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ULTRA-LOW DISPERSION SPECTROSCOPY OF STARS AND GALAXIES

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ABSTRACT

Application of ultra-low dispersion spectroscopy (10,000Å mm^{-1}) is described to study the nuclei of elliptical galaxies, the quasi-stellar objects and for the discovery of faint OB stars, reddened stars and red stars. The instrument used is an f/2 slitless spectrograph with a three degree quartz prism at the Cassegrain focus of the 102-cm Ritchey-Chrétien reflector at Kavalur. The spectra cover a field of 40 minutes of arc and the dispersion is 10,000Å mm^{-1}. Ultra low dispersion spectra (microspectra) were obtained for fifteen elliptical and three SO galaxies from the list of Ekers and Ekers (1973) who classified them as compact and extended sources from the observations of radio emission at 6 cm. From an analysis of microspectra and from direct photographs with graded exposure times, we find that all compact radio galaxies in the Ekers list also have optically compact nuclei. Some of these elliptical galaxies with compact nuclei show enhancement of intensity in the blue-violet region.

We have also applied this ultra-low dispersion technique to study the quasi-stellar objects. From an examination of microspectra of forty-three of the known quasi-stellar objects of different redshifts we find that the most striking characteristic of the spectra is their flat appearance. Comparisons with microspectra of stellar objects show up the QSO's to possess continuum energy distributions different from these objects. This characteristic flatness is also noticed in the microspectrum of the large redshift quasi-stellar objects like OH 471, and OQ 172 which do not have UV excess. Because of this characteristic difference in the appearance of the microspectra of the quasi-stellar objects and stellar objects, it is possible to detect new QSO's with this technique.

An application of this technique to detect red stars in our galaxy and in the Large Magellanic Cloud is discussed.

Key Words : low dispersion spectroscopy—quasi-stellar spectra—compact galaxies -red star detection

1. Introduction

The slitless spectrogram has been the principal means of spectral sampling employed in astrophysics. For large surveys of objects having gross characteristics that are easily recognisable, it has remained a technique without peer. Restrictions of light gathering power and the increasing number of objects in a field as one goes fainter have been a limitation. The first can be partially over come by decreasing the dispersion, a procedure which causes loss of information. If, however, the objects that are sampled have features recognizable at such low dispersion values, one can isolate these objects for later detailed scrutiny.

A procedure commonly used, is filter photography where intensities in bands of the spectrum of a thousand angstroms in width convey information on the spectral energy distribution of the object. More informative is the use of very low dispersion spectra as was first employed by Morgan, Meinel and Johnson (1954). Spectra of dispersion 30000Å mm^{-1} were able to differentiate between early type stars and intrinsically red stars or reddened O and B stars. The technique was exploited by Schulte (1956) to identify new members of the VI Cyg association, which is extremely reddened. Since then, there have been a few efforts to use low dispersions of the order of 2000 to 4000Å mm^{-1}. Markaryan (1967) has employed such a procedure to detect galaxies which show an UV excess, while Philip and Sanduleak (1965) with crossed objective prisms have determined spectral indices of galaxies in clusters. Hoag and Schroeder (1970) with a higher dispersion of 1000Å mm^{-1} have shown how slitless transmission grating spectra can be used for the detection of spectral features in the quasi-stellar objects that will permit even a measure of the redshift.

In what follows we describe our application of ultra-low dispersion (10000 Å mm⁻¹) to the study of the nuclei of elliptical galaxies, the quasi-stellar objects and surveys for the discovery of red and blue stars.

2. The Technique

We employ an f/2 slitless spectrograph with a three degree quartz prism at the Cassegrain focus of the 102-cm Ritchey Chrétien reflector at Kavalur. The spectra cover a field of 40 minutes of arc. Eastman Kodak 103a-E emulsion used in the Schmidt camera enables us to obtain spectra in the range 3500-6600 Å, with the green dip of insensitivity of the emulsion providing a wavelength reference for judgement by the eye. The spectra are unwidened and are about 250 microns in length along the dispersion.

