THE CORRELATION OF INTERSTELLAR REDDENING AND Lα ABSORPTION

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Abstract. For 61 stars whose interstellar Lα absorption was observed by OAO-2, the average relation of H I column density to $B-V$ color excess is equal to 5×10^{21} atoms cm^{-2} mag^{-1}. For a recent dust grain model this value implies that the density ratio $\langle\rho_{\text{HI}}/\rho_{\text{dust}}\rangle \approx 100$. A good correlation was found for deviations in the measurements of $N_{\text{H I}}$ and $E(B-V)$ from their mean values expected over the distances to the different stars, indicating an association of H I gas with dust.

The observation of 21-cm line radiation in both emission and absorption has been a traditional and very productive method of learning about the distribution of H I gas in space. The density of interstellar hydrogen may also be found by measuring the width of the Lα absorption feature in ultraviolet stellar spectra (Jenkins, 1970). At present, the amount of space probed by the Lα observations falls far short of the coverage by 21-cm surveys. However the 21-cm data are usually not well suited for comparisons with various absorptions observed toward stars, including reddening by dust, since the radio beam inevitably must sample an indefinitely long cone in space, instead of a volume of limited length and infinitesimal solid angle. In essence, Lα observations provide exactly the same sample volume as the other stellar measurements, and the derived hydrogen column densities are completely insensitive to the temperature of the gas.

At present, we have measured the strength of Lα absorption in the spectra of some 69 stars of spectral type B2 or earlier which were observed by the Wisconsin low-resolution scanner on board OAO-2. The experimental methods and results have already been presented in some detail by Savage and Jenkins (1972), and Figure 1 shows the correlation of hydrogen column densities against $B-V$ color excesses which was plotted in the original article. The determination of color excesses started with the intrinsic colors of Johnson (1963) which were applied to the spectral types assigned either by Lesh (1968) to northern stars or by Hiltner *et al.* (1969) to southern stars. These colors were compared with the photometric data of Iriarte *et al.* (1965) and Cousins and Stoy (1963) for the northern and southern objects, respectively. For all of the stars except those classified as emission line types, whose $E(B-V)$ values were considered to be less reliable, we obtained

$$\sum N_{\text{H I}} / \sum E(B-V) = 5\times10^{21}\ \text{atoms cm}^{-2}\ \text{mag}^{-1}.$$

It is of interest to derive a gas to dust mass ratio from the observation of $\sum N_{\text{H I}} / \sum E(B-V)$. A recent model for the interstellar grains of Gilra (1971) reproduces reason-

Greenberg and Van de Hulst (eds.), Interstellar Dust and Related Topics, 247–250.

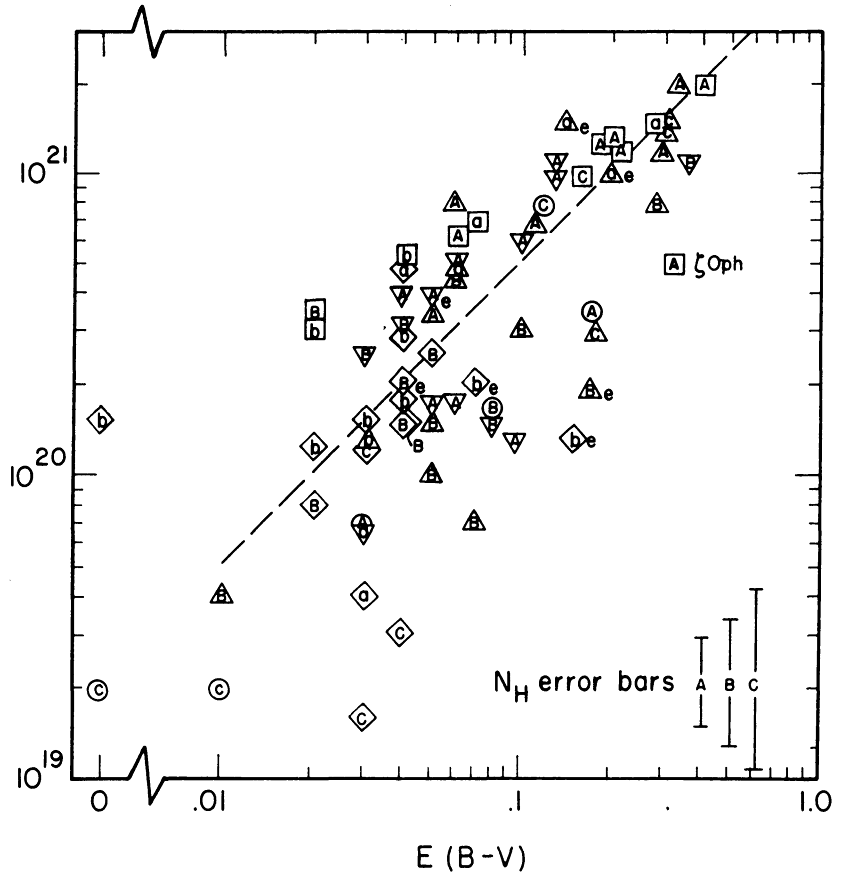

Fig. 1. A comparison of hydrogen column densities to color excesses for 69 stars. The shapes of the symbols denote different regions of the sky outlined in the original work by Savage and Jenkins (1972). The letters indicate the relative probable error in each of the determinations of $N_{\rm HI}$ with lower case letters indicating those measurements taken from stars of spectral type B2. An 'e' follows symbols for emission line stars, for which the $E(B-V)$ values are probably less accurate. The dashed line represents our average ratio of 5×10^{21} atoms cm^{-2} mag.$^{-1}$ from our observed $\Sigma N_{\rm HI}/\Sigma E(B-V)$. (Reproduced by courtesy of the *Astrophysical Journal*; University of Chicago Press, publisher.

ably well the basic observational data on the grains. For this model Gilra finds that 2.5×10^{-5} gm cm^{-2} is needed to produce 1 mag. of extinction at the V-filter. If we assume the ratio of total to selective extinction R_V is 3.0, then the gas to dust mass ratio implied by this model and the OAO-2 result is $<\varrho_{\rm HI}/\varrho_{\rm dust}> \approx 100$. This result can be changed by factors of 2 or 3 depending on the particular grain model selected.

