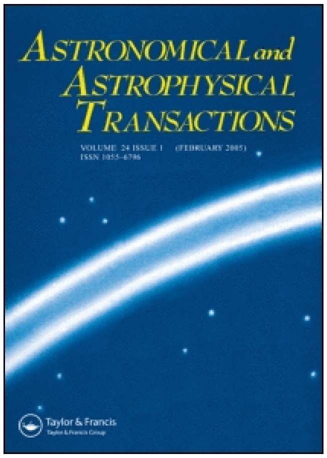

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THE DISTANCE SCALE AND THE ROTATION CURVE OF YOUNG SUPERGIANTS AND OPEN CLUSTERS

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The Hipparcos trigonometric parallaxes of 188 blue (O-type and B0–A3 I–II) supergiants with published *uvby* and H_β photometry are compared to the photomeric parallaxes of these stars based on the M_V absolute-magnitude calibration of Dambis (1990). The photometric distance scale is found to require only a minor correction – $\pi_{\rm Hip} = (1.03 \pm 0.04)\pi_{\rm Phot}$, i.e., $r_{\rm Hip} = (0.97 \pm 0.04)r_{\rm Phot}$, which is corroborated by applying the statistical-parallax technique to a sample of 106 blue supergiants with published radial velocities and Hipparcos proper motions ($r_{\rm True} = (0.98 \pm 0.08)r_{\rm Phot}$). The weighted mean distance-scale correction factor can thus be estimated at $r_{\rm True} = (0.97 \pm 0.03)r_{\rm Phot}$, thereby constraining the LMC distance modulus to $DM_{LMC} = 18.36 \pm 0.08$ (standard error) ± 0.07 (systematic error) and providing further evidence in favor of the so-called 'short' distance scale.

An expanded sample consisting of 106 blue supergiants with corrected photometric distances, published radial velocities, and Hipparcos proper motions, combined with 51 young open clusters ($\log t \leq 7.5$) with Hipparcos-based proper motions (Rastorguev *et al.*, 1999), mean radial velocities (Rastorguev *et al.*, 1999), and photometric distances based on ZAMS fitting (Dambis, 1999) is used to infer the following Galactic rotation-curve solution : vector of solar motion ($u_0 = 5.5 \pm 1.2$, $v_0 = 11.2 \pm 1.2$, $w_0 = 7.7 \pm 0.7$) km s^{-1}; rotation-curve parameters $\Omega_0 = 29.3 \pm 1.0$ km s^{-1} kpc^{-1}, $\Omega'_0 = -4.78 \pm 0.21$ km s^{-1} kpc^{-2}, and $\Omega''_0 = +1.07 \pm 0.21$ km s^{-1} kpc^{-3}), and velocity ellipsoid semiaxes $\sigma_u = 13.0 \pm 1.0$ km s^{-1}, $\sigma_v = 10.9 \pm 0.8$ km s^{-1}, and $\sigma_w = 5.8 \pm 0.7$ km s^{-1}.

KEY WORDS Distance scale, OB-stars, Galaxy, rotation curve

1 INTRODUCTION

Even the nearest OB-stars are very distant objects and therefore the distances to these stars are determined mainly by comparing their apparent magnitudes corrected for interstellar extinction with the absolute magnitudes that can be estimated from the known spectral types and luminosity classes or equivalent widths of hydrogen absorption lines. The unprecedented accuracy of parallaxes and proper motions measured within the framework of the Hipparcos (ESA, 1997) mission allowed the photometric distance scale of blue supergiants to be directly calibrated for the first time. We have already used the Hipparcos catalog data to calibrate the spectral-classification based distance scale of OB-stars and associations (Dambis *et al.*, 2001). However, the highly discrete nature of the principal distance indicator involved – the luminosity class – leaves the credibility of individual distances thus determined open to question. Here we use Hipparcos data combined with published photometry and radial-velocities to set – both directly and via statistical parallaxes – the zero point of our absolute-magnitude calibration $M_V(c_0, \beta)$ (Dambis, 1990) for blue supergiants based on photometric indices of Stroemgren's $uvby\beta$ system, and to estimate the parameters of the Galactic rotation curve using a sample made up of blue supergiants and young open clusters.

2 THE DATA

Our data sources for blue supergiants were the Hipparcos (ESA, 1997) catalog (trigonometric parallaxes and proper motions), the radial-velocity catalog by Barbier-Brossat and Figon (2000), and the $uvby\beta$ photoelectric catalog by Hauck and Mermilliod (1998). For young open clusters we use the mean radial velocities and Hipparcos-based proper motions as inferred by Rastorguev *et al.* (1999) and the photometric (ZAMS-fit) distances of clusters determined by Dambis (1999).

