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(*b*. Skåne, Denmark [now in Sweden], 14 December 1546; *d*. Prague, Czechoslovakia, 24 October 1601)

astronomy.

The second child and eldest son of Otto Brahe and his wife, Beate Bille, Tycho (Danish, Tyge) was born at the family seat, Knudstrup. He had five sisters and five brothers, including his still–born twin. Otto Brahe was a privy councillor and later became governor of Helsingborg Castle. probably Tycho and Christine, whose last name is unknown and who was not of noble family, were never formally married, but they lived together from about 1573 to the end of his life. They had five daughters and three sons; their daughter Elizabeth married Tycho's assistant, Franz Gansneb Tengnagel von Camp. Tycho's best observing was done on the island of Hven from 1576 to 1597. His observations of the nova of 1572 and several comets forced abandonment of the traditional celestial spheres, and his observations of Mars enabled Kepler to discover the laws of planetary motion. Information about his observatory and observational techniques was widely disseminated, and his geoheliocentric system gained numerous supporters.

Tycho was brought up by his paternal uncle, Jörgen Brahe, and from the age of seven was taught Latin and the preparatory subjects by a tutor. From April 1559 to February 1562 he attended the Lutheran University of Copenhagen, where the ologians and faculty were under the influence of Melanchthon as well as Aristotle and the Scholastics. Tycho must have begun his studies in the Faculty of Philosophy by applying himself first to the *trivium*; his study of the arts probably began under the lecturers in pedagogy, who emphasized the writing and speaking of Latin. No doubt he received instruction in the articles of faith from the Lutheran catechism on Sunday mornings. He must have studied Greek grammar and Greek and Latin literature, and probably also dialectic, attending lectures in Greek on Aristotle's *Dialectics* and lectures on the Latin rhetorical works and on Roman epistolary authors.

Since his family was a noble one, Tycho did not need a university degree to establish himself in a profession. Therefore, he must have entered on the study of the *quadrivium* as soon as he was able, without waiting to earn a degree. Ethics and singing were included in the university *quadrivium*; and at the chapter house of the cathedral, students practiced and heard lectures on singing. Also available lectures on hermonic theory, a mathematical discipline since the time of Pythagoras. From the lectures on the natural sciences and philosophy that Tycho may also have heard, he would have emerged as a convinced Aristotelian. By 1560 he was, no doubt, studying arithmetic, then Sacrobosco's *Sphaera* and Peter Apian's *Cosmographia*. His copies of the *Sphaera*, a medical handbook, an herbal, Gemma Frisius' edition of Apian's *Cosmographia*, and Regiomontanus' *Tabulae directionum* are preserved.

In 1561 and 1562 Tycho was probably attending lectures on Aristotle's *Physics*, Euclid's *Elements*, ptolemy's theory of the planets, and on astrology, which united astronomy with medicine. Tycho made friends with, and later wrote an epitaph for, Hans Fransden, from Ribe in Jutland (Johannes Franciscus Ripensis), who lectured on Hippocrates and Galen as well as on mathematics, acted as physician to the King, and prepared an annual astrological almanac. Tycho also made friends with Johannes Pratensis, who later became professor of medicine and whose copy of Ptolemy's *Almagest* Tycho probably inherited in 1576. On 21 August 1560 the occurrence at the predicted time of a solar eclipse, although only partial in Copenhagen, turned Tycho toward observational astronomy, which was not part of the university curriculum. He immediately obtained a copy of Stadius' *Ephemerides*, which is based on the *prutenic Tables* and, consequently, on the Copernican system.

So that he would be parted from friends interested in science and would study law, a necessary part of the education of a member of the nobility, Tycho's uncle sent him to the University of Leipzig, where he arrived in March 1562. With him, as tutor, went Anders Sörensen Vedel, only four years his senior. Vedel had spent less than a year attending lectures on divinity and studying history at the university, but he was later to distinguish himself as a historian. Except for two short visits, Tycho remained away from his homeland until 1570.

