ON BETA CEPHEI STARS: A SEARCH FOR BETA CEPHEI STARS*†‡

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Received September 30, 1966; revised January 9, 1967

ABSTRACT

The results of a photoelectric search for β Cephei stars among a sample of 153 early B stars, found in the nearest associations and galactic clusters, are presented. This search yielded 24 new β Cephei stars (including 5 tentative ones), thereby increasing the number of known β Cephei stars to 41. These new observations have extended considerably the limits of spectral type, luminosity class, absolute magnitude, period, and rotational velocity for these variables. The limits now become O9.5–B3 (spectral type), V–I (luminosity class), 3–10 hours (period), 0–>300 km/sec (rotational velocity). An examination of the period-luminosity relation leads to the tentative conclusion that those stars with periods $<0^d3$ obey a $p - l$ relation, but the stars with periods $\geq 0^d35$ do not. H-R diagrams of β Cephei variables and "normal" stars for individual associations and galactic clusters show that the β Cephei stars occupy no preferred position in relation to normal stars, i.e., many of these "normal" stars are at the same stage of evolution as the β Cephei stars.

I. INTRODUCTION

A primary purpose of this work has been to provide astronomers with a larger sample of β Cephei stars to study than has hitherto been available. Other important reasons for making such a search are (1) to determine more precisely the extent of the β Cephei phenomenon and (2) to discover, if possible, the evolutionary state of the β Cephei stars. To accomplish this a search for β Cephei stars, similar to that made by Lynds (1959), was made among members of the nearest associations and galactic clusters. The search was conducted photoelectrically, rather than spectroscopically, in order to minimize the amount of data reduction needed and to allow the observing program to be executed with a small telescope (16-inch) for which extensive photoelectric time was available. Only the results of the search program will be presented in this paper. The determination of the evolutionary state of the β Cephei stars will be the subject of a later paper. Since excellent summaries of the general observed characteristics of the β Cephei stars are available (Struve 1955; Ledoux and Walraven 1958) they have not been repeated here. Table 1 summarizes the photometric, spectroscopic, and period data for the previously known β Cephei stars. The major sources of these data are McNamara and Williams (1955), Schmalberger (1960), and Hitotuyanagi and Takeuti (1963). The intrinsic colors were evaluated by the method described in § VI.

II. THE SEARCH PROGRAM

The stars among which the search was made were: (1) found in associations and galactic clusters which have turn-off points between O9 and B3 (this criterion was chosen since I believed that the probability of discovering β Cephei variables would be increased if the search was confined to the more evolved early-type galactic clusters and associations); (2) between spectral types O9–B5 and luminosity classes IV–II (these

* Based on portions of a Ph.D. dissertation submitted to the University of Texas.

† *Publications of the Department of Astronomy, The University of Texas*, Series I, Vol. 1, No. 29.

‡ *Contributions from the Kitt Peak National Observatory*, No. 246.

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|| Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

bounds more than covered the observed luminosity–spectral-type range for β Cephei stars, but as the results summarized in § X show, the β Cephei stars are not confined to these luminosity classes; later searches should encompass *all* luminosity classes within the spectral-type range O9–B5); (3) not emission-line objects (the justification for this criterion is that no known β Cephei star is a Be star; the few Be stars inadvertently studied in this program showed *no* periodic behavior within the period range $0^{d}.1$–$1^{d}.0$). Some field stars were observed but these were few in number (20). The β Cephei stars were to be identified by discovering periodicities $<1^{d}$ in the light-curve data. Table 2 lists the 142 program stars investigated, in the following clusters and associations: Perseus I, Perseus II, Gemini I, Scorpius II, Lacerta I, Cepheus II, Cepheus III, NGC 1502, NGC 2169, NGC 7160, and NGC 7380. Most of the program stars are identified by their HD or BD numbers (cols. [1] and [2] of Table 2). Star identifications in galactic clusters

TABLE 1

PHOTOMETRIC, SPECTROSCOPIC, AND PERIOD DATA FOR PREVIOUSLY KNOWN β CEPHEI STARS*

Name	MK	V	$B-V$	$U-B$	$(U-B)_0$	M_v	log P	$v \sin i$ (BK)
γ Peg	B2.5 IV	2.83	−0.23	−0.87	−0.89	−3.04	−0.821	5
δ Cet	B2 IV	......	− .205	− .850	−0.88	−3.47	− .793	25
53 Ari	B2 IV	......	....	....	(−0.85)	(−3.0)	− .815	......
HD 21803	B2 IV	......	....	....	(−0.85)	−4.0	− .699	......
ν Eri	B2 III	4.12	− .195	− .860	−0.88	−4.09	− .750	31
β CMa	B1 II–III	1.99	− .235	− .970	−0.99	−4.80	− .602	38
ξ^1 CMa	B0.5 IV	4.35	− .240	− .980	−1.01	−4.43	− .660	33
15 CMa	B1.5 III	......	....	....	(−0.93)	−4.17	− .735	69
β Cru	B0.5 III	1.28	− .25	....	(−1.04)	−4.49	− .627	32
τ^1 Lup	B3 III	......	....	....	(−0.76)	−4.1	− .752	0
α Lup	B1 III	2.32	− .22	....	(−0.97)	−5.0	− .585	0
σ Sco	B1 III	2.86	+ .16	− .69	−1.00	−4.6	− .609	53
θ Oph	B2 IV	3.29	− .23	− .87	−0.89	−3.24	− .851	51
BW Vul	B2 III	6.44	− .130	− .870	−0.96	−4.42	− .697	26†
β Cep	B2 III	3.32	− .225	− .945	−0.96	−4.26	− .719	43
DD Lac	B2 III	5.18	− .135	− .860	−0.94	−4.15	− .705	79
EN Lac	B2 III	......	−0.145	−0.850	−0.93	−3.95	−0.767	37

* The values in parentheses have been derived from the MK spectral types.

† Determined by McNamara and Hansen (1961).

(col. [2] of Table 2) are due to Hoag, Johnson, Iriarte, Mitchell, Hallam, and Sharpless (1961). The remaining columns of Table 2 will be described in later sections. Initially, certain main-sequence B stars were selected as "standard" stars, but this preselecting of comparison stars was abandoned in favor of the method described later in this section. These "standard" stars are listed in parentheses with the program stars in Table 2.

Most of the photoelectric observations (86 out of 93 nights) were made at the Kitt Peak National Observatory (KPNO) with a 16-inch telescope (No. 4). All the observations with this particular telescope were made with the same *UBV* filter set and refrigerated 1P21. The photoelectric equipment (filters, photometers, etc.), typical of that available for each of the stellar telescopes at KPNO, is described by Landolt (1964). A number of observations were made with a different 16-inch telescope (2 nights) and the 36-inch telescope (1 night) at KPNO, and the McDonald Observatory 36-inch telescope (4 nights). On all occasions a refrigerated 1P21 was used; for all the KPNO observations the same filter set was used. Because the amplifier calibration proved unreliable, the data obtained at the McDonald Observatory were used only to improve the periods of some

TABLE 2

OBSERVATIONAL DATA

HD or BD	Star	MK	V	B-V	U-B	$(U-B)_0$	M_V	v sin i (km/sec) H	v sin i (km/sec) WH	v sin i (km/sec) BK	v sin i (km/sec) Adptd	NB	n	NU	n	NV	n	Results*	Notes
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
								PERSEUS I											
11734	59°360	B2 IV										20	3					C	1
12150	57°451	B2 IV	8.64	0.27	-0.53	-0.93	-4.8	173			170	24	6	18	4			C	
12509	63°281	B1 III	7.09	0.35	-0.54	-1.00	-6.5	93	0		60	24	6	18	4			C	
12567	63°287	B0.5 III	8.30	0.38	-0.56	-1.06	-5.5	158			160	23	6	9	2			C	
12727	56°425	B2 III	9.03	0.08	-0.72	-0.97	-3.7					10	3					C	
(12856)	56°429	B0pe										7	3					C	
(12857)	56°428											7	3					C	
12993	57°498	O5	8.95	0.20	-0.79	-1.20	-4.4					28	7	16	3	16	3	V	2
13036	58°384	B0.5: III:	8.55	0.53	-0.41	-0.97	-5.6		34		30	20	3					C	3
(13037)	57°499											13	4	8	4			C	
(13038)	57°501	A5 II										13	4	8	4			C	
13051	56°432	B1 IV::	8.70	0.14	-0.72	-1.04	-4.4	128	494		260:	16	3	16	3	16	3	βC	4
13267	56°438	B5 Ia										8	3					C	
13494	55°543	B1 III	9.30	0.18	-0.65	-0.97	-3.8	280			280	29	7					βC	
13544	53°480	B0.5 IV	8.88	-0.01	-0.82	-1.04	-3.7	332			330	30	6	9	2			βC	
13561	55°547	B0.5 Vp	8.83	0.09	-0.77	-1.07	-4.2					14	3					C	
13621	54°494	B0.5 IV	8.10	0.06	-0.78	-1.05	-4.7		144		140	31	6	9	2			C	5
13659	56°462	B1 Ib	8.65	0.56	-0.41	-0.99	-5.7					13	3					C	6
13716	57°525	B0.5 III	8.27	0.32	-0.59	-1.03	-5.4	235	34		160	29	7	15	3	15	3	EB?	7
13745	55°554	B0 III	7.86	0.16	-0.78	-1.15	-5.3	265			260	28	7	14	4			βC	
13758	57°527	B1 V	9.05	0.33	-0.53	-0.99	-4.6	≥278			≥280	22	8					EB	8
13831	56°469	B0 IV	8.26	0.10	-0.81	-1.14	-4.7	263	464		340	28	7	13	4			C	9
(13866)	56°475	B2 Ib	7.50	0.18	-0.64	-0.93	-5.5	0	24	45	39	28	7	13	4			βC	10
13890	56°478	B1 IIIp	8.50	0.19	-0.64	-0.97	-4.6	53			50	26	7	13	4			V	
13900	56°479	B1 IV	9.17	0.16	-0.66	-0.97	-3.9					13	3					C	11
13969	56°485	B1 IV	8.86	0.29	-0.59	-1.00	-4.6		34		30	13	3					C	12
14053	56°498	B0.5 III	8.43	0.24	-0.62	-1.00	-4.9	68			70	26	7	12	4			βC?	13
14302	55°587	B1 II-III	8.57	0.26	-0.56	-0.92	-4.7	36:			40:	13	3					C	
14331	55°590	B0 III	8.43	0.16	-0.76	-1.12	-4.8					13	3					C	
14422	Oo 2138	B0 IV:pe						≥285			≥280	12	3					V	14
15325	56°635	B1 IV	8.52	0.42	-0.47	-1.00	-5.3	213	74		160	31	6	9	2			C	
(15559)	54°567											8	3					C	
15571	56°648	B1 II	8.33	0.57	-0.43	-1.10	-6.1		24		20	20	3					C	
15642	54°569	B0 III	8.52	0.08	-0.84	-1.15	-4.4		434		430	8	3					C	15
15752	57°589	B0 III	8.74	0.49	-0.52	-1.14	-5.5	≥224			≥220	19	5	7	1			βC?	
(15912)	57°591											19	5	7	1			C	
16310	58°498	B1 II:	8.10	0.66	-0.36	-1.10	-6.6					28	7	16	3	16	3	C	
16429	60°541	O9.5 III	7.67	0.62	-0.38	-1.07	-6.9	233			230	26	5	9	2			βC	
232588	54°448	B1.5 III	8.63	0.07	-0.71	-0.94	-4.1					19	3					C	
236961	56°606	B1 II							144		140	9	3					C	16
56°473		B1 II	9.07	0.24	-0.63	-1.01	-4.3					27	7	13	4			βC	
56°545		B1 III	8.96	0.32	-0.54	-0.98	-4.6	≥294			≥290	27	7	13	4			βC	
56°589		B1 III	9.46	0.41	-0.48	-0.98	-4.4	130			130	20	5	7	1			βC	
57°513		B1 III	9.50	0.28	-0.56	-0.95	-3.9					8	3					C	
	Oo 1899	B2 II	8.53	0.32	-0.53	-0.97	-5.0					13	3					C	

*C = Constant; V = Variable; EB = Eclipsing binary; βC = β Cephei star.

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TABLE 2—Continued

HD or BD	Star	MK	V	B-V	U-B	$(U-B)_o$	M_V	v sin i (km/sec)				NB	n	NU	n	NV	n	Results	Notes
								H	WH	BK	Adptd								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
								PERSEUS II											
21438	HR 1074	B3 III	7.05	0.36	-0.32	-0.70	-2.3					16	2					C	
21856	34°674	B1 V	5.86	-0.06	-0.86	-1.04	-2.5			130	130	29	6	8	2			C	
23478	31°649	B3 IV	6.66	0.08	-0.56	-0.78	-1.9		344	160	170	28	6	8	2			C	17
23625	33°717	B2 V	6.56	0.08	-0.61	-0.85	-2.0			150	150	16	2					C	18
(24131)	HR 1191	B1 V	5.77	0.00	-0.80	-1.03	-2.7			120	120	29	6	8	2			C	
24640	HR 1215	B2 V	5.49	-0.03	-0.75	-0.93	-2.9			150	150	16	2					C	19
25539	32°714	B3 V	6.87	0.06	-0.60	-0.82	-1.7			100	100	16	2					C	
								NGC 1502											
	1	A2 V:n	7.93	0.07	0.01							28	6					C	20
	A							106			110	28	6					βC	21
	B											24	5					C	22
	3		9.56	0.43	-0.36	-0.84	-2.3	≥278			≥280	15	2					C	
	5	B1 Vn	9.61	0.55	-0.32	-0.90	-2.6	198			200	15	2					C	
	6	B1 V	9.66	0.57	-0.38	-1.01	-2.7					15	2					C	
								ORION I											
34511	-0°913	B5 V	7.39	-0.10	-0.69	-0.78	-1.2	3		35:	35:	39	12	26	8			C	
(34748)	-1°859	B1.5 V	6.30	-0.10	-0.78	-0.90	-2.4			270	270	39	12	26	8			C	23
35039	22 Ori	B2 IV	4.73	-0.18	-0.81	-0.86	-3.7	0		21	21	35	12	25	8			C	
(35673)	2°961	B9 V	6.50	0.00	-0.23	-0.26	-1.8					11	4					C	
35715	ψ Ori	B2 IV	4.56	-0.23	-0.94	-1.00	-3.4			166	166	35	12	25	8			βC?	24
36822	37 Ori	B0 IV								52	52	10	4					C	25
(36824)	5°958	B2 V	6.71	-0.15	-0.72	-0.78	-1.7			175	175	10	4					C	26
37756	-1°1004	B3 III	4.92	-0.22	-0.86	-0.88	-3.3			87	87	34	12	26	8			C	27
37776	-1°1005	B2 V	6.97	-0.14	-0.86	-0.96	-3.1:			155	155	35	12	25	8			βC?	
39291	55 Ori	B2 III	5.33	-0.19	-0.87	-0.91	-3.0			160	160	35	12	24	8			V	28
								NGC 2169											
13°1124	1		6.94	-0.09	-0.86	-1.00	-3.9	88:			90:	40	9	25	5	24	5	C	
13°1120	2	B2 V	8.13	-0.01	-0.63	-0.78	-2.7	≥240			≥240	40	9	25	5	24	5	βC	
	4	B2 V	8.61	-0.06	-0.80	-0.95	-2.2	158			160	12	3					C	
13°1123	5	B3 Vn	8.78	-0.06	-0.68	-0.80	-2.0	≥321			≥320	40	9	24	5	24	5	βC	
	6	B3 V	9.13	0.03	-0.53	-0.69	-1.8	≥266			≥270	10	3					C	
252215	9	B6 V	10.00	-0.02	-0.54	-0.69	-0.9	148			150	36	9	22	5			C	
252249	13°1121							248			250	10	3					C	
								GEMINI I											
(39340)	26°985	B3 V						≥333			≥330	27	7	5	2			V	
39746	27°914	B1 II	7.04	0.22	-0.67	-1.05	-5.8	193	204	260	250	27	7	5	2			C	
(42088)	20°1284	O6	7.55	-0.07	-0.89	-1.07	-5.8:	≥213		310	300:	13	2					C	
42379	21°1143	B1 II	7.42	0.34	-0.55	-1.00	-5.6	113	24	70	72	27	7	5	2			V	
42400	20°1302	B5 II	6.82	0.18	-0.45	-0.71	-5.3	≥210		>20	40:	26	7	5	2			C	
43078	22°1243	B0 IV	8.79	0.34	-0.57	-1.04	-4.2	173		135	139	28	7	3	2			βC	29
(43384)	23°1275	B3 Iab	6.23	0.45	-0.37	-0.80	-7.4:	71		≤20	25:	15	3					C	30
43703	23°1289	B1 IVp	8.62	0.42	-0.53	-1.08	-4.5	≥303			≥300	15	3					C	
43753	23°1297	B0.5 III	7.92	0.30	-0.64	-1.12	-4.9	153	84	70	79	28	7	3	2			C	
43818	23°1300	B0 II	6.92	0.30	-0.68	-1.15	-6.1	96		95	95	27	7	4	2			βC	
251847	23°1203	B1 IV	8.93	0.08	-0.76	-1.05	-3.3	133			130	27	7	5	2			C	
253049	20°1305	B2 IV	9.55	0.15	-0.55	-0.84	-2.7	258:			260:	13	2					C	
253683	19°1265	B0.5 IV	9.30	0.34	-0.58	-1.07	-3.7					13	2					C	31
254042	24°1176	B1 III	8.93	0.35	-0.58	-1.08	-4.1	>358			>360	16	3					C	32
254699	23°1286	B1 V	9.04	0.40	-0.46	-0.96	-4.0	128			130	28	7	4	2			EB	

