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THE SPECTRUM OF THE EXTRA-GALACTIC BACKGROUND RADIATION AT LOW RADIO FREQUENCIES

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The cosmic noise background radiation observed at meter and decameter wavelengths is generally considered to be due to several different spatial components. These include synchrotron radiation from cosmic ray electrons in the galactic disk, similar radiation from the galactic halo (although the relative importance of this component is a matter of considerable controversy), and an isotropic radiation component due to the integrated emission of all unresolved extra-galactic radio sources. Results of recent analyses of meter-wave measurements[1-3] place the brightness I_x of the isotropic component at about one-third the minimum total brightness observed at a frequency f of 100 MHz. The spectral index α_x of the isotropic radiation is thought to be about equal to the average spectral index ($\sim$0.8) observed for surveys of extra-galactic discrete sources[4] at f $\sim$ 100 MHz where

$$I_x \propto f^{-\alpha_x}$$

New low frequency measurements[5] obtained using the Radio Astronomy Explorer satellite (RAE-1) have extended the frequency range over which the background spectrum may be studied by more than a decade. At frequencies below 1 MHz, the effect of free-free absorption by electrons in the interstellar medium results in a very high attenuation of the extra-galactic radiation so that only the galactic disk component remains[6]. We may therefore utilize the low frequency measurements to determine the galactic radiation component. Then an extrapolation of the galactic spectrum back to higher frequencies results in the separation of the galactic and extra-galactic components over a much wider frequency range.

RAE-1 measurements of background spectra from 0.5 to 5 MHz averaged over angular regions of ~ 100° in extent have been combined with ground-based observations adjusted to comparable angular resolution to obtain average spectra from 0.5 to 100 MHz for several different directions including the galactic poles and the anti-center region (Fig. 1). Multiparameter least squares fits to the observed spectra were derived for analytical models of the form

$$I(f) = I_{g_1} f^{-\alpha_g} \left(\frac{1-e^{-\tau_g}}{\tau_g} \right) + I_{x_1} f^{-\alpha_x} e^{-\tau_g} F(\tau_x)$$

where $\tau_g = \tau_{g_1}/f^2$, $\tau_x = \tau_{x_1}/f^2$, and where I_{g_1}, τ_{g_1}, I_{x_1}, and τ_{x_1} are the galactic disk and isotropic (halo + extra-galactic) brightness and optical depth parameters at $f = 1$ MHz. Three functions, $F(\tau_x)$, were fit to the observed spectra:

$$F_1(\tau_x) = e^{-\tau_{xa}},$$

$$F_2(\tau_x) = (1-e^{-\tau_{xb}})/\tau_{xb},$$

$$F_3 = F_1 \cdot F_2.$$

The function F_1 would correspond to absorption by discrete regions of ionized hydrogen lying between the source and observer. This might be in the halos surrounding the various discrete sources which constitute the isotropic background or HII associated with our own galaxy but which lies outside the galactic emission disk. The function F_2 might represent absorption by HII regions that are uniformly mixed with emission regions in the extra-galactic sources or HII in the inter-galactic space absorbing sources at various distances giving rise to a spectral shape similar to that observed for our own galaxy. Absorption by electrons in inter-galactic space was postulated by Sciama[7] and also suggested by Bridle[8] to account for certain features of Reber's[9] 2.1 MHz southern sky survey. The function F_3 is simply a combination of F_1 and F_2 to allow for the simultaneous influence of both forms. Other processes which will result in spectral turnovers, such as synchrotron self-absorption and the Tsytovich-Razin effect, were not specifically included since the accuracy of the present measurements is not sufficient to permit us to distinguish between the effects of those processes and the effects defined by the simpler free-free absorption functions.

For the best fit curves derived in the manner described above, the rms deviation between the calculated spectra and the observations was less than 10% in all cases. For the region centered on the so-called "North halo minimum" ($\ell^{II} = 150^o$, $b^{II} = 50^o$) where the isotropic radiation component should be determined most reliably, the rms fit to the observations from 0.5 to 100 MHz was better than ±3%. The best fit spectral indices were quite close to independent determinations from ground-based measurements[1] and were $\alpha_g = 0.4 \pm 0.05$ and $\alpha_x = 0.8 \pm 0.1$. The 1 MHz optical depth for galactic thermal electrons was of order 1 for the direction of the galactic poles.

