A NEW LOOK AT THE PRIMARY DISTANCE INDICATORS

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Abstract

We examine the overall consistency of the primary distance indicators and ways for a satisfactory resolution of the Cepheid-RR Lyrae zero point discrepancy.

1 Introduction

The demand on higher precision in distance measurement has prompted us to examine the systematic uncertainties in the basic primary distance indicators. The need for higher accuracy made us look for overall consistency. The primary distance indicators are established in our Galaxy and its companions. Four basic methods provide primary distances in the near field and as far as Virgo: Cepheids, RR Lyrae, proper motions, and SN Type II. They agree within large uncertainties (Huterer, Sasselov, & Schecter 1995), but pairwise comparisons of the methods show clearly a systematic discrepancy between the Cepheids and RR Lyrae, in that the latter distances are smaller. This discrepancy has been discussed widely (see Walker 1995 and references therein), and is illustrated in Fig. 1 — in summary, RR Lyrae calibrations within our Galaxy (BW method, statistical parallaxes) have a zero point some 0.2—0.3 mag fainter. The RR Lyrae distance scale is the single largest uncertainty in deriving the ages of globular clusters (Chaboyer et al. 1996), through calibrating the luminosity of the main sequence turn-off. These ages are often compared to Hubble timescales, which depend on the Cepheid distance scale. Clearly any such comparison requires the satisfactory resolution of the Cepheid-RR Lyrae zero point discrepancy.

2 Cepheids vs. RR Lyrae

Let us assume that the discrepancy is due to (1) systematic overestimate of the Cepheid scale, (2) systematic underestimate of the RR Lyr scale, or (3) combination of the two, and explore some of the possibilities here.

It has been suggested (van den Bergh 1995) that the discrepancy shown in Fig. 1 might be due to a metallicity-dependent zero point of the Cepheid PL relation. We note that our calculations illustrated in Fig. 1 already account for such a metallicity effect, as estimated semi-empirically by Caldwell & Coulson (1987) with the use of theoretical model atmospheres. However, as theoretical estimates have been uncertain, we defer our discussion of this idea to the next section, where we report an empirical result for the metallicity effect on Cepheids.

Most recently, the discrepancy between "high" and "low" RR Lyrae zero points was strongly reinforced. The MACHO microlensing project published an impressive sample of double-mode RRd Lyrae variables in the LMC (Alcock et al. 1996). The distance to LMC can be derived independently (DM = 18.6±0.2), but the technique is unfortunately model(s) dependent with systematic uncertainties which are difficult to estimate. This LMC distance compares well with the one based on Cepheids (DM = 18.45±0.1). On the other hand, an equally impressive sample of galactic RR Lyrae stars was observed and analyzed by Layden et al. (1996) using the method of statistical parallax. The latter confirms the "low" zero point and gives DM = 18.28±0.13 mag to the LMC. These two new results are independent of the Cepheid distance scale and indicate that the problem may lie in part with the RR Lyrae stars themselves.
Figure 1: Projections of the distance ellipsoids for four distance methods for four local galaxies – the Large Magellanic Cloud, M31, M33, and IC1613. All these distances are shown with internal uncertainties, which may be an underestimate in the case of the RR Lyrae scale. The unmarked ellipse is the projection of the average distance ellipsoid, based on the simultaneous solution for 15 objects (see Huterer et al. 1995 for details).

3 Metallicity and the Cepheid zero point

The degree of dependence of Cepheid distances on chemical composition (metallicity) has been an open issue for many years. Here we report on a solution to this problem from new EROS microlensing survey data. EROS (Experience de Recherche d’Objets Sombres) is a collaboration between French astronomers and particle physicists to search for baryonic dark matter in the galactic halo through microlensing effects on stars in the LMC and SMC. We use the CCD data from the EROS survey to discover about 500 Cepheids and use their ≈3 million photometric observation for a differential comparison between LMC and SMC. For more details see Beaulieu et al. (1997) and Sasselov et al. (1997).

The metallicity effect on the Cepheids from our analysis is: metal deficiency makes Cepheids bluer, and the period-luminosity zero point shifts are small and depend on wavelength. Therefore the metallicity effect on Cepheid distances is large if the reddening is derived from the colors of the Cepheids. If one considers as reddening the color difference due to metal content, $Z$, in deriving the true distance modulus, $\mu$, of a given galaxy, then we find that the following correction should be applied: $\delta \mu = (0.44^{+0.1}_{-0.2}) \log \frac{Z_{LMC}}{Z}$. Such a technique, which derives true distance moduli and extinction simultaneously, has been used for M31, M33, and IC1613. The sign is such that the distances to metal-poor galaxies would be overestimated if the effect were ignored – Fig. 2. Obviously, this goes nicely into solving the discrepancy with the RR Lyrae distance estimate in IC1613, but not in M31 and M33. There is much to be desired, however, of the RR Lyrae distances to M31 and M33, where a modern set of observations is definitely needed (see Huterer et al. 1995 for more details).

4 Conclusions

Our study of systematic effects in the two most heavily weighted primary distance indicators – the Cepheids and RR Lyrae, led us to conclude:

(1) the Cepheids have a small metallicity dependence, which could translate to a large correction of the true DM for the standard distance technique;

(2) the Cepheid metallicity dependence is indeed in the right direction for metal-poor systems, but cannot
Figure 2: RR Lyrae vs. Cepheid distances after correcting for metallicity effects.

explain in full the discrepancy with the RR Lyr scale;

(3) hence, the Galactic RR Lyr scale may be underestimated, due to systematics in the BW and statistical parallax methods (see e.g. Krockenberger, these proceedings);

(4) the corrections due to the above systematics conserve the overall agreement found for all four primary indicators to 15 objects by Huterer et al. (1995);

(5) finally, the corrections due to the above systematics are (a) in the direction of decreasing GCs ages (by ∼20%), if the RR Lyrae zero point is rescaled to the Cepheids, and (b) converging $H_0$ estimates to $\approx 70$ km.s$^{-1}$Mpc$^{-1}$ due to the metallicity effects on the Cepheid scale.

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