Tony Fairall - AST 1000F - PART 1
EARLY BELIEFS AND THE HISTORICAL DEVELOPMENT OF ASTRONOMICAL KNOWLEDGE

Over the history of mankind, discoveries in astronomy have been seen as much more than mere 'scientific events' - they often had profound effects on society, and led to mystical and religious beliefs. Until very recently, what appeared in the sky above was remote and untouchable - and, understandably, the sky was often considered the realm of the supernatural.

ANCIENT ASTRONOMY

The influence of the Sun is obvious. It controls our daily lives and it is not surprising that numerous early civilisations adopted forms of Sun worship. In extreme forms, the Mexicans made human sacrifices to ensure the rising of the Sun. Many civilisations adopted sunrise as the beginning of the day, some others (eg Jewish) at sunset. The Babylonians divided the day into twelve hours and the night into twelve hours, the origin of our 24-hour day.

But aside from its daily cycle, there is also the annual cycle of the Sun. Apart from religious beliefs, there was the practical aspect relating to the planting of crops that had to relate to seasonal rainfall etc. Thus many civilisations sought to follow an annual calendar - though without any accurate knowledge of how many days there should be in a year. That calendar could be found in the sky - the most obvious indication being the cycle of constellations visible in the evening sky. This was the system used in much of sub-Saharan Africa, for example, where the conspicuous Isilemela (Pleiades) star cluster was frequently used as a calendar. As with other star patterns close to the Sun's apparent path in the sky, Isilimela would disappear into the Sun's glare for several weeks. They would re-emerge at the same time each year, from the twilight in the early morning. In southern Africa, that 'helical rising' marked the start of a new agricultural year, when fields must be dug and prepared for a new crop. The visibility of the cluster in the evening sky coincided with the growing season - and their disappearance from the sky (in March-April) generally represented the end of the rainy season. Almost all early civilisations had knowledge of the starry constellations and gave the stars names. It was common for the pattern or individual stars to represent creatures of Earth. The bushmen, for instance, took the three stars of the "Belt of Orion" to represent three Zebra.

In time, the Egyptians perfected this reoccurrence of constellations. Egypt has little rainfall but crops are grown after the annual flooding of the Nile. The flooding came only days after the helical rising of the bright star Sirius, thus the positions of the stars were monitored with some precision, for calendar purposes. There was also an association with deities. Sirius is believed to represent Isis, faithful companion to Osiris (Orion). In legend, she had to search the world, after the destruction of Osiris, to gather his pieces together and restore him. She is thus portrayed as a healer or restorer. The Great Pyramid of Khofu has a number of narrow shafts radiating from its central chambers, apparently to direct the spirit of the dead pharoah towards the stars. These are alligned towards Orion, Sirius and the North Celestial Pole. The pyramid itself is very accurately orientated north-south - presumably from astronomical observations. All Egyptian pyramids have their four faces alligned with the four cardinal points, even though the ancient Egyptians knew nothing of a spherical Earth and a North pole. The directions came from the sky above, not the ground below.

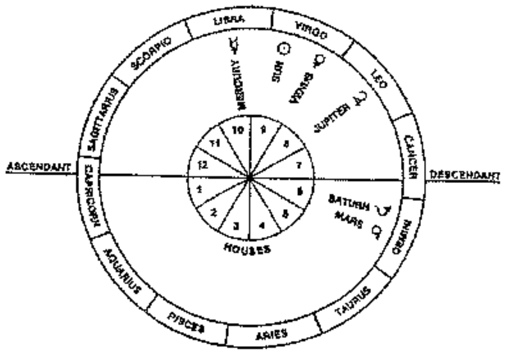
An alternative system of calendar keeping is apparent in Western Europe. The annual north- south cycle of the Sun can be measured by the shift in the rising (or setting) point on the eastern (or western) horizon. Observatories such as Stonehenge I (c 3000 BC) could fix the times of the midsummer and midwinter solstices to almost a day. Stonehenge I also investigated the rising and setting of the Moon, and was for its time a sophisticated attempt to record and measure the solar and lunar cycles. It may have even recorded the period of 18.6 years for the line of nodes to rotate (where the plane of the Moon's orbit around the Earth intersects the plane of the Earth's orbit about

