THE LIGHT CURVE OF THE ECLIPSING BINARY STAR XX LEO

Michele A. Stark
Michael T. Hamlin
Jeffrey R. Anderson
Felicia V. Berryman
Matthew A. Disbro
Craig Dyni
Timothy A. Gates
Jeffrey A. McKinney
Kevin W. Robinson
Shane T. Snavley
Thomas J. Stoltz
Horace A. Smith
Dept. of Physics and Astronomy
Michigan State University
East Lansing, MI 48824

Submitted July 7, 1999; revised November 22, 1999

Abstract

Light curves for the eclipsing binary XX Leo have been produced in the Johnson V and Cousins R bands. The light curves indicate that XX Leo is a contact or near-contact binary system with the relatively long period of 0.971130 day. The period of XX Leo has remained constant or nearly so since at least JD 2446110.

1. Introduction

XX Leo is listed in the *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985) as an eclipsing binary of the β Lyrae type, with a period of 0.97094 day. There is some dispute as to its classification, however, since Shaw (1994) included XX Leo in his list of near-contact systems. The precise period of XX Leo has also been disputed. Srivastava (1994) collected published times of minima observed during the period 1944–1991 and proposed a corrected period of 0.970939 day. He found that during the 1944–1991 interval the period was constant, but that there may have been a minor fluctuation around 1989. Caton and Burns (1993) observed XX Leo as part of a study of 21 eclipsing binary systems. They found that the light elements in the GCVS led to predicted minima which differed from those observed by about half a cycle. Caton and Burns determined a revised period of 0.9711296 day. Schmidt and Reiswig (1993) observed XX Leo as part of a variable star survey, producing partial V and V-R light curves. Shaw and Nicol (1998) reported photoelectric observations of XX Leo in the Washington system, and determined the period to be 0.9711305 day, a value close to that of Caton and Burns (1993).

We have obtained CCD observations of XX Leo to produce a complete light curve in both the Johnson V and Cousins R passbands. Using new and old times of minimum, we have redetermined the long term period behavior of XX Leo. Finally, we have used our light curves of XX Leo and the Binary Maker 2.0 program to perform a preliminary light curve analysis.

2. Observations

XX Leo was observed on 30 nights between March 8 and May 25, 1997. All observations were made using an ST-6 Santa Barbara Instrument Group CCD camera

