Rapid Photoelectric Spectrum Scanning Techniques

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Photoelectric spectrophotometry has been pursued with increasing success in recent years. In studies of single line profiles, restricted spectral regions, or stellar continua at low resolution, the photomultiplier offers an increase in speed of up to 20 times over the photographic emulsion and an output directly proportional to light intensity over a wide range of intensity. Difficulties in slow scanners have been caused chiefly by fluctuations in light due to seeing, guiding and extinction changes, necessitating either wide slits and photometric weather or ratio circuits. The technique of rapid scanning

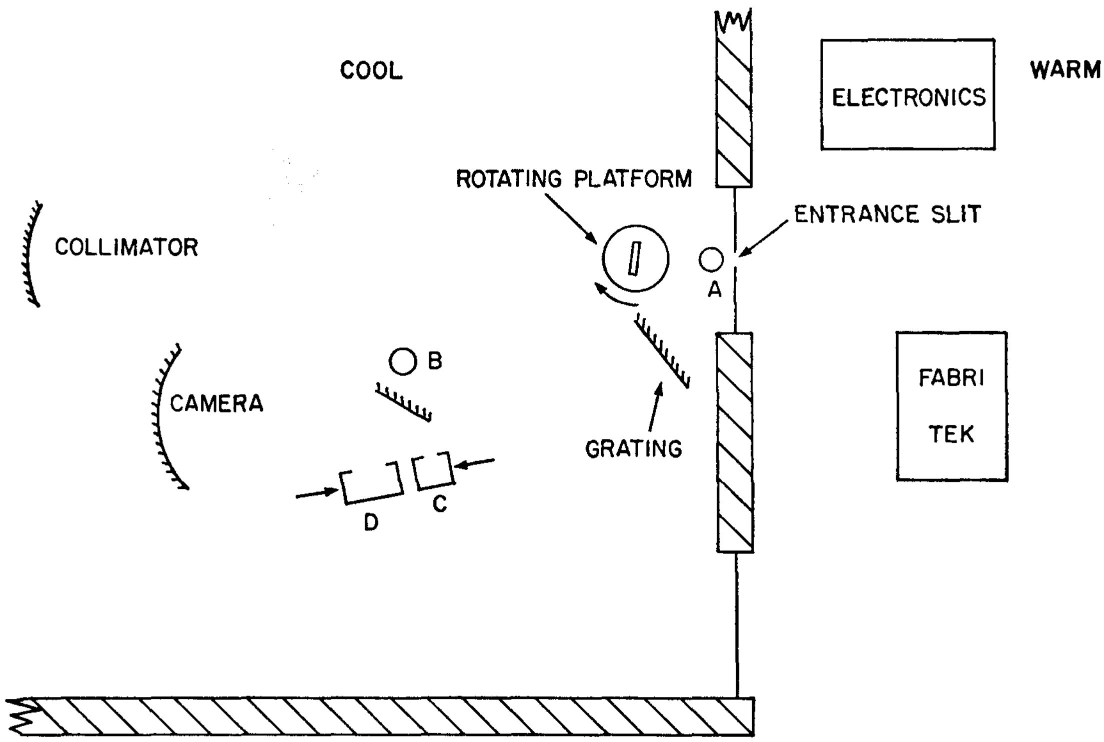

Fig. 1

and exact superposition of digital data from rapid scans offers a solution to these problems. The basic requirement for rapid scanning is therefore a multichannel analyser and a suitable triggering mechanism. I shall describe briefly the way this is being developed at the 48-inch telescope coudé of the Dominion Astrophysical Observatory, and other uses this instrument is being put to.

Figure 1 shows a plan of the relevant parts of the coudé spectrograph. The spectrograph is itself one of the fastest such instruments made—the system of high reflectance coatings, image slicer and mosaic grating making it equal in speed to the 200-inch coudé. At present there are four photomultipliers in the system: (A) which accepts light from behind the slit (or image slicer), (B) which looks at a stationery 60Å of spectrum, (C) which is movable, behind a single slit of adjustable width and (D) which accepts light from 500Å of spectrum, is movable and may be masked by a multi-slit diaphragm.

