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A NOTE ON THE ACCURACY OF PHOTOGRAPHIC PHOTOMETRY WITH SCHMIDT TELESCOPE

POZNÁMKA O PŘESNOSTI FOTOGRAFICKÉ FOTOMETRIE SCHMIDTOVÝM TELESKOPEM

ПРИМЕЧАНИЕ О ТОЧНОСТИ ФОТОГРАФИЧЕСКОЙ ФОТОМЕТРИИ ТЕЛЕСКОПОМ ШМИДТА

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1. INTRODUCTION

When studying very weak variable stars and luminous intensity-colour diagrams of star groups photometry by photographic means is used. The question arises, of course, what are the actual possibilities in photographic photometry if Schmidt and Maksutov cameras are used for these purposes. There are already a large number of such instruments in the northern hemisphere and it is therefore questionable whether there is any sense in building more Schmidt and Maksutov cameras with an inlet aperture of about 60 cm to 1 m. Leaving aside a broad discussion on the future of these systems for special purposes, we shall only pay attention to the possibilities for their use in normal observational techniques. It is well known that the advantage of such systems consists in the photographic documentation of a large stellar field. This permits photographic photometry and spectral classification of weak stellar objects, particularly of more extensive star clusters and associations. However, for such work to be done successfully, the instrument must satisfy certain requirements as regards perfection of the image. We have tried to analyze the material obtained so far by us from several instruments commonly used in the world today and to derive some conclusions which might contribute towards solving the question of further designs of instruments of a related type.

The results contained in this communication were obtained as secondary results when using the method to solve a different problem. It is thus necessary to supplement some of the conclusions by papers aimed directly at the method of treating observational material.

We chose the Schmidt camera at the Hamburg—Bergedorf observatory, with which we were able to work, as the standard basic and initial instrument. The diameter of its primary mirror is 120 cm and the correcting plate 80 cm. To the results obtained from this camera we added those respecting the quality of the image and other photographs: from the Schmidt camera AHD from

South Africa and a similar camera at the Tonanzintla observatory in Mexico·
The possibility of spectrophotometry was studied by Znojil [1] in his thesis, where he used photographs from the classical original small Schmidt camera, again from the Hamburg—Bergedorf observatory. The results of the latter paper will be reported on separately.

2. ACCURACY ATTAINABLE IN PHOTOMETRY OF STARS IN SEVERAL COLOURS IN STANDARD SCHMIDT CAMERA

The decisive factor in judging the maximum attainable accuracy in photometry is undoubtedly a comparison of the photoelectric standards with the quantities measured on the photographic plate. One can define the general condition that an ideal state is that when the mean squaer error of the photographic magnitude is the same as that of the photoelectric. It is assumed, of course, that both measurements are performed in corresponding wave-length regions. This condition seems to be exaggerated. It should not be forgotten, however, that by the term photoelectric standard we mean here e. g. photoelectrically measured stars in a small stellar field, e. g. in a star cluster in the international UBV system. Naturally, the mean square errors will be larger here than for normal photoelectric standards. It can thus be said that the mean square error of optimally exact photographic measurements will be comparable with the external accuracy of normal photoelectrically measured stellar magnitudes. If it is assumed that the mean external error of the photoeletric standard is of the order of $\pm$ 0.01 m, then, assuming double the value of the internal mean square error of photographic measurement, the resultant external mean square error should not exceed 0.025. In a paper published earlier by Vanýsek and Rohlfs [2] around 70 standards in the international UBV system are given; in this case only B and V are used in the star cluster NGC 752 measured from 8 photographs (four used in one colour) on an iris photometer with semi-automatic recording on punched cards. The mean square error of photoelectric standards, with the exception of one unexplained case, does not exceed the value of $\pm$ 0.02 m. It is thus clear that the above condition of the mean square error is attained. For stellar fields compared with these standards the error is double to treble, depending on the magnitude.

It can thus be said that the accuracy of one measurement on photographs taken with a good Schmidt system is about $\pm$ 0.03 m.

Five photographs from an AHD camera were used for the comparison made for measurements in the same way without using semi-automatic equipment for punch cards — which is not decisive in this case. Here the mean square error of the standards was about 3 to 4 times higher and unfortunately in some cases was up to an order higher for field stars. The colour system in which the photographs were taken did not agree sufficiently accurately with the international colour system.

