Determination of the LMC distance modulus from the
Classical Cepheid Period-Luminosity relation

Xavier Luri, J. Torra, F. Figueras
Departament d’Astronomia i Meteorologia, Universitat de Barcelona,
Avda. Diagonal 647, E-08028, Barcelona, Spain

A.E. Gómez, M.J. Goupil & J.P. Beaulieu
Observatoire de Paris-Meudon D.A.S.G.A.L., URA CNRS 335, F92195
Meudon CEDEX, France

Abstract. The distance modulus of the Large Magellanic Cloud (LMC) is the first step on the determination of the cosmic distance scale. In this paper it is obtained from a new calibration of the classical Cepheid Period-Luminosity (PL) relation.

Our new calibration is obtained by applying the LM method – a parametric method designed to obtain luminosity calibrations from astrometric information – to the Hipparcos data for Classical Cepheids. The resulting distance modulus is \(18.35 \pm 0.13\).

1. Introduction

The purpose of this paper is twofold. On the one hand, it is intended to be a complement of the Arenou & Luri paper in this volume, presenting an example of application of a parametric method for luminosity calibrations. On the other hand, a new result for the Cepheid PL relation using Hipparcos data is presented, and the LMC distance modulus is deduced from it.

2. The sample

Our working sample was formed by selecting all classical cepheids contained in the Hipparcos catalogue (ESA, SP-1200), even first overtone pulsators. The resulting sample contains 238 stars.

All data (including periods) were taken from the Hipparcos catalogue, except the radial velocities, that were taken from the Hipparcos Input Catalogue (Turon et al. 1992).

3. The LM method

As described in Arenou & Luri (this volume) parametrical methods can be applied to obtain unbiased luminosity calibrations. In our case, to obtain the PL relation of classical Cepheids we have used the LM method. This method,
using Maximum-Likelihood estimation and specifically designed for luminosity calibrations, is fully described in Luri et al. (1996). Its main advantages are:

- All the available information for each star can be used: apparent magnitude, position, trigonometric parallax, proper motions and radial velocities as well as other relevant astrophysical parameters (color index, period, etc.).

- It has been designed to fully exploit Hipparcos data for luminosity calibrations.
  - The observational selection criteria used to construct the sample of stars are taken into account. This is essential to obtain unbiased results (Brown et al., 1997 Arenou & Luri, this volume).
  - The effects of observational errors are also taken into account, thus avoiding biases (Arenou & Luri, this volume).

- It gives at the same time the kinematical properties and spatial distribution of the sample.

- It is able to handle inhomogeneous samples composed of groups of stars with different luminosity, kinematical or spatial characteristics.

- It provides an individual distance estimate with optimal statistical properties (Arenou & Luri, this volume).

4. Modeling of the sample

As described in Arenou & Luri (this volume), to apply a parametric method (the LM method in our case) it is necessary to model the physics and observational errors of the sample as well as the censorship applied for its construction. Each distribution (luminosity, velocity, spatial and error distribution) and the observational selection is described by a p.d.f. depending on a set of parameters. The values of these parameters are determined by applying the LM method to the sample.

In our case we have used the modeling described in this section to describe our sample of Hipparcos Cepheids.

4.1. Absolute magnitude distribution

- Linear mean PL relation: \( M_v = \alpha + \beta \log(P) \)

- Gaussian dispersion \( (\sigma_M) \) of the individual absolute magnitude around the mean relation

  Actually, the real intrinsic distribution has a Top-Hat shape, but combined with the errors in the estimation of the interstellar absorption it is reasonably well approximated by a Gaussian.

- Interstellar absorption from the 3D model by Arenou et al. (1992)
4.2. Velocity distribution

- Velocity ellipsoid: \( \Phi_K(U, V, W) = e^{-\frac{1}{2} \frac{(U-U_0)^2}{\sigma_U^2}} e^{-\frac{1}{2} \frac{(V-V_0)^2}{\sigma_V^2}} e^{-\frac{1}{2} \frac{(W-W_0)^2}{\sigma_W^2}} \)

- Galactic rotation: Oort-Lindblad model at first order with \( A = 14.4 \text{ km s}^{-1} \text{ kpc}^{-1}, B = -12.8 \text{ km s}^{-1} \text{ kpc}^{-1} \) and \( R_\odot = 8.5 \text{ kpc} \) (Kerr & Lynden-Bell, 1986).

