MAGELLANIC CLOUD CEPHEIDS: ABUNDANCES, REDDENINGS, P-L AND P-L-C RELATIONS. A REVIEW.

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1. INTRODUCTION

Magellanic Cloud cepheids are of special importance for studies of stellar pulsation, of stellar evolution, of the nature of the Clouds themselves and of the extragalactic distance scale. It is not possible to cover all aspects of this subject in a short review and fortunately this is probably unnecessary since a whole symposium on cepheids is planned for Toronto next year. This paper attempts the much more modest task of assessing the current status on three main topics; chemical abundances, reddenings and the P-L and P-L-C relations (including recent infrared work). Conflicting views on some of these topics have recently appeared in the literature and a survey of the situation seems rather desirable.

In concentrating on a limited number of topics, discussion has necessarily been confined to observations which seem of particular relevance. This has meant that certain important series of photometric observations of MC cepheids are not explicitly mentioned (though they are incorporated with other data where appropriate). Besides the pioneering work by Gascoigne and Kron (1965) and Gascoigne (1969) in BV this group includes UBVRI observations of long period cepheids by Eggen (1971, 1977) and BV photometry by Madore (1975) and Martin (1981). In addition to this photoelectric work there exists a very large body of photographic photometry. Much of the early photographic work was troubled by photometric scale errors though the material should be very useful for such matters as period variability. Two recent extensive photographic investigations have been carried out with considerable attention to the problem of photometric calibration. The scope of the Dunsink (Butler 1976, 1978, Wayman et al. 1983) and SAAO (Martin et al. 1981) programmes can be seen from Table 1. Though this material has been partially discussed (Butler 1976, 1978, Martin 1980a) it is very desirable that a discussion of the complete material be made. These observations should be particularly valuable for such problems as possible period-amplitude and period-luminosity-amplitude relations, forms of light curves, period changes etc. It is however important to remember that the survey of cepheids in the Clouds is by no means complete. Thus in a 40 x 30

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arcmin field around NGC 371 (SMC) where 47 cepheids were previously known, Lloyd Evans and Andrews found 25-30 more variables, almost certainly cepheids and mostly in the 16-18 magnitude range (Lloyd Evans 1977).

TABLE 1

	No. of observations in each colour	No. of cepheids
Dunsink Survey LMC (Fields I + II)	∿ 33	248
SMC	∿ 30	72
SAAO Survey LMC (Fields I + II + III)	∿ 45	213
SMC	∿ 60	180

2. ABUNDANCES

For a good many years a number of observational results have suggested that cepheids in the Clouds are metal deficient compared to those in the solar neighbourhood. These results include differing period-frequency distributions and bluer intrinsic colours. However interpretation is difficult because the period-frequency distribution depends on the (abundance sensitive) evolutionary tracks and also on the mass-function whilst the colours depend on the adopted reddenings. Fortunately the abundance problem has recently been put on a sounder footing by three independent investigations. Harris (1981) measured 45 SMC cepheids in the Washington 4 colour system and found [Fe/H] = -0.54. The calibration is partly from galactic stars of known metallicity and partly from models of Kurucz (1979) and Böhm-Vitense (1972). Pel, van Genderen and Lub (1981) used reddening free indices from the Walraven five colour system to obtain [Fe/H] = -0.70 ± 0.25 for eight SMC cepheids, calibrating their results using Kurucz models. Pel (1981) gives a useful summary of abundance work on cepheids including a preliminary [Fe/H] = -0.3 from Walraven photometry of LMC cepheids. The Washington and Walraven systems are to some extent complementary. There is some inevitable scatter in the Washington results due to a dependence on temperature and the intrinsic width in temperature of the instability strip. This is not a problem in the Walraven system. However the bands of the latter are further to the blue where possible deviations from the adopted reddening law may be more important. Both sets of results depend heavily on the adopted model atmospheres. Laney (1983b) has constructed rough curves of growth for 7 SMC and 5 LMC cepheids (and for 13 Galactic cepheids). He finds [Fe/H] = -0.06 ± 0.10 (LMC), -0.50 ± 0.08 (SMC).

