MOLECULAR CLOUDS NEAR SUPERNOVA REMNANTS

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ABSTRACT

A survey of 14 SNR's in the 4.8 GHz absorption line of H_2CO shows that two of them, W28 and W44, possibly interact with molecular clouds. The interaction leads to acceleration of a part of the molecular cloud to a velocity of $\sim$5 km s^{-1} without a significant increase in the kinetic temperature or turbulence.

The apparent long-term stability of galactic molecular clouds against gravitational collapse and subsequent star formation has stimulated proposals about possible sources of external pressure, such as shocks, which could upset this equilibrium and lead to collapse. The supernova blast wave was considered as such a shock by Herbst and Assousa (1977). This proposal can be tested by observations. The interaction between a supernova remnant (hereafter SNR) and a molecular cloud may result in a disturbance of the cloud such as changing of its geometry, introducing large velocity gradients, heating etc. Spectral line mapping of the molecular clouds toward SNR's might reveal cases of SNR-molecular cloud interactions and give details of the relevant physical processes. The observations presented here were aimed at (i) a search for clouds interacting with SNR's; (ii) measuring physical parameters of the disturbed molecular gas.

OBSERVATIONS

The observations were made with the Effelsberg 100-m radio telescope in the 4.8 GHz line of H_2CO. The beam width was 3'. The list of the supernova remnants chosen for this survey is given in Table 1. A "+" sign in the third column of the Table 1 indicates that H_2CO absorption was detected, a "+" sign in the fourth column shows which objects were partially mapped in H_2CO line, and the "-" sign in the fifth column shows that no indications of interaction as discussed in the Introduction were

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Table 1.

(1)	(2)	(3)	(4)	(5)
Galactic coordinates	Other name	H_2CO absorption	Line map	Physical interaction
6.4 - 0.1	W28	+	-	possible
11.4 - 0.1	-	-	-	
18.8 + 0.3	Kes 67	+	-	
21.8 - 0.6	Kes 69	+	+	-
23.0 - 0.3	W41	+	+	-
24.7 - 0.6	-	-	-	
32.8 - 0.1	Kes 78	+	-	
34.6 - 0.5	W44	+	+	possible
46.8 - 0.3	HC30	-	-	
74.0 - 8.6	Cygnus Loop	-	-	
78.1 + 1.8	DR4	+	+	-
84.2 - 0.8	-	+	+	-
127.3 + 0.7	-	-	-	
189.1 + 2.9	IC443	-	-	

seen on the maps. Negative results in the third column do not necessarily mean that there is no H_2CO absorption toward these supernova remnants, since the beam width is much smaller than the SNR size and the observations were limited to several points. Thus we could have missed a molecular cloud occupying only part of a SNR area. Such a case might be IC443 where De Noyer (1979) has found "shocked" OH absorption in the southern part of the remnant. We made no measurements there. Any H_2CO absorption is below our detection limit of about 0.05 K.

Two positive detections of interacting molecular clouds in Table 1 are W28 and W44. They were previously proposed as such by Goss et al. (1971) and Pastchenco and Slysh (1974) as a result of OH absorption observations. The present study provides more details on the geometry and kinematics because of our higher angular and velocity resolution, and more complete sampling of the area.

RESULTS

The optical depth map of H_2CO in the W28 region is shown in Fig. 1. There are two clouds on the map. One extended cloud at radial velocity 21 km s^{-1} consists of two brighter regions and extends from M20 to the edge of the SNR. It shows little variation of radial velocity and line width, and, on this basis and its geometry, may be a foreground cloud not related to the SNR. The second, more compact, cloud (3' x 15') has a central radial velocity 7 km s^{-1} and is located just on the edge of the SNR. The 6-cm continuum emission contours taken from the survey of Altenhoff et al. (1979) outline the SNR as well as nearby HII regions.

The 7 km s^{-1} cloud is shown in more detail on Fig. 2a, b. Fig. 2(a) is the absorption line equivalent width distribution (km s^{-1}). The dotted line shows the eastern border of the SNR, the crosses show the

