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BV Photometry of UX Arietis

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Abstract. Differential *BV* photometry of UX Ari obtained on 58 nights during 1984–85, 1985–86, 1986–87, and 1987–88 observing season is presented. We find that $(B-V)$ is phase dependent with the system being reddest at the light maximum and we interpret this as due to the variable fractional contribution by the G5 V component to the total light at shorter wavelengths. An analysis of the available data indicates that at larger amplitudes of the photometric wave the brightness at maximum increases and that at minimum decreases and both converge to $\Delta V \simeq 1.0$ mag at very low amplitudes. It implies that the low wave amplitudes are essentially due to more homogeneity in the surface distribution of spots rather than due to low levels of spot activity. The variation in wave amplitude is found to be near-sinusoidal with a period around 13–14 years.

Key words: *BV* photometry—RS CVn binaries—UX Arietis—spot activity

1. Introduction

The RS Canum Venaticorum binary UX Arietis (HD 21242, BD $+28°$ 0532) has been the object of several observational studies at wide wavelength regions (Walter, Charles & Bowyer 1978; Gibson, Hjellming & Owen 1975; Mutel & Weisberg 1978; Spangler 1977; Owen, Jones & Gibson 1976). It is a double-lined spectroscopic binary with an orbital period of 6.438 days and the spectral types of primary and secondary components are K0 IV and G5 V, respectively (Carlos & Popper 1971). This is one of the four RS CVn systems so far known to show Hα as pure emission feature above the continuum consistently at all times, the others being DM UMa, V711 Tau, and II Peg. Extensive photometric observations of UX Ari have been obtained by several investigators (Sarma & Prakasa Rao 1984; Busso, Scaltriti, & Cellino 1986 and references therein). We observed UX Ari as a part of a photometric programme of RS CVn systems and related objects. In this paper we present *BV* photometry of UX Ari obtained during the years 1984–88 and discuss its photometric properties.

2. Observations

We observed UX Ari on a total of 58 nights during the four observing seasons 1984–85 (11 nights), 1985–86 (6 nights), 1986–87 (23 nights), and 1987–88 (18 nights) with the

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34-cm reflector of Vainu Bappu Observatory, Kavalur using standard *B* and *V* filters. The comparison stars were 62 Ari (G5 III) and HR 999 (K2 II–III). All the observations were made differentially with respect to 62 Ari and transformed to the *UBV* system. The mean differential magnitudes and colours of the comparison stars, in the sense, 62 Ari minus HR 999, obtained during the four seasons are given in Table 1. Table 2 gives the results for the variable star UX Ari. Each value given in Table 2 is a mean of three

Table 1. The mean differential magnitudes and colours of comparison stars, in the sense, 62 Ari minus HR 999.

Season	ΔV	$\Delta(B-V)$
1984–85	1.111 ± 0.005	−0.477 ± 0.004
1985–86	1.089 ± 0.002	−0.467 ± 0.003
1986–87	1.095 ± 0.001	−0.455 ± 0.002
1987–88	1.084 ± 0.002	−0.466 ± 0.002

Table 2. The differential magnitudes and colours of UX Ari. The probable errors for each season are also given.

JD 2440000. +	ΔV	$\Delta(B-V)$
6052.3267	0.918 ± 0.016	−0.213 ± 0.011
6053.3294	0.945	−0.202
6054.2817	0.964	−0.238
6055.2335	1.107	−0.210
6055.3282	1.130	−0.236
6056.2801	1.132	−0.245
6084.1785	0.879	
6088.1282	1.113	−0.226
6089.1814	0.985	
6094.1884	1.095	−0.227
6095.0907	1.076	−0.249
6121.1317	1.020	−0.204
6468.1933	1.072 ± 0.004	−0.213 ± 0.007
6472.1370	0.919	−0.190
6473.0921	0.992	−0.200
6474.0850	1.045	−0.225
6475.0896	1.061	−0.227
6476.1016	0.953	
6802.2046	1.051 ± 0.005	−0.241 ± 0.006
6803.2137	1.077	−0.237
6816.1648	1.081	
6817.1815	1.026	
6818.1454	0.910	−0.182
6819.1571	0.911	−0.197
6820.1563	0.967	−0.211
6821.1375	1.031	
6823.1707	1.046	−0.217
6824.1510	0.977	−0.216