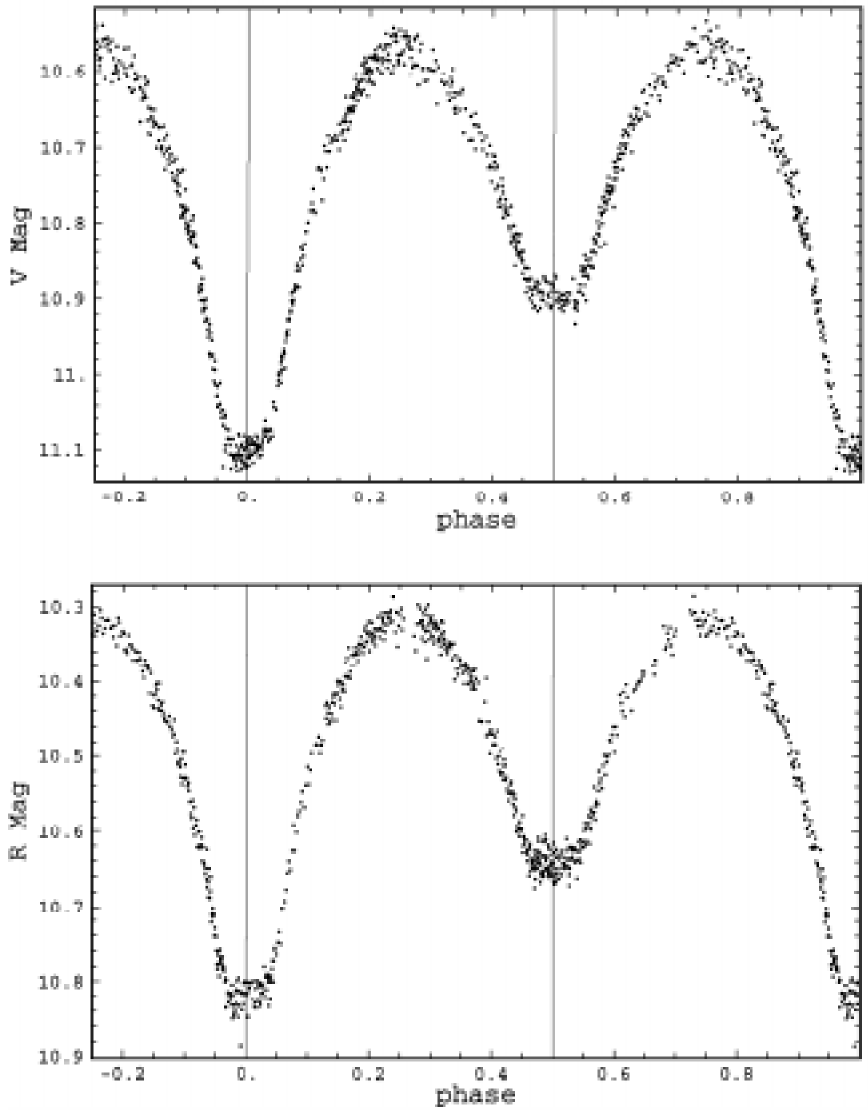

Figure 1. V and R light curves of XX Leo.

on the 0.6-m telescope at Michigan State University Observatory. Exposures were conventionally dark-subtracted and -corrected for nonuniform response with twilight flat-field exposures. On each frame, aperture photometry was obtained for XX Leo and three to five comparison stars, including the three comparison stars used by Schmidt and Reiswig (1993). Instrumental magnitudes were transformed to the standard system using color-terms determined from observations of stars in the open cluster M67, for which Schild (1983) provided standard V and R magnitudes. The three comparison stars for which Schmidt and Reiswig determined standard values were used to set the zero point of the transformation. Standard magnitudes for these stars are not listed in Schmidt and Reiswig (1993), but were kindly provided by Schmidt (1997). A list of observed V and R magnitudes is available from Horace A. Smith upon request.

3. Light curves

We combined our observations to produce light curves in both the Johnson V and Cousins R bands (Figure 1). Phasing of our data using the Caton and Burns (1993) period of 0.9711296 day yielded light curves with slightly less scatter than the alternative period of 0.970939 day (Srivastava 1994). The shape of the combined light curves is symmetric, with secondary minima midway between primary minima (indicating circular or nearly circular orbits).

The scatter of points about the mean light curve is consistent with observational error only. The standard deviation in V is aproximately 0.016 magnitude, and in R is about 0.015 magnitude. During the period March 8 through May 25, 1997, we observed six primary minima and were able to cover many phases multiple times in both V and R.

The secondary minimum has a flat bottom in both the V and the R light curves. The shape of primary minimum is less clear in our light curves, but may be slightly rounded. The light curves outside of minimum also show the rounded shape characteristic of tidal distortion in a close binary system. This shape of the curve implies that the two stars are in contact or in near contact (see Section 5). For XX Leo, the smaller, cooler star eclipses the larger, more luminous star (as well as partially eclipsing the contact point of the two) during primary minima.

The light curve of XX Leo resembles that of an A-type W UMa star, a contact binary system in which the larger star is hotter than the smaller. There are, however, some problems with the identification of XX Leo as an A-type W UMa system. The spectral type of A8, as listed in the GCVS, would be unusually early, although not unprecedented, for a W UMa-type system. A period as long as one day is also unusual, although not unprecedented, for W UMa stars. Rucinski (1998), reporting upon observations obtained during the OGLE project, noted the existence of a number of longer period contact systems, including a group of stars with periods from 1.3–1.5 days, that displayed all the characteristics of W UMa systems. He did, however, indicate that very few W UMa systems with periods around one day were detected in his studies, which may reflect a bias against the identification of eclipsing binaries with periods very close to one day, but which could also be a genuine property of those binary systems. The difference of 0.2 magnitude in the depths of primary and secondary minima is also atypically large for an A-type W UMa star. Rucinski (1997) found that only two out of 98 contact systems with periods of less than one day had differences in eclipse depths greater than 0.065 magnitude, making these systems very rare. On the classification scheme of Alcock *et al.* (1997), the XX Leo light curve would seem to fit into the category EB/6.

4. Long-term period behavior

We were able to find published times of 28 minima to supplement our timings of six primary minima. Shaw (1999) provided unpublished times for two additional secondary minima and one primary minimum. Times of these minima are listed in Table 1. New times of minimum based upon the observations reported here are listed in Table 2. Times of minimum listed in BBSAG Bulletins were taken from the database maintained at Cracow (Kurpinska-Winiarska *et al.* 1999).

An examination of the literature on XX Leo indicated that it is likely that some of the observed minima which were published as primary minima were really secondary and vice versa. In Table 1, column (2) identifies the type of minimum, primary or secondary, as published, whereas column (3) lists our identification of the minimum as primary or secondary. With our identification of minimum type, and with the assumption

Table 1. Published minima of XX Leo.