Within the errors these various results are in agreement with those for other young objects (e.g. HII regions cf. the convenient tabulation of Laney). In the following [Fe/H] = -0.15 (i.e. a deficiency of a factor D = 1.4) will be adopted for the LMC and [Fe/H] = -0.60, D = 4 for the SMC.

3. REDDENINGS AND ABSORPTIONS

In the past it has frequently been necessary to adopt some mean value for the reddening of each of the Magellanic Clouds. However for several problems involving cepheids it is essential to have good individual reddenings and for that reason the problem is dealt with at some length here. Attempts have been made to obtain individual reddenings using some form of period-intrinsic colour relation together with a measured colour. However the intrinsic width of the period-colour relation is too great for this method to have any real precision. Attempts have been made to use UBV photometry for reddening determinations of Cloud cepheids but they do not yield satisfactory results, essentially because the reddening and intrinsic lines are nearly parallel (cf. Cogan 1979). At least four multicolour systems do appear capable of handling this problem; the BVI system (Dean, Warren and Cousins 1978), the Walraven system (Pel 1978), the DDO system (Dean 1981a) and the Strömgren system (Feltz and McNamara 1980).

The most extensive work so far has been on the BVI system (Martin and Warren 1979, Martin 1980b, Martin, Warren and Feast (= MWF) 1979, Caldwell and Coulson 1983). The VBI intrinsic line now being used is a slight revision by Dr J Caldwell of that used by MWF. It depends on galactic cepheids of known reddening (in clusters). To determine reddenings the effect of abundance on this intrinsic line has to be estimated. MWF obtained $\overline{E}_{B-V} = 0.086$ using their uncorrected intrinsic line. They estimated the effect of D = 1.4 on the intrinsic line using Bell and Parson (1974) models and found a corrected $\overline{E}_{B-V} = 0.03$. Whilst such a value is by no means impossible it is lower than estimates for some other LMC objects. Dr J Caldwell has reinvestigated this problem using later models (Kurucz 1979, Bell and Gustafsson 1978). He finds the BVI intrinsic line to be less sensitive to metallicity than previously thought. These results give

TABLE 2

	D	No.	$\overline{E}_{B-V}$ (Corrected)	Disp
LMC	1.4	33	0.072	0.047
SMC	4.0	46	0.078	0.041

MWF pointed out the small dispersion in reddenings for their sample of LMC cepheids and a similar small dispersion is now found by Caldwell and Coulson for their SMC sample. This scatter is essentially independent of the absolute values of the reddenings which depend on abundance corrections from models. It is important to emphasize this point. An examination of recent papers by Clube and Dawe (1983) and by Stift (1982) shows that their discussions of the MWF P-L-C relation in the LMC could only have some validity if the dispersion in true reddenings for the SAAO sample was much greater (by a factor of ∿ 2) than the observed dispersion in Table 2. Attempts have been made to argue that the observed dispersion will be smaller than the true value due either to observational error or to finite width of the intrinsic line. But obviously, allowance for such effects will decrease the dispersion and the observed dispersion must be an upper limit to the true dispersion in the reddenings.

