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$T_b - N_{HI}$ CORRELATION IN THE GALACTIC PLANE

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ABSTRACT

Synchrotron emission at 408 MHz and HI column density have been used to find an evidence for the relationship between the Galactic magnetic field and the gas density. The observational data of the brightness temperature and HI column density, $T_b(408)$ and $N_{\rm HI}$, near the galactic plane between galactic longitudes $l = 62°$ and $l = 250°$ show a clear linear correlation of $T_b(408)$ = A(l, b) + B $N_{\rm HI}$, where A(l, b) is a background and forground radiation at the galactic coordinate. We found $(1.4 \pm 0.3)\ 10^{-21}$ for the slope B, which describes the strength of the syncrotron radiation from the HI cloud, and agrees with the value for the Milky Way obtained by Beuermann et al. (1985). We conclude therefore that a well defined nonthermal corelates with the HI column density originating from this HI cloud.

1. INTRODUCTION

The magnetic field strength may play an essential role in the understanding of the physical processes in the interstellar gas. Particularly its distribution in such medium is a very important datum which relates to structuring the dense cloud complexes as well as for the distribution and propagation of cosmic rays. In the presence of flux freezing the magnetic field B seems to scale with the gas density according to $B = B_i(n/n_i)^k$, where a range for the exponent lies in $1/3 \leq k \leq 1/2$ and the index i corresponds to the initial situation (Mouschovias 1985). The magnetic field strength in our Galaxy can be measured by the Zeeman effect. Troland & Heiles (1982) suggested in the study of the Zeeman effect that the theoretical argumen about the above density dependence of the field strength are incorrect. They concluded that the magnetic field is unlikely to play an important role in influencing large-scale motions of the gas due to the low magnetic energy densities in the regions of $0.1 \leq n(cm^{-3}) \leq 10^2$. However, Fleck (1983) showed that this "B versus n dilemma" can be resolved in terms of preferential mass flow along magnetic field lines as a result of an increase in the ratio of magnetic and gas pressure due to the cooling accomapanying HI cloud formation from the intercloud medium and the subsequent formation of molecules within these clouds. To the B - n relation, another approach has been carried out by Brown & Chang (1983) who compared the observations of the nonthermal galactic background component at 327 MHz with that of 21 cm HI emission. They derive an exponent k of 0.44, but Troland & Heiles (1986) critized their approach and pointed out that Zeeman measurements suggest no increase in field strength for particle densities

$n \leq 100\ cm^{-3}$. Berkhuijsen et al. (1993) presented the first observational correlation between the average magnetic field strength and the average gas volume density with $k = 0.65$, which is consistent with magnetic flux freezing if energy equipartition betweeen cosmic ray particles and magnetic fields holds. They suggest also that studies of the relationship between properties of the magnetic field and that of the gas in large clouds could be made by comparing the nonthermal radio continuum emission with that of HI and CO in order to obtain orientation and strength of the magnetic field as well as the distribution and density of the neutral gas. Beuermann et al. (1985) (hereafter BKB) noted that a fraction of the nonthermal continuum eimission at 408 MHz (Haslam et al. 1982) is connected with the HI cloud. If this component can be seperated from a total nonthermal emission, we can then test the question of the B - n relationship by comparing the brightness temperature with the HI column density. This is a main subject of this paper. The HI component of the brightness temperature at 408 MHz is seperated from the total brightness temperature. The purpose of this paper is to examine the existence of the B versus n relationship using a 408 MHz all sky survey and the available intergrated HI column density.

2. DATA AND REDUCTIONS

The Bonner 408 MHz all sky survey (Haslam et al. 1982) has a resolution of 0.85° and gives the brightness temperature at 408 MHz (K) in a grid of 1° interval of the galactic coodinate. According to the three-dimensional model of the galactic radio emission at 408 MHz (BKB) the Galaxy consists of a thick nonthermal radio disk with a thin disk embeded. In this model extended low density (ELD) HII regions, old supernova remnants and syncrotron emission from HI clouds are suggested to be possible constituents of the thin disk.

BKB model suggests 2.6×10^{20} WHz^{-1} of the total radiation power for the HI cloud component at 408 MHz. The expected brightness temperature from the HI component

$$T_{b,HI} = 1.3 \times 10^{-21} N_{\rm HI} \tag{1}$$

In Figure 1 we show longitude profiles for the observed $T_b(408)$ (uppper curve), the background component(lower curve) and the sum of the background component and the expected HI component(middle curve). Because of the contamination of other components in the brightness temperature, the correlation between $T_b(408)$ and $N_{\rm HI}$ would have a form:

$$\begin{aligned} T_b\ (408) &= T_{b,B} + T_{b,HI} \\ &= A + BN_{\rm HI} \end{aligned} \tag{2}$$

Eq. (2) holds only if T_b (408) has no contribution of thermal radiation and nonthermal discrete sources and in this case $T_{b,B}$ corresponds to the contribution of the thick radio disk in BKB model (background component). Therefore the regions of in any strong radio sources are not suitable to carry out such correlation study. These regions must be excluded from the further analysis in our study in contrast to Brown & Chang (1983) who used all data in the whole Galaxy in a similar study to ours.