The multichannel analyser is a Fabri Tek FT 1074 machine with 4000 memory addresses which may be used in one, two or four channel simultaneous input modes. It has a large number of operating modes and input/output controls which need not be described here, beyond specifying two different modes of cycling. The first (mode *a*) simply increments the memory address by external trigger and recycles, adding to existing memory data on a second arming trigger pulse. The second mode (*b*) cycles at a preset rate erasing the contents of each memory address immediately before sampling. Output is usually in the form of oscilloscope display, plotter and punched tape.

The Fabri Tek is used in three types of observation, which I shall describe briefly in turn.

1. *Rapid Spectrum Scanning*. This uses sampling mode (*a*) above, and photomultiplier C. The scanning is done by means of a rotating glass plate behind the slit (image slicer) (Fig. 2). As the plate rotates the spectrum image oscillates in the focal plane. The thickness of the plate determines the amplitude of the scan, and also the resolution of the scan, as the changing optical path length alters the focus continuously. This is a drawback to broad band scanning (which should be done by grating rotation) or low resolution techniques, although scans of 100 or 200Å should be possible at some 2–3Å resolution on the short focus camera and low resolution grating. For scans of 1Å or less the resolution

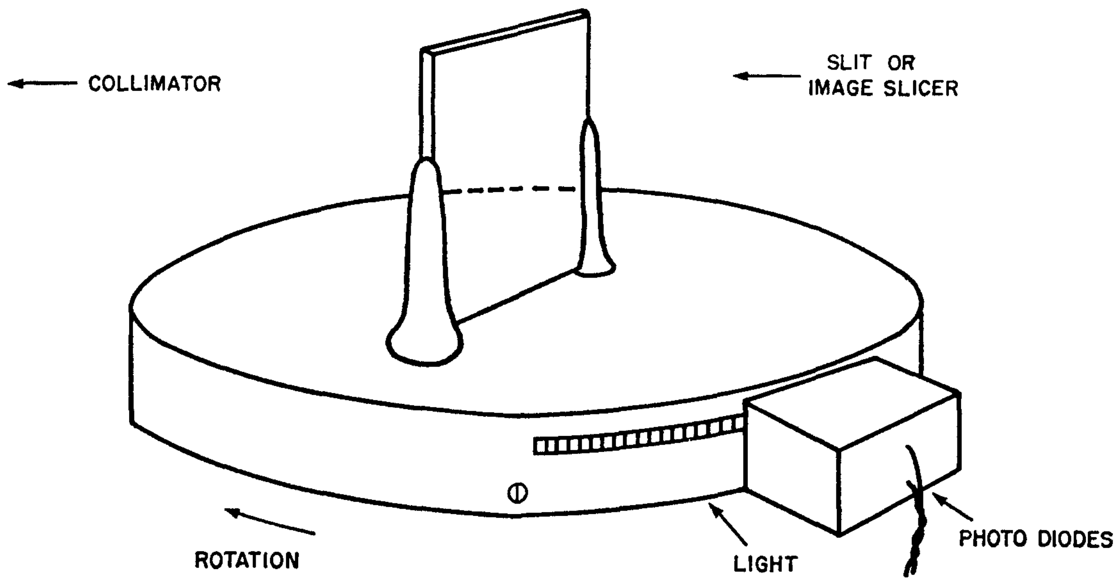

Fig. 2

is 20 μm (0.05Å) while for larger line scans (10–20Å) a mean resolution of some 0.5Å is obtained. A mechanical focus corrector, geared to the glass plate will improve this by a factor of 3 or more. A total scan encompassing some 120° of rotation is usable before reflection from the plate seriously depletes the signal, so that the apparatus is recording for $>1/2$ of the real time. The defocussing blur circle for a 0.8 mm plate (0.5Å scan) is some 10 μm. The scan scale is not linear with angle of rotation, but this is easily calibrated and thereafter removed in the computer processing. The glass plate is mounted on a turntable on the outside of which is a transparent scale marked with lines 1 mm apart. A light shining through the scale on to a