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Table 2. Continued

JD 2440000.+	ΔV	$\Delta(B-V)$
6825.1307	0.900	−0.203
6828.1479	1.076	−0.229
6829.1453	1.083	
6830.1361	1.014	−0.201
6831.1252	0.930	
6832.1144	0.911	−0.215
6835.1157	1.092	−0.232
6836.1188	1.051	−0.230
6847.0933	1.072	−0.232
6850.1023	0.934	−0.210
6852.1004	0.962	−0.210
6861.0949	1.063	
6862.0986	1.030	−0.228
7157.2139	1.023±0.007	−0.214±0.007
7179.1790	0.863	
7183.1431	1.042	−0.206
7184.1757	0.926	−0.218
7185.1586	0.868	−0.200
7196.0958	1.016	−0.220
7197.0931	0.907	−0.205
7198.0806	0.857	
7200.1590	0.996	−0.214
7201.1067	1.038	−0.217
7202.1278	1.040	−0.215
7203.1220	0.936	−0.213
7204.1056	0.876	−0.208
7206.0833	0.941	
7218.0806	0.876	
7231.0970	0.890	−0.206
7232.1028	0.974	−0.210
7233.0944	1.041	−0.225

to four independent measurements. The probable errors of the differential magnitudes and colours of the variable star for each observing season are also given in Table 2. The Julian days of observation were converted into orbital phases using the following ephemeris (Carlos & Popper 1971):

$$\text{JD } 2440133.766 + 6^{d}.43791\ E.$$

3. Results

The observations listed in Table 2 are plotted in Figs 1–4. The light curve, obtained during 1984–85 observing season (Fig. 1) is asymmetric, with the maximum and minimum occurring at $0^{p}.30$ and $0^{p}.90$, respectively. The amplitude of the wave is

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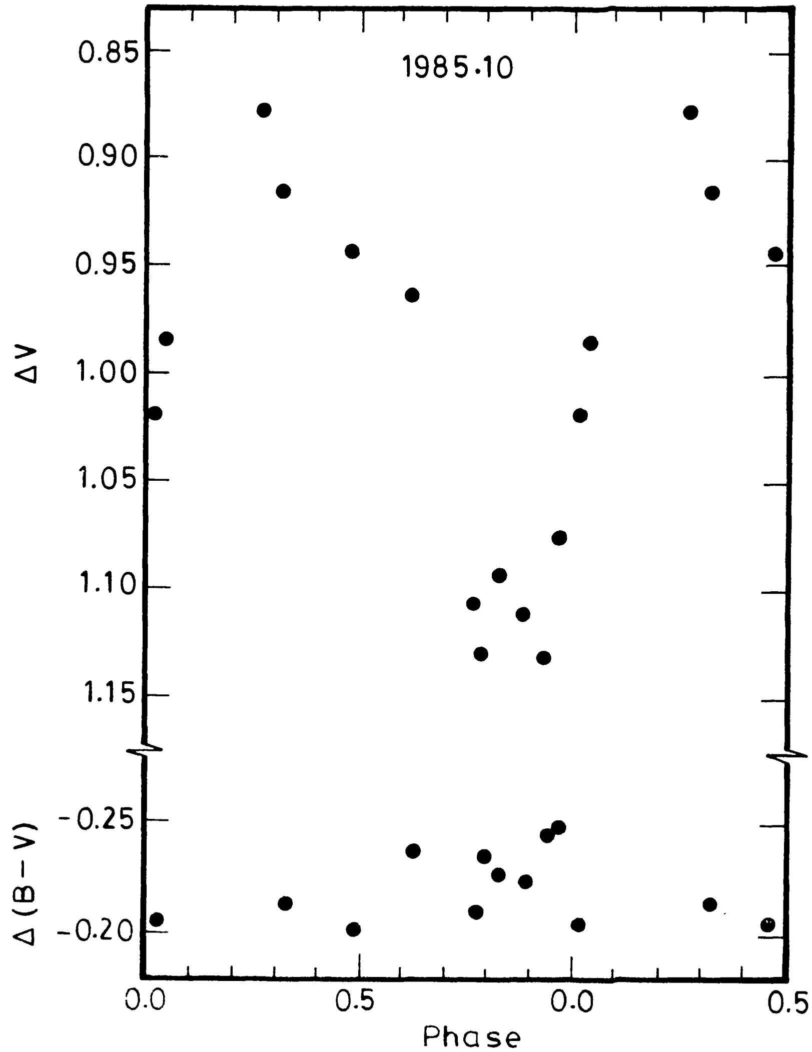

Figure 1. V and $(B-V)$ light curves of UX Ari during 1984–85 observing season. Phases are reckoned from JD 2440133.766 using the period 6.43791d.

