RADIO OBSERVATIONS (21-CM) OF DENSE DARK NEBULAE*

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Lilley[1] has shown that large complexes of cosmic dust are also marked concentrations of neutral hydrogen, as evidenced by the strength of the 21-cm radiation, which is observed considerably in excess of the average for the galactic latitude of the dark complex. Lilley arrived at this result from observations of the dark nebulae complexes in Perseus, Taurus, and Orion. Similar conditions are found in the Ophiuchus complex (Heeschen;[2] Christiansen and Hindman[3]). Lilley has found that the average value of the ratio of the space densities of gas to dust is approximately equal to 100. The problem is to discover to what extent the most marked concentrations of cosmic dust inside the complexes have neutral hydrogen associated with them, and in what proportion.

Our equipment has been described by Lilley.[1] The band width of our receiver is 15 kc/sec, equivalent to 3 km/sec at 21-cm wave length, and the separation between half-power points of our antenna is 1°7. Menon made observations of the 21-cm radiation for two of the strongest concentrations of dark nebulosity in the Taurus complex, one near Barnard 19 and 22, the other near Barnard 7 and 10[4]. Three suitable comparison fields were selected near by, each of which has at least three magnitudes less in overlying optical obscuration than the dark centers. If the gas and dust in the concentrations were in equal proportions to the average for the complex, the total integrated intensity from the 21-cm profile should be at least 50 percent greater in the local obscuration than in the comparison fields. Similarly, Lawrence made observations for a very dark center in the Ophiuchus complex, the region near ρ Ophiuchi, and for two less obscured comparison fields, one near α Scorpii, the other near the globular cluster Messier 4.

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† Temporarily assigned to Harvard Observatory by the National Bureau of Standards.

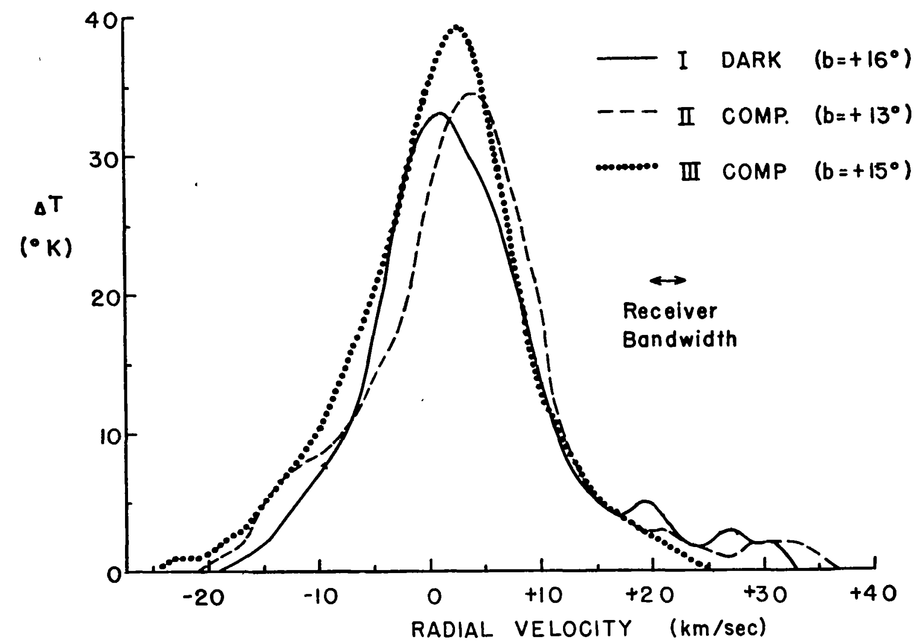

FIG. 1.—Reduced 21-cm profile for Taurus Center I and two comparison fields. In Figure 1, as in Figures 2 and 4, the ordinate ΔT represents the antenna temperature above the continuum, and the abscissa is the radial velocity reduced to the local standard of rest.

