OBSERVATIONS OF G320.4-1.2 AND SPECULATIONS ON SUPERNOVA REMNANT MORPHOLOGY

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The galactic radio source G320.4-1.2 (MSH15-52) consists of several components, the most prominent of which is situated in the north-west quadrant and is associated with the Hα nebula RCW89. Caswell et al. (1981) mapped the source at 1.4 GHz with a resolution of 50" arc and concluded that it was a single supernova remnant with all components having spectral index $\alpha \approx -0.34$. This SNR has become more significant with the recent discovery (Seward and Harnden, 1982) of an X-ray pulsar of period 150 ms at the position (1950) R.A. $15^h09^m59^s.5$, Dec. -58°56'57" near the centre of the remnant and the detection of this pulsar at radio frequencies (Manchester et al., 1982). The pulsar has some similarities to the Crab pulsar in that its period derivative is extremely high and hence its characteristic age low, ~1570 years, comparable to that of the Crab pulsar. Timing observations (Manchester and Durdin, unpublished) indicate that the pulsar is not a member of a binary system and hence that the pulsed X-ray emission is powered by rotational energy, as in the Crab pulsar.

We have mapped G320.4-1.2 with improved sensitivity using the Molonglo Observatory synthesis telescope (MOST), which operates at a frequency of 843 MHz (Mills, 1981). At this declination the beamwidth is 43" × 50" arc (R.A. × Dec.). Two maps, shown in Figures 1 and 2, were made, on 1982 June 15 and 17, the first of the whole field, 35' × 41' arc, and the second of the central portion, 11' × 13' arc, both centred on the pulsar. The two maps are independent, each requiring 12 h of observation. Neither map has been cleaned; there are some negative sidelobe responses around strong components in the south-east of the map but generally their effect is believed to be small.

The overall appearance of the remnant in Figure 1 is similar to that in the 1.4 GHz map of Caswell et al. (1981), which has comparable resolution. This is consistent with their observation that all portions of the remnant have approximately the same spectral index. A significant feature of the maps is the extension from the north-west component towards the pulsar, evident in Figure 1 but shown much more clearly in Figure 2, which has higher sensitivity (noise $\lesssim$1 mJy/beam). The pulsar

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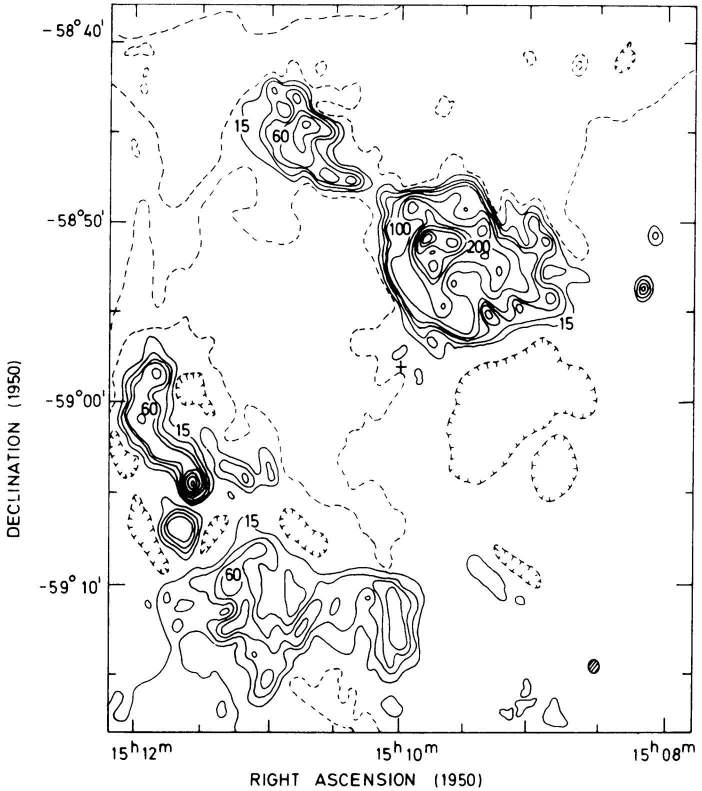

Figure 1. SNR G320.4-1.2 at 843 MHz. The half-power beamwidth is 43" × 50" arc (filled ellipse). Contour intervals are 0 (dashed), 15, 30, 45, 60, 100, 150, 200, 250, 300, 350 and 400 mJy/beam with respect to a locally defined zero. The position of PSR 1509-58 is indicated by the cross and the shaded ellipse represents the half-power beam.

