ASTRONOMY FOR NIGHT WATCHERS

J. B. Sidgwick

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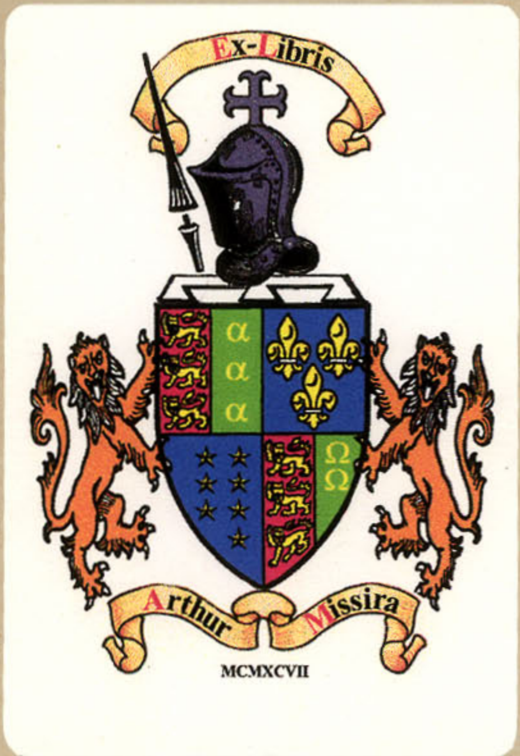

Park

280, Brooklands Rd
Baguley,
Nr Manchester.

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by

J. B. SIDGWICK
Member of the Société Astronomique de France
and of the British Astronomical Association

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Chapter 1

WHY STUDY ASTRONOMY?

Why study astronomy? Isn't it an abstruse and learned subject compounded of mathematics and incomprehensible jargon, a dry-as-dust occupation of old greybeards who 'star gaze' when they ought to be in bed? Is it not, in fact, something above the heads and beneath the notice of the ordinary man in the street?

No! Nothing could be further from the truth. The fascination of astronomy is there for all who still retain a capacity for appreciating beauty, whose eyes are not closed to the incredible wonders of the universe we inhabit, and who can still feel a thrill of awe in the face of mystery and eternity.

Throughout the ages man has stared up at the stars and wondered. The man has not been born who has never been moved by the immensity of a frosty starlit night, when the skies seem to coruscate with an infinity of flashing stellar points. The man is unborn, too, who has never thought, if only for a fleeting moment, 'I wish I knew something about it all.'

I want first of all to emphasize that this instinct is a valid one, and then to show that astronomy is *not* too difficult for the 'average man' to understand and enjoy. On the contrary, the amateur study of astronomy is a pursuit that can never grow stale and which can provide endless hours of absorbing interest, both by day and by night.

In the past it has been for many people an insuperable barrier in the way of the study of the stars that the evenings are the only time when recreation and social engagements are possible—sleeping and earning one's living occupying the remainder of the twenty-four hours. Who, getting up at 7 a.m., say, and working or travelling to and from work until

7 o'clock in the evening, is going to spend the few precious hours that remain to him in solitary state, star gazing on his rooftop?

But today, thanks to an eruption of barbarity and the shilly-shallying evasions of the political leaders of the west over the last decade, many thousands of men and women in this country find themselves on night duty in the open for ten, twenty, thirty, or more hours every week. They are the fire watchers, the roof spotters, the personnel of observer posts who nightly give warning of the death and destruction that shriek from the skies. For days or even weeks at a time there may be no 'incidents', no sinister beating in the sky. Boredom, not the bomber, is the insidious enemy of the civilian army of watchers by night. What an opportunity to make an acquaintance with the wonders of the night sky! There above them hangs the resplendent firmament, glorious with a million scintillating points, the Milky Way streaming down the sky like the ghost of a pathway to heaven—vista upon vista stretching away endlessly to the limit of human vision and far beyond. How easy to end once and for all the ennui of the long uneventful night watches and at the same time lay the foundations of an interest and a love that will last to the grave.

Even without any instrumental aid whatsoever, hours may be spent in tracing out the ancient constellation figures, learning their names and their long histories, the myths of classical Greece and Rome with which they are associated. Gradually, in this way, one learns to find one's way about the night sky. No longer is it just a riot of starry points, strange and indistinguishable one from another, as chaotic as a Cup Final crowd seen from an aeroplane. One by one the brighter star groups fall into place, and chaos gives way to order. The sky ceases to be a crowd of miscellaneous aliens and becomes a circle of familiar friends, each with his well-known appearance and personal idiosyncrasies. To see Orion striding over the eastern horizon on an autumn evening after six months' absence below the horizon is to experience the same thrill one feels when, quite

unexpectedly, one sees the face of an old friend who for months has been out of sight and out of mind.

If the night watcher has a pair of binoculars at his disposal a further and even more fascinating field is opened to him. In these days when giant new telescopes costing millions of dollars and weighing many tons have considerable news value, it is often imagined that without expensive equipment and a long technical training the pursuit of astronomy must be a waste of time, and the night skies a closed book. Nothing, once more, could be further from the truth. The amount one is able to see at any time depends, roughly speaking, upon the size of the lens that is gathering light and transmitting it to the retina. Look at your eye in a mirror, note the size of the pupil, and then compare it with the object glass of the smallest telescope or field glass. The difference between the two is a gauge of the new wonders that even the most modest instrument will reveal. To one who has previously relied solely on his unaided eyesight, the first view with binoculars of the crescent moon, or the Milky Way, or the star clusters in the constellation Perseus—the list could be extended indefinitely—is a revelation. The owner of a pair of field glasses holds the open sesame to realms of whose very existence his naked eyes never gave him the faintest inkling.

The amateur—many of whom began with the smallest instruments the work that later brought them fame—holds a distinguished position in the history of astronomy. His achievements would fill a book many times the size of this; here there is only space to mention two or three. One of the most fundamental properties of the sun is a tendency for all its activities and phenomena to fluctuate in intensity in recurrent cycles of some eleven years' duration. This was the discovery of Schwabe, a German amateur (he was an apothecary by profession) who began his observations of the sun with a small and inexpensive telescope in 1826. Every cloudless day for more than forty years he studied the face of the sun with his little telescope, noting how many spots were visible. In 1852 he was able to announce that sunspot activity fluctuates between a definite maximum and minimum in a period of about eleven years. This was one of the most significant discoveries ever made in solar research—the work of an amateur who indulged his astronomical ardour at such times as he could spare from the daily routine of earning a living.

Coming nearer our own times, the reader probably knows that Will Hay, the stage and screen star, is an accomplished amateur astronomer, and he may recollect that some ten years ago Hay discovered a bright spot on the surface of Saturn which was one of the most conspicuous markings ever observed on that planet. Another amateur whose love of astronomy has led him into the halls of fame is L. C. Peltier, an American farmer. Working his farm by day, night-time will find him in his home-made observatory, where between 1925 and 1939 he has discovered no less than six new comets. In an extremely interesting letter to me he describes his equipment and method of working. Neither is the one expensive and elaborate, nor the other esoteric or complicated: Peltier is a true amateur who has in recent years shown that 100-inch telescopes and the like have not yet elbowed the amateur from the niche he has carved for himself in the history of astronomical discovery.

It must be added that the systematic observation of the moon, planets, meteors and variable stars—to mention four instances only—is almost entirely in the capable hands of amateurs the world over at the present time, and astronomy owes to them most of its detailed knowledge of these bodies. This, however, is a digression beyond the scope of the present book, which aims merely at introducing the reader to the wonder and fascination of the night sky.

A few practical tips may perhaps be of value here. First, about binoculars. A large number of these have been issued to the defence services, and I envisage the reader as having access to a pair. 'Field glasses', with object glasses from 1·2 to 1·5 inches diameter, are superior to the smaller variety

known as opera glasses, and if they are modern prismatics so much the better. A magnification of from three to five times is ideal. With higher magnifications the field of view becomes objectionably small for stellar work, although ×7 or ×10 is very useful for observing the planets and the moon. Determining the magnification of the binoculars is a simple matter. Look at a brick wall through the left eyepiece with your right eye, keeping your left eye open. The two images of the wall, one formed by the naked eye and one by the optical train of the binoculars, are superimposed, and it is only necessary to count how many bricks of the former coincide with one of the latter to arrive at the magnification: if it is found, for example, that five bricks of the naked eye image coincide with one of the binocular image, then the magnification is five.

Most good binoculars are made on a hinged principle, whereby the distance separating the two tubes can be varied to suit different users. See that they are properly adjusted in this respect or a double image of the field will result and the glasses will be virtually useless. Good glasses also allow for the separate focusing of each eyepiece, since with most people the focus of the two eyes is not exactly the same. It is obviously of the greatest importance that each eyepiece should be focused as nearly perfectly as possible, and it is preferable to focus the instrument on a star, rather than on some distant terrestrial object.

Giving advice to experienced roof spotters and their kin on how best to keep warm while on night duty is probably asking for the reciprocal advice to teach my grandmother to suck eggs. But since such knowledge is an important item in the amateur astronomer's equipment, I shall risk one or two brief hints. Do not drink hot tea or coffee just before going out: its heating effect is only transitory and it renders one susceptible to chills on the stomach. The time to take a hot drink is when one comes in. It is an excellent plan to warm one's underclothes in front of a fire before going out. Loose-fitting clothes are better than tight, and the ideal type of garment is a thick woolly pullover or sweater several times too large. Wearing two pairs of gloves and trousers also makes a lot of difference: pyjama trousers inside the ordinary pair, and woollen gloves inside leather ones help materially to conserve warmth. Duplicated woollen socks inside loose-fitting boots such as gum boots or waders are a help, but even this will not keep the feet warm for long—the most difficult thing to achieve. The secret is not to stand or sit with the feet resting on the ground itself (or concrete roof or whatever it may be) but on some non-conducting material such as a piece of coco-nut matting or a thick coco-nut fibre doormat.

Lastly, one very important point. In order to catch a glimpse of faint objects such as the companions of some double stars, star clusters and nebulae near the limit of vision, etc., the binoculars must be held perfectly steady. This the hand, alone and unsupported, cannot do: the steadiest hand on earth may be holding the glasses but it will be found that the star images are dancing about like sparks over a furnace. It is imperative that some sort of support for the glasses, and/or the hands holding them, should be improvised. The best thing is possibly an ordinary step ladder, against the top step of which the hands holding the binoculars can be steadied. Alternatively, use can be made of an easy chair (if the object being observed is not too high in the sky) whose arms give firm support to the elbows. It is also worth noting in passing that the centre of the retina is not its most sensitive area. Therefore it often happens that a faint object is hardly discernible when the attention and the eyes are focused directly at it, while it is easily seen when the eyes are focused at a point a little way from it. In this way—by having a firm support for the glasses and by using indirect vision—faint objects can be detected that would otherwise inevitably remain invisible.

Having thus introduced the subject and cleared the ground of one or two preliminary points, let us set out on our voyage of discovery.

Chapter 2

THE FIRST NIGHT OUT—FINDING ONE'S BEARINGS

The Constellations

One of the first things we notice when we begin our observations on a starlit night is that the brighter stars are not distributed uniformly over the dome of the heavens, but in many cases fall into quite obvious groups. These groups are the constellations, and their identification will be the main concern of the beginner, for unless he can recognize the different constellations—or at any rate identify them with the help of the maps that follow—he will not yet have begun to know his way about the night skies, nor will he be able to find the many objects of interest for binocular study (listed in Appendix 2) which each constellation contains. But before we can get on with learning the geography of the night sky we must first acquaint ourselves with the way in which it behaves as a whole.

The Diurnal Rotation of the Star Sphere

Quite a short period of observation will reveal the fact that the stars, like the sun and moon, rise in the east, climb up the sky until due south, and then sink again towards the western horizon. Furthermore, observation on two consecutive nights will prove that they make one complete circuit of the star sphere in about twenty-four hours—if a certain bright star is seen to be rising at eight o'clock one evening, it will be rising again at about eight o'clock the following evening. The stars are sometimes called the fixed stars, for the reason that although they move round the heavens in twenty-four hours they do not change their positions relative to one another in doing so; it is as though they were fixed immovably to the inner side of a great sphere, at whose centre is the earth, which rotates once every twenty-four hours, carrying the stars with it. Two stars no more change their distance apart or direction from one another during this rotation *en bloc* than do London and Edinburgh on a child's terrestrial globe change their relative positions when the globe is set spinning.

We have likened the star sphere to a child's globe, with the proviso that whereas we are looking at the latter from the outside we observe the former from the inside. The analogy between the two brings out one or two further points. Just as the child's globe rotates between two pivots, the north and south poles, and has a great circle (the equator) inscribed round it midway between these two poles, so does the star sphere rotate between two pivots—the north and south celestial poles—and so too has it an imaginary girdle known as the celestial equator. In England the north celestial pole is situated some 40° above the north point of the horizon, or nearly half way between the horizon and the point overhead; the south celestial pole is of course invisible, since diametrically opposite the north celestial pole—i.e. below the southern horizon somewhere under our feet. The north celestial pole is easily found. Figure 1 illustrates the group of stars known as the Plough, part of the constellation of Ursa Major. Since it, in common with the rest of the star sphere, rotates about the north celestial pole, it may be found in any of the positions shown, or in some intermediate position. But it is nevertheless an unmistakable feature of the northern sky and easily identified. To give some idea of the size of the star group, the thick black line marked 'Scale' represents approximately the size of a 6-inch rule held at arm's length against the sky. Having found this star group—somewhat resembling a saucepan with a bent handle—it is only necessary to carry one's eye away from the Plough in the direction indicated by the dotted line for a distance about equal to five times that separating the two stars marked β and α (known as the Pointers) for it to alight upon a star which, though rather faint, cannot be mistaken, since no others lie near it. This star is Polaris, the Pole Star, and it marks almost exactly the position of the north

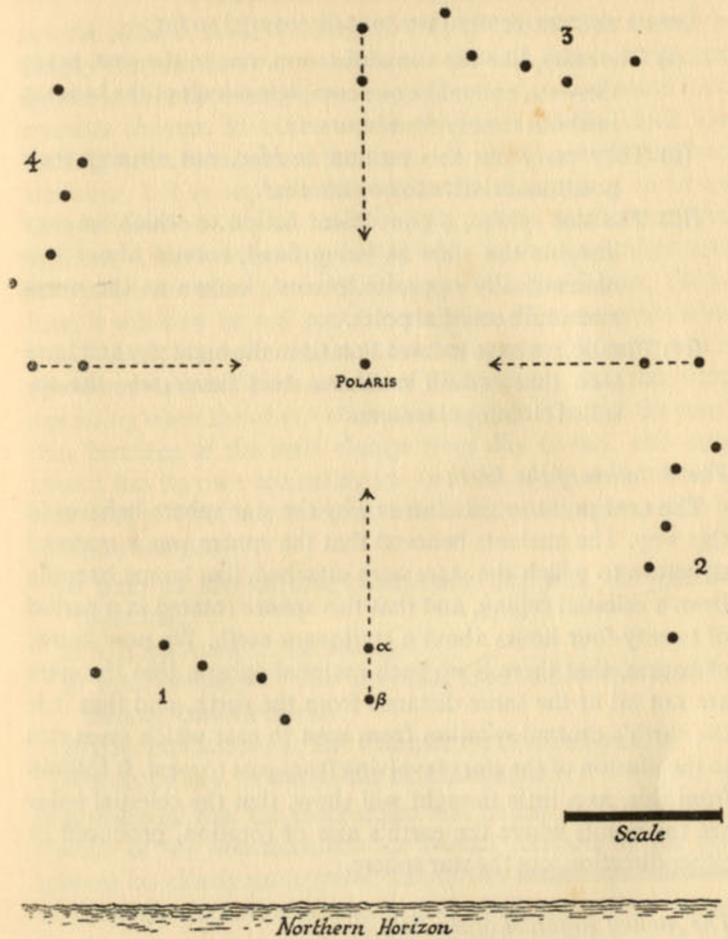


FIGURE 1

celestial pole. It can easily be seen from the diagram, or from the sky itself once the diurnal motions of the stars have become familiar, that any star whose distance from Polaris is less than the distance of Polaris above the northern horizon can never set: such stars are known as circumpolar stars, of which the Plough is an example.

Let us summarize what we have discovered so far:—

(i) The stars, like the sun and moon, rise in the east, set in the west, and make one complete circuit of the heavens in about twenty-four hours.

(ii) They carry out this motion *en bloc*, not altering their positions relative to one another.

(iii) The star sphere, a convenient fiction to which we may imagine the stars as being fixed, rotates about two diametrically opposite 'pivots', known as the north and south celestial poles.

(iv) Finally, we have located Polaris in the night sky and have seen that certain northern stars never set—the so-called circumpolar stars.

The Rotation of the Earth

The next point to get clear is why the star sphere behaves in this way. The ancients believed that the sphere was a material structure to which the stars were attached, like lamps hanging from a celestial ceiling, and that this sphere rotated in a period of twenty-four hours about a stationary earth. We now know, of course, that there is no such material sphere, that the stars are not all at the same distance from the earth, and that it is the earth's diurnal rotation from west to east which gives rise to the illusion of the stars revolving from east to west. It follows from this, as a little thought will show, that the celestial poles are the points where the earth's axis of rotation, produced in either direction, cut the star sphere.

The Annual Rotation of the Star Sphere

But if the star sphere rotated in exactly twenty-four hours (to continue describing the phenomena in these convenient but incorrect terms) the same stars would rise at the same time night after night and we should see the same constellations in the summer as we do in the winter. Now most people, ignorant as they may believe themselves to be of astronomy, know that this is not the case, and that the winter stars and constellations are

not the same as those of summer. Why is this so? The answer is simply that the stars do not make one diurnal circuit of the star sphere in *exactly* twenty-four hours, but in a period some four minutes shorter. In other words the hands of the clock are moving more slowly than the stars—clock time is slower than star time. Let us see how this works out. A star seen to be on the meridian[1] at 10 p.m. on one night will be on the meridian again at 9.56 the following night, 9.52, on the third night and 9.32 one week after the initial observation. At 10 p.m., therefore, it will now be well past the meridian. Three months later it will be setting below the western horizon at this hour and a new set of stars will be due south of the observer, stars that were just rising when the observations began. Thus it is that the compass bearings of the stars change from day to day, and each season has its own constellations (see the two-monthly maps, following p. 70). This slower rotation of the star sphere clearly occupies one year:

10 p.m. on day of first observation (say Jan. 1): star on meridian,
10 p.m. on April 1: star setting,
10 p.m. on July 1: star invisible, since below the horizon directly below Polaris,
10 p.m. on October 1: star rising above eastern horizon,
10 p.m. on Jan. 1: star on the meridian again.

It is essential that the mechanism and nature of this seasonal change of the constellations (or *annual* rotation of the star sphere) be clearly understood before the actual identification of the different constellations is embarked upon. The reason for this rotation is that the earth is not only spinning on its axis (hence the diurnal rotation of the stars) but is also revolving about the sun in a period of one year, hence steadily changing the observer's viewpoint of the sun and stars from minute to minute and from day to day.

[1] The meridian is a great circle about the star sphere which passes through the north and south points of the horizon, the celestial poles and the zenith (i.e. the point directly overhead).

The Ecliptic, or Sun's Path

One other aspect of this annual rotation must be cleared up. How does the star sphere's yearly motion from east to west affect the sun? Does the sun partake of it? No, clearly not. For when we said that there is a daily four minute discrepancy between star time and clock time we really meant that the discrepany is between star time and solar time, for we set our clocks by the sun. A few days' observation will show that the sun is always on the meridian at mid-day (that, indeed, is the definition of mid-day), not four minutes earlier each succeeding day. Since the star sphere is making its annual rotation behind the sun, the latter consequently appears to move across the background of the constellations from the west to east, completing one circuit in the same period of one year. The path that the centre of the sun's disc traces out upon the star sphere is known as the Ecliptic ; this is clearly the line of intersection of the plane of the earth's orbit about the sun produced to meet the star sphere. And since the earth's equator is inclined to the plane of its orbit at an angle of 23½°, so the ecliptic is inclined to the celestial equator at this same angle.

The Zodiac

The Zodiac is an imaginary parallel-sided band, 18° wide, described round the star sphere, down the centre of which runs the ecliptic. To this narrow band are confined the sun, moon and planets: they can never be seen in any other part of the sky than the zodiac—even the profoundest astronomical ignoramus would be surprised to see the sun or moon rising in the north! The zodiac is divided into twelve equal lengths, in each of which the sun is situated for one month of the year. These twelve constellations, to be described later, are called the Signs of the Zodiac.

The Motions of the Moon

We have now discussed and described the apparent motions of the stars and of the sun; those of the planets we will leave

until the next chapter, just remembering that the planets never stray more than 9° from the ecliptic. There now remains the moon with its varying appearances. The motion of the moon against the background of the stars duplicates that of the sun, except that for one year is substituted one month. Thus the moon makes an apparent diurnal rotation of the star sphere in about twenty-four hours, due to the earth's rotation. But owing to its own orbital motion about the earth, which is completed in twenty-seven days, it also makes a west to east circuit of the star sphere in that period. In other words, while being carried all the time from east to west along with the stars it has also a proper motion of its own from west to east. Thus it rises later each day: if it is on the meridian at 10 p.m. tonight, it will be considerably east of the meridian at 10 p.m. tomorrow night.

The Moon's Phases

So much for the moon's motions: what of its phases? Figure 2 pictures the earth and moon, each revolving about its own orbit, and the direction from which the sun's light is falling. It is clear that only one hemisphere of the moon can be illuminated at a time, but the angle from which this hemisphere is seen by an observer on the earth varies with the position of the moon in its orbit. A moment's examination of this figure will show that the appearances of the moon in positions *A* to *E* are those shown at the side of the diagram: at *A* the illuminated hemisphere is turned directly away from the earth and the moon is therefore invisible (new moon); at *B*, a little later, we have a glimpse of the illuminated hemisphere; at *C*, we can see half of it, the right-hand or western half; at *D* the hemisphere is turned directly towards us and therefore the moon is fully illuminated (full moon); at *E* it has moved round to the other side of the sun and is now approaching it again—the half of the sunlit hemisphere that is turned towards the earth is the left-hand or eastern half; gradually during the last week of the lunation the illuminated portion shrinks to a narrow crescent, the moon being visible low in the eastern sky before sunrise; finally, it becomes invisible altogether and it is new moon once more, four weeks after the preceding new moon.

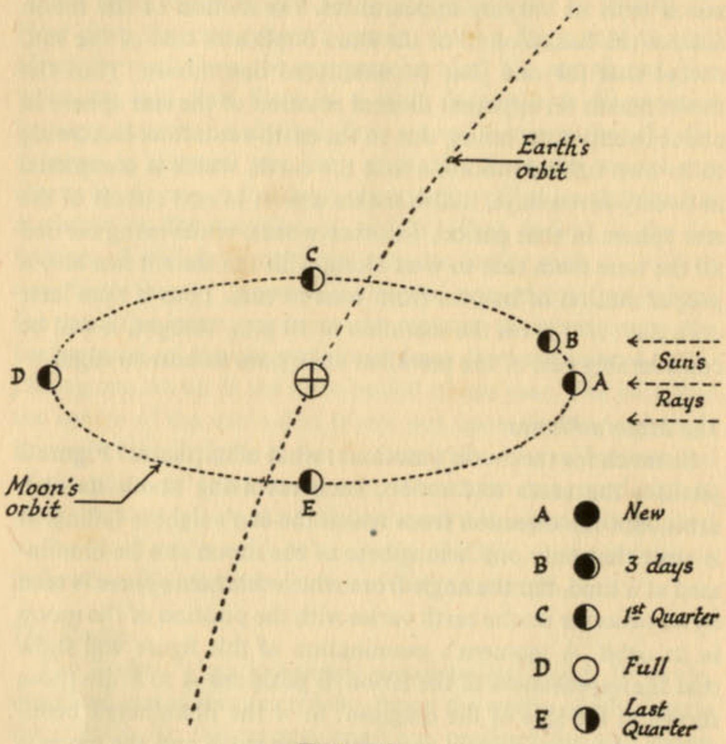


FIGURE 2

Stars, Planets, and Sun

Before proceeding with a detailed description of the planets it will be well to ensure that the reader is quite clear as to the difference between sun, moon, planets and stars. The sun is a giant globe of incandescent gases and molten solids; its temperature at the surface is about 6,000°, at its centre probably in the neighbourhood of 40,000,000°; in size and mass it compares with the planets as a cathedral compares with a pebble.

The stars are essentially similar to the sun—in fact the sun *is* a

star. That they look so different from the sun is simply a result of their much greater remoteness: even the nearest stars are 300,000 times as distant as the sun. For this reason the stars resemble the planets when seen with the naked eye—both are minute points of light. Yet when we reflect that this earth is a planet (and a fairly representative one) and the sun a star (again fairly typical), we shall see how different the two classes of body are: the difference between a star and a planet is the difference between the sun and the earth.

The moon may simply be regarded as a small planet. It is a cold, solid body in no way resembling the sun or the stars. It revolves about the earth and indirectly round the sun, being carried round the latter by the earth.

So far, then, we have discussed how the heavenly bodies move and behave. We have yet to learn something of what they are really like and then to start our exploration of the constellations. And if the reader feels that so far it has been rather stodgy going, let him reflect that no-one has enjoyed the great literature of the world who has not undergone the preliminary tedium of learning his A B C.

Chapter 3

THE PLANETS

The Structure of the Solar System

The planets are nine in number, each a world of the same general type or status as the earth. They all revolve about the sun in roughly circular orbits, the length of time taken to complete one such revolution (i.e. the planet's year) depending upon its distance from the sun. All these nine orbits lie in nearly the same plane,[1] and thus it is that no planet can stray more than a few degrees from the ecliptic. If you visualize the solar system situated at the centre of the star sphere and yourself as situated on the earth in the general plane of the orbits, you will appreciate that these other orbits, as silhouetted against the starry background, will all lie very close to one another.

The names of the planets in order from the sun outward are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto. Thus Mercury and Venus are always nearer the sun than the earth is, and the other planets further from it. The following figures are repeated from the table on p. 66:

Planet	*Distance from Sun (in millions of miles)*	*Period of revolution round the sun*
Mercury	36	88 days
Venus	67	225
Earth	93	365
Mars	141	687
Jupiter	483	11·9 years
Saturn	556	29·4
Uranus	1,783	84·0
Neptune	2,793	164·8
Pluto	3,670	247·7

[1] With one exception, see p. 29.

