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Research Note

The Light Variations of the Ap Star CQ UMa

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Summary. New *UBV* photoelectric measurements are presented for Ap variable CQ UMa. Period analysis based on all existing *UBV* data and discussion of CQ UMa as oblique rotator show that light variations are represented in the single-wave form with a period close to 2.45 d.

Key words: Ap variable – CQ UMa – period

1. Introduction

CQ UMa (HD 119213, HR 5153) was first recognized as a light variable on the basis of *UBV* photometry by Burke and Howard (1972). According to measurements over 28 nights, they found a light variability with a period of 1.706 d and amplitudes of $0^m.052$ and $0^m.056$ in *U* and *B*, respectively. The *V* magnitudes apparently remain constant.

Cowley et al. (1969) classified it as a SrCrEu peculiar star. This classification is in agreement with the preliminary results of elaborated spectroscopic investigation of this star conducted by Mikulašek and Grygar (1978). The star is also spectroscopic variable (Bonsack, 1974; Mikulašek, 1976) with the most prominent changes in the Cr II and Ca II lines. The spectral variations are in phase with the light variations.

Further photometric measurements were published by Winzer (1974) who also improved the original period, and found slight variability of the star in *V* in the antiphase to the *B* and *U* light curves. The *V* amplitudes were $0^m.005$. On the basis of observations done in an intermediate passband *uvby* system which is very suitable for Ap star photometry, Wolff and Morrison (1975) found two possible periods which fitted their measurements; 1.68 and 2.45 d, respectively, and then showed that the former period was false. Further *UBV* measurements done over 9 nights have been reported by Mikulašek et al. (1978) in their comprehensive study of the light variations of CQ UMa. In the same paper they combined all existing photometric observations. Besides those mentioned above, this also included ten-colour photometry by Schöneich et al. (1976) and Musielok (1976). In that way they obtained an improved value of the period $P = (2.449967 \pm 0.000025)$ d, which was previously derived by Mikulašek (1975).

Mikulašek (1976) and Mikulašek et al. (1978) have pointed out that the real photometric period of CQ UMa may be twice as large (i.e. about 4.90 d) as is the case with certain other Ap variable stars. Very tentatively they found in their "mean" light curve plotted with the double period (4.9 d) that odd and even maxima differ slightly (see Fig. 3 in Mikulašek et al., 1978).

The goal of the present paper is to investigate which one of the proposed periods is realistic. This period rediscussion is also supported with further observational material secured by the author in the years 1977 and 1978.

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Table 1. Journal of observations

JD 2 400 000^d +	Cycle and phase	V	B	U
43275.438	1031.776	6.291	6.378	6.402
43276.385	1032.163	6.292	6.379	6.397
43313.367	1047.258	6.288	6.397	6.418
43314.404	1047.681	6.294	6.400	6.424
43315.372	1048.076	6.284	6.365	6.385
43318.393	1049.309	6.282	6.416	6.432
43319.357	1049.703	6.289	6.392	6.419
43323.390	1051.349	6.289	6.420	6.439
43326.387	1052.572	6.289	6.428	6.449
43327.348	1052.964	6.284	6.376	6.400
43329.373	1053.790	6.283	6.388	6.417
43335.368	1056.238	6.280	6.393	6.412
43662.396	1189.721	6.286	6.382	6.401
43665.473	1190.976	6.297	6.368	6.387
43669.463	1192.605	6.288	6.405	6.431
43712.343	1210.107	6.292	6.374	6.391
43722.369	1214.200	6.286	6.394	6.412
43724.340	1215.004	6.295	6.366	6.390
43725.359	1215.420	6.289	6.442	6.455

2. Observations

UBV photoelectric observations presented in this paper were carried out at the Hvar Observatory using a 65-cm reflector. The telescope is equipped with a single-channel photometer described