TABLE 2—Continued

HD or BD	Star	MK	V	B-V	U-B	(U-B)$_0$	M_V	v sin i (km/sec)				NB	n	NU	n	NV	n	Results	Notes
								H	WH	BK	Adptd								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
							SCORPIUS II												
138485	ζ Lib	B2 Vnn								360	360	21	4	21	4			V	33
142096	λ Lib	B3 V	5.03	-0.02	-0.58	-0.74	-1.4			210	210	20	4	20	4			C	34
142184	-23°12569	B2 Vnn	5.42	-0.04	-0.62	-0.76	-1.1			400	400	20	4	20	4			V	35
142378	47 Lib	B5 V	5.97	0.00	-0.53	-0.67	-0.7					21	4	21	4			C	36
142883	-20°4364	B3: V	5.86	0.02	-0.48	-0.63	-2.0:					20	4	20	4			βC?	37
143018	π Sco	B1 V	2.90	-0.18	-0.91	-0.99	-3.4			163	163	24	5	24	5			C	38
145502	ν Sco AB	B2 IV-V	4.01	0.05	-0.65	-0.88	-2.9:			210	210	19	5	19	5			C	39
147165	σ Sco	B1 III	3.80:	0.16	-0.69	-1.00	-4.6			53	53	24	5	24	5			βC	40
147933	ρ Oph AB	B3 IV	4.59	0.24	-0.57	-0.95	-3.3			280	280	24	5	24	5			C	41
							CEPHEUS II												
202214	59°2334	B0 V	5.64	0.10	-0.76	-1.07	-4.72	3		55	55	39	7	26	3	23	2	C	42
203025	57°2309	B2 III	6.41	0.20	-0.49	-0.78	-4.67	206			210	44	8	31	4	28	3	EB?	43
203374	61°2112	B0 IVp	6.70	0.30	-0.73			≥353			≥350	44	8	31	4	28	3	C	44
203938	46°3294	B0.5 IV	7.08	0.46	-0.41	-0.96				235	235	13	4					C	
(204710)	44°3832	B8 Ib	6.95	0.26	-0.24	-0.42						13	4					C	
205139	59°2395	B1 II	5.53	0.12	-0.74	-1.05	-5.52	51			50	35	7	22	3	18	2	C	
216165	9 Cep	B2 Ib	4.73	0.27	-0.55	-0.88	-6.23	0		33	33	38	9	22	5	23	5	V	45
206773	57°2374	B0 V:pe	6.93	0.19	-0.82					460:	460:	39	9	25	5	24	5	C	46
207198	61°2193	O9 II	5.86	0.30	-0.66	-1.13	-5.77	51			50	14	4					C	
208185	62°1992	B2 V	7.37	0.10	-0.61	-0.88	-2.55		84		80	38	9	22	5	23	5	C	
208218	62°1994	B1 III	6.68	0.23	-0.57	-0.91	-4.75	0			0	40	9	25	5	25	5	C	
209339	61°2233	B0 IV	6.65	0.05	-0.82	-1.08	-4.90	≥263			≥260	41	9	26	5	26	5	C	
							NGC 7160												
208392	2	B1 IV:	7.04	0.26	-0.56	-0.96	-4.2	303			300	28	8					C	47
208440	3	B1 V	7.90	0.07	-0.73	-1.00	-2.8	178			180	15	4					C	
61°2213	4	B3 V	8.92	0.17	-0.46	-0.74	-1.8	218			220	30	9					EB?	
61°2215	5	B3 V	9.34	0.18	-0.49	-0.81	-1.5	226			230	30	9					C	
							NGC 7380												
215714	1		7.58	0.46	0.02	-0.39	-6.1					16	5					C	
215835	2	O6	8.58	0.34	-0.64	-1.15	-5.3					16	5					C	48
57°2602	3		8.64	0.61	0.17	-0.33	-5.4					15	5					C	
	4	B6 Vne	10.19	0.40	-0.12	-0.51	-3.4					26	9					EB	
	8	B1 V	10.67	0.27	-0.58	-1.00	-2.9					15	5					C	
	9	B1 V	10.68	0.36	-0.49	-0.97	-3.1					16	5					C	
							CEPHEUS III												
216532	61°2356	O8	8.02	0.54	-0.46	-1.11	-5.3	113	204	260:	243:	25	7	13	5			C	
216629	61°2361	B2pe	9.29	0.72	-0.19	-0.92		168			170	24	7	14	5			EB	49
216898	61°2370	O8	8.02	0.54	-0.48	-1.14	-4.7					10	2					C	
217035	62°2136	B0 V	7.75	0.46	-0.53	-1.12	-4.5	178	114		150	25	7	14	5			βC	
217312	62°2147	B0 IV	7.40	0.39	-0.54	-1.05	-3.9	70			70	10	2					C	
217463	62°2152	B2 V	9.00	0.54	-0.35	-0.94		304			300	10	2					C	50
217979	62°2162	B1 V	8.59	0.35	-0.50	-0.97	-3.7		114		110	10	2					C	
218066	62°2163	B1: V:	7.64	0.40	-0.52	-1.04	-3.8	≥215			≥220	25	7	13	5			C	51
218323	63°1928	B0.5 II	7.63	0.60	-0.38	-1.05	-5.8	68	134		90	10	2					C	
218342	62°2170	B0 IV	7.40	0.42	-0.54	-1.09	-4.7	53			50	10	2					C	
218537	62°2171		6.27	-0.03	-0.60	-0.74	-1.4	206			210	25	7	13	5			C	

TABLE 2—Continued

HD or BD	Star	MK	V	B-V	U-B	$(U-B)_0$	M_V	v sin i (km/sec)				NB	n	NU	n	NV	n	Results	Notes
								H	WH	BK	Adptd								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
							LACERTA I												
213420	6 Lac	B2 IV	4.50	-0.08	-0.73	-0.83	-4.9			76	76	9	3					C	52
(214680)	10 Lac	O9 V	4.87	-0.20	-1.04	-1.12	-4.4			29	29	22	5	9	2	9	2	C	
(215896)	47°3924											10	3					C	
216092	47°3931	B1 V	7.85	-0.07	-0.70	-0.82	-1.6		>500		>500	11	3					C	53
216200	14 Lac	B3 IV:	5.91	0.08	-0.51	-0.73	-3.9			225	225	22	5	9	2	9	2	V?	
217101	38°4904	B2 IV-V	6.17	-0.15	-0.80	-0.88	-3.1	223		150	158	9	3					C	
(48°3947)												9	3					C	
218674	48°3950	B3 IV	6.73	-0.01	-0.57	-0.73	-2.8	≥328			≥330	20	5	9	2	9	2	V	54
							FIELD STARS												
51756	-2°1856	B0.5 IV	7.23	-0.07	-0.91	-1.09		31			30	27	5	26	5			C	
53649	-8°1733	B0.5 III	9.12	0.26	-0.66	-1.08						19	5	18	5			EB?	
53667	-8°1734	B0.5 III	7.75	0.24	-0.71	-1.14						27	5	26	5			C	55
53754	-8°1737	B1 II	8.16	0.21	-0.66	-1.04						19	5	19	5			C	
53755	-10°1862	B0 V:										19	5	19	5			βC	
53756	-12°1777	B2 IV	7.32	-0.08	-0.78	-0.92						19	5	18	5			EB	
53974	-11°1790	B0.5 IV						163		170	170	19	5	19	5			βC	56
140543	-21°4180	B0.5 III	8.92	0.01	-0.89	-1.14						20	5	20	5			C	
149363	-5°4318	B0.5 III	7.80	0.01	-0.87	-1.12				95	95	27	5	27	5			C	57
149881	14°3086	B0.5 III										27	5	27	5			βC	
161961	-2°4458	B0.5 III								60	60	18	4	18	4			C	
165174	1°3578	B0.5 III										16	4	16	4			βC	
186994	44°3236	B0 III							154	135	136	15	5	14	5			C	
187879	40°3902	B1 IV:						53			50	15	5	11	3			C	58
188252	47°2939	B2 III						53			50	15	5	14	5			C	
189957	41°3569	B0 III							74		70	14	5	10	3			C	
192001	41°3642	O9.5 IV							104		100	9	3					C	
192539	31°4001	B2 III	7.29	0.13	-0.63	-0.89		0			0	15	5	11	5			C	59
193117	40°4090	O9.5 II	8.70	0.61	-0.42	-1.13						15	5	11	3			C	
193443	37°3879	O9 III	7.24	0.41	-0.54	-1.09			154		150	15	5	11	5			C	60

NOTES TO TABLE 2

1. Member? Also classified B1 V.
2. Also classified O9 III.
3. Also classified B0 Ib.
4. Also classified B1 Ia, B1 II.
5. Also classified B1 III:
6. Also classified B1 II.
7. Also classified B1 Ia.
8. Also classified B5 III, B5 IV.
9. Also classified B0 IIIp, B2 III.
10. Also classified B2 III.
11. Also classified B5 III.
12. Also classified B2 Ib.
13. Also classified B0.5 II-III, B1 II.
14. Also classified B1 V:pe.
15. Also classified B0 IV.
16. Member? Data from Jnl. de Obs. 43, 69, 1960.
17. Spectroscopic binary.
18. Also classified B3 V.
19. Spectroscopic binary.
20. Non-member.
21. Visual binary. X = +0.3, Y = -0.7 in Hoag et al. (1961).
22. X = +6.8, Y = +0.6 in Hoag et al. (1961).
23. Spectroscopic binary.
24. Also classified B1 IV, B1 V. Spectroscopic binary.
25. Also classified B0 III.
26. Also classified B3 V.
27. Also classified B2 IV, B3 IV. Spectroscopic binary.
28. Also classified B2 V.
29. Also classified B0.5 III.
30. Also classified B3 Ia, B3 Ib.
31. Also classified B3 III:
32. Also classified B0.5: IV:nn.
33. Also classified B2 V:, B3 III. Spectroscopic binary?
34. Also classifed B3 IV.
35. Also classified B3 Vne?
36. Visual binary.
37. Also classified B3 V.
38. Also classified B2 IV. Spectroscopic binary.
39. Also classified B2 IV?, B3 IV, B3 V. Spectroscopic binary.
40. Previously known β Cephei star.
41. Also classified B2 V.
42. Also classified O9, B0 II.
43. Spectroscopic binary.
44. Also classified B0 IVpe.
45. Also classified B2 I.
46. Also classified B0p, B0 Vp.
47. EM Cepheus.
48. DH Cepheus. Also classified O6n, O6nn, O6+O6.
49. Also classified B3e.
50. Also classified B8 II?
51. CW Cepheus. Also classified B3+B3 V.
52. Also classified B2 III.
53. Member?
54. Spectroscopic binary?
55. Also classified Oe5.
56. Also classified B2n.
57. Also classified B0.5 V.
58. V380 Cygnus.
59. Spectroscopic binary.
60. Also classified B0 Ib.

of the eclipsing binary stars discovered in the search program. Although different integrators were used in the photoelectric program at KPNO, excellent gain calibrations were available for each of them. No systematic changes in these calibrations were found, either on a nightly basis or over the 8-month period which was needed to complete the observing program. Mean gain tables were adopted for each integrator.

The search program was divided into two parts:

i) During a preliminary search in blue light (*B* of the *UBV* system) the stars were observed in groups within each association. Each star was observed long enough to obtain an observation of high weight, by repeated 10-sec integrations, and each group was observed, on the average, 10 times over a period of 2–4 nights. After the charts had been measured the raw magnitudes were obtained and the stars within each group were intercompared. This gave a series of Δ magnitudes for different combinations of stars. By computing the standard deviation (σ) for each of these combinations the comparison stars were selected. A typical value of σ for the comparison stars is $\sim$0.007 mag. The obvious and the marginal variables were noted and singled out for further observations. No differential corrections were made at this time because the whole program was to be completed in one observing season (October, 1964–June, 1965) and time would not allow such refinements. Because of this some spurious "variables" were noted in the initial survey, which also yielded a number of real variables as well as comparison stars for each association and galactic cluster. Table 3 gives the comparison stars and the values of σ derived by intercomparing comparison stars within a group.

ii) Follow-up observations, in *UB* or *UBV* colors, were made on these suspected variables. The stars were observed, in a fashion similar to the preliminary search routine, in groups of 4–7 members including one or two standard stars. Some 15–25 further observations were thereby obtained of each suspected variable. Later in the program, as time became the limiting factor, the preliminary search program was omitted and *U* and *B* observations made directly. This was only practicable because so large a percentage of the stars examined appeared to be variable ($\sim$30 per cent). This search among the program stars yielded 24 β Cephei stars (including 5 tentative cases), 9 eclipsing binaries (including 4 tentative cases), 3 variable emission-line or peculiar stars, and 8 variables of unknown type (see col. [19] of Table 2). The β Cephei stars, noted in Table 2, are discussed individually in § V. The other variable stars discovered in the search are the subject of a later paper. Columns (13)–(18) of Table 2 give the number of nights (n) each star was observed with the *B*, *U*, and *V* filters and the number of observations in blue (NB), ultraviolet (NU), and visual light (NV) for each program star.

III. THE LIGHT-CURVE DATA

The *B*, *V*, and *U* data, in the natural system of the telescope, were reduced differentially (including extinction corrections) with respect to the selected standard stars within each cluster and association. The extinction was determined each night from observations of *UBV* standard stars. The Δ magnitudes were not transformed to the *UBV* system because the light variations that I was trying to detect were of the same order of magnitude as the uncertainties of the transformations ($\Delta m \leq 0.02$). These results were combined with the heliocentric times to give the light-curve data, i.e., Julian date (heliocentric) versus ΔB (and/or ΔU and/or ΔV) for each of the suspected variables. Unfortunately it was not always possible to combine all the observations taken with the various telescopes because their natural systems were, in general, incompatible. This reduced the data available for Lacerta I, whence no periods could be determined for the two variable stars HD 218674 and 14 Lacertae. However, by intercomparing standard star observations taken with the other 16-inch telescope (No. 3) and the KPNO 36-inch telescope it was found that their natural systems were similar, so the data obtained with these instruments have been combined.

IV. THE DETERMINATION OF PERIODS

Using the method described by Lafler and Kinman (1965) the light-curve data were initially analyzed for periodicity on a CDC 1604 computer in the following way:

i) A number (n) of trial periods (P_n) were calculated according to the relation $P_n = P_0(1 + 0.2/\Delta t)^n$, where P_0 is the smallest period to be examined and Δt is the interval, in days, between the first and last observations. Generally the values $P_0 = 0\overset{d}{.}1$ and $\Delta t = 10$ were used. Initially the whole period range between $0\overset{d}{.}1$ and $1\overset{d}{.}0$ was scanned, but it was found that a disproportionate number of periods $> 0\overset{d}{.}7$ appeared, even though the variations were obviously better represented by some shorter period. Because of this the search was mainly confined to periods between $0\overset{d}{.}1$ and $0\overset{d}{.}5$. However, the actual value of n was set only after a careful inspection of the light-curve data. The objects which appeared to vary with periods $\geq 1^d$ were set aside to be examined later; these form the topic of a subsequent paper.

TABLE 3

ADOPTED COMPARISON STARS

Association or Galactic Cluster	Comparison Stars	Standard Error in B Magnitude (σ_B)	Standard Error in U Magnitude (σ_U)	Other Stars Used To Evaluate σ
Perseus I	HD 12509	0.0076	0.0100	HD 13621
Perseus I	HD 13621	.0062	...	HD 232588
Perseus I	HD 13831	.0050	...	HD 14331
Perseus I	HD 15912	.0082	...	HD 16310
Perseus I	HD 16310	...	...	...
Perseus II	HD 21856	.0060	.0073	HD 23478
Perseus II	HD 23478	...	...	...
NGC 1502	1	.0046	...	5
NGC 1502	5	...	...	...
Orion I	HD 34748	.0064	.0075	HD 35039
Orion I	HD 35039	...	...	...
NGC 2169	1	.0081	.0068	9
NGC 2169	9	...	...	...
Gemini I	HD 39746	...	...	...
Gemini I	HD 42400	.0079	.0089	HD 39746
Gemini I	HD 43753	.0052	.0074	HD 42400
Scorpius II	HD 142096	.0091	.0076	HD 142376
Scorpius II	HD 142376	...	...	...
Cepheus II	HD 203374	.0068	.0078	HD 205139
Cepheus II	HD 205139	...	...	...
Cepheus II	HD 208185	.0084	.0088	HD 208218
Cepheus II	HD 208218	...	...	...
NGC 7160	3	.0053	...	5
NGC 7160	5	...	...	...
NGC 7380	1	.0060	...	3
NGC 7380	8	.0077	...	1
Cepheus III	HD 216532	.0090	.0065	HD 218537
Cepheus III	HD 218537	...	...	...
Lacerta I	HD 214680	...	...	...
Lacerta I	HD 216092	...	...	...
Field star	HD 51756	.0068	.0065	HD 53667
Field star	HD 53667	...	...	...
Field star	HD 149363	.0114	0.0096	HD 161961
Field star	HD 161961	...	...	...
Field star	HD 186994	0.0076	...	HD 192539
Field star	HD 192539	...	...	...

ii) For each trial period the quantity θ defined by

$$\theta = \sum_{i=1}^{N} (m_i - m_{i+1})^2 / \sum_{i=1}^{N} (m_i - \bar{m})^2$$

was calculated, where m_i are the magnitudes from the light-curve data ordered according to phase and

$$\bar{m} = \sum_{i=1}^{N} m_i / N ,$$

N being the number of observations.

iii) Since the correct period is generally found among those periods with the smallest θ's, in each case the periods corresponding to the six smallest θ's were singled out for closer examination. The region around each of these periods was scanned more closely in equal increments of period in order to find the minimum value of θ. The six periods among which the true period would probably be found were thus evaluated.

iv) The phase-magnitude relations corresponding to these six periods were given by the computer in tabular and graphical form.

Before describing how the periods were finally determined it is necessary to discuss the way in which the data were chosen for submission to the computer. For most stars the blue data are bimodally distributed in time because of the search and follow-up nature of the observing program. Generally only one of these data groupings was analyzed at a time in order to minimize the number of trial periods needed for successful application of the method. The likely periods which resulted from the computer analysis were improved or rejected according to the appearance of the phase-magnitude relation and to the fit which could be made with the other portion of the data by slightly adjusting the period. An additional check on the periods found by this method was possible because of the existence of U and sometimes V data. These supplementary observations should show phase-magnitude relations similar to those of the blue data, i.e., one expects to find a correlation between ΔB, ΔV, and ΔU. When the amplitude of the light variation was very small (≤ 0.02 mag) it became difficult to gauge the significance of the probable periods; a statistical test (F-test) was then applied. In this test the ratio of the variance taken about a sine curve drawn through the data (by least squares) to the variance taken about the mean of the Δ magnitudes is an indication of the significance of the period chosen. The fitting of sine curves to the phase-magnitude relations is only justified if no beat periods are present. When they are present one will find a large scatter in the observational results; hence the F-test will indicate that the period has been determined with a low level of significance. Table 4 lists the new β Cephei stars, their periods, the estimated mean errors of these periods, the amplitude of the light variation, the standard deviation of the magnitudes, the standard deviation about the sine curve, and the significance of the period according to the F-test. Before the periods listed in Table 4 were adopted, multiples and submultiples of each period were tested to see if they could also represent the data. The quoted errors in the periods were estimated during final adjustment of the periods to the two groupings of data.