At Leipzig, although Vedel tried to keep his charge busy with the study of law, Tycho's interest in astronomy was not to be thwarted; and as late as May 1564 he was pursuing it secretly, while Vedel slept. During the daytime he attended to the studies prescribed by his uncle. He used what money he could save for the purchase of astronomical books, tables, and instruments. Not content with Stadius' *Ephemerides*, he also obtained the *Alphonsine Tables* and *Prutenic Tables*, and used the Ephemerides of Giovanni Battista Carellus(1557). To learn the constellations, he secretly used a globe no bigger than a fist.

A conjunction of Saturn and Jupiter in August 1563 was later regarded by Tycho as the turning point in his career. Although equipped with only a pair of compasses, he recorded his observations relative to it. The discrepancy between the time of the observed closest approach of the two planets and that computed from the tables, about a month using the *Alphonsine Tables*and a few days by the *Prutenic Tables*, greatly impressed Tycho. On 1 May 1564 he began observing with a radius, or cross staff, consisting of a three–foot arm along which could slide the center of an arm of half that length. Both arms were graduated. Bartholomaeus Scultetus subdivided the instrument for him by means of transversals. There was a fixed sight at the end of the longer arm that he held near his eye. To measure the angular distance between two objects, Tycho set the shorter arm at any graduation of the longer arm and moved a sight along the shorter arm until he saw the two objects through it and a sight at the center of the transversal arm. The required angle was then obtained from the graduations and a table of tangents. This instrument was not very accurate, but, since he could not get money from Vedel for a new one, he made a table of corrections to apply to it.

Tycho left Leipzig 17 May 1565 and traveled to Copenhagen via Wittenberg and Rostock. Of his family, only his mother's brother, Steen Bille, showed any sympathy for his scientific interests. When his Uncle Jörgen died, 21 June 1565, there was no longer any reason for him to remain at home. He reached Wittenberg 15 April 1566 and began studies under Caspar Peucer. He left after five months, however, arriving in Rostock 24 September and matriculating at the university soon thereafter.

On 29 December 1566, in an unfortunate duel with another Danish nobleman, part of Tycho's nose was cut off. This he replaced by what was long thought to be a composition of gold and silver, but probably had considerable copper content. When his tomb was opened 24 June 1901, a bright green stain was found on the skull at the upper end of the nasal opening.

At Rostock, Tycho met several men devoted to astrology and alchemy as well as to medicine and mathematics. He observed a lunar eclipse 28 October 1566 and a partial solar eclipse 9 April 1567. That summer he visited home, but was back in Rostock by 1 January 1568. He immediately began observations. although without an instrument until he used the cross staff 19 January. His last recorded observation in Rostock was 9 February. On 14 May 1568, King Frederick II of Denmark formally promised Tycho the first vacant canonry in the cathedral chapter at Roskilde, Zealand. He matriculated at the University of Basel in 1568 and, probably early in 1569, went to Augsburg via Lauingen in Swabia, where he met the astronomer Cyprian Leowitz. He entered into the intellectual life of Augsburg, where he made his first observation 14 April.

Among Tycho's friends in Augsburg were Johann Baptist Hainzel, an alderman, and his brother, Paul, the burgomaster,[1] who helped Tycho arrange for the manufacture of a wooden quadrant, suspended at the center, with a radius of about nineteen feet. The divisions marked on the arc and a plumb line gave altitude measures. Tycho does not seem to have used it himself, and it was destroyed in a storm in December 1574. Tycho also designed a portable sextant, which he used and gave to Paul Hainzel, and ordered a five–foot globe. His last recorded observation in Augsburg was made in Hainzel's presence 16 May 1570. At Augsburg he argued with Ramus, who advocated constructing a new astronomy based entirely on logic and mathematics, without recourse to any hypothesis. They agreed on the need for new and accurate observations before attempting to explain the celestial motions, and it is obvious that Tycho was aware of the need for good instruments to obtain those observations. He returned home in 1570, probably because of his father's poor health. On the way, in Ingolstadt, he met Philip Apian, son of Peter.

Although at his father's death, 9 May 1571, he and his brother Steen inherited Knudstrup, Tycho soon moved to Heridsvad Abbey, the home of his uncle, Steen Bille, where he devoted himself to chemical experiments until 11 November 1572. After sunset on that day, almost directly overhead, in the constellation Cassiopeia he noticed a star shining more brightly than all the others and immediately realized it had not been there before.

