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Edward G. Schmidt

University of Nebraska-Lincoln, eschmidt1@unl.edu

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THE BEHLEN OBSERVATORY VARIABLE STAR SURVEY: FIRST RESULTS

EDWARD G. SCHMIDT

Behlen Observatory, Department of Physics and Astronomy, University of Nebraska-Lincoln, Nebraska 68588

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ABSTRACT

Various light curve parameters are presented for the first 93 objects in a photometric survey of poorly studied variable stars. Stars from the General Catalogue of Variable Stars (GCVS) fainter than tenth magnitude, north of the equator which were classified as pulsating variables (but excluding the long period, semiregular, and irregular variables) were included. It is shown that two parameters, the acuteness and the rise time, are useful for characterizing the light curves. Several criteria are applied to the photometric data to test the classification of the stars. For 26 stars new or improved classifications are suggested. In particular, there are six eclipsing or ellipsoidal variables among the 79 stars classed in the GCVS as RR Lyrae stars. This suggests that there are likely to be four to five hundred binaries with short period which are misclassified as RR Lyrae stars. Additionally, four stars are reclassified as *s* Cepheids and three stars exhibit peculiarities which make their classification suspect. The periods of fourteen of the stars are found to be seriously in error while small adjustments for an additional eighteen are made. The cause of these discrepancies is discussed.

1. INTRODUCTION

A casual perusal of the General Catalogue of Variable Stars (hereafter referred to as GCVS; Kholopov 1985, 1987) shows that the information for a large fraction of variables is far from complete. For stars with maxima listed as fainter than tenth magnitude, 97% lack photoelectric photometry, 38% lack a period and the coordinates of 15% are given to an accuracy of only 1 arcmin. Even the most basic information on the form of the variation, the duration of light increase, $M - m$, is missing for two-thirds of the stars. It should also be noted that the information which is given is frequently in error (see, for example, Evans 1984; Loomis *et al.* 1988) even to the point of making the identification of many variables difficult (Lopez & Girard 1990). Thus, while we know of a large number of variable stars, our knowledge of their properties is very poor.

Some variable stars are of special interest for particular astrophysical problems. Examples include the short-period *s* Cepheids [for recent work see Schmidt & Gross (1990); Antonello *et al.* (1990)] and the long-period RR Lyrae stars (for a recent study see Schmidt *et al.* 1990). These represent a small fraction of the known Cepheids and RR Lyrae stars, respectively, and the studies cited depend on relatively small samples. There are also a number of variable stars which possess unique properties such as the short-period Cepheid V473 Lyr which exhibits long-term modulation (Burki *et al.* 1986), XZ Cet which has a period appropriate to a Bailey type ab RR Lyrae star but a peculiar light curve (Teays & Simon 1985) and the type-II Cepheid RU Cam which has a highly variable amplitude and which stopped pulsating for a considerable time (Demers & Fernie 1966). The mean magnitudes of the Cepheids in these studies are nearly all brighter than eleventh magnitude while the bulk of the RR Lyrae stars are brighter than twelfth magnitude. Yet two-thirds of Cepheids and more than 97% of RR Lyrae stars in the GCVS are fainter than these levels.¹ Thus, we could

greatly increase the sample of astrophysically interesting stars by searching among the fainter variables.

The interest in faint variable stars has been somewhat limited by the fact that available instrumentation did not permit detailed study of these objects. This situation is now changing. In recent years more sensitive detectors and new spectrograph designs have made it possible to carry out high-resolution spectroscopy at faint levels. This, coupled with the fact that more large telescopes are becoming available, will stimulate interest in faint variable stars.

Based on the above considerations, it was decided to carry out a photometric survey of poorly studied stars from the GCVS. This survey will include northern stars fainter than tenth magnitude which lack previous photoelectric photometry. We will generally include stars classified as pulsating variables but will exclude the long period, irregular, and semiregular variables. These latter groups as well as the eclipsing and eruptive variables have been omitted because they have distinctive properties which make it unlikely that many stars have been placed in these classes through error. Additionally, they are unlikely to yield much new information given the design of the observational program described below. However, such stars will occasionally be included for comparison purposes. There are about 1800 stars in the GCVS which fit within the criteria of this program. Results for the first 93 stars are presented in this paper.

2. THE OBSERVATIONS

The Behlen Observatory CCD photometry system has been described elsewhere (Schmidt 1988, 1990b) while the observational techniques were described by Schmidt *et al.* (1990). The reader is referred to those papers for such information. However, a point which should be repeated here is that other stars in the same CCD fields as the variables serve as comparison stars. Thus, accurate differential magnitudes are obtained even under poor photometric conditions.

The survey observations are made in the *V* and *R* bands. On photometric nights standard stars (from Landolt 1983) and extinction stars are observed. Color terms for the transformations to the standard system are then derived. Mean values over a period of a month or more are used to correct

¹ The variable star statistics in this paper were generated from a machine readable version of the Fourth Edition of the General Catalogue of Variable Stars provided by the Astronomical Data Center. The conversion of GCVS photographic magnitudes to *V* magnitudes given by Schmidt (1990a) was used in setting magnitude limits for the counts.

the magnitudes from all the nights in that interval (including both photometric and nonphotometric nights) for color effects. Individual zero points are determined on photometric nights to standardize the comparison stars so as to place the variable star differential magnitudes on the standard system. It should be noted that Behlen Observatory is not on a high-quality photometric site so we cannot demand high accuracy for absolute photometry. It is our general practice to accept the calibration of the comparison stars when the standard error from the scatter in V and in R is less than 0.015 mag.

