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

Daniel J. Majaess
Saint Mary’s University, Halifax, Nova Scotia, Canada
The Abbey Ridge Observatory, Stillwater Lake, Nova Scotia, Canada
dmajaess@ap.smu.ca

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 ($d \approx 260$ 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 that 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.

Subject headings:

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; Pietrzynski et al. 2006; Macri et al. 2006; Matsumura 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; Frenk 1997; Berdnikov et al. 2006; Majaess et al. 2009b); to constrain cosmological models by aiding to establish $H_0$ (Freedman & Madore 1996; Freedman et al. 2001; Tammann et al. 2002); to characterize extinction where such variables exist in the Galaxy and beyond (Caldwell & Coulson 1985; Turner 2001; Laney & Caldwell 2007; Kovtyukh et al. 2008; Majaess et al. 2008, 2009b,c); to deduce the sun’s displacement from the Galactic plane (Shapley 1918; Feroci 1968; Majaess et al. 2009); and to probe the age, chemistry, and dynamics 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 variables and Type II Cepheids, namely that the stars obey a common distance and Wesenheit period-magnitude relation.

2. Analysis & Discussion

A Wesenheit period-magnitude diagram demonstrates the continuity from RRc to W Vir variables (Fig. 1). The Wesenheit function describing the
Fig. 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 overplotted relation is Eqn. 1 after adjusting the zero-point. The fundamental mode period is plotted (log \( P_f \)).

OGLE LMC data is given by:

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

\[
W_{VI} = -2.45 \log P_f + 17.28
\]

The relation is reddening-free and relatively insensitive to the width of the instability strip, hence the reduced scatter in Fig. 1. Readers are referred to studies by van den Bergh (1968), Madore (1982), Opolski (1983), Madore & Freedman (2009), and Turner (2010) for an elaborate discussion on Wesenheit functions. The colour coefficient used here, \( \beta = 2.55 \), is that employed by Fouqué et al. (2007). RR Lyrae variables pulsating in the overtone were shifted by \( \log P_f \approx \log P_o + 0.13 \) so to yield the equivalent fundamental mode period (e.g., see Soszynski et al. 2003).

Gruberbauer et al. (2007), Soszynski 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. 2009). RV Tau variables were therefore excluded from the derived Wesenheit function which characterizes variables with pulsation periods \( P \lesssim 15^d \) (Eqn. 1).

A \( V-I \)-based reddening-free Type II Cepheid relation (Majaess et al. 2009) 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 & Wood 2002), Mackey & Gilmore (2003), LMC and SMC (Udalski et al. 1998, Soszynski et al. 2002, 2003, 2009), and the globular clusters M3 (Benkő et al. 2006), M15 (Corwin et al. 2008), NGC 6441 (Layden et al. 1999, Pritzl et al. 2003), M54 (Layden & Sarajedini 2004), 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, Soszynski et al. 2008), with an adopted zero-point to the LMC established from classical Cepheids and other means (\( \sim 18.50 \), Gibson 2000, Freedman et al. 2001, Benedict et al. 2002, Majaess et al. 2008). The distances to classical Cepheids were estimated using a Galactic calibration (Majaess et al. 2008) tied to a subsample of cluster Cepheids (e.g., Turner & 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. 2002b). The Majaess et al. (2008) relation is tied to Galactic classical Cepheids that exhibit near solar abundances (Andrievsky et al. 2002b). Applying the Majaess et al. (2008) relation to classical Cepheids observed in the LMC by Sebo et al. (2002) reaffirms the adopted zero-point (\( m - M \mid_0 = 18.44 \pm 0.12 \), Fig. 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.)
Applying the $VI$ reddening-free distance relation of Majaess et al. (2008) to classical Cepheids observed in the LMC by Sebo et al. (2002) yields a distance modulus of $(m - M)_0 = 18.44 \pm 0.12$. A decrease of $\approx 0.08$ magnitudes 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 that 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 (Fig. 3). Moreover, distances computed to RR Lyrae variables in the SMC, M33, and IC 1613 agree with that 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, 2008; Scowcroft et al. 2009; Majaess et al. 2009c). No corrections were made to account for differences in abundance.

