Irriducible Elements of Quality in High-Precision Photometry

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Abstract

A consise overview of the errors related to transformations of data from one photometric system to another is given.

1. Introduction

In the previous paper, Young considers the conditions that allow accurate transformations of measurements from an instrumental photometric system to a standard one for any object spectrum. As he points out, simple photometric systems (like the *UBV* system), do not have enough bands to capture the astrophysical information needed to distinguish between e.g. an unreddened G star and a heavily reddened B star. Also, systems with more bands (and even intermediate-bandwidth systems) show such deficiencies. This situation leads to complications when measuring binaries, as was already pointed out in 1955 by M. Ovenden at the IXth IAU General Assembly:

> Since the distribution of energy in the combined radiation of an unresolved double star is not necessarily the same as that in the spectrum of a single star of the same mean colour index, the transformation from one photometric system to another on the basis of colour index is not permissible. The problem is particularly serious for eclipsing binaries, where the relative contribution of the components to the total light varies throughout the eclipse. The comparison of different series of observations of the same binary in different photometric systems was possible only when the photometric systems are accurately defined.

The question simply is: how accurate can one perform photometric transformations in real life, that is, in the case where one combines data obtained in many (slightly) differing instrumental systems (eventually at different sites) into large, homogeneous datasets that extend over many months or years of time.

As an example, we reproduce in Fig. 1 the phase diagram of HD 46407, an eclipsing-binary Barium star with period 452.5 days and eclipse depth that barely exceeds $0\overset{m}{.}02$ in *V*. The data were obtained in different *uvby* "systems" at a single site (see Jorissen et al. 1992).

[1]Belgian Fund for Scientific Research (NFWO)

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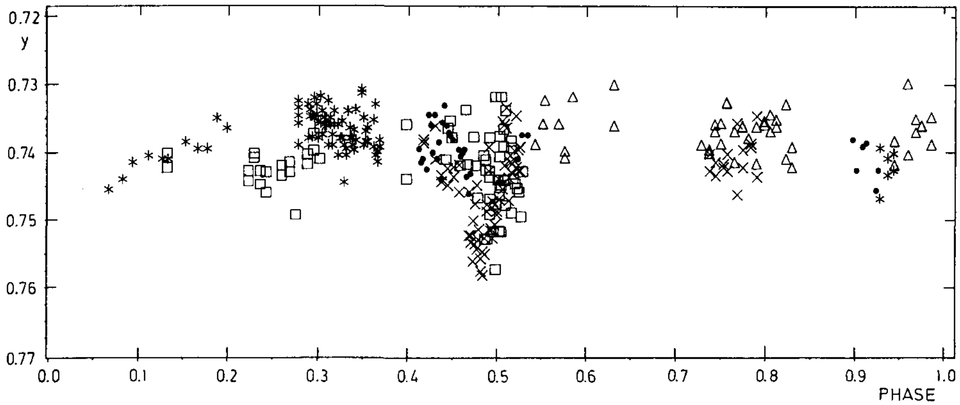

Figure 1: Phase diagram for HD 46407 in y for the $452^{d}.5$ eclipsing-binary Ba star. The different symbols refer to different cycles (from Jorissen et al. 1992).

The analysis of data of objects where the light curve exhibits intrinsic scatter, and where the measurements are obtained over a very long time-baseline—eventually at more than one site (networks)—can only yield conclusive results if the error budget is under control and if this budget is well known. The accuracy with which the transformation can be performed depends on

- the degree of excellence of the site(s)
- the quality of functioning of the observer(s)
- the compatibility of the detector(s)
- the unisonance of the photometric system(s)
- the congruence of the reduction schemes

The first item, the photometric quality of the site, seems a trivial factor. However, few observers do realize how crucial this element is for obtaining results of the highest quality. A *necessary* condition for a good site is that the atmosphere above that site is of high transparency. Fig. 2 gives a rough idea of the diversity of occurence of this qualification, but it is obvious that the prerequisite of high transparency must be more than occasionally fullfilled. But, as is well known, good sites may also yield periods of highly-variable (low) transparency, as is the case during several weeks or months following a major volcanic eruption.

The second point is one that is mostly not considered, since it is usually assumed that observers are qualified people. Though it is generally accepted that the replacement of an observer by a robotic system tends to eliminate personal errors, manual

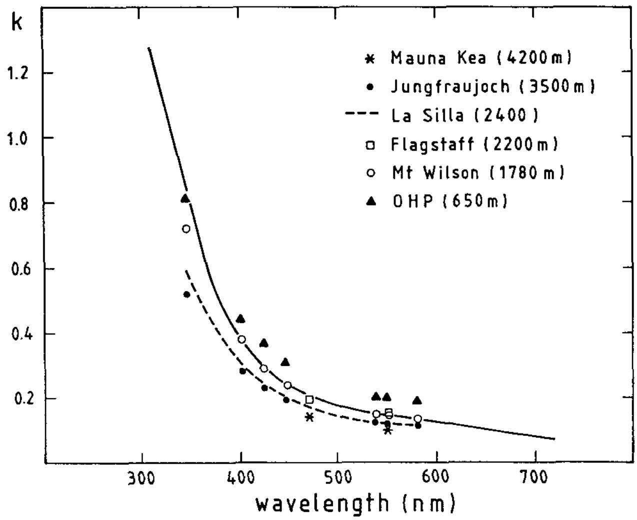

Figure 2: Atmospheric extinction coefficient in function of wavelength for different sites (from Sterken and Manfroid 1992a). The dashed curve is based on 7-color data from Rufener (1986), the full line covers data from Melbourne (1960).

