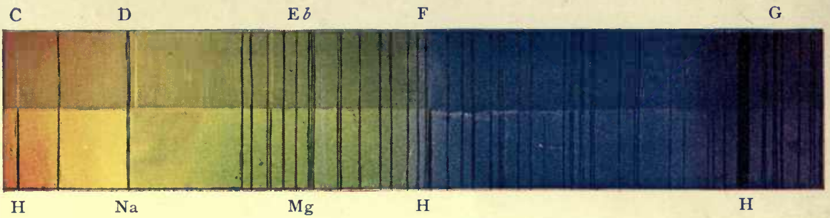
THE HEAVENS AND THEIR STORY

A. & W. MAUNDER

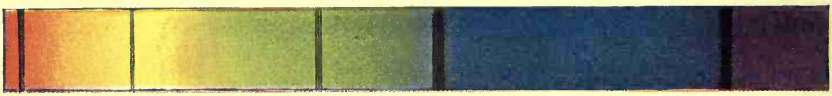
THE HEAVENS AND THEIR STORY

SPECTRUM OF A PROMINENCE.

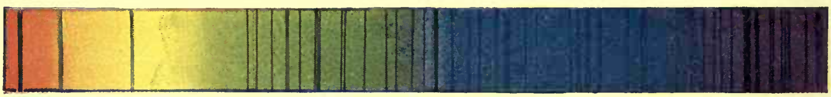


SPECTRUM OF THE SUN.

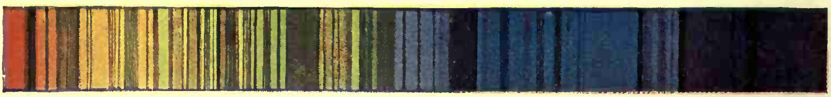
The letters above the spectrum are those by which the principal lines are distinguished. The letters below the spectrum indicate the substances to which the lines are due :—H, Hydrogen ; Na, Sodium ; Mg, Magnesium.



Type I.—Spectrum of Sirius.



Type II.—Spectrum of Arcturus.



Type III.—Spectrum of Antares.

Type IV.—Spectrum of a Red Star.

TYPES OF STELLAR SPECTRA.

THE HEAVENS

AND THEIR STORY

BY

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'THE ROYAL OBSERVATORY, GREENWICH, ITS HISTORY AND WORK'
'ASTRONOMY WITHOUT A TELESCOPE,'
'THE ASTRONOMY OF THE BIBLE'

WITH EIGHT COLOURED PLATES
AND THIRTY-EIGHT ASTRONOMICAL PHOTOGRAPHS
AND FIFTY-ONE OTHER ILLUSTRATIONS

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PREFACE

THE present book, which stands in the joint names of my wife and myself, is almost wholly the work of my wife, as circumstances prevented my taking any further part in it soon after it was commenced.

It is not intended as a text-book to teach astronomy; it has rather been written with the hope that the reader may be drawn by it to study astronomy for himself. The old story tells us that King Alfred was first stirred up to a desire to learn to read by his mother showing him the pictures in a beautifully illuminated book. And so it has been our desire to point our readers to some of the pictures presented to us by the heavens, in the hope that they may desire to spell out their meaning for themselves.

For 'the heavens are telling' stories of interest, stories of wonder, if we but have the eyes to see and the ears to hear. It is not necessary to be a rich man, and to build a great observatory, in order to become an astronomer. There were great astronomers before ever the telescope was invented; there have been astronomers even in our own days, there are some still living, whose work needs no other instrument than their eyes.

In the first book we have dealt with some of the lessons—only with some of them—which the open heavens can teach us, if we watch them with attention and thought. With no telescope, with no apparatus, there is still much that we can learn. It is true that the particular lessons treated of in this book were all learned by our forefathers long ago. But it will be a real benefit to ourselves if we work them out afresh, and to any one who has a soul capable of appreciating the wonder and beauty of Nature in her sublimest aspect, it cannot fail to be the source of real pleasure.

In the second book, a few—only a very few—of the lessons which we have learned concerning the sun, by means of the telescope, the spectroscope, and photography, are touched upon; particularly with regard to the question so often asked nowadays whether sun-spots have any influence on the earth. The third book is devoted to a few particulars respecting the planets and other members of the solar system; the design being to point out wherein they differ from the world whereon we live. The concluding book touches lightly on the structure of the stellar universe, and is intended to suggest, rather than to describe, the vastness and mystery of that great starry system of which our sun and his family occupy a small and insignificant corner. We start, therefore, with a little plot of ground upon this earth of ours, and watching from thence the sun, moon, and stars circling round it, we learn that our earth is a vast globe floating unsupported in space. Next, we study the sun—that other vaster globe that lights and warms us. Then we look round on our companion worlds, also like ourselves dependent on the sun for light and heat, and find that there is not one that is probably the home of intelligent life. So far, we learn of the greatness of the earth and of its importance; last of all we go into the depths of space to learn how small it is, how insignificant.

Our grateful acknowledgements are due to the many friends who have helped us in the matter of the illustrations: to the Astronomer-Royal, Sir W. H. M. Christie, K.C.B., for Plates XI., XVII., XIX., XXV., XXVI., XXXVI., LI., LVI., LVIII., LXI., LXII., and LXIII.; to the Royal Astronomical Society, for permission to use Plate XLIV., the reproduction of four of the late Mr. N. E. Green's drawings of Mars, also Plates XXIV.

and LX.; to M. E. M. Antoniadi, for Plates XLI. and XLIII.; to Miss Gertrude Bacon, for Plate XLII.; to Professor E. E. Barnard, for Plates LXVI. to LXXI. inclusive; to Mr. Franklin Adams, for Plate LIV.; to Lord Hampton and the Hon. Miss Edith Pakington, for Plate XXVII.; to Mr. F. W. Longbottom, for the photograph of the Plough stars in Plate LV.; to Miss L. Martin-Leake, for Plate XXVIII.; to Professor E. C. Pickering, for Plates XII. and XXIX.; to the Rev. T. E. R. Phillips, for Plates XXXVIII., XXXIX., and XL.,; to M. Puiseux, for Plates XLVI., XLVII., XLVIII., and XLIX.; to Professor Ritchey, for Plates L., LIX., and LXXII.; and to Professor Max Wolf, for Plates LVII. and LXIV.

E. WALTER MAUNDER.

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BOOK I

STORIES TOLD BY THE HEAVENLY MOVEMENTS

CHAPTER I

THE STORY TOLD BY THE SUN

'THE sweet singer of Israel' long ago proclaimed that the heavens had a message for us, something to say:

> The heavens declare the glory of God;
> And the firmament showeth His handywork.
> Day unto day uttereth speech,
> Night unto night showeth knowledge.

Yet David was well aware that though the heavens had this testimony to offer, it was not expressed in sounds. He was not dreaming of any fancied 'music of the spheres,' such as Shakespeare makes Lorenzo refer to in *The Merchant of Venice:*

> Look, how the floor of heaven,
> Is thick inlaid with patines of bright gold;
> There's not the smallest orb, which thou behold'st,
> But in his motion like an angel sings,
> Still quiring to the young-eyed cherubins:
> Such harmony is in immortal souls;
> But, whilst this muddy vesture of decay
> Doth grossly close it in, we cannot hear it.

David, on the contrary, knew

> There is no speech nor language;
> Their voice cannot be heard.

And yet, in a very real sense, they were speaking to those who cared to listen:

> Their line is gone out through all the earth,
> And their words to the end of the world.

This message of the glory of God, this testimony to 'His everlasting power and divinity,' is the first, the most important, word which the heavenly bodies have to make known to us. But they have also many other 'words,' much other 'knowledge,' to declare; equally without speech or language, or voice that can be heard, and yet not hard to be understood if we listen for them in the right way.

And men began so to listen from the very beginning; and astronomy, the study of the heavenly bodies, began when there was first a reasoning human being to look upon them. For there are two great lights in the sky which it is impossible to overlook: the sun and the moon. The first discoverer of the sun and of the moon must have been none other than the first man, the first living creature possessing intelligence, the first being 'made in the image of God.'

And he must have made this discovery in the beginning of time. For the first use which man made of his discovery of the sun and moon was to measure time. Until he had noticed the sun, and that he seemed to move, and was sometimes present and sometimes absent, it was not possible to measure the lapse of time at all.

So far as men were concerned, there was no time before that. Astronomy therefore began with the first man, and at the beginning of time; for without the sun and moon there is no means of dating, of reckoning time. Our time is given us by the two great lights. It was for this purpose that they had been originally made, for the command had gone forth :

'Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days, and years.'

But how is the sun 'for signs and for seasons'? It is quite clear how he is 'for days'; for when he is present it is light, it is day; and when he is absent, it is darkness and night.

At first sight it is not easy to see what the sun can tell us more than this, the difference between day and night. The sun himself does not change in appearance. He looks to-day exactly as he did yesterday, and one part of the sky across which he seems to move looks exactly like another. Since no voice is heard in his story, it must be spelled out as from a writing. But how can we spell out a story where all the letters from A to Z are alike in shape; where all the letters, words, and sentences are joined together in a chapter consisting of one unbroken, unswerving line; where one chapter is very like another?

This was the difficulty which the first beginners in astronomy had to encounter when they tried to spell out the story that the sun had to tell. But little by little they were able to do it, and we may, if we will, put ourselves in their place, and watching the sun, as with their eyes, read for ourselves what it was that the sun had to tell them.

The book in which the story told by the sun is written is the open sky, and the writing is simply the apparent place in the sky where we see the sun at this time or at that. The writing, therefore, is not all over the page, the margins are broader than the text, and the chapters are not all exactly alike. The sky, too, seems to rest on the earth at its lower edge, and to rise from it like a dome. The lower edge of the sky, therefore, is marked out by objects on the earth; and though one part of the sky overhead looks, during the daytime, just like another, the earth itself distinguishes one part of the skyline from another.

Our first forefathers, then, when they tried to spell out the story which the sun had to tell them, must have taken their stand in the open, where they could see the sky from horizon to horizon, and their first measuring instrument must have been the apparent circle of the earth. Let us do the same, and see what the sun can tell us under such conditions.

For myself, a dweller in the smoke-laden air of London, shut in by houses, the nearest spot from whence

I can watch the whole open page upon which the story told by the sun is written, is afforded by the 'Hilly Fields,' a pleasant little park close at hand, on the top of a rounded hill, that rises, like a miniature Ararat, above the flood of bricks and mortar which has submerged all the region round. Let us take our stand there, and see what it is that the sun has to tell; what the story that he writes for us on the face of the sky. (*See* PLATE I.)

Towards the east the Hilly Fields look down rather sharply on the valley of the Ravensbourne, the little river that separates Surrey from Kent, flowing due north to enter the Thames at Deptford Creek. The tower of the town hall at Catford—the ford so shallow that a cat would not object to cross it—rises almost due south of us. We can trace the course of the stream by the green spaces of the Recreation Ground, through which it winds, until its course is broken by a tiny fall, just at the foot of the venerable tower of St. Mary's Church, Lewisham, nearly south-east of our position. Further north, the course of the stream is hidden, but the hills on the opposite side of the little valley are clearly seen, and many good landmarks present themselves.

Starting from the north, there is, first of all, almost due north, the spire of St. John's Church, in the Lewisham High Road. Passing round to the east, Trinity Church, Blackheath Hill, is 29° from the north point; the spire of the Roman Catholic Church in Croom's

Hill lies 4° nearer the east. A little north of Trinity Church rise the four tall chimneys of the generating station which the London County Council so thoughtfully erected exactly on the meridian of Greenwich Observatory. From 37° to 40° stretch the roofs of Lansdowne Place. The trees of Greenwich Park hold the horizon line next, and no special landmark can be discerned until we come to the spire of St. John's Church, St. John's Park, at 58°. All Saints' Church, Blackheath, comes next at 66°; and St. James's, Kidbrook, at 70°. The great line of Shooter's Hill forms a background to these spires, and carries the tall chimney of the Brook fever hospital on its western slope at 74°. St. Michael's, Blackheath Park, stands at 77°, and the delicate spire of St. Margaret's, Lee, at 78°; the Wesleyan Church, Albion Road, at 82°; Christ Church, Lee, stands at 86°; Trinity Church, Lee, at 91°. Farther south, the Congregational Church in the Lewisham High Street is at 111°, whilst St. Mary's, Lewisham, is at 130°, and St. Mildred's, Burnt Ash Hill, lies almost midway between the two at 123°; the Catford Town Hall stands at 174°, and the Board School at Rushey Green is precisely due south.

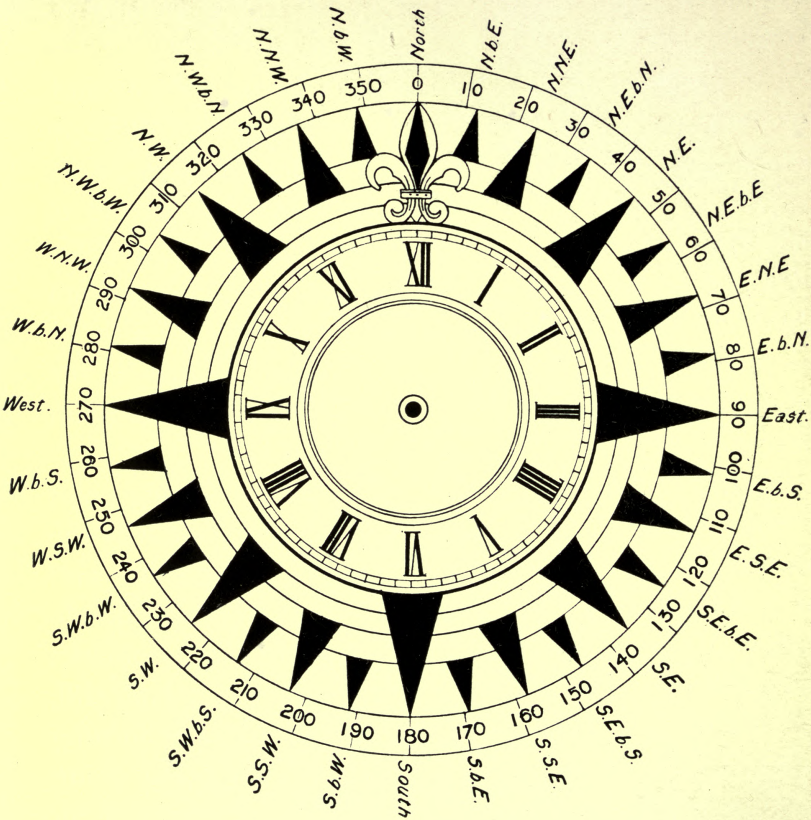
These spires and towers and houses stand up against the eastern sky as marks to which we can refer the sun when he comes up from the underworld at the break of day. Each day, then, is a separate chapter in

(a)

(b)

AN OPEN-AIR OBSERVATORY

The 'Hilly Fields' Park, London, S.E. Looking towards (*a*) the north-east, and (*b*) the south-east.



Relation of the Divisions of the Clock-face, the Compass, and the Circle.

the sun's story, each rising point is the heading and opening of the chapter, and there are 365 chapters in all.

We may begin to read our book where we will, and, for the greater convenience in the reading, we will begin in spring-time. It is March 21, and the sun rises at six o'clock. We see it first appear over the high ground to the east, midway between Trinity Church, Lee, and St. Mark's; in a word, almost due east of us. He does not climb up straight into the sky, but obliquely, with an ascent of 4 in 5, or at an angle of $38\frac{1}{2}°$, equal to the angle between the figure XII on a clock and a point nearly $6\frac{1}{2}$ minutes from it. (*See* PLATE II.)

When the sun rises the next morning, his rising point is not quite the same, but is shifted slightly towards the north. Morning by morning his rising point shifts, and in less than a week the sun rises over Christ Church, Lee. A fortnight later, and St. Margaret's, Lee, marks his point of first appearance, and two mornings later still, St. Michael's, Blackheath. Every succeeding morning shows a slight movement northward of the rising point, until, a month after the first observation, the spire of St. James's, Kidbrook, gives the signal for the sun's first appearance, and we see that the paths followed by the sun, in his daily travel from east to west, are not the same on succeeding days, but lie close to each other, much as cotton is wound upon a reel.

But, as the summer draws on, this northerly movement becomes less marked. The movement amounted to nearly 20° in the first month of observation; it is only a little over 14° in the second month, and after that it becomes very slow. The Colfe Grammar School is reached in the middle of June, when the sun rises 40° north of due east, only 5° short of the north-east point. And now we seem to have come to the end of the reel, and one turn of the cotton is piled on the top of the preceding one, so as to start another layer, for in ten days in June there is less movement than was observed from one morning to the next in March, and in the last ten days of June this movement, small as it is, is not northward, but back again towards the south. But though the sun rises now so far from the point of the horizon where he rose in March, his daily path, as he moves upward in the sky, still slants as it did then, at an incline of 4 in 5, that is, at an angle of 38½° to the horizon. (*See* PLATE III., fig. 1.)

Day by day, during these three months, March 21 to June 21, the sun has risen earlier. It rose at six o'clock on March 21, it rose before five on April 21, and at four o'clock on May 21. After this there was little change in the time of its rising, and it was a quarter to four when it rose on June 21.

Day by day, during these three months, the setting points of the sun have moved northward along the western horizon, to correspond with the movement of the rising points along the eastern, and the sun has set later each day. On March 21 he set soon after six o'clock, and very nearly due west. On April 21 he did not set until after seven, and he went down 19° north of the west point. On May 21 it was nearly eight o'clock before he set, at 33½° north of west. On June 21 he did not go down until eighteen minutes past eight, and his setting point was 40° north of west. Thus the days were longer as the time went by, lengthening out from twelve hours in March to fourteen in April, to almost sixteen in May, and to sixteen and a half hours on June 21.

But, throughout, the inclination to the horizon of the sun's path was the same at rising, the same at setting: an inclination of 4 in 5, or of 38½°.

At midday, when the sun was highest in the sky, and the shadows cast were shortest, he was always due south, straight over the Board School at Rushey Green. And on March 21, when he rose almost due east and set almost due west, he reached just this same elevation of 38½° from the horizon when he was due south; an upright stick four feet long would cast a shadow five feet in length; the sun's elevation was four in five.

But his noon-tide elevation on April 21 was very different. Then it was necessary to look up much higher in order to see him, and the shadow cast by a stick four feet in length, instead of being five feet long, was only three feet four inches. By May 21, the sun's elevation at noon was greater still, and the shadows were shorter: two feet five inches instead of five feet. On June 21 he was higher still, and the four-foot staff would throw a shadow only very little more than two feet long. (*See* PLATE III., fig. 2.)

After June 21 the sun begins to turn back over his old course; a second layer of cotton is being wound over the first. Each morning his rising place is a little farther to the south; each midday his height is a little less, and the shadows are a little longer; each evening his setting place is a little farther south. His path on July 23 is the same as it was on May 21; on August 22 as on April 21; on September 23 as on March 21. He then again rises about due east, attains a height of $38\frac{1}{2}^\circ$ at midday, and sets again about due west after a twelve-hour day.

But as autumn fades into winter he still continues his southerly course. He rises above the Congregational Church in the Lewisham High Street on October 28; the day is only ten hours long, and his setting point is 21° south of west. So, day by day, his rising point moves southward, his daily path is shorter, his midday height less, his setting point closer to the south-west; until, by December 22, he has reached his limit, and

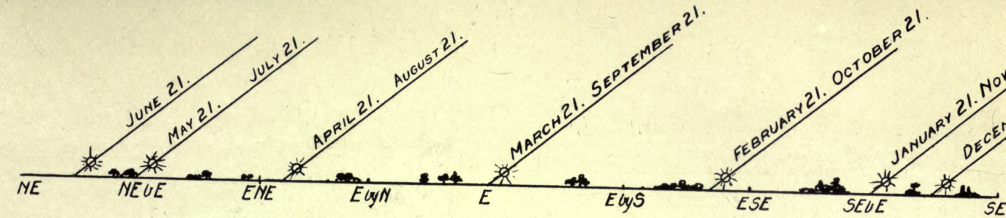


FIG. 1.—The Eastern horizon, showing rising points of the Sun at different times of the year.

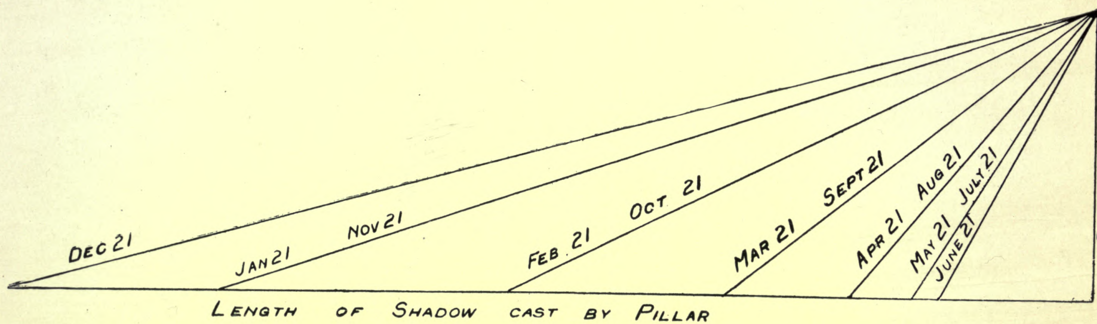
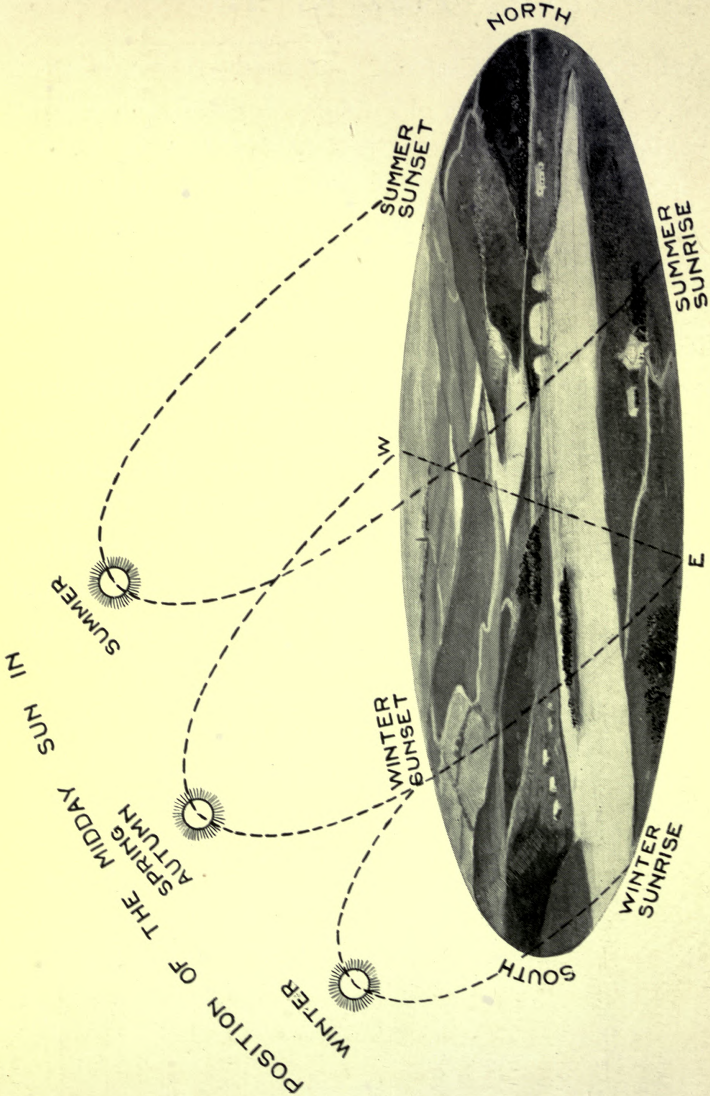


FIG. 2.—Varying lengths of shadow cast at noon at different times of the year.



Apparent daily paths of the Sun at different seasons of the year.

rises over St. Mary's Church, Lewisham, at six minutes past eight; he is only 15° high at noon, a four-foot staff casting a shadow close on fifteen feet in length, and he sets, after a day of seven hours and three-quarters, 40° south of the west point. Then again he turns back, winding his coil northwards, until the book of his year is finished in March, and a new year is begun.

Shakespeare refers to this change in the sun's place of rising when he describes the meeting of the conspirators in the orchard of Brutus, before the dawning of that fatal day whereon great Caesar fell. The time is supposed to be not yet three o'clock in the morning, and the date is the Ides of March, when the sun should not begin to rise until about three hours later; but Decius says:

> Here lies the east: doth not the day break here?

Casca says, 'No,' and Cinna replies:

> O, pardon, sir, it doth; and yon grey lines
> That fret the clouds are messengers of day.

Casca rejoins:

> You shall confess that you are both deceived:
> Here, as I point my sword, the sun arises;
> Which is a great way growing on the south,
> Weighing the youthful season of the year.
> Some two months hence up higher towards the north
> He first presents his fire; and the high east
> Stands, as the Capitol, directly here.

But long before the day of either Shakespeare or Caesar, men were wont, both in this land and in others, to 'weigh the season of the year' by the place of the sun's rising behind the landmarks of the horizon. What we have been doing on the Hilly Fields, and using the church spires of St. Margaret and St. Mary, the chimneys of the London County Council, or the water tower at Catford, in the doing, so men did long ago on Salisbury Plain, though we do not know whether the men were the Britons whom Caesar fought, or another and unknown race. For this they reared up the great circle of stones called Stonehenge. Just as they used the horizon as their measuring instrument, and the great stones as a graduation on it, so we use the horizon, with the spires and chimneys and towers outlined on it, as our measuring instrument. And the sun repeats to us the story that he told long ago to them.

This, then, is the first story which the sun tells to men; namely, that he has his appointed paths in the sky. He does not cross it at haphazard, rising anywhere, setting anywhere; but for each day in the year he has a definite rising point, a definite setting point, a definite path between the two. For each day in the year there are definite points of the compass at which the sun rises and sets, and these points are the same for that day year after year. There is a defined region on the eastern horizon along which the sun's rising shifts in regular order, and beyond which it never strays. In the words of Job, 'the dayspring is made to know its place.' The path of the sun up the sky, or down it, slants each day to the horizon in exactly the same way. The daily paths of the sun through the sky in the year form an unshifting, unchanging band of even width, the same band from year to year; and the width of this band is 47°, or like the arc between two clock-hands pointing nearly eight minutes apart. (*See* PLATE IV.)

If we leave the Hilly Fields and go northward towards the pole, or southwards towards the equator, we find that each 'dayspring' throughout the year has its appointed 'place,' just as it had at the Hilly Fields. The slant of the sun's path has altered, sloping still more as we go north, and becoming more erect as we go south. The sun's band is unaltered; the difference between the heights of the sun at noon in midwinter and midsummer is always the same: 47°, or nearly eight minutes between the hands on our clock. The band of the sun's daily paths is unchanged in breadth; it is merely swerving down or up in the sky.

These daily paths of the sun tell our directions on the earth. For he rises in the east,—on March 21 and September 21 due east. When he has reached his greatest height for the day, no matter what the season of the year, he is due south. He sets in the west,—on March 21 and September 21 due west.

The sun also marks out for us two great circles in the sky, the equator and ecliptic. The first is the central line of the sun's band, which, passing through the east and west points, is to the celestial vault what the terrestrial equator is on the earth. The one is, indeed, a projection of the other, and their poles point in the same direction. The ecliptic is another circle intersecting the celestial equator and so inclined to it that the angle between the two circles is half the width of the sun's band; that is to say, the angle between them is $23\frac{1}{2}^{\circ}$, or the angle that there is between two clock-hands pointing nearly four minutes apart.

And the sun tells us what is the shape of the earth. If the earth were flat, then the sun's path, as he rose in the east, would be inclined to the horizon line at the same angle wherever we were. It would also be inclined at a constant angle to the vertical, the direction given by a plumb-line, which is, of course, at right angles to the horizon line. But we find that as we move northward or southward the inclination of this path varies. As we go north, the sun mounts the sky more gradually; as we go south, the slant of his path becomes steeper.

But as it is the same sun that we see, whether we watch him from Cape Wrath, or from Land's End, or from Gibraltar, and the path that he follows is the same in each case, it must be the plumb-line, and by similar reasoning the horizon also, that changes its inclination. The earth, therefore, is not a level plane, but its surface at one place is inclined at an angle to its surface at another. And this is true of the surface of the water as well as of the land, for the sun's path shows this change of inclination to different parts of the sea just as clearly. The surface both of land and sea is thus gently bent into a great and regular curve, showing the earth to be a globe, just as the vault of heaven above us appears to be a hollow sphere. (*See* PLATE V., figs. 1 and 2.)

The sun also tells us our latitude on the earth. For just so far as the path that the sun traces out in the sky on March 21 or September 21 lies above the horizon, just so high as is the sun at noon on one of these days, just so many degrees of latitude lie between our standpoint and the north pole of the earth. In much the same way the sun tells us the size of the earth. The problem was actually worked out more than two thousand years ago by Eratosthenes, who noticed that the sun was exactly overhead at noonday at midsummer at Syene, now Assuan, where the first cataract of the Nile occurs. At the same time the sun was 7 degrees and one-fifth of a degree from the *zenith*, i.e. the overhead point, at Alexandria, due north of Syene. The distance between the two places in a north and south line had been measured as 5,000 *stadia*. Since $7\frac{1}{5}^\circ$ is the fiftieth part of 360°, the entire circumference of the earth must be 250,000 *stadia*. Our present measures give this circumference as nearly 25,000 miles; whence 10 *stadia* should equal one mile. The sun therefore told men not only the shape of the earth, but also its size.

A question that men very early asked was, 'Where does the sun go to when he sets? whence does he come when he rises?' The answer is soon given: he comes from the 'under world'; he passes below the earth. His path during the twenty-four hours is a complete circle, of which we see only the part that he traverses during the day. In winter time, when he is up for less than eight hours, two-thirds of that circle is below the earth; in summer time, when the day is sixteen hours long, only one-third of that circle is below. 'His going forth is from the end of the heaven, and his *circuit* unto the ends of it.'

The sun therefore tells us that there is a clear way under the earth. Does that clear way extend everywhere, right from the north to the south? That question the sun cannot answer for us. Watching him from the Hilly Fields, it would be possible to imagine that, far to the north, the earth rested on some great pillar, or support, and far to the south upon another. This was the very idea which the Babylonians held of old: they thought the earth stood upon two great

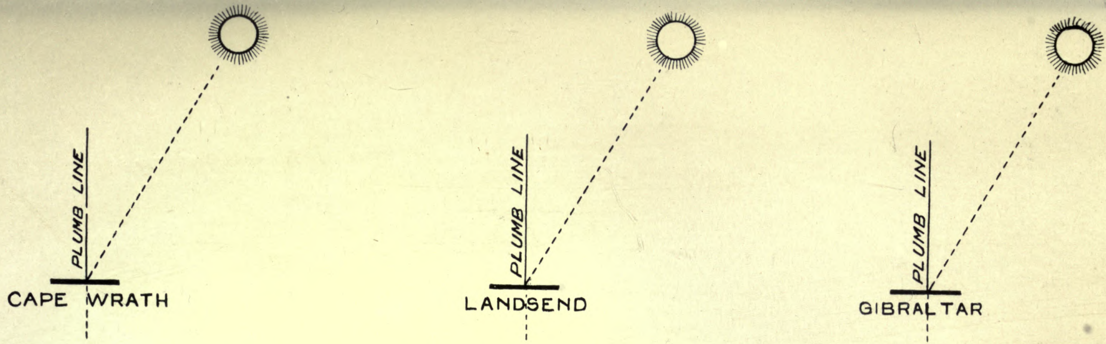


FIG. 1.—The noon-day height of the Sun at midsummer would be everywhere nearly the same, if the Earth were flat.

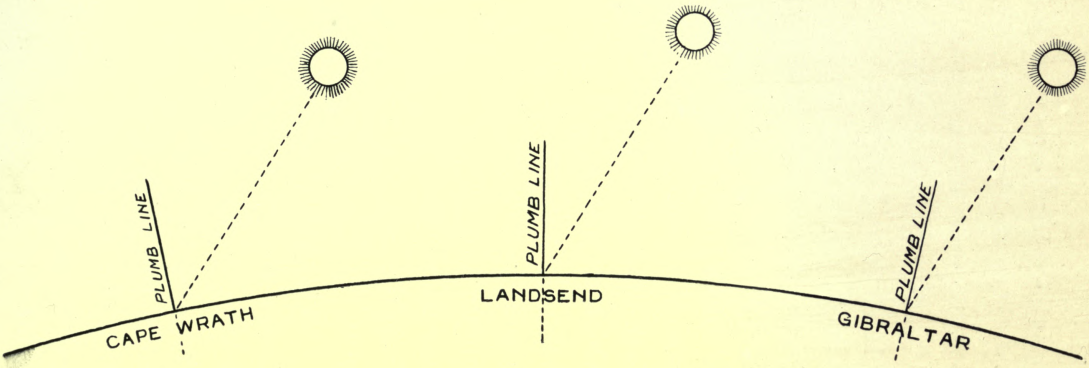
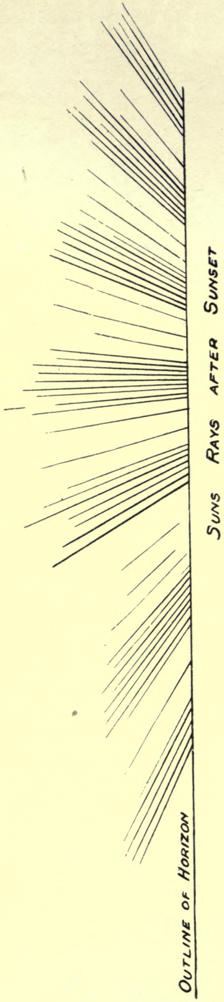
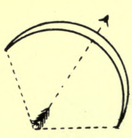


FIG. 2.—The noon-day height of the Sun at midsummer increases as we go South, showing that the Earth is round.





The middle of the bow of the crescent looks towards the Sun.

mountains, and that the sun passed every night through a vast tunnel or valley that lay between them. Two great scorpion men—so they imagined to themselves—stood on either side of this tunnel, or valley, at the gate of the west, and guarded the entrance to the under world, the abode of the dead.

So the sun has a full story to tell, a story told merely by the path which he follows day after day across the unmarked heavens. He tells men that the earth on which they dwell is a round globe, some 25,000 miles in circuit; he tells them that, for the most part at least, the earth is unsupported in space; there is a clear way under it. The sun, too, is not free to wander anywhere in the sky; he has a rigidly appointed path, a path which differs indeed from one day to the next, but is definitely fixed for each day throughout the year. For these changes of path run through a definite cycle which is completed in a year; after which they recur again in their former order. The movements of the sun are all in obedience to an unswerving law. He is set 'for signs and for seasons, and for days and for years.'

CHAPTER II

THE STORY TOLD BY THE MOON

> How like a queen comes forth the lovely moon,
> Walking in beauty to her midnight throne!
>
> CROLY.

WE do not need the help of the telescope to demonstrate to us the difference in appearance between the sun and the moon. They are the 'two great lights' set in the heavens; but whilst the 'greater light' is overpoweringly bright, we can look without flinching at the gentler radiance of the 'lesser.' From the earliest time that there have been men upon the earth, they have recognized two things about the moon. Her face was marked with spots or stains, showing like a map—marks that never changed. But whilst these marks or spots did not change, the moon herself changed. Sometimes she presented a broad, shining face, as round as the sun himself. Sometimes she showed only a narrow arch of light, the thin outline of a semi-circle.

These changes, or 'phases,' of the moon are obvious, and it is impossible to overlook them; they were as manifest to our forefathers before the Flood as to ourselves to-day. They are the letters by which the moon spells out her story to us; and the reading of that story, the intelligent watching of the phases of the moon, is astronomy—a small department of astronomy indeed, but quite a real one. The unintelligent watching of the phases of the moon produces myth and fable—very beautiful myths and fables, it may be, but unreal and unfruitful.

One of the most beautiful of these lunar myths was told by the Babylonians in the song of the Descent of Istar. Istar is described as the daughter of the Moon god, and among the Phoenician nations was called Ashtoreth, sometimes even Ashtoreth Karnaim, or 'Ashtoreth of the Horns.' The legend runs that Istar fixed her mind to go down

> To the House of Eternity,
> To the House men enter—but cannot depart from;
> To the Road men go—but cannot return.
> The abode of darkness and famine,
> Where earth is their food: their nourishment clay,
> Light is not seen: in darkness they dwell,
> Ghosts like birds flutter their wings there,
> On the door and gateposts the dust lies undisturbed.

Bright Istar descended through seven portals, but as she passed through each the porter made her shed, bit by bit, her jewels and her shining raiment, until when she reached the abode of darkness, she was bereft of everything. Then in the full assembly of the gods, the Sun came along with the Moon, his father, and weeping, spoke unto Hea, the king of the under world, and he bade that Istar should be allowed to come forth again. Again she passed back through the seven portals, and as she passed, the porters readorned her, bit by bit, with her jewels and her shining raiment, until at last she stood forth again, 'walking in beauty to her midnight throne,' in all her brightness and glory.

The story is beautiful, but it is the story of fancy, not of knowledge; it is not the story that the moon is writing for us to read. What she really tells us is that her changes of brightness depend absolutely upon the changes in her seeming distance from the sun. He it is who is responsible for her growth in breadth and brightness, from the thin arch of light which she shows at one time, to the full round shield we see a fortnight later; and then to her decrease again from that full circle to the thin curve in the fortnight which follows.

We shall see this plainly if we watch the moon night after night. It may be that some evening, soon after the sun has set, we see the moon as a narrow crescent in the western sky. If we think of the bright arch as a bow stretched for the shooting, then the point of the unseen arrow would be directed towards the place where the sun, now below the horizon, must be. The middle of the arch of the bow looks towards the sun. (*See* PLATE VI.)

The next evening, when the moon is first seen, she is higher above the western horizon than she was on the first evening, and she sets later. At the same time, her arch of light is not quite so narrow. The third evening she sets later still, and her bow is broader. Now she is still above the horizon when the stars begin to appear, and we can see her position with respect to them.

The same change continues to progress on the following evenings: each succeeding night we see that the moon has moved towards the east quite a long way amongst the stars—fully twenty times her own diameter. Each succeeding night we see that she is higher in the sky at the time of sunset, she sets later, and fuller and rounder does her disc become. At length the time comes when she is the entire breadth of the sky away from the sun; she rises as he sets, and does not set until he is about to rise on the following morning. She rides the sky the whole night through, and her circle is complete; she is 'full.' Then is she truly the queen of night. Sometimes the sun and the full moon are seen together, the one resting on the western horizon and the other on the eastern.

After this the moon rises later night after night, and does not set until after the sun has risen on the next morning. She still moves eastward amongst the stars, but she begins to shrink in her seeming size. When seen earlier in the month it was her western edge that was rounded, and the eastern dark; now it is the western edge that begins to shrink, whilst the eastern keeps its full curve.

Most people looking at the full moon think that it looks like a rather sad face. Two large, dark eyes are seen above a large and somewhat distorted mouth, twisted with a rather pained expression, towards the right of the face. Over the left eye, and quite near the side of the face, is seen a small, round, dark spot. This small spot was observed when the moon was only a few days old, but it is not seen long after the moon has become full. As the light passes from the more westerly edge, it withdraws from this spot, which is not seen again until the early days of another month. (*See* PLATE VII.)

During the mornings of the later part of the month the moon rises later and later, appearing to come closer and closer towards the sun, and at the same time the narrower becomes the arch of light which she displays, until she is seen, just before daybreak, a mere thin, semi-circular line of light, slanted towards the eastern horizon, where the sun is about to appear. The next three or four nights no moon is seen at all; morning and evening the sun rides the sky alone. Then comes an evening when once again a narrow crescent is seen in

PLATE VII.

NORTH

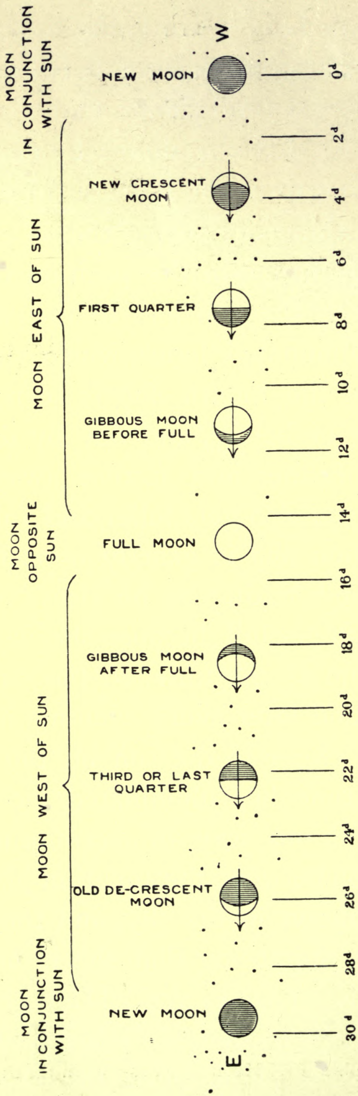
EAST

WEST

SOUTH

Photograph of Full Moon (erect as seen in the sky).

PLATE VIII.



Moon's progress from west to east during a month, and corresponding change of phase.

the sky, with its bow bent towards the western horizon where the sun has just gone down. It is by the association together of these several things that the moon tells us her story—tells us that she shines by no light of her own, but by reflecting to us the light of the sun.

We know these things by seeing that in every month there is a continual change in the position of the moon in the sky relative to the sun and to the stars, and in the shape of the illuminated figure which she shows us. In the first part of the month she is seen in the sky when the sun sets, or before, and day by day she sets later, thus getting farther and farther away from the sun. Day by day she also gets fuller and fuller. Then comes the time when she is exactly opposite the sun, rising as he sets and setting as he rises; and at this time of the month she is full, because she is turning the same face to the sun as she turns to the earth. After this she rises later and later every evening, and appears to come closer and closer to the sun on the other side, and at the same time her illuminated face begins to diminish. There is no way of accounting for this invariable association between the apparent place, relative to the sun, of the moon in the sky, and the change in her light, except by supposing that she is herself dark, and reflects his light. (*See* PLATE VIII.)

The moon also tells us that she is a round globe, not a mere flat disc, like a plate. For the change in her seeming shape is exactly the change which takes place when a dark globe is placed in different positions with respect to a strong light; the curves shown by the moon's defective edge are the curves which would be shown by the illuminated part of such a globe as seen from different directions.

Yet again, the moon tells us that she moves round the earth; not merely as the sun and the stars seem to do—once every day; but she moves *past* the sun and the stars, her seeming motion in the sky day by day being slower than that of either star or sun. And as the moon moves round the earth she always turns the same face towards us; the markings on her surface do not change their shape or, perceptibly, their position; more or less may be visible of them as the moon is more or less fully lighted up, but the markings themselves do not change.

This is a wonderful thing to have learned from the moon: that she is, of herself, a dark body, and not a 'light' at all. If we could imagine that the sun had become cold and dark we should never know of the existence of the moon, unless we guessed it by noting, after very careful watching, that the stars here and there were blotted out for a few minutes at a time. We could not talk with Croly of the lovely moon walking as a queen in beauty to her midnight throne; we should rather think that the starry heavens were haunted by a lurking thief who was continually pocketing the diamonds of the celestial treasure-house, and then dropping them again through the holes of his ragged pouch.

In the legend of the Descent of Istar, seven times did she go through the portals of the east, each time shedding a portion of her glory; seven times was she seen at the portals of the west in ever-increasing splendour. So the Babylonians conceived that the moon ruled as queen of the night, from her midnight throne in the upper world, during the fortnight from half-moon, through full, to half-moon again. Then for seven days, gradually discarding her glory from day to day, she descended towards the abode of darkness, where she remained unseen and lost until summoned forth by the sun. For seven days more, day by day, her glory was gradually restored to her, until, half-full again, she lit up the darkest hours of the night.

For it is the full moon that rules the night: when she fully reflects the light of the sun, she gives that light to the earth from sun setting to sun rising. In the city of the New Jerusalem we are told that 'the city had no need of the sun, neither of the moon, to shine in it.' In our cities to-day we certainly need the light of the sun, but we seem not to need the light of the moon; in the houses and in the streets there are artificial lights enough to make us indifferent as to whether the moon is shining or not, to make us even unaware of its presence. But in the country it is not so: men cannot work on the nights when sun and moon have gone down together; men will stumble when they even walk abroad. A writer, telling recently of his travels in Russia, mentions what seemed to him to be a crowning hardship of the poverty-stricken peasants. For, being too poor to afford even a rushlight on the long, dark, winter, moonless nights, there was nothing possible for them to do but to stay in bed from the early setting of the sun until the late break of day, even though the hours of daylight were too short for all that needed to be done in them.

The full moon is opposite to the sun: she sets as he rises, she rises as he sets; at midnight we may, then,

> Behold the wandering moon
> Riding near her highest noon.
>
> . . . . .
>
> Through the heaven's wide pathless way.

When the moon is full she not only gives most light, but she gives it for the greatest length of time; and in the night time, when there is no sunlight. Moreover, she is up the longest and rides nearest her highest noon in the winter time. For then the sun dips lowest below the horizon at midnight, and the full moon, being opposite to him, climbs to her highest, most nearly to the zenith.

Within the Arctic Circle, during the long night which lasts through the whole winter, though the days are unmarked, the months are divided into two fortnights—the one when it is always light, and the other when it is always dark. In the one :—

> Mark, what radiant state she spreads,
> In circle round her shining throne,
> Shooting her beams like silver threads ;
> This, this is she alone,
> Sitting like a goddess bright,
> In the centre of her light.

She is then Istar, queen of Heaven, reigning in the upper world, continuously clad in her shining robes of state. In the other, she is Istar of the Descent, shorn of her beams, abiding in darkness, and leaving the world in darkness.

Speaking precisely, the moon is 'new' when she is in conjunction, that is, when she is between the sun and the earth, and—turning her dark side towards us—is invisible. But, generally, the young moon that is first visible after conjunction with the sun is termed the 'new moon,' and such will be the meaning that we will ascribe to it.

The 'new moon' is, then, a very slender crescent of light, so slender that it cannot be seen in sunlight. It lies to the east of the sun, and, therefore, is seen over the western horizon, a little above the point where the sun has very lately gone down. If the conjunction of sun and moon occurred eighteen hours before sunset, it might be possible to perceive for a few minutes before it sets the thin crescent of the moon, in the twilight of the same evening; but if the time between conjunction and sunset were less than eighteen hours, then the moon's bow could not be seen until the following evening. Thus the interval of time between one new moon and another is uncertain by a day.

Many of the ancient nations—the Jews, Babylonians, and Assyrians—used true lunar months; not months of arbitrary lengths, as we do to-day. To these ancient nations the month began in the evening: it began with the observation of the first thin crescent of the young moon. The month contained a number of complete days; but this number was sometimes twenty-nine days and sometimes thirty, and they could not tell for long beforehand which months would have the one number of days, and which the other.

Our rule for telling the number of days in our months runs thus—

> Thirty days hath September,
> April, June, and November,
> All the rest have thirty-one,
> February has twenty-eight alone;
> But Leap Year coming once in four—
> February's days are one day more.

No such simple and general rule was possible for the Babylonian months, but yet these had several advantages of their own. There was then no need, with

Bottom, in *A Midsummer Night's Dream*, to cry out—

> A calendar, a calendar! look in the almanac,
> Find out moonshine, find out moonshine!

