

Chapter 1

Man and His Universe

1.1. Einstein's Eternal Mystery

Albert Einstein (1879–1955) made once a famous remark to the effect that the most surprising thing about the physical world is that it is intelligible. Writing to his friend Maurice Solovine¹ on March 30, 1952, i.e. few years before his death, Einstein said “You find it surprising that I think of the comprehensibility of the world (insofar as we are entitled to speak of such world) as a miracle or an eternal mystery. But, surely, *a priori*, one should expect the world to be chaotic, not to be grasped by thought in any way. One might (indeed should) expect that the world evidenced itself as lawful only so far as we grasp it in an orderly fashion. This would be a sort of order like the alphabetical order of words. On the other hand, the kind of order created, for example, by Newton's gravitational theory is of a very different character. Even if the axioms of the theory are posited by man, the success of such a procedure supposes in the objective world a high degree of order, which we are in no way entitled to expect *a priori*.”

Man's intelligence has been confronted through all the millennia of recorded history with his personal reality as well as with the reality of the physical universe. Sometimes, especially in antiquity but also in modern times, man has viewed his personal reality as dissolved, so to say, in the high reality of the physical universe. Sometimes, on the contrary, he has seen the universe as a byproduct of his own mind. None of these two viewpoints is entirely satisfactory. The physical universe can be rationally defined as the totality of matter and energy (including of

course, electromagnetic radiation) in coherent interaction with one another. Intelligibility, in its deepest sense, involves a higher quality in man, the observer, a quality which is spiritual in nature. All cultures, all developed languages, seem to contain, however veiled, this distinction between the physical realm, dominated by brute inexorable forces, and the spiritual realm. Man's intelligence can discern -"read-into"- the physical world, and in the spiritual world of his fellowmen as well, truth beauty, unity, etc. A distinctive characteristic of man's intellectual operations is that they can go wrong, they can make mistakes, in clear contrast with the generally deterministic behavior of the material world.

1.2. From Antiquity to the XVI Century

A cursory overview of the historical record brings forth the well known fact of man's curiosity and interest on cosmic regularities from the earliest antiquity. Astronomy is said to be the oldest of pure sciences. Soon afterwards men's interests in the heavens were connected with practical matters, the first of which was to provide a basis for the calendar. The Chinese, Egyptians and Mayas had all very old working calendars, based on astronomic observations,² which helped them to carry out in due time their agricultural labors, to record past events and to calculate in advance dates for future plans.

The time needed for Earth to complete an orbit around the sun is 365 days, 5 hr, 48 min and 46 sec. On the other hand the moon passes through its phases in 29 days and 12 hr, approximately, and twelve lunar months amount to slightly more than 354 days, 8 hr and 48 min. Therefore defining an exactly overlapping solar and lunar year meets with inescapable difficulties. On one hand, months and years cannot be divided exactly into days. On the other, years cannot be easily divided into months. To reconcile and harmonize solar and lunar records has been a major problem for men of ancient civilizations, and different peoples have used different intercalation procedures.

In the year 45 B.C., Julius Caesar, who as "pontifex maximus" had the power of regulating the calendar, added 90 days to the year 46 B.C.

(making up for accumulated delays) and changed the years' length to 365 and 1/4 days, introducing therefore the bissextile year, on the advice of the astronomer Sosigenes. This was pretty close, but sixteen centuries latter the accumulated surplus time had displaced the vernal equinox from March 21 (the date set in the 4th century) to March 11. In 1582 Pope Gregory XIII rectified this error excepting from the condition of bissextile those years ending in hundreds, unless they are divisible by 400. Then the actual solar year equal to 365.2421 days, was approximated by

$$365 + 1/4 - 1/100 - 1/400 = 365.2425 \text{ days} \quad (1.1)$$

which is close enough, so that correction of one day is required only after approximately 2500 years, a conveniently long time span.

The early astronomers of Babylonia, Assyria and Egypt were priests and a strong motivation for detailed study of the apparently irregular planetary motions (planet = "wanderer") was the preparation of horoscopes. An all pervasive trend³ in those ancient cultures, as well as in the most brilliant of them all, the Greek culture, was that going down from the higher realm of the fixed stars, incorruptible and moving in perfectly orderly fashion, to the realm of the planets, less orderly and incorruptible, and finally to the sublunary world, the degree of disorder increased steadily, being the lower governed to a greater or lesser extent by the higher realms. This explains the need for horoscopes to predict the future and the mixed character (astronomical - astrological) of their investigations of the heavens.

Table 1.1 gives succinctly some of the major achievements concerning astronomy up to the times just before Galileo and Newton.

The pattern of the constellations or star groupings was inherited by Greeks and Egyptians from the oldest Mesopotamian culture, which, more than 5000 years ago, divided the band of stellar background near the plain defined by the apparent diurnal rotation of the sun around the Earth in twelve equally spaced arc segments.

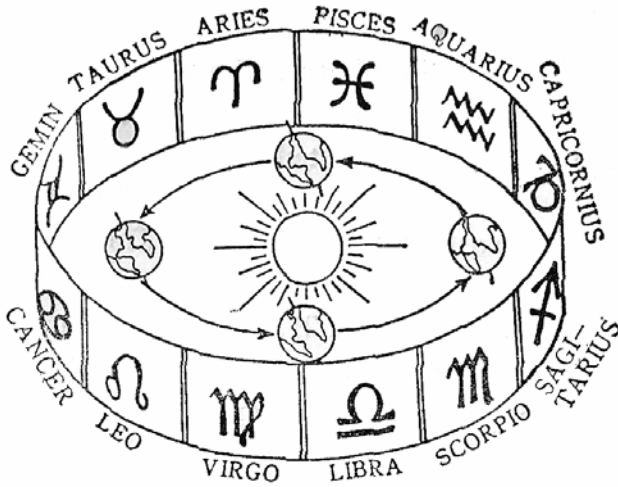


Fig. 1.1. Apparent trajectory of the sun through the sky.

