ON THE PATCHY STRUCTURE OF THE INTERSTELLAR ABSORBING LAYER

More than ten years ago it was clearly brought out that the interstellar absorbing medium has a very irregular, patchy structure. During the last years we in the Soviet Union have done some work with the purpose of studying in more detail the structure of the system of absorbing clouds. Some numerical parameters describing this variety of clouds were obtained.

As a rule each of the luminous diffuse nebulae is illuminated by some high–luminosity star. Are the stars and the corresponding nebulae connected genetically and dynamically or is this connection due to occasional meeting of a star and a nebula during their galactic motion?

In order to solve this question we decided to check by observations a conclusion that follows from the hypothesis of a chance meeting.

It is clear that each star can illuminate around itself merely a sphere of definite radius. A cloud situated within this sphere will attain sufficient illumination to be observed as a bright diffuse nebula. Evidently, the radius of such a sphere will be proportional to the square–root of the luminosity of the star.

Let us take a certain volume V of the galactic space. Stars of different spectral types and luminosities will appear in this volume. We consider the spheres illuminated by these stars. Because the luminosity function and the star density for each spectral class

$$O, B0, B1, B2-9, A, F, G, K, M$$

are known we can immediately obtain the total volume illuminated by stars of these spectral type. In the case of the chance connection between the nebulae and the illuminating stars, the probability for any cloud to be illuminated by a star of some type, let us say A–type, will be equal to the total sum of volume illuminated by all A–type stars within the volume, divided by the whole volume V. We are able to compute all these probabilities. If the hypothesis of the chance connection is true, then the numbers of nebulae illuminated by stars of different types will be proportional to the corresponding probabilities.

The comparison of computed probabilities with the observed numbers of diffuse nebulae illuminated by stars of different types showed very close proportionality. We may conclude, therefore, that the hypothesis of chance meeting should be accepted.

These considerations lead also to another important consequence. It is easy to show that the stars of all types together illuminate only about 1/2000 of the volume of interstellar space. This means that a nebula has a probability of about 1/2000 to be illuminated. It follows, that the number of all clouds in the Galaxy is about 2000 times larger than the number of the bright diffuse nebulae.

Following this line of argument we have established that the number of the cosmic clouds per ps^3 is about 1/10000,

$$n \approx \frac{1}{10000}.$$

If σ is the mean cross–section of a nebula, the mean number of clouds crossed by a ray along the path l will be equal to $l\,n\sigma$.

If, further, ε_0 is the mean optical thickness of a cloud expressed in a stellar magnitudes, the total absorption caused by these clouds will be

$$\Delta m = ln\sigma\varepsilon_0 = al,$$

where a is the mean absorption per parsec.

We know from the general data on the cosmic absorption the value of a (photographic or visual) and the order of magnitude of the cross–section σ.

Therefore, if we assume that the whole interstellar absorption is caused by our system of clouds (or opaque nebulae) we may derive the value of ε_0.

The first and very rough determination of ε_0 showed that it is of the order of $0^m.2$ or $0^m.3$ in the photographic region. It was clear that this value is not in contradiction to our ideas about the mean transparency of the diffuse nebulae.

It was concluded that the absorbing layer consists of a large number of discrete clouds, which are small compared with the distances between them. But it was desirable to have another, independent and more accurate method for the determination of ε_0.

The counts of extragalactic nebulae made by Prof. Shapley and Dr. Hubble have demonstrated that the numbers of nebulae brighter than a certain magnitude per square degree show considerable fluctuations. We have shown that even for a given galactic latitude these fluctuations far exceed the chance fluctuations innate to Poisson's Law. It seems at first sight that this may be attributed to the clustering tendency, which of course exists and the importance of which was emphasized by Shapley.

However, the clustering tendency alone is not able to account for the main part of the fluctuations. This is particularly clear from the following evidence: when we divide the whole sky into galactic latitude zones and determine the fluctuations in each of these zones separately, the relative magnitude of these fluctuations increases with the decrease of the galactic latitude of the zone.

It is evident, however, that the chance fluctuations in the numbers of the galactic absorbing clouds on the path of light coming from the different extragalactic nebulae will cause additional fluctuations in visible nebulae numbers.

It remains to investigate theoretically how these fluctuations depend on the galactic latitude b.

With this aim in view, let us compute

$$\overline{(N_m - \overline{N_m})^2} = \overline{N_m^2} - \overline{N_m}^2,$$

where N_m is the number of nebulae brighter than some m, per square degree. This number N_m in the absence of absorption must be

$$N_m = N_0 \cdot 10^{0.6m}.$$

The transparency of a cloud is $q = 10^{-0.4\varepsilon_0}$. Therefore n clouds in the line of sight diminish the brightness of nebulae q^n times. The observable number of nebulae should therefore be

$$N_m = N_0 \cdot 10^{0.6(m - r\varepsilon_0)} = N_0\, 10^{0.6m}\, q^{\frac{3}{2}n}.$$

