Part 1.3. Stellar Pulsation and the Distance Scale

https://doi.org/10.1017/S0252921100015700 Published online by Cambridge University Press

Radial and Nonradial Pulsations as Probes of Stellar Physics
ASP Conference Series, Vol. 259, 2002
C. Aerts, T.R. Bedding, & J. Christensen-Dalsgaard, eds.

Dwarf Cepheid Radii and the Distance Scale

C. D. Laney

South African Astronomical Observatory, PO Box 9, Observatory 7935, South Africa

M. Joner

Brigham Young University, Provo, Utah, U.S.A.

L. Schwendiman

Brigham Young University, Provo, Utah, U.S.A.

Abstract. Baade-Wesselink radii for dwarf Cepheids (High Amplitude Delta Scuti stars) can give luminosities and distances independent of the classical Cepheid distance scale. Using optical and IR photometry together with precision radial velocities, the authors have obtained radii and luminosities for 7 stars, and combined these with two from the literature, obtaining results consistent with the luminosities of the 3 dwarf Cepheids with good Hipparcos parallaxes. Classical Cepheids and dwarf Cepheids appear to fit the same PL and PR relations. The results imply 'bright' RR Lyrae absolute magnitudes giving an LMC distance modulus of 18.51–18.54, in agreement with the distance derived from classical Cepheids.

Dwarf Cepheids (HADS & SX Phe stars) are slowly rotating, radial pulsators with V amplitudes greater than 0.3 mag. McNamara (1997) argued that they could be the basis of an alternate method of calibrating the distance scale. He used $uvby\beta$ photometry and models to derive mean temperatures, metal abundances, surface gravities, M_V and M_{bol}, and found a period-luminosity relation from these semi-empirical calculations for fundamental mode pulsators:

$$M_V = -3.725\,\mathrm{Log}P - 1.933.$$

Using this he established M_V values for RR Lyrae and horizontal branch stars in globular clusters containing SX Phe stars, and in the Carina galaxy, deriving an LMC modulus of 18.57.

Our goal was to derive luminosities for HADS in a more purely empirical way, following the IR Baade-Wesselink technique used by Laney & Stobie (1995, LS95) for classical Cepheids. For 3 stars (BS Aqr, CY Aqr, RS Gru), D.H. McNamara obtained the first JK observations in 1985. Observations of BS Aqr continued during the 1990s, and RY Lep was added. After analysis of BS Aqr and CY Aqr made it clear that good results were by no means impossible, the present authors launched a more active observing program aimed at obtaining radii for a total of 10 relatively bright monoperiodic or double mode dwarf Cepheids. We report here on preliminary results for 7 monoperiodic stars. *VJHK* photometry and echelle radial velocities were obtained at the South African Astronomical Observatory, and *V* photometry from observations at Brigham Young University, supplemented in some cases by photometry and radial velocities from the literature.

Applying the LS95 method involves somewhat greater difficulties for our sample of dwarf Cepheids than for typical bright classical Cepheids in the solar neighbourhood. The amplitudes are considerably lower, for example, so that very large amounts of photometry are required in order to beat down the errors. The stars are typically fainter than most of those observed by LS95, and the K-band photometry correspondingly noisier. Hence, for some of the fainter stars observations at H have been substituted, as the H light curve mimics the K curve quite closely, but is much less noisy.

Phase-dependent anomalies (presumably caused, as with RR Lyrae stars, by shocks on the rising branch) made the use of full-phase BW solutions problematic for two stars in our sample. For RS Gru and AD CMi, we used only phases between 0 and 0.7 for BW solutions involving optical photometry. For RS Gru, where a well-determined solution could be derived without optical photometry, the K,J-K solution was unaffected by the phase range chosen, unlike the K,V-K solution. For the other 5 stars (BS Aqr, CY Aqr, EH Lib, ZZ Mic, RY Lep), all phases were included in the solutions, and no obvious anomalies connected with the rising branch were seen. A constant projection factor of 1.36 was employed, and error estimates in all quantities were used in deriving radii.

For the two stars where binarity is obvious in the radial velocities (RS Gru, RY Lep), an iterative procedure was used to separate the orbital and pulsational velocities. RS Gru has a relatively short orbital period (but longer than a week), and RY Lep a period of at least 500 days.

It should be noted that the phasing of the photometry and radial velocities is less certain for RY Lep than for the other stars, due to the anomalous behaviour of this star (Laney et al., 2001). In general, *V* photometry was used to establish phase behaviour so that the various data sets could be phased to together accurately. The results for all seven stars, together with two radii taken from the literature (Wilson et al., 1993; Milone et al., 1994), are :

	Log P	R		R(Mc)	Log R	Log R(Mc) -Log R	Mv	Mv(Mc)
RY Lep	-0.6475	4.63:	0.40:	4.74	0.6656	0.0102	0.68	0.47
BS Aqr	-0.7037	4.28	0.08	4.29	0.6318	0.0010	0.76	0.62
RS Gru	-0.8327	3.30	0.15	3.36	0.5185	0.0078	1.10	1.13
AD CMi	-0.9102	2.72	0.20:	2.95	0.4346	0.0353	1.54	1.30
EH Lib	-1.0535	2.54	0.15	2.24	0.4048	-0.0546	1.58	1.84
ZZ Mic	-1.1728	2.13:	0.20:	----	0.3283	------	1.98	----
CY Aqr	-1.2144	1.54	0.09	1.55	0.1875	0.0028	2.60	2.73
DY Her	-0.8279*	2.95	0.21	3.42	0.4698	0.0642	1.48	1.15
DY Peg	-1.1371**	2.21	0.26	1.87	0.3446	-0.0726	2.25	2.26

* Milone et al. (1994), converted to mean R and p = 1.36
** Wilson et al. (1998) "

https://doi.org/10.1017/S0252921100015700 Published online by Cambridge University Press

Colons mark the two most uncertain radii, both of which have formal internal errors of the order of 10%.

