Alfred Russel Wallace

Man's Place in the Universe

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Wallace A.

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Содержание

Alfred Russel Wallace
Man's Place in the Universe / A Study of the Results of Scientific Research in Relation to the Unity or Plurality of Worlds, 3rd Edition

'O, glittering host! O, golden line!
I would I had an angel's ken,
Your deepest secrets to divine,
And read your mysteries to men.'

'I said unto my inmost heart,
Shall I don corslet, helm, and shield,
And shall I with a Giant strive,
And charge a Dragon on the field?'

J.H. Dell.

PREFACE

This work has been written in consequence of the great interest excited by my article, under the same title, which appeared simultaneously in *The Fortnightly Review* and the *New York Independent*. Two friends who read the manuscript were of opinion that a volume, in which the evidence could be given much more fully, would be desirable, and the result of the publication of the article confirmed their view.

I was led to a study of the subject when writing four new chapters on Astronomy for a new edition of *The Wonderful Century*. I then found that almost all writers on general astronomy, from Sir John Herschel to Professor Simon Newcomb and Sir Norman Lockyer, stated, as an indisputable fact, that our sun is situated *in* the plane of the great ring of the Milky Way, and also very nearly in the centre of that ring. The most recent researches also showed that there was little or no proof of there being any stars or nebulæ very far beyond the Milky Way, which thus seemed to be the limit, in that direction, of the stellar universe.

Turning to the earth and the other planets of the Solar System, I found that the most recent researches led to the conclusion that no other planet was likely to be the seat of organic life, unless perhaps of a very low type. For many years I had paid special attention to the problem of the measurement of geological time, and also that of the mild climates and generally uniform conditions that had prevailed throughout all geological epochs; and on considering the number of concurrent causes and the delicate balance of conditions required to maintain such uniformity, I became still more convinced that the evidence was exceedingly strong against the probability or possibility of any other planet being inhabited.

Having long been acquainted with most of the works dealing with the question of the supposed *Plurality of Worlds*, I was quite aware of the very superficial treatment the subject had received, even in the hands of the most able writers, and this made me the more willing to set forth the whole of the available evidence—astronomical, physical, and biological—in such a way as to show both what was proved and what suggested by it.

The present work is the result, and I venture to think that those who will read it carefully will admit that it is a book that was worth writing. It is founded almost entirely on the marvellous body of facts and conclusions of the New Astronomy together with those reached by modern physicists, chemists, and biologists. Its novelty consists in combining the various results of these different branches of science into a connected whole, so as to show their bearing upon a single problem—a problem which is of very great interest to ourselves.

This problem is, whether or no the logical inferences to be drawn from the various results of modern science lend support to the view that our earth is the only inhabited planet, not only in the Solar System but in the whole stellar universe. Of course it is a point as to which absolute demonstration, one way or the other, is impossible. But in the absence of any direct proofs, it is clearly rational to inquire into probabilities; and these probabilities must be determined not by our prepossessions for any particular view, but by an absolutely impartial and unprejudiced examination of the tendency of the evidence.

As the book is written for the general, educated body of readers, many of whom may not be acquainted with any aspect of the subject or with the wonderful advance of recent knowledge in that department often termed the New Astronomy, a popular account has been given of all those branches of it which bear upon the special subject here discussed. This part of the work occupies the first six chapters. Those who are fairly acquainted with modern astronomical literature, as given in popular works, may begin at my seventh chapter, which marks the commencement of the considerable body of evidence and of argument I have been able to adduce.

To those of my readers who may have been influenced by any of the adverse criticisms on my views as set forth in the article already referred to, I must again urge, that throughout the whole of this work, neither the facts nor the more obvious conclusions from the facts are given on my own authority, but always on that of the best astronomers, mathematicians, and other men of science to whose works I have had access, and whose names, with exact references, I generally give.

What I claim to have done is, to have brought together the various facts and phenomena *they* have accumulated; to have set forth the hypotheses by which *they* account for them, or the results to which the evidence clearly points; to have judged between conflicting opinions and theories; and lastly, to have combined the results of the various widely-separated departments of science, and to have shown how they bear upon the great problem which I have here endeavoured, in some slight degree, to elucidate.

As such a large body of facts and arguments from distinct sciences have been here brought together, I have given a rather full summary of the whole argument, and have stated my final conclusions in six short sentences. I then briefly discuss the two aspects of the whole problem—those from the materialistic and from the spiritualistic points of view; and I conclude with a few general observations on the almost unthinkable problems raised by ideas of Infinity—problems which some of my critics thought I had attempted in some degree to deal with, but which, I here point out, are altogether above and beyond the questions I have discussed, and equally above and beyond the highest powers of the human intellect.

Broadstone, Dorset,
September 1903.

'The wilder'd mind is tost and lost,
O sea, in thy eternal tide;
The reeling brain essays in vain,
O stars, to grasp the vastness wide!
The terrible tremendous scheme
That glimmers in each glancing light,
O night, O stars, too rudely jars
The finite with the infinite!'

J.H. Dell.

'Who is man, and what his place?
Anxious asks the heart, perplext
In this recklessness of space,
Worlds with worlds thus intermixt:
What has he, this atom creature,
In the infinitude of Nature?'

F.T. Palgrave.

CHAPTER I

EARLY IDEAS AS TO THE UNIVERSE AND ITS RELATION TO MAN

When men attained to sufficient intelligence for speculations as to their own nature and that of the earth on which they lived, they must have been profoundly impressed by the nightly pageant of the starry heavens. The intense sparkling brilliancy of Sirius and Vega, the more massive and steady luminosity of Jupiter and Venus, the strange grouping of the brighter stars into constellations to which fantastic names indicating their resemblance to various animals or terrestrial objects seemed appropriate and were soon generally adopted, together with the apparently innumerable stars of less and less brilliancy scattered broadcast over the sky, many only being visible on the clearest nights and to the acutest vision, constituted altogether a scene of marvellous and impressive splendour of which it must have seemed almost impossible to attain any real knowledge, but which afforded an endless field for the imagination of the observer.

The relation of the stars to the sun and moon in their respective motions was one of the earliest problems for the astronomer, and it was only solved by careful and continuous observation, which showed that the invisibility of the former during the day was wholly due to the blaze of light, and this is said to have been proved at an early period by the observed fact that from the bottom of very deep wells stars can be seen while the sun is shining. During total eclipses of the sun also the brighter stars become visible, and, taken in connection with the fixity of position of the pole-star, and the course of those circumpolar stars which never set in the latitudes of Greece, Egypt, and Chaldea, it soon became possible to frame a simple hypothesis which supposed the earth to be suspended in space, while at an unknown distance from it a crystal sphere revolved upon an axis indicated by the pole-star, and carried with it the whole host of heavenly bodies. This was the theory of Anaximander (540 B.C.), and it served as the starting-point for the more complex theory which continued to be held in various forms and with endless modifications down to the end of the sixteenth century.

It is believed that the early Greeks obtained some knowledge of astronomy from the Chaldeans, who appear to have been the first systematic observers of the heavenly bodies by means of instruments, and who are said to have discovered the cycle of eighteen years and ten days after which the sun and moon return to the same relative positions as seen from the earth. The Egyptians perhaps derived their knowledge from the same source, but there is no proof that they were great observers, and the accurate orientation, proportions, and angles of the Great Pyramid and its inner passages may perhaps indicate a Chaldean architect.

The very obvious dependence of the whole life of the earth upon the sun, as a giver of heat and light, sufficiently explains the origin of the belief that the latter was a mere appanage of the former; and as the moon also illuminates the night, while the stars as a whole also give a very perceptible amount of light, especially in the dry climate and clear atmosphere of the East, and when compared with the pitchy darkness of cloudy nights when the moon is below the horizon, it seemed clear that the whole of these grand luminaries—sun, moon, stars, and planets—were but parts of the terrestrial system, and existed solely for the benefit of its inhabitants.

Empedocles (444 B.C.) is said to have been the first who separated the planets from the fixed stars, by observing their very peculiar motions, while Pythagoras and his followers determined correctly the order of their succession from Mercury to Saturn. No attempt was made to explain these motions till a century later, when Eudoxus of Cnidos, a contemporary of Plato and of Aristotle, resided for some time in Egypt, where he became a skilful astronomer. He was the first who systematically worked out and explained the various motions of the heavenly bodies on the theory of circular and uniform motion round the earth as a centre, by means of a series of concentric spheres, each revolving at a different rate and on a different axis, but so united that all shared in the motion round the polar axis. The moon, for example, was supposed to be carried by three spheres, the first revolved parallel to the equator and accounted for the diurnal motion—the rising and setting—of the moon; another moved parallel to the ecliptic and explained the monthly changes of the moon; while the third revolved at the same rate but more obliquely, and explained the inclination of the moon's orbit to that of the earth. In the same way each of the five planets had four spheres, two moving like the first two of the moon, another one also moving in the ecliptic was required to explain the retrograde motion of the planets, while a fourth oblique to the ecliptic was needed to explain the diverging motions due to the different obliquity of the orbit of each planet to that of the earth. This was the celebrated Ptolemaic system in the simplest form needed to account for the more obvious motions of the heavenly bodies. But in the course of ages the Greek and Arabian astronomical observers discovered small divergences due to the various degrees of excentricity of the orbits of the moon and planets and their consequent varying rates of motion; and to explain these other spheres were added, together with smaller circles sometimes revolving excentrically, so that at length about sixty of these spheres, epicycles and excentrics were required to account for the various motions observed with the rude instruments, and the rates of motion determined by the very imperfect time-measurers of those early ages. And although a few great philosophers had at different times rejected this cumbrous system and had endeavoured to promulgate more correct ideas, their views had no influence on public opinion even among astronomers and mathematicians, and the Ptolemaic system held full sway down to the time of Copernicus, and was not finally given up till Kepler's *Laws* and Galileo's *Dialogues* compelled the adoption of simpler and more intelligible theories.

We are now so accustomed to look upon the main facts of astronomy as mere elementary knowledge that it is difficult for us to picture to ourselves the state of almost complete ignorance which prevailed even among the most civilised nations throughout antiquity and the Middle Ages. The rotundity of the earth was held by a few at a very early period, and was fairly well established in later classical times. The rough determination of the size of our globe followed soon after; and when instrumental observations became more perfect, the distance and size of the moon were measured with sufficient accuracy to show that it was very much smaller than the earth. But this was the farthest limit of the determination of astronomical sizes and distances before the discovery of the telescope. Of the sun's real distance and size nothing was known except that it was much farther from us and much larger than the moon; but even in the century before the commencement of the Christian era Posidonius determined the circumference of the earth to be 240,000 stadia, equal to about 28,600 miles, a wonderfully close approximation considering the very imperfect data at his command. He is also said to have calculated the sun's distance, making it only one-third less than the true amount, but this must have been a chance coincidence, since he had no means of measuring angles more accurately than to one degree, whereas in the determination of the sun's distance instruments are required which measure to a second of arc.

Before the discovery of the telescope the sizes of the planets were quite unknown, while the most that could be ascertained about the stars was, that they were at a very great distance from us. This being the extent of the knowledge of the ancients as to the actual dimensions and constitution of the visible universe, of which, be it remembered, the earth was held to be the centre, we cannot be surprised at the almost universal belief that this universe existed solely for the earth and its inhabitants. In classical times it was held to be at once the dwelling-place of the gods and their gift to man, while in Christian ages this belief was but slightly, if at all, changed; and in both it would have been considered impious to maintain that the planets and stars did not exist for the service and delight of mankind alone but in all probability had their own inhabitants, who might in some cases be even superior in intellect to man himself. But apparently, during the whole period of which we are now treating, no one was so daring as even to suggest that there were other worlds with other inhabitants, and it was no doubt because of the idea that we occupied *the* world, the very centre of the whole surrounding universe which existed solely for us, that the discoveries of Copernicus, Tycho Brahé, Kepler, and Galileo excited so much antagonism and were held to be impious and altogether incredible. They seemed to upset the whole accepted order of nature, and to degrade man by removing his dwelling-place, the earth, from the commanding central position it had always before occupied.

CHAPTER II

MODERN IDEAS AS TO MAN'S RELATION TO THE UNIVERSE

The beliefs as to the subordinate position held by sun, moon, and stars in relation to the earth, which were almost universal down to the time of Copernicus, began to give way when the discoveries of Kepler and the revelations of the telescope demonstrated that our earth was not specially distinguished from the other planets by any superiority of size or position. The idea at once arose that the other planets might be inhabited; and when the rapidly increasing power of the telescope, and of astronomical instruments generally, revealed the wonders of the solar system and the ever-increasing numbers of the fixed stars, the belief in other inhabited worlds became as general as the opposite belief had been in all preceding ages, and it is still held in modified forms to the present day.