In this paper we choose the region of $50° < l < 250°$ and $-4° < b < +4°$. It is very easy to see where the observed T_b is strongly influenced by the radio sources (for example in the Cygnus region near l = 80°, in supernova remnant Cas A near l = 120°, and in Rosetta nebular near l = 205°). A comparison study in this region is impossible. But in the region where $T_{b,B} + T_{b,HI}$ approaches to

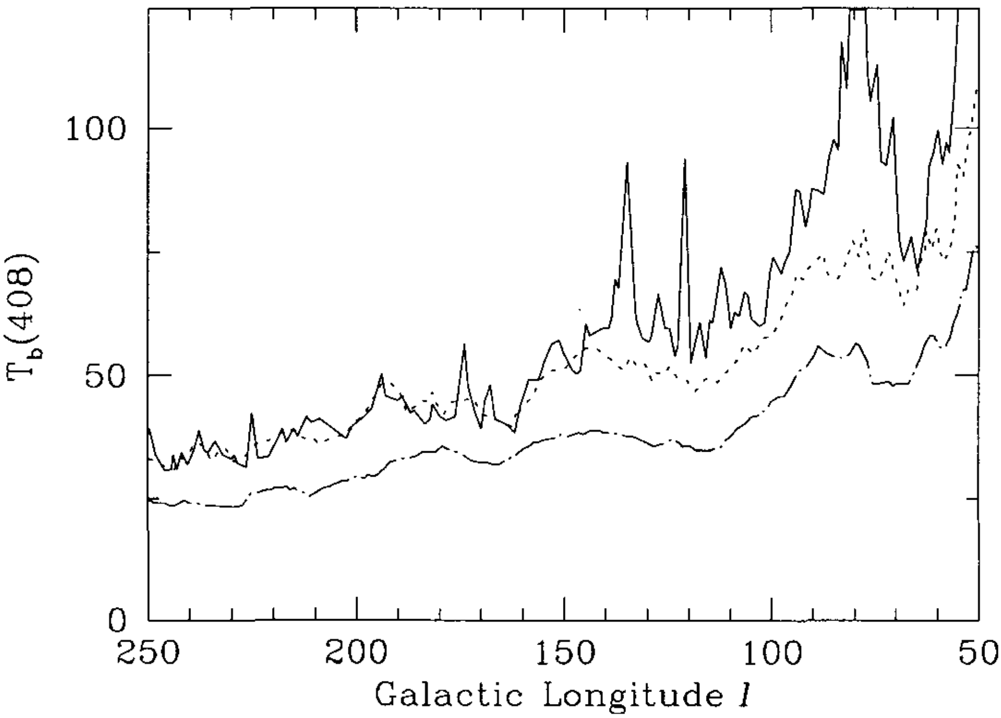

Figure 1. Longitude profile of T_b (408) (solid), the HI component (dotted) expected by BKB model and background component (dot dashed) near $b = 0°$.

T_b (408) it can be said that T_b (408) is not influenced by the sources and thus the T_b (408) - $N_{\rm HI}$ correlation study can be undertaken.

We corrected the contribution of the radio sources in T_b (408) as carefully as possible. For this correction the radiation flux of radio sources with S $\geq$2 Jy at 408 MHz is selected and then transformed to the brightness temperature at 408 MHz in K°:

$$T_b\ (408) = 0.78 \times S \tag{3}$$

This temperature has a peak at the position of the radio source.

There are also some discrete thermal radio sources identified in the 1420 MHz survey (Reich & Reich 1986). For these sources the contribution to the brightness temperature at 408 MHz is also calculated.

All terms estimated above are substracted from the total brightness temperature, T_b (408). Hereafter T_b (408) means the corrected brightness temperature.