The problem of the computation of $\overline{N_m}$ was reduced thus to the computation of $\overline{q^{\frac{3}{2}n}}$. At the same time, the computation of$\overline{N_m^2}$ was reduced to the computation of $\overline{q^3}$. Using Poisson's Law for the probability of n we have, after some algebra:

$$\overline{N_m} = N_0 \cdot 10^{0.6m} e^{-nb(1-q^{\frac{3}{2}})}.$$

Here n_b is the mean number of absorbing clouds crossed by the line of sight at the latitude b.
In the case of plane–parallel layers of clouds we have

$$n_b = n_{\frac{\pi}{2}} \csc b.$$

In the same way

$$\overline{N_m^2} = N_0^2 10^{1.2m} e^{-n_b(1-q^3)}$$

and

$$\frac{\overline{(N_m - \overline{N_m})^2}}{\overline{N_m^2}} = \exp\left(n_b(1 - q^{\frac{3}{2}})^2\right) - 1 = \exp\left(n_{\frac{\pi}{2}} \csc(b(1 - q^{\frac{3}{2}})^2\right) - 1. \tag{1}$$

On the other hand, we have

$$\tau_{\frac{\pi}{2}} = n_{\frac{\pi}{2}} \varepsilon_0, \tag{2}$$

where $\tau_{\frac{\pi}{2}}$ is the optical halfed thickness of the galactic absorbtion layer in the direction perpendicular to the galactic plane. According to the last determination of Parenago $\tau_{\frac{\pi}{2}} = 0^m.32$.
The equations (1) and (2) determine $n_{\frac{\pi}{2}}$ and ε_0. Using the counts of Shapley and Hubble we have computed the values of

$$\frac{\overline{(N_m - \overline{N_m})^2}}{\overline{N_m^2}}$$

for different latitudes and obtained a value of ε_0 of the order of $0^m.25$.

It is necessary to introduce a correction accounting for the dispersion of the limiting magnitude of different plates and for other observational conditions. This correction is somewhat indefinite. However, it is still certain that ε_0 is confined between

$$0^m.20 < \varepsilon_0 < 0^m.30.$$

It is clear from (2) that $n_{\frac{\pi}{2}}$ will be of the order of unity.
Prof. Kukarkin has determined the dispersion of photoelectric colour–excesses of extragalactic nebulae in different latitudes and obtained the mean colour–excess of one single cloud as equal to $0^m.05$. Multiplying this value by the corresponding factor he has found for the optical thickness of a cloud the approximate value

$$\varepsilon_0 = 0^m.27.$$

Dr. Markaryan (Byurakan) has determined the value of ε_0 from the comparison of the observed fluctuations in the numbers of stars counted in low latitudes with the theory of fluctuations of star numbers in these latitudes based on the model of a layer of clouds as described above. His theory contains too much algebra to be exposed here. He obtained $\varepsilon_0 \approx 0^m.25$.
We may conclude that ε_0 is really of this order, although we do not exclude that the value of ε_0 may vary in different regions of our galaxy.
The theory of fluctuations in the total brightness of stars contained in a square degree in the galactic equator may take a very simple and elegant form. The distribution function of this quantity, which is nothing else than the intensity of the stellar component of the Milky Way radiation, satisfies a certain functional equation.

In the derivation of this equation I have used an invariance principle similar to that in the theory of diffuse reflection from plane–parallel layers. It bases on the fact that the distribution function remains unchanged when the observer displaces himself by a distance Δr along the line of sight. This principle gives the following functional equation:

$$\Phi\text{"}(J) + \Phi(J) = \frac{1}{q}\Phi\left(\frac{J}{q}\right) \tag{3}$$

for the distribution function, when J is measured in some convenient units.
From the equation (3) is found to be the mean–square deviation of intensity

$$\frac{\overline{(J-\overline{J})^2}}{\overline{J}^2} = \frac{1-q}{1+q}. \tag{4}$$

Unfortunately we have not at our disposal a sufficient number of determinations of J at different points of the Milky Way to check the validity of (3) and of (4).
Some years ago, Academician Shajn called attention to the too weak correlation of the colour excesses of between B and O stars as determined by Stebbins and his co–workers, and the brightnesses of the corresponding regions of the Milky Way.

The theory of the cloud–structure of the absorbing layer explains this phenomenon. The stars of Stebbins's list have a mean distance above 1000 parsecs, while the fluctuations of the Milky Way brightness are caused chiefly by clouds at distances of 200–500 parsecs.
Therefore the sets of clouds responsible for these two phenomena are quite different and the correlation must be weak.

The problem under consideration is connected with the gas clouds also. Under the assumption that the interstellar gas has also such a patchy structure Dr. Melnicov has analysed the curve of growth for the interstellar lines and obtained dispersion velocities of the gaseous clouds of the order of 8km./sec.

Dr. Lyman Spitzer has told me that to be the observational data of W. S. Adams on the splitting of the interstellar lines into several components indicate that the number of the gas clouds crossed by the line of sight equals the number of the dust clouds computed from our theory. He identifies therefore the two systems of clouds. It follows from this identification that the clouds of interstellar gas should be comparatively small in size (about 8–10 parsecs in diameter). It is very important to confirm this conclusion observationally.

In connection with the problem considered in this brief report a large amount of observational work is being done at the Abastumani Observatory under Dr. Kharadze. The colour–indices of many thousands of stars in the selected areas are determined as well as the colours of many extragalactic nebulae.

However, the photo–electric data on the colour–indices of the external galaxies should be very important for the further study of the structure of the galactic absorbing layer.

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