RADIO EMISSION FROM THE REMNANTS OF THE SUPERNOVAE OF 1572 AND 1604

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In recent years, bright radio sources have been found lying close to the positions of the three galactic supernovae recorded in 1054, 1572 and 1604. The position and extent of the radio emission from the Crab nebula, the remnant of the 1054 supernova, is now well known (Mills,[1] Shakeshaft *et al*,[2] Costain *et al*[3]). Information concerning the other two sources is much less complete and very little information has been provided by optical observations.

Measurements have recently been made with the Cambridge radio telescope, working at a wavelength of 1·9 m, to obtain more accurate positions of these sources and to determine their angular size. The methods of observation used were the same as those employed in the earlier survey at a wavelength of 3·7 m (Ryle and Hewish[4]). At the new wavelength of 1·9 m the individual elements of the interferometer have beam-widths between half power points of 1·2° in right ascension and 7° in declination. The separation of the four elements is 307 λ in an east-west direction and 28 λ in a north-south direction. The increased resolving power of the system compared with its performance at 3·7 m made it possible to determine the positions of the sources more accurately and to measure the size of sources as small as 1′ of arc in diameter.

Tycho Brahé's nova.

In Table I the present measurements of the position of the source corresponding to Tycho Brahé's supernova of 1572 are given together with the original measurements of Hanbury Brown and Hazard,[5] the position determined during the Cambridge survey[2] of sources at 3·7 m, and the optical position of the supernova quoted by Baade[6] in coordinates of 1950·0. Fig. 1 shows a map of these various determinations.

TABLE I

	λ	α (1950·0)	δ (1950·0)
Hanbury Brown and Hazard[5]	1·9m	$00^h\ 21^m\ 49^s \pm 120^s$	$+64°\ 15' \pm 35'$
Shakeshaft *et al.*[2]	3·7m	$00^h\ 22^m\ 46^s \pm 5^s$	$+63°\ 57' \pm 5'$
Present observations	1·9m	$00^h\ 22^m\ 38{\cdot}3^s \pm 2^s$	$+63°\ 53' \pm 3'$
Supernova position Baade[6]		$00^h\ 22^m\ 00{\cdot}2^s \pm 3^s$	$+63°\ 52'\ 12'' \pm 23''$

Although the determinations of the declination of the radio source and the supernova agree within the limits of error, the right ascension of the radio source is some 35–40^s following the most probable position of the supernova. In the earlier radio observations it was suggested that the proximity of the very intense source in Cassiopeia might have affected the measured right ascension, but in the present observations such effects are quite negligible. The close agreement of the position derived from these observations and that obtained at 3·7 m confirms that the radio source does not coincide with the position of the supernova.

Measurements of the source at a wavelength of 1·9 m show that the visibility of the fringes, γ, using an aerial spacing of 307 λ on an east-west line, is 0·46 ± 0·03, corresponding to a diameter of 5·4′ of arc between half intensity points for a source having a Gaussian distribution of brightness over it. The outer parts of a source of this size would contain the