3. Nuclei of elliptical galaxies

Radio surveys of over two hundred nearby elliptical galaxies by Heeschen (1968, 1970a) and Rugstad and Ekers (1969) revealed that a few among them are radio sources but with lower radio luminosity than those usually considered to be radio galaxies. On the basis of their radio structure and spectra, Heeschen (1970b) was able to isolate a class of active sources in these galaxies that were confined to very restricted sizes and which displayed the variety of complex spectra found normally in the variable quasi-stellar sources and the radio galaxies. From these radio studies Heeschen suggested that the active elliptical galaxies have miniature quasi-stellar-like nuclei.

Stimulated by this finding, Heeschen, Morgan and Walborn (1971) examined the light distributions in some of these radio-emitting ellipticals and found major differences in the distribution of light intensity in the inner regions of these objects. Typical of their two extreme cases are NGC 4486 and NGC 4552. The former has a weak compact source in the nucleus with most of the radio flux, that follows the power law spectrum, coming from a larger region. NGC 4552 on the other hand has only a weak emitting compact source in the nucleus but with a spectrum that is flat. Heeschen *et al.* (1971) showed that the nuclear light intensity distribution for these two galaxies was quite dissimilar; NGC 4486 maintains a diffuse aspect on short exposure photographs while NGC 4552 shows a high surface brightness at the centre with a steep gradient of fall in intensity away from the nuclear region.

Our microspectra of these two galaxies show the striking difference in the appearance of these two categories. Since we use the 103a-E emulsion, the green gap of insensitivity is seen in the microspectrum of a star. When the source of radiation is extended, this gap is filled in by virtue of the extension of the source. The presence or absence of the green gap thus becomes our prime criterion of classifying a compact nucleus. For, when the nucleus is compact, its steep intensity gradient simulates the appearance of a starlike image, rendering our procedure of detection an easy possibility. The microspectrum also indicates the energy distribution until 3500 Å.

A recent study by Ekers and Ekers (1973) on 191 E and S0 galaxies for radio emission at 6 cm isolated 19 radio sources. Observations at high resolution enabled these 19 to be classified either as compact, extended or compact-extended sources.

We have obtained microspectra for fifteen elliptical and three S0 galaxies. All these, with the exception of NGC 3091; figure in the Eker's list of the 6 cm survey. We have examined microspectra of all these galaxies and categorize them, principally into two classes; concentrated and diffuse. When the spectrum shows up a nuclear concentration with a diffuse halo, we term it "concentrated-diffuse". Since the micro-spectrum method of classification rests on the evaluation of the intensity gradient in the nucleus, the "concentrated" have a very steep gradient, when compared to that of the "diffuse" category, exhibited by most nuclei. In Table 1 we list the type that we assign from such a consideration of the microspectrum. Also listed is the nature of the radio source associated with each object, as given by Ekers and Ekers. All the compact radio galaxies of this list are also seen to be optically "concentrated". NGC 4278 has a radio source classified as compact extended; the optical aspect is a "concentrated" nucleus. We, however, classify NGC 3078 that has a radio source of type CX, as one that has a fair measure of concentration of intensity in the nucleus and which is surrounded by a diffuse halo. We term