The extensive work by Pel (1976, 1978) on galactic cepheids in the Walraven system shows that the (B-L), (V-B) diagram is useful for reddening determinations. The method fits observations on the descending branch of the light curve with an intrinsic locus which must be corrected for abundance effects using model atmospheres. It is anticipated that extensive observations of Cloud cepheids in this system will be obtained. Recently van Genderen (1983a, b) has published preliminary observations of a few of the longer period cepheids in each Cloud and has derived reddenings adopting an intrinsic line based on D = 2 (LMC) and D = 5 (SMC). Comparison with BVI reddenings for those of the stars with apparently well determined reddenings (using D = 2 (LMC) and D = 4 (SMC), the nearest available results) gives a mean difference in E_{B-V}, vG - SAAO = + .07 ± .02 (17 stars). In fact the agreement between the two methods is almost certainly better than this. The intrinsic lines for metal deficient cepheids used by van Genderen depends on computations by Lub and Pel (1977) using Kurucz atmospheres. To apply these results to long period cepheids on their descending branches it is necessary to make a considerable linear extrapolation of the Lub-Pel results. If we omit the redder stars ($\overline{V-B}$ > 0.5) for which this effect is most important we find vG - SAAO = 0.03 ± 0.01 (11 stars). The dispersion shows that the standard error of a single comparison is 0.05. Van Genderen finds an average standard error of 0.04 for his reddenings of these stars. This indicates that the standard error of a VBI reddening is ∿ 0.03 which accords with other estimates (e.g. Feast and Balona 1980). Dr J Caldwell has kindly pointed out to me that for 10 cepheids in galactic clusters, the scatter in the BVI reddenings is also 0.03 (as found from a comparison with the cluster OB star reddenings). It is worth noting that the abundance determination for SMC cepheids by Pel, van Genderen and Lub (1981) does not depend on such long extrapolation of the models since the work refers to 10 day cepheids near maximum.

Some DDO photometry of Magellanic Cloud cepheids has been published (Dean 1981a, b) but has not yet been discussed from the point of view of reddening. Similarly McNamara and Feltz (1980) have observed MC cepheids in the Strömgren system. Details are not yet available but apparently they yield low reddenings for LMC cepheids. These workers also find that the galactic foreground absorption is small (E_{B-V} = 0.034 (LMC), 0.019 (SMC)).

Laney (1983a) has made a detailed spectroscopic study of cepheids in both Clouds and has shown that a consistent system of spectral types can be established. This eliminates a previous colour-spectral type anomaly for long-period cepheids. Comparing his results with a $(B-V)_0$ spectral type relation he deduces that the reddenings of his cepheids must be very small (less than ~ 0.05) slightly less than given by the multicolour observations.

Madore (1982) has attempted to derive reddenings for LMC cepheids by a new method. Amongst other things this depends upon the coefficient of the colour term (β) in the P-L-C relation being near 6 rather than near 2.7 as is derived in the next section. This high value of β seems to depend on an attempt to fit a number of low amplitude cepheids, having sinusoidal light curves and log P $\sim$ 0.5, into the P-L-C relation. In view of their distinctive physical characteristics (cf. Connelly 1980) these Cepheids have generally been recognized as overtone pulsators. In that case much too short a period has been adopted by Madore for these stars and in any case his reddenings are incompatible with those derived from multicolour photometry.

The above discussion suggests that the colours of Magellanic Cloud cepheids are naturally interpreted in terms of modest reddenings and metal deficiencies. It does not seem necessary to invoke blueing effects of companions to explain the colours of SMC cepheids as suggested by De Yoreo and Karp (1979). Companions are of course to be expected occasionally and some progress has been made by van Genderen (1977) to sort these out from Walraven photometry. The procedure is not entirely straightforward as can be seen in the extensive literature on the detection of companions to galactic cepheids.

4. P-L AND P-L-C RELATIONS IN B, V

Since Sandage (1958) showed that one would expect cepheids to be more accurately represented by a P-L-C than a P-L relation, several attempts have been made to determine the coefficient of the colour term. A weakness in the early work arises from the fact that for a P-L-C relation of the form,

$$\langle V_o \rangle = \alpha \log P + \beta (\langle B_o \rangle - \langle V_o \rangle) + \gamma \qquad (1)$$

theory suggests β will be close to 3. Since this is similar to $R = A_V/E_{B-V}$ it is not possible to distinguish an intrinsic colour term from differential reddening between cepheids unless individual reddenings are available. One of the aims of the BVI photometry as just discussed was to obtain these reddenings and as a result MWF claimed to have established empirically the existence of an intrinsic colour term. The recent literature has shown that there is some misunderstanding of the present status of the P-L-C relation and it is necessary to discuss at least four separate issues. These are: (1) Is the existence of a P-L-C relation empirically established?: (2) How accurately can β be determined?: (3) How well does the P-L-C relation conform to theory?: (4) What are the relative merits of the P-L and P-L-C relations for distance determination?