But it may be truly said that the later like the earlier belief is founded more upon religious ideas than upon a scientific and careful examination of the whole of the facts both astronomical, physical, and biological, and we must agree with the late Dr. Whewell, that the belief that other planets are inhabited has been generally entertained, not in consequence of physical reasons but in spite of them. And he adds:—'It was held that Venus, or that Saturn was inhabited, not because anyone could devise, with any degree of probability, any organised structure which would be suitable to animal existence on the surfaces of those planets; but because it was conceived that the greatness or goodness of the Creator, or His wisdom, or some other of His attributes, would be manifestly imperfect, if these planets were not tenanted by living creatures.' Those persons who have only heard that many eminent astronomers down to our own day have upheld the belief in a 'Plurality of Worlds' will naturally suppose that there must be some very cogent arguments in its favour, and that it must be supported by a considerable body of more or less conclusive facts. They will therefore probably be surprised to hear that any direct evidence which may be held to support the view is almost wholly wanting, and that the greater part of the arguments are weak and flimsy in the extreme.

Of late years, it is true, some few writers have ventured to point out how many difficulties there are in the way of accepting the belief, but even these have never examined the question from the various points of view which are essential to a proper consideration of it; while, so far as it is still upheld, it is thought sufficient to show, that in the case of some of the planets, there seem to be such conditions as to render life possible. In the millions of planetary systems supposed to exist it is held to be incredible that there are not great numbers as well fitted to be inhabited by animals of all grades, including some as high as man or even higher, and that we must, therefore, believe that they are so inhabited. As in the present work I propose to show, that the probabilities and the weight of direct evidence tend to an exactly opposite conclusion, it will be well to pass briefly in review the various writers on the subject, and to give some indication of the arguments they have used and the facts they have set forth. For the earlier upholders of the theory I am indebted to Dr. Whewell, who, in his *Dialogue on the Plurality of Worlds*—a Supplement to his well-known volume on the subject —refers to all writers of importance known to him.

The earliest are the great astronomers Kepler and Huygens, and the learned Bishop Wilkins, who all believed that the moon was or might probably be inhabited; and of these Whewell considers Wilkins to have been by far the most thoughtful and earnest in supporting his views. Then we have Sir Isaac Newton himself who, at considerable length, argued that the sun was probably inhabited. But the first regular work devoted to the subject appears to have been written by M. Fontenelle, Secretary to the Academy of Sciences in Paris, who in 1686 published his *Conversations on the Plurality of Worlds*. The book consisted of five chapters, the first explaining the Copernican Theory; the second maintaining that the moon is a habitable world; the third gives particulars as to the moon, and argues that the other planets are also inhabited; the fourth gives details as to the worlds of the five planets; while the fifth declares that the fixed stars are suns, and that each illuminates a world. This work was so well written, and the subject proved so attractive, that it was translated into all the chief European languages, while the astronomer Lalande edited one of the French editions. Three English translations were published, and one of these went through six editions down to the year 1737. The influence of this work was very great and no doubt led to that general acceptance of the theory by such men as Sir William Herschel, Sir John Herschel, Dr. Chalmers, Dr. Dick, Dr. Isaac Taylor, and M. Arago, although it was wholly founded on pure speculation, and there was nothing that could be called evidence on one side or the other.

This was the state of public opinion when an anonymous work appeared (in 1853) under the somewhat misleading title of *The Plurality of Worlds: An Essay*. This was written, as already stated, by Dr. Whewell, who, for the first time, ventured to doubt the generally accepted theory, and showed that all the evidence at our command led to the conclusion that some of the planets were *certainly* not habitable, that others were *probably* not so, while in none was there that close correspondence with terrestrial conditions which seemed essential for their habitability by the higher animals or by man. The book was ably written and showed considerable knowledge of the science of the time, but it was very diffuse, and the larger part of it was devoted to showing that his views were not in any way opposed to religion. One of his best arguments was founded on the proposition that '*the Earth's Orbit is the Temperate Zone of the Solar System*,' that there only is it possible to have those moderate variations of heat and cold, dryness and moisture, which are suitable for animal life. He suggested that the outer planets of the system consisted mainly of water, gases, and vapour, as indicated by their low specific gravity, and were therefore quite unsuitable for terrestrial life; while those near the sun were equally unsuited, because, owing to the great amount of solar heat, water could not exist on their surfaces. He devotes a great deal of space to the evidence that there is no animal life on the moon, and taking this as proved, he uses it as a counter argument against the other side. They always urge that, the earth being inhabited, we must suppose the other planets to be so too; to which he replies: —We know that the moon is not inhabited though it has all the advantage of proximity to the sun that the earth has; why then should not other planets be equally uninhabited?

He then comes to Mars and admits that this planet is very like the earth so far as we can judge, and that it may therefore be inhabited, or as the author expresses it, 'may have been judged worthy of inhabitants by its Maker.' But he urges the small size of Mars, its coldness owing to distance from the sun, and that the annual melting of its polar ice-caps will keep it cold all through the summer. If there are animals they are probably of a low type like the saurians and iguanodons of our seas during the Wealden epoch; but, he argues, as even on our earth the long process of preparation for man was carried on for countless millions of years, we need not discuss whether there are intelligent beings on Mars till we have some better evidence that there are any living creatures at all.

Several of the early chapters are devoted to an attempt to minimise the difficulties of those religious persons who feel oppressed by the immensity and complexity of the material universe as revealed by modern astronomy; and by the almost infinite insignificance of man and his dwelling-place, the earth, in comparison with it, an insignificance vastly increased if not only the planets of the solar system, but also those which circle around the myriads of suns, are also theatres of life. And these persons are further disquieted because the very same facts are used by sceptics of various kinds in their attacks upon Christianity. Such writers point out the irrationality and absurdity of supposing that the Creator of all this unimaginable vastness of suns and systems, filling for all we know endless space, should take any *special* interest in so mean and pitiful a creature as man, the imperfectly developed inhabitant of one of the smaller worlds attached to a second or third-rate sun, a being whose whole history is one of war and bloodshed, of tyranny, torture, and death; whose awful record is pictured by himself in such books as Josephus' *History of the Jews*, the *Decline and Fall of* *the Roman Empire*, and even more forcibly summarised in that terrible picture of human fiendishness and misery, *The Martyrdom of Man*; while their character is indicated by one of the kindest and simplest of their poets in the restrained but expressive lines:—

> 'Man's inhumanity to man
> Makes countless thousands mourn.'

It is for such a being as this, they say, that God should have specially revealed His will some thousands of years ago, and finding that His commands were not obeyed, His will not fulfilled, yet ordained for their benefit the necessarily unique sacrifice of His Son, in order to save a small portion of these 'miserable sinners' from the natural and well-deserved consequence of their stupendous follies, their unimaginable crimes? Such a belief they maintain is too absurd, too incredible, to be held by any rational being, and it becomes even less credible and less rational if we maintain that there are countless other inhabited worlds.

It is very difficult for the religious man to make any adequate reply to such an attack as this, and as a result many have felt their position to be untenable and have accordingly lost all faith in the special dogmas of orthodox Christianity. They feel themselves really to be between the horns of a dilemma. If there are myriads of other worlds, it seems incredible that they should each be the object of a special revelation and a special sacrifice. If, on the other hand, we are the only intelligent beings that exist in the material universe, and are really the highest creative product of a Being of infinite wisdom and power, they cannot but wonder at the vast apparent disproportion between the Creator and the created, and are sometimes driven to Atheism from the hopelessness of comprehending so mean and petty a result as the sole outcome of infinite power.

Whewell tells us that the great preacher, Dr. Chalmers, in his Astronomical Discourses, attempted a reply to these difficulties, but, in his opinion, not a very successful one; and a large part of his own work is devoted to the same purpose. His main point seems to be that we know too little of the universe to arrive at any definite conclusions on the question at issue, and that any ideas that we may have as to the purposes of the Creator in forming the vast system we see around us are almost sure to be erroneous. We must therefore be content to remain ignorant, and must rest satisfied in the belief that the Creator had a purpose although we are not yet permitted to know what it was. And to those who urge that in other worlds there may be other laws of nature which may render them quite as habitable by intelligent beings as our world is for us, he replies, that if we are to suppose new laws of nature in order to render each planet habitable, there is an end of all rational inquiry on the subject, and we may maintain and believe that animals may live on the moon without air or water, and on the sun exposed to heat which vaporises earths and metals.

His concluding argument, and perhaps one of his strongest, is that founded upon the dignity of man, as conferring a pre-eminence upon the planet which has produced him. 'If,' he says, 'man be not merely capable of Virtue and Duty, of universal Love and Self-Devotion, but be also immortal; if his being be of infinite duration, his soul created never to die; then, indeed, we may well say that one soul outweighs the whole unintelligent creation.' And then, addressing the religious world, he urges that, if, as they believe, God *has* redeemed man by the sacrifice of His Son, and *has* given to him a revelation of His will, then indeed no other conception is possible than that he is the sole and highest product of the universe. 'The elevation of millions of intellectual, moral, religious, spiritual creatures, to a destiny so prepared, consummated, and developed, is no unworthy occupation of all the capacities of space, time, and matter.' Then with a chapter on 'The Unity of the World,' and one on 'The Future,' neither of which contains anything which adds to the force of his argument, the book ends.

The publication of this able if rather vague and diffuse work, contesting popular opinions, was followed by a burst of indignant criticism on the part of a man of considerable eminence in some branches of physics—Sir David Brewster, but who was very inferior, both in general knowledge of science and in literary skill, to the writer whose views he opposed. The purport of the book in which he set forth his objections is indicated by its title—*More Worlds than One, the Creed of the Philosopher and the Hope of the Christian*. Though written with much force and conviction it appeals mainly to religious prejudices, and assumes throughout that every planet and star is a special creation, and that the peculiarities of each were designed for some special purpose. 'If,' he says, 'the moon had been destined to be merely a lamp to our earth, there was no occasion to variegate its surface with lofty mountains and extinct volcanoes, and cover it with large patches of matter that reflect different quantities of light and give its surface the appearance of continents and seas. It would have been a better lamp had it been a smooth piece of lime or of chalk.' It is, therefore, he thinks, prepared for inhabitants; and then he argues that all the other satellites are also inhabited. Again he says that 'when it was found that Venus was about the same size as the Earth, with mountains and valleys, days and nights, and years analogous to our own, the *absurdity* of believing that she had no inhabitants, when no other rational purpose could be assigned for her creation, became an argument of a certain amount that she was, like the Earth, the seat of animal and vegetable life.' Then, when it was found that Jupiter was so gigantic 'as to require four moons to give him light, the argument from analogy that *he* was inhabited became stronger also, because it extended to *two* planets.' And thus each successive planet having certain points of analogy with the others becomes an additional argument; so that when we take account of all the planets, with atmosphere, and clouds, and arctic snows, and trade-winds, the argument from analogy becomes, he urges, very powerful;—'and the absurdity of the opposite opinion, that planets should have moons and no inhabitants, atmospheres with no creatures to breathe in them, and currents of air without life to be fanned, became a formidable argument which few minds, if any, could resist.'

The work is full of such weak and fallacious rhetoric and even, if possible, still weaker. Thus after describing double stars, he adds—'But no person can believe that two suns could be placed in the heavens for no other purpose than to revolve round their common centre of gravity'; and he concludes his chapter on the stars thus:—'Wherever there is matter there must be Life; Life Physical to enjoy its beauties—Life Moral to worship its Maker, and Life Intellectual to proclaim His wisdom and His power.' And again—'A house without tenants, a city without citizens, presents to our minds the same idea as a planet without life, and a universe without inhabitants. Why the house was built, why the city was founded, why the planet was made, and why the universe was created, it would be difficult even to conjecture.' Arguments of this kind, which in almost every case beg the question at issue, are repeated *ad nauseam*. But he also appeals to the Old Testament to support his views, by quoting the fine passage in the Psalms—'When I consider Thy heavens the work of Thy fingers, the moon and the stars which Thou hast ordained; what is man that Thou art mindful of him?' on which he remarks—'We cannot doubt that inspiration revealed to him [David] the magnitude, the distances, and the final cause, of the glorious spheres which fixed his admiration.' And after quoting various other passages from the prophets, all as he thinks supporting the same view, he sets forth the extraordinary idea as a confirmatory argument, that the planets or some of them are to be the future abode of man. For, he says—'Man in his future state of existence is to consist, as at present, of a spiritual nature residing in a corporeal frame. He must live, therefore, upon a material planet, subject to all the laws of matter.' And he concludes thus:—'If there is not room, then, on our globe for the millions of millions of beings who have lived and died on its surface, we can scarcely doubt that their future abode must be on some of the primary or secondary planets of the solar system, whose inhabitants have ceased to exist, or upon planets which have long been in a state of preparation, as our earth was, for the advent of intellectual life.'

