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I. UBV photometry of selected members of the Pleiades and Alpha Persei clusters in 1999

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Abstract. The rotational brightness variations in magnetically active stars are due to the combined light contribution of cool spots and bright faculae on the stellar photosphere. The amplitude of the rotational brightness variations can be used to probe the dependence of the amount of photospheric magnetic fields associated to such inhomogeneities on global stellar parameters such as the rotation rate. However, the upper envelope of the amplitude values must be considered, since the rotational modulation amplitude represents a lower limit of the spots and faculae coverage, being their visibility modulation reduced by several factors. In order to determine accurately the maximum amplitude upper envelope and its dependence on global stellar parameters a program of photometric monitoring of ultra fast rotating active members of the Pleiades and Alpha Persei star clusters was undertaken in the fall of 1999. Light curves and period determinations of 21 target stars are presented as result from the first observing season. The newly determined values of amplitudes of the brightness variations versus rotation period have values as expected based on previous results.

Key words. stars: late-type – activity – rotation – starspots

1. Introduction

The brightness variability of late-type stars, on the time scale of the star's rotation period, is attributed to the combined light contribution of dark and bright inhomogeneities on the stellar photosphere, such as dark starspot and bright plages respectively, which are carried in and out-of-view as the star rotates (see e.g. Lanza & Rodonò 1999; Strassmeier & Linsky 1996). In ultra fast rotating stars, such as the active members of young open star clusters, on which the present program is focused, short- and long-term brightness variability is mainly dominated by dark spots, the plages contribution being negligible. The latter dominates the long-term variability in slow rotating stars, such as the Sun (e.g. Radick et al. 1989, 1998; Foukal & Lean 1988). The presence of dark spots is determined by the emergence into the photosphere of bundles of intense magnetic flux tubes, whose generation and intensification is attributed to the action of a hydromagnetic dynamo (Parker 1979; Schüssler 1983).

Therefore, the fraction of stellar photosphere covered by spots represents a measure of the photospheric magnetic filling factor by spots ($f_{\rm S}$), which may be used to probe the dependence of that fraction of photospheric magnetic activity confined to spots on global stellar parameters. However, the value of the spot coverage and, consequently, of the magnetic filling factor ($f_{\rm S}$) must be considered as a lower limit when it is inferred from the rotational brightness variability amplitude. In fact, several factors such as the inclination (i) of the star's rotation axis and the latitude where the spots or spot groups are centred, the total fractional area covered by spots and the asymmetric component of their longitudinal distribution, all play a key role in reducing the visibility modulation of the total spots area projected onto the stellar disk.

As predicted by the dynamo theory, which expects the magnetic flux density to decrease towards slow rotation rates, the maximum light curve amplitude from extended time series ($A_{\rm max}$) is found to be a decreasing function of the rotation period ($P_{\rm rot}$). However, analysing a large sample of single lower main-sequence stars of known rotation period and with well determined light curve amplitude, Messina et al. (2001) have noted that the data upper envelope in the rotation-amplitude relations displays different behaviours when considering the following different rotation period ranges:

$P \leq 1.10$ (d) (*ultra fast* rotators)
$P > 1.10$ (d) (*fast* rotators).

The existence of these rotation ranges is better seen considering K-type stars, which are the most numerous in the studied sample. In particular, the maximum light curve amplitude shows different decreasing slopes when passing from *ultra fast* to *fast* rotators. In order to better determine the maximum amplitude upper envelope position and its dependence on rotation period on a

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Table 1. Journal of the observations

HII number	HJD-2450000	Date (1999) October	November
250	1462–1492	10–13	8–10
324	1461–1492	9–13	9–10
335	1457–1492	5–13	10
345	1458–1492	6–13	8–10
625	1457–1492	5–13	8–10
686	1457–1492	6–13	8–10
738	1457–1492	6–13	8–9
739	1457–1492	6–13	8–10
882	1457–1492	5–11	8–10
1039	1457–1492	6–13	8–10
1532	1457–1492	5–13	8–10
1653	1462–1492	11–13	8–10
2244	1461–1490	10–13	8
3063	1457–1492	6–13	8–9
AP number	HJD–2450000	December (1999)	
15	1515–1517	2–4	
19	1515–1517	2–4	
32	1515–1517	2–4	
43	1515–1517	2–4	
93	1515–1516	2–3	
193	1515–1516	2–3	
244	1515–1517	2–4	

more statistically robust ground, a larger number of light curves is needed for each star. In fact, only from a large number of light curves covering a sufficiently extended time interval the amplitudes can reliably approach their maximum value. Therefore, a program of photometric monitoring of *ultra fast* rotating active members of the Pleiades and Alpha Persei star clusters was undertaken in the fall of 1999.

2. Observations

The photoelectric photometry presented in this paper was carried out in October 5–12, November 6–8 and December 2–4 1999 (Table 1) with the 91-cm Cassegrain telescope at the "M. G. Fracastoro" station of Catania Astrophysical Observatory on Mt. Etna (Italy).

The telescope feeds a single channel photon-counting photometer equipped with a cooled EMI 9893Q/350A photomultiplier and standard UBV filters. The program stars were observed differentially with respect to two close comparison stars:
HD 23654 (c1) ($V = 7.72$, $B-V = +1.23$, $U-B = +1.12$)
HD 23712 (c2) ($V = 6.46$, $B-V = +1.70$, $U-B = +2.07$)
for the Pleiades members, and
HD 22156 (c3) ($V = 7.32$, $B-V = +1.11$, $U-B = +0.84$)
HD 20296 (c4) ($V = 7.53$, $B-V = +0.06$, $U-B = -0.01$)
for the Alpha Persei members. The integration time in U, B and V filters for the program stars was set to 48, 24 and 24 s, respectively, and the observing sequence $c-v-v-c$ was employed, where (v) is the program star. The sky was measured close to each star. After sky background subtraction, the observations were corrected for atmospheric extinction and converted into the Johnson UBV system by means of standard stars which were observed each night. Due to the short duration of an observing sequence, the two $v-c$ values were finally averaged to obtain one single data point. No significant light variations were detected from the differential measures of the comparison stars, indicating that the light of the comparison stars was constant, within 0.015, 0.017, 0.020 mag in the V band and $B-V$ and $U-B$ colours, respectively.

