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Improved Photometric Accuracy and the Creation of an All-sky High-Accuracy Stellar Standard System

Aleksey Mironov, Andrey Zakharov and Anna Ambartsumyan

Sternberg Astronomical institute, Moscow, Russia

Abstract. Some astrophotometry problems require accuracy within $0^{m}_{.}001$–$0^{m}_{.}003$ mag, both in the random and systematic sense. Many research teams are planning now to carry out new sky surveys. These surveys will be made in different photometric systems and each photometric system will need its own standards. Thus, the main problem of photometric standardization becomes a task to construct the fundamental photometric catalog. Magnitudes of stars in the catalog have to be easily transformed to any specified photometric system without sacrifice of accuracy.

1. Introduction

The successful HIPPARCOS experiment and the GAIA project in preparation urge that a higher accuracy of photometric and spectrophotometric measurements is to be achieved. Many tasks currently require high accuracy of photometric measurements. For example, *i.*) There exists a problem of approaching microarcsecond astrometric accuracy. As optical aberrations depend on the wavelength of light, it is directly and closely connected with the task of accurately measuring stellar magnitudes and color indices. *ii.*) Investigation of variable light fluxes from stars often needs very accurate photometry – for instance when searching for extrasolar planets. *iii.*) A reliable transformation between different photometric systems demands precise and accurate measurements too.

All these and other problems require accuracies within $0^{m}_{.}001$–$0^{m}_{.}003$, both in the random and systematic sense. The aim of modern stellar photometry is that it must turn from practical astrophysics to astronomical metrology, as this has been the case in astrometry for a long time already.

Today many research teams are planning to carry out a number of sky surveys. No doubt, at least 10 to 20 large ground-based and space surveys will be held in the near decades aimed at different goals. It is clear that the surveys will be made in different photometric systems. Undoubtedly, the necessity will arise to compare the data to each other to assess both random and systematic errors. Each photometric system will need its own standards. Thus a new task arises to create an all-sky standard system, which can support any photometric system, and be suitable for any photometric band. Obviously, perfect standards are a set of stars for which an accurate spectral energy distribution at necessary spectral range is available. For such standards, one can easily calculate magnitudes in any band. Such a set of data could be a basis for any photometric band. We call such a set a photometric reference frame.

To have a possibility to tie some photometric measurement to reference stars at any time, the number of standards must range from one hundred thousand to one million stars in both hemispheres, from the brightest to, for instance, 15th magnitude. It is impossible to obtain so many high accuracy spectra. But we can approach this ideal under an additional condition. One may select only stars with "typical spectral energy distributions as standards; then the energy distribution can be reconstructed from photometric measurements in several broad photometric bands.

Astrophotometry always deals with comparing light fluxes from two sources in an instrumental photometric system defined by the response curves of the instrument together with variable transmission function of the Earth atmosphere. Thus, the observations are always made in different photometric bands and the obtained results are to be transformed into a uniform system defined by established response curves and zero-points.

Thus, the main problem of photometric standardization becomes a task of constructing the special star catalog. Magnitudes of stars in the catalog may be easily transformed to any specified photometric system without sacrifice of accuracy. By analogy with the term from astrometry, such a catalog may be called a fundamental photometric catalog. Strictly speaking, nowadays *there are no fundamental catalogs at all.*

One must use the reference system in the following way. After measuring a few standards from the fundamental catalog, you derive the transformation function. Using this transformation to complete reference standard catalog, you get several hundred thousands of high accuracy standards, in your own photometric system, for the complete sky.

2. The Construction of a Fundamental Photometric Catalog

A fundamental photometric catalog must be constructed by careful comparison of data from many individual catalogs. In this comparison one must reveal and correct systematic errors.

In practice the standard photometric reference frame is understood as a set of *models, agreements* and *prescriptions* which are used to obtain from observations, at any time, photometric properties of the detecting equipment, the Earth atmosphere transmission parameters, and magnitudes of program stars in established photometric bands. Such a standard photometric reference system must meet the following requirements:

1. The system has to be stable. It is necessary to verify stability of parameters for all stars from the fundamental catalog. Their possible brightness variations and spectral changes are to be thoroughly studied.