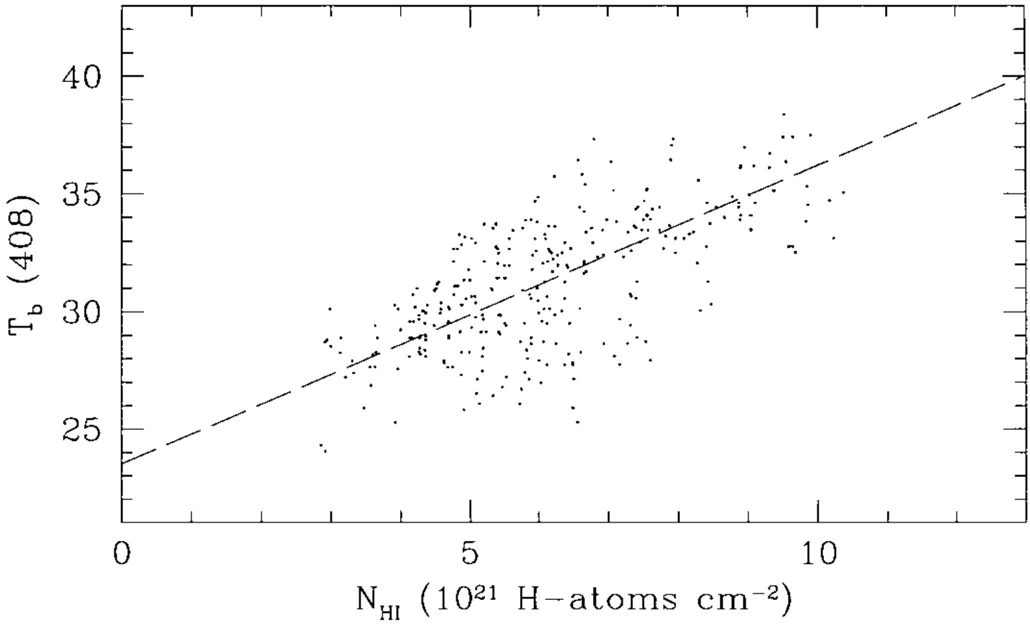

Figure 2. $T_b(408)$-$N_{\rm HI}$ correlation for region of $220° < l < 250°$. The slope of the correlation has been found by the least square method.

3. RESULTS AND DISCUSSIONS

Using a corrected brightness temperature and a HI column density in the grid of selected regions the parameters of the linear correlation, eq. (4), are found by the least square fitting.

Figure 2 shows the $T_b(408) - N_{\rm HI}$ correlation in the region of $220° < l < 250°$. Here we found a linear relationship:

$$T_b\ (408) = (23.52 \pm 0.53) + (1.27 \pm 0.08) N_{\rm HI} \tag{4}$$

Results in other regions for T_b (408) = A + B $N_{\rm HI}$ are listed in Table 1. T_b (408) and A is in unit of Kelvin and $N_{\rm HI}$ is in unit of $10^{21}{\rm H - atoms\,cm^{-2}}$. R is a linear correlations coefficient.

A correlation of $T_b(408)$ with $N_{\rm HI}$ is found everywhere along the galactic plane as BKB model suggests. The background component A in eq. (2) is typically stronger than the HI component. A increases systematically along the galactic plane. B is in the range of 1.0 - 2.0 with a mean value of 1.4 ± 0.3, which describes the strength of the syncrotron radiation from the HI cloud, and agrees with the value for the Milky Way obtained by Beuermann et al. (1985). T_b (408) correlates well with $N_{\rm HI} \geq 3 \times 10^{21}$ H-atoms $\rm cm^{-2}$. The poor correlation for small $N_{\rm HI}$ is probably caused by the variation of the background component.

The region of $176° < l < 189°$ shows also a poor correlation, which indicate that one should carry such correlation study very carefully as discussed later. Because of the strong contamination by the individual radio sourses, it is very hard to separate each contribution from the observed bright temperature (T_b (408)).

Given the synchrotron emissivity of the near-solar electron spectrum at 408 MHz, $\epsilon = (0.34 \pm$

Table 1. Results in galactic plane for T_b (408) = A + B $N_{\rm HI}$ in a given latitude region.

l	A	B	R
220°- 250°	23.52 ± 0.53	1.27 ± 0.08	0.717
145 - 149	41.04 ± 0.98	0.96 ± 0.12	0.813
155 - 166	33.98 ± 0.94	1.52 ± 0.14	0.746
176 - 189	41.81 ± 1.57	-0.33 ± 0.20	-0.199
190 - 200	33.02 ± 0.85	1.04 ± 0.12	0.751
210 - 219	24.95 ± 1.14	1.37 ± 0.15	0.727
62 - 70	51.90 ± 1.87	1.78 ± 0.16	0.897

$0.09)H_{\perp}^{1.8}{\rm Kkpc}^{-1}$ (BKB) and assuming the density of the relativistic electrons to be constant, we obtain for the mean line of sight values of the HI component

$$< B_{\perp}^{1.8} >= (12.7 \pm 4.2) < n > \qquad (5)$$

with $B_{\perp}$ in μG and n in H-atoms cm^{-3}.

A similar work has been reported by Brown & Chang (1983). They compared the observations of the nonthermal galactic background component at 327 MHz with that of 21 cm HI emission in the regions bounded by l = 10° - 250°, b = -10° - +10° without substracting the component which is probably not connected with HI gas. They derive an exponent k of 0.44, but Troland & Heiles (1986) critized their approach and pointed out that Zeeman measurements suggest no increase in field strength for particle densities $n \leq 100\ cm^{-3}$. However, our carefully corrected bright temperature in some selected region shows a clear linear correlaltion of T_b (408) and $N_{\rm HI}$, we conclude therefore that there is in fact a well defined nonthermal component at 408 MHz which is correlated with the HI column density and originates from this HI layer.

Troland & Heiles (1986) argued further that Brown & Chang (1983) compare two variables which are in fact not correlated - if two variable are each correlated with a third, then they appear to be correlated even though they are not. It is hard to find a clear proof to their contrary, but Berkhuijsen et al. (1993) could present a clear observational evidence of T_b (408)-$N_{\rm HI}$ correlation in their CO study in the SW arms of M31. Observational arguments of such correlation can be also found by Adler et al. (1991) and Fiebig & Güsten (1989). Our results indicates also a evidence of such correlation. More detailed analysis and discussion concerning this argument will be presented in the future.

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