A discussion on the reddening of long period Cepheids in the Magellanic Clouds

A. M. van Genderen

Leiden Observatory, Postbus 9513, NL-2300 RA Leiden, The Netherlands

Received August 20, accepted November 3, 1982

Summary. *VBLUW* photometry of 9 long-period Cepheids in the SMC (13\^d < P < 127\^d) and 20 in the LMC (16\^d < P < 134\^d) is used to determine the individual reddenings. For this purpose Cepheid loci are constructed in the V−B/B−L diagram with a metalabundance (A) of 1/5 and 1/2 of the solar abundance (A\_⊙) for the SMC and LMC Cepheids, respectively. Individual and average reddenings are compared with those of other studies on Cepheids and other types of supergiants. Usually the agreement is satisfactory. Exceptions are the comparisons with the reddenings for LMC Cepheids of Martin et al. (1979) and Madore (1982) which are systematically lower (by 0.07 mag) and higher (by 0.22 mag), respectively, than ours.

As a by-product the lower limit of the metal abundance for the SMC Cepheids is estimated to be about A = 1/6 A\_⊙.

Key words: Magellanic Clouds – Cepheids – photometry – interstellar absorption and extinction

1. Introduction

In two previous papers *VBLUW* photometry of Cepheids in the center of the Small Magellanic Cloud (SMC) has been discussed by the author (van Genderen, 1969b; 1977 hereafter called Paper I and II, respectively). These Cepheids appeared to be bluer than their galactic counterparts, a fact which has been also found by *UBV* photometrists (cf. Gascoigne and Kron, 1965; Butler, 1976). Besides the SMC Cepheids showed a conspicuous ultra violet excess in the L band (A\_eff \approx 3840 \AA). These characteristics are explained by a metal deficiency relative to the galactic Cepheids. In Paper II the lower limit of the metal abundance A of the SMC Cepheids could be roughly estimated with the aid of their position in the V−B/B−L diagram, viz. A \approx 1/5 A\_⊙. However it was not clear why the excess in the second ultraviolet pass band U (A\_eff \approx 3630 \AA) was not so outspoken. This fact can now be explained with the aid of theoretical colours based on the model atmospheres of Kurucz (1979) for metal poor F and G type supergiants with a micro turbulence of v\_mic = 4 km \cdot s\(^{-1}\) (see Fig. 8 of Lub and Pel, 1977).

New *VBLUW* photometry of short period Cepheids (8\^d < P < 15\^d) has been performed in 1979 after the move of the telescope from South Africa to Chile (at the ESO). The photometer was improved in several respects and besides the Cepheids were now selected in the outskirts of the SMC, where crowding of stars and reddening problems are much less disturbing. The metal abundance relative to Population I stars in the solar neighbourhood could be determined with much more certainty with the aid of the reddening free metal index [B−L]:A = 1/5 A\_⊙ (with extreme limits of 1/9 and 1/3 A\_⊙) (Pel et al., 1981, hereafter called Paper III).

So far no *VBLUW* photometry of LMC Cepheids has been published. Since it is important to know the metal abundance in order to determine a precise position of the intrinsic Cepheid locus in the V−B/B−L diagram, we give a short review. Pagel et al. (1978) and Lequeux et al. (1979) suggested a metal underabundance by a factor 1.4 and 1.4−2.1, respectively. Ca K line strengths of a few F type supergiants of Smith (1980) resulted in a factor 1.6. Unpublished *VBLUW* photometry by the author pointed into the direction of a factor 2. For a tentative average we shall use A = 1/2 A\_⊙ for the LMC.

The present paper discusses the reddening of long period Cepheids (13\^d < P < 134\^d) in the SMC and LMC based on *VBLUW* photometry made in the years before the move of the telescope to Chile in 1978. As a by-product the lower limit of the metal abundance of the SMC Cepheids is discussed.

