THE EXTINCTION IN THE SOLAR NEIGHBOURHOOD FROM THE HIPPARCOS DATA

J-L. Vergely[1], D. Egret[1], R. Freire Ferrero[1], B. Valette[2], J. Köppen[1,3]

[1]Observatoire de Strasbourg, F-67000 Strasbourg, France
[2]Institut de Physique du Globe de Paris, F-75007 Paris, France
[3]Institut für Astronomie und Astrophysik der Universität, D-24098 Kiel, Germany

ABSTRACT

With extinctions determined from Strömgren photometry and parallaxes from Hipparcos for a sample of 3700 stars, an inverse method is used to construct the 3-D distribution of absorbing interstellar matter in the solar neighbourhood. Also, we extract the statistical properties of the data. The average opacity is found 1.5 mag/kpc in A_V with a scale height of 70 pc. The correlation functions gives some indication for the cloud sizes.

Key words: extinction; ISM; photometry.

1. INTRODUCTION

The extinction induced by the interstellar medium in the solar neighbourhood alters the apparent brightness of the stars and can strongly the derived stellar intrinsic properties (absolute magnitude, intrinsic colour, etc). For this reason, it is important to know the influence of the interstellar medium on the radiation we receive from the stars, and to build models that permit quantify this influence at best.

To map the extinction in space, Johnson or Strömgren photometry and photometric parallaxes have been employed (Neckel & Klare 1980, Ducati 1986, Guarinos 1991). Trigonometric parallaxes increase the accuracy of the description of the nearest ISM.

Statistical studies have lead to the development of Poissonian models which consider one or two types of clouds (Schatzman 1950, Münch 1952, Scheffler 1967, Knude 1979, 1981). The tools used in these works are applied to calculate the characteristic values of the extinction parameters. With Monte-Carlo simulations we take into account the correlations of extinction along different lines of sight.

The improved distances from Hipparcos offer the possibility to re-assess the results of the earlier studies on the parameters and the spatial distribution of the extinction.

2. DETERMINATION OF THE EXTINCTION

Calibration relations: The color indices in the Strömgren photometry are taken from the Hauck-Mermilliod catalogue (1990). Using calibration relations, we calculate the color excess $E(b-y)$. Table 1 gives for the spectral type and the range of β-index the different calibration relations. Note that since β measures the equivalent width of the $H\beta$ line, it is not affected by extinction.

Table 1. Stellar groups and calibration relations used. Luminosity classes: III-V.

group	Sp.T.	β interval	calibration relation
1	B0-A0	$2.59 < \beta < 2.88$	Crawford (1978)
2	A0-A3	$2.87 < \beta < 2.93$	Hilditch et al. (1983)
3	A3-F0	$2.72 < \beta < 2.88$	Crawford (1979)
4	F0-G2	$2.56 < \beta < 2.72$	Crawford (1975)

For stars of each of the four groups, average extinctions are derived with distance bins of 25 pc; they are shown in Figure 1 as a function of distance. Stars close to the galactic plane ($|z| < 50$ pc) are selected. Group 1 with primarily young hot stars is systematically more reddened than the others. There could be several reasons: systematic error in the calibration relation, circumstellar extinction, concentration of the stars in the galactic plane, and association of the clouds with the stars.

We assume that there is no extinction up to a distance of 25 pc, in order to homogenize the calibration relations. Also, we shall neglect any circumstellar extinction. The error in the extinction can be, in a first approximation, considered as Gaussian. A dispersion of about 0.015 mag is adopted.