While some archeologists believe the original number⁴ of zodiacal constellations was six, this may have been changed at later times, resulting in the twelve familiar constellations depicted in Fig. 1.1. In the resulting division of the zodiac by Mesopotamian astronomers-astrologers there is a definite tendency to duplicate things: two serpents, two slayers of serpents, two fishes, two streams and the twins making up Gemini. By the year 3000 B.C. the easily recognizable constellations Taurus and Scorpio were at the two opposite equinoctial points (day and night of equal duration) corresponding to the days marking the beginning of spring (vernal equinox) and the beginning of fall (autumnal equinox).

An observer watching at sunrise in the vernal equinox could see the position of the sun in the zodiac at Taurus by the year 3000 B.C. Two thousand years later, however, Taurus had moved one step and what the observer could see at sunrise in the vernal equinox was the constellation of Aries. And so forth. Towards the end of the second century B.C. the great Greek astronomer Hipparchos, relying on ancient Babylonian records was able to describe this apparent periodic motion of the celestial spheres, which, we now know, is due to the precession of the Earth axis around a line perpendicular to the zodiacal plane.

Table 1.1. Landmark achievements concerning astronomy (BC–1600).

<u>YEAR</u>	<u>AUTHOR</u>	<u>ACHIEVEMENT</u>
1500	Kepler (1571–1630)	Laws of planetary motion
	Tycho Brahe (1546–1601)	Accurate and systematic observations
1000	Copernicus (1473–1543)	“De revolutionibus orbium celestium”
	Buridan (c.1358)	Impetus theory for celestial bodies
	Alfonsine Tables (c.1252)	Improved planetary data, compiled by moorish, jewish and christian scholars under Alphonse X of Castile.
500	Various arab scholars	Adoption of hindu numeral and decimal system, trigonometry.
	Tabit ibn-Korra (836–931)	Translator of Euclid, Apollonius, Archimedes and Ptolemy
0	Ptolemy (85–165)	“Almagest” Planetary data described by epicycles Use of angular parallax
-500	Hipparcos (190–120)	Accurate catalog of stars Precession of equinoxes
	Aristarchus (c.150)	Distance to Earth and moon First heliocentric proposal
	Erathostenes (284–192)	Diameter of Earth
	Chih Chen (about 350)	Oldest Chinese catalog of stars
	Aristotle (384–322)	Systematization of knowledge
-500	Pythagoras (c.572–c.497)	Spherical Earth
	Thales (c.640–c.552)	Angular diameter of sun as a fraction of zodiacal circle

A full round of precession amounts to about 26000 years, i.e.

$$(2160 \text{ years/constellation}) \times (12 \text{ constellations}) \approx 26000 \text{ years} \quad (1.2)$$

Some Greek philosophers fancied this very long period as the Great Year, that is, the time span after which an “eternal return” is completed and things in the universe start all over again. Of course, fairly accurate and sustained observations were required to identify and characterize this slow periodic motion in the heavens.

Very early observers could predict eclipses with fair accuracy, using their tables of lunar motion, although they did not understand their cause. Pythagoras (c.572–c.497) produced an ideal model of the universe in which this was conceived as a series of concentric imaginary spheres in which the sun, the moon and the five then known planets, as well as the Earth (and an imaginary counter-Earth) rotated around an invisible “central fire” (see Fig. 1.2), producing the “music of the spheres”.

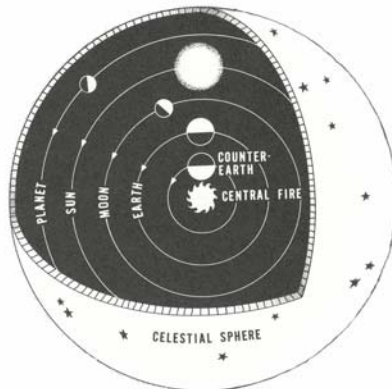


Fig. 1.2. Pythagorean model of the universe.

Erathostenes (284–192), using a very simple method, to be discussed in more detail later on, measured the central angle corresponding to a relatively long arc running South to North along the Nile river. In this way he was able to calculate within an error of only 5% the perimeter of the Earth, therefore proving its sphericity. Old reports of Egyptian sailors who had circumnavigated Africa clockwise had indicated that, in going upwards from what is now known as the cape of Good Hope, they had

seen the noon-day sun shining on them from behind, contrary to what happens in the northern hemisphere. But no one then, among the learned in the Pharaoh's Court made the proper connection between this observation and the sphericity of the Earth. The estimate of the Earth's diameter by Erathostenes was crucial for the next step. Aristarchus of Samos (c.150 B.C.) gave this gigantic step forward when, making use of elegant and daring geometrical arguments, he was able to estimate the size of moon and sun relative to that of the Earth, and to make a rough evaluation of the large distance from Earth to moon, and even the normous distance from Earth to sun, in terms of Earth diameters. The relative and absolute errors were, of course, considerable, due to the lack of precise instrumentation, but his achievement can be rightly characterized⁵ as "the first truly scientific step in the study of the cosmos" (more details on this later on). The large estimated size of the sun relative to the Earth led Aristarchus to make the first heliocentric conjecture recorded in history, and also to the conclusion that, if this conjecture were true, the Earth must be spinning around a certain axis of rotation.

Figure 1.3 depicts the arrangement of sun, Earth and planets according to the heliocentric proposal first intimated by Aristarchus and rediscovered by Copernicus many centuries after.

