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RECLASSIFIED AND NEW VARIABLES IN THE ARCHIVAL HARVARD COLLEGE OBSERVATORY LMC PHOTOMETRY

GARCIA-MELENDO, E.[1]; GOMEZ-FORRELLAD, J. M.[1,2]

[1] Esteve Duran Observatory Foundation, Montseny 46 – Urb. El Montanya, 08553 Seva, Spain, e-mail: duranobs@astrogea.org

[2] Grup d'Estudis Astronomics, Apdo. 9481, 08080 Barcelona, Spain, e-mail: jmgomez@astrogea.org

In 1960, Cecilia H. Payne-Gaposchkin and Sergei Gaposchkin initiated the task of studying the variable stars in the Magellanic Clouds, by analysing the photographic material collected on these small galaxies by the Harvard College Observatory (HCO) since the end of the 19th century. Their task entailed the identification and characterization of 3806 variables, most of them Cepheids. Lists of these variables were published in three summary catalogues (Payne-Gaposchkin and Gaposchkin, 1966; Gaposchkin, 1970; Payne-Gaposchkin, 1971).

Original brightness estimates were never published and lost for several years. Fortunately, thanks to Dr. Douglas Welch, the assistance of Dr. Martha Hazen of Harvard College Observatory, and the efforts of the members of the Royal Astronomical Society of Canada, Hamilton Centre, and of the Hamilton Amateur Astronomers, a fraction of these original photographic measurements were retrieved, converted into electronic format, and made public on the Internet at http://physun.physics.mcmaster.ca/HCO/. Photographic measurements are listed in the form of arbitrary brightness steps relative to comparison stars versus Julian Day, but they are sufficient to search for periodicities and compute light curves.

In the electronic format list, under 300 stars in the LMC are labeled as unknown type variables. After consulting the catalogues by Payne-Gaposchkin and Gaposchkin (1966) and Gaposchkin (1970), it was found that most of these were labeled as irregular variables. For all these objects, we performed a search on the SIMBAD database and also analysed the photometric data looking for periodicities using the DFT algorithm (Deeming, 1975). We found that 50 of these stars show strong periodicities but were misclassified and do not appear in the SIMBAD database, or remain as misclassified in the subsequent literature.

Results are presented in Tables 1 and 2. Table 1 lists the found Cepheids and Table 2 the eclipsing binary stars and long period variables. For both tables, in the first column is the Harvard Variable number (HV), second and third columns are the observing log for HCO measurements, and the fourth column includes the original variable type according to Gaposchkin (1970). He reported 418 irregular variables in the LMC, which he divided in two groups according to the found photographic amplitude of variation, and named as IN (Irregular Normal, amplitude < 1 mag) and II (Irregular Important, amplitude > 1 mag), we reference these variables as just "Irregular". When a variable is not listed in the LMC and SMC summary catalogues, and does not appear in the SIMBAD database, we fill the entry with a line. In Table 1 the column labeled "Epoch" refers to a maximum light epoch, whereas in Table 2 it indicates a minimum (primary if possible) epoch for eclipsing binary variables, and a maximum one for LPV if given. All epochs are listed in the form JD $-$ 2, 400, 000.0. To derive light curves we divided folded data in 25 bins where datapoints were averaged. Figures 1–4 depicts the averaged folded light curves of the found Cepheids, and Figures 5–7 those of the other variable types in Table 2, all of them in the form of the given arbitrary brightness steps versus phase. Error bars are also represented.

In the columns "Maximum photographic magnitude" and "Amplitude" in Tables 1 and 2 we give the photographic maximum brightness and amplitude as listed by Gaposchkin (1970). Since he did not give any information about the used comparison stars nor the transformation function from arbitrary brightness steps into magnitudes, it was not possible to obtain a reliable calibrated magnitude scale for the folded and averaged light curves.

