Detecting Problematic Observer Offsets in Sparse Photometry

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Abstract A heuristic method, based upon histogram analysis, is presented for detecting offsets pervasive enough to be symptoms of problematic observing technique or calibration. This method is illustrated by a study of scatter in AAVSO photoelectric photometry (PEP) for five well-observed variable stars.

1. Data

The PEP data (Table 1) were obtained from the AAVSO International Database (AID; AAVSO 2014a). PEP magnitudes are established differentially from a single comparison star, including a correction for differential extinction. Only V band observations processed by the AAVSO reduction software, PEPHQ (AAVSO 2014b), with transformations to standard magnitudes were considered. W Boo, RS Cnc, P Cyg, V441 Her, and R Lyr had the most observations on record which qualified. B–V colors for the stars range from 0.339 to 1.662, and delta B–V from –0.813 to 1.265. The median magnitude error for observations of any one star was 3 or 4 mmag. The data were taken between JD 2445380 and 2456598, inclusive.

Table 1: Star Data.

Star	*Number Observations*	*Number Observers*	*Pairs*	*First Pair JD*	*Last Pair JD*	*Var B–V*	*Δ B–V*
W Boo	1410	29	237	2446945	2456478	1.662	0.608
RS Cnc	1031	26	109	2446881	2455261	1.625	1.265
P Cyg	1155	20	127	2446287	2456223	0.412	0.498
V441 Her	1156	20	168	2446953	2456171	0.339	–0.813
R Lyr	1571	26	283	2447387	2455124	1.588	0.546

2. Method

For a given star, pairs of magnitudes measured the same night by different observers were selected. It was uncommon for these stars to have more than two observations on a single night; those nights with three observations were split into three pairs. Repeat observations by the same observer were not paired for examination. From a star's set of pairs, a list is made of observers consistently brighter above a threshold, *T*, than other observers. A second list, based on the same threshold, is made of consistently dim observers. From these two lists, a "sore-thumb" observer, *S*, appearing the most times above a threshold, *N*, in either list is assumed to posses a systematic offset, and that offset value is estimated. This is done by histogramming the differences between *S*'s measurements and those of other observers. The histogram is evaluated by median and interquartile range (IQR). The magnitude difference of *S* from some observer *O* for one observation, i, is computed as:

$$\Delta V_i = V_{Si} - (V_{Si} / \sigma_{Si}^2 + V_{Oi} / \sigma_{Oi}^2) \times \left[(\sigma_{Si}^2 \times \sigma_{Oi}^2) / (\sigma_{Si}^2 + \sigma_{Oi}^2)\right] \tag{1}$$

A search is conducted over a range of hypothetical offsets, *o*, so that the absolute value of the median, $\kappa = |\mu_{1/2}|$, is minimized:

$$d(\kappa(\{\Delta V_i - o\})) = 0 \tag{2}$$

If a minimal median is attained over a range of offsets, the center of this range is taken to be the offset. Once observer *S*'s magnitudes have been adjusted to minimize κ, the process is repeated to find other observers with offsets.

3. Examples

The following procedure was used to find highly-offset observers for RS Cnc, with *T*=30 mmag and *N*=10. Table 2 gives histogram parameters for key observers before adjustments were made; Table 3 gives the dim/bright summary. Of these observers, E is most frequently offset. E's histogram is shown in Figure 1. The offset is sought via a simple incremental search in both directions from 0, in steps of 1 mmag. E is found to have an offset value of –28. E's magnitudes are then adjusted by this offset, and a new list of dim/bright observers is created (Table 4). An offset is now estimated for B, and found to be 67. Because adjusting B will likely change E's histogram, it is necessary

Table 2: Selected histograms before adjustments (mmag.).

Observer	*Median*	*IQR*	*Pairs*
A	8	13	13
B	53.5	67	22
E	–12	35	53

Table 3: Frequently-offset observers, first iteration.

Observer	*Bright or Dim*	*Frequent Counterparts*
A	dim 11 times	E
B	dim 17 times	C, D, E
E	bright 27 times	A, B

Table 4: Frequently-offset observers, second iteration.

Observer	*Bright or Dim*	*Frequent Counterparts*
B	dim 17 times	C, D, E
E	bright 16 times	A, B

Table 5: Histograms after adjustments (mmag.).

Observer	*Median*	*IQR*	*Δ IQR*
A	3	5	62%
B	0	28	58%
E	0	21	40%

Table 6: Sore-thumb observers and their offsets (mmag).

