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Long-term stability of the light curves of CQ Ursae Majoris

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Abstract. New UBV observations of an Ap-star CQ Uma (HD 119213, HR 5153) are compared to all previously published photometry. An improved photometric rotation period, $P_{phot} = 2.^d4499086 \pm 0.^d0000047$, is derived, since the new observations more than triple the amount of UBV photometry of CQ UMa and the time span of the photometric observations now exceeds 21 years.

We analyze the long–term stability of the light curve, including the mean brightness, amplitude of the rotational modulation of brightness, the phase of the light minimum, and the photometric rotation period. All these characteristics show strong stability over the whole period of observations, indicating constancy of the spot configuration. If this result is interpreted also as a constancy of the magnetic field structure, any cyclic amplification of the magnetic field is excluded and the magnetic field is either a fossil or a steady dynamo field.

Key words: stars: CQ UMa – photometry – activity – variable

1. Introduction

The rotational modulation of brightness of the Ap–star CQ UMa was discovered by Burke & Howard (1972). The following physical parameters are given for CQ UMa by Mikulášek (1988): A2p(SrCrEu), $P_{phot} = 2.^d449909$, $v \sin i = (33 \pm 3)\ km\ s^{-1}$, $i = 53° \pm 14°$ and $R = (2.0 \pm 0.2) R_\odot$.

Various values for P_{phot} have been suggested by Burke & Howard (1972), Winzer (1974), Wolff & Morrison (1975), Mikulášek (1975), Mikulášek et al. (1978), Pavlovski (1979) and Musielok et al. (1980). The currently accepted ephemeris HJD$(2440747.746 \pm 0.007) + (2.^d449909 \pm 0.^d000011)$E of the light maximum in B (or Strömgren v) was derived by Mikulášek (1987) using all previously published photometry and the new Strömgren photometry by Pyper & Adelman (1985). Reviews of the eventful period finding "history" of CQ UMa have been published by Mikulášek et al. (1978), Pavlovski (1979) and Mikulášek (1987).

A simple oblique rotator spot model was applied to the light curves of CQ UMa by Mikulášek (1988) assuming that the maximum projected area of a circular dark spot centered at the magnetic south pole is visible at the photometric minimum in standard Johnson B or Strömgren v. The variation of the observed effective magnetic field as a function of the photometric phase is sinusoidal, with a mean of 650 ± 80 gauss and an amplitude of 810 ± 110 gauss (Mikulášek, 1988).

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Winzer (1974) discovered that the rotational modulation of brightness of CQ UMa in V occurs in antiphase with the modulation in U and B, which was confirmed for other longer wavelengths with ten–colour photometry by Schöneich et al. (1976). The amplitude of the rotational modulation of brightness as a function of wavelength is given by Mikulášek (1988). This function has a "null point", i.e. a wavelength (5200 Å) at which the amplitude of the modulation is zero.

CQ UMa is also a spectral variable (Bonsack 1974) and the light maximum in shorter wavelengths nearly coincides with the maximum intensities of the strongly variable CrII and CaII lines (Mikulášek, 1988). The shape of the β–index curve is similar to the light curves at wavelengths longer than the "null point", i.e. the minimum equivalent width of the H_β–line occurs nearly simultaneously with the maximum brightness in the longer wavelengths (Musielok & Madej 1988).

This paper presents a new intensive set of UBV photometry of CQ UMa. We make a detailed time–series analysis using this data combined with all available photometry. Special emphasis is placed on the study of the long–term stability of the light curve of this Ap–star, which may give clues concerning the origin of magnetic fields in Ap–stars generally.

2. Observations

2.1. New observations

The differential UBV observations of CQ UMa were made at the Mount Hopkins Observatory during two seasons: 53 nights between April 3 and June 20, 1990, and 46 nights between December 19, 1990 and June 30, 1991. The measurements were obtained with the 25 cm Automated Photoelectric Telescope (APT) described in detail by Boyd et al. (1984). All new photometry of CQ UMa and the comparison star HD 119992 (C1) is listed in the standard Johnson UBV system in Table 1 and plotted in Fig. 1 as a function of phase derived from the ephemeris (this ephemeris is derived in Sect. 3.1)

$$HJD_{min} = (2440748.781 \pm 0.042) + (2.4499086 \pm 0.0000047)E. \quad (1)$$

The average internal standard deviation of the differential observations of CQ UMa were $\pm 0.^m0053$, $\pm 0.^m0040$, and $\pm 0.^m0046$ in U, B, and V, respectively. All differential magnitudes with internal errors greater than $0.^m020$ are discarded by the APT. The UBV magnitudes of the secondary comparison star (C2) of the differential photometry, HD 120874 (A2–3V), were adopted from Mikulášek et al. (1978). Then the average UBV magnitudes