To measure the star's angular distances from the neighboring stars in Cassiopeia, Tycho used a sextant similar to the one he had left with Hainzel. The two arms of seasoned walnut, less influenced by climate than other woods and lighter than metal, were joined by a bronze hinge. A 30° arc, graduated by individual minutes, without transversals, was fixed to one arm; the other arm could slide along the arc. Square metal sights with holes through the centers were attached at the ends of the arms. Tycho later described this instrument in the *Mechanica* and in the *Progymnasmata*, by itself and, as used for the nova observations, in the plane of the meridian, pointing out a window with the end of the arm where the arc was fixed (this time a 60° arc) resting on the sill while the end of that arm, near the joining of the two arms, rested on a post some five feet inside the window. To make sure that this arm was horizontal, it was moved until a plumb line, hanging from the end of the arc, touched a mark in the middle of the arm. The plumb line would show any change in position of the instrument, thus indicating the correction to be made to the observation.

To make sure that observations made the same night were made under the same conditions, Tycho left the instrument clamped in position between such observations. He measured the angular distance of the new star, at both upper and lower culmination, from the star Schedar (α Cassiopeia), which crossed the meridian at nearly the same time, and found no parallax. He measured the distance of the nova from nine stars in Cassiopeia and found no variation between observations. Had the new star been as close to the earth as the moon, a parallax of 58´30´´ would have been found. Tycho observed the star until the end of March 1574, when it ceased to be visible. His records of its variations in color and magnitude identify it as a supernova. At first clear white, with the magnitude of Venus at its brightest, it grew yellowish and diminished in brightness to that of Jupiter. By February and March it was of the first magnitude and reddish, in April and May of the second magnitude and lead–colored. Thereafter its color did not change. By August it was a third–magnitude star, fourth–magnitude by October, hardly more than fifth–magnitude at the turn of the year, and sixth–magnitude or less in February 1574.

Tycho concluded that the phenomenon was not an atmospheric exhalation and was not attached to the sphere of a planet, since it did not move contrary to the direction of the diurnal rotation, but that it was situated in the region of the fixed stars. He called it a star, not a comet, because, as the ancients asserted, comets are generated in the upper regions of the air, not in the heavens. He noted that it twinkled like a star and did not have a tail like a comet. It could not be a comet with its tail turned away from the earth because Peter Apian and Gemma Frisius had shown that the tail of a comet is turned away from the sun. Tycho thought it not impossible that the star would again cease to be visible, as he wrote in a brief tract published in 1573, while the star was still visible. This tract, dedicated to Johannes Pratensis, at whose urging it had been printed, included an exchange of letters between the latter and Tycho, a section on the astrological significations of the star, the introduction to an astrological calendar, and that part of the calendar dealing with the lunar eclipse of December 1573.

All over Europe scholars observed the star. Some, using crude observational procedures, such as holding a thread before their eyes, assured themselves that the newcomer did not move relative to certain known fixed stars. Such observations, showing the star to be supralunar, were widely appreciated as necessitating an alteration in cosmological theories.

Tycho's scholarly treatise concerning the star, the *Progymnasmata* (1602), was the first volume of a proposed trilogy. The second chapter on planets having been printed and paged first, there was space in chapter 1 to describe the lunar theory, the complexity of which delayed publication of the volume. The work reprinted most of Tycho's 1573 tract and gave his carefully compiled observations of the nova, discussing its position in space and its expected annual parallax if the Copernican system were true. Tycho attempted to calculate the real diameters of the sun, moon, planets, and the nova from his measurements of their apparent diameters. He estimated the maximum distance of Saturn as 12,300 semidiameters of the earth, the distance of the fixed stars as 14,000—not all at the same distance—and that of the new star as 13,000. His estimate of the real diameter of the new star at its first appearance was 7–1/8 times that of the earth. He assigned the diminution in light to actual decrease in size. Galileo pointed out [2] the impossibly enormous sizes of the stars if Tycho's estimates of their diameters were correct. The *progymnasmata* also reprinted, summarized, or criticized the works on the nova by others. Tycho deplored Hagecius' use of clocks because of their inaccuracy. Because he was unable to observe the star with his sextant at upper culmination, Tycho used Hainzel's observations made at Augsburg with the big quadrant.

