# ATOMIC HYDROGEN IN AND AROUND THE GIANT MOLECULAR CLOUD NEAR W3 AND W4

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Abstract: Cold HI gas appears as self-absorption dips in the 21-cm line profiles in and around the giant molecular cloud near W3 and W4. The cold HI cloud is ∿150 pc long and extends along the galactic plane. It consists of several fragments, each of which is typically ∿25 pc in diameter and ( 1 - 4 ) × $10^4$ $M_\odot$ in mass. The $[H_2]/[HI]$ ratio is estimated to be 15 - 50. The mass of the entire HI cloud amounts to ∿$10^5$ $M_\odot$, which is comparable to that observed in CO emission.

## INTRODUCTION

We have analyzed the HI self-absorption features in and around the giant molecular cloud near W3 and W4. The region is a site of massive star formation. HI self-absorption features in dense clouds are caused by residual atomic hydrogen gas whose spin temperature, $T_S$, is in equilibrium with the gas kinetic temperature, as low as ∿20 K. Studies of HI self-absorption are expected to shed a new light on the physical and chemical conditions in giant molecular clouds.

The HI data are from the Maryland-Green Bank Galactic 21-cm Line Survey by Westerhout(1973). The method of data reduction is much the same as that applied to the M17 region by Sato and Fukui(1978), except that the spin temperature of cold HI was assumed to be 20 K uniformly. The radio continuum data are from Rohlfs et al.(1977), and the distance is assumed to be 3.0 kpc.

## RESULTS

Near W3 and W4, HI self-absorption features appear at velocities from -50 km $s^{-1}$ to -40 km $s^{-1}$. The velocities are similar to those of CO emission (e.g.,Lada et al. 1978). Here we concentrate on the features near -50 km $s^{-1}$, which are the most prominent in the velocity range above. Fig.1 gives the distribution of optical depth, τ(HI), at the velocity of maximum absorption near -50 km $s^{-1}$, superposed on the photograph taken in



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red light. The cold HI cloud extends nearly along the galactic plane from the western edge of W4 to ∿150 pc west. The most striking feature is that it is made up of several fragments. They are designated by the letters A - F and their peak positions are listed in Table 1. Each of the fragments is typically ∿25 pc in diameter at the half maximum of $\tau$(HI). At the edge of W4, the self-absorption dip disappears dramatically, suggesting that the cold HI cloud is associated with W4. Around W3, on the other hand, dips are severely blended and determination of expected profiles is ambiguous, so we excluded this region from our analysis (the excluded region is shown in Fig.1). The cold HI cloud is distributed similarly to the region of heavy optical extinction. Lada et al.(1978) presented CO maps in this region. Fragments C and D coincide well with the CO emission, while maxima differ a little from each other. As for fragment E, CO emission is detected only at its center, and fragments A, B, and F show no detectable CO emission. The HI linewidth is typically 4 km $s^{-1}$ and shows no systematic change. The velocity at the absorption maximum is nearly constant around -50 km $s^{-1}$ all over the cloud, and in each fragment no significant velocity gradient is recognized.

## PHYSICAL CONDITIONS IN THE HI CLOUD

The physical conditions inferred are summarized in Table 2. In the HI cloud with CO detection, the resemblance between the distribution of cold HI and that of CO suggests that these two species are well-mixed. $T_s$ is nearly equal to the gas kinetic temperature of 20 K inferred from CO observations. The $[H_2]/[HI]$ ratio is estimated to be 50 from N(HI)(column density of cold HI gas), $N(^{13}CO)$(Lada et al. 1978), and $[^{13}CO]/[H_2] = 2 \times 10^{-6}$(Dickman 1978). This value is fairly small compared with those derived in other molecular clouds; 100 - 350 in bright CO peaks near M17 (Sato et al. 1979), 120 in the $\rho$ Oph dark cloud (Myers et al. 1978), and 500 ± 300 in Heiles' Cloud 2 (Wilson and Minn 1977). Values as small as 13 - 70 have been derived in the diffuse region of the M17 complex (Sato et al. 1979), and these smaller values may be common among less dense regions.

