Multiple Periodic Variable Stars
IAU Colloquium No.29, Budapest, 1975

MULTIPLE PERIODIC RR LYRAE STARS
OBSERVATIONAL REVIEW

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Introduction

In this review paper I concentrate exclusively on the multiple periodic RR Lyrae stars and I do not wish to discuss the general problems of cluster variables. There are some excellent review papers on them (e.g. Preston, 1964).

The majority of the RR Lyrae stars repeat their light curves from cycle to cycle with astonishing regularity. It was, however, discovered already in the early days of variable star research that some of them showed conspicuous changes in the height of maxima of their light curve and simultaneously the time of maxima could not be fitted in by a linear formula.

Almost 70 years ago, Blazhko (1907) was the first who observed the possible periodic variations in the time of maxima of a short periodic cepheid variable. In the case of RW Dra (87.1906) he found that no constant period could satisfy the time of maxima and one had to postulate periodic changes in the fundamental period with a secondary period of 41.6 days. Later Blazhko carried out further studies on RR Lyrae type stars (Blazhko 1925, 1926) and found that XZ Cygni changed its light curve from cycle to cycle with a secondary period of 57.39 days.

One of the first remarks that the maximum light of some of the RR Lyrae stars might not be constant at different epochs comes from Sperra (1910). Curiously enough he stated that SU and SW Draconis were showing the effect, whereas modern photoelectric observations do not reveal any light curve variation concerning these two stars.

The striking changes in the maxima of the light curve of RR Lyrae which turned out to be periodic was first stated by

Shapley (1916) some 60 years ago. In his fundamental work Shapley wrote: "There can be no doubt that a real irregularity is present. An attempt was made to find a uniform period for the variations that would satisfy all the observations. This failed in part, perhaps because of insufficient data, but it seems that for the whole series the oscillation is roughly periodic with a varying amplitude" He obtained a secondary period of 40 days and an amplitude of 37 minutes for the time oscillation of the median magnitude of the ascending branch of RR Lyrae. These results were perfectly confirmed by Hertzsprung (1922).

Since Blazhko was the very first who demonstrated that the changes in the short periodic light curve could be satisfied by a longer period we usually refer to these periodic variations of the light curve as "Blazhko-effect".

Although many astronomers assailed the problems of multiple periodic RR Lyrae stars during the past 50 years we are still far from solving them. Some excellent papers (Detre 1956, 1962, Klepikova 1956, 1957, 1958, etc.) summarizing the observational results on multiple periodic RR Lyrae stars appeared during the past 20 years. I do not wish to reproduce them, therefore I would like rather to speak about some problems till now not yet discussed and some new observational results.

The first question I deal with is the frequency of multiple periodic RR Lyrae stars.

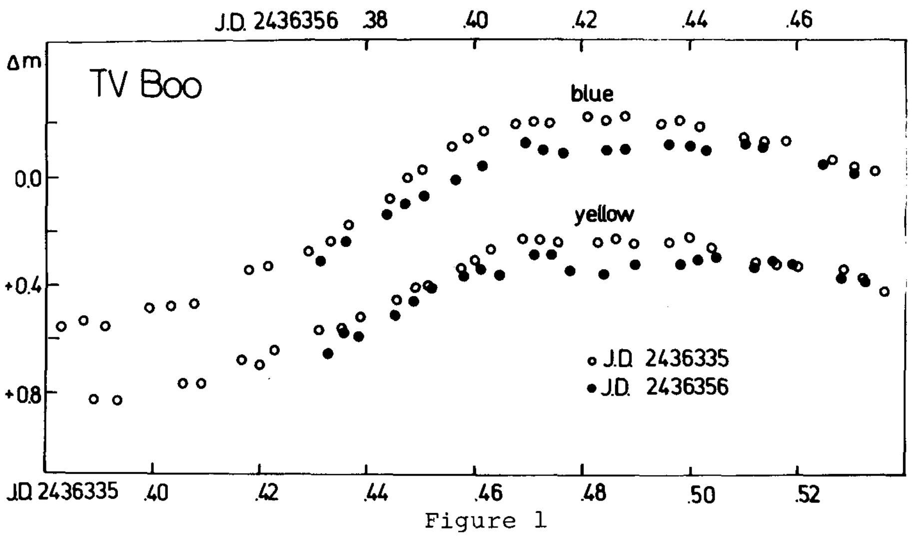

Figure 1

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The Frequency of RR Lyrae Stars with Blazhko-effect

Nearly 6000 RR Lyrae stars are listed in the Third Edition of the GCVS and its first and second supplements. We find, however, references to Blazhko-effect only in about 120 cases. It would mean that about 2% of the RR Lyrae stars would have Blazhko-effect. But it is obvious that a statistical investigation of this kind cannot be based on the very inhomogeneous data of the GCVS. In many cases, especially for RR Lyrae stars fainter than 13 magnitudes, the light curve variation remains unnoticed, while on the contrary it may also happen that the large scatter of the observations on the light curve due to observational errors in reality is inadvertently attributed to Blazhko-effect.

The discovery of any variations in the light curve of an RRc type star encounters special difficulties. The changes in the height of maximum are usually small and so accurate photoelectric observations can only settle the question whether an RRc-star has Blazhko-effect or not. Taking into account the observational difficulties mentioned as regards RRc type variables, at present we can only hope that a reasonable estimate might be only given for the frequency of RRab stars with Blazhko-effect.

