25. COMMISSION DE PHOTOMETRIE STELLAIRE

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SOUS-COMMISSION DES ETALONS DE GRANDEUR STELLAIRE

PRÉSIDENT: M. GREAVES.

MEMBRES: MM. Hertzsprung, Oosterhoff, Seares, Shapley, Stoy, Wesselink.

SOUS-COMMISSION DES SÉQUENCES DE MAGNITUDES

PRÉSIDENTE: MME PAYNE GAPOSCHKIN.

MEMBRES: MM. Vyssotsky, Wallenquist.

Since the last report of our Commission, now 10 years ago, there has been important progress in the development of photometric methods, notably the increase in sensitivity of the photoelectric cell. This improvement opens a wide field of useful work even with smaller instruments in the hands of skilled observers. As the cell can only deal with one object at a time, it is desirable that an increased number of instruments be adapted for this kind of work.

The photographic method, which is now antiquated in every case where the highest accuracy is required, will still maintain itself when the problem is to obtain approximate information about a large number of stars within a reasonable time and for the photometry of the very faintest stars which can be reached.

General photoelectric photometry should, of course, be effectuated in two colours, preferably selected in such a way that close similarity with ordinary photographic and photovisual magnitudes is achieved. Attention should be paid to the possibility of adding white dwarfs to standards of faint stars, among which there will otherwise, owing to selective extinction in space, be a natural lack of stars with small index of colour. Also from this point of view an examination of white dwarfs on constancy of brightness is wanted.

That the photoelectric cell, in spite of its high accuracy and the simplicity in the reduction of the measures, has so far rarely been used for general photometry, where comparison of stars far from each other in the sky is needed, has its reason in the necessity of a more precise knowledge of the differential extinction than is ordinarily available. The first thing to do, therefore, will be to establish a considerable number of fundamental stars of selected brightness and colour (avoiding double stars) evenly distributed all over the sky in the fashion adopted for the visual Potsdam photometry.

I see it as a preliminary task of this Commission to agree about recommendations in this line.

E. HERTZSPRUNG
President of the Commission

REPORT OF THE SUB-COMMISSION ON SEQUENCES OF MAGNITUDES

This sub-commission was established in recognition of the need for reliable standard magnitude sequences for investigations of stellar distribution, variable stars, galaxies, faint asteroids, and proper motion stars. (*Trans. I.A.U.* **6**, 341, 1938.)

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The existing sequences for variable stars constitute an enormous body of material. Unfortunately, however, very few of these sequences have been adequately investigated as to the system of magnitudes, i.e. as to zero point, scale, and colour equation.

Another large body of material is found in the Mt Wilson magnitudes in the Selected Areas north of $-15°$. These are well established as to system, but they do not afford means for other investigators to determine their individual colour equations.

It is very difficult to recommend an ideal method of standardizing sequences. Direct comparison with the North Polar Cap is not entirely satisfactory in cases of sequences remote from the pole, as systematic errors affecting the scale are introduced. (Weaver, *Ap. J.* **106**, 366, 1947; Wirtanen and Vyssotsky, *Ap. J.* **101**, 141, 1945; Bergstrand, *Trans. I.A.U.* **5**, 157, 1935). While the half-filter method seems to be much more promising as regards scales, it has been relatively little tried and it does not fix the zero point. The colour equation of any sequence can be determined either by direct comparison with the North Polar Cap or by a determination of effective wave-length with a coarse grating. Probably the most reliable method of determining scale and colour is by means of photoelectric photometry, although we cannot at present hope that very many sequences of faint stars can be established in this way.

In order to make progress toward establishing more nearly adequate sequences with well determined zero point, scale and colour equation, the sub-commission makes the following recommendations:

1. That well-determined sequences, photographic and photovisual, be established in several declination zones. The Harvard Standard Regions at $+15°$ (C regions) are being actively investigated at Harvard; those at $-45°$ (E regions), by Dr R. H. Stoy of the Cape Observatory. The D regions $(-15°)$ should receive similar study.

2. That these sequences be determined by more than one observatory, and that they be observed by photoelectric photometry as well as by photographic methods.