For the calendar was based on moonshine, and the day was dated according to the amount of moonshine, and by the time when the moon rose or set. When the moon was growing, and set before the middle of the night, those were the early days of the month. When the moon was full, and set as the sun rose, or rose as the sun set, that was the fourteenth or fifteenth day of the month, and then only could an eclipse of the moon take place. When the waning moon rode in the morning hours of the night, this was a sign that the month was drawing to a close, and when it had wholly vanished, on the twenty-eighth or twenty-ninth days of the month, then only could an eclipse of the sun occur. Moreover, from observing on the fourteenth or fifteenth days of the month whether the moon set or not before the sun rose, it could be judged whether or no that month would contain thirty days. We have a report to this effect from Balasî, an ancient Assyrian astronomer, which runs: 'When the moon is not seen with the sun on the fourteenth day of Adar, the day will complete Nisan.' And this is interpreted to mean that that month of Adar would contain thirty days.

If we frequently measure the time from one observation of the new moon until the next, we find that the number of days is either twenty-nine or thirty, so we cannot from this find out the true length of the month, or learn whether the months are all equally long, since there is an uncertainty of a full day in the observation itself. But if we try to measure the time of the other phases; if, for instance, we take the time from the waxing moon being exactly half full, until the waning moon is exactly half full again, we shall find that this 'fortnight' is not the same length in every month. In other words, the moon moves more quickly round the earth at some points of her path than at others, and she passes through her phases at a varying pace; and being at some times nearer to the earth than at others, she sometimes looks larger.

We do not know if the romantic writers of old Assyria treated the moon, upon whom all true lovers call, as erratically as do some novelists of the present day. Probably not, for they could not have failed to know that the young crescent moon is never seen to rise, or the thin arch of the old moon to set, and neither are ever seen high in the sky. If, in the morning dawn, before daybreak, we glimpse in the east a pale arc of light, we are sure that it is not the *crescent*, the young moon, but the *decrescent*, the old moon, soon to be lost in the rays of the pursuing sun. And since the moon is always the same solid globe, whether it is wholly lighted up, or only just touched with a thread of sunlight, it is impossible that we should ever see a star *through* its bulk, as the Ancient Mariner declared he had done, when he described

> The hornèd moon, with one bright star
> Within the nether tip.

The story told by the moon, therefore, is that the heavens contain dark bodies, as well as bright, and that she is one of the former, shining not by her own light, but by the light shed upon her by the sun. So, lighted by him, she travels through space unceasingly, a great round ball, unsupported by any pillars; travels round the earth, but always turns the same face towards it, though she does not turn the same face always to the sun.

CHAPTER III

THE STORY TOLD BY THE STARS

THE day sky is the page on which the sun writes his story. His writing does not cover all the page, but is kept within an even band of closely inscribed text. The margins of his page are very broad and fair and clean.

But if we turn to the night sky, we find that this page is written over also, but the handwritings here are by other writers than the sun, and the page has no margins. We have learnt to understand a little the language of the sun's book; with this knowledge we can also begin

> To read the page
> Where every letter is a glittering world.

The sun has just gone down behind the western bar, but his light is left behind. North, east, south, and overhead the sky is a deep blue, but in the west there is a rosy glow. Nothing else is to be seen. The blue deepens and the rosy glow fades; and, first here, then there, perhaps in the darkest east, or the clear zenith, or even in the light from the sun long set, there seems to be set a pin-point spark of light, fighting for its light to shine out even in the overpowering light left by the sun. And, as the straggling sunbeams are summoned below the western steep, hundreds of other stars spring out, as if from ambush, to harass and hustle away the rearguard of a retreating force.

Where do the stars of twilight spring from? Have they been there in ambush all the time, whilst the sun was marching across the day sky? or are they merely his camp-followers, keeping to his rear, but straggling over the whole region in the midst of which his road lies? We are under no doubt as to whether or not the sun is present. He ascends in pomp above the eastern bar; he marches in solitary state across the sky; none but the moon is ever seen to make any approach to him. But what about the stars? Can we tell if they are there, in hiding, in the sunlight? Can we tell if these are forming an invisible escort to the sun? If they, too, like the sun, write a history of their daily travel, how can we tell the different histories, and the different stars, from each other?

As the daylight fades, the stars are seen not near the low east only, but overhead, or in the north, or south, or even in the west. They have not, then, rushed up from the under world as the sun goes down, but they are there already. They have been there, but hidden in the sunlight. As we watch them, and the daylight fades, we see that they are moving; whether they are overhead or in the east, or south, or west, they are all moving towards the western skyline. Above the eastern skyline we see new stars climb; below the western horizon we see the stars, that we have been watching, descend. Not so in the north. Here all the stars indeed move; but some are moving west, some north, some south, and some east.

We began to read the story of the sun by watching his rising in the east. Let us begin to read the stories of the stars in the same way. And the first thing that we note is a difference between the two. The day-dawn is the messenger of the sun: he sends his beams to herald his approach. So great is his pomp and splendour that, silent as it is, there seems appropriateness in the expression of one writer that—

> The dawn comes up like thunder.

But with the stars there is none of this. Just above the eastern skyline, one moment there is no star; the next, there is a star. It was not, and it is. And as we watch the east, from the extremest south, even to the farthest north, we see them thus rising at its every point, a single scout there, a company here, all coming from below and mounting into the sky.

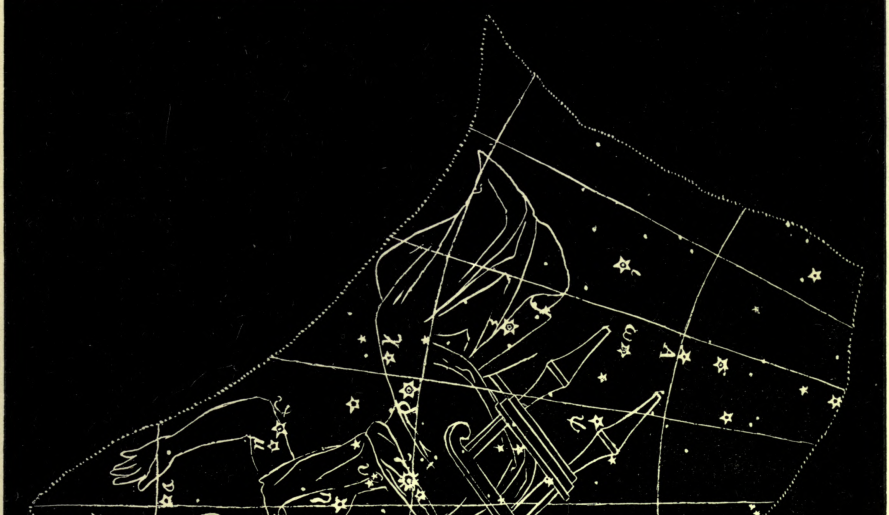
If we keep our watch on the east through all the long hours of the night, we see the silent ascent of the stars go on, until the horizon begins to pale, and the glitter of the stars seems swallowed up in the brightness of the dawn. One or two of the most brilliant we can hold steadily until they, too, are lost in the rays of the rising sun.

Are they all different, these stars that we have been watching rise through the long night? Have many of them, have any of them, risen for us a second time as we watched? How are we to tell one star from another? How are we to recognize a star when we see it? The sun needs no label, but how are we to name the stars? We can see no difference between one star and another, except in brightness. Can we tell whether the stars, like the moon, wax and wane?

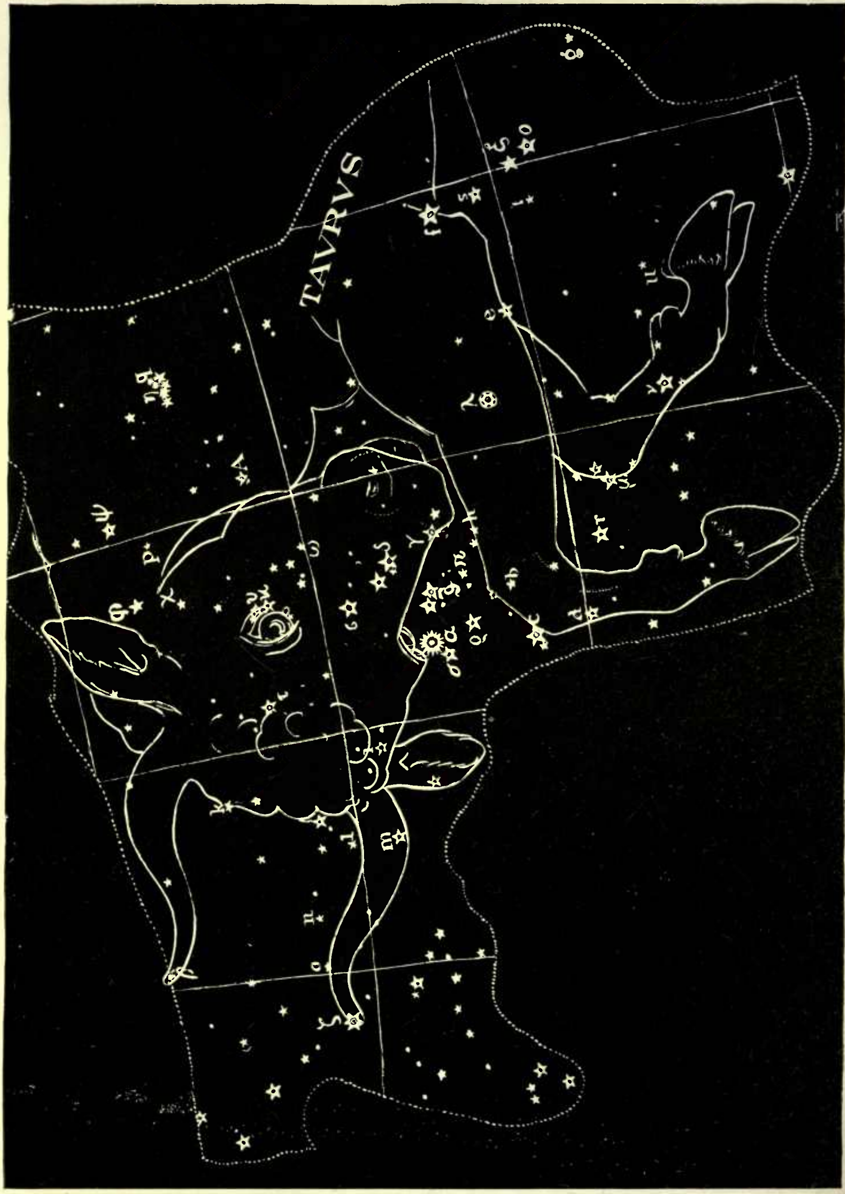
Then follow one up from the east. Like the sun, it climbs the ascent of heaven obliquely; its path is slanted to the horizon at the same angle of $38\frac{1}{2}°$, at the same inclination of 4 in 5, if we are watching from the Hilly Fields, or anywhere in the latitude of London. It mounts the sky until it hangs due south, then it descends and drops slantingly below the western horizon at the same angle that it mounted. If we follow the course of another star, it rises, perhaps, from a very different point of the eastern skyline, but it slants upwards at the same angle as did the sun or the other star; it reaches the highest point of its path when due south, and it sinks down below the west by the same inclined path. The stars may be of very different brightness, they may rise and set at different points of the skyline, they may mount to different heights; but they all mount and fall at the same steady, even pace, by the same slant of path.

Here, then, are the means by which we may distinguish the stars. They do not jostle or hurry each other, they keep an even pace, at unchanging distance from each other. In the north are many stars that do not rise or set, but move round in an unending circle; yet the stars that rise and set never alter their distances from these, whilst we see them above the skyline.

The stars never alter their distances from each other, and the stars differ in brightness. We can, then, fancy patterns or pictures nailed by the stars to the sky, and recognize the pattern again by the way the nails are driven in. Look, for instance, at the stars in the north. There are seven very brilliant stars swinging round in the sky every night; four of them are in a rough oblong like a country cart, three others curve like the shaft of the cart. These never change in brightness; we can recognize the seven again and again, and call them by the name of the Plough, or the Wain, or the Ladle, or the Dipper, as the fancy takes us. (*See* Plate LV.)



The Constellation of Cassiopeia, the Lady in the Chair.



The Constellation of Taurus—the Bull.

In the same circle swings another set of five stars, not so bright, in the shape of a sprawling W. This we may fancy marks the Chair of a Lady enthroned in it. (*See* Plate IX.) Farther to the south, amongst the stars that rise and set, we see a very little V-shaped group, of which none of the stars, except a yellow one at the end of one of the prongs, is very bright; following it is another little cluster of six stars, so close together that, as Tennyson sings of them, they seem

> Like a swarm of fireflies tangled in a silver braid.

We may imagine that we have a bull's head, outlined by the V-shaped group, and that its brightest star is the eye of the bull. The little cluster of brilliants we may fancy as a cluster of doves, or of maidens, or of grapes, sheltering on the shoulder of the bull. A bull's head is not really pictured here, any more than a man whose name is Smith is therefore an artificer in metals, but that is the name that has been given to the constellation, or grouping, of the stars. The reason why this name was given has a history of its own. (*See* Plate X.)

So the stars scattered over the sky are constellated or divided out into groups; and names, fanciful names they seem, are given to the different groups. The individual stars are recognized by their positions in or near the groups.

As the stars rise in the east we can recognize them by their places in the star groupings, and we can definitely tell that they do not rise oftener than once in the twenty-four hours. Night after night, as we watch them, we see that though, like the sun, they always rise with the same slant to the skyline, yet, unlike the sun, they do not shift their points of rising. At whatever point of the compass a star rises on one night, on every other night, and through the whole year round, it rises at that same. It makes the same slant in its path as does the sun, and makes its round in nearly the same time. Nearly, but not quite; for, as we watch the stars, dawn by dawn, that are last seen in the morning twilight near the sun, we notice at each break of day they are seen for a longer time, until they lose their pre-eminence, and other stars, nearer the rising sun, are seen. And evening by evening, the stars near the west, where the sun has set, are ever becoming less clearly seen, ever drawing into the sunlight, until they are glimpsed no longer. As the seasons pass, new stars occupy these positions, until as the year comes round we recognize again the stars we first saw. Each season, each time of the year, is marked by the setting and rising together of the sun and certain stars. For the stars gain on the sun, just as the sun gained on the moon; as the moon made one round of the sky in each month fewer than the sun did, so the sun makes one round of the sky in each year fewer than the stars do. The sun moves amongst the stars.

The stars last seen in morning twilight, those rising just before sunrise, are said to be rising *heliacally*. The stars just seen in the evening twilight, setting where the sun has set, are said to be setting *heliacally*. The stars that rise as the sun sets, and set as he rises, are said to rise and set *acronychally*.

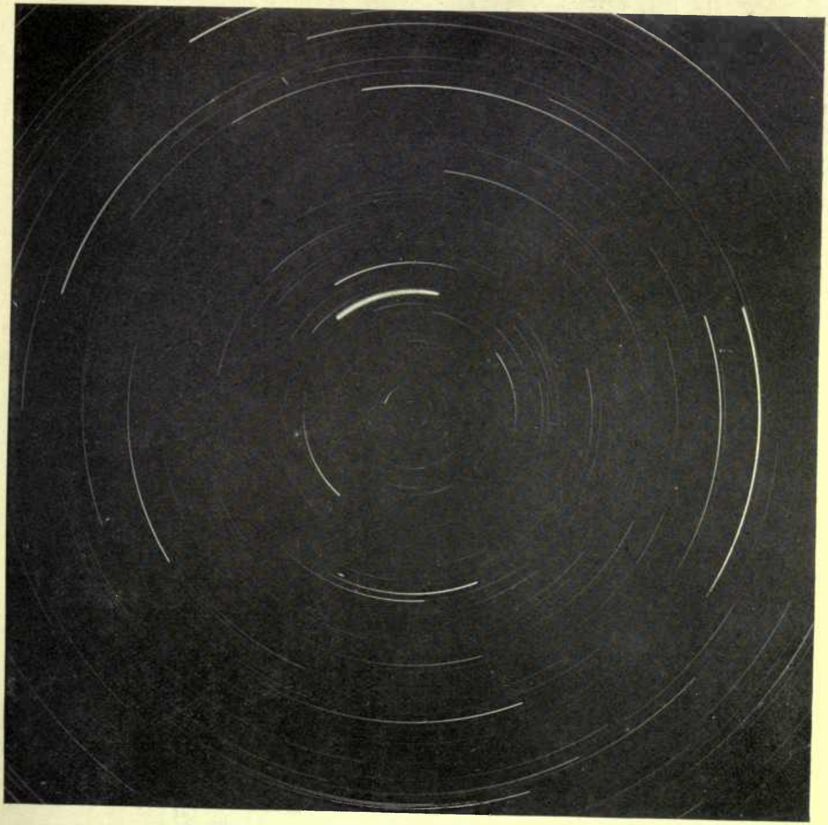
By means of the stars that rise and set heliacally, we can trace those amongst which the sun's path seems to be laid, and the belt of constellations through which his path, which is called the *ecliptic*, seems to lie is known as the *Zodiac*. These constellations are twelve in number, and form a complete band round the sky. Their names are preserved in the old rhyme—

> The Ram, the Bull, the Heavenly Twins,
> And next the Crab, the Lion, shines,
>   The Virgin and the Scales;
> The Scorpion, Archer, and Sea-goat,
> The Man that pours the water out,
>   And Fish with glittering tails.

If we watch a star rising at the point on the horizon which is due east, and take its height when it souths, we find, at the Hilly Fields, that it is $38\frac{1}{2}°$, the same height as the sun had at noon when he moved in the equator on March 21 or September 21. This star, then, marks out the equator in the night sky, as the sun marked it in the day sky. We have thus the two great circles of the ecliptic and the equator marked out both for daylight and for night; and, as we have seen, they are inclined to each other at an angle such as is made by the hands of a clock pointing four minutes apart.

If we draw a line from the south point through the sky to the north point, through the zenith, it will pass near a bright star, to which the front stars of the Plough, swinging round the northern sky, also point. This bright star wheels in a smaller circle than any other in the sky, and is nearly 90° from the equator, i.e. is close to its pole, just as the north pole of the earth is 90° of latitude from the earth's equator. It is near to this star that the axis of the earth is pointing, and if we measure its average height above the north point of the horizon at the Hilly Fields, we find that it is $51\frac{1}{2}°$, the 'complement' of the angle of $38\frac{1}{2}°$ given by the slant of the paths of the sun and the stars; that is, the angle required to make it up to 90°. Round this star, known as 'the Pole Star,' all the others seem to circle.

If we tilt a photographic camera so as to point to this region of the sky, and keeping it rigidly fixed, expose the plate to the starlight, we shall find on development that the stars have traced out parts of circles, more or less nearly complete, according to the length of time that the plate has been exposed. The diameters of these circles depend on the distances from the pole of the stars that drew them; the distinctness



Photograph of Trails of Stars near the North Pole, taken at the Royal Observatory, Greenwich.

Photograph of the Constellation of the Southern Cross. From the Annals of the Harvard College Observatory, Vol. xxvi. Part 2.

and breadth of the curving lines so drawn depend on the brightness of the stars. (*See* PLATE XI.)

If we leave the Hilly Fields and go northward, the Pole Star rises higher in the sky, and more and more stars wheel clear of the horizon, and are never lost to view. If we go southward, the Pole Star sinks lower, and fewer stars never set. But if we now look at the stars in the extreme south, we see that some have risen there that we never saw when standing on the Hilly Fields. Stars, then, there are, that never rise; there are constellations which on the Hilly Fields we can never see.

One of the most famous of the constellations that we, in England, never see, is the star group of the Southern Cross. (*See* PLATE XII.) It is not until we get near the tropics,—go down the Red Sea, or travel up the Nile—that it climbs over the southern horizon. And then it is only seen at seasons of the year when the sun is in the region of the zodiac that is remote from it.

Therefore, it would be impossible for Colonel Trench to say—as Mr. Mason represents him saying in *The Four Feathers*, on the night of his release from the Stone House in Omdurman—that for three years he had watched it every night.

If we go northward we find that the stars—and the sun likewise—rise in paths less inclined to the horizon, at a smaller slant. If we go southward we find they rise at a greater slant. And, as with the sun, this tells us that the earth is a round globe. If it were a level flat plain, the inclination of the axis of the sky to that plain would be everywhere the same, and so also would be the inclination of the apparent paths of the stars, for the whole of the starry heavens move as in one piece. So, like the sun, the stars enable us to measure the earth. If we measure the height of the Pole Star,—or rather of the Pole itself, which is the centre of the little circle round which that star appears to revolve,—and then travel southward until the Pole has sunken one degree lower, we shall find that we have travelled nearly seventy miles, or more nearly, sixty-nine miles, and that therefore the entire 360°, the whole circumference of the earth, must be about twenty-five thousand miles.

He that is dizzy thinks the world goes round.

Do all these myriad stars move round the earth, or does the earth turn round upon herself? The appearances, so far as we have described them, would be the same whichever happened, but surely it is simpler to suppose that it is the earth that turns.

The daily course of the sun told us that there is a clear way under the earth, but we could not learn from it—at least, not in England—that the earth was everywhere unsupported, that everywhere the way is clear. This the stars can tell. At every point of the western horizon, at all times, stars go down, and pass round through the under world to the eastern horizon, from every point of which they arise. At no point, even in the farthest north or most extreme south, is there a blank space in the sky where no stars wheel; nowhere in the under world can there be a support through which a star cannot pass. The Babylonians held that the earth is supported on two great mountains. The Hebrews had better read the story of the stars, for they wrote: 'He' (God) 'stretcheth out the north' (i.e. the northern circumpolar constellations) 'over empty space, and hangeth the earth upon nothing.'

CHAPTER IV

THE STORY TOLD BY THE PLANETS

Like as a star,
Without haste, without rest.

THIS is the characteristic of a star. It keeps its own appointed path unswervingly, moving at an unchanging pace. Its path is a circle, complete for those stars that wheel in the north, broken by the sky-line for the others. But no star retraces backwards its way, no star overtakes or lags behind its neighbour; there are no stragglers in the ranks of this great army.

Are we sure of this? The stars are very many; we cannot keep a continual watch on each one to see if ever it should err and stray aside. For the stars in the north, that wheel round the pole unceasingly, we can look upon them night after night, the whole year through; we can be certain that the Seven Stars keep the form of the Plough; that the W which forms the Lady's Chair never ceases to sprawl. But the more southern stars, those that for some part of every year are swallowed up in sunlight, can we be very sure that these always keep the same pattern; especially when we see but a little of the pattern?

During the short nights of May and June, a bright constellation is seen very low down in the southern sky. Its principal features are a curved line of bright stars, upright to our horizon, followed by a longer curve of yet brighter stars that lie along the horizon. In particular, three bright stars are seen close together, of which the middle is much the brightest, and is of an orange-red colour. There are very few stars in the sky that are of so pronounced a colour to the naked eye as this one is.

The ancients considered these stars as forming a giant scorpion, with his tail curled up to sting the foot of a man who was trampling upon him, and the bright reddish star is known as the Scorpion's Heart.

The star of the Scorpion's Heart rises year after year about three o'clock in the morning in the middle of February. But if we had been looking at Scorpio about the middle of February, 1907, we should have seen the pattern of the constellation quite altered. For north of the Scorpion's Heart was another star, very like it in brightness and in colour. And as the constellation reached the meridian, a little before the dawn blotted out the stars, these two stood out, the one above the other, like a couple of danger signals.

This star above the Scorpion's Heart had certainly not been always there. If we had looked out a little before daybreak on the first morning of the year, and watched the Scorpion's Heart rise in the south-east, we should not have seen its red companion near it then. But if we had looked farther to the south, we should have seen a reddish star, not nearly so bright as the Scorpion's Heart, already fairly high up in the sky, in a constellation known as 'the Virgin,' just about the place where her left foot is supposed to be resting upon one of the Scales, which the constellation between the Virgin and the Scorpion is considered to represent, and not far from its brightest star.

If, morning by morning, we had watched the Scorpion through the last fortnight in February, we could not help noticing that the new red star was moving relatively to the stars of the Scorpion. On February 14 it rose before the Scorpion's Heart; by the end of the month the two stars rose together; by the end of March, Antares, as the Scorpion's Heart is called, rose at midnight, but the stranger star not until an hour and twenty minutes later. It had now passed clear out of the Scorpion and was in the constellation of the Archer; it was passing amongst the stars in the same direction as the moon does; and it moved in the course of a single night over a space equal to the apparent diameter of the full moon. All through April, all through May, this movement of the stranger went on. By the end of

April, it had reached the middle of the constellation of the Archer, and was close to his brightest star, the one that marks his right shoulder.

And now the stranger star was one that it was not possible to overlook. Rising about midnight, and passing the meridian a little before dawn, it shone brightly low down in the southern sky; brightly, for it was now quite four or five times as bright as when it was close to Antares. No other star in all that region of the sky could rival it in brightness; none could compare with it in vividness of colour.

And so the red star went its way, across the constellation of the Archer; but as the month of May drew to a close, it became clear that it was moving much more slowly. It then took four or five days to move a distance equal to the moon's diameter, a distance for which a single day had been equal before. Night after night its rate of motion declined, until, early in June, it seemed to change the direction of its course, and instead of moving eastward among the stars, it began to turn southward; and before June had come to its close, it was hurrying westward, as if to overtake the stars that it had recently passed. By July 15 it had got back as far as the bright star in the shoulder of the Archer, a star which it had first passed on the north side on April 28; now it passed it well to the south, travelling almost with its original pace. Its speed toward the west soon slackened, and, as August began, the red star for several days remained almost motionless in the sky. But what a splendid object it was throughout July!—rising before sunset, on the meridian at midnight, setting at sunrise; visible, therefore, all the short night through, it shone with a lustre ten times as great as when it was noticed in February. No star in the whole sky, not even Sirius, the brightest of them all, could compare with it. It caught the notice of many, even of the dull, unobservant dwellers in cities, who asked with a tepid curiosity what that big red star might be. It was noticed, it could not fail to be noticed, by peasants and desert wanderers and savages the world over; and, no doubt, to many of them it seemed to shine with a baleful ill-omened light, and to threaten some undefined evil.

It is possible that there were some who formed a vague idea from the rapid motion of the star, and its increase in brightness, that it was some fiery enemy approaching the earth and destined to overwhelm it. If so, its movements during August and September would have reassured the timid watcher, though they added an element of fresh mystery. For, at the end of the first week in August, the red star came to a dead stop, and then, after a few evenings, recommenced again its progress towards the east. On September 2, it passed the star in the Archer's shoulder for the third time, still to the south of it, but much nearer than it had been before. As September went on, the pace of the red star quickened, until by the end of the month the original pace of about a moon's diameter in twenty-four hours had been fully regained; and early in October it had passed from the constellation of the Archer, in which it had followed so erratic a course, into that of the Seagoat. And thenceforward throughout the year, there was no break in the steadiness of its eastward progress. Evening by evening it set earlier, until by the end of the year it had gone down an hour before midnight. But during all this time its brightness had been fading, at first slowly, later more quickly, until as the old year expired, it was no brighter than it had been when it stood just above the Scorpion's Heart. It had come far enough since then, having passed through the whole of the constellations of the Scorpion, the Archer, the Seagoat, and the Waterpourer, or very nearly a third of the entire sky. (*See* PLATE XIII., fig. 1.)

Here was a star that obeyed a law quite different from that of the general starry host.

Is this the only one, or are there others? There are certainly others. For if we had been watching attentively the part of the heavens which the red star had reached in its wanderings as the year 1907 came to a close, we should have seen that there was another stranger star here. This is rather a dull region of the heavens: the neighbourhood of the more westerly of the two Fishes, where the constellations of the Fishes, the Waterpourer, and the Sea-monster meet. This region comes into view at about five o'clock in the morning at the end of March. It is up all night in September, and it is lost again in the sunset about the beginning of March. When the stars of the Western Fish begin to draw away from the sun, in the early mornings of April, 1907, a star much brighter than any of those which make up this constellation was seen in a void region of the sky somewhat to the south of them. Through April and through May it followed a steady course eastward, taking five or six days to travel over a space equal to the diameter of the full moon. Towards the middle of July, however, it came to a full stop, and then through August, September, and October, drifted westward until very nearly the end of November, when again it stopped in order to resume, in December, its eastward drift. The entire range of its wanderings, during these eight months, was only over a small part of a constellation, perhaps one-fiftieth part of the circle of the sky; but the movement amongst the stars, though much slighter than that of the red stranger, was quite evident. It moved more slowly, and it changed little in brightness. There was a dull leaden quality about its light, though it shone steadily; it was much brighter than all the stars near to it, but neither sparkled nor twinkled.

The midnight sky is in its greatest glory in winter. If we look out at eleven o'clock in the evening on the first of January, we see, due south before us, the beautiful constellation of Orion, the brightest in the sky. Lower down to the south-east, the great Dog, with flashing Sirius as its chief jewel, is shining; above Orion and Sirius, the rich stream of the Milky Way flows down from north-west to south-east; on the further border is the bright constellation of the Twins, Castor and Pollux; whilst Procyon, the lesser Dog, attends at their feet. Nearly overhead is Capella, one of the three brightest stars of the northern hemisphere, and the chief brilliant of the constellation, Auriga, Holder of the Reins; a little further west along the Milky Way is the long stream of stars that mark out Perseus; and below the feet of both, bending his head to repel the attack of Orion, is the Bull, with the bright star of Aldebaran shining as his eye. Nowhere else in our northern latitudes do we see such a glorious collection of stars.

But on the first day of 1907, this glorious collection of stars was rendered yet more brilliant by the presence in its midst of a star that far outshone them all. It shone with a serene and steady silver light, very unlike the quick twinkling of the chief stars around it. It lay nearly midway between the five bright stars, Capella, Aldebaran, Betelgeuse, Procyon, and Pollux; and was thus just within the constellation of the Twins, near the feet of Castor, the northern Twin. It was an object not possible to overlook. (*See* PLATE XIII., fig. 2.)

This serene star was no more stationary in the sky than the red one. It was moving throughout the whole of January, westward amongst the stars, but it never quite succeeded in escaping from the constellation of the Twins. It reached the border line between the Twins and the Bull about the end of February, and then it turned back and pursued an eastward course through March, April, and May, crossing the space equal to the moon's diameter in about three days. It was lost in the sunlight early in June, at which time it was drawing near to the Twin stars, Castor and Pollux. It was seen again at the beginning of August, early in the morning, when the Twin stars emerged again from neighbourhood to the sun. Then, for the rest of the year, it moved steadily eastward till the beginning of December, when it stood still for a second time, and then again retraced its steps. The whole of the last month of 1907, and the first three months of 1908, it was travelling westward, and it came to a stop for a third time at the end of March, 1908, in the middle of the constellation of the Crab, just as it had come to a stop the first time at the end of February, 1907, near the feet of the Twins. It had thus measured off in a year the whole of a constellation; and for a third of a year it had been travelling backwards amongst the stars over a third of a constellation, a

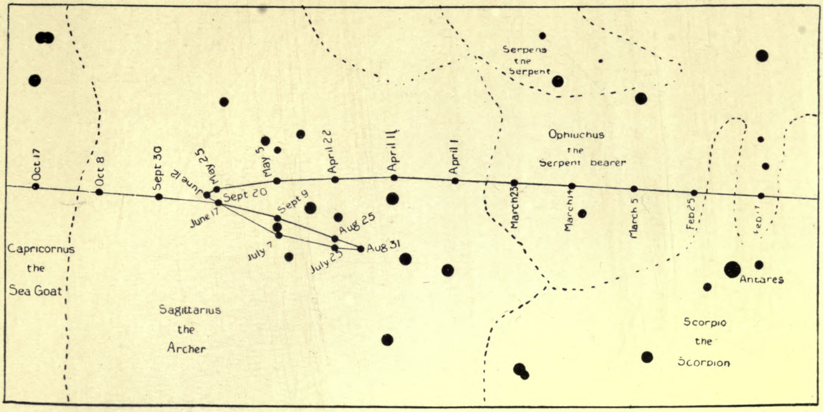


FIG. 1.—Apparent Path of Mars amongst the Stars during the year 1907.

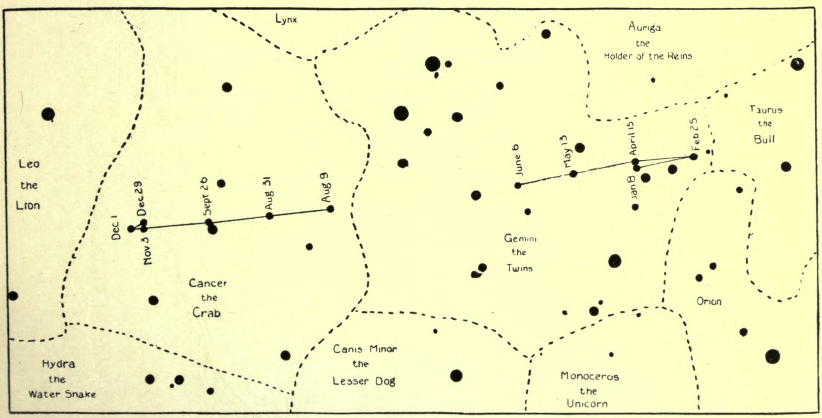


FIG. 2.—Apparent Path of Jupiter amongst the Stars during the year 1907.

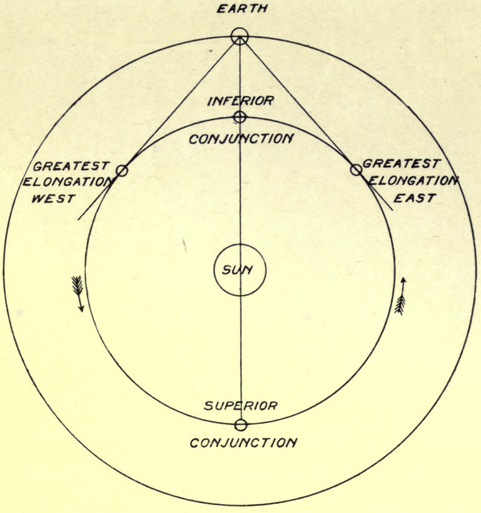


FIG. 1.—Elongations and Conjunctions of an Inner Planet.

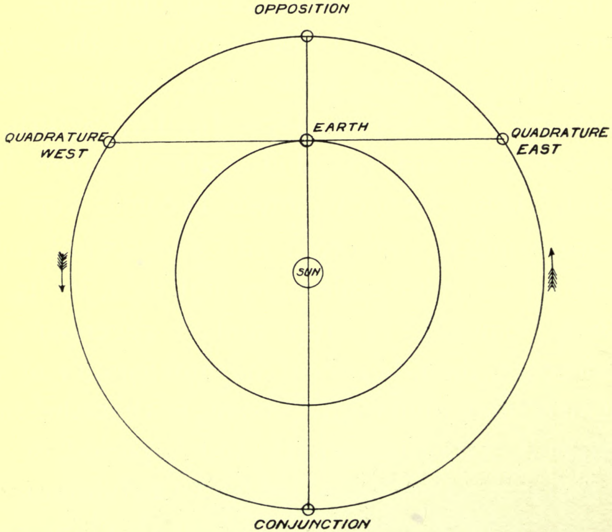


FIG. 2.—Quadratures, Opposition, and Conjunction of an Outer Planet.

thirty-sixth part of the circumference of the sky, or 10° of arc.

These three stars, the red star, the leaden star, and the serene star, are evidently quite unlike the rank and file of the heavenly host. We know them to-day, as the ancients knew them of old, as *planets*, that is to say, wanderers; and it was a very slow and tedious process by which men reached an understanding of their movements.

The names by which we know them to-day are those of three of the gods of ancient Rome. The red star is Mars; the serene, Jupiter; and the leaden star, Saturn. Their movements are like the movements of the moon, with one remarkable difference. The moon moves always eastward amongst the stars—moves rapidly eastward, more than twenty times its own diameter in a single day. Jupiter, Saturn, and Mars move eastward too, but each of them has a time when their eastward motion becomes very slow, then ceases, and is converted into a westward motion. This lasts for a considerable time, and then, in its turn, diminishes, comes to a stop, and is reversed. The great difference, then, between the movements of these three planets and that of the moon, is that the former pass through stationary points and a period of *retrogression*; that is, of westward, of backward motion.

This period of retrogression takes place at the time when the planet is opposite the sun, and is therefore visible all night. For Mars, it begins about six weeks before the planet is exactly opposite the sun, and lasts for about six weeks after. For Jupiter, it begins about two months before opposition, and lasts about the same time after. For Saturn, the half-period of retrogression is ten weeks. Then the rate of motion across the sky of the three planets is very different from that of the moon; for, while she traverses more than twenty times her own diameter in a day, Mars, at his quickest motion, takes an entire day to traverse a space equal to a single diameter of the moon; Jupiter takes three days, and Saturn five.

When we watch the 'morning stars' escaping from the rays of the rising sun, or the 'evening stars' being enmeshed in the rays of the setting sun, do we find that all of the former escape from the rising sun and all the latter are imprisoned by the setting sun; or is it sometimes the other way about? It is worth while to devote our mornings and our evenings for a time to making certain.

Let us suppose that we are beginning our watch in the February of 1906. It is more than a month before the spring equinox, and as we look, evening by evening, first the stars in the stream that the man pours from his watering-pot, then the stars in the Fishes, fade into the setting sun; morning by morning, the stars in the

Archer—half man, half horse—then the stars in the Sea-goat and the Waterpourer are earlier and earlier seen. Everything is as we expected: the stars keep on their steady march westward, there are no stragglers in their ranks, and the sun shifts steadily in the one direction past them. We have watched for a month and seen nothing out of rule; is there any need to watch longer?

It still wants a week until the equinox, and the sun has set nearly half an hour. The stars of the twin Fishes are lost in the twilight, but surely there is a star just over the west point of the horizon that has no place in the constellation of the Fishes. It shines with a silvery light, but more steadily than the other stars of the sky. And a little farther from the sun, a little farther to the north of the silvery star, there is another. It is fainter than the silvery star, but it twinkles like a real star. Then both set. Are these two stars new creations? How else should we not have seen them before when the other 'evening stars' were clearly seen? They are both set amongst the stars of the Fishes, but they are both much brighter than any of these.

But on the next evening, when they should have disappeared, both stars are yet more clearly seen. The 'evening stars' have shifted westward as regards the setting sun; the silver star and the twinkler have moved eastward, a little more into the dark and the open—they have moved eastward amongst the westering army of stars. For a day or two the twinkling star is seen, and then drifts back into the sunset glow, but the silver star takes a steady eastward path backwards through the stars, away from the sun.

During the summer months it travels backwards through the Twins, the Crab, the Lion, and the Virgin, its easterly motion just sufficient to keep it out of the sunset glow, but it has been growing brighter as it recedes; until, by September 20, it can be seen in the sky even as the sun is setting, and the distance between the two is as the distance between two hands of a clock pointing eight minutes apart.

But no farther does the silver star recede from the sun. After September 20, the sunlight begins to draw it back again; yet still it brightens, until, by October 26, there is no star in all the heavens can compare with it. Still it moves more slowly eastward, and yet more slowly, until, by November 9, it has ceased its easterly motion and is a brilliant star, fixed amongst the other stars, far outshining its neighbour, Antares, the jewel of the Scorpion. Then it begins its westerly movement, rushing more quickly than the other stars to be imprisoned in the rays of the setting sun, lost to sight before the third week of November is out.

But not for long. The first week of December is not over before a new star has arisen as herald of the sun.

> Hesperus, that leads
> The starry host, rides brightest.

But Hesperus, the silver evening star, is seen no more, and a silver morning star, Phosphorus, has risen. Phosphorus is moving westward, as Hesperus was moving when last we saw it. But Phosphorus ceases to move west by December 19; remains fixed, and again begins its eastward movement. By January 4, 1907, it has attained to all the brightness that Hesperus held on October 25, shining now in the head of the Scorpion, but giving it a jewel far surpassing all the other living sapphires of the sky. To the eastward it continues its road, gaining on the rising sun, and straying further from him. Phosphorus can be seen high in the morning sky even when the sun is lifting above the eastern horizon, and if we measure its distance from the sun on some morning near the end of the first week of February, we find it is very nearly that between the two hands of a clock pointing eight minutes apart. This would tell us that the western 'elongation' of Phosphorus was 48° very nearly, the same as the eastern 'elongation' of Hesperus. It is also its greatest elongation, for, after February 9, Phosphorus begins to sink back into the rays of the rising sun, unlike the stars of the Archer's bow amongst which it is shining low down in the eastern sky, much lower than was Hesperus when it shone amongst the stars of the Virgin in the west.

Phosphorus sinks back very slowly into the sun's rising during the long summer months of 1907. We see it threading its way through the stars of the Archer, the Sea Goat, the Waterpourer, the Fishes, the Ram, the Bull, and the Twins, until, at the end of July, we find it lying below the great Twin stars, Castor and Pollux. But the Twin stars are escaping from the sun's rising light, whilst Phosphorus is sinking into it, to be seen no more in the morning; though Hesperus reappears in the stars of the Scales when the long nights of November have come in.

In our watch, morning by morning, and evening by evening, we have come on no other stars than these that do not obey the Law of the Stars. We have discovered Saturn the leaden star, Jupiter the serene star, and Mars the red star. Also, we have discovered Phosphorus and Hesperus, and the twinkling star. Phosphorus and Hesperus, we are almost sure, are one and the same star; for the story of Phosphorus, of its movements in one direction or another, its stationary points amongst the stars, and its changes of brightness, is but the story of Hesperus as seen in a looking-glass. The star, Hesperus or Phosphorus, we call Venus.

The twinkling star is far harder to watch, and, indeed, here in England, it can only be seen occasionally. But if watched for, year after year, on every possible opportunity, its movements are seen to be just of the same character as those of Venus. The ancients had discovered this thousands of years ago, and we inherit from them the name Mercury, which we give to it.

These five wandering stars, or planets, do not obey wholly, though they seem to obey in part, the Law of the Sun. Like the sun, they shift their rising and their setting places, within limits, on the eastern and western skylines. But their change of rising and setting bears no relation to the seasons, and their pace across the sky is not steady and unswerving. They do not obey wholly, though they seem to obey in part, or at times, the Law of the Stars, for the latter have their places of rising and setting unalterable, and wheel continually without haste and without rest. They do not obey wholly, though they seem to obey in part, the Law of the Moon, for this never retraces its path nor stands still. They do not all even seem to obey the same law. The law that governs Saturn, Jupiter, and Mars seems different from the law of Venus and Mercury.

Let us take Jupiter and Venus, the two greatest and brightest stars in all the sky, and contrast them. In brilliancy and silver light they are rivals. But there is one great difference between them. Jupiter, like the moon, after emerging from the sun's setting rays, recedes farther and farther from him in the sky, until, when he is brightest, he rises, as does the full moon, in the east at sunset, rides his highest in the south at midnight, and sets in the west at sunrise, thus being opposite to the sun the whole night long. It was for this reason that the ancient Babylonians called Jupiter by the name 'Nibur'—'he who crosses over'—because he crossed the midnight meridian. And they also called him by the name of their chief god, Merodach, who represented the sun in his strength. For just as the sun passes through one of the twelve signs in a month, Jupiter passes through one of them in a year.

But Venus, so like Jupiter in lustre and brightness, is never opposite to the sun. The moon's movements would resemble hers, if we could suppose the moon to be stayed in the evening sky, when four days old, and sent back on her path; or, to use the Babylonian myth, if Istar had been stopped at the fourth portal and been sent back through the gates into the under world. So, therefore, as the Babylonians gave the name Merodach to Jupiter, they gave the name Istar to Venus, as well as to the moon. For she, like the moon, was an attendant on the sun—his handmaid and his bride.

It is worth while to step out under the open sky, and to watch the coming and going of these five planets, so seemingly capricious in their movements, so different from the unswerving, ordered march of the stars. It is also worth while to remember that long before men had telescopes, or any means for delicate measurement, they had not only detected these five wanderers, but they had mastered part of the secret of their movements, and had learned to predict long beforehand when they would appear, when they would seem to stand still in the sky, and when reverse their paths.

It is quite clear that the moon travels round the earth; is it not possible that Mercury and Venus travel round the sun? The interval between the time when Mercury is farthest from the sun as an evening star, to the east of him, and again to the time when he is farthest as a morning star to the west, is a little over six weeks. The interval from his greatest distance as a morning star to his next greatest distance as an evening star is a little over ten weeks. In all, the interval from one elongation to the same elongation again is about 116 days, or $16\frac{1}{2}$ weeks. If, therefore, we suppose that Mercury is travelling round the sun in a period of this length of time, as viewed from our earth, his apparent movements amongst the stars might be explained; and it is quite clear that we should have to suppose that Mercury was between us and the sun, midway in his passage from evening star to morning star; and beyond the sun, midway in his passage from morning star to evening star. (*See* PLATE XIV., fig. 1.)

Venus moves in a similar fashion to Mercury, but she swings through a wider arc and moves more slowly. She takes 143 days to fulfil her entire passage from her greatest distance in the east as evening star, to her greatest in the west as morning star; whilst she requires 441 days to pass behind the sun in her reverse course. Her entire period, as judged from the earth, is 584 days.

It is evident that Venus never recedes from the sun so far as the earth is. But suppose the sun had another attendant, that could move further from him than the earth. Clearly, instead of coming between the earth and the sun, it would pass behind the earth, and thus be seen opposite to the sun, just as the full moon is seen. Necessarily, it would then make its nearest approach to the earth, and would look large and bright. The sun appears to go round the earth once in a year. If this attendant on the sun took considerably more than a year to go round him, then we should have just exactly what we notice in the case of Mars, which takes seven weeks more than two full years between one 'opposition' and the next. If the attendant took several years to go round the sun, then it would be brought by the sun, at the end of a year, nearly to 'opposition,' but there would be a small distance still to be made up, because of the planet's own movement round the sun. Now, Jupiter travels from one opposition to the next in a year and thirty-four days, Saturn in a year and thirteen days. Hence, they take nearly twelve years, and nearly thirty years respectively, to travel round the sun, since thirty-four days is nearly the twelfth part of this apparent period of Jupiter, and thirteen days nearly the thirtieth part of this apparent period of Saturn. (*See* PLATE XIV., fig. 2.)

But does the sun travel round the earth, carrying all these planets with him, or is it the earth that travels round the sun, just as the other planets do? It would make no difference in the appearance of things, so far as observations made by the naked eye are concerned, which was the fact. But surely it is better to take the simpler explanation, and just as, when the stars had told us that the earth was a globe unsupported in space, it was easier to account for the apparent circuit of the stars round the earth by supposing that it was the earth that turned, so it is simpler to suppose that the earth travels round the sun, just as we see that the planets do, rather than that he travels round the earth, carrying all the planets, with their various motions round him. We know how difficult it is if we are sitting in a train in a railway station, side by side with another train, and we are watching the latter, to say which is moving, this train or that. The probability is that if the other train moves, we think it is ours; if it is our train, we think it is the other one, if our motion be smooth enough. But there is no motion so smooth and so swift as that of the heavenly bodies; they move without haste and without rest, and they jar over no stones in the road that they travel. So, as when we are in an express train, horses and hedges and trees seem to fly past us, whereas it is we that are flying past them, the sun seems to be circling round us in the course of a year whilst we are really circling round him. So in the pair of little sketches (*see* PLATE XV.), it is the tree that *seems* to have moved, not the man.

