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SPECTROPHOTOMETRIC MEASURES OF INTERSTELLAR LIGHT ABSORPTION

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In the last issue of these *Publications*[1] the writer presented the observational evidence for the existence of an interstellar light absorption in our Milky Way system. The conclusion that this absorption is selective, that it does not affect all wavelengths alike, was drawn from a discrepancy between color indices and spectral types (color excess) in distant star clusters. It is the purpose of the present paper to show that the selective effect of interstellar light absorption is directly observable in the intensity distribution of the continuous spectra of distant stars and can be measured by spectrophotometric methods. Such measures not only confirm the results of color-index observations but also furnish the law according to which the absorption increases with decreasing wave-length. This law is of great importance for drawing any conclusions concerning the nature of the absorbing medium and the physical process which produces the absorption.

The spectra of the brighter stars in several distant star clusters were photographed with the slitless quartz spectrograph attached to the Crossley reflector. With the use of Wratten and Wainwright Panchromatic plates these spectrograms cover the range from 3200 A to 6300 A. Immediately before and after the exposure on the cluster, similar observations were made of some relatively near and bright comparison stars of the same spectral type as the cluster stars. In order to avoid too large a range in exposure times, the comparison stars were observed with various diaphragms, each consisting of four circular apertures symmetrically arranged. The plates used for each series

[1] *Publ. A.S.P.*, **42**, 214, 1930.

were taken from the same box and developed simultaneously in the same tray.

When the spectrogram of a distant cluster star is compared with that of a near comparison star of the same spectral type, the great difference in intensity distribution due to interstellar light absorption is at once apparent. Figure 1 (Plate VIII) illustrates such a comparison between the brightest star in the cluster, N.G.C. 6910 (upper spectrum), and the comparison star Boss 5512 (lower spectrum). The two spectra were slightly widened by drifting and were measured with a Moll self-registering microphotometer. The tracings of this instrument are reproduced in Figure 2 (Plate VIII). The bottom line with the wave-length scale represents clear film, the top line, complete opacity; intermediate degrees of blackening are measured by the vertical scales at the right and the left.

Both figures show that the two stars have identical absorption lines and therefore belong to the same spectral class, while the intensity of the continuous spectrum differs widely. The distant star is relatively stronger in the red and yellow (6300–5500 A), but weaker in the blue and violet (5000–4000 A), and fades out rapidly for shorter wave-lengths, while the spectrum of the nearer star extends with considerable strength far into the ultra-violet (3200 A). From the equality of spectral class we must conclude that both stars have very nearly the same temperature, and that according to Planck's Law (assuming that they are perfect radiators) both send out light of the same spectral intensity distribution. Except for a constant which depends on the exposure times and the apparent magnitudes, the difference in the observed intensity distribution of the two stars must then represent the greater effect of interstellar light absorption on the distant star. Such abnormal intensity distribution is noticed in all of the five distant star clusters (N.G.C. 6910, 6913, 7380, 7510, I.C. 4996) so far observed; on the other hand, all but one[2] of the eight comparison stars agree among themselves in their intensity distribution.

To convert the degrees of plate blackening measured by the

[2] Boss 5150, situated near the dark division of the Milky Way, is relatively weak in the shorter wave-lengths. It must be somewhat more affected by interstellar absorption than the other comparison stars, all more than 5° distant from the galactic plane.

microphotometer into intensity ratios or magnitudes, the plates had to be calibrated for the different wave-lengths. The calibration curves were obtained by two independent methods: by sensitometer exposures through various color filters as well as from the spectrograms of the comparison stars which contain three equal exposures taken with different diaphragms of known aperture. The microphotometer measures were thus expressed in magnitudes, and the differences between the results of the cluster star and those of the comparison stars, corrected for atmospheric extinction, furnish the amount of absorption as a function of the wave-length. Table I contains the data for

