A CO (J = 1-0) SURVEY OF FIVE SUPERNOVA REMNANTS AT ℓ = 70° - 110°

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Abstract: A program of CO observations of five selected supernova remnants is in progress on the 4-m radio telescope at Nagoya. Here, we report observations of two supernova remnants, G78.2+2.1 (the γ Cygni SNR) and HB21. In these two remnants we have obtained evidence for the interaction between the supernova remnants and molecular gas.

Introduction: Since the middle 1970's indications of the interaction of supernova remnants (SNRs) with molecular gas, the densest component of the interstellar medium, have been searched for by several groups. Some of the previous observations of SNRs are difficult to interpret because of confusion due to unrelated clouds: e.g., W44 (Wootten, 1977; Dame, 1983), W28 (Wootten, 1981), and W50 (Huang et al., 1983). According to our re-examination of the published data, it seems that there are only two clear examples of interactions, namely IC443 and the Cygnus Loop. Discovery of shocked molecular gas having a wide linewidth in IC443 provides an unequivocal indication of the interaction (DeNoyer and Frerking, 1981), but it remains a unique example until now in spite of a few searches for broad molecular emission indicating shocks. On the other hand, in the Cygnus Loop, two small (~2 pc) molecular clouds on the western boundary of the remnant cause a distortion of the shell and an enhancement of the optical emission. In order to increase the number of the unambiguous examples of interacting SNRs, we have started to observe molecular clouds toward SNRs mainly using the Nagoya 4-m radio telescope. We compare the distribution of molecular clouds with X-ray and/or radio images of SNRs and search for morphological indications of interaction. Five SNRs were selected on the basis of three criteria: (a) the SNR is located within the galactic longitude range ℓ = 70° - 110° where confusion with unrelated clouds is not severe, (b) the SNR is relatively close, within ~5 kpc of the Sun, and (c) CO emission is detected toward the SNR area by the Columbia survey with the 1.2-m radio telescope (Huang, 1985; Cong, 1977; Israel, 1980). In this paper observations of G78.2+2.1 (the γ Cygni SNR) and HB21 with the 4-m radio telescope are reported. G78.2+2.1 is a circular SNR with a diameter of 62' and has a radio bright region in the southeast (Higgs et al., 1977). HB21 is a non-circular SNR with a size of ~1.5°. The distance to G78.2+2.1 is 1.6 kpc and that to HB21 is 1.1 kpc (Milne, 1979). Observations of another SNR, G109.1-1.0, are reported in Tatematsu et al. (1987a and b).

Observations: Observations were carried out with the Nagoya 4-m radio telescope of CO and ^{13}CO (J = 1-0) spectra between November 1986 and May 1987. This telescope has a half-power beamwidth of 2'.7 at 110

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GHz. A cooled Schottky diode receiver was employed, providing a receiver temperature of 200-250 K (DSB). Most of the spectra were obtained in the frequency switching mode, whereas some of them for G78.2+2.1 were obtained with position switching. We first observed areas covering the SNRs fully with coarse spacings, 8'-15', and then observed in CO the areas which show a hint of interaction with spacings of 3'. ^{13}CO observations were conducted at selected points. The intensity is calibrated by using the chopper-wheel method, corrected for beam efficiency, and expressed as the radiation temperature T_R.

Results and discussion:

(1) G78.2+2.1 --- There is a molecular cloud on the southeast side of the remnant. This cloud has different radial velocity components and the most conspicuous features which are likely associated with the SNR are two clumps as shown in Figures 1 and 2. These maps are close-ups of the southeastern quadrant of the SNR. These two clumps exist just on the northeast and southwest sides of the elongated radio bright region respectively. The southern clump is stronger than the northern one. Other than these clumps there are a few molecular clouds lying within the SNR shell including a filament crossing the remnant, but they show only weak CO emission. Close association between the two clumps and the elongated radio bright region suggests that dynamical interaction with these clumps has compressed the magnetic field of G78.2+2.1 and enhanced the radio intensity of this region. Furthermore, comparison with the soft X-ray image obtained with the Einstein Observatory (Higgs et al., 1983) reveals that the southern molecular clump shows an anticorrelation with the X-ray intensity (Figure 3). The most natural interpretation is that the southern clump

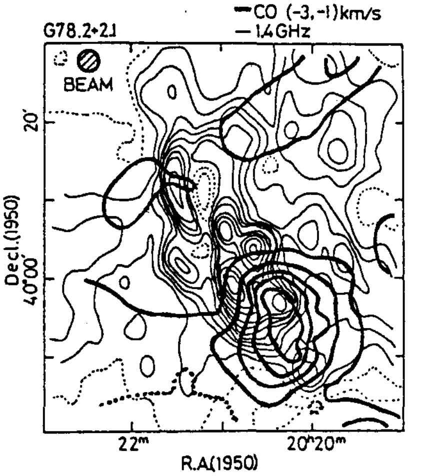

Fig. 1: The CO (J = 1-0) intensity integrated in the radial velocity range V(LSR) = (-3, -1) km/s around the southeastern part of G78.2+2.1. The contour interval is 6.7 K km/s. The 1.4-GHz map of the remnant (Higgs et al., 1977) is reproduced as thin lines.

