A statistical study of pulsating stars.

Twelfth paper: *The variables in the Magellanic clouds.*

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Özet : Küçük ve büyük Magellan bulutunda bulunan bir takım Cepheid tipi değişen yıldızlar analiz edilmiştir. Kullanılan ışık eğrileri H. Shapley ve yardımcıları tarafından neşredilen eğrilerdir. Her iki bulut için A(2) değerleri mütekabil logaritma değerlerine göre izdüşürülmüştür. Küçük bulutta *d* 1 seviyesi büyük buluttakinden ve bizim kendi sistemimizdekinden daha kısa peryodlara doğru uzanır. Bu nokta Shapley tarafından bir çok kerreler işaret edilmiştir. Bulutlardaki A(2) değerleri bizim kendi sistemimizdekinden sistematik olarak daha büyük görülür.

Küçük bulutta *d* 2 seviyesi pek belli değildir, büyük bulutta bu seviye hemen hemen görülmez. Her iki bulutta *d* 3 seviyesi açık olarak görülür. Değişkenlerin A(2) ve log P ye nazaran bulutlardaki dağılımı, Carina yıldız bulutu için bulunan dağılım ile mukayese edilebilir. Seviyelerin gözüktükleri dereceler populasyon tipleri ile alâkalı olabilir.

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Abstract: A number of Cepheid variables in the small and in the large Magellanic cloud are analysed. The light curves used are those published by *H. Shapley* and his associates. For the two clouds the values A(2) are plotted against the corresponding values of the logarithms. In the small cloud the *d* 1 level extends to shorter periods than in the large cloud and than in our own system. This point has repeatedly been emphasized by *Shapley*. In the clouds the values A(2) seem to be systematically larger than in our own system.

In the small cloud the level *d* 2 is poorly developed, in the large cloud this level is hardly visimle. In both clouds the level *d* 3 is very apparent. The distribution of the variables with respect to A(2) and log P in the clouds is comparable to that found for the star cloud in Carina. The degree to which the levels show up may be connected with the type of population.

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In the present paper I have analysed the variable stars in the small and in the large Magellanic cloud. The light curves of the variables in the small Magellanic cloud were taken from the paper by *H. Shapley, A.S. Carlston* and *V. Mc Kibben Nail* [1] while those in the large cloud were taken from the paper by *H. Shapley* and *V. McKibben* [2]. In the first of the papers quoted here, the authors give the light curves of fourty nine selected Cepheids. With a very few exceptions all have been analysed. It was our intention uniformly to cover all periods and when in the original list the differences between the consecutive periods were small, a few systems were dropped.

Altogether fourty four of the fourty nine systems were analysed The analysis was performed in exactly the same way as in the preceding papers of this series and therefore no further explanation is needed.

The results are collected in table 1. The first column in this table gives the H.V number of the variable as indicated in the list of *Shapley* a.o. while the next columns contain the logarithms of the periods, the median magnitude $(m_{max} + m_{min}) : 2$ and the values $\pi(1)$, A(2), A(3) and A(4) respectively. These latter values are those which result from the analysis of the light curve.

In the second paper quoted above [2], *H. Shapley* and *V. Mc Kibben* give the light curves of fourty selected Cepheids in the large Magellanic cloud. At the same time by a series of symbols, which have been taken over in table 2, they indicate the quality of their light curves. A=excellent; B = good: C = fair; D = poor. In addition they use the following set of symbols: *p* indicates that the variable is in a poor star field; *r* = rich star field; *i* = average star field; *c* = clear of nebulosity; *e* = on edge of obscuration; *o* = in obscured area; *o* ! = very dense obscuration; *d* = faint companion stars in contact and *d* ! = doubling distorts image and decreases range.

It is obvious that those systems marked *d* ! by *Shapley* and *Mc Kibben* are not suitable for our method of analysis. The values $\pi(1)$ and A(f) which result from our analysis in a general way describe the shape of the light curve. So if by doubling of the image the light curve is distorted for $\pi(1)$ and A(*f*) erroneous values will be obtained. Therefore all systems marked *d* I by *Shapley* and *McKibben* have been excluded from our list.

I have thought it advisable moreover to exclude a few of the systems marked *d*.

On the other hand I have included six systems of which light curves have recently been published by *H. Shapley* [3]. This group of six Cepheids consists out of three pairs The stars in each pair have similar period, but are different in apparent magnitude. *H. Shapley* states that for none of the stars the photometry is bothered by neighbouring stars.