It is pleasant to turn from such weak and trivial arguments to the only other modern works which deal at some length with this subject, the late Richard A. Proctor's *Other Worlds than Ours*, and a volume published five years later under the title—*Our Place Among Infinities*. Written as these were by one of the most accomplished astronomers of his day, remarkable alike for the acuteness of his reasoning and the clearness of his style, we are always interested and instructed even when we cannot agree with his conclusions. In the first work mentioned above, he assumes, like Sir David Brewster, the antecedent probability that the planets are inhabited and on much the same theological grounds. So strongly does he feel this that he continually speaks as if the planets *must* be inhabited unless we can show very good reason that they *cannot* be so, thus throwing the burden of proving a negative on his opponents, while he does not attempt to prove his positive contention that they are inhabited, except by purely hypothetical considerations as to the Creator's purpose in bringing them into existence.

But starting from this point he endeavours to show how Whewell's various difficulties may be overcome, and here he always appeals to astronomical or physical facts, and reasons well upon them. But he is quite honest; and, coming to the conclusion that Jupiter and Saturn, Uranus and Neptune, cannot be habitable, he adduces the evidence and plainly states the result. But then he thinks that the satellites of Jupiter and Saturn *may* be habitable, and if they may be, then he concludes that they *must*. One great oversight in his whole argument is, that he is satisfied with showing the possibility that life may exist now, but never deals with the question of whether life could have been developed from its earliest rudiments up to the production of the higher vertebrates and man; and this, as I shall show later, is the *crux* of the whole problem.

With regard to the other planets, after a careful examination of all that is known about them, he arrives at the conclusion that if Mercury is protected by a cloud-laden atmosphere of a peculiar kind it may possibly, but not probably, support high forms of animal life. But in the case of Venus and Mars he finds so much resemblance to and so many analogies with our earth, that he concludes that they almost certainly are so.

In the case of the fixed stars, now that we know by spectroscopic observations that they are true suns, many of which closely resemble our sun and give out light and heat as he does, Mr. Proctor argues, that 'The vast supplies of heat thus emitted by the stars not only suggest the conclusion that there must be worlds around these orbs for which these heat-supplies are intended, but point to the existence of the various forms of force into which heat may be transmuted. We know that the sun's heat poured upon our earth is stored up in vegetable and animal forms of life; is present in all the phenomena of nature—in winds and clouds and rain, in thunder and lightning, storm and hail; and that even the works of man are performed by virtue of the solar heat-supplies. Thus the fact that the stars send forth heat to the worlds which circle around them suggests at once the thought that on those worlds there must exist animal and vegetable forms of life.' We may note that in the first part of this passage the presence of worlds or planets is 'suggested,' while later on 'the worlds which circle round them' is spoken of as if it were a proved fact from which the presence of vegetable and animal life may be inferred. A suggestion depending on a preceding suggestion is not a very firm basis for so vast and wide-reaching a conclusion.

In the second work referred to above there is one chapter entitled, 'A New Theory of Life in other Worlds,' where the author gives his more matured views of the question, which are briefly stated in the preface as being 'that the weight of evidence favours my theory of the (relative) paucity of worlds.' His views are largely founded on the theory of probabilities, of which subject he had made a special study. Taking first our earth, he shows that the period during which life has existed upon it is very small in comparison with that during which it must have been slowly forming and cooling, and its atmosphere condensing so as to form land and water on its surface. And if we consider the time the earth has been occupied by man, that is a very minute part, perhaps not the thousandth part, of the period during which it has existed as a planet. It follows that even if we consider only those planets whose physical condition seems to us to be such as to be able to sustain life, the chances are perhaps hundreds to one against their being at that particular stage when life has begun to be developed, or if it has begun has reached as high a development as on our earth.

With regard to the stars, the argument is still stronger, because the epochs required for their formation are altogether unknown, while as to the conditions required for the formation of planetary systems around them we are totally ignorant. To this I would add that we are equally ignorant as to the probability or even possibility of many of these suns producing planets which, by their position, size, atmosphere, or other physical conditions can possibly become life-producing worlds. And, as we shall see later, this point has been overlooked by all writers, including Mr. Proctor himself. His conclusion is, then, that although the worlds which possess life at all approaching that of our earth may be relatively few in number, yet considering the universe as practically infinite in extent, they may be really very numerous.

It has been necessary to give this sketch of the views of those who have written specially on the question of the Plurality of Worlds, because the works referred to have been very widely read and have influenced educated opinion throughout the world. Moreover, Mr. Proctor, in his last work on the subject, speaks of the theory as being 'identified with modern astronomy'; and in fact popular works still discuss it. But all these follow the same general line of argument as those already referred to, and the curious thing is that while overlooking many of the most essential conditions they often introduce others which are by no means essential—as, for instance, that the atmosphere must have the same proportion of oxygen as our own. They seem to think that if any of our quadrupeds or birds taken to another planet could not live there, no animals of equally high organisation could inhabit it; entirely overlooking the very obvious fact that, supposing, as is almost certain, that oxygen is necessary for life, then, whatever proportion of oxygen within certain limits was present, the forms of life that arose would necessarily be organised in adaptation to that proportion, which might be considerably less or greater than on the earth.

The present volume will show how extremely inadequate has been the treatment of this question, which involves a variety of important considerations hitherto altogether overlooked. These are extremely numerous and very varied in their character, and the fact that they all point to one conclusion—a conclusion which so far as I am aware no previous writer has reached—renders it at least worthy of the careful consideration of all unbiassed thinkers. The whole subject is one as to which no direct evidence is obtainable, but I venture to think that the convergence of so many probabilities and indications towards a single definite theory, intimately connected with the nature and destiny of man himself, raises this theory to a very much higher level of probability than the vague possibilities and theological suggestions which are the utmost that have been adduced by previous writers.

In order to make every step of my argument clearly intelligible to all educated readers, it will be necessary to refer continually to the marvellous extension of our knowledge of the universe obtained during the last half-century, and constituting what is termed the New Astronomy. The next chapter will therefore be devoted to a popular exposition of the new methods of research, so that the results reached, which will have to be referred to in succeeding chapters, may be not only accepted, but clearly understood.

CHAPTER III

THE NEW ASTRONOMY

During the latter half of the nineteenth century discoveries were made which extended the powers of astronomical research into entirely new and unexpected regions, comparable to those which were opened up by the discovery of the telescope more than two centuries before. The older astronomy for more than two thousand years was purely mechanical and mathematical, being limited to observation and measurement of the apparent motions of the heavenly bodies, and the attempts to deduce, from these apparent motions, their real motions, and thus determine the actual structure of the solar system. This was first done when Kepler established his three celebrated laws: and later, when Newton showed that these laws were necessary consequences of the one law of gravitation, and when succeeding observers and mathematicians proved that each fresh irregularity in the motions of the planets was explicable by a more thorough and minute application of the same laws, this branch of astronomy reached its highest point of efficiency and left very little more to be desired.

Then, as the telescope became successively improved, the centre of interest was shifted to the surfaces of the planets and their satellites, which were watched and scrutinised with the greatest assiduity in order if possible to attain some amount of knowledge of their physical constitution and past history. A similar minute scrutiny was given to the stars and nebulæ, their distribution and grouping, and the whole heavens were mapped out, and elaborate catalogues constructed by enthusiastic astronomers in every part of the world. Others devoted themselves to the immensely difficult problem of determining the distances of the stars, and by the middle of the century a few such distances had been satisfactorily measured.

Thus, up to the middle of the nineteenth century it appeared likely that the future of astronomy would rest almost entirely on the improvement of the telescope, and of the various instruments of measurement by means of which more accurate determinations of distances might be obtained. Indeed, the author of the Positive Philosophy, Auguste Comte, felt so sure of this that he deprecated all further attention to the stars as pure waste of time that could never lead to any useful or interesting result. In his *Philosophical Treatise on Popular Astronomy* published in 1844, he wrote very strongly on this point. He there tells us that, as the stars are only accessible to us by sight they must always remain very imperfectly known. We can know little more than their mere existence. Even as regards so simple a phenomenon as their temperature this must always be inappreciable to a purely visual examination. Our knowledge of the stars is for the most part purely negative, that is, we can determine only that they do *not* belong to our system. Outside that system there exists, in astronomy, only obscurity and confusion, for want of indispensable facts; and he concludes thus:—'It is, then, in vain that for half a century it has been endeavoured to distinguish two astronomies, the one solar the other sidereal. In the eyes of those for whom science consists of real laws and not of incoherent facts, the second exists only in name, and the first alone constitutes a true astronomy; and I am not afraid to assert that it will always be so.' And he adds that—'all efforts directed to this subject for half a century have only produced an accumulation of incoherent empirical facts which can only interest an irrational curiosity.'

Seldom has a confident assertion of finality in science received so crushing a reply as was given to the above statements of Comte by the discovery in 1860 (only three years after his death) of the method of spectrum-analysis which, in its application to the stars, has revolutionised astronomy, and has enabled us to obtain that very kind of knowledge which he declared must be for ever beyond our reach. Through it we have acquired accurate information as to the physics and chemistry of the stars and nebulæ, so that we now know really more of the nature, constitution, and temperature of the enormously distant suns which we distinguish by the general term stars, than we do of most of the planets of our own system. It has also enabled us to ascertain the existence of numerous invisible stars, and to determine their orbits, their rate of motion, and even, approximately, their mass. The despised stellar astronomy of the early part of the century has now taken rank as the most profoundly interesting department of that grand science, and the branch which offers the greatest promise of future discoveries. As the results obtained by means of this powerful instrument will often be referred to, a short account of its nature and of the principles on which it depends must here be given.

The solar spectrum is the band of coloured light seen in the rainbow and, partially, in the dew-drop, but more completely when a ray of sunlight passes through a prism—a piece of glass having a triangular section. The result is, that instead of a spot of white light we have a narrow band of brilliant colours which succeed each other in regular order, from violet at one end through blue, green, and yellow to red at the other. We thus see that light is not a simple and uniform radiation from the sun, but is made up of a large number of separate rays, each of which produces in our eyes the sensation of a distinct colour. Light is now explained as being due to vibrations of ether, that mysterious substance which not only permeates all matter, but which fills space at least as far as the remotest of the visible stars and nebulæ. The exceedingly minute waves or vibrations of the ether produce all the phenomena of heat, light, and colour, as well as those chemical actions to which photography owes its wonderful powers. By ingenious experiments the size and rate of vibration of these waves have been measured, and it is found that they vary considerably, those forming the red light, which is least refracted, having a wave-length of about $^1/_{326000}$ of an inch, while the violet rays at the other end of the spectrum are only about half that length or $^1/_{630000}$ of an inch. The rate at which the vibrations succeed each other is from 302 millions of millions per second for the extreme red rays, to 737 millions of millions for those at the violet end of the spectrum. These figures are given to show the wonderful minuteness and rapidity of these heat and light waves on which the whole life of the world, and all our knowledge of other worlds and other suns, directly depends.

But the mere colours of the spectrum are not the most important part of it. Very early in the nineteenth century a close examination showed that it was everywhere crossed by black lines of various thicknesses, sometimes single, sometimes grouped together. Many observers studied them and made accurate drawings or maps showing their positions and thicknesses, and by combining several prisms, so that the beam of sunlight had to pass through them successively, a spectrum could be produced several feet long, and more than 3000 of these dark lines were counted in it. But what they were and how they were caused remained a mystery, till, in the year 1860, the German physicist Kirchhoff discovered the secret and gave to chemists and astronomers a new and quite unexpected engine of research.

It had already been observed that the chemical elements and various compounds, when heated to incandescence, produced spectra consisting of coloured lines or bands which were constant for each element, so that the elements could at once be recognised by their characteristic spectra; and it had also been noticed that some of these bands, especially the yellow band produced by sodium, corresponded in position with certain black lines in the solar spectrum. Kirchhoff's discovery consisted in showing that, when the light from an incandescent body passes through the same substance in a state of vapour or gas, so much of the light is absorbed that the coloured lines or bands become black. The mystery of more than half a century was thus solved; and the thousands of black lines in the solar spectrum were shown to be caused by the light from the incandescent matter of the sun's surface passing through the heated gases or vapours immediately above it, and thereby having the bright coloured lines of their spectra changed, by absorption, to comparative blackness.

Chemists and physicists immediately set to work examining the spectra of the elements, fixing the position of the several coloured lines or bands by accurate measurement, and comparing them with the dark lines of the solar spectrum. The results were in the highest degree satisfactory. In a large proportion of the elements the coloured bands corresponded exactly with a group of dark lines in the spectrum of the sun, in which, therefore, the same terrestrial elements were proved to exist. Among the elements first detected in this manner were hydrogen, sodium, iron, copper, magnesium, zinc, calcium, and many others. Nearly forty of the elements have now been found in the sun, and it seems highly probable that all our elements really exist there, but as some are very rare and are present in very minute quantities they cannot be detected. Some of the dark lines in the sun were found not to correspond to any known element, and as this was thought to indicate an element peculiar to the sun it was named Helium; but quite recently it has been discovered in a rare mineral. Many of the elements are represented by a great number of lines, others by very few. Thus iron has more than 2000, while lead and potassium have only one each.