The Apparent Motions of the Planets

How do these circum-solar motions appear to us, situated on the earth and observing the other planets against the background of the stars? Let us take the inner planets, Mercury and Venus, first. Figure 3 shows the sun, the earth, and an inner

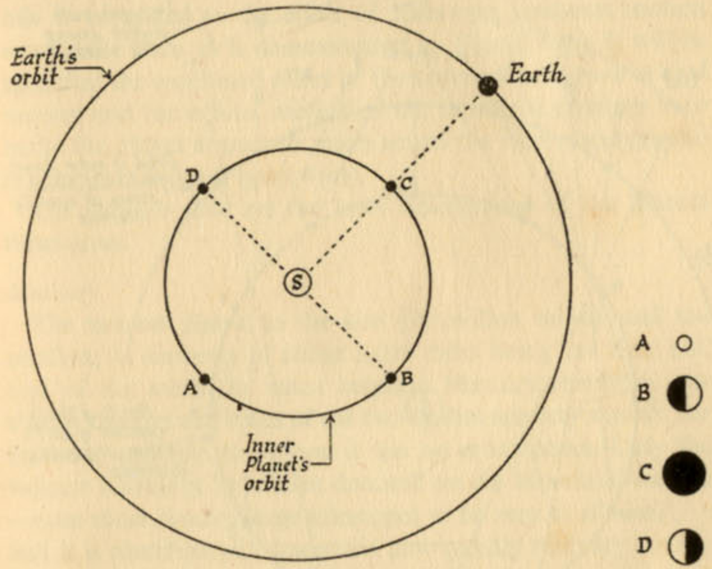


FIGURE 3

planet in four positions along its orbit; for simplicity's sake we will suppose that the earth does not move appreciably during the time required for the planet to complete one revolution about the sun—the truth of the account is not materially affected by so doing. When the planet is in position *A* it occupies the same region of the zodiac as the sun, i.e. is situated in the sky during the day and below the horizon at night, and is therefore invisible. As it moves towards *B* it will recede farther and farther from the sun until it is as far to the left, or east, of the sun as it is possible for it to go: it is an evening star. From

B to *C* it once more approaches the sun and becomes invisible, only to reappear on the other (right-hand, or west) side of the sun and recede from it until it reaches maximum elongation west at *D*. Once again the angular distance of the planet from the sun decreases, till position *A* is reached. An inner planet,

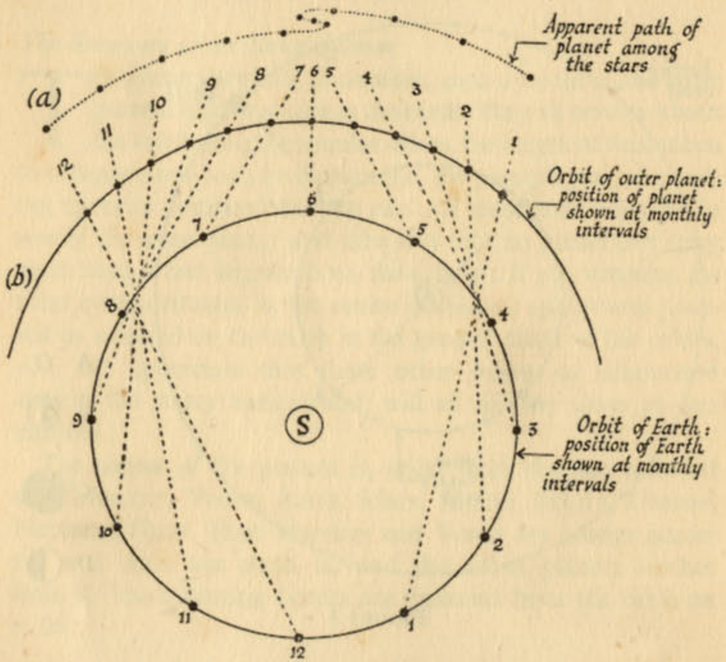


FIGURE 4

therefore, can never recede beyond a certain fixed distance along the zodiac from the sun; it appears alternately as a morning star (visible above the eastern horizon before sunrise) and as an evening star (visible above the western horizon after sunset). The maximum elongation (the angular distance SD or SB) of Mercury, the nearest planet to the sun, is 29°; of Venus, with an orbit twice as large as Mercury's, some 47°. Furthermore, in travelling round the orbit it will exhibit the same

cycle of phases as the moon, as shown at the edge of the diagram.

But the outer planets behave quite differently. Since the earth completes the circuit of its orbit in a considerably shorter period than these planets (see table, p. 66), the effect of the terrestrial observer 'catching up' and 'passing' the outer planets has to be added to the effect of their own west-east motion among the stars, as is demonstrated by Figure 4 (*b*). It will be seen that the combined effect of the outer planet's own orbital motion and the orbital motion of the terrestrial observer is to make the planet appear to move across the starry background in a series of loops (Figure 4 (*a*)).

The stage is now set for brief descriptions of the planets themselves.

Mercury

The nearest planet to the sun (36 million miles), and the smallest, its diameter of about 3,000 miles being less than half that of the earth. In many respects Mercury resembles our moon; the size and mass of the two bodies are very similar, for instance, and like the moon it has no atmosphere. Only the vaguest markings have been detected on the Mercurial surface —even these require large telescopes to be seen at all clearly— and it is therefore still uncertain how rapidly Mercury rotates on its axis. Such evidence as is available, however, seems to indicate that its period of axial rotation is the same as its period of revolution about the sun (88 days); in other words Mercury always turns the same hemisphere towards the sun, and its day is the same length as its year. If this is so, the temperature of the sunlit side must be in the neighbourhood of 350° C. to 420° C., and that of the hemisphere which never receives any direct heat or light from the sun, about −200° C.

Venus

Revolves round the sun at a distance of about 67 million miles in a period of 225 days. If Mercury resembles the moon, Venus is almost the twin sister of the earth:

	Earth	Venus
Diameter	7,963 miles	7,750 miles
Volume	1·00	0·92
Mass	1·00	0·81

The chief cause of Venus's surpassing brilliance is the fact that it is sheathed in a dense atmosphere of clouds, the solid surface of the planet being entirely hidden from our eyes. White clouds reflect, after snow, more of the incident light falling on them than almost any other substance. The chemical constitution of this deep and dense atmosphere is still in doubt, though carbon dioxide has been identified spectroscopically. Water vapour and oxygen do not appear to be present. What the surface of the planet, beneath its impenetrable muffler of vapour, may be like, is a mystery which will probably never be solved.

Mars

The next planet to the earth on the side farther from the sun. Its distance from the sun is 141 million miles, and when nearest the earth only 35 million miles separate the two planets; at such times Mars is brighter than any star and is surpassed only by Venus. It is the only planet on which surface markings can be observed and studied in any detail; for it is comparatively near the earth, has a clear atmosphere and, being an outer planet, can be observed on the meridian (the most favourable position) during the night.

Mars is a smaller body than the earth (respective diameters 4,215 and 7,927 miles) but in many respects the physical conditions at its surface resemble those of the earth more closely than any other planet. The spectroscope shows that the Martian atmosphere contains water vapour (clouds are often visible telescopically, floating above the Martian surface) and oxygen, though in smaller quantities than the terrestrial atmosphere; no toxic gases have been detected or suspected. Its temperature at the point where the sun is directly overhead varies from about freezing point to some 25° C. Elsewhere on the sunlit hemisphere it will of course be colder than this, and on the

night hemisphere very cold indeed by terrestrial standards. It rotates on its axis in 24 hrs. 37½ mins.

The surface markings consist of blue-green areas superimposed upon the general reddish background of the planet. In addition to these there are a number of fine streaks known as *canali*. There is no evidence that these are artificial canals or even that they are waterways. Finally, there are two 'polar caps'. These behave in the same manner as the terrestrial polar caps, shrinking in summer and increasing in size during the winter. They were accordingly thought to be composed of snow, ice, or hoarfrost, but more recent work has suggested that they may be atmospheric phenomena—great patches of fog, mist, concentrations of ice crystals in the air, or whatnot.

The dark markings undergo a regular seasonal change, associated with the 'melting' of the polar cap of the hemisphere which is turning from winter towards summer. It has been suggested that this annual darkening of the blue-green areas in the spring hemisphere may be the proliferation of some form of vegetation under the stimulus of increasing temperature and the liberation of moisture from the polar cap. This is very far from established, however. All we can safely say on the vexed question of life on Mars is: *if* there is life resembling the terrestrial form in its fundamental features elsewhere in the solar system besides this planet, then Mars (with its near-terrestrial conditions) is the place where we must look for it.

Mars has two small satellites, discovered in 1877, only visible in large telescopes.

Jupiter

The giant planet of the solar system. Its equatorial diameter of 88,640 miles is 11 times that of the earth, while its volume and mass are respectively 1,312 and 317 times as great as the earth's. Jupiter therefore contains enough material for a complete duplicate set of the remaining eight planets!

This great body has a retinue of ten (possibly eleven) satellites, four of which were discovered by Galileo—one of the first discoveries of the newly invented telescope—and may be seen with binoculars: the diameter of two of them exceeds 3,000 miles (that of our moon is 2,160) while the other two are more than 2,000 miles in diameter. The remaining six satellites are small and faint.

When viewed with a telescope, even the smallest, Jupiter is seen to be crossed by a complex system of dark belts. The rapid changes that occur in the detail of these prove them to be atmospheric: here, as in the case of Venus, the surface of the planet is hidden from our probing eyes by a dense vaporous atmosphere. The spectroscope shows that two of the main constituents of this atmosphere are methane (marsh gas) and ammonia. When we reflect that the temperature of the planet is some 130° C. below freezing point we can appreciate that Jupiter is no hospitable home for life as we know it.

Saturn

Unique as being the planet with the rings. Saturn itself is a giant planet only slightly smaller than Jupiter. Like its greater neighbour it is swathed in clouds, its surface being entirely hidden from us. It has a family of nine satellites,[1] a few of which are visible in small telescopes and the largest of which should be glimpsed with good binoculars. Saturn's temperature must be even lower than that of Jupiter, for its distance from the sun is nearly twice as great.

The rings lie in the equatorial plane of the planet and are composed of a vast number of separate fragments. The inner diameter of this vast structure is about 130,000 miles, its outer diameter 170,000 miles. Its thickness is small compared with its width, and when the rings are turned edge on to the terrestrial observer they vanish from sight!

Uranus and Neptune

Both are smaller planets than the giant Jupiter and Saturn, their diameters being about 32,000 miles, or four times that

[1] The discovery of a tenth has not been confirmed.

of the earth. Yet owing to their enormous distances both from the sun and from the terrestrial observer they are always faint features of the night sky and eluded detection till 1781, when Herschel discovered Uranus, and 1846 when Galle discovered Neptune. Nothing is known of their physical conditions, but their temperature must be very low indeed, and the spectroscope proves that they have cloud-laden atmospheres like Jupiter and Saturn. Uranus has a family of four satellites, Neptune only one.

Pluto

Pluto was discovered as recently as 1930. It is only visible in the largest telescopes and was discovered photographically. Its mean distance from the sun is 3,670 million miles (37 times greater than the earth's), at which distance it exhibits no sensible disc in even the largest telescope; at this distance, too, it receives only one-one thousand six hundredth as much solar heat and light as the earth does—its temperature is probably in the region of −250°. To an observer on Pluto the sun would appear as nothing more than an abnormally bright star. It is estimated from its known brightness and distance that it is probably about the same size as Mars. It completes one revolution round the sun in 248 years and its orbit has the extraordinarily high inclination to the ecliptic of 17°. Pluto, therefore, is the one planet that can stray beyond the limits of the zodiac.

The Planets in the Night Sky

Of the nine planets which are known to circle round the sun, two, Neptune and Pluto, can never be seen with the naked eye; a third, Uranus, is so faint that although just visible without instrumental aid it does not 'catch the eye', being indistinguishable from a very faint star; the appearances of another, Mercury, are so fleeting that most people have never caught a glimpse of it. This leaves only four planets that are easily and conspicuously seen with the naked eye—Venus, Mars, Jupiter, and Saturn.

Venus, as we know, can never be more than 47° along the zodiac from the sun, and therefore never sets more than a few hours after the sun nor rises more than a few hours before it. At its brightest, Venus is rivalled only by the sun and moon—no star and no other planet can approach it in brilliance. Most people have at some time or other been struck by this glittering gem of the twilit sky.

Mars, Jupiter, and Saturn, lying as they do outside the earth, may be seen in any region of the zodiac; indeed, when in opposition they are directly opposite the sun and therefore culminate at mid-night. Jupiter is the brightest of the three, and a conspicious object of the night sky, second only to Venus. Mars is usually less bright, but its conspicuous red tint easily distinguishes it from any other planet. Saturn is the faintest of the three, though still a bright object compared with most of the stars.

In their journeyings round the zodiac two or more planets often pass quite close to one another on the star sphere; such conjunctions are beautiful phenomena, especially when observed with binoculars. Frequently the planets and the moon come into conjunction with each other, and these too should be observed with whatever instrumental aid is available; occasionally the moon passes directly between the terrestrial observer and one of the planets, a phenomenon known as an occultation. These are fascinating to watch with binoculars, particularly when the planet disappears behind or reappears from the dark side of the moon. Regular watchers of the skies will not need to refer to almanacs for warning of conjunctions, since they will—some days or even weeks beforehand—have watched the two bodies drawing steadily nearer to one another. On the other hand it is advisable to be forewarned of occultations by keeping an eye on the almanac.

Finding the Planets

When Venus is at its brightest it is an absolutely unmistakable object. So, too, are Jupiter, Mars, and Saturn once the

amateur has become familiar with the constellations and knows the positions of the brighter stars. For a bright 'star' lying somewhere on the zodiac where it is known that no star is situated must be one of the planets, and its colour and brightness will usually tell the experienced observer which it is. Alternatively, of course, if their exact positions are discovered from an ephemeris such as the Nautical Almanac and then plotted upon a good star map,[1] a glance from the map to the sky will show whether or not the planet is above the horizon at the time of observation, and in the former event its identification will be a matter of seconds. In the case of Uranus, which to the naked eye is indistinguishable from a faint star, such a procedure is essential. Even when its position has been plotted on the map and the binoculars are directed towards the correct area of the sky, several faint 'stars' may be seen in about the predicted position of the planet and it will be impossible to decide which is Uranus. One thing, however, will give away its identity and clearly distinguish it from the stars—its motion. If the observer notes carefully the position of the suspected planet in relation to the near-by stars, perhaps making a simple map of the region, he will notice after a night or two that one of the faint points of light has slightly altered its position in relation to the others. This must therefore be the planet.

Mercury certainly will not be seen by accident, as Jupiter or Venus may easily be. The amateur who wishes to catch a glimpse of the Messenger of the Gods before he sinks below the horizon or is lost in the brightening glow of dawn must scan the eastern horizon shortly before sunrise during the autumn, or the western sky some twenty minutes after sunset during February and March, or thirty to forty minutes after sunset during April and May. Mercury will then be visible for about one and a half hours before setting, its distance from the sun at maximum elongation varying from 18° to 29°.

Neptune, though never visible to the naked eye, is within the

[1] Such as A. P. Norton's *Star Atlas and Reference Handbook* (Gall & Inglis, 1940).

reach of binoculars, and the amateur will be able to spot it by the same method as that already detailed for the locating of Uranus. It will be more difficult, however, in proportion as Neptune is fainter than Uranus and moves more slowly across the background of the stars.

Observing the Planets with Binoculars

Mercury, though found more easily, and observable over a longer period with the aid of binoculars than with the unaided eyesight, cannot be called an interesting object for binocular study. It does not present a sensible disc, and therefore the phases are not discernible, though this does not detract from the thrill of viewing a brother planet which few people—not even the great Copernicus—have ever seen.

Venus, on the other hand, does present a sensible disc in good binoculars when near inferior conjunction (its angular diameter is then about 60″) and the crescent phase can be distinctly seen. When at its brightest, Venus is one of the most severe optical tests to which an object glass or binoculars can be subjected—none but the best will give a clear, symmetrical, colourless image without any trace of fuzziness or 'flare'.

Mars is a beautiful object in binoculars, with its deep red tint, much accentuated when it is near the horizon and especially remarkable when it is in conjunction with the moon, Saturn, or Venus and the colours of the two bodies can be directly compared. The disc is not large enough to show any detail with binoculars, but it is interesting to reflect whilst gazing at this steady shining point of ruby light, that here (if anywhere in the solar system besides the earth) is the seat of life.

Jupiter, though four times as distant from the sun as Mars, is such a giant planet that it presents to terrestrial observers a larger disc than any of the other planets,[1] clearly visible in good binoculars. Such an instrument should also show the four brighter and larger satellites of Jupiter when they are well placed for observation. The temporary invisibility of a satellite

[1] Except Venus when nearest the Earth.

may be due to one of several causes: it may be so close to Jupiter itself that it is hidden in the latter's glare; it may be in occultation (hidden by the body of Jupiter); it may be in transit across the face of the planet; or suffering eclipse in Jupiter's shadow. It is fascinating to note the changing positions of these minute specks of light from night to night or even in the course of a single evening. The Nautical Almanac gives details of their positions, but it must be borne in mind that the sketches of Jupiter and its four moons there given represent their appearance in an inverting telescope; for use with binoculars they must be turned upside down.

The rings of Saturn cannot be seen with binoculars. The giant satellite Titan may just be glimpsed with good glasses when it is in the most favourable position, far from the planet.

With the equipment we are using, Uranus and Neptune are indistinguishable from faint stars, and their true nature is only revealed by their motion. Tracking down and finally identifying these remote and inconspicuous members of the sun's family of planets produces a distinct sense of personal achievement, and it is interesting to watch their stately progress among the stars of the celestial background. Pluto, as has been said, is invisible in all but the largest telescopes.

Chapter 4

THE MOON

Size and Distance

The moon revolves about the earth at a mean distance of 239,000 miles, completing one revolution every 27 days 8 hours. Its diameter is 2,160 miles and it is larger in comparison with the planet about which it revolves than any other satellite in the solar system; in this respect the moon and the earth are more like twin planets (the moon is not very much smaller than Mercury) than planet and satellite. Our large telescopes reveal objects on the lunar surface no larger than St. Paul's Cathedral.

Its Rotation

It is widely realized that the moon always turns the same hemisphere towards the earth, for its pattern of dark markings never changes. From this it might be concluded that the moon does not rotate on its axis. This is not so, however. A lunar observer whose line of sight lay past the earth would, in the course of one month's watching, find the entire circle of the heavens pass before his eyes. In other words he has rotated on his axis once, though this fact is liable to be disguised by the fact that during this time the moon has also revolved once about the earth. Thus the moon rotates on its own axis and revolves about the earth in the same period. It follows from this that we can never see more than half of the moon's total surface,[1] the 'far side' being for ever hidden from us.

Physical Conditions

The telescopic appearance of the moon—the total absence of twilight, the jet black shadows and glaring high-lights, and in

[1] Actually we can see a little more than half, owing to a rocking motion of the moon's axis known as libration.

general the crystal clear definition of its surface features—indicates that it has no atmosphere. This is confirmed by the spectroscope. If the moon has any atmosphere at all, its density cannot exceed one-hundred thousandth of the earth's—which for most purposes is indistinguishable from no atmosphere.

Our own atmosphere contains much water vapour which acts as a blanket for the earth, conserving its heat during the night (a cloudy night is warmer than a clear one) and protecting it from the direct heat of the sun during the day. But the moon has no such protective medium interposed between it and the sun, with the result that its temperature must oscillate much more violently than the terrestrial. The probable figures for the centres of the sunlit and unilluminated hemispheres are 120° C. and −80° C.

Given the former high temperature, and at best an almost non-existent atmospheric pressure, any liquid water that might once have existed on the moon must long ago have evaporated and been dissipated into space.

Summarizing, we may say of the moon; no water, extremes of temperature, negligible atmosphere. Is it any wonder, then, that the moon is always described as a dead world?

Pickering's New Selenography

Yet within the last fifty years Pickering and his followers have made observations which appear to suggest that astronomers may have been too hasty in coming to this conclusion. Pickering advocated and adopted a new method of lunar observation which has proved most fruitful—namely, the intensive scrutiny of some quite small area of the moon's surface (a crater floor, for instance) night after night for several lunations. In this way he discovered certain minute white patches which decrease in size as the sun rises high above them, but which begin to grow again when the earth's shadow passes over them during eclipses, and also towards sunset. Could these be patches of hoar-frost? No better explanation of the phenomena has been given.

Pickering also discovered a new type of surface marking which he christened Variable Spots. These are localized dark areas which behave like the partly bright areas except that they darken and grow with the sun's increasing altitude instead of shrinking. He suggested that they might be some primitive form of vegetable life, perhaps similar to our terrestrial lichens. Again, no-one has advanced a more satisfactory explanation of their behaviour. Nevertheless the whole question is still highly speculative, and it would be far from the truth to say that the existence of water and life on the moon has been established.

Lunar Eclipses

The plane of the moon's orbit is inclined at a small angle to that of the earth about the sun. When the moon is new (see Figure 2), therefore, it may be a short distance above or below the sun in the sky, or it may be directly between the earth and the sun. In the latter case we witness a solar eclipse. Similarly, when the moon is full, and directly opposite the sun, it may lie above or below the earth's shadow or it may pass through it; if the latter, it is said to be eclipsed. Lunar eclipses are always predicted in almanacs and are wonderful spectacles for observation with binoculars. The earth's shadow slowly sweeping across the lunar landscape is a scene of never palling grandeur. The eclipse may be either partial or total, depending on how nearly the moon passes through the centre of the earth's shadow. The totally eclipsed moon is often a beautiful sight, for some of the sun's light is refracted by the earth's atmosphere *into* the shadow and, falling upon the moon, faintly illuminates it with a dusky red light, so that the moon hangs like a copper shield against the deep blue of the night sky.

The Moon's Surface

Since the moon has no 'weather', its hills and mountains have been subjected to none of the processes of erosion that have smoothed and reduced our terrestrial hills from their primordial volcanic outlines. The moon has nothing resembling the

gently rolling Downs of Sussex or the undulating uplands of Wiltshire. The greater part of its surface is rugged and barren—a wilderness of the utmost complexity, angularity, and harsh-

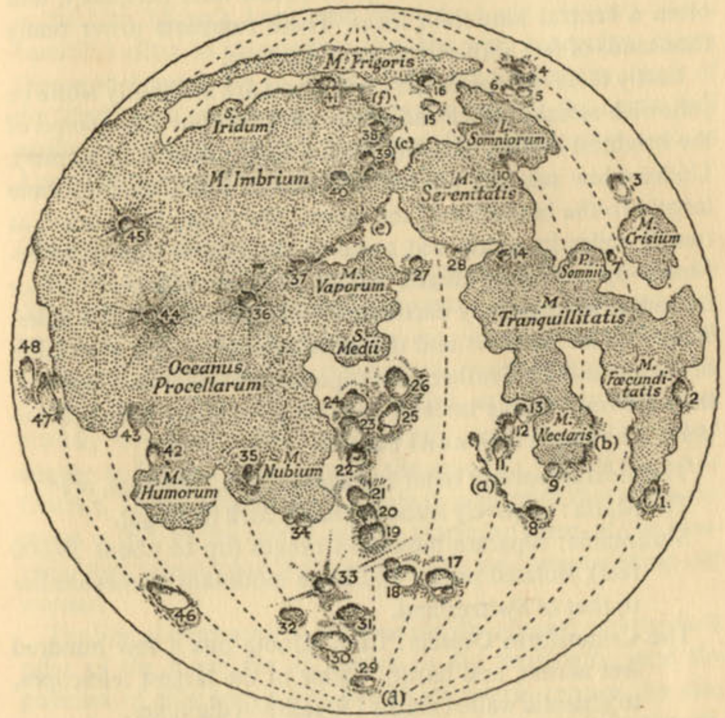


FIGURE 5

Position of terminator shown at the following lunar ages (Old Moon in italics): 13d, 12d, *26d*, 10d, 9d, *23d*, *22d*, 6d, *20d*, *19d*, 3d, *17d*.

ness. Towards the north of the disc lie a number of great plains, darker in tint than the mountainous regions. These plains, or maria (singular: mare), are the dark patches visible to the naked eye.

The most characteristic features of the lunar landscape as revealed by telescope or binoculars, however, are the crateriform objects. These are circular depressions in the surface of the moon, anything from one to 150 miles in diameter. All the larger ones have massive ramparts round their periphery, and often a central mountain mass. These ramparts tower many thousands of feet above the floor of the ring.

Lastly there are the bright rays. These are brilliantly white or yellowish streaks which radiate in all directions from some of the brightest craters (notably Tycho, Copernicus, and Kepler). Under a low sun they are invisible, but at Full they contribute largely to the brilliance of the moon. They may be as much as twenty miles in width, and some of the longest run—uninterrupted by mountain ranges, walled plains or whatever surface irregularities they may encounter—for more than 2,000 miles. They cast no shadows and therefore appear to be a coloration of the ground itself rather than topographical features. But why they are only visible under a high angle of illumination is unknown, as also is their exact nature.

The most important lunar surface features, therefore, are:

The Maria: relatively smooth plains, dark in colour.

Mountains: separate mountain ranges (up to about 30,000 feet), isolated peaks, and large mountain masses similar to that of Switzerland.

The Crateriform Objects: from minute pits a few hundred feet across, and hardly visible in the largest telescopes, to gigantic walled plains 150 miles in diameter.

The mysterious systems of Bright Rays.

Examples of all these features can easily been seen with binoculars and are described in the list at the end of the chapter.

Earthshine

We can see the moon only because light from the sun is reflected from it into our eyes. But in the same way solar light is reflected from the earth on to the moon. Thus the crescent of the new or old moon is directly illuminated by the sun, but light

reflected from the earth also falls upon the dark part of the lunar disc and thence is reflected back into our eyes, rendering this region dimly visible to the terrestrial observer. This phenomenon is known variously as Earthshine, 'The Old Moon in the New Moon's Arms' and the Ashy Light. At times it is a beautiful effect in the evening sky, but with binoculars it is a thousand times more so, a surprising amount of the detail of the 'dark' part of the lunar disc being visible; the maria will easily be made out, while some especially bright craters such as Aristarchus (see p. 46) may also be spotted.

Observing the Moon

To an airman, looking down on the earth far beneath, no difference can be distinguished between hilly country and flat: both look like a smooth plain. So, too, when we on earth look at the full moon, we gaze down upon mountains and valleys, ravines and great crater rings which are illuminated from directly overhead; they consequently cast no shadows and appear as flat and uneventful as the airman's view of the Lake District. To the uninitiated it comes as a surprise that when the moon is full, to the naked eye the glorious Queen of the Heavens, then telescopically she is a dowdy and uninteresting old woman.

The line of demarcation between the illuminated and the dark sides of the lunar disc is known as the terminator, and the position of this terminator (which of course crosses the disc twice in each lunation) is of paramount importance to the observer with binoculars or telescope. When on or near the terminator a mountain, say, casts impenetrably black shadows against which it is vividly silhouetted, every detail of its structure standing out starkly: a week or two later it is illuminated by a high instead of a slanting sun and it may appear as a bright featureless spot or even be totally invisible. When studying the formations described below and figured on the map, observe them when near the terminator. Because of the decisive importance of this factor in lunar observation, the position of the terminator at intervals of a few days is shown on the map, so as to give the beginner some idea of when during the month best to observe any particular district of the lunar landscape.

Short List of Objects for Binocular Study

Mare Crisium (Sea of Crises). Most conspicuous of the maria on account of its distinct outline and isolated position; clearly seen by the naked eye. It measures roughly 350 by 300 miles (area, 78,000 square miles). Jutting out 60 miles into the Mare from the south is the Promontorium Agarum, a mountain mass rising to some 11,000 feet above the surface of the plain. Best observed when the moon is 15–16 days old, or a day or two after new.

Mare Foecunditatis (Sea of Fertility). A large, ill defined, dark plain lying to the south of the Mare Crisium. On the north it opens into Mare Tranquillitatis. Area about 160,000 square miles.

Mare Nectaris (Sea of Nectar). One of the smaller maria, opening into the southern reaches of Mare Tranquillitatis. The Pyrenees Mountains form its western border.

Mare Tranquillitatis (Sea of Tranquillity). One of the largest of the Maria. A 'bay' in its north-west shore is called Palus Somnii (Marsh of Sleep). It is continuous with Mare Serenitatis on the north and Maria Nectaris and Foecunditatis on the south.

Mare Serenitatis (Sea of Serenity). One of the most prominent of the grey plains. A journey round its 'shore' would take the traveller some 1,850 miles (area about 125,000 square miles). On its north side the minor plain known as Lacus Somniorum (Lake of Dreams) opens into it. At Full, binoculars will show a narrow bright ray running across the mare from the direction of Menelaus; actually it emanates from Tycho, two thousand or so miles distant.

Mare Humorum (Sea of Humours). A small plain, 260 miles from north to south, 280 from east to west, area about 50,000 square miles. To its west lies Mare Nubium (Sea of Clouds),

which like it opens into the great Oceanus Procellarum (Ocean of Storms).

Sinus Medii (The Central Bay). An indistinct greyish area lying at the mean centre of the moon's visible hemisphere. Roughly 13,000 square miles.

Mare Imbrium (Sea of Showers). Largest of the maria; 750 by 670 miles. Bounded on the west by the Alps and the Apennines; on the north by the mountainous country separating it from Mare Frigoris (Sea of Cold); to the east it is continuous with Oceanus Procellarum. In its northern shore lies the conspicuous bay, Sinus Iridum (Bay of Rainbows). It looks as though carved out of the mountainous country that bounds the mare in this region, and at points the 135 mile line of cliffs towers 15,000 to 20,000 feet above the plain. The cape at each end of the bay (Laplace and Heracleides) can be made out with binoculars under suitable illumination.

Petavius (1).[1] A great walled plain, 100 miles in diameter. Its ramparts rise to a height of 10,000 feet on the east. Disappears utterly under high illumination.

Langrenus (2). Diameter, 80 miles. The interior and the large central mountain are very bright. Ramparts up to 10,000 feet.

Cleomedes (3). Diameter about 80 miles. Walls up to 9,000 feet on the west.

