APPROACHES TO PHOTOMETRIC CALIBRATIONS

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ABSTRACT. In this review an examination will be made of the experimental conditions which must be satisfied by multicolor photometric systems if the observational parameters are to be correlated unequivocally with physical quantities of the star. An inventory of error sources disturbing such calibrations contains: instability of the natural system, procedures of observation and reduction to outside the atmosphere and correlation with a standard system. The requirements desirable for the preparation of lists of standard stars, for the definition of the pass bands, for the "orthogonality" of the calibrated parameter, for the definition of the domain of validity of the calibration are listed. Some remarks are made on the concepts of "open" or "closed" calibrations.

1. INTRODUCTION

The evaluation of physical quantities by means of photometric observations often gives the impression of being a simple process, requiring little equipment and telescope time. When we need to know the color excess of a star of known spectral type, one UBV measurement is sufficient. The question is more critical, however, if the spectral type is unknown, and even more so if we want to determine other properties of the star also. We are faced by the hazards which may affect each step of the following process:

$$\star \rightarrow \begin{matrix}\text{photometric}\\ \text{observation}\end{matrix} \rightarrow \text{standardization} \rightarrow \text{calibration} \rightarrow \begin{matrix}\text{physical}\\ \text{quantities}\end{matrix}$$

The legitimate concern about the use of the latest available calibration sometimes causes one to neglect the precautions which are essential for the previous stages. My intention is to insist here on the importance of these precautions, which are all the more necessary if the number of filters is large and if the object is to evaluate several physical quantities characteristic of the star.

D. S. Hayes et al. (eds.), Calibration of Fundamental Stellar Quantities, 253–269.

We recall here that each photometric measurement is a direct measurement of the integral over the energy flux $E(\lambda)$ of the star filtered by a more or less wide passband $\phi_i(\lambda)$, and that the signal is recorded at ground-level through the absorbing atmospheric screen $A(\lambda, Fz, t)$. Therefore, the measurement made at time t through an air mass Fz corresponds to a complicated function

$$m_{i,z,t} = -2.5 \log \int E_t(\lambda)\phi_i(\lambda)A(\lambda,Fz,t)d\lambda$$

If an accurate measurement of $m_{i,z,t}$ is to be subjected to a calibration, its value outside the atmosphere must be determined:

$$m_{i,o,t} = -2.5 \log \int E_t(\lambda)\phi_i(\lambda)d\lambda$$

which can only be significant if, on one hand, the profile of the passband is well defined and conserved and, on the other hand, the reduction to outside the atmosphere is properly carried out.

The opinions which I express in the following pages are the result of twenty-five years of confronting the difficulties of ground-based photoelectric multicolor photometry. This is why many of my references will relate to the Geneva photometry which I have been practising continually since its creation in 1960; besides, it is the only photometry I know really well.

2. THE NATURAL SYSTEM

The natural system, or instrumental system, corresponds to the photoelectric responses of the equipment used by the photometrist during the observations. The natural system is therefore the product of the chromatic responses of all the reflecting, absorbing or even diffusing elements encountered along the optical path, beginning at the entrance of the telescope, multiplied by the response of the detector which is generally a photomultiplier. The whole equipment presents an analogical response which varies with time. Indeed, the reflectivity of the telescope mirrors, or the transmission of the elements in the photometer as well as of the filters can evolve with time and vary under the influence of external factors which are mainly governed by temperature. The same is also true for the detector. Quite often the observer has very little information concerning the natural system he is using. Is it stable? Is it sufficiently close to the definition of the standard system to be sensitive in the same manner to features in the stellar spectra? The answer to these questions must not remain vague. Let us begin with the question of stability and detail a few precautions.

The permanence of the system and the continuity of its use are tokens of stability. One must however remember that the aging of the reflective coating of the mirrors is rapid, and that it is also chromatic.

