A DIRECT DISTANCE TO THE LARGE MAGELLANIC CLOUD CEPHEID HV 12198 FROM THE INFRARED SURFACE BRIGHTNESS TECHNIQUE

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ABSTRACT

We report on the first application of the infrared surface brightness technique on a Cepheid in the Large Magellanic Cloud, the variable HV 12198 in the young globular cluster NGC 1866. From this one star, we determine a distance modulus of 18.42 ± 0.10 (random and systematic uncertainty) to the cluster. When the results on further member Cepheids in NGC 1866 become available, we expect to derive the distance to the LMC with a ±3%–4% accuracy, including systematic errors, from this technique.

Subject headings: Cepheids — galaxies: distances and redshifts — galaxies: individual (Large Magellanic Cloud) — globular clusters: individual (NGC 1866)

1. INTRODUCTION

The determination of the distance to our neighboring galaxy, the Large Magellanic Cloud, is a problem of fundamental astrophysical importance. Objects of any kind can be studied in the LMC in greater detail than in any other galaxy, but in order to know luminosities and true linear dimensions, we have to know an accurate distance to these objects. For the extragalactic distance scale, the LMC plays a fundamental role because most of the extragalactic distance calibrators, like Cepheids, are tied to the distance of the LMC, either directly or indirectly. Due to its prime astrophysical importance, there has been a large effort to determine the distance to the LMC from many different objects and with a variety of techniques. The current state of this subject has recently been reviewed comprehensively by Walker (1999). Currently, distance determinations for the LMC are scattered between 18.2 and 18.7 mag, a very unsatisfactory situation that clearly indicates the presence of significant systematic errors in most of the methods. Therefore, any new technique that holds the promise of yielding a truly accurate distance to the LMC is of great astrophysical relevance.

2. THE INFRARED SURFACE BRIGHTNESS TECHNIQUE

Following an original idea of Welch (1994), Fouqué & Gieren (1997) have calibrated two versions of a technique that employs the V, V–K and K, J–K magnitude/color combinations, respectively, to derive the angular diameter of a Cepheid variable, at any given phase of its pulsation cycle. This angular diameter can be combined with the instantaneous linear diameter of the pulsating star, at the same phase, which is derived from an integration of its observed radial velocity curve. Observing many such pairs of angular and linear diameters over the pulsation cycle, one can derive both the mean radius and the distance of the Cepheid variable from a simple regression analysis. The distance so derived is independent of the pulsation mode of the variable (although, in practice, application will be mostly restricted to fundamental-mode pulsators with their larger light and color amplitudes). An application of this infrared technique to a large number of Galactic Cepheids (Gieren, Fouqué, & Gómez 1997, 1998) has shown that the combined random and systematic uncertainty of a Cepheid distance can be as low as ~±3%, if the data used in the analysis are of excellent quality. In these papers, it was also shown that the distances from both versions of the method agree to within better than 2%. A very important feature of the technique is its very low sensitivity to the assumed reddening and to the Cepheid’s metallicity. These features make the infrared surface brightness technique an excellent tool for deriving direct, one-step Cepheid distances of very low systematic uncertainty to nearby galaxies, circumventing most of the problems due to uncertain absorption and metallicity corrections, and could provide the means to beat down finally the uncertainty of the LMC distance below the 3% level, which is scientifically so desirable.

3. THE LMC CLUSTER NGC 1866 AND ITS CEPHEID POPULATION

The ideal targets in the LMC for deriving a very accurate Cepheid distance from the infrared surface brightness technique are the young globular clusters. Several of these objects contain considerable numbers of Cepheid variables whose individual distances can be averaged to determine accurate mean cluster distances. Also, an analysis of the dispersion among the distances of a number of member Cepheids of a given cluster will yield the ultimate test of the true capabilities of the technique.

