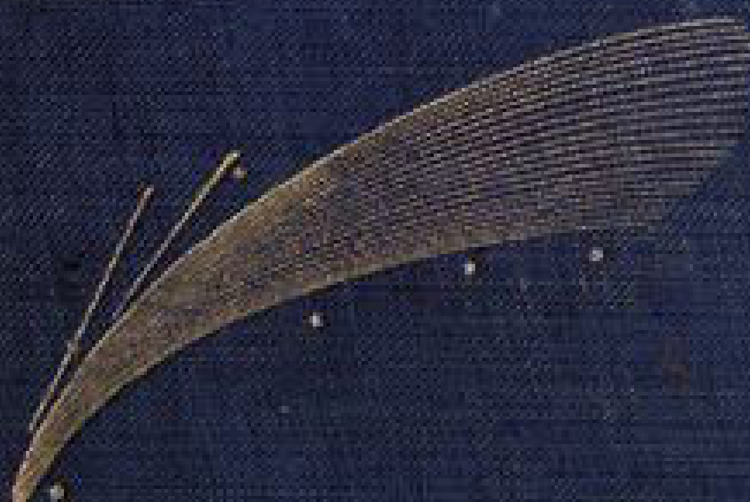

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ASTRONOMICAL CURIOSITIES

FACTS AND FALLACIES

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CURIOSITIES

FACTS AND FALLACIES

BY

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PREFACE

The curious facts, fallacies, and paradoxes contained in the following pages have been collected from various sources. Most of the information given will not, I think, be found in popular works on astronomy, and will, it is hoped, prove of interest to the general reader.

J. E. G.

September, 1909.

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CHAPTER I

The Sun

SOME observations recently made by Prof. W. H. Pickering in Jamaica, make the value of sunlight 540,000 times that of moonlight. This makes the sun's "stellar magnitude" minus 26·83, and that of moonlight minus 12·5. Prof. Pickering finds that the light of the full moon is equal to 100,000 stars of zero magnitude. He finds that the moon's "albedo" is about 0·0909; or in other words, the moon reflects about one-tenth of the light which falls on it from the sun. He also finds that the light of the full moon is about twelve times the light of the half moon: a curious and rather unexpected result.

M. C. Fabry found that during the total eclipse of the sun on August 30, 1905, the light of the corona at a distance of five minutes of arc from the sun's limit, and in the vicinity of the sun's equator, was about 720 candle-power. Comparing this with the intrinsic light of the full moon (2600 candle-power) we have the ratio of 0·28 to 1. He finds that the light of the sun in the zenith, and at its mean distance from the earth, is 100,000 times greater than the light of a "decimal candle" placed at a distance of one metre from the eye.[1] He also finds that sunlight is equal to 60,000 million times the light of Vega. This would make the sun's "stellar magnitude" minus 26·7, which does not differ much from Prof. Pickering's result, given above, and is probably not far from the truth.

From experiments made in 1906 at Moscow, Prof. Ceraski found that the light of the sun's limb is only 31·4 to 38·4 times brighter than the illumination of the earth's atmosphere very near the limb. This is a very unexpected result; and considering the comparative faintness of the sun's corona during a total eclipse, it is not surprising that all attempts to photograph it without an eclipse have hitherto failed.[2]

From Paschen's investigations on the heat of the sun's surface, he finds a result of 5961° (absolute), "assuming that the sun is a perfectly black body."[3] Schuster finds that "There is a stratum near the sun's surface having an average temperature of approximately 5500° C., to which about 0·3 of the sun's radiation is due. The remaining portion of the radiation has an intensity equal to that due to a black body having a temperature of about 6700° C." The above results agree fairly well with those found by the late Dr. W. E. Wilson.[4] The assumption of the sun being "a black body" seems a curious paradox; but the simple meaning of the statement is that the sun is assumed to act as a radiator as *if it were a perfectly black body heated to the high temperature given above*.

According to Prof. Langley, the sun's photosphere is 5000 times brighter than the molten metal in a "Bessemer convertor."[5]

Observations of the sun even with small telescopes and protected by dark glasses are very dangerous to the eyesight. Galileo blinded himself in this way; Sir William Herschel lost one of his eyes; and some modern observers have also suffered. The present writer had a narrow escape from permanent injury while observing the transit of Venus, in 1874, in India, the dark screen before the eyepiece of a 3-inch telescope having blistered—that is, partially fused during the observation. Mr. Cooper, Markree Castle, Ireland, in observing the sun, used a "drum" of alum water and dark spectacles, and found this sufficient protection against the glare in using his large refracting telescope of 13·3-inches aperture.

Prof. Mitchell, of Columbia University (U.S.A.), finds that lines due to the recently discovered atmospherical gases argon and neon are present in the spectrum of the sun's chromosphere. The evidence for the existence of krypton and xenon is, however, inconclusive. Prof. Mitchell suggests that these gases may possibly have reached the earth's atmosphere from the sun. This would agree with the theory advanced by Arrhenius that "ionised particles are constantly being repulsed by the pressure of light, and thus journey from one sun to another."[6]

Prof. Young in 1870, and Dr. Kreusler in June, 1904, observed the helium line D_3 as a *dark* line "in the spectrum of the region about a sun-spot."[7] This famous line, from which helium was originally discovered in the sun, and by which it was long afterwards detected in terrestrial minerals, usually appears as a *bright* line in the spectrum of the solar chromosphere and "prominences." It has also been seen *dark* by Mr. Buss in sun-spot regions. [8]

The discovery of sun-spots was claimed by Hariotte, in 1610, and by Galileo, Fabricius, and Scheiner, in 1611. The latter wrote 800 pages on them, and thought they were small planets revolving round the sun! This idea was also held by Tardè, who called them *Astra Borbonia*, and by C. Malapert, who termed them *Sydera Austricea*. But they seem to have been noticed by the ancients.

Although in modern times there has been no extraordinary development of sun-spots at the epoch of maximum, it is not altogether impossible that in former times these spots may have occasionally increased to such an extent, both in number and size, as to have perceptibly darkened the sun's light. A more probable explanation of recorded sun-darkenings seems, however, to be the passing of a meteoric or nebulous cloud between the sun and the earth. A remarkable instance of sun-darkening recorded in Europe occurred on May 22, 1870, when the sun's light was observed to be considerably reduced in a cloudless sky in the west of Ireland, by the late John Birmingham; at Greenwich on the 23rd; and on the same date, but at a later hour, in North-Eastern France—"a progressive manifestation," Mr. Birmingham says, "that seems to accord well with the hypothesis of moving nebulous matter." A similar phenomenon was observed in New England (U.S.A.), on September 6, 1881.

One of the largest spots ever seen on the sun was observed in June, 1843. It remained visible for seven or eight days. According to Schwabe—the discoverer of the sun-spot period—its diameter was 74,000 miles, so that its area was many times that of the earth's surface. The most curious thing about this spot was that it appeared near a *minimum* of the sun-spot cycle! and was therefore rather an anomalous phenomenon. It was suggested by the late Daniel Kirkwood that this great spot was caused by the fall of meteoric matter into the sun; and that it had possibly some connection with the great comet of 1843, which approached the sun nearer than any other recorded comet, its distance from the sun at perihelion being about 65,000 miles, or less than one-third of the moon's distance from the earth. This near approach of the comet to the sun occurred about three months before the appearance of the great sun-spot; and it seems probable that the spot was caused by the downfall of a large meteorite travelling in the wake of the comet.[9] The connection between comets and meteors is well known.

The so-called blackness of sun-spots is merely relative. They are really very bright. The most brilliant light which can be produced artificially looks like a black spot when projected on the sun’s disc.

According to Sir Robert Ball a pound of coal striking a body with a velocity of five miles a second would develop as much heat as it would produce by its combustion. A body falling into the sun from infinity would have a velocity of 450 miles a second when it reached the sun’s surface. Now as the momentum varies as the square of the velocity we have a pound of coal developing 90^2 $(= 450/5)^2$, or 8,100 times as much heat as would be produced by its combustion. If the sun were formed of coal it would be consumed in about 3000 years. Hence it follows that the contraction of the sun’s substance from infinity would produce a supply of heat for 3000 × 8100, or 24,300,000 years.

The late Mr. Proctor and Prof. Young believed “that the contraction theory of the sun’s heat is the true and only available theory.” The theory is, of course, a sound one; but it may now be supplemented by supposing the sun to contain a certain small amount of radium. This would bring physics and geology into harmony. Proctor thought the “sun’s real globe is very much smaller than the globe we see. In other words the process of contraction has gone on further than, judging from the sun’s apparent size, we should suppose it to have done, and therefore represents more sun work” done in past ages.

With reference to the suggestion, recently made, that a portion, at least, of the sun’s heat may be due to radium, and the experiments which have been made with negative results, Mr. R. T. Strutt—the eminent physicist—has made some calculations on the subject and says, “even if all the sun’s heat were due to radium, there does not appear to be the smallest possibility that the Becquerel radiation from it could ever be detected at the earth’s surface.”[10]

The eminent Swedish physicist Arrhenius, while admitting that a large proportion of the sun's heat is due to contraction, considers that it is probably the chemical processes going on in the sun, and not the contraction which constitute the *chief* source of the solar heat.[11]

As the centre of gravity of the sun and Jupiter lies at a distance of about 460,000 miles from the sun's centre, and the sun's radius is only 433,000 miles, it follows that the centre of gravity of the sun and planet is about 27,000 miles *outside* the sun's surface. The attractions of the other planets perpetually change the position of the centre of gravity of the solar system; but in some books on astronomy it is erroneously stated that the centre of gravity of the system is *always* within the sun's surface. If *all* the planets lay on the same side of the sun at the same time (as might possibly happen), then the centre of gravity of the whole system would lie considerably more than 27,000 miles outside the sun's surface.

With reference to the sun's great size, Carl Snyder has well said, "It was as if in Vulcan's smithy the gods had moulded one giant ball, and the planets were but bits and small shot which had spattered off as the glowing ingot was cast and set in space. Little man on a little part of a little earth—a minor planet, a million of which might be tumbled into the shell of the central sun—was growing very small; his wars, the convulsions of a state, were losing consequence. Human endeavour, human ambitions could now scarce possess the significance they had when men could regard the earth as the central fact of the universe."[12]

With reference to the late Prof. C. A. Young (U.S.A.)—a great authority on the sun—an American writer has written the following lines:—

"The destined course of whirling worlds to trace,
To plot the highways of the universe,
And hear the morning stars their song rehearse,
And find the wandering comet in his place;
This is the triumph written in his face,
And in the gleaming eye that read the sun
Like open book, and from the spectrum won
The secrets of immeasurable space."[13]

CHAPTER II

Mercury

AS the elongation of Mercury from the sun seldom exceeds 18°, it is a difficult object, at least in this country, to see without a telescope. As the poet says, the planet—

> "Can scarce be caught by philosophic eye
> Lost in the near effulgence of its blaze."

Tycho Brahé, however, records several observations of Mercury with the unaided vision in Denmark.

It can be occasionally caught with the naked eye in this country after sunset, when it is favourably placed for observation, and I have so seen it several times in Ireland. On February 19, 1888, I found it very visible in strong twilight near the western horizon, and apparently brighter than an average star of the first magnitude would be in the same position. In the clear air of the Punjab sky I observed Mercury on November 24-29, 1872, near the western horizon after sunset. Its appearance was that of a reddish star of the first magnitude. On November 29 I compared its brilliancy with that of Saturn, which was some distance above it, and making allowance for the glare near the horizon in which Mercury was immersed, its brightness appeared to me to be quite equal to that of Saturn. In June, 1874, I found it equal to Aldebaran, and of very much the same colour. Mr. W. F. Denning, the famous observer of meteors, states that he observed Mercury with the naked eye about 150 times during the years 1868 to 1905.[14]

He found that the duration of visibility after sunset is about 1^h 40^m when seen in March, 1^h 30^m in April, and 1^h 20^m in May. He thinks that the planet is, at its brightest, "certainly much brighter than a first magnitude star."[15] In February, 1868, he found that its brightness rivalled that of Jupiter, then only 2° or 3° distant. In November, 1882, it seemed brighter than Sirius. In 1876 it was more striking than Mars, but the latter was then "faint and at a considerable distance from the earth."

In 1878, when Mercury and Venus were in the same field of view of a telescope, Nasmyth found that the surface brightness (or "intrinsic brightness," as it is called) of Venus was at least twice as great as that of Mercury; and Zöllner found that from a photometric point of view the surface of Mercury is comparable with that of the moon.

With reference to the difficulty of seeing Mercury, owing to its proximity to the sun, Admiral Smyth says, "Although Mercury is never in *opposition* to the earth, he was, when in the house of Mars, always viewed by astrologers as a most malignant planet, and one full of evil influences. The sages stigmatized him as a false deceitful star (*sidus dolosum*), the eternal torment of astronomers, eluding them as much as terrestrial mercury did the alchemists; and Goad, who in 1686 published a whole folio volume full of astro-meteorological aphorisms, unveiling the choicest secrets of nature, contemptuously calls Mercury a 'squinting lacquey of the sun, who seldom shows his head in these parts, as if he was in debt.' His extreme mobility is so striking that chemists adopted his symbol to denote quicksilver."[16]

Prof. W. H. Pickering thinks that the shortness of the cusps (or "horns") of Mercury's disc indicates that the planet's atmosphere is of small density—even rarer than that of Mars.

The diameter of Mercury is usually stated at about 3000 miles; but a long series of measures made by Prof. See in the year 1901 make the real diameter about 2702 miles. This would make the planet smaller than some of the satellites of the large planets, probably smaller than satellites III. and IV. of Jupiter, less than Saturn's satellite Titan, and possibly inferior in size to the satellite of Neptune. Prof. Pickering thinks that the density of Mercury is about 3 (water = 1). Dr. See's observations show "no noticeable falling off in the brightness of Mercury near the limb." There is therefore no evidence of any kind of atmospheric absorption in Mercury, and the observer "gets the impression that the physical condition of the planet is very similar to that of our moon."[17]

Schröter (1780-1815) observed markings on Mercury, from which he inferred that the planet's surface was mountainous, and one of these mountains he estimated at about 11 miles in height![18] But this seems very doubtful.

To account for the observed irregularities in the motion of Mercury in its orbit, Prof. Newcomb thinks it possible that there may exist a ring or zone of "asteroids" a little "outside the orbit of Mercury" and having a combined mass of "one-fiftieth to one-three-hundredth of the mass of Venus, according to its distance from Mercury." Prof. Newcomb, however, considers that the existence of such a ring is extremely improbable, and regards it "more as a curiosity than a reality."[19]

M. Léo Brenner thinks that he has seen the dark side of Mercury, in the same way that the dark side of Venus has been seen by many observers. In the case of Mercury the dark side appeared *darker* than the background of the sky. Perhaps this may be due to its being projected on the zodiacal light, or outer envelope of the sun.[20]

Mercury is said to have been occulted by Venus in the year 1737.[21] But whether this was an actual occultation, or merely a near approach does not seem to be certain.

The first transit of Mercury across the sun's disc was observed by Gassendi on November 6, 1631, and Halley observed one on November 7, 1677, when in the island of St. Helena.

Seen from Mercury, Venus would appear brighter than even we see it, and as it would be at its brightest when in opposition to the sun, and seen on a dark sky with a full face, it must present a magnificent appearance in the midnight sky of Mercury. The earth will also form a brilliant object, and the moon would be distinctly visible. The other planets would appear very much as they do to us, but with somewhat less brilliancy owing to their greater distance.

As the existence of an intra-Mercurial planet (that is a planet revolving round the sun within the orbit of Mercury) seems now to be very improbable, Prof. Perrine suggests that possibly "the finely divided matter which produces the zodiacal light when considered in the aggregate may be sufficient to cause the perturbations in the orbit of Mercury."[22] Prof. Newcomb, however, questions the exact accuracy of Newton's law, and seems to adopt Hall's hypothesis that gravity does not act *exactly* as the inverse square of the distance, and that the exponent of the distance is not 2, but 2·0000001574.[23]

Voltaire said, "If Newton had been in Portugal, and any Dominican had discovered a heresy in his inverse ratio of the squares of the distances, he would without hesitation have been clothed in a *san benito*, and burnt as a sacrifice to God at an *auto da fé*."[24]

An occultation of Mercury by Venus was observed with a telescope on May 17, 1737.[25]

May transits of Mercury across the sun's disc will occur in the years 1924, 1957, and 1970; and November transits in the years 1914, 1927, and 1940.[26]

From measurements of the disc of Mercury during the last transit, M. R. Jonckheere concludes that the *polar* diameter of the planet is greater than the *equatorial*! His result, which is very curious, if true, seems to be supported by the observations of other observers.[27]

The rotation period of Mercury, or the length of its day, seems to be still in doubt. From a series of observations made in the years 1896 to 1909, Mr. John McHarg finds a period of 1·0121162 day, or 1^{d} 0^{h} 17^{m} 26^{s}·8. He thinks that "the planet possesses a considerable atmosphere not so clear as that of Mars"; that "its axis is very considerably tilted"; and that it "has fairly large sheets of water."[28]

CHAPTER III

Venus

VENUS was naturally—owing to its brightness—the first of the planets known to the ancients. It is mentioned by Hesiod, Homer, Virgil, Martial, and Pliny; and Isaiah's remark about "Lucifer, son of the morning" (Isaiah xiv. 12) probably refers to Venus as a "morning star." An observation of Venus is found on the Nineveh tablets of date B.C. 684. It was observed in daylight by Halley in July, 1716.

In *very* ancient times Venus, when a morning star, was called Phosphorus or Lucifer, and when an evening star Hesperus; but, according to Sir G. C. Lewis, the identity of the two objects was known so far back as 540 B.C.

When Venus is at its greatest brilliancy, and appears as a morning star about Christmas time (which occurred in 1887, and again in 1889), it has been mistaken by the public for a return of the "Star of Bethlehem."[29] But whatever "the star of the Magi" was it certainly was *not* Venus. It, seems, indeed absurd to suppose that "the wise men" of the East should have mistaken a familiar object like Venus for a strange apparition. There seems to be nothing whatever in the Bible to lead us to expect that the star of Bethlehem will reappear.

Mr. J. H. Stockwell has suggested that the "Star of Bethlehem" may perhaps be explained by a conjunction of the planets Venus and Jupiter which occurred on May 8, B.C. 6, which was two years before the death of Herod. From this it would follow that the Crucifixion took place on April 3, A.D. 33. But it seems very doubtful that the phenomenon recorded in the Bible refers to any conjunction of planets.

Chacornac found the intrinsic brightness of Venus to be ten times greater than the most luminous parts of the moon.[30] But this estimate is probably too high.

When at its brightest, the planet is visible in broad daylight to good eyesight, if its exact position in the sky is known. In the clear air of Cambridge (U.S.A.) it is said to be possible to see it in this way in all parts of its orbit, except when the planet is within 10° of the sun.[31] Mr. A. Cameron, of Yarmouth, Nova Scotia, has, however, seen Venus with the naked eye three days before conjunction when the planet was only 6¼° from the sun.[32] This seems a remarkable observation, and shows that the observer's eyesight must have been very keen. In a private letter dated October 22, 1888, the late Rev. S. J. Johnson informed the present writer that he saw Venus with the naked eye only four days before conjunction with the sun in February, 1878, and February, 1886.

The crescent shape of Venus is said to have been seen with the naked eye by Theodore Parker in America when he was only 12 years old. Other observers have stated the same thing; but the possibility of such an observation has been much disputed in recent years.

In the Chinese Annals some records are given of Venus having been seen in the Pleiades. On March 16, A.D. 845, it is said that "Venus eclipsed the Pleiades." This means, of course, that the cluster was apparently effaced by the brilliant light of the planet. Computing backwards for the above date, Hind found that on the evening of March 16, 845, Venus was situated near the star Electra; and on the following evening the planet passed close to Maia; thus showing the accuracy of the Chinese record. Another "eclipse" of the Pleiades by Venus is recorded in the same annals as having occurred on March 10, A.D. 1002.[33]

When Venus is in the crescent phase, that is near "Inferior conjunction" with the sun, it will be noticed, even by a casual observer, that the crescent is not of the same shape as that of the crescent moon. The horns or "cusps" of the planetary crescent are more prolonged than in the case of the moon, and extend beyond the hemisphere. This appearance is caused by refraction of the sun's light through the planetary atmosphere, and is, in fact, a certain proof that Venus has an atmosphere similar to that of the earth. Observations further show that this atmosphere is denser than ours.

Seen from Venus, the earth and moon, when in opposition, must present a splendid spectacle. I find that the earth would shine as a star about half as bright again as Venus at her brightest appears to us, and the moon about equal in brightness to Sirius! the two forming a superb “naked eye double star”—perhaps the finest sight of its kind in the solar system.[34]

Some of the earlier observers, such as La Hire, Fontana, Cassini, and Schröter, thought they saw evidence of mountains on Venus. Schröter estimated some of these to be 27 or 28 miles in height! but this seems very doubtful. Sir William Herschel severely attacked these supposed discoveries. Schröter defended himself, and was supported by Beer and Mädler, the famous lunar observers. Several modern observers seem to confirm Schröter’s conclusions; but very little is really known about the topography of Venus.

The well-known French astronomer Trouvelot—a most excellent observer—saw white spots on Venus similar to those on Mars. These were well seen and quite brilliant in July and August, 1876, and in February and November, 1877. The observations seem to show that these spots do not (unlike Mars) increase and decrease with the planet’s seasons. These white spots had been previously noticed by former observers, including Bianchini, Derham, Gruithuisen, and La Hire; but these early observers do not seem to have considered them as snow caps, like those of Mars. Trouvelot was led by his own observations to conclude that the period of rotation of Venus is short, and the best result he obtained was $23^h\ 49^m\ 28^s$. This does not differ much from the results previously found by De Vico, Fritsch, and Schröter.[35]

A white spot near the planet’s south pole was seen on several occasions by H. C. Russell in May and June, 1876.[36]

Photographs of Venus taken on March 18 and April 29, 1908, by M. Quénisset at the Observatory of Juvissy, France, show a white polar spot. The spot was also seen at the same observatory by M. A. Benoit on May 20, 1903.

The controversy on the period of rotation of Venus, or the length of its day, is a very curious one and has not yet been decided. Many good observers assert confidently that it is short (about 24 hours); while others affirm with equal confidence that it is long (about 225 days, the period of the planet’s revolution round the sun). Among the observers who favour the short period of rotation are: D. Cassini (1667), J. Cassini (1730), Schröter (1788-93), Mädler (1836), De Vico (1840?) Trouvelot (1871-79), Flammarion, Léo Brenner, Stanley Williams, and J. McHarg; and among those who support the long period are: Bianchini (1727), Schiaparelli, Cerulli, Tacchini, Mascari, and Lowell. Some recent spectroscopic observations seem to favour the short period.

Flammarion thinks that "nothing certain can be descried upon the surface of Venus, and that whatever has hitherto been written regarding its period of rotation must be considered null and void"; and again he says, "Nothing can be affirmed regarding the rotation of Venus, inasmuch as the absorption of its immense atmosphere certainly prevents any detail on its surface from being perceived."[37]

The eminent Swedish physicist Arrhenius thinks, however, that the dense atmosphere and clouds of Venus are in favour of a rapid rotation on its axis.[38] He thinks that the mean temperature of Venus may "not differ much from the calculated temperature 104° F." "Under these circumstances the assumption would appear plausible that a very considerable portion of the surface of Venus, and particularly the districts about the poles, would be favourable to organic life."[39]

The "secondary light of Venus," or the visibility of the dark side, seems to have been first mentioned by Derham in his *Astro Theology* published in 1715. He speaks of the visibility of the dark part of the planet's disc "by the aid of a light of a somewhat dull and ruddy colour." The date of Derham's observation is not given, but it seems to have been previous to the year 1714. The light seems to have been also seen by a friend of Derham. We next find observations by Christfried Kirch, assistant astronomer to the Berlin Academy of Sciences, on June 7, 1721, and March 8, 1726. These observations are found in his original papers, and were printed in the *Astronomische Nachrichten*, No. 1586. On the first date the telescopic image of the planet was "rather tremulous," but in 1726 he noticed that the dark part of the circle seemed to belong to a smaller circle than the illuminated portion of the disc.[40] The same effect was also noted by Webb.[41] A similar illusion is seen in the case of the crescent moon, and this has given rise to the saying, "the old moon in the new moon's arms."

We next come, in order of date, to an observation made by Andreas Mayer, Professor of Mathematics at Griefswald in Prussia. The observation was made on October 20, 1759, and the dark part of Venus was seen distinctly by Mayer. As the planet's altitude at the time was not more than 14° above the horizon, and its apparent distance from the sun only 10°, the phenomenon—as Professor Safarik has pointed out—"must have had a most unusual intensity."

Sir William Herschel makes no mention of having ever seen the "secondary light" of Venus, although he noticed the extension of the horns beyond a semicircle.

In the spring and summer of the year 1793, Von Hahn of Remplin in Mecklenburg, using excellent telescopes made by Dollond and Herschel, saw the dark part of Venus on several occasions, and describes the light as "grey verging upon brown."

Schröter of Lilienthal—the famous observer of the moon—saw the horns of the crescent of Venus extended many degrees beyond the semicircle on several occasions in 1784 and 1795, and the border of the dark part faintly lit up by a dusky grey light. On February 14, 1806, at 7 P.M. he saw the whole of the dark part visible with an ash-coloured light, and he was satisfied that there was no illusion. On January 24 of the same year, 1806, Harding at Göttingen, using a reflector of 9 inches aperture and power 84, saw the dark side of Venus "shining with a pale ash-coloured light," and very visible against the dark background of the sky. The appearance was seen with various magnifying powers, and he thought that there could be no illusion. In fact the phenomenon was as evident as in the case of the moon. Harding again saw it on February 28 of the same year, the illumination being of a reddish grey colour, "like that of the moon in a total eclipse."

The "secondary light" was also seen by Pastorff in 1822, and by Gruithuisen in 1825. Since 1824 observations of the "light" were made by Berry, Browning, Guthrie, Langdon, Noble, Prince, Webb, and others. Webb saw it with powers of 90 and 212 on a 9·38-inch mirror, and found it "equally visible when the bright crescent was hidden by a field bar."[42]

Captain Noble's observation was rather unique. He found that the dark side was "always distinctly and positively *darker* than the background upon which it is projected.”

The “light” was also seen by Lyman in America in 1867, and by Safarik at Prague. In 1871 the whole disc of Venus was seen by Professor Winnecke.[43] On the other hand, Winnecke stated that he only saw it twice in 24 years; and the great observers Dawes and Mädler never saw it at all![44]

Various attempts have been made to explain the visibility—at times—of the “dark side” of Venus. The following may be mentioned[45]:—(1) Reflected earth-light, analogous to the dark side of the crescent moon. This explanation was advocated by Harding, Schröter, and others. But, although the earth is undoubtedly a bright object in the sky of Venus, the explanation is evidently quite inadequate. (2) Phosphorescence of the planet’s atmosphere. This has been suggested by some observers. (3) Visibility by contrast, a theory advanced by the great French astronomer Arago. (4) Illumination of the planet’s surface by an aurora borealis. This also seems rather inadequate, but would account for the light being sometimes visible and sometimes not. (5) Luminosity of the oceans—if there be any—on Venus. But this also seems inadequate. (6) A planetary surface glowing with intense heat. But this seems improbable. (7) The Kunstliche Feuer (artificial fire) of Gruithuisen, a very fanciful theory. Flammarion thinks that the visibility of the dark side may perhaps be explained by its projection on a somewhat lighter background, such as the zodiacal light, or an extended solar envelope.[46]

It will be seen that none of these explanations are entirely satisfactory, and the phenomenon, if real, remains a sort of astronomical enigma. The fact that the “light” is visible on some occasions and not on others would render some of the explanations improbable or even inadmissible. But the condition of the earth’s atmosphere at times might account for its invisibility on many occasions.

A curious suggestion was made by Zöllner, namely, that if the secondary light of Venus could be observed with the spectroscope it would show bright lines! But such an observation would be one of extreme difficulty.

M. Hansky finds that the visibility of the “light” is greater during periods of maximum solar activity—that is, at the maxima of sun spots. This he explains by the theory of Arrhenius, in which electrified “ions emitted by the sun cause the phenomena of terrestrial magnetic storms and auroras." "In the same way the dense atmosphere of Venus is rendered more phosphorescent, and therefore more easily visible by the increased solar activity."[47] This seems a very plausible hypothesis.

On the whole the occasional illumination of the night side of Venus by a very brilliant aurora (explanation (4) above) seems to the present writer to be the most probable explanation. Gruithuisen's hypothesis (7) seems utterly improbable.

There is a curious apparent anomaly about the motion of Venus in the sky. Although the planet's period of revolution round the sun is 224·7 days, it remains on the same side of the sun, as seen from the earth, for 290 days. The reason of this is that the earth is going at the same time round the sun in the same direction, though at a slower pace; and Venus must continue to appear on the same side of the sun until the excess of her daily motion above that of the earth amounts to 179°, and this at the daily rate of 37′ will be about 290 days.

Several observations have been recorded of a supposed satellite of Venus. But the existence of such a body has never been verified. In the year 1887, M. Stroobant investigated the various accounts, and came to the conclusion that in several at least of the recorded observations the object seen was certainly a star. Thus, in the observation made by Rœdickœr and Boserup on August 4, 1761, a satellite and star are recorded as having been seen near the planet. M. Stroobant finds that the supposed "satellite" was the star χ_4 Orionis, and the "star" χ_3 Orionis. A supposed observation of a satellite made by Horrebow on January 3, 1768, was undoubtedly θ Libræ. M. Stroobant found that the supposed motion of the "satellite" as seen by Horrebow is accurately represented by the motion of Venus itself during the time of observation. In most of the other supposed observations of a satellite a satisfactory identification has also been found. M. Stroobant finds that with a telescope of 6 inches aperture, a star of the 8th or even the 9th magnitude can be well seen when close to Venus.[49]

On the night of August 13, 1892, Professor Barnard, while examining Venus with the great 36-inch telescope of the Lick Observatory, saw a star of the 7th magnitude in the same field with the planet. He carefully determined the exact position of this star, and found that it is not in Argelander's great catalogue, the *Durchmusterung*. Prof. Barnard finds that owing to elongation of Venus from the sun at the time of observation the star could not possibly be an intra-Mercurial planet (that is, a planet revolving round the sun inside the orbit of Mercury); but that possibly it might be a planet revolving between the orbits of Venus and Mercury. As the brightest of the minor planets—Ceres, Pallas, Juno, and Vesta—were not at the time near the position of the observed object, the observation remains unexplained. It might possibly have been a *nova*, or temporary star.[50]

Scheuten is said to have seen a supposed satellite of Venus following the planet across the sun at the end of the transit of June 6, 1761.[51]

Humboldt speaks of the supposed satellite of Venus as among "the astronomical myths of an uncritical age."[52]

An occultation of Venus by the moon is mentioned in the Chinese Annals as having occurred on March 19, 361 A.D., and Tycho Brahé observed another on May 23, 1587.[53]

A close conjunction of Venus and Regulus (α Leonis) is recorded by the Arabian astronomer, Ibn Yunis, as having occurred on September 9, 885 A.D. Calculations by Hind show that the planet and star were within 2′ of arc on that night, and consequently would have appeared as a single star to the naked eye. The telescope had not then been invented.[54]

Seen from Venus, the maximum apparent distance between the earth and moon would vary from about 5′ to 31′.[55]

It is related by Arago that Buonaparte, when going to the Luxembourg in Paris, where the Directory were giving a fête in his honour, was very much surprised to find the crowd assembled in the Rue de Touracour "pay more attention to a region of the heavens situated above the palace than to his person or the brilliant staff that accompanied him. He inquired the cause and learned that these curious persons were observing with astonishment, although it was noon, a star, which they supposed to be that of the conqueror of Italy—an allusion to which the illustrious general did not seem indifferent, when he himself, with his piercing eyes, remarked the radiant body." The "star" in question was Venus.[56]

CHAPTER IV

The Earth

THE earth being our place of abode is, of course, to us the most important planet in the solar system. It is a curious paradox that the moon's surface (at least the visible portion) is better known to us than the surface of the earth. Every spot on the moon's visible surface equal in size to say Liverpool or Glasgow is well known to lunar observers, whereas there are thousands of square miles on the earth's surface—for example, near the poles and in the centre of Australia—which are wholly unknown to the earth's inhabitants; and are perhaps likely to remain so.

Many attempts have been made by "paradoxers" to show that the earth is a flat plane and not a sphere. But M. Ricco has found by actual experiment that the reflected image of the setting sun from a smooth sea is an elongated ellipse. This proves mathematically beyond all doubt that the surface of the sea is spherical; for the reflection from a plane surface would be necessarily *circular*. The theory of a "flat earth" is therefore proved to be quite untenable, and all the arguments (?) of the "earth flatteners" have now been —like the French Revolution—"blown into space."

The pole of minimum temperature in the northern hemisphere, or "the pole of cold," as it has been termed, is supposed to lie near Werchojansk in Siberia, where a temperature of nearly -70° has been observed.

From a series of observations made at Annapolis (U.S.A.) on the gradual disappearance of the blue of the sky after sunset, Dr. See finds that the extreme height of the earth's atmosphere is about 130 miles. Prof. Newcomb finds that meteors first appear at a mean height of about 74 miles.[57]

An aurora seen in Canada on July 15, 1893, was observed from stations 110 miles apart, and from these observations the aurora was found to lie at a height of 166 miles above the earth's surface. It was computed that if the auroral "arch maintained an equal height above the earth its ends were 1150 miles away, so that the magnificent sight was presented of an auroral belt in the sky with 2300 miles between its two extremities."[58]

"Luminous clouds" are bright clouds sometimes seen at night near the end of June and beginning of July. They appear above the northern horizon over the sun's place about midnight, and evidently lie at a great height above the earth's surface. Observations made in Germany by Dr. Jesse, and in England by Mr. Backhouse, in the years 1885-91, show that the height of these clouds is nearly constant at about 51 miles.[59] The present writer has seen these remarkable clouds on one or two occasions in County Sligo, Ireland, during the period above mentioned.

M. Montigny has shown that "the approach of violent cyclones or other storms is heralded by an increase of scintillation" (or twinkling of the stars). The effect is also very evident when such storms pass at a considerable distance. He has also made some interesting observations (especially on the star Capella), which show that, not only does scintillation increase in rainy weather, but that "it is very evident, at such times, in stars situated at an altitude at which on other occasions it would not be perceptible at all; thus confirming the remark of Humboldt's with regard to the advent of the wet season in tropical countries."[60]

In a paper on the subject of "Optical Illusions" in *Popular Astronomy*, February, 1906, Mr. Arthur K. Bartlett, of Batter Creek, Michigan (U.S.A.), makes the following interesting remarks:—

"The lunar halo which by many persons is regarded as a remarkable and unexplained luminosity associated with the moon, is to meteorological students neither a mysterious nor an anomalous occurrence. It has been frequently observed and for many years thoroughly understood, and at the present time admits of an easy scientific explanation. It is an atmospheric exhibition due to the refraction and dispersion of the moon's light through very minute ice crystals floating at great elevations above the earth, and it is explained by the science of meteorology, to which it properly belongs; for it is not of cosmical origin, and in no way pertains to astronomy, as most persons suppose, except as it depends on the moon, whose light passing through the atmosphere, produces the luminous halo, which as will be seen, is simply an optical illusion, originating, not in the vicinity of the moon—two hundred and forty thousand miles away—but just above the earth's surface, and within the aqueous envelope that surrounds it on all sides.... A halo may form round the sun as well as the moon ... but a halo is more frequently noticed round the moon for the reason that we are too much dazzled by the sun's light to distinguish faint colours surrounding its disc, and to see them it is necessary to look through smoked glass, or view the sun by reflection from the surface of still water, by which its brilliancy is very much reduced."...

"A 'corona' is an appearance of faintly coloured rings often seen around the sun and moon when a light fleecy cloud passes over them, and should not be mistaken for a halo, which is much larger and more complicated in its structure. These two phenomena are frequently confounded by inexperienced observers." With these remarks the present writer fully concurs.

Mr. Bartlett adds—

"As a halo is never seen except when the sky is hazy, it indicates that moisture is accumulating in the atmosphere which will form clouds, and usually result in a storm. But the popular notion that the number of bright stars visible within the circle indicates the number of days before the storm will occur, is without any foundation whatever, and the belief is almost too absurd to be refuted. In whatever part of the sky a lunar halo is seen, one or more bright stars are always sure to be noticed inside the luminous ring, and the number visible depends entirely upon the position of the moon. Moreover, when the sky within the circle is examined with even a small telescope, hundreds of stars are visible where only one, or perhaps two or three, are perceived with the naked eye."

It is possible to have five Sundays in February (the year must of course be a "leap year"). This occurred in the year 1880, Sunday falling on February 1, 8, 15, 22, and 29. But this will not happen again till the year 1920. No century year (such as 1900, 2000, etc.) could possibly have five Sundays in February, and the Rev. Richard Campbell, who investigated this matter, finds the following sequence of years in which five Sundays occur in

February: 1604, 1632, 1660, 1688, 1728, 1756, 1784, 1824, 1852, 1880, 1920, 1948, 1976.[61]

In an article on “The Last Day and Year of the Century: Remarks on Time Reckoning,” in *Nature*, September 10, 1896, Mr. W. T. Lynn, the eminent astronomer, says, “The late Astronomer Royal, Sir George Airy, once received a letter requesting him to settle a dispute which had arisen in some local debating society, as to which would be the first day of the next century. His reply was, ‘A very little consideration will suffice to show that the first day of the twentieth century will be January 1, 1901.’ Simple as the matter seems, the fact that it is occasionally brought into question shows that there is some little difficulty connected with it. Probably, however, this is in a great measure due to the circumstance that the actual figures are changed on January 1, 1900, the day preceding being December 31, 1899. A century is a very definite word for an interval respecting which there is no possible room for mistake or difference of opinion. But the date of its ending depends upon that of its beginning. Our double system of backward and forward reckoning leads to a good deal of inconvenience. Our reckoning supposes (what we know was not the case, but as an era the date does equally well) that Christ was born at the end of B.C. 1. At the end of A.D. 1, therefore, one year had elapsed from the event, at the end of A.D. 100, one century, and at the end of 1900, nineteen centuries.... It is clear, then, that the year, as we call it, is an ordinal number, and that 1900 years from the birth of Christ (reckoning as we do from B.C. 1) will not be completed until the end of December 31 in that year, the twentieth century beginning with January 1, 1901, that is (to be exact) at the previous midnight, when the day commences by civil reckoning.” With these remarks of Mr. Lynn I fully concur, and, so far as I know, all astronomers agree with him. As the discussion will probably again arise at the end of the twentieth century, I would like to put on record here what the scientific opinion was at the close of the nineteenth century.

Prof. E. Rutherford, the well-known authority on radium, suggests that possibly radium is a source of heat from within the earth. Traces of radium have been detected in many rocks and soils, and even in sea water. Calculation shows that the total amount distributed through the earth’s crust is enormously large, although relatively small “compared with the annual output of coal for the world.” The amount of radium necessary to compensate for the present loss of heat from the earth "corresponds to only five parts in one hundred million millions per unit mass," and the "observations of Elster and Gertel show that the radio-activity observed in soils corresponds to the presence of about this proportion of radium."[62]

The earth has 12 different motions. These are as follows:—

1. Rotation on its axis, having a period of 24 hours.

2. Revolution round the sun; period 365¼ days.

3. Precession; period of about 25,765 years.

4. Semi-lunar gravitation; period 28 days.

5. Nutation; period 18½ years.

6. Variation in obliquity of the ecliptic; about 47″ in 100 years.

7. Variation of eccentricity of orbit.

8. Change of line of apsides; period about 21,000 years.

9. Planetary perturbations.

10. Change of centre of gravity of whole solar system.

11. General motion of solar system in space.

12. Variation of latitude with several degrees of periodicity.[63]

"An amusing story has been told which affords a good illustration of the ignorance and popular notions regarding the tides prevailing even among persons of average intelligence. 'Tell me,' said a man to an eminent living English astronomer not long ago, 'is it still considered probable that the tides are caused by the moon?' The man of science replied that to the best of his belief it was, and then asked in turn whether the inquirer had any serious reason for questioning the relationship. 'Well, I don't know,' was the answer; 'sometimes when there is no moon there seems to be a tide all the same.'"![64]

With reference to the force of gravitation, on the earth and other bodies in the universe, Mr. William B. Taylor has well said, "With each revolving year new demonstrations of its absolute precision and of its universal domination serves only to fill the mind with added wonder and with added confidence in the stability and the supremacy of the power in which has been found no variableness neither shadow of turning, but which—the same yesterday, to-day and for ever—

> "Lives through all life, extends through all extent,
> Spreads undivided, operates unspent."[65]

With reference to the habitability of other planets, Tennyson has beautifully said—

> "Venus near her! smiling downwards at this earthlier earth of ours,
> Closer on the sun, perhaps a world of never fading flowers.
> Hesper, whom the poets call'd the Bringer home of all good things;
> All good things may move in Hesper; perfect people, perfect kings.
> Hesper—Venus—were we native to that splendour, or in Mars,
> We should see the globe we groan in fairest of their evening stars.
> Could we dream of war and carnage, craft and madness, lust and spite,
> Roaring London, raving Paris, in that spot of peaceful light?
> Might we not in glancing heavenward on a star so silver fair,
> Yearn and clasp the hands, and murmur, 'Would to God that we were there!'"

The ancient Greek writer, Diogenes Laertius, states that Anaximander (610-547 B.C.) believed that the earth was a sphere. The Greek words are: μίσην τε τὴν γήν κεῖσθαι, κέντρυ τάξιν ἐπεχοῦσαν οὺσαν σφαιροειδῆ.[66]

With reference to the Aurora Borealis, the exact nature of which is not accurately known, "a good story used to be told some years ago of a candidate who, undergoing the torture of a *vivâ voce* examination, was unable to reply satisfactorily to any of the questions asked. 'Come, sir,' said the examiner, with the air of a man asking the simplest question, ‘explain to me the cause of the aurora borealis.’ ‘Sir,’ said the unhappy aspirant for physical honours, ‘I could have explained it perfectly yesterday, but nervousness has, I think, made me lose my memory.’ ‘This is very unfortunate,’ said the examiner; ‘you are the only man who could have explained this mystery, and you have forgotten it.’”[67] This was written in the year 1899, and probably the phenomenon of the aurora remains nearly as great a mystery to-day. In 1839, MM. Bravais and Lottin made observations on the aurora in Norway in about N. latitude 70°. Bravais found the height to be between 62 and 93 miles above the earth’s surface.

The cause of the so-called Glacial Epoch in the earth’s history has been much discussed. The Russian physicist, Rogovsky, has advanced the following theory—

“If we suppose that the temperature of the sun at the present time is still increasing, or at least has been increasing until now, the glacial epoch can be easily accounted for. Formerly the earth had a high temperature of its own, but received a lesser quantity of heat from the sun than now; on cooling gradually, the earth’s surface attained such a temperature as caused a great part of the surface of the northern and southern hemispheres to be covered with ice; but the sun’s radiation increasing, the glaciers melted, and the climatic conditions became as they are now. In a word, the temperature of the earth’s surface is a function of two quantities: one decreasing (the earth’s own heat), and the other increasing (the sun’s radiation), and consequently there may be a minimum, and this minimum was the glacial epoch, which, as shown by recent investigations, those of Luigi de Marchi (Report of *G. Schiaparelli, Meteorolog. Zeitschr.*, 30, 130-136, 1895), are not local, but general for the whole earth” (see also M. Neumahr, *Erdegeschicht*).[68]

Prof. Percival Lowell thinks that the life of geological palæozoic times was supported by the earth’s internal heat, which maintained the ocean at a comparatively warm temperature.[69]

The following passage in the Book of the Maccabees may possibly refer to an aurora—

“Now about this time Antiochus made his second inroad into Egypt. And it *so* befell that throughout all the city, for the space of almost forty days, there appeared in the midst of the sky horsemen in swift motion, wearing robes inwrought with gold and *carrying* spears, equipped in troops for battle; and drawing of swords; and *on the other side* squadrons of horse in array; and encounters and pursuits of both armies; and shaking of shields, and multitudes of lances, and casting of darts, and flashing of golden trappings, and girding on of all sorts of armour. Wherefore all men besought that the vision might have been given for food.”[70]

According to Laplace “the decrease of the mean heat of the earth during a period of 2000 years has not, taking the extremist limits, diminished as much as $\frac{1}{300}$th of a degree Fahrenheit.”[71]

From his researches on the cause of the Precession of the Equinoxes, Laplace concluded that “the motion of the earth’s axis is the same as if the whole sea formed a solid mass adhering to its surface.”[72]

Laplace found that the major (or longer) axis of the earth’s orbit coincided with the line of Equinoxes in the year 4107 B.C. The earth’s perigee then coincided with the autumnal equinox. The epoch at which the major axis was perpendicular to the line of equinoxes fell in the year 1250 A.D.[73]

Leverrier has found the minimum eccentricity of the earth’s orbit round the sun to be 0·0047; so that the orbit will never become absolutely circular, as some have imagined.

Laplace says—

“Astronomy considered in its entirety is the finest monument of the human mind, the noblest essay of its intelligence. Seduced by the illusions of the senses and of self-pride, for a long time man considered himself as the centre of the movement of the stars; his vain-glory has been punished by the terrors which his own ideas have inspired. At last the efforts of several centuries brushed aside the veil which concealed the system of the world. We discover ourselves upon a planet, itself almost imperceptible in the vast extent of the solar system, which in its turn is only an insensible point in the immensity of space. The sublime results to which this discovery has led should suffice to console us for our extreme littleness, and the rank which it assigns to the earth. Let us treasure with solicitude, let us add to as we may, this store of higher knowledge, the most exquisite treasure of thinking beings."[74]

With reference to probable future changes in climate, the great physicist, Arrhenius, says—

"We often hear lamentation that the coal stored up in the earth is wasted by the present generation without any thought of the future, and we are terrified by the awful destruction of life and property which has followed the volcanic eruptions of our days. We may find a kind of consolation in the consideration that here, as in every other case, there is good mixed with evil. By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind."[75]

The night of July 1, 1908, was unusually bright. This was noticed in various parts of England and Ireland, and by the present writer in Dublin. Humboldt states that "at the time of the new moon at midnight in 1743, the phosphorescence was so intense that objects could be distinctly recognized at a distance of more than 600 feet."[76]

An interesting proof of the earth's rotation on its axis has recently been found.

"In a paper in the *Proceedings* of the Vienna Academy (June, 1908) by Herr Tumlirz, it is shown mathematically that if a liquid is flowing outwards between two horizontal discs, the lines of flow will be strictly straight only if the discs and vessel be at rest, and will assume certain curves if that vessel and the discs are in rotation, as, for example, due to the earth's rotation. An experimental arrangement was set up with all precautions, and the stream lines were marked with coloured liquids and photographed. These were in general accord with the predictions of theory and the supposition that the earth is rotating about an axis."[77]

In a book published in 1905 entitled *The Rational Almanac*, by Moses B. Cotsworth, of York, the author states that (p. 397), "The explanation is apparent from the Great Pyramid's Slope, which conclusively proves that when it was built the latitude of that region was 7°·1 more than at present. Egyptian Memphis now near Cairo was then in latitude 37°·1, where Asia Minor now ranges, whilst Syria would then be where the Caucasus regions now experience those rigorous winters formerly experienced in Syria." But the reality of this comparatively great change of latitude in the position of the Great Pyramid can be easily disproved. Pytheas of Marseilles—who lived in the time of Alexander the Great, about 330 B.C.—measured the latitude of Marseilles by means of a gnomon, and found it to be about 42° 56′½. As the present latitude of Marseilles is 43° 17′ 50″, no great change in the latitude could have taken place in over 2000 years.[78] From this we may conclude that the latitude of the Great Pyramid has *not* changed by 7°·1 since its construction. There is, it is true, a slow diminution going on in the obliquity of the ecliptic (or inclination of the earth's axis), but modern observations show that this would not amount to as much as one degree in 6000 years. Eudemus of Rhodes—a disciple of Aristotle (who died in 322 B.C.)—found the obliquity of the ecliptic to be 24°, which differs but little from its present value, 23° 27′. Al-Sufi in the tenth century measured the latitude of Schiraz in Persia, and found it 29° 36′. Its present latitude is 29° 36′ 30″,[79] so that evidently there has been no change in the latitude in 900 years.

CHAPTER V

The Moon

THE total area of the moon's surface is about equal to that of North and South America. The actual surface visible at any one time is about equal to North America.

The famous lunar observer, Schröter, thought that the moon had an atmosphere, but estimated its height at only a little over a mile. Its density he supposed to be less than that of the vacuum in an air-pump. Recent investigations, however, seem to show that owing to its small mass and attractive force the moon could not retain an atmosphere like that of the earth.

Prof. N. S. Shaler, of Harvard (U.S.A.), finds from a study of the moon (from a geological point of view) with the 15-inch refractor of the Harvard Observatory, that our satellite has no atmosphere nor any form of organic life, and he believes that its surface "was brought to its present condition before the earth had even a solid crust."[80]

There is a curious illusion with reference to the moon's apparent diameter referred to by Proctor.[81] If, when the moon is absent in the winter months, we ask a person whether the moon's diameter is greater or less than the distance between the stars δ and ε, and ε and ζ Orionis, the three well-known stars in the "belt of Orion," the answer will probably be that the moon's apparent diameter is about equal to each of these distances. But in reality the apparent distance between δ and ε Orionis (or between ε and ζ, which is about the same) is more than double the moon's apparent diameter. This seems at first sight a startling statement; but its truth is, of course, beyond all doubt and is not open to argument. Proctor points out that if a person estimates the moon as a foot in diameter, as its apparent diameter is about half a degree, this would imply that the observer estimates the circumference of the star sphere as about 720 feet (360° × 2), and hence the radius (or the moon's distance from the earth) about 115 feet. But in reality all such estimates have no scientific (that is, accurate) meaning. Some of the ancients, such as Aristotle, Cicero, and Heraclitus, seem to have estimated the moon's apparent diameter at about a foot.[82] This shows that even great minds may make serious mistakes.

It has been stated by some writer that the moon as seen with the highest powers of the great Yerkes telescope (40 inches aperture) appears "just as it would be seen with the naked eye if it were suspended 60 miles over our heads." But this statement is quite erroneous. The moon as seen with the naked eye or with a telescope shows us nearly a whole hemisphere of its surface. But if the eye were placed only 60 miles from the moon's surface, we should see only a small portion of its surface. In fact, it is a curious paradox that the nearer the eye is to a sphere the less we see of its surface! The truth of this will be evident from the fact that on a level plain an eye placed at a height, say 5 feet, sees a very small portion indeed of the earth's surface, and the higher we ascend the more of the surface we see. I find that at a distance of 60 miles from the moon's surface we should only see a small portion of its visible hemisphere (about $\frac{1}{90}$th). The lunar features would also appear under a different aspect. The view would be more of a landscape than that seen in any telescope. This view of the matter is not new. It has been previously pointed out, especially by M. Flammarion and Mr. Whitmell, but its truth is not, I think, generally recognized. Prof. Newcomb doubts whether with any telescope the moon has ever been seen so well as it would be if brought within 500 miles of the earth.

A relief map of the moon 19 feet in diameter was added, in 1898, to the Field Columbian Museum (U.S.A.). It was prepared with great care from the lunar charts of Beer and Mädler, and Dr. Schmidt of the Athens Observatory, and it shows the lunar features very accurately. Its construction took five years.

On a photograph of a part of the moon's surface near the crater Eratosthenes, Prof. William H. Pickering finds markings which very much resemble the so-called "canals" of Mars. The photograph was taken in Jamaica, and a copy of it is given in Prof. Pickering's book on the Moon, and in *Popular Astronomy*, February, 1904.