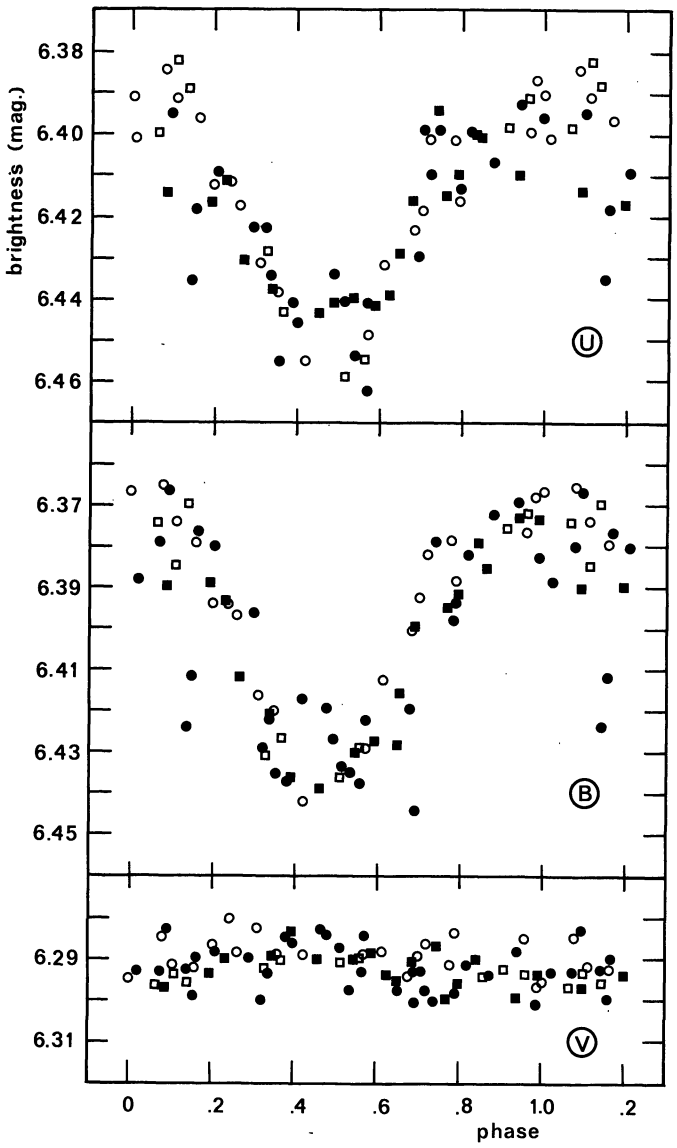

Fig. 1. The *U*, *B*, and *V* light curves of CQ UMa plotted with the 2.449967-d period. Symbols used are as follow: ● – Burke and Howard (1972), ■ – Winzer (1974), □ – Mikulašek et al. (1978), ○ – present paper. Note that open symbols represented Hvar observations

by Mayer (1977). A standard *UBV* system is reproduced with the following set of Schott filters: 2 mm UG 2 (*U*), 1 mm BG 12+2 mm GG 13 (*B*), and 2 mm GG 11 (*V*). The output of the unrefrigerated EMI 6256 S photomultiplier was fed into a strip-chart recorder in 1977 and into a pulse-counter in 1978.

As in the research by Mikulašek et al. (1978) HD 120874 was used as the comparison star. Accepted *UBV* values are: $V=6.458$, $B-V=0.086$, and $U-B=0.076$. Three other Ap stars in the vicinity of CQ UMa were also monitored: HD 118214, HD 120198, and HD 121409. Extinction was measured each night, and transformation from an instrumental to a standard system was made through measurements of the standard photometric clusters. All observations were reduced following procedures described extensively by Harmanec et al. (1977).

New 19 *UBV* measurements of CQ UMa are presented in Table 1. Cycles and phases are computed according to the ephemeris given by Mikulašek et al. (1978).

3. Period Search

The period search presented in this paper is based exclusively on *UBV* photometry. Four data sets were used: 28 measurements by Burke and Howard (1972), 18 measurements by Winzer (1974), 9 measurements by Mikulašek et al. (1978) and 19 measurements presented here. These data were checked using two computer programs kindly put at my disposal by Harmanec of the Astronomical Institute of the Czechoslovak Academy of Sciences. Program HEC 8 is based on the algorithm described by Bopp et al. (1970), while HEC 12 uses a Fourier-analysis method elaborated by Deeming (1975). All periods in the interval from 1.5 to 5.5 d were checked. Several periods fit the data sets. Of these periods of 2.45 d and 4.90 d are the most pronounced, while the others can be ruled out according to Tanner's well-known relation for spurious periodicity. It should be pointed out that the fit is better with a period of about 2.45 d.

The final step in establishing the period involved use of the program SPEL prepared for computing orbital elements of a spectroscopic binary which was kindly provided to me by Horn of the Astronomical Institute of the Czechoslovak Academy of Sciences. Shapes of the light curves of CQ UMa formally resembles a radial-velocity curve of a binary moving in an elliptical orbit. Through use of this program, it was possible to compute epochs of maximum light, period and amplitudes of the light curves by the least-square technique. Only *U* and *B* data sets were processed. The following final values were accepted:

$$\mathrm{JD_{Hel}(max)} = (2440747.5524)^{\mathrm{d}} + (2.449981)^{\mathrm{d}}\, E$$
$$\pm 0.0789 \quad \pm 0.000031$$

with amplitudes $0^{\mathrm{m}}.055$ and $0^{\mathrm{m}}.064$ for the *U* and *B* light curves, respectively. The results given above are in close agreement with the values published recently by Mikulašek et al. (1978). Thus, cycles and phases for new observations presented in Table 1 were computed according to their ephemeris. All available *UBV* data are also plotted in Fig. 1. For the purpose of our period analysis it was more interesting to use *O–C* values; i. e. observed values minus calculated values from the mean light curve. Such residuals did not show any peak at 4.90 d in Fourier expansion. Fourier analysis was made for the intrval from 0 to 1 c/d and shows only noise.

In conclusion it can be stated that a period of about 2.45 d is a real one. Discussion in the next paragraph would also support this statement.

4. Discussion

In this section results from application of the hypothesis of the oblique rotator (Deutsch, 1952) on CQ UMa are reported. The formula required by the oblique rotator is

$$R \sin i = (Pv \sin i)/50.6$$

where R is the radius given in units of solar radius, $v \sin i$ represents the observed rotational velocity in km s^{-1}, while P is the period of light, spectrum or magnetic variation expressed in days.

From a rotationally broadened profile of the Mg II 448.4 line, Mikulašek and Grygar (1978) recently estimated the projected rotational velocity, $v \sin i = (30 \pm 5)$ km s^{-1}. The radius of CQ UMa was computed according to the empirical relation between radius and $B-V$ colour index for Ap, Am, and A type stars derived by Babu (1977). The mean value of $0^m.105$ was accepted as the $B-V$ colour index of CQ UMa which yields a radius value of $R = (2.23 \pm 0.45)\ R_\odot$. Error in radius determination was estimated from the 20% error quoted in Babu's paper.

On the basis of the cited values for R, $v \sin i$ and P, it follows that under the model of oblique rotator and estimated errors in these values only the period of about 2.45 d can be real. Moreover, these values fit well in the radius-period relation for non-Si Ap stars derived by Stift (1974, 1976).

According to the period search described in Sect. 3 and in the foregoing discussion of CQ UMa as the oblique rotator, it can be concluded that light variations are in a single-wave with period close to 2.45 d.

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