Southern Horizons in Time-Domain Astronomy
Proceedings IAU Symposium No. 339, 2019
E. Griffin, ed.

doi:10.1017/S1743921318002405

On the Problem of Standardisation in Time-Domain Photometry

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Abstract. This presentation addressed some aspects of photometric standardisation and calibration that have a very significant effect on the accuracy of long time-baseline photometry. The difficulties were illustrated by examples of combinations of vintage photographic magnitudes with photomultiplier and CCD photometry, and with photometry from space. The case studies involved variability on time-scales of hours, years, decades and centuries. The examples went beyond classical problems of combining incongruent and ambiguous passbands, non-linear detectors and poor standardisation.

Keywords. Stars: imaging, stars: individual (AG Car, η Car, HD 34664, ZZ Cet, γ Dor), techniques: photometric, instrumentation: photometers

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1. Introduction

This presentation addressed some aspects of photometric standardisation that have a very significant effect on the accuracy of long time-baseline photometry.

Standardisation is the bringing into conformity of measurements with **'a'** standard. The principle is plain, and simple to express as Cousins (2001) did: *"there is nothing absolute in photometry, you always deal with standards"*. Standardisation concerns the creation of compatibility between different systems of measurement, in space and across time. The relation to the time domain was very well articulated by Landolt (2012): *"As each of you in your own way continues the beautiful, exquisite, important work of today, you can better appreciate and understand the art of photometry by reviewing the efforts of our predecessors."*

Landolt resolved to stay with the UBV system exactly because it had a tie to the past, viz. Johnson's use of a V magnitude defined by a filter whose effective wavelength approximated that of the sensitivity of the human eye. The UBV system stands on the *Johnsonian dictum*: that a reflecting telescope with aluminised mirror must be used, along with the unique 1P21 photomultiplier, the Johnson & Morgan (1951) three-filter set, together with observations of a set of proper standard stars.

Standardisers are often seen more as censors than as data collectors. This is a half truth, as the two following examples show vividly. Landolt (1968), while observing standard stars 40 years ago, discovered "just a new short-period blue variable" – a white-dwarf star with a period of 12.5 minutes – that became the prototype of the class of ZZ Cet variables. And Cousins (1992) observed γ Dor as an E-region standard in the 1950s, and found the star to be a periodic variable with amplitude $0\overset{\mathrm{m}}{.}015$ and a beat period of 23.5 days. This star later became the prototype of the class of γ Dor stars. That these 'founding' magnitudes and colours could be united with recent photometry is only due to the proper standardisation of this tabulated vintage photometry.

Johnson's prescription is a school example of a textbook instruction that is hard to implement in the real world of the contemporary photometric observer, and for many

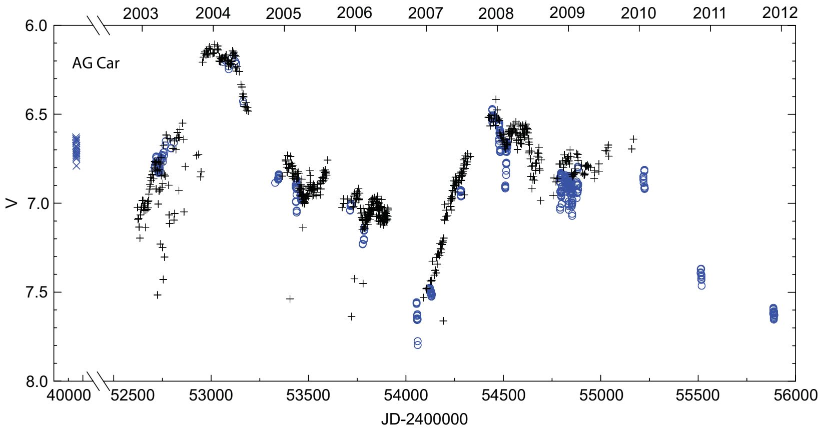

Figure 1. Variability of AG Car on a time-scale of one decade. ×: Bond & Landolt (1970), ○: *uvby* photometry collected by the author, +: based on ASAS-3 grade A data.