The question now arises, why are there such large differences in the accuracy obtainable in photographic determinations of stellar magnitude.

3. ANALYSIS OF IMAGE QUALITY BY EQUIDENSITY METHOD

A cursory glance at enlarged photographs from both the above-mentioned cameras shows the striking difference in the quality of the image. The deformation of the image on the picture from the AHD camera is quite clear. The causes of this deformation must very probably be sought in insufficient centering of the optical system. In order to judge the quality of the image from these two cameras, or of other cameras, we tried at the Institute to analyze the image formation on the plate by the equidensity method.

This method is universally known in scientific photography and is commonly used, particularly in radiation dosimetry, and the analysis of photographic pictures of interference effects; it has not yet found great application in astronomy although it could be used for analyzing flat objects such as comets, solar corona, nebulae etc.*

The equidensity method was used to analyze the photographs from the Schmidt camera of Hamburg observatory and Tonanzintla observatory and from the AHD camera. The deformation of the image of the AHD camera is quite clear, particularly for bright stars, just as for very bright stars of the Tonanzintla observatory camera. Nevertheless, a very important fact, which could be found by measuring on an iris photometer, should not be forgotten, i. e. that weak stars preserve their circular shape. Since equidensity lines enclose the star in points of the same blackening, it is obvious from the original picture that these stars may be treated quite well on an iris photometer. This instrument, as is well known, closes the centrally located star by its iris circular diaphragm in such a way that the edge of the latter encloses the image of the star in places of equal blackening; if this image is really centrally located, it is really circular and the distribution of the blackening in the pattern is symmetrical about the axis passing through the centre of the star perpendicular to the plane of the plate. On the other hand, brighter stars, i. e. about $V = 10.8\,m$ and brighter, first attain a distinctly elliptic and then a quite deformed shape. These shapes of the image exclude beforehand any possibility of symmetrical location in the iris photometer and thus also exclude the attainment of maximum possible accuracy.

As regards the photographs from the Schmidt camera at the Tonanzintla observatory, the slight ellipticity in the image of the stars is obviously caused by an error in guiding. We should like to use the photograph from this camera to demonstrate the difficulty involved in measuring dense stellar fields and as an example we give one distant star cluster near to the Carinae nebula. Such a dense stellar field greatly hampers not only correct centering of the image in the iris photometer but also the irregular transfer of densities between the different stars obviously lowers the resultant accuracy. However, we were not able to make more detailed measurements along these lines.

The equidensity analysis of the image of stars on the photograph from the large Schmidt camera at Hamburg shows the almost ideal circular shape of the stars in a large field of vision and only the bright stars in the second degree of equidensity treatment exhibit a trace of the deformation due to the carrier cross. This deformation appears with stars of the 9th magnitude during a two-minute exposure in the visual region. Since such deformation is absolutely symmetrical, it influences only the gradual curvature of the blackening curve. The choice of exposure time can naturally eliminate this influence.

We tried to analyze by the equidensity method a photograph from the 50 cm

* Note added in proof: N. Richter and W. Högner recently published some very interesting experiences in equidensity method applied in astronomy (A. N. 285, 5/6, 1963; Die Sterne, 40, p. 11, 1964).

camera of the Maksutov type at Kleť. However, even informative enlargements show deformation of the image, which in addition is slightly different at every point of the photograph, so that it was quite obvious that any further treatment of a photograph of such bad quality would be a waste of time. Since this photograph is the only one available from the above-mentioned camera, no preliminary conclusions can be drawn. One should note, however, the important difference between the low-quality photograph from the AHD camera and the equally low-quality photograph from the Maksutov camera at Kleť. While the weak stars from the AHD camera exhibit on the whole circular images, the weak stars from the Kleť camera are deformed in the same way; in addition the density distribution in the image, as follows from a preliminary measurement on a non-recording photometer, is very non-uniform. The origin of such deformations is not only in bad centering of the optical system, as was the case with the large probability in the AHD camera.

