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THE MEASUREMENT OF STELLAR SCINTILLATION

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The rapid variations in brightness and colour of the naked-eye stars have long been phenomena admired by poets and astronomers alike. Similarly, and presumably because of the relative rarity, the non-existence of twinkling in the naked-eye planets has also excited interest. To even consider thinking quantitatively about a twinkle would surely antagonize the most mediocre of poets, but nevertheless that is what I intend to do here.

By definition in this paper* stellar scintillation is the variations in brightness of stars caused by the passage of their light through the terrestrial atmosphere. Theories of scintillation are in a reasonably satisfactory condition and I do not intend to give more than a superficial explanation here as I shall be concerned mostly with the actual measurements. The fluctuations in brightness arise because of turbulence in the high atmosphere. Light from a star passing through this turbulent layer suffers varying amounts of refraction and dispersion as it passes through turbulent elements of differing refractive index and size. Consequently both shifts in apparent position and refractional defocusing arise. It is the latter effect that causes scintillation. The planets do not twinkle as they subtend finite angular diameters and this averages out the effects of the various turbulent elements.

Though rapid fluctuations in brightness of stars are of little interest to amateurs with small telescopes it will be appreciated that the turbulent layer causing stellar scintillation is the very same one as that affecting seeing conditions. The measurement of scintillation enables us to discover quantitative facts about this layer. The effect on a normal star image is to enlarge it and to destroy the appearance of diffraction rings. The actual turbulent elements themselves can readily be seen on examination of an out-of-focus star image: broad moving lines are seen running across the image and these arise from the turbulent elements being swept along by the prevailing wind in the upper atmosphere. An excellent summary of the effects of upper atmospheric and other types of disturbances that affect seeing conditions has recently been given by Dr Steavenson.[3]

Probably the most important papers so far written on the measurement of stellar scintillation are those by Ellison and Seddon[1] and by Nettelblad.[2] The apparatus used in both studies was essentially similar and I will refer only to the work of Ellison and Seddon. They attached a photomultiplier to the Cassegrain focus of the 36-inch reflector at Edinburgh and displayed the voltage fluctuations, due to brightness fluctuations of bright stars, on a cathode ray oscilloscope. These were then photographed by means of a continuously moving film. It is the express purpose of this paper to indicate an easier way of recording scintillation.

* Some authors include rapid changes in position in their definition of scintillation. This phenomenon is not considered here.

Instrumentation

A 24-inch reflector of 11 feet focal length was equipped with a photomultiplier at its Newtonian focus. It was decided to use the Newtonian focus and not the Cassegrain as the former comes closer to the focal lengths used by amateurs. The electronic equipment used was readily available as the Department of Physics of University College London had already installed it in connexion with their satellite-tracking programme. Only slight modifications were necessary to render the equipment suitable for stellar photometry.

The photomultiplier used was an E.M.I. 6097 and the E.H.T. supply came from a standard radiological unit capable of giving up to 5000 volts. With the bright star used in the present experiment it was only necessary to use 1000 volts.

The important feature of the experiment was the method of recording the rapid fluctuations in light amplitude—after transformation into voltage fluctuations. As already described, Ellison and Seddon solved this problem by photographing a cathode ray tube and then developing and examining the film. This introduces much labour. The reason for using this method as opposed to a pen recorder is purely a matter of time constants. The time constant of a pen recorder is rarely as small as 0·01 second, while a cathode ray oscilloscope has a time constant $\sim 10^{-6}$ second. The overall time constant of Ellison and Seddon's apparatus was about 0·2 milliseconds.

There are now commercially available recorders with adequately small time constants. These are the Ultraviolet Recorders, one of which was used in the experiment reported here. An Ultraviolet Recorder removes the neccesity of having large ink pens with high inertia by substituting a minute mirror as the active part of a galvanometer. A fine beam of intense ultraviolet light is deflected from the galvanometer mirror into a moving strip of special photographic recording paper. This recording paper is relatively insensitive to ordinary daylight but is highly sensitive to ultraviolet light. The paper develops itself automatically on exposure to mild daylight (taking about one minute for full development) and the ultraviolet trace shows as a black line on a white background. Consequently records of voltage changes can be made with great ease. Time marks (one second or tenth seconds) are automatically superimposed internally by the recorder.