The calibration relations suppose that the extinction law $f(\lambda) = E_{\lambda-V}/E_{B-V}$ does not vary from one region to the other in the wavelength interval covered by the Strömgren system. We assume that the extinction is proportional to the mass density of the

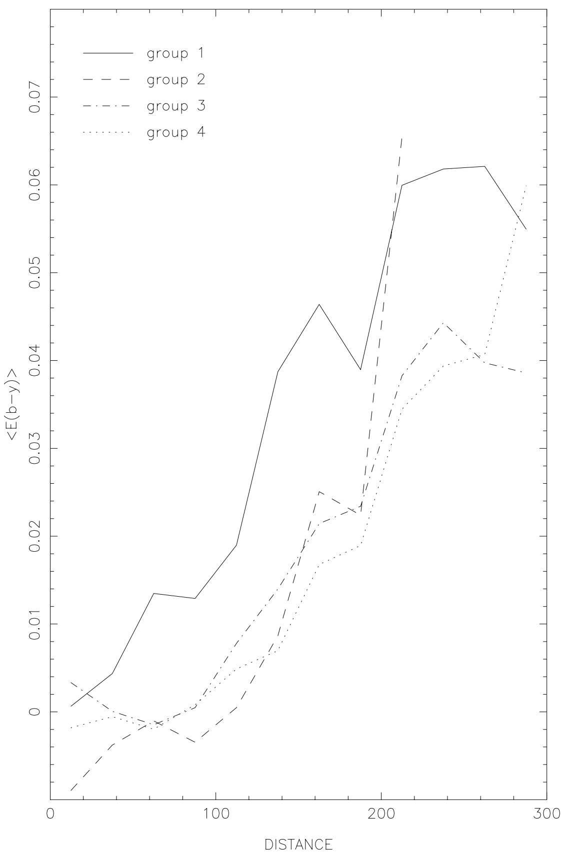

Figure 1. Extinction $< E(b-y) >$ averaged over 25 pc wide distance bins for the stars of the four groups which are close to the galactic plane $|z| <$ 50 pc.

medium. The excess $E(b-y)$ takes the form:

$$E(b-y) = \int_0^R k(r)\rho(r)dr \qquad (1)$$

where R is the distance of the considered star, $k(r)$ is the absorption coefficient and $\rho(r)$ the density of the medium at the radius r. In fact, we have only access to the opacity $\rho_{\rm ext}(r) = k\rho$.

3. 3-D MAPPING OF THE EXTINCTION

An inverse method is used, supposing that the opacity follows a Gaussian law with mean value $\overline{\rho}_{\rm ext}$ and dispersion σ_ρ. The relation (1) gives the extinction as a function of the opacity. This equation needs to be inverted to determine, in each point of the space, the opacity from the extinctions of the 3700 stars of the sample. This problem is underdetermined, because the sample of stars is limited to a finite number of lines of sight relatively spread-out. Therefore, we shall assume continuity of $\rho_{\rm ext}(r)$ and introduce a correlation distance ξ. The covariance $cov(r, r')$ between two points with radius r and r' becomes:

$$cov(r, r') = \sigma_\rho^2 \exp\left(-\frac{||r-r'||^2}{\xi^2}\right)$$

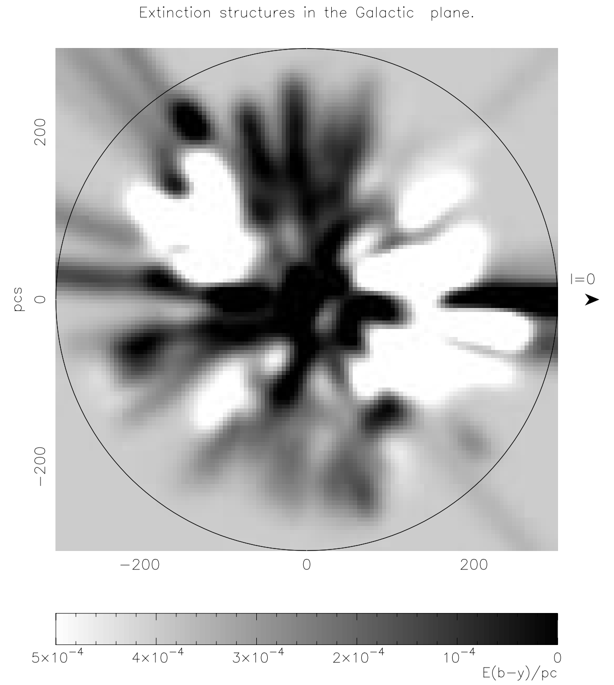

Figure 2. Extinction structures in the galactic plane, with a correlation length of 20 pc. The circle shows the region of the star sample: outside, no information can be obtained.