The magnitude differences may partly at least be due to obscurations and *Shapley* uses these pairs to indicate the risk when it is attempted to deduce differences in distance from a limited number of Cepheids. As long as the photometry has not been bothered, the shape of the light curve is not affected and therefore there is no objection against including the stars in our list. For these three pairs *Shapley* does not indicate any of his symbols A, B, C etc. and therefore for this latter group they do not appear in table 2.

Except for the extra final column which gives *Shapley's* description of the light curve, the arrangement of table 2 is identical to that of table 1.

The numbers in tables 1 and 2 were used to draw up figure 1.

In this figure the values A(2) were plotted against the corresponding logarithms of the period.

Black discs were used to indicate the variables in the small cloud and open circles to indicate the large cloud. In the figure there are also indicated the levels and sublevels *a* 1, *a* 2, *d* 1, *d* 2 and *d* 3 as provisionally adopted in the first and eighth paper of this series.

First let us consider the distribution of the variables with periods $<$ 10 days.

It appears that while both with the smaller and with the larger cloud the majority of the values A(2) are above the level *d* 1, this effect is greatest with the small cloud. However, in this respect the difference between the two clouds is not very large. The distribution of the variables in both clouds most closely resembles that found in the Carina star cloud, but with the Magellanic clouds there has been a shift of all values A(2) in upward direction.

TABLE 1.

Variable stars in the small Magellanic cloud analysed in the present paper

Design. H.V.	log P	$\frac{m_1 + m_2}{2}$	π (1)	A (2)	A (3)	A (4)
1505	0.097	16.42	0.769	0.469	0 235	0.134
1513	.134	16.55	.9[illegible]9	.257	.000	.000
10364	.176	16.57	.578	.640	.351	.263
2127	.262	16.10	.958	.187	.095	.032
1446	.272	16.62	.772	.405	.228	.221
2128	.356	16.01	.774	.471	.285	.110
2076	.398	16.12	.677	.539	.268	.122
1460	.464	15.98	.731	.468	.281	.210
2053	.508	16.16	.577	.591	.424	.118
11206	.532	16.07	.770	.458	.247	.114
2085	.571	16.29	.740	.507	.265	.134
858	.582	15.82	.800	.332	.259	.202
1619	.642	15.98	.858	.321	.089	.138
1425	.658	15.90	.740	.496	.230	.126
2031	.720	15.60	.776	445	.207	.148
1818	.737	16.16	.781	.487	.161	.095
815	.763	15.89	.746	.553	.155	.000
2124	.783	15.72	.743	.491	.232	.210
1492	.799	15.42	.818	.415	.176	.077
1400	.823	15.64	.823	.407	.184	.045
1855	.835	15.89	.821	.363	.152	.084
2081	.881	15.10	.819	.431	.114	.077
816	.900	15.61	801	.449	.161	.011
1338	.929	15.21	.901	.239	.195	.045
1790	.948	15.28	.826	.353	.085	—
2103	.953	15.49	.928	.158	.148	.161
836	.973	15.22	.910	.158	.190	.170
1334	.975	15.10	.940	.184	.170	.077
1768	.992	15 33	.850	.298	.182	—
2060	1.001	14 83	.979	.130	.063	—
818	1.015	15.15	0.909	0.173	0.200	0 130
1426	1.019	15.45	.900	.243	.152	.105
2017	1.057	14.99	.915	.259	.118	.100
857	1.078	14.77	.910	.253	.100	.084
856	1.085	15.28	.813	.321	.217	.167

TABLE 1 (continued)

Design.	log P	$\frac{m_1+m_2}{2}$	π (1)	A (2)	A (3)	A (4)
1365	1.094	15.18	0.829	0.276	0.190	0.158
1351	1.117	15.07	.838	.332	.164	0.45
827	1.129	14.80	.940	.182	.084	.055
1335	1.158	14.98	.916	.192	.122	.161
1328	1.200	14.46	.930	.228	.105	.045
1333	1 212	15.10	.949	.217	.045	—
1342	1.254	14.34	.958	.170	.118	.032
817	1.276	14.01	.910	.259	.095	.045
823	1 504	14.44	.751	.454	.221	.170
855	1.518	14.54	.834	.417	.170	.063