JD(hel)	*Type*[a]	*Type*[b]	*Method*[c]	*Reference*
2431169.379	P	P	PG(V)	Srivastava
2431169.418	P	P	vis	Srivastava
2442460.452	P	S	vis	Cracow Database
2442464.292	P	S	vis	Cracow Database
2442464.293	P	S	vis	Cracow Database
2442528.499	P	S	vis	Cracow Database
2442561.364	P	S	vis	Srivastava
2442561.384	P	S	vis	Cracow Database
2445402.423	P	P	PG	Cracow Database
2446110.852	S	S	PEP	Shaw (1999)
2446150.667	S	S	PEP	Shaw (1999)
2446165.719	P	P	PEP	Shaw (1999)
2447274.355	P	S	vis	Cracow Database
2447568.515	P	S	PG	Cracow Database
2448085.450	S	S	vis	Cracow Database
2448352.7082	P	P	PEP	Caton & Burns
2448564.374	S	P	PEP	Srivastava
2448690.6614	P	P	PEP	Caton & Burns
2448705.7101	S	S	PEP	Caton & Burns
2448733.391	S	P	PEP	Cracow Database
2448734.355	S	P	vis	Cracow Database
2448741.6457	S	S	PEP	Caton & Burns
2448755.226	S	S	vis	Cracow Database
2449028.592	P	P	vis	Cracow Database
2449046.575	P	S	PEP	Cracow Datbase
2449076.393	P	P	vis	Cracow Database
2449078.345	P	P	vis	Cracow Database
2449777.347	P	P	PEP	Cracow Database
2450570.406	P	S	vis	Cracow Database
2450571.374	P	S	vis	Cracow Database
2450849.485	P	P	vis	Cracow Database

[a] P: Primary Minimum, S: Secondary Minimum, as published
[b] P: Primary Minimum, S: Secondary Minimum, our identification
[c] PG: Photographic, vis: Visual, PEP: Photoelectric

Table 2. Primary minima of XX Leo determined from observations in this paper.

JD(hel)	*Mean Error*	*Filter*
2450539.688	0.003	V
2450540.663	0.003	V
2450542.600	0.003	R
2450572.722	0.007	V
2450573.675	0.003	V
2450575.625	0.003	R

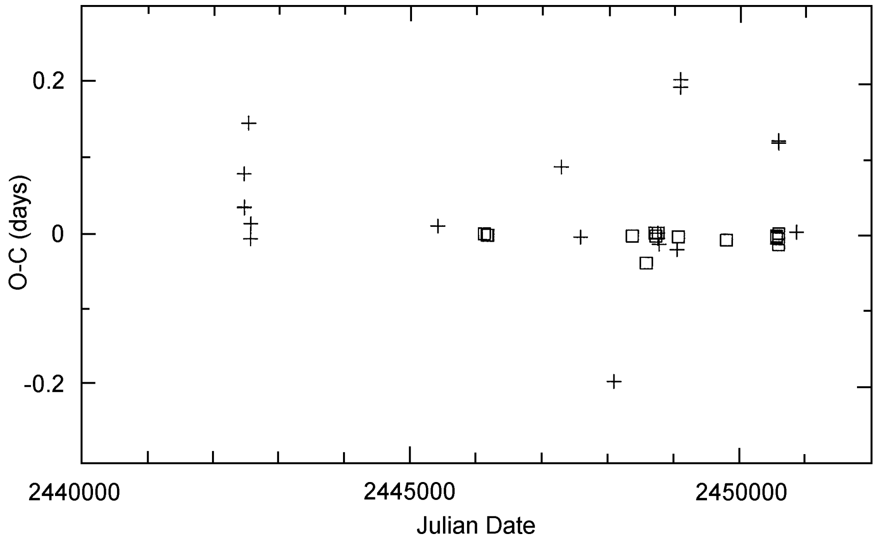

Figure 2. O-C diagram for XX Leo. Squares represent observations obtained with a CCD camera or photoelectric photometer. Crosses represent visual or photographic observations.

that secondary minima occur midway between primary minima, we obtain the following ephemeris for primary minima from a least-squares fit to minima observed either photoelectrically or with a CCD:

$$\text{Min I}_{(\text{hel.})} = \underset{\pm 0.001}{2448352.705} + \underset{\pm 0.000001}{0.971130}E \,, \qquad (1)$$

where E is the elapsed number of cycles. This period is very close to that found by Caton and Burns (1993) and Shaw and Nicol (1998). Figure 2 plots values of O-C from this ephemeris for the times of minimum in Tables 1 and 2, excluding the two earliest minima, which are far removed in time from the later observations.