The resulting inverse problem is linear and Gaussian (Valette & Vergely in preparation) and can be solved in one step. The results obtained are given in Figures 2 and 3. Structures smaller than ξ are partially smoothed. An analysis with a much larger number of stars should allow to decrease the correlation distance, and to resolve the details of the structures better. In a forthcoming work, the correspondence between extinction and molecular clouds will be done, imposing the positivity of the opacity and using a lognormal law distribution. This non-linear problem is solved by iteration.

4. STATISTICAL PROPERTIES OF THE STRUCTURES

We used different extinction models to calculate the characteristic parameters of the absorbing matter.

4.1. Homogeneous Model

We assume that the opacity $\rho_{\rm ext}$ decreases exponentially with height above the galactic plane. We take all the stars in the distance interval $(200-225$ pc). They are all affected by the extinction as follows:

$$E(b-y) = \frac{\rho_0 h_0}{|\sin(b)|}\left(1 - \exp\left(-\frac{R|\sin(b)|}{h_0}\right)\right)$$

where ρ_0 is the opacity in the galactic plane and h_0 the characteristic height. The best representation of

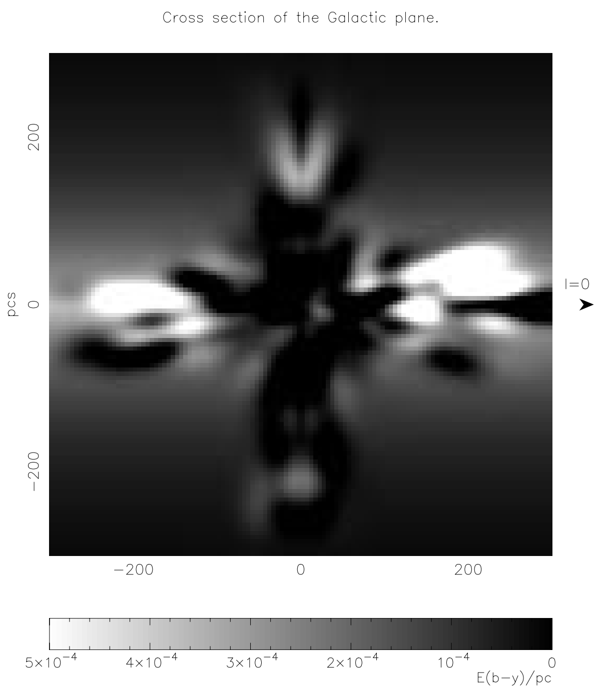

Figure 3. Cross section of the galactic plane. The length of correlation is 25 pc.

the data shown in Figure 4 is obtained by an opacity in the plane corresponding to 0.35 mag/kpc in E(b-y), i.e. 1.5 mag/kpc in the V band, and a scale height $h0 \simeq 70$pc. This is in good agreement with previous studies.

4.2. Inhomogeneous Medium

A homogeneous model is not consistent with the extinction histogram taken at different depths and $|z| < 40$ pc (Figure 5): The dispersion of the extinction is larger than the observational errors. To explain this dispersion, we test a model where the extinction is concentrated in small clumps.

