Milestones in Astronomy

Science Succeeds Superstition

By Ruth A. Sparrow

● ● ● Astronomy is perhaps the oldest of the sciences. From the birth of the world, man, uncivilized and civilized, has pondered on the nature of things, especially the common phenomena. What caused day and night? Why the change of seasons, the phases of the moon, and the movement of heavenly bodies? Things unexplainable became involved with superstition. If celestial events coincided with some terrestrial occurrence they were read as the signs of the times. Thus began astrology which teaches that the stars and planets can have an influence on the lives of human beings. A little patient study on the part of scholars brought to light the fact that there are 365¼ days to the year; eclipses were recorded, as were comets, new stars, meteor showers, and the conjunctions of the planets.

An early enquirer in the field of astronomy was Thales of Asia Minor (c. 600 B.C.). He was an astronomer of no mean rank and discovered the equinoxes and the solstices. It was Anaximander, a friend of Thales, who studied the phases of the moon, and it was he who also taught the Greeks how to measure time by a sundial.

Aristotle (c. 350 B.C.) summed up the state of the astronomical knowledge of his time and held the earth to be fixed in the center of the universe.

The obliquity of the ecliptic was discovered by Aristarchus of Samos (c. 250 B.C.). About a century later Hipparchus of Rhodes contributed what is known as the precession of the equinoxes.

Ptolemy, an Egyptian, (c. 130 A.D.) was the most distinguished and the last of the great men of the Alexandrine School. He put forth a theory of the universe of his own in *Almagestum*. While entirely erroneous, as was Aristotle's, it was, however, held to be true for over fifteen hundred years. He held that the earth is fixed in the center of the world and that the stars, moon, and sun revolve around it. The Museum owns the first printed edition of the *Almagestum* which was not published until 1528 in Venice.

After Ptolemy there was a lapse in the pursuit of astronomical knowledge. It was not until the middle of the fifteenth century that an event took place which exerted a great influence on all learning—the invention of printing from movable type. Printing became cheaper and duplication of copies more rapid, and people began to learn what was going on in the world. Shortly Columbus discovered America, and Magellan proved that the earth is a globe.

In 1530 there was published the first book (*De Principiis Astronomiae et Cosmographiae*, Antwerp, 1530) in which an accurate method was proposed for ascertaining longitude at sea. Gemma Frisius, a Flemish astronomer and mathematician, expounded the theory that a clock should be carried on board ship which would keep accurate standard time of the port of departure; longitude could then be established by comparing local time by observation of the sun with that given by the clock. The trouble was that clocks were a comparatively new invention, and no instrument had been perfected to keep accurate time on shore, let alone on ships. So there was no way of putting the theory in practice, and the idea lay dormant for over two centuries.

At about this time there was born in Poland one Nicolaus Copernicus, the first of a long line of men who can be rightly called the makers of astronomy. Copernicus was not an observer; his main objective was to formulate a new system of the world less complex than Ptolemy's. For over thirty years he worked on his theory and by 1533 had completed his great work, not published until the year of 1542. This epoch-making book, *De Revolutionibus Orbium Coelestium* (Nuremberg, 1543), reached Copernicus on the day of his death, May 24, 1543. His theory rejected Ptolemy's and is that the sun is the center of the universe around which all the planets, including the earth, move. At the time of publication such a theory was so revolutionary that it was placed on the *Index Librorum Prohibitorum,* and first editions such as the Museum's are excessively rare.

Within four years of Copernicus' death, Tycho Brahe, the great Danish observer, was born. Without him the Copernican theory would have remained an unconfirmed hypothesis, although Brahe himself did not accept the theory. But the observations which Tycho Brahe made from his island observatory at Uraniborg were to establish the heliocentric theory on a firm foundation. Brahe's observations formed the material from which Kepler's three laws were established.

