Southern Clusters for Standardizing CCD Photometry

Terry T. Moon
Centauri Observatory, 14 Ada St, Scottsdale, Tasmania 7260, Australia; texmoon0@gmail.com

Received November 7, 2016; revised November 24, 2016; accepted December 2, 2016

Abstract Standardizing photometric measurements typically involves undertaking all-sky photometry. This can be laborious and time-consuming and, for CCD photometry, particularly challenging. Transforming photometry to a standard system is, however, a crucial step when routinely measuring variable stars, as it allows photoelectric measurements from different observers to be combined. For observers in the northern hemisphere, standardized UBVRI values of stars in open clusters such as M67 and NGC 7790 have been established, greatly facilitating quick and accurate transformation of CCD measurements. Recently the AAVSO added the cluster NGC 3532 for southern hemisphere observers to similarly standardize their photometry. The availability of NGC 3532 standards was announced on the AAVSO Variable Star Observing, Photometry forum on 27 October 2016. Published photometry, along with some new measurements by the author, provide a means of checking these NGC 3532 standards which were determined through the AAVSO's Bright Star Monitor (BSM) program (see: https://www.aavso.org/aavsonet-epoch-photometry-database). New measurements of selected stars in the open clusters M25 and NGC 6067 are also included.

1. Choice of southern clusters for establishing standard magnitudes and colors

Stars in bright open clusters are well-suited for standardizing CCD photometry undertaken with small telescopes, the brighter stars in such clusters encompassing a range in magnitude from 6 to 11. While there are many bright southern clusters with stars in this magnitude range most of these clusters are young; their brighter stars being predominantly of earlier spectral types (e.g. NGC 4755). As such, their brighter stars do not span a suitably wide range of color index.

NGC 3532 is a cluster at a southern declination of about –59° that has a suitably wide range in the color indices of its stars. NGC 6067 is a more compact southern cluster (declination about –54°) with surrounding field stars of diverse spectral type. Both open clusters are readily visible from southern latitudes through low air masses. While further north, at a declination of about –19°, M25 also has bright stars that encompass a wide range of spectral type. As there were multiple sources of published UBV measurements for these three clusters, I concentrated on measuring selected brighter stars in or around these three clusters in V and I bands only.

2. Choice of BVI photometric passbands

The contemporary UBVRI system (Bessell 1990, 1995, 2005) has evolved from the original UBV system introduced by Johnson and Morgan (1953). Initially the UBV system was established with reference to only ten primary standard stars from spectral type B8 to K5. Further photometric standards were added by Johnson and Harris (1954), producing a system with accuracies of 0.02 to 0.03 in V, 0.01 to 0.015 in B–V, and 0.02 to 0.03 in U–B (Johnson and Harris 1954; Harmanec *et al.* 1994).

Despite observers using different detectors, filters, observing approaches, and processing techniques, V magnitudes and B–V indices have been routinely and reliably standardized to within 0.02 magnitude (Bohm-Vitense 1981; Henden and Kaitchuck 1990; Harmanec *et al.* 1994; Henden 2004, Bessell and Murphy 2011). Since its inception the original UBV system has been able to be reproduced using many different detectors ranging from photomultiplier tubes and photographic emulsions through photodiodes to, more recently, CCDs. Usefully, V and B–V can be readily related to the earlier photographic magnitude and color index and those of many other photometric systems (Harmanec 1998; Bessell 2000; Harmanec and Božić 2001).

Kron and Smith (1951), Johnson (1966), and Cousins (1976) all extended the original UBV system with R and I bands but they used different R- and I-band filter sets, resulting in substantially different RI systems (Bessell 1979; Bessell 1983; Bessell 2005). The UBVRI system in widespread use today has been developed by combining the Johnson UBV and Cousins RI systems. Passbands for this contemporary UBVRI system are defined by Bessell (1990, 2005) and Bessell and Murphy (2011). Measurements made using appropriate filter sets can then be readily and accurately standardized using values given in the lists published by Menzies *et al.* (1989), Landolt (1983, 1992) and Kilkenny *et al.* (1998). As the Johnson, Kron, and Eggen RI systems have fallen into disuse I have chosen to drop the subscripts, with UBV referring to the Johnson bands and RI to the Cousins bands.