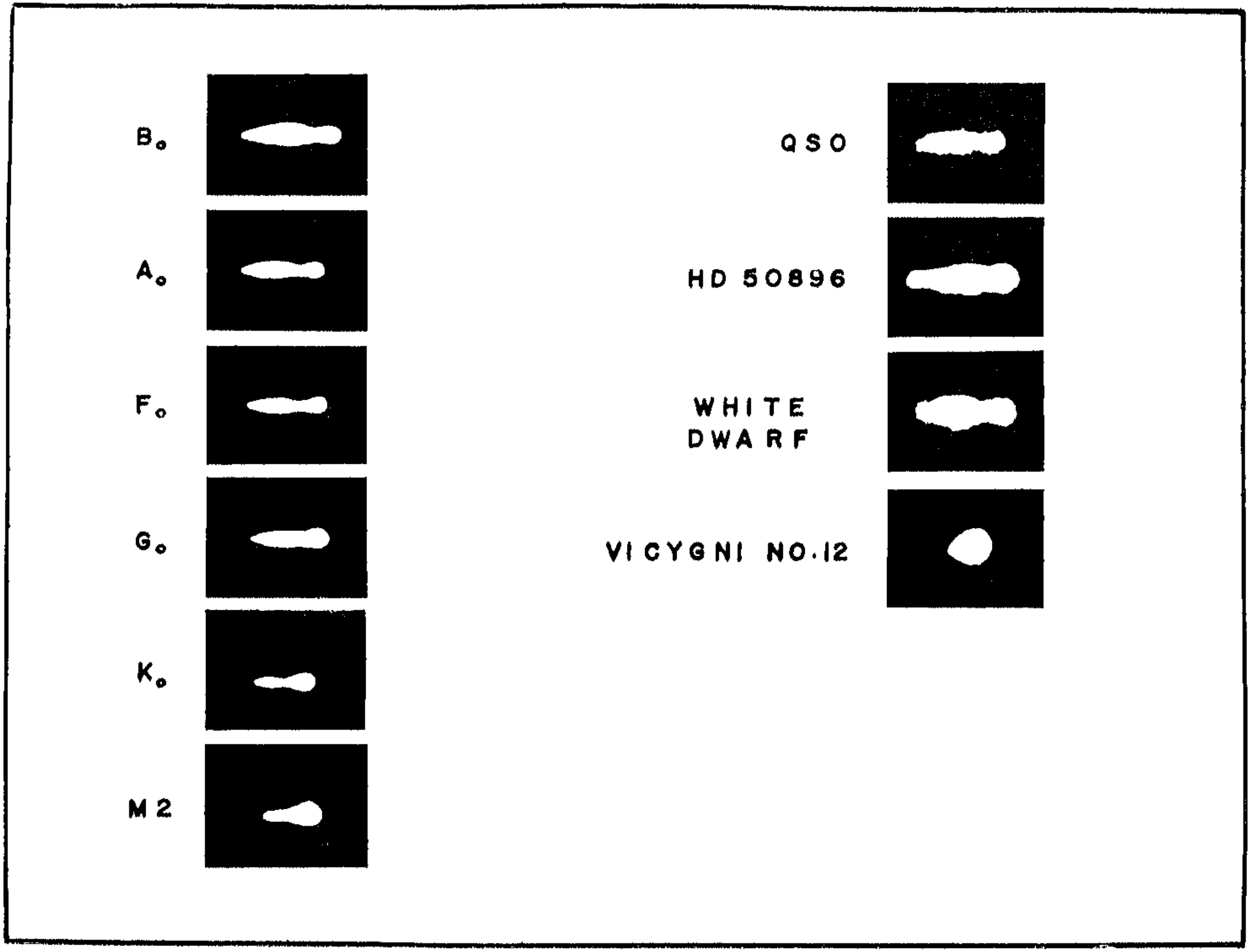

Fig. 1. Ultra-low dispersion spectra of various objects. Long wavelengths are to the right. The discontinuity in the density shortward of red is due to the sensitivity dip of the emulsion in the green.

Table 1. Concentration type of galaxy nuclei

NGC	Morphological type	Radio Source type	Optical source type	Remarks
383	S0	X	Diffuse-Concentrated	
741	E0	X	Concentrated	
1052	E3	C	Concentrated	Blue extended
1399	E2	X	Diffuse	
1587	E1	C	Concentrated	Blue extended
1600	E5	-	Concentrated	"
1700	E3	-	Concentrated	"
2911	S0	C	Concentrated	"
2986	E2	-	Concentrated	"
3078	E2	CX	Concentrated diffuse	"
3091	E3	-	Concentrated	"
3193	E2	-	Concentrated diffuse	"
3998	S0	C	Concentrated	"
4261	E3	X	Diffuse Concentrated	"
4278	E1	CX	Concentrated	"
4486	E0	XC	Diffuse	
4552	E0	C	Concentrated	
5077	E3	C	Concentrated	

galaxies like NGC 4261 as "diffuse-concentrated" since it has a faint concentration in the nucleus, in an otherwise diffuse outer domain.

