RADIO EMISSION FROM NOVAE AND SUPERNOVAE

By B. Y. MILLS,* A. G. LITTLE,* and K. V. SHERIDAN*

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Summary

Attempts have been made to observe the radio emission at 3·5 m from two supernovae and ten novae. Kepler's star was the only reasonably certain identification. A comparison with radio observations of other supernova remnants suggests a constant ratio between the present radio emission and the maximum emission of light. It is concluded that for common novae, which are not detectable as radio sources, this ratio must be smaller than for supernovae. The galactic radio emission near the plane of the Milky Way could be largely the integrated emission of supernova remnants but common novae could not contribute appreciably.

I. INTRODUCTION

In the course of the initial tests on the large 3·5 m radio telescope now in operation near Sydney, attempts were made to observe a considerable number of known celestial objects. Of these observations some, which have already been described (Mills 1955), led to general conclusions regarding the distribution of the galactic radio emission. Two components were identified, one having a discoidal distribution strongly concentrated towards the galactic plane and the other being nearly spherical and forming a " corona " surrounding the Galaxy. A series of observations were made in an attempt to elucidate the nature of the discoidal distribution by means of a direct study of two classes of object which there is reason to suppose might be associated with the radio emission, that is, novae, including supernovae, and emission nebulae. It is found however, that the data are not yet sufficient for a definite answer to this question, which will require a detailed study of the distribution of radio emission over large areas near the galactic plane preferably at more than one frequency. The results of a current survey of the southern sky should provide much of the necessary data ; meanwhile the present observations, which are described in this and a companion paper (Mills, Little, and Sheridan 1956), lead to some conclusions of interest.

It is well known that the intense radio source 05N2A may be identified with the Crab Nebula, which is the visible remnant of the supernova of 1054 A.D. This identification was first suggested by Bolton, Stanley, and Slee (1949) and has now been well established as the result of several independent investigations. A radio source has also been found close to the position of another well-known nova, that of Tycho Brahe (Hanbury Brown and Hazard 1952). Although no visible remnants of this nova have yet been discovered and, accordingly, a

* Division of Radiophysics, C.S.I.R.O., University Grounds, Sydney.

positive identification cannot be made, the positions are in agreement and, moreover, there is good reason for believing that this also was a supernova (Baade 1938). In addition, at the position of some other sources, notably 23N5A and 06N2A, nebulosities exist which could well be the remnants of supernovae.* More recently, also, a radio source of large angular size concentric with the Loop Nebula in Cygnus was detected by Walsh and Hanbury Brown (1955); it has been suggested by Oort (1946) that this nebula is a supernova remnant.

These results suggest very strongly that supernova outbursts lead to prolonged and intense radio emission from the gaseous remnants. It has even been suggested by Hanbury Brown (1954) and Shklovskii (1954) that all the non-thermal class I radio sources are supernova remnants. Shklovskii has attempted to identify the stronger sources with various ancient novae which he regards as supernovae, while Hanbury Brown has shown that, by making plausible estimates of the frequency of occurrence of supernovae in the Galaxy and the duration of their radio emission, it may be possible to account for the observed metre-wavelength radio emission near the galactic plane by their integrated emission. An extension of these ideas to ordinary novae is suggested by the identification of Nova Aquila 1918 with a strong radio source by Bolton, Stanley, and Slee (1954) but, as we shall see later, this identification is incorrect.

II. Observations

As a result of these considerations a number of special observations were made at the positions of bright novae and supernovae. In addition, records made for other purposes were searched for evidence of radio emission from fainter novae and from ancient novae of doubtful positional accuracy. The results are shown in Table 1, with the exception of those of the ancient novae which will be discussed later; data derived from published observations of northern novae are also included. The magnitude scale of Hanbury Brown and Hazard (1952) is used for specifying the radio measures, i.e. $m_{R(3\cdot5\mathrm{m})} = -53\cdot4 - 2\cdot5 \log_{10} S_{(3\cdot5\mathrm{m})}$. The optical magnitudes m have been taken from standard sources (e.g. Norton and Inglis 1943; Pawsey and Bracewell 1955); some are photographic and some visual magnitudes but the accuracy required does not warrant differentiating between them. No attempt is made to correct the radio magnitudes to a standard wavelength as the spectrum of these sources is not sufficiently well established. Accordingly the radio magnitude of Tycho Brahe's nova refers to the wavelength at which the measurement was made, that is, $1\cdot9$ m.

