Long-Term Stability in Classical Photometry

H. HENSBERGE, Koninklijke Sterrenwacht van België, Brussel, Belgium
J. MANFROID, Institut d'Astrophysique, Université de Liège, Belgium
C. STERKEN, Vrije Universiteit Brussel, Belgium

Introduction

Since October 1982, the Long-Term Photometry of Variables project (LT PV, see e.g. Sterken, 1983, Manfroid et al., 1991) is operational at ESO. Initially, several small photometric telescopes were used according to conditions of availability. Gradually, the need for one stable instrument was recognized, and today all observations are collected with the Danish 50-cm SAT. Among the large number of variable objects in the programme, there are some bright stars that are suspected of being microvariables on very long time-scales. It concerns magnetic CP stars for which there is evidence that the rotation period might be longer than 100 days, even as long as several tens of years. These stars show light variability that is modulated with the rotation period because the variation is due to their atmosphere's structure and composition which is not homogeneous over its surface. The amplitude of the light variations in the better known – somewhat faster rotating – CP stars is, in general, a few hundredths of a magnitude in the Strömgren photometric system. It is evident that the search for such variations over many years requires a differential approach, stable instrumentation, and a consistent observing and reduction procedure. This paper comments on our experience with stability of instrumentation and on the detection of light variations in γ Equulei, the slowest-rotating CP star known. According to magnetic observations (Mathys, 1990), this star is believed to rotate only once per century. Results on other CP stars, with periods ranging from 5 months to 10 years, are presented elsewhere (Hensberge, 1993).

Photometric Stability

Several recent papers refer to the loss of information resulting from the use of non-compatible versions ("clones", see Sterken, 1992) of a same photometric system and from the application of non-congruent transformation equations. Manfroid and Sterken (1992), for example, discern *conformity errors* and *reduction errors*. The former arise from the fact that the photometric systems have mutually different passbands, and that there is no way to evaluate the corrections needed to properly transform data from one system to another (see Sterken and Manfroid, 1987). The latter are of a purely methodological nature.

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 colour indices of composite objects (binaries) are transformed. Let us also point out that deviations from conformity will reflect in the derived extinction coefficients.

One must not forget that conformity errors are often unavoidable, since prescriptions of a purely practical origin (such as the availability of a given photometric system at La Silla) may force the investigators to rely on data coming from different such systems.

Reduction errors can be of two kinds: one class is due to the limited range of stellar types used in the colour-transformation procedure, and the other category are those errors that result when different transformation schemes are applied (see Manfroid 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 our long-term project. Some of the parameters in the reduction schemes have larger errors than others (for example, in Strömgren 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 colour indices. Such effects are random shifts that affect all measurements of a given star by a same amount (during a specific observing run). 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 may be of the order of several tenths of a magnitude (see Manfroid et al. 1992) and appear as method-dependent shifts. They show up most clearly for stars having colour indices that fall outside the range of standard values, where the colour-transformation relations are necessarily extrapolated. Again, differential photometry does not help, since the effects do not show up for the comparison stars (if their colour indices belong to the range of indices of standard stars). Since usual schemes of colour transformation do not adequately represent the effects of interstellar reddening (Manfroid, 1992), the application of a variety of differing colour transformation schemes must lead to problems.

As a consequence, we limit the discussion hereafter to observations obtained within one single version of the Strömgren system, viz. to simultaneous uvby photometry obtained with the Danish 50-cm SAT telescope. From a careful analysis of non-differential magnitudes and colours in a large sample of standard stars and numerous reference (comparison) stars, it seems that the coefficients of the transformation equations to the standard system do not show long-term trends. We nevertheless prefer to present the lightcurves of CP stars in the instrumental system, because we wish to avoid loss of information in the case that the shape of the lightcurve is considerably wavelength-dependent. It is known that in such cases (see Manfroid, 1992, Hensberge, 1993) the transformation equations may induce changes of non-physical origin in the shape of the (transformed) lightcurves.

The only instrumental trend of long-term character has been detected at the level of the dead-time correction associated with the v passband. That such an effect was present, was readily apparent in our v-data (and in the colour indices involving the v passband), of couples of comparison stars of considerably differing magnitudes. The effect was confirmed when we checked the non-differential results on bright stars afterwards. The nominal value for the deadtime, $8.8\ 10^{-8}$ s, changed at a rate of $1.7\ 10^{-8}$ s per 1000 days, resulting in a change of about 35% over the last 5 years! An example of a spurious effect produced by this drift is shown in Figure 1, that illustrates the case for two constant comparison stars that have substantially different apparent magnitude.