All the RRab stars with known secondary period are listed in Table 1. The stars are arranged according to the length of the fundamental period, P_O. P_B denotes the length of the secondary period often referred to as Blazhko-period.

In RR Gem the Blazhko-effect ceased to exist around 1940. The same happened in SW And about 1956. Photoelectric observations obtained at the Konkoly Observatory since that time have only shown variations of the hump on the ascending branch of the light curve of SW And. These changes seem to be periodic.

I left out from the list some frequently mentioned RR Lyrae stars with alleged Blazhko-effect. These are XX And, AT And and AN Ser. Our photoelectric observations made during the past 10-15 years have not revealed any light curve variations of

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these stars.

Now we can turn again to the problem of the frequency of the RRab stars with Blazhko-effect. The paper by Fitch et al. (1966) presents a fairly homogeneous and well-observed sample of RR Lyrae stars. Fifteen of the 90 RRab variables of Fitch et al. are also included in my list (Table 1). They definitely show the Blazhko-effect or used to show it (SW And and RR Gem).

So thus we can state with certainty that about 15-20% of the field RRab variables show light curve variations.

Table 1

RRab Lyrae Stars with Blazhko-effect

Star	P_o	P_B	ΔS	References
RS Boo	$0^d.377$	537^d	2	Oosterhoff BAN 10.101
RR Gem	.397	37	3	Budapest, unpublished
MW Lyr	.398	33.3		Mandel,Per.Zvezdy 17.335
SW And	.442	36.8	0	Balázs,Detre Bp.Mitt.36
RW Dra	.443	41.7	3	Balázs,Detre Bp.Mitt.27
RV Cap	.448	225.5	6	Tsessevich,Astr.Circ.757
TU Com	.461	75		Ureche,Babes-BolyaiStud. Jasc.1.73
TZ Cyg	.466	57.3	6	Muller, BAN 12.11
RV UMa	.468	90.1	8	Preston,Spinrad,Ap.J.147. 1025
AR Her	.470	31.6	6	Almár, Bp.Mitt.51
XZ Dra	.476	78	3	Batyrev,Per.Zvezdy 10.292
X Ret	.492	45:	3	Hoffmeister,Ver.Sonn.5.3.1
V674 Cen	.494	29.5:		Hoffmeister,Ver.Sonn.5.3.1
RZ Lyr	.511	116.7	9	Romanov, IBVS 205
V434 Her	.514	26.1		Rozovsky,Per.Zvezdy 15.211
SW Psc	.521	34.5		Ureche, IBVS 532
Y LMi	.524	33.4		Martynov, Eng.Bull.18
SZ Hya	.537	25.8	6	Kanyó, IBVS 490
UV Oct	.543	80:	9	Hoffmeister, Ver.Sonn.5.3.1
RW Cnc	.547	29.9		Balázs,Detre,Bp.Mitt.23
TT Cnc	.563	89	7	Szeidl, IBVS 278
RR Lyr	0.567	40.8	6	Preston et al.Ap.J.Supp.12.99

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Table 1 (cont.)

Star	P_o	P_B	ΔS	References
AR Ser	$0^d.575$	105^d	8	Szeidl, IBVS 220
DL Her	.572	33.6	6	Szeidl, IBVS 36
V365 Her	.613	40.6		Tsessevich, Astr.Zh.38.293
Z CVn	0.654	22.7	8	Kanyó, IBVS 146

Table 2

RRc Lyrae Stars with Blazhko-effect

Star	P_o	P_B	ΔS	References
TV Boo	$0^d.313$	$33^d.5$	8	Detre, Astr.Abh.Leipzig, 1965
BV Aqr	.364	11.6		Tsessevich, Vistas in Astr. vol.13
RU Psc	0.390	28.8	7	Tremko, Bp.Mitt.55

From Table 1 we can also see that the RR Lyrae stars with Blazhko-effect generally have rather low metal abundance. A rough estimate results in the following frequency of multiple periodic field RR Lyrae stars depending on metal abundance:

10% if ΔS=0-2; 20% if ΔS=3-5; 30% if ΔS=6-10

By studying the period changes of RR Lyrae stars Tsessevich (1972) came to the conclusion that "stars with shortage of calcium are characterized by the instability of their pulsations". His result may be connected with the previous statement.

In connection with the ceasing of the Blazhko-effect in SW And and RR Gem (and perhaps in XX And, AT And and AN Ser?) some interesting questions arise. Whether the starting of Blazhko-effect in an RR Lyrae star may happen more than once or all RR Lyrae stars inevitably become multiple periodic at least once during their life when observed with sufficient precision or for long enough intervals of time? Balázs-Detre and Detre (1962) have commented that probably there is no sharp distinction between single and multiple periodic variables. These questions cannot be answered at present. I must, however, emphasize that we have not yet observed commencement of the Blazhko-effect in an RR Lyrae star. Special attention should be paid to the RR Lyrae stars in globular clusters if we investigate the frequency of multiple periodic RR Lyrae stars. One of the best obeserved cluster is Messier 3, (Szeidl 1965, 1972). From the 105 well-observed RRab stars 36 show light curve variations, i.e. 35% of the variables. In Table 3 are given the frequency distribution according to period. The highest frequency occurs around P=0.56.