observers can outperform robotic systems when it comes to efficiency and planning (see Sterken and Manfroid 1992b, where it is shown that human observers worked at average airmasses that were systematically lower than when automatic mode was used).

And when it comes to the third point—that is, detectors—one should realize that, through the years, the changes in detectors have drastically modified the original photometric systems (the *UBV* system, for example, has been used as well with photographic emulsions, as with photomultiplier tubes, as with CCD detectors), and one must make sure that such changes (or even changes from one detector of a kind to a second one of a same type) do not reflect into the final data.

For discussing the fourth and fifth point, in what follows we shall assume that we have a perfect site, a perfect detector and photometer, versatile software, and a good observer.

2. Compatibility of systems and congruence of reductions

Manfroid and Sterken (1992) discern *conformity errors* and *reduction errors*. The former arise from the fact that the photometric systems have mutually different pass-bands, and that there is no way to evaluate the corrections needed to properly transform data from one system to another. The latter are of a purely methodological nature.

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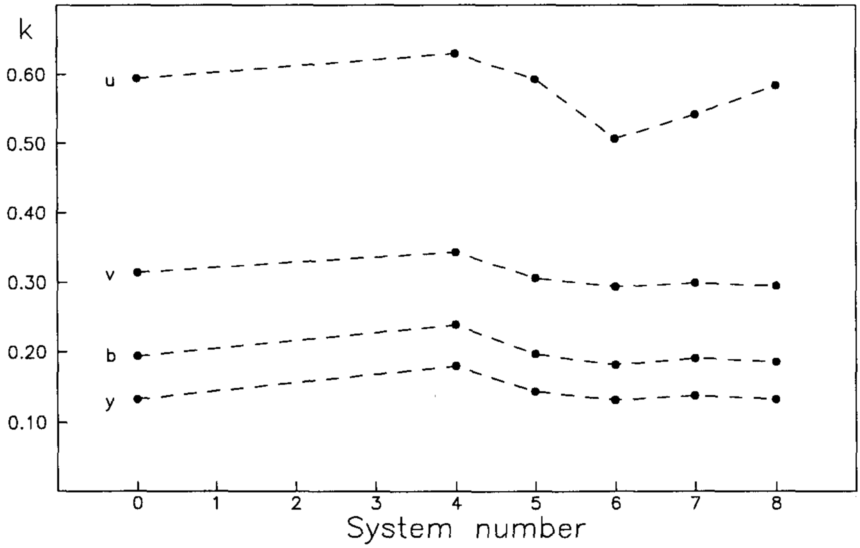

Figure 3: Atmospheric extinction coefficient in u, v, b and y for 6 instrumental *uvby* systems (based on data from Table 2 of Sterken and Manfroid 1992c).

One must not forget that conformity errors are often unavoidable, since prescriptions of a purely practical origin (such as the availibility of a given photometric system at one observing site) may force the investigators to rely on data coming from different such systems. It happens, however, that large passband-mismatches cause only small errors, whereas small passband-mismatches may invoke large discrepancies. As an example of the former situation, we refer to the observing campaign on BW Vulpeculae (a large-amplitude β Cephei star) by Sterken et al. (1992), where very different photometric systems have been put to use, with very little effect on the final astrophysical conclusions. As an example of the second situation, we refer to Sterken and Manfroid (1987), who illustrated that small passband mismatches (in *uvby*) lead to astrophysically contradictory results concerning the evolutionary state of pulsating B stars in the young open cluster NGC 3293. Manfroid (1992) demonstrates that conformity errors have a detrimental effect on the reddening vector, and consequently on the reddening-free indices, and that such is also the case when color indices of composite objects (binaries) are transformed. Let us also point out that deviations from conformity—even if they are small—will reflect in the derived extinction coefficients (see Fig. 3), and that such errors may strongly bias any interpretation of variations in atmospheric extinction.