The Sun rises over the Heelstone on the day of the summer solstice when seen from the center of the ring of stones.

the Sun - see Practical Session 4). There may be some astronomy incorporated in the elaborate structures of Stonehenge III (c. 2000 BC) - the twenty-nine and a half openings in the Sarcen circle may represent the period of the Moon. The celebration of the passing of the mid-winter Solstice in the northern hemisphere similarly dates back to antiquity.

A more detailed understanding of the Sun's annual movement developed in Mesopotamia, where it was appreciated that the Sun followed an annual cycle against the starry background. Of course, it is not possible to observe the starry background behind the bright disk of the Sun. However, the astronomers of the time took careful note of what constellations were visible, once it became dark, at the point where the Sun had set. Similarly they observed the sky at the point where the Sun would rise. In this way the accurately tracked the path of the Sun around the sky and recognised that there were approximately 360 days in a year (the origin of our modern 360 degrees in a circle). Their quest, however, was far from scientific. Rather, their religious beliefs held that the Sun was the most powerful and influential god. By tracking the course of this god, they hoped to foretell the fate of civilisations on Earth. It was believed to interact with the mystical quantities of the constellations. There were lesser gods as well and the ancient astrologers of Babylon identified the planets (wanderers) with these gods - the names are still carried today - as well as the Moon.

The seven moving heavenly bodies were also ranked from the slowest moving to the fastest (Saturn, Jupiter, Mars, Sun, Venus, Mercury, Moon). They also gave rise to the seven day week. Each hour of the week was watched over by one of the bodies, Saturn taking the 1st, 8th, 15th and 22nd hours, Jupiter (second slowest) taking the 2nd, 9th hours etc. of the first day (Saturn's Day). The first hour of the second day belonged to the Sun (hence Sun Day), that of the third day to the Moon, fourth day to Mars, fifth day to Mercury, sixth day to Jupiter and seventh day to Venus. The last hour of the seventh day belonged to the Moon, after which the sequence restarted.



Though originally, "astrology" was intended to predict the well being or otherwise of nations, in time it was extended to individuals, particularly kings. The chief attribute is the "birth sign" - the constellation in which the Sun god is situated at the moment of birth. (Of course we now know the Sun is not a god but an ordinary star, and the notion that it could interact with distant stars to control the destiny of any individual on Earth is totally absurd.) However the system was elaborated to include the influences of the planet gods as well, in terms of where they were situated