TABLE 2

Variable stars in the large Magellanic cloud analysed in the present paper

Design	log P	$\frac{m_1+m_2}{2}$	π (1)	A (2)	A (3)	A (4)	Ramarks
2809	0.400	15.89	0.725	0.509	0.243	0.134	B i c
2344	.401	16.45	.775	.436	.207	—	D i e ?
2796	.461	16.20	.684	.603	.268	.145	D i e
2368	.508	16 41	.896	.290	.114	.077	C i e ?
2361	.512	16 56	.682	.523	.290	.226	C i e
2472	.557	16.13	.851	.345	.155	.095	C p c ?
2795	.592	16.09	.801	.389	.202	.000	A i e ?
2788	.640	15.72	.812	.373	.230	.110	B i e ?
2334	.671	16.26	.851	.349	.200	.063	C i e ?
2826	.673	15.84	.827	.382	.000	.190	C p c
951	.688	16.19	.780	.444	.224	.118	C p c
2861	.694	16.03	.776	.471	.232	.130	B i c ?
2727	.775	15.55	.847	.417	.148	.000	B p o
2773	.803	15.57	.751	.510	.200	.126	B i c
2536	.804	15.16	.881	.345	.155	.045	B i e ?
2685	.816	15.12	.879	.375	.122	—	Aied ?
2790	.820	16.03	.825	.449	.155	—	C r e
935	.849	15.63	.855	.378	.134	.033	B i c ?
2491	.853	15.45	.840	.316	.263	.141	B p C
2752	.857	16.42	.880	.270	.219	.095	D p e

TABLE 2 (continued)

Design.	log P	$\frac{m_1 + m_2}{2}$	π (1)	A (2)	A (3)	A (4)	Remarks
927	.877	15.51	0.914	0.329	0.192	—	C p o !
2722	.905	15.12	.874	.348	.155	0.000	C i e ?
971	.968	15.14	.829	.400	.192	.063	A i e ?
952	.981	15.48	.961	.095	.148	.105	A i e ?
2787	1.058	14.66	.906	.235	.100	.045	C i e ?
905	1.074	14.99	.951	.193	.100	.000	Crod ?
2463	1.145	14.62	.896	.230	.195	.084	A p e?
1005	1.153	14.99	.958	.145	.105	.063	B r e
933	1.191	15.44	.840	.401	.173	.122	A p e
1005	1.272	14.70	.837	.283	.192	.161	A i e ?
1003	1.387	13.87	.881	.241	.179	.130	A i c ?
934	1.450	14.71	.864	.321	.141	.130	A i c ?
953	1.679	13.22	.854	.363	.173	.063	D i c ?
2447	2.074	13.14	.990	.032	.063	—	D p c?
5757	0.486	15.93	.916	224	.138	.110	—
5780	0.494	17.10	.888	.339	.110	.100	—
2634	0.616	15.41	.673	.574	.266	.122	—
5926	0.619	16.81	.874	.336	.063	.095	—
908	0.913	14.85	.869	.315	.071	.152	—
2300	0.922	16.35	.840	.375	.089	.110	—

It has repeatedly been pointed out by *H. Shapley*, that in the small cloud the Cepheids extend to far shorter periods than in the large cloud. This is also apparent in figure 1. It is curious that in the small cloud several of the short period Cepheids can be suspected to be associated with the levels *a* rather than with the *d* 1 level. In other words, some of these short period Cepheids actually might be R R. Lyrae stars of large period. Similar cases have been found to occur with the Cepheids in our own system. On the other hand especially in the small cloud the level *d* 1 is found to extend to far shorter periods than in our own system. To a lesser extent this is also true for the large Magellanic cloud. To see this, compare figure 1 with the diagram valid for Carina. On the *d* 1 level in Carina no points occur to the left of log P = 0.5. Both in the small and in the large Magellanic cloud such points do occur. In the small cloud the distribution of the points could largely be represented by a straight line parallel and above *d* 1, while at the upper left side the line would have to be curved. The scatter of the individual points would not be too large. With the large cloud the scatter of the individual points seems to be larger. With the large cloud at least one of the variables is definitely on the level *a* 2.

We next turn our attention to the distribution of the points for periods > 10 days. It is apparent at once that in both Magellanic clouds the level *d* 2 is poorly developed, while *d* 3 is strongly represented.

