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AN AUTOMATED SPECTRUM SCANNER

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ABSTRACT

A rapid-scan single channel spectrum scanner in the Ebert-Fastie arrangement has been constructed and successfully used on the Kavalur 102-cm reflector. The spectral region 3000-11000Å is covered with appropriate dry-ice cooled photomultipliers. Data acquisition is by a 4K computer with suitably developed software. Examples are given of use of the instrument in providing spectrum scans of Wolf-Rayet stars and gaseous nebulosities.

Key Words : spectrum scanner—instruments—computers—Wolf-Rayet spectra

1. Introduction

Photoelectric spectrophotometry plays a dominant role in present-day astronomy. The accurate measurement of intensity in narrow wavelength regions covering the spectrum is important in evaluating the continuous energy distribution, the intensities of absorption features, or the brightness of emission characteristics. Ground based measurements of these features have constituted our primary sources of data of this kind. Hence instruments employed for this purpose have to be such as to facilitate quick and accurate acquisition of data that is not limited by the problems of transparency variations.

Many photoelectric scanners have been described in the literature of the past two decades. Those of Liller (1957) and Oke (1969) have been the first of their kind exclusively employed in astronomical spectrophotometry. With the advent of the minicomputer, a measure of automation has been incorporated in spectrum scanning that enable fainter limits of photometric measurement. Bahng (1971), Honeycutt (1971), Haupt *et al.* (1976) have demonstrated the efficacy of such instruments. We describe in the following pages an instrument developed on similar lines for use at Kavalur on the 102-cm reflector.

2. The Scanner

The optical system adopted is of the Ebert-Fastie type with a spherical mirror of one metre radius. Entrance slots are incorporated in a circular diaphragm which can be selected at will. These permit a range of observations covering point and extended sources. Three of the slots are circular with diameters of 600, 800 and 1620 microns. The remaining two are rectangular with the longer dimension of 6mm, perpendicular to the dispersion. The widths parallel to the dispersion are 2000 microns and 250 microns respectively. The exit slot is a conventional spectrograph slit that can open to a maximum width of 6mm. A filter holder in front of this slot enables isolation of overlapping orders. The standard grating in use is one of 600 lines mm^{-1} that is blazed in the first order at 7500Å. A second grating of 1800 lines mm^{-1} and blazed at 5000Å has been used for nebular studies to measure intensities of the [N II] forbidden lines that flank Hα. The grating is driven through a worm wheel and gear by a stepping motor with 200 steps per revolution. Each step corresponds to 10Å and 3Å for the two respective gratings in the first order.

The scanner is fitted onto an offset arrangement that permits faint star guiding through an eyepiece on an X-Y arrangement. Different cold boxes fitted with quartz Fabry lenses, that image the primary mirror onto the photocathode, can be mounted at the exit slot end. Photomultipliers in common use on this instrument have been EMI 6256 B (S13), EMI 9558 (S20) and ITT-FW 118 (S1), that permit spectrophotometry from 3000Å to 11000Å.

The grating drive is linked to a dial gauge that permits wavelength estimation. A mercury spectral lamp is used for wavelength calibration. The lamp shines off the reverse diffuse side of the 45° mirror of the off-set guide and can be used for wavelength reference almost instantly. The scanner also has a manual fine control with readout that may be used additionally at will.

The scanner functions essentially as a signal averager in the rapid scan mode. The photoelectron pulses are amplified, discriminated, counted and stored in the appropriate memory location of an ECIL TDC -12 (4K, 12bit, 2μs) computer, which thus functions both as a multichannel scalar as well as the control unit for spectrometer operation. A maximum of 216 such channels is available in the forward scan and an equal number for the reverse scan, in the direction of decreasing wavelength. Alternately, the number of channels in the forward mode can be 432 if one does not use the reverse mode. The outputs for forward and reverse scans are treated separately and made available for printout by the teletypewriter, on command. Conversation with the computer, prior to commencement of a scan, pertains to parameters of system generation. By adjustment of the reference channel, the first channel for counts can be located at any position of the spectrum. This is usually done with the aid of the mercury light source, but can also be performed on the basis of the star spectrum measures obtained or the dial gauge reading. If reverse scans are also to be utilized, provision can be made for counteracting backlash by a known shift of channel nomenclature. This value has never exceeded one, as derived from repeated scans of the Hg emission spectrum. The first and last channels are specified, after which the choice of mode of scan remains. Where unknown features in a spectrum need to be surveyed or where over a wavelength region limited by the spectral sensitivity of the photomultiplier, the entire spectrum has to be depicted, the sequential mode with channel spacing can be specified. Alternatively, when certain known absorption or emission features have to be measured over widely separated portions of the spectrum the "random" predetermined mode is adopted and specific channel numbers to be covered, indicated to the computer. The duration of

