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Photometric Monitoring of Bright Be Stars. III. 1988–89 and 1992–95

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ABSTRACT. We report long-term photometric (BV) observations of 23 bright, active Be stars made in 1988 and 1989 and 1992–1995 with the 0.4-m telescope at the University of Toronto. Cumulative light curves, including observations made earlier at the University of Toronto, and with the Automatic Photometric Telescope Service in Arizona, are presented for several of the stars. Many of the stars show cyclic variations of up to 0.2 in V and B on time scales of a few years, as well as variations on time scales of about a day.

1. INTRODUCTION

The Be stars are hot stars (10,000–30,000 K) of luminosity classes III–V which have shown emission in at least one Balmer line on at least one occasion. The emission arises from hot gas in an equatorial disk around the star. As the definition suggests, the Be phenomenon is variable. The formation and dispersal of the disk leads to spectroscopic and photometric variations on time scales from weeks to years. There are also short-term photometric and absorption-line profile variations which are due to nonradial pulsation, or possibly rotation; see Balona et al. (1994) for a comprehensive review. A few Be stars show variations due to orbital motion and/or mass transfer in a close binary; those stars in our program which are binaries are: 4 (V839) Her: 46.194 d; 88 (V744) Her: 86.722 d; V923 Aql: 214.75 d; 60 (V1931) Cyg: 2.48 d (?); o And: 33.0847 d; KX And: 38.918 d (Pavlovski et al. 1997).

The present work is part of an international UBV photometric campaign on bright Be stars organized by Dr. Petr Harmanec (Ondřejov Observatory, Czech Republic), and is a continuation of our earlier work (Percy et al. 1988; Percy and Attard 1992). Observations made by Harmanec and his collaborators at Hvar Observatory (Croatia) over 20 years are now in press (Pavlovski et al. 1997). These observations cover the period up to 1990. They represent one of the most comprehensive and careful photometric surveys ever made of any class of variable stars. Dr. E. M. Halbedel (Corralitos Observatory, NM, USA) is also engaged in long-term photometric monitoring of a large sample of somewhat fainter Be stars.

The purpose of the campaign is to gather systematic long-term data on a sample of bright Be stars, to determine the nature and cause of the photometric variations, and their relationship to other variations in the stars.

2. OBSERVATIONS

The observations were made in V and B with the 0.4-m telescope on the main campus of the University of Toronto. Until 1994, they were made with the same DC photometer used previously (Percy et al. 1988), but the gradual decay of this old instrument was leading to occasional large random errors, so the DC photometer was replaced by an Optec SSP-3 solid-state photometer. Data acquisition and reduction was carried out with the RPHOT software package supplied by Optec. Otherwise, data reduction was as described previously (Percy et al. 1988; Percy and Attard 1992). All measurements were differential. For each program star, there is a primary comparison star, and a check star. The purpose of the check star is to monitor the constancy of the comparison star, and the quality of the data. For some stars, there is also a "red standard"—a second check star whose purpose is to monitor the quality of the transformation to the standard UBV system. There are no systematic differences between the photometry from the three different sources—the University of Toronto, the APT, and the AAVSO. The assumed magnitudes and colors of the comparison stars were taken from Harmanec et al. (1994).

The accuracy of the measurements was 0.007–0.009 mag, for each of the three sources of data, as determined from measurements of the check stars. As mentioned above, however, the DC photometer at the University of Toronto was subject to occasional random errors of up to 0.05 mag. Where the measurement of the check star was discordant, these errors could be detected, and the measurements of the program stars discarded. Where the error affected the (differential) measurement of the program star only, the situation is more problematic. Therefore, in Secs. 3 and 4 below, we emphasize trends in the results. Results which depend on the interpretation of a single measurement of a program star are considered uncertain.