Table 1: Cepheids

HV	Initial and final observing time: JD $-$ 2, 400, 000.0	N	Original variable type	Period (days)	Epoch	Max. pg. br.	Ampl.	Rem.
2286	12697.847–34748.499	422	Irregular	4.56272	12702.6	15.49	0.71	(1)
2357	13847.841–34748.499	410	Irregular	1.829460	13849.6	16.75	1.12	
2469	13875.807–34748.499	407	Irregular	2.66772	13878.2	16.31	0.44	
2501	13847.841–29203.426	176	Irregular	1.717088	13853.9	15.35	0.80	
2645	13877.808–34748.499	269	—	2.73766	13880.2	—	—	(2)
2655	13875.807–34748.499	277	Irregular	2.65942	13878.2	15.75	1.03	
2887	13876.814–33104.662	103	Irregular	1.891734	13879.3	15.95	0.68	
5712	13847.841–34748.499	458	Irregular	9.2021	13855.4	15.46	0.55	
5721	13847.841–34748.499	429	Irregular	2.82811	13849.5	15.72	0.82	
5773	13875.807–34748.499	399	Irregular	1.694576	13877.2	16.45	1.00	
5779	13875.807–34748.499	403	Cepheid?	25.056	13886.6	16.07	1.18	(3)
5805	12697.847–34748.499	437	Irregular	4.21435	12698.8	15.80	0.32	
5811	13877.808–34748.499	338	Irregular	4.02085	13881.2	16.17	0.90	
5873	13875.807–34748.499	361	—	2.056488	13877.4	—	—	(2)
5890	13847.841–34748.499	398	Irregular	1.937684	13849.9	17.15	0.60	
12034	13875.807–34748.499	498	—	5.83191	13878.6	—	—	(2)
12059	13847.841–34748.499	397	Irregular	2.75024	13849.8	16.71	0.70	
12435	13875.807–33718.266	256	—	4.05659	13877.7	—	—	(2)
12456	13876.814–33154.626	105	Irregular	2.95195	13880.9	17.16	0.34	
12469	13847.841–34748.499	407	Irregular	6.22927	13851.4	16.06	0.60	
12482	13847.841–34748.455	374	Irregular	39.314	13888.3	15.84	0.36	
12543	13876.814–33154.626	107	Cepheid	2.96383	13877.7	16.55	0.80	(4)
12593	13876.614–33178.615	112	Irregular	5.1058	13879.0	15.81	0.63	
12599	13894.749–34458.245	284	Irregular	2.73973	13895.5	16.55	0.73	
12755	13876.814–33154.626	106	Irregular	3.06231	13880.8	16.55	0.82	
12773	13876.814–33104.662	102	Cepheid?	4.0090	13879.3	16.49	0.51	(3)
12778	13875.807–33618.400	72	Irregular	3.07733	13879.4	16.27	1.06	
12786	13876.614–33178.615	100	Cepheid?	2.25383	13876.9	15.95	1.05	(3)
12799	13876.614–33178.615	105	Irregular	2.19124	13878.4	16.27	0.31	
12811	13875.807–34399.267	127	Irregular	4.80176	13880.1	16.88	0.35	
12966	13875.807–34748.499	339	—	2.693701	13876.7	—	—	(2,5)

Table 2: Eclipsing and long period stars

HV	Initial and final observing time: JD − 2,400,000.0	N	Original variable type	Type	Period (days)	Epoch	Max. pg. br.	Ampl.	Rem.
2240	13847.841–34748.499	416	Eclipsing	EA	65.701551	13893.5	14.96	1.33	
2433	12722.865–34748.499	429	—	EB	1.418044	12725.5	—	—	(2)
2595	11623.895–34748.499	450	Irregular	LPV	606.	—	13.03	0.81	
2635	13875.807–34748.499	355	Irregular	?	93.2	—	14.50	1.00	
2659	13875.807–34748.499	413	Irregular	EA/EB	1.919658	13879.6	16.03	0.58	
5703	23681.879–34748.499	458	Irregular	EA/EB	1.984795	12724.1	15.74	1.00	
5816	13847.841–34748.499	458	Eclipsing	EA	5.083092	13848.3	16.57	0.44	(6)
5876	13877.808–34748.499	384	Eclipsing	EB	3.502503	13880.4	16.73	0.44	(7)
11981	13847.841–34748.499	421	Irregular	EA/EB	4.643420	13849.1	17.08	0.71	
12053	13575.807–34748.499	418	Irregular	EA/EB	2.956570	13575.8	14.75	0.60	
12232	13876.814–34399.267	228	Irregular	EB	0.962995	13877.7	15.71	0.98	
12454	13876.814–33154.626	108	Irregular	EA:	3.234030	13879.6	16.18	1.32	
12466	13847.841–34748.499	325	Irregular	EA/EB	1.709208	13849.9	16.55	0.66	
12487	13875.807–34748.455	196	—	EB:	3.747154	13878.9	—	—	(2)
12540	13875.807–34748.499	383	Irregular	LPV	431.8	14052	16.20	0.71	
12597	13875.807–34458.245	430	—	EB	56.26	13930.3	—	—	(2)
12598	13875.807–34458.245	413	—	EB	1.421479	13878.2	—	—	(2)
12801	11627.875–34399.267	226	Irregular	EA	6.332834	11639.1	15.53	0.93	
12958	13922.617–33678.362	302	Irregular	EB:	6.060316	13928.6	15.22	0.78	

Remarks:

(1) Butler (1978) classifies this object as a Cepheid with an uncertain period of 2.7510 days.
(2) This object is not in the summary catalogues by Payne-Gaposchkin (1971) and Gaposchkin (1970) neither appears in SIMBAD database.
(3) Gaposchkin (1970), labeled this object as an uncertain Cepheid. He did not give a period.
(4) Gaposchkin (1970) indicates that this object is a Cepheid, but he does not give a period.
(5) Uncertain variable according to Hodge and Wright (1966).
(6) Characterized by Payne-Gaposchkin (1971) as an eclipsing variable with a period of 3.388762 days.
(7) Characterized by Payne-Gaposchkin (1971) as an eclipsing variable with a period of 1.270806 days but somewhat uncertain due to data scatter.

