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RADIO NOVAE

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ABSTRACT

Radio emission from two recent novae, Nova Delphini 1967 and Nova Serpentis 1970, has been detected at wavelengths of 11.1, 3.7, and 1.95 cm. The results are consistent with the thermal radiation of expanding envelopes of ionized gas at high emission measures.

Radio emission from Nova Delphini 1967 and Nova Serpentis 1970 was detected with the NRAO three-element interferometer during 1970 June, at wavelengths of 3.7 cm (8.085 GHz) and 11.1 cm (2.695 GHz). Both were detected subsequently with the 140-foot telescope at 1.95 cm (15.370 GHz) during July. They were observed again with the interferometer during August. The measured flux densities, with their rms errors, the total observing times, and the dates of observation, are given in Table 1. The interferometer spacings used for the June observations were 900, 1800, and 2700 m (corresponding to approximately 24300, 48600, and 72900 wavelengths at λ3.7 cm). In August, the spacings were 600, 1800, and 2400 m (16200, 48600, and 64800 wavelengths at λ3.7 cm).

The radio source associated with Nova Delphini 1967 is still unresolved by the interferometer at the longest spacings, and there is no evidence of confusion by nearby faint sources. This is also true for Nova Serpentis 1970 at λ3.7 cm. For the latter object, however, confusion effects are evident in the 11.1-cm data; this is undoubtedly a consequence of the much larger primary reception pattern of the interferometer at the longer wavelength.

The interferometer data were adequate for accurate measurements of the positions of the two sources. The necessary instrumental calibrations were made by reference to a large number of sources whose positions had been determined previously with the same instrument (Wade 1970). The results are given in Table 2, together with the published optical positions of the novae. The radio and optical positions coincide within better than 2 seconds of arc in both cases, which leaves little doubt of the validity of the identification of the radio objects with the corresponding novae.

The flux density at frequency ν (wavelength λ) for a thermally radiating source is given by

$$S_\nu = \frac{2k}{\lambda^2} \int\int_{\text{source}} T_e e^{-\tau_\nu} d\tau_\nu d\Omega \,, \tag{1}$$

where k is the Boltzmann constant; T_e is the electron temperature; $d\Omega$ is the elementary solid angle; and

$$d\tau_\nu \cong 0.08235\ T_e^{-1.35} \nu^{-2.1} dE \,, \tag{2}$$

where ν is in GHz and dE is in pc cm^{-6} (Oster 1961; Altenhoff *et al.* 1960). Here $dE = N_e^2 ds$ is the contribution to the emission measure made by a plasma element with an electron concentration N_e (in cm^{-3}) and a depth ds (in pc) along the line of sight. Since there are still too few data to justify a discussion of more complex models, let us assume that

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the plasma which contributes the major part of the radio emission can be described by an average electron temperature $\langle T_e \rangle$ and an average emission measure $\langle E \rangle$, and further that it subtends a solid angle Ω_s. Equation (1) then becomes

$$S_\nu = 2\lambda^{-2}k\langle T_e \rangle \Omega_s[1 - \exp(-0.08235\langle T_e \rangle^{-1.35}\langle E \rangle \nu^{-2.1})] . \tag{3}$$

Because nova envelopes expand, it must be remembered that Ω_s and $\langle E \rangle$, and perhaps $\langle T_e \rangle$, are functions of time.

TABLE 1

MEASURED FLUX DENSITIES

Nova	λ (cm)	Measured Flux Density S_ν (flux units)*	Observing Time (hours)	Date of Observation (1970)
Delphini 1967.....	11.1	0.021±0.003	10.5	June 21, 22
		0.022±0.003	2.3	August 7
	3.7	0.075±0.011	10.5	June 21, 22
		0.080±0.012	2.3	August 7
	1.95	0.14 ±0.02	2.0	July 25, 26
Serpentis 1970....	11.1	0.005±0.003	12.3	June 19, 23
	3.7	0.022±0.004	12.3	June 19, 23
		0.030±0.005	6.3	August 7
	1.95	0.10 ±0.03	1.5	July 25, 26

* 1 flux unit $= 10^{-26}$ W m^{-2} Hz^{-1}.

TABLE 2

RADIO AND OPTICAL POSITIONS

Nova	α (1950.0)	δ (1950.0)	Remarks
Delphini 1967.......	$20^h40^m04^s.25 \pm 0^s.06$	$+18°58'51''.5 \pm 1''.0$	Radio position
	$20^h40^m04^s.24$	$+18°58'51''.0$	Optical position (Seligman 1967)
Serpentis 1970......	$18^h28^m16^s.25 \pm 0^s.06$	$+02°34'42''.2 \pm 1''.5$	Radio position
	$18^h28^m16^s.36$	$+02°34'41''.5$	Optical position (Tokyo Observatory 1970)
	$18^h28^m16^s.18$	$+02°34'42''.8$	Optical position (Seki 1970)
	$18^h28^m16^s.29$	$+02°34'42''.1$	Optical position (Grosbol and Jorgenson 1970)

