The Acquisition of Photometric Data

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Abstract   The planning and execution of a typical observing run will be outlined. Particular attention will be addressed to details which aid in the acquisition of quality photometry.

1. Introduction

The astronomical literature utilizes a number of terms which describe the kind of photometry undertaken for a given project. A description of the terminology is in order.

Relative photometry is the kind of photometry which most observers, and certainly virtually all AAVSO observers, do in their studies. It is photometry tied into sets of standard stars established around the sky, with zero points which can be traced back through photometric history. Such measurements are not tied into any laboratory system, but are related to nearby standard stars, in a variety of photometric standard systems. Examples of such photometric systems are the UBVRI system of Johnson, Kron and Cousins, the Stromgren four-color (uvby) system, and the Sloan u'g'r'i'z' photometric system.

Absolute photometry is based on spectrophotometry, or photometry tied to a laboratory source, such as a black body cavity, or something similar, all as an integral part of the data acquisition process. Absolute photometry is based on physical units. In spite of the terminology used on occasion in some of the recent literature, only a small number of astronomers (for example, Art Code, James Gunn, Bev Oke, and Don Hayes) ever have done absolute photometry.

Differential photometry is the direct comparison of two or more stellar images, historically done using a photographic plate, or a photomultiplier, but now best done with CCD imaging. Many stellar images are obtained on the same photograph, or CCD image (frame), and hence can be measured, intercompared, with high precision because the air masses essentially are identical. (This is not necessarily a true statement for some of the large CCD arrays.) One directly compares the intensities of two nearby images, determining the difference in intensity, and perhaps then plotting the result versus time to search for a light variation of the object under study. Most of the observing done by AAVSOers is this kind of photometry.

Be aware that all sky photometry does *not* lead to absolute photometry!

2. Interesting history and useful references

There appeared in the literature some decades ago an interesting series of papers by Weaver (1946a–f, 1962). He summarized therein a review of the history of astronomical photometry up to the beginning of the photoelectric photometry era. An excellent history of astronomical photometry was published by Hearnshaw (1996), covering the development of astronomical photometry from the times of the ancients to the beginning of the current epoch of charge-coupled devices (CCDs) as the detector of choice. A discussion of the most used photometric system over the past sixty years, the Johnson-Kron-Cousins UBVRI photometric system, appeared in Landolt (2007a, 2011).

Along with the history of actually completing photometric observations, it is of interest to review the accuracies achieved by the techniques available over the decades. Most photometry was accomplished in the first half of the twentith century either using the human eye, or photography. Early attempts to do what we now call photoelectric photometry included, for example, observations by Stebbins (1910). Also read chapter 9 in Hearnshaw (1996). Photometric accuracies which were achieved over time have been on the order of and have improved from 0.25 magnitude for the human eye (under controlled conditions, the accuracy is under 0.1 magnitude; see Williams and Saladyga (2011)), to 0.02 magnitude for photographic plates, to 0.005 magnitude for all sky photoelectric and CCD photometry, 0.0005 magnitude for CCD derived differential photometry. Space-based instrumentation, such as the Kepler spacecraft, can do an order of magnitude better in accuracy.

The AAVSO photometrists have at their disposal a number of books which describe procedures in data acquisition and analysis. Four such books, listed in order of publication date, are by Henden and Kaitchuck (1982), Sterken and Manfroid (1992), Howell (2006) with particularly useful references in his Appendix A, and Warner and Harris (2006). A new book on CCD photometry is in preparation (Henden 2012). The different viewpoints and approaches are a positive in understanding and in aiding observers in defining an approach with which they are comfortable.

3. Thoughts on observing

The two photometric filter systems of most interest to AAVSO members are the UBVRI Johnson-Kron-Cousins system, and the Sloan u'g'r'i'z' filter system. These two filter systems have the advantage that both are broad band filter systems. Both tie into a huge history of data (UBVRI) and as a tie into recent sky survey projects (Sloan Digitial Sky Survey = SDSS). The AAVSO has taken advantage of these facts in its APASS (AAVSO Photometric All Sky Survey) sky survey, using the Johnson B and V filters, plus the g'r'i' filters from the Sloan system.