Freshly aluminized mirrors undergo a more rapid decrease of their reflectivity in the near ultraviolet than in the visible (Hass, 1955; Rufener, 1968). As it is desirable to use mirrors which are as clean as possible one could prefer a careful washing to a new aluminium coating. Our experience with a mirror protected by a wide-band interference coating of magnesium fluoride has been very satisfactory. This coating has been washed frequently without suffering any significant alteration. The chromatic properties of the coating have remained stable. If the cleanliness of the mirrors and other elements is beneficial to signal intensity, it is equally important to the reduction of diffused light. This diffused light increases the sky background and can in certain cases be chromatic. We have noted several times that it decreases rapidly with increasing distance to the optical axis. It is then necessary to introduce small corrections when we change the diameters of the diaphragms which define the measuring field. A further advantage of continued use of a natural system lies in the possibility of monitoring its evolution and of identifying the cause of each change noted.

We must insist here on the essential role of temperature regulation in the conservation of the passbands. Most absorbing glasses which are used to define the passbands show a variation of their cut-off wavelength with temperature. It is not uncommon to observe an effect of the order of $\Delta\lambda = 2\Delta T$ (λ in Å, T in °K). On the other hand, the chromatic response of the photomultiplier (PM) also varies with temperature. One generally observes a redward displacement of the sensitivity threshold of a cathode with increasing temperature. The maximum of the sensitivity function often decreases with increasing temperature. We therefore have to stabilize the temperatures of all the elements which influence the response curves of the natural system (Young, 1974a). In most photometers, the temperature of the photocathode is lowered radically so as to reduce the thermionic emission which uselessly increases the dark current. This is hazardous when the refrigeration is not regulated but only set to be as low as possible. This situation places the photocathode in a temperature field with a high gradient, all the more so since the entrance window is often heated to prevent condensation. The true temperature of the cathode is then very badly defined. It is by far preferable to have a true temperature regulation of the PM around a sufficiently low value so that thermionic emission would not be troublesome, but at which the thermal gradients are moderate and well localized by the construction of the insulating mounting. A second temperature regulation will be necessary for stabilizing the filters and possibly other technical elements related with the measurement of the PM current.

Several cases are reported, in the literature, of photometers having shown a sensitivity to the influence of disturbing fields such as magnetic, electric or gravitational fields (Young, 1974b). This type of subtle disturbance is often difficult to test systematically.

Magnetic fields act mainly on the PM; they can modify the distribution and the orientation of the initial velocities of the photoelectrons leaving the photocathode. Perturbations of gain and chromatic response have been reported (Rufener, 1966). A good protection is insured by properly installing a shielding of high magnetic permeability. Perturbations due to electric fields are difficult to eliminate completely. They enter at several levels. The stabilization of the voltages is generally sufficient and allows one to obtain stable PM gains as well as a permanence of the characteristics of the system which measures the photoelectric current. On the other hand, the effects of electromagnetic disturbances which propagate in the environment of the photometer, or in the power network, are more often than one may suspect the causes of instrumental instabilities. In particular, when a photon counting system is used to analyze the PM current, the frequency and origin of the disturbing pulses are not always recognized. The effects of gravity have also caused a few surprises which can, however, be prevented by a rigid construction of the photometer and by tests made with a stable calibration source which can be moved with the photometer. The use of an internal reference source has sometimes been proposed, but the stability of such a source can also present problems (Peytremann, 1964).

3. REPRODUCTION OF THE PASSBANDS

This is truly a subject on which most users of photometers do not have any direct influence. It is however of the utmost importance that the natural system imitates as well as possible the standard system. To make this possible it is therefore at first necessary that the standard system be well defined by a description of the elements used and by precise laboratory measurements. This question will be taken up later. When we wish to build a new photometer, we should choose components which have the same specifications as those which created the original natural system. These components are often no longer produced, having been replaced by new ones with better performance according to catalogs. This is the beginning of a series of compromises. In the past few years, the availability of new photocathodes which are highly sensitive in the red has become a source of many temptations. The use of photovoltaic, two-dimensional detectors such as the CCD is being generalized. How can one conserve the definition of the passbands? A scrutiny of colored glass catalogs suggests some solutions. One must, however, be very mistrusting; a combination defined on the basis of transmission and response curves given in the catalogs of the manufacturers is only a first approximation which must be controlled by laboratory measurements. It is certain that precise measurements made through badly reproduced passbands will later on be the cause of much uncertainty and dispersions which will affect in a very troublesome manner the significance of these measurements. A detailed example of this kind of difficulty has been presented by Olsen (1983) in the introduction of his catalog.