Hipparcos (190–120 B.C.), considered the greatest astronomer in antiquity, developed simple trigonometrical methods to determine angular positions of celestial bodies. He realized that astronomy requires systematic and accurate observations extended over long time spans, made use of old Babylonian observations and compared them with his own, discovering the precession of the equinoxes every 26000 years. Disregarding the heliocentric proposal of Aristarchus, he devised a geocentric scheme of cycles and epicycles (compounding of circular motions) in pursuit of the old greek aim of "saving the phenomena", i.e. providing a theory which could account for all the observed movements of sun and moon around the Earth. Ptolemy (A.C. 85–165), more than two centuries later, extended this scheme of epicycles to the planets, being able to predict their motion with considerable accuracy. His thirteen volume treatise, known by the name used by their later arab translators, the "Almagest", summarized a considerable amount of

ancient astronomical knowledge, and became the most authoritative book in astronomy for many centuries. Among other achievements, Ptolemy was able to make an accurate measurement of the distance from Earth to moon by means of the technique of angular parallax (see Fig. 1.4).

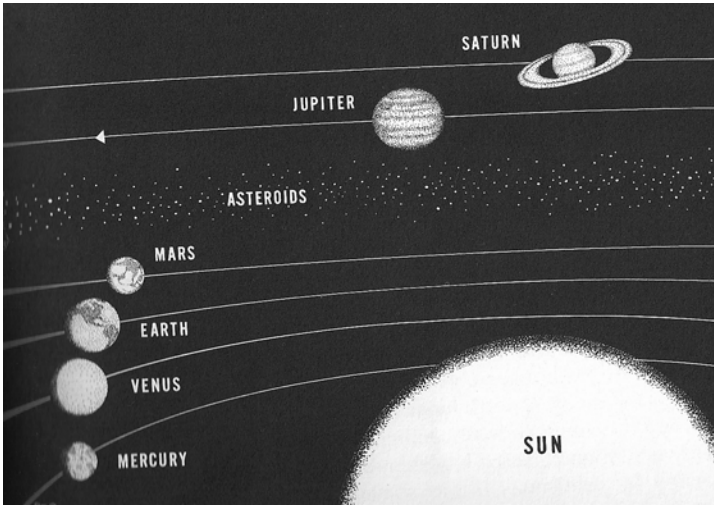


Fig. 1.3. Heliocentric System.

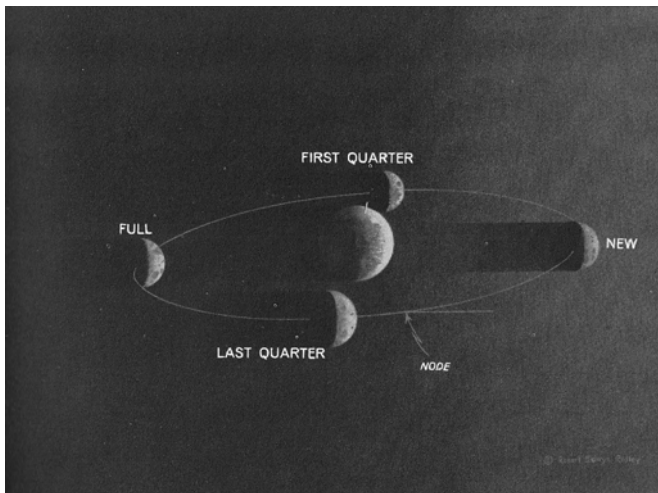


Fig. 1.4. Distance to the moon $D \approx d/\tan \alpha$ by angular parallax technique.

For a long period, after the fall and subsequent dissolution of the Roman Empire, astronomy as well as other branches of learning, in the West, became dormant. In a not too long period of time, and due probably in no small measure to generalized moral and civic decay, accompanied by the “*Volkerwanderung*” of the northern germanic peoples, the european population decreased steeply. Agriculture, manufacturing and commerce decreased also, and not surprisingly, so did cultural life, including preoccupations with the motion of the heavenly spheres.

By the ninth and tenth centuries of the Christian Era, arab Scholars in Baghdad and Corduva were very active in preserving, translating and commenting much of the classic Greek heritage. Tabit ibn-Korra (836–931) was the translator of Euclid, Apollonius, Archimedes and Ptolemy. The arabs made also an invaluable contribution to astronomy by adopting the hindu numeral and decimal system, which made uncumbersome the handling of very large numbers for distances and times, such as they often appear in the discussion of the heavens. In A.D. 1252, fifty moorish, jewish and christian scholars compiled and improved a complete set of planetary data in Toledo, under the patronage of Alfonse X of Castile. In the thirteenth century a new vitality was clearly discernible in medieval Europe. New beautiful cathedrals and new universities were built up. Renewed interest in all branches of learning became evident. And also in nature, as God’s handiwork. We may quote the words of St. Francis of Assisi:

Blessed be Thou, my Lord, by all Thou has created and specially blessed by our brother sun which shines and opens the day, and is beautiful in its splendour; it carries on thru heavens the news of its author. And by our sister moon, and by the clear stars that your power created, so limpid, so good looking, so alive as they are. Blessed be Thou, my Lord!

A century later John Buridan (?–c.1358), chancellor of the University of Paris, almost unadvertedly, introduced a new concept in dynamics, the concept of impetus, anticipating Newton’s first law, which he immediately extended to the motion of heavenly bodies, and , as it was well documented first by Pierre Duhem and more recently by Stanley L. Jaki, started a chain of events which would culminate in

Copernicus (1473–1543) “*De revolutionibus orbium celestium*”, and later in Newton’s (1642–1727) “*Principia*”. On the authority of Aristotle, the philosopher “par excellence” among both christian and arab scholars in the late middle ages, motion in the planetary world was somehow directed by the more perfect motions in higher spheres, and so on, up to the outermost sphere of fixed stars, indistinguishable⁶ from the prime mover. This implied a refined animistic and pantheistic world view, incomparably more rational than the ancient world views of Babylonians and Egyptians, among others, but a world view, nonetheless, hardly compatible with the idea of “inertial motion” which is implied in Buridan’s concept of “impetus”. This was therefore a momentous breaking point in the history of astronomy and cosmology in general, which was to bear fruit centuries later in the hands, first of Copernicus and then of Newton.

