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VARIATIONS OF THE RATIO OF TOTAL-TO-SELECTIVE EXTINCTION IN THE GALAXY

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Abstract. The results of the study of variations of total-to-selective extinction R_V near the Galactic plane ($-12^\circ \leq b \leq +12^\circ$) are presented. It is shown that variations of R_V range from 1.9 to 3.4 and it is not possible to determine its typical value for the Galaxy. The conclusion that variations of the parameter R_V closely correlates with the distribution of interstellar extinction is confirmed.

Key words: ISM: dust, extinction; Galaxy: structure; techniques: photometric

1. INTRODUCTION

Numerous investigations of the interstellar medium present evidence that the interstellar extinction law (ISEL) is not uniform in the Galaxy (see, e.g., Draine 2003 and Whittet 2003, and references therein). It shows variations that are dependent on the mean size, shape and composition of dust particles. Data concerning variations of the ISEL become of the utmost importance when estimating distances, determining physical parameters and/or recovering intrinsic spectral energy distributions of celestial objects. The safest way to account for the extinction accurately should be to determine the ISEL and the amount of the total extinction in the area under investigation. However, this requires additional investigation that is not always possible. Alternatively one should assume that a certain ISEL and amount of extinction is valid for given physical parameters of the interstellar medium for the selected location of the Galaxy. A great variety of the ISELs revealed in the 80-ties raised some doubts concerning the application of the uniform ISEL for all the locations of the Galaxy (see, e.g., Fitzpatrick & Massa 1990). Fortunately, important steps towards standardization of the ISEL have been made by Cardelli et al. (1989). They 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, $R_V = A_V/E_{B-V}$. Pronounced and systematic variations of R_V would have serious consequences for our understanding of Galactic structure and distance scale.

Up to the end of the 20th century variations of the ratio R_V were studied mainly on the basis of a comparatively small number of stars. However, at the present time the emergence of a number of new global photometric surveys opens new opportunities for systematic and thorough investigations of the ISEL. These new opportunities stimulated us to carry out investigation of variations of the parameter R_V on the basis of a large homogenous data set.

2. THE DATA

Our investigation is based on the well-known ratio (see, e.g., Whittet 2003)

$$R_V = 1.1\frac{E_{V-K}}{E_{B-V}} = 1.1k_{VK}, \tag{1}$$

where E_{V-K} and E_{B-V} are color excesses, while B, V and K are corresponding magnitudes in Johnson's photometric system (Johnson 1966).

Fitzpatrick (1999) derived more precise relation between parameter R_V and color-excess ratios:

$$R_V = 1.12k_{VK} + 0.02. \tag{2}$$

In order to calculate the above mentioned ratios of color excesses we have to compile a catalogue of B–V and V–K color indices of stars with known spectral types. The source of the B, V photometry was the catalogue *Tycho-2* (Høg et al. 2000), while that of K photometry – the database of the 2MASS survey (Cutri et al. 2003).

However, it is known that magnitudes B_T and V_T of the *Tycho-2* catalogue slightly differ from B and V magnitudes in the Johnson system due to differences in their passbands (ESA 1997). Also, for the same reason, we may expect some differences between the magnitude K_{2MASS} of the 2MASS survey and K of the Johnson system. In order to avoid systematic errors in the transformation of reddened and slightly reddened stars, we did not transform these data to the Johnson B,V,K system. Instead, we transformed intrinsic color indices $(B-V)_0$ and $(V-K)_0$ in the Johnson system to the color indices $(B_T-V_T)_0$ and $(V_T-K_{2MASS})_0$, respectively. Intrinsic color indices $(B-V)_0$ and $(V-K)_0$ were taken from Straižys (1992). Transformation formulae have been derived using $B-V$ and $V-K$ of O–G0 stars with small reddening selected from the catalogues of Morel & Magnenat (1978) and Ducati (1993).

The main source of spectral types of stars was an exhaustive compilation by Wright et al. (2003). In addition, we also used spectral types from Kharchenko (2003). From the above mentioned *Tycho-2* and 2MASS catalogues we selected stars with known spectral types earlier than G0 located close to the Galactic equator in the band with latitudes $-12° \leq b \leq +12°$. For selected stars we calculated color excesses $E_{B_T-V_T}$ and $E_{V_T-K_{2MASS}}$. We excluded stars with observational errors in B_T-V_T larger than 0.05 mag or with negative color excesses. Finally, we compiled a catalogue of color excesses containing 55 300 stars. Using the obtained color excesses we can calculate their ratios:

$$k_{VTKM} = \frac{E_{V_T-K_{2MASS}}}{E_{B_T-V_T}}. \tag{3}$$

These ratios are related to k_{VK}, which is used for calculation of the parameter R_V (see formula (1)), by the following expression:

$$k_{VK} = k_{VTKM} \cdot \frac{E_{B_T-V_T}}{E_{B-V}} \cdot \frac{E_{V-K}}{E_{V_T-K_{2MASS}}}. \tag{4}$$