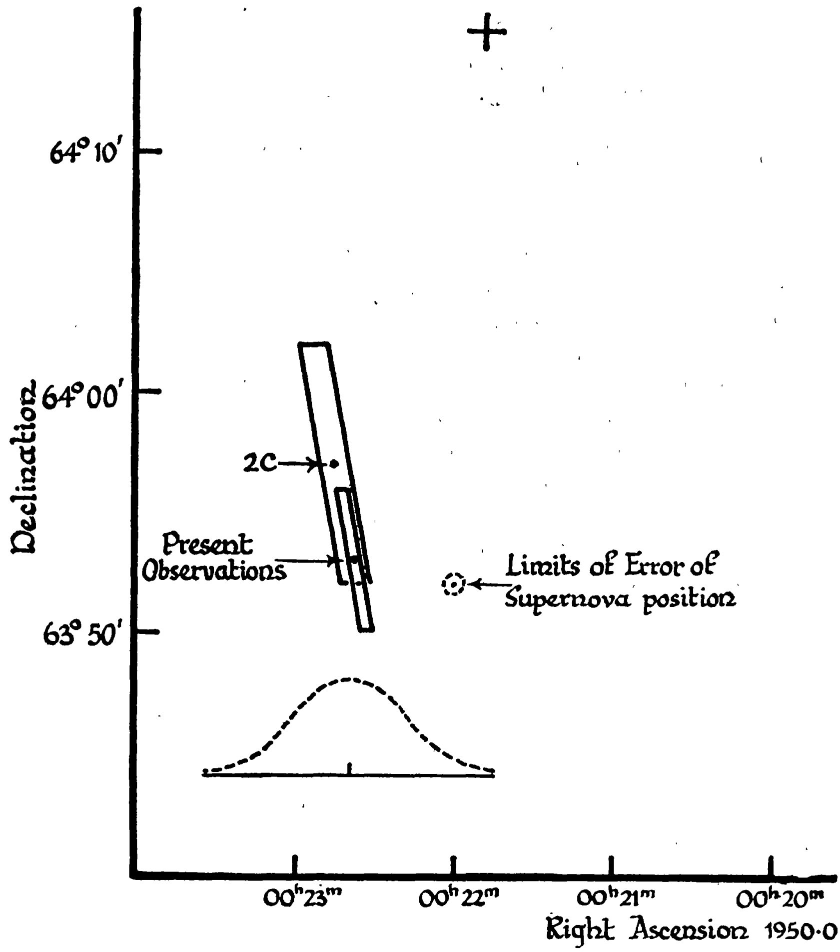

FIG. 1. Observations of Tycho Brahé's supernova. The dashed Gaussian curve indicates the size of the radio source. 2C is the position in the second Cambridge catalogue (reference 2). The cross indicates the position obtained by Hanbury Brown and Hazard; this has a probable error of 2^m in R.A. and 35′ in Declination.

position of the supernova. Thus, although there is a significant difference between the positions of the radio source and the supernova, it is likely that the radio emission is associated with the supernova remnant. On a recent plate taken with the 200-inch telescope at Mt. Palomar, a faint gaseous filament has been found lying close to the radio position and moving away from Tycho Brahé's position (private communication from Dr. Minkowski).

Kepler's nova.

The available observations of the radio source close to the position of Kepler's supernova of 1604 are given in Table II together with the optical position of the supernova and of the nebulous remnant found by Baade.[7]

Since the elevation of the source at Cambridge is only 16° at transit, the limits of error in the declination of the radio source are considerably

TABLE II

	λ	α 1950·0	δ
Shakeshaft *et al.*[2]	3·7m	$17^h\ 27^m\ 58^s \pm 15^s$	$-21^\circ\ 22' \pm 15'$
Mills *et al.*[8]	3·5m	$17^h\ 27^m\ 42^s \pm 6^s$	$-21^\circ\ 30' \pm 3'$
Present observations	1·9m	$17^h\ 27^m\ 47^s \pm 5^s$	$-21^\circ\ 16' \pm 10'$
Supernova		$17^h\ 27^m\ 38{\cdot}9^s \pm 4^s$	$-21^\circ\ 26'29'' \pm 1'$
Nebulous remnant Baade[7]		$17^h\ 27^m\ 36{\cdot}8^s$	$-21^\circ\ 26'28''$

greater than for Tycho Brahé's supernova. Because the axis of the interferometer is not exactly east-west, an error in declination gives an error in right ascension as shown in the map of Fig. 2. If the declination of the radio source is taken to be the same as that for the optical object, the agreement between the right ascensions obtained in all the radio observations and that of the optical remnant is very good.

