

SELF-ABSORPTION IN THE 21-CM RADIATION FROM GALACTIC NEUTRAL HYDROGEN

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I. INTRODUCTION

Narrow-band studies of the absorption by interstellar hydrogen of the continuum radiation from strong sources have, in many cases, revealed sharp features in the absorption profiles.^{1,2} Unpublished observations by the writer on additional sources of fairly low equivalent surface temperature and those by Heeschen³ and by Davies⁴ suggest the existence of clouds of neutral hydrogen having temperatures well below 125° K, which is the generally assumed temperature of galactic H I regions. This is further substantiated by the present observation of a region in which self-absorption occurs due to hydrogen at a temperature certainly no greater than 60° K.

If a "cool" cloud of this nature were situated in front of "hot" hydrogen providing background radiation that covered the frequency range corresponding to the radial-velocity component of the cool cloud, and, further, if no hot hydrogen appreciably contributing in the same range were in front of the cool cloud, a sharp absorption feature could be expected in a scan of the background radiation. Such a feature has been detected in the region $\alpha = 6^{\text{h}}17^{\text{m}}$, $\delta = +22^{\circ}35'$, not far from the anticenter of the Galaxy. The observations were made on the last two nights before the antennas were taken over for interferometric observations according to a predetermined program, and the data available are therefore very sketchy indeed. However, in view of the interesting implications of the observation and the probable delay before 21-cm work can be resumed, it has been felt worthwhile to publish these provisional results.

II. THE OBSERVATIONS

A frequency-switched radiometer was used in conjunction with a 90-foot equatorially mounted paraboloid to make the ob-

servations. The antenna has a beam width of $30' \times 35'$ at 1420 Mc/s. The receiver accepted both sidebands (60 Mc/s apart) and had two channels, each with a 3 db bandwidth of 7 kc/s and a spacing of 1.5 Mc/s. The single sideband excess noise temperature was approximately 1200°K . A second pen on the recorder registered changes in the output of an additional wideband (2 Mc/s) i.f. amplifier, thus enabling the simultaneous recording of both continuum and line radiation incident on the antenna. The advantage of this technique is illustrated by reference to Figure 1.

In Figure 1*a* we have a typical example of the absorption by neutral interstellar hydrogen of the continuum radiation from the