Table 3

P ±0.015	all	with Blazhko-effect	%
0.47	8	3	37.5
0.50	24	8	33.3
0.53	26	10	38.5
0.56	15	8	53.5
0.59	16	4	25.0
0.62	7	2	28.6
0.65	6	1	16.7
0.68-	3	0	0

The investigation of cluster variables in M15 has led to similar results. In this cluster the frequency of RR Lyrae stars with Blazhko-effect is about 25% /Barlai, 1975/.

The higher frequency of RRab stars with Blazhko-effect in clusters is well understandable and is in good agreement with the fact that this kind of RRab stars in the field are more frequent among the metal poor stars.

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Characteristics of Multiple Periodic RR Lyrae Stars

It was an open question for a long time whether RRc-type stars could have Blazhko-effect or not. Nevertheless it has been known that the light curve of some of them is unstable. Especially photoelectric measurements showed this phenomenon clearly. As an example I mention the RRc type variable T Sextantis for which Tifft and Smith (1958) found definite light curve variation particularly at maximum and around the hump.

Now we definitely know three RRc stars with periodic changes of their light curves (see Table 2). One of them is TV Bootis. It was invesitgated by Detre (1965) who found its secondary period to be 33.5 days. Figure 1. shows the two extreme forms of maxima in yellow and blue light. The hump is very pronounced if the maximum is fainter. The amplitude of the variation in the brightness of the maximum is 0.12 magn. in blue and 0.09 magn. in yellow light while the oscillation of the ascending branch is only $0^{d}.01$. These data indicate that the changes are small and can only detected by photoelectric observations.

Ten years ago or so Tremko (1964) analyzed the long series of observations of RU Psc. He was able to construct the O-C diagram of the star which shows that the fundamental period of RU Psc has undergone very rapid and complicated changes. The variation in its light curve is also small and is similar to that of TV Boo. Tremko derived a secondary period of 28.8 days for RU Psc.

The third known RRc star which shows Blazhko-effect is BV Aqr. Tsessevich obtained a secondary period of 11.6 days for this star. This value is the shortest secondary period ever observed for an RR Lyrae star.

Generally the RRab stars with Blazhko-effect show large changes in their light amplitudes. At present we know 27 RRab stars with secondary periods (Table 1). About half of them are thoroughly investigated (see e.g. Almár 1961, Klepikova, Balázs and Detre 1943, 1950, 1952, 1957) I do not wish here to speak of all of them in detail, I should like only to stress some points I think to be important.

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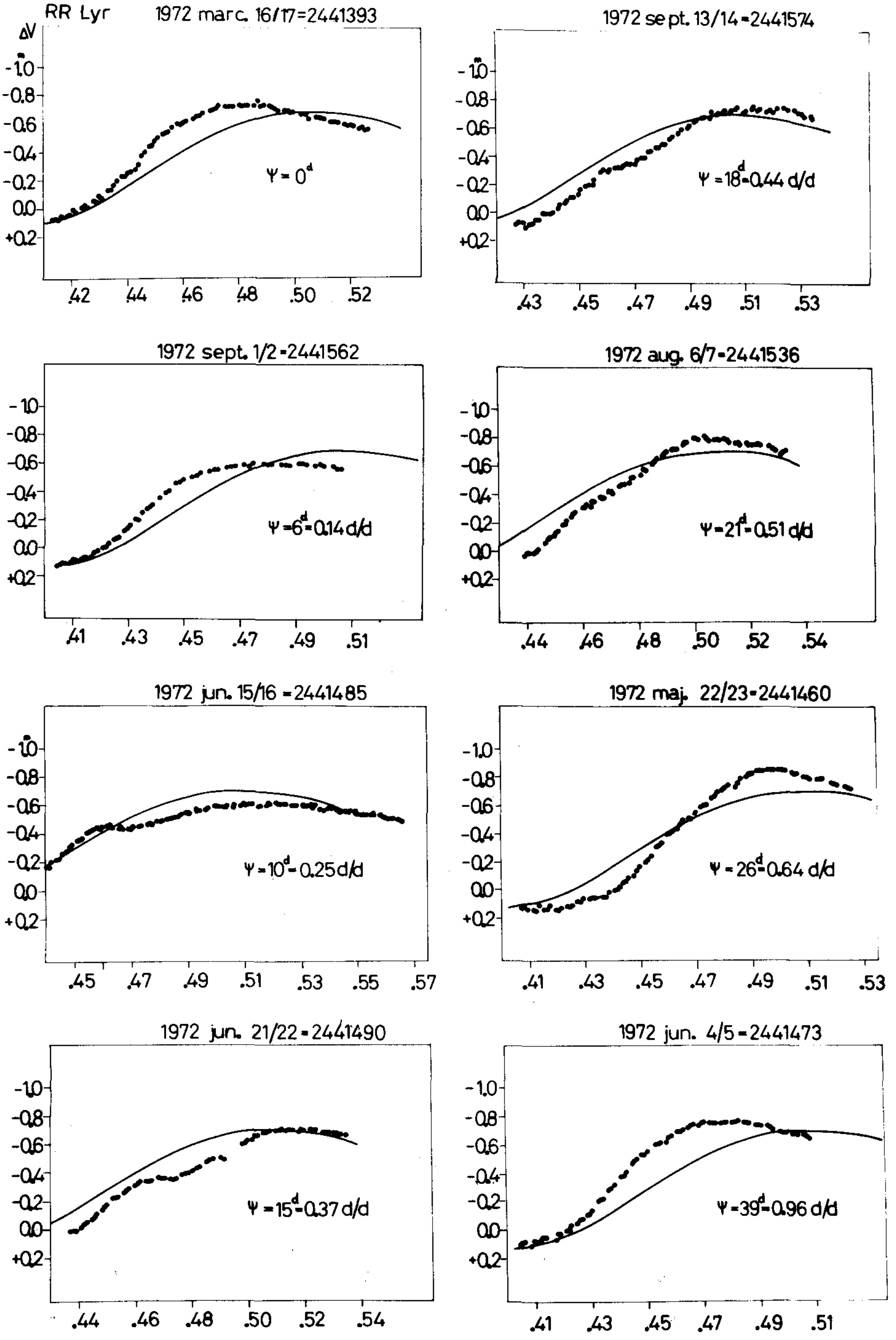