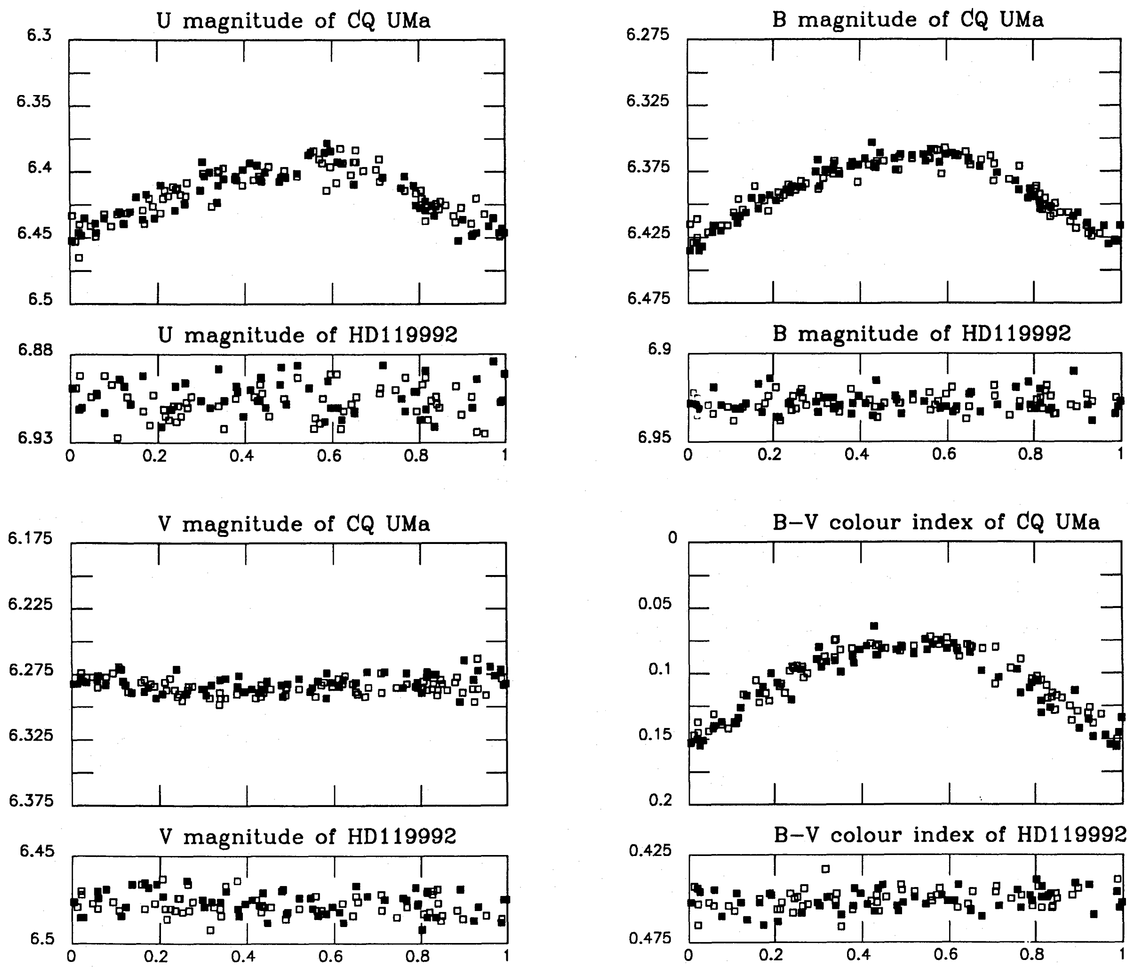

Fig. 1. The new standard Johnson UBV magnitudes and the $B-V$ colour index of CQ UMa (upper panels in each picture) plotted as function of phase derived from the ephemeris of Eq. 1. The simultaneous values for the comparison star HD 119992 are plotted on the same scale (lower panels). The observations from the first and second seasons are denoted by open and closed squares respectively

of the primary comparison star HD 119992 (F5V; Hirschfield & Sinnot 1982) in Table 2 were derived from differential photometry with respect to C2.

2.2. Previously published observations

All available photometry of CQ UMa is listed in Table 3, where a parameter SET is defined for the identication of a particular subset of photometry. The number of observing nights, the reference to the authors, the photometric system, the observing interval and the comparison star are also tabulated there. The subsets $SET = 1, 2, 4, 6$ and 8 contain all available UBV photometry of CQ UMa.

The UBV magnitudes of the comparison stars HD 120874 and HD 118214 published by Mikulášek et al. (1978) were adopted for this paper (Table 2). Consequently, the UBV magnitudes of CQ UMa in subsets $SET = 2$ and 4 are the same as those published by Mikulášek et al. (1978) (note that the photometry by Winzer (1974) is in the instrumental system). The UBV photometry by Pavlovski (1979) was adopted without any alterations, since he used the same values for the comparison star HD 120874 as given in our Table 2.

HD 120874 was used as the secondary comparison star to derive the UBV magnitudes of our comparison star HD 119992. Except for the B–magnitude, the new values of HD 119992 in Table 2 are quite similar to those published by Mikulášek et al. (1978). Since HD 119992 was also the comparison star used by Burke & Howard (1972), our new values were added to their differential magnitudes and these values will differ from those published by Mikulášek et al. (1978).

When the ephemeris of CQ UMa was derived by Mikulášek (1987) two erroneous B magnitude observations by Burke & Howard (1972) were excluded from the analysis. This approach is repeated and the discarded observations are the B magnitudes from $HJD = 2440762.6$ and $HJD = 2441127.6$. The U magnitude at the latter date was also excluded. One u magnitude observation by Pyper & Adelman (1985) on $HJD = 2445474.7$ and two U^{10} magnitudes by Musielok et al. (1980) on $HJD = 2442238.3$ and $HJD = 2442825.6$ were also excluded from the analysis. Mikulášek (1987) did not have to exclude the four extra points (U, u and U^{10}) mentioned above, since his analysis was based on B, v and X^{10} magnitudes.

