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Bi-annular Structure in Supernova Remnants*

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Abstract

In many supernova remnants the radio structure contains loop features. It is proposed that these loop features are generally due to an enhancement of the shell emission in two co-axial rings. This bi-annular enhancement is closely related to the cylindrical or barrel morphology possessed by most remnants and is probably formed early in the life of the remnant.

1. Introduction

Most supernova remnants (SNRs) are roughly circular in outline and brightest near the boundary. These observations led to the interpretation that SNRs consist of an expanding spherical shell of emitting material (e.g. van der Laan 1962). While this model describes the broad features of SNR emission very well, it has long been evident that there are significant departures from spherical symmetry. The most common of these is where the remnant has two bright arcs of emission on opposite sides of the remnant separated by regions of weaker or no emission. This has usually been interpreted as cylindrical enhancement of the shell emission (Kesteven 1987, present issue p. 815). In many recent maps with improved sensitivity and/or resolution it is observed that the shell structure breaks up into several often overlapping rings or loops of emission. These extra loops are often described as bridges or secondary shells.

In this paper I suggest that the rings or loops in the radio structure of many remnants are a basically bi-annular enhancement of the shell emission that is closely related to the cylindrical structure. The two rings are typically located near the ends of the 'barrel' with the same axis of symmetry. These enhancements are probably generated early in the life of the remnant and from the interaction of a biconical flow with the expanding shell. The biconical flow may have originated from the pre-supernova star or stellar system, it may be the supernova explosion itself, or it may be generated after the supernova by a compact object—pulsar or accreting binary system—within the remnant. Once established, the regions of enhanced emission are maintained by continued re-acceleration of the relativistic electrons in the turbulent boundary between the ejecta and the surrounding medium. The annular structure can therefore persist until the SNR finally dissipates in the interstellar medium.

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A central pulsar may also generate a centrally concentrated synchrotron nebula or plerion component (e.g. Weiler 1983). The relative strength of this and the shell component depends on many parameters and may range from infinity (for the Crab Nebula) to zero (for most remnants). The evolution of the two components—shell and pulsar-driven—appears to be independent. In this paper we consider only the shell component. A more complete discussion of the ideas presented here may be found in Manchester (1987).

2. Cylindrical and Annular Structures

Fig. 1 shows radio maps of two SNRs showing evidence for a cylindrical morphology. SN 1006 (Fig. 1*a*) is a classic example of the type with two bright arcs showing a bilateral symmetry about an axis passing through the faint regions. This clearly indicates a cylindrical or barrel morphology for the remnant (Kesteven 1987). We note that the brightest regions are located near the ends of the arcs—only the northern end of the western arc is not bright. Given the cylindrical morphology, these bright ends imply the existence of ring enhancements at the ends of the barrel. G296·5+10·0 (Fig. 1*b*) has a similar morphology except that in this case there is a bright ring at one end only.