Endymion (4). Diameter, 78 miles. Walls 15,000 feet on the west. Floor unusually dark.

Atlas (5). The twin and close neighbour of Hercules (q.v.). Diameter 55 miles. Walls 11,000 feet on the north.

Hercules (6). Diameter about 45 miles. Ramparts to 10,000 feet.

Proclus (7). One of the brightest formations on the moon, its ramparts at Full showing in binoculars as a brilliant white spot although its diameter is less than 20 miles.

Piccolomini (8). Situated at the southern end of the Altai Mountains. Diameter, 55 miles. Height of walls, 9,000 feet to 14,000 feet.

[1] Numbers or letters in brackets refer to the Lunar Map.

Altai Mountains (a). A mountain range running north-east from Piccolomini for a distance of 300 miles. Its western face is a precipitous cliff; individual peaks reach a height of 13,000 feet.

Fracastorius (9). Partially ruined, and appears as a bay in the southern shore of Mare Nectaris. Diameter about 60 miles.

Pyrenees (b). A mountain range, well seen when near the terminator, which forms the western border of Mare Nectaris. To the north it reaches a height of 12,000 feet.

Posidonius (10). A walled plain, 60 miles in diameter, situated on the promontory jutting out between Lacus Somniorum and Mare Serenitatis. Ramparts reach a maximum height of 6,000 feet.

Caucasus Mountains (c). A mountain mass which forms the north-east edge of Mare Serenitatis. Peaks from 12,000 feet to 18,000 feet. Note its shadows lying across the mare about First Quarter.

Catharina (11). The southernmost member of a row of three walled plains lying closely north of the Altais. Diameter about 70 miles. Ramparts, very irregular, rise of 16,000 feet.

Cyrillus (12). Contiguous with Catharina. Diameter, 65 miles.

Theophilus (13). The third member of this group. Diameter about 65 miles. At their highest point the ramparts are 18,000 feet above the floor of the ring.

Plinius (14). A ring plain 32 miles in diameter, lying on the northern edge of Mare Tranquillitatis.

Eudoxus (15). Lies north of the Caucasus Mountains, between them and Mare Frigoris. Diameter, 45 miles. Ramparts, 11,000 feet.

Aristoteles (16). The twin of Eudoxus, some 50 miles to the north of which it lies, on the shore of Mare Frigoris. Diameter, 50 miles; height of ramparts, 11,000 feet.

Maurolycus (17). One of the many fine walled plains in the region of the south pole which have to be observed when near the terminator. Diameter, 150 miles. Maximum height of walls, 18,000 feet. At Full it is invisible.

Stöfler (18). Resembles, and lies closely east of, Maurolycus. Irregular in shape and partially ruined. Diameter about 150 miles. Ramparts, 12,000 feet. Invisible at Full.

Walter (19). The southernmost member of a line of six great walled plains on the moon's central meridian (Nos. 19–24). Irregular in shape, from 80 to 100 miles across. Ramparts up to 10,000 feet.

Regiomontanus (20). Also irregular in shape; greatest diameter about 80 miles.

Purbach (21). Diameter, 70 miles. Ramparts, 8,000 feet.

Arzachel (22). Diameter, 65 miles. Massive ramparts reaching heights of from 10,000 feet to 13,000 feet.

Alphonsus (23). 80 miles in diameter. Walls low (5,000 feet to 9,000 feet) but very massive, being in places 15 miles wide.

Ptolemaus (24). The finest and most northern of the six. From 90 to 115 miles across. Walls, 13,000 feet.

Albategnius (25). A fine walled plain with a remarkably dark floor. Diameter, 80 miles. The massive ramparts, in places nearly 20 miles thick, rise to a height of 14,000 feet.

Hipparchus (26). Forms an interesting pair with Albategnius. A giant walled plain, somewhat irregular in shape, measuring 90 miles from east to west.

Manilius (27). A smaller formation than the foregoing, situated to the west of Mare Vaporum. Though only 25 miles in diameter its unusual brightness renders it clearly visible with binoculars under all illuminations. Ramparts 7,000 feet high.

Menelaus (28). An even smaller crater (diameter, 10 miles) lying on the shore of Mare Serenitatis at the foot of the Haemus Mountains (8,700 feet). Its ramparts rise about 6,000 feet above the floor. These are very bright, and the crater is conspicuous at Full despite its small size.

Leibnitz Mountains (d). A great range situated on the moon's limb at the south pole, only partially visible to terrestrial observers. It contains some of the highest peaks on the moon (30,000 feet). Well seen both at Full and during the First Quarter along the southern cusp.

Moretus (29). Lies close to the south pole and must be observed on or near the terminator, since it disappears at Full. Diameter about 75 miles. Ramparts massive, 9,000 feet. Notable in that its central mountain peak is one of the highest of this type of mountain on the moon (about 7,000 feet).

Clavius (30). Another gigantic walled plain in the vicinity of the south pole—the largest on the moon: diameter, 140–150 miles. Walls 12,000 feet high. Invisible at Full.

Maginus (31). About 110 miles in diameter. Ramparts, 14,000 feet. The floor is much darker than the surrounding country. Study this vast enclosure when it is near the terminator and reflect on the seemingly impossible fact that for about 3 days at Full it is entirely invisible.

Longomontanus (32). Resembles Maginus. Dark floor, diameter about 90 miles, ramparts up to 13,000 feet, invisible at Full.

Tycho (33). The centre of the largest and most brilliant of the ray systems. It is owing to the glaring white brilliance of all this region near Tycho under high illumination that so many of the greatest formations similar to those just described are invisible at Full. So bright is Tycho at this Quarter that it can be discerned by the knowing eye without optical aid, although only 55 miles in diameter.

Pitatus (34). A dark-floored ring lying on the southern edge of Mare Nubium. Diameter about 50 miles.

Bullialdus (35). A bright ring plain situated in Mare Nubium. Diameter, 38 miles. It lies on one of the bright streaks from Tycho.

Copernicus (36). One of the finest of the lunar rings. Diameter, 56 miles; ramparts 12,000 feet high. Lies on a bright patch in Mare Imbrium. Centre of a system of bright rays, and both it and its surroundings are very bright at Full. Best studied, therefore, near the terminator.

Eratosthenes (37). Lies between Copernicus and the Apennines. Diameter, 38 miles. Ramparts from 10,000 feet to 15,000 feet. Conspicuous central mountain. Invisible with binoculars at Full.

Apennines (e). Perhaps the grandest of the lunar mountain ranges. It towers 18,500 feet above the smooth expanse of Mare Imbrium, whose south-west border it forms for a distance of 500 miles. Even in binoculars it is a fine and arresting spectacle when near the terminator, its jet black shadows falling 100 miles across the plain. Most of its intricate detail is unfortunately invisible with such an instrument: the telescope shows it to be scored by great valleys and ravines, while lofty peaks rear earthward to heights of from 15,000 feet to 20,000 feet. More than 300 individual peaks have been mapped.

Cassini (38). The first of three ring plains situated at the western end of Mare Imbrium (Nos. 38–40). Diameter, 36 miles. Low ramparts.

Aristillus (39). Diameter, 35 miles. Ramparts 8,000 feet on the east, 11,000 feet on the west.

Archimedes (40). Diameter, 50 miles. Low (about 4,000 feet) massive walls.

Plato (41). A fine, distinct ring plain lying back from the north shore of Mare Imbrium. Notable for the dark tint of its floor. Diameter, 60 miles. Walls up to 5,000 feet.

Alps (f). A great mountain mass forming the north-west border of Mare Imbrium between the crater rings Plato and Cassini. Its highest peak, Mt. Blanc, towers 12,000 feet above the plain. The Alps are cleft by a great valley, 80 miles long and from 3½ to 6 miles wide, which connects Mare Imbrium with Mare Frigoris.

Gassendi (42). A ring plain, 55 miles in diameter, lying on the north-east shore of Mare Humorum. Walls from a few hundred to 10,000 feet high.

Letronne (43). A partially ruined ring, appearing as a bay in the south shore of Oceanus Procellarum (cf. Fracastorius). About 50 miles across.

Kepler (44). A small (diameter, 20 miles) bright crater, situated in Oceanus Procellarum. It lies on a bright patch which is very conspicuous at Full and is the centre of one of the great ray systems.

Aristarchus (45). Like Kepler, an isolated bright crater (probably the brightest spot on the moon) situated in Oceanus Procellarum. Quite featureless though very conspicuous at Full, it is best observed close to the terminator. Bright rays radiate from it under high illumination. Diameter, 30 miles. Walls, 7,000 feet.

Schickard (46). We now come to the eastern limb of the moon. Schickard is a fine walled plain, 135 miles from east to west. Ramparts from 4,000 feet to 10,000 feet.

Grimaldi (47). A vast walled enclosure, measuring about 150 by 130 miles. Ramparts, partially ruined, average some 4,000 feet in height. Its floor is perhaps the darkest spot on the moon: sharp eyesight can detect it without optical aid.

Riccioli (48). Lies between Grimaldi and the limb. Also dark, but less so than Grimaldi. Diameter, 106 miles.

Chapter 5

ASTEROIDS, COMETS AND METEORS

The Sweepings of the Solar System

The sun, the nine planets and their twenty-eight satellites do not represent the whole of the solar system, though these bodies are admittedly the most important if importance is to be measured in tons. Scattered throughout the system are millions upon millions of meteoric particles, material which we may perhaps regard as the detritus of creation—material which never condensed to form major bodies like the planets. These particles vary in size from bodies comparable with the smaller satellites down to minute specks of dust weighing but a small fraction of a gram. They are of three distinct types: asteroids, comets, and meteors.

The Asteroids

If you look at column 3 of the table on p. 66 you will notice that there is an abnormally wide gap between the orbits of Mars and Jupiter. Towards the close of the eighteenth century it was suggested that a still undiscovered planet might occupy this gap. A search was initiated and not one but *several* small planetary bodies were quickly discovered; since that time the discovery of these 'planetoids' or asteroids has proceeded apace, being greatly accelerated by the application of photography to astronomy; today between one and two thousand are known. It has been estimated that there must be something like 40,000 asteroids bright enough to be seen with our largest telescopes, but that their combined mass probably does not exceed 2 per cent of the moon's.

The diameters of the four largest are 488 miles (Ceres), 304 miles (Pallas), 248 miles (Vesta), and 118 miles (Juno). The smallest yet investigated have diameters of the order of one mile and it is probable that there is no sharp line of demarcation between the asteroids and meteors that could be held in the hand. Vesta, though not the largest, is the brightest of the asteroids and the only one that is ever visible to the naked eye. It is certain that not even the largest possess atmospheres, and it is likely that they are nothing more than barren lumps of rock. Many of them vary in brightness, probably indicating that they are not spheroids like the planets but are irregular in shape.

Many of the asteroidal orbits are very odd according to planetary standards. They are not confined to the zodiac—the greatest inclination of an asteroidal orbit to the ecliptic yet discovered is 48°. Furthermore, the orbits are often so elongated or eccentric that the solar distances of the asteroids vary enormously as they revolve about the sun. Thus an asteroid discovered in 1932 lies eight million miles within the orbit of Venus when at perihelion (nearest the sun) and at aphelion (when farthest from the sun) sixty-one million miles outside Mars. Its orbit thus lies athwart those of three major planets. This asteroid can approach within three million miles of the earth—our nearest neighbour after the moon. Another 1932 discovery, known as the Reinmuth planet, comes within ten million miles of the earth, and Eros (a larger body than either of these, having a diameter of about twenty miles) within some sixteen million miles.

Comets

The advent of large and brilliant comets has from time immemorial been regarded as presaging public woes, or death and calamity in high places. And conspicuous comets are indeed remarkable apparitions: in some cases they are bright enough to be visible in broad daylight, their immense tails streaming half way across the dome of the sky. Such comets, of rare occurrence, are seen to consist of a minute star-like nucleus, a misty hood or coma that surrounds it, and a great curved tail directed always away from the sun. The greater number of

comets, however, are small and faint objects only visible with instrumental aid; these are not normally differentiated into a clearly defined head and tail but appear simply as structureless hazy spots.

The last great comet to arrive at perihelion was Halley's, which returns every seventy-five years. On its return in 1910 it was visible to the naked eye for four and a half months, its length then being some twenty-eight million miles.

Their Behaviour and Orbits

Comets revolve around the sun, in common with all the other members of the solar system, but their orbits differ from those of planets in several important respects. In the first place they may be inclined to the ecliptic at any angle up to 90°; comets, therefore, are not confined to the zodiac but may appear in any part of the heavens. Secondly, they are highly eccentric—when at perihelion a comet may be only a few hundred thousand miles from the sun's surface, and at aphelion millions of miles beyond Pluto.

The shortest known period of revolution is 3·3 years, while the longest are several centuries or even millennia. Of these great periods of time the comet is only visible to terrestrial observers for a comparatively few months while the comet swings round the sun before receding once more to the farthermost confines of the solar system.

The tail of a comet always points away from the sun, even when the comet is moving from perihelion to aphelion and accordingly proceeding tail foremost. It therefore appears that some repellent agency is situated in the sun and that this always drives the tail away from the head. It is thought that this repulsive force is the pressure (infinitesimally small except in the sun's immediate vicinity) that light exerts upon any surface or particle which it strikes.

Comets are discovered at an average rate of five per annum, though as many as thirteen were discovered in 1932, a particularly good year. The vast majority of these are faint, tailless objects, only to be seen with telescopes or binoculars. About two-thirds of these discoveries are new comets never observed before, the remainder being the returns to perihelion of comets discovered on some previous occasion.

What is a Comet?

Comets are the largest bodies in the solar system: the coma of a well developed comet may measure several hundred thousand miles across, and the tail many millions of miles in length. Yet the mass of even the greatest comets is too minute to be detected and cannot exceed about 1/100,000 of the earth's. When the tail or even the head of a comet passes between us and a faint star, the latter suffers absolutely no diminution of its brightness. In 1910 the earth passed through the tail of Halley's comet without any effect whatsoever being observed, and on the same occasion the comet's head passed in transit across the sun's disc but was invisible in the most powerful telescopes.

It is thought that the head of a comet consists of a widely spaced swarm of meteoric bodies, and the coma and tail of highly rarefied gaseous or dusty material which is expelled from the head near perihelion by the light pressure of the sun. Spectroscopy shows that comets, at any rate when in the vicinity of the sun, shine partly by reflected sunlight and partly by virtue of their own radiation.

Comets and Meteors

In 1826 Biela discovered a comet with a period of 6·6 years. At the 1846 return the comet was seen to have split into two. At the next apparition in 1852 these two components were 1½ million miles apart. The comet was never seen again, but on subsequent occasions when it should have returned there was instead a brilliant display of meteors, and it has been discovered that the orbit of this meteor swarm is identical with that of Biela's comet. This argues a very close connection between the two classes of body, and substantiates our conception of the nature of the heads of comets. A similar identification of

cometary and meteoric orbits has been made in a number of other instances.

Observing Comets

Nowadays—with the universal professional use of photography in astronomy, and with amateurs scattered over the globe who systematically search for new comets with the appropriate equipment—there is little likelihood that the casual watcher of the skies will be allowed to claim a cometary discovery. Every year, however, comets are discovered which are within the reach of small telescopes and binoculars, and the location of these and their subsequent observation as they move rapidly across the background of the stars, brightening up to perihelion and then slowly fading into invisibility, is a fascinating occupation. Details of the position, rate and direction of movement, and brightness of newly discovered comets are given in such periodicals as *Nature* and the *Journal of the British Astronomical Association.*

Meteors

At some time or another everyone has seen a meteor, looking like a star that has slipped its moorings and is tumbling down from the firmament. These transient points of light are in reality small fragments or rock or metal ore, weighing usually only a few milligrams, which in the course of their journeyings round the sun are drawn into the earth's gravitational field. Hurtling through the atmosphere at velocities of many miles per second they are heated to incandescence by the resistance of the air, and all but the most massive are completely vaporized long before they can reach the earth's surface. Meteors are first visible at a height of about a hundred miles and the majority are burnt out while still more than thirty miles above us.

Meteor Swarms

The best way of making serious observations of meteors is to plot the track of each one carefully on a star map the moment it is seen. When this is done it will often be found that the tracks appear to diverge or radiate from a single point on the star sphere. This point is known as the radiant, and the meteors which, when caught in the earth's atmosphere, radiate from such a point, are said to constitute a meteor swarm. When a shower of this sort occurs it means that the earth is passing over the point at which its own orbit intersects that of the meteors, which like the earth are revolving about the sun. These meteors will of course be travelling in space in more or less parallel paths, and their apparent divergence from the radiant is merely an effect of perspective.

Every year when the earth reaches the point of intersection of the two orbits a shower will be observed, since there are stray meteors scattered round the entire orbit. But the simultaneous arrival of the earth and the swarm itself at the intersection of the two orbits may only occur at intervals of several years. Thus there is an exceptionally fine display of Leonid meteors every thirty-three years. Each swarm—of which hundreds are known, although even the few conspicuous ones do not usually yield more than a few score meteors per hour to any one observer—is named after the constellation in which the radiant lies; if there is more than one radiant in any constellation the designation of the bright star nearest to the radiant is prefixed, e.g. the ϵ Taurids, α Cygnids, etc., indicating that the radiants lie near ϵ Tauri and α Cygni respectively.

How many Meteors are there?

It has been calculated that although a single observer would count himself lucky to see as many as eighty meteors per hour even when the earth is passing through a swarm, the entire atmosphere of the earth every day sweeps up something like twenty or thirty million meteors bright enough to be seen by the naked eye. If telescopic meteors are included, this number becomes many times greater. Taking figures that must of course be widely speculative, but which probably err on the low side, let us say that 100 million meteors whose average weight is five

milligrams enter the atmosphere every twenty-four hours. Then the weight of the earth is increasing through meteoric additions at the rate of about 4,500 tons per annum!

Observing Meteors

A meteor is not in itself an interesting thing to observe—merely a moving dot or streak of light lasting a few seconds. But when swarms are studied by the careful plotting of their individual members on a star map, or when observations are made simultaneously from different stations, many interesting problems are uncovered. The systematic observation of meteors lies entirely in the hands of amateurs, and in this country the work is organized and the results collated by the British Astronomical Association. If any reader feels he would like to carry out work which is not only well within the scope of his qualifications and equipment, but which in addition will be of permanent value to science, he should get in touch with this body. For those who wish to observe meteors casually, the list of constellations in Appendix 2 contains details of all the more important meteor showers.

Chapter 6

THE STARS

We have already learnt that the stars are great spheres of incandescent gas—objects of the same general type as the sun. When we consider how much brighter the sun is than even the most brilliant star (Sirius), we will naturally and correctly conclude that the stars are many times more distant from the earth than the sun is. It is possible by various methods to determine the distance of the stars with considerable accuracy.

Finding the Distance of a Star

When an observer's viewpoint moves, near objects appear to change their positions against the background of more remote objects: thus the view from a railway carriage window consists of telegraph poles flashing past the more distant landscape. The nearer an object is to the observer, the greater will be this apparent displacement for a given shift on his part. In fact, the amount of the displacement is inversely proportional to the distance of the object, and the latter may easily be calculated from the former.

Now in a period of six months a terrestrial observer alters his position in space by some 186,000,000 miles[1] (the diameter of the earth's orbit) and one might suppose that this displacement of the observer would result in the nearer stars appearing to alter their positions against the background of the more distant stars. This is actually the case, but owing to the immense distances of even the nearest stars the shifts are extremely minute, and escaped detection until Bessel measured the first stellar distance in 1838. The parallactic shift of 61 Cygni, the star in question, only amounts to one-five thousandth of the apparent diameter of the moon. This corresponds to a linear distance of 64,800,000,000,000 miles.

[1] Leaving out of account the motion of the sun itself.

The Light Year

Obviously it is most inconvenient to express such enormous distances in units as small as the mile; instead, the 'light year' is employed. Light travels with a velocity of 186,000 miles per second, and this distance is accordingly known as a light second. Similarly, the distance that light travels in a year (6,000,000,000,000 miles) is one light year. Thus the distance of 61 Cygni is 10·8 L.Y.—a much more manageable expression.

The *nearest* star, Proxima Centauri, is 4·2 L.Y. distant from the sun; the most distant are hundreds of thousands of light years away.

A Star's Distance from its Luminosity

Unfortunately the parallactic shift becomes too small at distances greater than about 200 light years for this method to be used with any success, and the astronomer is therefore forced to fall back on alternative methods for stars more distant than this. If we can discover the real brightness, or luminosity, of a star we can immediately deduce its distance by a simple calculation. For the apparent brightness of any light source is inversely proportional to the square of its distance from the observer. Since we know how bright the star appears to be, we only require to know how bright it really is in order to deduce its distance.

Stellar Luminosities

These real brightnesses vary enormously as between different stars. In other words, if all the stars were brought to the same distance from the sun they would still appear to be of greatly differing brightnesses.

The most intrinsically brilliant stars have luminosities of the order of 50,000 times that of the sun; one star, S Doradus, is suspected of being 600,000 times more luminous than the sun. At the other end of the scale we have stars only 1/50,000 as bright as the sun. The difference between these two extremes of luminosity may be likened to, though still even greater than, the difference between a candle and the most powerful searchlight.

Stellar Magnitudes

A glance at the night sky shows that the stars differ among themselves in apparent brightness—differences dependent upon a combination of unequal luminosities and distances. These differences in apparent brightness are measured on the scale of stellar magnitudes, and it is important to realize at the outset that the 'magnitude' of a star is solely an indication of its brightness and has nothing whatever to do with its linear size.

Roughly speaking, the twenty brightest stars in the sky are of the first magnitude and the remainder of the stars visible to the naked eye are divided into five lower magnitudes, the faintest stars discernible on a clear, moonless night belonging to the sixth magnitude. The stars of each magnitude are 2·5 times as bright as those of the next lower magnitude, so that a first magnitude star is about 100 times brighter than one of the sixth magnitude. On the same scale, the magnitude of the sun is −27 and that of the faintest stars shown by the Mt. Wilson 100-inch reflector, 21.

The Temperatures of the Stars

A star resembles a lump of iron in that its temperature determines its colour: a star or an iron bar at red heat is cooler than one at white or blue heat. Thus we can obtain a rough idea of the temperature of a star just by looking at it, but the detailed examination of its spectrum enables us to reach a much more accurate result. Stellar temperatures vary over a smaller range than do their luminosities, the limits being (excluding exceptional cases) about 30,000° and 2,000°. The nature of the correlation between colour and approximate temperature is shown below:

Greenish or bluish white	30,000°–19,000°
Yellowish white	11,000°– 7,500°
Yellow	7,500°– 5,000°
Deep yellow or orange	5,000°– 3,000°
Red	3,000°– 2,600°

Size, Mass, and Density

The range of stellar size is, like luminosity, enormous. At the lower end of the scale lie the dwarfs, bodies comparable in size

with the planets; a typical white dwarf, Sirius B, is described on p. 87. At the other end are the giants, the greatest of which have diameters larger than that of the orbit of Mars: in other words, were a giant star like Betelgeuse or Antares to be substituted for the sun, Mercury, Venus, the Earth and Mars would all lie inside it. Such stars are as much larger than the sun as the latter is larger than the average planet.

Stellar mass, on the other hand, varies within comparatively small limits, the vast majority of the stars being less than 10 times and more than one-tenth as massive as the sun. It follows, therefore, that the density of the giants is exceedingly low, while that of the dwarfs is quite fantastically high, for the definition of density is $\frac{\text{Mass}}{\text{Volume}}$. Once these two quantities are known, a quick calculation reveals the fact that the density of a giant star such as Betelgeuse is about equivalent to what a physicist would describe as a tolerably good laboratory vacuum. The mass of a dwarf, on the other hand, is compressed into such a small space that the density is many times greater than that of lead: so tightly compressed, in fact, that one cubic inch of the matter of the dwarf Sirius B would weigh a ton.

The Sun as a Star

It is interesting to see where the sun stands in the stellar heirarchy, and the table below shows that it is in no respect outstanding and is indeed rather below the average in most instances—a petit bourgeois, in fact. The figures are approximate:

	Maximum	*Sun*	*Minimum*
Luminosity	50,000	1·00	0·00002
Temperature	30,000°	6,000°	2,600°
Diameter (miles)	400,000,000	864,000	8,000
Mass	10	1·00	0·1
Density	60,000 × water	1·4 × water	equivalent to good 'vacuum'

Variable Stars

There is a special class of stars which deserves mention since they are of great interest to observers with inexpensive equipment such as binoculars. These are stars whose brightness is not steady, but fluctuating, either regularly in recurrent cycles or else without apparent rhyme or reason. Five general types of variable may be distinguished.

(i) *Irregular Variables.* These are typically red stars, and the range of variation seldom exceeds half a magnitude or so. Betelgeuse is an example from among the brighter stars. The cause of this type of variation is unknown. Examples of irregular variables, as of all the other types, are given in Appendix 2.

(ii) *Long Period Variables.* Unlike the foregoing, their brightness fluctuates fairly regularly and predictably between definite maxima and minima. The range of the variation is usually several magnitudes, and they are therefore more noticeable than the irregular variables. The periods of these stars (i.e. the interval between successive maxima or minima) vary from several months to several years. The cause of the variation is thought to be the rhythmic pulsation of the star itself.

(iii) *Cepheids*, named after the variable, δ Cephei. The variation proceeds with clockwork regularity, the periods usually being measured in days. Cepheids also are probably pulsating stars. A most peculiar relationship has been discovered to exist between the periods and the luminosities (or intrinsic brightness) of these variables, such that the longer the period the more luminous is the star. This period-luminosity relationship is of the greatest value as furnishing us with an alternative method of determining stellar distances and the distances of star clusters (see pp. 62 sq), many of which contain Cepheids. For it is only necessary to measure the period of a Cepheid in order to deduce its intrinsic brightness, when a comparison of this with its observed brightness at once yields its distance. The reason for this relationship is unknown.

(iv) *Eclipsing Variables.* A variable of this type is not a single, isolated star but a binary system consisting of a pair of stars too close to one another to be observed individually.

These components revolve about one another in orbits which are seen edge on from the earth, with the result that at regular intervals the two stars eclipse one another. The relative size and brightness of the two stars, their distance apart and the inclination of their orbits to our line of sight are factors which affect the exact nature of the light variation, but all eclipsing variables have light curves of the same general type.

(v) *Novae*, or Temporary Stars. These are faint stars that suddenly brighten to a brilliant maximum and then fade again, very much more slowly and with many minor fluctuations of brightness, to their original magnitude. The light output during the short period of increasing brilliance (usually a matter of days) is stupendous, and has no parallel elsewhere in the universe of man's exploration. Nova Aquilae 1918, for example, increased its brightness 40,000 times in four days, while the 1885 nova in the Andromeda Nebula (see p. 78) emitted more light in six days than the sun emits in a million years. Up to the present, some fifty novae have actually been observed at the time of their occurrence (others have been discovered posthumously on photographic plates). Of these, perhaps the most famous, and certainly the brightest, was that observed by Tycho Brahe in 1574; this was visible to the naked eye for the unusually long period of 18 months, and at maximum was brighter than Venus and clearly visible by day. Now it is fainter than the twelfth magnitude. The cause of these cataclysmic explosions is unknown, but explosions within the interior of the star they almost certainly are.

Binary Stars

In two different instances we can discern that an apparently single star is in reality a pair of stars which are not individually visible. The first we have already noticed—eclipsing variables. The second is the type of star known as a spectroscopic binary, which is nothing more than an eclipsing variable which does *not* vary because the plane of the components' orbits does not pass near the earth, and consequently no eclipses are observed. The spectrum of such a star exhibits a periodic shifting or doubling of its lines, indicating that the star is alternately approaching and receding from the earth. This in turn indicates that it is travelling in an orbit about an invisible companion.

If, however, the components are much farther apart than those of either spectroscopic or eclipsing binaries, it becomes possible to detect them by direct vision: what appears to the naked eye to be a single star is seen in the telescope or binoculars to be a close pair of stellar points. Whereas the revolution periods of spectroscopic binaries are short (in some cases as short as one day), the components being relatively close to each other, the periods of visual binaries are not shorter than several years and as often as not are several centuries or even millennia. Many binaries which repay scrutiny with binoculars are listed in Appendix 2.

