textsc{vii}}}$ lies between $E_1$ and $E_2$, and so $\chi^2$ only changes when $E_{\text{O\textsc{vii}}}$ moves from one RMF bin to the next. As a result, plotting $\chi^2$ as a function of $E_{\text{O\textsc{vii}}}$ does not result in a smooth parabola, but instead results in a stepped function with the steps at the boundaries of the RMF energy bins. With such a $\chi^2$ curve, we find that the XSPEC error command is generally unable to calculate the uncertainty on $E_{\text{O\textsc{vii}}}$ (which is why we do not quote errors for $E_{\text{O\textsc{vii}}}$ in Tables 1 and 2). However, using XSPEC’s steppar command to estimate the uncertainty on $E_{\text{O\textsc{vii}}}$, we find that the 90% confidence interval typically spans $\gtrsim 10$ eV (i.e., similar to or greater than the splitting between the O\textsc{vii} resonance and forbidden lines). Therefore, it appears that we cannot measure $E_{\text{O\textsc{vii}}}$ with XMM-Newton with sufficient precision to use $E_{\text{O\textsc{vii}}}$ as a diagnostic of SWCX contamination. However, the XIS cameras on Suzaku, which have a higher spectral resolution than XMM-Newton’s EPIC-MOS cameras, may be able to detect a shift in the O\textsc{vii}

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**Figure 10.** (a) $I_{\text{O\textsc{vii}}} - \min(I_{\text{O\textsc{vii}}})$ and (b) $I_{\text{O\textsc{vii}}} - \min(I_{\text{O\textsc{vii}}})$ against $F^{2-5}_{\text{total}}/F^{2-5}_{\text{exgal}}$, where $\min(I)$ is the minimum measured intensity in the same direction as the $I$ measurement, and $F^{2-5}_{\text{total}}/F^{2-5}_{\text{exgal}}$ is a measure of the soft-proton contamination.

**Figure 11.** Comparison of the oxygen intensities obtained with extragalactic normalizations of 10.5 photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$ (Chen et al. 1997; abscissae) and 7.9 photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$ (calculated using X-ray source counts from Moretti et al. 2003; ordinates). The top panel shows the results for O\textsc{vii}, and the bottom panel for O\textsc{viii}. The dashed lines indicate equality.
Second, a set of observations have been observationally associated with times of enhanced SWCX emission due to the solar cycle (Robertson & Cravens 2003a; Koutrompa et al. 2006), which would be independent of the near-Earth solar wind proton flux. Finally, although an increase in the solar wind proton flux will tend to increase the overall brightness of the geocoronal emission, the amount of geocoronal emission seen in a given observation will depend on which part of the magnetosheath the sightline passes through, with the brightest emission coming from the sub-solar region (Robertson & Cravens 2003b). Because of XMM-Newton’s eccentric orbit, different observations of the same direction can sample different parts of the magnetosheath (e.g., Kuntz & Snowden 2008a).

We have investigated whether or not XMM-Newton sightlines that pass close to or through the sub-solar region of the magnetosheath lead to increased oxygen intensities. For each observation, we quantify how close the XMM-Newton sightline gets to the sub-solar region as follows. We use the orbital data file to establish XMM-Newton’s position during the observation. For each time during the observation, we step along the sightline, and for each point along the sightline that lies between the magnetopause and the bowshock, we measure the Earth-centered angle \( \theta \) between that point and the Earth–Sun line. We use the minimum value of \( \theta \), \( \theta_{\text{min}} \), at each time during the observation to quantify how close the XMM-Newton sightline gets to the sub-solar region—the smaller \( \theta_{\text{min}} \) is, the closer the sightline is to the sub-solar region, and \( \theta_{\text{min}} = 0^\circ \) means that the sightline crosses the Earth–Sun line in the magnetosheath. In general, \( \theta_{\text{min}} \) varies during the course of an XMM-Newton observation. Figure 14 illustrates three different types of observation relevant to this discussion. For observation 1, the sightline passes through the magnetosheath throughout the observation, and so \( \theta_{\text{min}} \) is defined throughout. For observation 2, \( \theta_{\text{min}} \) is defined for only part of the observation. For observation 3, the sightline never passes through the magnetosheath, and \( \theta_{\text{min}} \) is undefined throughout the observation.

