RR Lyrae and Type II Cepheid Variables Adhere to a Common Distance Relation

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Abstract Preliminary evidence is presented reaffirming that SX Phe, RR Lyrae, and Type II Cepheid variables may be characterized by a common Wesenheit period-magnitude relation, to first order. Reliable distance estimates to RR Lyrae variables and Type II Cepheids are ascertained from a single *VI*-based reddening-free relation derived recently from OGLE photometry of LMC Type II Cepheids. Distances are computed to RR Lyrae ($d \simeq 260$ pc) and variables of its class in the galaxies IC 1613, M33, Fornax dSph, LMC, SMC, and the globular clusters M3, M15, M54, ω Cen, NGC 6441, and M92. The results are consistent with literature estimates, and in the particular cases of the SMC, M33, and IC 1613, the distances agree with those inferred from classical Cepheids to within the uncertainties: no corrections were applied to account for differences in metallicity. Moreover, no significant correlation was observed between the distances computed to RR Lyrae variables in ω Cen and their metallicity, despite a considerable spread in abundance across the sample. In sum, concerns regarding a sizeable metallicity effect are allayed when employing *VI*-based reddening-free Cepheid and RR Lyrae relations.

1. Introduction

The study of Cepheids and RR Lyrae variables has provided rich insight into countless facets of our Universe. The stars are employed: to establish distances to globular clusters, the Galactic center, and to galaxies exhibiting a diverse set of morphologies from dwarf, irregular, giant elliptical, to spiral in nature (Udalski *et al.* 2001; Kubiak and Udalski 2003; Pietrzyński *et al.* 2006; Macri *et al.* 2006; Matsunaga *et al.* 2006, 2009; Ferrarese *et al.* 2007; Feast *et al.* 2008; Groenewegen *et al.* 2008; Gieren *et al.* 2008; Scowcroft *et al.* 2009; Majaess *et al.* 2009c); to clarify properties of the Milky Way's spiral structure, bulge, and warped disk (Tammann 1970; Opolski 1988; Efremov 1997; Berdnikov *et al.* 2006; Majaess *et al.* 2009b); to constrain cosmological models by aiding to establish H_0 (Freedman and Madore 1996; Freedman *et al.* 2001; Tammann *et al.* 2002); to characterize extinction where such variables exist in the Galaxy and beyond

(Caldwell and Coulson 1985; Turner 2001; Laney and Caldwell 2007; Kovtyukh *et al.* 2008; Majaess *et al.* 2008a, 2009b, 2009c); to deduce the sun's displacement from the Galactic plane (Shapley 1918; Fernie 1968; Majaess *et al.* 2009a); and to trace the chemistry, dynamics, and ages of stellar populations (Turner 1996; Luck *et al.* 1998; Andrievsky *et al.* 2002a; Mottini 2006), etc.

An additional bond beyond the aforementioned successes is shared between RR Lyrae, Type II Cepheids, and SX Phe variables, namely that to first order the stars obey a common distance and Wesenheit period-magnitude relation.

2. Analysis and discussion

A Wesenheit period-magnitude diagram demonstrates the underlying continuity from SX Phe to W Vir variables (Figure 1). The Wesenheit function describing the LMC data is given by:

$$W_{VI} = V - \beta (V - I)$$

$$W_{VI} = -2.45\, log\, P_f + 17.28 \quad (1)$$

The relation is reddening-free and relatively insensitive to the width of the instability strip, hence the reduced scatter in Figure 1. Readers are referred to studies by van den Bergh (1968), Madore (1982), Opolski (1983), Madore and Freedman (2009), and Turner (2010) for an elaborate discussion on Wesenheit functions. The color coefficient used here, $\beta = 2.55$, is that employed by Fouqué *et al.* (2007). RR Lyrae variables pulsating in the overtone were shifted by $log\, P_f \sim log\, P_o + 0.13$ so to yield the equivalent fundamental mode period (e.g., see Soszyński *et al.* 2003; Gruberbauer *et al.* 2007). Soszyński *et al.* (2008) convincingly demonstrated that the RV Tau subclass of Type II Cepheids do not follow a simple Wesenheit relation that also encompasses the BL Her and W Vir regimes (see also Majaess *et al.* 2009a). RV Tau variables were therefore excluded from the derived Wesenheit function which characterizes variables with pulsation periods $\prec$ 15d (Equation 1).

