The Determination of Stellar Distances[*]

Ways in Which Our Knowledge Is Being Extended

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THE interests of astronomers are divided between the study of the solar system and the great universe of stars of which the solar system is a mere unit. There are numerous problems still unsolved connected with the sun and planets, which attract physicists and mathematicians as well as astronomers. In the main, however, the efforts of astronomers during the present century have been devoted to the extension of our knowledge of the stellar universe. Observations on a large scale have been made in many different directions. Measurements of parallax, spectroscopic classification, proper motions, velocities in the line of sight, photometry, color determinations, double stars and variable stars have been extensively investigated. These different researches have thrown light on one another, and have all contributed towards a true description of the present state of the stellar universe. In such a description the most important element is the distance of the stars from us. A knowledge of the distance is essential to a complete determination of the position, the velocity, the luminosity and the mass of the star. On the other hand our general knowledge of the velocities, luminosities and masses of stars can be used as guides to their distances.

From the time of Copernicus, astronomers have looked for an annual movement in the apparent positions of the stars due to the shifting positions of the earth as it travels round the sun. This causes a star which is comparatively near to us to appear to describe an ellipse in the sky with reference to the background of more distant stars which are in the same direction as seen by us. The changes we see are small angular changes and provide a measure of the parallax or small angle subtended by the radius of the earth's orbit at the distance of the star. The parallax of a star is thus the reciprocal of the distance,—a parallax of one second of arc (1″) implying a distance of 200,000 times the distance of the sun from the earth, 0″.5 double this distance and so on. With the progress of astronomy it has become possible to measure angles with continually increasing accuracy. The large photographic telescopes especially have contributed to this. It is possible now with a very few photographs to determine a parallax as small as 0″.05, or measure a distance of 4 million times as great as that of the sun. Naturally, great care and special precautions must be taken both in obtaining photographs and in their measurement. The accuracy with which these angles can be measured may be put down as+0″.01, and considerable confidence can therefore be placed in measures of distance which are not more than 4 million times that of the sun, and even greater distances can be determined, though somewhat roughly.

Within a sphere of this radius, it should then be possible to locate all the stars which are sufficiently bright for observation. It is only necessary to know which to look for. For this the apparent movement of the star on the face of the sky forms a good guide. If stars of proper motion greater than 20″ a century be examined, about 1 in 5 are found to be within this limit of distance. Probably 800 stars may be ranged in this way, though up to the present the number known is under 100. It is important that the region of space around the sun should be thoroughly scrutinized. It provides us with information about all the individual stars and not merely the average results with which we have to be content in other cases.

Another method which has led to the determination of the distances of individual stars was published a few years ago by L. Boss. He found a loose collection of stars in the Hyades which were all apparently moving to one point in the sky. He interpreted this as meaning that these stars are actually moving in directions parallel to the line from the sun to this point of the sky. Further, the stars must all have the same velocity, or they would not remain in existence as a cluster. This velocity is determinable from spectroscopic observations of one of the stars, and when it is known, the angular motion of each star on the face of the sky can be used to find its distance. In this way the parallaxes of 40 stars ranging from 0″.021 to 0″.031 have been obtained. Other clusters of a similar character have been found. They give much food for thought, but are referred to here as contributing to the number of individual stars whose distances are known.

Let us next consider a method which gives the average distances of stars, although not the distances of individual stars. It was pointed out by Herschel that the community of direction of the proper motions of stars, i. e. of their angular motion on the face of the sky, might be explained by a movement of the solar system towards a point in the sky not far from the bright star Vega. A large number of subsequent researches have established this firmly. Further, spectroscopic observations of velocities in the line of sight, especially at the Lick Observatory, have determined the velocity of the solar system as 19.5 kilometres a second. This movement carries the solar system in one century 410 times the distance of the earth from the sun. The outlook from the solar system is thus perceptibly changed in a century. If the stars themselves were stationary, the distances of thousands of them could easily be determined from the extremities of such a long base-line, but as they are all moving, this cannot be done. We may, however, take a group of stars and, on the assumption that the peculiar motions of the stars themselves are haphazard, may attribute the general movement of the group to this motion of the solar system in the opposite direction. This method has been applied to find the mean distances of stars of different magnitudes. For example, those of magnitude 6, i. e. those just visible to the naked eye, are found to have a mean parallax of 0″.012, corresponding to an average distance of 18 million times the sun's distance. As we proceed to groups of fainter stars, the average distance increases, due to the inclusion of more distant stars, but in the group of fainter stars there are many which are no more distant than the brighter ones, these stars appearing fainter because they are intrinsically less luminous. It is found in this way that stars which are 100 times as faint as those just visible to us are not 10 times as far away, but only between 3 and 4 times the distance.

