STUDY OF INTERSTELLAR EXTINCTION IN THE GALAXY USING LARGE PHOTOMETRIC DATA BASES *

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The results of the study of variations of the interstellar extinction law in the visible to near infrared in the Milky Way band between galactic latitudes from $-20°$ to $+20°$ are presented. It is shown that a ratio of total-to-selective extinction, $R_V = A_V/E_{B-V}$, varies roughly proportionally to the density of obscuring interstellar clouds. It is found that frequency distribution of the ratios R_V is trimodal with peaks at 2.42, 2.81, and 3.14.

Keywords: interstellar extinction, Milky Way galaxy, stellar photometry

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1. Introduction

One of the main sources of information about interstellar dust is the spectral dependence of extinction of a certain interstellar cloud or the so-called interstellar extinction law (ISEL). Knowledge of the ISEL is important not only for the study of physical properties and origin of interstellar dust but also for correct evaluation of the amount of interstellar extinction in the direction of objects obscured by interstellar matter or for recovering their intrinsic spectrophotometric characteristics. Uncertainties or systematic variations of the ISEL may predetermine conclusions based on the data of heavily reddened objects, such as photometric distances, identification of physical groups of stars in colour–colour diagrams, and the age determination of clusters.

Numerous investigations have shown that the ISEL varies from one line of sight to another (see, e. g., Draine [1] and Whittet [2], and references therein). However, the general form of the extinction curve and its features remain the same for many investigated regions of the Milky Way. This fact has been successfully explored by Cardelli et al. [3] who have found that the extinction curve can well be parameterized with a few parameters and that variations of the ISEL can be characterized by one parameter, the ratio of total-to-selective extinction, $R_V = A_V/E_{B-V}$. The ISEL for diffuse interstellar medium may well be described by a

curve with $R_V = 3.1$, while variations of R_V are in the range of 2.2–5.5 [1]. It should be noted that R_V can also be treated as a rough indicator of interstellar dust grain size: regions with lower R_V have smaller grains, while regions with higher R_V have larger grains. In addition, many authors have determined that the ISEL in the near infrared (NIR, 1 μm $< \lambda < 5$ μm) is invariant and that extinction curve in this region may well be represented by a power law, $A_\lambda \sim \lambda^{-\beta}$, where $\beta = 1.8$ according to Martin & Whittet [4]. This value of β implies that the colour excess ratio $E_{J-H}/E_{H-K} = 1.8$. Some authors, however, report that this ratio ranges from 1.3 to 2.1 for different regions of the Milky Way (see, e. g., [5–9]). There is no definite answer whether these differences arise from differing properties of interstellar dust, or from inhomogeneous photometric data.

It is important to note that many investigations of the ISEL in the NIR made up to the end of the 20th century were based on photometry of a comparatively small number of stars carried out in slightly differing photometric systems. This could lead to false conclusions about differences or similarities of the ISEL in different regions of the Milky Way. Fortunately, with the beginning of the 21st century a number of new global photometric surveys in the IR emerged. Advantages of large surveys compared with small data sets obtained using different photometric systems and applying different methods are evident. They cover large areas of the sky and their data are more homogeneous

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than those selected from a variety of small catalogues. Such surveys coupled with homogeneous BV photometry enable researchers to carry out more precise and thorough investigations and to draw more coherent picture of variations of the ISEL in the galaxy.

The aim of the present work was to investigate possible variations of the ISEL in the whole Milky Way on the basis of 2MASS survey [10] and Tycho-2 photometry [11]. It is the extension of our previous work [12]. Present work is based on larger number of stars and includes higher galactic latitudes.

2. The data

Our investigation embraced the whole Milky Way between galactic latitudes $-20° < b < 20°$ since it was not expected to find many reddened stars at higher galactic latitudes. Analysis of variations of the ISEL is based on the colour difference method. For that purpose we compiled a catalogue of B_T, V_T, J, H, and K magnitudes of stars with known spectral types. Magnitudes B_T and V_T (mean wavelengths 0.42 and 0.52 μm, respectively) were taken from Tycho-2 catalogue [11], while magnitudes J, H, and K (mean wavelengths 1.24, 1.66, and 2.16 μm, respectively) from the catalogue 2MASS [10]. Sources of spectral types of stars were compilations of Wright et al. [13], Kharchenko [14], and Skiff [15]. We selected stars that were located in the Milky Way between galactic latitudes $-20° < b < 20°$ and that were "normal" in their spectral class, the latter being in the range from O to G7. Stars excluded from further analysis were as follows:

- Stars with observational errors in colour indices $B_T - V_T$ larger than 0.05 mag or with negative colour excesses.
- Stars that were recorded as variable stars.
- Double stars.
- Stars listed as having emission lines.
- Stars, for which peculiar colours were recorded.