Tycho's observations of the nova were separately recorded. His journal of observations skips from one made at Helsingborg 30 December 1570 to his entries of three distance measurements between the nova and known fixed stars made with a parallax instrument 10 May 1573. There are entries for 14 August and for a lunar eclipse observed at Knudstrup 8 December, for observations at Heridsvad in March and April 1574, and at Copenhagen at the end of April and May. None appear for 1575.

In September 1574, in the first lecture of his course for young noblemen at the University of Copenhagen, Tycho spoke of the skill of Copernicus, whose system, although not in accord with physical principles, was mathematically admirable and did not make the absurd assumptions of the ancients, who let certain bodies move irregularly in respect to the centers of the epicycles and eccentrics. Doubtless, Tycho had Copernicus' rejection of Ptolemy's equant in mind. The influence of the stars on nature—seasons, tides, weather—seemed obvious. If forewarned, thanks to astrology, men could conquer the influence of the stars on themselves, but Tycho had reservations concerning public calamities.

Soon after completing these lectures, early in 1575, and wondering where to settle permanently, Tycho went first to Kassel, where he visited Landgrave William IV. The two men, convinced of the need for systematic observations, observed together for more than a week, Tycho with some of his own portable instruments and the landgrave with his quadrants and torqueta. They made an accurate determination of the position of Spica. Their discussion of the retardation of the sun near sunset spurred Tycho later to study refraction at low altitudes. The landgrave was so impressed by Tycho's ability that he suggested to the Danish monarch that something be done to enable Tycho to pursue his astronomical studies in his native land.

Tycho's next stop was Frankfurt am Main. There, at the book fair, he purchased many pamphlets on the recent nova. He next journeyed to Venice via Basel, where he contemplated settling, and then returned to Augsburg, inquiring about instruments he had ordered during his previous visit. Wherever he went, he met the leading astronomers and, whenever possible, inspected their astronomical instruments.

At Regensburg, where the future emperor, Rudolph II, was crowned King of the Romans, 1 November 1575, Tycho met Rudolph's physician, Hagecius, who had written an excellent book on the nova of 1572. From him Tycho obtained a copy of Copernicus' *Commentariolus* and a copy of a letter from Hieronymo Mugnoz to Hagecius about the new star. It is probable that at the same time Tycho presented Hagecius with a copy of his tract on that star. At Saalfeld, on the return journey, Tycho saw the manuscripts of Erasmus Rheinhold, who had prepared the *Prutenic Tables*. In Wittenberg, Tycho examined the wooden parallactic instrument, or triquetrum, with which Wolfgang Schuler had observed the nova after his earlier observations with Johannes Praetorius, made with an old wooden quadrant, had resulted in the finding of a large parallax that was inconsonant with the results obtained by the landgrave.

Tycho reached home near the end of 1575. In February 1576, possibly because of the landgrave's recommendation, King Frederick II offered him the island of Hven in the Danish Sound and asked him to erect suitable buildings and construct instruments there. Tycho accepted, feeling that he could thus obtain in his native land the desired quiet and convenience. He immediately visited the island, and on 23 May a document was signed by the king conferring and granting in fee the island and its tenants and servants, with the rent therefrom; there was also the obligation to govern it in accordance with the law and to attend to the welfare of the inhabitants. Tycho was also given sufficient funds to augment his own, in order to erect a suitable residence and other buildings necessary to his work, and certain landholdings, the income from which, together with his own fortune, made it possible for him to lead an almost regal existence. From time to time additional sources of income were made available.

The island is roughly 2,000 acres in area. The inhabitants lived in a village near the northern coast and tilled about forty farms in common. Near the center of the island, at the highest point, about 160 feet above sea level, Tycho began construction of Uraniborg (heavenly castle), the edifice that was to be his home and observatory for more than twenty years. He made one observation of Mars in October 1576 and began observations of the sun 14 December. Although he probably moved into the building that winter, it was not completed until 1580, and even thereafter additions and alterations were made. On the island were the workshops of the artisans who constructed his instruments, a windmill, a paper mill begun in 1590 and completed in 1592, which could also be used to grind corn and prepare hides, and nearly sixty fishponds, one of which, for the use of the mill, was secured by a large dam.