We can already foresee unpleasant surprises due to the redward extension of the spectral responses of the new detectors which will be either badly, or not at all, taken into account. Two instructive examples of transformations and comparisons figure in the articles by Graham (1982) and especially by Landolt (1983). They reveal the difficulty of obtaining UBV measurements by means of an RCA 31034 PM with a Gallium-Arsenide cathode. The lack of definition of a passband cannot be corrected by a simple transformation made with the help of a few standard stars. One must actually maintain the content of spectral information which is summed up by the passband of the natural system. Figure 1 shows an example of a mismatch between two manufacturings of interference filters which were used for intermediate band photometry. The localization of a few important lines shows the order of magnitude of the potential problems.

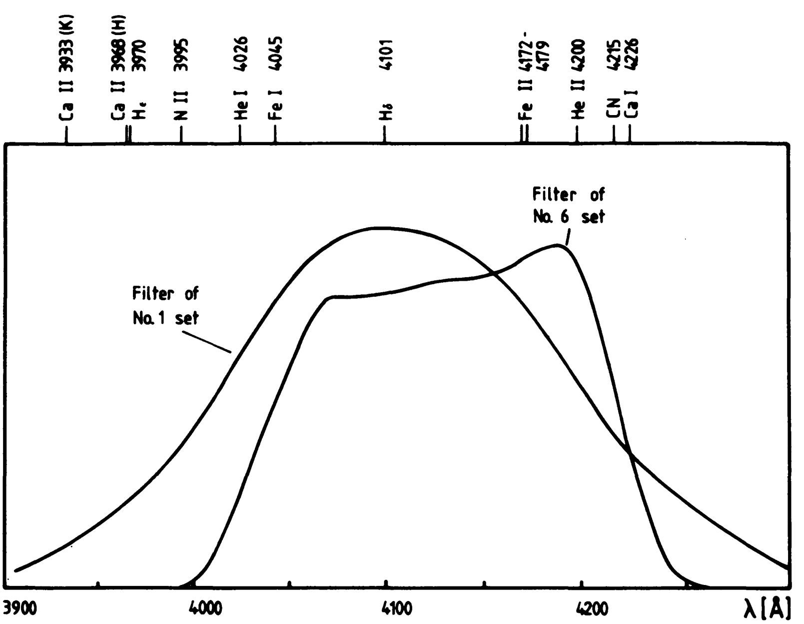

Fig. 1

Optical responses of two interference filters which have been used for intermediate band photometry. Differential effects uncorrectable by the standard transformation are to be expected if one considers the locations of some important lines.

4. PROCEDURES OF SIGNAL MEASUREMENT

Whether we measure the photoelectric current with a DC amplifier or with an amplifier adapted to photon counting, there is no real advantage in using large time-constants or long integration times. This filtering of high-to-medium frequencies ($f > 0.1$ Hz) often only serves to mask anomalies of the signal and to average them with the interesting part of the signal. A large variety of disturbances have time characteristics which correspond to frequencies > 10 Hz. We can mention disturbances of the electric field, scintillations due to cosmic radiation or to natural radioactivity as well as several atmospheric phenomena such as lightning, and some of the effects related to turbulence and scintillation. Bartholdi et al. (1984) have shown the advantage of rapidly sampling the signal while applying statistical tests calculated in real-time. This technique, which is made feasible by available microcomputers, allows one to recognize the anomalies of the observed time distribution of incident photons compared with the Poisson distribution. This procedure proved to be particularly interesting for judging the quality of recordings of low fluxes. It allows one, in certain cases, to filter out the anomalies. This leads us to recall again the advantages resulting from a planning of the observations which makes plentiful use of the differential method. On one hand, simultaneous measurements or rapid sampling through all passbands reduce the perturbations due to slow fluctuations of atmospheric transparency. On the other hand, the frequent use of comparison stars from an extended and varied list promotes the intercomparison of the observations and allows a monitoring, or even a filtering-out, of the very slow variations of atmospheric transparency.

