

25. COMMISSION DE PHOTOMÉTRIE STELLAIRE

PRÉSIDENT: M. F. H. SEARES, *Mount Wilson Observatory, Pasadena, California, U.S.A.*

MEMBRES: MM. J. Baillaud, Bemporad, Fabry, Greaves, Hagen, Halm, Hertzsprung, Jones, E. S. King, Lindblad, Melotte, Pannekoek, H. H. Plaskett, Sampson, Shapley, Turner, Vanderlinden, Van Rhijn, Von Zeipel.

MAGNITUDES

Cape Zone Catalogue. A notable contribution to stellar photometry is the catalogue of 20,843 photographic magnitudes in the Cape Zones, -40° to -52° , just issued under the direction of His Majesty's Astronomer. The investigation is important, first, because it successfully applies Kron's law of photographic action to the problem of standardizing magnitudes in accordance with the methods proposed by Jones and Halm (*Trans. Int. Astr. Union*, 2, 88, 1925); and, second, because it provides extensive data, on a fundamental photometric system, for stars of intermediate brightness in the southern hemisphere.

The general theoretical developments and the standardization of a South Polar Sequence have already been reported (*loc. cit.*). For the preparation of the catalogue, the following points are of importance.

According to Kron's law,

$$f(D) = It/\psi,$$

$$\psi = \frac{1}{2}(i^\alpha + i^{-\alpha}), \quad i = I/I_0,$$

where D is the diameter or opacity of the image, and I_0 the optimal intensity of the plate, *i.e.* that value of I for which the iso-actinic curve $f(D) = \text{const.}$ is a minimum. For a fully developed plate, I_0 depends chiefly, and perhaps only, on the speed of the emulsion. For i small, the general formula reduces to

$$f(D) \propto I^{1+\alpha} t$$

which is Schwarzschild's equation. Numerous tests indicate that for all plates, both fast and slow, $\alpha = 0.25$.

Accepting this value of α , Jones and Halm have developed methods for using the general equation; they have also shown that with a proper choice of plate (I_0) the simpler expression of Schwarzschild, or its equivalent,

$$m - m_0 = 2(\log t_0 - \log t)$$

is generally applicable to the problems of stellar photometry.

Plates of the same speed, exposed under similar conditions and fully developed, should show practically identical intensity scales (m , D). Differences in speed, transparency, and steadiness of seeing should affect the zero point but have little influence on the gradation. Such in fact proved to be the case. Examination of both Astrographic and C.P.D. plates showed that mean intensity scales based on three or more plates are practically coincident. Differences in zero point, on the other hand, cannot be disregarded.

To the limit of the C.P.D. each star in the zones appears on at least two Astrographic plates and on one C.P.D. plate. Observational data for dependable magnitudes were therefore available. The only thing lacking was a mean in-

tensity scale applicable to these photographs and data for determining the zero points of individual plates.

The intensity scale was established by transferring the magnitude scale of the South Polar Sequence to 24 sequences distributed along the -45° parallel, where the magnitudes could be correlated with diameters measured on Astrographic and C.P.D. plates. The result was checked and strengthened with the aid of Harvard magnitudes—visual magnitudes corrected for colour in the case of bright stars, and photographic magnitudes from Harvard Standard Regions for the fainter objects. The adopted scale was also based in part on an intensity scale obtained from a time scale specially determined with the aid of Kron's equations.

The zero point depends on Harvard visual magnitudes corrected for colour. This part of the reduction is based on Tables VI and VII, *Harvard Annals*, 80, No. 13, which give directly the photographic magnitude on the Harvard system corresponding to any C.P.D. magnitude. The Harvard system thus meant is the visual system of the 4-inch and 12-inch meridian photometers, corrected for colour. The stars used have an approximate mean photographic magnitude of 9.3, or about 8.8 on the Harvard visual scale. The zero points for individual Astrographic plates were found through the intermediary of C.P.D. magnitudes for stars on these plates.

The probable error of a single magnitude, including differential scale error, but not the uncertainty in zero point, is ± 0.19 mag. The probable error of the zero point of a single plate is ± 0.08 mag. The corresponding error for a catalogue magnitude is ± 0.13 mag.