Table 1 lists the program stars, the comparison stars, and the assumed magnitudes of the latter. Table 2 lists the number of observations made of each star, in the course of our program (Percy et al. 1988; Percy and Attard 1992). These numbers include measurements made earlier at the University of Toronto (Percy et al. 1988), with the Automatic Photometric Telescope (APT) Service in Arizona (Percy and Attard 1992), and through the American Association of

TABLE 1
Program and Comparison Stars

Program Star			Comparison						Check		Red Standard	
Variable	HR	HD	HR	HD	V	B	U		HR	HD	HR	HD
Theta CrB	5778	138749	5760	138341	6.473	6.669	6.795		5718	136849	5936	142908
(4 Her)	5938	142926	5982	144206	4.742	4.645	4.319		- - -	143418	5936	142908
88 V744 Her	6664	162732	6641	162132	6.495	6.580	6.655		6509	158414		
66 V2048 Oph	6712	164284	6719	164432	6.350	6.272	5.532		6690	163641	6770	165760
(MWC 601)	6873	168797	6928	170200	5.717	5.685	5.335		6900	169578	6925	170137
CX Dra	7084	174237	7060	173664	6.206	6.278	6.426		7028	172883	7123	175225
V1294 Aql	- - - -	184279	7400	183324	5.801	5.887	5.956		7397	183227	7404	183387
V923 Aql	7415	183656	7400	183324	5.801	5.887	5.956		7397	183227	7404	183387
2 ES Vul	7318	180968	7592	188260	4.587	4.537	4.408		7437	184606	7488	185958
(12 Vul)	7565	187811	7592	188260	4.587	4.537	4.408		7437	184606	7488	185958
(25 Cyg)	7647	189687	7613	188892	4.952	4.863	4.347		7769	193369	7689	191026
28 V1624 Cyg	7708	191610	7613	188892	4.952	4.863	4.347		7769	193369	7689	191026
P Cyg	7763	193237	7613	188892	4.952	4.863	4.347		7769	193369	7689	191026
QR Vul	7739	192685	7688	190993	5.075	4.907	4.232		7711	191747	7718	192004
55 V1661 Cyg	7977	198478	- - -	199311	6.690	6.769			- - -	199479	8255	205512
	8020	199478	- - -	199311	6.690	6.769			- - -	199479	8255	205512
59 V832 Cyg	8047	200120	- - -	199311	6.690	6.769			- - -	199479	8255	205512
60 V1931 Cyg	8053	200310	- - -	199311	6.690	6.769			- - -	199479	8255	205512
(MWC 363)	8103	201733	- - -	199311	6.690	6.769			- - -	199479	8255	205512
Omicron And	8762	217675	8622	214680	4.881	4.678	3.636		8733	217101	8766	217782
KX And	- - - -	218393	8805	218470	5.685	6.118	6.100		8705	216523		
KY And	- - - -	218674	8805	218470	5.685	6.118	6.100		8705	216523		
EW Lac	8731	217050	8805	218470	5.685	6.118	6.100		8705	216523		

TABLE 2
Summary of Observations of Program Stars

Program Star Variable	HR	HD	1988	1989	1990	1991	1992	1993	1994	1995
Theta CrB	5778	138749	15	13	*	*	14	24	8	7
(4 Her)	5938	142926			*	*	18	23	7	7
88 V744 Her	6664	162732		14	*	*	17	27	8	5
66 V2048 Oph	6712	164284	13+	8+	*+	*+	10+	13+	7+	10
(MWC 601)	6873	168797	18		*	*	11	13	5	9
CX Dra	7084	174237	16	21	*	*	18	22	14	8
V1294 Aql	---	184279	11	9			5	5	3	5
V923 Aql	7415	183656	11	9			5	7	3	9
2 ES Vul	7318	180968	17	19			5	19	8	9
(12 Vul)	7565	187811	17	19	*	*	4	23	9	7
(25 Cyg)	7647	189687	16	11				8	4	5
28 V1624 Cyg	7708	191610	28	10	*	*		24	6	7
P Cyg	7763	193237	10	12				8	4	5
QR Vul	7739	192685	10		*	*	4	4	3	5
55 V1661 Cyg	7977	198478	12	7						
	8020	199478	11							
59 V832 Cyg	8047	200120	13	4+	+	+	+	+	+	
60 V1931 Cyg	8053	200310	13	6						6
(MWC 363)	8103	201733	10							
Omicron And	8762	217675	16*	10*	*	*	4	14	5	4
KX And	---	218393	18	12	*	*	6	19	4	
KY And	---	218674	18	12			7	25	4	13
EW Lac	8731	217050	+	+	*+	*+	+	52+	+	5

* APT data (Percy and Attard 1992); + AAVSO data (Percy et al. 1996)

Variable Star Observers (AAVSO) photoelectric photometry program (Percy et al. 1996).

