CTB80: A SNR WITH A NEUTRON-STAR DRIVEN COMPONENT

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Abstract: Pulsar-like emission has been detected from the flat-spectrum component of the galactic radio source CTB80. The consequences for the source are discussed.

Introduction: Although it is widely accepted that neutron stars have their origin in supernovae, there are relatively few pulsars associated with supernova remnants. The best established cases are the Crab Nebula and Vela remnants, each of which has a central pulsar with a fairly high spin-down rate, consistent with the view that the neutron star still supplies substantial energy to the remnant (e.g. Manchester and Taylor, 1977). Searches for pulsar emission from other remnants have, however, failed to turn up additional candidates (Seiradakis and Graham, 1980; Manchester et al., 1983; Mohanty, 1983).

The hot surface of a neutron star can also be detected at X-ray wavelengths, and this strategy has turned up several candidates. Unresolved X-ray emission has been observed in the supernova remnants 3C58 (Becker et al., 1982), CTB80 (Wang and Seward, 1984) and RCW103 (Tuohy et al., 1983). All of these sources are weak, however, so it is impossible to say for certain whether their emission is pulsed (as in the case of PSR 0531+21, the Crab Nebular pulsar) or steady (as would be expected from a hot neutron star surface). In this paper I discuss the detection of an unresolved source in the unusual remnant CTB80 which has the characteristics of a radio pulsar. Clues to its interaction with the surroundings are found in morphological features, and they are discussed with reference to similar objects.

Observational results: CTB80 is an extended galactic radio source of unusual morphology (e.g., Angerhofer et al., 1981). Near its geometrical center, at the western edge of a bright radio plateau, lies a dominant flat spectrum component extended on scales of 0.5-1 arcmin (Strom et al., 1984), upon which my discussion will focus. The emission from this feature is unquestionably nonthermal (polarization was mapped in both of the papers just cited), but its spectrum is unusually flat: the flux density is virtually constant throughout the radio spectrum.

Maps made of this component at 2, 6 and 20 cm with the VLA show an almost unchanging structure, so the 20 cm brightness distribution can be taken as representative (Figure 1). The data were obtained in the A-configuration and have been CLEANed and restored with a 1.1 arcsec beam. The only significant difference between Figure 1 and the 2 and 6 cm maps is the presence of a point source near the southwestern apex of the triangularly-shaped plateau (arrow). Its nondetection at 6 cm

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dynamic pressure with the internal pressure of the hot spot. (In this and other calculations I will follow Blair et al., 1984, in assuming a distance to CTB80 of 2.5 kpc.)

If the neutron star is moving at a velocity v, its interaction with gas of density ρ produces a dynamic pressure ρv^2 which can be equated with p, the internal pressure of the hot spot. The usual energy equipartition assumption is made in estimating p for synchrotron emission, while ρ has been deduced from depolarization observed in adjacent regions. This gives $v \gtrsim 400$ km/s, a high value but by no means an unusual one for pulsars (Lyne et al., 1982). The neutron star would then be moving toward the hot spot (in the direction indicated by the arrow in Figure 1), and I will assume its velocity to be 500 km/s.

The fact that the hot spot has the same, flat, spectrum as the rest of the component suggests that it may represent a major center of particle acceleration. Its proximity to the neutron star is crucial in this respect, and I wish to point out its similarity to features in the Crab Nebula, in particular Wisp 1. The wisps near PSR 0531+21 have been studied by Scargle (1969) who suggests that they are compressional enhancements in the relativistic plasma. He has interpreted the activity and oscillatory motion of Wisp 1 in terms of a piston, feeding energy to the rest of the remnant. I suggest that Wisp 1 and the hot spot in CTB80 are regions of major particle acceleration, through which much of the energy released by each neutron star passes.

The physical properties of both the CTB80 hot spot and Wisp 1 are rather similar: size, 0.01-0.05 pc; minimum energy density, $0.5\text{-}1 \times 10^{-9}$ erg/cm^3; magnetic field directed along the feature's major axis; and elongated shape. But the most striking similarity is that in both cases the neutron star is moving toward the wisp-like feature. In CTB80 this is based on indirect arguments, but in the case of PSR 0531+21, the proper motion has actually been determined and found to correspond to a speed of 123 km/s (Wyckoff and Murray, 1977). In both objects the wisp/hot spot is elongated perpendicular to the line joining it with the neutron star: it has the morphology of a bow shock being pushed ahead of a fast moving object.