Figure 15 shows \( I - \min(I) \) for O vii and O viii plotted against \( \theta_{\text{min}} \). As noted in the figure caption, the different symbols indicate the different types of observation illustrated in Figure 14. Apart from the two observations exhibiting the brightest O vii enhancements, which have smaller-than-typical values of \( \theta_{\text{min}} \), there is no clear tendency for sightlines that pass closer to the sub-solar region of the magnetosheath to produce larger oxygen intensity enhancements. Our results indicate that a single factor such as the solar wind proton flux or the closeness of the sightline to the sub-solar region is usually not sufficient for determining if an observation is likely to be SWCX contaminated.

5.3. Oxygen Emission from the Galactic Halo

In order to study the emission from the Galactic halo, we must first remove the foreground emission. In Section 5.3.1, we apply various filters to our observations in order to reduce the SWCX contamination. We then use ROSAT shadowing data (Snowden et al. 2000) to model the foreground emission (due to SWCX and/or the LB) that remains after this filtering. We subtract this foreground emission and calculate deabsorbed halo intensities. In Section 5.3.2, we compare the halo intensities with a simple plane-parallel model for the halo, and in Section 5.3.3 we look at the O vii/O viii intensity ratio.

5.3.1. Removing the Foreground Emission

To reduce the SWCX contamination, we used only the results obtained with the proton flux filtering described in Section 3.4.
Figure 13. Oxygen intensity vs. average solar wind proton flux, for directions with multiple observations. Each panel shows four or five sets of observations; each set consists of multiple coincident observations. Panels (a)–(n) show the O\textsuperscript{vii} intensity, and panels (o)–(ab) the O\textsuperscript{viii} intensity. The intensities were obtained without the solar wind proton flux filtering described in Section 3.4. The bar in the lower-right corner of most panels indicates the typical error bar. The numbers in the legends indicate the data set number from Table 5 and, in parentheses, the number of observations in that data set with solar wind proton flux measurements. The lines are used to join observations from the same data set. Observations without proton flux measurements are not plotted. Note that data set 64 is not plotted, as only one of the two observations has a proton flux measurement.
As was noted in that section, the proton flux filtering will only help reduce contamination from geocoronal SWCX emission and heliospheric SWCX emission produced near the Earth. We therefore applied additional filters to our data to help further reduce the heliospheric SWCX contamination. In particular, we removed observations of low ecliptic latitudes ($|\beta| \leq 20^\circ$) and observations taken during high solar activity, as these observations are expected to be more strongly contaminated by heliospheric SWCX (see Section 2). Although the transition from solar maximum to solar minimum is gradual, we have taken 00:00UT on 2005 Jan 01 (MJD = 53371) as the boundary between high and low solar activity. At the time of writing, we are still at solar minimum, so all observations with MJD > 53371 are considered to be at low solar activity. After we applied all these filters, just 43 observations remained. As we wish to study the halo, we removed a further four observations with $|b| \leq 20^\circ$. The locations of the remaining 39 observations on the sky are shown in Figure 16. Note that the region with $|\beta| \leq 20^\circ$ cuts diagonally across the region with $120^\circ \leq l \leq 240^\circ$, so both Galactic hemispheres are approximately equally sampled.

Despite the above filtering, some foreground oxygen emission (either from SWCX or the LB) may have remained in our spectra. We modeled this foreground emission using the Snowden et al. (2000) catalog of SXRB shadows. This catalog contains foreground and background R12 (1/4 keV) count rates for 378 shadows in the ROSAT All-Sky Survey. For each of our XMM-Newton observing directions, we found the five nearest shadows in the catalog, and averaged their foreground count rates, weighted by the inverses of their distances from the XMM-Newton pointing direction; i.e.,

$$\text{Average foreground R12 count rate} = \frac{\sum_i R_i/\theta_i}{\sum_i 1/\theta_i},$$

where $R_i$ is the foreground R12 count rate for the $i$th shadow, whose center is at an angular distance $\theta_i$ from the XMM-Newton pointing direction. Using a Raymond & Smith (1977