A *VI*-based reddening-free Type II Cepheid relation (Majaess *et al.* 2009a) was used to compute the distance to RR Lyrae variables in the galaxies IC 1613 (Dolphin *et al.* 2001), M33 (Sarajedini *et al.* 2006), Fornax dSph (Bersier and Wood 2002; Mackey and Gilmore 2003), LMC and SMC (Udalski *et al.* 1998; Soszyński *et al.* 2003, 2009), and the globular clusters M3 (Benkő *et al.* 2006; Hartman *et al.* 2005), M15 (Corwin *et al.* 2008), NGC 6441 (Layden *et al.* 1999; Pritzl *et al.* 2003), M54 (Layden and Sarajedini 2000), ω Cen (Weldrake *et al.* 2007), and M92 (Kopacki 2001). The resulting distances are summarized in Table 1, along with estimates from classical and Type II Cepheids, where possible. The calibrators of the aforementioned relation were OGLE LMC Type II Cepheids (Udalski *et al.* 1999; Soszyński *et al.* 2008), with an adopted zero-point to the LMC established from classical Cepheids and other means (~ 18.50, Gibson 2000; Freedman *et al.* 2001; Benedict *et al.* 2002; Majaess *et al.*

2008a). The distances to classical Cepheids were estimated using a Galactic calibration (Majaess *et al.* 2008a) tied to a subsample of cluster Cepheids (e.g., Turner and Burke 2002) and new HST parallax measures (Benedict *et al.* 2007). Defining the relation strictly as a Galactic calibration is somewhat ambiguous, given that Milky Way Cepheids appear to follow a galactocentric metallicity gradient (Andrievsky *et al.* 2002a). The Majaess *et al.* (2008a) relation is tied to Galactic classical Cepheids that exhibit near solar abundances (Andrievsky *et al.* 2002a). Applying the Majaess *et al.* (2008a) relation to classical Cepheids observed in the LMC by Sebo *et al.* (2002) reaffirms the adopted zero-point ($(m-M)_0 = 18.44 \pm 0.12$, Figure 2). No correction was applied to account for differences in metallicity between LMC and Galactic classical Cepheids owing to the present results and contested nature of the effect (e.g., Udalski *et al.* 2001; Sakai *et al.* 2004; Pietrzyński *et al.* 2004; Macri *et al.* 2006; Bono *et al.* 2008; Scowcroft *et al.* 2009; Majaess *et al.* 2009c). A decrease of $\simeq 0.08$ magnitude would ensue if the correction proposed by Sakai *et al.* (2004) or Scowcroft *et al.* (2009) were adopted.

The distances cited in Table 1 to the globular clusters are consistent with those found in the literature (e.g., Harris 1996). A subsample of period distance diagrams demonstrate that the inferred distances are nearly constant across the entire period range examined (Figure 3). Moreover, distances computed to RR Lyrae variables in the SMC, M33, and IC 1613 agree with those inferred from classical Cepheids (Table 1). The results reaffirm that the slope and zero-point of *VI* reddening-free relations are relatively insensitive to metallicity (see also Udalski *et al.* 2001; Pietrzyński *et al.* 2004; Majaess *et al.* 2008a, 2009c). No corrections were made to account for differences in abundance. Consider the result for the SMC, which is founded on copious numbers of catalogued RR Lyrae and classical Cepheid variables (OGLE). SMC and Galactic classical Cepheids exhibit a sizeable metallicity difference (Δ[Fe/H] $\simeq 0.75$, Mottini (2006)). By contrast, SMC RR Lyrae variables are analogous to or slightly more metal-poor than their LMC counterparts (Udalski 2000). If the canonical metallicity corrections for RR Lyrae variables and classical Cepheids were equal yet opposite in sign as proposed in the literature (e.g., $\gamma - RR \simeq +0.3$ and $\gamma - Cep \simeq -0.3$ magnitude dex^{-1}), then the expected distances computed for SMC RR Lyrae variables and classical Cepheids should display a considerable offset (say at least $\simeq 0.25$ magnitude). However, that is not supported by the evidence, which instead implies a negligible offset separating the variable types (0.02 magnitude, Table 1). Similar conclusions are reached when analyzing distances to extragalactic RR Lyrae variables as inferred from a combined HST/HIP parallax for RR Lyrae (see Majaess *et al.* 2009c). In sum, comparing Cepheids and RR Lyrae variables at a common zero-point offers a unique opportunity to constrain the effects of metallicity. More work is needed here.

RR Lyrae variables in ω Cen provide an additional test for the effects of metallicity on distance, since the population exhibits a sizeable spread in

metallicity at a common zero-point ($-1.0 \geq$ [Fe/H] ≥ -2.4, Rey *et al.* (2000)). An abundance-distance diagram (Figure 4) compiled for RR Lyrae variables in ω Cen using *VI* photometry from Weldrake *et al.* (2007), and abundance estimates from Rey *et al.* (2000), offers further evidence implying that *VI*-based reddening-free distance relations are relatively insensitive to metallicity. A formal fit to data in Figure 4 is in agreement with no dependence and yields a modest slope of 0.1 ± 0.1 magnitude dex^{-1}. If that slope is real, metal-poor RR Lyrae variables are brighter than metal-rich ones. Uncertainties linked to the cited slope could be mitigated by acquiring additional abundance estimates and obtaining *VI* directly (see Weldrake *et al.* 2007). A minor note is made that although the variable in ω Cen designated V164 Cen is likely a Type II Cepheid (J2000 $13^h\,26^m\,14.86^s$ –47° 21' 15.17"), the variable designated V109 Cen may be anomalous or could belong to another variable class (J2000 $13^h\,26^m\,35.69^s$ -47° 32' 47.03", see numbering in Weldrake *et al.* 2007).

