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P. Popowski

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Is the Short Distance Scale a Result of a Problem with the LMC Photometric Zero Point?

Piotr Popowski

IGPP/LLNL; e-mail: popowski@igpp.ucllnl.org

Abstract. I present a promising route to harmonize distance measurements based on clump giants and RR Lyrae stars. This is achieved by comparing the brightness of these distance indicators in three environments: the solar neighborhood, Galactic bulge and Large Magellanic Cloud (LMC). As a result of harmonizing the distance scales in the solar neighborhood and Baade's Window, I derive the new absolute magnitude of RR Lyrae stars, $M_V(RR)$ at [Fe/H] $= -1.6$ in the range $(0.59 \pm 0.05, 0.70 \pm 0.05)$. Being somewhat brighter than the statistical parallax solution, but fainter than typical results of the main sequence fitting to Hipparcos data, these values of $M_V(RR)$ favor intermediate or old ages of globular clusters. Harmonizing the distance scales in the LMC and Baade's Window, I show that the most likely distance modulus to the LMC, $\mu_{\rm LMC}$ is in the range $18.24 - 18.44$. The Hubble constant of about 70 km/s/Mpc reported by the HST Key Project is based on the assumption that the distance modulus to the LMC equals 18.50. The results presented here indicate that the Hubble constant may be up to 12% higher. This in turn would call for a younger Universe and could result in some tension between the age of the Universe and the ages of globular clusters. I argue that the remaining uncertainty in the distance to the LMC is now a question of one, single photometric reference point rather than discrepancies between different standard candles.

1. Introduction

The determination of the Hubble constant, H_0, is of primary importance in astrophysics. The distance ladder approach implemented by the HST Key Project is one major way to achieve this goal. Most of the extragalactic distances are calibrated with respect to the LMC. Based on the H_0 determination presented by Mould et al. (2000), one has an approximate relation:

$$H_0 = 70 \frac{\rm km}{\rm s\,Mpc} \left[1 + 0.46\,(18.5 - \mu_{\rm LMC})\right]$$

Unfortunately, the distance to the LMC is a subject of strong debate. There are not only disagreements between results from different distance indicators, but even disagreements between different investigations in the case of the same standard candle. Here we check the consistency of two major distance indicators: RR Lyrae stars and clump giants.

2. The Method

The essence of the approach presented here is a comparison between clump giants and RR Lyrae stars in different environments. If answers from two distance indicators agree then either systematics have been reduced to negligible levels in both of them or biases conspire to produce the same answer. This last problem can be tested with an attempt to synchronize distance scales in three different environments, because a conspiracy of systematic errors is not likely to repeat in all environments. Here I show that combining the information on RR Lyrae and clump stars in the solar neighborhood, Galactic bulge, and LMC provides additional constraints on the local distance scale.

3. Assumptions and Procedure

I assume that: 1) A universal linear $M_V(RR)$ - [Fe/H] relation holds. I adopt a slope of 0.18 ± 0.03 and will calibrate a zero point in the process. 2) The absolute I-magnitude of clump giants in Baade's Window is approximately known. I adopt $M_{I,\mathrm{BW}} = -0.23 \pm 0.04$, which is in agreement with both the Hipparcos-based calibration and synthetic population models.

The zero point in $M_V(RR)$ - [Fe/H] relation is calibrated through comparison of clump giants and RR Lyrae stars in the solar neighborhood and Baade's Window. [As discussed by Popowski (2000; 2001), the clump giants in the bulge have unexpectedly redder $(V-I)_0$ colors than their counterparts in the solar neighborhood. The use of either these anomalous, uncorrected $(V-I)_0$ colors or $(V-I)_0$ corrected to the standard value results in two classes of solutions.] A calibrated $M_V(RR)$ - [Fe/H] relation is then used to determine $M_V(RR)$ in the LMC. $M_{V,\mathrm{LMC}}(RR)$ combined with dereddened apparent V-mags of RR Lyrae stars, $V_{0,\mathrm{LMC}}(RR)$, allows one to find μ_{LMC} [$V_{0,\mathrm{LMC}}(RR)$ may come either from OGLE or Walker (1992)]. Finally, μ_{LMC} and $I_{0,\mathrm{LMC}}(RC)$ can be combined to find $M_{I,\mathrm{LMC}}(RC)$. Popowski (2001) gives a more detailed description of the data and methodology (see also Table 1).