This gives us the clue to the meaning of those strange backward movements of Mars, Jupiter, and Saturn. The earth is nearer to the sun than they are, and moves round him in a shorter time. Hence there is one part of our path in which we pass them, and whilst we are passing them, since we are not conscious of our own movement, they seem to be going backwards in the sky. There is a further point. We have seen that Mercury and Venus appear only to wander from the sun to a restricted degree: Mercury is never more than about 30° from the sun, nor Venus much more than 45°. That means to say that 30° is the apparent size of half the orbit of Mercury as seen from the earth, and 46° of the orbit of Venus. This does not tell us how big those orbits actually are in miles, but it gives us the relative size of the two orbits, so that if we knew the scale of the one we should know

WHICH RAN : THE MAN OR THE TREE

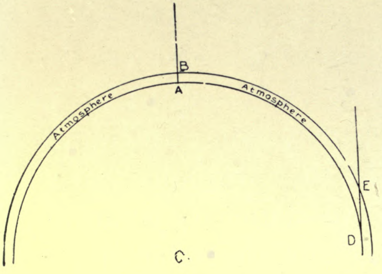


FIG. 1.—The light from the edge of the Sun's disc has passed through a much greater depth of his atmosphere than that from the centre.

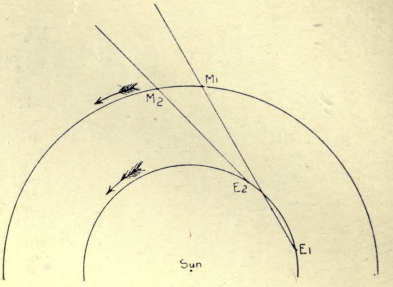


FIG. 2.—Illustrating the apparent forward motion (eastward) of an outer Planet.

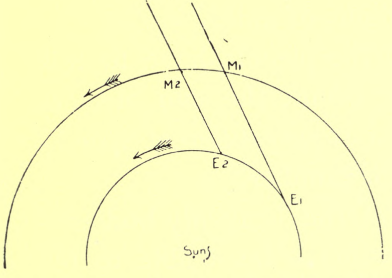


FIG. 3.—Illustrating the 'stationary points' of an outer Planet.

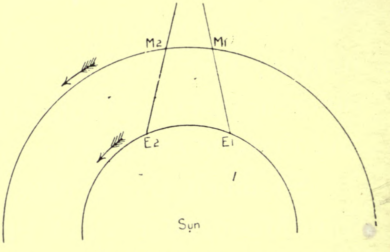


FIG. 4.—Illustrating the 'retrogression' (westward motion) of an outer Planet.

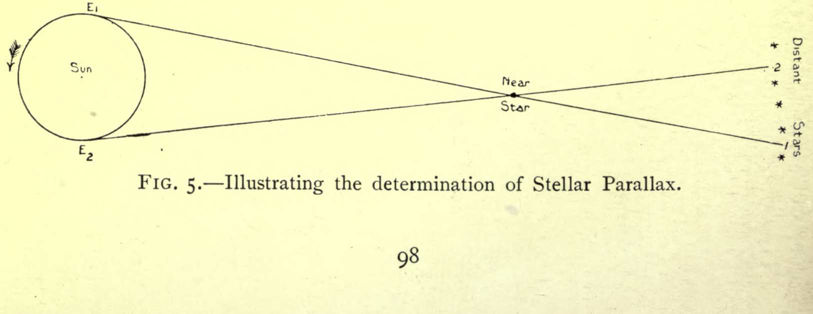


FIG. 5.—Illustrating the determination of Stellar Parallax.

the scale of the other, and also the scale of the earth's orbit. (*See* PLATE XVI., figs. 2, 3, and 4.)

Just in the same way the apparent swing backwards of Mars, Jupiter, or Saturn, whilst they are going backward in the sky between their two stationary points, is an indication of the apparent size of the orbit of the earth as seen from these three planets, and consequently of their relative distances. We could therefore draw a map of the Solar system to scale, but we could not tell the value of the scale, whether an inch represented hundreds, or thousands, or millions of miles.

This, then, is the story that the planets have to tell, namely, that they are moving round the sun at very different distances from him, and at very different speeds, and that the earth is one of their number.

So much the movements of the heavenly bodies—Sun, Moon, Stars, and Planets—have been able to tell us without the need for our using telescope or observatory. So much, and much more, men had read from those movements two thousand years ago. Is there any good, then, in our learning again what has been known so long?

There is every good. Those who wish to learn something of other sciences than astronomy, such as botany and geology, are never content merely to read about them in books. They go to the fields and rocks to see with their own eyes that which the masters in these sciences have known and taught long before. And they do rightly. It is by our own observation that we learn to know; it is by this that our perceptions become keener, and our interpretations more certain.

If we would begin our study of astronomy aright, let us go out, under the open sky; and what beauty, sublimity, and wonder greet us as we turn our eyes to the heavens! The movements of the machinery of men are with noise, dirt, and shaking; but this machine, infinitely greater than any man has ever produced, moves as easily as a thought. For the movements that we watch are those of the machine of God's own making, and how swift, smooth, silent, and inscrutable those movements are!

BOOK II

STORIES TOLD BY THE SUN

CHAPTER V

THE STORY TOLD BY THE SUN'S SURFACE

IN February, 1866, as I[1] was returning home from school one evening, I saw the sun, low down in the west, shining red through the mist. The sun was dim and red enough for me to look at him without blinking, and I saw plainly on him a round black spot, just as if a nail had been driven into him up to the head. It was the first time that I had ever seen anything on the surface of the sun.

If we are to see anything on the sun's face, we must be able to look at him. If the day is very clear, we are too dazzled by his light to see him. The impression that we get is that he has a round, glowing golden disc, all so overpoweringly brilliant that we cannot say that one part of it is any brighter than another part. For aught we could tell, it is a perfectly flat disc, as flat as a golden sovereign, or as our forefathers thought the earth to be.

We now know that the earth is not flat, but rounded

[1] E. Walter Maunder.

as a sphere or globe; the stories of the sun and stars told us that. But the atmosphere surrounds the earth and fits it like a skin, like a skin that, for the size of the earth, is not so thick as the skin of an apple is for the fruit. We know that the earth's skin of air is not thick, for the sky is much clearer overhead than towards the horizon, and if we could ascend high above the ground we should see that, of the circle of the earth beneath our feet, the region in the centre is the clearest, and the land lying near the borders in all directions is blurred and dim.

We cannot gaze at the sun when he is in the clear sky overhead; we can look steadily only at the low sun when his brightness is diminished by the thicker air of the horizon. Then we see that the golden disc is not equally bright, equally golden, all over. The centre is brightest and still of a golden yellow, but everywhere towards the border of the circle the brightness dims and the gold deepens into orange or red. It is not our atmosphere that causes this diversity, else the gold and orange would be in layers above our skyline; the difference must be in the sun himself: his dim border must be at a greater distance from us than his bright centre, and he must have an atmosphere of his own, lying thicker over his border than his middle, as we found our air lying thick on our horizon. The sun, then, is not a flat disc like a golden sovereign, but a globe, a sphere, rounded as the earth is round. (*See* Plate XVI., fig. 1.)

The next time that I saw the sun lying low and red in the west, I saw the black spot like the head of a nail again, but it had changed its place, and was now much further from the centre of the sun. Two or three days later it had gone.

I have seen similar spots with the naked eye on many occasions since. On November 18, 1882, Queen Victoria was holding a review in Hyde Park. The morning was somewhat foggy, and the sun shone dull and red through the thick air, so that it was easy to look at him. On this occasion there was a great spot on the sun; so big that it caught the attention of the soldiers who were marching across Blackheath, to go to the review, and they pointed it out to each other. Eleven years later, in August, 1893, I was on a voyage and watched the smoke from the steamer pass across the sun; every time that it did so, and I was able for the moment to look at the sun, I saw two great spots upon him. And so on other occasions. On one day in February, 1907, no fewer than four spots could be seen separately on the sun at the same time.

So the face of the sun changes, even to the naked eye. There are sometimes blemishes on it, and sometimes there are not. It is not possible to go much further than this in the study of the sun's surface without the aid of a telescope—we can see that the sun is a globe, that he has an atmosphere, and that spots come and go upon his face. We cannot tell whether it is always the same, or a different, face that he turns to us.

Every now and then we can see spots on the sun with the naked eye, and several such were seen in the centuries before the telescope was invented, yet the people who saw them did not recognize that the black blemishes were really spots on the sun's face. In the days of Charlemagne, one was recorded as lasting for eight days, but those in the Middle Ages, who read the record, thought that it was Mercury that was seen, passing straight between the earth and the sun. But Mercury it could not have been, for two reasons. The little planet takes only six weeks to pass from its east elongation to its west, over a space in the sky nearly two-thirds of a right-angle; it could not, when it seemed to be moving at its quickest pace, loiter for eight days of that time, over barely the one hundred and seventieth part of that space. Besides, the planet is so little that we can only see it with the naked eye when it is a bright point of light, not when it is but a black dot on the bright sun.

To study the features of the sun's face we must have a telescope, and we can use it in one of three ways. We can look at the sun directly through it—though in this case we must use a very dark glass to dim the glare of his light, which would blind us utterly. Or we can let the magnified image of the sun made by the lenses of the telescope fall upon a white card, and study the features that we see there. Or we can place, instead of the card, a photographic plate, and let the sun imprint his own image. In this last case, since the sun is very bright, the very brightest object we know, we must give very short exposures, perhaps but the one thousandth part of a second. PLATE XVII., fig. 1, shows the second of these methods as used at the Royal Observatory, Greenwich, by Flamsteed, the first Astronomer-Royal; and PLATE XVII., fig. 2, shows one of the 'photo-heliographs,' or photographic telescopes for solar work, now in use at the same observatory.

The spot that was seen in the days of Charlemagne lasted for eight days. It lay on the sun's face, when first it was seen, nearly a quarter of the sun's breadth away from the left-hand edge. But day by day it shifted its place, creeping right across its middle, until, on the last day that it was seen, it lay about a quarter of the sun's breadth from the right-hand edge. Either, then, the spot was moving on the sun, or the spot was fixed in its place and the sun was turning with it round in the same direction that we ourselves seem to move.

It is only rarely that we notice naked-eye spots, but very soon after the invention of the telescope Galileo turned his new instrument upon the sun, and in April, 1611, announced that he had discovered dar spots on the body of the sun. For in the telescop spots are frequently to be seen, and these may remai visible not for eight days only, but perhaps for thirtee or fourteen, appearing first at the very eastern edg of the sun, and crossing his face to disappear at h western edge. And these show that the sun himse is carrying the spots. They are not merely transi ing over his face, as Venus or Mercury transit, passin between the earth and the sun. For when the spo appear at the sun's eastern edge they are like a thi line along it; they seem but stains on him, muc foreshortened as they lie on a part of his globe th is turned much away from us. As day by day passe the spot group comes more clearly into view, until is fully presented in the centre of the sun's disc. The day by day, as it creeps on towards the west, it for shortens again, showing clearly that the sun is a glob and that he is turning round upon his axis. From the same spots we can tell how fast he is turning. For, sin the sun is a globe, we can only see half of it at any tim the hemisphere that is turned to us. But it seems to to take the sun thirteen or fourteen days to carry a sp from one boundary of that hemisphere to its other, a it takes, therefore, just so long to carry it again acro the hemisphere that we do not see round into sig again at the eastern edge. Thus the sun appears

Observing the Sun's Surface at Greenwich Observatory.

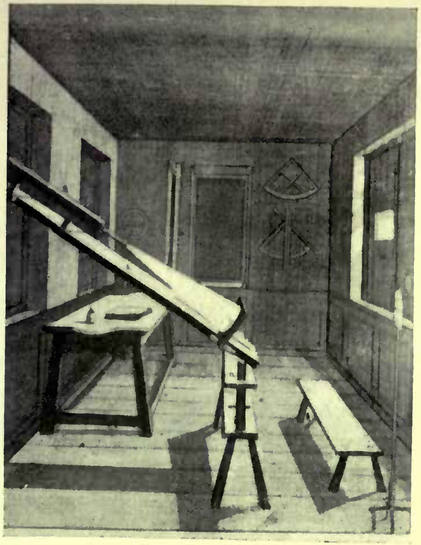


FIG. 1.—Projecting the Sun's Image. Flamsteed's method, 1676.

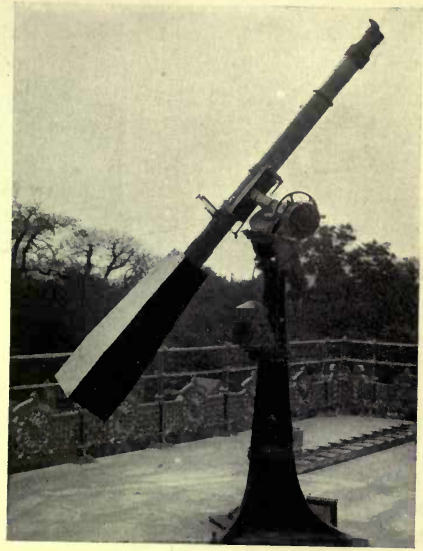


FIG. 2.—Photo-heliograph for photographing the Sun, 1908.

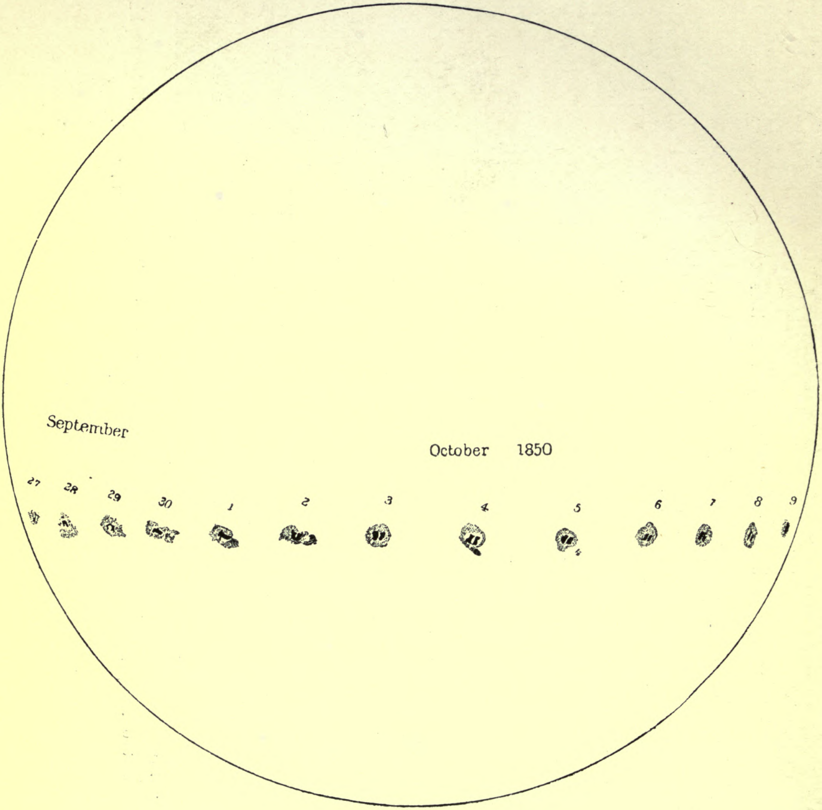


DIAGRAM SHOWING THE TRACK OF A SUN-SPOT ACROSS THE SUN'S DISC.

(*From a drawing made in September and October*, 1850, *by the late Father Sestini at the Georgetown College Observatory.*)

us to turn round in about twenty-seven days. In reality he turns round in less time by a couple of days, for, as the earth is travelling round the sun in the same direction as the spots do, we keep the spots longer in view than if we remained still; just as we might follow down the platform a train that is moving out of the station, to keep a departing friend a few seconds longer in sight. (*See* PLATE XVIII.)

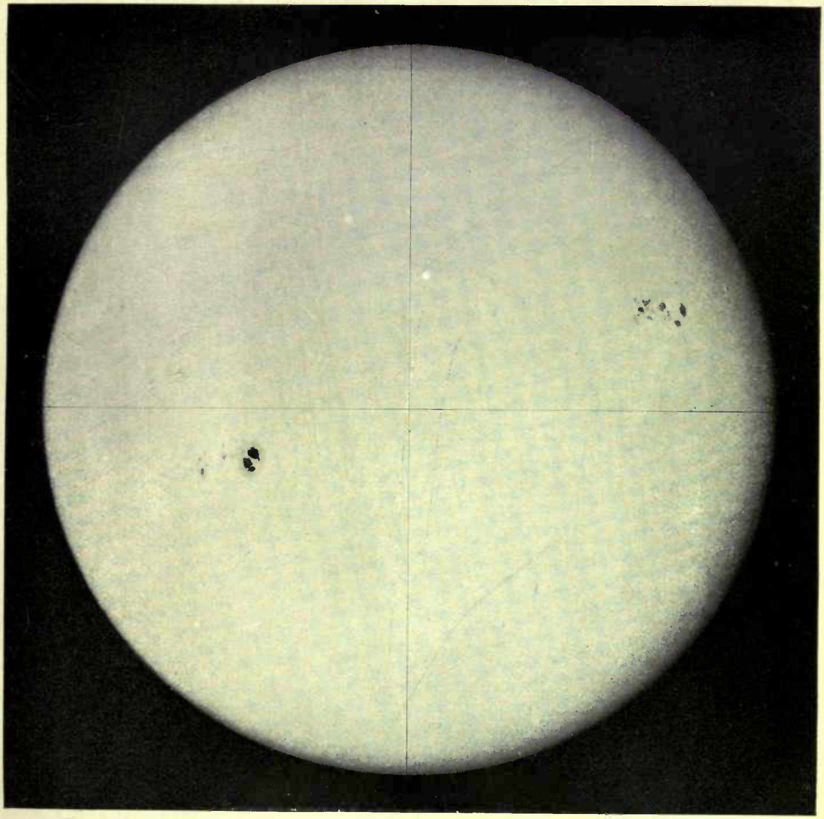
The spots go at the sun's western edge into the hemisphere that we do not see. Shall we ever see these spots again? How shall we recognize them if they are the same spots? How can we tell one spot from another? Do they always come up at the same point of the sun's eastern rim as the stars do on the earth's horizon, or do they shift their rising places like the moon and the planets? Do they wax and wane like the moon; do they wander to the east or to the west like the planets; or, like the stars, do they move without haste and without rest? or do none of these laws have anything to do with sun-spots?

A spot, when seen with the naked eye, is round and black, like a nail's head; and one nail is very like another. But that is because the naked eye is not powerful enough to see its details. Magnified by the telescope, and projected on the white card, or imprinted on the photographic plate, a spot is seen to have defined form and characteristics enough for it to be recognized again. But so has a cloud in the sky characteristics and a defined form, and just as clouds change so do sun-spots. The sun-spot of one day may have altered or lost every peculiarity by which we thought to remember it, ere the next has passed. A single spot may have broken up and become scattered into many; a group of spots may have coalesced into one.

Spots differ much in their shape and size, and in the length of time that they last. The most stable spots, those that change least and last the longest, are very nearly round. They appear black in the centre, which is not quite half as broad as the entire spot. In this black region, the *nucleus*, or *umbra*, of the spot, as it is called, there are sometimes points of intenser blackness, as if pits were sunk in the floor of a great cavity. Round the umbra is a lighter region, which surrounds it as the iris surrounds the pupil of an eye. This is called the *penumbra*, and is marked throughout by wavy lines flowing inwards, making the penumbra look as if it were built up of thatch straws. Where the penumbra borders on the umbra, it is ravelled out into a narrow fringe. Round the spot, outside the penumbra, the surface of the sun is brighter than usual, and seems to be heaped up; and every now and then, some of this intensely bright white stuff will, as it were, boil over, and either flow right across the spot, forming what is known as 'a bridge,' or else flow into it.

SOUTH

EAST



WEST

NORTH

Photograph of the Sun taken at the Royal Observatory, Greenwich, on July 14, 1905.

(Two streams of sun-spots of different types are seen.)

NORTH

EAST

WEST

SOUTH

THE SOLAR SURFACE, SHOWING THE GRANULATIONS. Diameter of Solar image = 3 feet.

(*From a photograph taken September*, 1883, 9*d*. 8*h*. 50*m*. 20*s*. *Paris Mean Time, at the Meudon Observatory, by the late Professor Janssen.*)

But spots are not generally seen singly; they are seen in groups. A very ordinary occurrence is for two very small spots to appear near each other. Then they grow very quickly and move apart as they grow. This movement is usually one of astonishing rapidity, since they travel away from each other at the rate of about 8,000 miles a day, five or six times as fast as an express train. The spot that leads is usually nearly round, and is dark and well defined. The spot that follows is often the larger of the two, but is not so dark, and not so regular in shape. Between the two a number of smaller spots generally appear, but these are not seen for long, as the bright surface of the sun seems to swell up in this region and to flow over these smaller spots, hiding them from view. The irregular spot in the rear disappears next, and the round leader remains alone and may sometimes last for several weeks, or even months, after the rest of the group has gone. (*See* PLATE XIX.)

Spots, therefore, change their form; they increase and diminish, they are born and die. Some never become more than a faint, tiny smirch, which may last only a few minutes and then melt again into the general brightness of the sun's surface. Others grow and spread and darken, and may last for days, weeks, or even months, crossing the sun's disc again and again. Some may develop slowly, and decay in the same fashion. Others may break out almost full grown, or may die down whilst apparently in full vigour.

But the spots are not the only markings upon the sun. As already noted, round the spots, and in the middle of their groups, we often see masses of material much more brilliant even than the general surface; as if the substance of the sun were here boiling over and eddying round and across the gaps made by the spots. Masses of similar shining matter are also seen by themselves near the rim of the sun, more generally near the east or west; in form they look like branches of gleaming coral. They are in the centre of the sun's disc also, but there their lustre is lost in the general brightness. They rise high into the sun's atmosphere like mountains, and its greater depth near the rim of the disc shades down the brilliancy of his surface, so that these bright masses—*faculae* they are called—shine out by contrast. These great groups of faculae, like the spots, come round into our sight over the eastern rim of the sun; we lose them in the brightness of the centre, and we see them again near the western rim before they disappear into the hidden hemisphere.

We have seen sun-spots and faculae on the surface of the sun; but what is that surface itself like? Its texture is not even; it has its pattern, a wonderful and ever-changing pattern. On what seems to be a dark, or at least less brilliant, background, there float minute grains of intense brightness, and of irregular form. If we do not magnify it much, the general effect is like the roughness of drawing-paper, or like the curdling of milk that is turning sour. But, greatly magnified, it seems to be formed of tiny granules which run together here and there into grains, which may be round in shape, or drawn out into pointed filaments, and these grains aggregate, and separate out to form the changing pattern on the sun's face. One observer describes them as being like snowflakes sparsely scattered over a greyish cloth, another likens them to 'willow-leaves,' figuring the sun over like basket-work; another sees them as simple rice grains in shape. Over the edges of the umbra of spots, they form the fringe of the penumbra, hanging over the blackness like thatch straw.

On some very beautiful photographs that Professor Janssen took of the sun, this pattern came up, at one time coarsely, at another time finely textured. At places the texture, whether coarse or fine, seems smeared and ill-defined, as if the pattern had been outlined in luminous ink, and ere it dried, a careless sleeve had brushed across it. What causes this smearing, or how long it lasts, we do not yet know. It might be supposed that it was due to small but very rapid currents in our own atmosphere which make the parts of the sun seen through them ill-defined, as landscape shimmers in extreme heat. But it seems clear that it arises from some cause in the sun itself, from some motion or whirling of the grains themselves, or of the sun's atmosphere above them, so rapid that the small fraction of a second for which the photograph was exposed was all too long for them to seem at rest. (*See* PLATES XX. and XXI.)

The story told by the sun's surface, as we see it or photograph it by means of a telescope, is one that we should not have been likely to guess from anything that we can see of it with the naked eye. The whole of that surface is in commotion and change. Bright as it is on the whole, there are parts which are much brighter than the rest; there are parts, too, which, though really bright, appear to be dark, appear even to be absolutely black, as compared with the general radiance. Yet even the blackest part of the darkest sun-spot is probably, surface for surface, thousands of times as bright as the full moon.

And these spots change, change rapidly, in a way that hints at the action of mighty forces below the surface.

Finally, the sun is a globe, turning upon his axis once in twenty-five days, and so presenting in turn every face towards us.

CHAPTER VI

THE STORY TOLD BY THE SUN AND THE PLANETS TOGETHER

SOME years ago my study window faced north-west and looked over London. One evening in August it was very clear as I[1] watched the sun go down, and I hoped to see him set behind the houses, and not lose him in the smoke of the chimneys before he reached them. He was very close to the skyline, when I saw in his lower right-hand edge a black piece bitten out: a bite which grew larger and larger, just as the moon, in a solar eclipse, seems to eat the sun. Yet I knew that there was no eclipse of the sun possible on that evening. Farther and farther did the round black body encroach, until, when the sun was nearly hidden, an upright tower, surmounted by a cross, was outlined on the reddened disc. It was St. Paul's that was eclipsing the sun; dome and tower together exactly fitting into the sun's round shield. (*See* PLATE XXII., fig. 1.)

We can cover up the sun's whole face more easily than by getting him to set behind St. Paul's to us at

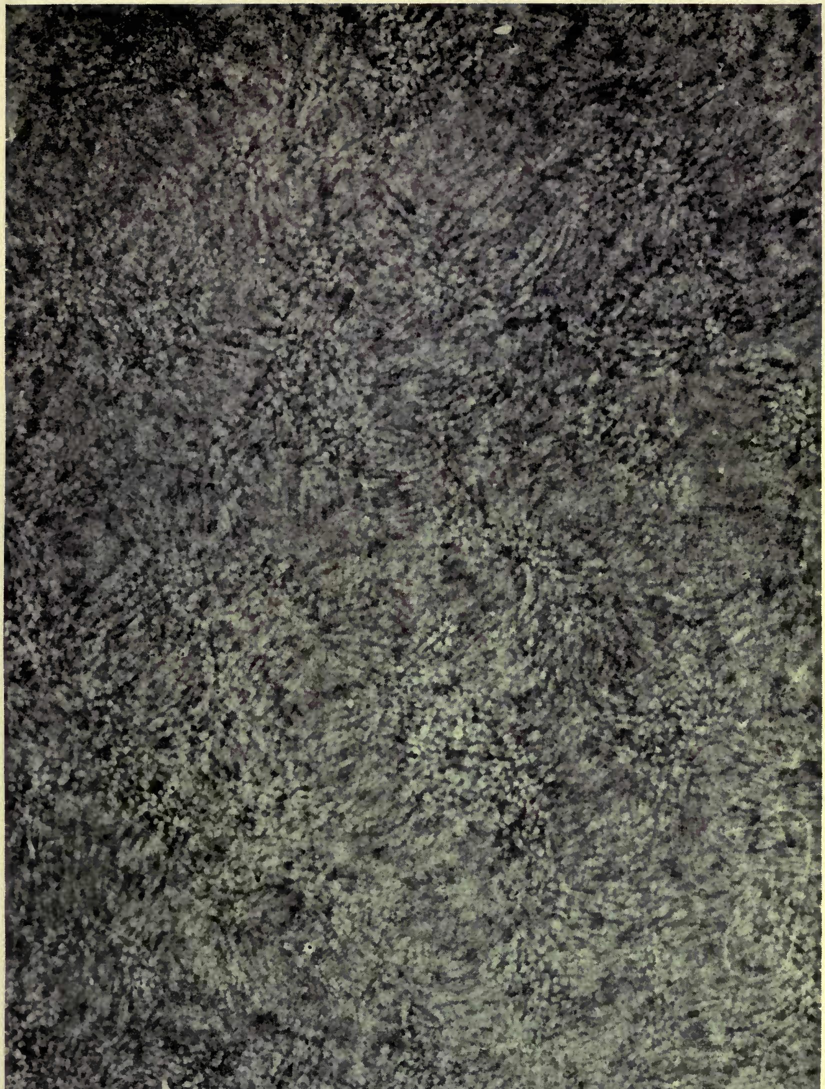
[1] E. Walter Maunder.

Blackheath. If a halfpenny is held at a distance of nine feet from one of our eyes, exactly between the eye and the sun, no whit of the sun will be seen; or if a threepenny-bit is held about five feet away, again the sun will be exactly hidden. So a threepenny-bit at five feet distance, a halfpenny at nine feet, the dome and cross of St. Paul's as seen from Blackheath, and the sun, if all in a straight line from the eye, will all appear exactly the same size. Now we can measure the distance to the threepenny-bit, and its size; to the halfpenny, and its size; to the dome and cross of St. Paul's, and their size; but how are we to measure the distance to the sun to get his size? We cannot pace the distance, or measure it with a chain.

Suppose that we are looking at a candle with both our eyes, and that the candle is not far off. If, whilst we are looking at it, we shut our right eye, the candle seems as if it had shifted a little to the right; if we shut the left eye instead, it seems to shift a little to the left. Yet the candle has not moved at all; it is simply that our eyes are two and a half inches apart, and we look first with one, and then with the other. The direction from the right eye to the candle is not quite the direction of the left eye to the candle. The whole shift that it appears to us to make is the width between the pupils of our two eyes, as this would appear to a person in the place of the candle. Now the width between our

WEST

NORTH



SOUTH

EAST

THE SOLAR SURFACE, SHOWING THE BLURRING OF THE GRANULATIONS.

Diameter of the Solar image = 3 feet.

(*From a photograph taken July* 10, 1887, 7*h*. 35*m*. 55*s*., *Paris Mean Time, at the Meudon Observatory, by the late Professor Janssen*.)

FIG. 1.—Sun setting behind St. Paul's.

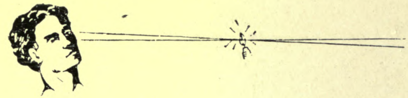


FIG. 2.—The distance of an object is judged by the use of two eyes.

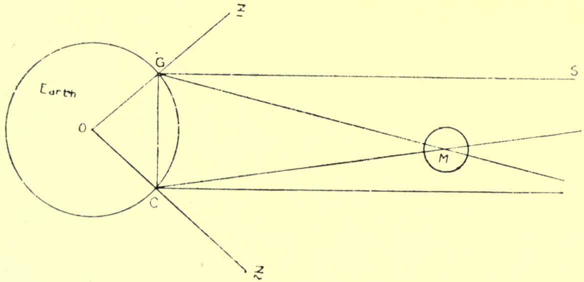


FIG. 3.—Determination of the distance of the Moon from the two observatories of Greenwich (G) and the Cape (C).

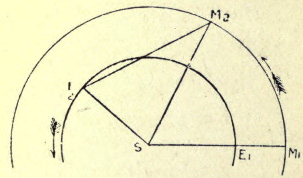


FIG. 4.—Determination of the relative distance from the Sun of Mars and the Earth.

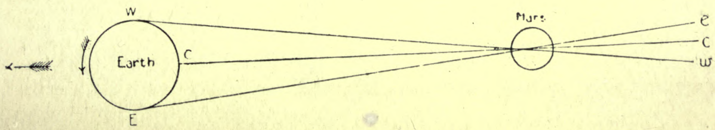


FIG. 5.—Determination of the distance of Mars by the Diurnal method.

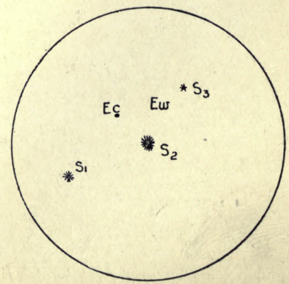


FIG. 6.—The minor Planet Eros

eyes to that person will seem greater or less according as he is near or far from us; the farther he goes away the closer together will our eyes appear to him. If we measure the distance between our eyes, and measure the shift that the candle seems to make, we can tell the distance that it is from us, even though we do not measure the distance to it. (*See* PLATE XXII., fig. 2.)

It is in exactly the same way that we can measure the distance to the moon, and so tell her real size. We do not do it by shutting first one eye and then the other, and measuring the shift of the moon in the sky, because the moon is so very far away, that her shift—the distance between our eyes as seen from the moon—is too small for us to perceive it. The moon is so far away that we must look at her direction from two points that are thousands of miles apart, instead of a few inches, in order to get a sufficient change in the place she seems to have.

But here are two difficulties. When we measured the distance of the candle by observing its apparent change of place as seen with the one eye and the other, we watched it shift with respect to something much more distant. But what is more distant than the moon? The stars, and to them we can refer the moon's place.

Instead of our two eyes we can take two very distant observatories. The Royal Observatory, Greenwich, was built largely in order to observe the moon; and in order to co-operate with it—to be, as it were, the second eye—the Royal Observatory at the Cape of Good Hope was built. Now these two observatories are 6,000 miles apart, and the moon, as seen from Greenwich, does not seem to be in precisely the same part of the sky as it is when seen from the Cape; indeed, the apparent change of place is two and a half times the apparent diameter of the moon, or nearly so. Now this is the apparent distance apart of two objects which are really a foot apart if viewed from a distance of forty feet, or a yard apart if viewed from forty yards. In other words, the moon is forty times the distance between the two observatories at Greenwich and the Cape, that is, nearly 240,000 miles; more exactly (for we have only dealt in round figures hitherto), 238,400 miles. (*See* PLATE XXII., fig. 3.)

But we have a far more difficult problem when we try to measure the distance of the sun. First of all, we cannot measure his position with reference to the stars, as they are not visible by daylight. Next, the sun is not an easy body to observe. He is large, with his rim ill-defined, and is so bright and hot that we cannot get his centre with precision. We should need to get his centre exact to the one eighth-thousandth part of a hair that we are holding about a foot distant, where we can see it best. Yet we could not tell where is the real rim of the sun by the breadth of many hairs.

The third difficulty is, as before, to get a ‘base-line’; that is, to get two places sufficiently far apart from whence to make our measurements.

The first two difficulties we can get over together by measuring the distance—that is, getting its shift with respect to the stars—of one of the sun's planets instead of the sun himself. We can always draw a map of the solar system, accurate to any degree we like to name, at any given moment, but we do not know the scale on which that map is drawn; we cannot say how many millions of miles should go to the inch.

Let us select the planet Mars. Let S be the sun, M_1M_2 be the orbit of Mars, E_1E_2 be the orbit of the earth. Then Mars makes one complete revolution in his orbit in 687 days, and the earth in hers in $365\frac{1}{4}$. We know both of these times by observing when Mars and the sun return to the same place amongst the stars. Note the date when Mars is in opposition; that is to say, when he lies in the same straight line from the earth to the sun. After a certain number of days, say four months, when the earth has reached E_2, note his elongation or apparent distance from the sun. This is the angle M_2E_2S. We know the length of time that it takes Mars to travel right round his orbit, and therefore we can tell how much of it he describes in 120 days; we can tell the angle M_1SM_2. Therefore we know the proportion that the distance SM_2 bears to the distance E_2S, though we do not know the actual measure of either. If we can measure the distance to Mars, therefore, we can tell the distance to the sun. (*See* Plate XXII., fig. 4.)

We can get over the difficulty about the length of the base line, from whose ends we should measure, without leaving the spot on which we are standing. The earth is a great spinning globe, and we who stand on its surface are some 8,000 miles away in the morning from where we were in space twelve hours before, even if the earth were not moving in her orbit round the sun. Suppose, now, that Mars is at opposition, and that we fix both Mars and the earth for a while in their places, preventing them from moving round the sun, but not preventing the earth from spinning on her axis, Mars, being on the other side from the sun, seems to rise as the sun sets, and sets as he rises. But the direction of Mars should seem to us to shift, as the earth turns round, from EM*e* as we saw him when rising, to WM*w* as we saw him when setting. We know the distance ECW, for it is the diameter of the earth, and we have just measured the angle EMW, so we can tell the distance EM. This is the principle of the method, but, of course, as neither Mars nor the earth have remained fixed in their places during the twelve hours or so that have elapsed between two observations, corrections have to be made for the distances that they have travelled. (*See* Plate XXII., fig. 5.)

Mars is the best of all the major planets, as it is outside the earth's orbit, and it is the nearest of those outside, but some of the minor planets are better than Mars for this purpose. One in particular, Eros, sometimes comes nearer to the earth than any other heavenly body except the moon, and it is also such a small point of light that there is no difficulty in deciding its centre. Figure 6 in Plate XXII. will indicate how the shift is measured. Suppose that S_1, S_2, and S_3 are stars, and E*e* is the position of Eros in the evening shortly after rising; E*w* the position in the morning shortly before setting. The distances of E*e* and E*w* from these stars are measured, and the differences between the measures when corrected for the motion of the little planet and of the earth, gives the shift in the interval of time between the two observations. (*See* Plate XXII., fig. 6.)

By this method, or by some method like it, it has been found that the average distance of the earth from the sun is 92,892,000 miles, but this value may perhaps be too great or too small by about 120,000 miles. This is the average distance, for as the earth does not move round the sun in a circle, they are nearer to each other at one time of the year than at another; in winter they come as close as ninety-one millions of miles; in summer they are as far away as ninety-four millions.

It is hard to picture such a distance to one's self, or even to conceive of it. There are about ninety-four millions of seconds in three years, so that if we travelled a mile in a second and went straight from the earth to the sun, we should not reach him in less than three years.

And if the sun is so far away, how big must he be? As nine feet is to the size of the halfpenny, so is ninety-three millions of miles to the size of the sun. This sum in proportion works out at 866,400 miles for the diameter of the sun; the diameter of the earth being only 7,920 miles, not the one-hundredth part. The sun's great globe would contain 1,300,000 of the quantity of matter in the earth.

Sir John Herschel long ago gave directions for making a model of the solar system to scale which will give an idea of how vast are the distances which separate its members. On a wide level common, place a globe two feet in diameter to represent the sun. At a distance of 82 feet from it put a mustard seed to represent Mercury; a pea at 142 feet would stand for Venus, and another pea at 215 feet for the earth; whilst Mars would be indicated by a peppercorn at 327 feet. A fair-sized orange nearly a quarter of a mile from the central globe would stand for Jupiter, whilst the minor planets would be represented by minute grains of sand, mostly from 500 to 600 yards from the centre, though some would be as near as Mars, others as far as Jupiter.

Saturn would be a small orange at two-fifths of a mile, Uranus a large cherry at three-quarters of a mile, and Neptune a plum at a mile and a quarter.

If these little models of the planets were set in motion, then, in a day, the mustard seed for Mercury would have to travel a yard; the peas representing Venus and the earth 24 inches and 22 inches respectively. Mars would move 18 inches, Jupiter $10\frac{1}{2}$, Saturn $7\frac{1}{2}$, Uranus 5, and Neptune 4 inches. The further off from the sun a planet is, the more slowly it moves in its orbit. The moon, on the same scale, would be a smaller seed than Mercury, moving with the earth, but at a distance of about $6\frac{2}{3}$ inches from it. Its daily motion round the earth would only amount to about two-thirds of an inch. (*See* PLATE XXIII.)

When we looked at the sun and saw a spot on it with the naked eye, it looked no bigger than the head of a small nail driven into it. But what must have been the size of that spot to be seen at all? If we placed a globe the size of the earth on the face of the sun, it would look no larger than a halfpenny at three hundred yards; but a halfpenny at three hundred yards' distance from us we could not see at all. A naked-eye spot cannot be smaller than 25,000 miles across, more than three times the diameter of the earth.

And many of the spots cover an area of a thousand million square miles or more. Cavities, they seem to yawn, so vast that they might swallow up Earths as peas might be poured into a saucer. If then the grains and granules on the sun are the flecks of foam, the faculae are the billows, and the spots are the eddies on this sea of flame, what vast powers and forces do we see here in action!

CHAPTER VII

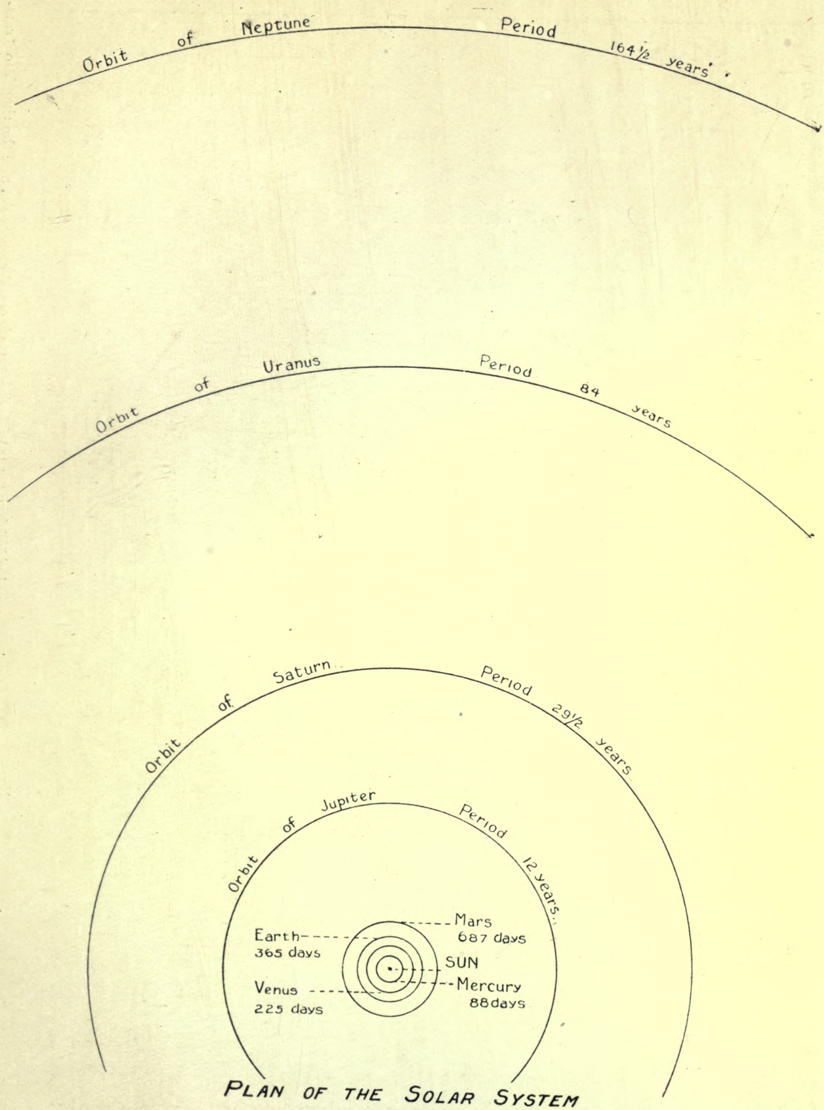
THE STORY TOLD BY SUN-SPOTS

SINBAD the Sailor relates in one of his adventures that he and his companions once encamped on what they took to be a desert island. Just as they were settling down to their evening meal, the supposed island began to sink, for it was a whale that had been wakened out of sleep by the inconvenience of having a fire lit on his back. There are certain points of resemblance that we may note between islands and whales, and certain points of difference. Both are situated in the oceans of our globe; both partake of the earth's daily rotation on its axis. But islands are fixed in their places; we define their position by their longitude and latitude on the earth; if we go, and return to them, we are sure of finding them in the same place as we left them. Not so with whales. They migrate, and where we have seen one once, we cannot expect to see it again. But, though whales do not obey the laws of islands, they are not wholly lawless. They may not remain fixed in the same spot, but they are constant to certain haunts.

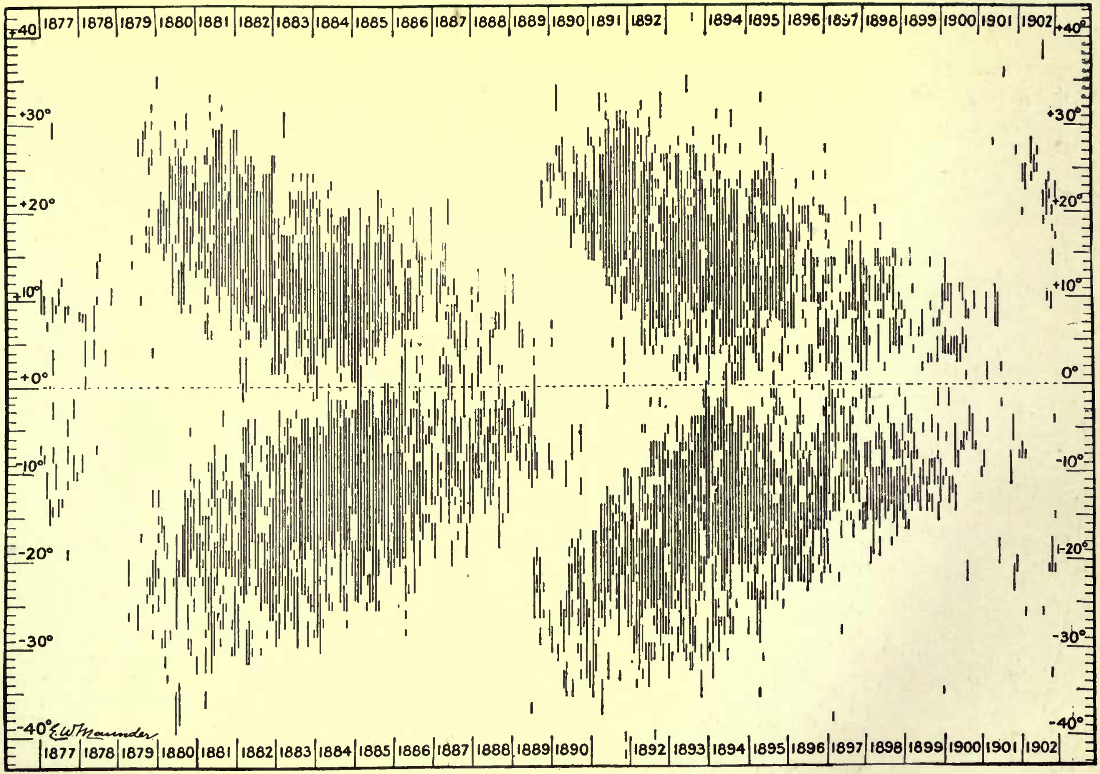
Whalers must sail to their peculiar localities, must seek them in their own seas to find them.

With sun-spots it is as with whales rather than with islands. They are not to be found everywhere on the sun's great sea of flame; they have their own peculiar haunts, beyond which they rarely stray; nor are they always to be seen upon the surface even in these.

Unlike islands they are not fixed, but they migrate, wandering to and fro. Our earth turns on her axis as a whole, and one part does not pass or lag behind another. Not so with sun-spots. If we were watching the spots on the sun's equator in order to determine the rate at which he turned, we should decide that he took about twenty-four and a half days to complete a rotation. If we watched the spots of latitude 35°, he would seem to take nearly twenty-seven days. This would be very much as if islands on the equator of our earth, like Sumatra and Borneo, had a day of twenty-three hours; whilst islands in the position of Japan would have a day of twenty-five hours. It is quite clear in such a case as this, that Japan would lag behind Sumatra and Borneo, which would gain about 2,000 miles upon it in every rotation of the earth. Such a state of things of course could not take place on any solid globe, and we know, therefore, that we are watching on the sun no solid structure, but rather the upper surface of a shell of glowing clouds—clouds that move far



PLAN OF THE SOLAR SYSTEM



DISTRIBUTION OF SPOT-CENTRES IN LATITUDE, ROTATION BY ROTATION, 1877–1902.

The sun's surface for the purpose of the above diagram has been divided into zones of latitude each one degree wide, and the time into 'rotations' of about 27¼ days. Wherever a spot-centre has fallen on one or more days during a given rotation in a particular degree of latitude, a line has been drawn across that particular degree. The diagram, therefore, represents the distribution of spots in latitude, but takes no account of their areas.

more freely, far more quickly, than any clouds in our atmosphere.