Measurements in five bands can be time-consuming and, for many observing programs, unnecessary. It is then prudent to consider the trade-off between numbers of bands in which measurements are made and the number of measurements of a particular star or group of stars. This can be critical when measuring short-period variations in a star or for accumulating measurements of a sufficiently large sample of long-period variables.

Challenges for standardizing measurements in the U-band are well documented (AAVSO 2011; Bessell 1990, 2005; Bessell and Murphy 2011; Bond 2005; Cousins 1966; Cousins and Jones 1976; Harmanec *et al.* 1994). The problems with accurately reducing and transforming such measurements to the standard system range from equipment vagaries such as poor response of CCDs in the ultraviolet region and the red leak of U filters, through a large correction for atmospheric extinction and adjustment of the zero-point for different temperature ranges, to astrophysical considerations associated with the Balmer jump.

In many instances an assessment of return on investment by observers undertaking CCD photometry of variable stars is likely to lead to a decision not to make U-band measurements.

Bessell (1990) also discusses the vagaries of measurement in the R band and problems that can arise in standardizing color indices constructed from it. Like Bond (2005), and in accord with a suggestion from Bessell (2003), I came to the conclusion that a good compromise is to focus on the BVI bands of the contemporary UBVRI system. I thus sought to investigate V, B–V, and V–I values for selected stars in the southern cluster NGC 3532, some of the brighter stars in M25, and stars in and around the more compact open cluster NGC 6067.

3. Equipment and techniques

The equipment and techniques used are described by Moon (2013) and follow methods outlined in the *AAVSO CCD Observing Manual* (AAVSO 2011). For CCD-camera measurements an observation in a particular band comprised a suitable number of stacked images. The general approach was to emulate that taken with photomultiplier tubes and photodiodes (e.g. as described by Optec 2012), where up to six consecutive measurements (each being a ten-second integration) are made for each observation, resulting in an observation spanning about a minute. The light frames taken were processed by subtracting dark frames taken at the same detector temperature and exposure time, then corrected using flat field images for the filter through which the light frames were taken.

AAVSO (2011) discusses the problems that can arise from short exposure times. Such effects were confirmed through analysis of 1-, 2-, and 4-second exposures. Where possible, CCD photometry of the clusters was standardized using standard stars (Menzies *et al.* 1989) measured using the same exposure times. Scaling factors were, however, determined for short exposure times and applied in those instances where longer exposures would have resulted in "saturation" for the stars being measured. (A similar situation arises when using photomultiplier tubes or photodiodes. Typical sensitivity settings of 1, 10, and 100 are notional and it is advisable to either measure standard, comparison, and program stars on the same sensitivity setting or determine the actual ratios of the sensitivity settings.)

4. NGC 3532

4.1. Published photometry

WEBDA (2014) gives V, B–V, and V–I values for many of the brighter stars in NGC 3532, with the cluster having been measured in UBV bands by Koelbloed (1959), Fernandez and Salgado (1980), and Claria and Lapasset (1988) and in UBVRI bands by Wizinowich and Garrison (1982). However, further examination of Wizinowich and Garrison (1982) photometry gave cause for concern as V-I values listed were inconsistent with the B–V values and spectral types. Reportedly, the I-band measurements were made on the Cousins system but the values listed are clearly discrepant.

More recently Clem *et al.* (2011) undertook a deep, wide-field CCD survey of the open cluster NGC 3532. Their new BVRI photometry covers a one square degree area reaching from the brighter stars in the cluster down to stars with V ~ 21. This catalogue thus appears to be the ideal source for choosing cluster stars to standardize BVI photometry. Importantly, Clem *et al.* (2011) compared their results with the other photometric studies of NGC 3532 listed in WEBDA. They also identified the discrepant RI values of Wizinowich and Garrison (1982) and a systematic difference in the V magnitudes, noting there were no other published measurements in RI bands that could help resolve the discrepancy. They did, however, note the excellent accord between their measured and the published values for the standard stars they observed.

Figure 1a shows the difference between the V magnitudes measured by Clem *et al.* (2011) and the average from other sources as a function of B–V; there is no appreciable color trend, with the average difference being –0.024 magnitude. Figure 1b shows the difference between B-V as measured by Clem *et al.* and the average from other sources. Again, there is good agreement, the average difference being 0.004 magnitude. Overall, there is good agreement of the measured V and B–V of Clem *et al.* with the mean values from the other sources listed in WEBDA for 41 of the brighter stars in NGC 3532.

