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Theoretical uncertainties on classical Cepheid pulsational quantities

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Abstract. The expected distribution of Cepheids within the instability strip directly reflects upon the predicted Period-Luminosity (*PL*) relation; however from a theoretical point of view this distribution is affected by the uncertaintes on several model inputs. We evaluated the effects on the theoretical *PL* relation of current uncertainties on the chemical abundances of Cepheids in the Large Magellanic Cloud (LMC) on the basis of new and updated sets of evolutionary and pulsational models. As a result, we found that current uncertainties on the LMC chemical composition affect significantly the loop extension and also reflect in the predicted topology of the instability strip; however their influence on the predicted pulsational parameters is negligible.

Key words. Stars:Cepheids – Stars:evolution – Stars:distances

1. Introduction

During the central helium burning phase intermediate mass stars show an excursion toward higher effective temperatures, in the Hertzprung-Russell (HR) diagram, then coming back toward the asymptotic giant branch (*blue loop*). During this evolutionary phase, a star crosses the instability strip becoming a Classical Cepheid. As widely discussed in the literature (see e.g. Robertson 1971; Stothers & Chin 1993; Sestito et al. 2002; Xu & Li 2004b), the formation and the extension of loops appear to be caused by the interaction of several factors and it is extremely sensitive to small changes either in the stellar chemical composition or in the model physical inputs. The main parameters which are expected to affect the blue loop morphology are: the He burning cross sections, the chemical composition, as well as the efficiencies of external convection, overshooting and mass loss. A detailed discussion of the dependence of Cepheid evolutionary properties on all these ingredients has been presented in Valle et al. (2009). In that paper we showed that, at least in the canonical evolutionary regime (neglecting overshooting and mass-loss), current uncertainties on the LMC Cepheid chemical abundances are the only important error sources, playing a role in the prediction of Cepheid properties. In the present paper we illustrate the effects of the LMC Cepheids chemical compo-

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sition uncertainties on evolutionary properties such as the He burning loop extension, and on pulsation properties such as the instability strip topology and the *PL* relations.

2. Evolutionary and pulsation models

The adopted evolutionary and nonlinear convective pulsation models (see Valle et al. 2009, for details) span a stellar mass range from 3-4$M_\odot$ to 13-14$M_\odot$, which covers the range of masses crossing the instability strip. The metallicities used for the models are consistent with the most recent estimates of [Fe/H] for LMC Cepheids (see Luck et al. 1998; Romaniello et al. 2008)

Assuming as central value [Fe/H]≈-0.40 and adopting the updated Asplund et al. (2005) mixture, instead of that by Grevesse & Noels (1993) widely used in the past, we obtained a value of $Z \approx 0.005$ as LMC metallicity.

We assumed the primordial helium abundance $Y_P = 0.248$ (Peimbert et al. 2007; Izotov et al. 2007) and for the Helium-to-metal enrichment ratio $\Delta Y/\Delta Z = 2$ (Jimenez et al. 2003). Thus with $Z \approx 0.005$ we obtained $Y \approx 0.26$, which we assume as standard value.

Our pulsational models are based on a nonlinear nonlocal time-dependent convective hydrodynamical code (Bono & Stellingwerf 1994; Bono et al. 1999a, and references therein). The physical ingredients of Cepheid pulsation models, and in particular the stellar opacity tables, have been updated in order to insure consistency between the pulsation and the evolutionary models. The new pulsation models have been constructed with the same chemical abundances of evolutionary models, covering the same range in stellar mass and assuming the luminosity predicted by the canonical Mass-Luminosity (*ML*) relation by Bono et al. (2000).

3. Effects of the chemical composition uncertainties

On the basis of the observed [Fe/H] range suggested by Luck et al. (1998) we allowed Z to vary in the range $0.0035 \leq Z \leq 0.008$. Taking into account the current uncertainties on $\Delta Y/\Delta Z$ (see e.g. Pagel & Portinari 1998; Gennaro et al. 2008), we allowed a variation of the original helium content from Y=0.26 to Y=0.28.

Figure 1 shows, for a 7 $M_\odot$ model, the effects on the blue loop extension of variations in the helium and metal contents within the uncertainties of these quantities. The left panel shows that increasing the metal content, at fixed helium abundance, the extension of the blue loop decreases, whereas the right panel shows that an increase of the helium content within its uncertainty range, at fixed metallicity, leads to more extended loops, even if the effect is reduced compared to that of lowering Z. The behaviour is similar for the other analysed model masses. The left panel of Fig. 2 shows the instability strips computed for the different metallicities corresponding to the cases Z_{low}=0.0035, Z=0.005, Z_{high}=0.008; whereas in the right panel of the same figure the effect on the instability strip of the Y variation within its uncertainty is shown (Y=0.26,Y_{high}=0.28). As already found (Bono et al. 1999b; Caputo et al. 2000) the predicted instability strip gets redder as the metallicity increases, while increasing the helium content from 0.26 to 0.28 at $Z = 0.005$ only produces a slight narrowing of the instability strip at the highest luminosity levels, likely due to the slightly reduced efficiency of the H ionization region in driving pulsation.

