The Diffuse Soft X-ray Sky

Dan McCammon
Physics Department, University of Wisconsin
Madison, WI 53706 U.S.A.
E-mail: mccammon@physics.wisc.edu

ABSTRACT

The MAXI experiment on the Japanese Experiment Module “Kibo” Exposed Facility (JEM-EF) is designed to provide high sensitivity to point sources and to observe each location often to track variability. However, the long total exposure time and all-sky coverage should permit gathering significant information on diffuse X-ray emission in favorable energy intervals. We speculate on the observational opportunities this might provide.

1. Introduction

MAXI is designed to monitor fluxes from a large number of point sources with high sensitivity. It covers most of the sky each orbit and is capable of detecting a few milli-Crab in one day and much fainter fluxes over longer intervals. Optimizing the instrument for point source sensitivity, unfortunately, also means minimizing its sensitivity to diffuse background X rays. This has been done rather well.

Despite this, MAXI’s all-sky coverage and very long exposure times offer a rare view of the diffuse sky — the best available all-sky maps in the 2-20 keV range are still the ones made thirty years ago by *HEAO-I*. MAXI will also make the very first all-sky survey done with the energy resolution of CCD detectors. We therefore look first at some of the outstanding questions remaining about the large-scale diffuse background, and then at how useful the diffuse MAXI data might be in different parts of its bandpass.

2. The Current Situation

Figure 1 shows the best all-sky maps available in the 0.1–0.3, 0.5–1, and 2–9 keV energy bands. A quick look at the figure makes a convincing case that each of these bands is dominated by a different source, and more careful analyses have shown that each is itself a superposition of more than one. So there is a lot to figure out!

2.1 The 0.1–0.3 keV band

All of the soft X-ray sky surveys to date have been made with conventional proportional counters, with E/ΔE going from ~1 at 0.2 keV to ~8 at 10 keV. The 0.1–0.3 keV band is however well separated from higher energy bands by the detector window’s carbon K edge at 0.284 keV. X rays in this band are thought to be produced largely by thermal emission from ~1.0×10^6 K interstellar gas, which at these temperatures is almost entirely in characteristic lines of the partially ionized metals in the gas.

Most of the observed flux comes from hot gas in a “local hot bubble” of ~100 pc radius surrounding the Sun. This provides a fairly uniform intensity within 20° of the Galactic plane, but at higher latitudes is up to five times as bright in an irregular pattern that anti-correlates with H I column density, presumably due to a larger extent of the hot gas in these directions. Snowden et al (1998) and Kuntz and Snowden (2000) have shown that some intermediate and high latitude bright areas are due to intense emission from large clumps of hot gas in the Galactic halo, also at ~1.0×10^6 K.

More recently, Cox (1998) has pointed out that charge exchange between highly ionized metals in the solar wind and interstellar neutral H and He passing through interplanetary space could be a significant contributor in this band. Lallement (2004) estimated that all of the 0.1–0.3 keV flux seen near the Galactic plane and an equal amount at other latitudes could be produced by this mechanism. Difficulties with fitting thermal emission models to detailed spectra in this energy range (Sanders et al 2001) lend credence to this possibility, but the atomic physics of the L lines that dominate this spectral region is complicated and there are no good predictions for how the charge exchange spectrum should be different from thermal emission. The solar wind models are also highly uncertain, so this important question remains unresolved.

2.2 The 0.5–1 keV band

In this band, the map is dominated by the North Polar Spur, part of the limb of the Loop I superbubble, and by a very bright region roughly 30° in radius surrounding the Galactic center and believed to lie at approximately this distance. This central emission is largely thermal with characteristic temperatures of 2–8×10^6 K. Stars must contribute some part of it, but is not known how much is truly diffuse. Resolved AGN provide up to ~60% of the observed intensity away from these areas and the Galactic plane, which is opaque to extragalactic radiation in this band for about ±6°.

The origin of the remaining flux at high latitudes and in the plane is unknown. It has long been expected that the Galaxy might have a hot halo, and these have been observed in a few other galaxies, but there are currently no satisfactory global models that incorporate this. Koutroumpa and Lallement (2007) have postulated that all of this unexplained general emission may be produced by solar wind charge exchange within the solar system.

