PHOTOGRAPHIC STUDIES OF NEGLECTED VARIABLES, II: MO AURIGAE, RY CANIS MINORIS, HI GEMINORUM, OO PUPPIS, AND OP PUPPIS

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Abstract

Observations on Harvard patrol plates have been used to determine new or improved periods for the poorly studied eclipsing binaries MO Aur, RY CMi, and HI Gem and the Cepheid variable OO Pup. OP Pup is a previously unrecognized Cepheid with a period of 2.6 days.

1. Introduction

This report is the second in a series of papers on neglected or unstudied variable stars, based on photographic estimates made on the Harvard College Observatory patrol plates. In these reports, a time of maximum or minimum means the midexposure time of a plate on which the variable is estimated to be at or very near its observed brightest or faintest light. Individual times are necessarily of low precision, being affected by estimating errors and, in the case of short-period variables, phase smearing from the long exposure times, typically 60 minutes.

Stars are chosen for study because they appear in the *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985) with unknown or uncertain types or periods. Thanks to CCD observations by Borovicka (1993), MO Aur, RY CMi, and HI Gem are now less neglected than they were when I estimated them on the Harvard plates in 1992. However, my observations provide additional times of minima and help to define the periods more precisely. OO Pup is listed in the GCVS as a possible Cepheid (DCEP:) with no period. OP Pup is listed as a suspected RR Lyrae variable (RR:) with no period.

2. MO Aurigae

MO Aur = S 10188 was reported as an eclipsing binary, amplitude 13.1–14.7 ptg, with one time of minimum (Hoffmeister 1968; Gessner and Meinunger 1973). Borovicka (1993) observed two additional times of minima and determined a period of 5.266723 days. I estimated MO Aur on 88 Harvard plates of the RH series and found four minima. Frank also recently published a time of minimum derived from a series of photographic observations (Hubscher *et al.* 1995). Table 1 lists all eight epochs of mid-eclipse. Borovicka's epoch and period produce large O-C residuals of +0.15 day for the early minima, so new light elements were determined. In equation (1), I adopted Borovicka's CCD timing (and estimated error) as the initial epoch and a period determined by a least-squares solution of the times in Table 1. Borovicka's timings are based on series of CCD observations during minima and have much higher precision than the plate minima. I therefore assigned weight 10 to Borovicka's timings, weight 5 to the Frank timing, and weight 1 to each Harvard and Sonneberg plate minimum.

$$\text{Min. I} = \text{HJD } \underset{\pm 0.002}{2449004.449} + \underset{\pm 0.0000024}{5.2666874}\, E \qquad (1)$$

The O-C residuals in Table 1 were calculated from this ephemeris. Borovicka reports that the eclipses are partial with a duration of 12 hours.

Table 1. Minima of MO Aurigae.

HJD 2400000+		*E*	*O-C*
27068.693	H	-4165	-0.006
28211.573	H	-3948	+0.003
28453.844	H	-3902	+0.007
33604.705	H	-2924	+0.047
38397.267	S	-2014	-0.076
49004.449	B	0	-0.003
49020.258	B	+3	+0.006
49399.451	F	+75	-0.002

H = Harvard, S = Sonneberg, B = Borovicka, F = Frank

Table 2. Minima of RY Canis Minoris.

HJD 2400000+		*E*	*O-C*
25346.370	S	-653	+0.001
25643.470	S	-562	-0.034
27419.778	H	-18	-0.007
27478.612	H	0	+0.053
30750.309	H	+1002	-0.002
31504.590	H	+1233	+0.012
31850.667	H	+1339	-0.024
49031.385	B	+6601	-0.904

S = Sonneberg, H = Harvard, B = Borovicka

3. RY Canis Minoris

RY CMi = 283.1928 was discovered by Hoffmeister (1930), who reported an amplitude of 11.9–14.9 ptg. From five times when the variable was significantly fainter than maximum, he estimated a period of 3.2654 days. Rugemer (1933) used observations by Kukarkin (1930) to improve the period to 3.265211 days, which is cited in the GCVS. Kukarkin examined 12 plates, on two of which RY CMi appeared only 0.3 and 0.4 magnitude fainter than maximum. Borovicka (1993) determined a time of minimum that yielded a very large (+0.8 day) O-C residual from Rugemer's light elements. I observed RY CMi on 101 Harvard plates of the RH and RB series and found five minima.

