NON-LOCAL ORIGIN OF A SUBSTANTIAL PORTION OF THE SOFT X-RAY BACKGROUND

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Comparison of the SAS-3 soft X-ray sky survey (F. Marshall and G. Clark 1984) with the 21-cm neutral hydrogen survey of Stark et al. (1984) confirms the well-known anticorrelation between the counting rates in the C-band (0.10-0.28 keV) and the column density of neutral hydrogen, and demonstrates that this anticorrelation is significant on all angular scales ranging from that of the general trend from the galactic equator to the poles down to the angular resolution of the detector ($2\overset{\circ}{.}7$ FWHM). Included in this general anticorrelation are numerous instances of what appear to be soft X-ray "shadows" of nearby (100-300 pc) 21-cm features, and several bright X-ray regions coincident with "holes" in the ISM.

The final set of selected data has an exposure of 2.2×10^4 cm^2 s sr, a sky coverage of 80%, and is free of spurious effects due to charged particles and solar radiations. It affords an improved opportunity to examine the validity of the two-component model of the X-ray background, introduced by Davidsen et al. (1977), whereby the C-band intensity in a given direction is represented as a sum of a constant term, I_1, due to unattenuated emission from a local "hot bubble" in which the solar system is immersed, and a term, $I_2\exp[-(N_H/N_{th})]$, due to emission from a diffuse source beyond the neutral hydrogen (e.g., the galactic corona). In this latter term N_H is the column density of neutral hydrogen and N_{th} is the theoretical attenuation column density due to photoelectric absorption in interstellar matter. When this model is used to predict the counting rates of a soft X-ray detector with a field of view that encompasses substantial variations in column density due to the clumping of interstellar matter in clouds with optical depths of the order of 1 or more, it implies a counting rate given by the formula

$$c' = C_1 + C_2 \exp\left[-N_i/N_{ap}\right] \qquad (1)$$

where c'_i is the predicted counting rate and N_i the average column density in the ith field of view. Clumping, which causes the apparent attenuation length, N_{ap}, to be greater than N_{th} (Bowyer and Field 1967, Bunner et al. 1967) must also cause spatial fluctuations in the C-band counting rates. The question therefore arises as to whether a two-component model can be constructed which fits both the anticorrelation and fluctuation properties of the survey data with clumping parameters that are consistent with other information about the ISM.

The C-band survey is displayed in Figure 1 in the form of an Aitoff-projection map, smoothed to an effective angular resolution of $4\overset{\circ}{.}5$ (FWHM). Figure 2 is a similar map of the neutral hydrogen column density data, most of which was measured with the Bell Telephone Laboratory Horn Antenna on 2° centers over most of the sky. The BTL survey has comparatively little sidelobe contamination and is well matched in angular resolution to our X-ray survey. The numerical analysis of correlations and fluctuations in the X-ray and radio data were carried out with unsmoothed data stored in arrays of elements corresponding to equal solid angles of $1\overset{\circ}{.}8 \times 1\overset{\circ}{.}8$.

For analysis of the fit to the two-component model the data were divided into eight sets corresponding to octants of the sky running from the galactic equator to pole between meredia of longitude separated by 90°. Figure 3 shows semilog correlation plots of the counting rates <u>versus</u> column densities after removal of data contaminated by identified discrete sources like the Cygnus Loop, Capella, and HZ 43. The curves are the least-squares fits of equation (1). The best fit is in the "second" octant defined by $0^{\circ}<b<90^{\circ}$, $90^{\circ}<l<180^{\circ}$ where:

$C_1 = 0.16\ s^{-1}$

$C_2 = 0.43\ s^{-1}$

$N_{ap} = 2.7 \times 10^{20}$ H-atoms cm^{-2}

The rms residual deviation between the model values and observed values of the counting rates in this octant is 13%, after allowance for Poisson fluctuations in the counting rates and estimates of baseline errors ($\pm 1 \times 10^{19}\ cm^{-2}$) and measurement errors ($\pm 5\%$) in N_i. Since fluctuations in systematic errors of the X-ray measurements can account for a good portion of the 13%, it is clear that the two-component model fits the data in the second octant very well indeed. For the SAS-3 soft X-ray detectors the value of N_{th} for thermal X rays from a 10^6 K plasma after attenuation by passage through 2×10^{20} H-atoms cm^{-2} of the ISM is $1.4 \times 10^{20}\ cm^{-2}$. Thus the fact that N_{ap} is substantially larger than N_{th}, first brought to light by Bowyer, Field, and Mack (1968), is confirmed here with particular clarity.