3. That the individual observers, when publishing sequences, include wherever possible either the colours or the spectra of the sequence stars.

It is realized that these recommendations involve a great amount of effort, but until satisfactory standard sequences are available it will be impossible to bring uniformity into the enormous existing mass of heterogeneous material.

CECILIA PAYNE GAPOSCHKIN
Chairman of the Sub-commission

ADDENDUM I

Report of the Sub-Commission on Standards of Stellar Magnitude

The task entrusted to the Sub-Commission was to report on the memorandum by Prof. E. Hertzsprung (*Trans. I.A.U.* **6**, 407, 1938) advocating that photographic magnitudes should be abandoned as standards as soon as possible and should be replaced by a system of monochromatic magnitudes to be obtained by spectral photometry of the region between H_δ and H_ϵ.

The advantages of monochromatic magnitudes over heterochromatic ones are well known. Monochromatic magnitudes are capable of precise definition in simple physical terms and most astronomers would agree that it is ideally desirable to set up a standard sequence or sequences of monochromatic magnitudes. But the Sub-Commission are at present concerned with a situation in which any recommendation as to the immediate future activities of astronomers must be guided by certain practical considerations. Stoy points out that 'many of the most important problems of the structure of our own Galaxy and of the extra-galactic nebulae depend on a knowledge of the brightness of the faintest stars which can be reached with our telescopes. To observe such stars the fastest plates, sensitive to a wide spectral range, must be used, while the work must be done with in-focus images. Since these magnitudes have ultimately to be compared with those of brighter stars, the latter have also to be observed in a similar manner. This leads us back to ordinary magnitudes of the type now in use.' A similar view is expressed by Seares who comments that 'there will always be stars so faint, that a wide spectral interval—e.g. the Pg region—must be used to observe them at all. To meet these needs the North Polar Sequence standards should be retained.'

Stoy makes the further comment that 'ordinary magnitudes are convenient parameters to express a rather indefinite function of the energy output of a star integrated over a limited spectral range when the star is being regarded as a member of the general stellar population. When we regard a star as an individual physical body we want to know something very much more specific, viz. the intensity distribution of the stellar radiation from end to end of the spectrum. It is possible to determine the magnitudes of several hundred thousand stars; on account of the vast labour involved it is possible to investigate the continuous spectrum of a few thousand selected stars only.' This view is shared by Greaves who considers that monochromatic magnitudes should refer to the continuous spectrum alone and thinks that while the establishment of sequences of such magnitudes is desirable it is primarily a matter for Commission 36, the aim being to obtain detailed knowledge of a limited number of stars and so to contribute to the astrophysical study of stars as individuals.

Oosterhoff considers that even if it be granted that the existing photographic standards be replaced by monochromatic ones the latter should be of the highest possible accuracy and it would be inadvisable to attempt to establish monochromatic sequences by the existing methods of photographic spectrophotometry. He remarks that 'in view of the difficulties met in photographic photometry on the one hand and the recent developments of photoelectric photometry on the other, it does not seem wise to determine a standard sequence with the aid of inferior methods. At this moment photoelectric magnitudes are usually far from being "monochromatic", but spectra are already being registered photoelectrically at the telescope, and the method would yield directly the "monochromatic" magnitudes required. A large telescope and a refined equipment would however be needed.' Hertzsprung expresses agreement with this view and Wesselink also thinks that the photoelectric cell should replace the photographic plate for the problem of determining standard magnitudes in a sequence of stars. He points out that photoelectric magnitudes are not sensitive to variations in focal setting and that whereas photographic magnitudes are complicated by the existence of a photographic analogue to the Purkinje effect there is no corresponding source of trouble in photoelectric work. Stoy refers to the development of photoelectric methods, but remarks that there is one field in which it appears that photographic methods will hold their own, viz. the determination of magnitudes where large numbers of stars can be observed together.