The observations of each program star have been analysed using a Scargle-Press period search routine to derive the period of the photometric modulation (Scargle 1982; Horne & Baliunas 1986). In Table 2 the author reports the Hertzprung (HII) and AP catalogue number, variable name, brightest V-band magnitude, mean $B-V$ and $U-B$ colours, V-band light curve amplitude, photometric period (P) obtained by the periodogram analysis and its uncertainty (ΔP), *false-alarm-probability* (FAP) of the peak frequency and number of observations ($N_{\rm obs}$).

3. Historical photometric observations

All the program stars listed in Table 2 were already known to be variable at optical wavelengths. They were selected for the present monitoring program on the basis of their rotation period within the range 0.4–1.1 days and with the aim of confirming the previously determined rotation periods and determining for each star the maximum light curve amplitude in the quoted rotation range. In this section a brief summary of the previous estimates of rotation period and light curve amplitudes is given:

HII 250: Marilli et al. (1997) discovered its optical variability obtaining a light curve amplitude of $\Delta V = 0.06$ mag and a period of $P = 0.84^{\rm d}$. This is the only star whose photometric period from the present monitoring program is quite different than previously determined.

HII 324 (=V632 Tau): Haro & Chavira (1973) discovered that it is a flare star. The first optical band light curves were obtained by Stauffer et al. (1987) with an amplitude of $\Delta V = 0.18$ mag and $\Delta V = 0.20$ mag in two different epochs.

HII 335 (=MX Tau): Haro & Chavira (1973) discovered that it is a flare star. The first optical band light curve was obtained by Stauffer et al. (1987) with a photometric period of $P = 0.36^{\rm d}$ and an amplitude of $\Delta V = 0.09$ mag.

HII 345: Marilli et al. (1997) discovered its optical variability with a photometric period of $P = 0.682^{\rm d}$ and an amplitude of $\Delta V = 0.065$ mag. Further photometry was collected by Krishnamurthi et al. (1998) who reported an amplitude of $\Delta V = 0.05$ mag and a longer period of $P = 0.81^{\rm d}$.

HII 625 (=V811 Tau): Meys et al. (1982) discovered that it is variable in the V-band with a period of $P = 0.43^{\rm d}$ and an amplitude of $\Delta V = 0.13$ mag. Stauffer et al. (1987) found the same period and an amplitude of $\Delta V = 0.18$ mag.

Table 2. Photometric properties inferred in the present monitoring: V-band brightest magnitude and mean colours, light curve amplitude, rotation period along with its uncertainty and false-alarm-probability and number of data points

Pleiades cluster program stars

HII number	Other name	$V_{\max}$ (mag)	$\langle B-V \rangle$ (mag)	$\langle U-B \rangle$ (mag)	ΔV (mag)	Period $\pm\Delta P$ (d)	FAP	$N_{\rm obs}$
HII 250		10.69	0.67	0.15	0.04	0.591 ± 0.002	0.19	13
HII 324	V632 Tau	12.90	1.11	0.75	0.29	0.411 ± 0.001	0.05	13
HII 335	MX Tau	13.65	1.31	0.60	0.10	0.4073 ± 0.001	0.08	15
HII 345		11.40	0.83	0.33	0.07	0.723 ± 0.003	0.26	12
HII 625	V811 Tau	12.61	1.20	0.69	0.11	0.421 ± 0.001	0.08	15
HII 686	OU Tau	13.40	1.00	0.32	0.15	0.391 ± 0.001	0.07	15
HII 738	V1041 Tau	12.28	1.17	0.67	0.13	0.854 ± 0.004	0.03	17
HII 739	V696 Tau	9.44	0.61	0.05	0.03	0.917 ± 0.003	0.17	14
HII 882		12.55	1.06	0.70	0.15	0.581 ± 0.001	0.02	16
HII 1039		13.04	1.20	0.84	0.08	0.784 ± 0.002	0.06	16
HII 1532		13.92	1.30	0.91	0.08	0.918 ± 0.002	0.04	16
HII 1653	V338 Tau	13.34	1.19	1.01	0.16	0.759 ± 0.003	0.16	11
HII 2244	V664 Tau	12.57	1.03	0.66	0.13	0.562 ± 0.001	0.18	12
HII 3063	V677 Tau	13.46	1.24	1.03	0.12	0.884 ± 0.001	0.04	13

Alpha Persei cluster program stars

AP number	Other name	$V_{\max}$ (mag)	$\langle B-V \rangle$ (mag)	$\langle U-B \rangle$ (mag)	ΔV (mag)	Period $\pm\Delta P$ (d)	FAP	$N_{\rm obs}$
AP 15		14.15	1.34	1.42	0.10	0.622 ± 0.012	0.11	11
AP 19	V531 Per	11.59	0.77	0.40	0.08	0.77 ± 0.03	0.10	11
AP 32	HE684	10.65	0.58	0.20	0.06	0.700 ± 0.013	0.05	13
AP 43		12.75	0.96	0.65	0.13	0.582 ± 0.011	0.05	12
AP 93		11.84	0.94	0.59	0.04	0.63 ± 0.04	0.32	10
AP 193		11.99	0.81	0.35	0.11	0.645 ± 0.02	0.12	14
AP 244		12.78	0.93	0.56	0.10	0.463 ± 0.01	0.40	10

HII 686 (=OU Tau): Haro & Chavira (1973) discovered that it is a flare star. The first optical band light curve was obtained by Van Leeuwen et al. (1987) with a period of $P = 0.396^{\rm d}$ and amplitude of $\Delta V = 0.18$ mag. Stout-Batalha & Vogt (1999) have recently confirmed the rotation period, reporting a light curve amplitude of $\Delta V = 0.11$ mag and $\Delta V = 0.23$ mag during their observations.

HII 738 (=V1041 Tau): Marilli et al. (1997) discovered its optical band variability with an amplitude of $\Delta V = 0.085$ mag and a period of $P = 1.46^{\rm d}$. Krishnamurthi et al. (1998) collected further photometry reporting an amplitude of $\Delta V = 0.09$ mag and a much shorter period of $P = 0.73^{\rm d}$ in agreement with that found in the present monitoring.

HII 739 (=V696 Tau): the optical band variability was discovered by Marilli et al. (1997) with an amplitude of $\Delta V = 0.05$ mag and a period of $P = 0.90^{\rm d}$.

HII 882: the optical band variability was discovered by Meys et al. (1982) with an amplitude of $\Delta V = 0.12$ mag and a period of $P = 0.579^{\rm d}$. Marilli et al. (1997) determined a period of $P = 0.604^{\rm d}$ and an amplitude of $\Delta V = 0.10$ mag.