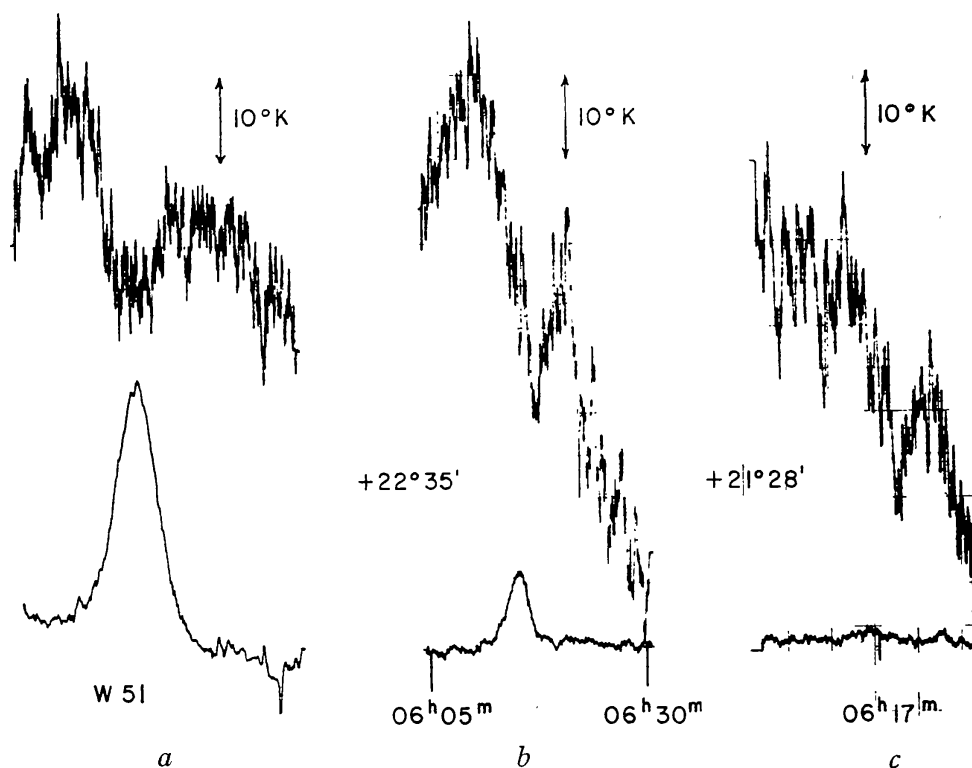


FIG. 1.—Samples of different types of 21-cm absorption: upper tracings record the line temperature and lower tracings the continuum temperature. The gains have been adjusted to give roughly the same scale for both. (*a*), Absorption of continuum radiation from source W 51. (*b*), Absorption of the line radiation from background hydrogen by a cool cloud near IC 443. (*c*), Same as (*b*) but at a different declination. The time constants used were 10^s, 5^s, and 5^s respectively.

source Westerhout 51. The lower tracing shows the increase in continuum radiation as the source drifts through the antenna beam. The upper tracing shows the variation of the emission from neutral hydrogen at a fixed frequency over the same range of right ascension. At this particular frequency we notice an apparent decrease in the intensity of the emission at the position of the source. In the presence of absorption, the source intensity at the signal frequency is less than that at the comparison frequency, and thus a deflection is caused in the opposite sense to that from emission. That this is really absorption is readily recognized by the coincidence in right ascension and similarity in shape of the continuum increase in the lower tracing and the apparent decrease of line emission in the upper. For a switched radiometer we can write¹

$$T'(\nu) = \overline{T(\nu)} - T_A [1 - e^{-\tau_s(\nu)}], \quad (1)$$

where $T'(\nu)$ is the temperature registered on the recorder, $\overline{T(\nu)}$ is the mean emission temperature obtained by interpolation across the absorption dip, T_A is the antenna temperature of the source, and $\tau_s(\nu)$ is the optical depth between the observer and the source within the solid angle subtended by the source. The second term gives the magnitude of the absorption dip at the position of the source and has a maximum value T_A when $\tau_s(\nu)$ approaches infinity.

Figure 1*b* is a drift curve taken at the declination of the source IC 443 in a search for possible absorption. Here the sharp dip in the general level of the emission curve is displaced with respect to the peak on the continuum record, and the magnitude of the dip (about 25° K) is considerably greater than the continuum antenna temperature T_A due to the source. Thus the dip cannot be due to absorption of the source. Figure 1*c* shows a drift curve taken at a nearby declination but well off the source. The dip is still apparent here, and must be due to self-absorption in an extended region of cool hydrogen.

By making some simplifying assumptions we can form a cloud model similar to that used by Hagen *et al.*¹ We split up the region in the antenna beam as shown in Figure 2, where the cool cloud (smaller than the beam) is surrounded by hot clouds. The deflec-

tion may be written as

$$T'(\nu) = \overline{T_1(\nu)} + \{e^{-\tau_3(\nu)} [\overline{T_2(\nu)} e^{-\tau_K(\nu)} + T_K(1 - e^{-\tau_K(\nu)})] + T_3(1 - e^{-\tau_3(\nu)})\} \frac{\Omega_K}{\Omega_B}, \quad (2)$$

where $\overline{T_1(\nu)}$ is the contribution from the region outside the solid angle Ω_K subtended by the cool cloud, and the subscripts 2, 3, and K refer to the regions behind, in front of, and within the cool cloud. It is seen from (2) that $T'(\nu)$, the temperature corresponding to the central minimum of the absorption ($\approx 60^\circ \text{ K}$), is the maximum value that T_K can assume. It is equal to T_K when $\Omega_K = \Omega_B$, $\tau_3 = 0$, and τ_K approaches infinity. In other words, the corrections for dilution in the antenna beam, for the optical depth of the cool cloud, and for the contribution from hot hydrogen in front of and around it would reduce the observed 60° K to a lower value.

