The study of the influence of interstellar extinction laws on the parameters of photometric system using astrophysical observations taken at EAO

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Abstract. In this work, connections between UBV (PSC UBV) photometric systems for various laws of interstellar extinction are calculated on the basis of digital database on astrophysical observations of Engelhardt astronomical observatory (EAO) and using the specialized software package for analyzing brightness characteristics. The following results are obtained: 1) when using various laws of interstellar extinction, the value of difference in the position of reaction curves is proportional to the difference between UBV dependencies and color indices; 2) the positions of reaction curves and connection curves between UBV and color indices are influenced by spectral characteristics of the filters used in observations; 3) the same applies to the transformation of stellar magnitudes from one standard system to another, as response curves as a rule significantly differ; 4) another conclusion is that for any separate model of interstellar extinction the differences in color between photometric systems do not depend on spectral and luminosity classes.

1. Introduction

It is well known that currently there are no photometric receivers capable of detecting the radiation in all possible wavelength ranges [1]. The reliability of the observations is also influenced by extinction when light propagates through interstellar environment [2]. Extinction is found to be significant in the direction of the center of our galaxy [3]. Light from the stars located inside or behind dense gas clouds and nebulae is strongly extinct [4]. The key role in light extinction plays dust (in second place is absorption in hydrogen lines) [5]. When investigating interstellar extinction, 2 problems have always been stated. The first problem is the extinction map construction. The second problem is the determination of a general extinction law in a rather large area but at the same time – accurate and detailed for many wavelengths. The solution of such a problem is essential for studying interstellar dust properties. As interstellar extinction in the blue part of the electromagnetic spectrum is greater than in the red one, it leads to reddening of light sources [6]. By comparing color indices of reddened and non-reddened stars of the same spectral and luminosity classes one finds the so-called color excess of a star. Depending on the part of the spectrum covered by the spectral sensitivity curve of a radiation receiver, one distinguishes various photometric systems for stellar magnitudes. 3-band photometric system UBV [7] is the most common. In any place in the space there is a substance that traps or
dissipates the light. Electing and analyzing stars that turn to red affected by frequency of the light shattered make it possible to study interstellar extinction by comparing star’s color levels. Before the twenty first century, the interstellar extinction was known as low noise [8]. The analysis of the interstellar extinction principles is shown in [9]. Previously it was thought that the impact of the interstellar extinction should be considered only in the region of density of the interstellar surroundings next to the area of the galaxy. It was believed as well that most of the material is held in stars. Based on the templates of the galaxy [10, 11], density of the interstellar surroundings nearby the Sun is 0.05MQ/pc³ (47%), for the interstellar matter it is 0.043–0.049MQ/pc³ (44%), and for the dark matter it is 0.01MQ/pc³ (9%) [8]. According to [12], it is 0.041MQ/pc³ (42.3%), 0.043MQ/pc³ (44.3%), and 0.013MQ/pc³ (13.4%). Nonetheless, the new observations at remote location from the Sun and in other spectral levels point to many options of the properties of the interstellar dust [13]. Therefore, in spite of the growth of spectroscopic observations of stars, photo- and astrometric observations will always be important regarding to the number of stars observed. Development of the all-sky catalogues Tycho-2, SuperCOSMOS, 2MASS, UCAC4, XPM, and the others gives the precise photography and astrometry for millions of stars (SDSS, DENIS) conducts with exploration of photometric systems [8]. The current studies of the celestial sphere in the spectrum varies from X-ray to radio are examples of studying the design of our galaxy. For a more accurate exploring of the galaxy, it takes some photometric systems and transformation algorithms among them. Some of the most widely used are SDSS (Sloan Digital Sky Survey), 2MASS (Two Micron All-Sky Survey), and WISE (Wide-field Infrared Survey Explorer). All of the above-mentioned make it possible to categorize objects by color spectrum [14].