The periods in Table 2 for the eclipsing binary variables were not directly obtained from the DFT analysis. This algorithm was implemented in our AVE software for photometric data analysis (Analisis de Variabilidad Estelar, or Stellar Variability Analysis), which allowed to compute the DFT, visually identify the peaks of the transformed data, and automatically display folded light curves for the selected periods. Inspection of light curve morphology indicated if photometric data had to be folded with a double period in the case of eclipsing binaries, which could also be done automatically by the software.

We performed a consistency check for the newly found Cepheids. A P–L diagram was plotted using the data in Table 1, including a list of photometrically observed LMC Cepheids by several authors compiled by Madore (1985) covering a wider range of periods. Average B apparent magnitudes for 26 of the 31 new Cepheids were estimated by adding to the available maximum brightness photographic magnitudes in Table 1, half of the variation amplitude also listed in the same table. Figure 8 illustrates the results. 23 of these match the short period end of the P–L diagram except HV 5779, HV 12482, and HV 2501. HV 5779 and HV 12482 lay about 2 magnitudes below the P–L line, suggesting that they might be Population II Cepheids. The case of HV 2501 is more uncertain, perhaps it is a distant Milky Way interloper, or even not a Cepheid variable. (The uncertainties of the photographic magnitudes might also contribute to the derivations.)