RR Lyrae variables in $\omega$ 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. If the metallicity corrections for RR Lyrae variables and classical Cepheids were equal yet opposite in sign as proposed in the literature (e.g., $\gamma_{RR} \approx +0.3$ & $\gamma_{Cep} \approx -0.3$ mag dex$^{-1}$), then the distances computed for SMC RR Lyrae variables and classical Cepheids should display a considerable offset (say at least $\approx 0.25$ mag). However, that is not supported by the evidence which instead implies a negligible offset separating the variable types (0.02 mag, 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.
Fig. 4.— Abundance-distance diagram for RR Lyrae variables in the globular cluster ω Cen. Open and filled circles are datapoints with metallicities inferred from [Fe/H]_hk and [Fe/H]_ΔS 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 poor ones. The fit is also in agreement with no correlation.

\[-1.0 \geq [\text{Fe/H}] \geq -2.4, \text{Rey et al.} \ (2000)\]. An abundance-distance diagram (Fig. 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 Fig. 4 is in agreement with no dependence and yields a modest slope of 0.1 ± 0.1 mag 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 is likely a Type II Cepheid (J2000 13:26:14.86 - 47:21:15.17), the variable designated V109 may be anomalous or could belong to another variable class (J2000 13:26:35.69 -47:32:47.03, see numbering in Weldrake et al. 2007).

Equation 2 of Majaess et al. (2009) was also employed to compute the distance to the brightest member of the variable class, RR Lyrae. VI photometry from The Amateur Sky Survey was utilized (Droege et al. 2006), although concerns persist regarding the survey’s zero-point and the star’s modulating amplitude. Nevertheless, the resulting distance of d ≃ 260 pc is consistent with the star’s parallax as obtained using HST (d = 262 ± 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 & 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:

\[JD_{\text{max}} = 2442923.4193 + 0.5668378 \times E \]  

(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 (Fig. 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. (2009) are systematically offset. However, the new Wesenheit relation performs better...
A reanalysis is anticipated once a sizeable sample of SX Phe variables becomes available. Yet meanwhile Eqn. 1 may be employed to evaluate 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 ($\phi$) established by Majaess et al. (2009) could be applied to Eqn. 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 & 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, and galaxies IC 1613, M33, Fornax dSph, LMC, and SMC agree with values in the literature and from other means (Table 1). A distance was computed for the nearby star RR Lyrae ($d \approx 260$ 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 (Fig. 1). That assertion is supported by noting that although RR Lyrae variables in ω Cen exhibit a sizeable spread in metallicity ($-1.0 \geq [Fe/H] \geq -2.4$, Rev et al. 2000), no statistically significant effect was observed on the computed distances (Fig. 1). 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, SX Phe, RR Lyrae, and Type II Cepheids essentially follow a common Wesenheit period-magnitude relation, although poor statistics for the SX Phe variables currently limits an elaborate analysis (Fig. 1).

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. 1999b).
Fig. 6.— The metal rich globular cluster NGC 6441 observed through a 10′′ telescope (left) and the Hubble Space Telescope (right). Image by Noel Carboni.

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 & Udalski 1999; Freedman et al. 2001; Macri 2001; Mochejska et al. 2000, 2001, 2002; 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 2006; Poretti et al. 2006; Majaess et al. 2009c). So too will obtaining mean multiband photometry, particularly $V_I$, for such variables in the field and globular clusters (Sawyer 1939; Demers & Wehlan 1977; Clement et al. 2001; Pritzl et al. 2003; Schmidt et al. 2004, 2005b, 2009; Horne 2005; Matsumaga et al. 2006; Randall et al. 2007; Rabídoux 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. 2002, 2009).

acknowledgements

I am grateful to D. Weldrake, D. Bersier, G. Kopacki, V. Scowcroft, L. Macri, B. Pritzl, K. Sebo, A. Mackey, T. Corwin, A. Dolphin, A. Sarajedini, J. Hartman, J. Benkő, A. Layden, A. Udalski & I. Soszyński (OGLE), whose comprehensive surveys were the foundation of the research, to the AAVSO and M. Saladyga, les individus au Centre de Données
astronumiques de Strasbourg et NASA ADS, L. Berdnikov, L. Szabados, J. F. Le Borgne, W. Renz, N. Carboni, and the RASC. The following works facilitated the preparation of this study: Wallerstein & Cox (1984), Freedman & Madore (1998), Feast (1994, 2001, 2008), Fernie (1969, 1976, 2002), Hoffleit (2002), Wallerstein (2002), Szabados (2006), Smith (2001), and Marconi (2009).

