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VARIABLE RADIO EMISSION FROM THE 4 DRACONIS SYSTEM

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ABSTRACT

The 4 Dra system, which contains an M3 giant and a cataclysmic binary, has been detected as a 6 cm radio source with the VLA. This radio emission is variable on time scales of weeks to months. A number of possible sources of the radio emission within the 4 Dra system are considered, and the observed time variability probably rules out optically thick free-free emission from the wind of the M3 giant as the dominant source. The major source of the observed radio emission is likely to be either the cataclysmic binary or shocked regions due to the interaction between the cataclysmic binary and the red giant wind.

Subject headings: stars: binaries — stars: radio radiation — stars: variables

I. INTRODUCTION

The M3 giant 4 Dra (CQ Dra; HD 108907) has a cataclysmic variable (CV) binary companion, which was discovered by Reimers (1985) from low-dispersion *International Ultraviolet Explorer* (*IUE*) spectra. This companion system is seen by the presence of UV continuum emission increasing toward shorter wavelengths, particularly below 1450 Å, and strong high-temperature emission lines of Si IV, C IV, and He II. High-temperature lines such as these are not present in the ultraviolet spectra of normal M giants (see, for example, Simon, Linsky, and Stencel 1982). The strength of the ultraviolet emission lines and the high degree of ionization observed indicated that 4 Dra was likely to be a radio source. Therefore, because the M giant primary star dominates the energy distribution of the system from the near-ultraviolet through the optical and into the infrared spectral region, radio observations offered a valuable source of additional information on the physical processes associated with the multiple nature of the 4 Dra system. R. Griffin and D. Reimers (1986, private communication) have determined the orbital period of the M3 III–CV spectroscopic binary to be 1706 days. The system 4 Dra is therefore a wide binary.

In this *Letter* I describe a study of the radio emission from the 4 Dra system. Red giants are weak sources of radio continuum emission in the form of optically thick, thermal free-free emission from their winds (Drake and Linsky 1986). Several searches also have been made for radio emission from cataclysmic variables (Córdova, Mason, and Hjellming 1983; Chanmugam and Dulk 1982; Dulk, Bastian, and Chanmugam 1983; Bookbinder and Lamb 1986). The only reported detections are of the magnetic CV AM Her by Chanmugam and Dulk, the DQ Her system AE Aqr by Bookbinder and Lamb, and the dwarf nova SU UMa by Benz, Fürst, and Kiplinger (1983).

TABLE 1
VLA OBSERVATIONS OF 4 DRACONIS

Date	Time (UT)	Array	Wavelength (cm)
1985 May 18	00:57:50–01:24:10	B	6
1985 Jul 31	19:14:00–19:29:30	C	2, 6
1986 Feb 14	08:12:40–12:30:20	D/A hybrid	6
1986 Feb 21	07:45:20–11:03:00	D/A hybrid	6

II. OBSERVATIONS

The 4 Dra system has been observed with the NRAO[1] Very Large Array (VLA) on four occasions over the period 1985 May 18 to 1986 February 21. The observations were obtained using two adjacent 50 MHz bandpasses. Details of the times of observation and the array configurations are given in Table 1. The absolute flux density scale was established by observations of 3C 286 and the calibrator 1311+678 was observed every 25 minutes or less for phase calibration of the source observations. The data were calibrated using the standard VLA reduction programs and radio maps made using the AIPS software. Initially maps were made using the complete set of observations obtained on each date using the CLEAN routine and then each data base was split into smaller time intervals to search for variability. The region around 4 Dra is free of strong extragalactic sources.

The mean flux densities derived from the observations on each date are presented in Table 2. The system 4 Dra was detected on 1985 May 18 and 1986 February 14 and 21, being, respectively, a 6 σ, 7 σ, and 4 σ 6 cm source on these

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

TABLE 2

OBSERVED MEAN FLUX DENSITIES OF THE 4 DRACONIS RADIO SOURCE

Date	Wavelength (cm)	Time On Source (minutes)	Flux Density (mJy)	Noise Level[a] (mJy; 3 σ rms)	Position (1950.0) $12^h27^m+69°28'$ $+\alpha$	$+\delta$
1985 May 18	6	26	0.36	0.16	55^s47	38″4
1985 Jul 31	6	16	< 0.23	0.23	...	...
1985 Jul 31	2	45	< 0.23	0.23	...	...
1986 Feb 14	6	220	0.18	0.07	55.44	38.6
1986 Feb 21	6	159	0.09	0.07	55.42	38.6

[a] Noise level as measured from final maps; depends on both time on source and number of operational antennae.

TABLE 3

FLUX DENSITY VARIATIONS OF 4 DRACONIS ON 1986 FEBRUARY 14

Time Interval	Time On Source (minutes)	Flux Density (mJy)	3 σ Noise Level[a] (mJy)
08:12:40–09:31:20	87	0.10	0.21
09:35:40–10:24:50	44	0.25	0.23
10:29:10–11:36:30	46	0.40	0.27
11:41:10–12:30:20	45	0.14	0.27

[a] Measured from maps; depends on both time on source and number of operational antennae.

dates. These standard deviations were measured from the actual noise in the individual maps. No evidence of circular polarization was detected for any of the observations. The optical position of 4 Dra is $\alpha(1950.0) = 12^h27^m55^s.42$, $\delta(1950.0) = +69°28'38''.8$, based on the position and proper motions given in the SAO Star Catalog. The mean radio position is within $\sim 0''.3$ of the optical position. Splitting the data base reveals that the radio flux is not constant over the time interval of the observation, particularly in the case of February 14 (see Table 3).