“*De revolutionibus orbium celestium*” by the polish “canonicum” Nicolaus Copernicus (1473–1543) had a truly revolutionary impact in the annals of astrophysical cosmology, which rescued from oblivium the old heliocentric proposal of Aristarchus, and did much more, incorporating the idea of inertial motion to the description of the wanderings of planetary bodies, but left for future scholars the mathematical description of these wanderings.

Tycho Brahe (1546–1601), the son of a rich Danish nobleman, and his collaborators, patiently and competently compiled, over a period of twenty years, the most accurate and complete set of astronomical observations the world had ever seen. His attitude towards Copernicus work was conservative, and he disliked the idea that the Earth was moving. There were some good reasons for this attitude, since his precise observations did not show any “parallax” for the bright, presumably close, stars against the background of the faintest and more distant stars (see Fig. 1.6). Only after almost two centuries were astronomers able to actually see the minute parallax of nearby stars due to their enormous distances from the sun. At the death of Tycho his records were passed on to Johannes Kepler (1571–1630), who had been his last assistant. Kepler spent nearly a decade trying to fit Tycho Brahe’s accurate observations, articularly of Mars, into a pattern of circular heliocentric motions.



Fig. 1.5. N. Copernicus.

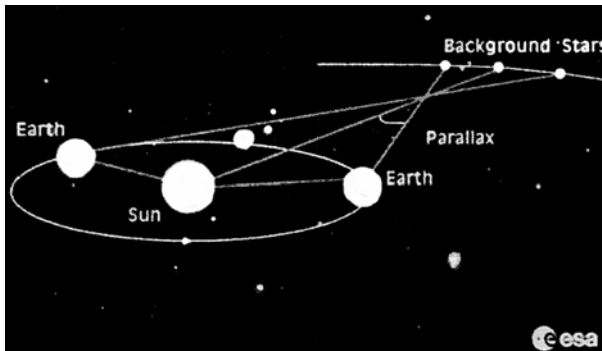


Fig. 1.6. Trigonometrical parallax of a nearby star.

A circle, as well as a sphere, were the kind of perfect geometrical objects then considered exclusively suitable to fit exactly the perfect harmony of the heavens. At last, he conceived the idea that Mars's orbit was an ellipse, with the sun at one focus of it, as developed in his greatest book, the "Astronomia Nova". This discovery led him to the three famous laws of planetary motion which bear his name. He was fully aware of the debt to Tycho's painstaking observations to achieve

this. According to Kepler,⁷ “The mind grasps a thing all the more correctly the closer it is to sheer quantities, that is, to its origin. The farther is a thing from quantities, the greatest is its share of darkness and error”. His 3rd. law, which presupposes the other two, states that the ratio of the cube of the semimajor axis of the elliptical orbit (average distance to the sun) to the square of the period (time of one revolution) is constant for all planets, bringing unity to where there was previously a jungle of epicycles and deferents. This law was arrived at by Kepler in an empirical way and later served as the final touchstone for Newton’s theory of gravitation (see Fig. 1.8).



Fig. 1.7. J. Kepler.

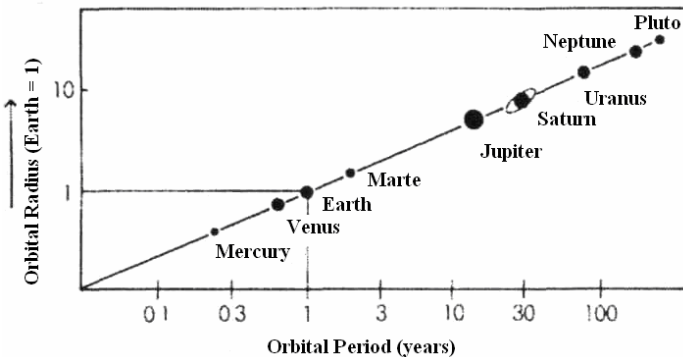


Fig. 1.8. Pictorial sketch of Kepler’s laws.

1.3. From Galileo and Newton to Kirchoff

Galileo Galilei (1564–1642), considered by many historians of science as the founder of modern physics and astronomy, made contributions certainly important in both fields, but his work, in a proper historical setting,⁷ is not conceivable without the advances made by the men discussed in the previous section. He seems to have been the first man to make use of the telescope for astronomical observations, discovering the four largest satellites of Jupiter and the phases of Venus, which he used in support of the Copernican theory. This theory had been taught at several European universities, Salamanca being an outstanding example, before Galileo, but it became a subject of hot theoretical polemics between Galileo and other Italian contemporary scholars, and the incident ended up, temporarily, with an ecclesiastical injunction forbidding Galileo to teach the Copernican system.



Fig. 1.9. Galileo Galilei.

Nevertheless he viewed the book of nature as complementary with Scripture in pointing out to the existence of a Creator, and to the human mind as a most special product of the same Creator of all. As it is well known, Galileo combined the empirical and the deductive method to describe the motion of uniformly accelerated motion, reaching the

conclusion that the time of free fall of bodies falling to ground from the same height is the same, regardless of their weight (contrary to the Aristotelian tenet). The law relating free fall distance (height = h) and free fall time (t),

$$h = \left(\frac{1}{2}\right) gt^2 = (\text{const.})t^2 \quad (1.3)$$

had been anticipated several decades before by the Spanish dominican friar Domingo de Soto (1494–1560), but only after being rediscovered and exploited by Galileo became widely appreciated. Galileo’s work in Mechanics plowed ground for the coming fundamental work of Newton (see Table 1.2).

