Cepheids and the distance ladder

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Abstract Classical Cepheids plays a key role in the calibration of the extragalactic distance scale. In spite of their importance, some uncertainties related to their properties remain. In particular, a general consensus on the possible dependence on the metallicity of the host galaxy of the Cepheid properties has not been reached yet. These uncertainties could produce significant systematic errors in the calibration of the secondary distance indicators we need to reach cosmologically significant distances and in turn in the evaluation of the Hubble constant H_0. Possible solutions are discussed.

1 Introduction

Classical Cepheids (CCs) are population I pulsating stars located in the Instability Strip (IS), a defined region of the color-magnitude diagram. They are very bright ($-2 < M_V < -7$ mag) and are characterized by light-curves with large amplitudes so that they have been observed by the *Hubble Space Telescope (HST)* out to about 25 Mpc ([7]). In particular, they obey to a characteristic period-luminosity relation (PLR) that is used as distance indicator and to calibrate secondary distance indicators, observed with *HST* in external galaxies, and in turn to obtain an estimate of H_0 (see e.g. [6, 19]. The PLR was traditionally considered linear and "universal" ([9, 5]), assuming the slope of the Large Magellanic Cloud (LMC) CC sample and setting the zero-point to the LMC distance modulus or on the basis of Galactic CCs with independent distance estimates. Actually, the advent of HST with the observation of many spiral galaxies in the Virgo Cluster with a large spread in metallicity, as well as new studies of the difference between Galactic and Magellanic CC properties (see e.g. [18, 21] and references therein), showed much evidence that the CC properties depend on the metallicity of the host galaxy. Despite the many efforts,

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from the theoretical and observational point of view, performed to understand the dependence of the CC properties on the chemical composition, there are still many doubts both on the sign and the size of this effect ([10, 20, 13, 11, 1, 18, 2] and references therein). Many studies were aimed at understanding the systematic errors in the extragalactic distance scale based on the CC PLR. In particular, the main error sources are: i) the dispersion of the PLR due to intrinsic factors such as the finite width of the IS, but also to the possible differential reddening in the studied galaxy and to a poor sampling of the CC light curves; ii) the errors due to the metallicity and reddening effects that can reach 15% and iii) the use of LMC as anchor galaxy in spite of its large spread in reddening and metallicity and the remaining uncertainties on its distance. Possible solutions to the previous problems are: i) to have a solid theoretical scenario; ii) to use the near -infrared bands where the effects due to metallicity and reddening are low or negligible and iii) to adopt a different anchor galaxy with a metallicity more similar to the majority of the galaxies observed by HST. In particular an interesting alternative to the LMC is the galaxy NGC 4258 that has an independent and very accurate (3%) geometrical measurement of the distance based on the kinematics of the hosted water masers ([11, 15, 16, 17, 8] and references therein).

2 Pulsational models

From the theoretical point of view, extensive sets of nonlinear convective pulsational models was computed ([3, 13] and references therein) for different chemical compositions — $0.0004 < Z < 0.04$, $0.25 < Y < 0.33$, $0.5 < \Delta Y/\Delta Z < 4$ — and for typical CC masses ranging from 3 to 13 $M_{\odot}$. These models allow us to obtain all the CC observables (light curves, periods, mean magnitudes), to predict the position of the CC IS in a color-magnitude diagram and to build theoretical PLRs and period-luminosity-color relations for different filters, that can be compared with the observed properties to check the models themselves, but also to obtain a theoretical calibration of the extragalactic distance scale. These models, in agreement with observational results (see e.g. [12]), predict that the CC ISs and the PLRs in different photometric filters are dependent on the adopted chemical composition, with the PLR getting flatter as Z increases. Moreover, the optical PLRs are not linear. Both these effects, as well as the intrinsic dispersion, decrease as the wavelength increases from the optical to the NIR bands. At very low metallicity, the dependence on the chemical composition becomes negligible with the predicted PLR at Z=0.0004 very similar to the one for Z=0.004 ([14]). These models combined with observational data can represent a powerful tool. An example of this application is presented in the next section.