V. INDIVIDUAL DISCUSSIONS OF THE NEW β CEPHEI STARS

This section is devoted to a description of some of the individual stars. All the stars identified (tentatively or otherwise) as β Cephei variables are included as well as those stars common to the survey made by Lynds (1959).

TABLE 4

PERIOD AND LIGHT-CURVE DATA FOR THE NEW β CEPHEI VARIABLES

Name	Period	Estimated Error	B Amplitude* U Amplitude (mag)	σ^2 Mean Line (10^{-4})	σ^2 Sine Curve (10^{-4})	Significance (Per Cent)
HD 13051..........	0$^{\rm d}$3746	0$^{\rm d}$0002	0.031	1.61	0.85	92
			.032	2.95	1.60	50
HD 13494..........	.21995	.00003	.020	0.83	0.38	96
			.024	1.44	0.85	70
HD 13544..........	.3908	.0001	.044	2.91	0.71	>99
			.057	1.86	0.95	0
HD 13745..........	.45039	.00005	.022	1.15	0.56	95
			.024	1.48	0.73	85
HD 13866..........	.28619	.00003	.032	1.35	0.28	>99
			.017	0.97	0.58	0
HD 14053..........	.20219	.00005	.017	1.50	1.12	70
			.013	1.06	0.83	0
HD 15752..........	.25942	.0003	.017	0.80	0.42	60
HD 16429..........	.37822	.0001	.036	2.72	0.69	>99
			.047	4.52	1.57	80
BD 56°473.........	.30595	.00005	.035	3.04	1.64	94
			.026	1.72	0.93	0
BD 56°545.........	.27500	.00005	.030	3.53	2.31	80
			.034	2.82	1.31	75
BD 56°589.........	.2007:	.0005	.029	2.92	1.83	60:
NGC 1502-A.......	.19028:	.00003	.018	1.40	0.93	80
HD 35715..........	.30806	.00005	.029	2.64	1.71	94
			.033	2.65	1.36	94
HD 37776..........	.37968	.00005	.030	2.95	1.92	94
			.025	2.23	1.25	90
NGC 2169-2........	.39912	.0001	.018	0.75	0.29	>99
			.015	0.72	0.47	65
NGC 2169-5........	.4033	.0002	.022	1.78	1.26	93
			.040	2.12	0.38	>99
HD 43078..........	.23887	.00005	.030	1.82	0.84	97
HD 43818..........	.21909	.00005	.031	2.44	1.31	94
HD 53755..........	.43389	.0002	.032	2.48	1.06	95
			.031	2.27	1.11	93
HD 53974..........	.12377	.0001	.027	1.71	0.72	95
			.027	2.42	1.42	50
HD 142883.........	.2872	.0001	.014	0.56	0.34	80
			.013	0.70	0.51	50
HD 147165†........	.2467	....	.045	3.82	1.52	95
			.067	6.38	1.40	>99
HD 149881.........	.3231	.0010	.008:	0.72	0.67	0
			.015	1.17	0.92	50
HD 165174.........	.2859:	.0001	.022	1.52	0.82	50
			.023	1.69	0.93	50
HD 217035.........	0.24544	0.00005	.016	0.75	0.44	93
			0.017	0.71	0.54	0

* Single entries refer to blue light-curve data.

† Previously known β Cephei variable.

a) New β Cephei Variables

HD 13051.—The *B*, *V*, and *U* data are equally well represented by a sine curve (Fig. 1) with period $0^{d}_{.}3746$. The amplitude in each of the three colors is ~0.030 mag. Petrie and Pearce (1962) quote a velocity of −49 km/sec. Considered a β Cephei variable.

HD 13494.—A sine curve (Fig. 2) fits the *B* and the *U* data to within the expected observational errors (~0.006 mag for *B* and ~0.009 mag for *U*). The period is $0^{d}_{.}21995$. A probable β Cephei variable.

HD 13544.—A period of $0^{d}_{.}3908$ fits the *B* data very well (see Fig. 3). Few observations are available in ultraviolet light, which accounts for the low significance quoted in Table 4. The amplitude of the variation is 0.044 and 0.057 mag in blue and ultraviolet, respectively. This star is a certain β Cephei variable.

HD 13745.—The amplitudes of the *B* and *U* variations are small (~0.020 mag), but a sine curve (Fig. 4) fits both sets of data to within the observational errors. The period

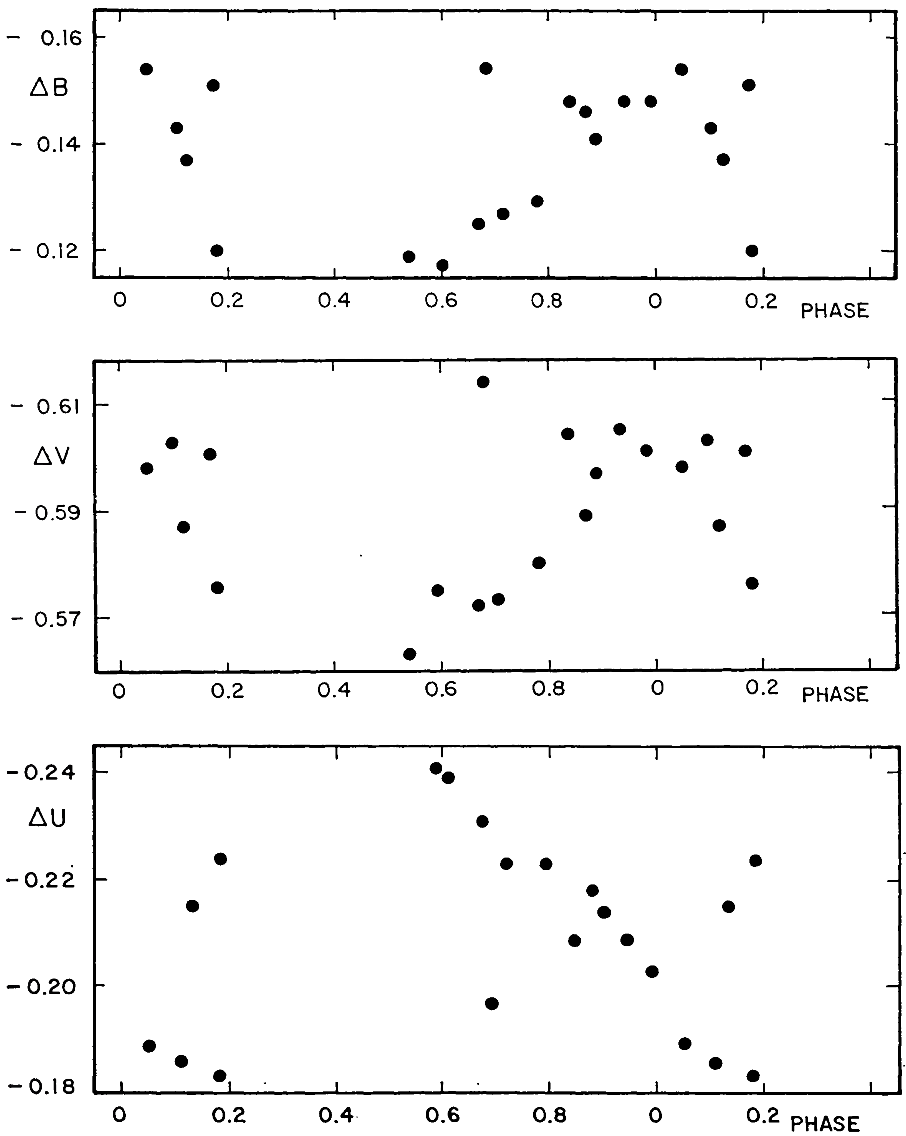

FIG. 1.—Photoelectric observations of HD 13051. The comparison star is HD 16310, and the magnitude differences are in the sense HD 16310 *minus* HD 13051.

0^d^45039 is the largest known of any β Cephei star. The radial velocity quoted by Wilson (1953) is -29.5 km/sec, but Petrie and Pearce (1962) give a velocity of -10 km/sec, indicating a possible variable radial velocity. Moreover, the cluster velocity for h and χ Persei is -44 km/sec (Johnson and Svolopoulos 1961). If this star is actually a member its velocity is probably variable. The absolute magnitudes determined by three methods disagree for this star, e.g., M_v(ZAMS) $= -5.3$, M_v(MK) $= -5.0$, and M_v(Hγ) $= -6.0$, where M_v(ZAMS), M_v(MK), and M_v(Hγ) are absolute magnitudes derived, respective-

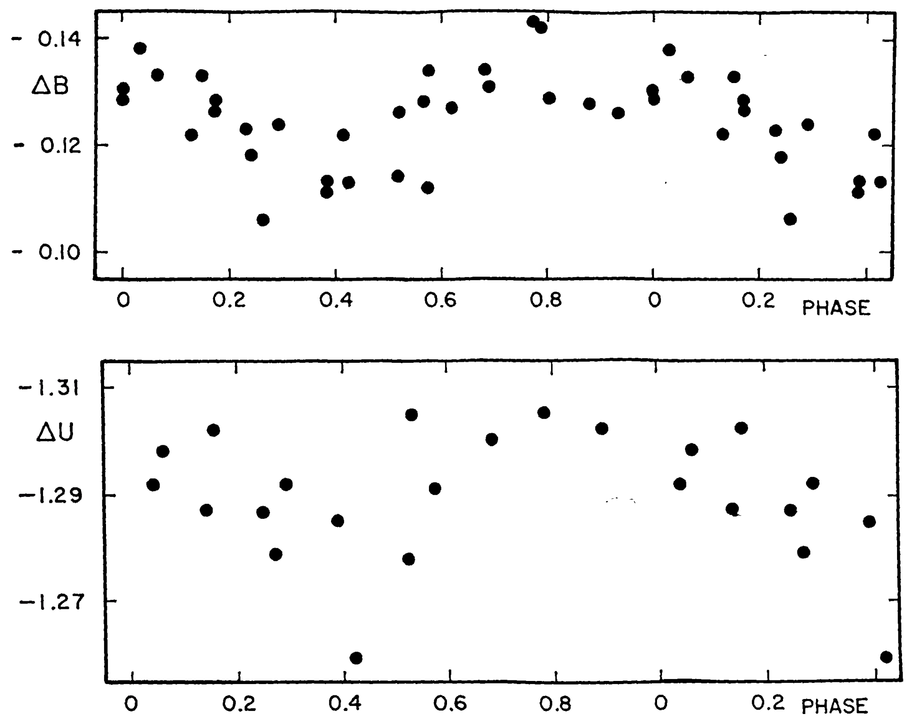

FIG. 2.—Photoelectric observations of HD 13494. The comparison star is HD 13831, and the magnitude differences are in the sense HD 13831 *minus* HD 13494.

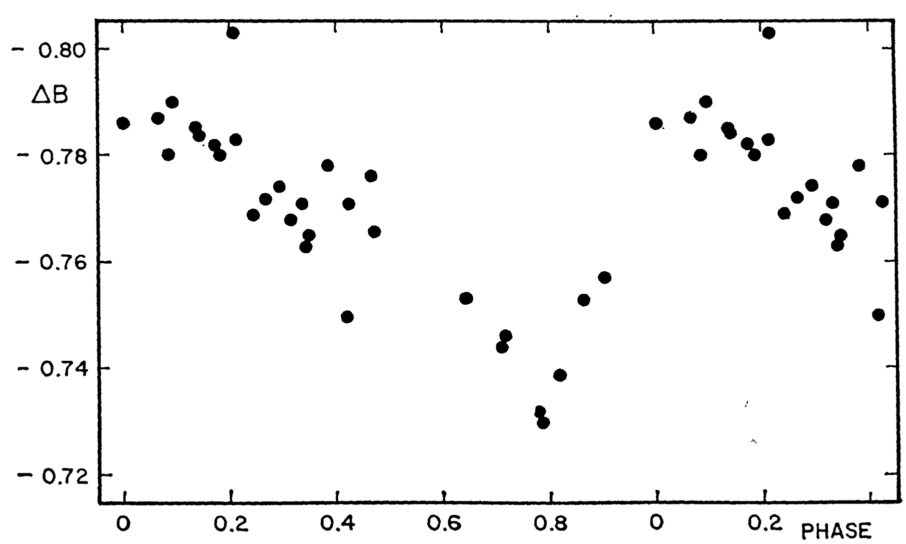

FIG. 3.—Photoelectric observations of HD 13544. The comparison star is HD 13621, and the magnitude differences are in the sense HD 13621 *minus* HD 13544.

ly, from (i) the distance modulus determined by fitting the unevolved part of a cluster sequence to the zero-age main-sequence (ZAMS); (ii) the MK classification; and (iii) the equivalent width of Hγ.

HD 13866.—Two periods, 0ᵈ28619 and 0ᵈ21955, well represented the *B* and *U* data, but the former period gave the best fit to a sine curve (see Fig. 5). The standard errors of the fit to curves of these periods were ~0.005 and 0.0075 mag, respectively, but because of this small difference the actual period must still remain in doubt. This star is classified B2 Ib by Johnson and Hiltner (1956) and B2 III by Bouigue (1959). It lies considerably above the rest of the β Cephei sequence in the H-R diagram, indicating that the supergiant classification is probably valid. The assumption that this star is a member of h and χ Persei is reasonable since it does share the radial motion of the cluster.

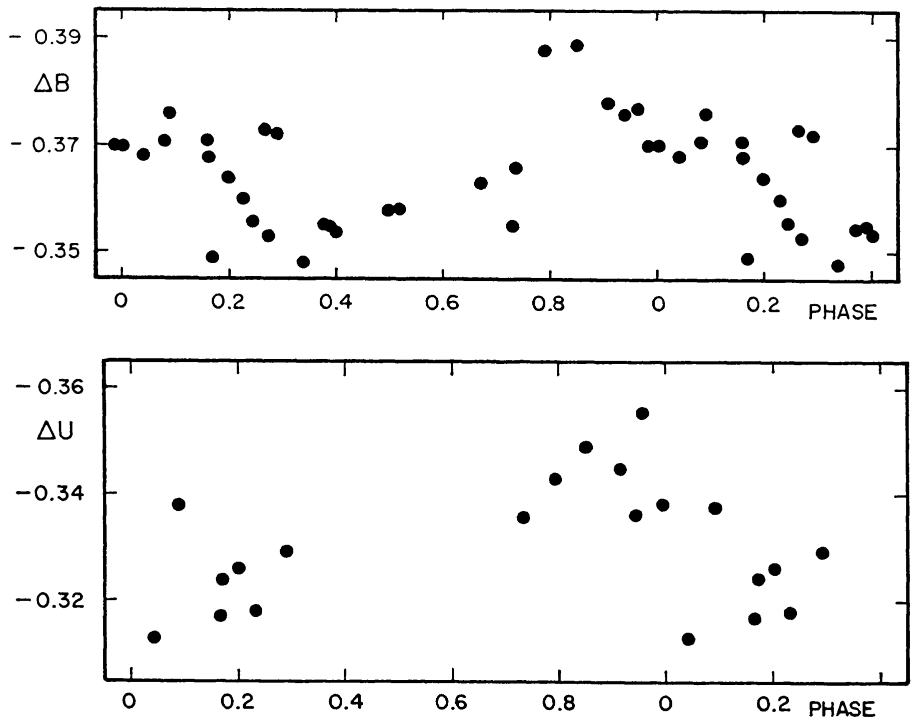

FIG. 4.—Photoelectric observations of HD 13745. The comparison star is HD 13831, and the magnitude differences are in the sense HD 13745 *minus* HD 13831.

Therefore, we may have confidence in the absolute magnitude quoted in Table 2. A new β Cephei variable.

HD 14053.—The variations have amplitudes of 0.017 and 0.013 mag in blue and ultraviolet light, respectively (see Fig. 6). Two deviant points in the *B* data have reduced the significance of the period, but a sine curve still fits very well (P = 0ᵈ20219). Because the *U* data are poorly distributed in phase, the period could not be checked so this star is *tentatively* classed as a β Cephei variable.

HD 15752.—The amplitude of the blue variation is small (~0.017 mag), but the standard error of the residuals about the sine curve is close to the expected observational errors (see Fig. 7). A *tentative* β Cephei variable.

HD 16429.—Two periods (0ᵈ37822 and 0ᵈ28292) fit the *B* and *U* data. The former period gave much smaller residuals than the latter period and, therefore, was adopted (see Fig. 8). This is the most luminous of all the known β Cephei variables (M_v = −6.9) and extends the sequence into the O stars (O9.5 III). No radial velocity is available which would enable its membership in h and χ Persei to be confirmed, thereby providing

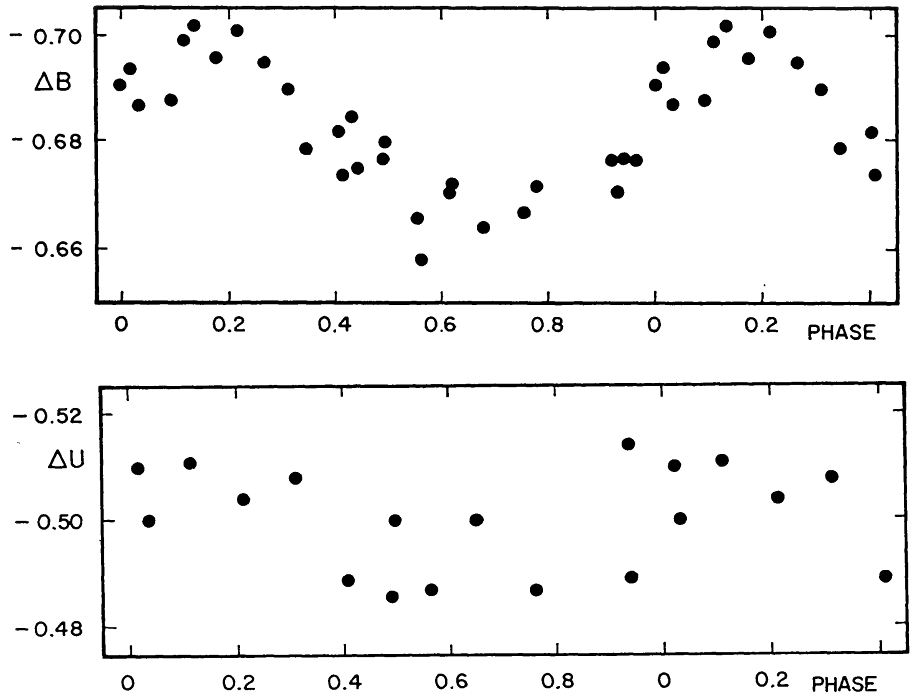

FIG. 5.—Photoelectric observations of HD 13866. The comparison star is HD 13831, and the magnitude differences are in the sense HD 13866 *minus* HD 13831.