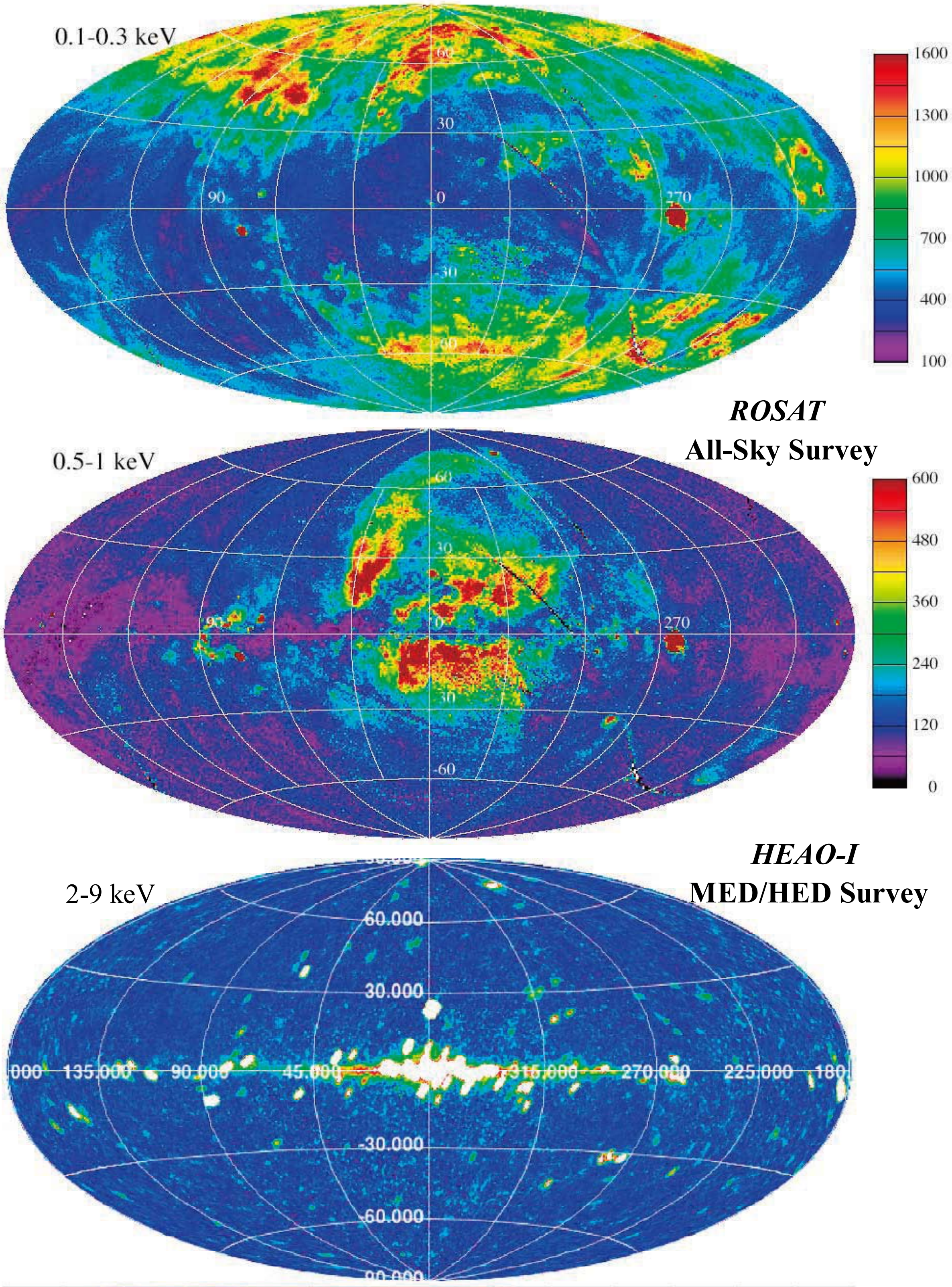

Fig. 1 Best all-sky diffuse background maps in the 0.1–9 keV region. *ROSAT* maps from Snowden et al. 1997. *HEAO-I* maps from Allen et al. 1994.

2.3 The 2-9 keV band

It is now generally thought that essentially all of the flux in this band is due to a superposition of extragalactic discrete sources, primarily AGN. The largest uncertainty in current estimates of the fraction that has been resolved, which ranges from ~1 at the low energy end to ~0.6 at 9 keV, is due to the questionable accuracy of normalization of the observed background spectrum. The best normalization from *HEAO-I* is ~35% lower than early rocket observations (McCammon & Sanders 1990, and references therein). Several more recent determinations have used various imaging telescopes. The throughput of these for a diffuse source is difficult to determine accurately, but these measurements seem to be converging on the higher normalization. Indeed, the background is somewhat over-resolved at the low energy end if the *HEAO-I* normalization is used.

In addition to the dominant extragalactic emission, there are at least two Galactic components. One is a narrow ridge confined to the Galactic plane with a scale height of about 1° (Worral et al. 1982). This has been studied extensively by a number of satellites, but it is still uncertain whether it is due entirely to stars or whether it has a truly diffuse component. The other has a scale height close to 30° (Iwan et al. 1982). It has similar spectral characteristics to the Galactic ridge emission, but has been little studied due to its much lower surface brightness and large extent.

3. MAXI, 0,1-0.3 keV

Figure 2 shows the MAXI CCD camera efficiency. It seems clear that there is no useful response below 0.3 keV.

4. MAXI, 0.5-1 keV

Here the response is small but useable, and the CCD energy resolution offers qualitative advantages over existing all-sky data. Spectral diagnostics for charge exchange are much better understood in this energy range, which is dominated by the K lines of O VII, O VIII, and Ne IX, as well as L lines of Fe XVII. However the best of these require resolving the helium-like triplets, so even CCD resolution doesn't help much.