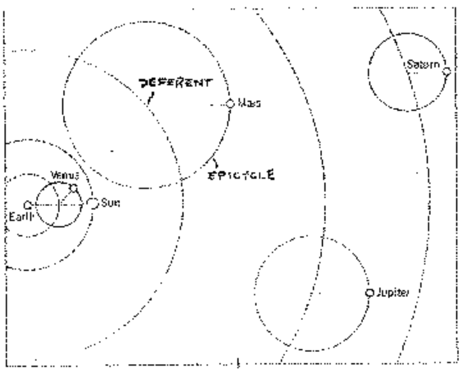
and the geometric angles between them. In addition the rising (ascendant) and setting (descendant) points of the Sun's path in the sky were used to establish a system of twelve "houses", each of which concerned aspects such as health, travel etc. The system was apparently perfected by the Babylonian astrologers around 500 B.C., since the "signs of the Zodiac" then matched the constellations they represent - they no longer do so today.
The whole idea might have died out but for its enthusiastic reception by the early Roman emperors (who obviously saw it as a celestial endorsement of their importance). Prominent citizens followed the emperor's example and soon a whole now industry had been established. Although astrology runs in conflict with Christian, Jewish and Muslim theology, its popularity nevertheless increased. This heritage, particularly from Roman times has been passed down through the ages and many European astronomers, of the 16 and 17th centuries, were practising astrologers as well.
While the Romans contributed little if any to the science of astronomy, Emperors Caesar and Augustus did reform the calendar (and are commemorated by the months July and August) and introduced the system of leap years every fourth year to keep the seasons in synchronisation with the calendar years (the Julian Calendar). But months in the Roman calendar were no longer true cycles of the Moon, but followed the Egyptian practice of forcing exactly twelve months in a year. The months we use today are derived from the Julian Calendar which also went along with changing the start of the year from March to January (the beginning of the financial year in the Roman civil service). We still retain the names September to December, though they are no longer the seventh to tenth months.
Other calendars have paid recognition to the true month, the cycle of changes in the Moon's phase over 29.5 days. The Moslem calendar runs in cycle with the Moon, and its year is 12 X 29.5 = 254 days, shorter than the Roman year. The Jewish calendar works on the Metonic cycle whereby 19 seasonal years are almost exactly 235 true months. Over the cycle, some years are 12 months long, other 13 months.
Astrology persists, even thrives, in modern times. It satisfies the psychological needs of individuals and therefore is commercially viable. A considerable industry flourishes, although it has no scientific basis - nor would it be expected to have any! Astrology is "anti-science", though many of its promoters may claim otherwise. Curiously, up to 1930, very few newspapers printed astrological horoscopes, but the journalistic success of a horoscope prediction at the birth of Princess Margaret of Britain, led to its spread.
Very sadly, only a few hundred thousand people on the planet today can claim some familiarity with the constellations of the night sky, whereas hundreds of millions of people are familiar with the "signs of the zodiac". Nowadays, many can say what (Sun) sign they were born under, but the precession of the Earth's axis (covered later in this course) has, since Babylonian times, generally shifted the dates of the Sun by one sign. For instance those who think they are born under Taurus, are more likely born when the Sun was in Aries!

GREEK ASTRONOMY

The Greeks were the first civilisation to make a 'scientific' study of nature and the celestial bodies. The tool of Greek science was largely geometry, coupled with the recognition of what were considered to be perfect shapes and perfect numbers as championed by Pythagoras.
Pythagoras (~ 500 BC), Aristotle (~ 350 BC) & Eratosthenes (~ 210 BC) believed the earth to be spherical. Eratosthenes measured its diameter by comparing shadow lengths of different places. His value happened to come out within 1 % of the true value (whereas years later, Columbus set off sailing westwards in the belief that the circumference of the Earth was only 60% of its true value). Although Aristotle considered a heliocentric solar system, he rejected it because of the absence of stellar parallax. He was also aware that the earth could be spinning and thus account for the rotation of the celestial sphere, but he rejected this possibility.

Aristarchus of Samos (-250 BC) is reported to have believed that the earth revolves around the sun. Thus the Greek approach was very much more scientific, though obsessed with perfect geometric forms - particularly circles - in interpretation. Undoubtedly, the greatest developments were made by Hipparchus (~140 BC). He produced a star map with most of the constellations and the magnitude system recognised today. He accurately determined the intervals between equinoxes and the effects of precession, as well as the length of the year.

THE PTOLEMAIC SYSTEM

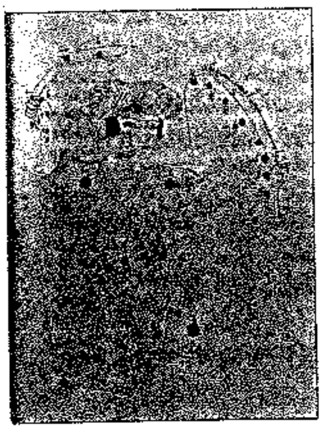


Retrograde motions and the layout of a geocentric model. To account for the observed sizes of the retrograde loops, the small circles carrying the planets outside the sun decrease in size, so that Mars has the largest and Saturn the smallest. The radii of these circles must align with the earth–sun radius for the retrograde motions to occur only at opposition. The center of its small circle for Venus must lie on the earth–sun line.