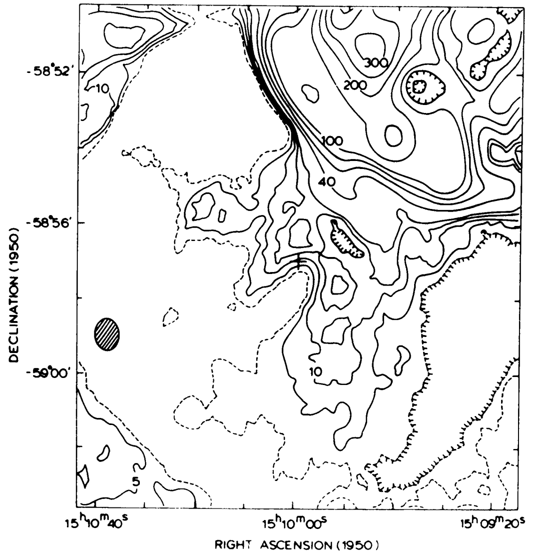

Figure 2. Region surrounding PSR 1509-58 at 843 MHz. The half-power beamwidth is 43" × 50" arc (filled ellipse). Contour intervals are 0 (dashed), 5, 10, 15, 20, 40, 60, 80, 100, 150, 200, 250 and 300 mJy/beam with respect to a locally defined zero. The pulsar position is indicated by the cross and the shaded ellipse represents the half-power beam.

itself lies on a steep gradient and is not detected, although its expected mean flux density is $\gtrsim$2 mJy. Taken together with the central location of the pulsar in the SNR and the agreement in estimated distances (Manchester et al., 1982), this extension provides convincing evidence for the association of PSR 1509-58 and G320.4-1.2. This is only the third such association known (after Crab and Vela) and hence of considerable significance. Of particular importance is the fact that this remnant clearly does not fall into the filled centre or plerion class. Several authors (e.g. Weiler and Panagia, 1980) have suggested that only plerions contain active pulsars.

The north-west (RCW89) component is elliptical in outline and has been interpreted as a separate SNR (e.g. Milne, 1970). However, it is unlikely that the pulsar is associated with this component alone as the implied pulsar space velocity is $\gtrsim$5000 km s^{-1}. Much more plausible is the interpretation of Caswell et al. (1981) that the entire source is a single remnant. We are then left with the problem of explaining the morphology of the remnant and the relative location of the pulsar.

A possible solution to this problem, which has wide implications, can be obtained by noting the existence of a mapping of the elliptical north-west component on to the south-east component with all lines connecting corresponding points passing through the pulsar position. This correspondence, illustrated in Figure 3a, immediately suggests that the SNR morphology is dominated by the conical loci of two diametrically opposed beams emitted by the rotating pulsar. We postulate synchrotron electrons which are (or were) generated by locations where these beams impacted on to regions of relatively high density, possibly the outer boundary of the expanding SNR cavity. The proposal is in this sense similar to beam models for extragalactic double radio sources (e.g. Blandford and Rees, 1974).

The beam loci shown in Figure 3a pass relatively close to the pulsar, implying that at the point of closest approach the beams are (or were) essentially directed toward us. Since we detect this pulsar in the radio and X-ray bands, the radio and X-ray beams must also be directed toward us at some rotational phase. If one accepts the oblique rotator magnetic-pole models for pulsar emission (e.g. Ruderman and Sutherland, 1975), which have strong observational support, then the radio and presumably the X-ray beams are emitted in opposite directions along the magnetic axis. Clearly the most economical hypothesis is to assume that the energetic beams are (or were) collimated along the same axis.