Table 1. The new APT observations of CQ UMa and the comparison star HD 119992 in the standard Johnson UBV system. The heliocentric Julian dates are given as $HJD - 2440000.0$

	CQ UMa			HD119992		
HJD	*U*	*B*	*V*	*U*	*B*	*V*
7984.760	6.389	6.358	6.283	6.919	6.929	6.481
7984.776	6.392	6.359	6.281	6.905	6.927	6.483
7987.755	6.415	6.389	6.285	6.912	6.931	6.477
7987.841	6.424	6.401	6.282		6.918	6.470
7987.977	6.437	6.413	6.277	6.898	6.929	6.481
7989.905	6.398		6.292			
7990.743	6.452	6.429	6.282	6.899	6.922	6.479
7990.764	6.439	6.425	6.280	6.892	6.925	6.472
7991.742	6.405	6.370	6.293	6.904	6.926	6.475
7991.774	6.405	6.369	6.283	6.897	6.930	6.478
7992.735	6.428	6.395	6.286	6.906	6.921	6.472
7992.765	6.425	6.409	6.291	6.904	6.924	6.469
7992.822	6.424	6.406	6.287			
7993.738	6.410	6.385	6.287	6.909	6.928	6.481
7993.755	6.412	6.387	6.292	6.918	6.932	6.474
7993.815	6.407	6.387	6.284	6.910	6.925	6.481
7994.737	6.401	6.360	6.282	6.908	6.937	6.484
7994.753	6.391	6.367	6.288	6.912	6.930	6.473
7995.726	6.440	6.421	6.277	6.904	6.929	6.477
7995.802	6.431	6.416	6.277	6.892		
7996.724	6.395	6.367	6.286	6.915	6.928	6.479
7996.813	6.398	6.364	6.285		6.928	6.483
7997.765	6.432	6.406	6.281			
8002.776	6.446	6.422	6.296			
8003.707	6.400	6.388			6.924	
8003.788	6.399	6.373	6.298			
8005.702		6.396				
8007.695	6.419	6.424	6.286	6.924	6.927	
8007.740	6.431	6.422	6.291	6.925		6.484
8008.695	6.398	6.367	6.293		6.931	6.484
8009.855	6.436	6.392	6.287	6.893	6.925	6.470
8010.753	6.419	6.397	6.282	6.920	6.928	
8010.815	6.430				6.919	6.463
8011.682		6.365		6.916	6.932	6.481
8015.672	6.425	6.405	6.284	6.903	6.924	6.477
8015.740	6.413	6.395	6.287	6.915	6.938	6.486
8016.703	6.407		6.278	6.891	6.919	
8016.741	6.392	6.363	6.276	6.912		
8017.672	6.432	6.415				
8018.735	6.406	6.367	6.289	6.902	6.936	6.479
8019.668	6.425	6.404		6.917	6.931	6.482
8019.731	6.427	6.407	6.279	6.910	6.934	6.487
8019.858	6.426	6.418	6.289	6.914	6.930	6.486
8020.662	6.417	6.393	6.278	6.917		6.480
8020.729	6.416	6.389	6.295	6.915	6.931	6.482
8020.883		6.380	6.293		6.925	6.492
8025.686		6.384	6.284	6.904	6.929	6.476
8025.804	6.425	6.376			6.928	6.479
8026.673		6.366	6.285			
8026.726	6.397	6.363				
8027.688	6.440	6.416	6.274	6.897	6.930	6.476
8027.865	6.428	6.401	6.279	6.912	6.930	6.480
8029.715	6.438	6.416	6.286	6.904	6.923	
8030.770	6.396	6.375	6.293	6.922	6.933	6.467
8032.674	6.430	6.404	6.288	6.904	6.930	
8033.799	6.413	6.377				
8036.689	6.413	6.371	6.282	6.893	6.927	6.479
8036.779	6.413	6.388	6.286			
8037.674	6.438					
8039.679	6.448	6.428	6.278	6.907	6.925	6.486
8040.677	6.409	6.383				
8041.685	6.419	6.386	6.280	6.897	6.926	6.483
8041.765	6.423	6.402	6.287	6.908	6.931	6.477
8042.681	6.419	6.391	6.281	6.911	6.936	6.480
8042.760	6.411	6.386	6.290	6.909	6.924	6.474
8043.676	6.381	6.363	6.282	6.922	6.932	6.477
8043.760	6.382					
8044.661	6.464	6.411	6.274		6.935	6.470
8044.753	6.448	6.416	6.285	6.902	6.934	6.480
8045.669	6.402	6.371	6.292	6.906	6.930	6.482
8045.807	6.402	6.374	6.291	6.905	6.928	6.486
8046.690	6.421	6.399	6.282		6.934	6.484
8047.707	6.417	6.382	6.287	6.907	6.920	6.466
8048.662	6.391	6.370	6.290	6.904	6.922	6.476
8048.792	6.389	6.382	6.274	6.902	6.918	6.472
