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SOFT DIFFUSE X-RAYS IN THE SOUTHERN GALACTIC HEMISPHERE

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ABSTRACT

A map is presented of the soft X-ray diffuse background flux in the C band (~0.13–0.28 keV) covering almost all of the southern galactic hemisphere. A comparison at constant galactic latitude of both C band and B band (~0.1–0.18 keV) soft X-ray data with neutral hydrogen maps shows that the intensity does decrease with increasing neutral hydrogen column density, N_H, but in a manner that is inconsistent with photoelectric absorption. We suggest that the inverse correlation is a displacement effect. X-ray emission regions appear to be where the cool gas is not. Further, the evidence against photoelectric absorption implies that the bulk of the cool gas is beyond the X-ray emitting regions. Fewer than 10^{20} H atoms cm^{-2} can be between the Sun and the X-ray emitting regions. The Sun appears to be surrounded by a soft X-ray emission region of ~ million degree gas.

Subject headings: interstellar: matter — X-rays: general

I. INTRODUCTION

At X-ray energies greater than ~2 keV, the diffuse background is isotropic and presumably extragalactic. At lower X-ray energies the diffuse background becomes anisotropic, exhibiting intensity variations as large as a factor of 4. Further, the X-ray intensity at energies less than 1 keV is larger than would be expected from an extrapolation of the spectrum observed at higher energies. Several experiments designed to detect possible shadowing of the low-energy diffuse background by extragalactic objects have concluded that, in certain directions, at least 75% (McCammon *et al.* 1971, 1976) to ~90% (Long, Agrawal, and Garmire 1976) of the measured flux is of galactic origin. The association of a soft X-ray enhancement with a galactic radio feature, the North Polar Spur, as well as the presence of a finite flux from the galactic plane, argue for a substantial galactic component. Our view is that essentially all of the soft X-ray diffuse background originates within the Galaxy.

We believe it likely that these X-rays are of thermal origin from a very hot phase of the interstellar gas with temperatures $\gtrsim 10^6$ K (Burstein *et al.* 1977). Among the possible alternatives are (1) spatially unresolved contributions from many discrete stellar objects and (2) some interstellar nonthermal mechanism. Observational evidence against the unresolved stellar source idea comes from Gorenstein and Tucker (1972), Vanderhill *et al.* (1975), and Levine *et al.* (1976). Arguments against nonthermal diffuse mechanisms such as the synchrotron process, inverse Compton effect, transition radiation, or line emission from low-energy cosmic ray ions have been reviewed by Kraushaar (1977) and by Williamson *et al.* (1974).

II. DESCRIPTION

The X-ray results presented here were obtained from a series of five sounding-rocket flights, using two similar instruments, flown between 1972 December and 1975 November. The X-ray detectors of each instrument were thin-window wire-walled proportional counters filled with P-10 counting gas (90% argon, 10% methane) at ~1 atmosphere. Each counter had a 6°.5 (FWHM) circular collimator with an antireflection coating and embedded permanent magnets to provide low-energy electron rejection. One counter of each instrument was equipped with a boron-coated Formvar window to provide B band ($0.1 \lesssim E < 0.18$ keV) data. To provide C band ($0.13 \lesssim E \lesssim 0.28$ keV) data, counters on four of the flights had a detector with a ~250 μg cm^{-2} Kimfol (polycarbonate) window. A counter on the fifth flight used a ~100 μg cm^{-2} Formvar-Lexan window. Further instrumental details are described in Williamson *et al.* (1974) and Burstein *et al.* (1977).

We have combined data from the five flights to produce the C band intensity map shown in Figure 1*a*. The map preparation scheme has been described by Williamson *et al.* (1974). The relative normalization of the five different sets of data was established in the areas of overlapping sky coverage. This preliminary normalization can and will be improved when laboratory calibrations are completed and allow the data from each flight to be expressed accurately in absolute units. We estimate a maximum uncertainty of 25% in the present normalizations and see no way that this uncertainty could change the conclusions to be presented. Similar maps for the B band and M band ($0.5 \lesssim E \lesssim 0.85$ keV) are in preparation for future publication.

