The Impact of Large-Scale Surveys on Pulsating Star Research
ASP Conference Series, Vol. 203, 2000
L. Szabados & D. W. Kurtz, eds.

Theoretical Models for Classical Cepheids: Mean Magnitudes and Colors and the Evaluation of Distance, Reddening and Metallicity

Marcella Marconi, Filippina Caputo, Vincenzo Ripepi

Osservatorio Astronomico di Capodimonte, Via Moiariello 16, I-80131 Napoli, Italy

Abstract. We present a detailed analysis of theoretical period–luminosity (PL) and period–luminosity–color (PLC) relations of classical Cepheids, as derived from nonlinear, nonlocal, time-dependent convective pulsating models with different masses and chemical compositions. The predicted PL and PLC relations turn out to depend on the pulsator metallicity and, to a minor extent, on the adopted averages (magnitude-weighted or intensity-weighted) over the light cycle in different bands. We show that the determination of the reddening and true distance modulus of a galaxy from the observed PL and PLC relations is constrained by the metallicity sensitivity of these relations. Moreover, the metallicity sensitivity itself provides us with a powerful tool for deriving self-consistent evaluations of distance, reddening and metallicity of the host galaxy, once Cepheid measurements in at least three photometric bands are available. To illustrate this point, we apply our relations to the BVK data for Cepheids in the Magellanic Clouds, assuming to be unaware of their metallicities. The three filter method is finally adopted to evaluate the metallicity of galactic Cepheids (BVI data) as a function of their position.

1. Introduction

In the last few years an extensive grid of nonlinear, nonlocal, time-dependent convective models for classical Cepheids has been produced by our group. Results have been already published in a series of papers (Bono et al. 1999a, b, c, and references therein). Here, we only remind that the two main advantages of nonlinear convective models are: 1) the possibility of investigating the long term behavior of pulsating models (nonlinearity), and then predicting light curves, amplitudes, mean magnitudes and colors, and 2) the capability of modeling both the blue and the red boundaries of the instability strip through the nonlinear coupling between pulsation and convection.

2. Dependence on Metallicity and Averaging Type

In Bono et al. (1999b) bolometric light curves derived from models are transformed into the BVK curves and intensity-weighted mean magnitudes, and colors have been derived. Then, theoretical optical and near-infrared PL and PLC

https://doi.org/10.1017/S0252921100058024 Published online by Cambridge University Press

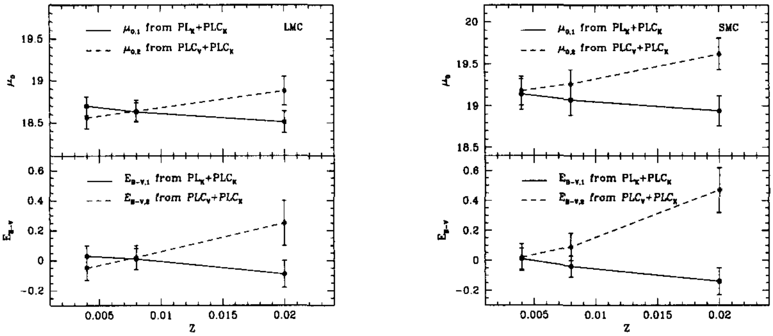

Figure 1. Reddening and true distance modulus of the LMC (left) and the SMC (right) as a function of metallicity.

relations are provided for each selected chemical composition, as least squares solutions through models. These relations turn out to depend on the adopted metal content as a consequence of the shift of the instability strip toward redder colors as the metallicity increases (Bono et al. 1999b, c). Similar relations for synthetic magnitude-weighted quantities were also derived, and differences between intensity-weighted and magnitude-weighted PL and PLC relations were investigated (Caputo et al. 1999a, hereinafter C99a). The main conclusions are that for PL relations and near-infrared PLC relations the error due to different types of averaging is negligible, whereas in the case of the optical PLC relation the systematic effect on the derived distance modulus can be as large as ± 0.10 mag (twice the rms dispersion).

3. The Sensitivity of PL and PLC Relations and Application to the Magellanic Clouds

The distance modulus $\mu_j PL_j$ of a galaxy obtained using a PL relation in the j band is related to the true distance modulus μ_0 by this relation:

$$\mu_j PL_j = \mu_0 + R_j E(B-V),$$

where $E(B-V)$ is the reddening and R_j is the ratio between total to selective extinction in the j band (e.g. Cardelli, Clayton, & Mathis 1989). In the case of PLC relations:

$$\mu_j PLC_j = \mu_0 + r_j E(B-V),$$

where r_j is a function of R_j and of the color term coefficient γ_j of PLC relation (see C99a for details). Two of these relations are sufficient to self-consistently derive the reddening and the true distance modulus. For instance, if we deal with VK data we can use two of the three relations PL(V), PL(K), PLC(VK). Due to the large dispersion of the PL(V) relations, the use of PL(K) and PLC(VK) is preferred. However, the theoretical PL and PLC relations depend on the metal content so that the values of $E(B-V)$ and μ_0 derived with the outlined procedure will depend on metallicity. In fact, the application of theoretical PL(K)

https://doi.org/10.1017/S0252921100058024 Published online by Cambridge University Press