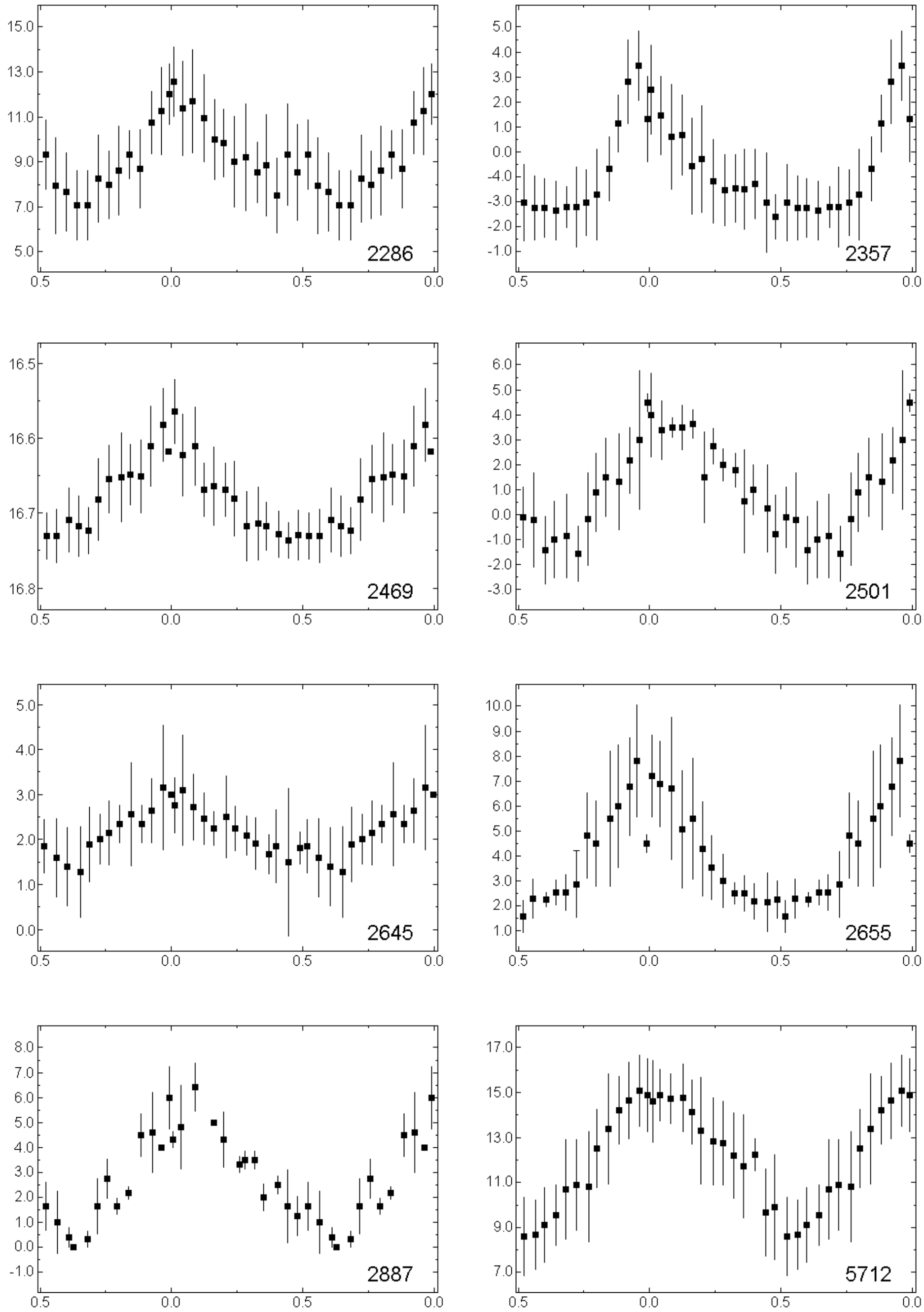

Figure 1. Folded light curves of the newly found Cepheids listed in Table 1

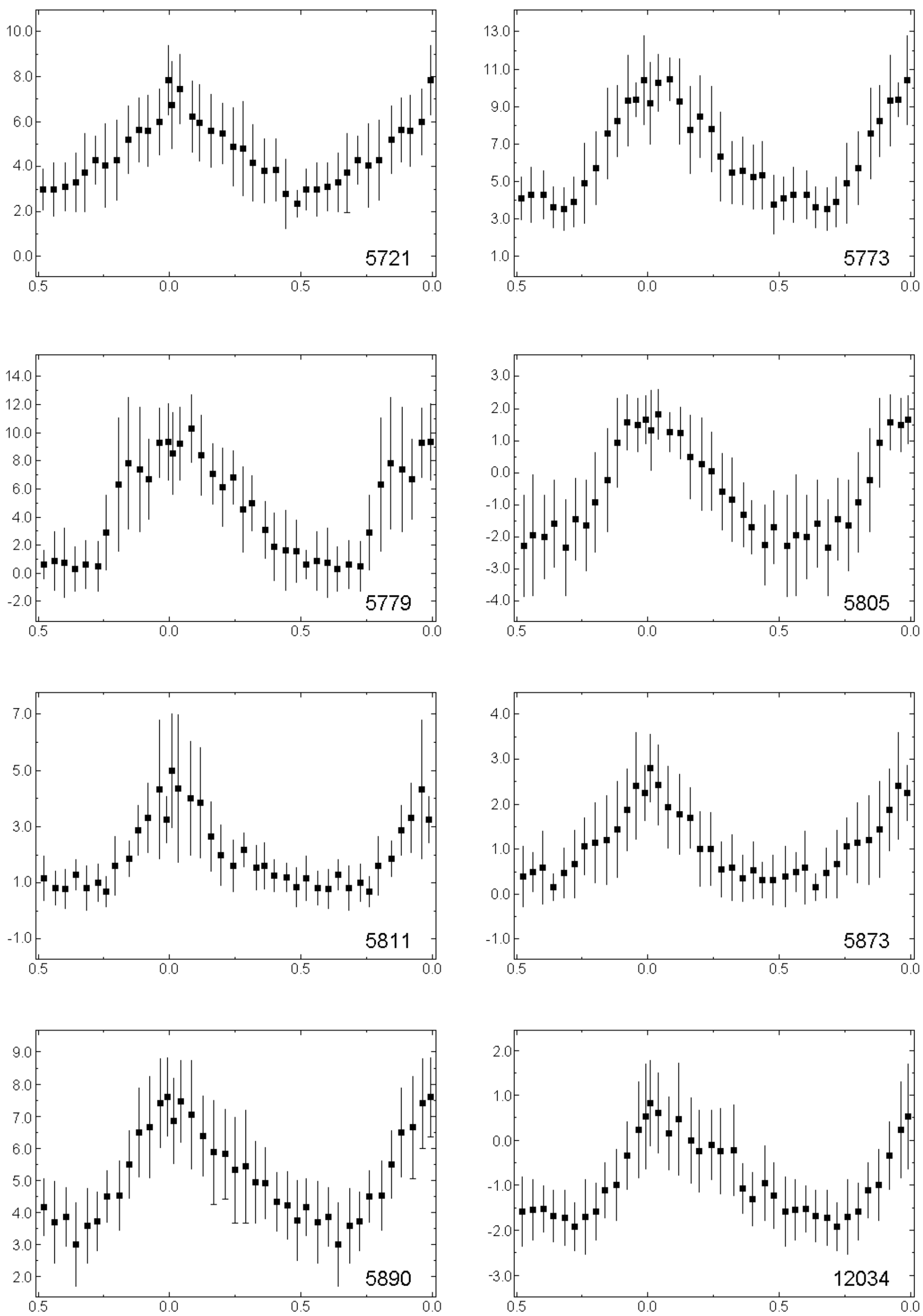

Figure 2. Folded light curves of the newly found Cepheids listed in Table 1 (cont.)

