



FIG. 5.

Maanen finds for Messier 101 an annual rotational component of 0".022 for a distance of 5' from the center. Combining this with the rotational velocity of 330 km. per sec. for a distance of 2' gives 0".00013 for the parallax of N. G. C. 4594. The result is of the same general order as that found by Curtis for spiral nebulae as a class from a discussion of their proper motion.⁷

¹ *Astroph. J.*, 15, 287 (1902).

² *Lick Obs. Bull.*, 278 (1916); *Pub. Astr. Soc. Pac.*, 28, 119-20 (1916).

³ *Leipzig, Vierteljahrsschr. astr. Ges.*, 49, 162 (1914).

⁴ *Ibid.*, 50, 97 (1915).

⁵ Van Maanen, these PROCEEDINGS, 2, 386, July 1916.

⁶ *Pop. Astr.*, 23, 21 (1915).

⁷ *Pub. Astr. Soc. Pac.*, 27, 217 (1915).

A SIMPLE METHOD FOR DETERMINING THE COLORS OF THE STARS

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Aside from visual estimates, such as those by Müller and Kempf in the *Potsdam Durchmusterung*, three methods of determining the colors of stars have been more or less widely applied. The earliest of



these involves only the use of the spectroscope; the determination of a star's spectral type at once fixes its color, at least within narrow limits. But usually spectroscopic observations are concerned with other physical factors and we ordinarily think of them as only incidentally determinations of color.

The second method depends upon a comparison of photographic and visual or photovisual¹ magnitudes. A red star, owing to a deficiency of light of shorter wave-lengths, makes little impression on the ordinary photographic plate. It will therefore be faint photographically even though visually bright. The light of a white star, on the other hand, affects strongly both the eye and the plate, and its photographic and visual brightness are essentially the same. The difference in the photographic and visual magnitudes is therefore frequently used as a measure of a star's color. This difference is commonly known as the color-index.

The third method determines the color of stars by finding the effective or predominating wave-lengths in the light which they emit.² The observations are made by means of a coarse objective grating attached to the end of the telescope. The central diffraction image of each star in the field will have adjoining it on either side tiny images of the first-order spectra. For a red star the blue ends of the spectral images will be weak; the distance separating the points of maximum photographic density is accordingly greater than for a bluer object. From the observed value of this distance the wave-length for the point of maximum density can be calculated. The result is the effective wave-length.

Since spectral type is determined mainly by the number, intensity, and position of the Fraunhofer lines, its relation to color, which depends upon the distribution of intensity in the continuous spectrum background, is not necessarily constant. Thus stars of the same type show differences in color whose origin may be traced to differences in their intrinsic luminosity or absolute magnitude; and any selective absorption or scattering of light during its passage through space must also introduce an element into the star's color which escapes a determination based upon spectral classification.³ The first method, therefore, does not necessarily give exact values of the color. Moreover, it cannot be used for very faint stars.

The second method is free from the objections attached to the first, but it is not always easy of application. Both the photographic and photovisual magnitudes must be known on the absolute scale. Aside from the difficulties arising from systematic errors in the slope of the scales, there are others, connected with the determination of their zero

points, which at present are likely to prove troublesome. With care satisfactory results can be obtained, but the operation is tedious at best, and the uncertainties are greatest for just those objects whose colors we should like most to know—the faint stars.

The third method, although spectroscopic in character, gives real values of the color, and not merely the spectral type. It is also free from the zero-point and scale errors which complicate precise determinations of the color-index; and although subject to its own peculiar errors, these do not seem to be very serious. The chief objection is that the method is wasteful of light, the limiting magnitude for the determination of effective wave-lengths being about three magnitudes less than that for direct photography.² If a large telescope is to be used, the size and weight of the objective grating are also objectionable and make it difficult to pass quickly from the determination of effective wave-lengths to other kinds of observational work.

The following method seems to offer some advantages, and has also the merit of simplicity and convenience. The limiting magnitude to which it can be applied should be about the same as that for which photovisual magnitudes can be determined. It consists simply in determining the ratio of exposure-times necessary to produce photographic and photovisual, or more briefly blue and yellow, images of the same size. For convenience, and also as a matter of precision, the images should be on the same plate. An isochromatic plate exposed behind a yellow filter registers the yellow image as usual. The same plate used without filter gives the blue image. This will include to some extent the effect of the longer wave-lengths, but owing to the relatively small sensitiveness of the isochromatic plate to the yellow and orange rays, the shorter wave-lengths will still be of predominating influence.