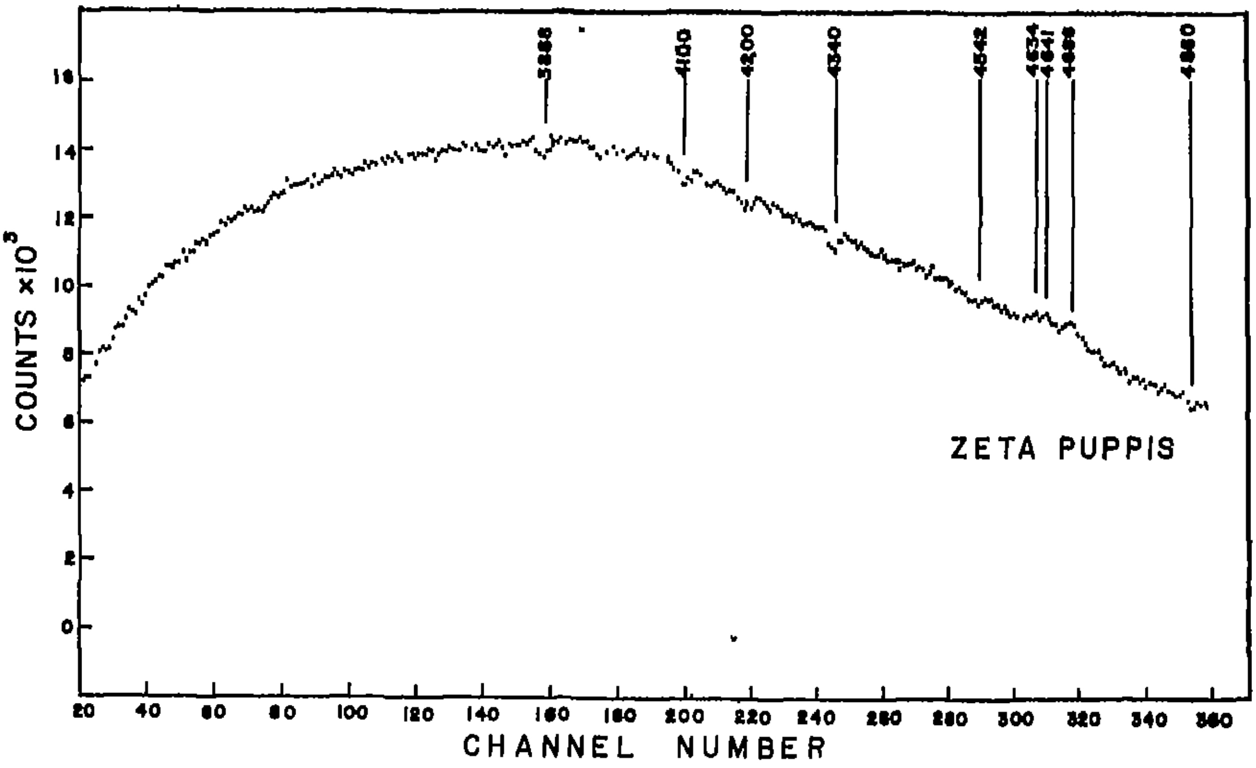

Fig. 1. Scan of Zeta Puppis with a 10Å exit slot. Note the Of characteristics with 4686Å and the N III multiplet 4634-40Å in emission.

photon counting in each channel is specified. This in principle can be any integral value greater than 1 millisecond, and depends on the experiment and the nature of the transparency of the sky. The total number of scans needed can also be communicated to the system. The facility exists, however, for the experiment to be stopped on command, at the end of any scan and can be continued again if the print-out of data indicates that the counts accumulated have to be augmented further.

The experimenter has two ways of monitoring the scanning. The first is on the oscilloscope where the build-up of the spectrum is indicated. The second is on the teletype where at the end of a predetermined interval, that is repetitive, the computer prints out the maximum and minimum values of counts stored in its memory. Such information is found to be sufficient for monitoring the count accumulation; it is satisfactory for both continuum measures as well as in cases where a large range in intensity, as for emission-line objects, is being recorded. In the latter case, where the peak intensity of the emission line is very much greater than the general level of the spectrum, the possibility of register overflow is accommodated in the software, by the automatic assignment of double word storage.