The derived spectrum of the isotropic component is shown in Figure 2 along with the results of independent estimates obtained at high frequencies. The agreement with other estimates can be seen to be very close. The spectrum in Figure 2 does not include effects of absorption in the galactic disk, and hence we see that at frequencies below 10 MHz the isotropic radiation must turn over sharply before it enters the galactic disk. We cannot uniquely determine which of the functions $F(\tau_x)$ best describe the low frequency end of the isotropic spectrum, but for any form the total optical depth at 1 MHz is approximately 5 ± 2. This result does not support the concept of an appreciable galactic halo contribution to the total radiation, since it does not seem reasonable to expect either a large disk of absorbing material outside the disk of galactic emission or a self-absorption mechanism that would turn over the halo radiation spectrum above 1 MHz. The limits thus imposed on the amount of halo radiation that can contribute to the isotropic component are that no more than one half of the total radiation coming from outside the disk at 100 MHz can be from a galactic halo.

The isotropic spectrum and its low frequency turnover do seem to be understandable in terms of absorption of extra-galactic radio emission at the sources or along the path between the sources and our own galaxy. If the extra-galactic sources have thermal electron densities comparable to or greater than our galaxy, then one would expect to see absorption with a 1 MHz optical depth $\gtrsim 2$ due to the ionized gas in the outer envelopes of the sources. All of the observed change in the spectrum could be accounted for by absorption in the radio galaxies which presumably comprise the isotropic component if their average electron density exceeds that in our own galaxy by about a factor of two. Any remaining absorption characterized by an optical depth of $\lesssim 3$ at 1 MHz may not be an unreasonable figure for absorption by inter-galactic electrons. For an inter-galactic medium at a temperature of 10^4 to 10^5 °K the required emission measures are $\langle N_e^2 L \rangle \lesssim 5$ to 130 cm^{-6} pc. If most of the radiation comes from a distance of about a Hubble radius, then the required inter-galactic electron density will be $\sim 10^{-4.5 \pm 0.5}\ \text{cm}^{-3}$.

In summary, an analysis of the cosmic noise background radiation from 0.5 to 100 MHz leads to an estimate of the spectrum of the extra-galactic radiation over this range which is in good agreement with independent determinations from meter-wave measurements. The isotropic brightness varies with frequency to the -0.8 ± 0.1 power of frequency above 10 MHz and is 5.5 (±2.0) x 10^{-22} W/(m^2 Hz sr) at 100 MHz. Below 10 MHz, the isotropic spectrum must turn over in a manner similar to that expected due to free-free absorption between the sources and our galaxy with an optical depth of order 5 at 1 MHz. This result provides independent confirmation of a similar conclusion derived by Bridle from observations at 2 MHz and suggests that the isotropic radiation may be absorbed by electrons in the sources and/or the inter-galactic medium. From the shape of the spectrum of the radiation component coming from outside the galactic disk, we deduce that any galactic halo radiation must constitute less than 15% of the minimum total brightness observed at 100 MHz. If the radius of the galactic halo is greater than 10 kpc and the semi-thickness of the galactic disk is less than 0.5 kpc, then the volume emissivity of the halo radiation must not be greater than one percent of the synchrotron emissivity in the disk.