The value of the spectroscope both to the chemist in discovering new elements and to the astronomer in determining the constitution of the heavenly bodies, is so great, that it became of the highest importance to have the position of all the dark lines in the solar spectrum, as well as the bright lines of all the elements, determined with extreme accuracy, so as to be able to make exact comparisons between different spectra. At first this was done by means of very large-scale drawings showing the exact position of every dark or bright line. But this was found to be both inconvenient and not sufficiently exact; and it was therefore agreed to adopt the natural scale of the wave-lengths of the different parts of the spectrum, which by means of what are termed diffraction-gratings can now be measured with great accuracy. Diffraction-gratings are formed of a polished surface of hard metal ruled with excessively fine lines, sometimes as many as 20,000 to an inch. When sunlight falls upon one of these gratings it is reflected, and by interference of the rays from the spaces between the fine grooves, it is spread out into a beautiful and well-defined spectrum, which, when the lines are very close, is several yards in length. In these diffraction spectra many dark lines are seen which can be shown in no other way, and they also give a spectrum which is far more uniform than that produced by glass prisms in which minute differences in the composition of the glass cause some rays to be refracted more and others less than the normal amount.

The spectra produced by diffraction-gratings are double; that is, they are spread out on both sides of the central line of the ray which remains white, and the several coloured or dark lines are so clearly defined that they can be thrown on a screen at a considerable distance, giving a great length to the spectrum. The data for obtaining the wave-lengths are the distance apart of the lines, the distance of the screen, and the distance apart of the first pair of dark lines on each side of the central bright line. All these can be measured with extreme accuracy by means of telescopes with micrometers and other contrivances, and the result is an accuracy of determination of wave-lengths which can probably not be equalled in any other kind of measurement.

As the wave-lengths are so excessively minute, it has been found convenient to fix upon a still smaller unit of measurement, and as the millimetre is the smallest unit of the metric system, the ten-millionth of a millimetre (technically termed 'tenth meter') is the unit adopted for the measurement of wave-lengths, which is equal to about the 250 millionth of an inch. Thus the wave-lengths of the red and blue lines characteristic of hydrogen are 6563.07 and 4861.51 respectively. This excessively minute scale of wave-lengths, once determined by the most refined measurement, is of very great importance. Having the wave-lengths of any two lines of a spectrum so determined, the space between them can be laid down on a diagram of any length, and all the lines that occur in any other spectrum between these two lines can be marked in their exact relative positions. Now, as the visible spectrum consists of about 300,000 rays of light, each of different wave-lengths and therefore of different refrangibilities, if it is laid down on such a scale as to be of a length of 3000 inches (250 feet), each wave-length will be $^1/_{100}$ of an inch long, a space easily visible by the naked eye.

The possession of an instrument of such wonderful delicacy, and with powers which enable it to penetrate into the inner constitution of the remotest orbs of space, rendered it possible, within the next quarter of a century, to establish what is practically a new science—Astrophysics—often popularly termed the New Astronomy. A brief outline of the main achievements of this science must now be given.

The first great discovery made by Spectrum analysis, after the interpretation of the sun's spectrum had been obtained, was, the real nature of the fixed stars. It is true they had long been held by astronomers to be suns, but this was only an opinion of the accuracy of which it did not seem possible to obtain any proof. The opinion was founded on two facts—their enormous distance from us, so great that the whole diameter of the earth's orbit did not lead to any apparent change of their relative positions, and their intense brilliancy which at such distances could only be due to an actual size and splendour comparable with our sun. The spectroscope at once proved the correctness of this opinion. As one after another was examined, they were found to exhibit spectra of the same general type as that of the sun—a band of colours crossed by dark lines. The very first stars examined by Sir William Huggins showed the existence of nine or ten of our elements. Very soon all the chief stars of the heavens were spectroscopically examined, and it was found that they could be classed in three or four groups. The first and largest group contains more than half the visible stars, and a still larger proportion of the most brilliant, such as Sirius, Vega, Regulus, and Alpha Crucis in the Southern Hemisphere. They are characterised by a white or bluish light, rich in the ultra-violet rays, and their spectra are distinguished by the breadth and intensity of the four dark bands due to the absorption of hydrogen, while the various black lines which indicate metallic vapours are comparatively few, though hundreds of them can be discovered by careful examination.

The next group, to which Capella and Arcturus belong, is also very numerous, and forms the solar type of stars. Their light is of a yellowish colour, and their spectra are crossed throughout by innumerable fine dark lines more or less closely corresponding with those in the solar spectrum.

The third group consists of red and variable stars, which are characterised by fluted spectra. Such spectra show like a range of Doric columns seen in perspective, the red side being that most illuminated.

The last group, consisting of few and comparatively small stars, has also fluted spectra, but the light appears to come from the opposite direction.

These groups were established by Father Secchi, the Roman astronomer, in 1867, and have been adopted with some modifications by Vogel of the Astrophysical Observatory at Potsdam. The exact interpretation of these different spectra is somewhat uncertain, but there can be little doubt that they coincide primarily with differences of temperature and with corresponding differences in the composition and extent of the absorptive atmospheres. Stars with fluted spectra indicate the presence of vapours of the metalloids or of compound substances, while the reversed flutings indicate the presence of carbon. These conclusions have been reached by careful laboratory experiments which are now carried on at the same time as the spectral examination of the stars and other heavenly bodies, so that each peculiarity of their spectra, however puzzling and apparently unmeaning, has been usually explained, by being shown to indicate certain conditions of chemical constitution or of temperature.

But whatever difficulty there may be in explaining details, there remains no doubt whatever of the fundamental fact that all the stars are true suns, differing no doubt in size, and their stage of development as indicated by the colour or intensity of their light or heat, but all alike possessing a photosphere or light-emitting surface, and absorptive atmospheres of various qualities and density.

Innumerable other details, such as the often contrasted colours of double stars, the occasional variability of their spectra, their relations to the nebulæ, the various stages of their development and other problems of equal interest, have occupied the continued attention of astronomers, spectroscopists, and chemists; but further reference to these difficult questions would be out of place here. The present sketch of the nature of spectrum-analysis applied to the stars is for the purpose of making its principle and method of observation intelligible to every educated reader, and to illustrate the marvellous precision and accuracy of the results attained by it. So confident are astronomers of this accuracy that nothing less than *perfect correspondence* of the various bright lines in the spectrum of an element in the laboratory with the dark lines in the spectrum of the sun or of a star is required before the presence of that element is accepted as proved. As Miss Clerke tersely puts it—'Spectroscopic coincidences admit of no compromise. Either they are absolute or they are worthless.'

Measurement of Motion in the Line of Sight

We must now describe another and quite distinct application of the spectroscope, which is even more marvellous than that already described. It is the method of measuring the rate of motion of any of the visible heavenly bodies in a direction either directly towards us, or directly away from us, technically described as 'radial motion,' or by the expression—'in the line of sight.' And the extraordinary thing is that this power of measurement is altogether independent of distance, so that the rate of motion in miles per second of the remotest of the fixed stars, if sufficiently bright to show a distinct spectrum, can be measured with as much certainty and accuracy as in the case of a much nearer star or a planet.

In order to understand how this is possible we have again to refer to the wave-theory of light; and the analogy of other wave-motions will enable us better to grasp the principle on which these calculations depend. If on a nearly calm day we count the waves that pass each minute by an anchored steamboat, and then travel in the direction the waves come from, we shall find that a larger number pass us in the same time. Again, if we are standing near a railway, and an engine comes towards us whistling, we shall notice that it changes its tone as it passes us; and as it recedes the sound will be in a lower key, although the engine may be at exactly the same distance from us as when it was approaching. Yet the sound does not change to the ear of the engine driver, the cause of the change being that the sound-waves reach us in quicker succession as the source of the waves is approaching us than when it is retreating from us. Now, just as the pitch of a note depends upon the rapidity with which the successive air-vibrations reach our ear, so does the colour of a particular part of the spectrum depend upon the rapidity with which the ethereal waves which produce colour reach our eyes; and as this rapidity is greater when the source of the light is approaching than when it is receding from us, a slight shifting of the position of the coloured bands, and therefore of the dark lines, will occur, as compared with their position in the spectrum of the sun or of any stationary source of light, if there is any motion sufficient in amount to produce a perceptible shift.

That such a change of colour would occur was pointed out by Professor Doppler of Prague in 1842, and it is hence usually spoken of as the 'Doppler principle'; but as the changes of colour were so minute as to be impossible of measurement it was not at that time of any practical importance in astronomy. But when the dark lines in the spectrum were carefully mapped, and their positions determined with minute accuracy, it was seen that a means of measuring the changes produced by motion in the line of sight existed, since the position of any of the dark or coloured lines in the spectra of the heavenly bodies could be compared with those of the corresponding lines produced artificially in the laboratory. This was first done in 1868 by Sir William Huggins, who, by the use of a very powerful spectroscope constructed for the purpose, found that such a change did occur in the case of many stars, and that their rate of motion towards us or away from us—the radial motion—could be calculated. As the actual distance of some of these stars had been measured, and their change of position annually (their proper motion) determined, the additional factor of the amount of motion in the direction of our line of sight completed the data required to fix their true line of motion among the other stars. The accuracy of this method under favourable conditions and with the best instruments is very great, as has been proved by those cases in which we have independent means of calculating the real motion. The motion of Venus towards or away from us can be calculated with great accuracy for any period, being a resultant of the combined motions of the planet and of our earth in their respective orbits. The radial motions of Venus were determined at the Lick Observatory in August and September 1890, by spectroscopic observations, and also by calculation, to be as follows:—

		By Observation.				By Calculation.			
Aug.	16th.	7.3	miles	per	second.	8.1	miles	per	second.
"	22nd.	8.9	"	"	"	8.2	"	"	"
"	30th.	7.3	"	"	"	8.3	"	"	"
Sep.	3rd.	8.3	"	"	"	8.3	"	"	"
"	4th.	8.2	"	"	"	8.3	"	"	"

showing that the maximum error was only one mile per second, while the mean error was about a quarter of a mile. In the case of the stars the accuracy of the method has been tested by observations of the same star at times when the earth's motion in its orbit is towards or away from the star, whose apparent radial velocity is, therefore, increased or diminished by a known amount. Observations of this kind were made by Dr. Vogel, Director of the Astrophysical Observatory at Potsdam, showing, in the case of three stars, of which ten observations were taken, a mean error of about two miles per second; but as the stellar motions are more rapid than those of the planets, the proportionate error is no greater than in the example given above.

The great importance of this mode of determining the real motion of the stars is, that it gives us a knowledge of the scale on which such motions are progressing; and when in the course of time we discover whether any of their paths are rectilinear or curved, we shall be in a position to learn something of the nature of the changes that are going on and of the laws on which they depend.

Invisible Stars and Imperceptible Motions

But there is another result of this power of determining radial motion which is even more unexpected and marvellous, and which has extended our knowledge of the stars in quite a new direction. By its means it is possible to determine the existence of invisible stars and to measure the rate of otherwise imperceptible motions; that is of stars which are invisible in the most powerful modern telescopes, and whose motions have such a limited range that no telescope can detect them.

Double or binary stars forming systems which revolve around their common centre of gravity were discovered by Sir William Herschel, and very great numbers are known; but in most cases their periods of revolution are long, the shortest being about twelve years, while many extend to several hundred years. These are, of course, all visible binaries, but many are now known of which one star only is visible while the other is either non-luminous or is so close to its companion that they appear as a single star in the most powerful telescopes. Many of the variable stars belong to the former class, a good example of which is Algol in the constellation Perseus, which changes from the second to the fourth magnitude in about four and a half hours, and in about four and a half hours more regains its brilliancy till its next period of obscuration which occurs regularly every two days and twenty-one hours. The name Algol is from the Arabic *Al Ghoul*, the familiar 'ghoul' of the Arabian Nights, so named—'The Demon'—from its strange and weird behaviour.

It had long been conjectured that this obscuration was due to a dark companion which partially eclipsed the bright star at every revolution, showing that the plane of the orbit of the pair was almost exactly directed towards us. The application of the spectroscope made this conjecture a certainty. At an equal time before and after the obscuration, motion in the line of sight was shown, towards and away from us, at a rate of twenty-six miles per second. From these scanty data and the laws of gravitation which fix the period of revolution of planets at various distances from their centres of revolution, Professor Pickering of the Harvard Observatory was able to arrive at the following figures as highly probable, and they may be considered to be certainly not far from the truth.

Diameter of Algol,	1,061,000	miles.
Diameter of dark companion,	830,000	"
Distance between their centres,	3,230,000	"
Orbital speed of Algol,	26.3	miles per sec.
Orbital speed of companion,	55.4	" " "
Mass of Algol,	$^4/_9$	mass of our Sun.
Mass of companion,	$^2/_9$	" " "

When it is considered that these figures relate to a pair of stars only one of which has ever been seen, that the orbital motion even of the visible star cannot be detected in the most powerful telescopes, when, further, we take into account the enormous distance of these objects from us, the great results of spectroscopic observation will be better appreciated.