On the first point the evidence given by MWF consists of 31 LMC cepheids (26 with log P < 1.7) for which individual reddenings were available. Their figure 4 shows that: (a) The $\langle V \rangle$, log P relation has substantial scatter (σ = 0.30): (b) The $\langle V_o \rangle$, log P relation has slightly less scatter (σ = 0.27): (c) The introduction of a colour term with β = 2.70 drastically reduces the scatter (σ = 0.14) except for the five 100 day cepheids. This demonstrates that a colour term exists. Arguments against this reduce to a claim that the real reddening scatter is substantially larger than the observed scatter which as we have seen cannot be the case.

Coulson and Caldwell are at present analysing BVI observations of 52 SMC cepheids. Initial solutions indicate that a significant intrinsic colour term near 3 is present.

It is well known that the application of the method of least squares to an equation such as (1) where there are observational errors in more than one variable, will lead to biased coefficients. In the case of the P-L-C relationship such a bias in determination of β can be demonstrated from actual LMC data (MWF), from an approximate analytical approach (Feast and Balona 1980) or by computer simulation (Brodie and Madore 1980). The method of maximum likelihood was devised to deal with problems of this kind (cf. Kendall and Stuart 1967) and using it, MWF obtained β = 2.70 for the LMC cepheids. Feast and Balona (1980) showed that this result is not significantly affected by taking into account a reddening induced correlation of errors in $\langle V_o \rangle$ and ($\langle B_o \rangle - \langle V_o \rangle$). Balona (1983) has set out the method in somewhat greater detail and finds that, for acceptable values of the various observational errors, the uncertainty in β is about 0.2.

The above results use errors estimated in a straightforward way from the observations. If errors in $\langle V_o \rangle$ and ($\langle B_o \rangle - \langle V_o \rangle$) were entirely dominated by errors in the reddening corrections and if these errors were large enough to entirely dominate the spread in the $\langle V_o \rangle$, log P and ($\langle B_o \rangle - \langle V_o \rangle$), log P diagrams, it is easily seen that a spurious value of β (= R = A_V/E_{B-V}) might be found. Such a suggestion has been made by Clube and Dawe (1983). As already indicated this would require the true spread in the reddenings to be greater than the apparent spread and is generally inconsistent with the numerical values of the errors, intrinsic scatter etc (cf. Feast and Balona 1980). Clube and Dawe also confuse intrinsic spread in the log P, ($\langle B_o \rangle - \langle V_o \rangle$) plane with (possible) intrinsic spread in the $(\overline{V-I})$, $(\overline{B-V})$ plane which is quite a separate issue. Much of their discussion of the spread in the P, C relation is based on a misunderstanding of Feast and Balona (1980) who actually discuss only cepheids with individual reddening corrections.

Some preliminary attempt has been made by Stift (1982) to deal with the P-L-C relation by computer simulation. However amongst other things his published results do not extend to the spread of intrinsic colours shown by MWFs sample of LMC cepheids. The very sweeping claims made by Stift can only be evaluated when full details covering the relevant range of parameters are given.

A detailed comparison with theory will not be given here but an investigation by Cogan (1980) indicates that the empirical P-L-C relation is in good accord with theoretical expectations (LMC). It will be important to study this again when the SMC results become available.

De Vaucouleurs (e.g. 1960) suggested that the LMC was a flattened system at about 27° to the plane of the sky and he attempted to find the sense of the tilt using available photographic data on cepheids. However these results were very uncertain. Gascoigne and Shobbrook (1978) made accurate observations of cepheids on the far East and West side of the LMC and found a significant effect consistent with de Vaucouleurs prediction and showing that the eastern edge of the LMC is nearer to us than the western (a difference in modulus of 0.12 for an angular separation of $6\overset{\circ}{.}5$). Apart from this, the scatter about the P-L-C relation is no more than can be anticipated from observational errors (cf. MWF). There can thus be no significant contribution to this scatter from either a large depth of the LMC or from abundance differences between cepheids. First crossing cepheids would be expected to be displaced by $\sim 0\overset{m}{.}3$ from cepheids on second or subsequent crossings of the instability strip (cf. Becker, Iben and Tuggle 1977). There is no evidence therefore for any of these in the SAAO BVI sample (log P < 1.7) of the LMC. Such cepheids are expected to be a very small percentage of the total population but it might be possible to use the large photographic programmes to select first crossing candidates for detailed photoelectric study.

