ON SOME PHOTOGRAPHIC AIDS FOR THE MEASUREMENT OF ASTRONOMICAL SPECTRA

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It is common experience that most solar and stellar spectra seldom have the sharpness and contrast that we see in spectra of a supergiant like Canopus or of a star like Pleione that is in its shell phase. The measurement of a wavelength of the line for purposes of a velocity or the evaluation of a distortion in a line profile needed to assess the contributor of the companion in a binary system are typical aspects of interest that have motivated several spectroscopic programmes. In the solar case the dispersions needed are so high that the spectral features recorded are diffuse and broad and hence call for special techniques of measurement. It is especially so with the two dimensional aspect of information sought for from either high dispersion solar spectra or monochromatic pictures of high spatial resolution.

There have been many devices of a general nature available in recent years that lighten appreciably the task of the measurer and the demands on his skill. As a consequence, there is much improvement in measurement accuracy, now available, and a greater array of phenomena accessible to quantitative appraisal. The Tomkins and Fred device that has evolved into the commercially available Grant machine, and the fast computer controlled microphotometers have all ushered in an era of measurement applications into routine use that make the utmost of the multiplex aspect of astronomical photography. There are of course special situations that call for modified approaches relevant to the specific task on hand. I propose to give a brief account of how we have, at Kodaikanal and Bangalore, tackled these situations by inexpensive photographic procedures that are simple, versatile and capable of much accuracy.

Most of these techniques of measurement have depended on the application of the Sabattier effect. The method of equidensities and the use of the Sabattier effect to generate them are detailed in the monograph of Lau and Krug (1957). The first astrophysical use seems to have been made by Schröter (1958)when he derived curves of constant density to investigate the sizes of chromospheric elements and their random Dopplershifts, as inferred from high resolution solar spectra. The techniques of equidensitometry gained considerable stimulus from the demonstrations by Högner and Richter (1964a, 1966) of the range of versatility in application. It is now standard procedure to use the Sabattier effect for photometry of the solar corona (Löchel and Högner 1965; Bappu and Bhatnagar 1969; Bappu, Bhattacharyya and Sivaraman 1973) or of comets (Richter and Högner 1964b) and of galaxies (Richter and Högner 1964b; Hodge and Brownlee, 1966).

There are numerous situations in astronomical spectroscopy where the features to be measured are broad and diffuse. In the case of stellar spectra, the shallowness of spectral lines in some stars, make velocity measures difficult and of doubtful accuracy. For bright stars, high contrast emulsions used to record the spectra have aided a great deal. Struve's (1940) radial velocity study of the important eclipsing binary system μ^1, Scorpii with Eastman process emulsion or our study (Ganesh and Bappu 1967) of the southern Wolf Rayet binary γ^2 Velorum with Ilford N-40 process emulsion and Ilford Thin Film Half-Tone plates are examples of how necessary it is to use emulsion of high contrast in such programmes where the spectral lines are broad and shallow. In subsequent studies made of γ^2 Velorum at Kavalur, we find that it is preferable to use even narrow spectra on high contrast emulsion than well widened spectra on the standard fast astronomical emulsions in common vogue.

Similar arguments prevail in the case of solar spectra where the very high dispersion employed spreads out over the emulsion any line which has the Doppler width consistent with the photospheric temperature. But, since solar spectra involve measurement of spectral characteristics of features on the solar surface that are of low contast, and which are subject to seeing fluctuations, a compromise on exposure time becomes very essential. One aims at obtaining exposures of the order of one to two seconds at moments of good seeing on emulsions equivalent in grain size and contrast to the Eastman type IV or type III.

A long time ago Evershed (1913) had developed the positive on negative method which by a process of visual subtraction yields results of greater precision and with a convenience of measurement unattained by the conventional micrometer method of line position measurement. The method is simple and works effectively even when spectra of dispersion ten times higher than that used by Evershed are employed. On recent occasions when we had been engaged in problems of the Evershed effect, much the same procedure (Bhatnagar,1966) has been followed with a minor variation; we now project the spectrum on a positive enlargement and obtain the 'grey' match visually or by photoelectric measurement of the minimum in the diffuse scattered light.