But besides the marvel of such a discovery by such simple means, the facts discovered are themselves in the highest degree marvellous. All that we had known of the stars through telescopic observation indicated that they were at very great distances from each other however thickly they may appear scattered over the sky. This is the case even with close telescopic double stars, owing to their enormous remoteness from us. It is now estimated that even stars of the first magnitude are, on a general average, about eighty millions of millions of miles distant; while the closest double stars that can be distinctly separated by large telescopes are about half a second apart. These, if at the above distance, will be about 1500 millions of miles from each other. But in the case of Algol and its companion, we have two bodies both larger than our sun, yet with a distance of only $2^1/_4$ millions of miles between their surfaces, a distance not much exceeding their combined diameters. We should not have anticipated that such huge bodies could revolve so closely to each other, and as we now know that the neighbourhood of our sun—and probably of all suns—is full of meteoric and cometic matter, it would seem probable that in the case of two suns so near together the quantity of such matter would be very great, and would lead probably by continued collisions to increase of their bulk, and perhaps to their final coalescence into a single giant orb. It is said that a Persian astronomer in the tenth century calls Algol a red star, while it is now white or somewhat yellowish. This would imply an increase of temperature caused by collisions or friction, and increasing proximity of the pair of stars.

A considerable number of double stars with dark companions have been discovered by means of the spectroscope, although their motion is not directly in the line of sight, and therefore there is no obscuration. In order to discover such pairs the spectra of large numbers of stars are taken on photographic plates every night and for considerable periods—for a year or for several years. These plates are then carefully examined with a high magnifying power to discover any periodical displacement of the lines, and it is astonishing in how large a number of cases this has been found to exist and the period of revolution of the pair determined.

But besides discovering double stars of which one is dark and one bright, many pairs of bright stars have been discovered by the same means. The method in this case is rather different. Each component star, being luminous, will give a separate spectrum, and the best spectroscopes are so powerful that they will separate these spectra when the stars are at their maximum distance although no telescope in existence, or ever likely to be made, can separate the component stars. The separation of the spectra is usually shown by the most prominent lines becoming double and then after a time single, indicating that the plane of revolution is more or less obliquely towards us, so that the two stars if visible would appear to open out and then get nearer together every revolution. Then, as each star alternately approaches and recedes from us the radial velocity of each can be determined, and this gives the relative mass. In this way not only doubles, but triple and multiple systems, have been discovered. The stars proved to be double by these two methods are so numerous that it has been estimated by one of the best observers that about one star in every thirteen shows inequality in its radial motion and is therefore really a double star.

The Nebulæ

One other great result of spectrum-analysis, and in some respects perhaps the greatest, is its demonstration of the fact that true nebulæ exist, and that they are not all star-clusters so remote as to be irresolvable, as was once supposed. They are shown to have gaseous spectra, or sometimes gaseous and stellar spectra combined, and this, in connection with the fact that nebulæ are frequently aggregated around nebulous stars or groups of stars, renders it certain that the nebulæ are in no way separated in space from the stars, but that they constitute essential parts of one vast stellar universe. There is, indeed, good reason to believe that they are really the material out of which stars are made, and that in their forms, aggregations, and condensations, we can trace the very process of evolution of stars and suns.

Photographic Astronomy

But there is yet another powerful engine of research which the new astronomy possesses, and which, either alone or in combination with the spectroscope, had produced and will yet produce in the future an amount of knowledge of the stellar universe which could never be attained by any other means. It has already been stated how the discovery of new variable and binary stars has been rendered possible by the preservation of the photographic plates on which the spectra are self-recorded, night after night, with every line, whether dark or coloured, in true position, so as to bear magnification, and, by comparison with others of the series, enabling the most minute changes to be detected and their amount accurately measured. Without the preservation of such comparable records, which is in no other way possible, by far the larger portion of spectroscopic discoveries could never have been made.

But there are two other uses of photography of quite a different nature which are equally and perhaps in their final outcome may be far more important. The first is, that by the use of the photographic plate the exact positions of scores, hundreds, or even thousands of stars can be self-mapped simultaneously with extreme accuracy, while any number of copies can be made of these star-maps. This entirely obviates the necessity for the old method of fixing the position of each star by repeated measurement by means of very elaborate instruments, and their registration in laborious and expensive catalogues. So important is this now seen to be, that specially constructed cameras are made for stellar photography, and by means of the best kinds of equatorial mounting are made to revolve slowly so that the image of each star remains stationary upon the plate for several hours.

Arrangements have been now made among all the chief observatories of the world to carry out a photographic survey of the heavens with identical instruments, so as to produce maps of the whole star-system on the same scale. These will serve as fixed data for future astronomers, who will thus be able to determine the movements of stars of all magnitudes with a certainty and accuracy hitherto unattainable.

The other important use of photography depends upon the fact that with a longer exposure within certain limits we increase the light-collecting power. It will surprise many persons to learn that an ordinary good portrait-camera with a lens three or four inches in diameter, if properly mounted so that an exposure of several hours can be made, will show stars so minute that they are invisible even in the great Lick telescope. In this way the camera will often reveal double-stars or small groups which can be made visible in no other way.

Such photographs of the stars are now constantly reproduced in works on Astronomy and in popular magazine articles, and although some of them are very striking, many persons are disappointed with them, and cannot understand their great value, because each star is represented by a white circle often of considerable size and with a somewhat undefined outline, not by a minute point of light as stars appear in a good telescope. But the essential matter in all such photographs is not so much the smallness, as the roundness, of the star-images, as this proves the extreme precision with which the image of every star has been kept by the clockwork motion of the instrument on the same point of the plate during the whole exposure. For example, in the fine photograph of the Great Nebula in Andromeda, taken 29th December 1888, by Dr. Isaac Roberts, with an exposure of four hours, there are probably over a thousand stars large and small to be seen, every one represented by an almost exactly circular white dot of a size dependent on the magnitude of the star. These round dots can be bisected by the cross hairs of a micrometer with very great accuracy, and thus the distance between the centres of any of the pairs, as well as the direction of the line joining their centres, can be determined as accurately as if each was represented by a point only. But as a minute white speck would be almost invisible on the maps, and would convey no information as to the approximate magnitude of the star, mistakes would be much more easily made, and it would probably be found necessary to surround each star with a circle to indicate its magnitude, and to enable it to be easily seen. It is probable, therefore, that the supposed defect is really an important advantage. The above-mentioned photograph is beautifully reproduced in Proctor's *Old and New Astronomy*, published after his greatly lamented death.

But besides the amount of altogether new knowledge obtained by the methods of research here briefly explained, a great deal of light has been thrown on the distribution of the stars as a whole, and hence on the nature and extent of the stellar universe, by a careful study of the materials obtained by the old methods, and by the application of the doctrine of probabilities to the observed facts. In this way alone some very striking results have been reached, and these have been supported and strengthened by the newer methods, and also by the use of new instruments in the measurement of stellar distances. Some of these results bear so closely and directly upon the special subject of the present volume, that our next chapter must be devoted to a consideration of them.

CHAPTER IV

THE DISTRIBUTION OF THE STARS

If we look at the heavens on a clear, moonless night in winter, and from a position embracing the entire horizon, the scene is an inexpressibly grand one. The intense sparkling brilliancy of Sirius, Capella, Vega, and other stars of the first magnitude; their striking arrangement in constellations or groups, of which Orion, the Great Bear, Cassiopeiæ, and the Pleiades, are familiar examples; and the filling up between these by less and less brilliant points down to the limit of vision, so as to cover the whole sky with a scintillating tracery of minute points of light, convey together an idea of such confused scattering and such enormous numbers, that it seems impossible to count them or to reduce them to systematic order. Yet this was done for all except the faintest stars by Hipparchus, 134 B.C., who catalogued and fixed the positions of more than 1000 stars, and this is about the number, down to the fifth magnitude, visible in the latitude of Greece. A recent enumeration of all the stars visible to the naked eye, under the most favourable conditions and by the best eyesight, has been made by the American astronomer, Pickering. His numbers are—for the Northern Hemisphere 2509, and for the Southern Hemisphere 2824, thus showing a somewhat greater richness in the southern celestial hemisphere. But as this difference is due entirely to a preponderance of stars between magnitudes $5^1/_2$ and 6, that is, just on the limits of vision, while those down to magnitude $5^1/_2$ are more numerous by 85 in the Northern Hemisphere, Professor Newcomb is of opinion that there is no real superiority of numbers of visible stars in one hemisphere over the other. Again, the total number of the visible stars by the above enumeration is 5333. But this includes stars down to 6.2 magnitude, while it is generally considered that magnitude 6 marks the limit of visibility. On a re-examination of all the materials, the Italian astronomer Schiaparelli concludes that the total number of stars down to the sixth magnitude is 4303; and they seem to be about equally divided between the northern and southern skies.

THE MILKY WAY

But besides the stars themselves, a most conspicuous object both in the northern and southern hemisphere is that wonderful irregular belt of faintly diffused light termed the Milky Way or Galaxy. This forms a magnificent arch across the sky, best seen in the autumn months in our latitude. This arch, while following the general course of a great circle round the heavens, is extremely irregular in detail, sometimes being single, sometimes double, sending off occasional branches or offshoots, and also containing in its very midst dark rifts, spots, or patches, where the black background of almost starless sky can be seen through it. When examined through an opera-glass or small telescope quantities of stars are seen on the luminous background, and with every increase in the size and power of the telescope more and more stars become visible, till with the largest and best modern instruments the whole of the Galaxy seems densely packed with them, though still full of irregularities, wavy streams of stars, and dark rifts and patches, but always showing a faint nebulous background as if there remained other myriads of stars which a still higher optical power would reveal.

The relations of this great belt of telescopic stars to the rest of the star-system have long interested astronomers, and many have attempted its solution. By a system of gauging, that is counting all the stars that passed over the field of his telescope in a certain time, Sir William Herschel was the first who made a systematic effort to determine the shape of the stellar universe. From the fact that the number of stars increased rapidly as the Milky Way was approached from whatever direction, while in the Galaxy itself the numbers visible were at once more than doubled, he formed the idea that the shape of the entire system must be that of a highly compressed very broad mass or ring rather less dense towards the centre where our sun was situated. Roughly speaking, the form was likened to a flat disc or grindstone, but of irregular thickness, and split in two on one side where it appears to be double. The immense quantity of the stars which formed it was supposed to be due to the fact that we looked at it edgewise through an immense depth of stars; while at right angles to its direction when looking towards what is termed the pole of the Galaxy, and also in a less degree when looking obliquely, we see out into space through a much thinner stratum of stars, which thus seem on the average to be very much farther apart.

But, in the latter part of his life, Sir William Herschel realised that this was not the true explanation of the features presented by the Galaxy. The brilliant spots and patches in it, the dark rifts and openings, the narrow streams of light often bounded by equally narrow streams or rifts of darkness, render it quite impossible to conceive that this complex luminous ring has the form of a compressed disc extending in the direction in which we see it to a distance many times greater than its thickness. In one very luminous cluster Herschel thought that his telescope had penetrated to regions twenty times as far off as the more brilliant stars forming the nearer portions of the same object. Now, in the case of the Magellanic clouds, which are two roundish nebular patches of large size some distance from the Milky Way in the Southern Hemisphere and looking like detached portions of it, Sir John Herschel himself has shown that any such interpretation of its form is impossible; because it requires us to suppose that in both these cases we see, not rounded masses of a roughly globular shape, but immensely long cones or cylinders, placed in such a direction that we see only the ends of them. He remarks that one such object so situated would be an extraordinary coincidence, but that there should be two or many such is altogether out of the question. But in the Milky Way there are hundreds or even thousands of such spots or masses of exceptional brilliancy or exceptional darkness; and, if the form of the Galaxy is that of a disc many times broader than thick, and which we see edgewise, then every one of these patches and clusters, and all the narrow winding streams of bright light or intense blackness, must be really excessively long cylinders, or tunnels, or deep curving laminæ, or narrow fissures. And every one of these, which are to be found in every part of this vast circle of luminosity, must be so arranged as to be exactly turned towards our sun. The weight of this argument, which has been most forcibly and clearly set forth by the late Mr. R.A. Proctor, in his very instructive volume *Our Place among Infinities*, is now generally admitted by astronomers, and the natural conclusion is that the form of the Milky Way is that of a vast irregular ring, of which the section at any part is, roughly speaking, circular; while the many narrow rifts or lanes or openings where we seem to be able to see completely through it to the darkness of outer space beyond, render it probable that in those directions its thickness is less instead of greater than its apparent width, that is, that we see the broader side rather than the narrow edge of it.