In the simplest case there will be for each star one yellow image and a series of three or four blue images, with the exposure times for the latter increasing in geometrical progression—as a constant ratio, 2 seems to be the most convenient. The diameters of the blue images, or their scale readings,⁴ are plotted against the logarithm of the exposure, and from the nearly linear curve thus derived can be read the exposure time for a blue image of the same size as the yellow image. The ratio of the interpolated exposure to that which produced the yellow image—the exposure ratio—compared with similar ratios for stars of known color, gives at once the color-index or color-class.³

Various modifications necessary to meet special conditions immediately suggest themselves; but whatever the details, consideration should

be given to the following points: First, if there are differences of gradation between the blue and yellow images, the exposure-ratios of bright and faint stars of the same color will be different. In other words, the ratios will depend upon the size of the images. The matter is easily investigated by observing repeatedly the same stars with different apertures and exposure times; the variation of exposure-ratio with the size of image can thus be determined. In practice it will be advantageous, wherever possible, to adjust exposure and aperture so that the resulting yellow image is of a standard size. Preliminary tests indicate that the systematic gradation difference for the blue and yellow images is small. Small deviations from the standard image are therefore of no consequence, and larger differences are readily taken into account in the reductions.

Second, atmospheric extinction reduces the intensity of blue light more than that of yellow and therefore modifies the exposure-ratio. Although the effect enters differentially, its influence is appreciable, except for small zenith distances. Tables of corrections can be derived by determining the exposure-ratio for the same star at different zenith distances.

Third, care should be taken to bring the plates into equilibrium with the atmospheric conditions before beginning the exposures; otherwise the absorption of moisture during the exposure may introduce variations of sensitiveness and gradation which are capable of influencing seriously the results.

No extensive test of the method has yet been made, but it has been tried sufficiently to demonstrate its practicability. About 40 plates, mainly of individual bright stars, were exposed on three successive nights, two or more plates being obtained on each of 10 different stars. Two yellow and five blue exposures were made on each plate; further three exposures through a filter transmitting to the violet of λ 4000 were also added in each case in order to test the precision of results derived from different regions of the spectrum. To avoid gradation errors, the apertures and exposure times were adjusted so that the images differ little from a standard size.

For the plate and filter used the exposure ratio of blue to yellow varies from about $\frac{1}{8}$ to $\frac{1}{3}$ for spectral types A to M. That of blue to ultra-violet would be a much smaller quantity but for the fact that the large exposure factor of the ultra-violet filter was offset by a change in the aperture—the exposures for blue and yellow always being made through a wire-gauze screen absorbing about 3 magnitudes.

PLATE	DATE	HOUR ANGLE	EXPOSURE-RATIOS	
			Blue/Yellow	Blue/Violet
P 3138	1916, June 25	25°W	0.168	0.496
3150	26	1E	0.156	0.542
3163	27	27E	0.178	0.558
3167	27	6E	0.180	0.595
3171	27	15W	0.158	0.600
3173	27	37W	0.164	0.533
3177	27	58W	0.172	0.547
Mean.....			0.168	0.553
Average deviation from mean.....			±0.007	±0.027
Change in ratio for 0.1 spectrum interval.....			0.004	0.014
Spectrum interval corresponding to average deviation.....			±0.180	±0.190

From the accordance of results for the same star, derived mainly upon different nights, it is found that the average deviation in the exposure-ratio from a single plate corresponds to about 0.2 of a spectrum interval, or 0.08 mag. in the color-index. The greater redness of stars of high luminosity, spectral type remaining the same, is easily seen in the results from even a single plate. The precision seems to be the same whether the yellow or the violet is used for comparison with the blue. As none of the results have yet been corrected for atmospheric extinction, the average deviation includes the effect of this disturbing factor. For illustration the results for seven plates on one of the stars, 72 *w* Herculis, are given in the table.

¹ Photovisual magnitudes express the visual brightness of a star, but are determined photographically. The procedure is the same as for the determination of photographic magnitudes, except that an isochromatic plate combined with a yellow filter is used instead of the ordinary photographic plate.

² See for example Hertzsprung, *Mt. Wilson Contr.*, No. 100; *Astroph. J.*, 42, 92 (1915).

³ These PROCEEDINGS, 1, 481 (1915).

⁴ *Mt. Wilson Contr.*, No. 80, 19; *Astroph. J.*, 39, 325 (1914).

STUDIES OF MAGNITUDES IN STAR CLUSTERS, III. THE COLORS OF THE BRIGHTER STARS IN FOUR GLOBULAR SYSTEMS

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In a former communication dealing with the probable sequence of spectral types in stellar development¹ it was shown that the brightest stars in the great Hercules cluster are of the redder spectral types, while