Figure 2

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It is remarkable that a part of the ascending branch of the light curve appears to be substantially constant in time and phase at different phases of the secondary period. If the secondary period is relatively short, this constant part occurs on the lower portion of the ascending branch and the phase variation is greatest at maximum (e.g. RW Cnc). If the secondary period is relatively long, the time oscillation of the lower portion of the rising branch has a fairly large amplitude (e.g. XZ Dra) (Detre, 1962). All this is, however, not a general rule. RR Lyrae itself is the brightest known of the cluster type variables having Blazhko-effect and therefore specially fits for detailed investigation. From Figure 2 we can get a rough idea how the light curve, the maximum, the hump and steepness of the ascending branch change and develope during the secondary cycle. In the Figure, 8 diagrams are given showing our separate photoelectric observations of the ascending branch of the light curve and the adjacent minimum and maximum on different nights at different ψ phases of the secondary period. For comparison the mean light curve has been drawn on each diagram. The light curves show the usual particulars of stars of this kind.

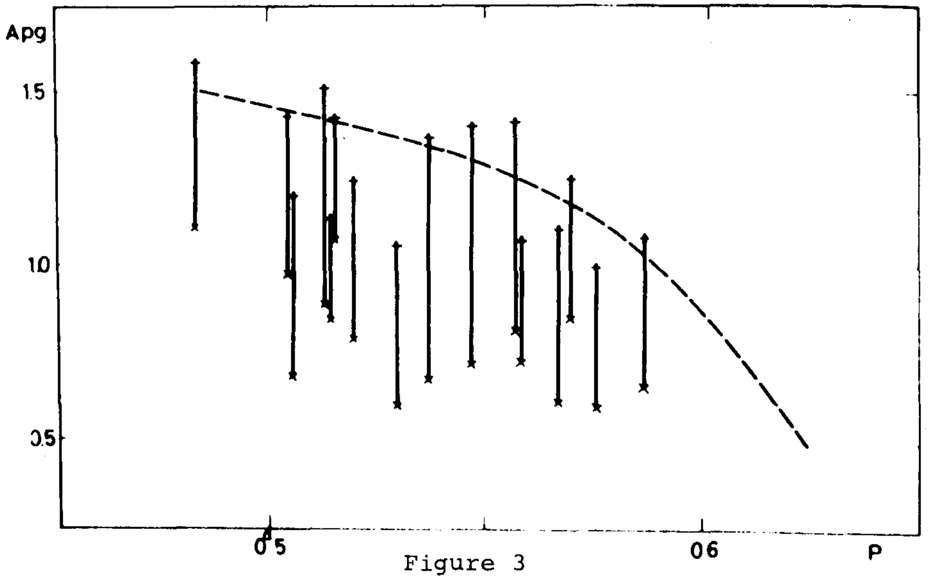

Figure 3

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In the same star, different cycles of the Blazhko-effect differ in length and amplitude as was first shown by Walraven (1948) for RR Lyr itself. In some cases (e.g. RW Cnc) these differences between successive cycles are especially striking. Attempts were made at representing these variations by longer periods of several months but they were not succesful. The reality of the reported additional periods of RR Lyrae and other variables were challanged (Detre, Balázs-Detre 1962). I am of the opinion that these variations are not periodic.

Sometimes the Blazhko-effect undergoes considerable changes. The most interesting common feature of all the RRab stars with Blazhko-effect is, however, that during these considerable changes the brightness of the highest maximum remains substantially constant while the lowest maximum varies (e.g. Almár, 1961). This result is in accordance whit that obtained for RR Lyrae stars in Messier 3. Figure 3 shows that the greatest amplitudes of variables with Blazhko-effect fit the period-amplitude relation valid for RR Lyrae stars with stable light curves. In some cases the greatest amplitude is below the expected value, probably because only smaller amplitudes have been observed at Budapest.

Figures 4 a,b,c show the variations of brightness and phase of maximum light of RR Lyrae in the years 1972, 1973 and 1974, respectively. Along the loops the corresponding phases of the secondary period are also given. The form of the loops changes insignificantly in the course of time.

In Figures 5 a-e the brightness variation and phase oscillation of the maxima of the light curves are separately plotted against the phase Ψ of the secondary period for some RR Lyrae stars with Blazhko-effect. It is immediately conspicuous that the phase shift $\Delta\Psi$ between the highest and the most positive shifted maximum is characteristic of multiple periodic RR Lyrae stars. Table 4 gives the $\Delta\Psi$ values of some RR Lyrae stars with Blazhko-effect. I am unable to find any connection between $\Delta\Psi$ and the fundamental or secondary period.

