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LOCAL GAS WITHOUT REDDENING: THE CONTRIBUTION OF STRAY RADIATION TO 21 CENTIMETER LINE MEASUREMENTS

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ABSTRACT

Previous studies of the relationship between H I column density N(H I) derived from 21 cm line measurements and reddening $E(B-V)$ have disagreed concerning the presence of a zero-point offset, i.e., a component of gas that produces no reddening. It was suspected that the putative effect may have been a result of errors produced by the stray radiation of paraboloidal radio telescopes. We have repeated a number of H I measurements with the Bell Telephone Laboratories horn reflector antenna. We confirm the presence of the zero-point offset in the gas-to-reddening relationship.

Subject headings: interstellar: matter — radio sources: 21 cm radiation

I. INTRODUCTION

Is there a "zero offset" in the relationship between gas and dust, or, in other words, does gas exist without reddening? Recent studies comparing reddenings with H I column densities N(H I) derived from 21 cm line data (Burstein and Heiles 1978, hereafter BH; Mirabel and Gergely 1979) find that, instead of a simple proportionality, the relation is

$$N(\text{H I}) = Z(1) + Z(2) \times E(B-V), \qquad (1)$$

with a positive value of $Z(1)$—a positive zero offset. On the contrary, studies that derive H I column densities from UV measurements of the Lyα line (Bohlin, Savage, and Drake 1978) find a zero, or very small negative, value for $Z(1)$.

The radio observers have been unable to state with certainty that their zero offsets are real. The offsets may have arisen from a specific instrumental effect, namely the reception of radiation from directions other than that where the telescope was pointed. Radio astronomers use the term "stray radiation" to describe this effect. This *Letter* determines the importance of stray radiation for the work of BH.

We are specifically concerned about stray radiation at large angles from the main beam. At high latitudes, where the 21 cm profile is very weak, large errors can be caused from stray radiation in the galactic plane where the profile is very strong. Stray radiation from large angles contributes excess 21 cm power which varies slowly with position because of the large angular scales involved. This is equivalent to a zero offset in the 21 cm integrated line intensity, exactly what is represented by the term $Z(1)$ in equation (1).

It is important to note that stray radiation from large angles has no multiplicative effect on the intensity scale. At high latitudes, differences between N(H I) on small angular scales are reproduced accurately because the contribution of stray radiation at large angles changes only slowly with position. That is, we expect

$$N(\text{H I})_{\text{HH}} = Y(1)_{(l,\,b)} + N(\text{H I})_{\text{true}}, \qquad (2)$$

where $Y(1)$ represents the radiation scattered from large angles which should vary only slowly with l and b.

We have employed the horn reflector antenna of the Bell Telephone Laboratories (BTL) at Crawford Hill, Holmdel, New Jersey, to investigate the effects of stray radiation on the Heiles and Habing (1974, hereafter HH) survey. This antenna is eminently suitable for such an investigation because the amount of stray radiation at large angles is extremely small, which is the very property that made this antenna suitable for the discovery of the 3 K cosmic background radiation (Penzias and Wilson 1965). The main-beam efficiency of this antenna is over 90% at 21 cm wavelength. Nearly all of the remaining 10% is contained in diffraction lobes which are located within 10° of the main beam (Penzias, Wilson, and Encrenaz 1970). The only disadvantage of this telescope is its relatively large half-power beamwidth

(HPBW), 2°5; we have specifically avoided directions in which N(H I) varies rapidly with position.

II. THE OBSERVATIONS

The horn reflector antenna had not been employed for astronomical observations for a number of years. One of us (A. A. S.) resurrected the 21 cm waveguide system used by Sanders, Wrixon, and Penzias (1972) with two modifications. The new system did not have the variable room-temperature attenuator used to balance the system, and it used a transistor amplifier cooled with liquid nitrogen instead of the helium-cooled maser. This GaAs FET amplifier was kindly loaned to us by J. Beiging of the Berkeley Radio Astronomy Laboratory.