III. ANALYSIS

Figure 1*b* shows the neutral-hydrogen column-density data compiled by Daltabuit and Meyer (1972). A comparison with Figure 1*a* suggests a tendency for I_C, the C band X-ray intensity, to be small where N_H, the hydrogen column density, is large. A correlation plot of I_C versus N_H verifies this impression in a general way,

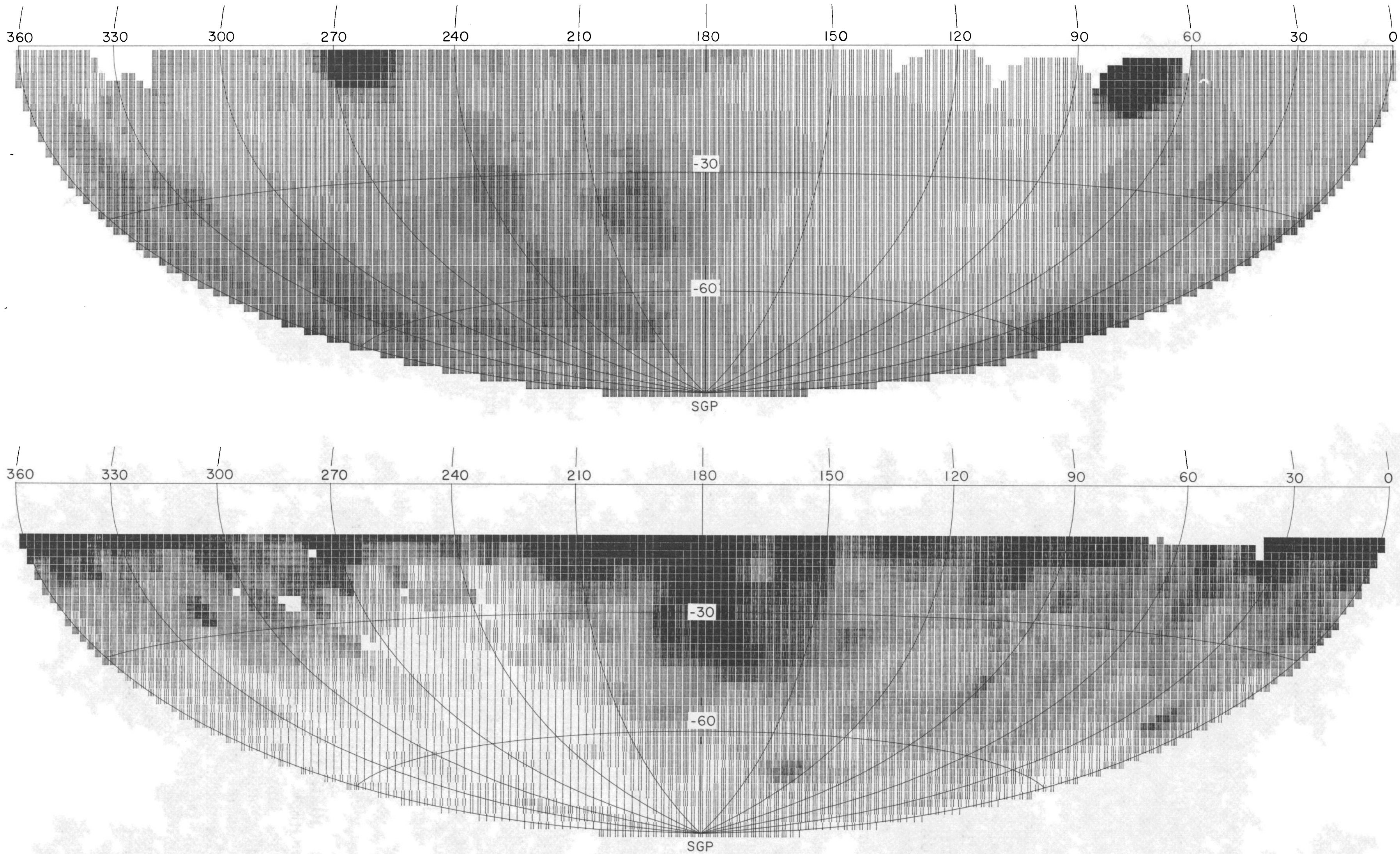

FIG. 1*a*.—C-band intensity map of the southern galactic hemisphere. The darkness of the shading is proportional to X-ray intensity. Two extremely intense features near the galactic plane at longitudes ~70° and ~260° are created by the Cygnus Loop and Vela supernova remnants.

FIG. 1*b*.—Map of the neutral hydrogen column density data compiled by Daltabuit and Meyer (1972). Each line of shading per resolution element corresponds to 10^{20} H atoms cm^{-2}. Blanks indicate no data.