~0.25 mag, *i.e.* ~0.03 mag smaller than the highest amplitude ever observed, which was obtained by Busso, Scaltriti & Cellino (1986) at a slightly earlier epoch. The above authors have reported that there was some evidence of a secondary minimum during the period of their observations. From Fig. 1 we find that the light curve has a sharp discontinuity near $0^p.60$. Unfortunately, our observations do not cover the light curve phases immediately after this.

The light curve obtained during 1985–86 season is given in Fig. 2. Though the observations are insufficient to determine the phase and brightness of the light maximum, they sufficiently cover the light minimum which occurs at ~$0^p.93$. There is a clear trend in $(B-V)$ which indicates that the system becomes redder as its brightness increases.

The 1986–87 light curve (Fig. 3) is nearly sinusoidal with an amplitude ~0.19 mag; the maximum and minimum occur at ~$0^p.40$ and ~$0^p.90$. The variation in $(B-V)$ is very evident from the figure, with the system being redder when brighter, and bluer when fainter.

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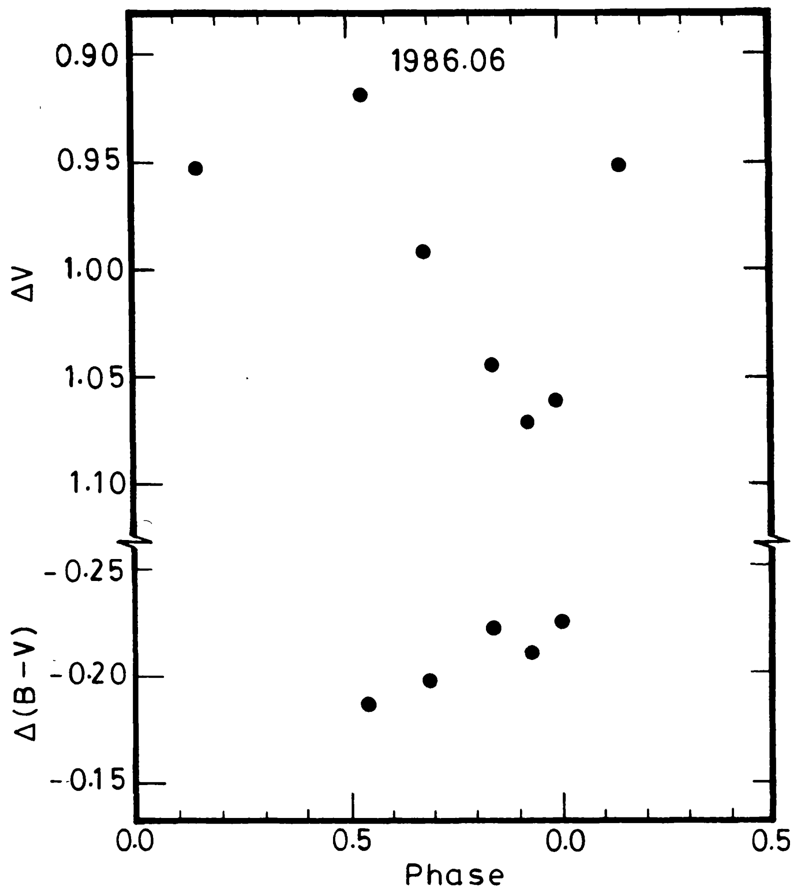

Figure 2. V and $(B-V)$ light curves of UX Ari during 1985–86 observing season. Phases are reckoned as in Fig. 1.

Fig. 4 shows the observations of the 1987–88 observing season. The brightness at light maximum and minimum differ significantly from that of the previous season; however, the amplitude of the wave is nearly the same. As before, $(B-V)$ shows a phase-dependent variation, but with a slightly smaller amplitude.

The photometric properties derived from our observations, together with those compiled from various sources, are given in Table 3. The phases of the light minima were determined by fitting a truncated Fourier series ($\mathscr{L}=A_0+A_1\cos\theta+A_2\cos 2\theta+B_1\sin\theta$) to the data of each season. The amplitudes of the light variation were directly taken from the respective graphs.