HII 1039: Pigatto & Rosino (1973) discovered that it is a flare star. The optical band variability was discovered by Meys et al. (1982) with an amplitude of $\Delta V = 0.03$ mag and an uncertain period of $P = 0.85^{\rm d}$. This is slightly longer than the period obtained in the present study.

HII 1532: Ambartsumian et al. (1972) discovered that it is a flare star. The first optical band light curve was obtained by Krishnamurthi et al. (1998) reporting an amplitude of $\Delta V = 0.06$ mag and a photometric period of $P = 0.78^{\rm d}$. This is shorter than the period derived in the present study.

HII 1653 (=V338 Tau): Haro & Chavira (1965) discovered that it is a flare star. The first optical band light curve was obtained by Krishnamurthi et al. (1998) reporting an amplitude of $\Delta V = 0.10$ mag and a photometric period of $P = 0.74^{\rm d}$.

HII 2244 (=V664 Tau): Haro & Chavira (1973) discovered that it is a flare star. The first optical band light curve was obtained by Stauffer et al. (1987) with an amplitude of $\Delta V = 0.17$ mag and with a photometric period of $P = 0.565^{\rm d}$.

HII 3063 (=V667 Tau): Haro & Chavira (1973) discovered that it is a flare star. The first optical band light curve was obtained by Prosser et al. (1995) with an amplitude of $\Delta V = 0.10$ mag and a photometric period of $P = 0.89^{\rm d}$.

AP 15: Stauffer et al. (1985) discovered its optical band variability with a period of $P = 0.64^{\rm d}$ and an amplitude of $\Delta V = 0.09$ mag.

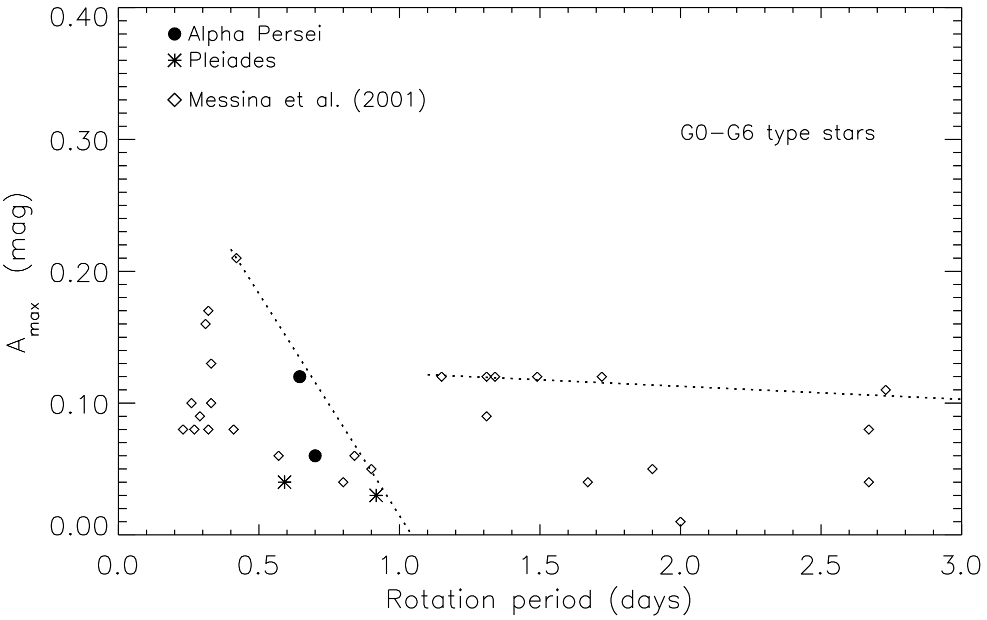

Fig. 1. A_{max} versus rotation period (P). Asterisks and bullets indicate the newly presented light curve amplitudes of the Pleiades and Alpha Persei members, respectively; diamonds indicate the amplitude values taken from Messina et al. (2001). Solid line is the fit to the data upper envelope from Messina et al. (2001)

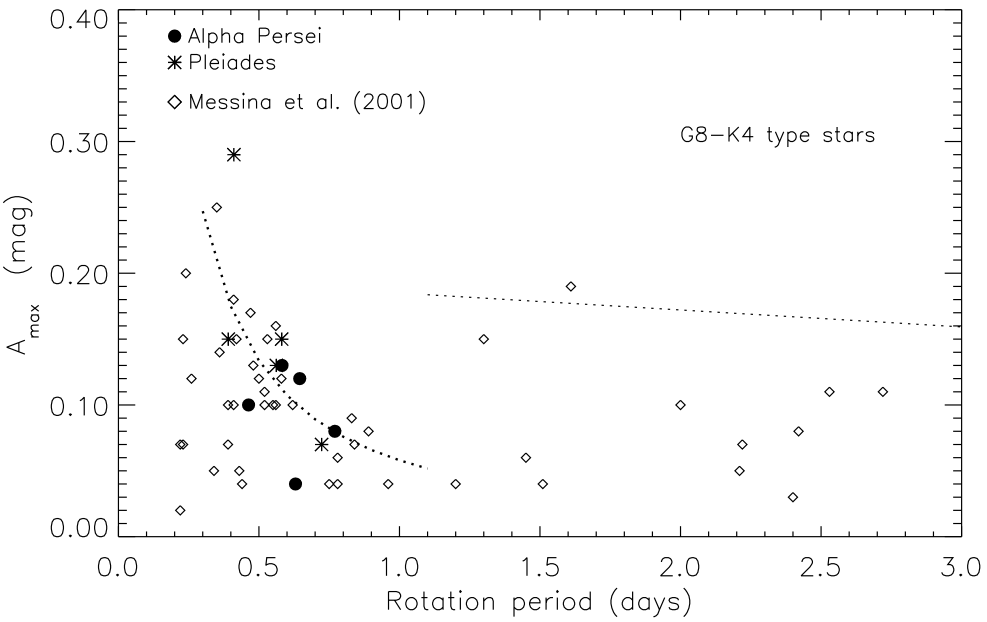

Fig. 2. As Fig. 1, but for G8-K4 type stars

AP 19 (=V531 Per, HE 622): Prosser et al. (1993b) discovered its optical band variability with a period of $P = 0.80^{\rm d}$ and an amplitude of $\Delta V = 0.045$ mag.

AP 32 (=HE 684): the optical band variability was discovered independently by Marilli et al. (1997) and O'Dell et al. (1997) who found the same period of $P = 0.75^{\rm d}$ and ΔV amplitudes of 0.065 and 0.03 mag, respectively.