In onclusion it can be said that the required accuracy in photometering stars photographically from the photographs of Schmidt or Maktusov cameras can be achieved only if the camera forms an image which can be treated in an iris photometer, i. e. circular and, as regards density, axially symmetrical in a relatively large field of vision. Cameras, which form deformed images as was shown with the AHD camera, can give relatively good results only for weaker stars where the deformation is not yet very pronounced, but in this case it must be borne in mind that the accuracy is worsened by at least half an order. As regards the above-mentioned Maksutov camera, the same or even worse is valid for it, although for a definitive result one would have to determine the cause of such considerable image deformations and only after lowering them could a decisive analysis be made.

We think, however, that this fact should be borne in mind primarily by designers of such instruments since, if the instrument does not provide really perfect image formation, its use is greatly limited or the photographs obtained with it may be of no great use at all. It should be remembered that almost every optical system gives more or less some image formation of the stellar field which often looks aesthetic but a closer analysis shows that it it is useless for scientific purposes.

4. SPECTROPHOTOMETRIC MEASUREMENT ON PHOTOGRAPHS TAKEN WITH SCHMIDT CAMERAS

Several Schmidt cameras have already been used for spectrophotometric measures, as is well known from the literature, but a detailed analysis, particularly for small instruments, has not yet been made. This was the task of the above-mentioned paper by Znojil [1], who evaluated the photographs taken with a small Schmidt camera in Bergedorf, the dimensions of which are: primary mirror 42 cm, diameter of correcting plate 34 cm; prism with refracting angle of 5.5° gives dispersion in the neighbourhood of H_γ 71 μm/mm. A detailed analysis of four photographs from this camera shows that about 70 and more spectral lines can be identified in the spectra and the resolving power for determining the wave-length is between 2 and 20 μm for H_β depending on the spectral region in which we are measuring. As regards the actual determination of the profile of the lines, in this case great accuracy can be achieved, as will be reported elsewhere. However, even in this case the camera has very good definition. For purposes of comparison, one can demonstrate the spectra obtained from the AHD camera, which has much larger dimensions, and from the small Schmidt camera, and the difference in quality is clear at first glance. In general, one can say that what was said about the necessary conditions of quality image formation for stellar photometry is valid to an even greater degree for spectrophotometry with Schmidt cameras.

5. USE OF EQUIDENSITIES FOR MEASURING IMAGE OF STARS TO DETERMINE STELLAR MAGNITUDES

In conclusion we should like to mention the possibilities of using equidensities for stellar photometry. As has already been stated, the equidensities obtained from stellar photographs represent places of equal blackening in the star image. If the image is of sufficiently high quality and centrally symmetrical, the equidensity is a certain analogy of the "corona" around the image of the star in an iris photometer. The magnitude of the "corona" in the iris photometer depends on the choice of photographic material and developer. In both cases the influences are constant although originally different, so that the analogy between the two effects is quite exact. On the other hand, it is well known that equidensities are successfully used in cases where the distance between two places on the plate must be measured exactly, e. g. on a photogram of interference effects, where the accuracy due to using equidensities is up to five-steps [3]. The preliminary results from copies of equidensity images of stars in the star cluster of NGC 752 indicate that this method deserves some attention. The equidensity method works on the basis of the Sabatier effect and its theoretical interpretation is outside the scope of the present paper. Nevertheless, we should like to mention our experience with this method. It was used for other purposes. An example is the case when we used the equidensity method to analyze the head of the comet 1959 k evaluated from photographs taken with a large 120 cm mirror telescope in Asiago. The first equidensity degree was taken two years previously at the Hamburg observatory on somewhat different material so that this example is rather of an illustrative nature. It is obvious even from the equidensity photographs of the head of the comet that this method could be used to analyze stellar images, as has already been stated.

An equidensity line is obtained in places where two regions of blackening, caused by illumination before and during the developing process, meet. If the

Values of γ for diapositive material

Material	Developer	γ
Agfa Dia hardt	methol-hydroquinone	1.73
Agfa Dia hardt	X-ray	2.05
Foma Dia C	rodinal	1.12—1.45
Foma Dia U	methol-hydroquinone	1.41—1.52
Foma Dia U	X-ray	2.00—2.52*)

*) High dependence on temperature of developer and developing time

slope of the gradation curve is smaller than 1 practically no equidenstyi line is obtained. Only for γ larger than 1 do we get an equidensity line, the width of which is given mainly by the slope of the straight part of the gradation curve. The following table gives the values for some materials available to us according to measurements at our Institute.