Experiments made in America by Messrs. Stebbins and F. C. Brown, by means of selenium cells, show that the light of the full moon is about nine times that of the half moon;[83] and that "the moon is brighter between the first quarter and full than in the corresponding phase after full moon." They also find that the light of the full moon is equal to "0·23 candle power,"[83] that is, according to the method of measurement used in America, its light is equal to 0·23 of a standard candle placed at a distance of one metre (39·37 inches) from the eye.[84]

Mr. H. H. Kimball finds that no less than 52 per cent. of the observed changes in intensity of the "earth-shine" visible on the moon when at or near the crescent phase is due to the eccentricity of the lunar orbit, and "this is probably much greater than could be expected from any increase or diminution in the average cloudiness over the hemisphere of the earth reflecting light to the moon."[85]

The "moon maiden" is a term applied to a fancied resemblance of a portion of the Sinus Iridum to a female head. It forms the "promontory" known as Cape Heraclides, and may be looked for when the moon's "age" is about 11 days. Mr. C. J. Caswell, who observed it on September 29, 1895, describes it as resembling "a beautiful silver statuette of a graceful female figure with flowing hair."

M. Landerer finds that the angle of polarization of the moon's surface—about 33°—agrees well with the polarizing angle for many specimens of igneous rocks (30° 51′ to 33° 46′). The polarizing angle for ice is more than 37°, and this fact is opposed to the theories of lunar glaciation advanced by some observers.[86]

Kepler states in his *Somnium* that he saw the moon in the crescent phase on the morning and evening of the *same* day (that is, before and after conjunction with the sun). Kepler could see 14 stars in the Pleiades with the naked eye, so his eyesight must have been exceptionally keen.

Investigations on ancient eclipses of the moon show that the eclipse mentioned by Josephus as having occurred before the death of Herod is probably that which took place on September 15, B.C. 5. This occurred about 9.45 p.m.; and probably about six months before the death of Herod (St. Matthew ii. 15).

The total lunar eclipse which occurred on October 4, 1884, was remarkable for the almost total disappearance of the moon during totality. One observer says that "in the open air, if one had not known exactly where to look for it, one might have searched for some time without discovering it. I speak of course of the naked eye appearance."[87] On the other hand the same observer, speaking of the total eclipse of the moon on August 23, 1877, which was a bright one, says—

"The moon even in the middle of the total phase was a conspicuous object in the sky, and the ruddy colour was well marked. In the very middle of the eclipse the degree of illumination was as nearly as possible equal all round the edge of the moon, the central parts being darker than those near the edge."

In Roger de Hovedin's *Chronicle* (A.D. 756) an account is given of the occultation of "a bright star," by the moon during a total eclipse. This is confirmed by Simeon of Durham, who also dates the eclipse A.D. 756. This is, however, a mistake, the eclipse having occurred on the evening of November 23, A.D. 755. Calvisius supposed that the occulted "star" might have been Aldebaran. Pingré, however, showed that this was impossible, and Struyck, in 1740, showed that the planet Jupiter was the "star" referred to by the early observer. Further calculations by Hind (1885) show conclusively that Struyck was quite correct, and that the phenomenon described in the old chronicles was the occultation of Jupiter by a totally eclipsed moon—a rather unique phenomenon.[88]

An occultation of Mars by the moon is recorded by the Chinese, on February 14, B.C. 69, and one of Venus, on March 30, A.D. 361. These have also been verified by Hind, and his calculations show the accuracy of these old Chinese records.

It has been suggested that the moon may possibly have a satellite revolving round it, as the moon itself revolves round the earth. This would, of course, form an object of great interest. During the total lunar eclipses of March 10 and September 3, 1895, a careful photographic search was made by Prof. Barnard for a possible lunar satellite. The eclipse of March 10 was not very suitable for the purpose owing to a hazy sky, but that of September 3 was "entirely satisfactory," as the sky was very clear, and the duration of totality was very long. On the latter occasion “six splendid” photographs were obtained of the total phase with a 6-inch Willard lens. The result was that none of these photographs “show anything which might be taken for a lunar satellite,” at least any satellite as bright as the 10th or 12th magnitude. It is, of course, just possible that the supposed satellite might have been behind the moon during the totality.

With reference to the attraction between the earth and moon, Sir Oliver Lodge says—

“The force with which the moon is held in its orbit would be great enough to tear asunder a steel rod 400 miles thick, with a tenacity of 30 tons to the square inch, so that if the moon and earth were connected by steel instead of gravity, a forest of pillars would be necessary to whirl the system once a month round their common centre of gravity. Such a force necessarily implies enormous tensure or pressure in the medium. Maxwell calculates that the gravitational stress near the earth, which we must suppose to exist in the invisible medium, is 3000 times greater than what the strongest steel can stand, and near the sun it should be 2500 times as great as that.”[89]

With reference to the names given to “craters” on the moon, Prof. W. H. Pickering says,[90] “The system of nomenclature is, I think, unfortunate. The names of the chief craters are generally those of men who have done little or nothing for selenography, or even for astronomy, while the men who should be really commemorated are represented in general by small and unimportant craters,” and again—

“A serious objection to the whole system of nomenclature lies in the fact that it has apparently been used by some selenographers, from the earliest times up to the present, as a means of satisfying their spite against some of their contemporaries. Under the guise of pretending to honour them by placing their names in perpetuity upon the moon, they have used their names merely to designate the smallest objects that their telescopes were capable of showing. An interesting illustration of this point is found in the craters of Galileo and Riccioli, which lie close together on the moon. It will be remembered that Galileo was the discoverer of the craters on the moon. Both names were given by Riccioli, and the relative size and importance of the craters [Riccioli large, and Galileo very small] probably indicates to us the relative importance that he assigned to the two men themselves. Other examples might be quoted of craters named in the same spirit after men still living.... With the exception of Maedler, one might almost say, the more prominent the selenographer the more insignificant the crater."

The mathematical treatment of the lunar theory is a problem of great difficulty. The famous mathematician, Euler, described it as *incredibile stadium atque indefessus labor*.[91]

With reference to the "earth-shine" on the moon when in the crescent phase, Humboldt says, "Lambert made the remarkable observation (14th of February, 1774) of a change of the ash-coloured moonlight into an olive-green colour, bordering upon yellow. The moon, which then stood vertically over the Atlantic Ocean, received upon its night side the green terrestrial light, which is reflected towards her when the sky is clear by the forest districts of South America."[92] Arago said, "Il n'est donc pas impossible, malgré tout ce qu'un pareil résultat exciterait de surprise au premier coup d'œil qu'un jour les météorologistes aillent puiser dans l'aspect de la Lune des notions précieuses sur *l'etat moyen* de diaphanité de l'atmosphère terrestre, dans les hemisphères qui successivement concurrent à la production de la lumière cendrée."[93]

The "earth-shine" on the new moon was successfully photographed in February, 1895, by Prof. Barnard at the Lick Observatory, with a 6-inch Willard portrait lens. He says—

"The earth-lit globe stands out beautifully round, encircled by the slender crescent. All the 'seas' are conspicuously visible, as are also the other prominent features, especially the region about *Tycho*. *Aristarchus* and *Copernicus* appear as bright specks, and the light streams from *Tycho* are very distinct."[94]

Kepler found that the moon completely disappeared during the total eclipse of December 9, 1601, and Hevelius observed the same phenomenon during the eclipse of April 25, 1642, when "not a vestige of the moon could be seen."[95] In the total lunar eclipse of June 10, 1816, the moon during totality was not visible in London, even with a telescope![95]

The lunar mountains are *relatively* much higher than those on the earth. Beer and Mädler found the following heights: Dörfel, 23,174 feet; Newton, 22,141; Casatus, 21,102; Curtius, 20,632; Callippus, 18,946; and Tycho, 18,748 feet.[96]

Taking the earth's diameter at 7912 miles, the moon's diameter, 2163 miles, and the height of Mount Everest as 29,000 feet, I find that

$$\frac{\text{Everest}}{\text{Earth's diameter}} = \frac{1}{1440}, \text{ and } \frac{\text{Dörfel}}{\text{moon's diameter}} = \frac{1}{492}$$

From which it follows that the lunar mountains are *proportionately* about three times higher than those on the earth.

According to an hypothesis recently advanced by Dr. See, all the satellites of the solar system, including our moon, were "captured" by their primaries. He thinks, therefore, that the "moon came to earth from heavenly space."[97]

CHAPTER VI

Mars

MARS was called by the ancients "the vanishing star," owing to the long periods during which it is practically invisible from the earth.[98] It was also called πυρόεις and Hercules.

I have seen it stated in a book on the "Solar System" by a well-known astronomer that the *axis* of Mars "is inclined to the plane of the orbit" at an angle of 24° 50′! But this is quite erroneous. The angle given is the angle between *the plane of the planet's equator* and the plane of its orbit, which is quite a different thing. This angle, which may be called the obliquity of Mars' ecliptic, does not differ much from that of the earth. Lowell finds it 23° 13′ from observations in 1907.[99]

The late Mr. Proctor thought that Mars is "far the reddest star in the heavens; Aldebaran and Antares are pale beside him."[100] But this does not agree with my experience. Antares is to my eye quite as red as Mars. Its name is derived from two Greek words implying "redder than Mars." The colour of Aldebaran is, I think, quite comparable with that of the "ruddy planet." In the telescope the colour of Mars is, I believe, more yellow than red, but I have not seen the planet very often in a telescope. Sir John Herschel suggested that the reddish colour of Mars may possibly be due to red rocks, like those of the Old Red Sandstone, and the red soil often associated with such rocks, as I have myself noticed near Torquay and other places in Devonshire.

The ruddy colour of Mars was formerly thought to be due to the great density of its atmosphere. But modern observations seem to show that the planet's atmosphere is, on the contrary, much rarer than that of the earth. The persistent visibility of the markings on its surface shows that its atmosphere cannot be cloud-laden like ours; and the spectroscope shows that the water vapour present is—although perceptible—less than that of our terrestrial envelope.

The existence of water vapour is clearly shown by photographs of the planet's spectrum taken by Mr. Slipher at the Lowell Observatory in 1908. These show that the water vapour bands *a* and near D are stronger in the spectrum of Mars than in that of the moon at the same altitude.[101]

The dark markings on Mars were formerly supposed to represent water and the light parts land. But this idea has now been abandoned. Light reflected from a water surface is polarized at certain angles. Prof. W. H. Pickering, in his observations on Mars, finds no trace of polarization in the light reflected from the dark parts of the planet. But under the same conditions he finds that the bluish-black ring surrounding the white polar cap shows a well-marked polarization of light, thus indicating that this dark ring is probably water.[102]

Projections on the limb of the planet have frequently been observed in America. These are known *not* to be mountains, as they do not reappear under similar conditions. They are supposed to be clouds, and one seen in December, 1900, has been explained as a cloud lying at a height of some 13 miles above the planet's surface and drifting at the rate of about 27 miles an hour. If there are any mountains on Mars they have not yet been discovered.

The existence of the so-called "canals" of Mars is supposed to be confirmed by Lowell's photographs of the planet. But what these "canals" really represent, that is the question. They have certainly an artificial look about them, and they form one of the most curious and interesting problems in the heavens. Prof. Lowell says—

"Most suggestive of all Martian phenomena are the canals. Were they more generally observable the world would have been spared much scepticism and more theory. They may of course not be artificial, but observations here [Flagstaff] indicate that they are; as will, I think, appear from the drawings. For it is one thing to see two or three canals and quite another to have the planet's disc mapped with them on a most elaborate system of triangulation. In the first place they are this season (August, 1894) bluish-green, of the same colour as the seas into which the longer ones all eventually debouch. In the next place they are almost without exception geodetically straight, supernaturally so, and this in spite of their leading in every possible direction. Then they are of apparently nearly uniform width throughout their length. What they are is another matter. Their mere aspect, however, is enough to cause all theories about glaciation fissures or surface cracks to die an instant and natural death."[103]

Some of the observed colour-changes on Mars are very curious. In April, 1905, Mr. Lowell observed that the marking known as Mare Erythræum, just above Syrtis, had "changed from a blue-green to a chocolate-brown colour." The season on Mars corresponded with our February.

Signor V. Cerulli says that, having observed Mars regularly for ten years, he has come to the conclusion that the actual existence of the "canals" is as much a subject for physiological as for astronomical investigation. He states that "the phenomena observed are so near the limit of the range of the human eye that in observing them one really experiences an effect accompanying the 'birth of vision.' That is to say, the eye sees more and more as it becomes accustomed, or strained, to the delicate markings, and thus the joining up of spots to form 'canals' and the gemination of the latter follow as a physiological effect, and need not necessarily be subjective phenomena seen by the unaccustomed eye."[104]

The possibility of life on Mars has been recently much discussed; some denying, others asserting. M. E. Rogovsky says—

"As free oxygen and carbonic dioxide may exist in the atmosphere of *Mars*, vegetable and animal life is quite possible. If the temperature which prevails upon *Mars* is nearer to -36° C. than to -73° C., the existence of living beings like ourselves is possible. In fact, the ice of some Greenland and Alpine glaciers is covered by red algæ (*Sphærella nivalis*); we find there also different species of rotaloria, variegated spiders, and other animals on the snow fields illuminated by the sun; at the edges of glacier snows in the Tyrol we see violet bells of *Soldanella pusilla*, the stalks of which make their way through the snow by producing heat which melts it round about them. Finally the Siberian town Verkhociansk, near Yakutsk, exists, though the temperature there falls to -69°·8 C. and the mean temperature of January to -51°·2, and the mean pressure of the vapour of water is less than 0·05mm. It is possible, therefore, that living beings have become adapted to the conditions now prevailing upon *Mars* after the lapse of many ages, and live at an even lower temperature than upon the earth, developing the necessary heat themselves."

M. Rogovsky adds, "Water in organisms is mainly a liquid or solvent, and many other liquids may be the same. We have no reason to believe that life is possible only under the same conditions and with the same chemical composition of organisms as upon the earth, although indeed we cannot affirm that they actually exist on Mars."[105] With the above views the present writer fully concurs.

Prof. Lowell thinks that the polar regions of Mars, both north and south, are actually warmer than the corresponding regions of the earth, although the mean temperature of the planet is probably twelve degrees lower than the earth's mean temperature.[106]

A writer in *Astronomy and Astrophysics* (1892, p. 748) says—

"Whether the planet Mars is inhabited or not seems to be the all-absorbing question with the ordinary reader. With the astronomer this query is almost the last thing about the planet that he would think of when he has an opportunity to study its surface markings ... no astronomer claims to know whether the planet is inhabited or not."

Several suggestions have been made with reference to the possibility of signalling to Mars. But, as Mr. Larkin of Mount Lowe (U.S.A.) points out, all writers on this subject seem to forget the fact that the night side of two planets are never turned towards each other. "When the sun is between them it is day on the side of Mars which is towards us, and also day on the side of the earth which is towards Mars. When they are on the same side of the sun, it is day on Mars when night on the earth, and for this reason they could never see our signals. This should make it apparent that the task of signalling to Mars is a more difficult one than the most hopeful theorist has probably considered. All this is under the supposition that the Martians (if there are such) are beings like ourselves. If they are not like us, we cannot guess what they are like."[107] These views seem to me to be undoubtedly correct, and show the futility of visual signals. Electricity might, however, be conceivably used for the purpose; but even this seems highly improbable.

Prof. Newcomb, in his work *Astronomy for Everybody*, says with reference to this question, “The reader will excuse me from saying nothing in this chapter about the possible inhabitants of Mars. He knows just as much about the subject as I do, and that is nothing at all.”

It is, however, quite possible that life *in some form* may exist on Mars. As Lowell well says, “Life but waits in the wings of existence for its cue to enter the scene the moment the stage is set.”[108] With reference to the “canals” he says—

“It is certainly no exaggeration to say that they are the most astonishing objects to be viewed in the heavens. There are celestial sights more dazzling, spectacles that inspire more awe, but to the thoughtful observer who is privileged to see them well, there is nothing in the sky so profoundly impressive as these canals of Mars.”[109]

The eminent Swedish physicist Arrhenius thinks that the mean annual temperature on Mars may possibly be as high as 50° F. He says, “Sometimes the snow-caps on the poles of Mars disappear entirely during the Mars summer; this never happens on our terrestrial poles. The mean temperature of Mars must therefore be above zero, probably about +10° [Centigrade = 50° Fahrenheit]. Organic life may very probably thrive, therefore, on Mars.”[110] He thinks that this excess of mean temperature above the calculated temperature may be due to an increased amount of carbonic acid in the planet’s atmosphere, and says “any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth’s surface by 4°; and if the carbon dioxide were increased fourfold, the temperature would rise by 8°.”[111]

Denning says,—[112]

“A few years ago, when christening celestial formations was more in fashion than it is now, a man simply had to use a telescope for an evening or two on Mars or the moon, and spice the relation of his seeings with something in the way of novelty, when his name would be pretty certainly attached to an object and hung in the heavens for all time! A writer in the *Astronomical Register* for January, 1879, humorously suggested that ‘the matter should be put into the hands of an advertising agent,’ and ‘made the means of raising a revenue for astronomical purposes.’ Some men would not object to pay handsomely for the distinction of having their names applied to the seas and continents of Mars or the craters of the moon."

An occultation of Mars by the moon is recorded by Aristotle as having occurred on April 4, 357 B.C.[113]

Seen from Mars the maximum apparent distance between the earth and moon would vary from 3½′ to nearly 17′.[114]

CHAPTER VII

The Minor Planets

UP to 1908 the number of minor planets (or asteroids) certainly known amounted to over 650.

From an examination of the distribution of the first 512 of these small bodies, Dr. P. Stroobant finds that a decided maximum in number occurs between the limits of distance of 2·55 and 2·85 (earth's mean distance from sun = 1), "199 of the asteroids considered revolving in this annulus." He finds that nearly all the asteroidal matter is concentrated near to the middle of the ring in the neighbourhood of the mean distance of 2·7, and the smallest asteroids are relatively less numerous in the richest zones.[115]

There are some "striking similarities" in the orbits of some of the asteroids. Thus, in the small planets Sophia (No. 251 in order of discovery) and Magdalena (No. 318) we have the mean distance of Sophia 3·10, and that of Magdalena 3·19 (earth's mean distance = 1). The eccentricities of the orbits are 0·09 and 0·07; and the inclinations of the orbits to the plane of the ecliptic 10° 29′ and 10° 33′ respectively.[116] This similarity may be—and probably is—merely accidental, but it is none the less curious and interesting.

Some very interesting discoveries have recently been made among the minor planets. The orbit of Eros intersects the orbit of Mars; and the following have nearly the same mean distance from the sun as Jupiter:—

Achilles (1906 TG), No. 588,
Patrocles (1906 XY), No. 617,
Hector (1907 XM), No. 624,

and another (No. 659) has been recently found. Each of these small planets "moves approximately in a vertex of an equilateral triangle that it forms with Jupiter and the sun."[117] The minor planet known provisionally as HN is remarkable for the large eccentricity of its orbit (0·38), and its small perihelion distance (1·6). When discovered it had a very high South Declination (61½°), showing that the inclination of the plane of its orbit to the plane of the ecliptic is considerable.[118]

Dr. Bauschinger has made a study of the minor planets discovered up to the end of 1900. He finds that the ascending nodes of the orbits show a marked tendency to cluster near the ascending node of Jupiter's orbit, a fact which agrees well with Prof. Newcomb's theoretical results. There seems to be a slight tendency for large inclinations and great eccentricities to go together; but there appears to be no connection between the eccentricity and the mean distance from the sun. The longitudes of the perihelia of these small planets "show a well-marked maximum near the longitude of *Jupiter's* perihelion, and equally well-marked minimum near the longitude of his aphelion," which is again in good agreement with Newcomb's calculations.[119] Dr. Bauschinger's diameter for Eros is 20 miles. He finds that the whole group, including those remaining to be discovered, would probably form a sphere of about 830 miles in diameter.

The total mass of the minor planets has been frequently estimated, but generally much too high. Mr. B. M. Roszel of the John Hopkins University (U.S.A.) has made a calculation of the probable mass from the known diameter of Vesta (319 miles, Pickering), and finds the volume of the first 216 asteroids discovered. From this calculation it appears that it would take 310 asteroids of the 6th magnitude, or 1200 of the 7th to equal the moon in volume. Mr. Roszel concludes that the probable mass of the whole asteroidal belt is between 1⁄50th and 1⁄100th of that of the moon.[120] Subsequently Mr. Roszel extended his study to the mass of 311 asteroids,[121] and found a combined mass of about 1⁄40th of the moon's mass.

Dr. Palisa finds that the recently discovered minor planet (1905 QY) varies in light to a considerable extent.[122] This planet was discovered by Dr. Max Wolf on August 23, 1905; but it was subsequently found that it is identical with one previously known, (167) Urda.[123] The light variation is said to be from the 11th to the 13th magnitude.[124] Variation in some of the other minor planets has also been suspected. Prof. Wendell found a variation of about half a magnitude in the planet Eunomia (No. 15). He also found that

Iris (No. 7) varies about a quarter of a magnitude in a period of about 6^h 12^m.[125] But these variations are small, and perhaps doubtful. The variability of Eros is well known.

The planet Eros is a very interesting one. The perihelion portion of its orbit lies between the orbits of Mars and the earth, and the aphelion part is outside the orbit of Mars. Owing to the great variation in its distance from the earth the brightness of Eros varies from the 6th to the 12th magnitude. That is, when brightest, it is 250 times brighter than when it is faintest.[126] This variation of light, is of course, merely due to the variation of distance; but some actual variation in the brightness of the planet has been observed.

It has been shown by Oeltzen and Valz that Cacciatore's supposed distant comet, mentioned by Admiral Smyth in his *Bedford Catalogue*, must have been a minor planet.[127]

Dr. Max Wolf discovered 36 new minor planets by photography in the years 1892-95. Up to the latter year he had never seen one of these through a telescope! His words are, "Ich selsbt habe noch nie einen meinen kleinen Planeten am Himmel gesehen."[128]

These small bodies have now become so numerous that it is a matter of much difficulty to follow them. At the meeting of the Royal Astronomical Society on January 8, 1909, Mr. G. F. Chambers made the following facetious remarks—

"I would like to make a suggestion that has been in my mind for several years past—that it should be made an offence punishable by fine or imprisonment to discover any more minor planets. They seem to be an intolerable nuisance, and are a great burden upon the literary gentlemen who have to keep pace with them and record them. I have never seen, during the last few years at any rate, any good come from them, or likely to come, and I should like to see the supply stopped, and the energies of the German gentlemen who find so many turned into more promising channels."

Among the minor planets numbered 1 to 500, about 40 "have not been seen since the year of their discovery, and must be regarded as lost."[129]

CHAPTER VIII

Jupiter

THIS brilliant planet—only inferior to Venus in brightness—was often seen by Bond (Jun.) with the naked eye in "high and clear sunshine"; also by Denning, who has very keen eyesight. Its brightness on such occasions is so great, that—like Venus—it casts a distinct shadow in a dark room.[130]

The great "red spot" on Jupiter seems to have been originally discovered by Robert Hooke on May 9, 1664, with a telescope of 2 inches aperture and 12 feet focus. It seems to have existed ever since; at least the evidence is, according to Denning, in favour of the identity of Hooke's spot with the red spot visible in recent years. The spot was also observed by Cassini in the years 1665-72, and is sometimes called "Cassini's spot." But the real discoverer was Hooke.[131]

The orbit of Jupiter is so far outside the earth's orbit that there can be little visible in the way of "phase"—as in the case of Mars, where the "gibbous" phase is sometimes very perceptible. Some books on astronomy state that Jupiter shows no phase. But this is incorrect. A distinct, although very slight, gibbous appearance is visible when the planet is near quadrature. Webb thought it more conspicuous in twilight than in a dark sky. With large telescopes, Jupiter's satellites II. and III. have been seen—in consequence of Jupiter's phase—to emerge from occultation "at a sensible distance from the limb."[132]

According to M. E. Rogovsky, the high "albedo of Jupiter, the appearance of the clear (red) and dark spots on its surface and their continual variation, the different velocity of rotation of the equatorial and other zones of its surface, and particularly its small density (1·33, water as unity), all these facts afford irrefragable proofs of the high temperature of this planet. The dense and opaque atmosphere hides its glowing surface from our view, and we see therefore only the external surface of its clouds. The objective existence of this atmosphere is proved by the bands and lines of absorption in its spectrum. The interesting photograph obtained by Draper, September 27, 1879, in which the blue and green parts are more brilliant for the equatorial zone than for the adjacent parts of the surface, appears to show that *Jupiter* emits its proper light. It is possible that the constant red spot noticed on its surface by several observers, as Gledhill, Lord Rosse, and Copeland (1873), Russel and Bredikhin (1876), is the summit of a high glowing mountain. G. W. Hough considers Jupiter to be gaseous, and A. Ritter inferred from his formulæ that in this case the temperature at the centre would be 600,000° C."[133]

The four brighter satellites of Jupiter are usually known by numbers I., II., III., and IV.; I. being the nearest to the planet, and IV. the farthest. III. is usually the brightest, and IV. the faintest, but exceptions to this rule have been noticed.

With reference to the recently discovered sixth and seventh satellites of Jupiter, Prof. Perrine has suggested that the large inclination of their orbits to the plane of the planet's equator seems to indicate that neither of these bodies was originally a member of Jupiter's family, but has been "captured by the planet." This seems possible as the orbits of some of the minor planets lie near the orbit of Jupiter (see "Minor Planets"). A similar suggestion has been made by Prof. del Marmol.[134]

Many curious observations have been recorded with reference to Jupiter's satellites; some very difficult of explanation. In 1711 Bianchini saw satellite IV. so faint for more than an hour that it was hardly visible! A similar observation was made by Lassell with a more powerful telescope on June 13, 1849. Key, T. T. Smyth, and Denning have also recorded unusual faintness.[135] A very remarkable phenomenon was seen by Admiral Smyth, Maclear, and Pearson on June 26, 1828. Satellite II., "having fairly entered on Jupiter, was found 12 or 13 minutes afterwards *outside the limb*, where it remained visible for at least 4 minutes, and then suddenly vanished." As Webb says, "Explanation is here set at defiance; demonstrably neither in the atmosphere of the earth, nor Jupiter, where and what could have been the cause? At present we can get no answer."[136] When Jupiter is in opposition to the sun—that is, on the meridian at midnight—satellite I. has been seen projected on its own shadow, the shadow appearing as a dark ring round the satellite.

On January 28, 1848, at Cambridge (U.S.A.) satellite III. was seen in transit lying between the shadows of I. and II. and so black that it could not be distinguished from the shadows, "except by the place it occupied." This seems to suggest inherent light in the planet's surface, as the satellite was at the time illuminated by full sunshine; its apparent blackness being due to the effect of contrast. Cassini on one occasion failed to find the shadow of satellite I. when it should have been on the planet's disc,[137] an observation which again points to the glowing light of Jupiter's surface. Sadler and Trouvelot saw the shadow of satellite I. double! an observation difficult to explain—but the same phenomenon was again seen on the evening of September 19, 1891, by Mr. H. S. Halbert of Detroit, Michigan (U.S.A.). He says that the satellite "was in transit nearing egress, and it appeared as a white disc against the dark southern equatorial belt; following it was the usual shadow, and at an equal distance from this was a second shadow, smaller and not so dark as the true one, and surrounded by a faint penumbra."[138]

A dark transit of satellite III. was again seen on the evening of December 19, 1891, by two observers in America. One observer noted that the satellite, when on the disc of the planet, was intensely black. To the other observer (Willis L. Barnes) it appeared as an ill-defined *dark* image.[139] A similar observation was made on October 9 of the same year by Messrs. Gale and Innes.[140]

A "black transit" of satellite IV. was seen by several observers in 1873, and by Prof. Barnard on May 4, 1886. The same phenomenon was observed on October 30, 1903, in America, by Miss Anne S. Young and Willis S. Barnes. Miss Young says—

“The ingress of the satellite took place at $8^h\ 50^m$ (E. standard time) when it became invisible upon the background of the planet. An hour later it was plainly visible as a dark round spot upon the planet. It was decidedly darker than the equatorial belt.”[141]

The rather rare phenomenon of an occultation of one of Jupiter’s satellites by another was observed by Mr. Apple, director of the Daniel Scholl Observatory, Franklin and Marshall College, Lancaster, Pa. (U.S.A.), on the evening of March 16, 1908. The satellites in question were I. and II., and they were so close that they could not be separated with the 11·5-inch telescope of the Observatory.[142] One of the present writer’s first observations with a telescope is dated May 17, 1873, and is as follows: “Observed one of Jupiter’s satellites occulted (or very nearly so) by another. Appeared as one with power 133” (on 3-inch refractor in the Punjab). These satellites were probably I. and II.

Jupiter has been seen on several occasions apparently without his satellites; some being behind the disc, some eclipsed in his shadow, and some in transit across the disc. This phenomenon was seen by Galileo, March 15, 1611; by Molyneux, on November 12, 1681; by Sir William Herschel, May 23, 1802; by Wallis, April 15, 1826; by Greisbach, September 27, 1843; and by several observers on four occasions in the years 1867-1895.[143] The phenomenon again occurred on October 3, 1907, No. 1 being eclipsed and occulted, No. 2 in transit, No. 3 eclipsed, and No. 4 occulted.[144] It was not, however, visible in Europe, but could have been seen in Asia and Oceania.[144] The phenomenon will occur again on October 22, 1913.[145]

On the night of September 19, 1903, a star of magnitude 6½ was occulted by the disc of Jupiter. This curious and rare phenomenon was photographed by M. Lucien Rudaux at the Observatory of Donville, France.[146] The star was Lalande 45698 (= BAC 8129).[147]

Prof. Barnard, using telescopes with apertures from 5 inches up to 36 inches (Lick), has failed to see a satellite through the planet’s limb (an observation which has been claimed by other astronomers). He says, “To my mind this has been due to either poor seeing, a poor telescope, or an excited observer.”[148] He adds—

"I think it is high time that the astronomers reject the idea that the satellites of Jupiter can be seen through his limb at occultation. When the seeing is bad there is a spurious limb to Jupiter that well might give the appearance of transparency at the occultation of a satellite. But under first-class conditions the limb of Jupiter is perfectly opaque. It is quibbling and begging the question altogether to say the phenomenon of transparency may be a rare one and so have escaped my observations. Has any one said that the moon was transparent when a star has been seen projected on it when it ought to have been behind it?"

Prof. Barnard and Mr. Douglass have seen white polar caps on the third and fourth satellites of Jupiter. The former says they are "exactly like those on Mars." "Both caps of the fourth satellite have been clearly distinguished, that at the north being sometimes exceptionally large, covering a surface equal to one-quarter or one-third of the diameter of the satellite."[149] This was confirmed on November 23, 1906, when Signor J. Comas Sola observed a brilliant white spot surrounded by a dark marking in the north polar region of the third satellite. There were other dark markings visible, and the satellite presented the appearance of a miniature of Mars.[150]

An eighth satellite of Jupiter has recently been discovered by Mr. Melotte at the Greenwich Observatory by means of photography. It moves in a retrograde direction round Jupiter in an orbit inclined about 30° to that of the planet. The period of revolution is about two years. The orbit is very eccentric, the eccentricity being about one-third, or greater than that of any other satellite of the solar system. When nearest to Jupiter it is about 9 millions of miles from the planet, and when farthest about 20 millions.[151] It has been suggested by Mr. George Forbes that this satellite may possibly be identical with the lost comet of Lexell which at its return in the year 1779 became entangled in Jupiter's system, and has not been seen since. If this be the case, we should have the curious phenomenon of a comet revolving round a planet!

According to Humboldt the four bright satellites of Jupiter were seen almost simultaneously and quite independently by Simon Marius at Ausbach on December 29, 1609, and by Galileo at Padua on January 7, 1610.[152] The actual priority, therefore, seems to rest with Simon Marius, but the publication of the discovery was first made by Galileo in his *Nuncius*

Siderius (1610).[153] Grant, however, in his *History of Physical Astronomy*, calls Simon Marius an "impudent pretender"! (p. 79).

M. Dupret at Algiers saw Jupiter with the naked eye on September 26, 1890, twenty minutes before sunset.[154]

Humboldt states that he saw Jupiter with the naked eye when the sun was from 18° to 20° above the horizon.[155] This was in the plains of South America near the sea-level.

CHAPTER IX

Saturn

TO show the advantages of large telescopes over small ones, Mr. C. Roberts says that "with the 25-inch refractor of the Cambridge Observatory the view of the planet Saturn is indescribably glorious; everything I had ever seen before was visible at a glance, and an enormous amount of detail that I had never even glimpsed before, after a few minutes' observation."[156]

Chacornac found that the illumination of Saturn's disc is the reverse of that of Jupiter, the edges of Saturn being brighter than the centre of the disc, while in the case of Jupiter—as in that of the sun—the edges are fainter than the centre.[157] According to Mr. Denning, Saturn bears satisfactorily "greater magnifying power than either Mars or Jupiter."[158]

At an occultation of Saturn by the moon, which occurred on June 13, 1900, M. M. Honorat noticed the great contrast between the slightly yellowish colour of the moon and the greenish tint of the planet.[159]

In the year 1892, when the rings of Saturn had nearly disappeared, Prof. L. W. Underwood, of the Underwood Observatory, Appleton, Wisconsin (U.S.A.), saw one of Saturn's satellites (Titan) apparently moving along the needlelike appendage to the planet presented by the rings. "The apparent diameter of the satellite so far exceeded the apparent thickness of the ring that it gave the appearance of a beautiful golden bead moving very slowly along a fine golden thread."[160]

In 1907, when the rings of Saturn became invisible in ordinary telescopes, Professor Campbell, observing with the great Lick telescope, noticed "prominent bright knots, visible ... in Saturn's rings. The knots were symmetrically placed, two being to the east and two to the west." This was confirmed by Mr. Lowell, who says, "Condensations in Saturn's rings confirmed here and measured repeatedly. Symmetric and permanent." This phenomenon was previously seen by Bond in the years 1847-56. Measures of these light spots made by Prof. Barnard with the 40-inch Yerkes telescope show that the outer one corresponded in position with the outer edge of the middle ring close to the Cassini division, and the inner condensation, curious to say, seemed to coincide in position with the "crape ring." Prof. Barnard thinks that the thickness of the rings "must be greatly under 100 miles, and probably less than 50 miles," and he says—

"The important fact clearly brought out at this apparition of *Saturn* is that the bright rings are not opaque to the light of the sun—and this is really what we should expect from the nature of their constitution as shown by the theory of Clerk Maxwell, and the spectroscopic results of Keeler."[161]

Under certain conditions it would be theoretically possible, according to Mr. Whitmell, to see the globe of Saturn through the Cassini division in the ring. But the observation would be one of great difficulty and delicacy. The effect would be that, of the arc of the division which crosses the planet's disc, "a small portion will appear bright instead of dark, and may almost disappear."[162]

A remarkable white spot was seen on Saturn on June 23, 1903, by Prof. Barnard, and afterwards by Mr. Denning.[163] Another white spot was seen by Denning on July 9 of the same year.[164] From numerous observations of these spots, Denning found a rotation period for the planet of about $10^h\ 39^m\ 21^s$.[165] From observations of the same spots Signor Comas Sola found a period $10^h\ 38^m{\cdot}4$, a close agreement with Denning's result. For Saturn's equator, Prof. Hill found a rotation period of $10^h\ 14^m\ 23^s{\cdot}8$, so that—as in the case of Jupiter—the rotation is faster at the equator than in the northern latitudes of the planet. A similar phenomenon is observed in the sun. Mr. Denning's results were fully confirmed by Herr Leo Brenner, and other German astronomers.[166]

Photographs taken by Prof. V. M. Slipher in America show that the spectrum of Saturn is similar to that of Jupiter. None of the bands observed in the planet's spectrum are visible in the spectrum of the rings. This shows that if the rings possess an atmosphere at all, it must be much rarer than that surrounding the ball of the planet. Prof. Slipher says that "none of the absorption bands in the spectrum of *Saturn* can be identified with those bands due to absorption in the earth's atmosphere," and there is no trace of aqueous vapour.[167]

In September, 1907, M. G. Fournier suspected the existence of a "faint transparent and luminous ring" outside the principal rings of Saturn. He thinks that it may possibly be subject to periodical fluctuations of brightness, sometimes being visible and sometimes not.[168] This dusky ring was again suspected at the Geneva Observatory in October, 1908.[169] M. Schaer found it a difficult object with a 16-inch Cassegrain reflector. Prof. Stromgen at Copenhagen, and Prof. Hartwig at Bamberg, however, failed to see any trace of the supposed ring.[170] It was seen at Greenwich in October, 1908.

A "dark transit" of Saturn's satellite Titan across the disc of the planet has been observed on several occasions. It was seen by Mr. Isaac W. Ward, of Belfast, on March 27, 1892, with a 4·3-inch Wray refractor. The satellite appeared smaller than its shadow. The phenomenon was also seen on March 12 of the same year by the Rev. A. Freeman, Mr. Mee, and M. F. Terby; and again on November 6, 1907, by Mr. Paul Chauleur and Mr. A. B. Cobham.[171]

The recently discovered tenth satellite of Saturn, Themis, was discovered by photography, and has never been seen by the eye even with the largest telescopes! But its existence is beyond all doubt, and its orbit round the planet has been calculated.

Prof. Hussey of the Lick Observatory finds that Saturn's satellite Mimas is probably larger than Hyperion. He also finds from careful measurements that the diameter of Titan is certainly overestimated, and that its probable diameter is about 2500 miles.[172]

The French astronomer, M. Lucien Rudaux, finds the following variation in the light of the satellites of Saturn:—

Japetus	from	9th	magnitude to	12th
Rhea	"	9	"	10·6
Dione	"	9·5	"	10·5

Tethys	"	9·8	"	10·5
Titan	"	8	"	8·6

The variation of light is, he thinks, due to the fact that the period of rotation of each satellite is equal to that of their revolution round the planet; as in the case of our moon.[173]

The names of the satellites of Saturn are derived from the ancient heathen mythology. They are given in order of distance from the planet, the nearest being Mimas and the farthest Themis.

1. Mimas was a Trojan born at the same time as Paris.

2. Enceladus was son of Tartarus and Ge.

3. Tethys was wife of Oceanus, god of ocean currents. She became mother of all the chief rivers in the universe, as also the Oceanides or sea nymphs.

4. Dione was one of the wives of Zeus.

5. Rhea was a daughter of Uranus. She married Saturn, and became the mother of Vesta, Ceres, Juno, and Pluto.

6. Titan was the eldest son of Uranus.

7. Hyperion was the god of day, and the father of sun and moon.

8. Japetus was the fifth son of Uranus, and father of Atlas and Prometheus.[174]

9. Phœbe was daughter of Uranus and Ge.

10. Themis was daughter of Uranus and Ge, and, therefore, sister of Phœbe.

In a review of Prof. Comstock's *Text Book of Astronomy* in *The Observatory*, November, 1901, the remark occurs, "We are astonished to see that Mr. Comstock alludes with apparent seriousness to the *nine* satellites of Saturn. As regards the ninth satellite, we thought that all astronomers held with Mrs. Betsy Prig on the subject of this astronomical Mrs. Harris." This reads curiously now (1909) when the existence of the ninth satellite (Phœbe) has been fully confirmed, and a tenth satellite discovered.

CHAPTER X

Uranus and Neptune

FROM observations of Uranus made in 1896, M. Leo Brenner concluded that the planet rotates on its axis in about 8½ hours (probably 8^h 27^m). This is a short period, but considering the short periods of Jupiter and Saturn there seems to be nothing improbable about it.

Prof. Barnard finds that the two inner satellites of Uranus are difficult objects even with the great 36-inch telescope of the Lick Observatory! They have, however, been photographed at Cambridge (U.S.A.) with a 13-inch lens, although they are "among the most difficult objects known."[175]

Sir William Huggins in 1871 found strong absorption lines (six strong lines) in the spectrum of Uranus. One of these lines indicated the presence of hydrogen, a gas which does not exist in our atmosphere. Three of the other lines seen were situated near lines in the spectrum of atmospheric air. Neither carbonic acid nor sodium showed any indications of their presence in the planet's spectrum. A photograph by Prof. Slipher of Neptune's spectrum "shows the spectrum of this planet to contain many strong absorption bands. These bands are so pronounced in the part of the spectrum between the Fraunhofer lines F and D, as to leave the solar spectrum unrecognizable.... Neptune's spectrum is strikingly different from that of *Uranus*, the bands in the latter planet all being reinforced in *Neptune*. In this planet there are also new bands which have not been observed in any of the other planets. The F line of hydrogen is remarkably dark ... this band is of more than solar strength in the spectrum of Uranus also. Thus free hydrogen seems to be present in the atmosphere of both these planets. This and the other dark bands in these planets bear evidence of an enveloping atmosphere of gases which is quite unlike that which surrounds the earth."[176]

With the 18-inch equatorial telescope of the Strasburgh Observatory, M. Wirtz measured the diameter of Neptune, and found from forty-nine measures made between December 9, 1902, and March 28, 1903, a value of 2″·303 at a distance of 30·1093 (earth's distance from sun = 1). This gives a diameter of 50,251 kilometres, or about 31,225 miles,[177] and a mean density of 1·54 (water = 1; earth's mean density = 5·53). Prof. Barnard's measures gave a diameter of 32,900 miles, a fairly close agreement, considering the difficulty of measuring so small a disc as that shown by Neptune.

The satellite of Neptune was photographed at the Pulkown Observatory in the year 1899. The name Triton has been suggested for it. In the old Greek mythology Triton was a son of Neptune, so the name would be an appropriate one.

The existence of a second satellite of Neptune is suspected by Prof. Schaeberle, who thinks he once saw it with the 36-inch telescope of the Lick Observatory "on an exceptionally fine night" in 1895.[178] But this supposed discovery has not yet been confirmed. Lassell also thought he had discovered a second satellite, but this supposed discovery was never confirmed.[178]

The ancient Burmese mention eight planets, the sun, the moon, Mercury, Venus, Mars, Jupiter, Saturn, and another named Râhu, which is invisible. It has been surmised that "Râhu" is Uranus, which is just visible to the naked eye, and may possibly have been discovered by keen eyesight in ancient times. The present writer has seen it several times without optical aid in the West of Ireland, and with a binocular field-glass of 2 inches aperture he found it quite a conspicuous object.

When Neptune was *visually* discovered by Galle, at Berlin, he was assisted in his observation by Prof. d'Arrest. The incident is thus described by Dr. Dreyer, "On the night of June 14, 1874, while observing Coggia's comet together, I reminded Prof. d'Arrest how he had once said in the course of a lecture, that he had been present at the finding of Neptune, and that 'he might say it would not have been found without him.' He then told me (and I wrote it down the next day), how he had suggested the use of Bremiker's map (as first mentioned by Dr. Galle in 1877) and continued, 'We then went back to the dome, where there was a kind of desk, at which I placed myself with the map, while Galle, looking through the refractor, described the configurations of the stars he saw. I followed them on the map one by one, until he said: "And then there is a star of the 8th magnitude, in such and such a position," whereupon I immediately exclaimed: "That star is not on the map."""[179] This was the planet. But it seems to the present writer that if Galle or d'Arrest had access to Harding's Atlas (as they probably had) they might easily have found the planet with a good binocular field-glass. As a matter of fact Neptune is shown in Harding's Atlas (1822) as a star of the 8th magnitude, having been mistaken for a star by Lalande on May 8 and 10, 1795; and the present writer has found Harding's 8th magnitude stars quite easy objects with a binocular field-glass having object-glasses of two inches diameter, and a power of about six diameters.

Supposed Planet beyond Neptune.—The possible existence of a planet beyond Neptune has been frequently suggested. From considerations on the aphelia of certain comets, Prof. Forbes in 1880 computed the probable position of such a body. He thought this hypothetical planet would be considerably larger than Jupiter, and probably revolve round the sun at a distance of about 100 times the earth's mean distance from the sun. The place indicated was between R.A. $11^h 24^m$ and $12^h 12^m$, and declination 0° 0′ to 6° 0′ north. With a view to its discovery, the late Dr. Roberts took a series of eighteen photographs covering the region indicated. The result of an examination of these photographs showed, Dr. Roberts says, that "no planet of greater brightness than a star of the 15th magnitude exists on the sky area herein indicated." Prof. W. H. Pickering has recently revived the question, and has arrived at the following results: Mean distance of the planet from the sun, 51·9 (earth's mean distance = 1); period of revolution, 373½ years; mass about twice the earth's mass; probable position for 1909 about R.A. $7^h 47^m$, north declination 21°, or about 5° south-east of the star κ Geminorum. The supposed planet would be faint, its brightness being from 11½ to 13½, according to the "albedo" (or reflecting power) it may have. [180]

Prof. Forbes has again attacked the question of a possible ultra-Neptunian planet, and from a consideration of the comets of 1556, 1843 I, 1880 I, and 1882 II, finds a mean distance of 105·4, with an inclination of the orbit of 52° to the plane of the ecliptic. This high inclination implies that "during the greatest part of its revolution it is beyond the zodiac," and this, Mr. W. T. Lynn thinks, "may partly account for its not having hitherto been found by observation."[181]

From a consideration of the approximately circular shape of the orbits of all the large planets of the solar system, Dr. See suggests the existence of three planets outside Neptune, with approximate distances from the sun of 42, 56, and 72 respectively (earth's distance = 1), and recommends a photographic search for them. He says, "To suppose the planetary system to terminate with an orbit so round as that of Neptune is as absurd as to suppose that Jupiter's system terminates with the orbit of the fourth satellite."[182]

According to Grant, even twenty years before the discovery of Neptune the error of Prof. Adams' first approximation amounted to little more than 10°.[183]

CHAPTER XI

Comets

WE learn from Pliny that comets were classified in ancient times, according to their peculiar forms, into twelve classes, of which the principal were: *Pogonias*, bearded; *Lampadias*, torch-like; *Xiphias*, sword-like; *Pitheus*, tun-like; *Acontias*, javelin-like; *Ceratias*, horn-like; *Disceus*, quoit-like; and *Hippias*, horse-mane-like.[184]

Of the numerous comets mentioned in astronomical records, comparatively few have been visible to the naked eye. Before the invention of the telescope (1610) only those which were so visible *could*, of course, be recorded. These number about 400. Of the 400 observed since then, some 70 or 80 only have been visible by unaided vision; and most of these now recorded could never have been seen without a telescope. During the last century, out of 300 comets discovered, only 13 were very visible to the naked eye. Hence, when we read in the newspapers that a comet has been discovered the chances are greatly against it becoming visible to the naked eye.[185]

Although comparatively few comets can be seen without a telescope, they are sometimes bright enough to be visible in daylight! Such were those of B.C. 43, A.D. 1106, 1402, 1532, 1577, 1744, 1843, and the "great September comet" of 1882.

If we except the great comet of 1861, through the tail of which the earth is supposed to have passed, the comet which came nearest to the earth was that of 1770, known as Lexell's, which approached us within two millions of miles, moving nearly in the plane of the ecliptic. It produced, however, no effect on the tides, nor on the moon's motion, which shows that its mass must have been very small. It was computed by Laplace that if its mass had equalled that of the earth, the length of our year would have been shortened by 2 hours 47 minutes, and as there was no perceptible change Laplace concluded that the comet's mass did not exceed $\frac{1}{5000}$th of the earth's mass. This is the comet which passed so near to Jupiter that its period was reduced to 5½ years. Owing to another near approach in 1779 it became invisible from the earth, and is now lost.[186] Its identity with the recently discovered eighth satellite of Jupiter has been suggested by Mr. George Forbes (see under "Jupiter"). At the near approach of Lexell's comet to the earth in 1770, Messier, "the comet ferret," found that its head had an apparent diameter of 2½°, or nearly five times that of the moon!

Another case of near approach to the earth was that of Biela's comet at its appearance in 1805. On the evening of December 9 of that year, the comet approached the earth within 3,380,000 miles.[187]

The comet of A.D. 1106 is stated to have been seen in daylight close to the sun. This was on February 4 of that year. On February 10 it had a tail of 60° in length, according to Gaubil.[188]

The comet of 1577 seems to have been one of the brightest on record. According to Tycho Brahé, it was visible in broad daylight. He describes the head as "round, bright, and of a yellowish light," with a curved tail of a reddish colour.[189]

The comet of 1652 was observed for about three weeks only, and Hevelius and Comiers state that it was equal to the moon in apparent size! This would indicate a near approach to the earth. An orbit computed by Halley shows that the least distance was about 12 millions of miles, and the diameter of the comet's head rather less than 110,000 miles, or about 14 times the earth's diameter.

According to Mr. Denning, "most of the periodical comets at perihelion are outside the earth's orbit, and hence it follows that they escape observation unless the earth is on the same side of the sun as the comet."[190]

It was computed by M. Faye that the *volume* of the famous Donati's comet (1858) was about 500 times that of the sun! On the other hand, he calculated that its *mass* (or quantity of matter it contained) was only a fraction of the earth's mass. This shows how almost inconceivably tenuous the material forming the comet must have been—much more rarefied, indeed, than the most perfect vacuum which can be produced in an air-pump. This tenuity is shown by the fact that stars were seen through the tail "as if the tail did not exist." A mist of a few hundred yards in thickness is sufficient to hide the stars from our view, while a thickness of thousands of miles of cometary matter does not suffice even to dim their brilliancy!

At the time of the appearance of the great comet of 1843, it was doubtful whether the comet had transited the sun's disc. But it is now known, from careful calculations by Prof. Hubbard, that a transit really took place between $11^h\ 28^m$ and $12^h\ 29^m$ on February 27, 1843, and might have been observed in the southern hemisphere. The distance of this remarkable comet from the sun at its perihelion passage was less than that of any known comet. A little before 10 p.m. on February 27, the comet passed within 81,500 miles of the sun's surface with the enormous velocity of 348 miles a second! It remained less than 2¼ hours north of the ecliptic, passing from the ascending to the descending node of its orbit in $2^h\ 13^m{\cdot}4$.[191] The great comet of 1882 transited the sun's disc on Sunday, September 17, of that year, the ingress taking place at $4^h\ 50^m\ 58^s$, Cape mean time. When on the sun the comet was absolutely invisible, showing that there was nothing solid about it. It was visible near the sun with the naked eye a little before the transit took place.[192] This great comet was found by several computors to have been travelling in an elliptic orbit with a period of about eight centuries. Morrison found 712 years; Frisby, 794; Fabritius, 823; and Kreutz, 843 years.[193]

The great southern comet of 1887 may be described as a comet without a head! The popular idea of a comet is a star with a tail. But in this case there was no head visible—to the naked eye at least. Dr. Thome of the Cordoba Observatory—its discoverer—describes it as "a beautiful object—a narrow, straight, sharply defined, graceful tail, over 40° long, shining with a soft starry light against a dark sky, beginning apparently without a head, and gradually widening and fading as it extended upwards."[194]

The great southern comet of 1901 had five tails on May 6 of that year. Two were fairly bright, and the remaining three rather faint. Mr. Gale saw a number of faint stars through the tails. The light of these seem to have been "undimmed." Mr. Cobham noticed that the stars Rigel and β Eridani shone through one of the faint tails, and "showed no perceptible difference."[195]

Prof. W. H. Pickering says that "the head of a comet, as far as our present knowledge is concerned, seems therefore to be merely a meteor swarm containing so much gaseous material that when electrified by its approach to the sun it will be rendered luminous" (*Harvard Annual*, vol. xxxii. part ii. p. 295) "... if the meteors and their atmospheres are sufficiently widely separated from one another, the comet may be brilliant and yet transparent at the same time."

In the case of Swift's comet of 1892 some periodical differences of appearance were due, according to Prof. W. H. Pickering, to a rotation of the comet round an axis passing longitudinally through the tail, and he estimated the period of rotation at about 94 to 97 hours. He computed that in this comet the repulsive force exerted by the sun on the comet's tail was "about 39·5 times the gravitational force."[196]

The comet known as 1902*b* approached the planet Mercury within two millions of miles on November 29 of that year. Prof. O. C. Wendell, of Harvard Observatory, made some observations on the transparency of this comet. He found with the aid of a photometer and the 15-inch telescope of the observatory that in the case of two faint stars over which the comet passed on October 14, 1902, the absorption of light by the comet was insensible, and possibly did not exceed one or two hundredths of a magnitude,[197] an amount quite imperceptible to the naked eye, and shows conclusively how almost inconceivably rarefied the substance of this comet must be.

