THE ASTROPHYSICAL JOURNAL, 352:300–302, 1990 March 20

CENTIMETER OBSERVATIONS OF SIX ECLIPSING "SERPENTID" BINARY STARS

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Received 1989 July 10; accepted 1989 September 16

ABSTRACT

Centimeter observations of the following eclipsing "Serpentid" binary stars have been performed: SY And, RX Cas, SX Cas, V367 Cyg, RZ Sct, and W Ser. RZ Sct and W Ser were detected at 3.6 cm, and V367 Cyg was detected at both 6 and 3.6 cm. It is suggested that these objects emit thermalized-gyrosynchrotron radiation as does β Lyr but at much lower levels, because the circumstellar environments are different.

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

I. INTRODUCTION

The "Serpentids" (Plavec 1980, 1989) are strongly interacting, quickly evolving binary stars, probably slightly more evolved than β Lyr. The hot star (B spectral type) and cool star (K spectral type) of a typical system are each of moderate mass. Mass transfer occurs via a plasma stream from the cool star to the hot one. Because the transferred mass carries considerable angular momentum, it forms a large, geometrically thick, high-opacity accretion disk around the hot star. Systemic mass loss occurs through an extended, low-opacity circumstellar envelope which surrounds the hot star and possibly the cool star as well.

Observationally, the Serpentids are very interesting objects. The lightcurves tend to be noisy (van Genderen 1973; Young and Snyder 1982; Akan 1987; Li and Leung 1987), probably because of variations in the accretion disks. The Keplerian periods are variable because of mass transfer and mass loss (Koch and Guinan 1978; Guinan and Tomczyk 1979). Thomson scattering in the disks and envelopes produces variable optical polarization (Shakhovskoi 1965; Elias 1989). The ultraviolet spectra of the Serpentids exhibit strong emission lines of highly excited species, such as Al III, C IV, Fe III, N V, Si III, and Si IV, arising from the low-opacity circumstellar envelopes (Plavec, Weiland, and Koch 1982). Although Serpentids are active binaries, they do not support hot spots or shocks at levels which produce strong X-rays (Guinan, Koch, and Plavec 1984) because the sizes of the accretion disks are comparable to the sizes of the orbits (the mass cannot fall deeply into the potential wells of the hot stars). Except for the null X-ray results, the weight of the observational evidence and the similarity to β Lyr (a strong stellar radio source) has suggested that the Serpentids may be *at least* weak radio sources.

Several VLA observations of the Serpentids RX Cas and SX Cas have been performed at 6 cm. The data of Florkowski (1983) have been reanalyzed by the present author and have yielded upper limits of ~ 600 μJy (3 σ). Torbett and Campbell (1989) have observed these binaries and published upper limits of ~ 100 μJy (3 σ). It must be noted, however, that their upper limit for SX Cas is invalid. The quoted right ascension is 0.5 hours too large, apparently caused by an error in the original Observe File. The present author has recreated the image and checked the image header file, verifying this conclusion.

II. OBSERVATIONS

In order to use the VLA as efficiently as possible in the study of close binaries, the author is in the process of conducting a series of "mini-surveys," one for each stage of binary star evolution characterized by Koch *et al.* (1989). The present mini-survey comprises six Serpentids: SY And, RX Cas, SX Cas, V367 Cyg, RZ Sct, and W Ser. Relevant data pertaining to these systems are listed in Table 1.

The observations were conducted using the NRAO[1] Very Large Array (VLA) in the B/C hybrid configuration on 1989 May 13. Antenna number 28 failed early in the run, so only 26 antennas were included in the map reductions. Observations were performed at both 6 and 3.6 cm, each with two IFs. The primary calibrator for this run was 3C 286. The secondary NRAO source calibrators (1950.0) were: 1741−038 (for RZ Sct and W Ser), 2005+403 (for V367 Cyg), 2352+495 (for SY And and SX Cas), and 0224+671 (for RX Cas).

The data were calibrated and edited using the DEC-10 routines at the VLA site. The calibrated and edited data were mapped at the VLA-AOC using natural weighting to maximize signal to noise (S/N). Some of the maps were CLEANed using the APCLN task in AIPS, but it was found that cleaning did not affect the position or flux determinations within their errors. Study of the shapes of the synthesized dirty beams determined that all detections are from point sources with no extended structure. V367 Cyg was the only source deemed strong enough to check for temporal variability; none was found within the errors. Also, none of these sources was considered strong enough to check for linear or circular polarization, although none was expected because of the high orbital inclinations (Mutel *et al.* 1987). The results of these map reductions are listed in Table 2.