For each star in the survey we obtain a light curve with a minimum of ten evenly spaced points. In many cases this is sufficient to characterize the star. However, additional points are often obtained around phases of rapid change to better define the light curve. Additional data are also required for stars with unknown or erroneous periods.

Table 1 lists 93 stars for which complete data have now been obtained. For each we list the number of comparison stars used (column 2), the standard errors of the comparison star magnitudes (columns 3 and 4), the number of pho-

tometric nights used to derive the comparison star magnitudes (column 5), the intensity mean magnitudes for the variables (columns 6 and 7), the Julian Date interval over which the observations were made (columns 8 and 9), and the number of light curve points obtained (column 10). A few stars which were previously discussed by Schmidt *et al.* (1990) and Schmidt & Gross (1990) are included for completeness.

3. LIGHT CURVE PARAMETERS

Due to the volume of data, we do not intend to publish individual data points or even light curves for most of the stars. Rather, parameters descriptive of the form of the variation are displayed in Table 2. The individual magnitudes are available for particular stars from the author through electronic mail or by sending a PC or Macintosh disk.

Since many of the stars were observed over relatively few cycles, our data are not suited to accurate period determination. Nonetheless, some of the published periods are found to

TABLE 1. Stars with complete observations.

Variable Comp. Stars										Variable Comp. Stars									
Variable	Comp.	Stars	Variables							Variable	Comp.	Stars	Variables						
			no. of stars	s.e. V (mmg)	s.e. R (mmg)	n	<V>	<R>	Obs. dates (J.D. - 2,440,000)	# obs									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ZZ And	2	9	12	5	13.10	12.83	8149	8210	15	LW Her	4	6	10	2	13.18	13.01	8102	8192	18
BK And	2	7	13	3	12.99	12.69	8112	8210	13	OX Her	2	18	5	2	13.02	12.76	7292	7464	43
CI And	3	11	12	2	12.24	11.98	8156	8227	12	V392 Her	1	7	31	2	13.09	13.86	7667	7705	12
DE And	2	11	5	2	13.82	13.46	8112	8206	16	V442 Her	2	7	8	3	12.81	12.60	8102	8192	26
DY And	2	9	13	4	13.26	13.00	8112	8210	16	V458 Her	2	6	9	2	13.10	12.84	7705	7720	20
FI And	1	4	2	2	14.46	14.22	8156	8206	10	V469 Her	3	13	10	3	14.30	14.04	7716	8022	16
GM And	1	4	6	2	12.96	12.70	7399	7548	36	V599 Her	1	14	18	3	14.03	13.76	7926	8055	21
GV And	1	10	8	2	13.64	13.36	8112	8192	15	V677 Her	1	3	15	2	13.75	13.53	8048	8075	13
HK And	3	13	12	2	14.17	13.93	8156	8192	11	V692 Her	1	3	17	2	13.96	13.67	7297	8344	39
V793 Aql	2	9	9	4	12.78	12.53	8109	8157	14	V719 Her	2	4	10	2	12.55	12.16	7569	8344	15
SY Ari	2	7	7	4	12.78	12.48	7872	7926	25	XX Leo	3	10	7	5	10.75	10.47	7848	7926	12
TU Ari	1	13	7	3	14.30	14.02	7896	8227	17	AX Leo	1	2	2	2	12.27	11.97	7953	8235	29
BH Aur	2	6	9	3	11.80	11.33	7946	8234	21	BT Leo	2	12	12	5	13.20	13.01	7667	7954	20
CR Aur	3	13	13	3	14.00	13.63	7954	8210	19	Y LMi	1	6	0	2	12.58	12.41	7953	8235	13
DN Aur	2	4	9	2	13.47	12.97	7946	8234	18	DR Lyr	1	10	5	2	14.33	13.39	6999	7439	33
GT Aur	2	10	14	7	12.19	11.67	7204	8156	15	NW Lyr	2	11	12	4	12.46	12.12	7318	8110	24
MV Aur	4	16	5	2	13.74	13.29	7953	8206	14	V462 Lyr	3	11	9	5	14.04	13.89	8109	8192	20
TY Cam	2	6	7	4	13.06	12.72	7514	7590	45	UW Mon	4	19	25	2	13.48	13.04	7896	7921	13
AS Cnc	3	8	10	3	12.59	12.34	7844	7899	20	V518 Mon	2	8	17	3	13.80	13.30	7872	7921	14
BD Cas	1	10	4	6	11.08	10.26	7057	7926	14	V756 Oph	3	3	8	2	13.57	13.25	7672	8344	16
BF Cas	4	14	16	3	12.47	11.68	7896	8227	14	V768 Oph	2	5	9	3	13.70	13.40	7322	7667	31
BR Cas	2	12	17	2	13.30	12.70	7446	7548	37	V773 Oph	3	12	15	2	13.49	13.16	7706	8344	14
NO Cas	2	8	9	7	11.41	10.73	7414	7897	84	V822 Oph	4	3	4	2	13.18	12.88	7706	8022	19
NY Cas	3	11	11	4	13.35	12.82	7872	8227	12	AN Per	4	20	20	2	14.33	13.78	7488	7611	36
OP Cas	3	12	11	4	11.87	10.95	7872	8205	10	CI Per	4	11	11	3	12.62	12.10	7872	7954	10
MU Cep	3	19	17	4	12.26	11.43	7771	7919	11	ET Per	2	10	10	4	13.11	12.69	7896	8112	14
UZ Com	1	9	8	4	13.25	12.98	7306	7672	38	GP Per	2	8	12	5	13.88	13.25	7399	7926	39
BW Com	1	11	7	15	14.60	14.31	7240	8075	104	HQ Per	2	11	10	4	11.60	10.87	7896	8206	12
CY Com	1	17	40	3	14.61	14.38	7569	8070	27	KN Per	2	2	10	2	11.52	11.24	7820	7825	12
FV Com	1	5	20	2	14.63	14.44	7953	8060	16	KV Per	4	8	16	6	13.86	13.43	7819	7896	32
GU Com	1	2	2	2	13.65	13.44	7953	8022	25	V375 Per	3	6	15	3	13.27	12.99	7953	8150	10
CV Cyg	3	5	5	2	13.93	13.71	7279	7465	45	V428 Per	5	5	7	6	13.37	12.24	7772	8156	40
V508 Cyg	3	12	17	2	12.78	12.15	7706	7774	18	SY Psc	2	12	15	2	12.88	12.64	7443	7821	19
V742 Cyg	2	6	12	2	15.84	15.13	7041	7467	40	DF Ser	2	4	5	2	12.78	12.56	7660	7672	14
V830 Cyg	4	6	12	3	14.57	14.25	7771	8156	22	U Sex	2	8	8	4	14.40	14.19	7848	7926	17
ZZ Del	2	16	6	3	12.86	12.59	7771	7814	17	V Sex	1	10	10	4	12.64	12.40	7245	7926	20
AK Gem	4	6	12	2	13.62	13.38	7872	7876	13	BR Tau	3	6	10	2	12.86	12.46	8160	8233	16
DT Gem	2	16	12	5	12.49	12.07	7872	8234	17	CN Tau	3	6	8	4	12.72	12.19	7513	7898	61
EW Gem	3	11	10	2	14.64	14.34	7872	7953	17	IY Tau	2	6	11	2	12.84	12.18	7876	7896	12
GQ Gem	2	5	8	3	14.43	14.14	7872	7926	19	SX Tri	3	3	11	2	14.60	14.30	7196	8227	25
KV Gem	2	11	7	6	12.16	11.73	7872	8344	56	AP UMa	2	18	16	3	14.04	13.78	7612	8235	16
CW Her	1	16	12	2	12.56	12.34	8048	8344	9	BD UMa	1	12	10	3	13.49	13.23	7953	8344	14
DL Her	1	7	6	4	12.46	12.17	8102	8156	11	BK UMa	2	15	11	4	12.89	12.60	7574	7896	25
EE Her	2	6	13	2	13.07	12.88	8048	8344	15	BV Vir	1	19	9	3	14.96	14.70	7246	7954	13
GY Her	1	6	14	3	12.66	12.45	8049	8157	18	AW Vul	2	---	---	0	---	---	7771	7823	8
HO Her	2	5	7	2	13.25	13.04	7977	8021	15	FH Vul	3	6	6	5	12.88	12.67	7771	7878	34
IL Her	3	7	12	3	14.50	14.24	7977	8344	17										