photodiode is used to provide 500 trigger pulses and 1 arming pulse, twice per revolution of the platform, in the present prototype model. Again irregularities in the scale may be calibrated out, the important point being that the scans are exactly superimposed. The apparatus seems to be very stable and reliable, without missing more than one trigger in half an hour's scanning. The platform rotates on a synchronous motor, at 1 revolution per sec. This synchronous speed means that a.c. pickup accumulates in the signal. Attempts to shield the photomultiplier completely were unsuccessful so that rather than use a non-synchronous motor and convert the a.c. pickup into noise, the pickup is recorded for each system setting and subtracted from the final data. In performance (Fig. 3), this prototype rapid scanner matches that of the slow ratio scanner, (1 per cent accuracy on a third magnitude star in 4 min) but with five time higher resolution, and digital data processing. Future developments on the short focus camera, and in connection with an image tube should make line scans at ≤ 0.5Å resolution possible down to eighth magnitude or fainter in 10 min.

2. *Radial velocity scanning*. Scanning photomultiplier D may be fitted with a high contrast replica spectrum which matches the stellar spectrum, and used in the manner pioneered by Griffin (Ap. J., 148, 465, 1967) to measure radial velocities directly. The present diaphragm contains replicas of some 200 lines at 2.5Å/mm, for late type stellar spectra. The technique of observing is to use the slow scanner

(a motor driven screw moving the photomultiplier in the focal plane) until the light maximum is located, using the comparison spectrum or a standard velocity star. The rapid scanner is then switched on, with a scan just wide enough to cover the turning point of the maximum (~1Å). Scans are made until the desired signal-to-noise is achieved and then the program stars are observed in a similar way. A computer program then fits curves through all the observed light maxima and converts the differences in position to radial velocity. The apparatus is still in development, but tests have indicated a performance of accuracies of ± 2 km s^{-1} for 3 min observing on a seventh magnitude star.