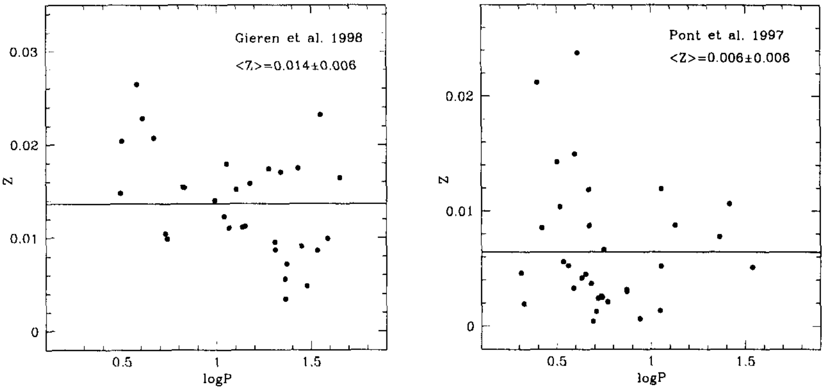

Figure 2. Metal abundances of galactic Cepheids as a function of the pulsation period. The average value with the standard rms error is labeled both for the sample by Gieren et al. (1998) (left) and the outer disc pulsators by Pont et al. (1997) (right).

and PLC(VK) to the VK data by Laney & Stobie (1994) for Cepheids in the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC) produces reddenings and distance moduli which decrease with the adopted metal abundance (see C99a). However, if the filter B is added and theoretical PLC(VK) and PLC(BV) relations are adopted, new estimates of $E(B-V)$ and μ_0 are provided, which now increase with metallicity.

The comparison of the two different sets of results constrains the metal abundance. The case of the Magellanic Clouds (BVK Cepheid data by Laney & Stobie 1994) is illustrated in Fig. 1. The resulting Z, $E(B-V)$ and μ_0 are 0.008, 0.02±0.08 mag, 18.63±0.12 mag for LMC, and 0.004, 0.01±0.08 mag, 19.16±0.17 mag for SMC, respectively. For a discussion of the comparison between these estimates and current empirical values in the literature see C99a.

4. The Metallicity of Galactic Cepheids

In the previous section we have shown that three bands are needed in order to properly constrain distance, reddening and metallicity of an extragalactic Cepheid sample. This result has also been confirmed by the investigation of theoretical multiwavelength relations by Caputo, Marconi, & Musella (1999b). In particular, these authors find that the combination of VR or VI data with theoretical PLC and Wesenheit relations (Madore 1982) can in principle provide accurate distance determinations for extragalactic Cepheids, but no information on $E(B-V)$ and Z. The three-filter method can also be applied to evaluate the metal abundance of galactic Cepheids. This has been done using the BVI data by Gieren, Fouqué, & Gómez (1998) and Pont, Queloz, & Bratschi (1997) and the theoretical PL(I), PLC(VI) and PLC(BV) (Caputo et al. 1999b) for various Z. The resulting metallicities as a function of the pulsation period are shown in Fig. 2. Since distances are also provided, we can assume a distance to

https://doi.org/10.1017/S0252921100058024 Published online by Cambridge University Press

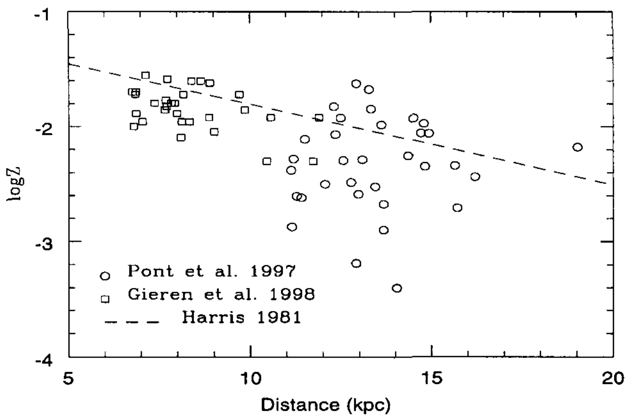

Figure 3. Metallicities versus galactocentric distances. The dashed line refers to the metallicity gradient suggested by Harris (1981).

the galactic center to constrain the metallicity gradient of the galactic disc. Fig. 3 shows the derived trend of metallicities versus the galactocentric distances for the two selected Cepheid samples, when a distance to the galactic center equal to 8.5 kpc is assumed. The metallicity gradient suggested by Harris (1981) is also plotted (dashed line).

References

Bono, G., Marconi, M., & Stellingwerf, R. F. 1999a, ApJS, 122, 167

Bono, G., Caputo, F., Castellani, V., & Marconi, M. 1999b, ApJ, 512, 711

Bono, G., Castellani, V., & Marconi, M. 1999c, ApJ, in press [astro-ph/9908014]

Caldwell, J. A. R. & Coulson, I. M. 1985, MNRAS, 212, 879

Caputo, F., Marconi, M., & Ripepi, V. 1999a, ApJ, 525, 784 [C99a; astro-ph/9906053]

Caputo, F., Marconi, M., & Musella, I. 1999b, ApJ, submitted

Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245

Dean, J. F., Warren, P. R., & Cousins, A. W. J. 1978, MNRAS, 183, 569

Gieren, W. P., Fouqué, P., & Gómez, M. 1998, ApJ, 496, 17

Harris, H. C. 1981, AJ, 86, 707

Laney, C. D. & Stobie, R. S. 1994, MNRAS, 266, 441

Madore, B. F. 1982, ApJ, 253, 575

Pont, F., Queloz, D., & Bratschi, P. 1997, A&A, 318, 416

Discussion

David Laney: One definite concern with your result is that your reddenings are smaller than the foreground values for both clouds.

Marcella Marconi: Possible explanations for this discrepancy are discussed in the paper by Caputo, Marconi, & Ripepi (1999a). The results are, anyway, dependent on the atmosphere models (colors) we are using. The reddening values derived by Caldwell & Coulson (1985) for the Magellanic Clouds with the BVI-method would also be decreased if solution (3) of the $B-V$ vs. $V-I$ intrinsic locus instead of solution (1) (see Dean et al. 1978) were adopted, and higher metal deficiencies (as derived on the basis of recent spectroscopic measurements) were assumed.