The positive on negative method meets with difficulty when the line is asymmetric, as it would be when the 'flag' effects of Evershed flow appear. It is in situations of this kind that equidensitometry can be used to much advantage. The equidensity contours can be chosen to have values that show up the phenomenon of asymmetry spatially on the solar surface feature. One thereby obtains the value of the displacement with respect to some suitably chosen origin as the sunspot umbra centre or the umbra-penumbra interface.

We encounter a similar problem in the measurement of radial velocities of lines in Wolf- Rayet spectra where the lines are very broad and sometimes asymmetric. Most spectroscopic orbits for binary systems with Wolf-Rayet components are based on micrometer measures made visually or in recent times by means of the Grant machine. The HeII 4686 emission line has very often an asymmetric line profile. The measurement of the centre of gravity of this emission feature poses much difficulty. By the methods of equidensitometry one can easily locate the midpoint of a section of the emission line at a convenient density level and measure its location with respect to the comparison lines. Figure 1 is a Sabattiered version of a spectrum of the Wolf-Rayet star HD 191765. This experience leads us to believe that the equidensitometry technique can also be used very effectively in the measurement of stellar magnetic fields and extended to objects that are not very sharp-lined.

For some time now we have been having a programme of the direct evaluation of chromospheric heights over active regions. When a sunspot that is very close to the limb is examined with a radial slit, the core of a strong line experiences a shift towards the limb. Such shifts, if carefully evaluated, are very effective in indicating the properties of a spot region at normal chromospheric heights. The diffuse nature of the seeing-affected sunspot image call for the use of techniques that keep errors to a minimum. We have adapted the

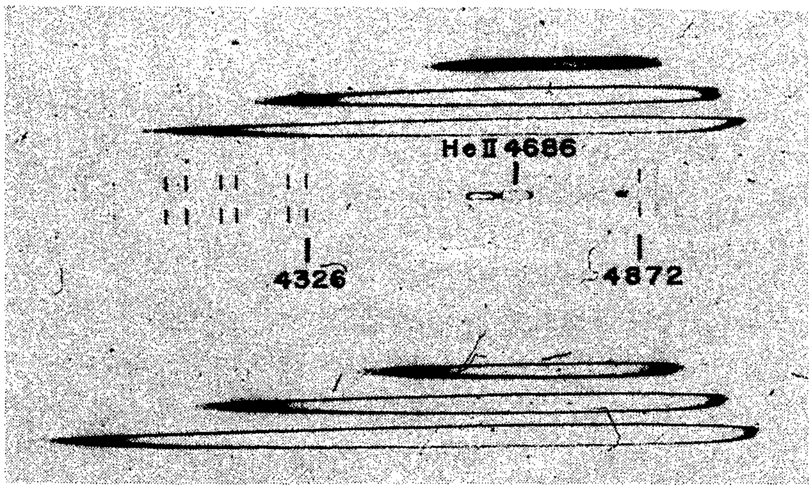

Figure 1. A Sabattiered version of the spectrum of the Wolf-Rayet star HD 191765 for measurement of velocity of HeII 4686.