Table 2 contains these five minima plus Hoffmeister's two faintest observations and Borovicka's timing. I have omitted Hoffmeister's three brighter observations and Kukarkin's two observations because they are not near minimum light and therefore do not contribute to greater precision of the period. My attempt to fit a common period to the eight best timings indicates that Borovicka's minimum is incompatible with the earlier data. A major period change must have occured at some time following the last Harvard minimum. The following light elements were calculated by least squares using only the first seven minima in Table 2 and apply only to the interval JD 2425000-32000.

$$\text{Min. I} = \text{HJD } 2427478.559 + 3.265222\,E \qquad (2)$$
$$\pm 0.013 \quad \pm 0.000015$$

The O-C residuals in Table 2 were calculated from equation (2). If a single period change occurred immediately after the last Harvard minimum, the current period would be 3.265055 days. In the near future, minima can be predicted by using Borovicka's recent epoch and this (upper limit) period. Borovicka reports that the eclipses may be total with a duration of constant light at minimum of about 0.3 hour.

4. HI Geminorum

Variability of HI Gem was discovered by Rigollet (1953). Kurochkin (1959) investigated the star on Moscow plates. He found a range of 12.3–13.4 ptg and 10 times of minima, but did not determine the period. I estimated HI Gem on 167 Harvard plates of the RH and Damon series using Kurochkin's comparison sequence and found 24 minima as defined by Kurochkin (estimated magnitude 12.9 or fainter).

I was unable to find the period, even with 34 times of minima, until I set aside the Moscow data. From the Harvard data alone I quickly found a period of 4.69 days. Seven of the 10 Moscow minima agree with this period. The remaining three minima, marked by an asterisk (*) in Table 3, are certainly erroneous, perhaps due to a mistake in

Table 3. Minima of HI Geminorum.

HJD 2400000+		*E*	*O-C*	*HJD 2400000+*		*E*	*O-C*
15100.380 *	K	—	—	40531.512	Sp	-1806	+0.168
19089.330 *	K	—	—	42154.573	H	-1460	-0.070
25330.549	H	-5046	+0.035	42445.637	H	-1398	+0.114
25344.552	H	-5043	-0.037	42811.636	H	-1320	+0.167
26334.401	Ki	-4832	-0.119	43252.553	H	-1226	+0.073
27120.401 *	Ki	—	—	43871.742	H	-1094	-0.032
27155.675	H	-4657	+0.123	45696.767	H	-705	-0.044
27474.612	H	-4589	+0.030	46029.865	H	-634	-0.051
27502.615	H	-4583	-0.117	46442.684	H	-546	-0.094
27807.668	H	-4518	-0.019	46461.607	H	-542	+0.062
28783.598	Ki	-4310	+0.056	46470.616	H	-540	-0.312
29285.490	K	-4203	-0.055	47174.707	H	-390	+0.037
29313.606	H	-4197	-0.089	47202.714	H	-384	-0.106
29365.310	K	-4186	+0.007	47446.854	H	-332	+0.070
31523.552	H	-3726	+0.107	47479.794	H	-325	+0.169
32269.390	R	-3567	-0.022	47587.592	H	-302	+0.060
32621.338	R	-3492	+0.055	47648.500	B1	-289	-0.023
32949.611	H	-3422	-0.085	47944.181	B1	-226	+0.086
34061.350	K	-3185	-0.258	47967.514	B1	-221	-0.039
34124.300 *	K	—	—	48014.388	B1	-211	-0.081
34127.300	K	-3171	+0.009	48605.600	B1	-85	-0.012
34826.350	K	-3022	+0.009	48619.651	B1	-82	-0.036
34826.410	K	-3022	+0.069	49004.397	B2	0	-0.002
35924.350	K	-2788	+0.171	49398.475	D	+84	-0.020
36163.588	Sp	-2737	+0.137	49689.365	Ha	+146	-0.008
39827.538	Sp	-1956	-0.064	49689.379	St	+146	+0.004

B1 = Borovicka visual, B2 = Borovicka CCD, D = Dedoch, H = Harvard, Ha = Hajek, K = Kurochkin, Ki = Kippenhahn, R = Rigollet, Sp = Splittgerber, St = Stepan; * = indicates erroneous; see text.

calculating or transcribing the Julian Date. Borovicka (1993) observed a CCD time of minimum and reported a period of 4.691610 days. More recently, he published six new visual timings and additional plate minima from the literature (Borovicka 1995). He also noted the three problematical Moscow minima and also one by Kippenhahn. Three visual timings have been reported by other Czech observers (Mikulasek and Zejda 1995).