A wide variety of articles analyze procedures and methods of these surveys from the original photometric system to the instrumental one. A very comprehensive review on the basic stellar photometric systems is given in [15]. A big breakthrough in the elaboration of systems like this took place after the Hipparcos/Tycho catalogues based on space monitoring and ground-based measurements (such as 2MASS) had emerged. The author comes to a conclusion that in the prospective photometric characteristics for the majority of the astronomic objects will be kept at digital databases of Virtual Observatories. In [16], the latest methodology for photometric sizing of astronomical pictures is discussed. With this technique, the assessment of a photometric system relies on the establishing of spectral features of the digital camera and color filters applied. This technique is allowing to produce stars’ calibrated light graph in various color levels. For the calibration of photometric systems one usually applies Vega system in which the A0 V Vega (Lyr) star is taken as the zero point of stellar magnitude in all spectral bands. For AB (ABSolute) system the calibrating zero-point matches Vega’s radiation density at the efficient wavelength of Johnson V (550 nm) [17]. It is worth noting the WISE (Wide-field Infrared Survey Explorer) mission [18] intended at digital picturing of the entire celestial sphere at frequencies 3.4, 4.6, 12, and 22 μm (W1, W2, W3, and W4) as well. Eventually, digital WISE Catalogue and Atlas including the database on astrometry and photometry for a half a billion celestial objects were developed.

However, there are no photometric receivers that are able to record the radiation in all the potential levels of wavelength. The credibility of observations also depends on the light extinction when coming through the interstellar conditions. In addition, it may be recalled that near the center of our galaxy the extinction is really high [8]. The light emitted by stars positioned inside or behind thick gas clouds or nebulosity is absorbed substantially [19]. The dust plays significant role in light extinction (on a small scale – hydrogen line absorption). When studying the interstellar extinction, there has always been a serious concern about two issues. The first issue is the composition of extinction map. The second issue is how to define a regular extinction law in a sufficiently big field for many variations of wavelength very precisely. The answer to this question is crucial for learning about the characteristics of interstellar dust. As interstellar extinction in the blue section of the visible level is greater than in the red one, which causes light rays to turn red. By measuring color levels of reddened and unreddened stars of the similar spectral and luminosity class one generates a so-called color overflow for a star. In accordance with ranges of the spectrum covered by spectral sensitivity line of a radiation
receiving device, one identifies several photometric forms for stellar magnitude. The UBV photometric system is the most often applied [17].

At the moment, there are studies where the influence of the UBV photometric system on rules of interstellar extinction has been shown. In article [20], from the satellite database and UBV photometry it was found that the graph of the main interstellar extinction for OB stars and the one of the average galactic extinction are very similar. However, the studies of relationship of interstellar extinction graph and polarization monitoring demonstrate that the modeling of the dimensional structure of interstellar magnetic fields by the use of the polarimetric method and UBV observations is possible [21]. However, the creators of the “extinction without standards” method [22] demonstrate that under certain circumstances one might generate more credible assessment of the results instability and improve the precision of the extinction curves, examine the extinction curves and its structure in local regions, and analyze the extinction in stellar consolidations including stars ranging from mid to late.

In spite of the great achievements in investigating the interstellar area, the primary problem of determining the influence of the UBV system on rules of interstellar extinction are still an open question. In this article, the research like this is performed by analyzing UBV measurement of basic and chosen regions included in the digital library of EAO. The UBV astronomical plates produced by the use of a telescope at EAO are applied in this research.

2. Methodology of identifying the correlation in a photometric system and a rule of interstellar extinction

The operation of adjustment instrumental stellar dimensions to the typical system is performed by monitoring basic stars with recognized stellar intensities and structuring the relation of the distinction between instrumental and typical stellar scales of color levels [17]. This relation is taken later to convert stellar dimensions of stars that belong to the region examined to the basic system. It is expected as well that rules of interstellar extinction for the region examined are similar the ones of the basic system, however, the radiation of stars of the examined region at various positions are subjected to particular extinctions whose rules are uncertain. The paper [23] proposes formulas for the conversion from various photometric systems to the Johnson’s UBV system. It is shown that for the conversion of two specified typical photometric systems, the non-linear transformation could be applied. The rules of interstellar extinction for various parts of the interstellar space are clearly distinct. And therefore, it is hard to create a photometric system, where the responding curves could be absolutely similar to those of the typical system.

If we regard particular components of the interstellar substance as something like “filter” with different sampling extinction, it is necessary to figure out how the conversion of the “filter” influences the relationships between various photometric systems. To establish the correlation between photometric system and rules of interstellar extinction, we determined the connection of the Schmidt telescope’s [24] UBV system and 5 different rules of interstellar extinction.