Equation 2 of Majaess *et al.* (2009a) was also employed to compute the distance to the brightest member of the variable class, RR Lyrae. *VI* photometry from The Amateur Sky Survey (Droege *et al.* 2006) was utilized, although concerns persist regarding the survey's zero-point and the star's modulating amplitude. Nevertheless, the resulting distance of $d \simeq 260$ pc is consistent with the star's parallax as obtained using HST ($d = 262 \pm 14$ pc, Benedict *et al.* 2002), and within the uncertainties of the HIP value (van Leeuwen *et al.* 2007; Feast *et al.* 2008). That reaffirms the robustness of the aforementioned relation to compute distances to variables of the RR Lyrae and Type II Cepheid class. RR Lyrae's phased *V* and *I* light-curves are displayed in Figure 5. An ephemeris from the GEOS RR Lyr database was adopted to phase the data (Boninsegna *et al.* 2002; Le Borgne *et al.* 2004, 2007), namely:

$$JD_{max} = 2442923.4193 + 0.5668378\,E \qquad (2)$$

The slope of the Wesenheit function derived from a combined sample of SX Phe, RR Lyrae, and Type II Cepheid variables detected in M3, ω Cen, and M15 is consistent with that determined from LMC RR Lyrae variables and Type II Cepheids (Figure 1). Presently, the distances computed to SX Phe variables discovered in M3 and ω Cen via the *VI* reddening-free Type II relation of Majaess *et al.* (2009a) are systemically offset. However, the new Wesenheit relation performs better (Equation 1). A reanalysis is anticipated once a sizeable sample of SX Phe variables become available. Yet meanwhile Equation 1 may be employed to evaluate simultaneously the distances to SX Phe, RR Lyrae, BL Her, and W Vir variables. Uncertainties are expected to be on the order of 5–15%. Indeed, the correction factor (ϕ) established by Majaess *et al.* (2009a) could be applied to Equation 1 to permit the determination of distances to the RV Tau subclass of Type II Cepheids.

Admittedly, further work is needed but the results are encouraging.

3. Summary and future work

A single *VI*-based reddening-free relation may be employed to simultaneously provide reliable distances to RR Lyrae variables and Type II Cepheids. The relation's viability is confirmed by demonstrating that distances to RR Lyrae variables in the globular clusters M3, M15, M54, ω Cen, M92, NGC 6441 (Figure 6), and galaxies IC 1613, M33, Fornax dSph, LMC, and SMC, agree with values in the literature and from other means (Table 1, see also Harris 1996). A distance was computed for the nearby star RR Lyrae ($d \sim 260$ pc) using mean *VI* photometry provided by The Amateur Sky Survey. The estimate is consistent with the HST parallax for the star ($d = 262 \pm 14$ pc, Benedict *et al.* 2002). The slope and zero-point of the *VI*-based relation appear relatively unaffected by metallicity to within the uncertainties (Table 1 and Figures 1, 3). That assertion is supported by noting that although RR Lyrae variables in ω Cen exhibit a sizeable spread in metallicity ($-1.0 \geq [Fe/H] \geq -2.4$, Rey *et al.* (2000)), no statistically significant effect was observed on the computed distances (Figure 4). Furthermore, the distances computed to RR Lyrae variables and classical Cepheids in the SMC, M33, and IC 1613 are consistent to within the uncertainties. No metallicity correction was applied. Finally, an underlying Wesenheit period-magnitude relation broadly unifies SX Phe, RR Lyrae, and Type II Cepheid variables of the population II instability strip, although somewhat imperfectly.