The time constant of the galvanometer used was 4 milliseconds, but there are 0·5 millisecond galvanometers available. As we are interested mostly in the 10 to 200 cps region and less so in the 200 to 1000 cps region the apparatus used was sufficiently sensitive to follow accurately most star scintillation and to serve as a systems test.

The disadvantage of a ultraviolet recorder is its cost. At £600 such a recorder is outside the means of most people, and in addition the galvanometers within the recorder burn out if more than a specified current passes through them (of the order of 20 milliamps). At £25 a time these make expensive fuses!

Between the photomultiplier and the recorder was a standard A.C. amplifier, built by A. C. Newton. The schematic layout of the whole apparatus is shown in Figure 1.

Observations

The observations were carried out on a clear transparent night at the beginning of October 1961; the night may roughly be described as good (excellent for Mill Hill). The first magnitude star Deneb was centred in a hole in a diaphragm just in front of the cathode of the photomultiplier attached to the 24-inch reflector. The hole was large enough to accept the whole star image and the star was purposely put out of focus on the cathode so that positional variations of cathode sensitivity would not produce spurious brightness fluctuations. A 6-inch guide telescope was used to keep the star centred in the hole. With the full aperture of 24 inches a current output of about 2 mA from the amplifier was recorded.

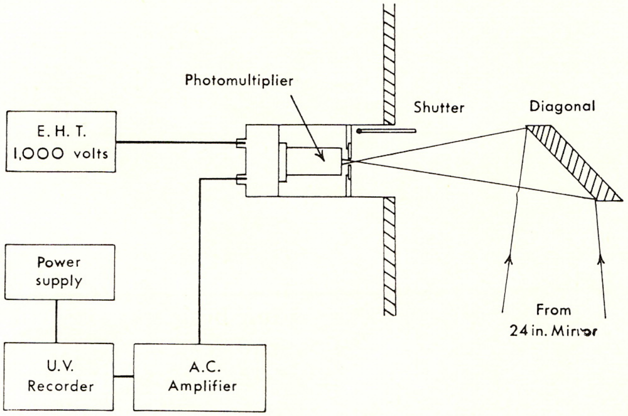

FIG. 1. Schematic layout of photometric apparatus.

A typical observation proceeded as follows. The gain of the amplifier was adjusted to give a good deflection of the galvanometer mirror when the star light was accepted. The light fluctuations were then recorded for 5 seconds with the recording paper running at 2 inches per second, and then 3 seconds at 6 inches per second. The latter (maximum) speed enables the full resolution of the recorder to be used. A shutter was then closed over the photomultiplier and the zero measured.

This procedure was repeated for various apertures of the telescope, using stops of 18, 15, 12, 9, 6 and 3 inches in decreasing order. The last four were offset so that the Newtonian secondary did not obscure any light. Each time the amplifier gain was adjusted to give good deflections.

It was checked that the contribution of the sky and the internal electronic noise was negligible compared with the star signal.