TABLE 2. Light curve parameters.

Star (1)		P (days) (2)	+/- (3)	source a (4)	J.D. max (5)	Amplitude		a		r	
						V (6)	R (7)	(8)		(9)	
ZZ	And	.5545326	.0002	G	8210.80	0.96	0.78	.264	.296	.066	.116
BK	And	.4215985	.0001	G	8150.923	1.00	0.78	.262	.364	.036	.124
CI	And	.4847185	.0002	G	8156.801	0.90	0.80	.302	.362	.040	.180
DE	And	.453635	.0001	G	8112.766	0.77	0.60	.362	.378	.060	.140
DY	And	.6030	.001	A	8166.70	0.80	0.58	.210	.394	.014	.214
FI	And	.564815	.001	G	8156.60	1.09	0.88	.222	.290	.028	.098
GM	And	.7067585	.00015	G	7548.63	0.87	0.72	.258	.282	.060	.072
GV	And	.528092	.00015	G	8156.73	1.00	0.78	.276	.306	.118	.148
HK	And	.51011	.0001	G	8166.67	1.16	0.94	.294	.362	.022	.150
V793	Aql	.4001	.0002	A	8157.588	0.44	0.37	.498	.518	.236	.252
SY	Ari	.5666815	.00002	G	8156.92	1.00	0.80	.262	.280	.058	.096
TU	Ari	.47075	.00005	A	7926.524	0.80	0.72	.528	.548	.310	.368
BH	Aur	.45612	.00001	A	7954.687	0.98	0.78	.248	.278	.084	.110
CR	Aur	.59141	.0001	G	8157.86	0.74	0.64	.300	.328	.160	.200
DN	Aur	.61688	.00005	S	7954.68 b	0.42	0.37	--	--	--	--
GT	Aur	4.40475	.002	G	7848.76	0.92	0.70	.354	.370	.116	.172
MV	Aur	.55359	.00015	G	7954.62	0.98	0.78	.340	.350	.000	.146
TY	Cam	.6700067	.0003	G	7547.86	0.93	0.73	.300	.334	.070	.088
AS	Cnc	.617520	.0003	G	7877.95	1.05	0.84	.306	.328	.026	.122
BD	Cas	3.650900	.0005	G	7926.59	0.47	0.39	.410	.428	.402	.412
BF	Cas	3.63029	.0016	G	8227.76	0.89	0.70	.354	.386	.100	.154
BR	Cas	.608289	.0002	G	7548.61	0.87	0.70	.392	.408	.100	.114
NO	Cas	2.5829	.0002	S	7771.69	0.32	0.24	.498	.548	.304	.358
NY	Cas	2.8230921	.002	G	7897.69	0.44	0.35	.444	.460	.310	.340
OP	Cas	5.5128	.005	G	8205.7	0.62	0.49	.400	.446	.128	.186
MU	Cep	3.767820	.0005	G	7772.83	0.68	0.52	.390	.428	.128	.150
UZ	Com	.736941	.00004	G	7317.76	0.56	0.47	.348	.386	.096	.126
BW	Com	.73359	.00002	G	7297.76	0.30	0.23	.326	.448	.112	.256
CY	Com	.757881	.00004	G	7625.65	0.71	0.52	.350	.384	.076	.126
FV	Com	.472469	.001	G	7953.902	1.12	0.88	.240	.332	.164	.192
GU	Com	.490785	.0001	G	7953.786	1.04	0.85	.298	.340	.140	.170
CV	Cyg	.73946	.00002	S	7465.73	1.24	1.05	.322	.384	.116	.142
V508	Cyg	.77969c	.00002	S	7774.85 b	0.68	0.68	--	--	--	--
V742	Cyg	.93645	.00005	A	7061.62	0.79	0.67	.430	.506	.160	.192
V830	Cyg	.73969	.0001	S	7820.75 b	0.33	0.70	--	--	--	--
ZZ	Del	.51959	.0002	A	7774.77	0.74	0.62	.318	.338	.078	.136
AK	Gem	.3462	.0001	S	7876.643	1.32	1.02	.242	.296	.026	.128
DT	Gem	.6112879	.00004	G	7876.92	0.50	0.37	.288	.334	.172	.288
EW	Gem	.52348	.0001	A	7876.69	1.10	0.78	.260	.292	.156	.222
GQ	Gem	.570570	.001	G	7897.73	0.85	0.68	.254	.316	.078	.112
KV	Gem	.43713	.00005	S	7872.914b	0.63	0.58	--	--	--	--
CW	Her	.6238405	.00005	G	8069.75	0.91	0.73	.226	.314	.000	.086
DL	Her	.59162786	.0002	G	8102.80	0.90	0.74	.306	.340	.086	.106
EE	Her	.4955363	.00002	G	8112.755	1.25	0.98	.280	.314	.064	.112
GY	Her	.52425	.00005	A	8157.60	0.92	0.74	.254	.300	.132	.154
HO	Her	.472694	.0007	G	8017.789	0.94	0.71	.282	.358	.022	.090

