SPECTRAL CLASSIFICATION FROM LOW DISPERSION OBJECTIVE PRISM SPECTRA TAKEN WITH THE UK 1.2m SCHMIDT TELESCOPE

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ABSTRACT

A thin prism (with a dispersion of 2480 Å/mm at H_γ and H_β) is now available for the UK 1.2m Schmidt telescope. A 60-min. unwidened exposure on a IIIa-J (hypersensitized) emulsion reaches fainter than 20 mag. The spectra are measured and digitised with the fast measuring machine COSMOS. A method to determine the red shift of faint galaxies and the spectral classes of faint stars and galaxies from the digitised spectra will be described.

1. INTRODUCTION

I shall report briefly on the work done at the Royal Observatory, Edinburgh by Cooke, Emerson, Kelly, Reddish and myself on automatic digitized spectrophotometry of low resolution objective prism spectra taken with the 1.2m UK Schmidt telescope.

The object of using a thin prism having very low dispersion on a Schmidt telescope is to reach very faint objects. For example, a 60 minute unwidened exposure on IIIa-J emulsion (hypersensitized) with the thin prism on the UK 1.2m Schmidt telescope reaches about $V = 21^{m}.0$. We have also a fast automatic measuring machine, COSMOS, which measures the coordinates, size, magnitude, orientation and shape of images (Pratt, 1977). It can also be used to measure spectra. The large number of objects which appear on the plate can be handled only by using such an automatic measuring machine.

In fields taken away from the galactic plane a large number of objects will be galaxies. The problem of analyzing

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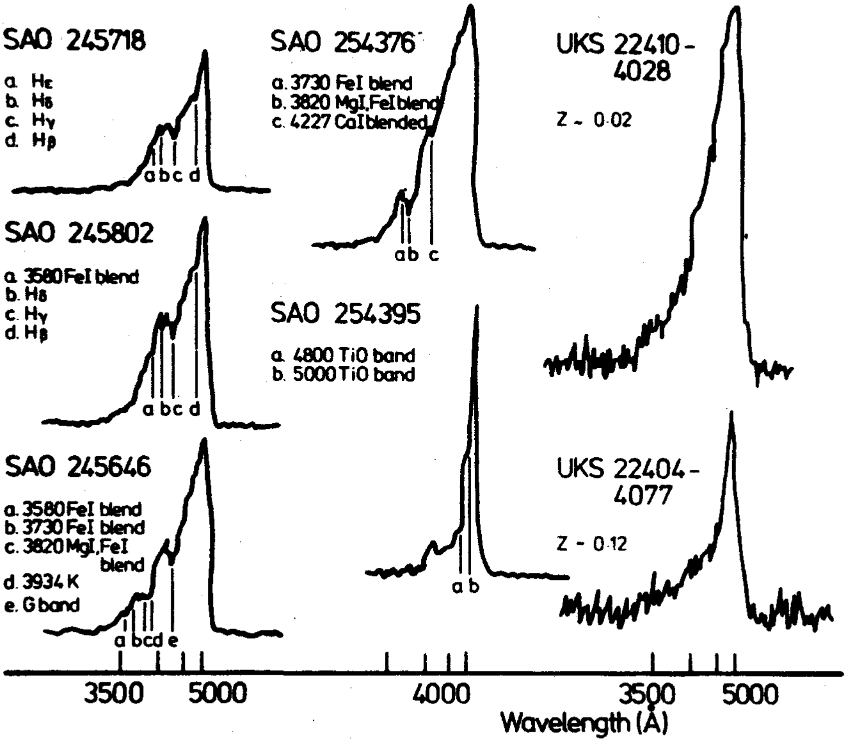

Fig. 1. Examples of objective prism spectra taken with the UK 1.2m Schmidt telescope from Nandy, et al. 1977.

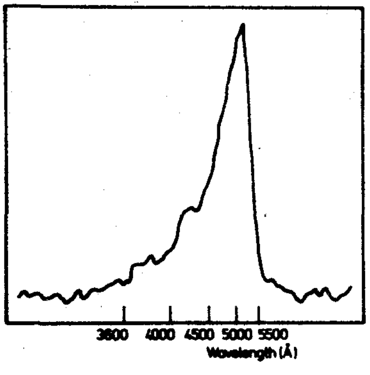

Fig. 2. The characteristic 4000 A feature in late type stars and galaxies E - S0/S_b.