4. Discussion

The light variation of RS CVn stars are attributed to spot activity on the surface of the cooler component of the system (Eaton & Hall 1979). Starspots that are distributed on the cooler companion modulate the observed light as the star rotates, giving rise to the wave-like distortion in the light curve. The changes in the light curve are attributed to the changes in the locations and distribution of spots on the stellar surface.

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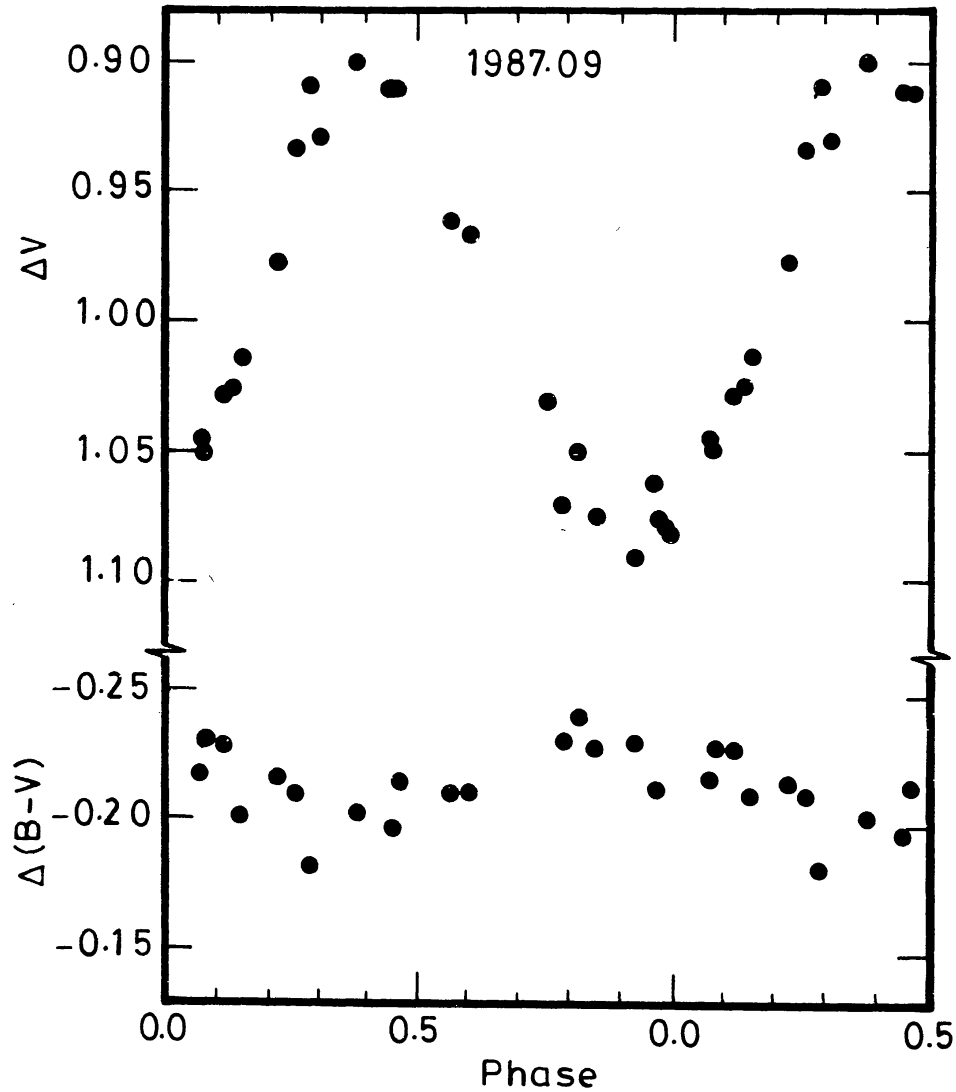

Figure 3. *V* and (*B* − *V*) light curves of UX Ari during 1986–87 observing season. Phases are reckoned as in Fig. 1.