Once this trend is taken out, the stability of the differential results is quite satisfactorily. Checks for presumably spurious long-term trends or instabi

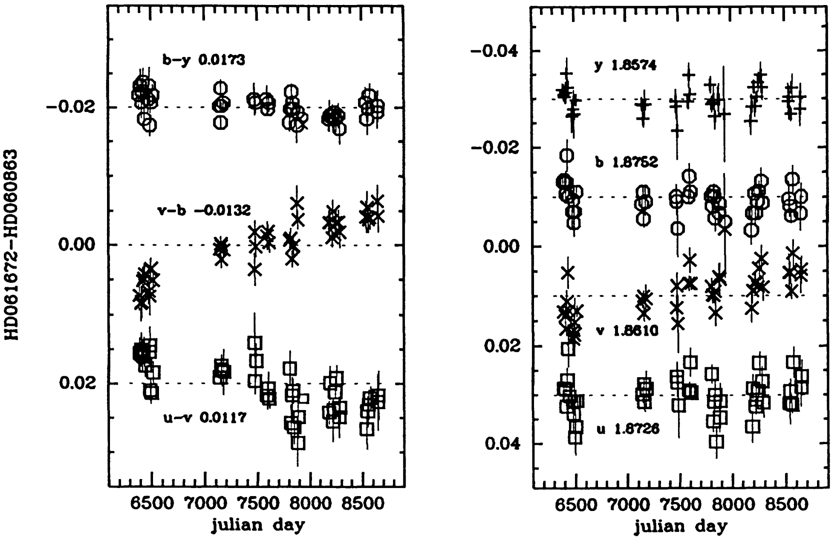

Figure 1: *Spurious effect produced by the drift in dead-time correction for the v-channel of the SAT telescope: differential photometry for two constant comparison stars of different brightness. The vertical scale is a relative scale; the mean magnitude and colour-index values are indicated.*

lities, over the 8 years covered, exclude effects exceeding a few thousands of a magnitude (it should be stressed, however, that comparison and programme stars were never very different in spectral type, the extreme case being the comparison between a late B and an early F-type star).

γ Equulei

γ Equ is an extreme sharp-lined late A star with a spectrum characterized by strong Sr lines and by a magnetic field with a strength of several kG. The literature on this star contains, from 1967 on, very different suggestions for the period of magnetic variations and light variations, including 9 days, 17.5 days, 10.5 months, almost 5 years, and 72 years (see references in Catalano and Renson, 1984). The discussed light variations, which are of very small amplitude, were – to our opinion – at best disputable or inconclusive. In addition, fast oscillations (period of about 12 minutes) have been detected (Kurtz, 1983) with an amplitude not exceeding 1 mmag. All the evidence on the magnetic field, collected from 1946 on at Lick, Mauna Kea, Tautenburg and La Silla Observatories (see Mathys, 1990), supports a very slow change of the integrated longitudinal component of the magnetic field with a polarity reversal around 1970–1971.

Now that a homogeneous set of photometric data becomes available in the LTPV project, we can deduce with confidence that the star gradually changes magnitude and colour on a time scale which is much longer than the time interval covered by our observations (see Fig. 2). The error bars refer to "internal error" estimates; there are indications that external errors are significantly larger (25%) only when u is involved.

The inferred rate of change is largest in the v passband (8 ± 0.6 mmag per 1000 days), a very common characteristic for late-A peculiar stars, but is also present in the other channels. Due to the simultaneous character of our photometry, the very small colour changes are detectable: in units of mmag per 1000 days they amount to 2 ± 0.4 in b–y, 4.5 ± 0.2 in v–b and –5 ± 0.7 in u–v. In spite of the caution to be taken when making comparisons with data from other sources, it is clear that the colours observed by Wolff and Morrison (1973) in 1963 and 1970–1971 are sufficiently similar to our results in order to suggest that these colour gradients most probably have changed during the two decades covered by the data.

Conclusions

Besides obvious disadvantages with respect to CCD photometry in applications in crowded fields or in fields with a complicated background, the relative simplicity of classical photomultiplier-based photometric equipment certainly has advantages in applications that rely on long-term stability requirements (though, it must be stressed, CCD systems may also prove to be very stable). Using small telescopes, and simple – but consistent – reduction efforts, the accuracy limits that are obtainable open interesting research possibilities in several fields demanding high-precision photometry over long time-intervals. The necessary condition, of course, is that one has access to the same instrumentation during the whole time interval covered by the project. The necessity for one or more observers to reside quasi-permanently on site is avoided by the elegant solution of central coordination of service observing for several such programmes inside one global project. The LTPV approach, applied at La Silla for more than a decade,