Ptolemy (~140 AD) built a scheme largely resting on Hipparchus' ideas that attempted to explain the complex wanderings of the planets in terms of perfect circular motions. It was of course an Earth-centred (Geocentric) picture.
The Moon and Sun followed perfectly circular orbits about the Earth, the Moon orbiting in 27.3 days and the Sun in a year. The "deferent" of a planet also followed a circular orbit in an interval we would now recognise as the sidereal period (the time now known for a planet to orbit the Sun). Each planet then followed around an "epicycle" - a second perfectly circular orbit in an interval we would now recognise as the synodic period (time between closest approaches to Earth).
Such a scheme appears to explain the gross movements of the Sun, Moon and Planets. Ptolemy incorporated it, together with much of the knowledge of Greek astronomy, in a 13 volume work called the Snytaxis.

ASTRONOMY IN THE NEAR EAST

Astrology still flourished in Mesopotamia - possibly the home of the three wise men who supposedly followed the star of Bethlehem, as described only in the gospel known as St. Matthew. There has been much debate as to the nature of the star, since we know from Chinese and Korean records that there was no bright star in the sky around the time when Christ was born (c. 6-4 BC). Some have suggested the "star" to have been a conjunction of planets - but that smacks strongly of astrology.


A


B

The heritage of Greek scientific work was taken up by numerous Arabic scholars. Ptolemy's work was translated and today is better known under its Arabic title - the Almagest. Although the Greek names for constellations have survived, the names of the stars still used today are Arabic in origin.

Al-sufi (10th Century) – Book of stars

CHINA AND KOREA
The sophisticated civilisations of the far East charted the skies and kept track of the movements and appearances of celestial bodies. The Chinese favoured smaller patterns of stars (asterisms) rather than the larger constellations. While the reasons for following the stars were associated with religious beliefs, the records are meticulous and today provide accurate information regarding appearances of comets, novas etc.

ECLIPSES
With so much emphasis on the Sun, eclipses were important events to most ancient civilisations. Both Chinese and Mesopotamian astronomers were apparently aware of the Saros interval of 18 years 11 days 8 hours that occurs between eclipses. Once the dates and times of a number of eclipses are recorded, further lunar eclipses can be predicted by adding one Saros interval and further solar eclipses (for nearly the same location) by adding three Saros intervals.

EUROPEAN DESIGNATIONS OF THE YEARS
In Roman times, years were named according to emperors or to "ab urbe condita" (from the founding of Rome). However, in 525 AD, a Roman monk Dionysius Exiguus, devised the present system of counting years from the birth of Jesus Christ, using a table drawn up previously by Cyril of Alexandria. Dionysius calculated that AD 1 corresponded to 754 AUC, but it seems that he overlooked an emperor who reigned for four years, so his AD 1 was off by that amount. The error has never been correlated, so the birth of Christ is currently thought to have occurred around 4 BC! Only in the 18th century, did historians however take to using the "BC" system. Care has to be taken in that the present system (A.D. or A.C.E., B.C. or B.C.E.) has no "zero" year. (The year 1 B.C. is followed by 1 A.D.).

WESTERN EUROPE
Until the middle ages, Western Europe was isolated from the scientific progress made by the Greeks and continued by the Arabs. The crusades changed that and the Roman Church recognised that the Ptolemaic system was far removed from astrological interpretations. Under the control of the church, much of Greek science was imported - similarly "Arabic" (Hindu) numerals were used to replace their clumsy Roman counterparts. The Ptolemaic system was adopted as the churches official view - and to dispute it as heresy! Yet the system did not stand up to close scrutiny, though some scholars attempted to remedy this by adding further epicycles.

NICHOLAS COPERNICUS (1473-1543)

Nicolaus Copernicus: "In the center rests the sun."
(Courtesy O. Gingerich)

Born in Poland, he studied at the university in Cracrow. Possibly under the influence of a professor at the University of Bologna, he developed a heliocentric (Sun-centred) model of the solar system. His relative distances of the planets from the Sun were close to the correct values. However, because it disputed the teachings of the church, he held back publication until he lay on his death bed. Copernicus, however, still kept to the Greek obsession for perfect circular motion. He even suggested adding epicycles to account for the non-uniform motion of Mars.