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**Figure 14.** Illustration of the $\theta_{\text{min}}$ parameter for three different types of XMM-Newton observation. The solid curves show the magnetopause and the bowshock (from Spreiter et al. 1966). The dotted ellipse shows the XMM-Newton orbit (note that the orbital orientation relative to the solar direction changes during the course of the year). The solid sections of the ellipse show XMM-Newton’s position during three hypothetical observations of a direction indicated by the arrows. For observation 1, $\theta_{\text{min}}$ is defined throughout the observation. For observation 2, $\theta_{\text{min}}$ is partially defined during the observation. For observation 3, $\theta_{\text{min}}$ is undefined throughout the observation. See the text for more details.

**Figure 15.** $I - \min(I)$ against $\theta_{\text{min}}$, for (a) and (b) O vii and (c) O viii. Panel (b) shows the same data as panel (a), but with a narrower $y$-axis range. Observations for which $\theta_{\text{min}}$ is defined throughout (observation 1 in Figure 14) are shown by horizontal bars indicating the range of $\theta_{\text{min}}$ during the observation. Observations for which $\theta_{\text{min}}$ is defined for only part of the observation (observation 2 in Figure 14) are shown by arrows, the left-hand ends of each indicating the minimum value of $\theta_{\text{min}}$ during the observation. Observations for which $\theta_{\text{min}}$ is undefined throughout (observation 3 in Figure 14) are shown by the crosses.
and updates) model with $T = 10^{6.08}$ K (Snowden et al. 2000) to model the foreground emission, we converted the foreground count rates calculated above to emission measures.\(^{14}\) We then used these emission measures with line emissivity data from APEC to calculate foreground O\(\text{vii}\) and O\(\text{viii}\) intensities, again assuming $T = 10^{6.08}$ K. The foreground O\(\text{vii}\) intensities calculated in this way are plotted in Figure 17. The foreground intensity tends to increase with Galactic latitude. The foreground O\(\text{viii}\) intensities follow the same trend, but are ${\sim}100$ times smaller.

Using this model to calculate the foreground oxygen intensities, $I_{\text{fg}}$, we can calculate the deabsorbed halo intensities, $I_{\text{halo}}$, from the observed intensities, $I_{\text{obs}}$:

$$I_{\text{halo}} = (I_{\text{obs}} - I_{\text{fg}}) e^{\sigma N_H},$$

where $\sigma$ is the photoelectric absorption cross section and $N_H$ is the hydrogen column density. For O\(\text{vii}\) we used $\sigma = 6.965 \times 10^{-22}$ cm\(^2\), calculated for $E_{\text{O\(\text{vii}\)}} = 0.57$ keV, and for O\(\text{viii}\) we used $\sigma = 4.740 \times 10^{-22}$ cm\(^2\), calculated for $E_{\text{O\(\text{viii}\)}} = 0.654$ keV. These cross sections were calculated using data from Bahcinińska-Church & McCammon (1992), with a revised He cross section from Yan et al. (1998), and Wilms et al. (2000) interstellar abundances. For $N_H$ we used the H\(\text{i}\) column density from the LAB survey (Kalberla et al. 2005).

The region with $120^\circ \leq \ell \leq 240^\circ$ includes two X-ray-bright regions: the Monogem Ring (a supernova remnant; Plucinsky et al. 1996) and the Eridanus Enhancement (a superbubble; Burrows et al. 1993; Snowden et al. 1995a). These features produce emission that is neither from the foreground (LB and/or SWCX) nor from the halo. As a result, the above-described procedure will not yield accurate halo intensities for observations within these features. The Monogem Ring lies within the excluded $|\beta| \leq 20^\circ$ region, and so is not a problem. Three of the 39 observations shown in Figure 16, however, are toward the Eridanus Enhancement. We therefore removed these three observations from our subsequent analysis.