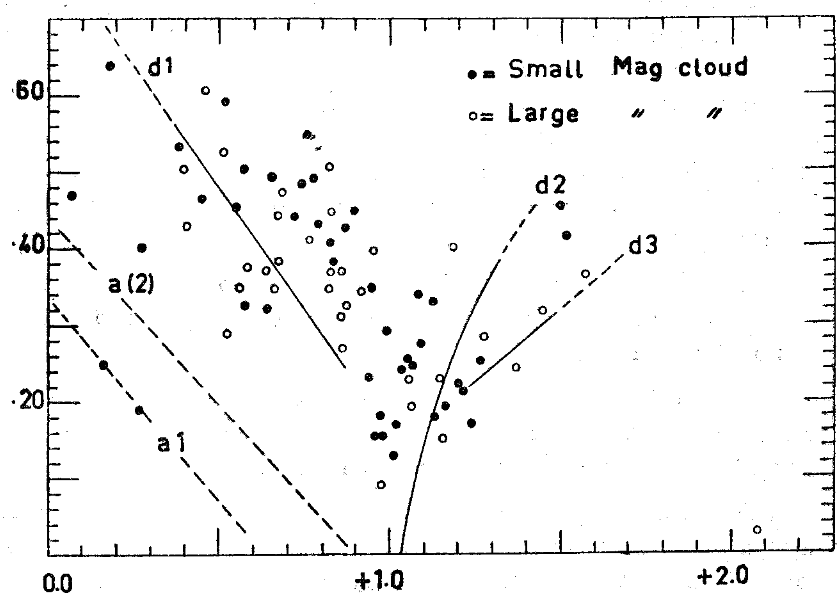

Fig. 1

We remember that in Carina also the level *d* 3 was better developed than *d* 2. In the small Magellanic cloud there seem to be some traces of the *d* 2 level. There is a steeply rising sequence of stars near log P = 1.0, to which also belong a few system in the large cloud.

Therefore relatively to the variables in our own galactic system, the level *d* 2 seems slightly to have been shifted, both in upward direction and towards the left. Before drawing any conclusions from this, we should remember that we have not been able very definitely to fix the shape of d 2 within our own system, so that the effect could be spurious.

With the large cloud we find the usual gap between the level d 1 and the d 2 and d 3 levels. With the small cloud the gap if present at all is not nearly so pronounced.

Among the list of Cepheids in the large Magellanic cloud, *H. Shapley* and *V. Mc Kibben* have included H. V. 2447 with $\log P = 2.074$. For a Cepheid this star has an unusually long period. Its A(2) value is such that it does not fit into any of our levels. As yet we only paid scant attention to the pulsating stars with periods of around 100 days and more. Eventually we hope to extend our analysis so as to include this additional periods. A priori it does not seem impossible that other levels may turn up in which H V 2447 could be fitted, but for the present we must let this matter rest. It is interesting to notice that the level d 2 was well developed in the Sagittarius cloud, while in that same cloud the level d 3 was absent. The stars in the Sagittarius cloud are considered to be population II stars.

In the Carina cloud d 2 is poorly developed while d 3 is well represented. The stars in the Carina cloud are thought to be population I stars

On the other hand the large Magellanic cloud is thought to represent mostly a I population while the small cloud is thought to be intermediate between I and II.

This makes us suspect that the Cepheids in the two populations are not entirely identical. From the material considered up till now, it would appear that the level d 2 is typical for stars in the direction of the central galactic bulge, while d 3 is more limited to the spiral arms. On the other hand Cepheids on the level d 2 certainly occur in the Cygnus cloud and the difference can only be relative.

Below $P = 10$ days, the differences are less pronounced, but as far as our present evidence goes, it seems that in the direction of the galactic center here the Cepheids are confined to a relative small area slightly above the d 1 level. The population I Cepheids seem to be more scattered, both as regards their periods and their values A(2). However, completely to clarify this point, some additional evidence is needed.

In this respect it should be remarked that *C. Payne—Gaposchkid* [4] from a Fourier analysis of the light curves of different Cepheids has concluded, that there is a difference between the «classical Cepheids» and the other ones. *C. Payne—Gaposchkin* however, finds that the difference is most pronounced with the periods smaller than 10 days, while this differenee is not very clear with the longer periods.

In my opinion the distinction between «classical» and «non classical» Cepheids is not entirely satisfactory. I have the definite impression that the distribution of the Cepheids in the globular cluster deviates from all three of the *d* levels. Later on we will consider this question in more details.

It would of course be tempting trying to ascertain whether differences in the level to which a variable belongs, corresponds to differences in (absolute) magnitude, the period remaining the same. I think however, that this attempt can better be postponed until later on. For this the reason is in the first place that first the existence of the different levels must be more accurately fixed. In the second place the selected light curves given by *H. Shapley* and c. a. [1, 2] were chosen in such a way as best to represent the gradual change of the shape of the light curve with increasing period. It is dubious whether they would have selected the identical set of curves for investigating the period magnitude relation.

As indicated in table 2 several of the stars are in or near obscurations. According to *H. Shapley* [3] this may lead to differences up to 1 magnitude and more. The magnitude differences, if present, which we can expect between the different levels, at best will be a fraction of a magnitude. A third reason why this part of the investigation should be postponed is that there is only little overlapping of the periods corresponding to the different levels, while the systems near the limits of the transitions are notoriously scarce.

On the other hand it is evident that at some future date this question will have to be considered, as it might throw additional light on the true shape of the period luminosity relation.

Literature :

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