The comet known as Morehouse (1908*c*) showed some curious and wonderful changes. Mr. Borelly found that five tails are visible on a photographic plate taken on October 3, 1908, and the trail of an occulted star indicates a slight absorption effect. According to M. L. Rabourdin, great changes took place from day to day, and even during the course of an hour! Similar changes were recorded by G. M. Gauthier; and Prof. Barnard, who photographed the comet on 30 nights from September 2 to October 13, states that the photographs of September 30 "are unique, whilst the transformation which took place between the taking of these and the taking of the next one on October 1 was very wonderful."[198] The spectrum showed the lines of cyanogen instead of the hydrocarbon spectrum shown by most comets.

Prof. Barnard has suggested that all the phenomena of comets' tails cannot be explained by a repulsive force from the sun. Short tails issuing from the comet's nucleus at considerable angles with the main tail point to eruptive action in the comet itself. The rapid changes and distortions frequently observed in the tails of some comets suggest motion through a resisting medium; and the sudden increase of light also occasionally observed points in the same direction.[199]

It was computed by Olbers that if a comet having a mass of $^1/_{2000}$th of the earth's mass—which would form a globe of about 520 miles in diameter and of the density of granite—collided with the earth, with a velocity of 40 miles a second, our globe would be shattered into fragments.[200] But that any comet has a solid nucleus of this size seems very doubtful; and we may further say that the collision of the earth with *any* comet is highly improbable.

It seems to be a common idea that harvests are affected by comets, and even "comet wines" are sometimes spoken of. But we know that the earth receives practically no heat from the brightest comet. Even in the case of the brilliant comet of 1811, one of the finest on record, it was found that "all the efforts to concentrate its rays did not produce the slightest effect on the blackened bulb of the most sensitive thermometer." Arago found that the year 1808, in which several comets were visible, was a cold year, "and 1831, in which there was no comet, enjoyed a much higher temperature than 1819, when there were three comets, one of which was very brilliant."[201] We may, therefore, safely conclude that even a large comet has no effect whatever on the weather.

From calculations on the orbit of Halley's comet, the next return of which is due in 1910, Messrs. Cowell and Crommelin find that the identity of the comet shown on the Bayeux Tapestry with Halley's comet is now "fully established." They find that the date of perihelion passage was March 25, 1066, which differs by only 4 days from the date found by Hind. The imposing aspect of the comet in 1066 described in European chronicles of that time is confirmed by the Chinese Annals. In the latter records the brightness is compared to that of Venus, and even with that of the moon! The comparison with the moon was probably an exaggeration, but the comet doubtless made a very brilliant show. In the Bayeux Tapestry the inscription on the wall behind the spectators reads: "*isti mirant stella*." Now, this is bad Latin, and Mr. W. T. Lynn has made the interesting suggestion that some of the letters are hidden by the buildings in front and that the real sentence is "*isti mirantur stellam*."[202] The present writer has examined the copy of the Bayeux Tapestry which is in the Dublin Museum, and thinks that Mr. Lynn's suggestion seems very plausible. But the last letter of *stellam* is apparently hidden by the comet's tail, which does not seem very probable!

The conditions under which the comet will appear in 1910 are not unlike those of 1066 and 1145. "In each year the comet was discovered as a morning star, then lost in the sun's rays; on its emergence it was near the earth and moved with great rapidity, finally becoming stationary in the neighbourhood of Hydra, where it was lost to view."[203] In 1910 it will probably be an evening star before March 17, and after May 11, making a near approach to the earth about May 12. About this time its apparent motion in the sky will be very rapid. As, however, periodical comets—such as Halley's—seem to become fainter at each return, great expectations with reference to its appearance in 1910 should not be indulged in.

The appearance of Halley's comet in A.D. 1222 is thus described by Pingré—a great authority on comets—(quoting from an ancient writer)—

"In autumn, that is to say in the months of August and September, a star of the first magnitude was seen, very red, and accompanied by a great tail which extended towards the top of the sky in the form of a cone extremely pointed. It appeared to be very near the earth. It was observed (at first?) near the place of the setting sun in the month of December."

With reference to its appearance in the year 1456, when it was of "vivid brightness," and had a tail of 60° in length, Admiral Smyth says,[204] "To its malign influence were imputed the rapid successes of Mahomet II., which then threatened all Christendom. The general alarm was greatly aggravated by the conduct of Pope Callixtus III., who, though otherwise a man of abilities, was a poor astronomer; for that pontiff daily ordered the church bells to be rung at noon-tide, extra *Ave-Marias* to be repeated, and a special protest and excommunication was composed, exorcising equally the Devil, the Turks, and the comet." With reference to this story, Mr. G. F. Chambers points out[205] that it is probably based on a passage in Platina's *Vitæ Pontificum*. But in this passage there is no mention made of excommunication or exorcism, so that the story, which has long been current, is probably mythical. In confirmation of this view, the Rev. W. F. Rigge has shown conclusively[206] that no bull was ever issued by Pope Callixtus III. containing a reference to *any* comet. The story would therefore seem to be absolutely without foundation, and should be consigned to the limbo of all such baseless myths.

With reference to the appearance of Halley's comet, at his last return in 1835, Sir John Herschel, who observed it at the Cape of Good Hope, says—

"Among the innumerable stars of all magnitudes, from the ninth downwards, which at various times were seen through it, and some extremely near to the nucleus (though not *exactly on it*) there never appeared the least ground for presuming any extinction of their light in traversing it. Very minute stars indeed, on entering its brightest portions, were obliterated, as they would have been by an equal illumination of the field of view; but stars which before their entry appeared bright enough to bear that degree of illumination, were in no case, so far as I could judge, affected to a greater extent than they would have been by so much lamp-light artificially introduced."[207]

It is computed by Prof. J. Holetschak that, early in October, 1909, Halley's comet should have the brightness of a star of about 14½ magnitude.[208] It should then—if not detected before—be discoverable with some of the large telescopes now available.

According to the computations of Messrs. Cowell and Crommelin, the comet should enter Pisces from Aries in January, 1910. "Travelling westward towards the star γ Piscium until the beginning of May, and then turning eastward again, it will travel back through the constellations Cetus, Orion, Monoceros, Hydra, and Sextans." From this it seems that observers in the southern hemisphere will have a better view of the comet than those in northern latitudes. The computed brightness varies from 1 on January 2, 1910, to 1112 on May 10. But the actual brightness of a comet does not always agree with theory. It is sometimes brighter than calculation would indicate.

According to Prof. O. C. Wendell, Halley's comet will, on May 12, 1910, approach the earth's orbit within 4·6 millions of miles; and he thinks that possibly the earth may "encounter some meteors," which are presumably connected with the comet. He has computed the "radiant point" of these meteors (that is, the point from which they appear to come), and finds its position to be R.A. 22^h $42^m \cdot 9$, Decl. N. 1° 18′. This point lies a little south-west of the star β Piscium.

According to Dr. Smart, the comet will, on June 2, "cross the Equator thirteen degrees south of Regulus, and will then move slowly in the direction of φ Leonis. The comet will be at its descending node on the ecliptic in the morning of May 16, and the earth will pass through the node on the comet's orbit about two and a half days later. The comet's orbit at the node is about 13 million miles within that of the earth. Matter repelled from the comet's nucleus by the sun with a velocity of about 216,000 miles per hour, would just meet the earth when crossing the comet's orbit plane. Matter expelled with a velocity of 80,000 miles per hour, as in the case of Comet Morehouse, would require seven days for the journey. Cometary matter is said to have acquired greater velocities than this, for (according to Webb, who quotes Chacornac) Comet II., 1862, shot luminous matter towards the sun, with a velocity of nearly 2200 miles per second. It is therefore possible that matter thrown off by the comet at the node may enter our atmosphere, in which case we must hope that cyanogen, which so often appears in cometary spectra, may not be inconveniently in evidence."[209]

Cyanogen is, of course, a poisonous gas, but cometary matter is so rarefied that injurious effects on the earth need not be feared.

If we can believe the accounts which have been handed down to us, some very wonderful comets were visible in ancient times. The following may be mentioned:—

B.C. 165. The sun is said to have been "seen for several hours in the night." If this was a comet it must have been one of extraordinary brilliancy.[210]

B.C. 146. "After the death of Demetrius, king of Syria, the father of Demetrius and Antiochus, a little before the war in Achaia, there appeared a comet as large as the sun. Its disc was first red, and like fire, spreading sufficient light to dissipate the darkness of night; after a little while its size diminished, its brilliancy became weakened, and at length it entirely disappeared.”[211]

B.C. 134. It is recorded that at the birth of Mithridates a great comet appeared which “occupied the fourth part of the sky, and its brilliancy was superior to that of the sun.” (?)[212]

B.C. 75. A comet is described as equal in size to the moon, and giving as much light as the sun on a cloudy day. (!)[213]

A.D. 531. In this year a great comet was observed in Europe and China. It is described as “a very large and fearful comet,” and was visible in the west for three weeks. Hind thinks that this was an appearance of Halley’s comet,[214] and this has been confirmed by Mr. Crommelin.

A.D. 813, August 4. A comet is said to have appeared on this date, of which the following curious description is given: “It resembled two moons joined together; they separated, and having taken different forms, at length appeared like a man without a head.” (!)[215]

A.D. 893. A great comet is said to have appeared in this year with a tail 100° in length, which afterwards increased to 200°![216]

A.D. 1402. A comet appeared in February of this year, which was visible in daylight for eight days. “On Palm Sunday, March 19, its size was prodigious.” Another comet, visible in the daytime, was seen from June to September of the same year.

When the orbit of the comet known as 1889 V was computed, it was found that it had passed through Jupiter’s system in 1886 (July 18-21). The calculations show that it must have passed within a distance of 112,300 miles of the planet itself—or less than half the moon’s distance from the earth—and “its centre may possibly have grazed the surface of Jupiter.”[217]

Sir John Herschel thought that the great comet of 1861 was by far the brightest comet he had ever seen, those of 1811 and 1858 (Donati’s) not excepted.[218] Prof. Kreutz found its period of revolution round the sun to be about 409 years, with the plane of the orbit nearly at right angles to the plane of the ecliptic.

On November 9, 1795, Sir William Herschel saw the comet of that year pass centrally over a small double star of the 11th and 12th magnitudes, and the fainter of the two components remained distinctly visible during the comet's transit over the star. This comet was an appearance of the comet now known as Encke's.[219] Struve saw a star of the 10th magnitude through nearly the brightest part of Encke's comet on November 7, 1828, but the star's light was not dimmed by the comet.

Sir John Herschel saw a cluster of stars of the 16th or 17th magnitude through Biela's comet, although the interposed cometary matter must have been at least 50,000 miles in thickness.[220]

Bessel found that on September 29, 1835, a star of the 10th magnitude shone with undimmed lustre through the tail of Halley's comet within 8 seconds of arc of the central point of the head. At Dorpat (Russia) Struve saw the same star "in conjunction only 2″·2 from the brightest point of the comet. The star remained continuously visible, and its light was not perceptibly diminished whilst the nucleus of the comet seemed to be almost extinguished before the radiance of the small star of the 9th or 10th magnitude."[221]

Webb says—

"Donati saw a 7 mg. star enlarged so as to show a sensible disc, when the nucleus of comet III., 1860, passed very near it. Stars are said to have started, or become tremulous, during occultations by comets. Birmingham observed the comet of Encke illuminated by a star over which it passed, August 23, 1868; and Klein, in 1861, remarked an exceptional twinkling in 5 mg. stars involved in the tail."[222]

The comet of 1729 had the greatest perihelion distance of any known comet;[223] that is, when nearest to the sun, it did not approach the central luminary within four times the earth's distance from the sun!

Barnard's comet, 1889 I., although it never became visible to the naked eye, was visible with a telescope from September 2, 1888, to August 18, 1890, or 715 days—the longest period of visibility of any comet on record. When last seen it was 6¼ times the earth's distance from the sun, or about 580 millions of miles,[224] or beyond the orbit of Jupiter!

Messier, who was called "the comet ferret," discovered "all his comets with a small 2-foot telescope of 2¼ inches aperture, magnifying 5 times, and with a field of 4°."[225]

It is a very curious fact that Sir William Herschel, "during all his star-gaugings and sweeps for nebulæ, never discovered a comet;"[226] that is an object which was afterwards *proved* to be a comet. Possibly, however, some of his nebulæ which are now missing, may have been really comets.

Sir William Herschel found the diameter of the head of the great comet of 1811 to be 127,000 miles. The surrounding envelope he estimated to be at least 643,000 miles, or about three-fourths of the sun's diameter.

On a drawing of the tails of the great comet of 1744 given in a little book printed in Berlin in that year, no less than 12 tails are shown! These vary in length and brightness. A copy of this drawing is given in *Copernicus*.[227] The observations were made by "einen geschichten Frauenzimmer," who Dr. Dreyer identifies with Christian Kirch, or one of her two sisters, daughters of the famous Gottfried and Maria Margaretta Kirch (*Idem*, p. 107). Dr. Dreyer thinks that the drawing "seems to have been carefully made, and not to be a mere rough sketch as I had at first supposed" (*Idem*, p. 185).

The tails of some comets were of immense length. That of the comet of 1769 had an absolute length of 38 millions of miles. That of 1680, 96 million of miles, or more than the sun's distance from the earth. According to Sir William Herschel, the tail of the great comet of 1811 was over 100 millions of miles in length. That of the great comet of 1843—one of the finest in history—is supposed to have reached a length of 150 millions of miles![228]

In width the tails of comets were in some cases enormous. According to Sir William Herschel, the tail of the comet of 1811 had a diameter of 15 millions of miles! Its volume was, therefore, far greater than that of the sun! [228]

According to Hevelius the comet of 1652 was of such a magnitude that it "resembled the moon when half full; only it shone with a pale and dismal light."[229]

Halley's comet at its next appearance will be examined with the spectroscope for the first time in its history. At its last return in 1835, the spectroscope had not been invented.

For the great comet of 1811, Arago computed a period of 3065 years; and Encke found a period of 8800 years for the great comet of 1680.[230]

The variation in the orbital velocity of some comets is enormous. The velocity of the comet of 1680 when passing round the sun (perihelion) was about 212 miles a second! Whereas at its greatest distance from the sun (aphelion) the velocity is reduced to about 10 feet a second!

CHAPTER XII

Meteors

MR. DENNING thinks that the meteor shower of the month of May, known as the Aquarids, is probably connected with Halley's comet. The meteors should be looked for after 1 a.m. during the first week in May, and may possibly show an enhanced display in May, 1910, when Halley's comet will be near the sun and earth.[231]

On November 29, 1905, Sir David Gill observed a fireball with an apparent diameter equal to that of the moon, which remained visible for 5 minutes and disappeared in a hazy sky. Observed from another place, Mr. Fuller found that the meteor was visible 2 hours later! Sir David Gill stated that he does not know of any similar phenomenon.[232]

Mr. Denning finds that swiftly moving meteors become visible at a greater height above the earth's surface than the slower ones. Thus, for the Leonids and Perseids, which are both swift, it has been found that the Leonids appear at an average height of 84 miles, and disappear at a height of 56 miles; and the Perseids at 80 and 54 miles respectively. "On the other hand, the mean height of the very slow meteors average about 65 miles at the beginning and 38 miles at the end of their appearance."[233]

During the night of July 21-22, 1896, Mr. William Brooks, the well-known astronomer, and director of the Smith Observatory at Geneva (New York), saw a round dark body pass slowly across the moon's bright disc, the moon being nearly full at the time. The apparent diameter of the object was about one minute of arc, and the duration of the transit 3 or 4 seconds, the direction of motion being from east to west. On August 22 of the same year, Mr. Gathman (an American observer) saw a meteor crossing the *sun's* disc, the transit lasting about 8 seconds.[234]

A meteor which appeared in Italy on July 7, 1892, was shown by Prof. von Niessl to have had an *ascending* path towards the latter end of its course! The length of its path was computed to be 683 miles. When first seen, its height above the earth was about 42 miles, and when it disappeared its height had increased to about 98 miles, showing that its motion was directed upwards![235]

In the case of the fall of meteoric stones, which occasionally occur, it has sometimes been noticed that the sound caused by the explosion of the meteorite, or its passage through the air, is heard before the meteorite is seen to fall. This has been explained by the fact that owing to the resistance of the air to a body moving at first with a high velocity its speed is so reduced that it strikes the earth with a velocity less than that of sound. Hence the sound reaches the earth before the body strikes the ground.[236]

The largest meteoric stone preserved in a museum is that known as the Anighita, which weighs 36½ tons, and was found at Cape York in Greenland. It was brought to the American Museum of Natural History by Commander R. E. Peary, the Arctic explorer.

The second largest known is that of Bacubirito in Mexico, the weight of which is estimated at 27½ tons.

The third largest is that known as the Williamette, which was found in 1902 near the town of that name in Western Oregon (U.S.A.). It is composed of metallic nickel-iron, and weighs about 13½ tons. It is now in the American Museum of Natural History.

A large meteorite was actually seen, from the deck of the steamer *African Prince*, to fall into the Atlantic Ocean, on October 7, 1906! The captain of the vessel, Captain Anderson, describes it as having a train of light resembling "an immense broad electric-coloured band, gradually turning to orange, and then to the colour of molten metal. When the meteor came into the denser atmosphere close to the earth, it appeared, as nearly as is possible to describe it, like a molten mass of metal being poured out. It entered the water with a hissing noise close to the ship."[237] This was a very curious and perhaps unique phenomenon, and it would seem that the vessel had a narrow escape from destruction.

In Central Arizona (U.S.A.) there is a hill called Coon Butte, or Coon Mountain. This so-called “mountain” rises to a height of only 130 to 160 feet above the surrounding plain, and has on its top a crater of 530 to 560 feet deep; the bottom of the crater—which is dry—being thus 400 feet below the level of the surrounding country. This so-called “crater” is almost circular and nearly three-quarters of a mile in diameter. It has been suggested that this “crater” was formed by the fall of an enormous iron meteorite, or small asteroid. The “crater” has been carefully examined by a geologist and a physicist. From the evidence and facts found, the geologist (Mr. Barringer) states that “they do not leave, in my mind, a scintilla of doubt that this mountain and its crater were produced by the impact of a huge meteorite or small asteroid.” The physicist (Mr. Tilghmann) says that he “is justified, under due reserve as to subsequently developed facts, in announcing that the formation at this locality is due to the impact of a meteor of enormous and unprecedented size.” There are numerous masses of meteoric iron in the vicinity of the “crater.” The so-called Canyon Diabolo meteorite was found in a canyon of that name about 2½ miles from the Coon Mountain. The investigators estimate that the great meteoric fall took place “not more than 5000 years ago, perhaps much less.” Cedar trees about 700 years old are now growing on the rim of the mountain. From the results of artillery experiments, Mr. Gilbert finds that “a spherical projectile striking solid limestone with a velocity of 1800 feet a second will penetrate to a depth of something less than two diameters,” and from this Mr. L. Fletcher concludes “that a meteorite of large size would not be prevented by the earth’s atmosphere from having a penetration effect sufficient for the production of such a crater.”[238]

The meteoric origin of this remarkable “crater” is strongly favoured by Mr. G. P. Merrill, Head Curator of Geology, U.S. National Museum.

The Canyon Diabolo meteorite above referred to was found to contain diamonds! some black, others transparent. So some have said that “the diamond is a gift from Heaven,” conveyed to earth in meteoric showers.[239] But diamond-bearing meteorites would seem to be rather a freak of nature. It does not follow that *all* diamonds had their origin in meteoric stones. The mineral known as periodot is frequently found in meteoric stones, but it is also a constituent of terrestrial rocks.

In the year 1882 it was stated by Dr. Halm and Dr. Weinhand that they had found fossil sponges, corals, and crinoids in meteoric stones! Dr. Weinhand thought he had actually determined three genera![240] But this startling result was flatly contradicted by Carl Vogt, who stated that the supposed fossils are merely crystalline conformations.[241]

Some meteorites contain a large quantity of occluded gases, hydrogen, helium, and carbon oxides. It is stated that Dr. Odling once "lighted up the theatre of the Royal Institution with gas brought down from interstellar space by meteorites"![242]

On February 10, 1896, a large meteorite burst over Madrid with a loud report. The concussion was so great that many windows in the city were broken, and some partitions in houses were shaken down![243]

A very brilliant meteor or fireball was seen in daylight on June 9, 1900, at 2^h 55^m p.m. from various places in Surrey, Sussex, and near London. Calculations showed that "the meteor began 59 miles in height over a point 10 miles east of Valognes, near Cherbourg, France. Meteor ended 23 miles in height, over Calais, France. Length of path 175 miles. Radiant point, 280°, 12°."[244]

It was decided some years ago "in the American Supreme Court that a meteorite, though a stone fallen from heaven, belongs to the owner of the freehold interest in the land on which it falls, and not to the tenant."[245]

With reference to the fall of meteoric matter on the earth, Mr. Proctor says, "It is calculated by Dr. Kleiber of St. Petersburgh that 4250 lbs. of meteoric dust fall on the earth every hour—that is, 59 tons a day, and more than 11,435 tons a year. I believe this to be considerably short of the truth. It sounds like a large annual growth, and the downfall of such an enormous mass of meteoric matter seems suggestive of some degree of danger. But in reality, Dr. Kleiber's estimate gives only about 25 millions of pounds annually, which is less than 2 ounces annually to each square mile of the earth's surface,"[246] a quantity which is, of course, quite insignificant.

According to Humboldt, Chladni states that a Franciscan monk was killed by the fall of an aërolite at Milan in the year 1660.[247] Humboldt also mentions the death by meteoric stones of a monk at Crema on September 4, 1511, and two Swedish sailors on board ship in 1674.[248]

It is a curious fact that, according to Olbers, "no fossil meteoric stones" have ever been discovered.[249] Considering the number which are supposed to have fallen to the earth in the course of ages, this fact seems a remarkable one.

On May 10, 1879, a shower of meteorites fell at Eitherville, Iowa (U.S.A.). Some of the fragments found weighed 437, 170, 92½, 28, 10½, 4 and 2 lbs. in weight. In the following year (1880) when the prairie grass had been consumed by a fire, about "5000 pieces were found from the size of a pin to a pound in weight."[250]

According to Prof. Silvestria of Catania, a shower of meteoric dust mixed with rain fell on the night of March 29, 1880. The dust contained a large proportion of iron in the metallic state. In size the particles varied from a tenth to a hundredth of a millimetre.[251]

It is sometimes stated that the average mass of a "shooting star" is only a few grains. But from comparisons with an electric arc light, Prof. W. H. Pickering concludes that a meteor as bright as a third magnitude star, composed of iron or stone, would probably have a diameter of 6 or 7 inches. An average bright fireball would perhaps measure 5 or 6 feet in diameter.[252]

In the Book of Joshua we are told "that the LORD cast down great stones from heaven upon them unto Azekah, and they died" (Joshua x. 11). In the latter portion of the verse "hailstones" are mentioned, but as the original Hebrew word means stones in general (not hailstones), it seems very probable that the stones referred to were aërolites.[253]

The stone mentioned in the Acts of the Apostles, from which was found "the *image* which fell down from Jupiter" (Acts xix. 35), was evidently a meteoric stone.[253]

The famous stone in the Caaba at Mecca, is probably a stone of meteoric origin.[253]

I

“Stones from Heaven! Can you wonder,
You who scrutinize the Earth,
At the love and veneration
They received before the birth
Of our scientific methods?

II

“Stones from Heaven! we can handle
Fragments fallen from realms of Space;
Oh! the marvel and the mystery,
Could we understand their place
In the scheme of things created!

III

“Stones from Heaven! With a mighty
Comet whirling formed they part?
Fell they from their lofty station
Like a brilliant fiery dart,
Hurl’d from starry fields of Night?”[254]

CHAPTER XIII

The Zodiacal Light and Gegenschein

ACCORDING to Gruson and Brugsch, the Zodiacal Light was known in ancient times, and was even worshipped by the Egyptians. Strabo does not mention it; but Diodorus Siculus seems to refer to it (B.C. 373), and he probably obtained his information from some Greek writers before his time, possibly from Zenophon, who lived in the sixth century B.C.[255] Coming to the Christian era, it was noticed by Nicephorus, about 410 B.C. In the Koran, it is called the "false Aurora"; and it is supposed to be referred to in the "Rubáiyát" of Omar Khayyam, the Persian astronomical poet, in the second stanza of that poem (Edward Fitzgerald's translation)—

> "Dreaming when Dawn's Left Hand was in the Sky,[256]
> I heard a voice within the Tavern cry,
> Awake, my Little ones, and fill the Cup,
> Before Life's Liquor in its Cup be dry."

It was observed by Cassini in 1668,[257] and by Hooke in 1705. A short description of its appearance will be found in Childrey's *Britannia Baconica* (1661), p. 183.

The finest displays of this curious light seem to occur between the middle of January and the middle of February. In February, 1856, Secchi found it brighter than he had ever seen it before. It was yellowish towards the axis of the cone, and it seemed to be brighter than the Milky Way in Cygnus. He described it as "un grande spectacle." In the middle of February, 1866, Mr. Lassell, during his last residence in Malta, saw a remarkable display of the Zodiacal Light. He found it at least twice as bright as the brightest part of the Milky Way, and much brighter than he had previously seen it. He found that the character of its light differed considerably from that of the Milky Way. It was of a much redder hue than the Galaxy. In 1874 very remarkable displays were seen in the neighbourhood of London in January and February of that year; and in 1875 on January 24, 25, and 30. On January 24 it was noticed that the “light” was distinctly reddish and much excelled in brightness any portion of the Milky Way.

Humboldt, who observed it from Andes (at a height of 13,000 to 15,000 feet), from Venezuela and from Cumana, tells us that he has seen the Zodiacal Light equal in brightness to the Milky Way in Sagittarius.

As probably many people have never seen the “light,” a caution may be given to those who care to look for it. It is defined by the Rev. George Jones, Chaplain to the “United States’ Japan Expedition” (1853-55), as “a brightness that appears in the western sky after sunset, and in the east before sunrise; following nearly or quite the line of the ecliptic in the heavens, and stretching upwards to various elevations according to the season of the year.” From the description some might suppose that the light is visible *immediately* after sunset. But this is not so; it never appears until twilight is over and “the night has fully set in.”

The “light” is usually seen after sunset or before sunrise. But attempts have recently been made by Prof. Simon Newcomb to observe it north of the sun. To avoid the effects of twilight the sun must be only slightly more than 18° below the horizon (that is, a little before or after the longest day). This condition limits the place of observation to latitudes not much south of 46°; and to reduce atmospheric absorption the observing station should be as high as possible above the level of the sea. Prof. Newcomb, observing from the Brienzer Rothorn in Switzerland (latitude 46° 47′ N., longitude 8° 3′ E.), succeeded in tracing the “light” to a distance of 35° north of the sun. It would seem, therefore, that the Zodiacal Light envelops the sun on all sides, but has a greater extension in the direction of the ecliptic.[258] From observations at the Lick Observatory, Mr. E. A. Fath found an extension of 46° north of the sun.[259]

From observations of the “light” made by Prof. Barnard at the Yerkes Observatory during the summer of 1906, he finds that it extends to at least 65° north of the sun, a considerably higher value than that found by Prof. Newcomb.[260] The difference may perhaps be explained by actual variation of the meteoric matter producing the light. Prof. J. H. Poynting thinks that possibly the Zodiacal Light is due to the "dust of long dead comets."[261]

From careful observations of the "light," Mr. Gavin J. Burns finds that its luminosity is "some 40 or 50 per cent. brighter than the background of the sky. Prof. Newcomb has made a precisely similar remark about the luminosity of the Milky Way, viz. that it is surprisingly small." This agrees with my own observations during many years. It is only on the finest and clearest nights that the Milky Way forms a conspicuous object in the night sky. And this only in the country. The lights of a city almost entirely obliterate it. Mr. Burns finds that the Zodiacal Light appears "to be of a yellowish tint; or if we call it white, then the Milky Way is comparatively of a bluish tint." During my residence in the Punjab the Zodiacal Light seemed to me constantly visible in the evening sky in the spring months. In the west of Ireland I have seen it nearly as bright as the brightest portions of the Milky Way visible in this country (February 20, 1890). The "meteoric theory" of the "light" seems to be the one now generally accepted by astronomers, and in this opinion I fully concur.

From observations made in Jamaica in the years 1899 and 1901, Mr. Maxwell Hall arrived at the conclusion that "the Zodiacal Light is caused by reflection of sunlight from masses of meteoric matter still contained in the invariable plane, which may be considered the original plane of the solar system."[262] According to Humboldt, Cassini believed that the Zodiacal Light "consisted of innumerably small planetary bodies revolving round the sun."[263]

The Gegenschein, or Counter-glow.—This is a faint patch of light seen opposite the sun's place in the sky, that is on the meridian at midnight. It is usually elliptical in shape, with its longer axis lying nearly in the plane of the ecliptic. It seems to have been first detected by Brorsen (the discoverer of the short-period comet of 1846) about the middle of the nineteenth century. But it is not easy to see, for the famous Heis of Münster, who had very keen eyesight, did not succeed in seeing it for several years after Brorsen's announcement.[264] It was afterwards independently discovered by Backhouse, and Barnard.

Prof. Barnard's earlier observations seemed to show that the Gegenschein does not lie exactly opposite to the sun, but very nearly so. He found its longitude is within one degree of 180°, and its latitude about 1°·3 north of the ecliptic.[265] But from subsequent observations he came to the conclusion that the differences in longitude and apparent latitude are due to atmospheric absorption, and that the object really lies in the ecliptic and *exactly* opposite to the sun.[266]

Barnard finds that the Gegenschein is not so faint as is generally supposed. He says "it is best seen by averted vision, the face being turned 60° or 70° to the right or left, and the eyes alone turned towards it." It is invisible in June and December, while in September it is round, with a diameter of 20°, and very distinct. No satisfactory theory has yet been advanced to account for this curious phenomenon. Prof. Arthur Searle of Harvard attributes it to a number of asteroids too small to be seen individually. When in "opposition" to the sun these would be fully illuminated and nearest to the earth. Its distance from the earth probably exceeds that of the moon. Dr. Johnson Stoney thinks that the Gegenschein may possibly be due to a "tail" of hydrogen and helium gases repelled from the earth by solar action; this "tail" being visible to us by reflected sunlight.

It was observed under favourable circumstances in January and February, 1903, by the French astronomer, M. F. Quénisset. He found that it was better seen when the atmosphere was less clear, contrary to his experience of the Zodiacal Light. Prof. Barnard's experience confirms this. M. Quénisset notes that—as in the case of the Zodiacal Light—the southern border of the Gegenschein is sharper than the northern. He found that its brightness is less than that of the Milky Way between Betelgeuse and γ Geminorum; and thinks that it is merely a strengthening of the Zodiacal Light.[267]

A meteoritic theory of the Gegenschein has been advanced by Prof. F. R. Moulton, which explains it by light reflected from a swarm of meteorites revolving round the sun at a distance of 930,240 miles outside the earth's orbit.

Both the Zodiacal Light and Gegenschein were observed by Herr Leo Brenner on the evening of March 4, 1896. He found the Zodiacal Light on this evening to be "*perhaps eight times brighter* than the Milky Way in Perseus." The "*Gegenschein distinctly visible* as a round, bright, cloud-like nebula below Leo (Virgo), and about twice the brightness of the Milky Way in Monoceros between Canis Major and Canis Minor."[268]

Humboldt thought that the fluctuations in the brilliancy of the Zodiacal Light were probably due to a real variation in the intensity of the phenomenon rather than to the elevated position of the observer.[269] He says that he was "astonished in the tropical climates of South America, to observe the variable intensity of the light."

CHAPTER XIV

The Stars

PLINY says that Hipparchus "ventured to count the stars, a work arduous even for the Deity." But this was quite a mistaken idea. Those visible to the naked eye are comparatively few in number, and the enumeration of those visible in an opera-glass—which of course far exceed those which can be seen by unaided vision—is a matter of no great difficulty. Those visible in a small telescope of 2¾ inches aperture have all been observed and catalogued; and even those shown on photographs taken with large telescopes can be easily counted. The present writer has made an attempt in this direction, and taking an average of a large number of counts in various parts of the sky, as shown on stellar photographs, he finds a total of about 64 millions for the whole sky in both hemispheres.[270] Probably the total number will not exceed 100 millions. But this is a comparatively small number, even when compared with the human population of our little globe.

With reference to the charts made by photography in the International scheme commenced some years ago, it has now been estimated that the charts will probably contain a total of about 9,854,000 stars down to about the 14th magnitude (13·7). The "catalogue plates" (taken with a shorter exposure) will, it is expected, include about 2,676,500 stars down to 11½ magnitude. These numbers may, however, be somewhat increased when the work has been completed.[271] If this estimate proves to be correct, the number of stars visible down to the 14th magnitude will be considerably less than former estimates have made it.

Prof. E. C. Pickering estimates that the total number of stars visible on photographs down to the 16th magnitude (about the faintest visible in the great Lick telescope) will be about 50 millions.[272] In the present writer's enumeration, above referred to, many stars fainter than the 16th magnitude were included.

Admiral Smyth says, with reference to Sir William Herschel—perhaps the greatest observer that ever lived—"As to Sir William himself, he could unhesitatingly call every star down to the 6th magnitude, by its name, letter, or number."[273] This shows great powers of observation, and a wonderful memory.

On a photographic plate of the Pleiades taken with the Bruce telescope and an exposure of 6 hours, Prof. Bailey of Harvard has counted "3972 stars within an area 2° square, having Alcyone at its centre."[274] This would give a total of about 41 millions for the whole sky, if of the same richness.

With an exposure of 16 hours, Prof. H. C. Wilson finds on an area of less that 110′ square a total of 4621 stars. He thinks, "That all of these stars belong to the Pleiades group is not at all probable. The great majority of them probably lie at immense distances beyond the group, and simply appear in it by projection."[274] He adds, "It has been found, however, by very careful measurements made during the last 75 years at the Königsbergh and Yale Observatories, that of the sixty-nine brighter stars, including those down to the 9th magnitude, only eight show any certain movement with reference to Alcyone. Since Alcyone has a proper motion or drift of 6″ per century, this means that all the brightest stars except the eight mentioned are drifting with Alcyone and so form a true cluster, at approximately the same distance from the earth. Six of the eight stars which show relative drift are moving in the opposite direction to the movement of Alcyone, and at nearly the same rate, so that their motion is only apparent. They are really stationary, while Alcyone and the rest of the cluster are moving past them."[275] This tends to show that the faint stars are really *behind* the cluster, and are unconnected with it.

It is a popular idea with some people that the Pole Star is the nearest of all the stars to the celestial pole. But photographs show that there are many faint stars nearer to the pole than the Pole Star. The Pole Star is at present at a distance of 1° 13′ from the real pole of the heavens, but it is slowly approaching it. The minimum distance will be reached in the year 2104. From photographs taken by M. Flammarion at the Juvisy Observatory, he finds that there are at least 128 stars nearer to the pole than the Pole Star! The nearest star to the pole was, in the year 1902, a small star of about 12½ magnitude, which was distant about 4 minutes of arc from the pole.[276] The estimated magnitude shows that the Pole Star is nearly 10,000 times brighter than this faint star!

It has been found that Sirius is bright enough to cast a shadow under favourable conditions. On March 22, 1903, the distinguished French astronomer Touchet succeeded in photographing the shadow of a brooch cast by this brilliant star. The exposure was $1^h\ 5^m$.

Martinus Hortensius seems to have been the first to see stars in daylight, perhaps early in the seventeenth century. He mentions the fact in a letter to Gassendi dated October 12, 1636, but does not give the date of his observation. Schickard saw Arcturus in broad daylight early in 1632. Morin saw the same bright star half an hour after sunset in March, 1635.

Some interesting observations were made by Professors Payne and H. C. Wilson, in the summer of 1904, at Midvale, Montana (U.S.A.), at a height of 4790 feet above sea-level. At this height they found the air very clear and transparent. "Many more stars were visible at a glance, and the familiar stars appeared more brilliant.... In the great bright cloud of the Milky Way, between β and γ Cygni, one could count easily sixteen or seventeen stars, besides the bright ones η and χ,[277] while at Northfield it is difficult to distinctly see eight or nine with the naked eye." Some nebulæ and star fields were photographed with good results by the aid of a 2½-inch Darlot lens and 3 hours' exposure.[278]

Prof. Barnard has taken some good stellar photographs with a lens of only 1½ inches in diameter, and 4 or 5 inches focus belonging to an ordinary "magic lantern"! He says that these "photographs with the small lens show us in the most striking manner how the most valuable and important information may be obtained with the simplest means."[279]

With reference to the rising and setting of the stars due to the earth's rotation on its axis, the late Sir George B. Airy, Astronomer Royal of England, once said to a schoolmaster, "I should like to know how far your pupils go into the first practical points for which reading is scarcely necessary. Do they know that the stars rise and set? Very few people in England know it. I once had a correspondence with a literary man of the highest rank on a point of Greek astronomy, and found that he did not know it!"[280]

Admiral Smyth says, “I have been struck with the beautiful blue tint of the smallest stars visible in my telescope. This, however, may be attributed to some optical peculiarity.” This bluish colour of small stars agrees with the conclusion arrived at by Prof. Pickering in recent years, that the majority of faint stars in the Milky Way have spectra of the Sirian type and, like that brilliant star, are of a bluish white colour. Sir William Herschel saw many stars of a redder tinge than other observers have noticed. Admiral Smyth says, “This may be owing to the effect of his metallic mirror or to some peculiarity of vision, or perhaps both.”[281]

The ancient astronomers do not mention any coloured stars except white and red. Among the latter they only speak of Arcturus, Aldebaran, Pollux, Antares, and Betelgeuse as of a striking red colour. To these Al-Sufi adds Alphard (α Hydræ).

Sir William Herschel remarked that no decidedly green or blue star “has ever been noticed unassociated with a companion brighter than itself.” An exception to Herschel’s rule seems to be found in the case of the star β Libræ, which Admiral Smyth called “pale emerald.” Mr. George Knott observed it on May 19, 1852, as “beautiful pale green” (3·7 inches achromatic, power 80), and on May 9, 1872, as “fine pale green” (5·5 inches achromatic, power 65).

The motion of stars in the line of sight, as shown by the spectroscope—should theoretically alter their brightness in the course of time; those approaching the earth becoming gradually brighter, while those receding should become fainter. But the distance of the stars is so enormous that even with very high velocities the change would not become perceptible for ages. Prof. Oudemans found that to change the brightness of a star by only one-tenth of a magnitude—a quantity barely perceptible to the eye-a number of years would be necessary, which is represented by the formula

$$\frac{5916 \text{ years}}{\text{parallax} \times \text{motion}}$$

for a star approaching the earth, and for a receding star

$$\frac{6195 \text{ years}}{\text{p} \times \text{m}}$$

This is in geographical miles, 1 geographical mile being equal to 4·61 English miles.

Reducing the above to English miles, and taking an average for both approaching and receding stars, we have

$$\frac{27{,}660 \text{ years}}{p \times m}$$

where p = parallax in seconds of arc, and m = radial velocity in English miles per second.

Prof. Oudemans found that the only star which could have changed in brightness by one-tenth of a magnitude since the time of Hipparchus is Aldebaran. This is taking its parallax as 0″·52. But assuming the more reliable parallax 0″·12 found by Dr. Elkin, this period is 4⅓ times longer. For Procyon, the period would be 5500 years.[282] The above calculation shows how absurd it is to suppose that any star could have gained or lost in brightness by motion in the line of sight during historical times. The "secular variation" of stars is quite another thing. This is due to physical changes in the stars themselves.

The famous astronomer Halley, the second Astronomer Royal at Greenwich, says (*Phil. Trans.*, 1796), "Supposing the number of 1st magnitude stars to be 13, at twice the distance from the sun there may be placed four times as many, or 52; which with the same allowance would nearly represent the star we find to be of the 2nd magnitude. So 9 × 13, or 117, for those at three times the distance; and at ten times the distance 100 × 13, or 1300 stars; of which distance may probably diminish the light of any of the stars of the 1st magnitude to that of the 6th, it being but the hundredth part of what, at their present distance, they appear with." This agrees with the now generally accepted "light ratio" of 2·512 for each magnitude, which makes a first magnitude star 100 times the light of a 6th magnitude.

On the 4th of March, 1796,[283] the famous French astronomer Lalande observed on the meridian a star of small 6th magnitude, the exact position of which he determined. On the 15th of the same month he again observed the star, and the places found for 1800 refer to numbers 16292-3 of the reduced catalogue. In the observation of March 4 he attached the curious remark, "Étoile singulière" (the observation of March 15 is without note). This remark of Lalande has puzzled observers who failed to find any peculiarity about the star. Indeed, "the remark is a strange one for the observer of so many thousands of stars to attach unless there was really something singular in the star's aspect at the time." On the evening of April 18, 1887, the star was examined by the present writer, and the following is the record in his observing book, "Lalande's étoile singulière (16292-3) about half a magnitude less than η Cancri. With the binocular I see two streams of small stars branching out from it, north preceding like the tails of comet." This may perhaps have something to do with Lalande's curious remark.

The star numbered 1647 in Baily's *Flamsteed Catalogue* is now known to have been an observation of the planet Uranus.[284]

Prof. Pickering states that the fainter stars photographed with the 8-inch telescope at Cambridge (U.S.A.) are invisible to the eye in the 15-inch telescope.[285]

Sir Norman Lockyer finds that the lines of sulphur are present in the spectrum of the bright star Rigel (β Orionis).[286]

About 8½° south of the bright star Regulus (α Leonis) is a faint nebula (H I, 4 Sextantis). On or near this spot the Capuchin monk De Rheita fancied he saw, in the year 1643, a group of stars representing the napkin of S. Veronica—"sudarium Veronicæ sive faciem Domini maxima similitudina in astris expressum." And he gave a picture of the napkin and star group. But all subsequent observers have failed to find any trace of the star group referred to by De Rheita![287]

The Bible story of the star of the Magi is also told in connection with the birth of the sun-gods Osiris, Horus, Mithra, Serapis, etc.[288] The present writer has also heard it suggested that the phenomenon may have been an apparition of Halley's comet! But as this famous comet is known to have appeared in the year B.C. 11, and as the date of the Nativity was probably not earlier than B.C. 5, the hypothesis seems for this (and other reasons) to be inadmissible. It has also been suggested that the phenomenon might have been an appearance of Tycho Brahé's temporary star of 1572, known as the "Pilgrim star"; but there seems to be no real foundation for such an hypothesis. There is no reason to think that "temporary" or new stars ever appear a second time.

Admiral Smyth has well said, "It checks one's pride to recollect that if our sun with the whole system of planets, asteroids, and moons, and comets were to be removed from the spectator to the distance of the nearest fixed star, not one of them would be visible, except the sun, which would then appear but as a star of perhaps the 2nd magnitude. Nay, more, were the whole system of which our globe forms an insignificant member, with its central luminary, suddenly annihilated, no effect would be produced on those unconnected and remote bodies; and the only annunciation of such a catastrophe in the Sidereal "Times" would be that a small star once seen in a distant quarter of the sky had ceased to shine."[289]

Prof. George C. Comstock finds that the average parallax of 67 selected stars ranging in brightness between the 9th and the 12th magnitude, is of the value of 0″·0051.[290] This gives a distance representing a journey for light of about 639 years!

Mr. Henry Norris Russell thinks that nearly all the bright stars in the constellation of Orion are practically at the same distance from the earth. His reasons for this opinion are: (1) the stars are similar in their spectra and proper motions, (2) their proper motions are small, which suggests a small parallax, and therefore a great distance from the earth. Mr. Russell thinks that the average parallax of these stars may perhaps be 0″·005, which gives a distance of about 650 "light years."[291]

According to Sir Norman Lockyer's classification of the stars, the order of *increasing* temperature is represented by the following, beginning with those in the earliest stage of stellar evolution:—Nebulæ, Antares, Aldebaran, Polaris, α Cygni, Rigel, ε Tauri, β Crucis. Then we have the hottest stars represented by ε Puppis, γ Argus, and Alnitam (ε Orionis). *Decreasing* temperature is represented by (in order), Achernar, Algol, Markab, Sirius, Procyon, Arcturus, 19 Piscium, and the "Dark Stars."[292] But other astronomers do not agree with this classification. Antares and Aldebaran are by some authorities considered to be *cooling* suns.

According to Ritter's views of the Constitution of the Celestial Bodies, if we "divide the stars into three classes according to age corresponding to these three stages of development, we shall assign to the first class, A, those stars still in the nebular phase of development; to the second class, B, those in the transient stage of greatest brilliancy; and to the class C, those stars which have already entered into the long period of slow extinction. It should be noted in this classification that we refer to relative and not absolute age, since a star of slight mass passes through the successive phases of its development more rapidly than the star of greater mass."[293] Ritter comes to the conclusion that "the duration of the period in which the sun as a star had a greater brightness than at present was very short in comparison with the period in which it had and will continue to have a brightness differing only slightly from its present value."[294]

In a valuable and interesting paper on "The Evolution of Solar Stars,"[295] Prof. Schuster says that "measurements by E. F. Nichols on the heat of Vega and Arcturus indicated a lower temperature for Arcturus, and confirms the conclusion arrived at on other grounds, that the hydrogen stars have a higher temperature than the solar stars." "An inspection of the ultraviolet region of the spectrum gives the same result. These different lines of argument, all leading to the same result, justify us in saying that the surface temperature of the hydrogen stars is higher than that of the solar stars. An extension of the same reasoning leads to the belief that the helium stars have a temperature which is higher still." Hence we have Schuster, Hale, and Sir William Huggins in agreement that the Sirian stars are hotter than the solar stars; and personally I agree with these high authorities. The late Dr. W. E. Wilson, however, held the opinion that the sun is hotter that Sirius!

Schuster thinks that Lane's law does not apply to the temperature of the photosphere and the absorbing layers of the sun and stars, but only to the portions between the photosphere and the centre, which probably act like a perfect gas. On this view he says the interior might become "hotter and hotter until the condensation had reached a point at which the laws of gaseous condensation no longer hold."

With reference to the stars having spectra of the 3rd and 4th type (usually orange and red in colour), Schuster says—

“The remaining types of spectra belong to lower temperature still, as in place of metallic lines, or in addition to them, certain bands appear which experiments show us invariably belong to lower temperature than the lines of the same element.

“If an evolutionary process has been going on, which is similar for all stars, there is little doubt that from the bright-line stars down to the solar stars the order has been (1) helium or *Orion* stars, (2) hydrogen or Sirian stars, (3) calcium or Procyon stars, (4) solar or Capellan stars.”

My investigations on “The Secular Variation of Starlight” (*Studies in Astronomy*, chap. 17, and *Astronomical Essays*, chap. 12) based on a comparison of Al-Sufi’s star magnitudes (tenth century) with modern estimates and measures, tend strongly to confirm the above views.

With regard to the 3rd-type stars, such as Betelgeuse and Mira Ceti, Schuster says, “It has been already mentioned that observers differ as to whether their position is anterior to the hydrogen or posterior to the solar stars, and there are valid arguments on both sides.”

Scheiner, however, shows, from the behaviour of the lines of magnesium, that stars of type I. (Sirian) are the hottest, and type III. the coolest, and he says, we have “for the first time a direct proof of the correctness of the physical interpretation of Vogel’s spectral classes, according to which class II. is developed by cooling from I., and III. by a further process of cooling from II.”[296]

Prof. Hale says that “the resemblance between the spectra of sun-spots and of 3rd-type stars is so close as to indicate that the same cause is controlling the relative intensities of many lines in both instances. This cause, as the laboratory work indicates, is to be regarded as reduced temperature.”[297]

According to Prof. Schuster, “a spectrum of bright lines may be given by a mass of luminous gas, even if the gas is of great thickness. There is, therefore, no difficulty in explaining the existence of stars giving bright lines.” He thinks that the difference between “bright line” stars and those showing dark lines depends upon the rate of increase of the temperature from the surface towards the centre. If this rate is slow, bright lines will be seen. If the rate of increase is rapid, the dark-line spectrum shown by the majority of the stars will appear. This rate, he thinks, is regulated by the gravitational force. So that in the early stages of condensation bright lines are more likely to occur. "If the light is not fully absorbed," both bright and dark lines of the same element may be visible in the same star. Schuster considers it quite possible that if we could remove the outer layers of the Sun's atmosphere, we should obtain a spectrum of bright lines.[298]

M. Stratonoff finds that stars having spectra of the Orion and Sirian types—supposed to represent an early stage in stellar evolution—tend to congregate in or near the Milky Way. Star clusters in general show a similar tendency, "but to this law the globular clusters form an exception."[299] We may add that the spiral nebulæ—which seem to be scattered indifferently over all parts of the sky—also seem to form an exception; for the spectra of these wonderful objects seem to show that they are really star clusters, in which the components are probably relatively small; that is, small in comparison with our sun.

If we accept the hypothesis that suns and systems were evolved from nebulæ, and if we consider the comparatively small number of nebulæ hitherto discovered in the largest telescopes—about half a million; and if we further consider the very small number of red stars, or those having spectra of the third and fourth types—usually considered to be dying-out suns—we seem led to the conclusion that our sidereal system is now at about the zenith of its life-history; comparatively few nebulæ being left to consolidate into stars, and comparatively few stars having gone far on the road to the final extinction of their light.

Prof. Boss of Albany (U.S.A.) finds that about forty stars of magnitudes from 3½ to 7 in the constellation Taurus are apparently drifting together towards one point. These stars are included between about R.A. $3^h\ 47^m$ to $5^h\ 4^m$, and Declination + 5° to + 23° (that is, in the region surrounding the Hyades). These motions apparently converge to a point near R.A. 6^h, Declination + 7° (near Betelgeuse). Prof. Boss has computed the velocity of the stars in this group to be 45·6 kilometres (about 28 miles) a second towards the "vanishing point," and he estimated the average parallax of the group to be 0″·025—about 130 years' journey for light. Although the motions are apparently converging to a point, it does not follow that the stars in question will, in the course of ages, meet at the "vanishing point."

On the contrary, the observed motions show that the stars are moving in parallel lines through space. About 15 kilometres of the observed speed is due to the sun's motion through space in the opposite direction. Prof. Campbell finds from spectroscopic measures that of these forty stars, nine are receding from the earth with velocities varying from 12 to 60 kilometres a second, and twenty-three others with less velocities than 38 kilometres.[300] It will be obvious that, as there is a "vanishing point," the motion in the line of sight must be one of *recession* from the earth.

It has been found that on an average the parallax of a star is about one-seventh of its "proper motion."[301]

Adopting Prof. Newcomb's parallax of 0″·14 for the famous star 1830 Groombridge, the velocity perpendicular to the line of sight is about 150 miles a second. The velocity *in* the line of sight—as shown by the spectroscope—is 59 miles a second approaching the earth. Compounding these two velocities we find a velocity through space of about 161 miles a second!

An eminent American writer puts into the mouth of one of his characters, a young astronomer, the following:—

> "I read the page
> Where every letter is a glittering sun."

From an examination of the heat radiated by some bright stars, made by Dr. E. F. Nicholls in America with a very sensitive radiometer of his own construction, he finds that "we do not receive from Arcturus more heat than we should from a candle at a distance of 5 or 6 miles."

With reference to the progressive motion of light, and the different times taken by light to reach the earth from different stars, Humboldt says, "The aspect of the starry heavens presents to us objects of *unequal date*. Much has long ceased to exist before the knowledge of its presence reaches us; much has been otherwise arranged."[302]

The photographic method of charting the stars, although a great improvement on the old system, seems to have its disadvantages. One of these is that the star images are liable to disappear from the plates in the course of time. The reduction of stellar photograph plates should, therefore, be carried out as soon as possible after they are taken. The late Dr. Roberts found that on a plate originally containing 364 stars, no less than 130 had completely disappeared in 9¼ years!

