The Survey of the Stars.¹

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AT the dawn of civilisation, when man awoke from his long intellectual slumber, nine muses were appointed to preside over his various activities. Only one muse was allotted to science, and that one was allotted to astronomy. Perhaps the high gods of Olympus who arrange these things had heard of no science beyond astronomy, or perhaps they thought it the only one worth encouragement; we do not know. But it is said that since then the claims of other sciences have been admitted, and a vast crowd of junior muses have been appointed to look after them. When they all meet in conclave, many of the latter report quite extraordinary rates of progress in their particular sciences, and it has sometimes been thought that astronomy, which started first in the race, has at times shown some tendency to lag behind.

To this Urania has always had a ready answer. She can point first to the immensity of her task; sciences such as geography, geodesy, and geology, whose field of action is limited to the surface of one tiny planet, can no doubt claim to be well on towards the completion of their tasks, but the exploration of an entire universe offers a task of a different order of magnitude. She can point also to the extraordinary difficulty of this task; after once the first obvious steps have been taken, the astronomer can get nothing of value except with instruments of almost incredible precision. Moreover, instead of being able to investigate phenomena when he pleases, he has to wait on Nature, and Nature moves very slowly in comparison with human life—the whole age of astronomy, as a science, bears the same relation to the ages of the stars that it studies, as does the last tick of the clock in the dying century to the century itself. Finally, she has often been heard to remark, with a mixture of pride and sorrow in her voice, that her science presents problems of such enthralling interest that only too few astronomers can be found to do their fair share of the fundamental work on which all progress must ultimately be based. We can rest assured that she is well satisfied when, as on the present occasion, our Society signals out for its highest honour one who has done not only a fair share, but also a lion's share, of most valuable fundamental work.

To the ancients the intrinsic difficulties of astronomical science did not loom large. The age of the universe meant much the same thing to them as the age of the human race, and the size of the universe was believed to be of the same order of magnitude as the size of the earth. The moon, they agreed, was about the size of the Peloponnese; the sun, as any one could see at an eclipse, was rather bigger. Aristarchus of Samos had, it is true, calculated that it must be eighteen or twenty times bigger, and had maintained that

the fixed stars must be very remote indeed. But he was far in advance of his time, even believing that the earth moved round the sun. The majority of the early astronomers held that the spheres of the moon, sun, planets, and fixed stars were all packed fairly closely together. For the most part they believed firmly in the principle they described as 'the economy of Nature,' which prohibited the leaving of any unnecessary unoccupied space between the heavenly bodies—surely no scientific belief has ever been so utterly unwarranted by the facts! With this supposed principle firmly rooted in their minds, they naturally felt confident that it was a simple matter to determine the distances of the various heavenly spheres with fair accuracy. Later, when the determination did not prove so easy as had been anticipated, it began to be felt that the impossibility of discovering any parallax motion whatever—any apparent change, that is, in the positions of the nearer stars as the earth performed its journey round the sun—presented an objection of real force against the Copernican system of astronomy.

It was on the absence of parallax motion that Ptolemy had based his argument that the earth was the unmoving centre of all the celestial spheres, and as century after century rolled by and no trace of parallax motion was forthcoming, it almost began to look as though Ptolemy had been right after all. Hooke, Römer, and Bradley, realising the fundamental importance of the question, attempted in turn to detect parallax displacements of the stars, and all their efforts ended in failure, although we must remember that Bradley's failure immediately resolved itself into a triumph—the discovery of aberration. This provided convincing evidence of the earth's orbital motion, but threw no light on the question of the distances of the stars.

Early in the seventeenth century, Kepler had maintained that the stars were probably of the nature of suns, and that our sun was similar to the other stars. The observation that the brightest of the stars appear, in modern terminology, some 25 magnitudes (10^{10} times) fainter than our sun, might well have suggested that the nearest of the stars must be some 100,000 times as distant as our sun, and so must have a parallax of the order of, at most, two seconds of arc. But, so far as I know, this type of argument scarcely appeared until Newton advanced it in his "System of the World." From the observed size of Saturn's disc he calculated that the sun must emit in all 2.1×10^9 times as much light as falls on Saturn. Although Saturn cannot re-emit all the light it receives, it appears rather brighter than a first magnitude star. Thus if the first magnitude stars are as luminous as the sun, they must be more than $\sqrt{(2.1 \times 10^9)}$ as distant as Saturn. Newton conjectured their distance to be about 100,000 times that of Saturn, representing a parallax of $0''.21$ —that is to say, he estimated that the first magnitude stars would

¹ From an address delivered to the Royal Astronomical Society on Feb. 11, referring to the award of the Gold Medal of the Society to Prof. Frank Schlesinger for his work on stellar parallax and astronomical photography.

appear to swing through an angle of only 0.42 seconds of arc in the sky as the earth moved from one end of its orbit to the other.

