COMPARISON OF RADIO AND X-RAY OBSERVATIONS OF SNR G109.1-1.0

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In this paper, we present a comparison of the radio and X-ray morphology of the supernova remnant G109.1-1.0, based on recent radio observations at 6 and 20 cm and investigate the relationship of the SNR to a neighbouring molecular cloud.

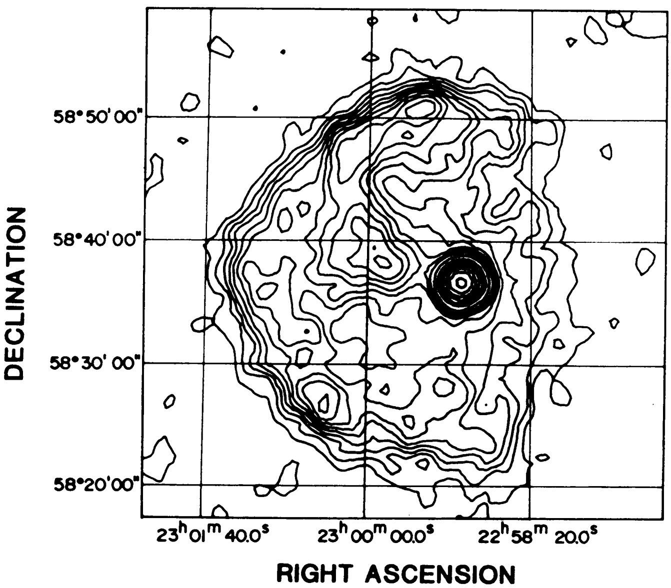

Figure 1. X-ray image of G109.1-1.0 obtained with the Einstein IPC detector, July 1980. Relative contour levels are 20, 30, 40, 52, 67, 83, 100, 118, 142, 200, 332, 470, 664, 940, 1328, 1878 and the map peak corresponds to a level of 2134.

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Figure 1 shows a contour plot of the X-ray emission (Gregory and Fahlman, 1980) with a resolution of 2.5 arcmin, obtained with the Einstein IPC detector in July 1980. At the center of curvature of the semi-circular shaped remnant is an X-ray pulsar (Fahlman and Gregory, 1981 & 1983). Also visible is a jet like feature emerging from the X-ray pulsar on the eastern side.

20 CM VLA OBSERVATIONS

VLA observations of G109.1-1.0 were obtained using C configuration in Sept. 1980 and D configuration in Oct. 1981 and the results combined to provide a map of the SNR at intermediate resolution. With a minimum baseline of 40 m, the array only provides reliable information on angular scales less than 15 arcmin. With an angular diameter of 33 arcmin, the SNR is slightly larger than the HPBW of 30 arcmin for the individual array antennas.

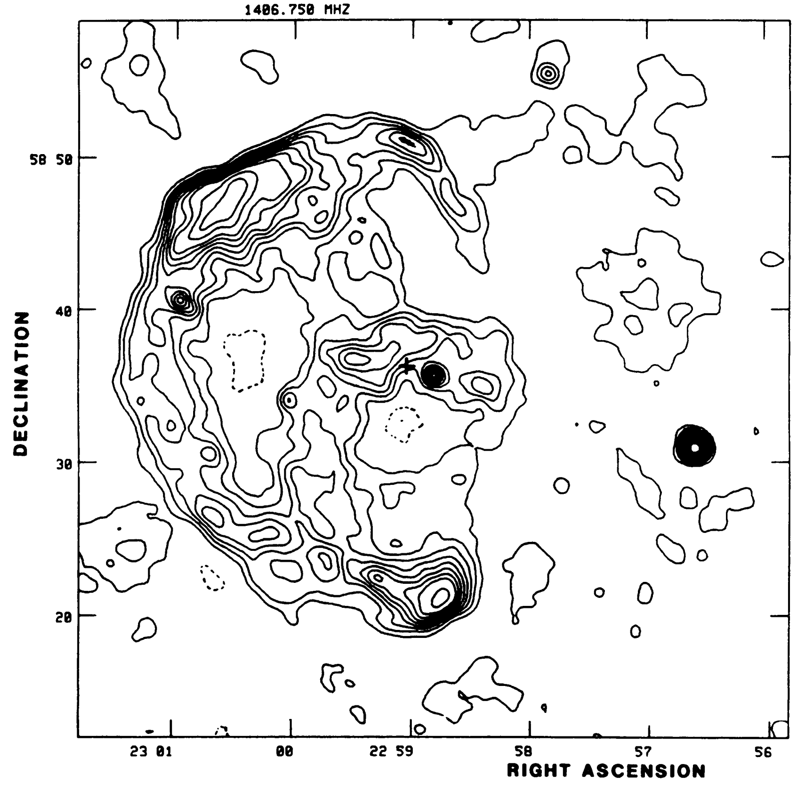

Figure 2. VLA 20 cm map of G109.1-1.0 at a resolution of 1 arcmin, not corrected for the primary beam of the array antennas.

