HIGH RESOLUTION RADIO OBSERVATIONS OF THE SNR G160.9+2.6 (HB9)

D.A. Leahy* and R.S. Roger**
* Dept. of Physics, University of Calgary, Canada
** Dominion Radio Astrophysical Observatory, National Research Council of Canada, Penticton

Abstract
G160.9+2.6 (HB9) is a supernova remnant of large angular diameter and low radio surface brightness. We report new observations of the continuum emission from HB9 at 408 MHz and 1420 MHz with angular resolutions of 3.5' and 1.0', respectively, which reveal significant filamentary structure not previously detected. The 1420 MHz field covers only the central and eastern parts of HB9. The 408-1420 MHz spectral index ($S \propto \nu^{\alpha}$) of regions common to both maps is α=-0.68, with no significant spatial variation. The radio filamentary structure closely follows the optical structure. X-ray emission from HB9 is more centrally concentrated than the radio or optical emission. The radio, optical, and particularly, the X-ray surface brightness are all diminished in the northern and north-western portions of the remnant, in directions approximately coincident with an extensive molecular cloud detected in CO.

Observations
The observations of HB9 were made with the DRAO synthesis telescope during the period Dec. 1986 to Feb. 1987. The telescope (Roger et al., 1973) receives left-hand circularly polarized radiation in the HI spectral band and in a 15 MHz continuum band at 1420 MHz which excludes the HI band. The telescope simultaneously receives right-hand circularly polarized radiation in a continuum band at 408 MHz (Veidt et al., 1985). The complex visibilities were calibrated and Fourier transformed to produce maps at 408 and 1420 MHz, which were subsequently cleaned. To produce a final 408 MHz map with accurate large scale structure, visibilities near the center of the uv plane were added from the single dish survey of Haslam et al., (1982) and combined with the synthesis data. For the 1420 MHz map, visibilities near the center of the uv plane were derived from the Effelsberg survey (Kallas and Reich, 1980).

Results
a) Radio Maps -
Figure 1 shows the 408 MHz map of HB9 with the full resolution of 3.5' (E-W) by 4.8' (N-S) and a contour interval of 12 K. HB9 is apparent as the 2-degree diameter extended source with a marked outer boundary except in the northwest sector. The 1420 MHz map of Figure 2 has been convolved to a resolution of 2' x 2', and has a contour interval of 0.25 K. Diffuse emission and several filamentary arcs are seen in the interior and along the edges of HB9. A number of

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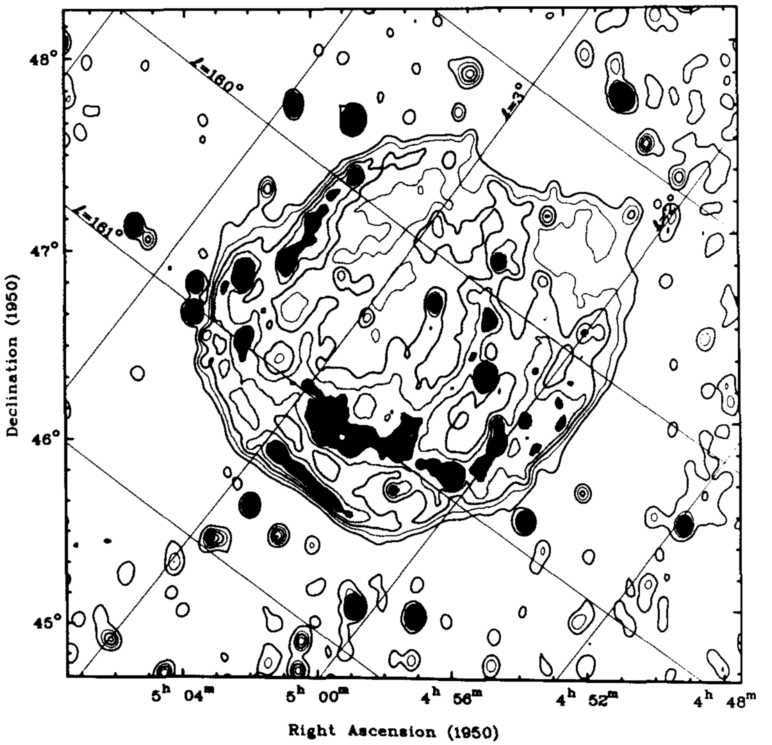

Figure 1. 408 MHz map of HB9. 3.5' (E-W) x 4.8' (N-S) resolution, contour interval 12K.

unresolved (probably extragalactic) radio sources also appear in these maps. The results of analysis of these will be presented elsewhere.

b) Spectral Index-

The 1420 MHz map was convolved to a resolution of 3.5' x 4.8' in order to directly compare the brightness temperatures with those from the 408 MHz map. Pixels within the area common to the two maps were compared. The brightness temperature of a pixel at 408 MHz versus its temperature at 1420 MHz was plotted (a T-T plot) for pixels with temperatures greater than 1 K in the 1420 MHz map and in the interior of HB9 (excluding any bright point sources). The slope in the T-T plot is equivalent to a spectral index of -0.68. Within errors this same index was derived from T-T plots for different subareas of the interior of HB9.

c) Comparison with Other Wavelengths-

The 2.7 GHz map of Reich et al., (1983) agrees closely with the 408 MHz structure. A low resolution (~30 arcminute) map of HB9 at 34.5 MHz has been presented by Dwarakanath et al., (1982). They also summarize flux density measurements, with care to correct all data to a common scale, and find a good fit with a power law spectrum with a