TABLE 2. (continued)

Star	P	source	J.D.	Amplitude	a		r	
(1)	(days)	+/-	a	max	V	R	(8)	(9)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IL	Her .578547	.00003	A	8110.81	0.81	0.67	.354 .394	.066 .100
LW	Her .3222	.0001	S	8112.781	0.66	0.52	.364 .390	.248 .280
OX	Her .757367	.0002	G	7370.72	0.60	0.50	.350 .418	.100 .134
V392	Her .5297446	.0003	G	7672.77	1.04	0.82	.312 .376	.042 .158
V442	Her .4417	.0002	A	8110.650	0.27	0.27	.315 .658	.432 .520
V458	Her .3599801	.001	G	7716.812	0.56	0.44	.446 .514	.164 .192
V469	Her .5964724	.0002	G	7977.86	0.96	0.78	.260 .310	.094 .178
V599	Her .75084	.0001	A	8022.65	0.72	0.54	.420 .480	.064 .090
V677	Her .475716	.0004	G	8074.777	1.08	0.88	.218 .304	.000 .076
V692	Her .736679	.00002	G	7306.87	0.73	0.62	.390 .438	.118 .144
V719	Her .400995	.000005	S	7713.668b	>.6	>.5	-- --	-- --
XX	Leo .970941	.002	G	7926.86 b	0.32	0.34	-- --	-- --
AX	Leo .726828	.0002	G	8022.73	0.66	0.58	.332 .354	.108 .214
BT	Leo .499727	.0001	G	7667.617	1.25	1.06	.188 .270	.098 .176
Y	LMi .5244710	.03	G	7953.69	1.32	1.06	.248 .270	.092 .164
DR	Lyr .8313502	.0004	G	7370.75	0.58	0.52	.474 .508	.124 .176
NW	Lyr 1.6011823	.00015	G	8075.70	1.04	0.82	.350 .402	.212 .220
V462	Lyr .37300	.00015	A	8166.631	0.56	0.42	.404 .504	.210 .342
UW	Mon .58236414	.002	G	7896.82	0.83	0.67	.300 .440	.020 .170
V518	Mon .34874473	.0002	G	7872.787	0.40	0.32	.496 .510	.252 .264
V756	Oph .46107	.00001	A	8110.639	1.27	1.02	.232 .252	.020 .076
V768	Oph .701895	.0002	G	7661.86	0.73	0.54	.302 .330	.082 .110
V773	Oph .5856928	.00005	G	7706.69	0.92	0.80	.304 .318	.074 .118
V822	Oph .53771	.00002	A	8022.77	0.98	0.83	.224 .280	.128 .142
AN	Per .6020	.0002	A	7591.57:	0.62	0.54	.238 .456	.000 .196
CI	Per 3.767	.01	S	7897.68	0.43	0.34	.480 .504	.230 .260
ET	Per .3940137	.00002	G	8112.912	1.23	1.04	.250 .264	.032 .088
GP	Per 2.04160	.0001	G	7919.67	1.12	0.94	.270 .284	.044 .090
HQ	Per 8.63793	.02	G	7919.6	0.44	0.36	.528 .544	.176 .244
KN	Per .866448	.008	S	7820.93 b	0.54	0.53	-- --	-- --
KV	Per .249121	.00006	G	7842.627	0.48	0.37	.452 .470	.264 .280
V375	Per .546074	.0001	G	8149.89	1.18	0.96	.202 .290	.000 .084
V428	Per 4.13	.03	S	7872.57	0.46	0.40	.430 .700	.170 .280
SY	Psc .67354111	.00003	G	7443.80	0.93	0.80	.252 .316	.046 .114
DF	Ser .43779512	.001	G	7661.826	1.32	0.98	.272 .328	.078 .110
U	Sex .533835	.00005	A	7896.96	1.24	1.04	.246 .300	.078 .118
V	Sex .48743	.00005	A	7898.939	0.90	0.74	.294 .414	.092 .138
BR	Tau .3905928	.00015	G	8233.701	1.32	1.05	.282 .300	.028 .080
CN	Tau 1.793	.001	S	7548.75	0.40	0.30	.412 .446	.184 .288
IY	Tau .3764897	.0002	G	7876.756	0.31	0.24	.384 .458	.338 .418
SX	Tri .7429594	.00007	G	7464.81	0.59	0.56	.370 .400	.108 .152
AP	UMa .577073	.00005	G	7659.75	0.87	0.74	.292 .304	.108 .146
BD	UMa .681147	.0002	G	8017.76	0.94	0.76	.322 .414	.026 .112
BK	UMa .6357	.0001	S	7876.99	0.41	0.40	.358 .424	.150 .186
BV	Vir .49659	.00002	A	7953.827	0.75	0.58	.278 .358	.040 .110
AW	Vul .8064514	.05	G	7771.77 b	>1.1	>1.1	-- --	-- --
FH	Vul .4054185	.00003	G	7837.667	1.36	1.11	.254 .266	.064 .076