Although the ephemeris does not fit some of the times of minimum obtained visually, it does satisfy most timings determined from photoelectric photometry or CCD observations. Only the photoelectrically-observed minimum at JD 2448564.374 is somewhat discrepant. We conclude that XX Leo has changed little if at all in period since JD 2446110. Before that date, the observed minima are too sparse to permit a determination of the long-term period-change behavior. As a consequence, our identifications of primary and secondary minima before JD 2446110 are uncertain.

5. Physical parameters

Shaw and Nicol (1998) reported a preliminary photometric solution for XX Leo, based upon their photoelectric photometry. They found XX Leo to be a near-contact system with a mass ratio $m_1/m_2 = 2.0$. The effective temperature of the primary was determined to be 7560K, and that of the secondary 5680K. They found that light from a third component was needed to make the theoretical light curves match those observed, although the nature of the third component was unclear.

Using our V and R light curves, we performed a preliminary photometric solution for XX Leo with the Binary Maker 2.0 program (Bradstreet 1993). Parameters in the Binary Maker 2.0 program were adjusted until the observed and predicted light curves were well-matched. Fitting in the Binary Maker 2.0 program is not automatic, but is done interactively with the goodness of fit judged by eye. Using the same gravity coefficients, inclination, limb darkening, and reflection coefficients as Shaw and Nicol, we arrived at a similar but not identical solution. The light curve was well-fit by a contact system (fillout factor = 0.17) with component effective temperatures of 6800K and 6000K, a third light contribution of 0.10, and a primary-to-secondary star-mass ratio of 3.3. However, a fit almost as good was achieved with component temperatures of 7100K and 6100K, with a fillout factor of 0.17, edge-on inclination, and a mass ratio of 4.0, with no third light contribution.

The derived temperature difference between the components is relatively large both in our models and in those of Shaw and Nicol. Such a large temperature difference may indicate that XX Leo is a near-contact rather than a contact system (Shaw 1994). A solution of the XX Leo system taking into account all of the high quality light curves now available would be worthwhile, but is beyond the scope of this paper.

6. Summary

Our observations confirm that XX Leo is a contact or near-contact binary system, rather than a β Lyrae system. The light curve indicates that XX Leo is similar to an A-type W UMa binary, but XX Leo has some properties atypical of such systems. We have produced a new ephemeris for XX Leo which is in good agreement with the earlier ephemerides of Caton and Burns (1993) and Shaw and Nicol (1998). This ephemeris indicates that XX Leo has not changed significantly in period since JD 2446110. We performed a preliminary light curve analysis with data from our V and R light curves using Binary Maker 2.0. This analysis indicated that the two components of XX Leo differ considerably in both mass and effective temperature. XX Leo merits a more complete light curve analysis.

7. Acknowledgements

We thank Scott Shaw for providing us with unpublished times of minimum light based upon his observations of XX Leo. We thank Ed Schmidt for providing magnitudes for comparison stars. This study was begun as a project in the AST202 class at Michigan State University, and was supported in part by grant AST9528080 from the National Science Foundation.

References

Alcock, C. *et al.* 1997, *Astron. J.*, **114**, 326.
Bradstreet, D. H. 1993, *Binary Maker 2.0*, Contact Software.
Caton, D., and Burns, W. 1993, *Inf. Bull. Var. Stars*, No. 3900.
Kholopov, P. N. *et al.* 1985, *General Catalogue of Variable Stars*, 4th ed., Moscow.
Kurpinska-Winiarska, M., Danielkiewicz-Krosniak, E., Kundera, T., and Jasko, H. 1999, *Eclipsing Binaries Minima Databas*e, Cracow Observatory, URL: http://www.oa.uj.edu.pl/ktt/
Rucinski, S. M. 1997, *Astron. J.*, **113**, 1112.
Rucinski, S. M. 1998, *Astron. J.*, **115**, 1135.
Schild, R. E. 1983, *Pub. Astron. Soc. Pacific*, **95**, 1021.
Schmidt, E. G. 1997, private communication.
Schmidt, E. G., and Reiswig, D. E. 1993, *Astron. J.*, **106**, 2429.
Shaw, J. S. 1994, *Mem. Soc. Ast. Ital.*, **65**, 95.
Shaw, J. S. 1999, private communication.
Shaw, J. S., and Nicol, S. 1998, *Int. Am.-Prof. Photoelec. Phot. Comm.*, No. 71, 57.
Srivastava, R. K. 1994, *Astrophys. and Space Sci.*, 219.