Various tests indicate that the Cape photographic scale agrees well with the Mount Wilson scale; and that when the Cape photographic magnitudes are corrected for colour the resulting photovisual scale also agrees with the Mount Wilson photovisual scale. The only discrepancy is a small difference in zero point:

$$\text{Mount Wilson} - \text{Cape} = + 0.04 \text{ mag.}$$

A correction in this sense, although uncertain in amount, is to be expected, because the Harvard visual magnitudes used for the Cape zero point differ systematically from the Mount Wilson scale. The uncertainty lies in the amount of the difference for southern stars. At the North Pole the reduction for H.Vis. = 8.8 is (*Mt Wilson Contr.* No. 288)

$$\text{M.W. Pv.} - \text{H.Vis.} = + 0.22 - 0.15 \times \text{colour},$$

or about $+ 0.10$ mag.

The investigation is reported with some detail because the success attained is worthy of careful attention in planning for the utilization of material in other Astrographic Zones. To obtain satisfactory results the plates must have received full or at least uniform development. Further, the measured diameters must be on a homogeneous system. With these conditions satisfied, the method should give excellent results. In this connection the 208 Harvard Sequences (*H.A.* 85, Nos. 1, 7, 8) established for the reduction of the Astrographic Zones and recently completed will be of service, especially when finally reduced to the international system.

Yerkes Photometry for 1550 Stars. The measurements of photographic and photovisual magnitudes for stars brighter than about 14 in the 45° zone of Selected Areas undertaken by Professor Parkhurst were finished at the time of

his lamented death, and the greater part of the manuscript had been prepared for the printer. This was completed by Miss Farnsworth, and the results are now available in *Publications of the Yerkes Observatory*, 4, Part 6. Much information relating to the instruments may be found in Part 5 of the same volume. Details of the methods used are fully discussed in the *Astrophysical Journal*, 62, 179, 1925.

Scales were established for each Area with the aid of objective gratings, the brighter stars being observed with the UV Triplet, the fainter ones, with the 24-inch reflector and the 40-inch refractor. The zero points depend partly on polar comparisons and partly on P.D. magnitudes (interval 5.0 to 8 ±) of white stars in the same fields, reduced to the international system by subtracting 0.30 mag. In deriving zero points for the photographic scales small corrections for colour were also applied. Much effort was expended in the endeavour to obtain accuracy and consistency in both zero point and scale.

The only detailed comparison with other results which can be made at present is with the unpublished photographic magnitudes of the *Mount Wilson Catalogue*. This, unfortunately, reveals systematic differences which vary considerably from field to field, but, in the mean, are approximately represented by

$$M.W. - \text{Yerkes} = -0.09 (m - 13.6).$$

The origin of this divergence requires further investigation. It may be remarked, however, that the Mount Wilson magnitudes, as shown by polar comparisons covering the interval 11–16, are in excellent agreement with the adopted scale at the pole. Mount Wilson magnitudes for brighter stars are much less reliable. For example two or three of the central stars for the Areas in the 45° Zone are certainly affected by large accidental errors. The remaining central stars, however, are in good systematic agreement with the magnitudes of the *Harvard-Groningen Durchmusterung* after reduction to the international scale and colour system. Compared with the Yerkes magnitudes, these same stars, having a mean of about 9.4, give the difference $M.W. - Y. = +0.41$, in agreement with the above formula.

The 36 Rumford Fields. The visual magnitudes in these fields measured at the Harvard, Yerkes, Lick, and McCormick observatories (*Mem. Amer. Acad. of Arts and Sciences*, 14, No. 4) are noteworthy for several reasons: The stars extend from magnitude 9 to 16; the measures are by different observers, with different instruments; and the fields, which are those of well-known variables, are scattered with some uniformity over the sky between declinations +90° and –20°. The magnitudes are therefore useful as standards for other investigations. Their relation to the photovisual scale is accordingly of special interest.

Mitchell and Alden (*Monthly Notices*, 86, 356, 1926) have applied the methods used for the Rumford fields to the comparison stars for Nova Persei No. 2 (1901) for which Seares had found photographic and photovisual magnitudes by polar comparisons. The differences are well represented by

$$\text{McCormick} - M.W. = -0.11 + 0.028 (M.W. - 14) + 0.134C.$$

Comparison with the photovisual magnitudes of Shapley and Miss Richmond for Pleiades stars gave

$$\text{McCormick} - M.W. = -0.58 - 0.006 (M.W. - 13) + 0.244C.$$

The scale difference is therefore small. The colour equation requires further investigation.