Since all the present observations have been made close to the galactic plane the sensitivity of the radio telescope is much less than before (Mills 1955) when the external galaxies under investigation were at relatively high galactic latitudes. The reduction in sensitivity is caused, firstly, by the higher brightness

* Originally it was thought that the nebulosity associated with 23N5A could not be a supernova remnant (Baade and Minkowski 1954), but as a result of further observations this possibility is now admitted by Minkowski (reported at the Jodrell Bank symposium on radio astronomy, 1955).

temperatures of the background radiation, which increase the "noise level" of the equipment and, secondly, because of the greater irregularities in the distribution and the higher source density, for which the angular resolution of the equipment is often inadequate.

The identification of Kepler's nova with a radio source may be considered as reasonably certain. Tracings of records obtained on three declinations straddling the nova are shown in Figure 1. The source position is $17^{\mathrm{h}}\,26^{\mathrm{m}}\cdot8$,

TABLE 1

NOVA OBSERVATIONS

Nova	Flux Density at 3·5 m (W m^{-2}(c/s)$^{-1}$ $\times10^{-26}$)	$m_{R(3\cdot5\mathrm{m})}$	m at Maximum	$m_{R(3\cdot5\mathrm{m})}-m$	Remarks
Southern Novae					
1604 Ophiuchi	38	7·5	−2	$9\frac{1}{2}$	Kepler's star, a supernova
1860 Scorpii ..	<10	> 9	7	>2	
1895 Carinae	<10	> 9	8	>1	
1895 Centauri	< 5	>10	7	>3	A supernova in NGC 5253
1898 Sagittarii	< 5	>10	4·7	>$5\frac{1}{2}$	
1899 Sagittarii	<10	> 9	8·5	>$\frac{1}{2}$	
1899 Aquilae ..	<10	> 9	7	>2	
1910 Sagittarii	<20	> 8·3	7·5	>$\frac{1}{2}$	
1917 Ophiuchi	<10	> 9	6·5	>$2\frac{1}{2}$	
1918 Aquilae ..	<10	> 9	−0·7	>$9\frac{1}{2}$	Wrongly identified as a strong radio source by Bolton, Stanley, and Slee (1954)
1925 Pictoris ..	< 5	> 9·7	1·1	>$8\frac{1}{2}$	
1942 Puppis ..	< 5	> 9·7	0·4	>$9\frac{1}{2}$	
Northern Novae					
1054 Tauri ..	1800	3·4	−6	$9\frac{1}{2}$	The Crab Nebula, a supernova
1572 Cassiopeiae	170*	6·0*	−4	10*	Tycho Brahe's star, a supernova

* Measured at a wavelength of 1·9 m.

$-21^\circ\,29'$ (1935) with a probable error of about $0^{\mathrm{m}}\cdot1$ in Right Ascension and $3'$ in declination; compared with the nova position of $17^{\mathrm{h}}\,26^{\mathrm{m}}\,44^{\mathrm{s}}\cdot9$, $-21^\circ\,25'\,55''$ (1935) and a position of $17^{\mathrm{h}}\,26^{\mathrm{m}}\,42^{\mathrm{s}}\cdot8$, $-21^\circ\,25'\,54''$ (1935) for a fragment of the gaseous remnant observed by Baade (1943). The identifications of three of the supernovae with radio sources are further supported by the remarkable agreement in the values of m_R-m, indicating an almost constant ratio between their present radio emission and their maximum light emission. This agreement is not as good as it appears, however, because of the probability that the optical obscuration is different in each case.

Most of the common novae were too faint for their radio emission to be detected if the same proportionality between radio and optical emission were preserved. However, the three brightest do give significant minimum values of $m_R - m$, and for these it may be concluded that the ratio of present radio emission to brightness at maximum does not exceed the corresponding ratio for supernovae. There is no detectable excess emission at the position of Nova Aquila 1918; the source which Bolton, Stanley, and Slee identified with the nova is probably an intense extended source about 1° away in a north-following direction.

