III. JOINT DISCUSSION ON THE LUMINOSITY OF CEPHEIDS

(18 August 1958)

ORGANIZING COMMITTEE: Dr S. C. B. Gascoigne (*Chairman*), Dr A. D. Code and Prof. P. P. Parenago.

MEETING CHAIRMAN: Prof. P. P. Parenago.

RECORDER: Dr H. C. Arp.

This discussion was organized by a committee consisting of Dr S. C. B. Gascoigne (*Chairman*), Dr A. D. Code and Professor P. P. Parenago. At the meeting proper Professor Parenago acted as Chairman and Dr H. C. Arp as recorder. Dr Arp's copy of the proceedings has been edited for publication by Gascoigne. Most of the contributions have had to be cut, some drastically, to accommodate them in the space available in these *Transactions*. Because of time limitations it has not been possible to submit the alterations to the authors concerned, and the editor must therefore take full responsibility for them. He would like to thank Dr Arp for a very thorough job as recorder, and for some valuable comments and suggestions; and Mrs Jane Basinski for competent editorial assistance.

The Discussion was opened by Professor Cecilia Payne-Gaposchkin, who spoke on 'Multiplicity in the Period-Luminosity Relation'. The manuscript for this was not received in time for publication. S. C. B. GASCOIGNE

1. CEPHEIDS IN GALACTIC CLUSTERS

JOHN B. IRWIN

(Communicated by H. Weaver)

In contrast to globular clusters, which contain large numbers of cepheid variables, galactic clusters have, in the past, been generally thought of as systems which lack such variables. A significant change in this position has taken place in the last three years, beginning with the observations, made in 1955, that S Normae was a probable member of NGC 6087, and U Sagittarii of M 25 (IC 4725) [1]. We now have photometric data for four cepheids in as many different clusters, with the expectation that such data for five additional cepheids will soon be available.

Cepheids in clusters can provide: (1) an independent check of the period-luminosity relation, (2) the normal, or unreddened colours of cepheids, and (3) may throw some light on the age and evolution of a cepheid. These advantages have stimulated two independent searches for additional cepheids in clusters. Van den Bergh [2] in 1957 searched the first five shipments of the Palomar Sky Charts and found four additional cepheids in clusters, namely: DL Cas in NGC 129, EV Sct in NGC 6664 and AO CMa and CV Mon in two anonymous clusters. Kraft [3], in 1957, using the coincidence of known positions of clusters and cepheids, and using the additional requirement that the cepheid should be at least as bright as one magnitude fainter than the fifth brightest star in the cluster, published three lists containing six, four and five cepheids; these lists might be described as most probable, probable and possible cluster members respectively. Because of an error in the position of NGC 7790 as given in Dreyer's *New General Catalogue*, an error that has been propagated through the literature, Kraft's lists have been recently corrected [4] in the sense that both CF Cas and the remarkable double cepheid CE Cas (discovered by G. A. Starikova) are within the boundaries of NGC 7790. The membership of CE and CF Cas in the cluster was known to Eggen in 1952, see Sandage [5].

The revised, combined lists show eleven cepheids within cluster boundaries, namely S Nor, U Sgr, EV Sct, CF Cas, CE a and CE b Cas, DL Cas, AO CMa, CV Mon, ER Car and GH Car. ER Car is probably not a member of NGC 3532. Koelbloed's unpublished observations of the cluster give both a distance and a colour excess substantially less than that found for the cepheid. Six additional *possible* cepheids in clusters are R Cru, AT Pup, UX Car, GI Car, T Cru and Y Sct. All of these stars and their respective clusters need further detailed photo-electric and spectroscopic attention. New possibilities undoubtedly exist.

Criteria for membership include (1) probability considerations, (2) proper motion criteria, (3) radial velocity criteria, and (4) the 'reasonableness' of the derived absolute magnitude and colour of the cepheid in question. If we consider a band 14 degrees wide centred on the galactic equator, it turns out that 0·54%, or 1/185 of the area of this band on the celestial sphere, is occupied by galactic clusters. Within this band are thirty-five known cepheids brighter than eighth photographic magnitude at maximum, seventy-four cepheids between eighth and tenth, and 124 cepheids between tenth and twelfth photographic magnitude at maximum. If we assume randomness of distribution within this 14 degree band, we can predict how many cepheids should accidentally fall within cluster limits and compare with the observed numbers. The comparison, shown in Table 1, indicates the high probability that most of the listed cepheids are physical, rather than optical members.