Tycho Brahe's great book *Astronomiae Instaurate Mechanica* (Nuremberg, 1602) contains many interesting full-page woodcuts showing his astronomical instruments. It contains important investigations on the new star of 1572 which he had discovered. This led to one of the important consequences in the history of astronomy; it became one of the foundations on which Kepler and later Newton built their astronomical observations. This work contains further researches.

Johannes Kepler was an advocate of the Copernican theory. He was an assistant to Tycho Brahe, and on Brahe's death was appointed his successor. Consequently he fell heir to much of Brahe's data. After special studies of Mars, based on this material, he published in *Astronomia Nova* (Prag, 1609) the first two of his three great laws: 1. Every planet moves in an ellipse of which the sun occupies one focus; 2. The straight lines joining the planets to the sun sweep out equal areas in equal times.

In 1610 there was presented to Kepler a means of precision of first importance; namely, the Galilean telescope. His studies were further facilitated by the invention of logarithms by John Napier in 1614. Several years later he issued *Harmonices Mundi* (Linz, 1619) in which he set forth his third law of planetary motion which further simplified the Copernican system: 3. The square of the periodic time of any planet is proportional to the cube of its mean distance from the sun.

Using data supplied by Tycho Brahe in reference to 777 stars, which he made the basis, Kepler issued the *Tabulae Rudolphinae* (Ulm, 1627). These tables remained for over a century the foundation of all planetary calculations.

Galileo's fame rests on his work as the virtual inventor of the telescope. He was quick to see the value of such an instrument and was the first to direct it to the sky. No sooner had he done this than he made innumerable startling discoveries. He discovered the mountains and valleys of the moon, the curious irregular black spots on the sun, the phases of Venus and Mars, Jupiter and its four moons, and the stellar nature of the Milky Way. He believed that these findings proved the Copernican theory.

All of these discoveries were distasteful to the adherents of Aristotle and Ptolemy. His work on the revolution of the heavenly bodies was condemned in 1615 and placed on the

Index Librorum Prohibitorum. He continued to teach the Copernican theory in defiance to the papal edict and was eventually called to Rome. He was ordered to stop his teachings, and all his arguments were of no avail. He returned to Florence where he lived quietly for several years. A cardinal who had befriended Galileo became pope, and again he asked that the ban be lifted from his book but again was unsuccessful. Then he did an unwise thing. He had published his *Dialogo . . . sopra i due Massimi Sistemi Mondo Tolemaico e Copernicano* (Florence, 1632). It was a masterly defense of the Copernican system. In it he employed all the resources of wit, fancy, reason, and eloquence to render the truth attractive. The book was immediately prohibited, not only for so-called heretical views but also for having offended the vanity of the pope, who believed himself satirized as the dull interpreter of the Ptolemaic system. This brought about Galileo's imprisonment and subsequent submission to torture. The entire edition was ordered sent to the Inquisition. Galileo was summoned to Rome and forced publicly to recant everything he believed and taught. He was then banished to a house in Florence where he remained a prisoner until his death in 1642.

The planet Saturn with its inexplainable appendages was one of the most wonderful objects first examined by Galileo's telescope. Later Saturn appeared to be single once more. This was a complete puzzle to Galileo, and it was not until 1656 that a Dutch astronomer, Christian Huygens, was able to suggest the ring form in a cypher. In his *Systema Saturnium* (Hague, 1659) he announced the discovery of the rings of Saturn and its fourth satellite. He explained all the phases of the ring which had been so puzzling: "The planet is surrounded by a slender flat ring, everywhere distinct from its surface, and inclined to the ecliptic."

At an early age Galileo discovered the law of the pendulum. The story is told of his noticing the swinging of one of the lamps hanging from the roof in the cathedral at Pisa. Using his pulse as a time measurer he counted the number of swings and saw that the lamp took the same time to swing in a small arc as in a larger one. In 1657 Huygens applied the pendulum to clocks. In 1673 *Horologium Oscillatorium* (Paris, 1673) was published. At the beginning is a description of pendulum clocks illustrated with diagrams of their mechanism. This is followed by the theoretical exposition of the motion of bodies, acceleration, and the fall of bodies along curves. Here is found the first exact calculation of the in-

ONE HUNDRED MILESTONES

"The hundred rare first editions of books epochal in the several fields of science, which the Museum is assembling under the title of 'Milestones of Science,' are unique and world-wide in their significance. They will bring renown to the Museum, to Buffalo, and to the United States," commented President Chauncey J. Hamlin in announcing the collection.