By analogy with the situation in the Crab Nebula, the energy which passes through the hot spot region to be deposited in the flat spectrum component must have originated in the rapidly rotating neutron star. Most of the energy radiated from the entire component appears as X-rays, with a luminosity of 4×10^{33} erg/s (Wang and Seward, 1984). Another estimate of the minimum rate at which energy is supplied to the component can be made from the parameters of the radio hot spot. It has a thickness of 0.01 pc or less so, for a speed of 500 km/s, it must be completely renewed in no more than 20 yr. This time scale combined with the minimum total energy (2×10^{42} erg) implies a rate of 3×10^{33} erg/s. Since much of the energy must pass through the hot spot without being radiated away, and some of it must produce expansion of the component, these values are lower limits.

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establishes a fairly steep spectrum ($\alpha \lesssim -2$), and it is found to be polarized at about the 30% level.

These facts - an unresolved, strongly polarized steep spectrum source immersed in a flat spectrum nonthermal radio component which appears to be part of a supernova remnant - are the signature usually associated with a pulsar: radio emission from a neutron star. This view is strengthened by the likelihood that the source also emits X-rays; the radio and X-ray point source positions agree within the errors (Becker et al., 1982). The existing radio data cannot be used to search for pulsed emission. The fact that no pulsar has been found at the source's position in existing surveys is, however, not inconsistent with what is known about its flux density and spectrum. I will now consider the consequences of this discovery, assuming that the object is indeed a neutron star associated with CTB80.

Discussion: One of the most striking aspects of the neutron star is its location: not centered on the bright plateau, but located near the southwestern rim, just behind the brightest peak on the ridge. It has been argued in the past (Strom et al., 1984) that there is evidence for a general westward motion in this component of CTB80, and the eccentric location of the neutron star would seem to underline this. Its proximity to the hotspot suggests a causal relationship, such as an interface between its atmosphere and the ambient medium. Following this line of thought, we can estimate the speed of the neutron star by equating the

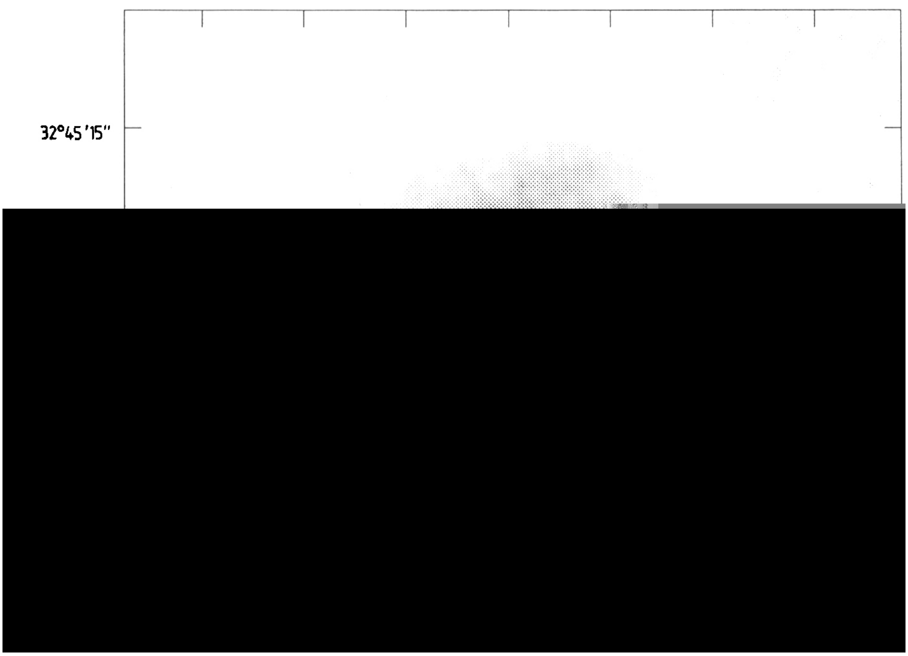

Fig. 1. 20 cm map of flat spectrum component, with point source (arrow) (copyright University of Chicago Press)

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We can now use these estimates in the usual way (e.g., Goldreich and Julian, 1969) to say something about the CTB80 neutron star. If its properties (mass, magnetic field strength, braking index) were precisely the same as those construed for PSR 0531+21, then the pulsar in CTB80 would be expected to have a period of 0.38 s, given the Crab Nebula's 5000 times greater luminosity and the 33 ms period of its pulsar. However, lower values for the magnetic field strength and perhaps mass of the CTB80 neutron star would shorten the period, possibly to under 0.1 s.

Conclusions: It is virtually certain that the flat spectrum component of CTB80 is driven by a neutron star which produces X-ray and radio emission. A search for pulsations is clearly desirable to tie down its period (which may be about 0.1 s) and determine the spin-down rate. The velocity I have estimated is sufficiently large that proper motion may be detectable in a few years.

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