The Determination of Stellar Distances.

By Dr. WILLIAM J. S. LOCKYER.

In his presidential address delivered before the Royal Astronomical Society, in connexion with the celebration of that society's centenary (see NATURE, June 24, p. 815), Prof. Eddington referred to six great landmarks of astronomical progress during that century. He pointed out that this was a record of advance which was *continuous*, and not in great waves followed by periods of exhaustion. As he further remarked, the centre of most rapid progress has shifted from time to time and the various branches of astronomy have had their ups and downs. In this second category may perhaps be placed the determinations of the parallaxes or distances of the stars, because quite recently a very great impetus has been given to this branch of astronomy by the introduction of a rapid and effective new method.

So long ago as 1837 the first successful attempt to determine the parallax of a star was accomplished by Bessel, who made his result known in the last month of 1838, showing that 61 Cygni had a parallax of about one-third of a second of arc. Since that date this research has been carried on continuously and we have now catalogues of the parallaxes of a large number of stars. Among the observatories measuring trigonometrical parallaxes to-day, may be mentioned Allegheny, Dearborn, Greenwich, McCormick, Mount Wilson, Oxford (Radcliffe), Swarthmore, and Yerkes, and these institutions secure material which provides about three or four hundred parallaxes a year.

It is interesting to note that in the early days it was thought that the brightest stars were the nearest to us, and therefore attempts were first made to determine their distances. It was soon found, however, that estimates of distance based upon apparent magnitude were wholly futile, for the greater number of the larger parallaxes determined were of stars of the fifth, sixth, and fainter magnitudes.

The work of measuring the parallax of a star may be considered one of the most delicate operations in the whole field of practical astronomy. There are three methods available. The *absolute* method consists in making meridian observations at different times of the year and then studying the resulting places after all known corrections have been made. The *differential* method may be classed under two sub-heads. The first consists in measuring the position of the star to be studied in relation to neighbouring stars at different times of the year. If the neighbouring stars in the field of view of the telescope be close to the star under examination, a wire micrometer is used, but if distant, the heliometer is the more efficient instrument. The second differential method utilises the sensitive plate and consists in photographing a star region at different times and eventually measuring the positions of the star in question in relation to the neighbouring stars.

It was not until the year 1914 that the spectroscope was applied to the determination of stellar distances, and the method now in use is that originated and developed by Prof. W. S. Adams and other astronomers at the Mount Wilson Observatory in California. It is based on the fact that the intrinsic brightness of a star has an appreciable effect on its spectrum. Thus, if two stars have the same type of spectrum but differ greatly in luminosity they will probably differ greatly in size, density, and in depth of their surrounding gaseous atmospheres. If this be so, then their spectra should exhibit variations in the intensity and character of such lines as are peculiarly sensitive to the physical conditions of the gases in which they find their origin, in spite of the general correspondence between the two spectra. If, as Prof. Adams states, "such variations exist and a relationship can be derived between the intensities of these lines and the intrinsic brightness of the stars in which they occur, we have available a means of determining the absolute magnitudes[1] of stars, and hence their distances."

It has been found that certain lines in stellar spectra do give indications of variation with absolute magnitude,

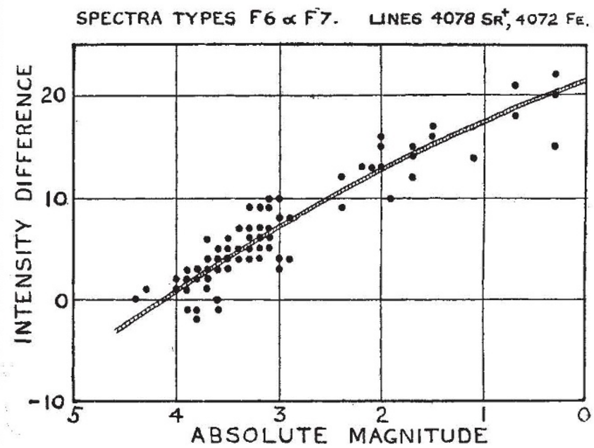

FIG. 1.

One of the fundamental curves formed from *known* parallaxes (black dots of stars of spectrum types F6 and F7.

When the intensity-difference in any star of these types has been determined, the absolute magnitude can be read off the curve and the parallax calculated.

and the detection of them we owe to Hertzsprung and Adams and Kohlschütter.

To determine the absolute magnitudes of stars any of three different sources of data can be utilised, namely, the trigonometrical parallaxes, parallactic motions, or proper motions. The most serviceable of these is the first, and reference to this alone will be made here.

The first step in the process is to have available a classification of star spectra based on detailed measurements of line intensities instead of on the more general eye estimations, estimations which have been extremely valuable up to the present time for the general classification of stars but are now superseded. Such a detailed classification for many of the brighter stars has been made and is being rapidly extended.

It is next necessary to construct a series of reduction curves for each type or class of spectrum or for small groups of types (see Fig. 1). These curves are based

[1] The absolute magnitude of a star is its apparent magnitude when reduced to unit distance. (Unit distance = Parallax of 0″·1.)