The great Sir Isaac Newton (1642–1726) came to be the unifier of Mechanics and Astronomy, with his famous theory of universal gravitation. In Einstein’s words in the foreword to a new edition of his “Optics”, Nature was to him an open book, whose letters he could read without effort’ ... In one person he combined the experimenter, the theorist, the mechanic, and not least, the artist in exposition”. His initial research was in Optics, being the discoverer of an admixture of distinct colours in white light after being refracted through a prism, and the first modern proponent of a corpuscular theory of light. But his most prominent achievements are to be found in Mechanics and Astronomy. In his “Principia”, composed in the short period between autumn of 1684 and spring of 1686, he displayed his consummate skills in theoretical physics, of which he was pioneer and master. There he solved the problem of the Keplerian motion of the planets, and the made use of the fact that a homogeneous gravitating sphere attracts at points outside it as if all its mass were concentrated at its centre. The force of attraction was postulated by him as it is well known, as given by

$$F_g = GMm/r^2 \quad (1.4)$$

where G is a gravitational universal constant, M the mass of the central sphere, m the mass located at the point in question, and r the distance from the centre of the sphere to the point. He tested the inverse square law of gravitation against the Moon’s motion with spectacular success, employing the recently improved measure of the Earth’s radius by Picard.

Table 1.2. Outstanding astronomical discovers (1600–1900).

<u>YEAR</u>	<u>AUTHOR</u>	<u>ACHIEVEMENT</u>
1900	Kirchhoff (1824–1887) Fraunhofer (1787–1826)	Spectroscopical analysis of solar and star light
	Bessel (1784–1864) Struve (1793–1864) Gauss (1777–1853)	First direct measurement of distance to a star (Lirae and 61 Cygny) “Theoria motus corporum celestium” Analysis of perturbations of planetary orbits
1800	Olbers (1758–1840)	Paradox of dark sky at night in an infinite (?) universe.
	Herschel, F.J (1792– 1871) Herschel, W. (1738– 1822)	Improved large telescopes Resolution of Milky way in stars Discovery of Uranus Discovery of binary stars: application of Kepler’s laws outside solar system.
	Laplace (1749–1827) Lagrange (1736–1813) Euler (1707–1783)	Celestial Mechanics
	1700	Lambert (1728–1777)
1600	Bradley (1693–1762)	Aberration of starlight Improved catalog of stars Nutation of Earth
	Halley (1656–1742)	Catalog of stars of Southern hemisphere Prediction of return of comet Halley
	Newton (1642–1727)	Discovery of “proper motion” of stars “Principia” (1687) Universal theory of gravitation Unification of Mechanics & Astronomy
	Galileo (1564–1642)	Theory of tides “Dialogue” (1632) Support of heliocentric theory First Use of telescope: sun spots

This was certainly a great leap forward, from the fall of a mere apple to the “falling” of the Moon, held in place by the centrifugal force due to its circular motion, and beyond.

In the “Principia”, Newton rejected the un-scientific view that our primary experiences about material, impenetrable bodies, all come from pure reason, as well as the opposite extreme view that science is made up only of pure observations. He gave⁹ a clear account of the moon’s motion, tides, the precession of the equinoxes and the equivalence of gravitational and inertial mass without any reference to hypothetical “ad hoc” mechanisms at all, like many of his predecessors while making use of the best data available to him. He followed an epistemological “middle road” between pure rationalism and pure positivism.

Halley (1656–1742), Newton’s contemporary and Bradley (1699–1762), some years afterwards, made important¹⁰ practical observations and contributions to experimental astronomy. Among other things, Halley made an extensive catalog of stars visible in the southern hemisphere, studied the highly exocentric trajectories of comets and predicted with very good accuracy the return of the comet which was afterwards named after him. He had noted the similarity on the orbits of comets observed in the years 1456, 1531, 1607 and 1682 (at time intervals of about $75 \frac{1}{2}$ years) and correctly predicted the coming back of the same comet in 1758, which was in due time observed, sixteen years after his death. Up to this time it was generally believed that the so called fixed stars remain absolutely fixed with respect our sun, but his careful measurements of Sirius, Procyon and Arcturus convinced him that the stars have characteristic random “proper motions”. Bradley, who succeeded Halley as astronomer Royal, made several important contributions. He discovered the so-called “aberration of starlight” due to the fact that the Earth’s annual motion in its orbit compounds in the observing telescope with the finite velocity of light, previously discovered by the Danish astronomer Roemer (1644–1710). He found this unexpectedly while doing methodic measurements in the star γ Draconis in the hope of detecting the stellar parallax, which, as we now know required much higher precision. Another important discovery of his, the nutation of the Earth’s axis, due to the changing direction of the gravitational attraction due to the Earth’s bulk at the equator, arose out from his work on the aberration of light

(see Fig. 1.10) Reasoning from Newton’s attribution of the precession of the equinoxes to the joint gravitational action of Sun and Moon on Earth, he concluded that nutation must arise from the fact that the Moon is sometimes above and sometimes below the ecliptic plane, and it should show the periodicity of the moon’s nodes (about 18.6 years).

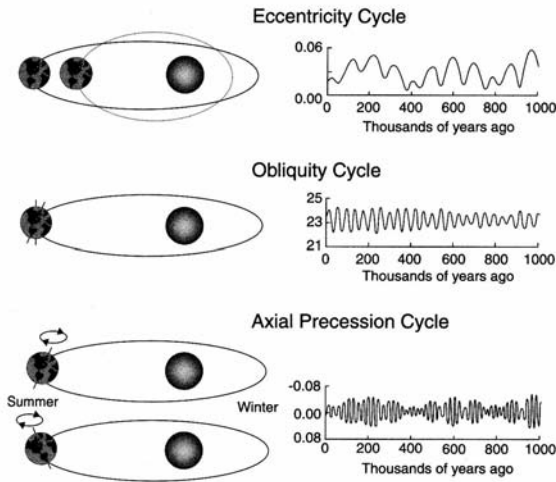


Fig. 1.10. Earth’s main motions and their periods in years.

