METAL ABUNDANCE AND THE LUMINOSITIES OF CEPHEIDS

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SUMMARY

Semi-empirical arguments are advanced to show that, for a fixed colour and period, a cepheid with $Z = 0.005$ will be less luminous than one with $Z = 0.02$ by about 0.4 mag. Considered as distance indicators cepheids are therefore rather sensitive to metal abundance. Some implications of this are discussed.

Relative to those in the LMC and the Galaxy, the SMC cepheids exhibit two well-marked anomalies (i) a considerable proportion have periods in the range 1–3 days, where very few appear in other galaxies, and (ii) at shorter periods they are bluer, by about 0.1 in $B-V$. It has been suggested that both effects could be explained if the SMC cepheids had a lower metal content $Z$ (Iben 1967; Christy 1971), and some aspects of this suggestion, especially its effect on the zero-point of the P–L–C relation, have been discussed by the writer (Gascoigne 1972). More recently Iben & Tuggle (1970) have published new results for the theoretical mass–luminosity relation for stars in the vicinity of the cepheid instability strip, with explicit formula for the dependence on $Y$ and $Z$, and Bell & Parsons have shown by their method of synthetic spectra that at a given $T_e$, cepheids with lower $Z$ will have bluer $(B-V)$ colours because the differential blanketing will then be lower (Bell & Parsons 1972). These two papers make it possible to show directly how the constants in the PLC relation depend on metal abundance.

Following Sandage & Tammann (1969), we begin with a quasi-homology relation, in our case taken from Cogan (1970)

$$\log P = -1.625 + 1.75 \log R - 0.75 \log M.$$ 

We use the Iben & Tuggle relation for the mean luminosity $L$ during core helium burning. For the two cases we consider this becomes

$$\log M = -0.090 + 0.251 \log L$$

$$\log M = -0.125 + 0.251 \log L$$

$(X, Y, Z) = (0.71, 0.27, 0.02)$ and $(0.72, 0.275, 0.005)$ respectively. These results agree well with those found by Robertson (1971) for $5 M_\odot$ stars. Bell & Parsons give for the dependence of $(B-V)$ on $T_e$

$$\log T_e = 3.886 - 0.175 (B-V)_0, \quad Z = 0.02$$

$$\log T_e = 3.887 - 0.222 (B-V)_0, \quad Z = 0.005.$$ 

For the bolometric correction we use, as did Sandage & Tammann (1969)

$$M_{bol} = M_V + 0.145 - 0.322 (B-V).$$
We find for $Z = 0.02$

$$M_V = -2.60 - 3.64 \log P + 2.55 (B-V)_0$$  \hspace{1cm} (1)$$

and for $Z = 0.005$

$$M_V = -2.51 - 3.64 \log P + 3.14 (B-V)_0$$  \hspace{1cm} (2)$$

where the appropriate time means have been taken for $B$ and $V$.

Thus for a given period and colour, the cepheid with the higher metal content will be brighter by $0.09 + 0.59 (B-V)_0$, about 0.4 mag in a typical case. Our main problem is to see what effect this factor has on the modulus of the SMC. First however we observe that compared with the galactic cepheids of known moduli, equation (1) predicts luminosities which are too bright by about 0.3 mag, a reflection of course of the well-known discrepancy between the evolutionary and pulsational masses for cepheids. One might say it arises here because we have inserted an evolutionary mass into a pulsational equation. If we accept an arbitrary variation of the zero-point, we find the form of (1) which best fits the galactic cepheids is

$$M_V = -2.32 - 3.64 \log P + 2.55 (B-V)_0$$  \hspace{1cm} (3)$$

a decrease in luminosity by 0.28 mag. If equation (3) applies also to the SMC cepheids, the 24 for which photoelectric photometry is available (Gascoigne 1969, Table IIa) yield a modulus of 19.36. The corresponding figure for the LMC is 18.74, with mean deviations per cepheid of 0.13 and 0.11 respectively.

Considering now cepheids with $Z = 0.005$, it seems best to assume that the same factor of 0.28 should apply to equation (2), which becomes

$$M_V = -2.23 - 3.64 \log P + 3.14 (B-V)_0$$  \hspace{1cm} (4)$$

and repeating the above calculation, we find that the modulus for an SMC with this lower metal abundance is 18.95, 0.41 less than before. The mean deviation has risen to 0.18, with departures from equation (4) which are clearly systematic, in the sense that the observations would be better satisfied by a coefficient for $(B-V)_0$ nearer 2 than 3.14. This point had already emerged from the fitting of empirical P–L–C relations to the data in Gascoigne (1969). The larger coefficient originates partly in the Bell & Parsons results, which nevertheless make sense in that they go in the direction one would expect physically.

If our arguments are correct, cepheid luminosities are unexpectedly sensitive to metal abundances. It follows that the small deviations of the galactic cepheids from the mean relation, 0.08 mag, imply a high degree of chemical homogeneity for these stars, appreciably more so than might have been expected from abundance analyses of field stars. As noted by Iben & Tuggle, larger deviations like that for VY Per could readily be explained by abundance differences which observationally would be quite minor.

It is easy to show that the mean period–luminosity relation is less dependent on $Z$ than is the P–L–C relation. For putting into equation (3) the mean relation for galactic cepheids,

$$(B-V)_0 = 0.37 + 0.26 \log P$$

we find

$$M_V = -1.38 - 2.98 \log P.$$
Metal abundance and the luminosities of cepheids

If we suppose that for $Z = 0.005$ the period–colour relation becomes

$$(B-V)_0 = 0.27 + 0.26 \log P$$

(for the SMC the observational relation in Gascoigne’s (1969) is)

$$(B-V)_0 = 0.24 + 0.306 \log P$$

equation (3) becomes

$$M_V = -1.38 - 2.82 \log P.$$ 

The difference between the two is $0.16 \log P$, which for normal cepheids would lie between $0.1$ and $0.2$ mag. And differences in slope of this order, as between say two different galaxies, or different parts of the same galaxy, would be made difficult to detect by the natural scatter about the mean relations.

The modulus of the SMC has been discussed many times. The principal sources are:

<table>
<thead>
<tr>
<th>m–M</th>
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<tbody>
<tr>
<td>cepheids $(Z = 0.02)$</td>
<td>19.36</td>
<td>Gascoigne (1969)</td>
</tr>
<tr>
<td>cepheids $(Z = 0.005)$</td>
<td>18.95</td>
<td>This paper</td>
</tr>
<tr>
<td>RR Lyraes $(M_V = 0.5)$</td>
<td>19.15</td>
<td>Graham (1973)</td>
</tr>
<tr>
<td>red giants $(M_V = -2.7)$</td>
<td>19.0</td>
<td>Gascoigne (1972)</td>
</tr>
<tr>
<td>H–β observations</td>
<td>~18.8</td>
<td>Osmer (1973)</td>
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</tbody>
</table>

Bearing in mind that for SMC cepheids the bluer intrinsic colours and period distribution both favour lower $Z$ values (for the latter point see especially Robertson 1973), the best current estimate for the SMC modulus probably lies between 19.0 and 19.1.

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REFERENCES