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Supernova Remnants with Jets*

M. J. Kesteven, J. L. Caswell, R. S. Roger,[A] *D. K. Milne, R. F. Haynes and K. J. Wellington*

Division of Radiophysics, CSIRO,
P.O. Box 76, Epping, N.S.W. 2121, Australia.
[A] Permanent address: Dominion Radio Astrophysical Observatory,
Herzberg Institute of Astrophysics, P.O. Box 248,
Penticton, BC V2A 6K3, Canada.

Abstract

Two examples are given of probable radio jet/supernova remnant associations: G332·4+0·1 and G315·8−0·0. In both cases the jet length is larger than the radius of the remnant's shell, and the jet diameter is barely resolved and substantially less than the observed shell thickness. The jet luminosity is 5–10% that of the shell. The G332·4+0·1 jet terminates in an extended plume whose luminosity is about 50% that of the shell.

1. Introduction

Recent high-resolution high-sensitivity studies of southern supernova remnants (SNRs) have revealed two cases of a radio jet/SNR association. Features described as jets have been reported in association with a number of SNRs—the Crab Nebula, for example. However, the jets reported here appear to belong to a new class. These new observations are of particular interest on several counts: the dimensions and energetics of the jets are substantially larger than any known galactic source jet; and the jets may represent a new facet of the supernova phenomenon.

2. Observations

The radio images were obtained with the Molonglo Observatory Synthesis Telescope (Mills 1981) at the observing frequency of 843 MHz. A 12 hour synthesis observation yields a beam of 44″ (in R.A.) × 44″ cosec(Dec.) (in declination), and a sensitivity of about 1 mJy per beam area.

(a) G332·4+0·1 (Kes 32)

This source is a well-established SNR; it has a spectral index of −0·5, and polarisation has been detected (Roger *et al.* 1985). Fig. 1 shows the contour map of the object; the results are summarised in Table 1.

The distance to the SNR is poorly defined, but probably lies in the region 3 to 7 kpc (see Roger *et al.* 1985). In Table 2 (listing derived parameters) a value of 5 kpc was used.

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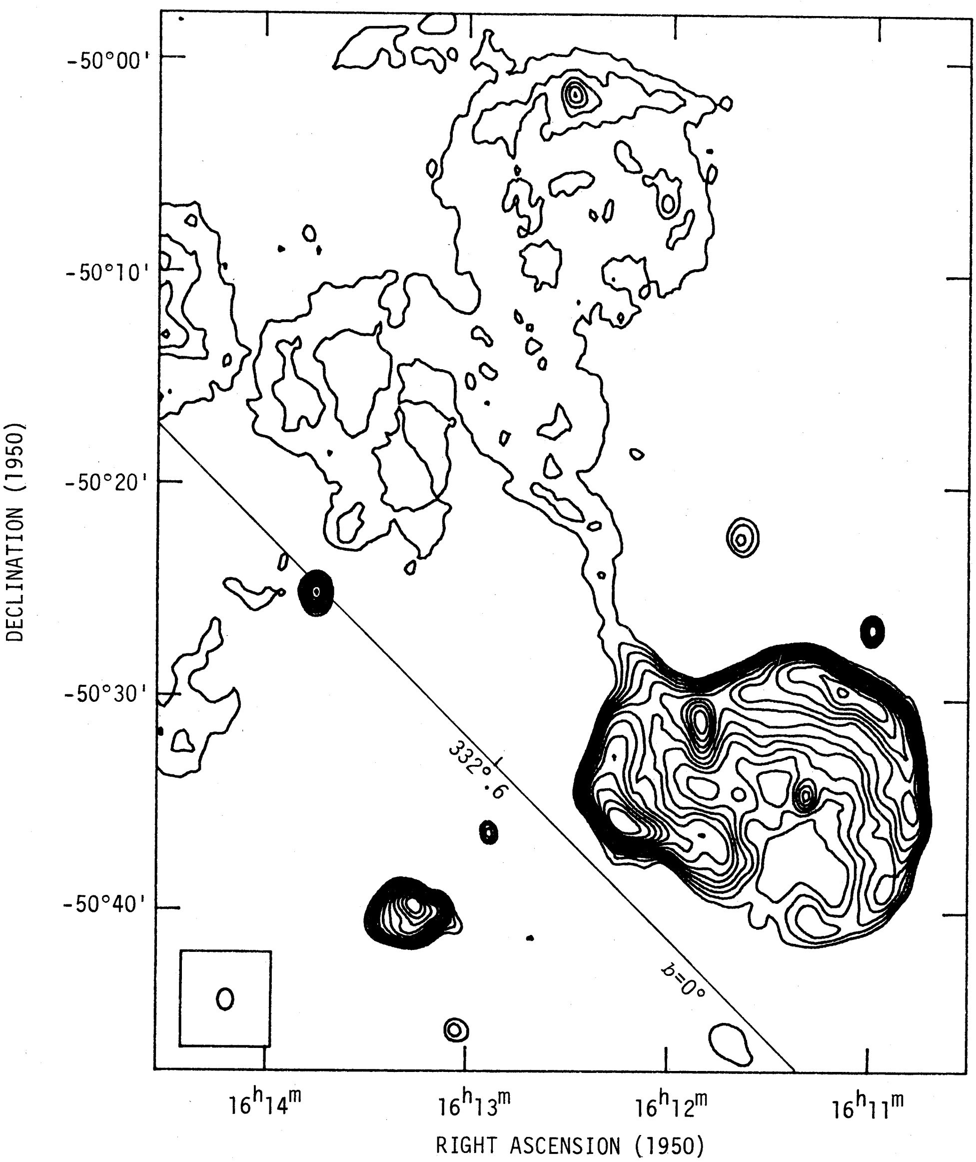