Typical of the diffuse nucleus in the galaxies we have surveyed is that of NGC 4486. The well known radio source associated with this galaxy is extended in nature with a certain amount of compactness. However the microspectra show no steepness of intensity gradient near the centre of the galaxy, as is easily seen on the direct photographs of this object.

Radio galaxies in general have a tendency to display emission lines, but this is by no means a well correlated characteristic. Ekers and Ekers show that compact nuclear sources are strongly correlated with the incidence of emission in the spectrum of the nucleus. However, NGC 4552 with a compact nucleus shows no lines in the spectrum as is the case also for NGC 3078, which has a compact extended radio source in the nucleus. Both nuclei are "concentrated" in our terminology. On the other hand NGC 4486 which has a radio source in its nucleus and is "diffuse" in appearance displays the forbidden lines of oxygen at 3727Å of good intensity.

The presence of 3727Å in the nuclear emission spectrum cannot be assessed from microspectra. But they do show up a characteristic of enhancement of radiation in the blue part of the spectrum that prevails in some of the nuclei we have examined, better than in others. In column five of Table 1 we indicate this feature. The "diffuse" nuclei do not have it. But what is striking is that NGC 4552, which is a fine example of light concentration in the nucleus does not display this characteristic.

We also have direct photographs taken with an f/6 focal reducer at the Cassegrain focus, of six of these galaxies in our list. These exposures are graded to enable an estimate of compactness in the visual image. The difference between compact and extended objects is quite striking. In terms of compactness, the gradation is NGC 3078, NGC 3998, NGC 4278, NGC 4261 and NGC 4486.

4. The quasi-stellar objects

The presence of an ultraviolet excess in the continuum energy distribution of most of the quasi-stellar objects has been an important criterion hitherto used to establish an optical identification from a knowledge of the radio position. Subsequent scrutiny, at the commonly used dispersions in nebular spectroscopy, provide the evaluation of the redshift, when a satisfactory set of lines can be measured in the spectrum. Sandage's (1965) discovery of radio quiet quasi-stellar objects, and that similar ultraviolet excesses prevail in their spectra, has prompted several searches for such objects in different areas of the sky. Richter and Sahakjan (1965), Braccesi, Formiggini and Gandolfi (1970) and Sandage and Luyten (1967) have undertaken many of these surveys. Since many other galactic objects also display enhanced intensities in the ultraviolet, a spectroscopic study of each object is called for, before its identity as a quasi-stellar object can be firmly established. In view of the fact that we need to have a large sample of such objects for detailed study, before we can elucidate the role of the quasi-stellar objects in our studies of cosmology, more definitive search techniques are needed that can easily improve on the candidacy of any particular object for a subsequent spectroscopic evaluation. We believe that the technique of microspectroscopy is capable of quick detection of a quasi-stellar object, with the advantage that it can be extended to faint limiting magnitudes.

We have obtained ultra-low dispersion spectra of forty-three of the known quasi-stellar objects (QSO) of different redshifts. The most striking characteristic of our spectra is the rather 'flat' appearance over the entire wavelength region from the violet to the yellow. The intensity in the red is usually higher than what one would expect from the gradients in the spectrum on either side of the green gap. Comparisions with similar microspectra of white dwarfs, and objects like HZ Hercules, show up the QSO's to possess continuum energy distributions different from these objects. On the redward side of the green gap the blackening, in the case of the QSO, shows a very slow increase until about 5900 Å. Thereafter the increase is very rapid, a pattern different from that followed by the white dwarfs or HZ Hercules. Similarly on the shortward side of 5000 Å, the combination of emulsion and continum energy for a white dwarf gives optimum blackening around 4200 Å. In the case of the QSO, such is not the case, and a gradient is maintained that is hardly steep. Thus, the combination of continuum energy distribution and emulsion used, renders detection of the quasi-stellar object, a simple task.