5. PROCEDURES OF REDUCTION TO OUTSIDE THE ATMOSPHERE

It would not be useful to undertake in this context a detailed analysis of all the reduction methods described in the literature. They are as varied as they are numerous in the details of their applications. The common basis of most of them is the Bouguer line which allows the evaluation of the magnitude outside the atmosphere m_o, and of the atmospheric extinction coefficient k, if several observations m_{zi} of the same star are made at different air-masses F_{zi}. A linear regression determined by least squares is applied to the relation

$$m_{zi} = m_o + k\, F_{zi}$$

One must insist on the fact that this model is rather unrealistic since it assumes that three hypotheses are satisfied: constancy of the star, stability of the response of the photometer, constancy and isotropy of the atmospheric extinction during the whole period of acquisition of the observations (5 to 7 hours). One can, in practice, hope to select a stable star.

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The photometer must be able to satisfy the desired requirements of stability; the third hypothesis, however, only has a chance of being satisfied accidentally. Nikonov (1952) and Young & Irvine (1967) have proposed methods which account for variability of the extinction. Rufener (1964) adopts a less restrictive form of the third hypothesis: the extinction can be slowly variable but it remains isotropic during the whole period of acquisition of the measurements. By grouping into quasi-simultaneous pairs the measurements of an ascending extinction star (M) with those of a descending one (D), it is possible to calculate for these stars their magnitudes outside the atmosphere and to obtain the instantaneous extinction at the time of each observation. The remaining measurements of the night are then reduced by interpolation. This method, called M + D, has been applied in the Geneva photometry for twenty years each time extinction was measured. This more realistic model allows a better understanding of the observations and explains the sometimes misleading results obtained through the use of the oversimplified Bouguer method. Figure 2 shows these effects in the frequently encountered case of a slow decrease of extinction during the night. When we do not wish to devote the necessary time to measure extinction by the M + D method, we use mean extinction coefficients. A planning of observations, which imposes a small dispersion of air masses around a predetermined value for the night (the so-called constant air mass night), allows an evaluation of the necessary corrections due to drifts of extinction to be made by readjusting the zero point with the help of a sufficient number of comparison stars. The reduction to outside the atmosphere is complicated by the effects due to the width of the passbands. The color of the star and the air mass along the line of sight modify the effective wavelength and consequently also the actual extinction coefficient. Among the number of solutions proposed to take this effect into account, the best approach is that of King (1952). Put into practice by Rufener (1964) it leads to a development into a series centered on the mean wavelength (λ_o) of the passband. A magnitude outside the atmosphere is then expressed by

$$m_o = m_z - F_z[k(\lambda_o) + \alpha + \beta C + \gamma F_z]$$

α, β and γ are coefficients which can be calculated as soon as one has a good knowledge of the profiles of the passbands and of the mean extinction. C is a color index which describes the energy distribution of the star. This way of proceeding thus distinguishes itself from the method which consists in introducing an extinction $k_1 + k_2 C$, whose coefficients k_1 and k_2 are determined empirically. We see that for evaluating atmospheric extinction as well as for compensating the effects due to the width of the passbands, we may choose between more or less perfect methods which are nothing but more or less accurate models of reality. It seems important to me to conserve for a given photometric system the method adopted by its initiators. Thus, if that procedure causes systematic errors, these would at least not become randomized by the choices of subsequent observers.

