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Period Variations of 99 Cepheid Variables

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Abstract: I evaluate times of maximum light of 99 cepheid variables from the times of discovery until about 2006 and give information on period changes. Annotated O-C diagrams are shown in the article BAVJ0074 “O-C Curves of 99 Cepheids” and can be used as a short summary of my findings on every single object.

The approximately 7000 maximum times the diagrams are based on are listed in the article BAVJ0073 “Maximum Times of 99 Cepheids” and will be part of the LcDB of the BAV.

Introduction BAV-Member and visual observer of bright Cepheids, I noticed that, contrary to the case of eclipsing binaries or RR-Lyr-stars, there were neither collections of older observations nor O-C-Diagrams available to compare my results with. I started to collect communications and scientific literature on my own since about 2001 and finally, in about 2004, came across the three works of the Hungarian Astronomer Szabados from ca. 1980 (Mitteilungen der Sternwarte der Ungarischen Akademie der Wissenschaften Nr. 70; Communications of the Konkoly Observatory of the Hungarian Academy of Sciences, Budapest, Nr. 76 and Nr. 77), essential for the present paper, but not covering some objects of my interest.

First cepheid type brightness variations have been discovered already in 1784. Studying the literature, I met with old techniques of observing as well as of reducing into a standard epoch and with various old conventions mystifying the modern reader. In the chapter on methods, I discuss the old methods and my way of dealing with them with the invariable intention to extract from the reports a time of maximum scaled in the way modern readers expect it, and to give each timing the weight it deserves taking into account its procedural shortcomings.

Methods: Since the middle of the 19th century astronomers knew that, on the one hand, the period of brightness variation of cepheids is so much shorter than those of Mira Stars that several days without observations can make a light curve unintelligible, and that, on the other hand, the period always is too long to be observed entirely in one night. Until the 1930ies (e.g., in the long discovery lists of Prof. Hoffmeister of Sonneberg), Cepheids were called "SPV" (short period variables) or German "kurzperiodisch" as opposed to the "LPV"s, the long period Mira Stars.

Until 1914 astronomers commonly reported Gregorian calendar dates and local times. The hour count started at mean noon and one day´s sunrise consistently was recorded to occur in the second half of the preceding day. I transformed such reports into Julian Day numbers and the Greenwich mean time familiar to modern readers and indispensable to create O-C-Diagrams.

The German astronomer Eduard Schönfeld (1828-1891) suggested to find in a scanty number of observations provisional maximum times with the help of template light curves. From several such provisional maximum times one could with mathematical procedures derive more refined periods, apply these to a greater number of observations covering many epochs, and finally find a "Normal" Maximum - a crucial methodical term for the Old. While 19th century visual observers published great numbers of provisional maximum times, published Normal Maximum times until 1920 are scarce. I extracted mean maximum times from groups of provisional times as well as from template curves given as tables matching phase counts with brightnesses. The Old applied similar methods to minima of Cepheid lightcurves and, with the help of M-m-values given in the publication, I transformed them into a maximum time. Such timings are in general of inferior quality and get weight 0/100. Only timings based on unreduced brightness reports and my own calculation of a maximum time deserve 10/100. I had no access to reports before 1860; such very early timings completely refer to Szabados papers, and, relying on Szabados´ examinations, I frequently gave them the weight 10/100.

About 1900 the first period of photographic surveys started, leading to many discoveries of new Cepheids in Harvard (Boston, USA), in Moscow (survey of Lydia Tserasskij), and by some others like the combined photographic and visual amateur observer Arthur S. Williams in England. The Harvard observers focussed on refining the template light curves by introducing "normal places", using a dubious mathematical procedure, which later was criticized and had to be dropped. Reference to a real time scale can be retrieved from earlier Harvard papers with substantial difficulties, as the authors do all they can to obscure such a reference by adopting start timings far outside the observing period, anchoring them on arbitrary phases of the lightcurve, calling the maximum light phase 0.5 and introducing reciprocals (of the period length). Omitting finally every mention of a real time scale, late Harvard reports of plate estimates around 1930 turn downright useless for period study.

On the other side of the Atlantic methodical development took a different and, for the purposes of period study, more appropriate direction: Several Dutch, German and Soviet authors left the template light curves and provisional maxima of the past behind and started to collect and publish great numbers of observations, covering many periods of one object´s brightness change. From these long communications, which a bystander might confuse with the page of a telephone directory, it is possible to derive en bloc "Normal" Maximum times. Though still using visual or photographic brightness estimates, such Normal times are much more assertive than the old provisional timings and generally get the weight 10/100 in my collection. Since the 1920ies photographic surveys reached fainter stars, namely in the Sonneberg department of the Potsdam Observatory in Germany and several observatories in Eastern Europe and the Soviet Union, infrequently also in Mount Wilson near Los Angeles or South African sites, while Harvard withdrew.