3. RESULTS

In this section, and in Table 3, we summarize the results on a star-by-star basis. Light curves of several of the stars are shown. See Harmanec (1983) and Pavlovski et al. (1997) for brief reviews of the previous literature on each star.

Where time scales of variability are quoted, these have been determined from inspection of the light curves. Formal period analysis is not appropriate, since the time scales are of the same order as the lengths of the datasets, and the variations are not likely to be strictly periodic in any case. Some Be stars show periodic variations on time scales of 0.5–2 days. Our data are not suited for determination and study of such periods, because they are typically obtained once a night, from a single site. Alias effects in the power spectra would be severe.

θ CrB; HR 5778; HD 138749 shows no conspicuous long-term variations in V or B.

4 (V839) Her; HR 5938; HD 142929 faded by 0.2 in V and B, starting in 1992 (Percy and Attard 1992), reaching a minimum in 1993; by 1996, it had returned to its previous brightness (see Fig. 1).

88 (V744) Her; HR 6664; HD 162732 has slowly brightened since 1989, after several years of fading, continuing the trend noted by Pavlovski et al. (1997) (see Fig. 2).

66 (V2048) Oph; HR 6712; HD 164284 slowly faded by 0.15 in V and B since 1982. There was a period of great activity in 1987–1991. AAVSO observations of 66 Oph have been published (Percy et al. 1996) (see Fig. 3).

NW Ser (MWC 601); HR 6873; HD 168797 showed little long-term variability, but there are short-term (hours to days) variations of up to 0.10 in V and B in every season. The amplitude of these may vary slightly from season to season, as noted by Pavlovski et al. (1997) (see Fig. 4).

CX Dra; HR 7084; HD 174237 show both long-term variations, and medium-term variations correlated with the 6.69603-day orbital period (Horn et al. 1992) (see Fig. 5).

2 (ES) Vul; HR 7318; HD 180968 showed no conspicuous long-term variations. There are known short-term variations of about 0.05 on a time scale of 0.61 or 1.27 days (Lynds 1959).

V923 Aql; HR 7415; HD 183656 was sparsely observed, but there appear to be long-term variations of 0.1 in V and B

TABLE 3
Ranges and Time Scales of Variability

Star	Range (V)	Time	Scale
θ CrB	4.1:-4.2:	none	
4 Her	5.73-5.96	4± yr	
88 Her	6.66-6.85	10± yr	
66 Oph	4.55-4.86	>15 yr, weeks	
MWC 601	6.07-6.22	none	*short
CX Dra	5.70-6.02	10± yr	*6.69603 d
2 Vul	5.35-5.55	none	*0.6/1.2 d
V923 Aql	5.98-6.18	10± yr	
V1294 Aql	6.87-7.3:	15± yr	
12 Vul	4.79-5.03	5± yr	*short
25 Cyg	5.09-5.21	long?	*0.21 d
28 Cyg	4.83-5.05	10± yr	*0.65 d
QR Vul	4.70-4.90	long?	*short
55 Cyg	4.75-4.90	(?)	
HR 8020	5.66-5.76	none	
59 Cyg	4.65-4.83	5± yr	
60 Cyg	5.25-5.55:	none	
EW Lac	5.15-5.47	several yr	*0.7/1.4 d
o And	3.55-3.78	8-9 yr	*1.57 d
KX And	6.88-7.28	yrs	*38.9 d
KY And	6.68-6.95:	>5 yr	*short

* derived from a variety of sources other than this work

on a time scale of a decade, confirming the results of Pavlovski et al. (1997) and Mennickent et al. (1994).