NGC 3532 standards were recently added to the AAVSO's VSP database. The values used are measurements from the AAVSO's Bright Star Monitor (BSM) program (AAVSO 2016) and provide a homogeneous source of well-transformed values from the brighter stars (~ 7th magnitude) down to about 11th magnitude. Figure 2 shows the differences between new AAVSO standard values and those of Clem *et al.* (2011) in V, B–V, and V–I. The 32 brighter stars of NGC 3532 used in this analysis were those measured in the AAVSO BSM program, by Clem *et al.*, and by the author, thus providing three independent sources for the V and I magnitudes.

Winizowich and Garrison (1982) claimed to have used the UBVRI photometer described by Fernie (1974) and values for Cousins E-region standards given by Menzies *et al.* (1980). Fernie describes the I-band filter for this photometer as a combination of Schott BG3 and RG610 glasses. This gives a passband that cuts on at about 660 nm and extends out past 1000 nm, matching the Johnson rather than the Cousins I-band (which cuts on at about 710 nm and only extends to around 900 nm). Fernie (1974) also notes that he used stars listed by Iriarte *et al.* (1965), i.e. measured on the Johnson RI system, to standardize

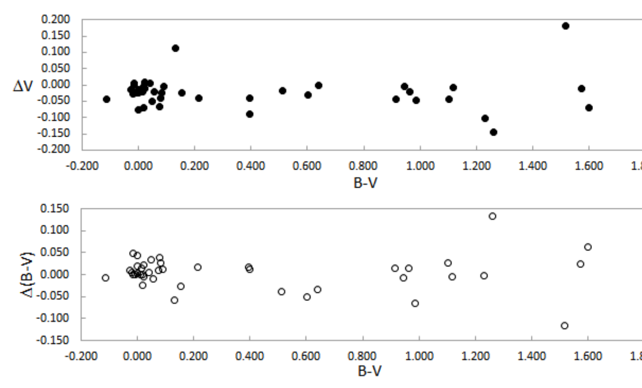

Figure 1. (a, upper plot) Difference between V magnitudes measured by Clem *et al.* (2011) and mean of other published photometry. (b, lower plot) Difference between B–V measured by Clem *et al.* and mean of other published photometry.

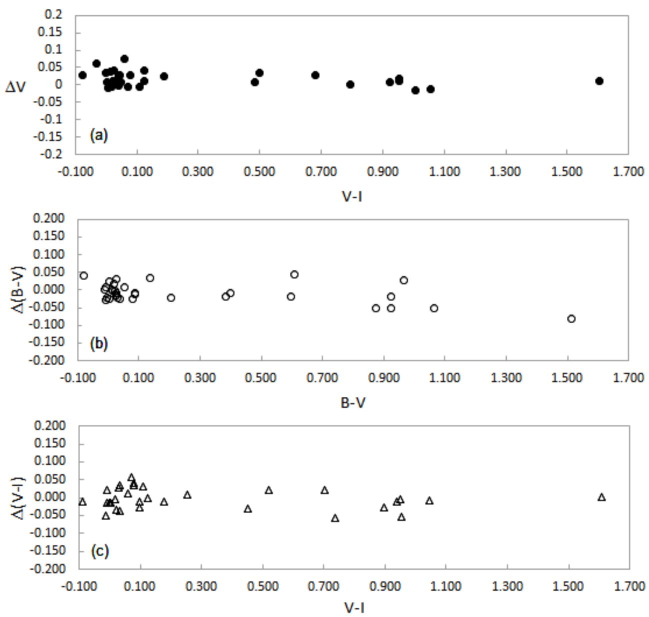

Figure 2. (a, upper plot) Difference between BSM_Berry and Clem *et al.* (2011) V magnitudes. (b, middle plot) Difference between BSM_Berry (AAVSO 2016) and Clem *et al.* B–V indices. (c, lower plot) Difference between BSM_Berry and Clem *et al.* V–I indices.

his system. The values of V–I given by Wizinowich and Garrison thus appear to have been made in the Johnson I-band but standardized against Cousins standards. Wizinowich and Garrison also noted that their V magnitudes were several hundredths of a magnitude fainter than those of Koelbloed (1959) and Fernandez and Salgado (1980). Owing to errors arising from their using a Johnson-like instrumental system and Cousins standards, Wizinowich and Garrison's measurements were not used in my analysis of BVI photometry for stars in NGC 3532.