Almost at the same time the converse of this argument began to appear. Although Bradley had not succeeded in obtaining a definite parallax for any star, he had proved in 1727 that that of γ Draconis could not exceed one second of arc. Assuming this result to be generally true for all stars, astronomers began to compute lower limits to the luminosities of the brighter stars and found that they were commensurate with that of the sun, as Kepler had maintained. In 1800 Herschel used this supposition to compute hypothetical parallaxes both for bright and for faint stars.

The year 1838 saw the whole situation suddenly transformed. For in that year Bessel, Struve, and Henderson independently found definite and distinctly different parallaxes for the three stars 61 Cygni, α Lyrae, and α Centauri, and it first became possible to assert, on incontrovertible evidence, that the stars were not all at the same distance from the earth. It was now for the first time conclusively proved that the system of the stars formed a three-dimensional and not a two-dimensional structure. A workable method had been found for sounding the depths of space, and the universe lay open for exploration.

The general feeling of astronomers at the time is well shown in the address delivered by Sir John Herschel when, eighty-six years ago, he handed our gold medal to Bessel. He said: "I congratulate you and myself that we have lived to see the great and hitherto impassable barrier to our excursion into the sidereal universe, that barrier against which we have chafed so long and so vainly—*aestuentes angusto limite mundi*—almost simultaneously overleaped at three different points. It is the greatest and most glorious triumph which practical astronomy has ever witnessed. . . . Let us trust that, as the barrier has begun to yield, it will speedily be effectually prostrated."

The difficulties of the problem were so great as to put out of the question any such speedy prostration of the barrier as my predecessor of eighty-six years back appears to have hoped for. Although astronomical ability of the highest order was brought to bear, progress was slow. In 1901 Newcomb compiled a catalogue of stars of known parallaxes; their total number is only 72, of which 15 are designated as being "subject to more doubt than usual," while one is damned with four little dots which, we are told, means that it is "entirely unreliable." Even including the unreliable parallaxes, astronomy had been exploring the universe thrown open to it sixty-three years earlier at the rate of only about one star a year. The appearance of Newcomb's table, however, marked the darkest hour before the dawn.

Within two years Schlesinger begun publishing photographic determinations of parallax, which showed a far higher level of accuracy than had hitherto been either attained or thought possible. Other astronomers speedily adopted photographic methods, and in due course a scheme of co-operation

was arranged between the seven observatories of Allegheny, Dearborn, Greenwich, McCormick, Mount Wilson, Sproul, and Yerkes. The results of this scheme of work up to the year 1924 are contained in Schlesinger's "General Catalogue of Parallaxes." This contains the parallaxes of 1870 stars to a very high degree of accuracy, and forms one of the most useful and valuable publications the working astronomer has ever seen. A comparison of this catalogue of 1870 parallaxes with Newcomb's 1901 Catalogue of 72 parallaxes gives a vivid picture of the work done in twenty-three years. While Newcomb's parallaxes show an average error of nearly a twentieth of a second, those in the Schlesinger catalogue seldom show a probable error of more than a hundredth of a second—the angle subtended by a pin-head at a distance of twenty miles! The gain in accuracy is the greater part of a decimal place, while the Schlesinger Catalogue contains twenty-six times as many stars as the earlier list.

Let us turn from this record of work achieved, to contemplate the realms which remain to be conquered. In measuring the distances of the stars, the natural unit of length is the 'parsec,' the distance of 19,100,000 million miles, at which a star has a parallax of one second of arc. There is no known star within one parsec of the sun. The number of known stars within spheres of radii 2, 3, 4 parsecs, drawn round the sun as centre, is 3, 6, 18 respectively. In this count binary systems are treated as single stars, although Proxima Centauri is deemed to be distinct from α Centauri, and the sun is not counted since its presence is a prerequisite to our making the calculation at all. Now if the stars in the neighbourhood of the sun were scattered at random, and were all known, the number of stars observed to lie in different spheres would be proportional to the cubes of their radii; if they were not all known, there would of course be a falling off from this law for the spheres of greatest radii, since distant stars are more likely to remain unknown than near stars. In particular, if the 18 known stars were the total inside a sphere of 4 parsecs radius, the numbers to be expected inside the three spheres of radii 2, 3, and 4 parsecs would be 2.2, 7.6, and 18 respectively. These are near enough to the actual numbers of 3, 6, and 18 to justify the hope that the great majority of the stars within 4 parsecs are known. But 4 parsecs is the greatest distance for which such a hope can be entertained. With 18 stars lying within 4 parsecs of the sun, there ought to be a further 17 lying at distances between 4 and 5 parsecs: only 6 such stars are known. There ought to be about 280 within 10 parsecs: Schlesinger's Catalogue contains only 86.