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the spectra is two-fold: (a) the identification of galaxies as opposed to stellar spectra and (b) the analysis of the spectra themselves for classification. I shall outline a method of separating stellar spectra from galaxy spectra by redshift, and a classification system based on colors constructed from COSMOS measurements. The overall aim of this work, however, is to study the distribution of E-SO-galaxies, their clustering properties, and the scale of local inhomogeneity. Any object (star or galaxy) with unusual color can be identified easily and studied individually.

The method which will be described here can be applied to objective prism spectra of any dispersion.

2. OBJECTIVE PRISM FOR THE UK 1.2m SCHMIDT TELESCOPE

The prism, which has a diameter of 1.26m, is made of Schott BK7 glass, and has a high ultraviolet transmission. The dispersion curve has been determined from measurements of 35 individual lines from a total of nine stars (Nandy et al., 1977). At H_γ and H_β the dispersions are 2480 Å/mm and 3515 Å/mm respectively, giving a resolution about 50 A at H_γ and 70 A at H_β. Even at these low dispersions several features are observed. Examples of stellar spectra taken from Nandy et al. (1977) are shown in Fig. 1.

The characteristic features which are common to late type stars and galaxies E to SO/Sb are the G-band followed by a sharp drop in intensity at about 4000 Å. This feature is sufficiently large to show up in our dispersion spectra (c.f. Fig. 2). The same feature shows up well in low resolution spectral scans of late type stars (Fay, et al., 1974). The constancy in position of the 4000 Å feature relative to the plate cut-off of the IIIa-J emulsion has been checked from a number of stars over a range of magnitudes. In an earlier work which was done in collaboration with Malcolm Smith, using the thin objective prism with the Curtis Schmidt telescope at CTIO, it has been shown that the redshift of galaxies can be obtained from the postion of the plate cut-off (5360 Å for IIIa-J emulsion) and the 4000 A feature to an accuracy of $\pm$ 0.02 in redshift, z (Cooke, et al., 1977).

3. MEASUREMENTS OF THE SPECTRA

The objective prism plate is measured, using the mapping mode of COSMOS which produces the transmission values (0 to 127)

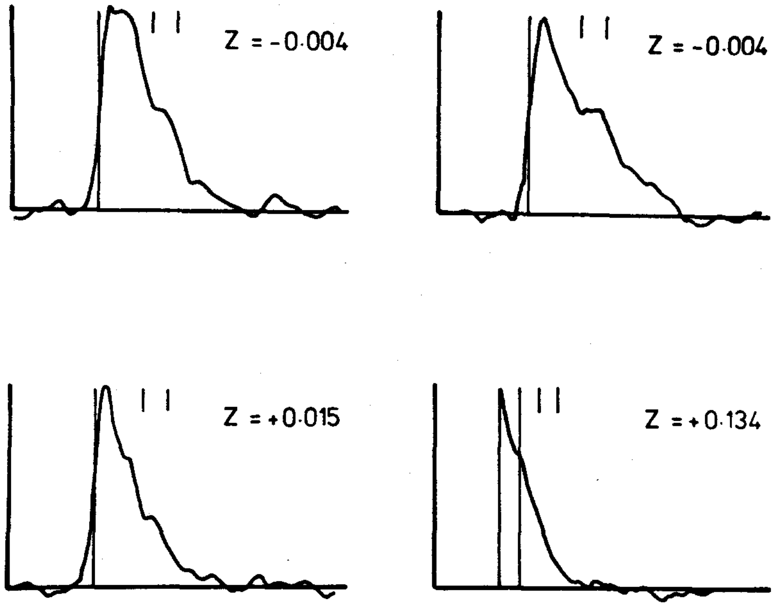

Fig. 3. Examples of the tracings of the spectra obtained from COSMOS data.

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at sixteen micron intervals. The corresponding areas on direct plates are measured in the COSMOS image-finding mode (coarse), and these measurements are used to produce a finding list of objects in the mapping data via a coordinate transformation. The COSMOS mapping data are then processed to extract spectra using the finding list. The plate transmission values are converted into relative intensity from the step wedge calibration using the following relation (Cooke, in preparation).

$$\log I = \gamma \log \left(\frac{T_O}{T - T_B} - 1\right) + \text{constant}$$

where T = COSMOS transmission values

I = intensity from step wedge

γ = slope of the calibration curve

T_o = scaling factor

T_b = transmission value when the plate is black

The slope of the calibration curve does not change with wavelength for IIIa-J emulsion. This calibration does not, however, take account of the change in the wavelength sensitivity of the emulsion. A few examples of the tracings of the spectra obtained from COSMOS data are shown in Fig. 3.