The scatter of the 100 day cepheids in the P-L and P-L-C diagrams has long been known. A proper understanding of these very luminous stars is essential if for no other reason than their potential importance in extragalactic distance scale problems. Van Genderen (1983) has suggested that the scatter results from a mixture of first and second crossing cepheids and this point obviously deserves detailed consideration. He has also emphasised that the theoretical P-L-C relation contains higher order terms (cf. Iben and Tuggle 1975). It would be important to find these observationally although rough estimates suggest that the effects will be small.

There has been some discussion recently about the relative merits of the P-L and the P-L-C relations as extragalactic distance indicators. It has been urged against the use of P-L-C relation that it is abundance sensitive. However, as Dr J Caldwell has pointed out to me, in the formulation of Iben and Tuggle there is a significant (though lower) abundance effect in the P-L relation. Furthermore whilst the P-L-C relation is relatively insensitive to reddening we require accurate reddening corrections for the P-L relation. If these reddenings are derived from cepheid colours then abundances are needed to estimate intrinsic colours. It is in fact not unreasonable to hope that for any galaxy in which cepheids can be measured it will be possible to obtain abundances for HII regions at least. There remains the major disadvantage that the P-L relation is a strip rather than a line and this can give rise to serious sampling problems.

The zero point of the P-L-C relations is derived from galactic cepheids of known distance (i.e. in clusters) in our Galaxy or from those with radii determinations.

For the LMC P-L-C relation

$$\langle M_V \rangle = -3.80 \log P + 2.70 (\langle B_o \rangle - \langle V_o \rangle) + \phi \qquad (2)$$

MWF found $\phi_1 = -2.39$ based on clusters with ZAMS fitting and scaled to a Hyades modulus of 3.03. Several writers (Stothers 1983, Fernie and McGonegal 1983, Caldwell 1983) have recently reconsidered this problem. Caldwell uses a ZAMS from Schmidt-Kaler (1982) which depends on the Hyades being metal rich and at a modulus of 3.28. He finds $\phi_2 = -2.46 \pm 0.05$ in good agreement with results from radii, $\phi_3 = -2.42 \pm 0.05$ (cf. MWF from Balona 1977). Despite this generally satisfying consistency there has been some concern over distances for calibrating clusters derived from Strömgren Hβ photometry (Schmidt 1980a, b, 1981, 1982a, b, 1983). These average $\sim 0^{m}.4$ less than those of Caldwell. This discrepancy has been much reduced in recent work by Balona and Shobbrook (1983). They re-calibrate the Hβ index using much new work by Shobbrook and with a tie directly to the Pleiades and ultimately to F stars of known parallaxes. Using their calibration with Schmidt's data and Caldwell's absorptions for the cluster cepheids one finds $\phi_4 = -2.26 \pm .06$. Evidently a mean ϕ_2, ϕ_3 and ϕ_4 differs little from ϕ_1 as adopted by MWF. These results must still be corrected for abundance effects. MWF estimated the correction as $-0^{m}.11$. Using Bell and Gustafsson models, Caldwell now estimates this to be $-0^{m}.16$. Thus the best current P-L-C (true) modulus for the LMC is 18.64. A useful estimate for the SMC should follow from the current work of Caldwell and Coulson.