Among the Cepheid-rich LMC clusters, the outstanding object is NGC 1866. It was the first LMC cluster in which Cepheid variables were detected (Arp & Thackeray 1967), and later surveys for more Cepheid variables in regions closer to the cluster center (Storm et al. 1988; Welch et al. 1991) turned up a total number of Cepheids in excess of 20 (which is about the same as all Cepheids in Galactic open clusters taken together!). Welch et al. (1991), in a pioneering study, were the first to collect radial velocity data for a significant fraction of the NGC 1866 Cepheids that indicated that all these objects (with the possible exception of one star) are indeed cluster members. A first Baade-Wesselink—type analysis to determine mean radii and distances for some of the outer cluster Cepheids was performed by Côté et al. (1991), using photometric data in the B and V bands. The distances derived in this work show a large dispersion. Similar work using the visual surface bright-
Fig. 1.—Radial velocity curve for the Cepheid HV 12198 in NGC 1866. The filled squares represent our new observations. The open squares represent the previous observations of Welch et al. (1991). The phases have been calculated with a period of 3.52279 days. The mean velocity of $299.8 \pm 1.5$ km s$^{-1}$ (internal and systematic error) supports cluster membership for HV 12198. There is no indication for spectroscopic binarity from the data.

Fig. 2.—$V$ light curve of HV 12198. The filled squares represent our new data. The open squares represent the literature data reported by Walker (1987) and Welch et al. (1991).

5. DISTANCE AND RADIUS OF THE CEPHEID VARIABLE HV 12198

At the present time, the data set and reductions are complete for the Cepheid HV 12198 (star "g" on the finder chart given by Arp & Thackeray 1967, located about 1.4 from the center of NGC 1866). Judging from its asymmetric light curve and the amplitudes of its light and radial velocity curves, this variable is most likely a fundamental-mode pulsator. A Fourier decomposition analysis of the light curves of all the NGC 1866 Cepheids, in order to determine their pulsation modes, will be presented in a forthcoming paper. For the purpose of this Letter, it suffices to recall that our method of distance determination does not depend on the pulsation mode. The relatively red
Fig. 4.—Linear displacements for HV 12198, derived from the radial velocity curve, plotted against the angular diameters at the same phases, derived from the \( VK \) photometry. The solid line is the inverse fit to the data that assumes larger relative errors on the angular diameters than on the linear displacements. The slope of the line yields the distance.

Fig. 3.—\( K \) light curve of HV 12198 from our new data.
just reflects the fact that the photometric variations and the radial velocity curve are very well defined by the present data. The radius value of 32.9 $R_\odot$ is in very good agreement with the radius of 30.6 $R_\odot$ that was predicted for a 3.5 day Cepheid by the period-radius relation of Gieren et al. (1998) that was calibrated on Galactic stars. This strengthens the recent finding of Gieren, Moffett, & Barnes (1999) that Cepheids of the Galaxy and both Magellanic Clouds appear to obey the same period-radius relation. It also implies that any dependence of the Cepheid period-radius relation on metallicity must be small enough to escape detection, within the accuracy of the radius determinations.

6. THE DISTANCE TO THE LMC

The distance of HV 12198 found in this Letter corresponds to a true distance modulus of $18.42 \pm 0.08$ mag for its host cluster NGC 1866. Taking into account a possible systematic error on the distance of $\pm 3\%$ (Gieren et al. 1997), the total uncertainty on the distance modulus is $\pm 0.10$ mag. This result is almost identical to the LMC distance modulus of 18.46 obtained by Gieren et al. (1998) from a comparison of LMC Cepheid period-luminosity relations in $VIJK$ passbands with the Galactic relation obtained from infrared surface brightness distances to some 30 Galactic Cepheids. Since this latter result has, in principle, a dependence on the poorly known metallicity effect on Cepheid luminosities, our current direct and metallicity-independent distance result for HV 12198 suggests that the effect of metallicity on Cepheid absolute magnitudes in optical and near-infrared photometric bands is small and might even be zero. However, this is a preliminary conclusion, which can be checked and quantified once the distance results for the other NGC 1866 Cepheids, and hence a more accurate LMC distance, become available. For the time being, let us also note that a slightly shorter distance modulus to the LMC than that of 18.5 favored by the Hubble Space Telescope Key Project team tends to bring the discrepant results on the distance of NGC 4258 (Herrnstein et al. 2000; Maoz et al. 2000) into better agreement. The low $\sim \pm 5\%$ uncertainty of the current distance determination for one Cepheid in NGC 1866 makes us optimistic that our study will achieve its principal goal of determining a Cepheid-based distance to the LMC that will have lower random and systematic uncertainty than any previous determination with Cepheids and that it will mean true progress toward the absolute calibration of the extragalactic distance scale.

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