Instead of classifying the stars according to their magnitude or apparent brightness, the spectroscope enables them to be arranged according to their physical characteristics. If the spectra of different stars are compared, it is found, and it is an extremely remarkable fact, that they can be arranged in one continuous series. The lines in the various spectra may be due to helium or hydrogen, iron or titanium, but the chemical composition of the star is not the essential of the grouping; otherwise they would not fall, as they do, into one orderly sequence. Broadly speaking, the spectroscopic classification arranges the stars according to their temperature. It agrees with classification according to color, the blue stars being hotter than the sun, the yellow stars of nearly the same temperature, and the red stars cooler. When the proper motions of these different groups of stars are examined, those of solar type are found to be nearer to us than either the blue stars or the red stars of the same magnitude. In addition, spectroscopic measurements show that the peculiar motions are different for these different groups, particularly a group of stars at a very high temperature known in the Harvard classification as B stars and distinguished by the presence of lines due to helium in their spectra, have very small, peculiar velocities. Their proper motions are thus mainly due to the movement of the solar system. If then we assume that they are wholly due to this, their distances can be obtained. On this principle, or somewhat similar ones, the distances of these stars have been determined by Kapteyn, Plummer and Charlier.

So far we have utilized the apparent movements of the stars as the key to their distances. There are, however, two other methods which can be employed. The first is of somewhat limited application, and depends on the fact, brought out by Russell, Ludendorff and others, that there is no great range in the masses of stars. This is determined from double stars whose distances are known and from stars which spectroscopic observation shows to be double. The mass of a double star is measured by the pull between its components. This pull is by Kepler's third law determined by the distance apart of the two stars and the time they take to complete a revolution about one another. If there is a double star at an unknown distance, and we may assume that its mass is, let us say twice that of the sun, we may infer from the period of revolution what is the distance apart of the two components. Comparison with the angular distance apart, found by discussion of double star observations, gives the distance of the star from us. The distance of the stars from one another depends on the cube root of the mass, so that so great a charge as an eight fold increase in the mass will only imply a two fold increase in the distance. This method is being developed in more detail as our knowledge of the actual masses of double stars of different types of spectra increases.

Methods of much wider application depend on our knowledge of the intrinsic luminosity of the stars. If we could say that a star would be equal in brightness to the sun when at the same distance from us we could infer at once its distance. This method was proposed by Huyghens and Lambert.[1] It cannot be applied in this crude manner because there are very great differences in luminosities among the stars: some, such as Canopus, give out more than a thousand times as much light as the sun, and a little star recently discovered by Barnard has only one three-thousandth part of the sun's luminosity. But there are types of stars in which there is not a great range of luminosity; for example, the B stars already referred to do not seem to have a great range. They are all very brilliant, say a hundred times as brilliant as the sun on the average, and they do not differ widely among themselves. Though some may be 3 times as bright as the mean and others only one-third as bright, half the stars will be found to be between these limits. In this manner Charlier has calculated the distances and positions of all the B stars. He finds that they form a spheroidal group with its short axis perpendicular to the plane of the milky way and one-third of the equatorial axis. The position of the centre of the group relative to the sun is also determined.

It is probable that this method may be extended to other groups of stars. The researches of Russell and Hertzprung have shown that the red stars may be divided into two groups, "giants" and "dwarfs," which are clearly separated. The "giant" red stars are of great luminosity, like the B stars, and there is not a very great range among them. The apparent magnitude should therefore be a very good measure of the distances of the class of stars and as they are many of them at such great distances that their movements, even in a century, are very small, will afford the most available and accurate means of finding their range.