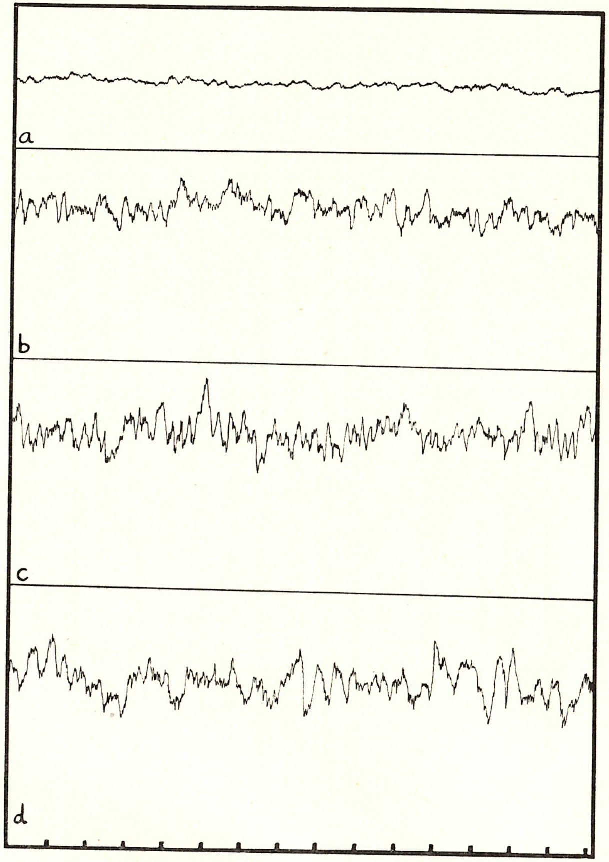

FIG. 2. Scintillation traces for various telescope apertures. The horizontal line below each tracing is the zero level. Short vertical lines mark tenths of seconds. (a) 24 inches (b) 18 inches (c) 15 inches (d) 12 inches.

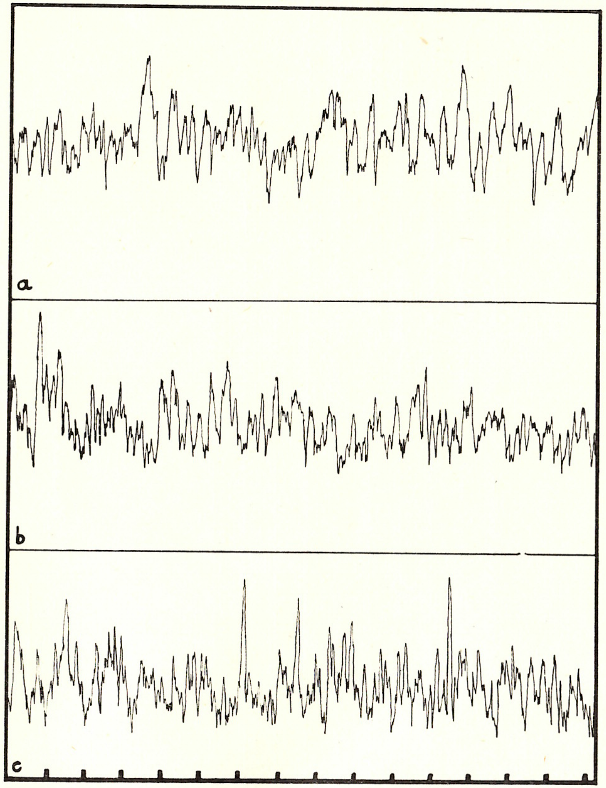

FIG. 3. As in Figure 2. (a) 9 inches (b) 6 inches (c) 3 inches.

Results

Typical tracings obtained with the various apertures are shown in Figure 2 and 3. It can be seen, confirming the work of Ellison and Seddon, that as the aperture gets smaller so the amplitude of scintillation increases. The amplitude of light variation is only about 10 per cent of the mean light level for 24 inches aperture and increases to about 130 per cent at 3 inches. The large increase obtained in stopping down from 24 inches to 18 inches is striking. My results agree well with Figure 7 given by Ellison and Seddon, and if one plots logarithms of aperture and amplitude of scintillation using both my data and that of Ellison and Seddon a straight line ensues giving the following law

$$\text{Amplitude} \propto (\text{aperture})^{-0 \cdot 6}$$

This is somewhat different from the straight inverse relationship often quoted.

Apart from light amplitude changes with aperture there are also frequency changes. With 24 inches aperture the strongest harmonic is in the region of 10 cps and the next strongest is about 250 cps, superimposed on the first. At 3 inches the strongest harmonic is in the region of 40 cps superimposed on a slow variation of 1 to 3 cps. The high frequency variations are more or less masked at 3 inches aperture; possibly they cease to exist at all.

Conclusion

An ultraviolet recorder is a very convenient instrument for use in the study of stellar scintillation. The ease with which one can examine immediately the light fluctuations and the speed with which each individual observation is made suggests that a much more extensive programme could be carried out.

I would like to express my sincere thanks to Mr K. Fea and Mr A. C. Newton for allowing me to use their satellite tracking apparatus and for providing invaluable help throughout the observational part of the experiment.

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3 Steavenson, W. H., *J. Brit. astron. Ass.* (1960) **70,** 204.

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