III. DISCUSSION

a) Distance Estimates

Only the distances to RX Cas and SX Cas have been determined within approximately $\pm 20\%$ (Anderson, Pavlovski, and Piirola 1988; Andersen *et al.* 1988). Distances and their formal errors for the other binaries have been roughly estimated by various methods. The distance to SY And was determined by using SX Cas and RX Cas as optical standard candles and assuming an extinction A_V of 0.8 mag kpc^{-1}. The distance to RZ Sct was determined in the same way, except that A_V was calculated using:

$$A_V = 2.1E(B-V) + 0.15p_V \,, \quad (1)$$

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

TABLE 1

SERPENTID DATA

Object	Spectral Type[a]	Orbital Period[b] (days)	Position [1950.0][c] R.A.	Position [1950.0][c] Decl.	Distance[d] (kpc)
SY And	A0 + K1	32.90864	$00^h10^m39^s.293$	+43°26′01″.05	0.70(0.12)
RX Cas	K1III + A5eIII	32.33010	03 03 15.350	+67 23 07.57	0.57(0.10)
SX Cas	B7eIII + K3III	36.5610	00 08 04.443	+54 36 48.35	0.53(0.08)
V367 Cyg	B8peIa + F4III	18.5972	20 46 06.404	+39 06 08.36	0.32(0.15)
RZ Sct	B3Ib	15.19070	18 23 48.968	−09 13 56.04	0.26(0.06)
W Ser	F5eIb(shell)	14.16540	18 06 58.299	−15 33 37.34	0.33(0.15)

[a] The spectral types are from the General Catalog of Variable Stars (Kholopov 1987).
[b] The periods are from: SY And (Ahnert 1976), RX Cas (Andersen, Pavlovski, and Piirola 1988), SX Cas (Andersen *et al.* 1988), V367 Cyg (Abt 1954), RZ Sct (Wilcken, McNamara, and Hansen 1976), and W Ser (Koch and Guinan 1978).
[c] All positions are from the SAO Catalog except for SY And (Taff 1989).
[d] Parenthesized quantities are formal 1 σ errors.

(Hiltner 1956), where the color excess $E(B-V) = +0.86$ (Wilcken, McNamara, and Hansen 1976) and the visual polarization $p_V = 0.95\%$ (Shakhovskoi 1965). The distances to V367 Cyg and W Ser were determined from the *IRAS* Point Source Catalog by using RX Cas as a 12 μm standard candle. This method eliminates the problem of extinction which is due to interstellar dust, but may present other problems arising from circumstellar dust emission and unknown orbital phases for the *IRAS* measures. All of these results are listed in Table 1.

b) *Discussion of Radio Luminosities*

The three detected binaries are all within 350 pc, while the others are at distances greater than 500 pc. This suggests that the Serpentids have a characteristic radio luminosity of order 10^{16} ergs s^{-1} Hz^{-1} (see Table 2), and that the VLA detectability limit of Serpentids is $\sim$400 pc. The data also support another interpretation which may contradict this. The detected binaries have periods between 14 and 18 days, while the undetected ones have periods between 32 and 36 days, which implies that a period-radio luminosity law may exist for these objects. Unfortunately, the short-period Serpentids in this mini-survey are also the closest ones, so there is no way to accept or reject either or both of these hypotheses with this small number of binaries and observations.

c) *The Emission Mechanism*

Radio observations of β Lyr, a close relative of the Serpentids, have been performed by Wade and Hjellming (1972) and Woodsworth and Hughes (1977). The average flux was $\sim$10 mJy (10 GHz), which corresponds to an average luminosity of 2×10^{18} ergs s^{-1} Hz^{-1} at 370 pc (Dobias and Plavec 1985). β Lyr was used as a standard candle in the VLA Serpentid proposal to estimate the fluxes; the estimated fluxes were calculated to be between 1–10 mJy. As is evident in Table 2, the observed fluxes and luminosities are considerably smaller than expected. This implies that if the emission mechanism for β Lyr and the Serpentids is the same, the conditions which produce the emission cannot be identical.

It has been suggested that the cm emission from β Lyr is nonthermal in nature (Gibson 1980). The Zeeman measures of Skul'skii (1985) indicate an average magnetic field of 1.5 kG, which strongly implies that the nonthermal emission is gyrosynchrotron radiation. The ionization level necessary to provide the free electrons cannot be produced by the flux of the B8IIp component, so Gibson (1980) cites collisional excitation via turbulent mass motion from the cool component to the accretion disk. Gibson (1980) also suggests that the cm radiation may be thermalized, because electrons moving in a 1.5 kG magnetic field emit most of their energy over time scales of hours (Tucker 1975), allowing for interactions with circumstellar gas.

