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Supernova Remnant Morphology: Are the Remnants Barrel-shaped?*

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Abstract

We argue that the majority of radio supernova remnants have a three-dimensional distribution of emissivity which is barrel-shaped, with little emission from the end caps. We examine briefly some mechanisms which could produce this distribution.

1. Introduction

Previous studies of radio supernova remnant (SNR) morphology have defined two classes: filled-centre (with the Crab nebula as archetype) and shell-type (with Tycho as a good example). This note is concerned with the shell-type remnants. These objects are roughly circular in appearance, with their brightness enhanced at the periphery. It has been argued that this morphology is due to a thin-walled spherical shell of emission, and this is the model adopted in many studies of the dynamics of supernovae and their interaction with the interstellar medium.

It has long been evident, however, that in few remnants is the brightness distribution circularly symmetric, as required in the spherical shell model (Whiteoak and Gardner 1968; Shaver 1969; Mills *et al.* 1984). The departures from symmetry have generally been ascribed to the interaction of the remnant with an inhomogeneous interstellar medium.

We suggest a simpler interpretation, namely that the remnant is barrel-shaped. Our argument proceeds in two steps:

(i) We show (in Section 2) that two high-latitude remnants (G296·5+10·0 and G327·6+14·6) have a morphology which can only be explained in terms of a distributon of emission which has cylindrical symmetry (i.e. the emission is barrel-shaped).

(ii) We then show (Section 3) that a large number of remnants have features in common with G296·5+10·0 and G327·6+14·6. High-resolution maps are now available for 70 remnants. From a study of these maps we conclude that the majority of remnants are barrel-shaped.

In Section 4 we examine briefly some mechanisms which might cause a supernova outburst to produce the morphology observed.

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Fig. 1. Grey-scale representation of the 843 MHz emission from G296·5+10·0.

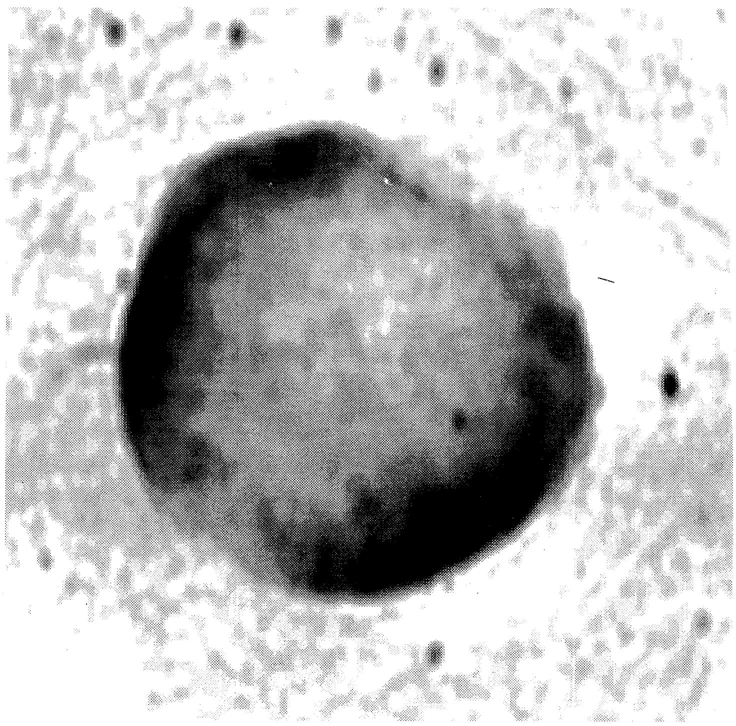

Fig. 2. Grey-scale representation of the 843 MHz emission from G327·6+14·6.

2. Two Unambiguous Examples: G296·5+10·0 and G327·6+14·6

G327·6+14·6, which is probably a young remnant, has been identified with the supernova outburst of 1006 AD. G296·5+10·0 is most probably an old remnant: Clark and Caswell (1976) estimated its age as >80 000 yr on the basis of its surface brightness at 408 MHz.

New high-resolution maps of these remnants are shown in Figs 1 and 2. The observations were made at a frequency of 843 MHz with the Molonglo Observatory Synthesis Telescope (MOST) (Mills 1981). Both images share a number of features:

(i) There is an axis of symmetry.

(ii) This axis is also an axis of brightness minimum—there is little (or no) emission from the regions where the axis intersects the remnant periphery.