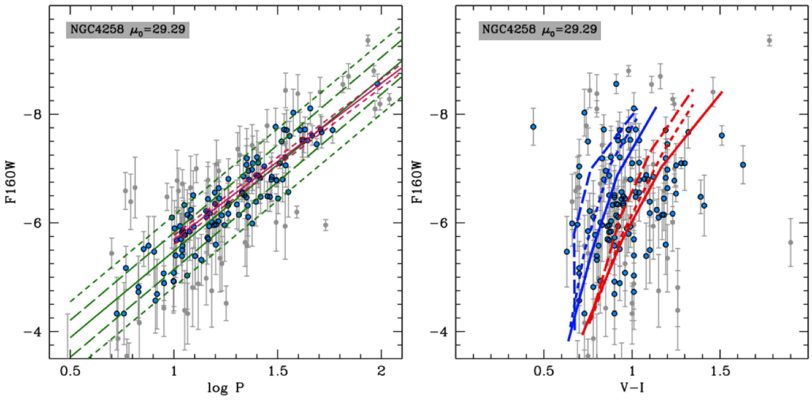

Fig. 1 Left: The PLR for the NGC4258 CCs in the F160W band. The dark blue and grey symbols have been used for good and rejected observed CCs (see [17] for details). In this panel, we also show the theoretical (Z = 0.02, Y = 0.28 and $logP > 1$; dark magenta solid line) and the observed (green solid line) F160W PLRs together with their confidence lines (dashed for the whole CC sample and long-dashed for the good ones). Right: comparison between observational and theoretical (blue and red boundaries) ISs in the plane (F160W, V I) for NGC 4258 CCs. For the theoretical ISs, we adopt three different chemical compositions: Z = 0.02; Y = 0.28 (solid), Z = 0.02; Y = 0.31 (dashed) and Z = 0.008; Y = 0.25 (long dashed).

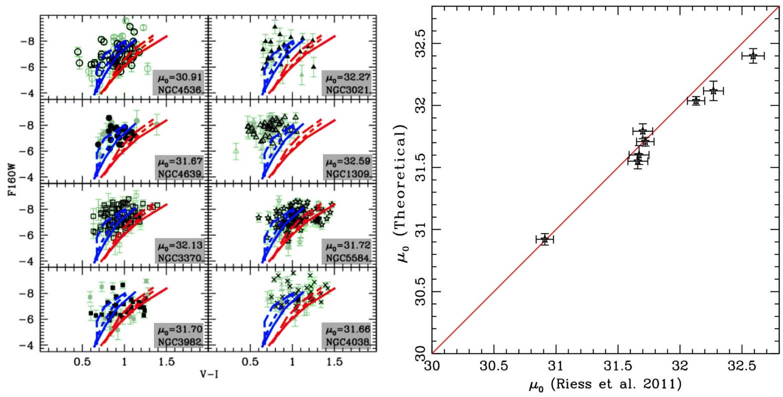

Fig. 2 Left: As in Fig. 1 (right panel) for all the other CC samples. In this case, dark and light green symbols represent good and rejected CCs (see [17] for details), respectively. Right: the comparison between the distance moduli obtained using our theoretical F160W PL for Z = 0.02 Y = 0.28 and for periods larger than 10 d and those obtained by [17]

3 Comparison with the Riess sample.

In order to obtain accurate (at 3%) and solid constraints to the Hubble constant H_0, [17] have observed with ACS@HST and WFC3@HST large CC samples in NGC 4258 and in eight SNIa host galaxies, both in the optical and near-infrared bands. In this work, they adopt NGC 4258 as anchor galaxy for the calibration of the distance scale. Pulsational models were transformed in the same photometric filters adopted by these authors. Fig. 1 shows a very good agreement between models and observations, in particular with the models for Z=0.02, adopting the modulus obtained by [17] using a metal-dependent Wesenheit relation. For the other galaxies of the sample, in the left panel of Fig. 2 the theoretical ISs, in the plane F160W-(V-I), for different chemical compositions, are compared with the Riess sample, finding that for the more distant galaxies CCs appear bluer and brighter. This could be due to an increasing crowding at larger distances. Applying the theoretical F160W-band PLR to the Riess CC samples, the moduli obtained are slightly different from those found by [17]. The right panel of Fig. 2 shows these differences versus the [17] moduli, pointing out that the differences increase at larger distances. Adopting the results obtained from the application of the theoretical PLRs to the Riess CC samples (without using any secondary indicator), it is possible to obtain for H_0 a value of 76.0 ± 1.9 km s^{-1}Mpc^{-1} [4], in good agreement, within the errors, with the value found by [17], using the SNIa distance scale calibrated on the CCs, but with a smaller error.

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