4.1 *Wave Amplitude and* ϕ_{min}

In almost all well-observed RS CVn systems such as V7 11 Tau, II Peg, and DM UMa the phases of the minima of the distortion-like wave seen in the light curve have been found to drift slowly with the orbital phase or to appear at arbitrary phases (Mekkaden, Raveendran & Mohin 1982; Mohin, Raveendran & Mekkaden 1986; Mohin *et al.* 1985). In the case of UX Ari, Wacker & Guinan (1987) have reported that light minimum has remained 'anchored' between $0^{p}.93$ and $0^{p}.95$ during the period 1980–86. Busso, Scaltriti & Cellino (1986) have interpreted the behaviour of ϕ_{min} of UX Ari in terms of a cyclic behaviour with a period of nearly 8 years. Further, they have pointed out that a good correlation exists between the wave amplitude and ϕ_{min}. In Fig. 5 we have plotted the phase of light minimum and the wave amplitude given in Table 3 against the mean epoch of observation and we see from the figure that

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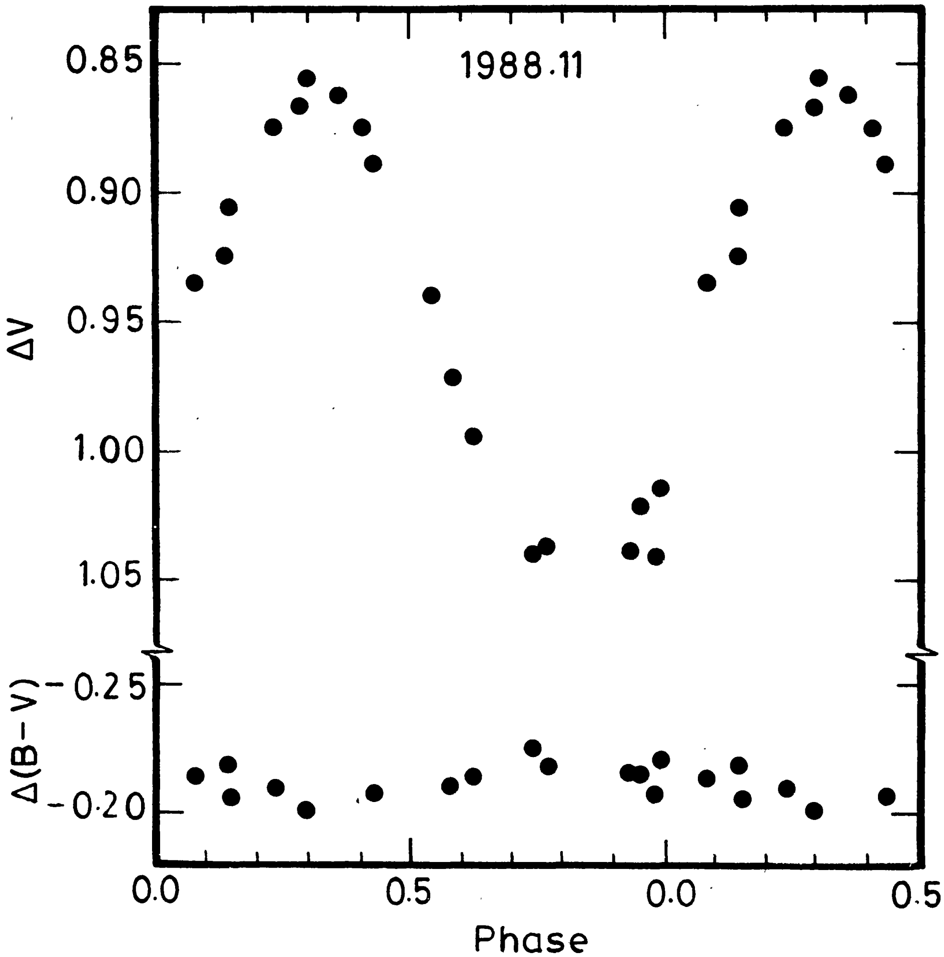

Figure 4. V and $(B-V)$ light curves of UX Ari during 1987–88 observing season. Phases are reckoned as in Fig. 1.

apparently there is no correlation between the two. In fact what we see is a near-sinusoidal variation in the wave amplitude and a secular decrease in the phase of light minimum.

4.2 $(B-V)$ *Variation*

Wacker & Guinan (1987) have reported that both of the Villanova colour curves of UX Ari are phase dependent with the star being reddest at light maximum. Zeilik *et al.* (1982) have also reported the phase dependency of the colour index. From Figs 2–4 it is clear that $(B-V)$ is redder close to light maximum and bluer close to light minimum. In Fig. 1 the behaviour is not so clear because of the slightly larger errors in $(B-V)$ measurement. We also find that the amplitudes of $(B-V)$ curves given in Figs 2 and 3 are significantly larger than that in Fig. 4. It is found that the brightness at minimum in Figs 2 and 3 are fainter than that in Fig. 4.