8053.695	6.406	6.369	6.289	6.899	6.924	6.481
8054.671	6.431	6.406	6.269	6.927	6.938	6.481
8055.682	6.402	6.365	6.286	6.893	6.926	6.480
8056.691			6.263			
8057.689	6.398	6.377	6.289	6.909	6.931	6.480
8058.680		6.381	6.285	6.900	6.935	6.485
8059.694		6.386	6.281			6.466
8060.675	6.383	6.364	6.292	6.922	6.922	6.473
8060.769	6.395	6.357	6.284	6.891	6.923	
8062.683	6.404	6.371	6.290	6.905	6.920	6.464
8245.046	6.421	6.403	6.273	6.911	6.928	6.485
8245.068			6.275			
8258.037	6.430	6.414	6.280			
8265.006	6.440	6.416	6.269			
8268.980			6.274			
8269.012	6.383	6.362	6.281	6.910	6.930	6.479
8269.049	6.391	6.361	6.284	6.910	6.933	6.482
8269.982	6.442	6.428	6.283	6.906	6.930	6.475
8270.012	6.451	6.435	6.282	6.899	6.928	6.476
8270.050	6.445	6.429	6.279	6.911	6.929	6.485
8388.690	6.399	6.361	6.280	6.910	6.930	6.488
8388.805	6.403	6.362	6.282	6.908	6.934	6.482
8389.804	6.435	6.406	6.264			
8390.687	6.423	6.387	6.290	6.896	6.922	6.464
8390.787	6.391	6.366	6.286		6.933	6.479
8391.700		6.371	6.273		6.933	6.473
8391.797	6.403	6.376	6.273	6.886	6.929	6.475
8392.687	6.434	6.420	6.283	6.913	6.929	6.469
8392.794	6.438	6.409	6.283	6.898	6.931	6.479
8393.680	6.403	6.374	6.292	6.887	6.926	6.469
8394.677	6.451	6.409	6.296		6.910	6.469
8395.676	6.413	6.375	6.286	6.906	6.927	6.475
8395.771	6.422	6.374			6.925	
8397.670	6.429	6.409	6.271	6.894	6.931	6.484
8397.764	6.418	6.395				
8398.670	6.400	6.363	6.278	6.886	6.923	6.474
8398.744	6.384	6.367	6.285			6.480
8399.655	6.447	6.414	6.279	6.910	6.929	6.487
8399.681	6.445	6.420	6.272	6.894	6.938	6.479
8400.677	6.409	6.369	6.279	6.888	6.930	6.476
8400.782	6.405	6.368	6.276	6.901	6.928	6.484
8401.703	6.411	6.382	6.285	6.905	6.919	6.474
8401.774	6.409	6.395	6.284	6.901	6.916	6.468
8402.701	6.435	6.403	6.288	6.892	6.917	6.465
8402.767	6.434	6.393	6.293		6.914	6.466
8403.674		6.358	6.280			6.484
8403.738	6.377			6.895		
8404.677	6.434	6.430	6.276	6.884		
8404.738	6.445	6.416	6.282	6.891	6.927	6.475
8405.674	6.402	6.371	6.284	6.898	6.934	6.480
8405.754	6.392	6.365	6.286	6.900	6.928	6.475
8406.684	6.424	6.388	6.281	6.901	6.929	6.478
8406.739	6.428	6.398	6.277	6.889	6.920	6.471
8407.762		6.389		6.911		
8409.792	6.445	6.416	6.276	6.903	6.919	6.474
8410.696	6.394	6.353	6.289	6.906	6.935	6.478
8411.690	6.432	6.401	6.275	6.921	6.932	6.485
8412.681	6.428	6.391	6.271	6.898	6.927	
8413.687	6.408	6.365	6.281	6.913	6.923	6.467
8414.686	6.438	6.421	6.279			6.470
8415.720	6.406	6.365	6.283	6.897	6.924	6.470
8417.748	6.402	6.386	6.291			
8422.677	6.399	6.374	6.283	6.910	6.925	6.476
8424.678	6.429	6.406	6.289	6.908	6.928	6.466
8425.681	6.386	6.362	6.288	6.899	6.927	6.474
8427.657	6.404	6.377	6.278	6.906	6.929	6.470
8428.672	6.402	6.389	6.274	6.912	6.930	6.475
8429.672	6.416	6.395	6.285		6.933	6.468
8430.671	6.384	6.368	6.293	6.918	6.931	6.483
8431.659	6.445	6.427	6.271		6.934	6.488
8432.663	6.397	6.370	6.288	6.915	6.924	6.477
8433.659	6.426	6.394	6.289	6.917	6.931	6.492
8434.652	6.409	6.397	6.290	6.921	6.936	6.473
8435.665	6.392	6.362	6.279	6.917	6.930	6.488
8436.657	6.447	6.435	6.280	6.910	6.931	6.485
8436.675	6.434	6.432	6.281			
8437.662	6.404	6.372	6.286	6.893	6.915	6.471