TABLE I

INTERSTELLAR LIGHT ABSORPTION AS A FUNCTION OF WAVE-LENGTH

Cluster N.G.C. 6910 (1 star) Distance, 2100 Parsecs Comparison Star: Boss 5512 Distance, 500 Parsecs		Cluster N.G.C. 6913 (3 stars) Distance, 2100 Parsecs Comparison Stars: Boss 5083, 5474 Mean Distance, 400 Parsecs	
Wave-Length	Observed Magnitude Difference	Wave-Length	Observed Magnitude Difference
6000 A	$-1^m.47$	6320 A	$-1^m.46$
5800	−1.26	6160	−1.37
5500	−1.12	5890	−1.25
5000	−0.48	5510	−1.02
4500	−0.09	5000	−0.59
4200	+0.17	4600	−0.16
4000	+0.42	4200	+0.16
3800	+0.68	4020	+0.37
3600	+0.95	3860	+0.52
3500	+1.10	3650	+0.80
3400	$+1^m.36$	3530	+0.87
		3470	+0.91
		3420	$+1^m.03$

the two clusters, N.G.C. 6910 and 6913, for which the measures have been completed.[3] In the first cluster only one cluster star (H.D. 194279) and one comparison star were observed as described above. In the cluster N.G.C. 6913, three stars of photographic magnitude 9.5–9.7 and spectral type B0 were compared

[3] These measures will be published with more detail in the *Lick Observatory Bulletins,* together with those of additional clusters.

with the two comparison stars of nearly the same spectral type and absolute magnitude:

	Visual Magnitude	Spectral Type	Distance in Parsecs	Galactic Latitude
Boss 5083	5.5	B0	500	+10°
Boss 5474	5.0	O9	350	− 5°

The distances of the comparison stars are all taken from the Mount Wilson spectroscopic parallaxes.[4] To avoid undue lengthening of exposure time, the spectra of N.G.C. 6913 (and of its comparison stars) were not widened and the spectral intensity was measured by moving the slit of the microphotometer across the spectrum at 13 different wave-lengths. The amount of light in each small wave-length interval was then derived by integrating the microphotometer curve converted to an intensity scale. In this way account was taken of the width as well as of the opacity of the narrow spectrum.

The results of Table I are represented graphically in Figure 3 by the dots; they furnish, of course, only the variation of interstellar light absorption with wave-length but leave the zero point undetermined. The latter was arbitrarily set at $\lambda = 4400$, approximately the effective wave-length of ordinary photographic magnitudes. That the absorption increases rapidly with decreasing wave-length is well illustrated by Figure 3. For these two clusters the absorption in the ultraviolet at $\lambda = 3400$ is about 2.5 magnitudes greater than in the red at $\lambda = 6300$.

The differential absorption effect between $\lambda = 4400$ and $\lambda = 5500$, easily interpolated from our figures, indicates how much the color index of the cluster stars exceeds that of the comparison stars. This is $+1^{m}_{.}12$ for N.G.C. 6910 and $+1^{m}_{.}01$ for N.G.C. 6913. Unfortunately, no accurate data on the color indices of the comparison stars are available, but we can calculate these approximately in the following way:

Normal color index of spectral type B0............	$-0^{m}_{.}33$
Selective absorption for mean distance of 450 parsecs	+0.14
Apparent color index of comparison stars..........	−0.19

From this we obtain the color index and the color excess of the cluster stars:

[4] *Contr. Mt. W. No. 262; Ap. J.*, 57, 294, 1923.

	N.G.C. 6910	N.G.C. 6913
Observed differential absorption between $\lambda = 4400$ and $\lambda = 5500$	$+1^{\mathrm{m}}12$	$+1^{\mathrm{m}}01$
Color index of cluster stars............	+0.93	+0.82
Color excess of cluster stars...........	+1.26	+1.15
Normal color excess for distance of cluster	+0.67	+0.67