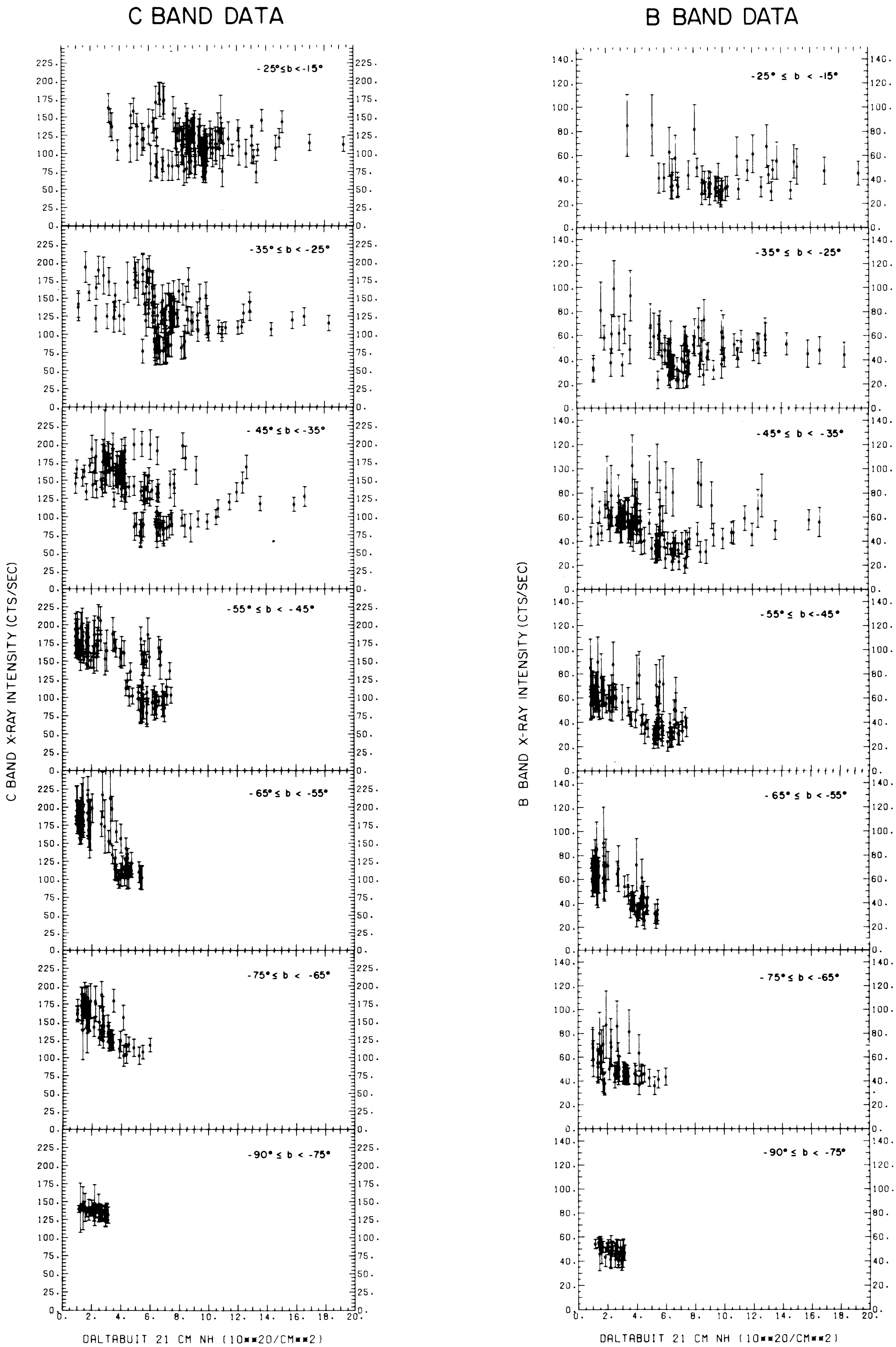

FIG. 2.—Graphs of C-band intensity (*left-hand column*) and B-band intensity versus neutral hydrogen column density (Daltabuit and Meyer 1972) for several different galactic latitude intervals.

but the scatter is very large and the meaning unclear. A general correlation of this kind was pointed out first by Bowyer, Field, and Mack (1968). With data available now over the entire southern galactic hemisphere, we are able to examine the correlation in reasonably narrow ranges of galactic latitude wherein all lines of sight traverse about the same distance through the Galaxy. Figure 2 shows I_C, the C band intensity, versus N_H, and I_B, the B band intensity, versus N_H in 10° intervals of galactic latitude from −25° to the south galactic pole. Measurements with less than 3 σ statistical significance are not plotted. An interesting pattern emerges. Consider first the C band data in the left-hand column of Figure 2. For small hydrogen column densities, up to 3 or 4×10^{20} cm^{-2}, the X-ray intensity remains constant. For larger values of N_H, the average X-ray intensity decreases but the data show a large amount of scatter. This pattern is most evident in the latitude range $-65° \leq b \leq -35°$, but persists from the highest galactic latitudes all the way down to $b \sim -25°$. The B band data have the same pattern with the dropoff in X-ray intensity occurring at about the same N_H, although the statistical accuracy is poorer.