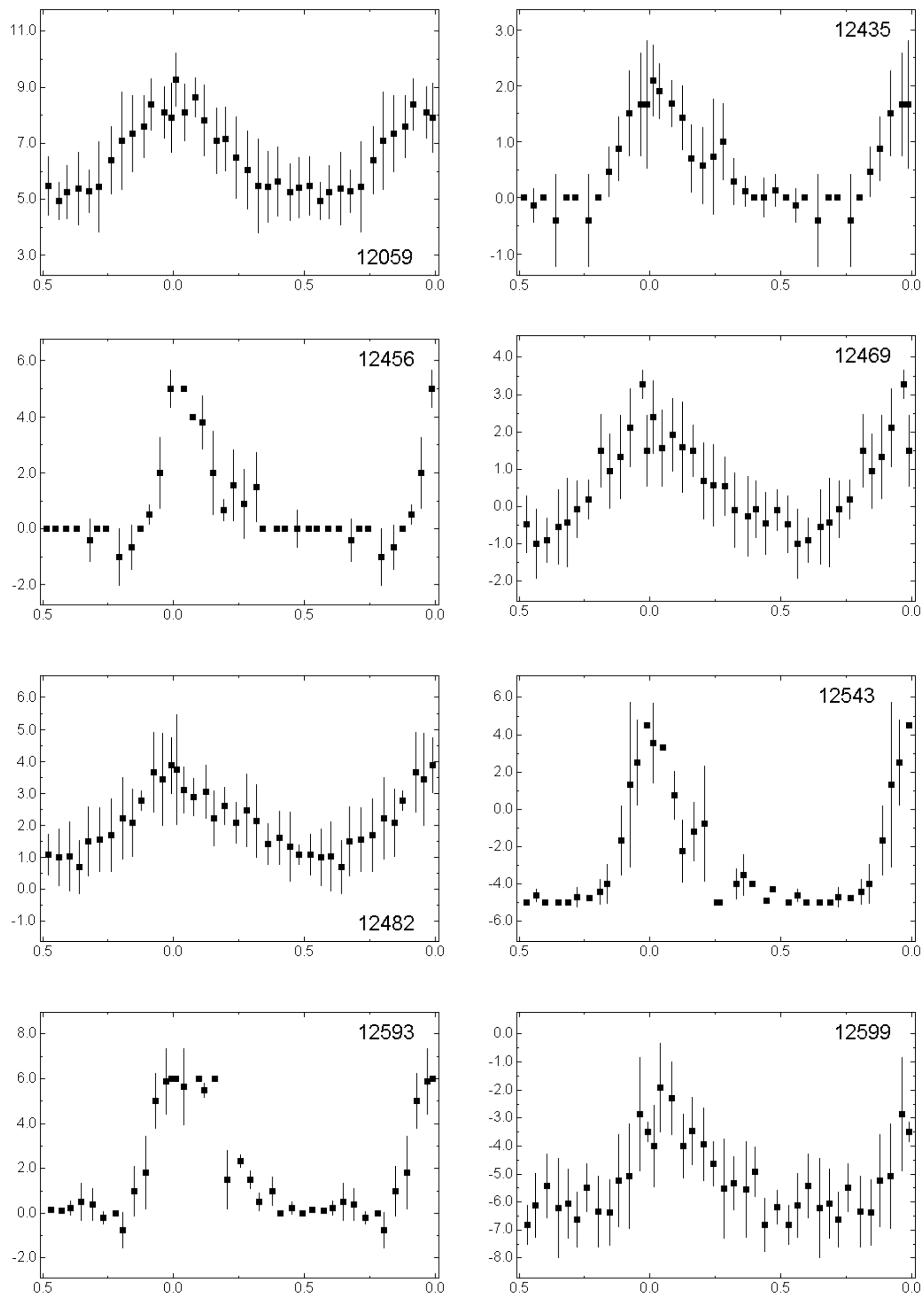

Figure 3. Folded light curves of the newly found Cepheids listed in Table 1 (cont.)