Star	S_1	S_2	*ΔB-V*
W Boo	A: 64	B: -49	0.608
RS Cnc	E: -25	B: 70	1.265
P Cyg	—	—	0.498
V441 Her	A: -41	E: 11	–0.813
R Lyr	A: 34	—	0.546

to iterate finding offsets for the two observers, and they converge to –25 for E and 70 for B. Once E and B have been adjusted, no other observers qualify as sore thumbs. The histogram improvements for A, B, and E are summarized in Table 5; E's final histogram is shown in Figure 2. Only one observer of R Lyr qualified as a sore thumb and none qualified for P Cyg (Table 6). Two observers each from V441 Her and W Boo qualified. If looser selection criteria for choosing outlying observers are permitted, allowing more adjustments to be made, the iteration process to establish stable offsets for all of them may not converge. From Table 6, it can be concluded that observers A and E have color correction (ε_V) errors. The signs of their offsets for each star either correlate or anti-correlate with the signs of the respective Δ B–V values.

4. Assumptions and limitations

The values of T and N were chosen to be conservative, but are otherwise arbitrary. No attempt was made to involve airmass in this analysis. Airmass data are not readily available for PEP observations in the AAVSO International Database (by convention, measurements are supposed to be taken at an airmass of 2 or less). The PEPHQ software approximates the first-order extinction

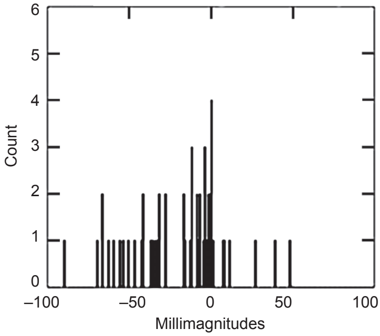

Figure 1. Observer E histogram before adjustment.

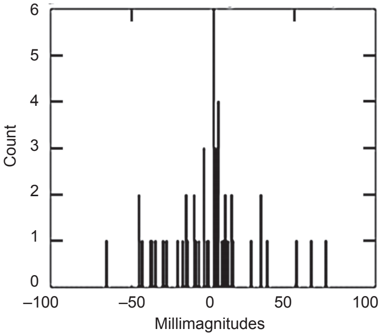

Figure 2. Observer E histogram after adjustment.

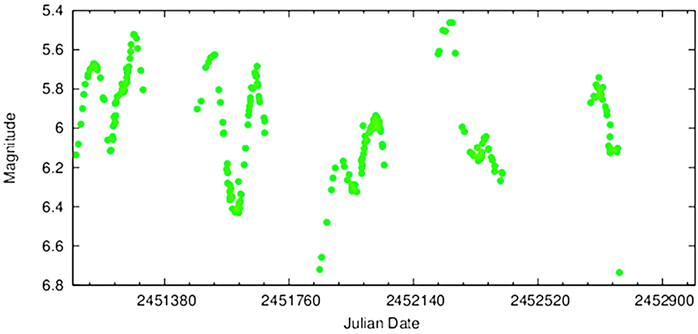

Figure 3. AAVSO light curve for RS Cnc, containing a moderately offset observer (highlighted in next figure).

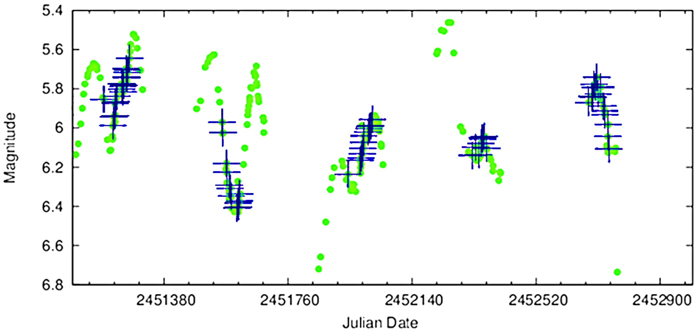

Figure 4. AAVSO light curve for RS Cnc, containing a moderately offset observer (identified by crosses).

coefficient, k_V, as a constant, 0.25. The observers found to have large offsets were, largely, active in disjoint time periods. Whether this technique would work with two or more highly-offset observers active simultaneously is unclear.

5. Conclusion

The method of this paper is simplistic, but the technique clearly detects observers with systematic offsets where limited data are available. While very large observer offsets may be readily apparent by visual inspection of a light curve, Figures 3, 4, and 5, illustrate a curve where the presence of a moderately offset observer (E), detected by this method, is not obvious.

6. Acknowledgements

Histograms in this paper were generated with MATPLOTLIB, a python graphics package developed by John Hunter (2012).

References

AAVSO. 2014a, observations from the AAVSO International Database (http://www.aavso.org).
AAVSO. 2014b, PEPHQ data reduction software.
Hunter, J. 2012, MATPLOTLIB graphics software (http://matplotlib.org/).