OBSERVATIONS OF "DENTS" IN THE RADIO SHELLS OF SNRs EXPANDING INTO DENSE CLOUDS

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Abstract: High resolution (~36"x90") radio maps of SNRs W28 and W44 observed with the OSRT at 327 MHz are presented. The distortions or dents in their shell structure are associated with the parts of the shells expanding into dense molecular clouds in their vicinity and provide direct observational evidence for interaction between them.

Introduction: The evolution of the radio brightness and the shell structure of supernova remnants (SNRs) strongly depends on the ambient density distribution in the surrounding interstellar medium (ISM). Thus, the differences in the structures of SNRs, particularly in the older remnants, are indeed the result of the interaction of the expanding shock wave with the surrounding interstellar gas. The propagation of a shock wave in a cloudy interstellar medium and its effects on the radio emission from SNRs have been well discussed, for example, by McKee and Cowie (1975) and Blandford and Cowie (1982). Recently Wootten (1977; 1982) mapped two dense molecular clouds observed in the CO in the vicinity of the SNRs W44 and W28 and concluded that they are interacting with the remnants. In this paper, we report high resolution radio observations of the shell structure in these two remnants and interpret the distortions observed in the radio shell in terms of possible interaction of the shock wave with these dense clouds.

Observations and results: The SNRs W44 and W28 were observed for a 3x10 hr period each, with the 4km Ooty Synthesis Radio Telescope (OSRT) at 327 MHz during 1985 and 1987 respectively. The configuration of OSRT was so chosen as to have a wider field of view of 90' in the north-south direction and 170' in the east-west direction (Swarup 1984; Sukumar 1986). OSRT sections were sampled every 25λ in order to minimise the north-south grating effects in maps, particularly for W44. The shortest spacings used for mapping are 50λ and 100λ for W28 and W44 respectively. The data were calibrated and CLEAN maps were obtained using the standard procedure for synthesis radio telescopes.

In Figures 1 and 2 are shown the OSRT contour maps of the brightness distribution in W28 and W44 at 327 MHz obtained with synthesised beams of 96"x36" at 6° PA and 87"x40" at 12° PA respectively. The overall shell structure of both W44 and W28 are quite consistent with the low resolution maps, for example at 10.6 GHz with a 2ʹ.8 beam (Kundu and Velusamy 1972). Unlike the high frequency maps, in the 327 MHz OSRT map the nonthermal remnant shell is seen more clearly without confusion from the thermal sources in the region. The

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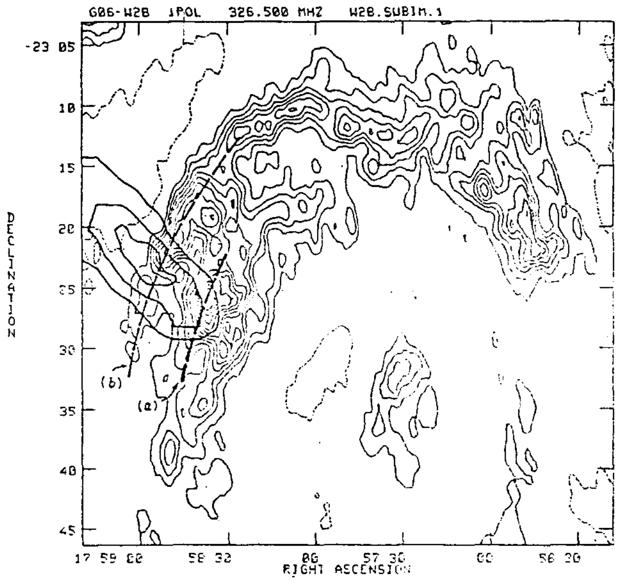

Fig.1 OSRT map of W28 at 327 MHz. Synthesised beam is 96"x36" at 6°PA. The contour interval 100 mJy/beam. The thick contours are CO column density (from Wootten 1981). For arcs 'a' & 'b' see text.

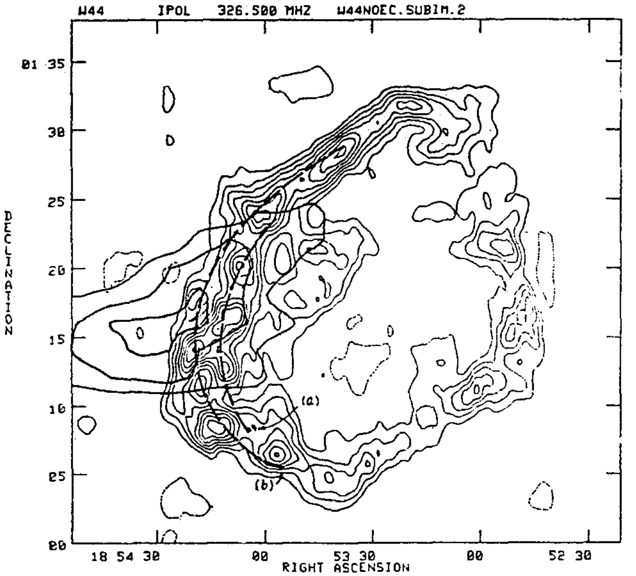

Fig.2 OSRT map of W44 at 327 MHz. Synthesised beam is 87"x40" at 12°PA. The contour interval 120 mJy/beam. Thick contours are CO column density (from Wootten 1977). For arcs 'a' & 'b' see text.