All 52 times of minima are collected in Table 3. The following light elements were determined by adopting Borovicka's CCD timing as initial epoch and introducing the 48 valid times in Table 3 into a least-squares solution, again giving weight 10 to Borovicka's CCD timing and weight 1 to the visual timings and plate minima.

$$\text{Min. I} = \text{HJD } 24449004.397 + 4.6916142\,E \qquad (3)$$
$$\pm 0.005 \quad \pm 0.0000068$$

The O-C residuals in Table 3 were calculated from this ephemeris. Borovicka reports that the eclipses are total with a duration of constant light at minimum of 5.5 hours. This explains the number of O-C residuals exceeding 0.1 day in Table 3.

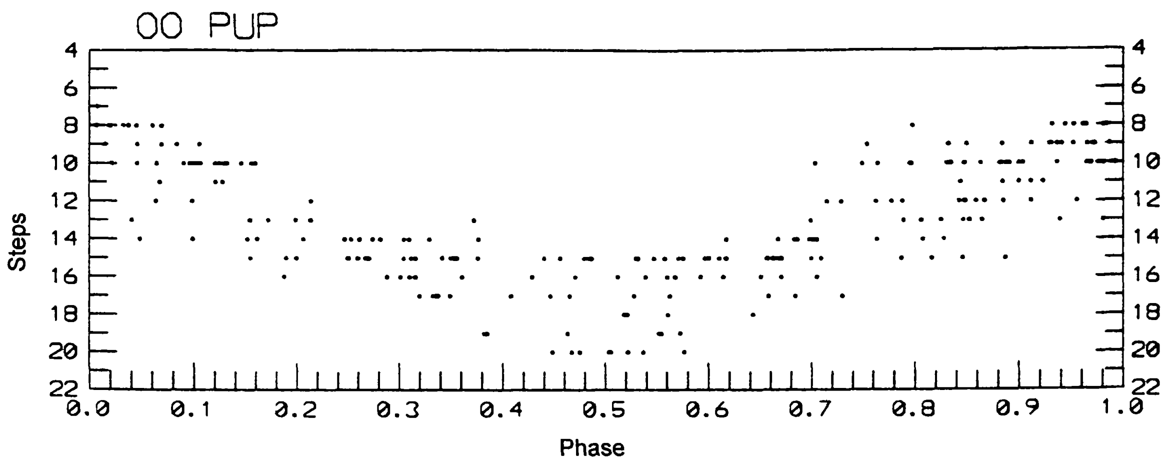

Figure 1. Harvard plate estimates of OO Puppis, made in step units (approximately 0.1 magnitude) and phased according to equation (4).

5. OO Puppis

OO Pup = S 3449 = 122.1943 was discovered by Hoffmeister (1943). Ahnert and Huth (1954) found an amplitude of 12.0–13.3 ptg and thought that OO Pup was probably a delta Cephei variable, but they did not have enough observations to find the period. I observed OO Pup on 249 Harvard plates of the RH, RB, and Damon series. A discrete Fourier transform analysis of the data quickly found a period near 10.98 days. Table 4 lists 18 times of maxima from the Harvard plates. These times were used in a least-squares solution to derive the following light elements:

$$\begin{aligned} \text{Max} = \text{HJD } &2432856.44 + 10.98612\ E \\ &\pm 0.11 \quad \pm 0.00018 \end{aligned} \qquad (4)$$

The O-C residuals in Table 4 were calculated from equation (4). The light curve (Figure 1) is essentially symmetrical.

It was difficult to identify OO Pup by comparing the Sonneberg chart with stars on the patrol plates at the published position. There is no star brighter than 15th magnitude at the GCVS position. A search of the area on the deeper Palomar Sky Survey print eventually resulted in a likely identification, and the variable was confirmed by its light changes. A later check of the *Guide Star Catalogue* (STScI 1989) showed that the variable is 2 arcminutes east of the GCVS position. OO Pup is GSC 5979:1909, RA 07^h 31^m 23^s, Decl. -16° 12.5' (1950).

Table 4. Maxima of OO Puppis.