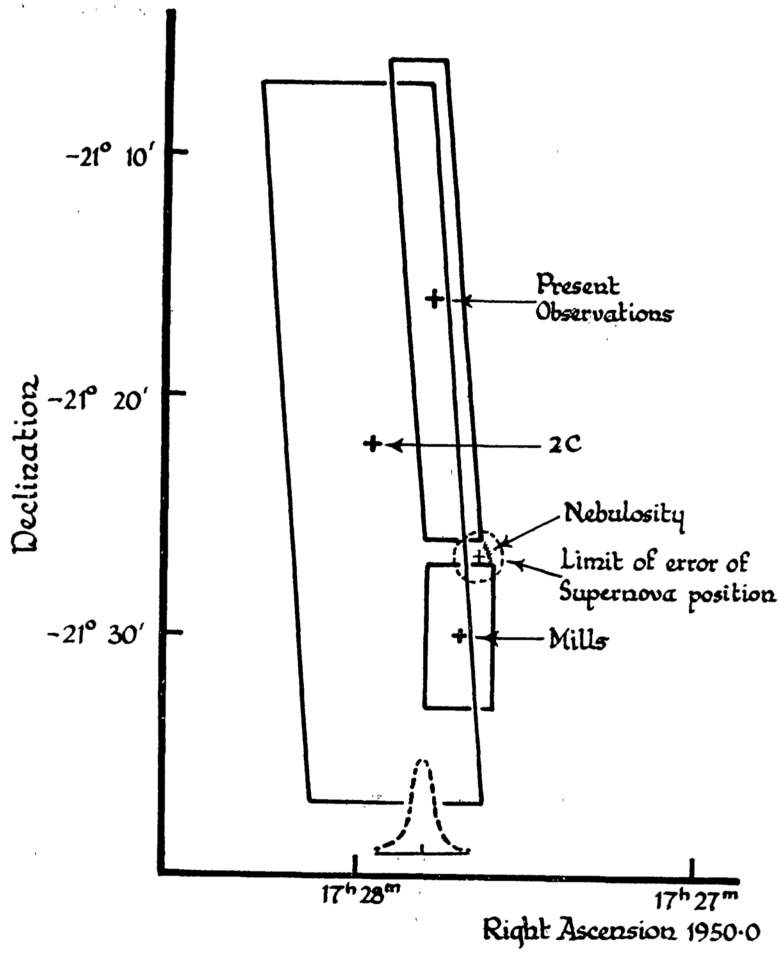

FIG. 2. Observations of Kepler's supernova. The dashed Gaussian curve indicates the upper limit to the size of the radio source. 2C is the position in the second Cambridge catalogue (reference 2).

Measurements made to determine the angular diameter of the source showed that, at 1·9 m, the visibility of the fringes, γ, at an aerial spacing of 307 λ in an east-west direction was $> 0{\cdot}95$, corresponding to a diameter to half intensity points of $< 1'$ of arc for a Gaussian source. A tracing of a record obtained with this source is shown in Fig. 3. The small angular

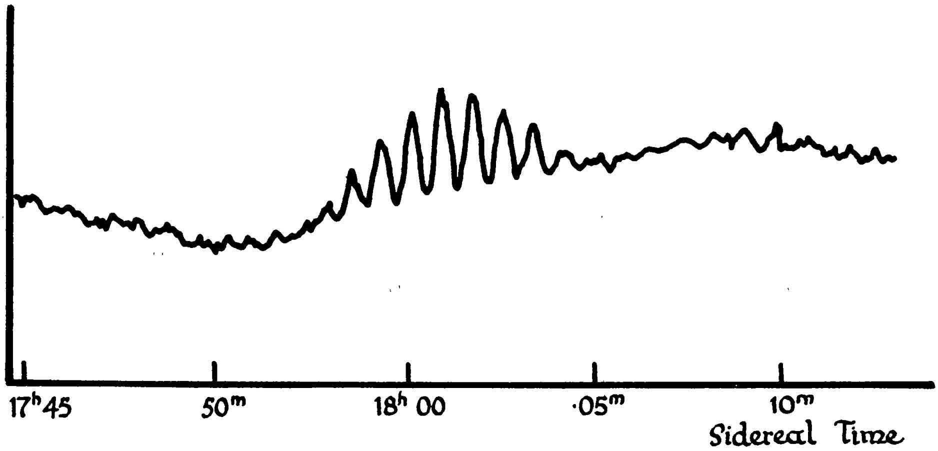

FIG. 3. Record showing the transit of Kepler's supernova, from which the angular diameter of the source is deduced.

diameter derived from these measurements is not compatible with the deductions of Rishbeth and Little;[9] these authors concluded that the source was partially occulted by the Moon and that its angular diameter was 10′ of arc.

The identification of these two radio sources with the remnants of the supernovae of 1572 and 1604 now seems fairly certain and it is of some interest to compare their radio emission with that of the Crab nebula.

The flux densities of the two sources were measured during the current series of experiments at a wavelength of 1·9 m and are given in Table III together with the flux density of the Crab nebula derived from the spectrum given by Adgie and Smith.[10] From the angular diameters of the sources, the apparent brightness temperatures at 1·9 m of the three sources have been calculated. The diameter of the Crab nebula at 1·9 m is taken to be the same as that derived from the lunar occultation of the source at 3·7 m (Costain *et al.*)[3]

TABLE III

Source	*Flux density* $wm^{-2}(c/s)^{-1}$	*Diameter*	*Apparent brightness temperature*
Crab nebula	$1660 \cdot 10^{-26}$	2′·7	$3{\cdot}4 \times 10^6$ °K
Kepler's nova	$50 \cdot 10^{-26}$	$< 1'$	$> 7{\cdot}5 \times 10^5$ °K
Tycho's nova	$100 \cdot 10^{-26}$	5·4′	$5{\cdot}1 \times 10^4$ °K

It is clear from the observations of the latter two sources that the surface brightness of supernovae remnants of the same age may differ very widely. It is not yet possible to calculate the relative volume emissivities for the two sources since there is little optical evidence available on their distances. It may, however, soon be possible to determine them from measurements of the interstellar 21 cm absorption and hence to make a comparison of the expansion velocities and volume emissivities of these two remnants with those of the Crab nebula.

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