It has been assumed by some writers on astronomy that the faint stars visible on photographs of the Pleiades are at practically the same distance from the earth as the brighter stars of the cluster, and that consequently there must be an enormous difference in actual size between the brighter and fainter stars. But there is really no warrant for any such assumption. Photographs of the vicinity show that the sky all round the Pleiades is equally rich in faint stars. It seems, therefore, more reasonable to suppose that most of the faint stars visible in the Pleiades are really far behind the cluster in space. For if *all* the faint stars visible on photographs belonged to the cluster, then if we imagine the cluster removed, a "hole" would be left in the sky, which is of course utterly improbable, and indeed absurd. An examination of the proper motions tends to confirm this view of the matter, and indicates that the Pleiades cluster is a comparatively small one and simply projected on a background of fainter stars.

It has long been suspected that the famous star 61 Cygni, which is a double star, forms a binary system—that is, that the two stars composing it revolve round their common centre of gravity and move together through space. But measures of parallax made by Herman S. Davis and Wilsing seem to show a difference of parallax between the two components of about 0·08 of a second of arc. This difference of parallax implies a distance of about 2¼ "light years" between the two stars, and "if this is correct, the stars are too remote to form a binary system. The proper motions of 5″·21 and 5″·15 seem to show that they are moving in nearly parallel directions; but are probably slowly separating." Mr. Lewis, however, thinks that a physical connection probably exists.[303]

Dante speaks of the four bright stars of the Southern Cross as emblematical of the four cardinal virtues, Justice, Temperance, Fortitude, and Prudence; and he seems to refer to the stars Canopus, Achernar, and Foomalhaut under the symbols of Faith, Hope, and Charity. The so-called "False Cross" is said to be formed by the stars κ, δ, ε, and ι of the constellation Argo Navis. But it seems to me that a better (although larger) cross is formed by the stars α Centauri and α, β, and γ of Triangulum Australis.

Mr. Monck has pointed out that the names of the brightest stars seem to be arranged alphabetically in order of colour, beginning with red and ending with blue. Thus we have Aldebaran, Arcturus, Betelgeuse, Capella, Procyon, Regulus, Rigel, Sirius, Spica and Vega. But as the origin of these names is different, this must be merely a curious coincidence.[304] And, to my eye at least, Betelgeuse is redder than Arcturus.

The poet Longfellow speaks of the—

> "Stars, the thoughts of God in the heavens,"[305]

and Drayton says—

> "The stars to me an everlasting book
> In that eternal register, the sky."[306]

Observing at a height of 12,540 feet on the Andes, the late Dr. Copeland saw Sirius with the naked eye less than 10 minutes before sunset.[307] He also saw Jupiter 3^m 47^s before sunset; and the following bright stars—Canopus, 0^m 52^s before sunset; Rigel (β Orionis) 16^m 32^s after sunset; and Procyon 11^m 28^s after sunset. From a height of 12,050 feet at La Paz, Bolivia, he saw with the naked eye in February, 1883, ten stars in the Pleiades in full moonlight, and seventeen stars in the Hyades. He also saw σ Tauri double.[308]

Humboldt says, "In whatever point the vault of heaven has been pierced by powerful and far-penetrating telescopic instruments, stars or luminous nebulæ are everywhere discoverable, the former in some cases not exceeding the 20th or 24th degree of telescopic magnitude."[309] But this is a mistake. No star of even the 20th magnitude has ever been seen by any telescope. Even on the best photographic plates it is doubtful that any stars much below the 18th magnitude are visible. To show a star of the 20th magnitude—if such stars exist—would require a telescope of 144 inches or 12 feet in aperture. To show a star of the 24th magnitude—if such there be—an aperture of 33 feet would be necessary![310]

It is a popular idea that stars may be seen in the daytime from the bottom of a deep pit or high chimney. But this has often been denied. Humboldt says, "While practically engaged in mining operations, I was in the habit, during many years, of passing a great portion of the day in mines where I could see the sky through deep shafts, yet I never was able to observe a star.”[311]

Stars may, however, be seen in the daytime with even small telescopes. It is said that a telescope of 1 inch aperture will show stars of the 2nd magnitude; 2 inches, stars of the 3rd magnitude; and 4 inches, stars of the 4th magnitude. But I cannot confirm this from personal observation. It may be so, but I have not tried the experiment.

Sir George Darwin says—

“Human life is too short to permit us to watch the leisurely procedure of cosmical evolution, but the celestial museum contains so many exhibits that it may become possible, by the aid of theory, to piece together, bit by bit, the processes through which stars pass in the course of their evolutions.”[312]

The so-called “telluric lines” seen in the solar spectrum, are due to water vapour in the earth’s atmosphere. As the light of the stars also passes through the atmosphere, it is evident that these lines should also be visible in the spectra of the stars. This is found to be the case by Prof. Campbell, Director of the Lick Observatory, who has observed all the principal bands in the spectrum of every star he has examined.[313]

The largest “proper motion” now known is that of a star of the 8½ magnitude in the southern hemisphere, known as Cordoba Zone V. No. 243. Its proper motion is 8·07 seconds of arc per annum, thus exceeding that of the famous “runaway star,” 1830 Groombridge, which has a proper motion of 7·05 seconds per annum. This greater motion is, however, only apparent. Measures of parallax show that the southern “runaway” is much nearer to us than its northern rival, its parallax being 0″·32, while that of Groombridge 1830 is only 0″·14. With these data the actual velocity across the line of sight can be easily computed. That of the southern star comes out 80 miles a second, while that of Groombridge 1830 is 148 miles a second. The actual velocity of Arcturus is probably still greater.

The poet Barton has well said—

“The stars! the stars! go forth at night,
  Lift up thine eyes on high,

And view the countless orbs of light,
    Which gem the midnight sky.
Go forth in silence and alone,
    This glorious sight to scan,
And bid the humbled spirit own
    The littleness of man.”

CHAPTER XV

Double and Binary Stars

PROF. R. G. AITKEN, the eminent American observer of double stars, finds that of all the stars down to the 9th magnitude—about the faintest visible in a powerful binocular field-glass—1 in 18, or 1 in 20, on the average, are double, with the component stars less than 5 seconds of arc apart. This proportion of double stars is not, however, the same for all parts of the sky; while in some regions double stars are very scarce, in other places the proportion rises to 1 in 8.

For the well-known binary star Castor (α Geminorum), several orbits have been computed with periods ranging from 232 years (Mädler) to 1001 years (Doberck). But Burnham finds that "the orbit is absolutely indeterminate at this time, and likely to remain so for another century or longer."[314] Both components are spectroscopic binaries, and the system is a most interesting one.

The well-known companion of Sirius became invisible in all telescopes in the year 1890, owing to its near approach to its brilliant primary. It remained invisible until August 20, 1896, when it was again seen by Dr. See at the Lowell Observatory.[315] Since then its distance has been increasing, and it has been regularly measured. The maximum distance will be attained about the year 1922.

The star β Cephei has recently been discovered to be a spectroscopic binary with the wonderfully short period of $4^h\ 34^m\ 11^s$. The orbital velocity is about 10½ miles a second, and as this velocity is not very great, the distance between the components must be very small, and possibly the two component bodies are revolving in actual contact. The spectrum is of the "Orion type."[316]

According to Slipher the spectroscopic binary γ Geminorum has the comparatively long period (for a spectroscopic binary) of about 3½ years. This period is comparable with that of the telescopic binary system, δ Equulei (period about 5·7 years). The orbit is quite eccentric. I have shown elsewhere[317] that γ Geminorum has probably increased in brightness since the time of Al-Sufi (tenth century). Possibly its spectroscopic duplicity may have something to do with the variation in its light.

With reference to the spectra of double stars, Mr. Maunder suggests that the fact of the companion of a binary star showing a Sirian spectrum while the brighter star has a solar spectrum may be explained by supposing that, on the theory of fission, "the smaller body when thrown off consisted of the lighter elements, the heavier remaining in the principal star. In other words, in these cases spectral type depends upon original chemical constitution, and not upon the stage of stellar development attained."[318]

A curious paradox with reference to binary stars has recently come to light. For many years it was almost taken for granted that the brighter star of a pair had a larger mass than the fainter component. This was a natural conclusion, as both stars are practically at the same distance from the earth. But it has been recently found that in some binary stars the fainter component has actually the larger mass! Thus, in the binary star ε Hydræ, the "magnitude" of the component stars are 3 and 6, indicating that the brighter star is about 16 times brighter than the fainter component. Yet calculations by Lewis show that the fainter star has 6 times the mass of the brighter, that is, contains 6 times the quantity of matter! In the well-known binary 70 Ophiuchi, Prey finds that the fainter star has about 4 times the mass of the brighter! In 85 Pegasi, the brighter star is about 40 times brighter than its companion, while Furner finds that the mass of the fainter star is about 4 times that of the brighter! And there are other similar cases. In fact, in these remarkable combinations of suns the fainter star is really the "primary," and is, so far as mass is concerned, "the predominant partner." This is a curious anomaly, and cannot be well explained in the present state of our knowledge of stellar systems. In the case of α Centauri the masses of the components are about equal, while the primary star is about 3 times brighter than the other. But here the discrepancy is satisfactorily explained by the difference in character of the spectra, the brighter component having a spectrum of the solar type, while the fainter seems further advanced on the downward road of evolution, that is, more consolidated and having, perhaps, less intrinsic brightness of surface.

In the case of Sirius and its faint attendant, the mass of the bright star is about twice the mass of the satellite, while its light is about 40,000 times greater! Here the satellite is either a cooled-down sun or perhaps a gaseous nebula. There seems to be no other explanation of this curious paradox. The same remark applies to Procyon, where the bright star is about 100,000 times brighter than its faint companion, although its mass is only 5 times greater.

The bright star Capella forms a curious anomaly or paradox. Spectroscopic observations show that it is a very close binary pair. It has been seen "elongated" at the Greenwich Observatory with the great 28-inch refractor —the work of Sir Howard Grubb—and the spectroscopic and visual measurements agree in indicating that its mass is about 18 times the mass of the sun. But its parallax (about 0″·08) shows that it is about 128 times brighter than the sun! This great brilliancy is inconsistent with the star's computed mass, which would indicate a much smaller brightness. The sun placed at the distance of Capella would, I find, shine as a star of about 5½ magnitude, while Capella is one of the brightest stars in the sky. As the spectrum of Capella's light closely resembles the solar spectrum, we seem justified in assuming that the two bodies have pretty much the same physical composition. The discrepancy between the computed and actual brightness of the star cannot be explained satisfactorily, and the star remains an astronomical enigma.

Three remarkable double-star systems have been discovered by Dr. See in the southern hemisphere. The first of these is the bright star α Phœnicis, of which the magnitude is 2·4, or only very slightly fainter than the Pole Star. It is attended by a faint star of the 13th magnitude at a distance of less than 10 seconds (1897). The bright star is of a deep orange or reddish colour, and the great difference in brightness between the component stars "renders the system both striking and difficult." The second is μ Velorum, a star of the 3rd magnitude, which has a companion of the 11th magnitude, and only 2½″ from its bright primary (1897). Dr. See describes this pair as "one of the most extraordinary in the heavens." The third is η Centauri, of 2½ magnitude, with a companion of 13½ magnitude at a distance of 5″·65

(1897); colours yellow and purple. This pair is "extremely difficult, requiring a powerful telescope to see it." Dr. See thinks that these three objects "may be regarded as amongst the most splendid in the heavens."

The following notes are from Burnham's recently published *General Catalogue of Double Stars*.

The Pole Star has a well-known companion of about the 9th magnitude, which is a favourite object for small telescopes. Burnham finds that the bright star and its faint companion are "relatively fixed," and are probably only an "optical pair." Some other companions have been suspected by amateur observers, but Burnham finds that "there is nothing nearer" than the known companion within the reach of the great 36-inch telescope of the Lick Observatory (*Cat.*, p. 299).

The well-known companion to the bright star Rigel (β Orionis) has been suspected for many years to be a close double star. Burnham concludes that it is really a binary star, and its "period may be shorter than that of any known pair" (*Cat.*, p. 411).

Burnham finds that the four brighter stars in the trapezium in the great Orion nebula (in the "sword") are relatively fixed (*Cat.*, p. 426).

γ Leonis. This double star was for many years considered to be a binary, but Burnham has shown that all the measures may be satisfactorily represented by a straight line, and that consequently the pair merely forms an "optical double."

42 Comæ Berenices. This is a binary star of which the orbit plane passes nearly through the earth. The period is about 25½ years, and Burnham says the orbit "is as accurately known as that of any known binary."

σ Coronæ Borealis. Burnham says that the orbits hitherto computed—with periods ranging from 195 years (Jacob) to 846 years (Doberck) are "mere guess work," and it will require the measures of at least another century, and perhaps a much longer time, to give an approximate period (*Cat.*, p. 209). So here is some work left for posterity to do in this field.

70 Ophiuchi. With reference to this well-known binary star, Burnham says, "the elements of the orbit are very accurately known." The periods

computed range from 86·66 years (Doolittle) to 98·15 years (Powell). The present writer found a period of 87·84 years, which cannot be far from the truth. Burnham found 87·75 years (*Cat.*, p. 774). In this case there is not much left for posterity to accomplish.

61 Cygni. With reference to this famous star Burnham says, "So far the relative motion is practically rectilinear. If the companion is moving in a curved path, it will require the measures of at least another half-century to make this certain. The deviation of the measured positions during the last 70 years from a right line are less than the average errors of the observations."

Burnham once saw a faint companion to Sirius of the 16th magnitude, and measured its position with reference to the bright star (280°·6: 40″·25: 1899·86). But he afterwards found that it was "not a real object but a reflection from Sirius" (in the eye-piece). Such false images are called "ghosts."

With reference to the well-known double (or rather quadruple) star ε Lyræ, near Vega, and supposed faint stars near it, Burnham says, "From time to time various small stars in the vicinity have been mapped, and much time wasted in looking for and speculating about objects which only exist in the imagination of the observer." He believes that many of these faint stars, supposed to have been seen by various observers, are merely "ghosts produced by reflection."

The binary star ζ Boötis, which has long been suspected of small and irregular variation of light, showed remarkable spectral changes in the year 1905,[319] somewhat similar to those of a *nova*, or temporary star. It is curious that such changes should occur in a star having an ordinary Sirian type of spectrum!

A curious quadruple system has been discovered by Mr. R. T. A. Innes in the southern hemisphere. The star κ Toucani is a binary star with components of magnitudes 5 and 7·7, and a period of revolution of perhaps about 1000 years. Within 6′ of this pair is another star (Lacaille 353), which is also a binary, with a period of perhaps 72 years. Both pairs have the same proper motion through space, and evidently form a vast quadruple system; for which Mr. Innes finds a possible period of 300,000 years.[320]

It is a curious fact that the performance of a really good refracting telescope actually exceeds what theory would indicate! at least so far as double stars are concerned. For example, the famous double-star observer Dawes found that the distance between the components of a double star which can just be divided, is found by dividing 4″·56 by the aperture of the object-glass in inches. Now theory gives 5″·52 divided by the aperture. “The actual telescope—if a really good one—thus exceeds its theoretical requirements. The difference between theory and practice in this case seems to be due to the fact that in the ‘spurious’ star disc shown by good telescopes, the illumination at the edges of the star disc is very feeble, so that its full size is not seen except in the case of a very bright star.”[321]

CHAPTER XVI

Variable Stars

IN that interesting work *A Cycle of Celestial Objects*, Admiral Smyth says (p. 275), “Geminiano Montanari, as far back as 1670, was so struck with the celestial changes, that he projected a work to be intituled the *Instabilities of the Firmament*, hoping to show such alterations as would be sufficient to make even Aristotle—were he alive—reverse his opinion on the incorruptibility of the spangled sky: ‘There are now wanting in the heavens,’ said he, ‘two stars of the 2nd magnitude in the stem and yard of the ship Argo. I and others observed them in the year 1664, upon occasion of the comet that appeared in that year. When they first disappeared I know not; only I am sure that on April 10, 1668, there was not the least glimpse of them to be seen.’” Smyth adds, “Startling as this account is—and I am even disposed to question the fact—it must be recollected that Montanari was a man of integrity, and well versed in the theory and practice of astronomy; and his account of the wonder will be found—in good set Latin—in page 2202 of the *Philosophical Transactions* for 1671.”

There must be, I think—as Smyth suggests—some mistake in Montanari’s observations, for it is quite certain that of the stars mentioned by Ptolemy (second century A.D.) there is no star of the 2nd magnitude now missing. It is true that Al-Sufi (tenth century) mentions a star of the *third* magnitude mentioned by Ptolemy in the constellation of the Centaur (about 2° east of the star ε Centauri) which he could not find. But this has nothing to do with Montanari’s stars. Montanari’s words are very clear. He says, “*Desunt in Cœlo duæ stellæ* Secundæ Magnitudinis *in* Puppi Navis *ejusve Transtris* Bayero β et γ, *prope* Canem Majoris, *à me et aliis, occasione præsertim Cometæ* A. 1664 *observatæ et recognitæ. Earum Disparitionem* cui Anno debeam, non novi; *hoc indubium, quod à die* 10 April, 1668, *ne* vestigium quidem *illarum adesse amplius observe; cæteris circa eas etium quartæ et quintæ magnitudinis, immotis.*” So the puzzle remains unsolved.

Sir William Herschel thought that "of all stars which are singly visible, about one in thirty are undergoing an observable change."[322] Now taking the number of stars visible to the naked eye at 6000, this would give about 200 variable stars visible at maximum to the unaided vision. But this estimate seems too high. Taking all the stars visible in the largest telescopes—possibly about 100 millions—the proportion of variable stars will probably be much smaller still.

The theory that the variation of light in the variable stars of the Algol type is due to a partial eclipse by a companion star (not necessarily a dark body) is now well established by the spectroscope, and is accepted by all astronomers. The late Miss Clarke has well said "to argue this point would be *enforcer une porte ouverte*."

According to Dr. A. W. Roberts, the components of the following "Algol variables" "revolve in contact": V Puppis, X Carinæ, β Lyræ, and υ Pegasi. Of those V Puppis and β Lyræ are known spectroscopic binaries. The others are beyond the reach of the spectroscope, owing to their faintness.

A very curious variable star of the Algol type is that known as R R Draconis. Its normal magnitude is 10, but at minimum it becomes invisible in a 7½-inch refracting telescope. The variation must, therefore, be over 3 magnitudes, that is, at minimum its light must be reduced to about one-sixteenth of its normal brightness. The period of variation from maximum to minimum is about 2·83 days. The variation of light near minimum is extraordinarily rapid, the light decreasing by about 1 magnitude in half an hour.[323]

A very remarkable variable star has been recently discovered in the constellation Auriga. Prof. Hartwig found it of the 9th magnitude on March 6, 1908, the star "having increased four magnitudes in one day, whilst within eight days it was less than the 14th magnitude."[324] In other words its light increased at least one-hundredfold in eight days!

The period of the well-known variable star β Lyræ seems to be slowly increasing. This Dr. Roberts (of South Africa) considers to be due to the component stars slowly receding from each other. He finds that "a very slight increase of one-thousandth part of the radius of the orbit would account for the augmentation in time, 30^{m} in a century." According to the theory of stellar evolution the lengthening of the period of revolution of a binary star would be due to the "drag" caused by the tides formed by each component on the other.[325]

M. Sebastian Albrecht finds that in the short-period variable star known as T Vulpeculæ (and other variables of this class, such as Y Ophiuchi), there can be no eclipse to explain the variation of light (as in the case of Algol). The star is a spectroscopic binary, it is true, but the maximum of light coincides with the greatest velocity of *approach* in the line of sight, and the minimum with the greatest velocity of *recession*. Thus the light curve and the spectroscopic velocity curve are very similar in shape, but one is like the other turned upside down. "That is, the two curves have a very close correspondence in phase in addition to correspondence of shape and period."[326]

The star now known as W Ursæ Majoris (the variability of which was discovered by Müller and Kempf in 1902), and which lies between the stars θ and υ of that constellation, has the marvellously short period of 4 hours (from maximum to maximum). Messrs. Jordan and Parkhurst (U.S.A.), find from photographic plates that the star varies from 7·24 to 8·17 magnitude.[327] The light at maximum is, therefore, more than double the light at minimum. A sun which loses more than half its light and recovers it again in the short period of 4 hours is certainly a curious and wonderful object.

In contrast with the above, the same astronomers have discovered a star in Perseus which seems to vary from about the 6th to the 7th magnitude in the very long period of 7½ years! It is now known as X Persei, and its position for 1900 is R.A. $3^h\ 49^m\ 8^s$, Dec. N. 30° 46′, or about one degree south-east of the star ζ Persei. It seems to be a variable of the Algol type, as the star remained constant in light at about the 6th magnitude from 1887 to 1891. It then began to fade, and on December 1, 1897, it was reduced to about the 7th magnitude.

On the night of August 20, 1886, Prof. Colbert, of Chicago, noticed that the star ζ Cassiopeiæ increased in brightness "by quite half a magnitude, and about half an hour afterwards began to return to its normal magnitude."[328] This curious outburst of light in a star usually constant in brightness is (if true) a very unusual phenomenon. But a somewhat similar fluctuation of light is recorded by the famous German astronomer Heis. On September 26, 1850, he noted that the star "ζ Lyræ became, for a moment, *very bright*, and then again faint." (The words in his original observing book are: "ζ Lyræ wurde einen *Moment sehr hell* und hierauf wieder dunkel.") As Heis was a remarkably accurate observer of star brightness, the above remark deserves the highest confidence.[329]

The variable star known as the V Delphini was found to be invisible in the great 40-inch telescope of the Yerkes Observatory on July 20, 1900. Its magnitude was, therefore, below the 17th. At its maximum brightness it is about 7½, or easily visible in an ordinary opera-glass, so that its range of variation is nearly, or quite, ten magnitudes. That is, its light at maximum is about 10,000 times its light at minimum. That a sun should vary in light to this enormous extent is certainly a wonderful fact. A variable discovered by Ceraski (and numbered 7579 in Chandlers' Catalogue) "had passed below the limit of the 40-inch in June, 1900, and was, therefore, not brighter than 17 mag."[330]

The late Sir C. E. Peck and his assistant, Mr. Grover, made many valuable observations of variable stars at the Rousden Observatory during many years past. Among other interesting things noted, Peck sometimes saw faint stars in the field of view of his telescope which were at other times invisible for many months, and he suggested that these are faint variable stars with a range of brightness from the 13th to the 20th magnitude. He adds, "Here there is a practically unemployed field for the largest telescopes." Considering the enormous number of faint stars visible on stellar photographs the number of undiscovered variable stars must be very large.

Admiral Smyth describes a small star near β Leonis, about 5′ distant, of about 8th magnitude, and dull red. In 1864 Mr. Knott measured a faint star close to Smyth's position, but estimated it only 11·6 magnitude. The Admiral's star would thereupon seem to be variable.[331]

The famous variable star η Argus, which Sir John Herschel, when at the Cape of Good Hope in 1838, saw involved in dense nebulosity, was in April, 1869, "seen on the bare sky," with the great Melbourne telescope, "the nebula having disappeared for some distance round it." Other changes were noticed in this remarkable nebula. The Melbourne observers saw "three times as many stars as were seen by Herschel." But of course their telescope is much larger—48 inches aperture, compared with Herschel's 20 inches.

Prof. E. C. Pickering thinks that the fluctuations of light of the well-known variable star R Coronæ (in the Northern Crown), "are unlike those of any known variable." This very curious object—one of the most curious in the heavens—sometimes remains for many months almost constant in brightness (just visible to the naked eye), and then rapidly fades in light by several magnitudes! Thus its changes of light in April and May, 1905, were as follows:—

1905, April	1	...	...	6·0	magnitude
"	11	...	...	7·3	"
"	12	...	...	8·4	"
May	1	...	...	11·4	"
"	7	...	...	12·5	"

Thus between April 1 and May 1, its light was reduced by over 5 magnitudes. In other words, the light of the star on May 1 was reduced to less than one-hundredth of its light on April 1. If our sun were to behave in this way nearly all life would soon be destroyed on the face of the earth.

M. H. E. Lau finds that the short-period variable star δ Cephei varies slightly in colour as well as in light, and that the colour curve is parallel to the light curve. Near the minimum of light the colour is reddish yellow, almost as red as ζ Cephei; a day later it is pure yellow, and of about the same colour as the neighbouring ε Cephei.[332] But it would not be easy to fully establish such slight variations of tint.

A remarkably bright maximum of the famous variable Mira Ceti occurred in 1906. In December of that year it was fully 2nd magnitude. The present writer estimated it 1·8, or nearly equal to the brightest on record—1·7 observed by Sir William Herschel and Wargentin in the year 1779. From photographs of the spectrum taken by Mr. Slipher at the Lowell Observatory in 1907, he finds strong indications of the presence of the rather rare element vanadium in the star's surroundings. Prof. Campbell finds with the Mills spectrograph attached to the great 36-inch telescope of the Lick Observatory that Mira is receding from the earth at the apparently constant velocity of about 38 miles a second.[333] This, of course, has nothing to do with the variation in the star's light. Prof. Campbell failed to see any trace of the green line of hydrogen in the star's spectrum, while two other lines of the hydrogen series "glowed with singular intensity."

Mr. Newall has found evidence of the element titanium in the spectrum of Betelgeuse (α Orionis); Mr. Goatcher and Mr. Lunt (of the Cape Observatory) find tin in Antares (and Scorpii). If the latter observation is confirmed it will be the first time this metal has been found in a star's atmosphere.[334]

It is a curious fact that Al-Sufi (tenth century) does not mention the star ε Aquilæ, which lies closely north-west of ζ Aquilæ, as it is now quite conspicuous to the naked eye. It was suspected of variation by Sir William Herschel. It was first recorded by Tycho Brahé about 1590, and he called it 3rd magnitude. Bayer also rated it 3, and since his time it has been variously estimated from 3½ to 4. If it was anything like its present brightness (4·21 Harvard) in the tenth century it seems difficult to explain how it could have escaped Al-Sufi's careful scrutiny of the heavens, unless it is variable. Its colour seems reddish to me.

Mr. W. T. Lynn has shown—and I think conclusively—that the so-called "new star" of A.D. 389 (which is said to have appeared near Altair in the Eagle) was really a comet.[335]

Near the place of Tycho Brahé's great new star of 1572 (the "Pilgrim Star"), Hind and W. E. Plummer observed a small star (No. 129 of d'Arrest's catalogue of the region) which seemed to show small fluctuations of light, which "scarcely include a whole magnitude." This may possibly be identical with Tycho Brahé's wonderful star, and should be watched by observers. The place of this small star is (for 1865) R.A. 0^h 17^m 18^s, N.P.D. 26° 37′·1. The region was examined by Prof. Burnham in 1890 with the 36-inch telescope of the Lick Observatory. "None of the faint stars near the place presented any peculiarity worthy of remark, but three double stars were found."[336]

With reference to the famous Nova (T) Coronæ—the “Blaze Star” of 1866—Prof. Barnard finds from careful comparisons with small stars in its vicinity that “the Nova is now essentially of the same brightness it was before the outburst of 1866 ... there seems to be no indication of motion in the *Nova*.”

With reference to the cause of “temporary” stars, or *novæ*, as they are now called by astronomers—the late Prof. H. C. Vogel said—

“A direct collision of two celestial bodies is not regarded by Huggins as an admissible explanation of the Nova; a partial collision has little probability, and the most that can be admitted is perhaps the mutual penetration and admixture of the outer gaseous envelopes of the two bodies at the time of their closest approach. A more probable explanation is given by an hypothesis which we owe to Klinkerfues, and which has more recently been further developed by Wilsing, viz. that by the very close passage of two celestial bodies enormous tidal disturbances are produced and thereby changes in the brightness of the bodies. In the case of the two bodies which form the Nova, it must be assumed that these phenomena are displayed in the highest degree of development, and that changes of pressure have been produced which have caused enormous eruptions from the heated interior of the bodies; the eruptions are perhaps accompanied by electrical actions, and are comparable with the outbursts in our own sun, although they are on a much larger scale.”[337]

It will be noticed that this hypothesis agrees with the fundamental assumption of the “Planetesimal Hypothesis” advocated by Professors Chamberlin and Moulton (see my *Astronomical Essays*, p. 324).

The rush of a comparatively small body through a mass of gaseous matter seems also a very plausible hypothesis. This idea was originally advanced by Prof. Seeliger, and independently by Mr. Monck.

With reference to the nebula which was observed round the great new star of 1901—Nova Persei—Prof. Lewis Bell supports the theory of Seeliger, which accounts for the apparent movements of the brightest portions of the nebula by supposing that the various parts of the highly tenuous matter were successively lighted up by the effects of a travelling electro-magnetic wavefront, and he shows that this theory agrees well with the observed phenomenon.[338] The “collision theory” which explained the sudden outburst of light by the meeting of two dark bodies in space, seems to be now abandoned by the best astronomers. The rapid cooling down of the supposed bodies indicated by the rapid decrease of light is quite inconsistent with this hypothesis.

The rapid diminution in the light of some of these “new stars” is very remarkable. Thus the new star which suddenly blazed out near the nucleus of the great nebula in Andromeda in August, 1885, faded down in 5 months from "the limit of visibility to the naked eye to that of a 26-inch telescope"! A *large* body could not cool in this way.

Mr. Harold K. Palmer thinks that the "complete and astonishingly rapid changes of spectral type observed in the case of *Nova Cygni* and *Nova Aurigæ*, and likewise those observed in *Nova Normæ*, *Nova Sagittarii* and *Nova Persei*, leave little doubt that the masses of these objects are small."[339]

No less than 3748 variable stars had been discovered up to May, 1907. Of these 2909 were found at Harvard Observatory (U.S.A.) chiefly by means of photography.[340]

The star 14. 1904 Cygni has a period of only 3 hours 14 minutes, which is the shortest period known for a variable star.

A very interesting discovery has recently been made with reference to the star μ Herculis. It has been long suspected of variable light with a period of 35 or 40 days, or perhaps irregular. Frost and Adams now find it to be a spectroscopic binary, and further observations at Harvard Observatory show that it is a variable of the Algol (or perhaps β Lyræ) type. The Algol variation of light was suggested by MM. Baker and Schlesinger. The period seems to be about 2·05 days.[341]

The northern of the two "pointers" in the Plough (so called because they nearly point to the Pole Star) is about the 2nd magnitude, as Al-Sufi rated it. It was thought to be variable in colour by Klein, Konkoly, and Weber; and M. Lau has recently found a period of 50 days with a maximum of "jaune rougeâtre" on April 2, 1902.

The famous variable star η Argus did "not exceed the 8th magnitude" in February, 1907, according to Mr. Tebbutt.[342] This is the faintest ever recorded for this wonderful star.

It is stated in *Knowledge* (vol. 5, p. 3, January 4, 1884) that the temporary star of 1876 (in the constellation of Cygnus) "had long been known and catalogued as a telescopic star of the 9th magnitude with nothing to distinguish it from the common herd." But this is quite erroneous. The star was quite unknown before it was discovered by Schmidt at Athens on

November 24 of that year. The remark apparently refers to the "Blaze Star" of 1866 in Corona Borealis, which *was* known previously as a star of about the 9th magnitude before its sudden outburst on May 12 of that year.

This "new star" of 1866—T Coronæ, as it is now called—was, with the possible exception of Nova Persei (1901), the only example of a *nova* which was known to astronomers as a small star previous to the great outburst of light. It is the brightest of the *novæ* still visible. It was the first of these interesting objects to be examined with the spectroscope. It was observed by Burnham in the years 1904-1906 with the great 40-inch telescope of the Yerkes Observatory (U.S.A.). He found its colour white, or only slightly tinged with yellow. In August and September, 1906, he estimated its magnitude at about 9·3, and "it would seem therefore that the Nova is now essentially of the same brightness it was before the outburst in 1866." It shows no indication of motion. Burnham found no peculiarity about its telescopic image. A small and very faint nebula was found by Burnham a little following (that is east of) the *nova*.[343]

The following details of the great new star of 1572—the "Pilgrim Star" of Tycho Brahé—are given by Delambre.[344] In November, 1572, it was brighter than Sirius, Vega, and Jupiter, and almost equal to Venus at its brightest. During December it resembled Jupiter in brightness. In January, 1573, it was fainter and only a little brighter than stars of the 1st magnitude. In February and March it was equal to 1st magnitude stars, and in April and May was reduced to the 2nd magnitude. In June and July it was 3rd magnitude; in September of the 4th, and at the end of 1573 it was reduced to the 5th magnitude. In February, 1574, it was 6th magnitude, and in March of the same year it became invisible to the naked eye.

From this account it will be seen that the decrease in light of this curious object was much slower than that of Nova Persei (1901) ("the new star of the new century"). This would suggest that it was a much larger body.

There were also changes in its colour. When it was of the brightness of Venus or Jupiter it shone with a white light. It then became golden, and afterwards reddish like Mars, Aldebaran, or Betelgeuse. It afterwards became of a livid white colour like Saturn, and this it retained as long as it was visible. Tycho Brahé thought that its apparent diameter might have been about 3½ minutes of arc, and that it was possibly 361 times smaller than the earth(!) But we now know that these estimates were probably quite erroneous.

Temporary stars were called by the ancient Chinese “Ke-sing,” or guest stars.[345]

A temporary star recorded by Ma-tuan-lin (Chinese Annals) in February, 1578, is described as “a star as large as the sun.” But its position is not given.[346]

About the middle of September, 1878, Mr. Greely, of Boston (U.S.A.), reported to Mr. E. F. Sawyer (the eminent observer of variable stars) that, about the middle of August of that year, he had seen the famous variable star Mira Ceti of about the 2nd magnitude, although the star did not attain its usual maximum until early in October, 1878. Mr. Greely stated that several nights after he first saw Mira it had faded to the 4th or 5th magnitude. If there was no mistake in this observation (and Sawyer could find none) it was quite an unique phenomenon, as nothing of the sort has been observed before or since in the history of this famous star. It looks as if Mr. Greely had observed a new or “temporary” star near the place of Mira Ceti; but as the spot is far from the Milky Way, which is the usual seat of such phenomena, this hypothesis seems improbable.

In the so-called Cepheid and Geminid variables of short period, the principal characteristics of the light variation are as follows:—

“1. The light varies without pause.

“2. The amount of their light variation is usually about 1 magnitude.

“3. Their periods are short—a few days only.

“4. They are of a spectral type approximately solar; no Orion, Sirian or Arcturian stars having been found among them.

“5. They seem to be found in greater numbers in certain parts of the sky, notably in the Milky Way, but exhibit no tendency to form clusters.

“6. All those stars whose radial velocities have been studied have been found to be binaries whose period of orbital revolution coincides with that of their light change.

“7. The orbits, so far as determined, are all small, *a* sin *i* being 2,000,000 kilometres or less.

“8. Their maximum light synchronizes with their maximum velocity of approach, and minimum light with maximum velocity of recession.

“9. No case has been found in which the spectrum of more than one component has been bright enough to be recorded in the spectrograms.”[347]

It is very difficult to find an hypothesis which will explain satisfactorily *all* these characteristics, and attempts in this direction have not proved very successful. Mr. J. C. Duncan suggests the action of an absorbing atmosphere surrounding the component stars.

On March 30, 1612, Scheiner saw a star near Jupiter. It was at first equal in brightness to Jupiter’s satellites. It gradually faded, and on April 8 of the same year it was only seen with much difficulty in a very clear sky. “After that date it was never seen again, although carefully looked for under favourable conditions.”

An attempted identification of Scheiner’s star was made in recent years by Winnecke. He found that its position, as indicated by Scheiner, agrees with that of the Bonn *Durchmusterung* star 15°, 2083 (8½ magnitude). This star is not a known variable. Winnecke watched it for 17 years, but found no variation of light. From Scheiner’s recorded observations his star seems to have reached the 6th magnitude, which is considerably brighter than the *Durchmusterung* star watched by Winnecke.[348]

With reference to the colours of the stars, the supposed change of colour in Sirius from red to white is well known, and will be considered in the chapter on the Constellations. The bright star Arcturus has also been suspected of variation in colour. About the middle of the nineteenth century Dr. Julius Schmidt, of Athens, the well-known observer of variable stars, thought it one of the reddest stars in the sky, especially in the year 1841, when he found its colour comparable with that of the planet Mars.[349] In 1852, however, he was surprised to find it yellow and devoid of any reddish tinge; in colour it was lighter than that of Capella. In 1863, Mr. Jacob Ennis found it “decidedly orange.” Ptolemy and Al-Sufi called it red.

Mr. Ennis speaks of Capella as "blue" (classing it with Rigel), and comparing its colour with that of Vega![350] But the present writer has never seen it of this colour. To his eye it seems yellowish or orange. It was called red by Ptolemy, El Fergani, and Riccioli; but Al-Sufi says nothing about its colour.

Of β Ursæ Minoris, Heis, the eminent German astronomer said, "I have had frequent opportunities of convincing myself that the colour of this star is not always equally red; at times it is more or less yellow, at others most decidedly red."[351]

Among double stars there are many cases in which variation of colour has been suspected. In some of these the difference in the recorded colour may possibly be due to "colour blindness" in some of the observers; but in others there seems to be good evidence in favour of a change. The following may be mentioned:—

η Cassiopeiæ. Magnitudes of the components about 4 and 7½. Recorded as red and green by Sir John Herschel and South; but yellow and orange by Sestini.

ι Trianguli. Magnitudes 5½ and 7. Secchi estimated them as white or yellow and blue; but Webb called them yellow and green (1862).

γ Leonis, 2 and 3½. Sir William Herschel noted them white and reddish white; but Webb, light orange and greenish yellow.

12 Canum Venaticorum, 2½ and 6½. White and red, Sir William Herschel; but Sir John Herschel says in 1830, "With all attention I could perceive no contrast of colours in the two stars." Struve found them both white in 1830, thus agreeing with Sir John Herschel. Sestini saw them yellow and blue in 1844; Smyth, in 1855, pale reddish white and lilac; Dembowski, in 1856, white and pale olive blue; and Webb, in 1862, flushed white and pale lilac.

On October 13, 1907, Nova Persei, the great new star of 1901, was estimated to be only 11·44 magnitude, or about 11½. When at its brightest this famous star was about zero magnitude; so that it has in about 6 years faded about 11½ magnitudes in brightness; in other words, it has been reduced to $\frac{1}{40000}$ of its greatest brilliancy!

CHAPTER XVII

Nebulæ and Clusters

IN his interesting and valuable work on "The Stars," the late Prof. Newcomb said—

"Great numbers of the nebulæ are therefore thousands of times the dimensions of the earth's orbit, and most of them are thousands of times the dimensions of the whole solar system. That they should be completely transparent through such enormous dimensions shows their extreme tenuity. Were our solar system placed in the midst of one of them it is probable that we should not be able to find any evidence of its existence"!

Prof. Perrine thinks that the total number of the nebulæ will ultimately be found to exceed a million.[352]

Dr. Max Wolf has discovered a number of small nebulæ in the regions near Algol and Nova Persei (the great "new star" of 1901). He says, "They mostly lie in two bands," and are especially numerous where the two bands meet, a region of 12 minutes of arc square containing no less than 148 of them. They are usually "round with central condensation," and form of Andromeda nebula.[353]

Some small nebulæ have been found in the vicinity of the globular clusters. They are described by Prof. Perrine as very small and like an "out of focus" image of a small star. "They appear to be most numerous about clusters which are farthest from the galaxy." Prof. Perrine says, "Practically all the small nebulæ about the globular clusters are elliptical or circular. Those large enough to show structure are spirals. Doubtless the majority of these are spirals."[354] This seems further evidence in favour of the "spiral nebular hypothesis" of Chamberlin and Moulton.

A great photographic nebula in Orion was discovered by Prof. Barnard in 1894. In a drawing he gives of the nebula,[355] it forms a long streak beginning a little south of γ Orionis (Bellatrix), passing through the star 38 Orionis north of 51 and south of 56 and 60 Orionis. Then turning south it sweeps round a little north of κ Orionis; then over 29 Orionis, and ends a little to the west of η Orionis. There is an outside patch west of Rigel. Barnard thinks that the whole forms a vast spiral structure; probably connected with the "great nebula" in the "sword of Orion," which it surrounds.

From calculations of the brightness of surface ("intrinsic brightness") of several "planetary" nebulæ made by the present writer in the year 1905, he finds that the luminosity is very small compared with that of the moon. The brightest of those examined (*h* 3365, in the southern hemisphere, near the Southern Cross) has a surface luminosity of only $\frac{1}{400}$ of that of the moon.[356] The great nebulæ in Orion and Andromeda seem to have "still smaller intrinsic brightness."

Arago says—

"The spaces which precede or which follow simple nebulæ, and *a fortiori* groups of nebulæ, contain generally few stars. Herschel found this rule to be invariable. Thus every time that, during a short interval, no star appeared, in virtue of the diurnal motion, to place itself in the field of his motionless telescope, he was accustomed to say to the secretary who assisted him (Miss Caroline Herschel), 'Prepare to write; nebulæ are about to arrive.'"[357]

Commenting on this remark of Arago, the late Herbert Spencer says—

"How does this fact consist with the hypothesis that nebulæ are remote galaxies? If there were but one nebula, it would be a curious coincidence were this one nebula so placed in the distant regions of space as to agree in direction with a starless spot in our sidereal system! If there were but two nebulæ, and both were so placed, the coincidence would be excessively strange. What shall we say on finding that they are habitually so placed? (the last five words replace some that are possibly a little too strong).... When to the fact that the general mass of nebulæ are antithetical in position to the general mass of the stars, we add the fact that local regions of nebulæ are regions where stars are scarce, and the further fact that single nebulæ are habitually found in comparatively starless spots, does not the proof of a physical connection become overwhelming?"[358]

With reference to the small elongated nebula discovered by Miss Caroline Herschel in 1783 near the great nebula in Andromeda, Admiral Smyth says, "It lies between two sets of stars, consisting of four each, and each disposed like the figure 7, the preceding group being the smallest."[359]

Speaking of the "nebula" Messier 3—a globular cluster in Canes Venatici—Admiral Smyth says, "This mass is one of those balls of compact and wedged stars whose laws of aggregation it is so impossible to assign; but the rotundity of the figure gives full indication of some general attractive bond of union."[360] The terms "compact and wedged" are, however, too strong, for we know that in the globular clusters the component stars must be separated from each other by millions of miles!

Prof. Chamberlin suggests that the secondary nebula (as it is called) in the great spiral in Canes Venatici (Messier 51) may possibly represent the body which collided with the other (the chief nucleus) in a grazing collision, and is now escaping. He considers this secondary body to have been "a dead sun"—that is, a dark body.[361] This would be very interesting if it could be proved. But it seems to me more probable that the secondary nucleus is simply a larger portion of the ejected matter, which is now being gradually detached from the parent mass.

Scheiner says "the previous suspicion that the spiral nebulæ are star clusters is now raised to a certainty," and that the spectrum of the Andromeda nebula is very similar to that of the sun. He says there is "a surprising agreement of the two, even in respect to the relative intensity of the separate spectral regions."[362]

In the dynamical theory of spiral nebulæ, Dr. E. J. Wilczynski thinks that the age of a spiral nebula may be indicated by the number of its coils; those having the largest number of coils being the oldest, from the point of view of evolution.[363] This seems to be very probable.

In the spectrum of the gaseous nebulæ, the F line of hydrogen (Hβ) is visible, but not the C line (Hα). The invisibility of the C line is explained by

Scheiner as due to a physiological cause, "the eye being less sensitive to that part of the spectrum in which the line appears than to the part containing the F line."[364]

An apparent paradox is found in the case of the gaseous nebulæ. The undefined outlines of these objects render any attempt at measuring their parallax very difficult, if not impossible. Their distance from the earth is therefore unknown, and perhaps likely to remain so for many years to come. It is possible that they may not be farther from us than some of the stars visible in their vicinity. On the other hand, they may lie far beyond them in space. But whatever their distance from the earth may be, it may be easily shown that their attraction on the sun is directly proportioned to their distance—that is, the greater their distance, the greater the attraction! This is evidently a paradox, and rather a startling one too. But it is nevertheless mathematically true, and can be easily proved. For, *their distance being unknown*, they may be of any dimensions. They might be comparatively small bodies relatively near the earth, or they may be immense masses at a vast distance from us. The latter is, of course, the more probable. In either case the *apparent* size would be the same. Take the case of any round gaseous nebula. Assuming it to be of a globular form, its *real* diameter will depend on its distance from the earth—the greater the distance, the greater the diameter. Now, as the volumes of spheres vary as the cubes of their diameters, it follows that the volume of the nebula will vary as the cube of its distance from the earth. As the mass of an attracting body depends on its volume and density, its real mass will depend on the cube of its distance, the density (although unknown) being a fixed quantity. If at a certain distance its mass is m, at double the distance (the *apparent* diameter being the same) it would have a mass of eight times m (8 being the cube of 2), and at treble the distance its mass would be 27 m, and so on, its *apparent* size being known, but not its *real* size. This is obvious. Now, the attractive power of a body varies directly as its mass—the greater the mass, the greater the attraction. Again, the attraction varies *inversely* as the square of the distance, according to the well-known law of Newton. Hence if d be the unknown distance of the nebula, we have its attractive power varying as d^3 divided by d^2, or directly as the distance d. We have then the curious paradox that for a nebula whose distance from the earth is unknown, its attractive power on the sun (or earth) will vary directly as the distance—the greater the distance the greater the attraction, and, of course, conversely, the smaller the distance the less the attractive power. This result seems at first sight absurd and incredible, but a little consideration will show that it is quite correct. Consider a small wisp of cloud in our atmosphere. Its mass is almost infinitesimal and its attractive power on the earth practically *nil*. But a gaseous nebula having the same *apparent size* would have an enormous volume, and, although probably formed of very tenuous gas, its mass would be very great, and its attractive power considerable. The large apparent size of the Orion nebula shows that its volume is probably enormous, and as its attraction on the sun is not appreciable, its density must be excessively small, less than the density of the air remaining in the receiver of the best air-pump after the air has been exhausted. How such a tenuous gas can shine as it does forms another paradox. Its light is possibly due to some phosphorescent or electrical action.

The apparent size of "the great nebula in Andromeda" shows that it must be an object of vast dimensions. The nearest star to the earth, Alpha Centauri, although probably equal to our sun in volume, certainly does not exceed one-hundredth of a second in diameter as seen from the earth. But in the case of the Andromeda nebula we have an object of considerable apparent size, not measured by seconds of arc, but showing an area about three times greater than that of the full moon. The nebula certainly lies in the region of the stars—much farther off than Alpha Centauri—and its great apparent size shows that it must be of stupendous dimensions. A moment's consideration will show that whatever its distance may be, the farther it is from the earth the larger it must be in actual size. The sun is vastly larger than the moon, but its apparent size is about the same owing to its greater distance. Sir William Herschel thought the Andromeda nebula to be "undoubtedly the nearest of all the great nebulæ," and he estimated its distance at 2000 times the distance of Sirius. This would not, however, indicate a relatively near object, as it would imply a "light journey" of over 17,000 years! (The distance of Sirius is about 88 "light years.")

It has been generally supposed that this great nebula lies at a vast distance from the earth, possibly far beyond most of the stars seen in the same region of the sky; but perhaps not quite so far as Herschel's estimate would imply. Recently, however, Prof. Bohlin of Stockholm has found from three series of measures made in recent years a parallax of 0″·17.[365]

This indicates a distance of 1,213,330 times the sun's distance from the earth, and a "light journey" of about 19 years. This would make the distance of the nebula more than twice the distance of Sirius, about four times the distance of α Centauri, but less than that of Capella.

Prof. Bohlin's result is rather unexpected, and will require confirmation before it can be accepted. But it will be interesting to inquire what this parallax implies as to the real dimensions and probable mass of this vast nebula. The extreme length of the nebula may be taken to represent its diameter considered as circular. For, although a circle seen obliquely is always foreshortened into an ellipse, still the longer axis of the ellipse will always represent the real diameter of the circle. This may be seen by holding a penny at various angles to the eye. Now, Dr. Roberts found that the apparent length of the Andromeda nebula is 2⅓ degrees, or 8400 seconds of arc. The diameter in seconds divided by the parallax will give the real diameter of the nebula in terms of the sun's distance from the earth taken as unity. Now, 8400 divided by 0″·17 gives nearly 50,000, that is, the real diameter of the Andromeda nebula would be—on Bohlin's parallax—nearly 50,000 times the sun's distance from the earth. As light takes about 500 seconds to come from the sun to the earth, the above figures imply that light would take about 290 days, or over 9 months to cross the diameter of this vast nebula.

Elementary geometrical considerations will show that if the Andromeda nebula lies at a greater distance from the earth than that indicated by Bohlin's parallax, its real diameter, and therefore its volume and mass, will be greater. If, therefore, we assume the parallax found by Bohlin, we shall probably find a *minimum* value for the size and mass of this marvellous object.

Among Dr. Roberts' photographs of spiral nebulæ (and the Andromeda nebula is undoubtedly a spiral) there are some which are apparently seen nearly edgeways, and show that these nebulæ are very thin in proportion to their diameter. From a consideration of these photographs we may, I think, assume a thickness of about one-hundredth of the diameter. This would give a thickness for the Andromeda nebulæ of about 500 times the sun's distance from the earth. This great thickness will give some idea of the vast proportions of the object we are dealing with. The size of the whole solar system—large as it is—is small in comparison. The diameter and thickness found above can easily be converted into miles, and from these dimensions the actual volume of the nebula can be compared with that of the sun. It is merely a question of simple mensuration, and no problem of "high mathematics" is involved. Making the necessary calculations, I find that the volume of the Andromeda nebula would be about 2·32 trillion times ($2{\cdot}32 \times 10^{18}$) the sun's volume! Now, assuming that the nebulous matter fills only one-half of the apparent volume of the nebula (allowing for spaces between the spiral branches), we have the volume = $1{\cdot}16 \times 10^{18}$. If the nebula had the same density as the sun, this would be its mass in terms of the sun's mass taken as unity, a mass probably exceeding the combined mass of all the *stars* visible in the largest telescopes! But this assumption is, of course, inadmissible, as the sun is evidently quite opaque, whereas the nebula is, partially at least, more or less transparent. Let us suppose that the nebula has a *mean* density equal to that of atmospheric air. As water is about 773 times heavier than air, and the sun's density is 1·4 (water = 1) we have the mass of the nebula equal to $1{\cdot}16 \times 10^{18}$ divided by $773 \times 1{\cdot}4$, or about 10^{15} times the sun's mass, which is still much greater than the probable combined mass of all the *visible* stars. As it seems unreasonable to suppose that the mass of an individual member of our sidereal system should exceed the combined mass of the remainder of the system, we seem compelled to further reduce the density of the Andromeda nebula. Let us assume a mean density of, say, a millionth of hydrogen gas (a sufficiently low estimate) which is about 14·44 times lighter than air, and we obtain a mass of about 8×10^7 or 80 million times the mass of the sun, which is still an enormous mass.

As possibly I may have assumed too great a thickness for the nebula, let us take a thickness of one-tenth of that used above, or one thousandth of the length of the nebula. This gives a mass of 8 million times the sun's mass. This seems a more probable mass if the nebula is—as Bohlin's parallax implies—a member of our sidereal system.

If we assume a parallax of say 0″·01—or one-hundredth of a second of arc—which would still keep the nebula within the bounds of our sidereal system—we have the dimensions of the nebula increased 17 times, and hence its mass nearly 5000 times greater (17^3) than that found above. The mass would then be 40,000 million times the sun's mass! This result seems highly improbable, for even this small parallax would imply a light journey of only 326 years, whereas the distance of the Milky Way has been estimated by Prof. Newcomb at about 3000 years' journey for light.

In Dr. Roberts' photograph many small stars are seen scattered over the surface of the nebula; but these do not seem to be quite so numerous as in the surrounding sky. If the nebula lies nearer to us than the fainter stars visible on the photograph, some of them may be obscured by the denser portions of the nebula; some may be visible through the openings between the spiral branches; while others may be nearer to us and simply projected on the nebula.