2. The observations

The observations have been made with the 90-cm light-collector of the former Leiden Southern Station in South Africa (the SAAO annex) between 1974 and 1978. Particulars and references on the *VBLUW* system can be found in Papers I–III and in a forthcoming paper which will appear in the Supplement Series. The last one will contain the individual observations, the light- and colour

<table>
<thead>
<tr>
<th>HW No</th>
<th>P (d)</th>
<th>V−B</th>
<th>B−V</th>
<th>B−U</th>
<th>V_f</th>
<th>(B−V)_f</th>
<th>(B−V) _f</th>
</tr>
</thead>
<tbody>
<tr>
<td>821</td>
<td>127.27</td>
<td>-2.066</td>
<td>.451</td>
<td>.433</td>
<td>.592</td>
<td>11.97</td>
<td>1.06</td>
</tr>
<tr>
<td>829</td>
<td>86.8</td>
<td>-2.043</td>
<td>.361</td>
<td>.340</td>
<td>.526</td>
<td>11.92</td>
<td>0.87</td>
</tr>
<tr>
<td>834</td>
<td>73.45</td>
<td>-2.149</td>
<td>.355</td>
<td>.332</td>
<td>.519</td>
<td>12.19</td>
<td>0.85</td>
</tr>
<tr>
<td>824</td>
<td>65.825</td>
<td>-2.218</td>
<td>.360</td>
<td>.336</td>
<td>.574</td>
<td>12.36</td>
<td>0.86</td>
</tr>
<tr>
<td>837</td>
<td>42.77</td>
<td>-2.577</td>
<td>.382</td>
<td>.353</td>
<td>.53</td>
<td>13.26</td>
<td>0.91</td>
</tr>
<tr>
<td>11182</td>
<td>39.199</td>
<td>-2.761</td>
<td>.439</td>
<td>.37</td>
<td>.55</td>
<td>13.71</td>
<td>1.03</td>
</tr>
<tr>
<td>817</td>
<td>18.897</td>
<td>-2.801</td>
<td>.258</td>
<td>.227</td>
<td>.48</td>
<td>13.84</td>
<td>0.63</td>
</tr>
<tr>
<td>1328</td>
<td>15.841</td>
<td>-2.903</td>
<td>.238</td>
<td>.258</td>
<td>.406</td>
<td>14.09</td>
<td>0.59</td>
</tr>
<tr>
<td>827</td>
<td>13.466</td>
<td>-3.062</td>
<td>.236</td>
<td>.206</td>
<td>.45</td>
<td>14.49</td>
<td>0.58</td>
</tr>
</tbody>
</table>
curves, a discussion on the improvement of the periods, a description of the transformation of our $V$ brightness and $V - B$ colour index (in log intensity scale) into equivalent $UBV$ parameters $V$ and $B - V$ (with subscript $J$ and in mag scale). Zero point errors in brightnesses and colours are usually smaller than 0.005 (in log intensity scale).

Light- and colour curves were obtained of seven long-period Cepheids in the SMC ($13 \leq P < 127$) and twenty in the LMC ($16 < P < 134$). The first sample is mainly situated in the less dense areas of the western part of the SMC along the bar, the second sample is distributed all over the LMC.

Table 1 summarizes several particulars of the seven SMC Cepheids and two specimen taken from Papers I (HV 824) and II (HV 821). The photometric data of HV 829 are based on an average of the observations of Paper I and new observations made in 1975 and 1976. Because of slight changes in the photometric system, observations of Paper I and II were transformed into the system of 1970/1978 by transformation formulae determined by Pel (1980). Table 2 gives the particulars of twenty LMC Cepheids.

Both tables list $\langle V \rangle$ (the intensity mean of the light curve transformed into log intensity), the average colour indices (with the exception of $U - W$ because of the faintness of the flux in the $W$ band) determined from the colour curves by reading them off at phase intervals of 0.1 and at last the $UBV$ parameters $V_j$ and $(B - V)_j$. If the scatter of the colour curves is too large, we only give an average value with the estimated error.

3. The $V - B/B - L$ and $V - B/B - U$ diagrams. Discussion

Figures 1 and 3 depict the $1 - B/B - L$ diagrams for the nine SMC Cepheids and a selection of nine LMC Cepheids, respectively, with the observed position of the loops. If the colour curves show too much scatter, only the average position is indicated (plus signs). Further the figures show a part of the main sequence (curved line) and the locus for galactic Cepheids (straight line) (Pel, 1978) and the loci for a metal abundance of $A = 1/5 A_\odot$ and $1/2 A_\odot$ for the SMC and LMC objects, respectively (dotted lines). Both loci were obtained by moving the galactic locus upwards with amounts determined by interpolating colours for supergiant models with $A = 1, 0.1, 0.01 A_\odot$ in the theoretical $V - B/B - L$ diagram. Such a diagram has been computed by Lub and Pel (1977, Fig. 8).