A very important step forward in the understanding of the cosmos was given in 1749, when the young John Heinrich Lambert (1728–1777) conceived the idea that the Milky Way is a lentil shape conglomerate of stars which looks the way we see it when viewed from the Earth’s position, around a sun located in its main plane. This rotating and stable arrangement of stars was contradiction free, unlike the one originally proposed by Newton for the system of stars, and became the basic pattern¹² of his description of the universe in the “Cosmological Letters” Lambert, who later became a member of the Berlin Academy of Science was a contemporary of Kant (1724–1804), who as an “amateur” in astronomy, had also conceived the Milky Way as a flattened spherical arrangement of stars. Kant, however, sought its stability in a compromise between attractive and repulsive forces, foreign to Newton’s gravitational theory. Lambert was aware of the fact that an infinite

universe suffered from the gravitational paradox. His work in cosmology, unlike his work in mathematics and optics, seems to have made little impact, until very recently. The realization that there are many more galaxies besides our own had to wait nearly two hundred years, until the beginning of the twentieth century.

Mention must be made, of course, of the great contributions by Euler (1707–1783), Lagrange (1736–1813) and Laplace (1749–1827) who carried forth in its fullness the application of Newton’s mechanical principles to the study of the planetary system, bringing almost to perfection the science of “Celestial Mechanics”.

W. Herschel (1738–1822), and his son F.J. Herschel (1792–1871) after 1816, made some of the most outstanding contributions to observational astronomy and to cosmology in post-newtonian times. W. Herschel constructed his own 5 and 1/2 feet telescope, and after becoming Court Astronomer to the King of England, his very large (20 feet) reflector telescope, with which he was able to resolve the Milky Way into individual stars. In 1787 he discovered Uranus, the next to last major planet. He also made the discovery of double star systems (binary stars), and made then an extensive catalogue of binary stars (moving around each other and therefore subject to Kepler’s laws), which in later years served to determine the vast interstellar distances within our own galaxy, and, from extensive counts, the overall size and shape of the Milky Way. He also made the discovery¹³ of the intrinsic motion of the Sun within our own galaxy, and was able to investigate many nebulae, globular clusters, and true galaxies (“island universes”) through space, though, at the time, it was not easy to decide whether they were comparable in size and star number to our own. F.J. Herschel helped his father in reducing observational data from the Northern Hemisphere, and made a journey with his family to Cape Town to do similar investigations in the Southern Hemisphere, where he spent four years. The Herschels are remembered also for their pioneer work on astronomical colour-photometry and for the use of photographic techniques. To make clear his dislike for the purely empiricist approach to reality, W. Herschel affirmed¹⁴: “Half a dozen experiments made with judgment by a person who reasons well, are worth a thousand random observations of insignificant matters of fact”.

Other great nineteenth century astronomers were Olbers (1758–1840), who pointed out the famous Paradox of dark sky at night in an infinite (?) universe, Gauss (1777–1853) who, in his “*Theoria motus corporum celestium*” made a penetrating analysis of the perturbations of planetary orbits by bodies other than the Sun, and Bessel (1784–1864), who finally solved the problem of the parallax of nearby stars by measuring the parallax (and therefore the distance) to 61 Cyngy, which by his good luck, was one of the stars nearest to our Sun.

By the end of the last century Kirchhoff (1824–1887) was making spectroscopical analysis of light from the Sun and from other star, using previous data by Fraunhofer (1787–1826), which confirmed that star surfaces were filled with the same kind of chemical elements observable here in the Earth’s surroundings.

1.4. The XX Century

The XX century is witness of a vast increase in the range of both astrophysical observations and theoretical work. It marks the advancement from consideration of merely our own Milky Way, to close attention to the entire observable universe. We can consider it as the true century of Astrophysical Cosmology (see Table 1.3). During the late XIX century and early XX century, considerable information was gained on the nature and composition of stars. Even when viewed with a large telescope a star is no more than a bright point of light, except, of course the Sun. But the sun can serve to us as a guide to the characterization of other stars. Setting on the horizon, the sun looks as a compact disk (the photosphere), surrounded by a hot semitransparent atmosphere, which glows with a dull red light (the chromosphere). When the moon covers the photosphere during an eclipse, the chromosphere becomes visible as a shining ring around the sun. The atmosphere of the sun as well as the outer corona, unlike its core (made up of “plasma”), is composed of atoms, like neon, iron, etc, which can absorb sunlight, hold it for a fraction of a second, and then reemit it with a characteristic wavelength and frequency. The wavelength (or frequency) carries on with it the trademark of the excited atom. Analysis of sunlight’s spectra showed that

some of the emitting ions are heavily ionized, having lost, f.i., thirteen electrons, which is an indication of the fact that their equivalent temperature is of the order of several millions kelvin. This gives us an idea of the tremendous amounts of energy being continuously liberated by fusion processes in the sun's interior, and similarly, in other stars. It is well known that the gravitational pull of the solar matter towards its centre is checked by the radiation and gas pressure originated in the fusion processes. We can learn a lot about the characteristics of a star by looking at the radiation emitted by it, which contains a continuous part indicative of the star's temperature and a discontinuous set of lines, which shows the trademarks of the atoms present in its atmosphere. A preliminary classification of stars by colour (or, equivalently, surface temperature) was designed by the first decade of the twentieth century.

Eight spectral types were arbitrarily defined and labeled by the capital letters OBAFGKMN (mnemotechnic rule: look for the initial letters of words in the sentence "Oh! be a fine girl, kiss me now") The surface temperature, the colour and one typical example are given in Table 1.4.

Shortly afterwards it was realized that the temperature of a star, which depends upon its bulk, is related to its intrinsic luminosity, i.e. the luminosity, or amount of light radiated per unit time which would be observed when the star is removed from its actual distance and placed at a standard distance from the observer, the same for all stars.

The Hertzsprung-Russell diagram, which leads to a relationship between luminosity and temperature, was discovered in 1911–1913 (see Fig. 1.11).