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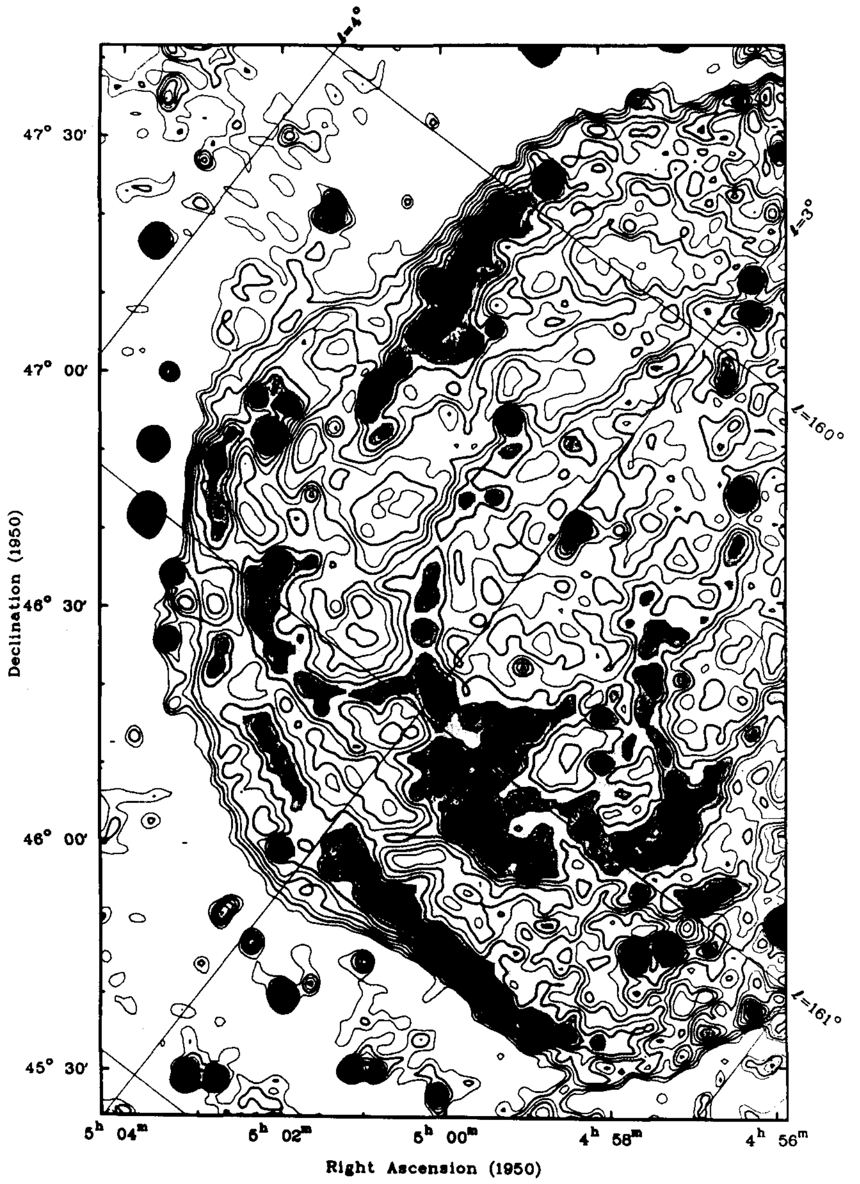

Figure 2. 1420 MHz map of HB9. 2' x 2' resolution, contour interval 0.25K.

spectral index from 34.5 to 2700 MHz of -0.58 ± 0.06. They also see no significant variation of 34.5-1400 MHz spectral index across the SNR. Willis (1973), in contrast, finds a spectral index of -0.44 with a possible steepening above 1.3 GHz. Our data, which lies on either side of the reported break at 1.3 GHz by Willis (1973), shows no evidence for a change of spectral index and is consistent with the result of Dwarakanath et al., (1982).

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An optical photograph (van den Bergh et al., 1973) reveals diffuse and filamentary emission throughout the central and southern portions of the remnant, being brightest along the southeastern rim. A comparison of the 408 and 1420 MHz maps with the optical photograph shows that the optical and radio filamentary structure agrees in position to the limits of the map resolutions (i.e., 3.5 and 1.0 arcminutes for 408 and 1420 MHz, respectively).

The Einstein IPC X-ray map (Leahy, 1987) shows HB9 to be brighter in the center than along the rim and also to have a region in the northwest part of the radio maps which is not seen in X-rays. The CO map of Huang and Thaddeus (1986), for radial velocities -12 to -30 km/s, shows that a molecular cloud overlaps the northern and northwestern boundary of HB9. This cloud has not distorted the shape of the boundary of HB9 in radio and optical, but is roughly associated with an area of diminished brightness. A comparison of CO and X-ray images shows that the edge of the molecular cloud coincides with the outer boundary of the X-ray emission. Thus, it appears that the X-ray brightness has been reduced by absorption, and that the cloud may lie on the near side of, or may be interacting with, HB9. Comparison of the CO map with the IRAS maps shows 60 and 100 micron emission coincidental with brighter CO emission from the molecular cloud.

Summary

The radio and optical structure are seen to agree closely in detail indicating that both radio and optical emission are associated with shocks propagating into sheets or filaments of material inside HB9. For the large scale appearance, the radio and optical are significantly brighter in the southern regions of the remnant. The X-ray structure (Leahy, 1987) shows the same tendency even more strongly. This may be caused by the presence of a molecular cloud along the line of sight to, or interacting with, the northwest portion of HB9.

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