The main building was erected exactly in the center of a square enclosure the walls of which were about 255 feet long, eighteen and one–half feet high, and seventeen feet wide at the base. At the center of each wall was a semicircular bend about seventy–six feet in diameter that enclosed a pavilion. There were gates at the eastern and western corners, and above the gates were kennels in which two English watchdogs were kept to warn of arrivals. At the northern corner was a small house for servants in the same Gothic–Renaissance style as the main house. A similar house at the southern corner housed a printing office. The press was installed in 1584. Four roads directed exactly to the cardinal points led from the main house to the gates and houses. Within the enclosure were herbaries and flower gardens and about 300 trees of various species.

The main house, too, was exactly square, its four walls, about fifty–one feet long and thirty–eight feet high, facing the four points of the sky. The rounded towers added on the south and north were eighteen and one–half feet in diameter, with eight and one–half–foot galleries encircling them. From the ground to the Pegasus weathervane, the house measured about sixty–four feet. Beneath the entire house was a cellar more than ten feet deep, divided into many rooms, and beneath the towers were the well and arrangements for storing food. The original four corridors on the ground floor, which met at right angles, were later reduced to three so as to make possible the establishment, behind the furnace, of a small chemical laboratory, thereby lessening the need to go down to the large subterranean one. There were a fountain that could turn, sending water in all directions, and pipes and pumping apparatus to distribute water to rooms on both floors. On the ground floor there were also a library, a kitchen, a table for collaborators in each corner of the building, and spare bedrooms. The observatories were on the upper level, the larger southern and northern ones containing several of the important, large instruments—such as the azimuthal semicircle, Ptolemaic rulers, brass sextant and azimuthal quadrant, and parallactic rulers that also showed azimuths. An octagonal gallery contained one of the globes on which an instrument could be placed and turned in all directions. At the very top of the house were eight bedrooms for assistants.

About a hundred feet south and slightly east of Uraniborg a separate observatory, Stjerneborg (castle of the stars), constructed about 1584, housed additional instruments in five subterranean rooms. Stone columns outside could be used to support Ptolemaic rulers or the portable armillae. There were also places for globes on which instruments could be placed and turned. In this building was a study with only the vaulted roof and the top of the walls above ground. On the ceiling was depicted the Tychonic system, and on the walls were the portraits of Timocharis, Hipparchus, Ptolemy, al–Battānī, King Alfonso X of Castile, Copernicus, Tycho, and the still unborn but hoped–for descendant, Tychonides, each with a legend beneath it—that for Tychonides expressing the wish that he would be worthy of his great ancestor.

The accuracy of the observations depended on the instruments and the care with which they were used. Although Tycho's were without magnification, error was minimized by their huge size and by the graduations carefully marked on them to facilitate angular measurements on the celestial sphere, altitudes, and azimuths. Tycho checked instruments against each other and corrected for instrumental errors. Unfortunately, he considered refraction negligible at altitudes above 70°. He observed regularly and achieved an accuracy within a fraction of a minute of arc, an accuracy unsurpassed from the time of Hipparchus to the invention of the telescope.

In the library was the globe, almost five feet in diameter, ordered from Augsburg. Tycho filled the cracks, restored the spherical shape with pieces of parchment, tested it for two years to see whether it would retain its shape and whether it would withstand the seasonal temperature changes, then covered it with brass sheets and again had it smoothed. On it he engraved the zodiac and the equator with their poles and, using transversal points, divided each degree of these circles into sixty minutes. The globe could be turned on an axis through its poles inside the meridian and horizon circles that were mounted on it and that were divided into degrees and minutes. A vertical brass quadrant marked in degrees and minutes indicated altitudes as well as azimuths along the horizon. On this globe, over the years, Tycho marked the exact positions, referred to the year 1600, of the fixed stars that he observed. He also investigated the planet motions with reference to this globe.

