Intensity Variations of the Soft X-ray Background: the Boundary Structure of the Local Hot Bubble at Low Galactic Latitudes

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Abstract. 42 *ROSAT* PSPC pointed observations in the Galactic plane ($l \sim 4° - 26°$) are mosaicked in order to study the spatial structure of the X-ray emitting gas in the Local Hot Bubble (LHB). Degree scale X-ray intensity variations are detected at the ±10% level in the $\frac{1}{4}$ keV band, which imply a likely influence from a clumpy boundary shell of the LHB in the observed $\frac{1}{4}$ keV band X-ray background. The possible origins of such a clumpy boundary structure of the LHB are discussed.

1 Introduction

In the Galactic plane, the $\frac{1}{4}$ keV band soft X-ray diffuse background (SXRB) is expected to originate within the LHB due to the substantial absorption cross-section of the ISM (e.g., $\tau \sim 1$ at ~30 pc, assuming n(H)~1 cm^{-3}). This "isolation" from the contribution of any flux of a more distant Galactic origin allows for the study of the detailed structure of the LHB by searching for the $\frac{1}{4}$ keV band X-ray intensity variations at various angular scales. Here we report detection of degree scale variations of the $\frac{1}{4}$ keV band SXRB in the Galactic plane ($l \sim 4° - 26°$), which implies an influence by a shell-like boundary structure of the LHB on the observed $\frac{1}{4}$ keV band SXRB.

2 Data

An R1L and R2 band (Snowden et al. 1994) mosaic of 42 *ROSAT* PSPC pointed observations are used in this study. All identified non-cosmic backgrounds (~22% of the total counts) are modeled and subtracted from the data as described in Snowden et al. (1994). The detected point sources and possible enhancements by SNRs and X-ray binaries are removed and the relative offsets between overlapping pointings are corrected (~9%). The final mosaic (Figure 1) covers ~60 degree^2 (l~$4° - 26°$, b~$-3° - +2°$) with an average exposure of ~8 ks. With a 10′ binning, an average of 6% statistics per pixel is achieved in the R1L+R2 band (Park, Finley, & Snowden 1997 for a detailed description of the data).

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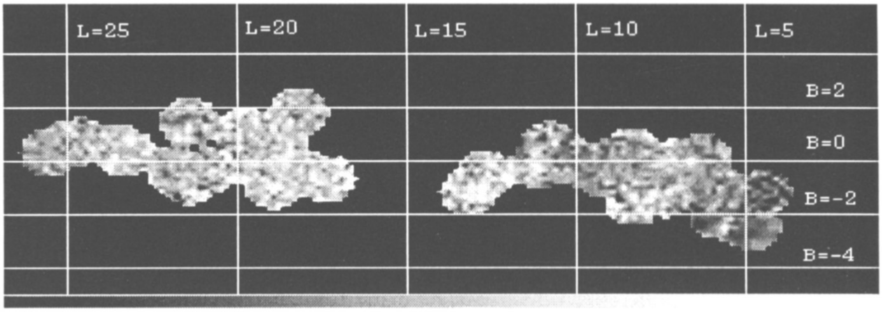

Fig. 1. The $\frac{1}{4}$ keV band (R1L+R2) mosaic of the 42 *ROSAT* PSPC pointings in the Galactic plane. The pixel size is 10′ and the data have been smoothed. The gray-scale ranges $0 - 800 \times 10^{-6}$ counts s^{-1} $arcmin^{-2}$.

3 Analysis and Results

In order to search for X-ray intensity variations along the Galacticplane, the data are first integrated across the plane in Galactic latitude, b, to create 10′ columns, typically within ±2° from the plane. With this integrated 1-D binning, the R1L+R2 band intensity variation along the plane is displayed in Figure 2a. The average flux is $\sim 400 \times 10^{-6}$ counts s^{-1} $arcmin^{-2}$. The X-ray intensity is spatially variable (reduced χ^2 >5 about the mean) at the ±10% level. A spatial Fourier transform reveals degree scale variations with an ~5.5° scale being the most prominent in all bands (Figure 2b). Sub-degree scale variations are investigated with a 2-D autocorrelation function (ACF). The ACF at angular scales $\lesssim$3° is displayed in Figure 3. The ACF in both the R1L and R2 bands indicates little correlation (formal errors include zero) at angular scales of $\lesssim$3°. The difference of the ACF between the three bands (R1L, R2, and R1L+R2) is not significant and lies within the statistical uncertainties. The average hardness ratio (1.35) of the mosaic implies a plasma temperature of $\sim 10^{6.1}$ K with no absorption which is consistent with that of Snowden et al. (1997) for emission from the LHB.

4 Discussion

Possible origins of the detected variations are discussed below.