REFERENCES

Andrievsky S. M. et al., 2002, A&A, 381, 32
Andrievsky, S. M., Kovtyukh, V. V., Luck, R. E., Lépine, J. R. D., Maciel, W. J., & Beletsky, Y. V. 2002, A&A, 392, 491
Benedict G. F. et al., 2002, AJ, 123, 473
Benedict G. F. et al., 2007, AJ, 133, 1810
Benk˝ o, J. M., Bakos, G.´A., & Nuspl, J. 2006, MNRAS, 372, 1657
Berdnikov L. N., Efremov Y. N., Glushkova E. V., Turner D. G., 2006, Odessa Astronomical Publications, 18, 26
Bersier, D., & Wood, P. R. 2002, AJ, 123, 840
Boninsegna, R., Vandenbroere, J., Le Borgne, J. F., & The Geos Team 2002, IAU Colloq. 185: Radial and Nonradial Pulsations as Probes of Stellar Physics, 259, 166
Bono, G., Caputo, F., Fiorentino, G., Marconi, M., & Musella, I. 2008, ApJ, 684, 102
Caldwell, J. A. R., & Coulson, I. M. 1985, MNRAS, 212, 879
Clement, C. M., et al. 2001, AJ, 122, 2587
Corwin, T. M., Borissova, J., Stetson, P. B., Catsela, M., Smith, H. A., Kurtev, R., & Stephens, A. W. 2008, AJ 135, 1459
Demers, S., & Wehlau, A. 1977, AJ, 82, 620
Dolphin, A. E., et al. 2001, ApJ, 550, 554
Droege, T. F., Richmond, M. W., Sallman, M. P., & Creager, R. P. 2006, PASP, 118, 1666
Efremov, Y. N. 1997, Astronomy Letters, 23, 579
Feast M., 1999, PASP, 111, 775
Feast M., 2001, arXiv:astro-ph/0110360
Feast M. W., Laney C. D., Kinman T. D., van Leeuwen F., Whitelock P. A., 2008, MNRAS, 386, 2115
Feast, M. W. 2008, arXiv:0806.3019
Fernie J. D., 1968, AJ, 73, 995
Fernie, J. D. 1969, PASP, 81, 707
Fernie D. 1976. The Whisper and the Vision - The Voyages of the Astronomers.
Fernie J. D., 2002, Setting sail for the universe : astronomers and their discoveries, Rutgers University Press, New Brunswick, NJ
Ferrarese L., Mould J. R., Stetson P. B., Tonry J. L., Blakeslee J. P., Ajhar E. A., 2007, ApJ, 654, 186
Fouqué P. et al., 2007, A&A, 476, 73
Freedman, W. L., & Madore, B. F. 1996, Clusters, Lensing, and the Future of the Universe, 88, 9
Freedman W. L. et al., 2001, ApJ, 553, 47
Gibson, B. K. 2000, Memorie della Societa Astronomica Italiana, 71, 693
Gieren, W., Pietrzyński, G., Soszynski, I., Bresolin, F., Kudritzki, R.-P., Storm, J., & Minniti, D. 2008, ApJ, 672, 266
Groenewegen M. A. T., Udalski A., Bono, G., 2008, A&A, 481, 441
Gruberbauer, M., et al. 2007, MNRAS, 379, 1498
Harris, W. E. 1996, AJ, 112, 1487
Hartman, J. D., Kaluzny, J., Szezs, A., & Stanek, K. Z. 2005, AJ, 129, 1596
Hoffleit, D. 2002, Misfortunes as blessings in disguise : the story of my life, by Dorrit Hoffleit Cambridge, MA: American Association of Variable Star Observers (AAVSO), 2002.
Horne, J. D. 2005, Journal of The American Association of Variable Star Observers (JAAVSO), 34, 61
Kopacki, G. 2001, A&A, 369, 862
Kovtyukh V. V., Souhila C., Luck R. E., Turner D. G., Beilik S. I., Andrievsky S. M., Chekholnadsokkhi F. A., 2008, MNRAS, 389, 1336
Kubiak M., Udalski A., 2003, Acta Astr., 53, 117
Laney C. D., Caldwell J. A. R., 2007, MNRAS, 377, 147
Lane D. J., 2007, 96th Spring Meeting of the AAVSO, http://www.aavso.org/aavso/meetings/spring07present/Lane.ppt
Layden, A. C., Ritter, L. A., Welch, D. L., & Webb, T. M. A. 1999, AJ, 117, 1313
Layden, A. C., & Sarajedini, A. 2000, AJ, 119, 1760
Le Borgne, J. F., Klotz, A., & Boer, M. 2004, IBVS, 5568, 1
Le Borgne, J. F., et al. 2007, A&A, 476, 307
Luck R. E., Moffett T. J., Barnes T. G., Gieren W. P., 1998, AJ, 115, 605
Madore B. F., 1982, ApJ, 253, 575
Madore, B. F., & Freedman, W. L. 2009, ApJ, 696, 1498
Mackey, A. D., & Gilmore, G. F. 2003, MNRAS, 345, 747
Macri, L. M., 2001, Ph.D. Thesis
Macri, L. M., Stanek, K. Z., Sasslov, D. D., Krockenberger, M., & Kaluzny, J. 2001, AJ, 121, 870
Macri, L. M., et al. 2001 (b), ApJ, 549, 721
Macri, L. M., Stanek, K. Z., Bersier, D., Greenhill, L. J., & Reid, M. J. 2006, ApJ, 652, 1133
Mociejska, B. J., 2002, Ph.D. Thesis
Majaess D. J., Turner D. G., Lane D. J., 2008, MNRAS, 390, 1539
Majaess D. J., Turner D. G., Lane D. J., Moncrieff K. E., 2008 (b), JAAVSO, 36, 90
Majaess, D. J., Turner, D. G., & Lane, D. J. 2009, MNRAS, 398, 263