TYCHO BRAHE (1546-1601)

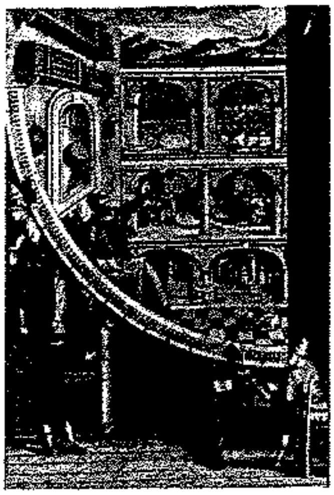


Figure 2–18 Tycho's observatory at Uraniborg, Denmark. Here Tycho is seen showing the mural quadrant (a marked quarter-circle on a wall) that he used to measure the altitudes at which stars and planets crossed the meridian.

As a result of his observations of the 1572 supernova (he could detect no parallax so it must be more distant than the moon), he gained the patronage of Frederick II of Denmark. This enabled him to build an elegant residence, housing the 'Uraniborg' observatory on the Island of Hveen. He made the most accurate positional observations to that time using sighting devices (e.g. mural quadrant), achieving accuracies of 1 arc minute and amassed thousands of observations, especially of the sun. He did not, however, accept the Copernican theory as he could not detect stellar parallax. He fell out with the king, and was exiled to Prague where he spent the remaider of his life. On his death, his observations were passed to his assistant Kepler.

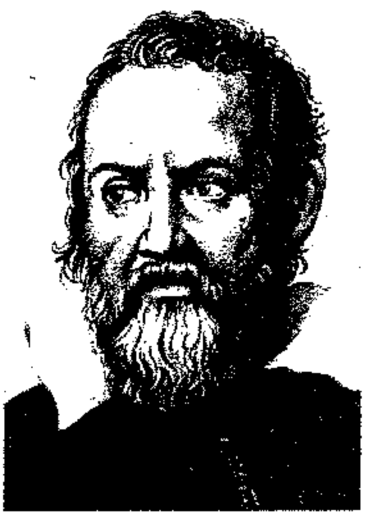
JOHANNES KEPLER (1571-1630)

Unlike his master, Kepler was convinced of the Heliocentric theory. He spent 20 years (1600-1620) trying to find a theory of planetary motion using Tycho's observations, concentrating on Mars. Finally he deduced its orbit is an ellipse, not a circle. He put forwards the following laws, which correctly describe planetary motion:

1. Each planet moves in an elliptical orbit about the Sun, which is at one focus of the ellipse.
2. The line joining the sun and planet sweeps out equal areas in equal times.
3. The orbital peroid squared is proportional to the cube of the semi-major axis of the ellipse.

Kepler demonstrated that the third law applied to all solar system bodies as well as the newly discovered moons of Jupiter.

GALILEO GALILEI (1564-1642)



Galileo (1564–1642). The versatile Italian scientist who built a telescope with which he saw that the moon was cratered and not the smooth disc everyone had previously assumed.

He investigated the laws of Physics. He experimented with pendulums, balls rolling down inclined planes, mirrors etc. to derive the laws of mechanics, especially the law of inertia. He built telescopes and used them to discover the four large moons of Jupiter, and to observe the phases of Venus, lunar craters and valleys and sunspots.

He widely publicised the heliocentric theory, against the authority of the church. Eventually he was charged, brought to trial, found guilty, for which he was put under 'house arrest' by the church for the last 10 years of his life. Only recently was the verdict of the trial overthrown by Pope John Paul II.