Amateurs of these times and less equipped professionals in distant but southern parts of the Soviet Empire combined many observations to one single maximum time and produced first class (10/100) results. During the same time, work with photoelectric equipment started.

In the USA, it resulted in the discovery of new Cepheid Variables by inadvertantly taking them as comparison stars, while there and in Germany first photoelectric examinations of bright and long known Cepheids appeared. From the very beginning, photoelectric observers published every single brightness measurement. All Maximum timings I derived from such photoelectric series and all photoelectric timings taken from the Szabados papers get the weight 100/100.

My collection has only few objects whose variability was discovered after 1950. Soon exclusively using photometry in the western hemisphere, while Soviet astronomers had to resign themselves to photography for a long time, research constantly proceeded to ever fainter stars unsuitable for amateur observers. Amateur observers of these times preferred to report single estimates to databases, but, contrary to the profit of such databases for the study of other types of variables, the greatest part of their entries on long known cepheids had nothing in them displaying any similarity to a cepheid brightness variation and proved to be useless. Other contemporary amateurs confined themselves to collecting only some 30 brightness estimates with consequent bad coverage of the crucial parts of the lightcurve, i.e. the ascending branch and the maximum, and applied too simplistic methods to establish a time of maximum brightness in their data sets. Such observations get the weight 10/100 only when I could review the single observations and find a maximum time of my own.

I attributed three possible weights to every single of my Maximum timings, which I used in the calculation of ephemerides and rates of period change. They appear as leads in the last column of entries in the LcDB, followed by the observer's name and the reference. All photoelectric or CCD results get 100/100, photographic or visual ones get 10/100 only, if of premium quality (see above), otherwise 0/100. In the German texts in the O-C diagrams near the ephemerides, I give the reference, which may be "unpubliziert" meaning "this paper".

The Maximum times of this collection generally cover the space between the year of discovery of brightness variability of an object and about 2006. The circumstances of discovery can be taken from the O-C diagrams in paper BAVJ0074, “O-C Curves of 99 Cepheids” or from the headnotes to paper BAVJ0073, “Maximum Times of 99 Cepheids”. Thanks to the exhaustive work of the Hungarian Astronomer Szabados, the data should be rather complete for the years before 1980. After this year, an increasingly great number of professional publications of single brightness measurements and measurements by automatic sky surveys will be missing due to my limited access to an up to date scientific library, most of all, though, to my inefficient and troublesome internet connection until the termination of the work in 2006.

Results: I collected 90,000 raw data (single observations or measurements) and ca. 7000 times of maximum light on 99 cepheid variables and built O-C diagrams. I did not perform further calculations if the diagram displayed no evidence of a continuous (secular) period change. If there was such evidence and the points of the diagram could be approximated by a parabola, I calculated by a least squares fit the quadratic term of a second-order parabola and a mean error (±1s). I finally transformed the value of this term into a rate of change scaled in seconds/year.

Table 1 lists cepheids with a continuous period change, and table 2 those without a period change. Table 3 compiles the erratic results of my investigations. All W Virginis (CWA) objects of my collection (PZ Aql, TW Cap, IX Cas, AP Her) show strange O-C diagrams with conspicuous, irregular period changes. Finally, some diagrams (FN Aql, RT Aur, RX Aur, Y Lac) display sinusoidal arrangements of the residuals. These residuals are generally small (<1/20 of the period) and hard to establish, even considering only photoelectric observations.

Table 1: Continuous period change

+ Continuous period increase positive parabola			- Continuous period decrease negative parabola		
22 stars - most positive rates first			13 stars - most negative rates first		
Star	period (days)	rate of change (seconds/year)	star	period (days)	rate of change (seconds/year)
BM Per	22,96	+ 17 ± 6	SV Vul	44,93	-245 ± 10
T Mon	27,04	+ 12 ± 2	VX Per	10,88	- 12,8 ± 0,3
CH Cas	15,09	+ 11 ± 3	RW Cas	14,79	- 11,1 ± 0,9
RU Sct	19,71	+ 10,3 ± 1,0	zet Gem	10,15	- 3,3 ± 0,2
CP Cep	17,86	+ 10,2 ± 0,8	W Gem	7,91	- 1,7 ± 0,2
Y Oph	17,13	+ 9,9 ± 0,8	AO Aur	6,76	- 0,9 ± 0,2
X Pup	25,97	+ 8 ± 2	RZ Gem	5,53	- 0,89 ± 0,08
SZ Aql	17,14	+ 5,3 ± 0,8	VV Cas	6,21	- 0,83 ± 0,09
CD Cyg	17,07	+ 5,2 ± 0,8	V Lac	4,98	- 0,82 ± 0,04
SV Mon	15,24	+ 3,7 ± 0,4	VZ Cyg	4,86	- 0,35 ± 0,06
TX Cyg	14,71	+ 3,3 ± 0,3	CS Ori	3,89	- 0,3 ± 0,1
RY Cas	12,14	+ 2,6 ± 0,4	T Vul	4,44	- 0,25 ± 0,05
VX Cyg	20,13	+ 2,5 ± 1	del Cep	5,37	- 0,091 ± 0,006
TY Sct	11,05	+ 1,7 ± 0,3			
Z Sct	12,90	+ 1,3 ± 0,4			
SY Aur	10,14	+ 1,1 ± 0,3			
SV Per	11,13	+ 1,1 ± 0,2			
TT Aql	13,75	+ 1,0 ± 0,2			
U Aql	7,02	+ 0,35 ± 0,07			
SY Cas	4,07	+ 0,28 ± 0,03			
eta Aql	7,18	+ 0,25 ± 0,02			
RR Lac	6,42	+ 0,14 ± 0,08			