4.2. New VI measurements of 41 of the brighter stars in NGC 3532

To check the I-band photometry of Clem *et al.* for the brighter stars in NGC 3532, I observed a selection of stars of different spectral types in the range of 6 < V < 11 on four nights in 2012–2013 and eight nights in 2015 in both V and I. Each night, extinction stars and Cousins E-region standards (Menzies *et al.* 1989) were also measured. The focus was on measurements of V and V–I as, discounting the photometry of Wizinowich and Garrison, the dispersions in V and B–V between the various sources were small (within acceptable transformation errors as discussed above). There was also good agreement with V and B–V from photographic UBV photometry, V from uvby and Geneva photometry, and V derived from Tycho B_T and V_T.

Table 1 lists the mean value of my measured V and V–I for 41 of the brighter stars in NGC 3532. Column 1 gives the Fernandez and Salgado (1980) number for each star; this is the numbering system used for NGC 3532 in both the GCPD (Mermilliod *et al.* 1997) and WEBDA (2014). Column 2 gives the HD, CPD, or GSC number as a cross-reference and Column 3 lists the spectral type.

Figure 3 compares my V and V–I measurements with those of Clem *et al.* There is no color trend for the V magnitudes, the average difference being 0.019 magnitude. For the V–I index there is also good agreement, with the average difference being –0.021 magnitude.

In summary, there is good agreement between the various published sources for V and B–V, and between my V–I

Table 1. V and V–I measured by the author for 41 brighter stars in NGC 3532 (light variations of star number 221 are appreciable).

Star	*HD/CPD/GSC*	*Sp. type*	*V*	*V–I*
4	–58 3069	A1V	8.959	0.076
19	96445	G6II–III	7.702	0.955
37	96260	A	9.319	0.021
38	–58 3044	A1V	9.556	0.091
40	96227	A2V	8.208	0.031
49	96305	A0/1IV–V	8.549	–0.023
50	96246	A0V	8.319	0.042
100	–58 3092	G9III	7.454	0.999
113	96472	A0IV	8.560	0.043
122	–58 3077	G6III	8.163	0.935
132	8627-02126		11.243	0.445
139	96245	A0	8.336	–0.01
152	96174	G8III	7.765	0.903
160	96175	G5	7.654	0.949
182	–58 3051		9.471	1.025
199	96489	A2III–IV	8.063	0.074
215	96564	B9IV	7.809	0.019
221	96544	K2II/III	6.069	1.217
236	96584	K3/4	8.225	1.592
246	96386	A0	9.815	0.086
273	96122	F2Ib	7.932	0.765
278	96137	A0IV	8.201	–0.042
285	–58 3004	A5III	10.597	0.189
317	96473	B9.5V	8.435	–0.021
337	96668	A0V	8.294	0.023
345	96620	A0IV	7.385	0.062
356	–58 3143		10.307	0.422
361	96653	A0III	8.37	0.049
362	–58 3139	A2V	9.585	0.121
363	96609	B9	8.591	0.007
380	96652	A2	9.247	0.05
409	96226	B8	8.037	–0.138
420	96059	A0III	8.008	0.049
447	96685	B9	9.676	0.223
448	–58 3151	G1:	9.951	0.618
473	95990	G	9.236	0.44
480	96247	G1 Iab/b	7.715	0.076
483	96285	A0V	8.998	–0.004
495	96755	A0	8.43	0.019
498	8628-0884	M4	10.599	2.653
522	96118	K3 III	7.644	1.33