Table 2. The values of the magnitudes used for the primary and secondary comparison stars of all available UBV photometry of CQ UMa. The identification is given on the first and the reference on the fifth column, respectively

	U	B	V	
HD 119992	6.905 ± 0.010	6.928 ± 0.005	6.477 ± 0.007	This paper
HD 120874	6.620 ± 0.012	6.544 ± 0.008	6.458 ± 0.009	Mikulášek et al. 1978
HD 118214	5.510 ± 0.013	5.562 ± 0.012	5.597 ± 0.011	Mikulášek et al. 1978

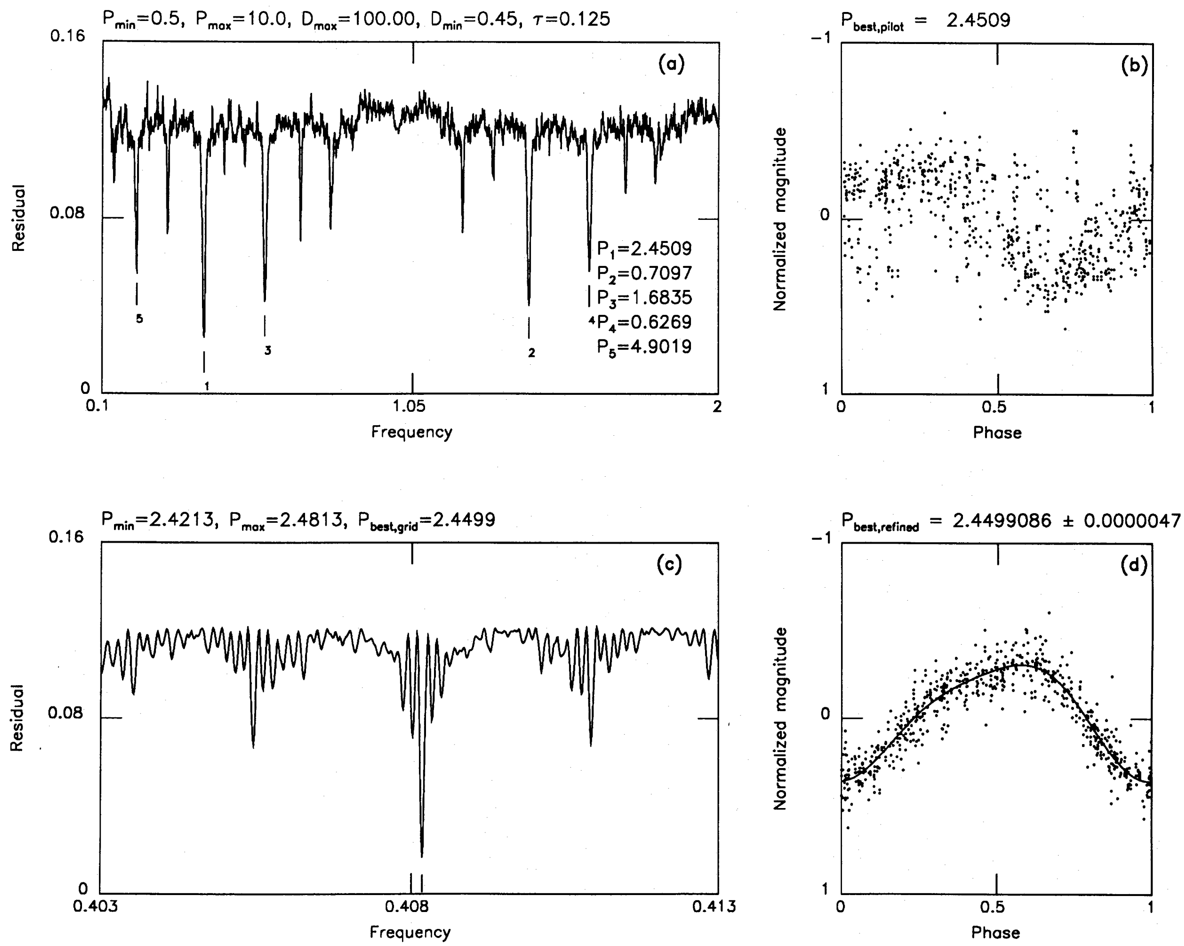

Fig. 2. The TSPA of all normalized photometry: (**a**) The periodogram of the pilot search and the best periods in their order of significance are shown and also marked with short vertical lines below the periodogram. The parameters P_{min}, P_{max}, D_{min}, D_{min} and τ are explained in text. (**b**) All normalized photometry plotted as a function of phase derived with $P_{best,pilot} = 2.^{d}4509$ using the zero point of Eq. 1. (**c**) The periodogram of the grid search between $2.^{d}4213$ and $2.^{d}4813$ using the form of the fit of Eq. 3. The best period, $P_{best,grid} = 2.^{d}4499$, is indicated by a short vertical line below the periodogram . (**d**) All normalized photometry plotted as function of phase derived with the final refined period $P_{best,refined} = 2.^{d}4499086 \pm 0.^{d}0000047$ using the zero point of Eq. 1

2.3. Normalized observations

The normalized magnitudes are useful in the period search and in the study of the phase coherence of the photometric minimum ϕ_{min} and maximum ϕ_{max}. The rotational modulation in the longer wavelengths occurs in antiphase to the modulation in wavelengths shorter than the "null point", and has in most cases an amplitude comparable to the average mean error of measurements (e.g V or y). The following magnitudes from the wavelengths shorter than the "null point" were normalized separately inside every SET: U, B (broad band: standard or instrumental), u, v, b (narrow band: standard or instrumental) and U^{10}, P^{10}, X^{10}, Y^{10} (ten colour photometry: instrumental). These normalized passbands are underlined in Table 3. For any $m(t_i)$ of the above magnitudes in an individual SET, the mean $\bar{m}$ and the deviation Δm from the mean were first derived. Then, the normalized magnitudes $m_n(t_i)$ were derived from the relation

$$m_n(t_i) = (m(t_i) - \bar{m})/(4\ \Delta m), \qquad (2)$$

where t_i are the observing times and the number 4 is an arbitrarily chosen scaling factor.

This normalization is more straightforward than the one adopted by Mikulášek et al. (1978). It increases the amount of

Table 3. All photometry of CQ UMa: the first column defines the subset number (SET) used for observations by the authors in the third column. N is the number of observing nights inside the subset. The fourth column gives the photometric system, with the normalized passbands underlined. The observing interval and the comparison star are given in the two last columns

SET	N	Author	Photometric system	Observing interval	Comparison star
1	28	Burke & Howard 1972	$\underline{UB}\ V$	12. 6. 1970 - 4. 7. 1971	HD119992
2	18	Winzer 1974	$\underline{UB}\ V$	1. 6. 1971 - 24. 5. 1972	HD118214
3	25	Wolff & Morrison 1975	$\underline{uvb}\ y$	17. 2. - 30. 5. 1973	HR120874
4	9	Mikulášek et al. 1978	$\underline{UB}\ V$	25. 5. 1973 - 16. 7. 1975	HD120874
5	20	Musielok et al. 1980	$\underline{U^{10}P^{10}X^{10}Y^{10}}\ Z^{10}$...	30. 6. 1974 - 7. 8. 1975	HD120874
6	19	Pavlovski 1979	$\underline{UB}\ V$	11. 5. 1977 - 4. 8. 1978	HD120874
7	25	Pyper & Adelman 1985	$\underline{uvb}\ y$	9. 4. 1980 - 28. 3. 1984	–
8	99	This paper	$\underline{UB}\ V$	3. 4. 1990 - 30. 6. 1991	HD119992

observations available for the period analysis by eliminating the differences of the mean brightness or the amplitude of the light curves as well as the differences between photometric systems. All information of the observations is used simultaneously and the need to analyse the observations in separate passbands and subsets is avoided. This normalization contains no assumption of the photometric rotation period or the overall shape of the light curve. However, it is based on the assumption that the shape of the light curve is reasonably similar in every separate passband and photometric system. The same assumption was also made by Mikulášek et al. (1978) and Mikulášek (1987). The differences of these shapes were found insignificant. This is illustrated in Fig. 2d showing all normalized photometry. The u and U^{10} passbands may show some deviations from the long–term average shape of the light curve, but even in these passbands (which also have the largest errors) the overall shape is reasonably similar.