4.2.1. Model with one type of cloud

Neglecting the correlation between the extinctions along different lines of sight, one can assume that the clouds are distributed randomly in space, leading to a model with a Poisson law. It can be demonstrated that the dispersion $\sigma_{\rm int}$ of the extinctions at a given depth is directly linked at the mean extinction (Köppen & Vergely in preparation):

$$\sigma_{\rm int}^2 = E_{\rm cloud} < E(b-y) >$$

where $E_{\rm cloud}$ is the characteristic extinction of a single cloud and $< E(b-y) >$ the mean extinction of the sample. Plotting $\sigma_{\rm int}^2$ as a function of $< E(b-y) >$ for a sample of stars with at $|z| < 25$ pc at different depths, we find:

$$E_{\rm cloud} \simeq 0.08 \text{ mag}$$

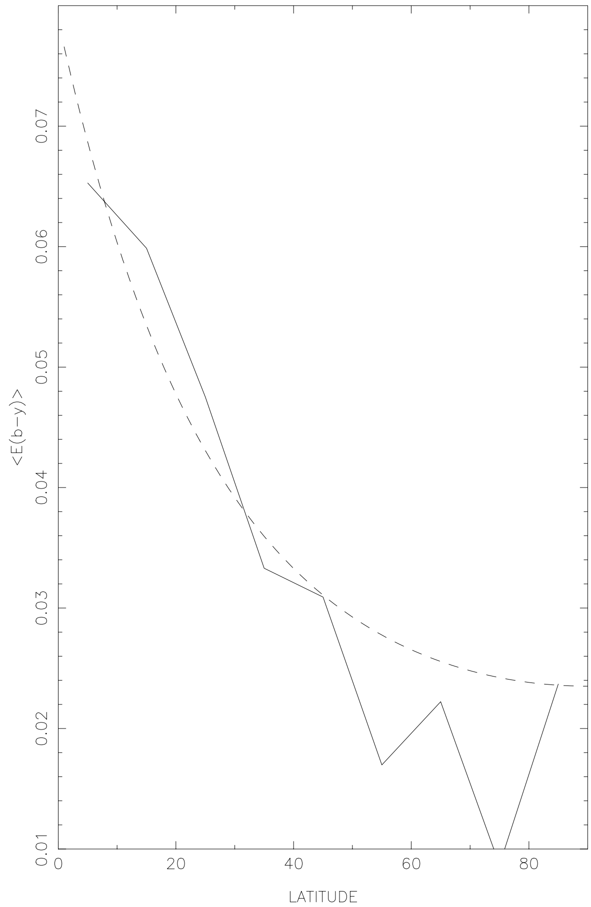

Figure 4. Variation at the mean extinction with latitude: observed (full line) and best model (dashed). $< E(b-y) >$ is determined with 10° bins in latitude for stars with distances from 200 to 250 pc.

which corresponds to the small clouds (e.g. Schatzman 1950). The mean number λ of clouds per kpc encountered in a line of sight in the galactic plane is:

$$\lambda = \frac{\rho_0}{E_{\rm cloud}} \simeq 4.4 \text{ clouds/kpc}$$

The number n of clouds encountered is Poisson distributed with parameter λR where R is the distance of the star:

$$P(n) = \frac{(\lambda R)^n}{n!} \exp(-\lambda R)$$

However, this probability law does not allow to reproduce correctly the extinction histogram at a given depth as found in the earlier works. For this reason, we test a two-clouds model.

4.2.2. Model with two types of clouds

Using Monte Carlo simulations, we can reproduce the extinction histogram and the angular correlation function $C(\alpha)$ (Figure 6) assuming two types