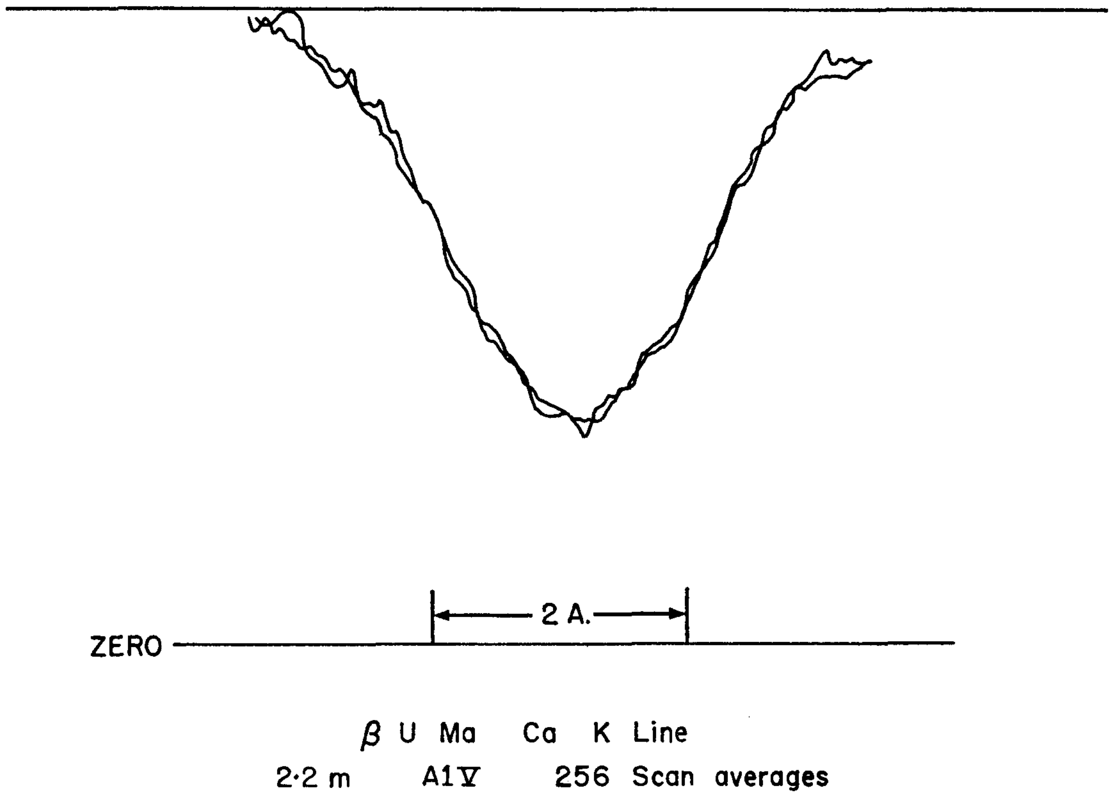

Fig. 3

3. *Lunar occultation fringes*. These are made with sampling mode *b* and using any or all of the photomultipliers A, B, D. The star to be occulted (dark limb disappearances only so far) is centred in a hole replacing the entrance slit, 5 or 15 arcsec in diameter and the signal continuously recorded and erased with 1 millisec resolution. The entire 4000 channels may be used, giving the observer a 4 sec reflex time to stop the Fabri Tek when the occultation occurs and prevent it from being erased. Alternatively 2000 channels may be used for the occultation and 2000 for timing pulses, so that the time of the event may be recorded to millisec accuracy. This allows a 2 sec reflex time. If the star is bright enough the aperture of photomultiplier D may be closed down and the event recorded with narrow band resolution at B and D and with filter wavelength resolution at A. The purpose of the observation is to record the diffraction fringes which give information on the angular size of the star (or stars if it is a binary). The narrower and more numerous the pass bands the more information is obtained. In practice information with a 500Å pass band can be used from fifth to seventh magnitude stars, while the brighter, more rare occultations may be observed in the multichannel mode, (Fig. 4). The recorded fringes are punched on paper tape and fed into a computer together with the stellar spectral type, wavelength band pass, and lunar cusp angle. The fringes are smoothed by Fourier methods and fitted to a series of model fringes calculated for the band pass and appropriate limb darkening, yielding a value for the stellar angular diameter. This topic will be discussed in full at a joint session of the 14th General Assembly of the I.A.U. in Brighton.

These developments are being carried out by a number of Dominion Astrophysical Observatory personnel, of whom Mr. J. M. Fletcher, Mr. D. H. Andrews, Mr. C. L. Morbey and Mr. J. Stilborn (University of Victoria) should be mentioned in particular.