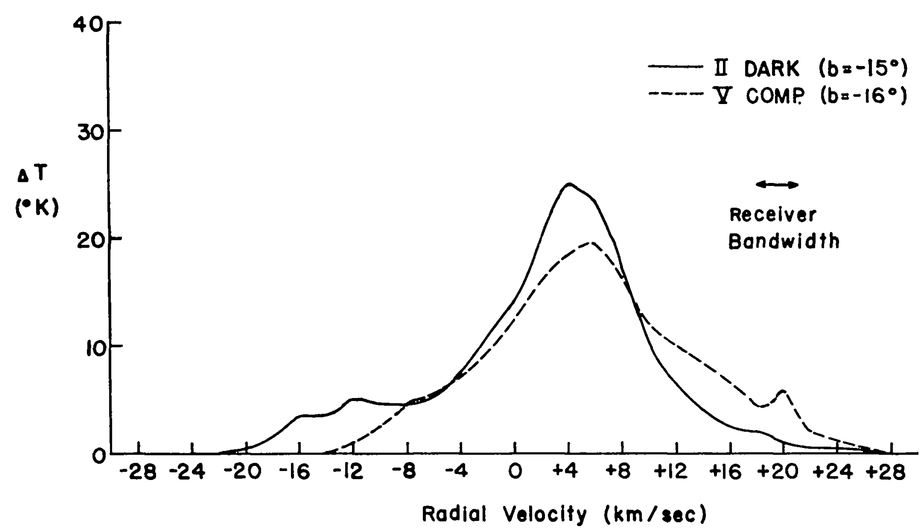

FIG. 2.—Reduced 21-cm profiles for Taurus Center II and comparison center.

The results are summarized in Table I. The tabulated quantities are: the galactic longitude (l) and latitude (b) of each center; the total number, N_H, of neutral hydrogen atoms in a

TABLE I

21-Cm Observations of Two Highly Obscured Centers in Taurus and One in Ophiuchus

Field	l	b	$N_H \times 10^{-21}$	τ_0	V_0 (km/sec)	η (km/sec)
			Taurus			
I Dark	141°	−13°	0.82	0.29	+5	8
II Dark	137	−15	0.64	0.24	+5	5–6
III Comp.	137	−9	1.50	0.43	+6	10
IV Comp.	135	−13	0.88	0.33	+5	7
V Comp.	137	−16	0.65	0.21	+6	7
			Ophiuchus			
I Dark	321	+16	1.04	0.32	0	8
II Comp.	321	+13	1.08	0.34	+6	8
III Comp.	319	+15	1.17	0.39	+4	8

cylindrical column of 1 cm^2 base calculated from the integrated intensity of the 21-cm profile; τ_0, the derived optical depth at the center of the 21-cm profile on the assumption that the kinetic temperature is equal to $T_0 = 120°K$; V_0, the radial velocity (of recession, in the present case) of the H(I) clouds relative to the local standard of rest; η, the mean random velocity, defined as the half-width at the frequency where $\tau = 0.368\ \tau_0$. We note that these observations were all made at galactic longitudes for which galactic rotation effects are negligible. We note, further, that it makes relatively little difference what value we assume for the kinetic temperature as long as $T_0 > 80°K$ throughout.

The tabulated results show clearly that the expected marked differences in N_H between dark fields and comparison centers is not observed, nor is there an indication for any marked differences in τ_0. The only clear-cut relationship is shown in Figure 3. This is the smoothed variation of N_H and τ_0 with galactic latitude, b, in the Taurus fields; the correlation exists whether we deal with a dark center or a comparison center. Hence, inside a dark complex the variations in density of interstellar dust are *not* accompanied by parallel variations in the density of neutral hydrogen atoms. The present data extend and confirm preliminary results obtained by van de Hulst, Muller, and Oort,[5] and by Heeschen.[2] We note further that the values of η for the dark and comparison

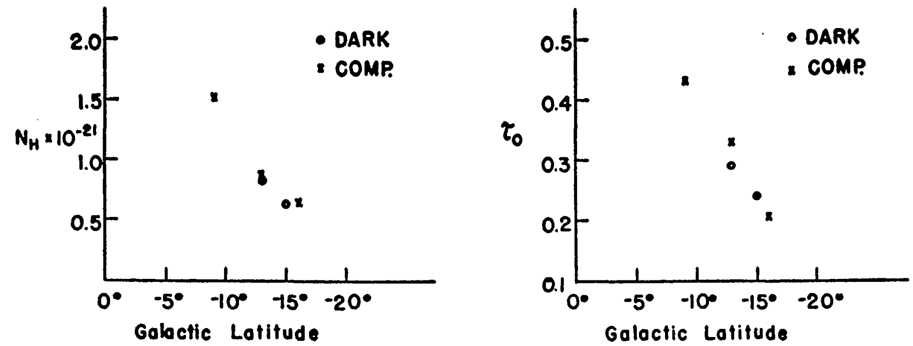

FIG. 3.—N_H and τ_0 versus galactic latitude for the Taurus Centers.

