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Combined helium and metallicity effects on the Cepheid distance scale: a theoretical investigation

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Abstract. The dependence of Cepheid pulsation properties on both helium and metal abundances is investigated on the basis of the results of new computed pulsation models spanning the whole range of metallicities of the galaxies analysed by the Hubble Space Telescope (HST) Key Project (KP). As a result, the predicted metallicity correction to the KP distance moduli, which rely on the adoption of *universal*, LMC based, PL relations, turns out to be negligible at the shorter periods (< 10 d) but to become important, and sensitive to the adopted Y to Z enrichment ratio $\Delta Y/\Delta Z$, at longer periods.

Key words. stars: variables: Cepheids – stars: oscillations – stars: distances

1. Introduction

As shown in a series of previous papers (Bono et al. 1999; Caputo, Marconi, & Musella 2000a) nonlinear convective pulsation models computed for metallicities from $Z = 0.004$ to $Z = 0.02$ and an assumed Y to Z enrichment ratio $\Delta Y/\Delta Z = 2.5$ predict that the pulsation properties of Cepheids depend on metallicity, and that the adoption of *universal* PL relations to derive extragalactic distances may introduce a systematic error. The derived metallicity correction to the HST KP distance moduli is -0.27 mag dex^{-1} (Caputo et al. 2000b) and at least its sign is supported by several empirical evidences. In particular the geometric maser distance to the galaxy NGC 4258 is in agreement with the Cepheid KP distance when theoretically corrected for the metallicity effect (see Caputo, Marconi, & Musella 2002), whereas the empirical correction provided by Kennicutt et al. (1998, hereafter K98) on the basis of HST Cepheid observations in two fields at different metallicity of the galaxy M 101 (0.24 mag dex^{-1}) goes in the opposite direction. In order to attempt to understand the discrepancy between the predicted and the empirical metallicity corrections, we examined possible limitations of our theoretical scenario and realized that as our models covered metallicities up to the solar values, many HST galaxies have

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metal abundances in the range $0.02 \leq Z \leq 0.05$. This occurrence forced us to extend the previous model set to $Z > 0.02$. Two sequences were computed at $Z = 0.03$ and $Z = 0.04$, for the same assumed $\Delta Y/\Delta Z = 2.5$ (see Fiorentino et al. 2002, hereafter F02). However as the metallicity increases the helium contribution, even for a fixed $\Delta Y/\Delta Z$, is expected to become more and more important. Moreover the dependence on the adopted $\Delta Y/\Delta Z$ needed to be investigated. For these reasons we extended the computations to new series of models with $\Delta Y/\Delta Z = 4.0$ (see F02 for details).

2. Results

The instability strips for the new model series at $Z = 0.03$, $Z = 0.04$ and $\Delta Y/\Delta Z = 2.5$ have been compared with the results previously obtained for the more metal-poor chemical compositions. This comparison shows that for $0.004 \leq Z \leq 0.03$ the instability strip moves toward redder colours as the metallicity increases, whereas if Z is increased from 0.03 to 0.04 the blue boundary moves redward and the red boundary moves blueward producing a narrowing of the instability region. This behaviour is due to the decrease of H abundance and then of the driving produced by the H ionization region (see F02 for details). On the other hand if the solar metallicity $Z = 0.02$ is fixed and $\Delta Y/\Delta Z$ is increased from 2.5 to 4 the instability strip moves blueward. This means that the helium and metallicity effects tend to compensate each other at the higher metal abundances and that the value of $\Delta Y/\Delta Z$ has to be taken into account when evaluating the theoretical metallicity correction. In fact the application of our PL(V) and PL(I) relations to the VI data of the HST KP galaxies provides distances that differ from the LMC PL based ones by a correction that is negligible (within 10%) at the shorter periods ($P < 10$ d) but is significant and dependent of the adopted $\Delta Y/\Delta Z$ for longer periods. In particular for $\Delta Y/\Delta Z \simeq 3.5$ the predicted correction matches the correction derived by K98. On this basis, it is quite clear that an independent evaluation of the still rather uncertain (see Pagel & Portinari 1998 and references therein) $\Delta Y/\Delta Z$ parameter is needed in order to constrain the metallicity correction to the extragalactic distance scale. The results of pulsation models (F02) seem to suggest that 4 is an upper limit for $\Delta Y/\Delta Z$, confirming independent evolutionary predictions (Bono et al. 2000). On the other hand, one could try to use the sensitivity of predicted relations (e.g. PL, PLC) to both Y and Z to simultaneously constrain these parameters. In particular by applying four theoretical relations depending, to different extent, on chemical composition, to Cepheid data in at least four filters, four equations should be obtained for the four unknown quantities distance, reddening, Y and Z. Such a procedure, once tested, could be a very promising technique to constrain the value of the fundamental but still too uncertain $\Delta Y/\Delta Z$ ratio.

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