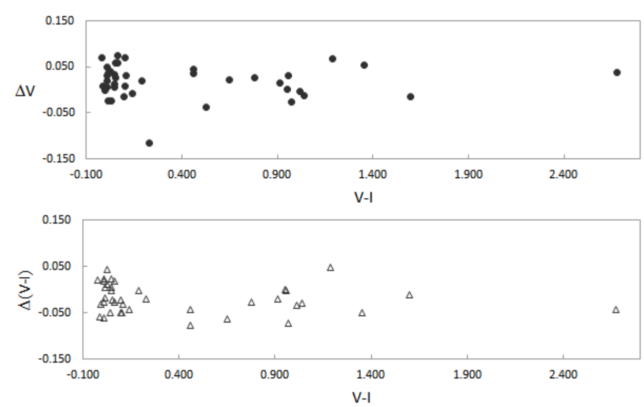

Figure 3. (a, upper plot) Difference between V magnitudes measured by the author and Clem *et al.* (2011). (b, lower plot) Difference between V–I measured by the author and that measured by Clem *et al.*

measurements and those of Clem *et al.* (2011). Importantly, the V and I measurements by the author and by Clem *et al.* are in excellent agreement with the new AAVSO standard values while B and V values by Clem *et al.* and from other sources are also in good agreement with the new AAVSO standard values. This strongly supports use of the new AAVSO NGC 3532 standards by southern hemisphere observers for standardizing their BVI photometry.

5. M25

V and B-V measurements of stars in M25 (WEBDA 2014) have been made by Niconov *et al.* 1957; Johnson 1960; Sandage 1960; Wampler *et al.* 1961; Landolt 1964; Stoy 1963; Marlborough 1964; Lee 1970; Stobie 1970; Eggen 1971; Schmidt 1971; Corben *et al.* 1972; Epps 1972; Cousins 1973; Klare and Neckel 1977; Gieren 1981; Schild *et al.* 1983; Pedreros 1984; Shobbrook 1992; and An *et al.* 2007. Unfortunately, there remains a paucity of I-band measurements for what are relatively bright stars. Twelve of the brighter stars in M25 were thus measured in V and I-band on five nights in 2015. On each night extinction stars and Cousins E-region standard stars (Menzies *et al.* 1989) were also measured.

Table 2 lists the V, B–V, and V–I values for twelve of the brighter stars in M25. Column 1 gives the cluster number for each star as used in WEBDA (2014) and GCPD (Mermilliod *et al.* 1997). Column 2 gives the HD or Tycho number as a cross-reference and Column 3 lists the spectral type from SIMBAD. The V magnitudes, and B–V and V–I color indices listed were determined as follows:

- V magnitudes given in Column 4 are the average of measurements from all available sources including measurements made by the author. No weightings were applied.
- B–V colors given in Column 5 were determined by averaging published measurements from all available sources. Again, no weightings were applied.
- V–I color indices listed in Column 7 are mostly the author's measurements. There are three sources for I-band measurements of HD 170657: Eggen (1971), Mermilliod *et al.* (1997), and Koen *et al.* (2010). There are also I-band measurements of HD 170886 by Eggen (1971) and listed in Mermilliod *et al.* (1997), and for HD 170820 listed in Mermilliod *et al.* (1997). All published values are in close agreement with my measurements. For these three stars, V–I values given in Table 2 are the averages of my measurements and published values; no weightings were applied.

Column 6 lists the number of sources used to determine B–V (for V, my measurements were combined with published values from the number of sources listed). There were no photoelectric measurements of B–V listed for stars 233 and 268; B–V for star 233 was thus determined using Tycho photometry but for star 268, the listed photographic measurement of B–V has been used. These B–V values are italicized to indicate that they were not derived from direct BV photoelectric measurements.

There are published V magnitudes derived from uvby photometry for six of these stars. On average, they differed from the V given in Table 2 by 0.011 magnitude. Geneva photometry was available for only three of the stars; again, agreement was good.

Table 2. V, B–V, and V–I for selected stars in M25.

Star	*HD/Tyc*	*Sp. Type*	*V*	*B–V*	*s*	*V–I*
26	170657	K2V	6.818	0.850	11	0.918
49	6274-1625-1	M2	9.071	1.927	4	2.543
70	6274-1131-1	F0V	8.980	0.427	3	0.541
91	170719	B5/7III	8.086	0.302	5	0.438
111	6274-1331-1	A1V	9.004	0.393	5	0.445
150	170820	K0III	7.385	1.567	7	1.638
163	170835	B2Ve	8.827	0.237	6	0.286
167	170836	B8II	8.956	0.307	3	0.418
153	170860	B9IV/V	9.404	0.318	4	0.475
174	6275-0720-1	M3III	8.961	2.028	2	2.621
233	170763	B8/9II/IIIe	8.935	*0.25*	1*	0.432
251	170886	G3/5Ib	6.949	1.385	3	1.436
268	170887	G8/K0III	7.966	*1.45*	1*	1.488

Table 3. V, B–V, and V–I for selected stars in NGC 6067.