New ML relations at the various chemical compostions were obtained by selecting the portions of the evolutionary tracks that cross the instability strip and performing a linear regression weighted on the evolutionary timescale, following the same procedure as in Bono et al. (2000).

As already performed in previous investigations (see e.g. Marconi et al. 2005, and references therein), for each fixed chemical composition, we populated the predicted instability strip according to an assumed mass distribution and using the *ML* relation for the selected Y and Z, with the requirement that only the region between the predicted blue and red edge of the corresponding instability strip should be populated. As a result of this procedure

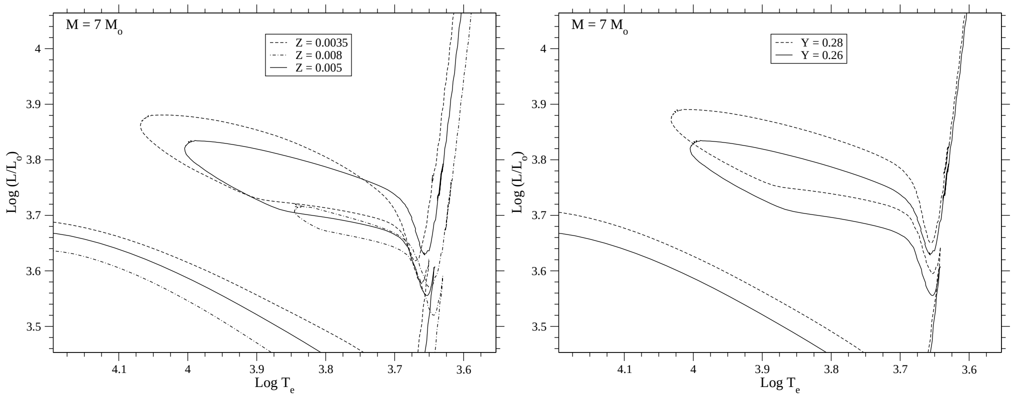

Fig. 1. Left panel: effect of a metallicity variation on the loop extension for a 7 M$_\odot$; the three different lines correspond to the standard (*std*) case (Z=0.005, solid line) Z_{low}=0.0035 (dashed line) and Z_{high}=0.008 (dot-dashed line). Right panel: as in the left panel but for a helium abundance variation and for cases: *std*, Y=0.26, solid line and Y_{high}=0.28, dashed line.

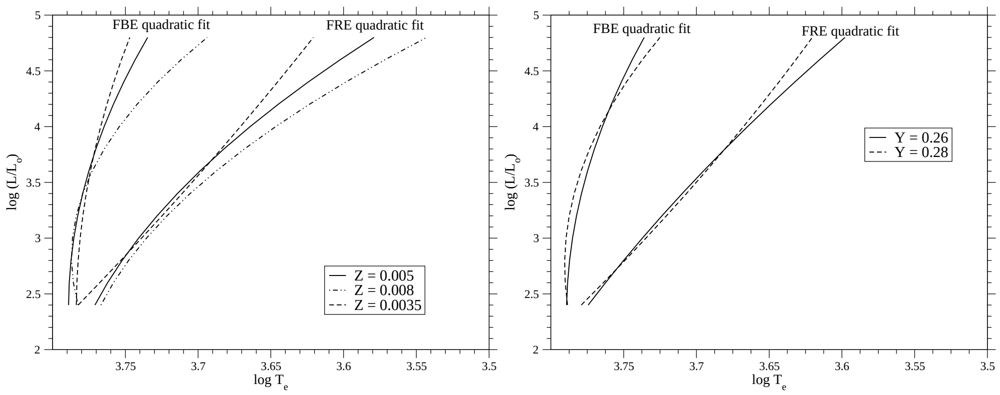

Fig. 2. Left panel: effect on the fundamental instability strip edges of a metallicity variation within its uncertainty (Z_{low}=0.0035, Z=0.005, Z_{high}=0.008). Right panel: as in the left panel but for a variation of the original helium abundance (Y=0.26,Y_{high}=0.28). In both panels the quadratic fits of the instability strip boundaries are shown.

synthetic PL relations at the various chemical compositions and *global* PL relations were obtained.