Shapley writes 'that the development of a photometry in a limited region of the spectrum would be a nice addition to what we have at the present time. But it will be a long time before we can safely or intelligently abandon the existing visual, photovisual, and, especially, the photographic magnitudes. The idea is good. Some years ago we experimented with the setting up of a series of monochromatic magnitudes. If they are done cleanly enough, and numerously enough, they can take the place of a lot of spectroscopy, absolute magnitude work, as well as standard photometry. But technically we are far from able to run through a good set of narrow magnitude standards for general use. In fact, as you may know, we have great difficulty in astronomy in getting anyone to work systematically on the basic photometry we all feel we need.'

Wesselink agrees with Hertzsprung that standard magnitudes should be nearly monochromatic, but criticizes Hertzsprung's contention that ordinary photographic magnitudes do not fulfil this requirement because of the marked variation of effective wave-length with colour. His criticism is briefly as follows:

Denote the energy distribution function by $i(\lambda)$ and the sensitivity function (ignoring any effect analogous to the Purkinje phenomenon) by $\phi(\lambda)$. The brightness is then

$$I=\int_0^\infty i(\lambda).\phi(\lambda).d\lambda.$$

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If we now put $$i(\lambda) = i(\lambda_0) + (\lambda - \lambda_0)\,\psi(\lambda),$$

we get $$I = i_0 \int_0^\infty \phi(\lambda)\,.\,d\lambda + \int_0^\infty (\lambda - \lambda_0)\,\psi(\lambda)\,.\,\phi(\lambda)\,.\,d\lambda,$$

where $$i_0 = i(\lambda_0).$$

If the second derivative of $i(\lambda)$ be considered negligible then

$$\psi(\lambda) = i'(\lambda_0) = i_0'$$

and we can make the second integral in the expression for I vanish by defining λ_0 so that

$$\int_0^\infty (\lambda - \lambda_0)\,\phi(\lambda) = 0.$$

We then have $$I = i_0 \int_0^\infty \phi(\lambda)\,.\,d\lambda,$$

so that I is proportional to i_0 and the heterochromatic magnitudes are thus identical with monochromatic magnitudes at wave-length λ_0. In practice (if all absorption lines are smoothed out) the second derivative $i''(\lambda)$ can be ignored and the magnitudes are accordingly essentially monochromatic. But the wave-length λ_0 is not the effective wave-length which may be defined as the weighted mean of λ with weight $i(\lambda)\,\phi(\lambda)$. λ_{eff} varies from star to star in virtue of the *first* derivative $i'(\lambda)$, but the magnitudes only cease to be essentially monochromatic if the second derivative cannot be safely ignored.

If Wesselink's argument be accepted then it would seem that since photographic (and other heterochromatic) magnitudes are essentially monochromatic they could be referred to standard monochromatic magnitudes at the appropriate wave-length. This would mean that although heterochromatic measures involving a considerable wave-length range are necessary for the faintest stars, the fundamental standard sequences could be monochromatic. To this argument Greaves raises the objection that the effect of spectral lines is being ignored. Two stars may have the same monochromatic magnitude at wave-length λ_0 and yet their heterochromatic magnitudes, referred to the same wave-length, may be different if the distribution of spectral lines is different for the two stars. He therefore considers that as long as certain problems demand the measurement of photographic magnitudes for faint stars, the standard sequences on which the measures must be based must also be photographic.

From the above it will be seen that as regards the answer to the immediate question referred to them the members of the Sub-Commission are unanimous in considering that at the present time the Commission should not attempt to replace the existing photographic standards of magnitude by the monochromatic standards envisaged by Prof. Hertzsprung. But this does not mean that the Sub-Commission regards the present standards as entirely satisfactory; the opinion of its members is rather that the time has not yet come for making specific recommendations for their replacement. By presenting his memorandum to the Commission Prof. Hertzsprung has done good service in stimulating discussion on matters which are fundamental to the whole subject of stellar photometry, and it is hoped that further discussion will take place at the Zürich meeting. The concluding portion of this report is intended to serve as a basis for such discussion.