Although the radio spectrum of V367 Cyg ($\propto \nu^{0.4 \pm 0.3}$) indicates that the emission mechanism is also thermalized-gyrosynchrotron radiation due to mildly relativistic, power-law electrons, the details cannot be the same as for β Lyr because of the different luminosities. For example, the accretion disks are believed to be larger (in terms of the orbital size) in Serpentids than in β Lyr, which means that the infalling

TABLE 2

RADIO OBSERVATIONS OF SERPENTIDS

Object	Phase[a]	Time on Source (minutes) 6 cm	Time on Source (minutes) 3.6 cm	Cm Flux[b] (μJy beam^{-1}) 6 cm	Cm Flux[b] (μJy beam^{-1}) 3.6 cm	Cm Luminosity[b] (10^{16} ergs s^{-1} Hz^{-1}) 6 cm	Cm Luminosity[b] (10^{16} ergs s^{-1} Hz^{-1}) 3.6 cm	EM_B[b] (AU^2) (10^6 K) 6 cm	EM_B[b] (AU^2) (10^6 K) 3.6 cm	Map Notes[c] 6 cm	Map Notes[c] 3.6 cm
SY And	0.49	20	20	···(50)	···(33)	···(3.0)	···(1.9)	···(0.40)	···(0.09)	A	A
RX Cas	0.76	20	41	···(47)	···(26)	···(1.8)	···(1.0)	···(0.25)	···(0.05)	···	···
SX Cas	0.59	41	40	···(34)	···(27)	···(1.1)	···(0.9)	···(0.16)	···(0.04)	···	A
V367 Cyg	0.13	20	40	324(45)	399(27)	4.0(3.7)	4.9(4.6)	0.61(0.59)	0.25(0.24)	A	A
RZ Sct	0.53	20	41	···(49)	110(29)	···(0.4)	0.9(0.5)	···(0.05)	0.05(0.02)	A, B	A
W Ser	0.32	20	42	···(48)	124(28)	···(0.6)	1.6(1.5)	···(0.09)	0.08(0.07)	A, B	···

[a] See the sources for the periods in Table 1.
[b] Parenthesized quantities are formal 1 σ errors.
[c] The notes are: A, unidentified point sources in the field-of-view; and B, unidentified extended structure in the field-of-view.

mass in the Serpentids is less turbulent because it does not fall so far into the potential well of the hot component (this is consistent with the Serpentid X-ray results mentioned previously). Even though the cm spectra of the other Serpentids are incomplete, it is tentatively assumed that the emission mechanism is the same as V367 Cyg, because these binaries are supposedly members of a single class of objects.

d) *Emission Measures*

Define the brightness emission measure by the following:

$$EM_B = 0.44\nu_{\rm GHz}^{-2} d_{\rm kpc}^2 f_{\mu\rm Jy} = R_{\rm AU}^2 T_{B6} \,, \qquad (2)$$

where $\nu_{\rm GHz}$ is the frequency in GHz, $d_{\rm kpc}$ is the distance to the system in kiloparsecs, $f_{\mu\rm Jy}$ is the specific flux in μJy, $R_{\rm AU}$ is the projected size of the emitting region in AU (assuming spherical symmetry), and T_{B6} is the brightness temperature of the emitting region in units of 10^6 K. The emission measures and their formal errors appear in Table 2.

The emission measures of the detected systems are of order 10^{-1}. According to Plavec, Weiland, and Koch (1982), the Serpentid ultraviolet emission lines arise from regions which are comparable in size to the orbits, i.e., $R_{\rm AU}$ of order unity. If this size is used as an upper limit, the lower limit of T_{B6} is 0.1, which is typical of thermalized-gyrosynchrotron sources (Dulk 1985).

IV. CONCLUSION

It is not clear if the Serpentids have a characteristic radio luminosity or if there is a period-radio luminosity law; observations of other Serpentids and Serpentid-like objects will be necessary. The emission is believed to be thermalized-gyrosynchrotron radiation similar to that of β Lyr, except at lower levels because of different circumstellar conditions. If 1 AU is assumed to be the upper limit of the emitting region size (comparable to the orbital size), the lower limit of the brightness temperature is 10^5 K, which is consistent with a gyrosynchrotron source. It is stressed, however, that better distance estimates (the dominant sources of error) and longer radio integration times are needed in order to reduce the large formal errors of the emission measures and luminosities.

Additional "mini-surveys" are planned for the near future. In addition, 6 and 3.6 cm observations of V367 Cyg at various phases have been proposed, as well as a detection experiment (not part of the mini-surveys) for other Serpentids and suspected Serpentids.

I am indebted to Robert H. Koch and Robert L. Mutel for their advice and suggestions concerning my VLA proposal and this paper. I am also very grateful to the following members of the VLA staff for their help: Patrick Crane, who provided extensive help in all aspects of my observations; Patrick Leahy, William Junor, and Timothy Bastian for their terminal-side assistance; and Donna Silva, the person who made the logistics of my VLA trip pain-free. I would also like to thank Laurence Taff for the accurate optical coordinates of SY And, Rex Rivolo for his help in generating the text and tables, and the anonymous referee for helpful comments. This work was done with the aid of the Zaccheus Daniel Fellowship available at the University of Pennsylvania and administered by the Pittsburgh National Bank.

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