5. P-L AND P-L-C RELATIONS IN THE INFRARED

McGonegal et al. (1982) have shown that important results can be obtained from the study of MC cepheids in the 1 to 2μ region. They find that single (random phase) observations at H (1.6μ) allows them to define a P-L relation with a scatter of only $\sigma = 0.25$ (cf. McAlary et al. 1983). Because of this and because infrared observations overcome some of the problems of interstellar absorption,* the method has great promise and is being actively followed up both in the Clouds and other galaxies. Laney (SAAO) and Stobie (ROE) are observing cepheids in both Clouds and in the Galaxy at J, H and K. The aim is to get good light curves for a limited number of cepheids. Matters such as the intrinsic width of the P-L relation can then be examined. They find that some MC cepheids have substantial infrared amplitudes ($\Delta H \sim 0^{m}.5$). After making small reddening

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* D Laney has pointed out that the distances to the galactic calibrating clusters depend on $R = A_V/E_{B-V}$ and uncertainties in R can thus significantly affect the calibration of infrared P-L relations.

corrections the SAAO infrared data (log P < 2.0) can be fitted by

$$\langle H_o \rangle = -3.34 \log P + \gamma$$

γ = 16.19 (17 stars LMC) and 16.61 (14 stars SMC). The dispersions, σ, are 0.10 (LMC) and 0.15 (SMC). A considerable reduction over the value for single (random phase) observations. Some evidence for an infrared colour term has also been found. SAAO infrared observations for 8 galactic calibrating cepheids gives a P-L zero point of -2.63. This leads to distance moduli of 18.82 (LMC) and 19.24 (SMC) (Δ mod = 0.42) provided there are no significant abundance effects at H. For the LMC it is probably best to take a straight mean of the above modulus with the P-L-C modulus (18.64) of the last section giving a mean true modulus of 18.73.

This paper depends exceptionally heavily on discussions with and results from Drs L A Balona, J A R Caldwell, I M Coulson, D Laney, R R Shobbrook and R S Stobie.

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DISCUSSION

McCarthy: Can you compare for us the distance modulus of the Small Cloud as derived by the IR method and by the P-L-C method? I would be interested to compare the differences between the Clouds.
Feast: Data for the SMC is at present being studied for a P-L-C relation. When this has been done, the comparison you suggest will be of interest.
Stift: I have a list of 11 points of criticism, and like to give them here!
(Editors note: Due to the speed with which these were given, Feast could not comment on each of them at once but later wrote his replies as they appear in the discussion below. Stift expanded slightly some of his questions after that. The references in Feast's answers can be found in his paper. Of the original 11 points 2 have been untracebly lost for eternity.)
Stift: 1. The Cape photographic cepheid surveys exhibit very large photometric errors; they do not constitute an improvement over previous surveys, such as e.g. Butler's (1976, 1978) which keep errors down to 0.04 to 0.05 mag.
Feast: The systematic and random errors in the Cape photographic work have been discussed in detail by Martin et al. (1981) and by Martin (1980a) and have been compared with earlier work. The errors appear to be at the level expected for careful photographic photometry.
Stift: 2. If canonical theory holds -which I do not believe- the Cape photoelectric SMC photometry is of no better precision than the Dunsink photographic LMC photometry, the rms error of a mean V magnitude being of the order of 0.04 to 0.05 for both.
Feast: The Cape photoelectric photometry of SMC Cepheids published earlier (Martin and Warren 1979; Martin 1981) is inadequate for the study of P-L-C relations since it contains BVI observations for very few stars (so individual reddenings cannot be derived) and some stars have very few observations. Discussion was therefore deferred until extensive BVI data became available (Coulson and Caldwell, to be published). The text above contains preliminary results from this latter data set.
Stift: 3. The BVI intrinsic Galactic Cepheid locus has been empirically established using the <u>lowest</u> published reddening values (see Fernie 1967). The intrinsic LMC Cepheid locus has not been shown by Martin, Warren and Feast for good reason, because it turns out that more than 1/3 of the stars exhibit negative or zero reddening.
Feast: The BVI intrinsic line in current use is a slight revision by Caldwell of that given by Dean, Warren and Cousins (1978) which is based on Cepheids with known reddening (i.e. in galactic clusters). Martin, Warren and Feast (1979) adjusted an earlier version of this line for abundance effects (Bell-Parsons models) and found a mean E(B-V)=0.03. With such a small mean reddening and with a standard error for a single E(B-V) determination of about 0.03, it is obvious statistically that some apparent negative reddenings will result. As indicated in the text, the newer models show that the BVI diagram is less sensitive to abundance than previously thought and higher mean