V1294 Aql; HD 184279 was sparsely observed, but there are conspicuous long-term cyclic variations of 0.3 in *V* and *B*, with a maximum around JD 2447000 and a minimum around JD 2449500, confirming the results of Pavlovski et al. (1997) and Mennickent et al. (1994).

12 Vul; HR 7565; HD 187811 shows both short-term variations, and long-term variations of 0.05 in *V* and *B* on a time scale of five years (see Fig. 6).

25 (V1746) Cyg; HR 7647; HD 189687 may show long-term variations of up to 0.05 in *V* and *B*.

28 (V1624) Cyg; HR 7708; HD 191610 shows both short-term variations (with a period of 0.64–0.66 days; see Pavlovski et al. (1997) for a review), and long-term variations over a decade (see Fig. 7).

QR Vul; HR 7739; HD 192685, in addition to short-term variations of up to 0.05 in *V* and *B*, may show long-term variations of the same order, confirming the results of Pavlovski et al. (1997).

55 (V1661) Cyg; HR 7977; HD 198478 showed an apparent brightening of 0.05 in *V* only in 1989, but this may be instrumental; see the note in Sec. 2.

HR 8020; HD 199478 showed no long-term variations.

59 (V832) Cyg; HR 8047; HD 200120 showed long-term variations of 0.1 in *V*, on a time scale of 2000 days. AAVSO observations of this star have been published (Percy et al. 1996) (see Fig. 8).

60 (V1931) Cyg; HR 8053; HD 200310 showed no conspicuous long-term variations.

EW Lac; HR 8731; HD 217050 shows both short-term variations (with a period of about 0.7 or 1.4 days) and long-term cyclic variations on a time scale of several years. AAVSO observations of this star have been published (Percy et al. 1996), and all of our measurements are being analyzed and published elsewhere (Harmanec et al. 1997).

o And; HR 8762; HD 217675, in addition to the well-known short-term variations with a period of 1.57 days, shows long-term variations on a time scale of 8–9 years, and

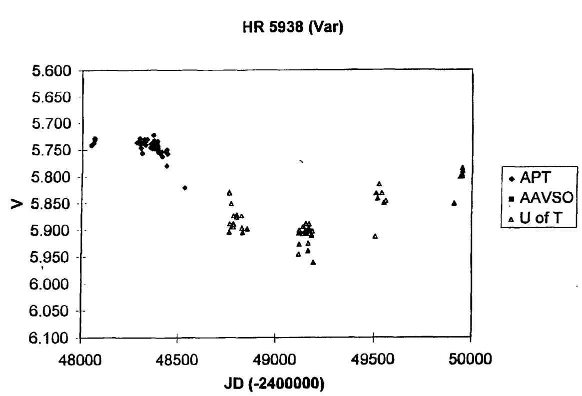

FIG. 1—The *V* light curve of 4 (V839) Her. After many years at constant brightness, the star faded, then brightened, over about 2000 days. The error bars on this and the subsequent figures are 0.007–0.009 mag (but note the comments in Sec. 2).

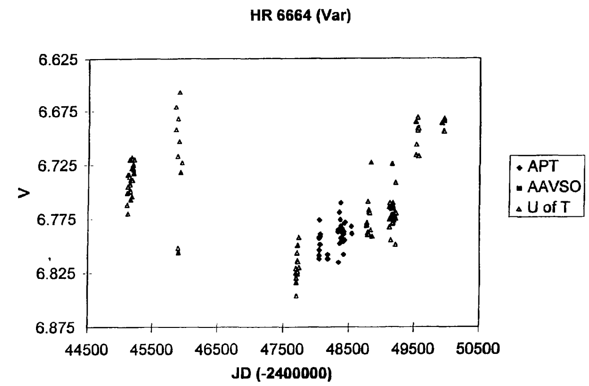

FIG. 2—The *V* light curve of 88 (V744) Her. The star faded, then brightened over about 4000 days.