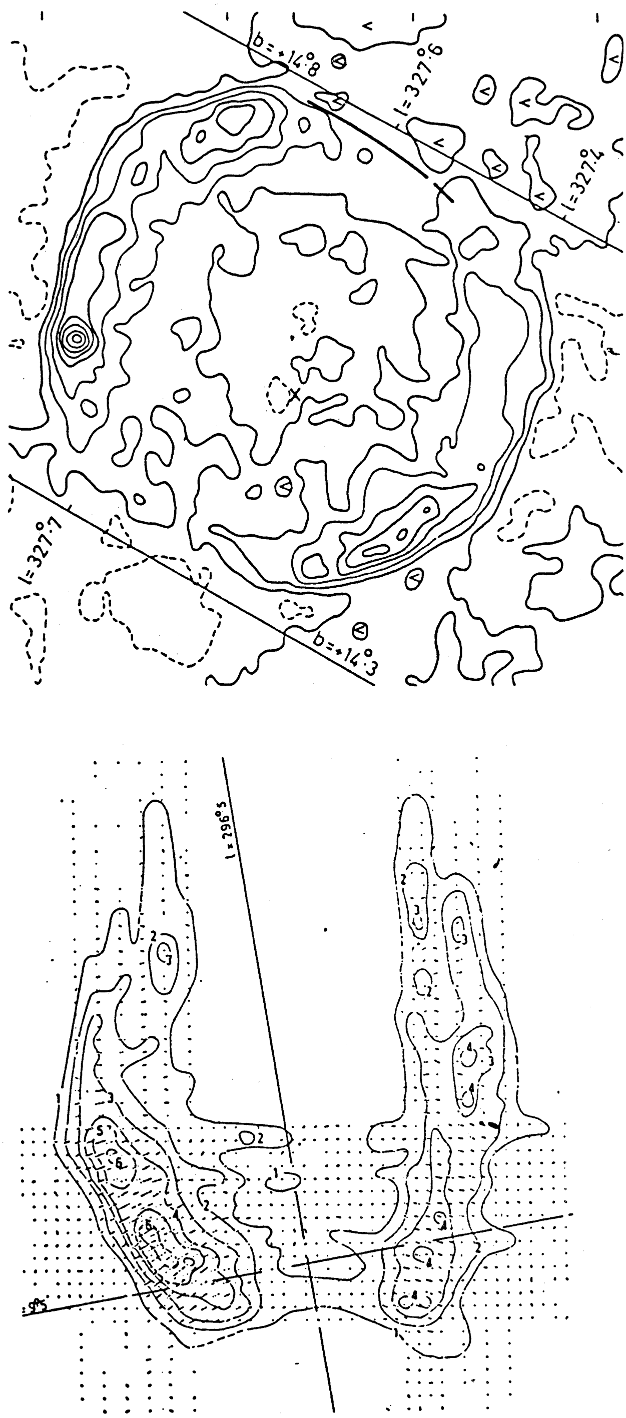
There are many other examples of remnants for which the structure is most easily interpreted as cylindrical (Kesteven 1987). However, there are other remnants where the structure is more complex with several overlapping loops of emission. Some examples of these are shown in Fig. 2. In most of these remnants the observed radio structure can be most simply interpreted as resulting from a basic bi-annular structure—two rings having a common axis of symmetry and separated in the direction perpendicular to their planes. The rings are located more or less symmetrically on the spherical SNR shell, although variations due to density inhomogeneities in the interstellar medium (ISM) or other factors may distort this simple picture.

CTA 1 (Fig. 2*a*) is a relatively large remnant with a second loop of emission across its centre, described by Sieber *et al.* (1979) as a bridge. As shown, this feature may be interpreted as a second ring—in this case the SNR is viewed from a direction close to that of the axis of symmetry.

G316·3+0·0 (Fig. 2*b*) is a good example of a remnant whose structure is dominated by two rings. This morphology accounts for all the major emission features, including the spur into the centre of the east side of the upper ring and the weak emission in the south–east. Despite the incompleteness of the rings, such a two-ring structure is the simplest way to describe the main features of the radio structure of this SNR. The two rings are approximately elliptical in form with roughly parallel major axes. The displacement of the two rings is approximately parallel to their major axes, which is not expected in the proposed model. This may be a result of non-uniform expansion of the shell. The bright portions of the rings may indicate regions where the shell has impacted into denser regions of the ISM, resulting in slower expansion in these directions.

Another remnant with two very clear rings is G109·1−1·0 (Fig. 2*c*). This remnant contains the X-ray source 1E 2259+586; Gregory and Fahlman (1983) suggested that the loop structure is generated by precessing jets from this object.

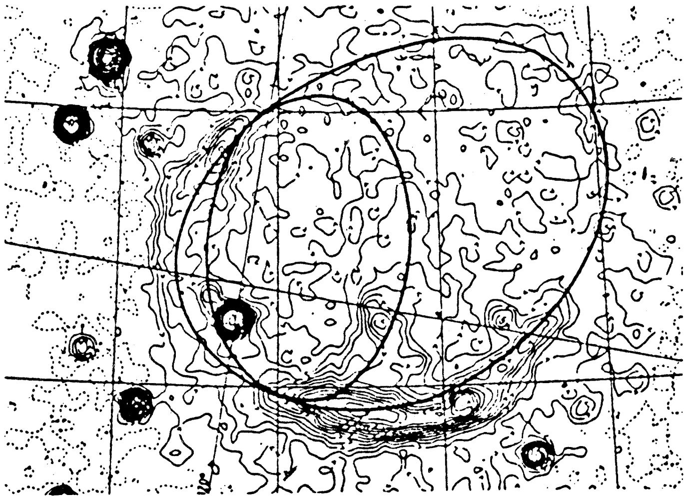
IC 443 (Fig. 2*d*) is a well-studied SNR in which there is a bright ring of emission to the north–east and a fainter and larger ring to the south–west. This structure