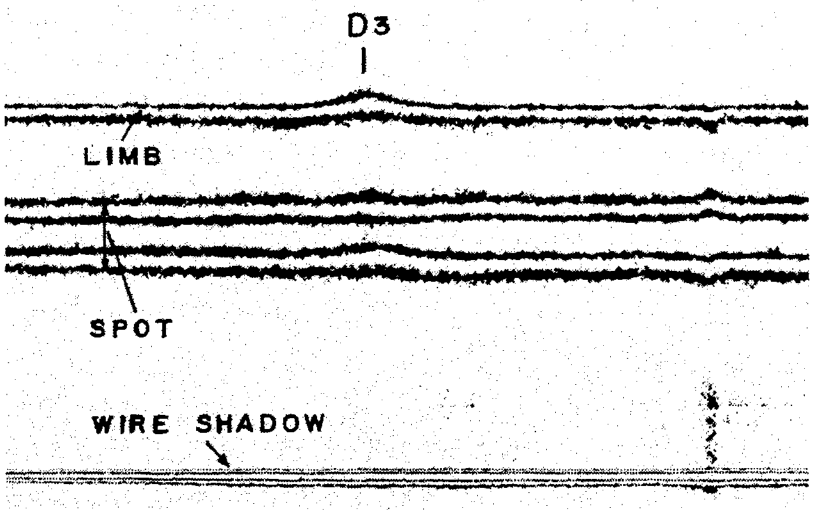

Figure 2. The neutral helium line in the chromosphere and over a sunspot.

equidensitometry technique for this purpose. By Sabattiering the spectrum negative we obtain graded contours whose position can be readily evaluated against a fiducial line in the continuum like a wire shadow across the spectrum. The wavelength dependence of the chromospheric feature is easily measured by a conventional micrometer, for where we would originally have a wide diffuse feature to set on, the photographic aids we have resorted to, give us a narrow line for measurement. Figures 2 and 3 are examples of such contours that we have used.

The Sabattier effect can also be used in applications where the image of the feature of interest is of very small dimensions. Two types of study, where we have also profitably used the equidensitometric technique, are briefly described below. The first refers to isophotes of the D_1, D_2 lines of sodium in comets. We have been interested for sometime in the behaviour of sodium emission in the cometary coma and tail. At the time when Comet Kohoutek had just passed perihelion passage, we tried to study the distribution of intensity in the coma of the comet in the D_1 and D_2 lines separately. For this experiment we had to obtain a monochromatic picture of the coma in each of the two lines of sodium. We did this by opening up the slit of the spectrograph to a width where the two D_1, D_2 slit images would begin to overlap. The grating used had high dispersive power so that one could make the entrance slit as wide as possible without losing the spectral resolution needed for the experiment. We were able to obtain monochromatic pictures that cover an area of 40" x 5" of the coma. The intensity gradients in the coma are steep. But by use of the Sabattier effect, we obtain the equidensities shown in Figure 4.

Another use of equidensitometry that we have utilised to advantage is in stellar photometry. Iris diaphragm photometry from exposed photographic plates of astronomical objects is one of the many areas actively pursued by astronomers. We find that a single stage Sabattiered plate of a cluster or known star field, can in combination with a measuring machine for measurement of diameters yield magnitudes of accuracy comparable to those obtained with an iris photometer. In Figure 5 we show a Sabattiered print of a portion of the central region of M67. In Figure 6 we note that the diameters of the star images measured correlate well over a large magnitude range with photoelectric magnitudes of the cluster derived by Eggen and Sandage (1964). The relationship is linear over most of the range plotted. Calibrated