Support for this approach is also obtained from the spectrophotometric studies of Oke, Neugebauer and Becklin (1970). The low values of the spectral index obtained by them for the QSO indicate the low gradients one should expect in the intensity distribution on the Eastman 103a-E emulsion. Spectral indices as obtained from power law representations for white dwarfs and blue stars, differ considerably from the values of -0.2 to 1.6 obtained by Oke *et al.* (1970). These authors also show that the radio quiet objects Ton 256, PHL 938 , and PHL 1070 observed by them indicate no differences from those that are strong radio emitters. Our microspectra of the radio quiet objects, Ton 153, Ton 157, Ton 256, Ton 490 Ton 1530, Ton 1542, and PHL 957, all display the characteristic flatness in the blackening on the emulsion that we see in similar spectra of the 36 radio emitters we have sampled.

Included in our first list of objects to be surveyed were five of those listed by Brown and McEwan (1972). Two of these at the time of study were beyond our limits of detection. Microspectra of the other three, PKS 0106-008, PKS 0808+019 and PKS 1705+018, show the characteristics of the quasi-stellar object, thus enabling us to confirm the optical identification.

The large redshift quasi-stellar objects like OH 471 and OQ 172 show no ultraviolet excess. Thus the ultraviolet excess criterion in the UBV technique has its limitations for QSO's with large redshifts. However the characteristics of the QSO microspectrum continue to be seen in these objects.

5. Faint star spectral classification

Information on spectral characterstics of large numbers of objects have traditionally depended on the slitless spectrogram covering a sizable field, from which gross astrophysical aspects are recognised for a large sample of stars. Spectral critieria employed for such a purpose would depend on the light availability,