The Life and Death of a Star

Our knowledge of stellar evolution is still in the speculative stage, and the following account (though the completest yet proposed) is known to be inadequate in certain important respects.

In its early youth a star is a giant of immense volume, low temperature and low density—a gigantic, super-inflated bubble of 'cool' gas. It can be demonstrated that such a body will contract, and that in doing so it will grow increasingly hotter. At a certain point in this process of contraction and rising temperature, however, the material of the star will become too dense to behave any longer as a gas, and thenceforward contraction will be accompanied by falling temperature. In the advanced stages of senile decrepitude the star will be a low-temperature dwarf; its size that of a planet but its mass that of a star. Finally it will cease to be incandescent and will ultimately cool entirely. As a star it will be 'dead'.

Thus in infancy a star is large and cool, at maturity medium-sized and very hot, in old age small and cool.

The sun appears to have progressed about half way along this road to extinction. The constant stream of energy that it is pouring out into space in all directions is costing it over four tons every second. But so vast a body is it that it could continue to lose mass at this rate for 15 million years to come, or 50,000 times as long as there has been life on this planet.

Chapter 7

THE GALAXY, STAR CLUSTERS AND NEBULAE

Is Space Full of Stars?

Every increase in telescopic power shows fainter and fainter stars, banking up in apparently endless perspectives of ever greater remoteness. Nevertheless, the stars do not go on for ever. On the contrary, all the stars that we can see with the naked eye or with the most powerful telescope belong to a single, finite system, or—if we like to regard it as such—gigantic star cluster beyond whose limits lies 'empty space'.

The Milky Way

To the naked eye the Milky Way appears as a luminous band with ill defined edges, which encircles the entire star sphere. Telescopic study—and still more, telescopic photography—shows that it consists of myriads of faint stars which are crowded so closely together that their integrated light appears as a faint luminosity. This apparent crowding together of stars in the Milky Way is only partly due to real crowding in space, and is primarily dependent on the fact that in the plane of the Milky Way the thickness of stars—or the distance to the edge of the system—is greater than in the direction at right angles to it. In other words the Galaxy of stars is a flattened structure whose major axis is many times longer than its minor axis. Stand a dinner plate on a table and place another plate upside down upon it, and you will gain a fair idea of what the stellar system would look like from outer space.

The Size of the Galaxy

All the figures here given are necessarily approximate and liable to revision, though probably not drastic revision. The major axis, or diameter, of the 'plate' is some 300,000 light years, and the sun is situated near the central plane (since the Milky Way divides the star sphere into two nearly equal portions), about 40,000 light years from the centre of the system; the minor axis or thickness of the Galaxy is probably not greatly in excess of 6,000 light years. All the stars visible to the naked eye lie within 3,000 light years of the sun, showing how small a section of the star system is visible without instrumental aid.

The mass of the Galaxy has been variously estimated as from 30 to 300 thousand million times that of an average star, such as the sun. The whole of this stupendous conglomeration of stars is in rotation about its minor axis, one revolution being completed in something like 300 million years.

Nebulae and Clusters

The careful searcher of the skies, especially if he is armed with binoculars or a small telescope, will notice many faint and ill defined patches of light resembling flecks of luminous mist, or minute detached portions of the Milky Way. These may either be vast and distant clouds of glowing gas, known as nebulae, or else clusters of stars whose components are too faint to be distinguished individually. A few of these clusters are near enough to the sun for their individual stars to be well separated and their true nature discerned with quite small instruments or even with the naked eye.

The Galactic or Open Clusters

The Pleiades is one of the brightest and angularly largest of this type of cluster, most of which are invisible without instrumental aid. They are irregular in shape and usually contain several hundred or thousand comparatively bright stars, well separated from one another. They are therefore well suited for observation with small instruments, and many examples are included in Appendix 2.

As their name indicates, they occur most commonly in or near the Milky Way. The brighter clusters are from 100 to

1,000 light years distant, but the majority are between 1,000 and 15,000 light years.

Globular Clusters

A typical globular cluster contains many thousands of faint stars which are condensed so strongly towards the centre of the cluster that even in large telescopes their individual images fuse into an undifferentiated blur of light. They are spherical in shape, great globes filled with stars, and in large instruments are among the most spectacular and gorgeous objects in the heavens.

The globular clusters are all very remote and therefore faint (the brightest are only just visible to the naked eye); the nearest is some 20,000 light years distant and the farthest about ten times as remote as this. They all appear to be of pretty much the same size, having diameters of about 100 light years, though the highly condensed central region is usually not more than five light years across.

Galactic or Gaseous Nebulae

Diffuse, irregular, structureless wisps or clouds of shining gas, occurring chiefly in the Milky Way region. Every conceivable shape, form and size is exhibited by these objects. They are comparatively near to the sun, their distances normally being measured in hundreds of light years. It is improbable that they are self-luminous, and were it not for the high temperature stars that are always found involved in them they would be invisible. Their density is inconceivably low: that of the great Orion nebula, visible to the naked eye and one of the grandest examples of its class, probably does not exceed one-millionth of the most perfect laboratory-produced vacuum!

Planetary Nebulae

In appearance totally unlike the diffuse galactic nebulae, they are so called because their telescopic appearance is reminiscent of that of a planet. They are small, circular, well defined discs of nebulous light, and high magnifications show that there is usually—probably always—a high temperature star (30,000°–50,000°) at their centre. Though they look like flat discs they are actually globes of rarefied gas. About 130 are known; they are mostly faint and unsuitable for observation with binoculars. The distance of the nearest is about 300 light years. The lines of oxygen, hydrogen and helium have been identified in their spectra.

Dark Nebulae

These are clouds of gas, identical with the bright diffuse nebulae but for the fact that they possess no involved stars bright and hot enough to illuminate them. They are therefore dark instead of bright, and can only be seen when silhouetted against the bright background of the Milky Way. They were at one time thought to be 'holes' or starless lanes running through the Galaxy but it has now been established that they are obscuring masses.

The Extragalactic Nebulae

All the objects so far described belong to the stellar system of which the sun is a member. But although space beyond the confines of the Galaxy is largely 'empty' it nevertheless contains many millions of nebulae at distances ranging from under a million to 500 million light years—the latter being the farthest that our giant telescopes can reach. Despite the vast numbers of extragalactic objects that are known to exist, space remains to all intents and purposes empty—frighteningly so, perhaps—and they are on the average one million light years apart.

It appears that some of the extragalactic nebulae are gaseous like the galactic nebulae, though of course incomparably larger. Such nebulae are spherical or elliptical in shape and appear to be quite structureless. Others, however, are resolvable (at any rate partially) into separate stellar points by long-exposure photography in conjunction with large telescopes, and the exemplars of this type also have a characteristic spiral structure, somewhat like that of a Catherine wheel. This fact of the stellar resolution of some of the spirals, together with their

sizes (deduced from their apparent sizes and their known distances), indicates that they are galaxies of stars similar to our own: island universes. An observer in one of these would describe our Galaxy as an 'extragalactic nebula'. This conclusion is borne out by the determinations of the masses of some of the nearer spirals, the results obtained ranging from 500 to 1,000 million times that of the sun.

Not the least intriguing feature of the island universes is the fact that they appear to be scattering helter-skelter in all directions, like fragments of some celestial H.E. bomb. The more distant an extragalactic nebula, the greater its velocity of recession. One of the most distant that has yet been investigated is hurtling away from us at a speed of 26,000 miles per second. An alternative to the 'bomb fragment' explanation of this universal recession of the extragalactic nebulae (including the Galaxy) supposes that they are not so much flying *through* space as being carried apart by the expansion of space itself.

As might be expected, considering their vast distances, the extragalactic nebulae are faint objects, only one being visible to the naked eye. This is the great spiral nebula in Andromeda (see p. 78), which owes its relative brightness and apparent size to its nearness, for it is only (!) about one million light years from the sun.

Appendix 1

SUMMARY OF DATA RELATING TO THE SUN, MOON, AND PLANETS

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Planet	*Sym-bol*	*Mean Solar Distance (miles)*	*Period of Revolution* (*days*)	*Period of Revolution* (*years*)	*Maximum Distance from Ecliptic*	*Angular Equatorial Diameter*
Mercury	☿	35,950,000	87·97	0·241	7° 0′ 12″	4″·7 –12″·9
Venus	♀	67,180,000	224·70	0·615	3° 23′ 38″	9″·9 – 64″·0
Earth	⊕	92,870,000	365·26	1·000	—	—
Mars	♂	141,500,000	686·98	1·881	1° 51′ 1″	3″·5 –25″·1
Ceres	⚳	257,000,000	1,681·45	4·603	10° 36′ 56″	0″·27–0″·69
Jupiter	♃	483,200,000	4,332·59	11·862	1° 18′ 28″	30″·5–49″·8
Saturn	♄	885,900,000	10,759·20	29·458	2° 29′ 29″	14″·7–20″·5
Uranus	♅	1,782,000,000	30,685·93	84·014	0° 46′ 22″	3″·4–4″·2
Neptune	♆	2,793,000,000	60,187·64	164·788	1° 46′ 38″	2″·2– 2″·4
Pluto	♇	3,670,000,000	90,600	247·7	17° 9′ 0″	Nil
Sun	☉	—	—	—	—	31′ 59″ (mean)
Moon	☽	238,857 (from ⊕)	27d. 7h. 43m. 11·5s.		5° 8′	31′ 5″ (mean)

(1)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Planet	*Dia-meter (miles)*	*Mass (⊕=1)*	*Volume (⊕=1)*	*Period of Axial Rotation*	*Sur-face Grav-ity (⊕=1)*	*Stellar Magnitude*	*Num-ber of Moons*
Mercury	3,125	0·04	0·06	? 88d.	0·27	−1·2 to +1·1	0
Venus	7,750	0·81	0·92	?	0·85	−4·3 to −3·3	0
Earth	7,963	1·00	1·00	23h. 56m. 4·1s.	1·00	—	1
Mars	4,231	0·11	0·15	24h. 37m. 22·6s.	0·38	−2·8 to +1·6	2
Ceres	488	? 0·000125	0·0002	?	? 0·04	7·1	—
Jupiter	87,225	316·94	1312	9h. 50m.– 9h. 55m.	2·64	−2·5 to −1·4	9 (? 11)
Saturn	71,937	94·9	734	10h. 14m.– 10h. 39m.	1·17	−0·4 to +1·2	9 (? 10)
Uranus	31,875	14·66	64	10h. 45m.	0·92	5·7	4
Neptune	31,250	17·16	60	? 15h.–16h.	1·12	7·6	1
Pluto	? 4000	? 0·6	?	?	?	13–15	? 0
Sun	864,100	331,950	1,300,000	24d. 15h. 36m. (equatorial)	27·89	−26·7	—
Moon	2,160	0·012	0·02	27d. 7h. 43m.	0·16	−12·5 (Full)	—

Notes

Column (6): Gives the inclination of each planet's orbit to the ecliptic.

Column (7): Explains why no planet save Jupiter and Venus in the crescent phase presents a sensible disc to small instruments such as field glasses. 1″ is the angle subtended by a halfpenny at a distance of 3½ miles.

Column (12): These figures depend upon the mass of the planet and also upon its radius.

Column (13): Gives the apparent brightness of the sun, moon, and planets expressed in terms of the Stellar Magnitude scale (see p. 56). Roughly speaking, the brightest stars visible to the naked eye are magnitude 1, and the faintest magnitude 6. A star as much brighter than a first magnitude star as the latter is than a second magnitude star would be magnitude 0. Similarly a star as much brighter than a magnitude 0 star as this is than a sixth magnitude star will have a magnitude of -6. And so on. Thus it can be seen from Column (13) that of the major planets, only Pluto is invisible with binoculars, although Neptune is invisible to the naked eye and Uranus only just visible.

Column (14): The discoveries of the 10th and 11th satellites of Jupiter and the 10th satellite of Saturn have not been confirmed. It is thought unlikely that Pluto has a satellite, though even if it had, no instrument at present in existence would be capable of showing it.

Appendix 2

THE CONSTELLATIONS

How to Find the Constellations

The four maps which follow these notes show the appearance of the night sky at midnight on the first day of January, April, July, and October, and on the other dates and times as stated. It will be noticed (*a*) that the constellations change with the seasons, as explained on p. 16, and (*b*) that the north and south points of each map are respectively at top and bottom, the east and west points on the left and right. To use one of the maps, therefore, it is most convenient to hold it above the head and to look up at it, facing south, when it will be correctly oriented.

Suppose the date is early January and the time midnight, and the reader wishes to identify the constellations that are visible. Using the appropriate map in the way described above, first find the Plough, which the map shows is situated in the north-east sky. This star group is easily recognized and is always visible, being circumpolar; it is therefore a useful starting point for celestial explorations at any time of the year. The map shows that south of the Plough—i.e. in the south-east sky—lies Leo; this, with its first magnitude Regulus, will be spotted without difficulty. Carrying the eye westwards from Leo, the twin first magnitude stars Castor and Pollux of the constellation Gemini will be seen. Closely south-west of these is the striking constellation of Orion, with Sirius, the brightest star in the firmament, to the south-east (i.e. to the left of and lower in the sky than Orion). Thence Auriga and the W-shaped Cassiopeia can be located. In this way more and more constellations are identified, the brighter and more conspicuous ones first and the fainter ones filled in afterwards.

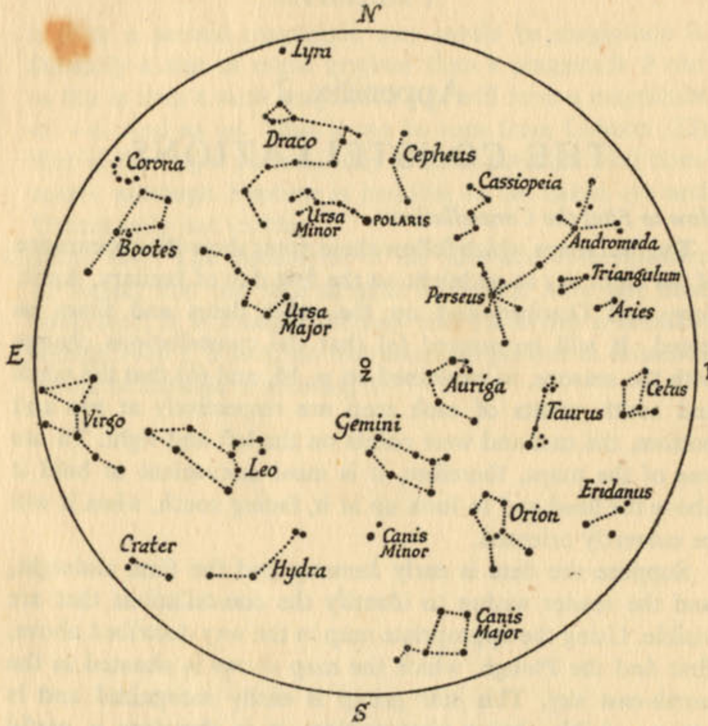


FIGURE 6

January 1st, 12 p.m.; February 1st, 10 p.m., etc.

Thus the entire dome of heaven can be covered, and even the complete beginner will find that after an hour's observation of this sort he will have familiarized himself with the appearance or 'shape' of the dozen or so bright constellations visible at the time. The procedure at any time of the year or any hour of the night is precisely the same.

Once this much has been achieved, the amateur astronomer will want to learn more about the constellations he has located. The seasonal star maps are accordingly followed by details of a large number of objects in each constellation which are of particular interest to observers with binoculars

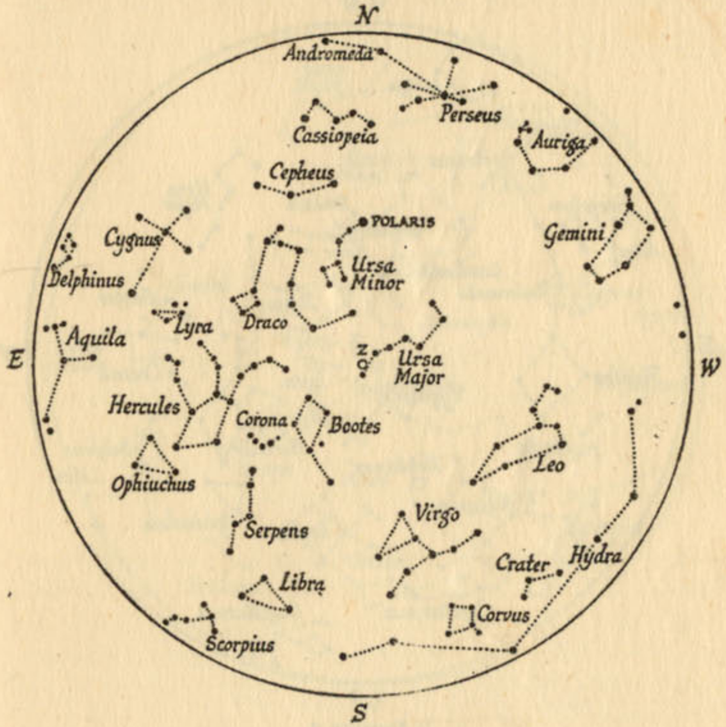


FIGURE 7

April 1st, 12 p.m.; May 1st, 10 p.m., etc.

and the naked eye, together with larger scale maps of each constellation.

Stellar Nomenclature

The brighter stars of each constellation are designated by a Greek letter followed by the name of the constellation in the genitive case. Thus the brightest star in Orion is α Orionis ($=\alpha$ of Orion). When the Greek alphabet is exhausted in any constellation, the nomenclature of its stars is carried on with Arabic numerals. Variable stars are normally designated by capital letters—e.g. R Andromedae, SU Cassiopeiae, etc.

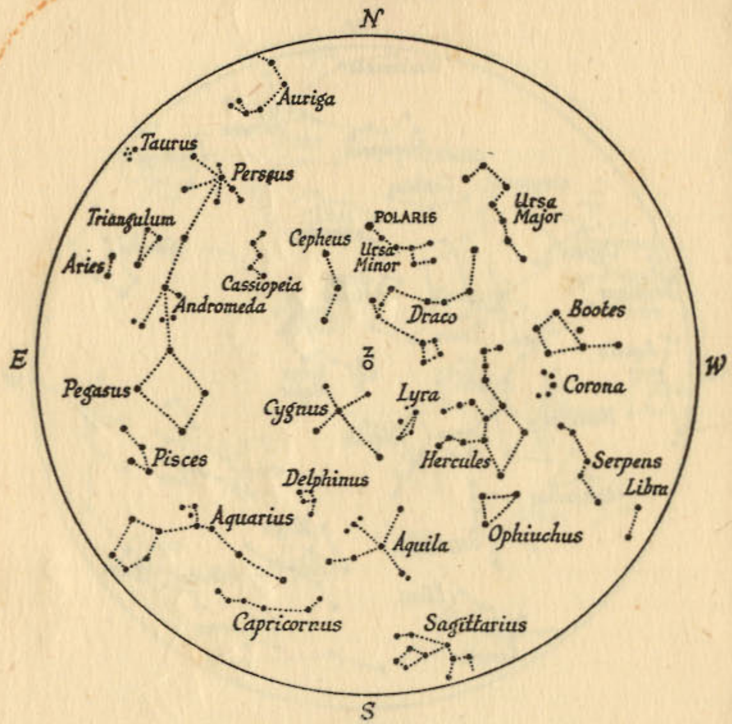


FIGURE 8

July 1st, 12 p.m.; August 1st, 10 p.m., etc.

The Greek alphabet runs as follows:

alpha	α	iota	ι	rho	ρ
beta	β	kappa	κ	sigma	σ
gamma	γ	lambda	λ	tau	τ
delta	δ	mu	μ	upsilon	υ
epsilon	ϵ	nu	ν	phi	ϕ
zeta	ζ	xi	ξ	chi	χ
eta	η	omicron	o	psi	ψ
theta	θ	pi	π	omega	ω

Nomenclature of Nebulae and Clusters

The two standard catalogues of these objects are (*a*) the catalogue of 103 nebulae and clusters compiled by Messier in

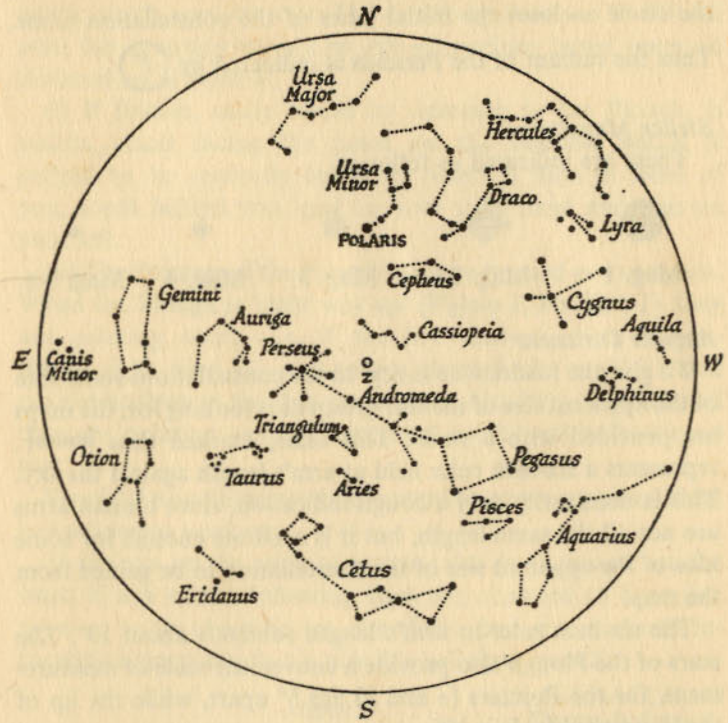


FIGURE 9

October 1st, 12 p.m.; November 1st, 10 p.m., etc.

1758, (*b*) the New General Catalogue of Sir John Herschel, published in 1888. A nebula or cluster is known by its number in either of these catalogues, preceded by M. in the case of the former and N.G.C. in the case of the latter. E.g. M.81, N.G.C.4254, etc.

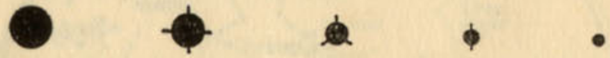
Meteor Radiants

These are marked on the constellation maps by a circle enclosing the Greek letter designating the radiant. Thus the position of the radiant of the ζ Bootids is indicated by (ζ).

Where the shower does not take the name of an individual star, the circle encloses the initial letter of the constellation name. Thus the radiant of the Perseids is indicated by (P).

Stellar Magnitudes

These are indicated as follows:



Mag. 1 Mag. 2 Mag. 3 Mag. 4 Mag. 5-6

Angular Distances

To give the reader who is new to the constellations some idea of the apparent size of the star group he is looking for, the maps are provided with a scale. This scale, marked thus |▬▬|, represents a six-inch ruler held at arm's length against the sky. This is necessarily only a rough indication, since human arms are not all the same length, but it is accurate enough for some idea of the apparent size of the constellation to be gained from the map.

The six-inch ruler at arm's length subtends about 13°. The stars of the Plough also provide a convenient scale of measurement, for the Pointers (α and β) are 5° apart, while the lip of the 'saucepan' (α–δ) is 10°.

The degree is divided into 60′ (minutes) and each minute into 60″ (seconds). Two stars which are about 30″ apart (1/1200 of the distance from α to δ Ursae Majoris) can just be separated with good binoculars; this is the angle that a halfpenny subtends at about 200 yards.

Finding One's Way by the Stars

This is a qualification which may nowadays be of value to any able-bodied man or woman, and the following notes may therefore be of interest.

Unless clouds obscure the sky, no-one who has even a nodding acquaintance with the heavens can ever be lost at night, in the sense that he does not know whether he is facing

north, south, east, or west. The cardinal points can be defined with fair accuracy merely by eye estimations based upon an observation of Polaris:

(i) If Polaris, easily found by reference to the Plough, is visible, stand facing the point on the horizon which is judged to be vertically below it. North is then in front of you, south behind you, east on your right hand and west on your left.

(ii) The Pointers of the Plough can also be used as a compass. When the Plough is 'right way up' (Figure 1, Position 1), they are pointing south—i.e. if the line through them is continued right over the star sphere through the zenith, it will cut the horizon at the due south point. Similarly, in Position 2 they are pointing west, in Position 3 north, and in Position 4 east.

Should the northern sky be obscured there are supplementary indications to work on:

(i) Objects on the celestial equator rise due east and set due west. If any of the following stars are observed to have just risen or to be about to set, therefore, they give accurate information upon which it is possible to orient oneself:

	Object	*Distance from Celestial Equator, in degrees*
Aquarius:	α (mag. 3)	1
	the 'Water Jar' (mags. 4)	within 2
Orion:	the Belt stars (mags. 2)	within 2
Cetus:	α (mag. 3)	4
	γ (mag. 3)	3
Procyon =	α Canis Minoris (mag. 1)	6
Head of Hydra including	α (mag. 3)	within 7
Virgo:	β (mag. 3)	3
	γ (mag. 3)	1
	ζ (mag. 3)	½
Serpens:	α (mag. 3)	7
	μ (mag. 3)	3
	η (mag. 3)	3

	Object	Distance from Celestial Equator, in degrees
Ophiuchus:	δ and ϵ (mags. 3)	within 5
	β (mag. 3)	5
Aquila:	α (mag. 1)	9
	δ (mag. 3)	3
	θ (mag. 3)	1
Pegasus:	θ (mag. 3)	6

Owing to the inclination of the ecliptic, the moon and planets are unreliable guides.

(iii) Orientation is also possible by many small indications which will not be lost upon the man or woman who is familiar with the constellations. For example, when Orion's belt is vertical it lies east-south-east; when at an angle of 45° with the horizon, due south; and when horizontal, west-south-west. Again, when the cross of Cygnus is lying on its side it is above the north-east horizon; when vertical with the horizon it marks the north-west.

With these indications the cardinal points can be determined at night within 10° easily. For more accurate purposes, as for marching on a bearing, tables have been compiled which give the compass bearings of representative bright stars at every hour of the year.[1]

Abbreviations

The following abbreviations are used in the lists of constellations and objects of interest:

M.C. (followed by date): Midnight Culmination, i.e. the approximate date on which the centre of the constellation lies on the meridian at midnight. This gives an indication of when each constellation should be looked for, i.e. whether it is a summer constellation, winter constellation, etc. The date of M.C. for each constellation is followed by the names and compass directions of adjacent constellations.

[1] W. A. Tilney, *Marching or Flying by Night Without a Compass* (Hugh Rees, 2s.).

L.Y.: light years.
Sp. bin.: spectroscopic binary.
L.P.V.: long period variable.
d.h.m.: days, hours, minutes.
⊙: the sun. Thus, 'Mass, 175⊙' means 'The mass of this star (or whatever it may be) is 175 times that of the sun'.
Mag.: stellar magnitude.

ANDROMEDA

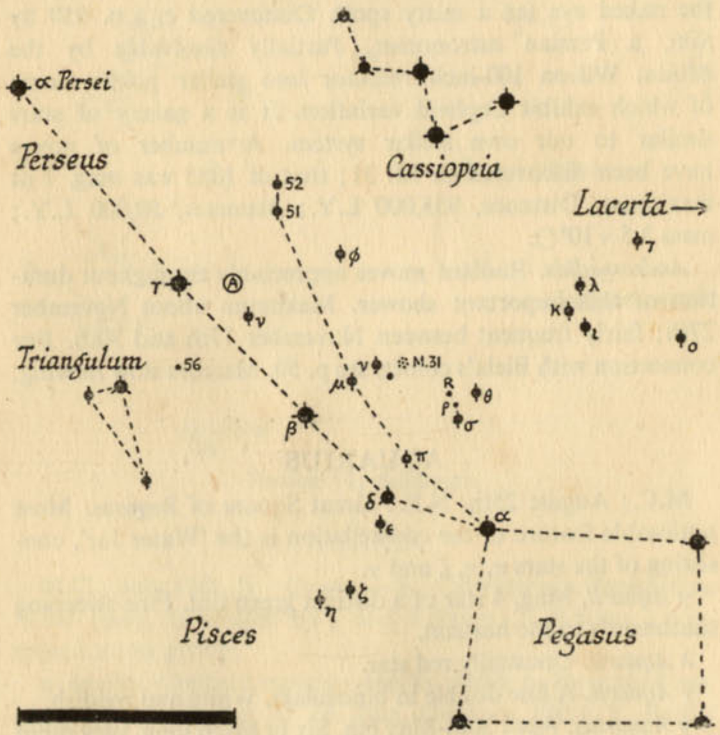


FIGURE 10. ANDROMEDA

M.C.: October 10th. N.: Cassiopeia—E.: Perseus—W.: Pegasus.