HJD 2400000+	*E*	*O-C*	*HJD 2400000+*	*E*	*O-C*
26363.428	-591	-0.215	30043.376	-256	-0.617
27539.236	-484	+0.078	30791.543	-188	+0.494
27890.288	-452	-0.426	31143.267	-156	+0.662
28253.328	-419	+0.072	31494.384	-124	+0.223
28593.608	-388	-0.217	32208.668	-59	+0.409
28627.543	-385	+0.759	32856.524	0	+0.084
28956.575	-355	+0.208	45348.012	+1137	+0.354
28966.596	-354	-0.758	46446.091	+1237	-0.179
29340.355	-320	-0.527	47258.847	+1311	-0.396

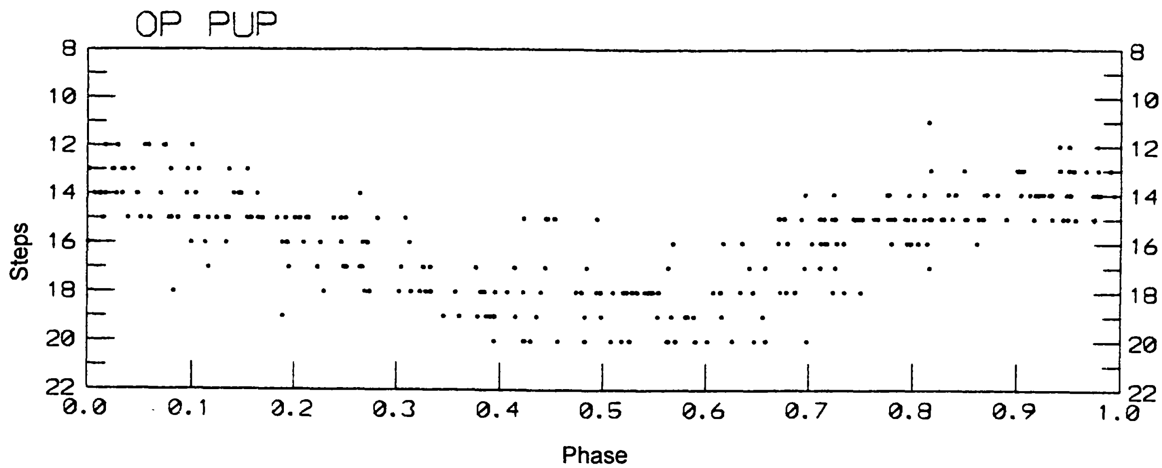

Figure 2. Harvard plate estimates of OP Puppis, made in step units (approximately 0.1 magnitude) and phased according to equation (5).

6. OP Puppis

OP Pup = 185.1932 = BV 1591 was first noted as variable by Hoffmeister (1933), who reported an amplitude of 10.5–11.5 ptg with short-period variations. Shachovskoi (1955) thought that OP Pup was RR Lyr type but did not determine a period. Strohmeier and Knigge (1974) also found variability but did not determine a period. I observed OP Pup on 299 Harvard plates of the RH, RB, and Damon series. Assuming RR Lyr variation, I used discrete Fourier transform analysis to search for periods shorter than 1 day. However, no significant peak appeared in the DFT power spectrum. I then began to search for periods longer than 1 day and the program quickly found a strong frequency peak equivalent to a period of 2.6 days. Table 5 contains 35 times of maxima from the Harvard plates. A least-squares solution of these times yields the following light elements:

$$\text{Max.} = \text{HJD } 2431144.447 + 2.598717\,E \qquad (5)$$
$$\pm 0.036 \quad \pm 0.000014$$

The O-C residuals in Table 5 were calculated from these light elements. The light curve (Figure 2) is nearly symmetrical and, with the period, indicates that OP Pup is a previously unrecognized Cepheid variable.

7. Acknowledgement

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Table 5. Maxima of OP Puppis.

HJD 2400000+	*E*	*O-C*	*HJD 2400000+*	*E*	*O-C*
25598.525	-2134	-0.259	29631.747	-582	-0.246
25619.516	-2126	-0.058	29665.647	-569	-0.130
26477.214	-1796	+0.063	29686.541	-561	-0.026
26490.210	-1791	+0.066	29717.359	-549	-0.392
26713.516	-1705	-0.118	29767.203	-530	+0.076
26768.397	-1684	+0.190	30367.404	-299	-0.026
26781.344	-1679	+0.143	30367.518	-299	+0.088
27017.891	-1588	+0.207	30668.886	-183	+0.004
27129.372	-1545	-0.057	30702.778	-170	+0.113
27189.291	-1522	+0.092	30809.258	-129	+0.046
27449.423	-1422	+0.352	31144.359	0	-0.088
27755.566	-1304	-0.154	32202.384	+407	+0.259
27810.486	-1283	+0.193	45086.840	+5365	+0.275
28511.471	-1013	-0.475	46151.908	+5775	-0.131
28623.538	-970	-0.153	46446.091	+5888	+0.397
28925.295	-854	+0.153	47258.847	+6201	-0.245
28956.575	-842	+0.248	47271.830	+6206	-0.256
28966.570	-838	-0.152			