Next, as to the peculiar haunts of sun-spots on the sun, we have seen in the Story told by the Sun's Surface that he turns on his axis in about twenty-five days, as the earth turns on hers in twenty-four hours; so that he, too, like the earth, has his poles and an equator. It is very rarely that any spots are found outside the parallels of the sun's latitude that are 35° north or south of the equator. A very few have been found in a latitude so far from the equator as 40°; one spot has been seen in 50°; but all of these were very small, and lasted for no longer than two or three days. The seas in which we find the solar whales are 'tropical' or 'sub-tropical.' Should we compare the spot-zones with those of our geography, we should include the whole of the inhabited region of the southern hemisphere; but we should exclude, in the northern hemisphere, all Europe, Canada, and all the northern confederacy of the United States, and all Siberia.

Nor do the solar spots migrate freely between these limits of 40° north and south of the solar equator. Rather there seem to be narrower zones within which the spots that arise there may move, but beyond which they may not transgress. This seems the first law laid upon them.

The next law seems to be that in any particular zone on the sun's surface spots do not arise at all times, but only at particular times do spots seem to be formed. There are long intervals when the zone breeds no spots at all. (*See* Plate XXIV.)

The third law seems to be that though spots do not stray from one zone to another, there is a bond of connexion between the different spot-breeding zones, for there is an order observed in the times of breaking out of spots in neighbouring zones.

Let us take an example from the southern hemisphere, and divide it into zones 5° wide.

Southern Hemisphere.

5° zone in Southern Hemisphere.	Period when spots were visible.	Period when no spots were visible.	Period when spots were visible.	Period when no spots were visible.
30°–35°	1880 July – 1881 Apr. } ¾ yr.	9 yrs.	1890 May – 1893 Nov. } 3½ yrs.	9 years.
25–30	1880 Feb. – 1884 Mar. } 4 yrs.	5¾ "	1889 Dec. – 1895 Mar. } 5¼ "	7 "
20–25	1880 July – 1885 Aug. } 5 "	4 "	1889 Aug. – 1896 Aug. } 7 "	4 "
15–20	1879 Dec. – 1887 Nov. } 8 "	1¾ "	1889 Aug. – 1898 Apr. } 8⅔ "	3⅙ "
10–15	1880 Dec. – 1888 Dec. } 8 "	2½ "	1891 June – 1900 Apr. } 8⅚ "	2¾ "
5–10	1881 May – 1890 Aug. } 9¼ "	2 "	1892 July – 1902 Feb. } 9⅔ "	1¾ "
0–5	1882 Mar. – 1889 Aug. } 7½ "	3⅓ "	1893 Dec. – 1903 June } 9½ "	2¼ "

There are several interesting points to note about this table. In the first place there is quite a long interval of time between two outbreaks of spots in any of the zones; always a year or two, perhaps many years; so that there is no doubt as to when an epidemic of spots begins and ends in any particular zone. Next, the time during which the outbreaks last is shorter, and the interval between the outbreaks is longer, for the zones which are farther from the equator, than for those nearer to it. It is as if our solar whales belonged to different species in the different zones, and sought the solar depths for periods of time that varied with their distance from the solar equator; and then brought the young schools to the surface to sport for lengths of time that again varied with their distance from the solar equator. Third, the whole time from the beginning or end of one outbreak of spots until the beginning or end of the next does not greatly differ for the different zones. If a school of solar whales stay long upon the surface, it must stay the shorter time below; and the two times together make up about eleven years. Fourth, the outbreak of spots in the zones far from the solar equator begins earlier, and therefore ends much earlier, than those outbreaks that are near the equator. This is so marked, that we have a new outbreak starting in the highest latitudes before the old outbreak in the lowest latitudes has subsided. During a period, then, of about eleven years we seem to have an outbreak of spots on the sun beginning in the regions farthest from his equator, and spreading to the lower zones, increasing for a while as it spreads. Finally it dies out at the equator, when a new outbreak of spots has already started in high latitudes. This period of change is called the sun-spot cycle.

The first spots of a cycle are few and small. During the next three, four, and five years they increase rapidly in number, and many of them in size, and they occur most frequently in latitudes that lie between 10° and 25° from the sun's equator. Their number, and the spots of large size, are fewer and fewer during the next six years or so, and the spots that appear are frequently in the lower latitudes. The last spots of a cycle, again are few and small.

What do we mean by *small* spots or *large* spots? We measure whitings by inches, whales by feet, and islands by miles. What is the measure that we should apply to sun-spots? We measure them in terms of the space on the sun's disc that they occupy: in millionths of the sun's visible surface. The smallest spot that we measure would occupy about the one millionth of the sun's disc, and the biggest might occupy as much as three thousand millionths. To know how big any sun-spot is, we must therefore know how big the sun is. This we found in the last chapter has a diameter of nearly a million miles, so that the surface of its hemisphere visible to us is more than a million million of square miles; therefore, the smallest spot we can measure covers an extent of ground of at least a million square

WEST

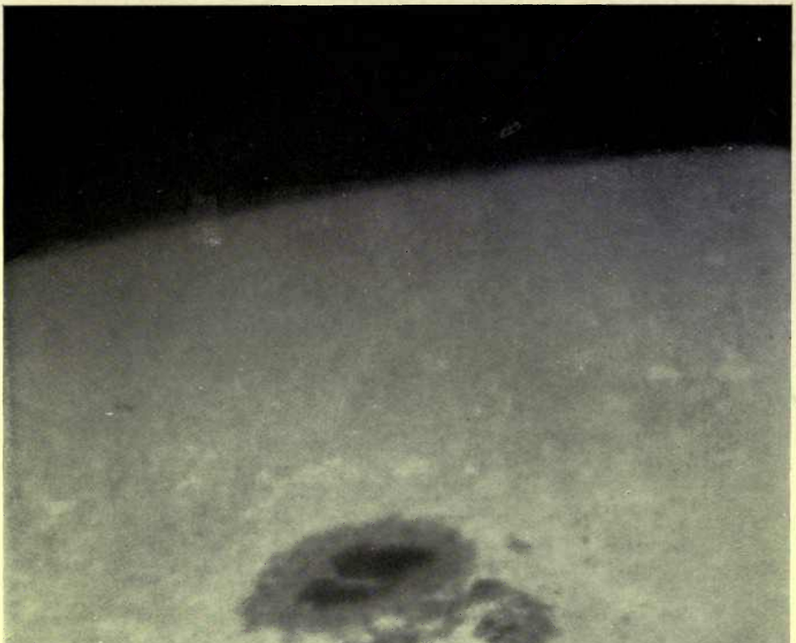
SOUTH

NORTH

EAST

PLATE XXVI.

WEST



EAST

Photograph of a great group of Sun-spots, taken at the Royal Observatory, Greenwich, August 3, 1906.

miles, the bigger spots hundreds or thousands of times this area. The smallest spot we measure would be about half the size of Russia, Poland, and Finland together; into the larger spots there might be poured worlds like ours as peas are poured into a saucer. (*See* Plate XXV.)

As a general rule, the bigger a sun-spot the longer it lives; but the life of any sun-spot, huge though it is, is but short, as we reckon time. Very many spots do not last through the twenty-four hours of our day; the area that an average spot of this longevity would occupy is about twelve millions of square miles. The average area of a group of spots lasting for eight days is about twenty-two millions. The longest time that any group of spots has lasted, during the last quarter of a century, has not been as much as seven months. The disturbances of the sun's surface are stupendous and on a vast scale, but they do not last for long.

The sun-spots do not stray from their peculiar zones, but in the zones they move with considerable freedom. The Law of the Stars is that they neither haste nor rest, they do not jostle each other nor lag behind. Not so with sun-spots. They move more quickly or more slowly, they may jostle each other or move apart; the same spot does not move always at the same pace. The very zones seem to move at different rates, the low latitude spots moving as a rule more rapidly than the high latitude. The rate at which the sun, as a whole, appears to turn round may not be the rate at which any spot travels; it is but the average rate of all the spots, taken at all times.

What causes the spots we do not yet know. We may never know, for their cause seems to lie deep down in the sun itself, and we can but see the sun's surface; we do not know how to probe beneath it. We cannot tell if it is the same cause that gives rise to the outbreak of spots in each zone, eleven years after eleven years. If the spots are the same, cycle after cycle, we have no means of recognizing them. We can recognize again a star by its place in the pattern of stars; we can do the same with a planet by its colour and its movements; we can know again an island on the earth, for it does not change its place; we can even know again a whale if it has had a harpoon driven into it; but how are we to know a sun-spot when it emerges again from the solar depths?

We do not know what makes the sun-spots, or what brings about their changes. We have learnt, nevertheless, some of the laws that seem to govern their changes, some of the fixed rules that they obey. Of the laws of faculae we know less than of sun-spots; we cannot see them except near the sun's edge. (*See* PLATE XXVI.) We know that they too lie in zones of latitude, and these zones extend farther from the sun's equator than do the sun-spot zones; that they diminish and increase in a cycle of years as do the sun-spots; that they move at a different rate from the sun-spots. We know that they change, but their forms are not defined as are the spots, and we do not know their manner of change, or their lengths of life. Of the grains and granules that cover the sun's whole face we know still less. We can see that they change continually and rapidly, but how they change, or if their changes run through a cycle, we do not know.

CHAPTER VIII

THE STORY TOLD BY THE SUN AND MOON TOGETHER

WE cannot see the stars in the daytime. This is not because the stars are not there, or have lost any of their brightness, but because the sun is himself so bright that he lights up the atmosphere, and we cannot distinguish the brightness of the stars from the brightness of the sky. We have to wait until the sun is gone down below the earth, and no longer lights up the night sky, to see the shining of the stars. We do not see the sun's bright faculae in the middle of his disc. That is not because there are no faculae in the middle of the sun's round disc, nor because the faculae there have lost their brightness. It is because the middle of the sun is as bright as the faculae that we cannot see the one for the other. We can only see the brightness of the faculae near the sun's edge where the sun's atmosphere has dimmed its brightness. We do not see the light of a candle if we hold it up between us and the sun. It is not that the candle flame has lost its light, but it is because the flame is not brighter than the sun. To see the shining of the lighted candle we must hold it away from the sunlight, or else we must put something, a book or some screen, between the flame and the sun.

How can we tell, then, that we see everything that there is on the sun, or near the sun? The sun has an atmosphere, we know, for it dims the sun's light near his edge. Can we see this atmosphere extending beyond the sun? Can we tell if there is anything but atmosphere surrounding the sun? Heliography is so different from geography that we cannot be certain unless we know; sun-spots, for instance, behave more like whales than like continents or islands.

It is no use to hold a screen up to shut off the sun's direct light. The sun still lights up the air in the sky so greatly that we could not distinguish any other light. We would need to hold the screen right outside the atmosphere, far away in the airless space that lies between us and the sun, where it would prevent the sunlight falling on the earth's air. We have no pole long and steady enough to hold up such a screen.

There is one object that might act as such a screen. The moon appears to us to be of very nearly the same size as the sun, and we know that she is in herself a dark globe. If, then, the moon were exactly in a line with the sun and earth, she would blot out a part or the whole of the sun. Here, then, is the screen that may allow us to see the sun's surroundings by covering up the sun itself. But to do so, the moon must cover the whole of the sun; if she only partially covers him, his uneclipsed part is brilliant enough, be it never so small an arc of sunshine, to drown the sky and all near him in a sea of light. When the moon completely covers up the sun's disc, she does so only for a short time; it may be for a few seconds, or at the very longest, eight minutes. She does so rarely; on an average there may be once in two or three years a total eclipse of the sun where it is possible to observe it. The whole amount of time available in half a century of eclipses may not exceed an hour.

One of the most impressive sights that the heavens afford us is an eclipse of the sun. When the sky is clear and the sun unclouded, then there is little time to spare for anything terrestrial. One observer, at Algiers, of the eclipse of 1900, describes it thus: 'The sky was deep purple, while over the sea was a strange light on the horizon; a compromise between a thunderstorm and a sunset. The colour faded from the sea and trees, a shouting and wailing arose from the square below, the light was fading; suddenly the moon slipped over the sun and the eclipse was total. A deep purple sky, a black globe, surrounded by a crimson glow, and above and below it a milk-like flame, stretching its long

PLATE XXVII.

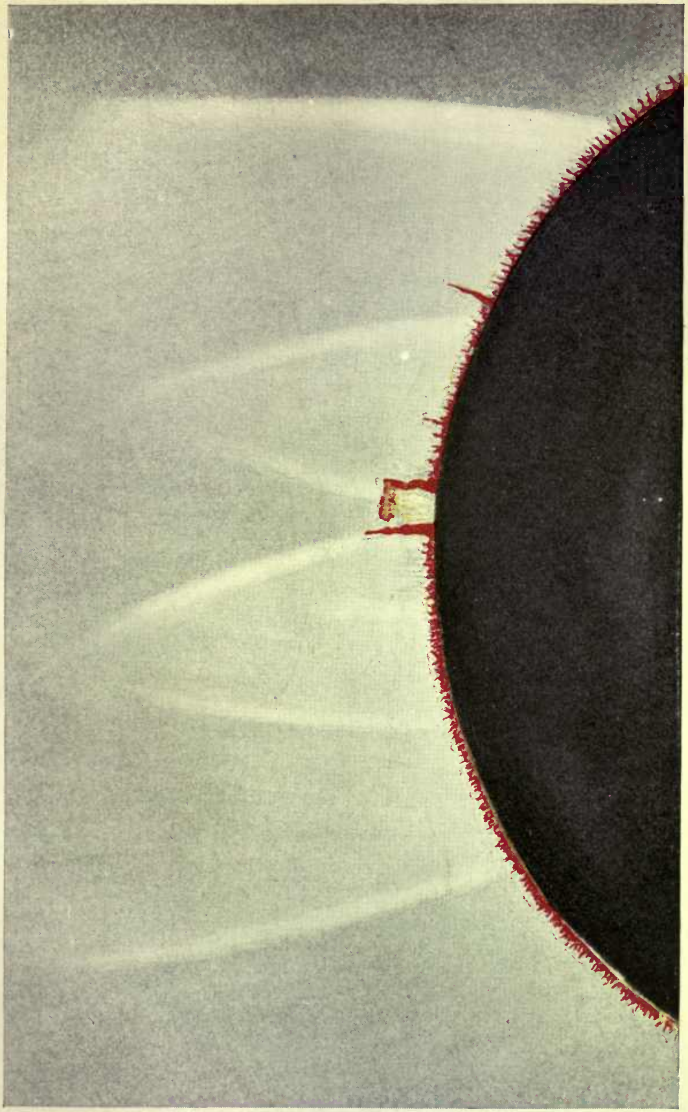
streamers away into the purple.' But when clouds hide the eclipsed sun, then the weird effects, upon landscape and seascape, of the sun darkened whilst it is yet day, are the only observations that can be made. An astronomer writes of the cloudy eclipse in Lapland of 1896: 'I observed that the clouds, which had been lightish grey, had suddenly assumed a very deep blackish-purple colour, while the whitish spaces between the clouds were glowing with a vivid amber-yellow tint. It seemed that the whole scene was illuminated by this amber light; the colours of objects around were quite perceptible, but much subdued. The distant hills were dark indigo, and the sea very dark, except where it reflected the streaks of amber light. The whole effect was lurid and impressive in a high degree.' And yet another observer of the same eclipse likened the cloud-covered sky to a purple pall with a golden fringe, canopied over the earth. Lord Hampton, also an observer of this same eclipse, painted the scene, and his painting is here reproduced by the kind permission of his son and daughter. (*See* Plate XXVII.)

There is not much time then for us to study the sun's surroundings. And when the moon has completely covered the sun, we see that there is so much in his surroundings that is novel and unlooked-for, that we have a good deal to study.

The moon has completely covered up the sun's disc;

and as the sun and moon appear to be just about the same size, the moon can only just cover the sun, with but little, if any, to spare. Instead of the brilliant orange-coloured sun, we see blackness, for the moon gets no light now except from the sunlit earth. But round this blackness, fringing it, is a bright, red, ragged rim. This does certainly not belong to the moon—whether we see her waxing, or full, or waning, we see her outline hard and sharp, either sharp moonshine or sharp blackness. This red, ragged rim belongs, then, to the sun—it looks as if he were covered with a fiery red Turkey carpet, whose burning pile was pulled and torn. Everywhere round the moon's edge is seen this red rim; everywhere, then, on the sun does it lie. (*See* PLATE XXVIII.)

But this red rim is not all. Here and there are tongues of flame. Not the peaceful, steady flame of a bat's-wing gas burner, but twisting, turning serpents' tongues. They are not always most like flaming tongues; sometimes they are tree-like: trees spreading as do the cedars in Turner's pictures, or burning, bent and bowing under a strong wind, and shedding their fiery leaves in the blast like a flaming shower. There are tongues of silver flame sometimes, as well as tongues or trees of red fire. And enveloping both in a wonderful, pure, cold radiance, stretching out far beyond them, is a silver glory: not a halo only, but a crown, a glory like nothing else that we see on earth or in



Telescopic View of the S.W. Quadrant of the Corona, May 28, 1900.
(*Drawn by Miss Lilian Martin-Leake.*)

the heavens. We must compare it to many things, for no one comparison can convey what it is like. It is like a silver mist, it is like ivory gauze, it is like the wings of an angel, it is like the petals of the lilies of heaven. Its form takes on here and there the shape of a flower-leaf, and when I saw the sun's eclipse in 1898 it seemed to me as if a child had been playing the game of 'Loves me, loves me not,' until but three or four of the sun-flower's petals had been left on the red-rimmed, black-hearted stalk. (*See* PLATE XXXVII.)

Red rim, fiery flames, and silver radiance—'chromosphere,' 'prominences,' and 'corona'—are there whether or not we can see them, whether or not the sun is eclipsed. In every eclipse we see them at the edge of the sun. But though we can only see them at the edge of the sun when it is undergoing eclipse, since the sun turns round, all must be everywhere on the sun's surface, no matter in what direction it is presented. On the sun's disc turned towards us there must be, not only the granules, spots, and faculae that we can see, but also the chromosphere, prominences, and corona that we do not see or recognize.

All these belong to the sun. What connexion have they with each other? What effect have they on each other?

These questions we can only answer in part as yet, for they are some of the problems that we are still trying to solve, and for the answer we go to the ends of the earth to see an eclipse of the sun. The corona we can, as yet, only see during a total solar eclipse. The spots, faculae, and granules we cannot see during an eclipse, for then they are covered by the moon. Prominences and chromosphere we see during an eclipse; but, by means of the spectroscope (*see* Chapter IX.), we can see the chromosphere and some of the prominences when the sun is not in eclipse; some of the prominences only—the scarlet ones, but not the white. Here, then, is a connecting-link, by which we may perhaps learn if sun-spots have aught to do with the corona.

As we have said, red rim, fiery flames, and silver corona are there whether we can see them or not; but they are not always the same. They are different in form and shape and place from one eclipse to another. Is this because they turn with the sun, and we see a different edge in each eclipse? or do all change continually, and in cycles of years, as do the spots, the faculae, and the granules on the sun's surface?

The prominences rotate with the sun. Whether the sun is eclipsed or not, whether we observe them without the spectroscope or with it, we see their form and their changes when they are on the edge of the sun. But we see them coming out of the visible hemisphere upon the eastern edge, and we can see them disappear

PLATE XXIX.

ERUPTIVE AND QUIESCENT PROMINENCES.

The upper group of prominences was observed on April 29, 1872, at $10^h\ 5^m$ a.m. It changed its form very rapidly. Its extreme height at the time of observation was 90,000 miles. The lower group was observed on April 15, 1872, at $10^h\ 0^m$ a.m. Extreme height, 70,000 miles. Observer, L. Trouvelot.

From 'Astronomical Engravings,' published by the Harvard College Observatory.

at the western into the sun's hemisphere that is turned away from us. In this way they behave just as do the sun-spots. Therefore, the differences in the prominences that we note at different times is due *in part* to different regions of the sun being presented edgewise to us. But only *in part*, for even as we watch the prominences stretching beyond the sun's edge, we note that they are changing, continually changing, as do sun-spots, and even more rapidly. We may watch a prominence spring actually into existence, flame up to a height of thousands of miles, and die out again; and all this within the space of time of two or three minutes. Or the prominence that we have watched on the eastern edge may last so long, as still to exist when it has traversed the sun's breadth and reached the western edge. Sun-spots change, and so do prominences. (*See* PLATE XXIX.)

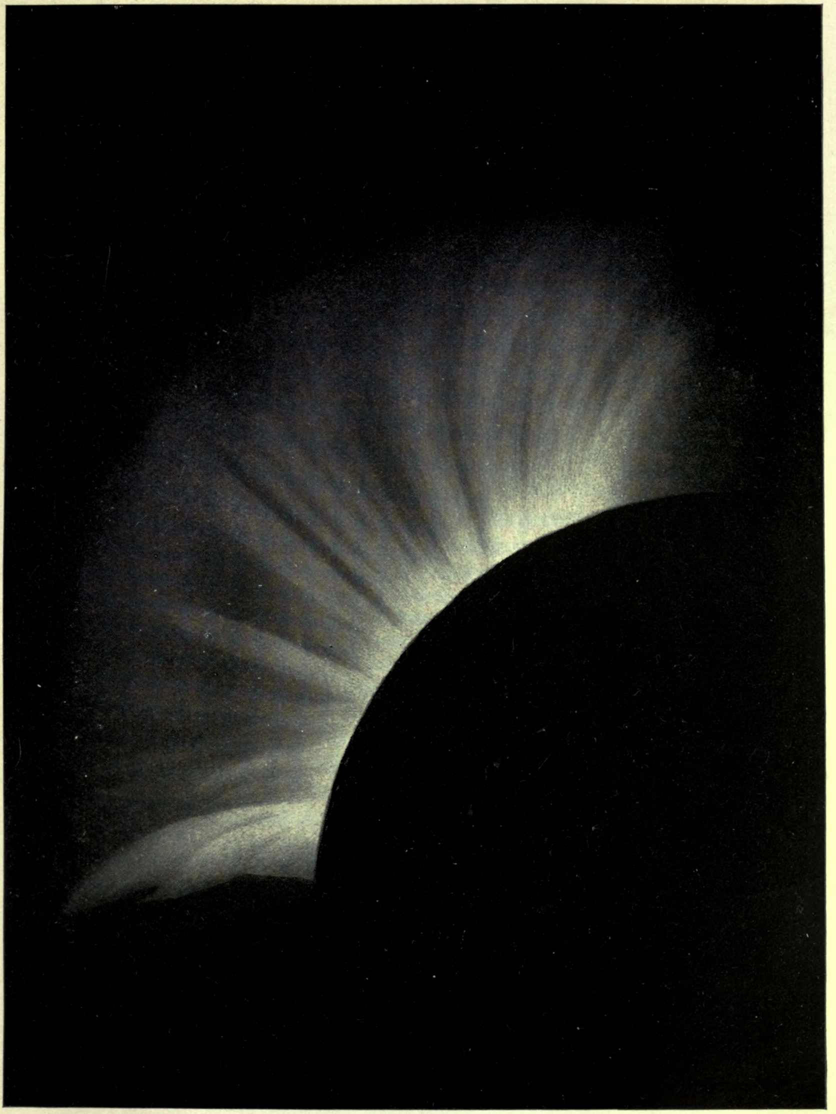
Both change in cycles. Sun-spots and faculae increase, multiply, diminish, and increase again, in cycles of about eleven years. So do prominences; though the three may not coincide, even within a year or two, in their epoch of greatest or least display. Sun-spots have their zones of latitude beyond which they are not found; so have faculae, but their zones extend further from the equator. So, too, prominences have their favourite zones, and their zones extend farther still, almost up to the sun's poles.

There are points of closer connexion still between sun-spots and prominences. There must be prominences where there are no spots, for we find those near the poles where these never break out. But if we observe with a spectroscope the place on the sun's edge where a great and changing spot is just coming or passing away, there we are sure, or almost sure, to find great and rapidly changing prominences. Sun-spots seem to spout forth prominences.

The corona seen during one eclipse is not the corona seen during another. Is this because the corona rotates with the sun, or because it changes in itself?

We cannot say that the corona rotates as do the prominences, spots, and faculae; we cannot say that it rotates as one with the sun, or not as one with the sun. We have failed to make any successful observations of the rotation of the corona on the sun itself.

But we do know that it changes its form, and we know that it does so in some sort of sympathy with the changing prominences and sun-spots. When there are many sun-spots, and they are scattered widely over the zones in which they may appear, then the silver petals of the great sunflower are many, and surround the whole of the stalk. The child has not begun to play the game of 'Loves me, loves me not,' has not plucked out any of the silver petals, but has only ruffled them, broken them, cramping one behind another in a bunch



SOUTHERN REGION OF THE CORONA OF MAY 18, 1901, showing the polar 'plumes.'

(*From a photograph by Mrs. Walter Maunder, taken in Mauritius.*)

EASTERN REGION OF THE CORONA OF MAY 18, 1901.
(*From a photograph by Mrs. Walter Maunder, taken in Mauritius.*)

here, or spreading them out thin there. But he plays his game as the spots diminish and creep downward to the sun's equator; the petals are ruthlessly pulled out, and if we look upon the eclipsed sun at such a time, we see but the short protecting leaves, and here or there a long petal remaining, looking longer by its solitariness; and when the cycle has reached its time of minimum activity, and the sun-spots lie only in two narrow zones to the north and to the south of the sun's equator, then the resemblance to the silver sunflower has departed, and the sun's corona has become like four great wings: angels' wings, folded wings; one pair stretched along to the east of the sun, the other pair to the west. Whilst round the north and south poles of the sun a beautiful row of fine plume-like rays is seen, each plume bending more or less away from the pole. The corona, like the prominences, the spots, and the faculae, has its cycle of changes, which it runs through in about eleven years. (*See* PLATE XXX.)

But there is a closer connexion still between the changes of spots, prominences, and the petals of the corona. Spots give forth or spout prominences, and the base of the corona petal seems to envelop or stand upon the spot group, though stretching out far beyond it on all sides. Directly above the prominence the material of the petal seems forced up to form a dome, or rather, a series of domes or groined arches. The prominence looks as if it were sheltered beneath a number of glass cases. (*See* PLATE XXXI.)

As the prominences and spots change, so they seem to change the form of the corona lying round and just above them. Nowadays, astronomers strive to observe an eclipse at places very far apart, because it takes time for the shadow of the moon to travel along its path on the earth. So the observers who watched the eclipse of 1901 in Mauritius watched it an hour and a half earlier than the observers who saw it in Sumatra. And it was thus found that, in such an interval of time, the shape of the corona near the chief spot and prominence underwent a distinct alteration.

What is the shape of the silver petals of the great sunflower? At the broad base of it we often find a spot or prominence, or both. Spots and prominences rise, live their life, which may be but a very short one, and die. And there rise again—in the same zone, it may be from the very same region—other spots. From these zones, from these very regions, perhaps, the great silver petals spring. If the active regions are in the high latitudes and in many zones, then many petals arise; if the sun is quiet and the few spots that break out lie near his equator, then the petals are few and lie folded along the equator.

But the petals do not have a round or pointed tip; the outermost groined arch that covers the place where the prominence is, or has been, is not complete, but seems to taper out indefinitely into a long, rod-like ray. How long the rod-like ray extends we cannot see. One that was photographed in the eclipse of 1898 was seen to stretch out from the sun for at least eleven millions of miles. In the Story told by the Sun and Earth together (Chapter X.), we shall see that such a length is probably but a small fraction, but a tithe, of its extent.

CHAPTER IX

THE STORY TOLD BY THE SUN'S BROKEN LIGHT

THE earliest astronomy was learned by the exercise of the unaided sight. Men watched where the sun appeared to rise and set, they noticed the changing phases of the moon, and how different constellations of stars were seen on different nights of the year, and from these, and many other such observations, they formed their first ideas of the relation of the earth to the rest of the universe. Three hundred years ago the telescope was invented, and 'astronomy' took on a much wider meaning. Men were able to read far more in sun, moon, planets, and stars than they had ever dreamed of before. But just as the astronomy of the telescope had advanced far beyond what was possible to the astronomy of the unassisted sight, so, fifty years ago, a new instrument extended men's powers of research far beyond anything which the telescope could have done, and gave birth to a yet newer and more searching astronomy still.

This newer astronomy might well be called the

'Story told by the Rainbow,' for the many-coloured arch of light 'seen in the cloud in the day of rain' is at once the type and an example of the principle of the new science.

We know that if sunlight is allowed to fall upon a triangular piece of glass, a rainbow-coloured strip of light emerges from it. At one time it was much the custom to have chandeliers and gasaliers of glass hung with a number of long, triangular glass pendants. The light falling on such a chandelier would pass through it to form a great number of beautifully coloured images on the wall behind. The light fell upon these prisms, as the triangular pieces of glass are called, as white light; it came forth as coloured light.

The explanation of this is simple. Light is made up of an infinite number of very small vibrations, or waves, and these waves are of different lengths, the longest giving us the impression which we call red; the shortest the impression which we call violet. Now, light moves forward in straight lines, but when it passes from one medium, like air, to another medium of a different density, like glass, it is bent out of its course and travels in a different straight line through the second medium. Passing out of that second medium again into the first, the course is again changed, and the amount by which it is changed on each occasion depends partly on the relative density of the two media, and partly on the angle at which it meets the new surface.

Here it is that the principle of the prism, of the triangle, comes in. A ray of light passing through a sheet of glass with parallel sides would be turned out of its course indeed, but its final course would be parallel to its original course, because its change of direction on leaving the glass would be just the reverse of that on entering it. But if the two sides of the piece of glass are greatly inclined to one another, in other words, if the glass is a prism, then the direction of the light after leaving the prism is quite different from that which it had before entering it.

This is what is called the *refraction* of light, but there is another effect. The very short waves of light are turned more out of their course than the very long. Consequently, the many different waves which entered the glass all in company leave it separately. If we had a company of men advancing at the double over smooth ground they would keep together, but if they came on a piece of difficult ground, irregular broken ground, with long grass or brushwood, wedged into the smooth plain, the stronger, bigger men would work their way through most quickly, and with least change of their direction; the smaller, weaker men would be most hindered, and the company would emerge no longer together, but straggling.

In like manner, light falling upon a prism enters it as a full company, compact and close, of all the different coloured rays, and when all the rays thus reach our eyes together, they produce upon us that sensation which we call white. But such white light leaving the prism, leaves it straggling, each colour following a different path, each colour therefore seen more or less separately, so that, instead of white light, we get a rainbow-tinted band.

Now let us make this experiment more carefully. We will take a western room on which the sun is shining as it nears its setting; we will close the shutters, but in one of the shutters we will bore a small round hole (A), so that the sunlight falls on the opposite wall and makes a round bright spot (*i*), there. If we place a triangular piece of glass (P), just inside the hole, we find that the spot of light has greatly changed its position on the wall and instead of being round it is about five times as long as it is broad—red at one end and violet at the other (V to R), and with the other colours of the rainbow somewhat less clearly seen in the middle. (*See* Plate XXXII., fig. 1.)

Now, it is clear if there are only seven colours, and therefore seven different little coloured spots of sunlight, that these must overlap, since the whole image is only five times as long as it is broad. None of the colours therefore are quite pure, and in the centre of the band they are still a good deal mixed.

Can we get over this? The simplest way to do so would be to have a very narrow slit instead of a round hole in the shutter. In that case, we should find that the colours were far purer than they were before, and we should find also, as did Professor Wollaston, the great chemist of more than a century ago, that the rainbow-tinted band was not complete; there were certain narrow dark spaces in it. In other words, the sun sends us a great number of different colours, but not every colour possible. This we can test by substituting a very bright artificial light, like the limelight, for the light of the sun; no matter how narrow and sharp we make the slit, we get no dark lines amongst the colours coming from the limelight.

It is not always convenient to set apart an entire room for the purpose of such an experiment, and a little instrument was devised for the study of the sun's *spectrum*, as the strip of rainbow light was called, which was at once much more convenient and more powerful. This instrument was called a *spectroscope*. A metal slit (S) was provided, the breadth of which could be regulated by a screw, and this admitted the light into a tube (A), carrying a lens, called a *collimator*, at the other end. The tube was of such a length that the slit was exactly in the focus of the lens, so that the rays of light diverging from the slit were rendered parallel by it; then came a box containing a prism (P), and the

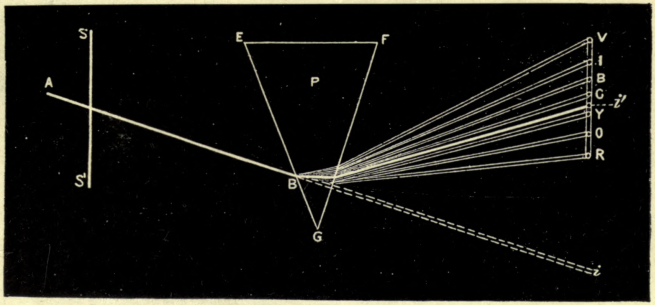


FIG. 1.—Path of Rays through a Prism.

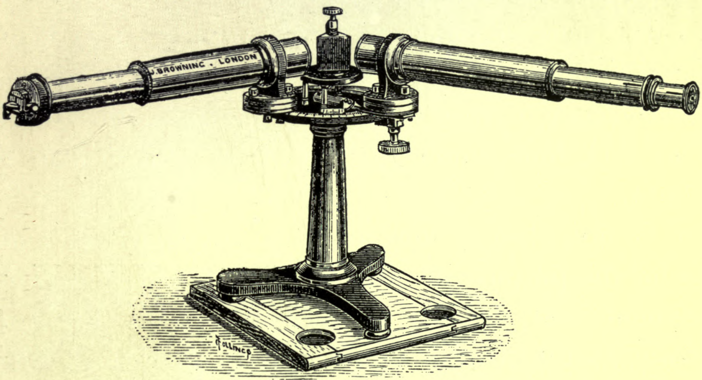


FIG. 2.—Simple Spectroscope.

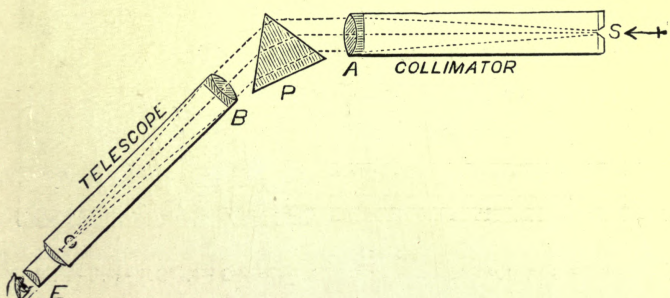


FIG. 3.—Plan of Simple Spectroscope.

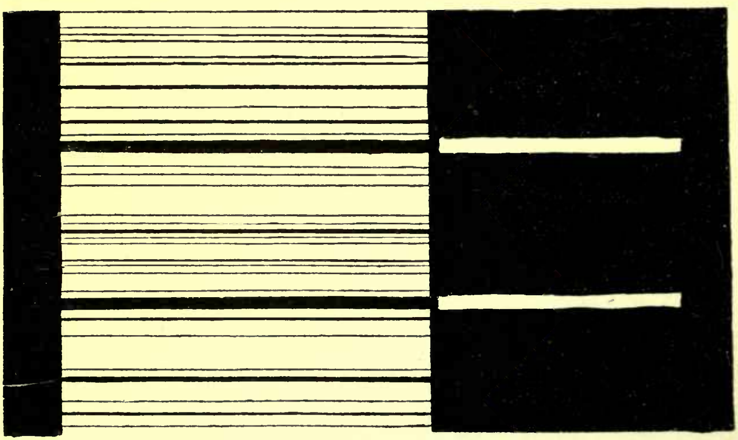


FIG. 1.—Coincidence of the D Lines in the Solar Spectrum with the Bright Lines of Sodium.

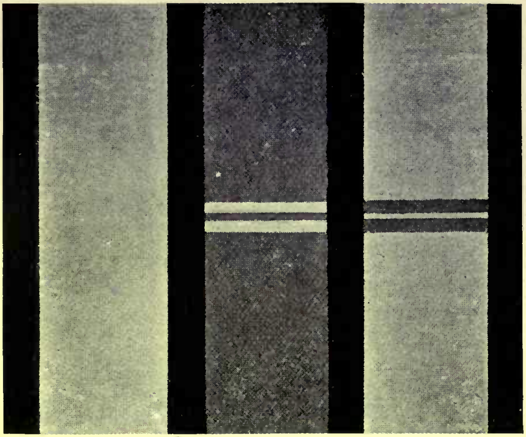


FIG. 2.—Reversal of D lines in Spectrum of Limelight.

(*a*) Continuous spectrum of white light.
(*b*) Bright lines of Sodium flame.
(*c*) Dark lines seen on viewing source of white light through the Sodium flame.

rays, after they had passed through the prism, were examined by a small telescope (B).

Such is the form of a simple spectroscope. Spectroscopes of great size and very complex form are now common, but such a simple spectroscope as that just described exemplifies the fundamental principle of all. (*See* PLATE XXXII., figs. 2 and 3.)

Turning such a spectroscope upon the sun, it was seen that its 'spectrum,' that is to say, the long coloured band into which the sun's light was spread out, was not a perfectly continuous one, but was interrupted by dark lines to the number of many hundreds, or, indeed, if a very powerful spectroscope be used, of many thousands; and that these lines were distributed irregularly throughout all the colours, making up a definite pattern which was the same from day to day. (*See* PLATE XXXIV.)

These lines of the spectrum are the characters in which 'the sun's broken light' tells its story, and at first they proved very hard to read. Some of the lines were evidently due to the influence of the earth's atmosphere, for they were seen when the spectroscope was turned upon the sun near his rising or setting, that is to say, when he was looked at through a great thickness of our atmosphere; but they got thinner, fewer, and fainter as the sun rose higher in the sky. Many more, obviously, belonged to the sun himself, since certain of the stars showed different sets of lines. The spectrum of Arcturus is very like that of the sun, but the spectra of Sirius and Vega, though very like each other, are quite different from that of the sun, or of Arcturus. The spectrum of Antares, again, is different from both. In short, many varieties were found amongst the spectra of stars; one star differed from another, not merely in its glory—in the amount of the light it gave—but in the quality of its light, and five principal types of star spectra were recognized. The white stars gave one type, like that of Sirius, some of the slightly greenish stars in the constellation of Orion giving a modified form of the same type; the yellowish stars quite another type, like that of Arcturus, or Alpha Centauri, or of the sun; the deeper coloured stars like Antares, the chief of the Scorpion, gave a third; and the red stars, of which there is no bright specimen, gave a fourth. (*See Frontispiece*, PLATE XXXIV.)

These dark lines in sun or star therefore are due to something in sun or star itself, sun and stars each sending us a message in their broken light.

It was a very common substance that gave the key to the interpretation of these strange gaps in the spectrum. If a candle or spirit-lamp be fed with a little common salt or carbonate of soda, a yellow tinge is given to the flame. When a spectroscope is turned upon such a flame a spectrum is seen which has a very bright line in the yellow, and, if the slit is made very narrow, it is seen that this bright line is really a very close pair of bright lines. These two lines are simply images of the slit, through which the light from the spirit lamp comes into the spectroscope; and we learn from it that the yellow light of the spirit lamp is due to two kinds of yellow light that differ very slightly the one from the other. In like manner the dark lines in the spectrum of the sun are negative images of the slit; the sun sends us light of many shades, but not of all, and the gaps or dark lines in the spectrum are in the places corresponding to the missing shades.

Now, if we look at the sun's spectrum we see, in the yellow, a close pair of very dark lines, corresponding in position to those given us by the carbonate of soda in the spirit lamp. They correspond so closely that if we allow sunlight to come through part of the slit of a spectroscope, and light from a sodium flame to come through another part of the same slit, we shall find that the bright lines from the flame are an exact prolongation of the dark lines in the sun. (*See* Plate XXXIII., fig. 1.)

We can go a step further. The limelight, as we have seen, gives us a complete spectrum—all the colours of the rainbow. A sodium flame gives us the two close bright lines. If, then, we look at a limelight through the spectroscope, and place a flame plentifully supplied with sodium between the spectroscope and the lime-light, what shall we see? A bright spectrum of all the colours with two lines specially bright in the yellow? No. We see a spectrum with the full succession of colours, except in the yellow, where there are two dark lines. Remove the sodium flame and the spectrum is complete. Remove the limelight, and have the sodium flame alone, and we have the two bright lines. View the limelight through the sodium flame, and in the place of two bright lines we have two dark ones. To the extent of these two dark lines we have built up an artificial solar spectrum. The sodium flame, which had the power of sending out light of these two particular shades, has also the power of stopping light of these two shades; and the lines which it gives look dark because they are so much fainter than the corresponding portion of the bright limelight spectrum. (*See* PLATE XXXIII., fig. 2.)

This is the reading of one set of characters written for us by the sun in his broken light. His bright surface sends out light of every shade—white light—but round him, enveloping him, are highly heated, glowing gases, themselves giving forth light of certain particular shades or colours, and therefore opaque to those same colours. These gases, if we could see them by themselves, would give us spectra of bright lines; but when we look at the body of the sun through them, they stop out the light corresponding to those lines and give us dark lines. In this way we have been able to recognize the presence round the sun of a number of elements with which we are familiar here, but in a different state. Hydrogen, here one of the two constituents of water, is there a free gas. Iron, nickel, cobalt, magnesium, and many other metals here always solids, are there always gases, glowing with intensity of heat. The same elements have been recognized also in the stars, but in apparently different proportions in different stars; at least, the evidence for their presence is given in different manner.

There are times and seasons when we can see these gases by themselves, apart from the sun's light. Some of them, as, for instance, hydrogen and calcium, surround the sun to such a depth that we can put the slit of the spectroscope pointing some distance away from the edge of the sun, and yet have some of these gases within its field of view. In this way we are able to recognize the presence round the sun of a shell three thousand miles deep, largely composed of hydrogen gas, from which great flames—prominences or protuberances, as they have been called—shoot up from time to time to a distance, in some cases, of more than 100,000 miles.

Of these prominences or red flames we first learnt during total eclipses of the sun, when the dark body of the moon had cut off the direct light of the sun from us, and a great number of the elements more closely surrounding the sun show their bright lines to us, for a couple of seconds, at the beginning and end of such a total eclipse.

The stories which have been told by the broken light of sun and stars would require an entire volume as large as this to summarize even in the briefest fashion. But there is one further fact told by them that must be mentioned here. They have not only told us that the sun is made up of elements known to us on the earth, and that those elements are there in an extremely highly heated condition, but they have been able to tell us of movements of those elements, or of sun and stars themselves. It sometimes happens that a vast quantity of glowing hydrogen gas is shot forth from the part of the sun that appears to us as its edge, and we then see it travelling away from the sun, for it is moving across our field of view; it seems to be moving on the vault of the sky. But it may happen that such a stream of hydrogen may rise from the very centre of the sun's disc and come straight towards us. Or it may be that we are watching a star, and that from some cause or another, the star is moving with great rapidity in a straight line either towards or away from the earth. These motions are what we call 'motion in the line of sight,' or 'radial motion,' because it is motion along a radius having the earth for its centre. Now, if the star or the hydrogen gas is coming towards us, then the fact of it so approaching us will make the waves of light appear little shorter than they really are ; we shall meet more of them in a second of time than we should otherwise have done. Any particular line, whether bright or dark, in the spectrum of the body thus approaching us, would therefore seem to be shifted just a little towards the violet end of the spectrum, the end of the short waves. If the body were moving away from us, the shift would seem to be towards the red, the end of the longer waves. In this way we have been told of movements towards us or away from us, whether of gas streams in the sun, or of stars far in the depths of space—movements which formerly it seemed hopeless that we should ever detect.

CHAPTER X

THE STORY TOLD BY THE SUN AND EARTH TOGETHER

WE have already seen how great are some of the spots that form upon the sun. Thus on February 13, 1892, there was a great group on the sun, the principal member of which was 92,000 English miles in extreme length, and 62,000 in extreme breadth. Smaller spots accompanying the chief disturbance were seen round it on every side, so that the entire group was 162,000 miles in extreme length, and 75,000 in extreme breadth. The area covered by the chief spot was close upon 3,000 *millions* of square miles, or, including the smaller spots that clustered so thickly round the central one, the area covered by the whole group was upwards of 3,500 millions of square miles. Such an area is more than seventeen times that of the entire surface of the terrestrial globe; or, to put the matter in another way, some seventy worlds as large as our own could have lain side by side in that immense hollow.

Even larger spots than this have occasionally been seen. In February, 1905, another great outbreak attained an area of very nearly 4,000 millions of square miles, and groups of half that size are not very infrequent objects.

Now, at first sight, it would seem as if a spot of such dimensions could not fail to produce a great effect upon the earth. If there was an object as bright as the sun, surface for surface, and of the same apparent size as the great spot of 1892, shining in the midnight sky, it would give us more light than 3,500 full moons, and 130,000 times as much as all the stars in the heavens put together. Now as the spot appears to us to be dark, it might seem that whilst it was marring the sun we were losing this enormous amount of sunlight. Indeed, when we compare the position of the earth with that of the other planets dependent on the sun for their light, it seems manifest that the spots represent a most important loss; for the entire sun does not look nearly as large from Uranus as this great spot appeared to us. Even Saturn, bright and readily seen as that planet is, does not receive much more than twice the light from the sun that we receive from a part of the sun equal in area to the sun-spot.

These figures have led many people to expect an immediate and striking change upon the earth in answer to the formation of a great spot upon the sun. The spot is so really vast, so much greater in size than the little world on which we live, that it seems quite natural at first sight to ascribe a great influence to it.

So, from time to time, we hear it said, if we have a hot season, that it is due to there being many spots upon the sun, or else to the sun being free from spots. And in just the same way we find the same said if we have cold seasons, or rainy seasons, or dry seasons. Any weather that is at all irregular is at once ascribed to the presence of spots on the sun, or to their absence. Now, the amount of rain that we get in England varies from one year to another. Let us take the rainfall as registered at Greenwich, and compare it with the area of the spots observed on the sun. It is only necessary to look at the two curves to see that they have no connexion with each other. There is a sort of regular swing about the changes in the sun-spot area in eleven years or so; there is no such regular swing in the changes of the rainfall. Sometimes a very dry year, sometimes a very wet year, falls when there are most spots on the sun; and exactly the same thing happens when the spots are very few. (*See* PLATE XXXV., fig. 1.)

But England may not be a fair example, and a much more hopeful and important inquiry has been set on foot as to whether the famines in India may not in some way correspond to the variations on the sun. So far, no connexion has been definitely established; the nearest approach to such a connexion being a possible greater

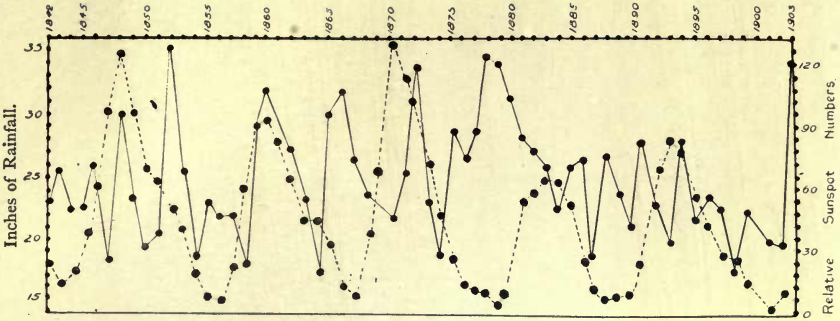


FIG. I.—CURVES OF SUN-SPOT AREAS AND ANNUAL RAINFALL.