In the HI cloud without CO detection, there is no direct evidence that $T_s$ is 20 K; but the lack of sharp, narrow HI emission features even in the region where the HI background emission is weak indicates that the spin temperature is not very high ($\lesssim$40 K) nor is the optical depth ($\tau$(HI)$\lesssim$0.5). The upper limit of the total particle density is given by the lack of detectable CO, and its lower limit is estimated from the total hydrogen column density inferred from the visual extinction. We estimate $A_V \gtrsim 1.5$ mag as a conservative value from eye-inspection of the Palomar Sky Survey Atlas.

## MASSES OF THE FRAGMENTS

The total masses of the HI fragments, M(total)'s, are estimated from the physical parameters above and listed in Table 1. The fragments appear to be in dynamical equilibrium and another independent estimate of the fragment masses is made from the HI linewidth through the virial theorem. The virial mass, M(virial) in Table 1, agrees fairly well with M(total), although M(virial) is systematically larger than M(total) by a factor of 2 - 3. This difference may be caused partly by the assumption of LTE in

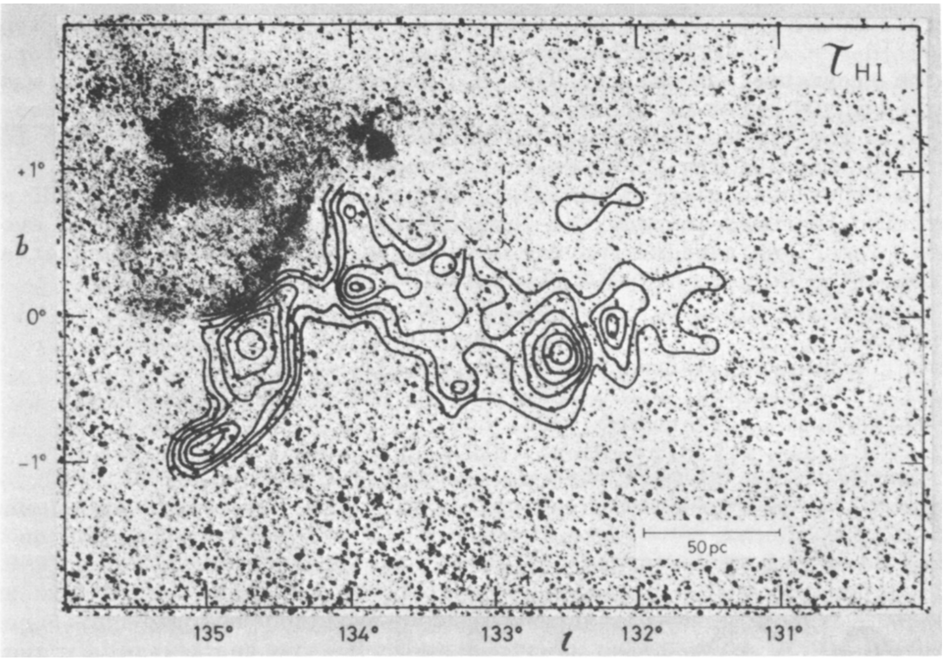


Figure 1. τ(HI) contours of 0.1, 0.15, 0.2, 0.25, 0.3, and 0.35 for the velocity of the maximum absorption near -50 km $s^{-1}$ superposed on the photograph taken in the red light.

Table 1. Sizes and masses of the fragments.

| fragment | ( l , b ) | diameter(pc)* | M(total)($\times 10^4 M_\odot$) | M(virial)($\times 10^4 M_\odot$) |
|---|---|---|---|---|
| A | ( 132°2, -0°1 ) | 20 | 0.4 - 0.7 | 2.5 |
| B | ( 132°5, -0°2 ) | 27 | 0.9 - 1.8 | 3.4 |
| C | ( 133°3, +0°1 ) | 31 | 2.3 | ** |
| D | ( 134°0, +0°2 ) | 18 | 0.9 | 3.1 |
| E | ( 134°7, -0°2 ) | 30 | 1.5 - 2.3 | 4.3 |
| F | ( 135°0, -0°9 ) | 20 | 0.4 - 0.8 | 1.0 |

* The diameter at half maximum in the τ(HI) map. D=3.0kpc is assumed.
** The profile is double-dipped and a reliable value cannot be derived.