Before entering on the consideration of the relations which the bulk of the stars we see scattered over the entire vault of heaven bear to this great belt of telescopic stars, it will be advisable to give a somewhat full description of the Galaxy itself, both because it is not often delineated on star-maps with sufficient accuracy, or so as to show its wonderful intricacies of structure, and also because it constitutes the fundamental phenomenon upon which the argument set forth in this volume primarily rests. For this purpose I shall use the description of it given by Sir John Herschel in his *Outlines of Astronomy*, both because he, of all the astronomers of the last century, had studied it most thoroughly, in the northern and in the southern hemispheres, by eye-observation and with the aid of telescopes of great power and admirable quality; and also because, amid the throng of modern works and the exciting novelties of the last thirty years, his instructive volume is, comparatively speaking, very little known. This precise and careful description will also be of service to any of my readers who may wish to form a closer personal acquaintance with this magnificent and intensely interesting object, by examining its peculiarities of form and beauties of structure either with the naked eye, or with the aid of a good opera-glass, or with a small telescope of good defining power.

A Description of the Milky Way

Sir John Herschel's description is as follows:—'The course of the Milky Way as traced through the heavens by the unaided eye, neglecting occasional deviations and following the line of its greatest brightness as well as its varying breadth and intensity will permit, conforms, as nearly as the indefiniteness of its boundary will allow it to be fixed, to that of a great circle inclined at an angle of about 63° to the equinoctial, and cutting that circle in Right Ascension 6h. 47m. and 18h. 47m., so that its northern and southern poles respectively are situated in Right Ascension 12h. 47m., North Polar Distance 63°, and R.A. 0h. 47m., NPD. 117°. Throughout the region where it is so remarkably subdivided, this great circle holds an intermediate situation between the two great streams; with a nearer approximation however to the brighter and continuous stream than to the fainter and interrupted one. If we trace its course in order of right ascension, we find it traversing the constellation Cassiopeiæ, its brightest part passing about two degrees to the north of the star Delta of that constellation. Passing thence between Gamma and Epsilon Cassiopeiæ, it sends off a branch to the south-preceding side, towards Alpha Persei, very conspicuous as far as that star, prolonged faintly towards Eta of the same constellation, and possibly traceable towards the Hyades and Pleiades as remote outliers. The main stream, however (which is here very faint), passes on through Auriga, over the three remarkable stars, Epsilon, Zeta, Eta, of that constellation called the Hædi, preceding Capella, between the feet of Gemini and the horns of the Bull (where it intersects the ecliptic nearly in the Solstitial Colure) and thence over the club of Orion to the neck of Monoceros, intersecting the equinoctial in R.A. 6h. 54m. Up to this point, from the offset in Perseus, its light is feeble and indefinite, but thenceforward it receives a gradual accession of brightness, and where it passes through the shoulder of Monoceros and over the head of Canis Major it presents a broad, moderately bright, very uniform, and to the naked eye, starless stream up to the point where it enters the prow of the ship Argo, nearly on the southern tropic. Here it again subdivides (about the star *m* Puppis), sending off a narrow and winding branch on the preceding side as far as Gamma Argûs, where it terminates abruptly. The main stream pursues its southward course to the 123rd parallel of NPD., where it diffuses itself broadly and again subdivides, opening out into a wide fan-like expanse, nearly 20° in breadth, formed of interlacing branches, which all terminate abruptly, in a line drawn nearly through Lambda and Gamma Argûs.

'At this place the continuity of the Milky Way is interrupted by a wide gap, and where it recommences on the opposite side it is by a somewhat similar fan-shaped assemblage of branches which converge upon the bright star Eta Argûs. Thence it crosses the hind feet of the Centaur, forming a curious and sharply-defined semicircular concavity of small radius, and enters the Cross by a very bright neck or isthmus of not more than three or four degrees in breadth, being the narrowest portion of the Milky Way. After this it immediately expands into a broad and bright mass, enclosing the stars Alpha and Beta Crucis and Beta Centauri, and extending almost up to Alpha of the latter constellation. In the midst of this bright mass, surrounded by it on all sides, and occupying about half its breadth, occurs a singular dark pear-shaped vacancy, so conspicuous and remarkable as to attract the notice of the most superficial gazer and to have acquired among the early southern navigators the uncouth but expressive appellation of the *coal-sack*. In this vacancy, which is about 8° in length and 5° broad, only one very small star visible to the naked eye occurs, though it is far from devoid of telescopic stars, so that its striking blackness is simply due to the effect of contrast with the brilliant ground with which it is on all sides surrounded. This is the place of nearest approach of the Milky Way to the South Pole. Throughout all this region its brightness is very striking, and when compared with that of its more northern course already traced, conveys strongly the impression of greater proximity, and would almost lead to a belief that our situation as spectators is separated on all sides by a considerable interval from the dense body of stars composing the Galaxy, which in this view of the subject would come to be considered as a flat ring or some other re-entering form of immense and irregular breadth and thickness, within which we are excentrically situated, nearer to the southern than to the northern part of its circuit.

'At Alpha Centauri the Milky Way again subdivides, sending off a great branch of nearly half its breadth, but which thins off rapidly, at an angle of about 20° with its general direction to Eta and *d* Lupi, beyond which it loses itself in a narrow and faint streamlet. The main stream passes on increasing in breadth to Gamma Normæ, where it makes an abrupt elbow and again subdivides into one principal and continuous stream of very irregular breadth and brightness, and a complicated system of interlaced streaks and masses, which covers the tail of Scorpio, and terminates in a vast and faint effusion over the whole extensive region occupied by the preceding leg of Ophiuchus, extending northward to the parallel of 103° NPD., beyond which it cannot be traced; a wide interval of 14°, free from all appearance of nebulous light, separating it from the great branch on the north side of the equinoctial of which it is usually represented as a continuation.

'Returning to the point of separation of this great branch from the main stream, let us now pursue the course of the latter. Making an abrupt bend to the following side, it passes over the stars Iota Aræ, Theta and Iota Scorpii, and Gamma Tubi to Gamma Sagittarii, where it suddenly collects into a vivid oval mass about 6° in length and 4° in breadth, so excessively rich in stars that a very moderate calculation makes their number exceed 100,000. Northward of this mass, this stream crosses the ecliptic in longitude about 276°, and proceeding along the bow of Sagittarius into Antinous has its course rippled by three deep concavities, separated from each other by remarkable protuberances, of which the larger and brighter forms the most conspicuous patch in the southern portion of the Milky Way visible in our latitudes.

'Crossing the equinoctial at the 19th hour of R.A., it next runs in an irregular, patchy, and winding stream through Aquila, Sagitta, and Vulpecula up to Cygnus; at Epsilon of which constellation its continuity is interrupted, and a very confused and irregular region commences, marked by a broad dark vacuity, not unlike the southern "coal-sack," occupying the space between Epsilon, Alpha, and Gamma Cygni, which serves as a kind of centre for the divergence of three great streams; one, which we have already traced; a second, the continuation of the first (across the interval) from Alpha northward, between Lacerta and the head of Cepheus to the point in Cassiopeiæ whence we set out, and a third branching off from Gamma Cygni, very vivid and conspicuous, running off in a southern direction through Beta Cygni, and *s* Aquilæ almost to the equinoctial, where it loses itself in a region thinly sprinkled with stars, where in some maps the modern constellation Taurus Poniatowski is placed. This is the branch which, if continued across the equinoctial, might be supposed to unite with the great southern effusion in Ophiuchus already noticed. A considerable offset, or protuberant appendage, is also thrown off by the northern stream from the head of Cepheus directly towards the pole, occupying the greater part of the quartile formed by Alpha, Beta, Iota, and Delta of that constellation.'

To complete this careful, detailed description of the Milky Way, it will be well to add a few passages from the same work as to its telescopic appearance and structure.

'When examined with powerful telescopes, the constitution of this wonderful zone is found to be no less various than its aspect to the naked eye is irregular. In some regions the stars of which it is composed are scattered with remarkable uniformity over immense tracts, while in others the irregularity of their distribution is quite as striking, exhibiting a rapid succession of closely clustering rich patches separated by comparatively poor intervals, and indeed in some instances by spaces absolutely dark *and completely void of any star*, even of the smallest telescopic magnitude. In some places not more than 40 or 50 stars on an average occur in a gauge-field of 15', while in others a similar average gives a result of 400 or 500. Nor is less variety observable in the character of its different regions in respect of the magnitudes of the stars they exhibit, and the proportional numbers of the larger and smaller magnitudes associated together, than in respect of their aggregate numbers.

In some, for instance, extremely minute stars occur in numbers so moderate as to lead us irresistibly to the conclusion that in these regions we see *fairly through* the starry stratum, since it is impossible otherwise that the numbers of the smaller magnitudes should not go on continually increasing ad infinitum. In such cases, moreover, the ground of the heavens is for the most part perfectly dark, which again would not be the case if innumerable multitudes of stars, too minute to be individually discernible, existed beyond. In other regions we are presented with the phænomenon of an almost uniform degree of brightness of the individual stars, accompanied with a very even distribution of them over the ground of the heavens, both the larger and smaller magnitudes being strikingly deficient. In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars nearly of a size, and of no great thickness compared with the distance which separates them from us. Were it otherwise we should be driven to suppose the more distant stars uniformly the larger, so as to compensate by their greater intrinsic brightness for their greater distance, a supposition contrary to all probability....

'Throughout by far the larger portion of the extent of the Milky Way in both hemispheres, the general blackness of the ground of the heavens on which its stars are projected, and the absence of that innumerable multitude and excessive crowding of the smallest visible magnitudes, and of glare produced by the aggregate light of multitudes too small to affect the eye singly, must, we think, be considered unequivocal indications that its dimensions in *directions where these conditions obtain* are not only not infinite, but that the space-penetrating power of our telescopes suffices fairly to pierce through and beyond it.'

In the above-quoted passage the italics are those of Sir John Herschel himself, and we see that he drew the very same conclusions from the facts he describes, and for much the same reasons, as Mr. Proctor has drawn from the observations of Sir William Herschel; and, as we shall see, the best astronomers to-day have arrived at a similar result, from the additional facts at their disposal, and in some cases from fresh lines of argument.

The Stars in Relation to the Milky Way

Sir John Herschel was so impressed with the form, structure, and immensity of the Galactic Circle, as he sometimes terms it, that he says (in a footnote p. 575, 10th ed.), 'This circle is to sidereal what the invariable ecliptic is to planetary astronomy—a plane of ultimate reference, the ground-plane of the sidereal system.' We have now to consider what are the relations of the whole body of the stars to this Galactic Circle—this plane of ultimate reference for the whole stellar universe.

If we look at the heavens on a starry night, the whole vault appears to be thickly strewn with stars of various degrees of brightness, so that we could hardly say that any extensive region—the north, east, south, or west, or the portion vertically above us—is very conspicuously deficient or superior in numbers. In every part there are to be found a fair proportion of stars of the first two or three magnitudes, while where these may seem deficient a crowd of smaller stars takes their place.

But an accurate survey of the visible stars shows that there is a large amount of irregularity in their distribution, and that all magnitudes are really more numerous in or near the Milky Way, than at a distance from it, though not in so large a degree as to be very conspicuous to the naked eye. The area of the whole of the Milky Way cannot be estimated at more than one-seventh of the whole sphere, while some astronomers reckon it at only one-tenth. If stars of any particular size were uniformly distributed, at most one-seventh of the whole number should be found within its limits. But Mr. Gore finds that of 32 stars brighter than the second magnitude 12 lie upon the Milky Way, or considerably more than twice as many as there should be if they were uniformly distributed. And in the case of the 99 stars which are brighter than the third magnitude 33 lie upon the Milky Way, or one-third instead of one-seventh. Mr. Gore also counted all the stars in Heis's Atlas which lie upon the Milky Way, and finds there are 1186 out of a total of 5356, a proportion of between a fourth and a fifth instead of a seventh.