Fig. 1. Contour map of G332·4+0·1. The contour levels are 38, 51, 65, 81, 100, 120, 150, 190, 230, 280, 340, 410 and 500 mJy per beam area. The synthesised beam is shown in the lower left corner.

(b) G315·8−0·0

The contour map of this source is shown in Fig. 2. The source is not well characterised because it is very weak; however, it probably is an SNR. It is not detected at 5 GHz at the level of 0·13 Jy per beam [unpublished original data from the Haynes *et al.* (1978) 5 GHz galactic plane survey] and, given the errors, this would suggest a spectral index steeper than −1, consistent with an SNR hypothesis.

No attempt has yet been made to measure the distance to the source. The formulae by Caswell and Lerche (1979) suggest a distance of ~20 kpc; but since the warp of

Table 1. Observed properties of the two SNRs and Jets

Property	G332·4+0·1	G315·8−0·0
Shell diameter	14′ arc	13′ arc
flux (843 MHz)	31 Jy	1·5 Jy
Jet length	9′ arc	8′ arc
diameter	1′ arc	1′ arc
flux	1 Jy	0·1 Jy
Plume flux	19 Jy	?(not detected)

Table 2. Derived properties for the SNRs and Jets

Property	G332·4+0·1	G315·8−0·0
Adopted distance	5 kpc	15 kpc
Shell size	20 pc	60 pc
843 MHz luminosity	8×10^{16} W Hz^{-1}	2×10^{16} W Hz^{-1}
Jet length (collimated section)	13 pc	35 pc
843 MHz luminosity	3×10^{15} W Hz^{-1}	2×10^{16} W Hz^{-1}

the galaxy in this direction would place the source somewhat above the mid-line of the galactic disk, this estimate could well be too large; we adopt 15 kpc.

3. Discussion

(a) Is the Jet–SNR Association Real?

There are three points that can be offered to support the case, though none is very strong. In effect we attack the alternative hypothesis (that we have a chance coincidence of an SNR and a 'field jet'):

(i) We have not seen jets in isolation in any of ~40 galactic fields examined.

(ii) We know of at least two such 'coincidences'.

(iii) They 'look right'. This latter propositon is hardly objective, but it is worth noting that in each case the jet is convincingly attached to the SNR; the jet is at its brightest in the vicinity of the contact point, and is directed radially outwards from the shell.

(b) Jet Properties

In what follows we assume that the jets are indeed associated with the SNR. This assumption alleviates the problem of the distance uncertainty; we can use the SNR shell as a unit of measurement, both for size and luminosity. But implicit in this assumption is a second problem; at what point in a supernova's evolution can a jet occur? What is the mechanism?

The parameters of interest are the ratio of shell radius to (collimated) jet length (of order 1 : 1), and the ratio of shell flux to jet flux (about 20 : 1). The plume of G332·4+0·1 has a lateral spread on either side of the jet axis of about one shell diameter and a total luminosity about 50% of the shell luminosity.