Star	*HD/Tyc*	*Sp. Type*	*V*	*B–V*	*s*	*V–I*
	145039	K7	8.883	*1.602*	1*	1.822
	145040	B8 IV	9.252	*0.061*	1*	0.038
	145041	K1 III	8.803	1.290	1	1.345
	145109	A2 e	8.724	0.260	1	0.179
	145110	B9 IV	6.528	0.020	1	0.049
229	145175	K3 III	8.640	1.280	1	1.337
	145304	B1/B2 III/IVe	8.820	0.127	2	0.422
	145324	A5 Ib/II	7.295	0.360	3	0.518
	145523	G2 V	7.808	0.580	2	0.618
	8710-2212-1	G8	9.644	*1.637*	1*	1.592
	8711-0788-1		9.656	*1.321*	1*	1.496
	8711-1458-1	G7	9.796	*1.203*	1*	1.081
261	8710-0033-1	K2 Ib	8.764	1.743	4	1.650
267	8710-0209-1	B2 III	9.031	0.181	5	0.314
271	8710-0125-1	B5 III	10.534	0.220	3	0.390
275	8710-0049-1	K3 (II)	9.141	1.793	7	1.900
276	8710-0126-1	K3 II+K3Ib	9.495	1.915	3	2.030
298	8710-0170-2	A7 II	8.995	0.500	5	0.748
303	8711-0530-1	K2 II-Ib	10.004	1.520	3	1.403
306	8711-1312-1	K3 II	10.051	1.663	6	1.792

V, B–V, and V–I listed here may prove useful to southern hemisphere observers for:

- Setting up suitable comparison stars for variables in M25 (such as V3508 Sgr) as the values currently listed for comparison stars have been largely derived from Tycho photometry.
- Occasional checking of the transformation coefficients used to standardize their photometry.

As M25 may be visible to some northern hemisphere observers, it could also provide a means for those collaborating with southern hemisphere observers to check that they have similarly standardized systems.

6. NGC 6067

WEBDA (2014) gives V, B–V for stars in NGC 6067 and the GCPD (Mermilliod *et al.* 1997) lists V and B–V for a number of brighter, field stars immediately surrounding the cluster. Piatti *et al.* (1998) and An *et al.* (2007) have measured V–I for a few of these cluster stars but there are no V–I values listed in the GCPD for the surrounding field stars. Eleven field stars and one cluster star were measured on nine nights in 2015 with the focus being on measuring their V–I indices. Measurements of several cluster stars from the 2011-12 season were also included.

Table 3 lists the V, B–V, and V–I values for nine stars in NGC 6067 and eleven fields surrounding it. Column 1 gives the cluster number as used in WEBDA (2014). Column 2 gives the HD or Tycho number as a cross-reference and Column 3 lists the spectral type from SIMBAD or WEBDA. The V magnitudes, and B–V and V–I color indices listed were determined as follows:

• V magnitudes given in Column 4 are the average of measurements from all available sources including measurements made by the author. No weightings were applied.

• B–V colors given in Column 5 were determined by averaging published measurements from all available sources. Again, no weightings were applied. For five of the stars (values shown in italics), the B–V was determined from the Tycho photometry.

• V–I color indices listed in Column 7 are mostly the author's measurements. For stars 267 and 275 the author's measurements were combined with published values. For stars 271, 276, 298, and 306 the published values are listed.

Column 6 lists the number of measurements from published sources used.

7. Concluding remarks and recommendations

New VI measurements of 41 brighter stars in NGC 3532, published BV measurements as listed in WEBDA, and the BVRI measurements published by Clem *et al.* (2011) confirm the veracity of the new NGC 3532 standard stars added to the AAVSO's VSP database. The only published photometry not in agreement, that of Winizowich and Garrison (1982), is shown to be discrepant owing to use of Cousins standards with a Johnson I-band filter.

The newly added NGC 3532 standards are well supported by published and new measurements and can be used with confidence by southern hemisphere observers for determining BVI transformation coefficients. As R-band measurements are of interest to those doing DSLR photometry, it would be useful for some southern hemisphere observers to check the values of the NGC 3532 standards in R-band.