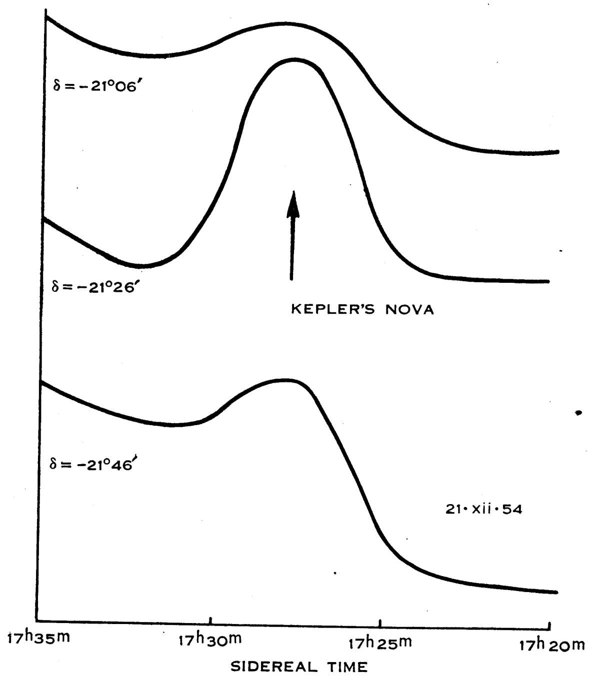

Fig. 1.—Tracings of three records at declinations near Kepler's nova.

Attempts made by Shklovskii (1954) to identify some strong radio sources with ancient novae are not convincing. Records taken in these regions with the present equipment generally reveal a number of sources within the uncertainty in position of the nova and there seems little justification for assuming that an identification can always be made with the strongest: progress must be dependent on the discovery of gaseous remnants at the position of the radio source. At least one of his suggested identifications is not supported by the accurate radio position now available, that is, the identification of the nova of 185 A.D. in Centaurus with the radio source 13S6A. Lundmark (1921) places the nova between α and β Centauri, whereas the position of the radio source is $13^h\,43^m{\cdot}0$, $-60°\,12'$ (1950) with probable errors of $0^m{\cdot}2$ in Right Ascension and $3'$ in declination: this is well outside Lundmark's limits.

III. Discussion

The most surprising result of these observations is the agreement between the values of m_R-m for Kepler's star and the two northern supernovae. Thus the subsequent radio emission of a type I supernova outburst, of which these are examples, appears to share in the uniformity of the optical spectrum and decay curve ; it would be very interesting to compare the spectra of the three radio sources. Shklovskii (1953) has suggested that the optical emission of the Crab Nebula has the same origin as the radio emission and that both are caused by the emission from relativistic electrons moving in a magnetic field ; this suggestion has now received substantial support from the measurement of strong linear polarization in the optical emission of the nebula (reported by Oort at the Jodrell Bank symposium on radio astronomy, 1955). It appears that the so-called " amorphous mass " of the nebula, which has a continuous spectrum, actually consists of a cloud of relativistic electrons. Despite the similar radio emission of the other supernova remnants, there is no corresponding similarity in their optical emission. Neither Kepler's nova, which has a remnant displaying a typical filamentary structure with strong emission lines, nor Tycho Brahe's nova, which has no visible remnant, appears to radiate at optical wavelengths by this mechanism. It would seem that, either their associated magnetic fields are much smaller than in the case of the Crab Nebula or, more probably, electron energies do not reach such high values. If electrons are being accelerated by a Fermi process in these remnants they may yet become visible.

The contribution of supernova remnants to radio emission near the galactic plane has been considered in detail by Hanbury Brown (1954). Quite apart from the correctness of the mechanism he assumes, his arguments show that, if their period of activity is 10^5 years and their rate of occurrence in the Galaxy about once in 20 years, corresponding to 5×10^4 active remnants, it is possible to account for the discoidal distribution by their integrated emission. The occurrence rate assumed is some 15 times that derived by Zwicky (1942) from a study of external galaxies, but is not inconsistent, since Zwicky found that some galaxies may be very prone to supernova outbursts and the Milky Way may be such a galaxy.*

The failure to detect radio emission from any common nova in the present observations may be used to show that their integrated emission is unlikely to be of any significance. Assuming that m_R-m for a nova is greater than that for a supernova, the radio emission from each must accordingly differ by a

* *Note added in Proof.*—In discussion with the authors, Minkowski has remarked that these differences are explicable if account is taken of the two forms of supernovae, type I associated with Population II and of very low occurrence frequency and type II associated with Population I and very frequent in Sb and Sc galaxies. Since the supernovae we discuss are all of type I, with an average recurrence period of hundreds of years, we may conclude that the integrated radio emission of all such supernova remnants in the Milky Way is likely to be insignificant. However, the possibility remains that type II supernova remnants, of which the intense radio source in Cassiopeia seems to be an example, may contribute significantly to the radio emission close to the galactic plane.

factor greater than the difference in their light emission at maximum brightness, that is, by a factor of about 10^4. The rate of occurrence of novae in the galaxy is probably of the order of 10 per year, so that, if the lifetime of their radio emission does not exceed that of supernovae, they can at most contribute a few per cent. of the total radio emission near the galactic plane.

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