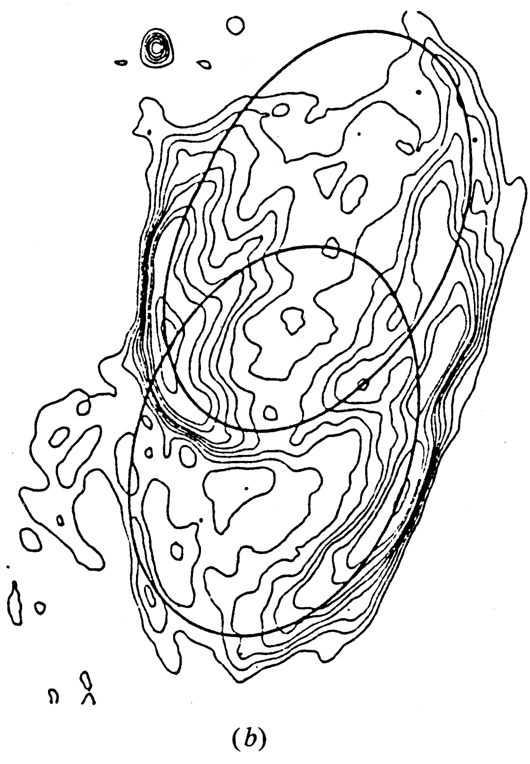
(*a*)

(*b*)

Fig. 1. Radio maps for two SNRs which have cylindrical symmetry: (*a*) G327·6+14·6 (SN 1006, Caswell *et al.* 1983) and (*b*) G296·5+10·0 (Milne and Dickel 1975).

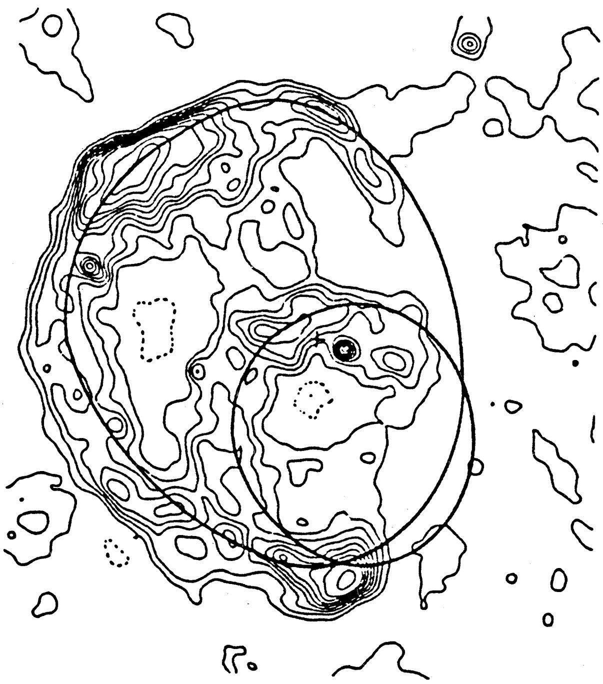


(*a*)



(*b*)

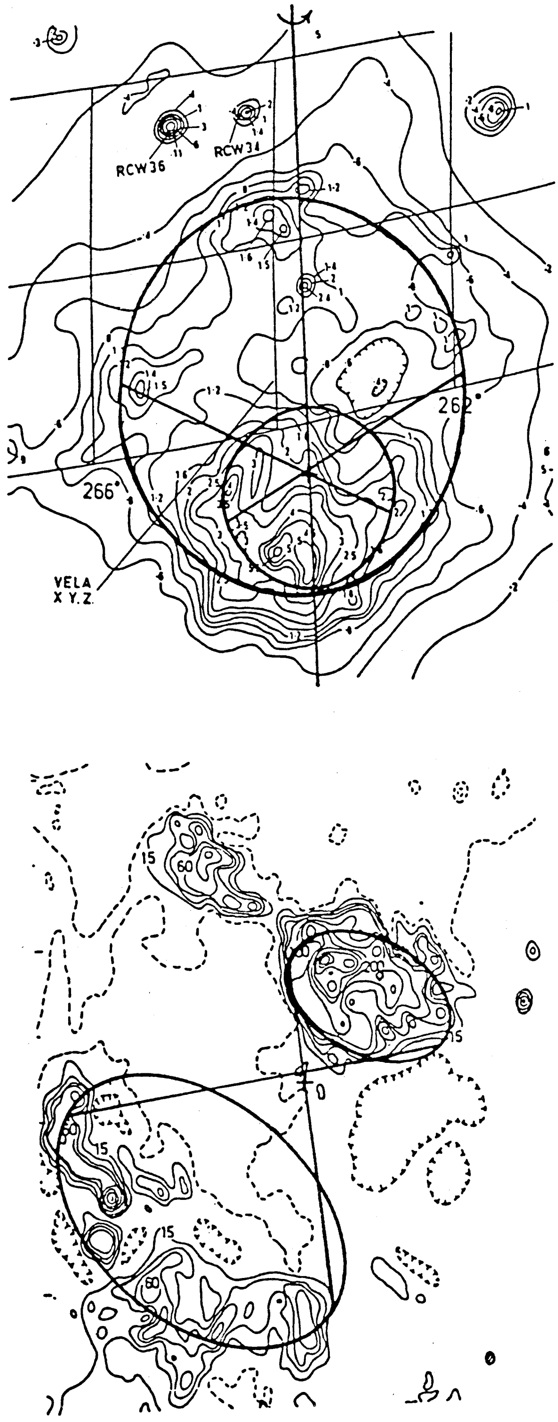
Fig. 2. Radio maps for four SNRs which show evidence for overlapping rings or loops of emission: (*a*) G119·5+10·2 (CTA 1, Sieber *et al.* 1979); (*b*) G316·3+0·0 (derived from the data of Milne *et al.* 1985); (*c*) G109·1−1·0 (Gregory *et al.* 1983); (*d*) G189·1+3·0 (IC 443, Hill 1972). The cross on the map of G109·1−1·0 marks the position of the X-ray source.