### 5.3.2. A Plane-parallel Model for the Halo Emission

Here, we examine a simple plane-parallel model for the Galactic halo. In such a model, the intrinsic emissivity, $\epsilon$, of the halo gas is assumed to depend only on the height above

$$I_{\text{halo}}(b) = I_{90} \csc|b|,$$

where $I_{90} = (1/4\pi) \int_{0}^{\infty} \epsilon(z) dz$ is the intrinsic halo intensity at $|b| = 90^\circ$.

We fitted the above model to the deabsorbed halo intensities that we derived from our observations using Equation (3). We fitted the model to the northern and southern Galactic hemispheres independently, using weighted least squares. Although most of our measurements have asymmetrical error bars, to simplify the fitting we assumed symmetrical errors, with the error on a given intensity being equal to the larger of the positive and negative errors.

The deabsorbed halo intensities are shown in Figure 18, along with the best-fitting plane-parallel halo models (shown with solid gray lines). For both lines, $I_{90}$ is slightly larger in the southern hemisphere. For O\(\text{vii}\), $I_{90}$ is $2.9 \pm 0.3$ L.U. in the south, against $2.1 \pm 0.2$ L.U. in the north. The corresponding values for O\(\text{viii}\) are $0.90 \pm 0.13$ L.U. in the south and $0.54 \pm 0.07$ L.U. in the north. The larger values of $I_{90}$ in the southern hemisphere may be due to the cluster of data points near $b = -20^\circ$. These observations are all near M31, and so may be contaminated by emission from M31’s own halo. If we remove this cluster of data points, we obtain the models shown by the dashed gray lines in Figure 18. In this case, there is no significant difference between the two hemispheres: the new values of $I_{90}$ in the south are $1.8 \pm 0.4$ L.U. for O\(\text{vii}\) and $0.5 \pm 0.2$ L.U. for O\(\text{viii}\).

There is some scatter in the halo intensity about the plane-parallel model. This suggests a patchiness to the halo emission, as previously noted by Yoshino et al. (2009). In addition, the O\(\text{vii}\) residuals are significantly correlated (at the 5% level) with Galactic latitude in the northern hemisphere, suggesting that the plane-parallel model may not be a good description of the general distribution of emitting material in the halo. However, this correlation is dominated by the two outermost data points, with $b = 32.7$ and $81.1$—if these two points are removed, the correlation is no longer significant. We therefore cannot currently rule out the plane-parallel halo model. However, our completed survey, spanning the whole range of $l$, and ideally combined with an SWCX model that would allow us to use a larger fraction of our observations, should allow us to distinguish
between different halo models (say, a plane-parallel model versus a Galactocentric model).

5.3.3. The Halo O vii/O viii Ratio

Figure 19 shows the halo O vii/O viii intensity ratio plotted against Galactic latitude. These ratios were calculated from the deabsorbed oxygen intensities, derived from the observations using Equation (3). Also shown in Figure 19 are the expected ratios for thermal plasmas in equilibrium at various temperatures, calculated using line emissivity data from APEC. The expected O vii/O viii intensity ratio decreases with increasing temperature as the plasma becomes more highly ionized.

The O vii/O viii ratios in Figure 19 typically imply a halo temperature of \( \sim 2-2.5 \times 10^6 \) K. Although there is some scatter in the data points in Figure 19, the large error bars mean that we cannot tell whether or not there is real variation in the temperature of the Galactic halo.

The halo temperature inferred from the O vii/O viii ratios is in good agreement with the results of studies of the Galactic halo with XMM-Newton or Suzaku, which have obtained temperatures of \( \sim 2-3 \times 10^6 \) K, assuming (as we have implicitly done so) a single temperature for the halo (Smith et al. 2007; Galeazzi et al. 2007; Yoshino et al. 2009; Lei et al. 2009; Gupta et al. 2009). While some studies find that an isothermal halo model is unable to explain all the available ultraviolet and X-ray data for the halo (Yao & Wang 2007; Shelton et al. 2007; Lei et al. 2009), such a model is useful for characterizing the X-ray emission. Kuntz & Snowden (2000) used a two-temperature model of the halo in their ROSAT All-Sky Survey analysis. The halo temperature inferred from our line intensity ratios lies between the temperatures of their two components \((1.1_{-0.6}^{+0.8}) \times 10^6\) and \((2.9_{-0.5}^{+0.8}) \times 10^6\) K, and is in reasonable agreement with the temperature of their hotter component.