The components of UX Ari are tentatively classified by Carlos & Popper (1971) as G5 V and K0 IV and according to them the spectrum in the visible region is dominated

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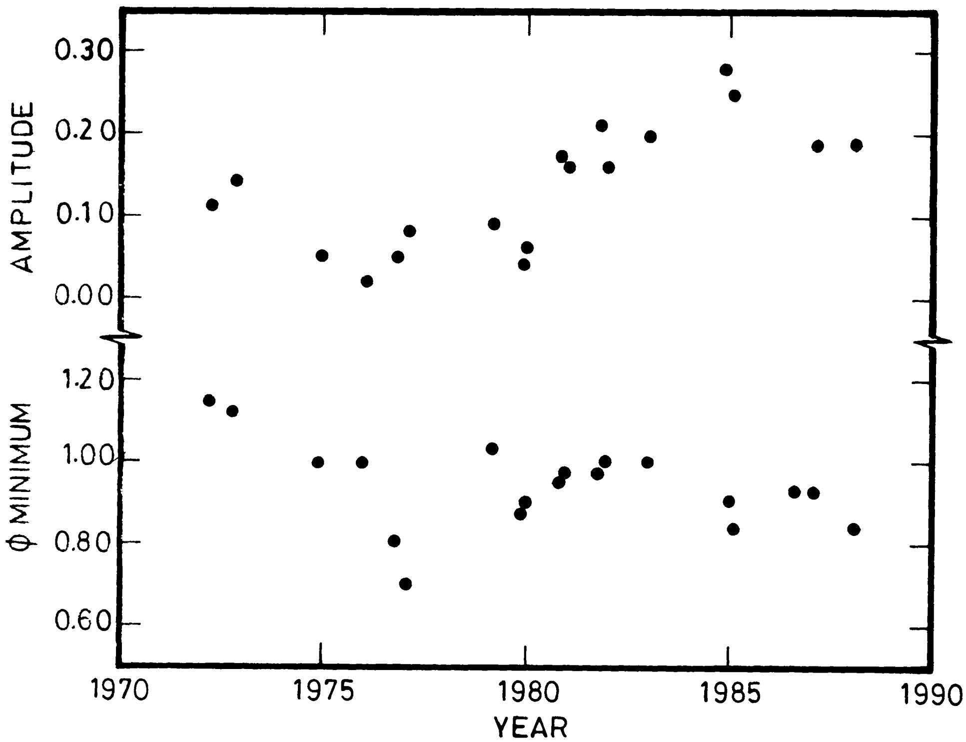

Figure 5. Plot of the wave amplitude and phase of light minimum against the mean epoch of observation.

by the G5 V component. The cooler component is not a normal subgiant since we would expect it to be more luminous by about 1.5–2.0 mag in V (Allen 1976).

From the observed $(B-V)$ of the system we have derived the expected $(B-V)$ of the cooler component at both the light maximum and minimum of 1986–87 season for a possible range of differences in V of both the components and the results are given in Fig. 6.

The conventional starspot model assumes that the spots are cooler than the surrounding photosphere and hence one would expect the star to be reddest at the light minimum. In chromospherically active single-lined RS CVn systems, it has been found that $(B-V)$ is redder or nearly constant at the light minimum (Mohin *et al.* 1985; Mohin, Raveendran & Mekkaden 1986; Vogt 1981). From Fig. 6, we find that the above situation would arise only if the cooler and active component is fainter than the hotter component by around 0.2 mag in V for an assumed $(B-V)$ of 0.7 for the hotter component. A bluer colour for the hotter component is not possible because it would imply that either the cooler component is brighter than the hotter or both are of equal brightness, contrary to the observations. We conclude that the $(B-V)$ variations seen in UX Ari is only a result of the variable fractional contribution by the hotter component (G5 V) to the total light at shorter wavelengths.