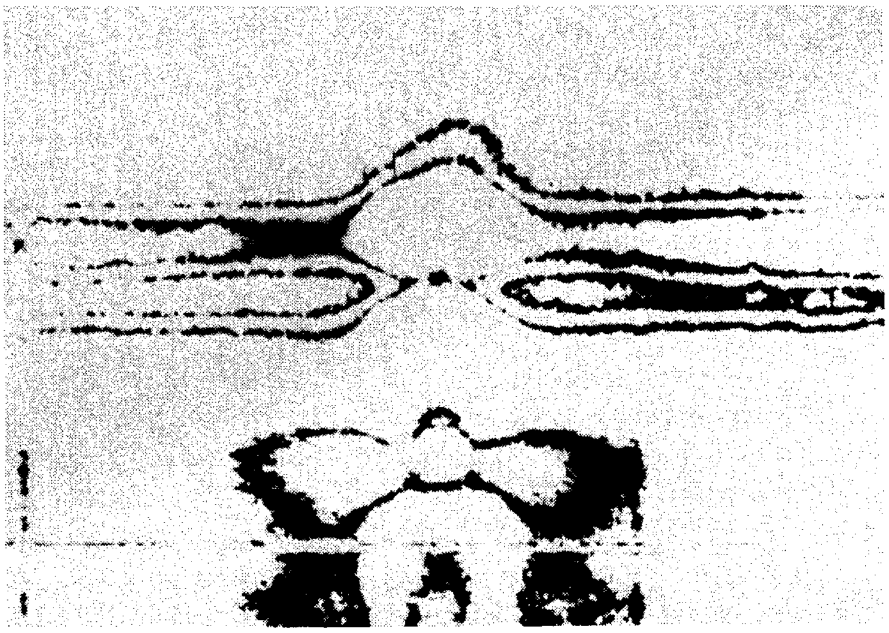

Figure 3. A twice Sabattiered print of a K-line spectrogram with radial slit through the spot umbra.

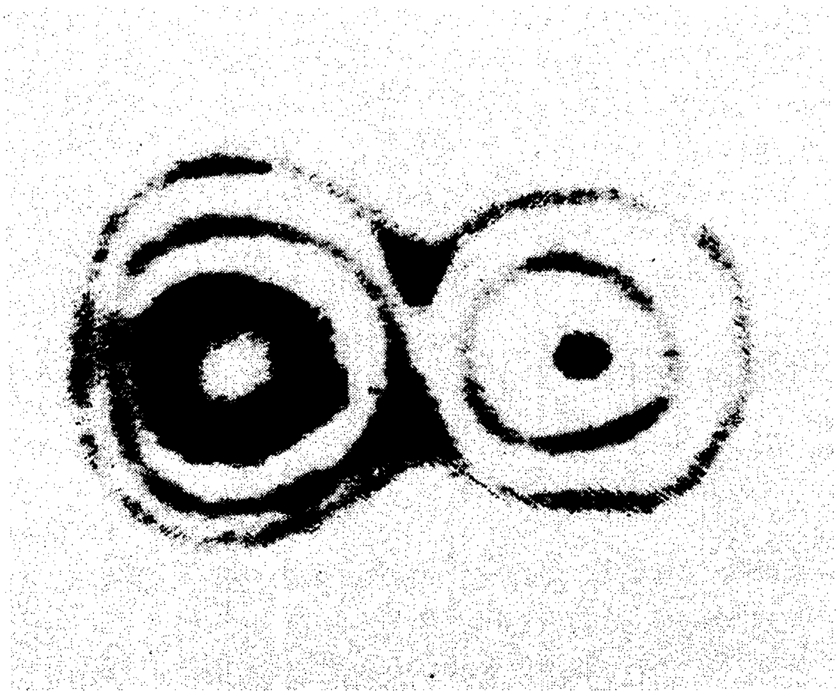

Figure 4. Equidensitometry of a photograph of the coma of Comet Kohoutek in D_1 and D_2 of Sodium.