Table 1

$m_{pg(max)}$	Predicted	Observed
<8·0	0·2	3
8·0 to 9·9	0·4	2
10·0 to 11·9	0·6	5
Totals	1·2	10

Because those clusters larger than half a degree in diameter account for three-fourths of the total cluster area, one would expect that optical coincidence, when it occurs, would usually take place near the edge of a large cluster. Such is the case for ER Car, which is probably not a physical member of NGC 3532, as has been previously mentioned.

Published proper motions are, in general, too inaccurate to be useful as a criterion for cluster membership. For example, the brighter companions of U Sgr have proper motion probable errors corresponding to ±35 km/sec in the individual tangential velocities. The case for fainter, more distant cepheids is worse.

Spectroscopic observations of numerous companions of S Nor and U Sgr by Feast [6], of U Sgr by Wallerstein [7] and of EV Sct and DL Cas by Kraft [4] confirm cluster membership in each case within the errors of observation. The data are given in Table 2.

Table 2

Cepheid	Cepheid velocity (km/sec)	Cluster velocity (km/sec)
S Nor	+ 3	+ 2±3
U Sgr	+ 4	+ 4±4
EV Sct	+23·5	+23±2
DL Cas	−11	−14±3

Three-colour observations by Irwin [8] of NGC 6087 and M 25, by H. L. Johnson [9] of M 25, by Arp [10] of NGC 6664 and by Sandage [5] of NGC 7790 have been used to derive the absolute magnitudes and colours of four cepheids. The colour excesses have been derived by the usual three-colour technique and have been checked spectroscopically, where possible, by Kraft [4]. Variable reddening has been allowed for in the case of M 25 and NGC 6664. The fit has been made to the zero-age main sequence at the fainter ends of the observed main sequences. The results are given in Table 3 and are shown in Fig. 1; colour data by Gascoigne and Eggen [12] for α UMi and δ Cep are included. The results are provisional and a definitive discussion will be published by Arp, Kraft and Sandage when data for additional cepheids in clusters are obtained this coming year.

Table 3

Cepheid	Period (days)	Eggen 1951 Type	$M_{B\ \mathrm{med}}$	$(B-V)_{0\ \mathrm{max}}$	$(B-V)_{0\ \mathrm{med}}$
EV Sct	3·09	C	−1·9	0·46	0·55
α UMi	3·97	C	—	0·48	0·50
CF Cas	4·87	AB	−2·5	0·51	0·72
δ Cep	5·37	AB	—	0·34	0·53
U Sgr	6·74	AB	−3·1	0·37	0·59
S Nor	9·75	C	−2·8	0·59	0·77

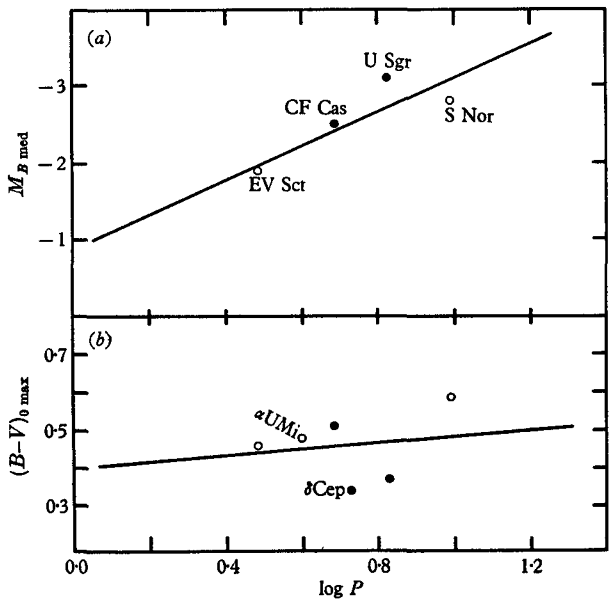

Fig. 1. (*a*) Median absolute magnitudes $M_{B\ \mathrm{med}}$ and (*b*) (B − V) colours at maximum light, plotted against log P for the cepheids in Table 3. Filled circles are type AB cepheids, open circles type C.