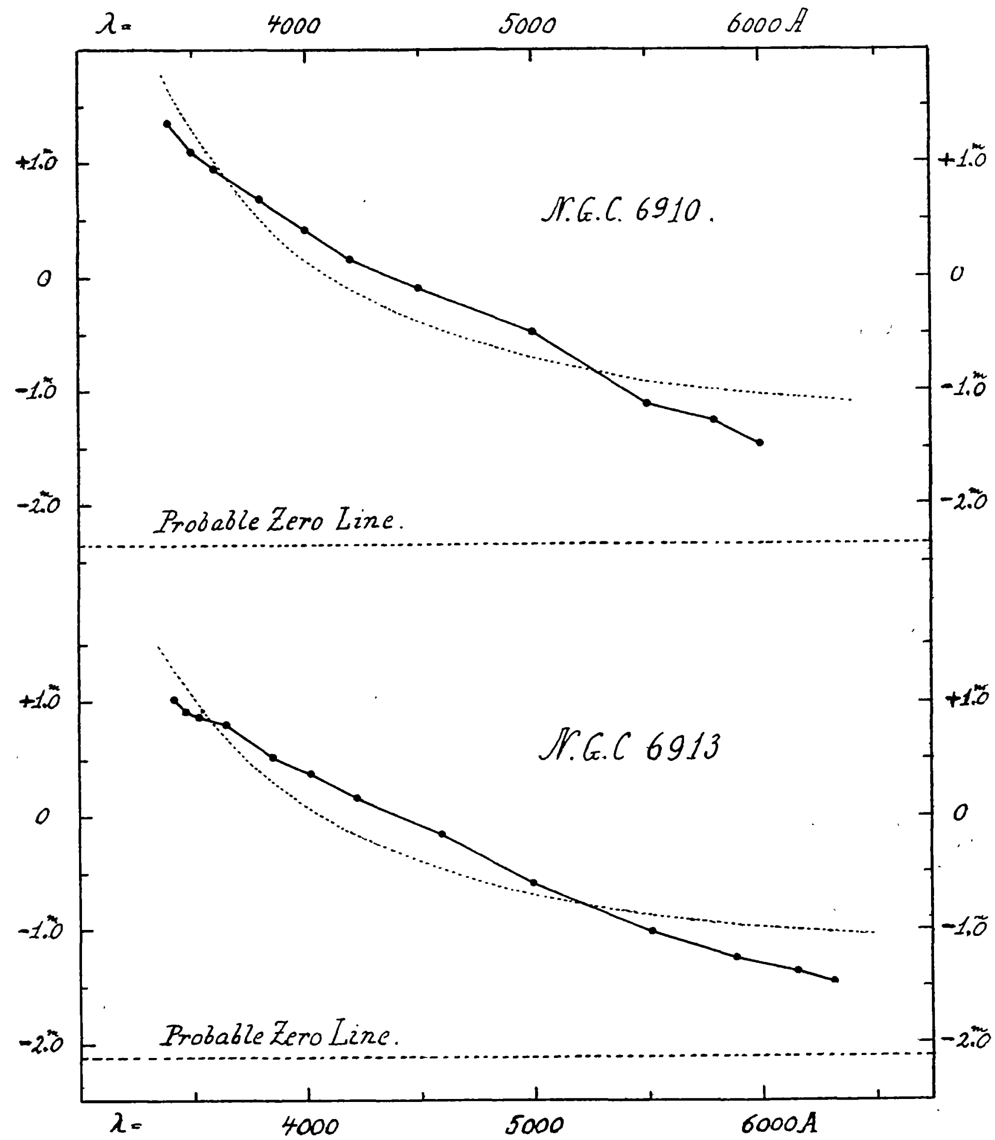

FIG. 3.—Interstellar light absorption as a function of wave-length. The dots joined by the broken line represent the measured amounts of light absorption (ordinates) in magnitudes as a function of the wave-length (abscissae). If measured from the "probable zero line" the ordinates give the absolute amounts of absorption. The dotted curves show the variation of absorption with wave-length according to Rayleigh's law.

The color indices of the four B0-type stars in these two clusters are nearly as large as those normally associated with spectral type K. This result is confirmed by a direct observation of the star H.D. 194279 in the cluster N.G.C. 6910 for which the visual magnitude in the *Henry Draper Catalogue* is given as 7.05. The photographic magnitude of this star was determined by the writer by comparison with the North Polar Sequence and found to be 8.04; this gives a color index of $+0^{m}99$, which closely confirms the result of the spectrophotometric measures. In fact, the reddish color of this B0 star is easily noticed in a small telescope (6-inch finder of 36-inch refractor). It is a curious coincidence that only 3′ north preceding this star another star of spectral type K2 (H.D. 194241, apparently a foreground star) is found. These two stars of nearly the same brightness appear so similar in color that the eye cannot distinguish between them, while the spectroscope shows the two stars to be near the opposite extremes of the stellar temperature scale.