AP 43: Stauffer et al. (1985) discovered optical band variability with $P = 0.56^{\rm d}$ and $\Delta V = 0.10$ mag.

AP 93: Prosser et al. (1993a) discovered optical band variability with $P = 0.62^{\rm d}$ and $\Delta V = 0.10$ mag.

AP 193: the optical band variability was discovered by O'Dell et al. (1997) who found a period of $P = 0.75^{\rm d}$ and a ΔV amplitude of 0.03 mag.

AP 244: Prosser et al. (1993b) discovered its optical band variability with a period of $P = 0.96^{\rm d}$ and a ΔV amplitude of 0.04 mag. The period $P = 0.46^{\rm d}$ found in this monitoring, is half than the previous determination. It may result from the relatively short observing time interval.

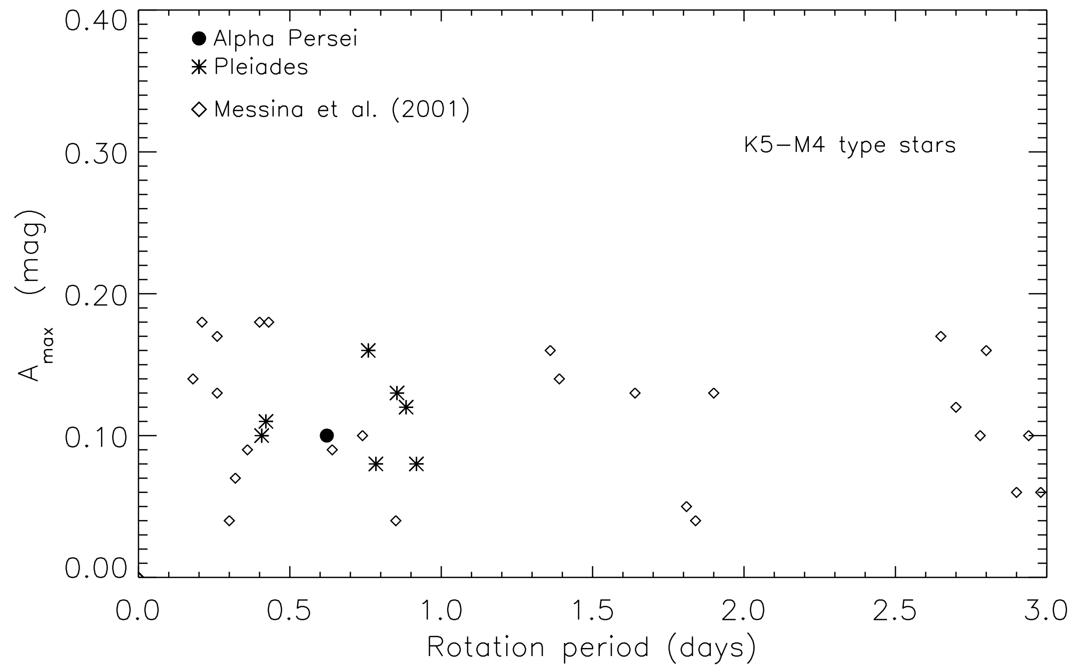

Fig. 3. As Fig. 1, but for K5-M4 type stars

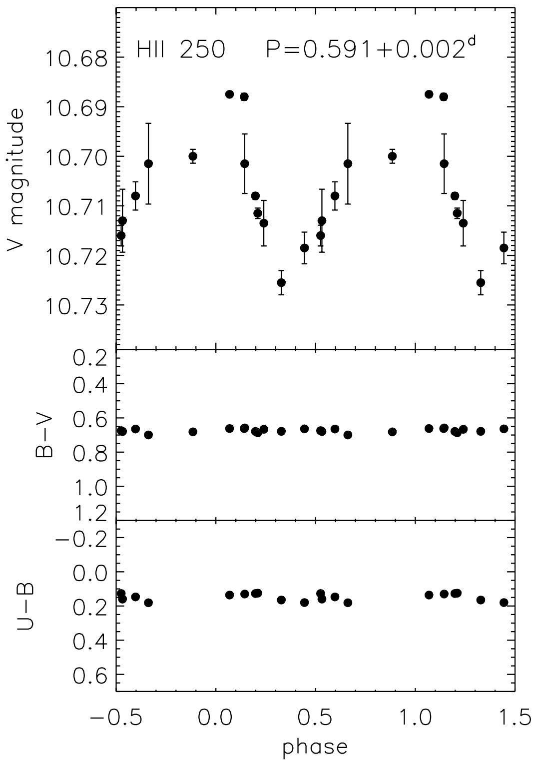

Fig. 4. HII 250 V-band light curve and colors collected over the interval 10–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.591 \cdot E$

4. Results

The new values of amplitude are binned per spectral type and are plotted along with the values presented in Messina et al. (2001) in Figs. 1–3. As expected from the variation of spotted regions area and because of the spatial redistribution on the stellar photosphere, the light curve amplitudes of the stars under analysis were found to be different compared to the previous determinations quoted in the previous section.

Nevertheless, if we consider the data upper envelope, as discussed by Messina et al. (2001), ultra fast rotators with $P < 1.1$ days, despite the high rotation rate, never show amplitudes larger than slower rotators in all the G, K and M mass regimes. The light curve amplitudes of stars with rotation period around 1 day are comparable to the light curve amplitudes of much slower rotators ($P \gtrsim 10$ days).

In conclusion, the new light curves amplitudes from this monitoring of active members in the Pleiades and Alpha Persei star clusters, selected in the 0.4–1.1 day rotation range, have values as expected based on previous results of Messina et al. (2001).