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Figure 4

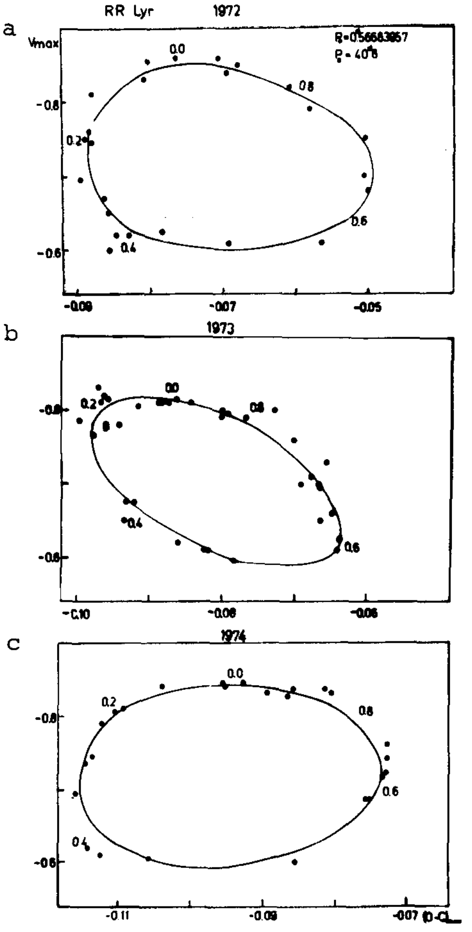

Table 4

star		ΔΨ	star		ΔΨ
RW Cnc	$+15^{d}$:	= +0.50	DL Her	+ 5	= +0.15
TT Cnc	+11	= +0.12	SZ Hya	+ 4.9	= +0.19
Z CVn	0	= 0.00	RR Lyr	+14.5	= +0.30
AR Her	+ 6.3	= +0.20	AR Ser	+52	= +0.49

The most interesting result on the Blazhko-effect of RR Lyrae was obtained in the last few years. At the 1968 Variable Star Colloquium Detre (1969) presented a figure based on our photoelectric observations representing the phase variation of the median brightness on the rising branch and the variation in the height of the visual maximum of RR Lyrae in the course of the 41-day secondary cycle from year to year between 1962 and 1968.In 1963 and 1967