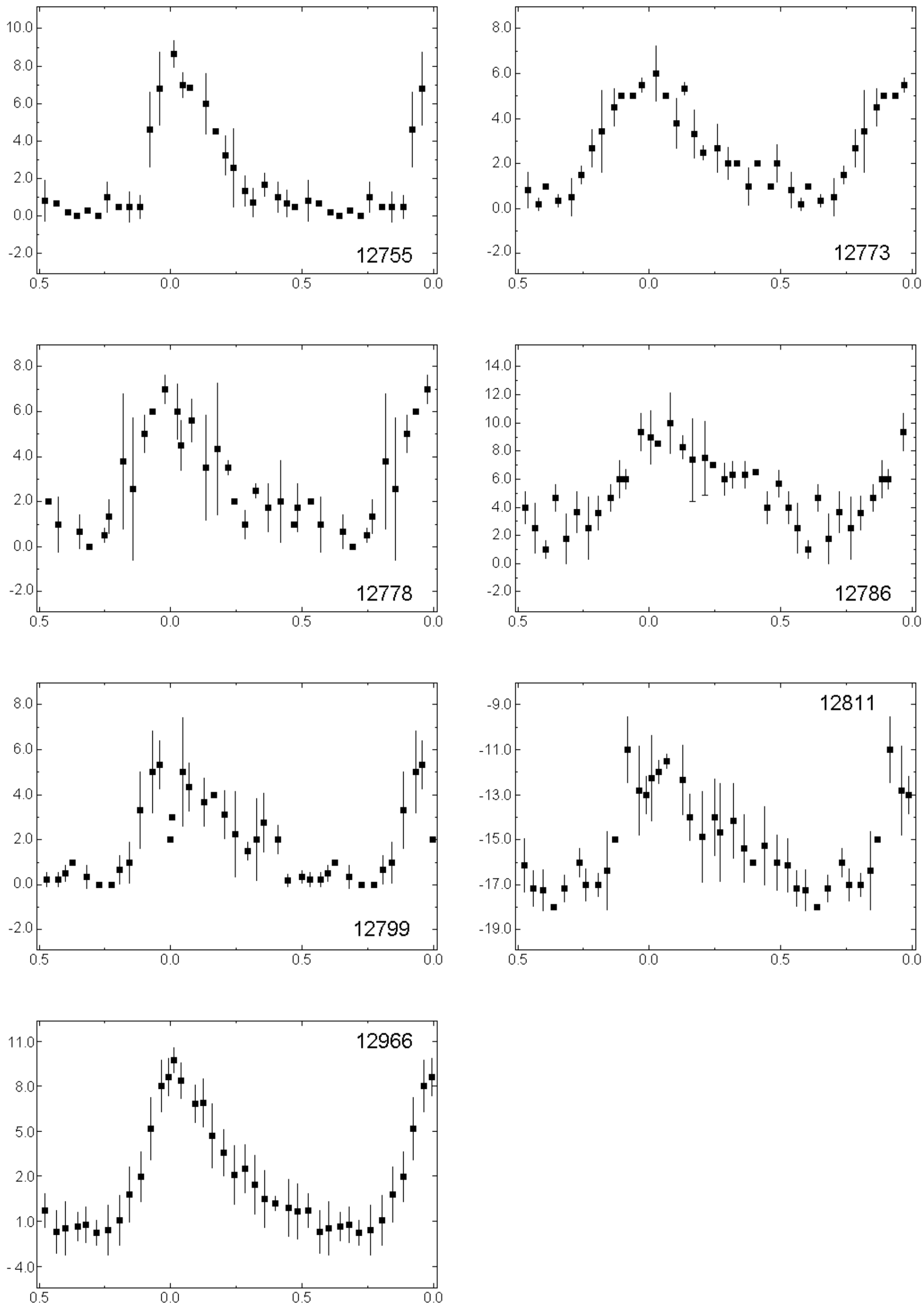

Figure 4. Folded light curves of the newly found Cepheids listed in Table 1 (cont.)