In the previous publication the average color excess for 8 open clusters was found to be $0^{m}32$ per 1000 parsecs; accordingly we should have expected a color excess of $0^{m}67$ for our two clusters, while the observed amount is nearly twice this figure. As the distances of these clusters cannot be much larger than assumed, we are led to the conclusion that interstellar light absorption is not the same in all galactic longitudes but is unusually large in the *Cygnus* region where our two clusters are situated, a few degrees apart, at the border of the dark division of the Milky Way. It should also be noted that the cluster N.G.C. 6910 is involved and surrounded by faint nebulosity. In this connection attention may be drawn to the fact that the three clusters, Messier 35, 36, and 37, in the *Auriga-Gemini* region have an abnormally small color excess for their distance, and that we have here perhaps the other extreme of an exceptionally high transparency.

It is possible to estimate the position of the zero lines in Figure 3 from which the ordinates have to be measured to give the absolute amounts of absorption. Even in case of a non-uniform distribution of the absorbing medium it is likely that there is a fixed proportion between the absolute (general) absorption of photographic light ($\lambda = 4400$) and the differential amount between photographic and visual light (color excess). On the average this proportion was previously found to be[5] $0^m.67 : 0^m.32 = 2.1$. With this ratio the zero line falls at $-2^m.35$ for N.G.C. 6910 and at $-2^m.12$ for N.G.C. 6913 as drawn in Figure 3. The absolute amount of absorption for red light thus appears to be relatively small, and the rapid decrease in absorption with increasing wave-length which is nearly proportional to the latter cannot continue at the same rate far into the red or infra-red; it would otherwise lead to negative values, which are impossible. The absorption–wave-length relation represented by the broken lines of Figure 3 must gradually flatten out for longer wave-lengths, reaching the zero line asymptotically at infinity.

Keeping in mind the impossibility of negative values for the absorption at any wave-length, the spectrophotometric measures will allow us to derive a minimum value for the general absorption at $\lambda = 4400$ quite independently of our previous result based on the distances and diameters of open star clusters. The general absorption at $\lambda = 4400$ cannot be less than 1.5 times the color excess, or not less than $0^m.5$ per 1000 parsecs on the average; a smaller ratio combined with our measures would lead to a negative absorption at $\lambda = 6300$. In order to avoid a sharp discontinuity at $\lambda = 6300$ in the absorption–wave-length relation, which is unlikely, this minimum value would have to be increased. We may, therefore, conclude from our spectrophotometric measures that the general photographic absorption of $0^m.67$ per 1000 parsecs derived from the distances and diameters of open star clusters cannot be much in excess of the true average value.

In the former paper referred to, the writer suggested that interstellar light absorption may be a consequence of light scattering by small particles, fine cosmic dust, thinly spread through the vast spaces occupied by our Milky Way system. If these particles are small compared with the wave-length of light, Rayleigh's Law that the absorption is inversely proportional to

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[5] *Lick Obs. Bull.*, 14, 167, 1930.

the fourth power of the wave-length should hold. In this case the observed absorption value v of Table I should be represented by the formula:

$$v = a\lambda^{-4} - c$$

The zero correction c (general absorption at $\lambda = 4400$) and the numerical coefficient a were determined by least squares solutions for each cluster, and the dotted curves in Figure 3 are the best representation of the spectrophotometric measures that can be made on the basis of Rayleigh's formula. Evidently the latter does not fit the observations, and interstellar light absorption cannot be purely a phenomenon of Rayleigh scattering.

This, however, does not exclude scattering as an explanation altogether. Most likely the absorbing medium is made up of particles of various sizes, ranging from free electrons and atoms, small solid dust particles, up to larger meteoric bodies. The known laws of scattering indicate that for a given mass per cubic parsec the light absorption by scattering increases with the size of the particles; it is much less for free atoms than for small solid particles; for larger bodies, however, light obstruction takes place which affects all wave-lengths alike and diminishes with increasing size of the bodies on account of their smaller number contained in a given mass. We must then expect that, in an absorbing medium made up of particles of all sizes, those particles which are comparable in size with the wave-length of light are most effective for producing absorption by scattering. For bodies of this size, however, Rayleigh's Law no longer holds. From the studies of H. Blumer[6] on light scattering by small spheres it appears that for a mixture of particles with diameters between 1×10^{-5} and 10×10^{-5} cm the absorption effect by scattering may vary with the wave-length in such a way as our observations indicate.

While scattering by small cosmic dust particles is probably the most important cause of interstellar light absorption for visible light ($\lambda > 4000$), it is possible that for shorter waves we may have an additional effect by photoelectric ionization of free atoms.

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[6] *Zeit. für Phys.*, **39**, 195, 1926.