THE GREGORIAN CALENDAR

The Julian calendar is too long by one day in 128 years and by the middle ages was starting to drift from the astronomical equinox. In 1582, Pope Gregory XIII, with the advice of Luigi Lilio Ghiraldi and Cristopher Clavius, reformed the calendar by not making century years leap years, unless they were divisible by 400. (i.e. 1700, 1800, 1900 were not leap years but 2000 was). In order to correct back to the astronomical equinox, the Pope cut out 9 days in October 1582. His edict was followed in Catholic countries, but not in Protestant or Eastern Orthodox ones! The British Empire only followed in"1752 (by which time an 11 day correction was required). Greece only officially adopted the calendar in 1924 (but the Greek Orthodox church still abides by the Julian calendar).

ISAAC NEWTON AND MODERN TRENDS

Newton (1642-1727). The English [illegible]

The workings of the solar system were finally understood by means of Newton's law of gravitation, which account for Kepler's empirical laws. Thus the orbiting of the planets was finally interpreted in terms of a simple mathematical formula and not any "perfect" geometrical form, nor because they represented the will of any gods.

From this time onwards, the discoveries concerning the nature of the cosmos took a quieter scientific path. It was a much more gradual process that came to realise that the stars were simply distant suns, though the first elusive "parallax" measurements to derive the distances to nearby stars were only successfully obtained in the 1830's. Although modern findings are equally as dramatic of some of the early discoveries, they often pass unnoticed by most of society. Even today, a good fraction of the population does not understand that stars are suns!

WILLIAM HERSCHEL

Plate 5. Portrait by Lemuel F. Abbott of Sir William Herschel, 1785. (By permission of the National Portrait Gallery, London)

Since Galileo's time, the telescope was used for exploring the heavens, but many early instruments had imperfect optics that limited their productivity. In the late 18th century, William Herschel, a noted musician in Bath (born Wilhelm Herschel in Hanover) turned to building telescopes as a hobby. He soon settled on a variation of Newton's reflector design, but the telescopes he made were superior to those in use by the 'professionals'. In combination with his skill in making telescopes (aside from composing music and performing), Herschel was a dedicated and meticulous observer. Thus in 1781, he discovered the planet Uranus. This enormous success led to him being given a pension from the king to pursue astronomy. He built larger telescopes, discovered double stars (evidence of Newton's laws operating in other stellar systems), discovered various satellites of planets and thousands of nebulae (only a few hundred had previously been catalogued). He attempted to map our stellar system (galaxy) and suggested that some of the nebulae he observed might be similar systems. For many years, he was ably assisted by his sister Caroline, herself a discover of numerous comets etc. He also discovered infra-red radiation.

JOHN HERSCHEL

The "admirable likeness," Pickersgill's portrait of Sir John Herschel. (By permission of the Master and Fellows of St. John's College, Cambridge.)

His son, John, proved to be a remarkable scientist. Aside from astronomy, his work in chemistry led to the hypo-fixing system of photography. He originated the words 'photography', 'positive' and 'negative', even 'snapshot', as a pioneer in that field (an extension of the use of the camera lucida - a device for sketching accurate pictures). He was an expert in botany and wrote a fundamental text of philosophy, In astronomy, he derived elliptical orbits for his father's double stars, re-observed the entire northern sky to check his father's nebulae - even adding a further five hundred. In order to complete this work in the southern hemisphere, he moved his telescopes to the Cape (1834-38), The telescopes were sited on the Feldhausen Estate (now central Claremont). He contributed to the colony's education system.

In his scientific papers (though not in his textbooks), Herschel believed many of his nebulae were separate stellar systems (i.e. galaxies). He even went so far as to describe the local supercluster of galaxies, centred on the Virgo Cluster.