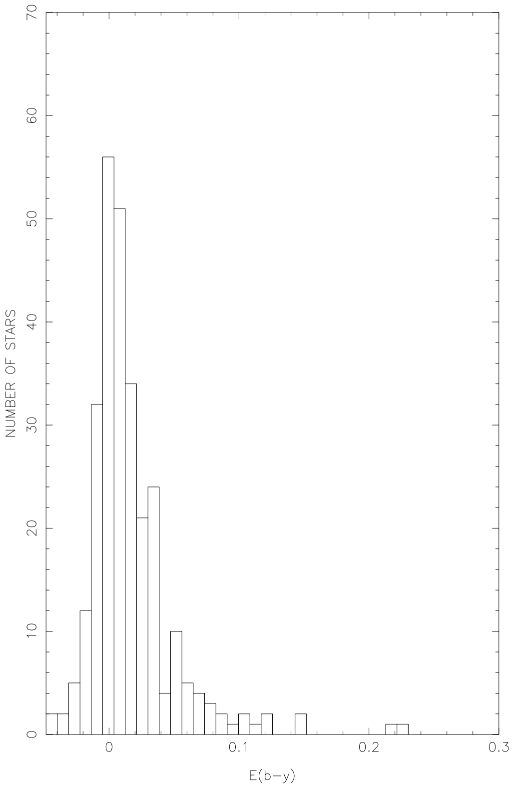

Figure 5. Histogram of the extinctions from stars in the distance interval 125 – 150 pc and $|z| < 40$ pc.

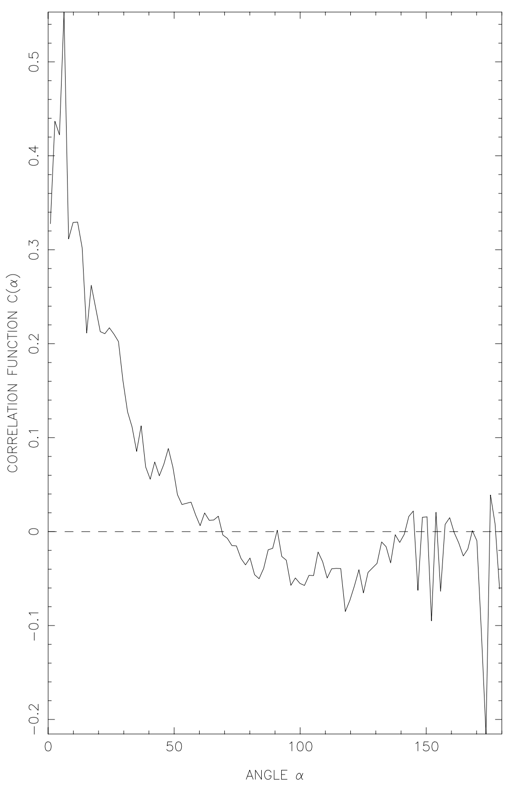

Figure 6. Correlation function of the extinctions for stars in the distance interval 100 – 150 pc.

of cloud. The correlation function is defined as:

$$C(\alpha) = \frac{1}{2\overline{E}^2} \frac{\sum_n (E_i - \overline{E})(E_j - \overline{E})}{n}$$

where α is the angle on the sphere between the lines of sight i and j, n is the number of pairs (i, j), $\overline{E}$ is the mean extinction at a given depth. In practice the angular separation α is considered at $\pm 1°$. Figure 6 shows the correlation function for a distance interval taken between 100 and 125 pc. $C(\alpha)$ remains significant up to 45° which implies the presence of large structures. Comparison with Figures 2 and 3 shows several structures at a distance of 100 pc. However the low level of the correlation function at small angles can only be matched by the introduction of small, i.e. unresolved clouds. For the parameters of the two types of clouds we find:

$$E_{\rm cloud1} \simeq 0.02 \qquad \phi_{\rm cloud1} \simeq 10 \text{ pc}$$
$$E_{\rm cloud2} \simeq 0.10 \qquad \phi_{\rm cloud2} \simeq 120 \text{ pc}$$

Since this is based principally on the correlation function, we consider these values still rather preliminary.

5. CONCLUSIONS

In this study, we have studied the extinction structures of the interstellar medium in two different ways: cartography and statistical approach. In the future, we will use the inverse method to extrapolate the value of extinction for the stars which have an Hipparcos parallax and compare the results with the Arenou model (1992). Statistical tools are to be used to determine the fractal characteristic of the clouds.

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