There remain numerous challenges and concerns to be addressed regarding the use of the distance indicators beyond the contested effects of metallicity (e.g., Udalski *et al.* 2001; Sakai *et al.* 2004; Pietrzyński *et al.* 2004; Macri *et al.* 2006; Bono *et al.* 2008; Scowcroft *et al.* 2009; Majaess *et al.* 2009c). For example, achieving a common photometric standardization is difficult and systemic offsets may be introduced, particularly across a range in color (e.g., Turner 1990; Saha *et al.* 2006). Yet another challenge is to establish a consensus on the effects of photometric contamination (e.g., blending, crowding) on the distances to variable stars in distant galaxies (Stanek and Udalski 1999; Macri 2001; Mochejska *et al.* 2000, 2001, Mochejska 2002; Freedman *et al.* 2001; Majaess *et al.* 2009c). Increasing the presently small number of galaxies with Cepheids observed in both the central and less-crowded outer regions is therefore desirable (e.g., Macri *et al.* 2006; Scowcroft *et al.* 2009). Unfortunately, a degeneracy complicates matters since the effects of metallicity and crowding may act in the same sense and be of comparable magnitude. Indeed, R (the ratio of total to selective extinction) may also vary as a function of radial distance from the centers of galaxies in tandem with the metallicity gradient. Efforts to disentangle the degeneracies are the subject of a study in preparation. Further research is warranted to examine the implications of anomalous values of R on the distances obtained from the standard candles (e.g., Macri *et al.* 2001b; Udalski 2003).

Lastly, the continued discovery of extragalactic SX Phoenicis, RR Lyrae, and Cepheids at a common zero-point shall bolster our understanding and enable firm

constraints to be placed on the metallicity effect (Szabados 2006a; Poretti *et al.* 2006; Majaess *et al.* 2009c). So too will obtaining mean multiband photometry, particularly *VI*, for such variables in the field and globular clusters (Clement *et al.* 2001; Pritzl *et al.* 2003; Schmidt *et al.* 2004, 2005a, 2005b, 2005c, 2009; Horne 2005; Matsunaga *et al.* 2006; Randall *et al.* 2007; Rabidoux *et al.* 2007; Corwin *et al.* 2008). A forthcoming study shall describe how related efforts are to be pursued from the Abbey-Ridge Observatory (ARO) (Lane 2007; Majaess *et al.* 2008b; Turner *et al.* 2009). AAVSO members drawn toward similar research may be interested in a fellow member's study entitled: "Using a Small Telescope to Detect Variable Stars in Globular Cluster NGC 6779" (Horne 2005). Modest telescopes may serve a pertinent role in variable star research (Percy 1980, 1986; Szabados 2003; Paczyński 2006; Turner *et al.* 2005, 2009).

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References

Andrievsky, S. M., Kovtyukh, V. V., Luck, R. E., Lepine, J. R. D., Maciel, W. J., and Beletsky, Y. V. 2002a, *Astron. Astrophys.*, **392**, 491.

Benedict, G. F., *et al.* 2002, *Astron. J.*, **123**, 473.

Benedict, G. F., *et al.* 2007, *Astron. J.*, **133**, 1810.

Benkő, J. M., Bakos, G. A., and Nuspl, J. 2006, *Mon. Not. Roy. Astron. Soc.*, **372**, 1657.

Berdnikov, L. N., Efremov, Y. N., Glushkova, E. V., and Turner, D. G. 2006, *Odessa Astron. Publ.*, **18**, 26.

Bersier, D., and Wood, P. R. 2002, *Astron. J.*, **123**, 840.

Boninsegna, R., Vandenbroere, J., Le Borgne, J. F., and The Geos Team 2002, in *Radial and Nonradial Pulsations as Probes of Stellar Physics*, eds. C. Aerts, T. R. Bedding, and J. Chirsensen-Dalsgaard, ASP Conf. Proc. 259, Astron. Soc. Pacific, San Francisco, 166.

Bono, G., Caputo, F., Fiorentino, G., Marconi, M., and Musella, I. 2008, *Astrophys. J.*, **684**, 102.