Magnitudes in high galactic latitudes. Malmquist (Lund, *Meddelanden*, Ser. II, No. 37) has derived photographic magnitudes on the international scale for about

3700 stars within 10° of the north galactic pole. The limiting magnitude is about 14.5. The scale was established by comparison with a neighbouring Harvard Standard Region. The agreement of $\log N$ with the mean distribution table (*Mt Wilson Contr.* No. 301) in the interval 12–14.5 is excellent. Brighter stars show a systematic divergence, mostly accounted for, however, by allowance for the presence of Coma Berenices. The colours of the stars are discussed below.

Miscellaneous Results. Numerous special investigations cannot be referred to for lack of space. The following should be mentioned, however: Heinemann at Heidelberg (*A.N.* 227, 193, 1926) has derived photographic magnitudes on the international scale for 471 stars in the cluster N.G.C. 752, and photovisual magnitudes and colour indices for 239 stars. The photovisual scale (interval 8–12) is in good agreement with the visual measures of Vogt (*A.N.* 221, 41, 1924).

Fessenkoff (*Photometrical Catalogue of 1155 Stars*, 1926) gives results of visual measures at Kharkow with a Zöllner photometer on stars between $+79^\circ.5$ and $+90^\circ$.

Zinner (*Veröffentlichungen, Bamberg*, 2, 1926) has formed a list of mean visual magnitudes for 2373 stars brighter than 5.51, based on all important estimates and measures from the earliest times down. The P.D. scale, very slightly modified to obtain a completely homogeneous system, is adopted as the normal to which all other systems are reduced. Corrections for both scale and colour are applied in the reduction. The resulting list gives the corrected magnitude as derived from each source, as well as the weighted mean. Slight secular changes for certain spectral types are suggested by reliable observations of the nineteenth century. The memoir is rich in historical and statistical data.

Radiometric Magnitudes. Pettit and Nicholson have now determined the radiometric magnitudes of 154 stars on a homogeneous system. The results refer to the zenith at Mount Wilson, and represent observations made with a thermocouple provided with a rock-salt window and a telescope involving two reflections from fresh silver. The following heat indices (visual – radiometric magnitude) have been found for giant stars:

A0	0.0	M0	1.8
F0	0.1	M2	2.2
G0	0.5	M4	2.9
K0	1.0	M6	4.2
K5	1.6	M8	5.0
8 Me variables at min. (M10) 8.5.			

Investigations in Progress. The determination of photographic magnitudes between 8 and 13 in the northern Selected Areas has been undertaken jointly at Harvard and at the Kapteyn Laboratory. Plates $3^\circ.5 \times 3^\circ.5$ will be measured with a thermopile. The spectra are being supplied by the Hamburg Observatory. The investigation will be extended to the southern Areas by means of plates and spectra taken at the La Paz Observatory.

Measures of photovisual magnitudes of 11,700 stars in the $+35^\circ$ to $+40^\circ$ A.G. Zone by von Zeipel at Upsala will probably be finished in 1928. (Cf. *Trans. Int. Astron. Union*, 2, 203, 1925).

Observation of the zone $+60^\circ$ to $+65^\circ$ by Bergstrand with a Zeiss triplet of 20 cm. is well advanced. One-third of the plates have been taken and measures with a thermo-electric photometer have been begun. The scale is established by an objective grating, and for zero point the results will be connected with neighbouring zones already observed at Greenwich.

Special attention has been given to the magnitudes of the Catania Astrographic Zone. With the aid of H.D. standards and a cubic formula connecting magnitude and diameter Bemporad at Naples has obtained results for about 40,000 stars between 6^h and 12^h of right ascension. The intervals 0-6^h and 18-24^h are being measured by Favaro at Catania.

Graff's visual measures of comparison stars for the 41 fields of Series VII of the *Atlas Stellarum Variabilium* are now available, the charts having just appeared. Measures for Series VIII have been finished, but the charts are not yet ready.