We employed part of the spectrometer that is normally used for mm wavelength observations with the BTL 7 m offset Cassegrain antenna at Crawford Hill. We used two NRAO-type filter banks of 128 channels each. One bank had a resolution and spacing of 12.5 kHz, which was obtained by using the standard 0.25 MHz-wide channels in conjunction with the BTL spectrum expander (Henry 1976); the other bank had the standard 0.25 MHz-wide filters without the spectrum expander and was used to determine accurate baselines for the first set. The 12.5 kHz channel bank covered a total velocity range of 337 km s^{-1}, which was centered at -50 km s^{-1} with respect to the local standard of rest (LSR) to better include negative intermediate and high velocity gas.

Because of equipment problems, we cannot independently derive an accurate intensity scale for the observations reported here. To establish our intensity scale, we used a noise diode coupled to the receiver by a waveguide directional coupler. Unfortunately, the output power of this diode changed between the time it was calibrated and the time it was used for these observations. In addition, it may have varied somewhat during the period of observation.

Owing to these difficulties, we calibrated our data from the 21 cm line survey of the galactic plane of Weaver and Williams (1974). In particular, we used the position $(l, b) = (+72°, -0°5)$ where the 21 cm line intensity near zero LSR velocity is remarkably constant over a large angular area. Our intensity scale matches that of HH if this brightness temperature is 125 K. In fact, we later determined this brightness temperature to be 118 K. Nevertheless, for the purposes of this *Letter* we adopt a scale that exactly matches that of HH.

We observed a subset of Table 1 of BH including objects near which N(H I) varied slowly with angle, as revealed by the maps of Heiles (1975). The observational procedure consisted of positioning the telescope about 2 minutes of time ahead of the source and integrating for 4 minutes, while keeping the telescope stationary with respect to the Earth.

Figure 1 plots $N(\text{H I})_{\text{HH}}$ versus $N(\text{H I})_{\text{BTL}}$, with the N(H I)'s derived from the standard optically thin equations and expressed in "BH units" (2.23×10^{18} cm^{-2}). It is evident by inspection of this figure that the value of $Y(1)$, averaged over all of the positions observed, is small. A formal least-squares fit yields

$$Y(1) = 30 \pm 8 \text{ BH units.} \tag{3}$$

Figure 2 shows a direct comparison of $N(\text{H I})_{\text{BTL}}$ with $E(B-V)$ from BH. The least-squares fit to these data yield

$$Z(1) = 96 \pm 9 \text{ BH units,}$$

$$Z(2) = 1754 \pm 93 \text{ BH units mag}^{-1}. \tag{4}$$

In both cases the quoted errors are mean errors.

III. DISCUSSION

The least-squares fits show that (a) stray radiation from large angles does affect the HH survey, and (b) the zero offset found by BH exists and their derived value, $Z(1) \approx 100$ BH units, is not greatly in error. We now briefly discuss the implications for these two areas and compare our results with UV studies.

a) *The HH Survey*

The data in Figure 1 imply that the error introduced by stray radiation in the HH survey, averaged over the positions observed, is about 30 BH units. The minimum N(H I) in the HH survey is somewhat less than 75 BH units, which persists over large areas at high positive galactic latitudes. Thus, stray radiation makes this value some 100% too large. This is similar in importance to the effect for the Bonn 100 m telescope; Kalberla, Mebold, and Reich (1980) and Kalberla, Mebold, and Velden (1980) found that stray radiation could increase profile areas by as much as 70% in extreme cases.