III. DISCUSSION

a) *Reality and Time Scales of Variability*

The data in Table 2 show evidence for long-term variability on time scales of a week to months, while those in Table 3 are suggestive of significant variations on hour time scales. Finer division of the available data does not provide a statistically significant shorter time scale for the variability but significant changes in emission level over a few tens of minutes cannot be excluded.

The presence of short time scale variability, even if on day to week time scales, places important constraints on the possible sources of radio emission within the 4 Dra system.

b) *The Origin of the Observed Emission*

The observed radio emission could originate from a number of regions in the 4 Dra system. In particular the red giant, the cataclysmic binary and shocked regions in the red giant wind are all potential sources of emission.

Red giants similar to 4 Dra are weak sources of continuum radio emission in the form of optically thick thermal free-free emission from their winds and also chromospheric blackbody emission. Based on the spherically symmetric stellar wind formulae of Wright and Barlow (1975) and Panagia and Felli (1975), the flux density at 6 cm, S_ν, expected from the wind from 4 Dra A, would be

$$S_\nu = 1.6 \times 10^{11} \left(\dot{M}_{\rm ion}/v_\infty\right)^{4/3} D^{-2} \text{ mJy},$$

where $\dot{M}_{\rm ion}$ is the ionized mass-loss rate, typically 2×10^{-9} $M_\odot/\text{yr}^{-1}$ for an M3 giant (Drake 1986); v_∞ is the wind terminal velocity; and D is the stellar distance in kiloparsecs. Reimers (1985) gives $v_\infty = 15$ km s^{-1}, based on Ca II emission-line profiles, and $D = 150$ pc. The wind should be nearly fully ionized due to the presence of 4 Dra B. Thus for a fully ionized wind a flux density as large as ~ 0.5 mJy might be possible. The chromospheric contribution is unlikely to be greater than 0.003 mJy given the small angular diameter of 4 Dra A (i.e., ~ 4 mas).

However, it is unlikely that the observed emission is due primarily to the red giant because of the observed variability. The stellar winds of such stars are thought to be large in extent with the angular size of a 10^4 K stellar wind source at a 0.5 mJy 6 cm level being ~ 52 mas, i.e., $\sim 13\ R_*$ across. With an outflow velocity of 15 km s^{-1} the travel time to 10 R_* is over a year. To significantly alter the radio emission a large fraction of the emitting volume must change, leading to a minimum expected time scale for variability at least of the order of a few months. Therefore, the observed time scales of variability strongly suggests that the red giant is not the major source of radio emission. Even if significant changes occurred in the photoionizing radiation from 4 Dra B, changes in the radio emission would be slow because recombination would occur on time scales of months.

An interesting limit on the ionized mass-loss rate from the M giant can be obtained from the mean flux density of 0.09 mJy obtained on 1986 February 21. This is the lowest mean level of emission observed, and if this were postulated to derive from 4 Dra A alone, it implies an upper limit for the ionized mass-loss rate of $6 \times 10^{-10}\ M_\odot$ yr^{-1}.

Cataclysmic variables are generally not detectable as radio sources; however, the two known cases and one possible example of emission from such systems are highly variable.

Chanmugam and Dulk (1982) and Dulk, Bastian, and Chanmugam (1983) showed that AM Her is a highly variable 6 cm source, which was seen to undergo a rapid outburst over a 10 minute period. Bookbinder and Lamb (1986) found AE Aqr to be extremely variable at both 6 and 20 cm on time scales ranging from a few minutes to a few hours. Also Benz, Fürst, and Kiplinger (1983) were able to detect the dwarf nova SU UMa only during optical outburst. The emission in these cases is thought to be nonthermal in nature. Therefore while it is not feasible to predict the expected radio emission from 4 Dra B, the presence of short time scale variability suggests that the secondary may be a more important source of radio emission than 4 Dra A.

The other attractive possibility is that the radio emission is due to an interaction between the components of the 4 Dra system. Dwarf novae often show high-velocity (~ 3000 km s^{-1}) winds from their accretion disks during outburst (Drew and Verbunt 1985), and if the 4 Dra B system possesses such a wind it would interact vigorously with the slower but more massive wind from 4 Dra A. Indeed the passage alone of 4 Dra B through the red giant wind should give rise to shock phenomena. The radio emission from hot stars is thought to arise primarily due to shocks forming in the winds from these stars (Abbott, Bieging, and Churchwell 1985; White 1985). However, without more detailed knowledge of the properties of 4 Dra B, it is difficult to make a quantitative estimate of the expected interactions and the radio emission which might result.

IV. CONCLUSIONS

Radio emission has been detected from the 4 Dra system on three separate occasions over the period 1985 May 18 to 1986 February 21. This emission is variable on time scales of weeks to months and is likely to be variable on time scales as short as hours. The emission could originate from a number of locations in the 4 Dra system. Given the observed variability, free-free emission from the wind of the red giant 4 Dra A seems the least likely dominant emission source. The cataclysmic variable 4 Dra B and shocked interacting regions between 4 Dra A and B are both possible locations of the emitting regions.

Further investigation of the radio properties of the 4 Dra system is impeded by the weakness and rapid variability of the emission. Ideally, simultaneous multifrequency observations with higher time resolution are required. New observations of 4 Dra will be sought with the VLA to monitor the emission on hour-to-day time scales, preferably with simultaneous ultraviolet observations, in order to further investigate the emission mechanisms and source properties.

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