reasons. Very few observers have acquired expert level in standardisation, and users of published and archived photometric data are even less proficient in matters of photometry. Moreover, a vast body of photometry is obtained with instruments at visitor-operated observing facilities where the spectrum of offered photometric systems is very limited, and where the observer has to use whatever photometer that is made available. Then there are the various ground- and space-based sky surveys – with their immense data flows – that define their own (often not standardised and even filterless) photometric systems. An additional element in time-domain astronomy is that not only do the science data carry a time stamp, but that the standards also carry a time stamp.

A couple of examples illustrate how the use of one single isolated set of magnitudes and colours (or even one single isolated magnitude) from not well-calibrated or poorly documented sources in the context of a larger set of modern-day ground-based or space-based photometric data can lead to totally spurious conclusions.

2. Special Stars with Special Problems

2.1. *AG Carinae*

AG Carina is a Luminous Blue Variable or S Doradus variable: a hot, luminous star that shows photometric and/or spectroscopic variations like S Doradus, and which has undergone an η Carinae- or P Cygni-type outburst. AG Car possesses a ring nebula with a size of $39 \times 30''$, see Thackeray (1950). In 1967 Bond & Landolt (1970) obtained about two dozen *UBV* measurements of AG Car, and reported a range of variability of $0\overset{\mathrm{m}}{.}04$. They used a standard *UBV* filter set, a refrigerated 1P21 photomultiplier tube, applied mean extinction coefficients, and observed numerous *UBV* standards each night. The star has been observed by many others since. One specific set of homogeneous *uvby* data was obtained by myself: Fig. 1 shows the V magnitudes derived from the differential y data, together with the data obtained by Bond & Landolt (1970). Note that there is no way of demonstrating that both datasets can be merged or combined; all we can say is that we trust – or do not trust – the standardisation of the y versus V magnitude scale. A third set of magnitudes, based on ASAS grade A data from the ASAS-3 catalogue, is also shown. Both datasets are differential magnitudes relative to the same comparison star, while Landolt's data are non-differential all-sky measurements. Figure 1 shows that the V-scale of the post-2003 data agrees fairly well, but that there are, from time to time, systematic differences between both light-curves, as well as quite a number of substantially deviating

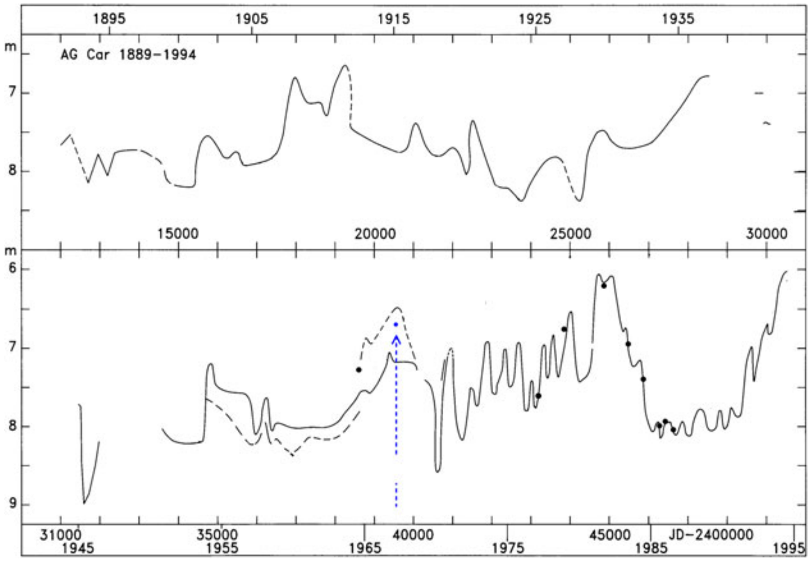

Figure 2. Light curve of AG Car over one century, based on Fig. 1 of van Genderen *et al.* (1997). The solid and dashed smooth curves were drawn through the various sets of data points, and the • symbols are isolated measurements. The vertical arrow points to the average V of Bond & Landolt (1970), the size of the symbol is $0^{\rm m}\!.045$ (3σ). This most reliable dataset is in discord with two series of visual estimates that mutually differ by $0^{\rm m}\!.2$–$0^{\rm m}\!.3$.