4.3. Spatial distribution

- Exponential disk: \( \Phi_S(x, y, z) = e^{-\frac{|z|}{Z_0}} \)

4.4. Error distribution

As we are dealing with an all-sky sample, we can safely assume that the astrometrical observational errors of the stars are uncorrelated and follow a Gaussian distribution (Arenou & Luri, this volume). We have also assumed Gaussian errors for radial velocity but we have considered negligible the errors in apparent magnitude, position and period.

4.5. Observational selection

As we have included all the classical Cepheids contained in the Hipparcos Catalogue, the only observational selection is the one of the catalogue itself.

The main censorship of the catalogue is in apparent magnitude: the catalogue is complete up to the Hipparcos magnitude \( H_p \simeq 7.9^m \) (the Survey) and its magnitude limit is \( H_p \simeq 12.5^m \). We have modeled this censorship with a selection function giving completeness up to a certain apparent magnitude \( m_c \) (estimated by the method together with the rest of parameters) and a linear decrease of the completeness up to the limiting magnitude (Figure 1).

On the other hand, we have considered the censorship on \((\pi_t, l, b, \mu_\alpha, \mu_\delta, v_r, P)\) not significant on average.

4.6. Groups

As pointed out in Sec. 2, our sample is a mixture of two types of Cepheids: fundamental pulsators and overtone pulsators. We have classified the stars in these two types using the Fourier coefficients obtained from the Hipparcos light curves: 204 were classified as fundamental pulsators and 34 as overtone pulsators.

We have also made two supplementary hypothesis:

1. The slopes of the PL relations for both groups have been fixed to the values for the SMC obtained by the EROS team (Sasselov et al., 1997): \( \beta_F = -2.72 \pm 0.07 \) (fundamental) and \( \beta_{OV} = -3.46 \pm 0.14 \) (overtones). Only the zero points of the PL relations have been determined, \( \alpha_F \) (fundamental) and \( \alpha_{OV} \) (overtones).

2. We have assumed that both groups have the same kinematic and spatial distributions (i.e. the same velocity ellipsoid and scale height).
5. Results

The application to our sample of the LM method with the modeling described above gives the following estimates for the zero points of the PL relations:

**Cepheids pulsating on the fundamental mode:** \( \alpha_F = -1.01^m \pm 0.13 \)

**Cepheids pulsating on the 1st overtone:** \( \alpha_{OV} = -1.26^m \pm 0.20 \)

On the other hand, the values obtained for the kinematical and spatial distribution parameters are \((U_0 = -9.0 \pm 1.5, V_0 = -10.3 \pm 1.2, W_0 = -7.5 \pm 0.6) \ km \ s^{-1},\) \((\sigma_U = 13.0 \pm 1.2, \sigma_V = 12.7 \pm 1.3, \sigma_W = 6.2 \pm 1.2) \ km \ s^{-1}\) and \(Z_0 = 97 \pm 7 \ pc.\)

6. LMC distance modulus

The LMC distance modulus can be calculated from the difference of zero points between our PL relation and the EROS apparent magnitude PL relation for the LMC (Sasselov et al. 1997). However, the difference of zero points has to be corrected of the effects of interstellar absorption and metallicity and thus two more assumptions are needed:

- We have assumed a value of \( E(B-V) = 0.1^m \) for the LMC extinction (from Freedman et al., 1994). Then, we have calculated the absorption from this value using the ratio \( R = \frac{A_B}{E(B-V)} = 3.311 \)
• We have assumed a correction of $0.043^m$ to take into account the effects on the zero points of the metallicity difference between the LMC and our Galaxy (Laney & Strobie, 1994)

Using these assumptions the resulting distance modulus for the LMC is:

$$(m - M)_0 = 18.35^m \pm 0.13$$

This result is in agreement with the “short” distance scale obtained from (for instance) RR-Lyrae (Luri et al. 1998) but not compatible with the “long” distance scale from other Hipparcos results for Cepheids (Feast & Catchpole, 1997). Please notice that the error estimation does not take into account the error in the value of $E(B - V)$ for the LMC.

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