The collection has already begun to "bring renown." One of the "Ten Books That Shook the World" exhibited at the Rare Book Show of the New York Times National Book Fair last month was Copernicus' "De Revolutionibus Orbium Coelestium," lent by the Museum because the Rare Book Committee could not locate another first edition in this country. Incidentally the Museum's collection includes all six of the "world-shakers" that pertain to the field of science.

This article by Ruth A. Sparrow, Librarian, is the second in a series of five in which she describes the books, field by field.

tensity of the force of gravity, and at the end are the important theorems on centrifugal force in circular motion, a theory which aided Newton in his discovery of the law of gravitation.

A contemporary of Huygens was Isaac Newton, one of the greatest men of science. He was born the year Galileo died. Early he began to meditate on the revolutions of the planets around the sun. Did gravity have anything to do with it? Galileo's researches on falling bodies, the relation between the space covered by a body in its descent and the time required for that descent, the planetary laws of Kepler—all these prepared the way for the work of Newton on gravity. For sixteen years he worked on the problem, not mentioning it to a person. In 1682 at a meeting of the Royal Society he heard Picard who provided the first accurate measure of a degree of a meridian. Using this to verify his theory, Newton went over his calculations and discovered that the attraction of the earth was the guiding force on the moon. The Newtonian law of universal gravitation is, in his own words: "The gravitational force acting between two bodies is inversely proportional to the square of their distance and directly proportional to the product of their masses."

This law had far-reaching results. The explanation of the tides was now simple. The cause of the precession of the equinoxes noted by Hipparchus was given reason. These brilliant discoveries were incorporated in the greatest book in exact science ever printed, Newton's *Principia* (*Philosophiae Naturalis Principia Mathematica*, London, 1687). The cost of printing the first edition was borne by Edmund Halley, the discoverer and predictor of the comet which bears his name. Halley edited the work and saw it through the press. Owing to the importance of the work and the comparatively small number of copies printed, this first edition became rare immediately after publication.

Newton's work was carried on by a school of French mathematicians, chief among whom was Pierre Simon LaPlace. Their aim was to show that Newton's theory was capable of explaining the observed motions of the bodies in the solar system. LaPlace is best known for his two famous books the *Systême du Monde* (1796) and *Traité de Mécanique Céleste* (Paris, 1798-1827). The Nebular Hypothesis was first tentatively put forth in the *System*. It supposes the solar system to be a flat disc-shaped nebula at a high temperature in rapid motion. The investigations of LaPlace in this work are of too technical a character for any save a highly mathematical mind. His *Mechanic*, however, is more simple and is his most famous work. In

MILESTONES IN ASTRONOMY

Almagestum by Claudius Ptolemy, Venice, 1528

De Principiis Astronomiae et Cosmographiae by Reinerus Gemma Frisius, Antwerp, 1530

De Revolutionibus Orbium Coelestium by Nicolaus Copernicus, Nuremberg, 1543

Astronomiae Instaurate Mechanica by Tycho Brahe, Nuremberg, 1602

Astronomia Nova, Prag, 1609; Harmonices Mundi, Linz, 1619; and Tabulae Rudolphinae, Ulm, 1627, by Johannes Kepler

Dialogo . . . sopra i due Massimi Sistemi del Mondo Tolemaico e Copernicano, by Galileo Galilei, Fiorenza, 1632

Systema Saturnium, sive de Causis Mirandorum Saturni Phaenomenon, Hage, 1659; Horologium Oscillatorium, sive de Motu Pendulorum, Paris, 1673, by Christian Huygens

Philosophiae Naturalis Principia Mathematica by Isaac Newton, London, 1687

Systême du Monde, Paris, 1796; Traité de Mécanique Céleste, Paris, 1798-1827, by Pierre Simon LaPlace

Theoria Motus Corporum Coelestium by Carl Friedrich Gauss, Hamburg, 1809 it he made a comprehensive attempt to carry out the principles which Newton had laid down. The work starts with the discoveries of Galileo, Huygens, and Newton and develops extremely valuable mathematical methods for applying them in a far more detailed and accurate way than Newton.