A more suitable method of utilizing the light of the stars to determine their distances has recently been devised by Adams. Although the spectra of the stars do fall into one unbroken line dependent on their temperature, there are small differences with respect to particular lines which he has discovered and examined. We know that changes in spectra are produced by differences of pressure. It is therefore not surprising that differences may be detected between the spectra of a large and a small star which are at the same temperature. Differences in the force of gravity and the density of the part of a star near its surface, from which light reaches us, and which we analyze in the spectroscope, are to be anticipated. Adams has found marked differences between the relative intensities of certain lines in stars which are similar in spectral type and apparent magnitude, but which are known to be at widely different distances from us. He has taken the stars which are known to have parallaxes greater than 0″.05 and compared their spectra with those of stars known to be at very much greater distances, but which appear to us to be equally bright. The latter stars are much more luminous than the former. His measurements of relative intensity are found to give a reliable estimate of the luminosity, and from the luminosities the distances are readily inferred. For example, if there are two stars of equal apparent magnitude, and the first is known to be nine times as luminous as the second, then its distance must be three times as great as that of the second. It seems likely that this method will be extensively developed and will add very materially to our knowledge of the distances of stars.

A very striking application of the peculiarities of the light from certain stars has been made by Hertzprung to determine the distance of the smaller Magellanic cloud. Miss Leavitt, of Harvard College Observatory, had shown from the study of variable stars in clusters that for a certain peculiar class of variables known as Cepheids there existed a relationship between the period of variability and the apparent magnitude of the star. As the stars in the same cluster may all be regarded as at the same distance from us, it fol-

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[*] From *Scientia*.

[1] Plummer, "The Observatory," 1916, p. 16.

lows that there is a relationship between the period of variability and the luminosity of a Cepheid variable. The necessary constant of the formula was inferred from a consideration of a number of the nearer Cepheid stars, whose mean distance could be derived from the solar motion. From this mean distance, combined with the observed magnitudes, the absolute brightness of Cepheids of different periods was derived. Now the smaller Magellanic cloud contains a number of Cepheid variables which are very faint on account of their great distance. From the period of their variability, combined with their apparent magnitude, the smaller Magellanic cloud was found to have a parallax of 0″.0003.

I have attempted to show in what unexpected ways our knowledge of the distances of the stars is being extended. We rely on accurate determinations of parallax to furnish distances, which are wholly independent of the luminosity and physical characteristics of the stars. These are extended statistically by the combination of the study of proper motions and of the velocities of stars to or from us determined by the spectroscope. We are thus enabled to discover the relation between the luminosities of stars and their physical characteristics indicated by their light and its analysis. These characteristics are then applied to determine the distances of stars which are too far away for their movements to be appreciable. It is to the correlation of widely different researches that recent progress is due.

Four-Cycle Versus Two-Cycle Diesel Engines

THERE is no problem connected with internal-combustion engines that has absorbed so much attention, and to which such a large amount of discussion has been given, as that of the relative merits of the four-cycle and the two-cycle principles. This is true in general for all types of internal-combustion engines, but where the Diesel engine is concerned the question is still more potent in that the Diesel principle lends itself well to units of comparatively large power on account of the fact that the fuel is only introduced into the cylinder at the moment of ignition. Thus for a given size of cylinder the heat stresses are, if anything, less with a Diesel engine than with a gas engine.

The larger the power, it is generally admitted, the better the case for the two-cycle principle, because of: 1. The limiting size of the exhaust valve of four-cycle engines for satisfactory working; 2. The better turning moment with two-cycle engines; 3. The smaller cylinder required with two-cycle engines to develop equal power in the same number of cylinders, although at a higher consumption of fuel per unit power developed.

Furthermore, the Diesel principle removes some of the most severe objections to the two-cycle principle. The scavenging with Diesel engines is carried out by air and air alone, instead of a mixture of air and gas, so that the danger of ignition of the incoming gas, or of the loss through the exhaust ports of part of the charge does not arise with the Diesel engine. The foregoing are the points around which general discussion has centered. In the following, attention is confined solely to the Diesel engine.

The practice hitherto of makers of Diesel engines is varied. Some few have stuck firmly to the two-cycle throughout a large range of power, others have confined themselves exclusively to the four-cycle, whereas a few of the largest manufacturers build four-cycle engines up to a maximum of some 200 to 250 b.h.p. per cylinder, and construct only two-cycle engines above that power per unit, on the assumption that the higher the cylinder power the greater the attractiveness of the two-cycle engine. Moreover, for special work, where lightness and compactness are of the highest importance, such as for submarine work, the two-cycle engine has been credited with a greater capacity for fulfilling these requirements than the four-cycle engine, and theoretically, looking superficially at the subject, double the number of impulses achieved by the two-cycle principle should have justified this choice.