Notes for TABLE 2

a. G indicates a period from the GCVS. A indicates a period adjusted with the data, and S indicates a case where the GCVS period is in error by more than 1%.

b. For eclipsing binaries the H.J.D. of minimum light is given and a and r are omitted.

c. For V508 Cyg a period of 0.78004 is also possible.

be completely spurious and in other cases the light curves from the present data can be improved by adjusting the periods slightly. Thus, we have sought the period for each star which produces the least light curve scatter. The uncertainty was then estimated. If the adjusted period did not differ from the catalogue value by more than this uncertainty, the catalogue period was adopted. Column two of Table 2 lists the adopted periods while the uncertainty of our estimate is listed in column three. A *G* in the fourth column indicates that the adopted period is from the GCVS while an *A* indicates that a small adjustment was made to the GCVS value. Cases where the adopted period differed by more than 1% from the catalogue, are identified by an *S* in the fourth column.

The fifth column of Table 2 lists the Heliocentric Julian Date of maximum light (except for a few eclipsing variables for which the epoch of minimum light is given) while the amplitudes in *V* and *R* are given in the sixth and seventh columns. Since the phase coverage is sparse, the magnitude and time of maximum were estimated by linearly extrapolating the rising and declining branches of the light curves to the point where they meet. Thus, the times of maximum are somewhat approximate; they are good enough to use in determining modern phases for these stars but should not be compared with older times of maximum to determine periods. The uncertainties in the amplitudes are generally dominated by the extrapolation to maximum since the minima tend to be broad and are reasonably well defined in sparse light curves. The relative amplitudes of *V* and *R* are little affected by the extrapolation since care was taken to extrapolate both colors in the same fashion.

It would be best to describe the light curves in terms of the Fourier parameters as has been done for many well observed variables. Since meaningful Fourier fitting is not possible with sparse light curves we have instead defined two parameters to measure the light curve shape quantitatively. These are the acuteness *a* and the rise time *r*.

The acuteness, given in column eight of Table 2, is the fraction of the cycle during which the star is brighter than the midmagnitude, $V(\text{mid}) = [V(\text{min}) - V(\text{max})]/2$. The accuracy of this quantity is limited by the phase coverage near the extrema and the midpoints of the light curve. Accordingly, the earliest and latest time possible for the crossings of midlight were estimated by visual examination of the light curves. This yielded a range within which *a* must lie. The range is small when there are data near midlight but large when this is not the case or when the times of crossing are ambiguous due to excessive scatter, bumps, or stillstands. This parameter is equivalent to the acuteness as defined by Stellingwerf & Donohoe (1987) although the definition is somewhat different. They and Stellingwerf & Dickens (1987) have shown that the acuteness is similar in behavior to the Fourier phase difference parameter $\Phi(21)$ for RR Lyrae stars while Andreasen (1988) has made a similar demonstration for classical Cepheids.

Column nine of Table 2 lists the rise time *r*. It is defined as the phase interval between the time the star passes through the magnitude $V(\text{min}) - 0.1A(V)$ during rising light and when it reaches the magnitude $V(\text{max}) + 0.1A(V)$, where $A(V)$ is the *V* amplitude. This definition avoids uncertainties which occur when either the maximum or the minimum is very flat. Again the range represents the possible limits given our phase coverage. This parameter is similar to the asymmetry parameter, $M - m$, in the GCVS, the skewness parameter of Stellingwerf & Donohoe (1987) and the rise

time used by Sandage (1981, and references therein). These latter two papers have shown the usefulness of such a parameter for studying the form of light curves. Stellingwerf & Dickens (1987) showed that the skewness (and thus the rise time) is similar in behavior to the Fourier amplitude ratio, $R(21)$ for RR Lyrae stars while Andreasen (1988) found a similar result for the classical Cepheids.

To investigate the behavior of *a* and *r*, we measured them from the RR Lyrae light curves of Lub (1977) and the Cepheid light curves of Moffett & Barnes (1980, 1984). Fourier decomposition of these same data was carried out by Simon & Teays (1982) and Moffett & Barnes (1985), respectively.

Figure 1 shows plots of the parameters *a* and *r* against the Fourier parameters $R(21)$ and $\Phi(21)$. In accord with previous investigators, *a* is better correlated with the phase difference, $\Phi(21)$ while *r* is better correlated with the amplitude ratio, $R(21)$.