(iii) There is no symmetry about an axis perpendicular to the axis defined above in (i).

These features cannot be reconciled with a spherical distribution of emission, but they do find a natural explanation in terms of a cylindrical distribution.

We suggest that these two objects are expanding in a uniform medium, with the result that their evolution has not degraded their inherent cylindrical symmetry. It is difficult to devise an evolution which would transform a spherical distribution to the form seen here.

A sphere from which the polar caps have been removed is the model adopted in the next section in order to predict the distribution of morphologies in a large sample of remnants. Using as a basis our examination of G296·5+10·0 and G327·6+14·6, we derive a ratio (wall thickness/radius) of 10% and a polar cap which subtends an angle of 90°.

Table 1. Observed and predicted distribution of SNR structures

Structure	Number observed	Number predicted
Ring-shaped	4	7
Two-arc: definite	21	
possible	23	49
Unclassifiable (transition cases?)	22	14

3. What Fraction of the Remnant Population is Barrel-shaped?

High-resolution maps are now available for 70 shell-type remnants. In few of these is the distribution of emission as simple and as symmetrical as in G296·5+10·0 and G327·6+14·6. However, many do share the morphological traits which mark them as barrels (albeit somewhat distorted): they have an axis of low emission and approximate symmetry. Barrels with their axis normal to the line of sight have a two-arc appearance; those with their axis pointing towards the observer will be ring-shaped. The distribution of the 70 remnants in the three categories 'two-arc', 'ring-shaped', and 'unclassifiable' is given in Table 1, where we also present the theoretical distribution based on the simple geometry defined in Section 2. There is reasonable agreement between the observed and predicted distributions, suggesting that the barrel-shape phenomenon can account for the morphology of the majority of the remnants.

4. Why are the Remnants Barrel-shaped?

(a) Remnants have Evolved from Spherical to Barrel-shaped

A remnant would evolve away from a spherical shape if its evolution took place in a medium with density gradients. However, numerical experiments (Tenorio-Tagle *et al.* 1985) do not suggest that this evolution will produce an abrupt decline in brightness, such as that seen in the southern section of G296·5+10·0. A uniform magnetic field could influence the evolution, since the expansion velocities are different in the directions parallel and perpendicular to the field. But the substantial disparity in energy densities in the remnant shell and the medium means that a departure from spherical symmetry can only be expected in the old remnants, and not in, for example, G327·6+14·6.

(b) Remnants are Inherently Barrel-shaped

The suggestion here is that the supernova outburst is itself barrel-shaped, and this morphology is preserved during the remnant's expansion. We note that Bodenheimer and Woosley (1983) have shown that in some categories of supernovae the outburst is