α Andromedae. Sp. bin.; luminosity, about 175⊙. Companion star is 'dark'; period, 97d.; mean distance from primary, some 20 million miles. Distance, about 116 L.Y.

56 Andromedae. Difficult double for binoculars. Mags. 6, 5·8; separation 181″.

R Andromedae. L.P.V. Alternately visible and invisible with binoculars: mag. 5·6–14·9. Period, 410d.

M. 31, N.G.C. 224. The Great Andromeda Nebula. Largest and brightest of the spirals, and the only one visible to the naked eye (as a misty spot). Discovered *c.* A.D. 950 by Sûfi, a Persian astronomer. Partially resolvable by the Mount Wilson 100-inch reflector into stellar points, some of which exhibit Cepheid variation. It is a galaxy of stars similar to our own stellar system. A number of novae have been discovered in M. 31; that of 1885 was mag. 7 at maximum. Distance, 935,000 L.Y.; diameter, 50,000 L.Y.; mass $3{\cdot}5 \times 10^9$⊙.

Andromedids. Radiant moves appreciably throughout duration of this important shower. Maximum about November 27th; fairly frequent between November 17th and 30th. For connection with Biela's comet, see p. 50. Meteors slow moving.

AQUARIUS

M.C.: August 25th. N.E.: Great Square of Pegasus. Most noticeable feature of the constellation is the 'Water Jar', consisting of the stars π, η, ζ and γ.

γ Aquarii. Mag. 4 star of a distinct green tint. Fine sweeping southwards to the horizon.

λ Aquarii. Unusually red star.

τ Aquarii. A fine double in binoculars. White and reddish.

γ Aquarids. April 30th-May 6th. Six or seven long, very rapid meteors per hour at maximum. Possibly associated with Halley's comet.

δ Aquarids. July 20th–August 25th, maximum about July 30th. Meteors typically long and slow moving.

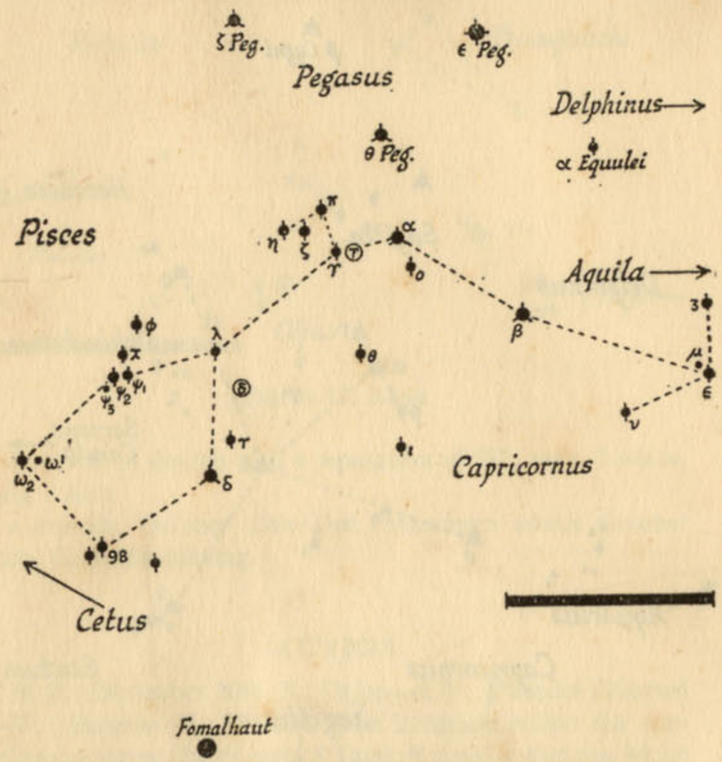


FIGURE 11. AQUARIUS

AQUILA

M.C.: July 15th. N.: Cygnus—S.: Capricornus, Sagittarius. Altair (mag. 1) flanked by γ and β (mags. 3, 4) form a conspicuous star group.

η Aquilae. Cepheid variable, totally visible to the naked eye. Mag. 3·7–4·5. Period, 7d. 4h. 14m. Distance, 650 L.Y. Radial velocity,[1] –9 m.p.s.

[1] The radial velocity of a star is its velocity of motion in the line of sight. A radial motion towards the earth is said to be negative, away from the earth positive. Thus 'radial velocity, –9 m.p.s.' means that the star is approaching us at a rate of 9 m.p.s.

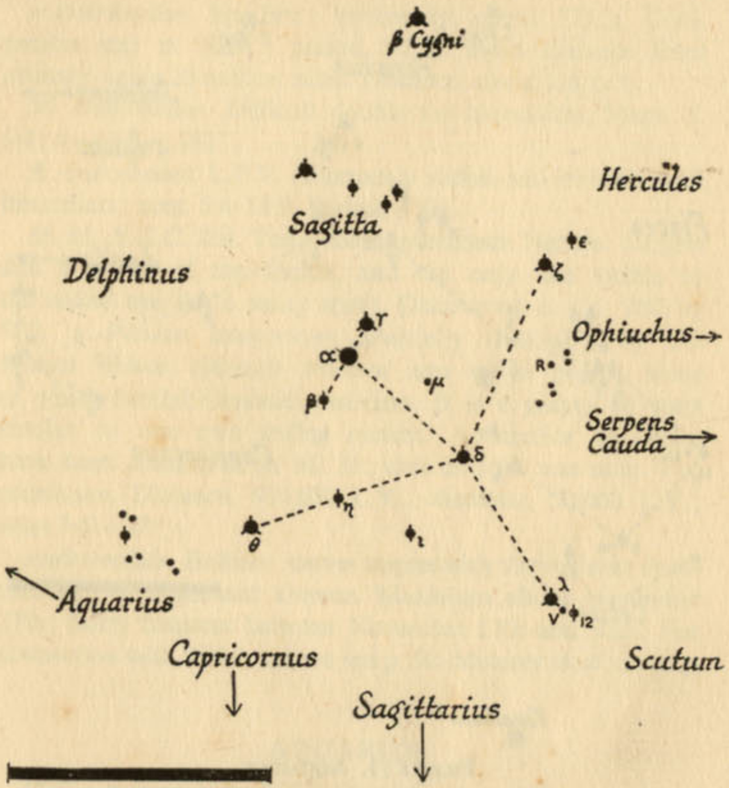


FIGURE 12. AQUILA

R Aquilae. L.P.V., visible with binoculars near maximum. Mag. 5·8–11·8. Period, 310d.

V Aquilae. A variable worth looking up on account of its intense red colour. Mag. 6·5 at maximum.

ARIES

M.C.: October 30th. N.: Triangulum, Andromeda—E.: Pleiades (Taurus)—W.: Pisces.

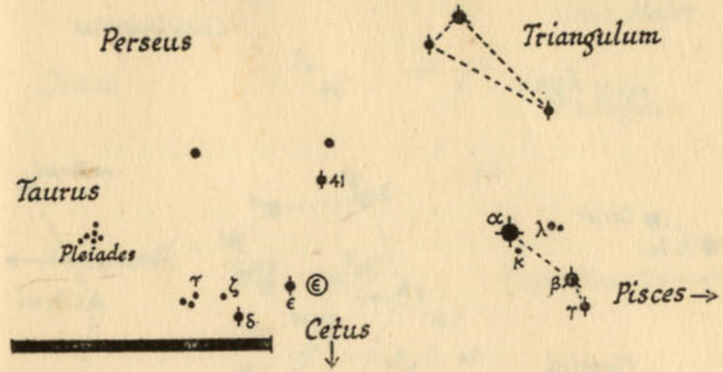


FIGURE 13. ARIES

λ Arietis. A double with a separation of 38″; mag. 5 white, mag. 8 blue.

ε Arietids. October 12th–23rd. Maximum about October 15th. Very slow moving.

AURIGA

M.C.: December 20th. S.: Orion—S.W.: Pleiades (Taurus) —W.: Perseus—E.: Gemini. Fine sweeping within the conspicuous curved line of stars, β Tauri, θ, β and α Aurigae, which terminates in the stellar triangle called the Kids.

α Aurigae. Capella, a fine yellow star, mag. 0·2, visible for part of every night of the year. Ptolemy (A.D. 150), Al Fagani (tenth-century Arab astronomer), and Riccioli all described Capella as red; it is possible that it has changed colour in quite recent times. Sp. bin.; period, 104d. Distance, 46 L.Y.; radial velocity, +19 m.p.s. Mass 5☉, diameter 9☉, luminosity 80☉ (approximate).

β Aurigae. Interesting sp. bin. Period, 3d. 23h. 2m.; diameters both 3☉; separation of centres of the two components, 7,650,000 miles; mass of A, 2·2☉; mass of B, 2·1☉; distance, 125 L.Y.

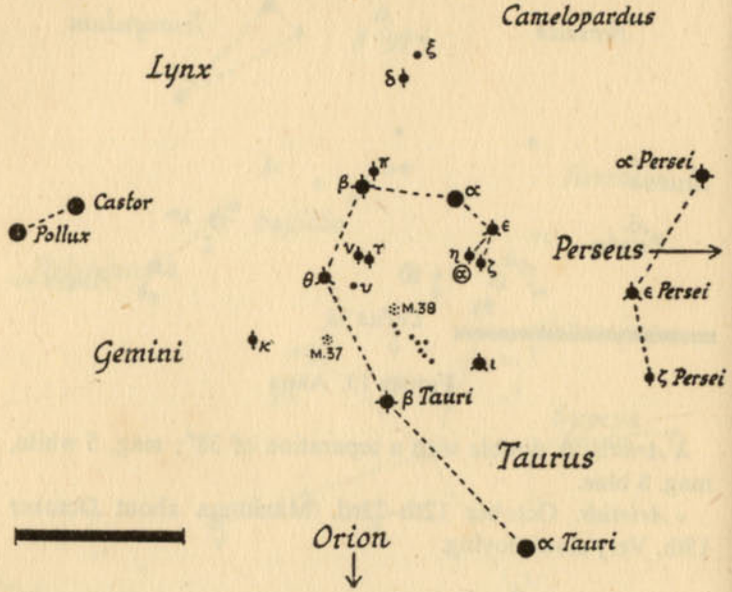


FIGURE 14. AURIGA

M. 37, N.G.C.2099. Fine open cluster, visible with good binoculars.

M. 38, N.G.C. 1912. A loose cluster, worth searching for with good glasses. Even if invisible, the sweeping hereabouts is very fine.

α Aurigids. February 5th–10th; very slow moving. A second shower of the same name from a near-by radiant occurs between August 12th and October 2nd; swift moving.

BOOTES

M.C.: May 1st. E.: Serpens, Corona—W.: Canes Venatici, Coma Berenices—S., S.W.: Virgo—N.: the Plough. α, ε, δ, β and γ outline a great kite flying the summer skies.

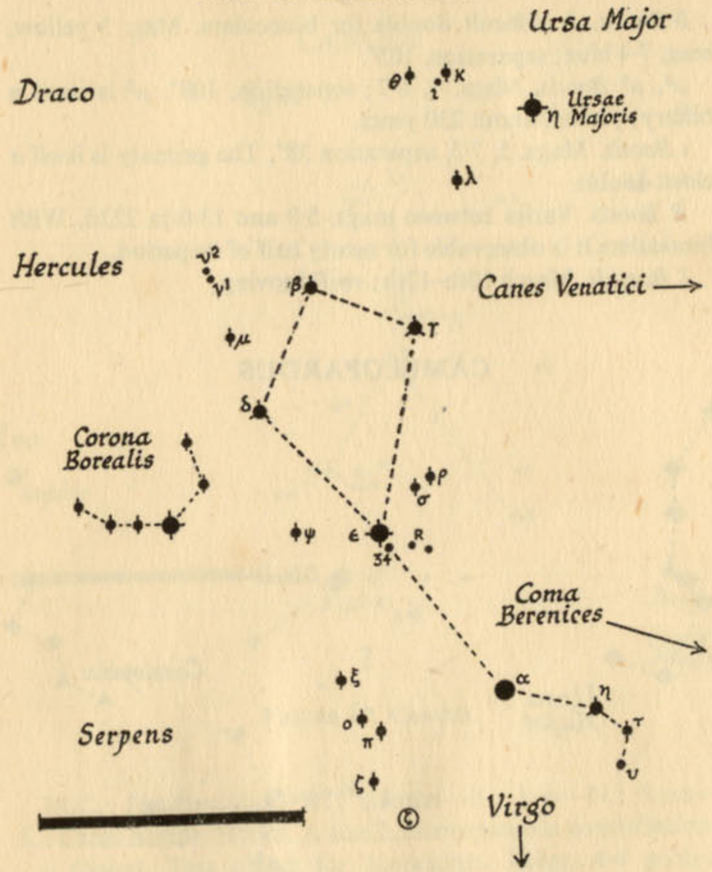


FIGURE 15. BOOTES

α Bootis. Arcturus, mag. 0·2, deep yellow; distance, 43 L.Y.; luminosity, 115☉; diameter, 25☉. Unusually large proper motion,[1] first noticed by Halley: 85 m.p.s., 3′ 50″ per century, or apparent diameter of moon since time of Ptolemy. Binoculars show several faint stars dotted round Arcturus.

[1] The proper motion of a star is its motion at right angles to the observer's line of sight.

δ *Bootis*. A difficult double for binoculars. Mag. 3 yellow, mag. 7·4 blue; separation, 105″.

μ^1, μ^2 *Bootis*. Mags. 4, 6·7; separation, 108″. μ^2 is itself a binary; period, about 230 years.

ι *Bootis*. Mags. 5, 7·5, separation 38″. The primary is itself a close double.

R Bootis. Varies between mags. 5·9 and 13·0 in 222d. With binoculars it is observable for nearly half of its period.

ζ *Bootids*. March 10th–12th; swift moving.

CAMELOPARDUS

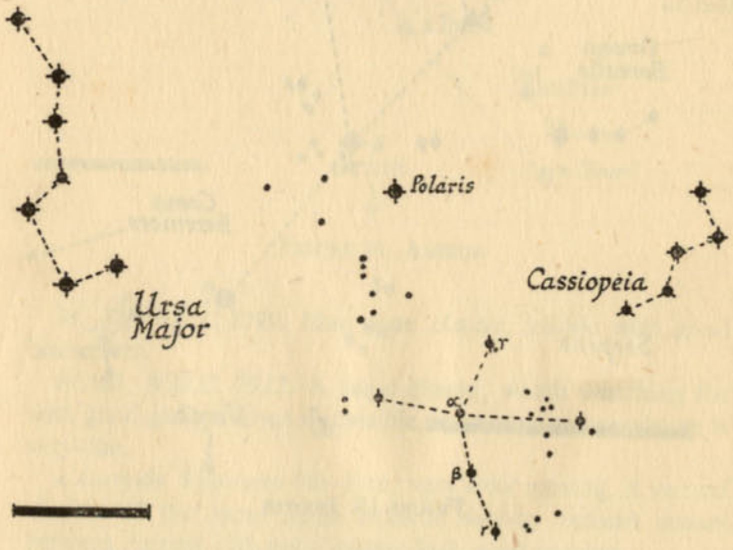


FIGURE 16. CAMELOPARDUS

A large, inconspicuous, circumpolar constellation, lying between Cassiopeia and Ursa Major, bounded on the south by Lynx, Auriga, and Perseus. Only six of the 150 stars visible to the naked eye are brighter than mag. 5.

CANCER

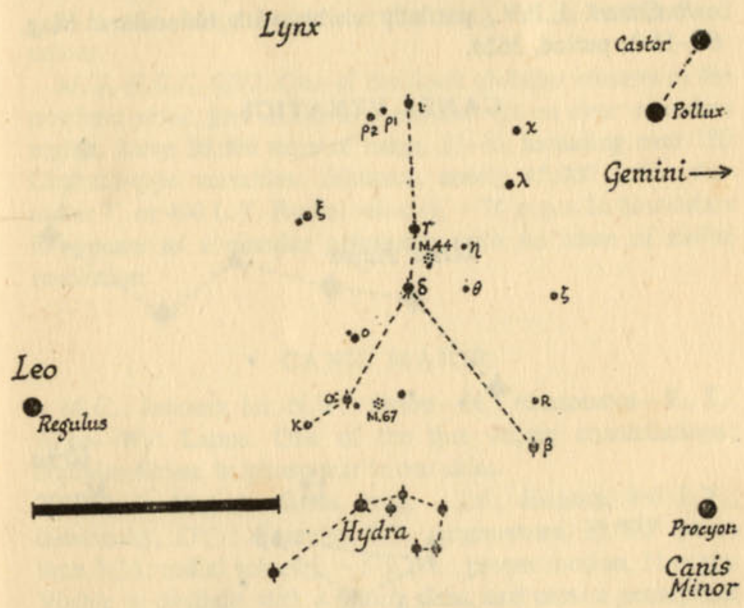


FIGURE 17. CANCER

M.C.: January 30th. W.: Gemini—E.: Leo—N.: Lynx—S.: Canis Minor, Hydra. A small, inconspicuous constellation.

ι *Cancri*. Test object for binoculars. Mags. 4·4 golden, 6·6 bluish-green; separation, 31″. Discovered by Herschel in 1782.

M. 44, N.G.C. 2632. The Praesepe, or Beehive Cluster. Visible to the naked eye as a misty spot. 500–600 stars (80 are visible with good glasses or the smallest telescope), yellowish and generally similar to the sun. Ideal object for binoculars. Distance, 450 L.Y.; diameter about 30 L.Y.

M. 67, N.G.C. 2682. Fine galactic cluster of some 500 stars (mags. 9–15), just visible as a nebulous spot in binoculars.

Diameter about $\frac{1}{2}°$, equivalent to 20 L.Y. at its estimated distance of 2,700 L.Y.

R Cancri. L.P.V., partially visible with binoculars. Mag. 6·2–11·2; period, 362d.

CANES VENATICI

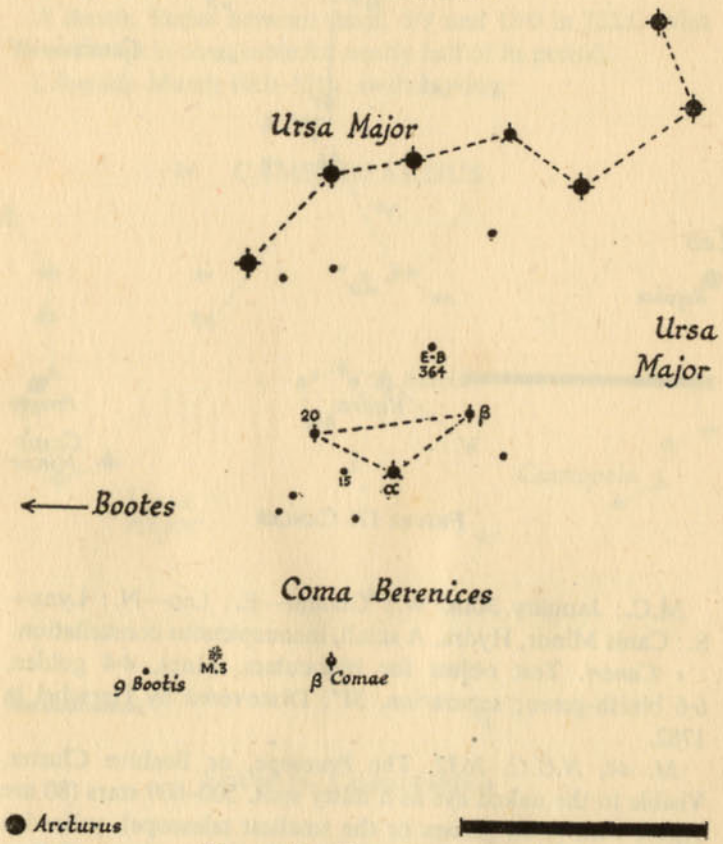


FIGURE 18. CANES VENATICI

M.C.: April 7th. N.: the Plough—E.: Bootes—W.: Ursa Major—S.: Coma Berenices.

15 Canum Venaticorum. Test object for binoculars. Mags. 5·5, 6; separation, 290″.

E–B. 364. Mag. 5 star worth finding for its brilliant red colour.

M. 3, N.G.C. 5272. One of the finest globular clusters in the northern skies: just visible to the naked eye on clear moonless nights. Some 30,000 stars of mags. 11–16, including over 130 Cepheid-type variables. Distance, nearly 45,000 L.Y.; diameter 7′, or 490 L.Y. Radial velocity, –78 m.p.s. In binoculars it appears as a circular nebulosity with no trace of stellar resolution.

CANIS MAJOR

M.C.: January 1st. N.W.: Orion—N.: Monoceros—E., S.: Argo—W.: Lepus. One of the fine winter constellations; contains Sirius, brightest star in our skies.

α Canis Majoris. Sirius, mag. –1·6; distance, 8·6 L.Y.; luminosity, $27\odot$; diameter, $2\odot$; temperature, 20,000° (more than $3\odot$); radial velocity, –5 m.p.s.; proper motion, 11 m.p.s. Visible in daylight with a $\frac{1}{2}$-inch glass, and casts a perceptible shadow on moonless nights. One of the most interesting binaries in the sky; its white dwarf companion was discovered in 1862 by Alvan Clark while testing a new $18\frac{1}{2}$-inch objective. Following are some of the data of Sirius B: mag. 8·4; separation from Sirius A, 2″–11″; period, 48 years; brightness, 0·0001 times Sirius A; size, about 3 times earth; mass, 250,000 times earth, 0·4 times Sirius A; density, $36{,}000\odot$, i.e. 5,000 times as dense as lead or 60,000 times that of water. In other words, 1 cubic inch of the matter of Sirius B weighs a ton, and although its diameter is only about 26,000 miles it contains approximately as much matter as the sun (diameter = 864,000 miles).

ν Canis Majoris. Triple; a beautiful sight in binoculars.

22 Canis Majoris. Compare the red tint of this mag. 3·5 star with the near-by ε (white).

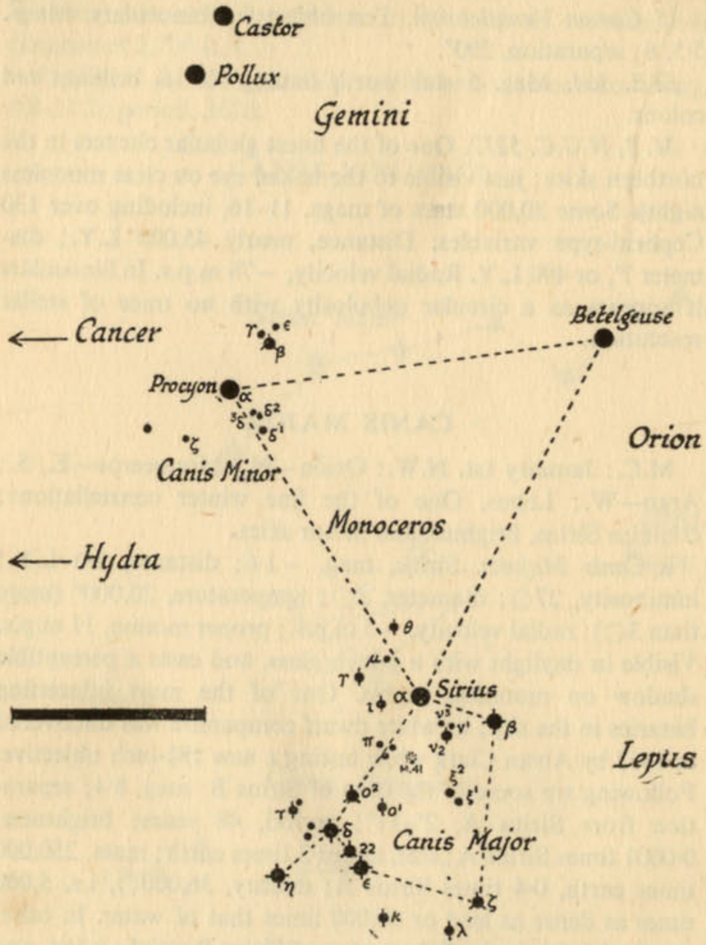


FIGURE 19. CANES MAJOR AND MINOR

δ Canis Majoris. Note the train of faint stars curling round this star towards o^1 and o^2. Fine sweeping hereabouts.

M. 41, N.G.C. 2287. A very fine cluster, visible to the naked eye 4° south of Sirius. Even binoculars show it as a wonderful object.

CANIS MINOR

M.C.: January 15th. W.: Orion—N.: Gemini—N.E.: Leo. A small constellation distinguished by the first magnitude Procyon.

α Canis Minoris. Procyon, mag. 0·4; a lovely, deep yellow star. Luminosity, 7☉; radial velocity, −2 m.p.s.; proper motion, 2′ per century. A binary system in some ways resembling that of Sirius. Procyon B, discovered by Schaeberle in 1896, is only visible in moderately large telescopes; mag. 14, separation 44″.

	A	*B*
Brightness:	5☉	0·0003☉
Weight:	0·25☉	0·3–0·25☉
Period:		39 yrs.

β Canis Minoris. Mag. 3. Binoculars show two faint companions, one noticeably reddish.

CAPRICORNUS

M.C.: August 8th. 20° N.: Delphinus—W.: Sagittarius—E., N.: Aquarius. A somewhat inconspicuous constellation.

α Capricorni. Naked eye double, α^1 and α^2 (mags. 3, 4) being separated by 6′ 16″. Their similar yellow tint and almost equal brightness render them a striking pair in binoculars. α^1 has a companion star 45″ distant, and α^2 a mag. 11 comes which is itself a close double. α^1 is estimated to be 1,600 L.Y. distant; radial velocity, −16 m.p.s. α^2 is much nearer the sun—about 108 L.Y.

β Capricorni. Mags. 3·3 orange, 6·2 blue; separation, 205″. Easy with binoculars. Distance about 465 L.Y.

M. 30, N.G.C. 7099. Globular cluster near 41 Capricorni (mag. 5·5). Tiny nebulous spot in binoculars.

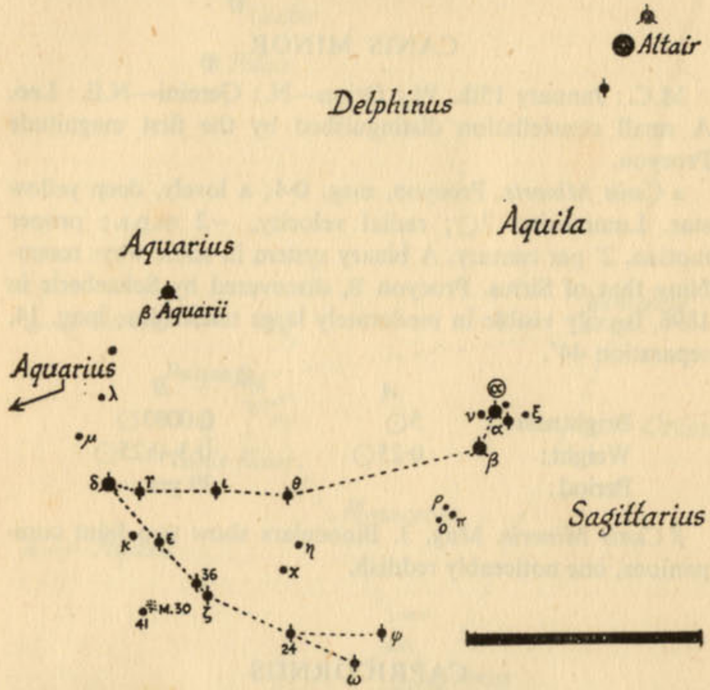


FIGURE 20. CAPRICORNUS

α Capricornids. July 18th–August 4th; maximum, about July 24th. Connected with comet 1881 V. Meteors long, bright and slow moving.

CASSIOPEIA

A circumpolar constellation lying 'across' the north celestial pole from Ursa Major and at about the same distance from Polaris as the Plough. Its characteristic M or W shape renders it easy to identify.

α Cassiopeiae. Severe test object for binoculars. Mag. 2 reddish, mag. 9 blue; separation, 62″. Primary an irregular variable, period about 80d., mag. 2·2–3·1.