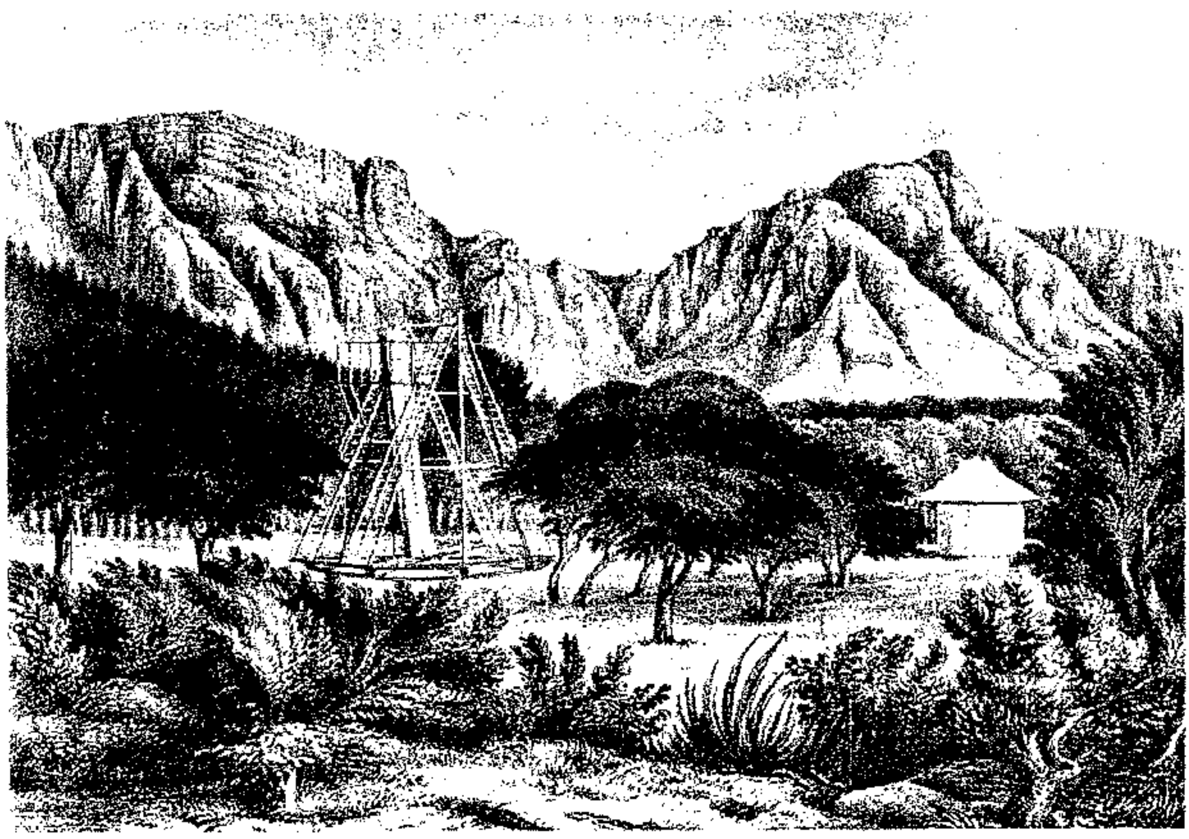


Plate 1. The twenty-foot reflector as erected at "Feldhausen." Delineation by Sir John; lithograph by G. H. Ford.

THE GREAT DEBATE

However by the end of the 19th century, the established picture of the 'universe' (as measured by the Dutch astronomer Kapteyn) was a flattened stellar system, with the Sun situated somewhere near the centre.