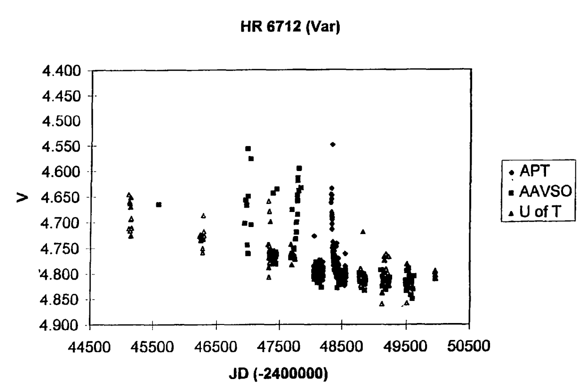

FIG. 3—The *V* light curve of 66 (V2048) Oph. The star underwent several brightenings between JD 2447000 and 2448500, superimposed on a general fading.

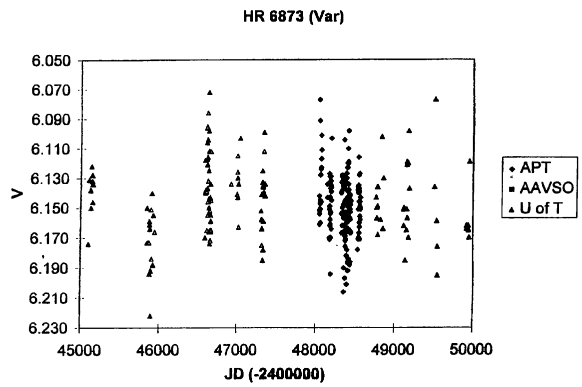

FIG. 4—The *V* light curve of NW Ser (MWC 601). The variability is dominated by short-term variability on a time scale of about a day.

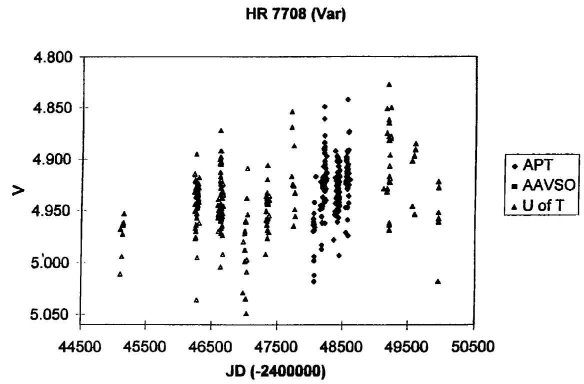

FIG. 7—The *V* light curve of 28 (V1624) Cyg. The variability is primarily on a time scale of about a day, but there also appears to be variability on a time scale of years.

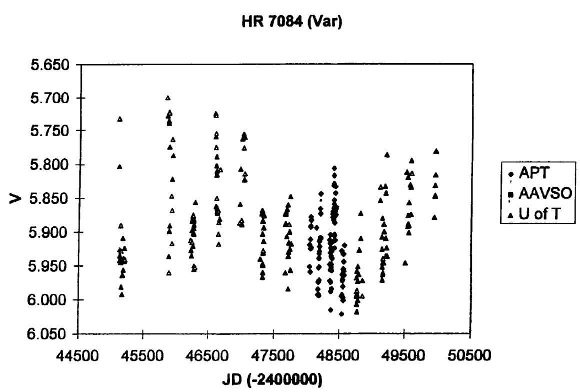

FIG. 5—The *V* light curve of CX Dra. There is significant variability within each season, some of it correlated with the 6.69603-day orbital period. There is also longer-term variability on a time scale of 4000 days.

an unusual light curve as noted by Pavlovski et al. (1997).

KX And; HD 218393 is an interacting binary with a period of 38.9 days; it shows conspicuous photometric variations on this time scale. It also showed variations from one season to the next (see Fig. 9).

KY And; HD 218674, in addition to short-term variations on a time scale of a day or so, showed long-term variations of 0.1 in *V* and < 0.05 in *B*. It brightened between JD 2447500 and 24448500, and faded since.

4. DISCUSSION

It is not surprising that all of the stars on the program show variability on many time scales; they were chosen because of that property. Nevertheless, they are not atypical of Be stars in general, as other studies (Mennickent et al. 1994; Pavlovski et al. 1997) have shown.

