Astrophysical Applications of Stellar Pulsation
ASP Conference Series, Vol. 83, 1995
R. S. Stobie and P. A. Whitelock, eds.

Uncertainties in the Galactic Cepheid Distance Scale

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Abstract. We have examined the uncertainties involved in using the visual surface brightness technique on Galactic Cepheid variables. The random error in a single Cepheid distance measurement is well determined to be ±8%. An upper limit to the systematic uncertainty is shown to be ±6% in distance. These combine for a single Cepheid to a typical uncertainty of ±10% and, for samples larger than ten Cepheids, to a typical uncertainty of less than ±6% in distance.

1. Introduction

Using the visual surface brightness technique on 100 Cepheids, Gieren, Barnes, & Moffett (1993) determined the Galactic Cepheid PL relation. This relation is an independent check on the PL relation determined from the cluster-fitting technique. Thus, it is important to understand the uncertainties in the visual surface brightness method. There are two questions to address: (1) what is the individual uncertainty in a Cepheid distance determined by the surface brightness technique (the random error), and (2) what is the uncertainty of the method itself (the systematic error)?

2. Random uncertainties

The random uncertainties are rather straightforward to understand. The surface brightness analysis involves fitting photometrically determined angular diameters to spectroscopically determined linear diameters, as discussed by Gieren et al. The fitting process calculates an uncertainty for each Cepheid's distance from the quality-of-fit, which is an internal random error. From our analyses of 100 Cepheids, the median uncertainty in distance for an individual Cepheid is found to be ±7.8%, *i.e.*, ±8%.

3. Systematic errors

Estimating the systematic uncertainty in distance measurements is rather more difficult. Hindsley & Bell (1989) carefully investigated the systematic errors in

the surface brightness method. The ones appropriate to the Gieren et al. analysis are (1) the choice of $E(B-V)$ (0.7–2.2%), (2) the choice of $A_V/E(B-V)$ (0.8–1.1%), (3) the choice of $E(B-V)/E(V-R)$ (3.1–3.6%), (4) phasing problems between the radial velocities and the photometry (4.0–4.7%), and (5) the choice of correction factor from radial velocity to pulsational velocity (2.0%). These combine to a typical value of ±6.1% uncertainty in distance.

The best way to estimate systematic uncertainty is to inter-compare fully independent methods of determining the same quantity. The Galactic Cepheid PL relation may be determined by means of surface brightness analyses and by means of the *completely independent* method of cluster fitting. The surface brightness analysis gives the Galactic Cepheid PL relation

$$\begin{aligned} M_V = \; & -1.371 \quad -2.986 \log P. \\ & \pm.095 \quad \pm.094 \end{aligned}$$

The cluster fitting method gives a relation (Gieren & Fouqué 1993)

$$\begin{aligned} M_V = \; & -1.329 \quad -2.911 \log P. \\ & \pm.134 \quad \pm.122 \end{aligned}$$

These independent methods of determining Cepheid distances differ by less than 35% of the combined sigma in slope and by less than 20% of the combined sigma in zero point. A straightforward interpretation is that there is no difference between the results and thus there can be *no significant systematic error in either of them.* In the worst case, the systematic difference between the relations is 0.12 mag, as measured at the middle of the period distribution. If this difference were wholly due to systematic error in the surface brightness technique, its systematic error would be 5.7% in distance. This is close to the systematic error estimated by Hindsley & Bell, ±6.1%. We adopt the conservative stance that ±6% is a reasonable upper limit for the systematic uncertainty in visual surface brightness distances.

4. Conclusions

We have shown that the random error in a single Cepheid distance measurement by the surface brightness method is ±8%. We have also shown that the systematic uncertainty is less than ±6% in distance. These combine for a single Cepheid to a typical uncertainty of ±10% in distance and for samples larger than ten Cepheids, appropriate to studies of other galaxies, to a typical uncertainty of less than ±6% in the distance.

References

Gieren, Barnes, & Moffett 1993, ApJ, 418, 135
Gieren, & Fouqué 1993, AJ, 106, 734
Hindsley, & Bell 1989, ApJ, 341, 1004