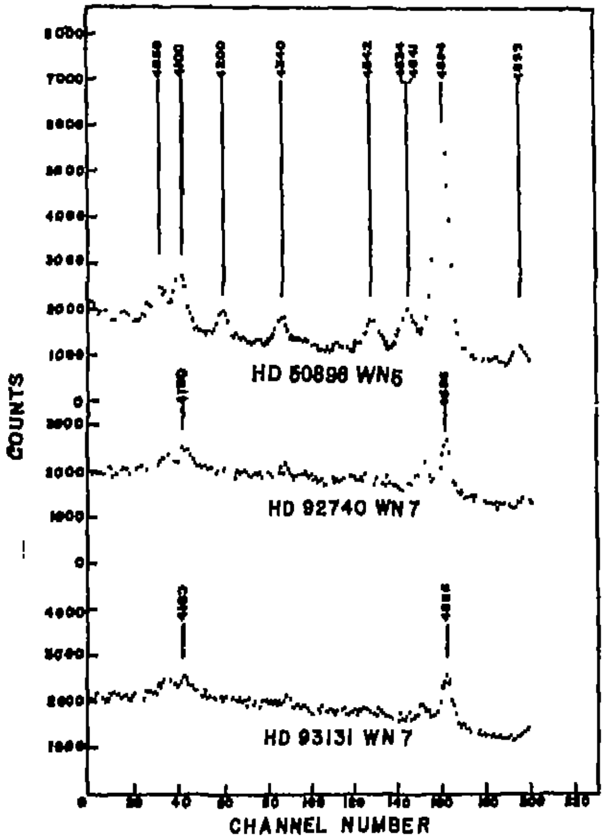

Fig. 2. Scans of three southern Wolf-Rayet stars of the nitrogen sequence.

3. Instrument Performance

The sensitivity of the instrument is derived from scans of stars whose continuum fluxes are well known. The hot stars with a minimum of absorption lines are admirable for this purpose. A conveniently located star that provides a demonstration of the instrument sensitivity is ζ Puppis. Figure 1 shows a scan of this star with 10Å resolution that covers the wavelength region 3300Å to 4900Å. The Pickering series are discernible. But the Of characteristics of the star with He II 4686Å and the N III 4634-42Å lines in emission are dominant.

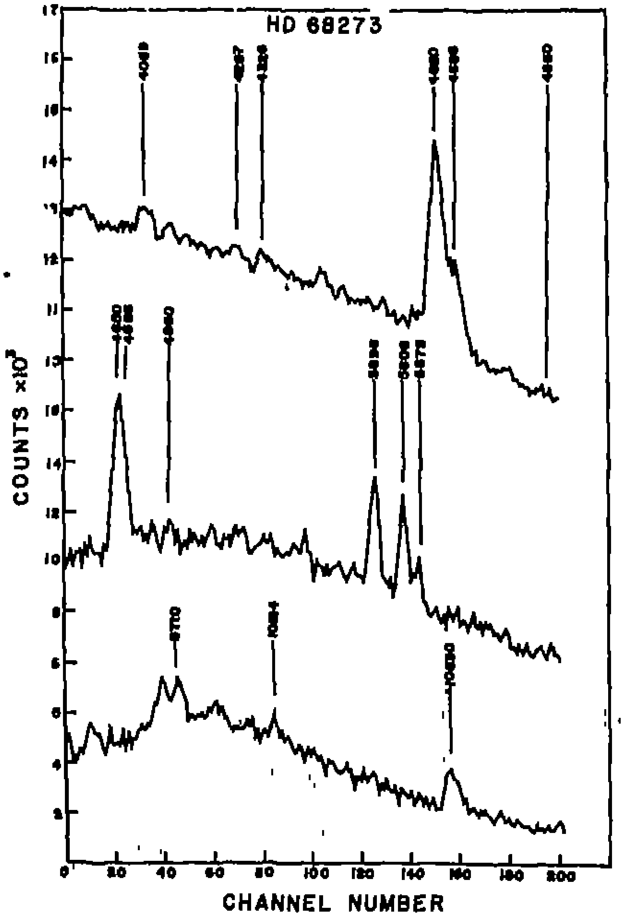

Fig. 3. Scans of γ^2 Velorum (HD68273) in the blue, yellow and near-infrared regions.