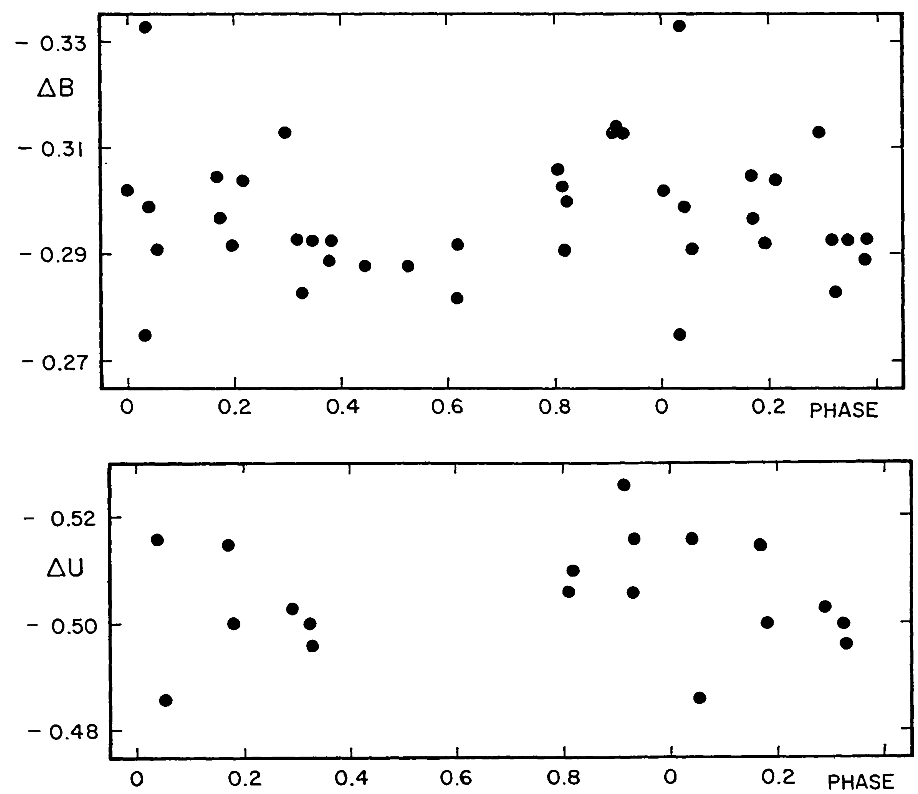

FIG. 6.—Photoelectric observations of HD 14053. The comparison star is HD 13831, and the magnitude differences are in the sense HD 13831 *minus* HD 14053.

a check on its absolute magnitude which is a magnitude brighter than its MK spectral type predicts. A certain β Cephei variable.

BD 56°473.—The amplitude of the light variation is 0.035 and 0.026 mag in blue and ultraviolet light, respectively. The standard error about the sine curve ($P = 0^d.30595$) is large for the B data (~0.013 mag) but is considerably smaller (~0.010 mag) for the U data (see Fig. 9). The absolute magnitudes are M_v(ZAMS) = −4.3, M_v(MK) = −5.1:, and M_v(Hγ) = −5.2. A certain β Cephei variable.

BD 56°545.—The amplitude of the light variation in the blue and ultraviolet light is ~0.030 mag. The standard error of the fit to a sine curve is large for the blue light (~0.015 mag) but can be reduced considerably (to ~0.012 mag) by omitting one widely

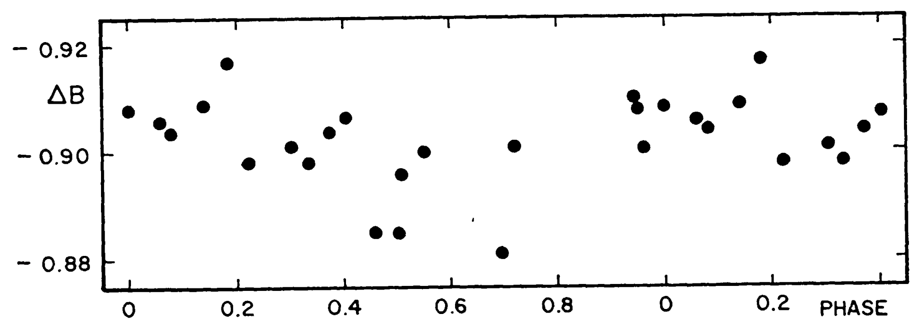

FIG. 7.—Photoelectric observations of HD 15752. The comparison star is HD 15912, and the magnitude differences are in the sense HD 15912 *minus* HD 15752.

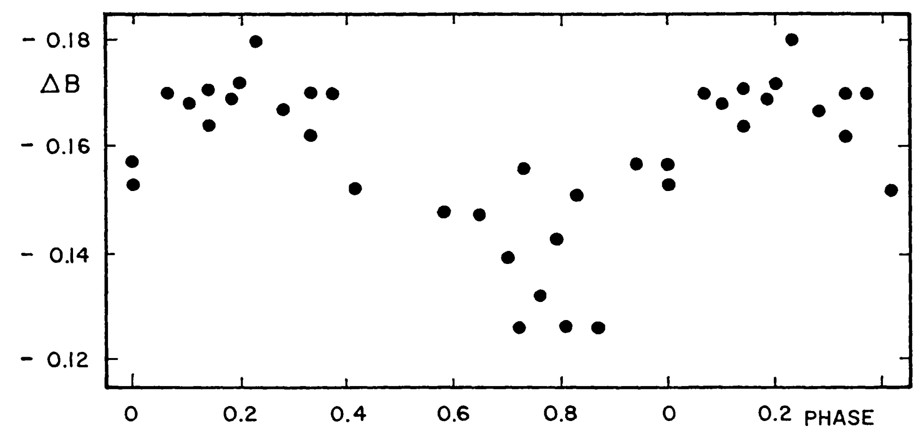

FIG. 8.—Photoelectric observations of HD 16429. The comparison star is HD 13621, and the magnitude differences are in the sense HD 13621 *minus* HD 16429.

deviant point (see Fig. 10). The standard error for the U data is reasonable (~0.011 mag). Wilson (1953) quotes a radial velocity of −48 km/sec. A probable β Cephei variable.

BD 56°589.—Three periods ($0^d.20072$, $0^d.40036$, and $0^d.40154$) fit the B and U data with rather large residuals. There is one deviant point whose omission could reduce the standard error to a tolerable ~0.010 mag. The data for $P = 0^d.20072$ is included in Table 4 since this period yields the smallest residuals (see Fig. 11). More observations are needed to resolve the ambiguity between the periods. A probable β Cephei variable.

NGC 1502-A.—This star is a visual binary, and it is not known which component is variable. At least two periods ($0^d.19028$ and $0^d.2094$) represent the B data. Unfortunately their harmonics also work. The period quoted in Table 4 resulted in the smallest residuals when sine curves were fitted (see Fig. 12). The blue amplitude is small (~0.018 mag), but it is probably real. A possible β Cephei variable.

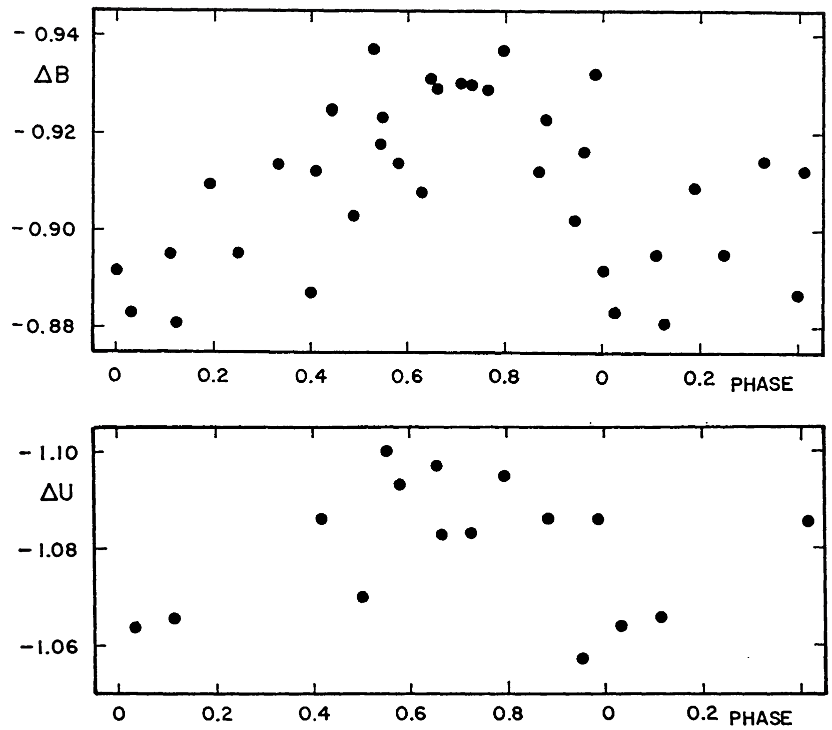

FIG. 9.—Photoelectric observations of BD 56°473. The comparison star is HD 13831, and the magnitude differences are in the sense HD 13831 *minus* BD 56°473.

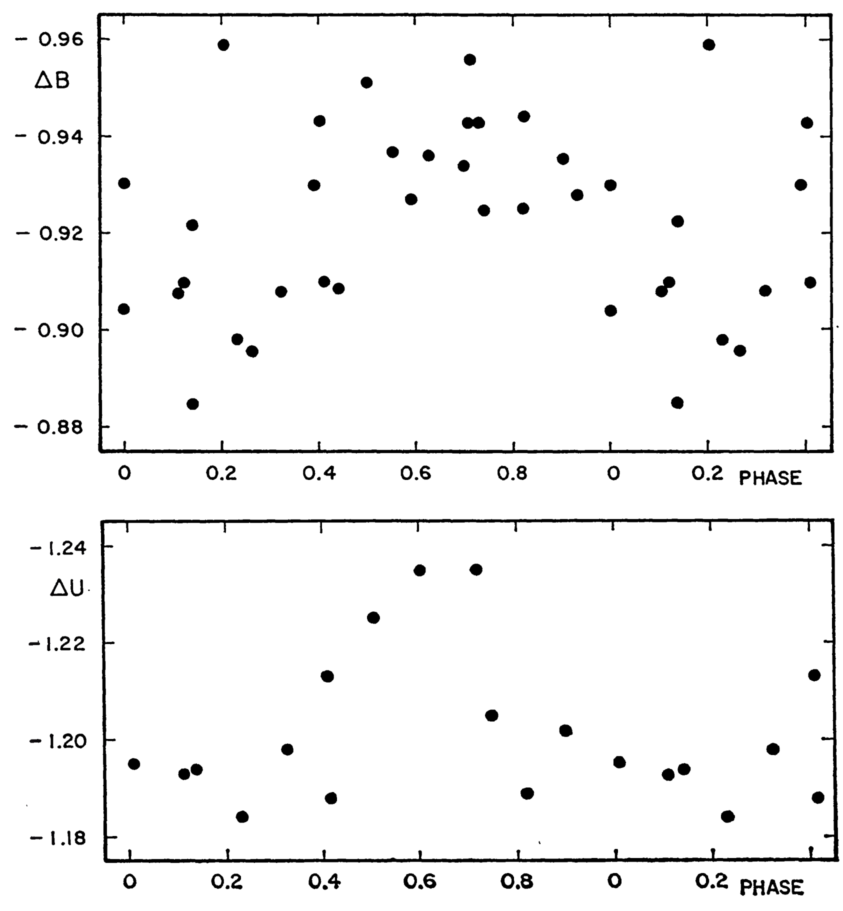

FIG. 10.—Photoelectric observations of BD 56°545. The comparison star is HD 13831, and the magnitude differences are in the sense HD 13831 *minus* BD 56°545.

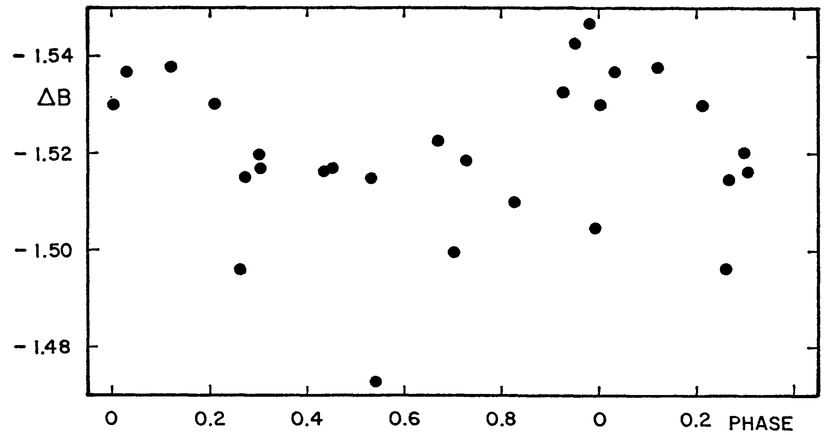

FIG. 11.—Photoelectric observations of BD 56°589. The comparison star is HD 15912, and the magnitude differences are in the sense HD 15912 *minus* BD 56°589.

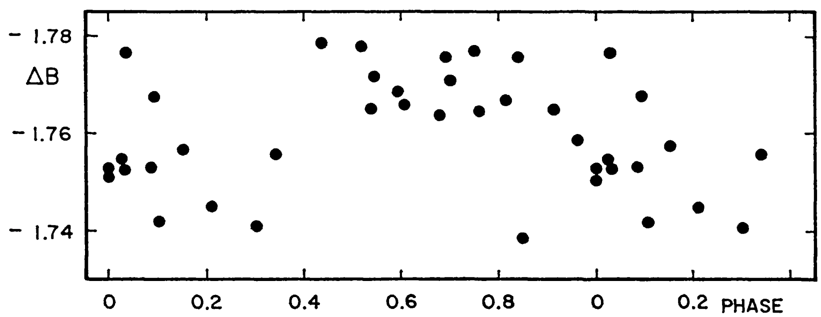

FIG. 12.—Photoelectric observations of NGC 1502-A. The comparison star is NGC 1502-1, and the magnitude differences are in the sense NGC 1502-A *minus* NGC 1502-1.

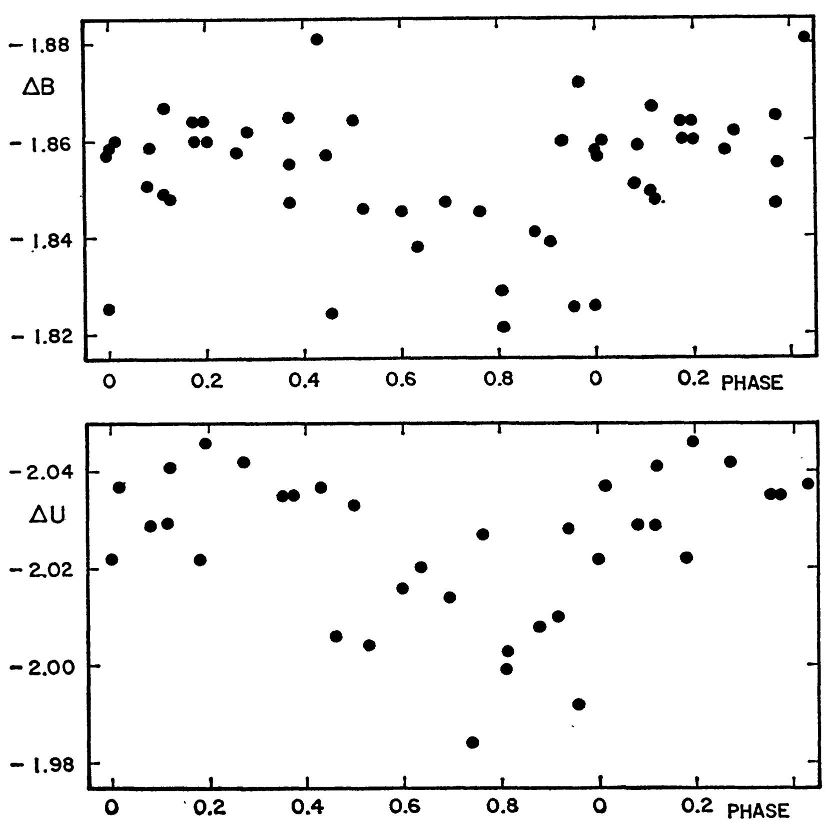

FIG. 13.—Photoelectric observations of HD 35715. The comparison star is HD 34748, and the magnitude differences are in the sense HD 35715 *minus* HD 34748.

HD 35715 (ψ Ori).—To quote Lynds (1959): "This spectroscopic binary with a period of 2.5 days (Plaskett 1908) has a long history of suspected variability in brightness (Shapley 1913; Cousins 1952; de Jager 1953) but the type is in doubt." A period of 0ᵈ30806 has been derived in this present work (see Fig. 13). A sine curve with this period was fitted to the *B* and *U* data. The standard error of this fit is rather large (~0.013 and 0.012 mag for the *B* and *U* observations, respectively), and therefore this star is *tentatively* identified as a β Cephei variable.