3 SETTING THE PHOTOMETRIC DISTANCE-SCALE ZERO POINT VIA TRIGONOMETRIC PARALLAXES

To set the zero point of our scale of photometric distances of blue supergiants, we compare the photometric parallaxes for 188 Galactic blue supergiants ($\pi_{\rm Phot} = 1/r_{uvby\beta}$) to the trigonometric parallaxes $\pi_{\rm Trig}$ of these stars adopted from the Hipparcos catalog (ESA 1997). The least-squares solution of the set of linear equations

$$\pi_{\rm Trig} = k_\pi \pi_{\rm Phot}$$

yields a parallax correction factor of $k = 1.03 \pm 0.04$, implying that photometric *distances* should be multiplied by $k_r = 1/k_\pi = 0.97 \pm 0.04$:

$$r_{\rm True} = (0.97 \pm 0.04) r_{uvby\beta}.$$

4 ESTIMATING THE PHOTOMETRIC DISTANCE-SCALE ZERO POINT VIA STATISTICAL PARALLAXES

To verify the result obtained in the previous section, we applied the statistical-parallax technique to independently set the zero point of the adopted photometric distance scale of blue supergiants. We used the rigorous version of the statistical-parallax technique as described in Murrey's (1983) book and in the paper by Hawley

Table. Parameters of the Galactic rotation curve solution for a combined sample of 106 blue supergiants and 51 young open clusters.

N	u_0 km/s	v_0 km/s	w_0 km/s/	Ω_0 km/s/	Ω'_0 km/s/ kpc	Ω''_0 km/s kpc^2	σ_u km/s kpc^3	σ_v km/s	σ_w km/s	A km/s kpc
157	5.5 ±1.2	11.2 ±1.2	7.7 ±0.7	29.3 ±1.0	-4.78 ±1.0	+1.07 ±0.21	13.0 ±0.21	10.9 ±1.0	5.8 ±0.8	17.0 ±0.7

et al. (1986). It consists in simultaneous determination of the set of kinematical parameters (the vector of the full space velocity and the components of the velocity dispersion tensor) and the correction factor to the initial distance scale to maximize the likelihood of the actual combination of the observed data (coordinates, relative distances, radial velocities, and proper motions). The concrete formulas for our case can be found in Rastorguev *et al.* (1999) and Dambis *et al.* (2000).

We applied the statistical-parallax technique to a sample of 106 blue supergiants with provisional distances $r_{\rm Phot}$ based on published $uvby\beta$ photometry (Hauck and Mermilliod 1998) and absolute-magnitude and intrinsic-color calibrations by Dambis (1990); proper-motion data from the Hipparcos (ESA, 1997) catalog, and mean radial velocities from the catalog of Barbier-Brossat and Figon (2000). Our free parameters in the likelihood-function maximization are the mean heliocentric velocity components of the association sample, u_0, v_0, and w_0 (in the directions of the Galactic center, Galactic rotation, and North Galactic Pole, respectively); the components of the velocity dispersion tensor, (σ_u, σ_v, and σ_w); the angular velocity of Galactic rotation at the solar Galactocentric distance, Ω_0 and its first two derivatives with respect to Galactocentric distance, Ω'_0, and Ω''_0, taken at the solar Galactocentric distance, R_0; and the distance-scale correction factor k converting the provisional distances into the true distances ($r_{\rm True} = k r_{\rm Phot}$). We adopted $R_0 = 7.1$ kpc for the distance of the Sun to the Galactic center (Dambis *et al.*, 1995; Rastorguev *et al.*, 1994; Glushkova *et al.*, 1998). The correction factor to the photometric distance scale of Dambis (1990) is $k = 0.98 \pm 0.08$, in excellent agreement with the result based on trigonometric parallaxes (see previous section). The weighted average of the two independent distance-scale correction factor determinations is:

$$\langle k \rangle = 0.97 \pm 0.03,$$

implying that the absolute magnitudes given by the calibration of Dambis (1990) should be reduced by $5 \log 10(0.97 \pm 0.03) = -0.07 \pm 0.07$.

5 THE DISTANCE MODULUS OF THE LMC

We now use the results obtained in the previous two sections to constrain the distance modulus of the LMC. To this end, we apply the corrected absolute-magnitude calibration $M_V(c_0, \beta)_{\mathrm{Corr}} = M_V(c_0, \beta)_{\mathrm{Dambis1990}} - 0.07$ to the $uvby\beta$ photometry of 26 blue supergiants in the LMC published by Shobbrook 1986; Shobbrook and Visvanathan 1987, Fitzpatrick 1988. The resulting mean distance modulus of the entire sample is: $DM_0\mathrm{LMC} = 18.36 \pm 0.08$ (standard error) ± 0.07 (standard error of the calibration zero point), and the standard error per star is $\sigma_{\mathrm{DM}} = 0.38^m$.

Our result agrees with the LMC distance-modulus estimates based on RR Lyrae statistical parallaxes (Dambis and Rastorguev, 2001) and corroborates the so-called 'short' distance scale.

6 GALACTIC ROTATION CURVE

Now, having set the zero point of the photometric distance scale of blue supergiants, we combine the sample of supergiants used in the statistical-parallax solution with a sample of 51 young open clusters ($\log t \leq 7.1$) for which ZAMS-fit distances (Dambis 1999), mean radial velocities, and Hipparcos-based proper motions (Rastorguev *et al.*, 1999) are available, to determine the parameters of the Galactic rotation curve. We did not correct the cluster distances, because Baumgardt *et al.* (2000) found them to be in excellent agreement with Hippparcos-based trigonometric parallaxes: $\pi_{\mathrm{Trig}} = 0.99\pi_{\mathrm{Dambis}}$. The results are summarized in the Table.

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