The dotted line shows the numbers of Sun-spots, year by year ; the continuous line the Annual Rainfall at Greenwich (expressed in inches) for the same years.

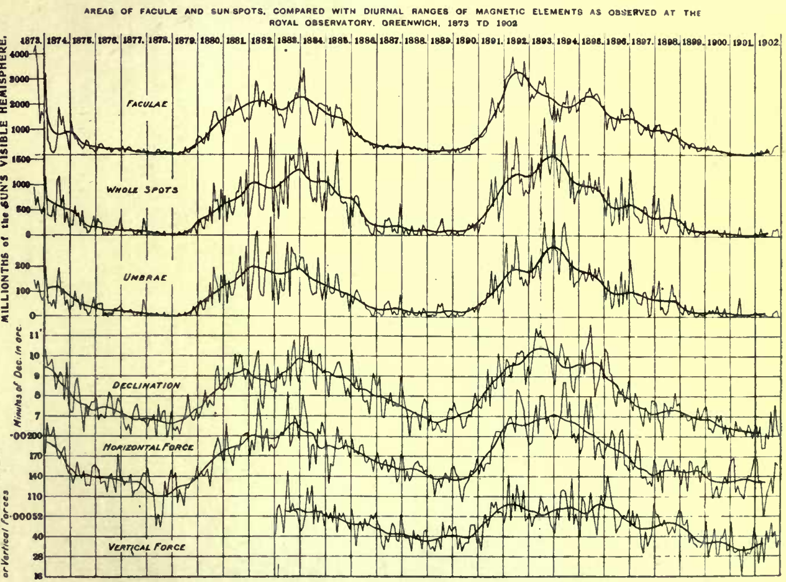
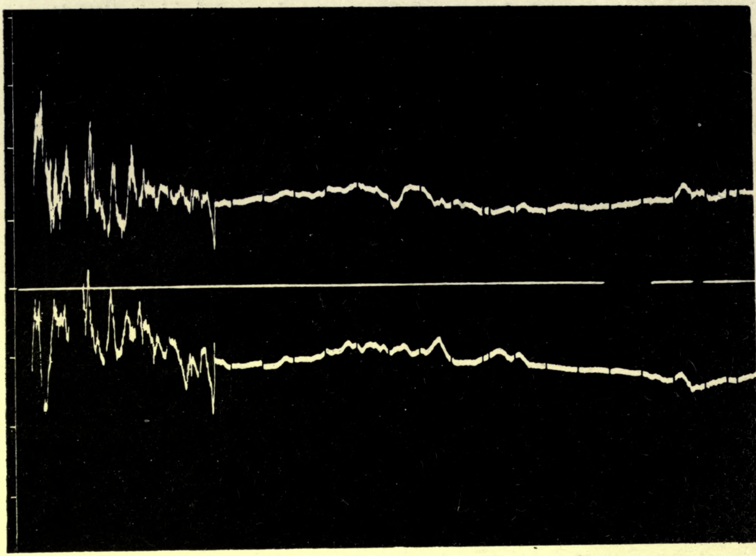
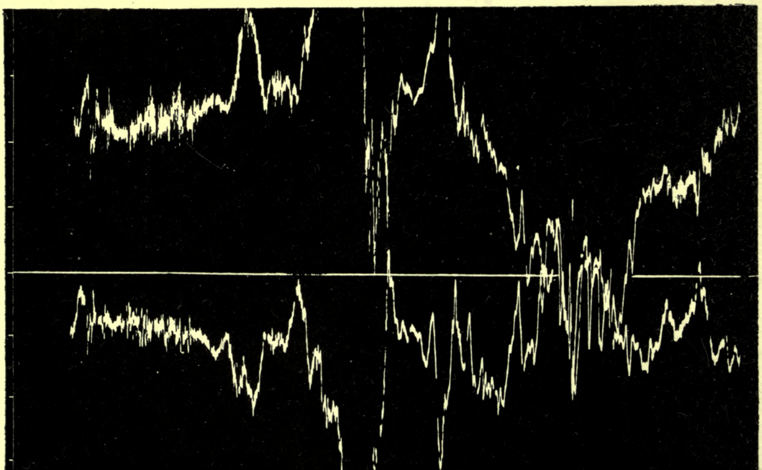


FIG. 2.—CURVES OF SUN-SPOT AREAS AND MAGNETIC DAILY RANGES.



Horizontal Force.
Declination.
1892, February 12 noon to February 13 noon.



Horizontal Force.
Declination.
1892, February 13 noon to February 14 noon.

PHOTOGRAPHIC TRACE OF MAGNETIC STORM OF FEBRUARY 13, 1892.

(*From the photographic registers taken at the Royal Observatory, Greenwich, from noon February* 12 *to noon February* 14.)

The upper register shows the abrupt beginning of the storm and the contrast between the normal and the disturbed traces.

frequency of famines or scarcities in *one* province of India—the Madras Presidency—when spots are relatively few.

And if we think over it, there is no reason for surprise that we should find it very difficult to make out any connexion of the kind. A spot like that of February, 1892, is enormous of itself, but it is a very small object compared with the sun; and spots of such size do not occur frequently, and last but a very short time. We have no right to expect, therefore, that a time of many sun-spots should mean any appreciable falling off in the light and heat we have from the sun. Indeed, since the surface round the spots is generally bright beyond the ordinary, it may very well be that a time of many spots means no falling off, but rather the reverse.

Is there no connexion, then, between these great changes on the sun and any kind of change on this earth of ours? The sun has upon him spots, faculae, prominences, and corona, that change and move, wax and wane, in sympathy, and according to some law. The sun turns round upon his axis and carries with him the spots, faculae, and prominences. Has that motion of his any effect upon us? Would it matter to us if he could not turn? Would it make any difference to us here if he were blank and unchanging, as, for the most part, he seems to be to the naked eye? Are any of the laws of the sun laid upon the earth? The corona is always surrounding the sun; the prominences may be there, though we cannot see them. Can they affect us here on the earth whether we should ever see them or not? Could they affect us here on the earth even if we hid ourselves in her depths, shut off by many feet of cold ground from the sight of the sun, from the knowledge of day and night, of summer heat or winter cold?

In a deep, windowless cellar, guarded from all light or heat or knowledge of the sun, there hangs a long steel bar, poised level by a silken thread fastened to its middle. It is balanced true, so that it moves neither up nor down, but the silk thread that suspends it allows it to move, as it will, to right or left. The room is not quite dark, for there is a lamp, and a ray of light from this falls on a little mirror on the steel bar, and is by it reflected to a sheet of photographic paper. The paper is wrapped round a drum which revolves, so that, if the steel bar remains steady, the ray of light reflected from the mirror upon it leaves a straight black trace on the moving paper. But if the bar swings to left or right, quickly or slowly, then the ray reflected from the mirror fastened to it dances to and fro upon the paper on the drum, and leaves behind it a wavy or a jagged line.

But why should the steel bar swing or quiver? It is hanging deep down in an underground cellar, where no breath of wind can ever come to stir it, where no overhead traffic can shake the earth and send it quivering. It is in the still depths, far from the madding crowd's ignoble strife. What disturbing message can make it quiver ?

But the sun has other messengers than his rays of light and heat: messengers that do not heed bolts and thick doors or walls ; that care not for darkness and cold. To such messages as these bring the steel bar responds day by day, year by year, cycle by cycle ; answering back not only to the movement of the sun as he runs his daily and his yearly course in our sky, but quivering in sympathy with the very state of the sun himself, whether he is suffering from a great outbreak of spots, prominences, and faculae, or whether he seems to have sunk back into quiescence.

The steel bar—a magnetic needle it is called—is balanced so that it will point nearly due north and south if undisturbed. But it does not remain undisturbed for long. From about nine in the morning till about two in the afternoon there is a feeble swing of the magnet to the west, and during the remaining hours it creeps back.

Day by day the magnetic needle swings to and fro, but the extent of the swing is not always the same. If we plot down the extreme distance of its pulse for each day, month by month, and year by year, we see that the swing is greater in the summer months, when the sun is long visible and high above the horizon, than in the winter months. But the average swing in the summer months for one year is not the same as for another, nor yet do the winter months give always the same swing. If we take the average of all the swings, year by year, we still find a steady progression. There is a pulse, too, in the years—a cycle—and the extent of the cycle is about eleven years, the same as the cycle of the sun-spots, the faculae, the prominences, and the corona.

Is this a coincidence merely, or is there any connexion between the sun's surroundings and the magnetized bar, swinging in the cold and dark? It cannot be a mere coincidence, for not only are the lengths of the cycles the same, but one can superpose them. The greater the number of spots and faculae, the greater the swing of the magnetic needle; when the sun sinks into a quiet state the swing of the needle is short and feeble. Thus in PLATE XXXV., fig. 2, in which the areas of sun-spots and faculae are exhibited diagrammatically year by year in comparison with the daily variation shown by the magnetic needles, it will be seen at once that the maxima of the solar curves correspond always with the maxima of the magnetic curves, and the minima with the minima. There is, then, a connexion between the state of the sun and the swing of the needle. But how close is it?

Every now and then—we cannot foretell when—a monster spot breaks out upon the sun. It passes across the sun's disc into his unseen hemisphere, and may come again round his eastern rim a second, even a third, fourth, and fifth time. We know it to be the same spot by its place upon the sun—its solar longitude and latitude.

Every now and then, without warning, the magnetic needle, swinging gently to and fro in the stillness, becomes violently agitated. It quivers and starts as if it were transmitting a panic-stricken message, uttered so hastily that light is not a writer quick enough to transcribe it. The quivering and the agitation may last for hours or days; then it ceases, and weeks may pass before the quiet swing is disturbed again. Who sent this message? Where does he stay? What does it mean?

In the November of 1882, a monster sun-spot, easily visible to the naked eye, crossed the sun, and when it was about halfway across, on November 17, a very violent magnetic storm, as these agitations of the magnetic needle are called, occurred. It began very sharply at ten o'clock in the evening. Ten years later, in February, 1892, a still greater spot, the one already referred to, appeared upon the sun, and when it had passed a little to the west of the sun's centre, on February 13, at five o'clock in the evening, a still more violent magnetic storm occurred than in 1882. It also began very suddenly. This great spot passed off the sun, and returning to the eastern edge, again crossed the sun's disc.

When it arrived at the same distance from the centre of the sun, there suddenly broke out again upon the earth a great magnetic storm. This was at ten-thirty on the morning of March 12, 1892. Eleven years later, in October, 1903, yet another giant sun-spot appeared, and when it had got a little more than halfway across the sun, there was a magnetic storm, but not a violent one. But a fortnight later, when an important, but smaller, spot had got into a central position on the sun's disc, a magnetic storm burst suddenly, at six o'clock in the afternoon of October 31, the most violent that has been experienced in the memory of man; so violent that it disturbed the submarine cables all over the world, and stopped the sending of any telegraphic messages. (*See* PLATE XXXVI.)

Had the spots and the storms anything to do with each other? They happened together, but though some monstrous spots came at the same time as monstrous storms, yet the biggest spot we have ever known of came with quite a feeble storm; and a spot of moderate size accompanied the most violent of all storms. Yet further, there are many spots and many storms, but we cannot link them all. Many great spots are accompanied by no storms at all; many storms occur when we cannot see a spot on the sun at all. Why does the law which connects them only seem to work sometimes? What is the association between them?

It is the great spot of 1892 that supplies the clue to the mystery. The time between the return of the spot to the same place is the apparent time that it takes the sun to turn on his axis, and that is the time that occurs over and over again as the interval between successive magnetic storms. On a particular region of the sun some commotion occurs: sun-spots, faculae, prominences, are formed; above the disturbed area a great petal-like streamer of corona arises, its apex drawn out into a rod-like ray, which extends from the sun to distances which may be expressed in scores or hundreds of millions of miles. Indeed, in the eclipse of 1898 such rays were photographed, and they have been photographed in other eclipses, though not to quite the same great extent. (*See* PLATE XXXVII.) In these rays the particles, whatever their nature, are not now connected with the sun, though they once were; each still keeps the direction and motion which it had when it left the sun. If, then, we could look down on the sun, we should see him spouting forth, from one region or another, as smoke issues from the funnel of a steamer, long rays, which remain as spirals behind him as he turns continually on his axis. The sun may go on spouting a coronal stream from the same region for months at a time, and in this region spots may break out and die, and again break out; for sun-spots are but one symptom of the sun's activity, and, perhaps, not even the most important symptom. As the earth moves round the sun, which is himself turning on his axis, the same long stream may strike and pass it, may strike and pass again, month after month, for many months at a time; or perhaps it may sometimes strike and sometimes miss. There is no reason for surprise, then, that sometimes a great sun-spot is not answered by a magnetic storm on earth, for the ray from it may have missed our little world. So, too, we may have a storm when there is no spot visible, for the coronal ray may have been shot forth before the spot has formed or may be still in action after the spot has been covered over or filled up.

The law that governs the changes of the sun, his waxing and waning cycles in spots and faculae and prominences, has its answer in the earth. It is under the influence of this law that the magnetic needle writes in the darkness and stillness of the cellar; it writes of great changes, great commotions, that are going on in the sun; and of the sending forth of these stupendous coronal rays, which we can only see at rare intervals, and by the accident, as it would seem, of the moon's dark body shutting off the sun's light, and allowing us to look upon the lesser brilliance of his surroundings.

It does not seem strange that such stupendous commotions on the sun should have an effect upon the earth. The spots are but a minor symptom in the great solar outbreak, and these spots, very many of them, could engulf the earth entirely. The wheel can certainly affect the fly upon it.

But can the fly affect the wheel? Can the earth exert any influence on the sun, or on the monstrous commotions upon it? The question seems to stand self-condemned as an utterly foolish one. But—*does* the earth influence the sun or the sun-spots?

The sun's equator and his poles are definite regions on him; they are fundamental positions on his surface, due to his turning on his axis. But the eastern rim, the western rim, and the central line of the sun, *as we see them*, are not definite and unaltering regions on him; each region of the sun takes up all these positions in turn. East on the sun is east and west is west only to us on the earth; they would not hold these same positions to another planet; an observer *on* the sun could not recognize them at all. The sun's visible hemisphere only differs from the sun's invisible hemisphere in the fact of the earth's relation to the two. If, then, the eastern half of the sun differs systematically from the western half, or the visible hemisphere in any way from the invisible hemisphere, those differences must be due to the earth.

We do not see the sun's invisible hemisphere, and therefore we cannot measure the spots that are there, or count them. But the sun is continually turning round, and we can count the spots that come into view round the eastern rim, and we can count the spots that disappear round the western rim. If the earth had no influence on sun-spots, the numbers that came on should be, in the long run, just about equal to the numbers that go off. If more spots in the long run come round than go off, then the earth's influence must tend to kill the spots. If more go off than come on, then the earth's influence must tend to develop them. We find that the earth tends to kill the spots, and that to a degree which is out of proportion to its size. In a period of eleven years, though 947 spots came round the east, only 777 went round the west. The earth put out 170 spots in eleven years.

If we measure the areas of all the spots when they were seen in the eastern half of the sun, and also in the western half, we find, similarly, that, in the long run, the eastern areas are greater than the western, for the earth tends to diminish the spots and to quiet down the commotions on the sun.

And if the earth tends to subdue the sun's agitation, so probably do the other planets—Mercury, Venus, Mars, Jupiter, and the rest—though their influences we can only suspect; we cannot yet measure.

We have seen how the sun influences the earth—by his heat, his light, and the changes in himself which produces magnetic storms on the earth. In how many other ways he dominates the earth we have yet to learn

—whether his changes cause our blizzards and our heat-waves, our hurricanes or earthquakes. We may know some time, definitely, that with his changes these things do come or do not come ; but we do not yet know.

Nor do we know by what means the earth influences the sun. We have seen that it tends to quiet some of his disturbances, but how we do not know. Nor do we know if sometimes, or by some means, it or any of the other members of his family may tend to rouse him to greater activity.

BOOK III

STORIES TOLD BY THE SUN'S FAMILY

CHAPTER XI

THE STORY TOLD BY THE PLANET JUPITER

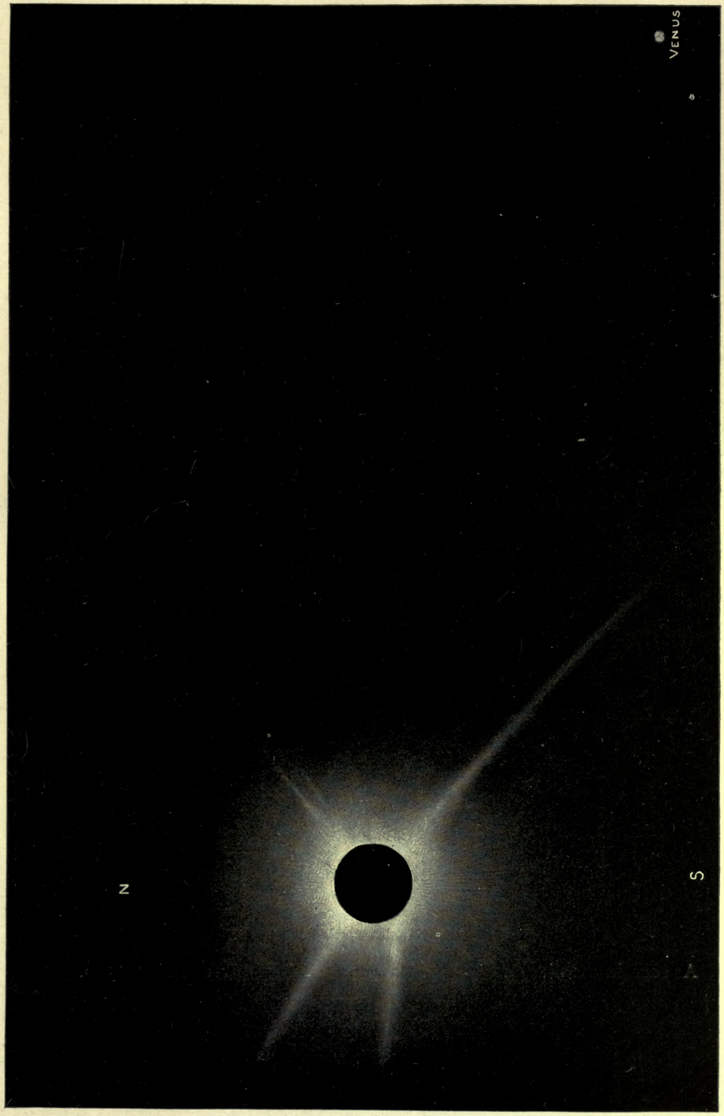
WE may think of a nation as a collection of families bound together by common laws. The head of a family is its representative in the nation; and in each family, laws special to it also hold good, though these laws must not run counter to the laws of the nation, else both nation and family will suffer.

We may think of the universe of stars as a collection of solar systems. We classify these suns by their resemblances to our sun, or by their differences from him. We may well believe that all, or many, of these suns have systems dependent on their control, but of only one such system have we any knowledge—that belonging to our sun. And, just as we may study the characters of the members of a family, so may we study the characteristics of the members of the solar system. Their individualities are distinct; they differ much amongst themselves and from the sun; yet some of them have traits that are distinctly sun-like.

The one planet that is more eminently sun-like than any of the others is the planet Jupiter. He is more than equal in size to all the other planets put together; he controls a numerous minor system of his own; like the sun, he has a spotty globe; he is a semi-sun.

But the sun has a diameter of 866,400 miles; the diameter of Jupiter is but a tithe of this. The sun is distant only some ninety-two millions of miles; Jupiter is more than four times as far even when at his nearest to us. We cannot see that Jupiter is not a mere point of light with the naked eye; we should have to magnify him at least fifty times to make him seem as big as the sun looks without the aid of a telescope.

If we look at Jupiter through a telescope which magnifies his actual size fifty times or even two hundred times, he seems to have a very different appearance from that of drawings of him in astronomical books. The picture of Jupiter in the book is perhaps drawn to a scale of two or three inches to the planet's diameter, and so if we held it at the distance from our eyes that we usually hold a book, it would cover up a space in the sky twenty or thirty times the breadth of the sun. When we are looking at the sun low down in the sky we are looking at him over trees, or houses, or hills. We know that these last are really larger than they may appear to us to be; we unconsciously compare the sun with them, knowing that the great light is vastly



Drawing made by Mr. W. H. Wesley from a photograph taken by Mrs. Walter Maunder of the Corona of January 22, 1898, showing long rod-like rays. The longest ray was traced for a length of six million miles.

JUPITER AND HIS SATELLITES.

As seen in a 12-inch reflector with a magnifying power of about 300.

more distant; so we unconsciously magnify his apparent size; we seem to see him covering a greater space than he really does.

But when we look at Jupiter in a telescope that magnifies him fifty times, we see him alone, cut off by the telescope tube from any houses, or trees, or hills with which to compare him; there is nothing to make us unconsciously magnify his appearance; he looks as he really is, a very small object; no bigger than a sixpence looks seven feet away. The drawing by the Rev. T. E. R. Phillips in PLATE XXXVIII. gives a good idea of the actual appearance of Jupiter and his moons in the field of a telescope when a magnifying power of about 300 is employed.

To the naked eye, the sun looks but a glowing disc of light. It is only rarely that the unassisted sight can see speck or flaw on his bright surface; and when the eye can see a spot, it looks like a round black nail's head driven into the sun. But Jupiter, when he is magnified to the same apparent size as the sun, does not look like this. His is no flawless disc of light, but one barred by parallel bands, bright and dark. Nor are the bands, whether bright or dark, quite uniform: the brightness seems coagulated here, the darkness knotted there.

If we enlarge the apparent size of both the sun and Jupiter, the differences in their appearances become more marked still. There is no colour on the face of the sun; there is but light and varying degrees of shade. We can trace out the direction and place of the sun's equator by diligent watching, for the spots and the faculae seem to move in parallels of latitude as the sun turns round. The spots and faculae themselves seem often to lengthen out along these parallels, but the length of the longest stream is short compared with the circle of the sun on which it lies. Spots and faculae seem to break out again and again along points in the same parallel. If the sun-spots and the sun's faculae remained permanently there and did not break out and disappear again completely, we should expect to find them, from what we know of them, to lie in dark and light bands parallel to the sun's equator.

If the spots and faculae were not evanescent, but permanent, or very long-lived, features on the sun, and were greatly increased in size and number, we should expect them to lie in bands parallel to his equator and to look very much like the appearance that Jupiter actually presents, but with the difference that we could not have expected that these bright and dark spots should show more than light and shade, and that some of them should become tinted with various colours.

In Plates XXXIX. and XL. there are two paintings of Jupiter by the Rev. T. E. R. Phillips; the first made on February 2, 1908, the other eight days later. In both of these pictures it is perfectly easy to pick out the position of Jupiter's equator: it is across the thickest part of the disc and parallel to all the light and dark bars.

But there are several other things to note about these pictures of Jupiter. There are many different colours on them, but the background seems to be a dull yellow which deepens and smears all round the border of the disc. In or under this yellow all the other markings seem to lie; it is the colour of Jupiter's atmosphere, and we see that it is an atmosphere, for it deepens near the horizons, where it seems to us to lie thicker on the rounded body of the planet. But on the sun we remember that we could see his bright markings, the faculae only, when near his rim, for only there was the bright body of the sun dimmed enough for us to distinguish the brightness of the faculae. We could not see the sun's faculae in the centre. But here, on Jupiter, it is in the centre that we see best all the markings, whether dark or light; towards his rim they fade into the yellow. This shows us two things about Jupiter: first, that the body of the planet is not very bright, and is nowhere as bright as the white spots; and second, that all the markings, light as well as dark, lie low down in the atmosphere of Jupiter, and can therefore be most clearly seen where Jupiter's atmosphere seems to us to be shallowest, namely, at his centre.

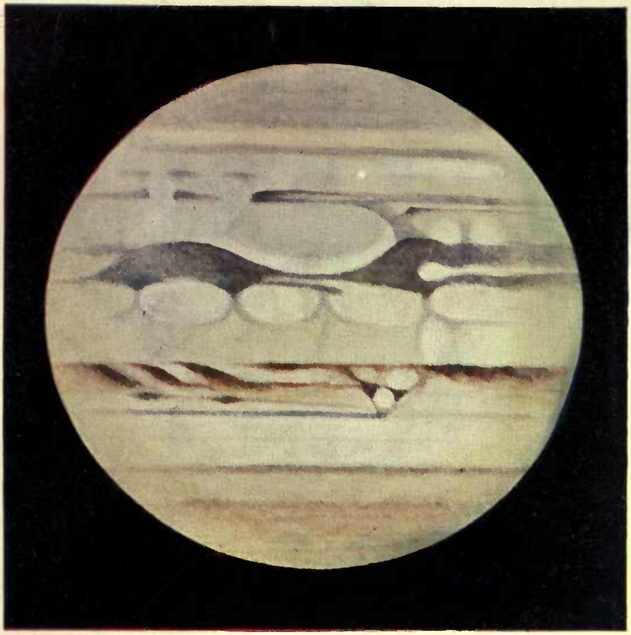
The next feature to be remarked is that round either the north or the south pole of Jupiter, there is nothing to be seen but greyness or yellowness, forming a broad cap. So in the sun we found that the spots ceased when they were about forty degrees north or south of the equator ; the faculae were to be found a little farther to the north or south, and the prominences yet farther. But it would seem that the regions near the poles, on both the sun and Jupiter, are undisturbed, inactive, and dull.

There is nothing on the sun that we can recognize as corresponding to the blue or crimson stripes in the northern hemisphere of Jupiter ; nothing even that we can compare with his even straight dark and light bands. And if we compare the shapes and appearance of the other white and dark markings with faculae and sun-spots, we find very striking differences. The faculae seem like mackerel clouds, or they sometimes mass together like cumuli ; the spots are irregular, ragged, and torn, with points of deeper blackness in the darkness of their centres, and thatches of brightness projecting over them. The white spots on Jupiter are smooth and round like drops of milk, or eggs. The dark markings are also smooth edged, with never a suspicion of shading towards central pits, or of overhanging thatch. And both light and dark are often tinted to a rosy or a purple glow.

The picture of February 10 is not the same as the

SOUTH

WEST



EAST

NORTH

JUPITER, 1908 February 2^d 9^h 40^m G.M.T.,
by the Rev. T. E. R. Phillips.

picture of February 2. We can recognize the yellowness of the northern cap, and the greyness of the southern, in both. We can see where one has a blue and a crimson stripe, that the other has too; we can find the same style of marking at the same parallel of latitude in both. But we cannot recognize the same marking unchanged in the same surroundings on the two paintings. Are we looking at different hemispheres of Jupiter, or has his surface changed? Both.

It takes about twenty-seven days for a marking on the sun's eastern edge to come a second time to the same position. The sun appears to us to turn round in *about* twenty-seven days, that is, in about twenty-five days in reality. We are in no uncertainty as to how long it takes the earth to turn round; it rotates in twenty-four hours, never faster or slower, and everything upon it rotates in the same piece, in the same time, land and sea, hill and valley, at the equator or at the tropics or at the poles. But as regards the sun we cannot give the time of its rotation with any such precision, and this because faculae and spots seem to rotate at different speeds. Not only are spots moving at different rates from faculae, but all differ according to their latitude; and they differ in their own latitude for some reason that we do not understand. According to the spots we choose, the sun may appear to turn round in any period between twenty-three and thirty-one days.

Jupiter turns round also on his axis, but his turning is shorter than the sun's, much shorter even than the earth's, though he is so much larger. But his method of turning is like that of the sun, rather than of the earth. We can only say that he turns round in *about* 9 hours 55 minutes. White spots give a different time of revolution from dark spots; the distance of a spot from Jupiter's equator also seems to affect its rate of moving; and the same spot—white, dark, or coloured—may move with different speeds at different times.

There are always spots and belts on Jupiter; he is never free from them, as the sun may be for perhaps years at a time. The spots of Jupiter are longer lived, too, than those on the sun; but they do change, it may be in colour, or size, or shape, or brightness; they may even disappear altogether for a time, and leave, as it were, the impress of where they have been.

The most remarkable of all the spots on Jupiter is shown on the first painting by Mr. Phillips, in the southern hemisphere of the planet. It is called the 'Great Red Spot,' and is the large grey oblong, lying in a white cup, which seems to have hollowed a broad dark band, lying to its north, as an egg might indent a cushion. Another dark, smooth band arches over it to the south. This great red spot owes its name, not to the colour that it now has, but to that which it has had once

SOUTH

WEST

EAST

NORTH

JUPITER, 1908 Feb. 10^{d} 13^{h} 35^{m} G.M.T.,
by the Rev. T. E. R. Phillips.

in the past. It has had a long history, if not a continuous one. The ingenious Mr. Hooke observed it in the days of Charles II. It appeared and vanished eight times between the years 1665 and 1708, and then it remained invisible until 1713. It became very conspicuous in 1878, and had then a brilliant colour. Since that date it has always been visible in large telescopes, though sometimes in small ones it has seemed as if it were itself gone, and had left only its impress in the south equatorial belt. Its impress remains clear whether itself be visible or not, and it drifts through the dark belt, or it may be the belt drifts past it ; or both move at different and at changing rates.

Now, whatever the spot or the belt may be, they are not rigidly attached to the planet's crust. We do not see Jupiter's crust at all ; we cannot even tell if he has a solid crust like our own earth. All the belts and spots that we see on him must hang suspended in his atmosphere. They are clouds in fact, clouds moving under the influence of his winds and air currents. Our clouds and fogs are made up of water-vapour, and of dust. We think that the clouds that form the sun's bright surface are made of carbon. Whether the clouds of Jupiter are made of water-vapour or of carbon, or of some other substance, we have as yet no means of finding out.

CHAPTER XII

THE STORY TOLD BY THE PLANET SATURN

IT is always the unexpected that happens in astronomy. If there is one thing of which we can feel sure, it is that when we come to study some new object, or some object in a new way, it will present to us some feature so unexpected, so bizarre, that, until we had witnessed its actuality there, we should have declared that such a feature was not only unnatural, but impossible. We have noticed that the sun's corona is one such feature; it is utterly unlike what we might expect in the sun's surroundings. We know of it, so to speak, by accident—by the accident that the moon sometimes hides, and only just hides, the sun; otherwise, though it exists, we could not know of its existence. We have pointed out that it is the vehicle to convey a disturbing power from the sun to the earth. It has been proved many a time and oft, proved without a flaw in the reasoning, that the sun, or its spots, *could not*, by any means, by any possibility, cause the magnetic storms on the earth.

But the fact remains that he does. We can never know; we can always learn.

But the commonplace planet Saturn is the planet that 'surprises by himself.' Turn back to the Story told by the Planets. The other four had special stories to tell for themselves. Mercury was the twinkler, glancing out for a moment, now to the east, now to the west, of the sun. Venus was the brightest jewel in all the heavens; the bright and morning star, the chief brilliant in the crown of the evening. Mars was the ruddy star, the blood-red star of war that alternately threatened and retreated with the years. Jupiter was the steady, bright-shining 'Hebrew,' who crossed over the meridian and paced out the heavens from end to end. But Saturn had nothing special to say for himself. He was only the yellowish star, duller than the rest, slow moving in his westward course, slower moving in his eastward; so slow and sluggish that the astrologers gave him as his metal, lead: heavy, dull, inert—of little use and less ornament.

He preserved this character through all the centuries until Galileo turned his newly invented telescope upon him, in the year 1610. What he saw is best given in his own words—

'I have observed with great admiration that Saturn is not a single star, but three together, which, as it were, touch each other. They have no relative motion, and are constituted in this form, the middle being much larger than the lateral ones. If we examine them with a glass of inferior power, the three stars do not appear very distinctly. Saturn has an oblong appearance somewhat like an olive, but by employing a glass which multiplies the superficies *more* than one thousand times, the three globes will be seen very distinctly and almost touching, with only a small dark space between them. I have already discovered a court for Jupiter, and now there are two attendants for this old man, who aid his steps and never leave his side.'

This observation was not generally accepted by the other scientists of Galileo's day, because they argued that they knew, and that, therefore, there could be no more room to learn. And Galileo himself received a great shock in perceiving that, during the next couple of years, the lateral bodies were diminishing, though they appeared to be immovable, both with respect to each other and to the central body. Toward the close of 1612 they vanished altogether, and his opponents were triumphant, whilst Galileo mourned—

'Are, perhaps, the two smaller stars consumed like spots on the sun? Have they suddenly vanished and fled? or has Saturn devoured his own children? or was the appearance indeed fraud and illusion, with which the glasses have for so long mocked me and many others who have observed with me? . . . The shortness of time, the unexampled occurrence, the weakness of my intellect, the terror of being mistaken, have greatly confounded me.'

But Galileo was not mistaken, and by the middle of 1613 he was able to announce that the lateral stars were reappearing. They enlarged more and more until, in 1616, he writes—

'Its two companions are no longer two small and perfectly round globes, as they have hitherto appeared to be, but are now bodies much larger, and of a form no longer round, but, as shown in the annexed figure, with the two middle parts obscured, that is to say, two very dark triangular-like spaces in the middle of the figure and contiguous to the middle of Saturn's globe, which later is seen, as always, perfectly round.'

It was not until forty years later that Huygens saw and described these strange lateral bodies as really parts of a ring which girdles the equator of Saturn.

We have finer and more powerful telescopes than Galileo made for himself; we are not so apt as he to be confounded by the terror of being mistaken; we ought not to be, like his opponents, inclined to know more than we learn. We may therefore study this beautiful drawing of the planet Saturn for the sake of that which it can teach us. (*See* PLATE XLI.)

First, then, Saturn itself is a globe. We do not see in this picture the entire hemisphere that is turned towards us, for the northern pole is hidden by his ring. We cannot see the curve of the planet through the bright ring; therefore that part of the ring is thick enough, or opaque enough, to prevent us seeing through it. The southern part of Saturn throws a shadow on the far side of the bright ring; therefore the planet is opaque to the sun's rays, and does not shine of himself, or not to any appreciable degree. The globe Saturn has dark belts and bright bands, dark spots and light spots, unmarked uniform polar caps; liker the sun than the earth, liker Jupiter than the sun. He is coloured, too, like Jupiter; unlike the sun, his poles are sometimes blue or olive-green; his spots show brown and purple and ruddy tints; his equatorial band is often of a delicate pinkish tinge. He turns, too, on his axis in about 10 hours 14 minutes, but various regions move at varying rates. He is so much more distant from us than Jupiter, and so much smaller than the giant semi-sun, that his belts and spots seem to us to have their irregular edges smoothed off and rounded. In all this he is but a lesser and more distant Jupiter.

But he has that which Jupiter has not. Girdling his bright equatorial band, his thickest diameter, there is poised a series of concentric flat rings; not attached to him, not touching him anywhere, but all hanging even and level with his equator, and the nearest edge fully nine or ten thousand miles from his surface.

The innermost ring is dusky, transparent, crape-like; we can see the curve and body of Saturn distinctly through it: it lies before his brighter surface like a veil. This ring, then, is not solid or opaque.

The crape ring has a sharp line of demarcation from the next ring, though there seems to be no space between the two. And the next ring is bright and very broad; but it is brighter at its outer border than at its inner; it is a little dusky at its inner edge, especially where we seem to see it spread out most at the two ends of the oblong—for, though the ring itself is truly circular, we are looking at it in perspective and see it as if elongated. Here it seems thin, almost as if we could see through it; here, too, it is not solid, at least, nor is the substance of which it is composed very closely woven together. Here and there, too, especially on the right-hand wing, there seems to be a darker line drawn, as if a cleavage was beginning which might separate the broad band into narrow rings.

Where this band is at its brightest, it ends, and a broad line of cleavage separates it from a duller band. Or it may be from a double band, for on the right-hand wing of this there is to be traced for a space a distinct tear, but one which does not seem to be continued all round into the left-hand wing. This wing is not uniform either, but appears gored, as are the seams of a dress;

it looks puckered and snipped as if to form a straight strip of material into a circular band.

Saturn's ring girds Saturn's equator, and his pole points, as ours does, at an angle to his path round the sun. As he pursues his journey, and we pursue ours, we see his equator and rings tilted at various angles; we look upon his northern pole and the northern face of the rings, or upon his southern pole and their southern face, or equator and rings are presented level to our eyes. This last is when we cannot see the rings at all, because, though the band in which they lie is nearly 40,000 miles broad, it is so thin that we cannot see it edgewise. It cannot be thicker than a hundred miles or so. It was at a time that the rings were so turned to us that Galileo made his horrifying observation that Saturn had become a solitary and single globe.

The rings do not shine of themselves; like Saturn, they receive their light from the sun. Sometimes, then, the sun is shining on their southern face whilst we are looking on their northern, or vice versa, and we again cannot see the rings, except where, at the cleavages near the elongations, we can, through them, see part of their sunlit face.

We can see through parts of the rings, so they are not solid or liquid, since it would be impossible to do so were they but a mile or so thick. But they must have something material in them, since they intercept the sunlight and cast a shadow on the globe where they come between him and the sun, just as a wreath of smoke or a cloud of dust will cast a shadow. Saturn's girdle is, in truth, a dust girdle; it is a ring, not solid, or liquid, or vaporous, but made up of solid particles which are 'free,' or move independently of each other, each in its own orbit, like a true satellitoid of Saturn. How big these bands of free satellitoids are we do not know; they may be rocks of many tons mass; they may be no more than pebbles in size; they may be true dust, such as the wind whirls down our streets; they may be no larger than those particles which form the substance of the corona's great petals, particles smaller than we can conceive. Saturn's rings may, indeed, be his corona—a corona which does not depart from the parent semi-sun in ever more widely extending spirals as does the sun's, but a corona whose particles are compelled to circle endlessly round the body that gave them forth. But this, too, we do not know.

Besides these rings of satellitoids, Saturn has true satellites, and we know of ten of them. Here we come upon another of the unexpected happenings; nay, more, on an happening that was 'impossible.'

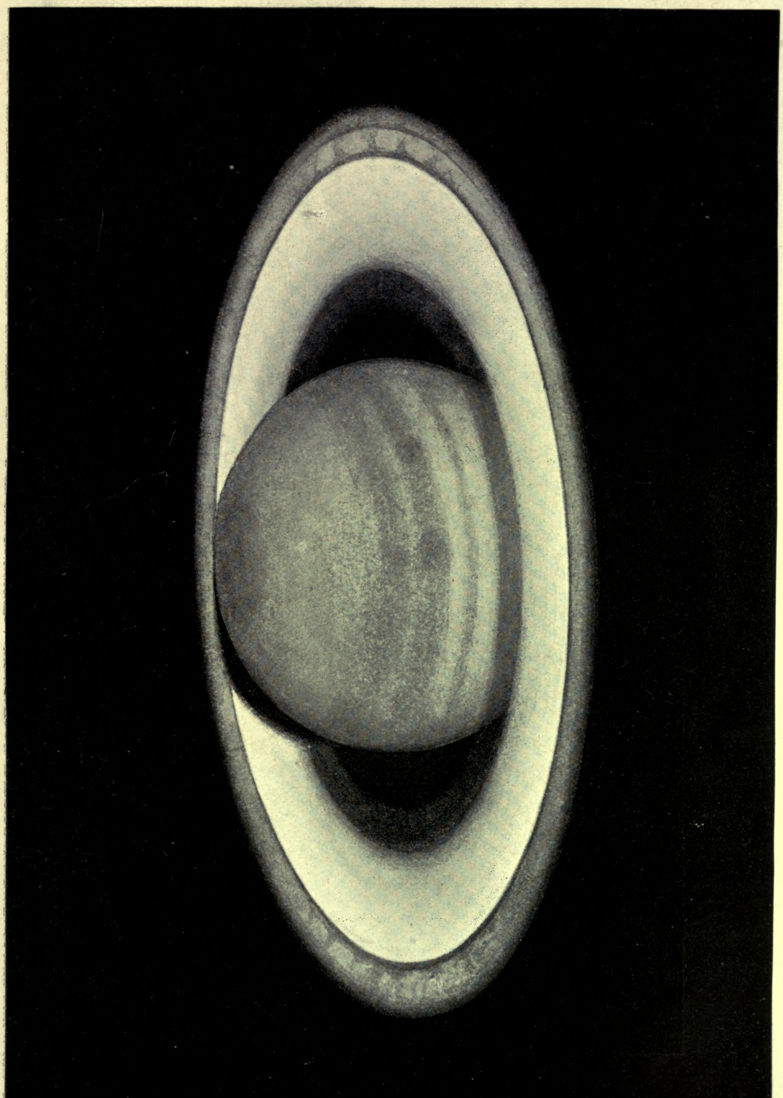
The sun, Mercury, Venus, the earth, the moon, Mars, Jupiter, and Saturn, all turn upon their axes, and their turning is all in the same sense; some do not turn from right to left, and others from left to right. Mercury, Venus, the earth, Mars, Jupiter, Saturn, all revolve round the sun, and they all move in the same direction, and it is the same sense in which all the bodies rotate. Laplace, the great mathematician, was greatly struck by this unanimity in the motion of the sun and his planets. It could not be simply a chance, he argued, that all these bodies, great and small, should all move in the one direction. His argument was greatly strengthened by the fact that all the moons of which he knew, the moons revolving round the earth, or Jupiter, or Saturn, all moved in the same direction round their planets, as these moved round the sun. The overwhelming probability was that all the planets and satellites in the solar system must move in this one direction. It seemed an inconceivable thing, almost an impossible thing, that any satellite or planet should pursue its course in a direction the opposite of its companions.

Nevertheless, this inconceivable thing has occurred; this thing that was considered wellnigh impossible has come to pass. Saturn, the planet of the unexpected, furnished the example.

It was but a few years ago that Professor W. H. Pickering discovered a small object on a photograph of Saturn, which he believed was a satellite, but which he could not find again for some years. Then, when at last such an object was again picked up and kept in view, its motions were so peculiar, and so puzzling, that 'confounded' by 'the terror of being mistaken,' he hesitated for long to announce that this little satellite, so distant from Saturn, so helpless and so small, was yet a rebel to the universal law that the great sun and the great Saturn obeyed; that little Phoebe, as the new satellite has been called, had struck out a new career for herself, and was revolving round Saturn in a direction contrary to all his other moons. It is better to learn than to know.

And yet a second example has chanced. For, within the last few months, Mr. Melotte at Greenwich Observatory has discovered a new satellite to Jupiter, an eighth in the 'court for Jupiter,' that Galileo discovered. This satellite of Jupiter, as yet unnamed, lies very far away from him, and like Saturn's Phoebe, pursues a course round him contrary to all his other moons.

There is one more instance that Saturn offers that learning is oftentimes the enemy of knowledge. The astrologers of times past, and of to-day, gave to Saturn as his metal, lead: the dull, inert, heavy. But we can weigh the earth, and the sun, and the planets, and of them all we find that Saturn's globe is made up of the lightest materials. He is seven hundred times the bulk of the earth, yet he only contains in all that huge bulk but ninety times the earth's mass. If Saturn could be thrown into our ocean, he would not sink but float, for his density is but three-quarters that of water, lighter than the substance of the sun, lighter than the substance of Jupiter, as light as wood. There seems an irony in this, which, were it possible, should teach astrologers that it is better to learn than to invent sham knowledge.



SATURN. By E. M. Antoniadi.

(1)

(2)

PHOTOGRAPHS FROM A BALLOON.

(1) The Parade, Douglas, Isle of Man. Good photographic conditions. Air moisture-laden; little sunlight. 1 p.m. on November afternoon. (2) Over the River Medway, Kent. Bad photographic conditions. Air dry and hazy. Bright sunlight; summer afternoon.

CHAPTER XIII

THE STORY OF VENUS AND MARS

Oh wad some power the giftie gie us
To see ourselves as ithers see us!

BURNS might have added that this one gift is not enough; we should need a second to enable us to recognize ourselves when thus seen.

Is there any other of the sun's planets like the earth? What do we look like from outside? Should we know ourselves to be what we are if we could look upon the earth from some other planet?

We can answer the first question partly if we put it in another way. We can say what members of the solar system are *not* earth-like. We can say at once that the sun, Jupiter, Saturn, Uranus, and Neptune are not as the earth is. Ours is a solid earth; these are not: they are globes of vapour, or at most fluid, current riddled, and without even a backwater of encrusted scum.

But of Mercury and the moons of other planets we know too little to guess at any likeness to ourselves.

There remain but three bodies amongst which we may seek our kin—our own moon, Venus, and Mars.

We look out over our earth and find on it bare mountains and deep valleys, craters and cañons, wide clefts and vast plains. On the moon we see all these things unmistakably. Good! The moon, then, is bone of our bone. But on the earth we also see flowing rivers and great tidal seas; snow, cloud, and mists, verdure and forest, follow upon these. On the moon there is nothing of all this; the moon is not flesh of our flesh. On the earth the hard rigid skeleton is covered above by living flesh; that is to say, by fertile soil and trees and verdure, of which the moon has nothing.

Suppose we then ascend above the earth, and, stage by stage, as we ascend, examine the prospect that lies beneath us. We ascend by daylight into a clear sky, so that the higher we go, nothing but an increasing thickness of unclouded atmosphere intervenes between us and the earth's surface.

What is the atmosphere? It is filled with exceedingly small particles, capable of reflecting or scattering light. Now, under the rays of the sun, these tiny particles have their sunward faces lit up, their earthward faces in shadow. At any height above the earth we can see skyward clearly, for we are looking at the sheltered faces of the little atmospheric particles, but when we are looking earthward the sunlit faces dazzle us and confuse the outlines of the objects on the earth. The higher we go the greater is the number of sunlit particles between us and the earth, and the more pronounced the haziness of her appearance, no matter how clear the atmosphere may be. With such an atmosphere as ours we can well believe that were we to look at the earth from but the distance of a hundred miles or so, which is yet well within the outermost confines of our air, we should see nothing below us but a dazzlingly white and uniform disc of light, with never a marking or shade to indicate which was land or water, ice or forest, and that although no cloud floated beneath us.

The amount of dust in the air varies astonishingly from time to time, and the difference of the appearance of the earth as seen from a balloon when the atmosphere is charged with dust particles and when it has been cleaned of them by heavy rain, is well illustrated by the two photographs in Plate XLII. We are indebted for these photographs, taken from a balloon, to the kindness of Miss Gertrude Bacon, daughter of the well-known aeronaut, the late Rev. J. M. Bacon. The upper photograph shows the Parade at Douglas, Isle of Man, on a November day when the air was laden with moisture. The lower photograph shows the Medway, in Kent, on a very bright day, but when the atmosphere was full of haze and dust.

Which of the two planets, Venus or Mars, that we have left for comparison with the earth, shows such an appearance? Without doubt, Venus. We never see her surface; she presents but a dazzling disc, with never a marking that we can be certain is not the result of eyes tired with too much brightness. Whether her atmosphere is clear or cloudy, or what lies behind that dazzling light, we do not know. (*See* PLATE XLV.) Mars shows us markings in plenty, some well defined, some ill defined. We can trace upon his face permanent configurations of all shapes and sizes, of all tints and shades. Certainly in his atmosphere, in his clouds and vapours, the planet Mars differs importantly from the planet earth.