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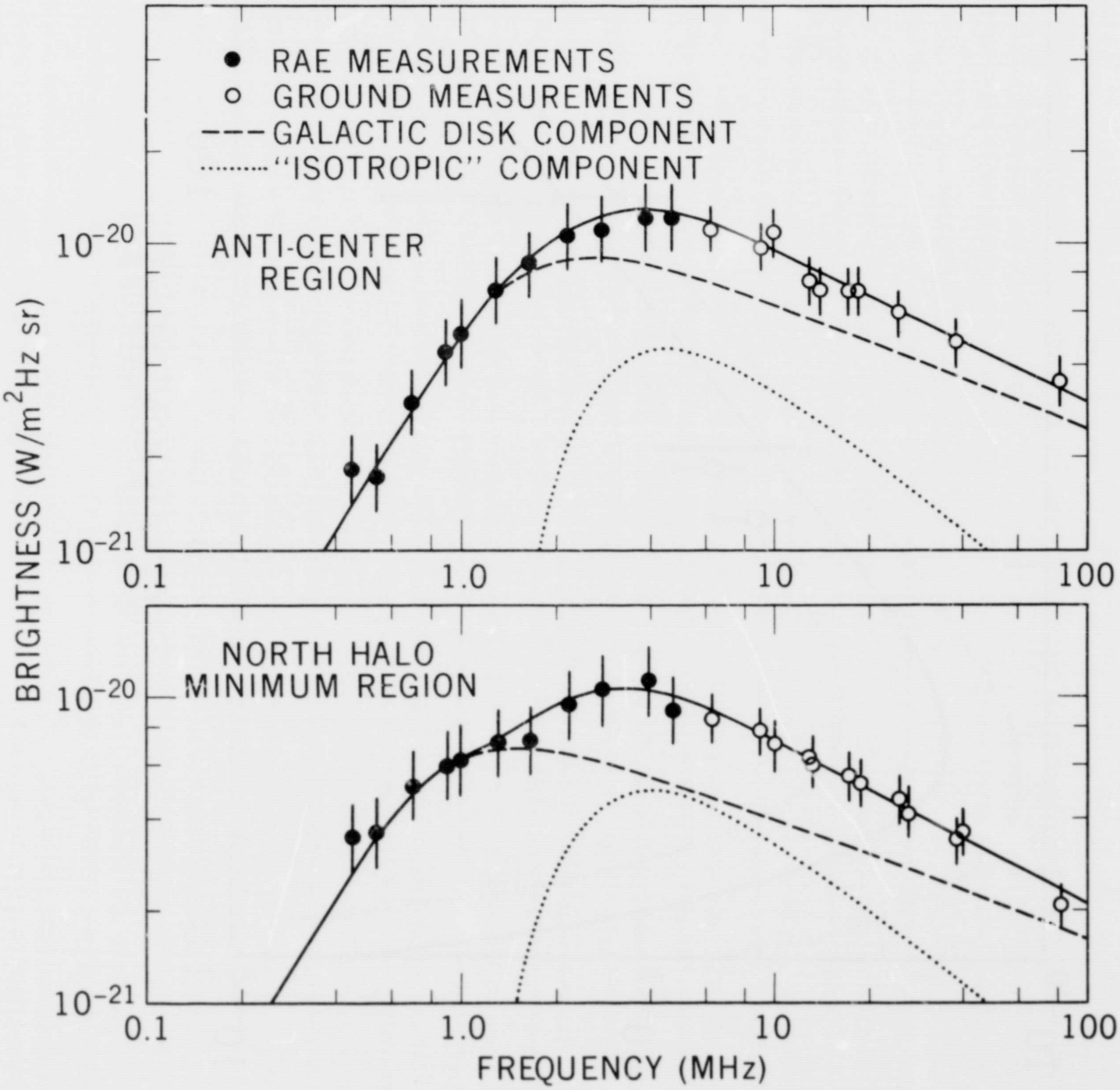
FIGURE CAPTIONS

Fig. 1 - Cosmic noise background spectra at low frequencies for the general regions of the galactic anti-center and the "north halo minimum" ($\ell \sim 150^{\circ}$, $b \sim 50^{\circ}$). The dashed and dotted curves show how the observed spectrum can be broken into a galactic disk component and quasi-isoptropic component.

Fig. 2 - Spectrum of the radiation component coming from outside the galactic disk after correction for free-free absorption by electrons in the disk. The dotted curves denote the magnitude of the uncertainty in this determination of the isoptropic spectrum. The high frequency measurements are y Bridle[1] (O), Shain[10] (I), Yates[2] (x), Yates and Wielebinski[11] (Δ), and Wall[3] et al.(●).