To evaluate the small-scale spatial fluctuations in the C-band rates that might be caused by clumping of the ISM, the difference between each counting rate and the mean rate in the immediate neighbor (8) elements of the counting rate map was evaluated. After allowance for Poisson fluctuations, the residual rms fluctuation in the second octant is 10%.

Monte Carlo simulations of the X-ray attenuation by the clumpy interstellar medium were carried out to explore the range of model parameters that yield results consistent with the above findings, namely that N_{ap} is about $2xN_{th}$ and C-band fluctuations on a scale of 2° are about 10%. Figure 3 illustrates the model. Figure 4 summarizes the results of many runs which yield mean values and standard deviations of N_{ap} and the rms fluctuation, F_x, for each set of model parameters. A parameter set which yields values close to those found for the second octant is as follows:

Distance to edge of local hot bubble = 104 pc

Mean density of HI outside bubble =
$0.75 \exp[-(z/h)^2]$ cm^{-3}, $h = 190$ pc

Distribution in radius of spherical clouds
$dm \sim R^{-4} dr$, $0.4\ \mathrm{pc} < R < 10\ \mathrm{pc}$

Density of H1 in clouds $n_c = 80\ \mathrm{cm}^{-3}$

Fraction of H1 in clouds $g = 0.75$

The results for this set and others in which one parameter is changed are shown in Figure 4 as ellipses centered on the means with radii equal to the standard deviations. Also shown are the results obtained for a model with parameters derived from the estimates of McKee and Ostriker (1977).

Clouds with approximately the above distribution of linear sizes and optical depths have been observed in radio and optical studies. However, detailed evaluations of the depression of mean transmission factors by clumping in mid-latitude fields of view where high-resolution 21-cm data are available consistently fail to yield values that can account for the high values of N_{ap}. The value of g (0.75) used in our model is probably unrealistically large. Moreover, the Wisconsin survey (McCammon et al. 1983) shows that the ratio of B-band to C-band counting rates is approximately independent of N_H, contrary to the expectation of an attenuation model with a substantial fraction of the absorbing gas not concentrated in clouds. Thus some mechanism or combination of mechanisms other than simple clumping must be found to increase the apparent attenuation column density of counting rates if the two-component model with absorption of a distant component is to be sustained.

If one accepts the view that C_2 does, indeed, represent the rate due to a galactic corona before attenuation, then one can estimate the soft X-ray luminosity of the galaxy from these data. Assuming a uniform corona in the form of a disc of radius 14 kpc, a density scale height of 10 kpc, and a temperature of 10^6 K, we find a coronal luminosity of 5×10^{39} ergs s^{-1}, which can easily be supplied by halo supernovae.

ACKNOWLEDGEMENT

This research was sponsored in part by a grant from the National Aeronautics and Space Administration under Contract NAS5-24441.