Figures 2 and 4 show the $V - B/B - U$ diagrams with the loops of Cepheids with reliable $B - U$ curves, otherwise the averages are
plotted (plus signs). Also are shown the main sequence (curved line) and the region covered by the galactic Cepheid loops (dotted curve) (Pel, 1978).

In all figures the arrows represent the reddening trajectories. HV numbers are indicated with the period between brackets. The moments of maximum brightness are indicated by circles.

It is clearly to be seen that the SMC loops cluster closely at the right of the locus for $A = 1/5 A_\odot$ (Fig. 1). An exception is HV 1328, which also according to its abnormal position in Fig. 2 may have a blue companion. The maximum of HV 824 lies on the locus for galactic Cepheids, but this is likely caused by the unreliable part of $B - L$ curve near maximum brightness. In Figs. 3 and 4 HV 2580 is a candidate to have a blue companion.

First we shall discuss the reddening of the SMC Cepheids. The systematic distribution of the loops along the $A = 1/5 A_\odot$ locus supports the result of Papers II and III. A close distance at the right of this locus can be expected if a small amount of foreground reddening is present: $E(B - V)_f = 0.05$ (Walraven and Walraven, 1971) and 0.04 mag (Azzopardi and Vigneau, 1977) or $E(V - B) \sim 0.02$. Although most of these Cepheids are situated in the outer areas, some reddening caused by dust in the SMC cannot be excluded. Table 1 lists the individual total reddening values (foreground as well as internal reddening), which were determined with respect to the locus of $A = 1/5 A_\odot$. Estimated errors are added. These redenings were found by shifting the descending branch of the loops onto the locus, at least if they are normal (narrow shaped and running counterclockwise and parallel to the locus). This method has been also applied by Pel (1978) on galactic Cepheids. If loops are not normal, because of a lower quality of the colour curves, we drew an average line through it and shifted this onto the locus. No reddening could be determined for HV 1328 because of a probable blue companion.

The average reddening for our sample $E(B - V)_J = 0.11$ mag, which is reasonable in view of the size of the foreground reddening (quoted above) and the expectation that the internal reddening outside the mainbody of the SMC will be small.

If we should use for example a locus for $A = 1/7 A_\odot$, no reddening at all would be present, which is highly unlikely. Thus it appears that the lower limit of the metal abundance of our long period Cepheids is $A \sim 1/6 A_\odot$. The upper limit is according to Paper III 1/3 $A_\odot$.

As mentioned in Sect. 1, the ultraviolet excess in the $U$ band is not so outspoken, but if the photometry is reasonably reliable a slight $B - U$ excess with respect to the region of galactic Cepheids must be visible. Indeed, the Cepheids in Fig. 2 have a preference for the upper part of the galactic Cepheid region similar to the Cepheids discussed in Paper II.

The redenings for the LMC Cepheids were determined in a similar way as the SMC Cepheids. Table 2 tabulates the redenings.
Fig. 3. The $V-B/B-L$ diagrams for a selection of the LMC Cepheids. The locus for galactic Cepheids ($A = A_0$) (straight line) and the locus for a metal abundance $A = 1/2 A_0$ (dotted line) are shown.

with the estimated errors. No reddening can be determined for HV 2580, because of a probable blue companion.

The average total reddening for the 19 LMC long period Cepheids amounts to $E(B-V)_T = 0.14$ mag. This value is comparable to that of Brunet (1975) based on $UBV$ photometry of 160 LMC supergiants viz. $E(B-V)_T = 0.12$ mag. Martin et al. (1976) and Vangioni-Flam et al. (1980) think that this value is underestimated, since there are very dusty regions, where only a few stars have been observed. Since this is often the case like for our sample of Cepheids, it is not surprising that both averages are nearly similar.

Further examples are the samples consisting of 43 B0–B3 type stars studied by Ardeberg and Maurice (1980) for which $E(B-V)_T = 0.12$ and of 44 O–A0 type stars studied by van Genderen et al. (1983) (in the $VBLUW$ system) for which $E(B-V)_T = 0.18$ mag. [It appears that the redenings in the last paper for stars in common with Brunet (1975) and Ardeberg and Maurice (1980) are systematically higher. This is probably due to a difference between the intrinsic $UBV$ and $VBLUW$ colours used for early type stars.]

The contribution of the foreground reddening is practically of the same order as for the SMC: 0.05, 0.07, and 0.07 mag according to Walraven and Walraven (1971), Iserstedt (1975), and Brunet (1975), respectively.