To attempt to conclude from the results of two-and four-cycle practice up to the present time without having reliable knowledge of all the facts, would simply open the way to a lenghty and probably useless controversy. It may be stated, however, that the two-cycle engine has not gained ground, in fact, the four-cycle if anything, even for higher and higher powers, is increasing in application and the claims to compactness and lightness of the two-cycle engine have not fully been substantiated by the results of actual practice.

It is not desired to forecast the distant future. It is sufficient to move in small steps, especially in internal combustion-work, and as throwing a certain light on the subject outlined herein. Messrs. Franco Tosi, of Milan, Italy, with commendable enterprise, have recently built two similar engines, one a two-cycle and one a four-cycle, which they have tested one against the other with a view to comprehensive comparison, and the results of these experiments deserve special attention.

In order that those tests may be regarded as comparative, the underlying principles of the two designs must be examined for sufficient similarity as a basis. From the drawings, which we hope to publish later, both show the same trend in design. Both are of the totally-enclosed, high-speed, forced-lubricated, trunk-position type of engine. The designed speed of revolution, and the method of carrying the main tension stresses are exactly the same in both cases, and the cylinder dimensions only vary slightly. The two-cycle engine has the six working cylinders in the center with a scavenging pump and a compressor at each end. The four-cycle engine has eight working cylinders with two compressors at the forward end as against the six working cylinders of the two-cycle engine. There are, naturally, a number of differences, apart from the main arrangement, required by the cycle of operation adopted, such as the cooling system of the two-cycle pistons and the scavenging valve gear, and with the four-cycle the valve gear and cylinder head for accommodating the various valves.

The next important point to which attention must be directed is the designed power of these engines, which is the same for both *i. e.*, 1,300 b.h.p., and which equals about 215 b.h.p. per cylinder, with the two-cycle and 160 b.h.p. per cylinder with the four-cycle engine. This size was chosen because the two-cycle engine is a standard submarine engine of the makers, and it is is to be noted in this connection that Messrs. Tosi are experienced designers of both two- and four-cycle Diesel engines. It might be urged that this size is not the best for a suitable comparison. If a lower power had been chosen then a great advantage might have lain with the four-cycle, certainly not conversely; but, on the other hand, if a larger size had been the subject of experiment it might be contended that the position—later to be exactly given—might have been reversed in favour of the two-cycle. There is the fact that with the four-cycle engine, two exhaust valves were accommodated in each cylinder head, and as has already been stated, it has been found in practice that under certain conditions the question of the exhaust valve has been a limiting factor in respect of the probable power output from a given cylinder and for a desirable reliability of continuous operation in practice. With this four-cycle engine, each cylinder has two inlet and two exhaust valves, and the exhaust valves are water cooled, not only in the cages, but also the valves themselves. This remains an outstanding point, although it must be conceded that 210 b.h.p. per cylinder for a two-cycle and 180 b.h.p. per cylinder for a four-cycle engine are no mean outputs, especially for the high-speed type of engine.

It remains to discuss the actual results, and to draw deductions therefrom. Lengthy tests were carried out, 145 hours continuous non-stop runs being made, and both engines developed their designed power of 1,300 b.h.p. at 300 r.p.m. It was found, however, that the two-cycle engine was not capable of developing higher than this figure, whereas the four-cycle engine at the same speed of revolution, 300 r.p.m., gave 1,450 b.h.p., and as a maximum power at higher revolutions developed 1,585 b.h.p. for a short period. As regards fuel and lubricating oil consumptions the advantage lies greatly in favour of the four-cycle engine. At full load, the four-cycle figure was 0.41 lb. of fuel, and lubricating oil per b.h.p. hour, whereas the two-cycle consumption was 0.573 lb. per b.h.p. hour. Fuel consumption tests were carried out at various powers and the advantage in this respect of the four-cycle at full power was well maintained at lesser powers.

In regard to flexibility, the four-cycle showed marked superiority. With the two-cycle engine at 300 r.p.m., the compression was 460 lbs. per sq. inch, whereas at 120 r.p.m., the compression fell to 315 lbs. per sq. inch, at which pressure the temperature generated would be insufficient to support combustion of heavy fuel oil, and so the engine would stop. With the four-cycle engine at 300 r.p.m., the compression pressure was 490 lbs. per sq. inch, and at 100 r.p.m., had only fallen to 445 lbs. per sq. inch.