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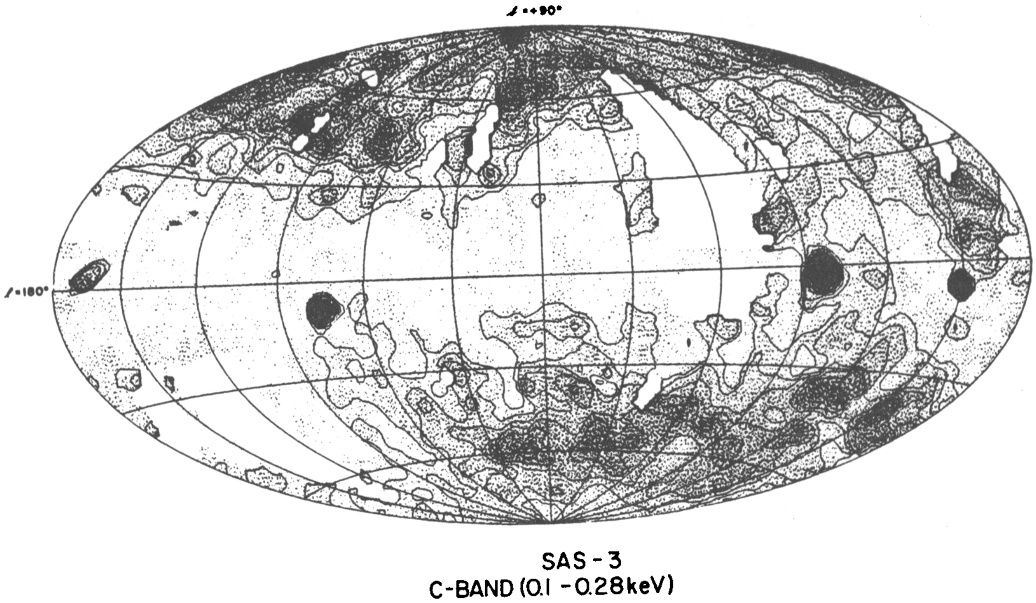
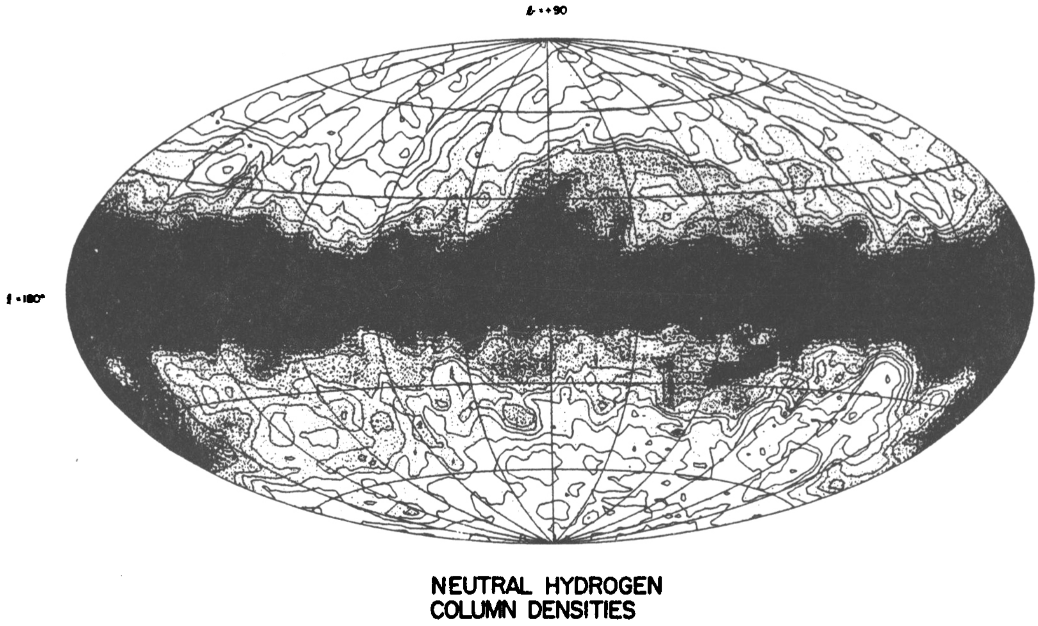


<u>Figure 1</u>: SAS-3 C-band (0.10-0.28 keV) survey map in Aitoff projection. Contours are at intervals of 0.05 cts s^{-1} from 0.20 to 0.45 cts s^{-1}.



<u>Figure 2</u>: Aitoff projection map of 21-cm survey data of Stark <u>et al.</u> (1984).

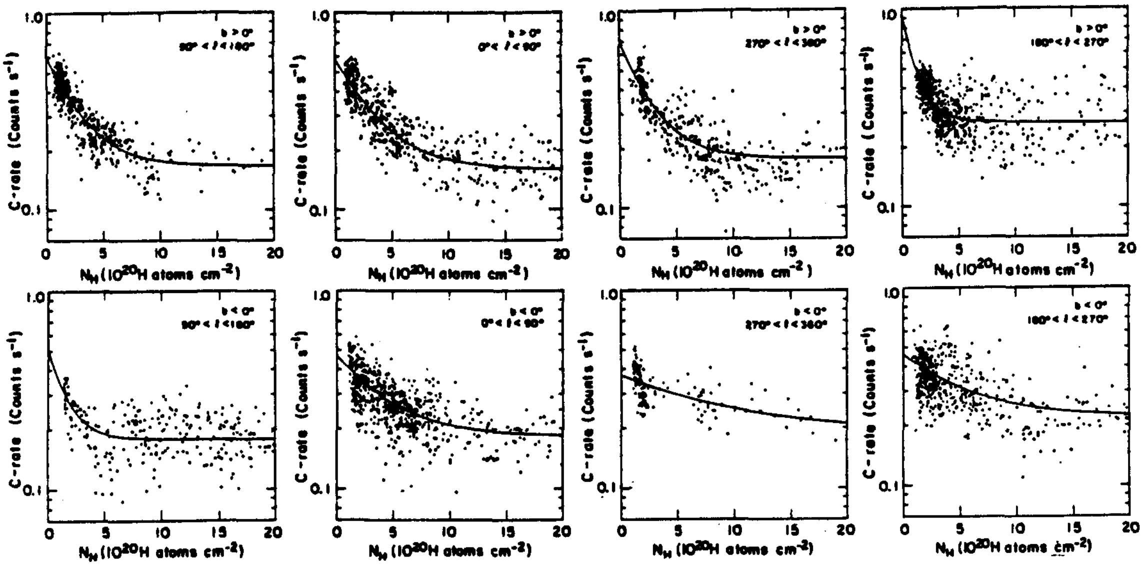


Figure 3: Semilog correlation distributions of C-band counting rates *versus* neutral hydrogen column densities, with best-fit two-component model curves.