In the plot of *a* against $\Phi(21)$ there are a number of outliers. The Cepheids which lie well to the left of the sequence in Fig. 1(a) (from left to right in the diagram, FN Aql, AA Gem, DX Gem, SZ Tau, EV Sct, V532 Cyg, and FF Aql) were omitted from consideration by Simon and Moffett due to difficulties in the Fourier decomposition arising from nearly sinusoidal light curves or inadequate phase coverage. On the other hand, the two Cepheids to the right of the sequence, DD Cep and Zeta Gem, were deemed by Simon and Moffett to have well determined values of $\Phi(21)$ in spite of nearly sinusoidal light curves. The two RR Lyrae stars which deviate are V341 Aql and HH Pup. V341 Aql, with $\Phi(21) = 6.89$, falls so far from the values for other RR Lyrae stars that it is likely to be in error. The other deviant RR Lyrae is HH Pup. This star has a peculiar light curve with a strong bump on the lower part of descending light. This has caused it to have a small value of *a* but does not seem to have affected its Fourier coefficients. No other similar light curve can be found in the photometry of Lub (1977). Thus, while the acuteness resembles $\Phi(21)$ in behavior, it does not give identical information.

The plot of *r* against $R(21)$ exhibits a different correlation for the RR Lyrae stars than for the Cepheids. This again shows that while *r* and $R(21)$ are similar, they do measure somewhat different properties of the curves.

The acuteness is plotted against period in Figs. 2(a) and 2(b). These diagrams are given to provide a basis for the interpretation of the acutenesses measured for the program stars. They can also be compared with the $\Phi(21)$ -period plots of Simon & Teays (1982, Fig. 1) and Simon & Moffett (1985, Fig. 1), respectively. Except for the stars which are outliers in Fig. 1(a), they resemble the earlier plots involving $\Phi(21)$.

In Fig. 2(b) the shortest period Cepheids (shorter than about three days) form a group (with *a* between 0.44 and 0.51) apart from the sequence of the bulk of the stars. Several of these objects have been previously recognized as *s* Cepheids (Antonello *et al.* 1990). While the use of *a* separates such objects from the normal Cepheids at the shortest periods, it will fail to do so at periods longer than five or six days.

In Fig. 3, *r* is plotted against period. In comparing Fig. 3(a) with the corresponding $R(21)$ plot (Fig. 2 of Simon & Teays 1982), it is immediately clear that in spite of a similar form, *r* does not separate the type *c* RR Lyrae stars from the type *ab*'s as well as does $R(21)$. A comparison of Fig. 3(b) with the corresponding $R(21)$ plot [Fig. 3 of Simon & Mof-

FIG. 1. Plots of the acuteness a and the rise time r against the Fourier decomposition parameters $R(21)$ and $\Phi(21)$. Filled symbols represent Cepheids observed by Moffett & Barnes (1980, 1984) and open symbols represent RR Lyrae stars observed by Lub (1977).

fett (1985)] again shows general similarity. However, in $R(21)$ there is considerably greater scatter at a given period among the long-period Cepheids than the short-period Cepheids while in r the scatter is more comparable. These factors combined with the differences between the RR Lyrae stars and the Cepheids in Fig. 1(d) indicate that r and $R(21)$ measure somewhat different properties of the light curves.

4. DISCUSSION

The information in Tables 1 and 2 was examined to detect erroneous classifications for these stars in the GCVS. The primary criteria applied were the appearance of the light curve, the acuteness (as compared with Fig. 2) and the period. However, cases are encountered where these criteria are not adequate. In particular, the light curves of some eclipsing binaries are difficult to distinguish from Bailey type c RR Lyrae stars if a period of half the correct value has been assumed (so that the two eclipses are superimposed). This is particularly true with sparse light curves and in the presence of light curve modulation. To search for such cases, the amplitudes of the V light curves were plotted against the R amplitudes. The majority of the stars scatter about a line with a slope of $A(R)/A(V) = 0.8$. The smaller amplitude at longer wavelength is a well-known phenomenon for pulsating stars and follows directly from the behavior of the Planck function. Stars which exhibited an R amplitude too large compared to their V amplitude were then regarded as suspected eclipsing stars. For each star a plot was also made of the V magnitude against the $V - R$ color. Since the variation

is dominated by the temperature change, pulsating stars will exhibit a nearly linear correlation between these two quantities although there will be some scatter due to the effects of radius change. On the other hand, stars which vary due to the geometrical effects of binarity (e.g., eclipsing binaries and ellipsoidal variables) will exhibit a variety of behaviors depending on the properties of the two components. This was found to be a strong technique for detecting binary variables among our sample. There are three stars in our sample which are classed as eclipsing binaries in the GCVS (CV Cyg, XX Leo, and AW Vul). Two of these behave very distinctly from the RR Lyrae stars in this diagram while, as discussed below, the third, CV Cyg, appears to be an RR Lyrae star which was misclassified due to a period error.

In Table 3 we list the stars for which the above criteria indicated a change in the GCVS classification. The footnotes to the table identify the criteria which led to the revision of the classification. A number of these are simply improvements to the catalogue information. These include five cases where we have assigned Bailey types to stars classed as RR in the catalogue and five cases of stars classed as CEP in the catalogue but which appear to be classical Cepheids based on the light curves and the galactic latitudes. The star BD Cas is classed as a CWB in the GCVS although it has a low galactic latitude. A comparison of its light curve with the type-II Cepheid light curves of Diethelm (1983) casts further doubt on its identification as a type-II Cepheid. In fact, it appears from its light curve to be an s -type classical Cepheid. This star together with two which were previously classed as RR Lyrae stars but found to have erroneous periods (NO Cas

FIG. 2. Plots of acuteness against period. RR Lyrae stars are plotted in (a) and Cepheids in (b).