Our previous work (Percy et al. 1988; Percy and Attard 1992) has been helpful in identifying stars with rapid variability (e.g., NW Ser), and stars with brightenings on time scales of weeks (e.g., 66 (V2048) Oph, CX Dra, 12 Vul, and QR Vul). Our cumulative photometry, and that of Pavlovski et al. (1997) and others, enables us to identify stars with long-term variability. Many of the stars show cycles of variability 1000–2000-days long. Since, for most of the stars,

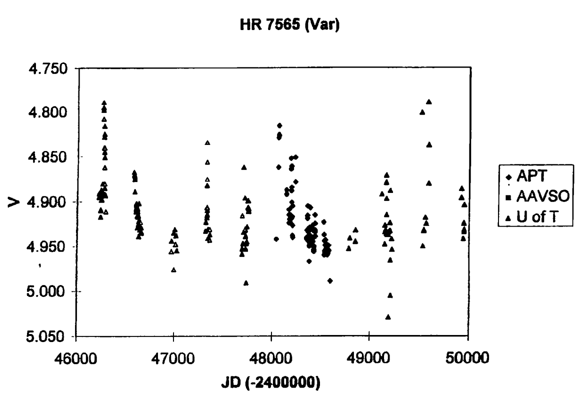

FIG. 6—The *V* light curve of 12 Vul. There is small variability on time scales from one day to 1500 days or more.

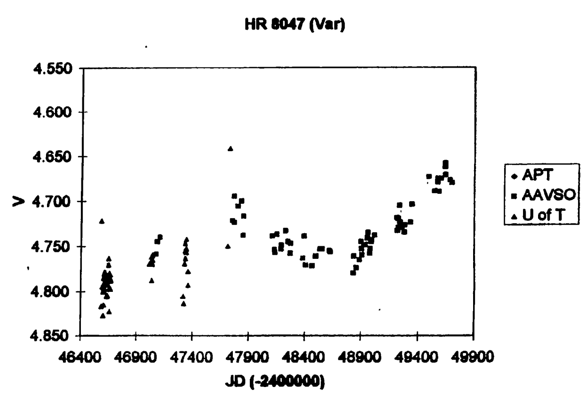

FIG. 8—The *V* light curve of 59 (V832) Cyg. The variability is primarily on a time scale of about 2000 days.

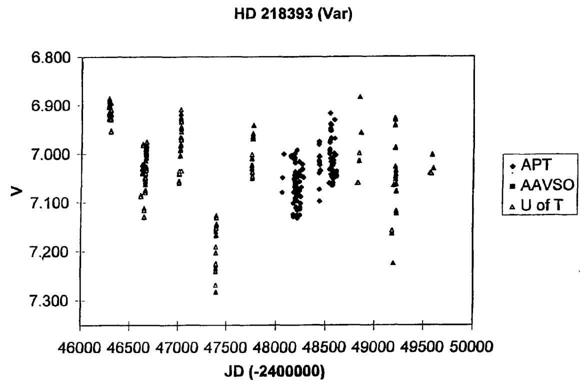

FIG. 9—The V light curve of KX And. During each season, the variability is correlated with the 38.9-day orbital period. There is also variability on a time scale of 1000 days or more.

only one or two cycles have been observed, these cycle lengths have statistical significance only. Nevertheless, it is interesting that the lengths of the cycles are roughly similar.

A few stars tend to remain at constant, "maximum" brightness, with occasional declines. These tend to be the so-called "shell stars" in which the equatorial disk is seen edge-on, and dims the star's light by scattering when the disc develops. This phenomenon was discussed by Harmanec (1983) in a review paper. It would be useful to re-examine this possibility, now that much more information is available on the long-term brightness variability of Be stars.

With regard to the stars which show brightenings on time scales of weeks: it is interesting that such variables have been "rediscovered" in the Magellanic Clouds in the course of gravitational microlensing surveys, and dubbed "bumpers" (Cook et al. 1995). Intensive, long-term photometric studies of bright variable stars can be very helpful in interpreting the results of the more limited surveys such as these.

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