In this diagram the "main sequence" corresponds to the hydrogen burning phase in the life of a star. Very heavy stars burn hydrogen quickly and then, after undergoing violent explosions (supernovae) in which a faint, distant star becomes temporarily extremely bright, and afterwards leaves the main sequence. Very light stars, on the other hand, burn hydrogen slowly. Our sun occupies an intermediate position on the main sequence and is now approximately half way in its hydrogen burning phase, which for stars with a mass alike the sun's mass is of the order of 10^{10} years.

Table 1.3. Cosmological advancements in the XX century.

1980	(1987) (1980's) Apollo XI Mission (1969) Bell (1967) Wagoner, Fowler, Hoyle (1967) Penzias–Wilson (1965)	Supernova 87 Connection between Cosmology and Elementary Particle Physics. First manned landing on the moon. First “pulsar” discovered Theory of light elements primordial nucleosynthesis. Observation of 3 K background radiation
1950	Hazard (1952) Burbidge, Fowler Hoyle (1957)	First “quasar” discovered Theory of nucleosynthesis of heavier elements in the core of stars.
1940	Alpher–Herman–Gamaw (1948)	Prediction of remanent background radiation Primitive theory of cosmic nucleosynthesis.
1930	Hubble–Humason (1928–30) Lemaître (1927)	Systematic measurements of galaxy distances & recession velocities Primitive “Big Bang” theory
1920	Friedmann (1922) Eddington (1919) Einstein (1917)/ De Sitter (1917)	General solutions of Einstein’s eqs. ($\Lambda \neq 0$) General solutions of Einstein’s eqs. ($\Lambda \neq 0$) Organized eclipse expedition which tested theory of General Relativity. General relativistic cosmological equations/ Special solution to Einstein’s equations predicting universal expansion.
1900	Slipher (1914) Hertzsprung–Russell (1911–13)	First report of observation of a receding galaxy (Andromeda) Diagram displaying relationship between luminosity and temperature (color) of typical stars.

Table 1.4. Classification of stars by spectral type.

Spectral Type	Pothosphere temperature	Color	Example
O	55,000	Blue	Orion's sword
B	25,000	Pale blue	Spica
A	11,000	Blue-white	Sirius, Vega
F	7,000	White	Procyon
G	6,000	Yellow	SUN, Capella
K	5,000	Pale orange	Aldebaran
M	3,300	Orange	Antares
N	2,800	Red	None visible

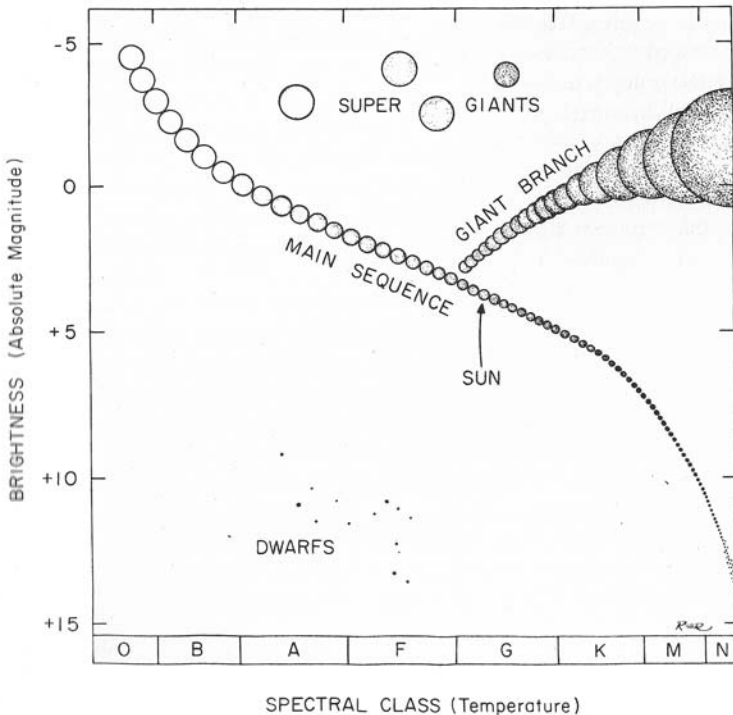


Fig. 1.11. Herzsprung–Russel diagram: Absolute magnitude vs. spectral class.

In 1914 Slipher,⁵ an American astronomer which was investigating the Andromeda nebula, as a good possible candidate for a new solar system in formation, discovered that the spectral lines appearing in the

light coming from this nebula were strongly shifted with respect to the corresponding lines of an emitting body at rest with respect to the observer. He correctly concluded that the Andromeda system, very far away from our system of stars, was receding at a very high speed away from us, interpreting the redshifting of spectral lines as due to the Doppler effect. This was immediately recognized as an epoch making discovery by the members of the American Astronomical Society attending the meeting in Evanston, Illinois at which Slipher reported his finding. Edwin Hubble, then an astronomy student attending the meeting, took good note of the significance of this observation, and conceived the idea (to be carried on to effect more than a decade later) of making a full scale exploration of similar systems through the vast spaces of the observable universe.

At about the same time, in the year 1917, Einstein, completely unaware of Slipher's observation was busy trying to apply his newly developed theory of General Relativity to the description of the whole universe. He was able to arrive at general relativistic cosmological equations, in which he introduced, somewhat arbitrarily, a repulsive "cosmological" term, which could compensate the universal attraction and therefore make room for a static distribution of star systems. Almost simultaneously, De Sitter, which had received a copy of Einstein's paper, obtained a special solution of the general relativistic equations which predicted a universal expansion for the cosmos as a whole.

Just after the end of the European War 1914–1918, which had forced a postponement of the initial plans, Sir Arthur Eddington, a leading British astronomer and theoretical physicist, organized an eclipse expedition to verify the bending of light by gravity, as predicted by Einstein's General Relativity. This occurred in 1919. The bending of light was verified, and Einstein became overnight a world celebrity. At the same time this confirmation of General Relativity provided strong indirect support for the favourable expectations concerning its application to the description of the cosmos.