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high resolution maps in Figures 1 and 2 show more details along the shells. W44 has a fairly thin radio shell over most parts, except in the east. In W28 the brightest emission is seen along the eastern part of the shell. The shell in W28 is thick and it is possible that it is a superposition of several thin shells.

Discussion: In Figures 1 and 2, we have also plotted the contours of CO column density of the molecular clouds in the vicinity of W28 and W44 observed by Wootten (1977, 1982). From the positional coincidence in both SNRs, parts of the eastern shell appear to be interacting with the molecular clouds. The densities in these clouds are high, ~1000 cm^{-3} or greater. Kinematic considerations suggest that these clouds are at the same distances as the SNRs and are interacting with the remnants (Wootten 1977; 1982). Such interaction will be observable in the structure of the radio shell of the remnant. It is interesting to note that both the remnants show enhanced emission peaks just behind the densest region of the clouds. Further conspicuous distortions in the shell structure are also seen in the parts of the shell over the cloud region.

In Figure 3 is shown a simple sketch of the expansion of a remnant shell into a dense cloud. If we consider the pressure balance between the cloud shock and the ISM shock, the velocity of the shock in the cloud is less than that in the ISM and is given by $V_{c\ell}^2 n_{c\ell} \sim \beta V_0^2 n_0$, where n_0 and $n_{c\ell}$ are the densities in the ISM and in the cloud respectively, and β is of the order of unity (McKee and Cowie, 1975). The radio emission in SNRs originates in a shell of swept up interstellar gas behind the shock wave, due to the increased density of relativistic electrons and the amplification of the magnetic field by compression and/or by Fermi acceleration. Thus the radio shell

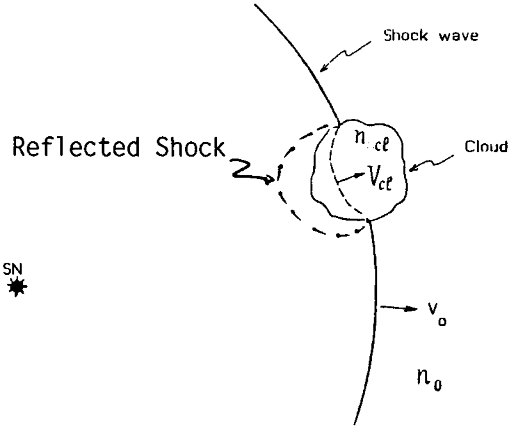

Fig. 3 Sketch of a shock wave colliding with a dense cloud.

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expanding into the cloud will be decelerated more and will show an inward displacement with respect to the parts of the shell expanding into the less dense ambient medium. From the observed geometry of the shell it may be possible to obtain $n_0/n_{c\ell} \sim (V_{c\ell}/V_0)^2$. However detailed modelling may be required taking into consideration the magnetic field, the adiabatic or isothermal shocks, the energy losses and the fact that the densities in these clouds are very high ($\geqslant 1000$ cm^{-3}).

Figures 1 and 2 depict the geometry of the shell as observed (arcs 'a') and that for a shell expanding into a homogeneous ambient medium (arcs 'b'). In W28, while the radio shell north of declination =-23°25' expands "freely", the southern part of the shell seems to be "stopped" by the dense cloud. Since little emission is seen beyond arc 'a' over the cloud region, the cloud is likely to extend along the line of sight at least as much as the extent of the remnant shell. In the case of W44 the apparent flattening of the arc'a' is quite consistent with the interaction between the shell and the cloud as indicated in Figure 3. However, the significant fraction of strong emission along the arcs 'a' and 'b' suggests that only a small portion of the shell along the line of sight is interacting with the cloud. It is also interesting that there is considerable emission near the remnant centre closely following the lowest contour of CO density.

OSRT radio maps thus provide direct observational evidence for the interaction between the remnants and dense clouds near W44 and W28. As the occurrence of dense clouds in the vicinity of SNRs is likely to be common, the distorted shell structures seen in most SNRs may be the result of similar interactions between the remnant shells and dense clouds.

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