There are a number of obvious tests of this proposal. Firstly, is it energetically feasible? This question was answered in the affirmative by Ostriker and Gunn (1971), who proposed that the entire supernova event was driven by the pulsar. The present proposal is more limited: only the nebular synchrotron emission is driven by the pulsar, although one could not rule out the possibility that impact of the beams significantly affects the nebular expansion.

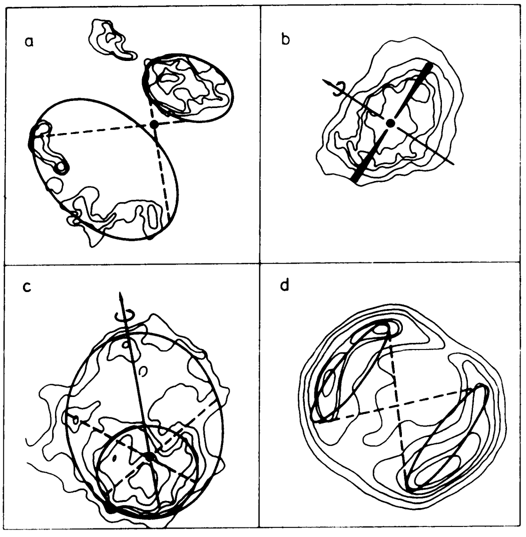

Figure 3. Schematic diagrams illustrating the loci of beams emitted by the central pulsar of (a) G320.4-1.2, (b) Crab nebula, (c) Vela SNR and (d) SN1006. A selection of contours is used to indicate the radio morphology of the SNR and the heavy ellipses represent the loci of the point of impact of the outer edge of the beam. Where known the orientation of the pulsar rotation axis is indicated. In the case of the Crab the configuration is degenerate (see text). The radio contours were obtained from the present paper (G320.4-1.2), Wilson (1972) (Crab), Day et al. (1972) (Vela), and Stephenson et al. (1977) (SN1006).

Secondly, are the other known examples of pulsar-SNR associations compatible with the proposal? Briefly, the answer is yes. In the case of the Crab pulsar, optical polarization observations (Kristian et al., 1970) indicate that the pulsar rotation axis is approximately perpendicular to the major axis of the nebula. Furthermore, the presence of a strong interpulse suggests that the rotation and magnetic axes are approximately perpendicular and that the rotation axis is approximately in the plane of the sky. This configuration, illustrated in Figure 3b, suggests that the Crab nebula is an oblate spheroid which we see edge-on. Because of the degeneracy involved this case cannot be claimed as strong evidence in support of the model but at least it is not inconsistent with it. The Vela association is more interesting. Weiler and Panagia (1980) suggest that the pulsar is associated with the more intense southern component, Vela X, but other authors (e.g. Milne, 1968) interpret the whole Vela XYZ complex as a single SNR. As for G320.4-1.2, a striking correspondence exists in the Vela SNR; as illustrated in Figure 3c, Vela X maps through the pulsar on to the outer boundary of the entire source with an approximately 1:2 ratio of radii. The orientation of the pulsar rotation axis, based on the intrinsic position angle of the radio pulse polarization (Hamilton et al., 1977) is consistent with the interpretation of the two ellipses shown in Figure 3c as the loci of beams emitted from the pulsar. In this case also a beam passes relatively close to the line of sight.

