Simultaneous Collocated Photometry

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Abstract Two telescopes equipped with single channel photometers are operated side-by-side, observing the same stars, to evaluate the consistency of their results. In fifteen paired V band observations, we find that the median absolute difference between the two systems is 6 mmag, and that they always agree within 2σ errors.

1. Background

During the observing of the outburst of Nova Delphini 2013, substantial discrepancies were noted among the photometry of AAVSO observers, and a major effort was undertaken to improve data quality (Henden 2013). This work continues, and it invites the question of how much agreement can be achieved among disparate observers. The exercise here described is an effort to provide a baseline answer to that question. We conceived to operate two nearly identical photometric instruments at the same location at the same time, and compare their results. The project was planned as part of the 2015 astronomy workshop for high school students at Pine Mountain Observatory (PMO) in central Oregon. PMO, a research facility of the University of Oregon, is located at an altitude of 6,300 feet in a desert environment. The systems consisted of Optec SSP3 photoelectric photometers (Optec 1997) with Johnson V filters, mated to 10- and 9.25-inch schmidt-cassegrain telescopes. For historical reasons, the two photometers are known as "Boris" and "Carlo." During the July workshop, observations were made of λ And and V642 Her. Those data were supplemented by observations of DM Cep in September. The three stars, all in the AAVSO Photoelectric Photometry (PEP) observing program (AAVSO 2015a), served as increasingly challenging targets as shown in Table 1. DM Cep, besides being dimmest and having the widest color contrast vis-a-vis its comparison star, was observed in a part of the sky subject to light pollution. The three stars vary slowly, so intrinsic brightness changes would be expected to be on the order of only 1 mmag. during a single observation (Watson *et al.* 2014). However, over the course of a night's series of observations, and certainly over successive nights, the variation could be much larger. Hence, we compare the agreement of each star's observations pairwise, rather than in aggregate.

Table 1. Stars in program.

Star	*No. Obs.*	*V Approx.*	*Comparison Star*	*Comparison Star V*	*Δ (B-V)*
λ And	4	3.8	HD 223047	4.99	–0.102
V642 Her	5	6.5	HD 159353	5.69	0.59
DM Cep	6	6.9	HD 211867	7.22	0.91

All data were reduced by the same software, written by one of us. Since the two telescopes would make their paired observations at the same airmass, no corrections were applied for differential extinction between the variables and their comparison stars. The magnitudes were transformed, however, to account for different spectral sensitivity of the two instruments. Transformation coefficients for AAVSO PEP systems are usually determined by observing a color-contrasting pair of stars (AAVSO 2015b). Boris and Carlo were calibrated on the same night in May 2015, using a star pair in Serpens (HD 140573, HD 140775). Table 2 shows the transformation values.

Table 2. Transformation data.

Photometer	*Telescope*	*eV*	*λ And V xform*	*V642 Her V xform*	*DM Cep V xform*
Boris	10"	–0.035	0.004	–0.021	–0.032
Carlo	9.25"	–0.027	0.003	–0.016	–0.025

2. PEP observations

The program and comparison stars were observed in the standard PEP observing sequence (AAVSO 2015c). In short, the variable is sampled three times, bracketed by four samples of the comparison. Each sample consists of three ten-second integrations of the star, followed by three integrations of the sky near the star. The star and sky counts are each averaged, and the latter subtracted from the former. Three differential magnitudes are computed for the variable, which are averaged for a final value. The error associated with this magnitude is computed as the standard deviation of the mean of the three values. The photometers are manually operated, so perfect synchronization between corresponding samples by Boris and Carlo was not

Table 3. Photometry summary.

I.D. of Observation from Figure 1	*Star*	*MJD*	*X*	*Boris V*	*err*	*Carlo V*	*err*	*ΔV*	*within 1σ*	*2σ*
A	λ And	57218.85	1.27	3.762	0.005	3.761	0.005	0.001	Yes	Yes
B	λ And	57218.87	1.20	3.760	0.003	3.764	0.001	-0.004	Yes	Yes
C	λ And	57219.83	1.37	3.784	0.015	3.763	0.002	0.021	No	Yes
D	λ And	57219.84	1.31	3.766	0.001	3.763	0.002	0.003	No	Yes
E	V642 Her	57218.76	1.14	6.477*	0.005	6.471	0.004	0.006	Yes	Yes
F	V642 Her	57218.78	1.15	6.486	0.005	6.480	0.003	0.006	Yes	Yes
G	V642 Her	57219.80	1.18	6.488	0.005	6.485	0.006	0.003	Yes	Yes
H	V642 Her	57219.81	1.21	6.482	0.002	6.479	0.004	0.003	Yes	Yes
I	V642 Her	57219.83	1.25	6.490	0.001	6.492	0.009	-0.002	Yes	Yes
J	DM Cep	57284.80	1.15	6.932	0.006	6.924	0.009	0.009	Yes	Yes
K	DM Cep	57284.82	1.16	6.923	0.003	6.933	0.006	-0.010	No	Yes
L	DM Cep	57284.83	1.17	6.926	0.002	6.933	0.005	-0.006	Yes	Yes
M	DM Cep	57284.85	1.18	6.922	0.002	6.929	0.002	-0.006	No	Yes
N	DM Cep	57284.86	1.20	6.925	0.006	6.927	0.001	-0.002	Yes	Yes
O	DM Cep	57284.88	1.21	6.920	0.011	6.934	0.004	-0.014	Yes	Yes