We find that the derived radii and M_V values are very similar to those derived by McNamara, with rather little scatter. For 6 stars in common:

$$\begin{aligned} \mathrm{Log}R(1997) &- \mathrm{Log}R(BW) = 0.00 \pm 0.01, \\ M_V 1997) &- M_V(BW) = -0.03 \pm 0.08. \end{aligned} \tag{1}$$

For 8 stars in common, including DY Her (Milone et al., 1994) and DY Peg (Wilson et al., 1998),

$$\begin{aligned} \mathrm{Log}R(1997) &- \mathrm{Log}R(BW) = 0.00 \pm 0.02, \\ M_V 1997) &- M_V(BW) = -0.06 \pm 0.07. \end{aligned} \tag{2}$$

The differences are not statistically significant, and even if applied change the LMC modulus derived by McNamara (1997) only marginally to 18.54 (6 star comparison) or 18.51 (8 stars). If for EH Lib we use the mean of the Wilson et al. radius and the radius derived here, the resulting LMC modulus is 18.53. All of these moduli are in excellent agreement with the classical Cepheid distance modulus derived using the same IR BW technique (18.58), or with the classical Cepheid modulus from cluster Cepheids (18.53) (Laney & Stobie, 1995b).

The Period-Radius relation for 9 dwarf Cepheids is

$$\begin{array}{lcccl} \mathrm{Log}\ R = & 1.098 & + & 0.694\,\mathrm{Log}\ P\,, & \sigma = 0.045. \\ & \pm.073 & & \pm.076 & \end{array}$$

which is identical within the errors with the relation for classical Cepheids (Laney 1999):

$$\begin{array}{lcccl} \mathrm{Log}\ R = & 1.109 & + & 0.721\,\mathrm{Log}\ P\,, & \sigma = 0.039. \\ & \pm.015 & & \pm.014 & \end{array}$$

If we combine the results for 57 classical and 9 dwarf Cepheids, we get:

$$\begin{array}{lcccl} \mathrm{Log}\ R = & 1.115 & + & 0.717\,\mathrm{Log}\ P\,, & \sigma = 0.038. \\ & \pm.006 & & \pm.005 & \end{array}$$

Thus HADS lie on the Cepheid PR relation.

The period-luminosity relation for 9 dwarf Cepheids is

$$\begin{array}{lcccl} M_V = & -1.24 & - & 2.96\,\mathrm{Log}\ P\,, & \sigma = 0.215, \\ & \pm.35 & & \pm.36 & \end{array}$$

which is again consistent (within the errors) with the relation for classical Cepheids. AD CMi does not appear to be subluminous, as was implied by a rather low-quality Hipparcos parallax (but not by the results of McNamara,

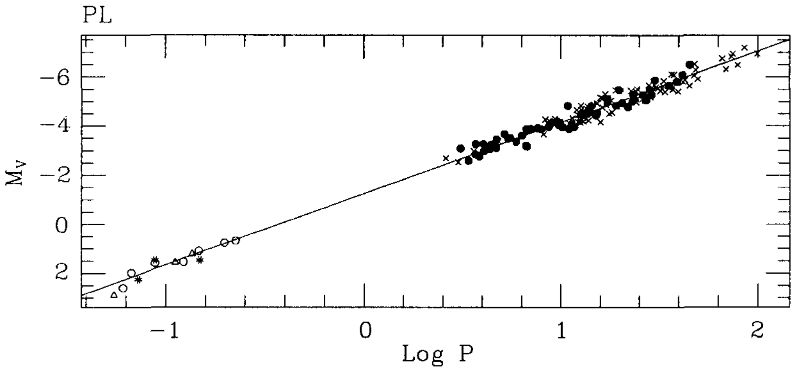

Figure 1. Period-luminosity relation for dwarf Cepheids with Baade-Wesselink radii derived here (open circles), with Baade-Wesselink radii from Wilson et al. (1993) and Milone et al. (1994) (asterisks), the three dwarf Cepheids with good Hipparcos parallaxes (triangles), galactic Cepheids (filled circles), and Magellanic Cloud Cepheids (crosses).

1997 or Breger, 1975), and the BW luminosities are clearly consistent with those of the three dwarf Cepheids with good Hipparcos parallaxes (Fig. 1). The combined relation for 57 classical and 9 dwarf Cepheids is

$$\begin{array}{lllll} M_V = & -1.29 & - & 2.92\,\mathrm{Log}\,P\,, & \sigma = 0.234. \\ & \pm.04 & & \pm.04 & \end{array}$$

Thus HADS appear to lie on the Cepheid PL relation, at least for Log$P >$ about -1.2. Fernie (1992) was right.

References

Breger, M. 1975, ApJ, 201, 653

Fernie, J.D. 1992, AJ, 103, 1647

Laney, C.D. & Stobie, R.S. 1995, MNRAS, 274,337

Laney, C.D. & Stobie, R.S. 1995b, in ASP Conf. Ser., Vol. 83, Astrophysical Applications of Stellar Pulsation, eds. R. Stobie P. Whitelock, (San Francisco ASP), 254

Laney, C.D., Joner, M., Schwendiman, L. 2001, in ASP Conf. Ser., Observational Aspects of Pulsating B- and A Stars, eds. C. Sterken & D. Kurtz, (San Francisco ASP), in press

McNamara, D.H. 1997, PASP, 109, 1221

Milone, E.F., Wilson, W.J., Fry, D.J.I, & Schiller, S.J. 1994, PASP, 106, 1120

Wilson, W.F., Milone, E.F., & Fry, D.J.I. 1993, PASP, 105, 809