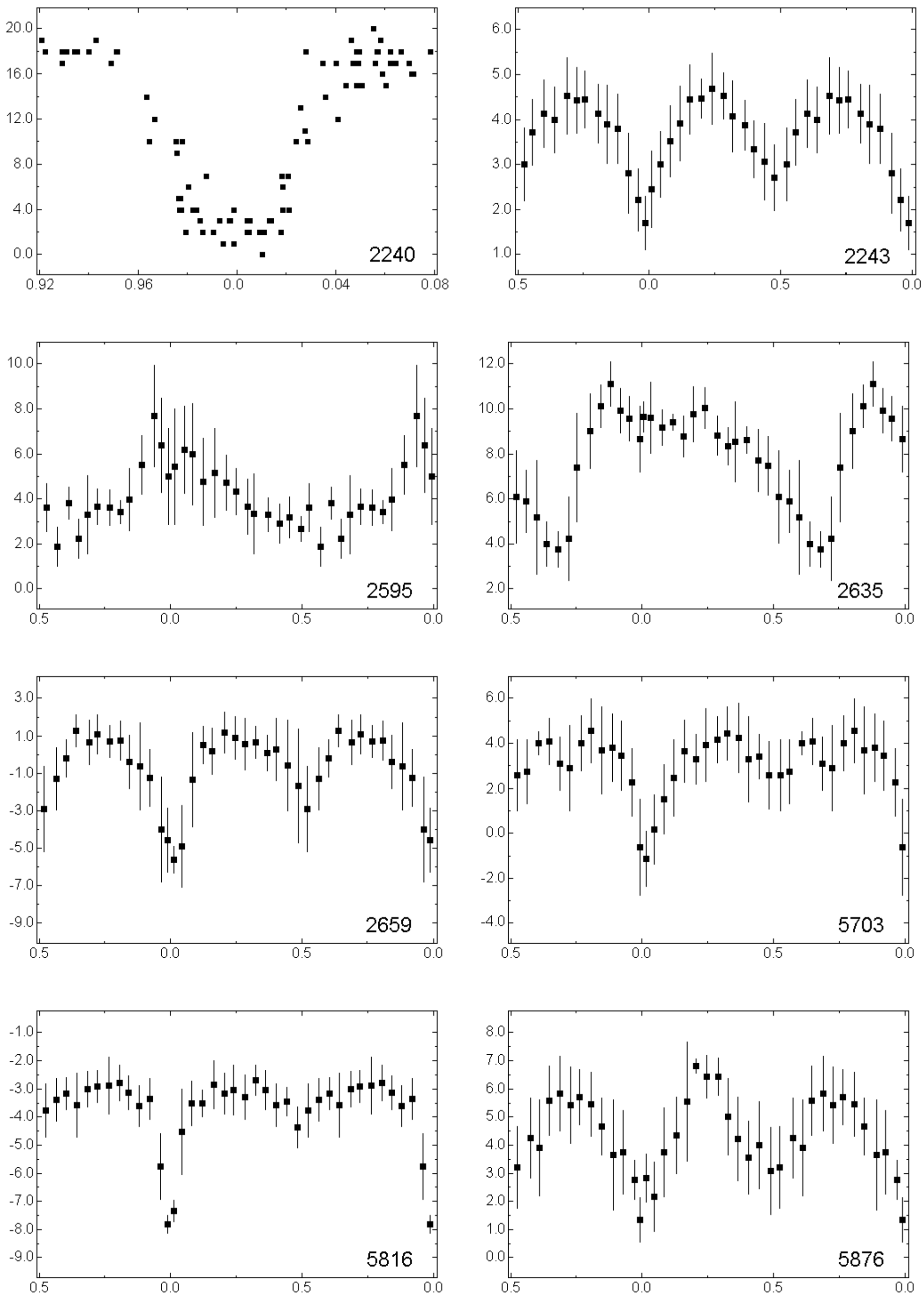

Figure 5. Folded light curves of eclipsing binary stars and other variables listed in Table 2

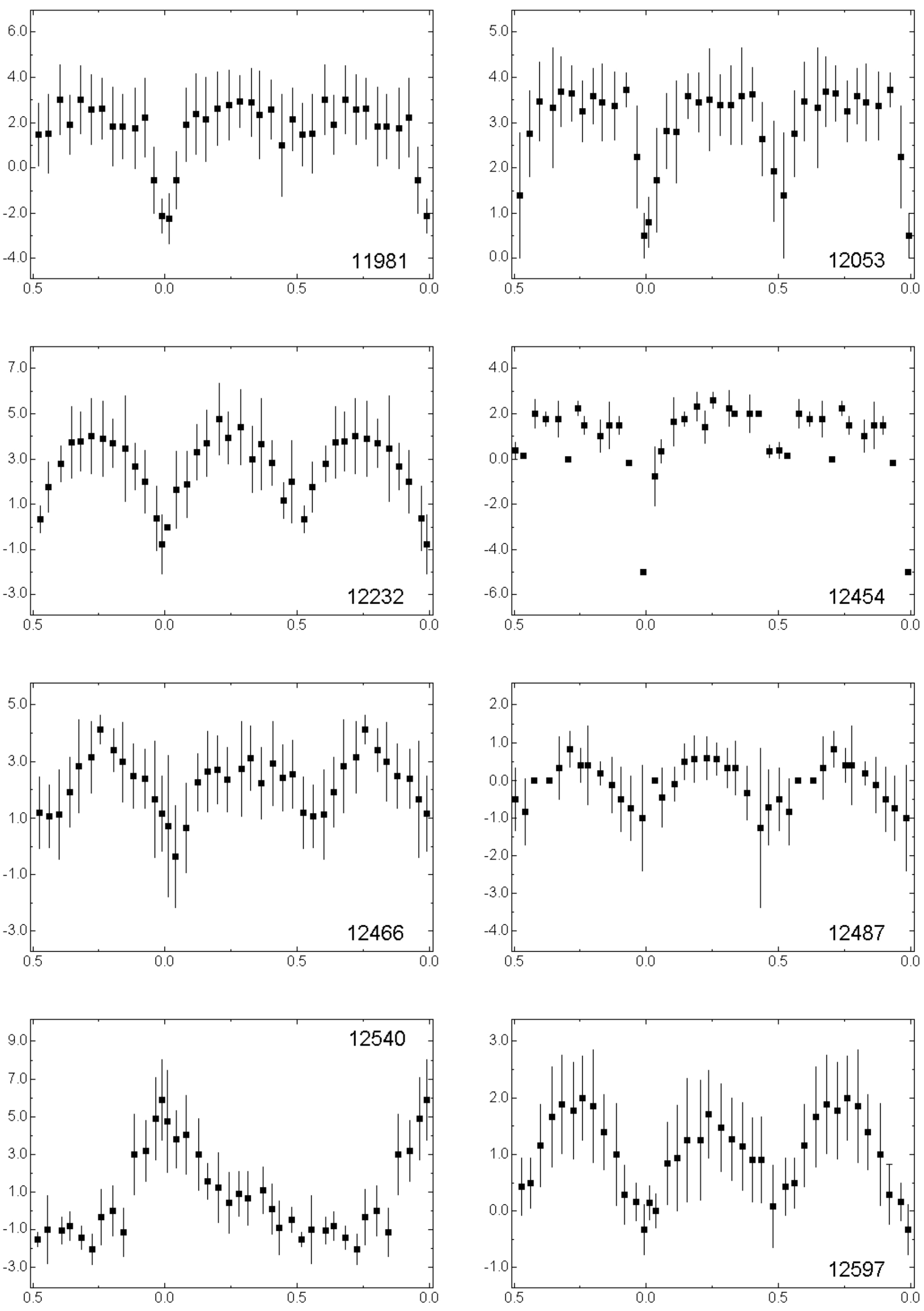

Figure 6. Folded light curves of eclipsing binary stars and other variables listed in Table 2 (cont.)