4. IDENTIFICATION OF GALAXIES AND STARS

There are two approaches to this problem: Using the method described by MacGillivray et al. (1976) the galaxies can be identified from the direct plate and the coordinates can be transferred on to the prism plate. The main disadvantage of this method is that any red shifted galaxy of almost stellar appearance may be missed. Alternatively the stellar spectra can be separated from the galaxy spectra by assuming that to a first approximation any object with $z < 0.02$ will be a star.

4.1. MEASUREMENT OF REDSHIFT

The method being considered for the measurement of redshifts is similar to that of Griffin, that is, by matching the position of the expected features to those present in the spectrum. This basic technique has been applied by Sandage and others who have correlated an expected galaxy spectrum at different redshifts with the observed spectrum to obtain the red shift. The correlation method has been refined by Cooke who has used the convolution technique described by Thompson (1971). Thompson's convolution function has been applied to a set of expected features. With the digitized spectrum $S(x_i)$ and a convolution function $C(x_j)$, the convolution spectrum is

$$T(x_i) = \Sigma\, C(x_j - x_i) * S(Xi)$$

$$\text{where} \quad C(x_j) = 1 \text{ for } |x| < X$$

$$= -1 \text{ for } X < |x| \;\; 2X$$

$$= 0 \text{ otherwise}$$

(4X is approximately the width of the feature).
The correlation function F(z) is defined as

$$F(Z\ ) = (T(\lambda) - P(\lambda(1 + z)))^2$$

where $P(\lambda(1 + z))$ is the convoluted expected spectrum. F(x) should go through a minimum at $z = z_o$, where z_o is the redshift.

Objects giving a poor correlation would not have the spectrum being considered and as such would be considered separately as a group. This group may contain the objects with early-type spectra (stars and galaxies) and peculiar spectra. The group with good correlation should consist of late type stars and galaxies of type E to Sa/Sb.

5. CLASSIFICATION OF SPECTRA FROM COSMOS MAPPING DATA

The classification parameters are based on the measurement of the strength of the 4000 Å feature and the color $(m_{4450} - m_{4900})$. The 4000 A feature is measured from the color $(m_{3600} - m_{4200})$. Since the wavelength dependence of the IIIa-J emulsion sensitivity has not been taken into account, colors are constructed relative to a star (referred to as a standard star) on the same plate.

$$C_1 = (m_{4450} - m_{4900})_{obj} - (m_{4450} - m_{4900})\ \text{st. star}$$

$$C_2 = (m_{3600} - m_{4200})_{obj} - (m_{3600} - m_{4200})\ \text{st. star}$$

The main difficulty at present arises from a problem with flare in the COSMOS light source. This results in the intensity calibration being unreliable for anything but the faintest images. As a consequence the analysis is currently only valid for faint spectra which, of course, have poor signal-to-noise ratio. Modifications to COSMOS at present under way will alleviate the problem.

An area of about 4 square degrees on a deep IIIa-J objective prism plate towards the direction of the South Galactic Pole has been measured. The color-color diagram (C_2 vs C_1) for stars for a field of one square degree in the magnitude range V = 18 - 19 (estimated) is shown in Fig. 4. The zero-point corresponds to K2: this has been determined by computing the predicted colors C_1 and C_2 from spectral scans of late type stars by Fay et al. (1974), assuming that the standard star is a G0, G5, K0, K2 or K5 main sequence star. The best fit with the observed sequence in the C_2 vs C_1 diagram is obtained if the standard star is a K2 main sequence star.

The same color-color diagram for the galaxies is shown in Fig. 5. The positions of the galaxies in this diagram are not significantly different for those of the stars. However, the color indices C_1 and C_2 of galaxies of different types and the direction of Doppler reddening for z = 0.1 can be computed from the energy distribution curves I(λ) from Pence (1976). Since a correlation between the type of the galaxy and its color indices is known to exist in the UBV system, a photometric classification of galaxies from their position in the color-color diagram is possible (Nandy, et al. 1978).