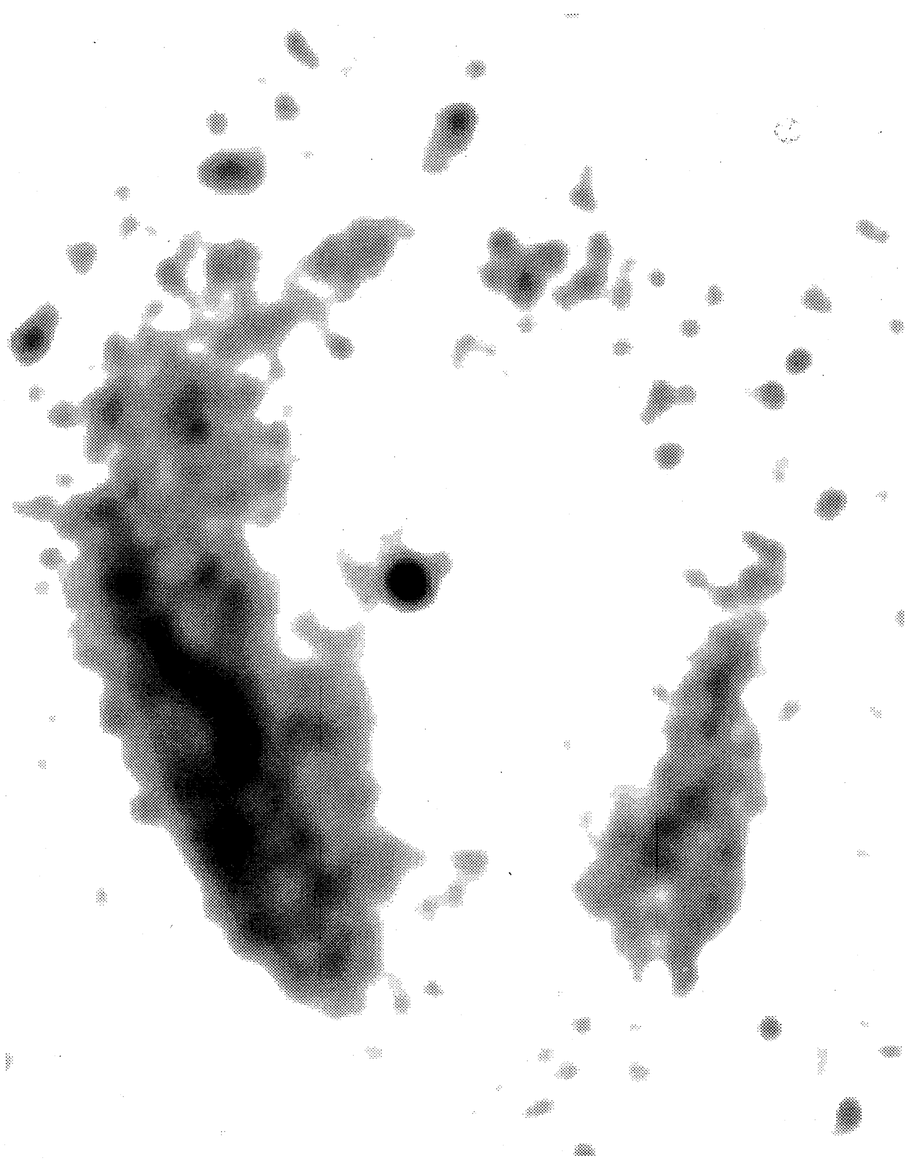

Fig. 3. Grey-scale representation of the X-ray emission from G296·5+10·0 (see Helfand and Becker 1984).

toroidal. Furthermore, Yungelson and Masevich (1983) have shown that some classes of low-mass binaries will evolve to a point where a toroidal supernova outburst is likely.

A variant of this picture would have a spherical blast wave interacting with a toroidal shell of pre-supernova material. Manchester (1986) has advanced this model in connection with his observation that many remnants have bi-annular markings superimposed on the overall barrel morphology. Future observations are needed to show whether toroidal outflows can occur in pre-supernova stars. We also need to determine how long a pre-supernova distribution of material can impose its signature on the subsequent evolution of the radio emission.

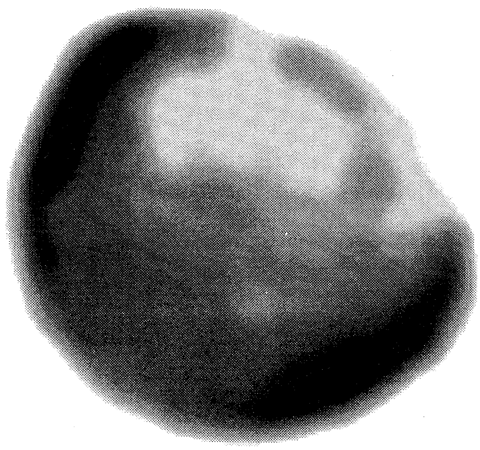

Fig. 4. Grey-scale representation of the X-ray emission from G327·6+14·6 (see Pye *et al.* 1981).

(c) Could it be an Illusion? Anisotropic Emission Perhaps?

This could result from a well-ordered magnetic field distribution, directed towards the observer in the regions of low brightness. The polarisation results would argue against this hypothesis: in G327·6+14·6 the magnetic field is azimuthal, as required; in G296·5+10·0 the field is generally radial, a contradiction (Milne 1987, present issue p. 771).

A further drawback is the fact that the X-ray morphology is very similar to the radio. In Figs 3 and 4 we show the X-ray images of G296·5+10·0 (Helfand and Becker 1984) and G327·6+14·6 (Pye *et al.* 1981). The correspondence between the radio and X-ray images is high. It is hard to devise a mechanism which will produce anisotropic radiation, at both X-ray and radio frequencies, in both young and old remnants.

5. Conclusions

Detailed examination of high resolution images of radio supernova remnants reveals a morphology which in many cases has a natural explanation in terms of a barrel-shaped distribution of emission. We suggest that the supernova outburst itself is essentially barrel-shaped, and that the subsequent evolution of the remnant maintains this morphology, subject to some deformations imposed by inhomogeneities of the interstellar medium.

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