The measured values of S_ν from Table 1 are plotted in Figure 1 as spectra for the two novae. The data for Nova Delphini 1967 are consistent with a thermal spectrum which is optically thick at 11.1 cm but which becomes optically thin at 1.95 cm. The dashed curve passing through the 3.7- and 1.95-cm points shows the thermal spectrum predicted by equation (3) for a model with $\langle T_e \rangle \Omega_s = 4.4 \times 10^{-8}$ ° K sterad and $\langle T_e \rangle^{-1.35}\langle E \rangle = 2.1 \times 10^3$. If we assume that $\langle T_e \rangle \simeq 10^4$ ° K, then $\Omega_s \simeq 4.4 \times 10^{-12}$ sterad and $\langle E \rangle \simeq 5.5 \times 10^8$ pc cm^{-6}. Defining an equivalent-disk diameter by $\Omega_s = \frac{1}{4}\pi\Theta_{\text{e.d.}}^2$, we find $\Theta_{\text{e.d.}} = 0''.5$. The flux density at 11.1 cm is greater than the curve fitted to the values at the higher frequencies would predict. This, however, is a well-known phenomenon in H II regions (Hjellming and Churchwell 1969); the explanation is that the dominant radiation at the longer wavelengths comes from the more tenuous outer layers when the source is optically thick, and hence the effective solid angle is greater. The equivalent-disk diameter at 11.1 cm would be $\Theta_{e.d.} = 0\overset{''}{.}74$ if the same $\langle T_e \rangle$ applies to all parts of the source. Data are needed at more frequencies in order that the spectrum can be better delineated, thereby permitting a more detailed analysis.

Although the data for Nova Serpentis 1970 in Figure 1 undoubtedly are affected somewhat by time-dependent changes, it clearly can best be described by an optically thick thermal spectrum. The dashed line drawn through the 3.7-cm point for June is such a spectrum. It corresponds to $\langle T_e \rangle \Omega_s = 1.1 \times 10^{-8}$ ° K sterad, if the optically thick limiting case of equation (3) is used. If $\langle T_e \rangle = 10^4$ ° K, then $\Omega_s = 1.1 \times 10^{-12}$ sterad, which implies an equivalent-disk diameter $\Theta_{e.d.} = 0\overset{''}{.}24$. Further, since there is no sign of a turnover in the spectrum at 1.95 cm, $\langle T_e \rangle^{-1.35} \langle E \rangle > 8000$. If $\langle T_e \rangle = 10^4$ ° K, this requires $\langle E \rangle > 2 \times 10^9$ pc cm^{-6}.

The data for Nova Serpentis 1970 suggest, but do not establish, that the radio flux

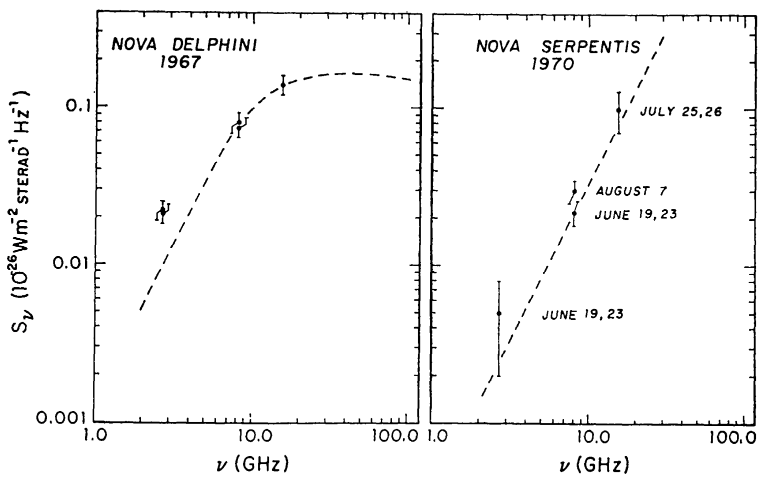

FIG. 1.—Radio spectra of Nova Delphini 1967 and Nova Serpentis 1970 (see Table 1). Dashed curves indicate thermal spectra discussed in text.

from this object is still increasing. The 3.7-cm data in Table 1 are consistent with an increase of nearly 50 percent during the 7-week interval separating the two periods of observation, but such a conclusion would be questionable in view of the uncertainties of the measurements. Further observations in the coming months should decide the matter.

A simple model of a nova envelope as a uniform plasma sphere expanding at a uniform rate would imply that $S_\nu \propto t^2$ (where t is the time since the outburst) during the early optically thick phase. However, $\langle E \rangle$ would vary as t^{-5}, and eventually the nova envelope would become optically thin. From this time onward the object would fade rapidly, with $S_\nu \propto t^{-3}$. Since the constants of proportionality would necessarily depend on frequency, the spectrum should be a function of time, with the changes proceeding more rapidly at the higher frequencies. It might be more realistic to expect that we actually are dealing with an asymmetrical expanding system of clumps which may be expanding individually as well. Observations of the temporal variation of the flux density at many frequencies will constrain severely the range of admissible models for the expansion of nova envelopes. For example, $\langle E \rangle \propto t^{-5}$ for a uniformly expanding sphere, whereas $\langle E \rangle \propto t^{-4}$ for a uniform shell of constant thickness. A change in shell thickness would affect the rate of change of $\langle E \rangle$.

Comprehensive radio data for recent novae will be a valuable complement to optical data, providing important additional information about the nova phenomenon.

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