(*c*)

(*d*)

Fig. 2. *(Continued)*



(*a*)

(*b*)

Fig. 3. Radio maps for two SNRs containing pulsars: (*a*) the Vela SNR (Day *et al.* 1972) and (*b*) G320·4 – 1·2 (Manchester and Durdin 1983). The ellipses indicate the two annular zones of enhanced emission and the diagonal lines show the boundaries of the postulated biconical flow which generated the rings. In both maps the position of the pulsar is marked with a cross.

has generally been interpreted as a double shell (e.g. Braun 1986); alternatively it may have the bi-annular structure described above. The combination of a small bright ring and a larger fainter ring seen in IC443 is not uncommon in SNRs (e.g. G332·2+0·2, Roger *et al.* 1985) and probably results from differences in the ISM density, as discussed above for G316·3+0·0.

For two of the four SNRs thought to contain pulsars the radio emission is dominated by the shell component. The radio structure of these two, the Vela SNR and G320·4−1·2 (which probably contains the 150 ms radio and X-ray pulsar PSR 1509−58), is shown in Fig. 3. The brighter region in the south of the Vela SNR is commonly known as Vela-X and, following Weiler and Panagia (1980), is generally thought to be directly driven by the Vela pulsar. However, Milne and Manchester (1986) have given strong arguments against this proposal and suggested instead that Vela-X is an enhanced zone of the shell emission. In the context of the bi-annular model, we interpret it as a second ring of emission, as indicated in Fig. 3*a*. It is interesting to note that the pulsar lies at the point of intersection of the lines which outline the originating biconical flow. This suggests that the pulsar has not moved far since it was born and hence has a small proper motion.

The radio emission of G320·4−1·2 (Fig. 3*b*) can also be interpreted as consisting of two rings, in this case non-overlapping. As in the Vela SNR, the pulsar lies very close to the intersection of the diagonal lines defining the biconical flow.

3. Discussion and Conclusions

Arc and loop structures are common in the radio emission from SNRs. Following Kesteven (1987) we interpret these structures as showing that the shell emission from most, if not all SNRs, has a cylindrical symmetry; that is, SNRs are barrel-shaped. We further postulate that most of the ring and loop structures observed in SNRs can be interpreted in terms of a bi-annular enhancement of the shell emission where the two rings are located at or near the ends of the barrel and share its symmetry axis. Different observed structures result from different viewing angles relative to the axis of symmetry—double arcs with bright ends when viewed from perpendicular to the axis and overlapping loops when viewed from directions close to that of the axis.

These enhancements are most probably generated early in the life of the remnant and persist as the remnant expands. Explanations in which the structure results from non-spherical flow either of the pre-supernova stellar wind or of the supernova ejecta are supported by the fact that thermal X-ray emission is often closely correlated with the radio emission and shows the same ring structure (e.g. in IC443, Petre *et al.* 1982). On the other hand, the close association of the pulsars in the Vela SNR and G320·4−1·2 with the ring structure suggests a model in which the enhancements are generated by a biconical pulsar wind. A further possibility is that precessing jets from a central accreting binary system may generate the ring pattern as suggested for G109·1−1·0 by Gregory and Fahlman (1983). Good evidence for such a mechanism is also given by the SS433/W50 system (Abell and Margon 1979; Hjellming and Johnston 1981). It is likely that different mechanisms operate in different remnants and possibly even in the same remnant.

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