4.3 *Spot Activity*

In Fig. 7 we have plotted the values of ΔV_{max} and ΔV_{min} given in Table 3 against the corresponding amplitude. From the figure we find that at larger amplitudes the

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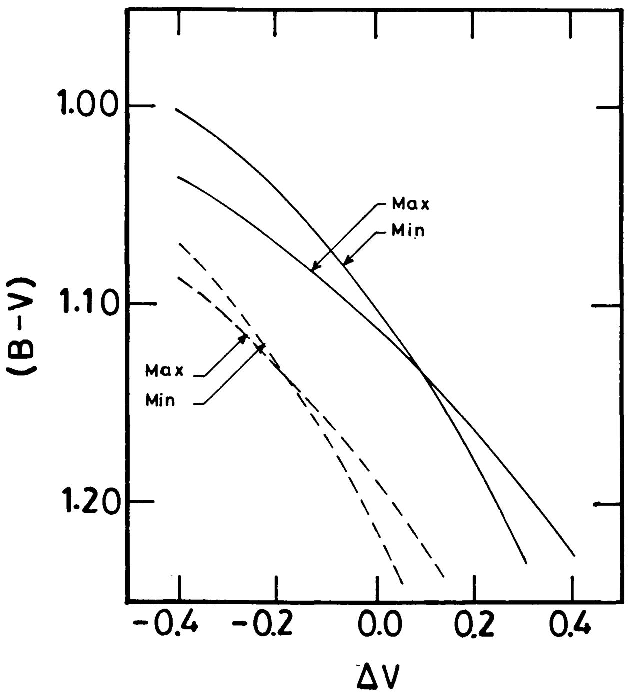

Figure 6. Derived $(B-V)$ values of the K0 IV component at maxima & minima (refer Fig. 3) for a possible range of the differences in V (K0 IV–G5 V). The two sets of curves are for the cases of assumed $(B-V)$ of 0.70 (continuous lines) and 0.65 (broken lines) for the G5 V component.

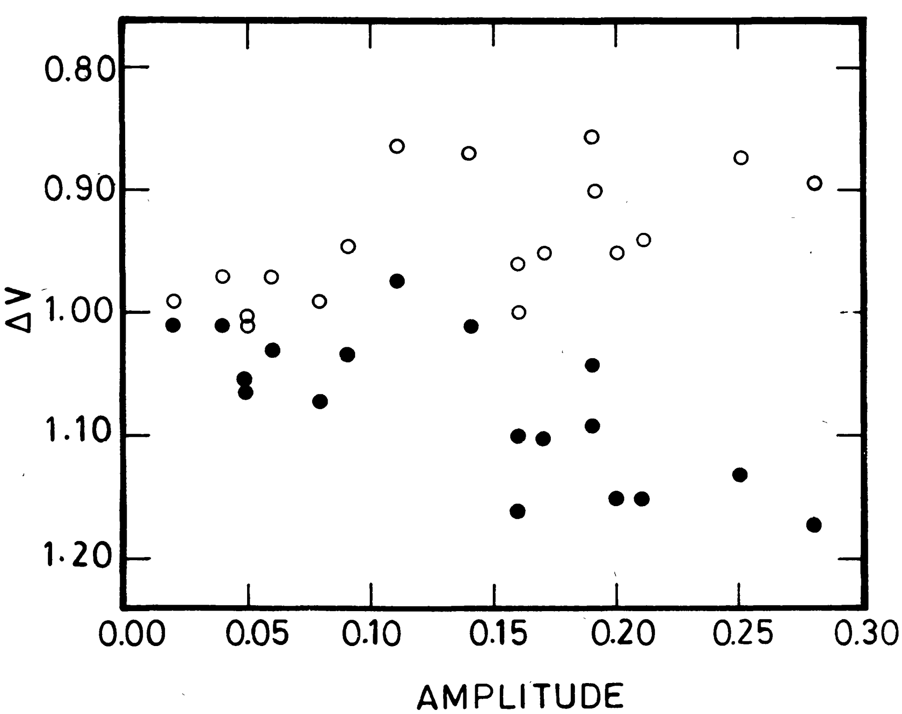

Figure 7. Plot of the brightness at light maximum (open circles) and light minimum (filled circles) against the wave amplitude.

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Table 3. Photometric properties of UX Ari.