Our normalization has two drawdacks: 1) if the observations contain two periodic functions (or more) added together, the normalization may eliminate the possibility of revealing both periods, since it distorts their interference curve (both the amplitude and the mean), 2) the residuals of the normalized magnitudes are not comparable, if the amplitudes of the original observations are not equal. Consequently the period analysis of the residuals must be applied only to the original observations. In the present case this is not the case (see Sect. 4).

3. The period analysis

3.1. All normalized photometry

The mathematical formulation of the three stage period finding analysis (TSPA) is described in detail by Pelt (1983, 1992). The three stages are performed in the following order: I) the pilot search, II) the grid search and III) the refinement of the period by a non–linear χ^2 fit.

The pilot search (Fig. 2a) derives the approximate best periods inside a very large period interval. The selected period interval was between $P_{min} = 0.^d5$ and $P_{max} = 10^d.0$. The parameters $D_{min} = 0.^d45$ and $D_{max} = 100.^d0$ define the maximum and minimum correlation interval in time used in deriving the periodogram of the pilot search. The parameter τ defines the correlation interval in phase and also very loosely the shapes of the light curve for which the periodogram of the pilot search will be sensitive.

The five best periods indicated by the pilot search were tested separately in the grid–search, where the form of the light curve fit is fixed. The form of the fit was:

$$Y(t) = M + Acos(\frac{k}{P}) + Bsin(\frac{k}{P}) + Ccos(\frac{2k}{P}) + Dsin(\frac{2k}{P}), \quad (3)$$

where $k = 2\pi t$. The free parameters are the mean M and the amplitudes A, B, C and D. The period P is a fixed parameter in the grid–search, i.e. any of the tested period values. The periodogram of the grid search (Fig. 2c) is the average of the square of the residuals of the chosen fit for the tested period value. At the third stage of TSPA the result of the grid search is refined with a non–linear χ^2 fit to the final value of the period by treating P also as free parameter in Eq. 3.

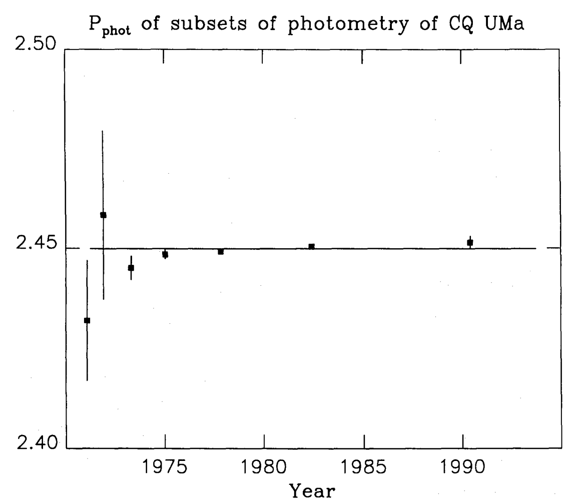

Fig. 3. One hundred bootstrap rounds were performed by applying TSPA between $P_{min} = 2.^d40$ and $2.^d50$ to separate subsets using the form of Eq. 3. The results are plotted as a function of the average observing times of every SET. The straight line outlines the value of P_{phot} of the ephemeris of Eq. 1

The pilot search for a second order Fourier approximation of the light curve of CQ UMa ($\tau = 0.125$) gave $2.^d4509$ as the best period. The three next significant minima of the periodogram are spurious periods predicted by the Tanner (1948) equation. The fifth significant period is twice the actual period. The grid search

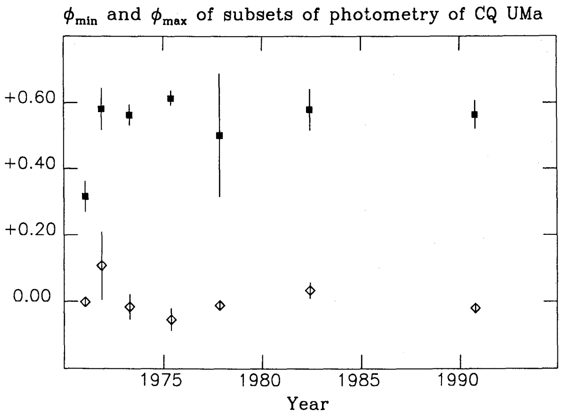

Fig. 4. The bootstrap analysis of separate subsets using Eq. 4 with P fixed to $2.^d4499086$. The results for ϕ_{min} and ϕ_{max} are denoted by open diamonds and closed squares, respectively

(Fig. 2c) gave $2.^d4499$, which was refined to $2.^d4499086$. All normalized photometry is shown in Fig. 2d.