As the spectral resolution near H_γ is 50 Å and near H_β is 70 Å, the method described above is based on narrow band multicolor systems. However one can construct a broad band by integrating over a large wavelength range to produce a color-index. Poor signal-to-noise ratio favors the use of larger values of ($\lambda_2 - \lambda_1$) and two are selected for demonstration here:

$$C = \int_{3400}^{5000} \frac{I_\lambda}{I_{5000}} d\lambda$$

$$UV = \int_{3400}^{4200} \frac{I_\lambda}{I_{5000}} d\lambda$$

The (C, UV) diagram is shown in Fig. 6 for all the faint objects in a field one square degree, whose images on a direct UK Schmidt plate are stellar. The spectral classification is based on higher dispersion spectra of 14 individual stars. The same diagram for galaxies is shown in Fig. 7. Figs. 7 and 8 follow slightly different sequences, but they are not significantly distinct to allow the separation of stars and galaxies spectroscopically. However the galaxies can be classified by standardizing the galaxy sequence with the galaxy types determined from higher dispersion spectra.

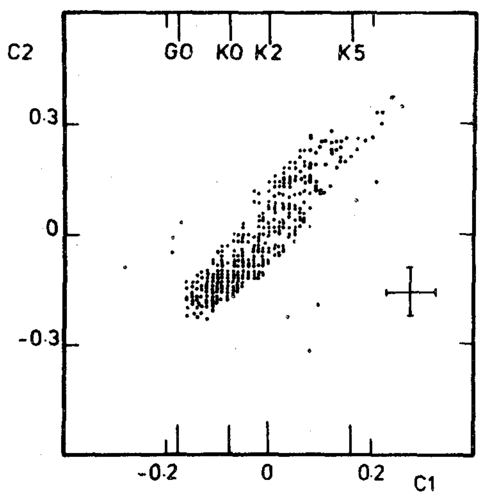

Fig. 4. The color-color diagram (C_2 vs C_1) for stars (see text).

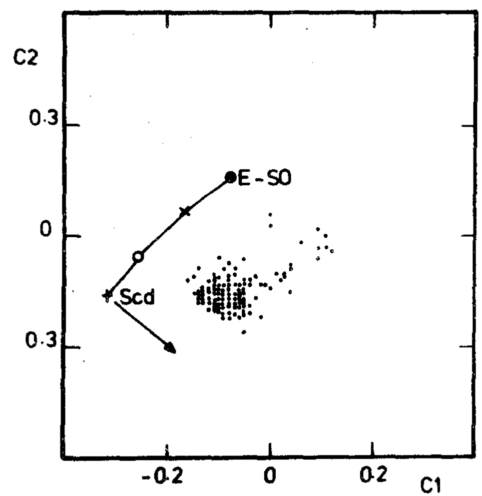

Fig. 5. (C_2 vs C_1) for galaxies, the solid line represents the predicted sequences for galaxies of different types. The arrow indicates the direction of Doppler reddening for z = 0.1.

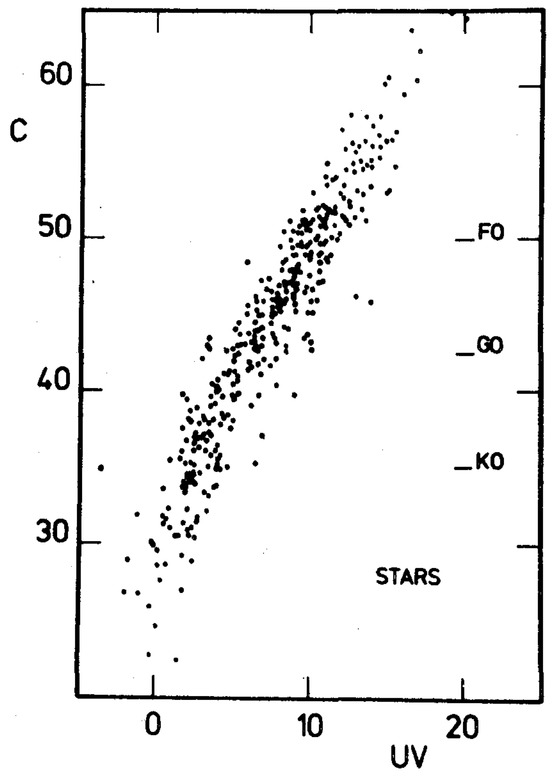

Fig. 6. The (C_1, UV) diagram for stars (see text).