Thus even now our survey of the universe is tolerably complete only to a distance of about 4 parsecs; beyond this the number of known stars increases nothing like so rapidly as the cube of the distance. With present-day accuracy, trigonometrical parallaxes can be estimated to a probable error of, let us say, 0".008, so that the parallaxes of stars within 100 parsecs may be said to have a real

physical significance. Of such stars there ought to be about 281,250, and at the present rate of progress the determination of their parallaxes would occupy astronomy for fully 1000 years to come.

Just now we compared astronomy's past 3000 years of existence to the last tick of the clock in a dying century; we may with equal justice compare the 3000 years next to come to the first tick in a new century—such is the proportion it bears to the total time our present stars may be expected to last. Looked at on this scale there may be thought to be plenty of time for a really exhaustive survey of the universe, and past progress may be accounted amazingly rapid. In one tick of the clock astronomy has come to birth, has developed the most difficult and accurate technique known to science, and has surveyed the universe, accurately and completely to 4 parsecs, and sketchily and imperfectly beyond. The next

tick of the clock should see the accurate survey extended to well beyond 100 parsecs, and astronomy has a whole century of life before it. I fear there may be a fallacy involved in the adoption of this point of view; it is that we do not know how long the human race will endure. At the very longest estimate, man has only existed for a hundred ticks of our clock, civilised man for only two or three, so that our race and civilisation would alike seem to be at the very beginning of their existence. Yet he would be a bold extrapolator who would assert with confidence that man is good for another three thousand million ticks of our clock on the ground that, if nothing unforeseen happens, the present stars will still be in existence at the end of that time. When we take a time-scale in terms of individual lives, we may still feel gratified at past progress, yet we cannot but feel awed by the magnitude of the task that remains.

On Rejuvenation.

FEW human beings will view the approach of old age with philosophic calm, so that any method by which the period of maturity may be prolonged and the onset of senility delayed will always arouse widespread interest and discussion. Within the last few years a considerable amount of attention has been directed to the subject of rejuvenation, following certain somewhat sensational operations on human beings and the higher apes. Although there is no doubt that the internal secretions of the genital glands exert a pronounced effect upon the rest of the body, yet it is by no means certain that old age can be attributed solely to their degeneration: in fact, the cells of the body as a whole suffer decay, so that it is probable that an operation affecting only one of the organs of the body, only one, moreover, of the number which influence the activities of the other cells throughout life, would have no more than a temporary effect at best.

Although removal of the genital glands has a profound influence upon the mentality and bodily structure of the subject, yet evidence as to its effects upon strength and endurance has been conflicting. M. D. Sumulong, in a recent paper (*Philippine Jour. Sci.*, Mar. 1926, p. 327), from experiments on guinea-pigs, concludes that castration is without definite influence upon their pulling power or endurance. Yet one of the characteristic results of a rejuvenating operation has been the increased physical vigour of the subject, suggesting again that decay of the genital glands is not the sole factor in old age. Finally, in discussing the results of human experiments, it is difficult to know how far the element of suggestion must be taken into consideration.

Various operations have been proposed for rejuvenating purposes; thus transplantation of the gland from another individual of the same, or a closely allied, species has been effective, especially in the female. In the male, the ligation of the efferent duct from the testicular gland has been advocated as a much simpler, withal as effective,

a procedure. It is of interest to note that the flatworm *Planaria* can be rejuvenated by starvation. It shrinks to one-quarter its adult size and becomes young again: if fed, it grows up: the process can be repeated indefinitely and the organism's life may be prolonged to twenty times the ordinary length (F. A. E. Crew, *Nineteenth Century*, Feb. 1927, p. 225). The infinitely more complex structure of the higher animals, however, prevents the recourse to such a simple expedient.

The justification for the operation of ligature of the efferent duct of the testes, or *vasoligation* as it is called, depends on the assumption that this procedure causes degeneration of the sex cells proper, thus permitting the interstitial cells to hypertrophy, with a consequent increase in the amount of the internal secretion produced by them. It might not even be necessary for them to hypertrophy: with degeneration of the sex cells the nutriment supplied to the whole gland by the blood stream might be sufficient for the full activity of the internal secretory cells, whereas with the sex cells present the former might fail to obtain all the food they required owing to the competition of the latter. In the period of full maturity both types of cells are probably sufficiently supplied by an efficient circulation.

Oslund has stated that vasoligation does not lead to degeneration of the sex cells unless the testis moves from its usual position in the scrotum into the abdomen. Y. Tamura and F. A. E. Crew, in experiments on the mouse (*Proc. Roy. Soc. Edin.*, 1926, vol. 46, p. 283), find that this operation is followed by degeneration of the sex cells, provided sufficient time has elapsed before the testis is examined. If the epididymis is removed, degeneration occurs much earlier. On the other hand, in neither case was the degeneration complete. The evidence, however, favours the assumption on which the operation of vasoligation is based.

From what has been said above, it is clear that the two functions of the testis are to a certain