To add to the difficulty of solving this celestial problem, the spectroscope shows that the Andromeda nebula is not gaseous. The spectrum is, according to Scheiner, very similar to that of the sun, and "there is a surprising agreement of the two, even in respect to the relative intensities of the separate spectral regions."[366] He thinks that "the greater part of the stars comprising the nucleus of the nebula belong to the second spectral class" (solar), and that the nebula "is now in an advanced stage of development. No trace of bright nebular lines are present, so that the interstellar space in the Andromeda nebula, just as in our stellar system, is not appreciably occupied by gaseous matter."[366] He suggests that the inner part of the nebula [the "nucleus"] "corresponds to the complex of those stars which do not belong to the Milky Way, while the latter corresponds to the spirals of the Andromeda nebula."[366] On this view of the matter we may suppose that the component particles are small bodies widely separated, and in this way the *mean* density of the Andromeda nebula may be very small indeed. They cannot be large bodies, as the largest telescopes have failed to resolve the nebula into stars, and photographs show no sign of resolution.

It has often been suggested, and sometimes definitely stated, that the Andromeda nebula may possibly be an "external" universe, that is an universe entirely outside our sidereal system, and comparable with it in size. Let us examine the probability of such hypothesis. Assuming that the nebula has the same diameter as the Milky Way, or about 6000 "light years," as estimated by Prof. Newcomb, I find that its distance from the earth would be about 150,000 "light years." As this is about 8000 times the distance indicated by Bohlin's parallax, its dimensions would be 8000 times as great, and hence its volume and mass would be 8000 cubed, or 512,000,000,000 times greater than that found above. That is, about 4 trillion (4×10^{18}) times the sun's mass! As this appears an incredibly large mass to be compressed into a volume even so large as that of our sidereal system, we seem compelled to reject the hypothesis that the nebula represents an external universe. The sun placed at the distance corresponding to 150,000 light years would, I find, shine as a star of less than the 23rd magnitude, a magnitude which would be invisible in the largest telescope that man could ever construct. But the combined light of 4 trillion of stars of even the 23rd magnitude would be equal to one of minus 23·5 magnitude, that is, 23½ magnitude brighter than the zero magnitude, or not very much inferior to the sun in brightness. As the Andromeda nebula shines only as a star of about the 5th magnitude the hypothesis of an external universe seems to be untenable.

It is evident, however, that the mass of the Andromeda nebula must be enormous; and if it belongs to our sidereal system, and if the other great nebulæ have similar masses, it seems quite possible that the mass of the *visible* universe may much exceed that of the *visible* stars, and may be equal to 1000 million times the sun's mass—as supposed by the late Lord Kelvin—or even much more.

With reference to the small star which suddenly blazed out near the nucleus of the Andromeda nebula in August, 1885, Prof. Seeliger has investigated the decrease in the light of the star on the hypothesis that it was a cooling body which had suddenly been raised to an intense heat by the shock of a collision, and finds a fair agreement between theory and observation. Prof. Auwers points out the similarity between this outburst and that of the "temporary star" of 1860, which appeared in the cluster 80 Messier, and he thinks it very probable that both phenomena were due to physical changes in the nebulæ in which they appeared.

The appearance of this temporary star in the Andromeda nebula seems to afford further evidence against the hypothesis of the nebula being an external universe. For, as I have shown above, our sun, if placed at a distance of 150,000 light years, would shine only as a star of the 23rd magnitude, or over 15 magnitudes fainter than the temporary star. This would imply that the star shone with a brightness of over a million times that of the sun, and would therefore indicate a body of enormous size. But the rapid fading of its light would, on the contrary, imply a body of comparatively small dimensions. We must, therefore, conclude that the nebula, whatever it may be, is not an external universe, but forms a member of our own sidereal system.

In Sir John Herschel's catalogue of Nebulæ and Clusters of Stars, published in 1833, in the *Philosophical Transactions* of the Royal Society, there are many curious objects mentioned. Of these I have selected the following:—

No. 496 is described as "a superb cluster which fills the whole field; stars 9, 10 ... 13 magnitude and none below, but the whole ground of the sky on which it stands is singularly dotted over with infinitely minute points." This is No. 22 of Sir William Herschel's 6th class, and will be found about 3 degrees south and a little east of the triple star 29 Monocerotis.

No. 650. This object lies about 3 degrees north of the star μ Leonis, the most northern of the bright stars in the well-known "Sickle," and is thus described by Sir John Herschel: "A star 12th magnitude with an extremely faint nebulous atmosphere about 10″ to 12″. It is between a star 8-9 magnitude north preceding, and one 10th magnitude south following, neither of which are so affected. A curious object."

No. 1558. Messier 53. A little north-east of the star α Comæ Berenices. Described as "a most beautiful highly compressed cluster. Stars very small, 12th ... 20th magnitude, with scattered stars to a considerable distance; irregularly round, but not globular. Comes up to a blaze in the centre; indicating a round mass of pretty equable density. Extremely compressed. A most beautiful object. A mass of close-wedged stars 5′ in diameter; a few 12th magnitude, the rest of the smallest size and innumerable." Webb says, "Not very bright with 3⁷⁄₁₀ inches; beautiful with 9 inches." This should be a magnificent object with a very large telescope, like the Lick or Yerkes.

No. 2018. "A more than usually condensed portion of the enormous cluster of the Milky Way. The field has 200 or 300 stars in it at once." This lies about 2° south-west of the star 6 Aquilæ, which is near the northern edge of the bright spot of Milky Way light in “Sobieski’s Shield”—one of the brightest spots in the sky.

No. 2093. “A most wonderful phenomenon. A very large space 20′ or 30′ broad in Polar Distance, and 1^m or 2^m in Right Ascension, full of nebula and stars mixed. The nebula is decidedly attached to the stars, and is as decidedly not stellar. It forms irregular lace-work marked out by stars, but some parts are decidedly nebulous, wherein no star can be seen.” Sir John Herschel gives a figure of this curious spot, which he says represents its “general character, but not the minute details of this object, which would be extremely difficult to give with any degree of fidelity.” It lies about 3 degrees west of the bright star ζ Cygni.

Among the numerous curious objects observed by Sir John Herschel during his visit to the Cape of Good Hope, the following may be mentioned:—

h 2534 (H iv. 77). Near τ^4 Eridani. Sir John Herschel says, “Attached cometically to a 9th magnitude star which forms its head. It is an exact resemblance to Halley’s comet as seen in a night glass.”... “A complete telescopic comet; a perfect miniature of Halley’s comet, only the tail is rather broader in proportion.”[367]

h 3075. Between γ Monocerotis and γ Canis Majoris. “A very singular nebula, and much like the profile of a bust (head, neck, and shoulders) or a silhouette portrait, very large, pretty well defined, light nearly uniform, about 12′ diameter. In a crowded field of Milky Way stars, many of which are projected on it.”[368]

h 3315 (Dunlop 323). In the Milky Way; about 3° east of the Eta Argûs nebula. Sir John Herschel says, “A glorious cluster of immense magnitude, being at least 2 fields in extent every way. The stars are 8, 9, 10, and 11th magnitudes, but chiefly 10th magnitude, of which there must be at least 200. It is the most brilliant object of the kind I have ever seen” ... “has several elegant double stars, and many orange-coloured stars.”[369] This should form a fine object in even a comparatively small telescope, and may be recommended to observers in the southern hemisphere. A telescope of 3-inches aperture should show it well.

Among astronomical curiosities may be counted “clusters within clusters.” A cluster in Gemini (N.G.C. 2331) has a small group of “six or seven stars close together and well isolated from the rest.”

Lord Rosse describes No. 4511 of Sir John Herschel’s General Catalogue of Nebulæ and Clusters (*Phil. Trans.*, 1864) as “a most gorgeous cluster, stars 12-15 magnitude, full of holes.”[370] His sketch of this cluster shows 3 rings of stars in a line, each ring touching the next on the outside. Sir John Herschel described it as “Cluster; very large; very rich; stars 11-15 magnitude (Harding, 1827),” but says nothing about the rings. This cluster lies about 5 degrees south of δ Cygni.

Dr. See, observing with the large telescope of the Lowell Observatory, found that when the sky is clear, the moon absent, and the seeing perfect, “the sky appeared in patches to be of a brownish colour,” and suggests that this colour owes its existence to immense cosmical clouds, which are shining by excessively feeble light! Dr. See found that these brown patches seem to cluster in certain regions of the Milky Way.[371]

From a comparison of Trouvelot’s drawing of the small elongated nebula near the great nebula in Andromeda with recent photographs, Mr. Easton infers that this small nebula has probably rotated through an angle of about 15° in 25 years. An examination I have made of photographs taken in different years seems to me to confirm this suspicion, which, if true, is evidently a most interesting phenomenon.

Dr. Max Wolf of Heidelberg finds, by spectrum photography, that the well-known “ring nebula” in Lyra consists of four rings composed of four different gases. Calling the inner ring A, the next B, the next C, and the outer D, he finds that A is the smallest ring, and is composed of an unknown gas; the next largest, B, is composed of hydrogen gas; the next, C, consists of helium gas; and the outer and largest ring, D, is composed—like A—of an unknown gas. As the molecular weight of hydrogen is 2·016, and that of helium is 3·96, Prof. Bohuslav Brauner suggests that the molecular weight of the gas composing the inner ring A is smaller than that of hydrogen, and the molecular weight of the gas forming the outer ring D is greater than that of helium. He also suggests that the gas of ring A may possibly be identical with the "coronium" of the solar corona, for which Mendelief found a hypothetical atomic and molecular weight of 0·4.[372]

With reference to the nebular hypothesis of Laplace, Dr. A. R. Wallace argues that "if there exists a sun in a state of expansion in which our sun was when it extended to the orbit of Neptune, it would, even with a parallax of 1⁄60th of a second, show a disc of half a second, which could be seen with the Lick telescope." My reply to this objection is, that with such an expansion there would probably be very little "intrinsic brightness," and if luminous enough to be visible the spectrum would be that of a gaseous nebula, and no known *star* gives such a spectrum. But some planetary nebulæ look like small stars, and with high powers on large telescopes would probably show a disc. On these considerations, Dr. Wallace's objection does not seem to be valid.

It is usually stated in popular works on astronomy that the spectra of gaseous nebulæ show only three or four bright lines on a faint continuous background. But this is quite incorrect. No less than forty bright lines have been seen and measured in the spectra of gaseous nebulæ.[373] This includes 2 lines of "nebulium," 11 of hydrogen, 5 of helium, 1 of oxygen (?), 3 of nitrogen (?), 1 of silicon (?), and 17 of an unknown substance. In the great nebulæ in Orion 30 bright lines have been photographed.[374]

D'Arrest found that "gaseous nebulæ are rarely met with outside the Milky Way, and never at a considerable distance from it."[375]

Mr. A. E. Fath thinks that "no spiral nebula investigated has a truly continuous spectrum." He finds that so feeble is the intensity of the light of the spiral nebulæ that, while a spectrogram of Arcturus can be secured with the Mills spectrograph "in less than two minutes," "an exposure of about 500 hours would be required for the great nebula in Andromeda, which is of the same spectral type."[376] Mr. Fath thinks that in the case of the Andromeda nebula, the "star cluster" theory "seems to be the only one that can at all adequately explain the spectrum obtained."[377]

Prof. Barnard finds that the great cluster in Hercules (Messier 13) is "composed of stars of different spectral types." This result was confirmed by Mr. Fath.[378]

From observations with the great 40-inch telescope of the Yerkes Observatory (U.S.A.), Prof. Barnard finds that the nucleus of the planetary nebula H. iv. 18 in Andromeda is variable to the extent of at least 3 magnitudes. At its brightest it is about the 12th magnitude; and the period seems to be about 28 days. Barnard says, "I think this is the first case in which the nucleus of a planetary or other nebula has been shown to be certainly variable." "The normal condition seems to be faint—the nucleus remaining bright for a few days only. In an ordinary telescope it looks like a small round disc of a bluish green colour." He estimated the brightness of the nebula as that of a star of 8·2 magnitude.[379] Even in a telescope of 4 inches aperture, this would be a fairly bright object. It lies about 3½ degrees south-west of the star ι Andromedæ.

The so-called "globular clusters" usually include stars of different brightness; comparatively bright telescopic stars of the 10th to 13th magnitude with faint stars of the 15th to 17th magnitude. Prof. Perrine of the Lick Observatory finds that (*a*) "the division of the stars in globular clusters into groups, differing widely in brightness, is characteristic of these objects"; (*b*) "the globular clusters are devoid of true nebulosity"; and (*c*) "stars fainter than 15th magnitude predominate in the Milky Way and globular clusters, but elsewhere are relatively scarce." He found that "exposures of one hour or thereabouts showed as many stars as exposures four to six times as long; the only effect of the longer exposures being in the matter of density." This last result confirms the late Dr. Roberts' conclusions. Perrine finds that for clusters in the Milky Way, the faint stars (15th to 17th magnitude) "are about as numerous in proportion to the bright stars (10th to 13th magnitude) as in the globular clusters themselves." This is, however, not the case with globular clusters at a distance from the Milky Way. In these latter clusters he found that "in the regions outside the limits of the cluster there are usually very few faint stars, hardly more than one-fourth or one-tenth as many as there are bright stars"; and he thinks that "this paucity of faint stars" in the vicinity of these clusters "gives rise to the suspicion that all regions at a distance from the Galaxy may be almost devoid of these very faint stars." The late Prof. Keeler's series of nebular photographs "in or near the Milky Way" tend to confirm the above conclusions. Perrine finds the northernmost region of the Milky Way "to be almost, if not entirely, devoid of globular clusters."[380]

According to Sir John Herschel, “the sublimity of the spectacle afforded” by Lord Rosse’s great telescope of 6 feet in diameter of some of the “larger globular and other clusters” “is declared by all who have witnessed it, to be such that no words can express.”[381]

In his address to the British Association at Leicester in 1907, Sir David Gill said—

“Evidence upon evidence has accumulated to show that nebulæ consist of the matter out of which stars have been and are being evolved.... The fact of such an evolution with the evidence before us, can hardly be doubted. I most fully believe that, when the modifications of terrestrial spectra under sufficiently varied conditions of temperature, pressure, and environment, have been further studied, this connection will be greatly strengthened.”

CHAPTER XVIII

Historical

THE grouping of the stars into constellations is of great antiquity. The exact date of their formation is not exactly known, but an approximate result may be arrived at from the following considerations. On the celestial spheres, or "globes," used by the ancient astronomers, a portion of the southern heavens of a roughly circular form surrounding the South Pole was left blank. This space presumably contained the stars in the southern hemisphere which they could not see from their northern stations. Now, the centre of this circular blank space most probably coincided with the South Pole of the heavens at the time when the constellations were first formed. Owing to the "Precession of the Equinoxes" this centre has now moved away from the South Pole to a considerable distance. It can be easily computed at what period this centre coincided with the South Pole, and calculations show that this was the case about 2700 B.C. The position of this circle also indicates that the constellations were formed at a place between 36° and 40° north latitude, and therefore probably somewhere in Asia Minor north of Mesopotamia. Again, the most ancient observations refer to Taurus as the equinoxial constellation. Virgil says—

"Candidus auratis aperit cum cornibus annum Taurus."[382]

This would indicate a date about 3000 B.C. There is no tradition, however, that the constellation Gemini was ever *seen* to occupy this position, so that 3000 B.C. seems to be the earliest date admissible.[383]

Prof. Sayce thinks that the "signs of the Zodiac" had their origin in the plains of Mesopotamia in the twentieth or twenty-third century B.C., and Brown gives the probable date as 2084 B.C.[384]

According to Seneca, the study of astronomy among the Greeks dates back to about 1400 B.C.; and the ancient constellations were already classical in the time of Eudoxus in the fourth century B.C. Eudoxus (408-355 B.C.) observed the positions of forty-seven stars visible in Greece, thus forming the most ancient star catalogue which has been preserved. He was a son of Eschinus, and a pupil of Archytas and probably Plato.

The work of Eudoxus was put into verse by the poet Aratus (third century B.C.). This poem describes all the old constellations now known, except Libra, the Balance, which was at that time included in the Claws of the Scorpion. About B.C. 50, the Romans changed the Claws, or Chelæ, into Libra. Curious to say, Aratus states that the constellation Lyra contained no bright star![385] Whereas its principal star, Vega, is now one of the brightest stars in the heavens!

With reference to the origin of the constellations, Aratus says—

"Some men of yore
A nomenclature thought of and devised
And forms sufficient found."

This shows that even in the time of Aratus the constellations were of great antiquity.

Brown says—

"Writers have often told us, speaking only from the depths of their ignorance, how 'Chaldean' shepherds were wont to gaze at the brilliant nocturnal sky, and to *imagine* that such and such stars resemble this or that figure. But all this is merely the old effort to make capital out of nescience, and the stars are before our eyes to prove the contrary. Having already certain fixed ideas and figures in his mind, the constellation-former, when he came to his task, applied his figures to the stars and the stars to his figures as harmoniously as possible."[386] "Thus *e.g.* he arranged the stars of *Andromeda* into the representation of a chained lady, not because they naturally reminded him (or anybody else) of such a figure, but because he desired to express that idea."

A coin of Manius Aquillus, B.C. 94, shows four stars in Aquila, and seems to be the oldest representation extant of a star group. On a coin of B.C. 43, Dr. Vencontre found five stars, one of which was much larger than the others, and concludes that it represents the Hyades (in Taurus). He attributes the coin to P. Clodius Turrinus, who probably used the constellation Taurus or Taurinus as a phonetic reference to his surname. A coin struck by L. Lucretius Trio in 74 B.C., shows the seven stars of the Plough, or as the ancients called them Septem Triones. Here we have an allusion to the name of the magistrate Trio.[387]

In a work published in Berne in 1760, Schmidt contends that the ancient Egyptians gave to the constellations of the Zodiac the names of their divinities, and expressed them by the signs which were used in their hieroglyphics.[388]

Hesiod mentions Orion, the Pleiades, Sirius, Aldebaran, and Arcturus; and Homer refers to Orion, Arcturus, the Pleiades, the Hyades, the Great Bear (under the name of Amaxa, the Chariot), and the tail of the Little Bear, or "Cynosura."

Hipparchus called the constellations Asterisms (ἀστερίσμος), Aristotle and Hyginus Σομάτα (bodies), and Ptolemy Σχημάτα (figures). By some they were called Μορφώσεις (configurations), and by others Μετεώρε. Proclus called those near the ecliptic Ζωδία (animals). Hence our modern name Zodiac.

Hipparchus, Ptolemy, and Al-Sufi referred the positions of the stars to the ecliptic. They are now referred to the equator. Aboul Hassan in the thirteenth century (1282) was the first to use Right Ascensions and Declinations instead of Longitudes and Latitudes. The ancient writers described the stars by their positions in the ancient figures. Thus they spoke of "the star in the head of Hercules," "the bright star in the left foot of Orion" (Rigel); but Bayer in 1603 introduced the Greek letters to designate the brighter stars, and these are now universally used by astronomers. These letters being sometimes insufficient, Hevelius added numbers, but the numbers in *Flamsteed's Catalogue* are now generally used.

Ptolemy and all the ancient writers described the constellation figures as they are seen on globes, that is from the outside. Bayer in his Atlas, published in 1603, reversed the figures to show them as they would be seen from the *interior* of a hollow globe and as, of course, they are seen in the sky. Hevelius again reversed Bayer's figures to make them correspond with those of Ptolemy. According to Bayer's arrangement, Betelgeuse (α

Orionis) would be on the left shoulder of Orion, instead of the right shoulder according to Ptolemy and Al-Sufi, and Rigel (β Orionis) on the right foot (Bayer) instead of the left foot (Ptolemy). This change of position has led to some confusion; but at present the positions of the stars are indicated by their Right Ascensions and Declinations, without any reference to their positions in the ancient figures.

The classical constellations of Hipparchus and Ptolemy number forty-eight, and this is the number described by Al-Sufi in his "Description of the Fixed Stars" written in the tenth century A.D.

Firminicus gives the names of several constellations not mentioned by Ptolemy. M. Fréret thought that these were derived from the Egyptian sphere of Petosiris. Of these a Fox was placed north of the Scorpion; a constellation called Cynocephalus near the southern constellation of the Altar (Ara); and to the north of Pisces was placed a Stag. But all these have long since been discarded. Curious to say neither the Dragon nor Cepheus appears on the old Egyptian sphere.[389]

Other small constellations have also been formed by various astronomers from time to time, but these have disappeared from our modern star maps. The total number of constellations now recognized in both hemispheres amounts to eighty-four.

The first catalogue formed was nominally that of Eudoxus in the fourth century B.C. (about 370 B.C.). But this can hardly be dignified by the name of catalogue, as it contained only forty-seven stars, and it omits several of the brighter stars, notably Sirius! The first complete (or nearly complete) catalogue of stars visible to the naked eye was that of Hipparchus about 129 B.C. Ptolemy informs us that it was the sudden appearance of a bright new or "temporary star" in the year 134 B.C. in the constellation Scorpio which led Hipparchus to form his catalogue, and there seems to be no reason to doubt the accuracy of this statement, as the appearance of this star is recorded in the Chinese Annals. The Catalogue of Hipparchus contains only 1080 stars; but as many more are visible to the naked eye, Hipparchus must have omitted those which are not immediately connected with the old constellation figures of men and animals.

Hipparchus' Catalogue was revised by Ptolemy in his famous work the *Almagest*. Ptolemy reduced the positions of the stars given by Hipparchus to the year 137 A.D.; but used a wrong value of the precession which only corresponded to about 50 A.D.; and he probably adopted the star magnitudes of Hipparchus without any revision. Indeed, it seems somewhat doubtful whether Ptolemy made any observations of the brightness of the stars himself. Ptolemy's catalogue contains 1022 stars.

Prof. De Morgan speaks of Ptolemy as "a splendid mathematician and an indifferent observer"; and from my own examination of Al-Sufi's work on the Fixed Stars, which was based on Ptolemy's work, I think that De Morgan's criticism is quite justified.

Al-Sufi's *Description of the Fixed Stars* was written in the tenth century and contains 1018 stars. He seems to have adopted the *positions* of the stars given by Ptolemy, merely correcting them for the effects of precession; but he made a very careful revision of the star magnitudes of Ptolemy (or Hipparchus) from his own observations, and this renders his work the most valuable, from this point of view, of all the ancient catalogues.

Very little is known about Al-Sufi's life, and the few details we have are chiefly derived from the works of the historians Abu'-l-faradji and Casiri, and the Oriental writers Hyde, Caussin, Sedillot, etc. Al-Sufi's complete name was Abd-al-Rahmän Bin Umar Bin Muhammad Bin Sahl Abu'l-husaïn al-Sufi al-Razi. The name Sufi indicates that he belonged to the sect of Sufis (Dervishes), and the name Razi that he lived in the town of Raï in Persia, to the east of Teheran. He was born on December 7, 903 A.D., and died on May 25, 986, so that, like many other astronomers, he lived to a good old age. According to ancient authorities, Al-Sufi—as he is usually called—was a very learned man, who lived at the courts of Schiraz and Baghdad under Adhad-al-Davlat—of the dynasty of the Buïdes—who was then the ruler of Persia. Al-Sufi was held in high esteem and great favour by this prince, who said of him, "Abd-al-Rahmän al-Sufi taught me to know the names and positions of the fixed stars, Scharif Ibn al-Aalam the use of astronomical tables, and Abu Ali al-Farisi instructed me in the principles of grammar." Prince Adhad-al-Davlat died on March 26, 983. According to Caussin, Al-Sufi also wrote a book on astrology, and a work entitled *Al-Ardjouze*, which seems to have been written in verse, but its subject is unknown. He also seems to have determined the exact length of the year, and to have undertaken geodetic measurements. The al-Aalam mentioned above was also an able astronomer, and in addition to numerous observations made at Baghdad, he determined with great care the precession of the equinoxes. He found the annual constant of precession to be 51″·4, a value which differs but little from modern results.

In the year 1874, the late M. Schjellerup, the eminent Danish astronomer, published a French translation of two Arabic manuscripts written by Al-Sufi and entitled "A Description of the Fixed Stars." One of these manuscripts is preserved in the Royal Library at Copenhagen, and the other in the Imperial Library at St. Petersburgh.[390]

Al-Sufi seems to have been a most careful and accurate observer, and although, as a rule, his estimates of the relative brightness of stars are in fairly good agreement with modern estimates and photometric measures, there are many remarkable and interesting differences. Al-Sufi's observations have an important bearing on the supposed "secular variation" of the stars; that is, the slow variation in light which may have occurred in the course of ages in certain stars, apart from the periodical variation which is known to occur in the so-called variable stars. More than 900 years have now elapsed since the date of Al-Sufi's observations (about A.D. 964) and over 2000 years in the case of Hipparchus, and although these periods are of course very short in the life-history of any star, still *some* changes may possibly have taken place in the brightness of some of them. There are several cases in which a star seems to have diminished in light since Al-Sufi's time. This change seems to have certainly occurred in the case of θ Eridani, β Leonis, ζ Piscis Australis, and some others. On the other hand, some stars seem to have certainly increased in brightness, and the bearing of these changes on the question of "stellar evolution" will be obvious.

In most cases Al-Sufi merely mentions the magnitude which he estimated a star to be; such as "third magnitude," "fourth," "small third magnitude," "large fourth," etc. In some cases, however, he directly states that a certain star is a little brighter than another star near it. Such cases—unfortunately not numerous—are very valuable for comparison with modern estimates and measures, when variation is suspected in the light of a star. The estimates of Argelander, Heis, and Houzeau are based on the same scale as that used by Ptolemy and Al-Sufi. Al-Sufi's estimates are given in thirds of a magnitude. Thus, "small third magnitude" means 3⅓, or 3·33 magnitude in modern measures; "large fourth," 3⅔ or 3·66 magnitude. These correspond with the estimates of magnitude given by Argelander, Heis, and Houzeau in their catalogues of stars visible to the naked eye, and so the estimates can be directly compared.

I have made an independent identification of all the stars mentioned by Al-Sufi. In the majority of cases my identifications concur with those of Schjellerup; but in some cases I cannot agree with him. In a few cases I have found that Al-Sufi himself, although accurately describing the position of the stars observed by *him*, has apparently misidentified the star observed by Hipparchus and Ptolemy. This becomes evident when we plot Ptolemy's positions (as given by Al-Sufi) and compare them with Al-Sufi's descriptions of the stars observed by him. This I have done in all cases where there seemed to be any doubt; and in this way I have arrived at some interesting results which have escaped the notice of Schjellerup. This examination shows clearly, I think, that Al-Sufi did not himself measure the *positions* of the stars he observed, but merely adopted those of Ptolemy, corrected for the effect of precession. The great value of his work, however, consists in his estimates of star magnitudes, which seem to have been most carefully made, and from this point of view, his work is invaluable. Prof. Pierce says, "The work which the learning of M. Schjellerup has brought to light is so important that the smallest errors of detail become interesting."[391]

Although Al-Sufi's work is mentioned by the writers referred to above, no complete translation of his manuscript was made until the task was undertaken by Schjellerup, and even now Al-Sufi's name is not mentioned in some popular works on astronomy! But he was certainly the best of all the old observers, and his work is deserving of the most careful consideration.

Al-Sufi's descriptions of the stars were, it is true, based on Ptolemy's catalogue, but his work is not a mere translation of that of his predecessor. It is, on the contrary, a careful and independent survey of the heavens, made from his own personal observations, each of Ptolemy's stars having been carefully examined as to its position and magnitude, and Ptolemy's mistakes corrected. In examining his descriptions, Schjellerup says, "We soon see the vast extent of his labours, his perseverance, and the minute accuracy and almost modern criticism with which he executed his work." In fact, Al-Sufi has given us a careful description of the starry sky as it appeared in his time, and one which deserves the greatest confidence. It far surpasses the work of Ptolemy, which had been without a rival for eight centuries previously, and it has only been equalled in modern times by the surveys of Argelander, Gould, Heis, and Houzeau. Plato remarked with reference to the catalogue of Hipparchus, *Cœlam posteris in hereditatem relictum*, and the same may be said of Al-Sufi's work. In addition to his own estimates of star magnitudes, Al-Sufi adds the magnitudes given by Ptolemy whenever Ptolemy's estimate differs from his own; and this makes his work still more valuable, as Ptolemy's magnitudes given in all the editions of the *Almagest* now extant are quite untrustworthy.

In the preface to his translation of Al-Sufi's work, Schjellerup mentions some remarkable discrepancies between the magnitudes assigned to certain stars by Ptolemy and Argelander. This comparison is worthy of confidence as it is known that both Al-Sufi and Argelander adopted Ptolemy's (or Hipparchus') scale of magnitudes. For example, all these observers agree that β Ursæ Minoris (Ptolemy's No. 6 of that constellation) is of the 2nd magnitude, while in the case of γ Ursæ Minoris (Ptolemy's No. 7), Ptolemy called it 2nd, and Argelander rated it 3rd; Argelander thus making γ one magnitude fainter than Ptolemy's estimate. Now, Al-Sufi, observing over 900 years ago, rated γ of the 3rd magnitude, thus correcting Ptolemy and agreeing with Argelander. Modern photometric measures confirm the estimates of Al-Sufi and Argelander. But it is, of course, possible that one or both stars may be variable in light, and β has actually been suspected of variation. Almost all the constellations afford examples of this sort. In the majority of cases, however, Al-Sufi agrees well with Argelander and Heis, but there are in some cases differences which suggest a change in relative brightness.

Among other remarkable things contained in Al-Sufi's most interesting work may be mentioned the great nebula in Andromeda, which was first noticed in Europe as visible to the naked eye by Simon Marius in 1612. Al-Sufi, however, speaks of it as a familiar object in his time.

Schjellerup says—

"For a long time many of the stars in Ptolemy's catalogue could not be identified in the sky. Most of these discordances were certainly due to mistakes in copying, either in longitude or latitude. Many of these differences were, however, corrected by the help of new manuscripts. For this purpose Al-Sufi's work is of great importance. By a direct examination of the sky he succeeded in finding nearly all the stars reported by Ptolemy (or Hipparchus). And even if his criticism may sometimes seem inconclusive, his descriptions are not subject to similar defects, his positions not depending solely on the places given in Ptolemy's catalogue. For, in addition to the longitudes and latitudes quoted from Ptolemy, he has described by alignment the positions of the stars referred to. In going from the brightest and best known stars of each constellation he indicates the others either by describing some peculiarity in their position, or by giving their mutual distance as so many cubits (*dzirâ*), or a span (*schibr*), units of length which were used at that time to measure apparent celestial distances. The term *dzirâ* means literally the fore-arm from the bone of the elbow to the tip of the middle finger, or an ell. We should not, however, conclude from this that the Arabians were so unscientific as to measure celestial distances by an ell, as this would be quite in contradiction to their well-known knowledge of Geometry and Trigonometry."

With reference to the arc or angular distance indicated by the "cubit," Al-Sufi states in his description of the constellation Auriga that the *dzirâ* (or cubit) is equal to 2° 20′. Three cubits, therefore, represent 7°, and 4 cubits 9° 20′.

In Al-Sufi's own preface to his work, after first giving glory to God and blessings on "his elected messenger Muhammed and his family," he proceeds to state that he had often "met with many persons who wished to know the fixed stars, their positions on the celestial vault, and the constellations, and had found that these persons may be divided into two classes. One followed the method of astronomers and trust to spheres designed by artists, who not knowing, the stars themselves, take only the longitudes and latitudes which they find in the books, and thus place the stars on the sphere, without being able to distinguish truth from error. It then follows that those who really know the stars in the sky find on examining these spheres that many stars are otherwise than they are in the sky. Among these are Al-Battani, Atârid and others."

Al-Sufi seems rather hard on Al-Battani (or Albategnius as he is usually called) for he is generally considered to have been the most distinguished of the Arabian astronomers. His real name was Mohammed Ibn Jaber Ibn Senan Abu Abdallah Al-Harrani. He was born about A.D. 850 at Battan, near Harran in Mesopotamia, and died about A.D. 929. He was the first to make use of sines instead of chords, and versed sines. The *Alphonsine Tables* of the moon's motions were based on his observations.

After some severe criticisms on the work of Al-Battani and Atârid, Al-Sufi goes on to say that the other class of amateurs who desire to know the fixed stars follow the method of the Arabians in the science of *Anva*[392] and the mansions of the moon and the books written on this subject. Al-Sufi found many books on the *anva*, the best being those of Abu Hanifa al-Dînavari. This work shows that the author knew the Arabic tradition better than any of the other writers on the subject. Al-Sufi, however, doubts that he had a good knowledge of the stars themselves, for if he had he would not have followed the errors of his predecessors.

According to Al-Sufi, those who know one of these methods do not know the other. Among these is Abu-Hanifa, who states in his book that the names of the twelve signs (of the Zodiac) did not originate from the arrangement or configuration of the stars resembling the figure from which the name is derived. The stars, Abu-Hanifa said, "change their places, and although the names of the signs do not change, yet the arrangement of the stars ceases to be the same. This shows that he was not aware of the fact that the arrangement of the stars does not change, and their mutual distances and their latitudes, north and south of the ecliptic, are neither increased nor diminished." "The stars," Al-Sufi says, "do not change with regard to their configurations, because they are carried along together by a physical motion and by a motion round the poles of the ecliptic. This is why they are called fixed. Abu-Hanifa supposed that they are termed fixed because their motion is very slow in comparison with that of the planets." "These facts," he says, "can only be known to those who follow the method of the astronomers and are skilled in mathematics."

Al-Sufi says that the stars of the Zodiac have a certain movement following the order of the signs, which according to Ptolemy and his predecessors is a degree in 100 years. But according to the authors of *al-mumtahan* and those who have observed subsequently to Ptolemy, it is a degree in 66 years. According to modern measures, the precession is about 50″·35 per annum, or one degree in 71½ years.

Al-Sufi says that the Arabians did not make use of the figures of the Zodiac in their proper signification, because they divided the circumference of the sky by the number of days which the moon took to describe it—about 28 days—and they looked for conspicuous stars at intervals which, to the eye, the moon appeared to describe in a day and a night. They began with *al-scharataïn*, "the two marks" (α and β Arietis) which were the first striking points following the point of the spring equinox. They then sought behind these two marks another point at a distance from them, equal to the space described by the moon in a day and a night. In this way they found *al-butaïn* (ε, δ, and ρ Arietis); after that *al-tsuraija*, the Pleiades; then *al-dabaran*, the Hyades, and thus all the "mansions" of the moon. They paid no attention to the signs of the Zodiac, nor to the extent of the figures which composed them. This is why they reckoned among the "mansions" *al-haka* (λ Orionis) which forms no part of the signs of the Zodiac, since it belongs to the southern constellation of the Giant (Orion). And similarly for other stars near the Zodiac, of which Al-Sufi gives some details. He says that Regulus (α Leonis) was called by the Arabians *al-maliki*, the Royal Star, and that *al-anva* consists of five stars situated in the two wings of the Virgin. These stars seem to be β, η, γ, δ, and ε Virginis, which form with Spica (α Virginis) a Y-shaped figure. Spica was called *simak al-azal*, the unarmed *simak*; the "armed *simak*" being Arcturus, *simak al-ramih*. These old Arabic names seem very fanciful.

Al-Sufi relates that in the year 337 of the Hegira (about A.D. 948) he went to Ispahan with Prince Abul-fadhl, who introduced him to an inhabitant of that city, named Varvadjah, well known in that country, and famous for his astronomical acquirements. Al-Sufi asked him the names of the stars on an astrolabe which he had, and he named Aldebaran, the two bright stars in the Twins (Castor and Pollux), Regulus, Sirius, and Procyon, the two Simaks, etc. Al-Sufi also asked him in what part of the sky *Al-fard* (α Hydræ) was, but he did not know! Afterwards, in the year 349, this same man was at the court of Prince Adhad-al-Davlat, and in the presence of the Prince, Al-Sufi asked him the name of a bright star—it was *al-nasr al-vaki*, the falling Vulture (Vega), and he replied, “That is *al-aijuk*” (Capella)! thus showing that he only knew the *names* of the stars, but did not know them when he saw them in the sky. Al-Sufi adds that all the women “who spin in their houses” knew this star (Vega) by the name of *al-atsafi*, the Tripod. But this could not be said even of “educated women” at the present day.

With reference to the number of stars which can be seen with the naked eye, Al-Sufi says, “Many people believe that the total number of fixed stars is 1025, but this is an evident error. The ancients only observed this number of stars, which they divided into six classes according to magnitude. They placed the brightest in the 1st magnitude; those which are a little smaller in the 2nd; those which are a little smaller again in the 3rd; and so on to the 6th. As to those which are below the 6th magnitude, they found that their number was too great to count; and this is why they have omitted them. It is easy to convince one’s self of this. If we attentively fix our gaze on a constellation of which the stars are well known and registered, we find in the spaces between them many other stars which have not been counted. Take, for example, the Hen [Cygnus]; it is composed of seventeen internal stars, the first on the beak, the brightest on the tail, the others on the wings, the neck and the breast; and below the left wing are two stars which do not come into the figure. Between these different stars, if you examine with attention, you will perceive a multitude of stars, so small and so crowded that we cannot determine their number. It is the same with all the other constellations.” These remarks are so correct that they might have been written by a modern astronomer. It should be added, however, that *all* the faint stars referred to by Al-Sufi—and thousands of others still fainter—have now been mapped down and their positions accurately determined.

About the year 1437, Ulugh Beigh, son of Shah Rokh, and grandson of the Mogul Emperor Tamerlane, published a catalogue of stars in which he corrected Ptolemy’s positions. But he seems to have accepted Al-Sufi’s star magnitudes without any attempt at revision. This is unfortunate, for an *independent* estimate of star magnitudes made in the fifteenth century would now be very valuable for comparison with Al-Sufi’s work and with modern measures. Ulugh Beigh’s catalogue contains 1018 stars, nearly the same number as given by Ali-Sufi.[393]

CHAPTER XIX

The Constellations[394]

CURIOUS to say, Al-Sufi rated the Pole Star as 3rd magnitude; for it is now only slightly less than the 2nd. At present it is about the same brightness as β of the same constellation (Ursa Minor) which Al-Sufi rated 2nd magnitude. It was, however, also rated 3rd magnitude by Ptolemy (or Hipparchus), and it may possibly have varied in brightness since ancient times. Admiral Smyth says that in his time (1830) it was “not even a very bright third size” (!)[395] Spectroscopic measures show that it is approaching the earth at the rate of 16 miles a second; but this would have no perceptible effect on its brightness in historical times. This may seem difficult to understand, and to some perhaps incredible; but the simple explanation is that its distance from the earth is so great that a journey of even 2000 years with the above velocity would make no *appreciable* difference in its distance! This is undoubtedly true, as a simple calculation will show, and the fact will give some idea of the vast distance of the stars. The well-known 9th magnitude companion to the Pole Star was seen *by day* in the Dorpat telescope by Struve and Wrangel; and “on one occasion by Encke and Argelander.”[396]

The star β Ursæ Minoris was called by the Arabians *Kaukab al-shamáli*, the North Star, as it was—owing to the precession of the Equinoxes—nearer to the Pole in ancient times than our present Pole Star was *then*.

The “Plough” (or Great Bear) is supposed to represent a waggon and horses. “Charles’ Wain” is a corruption of “churl’s wain,” or peasant’s cart. The Arabians thought that the four stars in the quadrilateral represented a bier, and the three in the “tail” the children of the deceased following as mourners! In the Greek mythology, Ursa Major represented the nymph Callisto, a daughter of Lycaon, who was loved by Jupiter, and turned into a bear by the jealous Juno. Among the old Hindoos the seven stars represented the seven Rishis. It is the Otawa of the great Finnish epic, the "Kalevala." It was also called "David's Chariot," and in America it is known as "The Dipper."

Closely north of the star θ in Ursa Major is a small star known as Flamsteed 26. This is not mentioned by Al-Sufi, but is now, I find from personal observation, very visible, and indeed conspicuous, to the naked eye. I find, however, that owing to the large "proper motion" of the bright star (1″·1 per annum) the two stars were much closer together in Al-Sufi's time than they are at present, and this probably accounts for Al-Sufi's omission. This is an interesting and curious fact, and shows the small changes which occur in the heavens during the course of ages.

Close to the star ζ, the middle star of the "tail" of Ursa Major (or handle of the "Plough"), is a small star known as Alcor, which is easily visible to good eyesight without optical aid. It is mentioned by Al-Sufi, who says the Arabians called it *al-suha*, "the little unnoticed one." He says that "Ptolemy does not mention it, and it is a star which seems to test the powers of the eyesight." He adds, however, an Arabian proverb, "I show him *al-suha*, and he shows me the moon," which seems to suggest that to some eyes, at least, it was no test of sight at all. It has, however, been suspected of variation in light. It was rated 5th magnitude by Argelander, Heis, and Houzeau, but was measured 4·02 at Harvard Observatory. It has recently been found to be a spectroscopic binary.

The constellation of the Dragon (Draco) is probably referred to in Job (chap. xxvi. v. 13), where it is called "the crooked serpent." In the Greek mythology it is supposed to represent the dragon which guarded the golden apples in the Garden of the Hesperides. Some have suggested that it represented the serpent which tempted Eve. Dryden says, in his translation of Virgil—

> "Around our Pole the spiry Dragon glides,
> And like a wand'ring stream the Bears divides."

The fact that the constellation Boötis rises quickly and sets slowly, owing to its lying horizontally when rising and vertically when setting, was noted by Aratus, who says—

"The Bearward now, past seen,
But more obscured, near the horizon lies;
For with the four Signs the Ploughman, as he sinks,
The deep receives; and when tired of day
At even lingers more than half the night,
When with the sinking sun he likewise sets
These nights from his late setting bear their name."[397]

The cosmical setting of Boötis—that is, when he sets at sunset—is stated by Ovid to occur on March 5 of each year.

With reference to the constellation Hercules, Admiral Smyth says—

"The kneeling posture has given rise to momentous discussion; and whether it represents Lycaon lamenting his daughter's transformation, or Prometheus sentenced, or Ixion ditto, or Thamyrus mourning his broken fiddle, remains still uncertain. But in process of time, this figure became a lion, and Hyginus mentions both the lion's skin and the club; while the right foot's being just over the head of the Dragon, satisfied the mythologists that he was crushing the Lernæan hydra.... Some have considered the emblem as typifying the serpent which infested the vicinity of Cape Tænarus, whence a sub-genus of Ophidians still derives its name. At all events a poet, indignant at the heathen exaltation of Hevelius, has said—

"'To Cerberus, too, a place is given—
His home of old was far from heaven.'"[398]

Aratus speaks of Hercules as "the Phantom whose name none can tell."

There were several heroes of the name of Hercules, but the most famous was Hercules the Theban, son of Jupiter and Alcmene wife of Amphitryon, King of Thebes, who is said to have lived some years before the siege of Troy, and went on the voyage of the Argonauts about 1300 B.C. According to some ancient writers, another Hercules lived about 2400 B.C., and was a contemporary of Atlas and Theseus. But according to Pétau, Atlas lived about 1638 B.C., and Lalande thought that this chronology is the more probable.

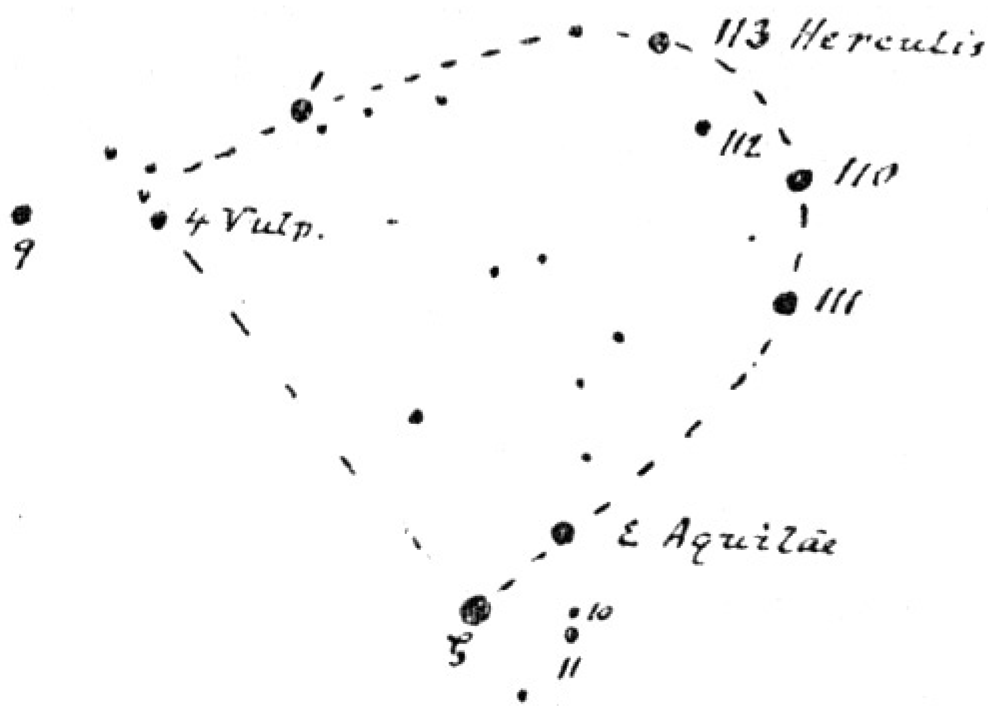
The small constellation Lyra, which contains the bright star Vega, is called by Al-Sufi the Lyre, the Goose, the Persian harp, and the Tortoise. In his translation of Al-Sufi's work, Schjellerup suggests that the name "Goose" may perhaps mean a plucked goose, which somewhat resembles a Greek lyre, and also a tortoise. The name of the bright star Vega is a corruption of the Arabic *vâki*. Ptolemy and Al-Sufi included all the very brightest stars in the "first magnitude," making no distinction between them, but it is evident at a glance that several of them, such as Arcturus and Vega, are brighter than an average star of the first magnitude, like Aldebaran.

The constellation Perseus, which lies south-east of "Cassiopeia's Chair," may be recognized by the festoon formed by some of its stars, the bright star α Persei being among them. It is called by Al-Sufi "*barschânsch*, Περσεύς, Perseus, who is *hamil râs al-gul*, the Bearer of the head of *al-gul*." According to Kazimirski, "*Gul* was a kind of demon or ogre who bewilders travellers and devours them, beginning at the feet. In general any mischievous demon capable of taking all sorts of forms." In the Greek mythology Perseus was supposed to be the son of Jupiter and Danæ. He is said to have been cast into the sea with his mother and saved by King Polydectus. He afterwards cut off the head of Medusa, one of the Gorgons, while she slept, and armed with this he delivered Andromeda from the sea-monster.

The constellation Auriga lies east of Perseus and contains the bright star Capella, one of the three brightest stars in the northern hemisphere (the others being Arcturus and Vega). Theon, in his commentary on Aratus, says that Bellerophon invented the chariot, and that it is represented in the heavens by Auriga, the celestial coachman. According to Dupuis, Auriga represents Phæton, who tried to drive the chariot of the sun, and losing his head fell into the river Eridanus. The setting of Eridanus precedes by a few minutes that of Auriga, which was called by some of the ancient writers Amnis Phaï-tontis.[399] Auriga is called by Al-Sufi *numsick al-ainna*—He who holds the reins, the Coachman; also *al-inâz*, the She-goat. M. Dorn found in Ptolemy's work, the Greek name 'Ηνίοχοι, Auriga, written in Arabic characters. Al-Sufi says, "This constellation is represented by the figure of a standing man behind 'He who holds the head of *al-gûl*' [Perseus], and between the Pleiades and the Great Bear."

Capella is, Al-Sufi says, "the bright and great star of the first magnitude which is on the left shoulder [of the ancient figure] on the eastern edge of the Milky Way. It is that which is marked on the astrolabe as *al-aijûk*." The real meaning of this name is unknown. Schjellerup thought, contrary to what Ideler says, that the name is identical with the Greek word Αϊξ (a goat). Capella was observed at Babylon about 2000 B.C., and was then known as Dilgan. The Assyrian name was *Icu*, and the Persian name *colca*. It was also called Capra Hircus, Cabrilla, Amalthea, and Olenia. In ancient times the rising of Capella was supposed to presage the approach of storms. Ovid says, "Olenia sidus pluviale Capellæ."

The constellation Aquila is called by Al-Sufi *al-ukab*, the Eagle, or *al-nasr al-tâïr*, the flying vulture. According to the ancient poets the eagle carried nectar to Jupiter when he was hidden in a cave in Crete. This eagle also assisted Jupiter in his victory over the Giants and contributed to his other pleasures. For these reasons the eagle was consecrated to Jupiter, and was placed in the sky. Al-Sufi says, "There are in this figure three famous stars [γ, α, and β Aquilæ], which are called *al-nasr al-tâïr*." Hence is derived the modern name Altair for the bright star α Aquilæ. Al-Sufi says that the "common people" call "the three famous stars" *al-mîzân*, the Balance, on account of the equality of the stars." This probably refers to the approximately equal distances between γ and α, and α and β, and not to their relative brightness. He says "Between the bright one of the tail [ξ Aquilæ] and the star in the beak of the Hen [β Cygni] in the thinnest part of the Milky Way, we see the figure of a little earthen jar, of which the stars begin at the bright one in the tail, and extend towards the north-west. [This seems to refer to ε Aquilæ and the small stars near it.] They then turn towards the east in the base of the jar, and then towards the south-east to a little cloud [4, 5, etc. Vulpeculæ, a well-known group of small stars] which is found to the north of the two stars in the shaft of the Arrow [α and β Sagittæ]. The cloud is on the eastern edge of the jar, and the bright one on the tail on the western edge; the orifice is turned towards the flying Vulture [Aquila], and the base towards the north. Among these are distinguished some of the fourth, fifth, and sixth magnitudes [including, probably, 110, 111, 112, 113 Hercules, and 1 Vulpeculæ] and Ptolemy says nothing of this figure, except the bright star in the tail of the Eagle" (see figure). The above is a good example of the minute accuracy of detail in Al-Sufi's description.

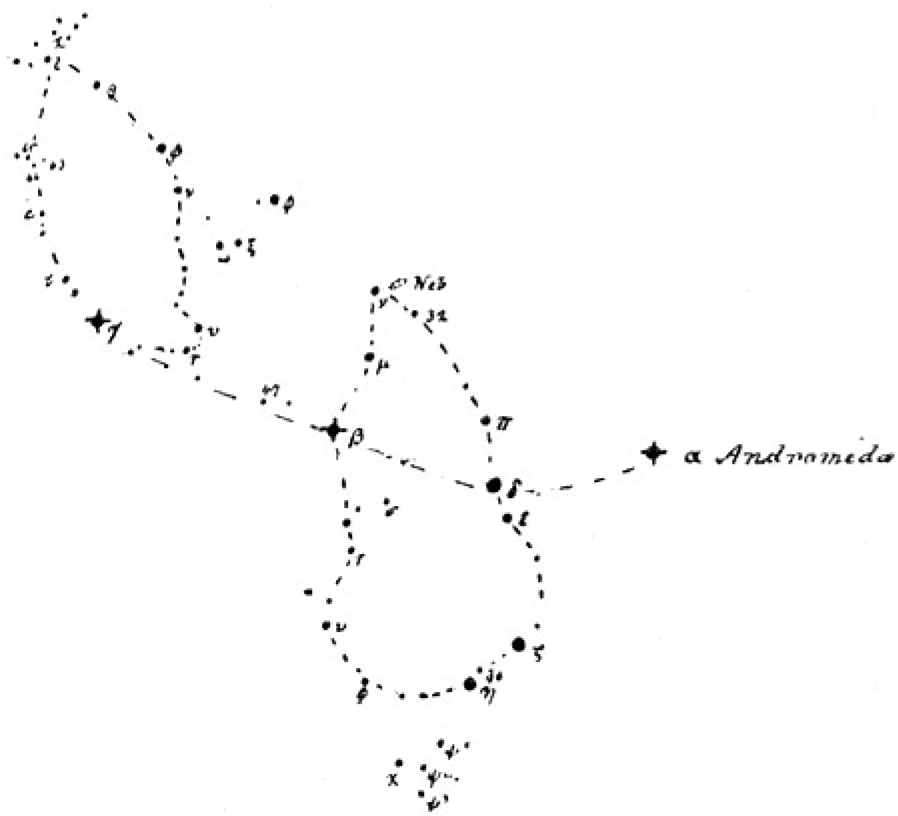


AL-SUFI’S “EARTHEN JAR.”