Because of its importance for statistical investigations involving magnitudes and colours, the Henry Draper Extension demands special attention. Three sections have already appeared (*H.A.* 100, Nos. 1, 2, 3).

The comparison stars for about 200 long-period variables, which at minimum are fainter than the thirteenth magnitude, are being systematically measured with the wedge photometer by Mitchell and Alden. The methods are those successfully used for the Rumford fields.

Turner has continued his compilation of star-counts from Astrographic Zones, and in *Monthly Notices*, 85, 610, 1925, has given a provisional general survey of the distribution of stars of mean magnitude 11.

The copy for the *Mount Wilson Catalogue of Selected Areas* should be in the hands of the printer by the time this report is issued. Discussion of the results in their relation to structural features of the galactic system has been made by Seares and Miss Joyner (*Mt Wilson Contr.* Nos. 346, 347), and van Rhijn proposes to undertake a final discussion which will include detailed counts from the *Harvard-Groningen Durchmusterung*, the *Draper Catalogue*, etc.

MEASURES OF COLOUR

Cape Colour Indices. The photographic magnitudes of the *Cape Zone Catalogue*, compared with Harvard visual magnitudes, give colour indices for about 17,600 stars in the -45° zone of declination. This abundant material leads to most interesting results, which can be only briefly summarized here. (1) In general, colour index for a given spectral type decreases with increasing apparent magnitude. The change, which is negligible or small for early types, but conspicuous for late types, is attributed to the larger percentage of dwarfs among stars of faint apparent magnitude. (2) The mean colour index for all spectral types together increases with galactic latitude. (3) The frequency curves for the colour indices of different spectral types can be resolved into error curves of constant moduli, having maxima at

$$\text{C.I.} = 0.45n - 0.92; \quad n = (0?, 1, 2, \dots 6).$$

The dispersion in the individual error curves corresponds to the error of observation. Hence, the observed distribution of colour indices can be accounted for by the mixture of six or seven preferential values, defined as above. The percentage of the different preferential values varies with spectrum, apparent magnitude, and galactic position. That the phenomenon has a physical basis, and is not the result of an artificial analysis analogous to representations by a Fourier series, is suggested by the facts that colour indices for bright and faint stars and for entirely different stars in the Harvard Standard Regions lead to the same preferential values, that the reciprocal temperatures of Wilsing and Hertzsprung both show a similar phenomenon, the preferential temperatures corresponding closely with the preferential colour indices, and that the dispersion in the error

curves is accounted for by observational uncertainty in the colour indices. The preferential temperatures based on all of these data are expressed by

$$T_n = 18150/n \quad (n = 0?, 1, \dots 6).$$

Yerkes Colour Indices. Symmetrically placed in the sky with respect to the Cape Zone are the 1483 colour indices resulting from Parkhurst's measures of photographic and photovisual magnitudes in the Selected Areas at $+45^\circ$. For a grouping according to photovisual magnitude, the mean colour index for all spectral types together decreases slightly with increasing magnitude; at least there is no pronounced increase in colour; for a grouping according to galactic latitude, the mean colour decreases with increasing latitude. Neither of these results would be anticipated from general considerations of stellar distribution.

Greenwich Effective Wave-Lengths. Colour equivalents for all stars down to 10.5, declination $+80^\circ$ to $+90^\circ$ (4472 stars), have been measured and published by Dyson, Davidson and Martin. Potsdam visual and Harvard photographic magnitudes are also given for most of the stars. Within the magnitude interval covered there is little evidence of change in the percentage of different colours. The measures show clearly that giant stars are redder than dwarfs of the same spectral type, but the differences are scarcely large enough to be used as a criterion of luminosity for individual stars.

Exposure Ratios and the Method of Tikhoff. Baade and Malmquist (Hamburg, *Mitteilungen*, 5, No. 21) have independently determined the colours of the Polar Sequence by means of exposure ratios, and have extended the list of known colours by including all stars in *H.A.* 48 within $30'$ of the pole. The results are standardized on the international colour system and afford useful material for improving the colour index of individual stars.