Can we then say that, of all the planets, Venus is nearest in kin to the earth? If we could look upon them from a common distance, we might see no difference in their uniform brightness. But we know what is beneath the earth's atmosphere; we do not know what is beneath that of Venus. The lesson that the planet Saturn has taught us, we must not forget here: We cannot *know* what we are not able to *learn*. So far we have not learned, even yet, how long it takes Venus to turn upon her axis. This is because there is no marking on her that we can recognize again. We can only tell the time *more or less* that it takes the sun, Jupiter, or Saturn to turn round, not because there are no markings that we cannot recognize again, but because the time given by one marking differs more or less from the time given by another, and the pace, at which any given marking moves, varies from time to time. But Mars is in a different case from all these. He has markings that can be recognized, no matter by whom or where they are observed. These markings all move together, all in a piece, as the planet turns; each and all turn round in the same time, and as the turning has been watched for more than two hundred years, we can say with certainty and precision that Mars rotates on his axis in 24 hours 37 minutes 22·67 seconds, and that this time is certainly not more than the one-fiftieth of a second out from the true length of his 'day.'

So a 'day' of Mars is only a few minutes longer than a day on the earth. Let us examine the beautiful painting (Plate XLIII.) that M. Eugene Antoniadi has made of one of the sides that he presents to us every twenty-four or more hours.

The whole is round and yellowish, but the deeper yellow is near the centre of the disc where the least thickness of his atmosphere comes between us and his actual surface. Towards his rim, his horizons to us, the yellow pales into white, so, like the sun and the earth, Mars has an atmosphere, and we see more of Mars himself at the centre of the disc, and more of his atmosphere at his horizons. On the sun, the centre is brighter than the horizons, because it is the sun himself that is shining, not merely reflecting the light from elsewhere, and his atmosphere tends to dim his light. Mars is brightest near the rim, for he shines only by light reflected from the sun, his atmosphere being a better reflector than his surface, and in this he is like the earth.

In the north of Mars we see a small round dazzlingly white patch, as if marking out his north pole. So brilliantly white it is we can only liken it to snow, and we have such a snow-white patch round the north pole of the earth, so that we readily connect this polar cap of Mars with our polar ice and snow. We see the whole of the Martian polar cap, because when this picture was painted, it was the north pole of Mars that was turned to us, his south cap was not then visible. Mars, like the earth, has his summer and winter, and another point of similarity between the polar caps of the earth and of Mars is that in the summer of the Martian northern hemisphere, his north polar cap diminishes, just as ours does under like conditions. We think it probable, then, that the polar caps of Mars are made up of ice and snow; but we do not actually know, and we do not yet see how to find it out for certain.

But if the caps are made up of ice and snow, then we naturally think that the dark ring, which spreads as the cap diminishes, surrounding the north polar cap, is

MARS, by E. M. Antoniadi.

melting ice—is water. And if this darkness round the cap is water, so perhaps are the other dark markings that we see. Perhaps, then, the dark areas on Mars are seas and lakes, and the light are continents and islands. Where the two border on each other we may see inlets and bays, promontories and capes. According to this assumption, the markings on Mars have been named. The large dark triangle, not unlike the northern continent of America in shape, is called the 'Hour-glass Sea' or 'Syrtis Major.' 'Dawes Forked Bay,' like the opened beak of a bird, lies in the south and nearly as far to the right as the Kaiser Sea is to the left; a great continent lies between these, and to their north, its northern portion being called 'Arabia,' along whose border a long inlet, the 'Protonilus,' lies; and at the end of this inlet is 'Lake Ismenius'; whilst 'Lake Arethusa' comes between 'Lake Ismenius' and the north polar cap. The continent 'Libya' lies to the extreme left-hand of the 'Syrtis Major,' and 'Thymiamata' and 'Edom' are on either side of 'Dawes Forked Bay.'

The four drawings given in Plate XLIV. are by the late Mr. N. E. Green, F.R.A.S., drawing-master to Queen Victoria, and the truest astronomical artist of his day. They are taken from a superb series of twelve, published in Vol. XLIV. of the 'Memoirs of the Royal Astronomical Society.' The entire series presents a complete rotation of the planet, so that all its varying aspects can be easily followed. The four selected from that series give a view of about three-fourths of the planet's rotation.

The first of the above drawings shows the end of a long, dark, straight marking, which used at one time to be called by astronomers the 'Maraldi Sea'; it is now known by two names—the 'Mare Sirenum' and the 'Mare Cimmerium.' It is the latter half of this marking which forms the chief feature of the drawing. The dark marking sloping from above the centre towards the right is the 'Mare Tyrrhenum.' In the next drawing the 'Mare Cimmerium' has passed out of view, and the 'Mare Tyrrhenum' has moved over to the left of the picture; whilst 'The Hour-Glass Sea' or 'Syrtis Major' has come into view on the right. The 'Syrtis Major' is seen fully presented in the third design, and the little double triangle of 'Dawes Forked Bay' has just come into view on the extreme right. The last picture shows a still further rotation of the planet on its axis.

It all looks very like another earth, an earth whose continents and seas are differently distributed, with more land than water, instead of more water than land, as with us.

We can see the 'continents' and 'seas' on Mars quite easily, though they are slightly hazy and ill-defined. We see them just as distinctly as we should see the seas and continents of the earth if we looked down on it, on a perfectly clear sunshiny day, from a height of a dozen miles or so. And this is where the difficulty comes in. For we are looking at the surface of Mars not only through the whole thickness of our atmosphere, but also through the whole thickness of his. Ours is trouble enough to us, though we are observing at night with no sun to light it up and dazzle us, even if we choose the best and clearest climates we can for the observation—it may be the desert of Arizona with Professor Lowell, or the clear equatorial skies of Ceylon with Major Molesworth, where neither cloud nor haze nor unsteady air may greatly trouble us. But the sun is shining full on Mars, else we could not see him at all. Changing our station on the earth, and securing the best climate it affords, will not affect one whit the conditions on Mars itself; we can avoid our cloud or haze to some extent, but we cannot get away from his bad weather conditions; from haze or cloud on him; from the lighting up of his air particles even when his atmosphere is at its clearest; from the reflection of their dazzling light which should prevent us seeing clearly, or seeing at all, down to his surface.

But we do see down to his surface, and we see it not so very indistinctly. So the atmosphere of Mars must be very different from that of the earth; it must be very much less dense, and very much more transparent, even when scattering and reflecting the sun's rays.

Now there are two ways in which we can speak of the atmosphere of Mars as being less than ours; it may be shallower, or it may be less dense, less closely packed. And here we are able to speak with certain knowledge. We know that as we climb a mountain on the earth, or go up in a balloon, the air becomes rarer and rarer as we ascend. If, on the other hand, we go down into a deep mine, it becomes denser and denser the farther we descend, and the reason of this is obvious. At any level the air is compressed by the total weight of all the air above it. On the earth, therefore, we find that when we have climbed three and a half miles, that is to say, a little higher than the top of Mont Blanc, we have passed through half the atmosphere as to weight; the pressure upon us is only one-half what it was at the sea-level. Another three and a half miles would take us through half the remainder, and the pressure would be reduced to one-quarter; and so on, every additional three and a half miles upward would reduce the pressure by one-half. The mercury in a barometer which stood at thirty inches at the sea-level, would stand fifteen inches high at three and a half miles, seven and a half inches high at seven miles, three and three-quarters at ten and a half miles, and so on.

1877 Sept. 18^d 11^h 45^m
Longitude, 232°

1877 Sept. 15^d 11^h 10^m
Longitude, 250°

1877 Sept. 10^d 11^h 20^m
Longitude, 297°

1877 Sept. 8^d 12^h 30^m
Longitude, 332°

MARS, by the late N. E. Green.

Now, on the planet Venus, which is very nearly as large, and very nearly as heavy a planet as the earth, this rate of decline of the mercury would be very nearly the same. It would take an ascent of four miles to reduce the atmospheric pressure by one-half. There would be no very great difference, therefore, in the distribution of an atmosphere on Venus and on the earth.

But the case is very different when we come to Mars. He is a much lighter planet and a much smaller planet than the earth, and the 'pull' which its attraction exercises at his surface is much less than it is with the earth. His atmosphere, therefore, is piled much more loosely above his surface; the weight of a given amount of air is much less on Mars than it is here. We should have to ascend nine miles above Mars to pass through half his atmosphere by weight; eighteen miles to pass through three-quarters; and twenty-seven miles to pass through seven-eighths. At twenty-seven or twenty-eight miles above Mars we have, therefore, passed through only seven-eighths of his atmosphere; at the same height above the earth we have passed through about $\frac{255}{256}$ of ours. If, therefore, the air at the surface with us was thirty-two times as dense as that at the surface of Mars, at twenty-seven or twenty-eight miles the density would be about the same in both cases. If the total atmosphere of Mars bears the same proportion to the total weight of the planet as it does with us, then the aneroid barometer would give the pressure at the surface as about one-eighth the pressure here. In other words, the atmospheric density would be about equal to that which we should get could we mount in a balloon ten miles above the surface of the earth, a height at which nothing that we know of could live. On Venus there would be no very perceptible difference from the condition of things here.

Our atmosphere is necessary for our life and vegetation; the atmosphere of Mars is both deeper and much less closely packed than our own, and we have no reason to suppose that it is sufficiently dense even close to the surface to support any form of life with which we are acquainted here.

It must differ from our atmosphere in another feature. The attraction of Mars being so much less powerful than of the earth, the winds of Mars must be far gentler than ours. A stone dropped on the earth will fall, in obedience to the earth's pull, sixteen feet in a second; on Venus it would fall fourteen feet; on Mars six feet. So if, from some cause or another, the air in one region of the earth should become heavier than in the region round about, the heavier air tends to move to regions where the pressure is less, and a wind is set up. A similar wind on Venus would be not quite so violent; on Mars it would be quite feeble. On Jupiter, on the other hand, where the stone would fall forty-one feet in a second, the same difference of atmospheric pressure would set up a terrible hurricane.

We can now realize to some extent the atmospheric conditions of Mars; it is very rare, rarer than we have any experience of here on earth; it is slow moving and stagnant, which again is not favourable for life; and there is little difference between the density of different layers. This last means that clouds do not form readily, nor rain.

From our point of view, the atmosphere of Mars, though thin, is deep. We see the markings on his surface, his 'seas' and 'continents,' but we see them somewhat hazily and indistinctly; the extraordinary thing is not that we see them so, but that they are visible at all. Mars has an atmosphere—we can see it thickening towards his horizons—and it would be impossible for us to see any object on his surface except indistinctly, hazily, and ill-defined.

But there are some objects on him that have been seen with much distinctness, without any haziness or want of definition. There is no doubt about them; any one can see them who has good eyes, a good telescope, and clear enough atmosphere. The same objects are so recognized again and again; they have been seen for many years; they are long and straight and narrow—lines in fact. The better the telescope, the clearer our air, the narrower and more distinctly they are seen. The man who first drew attention to them, Schiaparelli, the greatest living Continental astronomer, called them, in his native Italian tongue, 'canali,' which has been literally rendered 'canals,' though 'channels' would have been the better word. For they have been seen not only as dark lines intersecting the continents, but as darker lines running through the dark seas, and sometimes as bright lines bridging the lakes.

We have said it is impossible; and yet these strange markings on Mars have been *seen*—some have actually been photographed by Professor Lowell's assistant, Mr. Lampland. But are these markings on Mars actually as we see them, or do we only see them like that? In other words, does the explanation of the impossibility which has occurred lie in our being unable to see rightly?

We know that we cannot always see rightly. If we look at a big spot on the sun with the naked eye, it appears like a round black nail driven to its head into a golden plate. But that round dark nail is not the real shape of the spot as we see it magnified in the telescope. The jagged surrounding thatch, the bright bridges, the great number of smaller outlying spots, are not suggested by the sharp black dot which is all we see with the naked eye.

If there were another spot upon the sun large enough to be seen by the naked eye, it would also seem to us like a black round dot; and if it were so near to the first spot that the space (though in reality it might be very great) was not large enough for the naked eye to see it, these two spots would seem to us merged into one elongated one. If, beyond the second, a third spot lay, and then a fourth, and many more in a straggling and uneven row across the sun, we should not see these as separate dots, but all merged into one even line, as sharp and defined in its edges as the black dots have already been. This string of spots across the sun would look to us like a sharp black line, without indentations or gaps. Yet if we did not look at it with the naked eye, but magnified it in the telescope, we should not see it thus, but as an irregular and detached series of spots, themselves irregular and broken. The apparent sharpness would have been due, not to the actual sharpness and definiteness of the object, but to the inability of our eyes to detect the small gaps and irregularities.

So we have no right to conclude that the straight, sharp, even 'canals' we see on the surface of Mars are really as artificial as they seem to us. Markings there are certainly, small, irregular, unevenly distributed; and since Mars is a very small and very distant object, our small telescopes cannot make these separately visible at all, our greater telescopes can only show them as merged into even sharp lines, as do our eyes with sun-spots lying near together. But our greatest telescopes begin to show some of these lines as losing their sharpness, as varying their regularity with nodules, curves, and gaps; they are beginning to get at the actual markings which, by their seeming junction, give rise to the hard, straight lines that have been called the 'canals.'

We are not sure that we should not see 'canals,' somewhat like the Martian ones, if we ascended high above the earth. The Gulf of California and the Red Sea would look like perfect 'canals'; the Aleutian Islands, or the Japanese, might well seem to be bright bridges in the Yellow Sea, when looked at from a height of fifty or a hundred thousand miles; or the North American lakes unite into a narrowish, dark streak under the same conditions—that is if we could see these features on the earth at all.

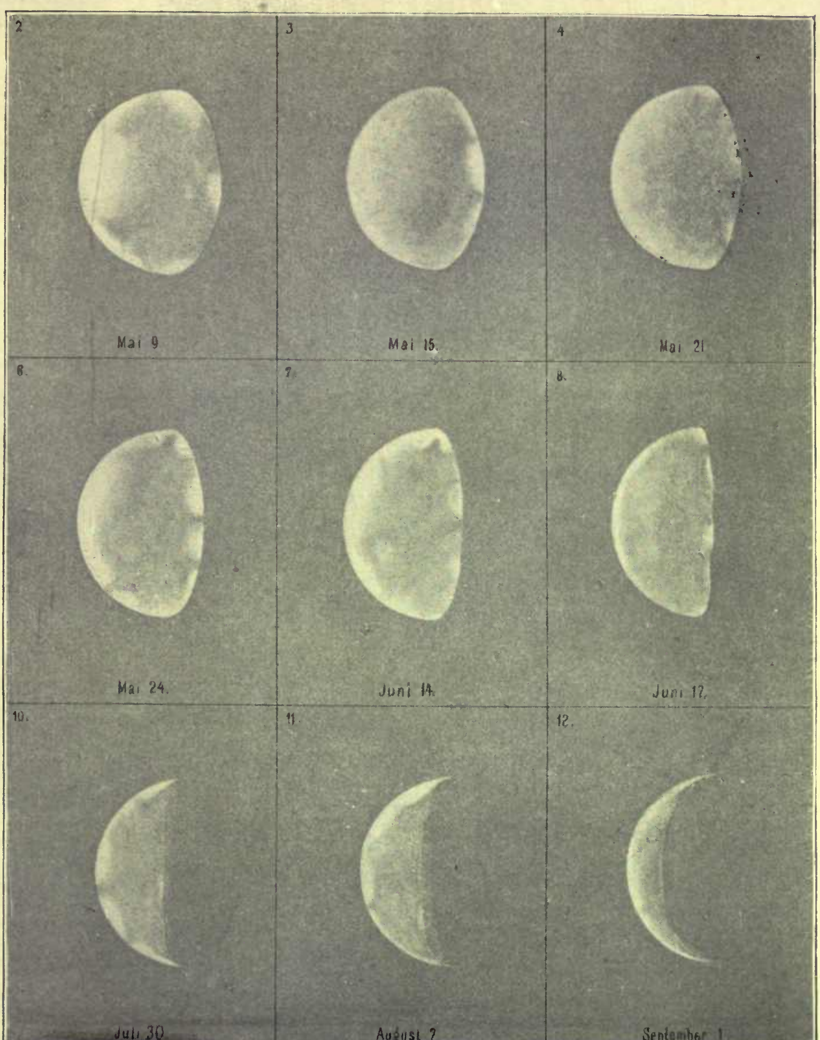
We must therefore leave the question as to what planet is nearest in kin to us without a final answer. We know that in many important particulars Mars differs from the earth. We know very little about Venus, but what we do know of her size and atmosphere and weight is all in favour of her being a true sister planet to the earth. There remains the yet unsolved problem as to the time in which she rotates on her axis. If her day is about the same length as ours, she may well be the abode of life and of intelligence; if her day is the same length as her year, so that she always turns one and the same face to the sun, then one half her surface must be burned to a cinder, the other half chained in eternal ice.

CHAPTER XIV

THE STORY TOLD BY THE MOON

THE sun is shining on a house. It is a house furnished and inhabited, and muslin curtains hang before the windows. The house is light within, for the muslin curtains do not keep out the sun; but from outside no one can see through them to the people or furnishing within. Such a house is the Earth, lighted up by the sun, but screened from the impertinent scrutiny of those outside by her curtains of the air. Such a house may Venus be, but she, too, is screened from our prying by her veil, and we have no opportunity of looking behind it. (*See* PLATE XLV.)

The sun is shining on a house. There are no curtains veiling its windows, so we can see through them into it, and we find no furnishing there. The house is not inhabited, though it may have been once, or may perhaps be again. Such a house is Mars. Men such as we are can scarcely live there now, though in the past or in the future the planet may provide a fitting home for them.

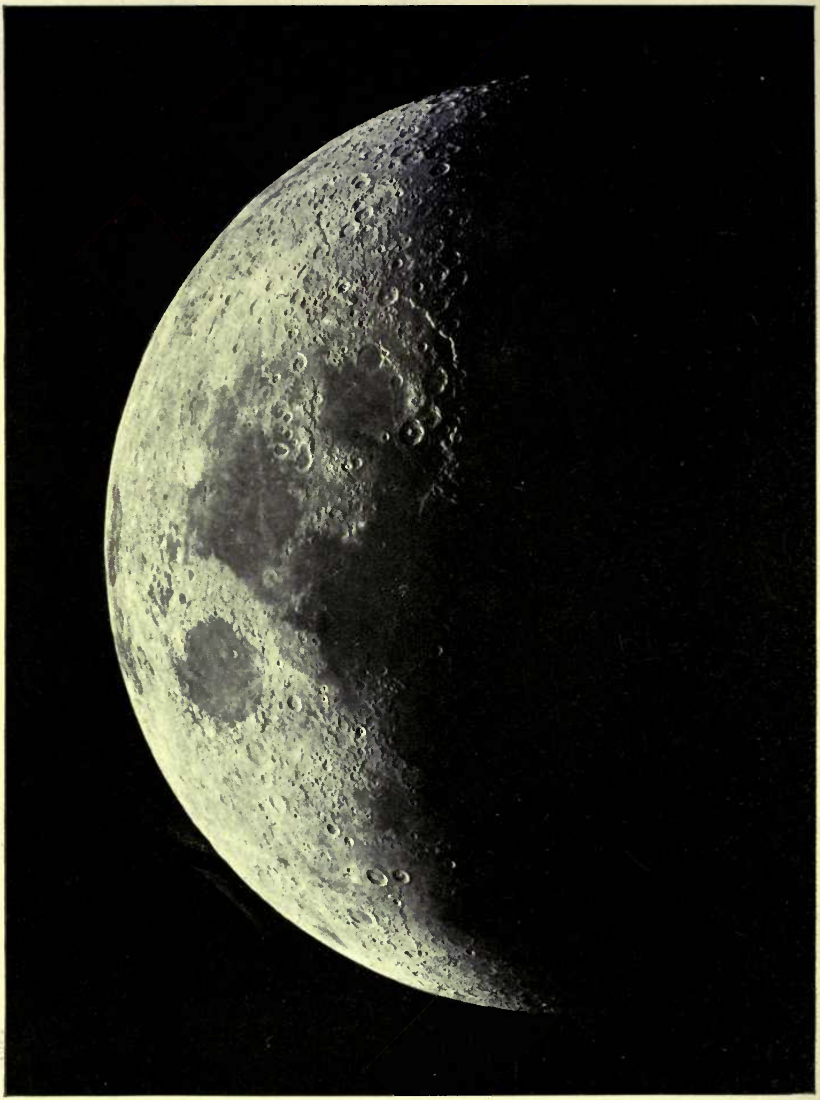


Drawings of Venus in 1871, made at the Bothkamp Observatory.

PLATE XLVI.

SOUTH

WEST



EAST

NORTH

Photograph of the Moon, taken by M. Puiseux, April 5, 1900. Moon's Age, 6 days.

(The Moon is shown as seen in an inverting telescope.)

The sun is shining on a house. He can shine in where he will, for it is but the shell of a house. Any one can look in from outside and see that it is not in fit state to be furnished for the habitation of man. Such a house is the Moon; a house where life can find no place to dwell in. Because the moon is a dead world, a mere world-shell, there is offered no bar to our prying where we will. Where the sun holds the candle to guide us, there we may look. The moon neither assists nor resists.

There are two bodies in the heaven which appear to us to be of the same size. These two bodies are the only ones that we can find exercising any real influence on the earth. They are the sun and the moon. The sun has already told his story; how he turns round and bears with him the spots, faculae, and prominences which, from time to time, break out on him, and how this turning has consequences upon our earth. The sun's disc can be easily seen by the naked eye, and usually is unblemished. But sometimes one or more round black spots mar his fair surface, and then we see that from day to day they seem to move across his face; in truth, the sun is turning and the spots turn with him.

The moon's disc can as easily be seen by the naked eye, but it is never unblemished; great grey stains curve in a chain along her upper part, and the brightness of the rest of her is not uniform: some parts are almost dull, and at other points she glitters as if she were set with diamonds. There are always the same grey stains, the same gleaming points of light when the moon is full. (*See* PLATES VII., XLVI., and XLVII.)

And when the moon is not full? When the moon is still young and the silver bow of the evening has widened enough for us to see any markings on it, in the upper half we trace a dark oval stain like a sun-spot, that has just come over the eastern edge. But as the sunlight creeps over the moon, the stain does not move as does the sun spot—it always keeps its oval shape; it never comes to the centre of the moon's disc, presenting the full round; it never shifts its place, though the sunlight passes over it and leaves it again in darkness. And so with the other bright points of light or dark stains; they are in the sunshine or they are in darkness, but they do not alter or move. The moon has been taken by poets and philosophers in all ages as the emblem of fickleness and change. But she is no true emblem; the dead cannot be fickle; it is the sunlight on her, not she, that changes. She does not suffer change in herself; she does not alter her face, for she does not seem to us to turn upon her axis. The moon is but a

> batter'd caravanserai
> Whose doorways are alternate night and day.

The moon is an interesting body to the naked eye because we can, even unassisted, study some of her features. But she gains beyond measure in beauty and interest when seen in the telescope, unlike many other astronomical objects, such as the planets Venus and Mercury for instance. Her bright parts shine like the purest silver, her parts in shadow are in blackest contrast, her grey stains are not dull greyness, but give evidences of innumerable shades and inexhaustible details. The moon is herself so black, so dependent on the sun's light to make her visible, that as the sun begins to rise on any part of her, little points of brightness, like constellations, spring up where they seem quite detached from her, for they are the protruding tips of her mountains that themselves catch the first rays, but shelter their sloping sides and valleys from the sunlight. The rays creep down towards the hollows, and the constellated points of light increase and run together, forming here a round ringed wall, there a straight ridge, or again, a solitary central peak within a crater. The call for the month-long day has come :

> Awake ! for Morning in the Bowl of Night
> Has flung the Stone that puts the stars to flight :
> And Lo ! the Hunter of the East has caught
> The Sultan's Turret in a noose of Light,
> Dreaming when Dawn's Left Hand was in the Sky.

Like many another fair lady, the moon's photographs cannot be made to do her full justice. Other heavenly bodies there are that we fail to see completely, or perhaps at all, with the eye, either aided or not by a telescope. Such bodies are comets and nebulae, and to study these fully we must photograph them. But parts of the moon are so bright, and parts so dull, that a photograph, timed not to over expose the first, will fail to show the second; and exposed sufficiently to photograph the fainter parts, will show the brighter lost in a confused glare. So we must photograph her under many conditions of sunlight, and with varying times of exposure.

The photograph given in PLATE VII. was taken when the moon was nearly at the full. It is usual with representations of the heavenly bodies to place the south pole at the top, the east being at the right hand, but in this instance the moon is shown as seen in the sky.

In the first place, it will be noted that the edges of the moon which are in full sunlight are perfectly sharp. Neither are the moon's features near her borders any less clearly defined, any more misty, than at her centre. There is no atmosphere on the moon; none, at least, that we can detect by even the most delicate method. Therefore, there is no cloud, no rain, no vapour even. And if there is no vapour-laden atmosphere on the moon, neither are there oceans or rivers, snow or dew. The earlier observers of the moon through the newly

SOUTH

WEST

EAST

NORTH

Photograph of the Moon, taken by M. Puiseux, September 12, 1903. Moon's age, 19 days.

(The Moon is shown as seen in an inverting telescope.)

PLATE XLVIII.

THE 'SEA OF CLOUDS,' showing the settling down of the Lunar Surface.
(*From the Photographic Atlas of the Moon of the Paris Observatory, by MM. Loewy and Puiseux.*)

discovered telescope did not realize this. When they saw craters and mountains similar to those on the earth they jumped to the conclusion that the low, level, grey markings were the lunar seas, and named them thus, and so we call them to this day. Milton, in his *Paradise Lost*, makes Galileo discover

> Rivers or mountains on her spotty globe.

But Galileo himself denies this, and on February 28, 1616, he wrote: 'I do not believe that the body of the moon is composed of earth and water; and, wanting these two elements, we must necessarily conclude that it wants all the other things which, without these elements, cannot exist or subsist.'

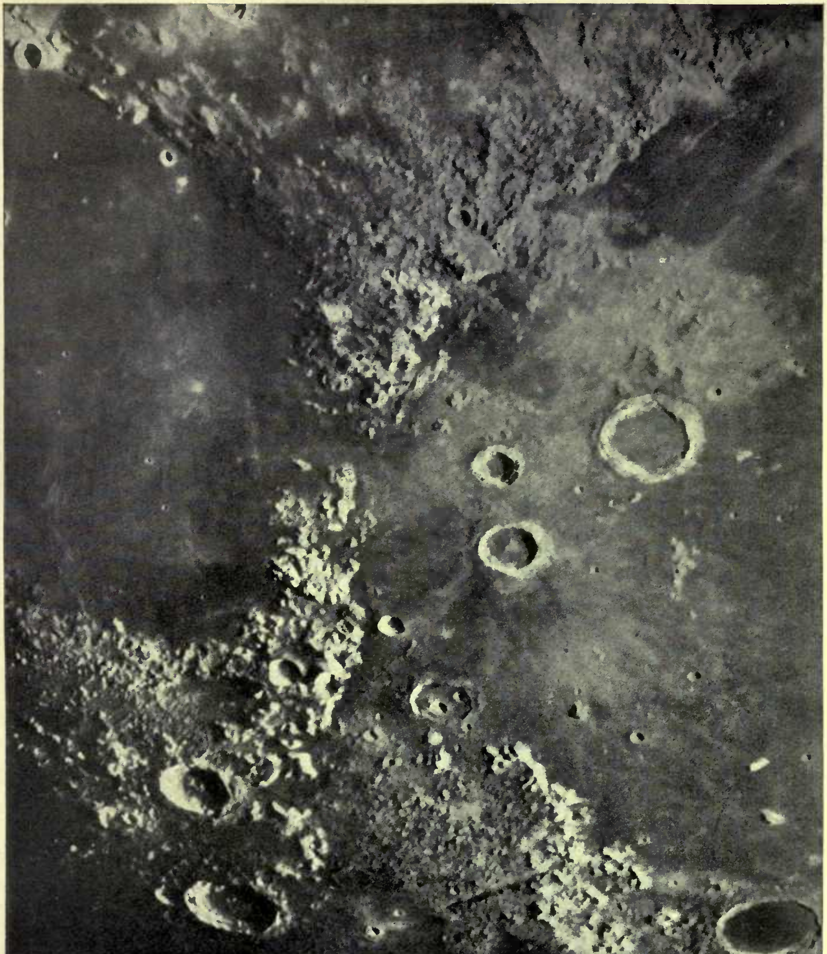
There is no doubt that some time or other the great grey lunar 'seas' were filled with a flowing tide, but that tide was probably of molten lava, and not water, as our oceans are. Most of the lunar seas form a chain curving through the northern hemisphere, not along the moon's equator. So marked is the divergence of this 'sea-band' from the moon's equator, that some have urged that the moon's axis of rotation has shifted since the 'seas' were formed. Somewhere Mark Twain says that 'there is not a parallel of latitude but thinks it should have been the equator if it had had its rights,' and on the moon it certainly looks as if one of these rebellious circles had brought about a successful treason. The belt of seas are named thus, from left to right: the Seas of Fruitfulness, of Peace, of Serenity, of Showers, and of Storms. The Sea of Nectar lies to the south of the Sea of Fruitfulness, and the Sea of Crises, the oblong sea like a sun-spot, lies to its north. And the Sea of Clouds lies to the south and east again of the Sea of Storms.

PLATE XLVIII., which shows part of the Sea of Clouds and the little neighbouring Sea of Dews, exhibits very clearly the evidence of the 'settling down' of the moon's surface at some period. The centre of the photograph shows a number of long, curved, concentric cracks, concave to the east, and cutting through both plain and highland. A great but partly ruined walled-plain lies on one of these cracks, just above the middle of the picture, and looks as if it had partly sunk or partly dissolved under the rising of the tide of molten lava. Nearer the east of the picture a number of curving ridges are seen practically concentric with these cracks, and are due, no doubt, to the same disturbance at a later stage of its action.

The chief mountain ranges on the moon are gathered together and separate the Sea of Serenity from the Sea of Showers. The Apennines form the most southerly ridge. A broad pass cuts through their northern end, and the Caucasus range trends to the west, whilst the Alps trend to the east, forming the northern boundary

SOUTH

WEST



EAST

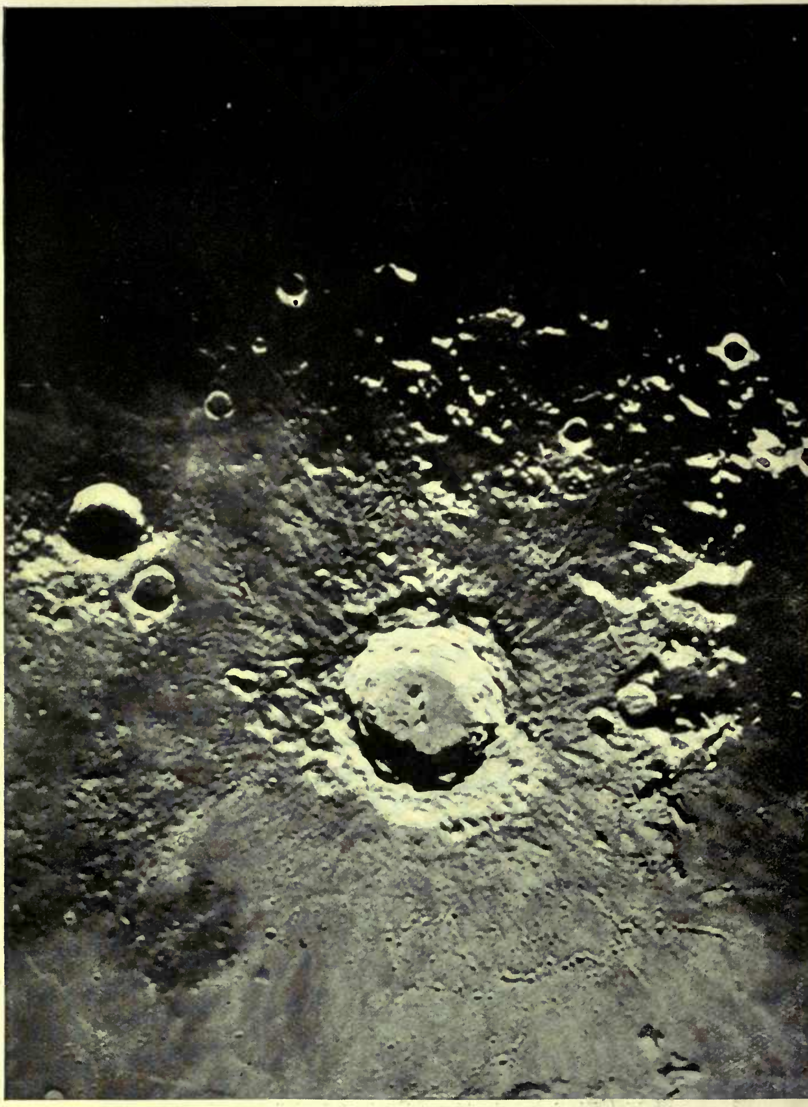
NORTH

THE CHIEF MOUNTAIN RANGES OF THE MOON.

(*From the Photographic Atlas of the Moon of the Paris Observatory, by MM. Loewy and Puiseux.*)

PLATE L.

EAST



WEST

COPERNICUS, the grandest of the Lunar Ring-plains. Diameter, 56 miles; height of wall, 12,000 feet.

(From a photograph taken by Professor G. W. Ritchey, at the Yerkes Observatory, U.S.A.)

of the Showery Sea. The Carpathians form its southern. (*See* Plate XLIX.)

The full moon looks rather like a badly peeled silver orange, the seas being the portions where the skin has been torn off. The resemblance is increased by a brilliant round crater in the southern hemisphere named Tycho, which marks the place where the orange stalk had joined, and from this place a great number of bright rays radiate, as if to show the divisions of the fruit. These lunar 'rays' are only seen when the moon is near her full, and we do not know to what they are due. They extend into the hemisphere of the moon that we never see, as well as in some cases right across the hemisphere which is always turned to us. One such ray can be seen surmounting every obstacle and radiating from Tycho through the Sea of Serenity, and continuing almost to the northern edge. There are other systems of rays besides those from Tycho. Another system radiates from the great ring-plain Copernicus, which lies between the Seas of Showers, of Storms, and of Clouds. (*See* Plate L.)

But the most remarkable features of the moon are its craters and walled plains of all sizes, and in all states of preservation or decay. Craters and craterlets are seen everywhere: on the beds of the great solid 'seas,' aligning the 'rays,' on the slopes and summits of the mountain ranges, in the valleys, on the crater walls of other volcanic peaks; in the depths of their hollows; obliterating other craters. The very 'seas' seem but the giant remnants of some earlier and still more stupendous volcanic outburst; while the mountain ranges appear as half-broken-down crater walls to the 'seas.'

It is in the south, however, near the moon's pole, that the craters are seen in greatest numbers. The whole surface in this region is pock-marked, riddled with pits and holes.

These pits have usually ring-like walls about them, which slope very steeply to a central cavity, and more gently towards the surrounding country. They vary greatly in size; the largest are more than a hundred miles in diameter, while the smallest discernible are less than a half-mile across. The number increases as the size diminishes; there are many thousands of them, so small that they are revealed only when sought for with the most powerful telescopes and with the best seeing.

In all these pits, except those of the smallest size, and possibly in these also, there is within the ring wall, and at a considerable, though variable, depth below its summit, a nearly flat floor, which often has a central pit of small size or, in its place, a steep rude cone. On the floors of the larger craters, numerous small pits, or craterlets, are found. The lunar pits certainly suggest that these features are volcanoes, and probably they are in some way nearly analogous to the volcanic vents on the earth. At some time in the moon's history these allowed her pent-up energies to burst forth, and are evidence of the violence of her activity at such a time.

But whatever may have been the violence of the moon's activity in the past, it is all spent now. No new pits are now formed, no old ones are being defaced. We mark no sure change on any part of the moon, and the few instances of a slight suspected change are due to the crumbling of a crater wall, perhaps from sheer force of gravity, perhaps to the impact of a meteorite which has upset its unstable equilibrium. One of the best known instances of suspected change is the little crater Linné, seen as a white spot in the great plain, the 'Sea of Serenity,' on the west side of PLATE XLIX.

The moon is the heavenly body which we know most intimately; we have mapped its surface more fully than we have explored many parts of our own globe. Yet all our scrutiny fails to yield us any evidence of forms of life upon her such as we know here; or even of the power to live. So far as we know there is no home for life in the solar system, other than on our own world. Saturn and Jupiter are not yet sufficiently condensed. The moon is condensed and solid, but she has no atmosphere. Mars is solid and with an atmosphere, but that atmosphere is insufficient for the sustenance of life in the forms in which we know it, and the planet does not receive sufficient light and heat from the sun. Venus alone is a possible sister world, and we deem her possible, simply because we know so little about her.

CHAPTER XV

THE STORY TOLD BY COMETS

THERE is a strong family likeness between all the members of the solar system that we have just described. They are all globes revolving round the sun in orbits that are very nearly circles, and all in the same direction; all the orbits lie in a thin slice of space; to all of them the sun rises in the east, and sets in the west. They have their individual characteristics, it is true—thus our moon is without any atmosphere that we can perceive, and Saturn is distinguished from all other planets by his wonderful ring—but their resemblances are more pronounced than their differences.

The sun is, without doubt, also of the same family. He, too, is a globe, revolving on his axis in the same direction as his dependants, and some of the characteristics of his surface have analogies upon several of them; on Jupiter, for instance, and on Saturn.

Though the sun belongs to the same family as the planets, he differs from them in two very important particulars. The first is in his stupendous bulk and mass; in both he is greater than all his family put together by many hundred times. The second is in his possession of a corona, in the long, rod-like rays, the fingers he stretches out as if to touch his family. We know of nothing upon the earth to correspond; we know of nothing like it, even on the giant planet Jupiter. What are the conditions for a corona? Does the sun possess it because of his great size, or because he is a highly heated body?

If we look elsewhere for a corona, we do not find one on the ponderous planet Jupiter, the largest, heaviest, and probably the most highly heated of all the planets, but we find what resembles it very closely in those members of the solar system that seem of least weight and feeblest influence. These members are called comets, and are of all degrees of brilliancy, from the most faintly shining mist which is only photographed in a powerful telescope by long exposure, to objects so bright that they can even be distinguished in the glare of the noonday sun. There are, on an average, some twenty or thirty bright comets to be seen in a century, that is to say, comets that are conspicuous to the naked eye. During the last quarter of a century, however, we seem to have fallen into a blank space, for only one bright comet has been seen since 1882, and this one was not visible to dwellers in northern latitudes.

Comets, whether they are faint telescopic ones, or bright and visible to the naked eye, have three features, not indeed separate and distinct, but merging into each other. The *nucleus* and *coma* together form the head; the *nucleus* in a naked-eye comet appearing like a star, shining through a patch of mist or fog, which is the *coma*. Stretching away from the comet is the *tail*, or perhaps the tails. These narrow in near the head, and not only diverge from each other as they recede, but themselves grow wider and more diffuse, so that they are always more or less fan shaped. (*See* PLATE LI.)

The most brilliant of all the comets in the memory of living men was that of 1858, known by the name of its discoverer, Donati. It was first seen on June 2, but was then only visible through a telescope, and as a faint, white mist, without tail or nucleus. In the middle of August a little tail began to be seen, and the comet became visible to the naked eye early in September. From this time it increased enormously in its proportions and splendour, and for a whole month it could be seen night after night. After October 10 it began to fade away, and as it was then also travelling towards the south, it was lost to observers in the northern hemisphere. To watchers in the south it remained visible in the telescope until the March of 1859. When at its brightest, the nucleus was equal in lustre to Arcturus, which indeed appeared involved in its tail on October 5, and the tail itself stretched out like a scimitar whose curving blade was over fifty millions of miles in length. (*See* PLATE LII.)

But this great blade was not the only tail. On September 16 an observer at the Strasburg Observatory saw a faint outer envelope, like the thinnest of veils, flung over and away from the comet's head, and on the next evening a narrow straight ray, a secondary tail, that seemed like a strand that had sprung to the straight from the curved edge of the blade. This secondary tail was visible for nearly three weeks, and during part of the time a third tail was to be seen, straight like the second, and lying between it and the curved blade-like tail. This great blade was not evenly bright, but its outer edges were more illuminated than its centre, as if the nucleus cast a curving shadow. The tail seemed formed by the envelopes thrown off one after another from the nucleus towards the sun, and then cast backwards right and left to form the great branches of the blade-like tail.

The coma, or the envelopes, seem drawn out of the nucleus towards the sun, but the matter which thus seems to be drawn out is soon swept away, as fast as it is formed, in a contrary direction. Mr. R. A. Proctor likened it to the steam from the funnel of an engine, a funnel directed forwards, not upwards, and rushing against a hurricane; for the tail, which seems made up of the matter drawn to him by the sun from the nucleus,

DANIEL'S COMET, 1907, *d*.
(*From a photograph taken at the Royal Observatory, Greenwich, August* 10, 1907.)

PLATE LII.

DONATI'S COMET, October 5, 1858, seen near Arcturus.
(*From Guillemin's 'Les Comètes.'*)

is continually swept away from the sun. Thus, in the comet observed by Sir Isaac Newton in 1680–81, as it approached the sun, its tail, which was some ninety millions of miles in length, pointed back almost along the orbit. But when, a few days later, the comet had made its nearest approach to the sun, and was receding from him, its tail, still of huge length, was pointing forward, almost straight before the comet in the direction in which it was moving, and in the opposite direction to that which it had a few days previously. Now, we cannot imagine that a comet's tail can be brandished like a stick, so that we must believe that these were two different tails, and that the matter of which they were composed comes from the comet's head, just as the matter of which the coronal rays are made comes from the sun. Both sun and comet give of their substance continually to form their tails. The sun's bulk is so stupendous that he can afford to throw off his long coronal rays; the loss would make no appreciable difference to him even if the ray contained a quantity of matter. But the head of a comet is but a small thing: it cannot continue for a length of time to supply a tail that may stretch into hundreds of millions of miles, if there is much in the tail; each time that a comet approaches near to the sun, it develops a coma and a tail, and thereby expends itself; the tail must therefore be almost inconceivably attenuated, or else each time it returned the comet would become smaller, until it had become too faint and small to be seen at all.

For comets resemble the other members of the solar system in this one respect: they all obey the law of gravity. As all the planets move in orbits of which the sun occupies a focus, so do all comets, but the paths they follow may greatly differ from the orbits of the planets or from each other. For sometimes we see a comet that travels in a path of moderate extent; sometimes one whose nearest point to the sun lies within the corona, but whose farthest is many thousands of millions of miles away from him, and whose 'year' of travelling round it must be measured in millenniums. So, too, comets do not confine their paths within the thin slice of space wherein the orbits of the planets lie; their paths may be inclined to this at any angle that may be named. Some may pursue a path in the same direction that the planets move, others, many others, revolve round the sun in a contrary direction.

Sir Isaac Newton was the first to show that a body moving under the influence of the sun's attraction, must follow one of three paths, either an ellipse, a parabola, or an hyperbola. The ellipse is a closed curve, of which the circle is a particular example; but an hyperbola or parabola is not closed, each of them extends without end in two branches. In the case of the hyperbola these branches continually diverge from each other, but in a parabola they become ultimately two parallel straight lines. (*See* PLATE LIII., fig. 1.)

Suppose that we have a beam of light coming through the lens of a magic-lantern and falling on the white sheet. If the lantern is fair and square to the sheet, there is a circular disc of light upon it. But if we twist the lantern a little askew, the circular disc of light on the screen becomes oval-shaped; it is an ellipse, and the more askew we twist the lantern the more elongated the ellipse becomes, the long sides of the oval tend to open out, until, when the sheet is parallel to the far side of the beam, or cone of light that we see issuing from the lens, these two sides to the oval do not close in again to each other, but become parallel straight lines; the ellipse of light has become a parabola. If we turn the lantern still farther askew to the sheet, the sides of the parabola diverge instead of being parallel, and the parabola of light has become an hyperbola.

If, then, a comet were moving round the sun in an ellipse, however long stretched out that ellipse might be, the comet would return at last to the neighbourhood of the sun. Its 'year' might be a long one, but it would have its limits. But if a comet were moving in a parabola or an hyperbola, then, when once it had passed away from the sun, it would never return, but would retreat slowly, and yet more slowly, farther and farther from him. In most cases all that we can say of a comet is that its path is probably a very long ellipse, almost a parabola, so that the comet flies out to an immense distance, not returning for hundreds, or, it may be, thousands or tens of thousands of years. Yet even when they lie in space many millions of miles beyond the farthest planet, they still seem to have a part in that motion through space that the whole solar system has. All the comets of which we have knowledge form a genuine part of the solar family; and they are not, so far as we can tell, visitors to us from other suns.

If, as these comets return to the sun from the region where they have been moving far beyond the planets, they should chance to pass near where a great planet is circling, two things may happen: the comet may get either a pull from the planet which will increase its speed and send it out from the sun even farther than before, or one that may diminish its speed, so that the comet moves in a smaller orbit, where we can see it swinging again and again past the sun. These last are called periodic comets. Jupiter has been the most powerful of the planets in forming a family of them, but the greatest of all the periodic comets probably owes its present orbit to a 'pull' by Neptune many hundreds of years ago.

This is Halley's comet, which we expect to return to a near approach to the sun in the year 1910. It is the first comet whose return was predicted, for it was seen during the time of the first Astronomer-Royal at Greenwich Observatory and from his observations, Halley, the second Astronomer-Royal, found its orbit, identified it with a comet seen by Kepler in 1607, and foretold that it would again return about 1758. It did actually return in 1759, a little later than Halley had predicted, for the pull of Jupiter and Saturn was sufficient to keep it back a little. It was again seen in 1835, and we hope that it is still in existence to return again within the next year or two. But we cannot predict with certainty that a comet will return, especially a comet that goes so far beyond the confines of the solar system as Halley's does. There may be planets out there, of which we know nothing, that may pull it into a new and unknown orbit, or it may have split up as other comets have been known to do; or it may have expended all its substance in its tail. For it would seem to have been diminishing in brightness at each return to the sun, at each display of its splendid tail. An early record of its appearance was in the days of the conquest of England by William the Norman, when it was a fear-inspiring sight. William's Queen Matilda worked into her Bayeux tapestry the appearance that it presented to them. So, too, when it appeared in the thirteenth and fourteenth centuries, it struck terror into all the nations. But it was not to be compared to some other comets of the first half of the nineteenth century, when it appeared in 1835, and if it comes again in 1910, it may seem but as a spendthrift noble at a Court: dull, lustreless, and bereft of all its former shining train. (*See* PLATE LIII., fig. 2.)

BOOK IV

STORIES TOLD BY THE STARS AND NEBULAE

CHAPTER XVI

THE STORY TOLD BY THE STAR IN THE CENTAUR

Star Distances

DOES the sun go round the earth, or does the earth go round the sun? Which is the right doctrine to hold, the first or the second? When we ask the question to-day, certainly nine hundred and ninety-nine persons out of every thousand would affirm the second. But if it had been asked three or four centuries ago, the majority would have been as great in affirming the first. So it is no proof that a given assertion is true, that every one believes it.