The absolute magnitude data (Fig. 1*a*) suggest a period-luminosity law:

$$M_{B\ \mathrm{med}} = -0{\cdot}9 - 2{\cdot}2 \log P \tag{1}$$

with some indication that the type C cepheids (open circles) are half a magnitude fainter than the type AB cepheids at a given period. The slope of −2·2 is assumed and is taken from Arp's results [11] in the Small Magellanic Cloud. Equation (1) is in reasonable agreement with the results of Blaauw and Morgan's [13] proper-motion analysis of eighteen bright cepheids.

The best straight-line fit to the colour results gives (see Fig. 1*b*)

$$(B-V)_{0\ \mathrm{max}} = 0{\cdot}40 + 0{\cdot}085 \log P, \tag{2}$$

where the assumed slope is identical to that used by the Leiden observers [14], but has been transformed to the $B-V$ system. The zero-point, however, is $0^{\mathrm{m}}13$ *redder*. There is also the indication that the type C cepheids are redder than the type AB cepheids at maximum light, the amount being $0^m\!\cdot 11$. If, instead of colour at maximum, the median colour is used, the resulting equation would be:

$$(B-V)_{0\ \mathrm{med}} = 0{\cdot}36 + 0{\cdot}36 \log P, \tag{3}$$

where the slope is derived from equation (2) plus half of Eggen's [15] 1951 *colour amplitude* slope transformed to the $B-V$ system. Equation (3) slightly reduces the scatter and virtually eliminates the systematic difference between cepheid types—at least for this scanty data. It is still too early to compare the usefulness of these two different approaches.

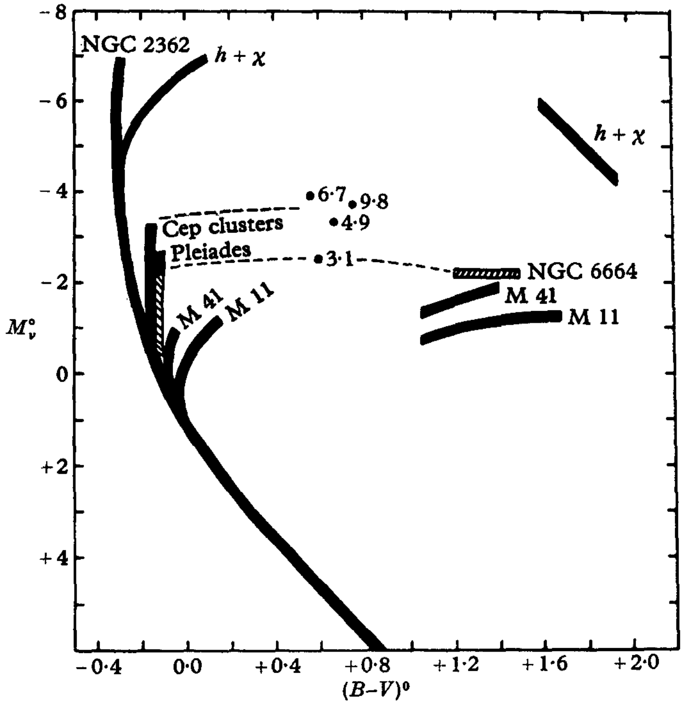

Fig. 2. Schematic colour-magnitude relation between cepheids, supposed evolving from left to right, and cluster stars.

Fig. 2 is from an unpublished discussion by Kraft [14] and shows the schematic colour-magnitude relation between the cepheids and the cluster stars. Evolutionary arguments suggest, as do the observations, that the cluster stars are evolving approximately horizontally across the diagram, and in crossing a relatively narrow region of instability, become cepheid variables; see Sandage [16]. Information as to the relative ages of the cepheids can be derived from the character of the colour-magnitude diagrams of the clusters in which those cepheids are located.