FIG. 3. The rise time plotted against the period. RR Lyrae stars are shown in (a) and Cepheids in (b).

TABLE 3. Stars with revised types.

Star	Classification		Reason
	GCVS	Revised	
DY And	RR	RRAB	a, b
TU Ari	RRAB	RRC	a, b
CR Aur	RR	RRAB	a, b
DN Aur	RRC	E or ELL	a, b, c
GT Aur	CEP	DCEP	a, d
BD Cas	CWB	DCEPS	a, d
NO Cas	RRAB	DCEPS	a, b, d, e
MU Cas	CEP	DCEP	a, d
CV Cyg	EW/DW	RRAB	a, c
V508 Cyg	RRC	E or ELL	a, b, c, f
V742 Cyg	CWB	?	a
V830 Cyg	RRAB	E or ELL	a, c, f
DT Gem	RRC	RRAB	a, b
EW Gem	RR	RRAB	a, b
KV Gem	RRC g	E	a, c, f
V442 Her	RRAB	?	a, c, f
V719 Her	RRAB g	E	a, c, f
CI Per	CEP:	DCEPS	a, b, d
GP Per	CEP	DCEP	a, b, d
HQ Per	CEP	DCEP	a, b, d
KN Per	RRC	E or ELL	a, b, c, f
V428 Per	RR	DCEP h	a, d, e
CN Tau	RRAB	DCEPS	a, b, e
IY Tau	RRAB	RRC:	a, b
BK Uma	RRC	?	a, b, c, e, f
BV Vir	RR	RRAB	a, b

- a Appearance of light curve
- b Acuteness and rise time
- c Color-magnitude plot
- d Galactic latitude
- e Period revision
- f Comparison of V and R amplitudes
- g EW possible
- h Possibly a double mode pulsator

and CN Tau) and one other classed as CEP: (CI Per) add four new members to the short-period *s*-Cepheid group. Antonello *et al.* (1990) have argued for a definition of the *s* Cepheids in terms of the Fourier parameters. However, the discussion above indicates that the use of *a* should be equivalent for stars with the periods of these four objects. One star which was previously classed as an eclipsing star, CV Cyg, turns out to be an RR Lyrae star when the period is corrected.

The six stars classed as RR Lyrae stars in the GCVS which appear to be binaries of short period represent the most significant reclassifications. There are remarks in the GCVS indicating that two of these, KV Gem and V719 Her, may be eclipsing stars but there is no indication that any of the other four have been previously recognized as such. The light curves are plotted in Fig. 4 using a period twice what would have been derived assuming them to be pulsating stars. It can be seen that some of these objects show scatter and there is little evidence for a flat region in the light curve. This is consistent with their being close binaries with possible interactions. V830 Cyg has a close companion which degrades the photometry and no doubt causes the excessive scatter for

FIG. 4. Light curves of stars reclassified as eclipsing binaries. Filled symbols represent *V* magnitudes and open symbols represent *R* magnitudes.

that star. Nonetheless, the conclusion that it is a binary variable is firm.

It is sometimes difficult to distinguish between ellipsoidal variables and eclipsing binaries using light curves. KV Gem appears to have flat maxima in its light curve which is inconsistent with an ellipsoidal variable while the depths of the minima in V719 Her differ too much for such an object (Hall 1990). However, for the others, we cannot distinguish between the two possibilities on the basis of the present photometry. Further photometry might help in the cases of KN Per and DN Aur but more extensive studies will be needed to reach a definitive conclusion.

These new binary variables represent 7 1/2% of the 79 supposed RR Lyrae stars in this sample. If we assume that there is a similar degree of contamination of the remaining

RR Lyrae stars fainter than tenth magnitude (about 6060 stars) this suggests that there are four to five hundred binary stars in the GCVS which are erroneously classed as RR Lyraes. Given that there seem to be more such errors among the RRC stars than among the RRAB stars, and RRC's number less than 400 in the GCVS, the field RRC stars may be significantly less common than the GCVS would indicate. On the other hand, there are fewer than 1200 binary variables listed in the GCVS with periods less than one day. Thus, the reclassification of presumed RR Lyraes could represent a significant increase in the numbers of such stars. It is likely that many of them will prove to be interesting binary systems given their short periods.

There are three stars in Table 3 for which we have indicated an unknown type. The light curves of two of these objects

and one other star of special interest, V428 Per, are shown in Fig. 5 and each will be discussed individually. The status of V742 Cyg was previously discussed by Schmidt *et al.* (1990).

V442 Her. This star has a period appropriate to a type ab RR Lyrae star but the light curve shown in Fig. 5 does not match any other RR Lyrae in either the present study or that of Lub (1963). In particular, there is a stillstand during rising light which lasts about a third of the cycle. Often the adoption of an incorrect period can produce peculiar light curve forms when there are relatively few data points. However, data from one night spans the stillstand so it cannot be removed by adopting a different period. In any event, a period search failed to reveal any other acceptable period. A further peculiarity of this star is the amplitude in R is the same as that in V and consequently the star exhibits little color change during its variation. Finally, there is some evidence for the presence of a second period after the principal

variation is removed. With the small number of data points it is not possible to prove the existence of a second period or determine an unambiguous value for it. One possibility is 0.306 days. This is about 0.7 of the fundamental and is plausible for the first overtone. This appears to be a star which will reward further investigation.

V428 Per. No period could be found for this star which produced acceptably small scatter and the period given in Table 2 is approximate. Given the revised period and the galactic latitude, V428 Per should be reclassified as a classical Cepheid. The light curve scatter further suggests that it may be a double mode Cepheid since its period falls within the correct range (Balona 1985). There are only about a dozen such stars known. Since they are of theoretical interest further observations should be made to confirm this.