The contribution from stray radiation that we have derived is averaged over many positions. It is possible that there are some positions where the contribution is even larger. As part of the 21 cm observational program with the horn reflector, we also surveyed all large sections of sky where N(H I) is small. We shall report on these more extensive data and related matters in a later paper.

b) *The Zero Offset: Gas without Reddening*

We, together with BH and Mirabel and Gergely (1979), find a zero offset in the relation between N(H I) and $E(B-V)$. Previous studies by radio observers, of which we take Knapp and Kerr (1974) as the illustrative example, did not. The reason for this discrepancy is simple and has nothing to do with stray radiation. The

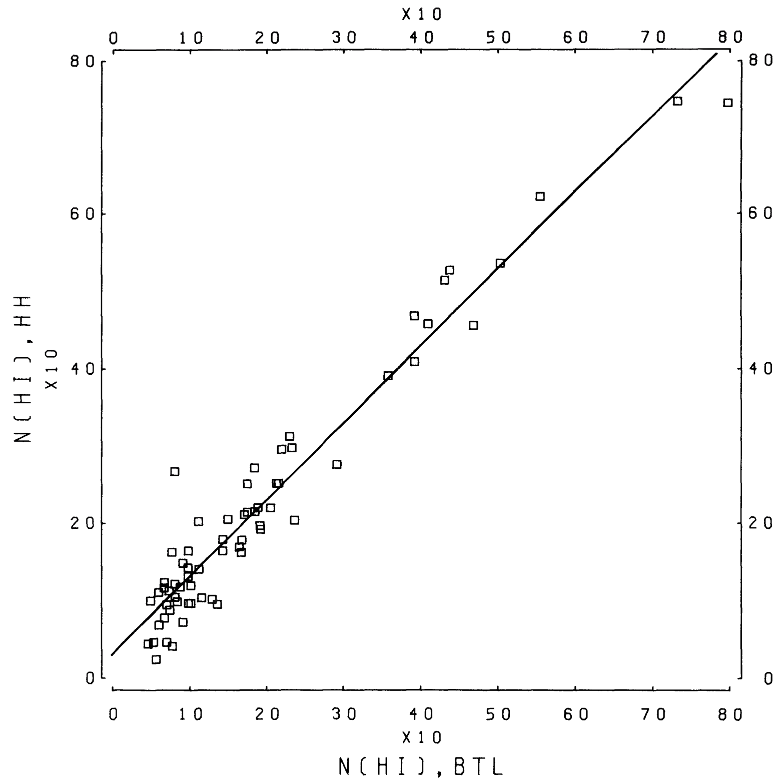

FIG. 1.—N(H I) measured by HH vs. N(H I) measured at BTL in the present work. The BTL intensity scale has been adjusted to precisely match that of HH. The straight line is the least-squares fit (eq. [3]).