The southern portion of Aquila was formerly called Antinous, who was said to have been a young man of great beauty born at Claudiopolis in Bithynia, and drowned in the Nile. Others say that he sacrificed his life to save that of the Emperor Hadrian, who afterwards raised altars in his honour and placed his image on coins.[400]

The constellation Pegasus, Al-Sufi says, “is represented by the figure of a horse, which has the head, legs, and forepart of the body to the end of the back, but it has neither hind quarters nor hind legs.” According to Brown, Pegasus was the horse of Poseidon, the sea god. Half of it was supposed to be hidden in the sea, into which the river Eridanus flowed.[401] In the Greek mythology it was supposed to represent the winged horse produced by the blood which fell from the head of Medusa when she was killed by Perseus! Some think that it represents Bellerophon’s horse, and others the horse of Nimrod. It was also called Sagmaria and Ephippiatus, and was sometimes represented with a saddle instead of wings.

In describing the constellation Andromeda, Al-Sufi speaks of two series of stars which start from the great nebula in Andromeda; one series going through 32 Andromedæ, π, δ, and ε to ζ and η; and the other through ν, μ, β Andromedæ into the constellation Pisces. He says they enclose a fish-shaped figure called by the Arabians *al-hût*, the Fish, *par excellence*. He speaks of two other series of stars which begin at τ and υ, and diverging meet again at χ Persei, forming another "fish-like figure." The eastern stream starts from τ and passes through 55, γ, 60, 62, 64, and 65 Andromedæ; and the western stream from υ through χ 51, 54, and *g* Persei up to χ Persei. The head of the first "fish," *al-hût*, is turned towards the north, and that of the second towards the south (see figure).



AL-SUFI'S "FISHES" IN ANDROMEDA.

Al-Sufi says that the stars α Persei, γ, β, δ, and α Andromedæ, and β Pegasi form a curved line. This is quite correct, and this fine curve of bright stars may be seen at a glance on a clear night in September, when all the stars are high in the sky.

The first constellation of the Zodiac, Aries, the Ram, was called, according to Aratus and Eratosthenes, κρίος. It is mentioned by Ovid under the name of Hellas. It was also called by the ancients the Ram with the golden horns. Manilius (fourth century B.C.) called it "The Prince." It is supposed to have represented the god Bel. Among the Accadians the sign meant "He who dwells on the altar of uprightness." It first appears on the Egyptian Zodiac; and it was sacred to Jupiter Ammon. In the Greek mythology it was supposed to represent the ram, the loss of whose fleece led to the voyage of the Argonauts. In the time of Hipparchus, about 2000 years ago, it was the first sign of the Zodiac, or that in which the sun is situated at the Vernal Equinox (about March 21 in each year). But owing to the precession of the equinoxes, this point has now moved back into Pisces.

The brightest star of Aries (α) is sometimes called Hamal, derived from the Arabic *al-hamal*, a name given to the constellation itself by Al-Sufi. In the Accadian language it was called *Dilkur*, "the dawn proclaimer." Ali-Sufi says that close to α, "as if it were attached to it," is a small star of the 6th magnitude, not mentioned by Ptolemy. This is clearly κ Arietis. The fact of Al-Sufi having seen and noticed this small star, which modern measures show to be below the 5th magnitude, is good evidence of his keen eyesight and accuracy of observation.

According to Al-Sufi, the stars β and γ Arietis were called by the Arabians *al-scharatain*, "the two marks." They marked the "first mansion of the moon," and ε, δ, and ρ the second mansion. With reference to these so-called "mansions of the moon," Admiral Smyth says—

"The famous *Manazil al-kamar*, i.e. Lunar mansions, constituted a supposed broad circle in Oriental astronomy divided into twenty-eight unequal parts, corresponding with the moon's course, and therefore called the abodes of the moon. This was not a bad arrangement for a certain class of gazers, since the luminary was observed to be in or near one or other of these parts, or constellations every night. Though tampered with by astrologers, these Lunar mansions are probably the earliest step in ancient astronomy."[402]

Taurus, the second constellation of the Zodiac, was in ancient times represented by the figure of a bull, the hinder part of which is turned towards the south-west, and the fore part towards the east. It had no hind legs, and the head was turned to one side, with the horns extended towards the east. Its most ancient name was *Te*, possibly a corruption of the Accadian *dimmena*, "a foundation-stone." The Greek name is ἀθώρ (θωώρ, Eusebius). In the old Egyptian mythology Taurus represented the god Apis. According to Dupuis it also represented the 10th "labour of Hercules," namely, his victory over the cows of Geryon, King of Spain.[403] It was also supposed to represent the bull under the form of which Jupiter carried off Europa, daughter of Agenor, King of the Phœnicians. It may also refer to Io or Isis, who is supposed to have taught the ancient Egyptians the art of agriculture.

Aldebaran is the well-known bright red star in the Hyades. It was called by Ptolemy *Fulgur succularum*. Ali-Sufi says it was marked on the old astrolabes as *al-dabaran*, "the Follower" (because it follows the Hyades in the diurnal motion), and also *ain al-tsaur*, the eye of the bull. It may be considered as a standard star of the 1st magnitude. Modern observations show that it has a parallax of 0″·107. It is receding from the earth, according to Vogel, at the rate of about 30 miles a second; but even with this high velocity it will take thousands of years before its brightness is perceptibly diminished. It has a faint companion of about the 10th magnitude at the distance of 118″, which forms a good "light test" for telescopes of 3 or 4 inches aperture. I saw it well with a 4-inch Wray in the Punjab sky. The Hyades were called *Succulæ* by the Romans, and in the Greek mythology were said to be children of Atlas.

The star β Tauri, sometimes called Nath, from the Arabic *al-nátih*, the butting, is a bright star between Capella and γ Orionis (Bellatrix). It is on the tip of the horn in the ancient figure of Taurus, and "therefore" (says Admiral Smyth) "at the greatest distance from the hoof; can this have given rise to the otherwise pointless sarcasm of not knowing B from a bull's foot?"[404] Al-Sufi says that an imaginary line drawn from the star now known as A Tauri to τ Tauri would pass between υ and κ Tauri, which is quite correct, another proof of the accuracy of his observations. He also says that the star ω Tauri is exactly midway between A and ε, which is again correct. He points out that Ptolemy's position of ω is incorrect. This is often the case with Ptolemy's positions, and tends to show that Ptolemy adopted the position given by Hipparchus without attempting to verify their position in the sky. Al-Sufi himself adopts the longitudes and latitudes of the stars as given by Ptolemy in the *Almagest*, but corrects the positions in his *descriptions*, when he found Ptolemy's places erroneous.

The famous group of the Pleiades is well known; but there is great difficulty in understanding Al-Sufi's description of the cluster. He says, "The 29th star (of Taurus) is the more northern of the anterior side of the Pleiades themselves, and the 30th is the southern of the same side; the 31st is the following vertex of the Pleiades, and is in the more narrow part. The 32nd is situated outside the northern side. Among these stars, the 32nd is of the 4th magnitude, the others of the 5th." Now, it is very difficult or impossible to identify these stars with the stars in the Pleiades as they are at present. The brightest of all, Alcyone (η Tauri), now about 3rd magnitude, does not seem to be mentioned at all by Al-Sufi! as he says distinctly that "the brightest star" (No 32 of Taurus) is "outside" the Pleiades "on the northern side." It seems impossible to suppose that Al-Sufi could have overlooked Alcyone had it the same brightness it has now. The 32nd star seems to have disappeared, or at least diminished greatly in brightness, since the days of Al-Sufi. More than four stars were, however, seen by Al-Sufi, for he adds, "It is true that the stars of the Pleiades must exceed the four mentioned above, but I limit myself to these four because they are very near each other and the largest [that is, the brightest]; this is why I have mentioned them, neglecting the others." A full examination of the whole question is given by Flammarion in his interesting work *Les Étoiles* (pp. 289-307), and I must refer my readers to this investigation for further details.

According to Brown, Simonides of Keos (B.C. 556-467) says, "Atlas was the sire of seven daughters with violet locks, who are called the heavenly *Peleiades*."[405] The name is by some supposed to be derived from the Greek πλείων, full. The Old Testament word *Kimah* (Job ix. 9 and xxviii. 31) and Amos (v. 8) is derived from the Assyrian *Kimta*, a "family." Aratus describes the Pleiades in the following lines:—

> "Near his[406] left thigh together sweep along
> The flock of Clusterers. Not a mighty span
> Holds all, and they themselves are dim to see,
> And seven paths aloft men say they take,
> Yet six alone are viewed by mortal eye.

These seven are called by name Alkyonî
Kelainî, Meropî and Steropî
Taygetî, Elecktrî, Maia queen.
They thus together small and faint roll on
Yet notable at morn and eve through Zeus."[407]

The Pleiades are mentioned by Ovid. According to the ancient poets they were supposed to represent the children of Atlas and Hesperus, and on this account they were called Atlantids or Hesperides. From the resemblance in sound to the word πλείας, a pigeon, they were sometimes called "the doves," and for the same reason the word πλεῖν, to navigate, led to their being called the "shipping stars." The word πλείας was also applied to the priestesses of the god Zeus (Jupiter) at Dordona, in the groves of which temple there were a number of pigeons. This is, perhaps, what Aratus refers to in the last line of the extract quoted above. According to Neapolitan legends, the name of Virgil's mother was Maia. The mother of Buddha, the Hindoo *avatar*, was also named Maia. In Italy the Pleiades were called *Gallinata*, and in France *poussinière*, both of which mean the hen and chickens, a term also given to them by Al-Sufi. The old Blackfoot Indians called them "The Seven Perfect Ones." The Crees and Ojibway Indians called them the "Fisher Stars." The Adipones of Brazil and some other nations claimed that they sprang from the Pleiades! The Wyandot Indians called them "The Singing Maidens."

Photographs show that the brighter stars of the Pleiades are involved in nebulosity. That surrounding Maia seems to be of a spiral form. Now, there is a Sanscrit myth which represents Maia as "weaving the palpable universe," for which reason she was "typified as a spider." This seems very appropriate, considering the web of nebulous light which surrounds the stars of the group. Maia was also considered as a type of the universe, which again seems appropriate, as probably most of the stars were evolved from spiral nebulæ.

The name Hyades is supposed to be derived from the Greek word ὑεῖν, to rain, because in ancient times they rose at the rainy season.

In ancient Egypt, Aldebaran was called *ary*; and the Pleiades *chooa*, a word which means "thousands." The name Aldebaran seems to have been originally applied to the whole of the Hyades group. Aldebaran was also called by the Arabians *al-fanik*, the great Camel, and the Hyades *al-kilas*, the young Camels. The two close stars υ and κ Tauri were called *al-kalbaïn*, the dogs of Aldebaran. La Condamine states that the Indians of the Amazon saw in the Hyades the head of a bull.

Gemini, the Twins, is the third constellation of the Zodiac. It was also called Gemelli, etc. According to Dupuis it represents the 11th "labour of Hercules"—his triumph over the dog Cerberus.[408] But some of Dupuis' ideas seem very fanciful. The Twins are usually called Castor and Pollux, but they were also called by the ancient writers Apollo and Hercules; Jason and Triptolemus; Amphion and Zethus; and Theseus and Peritheus. In Egypt they represented the deities Horus and Hippocrates. Brown thinks that the "Great Twins" were originally the sun and moon, "who live alternately. As one is born the other dies; as one rises the other sets."[409] This applies to the full moon, but does not seem applicable to the other lunar phases.

Gemini was the constellation to which Dante supposed himself transported when he visited the stellar heavens.[410] He says he was born under the influence of this "sign."

Cancer, the Crab, is the next sign of the Zodiac. In the Greek mythology it was supposed to have been placed in the sky by Juno to commemorate the crab which pinched the toes of Hercules in the Lernæan marsh. The Greek name was τυβί. According to Dupuis it represents the 12th "labour of Hercules"—his capture of the golden apples in the Garden of the Hesperides, which were guarded by a Dragon. This Dragon is Draco, which was also called Custos Hesperidum.[411] But the connection between a crab and the myth of the golden apples is not obvious—unless some reference to "crab apples" is intended! Among the Romans, Cancer was consecrated to Mercury, and by the ancient Egyptians to their god Anubis.

The well-known cluster in Cancer called the Præsape, Al-Sufi says, is "a little spot which resembles a cloud, and is surrounded by four stars, two to the west [η and θ Cancri] and two to the east" [γ and δ]. This cluster is mentioned by Aratus, who calls it the "Manger." The word Præsape is often translated "Beehive," but there can be no doubt that it really means

“Manger,” referring to the stars γ and δ Cancri, which the ancients called Aselli, the ass’s colts. These were supposed to represent the asses which in the war of Jupiter against the Giants helped his victory by their braying!

Admiral Smyth says in his *Bedford Catalogue* (p. 202) that he found γ and δ Cancri both of 4th magnitude; but the photometric measures show that δ is now distinctly brighter than γ. An occultation of δ Cancri by the moon is recorded as having occurred on September 3, B.C. 240.

The fine constellation Leo, the Lion, is the next “sign” of the Zodiac, and is marked by the well-known “Sickle.” According to Dupuis, it represents the first “labour of Hercules”—the killing of the Nemælian lion. Manilius called it Nemæus. It was also called Janonus sidus, Bacchi sidus, etc. The Greek name was μεχίρ, μεχείρ, or μεχός. In ancient Egypt, Leo was sacred to Osiris, and many of the Egyptian monuments are ornamented with lions’ heads. It is stated in the Horapolla that its appearance was supposed to announce the annual rising of the Nile.

Regulus (α Leonis) is the brightest and most southern of the stars in the “Sickle.” Al-Sufi says “it is situated in the heart and is of the 1st magnitude. It is that which is called *al-maliki*, the royal star. It is marked on the astrolabe as *kalb al-asad*, the Heart of the Lion” (whence the name Cor Leonis). Modern photometric measures make it about 1·3 magnitude. It has an 8½ magnitude companion at about 177″ distance (Burnham) which is moving through space with the bright star, and is therefore at probably the same distance from the earth as its brilliant primary. This companion is double (8·5, 12·5: 3″·05, Burnham). The spectroscope shows that Regulus is approaching the earth at the rate of 5½ miles a second. Its parallax is very small—about 0″·022, according to Dr. Elkin—which indicates that it is at a vast distance from the earth; and its brightness shows that it must be a sun of enormous size. Ptolemy called it βασιλίσκος, whence its Latin name Regulus, first used by Copernicus as the diminutive of *rex*.[412]

The next constellation of the Zodiac is Virgo, the Virgin. It was also called by the ancients Ceres, Isis, Erigone, Fortuna, Concorda, Astræa, and Themis. The Greek name was φαμένωθ. Ceres was the goddess of the harvest. Brown thinks that it probably represents the ancient goddess Istar, and also Ashtoreth. According to Prof. Sayce it is the same as the Accadian sign of "the errand of Istar, a name due to the belief that it was in August that the goddess Astarte descended into Hades in search of her betrothed, the sun god Tammuz, or Adonis, who had been slain by the boar's tusk."[413] The ear of corn (Spica) is found on the ancient Egyptian monuments, and is supposed to represent the fertility caused by the annual rising of the Nile. According to Aratus, the Virgin lived on earth during the golden age under the name of Justice, but that in the bronze age she left the earth and took up her abode in the heavens.

"Justice, loathing that race of men,
Winged her flight to heaven."

The Sphinx near the Great Pyramid has the head of a virgin on the body of a lion, representing the goddess Isis (Virgo) and her husband Osiris (Leo).

Al-Sufi's 5th star of Virgo is Flamsteed 63 Virginis. Al-Sufi says it is a double star of the 5th magnitude. In Al-Sufi's time it formed a "naked-eye double" with 61 Virginis, but owing to large proper motion, 61 has now moved about 26 minutes of arc towards the south, and no longer forms a double with 63. This interesting fact was first pointed out by Flammarion in his work *Les Étoiles* (p. 373).

Libra, the Balance, is one of the "signs" of the Zodiac, but originally formed the claws of the Scorpion. It was called Juguna by Cicero, and Mochos by Ampelius. The Greek name was φαρμουθέ. Virgil suggests that it represented the justice of the emperor Augustus, honoured by the name of a constellation; but probably this refers to the birth of Augustus under the sign of Libra, as Scaliger has pointed out. According to Brown, "the daily seizing of the dying western sun by the claws of the Scorpion of darkness is reduplicated annually at the Autumnal Equinox, when the feeble waning sun of shortening days falls ever earlier into his enemy's grasp;"[414] and he says, "The Balance or Scales (Libra), which it will be observed is in itself neither diurnal nor nocturnal, is the only one of the zodiacal signs not Euphratean in origin, having been imported from Egypt and representing originally the balance of the sun at the horizon between the upper and under worlds; and secondarily the equality of the days and nights at the equinox."[415]

According to Houzeau, Libra was formed at the beginning of the second century B.C., and it does not appear in any writings before those of Geminus and Varron.[416]

Milton says in *Paradise Lost*:—

> "The Eternal to prevent such horrid fray,
> Hung forth in heaven his golden scales, yet seen
> Betwixt Astræa and the Scorpion's sign."

(Here Astræa is Virgo.)

It is worth noticing that both Ptolemy and Al-Sufi rated the star κ Libræ as two magnitudes brighter than λ Libræ. The two stars are now practically of equal brightness (5th magnitude), and it seems impossible to believe that this could have been the case in Al-Sufi's time. Surely a careful observer like Al-Sufi, who estimated the relative brightness of stars to a third of a magnitude, could not possibly have made an error of two magnitudes in the brightness of two stars near each other! It should be stated, however, that κ Libræ was rated 5th magnitude by Argelander and Heis, and λ, 6th magnitude by the same excellent observers.

The next "sign" of the Zodiac, Scorpion, was consecrated by the Romans to Mars, and by the Egyptians to Typhon.[417] It was called *Nepa* by Cicero, *Martis sidus* by Manilius, and *Fera magna* by Aratus. The Greek name was πάχον.

Mr. E. B. Knobel has called attention to a curious remark of Ptolemy with reference to the bright star Antares (α Scorpii), "Media earum quæ *tendit ad rapinam* quæ dicitur Cor Scorpionis"; and he made a similar remark with reference to Betelgeuse (α Orionis) and others. But Mr. Robert Brown[418] explains the remark by the fact that in ancient times these stars rose in the morning at a time when caravans were exposed to dangers from robbers. Thus the term had nothing to do with the aspect or colour of these stars, but was merely a reference to their supposed astrological influence on human affairs.

In the Egyptian *Book of the Dead*, Silkit was a goddess who assumed the form of a scorpion in the sky. She was supposed to be the daughter of *Ra*.

With reference to stars "outside" the ancient figure of Scorpio, the first, Al-Sufi says, "is a star which immediately follows *al-schaulat*" [λ] and κ, "it is of small 4th magnitude; Ptolemy calls it νεφελοείδης" [nebulous]. Schjelerup, in his translation of Al-Sufi's work, does not identify this object; but it is very evidently γ Telescopii, which lies exactly in the position described by Al-Sufi. Now, it is a very interesting and curious fact that Ptolemy called it nebulous, for in the same telescopic field with it is the nebula *h* 3705 (= Dunlop 557). Dunlop describes it as a "small well-defined rather bright nebula, about 20″ in diameter; a very small star precedes it, but is not involved; following γ Telescopii." Sir John Herschel at the Cape found it fairly resolved into very faint stars, and adds, "The whole *ground* of the heavens, for an immense extent is thickly sown with such stars. A beautiful object."[419] This perhaps accounts for the nebulous appearance of the star as seen by Ptolemy.

Several *novæ* or temporary stars are recorded as having appeared in Scorpio. One in the year B.C. 134 is stated by Pliny to have induced Hipparchus to form his catalogue of stars. This star was also observed in China. Its exact position is unknown, but Flammarion thinks it may possibly have appeared about 4° north of the star β Scorpii. Another new star is said to have appeared in A.D. 393, somewhere in the Scorpion's tail. One in A.D. 1203 and another in 1584 are also mentioned, the latter near π Scorpii.

The constellation Scorpio seems to be referred to by Dante in his *Purgatorio* (ix. 4-6) in the lines—

> "De gemma la sua fronte era lucenta
> Poste in figura del fredda animale
> Che con la coda percota la genta,"

perhaps suggested by Ovid's remark—

> "Scorpius exhibit caudaque menabitur unca."[420]

Next to Scorpio comes Sagittarius, the Archer. It is said to have been placed in the sky as a symbol of Hercules, a hero who was held in the greatest veneration by the ancient Egyptians. The horse, usually associated with this constellation, was a symbol of war. It was also called by the ancients

Chiron, Arcitenens, Minotaurus, Croton, etc. The Greek name was παυνί, or παωνί. Chiron was supposed to be the son of Saturn and Phillyra, and first taught men to ride on horses. The name is derived from the Greek χείρ, a hand. Some writers, however, think that Chiron is represented by the constellation of the Centaur, and others say that Sagittarius represents the Minotaur loved by Persephone. According to Dupuis, Sagittarius represents the 5th "labour of Hercules," which consisted in hunting the birds of the lake Stymphalus, which ravaged the neighbouring countries. These birds are perhaps represented by Cygnus, Altair, and the Vulture (Lyra). The Lyre probably represents the musical instrument which Hercules used to frighten the birds.[421]

According to Al-Sufi, the Arabians called the stars γ, δ, ε, and η Sagittarii which form a quadrilateral figure, "the Ostrich which goes to the watering place," because they compared the Milky Way to a river. They compared the stars σ, φ, τ, and ζ Sagittarii, which form another quadrilateral, to an ostrich which has drunk and returns from the "watering place." He says that the star λ Sagittarii forms with these two "ostriches" a tent, and certainly the figure formed by λ, φ, ζ, ε, and δ is not unlike a tent. Al-Sufi says more about these "ostriches"; but the ideas of the old Arabians about the stars seem very fanciful.

A "temporary star" is recorded in the Chinese Annals of Ma-touan-lin as having appeared in May, B.C. 48, about 4° distant from μ Sagittarii. Another in the year 1011 A.D. appeared near the quadrilateral figure formed by the stars σ, τ, ζ, and φ Sagittarii. This may perhaps be identified with the object referred to by Hepidannus in the year 1012, which was of extraordinary brilliancy, and remained visible "in the southern part of the heavens during three months." Another is mentioned near the same place in A.D. 386 (April to July).[422] The number of "temporary stars" recorded in this part of the heavens is very remarkable.

According to Brown, Sagittarius is depicted on a stone, cir. B.C. 1100, found at Bâbilu, and now in the British Museum.[423]

The next of the "signs of the Zodiac" is Capricornus, the Goat. In the Arabo-Latin edition of Ptolemy's *Almagest* it is called Alcaucurus. It is supposed to represent Amalthea, the goat which nursed Jupiter. According to Dupuis it represented the 6th "labour of Hercules," which was the cleaning out of the Augean stables.[424]

α_2 Capricorni is the northern of two stars of the 4th magnitude (α and β Capricorni). It really consists of two stars visible to the naked eye. The second of these two stars (α_1) is not mentioned by Al-Sufi, but I find that, owing to proper motion, they were nearer together in his time (tenth century), and were evidently seen by him as one star. β Capricorni (about 3rd magnitude) is a very wide double star (3½, 6; 205″), which may be seen with any small telescope. The fainter star was found to be a close double by Burnham. At present β is brighter than α, although rated of the same brightness by Al-Sufi.

Aquarius is the next "sign of the Zodiac." It is supposed to represent a man pouring water out of an urn or bucket. Other names given to this constellation were Aristæus, Ganymede, Cecrops, Amphora, Urna, and Aqua tyrannus. According to Dupuis it represents the 7th "labour of Hercules," which was his victory over the famous bull which ravaged Crete.[425] But the connection between a bull and a bucket is not obvious. Aquarius is represented in several places on the Egyptian monuments. Some of the ancient poets supposed that it represented Deucalion (the Noah of the Greek story of the Deluge); others thought that it represented Cecrops, who came to Greece from Egypt, built Athens, and was also called Bifornis. Others say that he was Ganymede, the cup-bearer of the gods.

There is some difficulty about the identification of some of Al-Sufi's stars in Aquarius. His sixth star (Fl. 7) is nearly 10° south-west of β Aquarii, and is, Al-Sufi says, "the following of three stars in the left hand, and precedes the fourth [β] ... it is of the 6th magnitude. Ptolemy calls it third, but in reality it is very faint" [now about 6th magnitude]. The seventh [μ] is the middle one of the three and about 4½ magnitude, although Al-Sufi calls it "small fifth" [Ptolemy rated it 4]. The eighth star, ε, is the preceding of the three and about 3·8, agreeing closely with Al-Sufi's 4·3. Ptolemy rated it 3. This star is mentioned under the name *nou* in the time of *Tcheou-Kong* in the twelfth century B.C. Al-Sufi says, "These three stars are followed by a star of the 5th magnitude which Ptolemy has not mentioned. It is brighter than the sixth star" [Fl. 7]. This is evidently ν Aquarii. If, however, we plot Ptolemy's positions as given by Al-Sufi, it seems probable that *Ptolemy's* sixth star was really ν, and that either μ or Fl. 7 was not seen by him. As Ptolemy called his seventh star 4th magnitude, and his sixth and eighth stars 3rd magnitude, some considerable change of brightness seems to have taken place in these stars; as ν is now only 4½ and Fl. 7 only a bright sixth. Variation was suspected in Fl. 7[426] by Gould. I found it very reddish with binocular in October, 1892. Burnham found it to be a close double star, the companion being about 12th magnitude at a distance of only 2″. It is probably a binary.

According to Al-Sufi, the Arabians called the second and third stars of the figure (α and ο Aquarii) *sad al-malik* (*malk* or *mulk*), "the Good Fortune of the king." They called the fourth and fifth stars (β and ξ Aquarii) with the twenty-eighth star of Capricornus (*c*) *sad al-sund*, "the Good Fortune of the Happy Events." "This is the 24th mansion of the moon." These stars rose at the time of year when the cold ends, and they set at the time the heat ends. Hence, Al-Sufi says, "when they rise the rains begin, and when they set the unhealthy winds cease, fertility abounds, and the dew falls." Hence probably the Arabic names. This, of course, applies to the climate of Persia and Arabia, and not to the British Isles. Al-Sufi says, "They call the 6th, 7th, and 8th stars *sad bula*, 'The Good Fortune which swallows up!' This is the 23rd mansion of the moon. They say that it is so called because that at the time of the Deluge it rose at the moment when God said, 'O earth! absorb the waters' (Koran, chap, xi., v. 46). They called the stars γ, π, ζ and η Aquarii *sad al-achbija*, 'the the Good Fortune of the tents'; this is the 25th mansion of the moon, and they give them this name because of these four stars, three form a triangle, the fourth [ζ] being in the middle." The three were considered to form a tent.

The Arabians called the bright star Fomalhaut "in the mouth of the southern fish *al-dhifda al-auval*, 'the first Frog,' as the bright one on the southern point of the tail of Kîtus [Cetus] is called *al-dhifda al-tsani* [β Ceti], 'the second Frog.'" Fomalhaut was also called *al-zhalim*, "the male ostrich."

Al-Sufi says, "Some of the Arabians state that a ship is situated to the south of Aquarius." The stars in the Southern Fish (Piscis Australis) seem to be here referred to.

The constellation Pisces, the Fishes, is the last of the "signs of the Zodiac." The Fishes appear on an ancient Greek obelisk described by Pococke. Among the Greeks this sign was consecrated to Venus; and in Egypt to Nepthys, wife of Typhon and goddess of the sea. Pisces is said to end the Zodiac as the Mediterranean Sea terminated Egypt. This idea was suggested by Schmidt, who also conjectured that the Ram (Aries) was placed at the beginning of the Zodiac because Thebes, a town sacred to Jupiter Ammon, was at the beginning of Egypt in ancient times; and he thought that the constellation Triangulum, the Triangle, represented the Nile Delta, Eridanus being the Nile.[427] The constellation was represented in ancient times by two fishes connected by a cord tied to their tails. The southern of these "fishes" lies south of the "Square of Pegasus," and the northern between Andromeda and Aries. According to Manilius, the origin of these fishes is as follows: Venus, seeing Typhon on the banks of the river Euphrates, cast herself with her son into the river and they were transformed into fishes!

Some of the Arabians substituted a swallow for the northern of the two fishes—the one below Andromeda. The swallow was a symbol of Spring. According to Dupuis, Pisces represents the 8th "labour of Hercules," his triumph over the mares of Diomed which emitted fire from their nostrils.[428] But the connection between fishes and mares is not obvious, and some of Dupuis' ideas seem very fanciful. Here he seems to have found a "mare's nest."

The constellation Cetus, the Whale, represents, according to ancient writers, the sea monster sent by Neptune to devour Andromeda when she was chained to the rock. Aratus calls Cetus the "dusky monster," and Brown remarks that "the 'Dusky Star' would be peculiarly appropriate to Mira (the wondrous ο Ceti)."[429] Cetus was also called Canis Tritonis, or Dog of the Sea, Bayer in his Atlas (1603) shows a dragon instead of a whale, finding it so represented on some ancient spheres. Al-Sufi calls it Kîtus or κητος, the whale. He says, "it is represented by the figure of a marine animal, of which the fore part is turned towards the east, to the south of the Ram, and the hinder part towards the west behind the three 'extern' stars of Aquarius."

Al-Sufi does not mention the variable star o Ceti, now called Mira, or the "wonderful," nor does he refer to any star in its immediate vicinity. We may, therefore, conclude that it was near a minimum of light at the time of his observation of the stars of Cetus.

The constellation of Orion, one of the finest in the heavens, was called by Al-Sufi *al-djabbar*, "the Giant," and also *al-djauza*, "the Spouse." The poet Longfellow says—

> "Sirius was rising in the east
> And, slow ascending one by one,
> The kindling constellations shone
> Begirt with many a blazing star
> Stood the great giant Al-gebar
> Orion, hunter of the beast!
> His sword hung gleaming at his side
> And on his arm, the lion's hide—
> Scattered across the midnight air
> The golden radiance of its hair."

Al-Sufi says it "is represented by the figure of a standing man, to the south of the sun's path. This constellation very much resembles a human figure with a head and two shoulders. It is called *al-djabbar*, 'the Giant,' because it has two thrones, holds a club in his hand, and is girded with a sword." Orion is supposed to have been a son of Neptune; but there are many stories of the origin of the name. It is also said to be derived from the Greek word ὥρα, because the constellation was used to mark the different times of the year. According to the ancient fable, Orion was killed by a scorpion, and was placed in the sky at the request of Diana. According to Houzeau, the name comes from *oriri*, to be born. Scorpio rises when Orion sets, and he thinks that the idea of the ancients was that the Scorpion in this way kills the giant Orion.

In ancient Egypt Orion was called *Sahu*. This name occurs on the monuments of the Ptolemies, and also on those of the Pharaohs. It is also mentioned in the *Book of the Dead*. It seems to have been considered of great importance in ancient Egypt, as its heliacal rising announced that of Sirius, which heralded the annual rising of the Nile.

The constellation Eridanus lies south of Taurus, east of Cetus, and west of Lepus. In ancient times it was supposed to represent the Nile or the Po. Ptolemy merely calls it Ποταμοῦ ἀστερισμὸς, or asterism of the river. It was called Eridanus by the Greeks, and Fluvius by the Romans. It appears to correspond with the Hebrew Shicor. Al-Sufi calls it *al-nahr*, "the River."

One of the most interesting points in Al-Sufi's most interesting work is the identity of the bright star known to the ancient astronomers as *achir al-nahr*, "the End of the River," and called by Ptolemy 'Εσχατος τοῦ ποταμοῦ, "the Last in the River." Some astronomers have identified this star with α Eridani (Achernar), a bright southern star of the 1st magnitude, south of Eridanus. But Al-Sufi's description shows clearly that the star he refers to is really θ Eridani; and the reader will find it interesting to follow his description with a star map before him. Describing Ptolemy's 34th star of Eridanus (the star in question), he says, "the 34th star is found before [that is west of] these three stars [the 31st, 32nd, and 33rd, which are υ^2, Du, and υ′ in Proctor's Atlas], the distance between it and that of the three which is nearest being about 4 cubits [9° 20′]. It is of the first magnitude; it is that which is marked on the southern astrolabe, and called *achir al-nahr*, 'the End of the River.' There are before this bright one two stars, one to the south, [σ Eridani, not shown in Proctor's small Atlas], the other to the north [ι Eridani]; Ptolemy does not mention these. One of these stars is of the 4th magnitude, the other of the 5th. There is behind the same [that is, east of it] a star of the 4th magnitude distant from it two cubits [ε Eridani]. To the south of the three stars which follow the bright one there are some stars of the 4th and 5th magnitudes, which he [Ptolemy] has not mentioned."

Now, a glance at a star map of this region will show clearly that the bright star referred to by Al-Sufi is undoubtedly θ Eridani, which is therefore the star known to the ancients as the "End of the River," or the "Last in the River."

The position given by Ptolemy agrees fairly well with Al-Sufi's description, although the place is slightly erroneous, as is also the case with Fomalhaut and β Centauri. It is impossible to suppose that either Ptolemy or Al-Sufi could have seen α Eridani, as it is too far south to be visible from their stations, and, owing to the precession of the equinoxes, the star was still further south in ancient times. Al-Sufi says distinctly that the distance between Ptolemy's 33rd star (which is undoubtedly *h* Eridani, or Proctor's υ′) and the 34th star was "4 cubits," or 9° 20′. The actual distance is about 9° 11′, so that Al-Sufi's estimate was practically correct. Halley, in his *Catalogus Stellarium Australium*, identifies Ptolemy's star with θ Eridani, and Baily agreed with him.[430] Ulugh Beigh also identifies the "Last in the River" with θ Eridani. The Arabic observer Mohammed Ali Achsasi, who observed in the seventeenth century, called θ Eridani *Achr al-nahr*, and rated it first magnitude.[431] To argue, as Bode and Flammarion have done, that Ptolemy and Al-Sufi may have heard of α Eridani from travellers in the southern hemisphere, is to beg the whole question at issue. This is especially true with reference to Al-Sufi, who says, in the preface to his work, that he has described the stars "as seen with my own eyes." α Eridani is over 11 "cubits" from *h* Eridani instead of "4 cubits" as Al-Sufi says. This shows conclusively that the star seen by Al-Sufi was certainly *not* α Eridani. The interest of the identification is that Al-Sufi rated θ Eridani of the *first* magnitude, whereas it is now only 3rd magnitude! It was measured 3·06 at Harvard and estimated 3·4 by Stanley Williams, so that it has evidently diminished greatly in brightness since Al-Sufi's time. There is an interesting paper on this subject by Dr. Anderson (the discoverer of Nova Aurigæ and Nova Persei) in *Knowledge* for July, 1893, in which he states that the "Last in the River," according to the statements of Hipparchus and Ptolemy, *did* rise above their horizon at a certain time of the year, which α Eridani could not possibly have done. This seems sufficient to settle the question in favour of θ Eridani. Dr. Anderson says, "It is much to be regretted that Professor Schjellerup, the able and industrious translator of Sufi, has allowed this to escape his notice, and helped in the preface and note to his work to propagate the delusion that α Eridani is Ptolemy's 'Last in the River'"; and in this opinion I fully concur. Al-Sufi's clear account places it beyond a doubt that the star known to Hipparchus, Ptolemy, Al-Sufi, and Ulugh Beigh as the "Last in the River" was θ Eridani. θ must have diminished greatly in brightness since Al-Sufi's time, for in ranking it as 1st magnitude he placed it in a very select list. He only rated thirteen stars in the whole heavens as being of the 1st magnitude. These are: Arcturus, Vega, Capella, Aldebaran, Regulus, β Leonis, Fomalhaut, Rigel, θ Eridani, Sirius, Procyon, Canopus, and α Centauri. *All* these stars were actually *seen* by Al-Sufi, *and described from his own observations*. He does not mention α Eridani, as it was not visible from his station in Persia.

θ Eridani is a splendid double star (3·40, 4·49: 8″·38, 1902, Tebbutt). I found the components white and light yellow with 3-inch refractor in the Punjab. Dr. Gould thinks that one of the components is variable to some extent. This is interesting, considering the brilliancy of the star in Al-Sufi's time. The brighter component was found to be a spectroscopic binary by Wright, so that on the whole the star is a most interesting object.

The small constellation Lepus, the Hare, lies south of Orion. Pliny calls it Dasypus, and Virgil Auritus. In ancient Egypt it was the symbol of vigilance, prudence, fear, solitude, and speed.[432] It may perhaps represent the hare hunted by Orion; but some say it was placed in the sky to commemorate a terrible plague of hares which occurred in Sicily in ancient times.

A little north-west of the star μ Leporis is Hind's "crimson star" (R.A. 4^h 53^m, S. 14° 57′, 1900) described by him as "of the most intense crimson, resembling a blood drop on the background of the sky; as regards depth of colour, no other star visible in these latitudes could be compared with it." It is variable from about the 6th to the 8th magnitude, with a period of about 436 days from maximum to maximum.

The constellation Canis Major, the Great Dog, is remarkable for containing Sirius, the brightest star in the heavens. In the Greek mythology it was supposed to represent a dog given by Aurora to Cephalus as the swiftest of all dogs. Cephalus wished to match it against a fox which he thought surpassed all animals for speed. They both ran for so long a time, so the story goes, that Jupiter rewarded the dog by placing it among the stars. But probably the dog comes from Anubis, the dog-headed god of the ancient Egyptians. According to Brown, Theogirius (B.C. 544) refers to the constellation of the Dog.[433] He thinks that Canis Major is probably "a reduplication" of Orion; Sirius and β Canis Majoris corresponding to α and γ Orionis; δ, 22, and ε Canis Majoris to the stars in Orion's belt (δ, ε, and ζ Orionis); and η; and κ Canis Majoris with κ and β Orionis.[434]

The Arabic name of Sirius was *al-schira*, which might easily be corrupted into Sirius. The Hebrew name was Sihor. According to Plutarch, the Ethiopians paid regal honours to the Celestial Dog. The Romans used to sacrifice a dog in its honour at the fetes called Robigalia, which were held on the seventh day before the Calends of May, and nine days after the entry of the sun into Taurus. Pliny says, “Hoc tempus Varro determinat sole decimam partem Tauri obtinenti quod canis occidit, sidus per se vehemens,” etc.[435]

Owing to some remarks of Cicero, Horace, and Seneca, it has been supposed that in ancient times Sirius was of red colour. Seneca says, “Nec mirum est, si terra omnis generis et varia evaporatio est; quam in cœlo quoque non unus appareat color rerum, sed acrior sit Caniculæ rubor, Nartis remissior, Jovis nullus, in lucem puram nitore perducto.”[436] It is now brilliantly white with a bluish tinge. But this change of colour is somewhat doubtful. The remarks of the ancient writers may possibly refer to its great brilliancy rather than its colour. Al-Sufi says nothing about its colour, and it was probably a white star in his time. If it were red in his day he would most probably have mentioned the fact, as he does in the case of several red stars. Brown, however, quotes the following from Ibn Alraqqa, an Arabian observer:—

> “I recognize Sirius *shining red*, whilst the morning is becoming white.
> The night fading away, has risen and left him,
> The night is not afraid to lose him, since he follows her.”

Schjellerup thinks that it is very doubtful that Sirius was really red as seen by Hipparchus and Ptolemy. But in an exhaustive inquiry made by Dr. See on the supposed change of colour,[437] he comes to the conclusion that Sirius was really red in ancient times. Seneca states distinctly that it was redder than Mars (see extract above), and other ancient writers refer to its red colour. It has been generally supposed that the Arabian astronomer Alfraganus, in his translation of Ptolemy’s *Almagest*, refers to only five red stars observed by Ptolemy, namely, Arcturus, Aldebaran, Betelgeuse, Antares, and Pollux. But Dr. See shows that this idea is due to a mistranslation of Alfraganus by Plato Tibertinus in 1537, and that Ptolemy did not speak of “five red stars,” but five *nebulous* stars, as stated by Christmann and Golius. Ptolemy described Sirius as ὑπόκιρρος, “fiery red,” the same word used with reference to the other stars mentioned above. The change of colour, if any, probably took place before Al-Sufi’s time.

Dr. See says—

“Prof. Newcomb rejects the former well-authenticated redness of Sirius, because he cannot explain the fact. But the ink was scarcely dry on his new book on the stars, in which he takes this position, when Nova Persei blazed forth in 1901; and observers saw it change colour from day to day and week to week. Could any one explain the cause of these numerous and conspicuous changes of colour? Shall we, then, deny the changes of colour in Nova Persei, some of which were noticed when it was nearly as bright as Sirius?”[438]

On the ceiling of the Memnonium at Thebes the heliacal rising of Sirius is represented under the form and name of Isis. The coincidence of this rising with the annual rising of the Nile is mentioned by Tibullus and Aclian. About 4000 B.C. the heliacal rising of Sirius coincided with the summer solstice (about June 21) and the beginning of the rising of the Nile. The festival in honour of this event was held by the Egyptians about July 20, and this marked the beginning of the sacred Egyptian year. On the summit of Mount Pelion in Thessaly there was a temple dedicated to Zeus, where sacrifices were offered at the rising of Sirius by men of rank who were chosen for the purpose by the priests and wore fresh sheepskins.

Sirius seems to have been worshipped by the ancient Egyptians under the name of Sothis, and it was regarded as the star of Isis and Osiris. The last name without the initial O very much resembles our modern name.

According to Al-Sufi, the Arabians called Sirius *al-schira al-abûr*, “Sirius which has passed across,” also *al-schira al Jamânija*, “the Sirius of Yémen.” He says it is called *al-abûr*, “because it has passed across the Milky Way into the southern region.” He relates a mythological story why Sirius “fled towards the south” and passed across the Milky Way towards Suhail (Canopus). The same story is told by Albufaragius[439] (thirteenth century). (The story was probably derived from Al-Sufi.) Now, it seems to me a curious and interesting fact that the large proper motion of Sirius would have carried it across the Milky Way from the eastern to the western border in a period of 60,000 years. Possibly the Arabian story may be based on a tradition of Sirius having been seen on the opposite, or eastern, side of the Milky Way by the men of the early Stone Age. However this may be, we know from the amount and direction of the star’s proper motion that it must have passed across the Milky Way from east to west within the period above stated. The Arabic name *al-abûr* is not, therefore, a merely fanciful one, but denotes an *actual fact*. The proper motion of Sirius could not possibly have been known to the ancients, as it was only revealed by accurate modern observations.

The little constellation Canis Minor, the Little Dog, lies south of Gemini and Cancer. Small as it is, it was one of the original forty-eight constellations of Ptolemy. In the Greek mythology it was supposed to represent either one of Diana's hunting dogs, or one of Orion's hounds. Ovid calls it the dog of Icarus. Others say it was the dog of Helen, who was carried off by Paris. According to the old poets, Orion's dog, or the dog of Icarus, threw himself into a well after seeing his master perish. The name Fovea, given to the constellation by Bayer, signifies a pit where corn was deposited. This comes from the fact that the rising of the star Procyon (α Canis Minoris) indicated the season of abundance. But Lalande thought it more probable that the idea of a pit came from the Greek σειρὸς, which means a corn store, and that it was confounded with Sirius.

The name of the bright star Procyon (α Canis Minoris) is derived from the Greek προκύων, "the advanced day," because it appeared in the morning sky before Sirius. Procyon was called by the Hindoos Hanouman after their famous monkey god, from whose tail a bridge is said to have been formed to enable the army of Rama to pass from India to Ceylon. Al-Sufi says that the star was marked on the old astrolabes as *al-schira al-schamia*, "the Syrian Sirius." It was also called, he says, *al-schira al-gumaisa*, "the Sirius with blear eyes" (!) from weeping because Sirius had passed across the Milky Way, Procyon remaining on the eastern side. Here we have the same legend again. The proper motion of Procyon (about the same in amount and direction as that of Sirius) shows that the star has been on the eastern side of the Milky Way for many ages past. About 60,000 years hence, Procyon will be near the star θ Canis Majoris, and will then—like Sirius—have passed across the Milky Way.

Argo, the Ship, is a large constellation south of Hydra, Monoceros, and Canis Major. It is called by Al-Sufi *al-safîna*, "the Ship." It is supposed to represent the first ship ever built. The name is derived from the builder Argo, or from the Greek word 'Αργὸς. This ship is said to have been built in Thessaly by order of Minerva and Neptune, to go on the expedition for the conquest of the golden fleece. The date of this expedition, commanded by Jason, is usually fixed at 1300 or 1400 B.C. With reference to the position of this supposed ship in the sky, Proctor says, "It is noteworthy that when we make due correction for the effects of precession during the past 4000 years, the old constellation Argo is set on an even keel, instead of being tilted some 45° to the horizon, as at present when due south." He connects Argo with Noah's Ark.

The brightest star of Argo is Canopus, called Suhaïl by Al-Sufi. It is the second brightest star in the heavens; but it is not visible in northern latitudes. The Harvard photometric measures make it nearly one magnitude brighter than the zero magnitude, about two magnitudes brighter than Aldebaran, and about half the brightness of Sirius. This fine star has been suspected of variable light. Webb says, "It was thought (1861) in Chili brighter than Sirius." Observing it in the Punjab, the present writer found it on several occasions but little inferior to Sirius, although very low on the southern horizon. From recent observations by Mr. H. C. McKay in Australia, he believes that it is variable to the extent of at least half a magnitude.[440] But it is difficult to establish variations of light in very bright stars. The parallax of Canopus is *very* small, so its distance from the earth is very great, and it must be a sun of gigantic size. According to Al-Fargani, Canopus was called the star of St. Catherine by the Christian pilgrims in the tenth century.[441] It was called Suhaïl by the old Arabians, a name apparently derived from the root *sahl*, "a plain"; and Schjellerup suggests that the name was probably applied to this and some other southern stars because they seem to move along a plain near the southern horizon. Al-Sufi says that he measured the latitude of Schiraz in Persia, where he observed, and found it to be 29° 36′; and hence for that place Canopus, when on the meridian, had an altitude of about 9°. Canopus was the ancient name of Aboukir in Egypt, and is said to have derived its name from the pilot of Menelaus, whose name was Kanobus, and who died there from the bite of a snake. The star is supposed to have been named after him, and it was worshipped by the ancient Egyptians.

Al-Sufi does not mention the famous variable star η Argûs, which, owing to the precession of the equinoxes, he might possibly have seen *close to the horizon*, if it had been a bright star in his day. It lies between φ Velorum and α Crucis. Both of these stars are mentioned by Al-Sufi, but he says nothing of any bright star (or indeed any star) between them. This negative evidence tends to show that η Argûs was not visible to the naked eye in Al-Sufi's time. This extraordinary star has in modern times varied through all degrees of brightness from Sirius down to the 8th magnitude! Schönfeld thought that a regular period is very improbable. It seems to be a sort of connecting link between the long period variables and the *novæ* or temporary stars. It is reddish in colour, and the spectrum of its light is very similar to that of the temporary stars. Whether it will ever become a brilliant object again, time alone can tell; but from the fact that it was presumably faint in Al-Sufi's time, and afterwards increased to the brightness of Sirius, it seems possible that its light may again revive.

The long constellation Hydra lies south of Cancer, Leo, Crater, Corvus, Virgo, and Libra. It was also called Asina, Coluber, Anguis, Sublimatus, etc. In the Greek mythology it was supposed to represent the Lernæan serpent killed by Hercules. According to Ovid, who fixed its acronycal rising for February 14, it had a common origin with Corvus and Crater. Apollo, wishing to sacrifice to Jupiter, sent the Crow with a cup to fetch water. On his way to the well the Crow stopped at a fig tree and waited for the fruit to ripen! Afterwards, to excuse his delay, he said that a serpent had prevented him from drawing the water. But Apollo, to punish the Crow for his deception, changed his plumage from white to black, and ordered the serpent to prevent the Crow from drinking.[442] Hydra was called by Al-Sufi *al-schudja*, "the Serpent, or Hydra." He says that "it contains twenty-five stars in the figure and two 'outside', and its head is to the south of the southern scale of the Balance" (α Libræ). But this is clearly a mistake (one of the very few errors to be found in Al-Sufi's work), for he goes on to say that the head is composed of four stars forming a figure like the head of a horse, and he adds, "This head is in the middle between *al-shira al-gumaisa* [Procyon] and *Kalb al-asad* [Regulus] the Heart, inclining from these two stars a little to the south." This clearly indicates the stars δ, ε, η, and σ Hydræ which, with ζ Hydræ, have always been considered as forming the Hydra's head. These stars lie south of α and β Cancri, not south of Libra as Al-Sufi says (doubtless by a slip of the pen).

Ptolemy's 12th star of Hydra (α Hydræ) is, Al-Sufi says, "the bright red star which is found at the end of the neck where the back begins; it is of the 2nd magnitude. It is that which is marked on the astrolabe as *unk al-schudja*, ‘the neck of the serpent,’ also *al-fard*, ‘the solitary one.’” Al-Sufi’s estimate of its brightness agrees well with modern measures; but it has been suspected of variable light. Sir John Herschel’s estimates at the Cape of Good Hope varied from 1·75 to 2·58 magnitude. He thought that its apparent variation might be due to its reddish colour, and compares it to the case of α Cassiopeiæ. But as this latter star is now *known* to be irregularly variable it seems probable that α Hydræ may be variable also. Gemmill found it remarkably bright on May 9, 1883, when he thought it nearly equal to Pollux (1·2 magnitude). On the other hand, Franks thought it nearer the 3rd than the 2nd magnitude on March 2, 1878. On April 9, 1884, the present writer found it only slightly less than Regulus (1·3 magnitude). On April 6, 1886, how-ever, it was considerably less than Regulus, but half a magnitude brighter than β Canis Minoris, or about 2½ magnitude. In the Chinese Annals it is called the “Red Bird.” In a list of thirty stars found on a tablet at Birs-Nimroud, it is called “The son of the supreme temple.” Although to the naked eye deserving the name of Alphard or “the solitary one,” it is by no means an isolated star when examined with a telescope. It has a faint and distant companion, observed by Admiral Smyth; and about 25′ to the west of it Ward saw a small double star (8, 13: 90°: 50″). With a 3-inch refractor in the Punjab, I saw a small star of about 8½ magnitude to the south and a little east of the bright star, probably identical with Smyth’s companion. Farther off in the same direction I saw a fainter star, and others at greater distances in the field. There is also a faint star a little to the north. I also saw Ward’s double with the 3-inch telescope.

There is some difficulty in identifying the stars numbered by Ptolemy 13, 14, and 15 in Hydra. Having plotted a map from Ptolemy’s positions (as given by Al-Sufi), I have come to the conclusion that Ptolemy’s stars are 13 = κ Hydræ; 14 = υ; and 15 = λ Hydræ, probably. From the clear description given by Al-Sufi of the stars observed by *him*, I find that *his* stars are 13 = υ_1; 14 = υ_2; and 15 = λ Hydræ. We must, therefore, conclude that Ptolemy and Al-Sufi saw only three stars where now there are four,[443] and that κ Hydræ was not seen, or at least is not mentioned by Al-Sufi. κ is, therefore, probably variable. It was rated 4 by Tycho Brahé, Bayer, and Hevelius; it is at present about 5th magnitude. If Ptolemy did not see υ_2 it is probably variable also, and, indeed, it has been suspected of variable light.[444]

The small constellation of Crater, the Cup, lies north of Hydra, and south of Leo and Virgo. Al-Sufi calls it *al-batija*, "the Jar, or Cup." He says the Arabians called it *al-malif*, "the Crib, or Manger." According to Brown, the stars of Crater exactly form a Bakhian κάνθαρος, with its two handles rising above the two extremities of the circumference.[445] An Asia Minor legend "connected Crater with the mixing of human blood with wine in a bowl." Crater is referred to by Ovid in the lines—

> "Dixit et antiqui monumenta perennia facti
> Anguis, Avis, Crater sidera, juncta micunt."