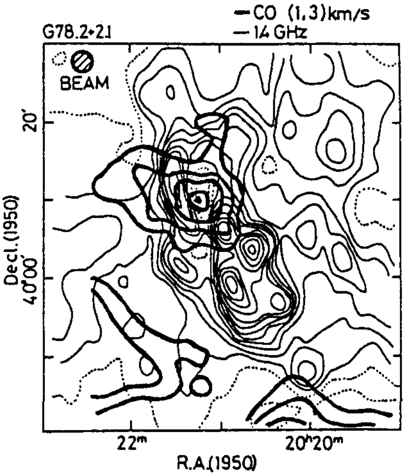

Fig. 2: The same as Fig. 1 but for V(LSR) = (1, 3) km/s with a lowest contour level of 8.7 K km/s and a contour interval of 3.3 K km/s.

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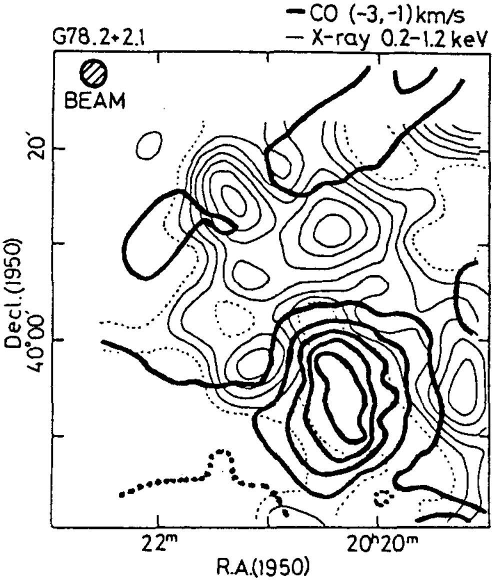

Fig. 3: The 0.2-1.2 keV X-ray map of the southeastern part of G78.2+2.1 (Higgs et al., 1983) is shown as thin lines. The V(LSR) = (-3, -1) km/s CO map with a contour interval of 6.7 K km/s is illustrated as thick lines.

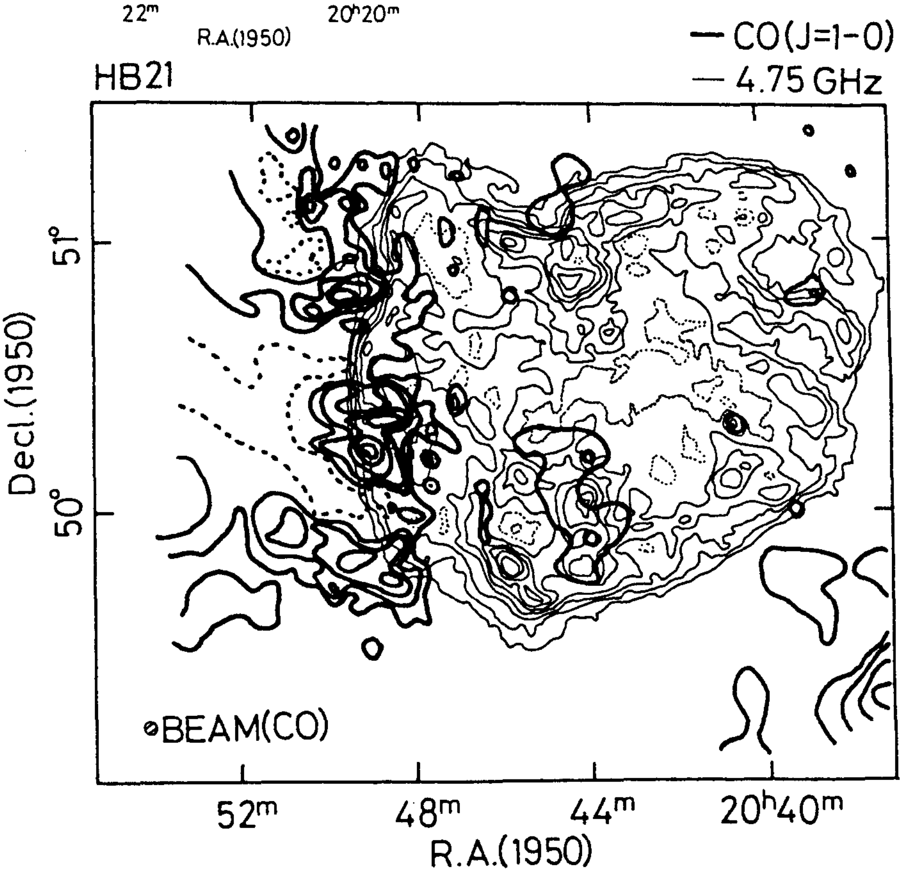

Fig. 4: The integrated CO (J = 1-0) map around HB21 with a contour interval of 8 K km/s. The 4.75-GHz map of the remnant (Reich et al., 1983) is reproduced as thin lines.

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lies just on the near side of the remnant shell and absorbs the X-ray emission from the remnant interior. The column density of the southern clump is deduced as $N(H_2) = 1 \times 10^{22}$ cm^{-2} from CO and ^{13}CO line data. This value is large enough to explain the X-ray map in terms of absorption.

(2) HB21 --- The integrated CO intensity map is superposed on the radio map of HB21 obtained by Reich et al. (1983) (Figure 4). The cloud on the east of the remnant is the westmost part of the giant molecular cloud Kh141. The nearly straight shape of the eastern boundary of HB21 can be well explained as a result of the interaction with the molecular cloud. This is the second example of the global anisotropic expansion of an SNR due to a molecular cloud; the other is G109.1-1.0 (Tatematsu et al. 1987a). There are molecular clumps on the western boundary of the cloud. They apparently form a string of beads along the eastern boundary of HB21. The clump at R.A. = 20^h49^m, Decl. = 50°15' has a mass of 2000 $M_\odot$; the other clumps are less massive.

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