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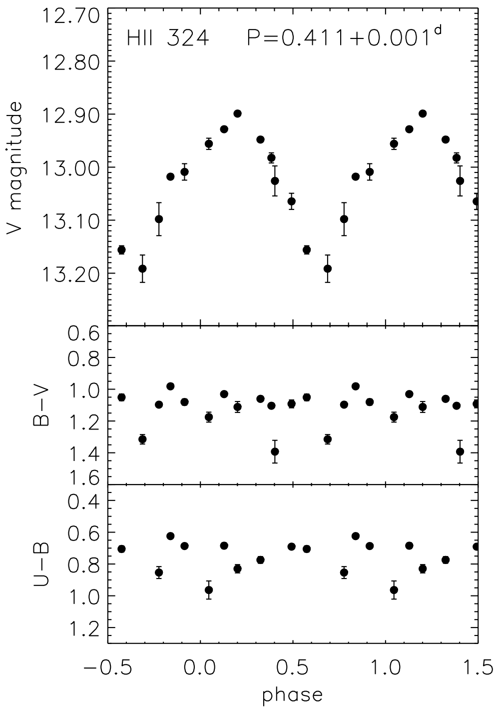

Fig. 5. HII 324 (=V632 Tau) V-band light curve and colors collected over the interval 9–13 Oct. and 9–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.411 \cdot E$

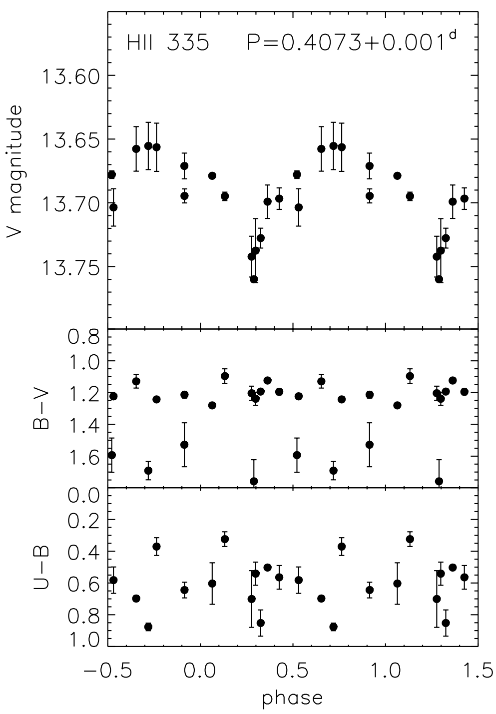

Fig. 6. HII 335 (=MX Tau) V-band light curve and colors collected over the interval 5–13 Oct. and 10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.4073 \cdot E$

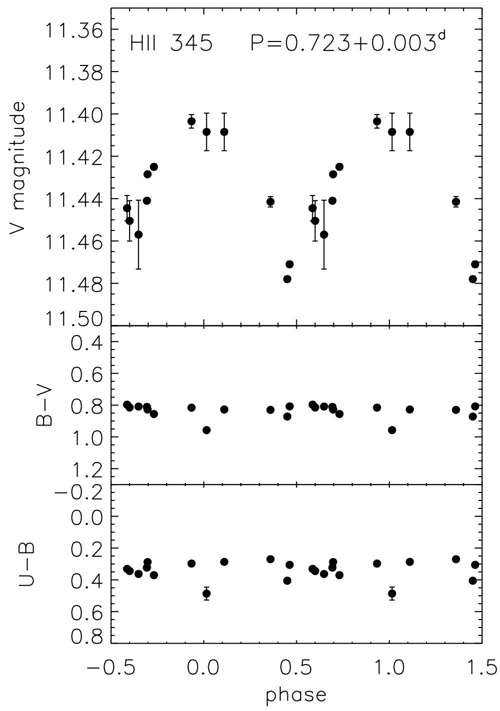

Fig. 7. HII 345 V-band light curve and colors collected over the interval 6–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.723 \cdot E$

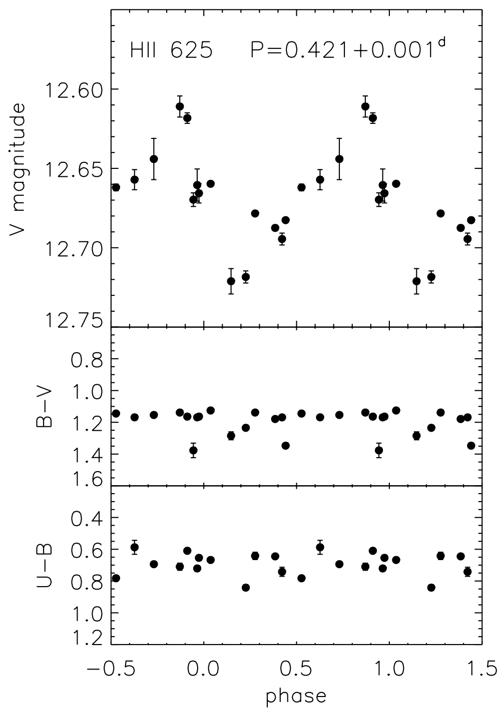

Fig. 8. HII 625 (=V811 Tau) V-band light curve and colors collected over the interval 5–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.421 \cdot E$

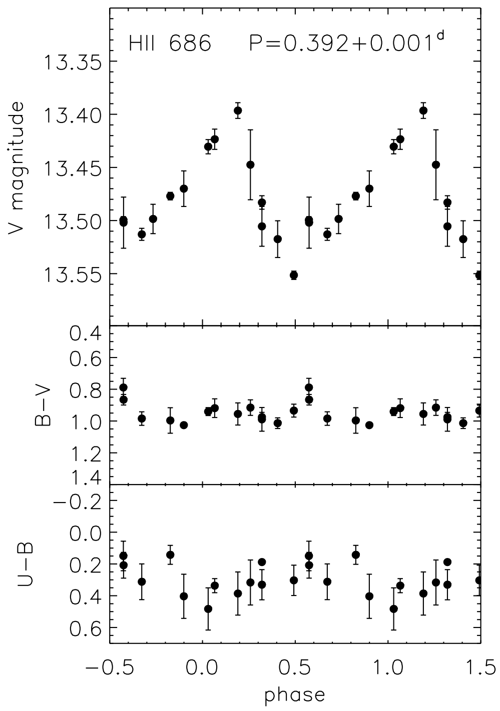

Fig. 9. HII 686 (=OU Tau) V-band light curve and colors collected over the interval 6–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.391 \cdot E$

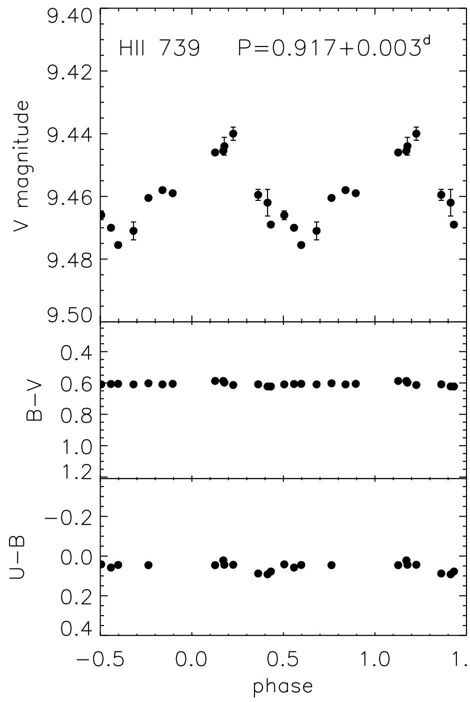

Fig. 11. HII 739 (=V696 Tau) V-band light curve and colors collected over the interval 6–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.917 \cdot E$