The final compilation contained about 94000 stars. Procedure of calculation of colour excess ratios was similar to that used in our previous paper [12]. Colour excesses E_{B-V}, E_{V-J}, E_{V-H}, E_{V-K}, E_{J-H}, and E_{H-K} were evaluated using intrinsic colour indices from Straižys [16]. These colour excesses enabled us to compute colour excess ratios E_{V-J}/E_{B-V}, E_{V-H}/E_{B-V}, and E_{V-K}/E_{B-V} that were sensitive to variations of the ISEL in the optical and IR regions of
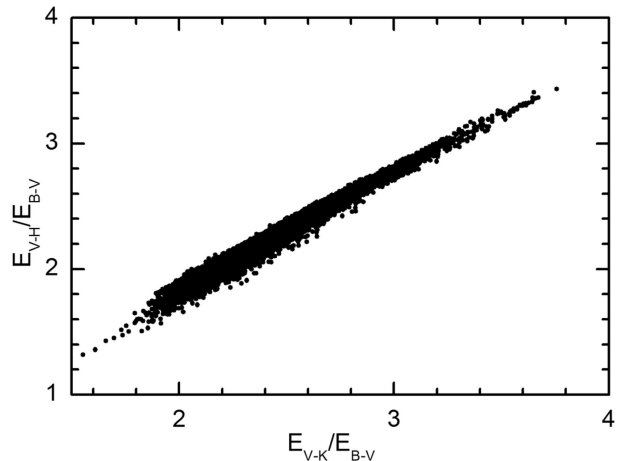

Fig. 1. Relationship between colour excess ratios E_{V-K}/E_{B-V} and E_{V-H}/E_{B-V}.

the spectrum, and E_{J-H}/E_{H-K}, which should show variations in the NIR.

3. Results and discussion

The main indicator of variations of the ISEL is the colour excess ratio E_{V-K}/E_{B-V}, which has well established relationship with the ratio R_V (see, e.g., [2, 17]). Since the passbands J and H are also located in the NIR, variations of the E_{V-J}/E_{B-V} and E_{V-H}/E_{B-V} should mimic variations of the ratio E_{V-K}/E_{B-V}, thus confirming the reality of changes of the ISEL. As an example we present Fig. 1, which demonstrates good correlation between ratios E_{V-K}/E_{B-V} and E_{V-H}/E_{B-V}. Similar correlation was obtained for the ratios E_{V-K}/E_{B-V} and E_{V-J}/E_{B-V} as well. Distribution of the E_{V-K}/E_{B-V} values in the plane of galactic longitudes and latitudes is shown in Fig. 2. Since the average error of this ratio is of the order of 0.07, we can conclude that these variations are statistically significant. Variations of the E_{V-K}/E_{B-V} are in the range from 1.9 to 3.65, which corresponds to the range of the ratios R_V from 2.0 to 3.8. We did not get extremely large values of the E_{V-K}/E_{B-V} due to smoothing effect, which is determined by our method of computation of the colour excess ratios. Therefore, we were not able to identify compact regions (individual associations and/or clusters) with extremely large colour excess ratios E_{V-K}/E_{B-V}. It seems that variations of the E_{V-K}/E_{B-V} are quite irregular and it is difficult to select its most typical value for the whole Galaxy. Regions with higher values of the E_{V-K}/E_{B-V} concentrate towards the galactic equator, while regions with the lowest ratios E_{V-K}/E_{B-V} are mostly found
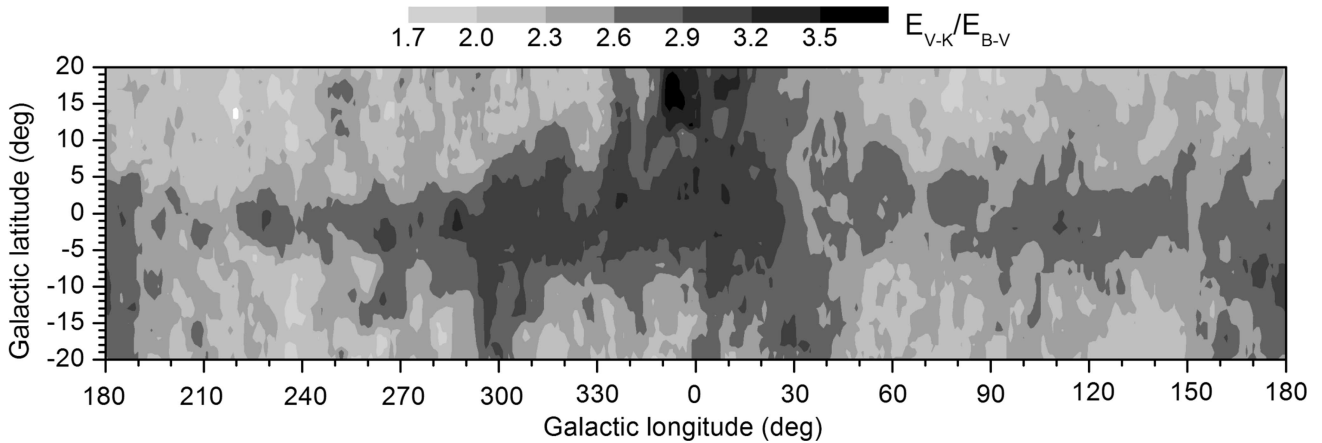
Fig. 2. Distribution of the ratios E_{V-K}/E_{B-V} in galactic coordinates. Darker areas correspond to larger values of the ratios E_{V-K}/E_{B-V} (see panel).
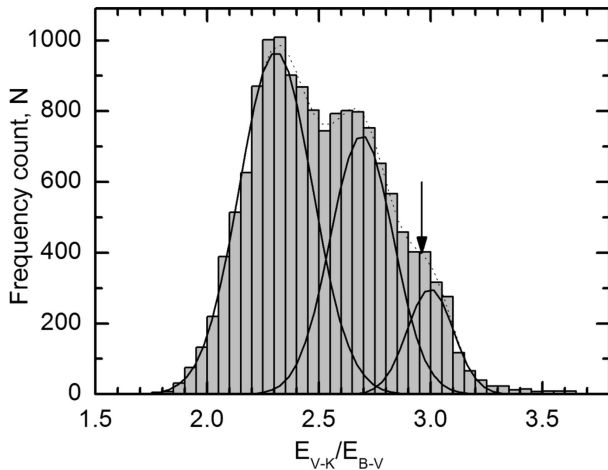