The color-excess ratios $\frac{E_{B_T-V_T}}{E_{B-V}}$ and $\frac{E_{V-K}}{E_{V_T-K_{2MASS}}}$ were derived using data of about 500 reddened OB stars from the catalogues of Morel & Magnenat (1978) and Ducati (1993) common with the *Tycho-2* observations. Combining formulae (2) and (4), and inserting the determined values of the color-excess ratios, we get the final expression for the calculation of the parameter R_V:

$$R_V = 1.039 k_{VTKM} + 0.02 \tag{5}$$

3. RESULTS

In order to have sufficient statistics, we selected a field of aperture of $4° \times 4°$. Color excesses of stars from such a field were plotted on the two-color diagram and a slope of the reddening line forced through the origin has been calculated using the least-square fit. With this aperture we scanned the band of the Milky Way between Galactic latitudes from –12° to +12° shifting the center of the aperture with a step of 1° in Galactic longitude and/or latitude. Calculated color-excess ratios have been transformed to the parameters R_V using relation (5). Finally, we obtained a 360×21 matrix of ratios R_V, which is plotted in Figure 1 as a 2D map in the (ℓ, b) plane. The dependence of R_V on Galactic latitude b for the selected longitudes ℓ is given in Figure 2.

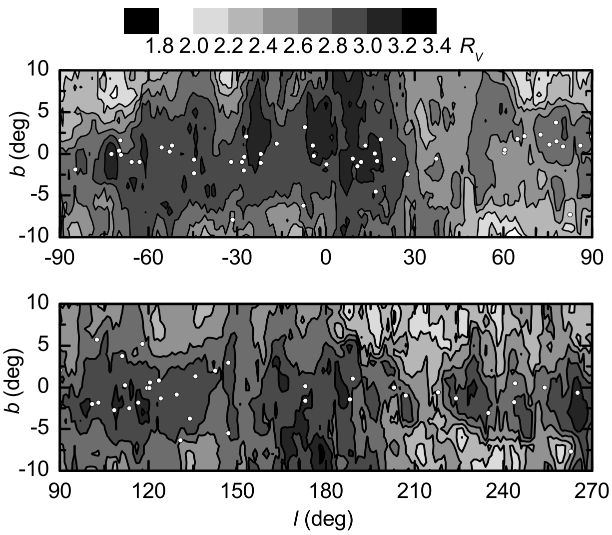

Fig. 1. 2D map of the distribution of the parameter R_V. Empty circles mark the location of OB associations (Ruprecht 1966).

Our results show that the parameter R_V ranges from 1.9 to 3.4. Since the average error of the ratio k_{VTKM} is of the order 0.07, we can conclude that these variations are statistically significant. However, we did not get extremely large values of R_V due to smoothing effect. It is evident that variations of R_V are quite irregular and it is not possible to select its most typical value for the whole Galaxy. It seems that our results do not justify the common practice to use some average value of the parameter R_V for most areas of the Galaxy.

Examination of our data indicates that there is a noticeable dependence of R_V on b. Larger values are found in areas close to the Galactic equator, while smaller values – for higher latitudes.

Since most of stars used in the present study are located closer than one kpc, our 2D R_V map has been compared with the distributions of interstellar extinction up to the distance of one kpc given by Pandey

& Mahra (1987) and Neckel & Klare (1980). The comparison revealed that these distributions closely resemble each other, confirming the widely accepted conclusion that parameter R_V is correlated with the extinction. This correlation naturally explains the dependence of R_V on b since interstellar dust clouds tend to concentrate towards the Galactic plane. It is important to note that higher values of R_V concentrate in the region towards the Galactic center, in the direction of which we observe many dense dust clouds. On the contrary, we find comparatively low R_V values when viewing into inter-arm region ($\ell \approx 215°$) where the extinction is quite low.

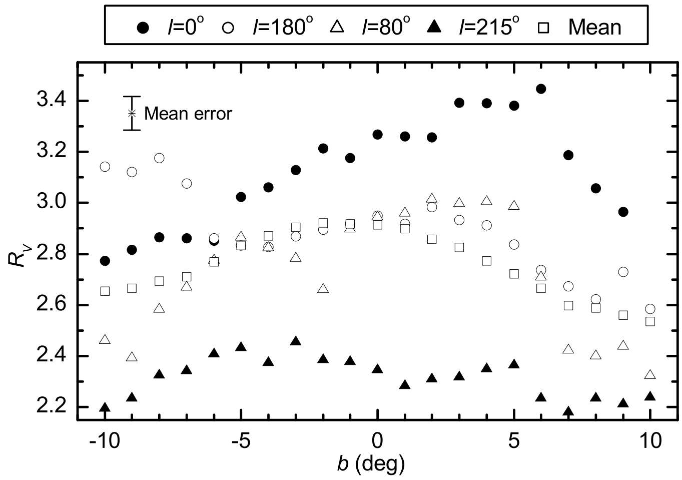

Fig. 2. The dependence of the parameter R_V on Galactic latitude for selected Galactic longitudes.

The distribution of OB associations (see Figure 1), which are mainly located in the vicinity of dense dust clouds, also coincides with the areas of higher R_V values, thus supporting the above mentioned conclusion. Obviously, we may assume that the average R_V value for the Galaxy derived using mainly OB stars from OB associations would be larger than that determined with inclusion of stars located outside OB associations.

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