For variables in M25, such as V3508 Sgr, there are currently no I-band measurements for the comparison stars. Also, their assigned V and B–V values have been largely derived from Tycho photometry. The BVI photometry listed in Table 2 thus provides a resource for determining BVI magnitudes and colors for M25 variable and comparison stars. Additionally, this BVI photometry may be used to check transformation coefficients. Where northern and southern hemisphere observers are collaborating, M25 may also provide an additional means to check if their systems are similarly standardized, as it is at a southern declination of only –19°.

BVI photometry for stars in and around NGC 6067 (Table 3) can be used to establish comparison stars with well-determined magnitudes for variables near NGC 6067. An example is QZ Nor, for which AAVSO comparison stars are yet to be chosen. Again, the BVI photometry listed may be used to check transformation coefficients.

References

AAVSO. 2011, *AAVSO CCD Observing Manual* (https://www.aavso.org/ccd-observing-manual).

AAVSO. 2016, BSM_Berry (https://www.aavso.org/bsm-berrys-enclosure-setup).

An, D., Terndrup, D. M., and Pinsonneault, M. H. 2007, *Astrophys. J.*, **671**, 1640.

Bessell, M. S. 1979, *Publ. Astron. Soc. Pacific*, **91**, 589.

Bessell, M. S. 1983, *Publ. Astron. Soc. Pacific*, **95**, 480.

Bessell, M. S. 1990, *Publ. Astron. Soc. Pacific*, **102**, 1181.

Bessell, M. S. 1995, in *New Developments in Array Technology and Applications*, eds. A. G. D. Philip, K. A. Janes, A. R. Upgren, IAU Symp. 167, Kluwer Academic Publishers, Dordrecht, 175.

Bessell, M. S. 2000, *Publ. Astron. Soc. Pacific*, **112**, 961.

Bessell, M. S. 2003, personal communication, Mt. Stromlo Observatory, February.

Bessell, M. S. 2005, *Ann. Rev. Astron. Astrophys.*, **43**, 293.

Bessell, M. S., and Murphy, S. J. 2011, arXiv:1112.2698 [astro-ph.SR].

Bohm-Vitense, E. 1981, *Ann. Rev. Astron. Astrophys.*, **19**, 295.

Bond, H. E. 2005, *Astron. J.*, **129**, 2914.

Claria, J. J., and Lapasset, E. 1988, *Mon. Not. Roy. Astron. Soc.*, **235**, 1129.

Clem, J. L., Landolt, A. U., Hoard, D. W., and Wachter, S. 2011, *Astron. J.*, **141**, 115.

Corben, P. M., Carter, B. S., Banfield, R. M., and Harvey, G. M. 1972, *Mon. Not. Astr. Soc. S. Afr.*, **31**, 8.

Cousins, A. W. J. 1966, *Observatory*, **86**, 69.

Cousins, A. W. J. 1973, *Mon. Not. Astr. Soc. S. Afr.*, **32**, 11.

Cousins, A. W. J. 1976, *Mem. Roy. Astron. Soc.*, **81**, 25.

Cousins, A. W. J., and Jones, D. H. P. 1976, *Mem. Roy. Astron. Soc.*, **81**, 1.

Eggen, O. J. 1971, *Astrophys. J., Suppl. Ser.*, **22**, 389.

Epps, E. A. 1972, *Roy. Obs. Bull.*, No. 176, 127.

Fernandez, J. A., and Salgado, C. W. 1980, *Astron. Astrophys., Suppl. Ser.*, **39**, 11.

Fernie, J. D. 1974, *Publ. Astron. Soc. Pacific*, **86**, 838.

Gieren, W. 1981, *Astrophys. J., Suppl. Ser.*, **47**, 315.

Harmanec, P. 1998, *Astron. Astrophys.*, **335**, 173.

Harmanec, P., and Božić, H. 2001, *Astron. Astrophys.*, **369**, 1140.

Harmanec, P., Horn, J., and Juza, K. 1994, *Astron. Astrophys., Suppl. Ser.*, **104**, 121.

Henden, A. A. 2004, "Tricks for High-Precision CCD Photometry" (www.phys.vt.edu/~jhs/phys3154/photometryhighpre.pdf).