In 1922, Alexander Friedmann a Russian meteorologist and mathematician, and, independently, five years later, George Lemaitre, a Belgian priest and mathematician, who would become in the future President of the "Pontificia Academia Scientiarum" in Rome, arrived at a

general set of solutions to Einstein's dynamical equations for the cosmos, which included three cases: closed (oscillating) universe, with space curvature $k > 0$; euclidean (expanding just at escape velocity) universe, with $k = 0$; and open (expanding at higher velocity) universe, with $k < 0$. Also, Lemaitre was the first to describe the initial stages of the dense, exploding universe as a primeval atom, which can be considered as the primitive version of the "Big Bang" theory.

The years 1928–1930 witnessed the successful systematic measurements¹⁶ of galaxy distances and recession velocities by Hubble and Humarson, in the 100 inch mirror Mount Wilson telescope, which lead to the discovery of Hubble's law (see Fig. 1.12). These investigations were carried on to further distances with the new 200 inch mirror telescope at Mount Palomar. The original measure of Hubble's constant,

$$H_0 = \dot{R}/R = (v/d) = 500 \text{ Km/sec/Mpc} \cong [2 \times 10^9 \text{ years}]^{-1} \quad (1.5)$$

where one Mpc (megaparsec) = 3.26×10^6 light years, was successively corrected for errors in the determination of the distance scale, leading to its presently accepted value,

$$H_0 = (75.3 \pm 30) \text{ Km/sec/Mpc} \cong [13 \pm 4 \times 10^9 \text{ years}]^{-1} \quad (1.6)$$

which implies an increase in size of the order of seven times the original estimates. Large errors like this are not uncommon in the history of physics, but what was epoch making was the formulation of an important cosmic law, Hubble's law. After the pioneering numerical estimates were performed, more refined measurements would come in due time.

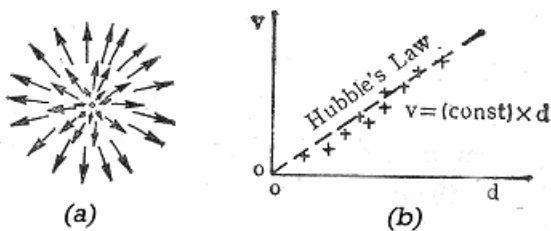


Fig. 1.12. (a) Expansion of galaxies at radial velocities increasing with distance (b) Schematic representation of v (velocity) vs. d (distance) observed by Hubble and Humarson.

During the period preceding the Second World War, and in wartime, the attention of most physicists, both in Europe and America, was primarily focused in research topics directly or indirectly related to the war effort, such as the development of radar systems and the “Manhattan” project to build a fission bomb.

Two young collaborators of George Gamow, who were investigating in 1948 the possibility of nucleosynthesis in the early stages of the expanding universe, predicted that a remnant cosmic radiation background of about 5 K should be present in the universe as a result of the cooling down of the very intense (high temperature) radiation background at the time of nucleosynthesis. Alpher’s dissertation was published the same month as the joint paper in the British journal “Nature” in which the 5 K prediction was reported. At the time, no one seems to have paid much attention to this bold prediction, which seventeen years later was fully vindicated by the experimental finding of the radioastronomers A.A. Penzias and R. Wilson, who, as is often the case, were looking for another thing.

In 1957, Burbidge, Fowler and Hoyle worked out a theory of the nucleosynthesis of the heavier elements in the core of stars, which was able to account satisfactorily for the main data available from spectroscopic analyses. A second or third generation star, like our sun, contains from the beginning a small percent of heavy elements resulting from supernova explosions of stars from a previous generation.

Hazard (1962) discovered the first quasi-stellar object (“quasar”), characterized by its extraordinary brightness, much larger than that of an ordinary galaxy, and its large recession velocity. After this, many other “quasars” were discovered by various investigators, giving clues, not yet completely understood, of the state of the cosmos at early times.

The detection of an isotropic and uniform 3 K blackbody radiation coming from all directions of the universe, experimentally performed by Penzias and Wilson in 1965, confirmed the prediction of Alpher, Herman and Gamow, made on the basis of the Big Bang theory some years before, and was instrumental in favouring the Big Bang theory over its main rival theory at the time, the so called steady-state theory. It is worth noting that the steady-state theory assumed continuous creation out of

nothing in the universe, thus violating the principle of matter/energy conservation. This is a clear indication of how far some, otherwise competent theorists were willing to go in their theoretical efforts to describe the cosmos.

In 1967 Bell discovered and characterized the first “pulsar”, strange pulsating radio source which was later identified with a rotating neutron star, and was located relatively close to us in our own galaxy. These “pulsars” can be the result of collapse after a supernova explosion of a star with appropriate initial mass. In the same year, Wagoner, Fowler and Hoyle produced the theory of “primordial” (that is produced at very early times) nucleosynthesis of He and traces other light elements, which, unlike the heavier elements, seem to be more or less uniformly distributed throughout cosmic space.

The year 1969 witnessed, as all those with sufficient age may remember, a man on the Moon (Apollo XI Mission). The 1970’s saw the awakening of theoretical efforts to connect Cosmology and Elementary Particle Physics. This provided interesting insights into the allowable number, type and degeneration of neutrinos, and into the number and properties of weakly interacting particles.

Very recently (1987) contemporary astronomers had the unique opportunity of investigating closely the initial stages of a supernova explosion outside our galaxy, the Supernova 87, with all the sophisticated instrumentation at their disposal.

Current investigations on “black holes”, the so called “missing mass” (a misnomer, because we do not know whether this mass really exists), the astonishingly large photon to baryon ratio in the cosmos, etc., leave many open questions.

The story of observational and theoretic investigations on the universe, which begins to look more like a cozy place for Earth and men than the vast punctuated nothingness previously envisioned by some, goes on.

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