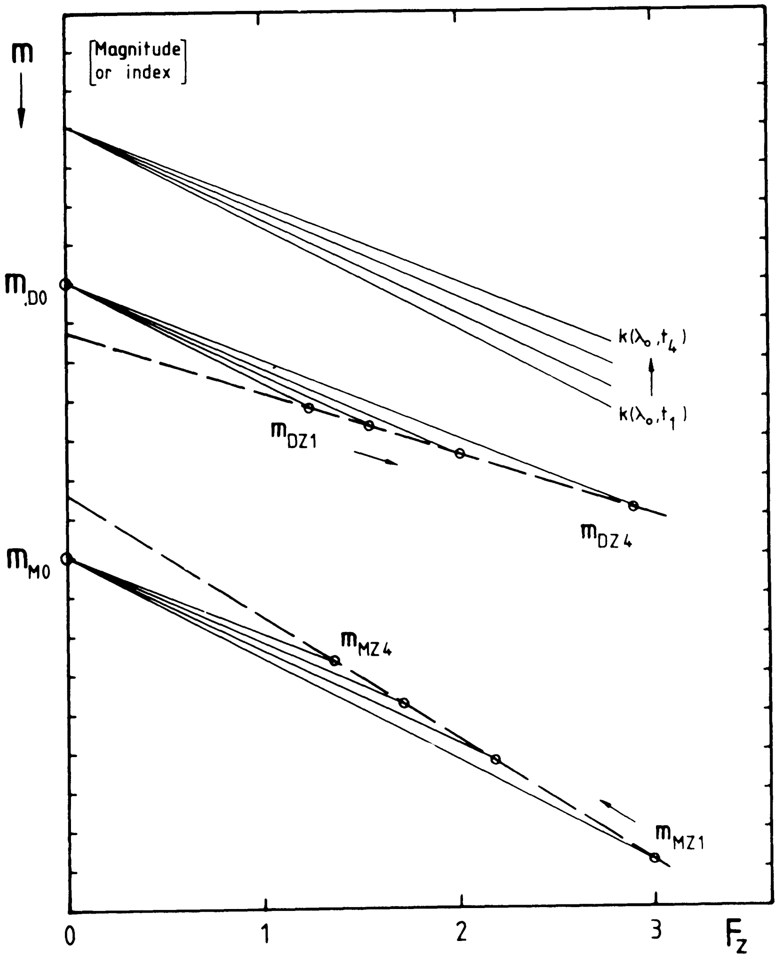

Fig. 2

Simulation of a night with variable extinction. The adopted decreasing values (0.260, 0.240, 0.220, 0.200) of the instantaneous extinction coefficient are shown at the top of the figure. The m_{Mo} and m_{Do} correspond to the true values outside the atmosphere of the stars M and D (these can be unknown). The real observations made at the times t_i would be close to the synthetic values m_{MZi} and m_{DZi} represented here by open circles. The two Bouguer lines which one would be tempted to adopt are represented by the broken lines. The M + D method described in the text allows one to determine the values m_{MO} and m_{Do} and the i values $k(\lambda_o, t_i)$. Tick marks of the ordinate scale correspond to 0.1 mag.

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6. CORRELATION OF THE OBSERVATIONS WITH A STANDARD

In the best case, where the natural system is close to the standard one, we confirm that a linear transformation is sufficient to transform the observations of any given night into standardized measurements. Let C^s_{1-2} and C^n_{1-2} be a color index in the standard and natural system, respectively.

$$C^s_{1-2} = aC^n_{1-2} + b$$

Rufener (1968) has formulated the approximations to the coefficients

$$a = \varepsilon\left(1+\frac{\Delta\lambda}{\lambda_2-\lambda_1}\right) = \frac{\lambda_2\lambda_1}{\lambda^s_2\lambda^s_1}\;\frac{(\lambda^s_2-\lambda^s_1)}{(\lambda_2-\lambda_1)}$$

with λ_2, λ_1 the mean wavelengths of the natural system

λ^s_2, λ^s_1 the mean wavelengths of the standard system

$$\Delta\lambda = (\lambda^s_2 - \lambda^s_1) - (\lambda_2 - \lambda_1)$$

$$\varepsilon = \frac{\lambda_1\lambda_2}{\lambda^s_1\lambda^s_2}$$

$$b = \Delta\Phi_{1-2}+(\Phi_1-\Phi_2)\left[1-\varepsilon-\frac{\Delta\lambda}{\lambda_2-\lambda_1}\right] - \Delta k_{1-2}\bar{F}_z\cdot\varepsilon\left(1+\frac{\Delta\lambda}{\lambda_2-\lambda_1}\right)$$

$$\cong \Delta\Phi_{1-2} - \Delta k_{1-2}\cdot\bar{F}_z$$

with Φ_1, Φ_2 the magnitudes of the passbands of the natural system $\Phi = -2.5 \log \int \phi(\lambda)d\lambda$

and $\Delta\Phi_{1-2} = (\Phi^s_1-\Phi^s_2) - (\Phi_1-\Phi_2)$ the difference between the passbands of the standard and the natural system.

We notice that the coefficient "a" only depends on changes of mean wavelengths between the standard and natural systems. The term "b" is more complicated; it represents the zero point of the transformation. The main term reflects the change in magnitude of the passbands while the second term involves the error in the extinction coefficient used (Δk_{1-2}). The factor $\bar{F}_z$ expresses the mean air mass used during the observations of the given night. We see here the advantage of a limited dispersion of the individual values of F_z if it is our aim to estimate the term Δk_{1-2} and to monitor its evolution during the night.