Malmquist has extended the investigation to 3700 stars in high galactic latitudes (Lund, *Meddelanden*, Ser. II, No. 37). Grouped according to magnitude (for details of magnitudes, see above), the mean colours show a decrease between magnitudes 9 and 10. Below 11 the customary increase with increasing magnitude appears; but the means are not greater than those found by Seares (*Mt Wilson Contr.* No. 287) for all latitudes together. Larger values are to be expected in high galactic latitudes, and the spectra of the *Henry Draper Extension* indicate that the observed values should be larger.

Miss Cannon has classified the spectra of several hundred stars in Malmquist's list. An investigation by Shapley and Miss Walton (*Harvard Bulletin*, 859) reveals that the relation between spectral type and colour shows a considerable shift relative to the standard relation of bright stars, the colour of the faint stars at the galactic pole being found lower. The signification of this phenomenon is not clear. The spectral types are mostly G-M.

Öpik (Tartu, *Publications*, 26, No. 3, 1925) has used Tikhoff's method of determining colours for a list of 104 bright stars, including, however, both giants and dwarfs. The dependence of colour on absolute magnitude is well shown, and is found to extend to M stars, a result of interest because certain other methods fail to show colour differences for giant and dwarf M's, probably because of the particular spectral regions compared.

Stars of large proper motion up to magnitudes 8.5-10.0 are also included in a programme for determination of colour equivalents according to Tikhoff's method. On the other hand an investigation by Öpik just completed gave the interesting result that the colours of red *giant* stars permit a determination of the

absolute magnitudes with high accuracy (p.e. 0.3–0.4 mag.), the spectral type being known. Thus bright red stars deserve special attention in the investigations upon colour indices.

Vanderlinden has made an extensive series of observations with the 60-inch reflector at Mount Wilson for the determination of effective wave-lengths of faint stars of large proper motion and known parallax, of stars in and near Praesepe and in M 51, and of the central stars in giant planetary nebulae. Observations with the 2-foot Yerkes reflector will give the colours of stars to photographic magnitude 14.5 in Selected Areas 40 and 41.

A comparison with Parkhurst's photometric results shows that systematic differences exist between the colour-indices of Parkhurst and those derived from effective wave-lengths using the stars of the Polar Sequence for calibration. With the new results the average colour in the two areas becomes nearly the same, instead of the difference + 0.46 found by Parkhurst.

Schilt reports that he finds by plotting Parkhurst's colour indices against the quantity $H = m + 5 \log \mu$ differences in the characteristic curves for different Selected Areas, which might depend on systematic errors in the colour indices like those indicated in the work of Vanderlinden.

Lundmark has measured effective wave-lengths for small extra-galactic nebulae and for nuclei of some of the big nebulae, in all about 300 objects, from plates taken with the 60-inch reflector at Mount Wilson. Evaluation of the scale has been made by using von Zeipel's colour indices for the cluster Messier 37. The results will soon be published.

The colour equation and scale differences of the Bergedorf visual magnitudes of faint stars in the Pleiades relative to Mount Wilson photovisual measures is discussed by Graff in *A.N.* 221, 31, 1924.

SPECTRAL PHOTOMETRY

The 30-inch reflector at Greenwich is being used for spectrophotometric observations by the method of crossed grating and prism. Relative temperatures (on the assumption of black body radiation) for 22 bright stars of types B and A have been obtained by Greaves, Davidson, and Martin. (*Monthly Notices*, 86, 33, 1925; 87, 352, 1927.)

Lindblad (*Nova Acta Reg. Soc. Sci. Upsaliensis*, Ser. IV, 6, No. 5, 1925, and *Ibid.*, *Volumen extra ordinem editum*, 1927) has applied the spectral photometric criteria developed by him to about 2000 stars in the Greenwich Astrographic Zones. Short and narrow spectra are used (dispersion 1.4 mm. H γ to H ϵ) and the limiting magnitude is about 9.5. For types F8 and later the relative intensity in two closely adjacent regions on opposite sides of the G band affords an excellent measure of colour, while the cyanogen absorption relative to that in an adjacent region determines the absolute magnitude. The earlier measures were estimates obtained with the aid of graduated exposures. Now a Schilt photometer is used to measure spectra obtained with a prism and crossed grating. With this improvement in method, the systematic observation of the zone + 65° to + 70° has been undertaken at Upsala by Lindblad and Öhman and will be continued at Stockholm. For the early types the integrated intensities of hydrogen lines, and particularly the relative values of H γ and H δ for the same mean intensity of these lines, promise to play an important part.