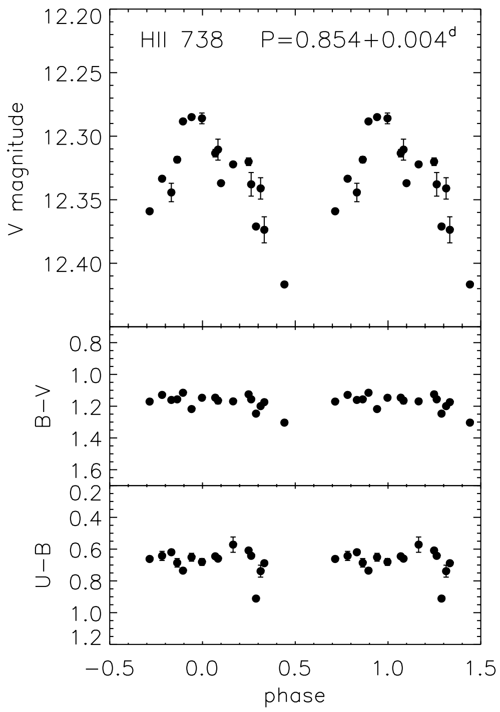

Fig. 10. HII 738 (=V1041 Tau) V-band light curve and colors collected over the interval 6–13 Oct. and 8–9 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.854 \cdot E$

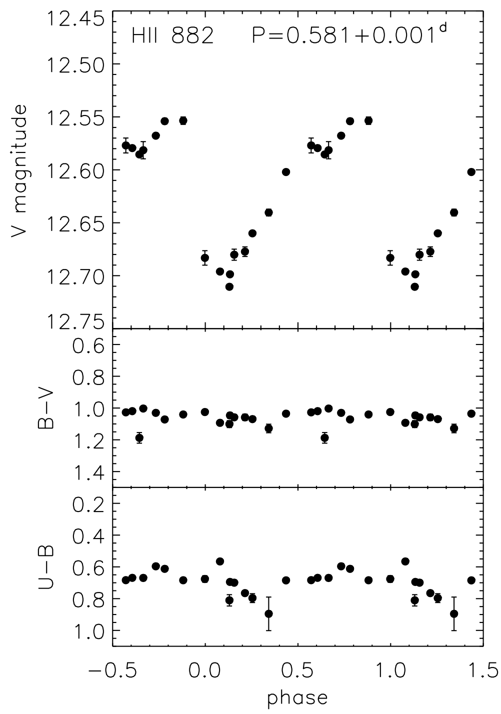

Fig. 12. HII 882 V-band light curve and colors collected over the interval 5–11 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.581 \cdot E$

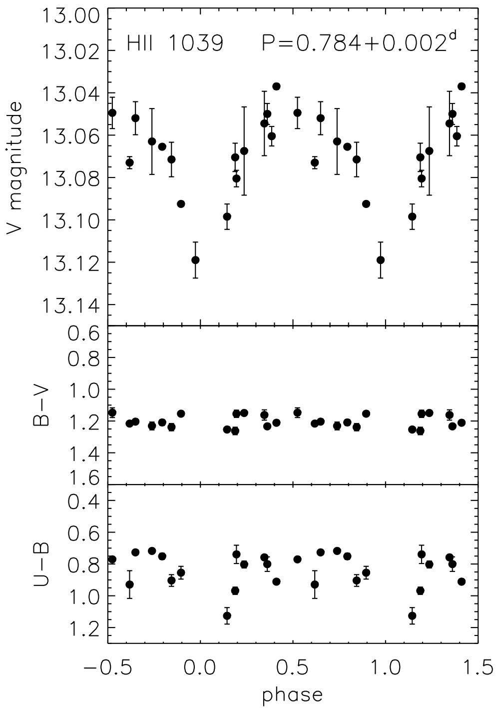

Fig. 13. HII 1039 V-band light curve and colors collected over the interval 6–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.784 \cdot E$

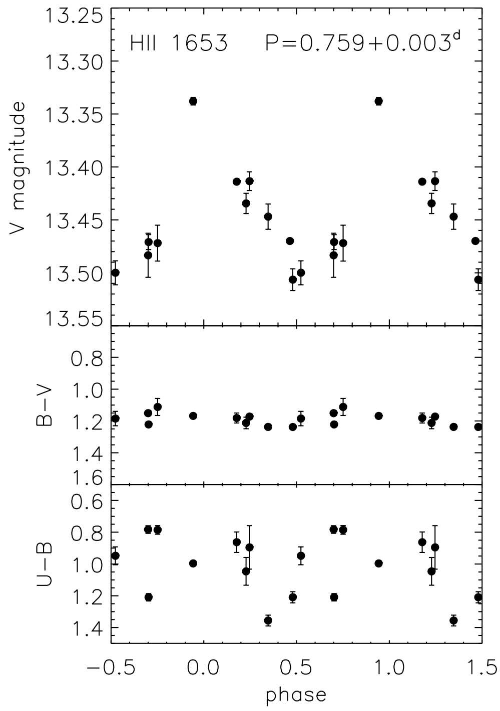

Fig. 15. HII 1653 (=V338 Tau) V-band light curve and colors collected over the interval 11–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.759 \cdot E$

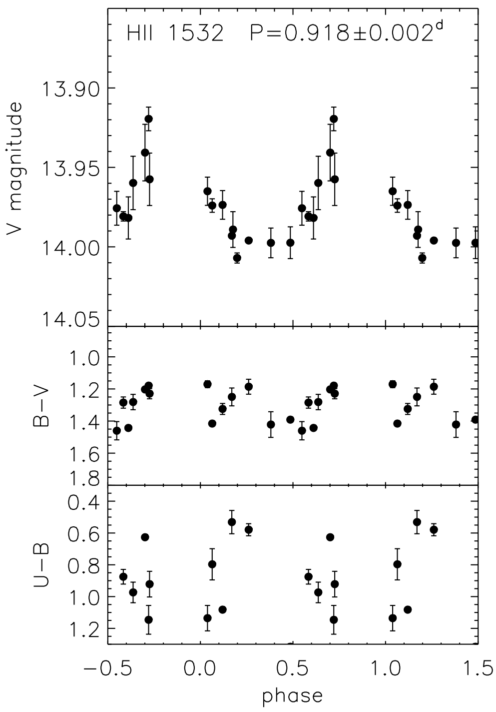

Fig. 14. HII 1532 V-band light curve and colors collected over the interval 5–13 Oct. and 8–10 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.918 \cdot E$