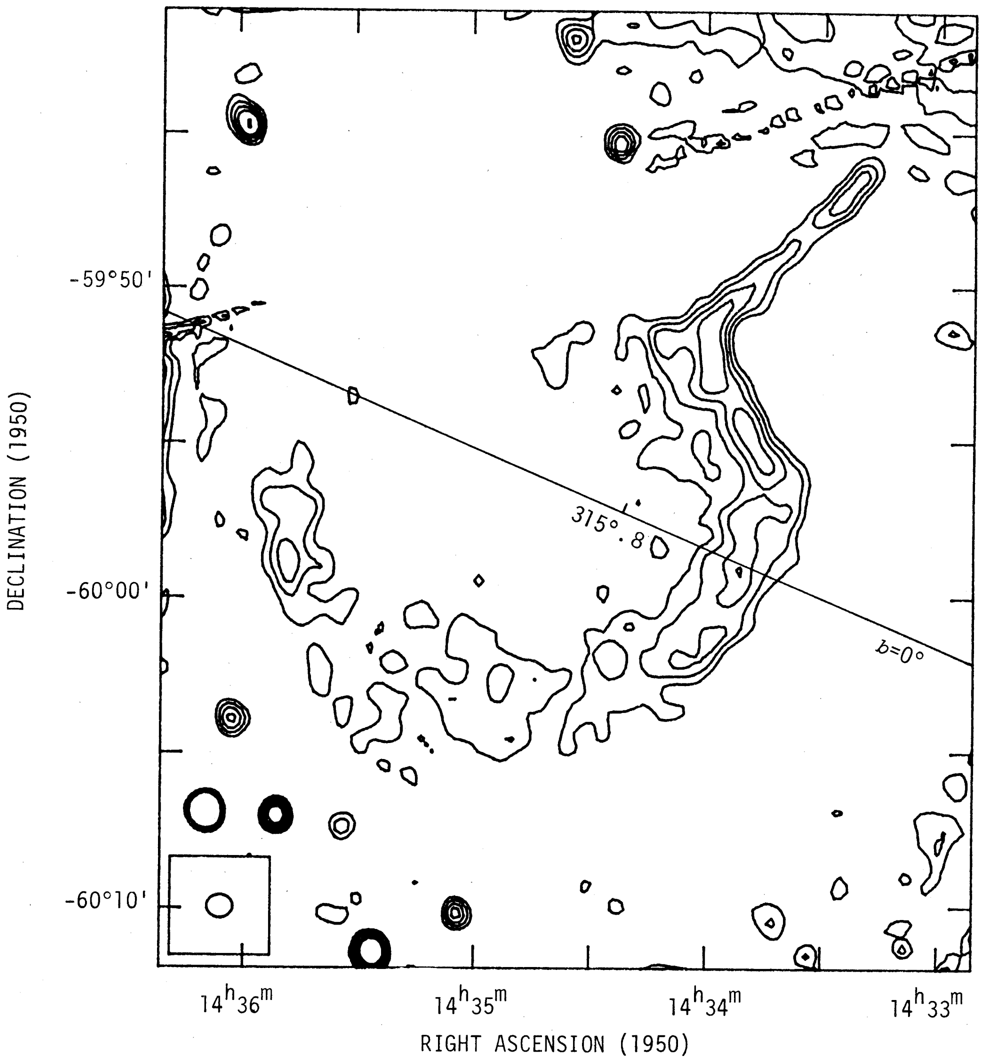

Fig. 2. Contour map of G315·8−0·0. The contour levels are at 2·5, 5, 7·5, 10, 15 and 20 mJy per beam area. The synthesised beam is shown in the lower left corner. The regular 'caterpillar' tracks running obliquely to the north of the remnant are the result of a system 'glitch'.

The degree of collimation is high, with an upper limit to the opening angle of <10°.

The two jets are somewhat different in appearance: G315·8−0·0 is well collimated over its entire length, with no evidence of a plume, or lateral spreading, while the G332·4+0·1 jet has a number of 'wiggles'. These appear to be excursions around a single axis, rather than the result of a random walk.

If we believe that the jet only became active at the time of the supernova, we then have the following properties to explain:

(i) The jet velocity has to be comparable with the initial shell velocity, or around 10000 km s^{-1}.

(ii) The jet has to be fed for a substantial period of the remnant's life, or for 5000 yr or so.

(iii) The extent of the lateral spreading of the G332·4+0·1 plume is comparable with the size of the shell; this suggests that the spreading occurs at a fairly high velocity of around 3000 $\mathrm{km\,s^{-1}}$. An alternative hypothesis is that the jet phenomenon precedes the outburst. On this view the jet is now simply being overtaken by the expanding shell. One could then also argue that the difference between G332·4+0·1 and G315·8−0·0 is the time interval which elapsed between the onset of the jet and the outburst—relatively short in the case of G315·8−0·0 (several times the present age of the remnant) and long in the case of G332·4+0·1 (100000 years perhaps). A difficulty with this hypothesis is that it requires the jet to remain visible for several thousand years after being switched off.

(c) How Common are These Events?

The answer is probably not very. High-resolution maps are available for about 100 SNRs. Of these, only G348·7+0·1 has a projection beyond the shell that remotely resembles the jets discussed here; even in this case, it may well not be a jet of the same kind, since it lacks the small ratio of jet diameter to length, and a more natural explanation may be local disruption to the expanding shell.

The Crab Nebula has a limb-brightened optical feature projecting about 1 pc beyond the northern edge of the remnant (van den Bergh 1970); a very weak radio counterpart has also been detected (Velusamy 1984). This jet does not seem to fall into the same category as the jets discussed in this paper, as judged by the ratio of jet to shell size and radio brightness. A similar situation holds with most of the previously reported galactic jets—Sco X-1, Cyg X-3 and CH-Cyg (Perley 1985; Hjellming and Johnston 1985). The present activity in SS 433 also occurs on a very small size scale; but, as there is evidence that the large-scale structure of the parent remnant (W 50) is affected (Margon 1984), it is possible that the two jets presented here are of the same class as SS 433.

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