Reduction errors can be of two kinds: one class is due to the limited range of stellar types used in the color-transformation procedure, and the other category are those errors that result when different transformation schemes are applied (see Manfroid

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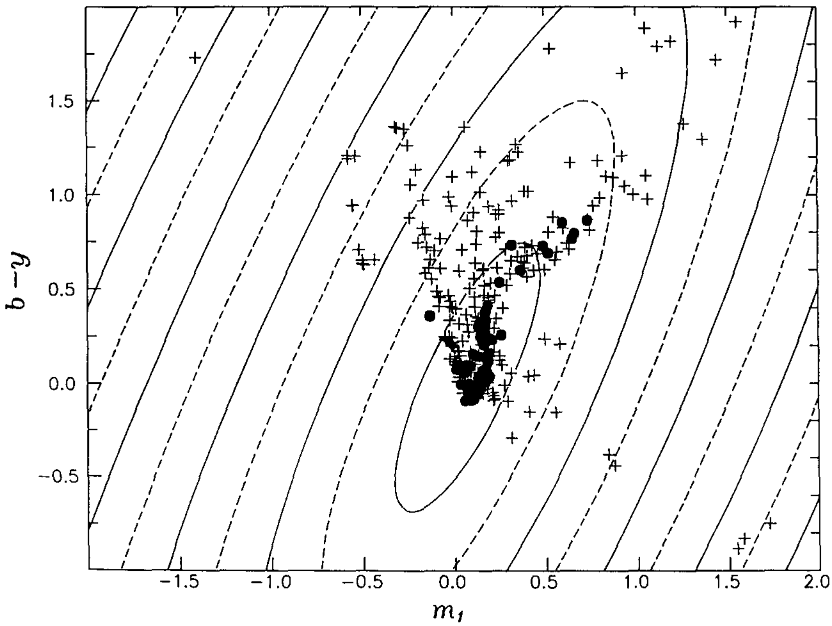

Figure 4: Standard deviation of inter-run variations in m_1 as a function of $b-y$ and m_1. Adjacent contours are separated by $0\overset{m}{.}005$. Crosses are variable stars, dots are standard stars (from Sterken and Manfroid 1992a).

et al. 1992).

Reduction errors of the first category are typical for batches of data that are treated with a consistent method of reduction, as is the case in long-term and network projects. Some of the parameters in the reduction schemes have larger errors than others (for example, in *uvby* photometry the ratio of the uncertainties of the coefficients in the transformation equation of m_1 to the coefficient related to the $b-y$ transformation may amount to a factor of five), and the resulting errors are appreciably large for stars with extreme color indices. Such effects are random shifts that affect all measurements of a given star by a same amount (during a specific observing run). In Fig. 4 we show, as an example, the standard deviation of the inter-run variations in m_1 as a function of $b-y$ and m_1 for discrete observing runs of several weeks duration each. Adjacent contours are separated by $0\overset{m}{.}005$. The figure makes clear that the application of differential photometry will not help, unless one compares (exotic) stars that are located very close to each other in that diagram.

Reduction errors of the second type are *extrapolation errors* that occur when different schemes of transformations are applied. Such situations typically occur when data, obtained and reduced by individual observers, are being taken from the literature and are combined in quasi-homogeneous datasets. These errors are of the order of several tenths of a magnitude (see Manfroid et al. 1992) and appear as method-dependent shifts, and show up for stars having color indices that fall outside

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the range of standard values, where the color-transformation relations are necessarily extrapolated. Again, differential photometry does not help, since the effects do not show up for the comparison stars (if their color indices belong to the range of indices of standard stars). Since usual schemes of color transformation do not adequately represent the effects of interstellar reddening (Manfroid 1992), the application of a variety of differing color transformation schemes must lead to problems.

3. Conclusions

The further deployment of long-term projects and multisite networks is imposing a stringent requirement of homogeneity. The importance and usefulness of any photometric system will depend on the activity of the system in terms of numbers of users, the rate of collection of data, and the geographical spread of the sites where the system is implemented, and on the extent of the ever expanding field of astronomy that must be covered by any system put to use. All of this urgently calls for the elaboration and publication of uniform and solid reduction procedures, not only for the sake of global and long-term campaigns, but also for the small batches of data that, on an individual basis, are submitted for publication.

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https://doi.org/10.1017/S0252921100007429 Published online by Cambridge University Press

Discussion

T.J. Kreidl: *It certainly seems that not only the tightening of uniformity of filters and the resulting better transformations, but also the economic advantage and improved uniformity of a large number of filter sets could be realised if many observatories pooled their orders for filters.*

Young: Large filter orders do not completely eliminate variations from one filter to the next. Manufacturing processes, even, can produce significant differences between individual filters made in large batches.

Sterken: Sure, your are right, but Kreidl is right too in the sense that the differences between filters will be a magnitude less than those to be expected when each of us separately orders filters to be manufactured. You should not forget also that some of us are somewhat forced to place filter orders with manufacturers inside our own country, a procedure that adds to the confusion, whereas a bulk-purchase should avoid such problems. So the truth lies somewhere in the middle.

W. Tobin: *Do you have any comment concerning whether in Strömgren reductions it is better to use m_1 and c_1 directly, or reduce in (u-b) and (v-b), which seems simpler, and then compute m_1 and c_1?*

Sterken: We work with (b-y), m_1 and c_1 for all-sky photometry, and the transformations are established for all stars observed. Reductions with (u-b) and (v-b) instead of m_1 and c_1 are often applied to subsets of stars (e.g. only B, or B and A type stars).

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