The star α Crateris was rated 4th magnitude by Al-Sufi and all other observers, and the Harvard measures make it 4·20, a satisfactory agreement. It has three companions noted by Admiral Smyth. One of these he called "intense blood colour." This is R Crateris, now known to be variable from above the 8th magnitude to below the 9th. Sir John Herschel called it an "intense scarlet star, a curious colour." With 3-inch refractor in the Punjab I found it "full scarlet." It is one of an open pair, the further of the two from α. There is a third star about 9th magnitude a little south of it. Ward saw a 13th magnitude star between α and R with a 2⅞-inch (Wray) refractor. This I saw "readily" with my 3-inch. Smyth does not mention this faint star, although he used a much larger telescope.

Corvus, the Crow, is a small constellation, north of Hydra. Aratus says "the Crow form seems to peck the fold of the water snake" (Hydra). The victory which Valerius Corvinus is said to have owed to a crow has given it the name of Pomptina, because the victory took place near the Pontine marshes.[446] A quadrilateral figure is formed by its four brightest stars, γ, δ, β, and ε Corvi. This figure has sometimes been mistaken for the Southern Cross by those who are not familiar with the heavens. But the stars of the Southern Cross are much brighter.

The constellation Centaurus, the Centaur, lies south of Hydra and Libra, and north of the Southern Cross. According to Dupuis, Centaurus represents the 3rd "labour of Hercules," his triumph over the Centaurs.[447] The Centaurs were supposed to be a people living in the vicinity of Mount Ossa, who first rode on horses. The constellation was also called Semivir, Chiron, Phobos, Minotaurus, etc. Al-Sufi says it "is represented by the figure of an animal, of which the forepart is the upper part of a man from the head to end of the back, and its hinder part is the hinder part of a horse, from the beginning of the back to the tail. It is to the south of the Balance [Libra] turning its face towards the east, and the hinder part of the beast towards the west."

Al-Sufi describes very clearly the four bright stars of the famous "Southern Cross." Owing to precession these stars were some 7° further north in the tenth century than they are at present, and they could have been all seen by Al-Sufi, when on the meridian. In the time of Ptolemy and Hipparchus, they were still further north, and about 5000 years ago they were visible in the latitude of London. Dante speaks of these four stars as emblematical of the four cardinal virtues, Justice, Temperance, Fortitude, and Prudence.

Closely south-east of α and β Crucis is the dark spot in the Milky Way known as the "Coal Sack," which forms such a conspicuous object near the Southern Cross. It was first described by Pinzon in 1499; and afterwards by Lacaille in 1755. Although to the naked eye apparently black, photographs show that it contains many faint stars, but, of course, much less numerous than in the surrounding regions. The dark effect is chiefly caused by contrast with the brilliancy of the Milky Way surrounding it.

Al-Sufi also mentions the bright stars α and β Centauri which follow the Southern Cross. He says that the distance between them "is four cubits," that is about 9° 20′, but it is less than this now. α has a large "proper motion" of 3″·67 per annum, and was farther from β in Al-Sufi's time than it is at present. This, however, would not *wholly* account for the difference, and Al-Sufi's over-estimate is probably due to the well-known effect by which the distance between two stars is *apparently* increased when they are near the horizon. Several of Al-Sufi's distances between southern stars are over-estimated, probably for the same reason.

The constellation Lupus, the Wolf, is south of Libra and Scorpio. It lies along the western border of the Milky Way. According to ancient writers it represents Lycaon, King of Arcadia, a contemporary of Cecrops, who is said to have sacrificed human victims, and on account of his cruelty was changed into a wolf. Another fable is that it represents a wolf sacrificed by the Centaur Chiron. According to Brown, Lupus appears on the Euphratian planisphere discovered by George Smyth in the palace of Sennacherib. Al-

Sufi called it *al-sabu*, “the Wild Beast.” It was also called *al-fand*, “the Leopard,” and *al-asada*, “the Lioness.”

Ara, the Altar, lies south of Scorpio. According to ancient writers it represents an altar built by Vulcan, when the gods made war against the Titans. It is called by Al-Sufi *al-midjman*, “the Scent Box,” or “the Altar.”

The little constellation Corona Australis, the Southern Crown, lies south and west of Sagittarius, east of Scorpio, and west of Telescopium. Aratus refers to the stars in Corona Australis as—

> “Other few
> Before the Archer under his forefeet
> Led round in circle roll without a name.”[449]

But the constellation was known by the names Caduceus, Orbiculus, Corona Sagittarii, etc. The ancient poets relate that Bacchus placed this crown in the sky in honour of his mother Semele.[450] Others say that it represents the crown conferred on Corinne of Thebes, famous as a poet.

The small constellation Piscis Australis, or the Southern Fish, lies south of Capricornus and Aquarius. In the most ancient maps it is represented as a fish drinking the water which flows from the urn of Aquarius.

A good many constellations have been added to the heavens since the days of Al-Sufi, and notes on some of these may be of interest.

Camelopardalis.—This constellation first appears on a celestial planisphere published by Bartschius in the year 1624. It was not formed by Bartschius himself, but by the navigators of the sixteenth century. It lies south of Ursa Minor, north of Perseus and Auriga, east of Draco, and west of Cassiopeia. It contains no star brighter than the 4th magnitude.

Lynx.—This constellation is south of Camelopardalis and Ursa Major, and north of Gemini and Cancer. It was formed by Hevelius in 1660, and he called it the Lynx, because, he said, it contained only faint stars and “it was necessary to have the eyes of a lynx” to see them! Some of them were, however, observed by Ptolemy and Al-Sufi, and are mentioned by the latter under Ursa Major.

Canes Venatici, or the Hunting Dogs.—This was formed by Hevelius in 1660. It lies south of the Great Bear's tail, north of Coma Berenices, east of Ursa Major, and west of Boötis. Its brightest stars α (12) and β (8) were observed by Al-Sufi, and included by him in the "extern" stars of Ursa Major.

Coma Berenices.—This constellation lies between Canes Venatici and Virgo. Although it was not included among the old forty-eight constellations of Ptolemy, it is referred to by Al-Sufi as the Plat, or Tress of Hair, and he included its stars Flamsteed 12, 15, and 21 in the "extern" stars of Leo. It was originally formed by the poet Callimachus in the third century b.c., but was not generally accepted until reformed by Hevelius. Callimachus lived at Alexandria in the reigns of Ptolemy Philadelphus and Ptolemy Euergetes, and was chief librarian of the famous library of Alexandria from about b.c. 260 until his death in b.c. 240. Eratosthenes was one of his pupils. The history of the constellation is as follows: Berenice, wife of Ptolemy Euergetes, made a vow, when her husband was leaving her on a military expedition, that if he returned in safety she would cut off her hair and consecrate it in the temple of Mars. Her husband returned, and she fulfilled her vow. But on the next day the hair had disappeared—stolen from the temple—and Conon the mathematician showed Ptolemy seven stars near the constellation of the Lion which did not belong to any constellation. These were formed into a constellation and called Berenice's Hair. Conon is referred to by Catullus in the lines—

"Idem me ille Conon cœleste numine vidit
E. Berenico vertice Cæsariem."

Coma Berenices first occurs as a distinct constellation in the catalogue contained in the Rudolphine Tables formed by Kepler (epoch 1600) from the observations of Tycho Brahé.[451] Bayer substituted a sheaf of corn, an idea derived from an ancient manuscript.

Leo Minor.—This small constellation lies between Ursa Major and Leo, and east of the Lynx. It was formed by Halley about the year 1660; but is referred to by Al-Sufi, who includes one of its stars (Fl. 41) in the "extern" stars of Leo. There are, however, several brighter stars in the group. The brightest, Fl. 46, was measured 3·92 at Harvard. The star Fl. 37 was called *præcipua* (or brightest) by Tycho Brahé, and rated 3, but as it was measured only 4·77 at Harvard it may possibly have diminished in brightness.

Sextans.—This constellation lies south of Leo, and north and east of Hydra. It was formed by Hevelius about the year 1680. According to the Harvard photometric measures its brightest star is Fl. 15 (4·50).

Monoceros, or the Unicorn, lies south of Gemini and Canis Minor, north of Canis Major and Argo, east of Orion, and west of Hydra. It appears on the planisphere of Bartschius, published in 1624. According to Scaliger it is shown on an old Persian sphere. One of its stars, Fl. 22, is mentioned by Al-Sufi among the "extern" stars of Canis Major (No. 1). Another, Fl. 30, is given under Hydra ("Extern" No. 1) and Fl. 8, 13, and 15 are apparently referred to in Gemini. The star 15 Monocerotis is a little south of ξ Geminorum, and was measured 4·59 magnitude at Harvard. It was at one time supposed to be variable with a short period (about 3½ days), but this variation has not been confirmed. The spectrum is of the fifth type—with bright lines—a very rare type among naked-eye stars. It is a triple star (5, 8·8, 11·2: 2″·9, 16″·3) and should be seen with a 4-inch telescope. It has several other small companions, one of which (139°·2: 75″·7) has been suspected of variation in light. It was estimated 8½ by Main in 1863, but only 12 by Sadler in 1875. Observing it on March 28, 1889, with 3-inch refractor, I found it about one magnitude brighter than a star closely preceding, and estimated it 8 or 8½ magnitude. It is probably variable and should be watched.

Scutum Sobieski.—This is, or was, a small constellation in the southern portion of Aquila, which was formed by Hevelius in 1660 in honour of the Polish hero Sobieski. Its principal stars, which lie south-west of λ Aquilæ, were mentioned by Al-Sufi and are referred to by him under that constellation. It contains a very bright spot of Milky Way light, which may be well seen in the month of July just below the star λ Aquilæ. Closely south of the star 6 Aquilæ is a remarkable variable star R Scuti (R.A. 18^h 42^m·2, S. 5° 49′). It varies from 4·8 to 7·8 with an irregular period. All the light changes can be observed with a good opera-glass.

Vulpecula, the Fox.—This modern constellation lies south of Cygnus, north of Sagitta and Delphinus, east of Hercules, and west of Pegasus. It was formed by Hevelius in 1660. One of its stars, 6 Vulpeculæ, is mentioned by Al-Sufi in describing the constellation Cygnus. Closely north-west of 32 Vulpeculæ is the short-period variable T Vulpeculæ. It varies from 5·5 to 6·2 magnitude, and its period is 4·436 days. This is an interesting object, and all the changes of light can be observed with an opera-glass.

Lacerta.—This little constellation lies south of Cepheus and north of Pegasus. Its formation was first suggested by Roger and Anthelm in 1679, and it was called by them "The Sceptre and the Hand of Justice." It was named Lacerta by Hevelius in 1690, and this name it still retains. Al-Sufi seems to refer to its stars in his description of Andromeda, but does not mention any star in particular. It brightest star Fl. 7 (α Lacertæ) is about the 4th magnitude. About one degree south-west of 7 is 5 Lacertæ, a deep orange star with a blue companion in a fine field.

There are some constellations south of the Equator which, although above Al-Sufi's horizon when on the meridian, are not described by him, as they were formed since his time. These are as follows:—

Sculptor.—This constellation lies south of Aquarius and Cetus, and north of Phœnix. Some of its stars are referred to by Al-Sufi under Eridanus as lying within the large triangle formed by β Ceti, Fomalhaut, and α Phœnicis. The brightest star is α, about 12° south of β Ceti (4·39 magnitude Harvard). About 7° south-east of α is the red and variable star R Sculptoris; variable from 6·2 to 8·8 magnitude, with a period of about 376 days. Gould describes it as "intense scarlet." It has a spectrum of the fourth type.

Phœnix.—This constellation lies south of Sculptor. Some of its stars are referred to by Al-Sufi, under Eridanus, as forming a boat-shaped figure. These are evidently α, κ, μ, β, ν, and γ. α is at the south-eastern angle of Al-Sufi's triangle referred to above (under "Sculptor"). (See Proctor's Atlas, No. 3.)

Fornax, the Furnace, lies south of Cetus, west of Eridanus, and east of Sculptor and Phœnix. It was formed by Lacaille, and is supposed to represent a chemical furnace with an alembic and receiver! Its brightest star, α Fornacis, is identical with 12 Eridani.

Cælum, the Sculptor's Tools, is a small constellation east of Columba, and west of Eridanus. It was formed by Lacaille. The brightest stars are α and γ, which are about 4½ magnitude. α has a faint companion; and γ is a wide double star to the naked eye.

Antlia, the Air Pump, lies south of Hydra, east and north of Argo, and west of Centaurus. It was formed by Lacaille. It contains no star brighter than 4th magnitude. The brightest, α, has been variously rated from 4 to 5, and Stanley Williams thinks its variability "highly probable."

Norma, the Rule, lies south of Scorpio. It contains no star brighter than the 4th magnitude.

Telescopium.—This modern constellation lies south of Corona Australis, and north of Pavo. Its stars α, δ, and ζ, which lie near the northern boundary of the constellation, are referred to by Al-Sufi in his description of Ara.

Microscopium.—This small constellation is south of Capricornus, and west of Piscis Australis. Its stars seem to be referred to by Al-Sufi as having been seen by Ptolemy, but he does not specify their exact positions. It contains no star brighter than 4½ magnitude.

South of Al-Sufi's horizon are a number of constellations surrounding the south pole, which, of course, he could not see. Most of these have been formed since his time, and these will now be considered; beginning with that immediately surrounding the South Pole (Octans), and then following the others as nearly as possible in order of Right Ascension.

Octans.—This is the constellation surrounding the South Pole of the heavens. There is no bright star near the Pole, the nearest visible to the naked eye being σ Octantis, which is within one degree of the pole. It was estimated 5·8 at Cordoba. The brightest star in the constellation is ν Octantis (α, Proctor), which lies about 12 degrees from the pole in the direction of Indus and Microscopium. The Harvard measure is 3·74 magnitude.

HYDRUS, the Water-Snake, is north of Octans in the direction of Achernar (α Eridani). The brightest star is β, which lies close to θ Octantis. The Harvard measure is 2·90. Gould says its colour is "clear yellow." It has a large proper motion of 2″·28 per annum. Sir David Gill found a parallax of 0″·134, and this combined with the proper motion gives a velocity of 50 miles a second at right angles to the line of sight. γ Hydri is a comparatively bright star of about the 3rd magnitude, about 15½ degrees from the South Pole. It is reddish, with a spectrum of the third type.

HOROLOGIUM, the Clock, is north of Hydra, and south of Eridanus. Three of its stars, α, δ, and ψ, at the extreme northern end of the constellation, seem to be referred to by Al-Sufi in his description of Eridanus, but he does not give their exact positions. Most of the stars forming this constellation were below Al-Sufi's horizon.

RETICULUM, the Net, is a small constellation to the east of Hydrus and Horologium. The brightest star of the constellation is α (3·36 Harvard, 3·3 Cordoba, and "coloured").

DORADO, the Sword Fish, lies east of Reticulum and west of Pictor. It contains only two stars brighter than the 4th magnitude. These are α (3·47 Harvard) and β (3·81 Harvard, but suspected of variation). About 3° east of α Reticuli is the variable star R Doradus. It varies from 4·8 to 6·8, and its period is about 345 days. Gould calls it "excessively red." It may be followed through all its fluctuations of light with an opera-glass.

MENSA, or Mons Mensa, the Table Mountain, lies between Dorado and the South Pole, and represents the Table Mountain of the Cape of Good Hope. It contains no star brighter than the 5th magnitude.

PICTOR, the Painter's Easel, lies north of Doradus, and south of Columba. It contains no very bright stars, the brightest being α (3·30 Harvard).

VOLANS, the Flying Fish, is north of Mensa, and south and west of Argo. Its brighter stars, with the exception of α and β, form an irregular six-sided figure. Its brightest star is β (3·65) according to the Harvard measures. The

Cordoba estimates, however, range from 3·6 to 4·4, and Gould says its colour is “bright yellow.” Williams rated it 3·8.

Chamælion.—This small constellation lies south of Volans, and north of Mensa and Octans. None of its stars are brighter than the 4th magnitude, its brightest being α (4·08 Harvard) and γ (4·10).

Argo.—This large constellation extends much further south than Al-Sufi could follow it. The most southern star he mentions is ε Carinæ, but south of this are several bright stars. β Carinæ is 1·80 according to the Harvard measures; υ Carinæ, 3·08; θ, 3·03; ω, 3·56; and others. A little north-west of ι is the long-period variable R Carinæ (9^h 29^m·7, S. 62° 21′, 1900). It varies from 4·5 at maximum to 10 at minimum, and the period is about 309·7 days. A little east of R Carinæ is another remarkable variable star, *l* Carinæ (R.A. 9^h 42^m·5, S. 62° 3′). It varies from 3·6 to 5·0 magnitude, with a period of 35½ days from maximum to maximum. All the light changes can be observed with an opera-glass, or even with the naked eye. It was discovered at Cordoba. The spectrum is of the solar type (G).

Musca, the Bee, is a small constellation south of the Southern Cross and Centaurus. Its brightest stars are α (2·84 Harvard) and β (3·26). These two stars form a fine pair south of α Crucis. Closely south-east of α is the short-period variable R Muscæ. It varies from 6·5 to 7·6 magnitude, and its period is about 19 hours. All its changes of light may be observed with a good opera-glass.

Apus, the Bird of Paradise, lies south-east of Musca, and north of Octans. Its brightest star is α, about the 4th magnitude. Williams calls it “deep yellow.” About 3° north-west of α, in the direction of the Southern Cross, is θ Apodis, which was found to be variable at Cordoba from 5½ to 6½. The spectrum is of the third type, which includes so many variable stars.

Triangulum Australis, the Southern Triangle, is a small constellation north of Apus, and south of Norma. A fine triangle, nearly isosceles, is formed by its three bright stars, α, β, γ, the brightest α being at the vertex. These three stars form with α Centauri an elongated cross. The stars β and γ are about 3rd magnitude. β is reddish. ε (4·11, Harvard) is also reddish, and is nearly midway between β and γ, and near the centre of the cross above referred to. α is a fine star (1·88 Harvard) and is one of the brightest stars in the sky—No. 33 in a list of 1500 highest stars given by Pickering. About 1° 40′ west of ε is the short-period variable R Trianguli Australis (R.A. 15^h $10^m \cdot 8$, S. 66° 8′) discovered at Cordoba in 1871. It varies from 6·7 to 7·4, and the period is about 3^d $7^h \cdot 2$. Although not visible to ordinary eyesight it is given here, as it is an interesting object and all its light changes may be well seen with an opera-glass. A little south-east of β is another short-period variable, S Trianguli Australis (R.A. 15^h $52^m \cdot 2$, S. 63° 30′), which varies from 6·4 to 7·4, with a period of 6·3 days; and all its fluctuations of light may also be observed with a good opera-glass.

Circinus, the Compass, is a very small constellation lying between Triangulum and Centaurus. Its brightest star, α, is about 3½ magnitude, about 4° south of α Centauri.

Pavo, the Peacock, lies north of Octans and Apus, and south of Telescopium. Its brightest star is α, which is a fine bright star (2·12 Harvard). κ is a short-period variable. It varies from 3·8 to 5·2, and the period is about 9 days. This is an interesting object, as all the fluctations of light can be observed by the naked eye or an opera-glass. ε Pavonis was measured 4·10 at Harvard, but the Cordoba estimates vary from 3·6 to 4·2. Gould says “it is of a remarkably blue colour.”

Indus.—This constellation lies north of Octans, and south of Sagittarius, Microscopium, and Grus. One of its stars, α, is probably referred to by Al-Sufi in his description of Sagittarius; it lies nearly midway between β Sagittarii and α Gruis, and is the brightest star of the constellation. The star ε Indi (4·74 Harvard) has a remarkably large proper motion of 4″·68 per annum. Its parallax is about 0″·28, and the proper motion indicates a velocity of about 49 miles a second at right angles to the line of sight.

Toucan.—This constellation lies north of Octans, and south of Phœnix and Grus, east of Indus, and west of Hydrus. Its brightest star is α, of about the 3rd magnitude.

There are seven “celestial rivers” alluded to by the ancient astronomers:—

1. The Fish River, which flows from the urn of Aquarius.

2. The "River of the Bird," or the Milky Way in Cygnus.

3. The River of the Birds—2, including Aquila.

4. The River of Orion—Eridanus.

5. The River of the god Marduk—perhaps the Milky Way in Perseus.

6. The River of Serpents (Serpens, or Hydra).

7. The River of Gan-gal (The High Cloud)—probably the Milky Way as a whole.

There are four serpents represented among the constellations. These are Hydra, Hydrus, Serpens, and Draco.

According to the late Mr. Proctor the date of the building of the Great Pyramid was about 3400 B.C.[452] At this time the Spring Equinox was in Taurus, and this is referred to by Virgil. But this was not so in Virgil's time, when—on account of the precession of the equinoxes—the equinoctial point had already entered Pisces, in which constellation it still remains. At the date 3400 B.C. the celestial equator ran along the whole length of the constellation Hydra, nearly through Procyon, and a little north of the bright red star Antares.

The star Fomalhaut (α Piscis Australis) is interesting as being the most southern 1st magnitude star visible in England, its meridian altitude at Greenwich being little more than eight degrees.[453]

With reference to the Greek letters given to the brighter stars by Bayer (in his Atlas published in 1603), and now generally used by astronomers, Mr. Lynn has shown that although "Bayer did uniformly designate the brightest stars in each constellation by the letter α,"[454] it is a mistake to suppose—as has often been stated in popular books on astronomy—that he added the other Greek letters *in order of brightness*. That this is an error clearly appears from Bayer's own "Explicatio" to his Atlas, and was long since pointed out by Argelander (1832), and by Dr. Gould in his *Uranometria Argentina*. Gould says, "For the stars of each order, the sequence of the letters in no manner represents that of their brightness, but depended upon the positions of the stars in the figure, beginning usually at the head, and following its course until all the stars of that order of magnitude were exhausted." Mr. Lynn says, "Perhaps one of the most remarkable instances in which the lettering is seen at a glance not to follow the order of the letters is that of the three brightest stars in Aquila [Al-Sufi's 'three famous stars'], γ being evidently brighter than β. But there is no occasion to conjecture from this that any change of relative brightness has taken place. Bayer reckoned both of these two of the third magnitude, and appears to have arranged β before γ, according to his usual custom, simply because β is in the neck of the supposed eagle, and γ at the root of one of the wings."[455] Another good example is found in the stars of the "Plough," in which the stars are evidently arranged in the order of the figure and not in the order of relative brightness. In fact, Bayer is no guide at all with reference to star magnitudes. How different Al-Sufi was in this respect!

The stars Aldebaran, Regulus, Antares, and Fomalhaut were called royal stars by the ancients. The reason of this was that they lie roughly about 90° apart, that is 6 hours of Right Ascension. So, if through the north and south poles of the heavens and each of these stars we draw great circles of the sphere, these circles will divide the sphere into four nearly equal parts, and the ancients supposed that each of these stars ruled over a quarter of the sphere, an idea probably connected with astrology. As the position of Aldebaran is R.A. $4^h\ 30^m$, Declination North 16° 19′, and that of Antares is R.A. $16^h\ 15^m$, Declination South 25° 2′, these two stars lie at nearly opposite points of the celestial sphere. From this it follows that our sun seen from Aldebaran would lie not very far from Antares, and seen from Antares it would appear not far from Aldebaran.

The following may be considered as representative stars of different magnitudes. For those of first magnitude and fainter I have only given those for which all the best observers in ancient and modern times agree, and which have been confirmed by modern photometric measures. The Harvard measures are given:—

Brighter than	"zero magnitude"	Sirius (-1·58); Canopus (-0·86)
Zero magnitude	... ...	α Centauri (0·06)

0 to 0·4 magnitude	... ...	Vega (0·14); Capella (0·21); Arcturus (0·24); Rigel (0·34)
0·5 magnitude	... ...	Procyon (0·48)
1st "	... ...	Aldebaran (1·06)
2nd "	... ...	α Persei (1·90); β Aurigæ (2·07)
3rd "	... ...	η Boötis (3·08); ζ Capricorni (2·98)
4th "	... ...	ρ Leonis (3·85); λ Scorpii (4·16); γ Crateris(4·14); ρ Herculis (4·14)
5th "	... ...	o Pegasi (4·85); μ Capricorni (5·10)

CHAPTER XX

The Visible Universe

SOME researches on the distribution of stars in the sky have recently been made at the Harvard Observatory (U.S.A.). The principal results are:—(1) The number of stars on any "given area of the Milky Way is about twice as great as in an equal area of any other region." (2) This ratio does not increase for faint stars down to the 12th magnitude. (3) "The Milky Way covers about one-third of the sky and contains about half of the stars." (4) There are about 10,000 stars of magnitude 6·6 or brighter, 100,000 down to magnitude 8·7, one million to magnitude 11, and two millions to magnitude 11·9. It is estimated that there are about 18 millions of stars down to the 15th magnitude visible in a telescope of 15 inches aperture.[456]

According to Prof. Kapteyn's researches on stellar distribution, he finds that going out from the earth into space, the "star density"—that is, the number of stars per unit volume of space—is fairly constant until we reach a distance of about 200 "light years." From this point the density gradually diminishes out to a distance of 2500 "light years," at which distance it is reduced to about one-fifth of the density in the sun's vicinity.[457]

In a letter to the late Mr. Proctor (*Knowledge*, November, 1885, p. 21), Sir John Herschel suggested that our Galaxy (or stellar system) "contained within itself miniatures of itself." This beautiful idea is probably true. In his account of the greater "Magellanic cloud," Sir John Herschel describes one of the numerous objects it contains as follows:—

"Very bright, very large; oval; very gradually pretty, much brighter in the middle; a beautiful nebula; it has very much the resemblance to the Nubecula Major itself as seen with the naked eye, but it is far brighter and more impressive in its general aspect as if it were doubled in intensity. Note —July 29, 1837. I well remember this observation, it was the result of repeated comparisons between the object seen in the telescope and the actual nubecula as seen high in the sky on the meridian, and no vague estimate carelessly set down. And who can say whether in this object, magnified and analysed by telescopes infinitely superior to what we now possess, there may not exist all the complexity of detail that the nubecula itself presents to our examination?"[458]

The late Lord Kelvin, in a remarkable address delivered before the Physical Science Section of the British Association at its meeting at Glasgow in 1901, considered the probable quantity of matter contained in our Visible Universe. He takes a sphere of radius represented by the distance of a star having a parallax of one-thousandth of a second (or about 3000 years' journey for light), and he supposes that uniformly distributed within this sphere there exists a mass of matter equal to 1000 million times the sun's mass. With these data he finds that a body placed originally at the surface of the sphere would in 5 million years acquire by gravitational force a velocity of about 12½ miles a second, and after 25 million of years a velocity of about 67 miles a second. As these velocities are of the same order as the observed velocities among the stars, Lord Kelvin concludes that there *is* probably as much matter in our universe as would be represented by a thousand million suns. If we assumed a mass of ten thousand suns the velocities would be much too high. The most probable estimate of the total number of the visible stars is about 100 millions; so that if Lord Kelvin's calculations are correct we seem bound to assume that space contains a number of dark bodies. The nebulæ, however, probably contain vast masses of matter, and this may perhaps account—partially, at least—for the large amount of matter estimated by Lord Kelvin. (See Chapter on "Nebulæ.")

In some notes on photographs of the Milky Way, Prof. Barnard says with reference to the great nebula near ρ Ophiuchi, "The peculiarity of this region has suggested to me the idea that the apparently small stars forming the ground work of the Milky Way here, are really very small bodies compared with our own sun"; and again, referring to the region near β Cygni, "One is specially struck with the apparent extreme smallness of the general mass of the stars in this region." Again, with reference to χ Cygni, he says, "The stars here also are remarkably uniform in size."[459]

Eastman's results for parallax seem to show that "the fainter rather than the brighter stars are nearest to our system." But this apparent paradox is considered by Mr. Monck to be very misleading;[460] and the present writer holds the same opinion.

Prof. Kapteyn finds "that stars whose proper motions exceed 0″·05 are not more numerous in the Milky Way than in other parts of the sky; or, in other words, if only the stars having proper motions of 0″·05 or upwards were mapped, there would be no aggregation of stars showing the existence of the Milky Way."[461]

With reference to the number of stars visible on photographs, the late Dr. Isaac Roberts says—

"So far as I am able at present to judge, under the atmospheric conditions prevalent in this country, the limit of the photographic method of delineation will be reached at stellar, or nebular, light of the feebleness of about 18th-magnitude stars. The reason for this inference is that the general illumination of the atmosphere by starlight concentrated upon a film by the instrument will mask the light of objects that are fainter than about 18th-magnitude stars."[462]

With reference to blank spaces in the sky, the late Mr. Norman Pogson remarked—

"Near S Ophiuchi we find one of the most remarkable vacuities in this hemisphere—an elliptic space of about 65′ in length in the direction of R.A., and 40′ in width, in which there exists *no* star larger than the 13th magnitude ... it is impossible to turn a large telescope in that direction and, if I may so express it, view such black darkness, without a feeling that we are here searching into the remote regions of space, far beyond the limits of our own sidereal system."[463]

Prof. Barnard describes some regions in the constellation Taurus containing "dark lanes" in a groundwork of faint nebulosity. He gives two beautiful photographs of the regions referred to, and says that the dark holes and lanes are apparently darker than the sky in the immediate vicinity. He says, "A very singular feature in this connection is that the stars also are absent in general from the lanes." A close examination of these photographs has given the present writer the impression that the dark lanes and spots are *in* the nebulosity, and that the nebulosity is mixed up with the stars. This would account for the fact that the stars are in general absent from the dark lanes. For if there is an intimate relation between the stars and the nebulosity, it would follow that where there is no nebulosity in this particular region there would be no stars. Prof. Barnard adds that the nebulosity is easily visible in a 12-inch telescope.[464]

With reference to the life of the universe, Prof. F. R. Moulton well says—

“The lifetime of a man seems fairly long, and the epoch when Troy was besieged, or when the Pharaohs piled up the pyramids in the valley of the Nile, or when our ancestors separated on the high plateaux of Asia, seems extremely remote, but these intervals are only moments compared to the immense periods required for geological evolutions and the enormously greater ones consumed in the developement of worlds from widely extended nebulous masses. We recognize the existence of only those forces whose immediate consequences are appreciable, and it may be that those whose effects are yet unseen are really of the highest importance. A little creature whose life extended over only two or three hours of a summer’s day might be led, if he were sufficiently endowed with intelligence, to infer that passing clouds were the chief influence at work in changing the climate instead of perceiving that the sun’s slow motion across the sky would bring on the night and its southward motion the winter.”[465]

In a review of my book *Astronomical Essays* in *The Observatory*, September, 1907, the following words occur. They seem to form a good and sufficient answer to people who ask, What is there beyond our visible universe? “If the stellar universe is contained in a sphere of say 1000 stellar units radius, what is there beyond? To this the astronomer will reply that theories and hypotheses are put forward for the purpose of explaining observed facts; when there are no facts to be explained, no theory is required. As there are no observed facts as to what exists beyond the farthest stars, the mind of the astronomer is a complete blank on the subject. Popular imagination can fill up the blank as it pleases.” With these remarks I fully concur.

In his address to the British Association, Prof. G. H. Darwin (now Sir George Darwin) said—

“Man is but a microscopic being relatively to astronomical space, and he lives on a puny planet circling round a star of inferior rank. Does it not, then, seem futile to imagine that he can discover the origin and tendency of the Universe as to expect a housefly to instruct us as to the theory of the motions of the planets? And yet, so long as he shall last, he will pursue his search, and will no doubt discover many wonderful things which are still hidden. We may indeed be amazed at all that man has been able to find out, but the immeasurable magnitude of the undiscovered will throughout all time remain to humble his pride. Our children’s children will still be gazing and marvelling at the starry heavens, but the riddle will never be read.”

The ancient philosopher Lucretius said—

> “Globed from the atoms falling slow or swift
> I see the suns, I see the systems lift
> Their forms; and even the system and the suns
> Shall go back slowly to the eternal drift.”[466]

But it has been well said that the structure of the universe “has a fascination of its own for most readers quite apart from any real progress which may be made towards its solution.”[467]

The Milky Way itself, Mr. Stratonoff considers to be an agglomeration of immense condensations, or stellar clouds, which are scattered round the region of the galactic equator. These clouds, or masses of stars, sometimes leave spaces between them, and sometimes they overlap, and in this way he accounts for the great rifts, like the Coal Sack, which allow us to see through this great circle of light. He finds other condensations of stars; the nearest is one of which our sun is a member, chiefly composed of stars of the higher magnitudes which “thin out rapidly as the Milky Way is approached.” There are other condensations: one in stars of magnitudes 6·5 to 8·5; and a third, farther off, in stars of magnitudes 7·6 to 8. These may be called opera-glass, or field-glass stars.

Stratonoff finds that stars with spectra of the first type (class A, B, C, and D of Harvard) which include the Sirian and Orion stars, are principally situated near the Milky Way, while those of type II. (which includes the solar stars) "are principally condensed in a region coinciding roughly with the terrestrial pole, and only show a slight increase, as compared with other stars, as the galaxy is approached."[468]

Prof. Kapteyn thinks that "undoubtedly one of the greatest difficulties, if not the greatest of all, in the way of obtaining an understanding of the real distribution of the stars in space, lies in our uncertainty about the amount of loss suffered by the light of the stars on its way to the observer."[469] He says, "There can be little doubt in my opinion, about the existence of absorption in space, and I think that even a good guess as to the order of its amount can be made. For, first we know that space contains an enormous mass of meteoric matter. This matter must necessarily intercept some part of the star-light."

This absorption, however, seems to be comparatively small. Kapteyn finds a value of 0·016 (about 1⁄60th) of a magnitude for a star at a distance corresponding to a parallax of one-tenth of a second (about 33 "light years"). This is a quantity almost imperceptible in the most delicate photometer. But for very great distances—such as 3000 "light years"—the absorption would evidently become very considerable, and would account satisfactorily for the gradual "thinning out" of the fainter stars. If this were fully proved, we should have to consider the fainter stars of the Milky Way to be in all probability fairly large suns, the light of which is reduced by absorption.

That some of the ancients knew that the Milky Way is composed of stars is shown by the following lines translated from Ovid:—

> "A way there is in heaven's extended plain
> Which when the skies are clear is seen below
> And mortals, by the name of Milky, know;
> The groundwork is of stars, through which the road
> Lies open to great Jupiter's abode."[470]

From an examination of the distribution of the faint stars composing the Milky Way, and those shown in Argelander's charts of stars down to the 9½ magnitude, Easton finds that there is "a real connection between the distribution of 9th and 10th magnitude stars, and that of the faint stars of the

Milky Way, and that consequently the faint or very faint stars of the galactic zone are at a distance which does not greatly exceed that of the 9th and 10th magnitude stars."[471] A similar conclusion was, I think, arrived at by Proctor many years ago. Now let us consider the meaning of this result. Taking stars of the 15th magnitude, if their faintness were merely due to greater distance, their actual brightness—if of the same size—would imply that they are at 10 times the distance of stars of the 10th magnitude. But if at the same distance from us, a 10th magnitude star would be 100 times brighter than a 15th magnitude star, and if of the same density and "intrinsic brightness" (or luminosity of surface) the 10th magnitude would have 10 times the diameter of the fainter star, and hence its volume would be 1000 times greater (10^3), and this great difference is not perhaps improbable.

The constitution of the Milky Way is not the same in all its parts. The bright spot between β and γ Cygni is due to relatively bright stars. Others equally dense but fainter regions in Auriga and Monoceros are only evident in stars of the 8th and 9th magnitude, and the light of the well-known luminous spot in "Sobieski's Shield," closely south of λ Aquilæ, is due to stars below magnitude 9½.

The correspondence in distribution between the stars of Argelander's charts and the fainter stars of the Milky Way shows, as Easton points out, that Herschel's hypothesis of a uniform distribution of stars of approximately equal size is quite untenable.

It has been suggested that the Milky Way may perhaps form a ring of stars with the sun placed nearly, but not exactly, in the centre of the ring. But were it really a ring of uniform width with the sun eccentrically placed within it, we should expect to find the Milky Way wider at its nearest part, and gradually narrowing towards the opposite point. Now, Herschel's "gages" and Celoria's counts show that the Galaxy is wider in Aquila than in Monoceros. This is confirmed by Easton, who says, "*for the faint stars taken as a whole, the Milky Way is widest in its brightest part*" (the italics are Easton's). From this we should conclude that the Milky Way is nearer to us in the direction of Aquila than in that of Monoceros. Sir John Herschel suggested that the southern parts of the galactic zone are nearer to us on account of their greater *brightness* in those regions.[472] But greater width is a safer test of distance than relative brightness. For it may be easily shown than the *intrinsic* brightness of an area containing a large number of stars would be the same for *all* distances (neglecting the supposed absorption of light in space). For suppose any given area crowded with stars to be removed to a greater distance. The light of each star would be diminished inversely as the square of the distance. But the given area would also be diminished *directly* as the square of the distance, so we should have a diminished amount of light on an equally diminished area, and hence the intrinsic brightness, or luminosity of the area per unit of surface, would remain unaltered. The increased brightness of the Milky Way in Aquila is accounted for by the fact that Herschel's "gages" show an increased number of stars, and hence the brightness in Aquila and Sagittarius does not necessarily imply that the Milky Way is nearer to us in those parts, but that it is richer in small stars than in other regions.

Easton is of opinion that the annular hypothesis of the Milky Way is inconsistent with our present knowledge of the galactic phenomena, and he suggests that its actual constitution resembles more that of a spiral nebula. [473] On this hypothesis the increase in the number of stars in the regions above referred to may be due to our seeing one branch of the supposed "two-branched spiral" projected on another branch of the same spiral. This seems supported by Sir John Herschel's observations in the southern hemisphere, where he found in some places "a tissue as it were of large stars spread over another of very small ones, the immediate magnitudes being wanting." Again, portions of the spiral branches may be richer than others, as photographs of spiral nebulæ seem to indicate. Celoria, rejecting the hypothesis of a single ring, suggests the existence of *two* galactic rings inclined to each other at an angle of about 20°, one of these including the brighter stars, and the other the fainter. But this seems to be a more artificial arrangement then the hypothesis of a spiral. Further, the complicated structure of the Milky Way cannot be well explained by Celoria's hypothesis of two distinct rings one inside the other. From analogy the spiral hypothesis seems much more probable.

Considering the Milky Way to represent a colossal spiral nebula viewed from a point not far removed from the centre of the spiral branches, Easton suggests that the bright region between β and γ Cygni, which is very rich in comparatively bright stars, may possibly represent the "*central accumulations of the Milky Way*," that is, the portion corresponding to the nucleus of a spiral nebula. If this be so, this portion of the Milky Way should be nearer to us than others. Easton also thinks that the so-called “solar cluster” of Gould, Kapteyn, and Schiaparelli may perhaps be “the expression of the central condensation of the galactic system itself, composed of the most part of suns comparable with our own, and which would thus embrace most of the bright stars to the 9th or 10th magnitude. The distance of the galactic streams and convolutions would thus be comparable with the distances of these stars.” He thinks that the sun lies within a gigantic spiral, “in a comparatively sparse region between the central nucleus and Orion.”

Scheiner thinks that “the irregularities of the Milky Way, especially in streams, can be quite well accounted for, as Easton has attempted to do, if they are regarded as a system of spirals, and not as a ring system.”

Evidence in favour of the spiral hypothesis of the Milky Way, as advocated by Easton and Scheiner, may be found in Kapteyn’s researches on the proper motions of the stars. This eminent astronomer finds that stars with measurable proper motions—and therefore in all probability relatively near the earth—have mostly spectra of the solar type, and seem to cluster round “a point adjacent to the sun, in total disregard to the position of the Milky Way,” and that stars with little or no proper motion collect round the galactic plain. He is also of opinion that the Milky Way resembles the Andromeda nebula, “the globular nucleus representing the solar cluster, and the far spreading wings or whorls the compressed layer of stars enclosed by the rings of the remote Galaxy.”

With reference to the plurality of inhabited worlds, it has been well said by the ancient writer Metrodorus (third century B.C.), “The idea that there is but a single world in all infinitude would be as absurd as to suppose that a vast field had been formed to produce a single blade of wheat.”[474] With this opinion the present writer fully concurs.

CHAPTER XXI

General

THE achievements of Hipparchus in astronomy were very remarkable, considering the age in which he lived. He found the amount of the apparent motion of the stars due to the precession of the equinoxes (of which he was the discoverer) to be 59″ per annum. The correct amount is about 50″. He measured the length of the year to within 9 minutes of its true value. He found the inclination of the ecliptic to the plane of the equator to be 23° 51′. It was then 23° 46′—as we now know by modern calculations—so that Hipparchus' estimation was a wonderfully close approximation to the truth. He computed the moon's parallax to be 57′, which is about its correct value. He found the eccentricity of the sun's apparent orbit round the earth to be one twenty-fourth, the real value being then about one-thirteenth. He determined other motions connected with the earth and moon; and formed a catalogue of 1080 stars. All this work has earned for him the well-merited title of "The Father of Astronomy."[475]

The following is a translation of a Greek passage ascribed to Ptolemy: "I know that I am mortal and the creature of a day, but when I search out the many rolling circles of the stars, my feet touch the earth no longer, but with Zeus himself I take my fill of ambrosia, the food of the gods."[476] This was inscribed (in Greek) on a silver loving cup presented to the late Professor C. A. Young, the famous American astronomer.[477]

Some curious and interesting phenomena are recorded in the old Chinese Annals, which go back to a great antiquity. In 687 B.C. "a night" is mentioned "without clouds and without stars" (!) This may perhaps refer to a total eclipse of the sun; but if so, the eclipse is not mentioned in the Chinese list of eclipses. In the year 141 B.C., it is stated that the sun and moon appeared of a deep red colour during 5 days, a phenomenon which caused great terror among the people. In 74 B.C., it is related that a star as large as the moon appeared, and was followed in its motion by several stars of ordinary size. This probably refers to an unusually large "bolide" or "fireball." In 38 B.C., a fall of meteoric stones is recorded "of the size of a walnut." In A.D. 88, another fall of stones is mentioned. In A.D. 321, sun-spots were visible to the naked eye.

Homer speaks of a curious darkness which occurred during one of the great battles in the last year of the Trojan war. Mr. Stockwell identifies this with an eclipse of the sun which took place on August 28, 1184 B.C. An eclipse referred to by Thucydides as having occurred during the first year of the Peloponnesian War, when the darkness was so great that some stars were seen, is identified by Stockwell with a total eclipse of the sun, which took place on August 2, 430 B.C.

A great eclipse of the sun is supposed to have occurred in the year 43 or 44 B.C., soon after the death of Julius Cæsar. Baron de Zach and Arago mention it as the first annular eclipse on record. But calculations show that no solar eclipse whatever, visible in Italy, occurred in either of these years. The phenomenon referred to must therefore have been of atmospherical origin, and indeed this is suggested by a passage in Suetonius, one of the authors quoted on the subject.

M. Guillaume thinks that the ninth Egyptian plague, the thick "darkness" (Exodus x. 21-23), may perhaps be explained by a total eclipse of the sun which occurred in 1332 B.C. It is true that the account states that the darkness lasted "three days," but this, M. Guillaume thinks, may be due to an error in the translation.[478] This explanation, however, seems very improbable.

According to Hind, the moon was eclipsed on the generally received date of the Crucifixion, A.D. 33, April 3. He says, "I find she had emerged from the earth's dark shadow a quarter of an hour before she rose at Jerusalem (6^h 36^m p.m.); but the penumbra continued upon her disc for an hour afterwards." An eclipse could not have had anything to do with the "darkness over all the land" during the Crucifixion. For this lasted for three hours, and the totality of a solar eclipse can only last a few minutes at the most. As a matter of fact the "eclipse of Phlegon," a partial one (A.D. 29, November 24) was “the only solar eclipse that could have been visible in Jerusalem during the period usually fixed for the ministry of Christ.”

It is mentioned in the Anglo-Saxon Chronicle that a total eclipse of the sun took place in the year after King Alfred’s great battle with the Danes. Now, calculation shows that this eclipse occurred on October 29, 878 A.D. King Alfred’s victory over the Danes must, therefore, have taken place in 877 A.D., and his death probably occurred in 899 A.D. This solar eclipse is also mentioned in the Annals of Ulster. From this it will be seen that in some cases the dates of historical events can be accurately fixed by astronomical phenomena.

It is stated by some historians that an eclipse of the sun took place on the morning of the battle of Crecy, August 26, 1346. But calculation shows that there was no eclipse of the sun visible in England in that year. At the time of the famous battle the moon had just entered on her first quarter, and she was partially eclipsed six days afterwards—that is on the 1st of September. The mistake seems to have arisen from a mistranslation of the old French word *esclistre*, which means lightning. This was mistaken for *esclipse*. The account seems to indicate that there was a heavy thunderstorm on the morning of the battle.

A dark shade was seen on the waning moon by Messrs. Hirst and J. C. Russell on October 21, 1878, “as dark as the shadow during an eclipse of the moon.”[479] If this observation is correct, it is certainly most difficult to explain. Another curious observation is recorded by Mr. E. Stone Wiggins, who says that a partial eclipse of the sun by a dark body was observed in the State of Michigan (U.S.A.) on May 16, 1884, at 7 p.m. The “moon at that moment was 12 degrees south of the equator and the sun as many degrees north of it.” The existence of a dark satellite of the earth has been suggested, but this seems highly improbable.

The sun’s corona seems to have been first noticed in the total eclipse of the sun which occurred at the death of the Roman emperor Domitian, A.D. 95. Philostratus in his *Life of Apollonius* says, with reference to this eclipse, “In the heavens there appeared a prodigy of this nature: a certain *corona* resembling the Iris surrounded the orb of the sun, and obscured its light.”[480] In more modern times the corona seems to have been first noticed by Clavius during the total eclipse of April 9, 1567.[481] Kepler proved that this eclipse was total, not annular, so that the ring seen by Clavius must have been the corona.

With reference to the visibility of planets and stars during total eclipses of the sun; in the eclipse of May 12, 1706, Venus, Mercury, and Aldebaran, and several other stars were seen. During the totality of the eclipse of May 3, 1715, about twenty stars were seen with the naked eye.[482] At the eclipse of May 22, 1724, Venus and Mercury, and a few fixed stars were seen.[483] The corona was also noticed. At the eclipse of May 2, 1733, Jupiter, the stars of the "Plough," Capella, and other stars were visible to the naked eye; and the corona was again seen.[483]

During the total eclipses of February 9, 1766, June 24, 1778, and June 16, 1806, the corona was again noticed. But its true character was then unknown.

At the eclipse of July 8, 1842, it was noticed by observers at Lipesk that the stars Aldebaran and Betelgeuse (α Orionis), which are usually red, "appeared quite white."[484]

There will be seven eclipses in the years 1917, 1935, and 1985. In the year 1935 there will be five eclipses of the sun, a rare event; and in 1985 there will be three total eclipses of the moon, a most unusual occurrence.[485]

Among the ancient Hindoos, the common people believed that eclipses were caused by the interposition of a monstrous demon called Raha. This absurd idea, and others equally ridiculous, were based on declarations in their sacred books, and no pious Hindoo would think of denying it.

The following cases of darkenings of the sun are given by Humboldt:—

According to Plutarch the sun remained pale for a whole year at the death of Julius Cæsar, and gave less than its usual heat.[486]

A sun-darkening lasting for two hours is recorded on August 22, 358 A.D., before the great earthquake of Nicomedia.

In 360 A.D. there was a sun-darkening from early morn till noon. The description given by the historians of the time corresponds to an eclipse of the sun, but the duration of the obscurity is inexplicable.

In 409 A.D., when Alaric lay siege to Rome, "there was so great a darkness that the stars were seen by day."

In 536 A.D. the sun is said to have been darkened for a year and two months!

In 626 A.D., according to Abul Farag, half the sun's disc was darkened for eight months!

In 934 A.D. the sun lost its brightness for two months in Portugal.

In 1090 A.D. the sun was darkened for three hours.

In 1096, sun-spots were seen with the naked eye on March 3.

In 1206 A.D. on the last day of February, "there was complete darkness for six hours, turning the day into night." This seems to have occurred in Spain.

In 1241 the sun was so darkened that stars could be seen at 3 p.m. on Michaelmas day. This happened in Vienna.[487]

The sun is said to have been so darkened in the year 1547 A.D. for three days that stars were visible at midday. This occurred about the time of the battle of Mühlbergh.[488]

Some of these darkenings may possibly have been due to an enormous development of sun-spots; but in some cases the darkness is supposed by Chladni and Schnurrer to have been caused by "the passage of meteoric masses before the sun's disc."

The first observer of a transit of Venus was Jeremiah Horrocks, who observed the transit of November 24 (O.S.), 1639. He had previously corrected Kepler's predicted time of the transit from $8^h\ 8^m$ a.m. at Manchester to $5^h\ 57^m$ p.m. At the end of 1875 a marble scroll was placed on the pedestal of the monument of John Conduitt (nephew of Sir Isaac Newton, and who adopted Horrocks' theory of lunar motions) at the west end of the nave of Westminster Abbey, bearing this inscription from the pen of Dean Stanley—

“Ad majora avocatus
quæ ob hæc parerga negligi non decuit”
IN MEMORY OF
JEREMIAH HORROCKS
Curate of Hoole in Lancashire
Who died on the 3^{d} of January, 1641, in or near his
22^{d} year
Having in so short a life
Detected the long inequality in the mean motion of
Jupiter and Saturn
Discovered the orbit of the Moon to be an ellipse;
Determined the motion of the lunar aspe,
Suggested the physical cause of its revolution;
And predicted from his own observations, the
Transit of Venus
Which was seen by himself and his friend
WILLIAM CRABTREE
On Sunday, the 24th November (O.S.) 1639;
This Tablet, facing the Monument of Newton
Was raised after the lapse of more than two centuries
December 9, 1874.[489]

The transit of Venus which occurred in 1761 was observed on board ship(!) by the famous but unfortunate French astronomer Le Gentil. The ship was the frigate *Sylphide*, sent to the help of Pondicherry (India) which was then being besieged by the English. Owing to unfavourable winds the *Sylphide* was tossed about from March 25, 1761, to May 24 of the same year. When, on the later date, off the coast of Malabar, the captain of the frigate learned that Pondicherry had been captured by the English, the vessel returned to the Isle of France, where it arrived on June 23, after touching at Point de Galle on May 30. It was between these two places that Le Gentil made his observations of the transit of Venus under such unfavourable conditions. He had an object-glass of 15 feet (French) focus, and this he mounted in a tube formed of “four pine planks.” This rough instrument was fixed to a small mast set up on the quarter-deck and worked by ropes. The observations made under such curious conditions, were not, as may be imagined, very satisfactory. As another transit was to take place on June 3, 1769, Le Gentil made the heroic resolution of remaining in the southern hemisphere to observe it! This determination was duly carried out, but his devotion to astronomy was not rewarded; for on the day of the long waited for transit the sky at Pondicherry (where he had gone to observe it) was clouded over during the whole phenomenon, "although for many days previous the sky had been cloudless." To add to his feeling of disappointment he heard that at Manilla, where he had been staying some time previously, the sky was quite clear, and two of his friends there had seen the transit without any difficulty.[490] Truly the unfortunate Le Gentil was a martyr to science.

The famous German astronomer Bessel once said "that a practical astronomer could make observations of value if he had only a cart-wheel and a gun barrel"; and Watson said that "the most important part of the instrument is the person at the small end."[491]

With reference to Father Hell's supposed forgery of his observations of the transit of Venus in 1769, and Littrow's criticism of some of the entries in Hell's manuscript being corrected with a different coloured ink, Professor Newcomb ascertained from Weiss that Littrow was colour blind, and could not distinguish between the colour of Aldebaran and the whitest star. Newcomb adds, "For half a century the astronomical world had based an impression on the innocent but mistaken evidence of a colour-blind man respecting the tint of ink in a manuscript."