Henden, A. A., and Kaitchuck, R. H. 1990, *Astronomical Photometry*, Willmann-Bell, Richmond, VA.

Henden, A. A., *et al.* 2014, *AAVSO Guide to CCD Photometry*, (http://www.aavso.org/sites/default/files/publications_files/ccd_photometry_guide/CCDPhotometryGuide.pdf).

Iriarte, B., Johnson, H. L., Mitchell, R. I., and Wisniewski, W. K. 1965, *Sky & Telescope*, **30**, 21.

Johnson, H. L. 1960, *Astrophys. J.*, **131**, 620.

Johnson, H. L. 1966, *Ann. Rev. Astron. Astrophys.*, **4**, 193.

Johnson, H. L., and Harris III, W. W. 1954, *Astrophys. J.*, **120**, 196.

Johnson, H. L., and Morgan, W. W. 1953, *Astrophys. J.*, **117**, 313.

Kilkenny, D., van Wyk, F., Roberts, G., Marang, F., and Cooper, D. 1998, *Mon. Not. Roy. Astron. Soc.*, **294**, 93.

Klare, G., and Neckel, T. 1977, *Astron. Astrophys., Suppl. Ser.*, **27**, 215.

Koelbloed, D. 1959, *Bull. Astron. Inst. Netherlands*, **14**, 265.

Koen, C., Kilkenny, D., van Wyk, F., and Marang, F. 2010, *Mon. Not. Roy. Astron. Soc.*, **403**, 1949.

Kron, G. E., and Smith, J. L. 1951, *Astrophys. J.*, **113**, 324.

Landolt, A. U. 1964, *Astrophys. J., Suppl. Ser.*, **8**, 352.

Landolt, A. U. 1983, *Astron. J.*, **88**, 439.

Landolt, A. U. 1992, *Astron. J.*, **104**, 340, 436.

Lee, T. A. 1970, *Astrophys. J.*, **162**, 217.

Marlborough, J. M. 1964, *Astron. J.*, **69**, 215.

Menzies, J. W., Banfield, R. M., and Laing, J. D. 1980, *S. Afr. Astron. Obs. Circ.*, No. 1, 149.

Menzies, J. W., Cousins, A. W. J., Banfield, R. M., and Laing J. D. 1989, *S. Afr. Astron. Obs. Circ.*, No. 13, 1.

Mermilliod, J.-C., Mermilliod, M., and Hauck, B. 1997, "General Catalogue of Photometric Data (GCPD). II," *Astron. Astrophys., Suppl. Ser.*, **124**, 349 (http://obswww.unige.ch/gcpd/gcpd.html).

Moon, T. T. 2013, *J. Amer. Assoc. Var. Star Obs.*, **41**, 360.

Niconov, V. B., Nekrasova, S.V., Polosuina, N. S., Rachkouvsky, N. D., and Chuvajev, W. K. 1957, *Izv. Krym. Astrofiz. Obs.*, **17**, 42.

Optec Inc. 2012, Model SSP-3 Solid-State Stellar Photometer, Lowell, MI (http://www.optecinc.com/).

Pedreros, M. H. 1984, Ph.D. thesis, University of Toronto.

Piatti, A. E., Clariá, J. J., and Bica, E. 1998, *Astrophys. J., Suppl. Ser.*, **116**, 263.

Sandage, A. R. 1960, *Astrophys. J.*, **131**, 610.

Schild, R. E., Garrison, R. F., and Hiltner, W. A. 1983, *Astrophys. J., Suppl. Ser.*, **51**, 321.

Schmidt, E. G. 1971, *Astrophys. J.*, **165**, 335.

Shobbrook, R. R. 1992, *Mon. Not. Roy. Astron. Soc.*, **255**, 486.

Stobie, R. S. 1970, *Mon. Not. Roy. Astron. Soc.*, **148**, 1.

Stoy, R. H. 1963, *Mon. Not. Astron. Soc. S. Afr.*, **22**, 157.

Wampler, J., Pesch, P., Hiltner, W. A., and Kraft, R. P. 1961, *Astrophys. J.*, **133**, 895.

WEBDA. 2014, database (http://www.univie.ac.at/webda/webda.html).

Wizinowich, P., and Garrison, R. F. 1982, *Astron. J.*, **87**, 1390.