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Figure 5a

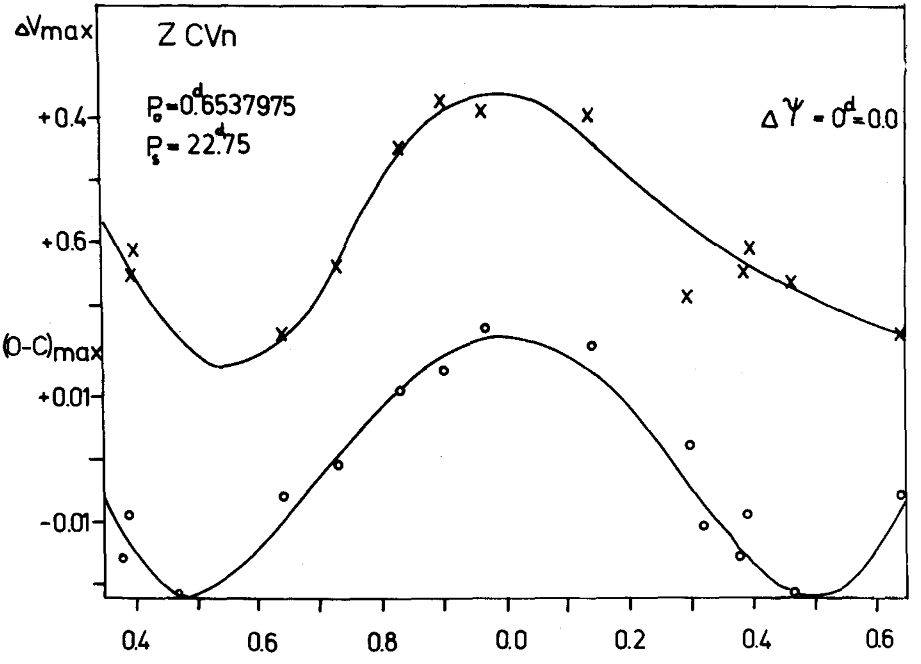

Figure 5b

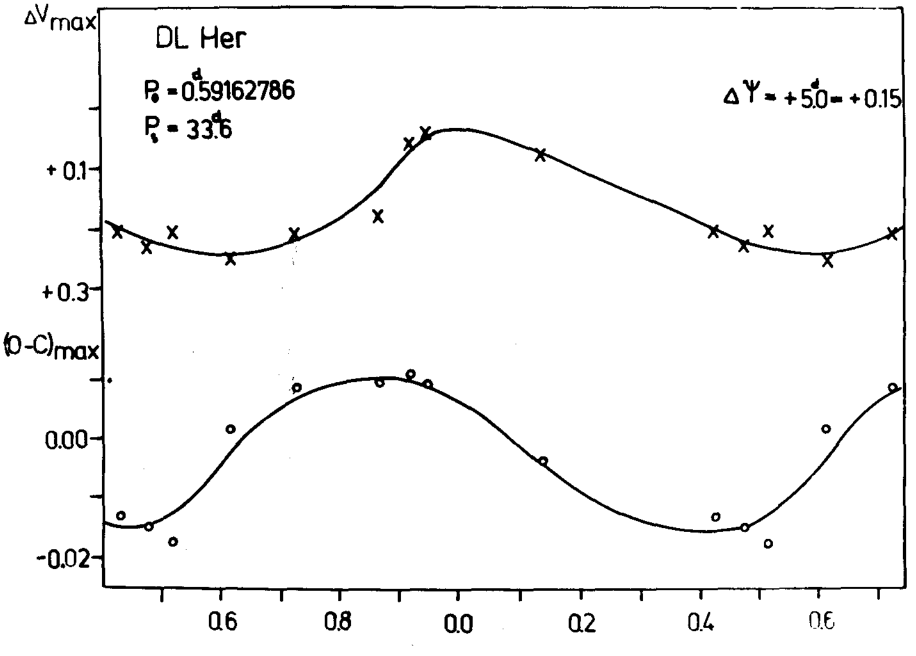

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Figure 5c

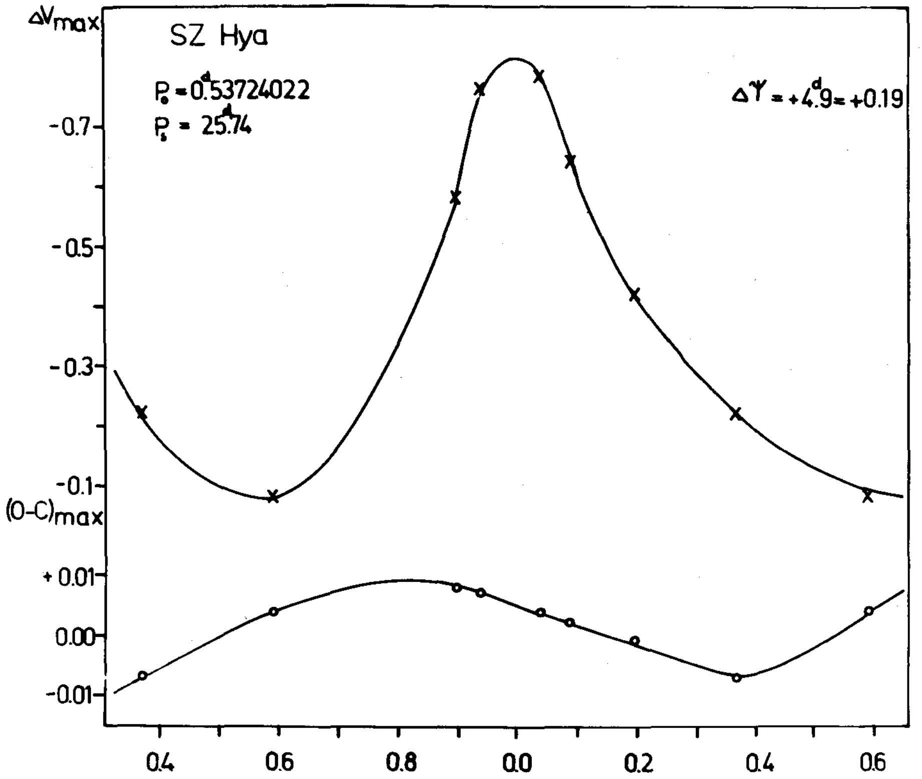

Figure 5d

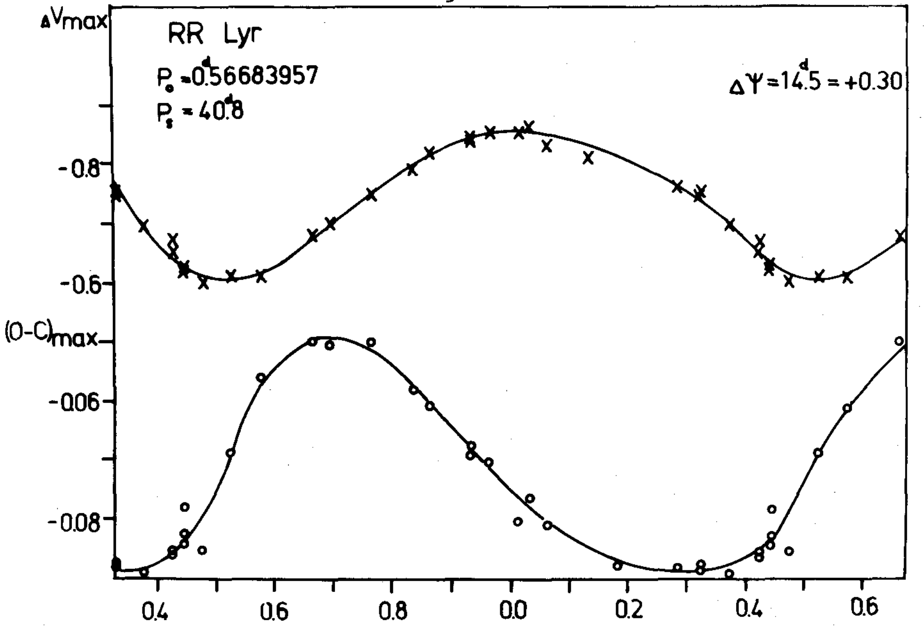

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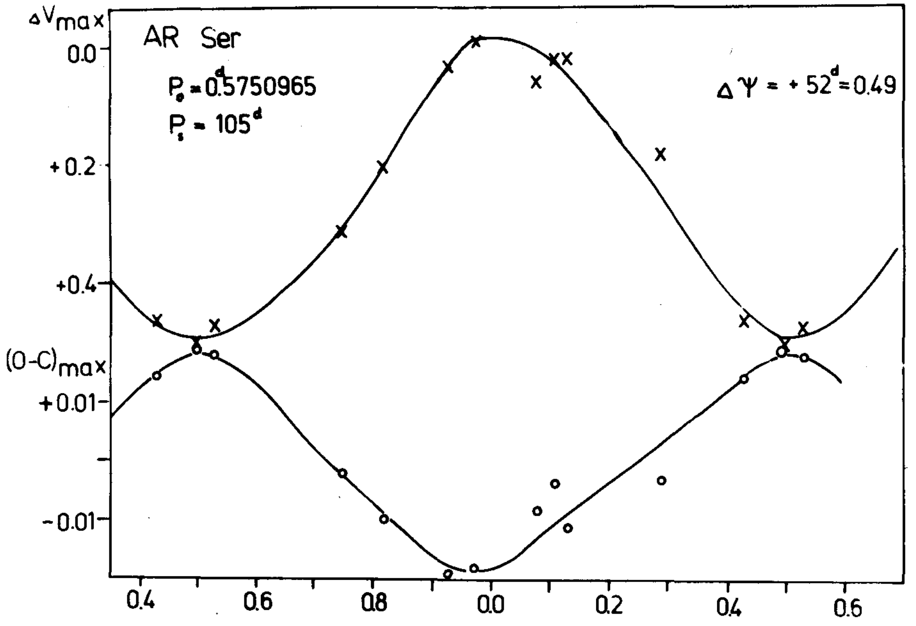
Figure 5e



the variations connected with the 41-day cycle were very small, while they were strong in other years. In 1971 the amplitudes were very small again. In this way a 4-year cycle became apparent. To our great satisfaction, this year we were also able to observe the transition from an old 4-year cycle to a new one. Thus the existence of the 4-year period is definitely established. Discussing old visual and photographic observations we were able to follow this long period cycle back to 1935 (Detre and Szeidl, 1973). In Figure 6 the phase variation of the median brightness on the ascending branch and the variation in the height of the visual maximum of RR Lyrae are given during the last 4-year cycle.

At the end of an old 4-year cycle the amplitude of the maximum variations is smaller than 0.1 magn., and then very rapidly becomes as large as 0.2-0.3 magn.

Most interesting is the phase-shift in the 41-day period following the transition from an old 4-year cycle to a new one. The $O'-C'$ value of the most positive-shifted ascending branches was +19 days throughout 1967-71, +29 days during 1971-75, while for the new cycle it is +19 days, i.e. the beginning of a new cycle is accompanied by a phase shift of 10 days, about a quarter of the 41-day period. After each discontinuity the $O'-C'$

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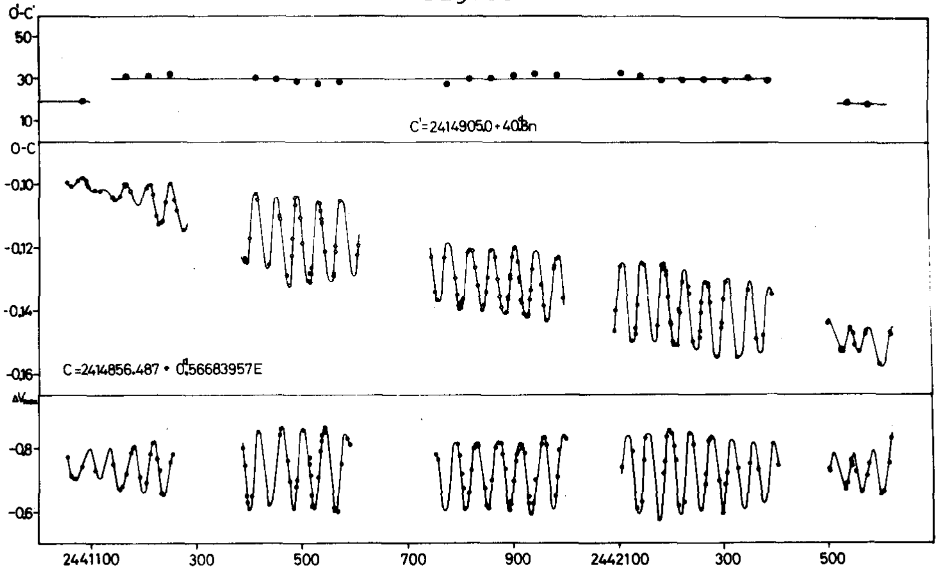
Figure 6