As noted above, the O vii/O viii intensity ratios, and hence the inferred halo temperatures, have large error bars. Tighter constraints on the halo temperature can be obtained by fitting thermal plasma models to the spectra, as this technique uses more of the information contained in the spectra. In a forthcoming paper we will present such an analysis of our spectra, and also describe the implications of the results for models of the hot halo (D. B. Henley et al. 2010, in preparation).

6. SUMMARY

We have presented measurements of the SXRB O vii and O viii intensity between \( l = 120^\circ \) and \( l = 240^\circ \), extracted from archival XMM-Newton observations. We have not restricted ourselves to blank-sky observations—if an observation target is not too bright or too extended, we excluded a region surrounding the target, and extracted an SXRB spectrum from the remainder of the field of view.

In an attempt to reduce SWCX contamination, we removed times of high solar wind proton flux from the data. We measured oxygen intensities both with and without this proton flux filtering. Without the filtering, we obtained measurements from 586 XMM-Newton observations, and with the filtering from 303 observations. Four observations appear in the latter set but not in the former (see Section 4.2), so we have obtained measurements from a total of 590 XMM-Newton observations.

We have found a very large range of oxygen intensities: 0.5 to 313 L.U. for O vii and 0.0 to 11.3 L.U. for O viii. For a total of 69 directions we have multiple observations, whose variation in the oxygen line intensities can be used to constrain models of SWCX emission. Some observations exhibit extremely bright
SWCX emission, the brightest being an enhancement in the O vii intensity of \(~25\) L.U. over two other observations of the same direction. However, most SWCX enhancements are \(~4\) L.U. for O vii and \(~2\) L.U. for O viii.

For He-like \(\alpha\) emission due to SWCX, the forbidden line is expected to be the brightest component, whereas for a hot collisionally excited plasma the resonance line is expected to be brightest (Wargelin et al. 2008). However, for observations exhibiting enhanced emission due to SWCX, we do not see a clear tendency for the O vii centroid energy to shift toward that of the O viii forbidden line, apparently because the uncertainties in the measured O vii centroids are too large. We also find that enhanced SWCX emission is not universally associated with the sightline passing close to the sub-solar region of the magnetosheath.

We have used our measurements to look at the oxygen emission from the Galactic halo. To this end, we applied various filters to our results in an attempt to reduce SWCX emission from the Galactic halo. To this end, we applied various filters to our results in an attempt to reduce SWCX emission from the Galactic halo. For He-like K\(\alpha\) emission due to SWCX, the forbidden line is expected to be the brightest component, whereas for a hot collisionally excited plasma the resonance line is expected to be brightest (Wargelin et al. 2008). However, for observations exhibiting enhanced emission due to SWCX, we do not see a clear clear tendency for the O vii centroid energy to shift toward that of the O viii forbidden line, apparently because the uncertainties in the measured O vii centroids are too large. We also find that enhanced SWCX emission is not universally associated with the sightline passing close to the sub-solar region of the magnetosheath.

We have used our measurements to look at the oxygen emission from the Galactic halo. To this end, we applied various filters to our results in an attempt to reduce SWCX contamination. As well as the above-mentioned proton flux filtering, we removed observations from low ecliptic latitude contamination. As well as the above-mentioned proton flux filtering, we removed observations from low ecliptic latitude contamination. We applied various filters to our results in an attempt to reduce SWCX emission from the Galactic halo. To this end, we applied various filters to our results in an attempt to reduce SWCX emission from the Galactic halo. For He-like K\(\alpha\) emission due to SWCX, the forbidden line is expected to be the brightest component, whereas for a hot collisionally excited plasma the resonance line is expected to be brightest (Wargelin et al. 2008). However, for observations exhibiting enhanced emission due to SWCX, we do not see a clear clear tendency for the O vii centroid energy to shift toward that of the O viii forbidden line, apparently because the uncertainties in the measured O vii centroids are too large. We also find that enhanced SWCX emission is not universally associated with the sightline passing close to the sub-solar region of the magnetosheath.

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