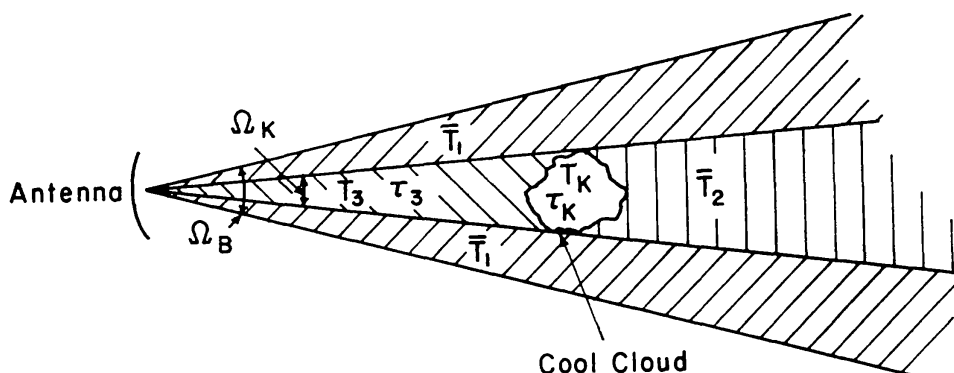


FIG. 2.—A simple model for computing the effect of a cool cloud on the antenna temperature.

The observations of the region consisted of about 30 drift curves taken over a range of declination at various frequencies, and a frequency scan in one position. The results are presented in two ways.

Figure 3a shows the results of the drift curves taken at two different frequencies corresponding to velocities of $+8.3$ and $+10$ km/sec. The numbers indicate the depth of absorption in $^\circ \text{ K}$. Figure 3b shows the variation in the depth of absorption for different velocities over a range of right ascension at $\delta = +22^\circ 35'$.