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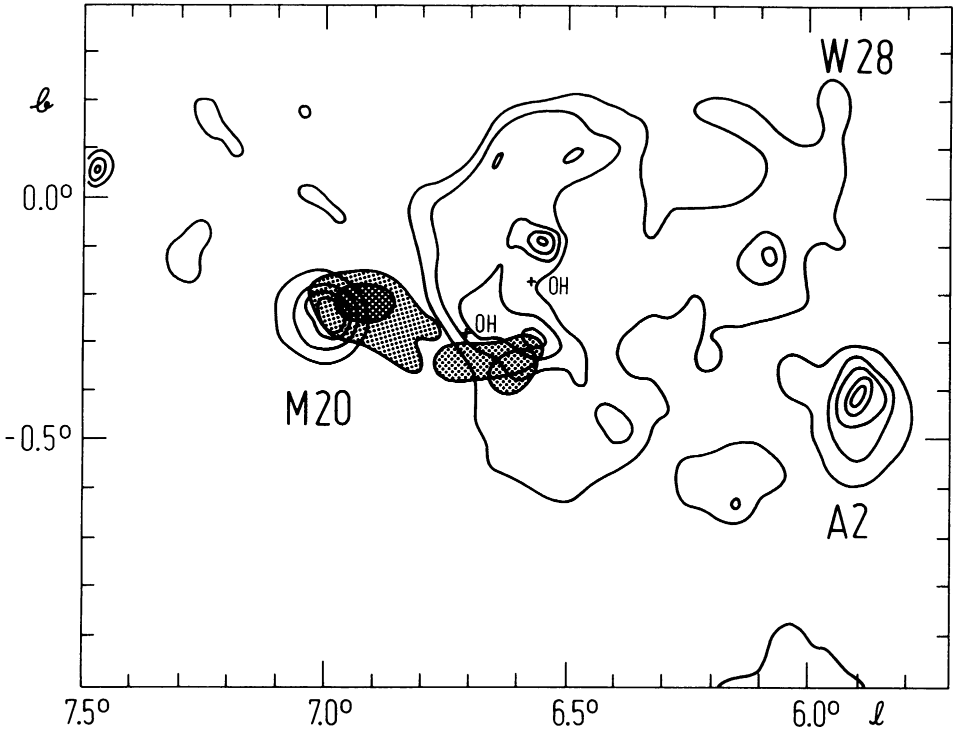

Fig. 1.

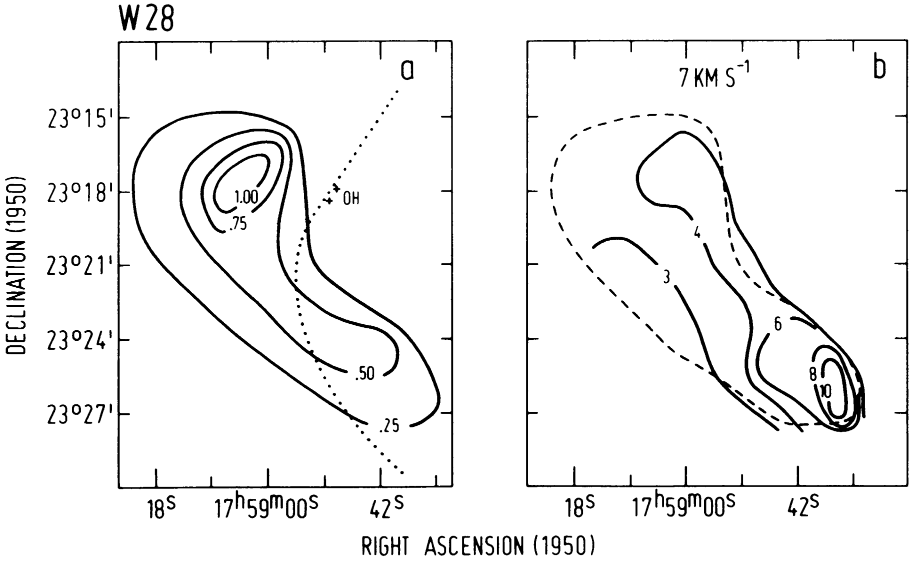

Fig. 2.

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positions of 1720 MHz OH masers. Fig. 2b shows line width distribution ($km\ s^{-1}$) across the cloud outlined by the 0.25 $km\ s^{-1}$ contour from Fig. 2a. It is evident that the line width, although otherwise constant (3.5 $km\ s^{-1}$), sharply increases to 10 $km\ s^{-1}$ at the lower right where the cloud is projected on the SNR. The radial velocity in this region rapidly increases from 4 to 8 $km\ s^{-1}$ as one goes from right to left. The geometry, radial velocity and line width variation are suggestive of an interaction between the cloud and the SNR.