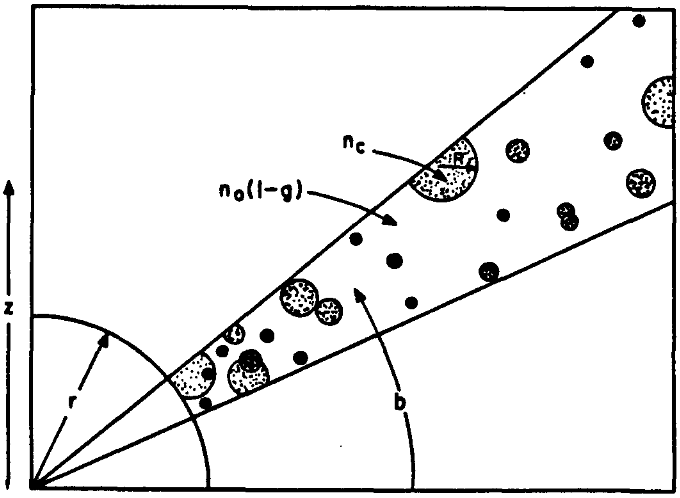


Figure 4: Schematic diagram of the model used in Monte Carlo simulations of attenation and spatial fluctuation of the C-band rate with a clumpy

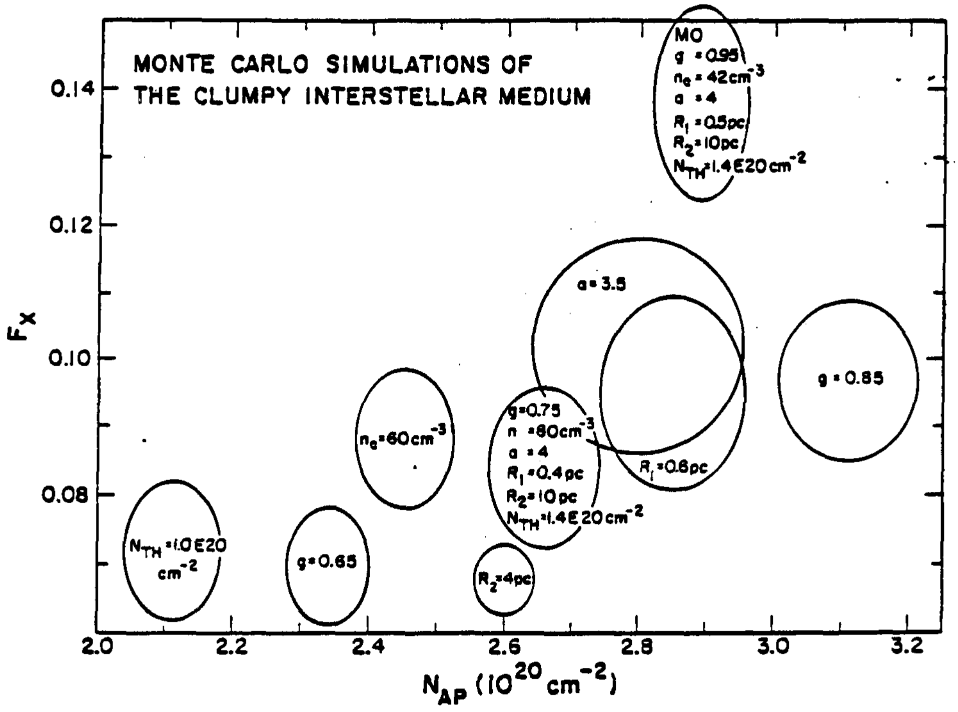


Figure 5: Results of Monte Carlo runs to determine mean values (ellipse centers) and standard deviations (ellipse radii) of N_{ap} and F_x for many trials with each of the sets of parameters indicated in the ellipses. Where only a single parameter is specified the others are assumed to have the values in the ellipse centered at $F_x = .08$ and $N_{ap} = 2.7 \times 10^{20}$ cm^{-2}.