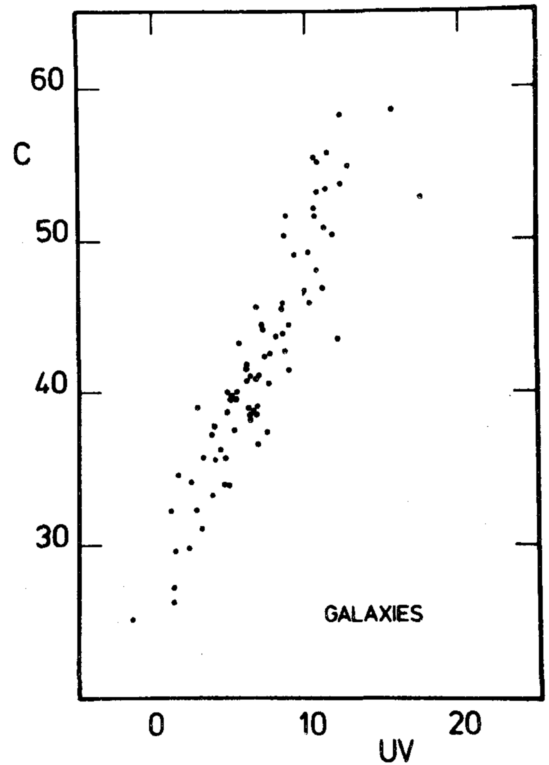

Fig. 7. The (C_1, UV) diagram for galaxies (see text).

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DISCUSSION

Andrillat: Is it possible to take into account the large emissions which are found in the nuclei of peculiar galaxies, like the Seyfert galaxies?

Nandy: No. We are concerned only with the group with good correlation to the predicted spectrum and this consists of late type stars and galaxies of type E to Sa/Sb.

Mould: Have you tried any laboratory tests to determine the constancy of the IIIa-J plate cut-off say from batch to batch, and do you think it would be useful to have a wavelength calibration on the plates?

Nandy: Malcolm Smith may be able to answer this question.

Smith: This is being watched very carefully. Thus far for a single batch we have found a constancy for the cut-off for the IIIa-J plate to ±10 Å.

Cowley: The little shelf on these spectra, which appears between the G-band and the strong absorption shortward of CaII H+K and CN, is very sensitive to metal abundance, and it almost goes away in the most metal poor stars. Do you have plans to make use of the abundance sensitivity of this feature?

Nandy: Yes, we have. The present dispersion may be too low for the quantitative estimates of the absorption shortward of 3280 Å. Also the emission sensitivity of IIIa-J in the ultraviolet is low.

Spinrad: The 4000 Å discontinuity is abundance sensitive, as Cowley remarked. In the integrated spectra of galaxies, it is sensitive to the number of hot stars which dilute it. In Sc galaxies I find the amplitude too small to utilize as a redshift criterion on my digital spectra.

Nandy: We have not been able to classify galaxies into ellipticals, or Sa, Sb or Sc. We have assumed that the galaxies E to Sa/Sb/Sc show the G-band and the discontinuity near 4000 Å of the Sc galaxies shows the G-band. It may be possible to determine the redshift with more accuracy. However, if the correlation with the predicted spectrum is poor (which means that its redshift cannot be determined) these objects will be considered separately.

Coyne: Is the error larger for larger Z?

Nandy: It is likely to be larger for larger Z. The value $\Delta Z = \pm 0.02$ has been determined by comparing the redshifts determined from spectra taken at higher dispersion with those described here for 5 galaxies.

Coyne: What is the largest Z measurable, i.e., when does the G band meet the plate cut-off?

Nandy: About $Z \approx \pm 0.25$.

Coyne: Is there any way to use another emulsion to extend this technique to larger Z?

Nandy: It should be possible to extend to higher redshift by using a red emulsion which has no green gap, and a higher dispersion at Hγ. The dispersion of this present prism in the red is very low indeed.

Fehrenbach: The method you have described is possible only because of two factors: the COSMOS machine and the IIIa-J plate. The displacement of the sensitivity curve introduces a constant ΔZ that has only to be subtracted.

Geyer: Perhaps you should consider using a filter device similar to that which was used in former days when radial velocity measurements were made (neodymium 10M filter). In my opinion this is safer than relying on the long wave cut-off of the plate.

Fehrenbach: As an answer to Dr. Geyer. The use of a Neodymium-chloride filter is not a good solution. The position of the band depends on the exposure time and this filter is very absorbing. The method described by Nandy, "the length of the spectrum," is better.

Schmidt-Kaler: Just to keep the record straight, the problem of automatic digitization of spectrophotometry of F and G stars was investigated some time ago by Dr. G. I. Thompson. He had the problem of determining the stellar continuum. The accuracy of the equivalent width is critically dependent on the fitted continuum.

Fehrenbach: The emission line galaxies have different spectral separations and are surely abnormal with respect to your contours.

Nandy: All objects which do not give a good correlation with the expected spectrum at different redshifts would be considered separately as a group. This group might contain the objects with early type spectra, e.g. stars and emission line galaxies.