Three hundred years ago the gates of the sky were thrown wide. A young Italian professor of mathematics, Galileo Galilei by name, heard a rumour that a Dutch optician had made some glasses that appeared to bring far things near. This rumour set Galileo thinking, and he said: 'It appeared to me that it depended upon the laws of perspective. I reflected on the manner of constructing it, and was at length so entirely successful that I made a spy-glass which far surpasses the report of the Flanders one.' The principle on which Galileo constructed his telescope was that which we to-day use in an opera-glass. When he had constructed one powerful enough to magnify an object about twenty times, Galileo turned it on the heavens, and, without leaving Italy, became the Columbus of a new and greater world. He discovered four moons to Jupiter; he observed the mountains on the moon, and measured the height of some of them; he discovered the phases of Venus; he observed a curious triple appearance of Saturn, which we have since learned to be due to its rings; he found innumerable new stars and nebulae, and he also found spots on the sun. Like the Ancient Mariner, he was

> . . . the first that ever burst
> Into that silent sea;

and where everything was new, everything was to be discovered. Of all astronomers, surely he was the most fortunate, the one most to be envied.

But there was another side to the shield. His discoveries made the name of Galileo famous throughout the length and breadth of Europe, and brought him many friends. But they also brought him enemies, and these were the more powerful. The scientific writers held most in esteem in those days were the old Greek philosophers, who taught that the universe was constructed as they conceived it ought to be, not as they might have observed it to be; and the ideas of these philosophers were held by the world of Galileo's day, but were weighed and found false by Galileo. He became an old man, weighed down by family griefs and afflicted with many diseases. He was a devout Catholic, and he was accused of teaching that which led his pupils to err from the Catholic faith. He was called upon to abjure this teaching, and this he did on June 22, 1633, in the following words—

'Because I have been enjoined, by this Holy Office, altogether to abandon the false opinion which maintains that the sun is the centre and immovable, and forbidden to hold, defend, or teach, the said false doctrine in any manner; and because . . . I held and believed that the sun is the centre of the world and immovable, and that the earth is not the centre and movable. . . . Therefore with a sincere heart and unfeigned faith, I abjure, curse, and detest the said errors and heresies, and, generally, every other error and sect contrary to the said Holy Church.'

Galileo had based his belief that the earth went round the sun, and was therefore merely a planet like other planets, on the resemblances between the earth and the moon, and the more distant heavenly bodies. Venus, he showed, had her phases like the moon, so that both earth and planets got their light from the sun, and were dark when turned away from him. He brought forward the resemblance between Jupiter, with his family of small bodies, and the sun, with his family of planets. All these, however, were analogies only, and, however convincing they might be, they were not proofs.

But Galileo also showed that it was more probable that the earth went round the sun, instead of the other way about, since the motions of the planets were thus seen to be less complex. Further, if the stars were all distinct and independent bodies, and not immovably fixed in a crystal sphere, he urged that it was improbable that the laws controlling their motion about a fixed earth should result in revolutions timed uniformly for all, and at the same time of enormous rapidity. The precession of the equinoxes, too, in virtue of which the direction of the earth's axis in space moves slowly, completing a revolution in about 26,000 years, would make the motions of the different stars inconceivably complex. Above all, Galileo relied on the ebb and flow of the tides as showing the motion of the earth both on her axis and round the sun. These, however, we know are really unconnected, and Galileo was relying here on a false argument.

But there was a difficulty which was as fatal to the doctrine of the earth going round the sun—unless the stars were all immovably fixed in a crystal sphere—as the precession of the equinoxes was fatal to the doctrine that both sun and stars went round the earth. Galileo recognized this difficulty, and to the end of his life hoped against hope that evidence would be forthcoming to clear it away. But all his efforts, and those of other astronomers, were worse than unavailing; the more powerful their instruments, the more exact and careful their observations, this fatal difficulty to the truth of the doctrine that the earth went round the sun only became the more pronounced. There are those who consider that Galileo sinned against the light when he abjured the doctrine 'that the sun is the centre of the world and immovable, and that the earth is not the centre and movable.' 'There are those,' as Sir Oliver Lodge says, 'who lament that he did not hold out, and accept the crown of martyrdom.' But instead of sinning against the light when he abjured, Galileo knew that he had failed to procure essential evidence for the truth of the doctrine that the earth moves. Until he could procure that evidence, he could not be sure of the truth of that doctrine; he ought not to be sure of it. That evidence was not procured until wellnigh two hundred years after Galileo's death.

The difficulty in the way of accepting the doctrine that the earth moves round the sun may be explained thus. If we are looking at the picture of a landscape, with trees, streams, men, and animals in it, we cannot get any of these objects to shift their positions with regard to any of the other objects, no matter from what point of view we regard the picture, no matter how perfectly they are represented in perspective. We may shut first the right eye and then the left, we may regard the picture from above or from below, we may look at it from any angle to the incident light; but the picture simply shifts to us as a whole, with its trees, streams, men, and animals. We cannot by any means superpose one of the objects on another, or separate between two that touch. This is because they are all on the canvas, all at the same distance from us; their perspective effect is but make believe.

But it is different if we are looking at the real landscape, no matter how still and fixed the objects may remain. Then, the looking with the right eye or the left, the shifting from one point of view to another, will bring some of the objects more into line, will tend to throw others apart. This is because they are at different distances from us. Though the objects remain immovable, and it is ourselves who shift about, all the objects will seem to move, and the nearer objects will seem to move more than the more distant ones.

Now, the distance of the sun from the earth is about 93,000,000 miles; so that if the earth goes round the sun, the sun and the stars really remaining fixed, the earth is in June fully 186,000,000 miles away from the spot where she is in December; and 186,000,000 miles is no small distance. Such a shift of the earth ought to make the stars, if they are at different distances away, appear to shift among themselves. Now the stars look as if they are at different distances; the bright stars certainly seem to stand out well in front of the starry background of the Milky Way. As the earth gives her half-yearly swing of 186,000,000 miles, these bright jewels in the foreground should swing out towards the opposite direction, across the fainter star-set background. They ought to swing as the earth swings; they *must* swing as the earth swings.

But they did not, let Galileo test each and every star with his most perfect telescopes. They did not shift to and fro, no single one of them, as Galileo's great astronomical successors tested them with telescopes incomparably more powerful and more accurate than his. The Astronomers-Royal of Greenwich, one after another, searched for a swing to and fro in star after star, for a swing corresponding to the earth's swing round the sun, and no star gave it. The ingenious Mr. Hooke, the incomparable Sir William Herschel, whose telescope seemed able to peer even to the very outermost confines of the stars, all these searched for the swing of even a single star, and failed to find it. And now it was nigh two centuries since Galileo had expressed his belief that the earth did move and not the sun, and had abjured it.

Are the stars all, then, like the men and trees of the picture we described, some painted in small so as to look far off, some painted in large as if they were near, but all at the same distance from us so that they cannot seem to shift to each other as we shift our position? Are the stars really set like jewels on a crystal globe, as men used to believe very long ago, so that they cannot move from their setting?

Not so. During the two hundred years since Galileo died, evidence was continually accumulating that the stars did move from their setting, each with its own 'proper motion.' Flamsteed, the first Astronomer-Royal, and Bradley, the third, each made catalogues of stars, giving their exact places in the sky; but the stars in the two catalogues had not quite the same places; the stars had moved slightly, not all in the same way, not all in the same direction, but indiscriminately, one a good distance that way, another but a small distance this way. It was not that either Flamsteed or Bradley were careless and inexact in marking down the place where they saw the stars, for in the catalogues that have been since made the same movements are emphasized. Each star has its own motion, its 'proper motion,' as it is called; but it is a steady motion, straight on, year after year, not the swing to and fro in a year, which

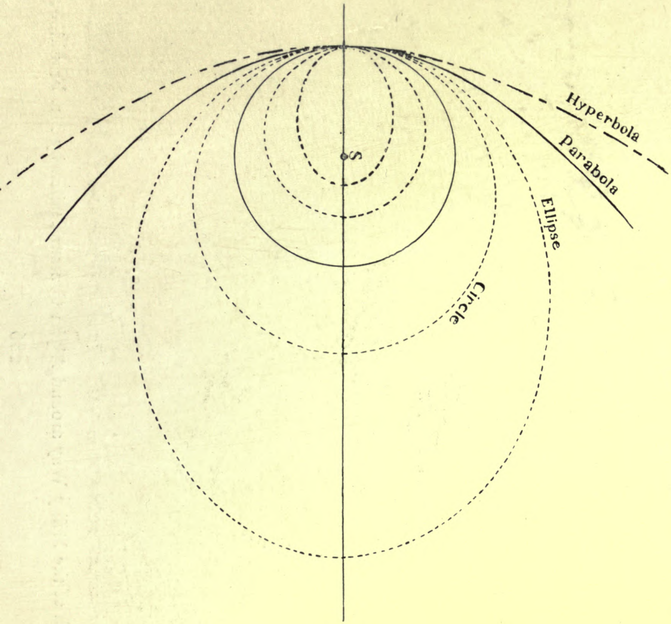
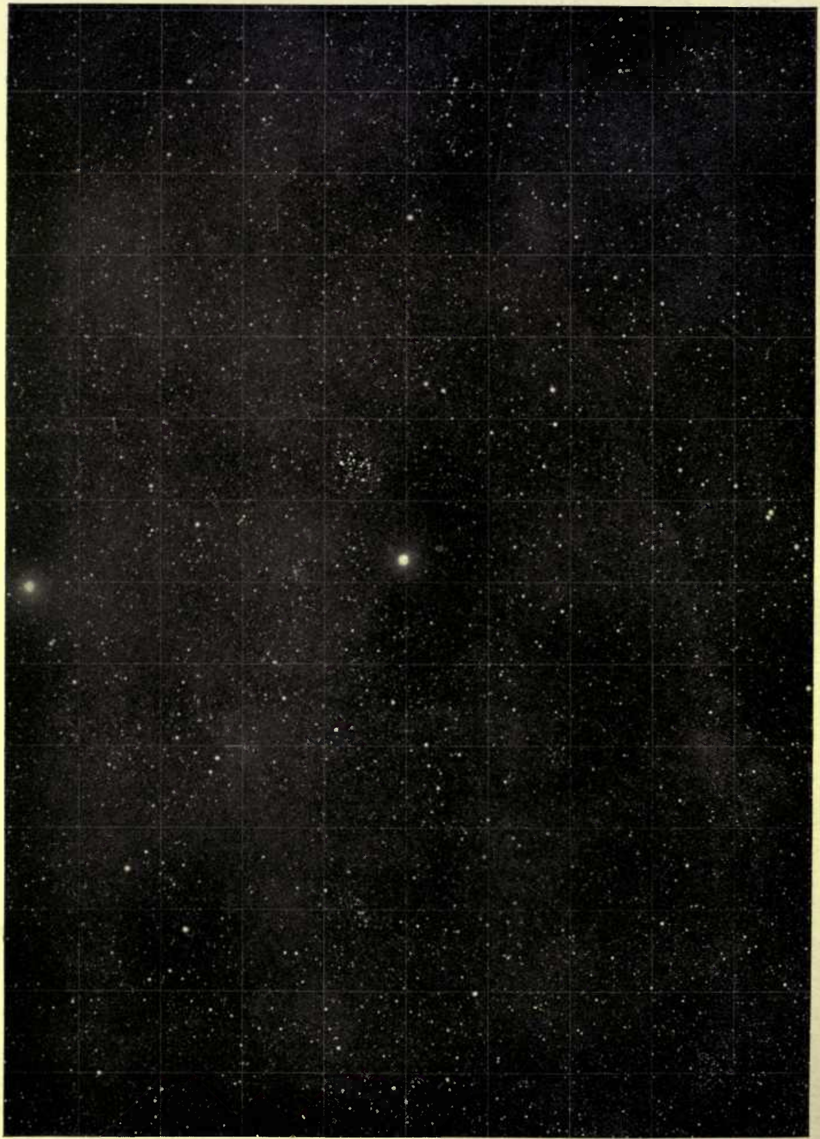


FIG. 1.—Forms of Cometary Orbits.

FIG. 2.—Halley's Comet, from the Bayeux Tapestry.



Photograph of the Milky Way around Alpha Centauri, taken by Mr. Franklin-Adams.

the earth's revolution round the sun should make it seem to have. And later still, when the spectroscope has been used on the light of the stars, it has been found that they have their 'proper motions' towards us, or from us, as well as their 'proper motions' along the face of the sky. And these proper motions in the direction of a line joining the star to us are very great and rapid motions, amounting, it may be, to scores of miles in each second of time. So the stars truly move from their places.

At last, a little more than two centuries after Galileo had abjured his belief in the movability of the earth, evidence was forthcoming that the earth did swing to and fro, by the little corresponding swing that was observed in the case of two stars. The evidence for both was forthcoming almost at the same time, in the winter of the year 1838–39, by two observers, for one of the stars could only be seen by those in the southern hemisphere, and the other by those in the northern.

The southern star is the brightest in the constellation of the Centaur, the third brightest star in the whole heavens. It has a large 'proper motion' of about three and a half seconds of arc annually; that is to say, in about six hundred years it would move from its place among the stars by a distance equal to the apparent size of the moon. A Royal Observatory had been lately completed at the Cape of Good Hope in order to supplement for the southern hemisphere the observations made at the Royal Observatory at Greenwich ; and it was by Henderson, Director of the Cape Observatory, that the observations were made which showed that Alpha Centauri had a swing in a year of about a second of arc. Such a swing would be about the width that a sixpence would seem to have, if it were held up at Charing Cross for an observer at Millbank to measure. But such a swing would mean that the star Alpha Centauri is distant from us about 206,265 times 93 millions of miles, a distance that we cannot conceive of in our own mind. (*See* PLATE LIV.)

And yet Alpha Centauri is not even so near to us as that, for Henderson's measures made the swing too large, and later observers have reduced the shift to and fro to only three-fourths of a second of arc, which means that the star is 206,265 times $\frac{4}{3}$ times 93 millions of miles away from us. This shift of the star in a year is only just about as much as the apparent shift in the sky that the cross on the top of St. Paul's would appear to us to have, if we looked at it first with the right eye, and then with the left, from a distance about two miles away, say from the roof of the Tate Gallery. The shift is due to the swing of the earth in her huge orbit, round the sun, of 186,000,000 miles in span ; the star appears to describe in fact a miniature copy in the sky of the earth's orbit, but this copy, so minute, is the exact representation in size and shape of the orbit described by the earth, as it would be seen by an inhabitant of Alpha Centauri,—if he could perceive the earth at all.

Is it any wonder that Galileo failed to detect or measure a shift so small? Besides, no star in the northern hemisphere has so great a one. For Alpha Centauri is the nearest neighbour that we know of amongst the stars, and Galileo never saw a star that lies so far to the south. The number of miles that this nearest star is distant is so great that the recital of their number conveys no meaning to us. We prefer to express his distance by the time that it takes the light from him to reach us, and that time we do not measure in seconds or in hours, but in years. It takes over four years for the light from the nearest star to travel to us; if Alpha Centauri was extinguished to-day and became darkness, then more than four years would elapse before we should know it.

The star whose shift was measured at the same time as Alpha Centauri is not so near; it takes eight years for its light to travel to us. This star is an insignificant one in the Swan. It is only faintly visible to the naked eye, for it is but of the sixth magnitude, and is not dignified by a letter, a name, or a Greek letter, but only by a number. It is No. 61 in the constellation of the Swan. Its shift in the sky is about as much as the shift of the cross of St. Paul's would appear to be when viewed first with one eye and then with the other from a distance of four miles.

No doubt, by this time, you do not wonder so much that such a shift cannot be measured with extreme exactness, as that such a shift can be even conceived of, much less measured at all. How can a measure be made of a displacement so small that the keenest eye could not see it?

Practically, what is done is this. A star which is either very bright, or has a large 'proper motion,' is supposed to be much nearer in actuality than the surrounding stars, which are fainter, or do not seem to move so quickly across the sky. Throughout the year a great number of measures are made of the distance of this star from as many other stars as possible, and these measures are repeated year after year. The measures may be made either directly with a measuring machine —a micrometer—at the telescope, or with the micrometer on photographs of the region in which the star lies. The neighbouring stars are supposed to be so far off that they do not shift at all, so that if the measures seem to show that the bright or quickly moving star has swung ever so little as regards the other stars, this swing is supposed to be all its own, and due to its nearness. (*See* PLATE XVI., fig. 5.)

In all the myriads of stars, there are only about thirty whose distances we have measured at all, and of none of these can we be sure that we know the real distance within several hundreds of thousands of millions of miles. Alpha Centauri is our nearest neighbour as far as we know, and is distant over four light years. The next nearest is a little star too faint to be seen without a telescope, and light takes seven years to come from this star to us. Next comes No. 61 in the Swan, distant eight light years; and then Sirius, the brightest star in the whole sky, but its light, that we now see, left it more than eight and a half years ago. No other star that we know of as yet, is nearer to us than a distance that it takes ten years to cross; from the Pole star the light we see to-night left it forty-four years ago.

So, though we know now for a certainty that the earth does move, and swings round the sun, we have not been able to send our fathoming line very far into space. We cannot measure out the depths of the stars, for we can barely and uncertainly touch their nearest fringe.

CHAPTER XVII

THE STORY TOLD BY THE STARS IN THE PLOUGH

Star Drift

THERE are seven stars that every one knows, for year in and year out they are always present in our skies, shining in the north. The Romans called them the Seven Plough Oxen, ever treading the same unseen furrow in the sky. Dante, the poet, named them the Lords of Cold, as hanging continually over the frozen regions of the north; we ourselves call them the Plough, or Charles' Wain, that is, the waggon of the churl or peasant. These seven stars are part of a larger constellation, the Great Bear; the Plough itself being the hindquarters of the beast, and its Handle the tail possessed by the heavenly bear, unlike his curtailed brothers on the earth.

Each of the seven stars had a special name given to it by the Arabs, and we, to-day, either use these names or one of the first seven letters of the Greek alphabet. The stars are named Dubhe, Merak, Phecda, and

Megrez in the ploughshare, the line from Merak to Dubhe passing through the Pole star, so that these are sometimes called the Pointers; and Alioth, Mizar, and Benatnasch in the plough handle. Megrez is the faintest star of the seven, and Mizar has a fainter star very close to it called Alcor. Mizar and Alcor can be seen as two stars by those with average good sight.

Long ago, men thought that the heavens moved round the earth and that they were built up of a series of transparent crystal spheres. Seven inner spheres carried the 'seven planets,' that is, the sun, the moon, Mercury, Venus, Mars, Jupiter, and Saturn. An eighth sphere carried all the stars, so that these were placed all at the same distance from us, like lights in the roof of a vast dome, and the shape of any group of stars, as we saw it, was its true shape. But the star in the Centaur told us that all the stars are not at the same distance from us, not even all the stars that look to us of the same brightness. We have measured the distances roughly of only thirty or forty stars, and these lie at very different distances. For all the rest their annual shift, or 'parallax,' is too small to be measured, but we cannot believe that, though immeasurably small, it is the same for all. They, too, are at vastly different distances from us and from each other. Are they all then disconnected? Do any of the stars form groups? Have we been foolish in calling all these stars in the

Plough by one name, as if they were members of one family?

If the old idea were true that the stars were fixed in a crystal sphere, then they could not alter their places with regard to each other. But just as we have been able within the last seventy years to measure 'annual parallax,' that is, the yearly shift in the position of a star, so, too, we have been able to measure 'proper motion,' the motion across the sky peculiar to each star. In most cases this is a very small amount indeed, but it can be found more easily than parallax, because its effect accumulates year after year. If, then, we are able to observe a star over a period of fifty, a hundred, or a hundred and fifty years, a very minute annual movement will have brought the star over a distance that is quite easy to see and to measure. It so happens that for something like three thousand stars we have really accurate observations, which go back nearly one hundred and fifty years. These were the observations of the places of stars, made by Bradley, the third Astronomer-Royal. These observations we compare with those made quite recently, and so get the 'proper motions' of these stars.

Some years ago the late Mr. R. A. Proctor drew out a chart of the sky, in which he indicated for some sixteen hundred stars the rates and directions of their 'proper motions'; and it became evident from this chart that there were companies amongst the stars, groups of stars moving in fellowship together through space, having the same direction, and moving at the same rate. Of these companies, the most striking was found in the constellation of the Plough.

It is not all the seven stars that move thus together; the foremost, Dubhe, and the hindermost, Benatnasch (at the extremity of the handle), have a different direction. But the other five show a striking similarity in their paths.

This, of itself, would make us think that the five stars form a true brotherhood; but there is in their spectra another indication of family likeness. The five middle stars of the Plough are made of the same materials, which are combined in the same way, but they differ in this respect from the first and last. The spectroscope gives still further evidence that these five are a travelling company, for it shows that they are coming in our direction, and all with the same rapid speed, or very nearly the same, of about eighteen miles a second.

So these five great suns form one company, making a common pilgrimage through space, just as the sun and his family of planets travel together. But only ninety-three millions of miles separate the earth from the sun; not quite three thousand millions separate Neptune, the furthest planet, from him. What can be the distance that separates Merak from Mizar? Of what nature can be the bond between them?

We can point one leg of a compass to Merak and the other to Mizar, and measure on a protractor the angle that they make as about 19°. So, too, we can measure with the compass the diameter of the sun or of the moon, and find that they each cover about half a degree. But we cannot say how many miles go to the degree, the minute, or the second, until we know the distances of Merak and Mizar from us, just as, until we learned that the sun is distant about ninety-three millions of miles, and the moon about 238,400, we could not tell that, in the one case, about half a degree meant 866,400 miles, and in the other 2,163 miles. How are we to find the distances of Merak and Mizar so as to know how many miles, or light years, go to the 19° or more that separate them? If they were as near as Alpha, the bright star in the Centaur, which is our nearest neighbour amongst the suns, then each second would mean $\frac{4}{3}$ multiplied by 206,265 multiplied by ninety-three millions of miles; and there are 3,600 seconds in each degree; or, in all, 1,750,000 millions of millions of miles between Merak and Mizar. But they are at an untold distance further than Alpha in the Centaur, therefore each second of arc means an untold number of millions of miles more with them than it does at the nearer star.

The yearly shift of any of these five stars is too small for us to see or to measure, but it is possible to gauge their distance from us—of course, only very inaccurately—from the manner in which the five stars lie, and the direction in which they are all travelling. In the diagram of the Plough (PLATE LV. fig. *2a*) given herewith, we see that four out of the five stars lie very nearly on a straight line, and the directions in which the proper motions of the five stars carry them lie very nearly in this line, or else parallel to it. Mizar seems to lead the procession of five, and Merak brings up the rear, whilst Phecda marches a little on one side, like a sergeant bringing out his policemen to their beats. If it were a celestial globe on which we were looking, and not a flat sheet of paper, the four stars would seem to lie very closely to a circle that passes through the centre of the globe, and the motions of all the five stars would seem to lie very nearly, but not quite, parallel to this circle. This means that we on the earth and these four stars lie in one plane, in a thin slice of space; that Phecda lies so as to make that thin slice somewhat thicker; and that all the stars are moving so as not to leave it. They all move in one plane, just as the earth and the other planets do in the ecliptic plane.

Now the proper motions of all these stars are very nearly indeed in the same direction, but not quite. It seems quite reasonable to suppose that all five are really moving at the same actual pace and in the same actual direction, but that the small differences in these paces and directions that we see are due to the five stars being at different distances from us. We see them moving with a perspective effect; and if we compare the motions together we find that the perspective point, 'the vanishing point,' as it is called in drawing, is situated just about the place in the sky where the forefoot of the Seagoat nearly touches the hindquarters of the man-horse, who is called the Archer. It is towards this point that they are actually moving in space, and we see this motion partly projected on the sky as 'proper motion,' partly as motion directly towards us as measured in the spectroscope. The actual motion of the star company through space is compounded of these two motions, and, since we know the direction of the whole, we can find a proportion between the two. But the motion towards us is measured in miles per second, and the 'proper motion' is measured in seconds of arc. We have, therefore, got what we wanted in this particular case, and find that, at Mizar, a second of arc is equal to about 60 times 206,265 times 93 millions of miles. Light takes about four years to reach us from the star in the Centaur; it takes, on this estimate, one hundred and eighty years to travel from the Plough stars.

As observed above, if we point the two legs of a compass, one towards Mizar, and the other towards Merak, we find the angle between them is about 19°. If these stars are at about the same distance—more or less—from us, then the distance of Merak from Mizar must be about one-third the distance of Mizar from us. If Merak is more distant than Mizar, as is probable, then the distance between them is greater than a third of the distance to us. But this implies that it must take sixty years at least for light to travel from the van to the rearmost of this great company. To bridge the distance even from Mizar to its near neighbour, Alioth, light must take at least fourteen years.

We look upon our sun as being isolated in space, for light which travels faster than we can conceive cannot cover the distance between our nearest neighbour and ourselves in less than four years. Yet we can count several stars nearer to us than Alioth is to Mizar. Both Altair and Sirius are, for instance; but they are not of our kin, they are not made of the same stuff and they do not travel in our company. All the stars whose yearly shift we have measured are closer to us than Mizar is to Merak, for Polaris, the farthest from us, is but distant forty-four light years, whilst these great twin suns of the Plough are separated by sixty light years. Were our earth a planet of Mizar's, then, even with our most delicate instruments, we could not see or measure the yearly shift of Merak.

These five stars are amongst the brightest in our northern heavens, and yet they are enormously distant from us. In just the same proportion, they must be enormously great. Most of them are fully of the second magnitude of brightness, yet if we circled round Mizar, and looked from that distance upon our sun, we would account him but of the eighth magnitude.

Mizar is itself a double star; this has been told us by the spectroscope, and also that the twin stars lie 140 millions of miles apart, though this vast space is so dwarfed to us by distance that we can never distinguish them separately. But this twin Mizar has also another star, a faint one of the fourth magnitude, circling in ten thousand years, at a seeming distance from it of fourteen seconds; and yet a third, Alcor, far from it, but yet moving with it, as bound in the same chains.

The picture presented to us of these five suns, so vastly superior to our own in brightness and size, and, in the case of Mizar, consisting itself of so complex a system of suns, the whole five separated by infinitudes of space, but subject to the same impulse and travelling on the same journey—this picture gives us a hint of manners and systems in the star depths far transcending our own. We may liken our ruling sun and his little dependants to some small, isolated, country village, remote from telegraph or rail, where the movement of the great world is hardly felt. Its great man is the local squire, and the villagers hardly dream that a more important personage exists. His word is their simple law, his decision final; round him, as its centre, their life revolves.

FIG. 1.—THE STARS OF THE PLOUGH.

(*From a photograph by F. W. Longbottom.*)

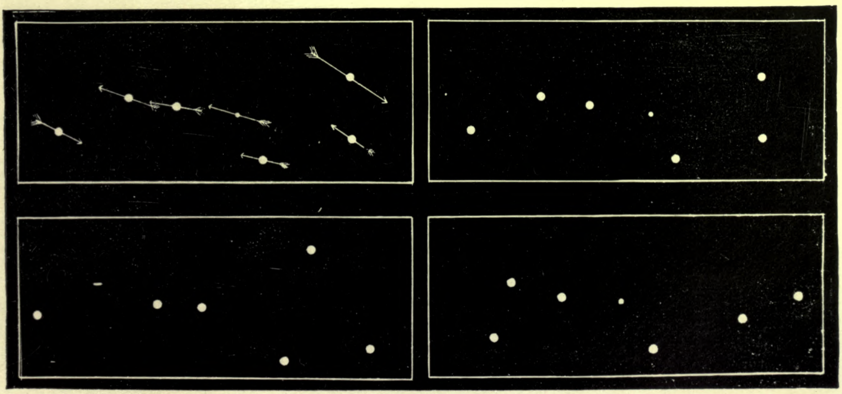


FIG. 2.—DRIFT OF THE STARS OF THE PLOUGH.

(*a*) Showing amount and direction of drift. (*b*) Appearance of the Plough 100,000 years ago. (*c*) Appearance of the Plough at the present time. (*d*) Appearance of the Plough 100,000 years hence.

THE GREAT NEBULA OF ORION.

(Photographed at the Royal Observatory, Greenwich.)

Yet, perchance, there filters down to them, from time to time, some hint or rumour of a greater world without, of greater, more important, persons than their squire. They hear of the five great powers of Europe, of their rulers, of the great statesmen who guide them. They hear of arbitrations and conferences, of intricate diplomacy, whose course they find it hard to follow. In something like their perplexity we watch this vast star-system of suns, so much greater than our own, of motions on a scale for which the law of gravity seems hopelessly inadequate. And we are like the villagers in another respect. Their news from afar reaches them much after date. The latest European crisis is known to them it may be a week, it may be two, after the event. Our news from the five great suns of the Plough is older still. It has come to us on the wings of light, without hindrance or delay, one hundred and eighty-five thousand miles in every second of time, but it has been a hundred and eighty years in the coming. We see these five suns, not as they are, nor where they are, but as they were, and where they were when the first Hanoverian George was come to the throne of England.

As far as we know, our sun is a solitary one, bound to no others by invisible bonds, nor travelling with any others to the same goal. He has neighbours nearer to him than any two of the great Plough stars are to each other; but these neighbours of his are not made of his stuff, they are not flesh of his flesh, or they are travelling in divergent ways. But the Plough stars are five great suns—Mizar and his family we may count as one, even as Jupiter and his moons count for one in the planets of the sun—moved by the same impulse, and carved out, we must believe, from the same great block of world-stuff, though they lie so far apart. The five great confederates lie in a wilderness, a void ; for though there are many other stars, faint or bright, that seem to lie near them, yet none of them partakes of their motion ; they all lie nearer us, or else in the far depths of space beyond. For we cannot conceive that any alien force could dare to intrude within the spheres controlled by the vast confederacy, or, if intruding, could resist, for a moment, their sway.

We see, then, that the great block of space occupied and controlled by the five confederate suns is not a crowded one ; not nearly so crowded as the space in which our sun moves. The stars are, then, not distributed evenly throughout the universe. Are there regions more crowded than where the sun is ?

CHAPTER XVIII

THE STORY TOLD BY THE NEBULAE

AMONGST the stories told by the sun was the one he told in concert with the moon, when the latter, in a total eclipse, screens our atmosphere for a short time from the sun's bright illumination, and shows us that he is surrounded by a wonderful halo, the corona. Again, in the solar system we have seen that there are sundry strange, filmy bodies, erratic in movement and weird in form, that we know as comets; like the corona in their peculiar filmy appearances. And far out in the star depths we meet again, faint diffused objects, weird in shape and shining with much the same sort of filmy light that we have already recognized in corona and comet.

These are the nebulae. Many thousands of these are known, and a volume could easily be written simply to describe the chief classes into which they may be divided. But there is one nebula which stands out as by far the most beautiful and mysterious of them all: the great nebula in the constellation Orion.

The great nebula is easily found if we know the constellation of Orion, the brightest in the entire sky. Three bright stars mark the giant's girdle, and below them shines

> A single misty star
> Which is the second in a line of stars
> That seem a sword beneath a belt of three.

The misty star grows in a powerful telescope into a vast filmy cloud of glowing emerald light. It is not a regular diffused glow; in one place it is, as it were, curdled into greater brilliance, and close at hand faint arches are flung out into space. Elsewhere, it is carded and combed like wool or tangled hair. But, most striking of all, some of its brightest portions have edges sharp as in an engraving and border regions of intense blackness. (*See* PLATE LVI.)

The first mystery about the nebulae, in particular about such a nebula as that in Orion, is that we can see any form in it. None of the stars are so near, or so large, as to offer any visible size even in the most powerful telescope; indeed, the greater and more powerful the telescope, the sharper and smaller becomes the point of light which is all we see of a star. We can quite understand why this is, for if Sirius even, the brightest of all the stars, were so huge as to fill the entire space between the earth and the sun—93,000,000 of miles—that is to say, if it were more than one hundred times the diameter of our sun, and more than a million times its volume, it would still only be one-third of a second of arc in diameter, or about the apparent size of a halfpenny seen nine miles away.

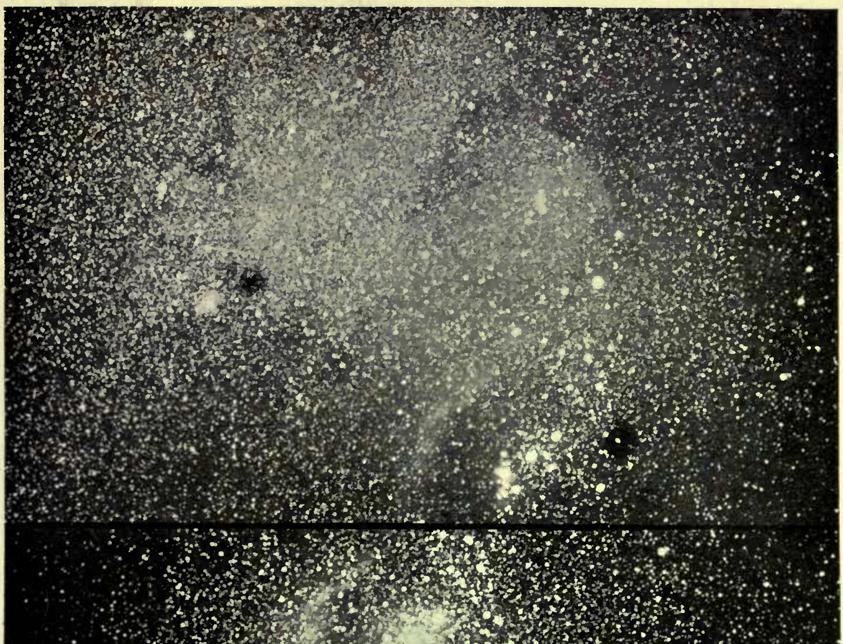
But the great nebula in Orion, and nebulae in general, are not mere points of light; they are objects. The central, most brilliant, part of the Orion nebula appears very considerably larger than the full moon, and its outer extensions are several degrees in length.

One of two things then. Either the nebula is very near us; or it is enormously large. But it is not near us; it is no nearer us than the stars are. Hitherto, all attempts to discover a 'parallax' for a nebula have failed; there is no difference, that we can see, in the place of a nebula when observed from one end of the earth's orbit, and when observed from the other, 186,000,000 of miles away. Of course a large, diffused, filmy object like a nebula, often very irregular in shape, is not at all an easy object to measure, and the argument for their great distance is, therefore, not quite so direct as in the case of stars. But in not a few cases stars are found which at least appear to be enmeshed in a nebula, and such stars show no shift that we can detect as the earth swings round in her orbit.

Suppose that this nebula in Orion is as near to us as the five stars of the Plough—and we have no reason to suppose that it is such a close neighbour to us—suppose, in other words, that it takes light at least one hundred and eighty years to cross the space between us and the nebula, then the central and most brilliant part of the nebula must be so enormous that it would more than half fill the space between us and our neighbouring star, Alpha Centauri. But the greater its distance the greater its real size must be, and we have made a very modest estimate of its distance; it is probably even farther away. In this case, both our sun and his twin, Alpha Centauri, distant from him more than four light years, might both be deeply engulfed in the densest central meshes of such a nebula. But the bright central portion is but a small part of the whole, for the nebula sends its spirals and branches far and wide. Were our sun in such a nebula, its tentacles would reach out to and enfold not only Alpha Centauri, but the star in the Swan, Sirius, and every star whose shift we can measure as the earth swings round in her orbit; even Polaris itself, from whom it takes forty-four years at least for light to come.

Light is the swiftest messenger we know, but it takes at least sixty years for it to speed between Merak and Mizar, and it certainly cannot traverse the distance between the most outlying parts of the great nebula in Orion in much less time. But, as far as we can see, Merak and Mizar and the other stars of the Plough

NORTH



WEST

SOUTH

NEBULOSITIES IN THE CONSTELLATION OF ORION.

(*From photographs by Dr. Max Wolf.*)

The two photographs overlap by nearly an inch in the N.-S. direction; but the southern photograph is displaced two-thirds of an inch towards the East as compared with the northern.

THE GREAT NEBULA IN ANDROMEDA.

(*Photographed at the Royal Observatory, Greenwich.*)

are isolated; no visible connexion stretches between them, no filmy cloud or tentacle enfolds them. The Plough stars travel to a common goal, under a common law; but we cannot see what binds them all together. In the nebula we seem to see such a bond. The space between the stars is filled up with star mist, mist that seems infinitely rarer than even the shining veil that we see in coronal ray or in comet's tail. Both these shine, in part at least, by reflection from the sun; but the star mist shines of itself. It must, therefore, be a luminous gas, a gas that is less dense than any vacuum that we can make. It passes our comprehension how such a rare gas can assume and retain the definite forms such as we see in Professor Max Wolf's beautiful photographs of the Orion nebula. It looks as if the gas was in violent motion under the influence of some powerful force, but how or when or where the force is impressed we cannot see. (*See* PLATE LVII.)

The Orion nebula is the greatest in the heavens; it is an 'irregular' nebula, but with outlying spiral branches. But it has a rival, running it near in beauty and size. This is the great nebula in Andromeda, one of the 'regular,' or spiral, nebulae. This nebula can really be seen by the naked eye, and the old Arabic astronomers were familiar with the 'little cloud' near the most northern of the three stars in the girdle of Andromeda; but this 'little cloud' in the first telescope took on the appearance of a 'candle shining at night through a semi-transparent horn,' and in the more powerful telescopes of the later centuries it showed as a steady luminous cloud, gradually brightening from the circumference to the centre, where it abruptly condensed to a small nucleus of indistinct outline under high magnifying powers, but containing no star. The telescope, too, extended its borders to a great distance, and showed strange dark rifts, or 'canals,' whose connexion with the nebula it was very hard to understand.

For the eye at the telescope is not very capable of seeing nebulae; a nebula such as Andromeda's extends over a large space in the sky, and the more powerful the telescope, the more confined the space that can be seen at a time; it is like surveying a glacier through a pinhole. It was not until the photographic plate was substituted for the eye and eye-piece of a telescope that we could learn what is the true form of the nebula, and the meaning of the dark 'canals.' (*See* PLATE LVIII.)

Then the nebula was seen to be of a form that distinctly recalls the appearance of the ringed planet Saturn. But Saturn, though the lightest of the planets, is still a globe with defined edges. In the nebula the central glowing nucleus is not globular, but is undefined and merges into the rings. For rings are there, inconceivably more huge, and not so regular, as the rings of Saturn, but showing divisions—for the dark 'canals' are, in the photographs, seen to be but divisions—with blotches and differences in brightness, such as that between Saturn's crape ring and the others.

Saturn's rings are neither solid, liquid, nor gaseous, but seem made up of a number of solid particles which revolve independently and freely round the planet, like so many little satellitoids. We do not know how big these particles may be; they may be mere fog or mist particles, they may be of the size of dust, or of pebbles, or even of great boulders. So, too, as far as we can tell, the nucleus and the rings of the nebula in Andromeda are not gaseous, but are composed of solid particles. But here the particles cannot be of the size even of those in fog or smoke; they must be smaller than anything that we can conceive of, and they cannot lie close together. For we cannot consider nebulae as being merely painted in the sky, having length and breadth, but no thickness. Through many of them we must be looking through their greatest thickness, a thickness as great as that of the length or breadth as we see it in the sky. This thickness must amount to millions of millions of miles, and yet we can see through it. The matter in such a huge volume must be inconceivably attenuated, inconceivably light; else it would be as opaque as a wall, and the attraction of its mass would perturb the universe. The most empty vacuum that we can make is crowded as compared with the emptiness in any part of the nebula. Yet it shines by its own light.

There are very many nebulae in the sky, some composed of diffused particles, very sparsely scattered, but self-luminous like the one in Andromeda, some composed in whole or in part of glowing gas like the one in Orion. Most of them assume the spiral form; even the 'irregular' nebula of Orion has been shown by Dr. Max Wolf to have outlying, far-extending, spiral branches. Whence comes such a spiral form? Is it always there, or can we ever watch it forming?

It is only within the last decade that an event happened which gives some sort of answer to these questions. In the early part of the year 1901, a 'new star' burst out in the constellation Perseus. In a few days it sprang from invisibility to the first magnitude. After February 24 it slowly faded, but with many fluctuations in light, until, in August, it was but of the sixth or seventh magnitude. By this time its spectrum had become more like that of a gaseous nebula than like that of a true star; but when Professor Barnard examined it with the great telescope of the Yerkes Observatory, the most powerful in the world, in early September, he could detect no trace of nebulosity. But on the night of September 20, Professor G. W. Ritchey, also of the Yerkes Observatory, photographed the 'new star' with a reflecting telescope of two feet

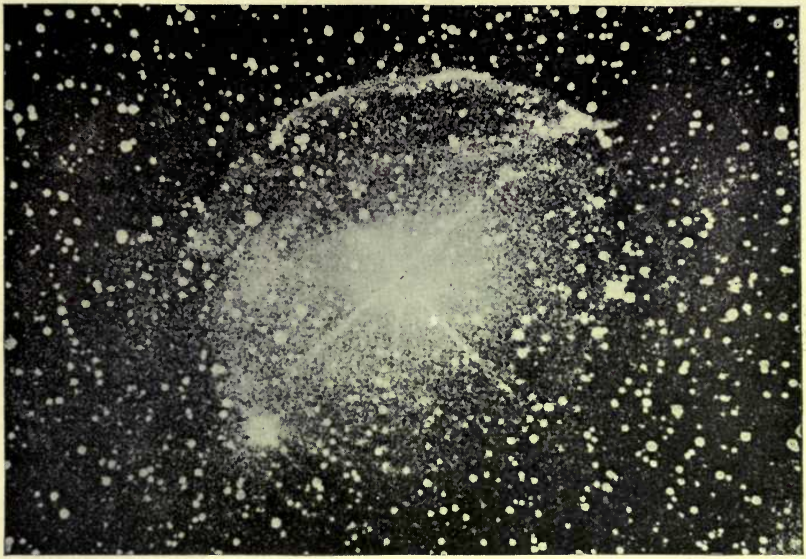


FIG. 1.—Nebula about Nova Persei, September 20, 1901.

FIG. 2.—Nebula about Nova Persei, November 13, 1901.
(*Photographed by Professor G. W. Ritchey at the Yerkes Observatory.*)

PLATE LX.

The Great Comet of 1882, as photographed at the Royal Observatory, Cape of Good Hope.

aperture, giving an exposure of four hours, and on this photograph were seen two wisps of nebulosity, extending from the new star to the west, then curving toward the north. The new star had given off a nebula of complex form, whose interlacing branches seemed to be of a spiral form. In the middle of November, at two American observatories—at the Yerkes and at the Lick—photographs with long exposure were again taken; and it was seen that not only was the spiral nebula round the star more pronounced and distinct, but that parts of it had moved, as it were, along the spiral branches, extending outwards, and at a rate that would have carried the moving parts over about eleven minutes of arc in a year. On September 20 the nebula almost fitted into a square on the sky of about fifteen minutes (just under half the apparent diameter of the moon); on November 13 it fitted into a rectangle of about seventeen minutes by sixteen. (*See* PLATE LIX.)

Now, is it probable that the nebula was actually spreading out in space in this rapid and peculiar way? Might it not be possible that the spiral nebula was always there, though dark, and when the star in its centre burst out, its light illuminated the dark nebula travelling from the star out to the outlying branches? On this assumption, it would take light a year to travel across a distance which to us appears eleven minutes of arc in size. If this is so, then the new star and nebula in Perseus must be distant from us at least three hundred light years; that is to say, the outburst of the star and the lighting up of the nebula actually took place about the time that Galileo first turned his telescope upon the heavens, and the news of this great stellar catastrophe, though speeding to us on the wings of light, only reached us in the year 1901. It also means that seven months after the first outburst of the 'new star' the nebula was lighted up to a length and breadth of eight and a half millions of millions of miles, or about a third of the distance from the sun to Alpha Centauri.

Now, whether the outbursting new star shot forth the spirals, or whether it simply lighted up the nebula, it is quite certain that the two are in closest connexion. The nebula is an appendage of the star; the star is involved in the nebula. In this case, at least, it is evident that the phenomena are not distinct.

But there are other cases where the connexion of stars with nebulae, where the evidence of stars being bound together by nebulous bonds is even more distinct. The most notable of all these is to be found in the cluster of the Pleiades.

This little group was happily described by Tennyson as—

> . . . like a swarm of fireflies tangled in a silver braid.

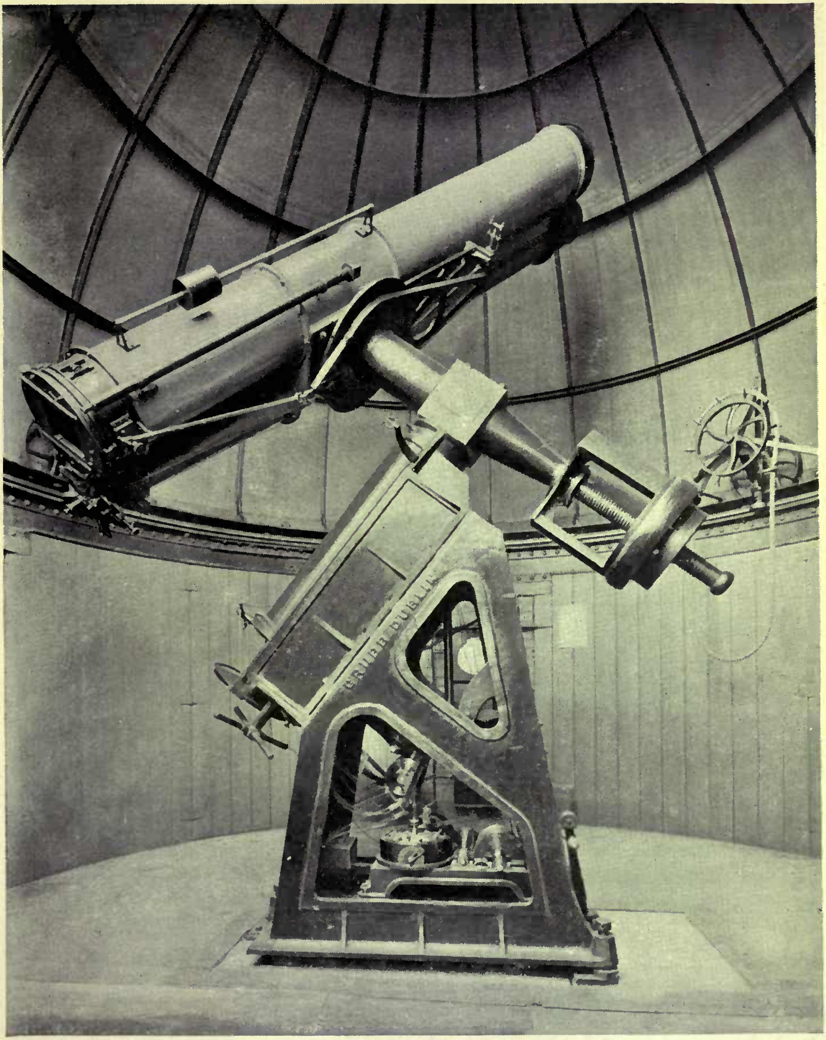
For they seem so close together that the eye connects them up by chains of light. When seen through a telescope the light chains are broken; and the more powerful the telescope, the more stars come into view; but each star stands out distinctly, unsheathed in nebulous light.

But it is not the eye at the telescope that teaches us most about the cluster of the Pleiades, but the photographic plate. For the eye sees all that it can see at once; prolonged gazing will strain the sight without increasing knowledge. But the sensitive plate does not tire, and, unlike the eye, it sums up the sensations it receives during its whole length of exposure. A very faint, dim light, if falling on the plate for a long time, will be as effectual in its impression as a bright light in a short time. Photographs of different exposures will give information of different kinds.