The reasons for a fall in compression with a decrease in the speed of revolution are as follows:—1. Decreased revolutions are almost always accompanied by a diminution of power output, which means less fuel consumed, making for a cooler cylinder, and so less heat to be taken up by the induction air, and so a lower final compression pressure. 2. The compression leakage per cent. past the main tube rings is a function of the size of cylinder and of time. The smaller the time of compression, the less the leakage, so that when running at slow speeds the compression is lowered due to this cause. 3. Again, with slow running, the time element allows more heat to pass to the cylinder jacket, further reducing the pressure and temperature of final compression. These three causes are common to both two- and four-cycle engines. With two-cycle engines, the reason for the compression pressure dropping much more rapidly with reduced revolutions than with the four-cycle engine is on account of the scavenging air pressure.

The slower the speed of running the lower the pressure of the scavenging air, because of the lesser resistance against which the scavenging pump is required to deliver. In the working cylinder, where less fuel is being burnt, there are less gases to be expelled. Further, the time element enters into the question of leakage of scavenging air through the exhaust ports, so that, whereas at 300 r.p.m., the scavenging air pressure may be as high as from 5 to 6 lbs. per sq. inch at 120 r.p.m., it would be as low as 1.5 to 2.5 lbs. per sq. inch and the scavenging air pressure is that at which compression begins, and the final compression pressure falls in direct proportion on this account alone. On the other hand, with four-cycle engines, the pressure at which compression begins is substantially the same, irrespective of the speed of revolutions. This experiment further showed that the noise of running of the two-cycle engine was very much more than with the four-cycle, due to the suction of the scavenging pumps and the high speed of the valve gear. With two-cycle engines, the valve gear operates at engine speed, and with four-cycle engines at half-engine speed.

Messrs. Franco Tosi have decided, in future, to abandon the two-cycle principle, and to confine themselves to the four-cycle for reasons substantially as stated, which may finally be recapitulated:—1. Elimination of the scavenging air pumps with their receivers, diminishing thus the size of the engine and decreasing the noise. The four-cycle engine of equal power is, approximately, the same size and of the same weight as the two-cycle. 2. Lesser amount of heat units abstracted by the cooling water and the four-cycle engine contributing to the lower-fuel consumption with the four-cycle engine. 3. The inefficiency of scavenging with two-cycle engines, as compared with the four-cycle. 4. The possibility of using higher piston speeds with the four-cycle engine. 5. Greater flexibility of the four-cycle engine. 6. Simpler mechanical parts of the four-cycle engine. 7. The fuel pumps and valve gear of the four-cycle engine only ran at half-engine speed, making thus for easy running conditions.—*Engineering.*

Backing Photographic Plates

As soon as the photographic public realized the advantages to be obtained by backing gelatine plates, the plate-makers were not slow in supplying very efficiently backed plates as a regular line. Of course, they charged for the extra work, but the charge was trifling and the plates were cheap, so that we were very willing to avail ourselves of the convenience and to use backed plates whether the subject necessitated it or not. Now that plates have touched what, we hope, will be the high-water mark in price, the cost of backing has also increased, and we may well consider whether it is not worth while to revert to the old method of backing such plates as are actually required just before use. This used to be a simple matter in the old days, for few, if any, color sensitive plates were used, and a red or orange pigment sufficed for backing. This is hardly sufficient for orthochromatic plates, especially when a screen is used and the light transmitted is very similar to that reflected from the backing. Hence there has been a tendency to use a black pigment, such as lamp-black, instead of burnt sienna or umber, the black being quite efficent even with panchromatic plates. All that is needed is a little lamp-black, ground in water or beer, from the oilshop, some caramel, and a few drops of glycerine (if obtainable). The color is mixed with the caramel and as much water as may be necessary, and smeared thinly over the glass side of the plate. If the plate is to be used at once, there is no need to allow the backing to dry; but if a number of plates have to be prepared in advance, they must be placed in a rack and covered up until the color has dried on. It will be found, if methylated spirit is used instead of water in thinning the color, that the drying will be effected much more quickly. If a calcium box be handy, the plate rack may be placed therein, and there will then be no danger of the film becoming damp through the proximity of the backing.—*Brit. Journ. of Photography.*