γ Cassiopeiae. Even more difficult. Mags. 2, 9; 432″. Distance about 148 L.Y.

ζ Cassiopeiae. Lies in a beautiful field.

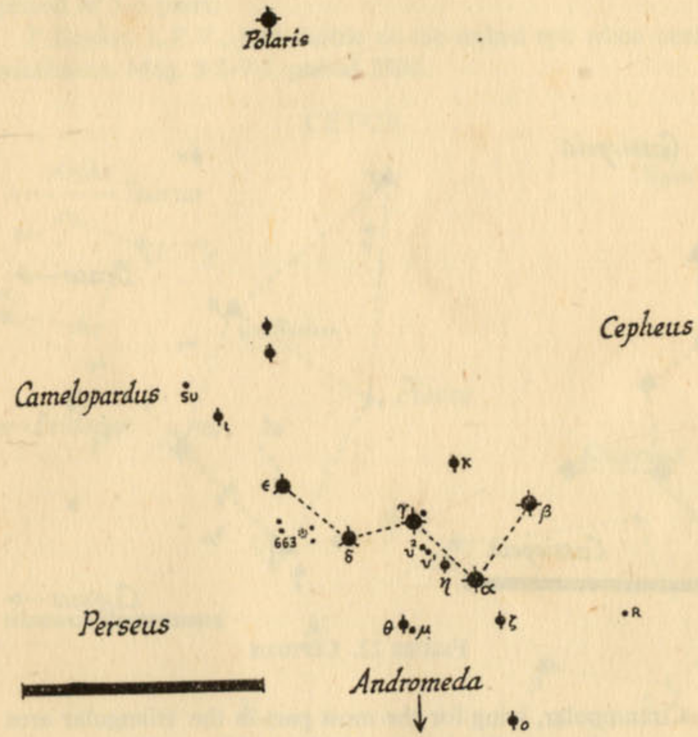


FIGURE 21. CASSIOPEIA

R Cassiopeiae. L.P.V. of striking deep red colour; mag. 5–12; period, 430d.

SU Cassiopeiae. Cepheid, entirely visible with binoculars. Mag. 5·9–6·3; period, 1d. 22h. 48m.

N.G.C. 663. Telescopically a fine galactic cluster; visible in binoculars.

CEPHEUS

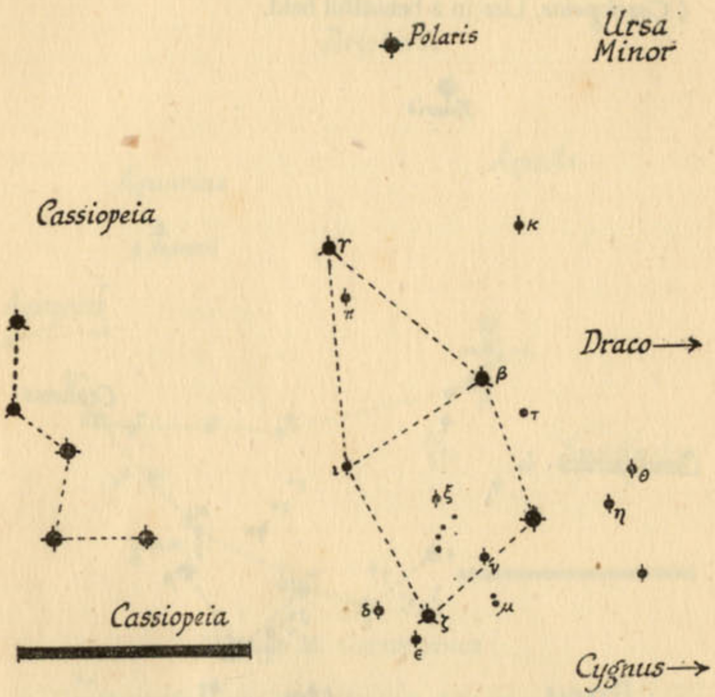


FIGURE 22. CEPHEUS

Circumpolar, lying for the most part in the triangular area between Cygnus, Cassiopeia, and Ursa Minor. Uninteresting to the naked eye but fine binocular sweeping, especially between ι and α and the Milky Way.

δ *Cephei.* Type star of the Cepheid variables (see p. 58). δ is actually an easily separated double (41″), the yellow primary being the variable. Mag. 3·6–4·3; period, 5d. 8h. 48m. Comes mag. 7·5 bluish. Having a comparison star so near makes the fluctuating brightness of δ all the more easily observed. Distance about 295 L.Y.

μ *Cephei.* A variable of unusually deep red colour, more noticeable with binoculars or a small telescope than with the naked eye; comparison with the white α Cephei emphasizes its red tint. μ varies irregularly between mags. 3·7 and 4·7 in a period of 5–6 years.

T Cephei. L.P.V., just visible to the naked eye when near maximum. Mag. 5·2–9·5, period 390d.

CETUS

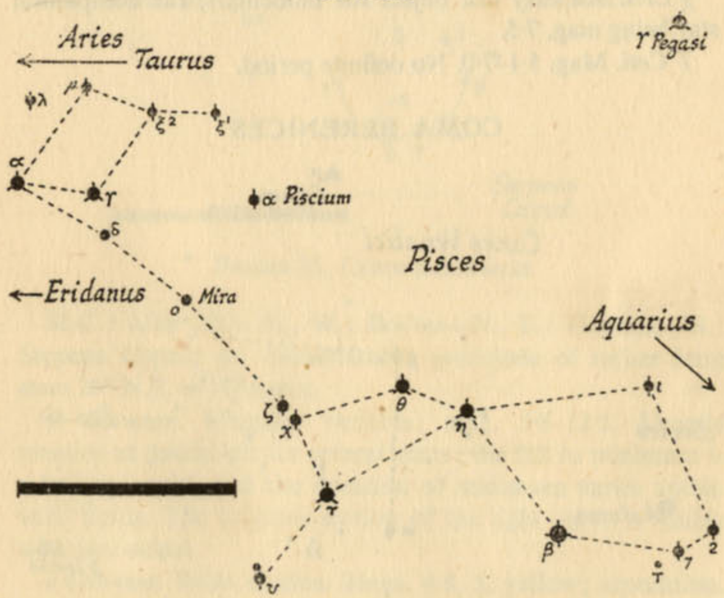


FIGURE 23. CETUS

M.C.: October 15th. W.: Pisces, Aquarius—N.: Aries—E.: Taurus, Eridanus. A straggling, inconspicuous constellation.

o Ceti. Mira, the 'Wonder Star'. A notable L.P.V. of a deep red tint, discovered by Fabricius in 1596. Both period (331d.) and range of variation (maximum 1·7–5, minimum 8·5–9·7) are irregular. Alternately visible to the naked eye for about six months and invisible for about five months, but the whole of its fluctuation may be followed with binoculars. Duration of maximum is several weeks; waning occupies some eight months; the rise to maximum usually several weeks. Mira has a white dwarf companion, discovered in 1923 at a distance of 1″. Diameter of Mira A, about 400⊙; of Mira B, 0·04⊙. The primary is thus one of the largest stars yet investigated (surpassed only by Antares) and the comes one of the smallest. Distance, over 650 L.Y.; radial velocity about +40 m.p.s.

χ Ceti. An easy test object for binoculars, the companion star being mag. 7·5.

T Ceti. Mag. 5·1–7·0. No definite period.

COMA BERENICES

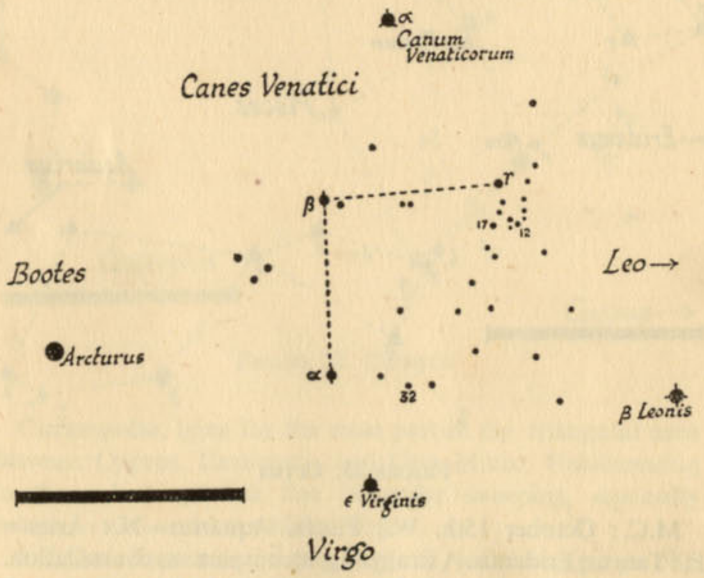


FIGURE 24. COMA BERENICES

M.C.: April 1st. W.: Leo—E.: Bootes—N.: Canes Venatici —S.: Virgo. A small constellation, inconspicuous to the naked eye but full of interest when swept over with binoculars.

12 Comae. Mags. 4·5, 8, yellow and bluish; separation, 66″.

17 Comae. A wide double: mags. 4·8, 6; separation, 145″.

32 Comae. A wide and faint double: mags. 5·6, 6; 195″.

CORONA BOREALIS

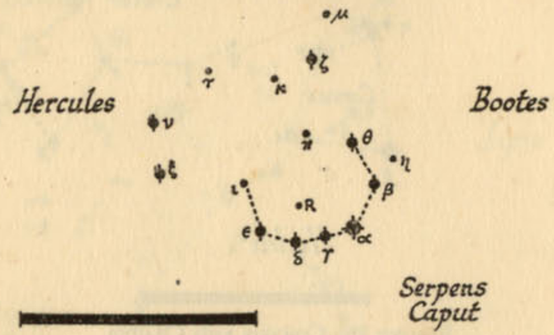


FIGURE 25. CORONA BOREALIS

M.C.: May 20th. N., W.: Bootes—N., E.: Hercules—S.: Serpens Caput. An unmistakable semicircle of rather faint stars 20° N.E. of Arcturus.

R Coronae. Irregular variable; mag. 5·8–12·5. Usually remains at maximum for several years; the fall to minimum is relatively rapid, and the duration of minimum varies within wide limits. The brighter section of the light curve is visible with binoculars.

ν Coronae. Wide double. Mags. 4·8, 5, yellow; separation, 370″.

CORVUS AND CRATER

CORVUS

M.C.: March 28th. N.: Virgo—S.: Hydra—18° N.E.: Spica (α Virginis).

ζ Corvi. Binoculars show a faint companion. Radial velocity of primary, −13 m.p.s.

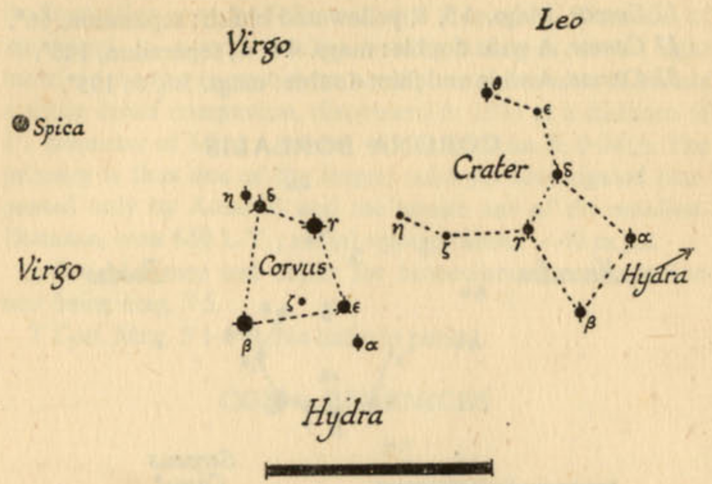


FIGURE 26. CORVUS AND CRATER

CRATER

A small and undistinguished constellation lying due west of Corvus. No objects of specific interest for observation with binoculars, but some attractive sweeping.

CYGNUS

M.C.: July 30th. W.: Lyra—E.: Pegasus. Might aptly be called the Northern Cross. Fine sweeping in this rich area of the Milky Way.

β Cygni. One of the most beautiful doubles in our skies. Mags. 3·2 deep yellow, 5·5 green; separation, 35″. Good binoculars held steady will split it, but the strikingly contrasted colours will not be obvious. Distance, some 160 L.Y.; radial velocity, −15 m.p.s.

o² Cygni. Wide triple: mags. 4, 5·5, 7·5; separation, 358″, 107″.

61 Cygni. The first star whose distance was measured (see p. 54): 10 L.Y. It is a binary, invisible as such with binoculars;

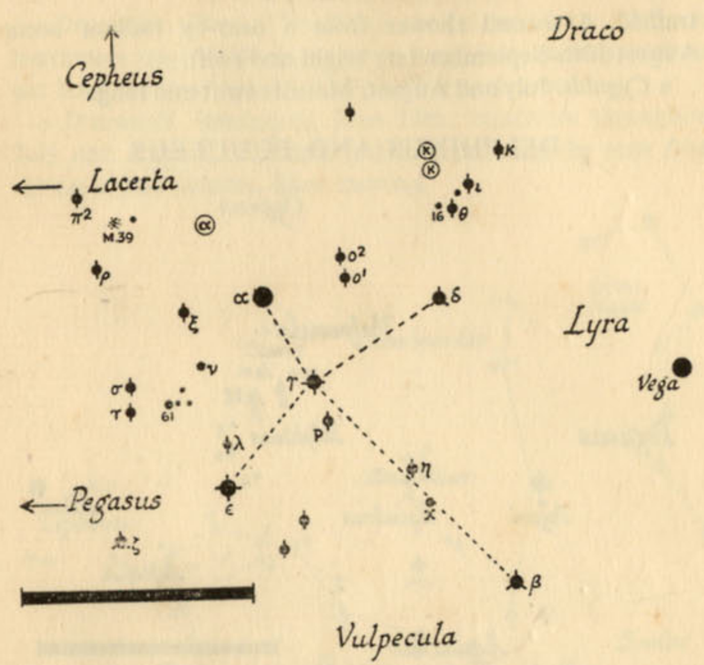


FIGURE 27. CYGNUS

period about 1,000 years. Abnormally large proper motion of 50 m.p.s., equivalent to 9′ per century. Easily picked up by binoculars with the help of the accompanying map, and worth finding for its historical interest.

16 Cygni. Inconspicuous double: mags. 5·1, 5·3; separation, 39″.

R Cygni. Red variable; mag. 6·0–13·9; period, 426d. Easily found at maximum close to *θ* Cygni. Radial velocity −21 m.p.s.

χ Cygni. L.P.V. of the Mira (*o* Ceti) type. Mag. 4·2–13·7, i.e. 9,500 times brighter at maximum than at minimum. Period, 410d.

M. 39, N.G.C. 7092. Fine open cluster, just visible to the naked eye when its position is known beforehand.

κ Cygnids. January 17th; slow moving meteors, often trained. A second shower from a near-by radiant occurs August 10th–September 1st; bright and swift.

α *Cygnids*. July and August. Meteors swift and long.

DELPHINUS AND EQUULEUS

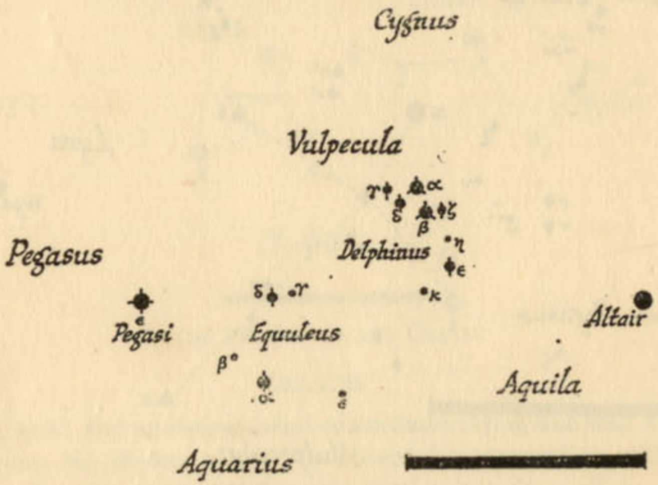


FIGURE 28. DELPHINUS AND EQUULEUS

DELPHINUS

M.C.: July 30th. N.: Vulpecula, Cygnus—W.: Aquila—S.: Aquila, Aquarius—E.: Pegasus, Equuleus. Small but unmistakable constellation. Good sweeping.

EQUULEUS

Closely S.E. of Delphinus; one of the smallest constellations. No objects of interest.

DRACO

Circumpolar; M.C.: April 25th. Faint constellation straggling half way round Polaris (see map). Few interesting objects for binoculars.

ι *Draconids*. June 27th–30th; maximum, June 28th. At maximum may yield about seven very slow moving meteors per hour. Connected with the Pons-Winnecke comet.

γ *Draconids*. Maximum, June 25th; continues throughout July and August, and stray γ Draconids may be seen from spring to late autumn. Slow moving.

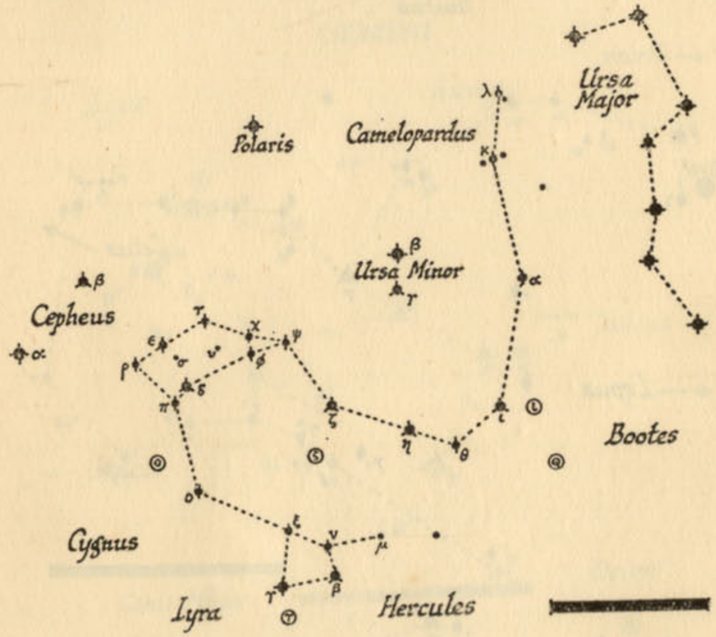


FIGURE 29. DRACO

o *Draconids*. Slow moving meteors. August 21st–23rd; maximum, August 22nd.

ζ *Draconids*. August 21st–30th. Usually indistinguishable from o Draconids unless plotted on a star map, though characteristically brighter than the latter.

Quadrantids. December 28th–January 4th; 30 per hour at maximum (January 2nd–3rd). For observers in the British Isles the radiant is circumpolar, as are those of the other

Draconid showers. Paths usually long. A second shower from an almost identical radiant occurs on October 2nd; slower than the January meteors.

ERIDANUS

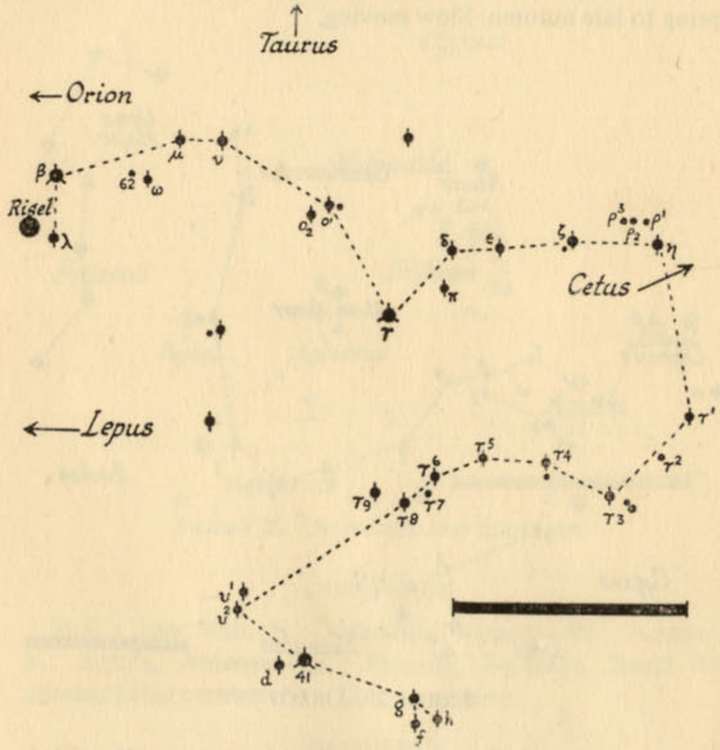


FIGURE 30. ERIDANUS

M.C.: November 10th. E., N.E.: Orion—N.: Taurus—W.: Cetus. Straggling constellation only partially above the horizon in our latitudes.

β Eridani. Marks an area worth sweeping over. Distance, 70 L.Y., decreasing at the rate of about 2½ L.Y. per 1000 years.

o Eridani. Naked eye pair, mags. 4, 4·5. o^2 has a faint companion, very near or below the reach of good binoculars: mag. 9·4, separation 85″. This binary, 15 L.Y. distant, was discovered by Herschel in 1783.

62 Eridani. Faint double: mags. 6, 8; separation, 63″.

GEMINI

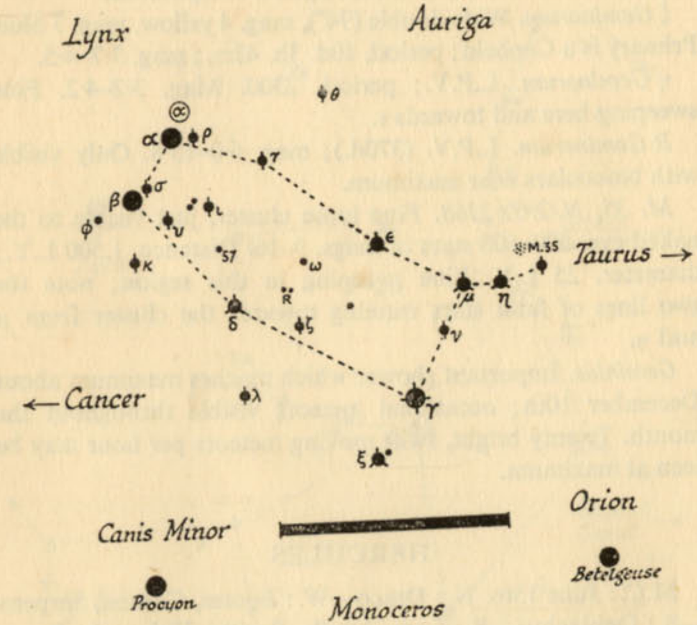


FIGURE 31. GEMINI

M.C.: January 5th. S.W.: Orion—W.: Taurus—E.: Leo—S.: Canis Minor.

α Geminorum. Castor. One of the loveliest doubles in the heavens, but too close (3″·9, closing) for binoculars. A true binary, period about 350 years. Both components are sp. bins., periods 2·9d. and 9·2d. A faint red companion 73″ distant, also a member of the system, is itself a close eclipsing binary, period 0·8d. Castor is thus a sextuple star. Distance, 43 L.Y. Other data:

	Castor A	*Castor B*	*Castor C*
Brightness:	23⊙	10⊙	0·04⊙
Mass:	5·5⊙		*c.* 3⊙

Note contrasted colours of Castor (white) and Pollux (deep yellow). Both stars have several optical companions.

ζ Geminorum. Wide double (94″), mag. 4 yellow, mag. 7 blue. Primary is a Cepheid; period, 10d. 3h. 43m.; mag. 3·7–4·5.

η Geminorum. L.P.V.; period, 230d. Mag. 3·2–4·2. Fine sweeping here and towards ε.

R Geminorum. L.P.V. (370d.); mag. 6·0–13·8. Only visible with binoculars near maximum.

M. 35, N.G.C. 2168. Fine loose cluster, just visible to the naked eye. 500–600 stars of mags. 9–16. Distance, 1,500 L.Y.; diameter, 25 L.Y. Fine sweeping in this region; note the two lines of faint stars running towards the cluster from μ and η.

Geminids. Important shower which reaches maximum about December 10th; occasional meteors visible throughout the month. Twenty bright, swift moving meteors per hour may be seen at maximum.

HERCULES

M.C.: June 15th. N.: Draco—W.: Bootes, Corona, Serpens—S.: Ophiuchus—E.: Lyra, Aquila, Sagitta, Vulpecula. Large constellation lying within the triangle α Lyrae, α Aquilae, α Coronae.

α Herculis. Irregular variable; unusually red star for one so bright; very fine telescopic double. The brighter member of the pair is variable; period (irregular), 88d.; mag. 3·0–3·9. Distance about 460 L.Y.

γ Herculis. Difficult double owing to the faintness of the companion. Mags. 3·8, 8; separation, 40″.

68 Herculis. Eclipsing variable. Mag. 4·8–5·3; period, 2d. 1h. 12m.

S Herculis. L.P.V. (300d.); mag. 5·9–12·5.

M. 13, N.G.C. 6205. One of the finest globular clusters, being

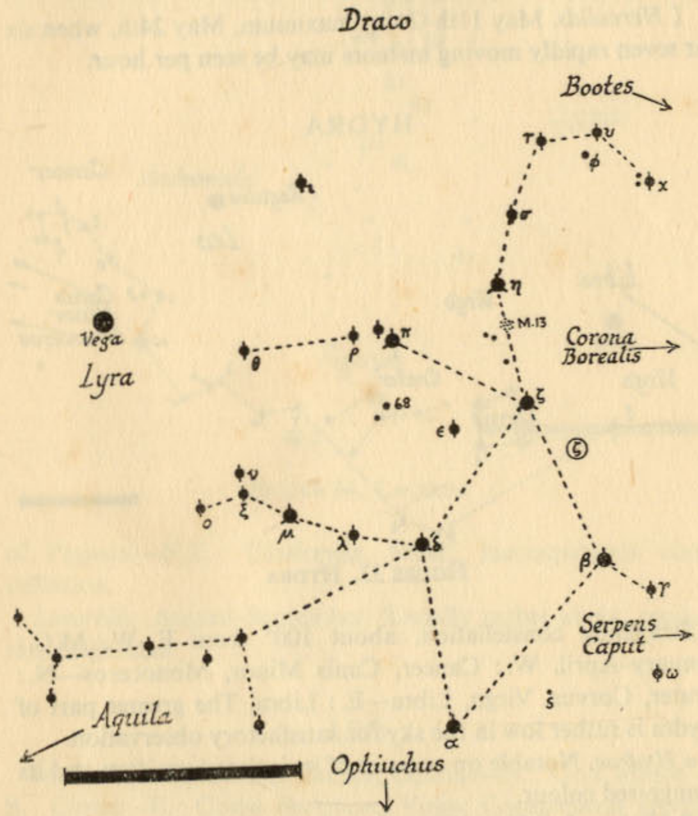


FIGURE 32. HERCULES

both angularly large (diameter about 6′) and brighter than most. Discovered by Halley, 1716. When its position is known, naked eyesight shows it as a mag. 6 star on moonless nights. A telescope is required to begin resolution of the individual stars, mags. 12–15. Photography shows that it contains some 30,000 stars brighter than mag. 21; total number probably in the neighbourhood of 100,000. Probable distance, 36,000 L.Y., corresponding to diameter of some 320 L.Y. Radial velocity about −200 m.p.s.

ζ Herculids. May 11th–24th; maximum, May 24th, when six or seven rapidly moving meteors may be seen per hour.

HYDRA

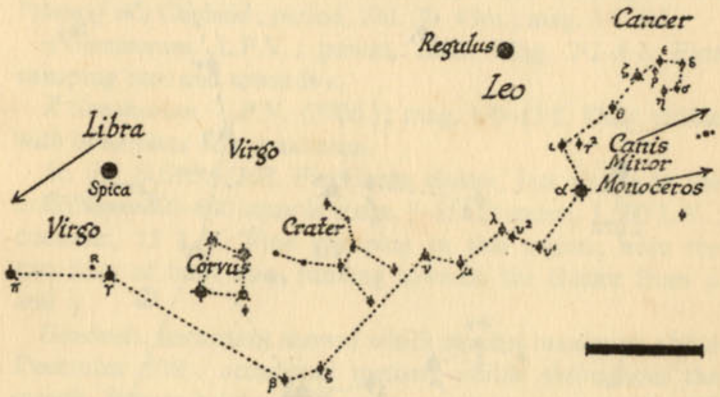


FIGURE 33. HYDRA

Straggling constellation, about 100° from E.–W. M.C.: January–April. W.: Cancer, Canis Minor, Monoceros—N.: Crater, Corvus, Virgo, Libra—E.: Libra. The greater part of Hydra is rather low in the sky for satisfactory observation.