4.1 Magnetic Rayleigh-Taylor (R-T) Instability

A SNR in the adiabatic phase is R-T unstable. Assuming an $\sim 10^5$ year old blast wave in a pre-existing local cavity ($n \sim 0.004$ cm^{-3}) "reheated" by a SN explosion, the critical wavelength of the magnetic R-T instability, λ, can be estimated (Table 1) with a typical Galactic midplane magnetic field B =

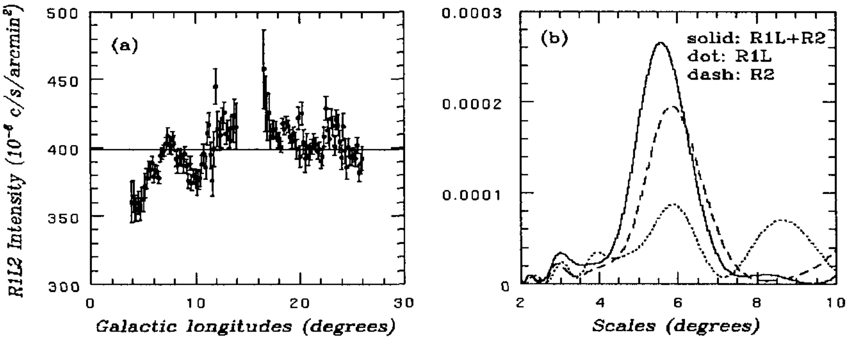

Fig. 2. (a) The $\frac{1}{4}$ keV band intensity along the Galactic plane. Each point presents a 10′ column integrated across the plane. The horizontal line is the mean. (b) Spatial Fourier transform of the R1L, R2, and R1L+R2 band X-ray intensities .

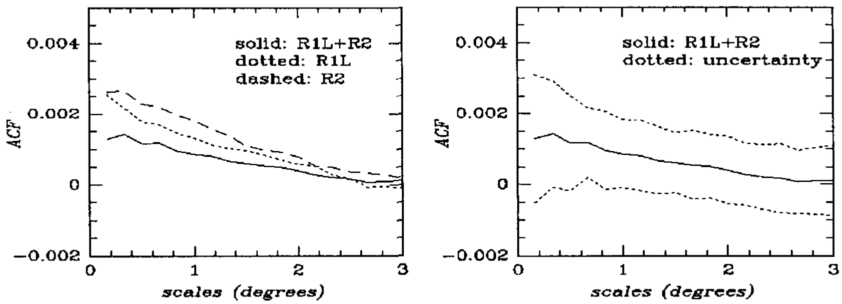

Fig. 3. The ACF of the $\frac{1}{4}$ keV band X-ray intensity for angular scales $\lesssim 3°$. The left panel shows the ACF for the R1L, R2, and R1L2 bands. The right panel shows the R1L2 band ACF and its formal uncertainty.

5 μG, a plasma temperature of the LHB T$\sim 10^{6.1}$ K, and a stored thermal energy $E_{TH} = 1 - 3 \times 10^{50}$ ergs (see Park, Finley, & Snowden [1997] for the detailed calculation). The range of λ is remarkably consistent with the detected $\sim$5.5° scale variation given the inaccuracies embedded in the simple spherical blast wave model. With this model the detected ±10% variation at $\sim$5.5° scale can be attributed to the path-length variation of the wave-like boundary structure due to the magnetic R-T instability.

4.2 Inhomogeneous ISM

If the blast wave of the LHB is in the radiative phase ($\tau \gtrsim 10^6$ yr), the boundary shell can become clumpy due to inhomogeneities in the ISM. For

Table 1. Modeled λ of a magnetic R-T instability at the boundary of the LHB

R_{LHB} (pc)	E_{TH} (10^{50} erg)	λ (pc)	Observable angular size (°)
50	1.0	1.9	2.2
	2.0	4.1	4.7
	3.0	5.8	6.6
75	1.0	0.8	0.9
	2.0	1.7	2.0
	3.0	2.5	2.9

example, absorption by typical interstellar cloudlets (angular size 2 – 5 pc, internal density 1 – 3 cm^{-3}, Heiles 1967) are reasonable to produce detected $\lesssim$5.5° scale variation at ±10% level.

4.3 Emission Variations at the Boundary Layer

The emission variation at the LHB boundary such as electron density fluctuation (Phillips & Clegg 1992) may also produce the observed intensity variations.

4.4 The Local Fluff (LF) and Embedded Clouds

Due to the low N_H ($\lesssim 3 \times 10^{18}$ cm^{-2}), the LF is unlikely to be the source of the ±10% variation (required $N_H \sim 10^{19}$ cm^{-2}). Observations of local interstellar clouds with $N_H \gtrsim 10^{19}$ cm^{-2} inside of the LHB (e.g., Kerp, Herbstmeier, & Mebold 1993) may indicate that the detected variations can be due to absorption by embedded clouds.

5 Conclusions

Degree scale intensity variations (at ±10% level) in the $\frac{1}{4}$ keV SXRB are detected in the Galactic plane. The origin of these small-scale variations is most likely the presence of R-T instability and/or clumpy cooler ISM at the boundary of the LHB. Variations due to absorption by embedded clouds cannot, however, be ruled out.

References

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