Within the error limits TSPA gives the same result for the first order Fourier approximation of the light curve. Finally, the power spectrum method (Press & Teukolsky 1988) was applied as an independent checking routine, which confirmed our result. The advantage of TSPA is that it can find a periodic function of any shape and it also gives a unique value of the final period and its error. Most of the traditional methods (e.g. power spectrum) are limited to sinusoidal shapes and test a discrete set of periods. It is evident that a second order Fourier fit is required to describe the asymmetric light curve of CQ UMa. For a fixed P_{phot} a suitable form for the light curve fit is

$$Y(\phi) = M + A_1 \, cos[2\pi(\phi - \phi_1)] + A_2 \, cos[4\pi(\phi - \phi_2)], \qquad (4)$$

where ϕ is the photometric phase derived from Eq. 1. The free parameters are the mean M, and the amplitudes A_1 and A_2 of the first and second order terms with their minima at ϕ_1 and ϕ_2, respectively.

The zero point of the ephemeris, i.e. the occurrence of the photometric minimum, was derived with the bootstrap method. P_{phot} was fixed at $2.^d4499086$ and 100 bootstrap rounds for fits of the form of Eq. 4 were performed for all normalized photometry. The formulation of this non–parametric bootstrap for the regression coefficients can be found in Efron & Tibshirani (1986). The advantage of the bootstrap is that the values and errors of the photometric minimum ϕ_{min} and maximum ϕ_{max} (and the total amplitude) of a second order Fourier fit can be derived, although their analytical forms remain undetermined.

The new ephemeris gives $\phi_{min} = 0.000 \pm 0.017$, while the maximum will be at $\phi_{max} = 0.572 \pm 0.031$. "Traditionally" the zero point of the ephemeris of CQ UMa has always referred to the photometric maximum (see e.g. Mikulášek et al. 1978). However, the maximum of the light curve is flat while the minimum, on the other hand, is very sharp (Figs. 1, 2d, and 5). Consequently this feature is more suitable for an accurate determination of the ephemeris. The "traditional" zero point for the maximum brightness would be at HJD(2440747.732$\pm$0.076). The zero point of Eq. 1 is placed, following the approach of the previous authors, before the first observation by Burke & Howard (1972). Our final value for P_{phot} is within the error limits of the value published by Mikulášek (1987) and a very close agreement is achieved for the zero point of the ephemeris. The accuracy of our zero point is lower, although the period is considerably more accurate and the zero point is fixed to the sharp light minimum. The bootstrap gives this error and since we do not know how the error of this parameter was derived by Mikulášek (1987), we only note that the equations of ϕ_{min} and ϕ_{max} of a second order Fourier fit (and the error) are far from trivial to derive analytically.

3.2. Subsets of normalized photometry

All normalized photometry (Sect. 3.1.) was used to derive the photometric rotation period and the ephemeris of CQ UMa . This section studies the possible changes of P_{phot}, ϕ_{min} and ϕ_{max} inside separate subsets of normalized photometry.

TSPA was made between $P_{min} = 2.^d40$ and $P_{max} = 2.^d50$ to the form of Eq. 3 with P as a free parameter and repeated for 100 bootstrap rounds for every subset. The subset $SET = 4$ was omitted from this bootstrap, since it contains only nine nights of observations. The result in Fig. 3 shows that the rotation period of CQ UMa has remained constant. The first two subsets may have contained good observations, discarded (or erroneous, accepted) by Burke & Howard (1972) and Winzer (1974), since both these previously mentioned studies of P_{phot} arrived at the (spurious) periods near $1.^d7$. In any case, Fig. 3 excludes the possibility of strong differential rotation, which was already indicated by the phase coherence in Fig. 2d.

The form of Eq. 4 was then chosen, with P fixed to $2.^d4499086$, and the subsets were bootstrapped for 100 rounds to derive the values of ϕ_{min} and ϕ_{max} ($SET = 4$ was again excluded). Fig. 4 shows that the phase coherence for ϕ_{min} is more convincing than for ϕ_{max}. This follows directly from the shallow shape of the light maximum compared to the very sharp shape of the minimum of the light curves. Conclusively, the phase coherence of both these parameters is satisfactory.

4. The long–term UBV photometry

Normalized magnitudes are suitable for study of P_{phot}, ϕ_{min} and ϕ_{max}. However, the original magnitudes must be used for the study of the possible changes of the mean brightness or the amplitude of the rotational modulation of brightness. All standard Johnson UBV photometry of CQ UMa is shown in Fig. 5. As an exception, the observations by Winzer (1974) are in the instrumental UBV system. No significant changes seem to have occurred in the light curve of CQ UMa. The mean values and amplitudes of all plotted parameters of different subsets are the same within $\pm0.^m015$ or less. The photometric maximum has shifted, but these shifts occur at random and are most prominent in the subsets with only a few observations. Consequently they can be attributed to the shallow shape of the light maximum. The stability of the sharp light minimum is convincing. The modulation of the $B-V$ colour index has a remarkably high amplitude, since the modulation in V occurs in antiphase to B. Mikulášek et al. (1978) noted that this anomalous energy distribution of CQ UMa is closest to that of a normal main sequence star at the phase of the photometric maximum in B and U.