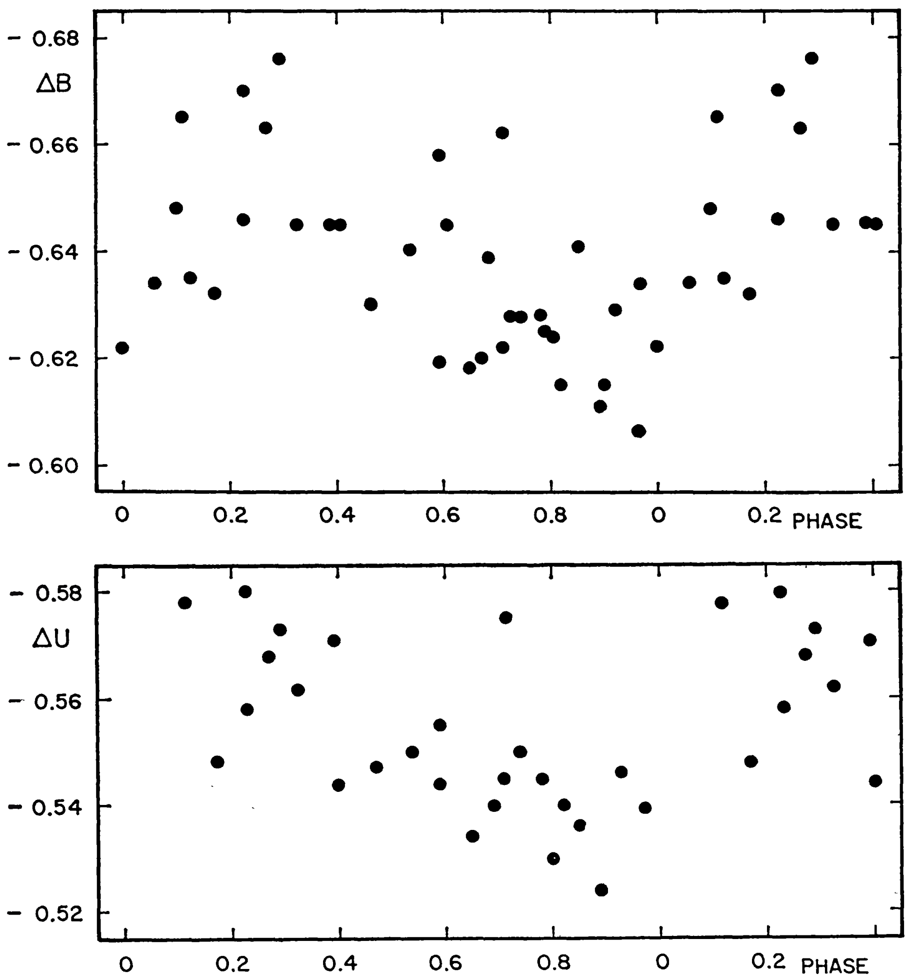

FIG. 14.—Photoelectric observations of HD 37776. The comparison star is HD 34748, and the magnitude differences are in the sense HD 34748 *minus* HD 37776.

HD 37776.—This star was thought to be variable (~0.03–0.040 mag) by Lynds (1959). This present material confirms these results. A period of 0ᵈ37968 was fitted to the *B* and *U* data (see Fig. 14) whose amplitudes are 0.030 and 0.025 mag, respectively. The residuals are large in the *B* data but are tolerable in the *U* data. A *tentative* β Cephei star.

NGC 2169-2 (BD 13°1120 or HD 252214).—Two periods (0ᵈ39912 and 0ᵈ28297) represent the data within the observational errors. The former period was adopted since it gave smaller residuals and larger amplitudes in the *V* and *U* data than the latter. The visual results are not given in Table 4. The *B*, *V*, and *U* data are presented in Figure 15. The radial velocity is variable according to Hayford (1932). A β Cephei variable.

NGC 2169-5 (BD 13°1123 or HD 252248).—One period (0ᵈ4033) was found. The amplitudes of the variations in the *B*, *V*, and *U* data are 0.022, 0.033, and 0.040 mag, respectively (see Fig. 16). The standard error of the fit is within the observational errors for the V and U data, but the B data are distorted by one bad observation. It shares the radial motion of NGC 2169. The absolute magnitudes are M_v(ZAMS) = -2.0, M_v(MK) = -1.7, and M_v(Hγ) = -4.4. This latter value is highly questionable but may, in part, be caused by the high rotation of the star ($v \sin i \geq 320$ km/sec). A β Cephei variable.

HD 43078.—A period of $0^d_.23887$ represents the variations of the B data (see Fig. 17). The amplitude of the variation is 0.030 mag. A β Cephei variable.

HD 43818.—The B data are well represented by a period of $0^d_.21909$ (see Fig. 18). The amplitude of the variation is 0.031 mag. A β Cephei variable.

HD 53755.—A sine curve of period $0^d_.43389$ and amplitude in blue and ultraviolet light of 0.032 and 0.031 mag, respectively, well represents the data (see Fig. 19). The standard error of the fit about these curves is 0.010 mag. Moore (1932) states that the radial velocity is variable. A β Cephei star.

HD 53974.—The B and U data are well represented by sine curves ($P = 0^d_.12377$) with amplitudes $\sim$0.027 mag (see Fig. 20). This period is the shortest of any known β Cephei star.

HD 142883.—A sine curve of period 0.2872 fits the B and U data within the ob-

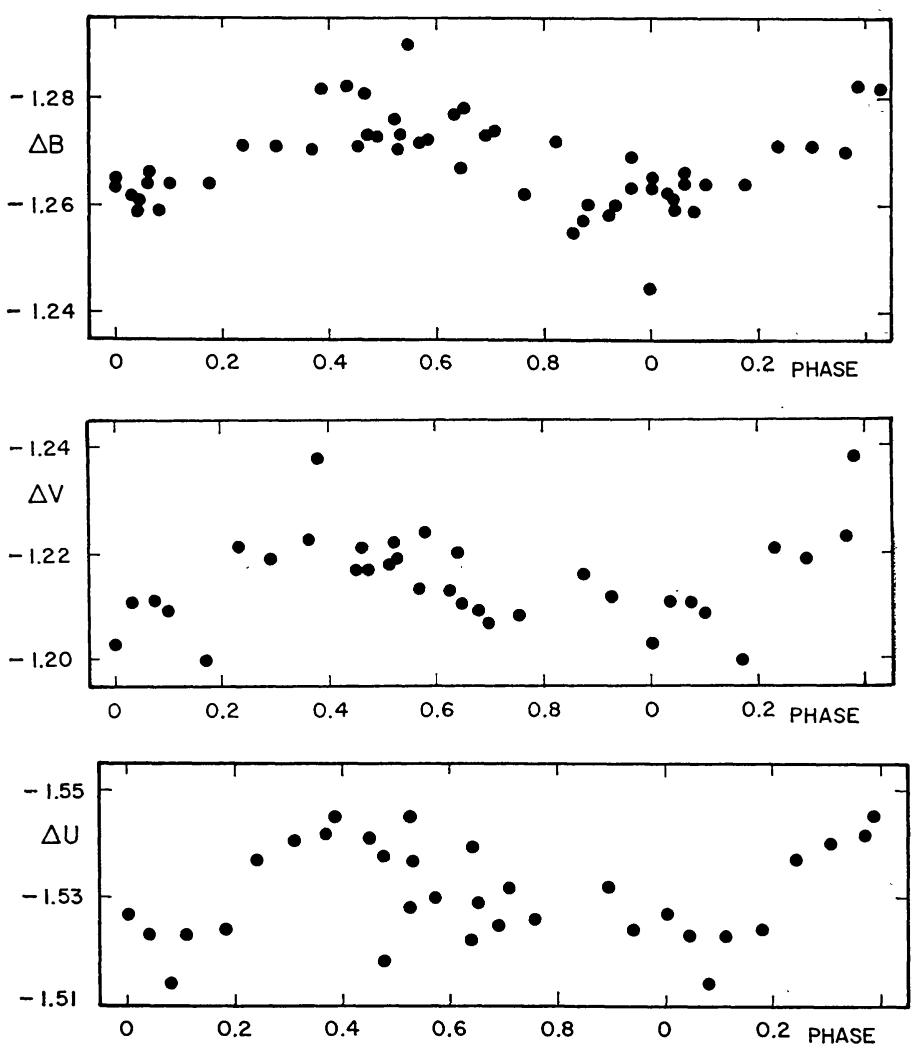

FIG. 15.—Photoelectric observations of NGC 2169-2. The comparison star is NGC 2169-1, and the magnitude differences are in the sense NGC 2169-1 *minus* NGC 2169-2.

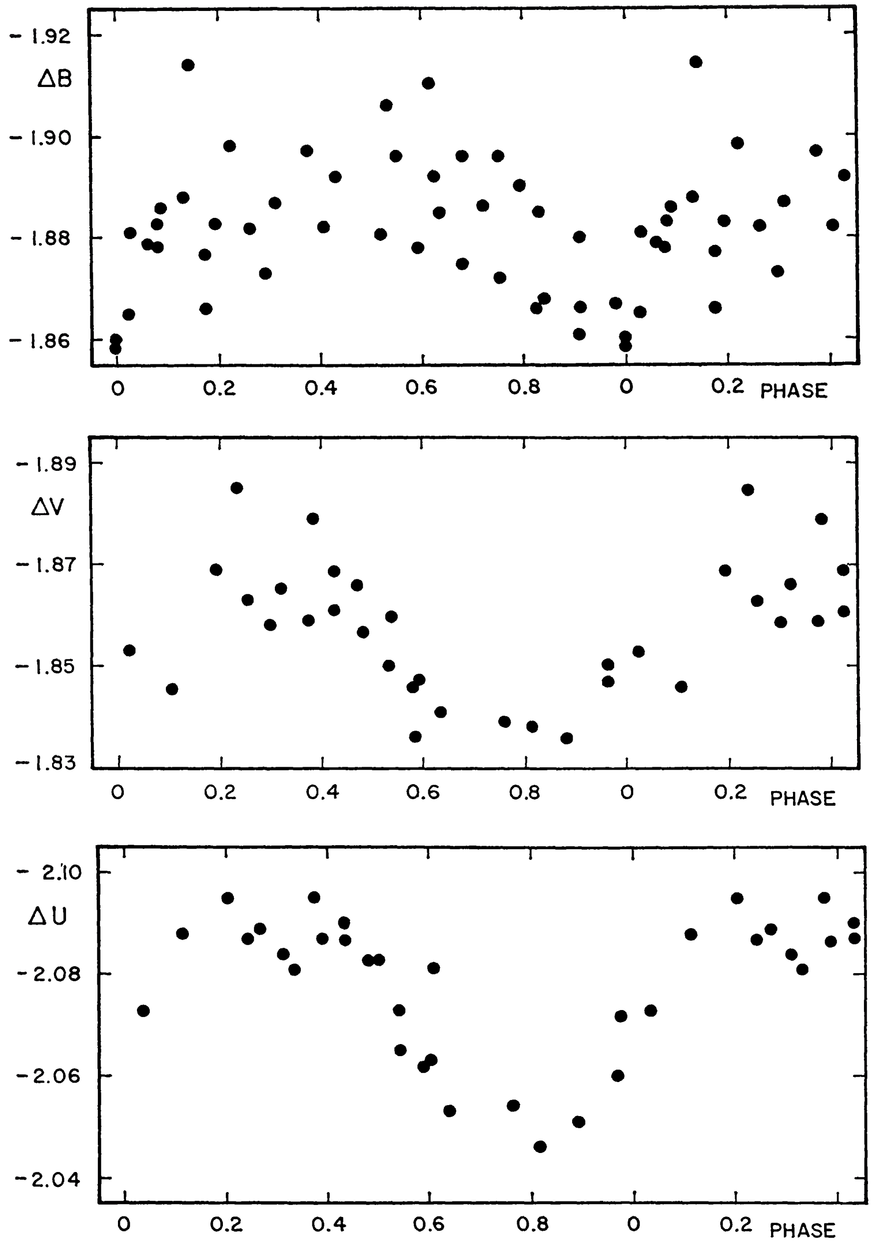

FIG. 16.—Photoelectric observations of NGC 2169-5. The comparison star is NGC 2169-1, and the magnitude differences are in the sense NGC 2169-1 *minus* NGC 2169-5.

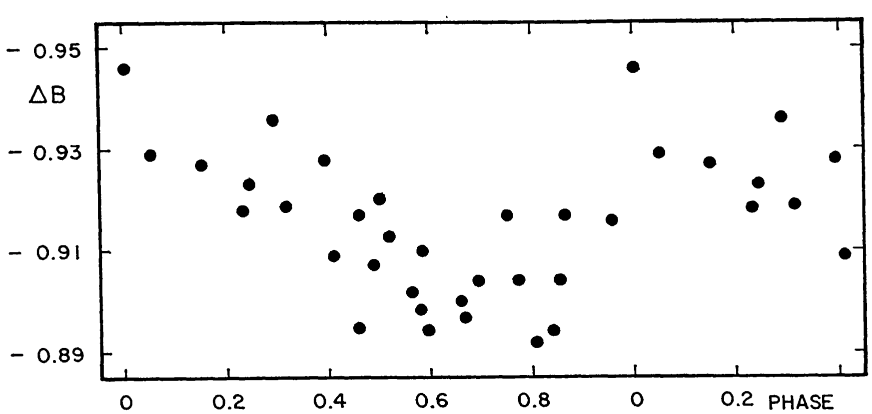

FIG. 17.—Photoelectric observations of HD 43078. The comparison star is HD 43753, and the magnitude differences are in the sense HD 43753 *minus* HD 43078.

servational errors (see Fig. 21). However, because of the extremely small amplitude of variation (~0.014 mag in blue light and ~0.013 mag in ultraviolet light) this star must be considered a *tentative* β Cephei variable.

HD 149881.—This star was found to be constant (<0.01 mag) by Walker (1952). However, Lynds (1959) suggested that it may be a β Cephei star. The present work supports the results of Lynds. A sine curve with period 0ᵈ3231 represents the data better than the significance test indicates since part of the excessive standard error is due to

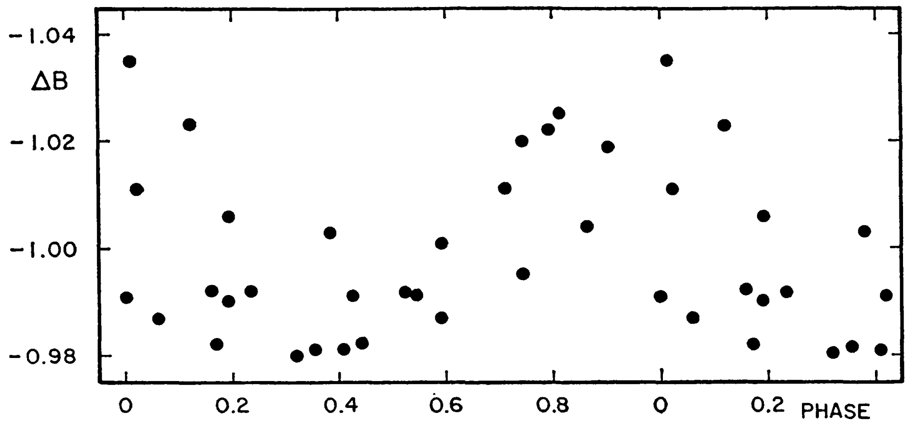

FIG. 18.—Photoelectric observations of HD 43818. The comparison star is HD 43753, and the magnitude differences are in the sense HD 43818 *minus* HD 43753.

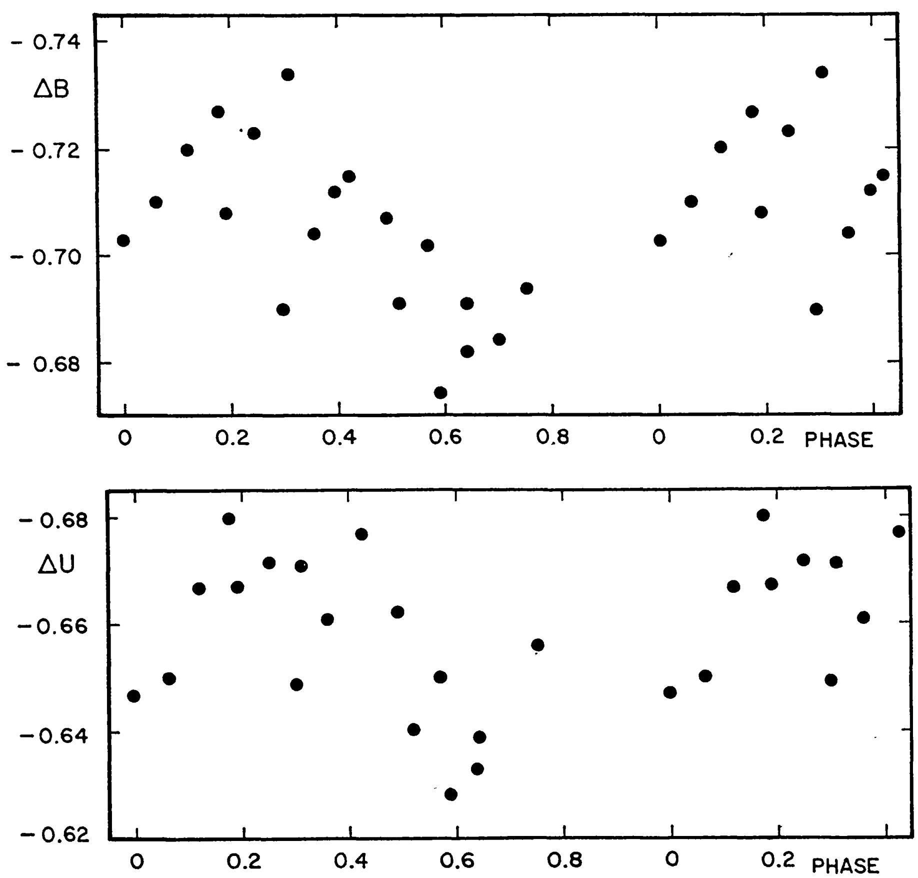

FIG. 19.—Photoelectric observations of HD 53755. The comparison star is HD 51756, and the magnitude differences are in the sense HD 53755 *minus* HD 51756.

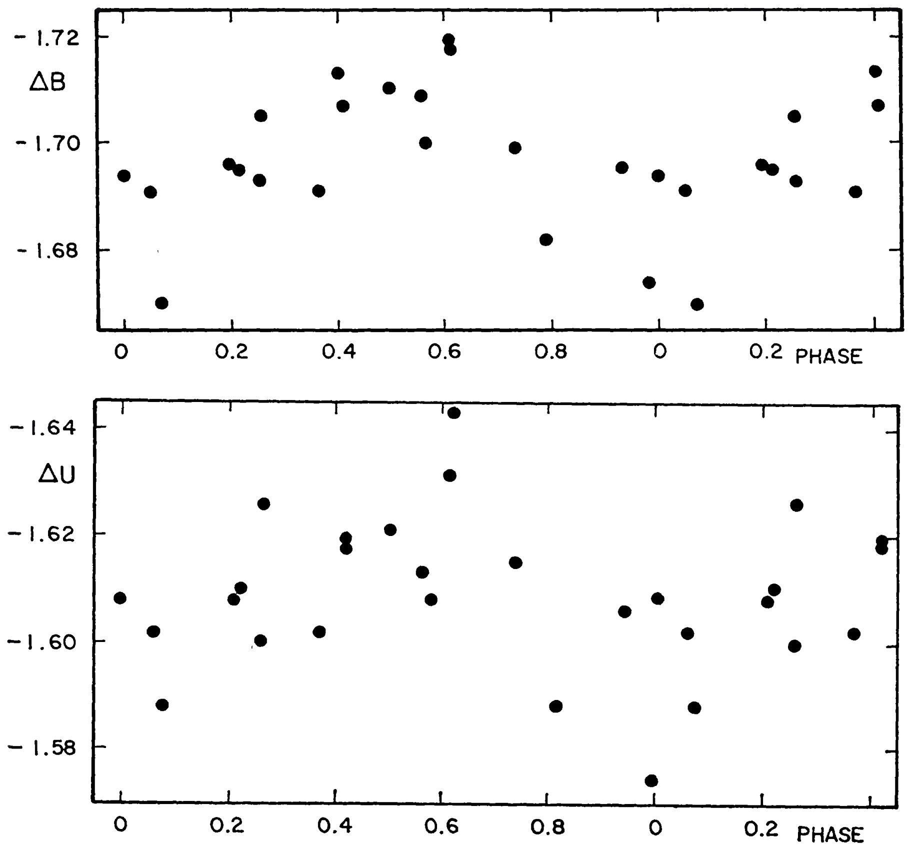

FIG. 20.—Photoelectric observations of HD 53974. The comparison star is HD 51756, and the magnitude differences are in the sense HD 53974 *minus* HD 51756.

