COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS
Number 1900

Konkoly Observatory
Budapest
1980 December 29

HU ISSN 0374-0676

DETERMINATIONS OF SIX TIMES OF MINIMA, AND A NEW EPHEMERIS FOR BS Dra

During a recent investigation of the photometric orbit of BS Dra by Popper and Etzel[1], it became necessary to redetermine the ephemeris of the system. The B, V observations used in the determinations of the six additional times of minima given here were described by Popper and Dumont.[2] These determinations were then combined with all previous ones known at the time to derive the new ephemerides given below.

The determinations of the times of minima made use of the symmetry of the eclipses to determine the temporal mean of the ascending and descending branches in a manner very similar to the method of Hertzsprung.[3] Observations on the steeper portions of the curve were reflected onto the opposite branch by linear interpolation to give a time of minimum for each observation. The mean of all these gave the time of minimum determination, along with an estimate of the uncertainty. This method was automated by computer programming to allow flexibility. It was found to be a superior method compared to polynomial fitting of the observations within the minima. Such a method, using third-order polynomials, was proposed by Breinhorst et al.[4] for use with asymmetric light curves. Whereas the results of the simple temporal averaging were fairly insensitive to the selection of observations for a given eclipse, the polynomial fitting was sensitive both to the distribution of the observations and to the order of the polynomial. Polynomial orders of two to five were used in the tests. Similar problems with polynomial fitting, and other such methods, were reported by Van Diest[16] in connection with asymmetric minima. Table I lists the results of the determinations for six observed minima.

Table I

Mean B & V Determinations of Times of Minima for BS Dra
From the Observations of Popper and Dumont[2]

Date U.T.	Minima P/S	No. Obs. V/B	HJD (obs) +2400000	s.e.
13 Jul 72	P	35/31	41511.8842	±.0006
18 Jul 72	S	16/16	41516.9311	±.0007
14 Aug 72	S	42/41	41543.8428	±.0005
19 Aug 72	P	12/15	41548.8891	±.0005
1 Jun 73	P	52/52	41834.8302	±.0004
22 Oct 73	S	15/17	41977.8009	±.0006

A search of the literature available at the time when the investigation by Popper and Etzel was commencing yielded 36 other determinations of times of minima. These, along with the determinations from Table I, are given in Table II. Also given are the epoch and O-C (computed from the adopted ephemeris), the weight and type of determination, and the reference(s). Unit weights were generally assigned to photoelectric (pe) determinations in one filter, double weights to the average of two-color photoelectric determinations, weights of 0.2 to visual estimates (vis), and 0.1 to photographic values (pg). Some photographic determinations were rejected due to their obviously poor quality, but the remaining ones did improve the period derived from using the photoelectric observations alone.

Table II

Ephemeris Solution for BS Dra -- All Determinations
Assuming $J.D._{min}$ = 2,441,461.4245 + 3.3640103 E

HJD (obs) +2400000	Epoch	O - C	wt.	Method	ref.
26444.467	-4464.0	-.016	0.1	pg	5
26942.369	-4316.0	.013	0.1	pg	5
26942.390	-4316.0	.034	0.0	pg	5
26942.408	-4316.0	.052	0.0	pg	5
27216.522	-4234.5	-.001	0.1	pg	5
27312.396	-4206.0	-.001	0.1	pg	5
28020.522	-3995.5	.001	0.1	pg	5
28782.422	-3769.0	-.048	0.0	pg	5
28809.373	-3761.0	-.009	0.1	pg	5
29911.460	-3671.5	-.001	0.1	pg	5
29438.467	-3574.0	.015	0.1	pg	5
36420.422	-1498.5	-.033	0.0	pg	5
36452.368	-1489.0	-.045	0.0	pg	5
41392.452	- 20.5	-.010	0.2	vis	6
41461.4252	0.0	.0007	2.0	pe	7, 8
41471.5163	3.0	-.0003	1.0	pe	7, 8
41471.5166	3.0	.0000	1.0	pe	7, 8
41488.3335	8.0	-.0031	1.0	pe	7, 8
41488.3345	8.0	-.0021	1.0	pe	7, 8

Table II (Continued)

HJD (obs) +2400000	Epoch	O - C	wt.	Method	ref.
41493.3817	9.5	-.0009	1.0	pe	7, 8
41493.3838	9.5	.0012	1.0	pe	7, 8
41498.4290	11.0	.0004	1.0	pe	9
41508.5199	14.0	-.0008	1.0	pe	9
41511.8842	15.0	-.0005	2.0	pe	This study
41516.9311	16.5	.0004	2.0	pe	This study
41543.8428	24.5	.0000	2.0	pe	This study
41548.8891	26.0	.0003	2.0	pe	This study
41594.3040	39.5	.0011	1.0	pe	7
41631.3123	50.5	.0052	1.0	pe	9
41772.5934	92.5	-.0021	1.0	pe	9
41794.4600	99.0	-.0016	1.0	pe	9
41826.4196	108.5	.0000	1.0	pe	7, 8
41834.8302	111.0	.0005	2.0	pe	This study
41977.8009	153.5	.0008	2.0	pe	This study
42302.4277	250.0	.0006	1.0	pe	8, 10
42302.4280	250.0	.0009	1.0	pe	8, 10
42371.3907	270.5	.0014	1.0	pe	10
42435.312	289.5	.006	0.2	vis	11
42529.491	317.5	-.007	0.2	vis	12
42958.405	445.0	-.004	0.2	vis	13
42990.368	454.5	.001	0.2	vis	14
43059.321	475.0	-.008	0.2	vis	15

It was initially assumed that the separations of the minima were exactly $0^P.5$ from individual preliminary ephemeris solutions on the primary and secondary eclipses. The subsequent analysis by Popper and Etzel showed $e \cos \omega$ to be less than 0.0001 and there is also no significant difference in the average weighted O-C for the two minima.

The adopted ephemeris and standard errors for the 42 determinations in Table II are:

$$J.D._{min} = \underset{\pm .0004}{2{,}441{,}461.4245} + \underset{\pm .0000006}{3.3640103}\ E,$$

with the standard error of one minimum of normalized unit weight being 0.0025 days, which is a slightly shorter period than found by Ibanoglu et al.[8] A solution setting all photoelectric determinations equal to unit weight, regardless of the number of colors used for a single quoted value, gave the same solution. A test solution using only the 23 photoelectric determinations yielded the ephemeris

$$J.D._{min} = \underset{\pm .0004}{2{,}441{,}461.4244} + \underset{\pm .0000038}{3.3640144}\ E,$$

with a standard error of 0.0014 days, which is essentially identical to that found by Ibanoglu et al. The difference between the two values of the period

illustrates the value of including earlier low-weight photographic determinations for improving the period. It is noteworthy to point out the usefulness of visual determinations even in this mechanized era of astronomy.

This work was supported under NSF Grant AST77-22672 Popper/Plavec.

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