** See section 4.2.*

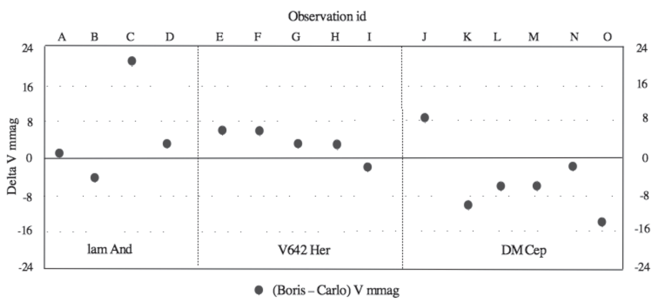

Figure 1. Delta V.

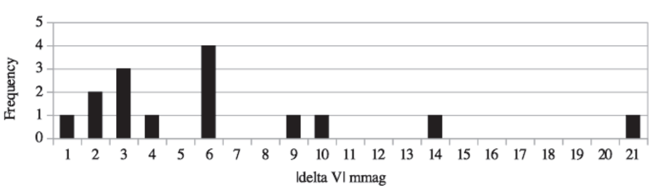

Figure 2. Histogram of |Delta V|.

possible, but we strove to keep them within 1 to 2 minutes of each other. There was an anomaly in the first Boris observation of V642 Her, which is discussed below. Table 3 summarizes the magnitudes and errors of the observations, and indicates if the 1σ error bars overlapped. Airmasses are given in column X. All observations overlapped at 2σ. Figure 1 shows the magnitude differences.

3. Results

The differences between magnitudes ran from –0.014 to +0.020, the bulk falling in a band from –0.006 to +0.006, the median absolute difference being 0.006 (Figure 2). The median 1σ errors for all observations by Boris and Carlo were 0.005 and 0.004, respectively. Eleven of the fifteen pairs of magnitudes agreed within 1σ errors, close to the ten pairs one would theoretically expect. Boris yielded mostly dimmer magnitudes than Carlo for λ And and V642 Her, while the reverse was true for DM Cep.

Conducting the experiment was a logistical challenge, hence the limited amount of data. A single observation takes at least fifteen minutes. Neither of the telescopes were permanently mounted, so all the equipment had to be set up and torn down for observing sessions, and observer schedules had to be coordinated. While all data were collected in the absence of moonlight, we did not have the luxury of choosing the best photometric nights.

Photoelectric equipment was used for this study, both because it was readily available, and because PEP calibration, operation, and data reduction are simpler than for CCD systems. The lower sensitivity of the SSP3 restricted us to brighter stars. Note that if the very bright star λ And were to be excluded from the analysis, the median difference between Boris and Carlo would still be 6 mmag. It would be very interesting to see this experiment repeated with CCDs.

4. Notes

4.1. Magnitudes

Reference magnitudes used in this study came from the *General Catalog of Photometric Data* (GCPD) database (Mermilliod *et al.* 1997), mean UBV system values. The GCPD lists two different "standard" V magnitudes for calibration star HD 140573, 2.66 and 2.65, which differ from the mean, 2.638, with corresponding B–V indexes of 1.165 and 1.168. If the average of the two standards is used in the analysis, eV values for Boris and Carlo become –0.013 and –0.005, respectively. The median absolute difference between Boris and Carlo magnitudes remains 6 mmag, and 1σ and 2σ agreements still hold.

4.2. Boris V642 Her anomaly

Table 4 shows all nine star integrations for the MJD 57218.76 observation of V642 Her by Boris. Integration number one of sample three is clearly discordant with the others, and this is almost certainly due to "cockpit error." Carlo was operated by an experienced PEP observer, but Boris was run by a rotation of

Table 4. Anomalous Boris V642 Her integration.

Sample	*Integration 1*	*Integration 2*	*Integration 3*
1	400	405	402
2	402	397	400
3	375*	400	400

observers who had had only a familiarization session beforehand. The Optec photometers have a flip mirror that directs light either to the sensor or to an eyepiece with a target reticle. A sample is taken by centering the star in the eyepiece, then flipping the mirror and collecting three integrations. The integration circuitry, however, is not synchronized to the mirror movement. The integrator runs in continuous ten second cycles, latching and displaying the value of the previous count during the current integration. When the mirror is moved, the operator must be careful to discard the integration in progress. If the flip is completed very shortly after the start of an integration, it can appear, from the large subsequent count, that the mirror moved just at the end of the prior integration, and that the new count represents a full integration. Upon seeing the next integration, an experienced observer will recognize what happened and discard the partial count. It seems likely that the Boris operator did not do this. The 375 integration, was, therefore, excluded from the analysis, and a value of 400 used as the average integration for sample three. If the suspect integration were to be kept, the results of the observation would be V = 6.486 and σ = 0.012, which still puts it within 1σ agreement with Carlo, and the median absolute difference between all Boris and Carlo magnitudes would remain 6 mmag.

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