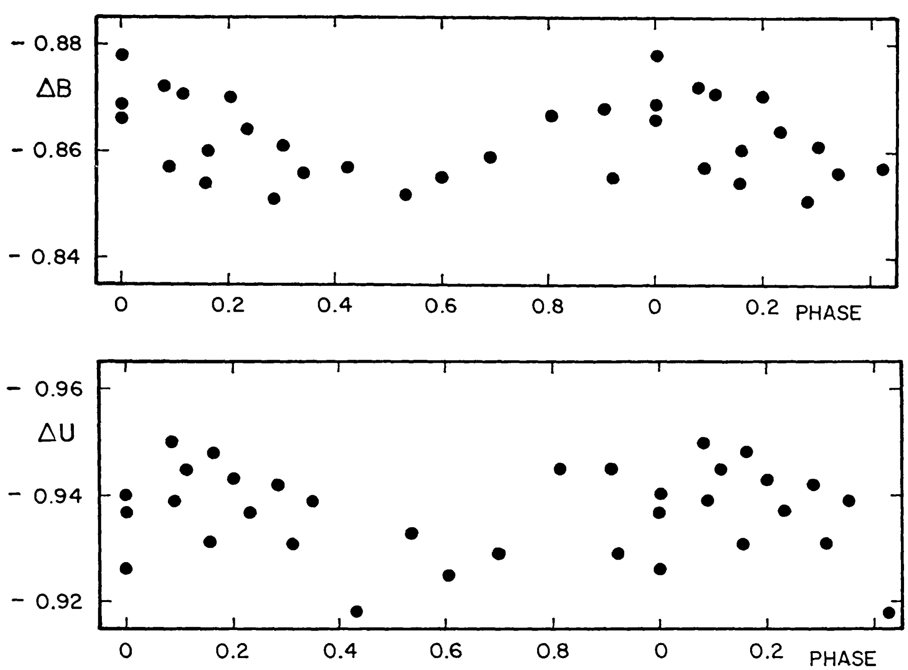

FIG. 21.—Photoelectric observations of HD 142883. The comparison star is HD 142096, and the magnitude differences are in the sense HD 142096 *minus* HD 142883.

two deviant observations. The B and U data are presented in Figure 22. The results of Plaskett and Pearce (1930) indicate a variable radial velocity. Since this star is a field star, only spectroscopic absolute magnitudes are available but these are in good agreement: M_v(MK) = -4.7 and M_v(Hγ) = -5.0. A β Cephei variable.

HD 165174.—Lynds (1959) tentatively classed this star as a β Cephei variable with a period of $0^d.2890$. His observations indicate the probable presence of a beat period. The amplitude in visual light found by Lynds was ~0.020 mag, which agrees well with the present results of 0.022 and 0.023 mag for the blue and ultraviolet light, respectively. From the present data a period of $0^d.2859$: was derived (see Fig. 23) which differs slightly from Lynd's period. The radial velocities quoted by Plaskett and Pearce (1930) have a range of 25 km/sec, a fact which may indicate variability. The spectroscopic absolute

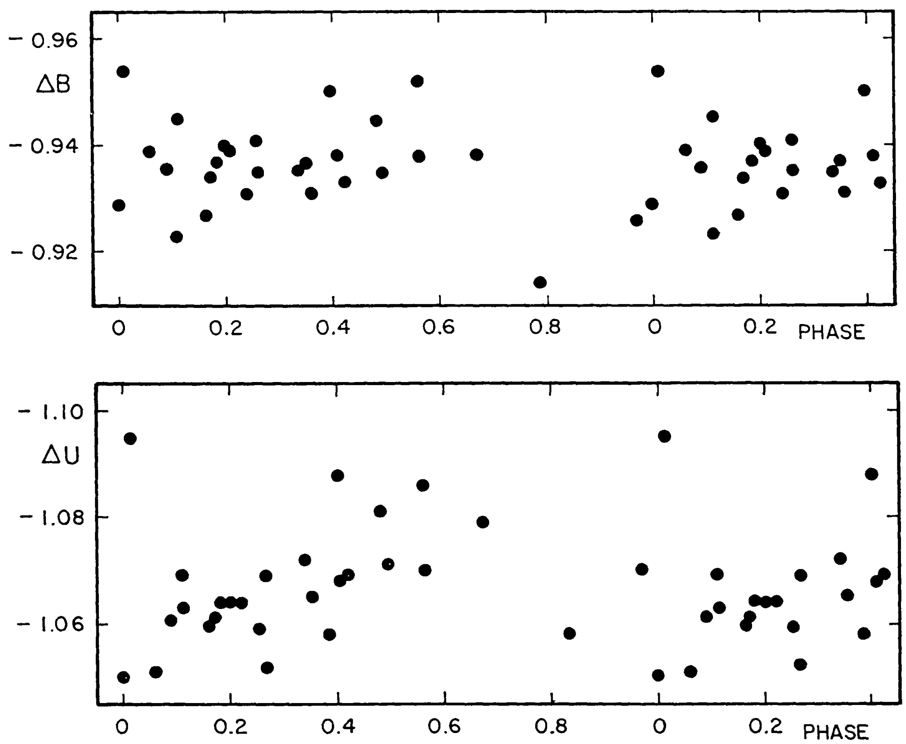

FIG. 22.—Photoelectric observations of HD 149881. The comparison star is HD 149363, and the magnitude differences are in the sense HD 149881 *minus* HD 149363.

magnitudes available for this star are in fair agreement, i.e., M_v(MK) = -4.7, and M_v(Hγ) = -5.3. A β Cephei variable.

HD 217035.—A sine-curve ($P = 0^d.24544$) fits the B and U data to within the observational errors (see Fig. 24). The amplitude of the variation in blue and ultraviolet light is rather small (~0.016 mag). The radial velocity is variable (Petrie and Pearce 1962). For this star the absolute magnitude quoted in Table 2 ($M_v = -4.5$), which was taken from Borgman and Blaauw (1964), agrees with the MK absolute magnitude ($M_v = -4.1$) but differs from the Hγ absolute magnitude ($M_v = -3.2$). A β Cephei variable.

b) Stars in Common with Lynds (1959)

A few other interesting stars are also included.

HD 12509.—Petrie and Pearce (1962) claim that β Cephei–type variations in line width have been observed in this star. This writer's photoelectric observations indicate constancy within 0.010 mag in blue and ultraviolet light. Final identification of this star with the β Cephei variables must, therefore, await spectroscopic confirmation.

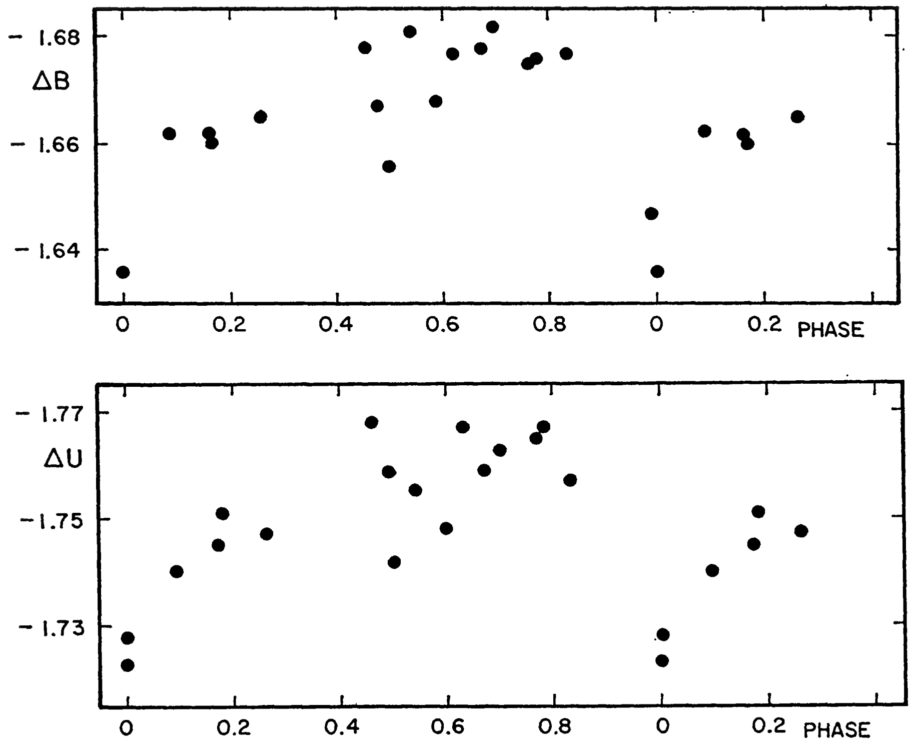

FIG. 23.—Photoelectric observations of HD 165174. The comparison star is HD 149363, and the magnitude differences are in the sense HD 165174 *minus* HD 149363.

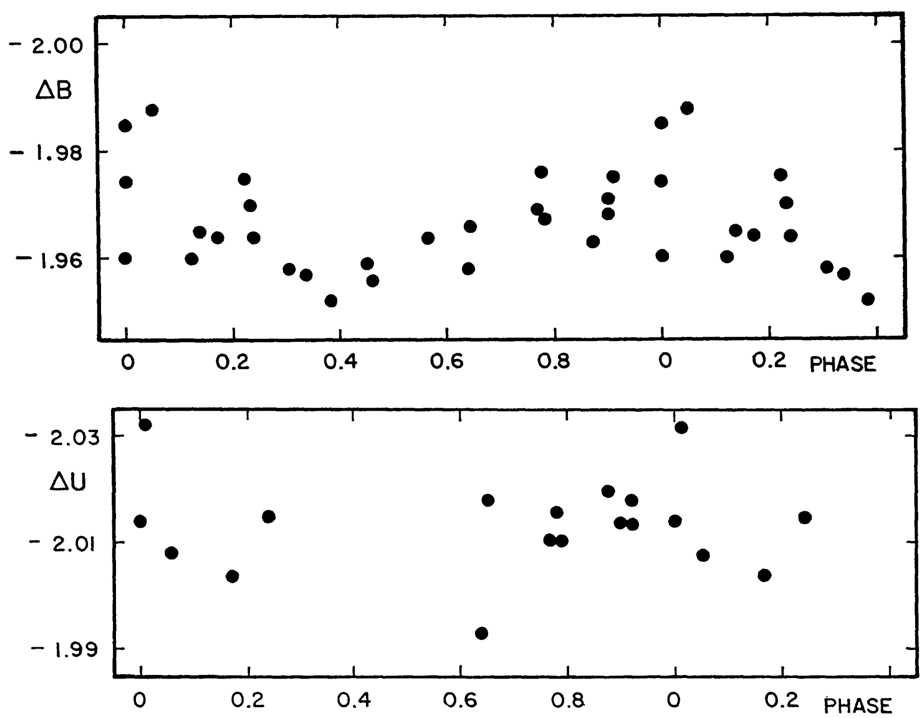

FIG. 24.—Photoelectric observations of HD 217035. The comparison star is HD 218537, and the magnitude differences are in the sense HD 218537 *minus* HD 217035.

HD 36822 (φ^1Ori).—In agreement with Lynds (1959) the present observations indicate no change in brightness.

HD 37756.—Lynds (1959) thought this star was variable, but the present observations indicate constancy within 0.01 mag.

In agreement with Lynds (1959) the six stars listed below were found to be constant in brightness.

HD 188252	HD 208218
HD 203374	HD 209339
HD 205139	HD 217101

VI. INTRINSIC COLORS

The method of obtaining the intrinsic colors of O and B stars from *UBV* observations has been outlined by Johnson (1958) and Crawford (1958). Two equations are used to derive the values of $(U - B)_0$ and $(B - V)_0$ from photoelectric data. The first equation, which relates the color excesses, has been determined observationally for O stars by Johnson and Hiltner (1956). The relation is

$$E_{U-B}/E_{B-V} = X + cE_{B-V} , \quad (1)$$

where c is a small numerical constant. Johnson (1958) used the data of Lindholm (1957) to relate X to $(B - V)_0$ for spectral types O9 to A0, thereby enabling equation (1) to be generally applied to early-type main-sequence stars. Equation (1) is now written

$$E_{U-B}/E_{B-V} = A[(B - V)_0] + cE_{B-V} , \quad (2)$$

where X has been replaced by some function of $(B - V)_0$. The second equation, which relates $(B - V)_0$ and $(U - B)_0$, is

$$(U - B)_0 = a(B - V)_0 + b \quad (3)$$

for main-sequence, giant, and supergiant stars. Equations (2) and (3) are solved for $(U - B)_0$ and $(B - V)_0$ by successive approximations (see Crawford 1958).

Recent work by Wampler (1961) and Serkowski (1963) has made it necessary to revise equations (2) and (3). From a study of twelve groups of O stars, which were distributed in galactic longitude (l), Wampler (1961) suggested that the ratio of the color excesses was a function of galactic longitude, i.e.,

$$E_{U-B}/E_{B-V} = f(l) . \quad (4)$$

Moreover, the curvature term found by earlier investigators arose because of this dependence on l. This is the view adopted here. By assuming a value of $(B - V)_0 = -0.32$ for O stars, and applying equations (3) and (4), Wampler found that $(U - B)_0 = g(l)$ and furthermore, that $(U - B)_0$ was strongly correlated with E_{U-B}/E_{B-V}. This suggests that equation (3) should be modified so that $(U - B)_0 = h[l, (B - V)_0]$. However, current data are insufficient to redefine the color-color relation at different galactic longitudes, so we must assume that $(U - B)_0$ is constant for O stars throughout the Galaxy. If we assume that the intrinsic colors of O stars are those given by Serkowski (1963), i.e., $(B - V)_0 = -0.32$ and $(U - B)_0 = -1.14$, then the reddening lines for these stars must pass through this point. This condition reduces the amplitude of the variation of E_{U-B}/E_{B-V} with l, but does not destroy the dependence. However, since the amplitude of this variation is small, a mean value of E_{U-B}/E_{B-V}, weighted according to the number of stars, has been adopted. The mean value of E_{U-B}/E_{B-V} is, therefore, 0.76.

The function $A[(B - V)_0]$ was re-evaluated by Serkowski (1963), who found:

$$A[(B - V)_0] = 0.58 - 0.33(B - V)_0 . \quad (5)$$

It is apparent from Serkowski's data that $A[(B - V)_0]$ is independent of luminosity class over the range V–II. The results of these investigations suggest that equation (4) should be modified so that

$$E_{U-B}/E_{B-V} = 0.76 + A[(B - V)_0]. \quad (6)$$

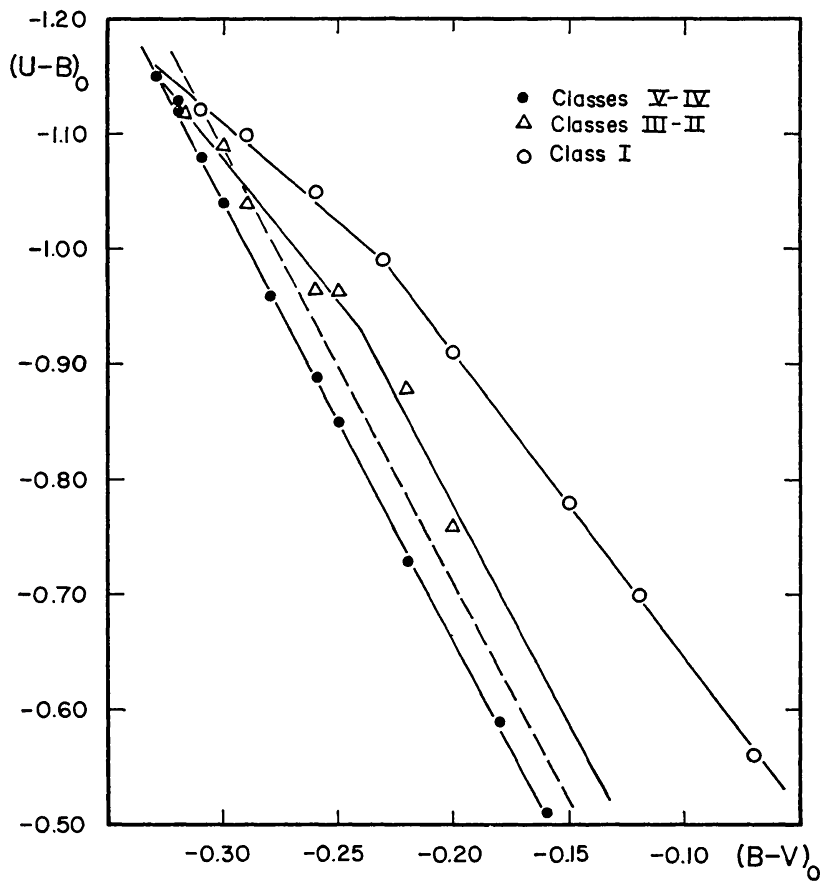

FIG. 25.—Intrinsic color-color relations for O-B stars (Serkowski 1963). The solid lines represent the adopted relations for each luminosity grouping. The dashed line represents Johnson's (1965) relation for luminosity classes V–III.