The influence of changes in the wavelength is of the second order for this term b. In the unfavorable case where the natural and standard systems differ seriously, the transformation is no longer linear; moreover, it is no longer unique. Stars reddened or not by interstellar matter, evolved to different degrees, of various chemical compositions, etc.... would each have to be treated by different transformations; by overstatement, the relation between the natural system and the standard system becomes in a certain sense a photometric diagram. There is no good solution in this case; Young (1974c) who examined a few approaches was not able to draw a conclusion.

7. NETWORKS OF COMPARISON AND STANDARD STARS

We must first explain the distinction implied by this title. In view of applying the principle of differential measurement as conveniently as possible, the photometrist must have at his disposal a collection of comparison stars. These must be in sufficient number, well distributed over the sky, present a good spread in V magnitudes, easy to identify, without troublesome neighboring stars. They have to be thoroughly intercompared so that the probability of finding a variable among them, even of small amplitude, is practically zero. On the other hand, this same photometrist needs a network of standard stars. These must cover the whole HR diagram, the whole range of reddening by interstellar matter and all populations. They should be measured from the origin of the system onwards, and thus be able to guarantee the conservation of the system. Here also, convenience of use requires a distribution over the whole sky and a strong intercomparison. In practice, the same stars could serve as comparison and standard stars. We must note however that in the case of the comparison stars we would be tempted to eliminate all microvariables (supergiants, CP stars, extremely red stars etc....). This choice would not be desirable from the point of view of the standard stars which have to represent all types. When we establish these collections, we can distinguish between the standardization of the colors (indices) and of the magnitude (V) by using different weightings. One common but risky practice has to be avoided, namely that of choosing for the one or other purpose stars from a compilation catalog. It is truly necessary to use stars chosen in lists of primary or secondary standards and, as a last resort, stars which have been at least strongly intercompared and measured frequently.

8. GLOBAL TREATMENT

Several authors have proposed a global treatment of the reduction to outside the atmosphere and of the correlation with a standard. This attitude is the result of the desire to make better use of all the available elements of information with the help offered by computers.

Harris et al. (1981), Popper (1982) and Manfroid and Heck (1983, 1984) have contributed with insight to present this new orientation, with all its advantages and drawbacks. As Popper (1982) points out, the benefit lies less in the mixing of both problems but rather in the better use made of the constancy of certain parameters during several nights of a same series, thereby often allowing to improve their estimate. Let us note, however, that this type of treatment will not be better than is allowed by the model chosen for the interpretation. There is the danger that a global solution will lead the observer to increasingly neglect the strictness of the planning of his observations for each night. The above authors do stress, however, the importance of the latter. The use of a more complicated model, which takes into account the variation of extinction during the night, could also be incorporated into the global treatment. The optimization by least squares of the adopted model may render more difficult the separation of extinction anomalies from variations of the natural system due to accidental circumstances which it is important to recognize. In Geneva we treat both problems consecutively; to maintain homogeneity, we do not intend to unify the treatment. My lack of experience does not allow me to judge the extent of a possible gain that might be achieved.

9. DESCRIPTION OF THE PASSBANDS

This question presents at least two aspects. First, the physical definition of the photometric system which usually figures in the first publications describing it. This technical aspect is important as soon as the question of reproducing the system arises. Of greater importance for the user is the exact description of the passbands which characterize the standard system. One may choose for example to present, as a function of wavelength with steps of maybe 25 to 50 Å, the response of each passband to an equienergetic flux expressed in units proportional to photons per second. It is difficult to calibrate this description by direct measurements with a primary spectrophotometric standard. We should at least dispose of an indirect calibration so that by filtering the spectrophotometric distributions of stars considered as secondary standards we reproduce, by numerical integration, the corresponding indices in the system considered. For some systems it will be necessary to apply, before the comparison is made, a normalization fixed at the origin of these systems. The calibration of the passbands will then depend on the absolute reference calibration adopted for the spectrophotometric distributions of the secondary calibration stars. D.S. Hayes will certainly discuss this question during this symposium (Hayes 1985). It would be desirable for these stellar standards to have a continuous spectrophotometric description from 3000 to 10,000 Å, including the effects of the lines. It would also be useful to dispose, among these secondary standards, of stars covering the whole HR diagram and, if possible, also strongly reddened ones as well as representatives with extreme chemical compositions.