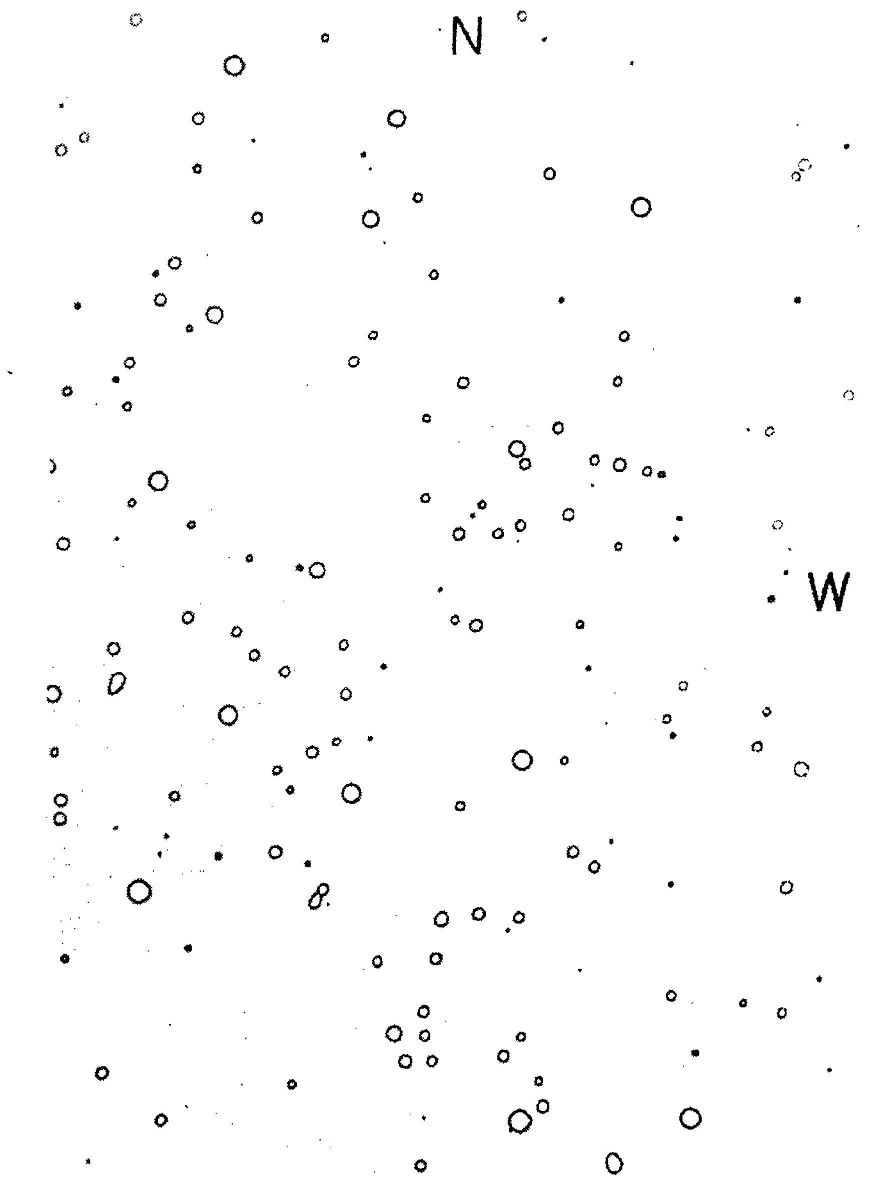

Figure 5. A single Sabattiered print of M67 taken with the 102cm Ritchey-Chretien reflector at Kavalur.

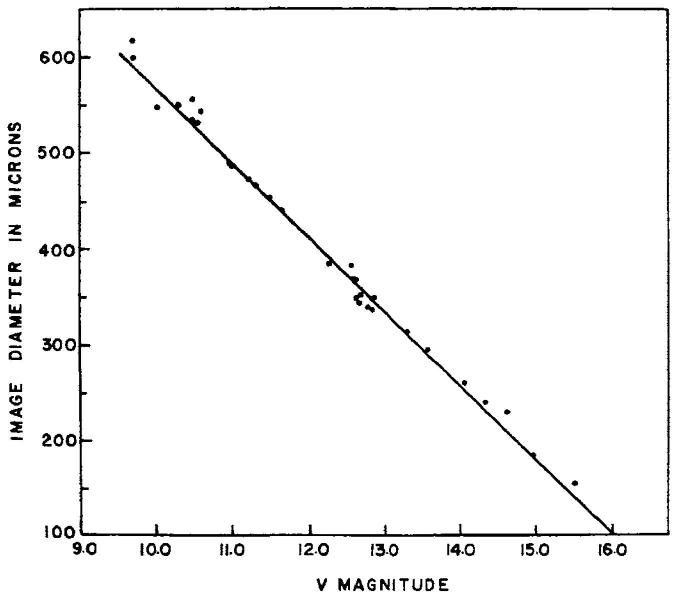

Figure 6. The linear relation between image diameters measured on a Sabattiered print and photoelectric V magnitudes of Eggen and Sandage.

equidensitometry can thus be used for magnitude determinations also.

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DISCUSSION

HOAG : Is there not a degradation of the astrometric properties of Sabattier prints ?

BAPPU : We do not apply astrometric techniques to these prints.