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Distance to the Virgo cluster and estimation of the Hubble constant

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Determination of the Hubble constant (H_0) which is a natural scale length of the Universe is one of the fundamental problems in astronomy related to the study of the large scale structure as well as large scale geometry of the Universe. An accurate measurement of the distance to our nearest cluster of galaxies, Virgo Cluster, would go a long way to solve the present debate about the value of H_0. The Cepheid Period-Luminosity (PL) relation has been proved to be a reliable standard candle for distances up to ~ 20 Mpc. M100 is a nearly face-on spiral galaxy in the Virgo Cluster, and is supposed to be similar to our Milky Way Galaxy in terms of age, evolution, metallicity, etc. Ferrarese et al. (1996) reported observation of 72 Cepheid variables in this galaxy by the Hubble Space Telescope (HST), from which they estimated its distance to be 16.1 ± 1.3 Mpc. They adopted a recession velocity of 1396 Km s^{-1} for Virgo, and determined the value of H_0 to be 86 ± 24 Km s^{-1} Mpc^{-1}.

We have reanalyzed the HST data on M100 Cepheids to obtain the distance after taking care of many systematic and observational uncertainties, such as, the PL relation to be used for classical Cepheids with periods between 15 and 60 days, uncertainty in the determination of periods of the Cepheids, and effects due to incompleteness and extinction.

The slope and intercept of the period-luminosity diagram is conventionally derived by using the LMC Cepheids in the period range of 3 to 60 days. The value of the slope is usually taken as –2.77. We have calibrated the slope of the period–V magnitude diagram by selecting only the Cepheids in the period range of 15 to 60 days in LMC as well as three distant spirals for which HST data is available. This period range is chosen in order to avoid multi-mode pulsators at low periods, which heavily bias the PL slope due to their numerical strength. The average slope arrived at is –3.45, though error of the order of 0.15 is possible. We have used Hipparcos parallaxes for nearby Cepheids to determine the intercept of the period –V magnitude relation and have adopted a value of –4.24 for the mean absolute V–magnitude for a Cepheid of period 10 days.

At low periods, the lower luminosity of the Cepheids might cause many of them to escape detection, and *for a fixed period of the Cepheid, the fainter ones will be generally missed.* The probability of detection of a Cepheid, p, can be approximately by some positive power r of the flux f received from the Cepheid ($p \propto f^{\tau}$), and this index of power will be governed by the details of observation. Since this number cannot be determined theoretically, we have estimated it to be nearly 2 from an exponential fit to the ratio of the number densities of observed M100 and Galactic Cepheids as function of their periods, for the period range of 15 to 60 days.

The intrinsic scatter of the period-luminosity relation will determine the extent of incompleteness at a specified period. However, if extinction correction cannot be carried out independently, as is the case here, the incompleteness correction varies as the square of the observed scatter in the period–V-magnitude diagram. We find that the term to be added to the V-magnitude for Cepheids below a certain period cutoff in order to correct for the incompleteness, is proportional to $\sigma_{\rm eff}^2 \gamma / |\alpha|$, where $\sigma_{\rm eff}$ is the effective scatter of the PL relation (= 0.35), γ is a constant (= 6.29), and α is the slope of the PL relation (= –3.45).

The extinction correction for the Cepheids in M100 was based on results derived for Galactic Cepheids, which was carried out iteratively by determining the position of the instability strip on the log $T_{\rm eff}$–log g plane and matching the model atmosphere colors for that strip with dereddened colors of observed Cepheids. The reddenings were derived by using an extinction-independent quantity Q defined in terms of the standard broadband filter colors and based on the R_V-dependent extinction law for different wavelengths (Cardelli et al., 1989) valid for grain-dominated interstellar medium.

$$Q \simeq -(U - B) + 1.01\,(B - V) - 0.21\,(V - I).$$

Period-color and amplitude-color relations obtained for Galactic Cepheids were used to estimate the reddening $E(V - I)$ for M100 Cepheids. However, due to uncertainty in the value of observed $(V - I)$ the error in the extinction could be large.

The final result for the Cepheids in the spiral M100 in Virgo cluster, after the corrections for incompleteness and extinction, is given by the period-luminosity relation,

$$\langle V \rangle_0 = -3.45 \log(P) + 30.75$$

The major sources of error in the distance estimate to the Virgo Cluster lie in the determination of periods, extinction correction, incompleteness effects, slope of the period-luminosity relation, the calibration of local Cepheids and the uncertainty in the position of M100 relative to the centre of the Virgo Cluster. The total error is estimated to be nearly 0.35 mag. Thus, a conservative estimate to the distance to the centre of Virgo Cluster would be 20.3 ± 3.9 Mpc.

The observed structures within 100 Mpc indicate that there is no reason to expect an infall velocity on to Virgo Cluster of more than 70 Km s^{-1} (cf. Rowan-Robinson, 1988). Assuming this infall velocity, i.e., a Virgo recession velocity of 1140 Km s^{-1}, we obtain an estimate of the Hubble Constant to be

$$H_0 = 56 \pm 12 \text{ Km s}^{-1} \text{ Mpc}^{-1}$$

Reference

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