Caldwell, J. A. R., and Coulson, I. M. 1985, *Mon. Not. Roy. Astron. Soc.*, **212**, 879.
Clement, C. M., *et al.* 2001, *Astron. J.*, **122**, 2587.
Corwin, T. M., Borissova, J., Stetson, P. B., Catelan, M., Smith, H. A., Kurtev, R., and Stephens, A. W. 2008, *Astron. J.* **135**, 1459.
Dolphin, A. E., *et al.* 2001, *Astrophys. J.*, **550**, 554.
Droege, T. F., Richmond, M. W., Sallman, M. P., and Creager, R. P. 2006, *Publ. Astron. Soc. Pacific*, **118**, 1666.
Efremov, Y. N. 1997, *Astron., Lett.*, **23**, 579.
Feast, M. W. 1999, *Publ. Astron. Soc. Pacific*, **111**, 775.
Feast, M. W. 2001, arXiv:astro-ph/0110360.
Feast, M. W. 2008, arXiv:0806.3019.
Feast, M. W., Laney, C. D., Kinman, T. D., van Leeuwen, F., and Whitelock, P. A. 2008, *Mon. Not. Roy. Astron. Soc.*, **386**, 2115.
Fernie, J. D. 1968, *Astron. J.*, **73**, 995.
Fernie, J. D. 1969, *Publ. Astron. Soc. Pacific*, **81**, 707.
Fernie, J. D. 1976, *The Whisper and the Vision: The Voyages of the Astronomers*, Clarke, Irwin, and Co., Toronto.
Fernie, J. D. 2002, *Setting Sail for the Universe: Astronomers and Their Discoveries*, Rutgers Univ. Press, New Brunswick, NJ.
Ferrarese, L., Mould, J. R., Stetson, P. B., Tonry, J. L., Blakeslee, J. P., and Ajhar, E. A. 2007, *Astrophys. J.*, **654**, 186.
Fouqué, P., *et al.* 2007, *Astron. Astrophys.*, **476**, 73.
Freedman, W. L., and Madore, B. F. 1996, in *Clusters, Lensing, and the Future of the Universe*, eds. V. Trimble and A. Reisenegger, ASP Conf. Proc. 88, Astron. Soc. Pacific, San Francisco, 9.
Freedman, W. L., *et al.* 2001, *Astrophys. J.*, **553**, 47.
Gibson, B. K. 2000, *Mem. Soc. Astron. Ital.*, **71**, 693.
Gieren, W., Pietrzyński, G., Soszyński, I., Bresolin, F., Kudritzki, R.-P., Storm, J., and Minniti, D. 2008, *Astrophys. J.*, **672**, 266.
Groenewegen, M. A. T., Udalski, A., and Bono, G. 2008, *Astron. Astrophys.*, **481**, 441.
Gruberbauer, M., *et al.* 2007, *Mon. Not. Roy. Astron. Soc.*, **379**, 1498.
Harris, W. E. 1996, *Astron. J.*, **112**, 1487.
Hartman, J. D., Kaluzny, J., Szentgyorgyi, A., and Stanek, K. Z. 2005, *Astron. J.*, **129**, 1596.
Hoffleit, D. 2002, *Misfortunes As Blessings in Disguise: The Story of My Life*, AAVSO, Cambridge, MA.
Horne, J. D. 2005, *J. Amer. Assoc. Var. Star Obs.*, **34**, 61.
Kopacki, G. 2001, *Astron. Astrophys.*, **369**, 862.
Kovtyukh, V. V., Soubiran, C., Luck, R. E., Turner, D. G., Belik, S. I., Andrievsky, S. M., and Chekhonadskikh, F. A. 2008, *Mon. Not. Roy. Astron. Soc.*, **389**, 1336.
Kubiak, M., and Udalski, A. 2003, *Acta Astron.*, **53**, 117.
Lane, D. J. 2007, http://www.aavso.org/aavso/meetings/spring07present/Lane.ppt

Laney, C. D., and Caldwell, J. A. R. 2007, *Mon. Not. Roy. Astron. Soc.*, **377**, 147.
Layden, A. C., Ritter, L. A., Welch, D. L., and Webb, T. M. A. 1999, *Astron. J.*, **117**, 1313.
Layden, A. C., and Sarajedini, A. 2000, *Astron. J.*, **119**, 1760.
Le Borgne, J. F., Klotz, A., and Boer, M. 2004, *Inf. Bull. Var. Stars*, No. 5568, 1.
Le Borgne, J. F., *et al.* 2007, *Astron. Astrophys.*, **476**, 307.
Luck, R. E., Moffett, T. J., Barnes, T. G., and Gieren, W. P. 1998, *Astron. J.*, **115**, 605.
Mackey, A. D., and Gilmore, G. F. 2003, *Mon. Not. Roy. Astron. Soc.*, **345**, 747.
Macri, L. M. 2001, Ph.D. Thesis.
Macri, L. M., Stanek, K. Z., Sasselov, D. D., Krockenberger, M., and Kaluzny, J. 2001a, *Astron. J.*, **121**, 870.
Macri, L. M., *et al.* 2001b, *Astrophys. J.*, **549**, 721.
Macri, L. M., Stanek, K. Z., Bersier, D., Greenhill, L. J., and Reid, M. J. 2006, *Astrophys. J.*, **652**, 1133.
Madore, B. F. 1982, *Astrophys. J.*, **253**, 575.
Madore, B. F., and Freedman, W. L. 2009, *Astrophys. J.*, **696**, 1498.
Majaess, D. J., Turner, D. G., and Lane, D. J. 2008a, *Mon. Not. Roy. Astron. Soc.*, **390**, 1539.
Majaess, D. J., Turner, D. G., and Lane, D. J. 2009a, *Mon. Not. Roy. Astron. Soc.*, **398**, 263.
Majaess, D. J., Turner, D. G., and Lane, D. J. 2009b, *J. Amer. Assoc. Var. Star Obs.*, **37**, 179.
Majaess, D. J., Turner, D. G., and Lane, D. J. 2009c, arXiv:0909.0181.
Majaess, D. J., Turner, D. G., Lane, D. J., and Moncrieff, K. E. 2008b, *J. Amer. Assoc. Var. Star Obs.*, **36**, 90.
Marconi, M. 2009, arXiv:0909.0900.
Matsunaga, N., Feast, M. W., and Menzies, J. W. 2009, *Mon. Not. Roy. Astron. Soc.*, **397**, 933.
Matsunaga, N., *et al.* 2006, *Mon. Not. Roy. Astron. Soc.*, **370**, 1979.
Mochejska, B. J. 2002, Ph.D. Thesis.
Mochejska, B. J., Macri, L. M., Sasselov, D. D., and Stanek, K. Z. 2000, *Astron. J.*, **120**, 810.
Mochejska, B. J., Macri, L. M., Sasselov, D. D., and Stanek, K. Z. 2001, arXiv: astro-ph/0103440.
Mottini, M. 2006, Ph.D. Thesis.
Opolski, A. 1983, *Inf. Bull. Var. Stars*, No. 2425, 1.
Opolski, A. 1988, *Acta Astron.*, **38**, 375.
Paczyński, B. 2006, *Publ. Astron. Soc. Pacific*, **118**, 1621.
Percy, J. R. 1980, *J. Roy. Astron. Soc. Canada*, **74**, 334.
Percy, J. R. 1986, *The Study of Variable Stars Using Small Telescopes*, Cambridge Univ. Press, Cambridge, UK.