4. Results and Sensitivity to Assumptions

The results are presented in Table 1. The first three columns describe assumptions and data input, and the last three columns give the solutions. Most of the significant systematic effects are taken into account through the analysis of four cases presented in Table 1. In particular, μ_{LMC} increases with fainter $V_{0,\mathrm{LMC}}(RR)$. Note that, in this method, μ_{LMC} is *insensitive* to a controversial dereddened I-mags of the LMC clump giants, $I_{0,\mathrm{LMC}}(RC)$.

5. Overview Conclusions

Requirement of consistency between standard candles in different environments is a powerful tool in calibrating absolute magnitudes and obtaining distances. If anomalous character of $(V-I)_0$ in Baade's Window is real, then the distance scale tends to be shorter. In particular, $M_V(RR) = 0.70 \pm 0.05$ at [Fe/H] $= -1.6$,

Solution	$I_{0,\mathrm{LMC}}(RC)$	$V_{0,\mathrm{LMC}}(RR)$	$M_V(RR)^a$	$M_{I,\mathrm{LMC}}(RC)$	μ_{LMC}
anomalous + OGLE	17.91 ± 0.05	18.94 ± 0.04^a	0.70 ± 0.05	-0.33 ± 0.09	18.24 ± 0.08
anomalous + Walker	17.91 ± 0.05	18.98 ± 0.03^b	0.70 ± 0.05	-0.42 ± 0.09	18.33 ± 0.07
standard + OGLE	17.91 ± 0.05	18.94 ± 0.04^a	0.59 ± 0.05	-0.44 ± 0.09	18.35 ± 0.08
standard + Walker	17.91 ± 0.05	18.98 ± 0.03^b	0.59 ± 0.05	-0.53 ± 0.09	18.44 ± 0.07

[a] at [Fe/H] = −1.6
[b] at [Fe/H] = −1.9

Table 1. The solutions are classified according to $(V-I)_0$ colors in the Galactic bulge (uncorrected – *anomalous* or corrected – *standard*), and the source of LMC RR Lyrae photometry: Udalski et al. (1999) – *OGLE* or Walker (1992). The errors in $M_V(RR)$, and $M_{I,\mathrm{LMC}}(RC)$ include the uncertainty in the slope of the $M_V(RR)$ – [Fe/H] relation as well as 0.1 dex uncertainty of metallicity difference between different stellar systems. Note that $M_{I,\mathrm{LMC}}(RC)$ depends on $I_{0,\mathrm{LMC}}(RC)$, whereas μ_{LMC} does not. As a result, the error in μ_{LMC} is smaller.

and the distance modulus to the LMC is in the range $\mu_{\mathrm{LMC}} = 18.24 \pm 0.08$ to $\mu_{\mathrm{LMC}} = 18.33 \pm 0.07$. If $(V-I)_0$ color of stars in Baade's Window is in error and should be standard, then distance scale tends to be longer. In particular, one can obtain $M_V(RR) = 0.59 \pm 0.05$ at [Fe/H] = −1.6, and the distance modulus from $\mu_{\mathrm{LMC}} = 18.35 \pm 0.08$ to $\mu_{\mathrm{LMC}} = 18.44 \pm 0.07$. Reported μ_{LMC} does not depend on the assumed value of the dereddened I-magnitude of the LMC clump giants. The above results are fully consistent with the Tip of the Red Giant Branch (TRGB) method as showed by Bersier (2000) and Udalski (2000).

It is surprising that two reasonable adjustments: one of the $(V-I)_0$ color of clump giants in the Galactic bulge and another of the RR Lyrae photometry in the LMC could change the estimate of μ_{LMC} by as much as 0.2 magnitudes. The very short distance scale could in principle be a purely photometric phenomenon, namely a problem with calibration of the photometric zero points!

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