In view of some obvious differences between galactic and Small-Magellanic-Cloud cepheids [11] it is vitally important that the period-luminosity law for the former be derived, if possible, from observations of galactic cepheids alone. Since none of the previously mentioned variables have periods longer than 10·4 days, the discovery of longer-period cepheids in clusters or associations or with companions assumes special importance. Kraft [17] has called attention to the 30-day cepheid AQ Pup which may be a member of the stellar association II Puppis [18]. This association has been studied in preliminary fashion by Munch [19]. AQ Pup has two fainter companions approximately 15″ and 25″ distant which could be individually observed both photo-electrically and spectroscopically under favourable conditions.

Eggen [20] has recently pointed out that δ Cep and α UMi may be members of the α Persei group. Attention should also be called to the fact that a considerable number of cepheids have distant, possibly physical, companions and there are some cepheids that are close visual binaries. Probably the most precise technique for determining absolute magnitudes and spectral types of early type stars is Strömgren's [21] photo-electric technique using narrow-band colour filters. This method has obvious application both to cluster companions and single companions of cepheids and could perhaps be extended, with profit, to the cepheids themselves.

In conclusion, the study of companions of cepheids is only in its beginning, but would seem to be richly rewarding.

REFERENCES

[1] Irwin, J. B. *M.N.A.S.S.A.* **14**, 38, 1955.
[2] van den Bergh, S. *Ap. J.* **126**, 323, 1957.
[3] Kraft, R. P. *Ap. J.* **126**, 225, 1957.
[4] Kraft, R. P. *Ap. J.* **128**, 161, 1958.
[5] Sandage, A. *Ap. J.* **128**, 150, 1958.
[6] Feast, M. W. *M.N.R.A.S.* **117**, 193, 1957.
[7] Wallerstein, G. *P.A.S.P.* **69**, 172, 1957.
[8] Irwin, J. B. *Astr. J.* **63**, 197, 1958.
[9] Johnson, H. L. Unpublished.
[10] Arp, H. C. *Ap. J.* **128**, 166, 1958.
[11] Arp, H. C. *Astr. J.* **63**, 45, 1958.
[12] Gascoigne, S. C. B. and Eggen, O. J. *M.N.R.A.S.* **117**, 430, 1957.
[13] Blaauw, A. and Morgan, H. R. *B.A.N.* **12**, 95, 1954.
[14] Kraft, R. P. *A.A.S. Symposium.* Indianapolis, December 1957. Unpublished.
[15] Eggen, O. J. *Ap. J.* **113**, 367, 1951.
[16] Sandage, A. *Ap. J.* **127**, 513, 1958.
[17] Kraft, R. P. Personal communication.
[18] Markarian, B. E. *Doklady, Akademia Nauk, Armenian Soviet Republic*, **15**, 11, 1952.
[19] Munch, L. *Bull. Tonantzintla Obs.* **9**, 29, 1954; also *Astr. J.* **56**, 178, 1951; also *Ap. J.* **113**, 309, 1951.
[20] Eggen, O. J. *Observatory*, **78**, 76, 1958.
[21] Strömgren, B. *Proc. Third Berkeley Symposium on Math. Statistics and Probability*, vol. **3**, p. 49 (University of California Press).

2. PHOTO-ELECTRIC OBSERVATIONS OF MAGELLANIC CLOUD CEPHEIDS

S. C. B. GASCOIGNE

(Communicated by B. J. Bok)

Photo-electric observations of cepheids in the Magellanic Clouds were begun with Dr G. E. Kron in 1951, with the objects of learning something about the colours and the scatter in the $P-L$ relation of the Cloud cepheids, and hence also of those in the Galaxy, the tacit assumption being that these two groups of stars are members of the same family and have the same intrinsic properties. It became clear at once that this assumption would need justification, the Cloud cepheids being bluer than those in the Galaxy to an extent difficult to explain by reddening of the galactic cepheids. Since then much of the interest of the work has centred around the problem of what differences, if any, exist between the Cloud

https://doi.org/10.1017/S0251107X00021374 Published online by Cambridge University Press