In Fig. 3 we show the residuals of our *global* PL relations, for $\log P < 1.5$ in the V, I bands and over the whole period range for the K band, with respect to the empirical relations by Freedman et al. (2001) (for V and I) and Persson et al. (2004) (for the K band). According to this plot we find differences smaller than 0.2 mag (in absolute value) in all the bands. Considering that this difference is comparable with the intrinsic dispersions of theoretical and empirical relations, we conclude that the pulsation properties of Cepheids are not significantly affected by the errors on LMC Cepheid chemical abundances.

4. Conclusions

On the basis of an updated set of evolutionary and pulsation models for Classical Cepheids in the LMC we have investigated the effect of the uncertainties on the chemical composition of

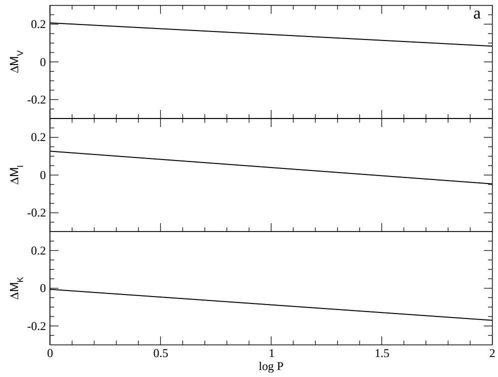

Fig. 3. Residuals of the present linear PL relations for log $P < 1.5$ in the V, I bands and over the whole period range for the K band with respect to the empirical relations by Freedman et al. (2001) (for V and I) and Persson et al. (2004) (for the K band).

these pulsators on their predicted evolutionary and pulsational properties, as well as the implications for the theoretical calibration of the Cepheid distance scale. As a result we have found that the uncertainties in the metal and helium abundances of LMC Cepheids, affect the results of the evolutionary computations and the topology of instability strip but do not influence significantly the predicted pulsational scenario.

References

Asplund, M., Grevesse, N., & Sauval, A.J. 2005, in "Cosmic Abundances as Records of Stellar Evolution and Nucleosynthesis", eds. F.N. Bash, & T.J. Barnes, ASP Conf. Series, 336, 25

Bessel, M.S., Castelli, F., & Plez, B. 1998, A&A, 333, 231

Bono, G., & Stellingwerf, R.F. 1994, ApJS, 93, 233

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., Caputo, F., Cassisi, S., et al. 2000, ApJ, 543, 955

Brocato E., Caputo, F., Castellani, V., Marconi, M., Musella, I. 2004, AJ, 128, 1597

Caputo, F., Marconi, M., & Musella, I. 2000, A&A, 354, 610

Chieffi, A., & Straniero, O. 1989, ApJS, 71, 47

Degl'Innocenti, S., Prada Moroni, P.G., Marconi, M., & Ruoppo, A. 2008, Ap&SS, 316, 25

Freedman, W.L., Madore, B.F., Gibson, B.K., et al. 2001, ApJ, 553, 47

Gennaro, M., Prada Moroni, P.G., & Degl'Innocenti, S. 2008, proceedings of 52^o congresso SAIt, Memorie della Società Astronomica Italiana, in publication

Grevesse, N. & Noels, A. 1993 in "Origin and Evolution of the elements", ed. N. Prantzos, E. Vangioni-Flam, M. Cassé (Cambridge Univ. Press, Cambridge), p. 15

Iglesias, C., & Rogers, F.J. 1996, ApJ, 464, 943

Izotov, Y.I., Thuan, T.X., & Stasińska, G., 2007, ApJ, 662, 15

Jimenez, R., Flynn, C., MacDonald, J., & Gibson, B.K. 2003, Science, 299, 1552

Luck, R.E., Moffett, T.J., Barnes, T.G. III, & Gieren, W.P. 1998, AJ, 115, 605

Marconi, M., Musella, I., & Fiorentino, G. 2005, ApJ, 632, 590

Pagel, B.E.J., & Portinari, L. 1998, MNRAS, 298, 747

Peimbert, M., Luridiana, V., Peimbert, A., & Carigi, L. 2007, Astronomical Society of the Pacific Conference Series, 374, 81

Persson, S.E., Madore, B.F., Krzemiński, W., et al. 2004, AJ, 128, 2239

Robertson, J.W. 1971, ApJ, 170, 353

Romaniello, M., Primas, F., Mottini, M., et al. 2008, A&A, 488, 73

Sestito, P., Castellani, V., Degl'Innocenti, S., & Prada Moroni, P.G. 2002, in "Observed HR diagrams and stellar evolution: the interplay between observational constraints and theory", eds. T. Lejeune & J. Fernandes, ASP Conf. Series 274, 73.

Stothers, R.B. & Chin, C. 1993, ApJ, 412, 294

Xu H.Y., & Li, Y. 2004b, A&A, 418, 225

Valle, G., Marconi, M., Degl'Innocenti, S., Prada Moroni, P.G. 2009, A&A, in press