In the southwest room on the ground floor at Uraniborg, affixed to a wall in the plane of the meridian, was Tycho's most famous instrument, the mural quadrant with a radius of about six feet. The degrees marked off on its arc were so far apart that each minute was divided by transversal points into six subdivisions of ten seconds each, making it possible to read off measurements of five seconds. In a wall pointing exactly east and west, and over the center of the quadrant, was a square hole that could be opened and closed and that contained a brass cylinder along both sides of which the observer could sight, using one of two pinnules on the quadrant. Each pinnule had a square plane the width of which was exactly equal to the diameter of the cylinder. Each side of the plane had a slit for use in determining a star's altitude and meridian transit at the same time. To determine the altitude alone, which was done to the sixth of a minute, an observer looked through the upper and lower slits and the corresponding sides

of the cylinder, and an assistant entered the reading on the record. A third person watched two clocks when the observer at the pinnule signaled, and the time was noted in the ledger. Two clocks that gave seconds as accurately as possible and could be checked against each other were necessary. Tycho had four. Elsewhere he expressed his distrust of clocks, preferring to check the time by observation. Despite his faith in this quadrant, he also consulted other large instruments.

Inside the quadrant's arc, for ornamental purposes, was painted a life–size portrait of Tycho seated at a table, with arm outstretched as though pointing to the cylinder. In a niche in the wall, above and near the head, was a brass globe fitted with interior wheels. It could turn to imitate diurnal rotation and to show the paths of the sun and moon and the lunar phases.

The smaller southern observatory housed a brass armillary instrument with four armillae, or rings; the smaller northern observatory, another with three armillae. In the northern tower were the sextant with which one observer could measure distances, the bipartite arc for measuring small angular distances, and the sextant with which Tycho had observed the nova. Among his other instruments were several smaller quadrants and sextants of various designs for various purposes, an astronomical radius, an astronomical ring, a small astrolabe, an azimuth semicircle, and some parallactic or ruler instruments, one of which had belonged to Copernicus.

In these fantastically ornate but exceedingly useful observatories, Tycho watched the skies and trained his assistants. Some of the larger instruments could not have been used without their aid. Among these assistants were Peter Jacobsøn Flemløs, Longomontanus, Elias Olsen, Gellius Sascerides (who stayed six years), Otto Islandus (Oddur Einarsson, who was bishop in Iceland), and Willem Blaeu (who later made excellent maps and globes). Paul Wittich, who was an assistant at Uraniborg in 1580 and who, at Kassel in 1584, described Tycho's instruments, including the transversal divisions, so impressed the landgrave that he had his instrument maker, Joost Bürgi, alter his instruments to conform to the description. Wittich was probably largely responsible for the development of the prosthaphaeretic method (from πρόσθεσις [addition] and ἀφαίρεσις [subtraction] for simplifying trigonometrical computations by replacing multiplications and divisions with additions and subtractions. This is the basis of the set of rules for solving plane and spherical triangles, *Triangulorum planorum et sphaericorum praxis arithmetica*, drawn up, without proof, by Tycho and made available in numerous manuscript copies for the use of his assistants. Wittich also revealed this method at Kassel, to the annoyance of Tycho; he was even more annoyed, however, by the inclusion of the first two rules in a book by Nicolai Reymers Bār (Ursus), printed at Strasbourg in 1588. Afterward the method was further developed by other mathematicians. Ursus had visited Hven in 1584. Tycho was also visited by members of the nobility, possibly including Frederick II and certainly Frederick's son, the future Christian IV (1592), as well as James VI of Scotland, the future James I of England (1590). Christoph Rothmann, Landgrave William IV's mathematician, was there from 1 August to 1 September 1590.

Although Tycho saw no objection to the adoption of the Gregorian calendar by the Protestant world, since questions of theology were not involved, he does not seem to have used it until early 1599, when, on the Continent, he began to date his letters in the new style. His first observation so dated was made 22 July of that year.

From Hven, Tycho carried on a vast correspondence that kept alive the personal contacts made in his student days, apprised the scholarly world of his work, and provided him with the observations of others for comparison with his own. Although Tycho and William IV never met again after Tycho's 1575 visit to Kassel, in later years they exchanged letters, sending each other records of their observations. The correspondence, including letters between Tycho and Rothmann, was printed at Uraniborg in 1596. It begins with data concerning the comet of 1585 and largely concerns the techniques of observation, the instruments used, and their divisions. Appended is a description of Hven, with its observatories and instruments. The majority of Tycho's other letters, written between 14 January 1568 and 30 April 1601, first appeared in print in the *Opera omnia*. They provide a survey of observational astronomy in the last three decades of the sixteenth century, having achieved that dissemination of ideas which is now the province of learned journals.