Our figure for the overall ratio of hydrogen column density to reddening is biased toward regions of space having a less than average amount of obscuration. For the 61 stars considered, the average color excess per unit distance

$$\sum E(B-V)/\sum r = 0.28 \text{ mag. kpc}^{-1}$$

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whereas one would expect a value of 0.61 mag. kpc^{-1} if one were looking in random directions within 1 kpc of the Sun (Spitzer, 1968). This selection effect is a consequence of our being restricted to stars whose brightness near 1216 Å is above a certain observational limit. Since $E(1216-V)$ is generally as much as 6 times $E(B-V)$ (Bless and Savage, 1972), stars with little reddening are given a distinct advantage in appearing on our observing list.

The strong attenuation of ultraviolet radiation by dust also precludes our verifying whether or not the ratio of H I to dust decreases in very dense clouds (with $A_V \gtrsim 3$), as some past studies have indicated (Van de Hulst *et al.*, 1954; Heeschen, 1955; Bok *et al.*, 1955; Varsavsky, 1968; Garzoli and Varsavsky, 1966; Gosachinskii, 1966; Kerr and Garzoli, 1968; Mesaros, 1968). This decrease has been interpreted as indirect evidence that the formation of H_2 may be depleting the H I in dark clouds. It is

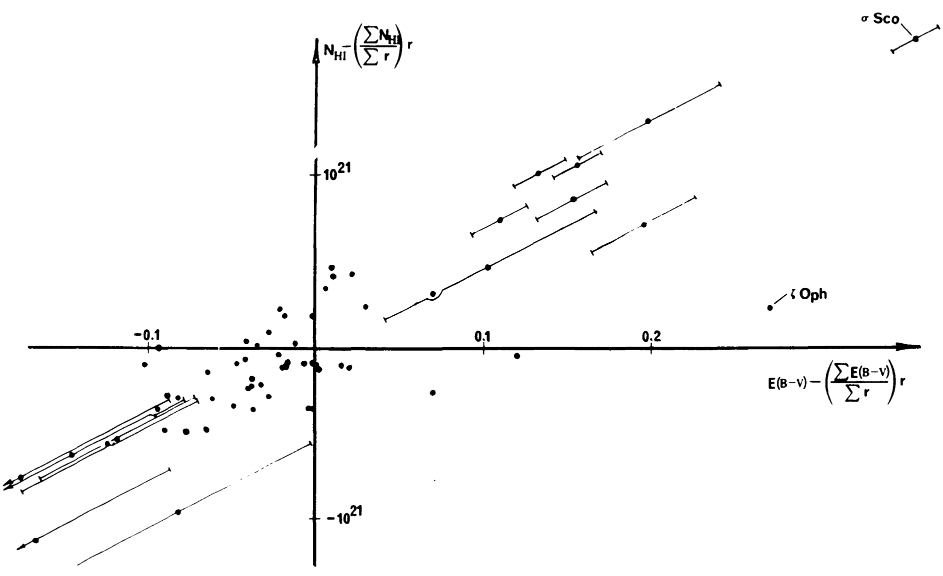

Fig. 2. Excursions in the values of N_{HI} (in atoms cm^{-2}) and $E(B-V)$ from the mean amounts expected over the distance r to each star. Those points which are more crucial in showing the correspondence of gas and dust have error bars which indicate the displacement which could result from the expected error of 30% in r.

tempting to speculate, however, that the relative deficiency for ζ Oph (see Figures 1 and 2) could be attributed to molecule formation; this star exhibits a good number of interstellar molecular features in its visible spectrum (Herbig, 1968).

One might question whether the apparent correlation of gas and dust is simply a result of our observing stars at various distances. It is natural to expect more distant stars to have both more reddening and more H I, even if there were no relation between the collections of gas and dust in space. However if we examine the behavior of deviations of N_{HI} and $E(B-V)$ from the expected values over the distance to each star, we find a convincing demonstration for the physical association of gas with dust.

Figure 2 is a plot of $N_{\mathrm{H\,I}} - (\sum N_{\mathrm{H\,I}} / \sum r)r$ vs $E(B-V) - (\sum E(B-V) / \sum r)r$ for all 61 stars (the 8 emission-line stars were not included). The correlation coefficient for this scatter diagram is equal to 0.85. In principle, there could be no actual relationship in the fluctuations of gas and dust density, but one might arrive at the false impression that such a correlation existed if there were large *random* errors in the distances to the stars. However we estimate our error in distance to be around 30%, and this much uncertainty could not produce the large displacements which convince us that H I and reddening are correlated. The principal contribution to the distance error is from the error in estimating the star's absolute magnitude.

Note added in proof. The discussion in the last paragraph and Figure 2 were not presented at the Conference but were prepared afterwards in response to a question from the audience.

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