The residuals of the light curve fits of the original UB magnitudes of CQ UMa showed no periodicity. Furthermore, no periodicity was found from the UBV magnitudes of the comparison star HD 119992. Thus the observations of CQ UMa do not seem to contain two (or more) periodic functions, and the

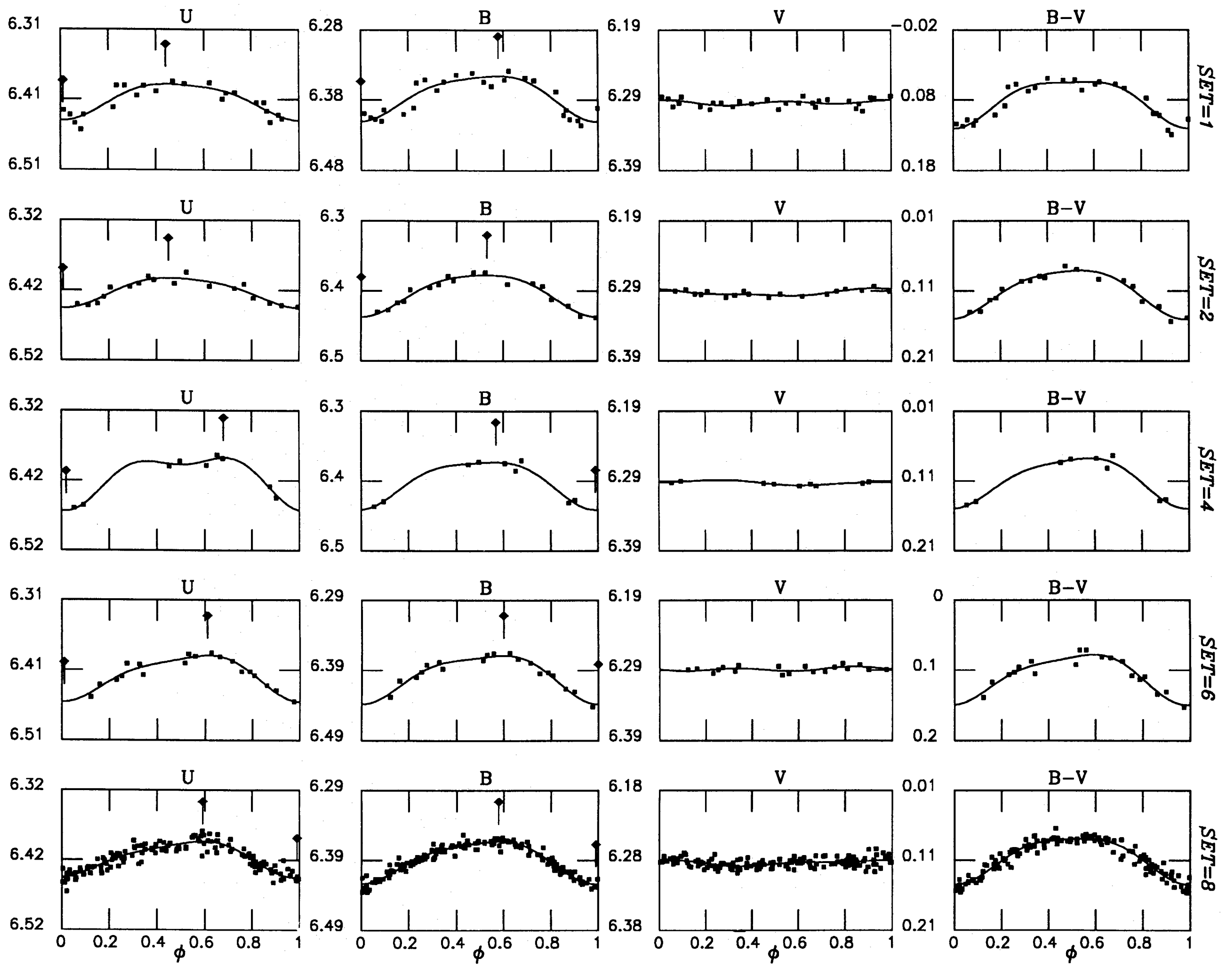

Fig. 5. All UBV light curves and $B - V$ colour index curves plotted as a function of the phase derived according to Eq. 1. The form of the fit was that of Eq. 4. The values of ϕ_{min} and ϕ_{max} in U and B passbands are indicated by lines with closed diamonds on top. The centre tick of the ordinate of every parameter is at the average value observed during the respective subset and the scale of every picture is the same. Note that none of the plotted parameters shows significant changes, i.e. changes greater than $\pm 0.^{m}015$

previously mentioned drawbacks of the normalization should not mislead the TSPA of CQ UMa.

5. Conclusions

The accuracy of P_{phot} of CQ UMa has been improved. The new ephemeris is in accordance with the previous one by Mikulášek (1987). The phase coherence of the light minimum and, to a lesser extent, the light maximum, is excellent. This phase coherence places very strict limits to the possibility of redistribution or migration of the spot distribution, i.e. any short–term evolution. The period analysis of separate subsets excludes the possibility of any detectable differential rotation in CQ UMa. Long–term UBV photometry shows no significant changes in the mean brightness or the amplitude of the rotational modulation of brightness between separate subsets. The small discrepancies of the mean brightness can be attributed to inaccuracies of the comparison star magnitudes ($\pm 0.^{m}015$) and/or errors in the transformations from the intrumental to the standard system. The minor differencies of the shapes and amplitudes of the light curve between different subsets seem to arise from the small amount of observations in some subsets and/or a few errors among the measurements, which distort the light curve.

A general discussion of the characteristics of the "fossil magnetic fields" can be found in the review by Moss (1986), where it is noted that the current debate of the origin of the magnetic fields of the Ap–stars is between proponents of the contemporary dynamo and fossil field theories. Given a connection between the superficial spots and the strong magnetic fields of the Ap–stars, then our analysis has some relevance to this question. The study performed in this paper indicates that time scale and extent of any detectable changes of the spot configuration of the Ap–star CQ UMa are far from being as drastic or radical as those exhibited by the rapidly rotating cool late–type stars with dynamo generated magnetic fields. Hence, the present analysis of all currently available photometry of CQ UMa seems to favour the alternative of fossil magnetic field generated spot configurations (see also Moss 1989). However, the possibility of a stationary (non–oscillating) dynamo in this Ap–star can not be excluded.

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