Shortly after sunset on 13 November 1577, Tycho noticed, for the first time, a large comet with a very long tail. Although he later heard that the comet had been seen in the Northwendic Sea on 9 November, in his opinion it had begun with the new moon that had occurred shortly before, on 10 November at one hour after midnight.[3] He observed from 13 November to 26 January, by which time it was barely distinguishable. He used a radius and a sextant, and occasionally a quadrant with an azimuth circle—the larger instruments were not yet all installed. He fixed the quadrant in the meridian. Shortly after the comet ceased to be visible, he described it in a short German tract, first published in 1922.[4]

Five hours after noon on 13 November, Tycho found the comet 26°50´ from the bright star in Aquila and 21°40´ from the lowest star in the horn of Capricorn, toward which the tail was stretched. Using trigonometry, he computed the comet's position as 7°15´ in Capricorn, with a declination of 8°20´ north of the ecliptic. In the next twenty–four hours it moved 3°30´ in its circle. Having found it moved more rapidly in the beginning, Tycho decided it had moved 4° in its circle each of the days before he saw it, at new moon having been near the ecliptic beneath the twenty–fifth degree of Sagittarius in the line of the Milky Way, which he considered the place whence comets usually come. He traced the comet's path from west to east. It had described a quarter of a great circle from the twenty–fifth degree of Sagittarius in the ecliptic, intersecting the equator at an angle of 34° at a point 300°40´ from the vernal equinox. Its rate of motion gradually decreased, so that in the end it moved only 20´ in a day, or 4°20´ from 13 January to 26 January. Its tail, 22° long in the beginning, gradually became smaller and shorter, and could scarcely be seen in January. Tycho used the direction of comets' tails as evidence that the tails are merely solar rays transmitted through the head of the comet, an argument against Aristotle's theory of the formation of the tail out of "dry fatness."

In the first chapter of the untitled German tract, Tycho described Aristotle's theory of comets and objected to it on the grounds that the star in Casiopeia four years before had been supralunar, having had no parallax and having remained stationary like the fixed stars, for which reasons many had abandoned the Aristotelian theory in favor of the belief that something new can be born in the heavens. Tycho suggested that other comets could be born there, and are not composed of dryness and fatness pulled up from the earth. He said that Aristotle's proof had been based on meditation, not mathematical observation or demonstration, whereas comets *are* generated in the heavens.

Tycho referred frequently to his still incomplete Latin work on the same phenomenon, considering the two works as serving different purposes. The German one was intended for a wider audience than could be reached by a work in Danish, but it was meant for a less skilled audience than the one for whom the Latin work was written. Because it could reach only the literate, the German work would have an intelligent audience, but not one expected to be trained in mathematics. Repeatedly Tycho referred to the mathematical explanations in the Latin work, which the "masters" could read and understand. Indeed, the numerical values, such an important part of the Latin work, are almost entirely absent from the German. Tycho's main objective was to determine the comet's distance from the earth as a means of refuting Aristotle. He was also concerned with the comet's physical appearance—color, magnitude, and the direction of the tail.

As clearly as anything he wrote, this tract shows Tycho as a product of his times. Breaking with established tradition, he knew exactly where he stood in the historical development of astronomy. Moreover, the tract demonstrates how early and how fully he understood the implications of his break and stresses his insistence on putting observation above deduction by reasoning. Emphasis is placed on the comet's lack of parallax and the resultant untenability of the so–called Aristotelian doctrine of solid spheres in an unchanging heaven. It hints at Tycho's own system of the universe, on which he was already working. It deals at length with the astrological implications of this fiery sign, but secondarily to the observational revelations.