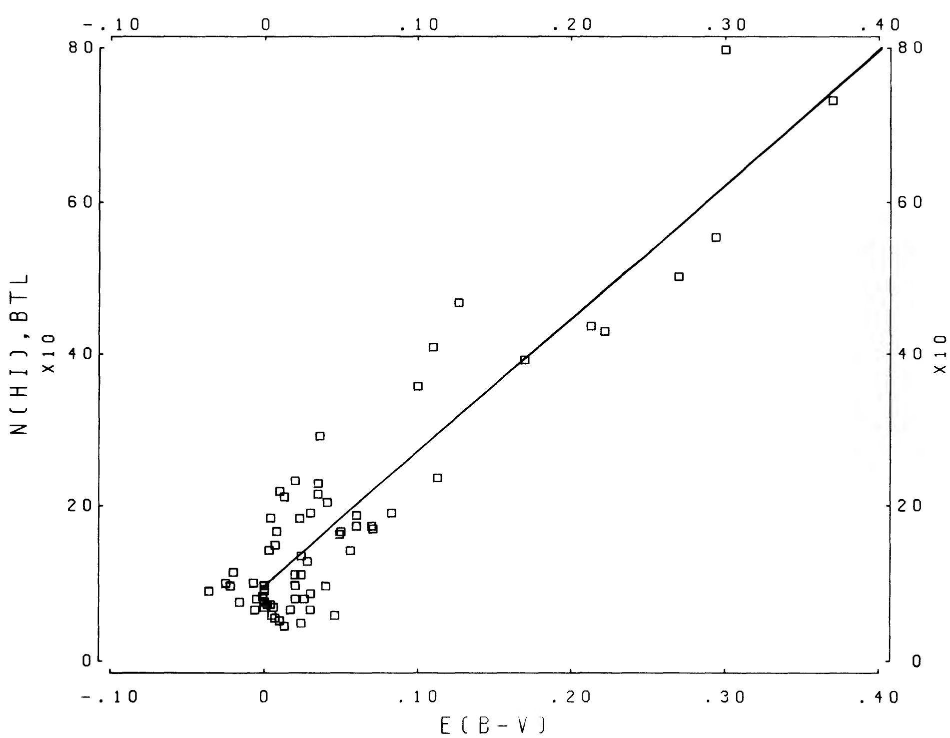

FIG. 2.—N(H I) measured at BTL in the present work vs. $E(B-V)$ from BH for objects having $E(B-V) < 0.3$ and no rapid variation of N(H I) with angle. The straight line is the least-squares fit (eq. [4]).

previous studies used earlier values of $E(B-V)$'s, most of which are traceable to the compilation by van den Bergh (1967). The $E(B-V)$'s in this compilation are 0.06 mag too high, because they were based on the assumption that the reddening in the galactic polar caps is 0.06 mag. This assumption is now known to be incorrect; instead, the reddening is approximately zero (Burstein and McDonald 1975; BH; Mirabel and Gergely 1979).

Consequently, we must consider the zero offset to be well established by radio studies, even by earlier studies such as that of Knapp and Kerr (1974) which did not explicitly find an offset.

c) *Comparison with UV Studies*

All radio studies show the zero offset. However, the UV studies, which observe the Lyα line, do not. The most recent and comprehensive study is that of Bohlin, Savage, and Drake (1978, hereafter BSD). One possibility for this disagreement is systematic errors in the $E(B-V)$'s used by BSD. BSD do not quote the source of their $E(B-V)$'s and in their discussion imply that $E(B-V)$'s smaller than 0.04 are untrustworthy because of systematic errors. As discussed above, we believe that the $E(B-V)$'s used by BH are correct.

Another possibility is that the discrepancy is caused by the difference between the types of stars sampled by BH and BSD. The radio studies used globular clusters and other distant, high-latitude stars as test objects, so that all of the interstellar matter could be assumed to lie in front of the objects. In contrast, the UV study used bright UV stars as test objects; these stars tend to be located near the galactic plane where the interstellar gas is denser. The discrepancy could be explained if the amount of reddening-free gas varies with both z and distance from the Sun.

IV. POSSIBLE RAMIFICATIONS FOR THE LOCAL INTERSTELLAR MEDIUM

The existence of a positive zero offset is surprising. If it is real, it may apply only to interstellar matter that is located nearby, because the stars in our sample are located mainly at high latitudes. If so, it may be a result of modification of nearby grains by a shock. It is well known that the Sun is located in a region containing much less interstellar H I than usual (e.g., Heiles 1980; Fried *et al.* 1980). Modern astrophysical theory pictures such holes as produced by deposition of energy into the interstellar medium by stellar winds and supernovae (Cox and Smith 1974; Castor, McCray, and Weaver 1975; McKee and Ostriker 1977). Matter is swept from the hole by a strong shock, behind which gas is strongly heated and compressed and dust grains are modified (see reviews by Salpeter 1977; McCray and Snow 1979).

Two additional observational data support this possibility. One is the variability in the gas-to-dust ratio by a factor of 2 from average, found by BH; such variability could result from differing grain sizes in different gas parcels. The other is the correlation of the intensity of the diffuse UV background with H I column density at high latitudes and the variability of this correlation with position (Paresce, McKee, and Bowyer 1980). This UV is interpreted as galactic starlight back-scattered by dust grains associated with the H I gas.

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