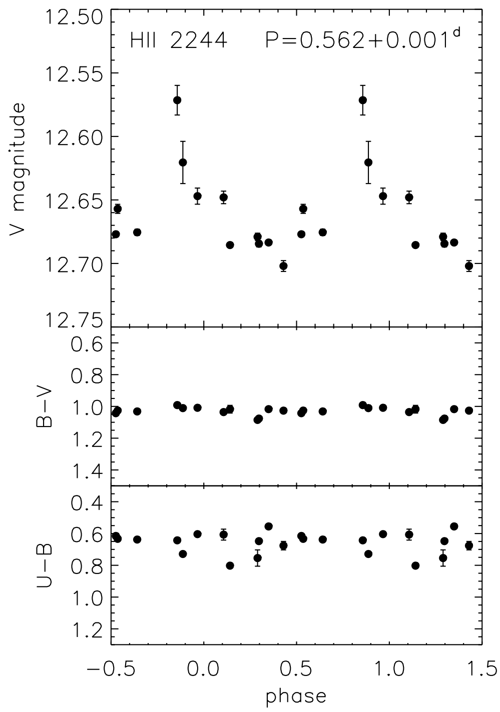

Fig. 16. HII 2244 (=V664 Tau) V-band light curve and colors collected over the interval 10–13 Oct. and 8 Nov. 1999. Phases are reckoned from the photometric ephemeris 2451457.4167 + $0.562 \cdot E$

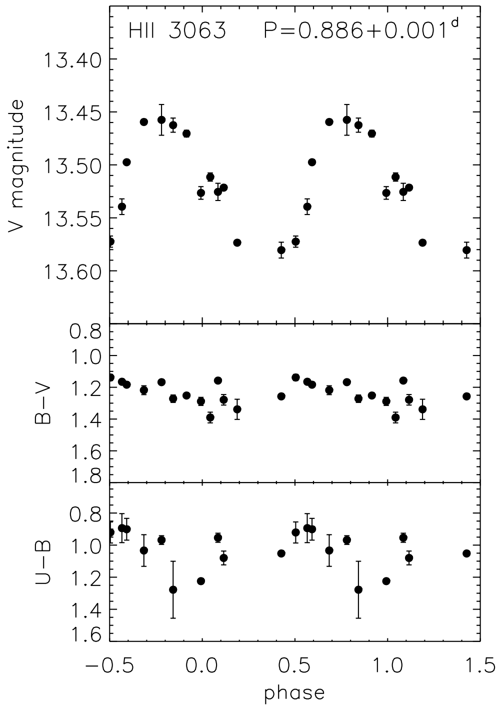

Fig. 17. HII 3063 (=V667 Tau) V-band light curve and colors collected over the interval 6–13 Oct. and 8–9 Nov. 1999. Phases are reckoned from the photometric ephemeris $2451457.4167 + 0.884 \cdot E$

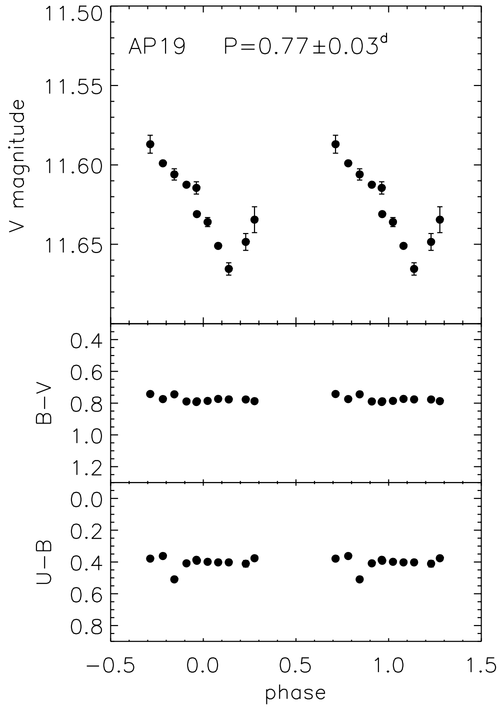

Fig. 19. AP 19 (=V531 Per, HE622) V-band light curve and colors collected over the interval 2–4 Dec. 1999. Phases are reckoned from the photometric ephemeris $2451515.0 + 0.77 \cdot E$

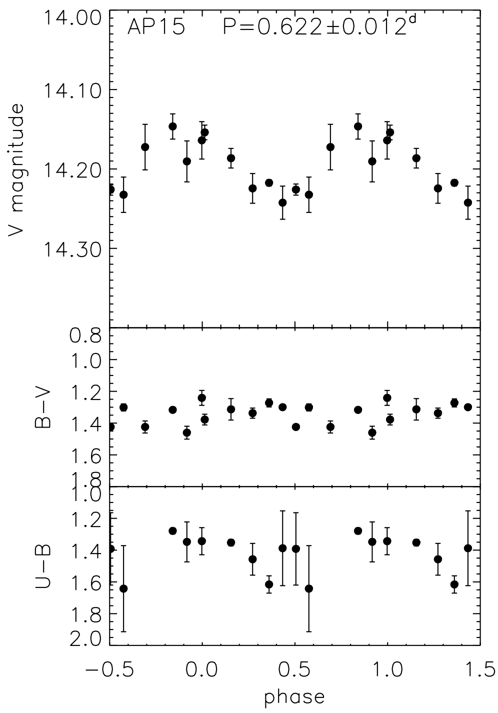

Fig. 18. AP 15 V-band light curve and colors collected over the interval 2–4 Dec. 1999. Phases are reckoned from the photometric ephemeris $2451515.0 + 0.622 \cdot E$