It will probably be generally agreed that photographic magnitudes do not provide entirely satisfactory standards. In addition to the difficulties inherent to any system of heterochromatic magnitudes they suffer from the existence of the photographic Purkinje effect, which means that the sensitivity factors $\phi(\lambda)$ are not functions of λ alone but involve the brightness itself. Further, the factors $\phi(\lambda)$ involve the transmissive properties of the atmosphere and the optical train used as well as the characteristics of the photographic emulsion. To make photographic (or any other heterochromatic) magnitudes strictly self-consistent it would be necessary for each observer to work at a definite altitude as well as employing a definite instrument working under definite conditions; for photographic magnitudes these definite conditions would include the use of a definite emulsion and a definite exposure time. Each such set of observations would define a separate system of magnitudes and the relationships between the various systems would involve colour. This means that if each separate system of photographic magnitudes is to be reduced to any common standard the magnitude measures must be accompanied by measures of colour, a fact which has been pointed out by Seares and others and which has been stressed by Stoy who remarks that 'magnitudes are a function of two independent variables, the total energy received from a star and the spectral distribution of this energy. In the ideal case of a star radiating like a black body of temperature T the magnitude would be a function of its surface area and of T. Actual stars do not radiate exactly as black bodies, but if we are comparing star with star, we can assume that the great majority have energy distributions which can be specified by a parameter similar to T (for exceptional objects like planetary nebulae, Wolf-Rayet stars, etc., magnitudes can have no precise meaning).'

It is to be feared that some astronomers still do not realize the desirability for accompanying measures of magnitude by measures 'of a parameter similar to T'. Indeed it is somewhat doubtful if this will be enough if magnitudes are to have 'precise meaning'. It is too little realized that any measure of heterochromatic magnitude is a composite measure of the energy received in the continuous spectrum of a star and of the strengths of the spectral lines, and that the contribution of the latter to the total brightness can amount to something of the order of half a magnitude. This means that if two stars have the same surface area and if their outputs of continuous radiation are the same it still can happen that the magnitudes can be substantially different (e.g. as between supergiants and main sequence stars). It is possible that a third parameter, expressing average line intensity, is required; it could be obtained perhaps by magnitude operations using a filter which isolates the higher members of the Balmer series.

But, on the other hand, in spite of the undoubted difficulties which beset the use of heterochromatic magnitudes in general and of photographic magnitudes in particular there remains the fact that for the elucidation of some of the most important problems in astronomy we require measures of brightness of the faintest objects accessible to observation and for these measures there is no practicable alternative to photographic magnitudes, since we cannot afford to lose light by restricting the range of wave-length used. But it is important that observers should realize the inherent difficulties. It is especially important that it should be realized that every instrument, working under prescribed conditions, will, if high accuracy is the aim, define its own magnitude system and that this system will differ from other systems by a colour term and, possibly, by an additional term involving average line intensity. A consequence of this is that when high accuracy is contemplated, plates taken with a given instrument cannot be calibrated for scale by exposing them to sequences which have been 'standardized' with different instruments working under different conditions. It would seem obvious that magnitudes in one individual system cannot be standardized by using magnitudes appertaining to other and different systems, but this does not seem to have been always appreciated. Of course, if the highest accuracy is not the aim, the differences between two systems obtained under broadly similar conditions can be ignored and the technique becomes easier.

With regard to monochromatic magnitudes this term appears to have been used by different people in different senses. By monochromatic magnitudes some astronomers mean magnitudes appertaining to the continuous spectrum alone; the determination of such would require the employment of the technique of spectrophotometry using an adequate dispersion. Monochromatic magnitudes in this sense could only be practicably measured for a limited number of bright stars; they would form a welcome addition to astrophysical data and are a matter for the attention of Commission 36 rather than Commission 25. But from Prof. Hertzsprung's memorandum it appears that he contemplates magnitudes restricted to a comparatively narrow range of wave-length but integrating all the spectral lines in that range. For some wave-length ranges the contribution made by the lines to the total magnitude would be greater than for photographic magnitudes and for others it would be less. It should be noticed that two such monochromatic systems, centred at the same wave-length, but employing different wave-length ranges, will not necessarily be identical magnitude systems since the line contributions may be different; similarly a heterochromatic system may be essentially monochromatic at wave-length λ_0 in Wesselink's sense, but the magnitudes may not be identical with those of a monochromatic system at wave-length λ_0. This is an argument against any attempt to lay down monochromatic standards on which the photographic magnitudes of the fainter stars are to be based. But, of course, it is not to be implied that monochromatic magnitudes of this kind would not have their uses. One use has already been suggested; magnitudes obtained by employing a filter restricting transmission to the higher members of the Balmer series may provide, when compared with other magnitudes, a measure of average line intensity (in this way we could get a numerical measure of the *c* characteristic).