It is *most* important to use a filter if at all possible! An observer will not be able to reach as faint magnitudes when using a filter, but the resulting measurement

will have more lasting scientific value. That is because an image through a standard filter, say Johnson V, is more easily compared to other observers' data. The transformation relations between the data sets have a better likelihood of being linear, of being a straight-line relation, of being better correlated.

Unfiltered images may be used to determine times of maxima or minima for variable celestial objects. However, one cannot as easily relate unfiltered data to other data sets. The relation between an unfiltered image formed from photoms from across the spectrum and an image resulting from a filtered image defined by a filter's band width, is not cleanly, linearly, defined.

While there is no one precisely correct way to observe, one that has proved fruitful has been described in some detail by Landolt (2007a). More specific situations are covered in several of his papers which provide standard stars for calibration of data taken using the UBVRI photometric system filters (Landolt 1983, 1992, 2007b, 2009; Landolt and Uomoto 2007). Much of what follows will be based upon this material, particularly from Landolt (2007a). No matter the observing program in which one uses CCDs as the detector, one has to obtain dark frames, bias frames, and dome flats or sky flats, for *each* night's observing in order to obtain the most accurate results. The dark and dome flat frames can be obtained during the afternoon. Suggestions may be obtained from AAVSO manuals and from books such as Howell (2006) and Henden (2012). Comparison stars should approximate the variable star as closely as possible, both in magnitude and color index.

A night's observing plan depends upon the program, of course. The most rewarding program is one which incorporates good science and is fun to pursue. So find a star, or a class of variable star, and observe and learn about them! If the need, or sky conditions, demand or allow differential photometry only, then one need know only the coordinates of the object or objects to be observed that night. The assumption is that the comparison stars exist in the field of the program object. They should approximate the brightness and color index of the variable star to provide the most consistent results. If non-photometric skies persist, one must ensure that the photometric measures, the CCD frames, will include the appropriate stars, in brightness and color index, which will permit good differential photometry to be done. The AAVSO chart and photometric sequence team in many instances will have provided an appropriate comparison star sequence. If the observer happens to be blessed with a proper astronomical environment, that is, a clear and photometric sky with some regularity, then the opportunity exists for the observer to establish a photometric sequence. For the majority of AAVSO observations, the observer will take a series of exposures of sufficient length to provide a good signal to noise ratio for the program object.

Since AAVSO members primarily are interested in variable stars, the observer must time observations as accurately as possible. The time at which each frame, each image, was exposed, must be recorded. The shorter the period of the variable star, the more accurate must be the timing measure. The time of the final magnitude determination should be taken as the central time of

the exposure. The central time of the exposure should be converted to the Heliocentric Julian Day (HJD). An AAVSO data submittal form can accept either the Julian Day (JD), that is the barycentric Julian Day, or the HJD. The HJD is the more accurate number, and especially is needed, is a must, for the short period variables. The JD is usable for the long period variable stars since their periods are long. Long term, though, even data for stars of long period benefit if the timings of observations are given in HJDs.

On the other hand, on photometric nights when the observational program involves standardization work, or all sky relative photometry, then the observer needs to plan more carefully. A sufficient number of appropriately placed, during the night, measures of extinction and transformation stars need to be observed (see Figures 4 and 5 in Landolt (2007a), together with the associated discussion). One must realize that extinction can and does vary throughout the night (see Landolt 2007a, Figure 8 and page 41). Although an observer can record images of fainter objects if a filter is not used, it is important to realize that photometric results have enhanced value if a filter is used in the light path. A Johnson V filter is preferred; its use will allow the best tie-ins to the AAVSO sequences and to most photometric systems, and hence enhances the value of the data.

When doing all sky relative photometry, an observer will want to intersperse standard star images with program star images with standard star images, and so on. This procedure is repeated throughout a night, the number of repetitions depending upon the length of the night. It is useful to observe in a pattern, like VBUUBV, so that one can average measures, images, frames, around a common air mass. This procedure works best for short exposures and when the CCD has a short read-out time.