reddenings are found. It must be stressed that the mean reddening (which depends on the absolute position of the BVI intrinsic line) is unimportant in establishing the existence of a P-L-C relation. It is the correction for differential reddening between Cepheids that is relevant. With regard to the first sentence it should be noted that Pel's intrinsic colours for Cepheids in the Walraven system (1978 A. Ap. 62, p 75) lead to slightly lower reddenings for galactic Cepheids than the adopted BVI intrinsic colours.

Stift: 4. The Dunsink surveys show that abundance differences within the LMC are probably important (Wayman, Stift, and Butler 1983); this enhances the true scatter in the observed reddenings due to a wider intrinsic Cepheid locus.

Feast: It will be interesting to see the Dunsink results, though it is obviously very difficult to obtain unambiguous evidence of abundance variations from BV photometry alone. As indicated in the text, any intrinsic scatter in the BVI locus will increase the observed reddening scatter which is thus an upper limit to the true scatter. Thus the wider the intrinsic line, the lower the true scatter in differential reddening and the more obvious the need for a P-L-C relation is.

Stift: 5. Compared to all other surveys the Cape photoelectric LMC photometry shows abnormally high scatter about the P-L relation and at the same time abnormally low scatter about the P-L-C relation. It is virtually impossible to rederive the published mean magnitudes from the original observations.

Feast: It is the significant spread (at a given period) in magnitude and colour for Cepheids in the Cape LMC BVI programme that makes the sample well suited for the determination of the P-L-C relation. Whether Cepheids at the extremes of colour and luminosity at a given period (i.e. at the edges of the instability strip) are frequent or rare in the LMC can only be determined when extensive photoelectric multicolour photometry has been carried out. In view of the lack of individual reddenings in other surveys and of the higher errors in photographic work, it is not clear that any higher spread (should it exist) in a P-L-C relation is a matter of significance.

Stift: 6. The initially published Cape SMC Cepheid photometry (Martin et al. 1981) bears no resemblance to the preliminary P-L-C relation presented by Feast. For the SMC the scatter about the original P-L-C relation is about 50% larger than for the LMC.

Feast: The paper mentioned by you contains only photographic (BV) photometry. In view of the lack of individual reddening corrections and the lower accuracy of photographic work compared to photoelectric, a higher scatter would indeed be anticipated. Regarding photoelectric work I refer to what I said after your point 2. **Stift:** The Tables in Martin et al. (1981) clearly say "photoelectric"!

Stift: 7. Stift (1982) and Clube and Dawe (1983) have demonstrated that the maximum likelihood estimator given by Feast and Balona (1980) as applied to MC Cepheids leads to wrong results. Only the assumption of an arbitrary value for the error of a (B-V) determination yields the canonical value of $\beta = 2.70$.

Feast: These statements are incorrect. The approximation adopted by Clube and Dawe is discussed in the text. Essentially they assume the spread in the P-L relation is due to differential reddening. That this is not so for the Cape LMC BVI sample is shown by the small scatter in the observed reddenings (c.f. also the answer at (4) above). From your second sentence it seems that you base your conclusion on Table 3 of Stift (1982). This table is calculated using one possible maximum likelihood estimator (though not the model used by Martin, Warren and Feast, nor that used in the discussion of correlation errors by Feast and Balona 1980 or Balona 1983). In this model a value of σ_0(B-V) is adopted and the remaining parameters are then calculated. Amongst the derived parameters is σV which must evidently be compatible with directly estimated values for σV. The first two colums below are from Stift (1982), Table 3. The values of σV which come directly from these solutions have been added.