Regarding data presently available we may mention Straižys & Sviderskienė (1972) and more recently Glushneva (1982) and Gunn & Stryker (1983). The type of approach briefly described above has been made in particular by Hayes (1975) and by Buser (1978). A variant which allows to optimize this calibration procedure by distinguishing the optical response of each passband from the electrical response of the detector has been proposed and applied by Rufener & Maeder (1971) to the passbands of the Geneva photometry.

As soon as an adequate description of the passbands has been realized by means of a variety of secondary standards for which a consensus exists regarding their absolute calibration, numerous comparisons between stellar model atmospheres and observations can then be considered by confronting the synthetic photometry with the actual measurements. The reliability of the inferences made depends then obviously on the exactness of the description of the standard passbands.

10. CHOICE OF THE PARAMETER TO BE CALIBRATED

It is often a heuristic approach which leads to the selection of a photometric parameter P presenting a variation destined to be correlated to a given physical parameter x_c. Before calibrating this correlation it is preferable to check the "orthogonality" of the future parameter P, or at least to seek the best formulation, in view of obtaining the highest independence of P relatively to variations of the other physical quantities (x_i) of the star and of the interstellar medium. In other words, it is desirable to optimize the definition of the parameter P in such a manner that one obtains a maximum for $\partial P/\partial x_c$ and a minimum for $\partial P/\partial x_i$ for all $i \neq c$. This task is not trivial; it can be undertaken via a geometrical fine analysis of the n-dimensional hyperspace corresponding to the n independent color indices of a photometry. An interesting approach consists in selecting first as coordinates combinations of indices which are reddening-free but sensitive to intrinsic differences of the spectral energy distribution. In the Geneva photometry, for example, such a reddening-free space was used by Cramer and Maeder (1979) who defined three orthogonal parameters X, Y and Z which are correlated with the effective temperature, the surface gravity and the spectral peculiarity of B-type stars respectively. Such an analysis requires that the photometric system used has already been applied to the greatest possible variety of stars with distinct properties, so that this optimization can be validly carried out and verified.

We must recall here that the number of discernable independent parameters cannot exceed the number of passbands of the photometry; it is always smaller by one unit.

On the other hand, the number of physical quantities and evolutionary or random circumstances which can influence the spectral energy distribution is large; therefore a certain danger always exists in hastily applying a correlation with x_c which proves to be more or less parallel with one x_i, or with a combination of the latter.

We can be tempted to orient the choice of a photometric parameter in a prospective manner by using synthetic photometry applied to a set of spectrophotometric continua, or even to a grid of model atmospheres, filtered by the passbands. This procedure might seem alluring; it has however only rarely contributed to the perfecting of an optimized parameter. There is, among the criteria for choosing a parameter, what we may call its resolution or its sensitivity. This is an evaluation of the following type:

$$\Delta x_c = \frac{\partial x_c}{\partial P} \cdot 2\sigma_P$$

where σ_P is the standard deviation characteristic of the experimentally obtained parameter P.

11. DISTINCTION BETWEEN "OPEN" AND "CLOSED" CALIBRATIONS

The establishment of a calibration can be undertaken within extremely different contexts and lead to opposed practical choices. This will clearly influence the resulting performance. By schematizing extreme circumstances, I propose to confront two cases, the one defined as "open", the other as "closed". To the first belong the UBVRI and uvby,β photometries and to the latter correspond, for example, the Geneva photometry and probably also that of Walraven. We tabulate below the options which distinguish both orientations.