It is seen that the most suitable material available was the emulsion Foma Dia U, treated in a developer used for X-ray photographs, with which, according to our measurements, it is possible to obtain $\gamma = 2$ and more while preserving the linearity of the blackening curve for a large range of densities. Higher values of γ lead to a considerable narrowing of the equidensity line so that the grain of the emulsion influences its shape. The probable density of the centres of the equidensities was determined by measurement on an equidensity-treated photograph of the copying aperture of the diaphragm, where the width of the equidensity line was 5×10^{-2} mm and the difference in densities between the blackened area and the equidensity was 0.50 to 0.90 according to the type of developer used, for a maximum blackening of 1.50 to 1.60.

It is obvious, of course, that the use of other materials and especially prepared developers will permit much higher quality and greater perfection of the equidensities. The decisive factor for extending this method is the compilation of rapid instructions for testing a procedure permitting at least the first degree of equidensities to be obtained rapidly and reliably from each photograph of the stellar field of average quality. In this way the method could at least partly replace the very expensive iris photometer and make it possible to obtain the stellar magnitudes. The enlarged equidensity image, whether projected or permanently recorded on other photographic material, can be measured by common measuring aids of the simplest type.

REFERENCES

[1] ZNOJIL V., thesis, Prague 1963.

[2] ROHLFS K., VANÝSEK V., Hamburger Mitt. No. 10, 1962.

[3] LAU E., KRUGG W., Die Aequidensitometrie, Berlin 1957.

SUMMARY

Some experiences with measurements on photographic plates taken by various Schmidt and Maksutov cameras are discussed.

SOUHRN

Diskutují se některé zkušenosti získané při proměřování desek z různých přístrojů typu Schmidta a Maktusova.

РЕЗЮМЕ

Приводится дисскусия результатов измерений пластинок из некоторых камер типа шмидта и Максутова.

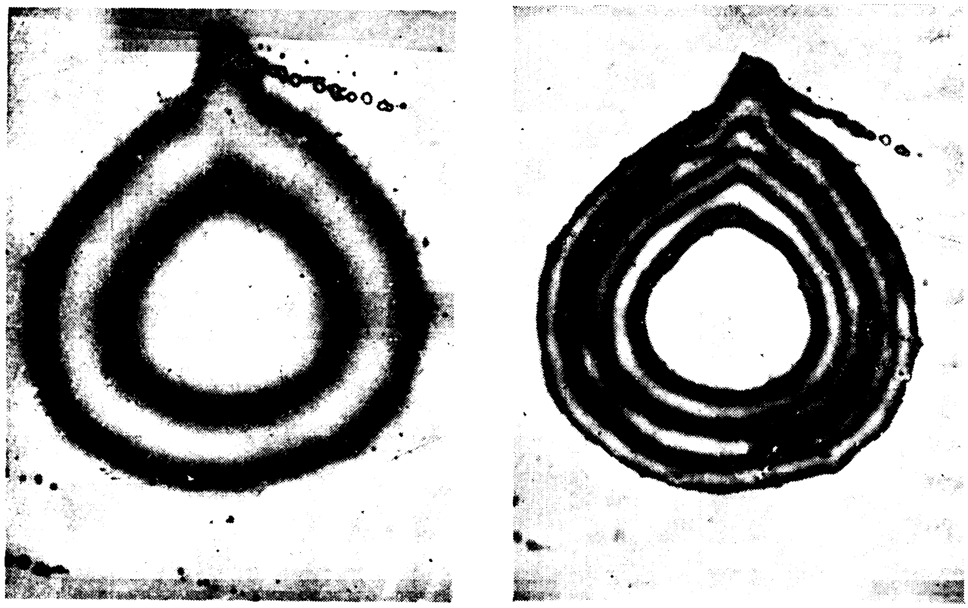

Fig. 1a) and b): Second and third equidensity steps of a picture of comet 1959 k taken with the Asiago refractor.