Although not published within the interval covered by this report, the work of Jules Baillaud (*Bulletin astronomique, Mémoires et variétés*, 4, Part 3, 1924) should be mentioned because of the care taken to exclude systematic error.

PHOTOMETRIC METHODS

In addition to the description of methods included in the above citations, reference may be made to Motherwell's work with a 6-inch doublet (*Dominion Observatory Pub.* 8, No. 7, 1925), and especially to the fundamental investigation of Eberhard, *Photographisch-Photometrische Untersuchungen* (Potsdam, *Publikationen*, 26, No. 1).

Several methods of measuring colour have been critically discussed by Sternberk (Berlin-Babelsberg, *Veröffentlichungen*, 5, No. 2), with a view to increase in precision and economy of time at the telescope. Eberhard (*Probleme der Astronomie, Festschrift für Hugo v. Seeliger* (1924), p. 106) shows that variations in the thickness of the photographic film have great influence on measures of effective wave-length.

GENERAL REMARKS

En résumé, the points to be stressed are mainly those embodied in the resolutions adopted by the Union in 1925. (*Trans. Int. Astron. Union*, 2, 238, 1925.) A survey of recent investigations reveals a gratifying accumulation of photometric data, but there still remain serious obstacles in the way of full utilization of the results now available. The difficulty, as usual, is the uncertain relationship of the various photometric systems in respect to zero point, scale, and colour equation. The differences for the Harvard visual and the Mount Wilson photovisual magnitudes of stars at the pole are well known (*Mt Wilson Contr.* No. 288). Could it be established that the Harvard magnitudes of these stars are accurately representative of Harvard visual magnitudes in all parts of the sky, an important step would have been taken, for it would then be possible to reduce all the important collections of visual magnitudes to a homogeneous photovisual system. The Mount Wilson photovisual scale still lacks direct confirmation, but the indirect test afforded by combining various accordant systems of colour indices with the accepted photographic scale leaves little doubt as to its substantial accuracy.

The unification of existing visual magnitudes by some method of intercomparison which will include the photovisual magnitudes of the polar stars is therefore a desideratum of first importance. And what is said of the data for stars at large also applies to results for special classes of objects, such as clusters, double stars, etc.

Among special classes of stars, those of large proper motion and faint apparent magnitude are in urgent need of observation. Both colours and magnitudes are required. Preference should be given to stars of known parallax and to those under observation for parallax determination. The extension of our knowledge of the luminosity function is dependent on accurate data for these objects.

The successful reduction of the Cape Astrographic Zones to a homogeneous photometric system by Jones and Halm is worthy of the careful attention of those responsible for the discussion of the magnitudes of other zones.

The scale difference of 9 per cent. between the Yerkes and Mount Wilson photographic scales in the Selected Areas of the 45° zone is evidence that the

difficulties of photographic photometry are not easily overcome and point to the necessity for every possible precaution, if systematic errors are to be avoided.

Because of the theoretical consequences involved, the evidence for the existence of preferential colour indices as real physical characteristics should be critically examined. That already presented by Jones and Halm should stimulate the systematic observation of colours of stars. The relation of mean colour to apparent magnitude and galactic latitude is still very imperfectly known. The data have a direct bearing on the problems of stellar distribution, and, independently of such considerations, are important for the comparison of photographic and visual or photovisual magnitude systems.

Because of their great astrophysical significance, attention is again directed to the importance of radiometric and spectrophotometric observations. At the same time, the inherent difficulties of spectral photometry must be realized by the observer. Independent methods of procedure probably must be devised as a control if the results are to be really significant.

The following resolution was accepted at the suggestion of MM. Grouiller and de Roy.

The Commission formulates the wish that visual sequences of comparison stars should be determined as soon as possible for those variable stars in Nijland's List I (*Transactions Int. Astron. Union*, 2, 104), for which such sequences do not yet exist.

The Commission insists that notably in this particular case these photometric measures should be referred to a well determined photometric system (international photovisual sequence) and that each observer determines and gives the chromatic equation with reference to this basic system.

F. H. SEARES

President of the Commission