In either situation an observer must keep good notes, an informative log book, so that during analysis one can recover and remember sky conditions, equipment behavior, and so on. State the size of the aperture used during data reductions. One must use the same size aperture for standard stars and for program stars in all sky photometry, and for the variable star and the comparison star(s) when doing differential photometry. Such information particularly is important during attempts to understand errant (outlying) data points. Such information is crucial for future users of the data, either the observer who by that time has forgotten just what happened at the telescope, or the person who downloaded the data, and now needs to understand how to meld the observer's measurements with data from other sources.

Given a "raw" CCD data frame, one immediately can difference the signal between a variable star and a comparison star, then add that difference to the comparison star's known magnitude, and get the magnitude of the variable at the moment of exposure. However, to get the best accuracy, the most accurate final magnitude for the variable object, whether or not the data were taken under a photometric sky or through cirrus, say, one first should subtract the bias frame and divide out the flat frame. One should apply extinction corrections, too. Here, on a non-photometric night, is the one time when it is useful to use "mean extinction coefficients." The observer is encouraged to reference the

detailed explanations in the *AAVSO CCD Observing Manual* (AAVSO 2011), as well as the reference books cited earlier.

Final results from all sky photometry will include magnitudes, color indices, and HJDs. Final results for differential photometry obtained under non-photometric skies, will include HJDs and associated differential magnitudes.

4. Acknowledgements

References

AAVSO 2011, *The AAVSO CCD Observing Manual*, AAVSO, Cambridge, MA.
Hearnshaw, J. B. 1996, *The Measurement of Starlight: Two Centuries of Astronomical Photometry*, Cambridge Univ. Press, Cambridge.
Henden, A. A., 2012, in preparation.
Henden, A. A., and Kaitchuck, R. H. 1982, *Astronomical Photometry*, Van Nostrand Reinhold, New York.
Howell, S. B. 2006, *Handbook of CCD Astronomy*, Cambridge Univ. Press, Cambridge.
Landolt, A. U. 1983, *Astron. J.*, **88**, 439.
Landolt, A. U. 1992, *Astron. J.*, **104**, 340.
Landolt, A. U. 2007a, in *The Future of Photometric, Spectrophotometric, and Polarimetric Standardization*, ed. C. Sterken, ASP Conf. Ser., 364, 27.
Landolt, A. U. 2007b, *Astron. J.*, **133**, 2502.
Landolt, A. U. 2009, *Astron. J.*, **137**, 4186.
Landolt, A. U. 2011, in *Astronomical Photometry: Past, Present and Future*, eds. E. F. Milone and C. Sterken, Astrophys. Space Sci. Libr., 373, 107.
Landolt, A. U., and Uomoto, A. K. 2007, *Astron. J.*, **133**, 2429.
Stebbins, J. 1910, *Astrophys. J.*, **32**, 185.
Sterken, C., and Manfroid, J. 1992, *Astronomical Photometry: A Guide*, Springer-Verlag, Berlin.
Warner, B. D., and Harris, A. W. 2006, *A Practical Guide to Lightcurve Photometry and Analysis*, Springer Science and Business Media, New York.
Weaver, H. F. 1946a, *Popular. Astron.*, **54**, 211.
Weaver, H. F. 1946b, *Popular Astron.*, **54**, 287.
Weaver, H. F. 1946c, *Popular Astron.*, **54**, 339.
Weaver, H. F. 1946d, *Popular Astron.*, **54**, 389.
Weaver, H. F. 1946e, *Popular Astron.*, **54**, 451.
Weaver, H. F. 1946f, *Popular Astron.*, **54**, 504.
Weaver, H. F. 1962, *Handb. Phys*, **54**, 130.
Williams, T. R., and Saladyga, M. 2011, *Advancing Variable Star Astronomy: The Centennial History of the American Association of Variable Star Observers*, Cambridge Univ. Press, Cambridge, 44.