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Early maps made from the data showed the shell structure of the SNR within a negative bowl shaped region, characteristic of a source with undersampled low spatial frequencies. Experiments were carried out to remove the bowl by inserting a zero spacing flux density and through the use of the clean algorithm. Although the negative bowl was largely removed by this procedure, the maps obtained only provided valid information about angular scales < 15 arcmin.

The resolution of the VLA data is limited by the maximum baseline in C configuration to 12 arcsec, however, the map shown in figure 2 has a resolution of 1 arcmin as a result of tapering in the uv plane. Figure 3 shows the same result after correction for the primary beam response of the individual antennas.

Figure 3. The same as figure 2 but corrected for the primary beam of the array antennas. Peak flux = 0.60 Jy/Beam. Contour levels = 0.30E-02 x (-2, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, 16, 20, 24, 28, 32, 36, 40).

6 CM SINGLE DISH OBSERVATIONS

The 6 cm radio observations were obtained in August 1980 with the NRAO 91 m transit telescope, as part of an on going survey of the Northern Milky Way for variable radio sources (Gregory & Taylor, 1981). The observations consists of driving the telescope in declination back and forth across the galactic plane, with earth rotation providing motion in the right ascension coordinate. Full sampling of the region was obtained by interleaving scans on successive days, to provide a series of parallel north bound scans, separated by 1.5 arcmin and a series of south bound scans with the same separation. The telescope HPBW is 2.9 arcmin in RA and 3.2 arcmin in declination. A dual channel beam switching receiver system was used with an effective system temperature of 46 K and a bandwidth of 580 MHz. The dish gain at the source declination is 0.8 K/Jy. Both telescope feeds are sensitive to right hand circulation polarization and are separated by 7.2 arcmin. Because of beam switching, the observations yield directly a differential map. The differential observations were converted to a total intensity map using two different methods. The first of these is the analytic reconstruction method developed by Emerson, Klein and Haslam (1980). The second approach involved the use of a maximum entropy deconvolution program developed by S.F. Gull, G.J. Daniels and J. Skilling at Cambridge University.

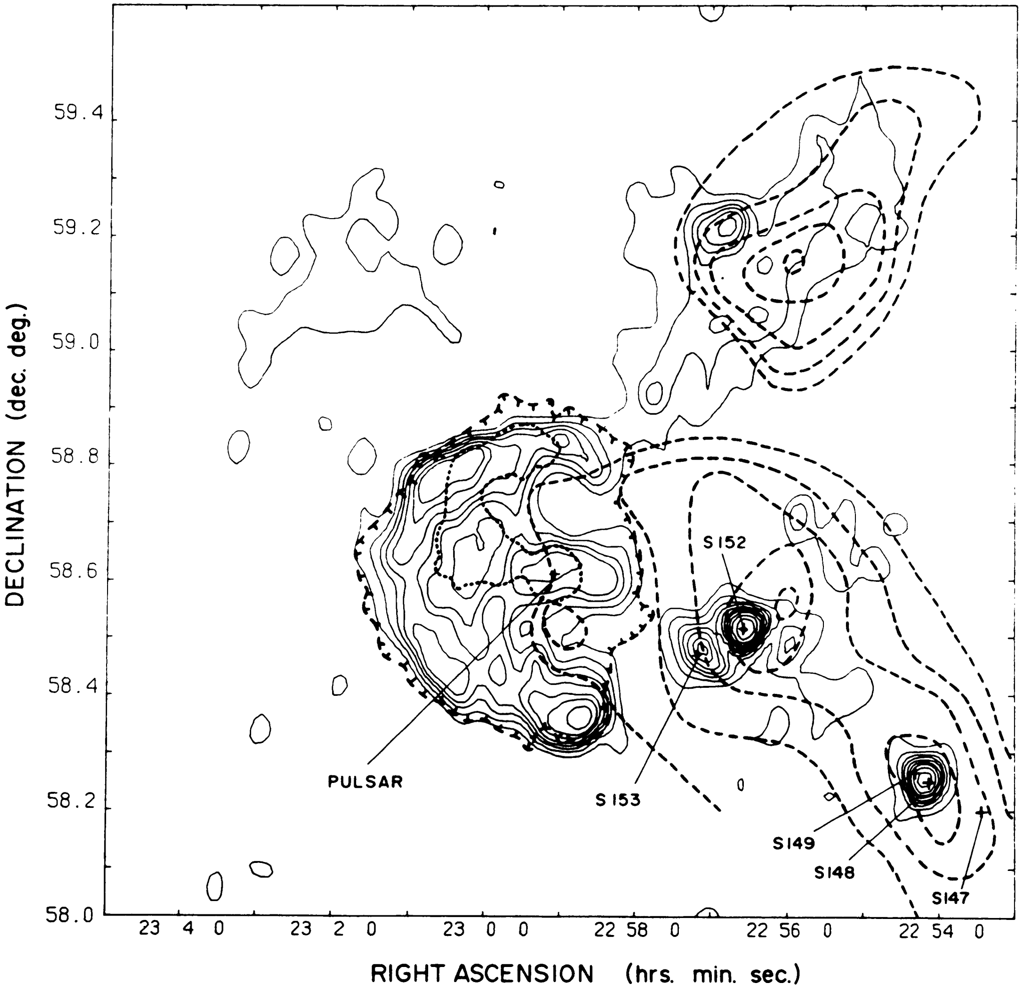

Figure 4. Radio map of G109.1-1.0 obtained with the NRAO 91 m telescope at a wavelength of 6 cm. Superposed are X-ray and CO emission contours shown as dashed lines.

