A COMPRESSED CLOUD IN THE VELA SUPERNOVA REMNANT

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INTRODUCTION

Our previous interstellar line survey, carried out with the Copernicus satellite, was limited to selected lines in only four bright stars (ref. 1). Nevertheless, our data revealed the presence of numerous absorbing, primarily ionized gaseous sheets and filaments, that had evidently been shocked, compressed, and accelerated by interaction with the SNR.

The significance of the interaction of supernovae with interstellar clouds was first stressed by Öpik (ref. 2), who suggested that star formation would be initiated. More recent studies have supported this viewpoint, although the direct evidence for triggering of star formation by supernovae is very tenuous. Herbst and Assousa (ref. 3,4) emphasized the location of young stellar associations at the edges of expanding shells of gas: such shells are not necessarily old SNR, however. A more direct connection was sought by Wootten (ref. 5) who found evidence for compression by a factor $\sim$10, heating, and enhanced line broadening in molecular clouds near the SNR W44 and W28.

Another connection between a supernova and star formation has been inferred from the presence of excess ^{26}Mg in certain inclusions in the Allende meteorite, taken to indicate that the unstable isotope ^{26}Al was injected into the protosolar nebula within $\sim 10^6$ yr of the nucleosynthesis of the ^{26}Al in a nearby supernova (ref. 6). Such circumstantial evidence suggests that interaction with the supernova may both have enriched and initiated the collapse of the interstellar cloud destined to form the sun and the solar system.

Finally, recent models of spiral structure have utilized supernova-induced star formation as a means of enabling star formation to be self-propagating in the galactic disk (ref. 7,8). To justify this type of theoretical work, one would like to know whether there is any evidence for the extreme compression of ambient gas near a SNR that is required to initiate star formation.

In an attempt to shed light on these issues and to further elucidate the nature of the interstellar medium in the vicinity of the Vela SNR, we have undertaken an extensive study with the IUE of interstellar absorption lines toward 35 stars in the vicinity of the Vela SNR. Observations of interstellar absorption, in particular of CI, towards one of these stars, HD 72350 (type B4 III), are of sufficient interest that we report here a preliminary analysis of this data before the entire survey has been reduced.

OBSERVATIONS

In June 1979 we obtained high resolution IUE spectra of 35 stars in the field of the Vela Supernova Remnant. From the video displays of the short wavelength echelle spectra it was clear that HD 72350 showed multiplet structures in all of the C I transitions which were especially prominent, indicating that the excited fine-structure levels are heavily populated. Two additional short-wavelength exposures of this star were recorded in September 1979 to verify this result and improve the net signal-to-noise ratio.

Column densities of various species were derived using curves of growth based on Voigt profiles. For unresolved blends of two or more transitions from C I, special curves of growth were calculated to derive the total equivalent width of the partially overlapping components. Table 1 lists the derived column densities as a function of the velocity dispersion parameter b, averaged from all but the weakest lines. We calculated the standard error of the results for cases where we measured three or more lines, and these dispersions are shown in parentheses after the respective entries. For our study of cloud compression, our primary objective is to derive column densities of neutral carbon atoms, i.e. (N(CI), N(CI*) and N(CI**), in the three levels of fine structure excitation, $^3P_0$, $^3P_1$ and $^3P_2$, respectively. From the standard errors in Table 2, we see that the best internal consistency for the column densities occurs for $b \geq 10$ km s^{-1}. Within the range $10 \leq b \leq 20$ km s^{-1}, the total column density of neutral carbon varies by a factor of three, but the ratios of C I, C I* and C I** populations are relatively insensitive to the choice of b. Our inability to detect the weaker transitions indicates that the absorptions we have measured do not have heavily saturated cores. In particular, our detection limit for λ1276.48 forces us to conclude that log N(CI) < 14.7 for any b greater than 4 km s^{-1}, if log fλ for this transition is about 0.8 (this line strength is based on a preliminary analysis of C I absorption data recorded by ref. 10; see also ref. 11). Hence, we are confident that the conspicuousness of the excited lines is attributable to a strong excitation of carbon rather than a large difference in line saturations.