Pietrzyński, G., Gieren, W., Udalski, A., Bresolin, F., Kudritzki, R. -P., Soszyński, I., Szymański, M., and Kubiak, M. 2004, *Astron. J.*, **128**, 2815.
Pietrzyński, G., *et al.* 2006, *Astron. J.*, **132**, 2556.
Pritzl, B. J., Smith, H. A., Stetson, P. B., Catelan, M., Sweigart, A. V., Layden, A. C., and Rich, R. M. 2003, *Astron. J.*, **126**, 1381.
Poretti, E., *et al.* 2006, *Mem. Soc. Astron. Ital.*, **77**, 219.
Rabidoux, K., *et al.* 2007, *Bull. Amer. Astron. Soc.*, **39**, 845.
Randall, J. M., Rabidoux, K., Smith, H. A., De Lee, N., Pritzl, B., and Osborn, W. 2007, *Bull. Amer. Astron. Soc.*, **38**, 276.
Rey, S.-C., Lee, Y.-W., Joo, J.-M., Walker, A., and Baird, S. 2000, *Astron. J.*, **119**, 1824.
Saha, A., Thim, F., Tammann, G. A., Reindl, B., and Sandage, A. 2006, *Astrophys. J., Suppl. Ser.*, **165**, 108.
Sakai, S., Ferrarese, L., Kennicutt, R. C., Jr., and Saha, A. 2004, *Astrophys. J.*, **608**, 42.
Sarajedini, A., Barker, M. K., Geisler, D., Harding, P., and Schommer, R. 2006, *Astron. J.*, **132**, 1361.
Schmidt, E. G., Hemen, B., Rogalla, D., and Thacker-Lynn, L. 2009, *Astron. J.*, **137**, 4598.
Schmidt, E. G., Johnston, D., Langan, S., and Lee, K. M. 2004, *Astron. J.*, **128**, 1748.
Schmidt, E. G., Johnston, D., Langan, S., and Lee, K. M. 2005a, *Astron. J.*, **129**, 2007.
Schmidt, E. G., Johnston, D., Langan, S., and Lee, K. M. 2005b, *Astron. J.*, **130**, 832.
Schmidt, E. G., Langan, S., Rogalla, D., and Thacker-Lynn, L. 2005c, *Bull. Amer. Astron. Soc.*, **37**, 1334.
Scowcroft, V., Bersier, D., Mould, J. R., and Wood, P. R. 2009, *Mon. Not. Roy. Astron. Soc.*, **396**, 1287.
Sebo, K. M., *et al.* 2002, *Astrophys. J.* S, **142**, 71.
Shapley, H. 1918, *Astrophys. J.*, **48**, 279.
Smith, H. A. 2004, *RR Lyrae Stars*, Cambridge Univ. Press, Cambridge, UK, 166.
Soszyński, I., *et al.* 2002, *Acta Astron.*, **52**, 369.
Soszyński, I., *et al.* 2003, *Acta Astron.*, **53**, 93.
Soszyński, I., *et al.* 2008, *Acta Astron.*, **58**, 293.
Soszyński, I., *et al.* 2009, *Acta Astron.*, **59**, 1.
Stanek, K. Z., and Udalski, A. 1999, arXiv:astro-ph/9909346.
Szabados, L. 2003, in *The Future of Small Telescopes in the New Millennium. Vol. 3*, ed. T. D. Oswalt, Astrophys. Space Sci. Lib., 289, Kluwer, Dordrecht, 207.
Szabados, L. 2006a, *Commmun. Konkoly Obs.*, **104**, 105.
Szabados, L. 2006b, *Odessa Astron. Publ.*, **18**, 111.
Tammann, G. A. 1970, in *The Spiral Structure of Our Galaxy*, ed. W. Becker and G. T. Kontopoulos, IAU Symp. 38, 236.