Year	Amplitude	ϕ_{min}	ΔV_{max}	ΔV_{min}	Ref.
1972.2	0.11	0.14	+0.865	+0.975	1
1972.8	0.14	0.12	0.870	1.010	1
1974.9	0.05	0.99	1.015	1.065	1
1976.0	0.02	1.00	0.990	1.010	2
1976.8	0.05	0.80	1.005	1.055	1
1977.1	0.08	0.70	0.990	1.070	1
1979.2	0.09	0.03	0.945	1.035	1
1979.9	0.04	0.87	0.970	1.010	1
1980.0	0.06	0.90	0.970	1.030	1
1980.8	0.17	0.95	0.950	1.120	1
1981.0	0.16	0.97	0.960	1.120	1
1981.8	0.21	0.97	0.940	1.150	3
1982.0	0.16	1.00	1.000	1.160	2
1983.0	0.20	1.00	0.950	1.150	2
1984.9	0.28	0.90	0.890	1.170	4
1985.10	0.25	0.84 ± 0.03	0.879	1.131	5
1986.06	–	0.93 ± 0.01	–	1.072	5
1987.09	0.19	0.93 ± 0.01	0.900	1.092	5
1988.11	0.19	0.84 ± 0.01	0.857	1.042	5

References:
1. Guinan *et al.* (1981)
2. Sarma & Prakasa Rao (1984)
3. Zeilik *et al.* (1982)
4. Busso *et al.* (1986)
5. Present study.

brightness at maximum increases and the brightness at minimum decreases and both converge to $\Delta V \simeq 1.0$ at very low amplitudes. Sarma & Prakasa Rao (1984) have attributed the low amplitude of the wave in UX Ari to a low spot activity and the high amplitude to high spot activity. The amplitude of the wave depends only on the asymmetry in the distribution of the spots on the rotating stellar surface. Since we find that the brightness at both light maximum and minimum converge at low amplitudes, it appears that most of the amplitude variations is essentially due to changes in the longitudinal distribution of spots rather than due to changes in the level of spot activity. Therefore, low amplitude light curves of UX Ari are indicative of homogeneous distribution in longitude of spots rather than low activity level, as found in V711 Tauri by Bartolini *et al.* (1983).

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References

Allen, C. W. 1976, *Astrophysical Quantities*, Third edn, Athlone Press, London.
Bartolini, C., Blanco, C., Catalano, S., Cerruti-Sola, M., Eaton, J. A., Guarnieri, A., Hall, D. S.,

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1989JApA...10...35M

Henry, G. W., Hopkins, J. L., Landis, H. J., Louth, H., Marilli, E., Piccioni, A., Renner, T. R., Rodonò, M., Scaltriti, F. 1983, *Astr. Astrophys.*, **117,** 149.
Busso, M., Scaltriti, F., Cellino, A. 1986, *Astr. Astrophys.*, **156,** 106.
Carlos, R. C., Popper, D. M. 1971, *Publ. astr. Soc. Pacific* **83,** 504.
Eaton, J. A., Hall, D. S. 1979, *Astrophys. J.*, **227,** 907.
Gibson, D. M., Hjellming, R. M., Owen, F. N. 1975, *Astrophys. J.*, **200,** L99.
Guinan, E. F., McCook, G. P., Pragola, J. L., O'Donnell, W. C., Weisenberger, A. C. 1981, *Publ. astr. Soc. Pacific* **93,** 495.
Mekkaden, M. V., Raveendran, A. V., Mohin, S. 1982, *J. Astrophys. Astr.*, **3,** 27.
Mohin, S., Raveendran, A. V., Mekkaden, M. V., Hall, D. S., Henry, G. W., Lines, R. D., Fried, R. E., Louth, H., Stelzer, H. J. 1985, *Astrophys. Sp. Sci.*, **115,** 353.
Mohin, S., Raveendran, A. V., Mekkaden, M. V. 1986, *Bull. astr. Soc. India*, **14,** 48.
Mutel, R. L., Weisberg, J. M. 1978, *Astr. J.*, **83,** 1499.
Owen, R. N., Jones, T. W., Gibson, D. M. 1976, *Astrophys. J.*, **210,** L27.
Sarma, M. B. K., Prakasa Rao, B. V. N. S. 1984, *J. Astrophys. Astr.*, **5,** 159.
Spangler, S. R. 1977, *Astr. J.*, **82,** 169.
Vogt, S. S. 1981, *Astrophys. J.*, **247,** 975.
Wacker, S. W., Guinan, E. F., McCook, G. P., Lochner, J., Paćzkowski, B. G. 1986, *Inf. Bull. Var. Stars*, No. 2920.
Wacker, S. W., Guinan, E. F. 1987, *Inf. Bull. Var. Stars*, No. 3018.
Walter, F., Charles, P., Bowyer, S. 1978, *Astrophys. J.*, **225,** L119.
Zeilik, M., Elston, R., Henson, G., Smith, P. 1982, *Inf. Bull. Var. Stars*, No. 2168.

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