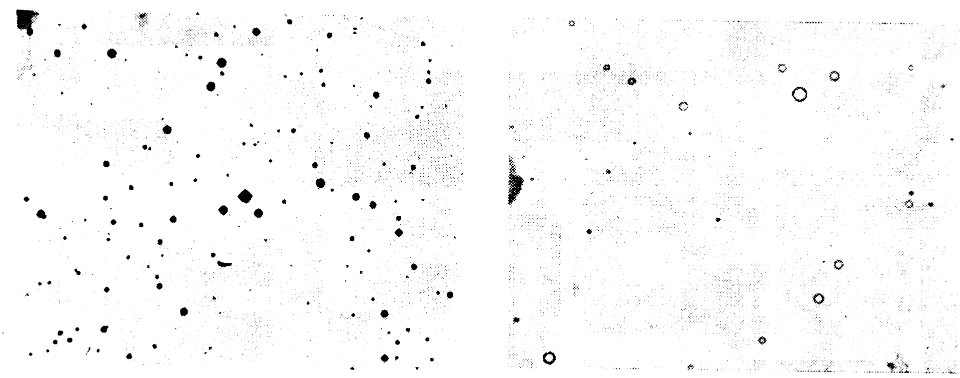

Fig. 2 a) and b): A negative print of open cluster NGC 752 and the first equidensity step of the same stellar field.

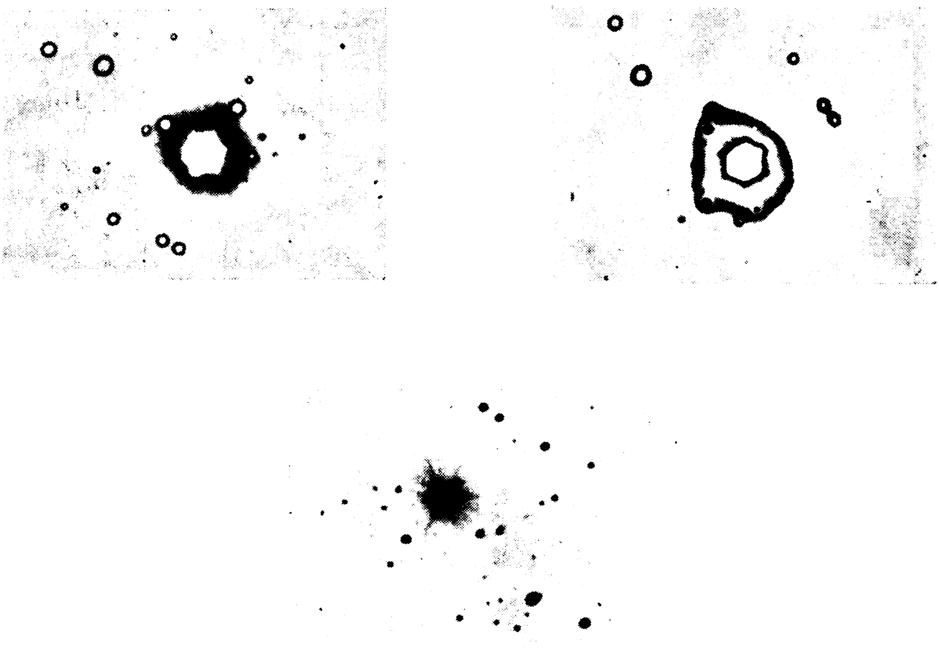

Fig. 3 a), b), c): An enlargement print of an AHD plate reproducing the first and second equidensity steps around the image of a bright star. The original negative reproduction see 3 c).

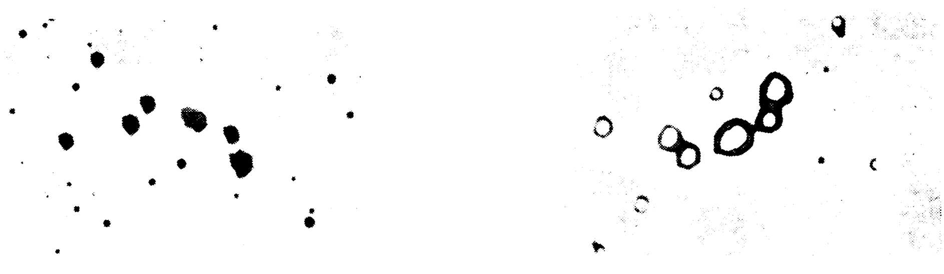

Fig. 4: The central part of an AHD plate reproducing the second equidensity step. Original reproduction at the top.