Simple photoelectric absorption cannot account for the X-ray intensity decreasing in this manner with increasing N_H. An N_H value of 4×10^{20} cm^{-2} corresponds to at least two optical depths in the carbon band. More importantly, the B band absorption cross section is at least a factor of 2 greater than that for the C band (using the cross sections of Brown and Gould (1970). Hence, any photoelectric absorption affecting the C band should affect the B band at a substantially lower value of N_H. That both the B band and C band intensities remain constant out to an $N_H \gtrsim 3 \times 10^{20}$ cm^{-2} implies that there must be little neutral material ($\lesssim 1 \times 10^{20}$ cm^{-2}, the minimum N_H seen in any direction) between the Sun and the surrounding emission regions. This is consistent with the low column densities of neutral hydrogen derived by Bohlin (1975) for nearby stars and with the very low interstellar absorption inferred from extreme-ultraviolet observations of HZ 43 (Margon *et al.* 1976*b*) and Feige 24 (Margon *et al.* 1976*a*). (The B band and C band data would have the same N_H dependence if a very large fraction of the interstellar gas were in optically thick clouds. Although the 21 cm measurements of Greisen [1973*a*, *b*, 1976] suggested that this was the case near the galactic plane, recent Arecibo results [Dickey, Salpeter, and Terzian 1977] indicate that this is not true at the moderate to high galactic latitudes of interest here.)

We have suspected for some time, but on the basis of less direct evidence, that the apparent inverse correlation of soft X-ray intensity with neutral hydrogen was a displacement effect. X-ray emission regions seem to be where the cool gas is not. Further, since there is evidence against photoelectric absorption, the bulk of the N_H must be behind the X-ray emitting regions. An ultra-naive model based on this idea would have $I_{XR} \propto (1 - N_H/N_0)$, where N_0 is a free parameter for a given latitude. Where N_H is small, there is much room for an X-ray emission region. As N_H gets large there is less room, and if N_H ever became equal to N_0 there would be no room left and no X-rays. This is shown schematically in Figure 3 for an arbitrary intermediate latitude. We imagine a region of hot gas near the solar system. Fluctuations in the location of the boundary between this hot gas and cool H I are responsible for the gross dependence of X-ray intensity on N_H. Irregularities in the outer boundary of the cool gas account for the horizontal spread of the data points of Figure 2 about the nominal $(1 - N_H/N_0)$ dependence. The similarity of the C band and B band data requires that most of the observed soft X-rays come from this "local" region.

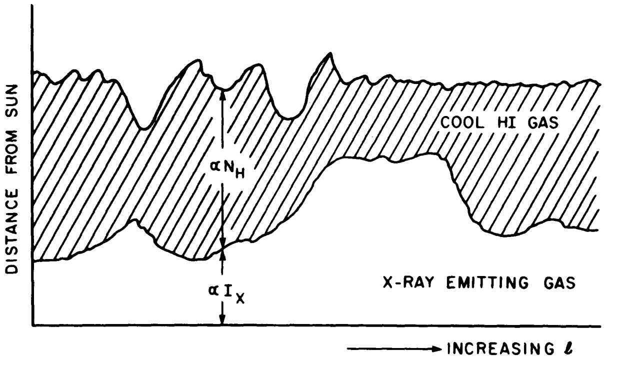

FIG. 3.—Schematic picture of the hypothesized distribution of X-ray emitting gas and neutral hydrogen (distance from the Sun as a function of galactic longitude) at an arbitrary intermediate galactic latitude. At a different galactic latitude a quantitatively different but qualitatively similar distribution would result.

IV. CONCLUSIONS

The inverse correlation between N_H and soft X-ray intensity appears to be due to displacement rather than to absorption. Because the B band and C band soft X-ray intensities have similar dependence on N_H at constant latitude, the amount of neutral absorbing material between the Sun and the X-ray emitting region(s) must be small, $\lesssim 1 \times 10^{20}$ cm^{-2}. The bulk of the neutral hydrogen is farther from us than is the soft X-ray emitting gas. The Sun appears to be surrounded by a soft X-ray emission region of ~million-degree gas.

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