Substitute equation (5) into equation (6) and apply the condition that $E_{U-B}/E_{B-V} = 0.76$ when $(B - V)_0 = -0.32$; then equation (6) becomes

$$E_{U-B}/E_{B-V} = 0.65 - 0.33(B - V)_0 . \quad (7)$$

The color-color relations for main-sequence and subgiant stars (V, IV), giant stars (III, II), and supergiant stars (I) have been derived from Serkowski (1963). Figure 25 gives $(B - V)_0$ versus $(U - B)_0$ for each group. The relation for luminosity classes IV and V is

$$(U - B)_0 = 3.80(B - V)_0 + 0.10 , \qquad -0.08 \geq (B - V)_0 > -0.33 . \quad (8)$$

The data are quite limited for giant stars, and in fact the useful data do not extend later than B3. In order to define $(B - V)_0 = g[(U - B)_0]$, for later spectral types, the work of Johnson (1965) was examined. A plot of $(B - V)_0$ versus $(U - B)_0$, made from his data (see Fig. 25) for stars of luminosity classes V–III, yields a slope almost identical with that obtained from Serkowski's main-sequence and subgiant stars. However, because Johnson has grouped a range of luminosity classes (V–III) together, this curve is shifted to the red along the $(B - V)_0$ axis. One can therefore assume that $(\text{slope})_{\text{IV,V}} = (\text{slope})_{\text{II,III}}$ for $(B - V)_0 > -0.24$. Also, it is apparent from Figure 25 that the $(B - V)_0$ versus $(U - B)_0$ relation is not linear so it has been represented by the two relations

$$(U - B)_0 = 3.80(B - V)_0 - 0.02\,, \qquad (B - V)_0 > -0.24 \tag{9}$$

and

$$(U - B)_0 = 2.31(B - V)_0 - 0.38\,, \qquad -0.24 \geq (B - V)_0 > -0.33\,. \tag{10}$$

By making a similar approximation the relations for the supergiants are written as

$$(U - B)_0 = 2.67(B - V)_0 - 0.38\,, \qquad -0.07 > (B - V)_0 > -0.23 \tag{11}$$

and

$$(U - B)_0 = 1.71(B - V)_0 - 0.60\,, \qquad -0.23 \geq (B - V)_0 > -0.31\,. \tag{12}$$

Equations (7)–(12) have been used to evaluate the intrinsic colors which appear in Table 1 and column (7) of Table 2. The *UBV* photometry and MK spectral types from which these colors have been derived (see cols. (3)–(6) of Table 2) were taken from Sharpless (1952, 1954); Crawford, Limber, Mendoza, Schulte, Steinman, and Swihart (1955); Harris (1955, 1956); Johnson and Morgan (1955); McNamara and Williams (1955); Morgan, Code, and Whitford (1955); Hiltner (1956); Johnson and Hiltner (1956); Roman (1956); Walker (1957); Bertiau (1958); Blaauw, Hiltner, and Johnson (1959); Hardie and Seyfert (1959); Barbier and Boulon (1960); Hardie, Seyfert, and Gulledge (1960); Crawford (1961); Hardie and Crawford (1961); Hoag *et al.* (1961); Borgman and Blaauw (1964); Hardie, Heiser, and Tolbert (1964); Jaschek, Conde, and de Sierra (1964); Wildey (1964); Hoag and Applequist (1965); Morgan, Hiltner, Neff, Garrison, and Osterbrock (1965); and Hill (unpublished). Where two or more *UBV* measures were available for the same star a mean value was adopted.

VII. ABSOLUTE MAGNITUDES

Most of the stars included in this search program are located in clusters whose distance moduli are reliably known. These distance moduli have been found by making the usual assumption that $A_V/E_{B-V} = 3.0$, but there is evidence that this value may be larger in some parts of the galaxy (Johnson 1965). However, the majority of the clusters and associations which have been investigated in this study are not highly reddened, so the errors which result from using an incorrect ratio will, hopefully, be small.

The distance modulus (9.3) of Cepheus III generally quoted in the literature (Blaauw *et al.* 1959) is probably incorrect. Johnson (1965) has shown that in this direction $A_V/E_{B-V} = 5.4$, whereas the distance modulus was found by Blaauw *et al.* (1959) assuming that $A_V/E_{B-V} = 3.0$. Because of this uncertainty I have adopted Borgman and Blaauw's (1964) spectroscopic absolute magnitudes for this association, since they are independent of the ratio of total to selective absorption.

The absolute magnitudes for the members of Cepheus II were taken from Kopylov (1958). In Scorpius II the absolute magnitudes have, in general, been taken from Bertiau (1958) and Borgman and Blaauw (1964) or derived by assuming a distance modulus of 6.18 (Hardie and Crawford 1961). In the remaining clusters and associations the absolute magnitudes of the individual members were determined by using the known distance moduli and assuming that the absorption $A_V = 3.0\, E_{B-V}$. The adopted distance modulus of each cluster and association is given in Table 5 along with the source of these distance moduli. The absolute magnitudes of the previously known β Cephei stars which appear in Table 1 have been taken from Hitotuyanagi and Takeuti (1963). The adopted absolute magnitudes for the program stars are given in column (8) of Table 2. Spectroscopic absolute magnitudes determined from the MK spectral types and the equivalent width of Hγ (Hoag and Applequist 1965; Petrie 1964) are generally in good agreement with the photometric absolute magnitudes given in Table 2. In those cases where there is a marked difference between the variously determined absolute magnitudes it is noted in the discussion of the individual stars.

VIII. ROTATIONAL VELOCITIES

Spectra were taken on 9 nights with the Meinel spectrograph at two dispersions, 63 Å/mm (830 line grating) and 126 Å/mm (400 line grating), with the 36-inch and the 84-inch reflectors at KPNO. About 170 spectra (on Eastman Kodak IIaO plates) of the program stars and 42 spectra of the standard stars needed to calibrate the visual estimates of $v \sin i$ were used for the measurements. Most of the program star spectra were widened to 0.29 mm, but for the brighter stars and most of the rotational velocity standards the spectra were widened to 0.58 mm.

TABLE 5

ADOPTED DISTANCE MODULI

Association or Galactic Cluster	$V_0 - M_v$	Source
Per I	11.8	Johnson *et al.* (1961)
Per II	7.7	Johnson *et al.* (1961)
NGC 1502	9.8	Mean value from Hoag (1965)
Ori I	8.2	Johnson and Hiltner (1956); Borgman and Blaauw (1964); Hardie *et al.* (1964)
NGC 2169	10.2	Mean value from Hoag (1965)
Gem I	11.1	Hardie and Seyfert (1959)
Sco II	6.18	Hardie and Crawford (1961)
NGC 7160	9.6	Mean value from Hoag (1965)
NGC 7380	11.9	Mean value from Hoag (1965)
Lac I	8.9	Crawford (1961)

It was realized at the outset of this work that rotational velocities obtained at 126 Å/mm would be rather crude, but they would serve the purpose in hand; i.e., to answer the question as to whether the β Cephei stars found in the photoelectric program had high or low rotational velocities. The standard stars and their velocities were taken from a paper by McNamara and Larsson (1962), based on the system of Slettebak and Howard (1955). A list of the standard stars used at both dispersions, as well as the number of spectra of individual stars, is given in Table 6 along with the assumed rotational velocities. The actual estimates of $v \sin i$ were made visually using the spectrum comparator at KPNO. The He I lines at λ4026 and λ4471 were used for the estimates, which were made independently. The method used to obtain $v \sin i$ was to bracket the lines of unknown rotational broadening by the known lines of what appeared to be the two closest standard stars and to interpolate between the standard projected rotational velocities. For very large velocities it was only possible to say that the observed line broadening corresponded to a rotational velocity greater than some standard value. Mean values of $v \sin i$ derived from the two lines establish the rotation for each star. The internal errors in a determination of $v \sin i$, found by comparing $v \sin i$ from the two lines (λ4026 and λ4471), are, respectively, 55 and 72 km/sec for the 63 and 126 Å/mm data.

These two sets of data make up two rotational velocity systems which, ideally, should have been individually compared with pre-existing systems. The only system with enough stars in common with my own to permit a meaningful comparison to be made was that of Boyarchuk and Kopylov (1964). Even here there were not enough stars in each set to allow a valid comparison, so the results from both sets of data were combined. Another group of rotational velocities were made available, before publication, by Drs. G. A. H. Walker and S. M. Hodge of the Dominion Astrophysical Observatory, Victoria, British Columbia. It was necessary to compare this system with that of Boyarchuk and Kopylov since it was evident that serious systematic differences were present. Boyarchuk and Kopylov's catalogue has been criticized by Treanor (1960) on the basis that he has given too much weight to the line-width measures of Huang (1953). Nevertheless, this catalogue represents the only attempt to reduce all of the known rotational velocities to

TABLE 6

ROTATIONAL VELOCITY STANDARDS

Name	HD or BD	MK	$v \sin i$	No. of spectra	Name	HD or BD	MK	$v \sin i$	No. of spectra
63 Å/mm DATA									
γ Peg	886	B2 IV	0	1	ξ Ori	42560	B3 V	230	3
δ Cet	16582	B2 IV	0	3	υ Cyg	202904	B2 V	280	1
ξ^1 CMa	46328	B0.5 IV	0	1	ζ Tau	37202	B2p	310	3
15 CMa	50707	B1 V	40	2	60 Cyg	200310	B1 V	320	2
λ Tau	25204	B2	110	4	HR 8731	47°3985	B2p	340	2
κ Hyd	83754	B5 V	190	2	19 Mon	52918	B1 V	350	2
ξ Cas	3901	B2 V	230	1	ψ Per	22192	B2p	390	1
126 Å/mm DATA									
δ Cet	16582	B2 IV	0	2	ξ Ori	42560	B3 V	230	2
ξ^1 CMa	46328	B0.5 IV	0	1	ζ Tau	37202	B2p	310	1
15 CMa	50707	B1 V	40	1	19 Mon	52918	B1 V	350	1
λ Tau	25204	B2	110	3	ψ Per	22192	B2p	390	1
κ Hyd	83754	B5 V	190	2					

a common system. The work that would be needed to recalibrate the many systems, to enable Hill's and Walker and Hodge's data to be more accurately transformed, cannot be justified in view of the rather large errors in these latter systems. Consequently, the shortcomings of this catalogue will be manifest also in the velocities quoted in Table 2. A description of the method used to derive the transformations between the various systems follows.

By using a statistical method described by Deeming (1967) it is possible, under certain conditions, to determine the linear relations between three variables which may all be subject to error. Using this method two relations between the systems of Boyarchuk-Kopylov and Walker-Hodge, Boyarchuk-Kopylov, and Hill have been derived from the data given in Tables 7 and 8. It was not possible to relate the system of Hill to that of Walker and Hodge because of a lack of stars common to both. A solution to this problem was found by making four assumptions: (1) The errors in each of the systems are independent. (2) There is a linear physical relation between systems *A* and *B* of the form $A_t = aB_t + b$, where A_t and B_t refer to the true values of A and B, respectively. (3) There is no scale difference between the systems of Boyarchuk-Kopylov and Walker-Hodge. (4) There is no scale difference between the systems of Boyarchuk-Kopylov and Hill.

The transformations and standard errors between the systems were found to be

$$BK_t = H_t - 22\ , \qquad BK_t = WH_t + 70\ ,$$

and

$$BK_0 \pm 18 = (H_0 \mp 53) - 22\ , \qquad BK_0 \pm 18 = (WH_0 \mp 70) + 70\ ,$$

where the rotational velocity systems of Boyarchuk-Kopylov, Walker-Hodge, and myself are denoted by BK, WH, and H, respectively. The "0" and t subscripts indicate the observed and true rotational velocities, respectively. Figures 26 and 27 show how well these relations fit the data. Columns (9)–(12) of Table 2 give the available rotational

TABLE 7

ROTATIONAL VELOCITIES (IN KM/SEC) OF STARS COMMON TO THE SYSTEMS OF BOYARCHUK AND KOPYLOV AND OF HILL

HD	$v \sin i$ H	$v \sin i$ BK	HD	$v \sin i$ H	$v \sin i$ BK
13866........	22	45	43753........	175	70
35039........	0	21	43818........	118	95
35149........	290	273	46328........	40	33
35730........	95	72	50707........	35	69
37018........	268	95	53974........	185	170
37040........	135	150	83754........	240	195
37129........	75	70	202214.......	25	55
39746........	215	260	202904.......	255	255
42379........	135	70	206165.......	15	33
43078........	195	135	217101.......	245	150

TABLE 8

ROTATIONAL VELOCITIES (IN KM/SEC) OF STARS COMMON TO THE SYSTEMS OF BOYARCHUK AND KOPYLOV AND OF WALKER AND HODGE

HD	$v \sin i$ WH	$v \sin i$ BK	HD	$v \sin i$ WH	$v \sin i$ BK
1743.......	− 30	70	191489.....	+210	390
2451.......	+ 40	135	191917.....	− 30	45
6675.......	− 60	70	197460.....	+100	200
10125......	+ 10	95	202124.....	− 70	120
13866......	− 50	45	211835.....	+210	265
15785......	− 50	120	214432.....	+130	185
23478......	+270	160	215733.....	− 20	70
35730......	+160	72	216534.....	+ 30	65
39746......	+130	260	216684.....	+ 40	125
42379......	− 50	70	218325.....	+300	220
43753......	+ 10	70	223987.....	− 10	95
46149......	+ 40	85	224424.....	− 30	85
186994.....	+ 80	135	225146.....	+100	95
191139.....	+ 40	60	225160.....	− 50	120

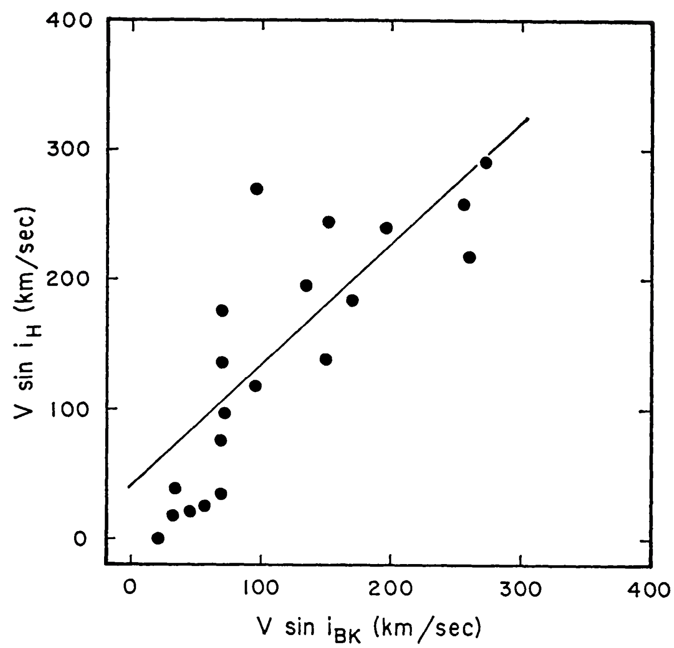

FIG. 26.—Relation between the rotational velocities of Boyarchuk and Kopylov and of Hill. The line represents the adopted relation between the two systems.

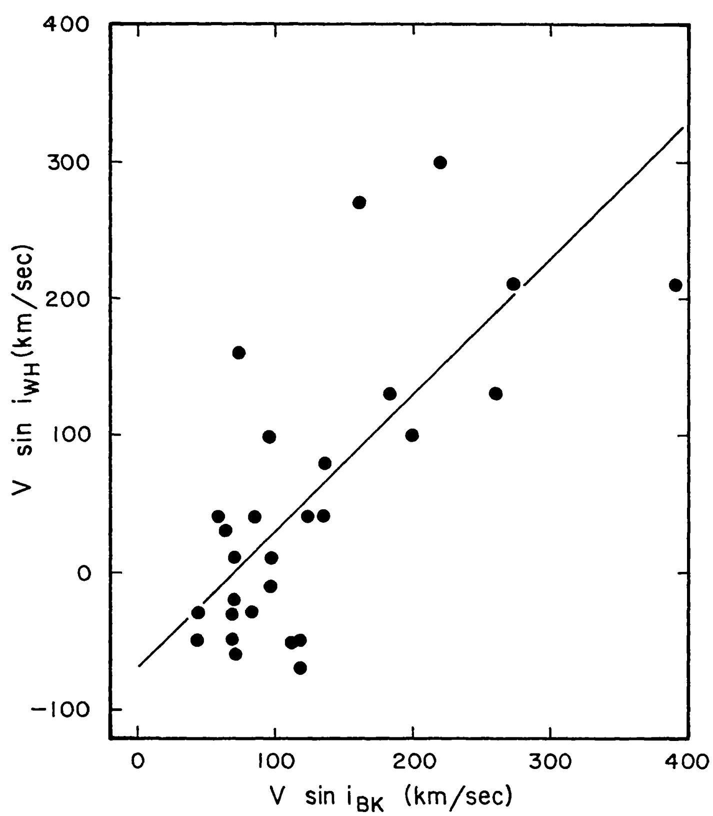

FIG. 27.—Relation between the rotational velocities of Boyarchuk and Kopylov and of Walker and Hodge. The line represents the adopted relation between the two systems.

velocities for the program stars. The rotational velocities listed have been transformed to the *BK* system.

An examination of the rotational velocity data for the new β Cephei stars (Table 9) shows that there is *no* preferred rotational velocity, contrary to what had previously been thought by, e.g., McNamara and Hansen (1961). The probable explanation for the low rotational velocities previously found for the β Cephei stars will be given in the following section.

Table 9 summarizes the observational data, described in this and previous sections, for the new β Cephei stars.

TABLE 9

PHOTOMETRIC, SPECTROSCOPIC, AND PERIOD DATA FOR NEW β CEPHEI STARS*

Name	Assoc. or Cluster	MK	$(B-V)_0$	$(U-B)_0$	M_v	log *P*	*v* sin *i*
HD 13051..........	Per I	B1 IV::	−0.30	−1.04	−4.4	−0.426	260:
HD 13494..........	Per I	B1 III	− .26	−0.97	−3.8	− .658	280
HD 13544..........	Per I	B0.5 IV	− .30	−1.04	−3.7	− .408	330
HD 13745..........	Per I	B0 III	− .33	−1.15	−5.3	− .346	260
HD 13866..........	Per I	B2 Ib	− .22	−0.92	−5.5	− .543:	39
HD 14053..........	Per I	B0.5 III	− .27	−1.00	−4.9	− .693	70
HD 15752..........	Per I	B0 III	− .33	−1.14	−5.5	− .586	≥220
HD 16429..........	Per I	O9.5 III	− .30	−1.07	−6.9	− .422	230
BD 56°473..........	Per I	B1 II	− .27	−1.01	−4.3	− .514	....
BD 56°545..........	Per I	B1 III	− .26	−0.98	−4.6	− .561	≥290
BD 56°589..........	Per I	B1 III	− .26	−0.98	−4.4	− .697:	130
A..................	NGC 1502	....	....	....	....	− .720:	110†
HD 35715..........	Ori I	B2 IV	− .29	−1.00	−3.4	− .511	166
HD 37776..........	Ori I	B2 V	− .28	−0.96	−3.1:	− .420	155
2..................	NGC 2169	....	− .23	−0.78	−2.7	− .399:	≥240
5..................	NGC 2169	....	− .24	−0.80	−2.0	− .395	≥320
HD 43078..........	Gem I	B0 IV	− .29	−1.04	−4.2	− .622	139
HD 43818..........	Gem I	B0 II	− .33	−1.15	−6.1	− .660	95
HD 142883.........	Sco II	B3:V	− .19	−0.63	−2.0:	− .542	....
HD 217035.........	Cep III	B0 V	− .32	−1.12	−4.5	− .611	150
HD 53755..........	Field star	B0 V:	....	....	....	− .362	....
HD 53974..........	Field star	B0.5 IV	(− .30)	(−1.04)	(−4.4)	− .907	170
HD 149881.........	Field star	B0.5 III	(− .29)	(−1.04)	(−4.7)	− .491	....
HD 165174.........	Field star	B0.5 III	(−0.29)	(−1.04)	(−4.7)	−0.544:	....