All-sky maps in some of these lines would be of great benefit in untangling the existing problem. The brightest line is O VII, which unfortunately falls at a minimum in the response. We can calculate the total signal that might be obtained in this line: The CCD detectors total 200 cm^2 area, times 1.5° × 1.5° × 0.67 projected area factor × 5% efficiency ⇒ 0.0047 cm^{2}sr at 570 eV. The average O VII flux is ~3 line units (1 L.U. = 1 photon cm^{-2}s^{-1}sr^{-1}), giving 0.014 cts s^{-1}. We can estimate the background rate from the ASCA CCD rate 6×10^{-4} cts cm^{-2} s^{-1} keV^{-1} × 200 cm^2 × 0.1 keV ⇒ .012 cts s^{-1}, which assumes 0.1 keV FWHM spectral resolution. Two years observing with 70% efficiency would then give ~600 counts for every 5°×5° on the sky, with ~1:1 signal to background. The typical intensity in O VIII is a few times smaller, but the detector efficiency doubles at the higher energy, so comparable statistics could be achieved. These estimates are comparable to those presented by the MAXI team in October, 2007, based on ROSAT R45 band fluxes. The relatively high CCD operating temperature, radiation damage, and non-gaussian tails on the low energy side of the lines all tend to reduce the resolution and make the signal to noise ratio worse.

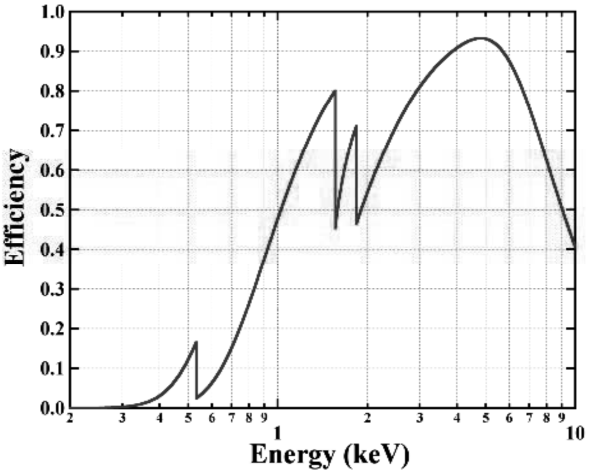

Fig. 2 MAXI CCD camera efficiency

One problem with interpreting these results is that there are sporadic contributions to these oxygen lines from solar wind charge exchange in the Earth's geocorona that are up to several times larger than the quiet background that come and go on time scales of ~1 day, in addition to the more slowly varying interplanetary contribution, where the rapid variations in solar wind flux are averaged by the long transit time through the solar system. There are not enough counts to track these changes for individual directions in the sky, so cleaning up the data would require an independent understanding of the charge exchange contribution. It is possible that something useful could be obtained by summing the line fluxes over the entire sky. This would allow monitoring the total sky flux to a few percent with 1 day time resolution.

5. MAXI, 2-9 keV

In this energy range the primary camera would be the gas slit cameras. These are conventional proportional counters and do not have the high energy resolution of the CCDs, but they have much more effective area. We can estimate the counting rate: integrating the background spectrum gives ~7 photons cm^{-2} s^{-1} sr^{-1}. The cameras total 5000 cm^2 × 1.5° × 1.5° × 0.7 projected area factor ⇒ 2.4 cm^{2}sr, giving about 17 counts s^{-1}. The background should be about 5×10^{-4} cts cm^{-2} s^{-1} keV^{-1} × 5000 cm^2 × 7 keV = 18 cts s^{-1}, so again we have about 1:1 signal to background ratio. Two years of observing with 70% efficiency then gives ~76,000 cts per 1.5°×1.5° pixel. This could give a fantastic improvement on the *HEAO-I* maps, but will require a very thorough understanding of the detector backgrounds. The 15 times per day coverage of each point over a two-year

This document is provided by JAXA.

period will provide much opportunity for studying these backgrounds, but it will be a major effort.

The payoff will be maps and spectral information that could provide much detailed information on the large scale height Galactic component of the diffuse background (the Galactic ridge will be far too source-confused), better measurements of X-ray background fluctuations due to nearby large scale structure in the Universe, and possibly a good measurement of the Compton-Getting effect in X-rays. If the solid angle of the collimators and counter efficiency are accurately calibrated, the uncertainties in the normalization of the background spectrum could be reduced. This would require careful evaluation of reflections from the collimator as a function of energy.

I thank Tatehiro Mihara and Emi Miyata for explaining many details of the MAXI cameras and their response.

6. References

Allen J. et al. 1994 Legacy, 5, 27
Cox D.P. 2008, Lecture Notes in Physics, 506, 121
Iwan D. et al. 1982, Ap.J.260, 111
Koutroumpa D. et al. 2007, A&A 475, 901
Kuntz K.D. & Snowden S.L. 2000, Ap.J. 195, 215
Lallement R. 2004, A&A, 418, 143
McCammon D.& Sanders W.T. 1990 ARA&A 28, 657
Sanders W.T. et al. 2001, Ap.J. 554, 694
Snowden S.L. et al. 1997 Ap.J. 485, 125
Snowden S.L. et al. 1998, Ap.J. 493, 715
Worrall D.M. et al 1982, Ap.J. 255,111

This document is provided by JAXA.