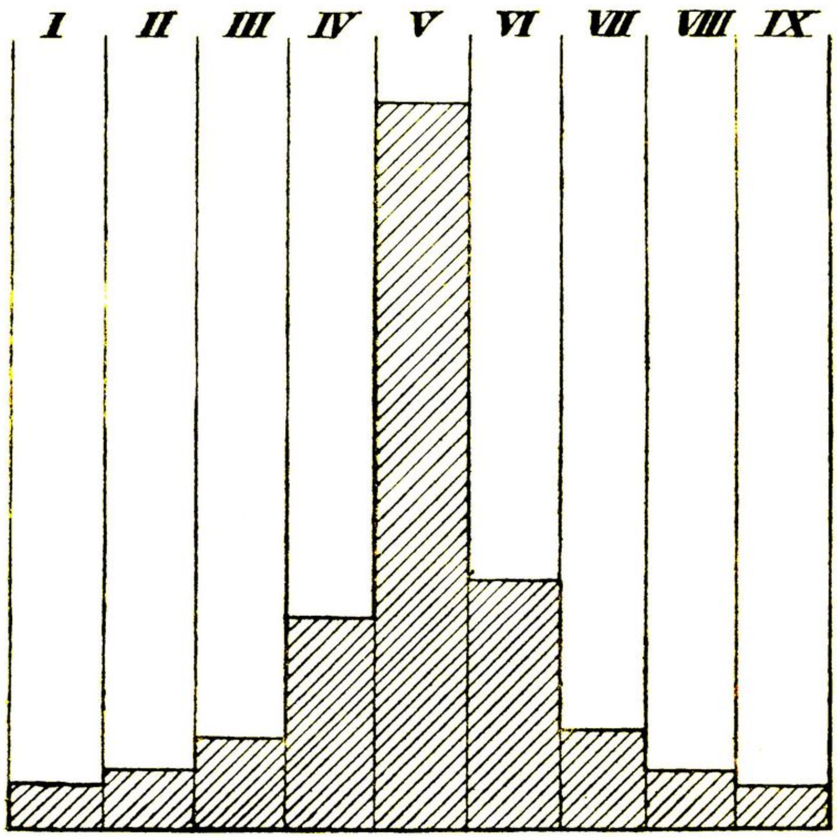
The late Mr. Proctor in 1871 laid down on a chart two feet diameter all the stars down to magnitude $9^1/_2$ given in Agrelander's forty large charts of the stars visible in the northern hemisphere. They were 324,198 in number, and they distinctly showed by their greater density not only the whole course of the Milky Way but also its more luminous portions and many of the curious dark rifts and vacuities, which latter are almost wholly avoided by these stars.

Later on Professor Seeliger of Munich made an investigation of the relation of more than 135,000 stars down to the ninth magnitude to the Milky Way, by dividing the whole of the heavens into nine regions, one and nine being circles of 20° wide (equal to 40° diameter) at the two poles of the Galaxy; the middle region, five, is a zone 20° wide including the Milky Way itself, and the other six intermediate zones are each 20° wide. The following table shows the results as given by Professor Newcomb, who has made some alterations in the last column of 'Density of Stars' in order to correct differences in the estimate of magnitudes by the different authorities.

Regions.	Area in Degree.	Number of Stars.	Density.
I.	1,398.7	4,277	2.78
II.	3,146.9	10,185	3.03
III.	5,126.6	19,488	3.54
IV.	4,589.8	24,492	5.32
V.	4,519.5	33,267	8.17
VI.	3,971.5	23,580	6.07
VII.	2,954.4	11,790	3.71
VIII.	1,796.6	6,375	3.21
IX.	468.2	1,644	3.14

N.B.—The inequality of the N. and S. areas is because the enumeration of the stars only went as far as 24° S. Decl., and therefore included only a part of Regions VII., VIII., and IX.

DIAGRAM OF STAR-DENSITY



From Herschel's Gauges
(as given by Professor Newcomb, p. 251).

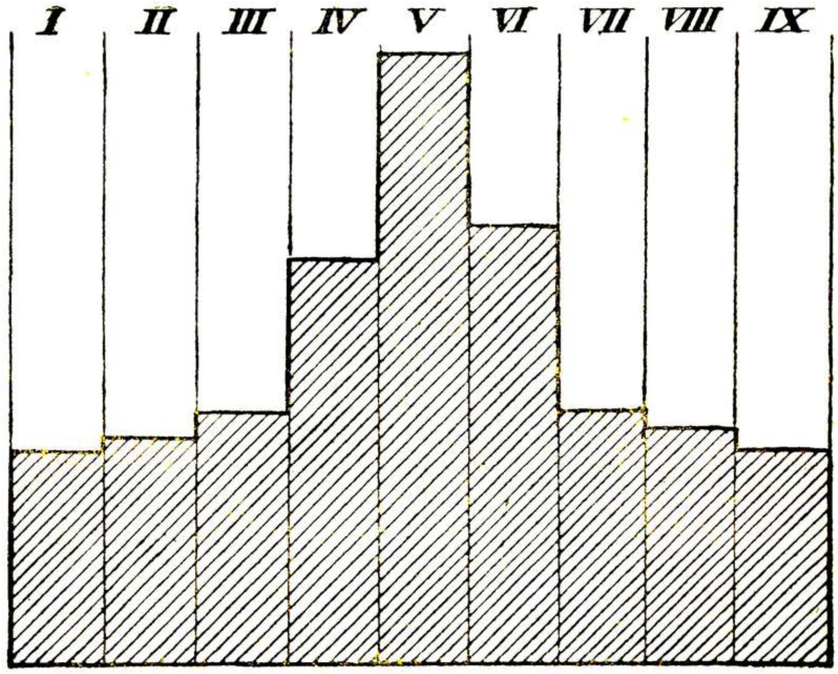
Upon this table of densities Professor Newcomb remarks as follows:—'The star-density in the several regions increases continuously from each pole (regions I. and IX.) to the Galaxy itself (region V.). If the latter were a simple ring of stars surrounding a spherical system of stars, the star-density would be about the same in regions I., II., and III., and also in VII., VIII., and IX., but would suddenly increase in IV. and VI. as the boundary of the ring was approached. Instead of such being the case, the numbers 2.78, 3.03, and 3.54 in the north, and 3.14, 3.21, and 3.71 in the south, show a progressive increase from the galactic pole to the Galaxy itself. The conclusion to be drawn is a fundamental one. The universe, or at least the denser portion of it, is really flattened between the galactic poles, as supposed by Herschel and Struve.'

But looking at the series of figures in the table, and again as quoted by Professor Newcomb, they seem to me to show in some measure what he says they do not show. I therefore drew out the above diagram from the figures in the table, and it certainly shows that the density in regions I., II., and III., and in regions VII., VIII., and IX., may be said to be 'about the same,' that is, they increase very slowly, and that they *do* 'suddenly increase' in IV. and VI. as the boundary of the Galaxy is approached. This may be explained either by a flattening towards the poles of the Galaxy, or by the thinning out of stars in that direction.

In order to show the enormous difference of star-density in the Galaxy and at the galactic poles, Professor Newcomb gives the following table of the Herschelian gauges, on which he only remarks that they show an enormously increased density in the galactic region due to the Herschels having counted so many more stars there than any other observers.

Region, .	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Density, .	107	154	281	560	2,019	672	261	154	111

DIAGRAM OF STAR-DENSITY



From a table in The Stars (p. 249).

But an important characteristic of these figures is, that the Herschels alone surveyed the whole of the heavens from the north to the south pole, that they did this with instruments of the same size and quality, and that from almost life-long experience in this particular work they were unrivalled in their power of counting rapidly and accurately the stars that passed over each field of view of their telescopes. Their results, therefore, must be held to have a comparative value far above those of any other observer or combination of observers. I have therefore thought it advisable to draw a diagram from their figures, and it will be seen how strikingly it agrees with the former diagram in the very slow increase of star-richness in the first three regions north and south, the sudden increase in regions IV. and VI. as we approach the Galaxy, while the only marked difference is in the enormously greater richness of the Galaxy itself, which is an undoubtedly real phenomenon, and is brought out here by the unrivalled observing power of the two greatest astronomers in this special department that have ever lived.

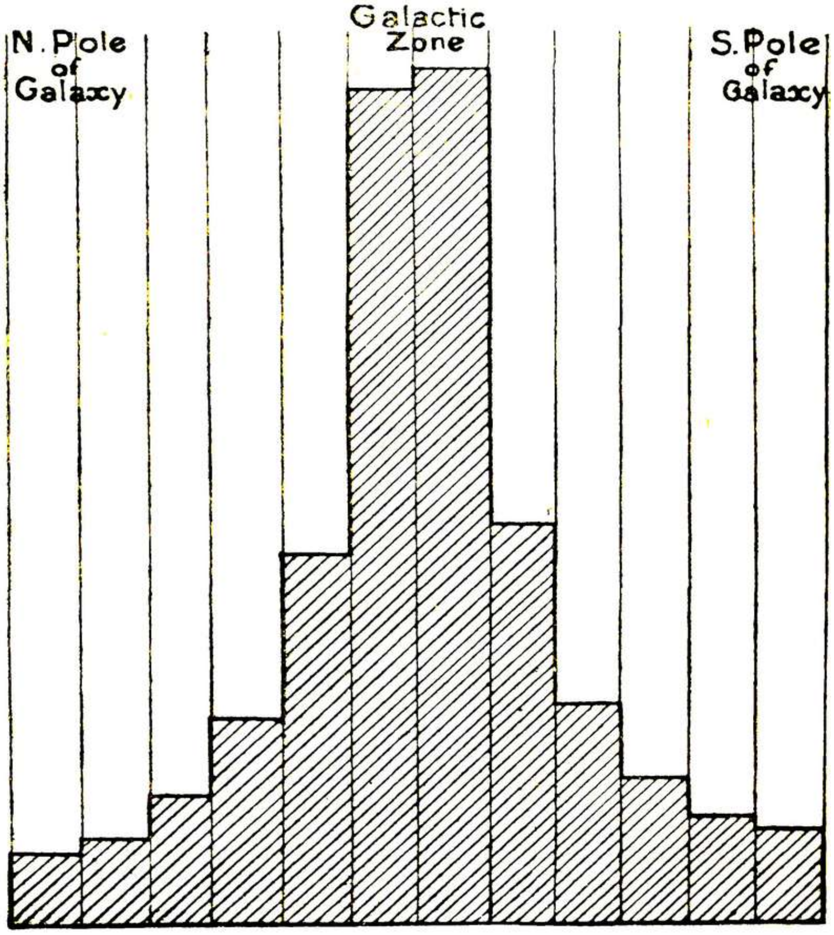
We shall find later on that Professor Newcomb himself, as the result of a quite different inquiry arrives at a result in accordance with these diagrams which will then be again referred to. As this is a very interesting subject, it will be well to give another diagram from two tables of star-density in Sir John Herschel's volume already quoted. The tables are as follows:—

Zones of Galactic	Average number of Star
North Polar Distance.	per Field of 15'.
0° to 15°	4.32
>15° to 30°	5.42
30° to 45°	8.21
45° to 60°	13.61
60° to 75°	24.09
75° to 90°	53.43

Zones of Galactic	Average number of Stars
South Polar Distance.	per Field of 15'.
0° to 15°	6.05
15° to 30°	6.62
30° to 45°	9.08
45° to 60°	13.49
60° to 75°	26.29
75° to 90°	59.06

In these tables the Milky Way itself is taken as occupying two zones of 15° each, instead of one of 20° as in Professor Newcomb's tables, so that the excess in the number of stars over the other zones is not so large. They show also a slight preponderance in all the zones of the southern hemisphere, but this is not great, and may probably be due to the clearer atmosphere of the Cape of Good Hope as compared with that of England.

DIAGRAM OF STAR-DENSITY.



From Table in Sir J. Herschel's Outlines of Astronomy (10th ed., pp. 577-578).

It need only be noted here that this diagram shows the same general features as those already given, of a continuous increase of star-density from the poles of the Galaxy, but more rapidly as the Galaxy itself is more nearly approached. This fact must, therefore, be accepted as indisputable.

Clusters and Nebulæ in Relation to the Galaxy

An important factor in the structure of the heavens is afforded by the distribution of the two classes of objects known as clusters and nebulæ. Although we can form an almost continuous series from double stars which revolve round their common centre of gravity, through triple and quadruple stars, to groups and aggregations of indefinite extent—of which the Pleiades form a good example, since the six stars visible to the naked eye are increased to hundreds by high telescopic powers, while photographs with three hours' exposure show more than 2000 stars—yet none of these correspond to the large class known as clusters, whether globular or irregular, which are very numerous, about 600 having been recorded by Sir John Herschel more than fifty years ago. Many of these are among the most beautiful and striking objects in the heavens even with a very small telescope or good opera-glass. Such is the luminous spot called Praesepe, or the Beehive in the constellation Cancer, and another in the sword handle of Perseus.

In the southern hemisphere there is a hazy star of about the fourth magnitude, Omega Centauri, which with a good telescope is seen to be really a magnificent cluster nearly two-thirds the diameter of the moon, and described by Sir John Herschel as very gradually increasing in brightness to the centre, and composed of innumerable stars of the thirteenth and fifteenth magnitudes, forming the richest and largest object of the kind in the heavens. He describes it as having rings like lace-work formed of the larger stars. By actual count, on a good photograph, there are more than 6000 stars, while other observers consider that there are at least 10,000. In the northern hemisphere one of the finest is that in the constellation Hercules, known as 13 Messier. It is just visible to the naked eye or with an opera glass as a hazy star of the sixth magnitude, but a good telescope shows it to be a globular cluster, and the great Lick telescope resolves even the densest central portion into distinct stars, of which Sir John Herschel considered there were many thousands. These two fine clusters are figured in many of the modern popular works on astronomy, and they afford an excellent idea of these beautiful and remarkable objects, which, when more thoroughly studied, will probably aid in elucidating some of the obscure problems connected with the constitution and development of the stellar universe.