2. The system should be easy to use. For this purpose a rather dense network of standards all over the sky has to be created. Theoretically, a number of reference objects should reach 1–6 millions. Thus, while using a large ground-based telescope with a field of view of typically 10×10 arc minutes, would normally contain 1–4 reference objects.

3. The system should contain standards in different ranges of stellar magnitudes. The brightest standard stars are to be studied according to a special

program. The magnitudes of standard stars from different ranges should be well coordinated to each other. Most standard stars of the system may belong to the range 9th–14th stellar magnitudes. The system should contain also some stars of magnitude 15 to 20.

4. The system should maintain high precision. The precision of individual ground-based magnitude measurements is considered to be $0\overset{\mathrm{m}}{.}01$ (normal observational precision). The standards of the reference system should be measured with an accuracy 3–10 times better.

5. The system should be free from systematic errors. From the systematic point of view, the accuracy of reference standards should be independent of their position in the sky, brightness, color and other parameters.

The standard stars have to meet the following requirements: *i*) their magnitudes have to be constant within $0\overset{\mathrm{m}}{.}001$–$0\overset{\mathrm{m}}{.}003$; and *ii*) the spectral energy distributions of the standard stars should provide simple and non-ambiguous magnitude transformation from an instrumental photometric system into the standard one and vice versa, as well as from the standard system to any other photometric system; the mean error of such transformations should be less than $0\overset{\mathrm{m}}{.}001$–$0\overset{\mathrm{m}}{.}003$. In particular, binary and multiple stars have to be excluded.

To implement the system, the following models and parameters should be defined and approved: *i*) a set of response curves of extra-atmospheric photometric bands; *ii*) the models for atmospheric extinction; and *ii*) a set of energy distributions in the spectra of standard stars from the fundamental catalog. Moreover, the following techniques should be defined and approved: *i*) a technique to accurately determine atmospheric extinction; *ii*) a technique for magnitude transformations between the systems; and *iii*) a technique for checking response curves using observations of standard stars in recommended bands.

Only a combination of all these conditions can lead to the creation of a reference system of photometric standards which would meet modern requirements in accuracy. To construct a fundamental photometric catalog, hard work of many astronomical observatories is obviously needed.

This work can be carried out in several steps. First, preliminary models and techniques should be established. In doing so, the experience of creating the Tien-Shan catalog of bright stars can be taken into account.

At the same time, magnitudes of those stars which are common to various catalogs are to be compared. First of all, the magnitudes should be compared which are included in such catalogs as HIPPARCOS and TYCHO, the $WBVR$ Tien-Shan Catalog, the Vilnius Catalog, the UBV, VRI Catalogs, 2MASS, SDSS and some others. On the basis of these comparisons, candidate stars are to be selected for the fundamental catalog. It should be emphasized that to carry out such comparisons and analyses one needs to have not only published averaged magnitudes, but also individual estimates. Otherwise, variability of stars could hardly be estimated. To carry out the corresponding research, appropriate databases and techniques should be made accessible.

At the first steps of working out the list of reference standard stars, not so many objects can be selected, for instance 100,000 objects. It is worth mentioning that comparisons of magnitudes from the $WBVR$ Tien-Shan Catalog and

HIPPARCOS and TYCHO Catalogs have already been carried out at Sternberg Institute 5 years ago. As a result, approximately 6,000–8,000 candidate stars have been selected for the fundamental catalog. After comparing them to other databases, these stars can be considered the basis of a reference system of standards among the northern bright stars.

Selecting candidates for reference standards in fainter magnitude ranges is a much more complicated task because we do not have any photometric survey of 9–14th mag stars with the required accuracy. To solve the task, a space survey like earlier planned FAME and DIVA projects would be desirable. Ground-based surveys will be useful (SDSS, 2MASS, etc.) too. At the next steps of the work at the observatories involved, observations have to be carried out aimed at independent measurements of magnitudes in recommended photometric bands.

Considerable organizing effort of IAU Commissions, especially of IAU Commission 25, would be indispensable. In particular, they might *i.)* expertize and approve the recommended lists of stars, models and techniques; *ii.)* recommend lists of stars for observations, which were chosen as candidates for the reference standards; *ii.)* prepare drafts of corresponding IAU resolutions.

Aleksey Mironov