α Hydrae. Notable on account of its isolated position and its orange-red colour.

R Hydrae. L.P.V. (415d.); mag. 4–10.

LACERTA

Partly circumpolar; M.C.: August 25th. E.: Andromeda—W.: Cygnus—S.: Pegasus—N.: Cepheus—S.E.: Great Square

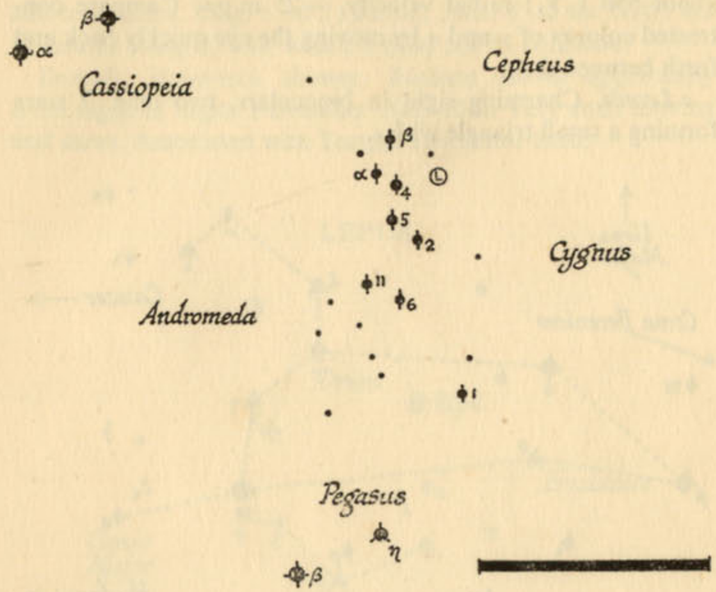


FIGURE 34. LACERTA

of Pegasus—N.E.: Cassiopeia. Small, inconspicuous constellation.

Lacertids. August–September. Usually rather short, moderate brightness.

LEO

M.C.: March 1st. W.: Cancer, Gemini—N.: Ursa Major—S.: Crater—E.: Coma Berenices, Virgo. Conspicuous group, somewhat resembling a crouching lion.

α Leonis. Regulus. Wide double: mags. 1·3, 8·5; separation about 3′. Probably a binary. Lies almost exactly on the ecliptic; distance, about 56 L.Y.

γ Leonis. Probably an optical pair. Primary a very fine binary (period, 407 years), not separable with binoculars. Distance about 550 L.Y.; radial velocity, −25 m.p.s. Compare contrasted colours of γ and α by moving the eye quickly back and forth between them.

ε Leonis. Charming sight in binoculars, two mag. 7 stars forming a small triangle with ε.

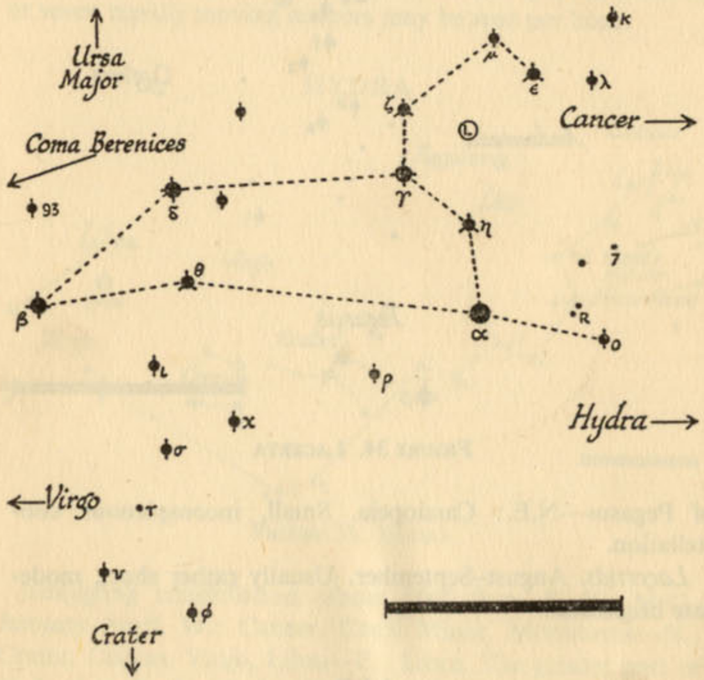


FIGURE 35. LEO

ζ Leonis. Two, possibly three, companions to ζ are shown by binoculars.

Three faint doubles are:

τ Leonis. Mags. 5·5 yellowish-white, 7 pale blue; 90″.

7 Leonis. Mags. 6, 8; 42″.

93 Leonis. Mags. 4·7, 8·4; 74″.

R Leonis. Deep red L.P.V., partially visible with naked eye

and binoculars. Mag. 5–10·5; period, 310d. ½° to the N.W. lies 18 Leonis (mag. 6) with which it must not be confused.

Leonids. Important shower. Radiant moves appreciably from night to night. November 10th–15th. Very swift moving and short. Associated with Temple's comet of 1866.

LEPUS

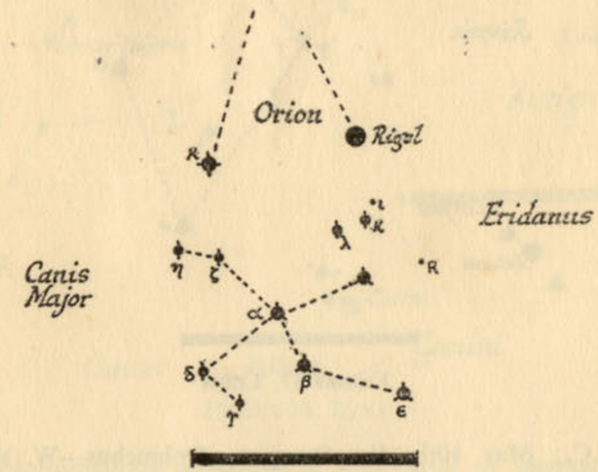


FIGURE 36. LEPUS

M.C.: December 15th. N.: Orion—E.: Canis Major—W.: Eridanus.

γ Leporis. Mags. 3·8 yellow, 6·4 reddish; separation, 95″. A third companion is invisible with binoculars.

ι Leporis. Closely W. lies a mag. 5·5 deep red star.

R Leporis. Interesting L.P.V., just visible to the naked eye at maximum. Of abnormally deep red colour, its telescopic appearance has been likened to a drop of blood suspended against the sky. Mag. 6–10·4; period, about 420d. Commonly known as Hind's 'Crimson Star'.

LIBRA

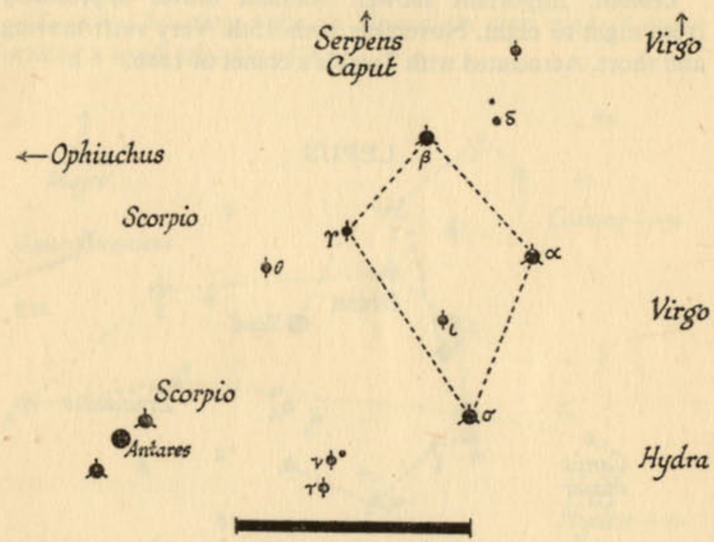


FIGURE 37. LIBRA

M.C.: May 10th. E.: Scorpius, Ophiuchus—W.: Virgo. Inconspicuous constellation, pointed at by the Scorpius triplet of bright stars, τ, α and σ.

α Librae. Mags. 3, 5·3; separation, 230″. Separable by acute naked eyesight. Distance about 72 L.Y.

β Librae. In general, green or blue stars are all faint, usually the comites of binaries; β Librae (green) is the only exception.

δ Librae. Algol-type eclipsing variable. Mag. 4·9–6·2; period, 2d. 7h. 51m. Discovered as recently as 1859.

LYNX

Partly circumpolar; M.C.: January 15th. N.: Camelopardus—W.: Auriga—S.: Gemini, Cancer—E.: Ursa Major. Large

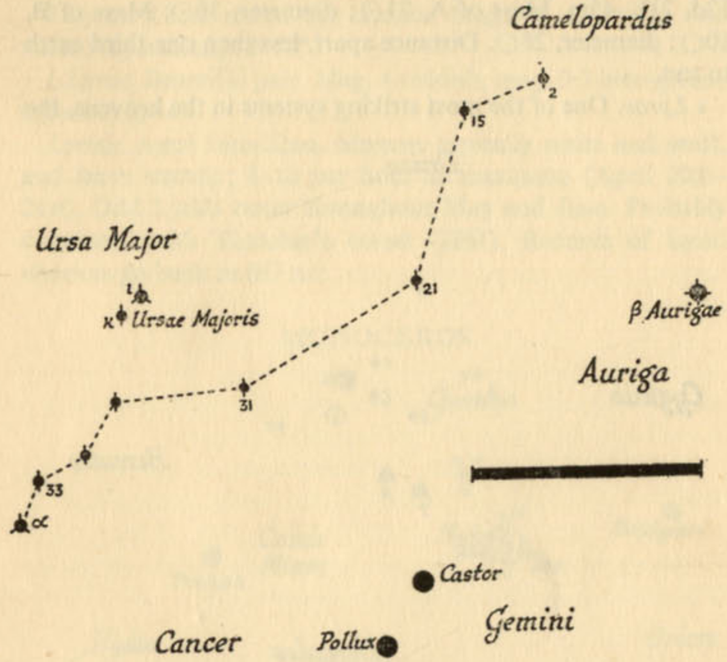


FIGURE 38. LYNX

but inconspicuous constellation with little of interest for binocular observation.

LYRA

M.C.: July 1st. E.: Cygnus—S., W.: Hercules—N.: Draco. α is the brightest star in the summer skies. Fine sweeping hereabouts and towards Cygnus.

α Lyrae. Vega. Mag. 0·2, bluish white. Distance about 25 L.Y.; luminosity, 50$\odot$; diameter, 2·5$\odot$. It is towards this part of the star sphere that the sun is moving with a velocity of 13 m.p.s.

β Lyrae. Eclipsing variable, the whole variation visible to the naked eye: mag. 3·4–4·1, secondary minimum at 3·8; period,

12d. 21h. 45m. Mass of A, 21$\odot$; diameter, 36$\odot$. Mass of B, 10$\odot$; diameter, 28$\odot$. Distance apart, less than one-third earth to sun.

ϵ *Lyrae*. One of the most striking systems in the heavens, the

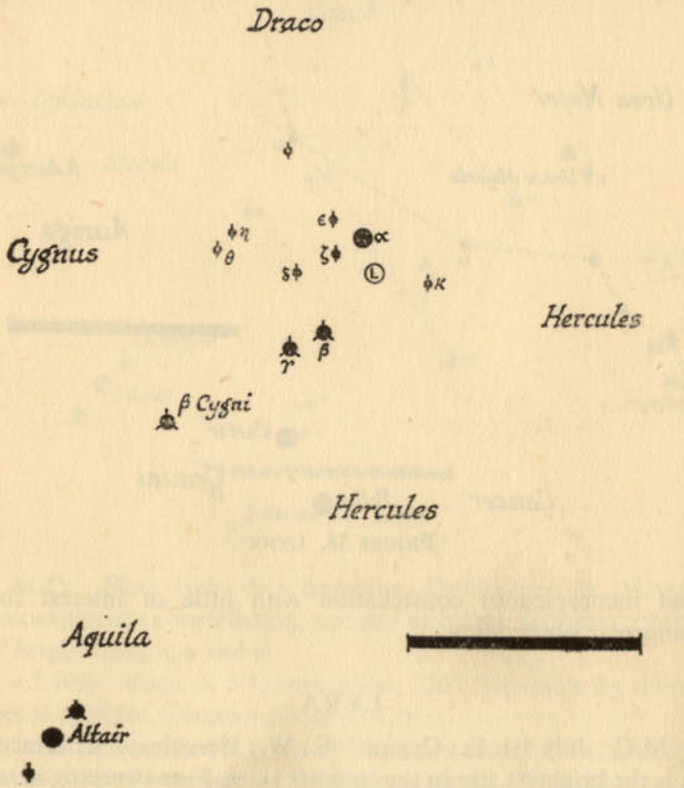


FIGURE 39. LYRA

celebrated 'double double'. Acute naked eyesight shows ϵ to be double—mags. 4, 5; separation, 3′ 28″—but binoculars are needed to show this clearly. A small telescope reveals that both ϵ^1 and ϵ^2 are themselves double, their respective separations being 2″·9 and 2″·3.

δ *Lyrae*. Close naked eye double. Mags. 4, 5, orange and white; separation, 12′ 30″.

ζ *Lyrae*. Beautiful pair. Mag. 4 reddish, mag. 5·5 blue-green; separation, 44″.

Lyrids. April 16th-22nd. Meteors typically white and swift, and leave streaks; 8–10 per hour at maximum (April 20th–21st). Odd Lyrids occur throughout May and June. Probably connected with Thatcher's comet (1861). Records of Lyrid showers go back to 687 B.C.

MONOCEROS

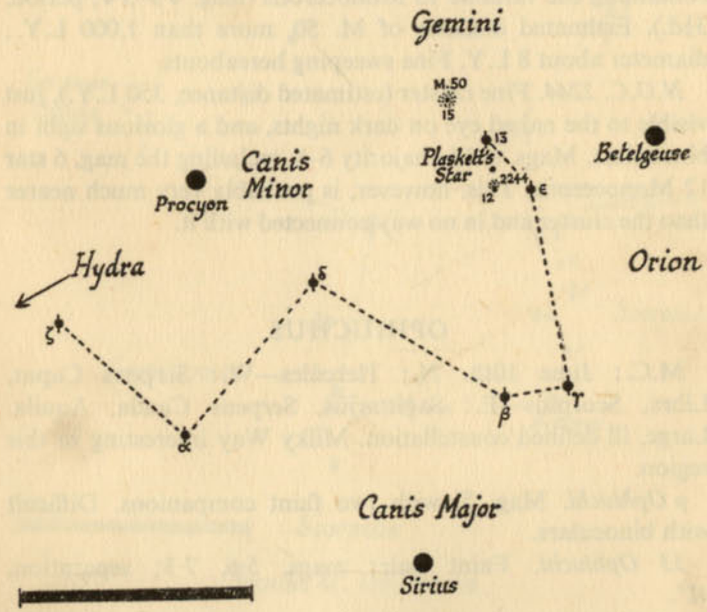


FIGURE 40. MONOCEROS

M.C.: January 5th. S.: Canis Major—W.: Orion—E.: Canis Minor—N.: Gemini. Inconspicuous to the naked eye, but a wonderful area of sky with binoculars or telescope.

ε Monocerotis. Marks a fine area for low power sweeping, such as is provided by binoculars.

1309 Monocerotis. Plaskett's Star. A close binary (mag. 6) with some of the most unusual features of any star yet investigated. Period, 14½d.; separation, 56,000,000 miles (5/8 earth–sun); orbital velocity, 155 m.p.s.; mass of primary 76⊙, of comes 63⊙; luminosity, about 30,000⊙; distance, about 10,000 L.Y. These two stars are the most massive known; stellar masses approaching even 50⊙ are exceedingly rare.

M. 50, N.G.C. 2323. Nebulous cluster, some 20′ in diameter, containing the variable 15 Monocerotis (mag. 4·9–5·4; period, 3½d.). Estimated distance of M. 50, more than 1,000 L.Y.; diameter about 8 L.Y. Fine sweeping hereabouts.

N.G.C. 2244. Fine cluster (estimated distance, 350 L.Y.), just visible to the naked eye on dark nights, and a glorious sight in binoculars. Mags. 6–14, majority 6–8, including the mag. 6 star 12 Monocerotis. This, however, is probably very much nearer than the cluster and in no way connected with it.

OPHIUCHUS

M.C.: June 10th. N.: Hercules—W.: Serpens Caput, Libra, Scorpius—E.: Sagittarius, Serpens Cauda, Aquila. Large, ill defined constellation. Milky Way interesting in this region.

ρ Ophiuchi. Mag. 5, with two faint companions. Difficult with binoculars.

53 Ophiuchi. Faint pair: mags. 5·6, 7·3; separation, 41″.

67 Ophiuchi. Mag. 4 yellow, mag. 8 reddish; separation, 54″.

M. 19, N.G.C. 6273. Cluster, just visible to the naked eye and easily swept up with binoculars. Mag. 6·8, diameter about 5′. One distance estimate is 52,000 L.Y.

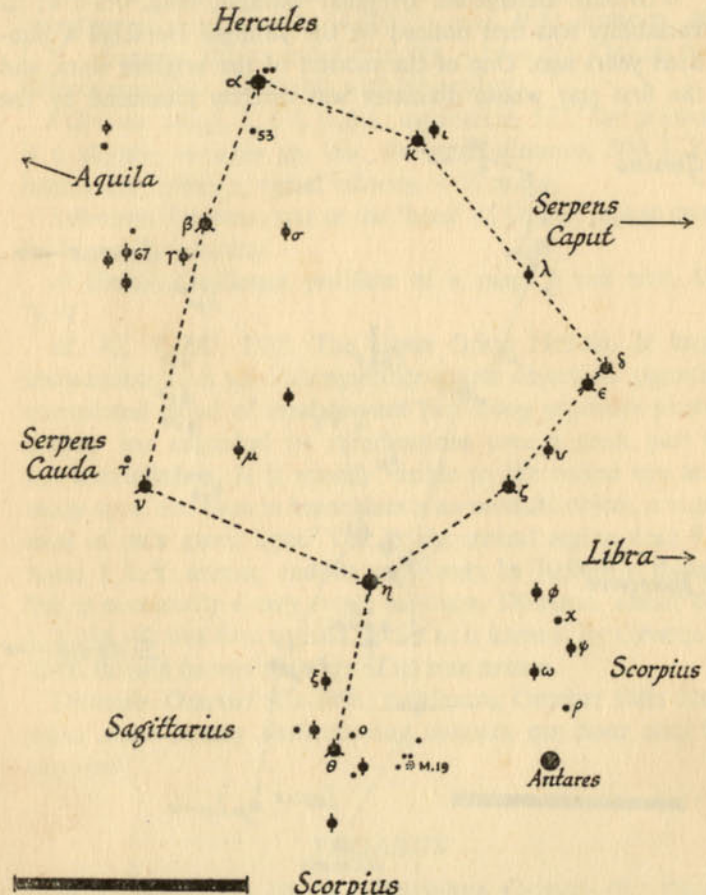


FIGURE 41. OPHIUCHUS

ORION

M.C.: December 15th. W.: Taurus, Eridanus—S.: Lepus—E.: Monoceros, Gemini. The finest winter constellation. Good sweeping.

α Orionis. Betelgeuse. Irregular variable, mag. 0·5–1·4; its variability was first noticed by the younger Herschel a hundred years ago. One of the reddest of the brighter stars, and the first star whose diameter was directly measured by the

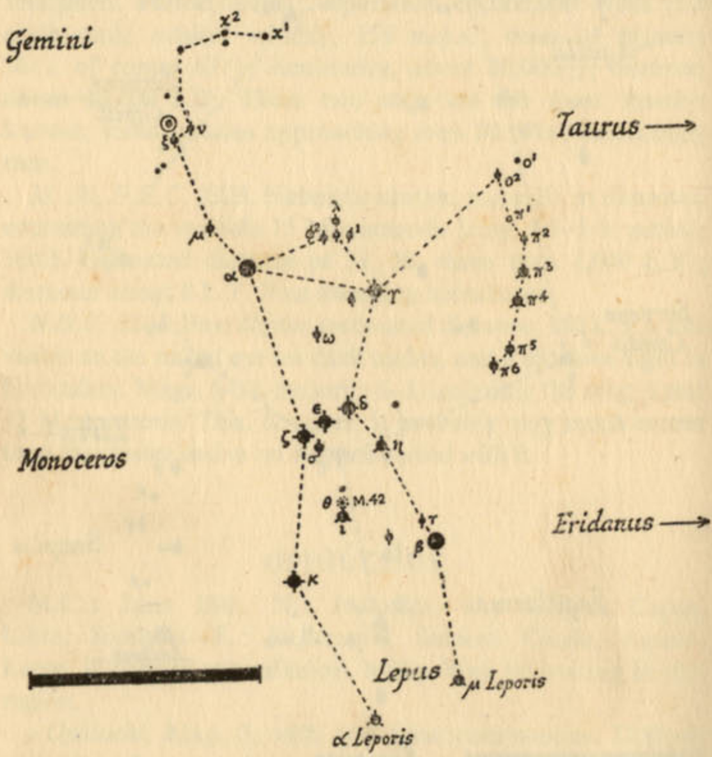


FIGURE 42. ORION

Mount Wilson interferometer (1920). Betelgeuse is actually pulsating (no doubt the cause of the light variation), its mean diameter being 300 million miles, i.e. greater than the orbit of Mars, or 350⊙. Volume, 27,000,000⊙; mass, 35⊙; density, 0·001 times that of air; brightness, 1,600⊙; distance, 240 L.Y.

β Orionis. Rigel. One of the intrinsically brightest stars yet investigated. Luminosity, 14,000⊙; mag. 0·3; distance, 460 L.Y.; diameter, 35⊙; radial velocity, +14 m.p.s. One or two faint companions are visible with binoculars.

δ Orionis. Mags. 2, 6·8, white; separation, 52″. The primary is a slightly variable sp. bin. Probable distance, 300 L.Y.; luminosity, 3,000⊙; radial velocity, +12 m.p.s.

λ Orionis. Brightest star in the 'head' of Orion; repays careful binocular scrutiny.

π^5 Orionis. Indicates position of a mag. 6 red star, 15′ N.W.

M. 42, N.G.C. 1976. The Great Orion Nebula. In large instruments it is an incomparably grand object—a gigantic, convoluted cloud of incandescent gas. Long exposure photography has extended its ramifications over a great part of the constellation. It is plainly visible to the naked eye as a misty spot, and even in binoculars is an unusual object, a vague mist of pale green light. The bright central region near θ is some 3 L.Y. across, and its mass may be 10,000⊙, though this is necessarily a very rough estimate. Distance, about 600 L.Y. M. 42 was first noticed, so far as is known, by Cysatus in 1618, though he was unaware of its true nature.

Orionids. October 9th–29th; maximum, October 18th–20th, when some twenty swift moving meteors per hour may be expected.

PEGASUS

M.C.: September 1st. W.: Delphinus, Cygnus—E.: Pisces, Andromeda—N.: Lacerta—S.: Aquarius. The Great Square of Pegasus is one of the landmarks of the night skies.

π Pegasi. Beautiful pair in binoculars. Mags. 4·5, 6, both yellow; well separated.

β Pegasi. Irregular variable, mag. 2·2–2·8, reddish. A giant star, diameter about 87⊙. Distance, 325 L.Y.

η Pegasids. Very rapid meteors. About May 30th.

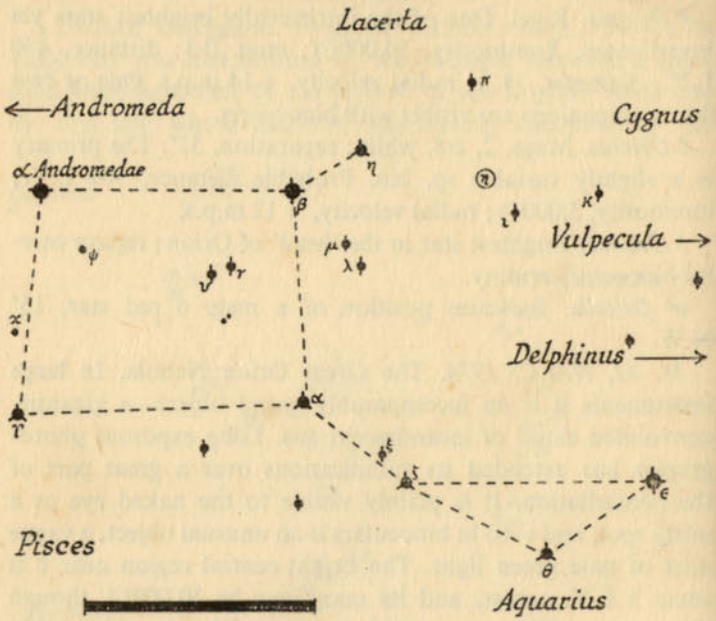


FIGURE 43. PEGASUS

PERSEUS

Partially circumpolar. M.C.: November 10th. W.: Andromeda, Triangulum—E.: Auriga—N.: Cassiopeia—S.: Taurus. Fine sweeping, rich star fields.

α Persei. Situated in a beautiful field of faint stars.

57 Persei. Wide double, 114″; mags. 5 yellow, 6 bluish.

β Persei. Algol (Arabic: the Demon). Type star of the Algolid or dark-eclipsing variables. First detected by Montanari (1672). Some data of this interesting binary-variable are:

	Bright Primary	*Dark Companion*
Diameter:	1,250,000 miles	1,450,000 miles
Mass:	0·37⊙	
Separation:	3,000,000 miles	
Distance:	60 L.Y.	

The whole of the variation is visible to the naked eye. A steady maximum of mag. 2·3 is maintained for about 59h. with a fall of 0·05 mags. to a secondary minimum after 29½ h.; it then fades

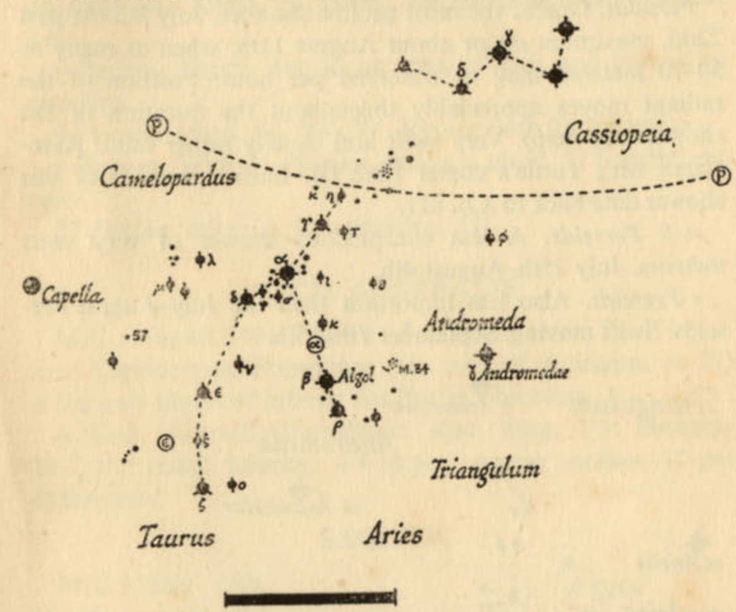


FIGURE 44. PERSEUS

to mag. 3·7 in a space of some 5h.; minimum is maintained for from 18–20m., when the rise to maximum is made in 5h. One complete cycle therefore occupies 2d. 20h. 49m., the period in which the two components revolve about their mutual centre of gravity.

ρ Persei. Irregular variable. Mag. 3·3–4·1.

M. 34, N.G.C. 1039. Loose galactic cluster, just visible to the naked eye on moonless nights. Component stars average mag. 9. Distance, 1,700 L.Y.; diameter about 35′.

N.G.C. 869/884. The famous 'Double Cluster', clearly visible to the naked eye, and a superb spectacle in binoculars or a small telescope. The two clusters, each about 45′ in diameter, are of the loose galactic type and the finest specimens in the northern skies. They were well known to the ancients and are mentioned by Hipparchus and Ptolemy.