Majaess, D. J., Turner, D. G., & Lane, D. J. 2009 (b), JAAVSO, 37, 179

Majaess, D. J., Turner, D. G., & Lane, D. J. 2009 (c), arXiv:0909.0181

Marconi, M. 2009, arXiv:0909.0900

Matsunaga, N., et al. 2006, MNRAS, 370, 1979

Matsunaga, N., Feast, M. W., & Menzies, J. W. 2009, MNRAS, 397, 933

Mochejska, B. J., Macri, L. M., Sasselov, D. D., & Stanek, K. Z. 2000, AJ, 120, 810

Mochejska, B. J., Macri, L. M., Sasselov, D. D., & Stanek, K. Z. 2001, arXiv:astro-ph/0103440

Mochejska, B. J., 2002, Ph.D. Thesis

Mottini, M., 2006, Ph.D. Thesis

Ngeow, C., & Kanbur, S. M. 2006, ApJ, 650, 180

Opolski A., 1983, IBVS, 2425, 1

Opolski A., 1988, Acta Astr., 38, 375

Percy J. R., 1980, JRASC, 74, 334

Percy, J. R. 1986, Study of Variable Stars using Small Telescopes

Pietrzyński, G., Gieren, W., Udalski, A., Bresolin, F., Kudritzki, R.-P., Soszyński, I., Szymański, M., & Kubiak, M. 2004, AJ, 128, 2815

Pietrzyński, G., et al. 2006, AJ, 132, 2556

Pritzl B. J., Smith H. A., Stetson P. B., Catelan M., Sweigart A. V., Layden A. C., Rich R. M., 2003, AJ, 126, 1381

Poretti, E., et al. 2006, Memorie della Societa Astronomica Italiana, 77, 219

Rabidoux, K., et al. 2007, Bulletin of the American Astronomical Society, 38, 845

Randall, J. M., Rabidoux, K., Smith, H. A., De Lee, N., Pritzl, B., & Osborn, W. 2007, Bulletin of the American Astronomical Society, 38, 276

Rey, S.-C., Lee, Y.-W., Joo, J.-M., Walker, A., & Baird, S. 2000, AJ, 119, 1824

Saha, A., Thim, F., Tammann, G. A., Reindl, B., & Sandage, A. 2006, ApJS, 165, 108