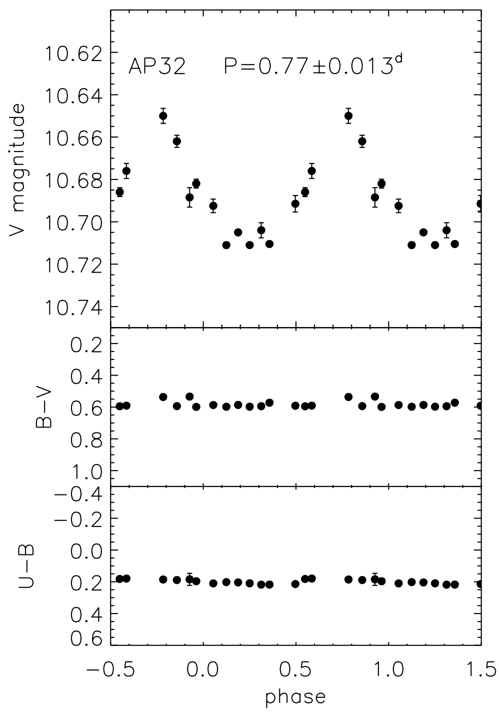

Fig. 20. AP 32 (HE684) V-band light curve and colors collected over the interval 2–4 Dec. 1999. Phases are reckoned from the photometric ephemeris $2451515.0 + 0.70 \cdot E$

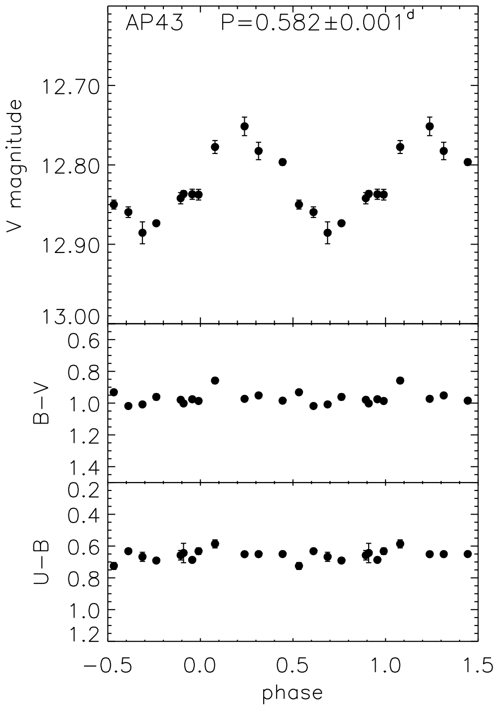

Fig. 21. AP 43 V-band light curve and colors collected over the interval 2–4 Dec. 1999. Phases are reckoned from the photometric ephemeris 2451515.0 + $0.582 \cdot E$

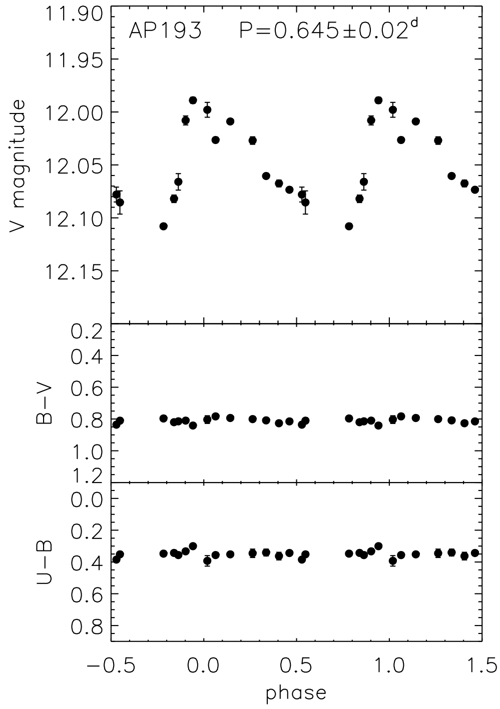

Fig. 23. AP 193 V-band light curve and colors collected over the interval 2–3 Dec. 1999. Phases are reckoned from the photometric ephemeris 2451515.0 + $0.645 \cdot E$

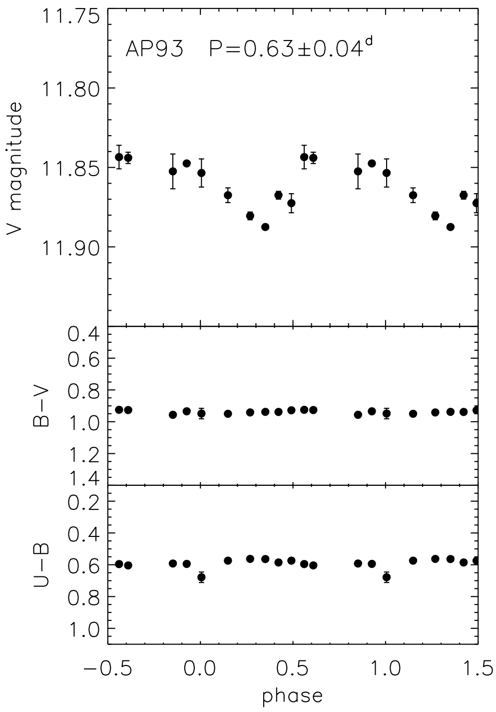

Fig. 22. AP 93 V-band light curve and colors collected over the interval 2–3 Dec. 1999. Phases are reckoned from the photometric ephemeris 2451515.0 + $0.63 \cdot E$

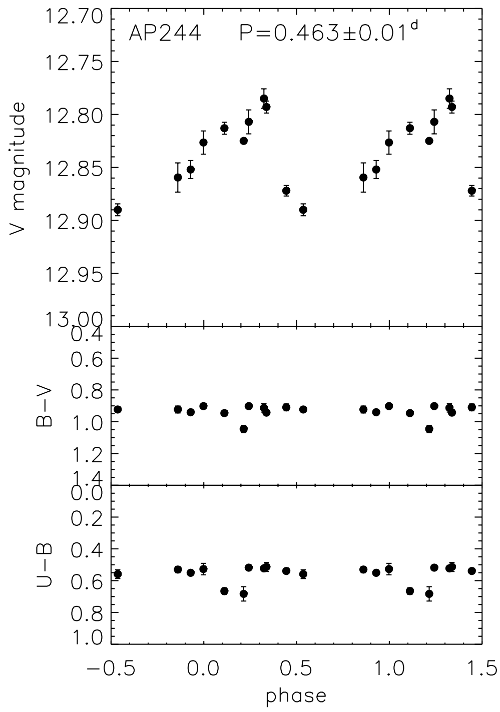

Fig. 24. AP 244 V-band light curve and colors collected over the interval 2–4 Dec. 1999. Phases are reckoned from the photometric ephemeris 2451515.0 + $0.463 \cdot E$

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