Tammann, G. A., Reindl, B., Thim, F., Saha, A., and Sandage, A. 2002, in *A New Era in Cosmology*, eds. N. Metcalfe and T. Shanks, ASP Conf. Proc. 283, Astron. Soc. Pacific, San Francisco, 258.
Turner, D. G. 1990, *Publ. Astron. Soc. Pacific*, **102**, 1331.
Turner, D. G. 1996, *J. Roy. Astron. Soc. Canada*, **90**, 82.
Turner, D. G. 2001, *Odessa Astron. Publ.*, **14**, 166.
Turner, D. G. 2010, *Astrophys. Space Sci.*, **326**, 219.
Turner, D. G., and Burke, J. F. 2002, *Astron. J.*, **124**, 2931.
Turner, D. G., Majaess, D. J., Lane, D. J., Szabados, L., Kovtyukh, V. V., Usenko, I. A., and Berdnikov, L. N. 2009, in *Stellar Pulsation: Challenges For Theory and Observation*, AIP Conf. Proc. 1170, Amer. Inst. Physics, Melville, NY, 108.
Turner, D. G., Savoy, J., Derrah, J., Abdel-Sabour Abdel-Latif, M., and Berdnikov, L. N. 2005, *Publ. Astron. Soc. Pacific*, **117**, 207.
Udalski, A. 1998, *Acta Astron.*, **48**, 113.
Udalski, A. 2000, *Acta Astron.*, **50**, 279.
Udalski, A. 2003, *Astrophys. J.*, **590**, 284.
Udalski, A., Soszyński, I., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., and Żebruń, K. 1999, *Acta Astron.*, **49**, 223.
Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., and Żebruń, K. 1998, *Acta Astron.*, **48**, 1.
Udalski, A., Wyrzykowski, Ł, Pietrzyński, G., Szewczyk, O., Szymański, M., Kubiak, M., Soszyński, I., and Żebruń, K. 2001, *Acta Astron.*, **51**, 221.
van den Bergh, S. 1968, *J. Roy. Astron. Soc. Canada*, **62**, 145.
van Leeuwen, F., Feast, M. W., Whitelock, P. A., and Laney, C. D. 2007, *Mon. Not. Roy. Astron. Soc.*, **379**, 723.
Wallerstein, G. 2002, *Publ. Astron. Soc. Pacific*, **114**, 689.
Wallerstein, G., and Cox, A. N. 1984, *Publ. Astron. Soc. Pacific*, **96**, 677.
Weldrake, D. T. F., Sackett, P. D., and Bridges, T. J. 2007, *Astron. J.*, **133**, 1447.

Table 1. Distances to the sample.

Object	*$(m - M)_0$ (RR)*	*$(m - M)_0$ (TII)[b]*	*$(m - M)_0$ (TI)*	*Photometry*
IC 1613	24.40 ± 0.12	—	24.50 ± 0.12[a]	(6)
	—	24.52 ± 0.16 (n = 2)	24.35 ± 0.09	(9)
SMC	18.91 ± 0.08	18.85 ± 0.11	18.93 ± 0.10	(7, 8)
M33	24.54 ± 0.14	—	—	(9)
	—	24.54 (n = 1)	24.43 ± 0.14 (i) / 24.67 ± 0.07 (o)[c]	(10)
	—	24.5 ± 0.3	24.40 ± 0.17 (i)	(11)
Fornax dSph	20.53 ± 0.08	—	—	(5)
	20.57 ± 0.11	—	—	(4)
M54	17.15 ± 0.16	17.13 ± 0.06	—	(3)
M92	14.57 ± 0.12	—	—	(2)
NGC 6441	15.70 ± 0.06	15.69 ± 0.10	—	(1)
	15.74 ± 0.11	—	—	(16)
M3	15.04 ± 0.11	—	—	(12)
	15.04 ± 0.07	—	—	(15)
ω Cen	13.58 ± 0.14	—	—	(13)
M15	14.90 ± 0.11	—	—	(14)

Note: References: (1) Pritzl et al. 2003; (2) Kopacki 2001; (3) Layden and Sarajedini 2000; (4) Bersier and Wood 2002; (5) Mackey and Gilmore 2003; (6) Dolphin et al. 2001; (7) Udalski et al. 1998; (8) Soszyński et al. 2002; (9) Sarajedini et al. 2006; (10) Scowcroft et al. 2009; (11) Macri et al. 2001a; (12) Hartman et al. 2005; (13) Weldrake et al. 2007; (14) Corwin et al. 2008; (15) Benkő et al. 2006; (16) Layden et al. 1999.