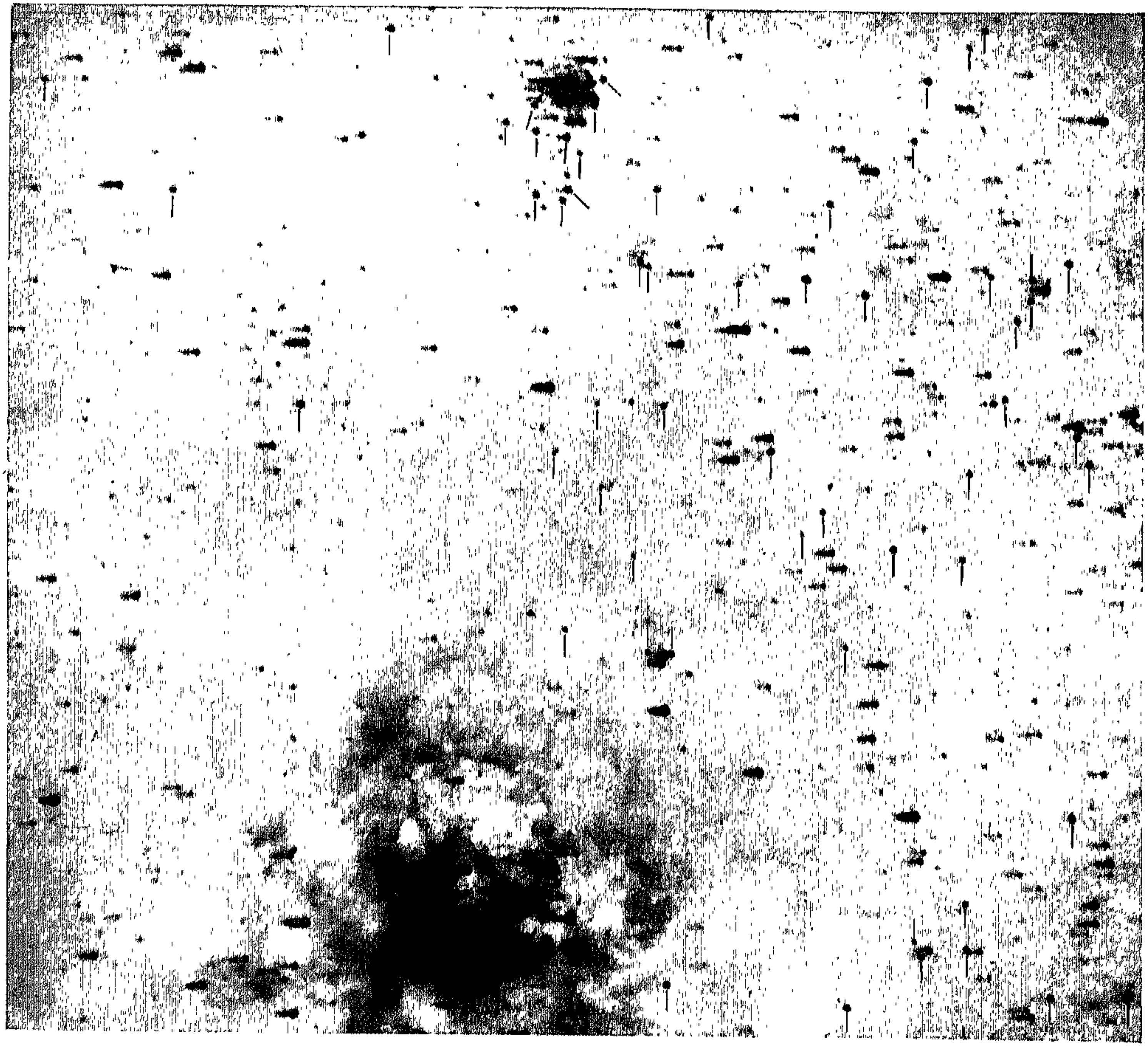

Fig. 2. Red stars in the region of 30 Doradus in the Large Magellanic Cloud.

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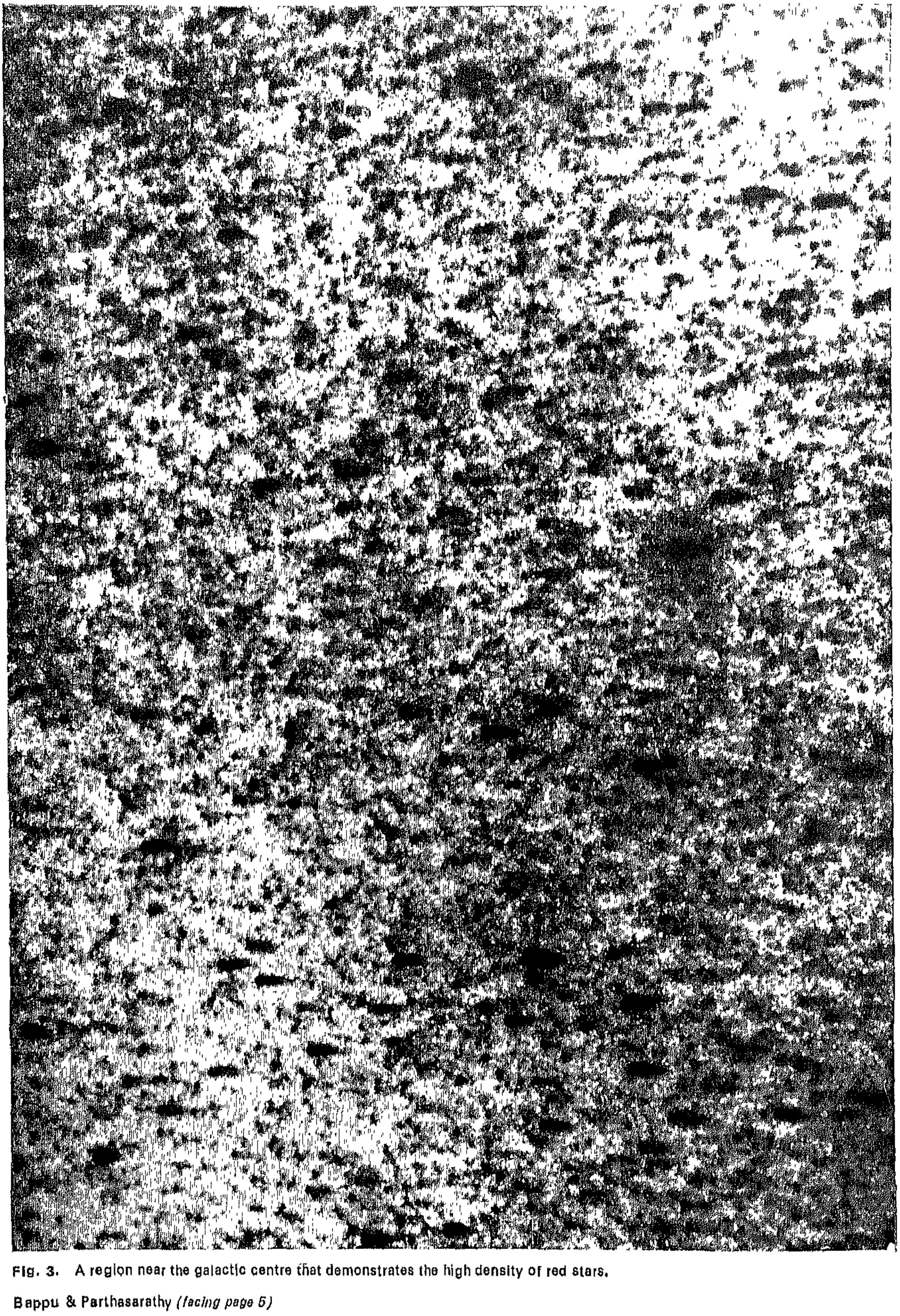