σ(B-V)	β	σV
0.02	2.34	0.10
0.03	2.48	0.08
0.04	2.71	0.03
0.05	3.09	variance negative

From external evidence Martin, Warren, and Feast found σ(B-V)= 0.04 and σV= 0.03. Thus in this model, β cannot deviate from 2.7 by more than 0.2 without σV departing radically from its observed value. (For a detailed discussion of this question in a model which takes into account partial correlation of errors, see Balona 1983).

Stift: 8. Although first crossings can be neglected in the LMC the same is probably not true for the SMC (Stift, this symposium).

Feast: It will be interesting to see if first crossing candidates emerge when the BVI data for SMC Cepheids is fully analysed.

Stift: 9. Why use zero points when it has been demonstrated that chance selection effects are devastating? It should be remembered that the Cape P-L-C relation zero point is extrapolated to log P= 0.0 from a sample of only 26 Cepheids with periods confined between 0.9 and 1.7 in log P!

Feast: This question seems to refer to the discussion as to whether to fix a zero point at log P =0 or at some other value (say log P =0.8). It is clearly necessary, in comparing different cepheid samples to use P-L-C or P-L relations with identical period and colour coefficients (allowing suitably for abundance effects). In that case it is a matter of indifference at which period the zero point is given. Because of the considerable width of the P-L relation, serious statistical selection effects can arise unless care is taken. The P-L-C relation is not subject to this problem. **Stift:** No, see my poster!

Pel: I have only three points...... Firstly, we have now extended our SMC and LMC Cepheid samples, and also done more work on the calibration of the Walraven photometry. My present best numbers for the mean metallicity of Cloud Cepheids are Fe/H =-0.6 for the SMC and -0.2 for the LMC, which is very close to the values you used.

Secondly, I share your hesitation about the rather high reddenings that van Genderen obtained for long-period Cepheids in the Clouds. The Cepheids in our Fe/H programme were observed in a way which is not ideal for reddening determinations, but for these stars with shorter periods I estimate reddenings smaller than 0.10 (including the foreground).

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Finally, I became worried also about the galactic zero-point calibration after seeing Schmidt's results for some of the open clusters with Cepheids. I have now analysed quite extensive Walraven photometry for NGC6087, the cluster containing S Nor. By fitting NGC6087 to the Pleiades photometry of van Leeuwen, and using also van Leeuwen's Pleiades distance, which is based on a fit to nearby stars with trigonometric parallaxes, one bypasses the Hyades entirely. The surprising result for NGC6087 is a distance which differs hardly from the one adopted in 1969 by Sandage and Tammann, whereas from the revised Hyades distance one would expect an increase of about 0.25 mag in distance modulus with respect to the old calibration.

Feast: Regarding your last point, this may be another indication that allowance needs to be made for a higher metallicity in the Hyades compared to clusters containing Cepheids. Some allowance for this is made in the Schmidt-Kaler calibration used by Caldwell.

McNamara: The m_1-(b-y) diagram of the LMC Cepheids indicates that the reddening is very small, 0.04 mag, probably due only to galactic foreground extinction.

Frogel: Is it possible to test for a dependence of metallicity of the Cepheids on period (i.e. mass), so that metal enrichment history can be investigated?

Pel: For individual Cepheids the present photometric determinations of metallicity are still very inaccurate, but for sufficiently large samples one can get a reasonably accurate mean Fe/H. One could do this for different period intervals of Cepheids, but this would provide little information on the chemical history of the Clouds, since all Cepheids are very young stars.

Dufour: Nebular abundance studies of LMC and SMC HII regions suggest depletions in the CNO group elements 2 or 3 times greater in eaCh cloud than you used for the Cepheids. How would such significantly larger depletions in reality affect your distance modulus results?

Feast: I don't think that this sort of problem has been investigated in any detail. However, the metallicity effects on the P-L-C relation come mainly through a change in the (B-V)-temperature relation (c.f. Gascoigne, M.N. 166, p 25p, 1974). Since this is primarily due to line blanketing changes, it is the abundances of elements such as iron etc., which are of most importance, I presume.

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