The maximum times of TX Cyg, T Mon, SV Mon, Y Oph, and SV Vul in fact are arranged in polygonal patterns, which only slightly resemble a parabola and should be approximated by more complicated functions or by a set of straight lines. Nevertheless, there is a secular period change, which clearly always goes in one direction (increase or decrease) and is superseded by higher-order variations. In the diagram, these variations distort the smooth standard parabola. The rate values given in table 1 on these stars can be used to estimate the global rate of period change.

Table 2: Constant period

50 stars (GCVS sorting)								
star		period (days)	star		period (days)	star		period (days)
V493	Aql	2,99	CF	Cas	4,88	RS	Ori	7,57
Y	Aur	3,86	CG	Cas	4,37	GQ	Ori	8,62
FF	Aql	4,47	CY	Cas	14,38	UY	Per	5,37
FM	Aql	6,11	AK	Cep	7,23	VY	Per	5,53
V600	Aql	7,24	X	Cyg	16,39	AS	Per	4,97
YZ	Aur	18,19	SU	Cyg	3,85	AW	Per	6,46
BK	Aur	8,00	SZ	Cyg	15,11	S	Sge	8,38
RW	Cam	16,42	VY	Cyg	7,86	Y	Sgr	5,77
RX	Cam	7,91	BZ	Cyg	10,14	XX	Sgr	6,42
CK	Cam	3,29	V459	Cyg	7,25	AY	Sgr	6,57
RY	CMa	4,68	AA	Gem	11,30	SS	Sct	3,67
TV	CMa	4,67	Z	Lac	10,89	CM	Sct	3,92
TW	CMa	7,00	BG	Lac	5,33	ST	Tau	4,03
SU	Cas	1,95	TZ	Mon	7,42	U	Vul	7,99
SW	Cas	5,44	AC	Mon	8,01	X	Vul	6,32
UZ	Cas	4,26	BE	Mon	2,71	DG	Vul	13,61
CD	Cas	7,80	CV	Mon	5,38			

Table 3: Period change other than continuous
(cyclic, chaotic etc.)

14 stars (GCVS sorting)			
star		period (days)	remark
FN	Aql	9,48	constant period; possibly cyclic pattern of the residuals
PZ	Aql	8,76	few data; irregular period changes
RT	Aur	3,73	many good data; small cyclic or irregular period variations
RX	Aur	11,62	cyclic pattern of the residuals
TW	Cap	28,6	conspicuous irregular period changes
TU	Cas	2,14	atypical pulsation; constant basic period
IX	Cas	9,15	conspicuous irregular period changes
DT	Cyg	2,50	small irregular or cyclic pattern of the residuals
V532	Cyg	3,28	considerable irregular period changes
AP	Her	10,4	conspicuous irregular period changes
X	Lac	5,44	irregular period changes
Y	Lac	4,32	constant period; possibly cyclic pattern of the residuals
GY	Sge	51,59	late discovery, few data; general rate of period increase possibly larger than +1000 sec/year
S	Vul	68,00	early discovery, many data; irregular fluctuations, rate of general period increase larger than +300 sec/year

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Sternwarte, Prof. Norbert Przybilla opened for me the historical part of Bamberg Observatory library, which is excellently equipped with older scientific papers and periodicals so essential for this work, and furnished me with one of the most remarkable publications used here, a late 19th century astronomical PhD Thesis. The office clerk of the observatory, Mrs. Day provided for it, that after having spent a complete day in the library I could make my way home with a bag full of photocopies. The centre of this paper are the more than 100 diagrams and the extensive 7000-entries list, compiled in the era of 3,5-inch-discs by a person (that is me) only perfunctorily familiar with the computing techniques of the early 2000 years, even less with those of database construction. Consequently present day chairman of the BAV and editor of its publications, Prof. Lienhard Pagel had much work to reorganize them in a way, that they can be read and searched with today´s electronic devices.