Metallicity effects on synthetic Cepheid 
Period-Luminosity relations.

I. Musella 
Osservatorio Astronomico di Capodimonte, via Moiariello 16, I–80131 
Napoli, Italy (ilaria@na.astro.it)

Abstract. On the basis of new theoretical results (Bono, Marconi & 
Stellingwerf, 1998, hereinafter BMS; Bono, Caputo, Castellani & Mar-
coni, 1998, hereinafter BCCM) useful predictions concerning the Period-
Luminosity (PLR) and Period-Luminosity-Color (PLCR) relations both 
for optical and infrared magnitudes are presented. It is shown that, fol-
lowing the dependence of the instability strip on metallicity, there is a 
non negligible dependence of the PLRs and PLCRs on the metallicity of 
the pulsating stars, mainly for optical bands. In particular theoretical 
results predict a dependence of the PLR on metals which is reversed with 
respect to current empirical evaluations (see for instance Gould 1994, 
Sasselov et al. 1997, Kennicutt et al. 1998, hereinafter K98). To give 
a possible explanation for this discrepancy the typical observational pro-
cedures used to estimate extragalactic distances through Cepheid PLRs 
are here tested, with the aim of disentangling, if possible, the reddening 
and metallicity effects. To this purpose, synthetic PLRs for different 
metallicities were produced and treated as typical observational samples.

1. Introduction

The theoretical models computed by BMS are characterized by three differ-
ent chemical compositions, namely Y=0.25 - Z=0.004, Y=0.25 - Z=0.008, and 
Y=0.28 - Z=0.02, corresponding to the composition of Cepheids belonging to 
Small Magellanic Cloud (SMC), Large Magellanic Cloud (LMC) and the Galaxy 
respectively. Following the procedure outlined in K98, I have used the theoreti-
cal predictions by BMS and BCCM to construct simulated Cepheid data sets for 
the three different adopted chemical compositions. Cepheid masses have been 
derived from a mass distribution given by $dn/dm = m^{-3}$ over the mass range 5-
11M$_\odot$. The corresponding luminosities have been obtained from the ML relation 
derived in the assumption of negligible core overshooting (see BMS and BCCM 
for details). The location of the predicted instability strip boundaries in the PL 
plane is used in order to constrain the position of the simulated Cepheid sam-
pies. At variance with K98 simulation, I did not introduce artificial foreground 
reddening to keep, if any, only the contribution of metallicity.
Figure 1. **Left plot:** Simulated PLRs for the three specified metallicities are plotted. See text for details. **Right plot:** The derived linear PL slopes are plotted versus log $Z$ for the six selected bands. See text for details.

2. **The simulated PL relations**

In the left plot of Figure 1 the simulated PLRs obtained for the three specified metallicities and for the 6 bands $BVRIJK$ are shown. As already known, the dispersion of the PLR decreases moving toward longer wavelengths. For each PL distribution I have performed both a linear and a quadratic fit. In each panel the solid line refers to the linear regression and the dot-dashed line corresponds to the quadratic one. Moreover, in the case of Z=0.004 and Z=0.02 I have also computed the least square linear (dashed line) and quadratic (dotted line) solutions assuming the same dependence on period of the Z=0.008 case and leaving free only the zero-point. In fact, usually, in the observational procedure, the extragalactic Cepheid distance scale is determined by adopting the slope derived from LMC Cepheids. The complete list of the coefficients of these relations will be reported in a future paper (Caputo, Marconi & Musella, in preparation).

I wish to remark that, in agreement with the discussion in BCCM, present fits indicate a quite clear overluminosity of metal-poor Cepheids. This trend is in contrast with several empirical predictions (the references are quoted in the abstract). I also note that the middle and right panels of this plot reveal an intersection between the true relations for a given metallicity and the corresponding relations obtained assuming the period dependence of the Z=0.008 case. These results clearly show that the metallicity effect is critically dependent on the period range covered by the observational samples.

The right plot in Figure 1 shows the behavior of the linear PL slopes versus log $Z$ for the six selected bands. The trend of this dependence is well reproduced by a linear fit ($slope = a \ast \log Z + b$). It is evident that the slope depends on metallicity and the effect decreases toward longer wavelengths. Therefore the

$$slope = a \ast \log Z + b$$
assumption of a universal slope is not an accurate approximation, especially in the optical bands.

