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Cepheid distance to the virgo cluster

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Abstract. HST data on Cepheid variables in one Virgo Cluster spiral galaxy is re-analyzed, taking into account flux-limited incompleteness in the sample and calibration of the period–luminosity relation in the relevant period range. Distance to the Virgo Cluster is estimated to be 19.6 ± 1.7 (random) ± 2.6 (systematic) Mpc.

Keywords. Cepheids; distance scale; hubble constant.

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1. Introduction

A measurement of the distance to the Virgo Cluster by a direct method along with a realistic error estimate would go a long way to settle the present debate over the value of the Hubble Constant. Ferrarese *et al* [1] obtained a distance of 16.1 ± 1.3 Mpc from Cepheid observations in M100, a nearly face-on spiral galaxy in the Virgo Cluster with the Hubble Space Telescope (HST). This work is a re-analysis of the HST data on Cepheids in M100, based on our study of Galactic Cepheids. Two major aspects of this analysis are the calibration of the Cepheid period–luminosity (PL) relation (§ 2) and correction for flux-limited incompleteness (§ 3) in the observed sample.

2. Slope and zero point of the Cepheid period–luminosity relation

Normally, a single PL relation is used for the entire range of Cepheid periods from $\lesssim 3$ days to above 60 days, and a slope of -2.77 is accepted. However, this is untenable when we use Cepheids as standard candles, because while the local PL relation is essentially governed by the numerous short period Cepheids, these are preferentially missed in the distant target galaxies due to their lower brightness.

We determine the slope of the PL relation from several independent analyses, which are summarized in table 1. Taking all the results into account, we conclude that there is a definite increase of the slope of the PL relation as we go from short periods to $\log(P) \geq 1.15$. At the range $1.15 \leq \log(P) \leq 1.85$, which is the relevant period range for the M100 Cepheids, the slope has a value between -3.0 and -3.5. We adopt the canonical value of -3.25 ± 0.25. However, in view of the scatter in the reported value of colors between various groups, we cannot determine the slope to further accuracy.

Table 1. Various methods for determining the slope of the period–luminosity relation.

Galaxy	Source of data	Method of analysis	Slope	Error
Milky Way	Gieren *et al* (1998) [2]	Barnes–Evans technique	-3.30	± 0.30
LMC	Various observers	Without extinction correction	-3.22	± 0.20
		With extinction correction	-3.25	± 0.25
IC4182	Saha *et al* (1994) [3]	With and without extinction correction	-3.20	± 0.20
	Our adopted value for $1.15 \leq \log(P) \leq 1.85$		-3.25	± 0.25

Table 2. Various estimates of the zero point of the period–luminosity relation.

Source	Method of determination	M_V at $P = 10$d	Error
Feast and Catchpole [5]	HIPPARCOS parallaxes	-4.24	± 0.10
Feast, Pont and Whitelock [6]	HIPPARCOS proper motions	-4.28	± 0.13
Gieren *et al* [2]	Barnes–Evans technique	-4.06	± 0.03
Madore and Freedman [7]	LMC distance	-4.16	
(same + Beaulieu *et al*) [4]	Metallicity correction	-4.30	
Our adopted value		-4.24	± 0.10

Conventionally, the zero point of the PL relation is determined by estimation of the LMC distance modulus. However, the LMC distance modulus derived through different methods vary between 18.3 and 18.7 mag. Also, the metallicity dependence of the zero point of the PL relation [4] adds to the uncertainty in the estimation of LMC distance through Cepheids. Thus we prefer additional calibrations of the zero point through several independent and complimentary methods. These include the recent parallax and proper motion measurements of nearby Cepheids by the HIPPARCOS satellite and the infrared Barnes–Evans surface brightness technique, which is insensitive to Cepheid metallicity and reddening. The various methods and our adopted value of the zero point are summarized in table 2.

So our final adopted period–luminosity relation is $M_V = -3.25(\log(P) - 1) - 4.24$.

3. Incompleteness effects in M100 Cepheid observations

About 70 Cepheid variables in M100 were observed in the V and I bands by the Hubble Space Telescope under the Key Project on the Extragalactic Distance Scale [1]. From this sample, we have analyzed 60 Cepheids which have periods between 15 and 70 days.

At the low signal to noise levels for the short period M100 Cepheids there is possibility of only the brighter Cepheids being preferentially detected, thus causing a systematic over-estimation of the brightness at a fixed period. On comparing the number density of Cepheids as a function of period of the HST sample of Cepheids in M100 with the reasonably complete sample of Galactic Cepheids (taken from the Galactic Catalogue of Variable Stars [8]), we find the distributions to be very similar at long periods, which is not surprising since we do not expect any flux-limited incompleteness for the brighter long period Cepheids. However, at periods shorter than 30 days the number density of M100 Cepheids shows a sharp decrease as compared to the Galactic distribution. This we attribute to a systematic incompleteness due to the sample being flux–limited.

We also find that the best fit slope of the PL relation for long period Cepheids ($\log(P) > 1.47$) in M100 is -3.2, which agrees well within errors with the expected value. On the other hand, a much shallower PL relation with a slope of -2.2 is obtained for the shorter period Cepheids ($\log(P) \leq 1.47$). This confirms the proposition that there exists a systematic bias (commonly known as the Malmquist bias) due to flux-limited incompleteness at short periods.

Based on a simple mathematical analysis of the number density distribution of M100 Cepheids and a numerical simulation of the incompleteness problem, we find that a correction of 0.36 mag for Cepheids with periods shorter than 25 days is necessary to offset the bias.

4. Distance to virgo cluster and the hubble constant

Extinction correction for M100 Cepheids was carried out on the basis of period–color–amplitude relations obtained from analysis of Galactic Cepheids. The final result for the Cepheid variables in M100, after corrections for incompleteness and extinction, is given by the period–V-magnitude relation:

$$\langle V\rangle_0 = -3.20\,(\log(P) - 1.48) + 25.65 \tag{1}$$

which gives a distance modulus of 31.46 mag, with the adopted slope and zero point of the PL relation and the overall correction of 0.05 mag due to shift in the observational zero point calibration [1]. Taking into account all the systematic and random errors involved in the analysis and the position of M100 relative to the center of Virgo Cluster, the distance to the Virgo Center is estimated to be 19.6 ± 1.7 (random) ± 2.6 (systematic) Mpc.

Adopting a Virgo recession velocity of 1170 ± 80 km s^{-1}, the Hubble Constant is

$$H_0 = 60 \pm 5\ (\mathrm{random}) \pm 8\ (\mathrm{systematic})\ \mathrm{km\,s^{-1}\,Mpc^{-1}} \tag{2}$$

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