Sakai, S., Ferrarese, L., Kennicutt, R. C., Jr., & Saha, A. 2004, ApJ, 608, 42

Sarajedini, A., Barker, M. K., Geisler, D., Harding, P., & Schommer, R. 2006, AJ, 132, 1361

Sawyer, H. B. 1939, Publications of the David Dunlap Observatory, 1, 125

Schmidt, E. G., Johnston, D., Langan, S., & Lee, K. M. 2004, AJ, 128, 1748

Schmidt, E. G., Johnston, D., Langan, S., & Lee, K. M. 2005 (c), AJ, 130, 832

Schmidt, E. G., Johnston, D., Langan, S., & Lee, K. M. 2005 (b), AJ, 129, 2007

Schmidt, E. G., Langan, S., Rogalla, D., & Thacker-Lynn, L. 2005 (d), Bulletin of the American Astronomical Society, 37, 1344

Schmidt, E. G., Hemen, B., Rogalla, D., & Thacker-Lynn, L. 2009, AJ, 137, 4598

Sebo, K. M., et al. 2002, ApJS, 142, 71

Shapley, H. 1918, ApJ, 48, 279

Smith, H. A. 2004, RR Lyrae Stars, by Horace A. Smith, pp. 166. ISBN 0521548179. Cambridge, UK: Cambridge University Press, September 2004

Soszynski, I., et al. 2002, Acta Astronomica, 52, 369

Soszynski, I., et al. 2003, Acta Astronomica, 53, 93

Soszynski, I., et al. 2008, Acta Astronomica, 58, 293

Soszynski, I., et al. 2009, Acta Astronomica, 59, 1

Stanek, K. Z., Zaritsky, D., & Harris, J. 1998, ApJL, 500, L141

Stanek, K. Z., & Udalski, A. 1999, arXiv:astro-ph/9909346

Szabados, L. 2003, Astrophysics and Space Science Library, 289, 207

Szabados, L. 2006, Communications of the Konkoly Observatory Hungary, 104, 105

Szabados, L. 2006 (b), Odessa Astronomical Publications, 18, 111

Tammann, G. A. 1970, The Spiral Structure of our Galaxy, 38, 236

Tammann, G. A., Reindl, B., Thim, F., Saha, A., & Sandage, A. 2002, A New Era in Cosmology, 283, 258

Thim, F., Tammann, G. A., Saha, A., Dolphin, A., Sandage, A., Tolstoy, E., & Labhardt, L. 2003, ApJ, 590, 256

Turner, D. G. 1990, PASP, 102, 1331

Turner D. G., 1996, JRASC, 90, 82

Turner D. G., 2001, Odessa Astr. Publ., 14, 166

Turner D. G., Burke J. F., 2002, AJ, 124, 2931

Turner D. G., Savoy, J., Derrah, J., Abdel-Sabour Abdel-Latif, M., & Berdnikov, L. N. 2005, PASP, 117, 207

Turner, D. G. 2010, Ap&SS, 5

Turner, D. G., Majaess, D. J., Lane, D. J., Szabados, L., Kovtyukh, V. V., Usenko, I. A., & Berdnikov, L. N. 2009, American Institute of Physics Conference Series, 1170, 108

Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Zebrun, K. 1998, Acta Astronomica, 48, 1

Udalski, A. 1998 (b), Acta Astronomica, 48, 113
Udalski A. et al., 1999, Acta Astr., 49, 223
Udalski, A. 2000, Acta Astronomica, 50, 279
Udalski, A., Wyrzykowski, L., Pietrzynski, G., Szewczyk, O.,
Szymanski, M., Kubiak, M., Soszynski, I., & Zebrun, K.
2001, Acta Astronomica, 51, 221
Udalski, A. 2003, ApJ, 590, 284
van den Bergh S., 1968, JRASC, 62, 145
van Leeuwen, F., Feast, M. W., Whitelock, P. A., & Laney,
C. D. 2007, MNRAS, 379, 723
Wallerstein, G., & Cox, A. N. 1984, PASP, 96, 677
Wallerstein, G. 2002, PASP, 114, 689
Weldrake, D. T. F., Sackett, P. D., & Bridges, T. J. 2007, AJ,
133, 1447

This 2-column preprint was prepared with the AAS \LaTeX
macros v5.2.