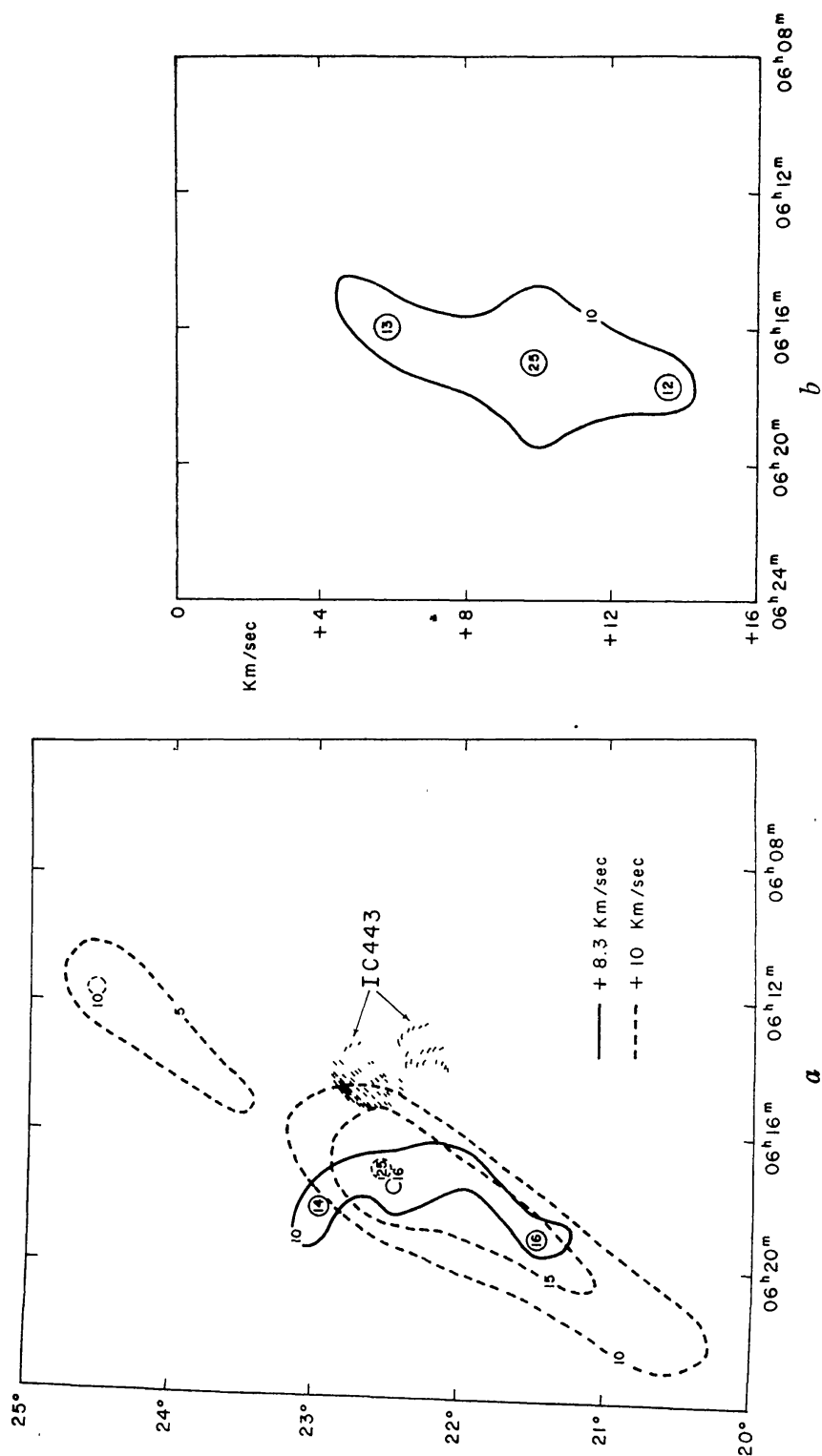


FIG. 3.—(a), The spatial distribution of the absorption at two different radial velocities (+8.3 and +10 km/sec). (b), The variation in the depth of the absorption for different radial velocities over a range of right ascension at $\delta = +22^\circ 35'$. In both figures the numbers indicate the depth of the absorption in $^\circ\text{K}$.

Both figures indicate considerable complexity in the spatial and velocity patterns of the absorption structure, probably reflecting a similar complexity in the density and velocity distribution of the cloud or group of clouds responsible.

Figure 3*a*, for example, shows that the absorption at +8.3 km/sec extends perhaps $3/4^\circ$ in right ascension and 2° in declination, whereas at +10 km/sec the effects are visible for at least 5° in δ . The frequency scan at 6^h15^m , $+22^\circ35'$ showed a sharp absorption dip centered at +10 km/sec, confirming the rapid change in depth of absorption indicated by the contours of Figure 3*a* at +10 and +8.3 km/sec.

III. DISCUSSION

The spread in radial velocity (+4 to +14 km/sec) of the absorption over the region and the variation of cloud size with the radial-velocity component observed suggest the possibility of some kind of systematic motion within the complex. A detailed analysis, however, must await further observations. Examination of a print of the area from the Palomar Sky Survey shows that within the limits of the present data the region of 21-cm absorption agrees reasonably well with the outline of the most strongly obscured regions on the print. This is indeed what one would expect from the computations of Spitzer and Savedoff on the temperature of interstellar matter.⁵ The cooling mechanisms for H I regions discussed by them require a high density of both gas and dust to lower the temperature to the observed value.

It is difficult to determine from the print whether the supernova remnant IC 443 is in front of or partially embedded in the obscuration. The drift curves whose results are given in Figure 3*b* are at the declination of the source associated with the remnant and over a range of right ascension including its position. No absorption of its continuum radiation was detected in the frequency range of the observations in contrast to the absorption by the cool cloud of the background 21-cm radiation. It appears that IC 443 cannot be behind the cloud. To explain the distribution of the strong optical and radio emission observed from IC 443, Minkowski has suggested that the matter at the northeast edge of the

nebula might be encountering interstellar matter of particularly high density.⁶ This might possibly be the dense absorbing cloud outlined by the +10 km/sec contour of Figure 3*a*, whose angular size would seem to place it within a kiloparsec of the sun. Minkowski considers 2000 parsecs as a possible distance for the remnant, but these observations would favor the lower value of about 700 parsecs preferred by the Burbidges from theoretical considerations.⁷

IV. ACKNOWLEDGMENT

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¹ J. P. Hagen, A. E. Lilley, and E. F. McClain, *Ap. J.*, **122**, 361, 1955.

² C. A. Muller, in *Paris Symposium on Radio Astronomy*, R. N. Bracewell, ed. (Stanford, Calif.: Stanford University Press, 1959), p. 360.

³ D. S. Heeschen, *Ap. J.*, **121**, 569, 1955.

⁴ R. D. Davies, *Revs. Modern Phys.*, **30**, 931, 1958.

⁵ L. Spitzer, Jr., and M. P. Savedoff, *Ap. J.*, **111**, 593, 1950.

⁶ R. Minkowski, in *Paris Symposium on Radio Astronomy*, R. N. Bracewell, ed. (Stanford, Calif.: Stanford University Press, 1959), p. 321.

⁷ E. M. Burbidge and G. R. Burbidge, in *Paris Symposium on Radio Astronomy*, R. N. Bracewell, ed. (Stanford, Calif.: Stanford University Press, 1959), p. 323.