In 1801 a strange object was noted in the sky, and astronomers were quick to study it. But it was lost in the sun's rays, and there were fears that it might not be seen again. At this point Carl Friedrich Gauss, a young and obscure tutor, solved the problem by the method of least squares, his own mathematical device, and assigned the missing object a place in the constellation of Virgo. Later that year it was seen there by several astronomers. It was not until some years later that Gauss' astronomical treatise, *Theoria Motus Corporum Coelestium* (Hamburg, 1809) was published. In it are introduced his theory of curvilinear triangulation; it propounds the four formulae in spherical trigonometry which are known as "Gauss' analogies."

Astronomical research does not stop with these books; even today new theories and new discoveries are being made. And with the installation of the two-hundred-inch telescope on Mt. Palamar, who knows what is still to be learned in this great science?

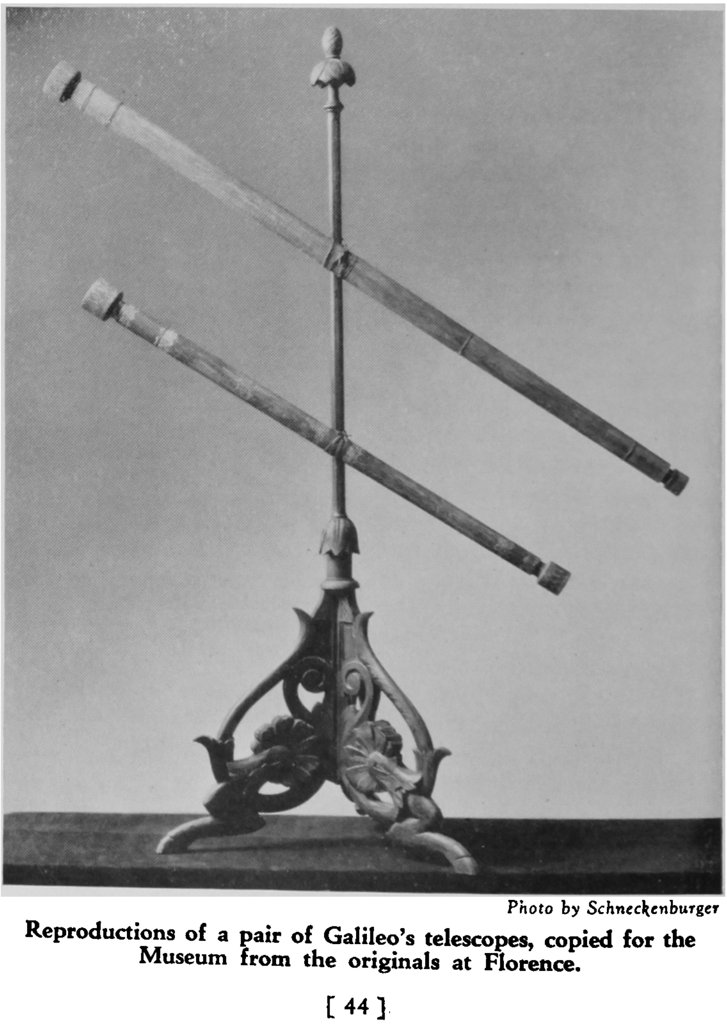

Photo by Schneckenburger

Reproductions of a pair of Galileo's telescopes, copied for the Museum from the originals at Florence.