3. Cardelli law

One typical observational procedure to determine Cepheid relative distances is the multiwavelength method described in Freedman et al. (1988). In this procedure, taking advantage of the multicolor (BVRI with the possible addition of JHK) apparent relative distance moduli (of the target galaxy with respect to LMC) and assuming that all the wavelength dependence of these relative moduli is due to the extinction, it is possible to fit all the data simultaneously with an interstellar extinction law. In particular, it is assumed that the reddening law for the LMC and the target galaxy is the same as for the Galaxy and the law derived by Cardelli et al. (1989, hereinafter C89) is used. In this way it is possible to derive the true relative (to LMC) distance modulus and the total extinction for the Cepheids of the target galaxy. It is obvious that with this procedure it is impossible to discriminate between the reddening contribution and the metallicity one, if any. The HST Key Project, disposing of only two bands (VI), makes use of a modified version of this method, assuming that the color excess is equal to the difference between the apparent distance moduli in the two bands.

In the present test the zero-point differences (at fixed period coefficients) can be considered as apparent relative distance moduli. Since absorption is not included and I am assuming a null distance for all the Cepheid samples, the obvious result of the application of the C89 law must be zero for both the true relative distance modulus and the absorption coefficient must. Any deviation from this result can only be ascribed to the metallicity contribution.

The left plot in Figure 2 presents the results of the application of the C89 law to three different cases: the difference in the zero-points between the Z=0.004 and the Z=0.008 linear relations, both with the Z=0.008 slope (upper panel); the difference in the zero-point between the Z=0.02 and Z=0.008 linear relations, both with the Z=0.008 slope (middle panel); the difference in the zero-point between the Z=0.02 and Z=0.004 linear relations, both with the Z=0.004 slope (lower panel). In each panel, the solid line refers to the BVRI C89 fit, whereas the dashed line represents the result of the HST Key Project procedure. The resulting true distance modulus differences and absorption coefficients are labeled. I notice that almost all the contribution of metallicity is included in the absorption coefficient, while the true relative distance moduli are remarkably close to zero. In the application of C89 law I have not considered the NIR bands, since the apparent relative moduli in J and K are almost identical due to negligible metallicity effects on these bands. As a result the application of an extinction law does not make sense. Finally, in the right plot of Figure 2, I report the true relative distance moduli obtained by the multiwavelength method versus \( \Delta(\log Z) = \log(Z/Z_{\text{ref}}) \), where \( Z_{\text{ref}} \) deals with the fixed slope adopted in the three panels of the left plot of Fig. 2. An opposite trend is derived with the BVRI method and the HST Key Project approach. In fact, for each \( \Delta(\log Z) \), the true relative moduli obtained using the two different methods show an opposite sign, even though in agreement within the errors. I also notice that the VI procedure
gives a less accurate value. As a possible explanation for the opposite behavior predicted by the two approaches, it is worth noticing that the two absorption coefficients are very different. Indeed, in the HST Key Project, these absorption values are obtained from color excesses $E(V-I)$ which are assumed equal to the differences between the V and I apparent moduli. Since the metallicity effects are differently important in different bands, and in particular in V and I, the quoted procedure may conceal part of the metallicity contribution, and even reverse its effect. Thus, one could conclude that the reason why the application of the multiwavelength method and the VI procedure provides opposite signs for the metallicity dependence of relative distances has to be searched in the not proper assumption, in the HST Key project approach, that all the difference between V and I apparent relative distance moduli is due to absorption effects and that the metallicity contribution is negligible.

Acknowledgments. I would like to thank Filippina Caputo and Marcella Marconi for their contributions.

References

Bono, G., Marconi, M., Stellingwerf, R.F., 1998, ApJ, in press
Bono, G., Caputo, F., Castellani, V., Marconi, M., 1998, ApJ, in press
Caputo, F., Marconi, M., Musella, I., in preparation
Cardelli, J.A., Clayton, G.C., Mathis, J.S., 1989, ApJ, 345, 245
Freedman, W.L, 1988, ApJ, 326, 691
Gould, 1994, ApJ, 426, 542
Kennicutt R.C., et al., 1998, ApJ, 498, 181
Sasselov, D.D., et al., 1997, A&A, 324, 471
This figure "musella1a.gif" is available in "gif" format from:

http://arxiv.org/ps/astro-ph/9901043v2