Table 2. Physical conditions in the cold HI fragments.

| | $T_s$(K) | $\tau^{MAX}$(HI) | n(HI)($cm^{-3}$) | $[H_2]/[HI]$ | n(total)($cm^{-3}$) |
|---|---|---|---|---|---|
| fragments with CO detection | 20 | 0.36 | 0.7 | 50 | 35 |
| fragments without CO detection | ≲40 | ≲0.47 | ≲1.8 | 15 - 50 | 20 - 35 |

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the calculation of N($^{13}$CO) by Lada et al.(1978), or by the assumption of [$^{13}$CO]/[$H_2$] = $2 \times 10^{-6}$. The mass of the entire HI cloud, summed for all the fragments, amounts to $\gtrsim 10^5$ $M_\odot$, which is comparable to the mass observed in CO emission (Lada et al. 1978). Most of the mass is contained in the fragments without CO detection, and this leads us to revise upward the mass of the W3/W4 molecular complex by a factor of 2.

In other molecular clouds also, we have started analyses of HI self-absorption features in order to investigate early stages of cloud evolution. The HI data reduction was done on the FACOM 230-58 computer at the Computing Center, Tokyo Astronomical Observatory.

## REFERENCES

Dickman, R.L. 1978, Astrophys. J. Suppl., 37, 407.
Lada, C.J., Elmegreen, B.G., Cong, H.-I., and Thaddeus, P. 1978, Astrophys. J. (Letters), 226, L39.
Myers, P.C., Ho, P.T.P., Schneps, M.H., Chin, G., Pankonin, V., and Winnberg, A. 1978, Astrophys. J., 220, 864.
Rohlfs, K., Braunsfurth, E., and Hills, D.L. 1977, Astron. Astrophys. Suppl. 30, 369.
Sato, F. and Fukui, Y. 1978, Astron. J., 83, 1607.
Sato, F., Fukui, Y., and Hasegawa, T. 1979, this issue.
Westerhout, G. 1973, Maryland-Green Bank Galactic 21-cm Line Survey, (University of Maryland, College Park, Maryland), 3rd ed.
Wilson, T.L. and Minn, Y.K. 1977, Astron. Astrophys., 54, 933.

## DISCUSSION FOLLOWING FUKUI

*Blitz:* The association of giant molecular complexes with HI may be a general property of these complexes. The Rosette molecular complex and the Mon OB1 complex both seem to be embedded in HI clouds, seen in emission, with masses comparable to the molecular masses. Furthermore, examination of Heiles' HI maps of narrow lines shows that there tend to be large HI enhancements coincident with the molecular complexes mapped to date in the second and third quadrants.

*Fukui:* We are extending the HI-dip studies to the other giant molecular clouds, and hope to examine statistically what fraction of the molecular clouds have such massive less dense components.

*Federman:* How did you determine the ratio ($H_2$)/(HI) in regions where no CO emission is seen?

*Fukui:* The upper limit to the ratio comes from the upper limit to the CO brightness temperature, and the lower limit from the visual extinction. The estimate of the visual extinction ($\gtrsim$1.5 mag) is crude, and we are now planning a detailed star count in this region with Ohtani and his associates at Kyoto.

*Dickel:* Why did you adopt 4 kpc for the distance to W3 and W4 when the OB association is at 2 kpc (Ishida, 1969, MNRAS 144, 55; Ishida, 1970, Publ. A.S. Japan 22, 277; Agura and Ishida, 1976, Publ. A.S. Japan 28, 651).

*Fukui:* We have no strong objection to the distance of 2 kpc. The distance of 3 kpc was just assumed.