But for the purpose of the present work the most interesting fact connected with star-clusters is their remarkable distribution in the heavens. Their special abundance in and near the Milky Way had often been noted, but the full importance of the fact could not be appreciated till Mr. Proctor and, later, Mr. Sidney Waters marked down, on maps of the two hemispheres, all the star-clusters and nebulæ in the best catalogues. The result is most interesting. The clusters are seen to be thickly strewn over the entire course of the Milky Way, and along its margins, while in every other part of the heavens they are thinly scattered at very distant intervals, with the one exception of the Magellanic clouds of the southern hemisphere where they are again densely grouped; and if anything were needed to prove the physical connection of these clusters with the Galaxy it would be their occurrence in these extensive nebulous patches which seem like outlying portions of the Milky Way itself. With these two exceptions probably not one-twentieth part of the whole number of star-clusters are found in any part of the heavens remote from the Milky Way.

Nebulæ were for a long time confounded with star-clusters, because it was thought that with sufficient telescopic power they could all be resolvable into stars as in the case of the Milky Way itself. But when the spectroscope showed that many of the nebulæ consisted wholly or mainly of glowing gases, while neither the highest powers of the best telescopes nor the still greater powers of the photographic plate gave any indications of resolvability, although a few stars were often found to be, as it were, entangled in them, and evidently forming part of them, it was seen that they constituted a distinct stellar phenomenon, a view which was enforced and rendered certain by their quite unique mode of distribution. A few of the larger and irregular type, as in the case of the grand Orion nebula visible to the naked eye, the great spiral nebula in Andromeda, and the wonderful Keyhole nebula round Eta Argûs, are situated in or near the Milky Way; but with these and a few other exceptions the overwhelming majority of the smaller irresolvable nebulæ appear to avoid it, there being a space almost wholly free from nebulæ along its borders, both in the northern and southern hemispheres; while the great majority are spread over the sky, far away from it in the southern hemisphere, and in the north clustering in a very marked degree around the galactic pole. The distribution of nebulæ is thus seen to be the exact opposite to that of the star-clusters, while both are so distinctly related to the position of the Milky Way—the ground-plane of the sidereal system, as Sir John Herschel termed it—that we are compelled to include them all as connected portions of one grand and, to some extent, symmetrical universe, whose remarkable and opposite mode of distribution over the heavens may probably afford a clue to the mode of development of that universe and to the changes that are even now taking place within it. The maps referred to above are of such great importance, and are so essential to a clear comprehension of the nature and constitution of the vast sidereal system which surrounds us, that I have, with the permission of the Royal Astronomical Society, reproduced them here. (See end of volume.)

A careful examination of them will give a clearer idea of the very remarkable facts of distribution of star-clusters and nebulæ than can be afforded by any amount of description or of numerical statements.

The forms of many of the nebulæ are very curious. Some are quite irregular, as the Orion nebula, the Keyhole nebula in the southern hemisphere, and many others. Some show a decidedly spiral form, as those in Andromeda and Canes Venatici; others again are annular or ring-shaped, as those in Lyra and Cygnus, while a considerable number are termed planetary nebulæ, from their exhibiting a faint circular disc like that of a planet. Many have stars or groups of stars evidently forming parts of them, and this is especially the case with those of the largest size. But all these are comparatively few in number and more or less exceptional in type, the great majority being minute cloudy specks only visible with good telescopes, and so faint as to leave much doubt as to their exact shape and nature. Sir John Herschel catalogued 5000 in 1864, and more than 8000 were discovered up to 1890; while the application of the camera has so increased the numbers that it is thought there may really be many hundreds of thousands of them.

The spectroscope shows the larger irregular nebulæ to be gaseous, as are the annular and planetary nebulæ as well as many very brilliant white stars; and all these objects are most frequent in or near the Milky Way. Their spectra show a green line not produced by any terrestrial element. With the great Lick telescope several of the planetary nebulæ have been found to be irregular and sometimes to be formed of compressed or looped rings and other curious forms.

Many of the smaller nebulæ are double or triple, but whether they really form revolving systems is not yet known. The great mass of the small nebulæ that occupy large tracts of the heavens remote from the Galaxy are often termed irresolvable nebulæ, because the highest powers of the largest telescopes show no indication of their being star-clusters, while they are too faint to give any definite indications of structure in the spectroscope. But many of them resemble comets in their forms, and it is thought not impossible that they may be not very dissimilar in constitution.

We have now passed in review the main features presented to us in the heavens outside the solar system, so far as regards the numbers and distribution of the lucid stars (those visible to the naked eye) as well as those brought to view by the telescope; the form and chief characteristics of the Milky Way or Galaxy; and lastly, the numbers and distribution of those interesting objects—star-clusters and nebulæ in their special relations to the Milky Way. This examination has brought clearly before us the unity of the whole visible universe; that everything we can see, or obtain any knowledge of, with all the resources of modern gigantic telescopes, of the photographic plate, and of the even more marvellous spectroscope, forms parts of one vast system which may be shortly and appropriately termed the Stellar universe.

In our next chapter we shall carry the investigation a step further, by sketching in outline what is known of the motions and distances of the stars, and thus obtain some important information bearing upon our special subject of inquiry.

CHAPTER V

DISTANCE OF THE STARS—THE SUN'S MOTION THROUGH SPACE

In early ages, before any approximate idea was reached of the great distances of the stars from us, the simple conception of a crystal sphere to which these luminous points were attached and carried round every day on an axis near which our pole-star is situated, satisfied the demands for an explanation of the phenomena. But when Copernicus set forth the true arrangement of the heavenly bodies, earth and planets alike revolving round the sun at distances of many millions of miles, and when this scheme was enforced by the laws of Kepler and the telescopic discoveries of Galileo, a difficulty arose which astronomers were unable satisfactorily to overcome. If, said they, the earth revolves round the sun at a distance which cannot be less (according to Kepler's measurement of the distance of Mars at opposition) than $13^1/_2$ millions of miles, then how is it that the nearer stars are not seen to shift their apparent places when viewed from opposite sides of this enormous orbit? Copernicus, and after him Kepler and Galileo, stoutly maintained that it was because the stars were at such an enormous distance from us that the earth's orbit was a mere point in comparison. But this seemed wholly incredible, even to the great observer Tycho Brahé, and hence the Copernican theory was not so generally accepted as it otherwise would have been.

Galileo always declared that the measurement would some day be made, and he even suggested the method of effecting it which is now found to be the most trustworthy. But the sun's distance had to be first measured with greater accuracy, and that was only done in the latter part of the eighteenth century by means of transits of Venus; and by later observations with more perfect instruments it is now pretty well fixed at about 92,780,000 miles, the limits of error being such that $92^3/_4$ millions may perhaps be quite as accurate.

With such an enormous base-line as twice this distance, which is available by making observations at intervals of about six months when the earth is at opposite points in its orbit, it seemed certain that some parallax or displacement of the nearer stars could be found, and many astronomers with the best instruments devoted themselves to the work. But the difficulties were enormous, and very few really satisfactory results were obtained till the latter half of the nineteenth century. About forty stars have now been measured with tolerable certainty, though of course with a considerable margin of possible or probable error; and about thirty more, which are found to have a parallax of one-tenth of a second or less, must be considered to leave a very large margin of uncertainty.

The two nearest fixed stars are Alpha Centauri and 61 Cygni. The former is one of the brightest stars in the southern hemisphere, and is about 275,000 times as far from us as the sun. The light from this star will take $4^1/_4$ years to reach us, and this 'light-journey,' as it is termed, is generally used by astronomers as an easily remembered mode of recording the distances of the fixed stars, the distance in miles—in this case about 25 millions of millions—being very cumbrous. The other star, 61 Cygni, is only of about the fifth magnitude, yet it is the second nearest to us, with a light-journey of about $7^1/_4$ years. If we had no other determinations of distance than these two, the facts would be of the highest importance. They teach us, first, that magnitude or brightness of a star is no proof of nearness to us, a fact of which there is much other evidence; and in the second place, they furnish us with a probable minimum distance of independent suns from one another, which, in proportion to their sizes, some being known to be many times larger than our sun, is not more than we might expect. This remoteness may be partly due to those which were once nearer together having coalesced under the influence of gravitation.

As this measurement of the distance of the nearer stars should be clearly understood by every one who wishes to obtain some real comprehension of the scale of this vast universe of which we form a part, the method now adopted and found to be most effectual will be briefly explained.

Everyone who is acquainted with the rudiments of trigonometry or mensuration, knows that an inaccessible distance can be accurately determined if we can measure a base-line from both ends of which the inaccessible object can be seen, and if we have a good instrument with which to measure angles. The accuracy will mainly depend upon our base-line being not excessively short in comparison with the distance to be measured. If it is as much as half or even a quarter as long the measurement may be as accurate as if directly performed over the ground, but if it is only one-hundredth or one-thousandth part as long, a very small error either in the length of the base or in the amount of the angles will produce a large error in the result.

In measuring the distance of the moon, the earth's diameter, or a considerable portion of it, has served as a base-line. Either two observers at great distances from each other, or the same observer after an interval of nine or ten hours, may examine the moon from positions six or seven thousand miles apart, and by accurate measurements of its angular distance from a star, or by the time of its passage over the meridian of the place as observed with a transit instrument, the angular displacement can be found and the distance determined with very great accuracy, although that distance is more than thirty times the length of the base. The distance of the planet Mars when nearest to us has been found in the same way. His distance from us even when at his nearest point during the most favourable oppositions is about 36 million miles, or more than four thousand times the earth's diameter, so that it requires the most delicate observations many times repeated and with the finest instruments to obtain a tolerably approximate result. When this is done, by Kepler's law of the fixed proportion between the distances of planets from the sun and their times of revolution, the proportionate distance of all the other planets and that of the sun can be ascertained. This method, however, is not sufficiently accurate to satisfy astronomers, because upon the sun's distance that of every other member of the solar system depends. Fortunately there are two other methods by which this important measurement has been made with much greater approach to certainty and precision.

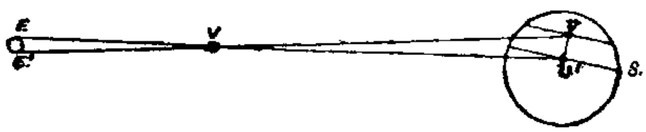


Diagram illustrating the transit of Venus.

The first of these methods is by means of the rare occasions when the planet Venus passes across the sun's disc as seen from the earth. When this takes place, observations of the transit, as it is termed, are made at remote parts of the earth, the distance between which places can of course easily be calculated from their latitudes and longitudes. The diagram here given illustrates the simplest mode of determining the sun's distance by this observation, and the following description from Proctor's *Old and New Astronomy* is so clear that I copy it verbally:—'V represents Venus passing between the Earth E and the Sun S; and we see how an observer at E will see Venus as at v', while an observer at E' will see her as at v. The measurement of the distance v v', as compared with the diameter of the sun's disc, determines the angle v V v' or E V E'; whence the distance E V can be calculated from the known length of the base-line E E'. For instance, it is known (from the known proportions of the Solar System as determined from the times of revolution by Kepler's third law) that E V bears to V v the proportion 28 to 72, or 7 to 18; whence E E' bears to v v' the same proportion. Suppose, now, that the distance between the two stations is known to be 7000 miles, so that v v' is 18,000 miles; and that v v' is found by accurate measurement to be $^1/_{48}$ part of the sun's diameter. Then the sun's diameter, as determined by this observation, is 48 times 18,000 miles, or 864,000 miles; whence from his known apparent size, which is that of a globe $107^{1}/_{3}$ times farther away from us than its own diameter, his distance is found to be 92,736,000 miles.'

Of course, there being two observers, the proportion of the distance v v' to the diameter of the sun's disc cannot be measured directly, but each of them can measure the apparent angular distance of the planet from the sun's upper and lower margins as it passes across the disc, and thus the angular distance between the two lines of transit can be obtained. The distance v v' can also be found by accurately noting the times of the upper and lower passage of Venus, which, as the line of transit is considerably shorter in one than the other, gives by the known properties of the circle the exact proportion of the distance between them to the sun's diameter; and as this is found to be the most accurate method, it is the one generally adopted. For this purpose the stations of the observers are so chosen that the length of the two chords, v and v', may have a considerable difference, thus rendering the measurement more easy.

The other method of determining the sun's distance is by the direct measurement of the velocity of light. This was first done by the French physicist, Fizeau, in 1849, by the use of rapidly revolving mirrors, as described in most works on physics. This method has now been brought to such a decree of perfection that the sun's distance so determined is considered to be equally trustworthy with that derived from the transits of Venus. The reason that the determination of the velocity of light leads to a determination of the sun's distance is, because the time taken by light to pass from the sun to the earth is independently known to be 8 min. 13[1]

Конец ознакомительного фрагмента.