[a]See discussion Dolphin et al. (2001). [b]Presently, the distance estimates for extragalactic Type II Cepheids should be interpreted cautiously owing to poor statistics and other concerns (Majaess et al. 2009c). [c]Distances to classical Cepheids occupying the outer (o) and inner (i) regions of M33.

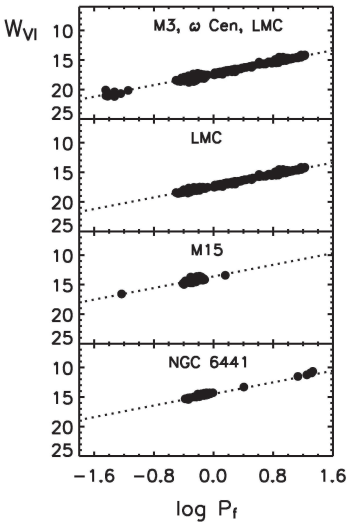

Figure. 1. Wesenheit diagrams demonstrate that SX Phe, RR Lyrae, and Type II Cepheid variables follow a common period-magnitude relation. Variable stars belonging to the globular clusters ω Cen and M3 were shifted in magnitude space to match the LMC. The over-plotted relation is Equation (1) after adjusting the zero-point. The fundamental mode period is plotted (log P_f).

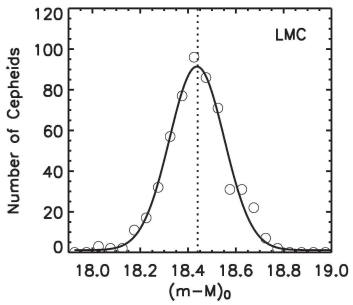

Figure. 2. Applying the *VI* reddening-free distance relation of Majaess *et al.* (2008a) to classical Cepheids observed in the LMC by Sebo *et al.* (2002) yields a distance modulus of $(m - M)_0 = 18.44 \pm 0.12$.

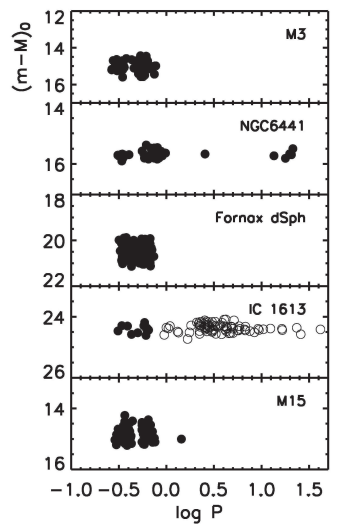

Figure. 3. Period-distance diagrams for a subsample of objects studied. Filled circles represent RR Lyrae variables and Type II Cepheids, while open circles denote classical Cepheids.

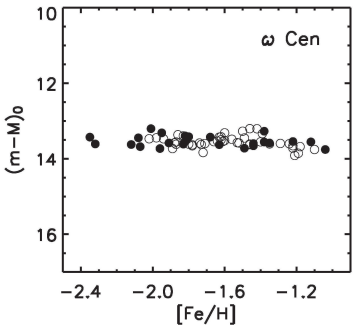

Figure. 4. Abundance-distance diagram for RR Lyrae variables in the globular cluster ω Cen. Open and filled circles are data points with metallicities inferred from $[Fe/H]_{hk}$ and $[Fe/H]_{\Delta S}$ methods (see Rey *et al.* 2000). A formal fit yields a modest slope of 0.1 ± 0.1 mag dex^{-1} and implies that metal-poor RR Lyrae variables are brighter than metal-rich ones. The fit is also in agreement with no correlation.

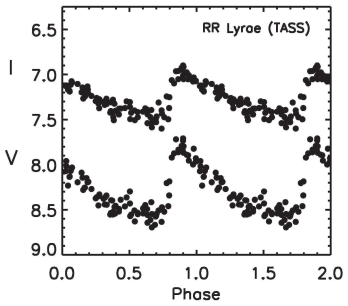

Figure. 5. *V* and *I* light-curves for RR Lyrae phased using equation 2. The *V*-band photometry is offset by +0.5 magnitude. The distance to RR Lyrae using The Amateur Sky Survey photometry is $d \simeq 260$ pc (see text).

Figure. 6. The metal rich globular cluster NGC 6441 observed through a 10-inch telescope (left) and the Hubble Space Telescope (right). Image by Noel Carboni.