BK UMa. This star has a (revised) period and light curve appropriate to a Bailey type ab RR Lyrae star. However, the amplitude in R is equal to that in V . This could be caused by a blue companion which would reduce the amplitude of the combined light more in the visual than in the red. The relatively small amplitude of this star supports this suggestion. However, it should cause this object to appear bluer than other RR Lyrae stars of similar period. This is not the case. Again further investigation of this object seems in order.

The periods indicated by the present photometry for more than one-third of the stars differed from the values in the GCVS. These stars are indicated by an A or S in column 4 of Table 2 and are relisted in Table 4 along with their catalogue periods (column 2), the revised periods (column 3), and the ratios of the periods (column 4). The last column of the table indicates the probable cause of the discrepancy as discussed below.

There are several possible causes of these discrepancies. For the stars reclassified as binaries the period should be doubled. The revised periods are indeed twice the GCVS values for four such stars, DN Aur, V508 Cyg, KV Gem, and KN Per. Additionally, there are two stars, DY And and V793 Aql, for which the period in the GCVS is given to only three places and we have simply improved the determination. As is well known (see, for example, Lafler & Kinman 1965) a common period error arises due to aliasing with one day. The new periods for the stars NO Cas, AK Gem, CN Tau reflect this situation while for V719 Her the catalogue period was the result of both aliasing and assuming half of the correct period in a binary system.

Two other causes of erroneous periods are the phase shifts associated with the Blazhko effect and errors in the cycle count between seasons. The former is more likely to affect the present period determinations since we have a limited number of data points. We can estimate its size by noting that for RR Lyrae the phase of maximum shifts by about 0.05 cycles over its 41 day Blazhko cycle (Walraven 1949). Given the intervals of observation for the stars in this program, this can cause a period error which is several times larger than the error estimates in Table 2. Difficulties with cycle counts will not affect most of the revised periods because we have usually observed a particular star only during one season. For an error of one cycle over a year, this type of error will alter the period by P/n , where n is the number of cycles in a year. For nine stars, BH Aur, EW Gem, GY Her, IL Her, V599 Her, V756 Oph, V822 Oph, U Sex, and BV Vir, the period discrepancies are consistent with the Blazhko effect but not with a cycle count error. For these stars the GCVS periods are to be preferred. On the other hand, for

FIG. 5. Light curves of stars with peculiarities. Filled and open symbols represent V and R magnitudes, respectively.

TABLE 4. Stars with revised periods.

Star	Period		P(rev) P(GCVS)	Cause	Star	Period		P(rev) P(GCVS)	Cause
	GCVS	Revised				GCVS	Revised		
DY And	0.604	0.6030	0.998	a	LW Her	0.31836	0.3222	1.012	b
V793 Aql	0.398	0.4001	1.005	a	V442 Her	0.4420840	0.4417	0.9991	c or f
TU Ari	0.4716555	0.47075	0.99808	b	V599 Her	0.750618	0.75084	1.0003	c
BH Aur	0.4560898	0.45612	1.00007	c	V719 Her	0.335870	0.400995	1.19390	d and e
DN Aur	0.307	0.61688	2.01	d	V462 Lyr	0.372512	0.37300	1.0013	c or f
NO Cas	0.719472	2.5829	3.5900	e	V756 Oph	0.4610295	0.46107	1.0001	c
CV Cyg	0.9834308	0.73946	0.75192	b	V822 Oph	0.5376777	0.53771	1.0001	c
V508 Cyg	0.389766	0.77969	2.0004	d	AN Per	0.602818	0.6020	0.9986	c or f
V742 Cyg	0.93946	0.93645	0.99680	f	CI Per	3.3779	3.767	1.115	b
V830 Cyg	0.40147246	0.73969	1.8424	b	KN Per	0.433224	0.866448	2.000	d
ZZ Del	0.52019172	0.51959	0.99884	c or f	V428 Per	0.664191	4.13	6.22	b
AK Gem	0.52934	0.3462	0.6419	e	U Sex	0.5340080	0.533835	0.999676	c
EW Gem	0.523683	0.52348	0.99961	c	V Sex	0.4880788	0.48743	0.99867	f
KV Gem	0.2185467	0.43713	2.0002	d	CN Tau	0.642062	1.793	2.793	e
GY Her	0.5243814	0.52425	0.99975	c	BK UMa	0.389133	0.6357	1.634	b
IL Her	0.578466	0.578547	1.00014	c	BV Vir	0.496656	0.49659	0.99987	c

- a. Improvement to GCVS period.
 b. Unexplained discrepancy.
 c. Revised period possibly affected by Blazhko effect.
 d. Period doubled due to recognition of star as a binary.
 e. Alias of true period with one day caused erroneous GCVS period.
 f. Error in GCVS period evidently due to error in cycle count.

V742 Cyg and V Sex, the discrepancy is consistent with a cycle count error but not the Blazhko effect. For these stars the GCVS periods should be regarded as suspect. There are four stars, ZZ Del, V442 Her, V462 Lyr, and AN Per for which either effect would suffice and, again, there is no reason not to use the GCVS periods.

Finally, there are seven stars, TU Ari, CV Cyg, V830 Cyg, LW Her, CI Per, V428 Per, and BK UMa with period discrepancies which cannot be explained by any of the above mechanisms. Some of these may be simple errors in the values reported but without reanalyzing the data from which they come, it is not possible to determine the source of the errors. In any event, the catalogue periods of these stars do not fit the present data and catalogue periods should be regarded as incorrect.

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