It is recorded that on February 26, B.C. 2012, the moon, Mercury, Venus, Jupiter, and Saturn, were in the same constellation, and within 14 degrees of each other. On September 14, 1186 A.D., the sun, moon, and all the planets then known, are said to have been situated in Libra.[492]

In the Sanscrit epic poem, "The Ramaya," it is stated that at the birth of Rama, the moon was in Cancer, the sun in Aries, Mercury in Taurus, Venus in Pisces, Mars in Capricornus, Jupiter in Cancer, and Saturn in Libra. From these data, Mr. Walter R. Old has computed that Rama was born on February 10, 1761 B.C.[493]

A close conjunction of Mars and Saturn was observed by Denning on September 29, 1889, the bright star Regulus (α Leonis) being at the time only 47′ distant from the planets.[494]

An occultation of the Pleiades by the moon was observed by Timocharis at Alexandria on January 29, 282 B.C. Calculations by Schjellerup show that Alcyone (η Tauri) was occulted; but the exact time of the day recorded by Timocharis differs very considerably from that computed by Schjellerup.[495] Another occultation of the Pleiades is recorded by Agrippa in the reign of Domitian. According to Schjellerup the phenomenon occurred on November 29, A.D. 92.

"Kepler states that on the 9th of January, 1591, Mæstlin and himself witnessed an occultation of Jupiter by Mars. The red colour of the latter on that occasion plainly indicated that it was the inferior planet."[496] That is, that Mars was nearer to the sun than Jupiter. But as the telescope had not then been invented, this may have been merely a near approach of the two planets.

According to Kepler, Mæstlin saw an occultation of Mars by Venus on October 3, 1590. But this may also have been merely a near approach.[496]

A curious paradox is that one can discover an object without seeing it, and see an object without discovering it! The planet Neptune was discovered by Adams and Leverrier by calculation before it was seen in the telescope by Galle; and it was actually seen by Lalande on May 8 and 10, 1795, but he took it for a *star* and thus missed the discovery. In fact, he *saw* the planet, but did not *discover* it. It actually appears as a star of the 8th magnitude in Harding's Atlas (1822). The great "new star" of February, 1901, known as Nova Persei, was probably seen by some people before its discovery was announced; and it was actually noticed by a well-known American astronomer, who thought it was some bright star with which he was not familiar! But this did not amount to a discovery. Any one absolutely ignorant of astronomy might have made the same observation. An object must be *identified* as a *new* object before a discovery can be claimed. Some years ago a well-known Irish naturalist discovered a spider new to science, and after its discovery he found that it was common in nearly every house in Dublin! But this fact did not detract in the least from the merit of its scientific discovery.

There is a story of an eminent astronomer who had been on several eclipse expeditions, and yet was heard to remark that he had never seen a total eclipse of the sun. "But your observations of several eclipses are on record," it was objected. "Certainly, I have on several occasions made observations, but I have always been too busy to look at the eclipse." He was probably in a dark tent taking photographs or using a spectroscope during the totality. This was observing an eclipse without seeing it!

Humboldt gives the credit of the invention of the telescope to Hans Lippershey, a native of Wesel and a spectacle-maker at Middleburgh; to Jacob Adreaansz, surnamed Metius, who is also said to have made burning-glasses of ice; and to Zachariah Jansen.[497]

With reference to the parabolic figure of the large mirrors of reflecting telescopes, Dr. Robinson remarked at the meeting of the British Association at Cork in 1843, "between the spherical and parabolic figures the extreme difference is so slight, even in the telescope of 6-feet aperture [Lord Rosse's] that if the two surfaces touched at their vertex, the distance at the edge would not amount to the 1⁄10000 of an inch, a space which few can measure, and none without a microscope."[498]

In the year 1758, Roger Long, Lowndean Professor of Astronomy at Cambridge, constructed an "orrery" on a novel principle. It was a hollow metal sphere of about 18 feet in diameter with its fixed axis parallel to the earth's axis. It was rotated, by means of a winch and rackwork. It held about thirty persons in its interior, where astronomical lectures were delivered. The constellations were painted on the interior surface; and holes pierced through the shell and illuminated from the outside represented the stars according to their different magnitudes. This ingenious machine was much neglected for many years, but was still in existence in Admiral Smyth's time, 1844.[499]

A "temporary star" is said to have been seen by Hepidanus in the constellation Aries in either 1006 or 1012 A.D. The late M. Schönfeld, a great authority on variable stars, found from an Arabic and Syrian chronicle that 1012 is the correct year (396 of the Hegira), but that the word translated Aries would by a probable emendation mean Scorpio. The word in the Syrian record is not the word for Aries.[500]

Mr. Heber D. Curtis finds that the faintest stars mentioned in Ptolemy's Catalogue are about 5·38 magnitude on the scale of the Harvard

Photometric Durchmustering.[501] Heis and Houzeau saw stars of 6-7 magnitude (about 6·4 on Harvard scale). The present writer found that he could see most of Heis' faintest stars in the west of Ireland (Co. Sligo) without optical aid (except short-sighted spectacles).

With reference to the apparent changes in the stellar heavens produced by the precession of the equinoxes, Humboldt says—

"Canopus was fully 1° 20′ below the horizon of Toledo (39° 54′ north latitude) in the time of Columbus; and now the same star is almost as much above the horizon of Cadiz. While at Berlin, and in northern latitudes, the stars of the Southern Cross, as well as α and β Centauri, are receding more and more from view, the Magellanic Clouds are slowly approaching our latitudes. Canopus was at its greatest northern approximation during last century [eighteenth], and is now moving nearer and nearer to the south, although very slowly, owing to its vicinity to the south pole of the ecliptic. The Southern Cross began to become invisible in 52° 30′ north latitude 2900 years before our era, since, according to Galle, this constellation might previously have reached an altitude of more than 10°. When it had disappeared from the horizon of the countries of the Baltic, the great pyramid of Cheops had already been erected more than five hundred years. The pastoral tribe of the Hyksos made their incursion seven hundred years earlier. The past seems to be visibly nearer to us when we connect its measurement with great and memorable events."[502]

With reference to the great Grecian philosopher and scientist Eratosthenes of Cyrene, keeper of the Alexandrian Library under Ptolemy Euergetes, Carl Snyder says, "Above all the Alexanders, Cæsars, Tadema-Napoleons, I set the brain which first spanned the earth, over whose little patches these fought through their empty bootless lives. Why should we have no poet to celebrate so great a deed?"[503] And with reference to Aristarchus he says, "If grandeur of conceptions be a measure of the brain, or ingenuity of its powers, then we must rank Aristarchus as one of the three or four most acute intellects of the ancient world."[504]

Lagrange, who often asserted Newton to be the greatest genius that ever existed, used to remark also—"and the most fortunate; we do not find more than once a system of the world to establish."[505]

Grant says—

“Lagrange deserves to be ranked among the greatest mathematical geniuses of ancient or modern times. In this respect he is worthy of a place with Archimedes or Newton, although he was far from possessing the sagacity in physical enquiries which distinguished these illustrious sages. From the very outset of his career he assumed a commanding position among the mathematicians of the age, and during the course of nearly half a century previous to his death, he continued to divide with Laplace the homage due to pre-eminence in the exact sciences. His great rival survived him fourteen years, during which he reigned alone as the prince of mathematicians and theoretical astronomers.”[506]

A writer in *Nature* (May 25, 1871) relates the following anecdote with reference to Sir John Herschel: “Some time after the death of Laplace, the writer of this notice, while travelling on the continent in company with the celebrated French *savant* Biot, ventured to put to him the question, not altogether a wise one, ‘And whom of all the philosophers of Europe do you regard as the most worthy successor of Laplace?’ Probably no man was better able than Biot to form a correct conclusion, and the reply was more judicious than the question. It was this, ‘If I did not love him so much I should unhesitatingly say, Sir John Herschel.’” Dr. Gill (now Sir David Gill), in an address at the Cape of Good Hope in June, 1898, spoke of Sir John Herschel as “the prose poet of science; his popular scientific works are models of clearness, and his presidential addresses teem with passages of surpassing beauty. His life was a pure and blameless one from first to last, full of the noblest effort and the noblest aim from the time when as a young Cambridge graduate he registered a vow ‘to try to leave the world wiser than he found it’—a vow that his life amply fulfilled.”[507]

Prof. Newcomb said of Adams, the co-discoverer of Neptune with Leverrier, “Adams’ intellect was one of the keenest I ever knew. The most difficult problem of mathematical astronomy and the most recondite principles that underlie the theory of the celestial motions were to him but child’s play.” Airy he regarded as “the most commanding figure in the astronomy of our time.”[508] He spoke of Delaunay, the great French astronomer, as a most kindly and attractive man, and says, “His investigations of the moon’s motion is one of the most extraordinary pieces of mathematical work ever turned out by a single person. It fills two quarto volumes, and the reader who attempts to go through any part of the calculations will wonder how one man could do the work in a lifetime."[509]

Sir George B. Airy and Prof. J. C. Adams died in the same month. The former on January 2, 1892, and the latter on January 22 of the same year.

It is known from the parish register of Burstow in Surrey that Flamsteed (Rev. John Flamsteed), the first Astronomer Royal at Greenwich, was buried in the church at that place on January 12, 1720; but a search for his grave made by Mr. J. Carpenter in 1866 and by Mr. Lynn in 1880 led to no result. In Mrs. Flamsteed's will a sum of twenty-five pounds was left for the purpose of erecting a monument to the memory of the great astronomer in Burstow Church; but it does not appear that any monument was ever erected. Flamsteed was Rector of the Parish of Burstow.[510] He was succeeded in 1720 by the Rev. James Pound, another well-known astronomer. Pound died in 1724.[511]

Evelyn says in his Diary, 1676, September 10, "Dined with Mr. Flamsteed, the learned astrologer and mathematician, whom his Majesty had established in the new Observatory in Greenwich Park furnished with the choicest instruments. An honest sincere man."[512] This shows that in those days the term "astrologer" was synonymous with "astronomer."

In an article on "Our Debt to Astronomy," by Prof. Russell Tracy Crawford (Berkeley Astronomical Department, California, U.S.A.), the following remarks occur:—

"Behind the artisan is a chemist, behind the chemist is a physicist, behind the physicist is a mathematician, and behind the mathematician is an astronomer." "Were it not for the data furnished by astronomers, commerce by sea would practically stop. The sailing-master on the high seas could not determine his position, nor in what direction to head his ship in order to reach a desired harbour. Think what this means in dollars and cents, and estimate it if you can. For this one service alone the science of astronomy is worth more in dollars and cents to the world in one week than has been expended upon it since the beginning of civilization. Do you think that Great Britain, for instance, would take in exchange an amount equal to its national debt for what astronomy gives it? I answer for you most emphatically, 'No.'"

In his interesting book, *Reminiscences of an Astronomer*, Prof. Simon Newcomb says with reference to the calculations for the *Nautical Almanac* (referred to in the above extract)—

"A more hopeless problem than this could not be presented to the ordinary human intellect. There are tens of thousands of men who could be successful in all the ordinary walks of life, hundreds who could wield empires, thousands who could gain wealth, for one who could take up this astronomical problem with any hope of success. The men who have done it are, therefore, in intellect the select few of the human race—an aristocracy ranking above all others in the scale of being. The astronomical ephemeris is the last outcome of their productive genius."

In a paper on the "Aspects of American Astronomy," Prof. Newcomb says, "A great telescope is of no use without a man at the end of it, and what the telescope may do depends more upon this appendage than upon the instrument itself. The place which telescopes and observatories have taken in astronomical history are by no means proportional to their dimensions. Many a great instrument has been a mere toy in the hands of its owner. Many a small one has become famous. Twenty years ago there was here in your city [Chicago] a modest little instrument which, judged by its size, could not hold up its head with the great ones even of that day. It was the private property of a young man holding no scientific position and scarcely known to the public. And yet that little telescope is to-day among the famous ones of the world, having made memorable advances in the astronomy of double stars, and shown its owner to be a worthy successor of the Herschels and Struves in that line of work."[513] Here Prof. Newcomb evidently refers to Prof. Burnham, and the 6-inch telescope with which he made many of his remarkable discoveries of double stars. With reference to Burnham's work, Prof. Barnard says—

"It represents the labour of a struggling amateur, who during the day led the drudging life of a stenographer in the United States court in Chicago, and at night worked among the stars for the pure love of it. Such work deserves an everlasting fame, and surely this has fallen to Mr. Burnham."

Admiral Smyth says—

"A man may prove a good astronomer without possessing a spacious observatory: thus Kepler was wont to observe on the bridge at Prague; Schröter studied the moon, and Harding found a planet from a *gloriette*; while Olbers discovered two new planets from an attic of his house."[514]

It is probably not generally known that "some of the greatest astronomers of modern times, such as Kepler, Newton, Hansen, Laplace, and Leverrier, scarcely ever looked through a telescope."[515]

Kepler, who always signed himself Keppler in German, is usually supposed to have been born on December 21, 1571, in the imperial town of Weil, but according to Baron von Breitschwert,[516] he was really born on December 27, 1571, in the village of Magstadt in Wurtemberg.

According to Lieut. Winterhalter, M. Perrotin of the Nice Observatory declared "that two hours' work with a large instrument is as fatiguing as eight with a small one, the labour involved increasing in proportion to the cube of the aperture, the chances of seeing decreasing in the same ratio, while it can hardly be said that the advantages increase in like proportion."[517]

The late Mr. Proctor has well said—

"It is well to remember that the hatred which many entertain against the doctrine of development as applied to solar systems and stellar galaxies is not in reality a sign, as they imagine, of humility, but is an effort to avoid the recognition of the nothingness of man in the presence of the infinities of space and time and vitality presented within the universe of God."[518]

Humboldt says—

"That arrogant spirit of incredulity, which rejects facts without attempting to investigate them, is in some cases almost more injurious than an unquestioning credulity. Both are alike detrimental to the force of investigations."[519]

With reference to the precession of the equinoxes and the changes it produces in the position of the Pole Star, it is stated in a recent book on science that the entrance passage of the Great Pyramid of Ghizeh is inclined at an angle of 30° to the horizon, and therefore points to the celestial pole. But this is quite incorrect. The Great Pyramid, it is true, is situated close to the latitude of 30°. But the entrance passage does not point exactly to the pole. The inclination was measured by Col. Vyse, and found to be 26° 45′. For six out of the nine pyramids of Ghizeh, Col. Vyse found an *average* inclination of 26° 47′, these inclinations ranging from 25° 55′ (2nd, or pyramid of Mycerinus) to 28° 0′ (9th pyramid).[520] Sir John Herschel gives 3970 B.C. as the probable date of the erection of the Great Pyramid.[520] At that time the distance of α Draconis (the Pole Star of that day) from the pole was 3° 44′ 25″, so that when on the meridian *below* the pole (its lower culmination as it is termed) its altitude was 30° - 3° 44′ 25″ = 26° 15′ 35″, which agrees fairly well with the inclination of the entrance passage. Letronne found a date of 3430 B.C.; but the earlier date agrees better with the evidence derived from Egyptology.

Emerson says—

> “I am brother to him who squared the pyramids
> By the same stars I watch.”

From February 6 to 15, 1908, all the bright planets were visible together at the same time. Mercury was visible above the western horizon after sunset, Venus very brilliant with Saturn a little above it, Mars higher still, all ranged along the ecliptic, and lastly Jupiter rising in the east.[521] This simultaneous visibility of all the bright planets is rather a rare occurrence.

With reference to the great improbability of Laplace’s original Nebular Hypothesis being true, Dr. See says, “We may calculate from the preponderance of small bodies actually found in the solar system—eight principal planets, twenty-five satellites (besides our moon), and 625 asteroids—that the chances of a nebula devoid of hydrostatic pressure producing small bodies is about 2^{658} to 1, or a decillion decillion $(10^{66})^{6}$ to the sixth power, to unity. This figure is so very large that we shall content ourselves with illustrating a decillion decillion, and for this purpose we avail ourselves of a method employed by ARCHIMEDES to illustrate his system of enumeration. Imagine sand so fine that 10,000 grains will be contained in the space occupied by a poppy seed, itself about the size of a pin's head; and then conceive a sphere described about our sun with a radius of 200,000 astronomical units[522] (α Centauri being at a distance of 275,000) entirely filled with this fine sand. The number of grains of sand in this sphere of the fixed stars would be a decillion decillion[523] $(10^{66})^6$. All these grains of sand against one is the probability that a nebula devoid of hydrostatical pressure, such as that which formed the planets and satellites, will lead to the genesis of such small bodies revolving about a greatly predominant central mass."[524] In other words, it is practically certain that the solar system was *not* formed from a gaseous nebula in the manner originally proposed by Laplace. On the other hand, the evolution of the solar system from a rotating spiral nebula seems very probable.

Some one has said that "the world knows nothing of its greatest men." The name of Mr. George W. Hill will probably be unknown to many of my readers. But the late Prof. Simon Newcomb said of him that he "will easily rank as the greatest master of mathematical astronomy during the last quarter of the nineteenth century."[525] Of Prof. Newcomb himself—also a great master in the same subject—Sir Robert Ball says he was "the most conspicuous figure among the brilliant band of contemporary American astronomers."[526]

An astronomer is supposed to say, with reference to unwelcome visitors to his observatory, "Who steals my purse steals trash; but he that filches from me my clear nights, robs me of that which not enriches him, and makes me poor indeed."[527]

Cicero said, "In the heavens there is nothing fortuitous, unadvised, inconstant, or variable; all there is order, truth, reason, and constancy"; and he adds, "The creation is as plain a signal of the being of a God, as a globe, a clock, or other artificial machine, is of a man."[528]

"Of all the epigrams attributed rightly or wrongly to Plato, the most famous has been expanded by Shelley into the four glorious lines—

> "'Thou wert the morning star among the living
>   Ere thy pure light had fled,

Now having died, thou art as Hesperus, giving
New splendour to the dead.'"[529]

Sir David Brewster has well said,[530] "Isaiah furnishes us with a striking passage, in which the occupants of the earth and the heavens are separately described, 'I have made the earth, and created man upon it: I, even My hands, have stretched out the heavens, and all *their* host have I commanded' (Isaiah xlv. 12). But in addition to these obvious references to life and things pertaining to life, we find in Isaiah the following remarkable passage: 'For thus saith the Lord that created the heavens; God Himself that formed the earth and made it; He hath established it, *He created it not* IN VAIN, He formed *it to be inhabited*' (Isaiah xlv. 18). Here we have a distinct declaration from the inspired prophet that the *earth would have been created* IN VAIN *if it had not been formed to be inhabited*; and hence we draw the conclusion that as the Creator cannot be supposed to have made the worlds of our system and those in the sidereal system in vain, they must have been formed to be inhabited." This seems to the present writer to be a good and sufficient reply to Dr. Wallace's theory that our earth is the only inhabited world in the Universe![531] Such a theory seems incredible.

The recent discovery made by Prof. Kapteyn, and confirmed by Mr. Eddington, of two drifts of stars, indicating the existence of *two* universes, seems to render untenable Dr. Wallace's hypothesis of the earth's central position in a single universe.[531]

NOTE ADDED IN THE PRESS.

While these pages were in the Press, it was announced, by Dr. Max Wolf of Heidelberg, that he found Halley's comet on a photograph taken on the early morning of September 12, 1909. The discovery has been confirmed at Greenwich Observatory. The comet was close to the position predicted by the calculations of Messrs. Cowell and

Crommelin of Greenwich Observatory (*Nature*, September 16, 1908).

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Footnotes:

[1] *Comptes Rendus*, 1903, December 7.

[2] *Nature*, April 11, 1907.

[3] *Astrophysical Journal*, vol. 19 (1904), p. 39.

[4] *Astrophysical Journal*, vol. 21 (1905), p. 260.

[5] *Knowledge*, July, 1902, p. 132.

[6] *Nature*, April 30, 1903.

[7] *Ibid.*, May 18, 1905.

[8] *Ibid.*, May 18, 1905.

[9] *Nature*, June 29, 1871.

[10] *Nature*, October 15, 1903.

[11] *The Life of the Universe* (1909), vol. ii. p. 209.

[12] *The World Machine*, p. 234.

[13] Quoted in *The Observatory*, March 1908, p. 125.

[14] *The Observatory*, September, 1906.

[15] *Nature*, March 1, 1900.

[16] *Cycle of Celestial Objects*, p. 96.

[17] *Ast. Nach.* No. 3737.

[18] *Observatory*, September, 1906.

[19] *Nature*, November 29 and December 20, 1894.

[20] *Bulletin, Ast. Soc. de France*, July, 1898.

[21] *Observatory*, vol. 8 (1885), pp. 306-7.

[22] *Nature*, October 30, 1902.

[23] Charles Lane Poor, *The Solar System*, p. 170.

[24] Smyth, *Celestial Cycle*, p. 60.

[25] Denning, *Telescopic Work for Starlight Evenings*, p. 225.

[26] *The Observatory*, 1894, p. 395.

[27] *Ast. Nach.* 4333, quoted in *Nature*, July 1, 1909, p. 20.

[28] *English Mechanic*, July 23, 1909.

[29] *Nature*, December 22, 1892.

[30] *Celestial Objects*, vol. i. p. 52, footnote.

[31] *Ibid.*, p. 54.

[32] *Astronomy and Astrophysics*, 1892, p. 618.

[33] *Nature*, August 7, 1879.

[34] *The World of Space*, p. 56.

[35] *Nature*, September 15, 1892.

[36] *Observatory*, 1880, p. 574.

[37] *Knowledge*, November 1, 1897, pp. 260, 261.

[38] *Worlds in the Making*, p. 61.

[39] *Ibid.*, p. 48.

[40] *Nature*, June 1, 1876.

[41] *Cel. Objects*, vol. i. p. 66 (5th Edition).

[42] *Celestial Objects*, vol. i. p. 65 (5th Edition).

[43] *Ast. Nach.* No. 1863.

[44] *Nature*, June 1, 1876.

[45] *Ibid.*, June 8, 1876.

[46] *Nature*, October 17, 1895.

[47] *Ibid.*, July 27, 1905.

[48] *Celestial Cycle*, p. 107.

[49] *Nature*, October 6, 1887.

[50] *Ast. Nach.*, No. 4106.

[51] *Copernicus*, vol. ii. p. 168.

[52] *Cosmos*, vol. iv. p. 476, footnote.

[53] Denning, *Telescopic Work for Starlight Evenings*, p. 153.

[54] *Ibid.*, p. 154.

[55] *Nature*, July 13, 1876.

[56] P. M. Ryves in *Knowledge*, June 1, 1897, p. 144.

[57] *Bulletin, Ast. Soc. de France*, August, 1905.

[58] *Nature*, April 5, 1894.

[59] *Nature*, May 14, 1896. Some have attributed these “luminous clouds” to light reflected from the dust of the Krakatoa eruption (1883).

[60] *The Observatory*, 1877, p. 90.

[61] *Popular Astronomy*, vol. 11 (1903), p. 293.

[62] *Popular Astronomy*, vol. 13 (1905), p. 226.

[63] *Nature*, July 25, 1901 (from Flammarion).

[64] *Popular Astronomy*, vol. 11 (1903), p. 496.

[65] *Kinetic Theories of Gravitation*, Washington, 1877.

[66] *The Observatory*, June, 1894, p. 208.

[67] *Nature*, June 8, 1899.

[68] *Astrophysical Journal*, vol. 14 (1901), p. 238, footnote.

[69] *Mars as the Abode of Life*, p. 52.

[70] Second Book of the Maccabees v. 1-4 (Revised Edition).

[71] Humboldt's *Cosmos*, vol. i. p. 169 (Otté's translation).

[72] Quoted by Grant in *History of Physical Astronomy*, p. 71.

[73] *Ibid.*, pp. 100, 101.

[74] *Exposition du Système du Monde*, quoted by Carl Snyder in *The World Machine*, p. 226.

[75] *Worlds in the Making*, p. 63.

[76] *Cosmos*, vol. i. p. 131.

[77] *The Observatory*, June, 1909, p. 261.

[78] *Astronomical Essays*, pp. 61, 62.

[79] *Encyclopædia Britannica* (*Schiraz*).

[80] *Monthly Notices*, R.A.S., February, 1905.

[81] *Nature*, March 3, 1870.

[82] *Ibid.*, March 31, 1870, p. 557.

[83] Prof. W. H. Pickering found 12 times (see p. 1).

[84] *Nature*, January 30, 1908.

[85] *Nature*, September 5, 1901.

[86] *Ibid.*, July 31, 1890.

[87] *Nature*, October 16, 1884.

[88] *Nature*, February 19, 1885.

[89] *Nature*, January 14, 1909, p. 323.

[90] *Photographic Atlas of the Moon, Annals of Harvard Observatory*, vol. li. pp. 14, 15.

[91] *Nature*, January 18, 1906.

[92] Humboldt's *Cosmos*, vol. iv. p. 481.

[93] *Ibid.*, p. 482.

[94] *Monthly Notices*, R.A.S., June, 1895.

[95] Humboldt's *Cosmos*, vol. iv. p. 483 (Otté's translation).

[96] Grant, *History of Physical Astronomy*, p. 229.

[97] *Popular Astronomy*, vol. xvii. No. 6, p. 387 (June-July, 1909).

[98] *Nature*, October 7, 1875.

[99] *Mars as an Abode of Life* (1908), p. 281.

[100] *Knowledge*, May 2, 1886.

[101] *Nature*, March 12, 1908.

[102] *Bulletin, Ast. Soc. de France*, April, 1899.

[103] *Astronomy and Astrophysics* (1894), p. 649.

[104] *Nature*, April 20, 1905.

[105] *Astrophysical Journal*, vol. 14 (1901), p. 258.

[106] *Nature*, August 22, 1907.

[107] *Popular Astronomy*, vol. 12 (1904), p. 679.

[108] *Mars as an Abode of Life*, p. 69.

[109] *Ibid.*, p. 146.

[110] *Worlds in the Making*, p. 49.

[111] *Worlds in the Making*, p. 53.

[112] Denning, *Telescopic Work for Starlight Evenings*, p. 158.

[113] *Ibid.*, p. 166.

[114] *Nature*, July 13, 1876.

[115] *Nature*, May 2, 1907.

[116] *Nature*, May 30, 1907.

[117] *Publications of the Astronomical Society of the Pacific*, August, 1908.

[118] *Monthly Notices*, R.A.S., 1902, p. 291.

[119] *Monthly Notices*, R.A.S., February, 1902, p. 291.

[120] *Nature*, May 24, 1894.

[121] *Ibid.*, February 14, 1895.

[122] *Ibid.*, September 14, 1905.

[123] *Ibid.*, September 21, 1905.

[124] *Ibid.*, September 28, 1905.

[125] *Ibid.*, July 13, 1905.

[126] *Nature*, November 3, 1898.

[127] *Ibid.*, July 14, 1881, p. 235.

[128] Quoted in *The Observatory*, February, 1896, p. 104, from *Ast. Nach.*, No. 3319.

[129] *Monthly Notices*, R.A.S., February, 1909.

[130] *Celestial Objects*, vol. i. p. 163.

[131] *Nature*, December 29, 1898.

[132] *Celestial Objects*, vol. i. p. 166.

[133] *Astrophysical Journal*, vol. 14 (1901), pp. 248-9.

[134] *Nature*, August 27, 1908.

[135] Webb's *Celestial Objects*, vol. i. p. 177.

[136] *Ibid.*, vol. i. p. 187.

[137] *Celestial Objects*, vol. i. p. 186.

[138] *Astronomy and Astrophysics*, 1892, p. 87.

[139] *Ibid.*, 1892, pp. 94-5.

[140] *Observatory*, December, 1891.

[141] *Popular Astronomy*, vol. 11 (1903), p. 574.

[142] *Ibid.*, October, 1908.

[143] *Bulletin, Ast. Soc. de France*, August, 1907.

[144] *Nature*, August, 29 1907.

[145] *Ibid.*, March 7, 1907.

[146] *Bulletin, Ast. Soc. de France*, June, 1904.

[147] *The Observatory*, October, 1903, p. 392.

[148] *Astronomy and Astrophysics*, 1894, p. 277.

[149] *Nature*, November 18, 1897.

[150] *Journal*, B.A.A., January, 1907.

[151] *Journal*, B.A.A., February, 1909, p. 161.

[152] *Cosmos*, vol. ii. p. 703.

[153] *Ibid.*

[154] Denning, *Telescopic Work for Starlight Evenings*, p. 349.

[155] *Cosmos*, vol. iii. p. 75.

[156] *Journal*, B.A.A., June, 1896.

[157] *Celestial Objects*, vol. i. p. 191.

[158] *Nature*, May 30, 1901.

[159] *Bulletin, Ast. Soc. de France*, August, 1900.

[160] *Astronomy and Astrophysics*, 1892.

[161] *Astrophysical Journal*, January, 1908, p. 35.

[162] *Nature*, May 22, 1902.

[163] *Ibid.*, July 9, 1903.

[164] *Ibid.*, July 16, 1903.

[165] *Nature*, September 24, 1903.

[166] *Ibid.*, October 8, 1903.

[167] *Astrophysical Journal*, vol. 26 (1907), p. 60.

[168] *Nature*, January 30, 1908.

[169] *Ibid.*, October 15, 1908.

[170] *Ibid.*, October 29, 1908.

[171] *Journal*, B.A.A., March, 1908, and June 22, 1908.

[172] *Nature*, June 25, 1903.

[173] *Bulletin, Ast. Soc. de France*, June, 1904.

[174] *Pop. Ast.*, vol. 12, pp. 408-9.

[175] *Nature*, August 29, 1889.

[176] *Astrophysical Journal*, vol. 26 (1907), p. 62.

[177] *Bulletin, Ast. Soc. de France*, January, 1904.

[178] Humboldt's *Cosmos*, vol. iv. p. 532.

[179] *Copernicus*, vol. ii. p. 64.

[180] *Knowledge*, May, 1909.

[181] *Journal*, British Astronomical Association, January, 1909, p. 132.

[182] *Ast. Nach.*, No. 4308.

[183] *History of Physical Astronomy*, p. 204.

[184] Smyth's *Celestial Cycle*, pp. 210, 211.

[185] Poor, *The Solar System*, p. 274.

[186] *Celestial Cycle*, p. 246.

[187] *Nature*, October 2, 1879.

[188] *Ibid.*, May 6, 1880.

[189] *Ibid.*, February 19, 1880.

[190] *Nature*, September 30, 1897.

[191] *Nature*, August 5, 1875.

[192] *Ibid.*, October 12, 1882, and *Copernicus*, vol. iii. p. 85.

[193] *Nature*, May 8, 1884.

[194] *Ibid.*, June 16, 1887.

[195] *Journal*, B.A.A., December 13, 1901.

[196] *Nature*, September 20, 1900.

[197] *Ast. Nach.*, No. 3868, and *Nature*, March 12, 1903.

[198] *Nature*, November 13, 1908.

[199] *Nature*, December 7, 1905.

[200] *Celestial Cycle*, p. 259.

[201] *Celestial Cycle*, p. 260.

[202] *Journal*, B.A.A., April, 1907.

[203] *Monthly Notices*, R.A.S., March, 1908.

[204] *Celestial Cycle*, p. 231.

[205] *Journal*, B.A.A., July, 1908.

[206] *Popular Astronomy*, October, 1908.

[207] *Cape Obs.*, p. 401.

[208] *Nature*, July 2, 1908.

[209] *Journal*, B.A.A., January 20, 1909, pp. 123-4.

[210] Chambers' *Handbook of Astronomy*, Catalogue of Comets.

[211] Seneca, quoted by Chambers, *Handbook*, vol. i. p. 554 (Fourth Edition).

[212] *Ibid.*

[213] *Ibid.*

[214] *Ibid.*, p. 534.

[215] *Ibid.*

[216] Ma-tuoan-lin, quoted by Chambers, *Handbook*, p. 570.

[217] *Astronomy and Astrophysics*, 1893, p. 798.

[218] *The Observatory*, October, 1898.

[219] Grant's *History of Physical Astronomy*, p. 293.

[220] *Ibid.*, p. 294.

[221] Humboldt's *Cosmos*, vol. i. pp. 89, 90 (Otté's translation).

[222] *Celestial Objects*, vol. i. p. 211, footnote.

[223] Denning, *Telescopic Work for Starlight Evenings*, p. 248.

[224] *Ibid.*, p. 248.

[225] *Ibid.*, p. 250.

[226] *Ibid.*, p. 231.

[227] Vol. iii. p. 106.

[228] Grant's *History of Physical Astronomy*, p. 298.

[229] *Ibid.*, p. 305.

[230] Humboldt's *Cosmos*, vol. i. p. 95.

[231] *Nature*, April 30, 1908.

[232] *Bulletin, Ast. Soc. de France*, May, 1906.

[233] *Nature*, November 24, 1904.

[234] *Ibid.*, September 10, 1896.

[235] *Ibid.*, June 29, 1893.

[236] *Journal*, B.A.A., May 22, 1903.

[237] *Nature*, December 13, 1906, p. 159.

[238] *Nature*, September 13, 1906.

[239] *Nature*, October 12, 1905, p. 596.

[240] *Knowledge*, January 13, 1882.

[241] *Ibid.*, January 20, 1882.

[242] *Popular Astronomy*, June-July, 1908, p. 345.

[243] *The Observatory*, March, 1896, p. 135.

[244] *The Observatory*, February, 1900, pp. 106-7.

[245] *Knowledge*, March, 1893, p. 51.

[246] *Ibid.*, July 3, 1885, p. 11.

[247] *Cosmos*, vol. i. p. 108 (Otté's translation).

[248] *Ibid.*, vol. i. p. 124.

[249] *Ibid.*, vol. i. p. 119, footnote.

[250] *Copernicus*, vol. i. p. 72.

[251] *Ibid.*

[252] *Astrophysical Journal*, June, 1909, pp. 378-9.

[253] *Knowledge*, July, 1909, p. 264.

[254] Quoted by Miss Irene E. T. Warner in *Knowledge*, July, 1909, p. 264.

[255] *The Observatory*, November, 1900.

[256] Or, "Before the phantom of false morning died" (4th edition); *The Observatory*, September, 1905, p. 356.

[257] *The Observatory*, July, 1896, p. 274.

[258] *Journal*, B.A.A., January 24, 1906.

[259] *Ast. Soc. of the Pacific*, December, 1908, p. 280.

[260] *Nature*, November 1, 1906.

[261] *Ibid.*, November 22, 1906, p. 93.

[262] *Nature*, August 30, 1906.

[263] *Cosmos*, vol. i. p. 131, footnote.

[264] *Nature*, December 16, 1875.

[265] *Ibid.*, July 23, 1891.

[266] *Bulletin, Ast. Soc. de France*, April, 1903.

[267] *Bulletin, Ast. Soc. de France*, April, 1903.

[268] *The Observatory*, May, 1896. The italics are Brenner's.

[269] *Cosmos*, vol. iv. p. 563.

[270] For details of this enumeration, see *Astronomical Essays*, p. 222.

[271] *Nature*, June 11, 1908.

[272] *Popular Astronomy*, vol. 14 (1906), p. 510.

[273] *Bedford Catalogue*, p. 532.

[274] *Popular Astronomy*, vol. 15 (1907), p. 194.

[275] *Popular Astronomy*, vol. 15 (1907), p. 195.

[276] *Bulletin, Ast. Soc. de France*, February, 1903.

[277] Here χ is probably 17 Cygni, χ being the famous variable near it.

[278] *Popular Astronomy*, vol. 13 (1904), p. 509.

[279] *Astrophysical Journal*, December, 1895.

[280] *The Observatory*, July, 1895, p. 290.

[281] *Celestial Cycle*, p. 302.

[282] *Nature*, December 13, 1894.

[283] *Histoire Celeste*, p. 211.

[284] *Nature*, October, 1887.

[285] *Ibid.*, August 29, 1889.

[286] *Science Abstracts*, February 25, 1908, pp. 82, 83.

[287] *Bedford Catalogue*, pp. 227-8.

[288] *Knowledge*, February 1, 1888.

[289] *Celestial Cycle*, p. 280.

[290] *Popular Astronomy*, February, 1904.

[291] *Ibid.*, vol. 15 (1907), p. 444.

[292] *Journal*, B.A.A., June, 1899.

[293] *Astrophysical Journal*, vol. 8 (1898), p. 314.

[294] *Astrophysical Journal*, vol. 8, p. 213.

[295] *Ibid.*, vol. 17, January to June, 1902.

[296] *Astronomy and Astrophysics*, 1894, pp. 569-70.

[297] *The Study of Stellar Evolution* (1908), p. 171.

[298] *Astrophysical Journal*, January, 1905.

[299] *Journal*, B.A.A., June, 1901.

[300] *Ast. Soc. of the Pacific*, December, 1908.

[301] *The Observatory*, November, 1902, p. 391.

[302] *Cosmos*, vol. iv. p. 567 (Otté's translation).

[303] *Journal*, B.A.A., February, 1898.

[304] *The Observatory*, April, 1887.

[305] *Evangeline*, Part the Second, III.

[306] *Legend of Robert, Duke of Normandy.*

[307] *Copernicus*, vol. iii. p. 231.

[308] *Ibid.*, p. 61.

[309] *Cosmos*, vol. i. p. 142.

[310] These apertures are computed from the formula, minimum visible = 9 + 5 log. aperture.

[311] *Cosmos*, vol. iii. p. 73.

[312] *Darwin and Modern Science*, p. 563.

[313] *Journal*, B.A.A., October, 1895.

[314] Burnham's *General Catalogue of Double Stars*, p. 494.

[315] *Journal*, B.A.A., November 18, 1896.

[316] *Ibid.*, B.A.A., January, 1907.

[317] *Studies in Astronomy*, p. 185.

[318] *Knowledge*, June, 1891.

[319] Seen by Drs. Ludendorff and Eberhard, *The Observatory*, April, 1906, p. 166, quoted from *Ast. Nach.*, No. 4067.

[320] *The Observatory*, January, 1907, p. 61.

[321] *Astronomy and Astrophysics*, 1894.

[322] Smyth's *Celestial Cycle*, p. 223.

[323] *Nature*, February 7, 1907.

[324] *Ibid.*, March 19, 1908.

[325] *Popular Astronomy*, vol. 15 (1907), p. 9.

[326] *Astrophysical Journal*, June, 1907, p. 330.

[327] *Ibid.*, vol. 22, p. 172.

[328] *Nature*, November 18, 1886.

[329] *Astrophysical Journal*, vol. 17 (1903), p. 282.

[330] *Astrophysical Journal*, vol. 12 (1900), p. 54.

[331] *Nature*, March 21, 1878.

[332] *Bulletin, Ast. Soc. de France*, June, 1904.

[333] *Journal*, B.A.A., vol. 17 (1903), p. 282.

[334] *Nature*, June 20, 1909.

[335] *The Observatory*, vol. 7 (1884), p. 17.

[336] *The Observatory*, vol. 14 (1891), p. 69.

[337] *Astronomy and Astrophysics*, 1896, p. 54

[338] *Nature*, August 28, 1902.

[339] *Astrophysical Journal*, October, 1903.

[340] *Nature*, May 30, 1907.

[341] *Popular Astronomy*, February, 1909, p. 125.

[342] *The Observatory*, May, 1907, p. 216.

[343] *Astrophysical Journal*, May, 1907.

[344] *Histoire de l'Astronomie Moderne*, vol. i. pp. 185-6.

[345] Humboldt's *Cosmos*, vol. iii. p. 210 (Otté's translation).

[346] *Ibid.*, vol. iii. pp. 213-14.

[347] J. C. Duncan, *Lick Observatory Bulletin*, No. 151.

[348] *Astrophysical Journal*, vol. 17, p. 283.

[349] *The Origin of the Stars*, p. 143.

[350] *Ibid.*, p. 135.

[351] Quoted by Ennis in *The Origin of the Stars*, p. 133.

[352] *Astrophysical Journal*, vol. 20 (1904), p. 357.

[353] *Nature*, March 8, 1906.

[354] *Astronomical Society of the Pacific*, August, 1908.

[355] *Astronomy and Astrophysics*, 1894, p. 812.

[356] *The Observatory*, May, 1905.

[357] This is a misquotation. See my *Astronomical Essays*, p. 135.

[358] *Nature*, February 3, 1870.

[359] *Bedford Catalogue*, p. 14.

[360] *Ibid.*, p. 307.

[361] *Astrophysical Journal*, vol. 14, p. 37.

[362] *Ibid.*, vol. 9, p. 149.

[363] *Nature*, July 20, 1899.

[364] *Ast. Nach.*, No. 3476.

[365] *Astronomische Nachrichten*, No. 4213.

[366] *Astrophysical Journal*, vol. 9, p. 149.

[367] *Cape Observations*, p. 61.

[368] *Ibid.*, p. 85.

[369] *Cape Observations*, p. 98.

[370] *Transactions*, Royal Dublin Society, vol. 2.

[371] *Ast. Nach.*, 3628, quoted in *The Observatory*, April, 1900.

[372] *Nature*, April 8, 1909.

[373] *Problems in Astrophysics*, p. 477.

[374] *Ibid.*, p. 499.

[375] *Copernicus*, vol. iii. p. 55.

[376] *Lick Observatory Bulletin*, No. 149.

[377] *Ibid.*

[378] *Ibid.*

[379] *Monthly Notices*, R.A.S., April, 1908, pp. 465-481.

[380] *Lick Observatory Bulletin*, No. 155 (February, 1909).

[381] *Outlines of Astronomy*, par. 870 (Edition of 1875).

[382] *Georgics*, i. II. 217-18.

[383] See paper by Mr. and Mrs. Maunder in *Monthly Notices*, R.A.S., March, 1904, p. 506.

[384] *Primitive Constellations*, vol. ii. p. 143.

[385] *Recherches sur l'Histoire de l'Astronomie Ancienne*, by Paul Tannery (1893), p. 298.

[386] *Primitive Constellations*, vol. ii. p. 225.

[387] *Nature*, October 2, 1890.

[388] Lalande's *Astronomie*, vol. i. pp. 243-4.

[389] Lalande's *Astronomie*, vol. i. pp. 242-3.

[390] There are three copies of Al-Sufi's work in the Imperial Library at Paris, but these are inaccurate. There is also one in the British Museum Library, and another in the India Office Library; but these are imperfect, considerable portions of the original work being missing.

[391] *Harvard Annals*, vol. ix. p. 51.

[392] The science of the risings and settings of the stars was called *ilm el-anwa* (Caussin, *Notices et Extraits des Manuscrits de la Bibliothèque due Roi*, tome xii. p. 237).

[393] See Mr. E. B. Knobel's papers on this subject in the *Monthly Notices*, R.A.S., for 1879 and 1884.

[394] In reading this chapter the reader is recommended to have a Star Atlas beside him for reference; Proctor's smaller Star Atlas will be found very convenient for this purpose. On the title-page of this useful work the author quotes Carlyle's words, "Why did not somebody teach me the constellations and make me at home in the starry heavens which are always overhead, and which I don't half know to this day?"

[395] *Bedford Catalogue*, p. 29.

[396] *Cosmos*, vol. iii. p. 87.

[397] *Heavenly Display*, 579-85.

[398] *Bedford Catalogue*, p. 385.

[399] Lalande's *Astronomie*, vol. iv. p. 529.

[400] Lalande's *Astronomie*, vol. i. pp. 268-9.

[401] *Primitive Constellations*, vol. i. p. 48.

[402] *Bedford Catalogue*, pp. 27, 28.

[403] Lalande's *Astronomie*, vol. iv. p. 492.

[404] *Bedford Catalogue*, p. 120.

[405] *Primitive Constellations*, vol. i. p. 143.

[406] Perseus.

[407] *Heavenly Display*, 254-8, 261-5, quoted by Brown in *Primitive Constellations*, vol. i. p. 274.

[408] Lalande's *Astronomie*, vol. iv. p. 493.

[409] *Primitive Constellations*, vol. i. p. 292.

[410] *Paradiso*, xxii. 111.

[411] Lalande's *Astronomie*, vol. iv. p. 493.

[412] *Bedford Catalogue*, p. 225.

[413] *Nature*, April 6, 1882.

[414] *Primitive Constellations*, vol. i. p. 68.

[415] *Ibid.*, vol. i. p. 71.

[416] *Bibliographie Gènèrale de l'Astronomie*, vol. i. Introduction, pp. 131, 132.

[417] Lalande's *Astronomie*, vol. i. p. 296.

[418] *Primitive Constellations*, vol. i. p. 74.

[419] *Cape Observations*, p. 116.

[420] *Metamorphoses*, xv. 371.

[421] Lalande's *Astronomie*, vol. iv. p. 487.

[422] *Monthly Notices*, R.A.S., April 14, 1848.

[423] *Prim. Const.*, vol. ii. p. 45.

[424] Lalande's *Astronomie*, pp. 472-3.

[425] Lalande's *Astronomie*, vol. iv. p. 485.

[426] This star is not shown in Proctor's small Atlas, but it lies between μ and ν, nearer to μ.

[427] Lalande's *Astronomie*, vol. i. p. 247.

[428] Lalande's *Astronomie*, vol. iv. p. 489.

[429] *Primitive Constellations*, vol. i. p. 91.

[430] *Memoirs*, R.A.S., vol. xiii. 61.

[431] *Monthly Notices*, R.A.S., June, 1895.

[432] Lalande's *Astronomie*, vol. i. p. 274.

[433] *Primitive Constellations*, vol. i. p. 143.

[434] *Primitive Constellations*, vol. i. p. 278.

[435] Lalande's *Astronomie*, vol. iv. p. 468.

[436] *Quæst. Nat.*, Lib. 1, Cap. I. § 6; quoted by Dr. See. "Canicula" is Sirius, and "Nartis," Mars.

[437] *Astronomy and Astrophysics*, vol. 11, 1892.

[438] *The Observatory*, April, 1906, p. 175.

[439] Houzeau, *Bibliographie Gènèrale de l'Astronomie*, vol. i., Introduction, p. 129.

[440] *English Mechanic*, March 25, 1904, p. 145.

[441] Humboldt's *Cosmos*, vol. iii. p. 185, footnote (Otté's translation).

[442] Lalande's *Astronomie*, vol, i. p. 277.

[443] This was pointed out by Flammarion in his work *Les Étoiles*, page 532; but his identifications do not agree exactly with mine.

[444] See Proctor's Map 7, now x.

[445] *Primitive Constellations*, vol. i. p. 106.

[446] Lalande's *Astronomie*, vol. i. p. 278.

[447] Lalande's *Astronomie*, vol. iv.

[448] *Primitive Constellations*, vol. i. p. 112.

[449] *Ibid.*, vol. i. p. 113.

[450] Lalande's *Astronomie*, vol. i.

[451] W. T. Lynn in *The Observatory*, vol. 22, p. 236.

[452] *Knowledge*, May 1, 1889. Sir John Herschel, however, gives 3970 B.C.

[453] *The Observatory*, November 1907, p. 412.

[454] This is not, however, *invariably* the case, as pointed out by Mr. Denning in *The Observatory*, 1885, p. 340.

[455] *The Observatory*, vol. 8 (1885), pp. 246-7.

[456] *Harvard College Observatory Annals*, vol. xlviii. No. 5.

[457] *Popular Astronomy*, vol. 15 (1907), p. 529.

[458] *Cape Observations*, p. 77.

[459] *Monthly Notices*, R.A.S., March, 1899.

[460] *Nature*, February 13, 1890.

[461] *Popular Astronomy*, vol. 15 (1907), p. 530.

[462] *Photographs of Star-Clusters and Nebulæ*, vol. ii. p. 17.

[463] *Monthly Notices*, R.A.S., May 9, 1856.

[464] *Astrophysical Journal*, vol. 25 (1907), p. 219.

[465] *Popular Astronomy*, vol. 11 (1903), p. 293.

[466] Translated by W. H. Mallock, *Nature*, February 8, 1900, p. 352.

[467] Howard Payn, *Nature*, May 16, 1901, p. 56.

[468] Howard Payn, *Nature*, May 16, 1901, p. 56.

[469] *Contributions from the Mount Wilson Solar Observatory*, No. 31.

[470] Quoted by Denning in *Telescopic Work for Starlight Evenings*, p. 297.

[471] *Astrophysical Journal*, March, 1895.

[472] *Outlines of Astronomy*, Tenth Edition, p. 571.

[473] *Astrophysical Journal*, vol. 12, p. 136.

[474] *De Placitis.* Quoted by Carl Snyder in *The World Machine* p. 354.

[475] *Popular Astronomy*, vol. 14 (1906), p. 638.

[476] Article on "The Greek Anthology," *Nineteenth Century*, April, 1907, quoted in *The Observatory*, May, 1907.

[477] *Popular Astronomy*, vol. 13 (1905), p. 346.

[478] *Bulletin de la Soc. Ast. de France*, April, 1908.

[479] *The Observatory*, vol. 11, p. 375.

[480] Grant, *History of Physical Astronomy*, p. 364.

[481] *Ibid.*, p. 377.

[482] *Ibid.*, p. 366.

[483] *Ibid.*, p. 367.

[484] Grant, *History of Physical Astronomy*, p. 370.

[485] *Nature*, July 25, 1889.

[486] *Cosmos*, vol. iv. p. 381.

[487] *Cosmos*, vol. iv. pp. 381-6.

[488] *Ibid.*, vol. i. p. 121.

[489] *The Observatory*, vol. 6 (1883), pp. 327-8.

[490] *Nature*, June 25, 1874.

[491] *Popular Astronomy*, May, 1895, "Reflectors or Refractors."

[492] Denning, *Telescopic Work for Starlight Evenings*, p. 225.

[493] *Nature*, November 2, 1893.

[494] *Telescopic Work*, p. 226.

[495] *Copernicus*, vol. i. p. 229.

[496] Grant, *History of Physical Astronomy*, p. 433.

[497] *Cosmos*, vol. ii. p. 699.

[498] Grant, *History of Physical Astronomy*, p. 536, footnote.

[499] *Bedford Catalogue*, p. 179.

[500] *The Observatory*, July, 1891.

[501] *Nature*, September 3, 1903.

[502] *Cosmos*, vol. ii. p. 669.

[503] *The World Machine*, p. 80.

[504] *Ibid.*, p. 89.

[505] Grant, *History of Physical Astronomy*, p. 107.

[506] Grant, *History of Physical Astronomy*, p. 113.

[507] *Nature*, August 11, 1898.

[508] *Ibid.*, August 18, 1898.

[509] *Ibid.*, October 20, 1898.

[510] *The Observatory*, vol. iv. (1881), p. 234.

[511] W. T. Lynn, *The Observatory*, July, 1909, p. 291.

[512] Quoted in *The Observatory*, July, 1902, p. 281.

[513] *Astrophysical Journal*, vol. 6, 1897, p. 304.

[514] *Celestial Cycle*, p. 367.

[515] *The Observatory*, vol. 5 (1882), p. 251.

[516] Quoted by Humboldt in *Cosmos*, vol. ii. p. 696, footnote.

[517] Quoted by Denning in *Telescopic Work*, p. 347.

[518] *Knowledge*, February 20, 1885, p. 149.

[519] Humboldt's *Cosmos*, vol. i. p. 123.

[520] *Outlines of Astronomy*, par. 319; edition of 1875.

[521] *Bulletin de la Soc. Ast. de France*, March, 1908, p. 146.

[522] An "astronomical unit" is the sun's mean distance from the earth.

[523] This is on the American and French system of notation, but on the English system, $10^{66} = 10^{60} \times 10^{6}$ would be a million decillion.

[524] *Astronomical Society of the Pacific*, April, 1909 (No. 125), and *Popular Astronomy*, May, 1909.

[525] *Nature*, July 22, 1909.

[526] *Ibid.*

[527] *The Observatory*, vol. 9 (December, 1886), p. 389.

[528] *De Nat. Deorum*, quoted in Smyth's *Cycle*, p. 19.

[529] *The Observatory*, May, 1907.

[530] *More Worlds than Ours*, p. 17.

[531] *Man's Place in Nature.*

Transcriber's Notes:

Foonote 48 appears on page 28 of the text, but there is no corresponding marker on the page.

Foonote 448 appears on page 295 of the text, but there is no corresponding marker on the page.

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