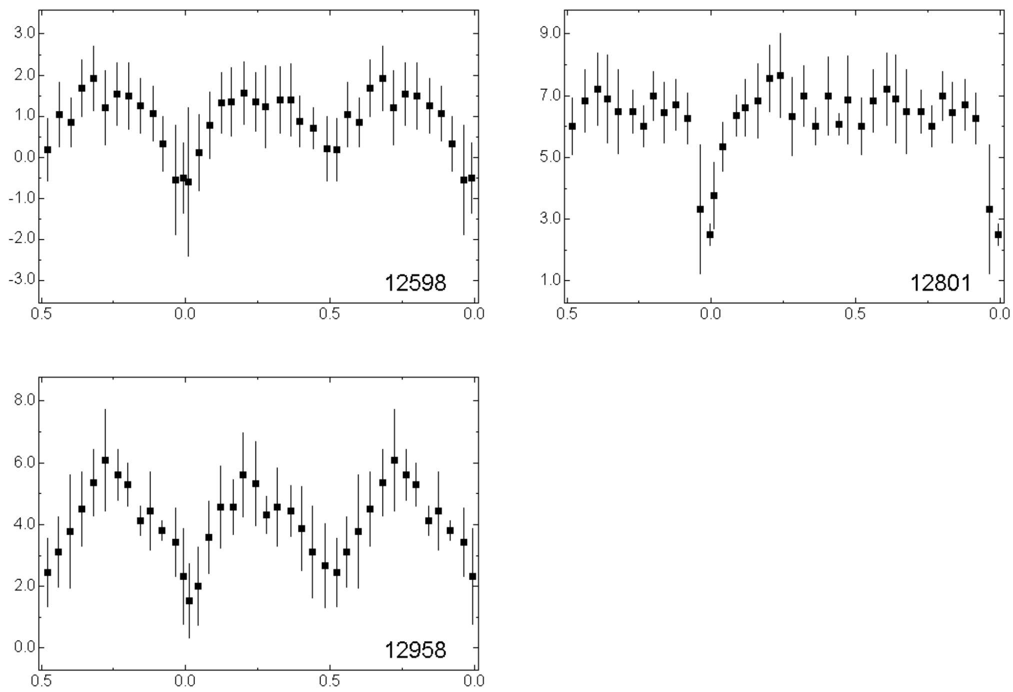

Figure 7. Folded light curves of eclipsing binary stars and other variables listed in Table 2 (cont.)

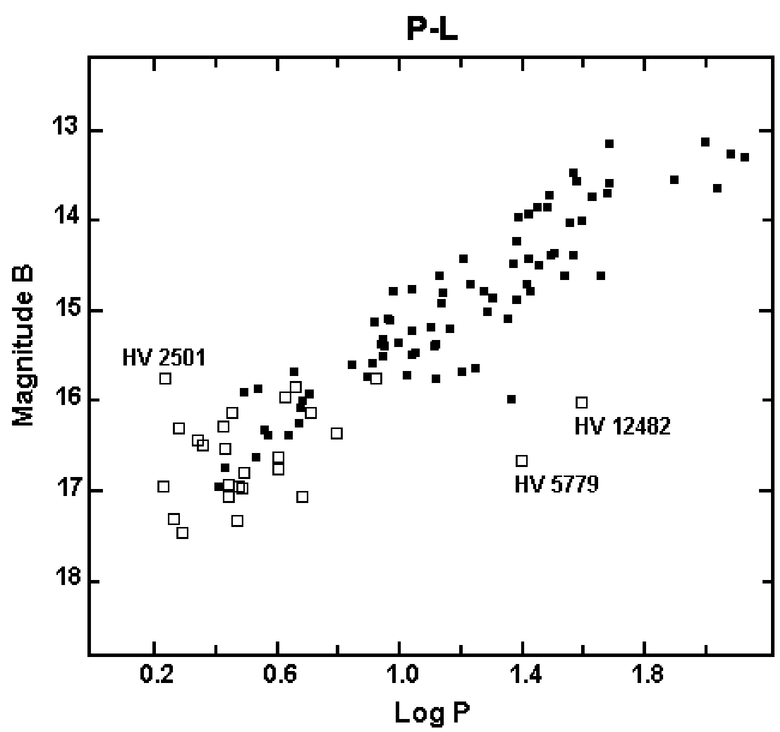

Figure 8. *P–L* diagram where open squares represent Cepheids listed in Table 1 and small solid squares Cepheids compiled by Madore (1985)

In Table 2 is HV 2240. Although this star was correctly characterised by Gaposchkin (1970) and Payne-Gaposchkin (1971) as an eclipsing binary, it is worth mentioning some new information obtained from the original photographic data set. Payne-Gaposchkin (1971) gives a period of 65.724613 days for this variable, but we found that data are better folded with a period of 65.702 days. In Figures 5–7 the light curve of HV 2240 is depicted around phase 0.0 showing that main eclipses are occultations. Butler (1978) supplied B and V data on this star but his photometric observations did not show a complete primary minimum, although they indicated that during the detected eclipses HV 2240 fades at least 2 magnitudes in V, and that the $B-V$ color index changes from 0.14 at maximum light to 0.72 at minimum. Even though the secondary eclipse does not appear in ours or Butler's light curve, these results strongly suggest that the secondary eclipse might be very shallow, and that the 65.7 day period is the real one.

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