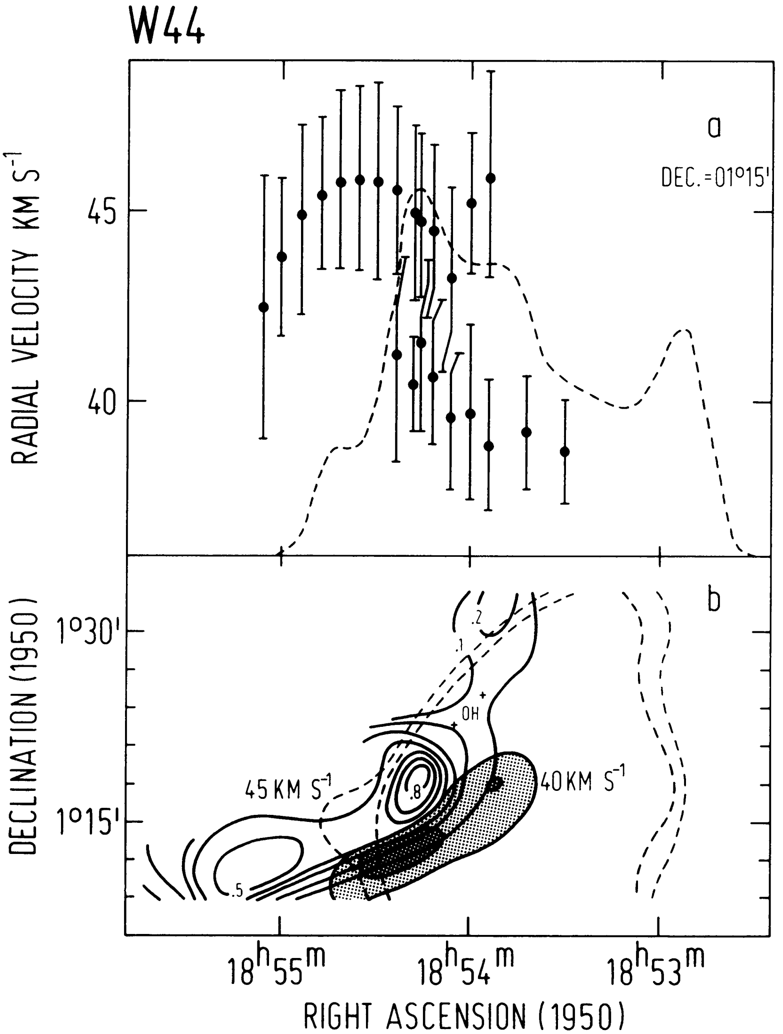

Fig. 3a, b.

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The H_2CO optical depth distribution in the W44 region is shown in Fig. 3b where the hatched area shows a velocity feature at about 40 km s^{-1} as compared to a 45 km s^{-1} feature. Dashed lines show contours of 6 cm continuum emission from the SNR W44, crosses are positions of 1720 MHz OH masers. The two velocity features partly overlap just at the eastern edge of the SNR. The velocity variation of the two features across the SNR is shown on Fig. 3a, a right ascension cross-section at declination 01° 15'. Bars indicate the line width. The dashed line is the 6 cm continuum antenna temperature. Going from left to right in the figure, the main 45 km s^{-1} component gradually disappears but its central velocity remains relatively constant. Just at the edge of the SNR a second feature appears with a radial velocity close to that of the first (45 km s^{-1}) feature. Moving still further to the right its radial velocity gradually decreases to 39 km s^{-1} at the center where it also disappears. The behaviour is suggestive of a cosine variation of the radial velocity, which might be expected from spherical expansion with a velocity of about 6 km s^{-1}. Note that the line width of the 40 km s^{-1} feature is the same (or even smaller) than that of 45 km s^{-1} feature.

DISCUSSION

Both W28 and W44 show H_2CO molecular clouds with a variation of radial velocity closely matched to the SNR's geometry, as might be expected if they were disturbed by the SNR's expansion. It appears that there is a parent molecular cloud which presumably existed long before the SN explosion, part of which was accelerated by the SNR expansion to a velocity about 5 km s^{-1}. No extra turbulence was added to this accelerated part of the cloud since the line width has not changed appreciably. Physical parameters of the accelerated part of the cloud may be estimated from the absorption line data as well as from CO observations available for W44 (Wootten, 1977). They are summarized in Table 2.

Table 2

Physical properties of the accelerated part of the molecular clouds

1.	Final acquired velocity	5 km s^{-1}
2.	Velocity dispersion	3 km s^{-1}
3.	Temperature	15 K
4.	Size	2 - 5 pc
5.	Density	2 x 10^3 cm^{-3}
6.	Mass	$\sim 10^3$ $M_\odot$

Velocity dispersion, temperature and density seem to be the same as in the parent cloud. This is in conflict with current ideas about shock wave heating and compression (Hollenbach, 1979) of the interstellar matter. The 1720 MHz OH masers appear to be intimately related to the interaction between SNR's molecular clouds. Their position, slightly offset from the molecular clouds and within the contours of SNR's, suggests that they are now behind the shock front and may be products of cooling of the shocked material.

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DISCUSSION FOLLOWING SLYSH

Radhakrishnan: Is not 5 km s^{-1} a very small velocity?

Slysh: 5 km s^{-1} is correct from the point of view of conservation of momentum, that is to say that a 500 km s^{-1} shock propagating in a medium with 10 cm^{-3} density can accelerate a molecular cloud of 1000 cm^{-3} density to 5 km s^{-1}.

Hollenbach: Although a 5 km s^{-1} shock heats the gas to $\simeq$ 1500 K, would rapid cooling not make most of the post-shock gas cold, as required?

Slysh: I am not sure that the time available is sufficient for cooling to 15 K.

Elmegreen: How were the ages of the supernovae determined?

Slysh: The ages come from optical (W28) and radio astronomy data, and are in the range 10,000-50,000 years.