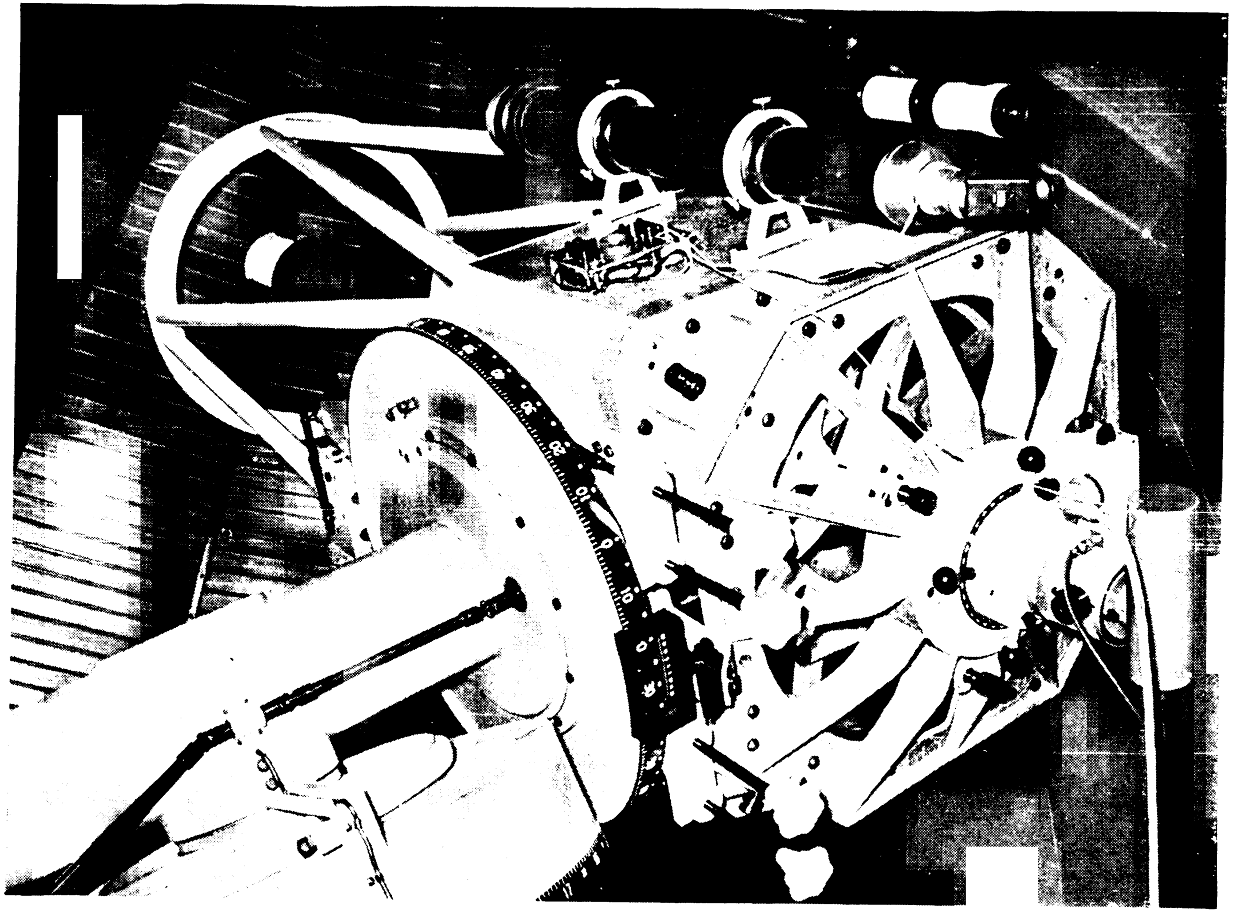

Fig. 1: 65-cm reflector of the Astronomical Institute, Charles University.