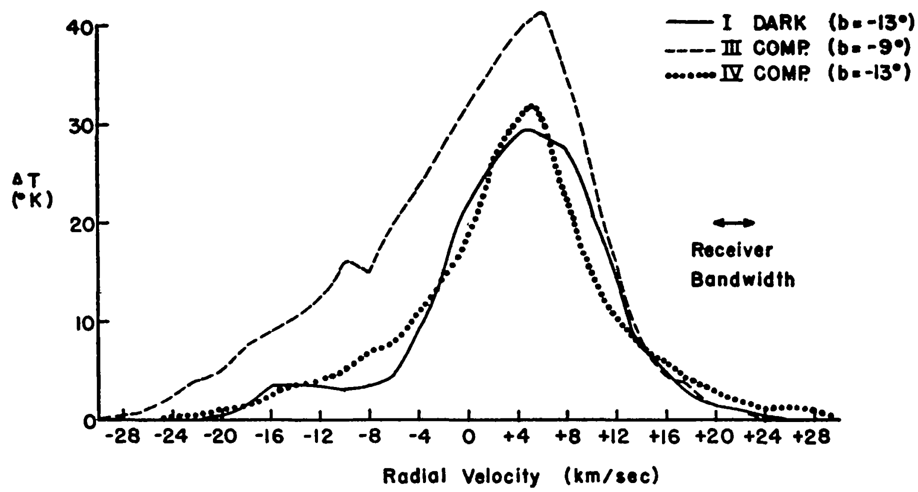

FIG. 4.—Reduced 21-cm profiles for the Ophiuchus Center and two comparison fields.

centers are quite similar except for the one outstandingly small value for Taurus Center II. The tabulated values of η have not been corrected for band width, but this neglect does not affect our basic conclusion.

There remains the possibility that the neutral hydrogen in the dark centers is mostly in molecular form and, hence, that we shall not observe any increases in N_H or τ_0, even though hydrogen may be present in constant proportion to the dust. This possibility can obviously not be ruled out by our approach to the problem. Van de Hulst, Muller, and Oort[5] have suggested that the solution could also be found in a lower kinetic temperature for the dark centers, when compared with the average for the entire dark complex. This solution can probably be ruled out. If temperature differences of the required amount did exist, then we should expect the line profiles to have the flat-topped appearance associated with saturation. We find, instead, that all profiles seem to be those of nonsaturated lines. For the time being, we seem, therefore, to be justified in proceeding on the working hypothesis that the densest concentrations of cosmic dust inside the Taurus and Ophiuchus complex are not also extra-strong concentrations of interstellar neutral hydrogen.

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[1] A. E. Lilley, *Ap. J.* (in press); paper presented at the Ann Arbor meeting (June 1954) of the American Astronomical Society.

[2] D. S. Heeschen, *Ap. J.* (in press); paper presented at the Ann Arbor meeting (June 1954) of the American Astronomical Society.

[3] W. N. Christiansen and J. V. Hindman, *Austr. J. Sci. Res.*, A, **5**, 437, 1952.

[4] E. E. Barnard, *A Photographic Atlas of Selected Regions of the Milky Way*, Carnegie Institution of Washington, 1927.

[5] H. C. van de Hulst, C. A. Muller, and J. H. Oort, *B.A.N.*, **12**, 130, 1954.

PRELIMINARY RESULTS FROM RADIO OBSERVATIONS AT 21 CM IN GALACTIC LONGITUDES 60° TO 130°*

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Observations with the Agassiz Station Radio Telescope have been taken at every 5° of galactic longitude in the galactic plane from $l = 60°$ to $l = 130°$. The radio telescope has an angular resolution of 1°7 and a frequency resolution of 15 kc/sec, which is equivalent to 3 km/sec in radial velocity. The observations consist of a pair of scans, giving the intensity of the hydrogen radiation as a function of frequency, for each position.

Each pair of scans shows three spiral arms as pronounced

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