* The values in parentheses have been derived from the MK spectral types.

† This value refers to the northern component. The projected rotational velocity for the southern component is ≥190 km/sec.

IX. DISCUSSION

a) The Period-Luminosity Relation

Since the previously known β Cephei stars obey fairly well-defined *p-l* (period-luminosity) or *p-c-l* (period-color-luminosity) relations, it was anticipated that the variables discovered in this survey would also conform to such relations. This has not proved to be the case, as shown by the period-absolute magnitude data of Tables 1 and 9, plotted in Figure 28. Rather than a simple *p-l* relation, there appear to be two sequences. The first is an extension of the original *p-c-l* (or *p-l*) relation; the second sequence, centered approximately at log $P \sim -0.45$ (or $P \sim 0^d.35$), seems independent of period.

Six stars deviate markedly from the mean *p-l* line. The uncertainties in the ordinate of Figure 28 are not large enough to explain this, since the absolute magnitudes determined by the three different methods described earlier (see § VII) are in good agreement (with the exception of NGC 2169-5). From these results one concludes that the errors (if they do exist) must be in the periods. As mentioned previously (see § IV) trial periods in a fine mesh between $0^d.1$ and $0^d.5$ were examined for minimum θ. There is no obvious reason why this analysis should yield periodicities of $\sim 0^d.4$ unless they really do exist. While some of the periods adopted may be higher harmonics of a fundamental period, multiples and submultiples of *all* the periods quoted in Table 4 have been tested. Despite the above comments I recognize that some of the periods may be in error, since continuous observations on any star over a full cycle were never available and since the presence of beat periods will have some effect on the period determinations. Clearly, more extensive observations are needed, especially on the six most deviant stars, before a final decision can be made regarding the reality of the deviations in Figure 28. If valid, these observations may show that a subclass of variables exists within the β Cephei

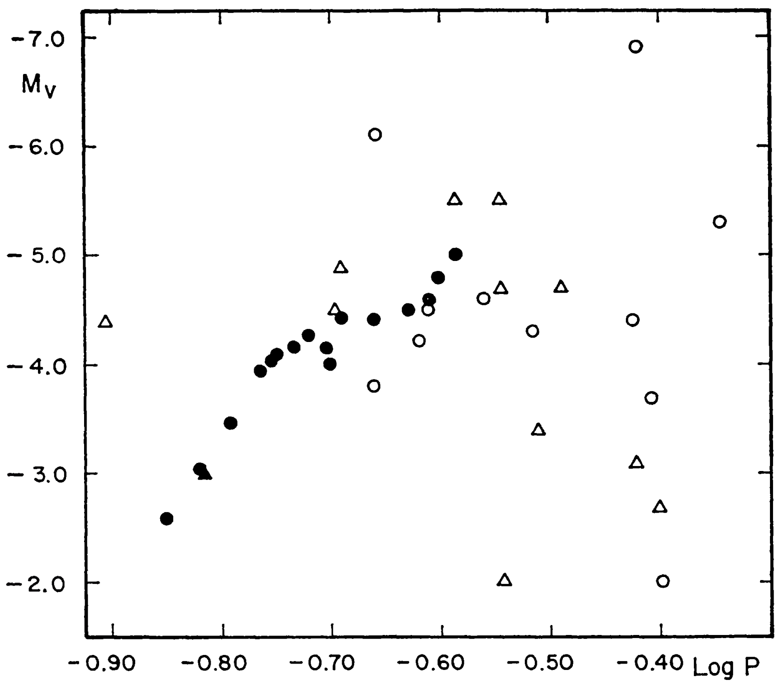

FIG. 28.—Period-luminosity relation for β Cephei stars. Open symbols represent new β Cephei variables, and filled symbols represent previously known β Cephei stars. Reliable data are given by circles and uncertain data by triangles.

stars, or that another class of variables exists among the early B stars. Figure 28 raises the further question as to why none of the longer period variables were previously found by other observers. The answer is not obvious, but perhaps the following comments may provide a few clues:

i) Many of the previously known β Cephei stars were found in radial velocity surveys. Such surveys would naturally tend to favor the discovery of variable radial velocities in sharp-lined stars rather than in rotationally broadened wide-lined objects whose radial velocities could not be measured with accuracies comparable to their sharp-lined counterparts. In this context it is probably significant that the stars which deviate the most from the mean p-l relation have the larger rotational velocities (see Fig. 29).

ii) No extensive radial velocity survey has yet been made for the sole purpose of finding β Cephei variables; e.g., a recent search by Pagel (1956) included only seven stars. The reason for this is probably found in the relatively large amount of data processing that is involved with the measurement of radial velocities.

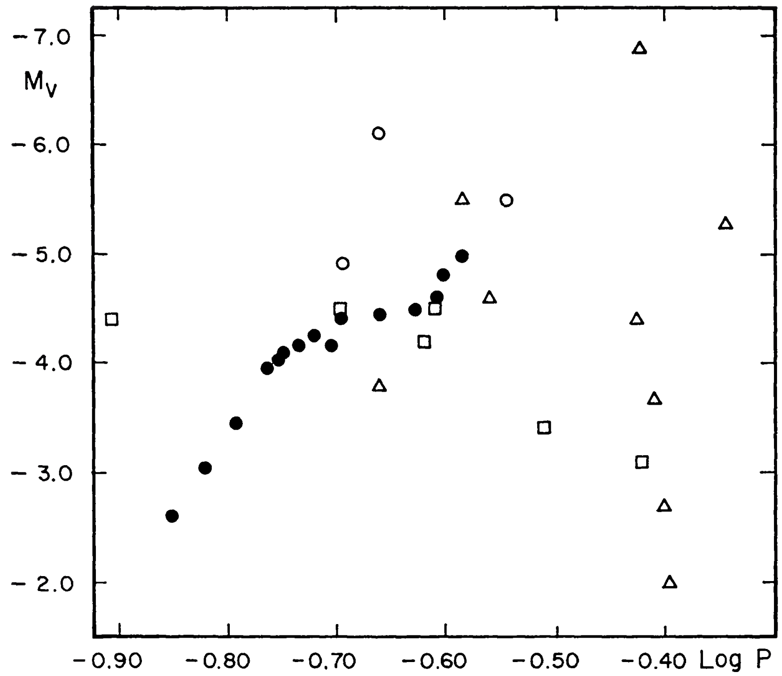

FIG. 29.—Period-luminosity-rotational velocity relation for β Cephei stars. The open symbols represent new β Cephei stars and the filled symbols represent previously known β Cephei stars. The circles refer to $v \sin i < 100$ km/sec; squares refer to $100 \leq v \sin i < 200$ km/sec; triangles refer to $v \sin i \geq 200$ km/sec.

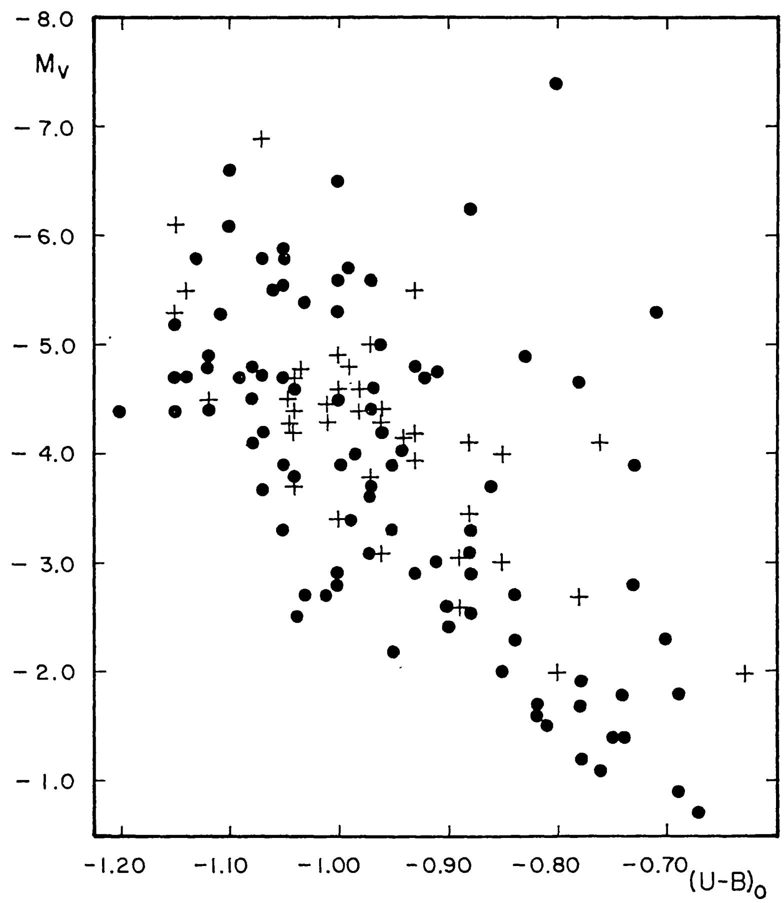

FIG. 30.—Intrinsic color–absolute-magnitude diagram for all the cluster and association program stars; β Cephei variables are denoted by crosses and normal stars by filled circles.

iii) The photoelectric searches of Walker (1952) and Lynds (1959) were not quite as extensive as this author's. Moreover, I purposely chose to examine stars in evolved clusters where it was thought that the probability of finding β Cephei stars would be increased. This in fact has resulted in the discovery of more β Cephei stars and apparently has increased the probability of finding variables with longer periods.

b) Cluster and Association H-R Diagrams

It is important to see where the non-varying program stars are located with reference to the β Cephei stars in an H-R diagram. The data from Tables 1 and 2 were used for this purpose and the results are shown in Figure 30. Furthermore, if individual H-R diagrams are constructed for those associations and clusters which have β Cephei members (see Fig. 31), then we see that the β Cephei stars cannot be recognized on the basis of their occupying preferred positions in the cluster or association H-R diagram. It is, therefore, probable that many of the non-varying stars are at the same stage of evolution as the β Cephei stars. These results imply that any theory which explains the observed characteristics of the β Cephei stars must also be capable of explaining why some stars are brightness variables (i.e., β Cephei stars) and why other stars which are at the same stage of evolution are apparently constant in brightness.

X. SUMMARY OF OBSERVATIONAL RESULTS

i) Twenty-four β Cephei stars (including five tentative members) have been discovered in a sample of 153 early B stars which were taken, in general, from the nearest associations and galactic clusters. This brings the total number of listed β Cephei stars to forty-one.

ii) The spectral range of the β Cephei sequence has been increased from B0–B3 to O9.5–B3.

iii) The observed range in luminosity class has been increased from (IV–V)–II to V–I.

iv) The new periods range from 3 to 10 hours, compared to the previous span of $3\frac{1}{2}$ to $6\frac{1}{2}$ hours.

v) The projected rotational velocities range from 0 to >300 km/sec in contrast to the uniformly rather low rotational velocities which had previously been observed.

vi) Those stars with periods $P \geq 0^{d}35$ do not obey a period-luminosity or period-color-luminosity relation but those stars with $P < 0^{d}3$ do appear to obey one. However, this must be regarded as a tentative conclusion.

vii) H-R diagrams of β Cephei variables and "normal" stars for individual associations and galactic clusters show that the β Cephei stars occupy no preferred position in relation to normal stars; i.e., many of these "normal" stars are at the same stage of evolution as the β Cephei stars.

Particular thanks are due to Dr. H. J. Smith for introducing me to problems of the β Cephei stars and for guidance and support through various aspects of this research; also to Dr. T. J. Deeming, who spent many hours discussing the results and who helped shape the final draft of the dissertation from which this, and later papers, have been derived. I appreciate the pertinent comments of Drs. N. J. Woolf, A. T. Young, and D. S. Evans on much of this research, and the help of Mr. F. Lopez-Lopez, who wrote the *UBV* program used at the University of Texas. Mr. P. R. Jordahl offered useful editing advice, and Dr. D. M. Young, Director of the University Computation Center, made available generous amounts of computer time for data reductions. Grateful acknowledgment is made for the support of a University of Texas fellowship during the academic years 1964–1966.

I also wish to thank Dr. N. U. Mayall, Director of Kitt Peak National Observatory, for granting the extensive telescope time necessary for this research. My appreciative

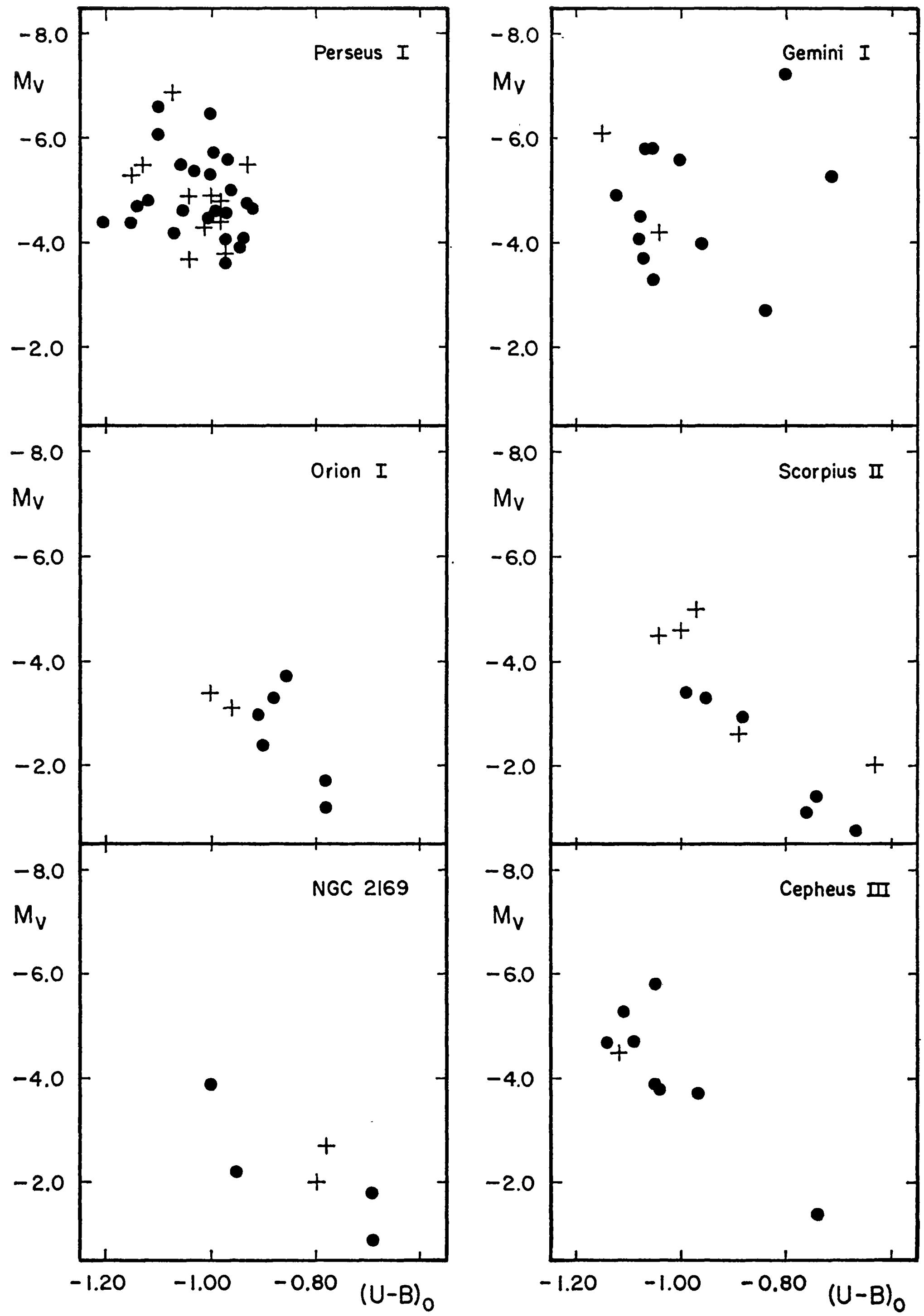

FIG. 31.—Intrinsic color-absolute-magnitude diagram for individual clusters and associations; β Cephei variables are denoted by crosses and normal stars by filled circles.

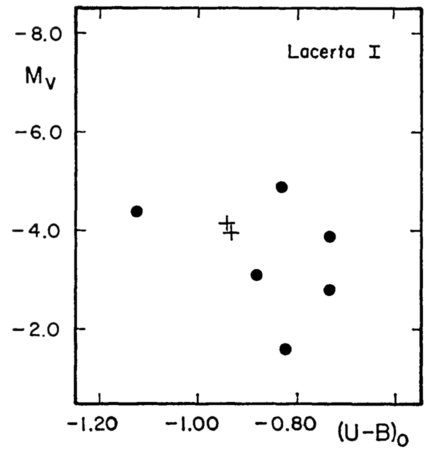

FIG. 31—*Continued*

congratulations go to Kitt Peak National Observatory and the National Science Foundation for sponsoring and encouraging the program which allows graduate students the use of fine facilities and which also gives them the opportunity to work with the excellent Kitt Peak staff. In particular Messrs. R. Barnes and J. C. Golson helped sustain me during the long months of observing, Drs. D. H. Schulte and D. L. Crawford made available their photometric reduction program, and Mrs. R. Barnes ran these reductions on the Kitt Peak computer; to all these I am grateful. Drs. G. A. H. Walker and S. M. Hodge, of the Dominion Astrophysical Observatory, generously made available their rotational velocity results before publication.

Finally I thank my wife, who was responsible for reducing much of the data and who has been a continuous source of encouragement throughout this work.

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