One can ask a third question: how do SNRs which have no detectable pulsar fit into the proposal? Let us first assume that all SNRs contain active pulsars. According to the model proposed here the radio morphology should consist of two elliptical components of similar ellipticity. The ellipticity, separation and relative size of the two components will be determined by the pulsar geometry and variations in the density of the interstellar medium. Most recognized SNRs have a shell morphology with a central minimum. It has long been known that many of these shell-type remnants have a bimodal structure - a good example is SN1006, shown in Figure 3d. Shaver (1969) suggested that this bimodal structure resulted from compression of the interstellar magnetic field. However, the orientation of the structure in many SNRs (e.g. Caswell, 1977) is not aligned with the galactic plane, as would be predicted by this mechanism. We propose that this bimodal structure results from the beam modulation described above when the pulsar rotation axis is roughly in the plane of the sky. Provided the rotation and magnetic axes are not perpendicular (as in the case of the Crab pulsar) one will then see the two ellipses approximately edge-on, as indicated in Figure 3d. An important point is that in this situation the pulsar beams are *not* directed in the line of sight and hence no pulses will be detectable. This will also be true when the rotation axis is close to the line of sight and the angle between the magnetic and rotation axes is not small. The SNR will then consist of two ellipses with a large degree of overlap. Such remnants are also classified as shell-type. The model therefore provides a natural explanation for the non-detection of pulsars in shell-type SNRs - only when the beams are directed toward the observer will pulsars be detectable and only in this case will the SNR have significant central emission and be classified as a plerion.

On the basis of this model one can predict which SNRs have potentially detectable pulsars and furthermore the exact location of the pulsar or, at least, its exact location when the SNR was very young. Clearly it will be of interest to search for these pulsars. It will also be of considerable interest to test the applicability of the model to a wider range of SNRs - for this we require high-resolution, high-sensitivity radio maps.

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DISCUSSION

SALVATI: a) Given your geometry for MSA 15-52, we should be outside the precession cone of the beams. How can we detect the radio pulses? b) In order to perturb appreciably the structure of the radio remnant, the beams must be energetic and the pulsar quite fast. How is this reconciled with the evidence that pulsars are born slow?

MANCHESTER: a) Firstly, I should point out that in this model the beam motion is assumed to result from rotation of the pulsar, not precession as in the case of SS433. In answer to your question, small differences in orientation of the radio and energetic beams might be expected if they are collimated at, for example, different radial distances from the star in the pulsar magnetosphere. Also there is some evidence (Narayan and Vivekanand, 1982, preprint) that pulsar radio beams are elongated in the latitude direction. b) It is true that pulsars must be born with relatively short period, say <10 ms, to be sufficiently powerful. In my view the evidence that pulsars are born slow is not strong. The number of missing short-period pulsars is quite small and these could easily have been missed in the large scale surveys (see Manchester, et al., this volume).

DANZIGER: A third epoch direct plate of the Vela Pulsar has been obtained at La Silla in order to measure the proper motion of this pulsar. The epoch and positions are summarised below. Within the errors there is no detectable proper motion. This means that if the pulsar is at a distance of 500 psc its maximum motion in the plane of the sky is 70 - 100 km/sec. It could not have originated near the centre of the radio shell if the age is $\sim 10^4$ years, but must have been born near its present position in the Vela X complex.

Epoch	Position	
1975.2	$08^h33^m39^s.22 \pm 0^s03$	$-45°00'10''1 \pm 0''33$
1977.3	$08^h33^m39^s.30 \pm 0^s02$	$-45°00'10''3 \pm 0.3$
1981.9	$08^h33^m39^s.23$	$-45°00'10''2$

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MANCHESTER: This result is very interesting and is completely consistent with the present proposal which requires the pulsar still to be near its position at birth. In a few more years it should be possible to determine whether or not the pulsar was born at the centre of Vela X.

GIOVANNELLI: If all the SNRs (at least Type II) contain active pulsars; i) which is the birth rate of SN you can compute? ii) is this value in agreement with those given in different papers during this meeting ($\sim$ 50 - 70 yr)?; it seems to me, at the first look, higher than the mentioned ones.

MANCHESTER: Recent calculations of pulsar birthrates (Lyne, Manchester and Taylor, in preparation), give mean intervals of 20 - 60 years between births. This is fully consistent with the value of 30 years quoted by Mills and the range of 25 - 80 years quoted by Dickel at this meeting for the mean interval between SNR births in our Galaxy.