The computation was carried out by tabular integration of energy distribution graphs \(I(\lambda)\), response graphs of the system \(\varphi(\lambda)\), and starlight transportation made by interstellar substance \(\tau(\lambda)\) according to the expression:

\[
m_{UBV} - m_{ubv} = -2.5 \log \frac{\int I(\lambda) \varphi_{UBV}(\lambda) \tau^x(\lambda) d\lambda}{\int I(\lambda) \varphi_{ubv}(\lambda) \tau^x(\lambda) d\lambda} + \text{cont},
\]

where \(m_{UBV}\) and \(m_{ubv}\) are magnitudes in the system of UBV and of telescope. \(\tau^x(\lambda)\) – starlight transportation by dust particles \(x\). The interstellar extinction for astronomical bodies characterized by different spectral classes is unequal, when the radiation goes through the same interstellar substance. We may therefore conclude, the difference in magnitudes dependence on dust particles in the heterochromous case is not linear.

The response graphs for systems under consideration are shown in figure 1.
3. Interstellar extinction simulation

First of all, we needed to define the starlight transportation by a single portion of interstellar substance for abnormal rules of interstellar extinction (Table 1, № 2–5). To determine \( \tau(\lambda) \), color excess relations were applied. The full extinction could be calculated as:

\[
A_m = (R - \frac{E_{V-m}}{E_{B-V}})E_{B-V}.
\]  

When performing the calculations, we applied energy distribution for stars with spectral classes ranging from 0 to M2, luminosity classes I, III, V, and interstellar extinction rules given in Table 1.

| №  | Laws of interstellar extinction | R   | X   | Reference |
|----|---------------------------------|-----|-----|-----------|
| 1  | Whitford                        | 3.2 | 0.72| [17]      |
| 2  | σ Sco                           | 3.8 | 0.62| [25]      |
| 3  | Orion Nebula Region             | 4.8 | 0.82| [6]       |
| 4  | NGC 2244                        | 5.9 | 0.69| [7]       |
| 5  | Cygnus and Orion                | 7.2 | 0.76| [26]      |

Table 1 also contains the values characterizing interstellar extinction rule:

\[
R = \frac{A_V}{E_{B-V}},
\]  

\[
X = \frac{E_{U-B}}{E_{B-V}}
\]

where \( A_V \) is the full radiation extinction in the V band. The coefficient \( R \) is necessary for the transformation from color excess to the absolute magnitude of extinction. The color excess of a star \( E_{B-V} \) is \( A_B - A_V = 1.086(\tau(B) - \tau(V)) \) given in magnitude of a star.

Taking into account the fact that both heterochromatic and monochromatic extinctions in the efficient range of wavelength are equal, a smooth line may be plotted by the corresponding points \( (A_m, \lambda_e) \), where \( \lambda_e \) is the effective wavelength related to the spike of the spectrum. From this graph for the
effective wavelengths related to the values of V and I in the 6-color system by [27] were produced the ones of the full extinctions $A_V - A_I$. The difference $A_V - A_I$ gives the value of color excess $E_{B-I}$, which corresponds to the observed amount of interstellar substance X.

The response graphs for the systems under consideration are shown in figure 1. When performing calculation procedures, we applied stars’ energy distribution for spectral classes ranging from 0 to M2 and luminosity classes I, III, V as well as rules of interstellar extinction given in Table 1. Table 1 also contains parameters responsible for the rules of interstellar extinction:

$$K(\lambda) = \frac{A_m}{1.088x}$$  \hspace{1cm} (5)

The light transportation by a separate portion of interstellar substance is expressed as

$$\tau(\lambda) = e^{-K(\lambda)}.$$  \hspace{1cm} (6)

A criterion for evaluating the accuracy at plotting the graph of the correlation of full extinction and efficient ranges of wavelength is closeness of the calculated and measured color excesses for the amount of the interstellar substance under consideration.

4. Results and Discussion

Finally, we may summarize:

I) When applying various rules of interstellar extinction, the difference in the location of the responding curves is directly proportionate to the distinction of the correlation of UBV on color levels.

II) The spectral variations of the filters have a special influence on the location of the responding graphs and the connection curves between UBV and color levels. As much is true for the transformation of stellar magnitudes from one typical system to another, for responding graphs are not equal.

III) For a single sample of interstellar extinction, the distinction in colors between photometric systems is completely independent of spectral and luminosity class.

The new technique as well as the produced results will allow for the new form of analyzing the interstellar extinction characteristics with the use of astronomical photoplates produced at other telescopes of Engelhardt astronomical observatory. The authors are also currently working on a possibility of using the up-to-date catalogues, including WISE, 2MASS, and SDSS, in the data reduction and performing a comparative analysis of the influence of various photometric characteristics on revealing relations between the original and instrumental photometric systems.

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