It is clear that there is plenty of scope for useful and stimulating discussion, but most astronomers will probably agree that this is not a matter on which Commission 25 should attempt to issue anything in the nature of a directive. The disadvantages of the present magnitude system are already obvious to many, and attempts to remove them may safely be left to individual enterprise. On the other hand, many astronomers are anxious to obtain answers to the problems which require a photometric approach (e.g. problems of galactic structure) and will push ahead employing the existing photographic technique which has been shown to be quite effective for many purposes. The best service that the Commission can perform at present is to stimulate discussion and research on the one hand, and, on the other, to emphasize that the study of some very important problems can be advanced by systematic work on established lines.

W. M. H. Greaves
Chairman of the Sub-Commission

ADDENDUM II

At the request of the Chairman, Prof. Redman gave some details of a large photometric programme being followed under the direction of Dr Stoy at the Cape. The work started when it was decided to measure accurate magnitudes in conjunction with a positional programme, viz. the photographic repetition of the A.G. zones. This original programme is still being continued (photovisual and photographic magnitudes between about 7 and $10^{m}\cdot5$ *pv*), but during its early stages it was discovered that the available standard stars in the southern sky were entirely unsatisfactory, so that another large programme was commenced, devoted to standardizing the magnitudes of stars in the E regions at -45° declination, over the range of brightness just mentioned. Using the twin photometric cameras (4-component Ross-type lenses, 35 in. focal length, 5 in. aperture stopped to 3 in.) at first at the Cape and later at Pretoria, extensive intercomparisons of the E regions have resulted in a self-consistent system of magnitudes (*pg* and *pv*) with a mean error per star of about $0^{m}\cdot02$ or $0^{m}\cdot03$. The scale of the magnitudes has been checked by measures using the Fabry method. It is of the highest importance that the magnitudes should be reduced to the accepted international photographic and photovisual systems, and thus the outstanding problem at present is to provide an accurate link with the N.P.S. Extensive intercomparisons have been made between the E regions on the one hand and the Pleiades, Hyades, Praesepe, and the Eros comparison stars on the other, but the results have not so far been entirely satisfactory. Now the Cape cameras have been moved to Cambridge, England, where it is intended to intercompare the Kapteyn areas at $+15^\circ$ declination with the region around the North Pole with the highest possible accuracy. Subsequently the cameras will be returned to the Cape, where the E regions will be photographed against the $+15^\circ$ Kapteyn areas. The aim is to continue this work until systematic differences between the E region magnitudes and those at the North Pole do not exceed about $0^{m}\cdot02$ in scale, zero, or colour characteristics, over the range $7^{m}\cdot0$ to $10^{m}\cdot5$ *pv*.

Report of meeting

PRESIDENT: Prof. E. HERTZSPRUNG.

SECRETARY: Prof. H. L. VANDERLINDEN.

Prof. W. M. H. Greaves reads his report of the Sub-Commission on Standards of stellar magnitudes. He considers first the points of view expressed by different authors (Stoy, Oosterhoff, Wesselink, etc.) and lays stress on the actual fundamental basis of stellar photometry.

The Commission recommends that the report by Prof. Greaves be included in the printed report of the Commission.

Dr Redman reports on the photometric work of Stoy on the determination of standards of photographic and photovisual magnitudes in the region of $-45°$ declination and the reduction of those magnitudes to the international scale of the North Polar sequence; the mean error aimed at is of the order of $\pm 0{\cdot}01$ or $0{\cdot}02$ magnitude.

An abstract of Dr Redman's report will be added to the report of the Commission.

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