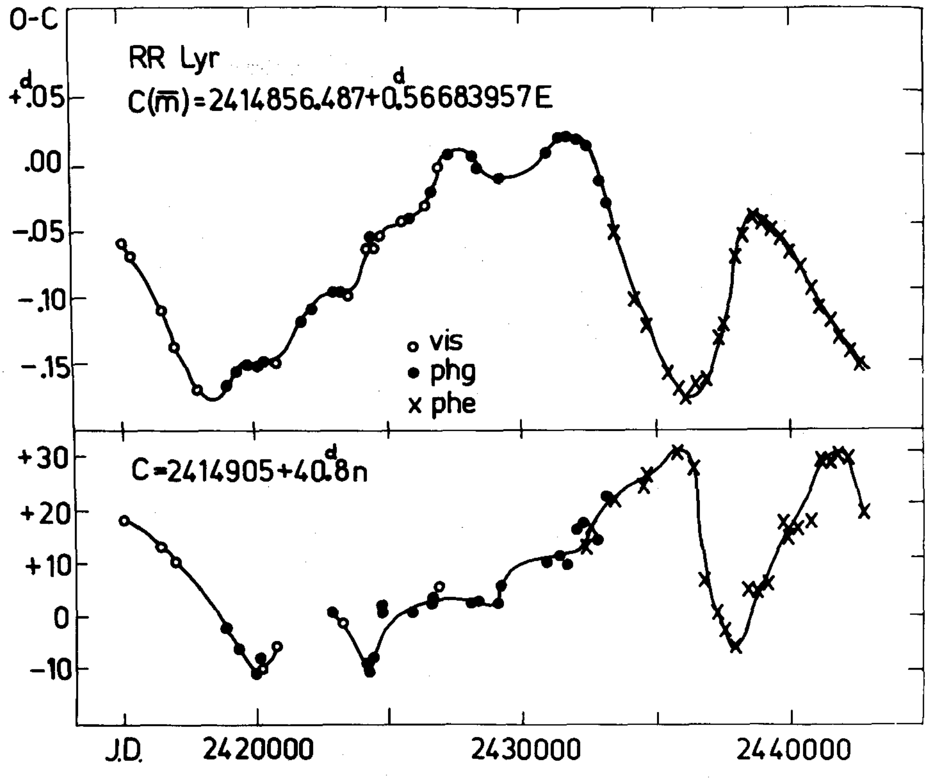
of the secondary period remains constant during one and the same 4-year cycle, during the past 40 years only a very strong cycle seems to be an exception.

Long period variations in the Blazhko-effect are known for other RR Lyrae type variables, as well.

These are : XZ Cyg	$P_1 \approx 9$ years	(Klepikova, 1958)
RV UMa	7 years	(Kanyó, 1975)
RW Dra	10 years	(Budapest,unpublished)

These long periods may remind us of the solar cycle. The magnetic field intensity of one cluster type variable was only measured. Babcock (1958) obtained 20 measures for RR Lyrae itself. If we arrange these observations according to the phases of the main (P_O) and secondary period (P_B) we do not find any correlation with the main period but a separation of positive and negative values exists in the course of the 41-day secondary period as was shown by Detre (1962). Brightest maxima appear to coincide with largest negative,lowest maxima with the largest positive values of the magnetic field intensity. Preston's magnetic observations of RR Lyr (Preston, 1967) in 1963 coincide with the minimum of a 4-year cycle, while those in 1964 with the beginning of a weak 4-year cycle. That may be the explanation of why he could not find a

Figure 7



measurable field. On the bases of all these we suggest that the Blazhko-effect of RR Lyrae stars may be connected with their magnetic field. If true, it may be of fundamental importance in understanding the nature of Blazhko-effect.

Briefly I should like to mention the problems of O-C diagrams of multiple periodic RR Lyrae stars. The O-C diagrams of the main period of this kind of variables are usually very complicated (Szeidl, 1965). In Figure 7 the O-C diagram of RR Lyrae is given. The O′-C′ diagram for its secondary period is also drawn in. The two diagrams seem to be the mirror image of each other. This is characteristic of RR Lyrae stars with Blazhko-effect (Ustinov, 1951; Balázs and Detre, 1962), but it is not a general rule. As can be seen from Figure 7 the main and secondary period of RR Lyrae have not always changed in opposite direction.

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Discussion to the paper of SZEIDL

FROLOV: Does the U-B versus B-V loop always have the same counter-clockwise direction for RRab stars with a Blazhko-effect, or can the direction of circulation sometimes change with the phase of the Blazhko-effect?

SZEIDL: I have not found that the direction changes with phase of the Blazhko-effect.

DZIEMBOWSKI: Tsessevich has suggested some time ago that the radial velocity curves of some RR Lyrae stars with Blazhko-effect may be interpreted as a beat phenomenon of two oscillations with close frequencies. Could you comment on this?

SZEIDL: In my opinion, the radial velocity curves are not accurate enough. I do not think that any modern models can account for the period ratio in the case of RR Lyrae stars with a Blazhko-effect.

DZIEMBOWSKI: But if we admit the possibility of nonradial pulsation, we cannot rule out the above interpretation on theoretical grounds. Are there any direct observational evidences against it?

SZEIDL: I think there are. I mention two. There is always a point on the ascending branch of a multiperiodic variable which does not vary during the secondary period. There is another interesting fact. A new 4-year cycle of RR Lyrae always begins with a phase shift in the 41-day period.

TREMKO: The Blazhko-effect was present in RU Psc both in the period and in the light variations. The variations of the primary period in the past were also found, and thus the long period variations of the Blazhko-effect are to be expected.

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WOLFF: I was interested in your comments on the possible reason for the discrepancy in the magnetic field measurements of Babcock and of Preston. If your hypothesis is correct when would you expect the field to be detectable again?

SZEIDL: Preston's magnetic measurements were made in 1963 and in 1964. In 1963, the Blazhko-effect of RR Lyrae was very weak. The 4-year cycle was in minimum. Then a weak new cycle developed. If the hypothesis is correct, I expect the field to be detectable in the next 3 years. I expect a new minimum in the Blazhko-effect around 1979.

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