The instrument was designed for spectrophotometry of Wolf-Rayet stars and therefore has many of the features needed to cover the range in intensity of the spectrum as well as the means of obtaining line contours within the limitations of resolution of a slitless instrument. Figure 2 shows scans in the 4000-4860 region of three stars of the nitrogen sequence HD 50896 (WN5), HD 92740 (WN7) and HD 93131 (WN7), obtained with the Kavalur instrument, with spectral resolution of 10Å. The gross characteristics that form the basis of Lindsey Smith's (1968) classification are apparent. The ionized helium line at 4686Å is dominant in HD 50896, with the line at 4200Å of appreciable intensity. The intensity of N III in the 4634Å complex weakens with respect to He II 4686Å as we go over from WN7 to WN5, while N IV 4058Å picks up in intensity. Even in the same spectral class there are subtle differences between HD 92740 and HD 93131. Notice the intensity of N IV 4058, in comparison to He II 4340Å or N III 4380. One finds the 4058Å line stronger in HD 93131 than in HD 92740.

A few representative scans of the Wolf-Rayet binary γ^2 Velorum, that cover a good spectral range, can be seen in Figure 3. The blue scan shown in the figure is with an exit slot of 4Å, and has been obtained in the second order of the grating with a channel spacing of 5Å. The yellow scan was recorded in the first order with channel spacing of 10Å. The effect on resolution of the channel spacing is immediately apparent when one examines the 4650-4686Å complex. At the bottom of the diagram is the infrared scan obtained with the S1 photo-sensitive surface. This shows among other features the He I emission line at 10830Å. A 10Å exit slot was used in this scan. The P Cygni aspect of 10830Å is striking.

Closely spaced emission lines are better resolved with the 1800-line grating, and the spectrometer can therefore be very useful in studies of gaseous nebulosities. With the entrance slot rectangular in shape and with the longer dimension parallel to the grating ruling, a scan of the ionization front near the trapezium in the Orion Nebula is shown in Figure 4. The region covers the wavelength domain 6500-6750Å for providing $H\alpha$, [N II] and [S II] ratios. A separate scan of the Ne spectrum establishes the wavelength scale for the different channels. The entrance slot admitted a portion of the nebula 96′ x 8′ in extent and the scan was performed with a resolution of 6Å. The [N II] lines are well separated from $H\alpha$, which is very intense. The [S II] lines are also well resolved.

4. Summary

The automated spectrum scanner in the single channel mode has now been in operation for several months with a performance that has been very satisfactory. When it functions in the rapid scan mode, poor transparency has little noticeable effect on the data obtained, specially when only relative spectrophotometry is the goal. This has been demonstrated earlier by Bahng (1971) and Honeycutt (1976). Our own experience confirms that much useful material can be obtained even when transparency conditions are so poor that only spectroscopy may have provided a result during the night. Besides this advantage, the possibility of photoelectric precision with averaged signals integrated over seconds of photon counting and over an extended spectral region, does indeed offer numerous possibilities in measurement of intensities, relative spectral indices etc. that are needed in galactic and extra-galactic astronomy.

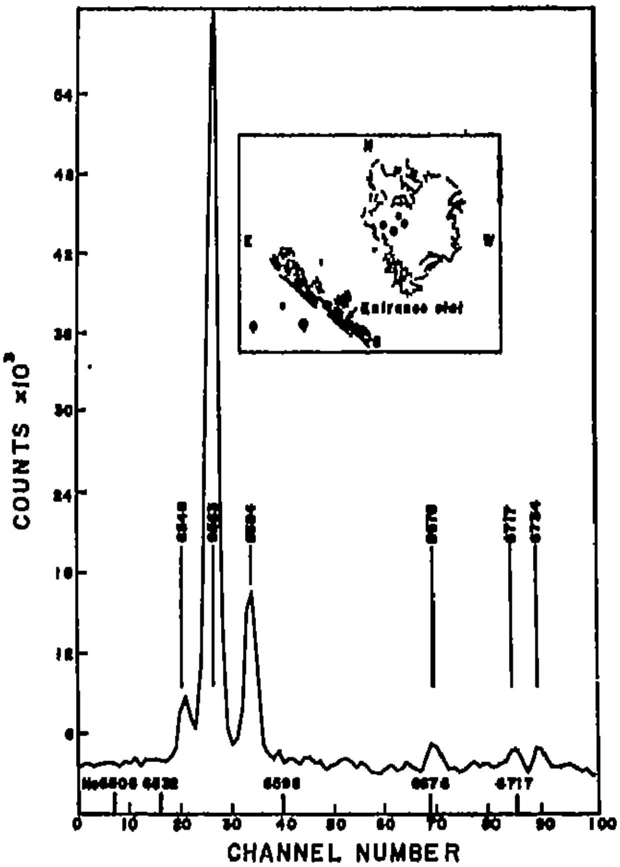

Fig. 4. A scan of the region 6630-6750 Å in the Orion Nebula.

Acknowledgments

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