● RAE MEASUREMENTS
○ GROUND MEASUREMENTS
--- GALACTIC DISK COMPONENT
······ "ISOTROPIC" COMPONENT
ANTI-CENTER REGION
NORTH HALO MINIMUM REGION
BRIGHTNESS (W/m^{2}Hz sr)
10^{-20}
10^{-21}
0.1
1.0
10
100
FREQUENCY (MHz)

Fig. 1

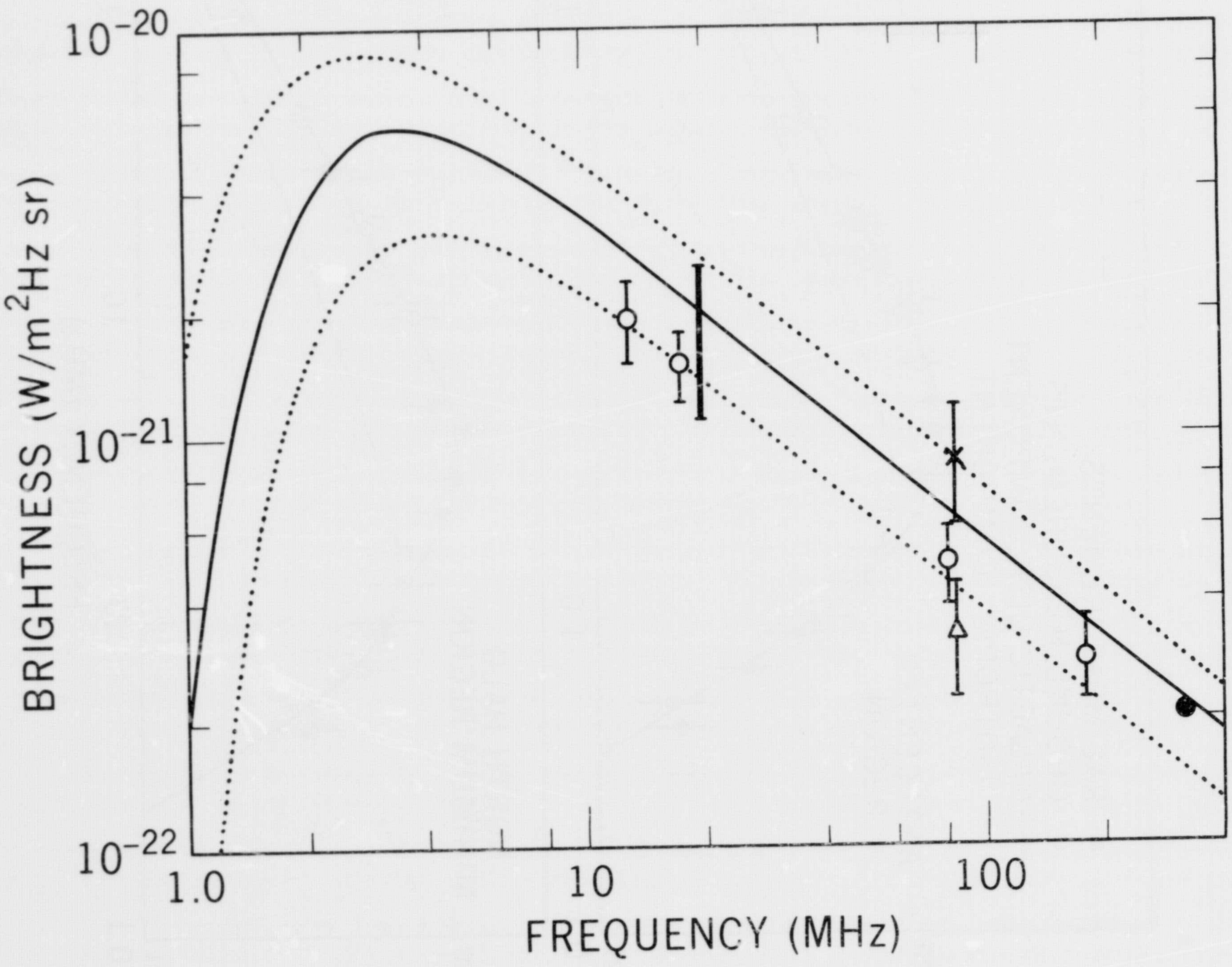


Fig. 2