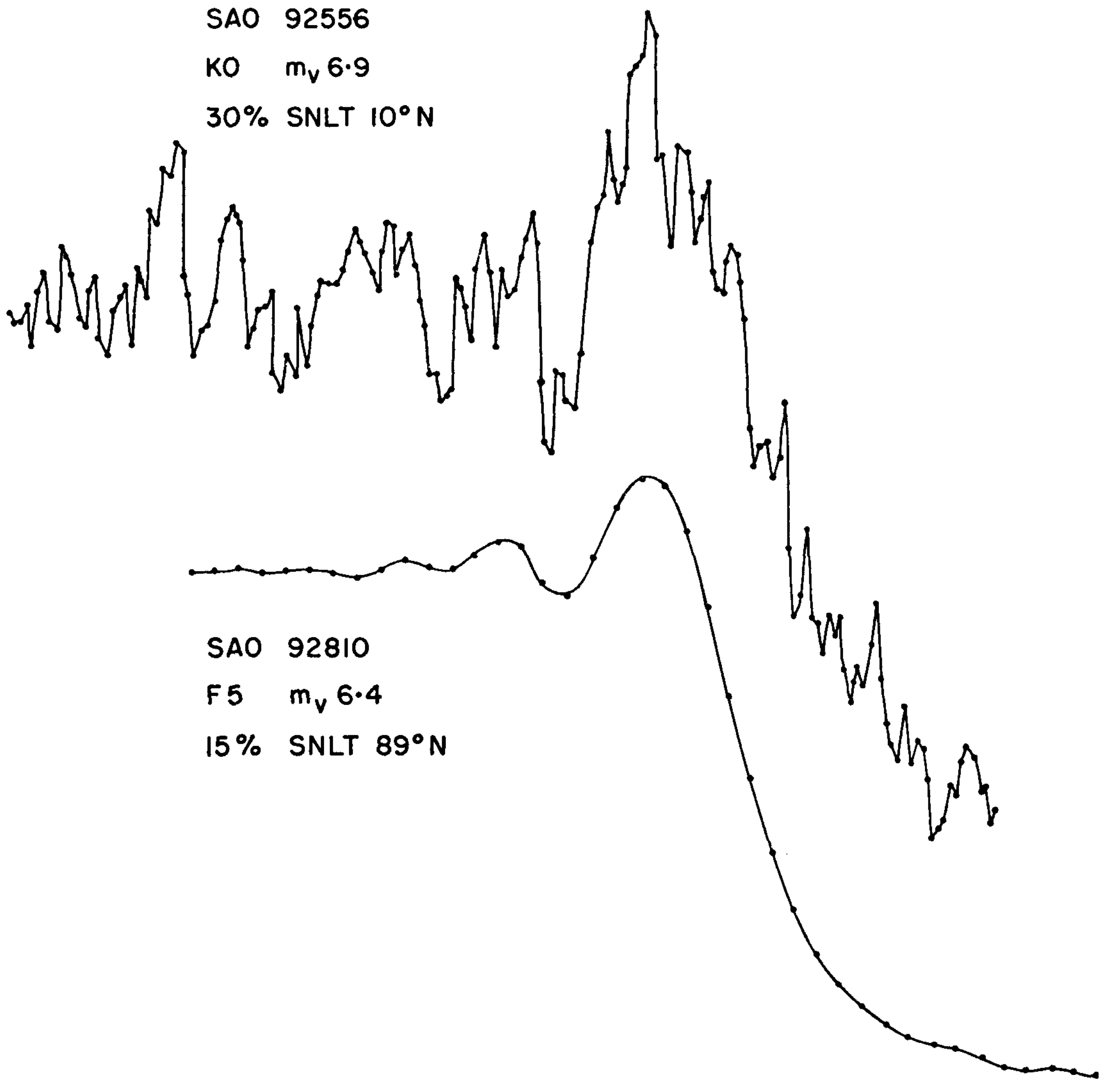

Fig. 4

DISCUSSION

A. Behr: At what spectral type have you been able to measure radial velocities of seventh-magnitude stars to ± 2 km s^{-1}?

J. B. Hutchings: Stars of spectral type K, sometimes G. We look at a spectral range of about 500Å, and have a replica spectrum containing about 200 features.

P. Gillingham: For the quoted performance, was the image-slicer used?

J. B. Hutchings: Yes.

W. Liller: You said this was a preliminary result, and capable of improvement; what do you think the ultimate velocity accuracy will be?

J. B. Hutchings: I can foresee improvement by a couple of magnitudes (magnitude limit for the quoted accuracy), but feel we should eventually be able to do better than that.

E. W. Dennison: Do you use pulse counting photometers? Does the scanning quartz plate shift the monitor spectrum also?

J. B. Hutchings: We use the photomultipliers in the d.c. mode. For rapid scanning we use only a single channel; the monitor is used for slow scanning.

R. B. DUNN: Do you worry much about the dead time in the scanner? Would there be any advantage in keeping the individual scans separate so that you could cross-correlate them and perhaps improve the wavelength accuracy?

J. B. HUTCHINGS: That would be nice if we could do it, but at the moment we do not have magnetic recording.

W. C. LIVINGSTON: What limits the speed of your rotating plate scanner? Would there not be an advantage in reducing scintillation noise for bright stars if you rotated this plate at 10 rotations per sec, or even faster?

J. B. HUTCHINGS: Yes, so long as we can remove the a.c. pickup. The present speed is arbitrarily chosen for our initial runs.