outliers. We know of these differences *only because sections of the light-curves overlap.* Figure 2 displays the schematic light-curve of AG Car over one century. It is based on visual estimates, and on photographic and photoelectric photometry from various sources in the literature.

2.2. η *Carinae*

η Car is an even more enigmatic LBV; it has an historical record of visual-magnitude estimates, photographic photometry, photoelectric measurements and CCD imaging. Since its eruptions in the 1830s and the following years, η Car has been the subject of several photometric investigations that, unfortunately, leave an appreciable margin of doubt on the exact quantification of η Carinae's magnitude and colour. This is because the internal level of precision of the acquired data blocks is quite often correctly described, though at the same time a proper assessment of the external accuracy of the data falls short, specifically for datasets spanning years or decades. See Workshop 14 (p. 279) for more details.

2.3. *The B[e] Supergiant Hen-S22*

Hen-S 22 (HD 34664) is a luminous star of the LMC that was studied for the first time by Henize (1956), who listed it as an $11^{\rm m}\!.4$ object. It exhibits the B[e] phenomenon: its spectrum is dominated by a curtain of narrow emission lines. Shore (1992) describes how the star underwent massive shell ejection, and concludes that S 22 was probably in the LBV shell-ejection phase, possibly with dramatic changes to come; its optical brightness appeared to have increased by more than one magnitude since 1983. Figure 3 shows the V-type magnitudes derived from various sources. Although at first glance the light-curve reveals strong variability during half a century before 1970, the data collected during

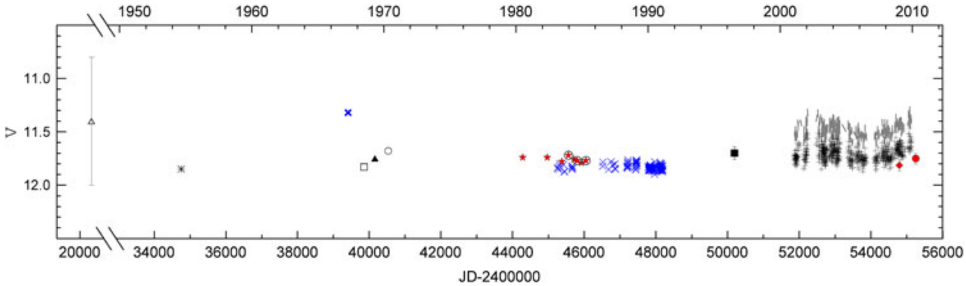

Figure 3. V light curve of S 22, adapted from Sterken (2011). The leftmost point is from the Henry Draper Catalogue: the observing date probably is around 1917, and this photographic magnitude is not directly comparable with V. The ■ data point was obtained with the IUE Fine Error Sensor that measured unfiltered light in a passband with a bandwidth that was a factor 3 to 10 larger than the passbands used for the other magnitudes in this plot. The grey symbols represent ASAS-3 grade A data, and the black ones below are the same data but shifted to fit one single ground-based V measurement obtained near the end of that data window.

the last four decades show – besides evidence for systematic effects – signs of only mild variability. That is not surprising, for the this data set involves half a dozen different V filters, and 11 dissimilar detectors.

3. Conclusion

Differences between photometric systems cause tie-in problems when combining magnitudes and colours of stars with peculiar spectra, and may result in severe discrepancies that render light-curves with a long time-baseline critically dependent on the instrumental set-up. Developers of ground- and space-based time-domain astronomy, when designing and implementing their projects, should take expert standardisers on board.

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