Fig. 3. Frequency histogram of the ratios E_{V-K}/E_{B-V}. Overlaid on the histogram is the trimodal Gaussian distribution. The vertical arrow indicates the value of the ratio E_{V-K}/E_{B-V} corresponding to $R_V = 3.1$.

at large galactic latitudes. Also, the ISEL is not uniform towards different directions of the galactic equator. The wide region of large E_{V-K}/E_{B-V} values stretches in the environs of the Galactic Centre, and the region of low ratios E_{V-K}/E_{B-V} lies in the direction of galactic longitudes 210°–220°. The latter line of sight corresponds to the direction of the inter-arm region where lower density of interstellar matter is expected. Area of large ratios E_{V-K}/E_{B-V} around galactic longitude of 355° and latitude of 17° is located in the region of dark ρ Ophiuchi clouds. Consequently, our results confirm the conclusion of earlier authors that the ratio R_V varies roughly proportionally to the density of obscuring interstellar clouds. Frequency distribution of the ratios E_{V-K}/E_{B-V} is shown in Fig. 3. It is evident that this histogram is rather asymmetric and has three distinct peaks. This histogram was fitted by compos-

ite Gaussian distribution that was derived by adding three single Gaussian distributions. Maximums of distributions are located at the ratios E_{V-K}/E_{B-V} 2.31, 2.69, and 3.00, which correspond to the R_V values of 2.42, 2.81, and 3.14, respectively. The average value of $R_V = 3.1$ established for diffuse interstellar clouds is close to the third maximum. It seems that distribution of the ratios E_{V-K}/E_{B-V} is trimodal. If this is the case, then we should be able to separate three different families of clouds, each of which is characterized by a particular composition and / or size distribution of dust grains. Solution of this problem requires further studies of properties of the ISEL and interstellar dust.

Ratios E_{J-H}/E_{H-K} computed in the present work have shown larger diversity of values than expected according to cited literature [5–9]. We assume that this diversity is not real but caused by inaccuracies of intrinsic colour indices. In order to make more definite conclusion about variations of the ratio E_{J-H}/E_{H-K} further investigations are needed.

Acknowledgements

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DIDELIŲ FOTOMETRINIŲ DUOMENŲ BAZIŲ PANAUDOJIMAS TARPŽVAIGŽDINEI EKSTINKCIJAI GALAKTIKOJE TIRTI

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Santrauka

Ištyrinėtos tarpžvaigždinės ekstinkcijos dėsnio variacijos priklausomai nuo galaktinės ilgumos ir platumos. Rasta, kad daugiklis $R_V = A_V/E_{B-V}$, apibūdinantis tarpžvaigždinės ekstinkcijos dėsnį, kinta maždaug proporcingai tarpžvaigždinių debesų tankiui. Pagal šio daugiklio verčių pasiskirstymą nustatytos trys charakteringos jo vertės: 2,42, 2,81 ir 3,14.