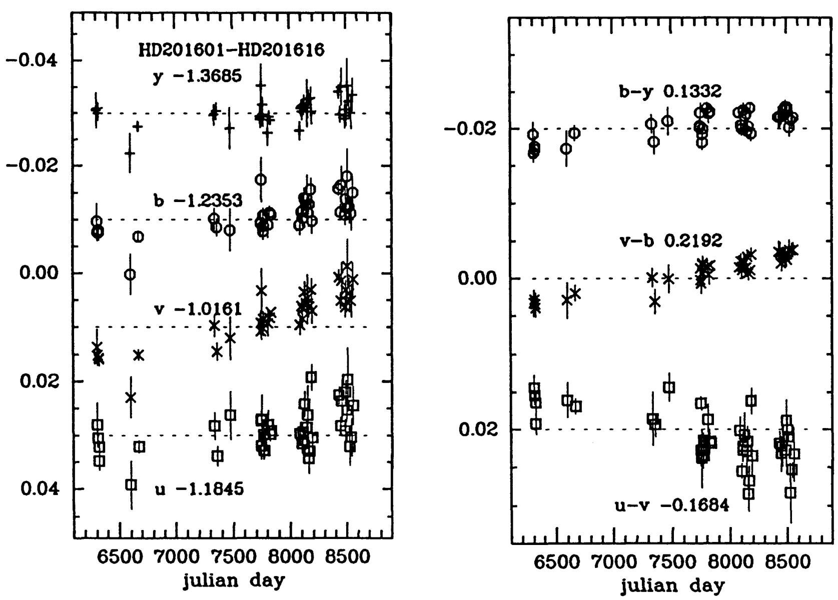

Figure 2: *Magnitude and colour changes on time scales that exceed the actual coverage of the LTPV project: differential photometry of γ Equ (HD 201601) relative to HD 201616. The vertical scale is a relative scale; the mean magnitude and colour-index values are indicated.*

not only widened the scope of photometric precision, it also yielded a considerable amount of new astrophysical discoveries combined with novel insights in handling of photometric data and a broader understanding of instrumental performance at an unprecedented high level of cost-effectiveness.

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The Contribution of Detailed Analyses of F, G and K Stars to the Knowledge of the Stellar Populations of the Galactic Disk

G. CAYREL DE STROBEL, Observatoire de Paris, Meudon, France

Introduction

Five subsystems of stars have been clearly identified in the Galaxy: the Halo, the Thick Disk, the Thin Disk, the Spiral Arms and the Galactic Bulge. The stars which populate the Halo are very old and are known also as Population II (Pop. II). Those of the Thick Disk are old stars, almost as old as the Halo stars, and are known as intermediate Pop. I stars. The stars of the Thin Disk, which are true Pop. I stars, may have any age between 0 and 10 Gy (10×10^9 years), or even more. The Thin Disk population may be split in "young" Thin Disk, and in "old" Thin Disk Pop I stars (Nissen and Schuster 1991). The youngest Pop. I stars are found in the Spiral Arms. In the Galactic Bulge exists the full span of populations and of stellar ages. The Halo and the Bulge are called the spheroidal stellar components of the Galaxy; their spatial distribution is strongly centrally concentrated, in contrast with the Disk and Spiral Arm populations.

The knowledge of the age, the kinematics, and the chemical composition of a star is essential for determining the subsystem to which the star belongs. Unfortunately, the age of a star is not an easy parameter to determine, too many assumptions on the internal structure and the state of evolution of the star must be made, before being able to attribute an age to a star. We are still arguing about the age of the oldest stars of the Halo, born soon after the Universe. The age of the oldest stars lies inside a bracket of at least 5 Gy (from 13 to 18 Gy). If we want to attribute a turn-off age to a star, the star must, first, be in its "turn-off" stage of evolution, and, second, must fit a reliable isochrone, constructed with the help of a grid of evolutionary models computed with a good input physics, and having very similar chemical composition (X, Y, Z), as that of the star to be dated.

The study of the chemical composition of stars belonging to different subsystems is of great importance, because the variation of metallicity as a function of space and time is a central problem for the knowledge of the chemical evolution of our Galaxy and of other galaxies.

Very interesting is the help we can derive from long-lived low-mass stars, evolving slowly, for the study of the chemical evolution of the Galaxy. Indeed, it is among late F, G and K stars, having effective temperatures between 6000 K and 4000 K, that evolution has not depleted the initial stellar populations of the Galaxy, and that the full span of stellar ages is still present. The extended convective zones of low-mass stars prevent the formation of peculiar abundances at their surface, with, however, the exception of lithium for some F stars and hotter G stars. Therefore, the abundances of the elements found in analysing in detail an atmosphere of a low-mass star give direct information about the chemical composition of the interstellar cloud out of which the star was formed.

In general, late F, G and K stars are used to study stellar populations, the abundance gradients across the Galactic Disk, the constraints on primordial nucleosynthesis imposed by the chemical composition of extremely metal deficient objects, the connection between kinematic and dynamic evolution of our Galaxy and of other galaxies. F, G and K stars have also another advantage: their spectra are easier to analyse than the spectra of hotter stars with broadened spectral lines and which require analyses based on Non-LTE (Local Thermodynamic Equilibrium) model atmosphere computations, and of cooler stars in which molecular bands become a serious problem.

We use as a metal abundance indicator, the well-known parameter:

$$[Fe/H] = \log (Fe/H)^* - \log (Fe/H)$$

which represents the logarithmic difference between the relative abundance of iron with respect to hydrogen in the atmosphere of a star, and the relative abundance of iron with respect to hydrogen in a standard star. Following Gilmore and Reid (1983), Gilmore and Wyse (1985), Rich (1990), we define in Table 1 four abundance intervals Δ [Fe/H] constructed with stars belonging to different subsystems.

However, if these four population criteria are defined kinematically, and non-chemically, each of them has a spread in metallicity, and there is some overlapping in their metallicity distribution (Laird et al. 1989). The best way to differentiate a Halo from a Thick Disk star having the same [Fe/H] value, say, 1.2 dex, is the analysis of their galactic orbits. Indeed, both chemical composi-