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RESULTS

Figure 4 shows the maximum entropy map derived from the 6 cm, 91 m telescope observations. The map is of a 1°.6 field and shows clearly the SNR and its environment. Superposed on the radio map are contours of $C^{12}O$ emission (thick dashed line), a hatched "T" contour representing the outer boundary of the X-ray emission and the X-ray contour which best defines the jet (thin dashed line). The $C^{12}O$ emission is taken from the results of F. Israel (1980). At least 4 neighbouring sharpless HII regions are indicated on the map, S152, S153, S148 and S149. The maximum entropy method yields an image with a resolution dependent on the signal to noise ratio. Cross-sections through the peak of S152 exhibit a FWHM of 1.9 x 1.7 arcmin. The intrinsic size of S152, as determined by VLA observations (Gregory and Fahlman, 1981), is approximately 40 arcsec.

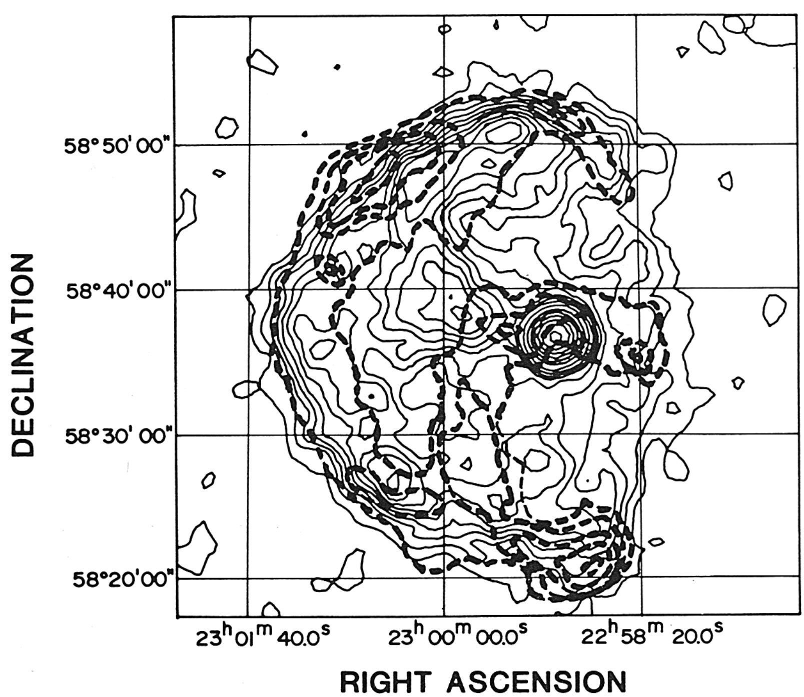

Figure 5. X-ray contours of figure 1 with 20 cm VLA contours superposed as dashed lines.

There is a very good agreement between the 6 and 20 cm radio maps. The emission in both is strongest in the south west with a second bright region in the north east. In both cases, the emission resembles two intersecting arcs. The fainter of the two arcs starts in the south west and passes through the central region of the remnant, finally curving westward just north of the pulsar. Several compact sources are also evident in the VLA map, including one, only 2 arcmin west of the X-ray pulsar. These have been studied at higher resolution and will be discussed in a subsequent paper. Also, a very sensitive search for a radio counterpart to the X-ray pulsar was carried out, but none was found (3σ upper limit = 200 μJy).

The 6 cm map shows radio emission extending to the north west of the SNR. There also appears to be a second molecular cloud overlapping some of this emission, at a considerable distance from the SNR. This radio emission is probably unrelated to the SNR and additional VLA observations of this region show that two of the components, between the SNR and the second molecular cloud, have a double structure, characteristic of extragalactic sources.

The X-ray and radio emission are compared in detail in figure 5, which shows 20 cm VLA contours superposed on the X-ray contours of figure 1.

CONCLUSIONS

Comparison of the radio, X-ray and CO contours leads to the following main conclusions.

1) The overall extent of the radio and X-ray emission is very similar, however, there are marked differences in the distribution of X-ray and radio emission within the remnant.

2) The jet like structure, apparent at X-ray wavelengths, doesn't have a radio counterpart.

3) The radio emission resembles two intersecting arcs.

4) There is no compact radio source associated with the X-ray pulsar. The 3σ upper limit on the continuous radio emission from the X-ray pulsar, at 20 cm, is 200 μJy.

5) Radio and X-ray peaks do not coincide in position. The radio peaks occur on the outer sloping edges of the X-ray emission.

6) The location of the $C^{12}O$ emission strongly suggests a physical interaction between the SNR and the neighbouring molecular cloud.

This interaction would provide a natural explanation for the semi-circular appearance of the SNR. A similar conclusion was reached by Heydari-Mayleri et al. (1981) based on $C^{13}O$ observations.

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