# 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 $\sim 30$ pc, assuming n(H)$\sim$1 cm$^{-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 ($\sim$22% of the total counts) are modeled and subtracted from the data as described in Snowden et al. (1994). The detected point sources and possible enhancements by SNRs and X-ray binaries are removed and the relative offsets between overlapping pointings are corrected ($\sim$9%). The final mosaic (Figure 1) covers $\sim$60 degree$^2$ ($l\sim$4° – 26°, $b\sim$-3° – +2°) with an average exposure of $\sim$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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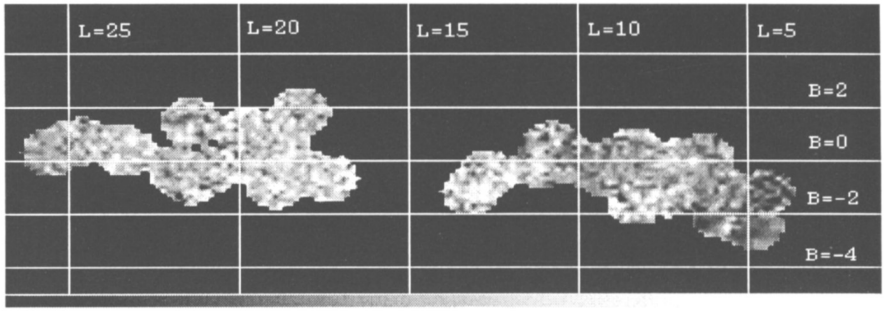


**Fig. 1.** The $\frac{1}{4}$ keV band (R1L+R2) mosaic of the 42 *ROSAT* PSPC pointings in the Galactic plane. The pixel size is $10'$ and the data have been smoothed. The gray-scale ranges $0 - 800 \times 10^{-6}$ counts $s^{-1}$ $arcmin^{-2}$.

## 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 $\pm 2°$ 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 $\chi^2$ $>5$ about the mean) at the $\pm 10\%$ level. A spatial Fourier transform reveals degree scale variations with an $\sim 5.5°$ 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 $\leq 3°$ 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 $\leq 3°$. 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, $\lambda$, can be estimated (Table 1) with a typical Galactic midplane magnetic field B =

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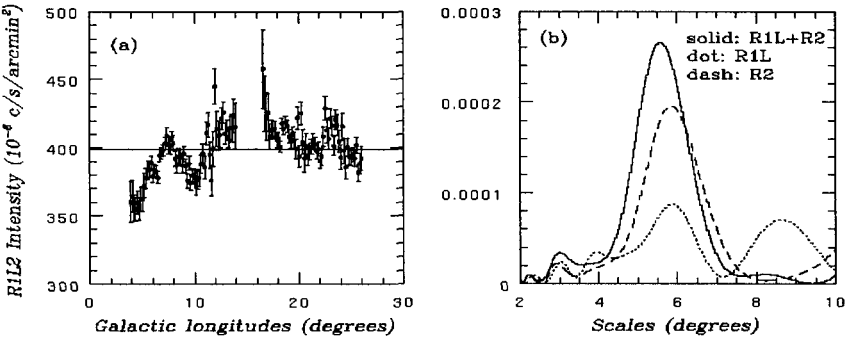


**Fig. 2.** (a) The $\frac{1}{4}$ keV band intensity along the Galactic plane. Each point presents a 10′ column integrated across the plane. The horizontal line is the mean. (b) Spatial Fourier transform of the R1L, R2, and R1L+R2 band X-ray intensities .

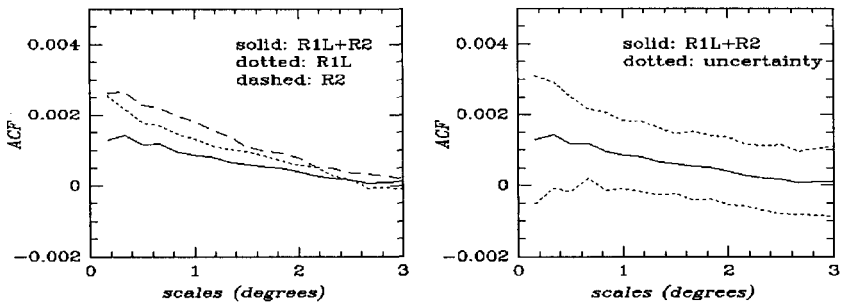


**Fig. 3.** The ACF of the $\frac{1}{4}$ keV band X-ray intensity for angular scales $\lesssim 3°$. The left panel shows the ACF for the R1L, R2, and R1L2 bands. The right panel shows the R1L2 band ACF and its formal uncertainty.

5 $\mu$G, 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 $\lambda$ 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 $\pm 10\%$ 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

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**Table 1.** Modeled $\lambda$ of a magnetic R-T instability at the boundary of the LHB

| $R_{LHB}$ (pc) | $E_{TH}$ ($10^{50}$ erg) | $\lambda$ (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 $\pm 10\%$ 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 $N_{\rm H}$ ($\lesssim 3 \times 10^{18}$ $cm^{-2}$), the LF is unlikely to be the source of the $\pm 10\%$ variation (required $N_{\rm H} \sim 10^{19}$ $cm^{-2}$). Observations of local interstellar clouds with $N_{\rm H} \gtrsim 10^{19}$ $cm^{-2}$ 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 $\pm 10\%$ 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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