If we assume log N(H) = 20.8 from the star's B-V color excess of 0.14 (ref. 12) and the general gas to reddening ratio of 4.8×10^{21} atoms cm^{-2} mag^{-1} (ref. 13), we find that the relative abundances of N I and O I are consistent with the cosmic abundance ratio if b ranges between 10 and 12 km s^{-1}. From earlier research works on ultraviolet interstellar data, we know that velocity dispersions of atoms in a stage of ionization below the dominant one for H I regions generally exhibit a lower b than those species in their dominant stages (e.g. see Figure 2 of ref. 14), so our N I and O I b values should exemplify only an upper limit for the b of C I. Doublet ratios for the Ca II and Na I absorptions in the visible yield b values of 10 and 5 km s^{-1}, respectively (ref. 9). The value for sodium appears to be too low perhaps because the equivalent widths were not very accurate; 8 km s^{-1} would be acceptable, but a larger b value implies the D lines are virtually unsaturated which is inconsistent with the observed line strength ratio. From the above considerations, we feel that it is reasonable to assume that the most probable value of b for C I is 12 km s^{-1}.

TABLE 1.-COLUMN DENSITIES (LOG NL) FOR LIGHT ELEMENTS IN THE H I REGION IN FRONT OF HD 72350

Element	No. of Lines	log NL for various b-values 8	10	12	15	20	Notes
CI	3	15.3(0.4)	14.8(0.2)	14.6(0.2)	14.4(0.2)	14.4(0.2)	
CI*	9	15.5(0.5)	15.1(0.3)	14.8(0.2)	14.7(0.2)	14.6(0.2)	
CI**	8	14.8(0.2)	14.6(0.1)	14.5(0.1)	14.4(0.1)	14.3(0.1)	
CI(total)	22	15.8	15.4	15.1	15.0	14.9	1
NI	3	17.6(0.3)	17.1(0.4)	16.3(0.4)	15.5(0.3)	15.0(0.2)	
OI	1	18.0	17.7	17.2	16.2	15.4	
OI*	1	<13.9	<13.9	<13.8	<13.8	<13.8	
Mg I	2	13.3	13.2	13.2	13.2	13.2	
CO	5	14.2(0.1)	14.2(0.1)	14.2(0.1)	14.2(0.1)	14.2(0.1)	
Na I	2	12.8	12.4	12.3	12.3	12.3	2
Ca II	2	13.2	12.9	12.8	12.7	12.7	2

Notes: 1-Includes two blends of CI* and CI** features.
2-From optical spectra (ref. 9).

THE NEUTRAL CARBON ABSORPTION LINE REGION

CAN THE CI ABSORPTION BE CIRCUMSTELLAR?

Prior to discussing the implications of the CI populations in Table 2 we must demonstrate that the observed cloud is not a circumstellar feature whose CI levels are pumped by radiation from HD 72350. Radiation from B4 III star is capable of ionizing CI. We first have shown that there is a negligible amount of CI recombination in the CII zone. Moreover, a sufficiently great column density is needed to shield CI near HD 72350 from the carbon ionizing photons that there can only be a negligible amount of CI at high pressure ($p/k \gg 10^3$ cm^{-3} K) near the star. Finally, the stellar radiation field is not sufficiently intense to radiatively pump the CI without requiring an excessive large column density of shielding CII.

PROPERTIES OF THE C I CLOUD

Since we have shown that the cloud containing the CI is not circumstellar, we can adopt the perspective that it is normal interstellar material subjected to unusual physical conditions. From the fine-structure population ratios $f_1 \equiv CI^*/CI_{total}$ and $f_2 \equiv CI^{**}/CItotal$ we may arrive at permitted combinations of pressure and temperature using the diagrams for collisional equilibria in H I regions given by ref. 15. Figure 1 shows the combinations of pressure and temperature which are consistent with our population ratios, allowing for reasonable errors in column densities.

However, there are two additional constraints, shown in the figure, which we may impose on the conditions. First, we can require that a solution for the ionization equilibrium between CI and CII (ref. 15) not give a computed value N(CI) less than the observed value assuming log N(H) = 20.8, a cosmic abundance ratio for C/H, and an ionization rate $\Gamma_C = 2 \times 10^{-10}$ s^{-1} for the general interstellar medium. (This argument is only a limiting case because the computed value could greatly exceed the observed N(CI)/N(H) if much of the reddening was not associated with the CI region.) This constraint may be even stronger than shown here, since there is a good chance that Γ_C in the Vela region is higher than the usual interstellar value and some of the free carbon atoms are depleted onto grains.

The second constraint comes from our upper limit for N(OI*). If we solve for the collisional equilibrium for the O I fine structure levels, assume a cosmic abundance ratio for C/O, and compute the total carbon density from the ionization equilibrium (see above), we obtain log T < 2.1. This result is independent of log p/k because the computed ratios OI*/OI and C/CI both scale approximately linearly with pressure.