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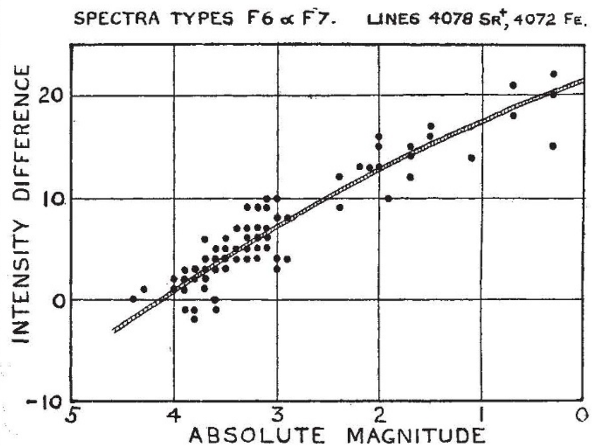

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on the calculation of absolute magnitudes of stars as determined from the apparent magnitudes (which are known) and from the trigonometrical parallaxes (also known) obtained from one or other of the methods previously described. The equation for this computation is as follows:

$$\text{Absolute Mag.} = \text{Apparent Mag.} + 5 + 5 \log (\text{Parallax}).$$

Stars of the same type of spectrum but of different absolute magnitudes are then compared with one another and the relative intensities of selected pairs of lines carefully measured. Curves are then drawn showing as ordinates the observed differences of intensities for each selected pair of lines, and as abscissæ the absolute magnitudes.

With these data it is a simple matter to determine the parallax of any star. Thus, it is only necessary to (1) determine first its type of spectrum, (2) measure the differences of intensities of certain lines in it and refer these values to the curves for that type; the next step is to (3) note from the curve the corresponding absolute magnitude, and lastly (4) determine the parallax from this absolute magnitude by means of the same formula as given above but arranged in a different order, thus:

$$5 \log (\text{parallax}) = \text{Absolute Mag.} - \text{Apparent Mag.} - 5,$$

in which all the members on the right-hand side of the equation are now known quantities.

Thus a single photograph of the spectrum of a star is sufficient for the determination of the star's distance. Naturally greater accuracy is obtained when more than one photograph is examined and several pairs of lines in them are used, but this involves very little extra labour.

The rapidity with which the determinations of parallax can be secured, when once the fundamental curves are formed, is far in excess of that of the older methods. The large powerful instruments of the present day are capable of photographing the spectra of very faint stars, so that a rapid survey of the whole heavens, at any rate to stars of about magnitude 6·5, will be accomplished in the near future.

At the recent meeting of the International Astronomical Union in Rome, great attention was paid to organising this work on an international basis. The Parallax Commission pointed out that there is a large amount of latent information regarding stellar distances in the long series of spectrograms obtained for other purposes at many observatories, and it is to be hoped that these data would be utilised.

A year ago the spectroscopic determinations of parallax were confined entirely to the United States at the Observatories of Mount Wilson and Harvard College. The Astrophysical Observatory at Victoria, B.C., now proposes to examine their slit spectrograms for this purpose.

In this country the only observatory occupied at present with this work is the Norman Lockyer Observatory at Sidmouth. For more than a year the large collection of spectrograms has been undergoing measurements in this connexion, and a large number of new photographs has been taken. An interesting point in this observatory's work is that the measurements of the intensity differences between pairs of lines are being determined by a method originated by the writer, which is different from either of those used at the American observatories. Thus an independent check on the American results is rendered possible.

It is necessary to point out, however, that this research on so large a scale could not have been undertaken had it not been for the opportune assistance rendered by the Department of Scientific and Industrial Research. This Department appointed Mr. W. B. Rimmer, D.I.C., in July 1921 as a research assistant, and his appointment was due to terminate towards the latter end of this year. It is with very great satisfaction that it may now be stated that it has been extended to September of next year. The work is so far advanced that now most of the fundamental curves are completed. It is hoped, therefore, to publish shortly the spectroscopic parallaxes of about 500 stars, followed after a short interval by another 500.

It is satisfactory, therefore, to record that in this new impetus given to the investigation of the distances of the stars, this country is taking a part, and it is hoped that other observatories here which have useful material will join in and discuss it from this point of view.

This line of research should also provide an interesting field of work for the amateur astronomer. The instrumental equipment required need be only on a moderate scale, for a five-inch telescope, fitted with a suitable prism, would meet the case, if a larger one were not available. It is a definite and straightforward piece of research which would be a valuable contribution to astronomy.

Short-wave Directional Wireless Telegraph.[1]

By C. S. FRANKLIN.

DIRECTIONAL wireless telegraphy is by no means a new development, for Hertz made use of reflectors at the transmitting as well as the receiving ends in order to augment the effects, and to prove that the electric waves which he had discovered obeyed, to a considerable degree, the ordinary optical laws of reflection. Senatore Marconi, in his earliest endeavours to develop a telegraph system using electric waves, also employed reflectors to increase the range and get directional working.

The discovery by Marconi of the great increase of range obtained by the use of longer waves, and the earthed vertical aerial, practically stopped development on directional lines for the time being. The demand of the time was for increased ranges; and as the first practical application of wireless telegraphy, namely, working to and between ships, required "all round" working, there was very little call for directional systems.

To-day the range has arrived at the maximum possible on the earth, and the wave-length has increased to such an extent that the frequencies pro-

[1] From a paper read before the Institution of Electrical Engineers on May 3.