It is of importance to discuss in short the influence of possible companions on the redenings just derived. As demonstrated by the Cepheids HV 1328 and HV 2580, the presence of bright blue companions is at once visible in the $V-B/B-L$ and $V-B/B-U$ diagrams. In the first mentioned diagram the star’s distance to the locus is increased, causing an overestimate of the reddening. If the companion is a bright red star, the shift in this diagram will take place along the locus downwards, thus leaving the estimated reddening nearly unaltered. In both cases the shape of the loops will become odd, making the reddening determination more difficult. The fact that we found only two out of 29 Cepheids to be double, sounds abnormally low in view of the results of other studies, revealing percentages of 20–30% (e.g. Paper II; Pel (1978); see also the IUE satellite studies on Cepheids by Eichendorf et al., 1982). The reason for this lack is that most Cepheids of our sample were selected by examining previous multicolour photometry. This does not imply that the rest of our sample is free of companions (other suspected doubles might be HV 827 and HV 12815). We are however sure that possible companions are not bright enough to have much influence on the position of the loops in the two-colour
diagrams. Therefore the error in our reddenings caused by possible companions must be regarded as small.

As a comparison we also list in Table 2 the reddenings of two other references. First we mention the four Cepheids HV 883, 2447, 2369, and 900 of which the reddenings of the present paper agree very well with those of van Genderen (1969a). In that paper (Sect. 1.5) the extinction in blue light is estimated by means of diagrams making use of the deviations of the Cepheids with respect to the average $P-L$ relation. This $P-L$ relation is adopted to be a straight line. (The good agreement between the results based on the two methods disappears, if a curved $P-L$ relation is used.) Secondly, Table 2 lists also the reddenings of Cepheids in common with Martin et al. (1979) based on $BV1$ photometry. The average reddening for their Cepheids in common with us amounts to $E(B-V)_n=0.07$ mag (the average for all their Cepheids amounts to 0.09 mag). This differs appreciably from what we find, viz. 0.18 mag. The inconsistency would disappear if we make use of a locus for $A=1/4 A_V$, but this seems to be rather unlikely in view of the metal abundance found by the authors mentioned in Sect. 1. Besides the method of Martin et al. (1979) to find reddenings is such that they increase with the metal abundance. Consequently, the inconsistency would then become even greater.

A more serious difference exists with Madore's (1982) work. He determined a formula to derive $E(B-V)_i$ from reddening independent parameters (period and amplitude) and a so called Wesenheit function. Using his Eq. (5) for the Cepheids of Table 2, the average reddening turns out to be 0.36 mag, which is nearly three times as high as our value and six times as high as that of Martin et al. (1979). In this context it is of interest to mention that if we adopt solar abundance for the LMC Cepheids, our average reddening would increase to $\sim 0.24$ mag. This can then be considered as an extreme upper limit. If the metal abundance of the LMC Cepheids turns out to be deficient by a factor 1.5 (instead of 2.0), then the average reddening would amount to $\sim 0.18$ mag. It is also important to mention that zero-point errors in our $V-B$ and $B-L$ colours by at most $\pm 0.005$ in log intensity scale are too small to have much influence on the reddening estimations.

Further research on the reddening problem is clearly required to investigate why the results of Martin et al. (1979) and of Madore (1982) differ so much from ours and from each other. It is certain that reddening cannot be ignored as is also shown convincingly by the infrared photometry of McGonegal et al. (1982).

However, the precise amount is still a matter of debate as is evident from our discussion. It must however be stressed that reddenings found so far with the $V-B/B-L$ diagram appear to be very reliable as is demonstrated by Pel (1978). Also the reddening of the short-period Cepheid HR 7308, which has been observed in the $VBLUW$ system (van Genderen, 1981), appeared to be in perfect agreement with a recent $UBV$ determination by Fernie (1982).

Acknowledgement. I am much indebted to the referee Dr. W. Eichendorf for some valuable remarks.

References


Postscript: Just after this paper was accepted, the author became aware of a very recent paper by Stift (1982, Astron. Astrophys. 112, 149). Stift seems to have found an explanation for the too low reddenings of Martin et al. (1979) and claims that a global reddening for the LMC in the order of $E(B-V)_i\sim 0.15$ (thus close to our value of 0.14) is found by his numerical simulations of the Cepheid instability strip.