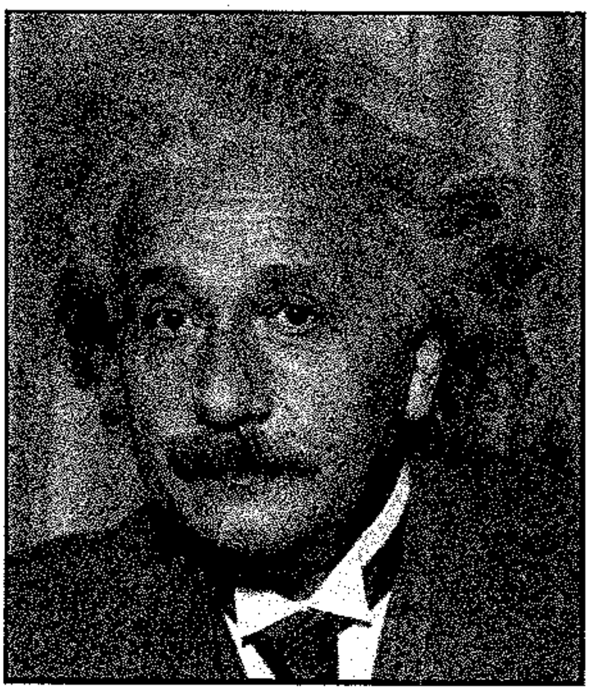
However, there was ongoing controversy of the nature of the 'spiral nebulae'. Whilst we now know them to be external galaxies, many investigators then held the view that they were individual stars in the process of formation. Around this time, Harlow Shapley (later director of Harvard Observatory) established distances to globular clusters and correctly concluded that since these systems were strongly concentrated in one part of the sky, the Sun could not be in the centre of its stellar system (i.e. galaxy) but was rather removed far from the centre.

His overestimate of the size of our galaxy led him to support the 'Kapteyn' universe and a classic debate was held in 1919 where he was opposed by Curtis, who supported an 'island universe' picture.

In 1924 Edwin Hubble (left) resolved the debate by discovering Cepheid variable stars in the Great Galaxy in Andromeda (the most prominent of the spiral nebulae), from which he derived its true distance. Thus the previous kapteyn universe became one galaxy amongst numerous others. Larger telescopes discovered great numbers of galaxies, many apparently clustered.

COSMOLOGY

Hubble made a further enormous contribution - he discovered that all galaxies were receding from our galaxy, with speeds in proportion to their distance. In parallel to these discoveries, conventional Newtonian physics had been shaken by the remarkable Relativity theories of Albert Einstein. Einstein had become an overnight celebrity when his predictions of General Relativity were verified during a 1919 solar eclipse.



The theory of General Relativity had also enabled the universe to be modelled mathematically. However, Einstein resorted to a 'fudge factor' in order to produce 'static' solutions. He was therefore amazed at Hubble's discovery as it showed the universe was not static but expanding. The expansion also implied a beginning of the universe in a form generally termed 'the hot big bang'. In the 1950s, the hot big bang theory was contested by the 'steady state' theory of Bondi and Hoyle, whereas continuous creation occurred to fill up the spaces created by expansion. However counts of distance radio sources implied that evolutionary effects had occurred. The steady state was finally ruled out by the discovery in 1965 of the cosmic microwave background - an image of the early universe as predicted by the hot big bang.

THE SPACE AGE

Since the 1960s we have seen a "golden age" of planetary exploration. The Moon was visited by astronauts and comprehensive geological samples brought back for analysis. Unmanned spacecraft have landed on Venus and Mars, the recent Mars rovers being incredibly successful. All other major planets, and their numerous satellites, have been photographed close up by the passing spacecraft, or orbiting spacecraft in the case of Jupiter and Saturn. Spacecraft have successfully landed on asteroids and the moon Titan.

At the same time, remarkable objects have been discovered in space, particularly active nuclei of galaxies (radio jets or superluminous quasars), pulsars (believed to be spinning neutron stars) and possible evidence of black holes.

LARGE-SCALE STRUCTURES AND COSMOLOGY

Since the 1970's the mapping of the large-scale distribution of galaxies has revealed remarkable large superclusters or 'great walls'. Equally unexpected were gigantic voids. The presence of structure on such gigantic scales has brought about considerably revision of cosmological scenarios. Today, there is a general consensus on the existence of considerable dark matter in the universe - similarly there is a belief of an early 'inflationary' expansion stage (where the universe may have grown fantastically large in only a split second).

Since 1997, observations of distant supernova explosions have indicated that the expansion of the universe, far from slowing down, is currently accelerating. The cause is attributed to 'dark energy', a sort of antigravity. The recent observations of the universe by the Wilkinson Microwave Anisotropy Probe put the age of the universe at 13.7 billion years. The mass-energy content of the universe is divided in 4% normal matter, 22% dark matter and 73% dark energy.