DISCUSSION

From Fig. 1 we see that the temperature of the cloud lies between 25 and 100°K and P/K is greater than 10^4, and could be 10^6 or larger. The minimum density is about 250 hydrogen atoms/cm^3, and the density could easily be 3×10^3 or substantially higher. Such conditions could be realized by compression of pre-existing clouds by a supernova shock moving at about 400 km s^{-1} through the intercloud medium. Such a shock could compress the gas by a factor 300 so the shocked cloud could have had an initial density of order 10 cm^{-3}. The origin of shock clouds within the Vela B association poses an interesting problem. They are likely to be material left over from the formation of stars that have recently reached the main-sequence of the association.

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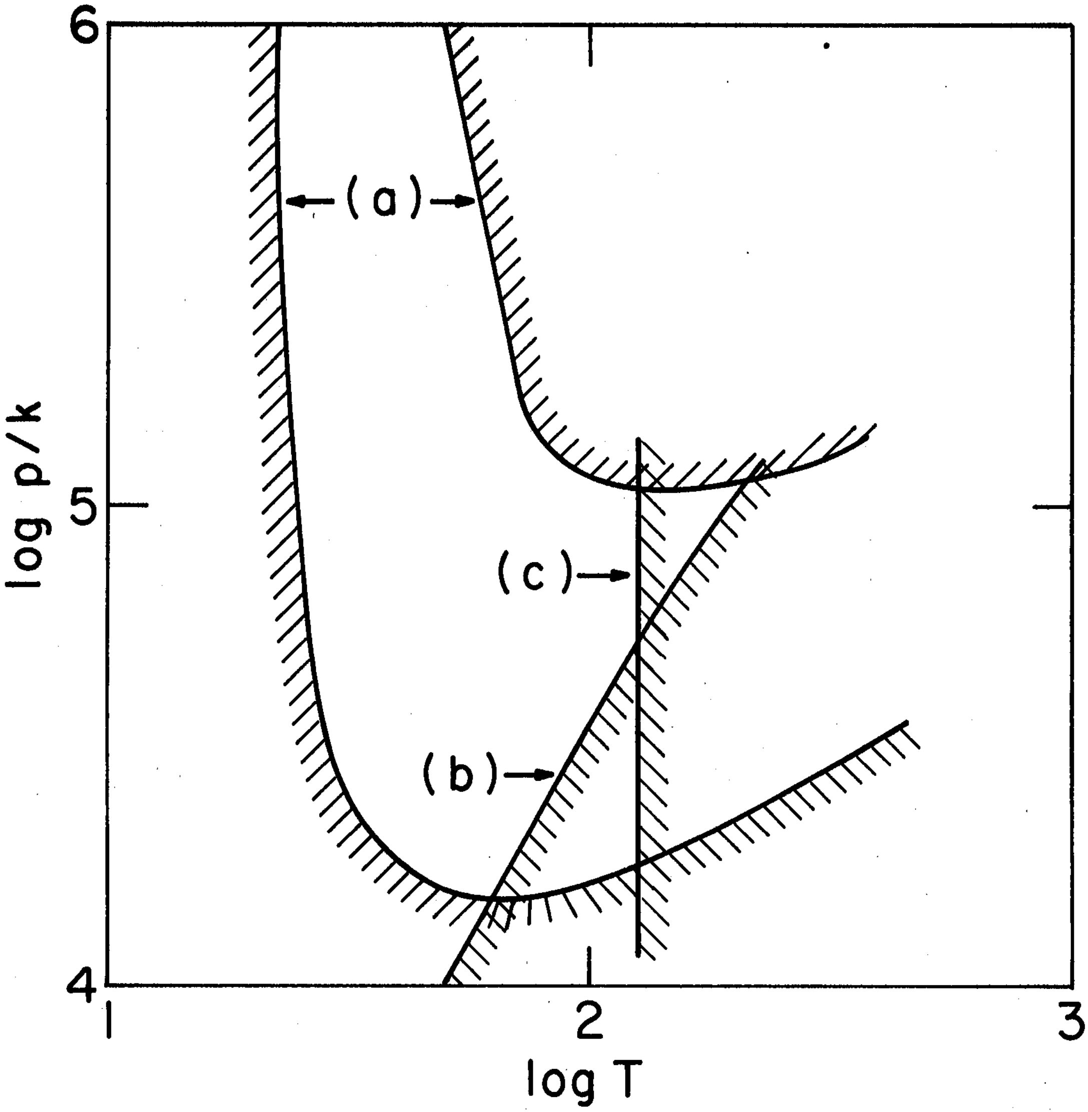

Fig. 1. Allowed pressures and temperatures for the CI cloud. Excluded areas are the shaded side of the lines. Lines marked (a) are from CI fine-structure excitation. Line (b) is from the relative abundance and ionization equilibrium of carbon. Line (c) is from the absence of observed absorption from OI*.