Perseids. One of the most prolific showers. July 8th–August 22nd, maximum on or about August 11th, when as many as 50–70 meteors may be observed per hour. Position of the radiant moves appreciably throughout the duration of the shower (see map). Very swift and usually rather faint. Associated with Tuttle's comet 1862 III. Earliest records of this shower date back to A.D. 811.

α–β Perseids. A less conspicuous shower of very swift meteors. July 25th–August 4th.

ε Perseids. Also less important than the July–August Perseids. Swift moving. September 7th–15th.

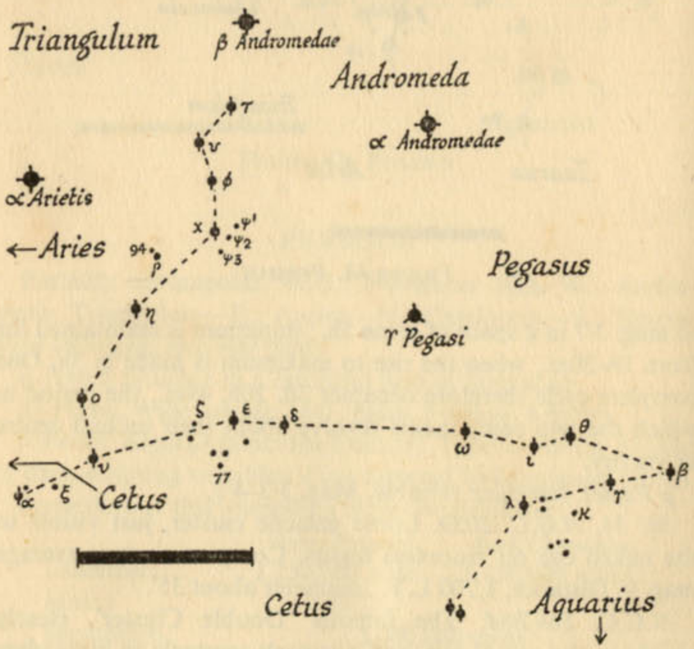


FIGURE 45. PISCES

PISCES

M.C.: September 25th. W.: Pegasus—E.: Aries—N.: Andromeda—S.: Cetus, Aquarius. An inconspicuous constellation.

κ Piscium. Guide star to an area of rich and interesting sweeping.

ψ Piscium. Mags. 5·6, 5·8; 30″. Rather close for binoculars.

ρ Piscium. With 94 Piscium makes a mags. 5, 6 naked eye pair.

77 Piscium. Mags. 6, 7; separation, 33″.

PISCIS AUSTRALIS

M.C.: August 25th. Lies very low in our skies, S. of Aquarius, Capricornus. Fomalhaut (see map of Aquarius, p. 79) is the only object of interest for British observers.

α Piscis Australis. Fomalhaut. Red. Mag. 1·3; distance, 24 L.Y.; radial velocity, +4 m.p.s.; proper motion, 1° per 6,000 years.

SAGITTA

M.C.: July 15th. N.: Cygnus (β)—S.: Aquila (α). A small, faint constellation. Fine sweeping, notably in the region of η and γ.

ε Sagittae. Mags. 6, 7·8; separation, 92″. Within reach of an experienced eye and good binoculars.

α and *β Sagittae.* Both wide doubles.

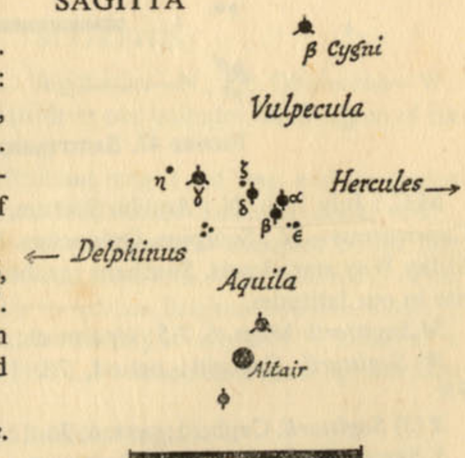


FIGURE 46. SAGITTA

SAGITTARIUS

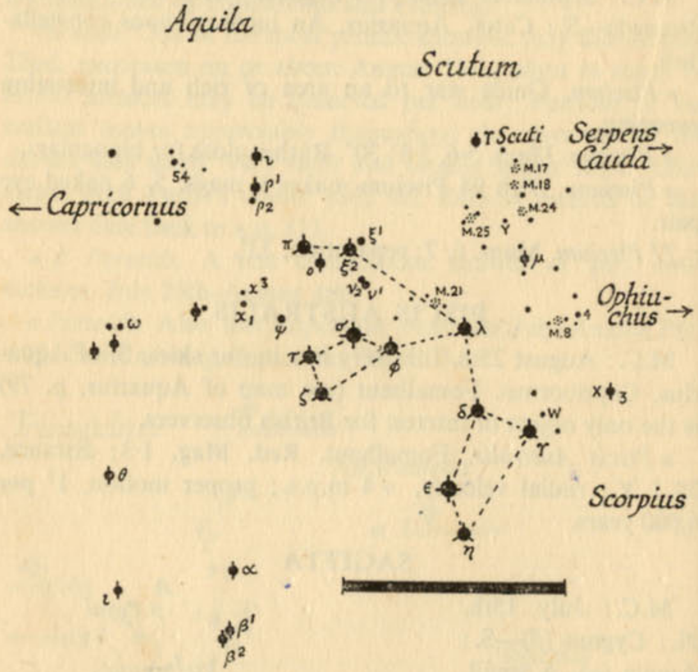


FIGURE 47. SAGITTARIUS

M.C.: July 10th. N.: Aquila, Scutum, Serpens Cauda—E.: Capricornus—W.: Scorpius, Ophiuchus. Fine sweeping; dense Milky Way star clouds. Southern reaches of Sagittarius never rise in our latitudes.

54 Sagittarii. Mags. 6, 7·5; separation, 45″.

W Sagittarii. Cepheid; period, 7d. 14h. 10m. Mag. 4·8–5·8.

X (3) Sagittarii. Cepheid; period, 7d. 15m. Mag. 4·4–5.

Y Sagittarii. Cepheid. Period shorter, and mag. lower, than the two preceding: 5d. 18h. 30m.; 5·4–6·5.

M. 8, N.G.C. 6523. Fine nebulous cluster, visible to the naked eye. Appears as a loose cluster of rather faint stars, somewhat resembling a miniature Pleiades, the nebulosity not being visible in binoculars; even the individual stars may not be seen, the object then appearing as a structureless patch of misty light. Fine sweeping in this region; cluster prettily placed between two 5·5 mag. stars. Estimated distance, 1,600 L.Y.

M. 22, N.G.C. 6656. Fine globular cluster, just visible to the naked eye. Unusually large and bright for this type of object, and only its low declination prevents it rivalling the Hercules cluster. The 50,000-odd stars are of mags. 10–15; resolution impossible with binoculars. Distance, about 27,000 L.Y.; diameter about 250 L.Y. Discovered 1665.

M. 24, N.G.C. 6603. Magnificent star cloud; to the naked eye, a protuberance from the Milky Way; with binoculars, an ill defined luminous patch. Fine sweeping all over this very rich region of the galaxy.

SCORPIUS

M.C.: June 3rd. E.: Sagittarius—N., E.: Ophiuchus—W.: Libra. Only partially visible in our latitudes. Rich region of the galaxy: very fine sweeping.

α Scorpii. Antares. Brilliant mag. 1 red star, and the largest yet measured; diameter, 370,000,000 miles, or about 430☉. Were it transported to the position now occupied by the sun, the orbits of Mercury, Venus, the Earth, Mars, and many of the asteroids would lie below its surface. Brightness, about, 3,000☉; hence, area for area, its luminosity is only 0·01☉. Distance in the neighbourhood of 360 L.Y. Binoculars show several faint companions.

μ Scorpii. Naked eye double. Mags. 3, 4.

ν Scorpii. Test object for binoculars. Mags. 4·2, 6·5; separation, 41″. Both are close binaries.

λ Scorpii. Guide star to the clusters M. 6 and M. 7, both visible in binoculars.

ω Scorpii. Two mag. 4·5 stars, well placed in relation to *β*.

FIGURE 48. SCORPIUS

22 Scorpii. Mag. 5, with two faint companions.

M. 80, N.G.C. 6093. A fine cluster, appearing in binoculars as a circular nebula 5½′ in diameter; mag. 7·8. The variable T Scorpii appears to be centrally placed within the cluster but is probably very much nearer to the sun. M. 80 contains thousands of stars, average mag. 14. Distance, about 65,000 L.Y. Beautiful neighbourhood.

M. 4, N.G.C. 6121. Cluster of faint stars, about 1½° W. of Antares. Diameter, 12′.

M. 6, N.G.C. 6405. } Fine open clusters, well seen in binoculars.
M. 7, N.G.C. 6475. }

α Scorpiids. June 2nd–17th. Very slow moving.

SCUTUM

M.C.: July 1st. N., E.: Aquila—N., W.: Serpens Cauda—S.: Sagittarius. Small and undistinguished constellation.

R Scuti. Irregular variable, mag. 4·8–7·8.

M. 11, N.G.C. 6705. Fine globular cluster, situated on the N. edge of one of the Sagittarius star clouds. May just be seen

with the naked eye; nebulous spot in binoculars. Diameter about 5′ (25 L.Y.); distance, 15,000 L.Y.

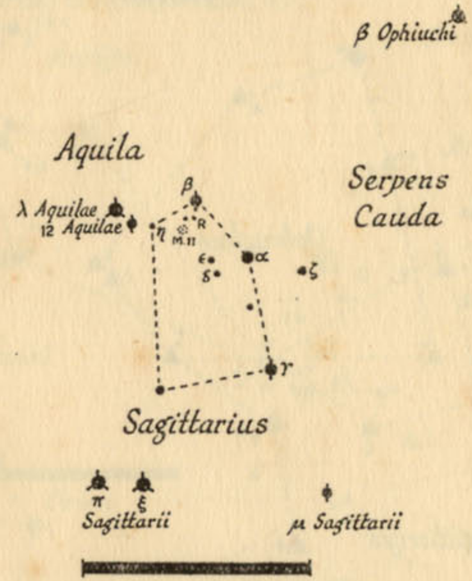


FIGURE 49. SCUTUM

SERPENS

Two separate constellations, (*a*) Serpens Caput, (*b*) Serpens Cauda.

(*a*) M.C.: May 20th. N.: Corona—E.: Hercules, Ophiuchus—W.: Bootes, Virgo—S.: Libra.

(*b*) M.C.: June 25th. N.: Ophiuchus, Aquila—E.: Aquila, Scutum—W.: Ophiuchus.

R Serpentis. Variable. Mag. 5·5–13·4. Period, 357d. (slightly irregular).

M. 5, N.G.C. 5904. A glorious globular cluster. Mag. 6·5 diameter, 15′. Mags. of the individual stars, 11–15. Distance probably about 40,000 L.Y.; radial velocity, −6 m.p.s.

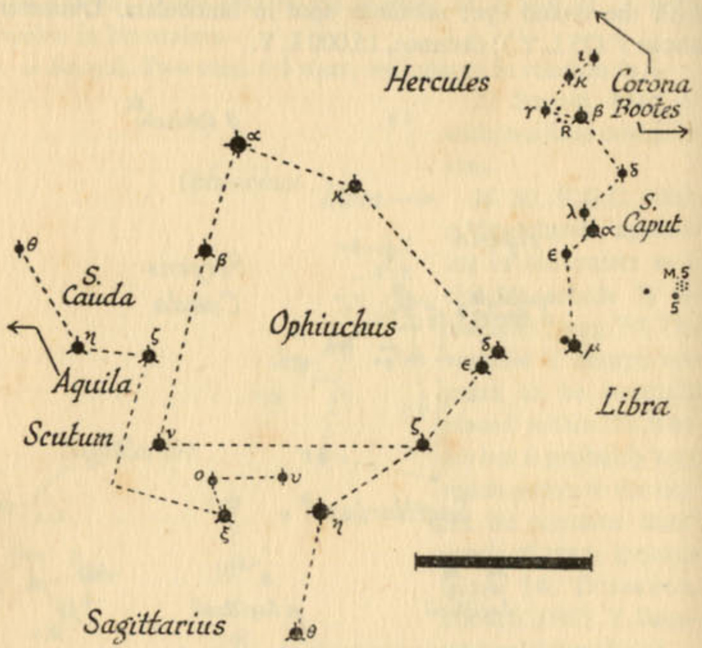


FIGURE 50. SERPENS

TAURUS

M.C.: December 1st. E.: Orion, Gemini—W.: Aries, Cetus —N.: Auriga, Perseus—S.: Eridanus. Conspicuous constellation, containing the Pleiades and Hyades clusters.

α *Tauri.* Aldebaran. Mag. 1, reddish (compare it with the remarkably white β Tauri). A mag. 11 comes is not visible with binoculars. Diameter, about 35☉; brightness, 90☉; distance, 57 L.Y.; radial velocity, +34 m.p.s.

θ *Tauri.* Easy naked eye double, worth viewing with binoculars; mags. 4, 4; separation, 5′ 30″. θ^1 (the southernmost) is greenish white, θ^2 yellowish.

σ^1, σ^2 *Tauri.* Another wide double. Mags. 5, 5; separation, 7′.

φ *Tauri.* Difficult, owing to faintness of comes. Mag. 5 reddish, 8 blue; separation, 50″.

τ *Tauri.* Another pair with widely differing magnitudes: 4, 7, white and blue; separation, 63″.

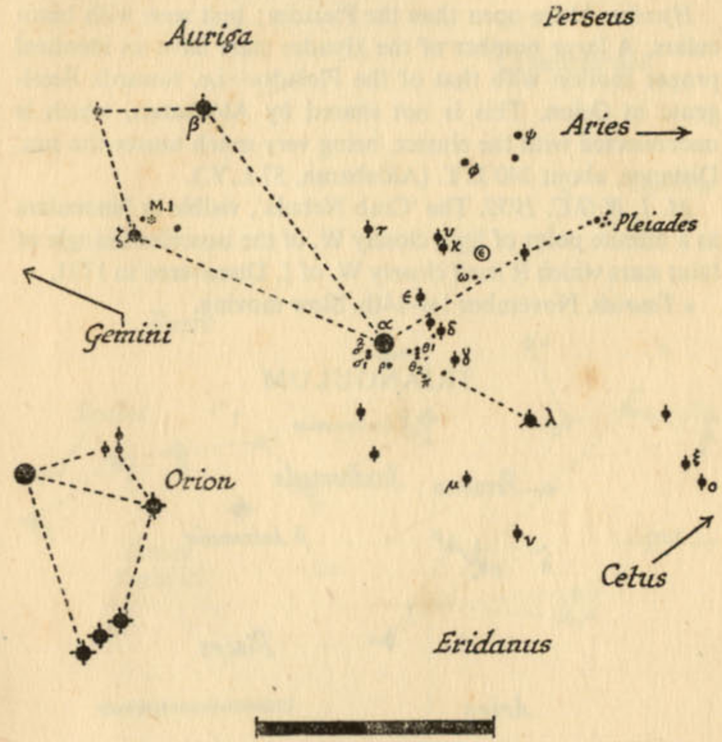


FIGURE 51. TAURUS

λ *Tauri.* Algolid (dark-eclipsing) variable. Mag. 3·4–4·3. Period, 3d. 22h. 52m.

Pleiades. The finest of the very open clusters; somewhat reminiscent of a miniature Plough. Six or seven stars will probably be seen with the naked eye, though as many as eleven, twelve, and even fourteen have been claimed without optical aid. Distance about 350 L.Y.; some 12 L.Y. from end to end. The brighter components have a common proper motion of about 6″ per century towards Betelgeuse. Photography has revealed that the whole cluster is involved in diffuse nebulosity.

Hyades. More open than the Pleiades; best seen with binoculars. A large number of the Hyades stars have an identical proper motion with that of the Pleiades—i.e. towards Betelgeuse in Orion. This is not shared by Aldebaran, which is unconnected with the cluster, being very much nearer the sun. Distance, about 140 L.Y. (Aldebaran, 57 L.Y.).

M. 1, N.G.C. 1952. The 'Crab Nebula', visible in binoculars as a minute point of light closely W. of the isosceles triangle of faint stars which is itself closely W. of ζ. Discovered in 1731.

ε Taurids. November 1st–14th. Slow moving.

TRIANGULUM

FIGURE 52. TRIANGULUM

M.C.: October 25th. N.: Andromeda—S.: Aries. Small but easily identified.

R Trianguli. L.P.V. visible with binoculars at and near maximum. Mag. 5·8–12. Period, 270d.

URSA MAJOR

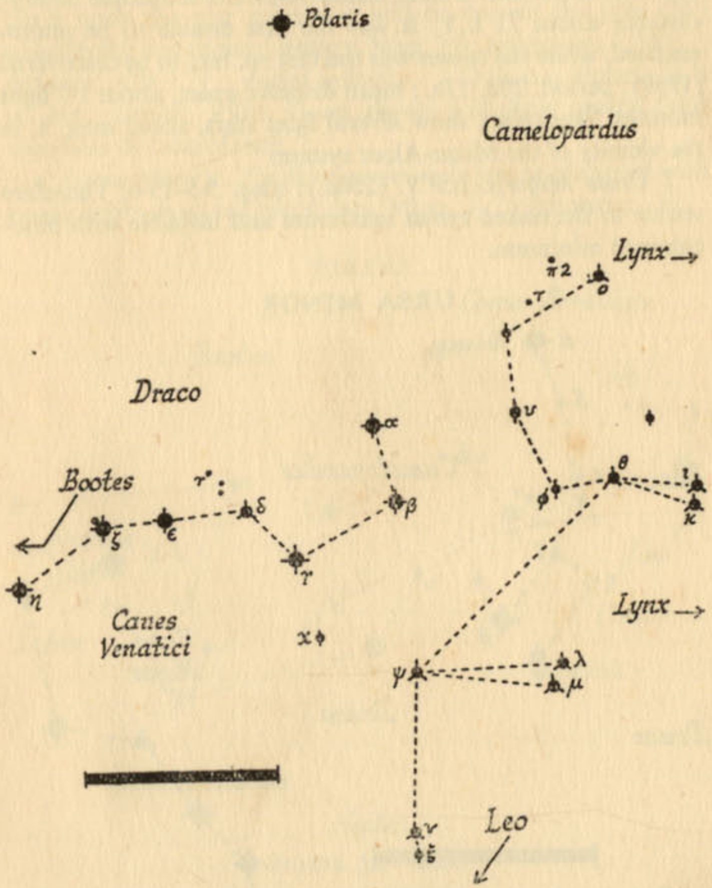


FIGURE 53. URSA MAJOR

Circumpolar. Lies roughly between Leo–Canes Venatici and the pole.

ζ Ursae Majoris. Mizar. Forms with Alcor (mag. 5, distant 11′ 30″) an easy naked eye pair. It is interesting to reflect, while looking at Mizar and Alcor, that light takes 90d. to cross the gap between them (c.f. 8 m. from sun to earth, $4\frac{1}{2}$ years from sun to nearest known star). Mizar itself is a telescopic binary; distance about 72 L.Y. It was the first double to be photographed, while the comes was the first sp. bin. to be discovered (1889): period, 20d. 13h.; mean distance apart, about 1·7 light minutes. Binoculars show several faint stars, about mag. 8, in the vicinity of the Mizar-Alcor system.

T Ursae Majoris. L.P.V. (254d.); mag. 5·5–13·6. Therefore visible to the naked eye at maximum and invisible with binoculars at minimum.

URSA MINOR

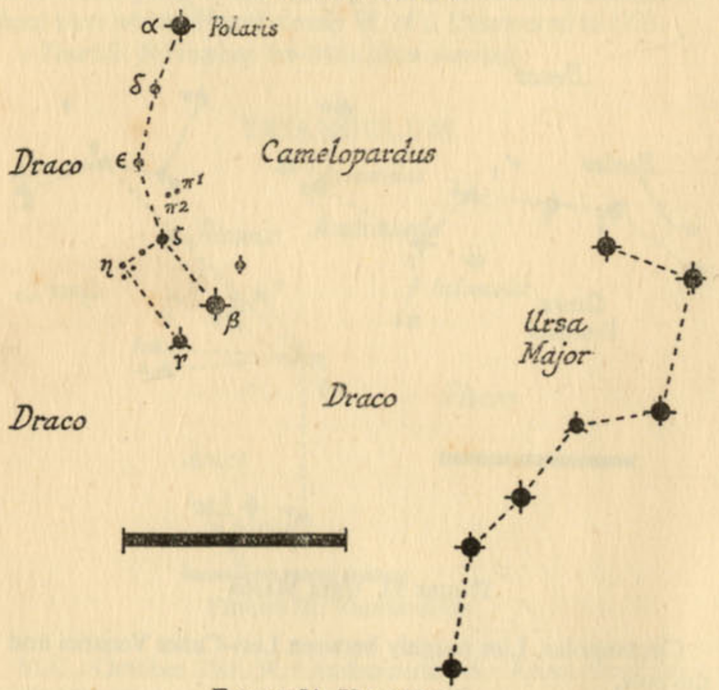


FIGURE 54. URSA MINOR

Circumpolar. Lies N. of the Plough between Draco and Polaris.

α Ursae Minoris. Polaris is situated rather more than 1° from the true celestial pole, and therefore describes a small diurnal circle upon the star sphere; it will be nearest the pole (25′) towards the end of next century. Mag. 2·0; brightness, 2,500☉; distance, 470 L.Y.; radial velocity, −15 m.p.s. Polaris is a sp. bin.; period, 3·97d. Good glasses will show several faint stars near by, one of mag. 7.

π^1 Ursae Minoris. The faint comes may just be glimpsed with good, firmly mounted binoculars. Mags. 6, 7; separation, 30″.

VIRGO

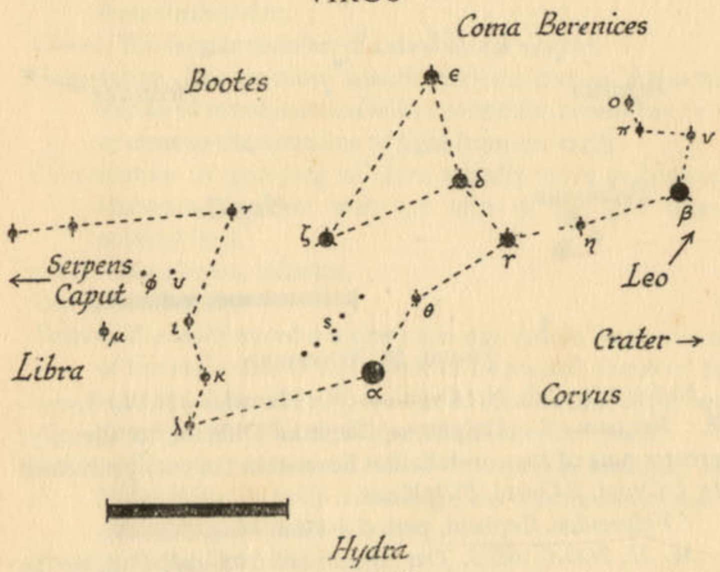


FIGURE 55. VIRGO

M.C.: April 10th. W.: Leo—S.W.: Crater, Corvus—S.: Hydra—E.: Libra, Serpens Caput—N.: Bootes, Coma Berenices.

α Virginis. Spica, mag. 1. Clear white colour (compare with the red δ); brightness, 1,500☉; distance, 235 L.Y.

S Virginis. L.P.V. (372d.). Mag. 5·6–12·5.

VULPECULA

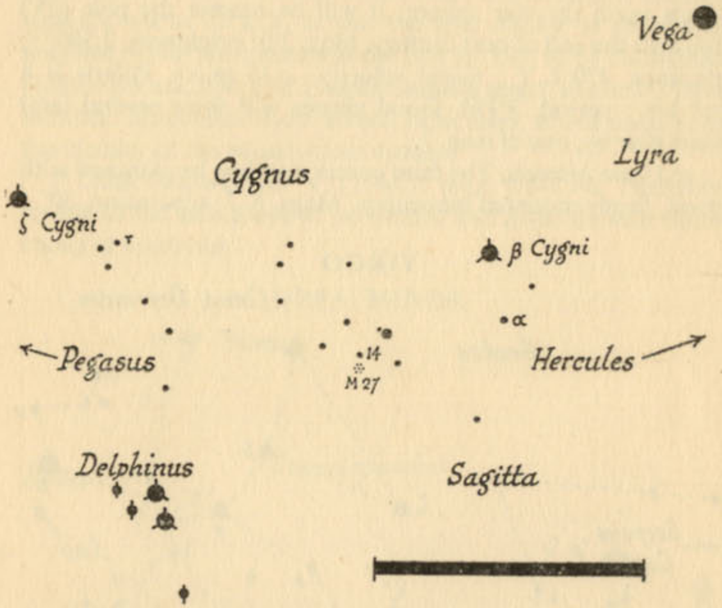


FIGURE 56. VULPECULA

M.C.: July 25th. N.: Cygnus—W.: Hercules—N.W.: Lyra—E.: Pegasus—S.: Delphinus, Sagitta. Difficult to identify; greater part of the constellation lies within the triangle formed by ζ Cygni, β Cygni, Delphinus.

T Vulpeculae. Cepheid, period 4·436d. Mag. 5·2–6.4.

M. 27, N.G.C. 6853. The 'Dumb-bell Nebula', $\frac{1}{2}°$ S. of the mag. 5 star 14 Vulpeculae. Appears as a small, featureless, nebulous spot in binoculars. Estimated distance, 550 L.Y.

GLOSSARY OF TERMS AND ABBREVIATIONS

Aphelion. That point on the orbit of a planet or comet at which it is farthest from the sun.

Circumpolar stars. Those which can never set, since their angular distance from the celestial pole is less than that of the pole from the horizon.

Comes. The fainter member of a double star system.

Conjunction. One or more planets and the sun or moon are said to be in conjunction with one another when they lie on or close to the same line of sight from the earth.

Constellation. A grouping of stars, usually more or less conspicuous, together with the area of the star sphere covered by it.

d.h.m. Days, hours, minutes.

Diurnal. 24-hourly.

Ecliptic. The path traced out upon the star sphere by the centre of the sun's disc in the course of its annual circuit of the heavens. Alternatively, the line of intersection of the produced plane of the earth's orbit with the star sphere.

Galaxy. The star system of which the sun is a member; the Milky Way; or (with a small 'g') any other star system or extragalactic nebula.

Greek alphabet. See p. 72.

L.P.V. Long period variable.

Luminosity. The intrinsic brightness of a star.

L.Y. Light year. The distance travelled by a ray of light in one year (nearly six billion miles).

M.C. Midnight culmination, i.e. the approximate date at which the centre of a constellation is on the meridian at midnight. This gives an indication of the season during which each constellation should be looked for.

Mag. Stellar magnitude; the unit of measurement of the apparent brightness of a star or other celestial object.

Meridian. The great circle which passes through the zenith, the celestial poles, and the north and south points of the horizon.

Occultation. The passage of one celestial body behind a nearer one, as seen by a terrestrial observer.

Opposition. Any two celestial bodies are said to be in opposition when they are diametrically opposite each other on the star sphere.

Parallax. An apparent displacement of a distant object as the result of a change in the position of the observer.

Perihelion. That point on the orbit of a planet or comet at which it is nearest to the sun.

Primary. The brighter member of a double star system.

Proper motion. The component of a star's motion in a plane at right angles to the observer's line of sight.

Radial velocity. The velocity of a star or other body in the observer's line of sight.

Radiant. The point on the star sphere from which the individual members of a meteor shower appear to radiate.

Sp. bin. Spectroscopic binary.

Star sphere. The illusory sphere, popularly called the dome of heaven, to which the celestial bodies appear to be attached.

Terminator. The demarcation line on the lunar surface which separates the sunlit and the dark hemispheres.

Transit. The passage, as seen from the earth, of one celestial body across the face of a more distant one.

Zenith. The point on the star sphere which is vertically above the observer.

Zodiac. An 18°-wide zone on the star sphere within which the ecliptic is centrally placed.

⊙ The sun. Hence 'Mass 175⊙' means 'mass is 175 times that of the sun'.

° ′ ″ Degrees, minutes, seconds.

INDEX

ASTRONOMY FOR
NIGHT WATCHERS

J. B.
Sidgwick

Faber