If we look at the starry heavens we cannot fail to notice—as in the words of the Apostle—that 'one star differeth from another star in glory.' Men have therefore divided them into six classes, according to their brightness—classes which are commonly spoken of now as magnitudes. The ordinary 6th-magnitude star is one which can be clearly seen by average sight on a good night, and it gives us about one-hundredth the light of an average 1st magnitude star. Sirius, the brightest of all the fixed stars, would require some two and a half million stars of the 14th magnitude to equal it in light.

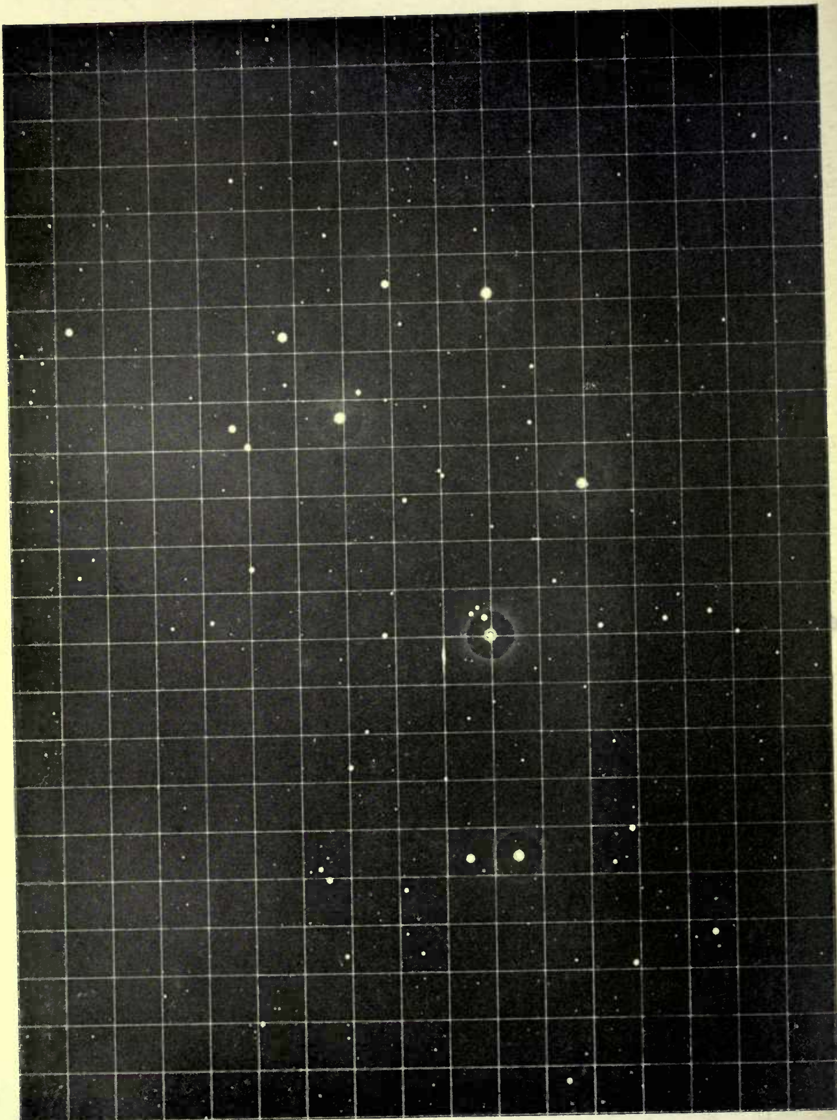
Several years ago, some observatories began to make a census of the stars which would embrace all those from the brightest down to the 14th magnitude. The work went on steadily until the observers entered on the region of the Milky Way; but here the numbers of the stars presented to them were so great as to baffle all ordinary means of observation; and the census threatened to come to a complete standstill for lack of power to deal with the wealth of material.

Just at this time immense interest was caused in the astronomical world by the appearance of the great comet of 1882. It was watched and observed and sketched by countless admirers, but more important still, it was photographed, and some of its photographs (Plate LX.), taken at the Royal Observatory, Cape of Good Hope, showed not only the comet with marvellous beauty of detail, but also thousands of stars; and the success of these photographs suggested to Sir David Gill, then Director of the Cape Observatory, that in photography, more or less prolonged, we possessed the means for making a complete sky census, even to the 14th magnitude. This project was thought over in all its bearings, and in 1887, a great conference of astronomers at Paris resolved upon an international scheme for photographing the entire heavens. The form of telescope by which the scheme has been carried out is represented in Plate LXI.



The 'Astrographic Telescope' of the Royal Observatory, Greenwich, i.e. the Photographic Telescope in use for the International Photographic Chart of the Heavens.

PLATE LXII.



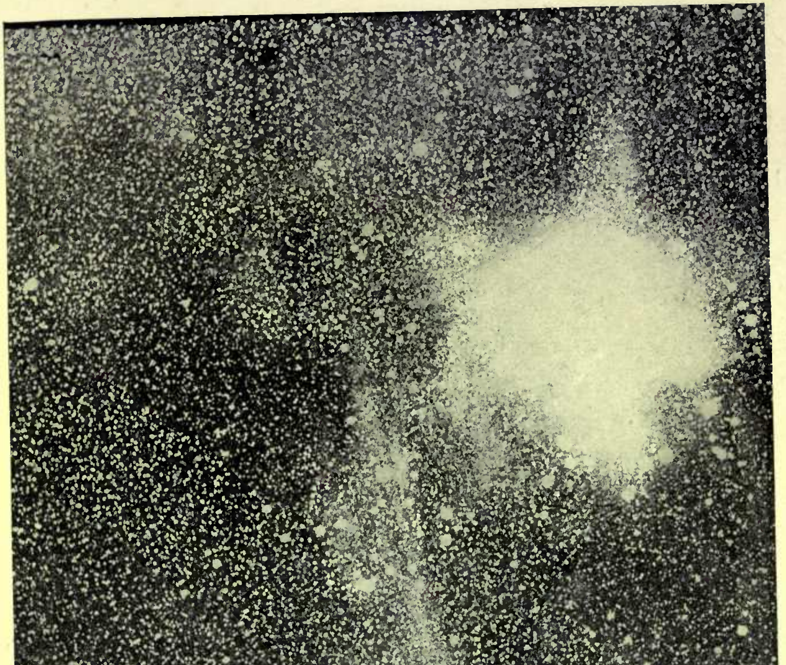
THE STARS OF THE PLEIADES.

A telescopic camera turned on the Pleiades, then, will succeed only in getting those stars visible to the naked eye if the exposure is but for a few seconds; but as the seconds are prolonged to minutes, more and more stars appear on the plate, just as more were seen with the increase in power of the telescope. The accompanying photograph (Plate LXII.) had an exposure of forty minutes, the standard time for those taken to form part of the great International Chart of the Heavens. For this, eighteen observatories, scattered over the face of the earth, are federated to photograph the entire sky in two series, one with but half a dozen minutes' exposure in order to form a great catalogue of the brighter stars, the other with an exposure of forty minutes, so that all stars down to the fourteenth magnitude may be charted. On this photograph there is a 'reseau,' or cross-scale, printed, in order to give the positions of the stars with reference to these cross-lines. But if the minutes of exposure be prolonged to hours, then the form of the great stars is lost in patches and clouds of filmy mist; patches and clouds that are shredded and combed into wisps and threads, as flax on a distaff. Not only is the star mist that shrouds the great stars combed out into these curious straight lines, but straight wisps of nebulosity join star to star. (*See* Plate LXIII.)

On the short exposure photographs, the stars stand out sharp, clear, distinct, and unveiled. On the long exposure photographs in the places where should be the stars, there are dense patches of nebulosity; to each of the greater stars its own nebulous veil. And with the increase of exposure, the nebulous veil deepens and extends, but centres still round the places of the stars, until, as in the wonderful photograph (PLATE LXIV.), by Dr. Max Wolf, the entire group of the stars of the Pleiades is masked by a vast nebula which stretches its arms far beyond it into space. In a total eclipse of our sun, when his brightness is screened, we see and can photograph a nebulous veil surrounding him; and the longer the exposure, the more extended seems his nebula. So in the Pleiades, with greater exposure we find these stars shrouded in nebulae—in veils which we might speak of as their coronae, but coronae on an immeasurably greater scale than that which surrounds our sun.

THE NEBULOSITIES OF THE PLEIADES.

(Photographed at the Royal Observatory, Greenwich.)



THE EXTERIOR NEBULOSITIES OF THE PLEIADES.

(From a photograph taken January 9 and 10, 1896, by Dr. Max Wolf. Exposure 11 hours.)

CHAPTER XIX

THE STORY TOLD BY THE MILKY WAY

THE earth is very differently populated in different parts. There, in the Australian bush, a man may need to ride for a day in order to visit his nearest neighbour; here, in London, millions of persons are crowded into a plot of ground fifteen miles square.

So, in the universe of stars. In the story by the five great brothers of the Plough, it was told that they held sway over a vast space, so long that it extended over the eighteenth of the whole heavens' span; a sway so unchallenged that, for aught we could see, the five confederates were there alone, their domain swept bare of rivals. This quarter of the universe is certainly not a crowded one.

But there are parts of the sky which certainly appear to be crowded. There is that

> Broad and ample road whose dust is gold
> And pavement stars, as stars to thee appear,
> Seen in the Galaxy, that Milky Way,
> Which nightly as a circling zone thou seest
> Powdered with stars.

and in this description, Milton has touched on the two wonderful characteristics of the Milky Way. It is a starry zone, a visible belt, spanning the vault of heaven, just as the equator and ecliptic are imaginary belts. It is strewn with powdered stars; stars so small and faint that the naked eye cannot perceive them singly, yet set so closely together that they form a golden road by the shining of their numbers, for the eye confuses their innumerable points of light into a continuous star surface. But the telescope shows them to be separate stars, and the more powerful the telescope the more widely does it separate them, the more of star-points does it bring into view. The five stars of the Plough are moving together to a common goal, under a common impulse; but in the vast spaces between them, the most powerful telescope, the most prolonged exposure, brings out but few stars, and has not hitherto given evidence of any nebulous bonds linking them together. In the family of the Pleiades, on the other hand, the photographic plate shows that the great stars are bound together by straight nebulous ribbons, and on these ribbons are strung fainter stars, as beads might be threaded on a string. But the Plough stars and the Pleiades each form a single community; does the Milky Way form one also? The Milky Way spans the heavens in a complete and great circle; the Plough stars stretch over but the eighteenth of this, and the Pleiades might almost be covered by the full moon. If the Milky Way is a unity, does it take after the vast emptinesses of the Plough, or the vast crowdedness of the Pleiades ?

Since the Milky Way is a girdle to the sky, inclined to both equator and ecliptic, some part of it can be seen on any night of the year ; but in spring time it lies at night close to the northern horizon, and is too low in the sky to be well observed. Its sweep at midnight in mid-July, in this country, is from the north-eastern horizon, where the constellation Auriga is just rising, through Perseus and Cassiopeia on to Cygnus in the zenith ; descending again on the other side through Aquila, Serpens, Sagittarius, and Scorpio to the horizon in the south-west. It continues to cross the zenith at midnight until mid-December, when it sweeps upward from the south-eastern horizon in Argo between Orion and Gemini to the zenith now marked by the constellation Auriga ; from whence it passes downwards through Perseus and Cassiopeia to the north-west horizon, where the constellation Cygnus is setting. It makes its nearest approach to the north pole of the heavens in the constellation Cassiopeia, where it is broad and rather faint. This part is always visible to dwellers in this country, at all times of the year, and at any time of the night. It makes its nearest approach to the south pole of the heavens in the constellation of the Southern Cross, where it is rather narrow, and exceedingly brilliant. This part, being always below our horizon, is never visible to us, but it is always to be seen by the dwellers in the southern hemisphere, and it helps very greatly to make their starry heavens more brilliant than ours. It crosses the equator in the constellations of the Unicorn and of the Eagle. In the first it is at its broadest and faintest, indeed, the whole section of the Milky Way, from the Unicorn to Cassiopeia, is wide and dim. But in the Eagle it is divided into two great branches which have sprung up in the Swan, both of them narrow and very brilliant.

There are two ways by which we can read, at least in part, the story told by the Milky Way. We can study it and draw it as the naked eye sees it, or we can photograph it, or parts of it, with different sorts of telescopes and different lengths of exposure. By the first way, we draw its form or outline, marking in the hollows, and tracing out the spurs and branches; giving due value to the different grades of brightness. This is the method pursued by many astronomers, but it is not the one that we will now adopt; so that we will only quote here the opinion of Dr. Easton, one of the most thorough of these students of the Milky Way. He judges that the Milky Way is one system as a whole, but a system with perhaps two or more long spirals, certainly with many small spurs and branches. This spiral girdle of the Milky Way, he says, completely surrounds the solar system, but though we lie in its plane, we do not lie at the centre of the ring, but are nearer to those parts that are broad and faint, and further from those that are narrow and bright. He argues this last on the supposition that the Milky Way is just about as thick as it is broad, and does not extend to an indefinitely great distance; as it were, our sun is situated inside a ring, not inside a hole in a board. The nearer we are to one side of the ring the larger does it there appear to be, but also the larger appear the spaces between the stars, and the greyer is the whole. The farther we are from one side of the ring the narrower does it appear, the spaces between the stars seem to close up, and the stars coming closer together give a more brilliant effect. So a flock of crows at a distance seems a small black cloud, but the nearer they come the larger and greyer does the cloud appear, until it seems no longer a cloud, but we see the several birds.

But we are going to examine the Milky Way from another point of view; we will not consider its form and constitution as a whole, but examine samples of it, as it were; studying only small portions of it, photographed in this region or in that. First we will study a photograph of the region of the Swan, where the Milky Way divides into two great branches. The photograph

(Plate LXV.) was taken[1] in the second week of August, in 1900, with an exposure of six and a half hours. The scale of the photograph is very small, so that it covers a very wide area—about one thousand degrees in all. The moon on this photograph would have a diameter of about the one-thirteenth of an inch, and the whole breadth of the Milky Way in both its branches is comprised well within the borders of the plate. The brightest star near the centre of the photograph is Alpha Cygni, the most brilliant in the constellation of the Swan. No. 61 Cygni, our nearest neighbour but two, is one of the small stars about one-fifth of the way from Alpha to the south-east corner of the plate.

This photograph shows that the Milky Way in Cygnus is not merely double, but is divided into five fairly distinct regions, separated from each other by lanes that look comparatively dark. The most westerly of the branches is roughly crescent shaped, and the whole of this region appears to be covered by a diffuse, but not uniform, faint cloud, which gives the appearance of nebulosity, but which is seen to be, if the plate be examined under a microscope, not nebulosity, but faint, fairly well defined stars. The next region, rather more to the east, is smaller, but more striking, since not only are the faint stars aggregated so as to suggest a nebulous bed, but brighter stars are also massed

[1] By Annie S. D. Maunder.

EAST

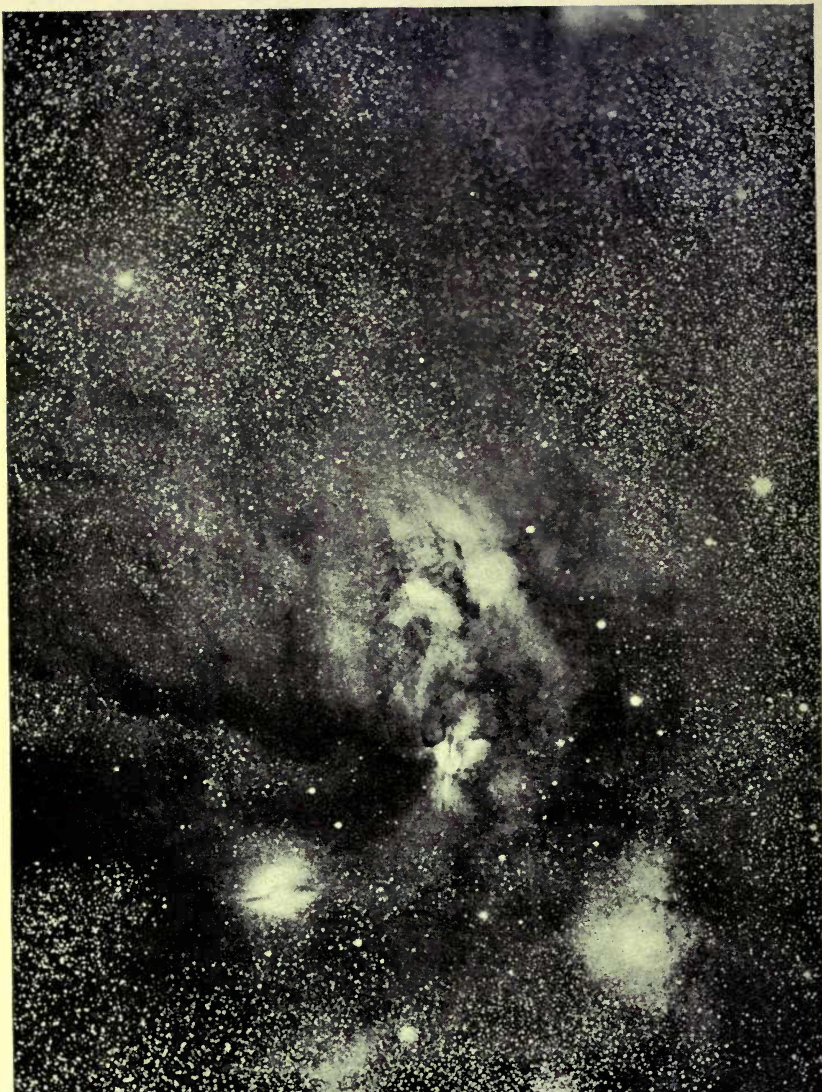
WEST

SOUTH

THE MILKY WAY IN CYGNUS.

NORTH

EAST



SOUTH

REGION OF NEBULA, RHO OPHIUCHI.

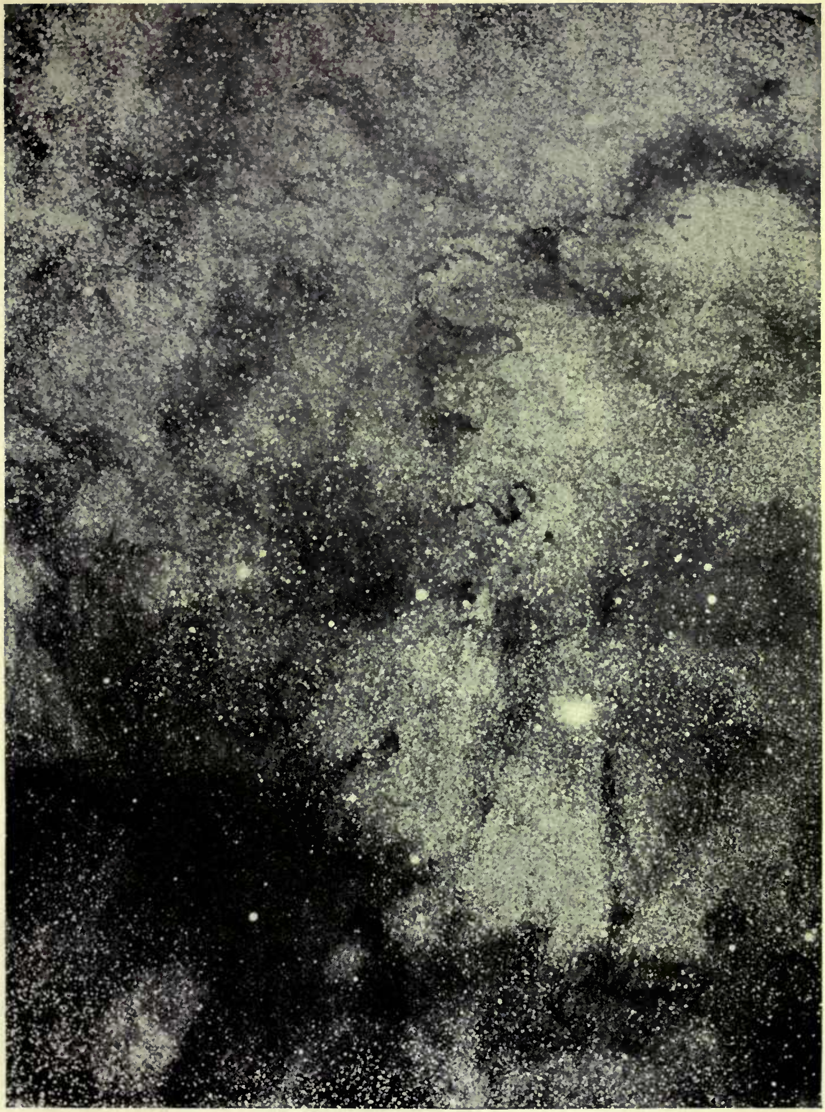
(*Photograph by Professor E. E. Barnard.*)

together, giving the appearance of numerous and superimposed layers of stars, whose brightness diminishes with their distance from us. More to the east, again, there is a huge region, not seeming to differ in its composition, so far as this photograph can show, from the first two, except in the greater frequency of its local aggregations of both bright and faint stars, and its more numerous channels where no stars appear, or only a few sporadic ones.

But the next region to the east is the most interesting of all. It is small, and Alpha Cygni lies on its western border. To the unassisted eye, this region appears on the negative from which this photographic print is taken to consist of a dense nebulous patch, intersected by extremely fine streaks. Under a magnifying-glass, the nebulosity, *to some extent*, resolves itself into faint and fainter streams and bands of stars, these being again bound together by still fainter bands, which are *not always* capable of being resolved into separate stars. The streaks are some of the spaces where no star or connecting-stuff is seen, between the streams and the bands that are not capable of being resolved into stars. Many of the stars and the bands form themselves into connected spirals. There is one due east of Alpha Cygni, half superposed on the most brilliant of the regions of the Milky Way. An even more curious feature on the original negative is a hole, slightly elliptical, but about the diameter of the full moon, situated about halfway between Alpha and the north-east corner of the photograph. But on this photograph, though the general form and structure of the Milky Way in Cygnus is well shown, there is probably no true nebulosity—except perhaps in the bright region due east of Alpha—but only apparent nebulosity due to the aggregation of small discrete stars too faint to be separately perceived by the unaided eye. From this photograph alone, then, we cannot judge whether the Milky Way is really a connected structure, or only appears to be so by the perspective crowding of the stars. To judge of this we will examine six beautiful photographs taken by Professor E. E. Barnard with a telescope whose object-glass measured ten inches instead of the one and a half inches of the little lens with which the Cygnus photograph was taken. Professor Barnard gave exposures to these photographs of from four and a half to five and a half hours. The Cygnus plate was taken just at the starting point of the two great branches of the Milky Way. These continue separately their course southward past the equator, where they are most brilliant; and three of Professor Barnard's photographs are taken of the Milky Way's western branch where it passes through the constellation of the Serpent-holder, and three of its eastern branch, where it lies in the constellation of the Archer.

NORTH

EAST



WEST

SOUTH

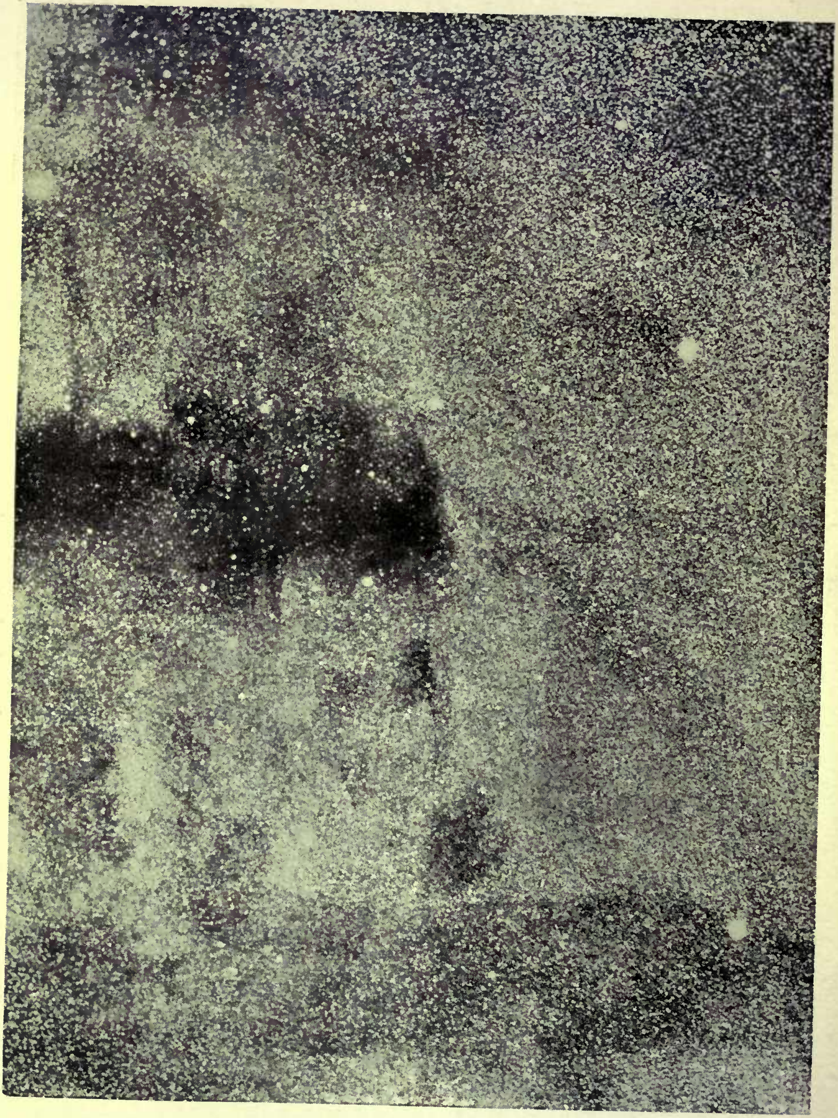
REGION OF THETA OPHIUCHI.

(*Photograph by Professor E. E. Barnard.*)

PLATE LXVIII.

NORTH

EAST



WEST

SOUTH

PHOTOGRAPH OF THE GREAT RIFT NEAR THETA OPHIUCHI.

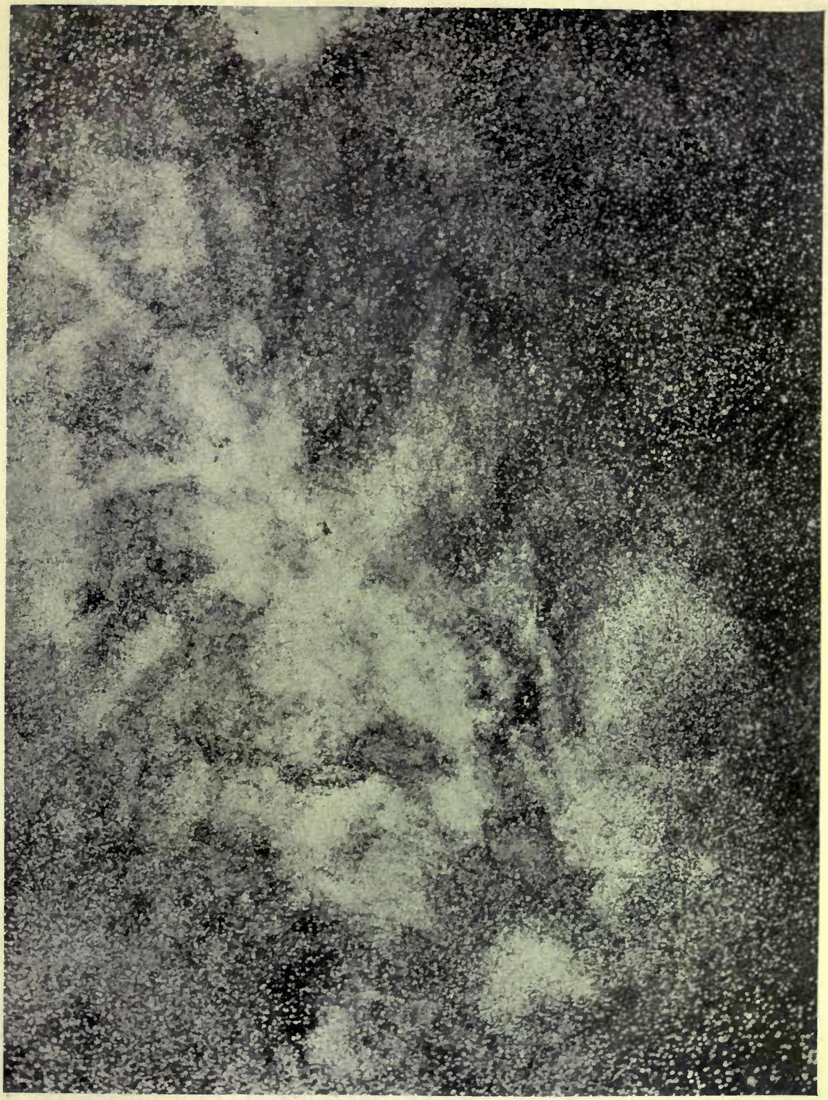
(*Photograph by Professor E. E. Barnard.*)

The first of Prof. Barnard's photographs (Plate LXVI.) is of the region where the foot of the Serpent-holder is pressing down upon the head of the Scorpion. To the west of the picture there are stars in plenty, separate stars such as were seen in the Cygnus photograph. In the centre of the picture there is also a great mass of something that is not merely layer on layer of stellar points crowded into one; it seems in part to be truly nebulous star mist, and in part to be made up of powdered stars. But there is something in this picture that is more remarkable than either crowded stars or powdered star mist; there are long and short, straight and crookedly winding lanes and rifts that are empty, almost entirely empty, of stars, great or small, or of star fog, glowing or dim, speckled or curdled. These channels run everywhere, cutting through the star crowds and the nebula equally, and impressing blackness upon them. The next two photographs (Plates LXVII. and LXVIII.) are of the region of the foot of the Serpent-holder which is being stung by the tail of the Scorpion. Here the stars sometimes appear simply crowded together, sometimes they look as if they are powdered into a nebulous bedwork. But whichever their condition, the narrow or broad rifts and channels plough through them. In the north-west of Plate LXVII. there is a broad bow that seems half filled with grey star stuff, with a few separate stars sprinkled upon it. A little further to the east and south a giant note of interrogation is scooped out of the nebulous froth; this, too, is half filled with nebula. Farther to the south, again, there is, as it were, a black **S** imprinted on the stars, but with the ink smeared off from its tail towards the east. All along the whole south there is an irregular great grey patch, but the grey bed of the channel is seamed and scored by blacker rifts. On the whole there is more nebula here than star dust, and the nebulosity looks curdled like whey because of the rifts and channels.

In Plate LXVIII., which is near the same region as the second, we have principally to do with star crowdings and with rifts, rather than with nebulosity and rifts. Consider the great straight band running from the centre to the south-west corner, which is evidently a dark channel, across which the stars have drifted just as snowflakes cover again a path that has been swept. Running from the centre due east there is a broader, less regular, band, like a river with flat wet banks, let us say, on which the falling snowflakes melt when fallen.

The next two photographs are parts of the constellation of the Archer. In Plate LXIX. the stars are certainly so crowded together that we cannot see between them, yet where they seem to thin we see that they lie imbedded in a grey, nebulous mist. The whole might almost do for a photograph of a mackerel sky. But in Plate LXX. the stars are certainly not

NORTH



EAST

WEST

SOUTH

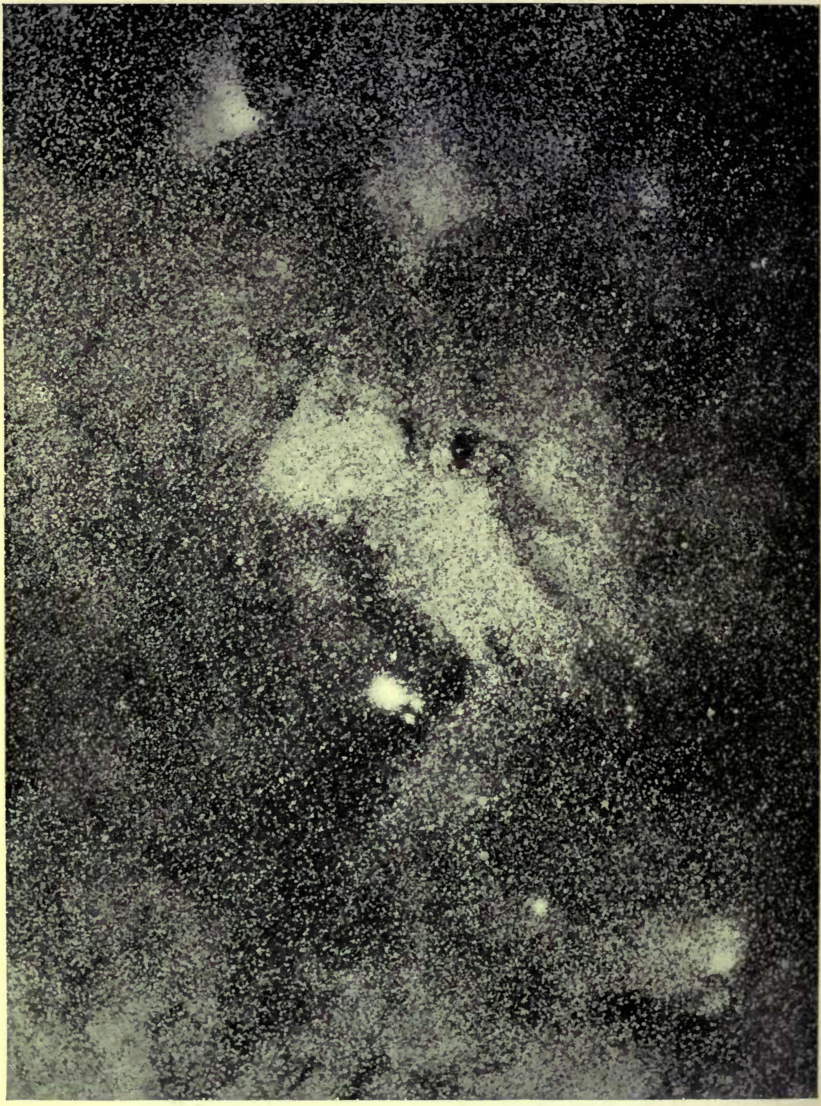
GREAT STAR CLOUD IN SAGITTARIUS.

(*Photograph by Professor E. E. Barnard.*)

PLATE LXX.

NORTH

EAST



WEST

SOUTH

SMALL STAR CLOUD IN SAGITTARIUS.

(*Photograph by Professor E. E. Barnard.*)

so crowded in many places, we can see everywhere between them into blackness. There are one or two black channels here, or channels that are sprinkled over quite thickly. Almost in the centre of the plate there is a large, very black hole, with but a star or two upon it, and this hole is evidently connected with the principal dark channel, which seems to run from the hole towards the south-west, behind the stars. But there are other bands, bright ones, or bridges, shall we say, in which the stars do not seem to be unduly crowded, but they seem to be in, or upon, or behind a nebulous ribbon. The most noteworthy of these runs from the great star-cloud in the centre of the picture in a slightly south-easterly direction.

The sixth picture is from the little triangular space between the constellations of the Archer, the Eagle, and the Serpent, which the astronomers of the late middle ages devoted to form a new constellation, that of Sobieski's shield. This contains a famous cluster of stars, visible to the naked eye, and called 'the flock of wild ducks.' It lies a little to the north of the centre of the picture. (*See* PLATE LXXI.)

The stars are certainly crowded in this picture, though not so crowded that they often run together to form a continuous cloud-like surface. But here and there weirdly shaped channels are seen, some absolutely sharp and black, as if engraved and inked in, containing no star or nebulous matter. Note the sharp figure, as of a 7 (upside down) in the north-west quarter of the photograph. Note the V (lying sideways) in the north-east and very near the eastern edge. One arm of the V stops abruptly, as if it dipped down deep below the stars, or they had drifted over it, and then continues as abruptly farther on. In the very centre of the plate is a curious four-branched figure, only slightly obliterated by stars, the junction of the four branches being marked by a sharp, round hole, and the north-west branch straggling broadly into another hole, out of which one might have imagined that the 'flock of wild ducks' had flown.

Now, what is the meaning of these extraordinary vacant lanes in the Milky Way? Not only are they often devoid of stars, but they seem to be darker even than the surrounding sky. Neither stars nor nebulae appear in them. Are they really vacant spaces, or do they contain some black substance that hides the stars and nebulae from our view?

How can we answer this question? We do not yet know; but whether these lanes be empty or full, they teach us one thing about the Milky Way, that it is one structure; its different parts are not unconnected with each other. For, suppose that the channels are really vacant of stars and star mist, then some force has acted on all the Milky Way in that region to sweep these channels bare. The presence of the lanes shows that the Milky Way has a definite form and structure of its own; that its parts form a body.

And suppose that the channels are due to some black substance, to an opaque nebula which blots out the bright stars and star mist, then consider the black hole which we saw in the centre of the fifth of Professor Barnard's pictures. It was large and quite black, so that it is evident that if there is black stuff there, it is between us and the Milky Way, for it blots out the Milky Way. But from this hole, we saw that several channels ran to the south-west, channels that were not black on the whole but overlaid fairly thickly by a layer of stars, stars that evidently form part and parcel with those that are adjacent and fairly remote from the channels, and the farther from the hole, the more thickly do the stars lie upon the channel, blotting it out. We can even trace the channels out into the comparatively vacant spaces to the south-west, out beyond the great star-cloud which occupies the centre of the picture.

Whether the hole and channels, then, be made up of emptiness or of black absorbing stuff, it is evident that it lies askew to this great star-cloud. The black round patch is in the forefront of it, the channels work back to its further end. The star-cloud, the 'hole,' and the channels are mixed up together; they form a composite whole.

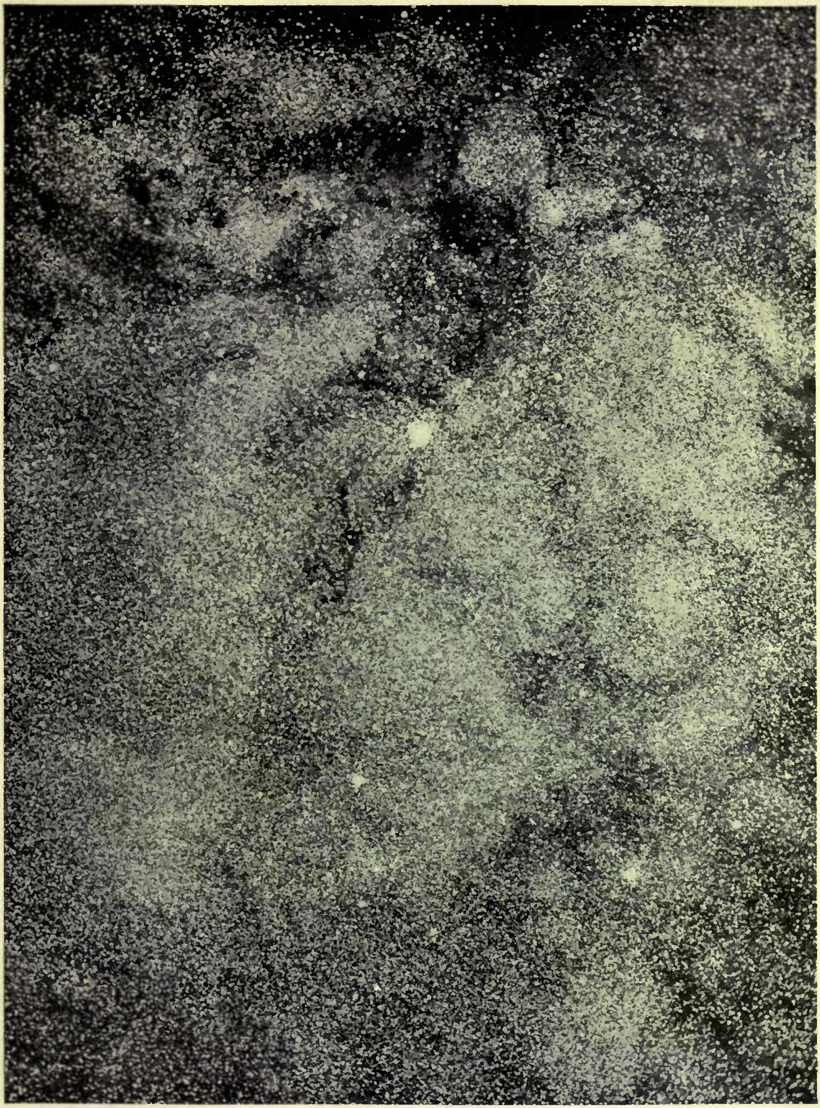
The story that the Plough stars told us was that they were of one family; bound upon a common pilgrimage, vast and distant. The story that the nebulae of Orion, of Andromeda, and of the Pleiades told us, was that they each were one also, bound by ties of inconceivable attenuateness, but bound securely; wonderful in form, vast spiral structures, though how vast or how distant we do not know. So, too, the story that the Milky Way tells us is, that it is one, vaster than we can conceive, more distant than we can conceive, but yet one, because of the complicated structure uniting its parts.

. . . . .

Such are a few of the stories which 'the heavens are telling.' Some of them were read by men thousands of years ago; some we are only just now beginning to spell out. But they are all stories of that great building which the hands of God have reared. First of all, men learnt how the world on which they lived was set amongst the shining lights of heaven, and how these seemed to move around it. They learned in time the shape and size of that world; then of the size and distance of moon and sun and planets. They learned of the different states and conditions of the sun and the planets, and their relations to each other as members of the same system. Then, greatly daring, they have soared upwards to the stars, and tried to stretch the line of thought out to the uttermost depths of that unfathomable immensity. And

NORTH

EAST



WEST

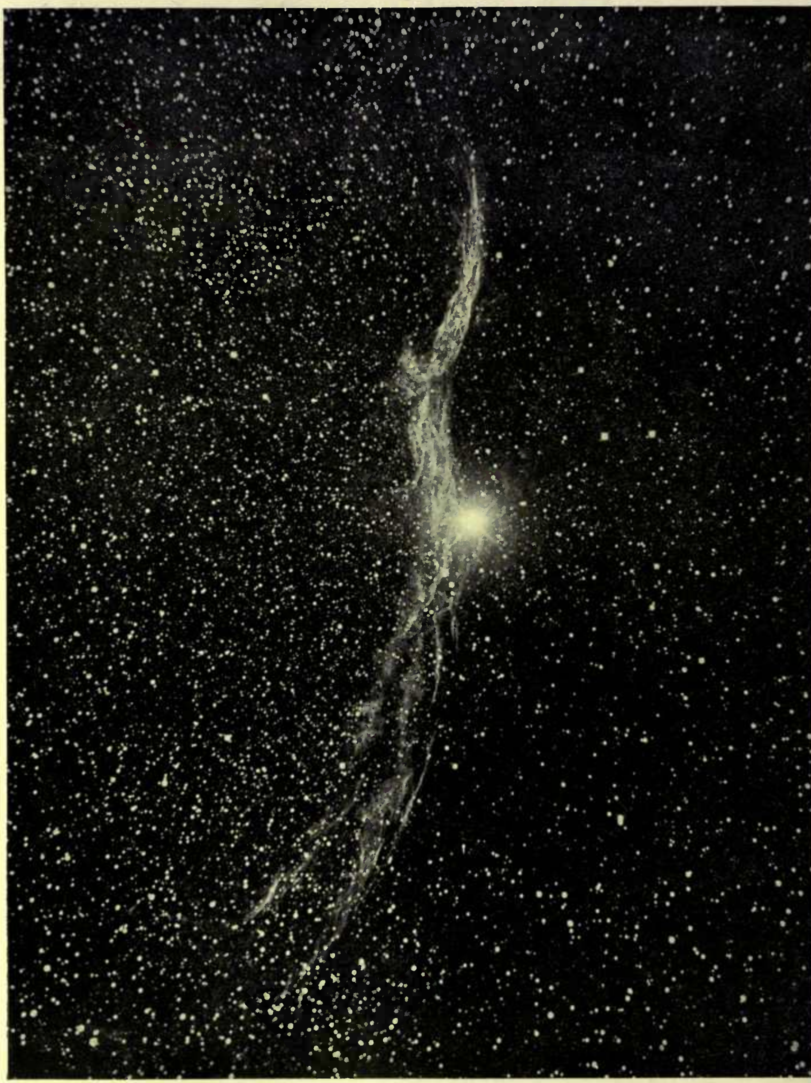
SOUTH

REGION OF CLUSTER, MESSIER 11.
(*Photograph by Professor E. E. Barnard.*)

PLATE LXXII.

NORTH

EAST



WEST

SOUTH

THE VEIL NEBULA IN CYGNUS (New General Cata. No. 6960).

(*From a photograph taken at the Yerkes Observatory, by Professor G. W. Ritchey.*)

'Frontiers quickening under prophetic motions from God.'

there they have still found the tokens of structure; all that we see is part of one building. But of its immensity what can we say? The only thing that saves us from being crushed by the immensity of the proportions which are here revealed to us, is that the human mind refuses to realize the significance of the figures by which those distances are expressed. Were it otherwise, the human spirit would be overwhelmed, as in the old German rhapsody that De Quincey translated.

'God called up from dreams a man into the vestibule of heaven, saying, "Come thou hither, and see the glory of My house." And to the angels which stood around His throne, He said, "Take him, strip from him his robes of flesh; cleanse his vision, and put a new breath into his nostrils, only touch not with any change his human heart, the heart that weeps and trembles." It was done; and with a mighty angel for his guide the man stood ready for his infinite voyage; and from the terraces of heaven, without sound or farewell, at once they wheeled away into endless space. Sometimes with the solemn flight of angel wings they passed through zaharas of darkness, through wildernesses of death, that divided the worlds of life; sometimes they swept over frontiers that were quickening under prophetic motions from God. Then, from a distance which is counted only in heaven, light dawned for a time through a shapeless film; by unutterable pace the light swept to them, they by unutterable pace to the light. In a moment the rushing of planets was upon them; in a moment the blazing of suns was around them.

'Then came eternities of twilight, that revealed but were not revealed. On the right hand and on the left towered mighty constellations, that by self-repetitions and answers from afar, that by counter-positions, built up triumphal gates, whose architraves, whose archways, horizontal, upright, rested, rose, at altitude, by spans that seemed ghostly from infinitude. Without measure were the architraves, past number were the archways, beyond memory the gates. Within were stairs that scaled the eternities around; above was below and below was above, to the man stripped of gravitating body; depth was swallowed up in height unsurmountable, height was swallowed up in depth unfathomable. Suddenly, as thus they rode from infinite to infinite, suddenly, as thus they tilted over abysmal worlds, a mighty cry arose that systems more mysterious, that worlds more billowy, other heights and other depths, were coming, were nearing, were at hand.

'Then the man sighed and stopped, shuddered and wept. His overladen heart uttered itself in tears, and he said, "Angel, I will go no farther; for the spirit of man acheth with this infinity. Insufferable is the glory of God. Let me lie down in the grave, and hide me from the persecution of the Infinite, for end I see there is none." And from all the listening stars that shone around issued a choral voice, "The man speaketh truly: end there is none that ever yet we heard of!" "End is there none?" the angel solemnly demanded; "is there indeed no end? And is this the sorrow that kills you?" But no voice answered, that he might answer himself. Then the angel threw up his glorious hands to the heaven of heavens, saying, "End is there none to the universe of God. Lo! also, there is no beginning."'

When I consider the heavens, the work of Thy fingers,
The moon and the stars, which Thou hast ordained;
What is man, that Thou art mindful of him?
And the son of man, that Thou visitest him?
For Thou hast made him a little lower than the angels,
And hast crowned him with glory and honour.

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