Nature and origin of the data	Circumstances for a calibration open	closed
multiband photometric system	Popular system, frequently copied. Great variety of natural systems	Stable experimental system, under single supervision
Acquisition of the observations	Heterogeneous procedures of measurement and reduction to outside the atmosphere	Complete homogeneity of the method of treatment
Available data	Compilation and means of results dispersed in the literature	One single source of compilation

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Origin of the physical reference parameters	Collection of estimates having met with a wide consensus	Possibly, physical parameters taken from a small number of primary standards
Form of the calibration	Mean standard correlation, tabulated and immediately accessible	More confidential calibration, requiring a complex critical analysis
Number of persons contributing to this condition	Often more than 100	Maybe less than 10
Performance	Rather rough possibilities of discrimination	Limit of discrimination finer by a factor 2 to 3. Could lead to the estimate of physical parameters without publication of the intermediary stages

We note, in the case of the Geneva photometry, the application by M. Grenon of the completely "closed" case with the elaboration of a series of algorithms to determine the T_{eff}, the absolute magnitude, the chemical composition (Fe/H) and consequently the photometric parallax of F, G, K, M-type stars. This calibration is applied to the individual measurements before they are averaged. The n estimates of the physical parameters corresponding to the n measurements, and their subsequent mean with its standard deviation, are shown to be more favorable for interpretation than the estimate based on the mean of the photometric measurements above. This way of analyzing the individual measurements is illustrated by the examples of Table I; it reveals the cases for which ambiguities are to be feared and also provides a concrete appreciation of the sensitivity attained.

12. CONCLUSIONS

To conclude, I would like to insist once again on the preliminary requirements which seem to me to be most important for the elaboration or use of photometric calibrations with a sufficiently high guarantee of security and resolution.

Insure the greatest experimental rigor to define the natural system, systematically maintain the procedures of reduction to outside the atmosphere and of correlation with a reliable and homogeneous standard.

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Insert the new measurements in an extended collection of reference stars for which a consensus exists, or will exist, regarding the values of the characteristic physical quantities.

Precise description of the standard passbands and of the possible normalizations (zero point) necessary for the observed color indices to correspond to the synthetic photometry of the best available spectrophotometric continua, which are themselves compared with the best absolute primary standards.

Checking of the degree of orthogonality of the chosen photometric parameters, together with a precise definition of the domain of application and possible resolution.

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TABLE I

No. HD	TS	m_V	B_2-V_1	T_{eff}	M_V	$\pi_{phot.}$	Fe/H
20 807	G2V	--	.365	5766	5.16	.095	- .21
		5.223	.357	5715	5.15	.097	- .24
		5.220	.365	5773	5.06	.093	- .12
discarded measure		5.217	.345	[5830	4.75	.081	.02]
		5.225	.359	5747	5.10	.094	- .19
		5.225	.358	5726	5.17	.098	- .26
		5.229	.354	5762	5.06	.092	- .19
		5.226	.359	5739	5.15	.097	- .24
		5.216	.356	5789	4.94	.088	- .08
		5.219	.353	5781	4.97	.089	- .12
mean parameters		5.223	.358	5755	5.08	.094	- .18
standard deviation		.004	.004	25	.08	.004	.06
99 492	K2V	7.564	.617	4847	6.28	.055	.41
		--	.608	4845	6.21	.052	.26
discarded measure		7.556	.630	[4651	6.59	.064	---]
		7.566	.610	4899	6.07	.050	.61
		7.573	.627	4850	6.32	.056	.48
		7.582	.613	4913	6.08	.050	.64
mean parameters		7.568	.618	4871	6.19	.053	.48
standard deviation		.010	.009	33	.11	.003	.16

DISCUSSION

ARDEBERG: I find your definition of closed and open photometric systems a quite provocative one. May I propose an equally provocative definition? An open photometric system is a system open to use by the astronomical community, whereas a closed system is one closed off from such use. I think that we should take care not to create systems bent into themselves but rather systems that can solve pending astrophysical problems. I suggest as the best approach to apply, using your terminology, open systems with reduction methods as closed as possible.

RUFENER: I agree with your last sentence. The distinction proposed between open and closed calibration processes underlies two alternative approaches which I hope can be complimentary in their usefulness.

PAPOULAR: Our experience in near- and mid-infrared photometry closely confirms the statement by Dr. Rufener to the effect that good photometry requires differential measurements and intercomparisons between program star, standard star and sky to be made at a high rate and with small integration times. Now, photometers in big observatories are usually under the responsibility of the staff. Would it not be worthwhile, therefore, for IAU officials to help us induce these members of the staff into modifying their acquisition procedures in the directions suggested above?

RUFENER: Often it is difficult to transform existing equipment. We can hope that new photometers will permit such practices.