Fig. 3. A region near the galactic centre that demonstrates the high density of red stars.

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and in the quest for such information on objects at fainter and fainter levels of detectability, one resorts to gross characteristics as a means of evalution. The microspectrum permits assessment of spectral classes of objects fainter than those that have been studied with the aid of the spectral line or band as the criterion.

Earlier efforts (Morgan, Meinel and Johnson, 1954, and Schulte, 1956) with spectra of low disperson have used this theme to advantage. We present herewith some samples obtained by this approach and which we are employing with success on extended observing programmes. Figure 1 shows the different kinds of images obtained for different classes and objects. The principal criterion for classification is the shape of the stellar spectrum and also the density in different portions of the image. Early-type stars give spectrum images in which the short wavelength region is very intense. The shape of this part of the spectrum is one of the indicators that affords determination of the spectral type for the early-type stars. A main sequence A star would appear blue from a comparison of the red and blue parts of the spectrum but would not have a strong ultraviolet extension because of Balmer lines and continuum. As one proceeds to later spectral types the blue part of the spectrum weaknes and the shape and extent of the blue spetrum changes progressively. For very late type-stars the classification that we have developed has high accuracy. To test this criteria of spectral classification we have determined the spectral types of the stars in the clusters h and χ Persei and in the VI Cygni association. A comparison of the spectral types determined by our method with the known spectral types for the stars in h and χ Persei and VI Cygni show satisfactory agreement. It is our experience that a proper spectral class can be assigned by a practised observer to within half a spectral class.

But by far the easiest application of the microspectrum technique is in the detection of red stars and blue stars, both of which are of much interest in the study of galactic and extragalactic structure. For red stars, the microspectrum shows up the star image as a dot with little radiation in the blue and permits the detection of these objects with ease. Figure 3 strikingly depicts the large number of red stars in regions located near the galactic centre. We have currently a programme of detecting red stars in the direction of the Large Magellanic Cloud. The results of this survey will appear later in these Bulletins, but we show here in Figure 2 a survey of red stars we have made in the 30 Doradus region with the aid of microspectra. Earlier surveys of this kind have been accomplished by the laborious procedure of colour differences for red star detection. The microspectrum has the advantage of accuracy and speed.

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