De mundi aetherei recentioribus phaenomenis (1588), on the comet of 1577, the second volume of Tycho's proposed trilogy, was printed on his own press and is profusely illustrated with useful diagrams. Chapter 1 records in detail, day by day, each of Tycho's observations of the comet. The next chapter gives his positional data, computed from his observations, for the comparison stars used in observing the comet. In chapter 3 the comet's latitude and longitude for each day are derived by means of spherical trigonometry, using observed angular distances of the comet from certain fixed stars. The diagrams, but not the mathematical steps, are reproduced. Chapter 4 treats the comet's right ascension and declination with respect to the equator, and chapter 5 deals with the portion of a circle described by the comet, ending with a table of its daily motion, latitude, longitude, right ascension, and declination (first southern, then northern) for 9 November 1577 to 26 January 1578. Chapter 6 treats the comet's parallax as a measure of its distance from the earth and states that the comet was in the etherial rather than the elementary region and moved in a great circle. Tycho's observations of the comet's angular distance from certain fixed stars are compared with those of other observers in other localities. Chapter 7 deals with past writings about the direction of comet tails and with the 1577 comet's tail, which was directed away from Venus. In chapter 9, however, Tycho states his opinion that this was an illusion, since it would seem more likely that the tail be directed away from the sun. Chapter 8 discusses the comet's position in regard to the planetary spheres.

Since his observations of the nova of 1572 and the comet of 1577 had made him discard the reality of the spheres, Tycho included a description of his own geoheliocentric system of the universe. The comet, whose greatest elongation from the sun was 60°, moved about that body in a circle outside that of Venus, that part of the circle where Tycho observed the comet being closer to the earth than Venus was. Moreover, the comet's orbit, inclined to the ecliptic at an angle of 29°15´, was not a true circle, but an oval. Chapter 9 is concerned with the actual size of the comet and its tail, the diameter of the head being 3/14 of the diameter of the earth, and the length of the tail in November being ninety–six semidiameters if turned from Venus. The tenth and last chapter summarizes in detail the observations of others, both of those who found the comet supralunar and those who thought they found it sublunar.

At least six later comets were visible to the naked eye before Tycho left his island. The comets of 1580, 1582, 1585, and 1590 were supposed to be treated in the third volume of the trilogy, but that volume was never written. Tycho observed the comet of 1580

from 10 October to 25 November and again on 13 December, after it had passed perihelion. On 12, 17, and 18 May 1582 he observed another comet. By 1585 his major astronomical instruments, including a large armillary instrument at Stjerneborg, had been installed. His excellent observations of the tailless comet visible in October and November of that year appeared in 1586 in the first book printed on the island, the *Diarium astrologicum et metheorologicum* of his assistant Elias Olsen. They were more fully preserved in manuscript and studied in detail in the nineteenth century. The comet of 1590 was observed at Hven the end of February and the beginning of March, whereas that of 1593 was not observed at Hven but at Zerbst in Anhalt (Seruesta Anhaldinorum) by one of Tycho's former students, Christiernus Johannis Ripensis. Tycho saw the comet of 1596 in Copenhagen on 14, 15, and 16 July. More complete observations were made at Uraniborg on 18, 21, 24, and 27 July.

Hinted at in the German tract on the comet of 1577, probably first worked out by 1583, and first described in print in the 1588 Latin work on the comet of 1577, the Tychonic system was never presented in detail. In it the earth is at rest in the center of the universe, and there is still need for a sphere of fixed stars revolving in twenty–four hours. The planets circle the sun while the sun circles the earth. The orbits of Mercury and Venus intersect the orbit of the sun in two places but do not encompass the earth. The orbit of Mars also twice intersects that of the sun, but encloses the earth and its orbiting moon. The orbits of Jupiter and Saturn enclose the entire path of the sun.

Tycho prized parts of the Copernican doctrine or

at least acknowledged the abilities of its originator, but could not bring himself to accept a sun–centered universe. His reluctance to do so can be ascribed partly to his respect for Scripture and partly to his feeling of common sense, but largely to his inability to conceive of a universe so immense that an observer as accurate as he knew himself to be could not detect any stellar parallax, the necessary consequence of the earth's motion around the sun. The Tychonic system was timely and gained acceptance in many quarters. It did not bring its author into conflict with the ologians, yet it cared for observed phenomena, including the motion of comets through space, which had necessitated Tycho's rejection of the Aristotelian spheres. It could account for the phases of Venus, first observed by Galileo and not explicable by the Aristotelian and Ptolemaic schemes.

Just as Tycho was only one of a number of observers who stressed the supralunar position of comets and novae, so his compromise theory of the universe was only one of a number that accentuated the abandonment of Aristotelian tradition and helped prepare men to accept the Copernican doctrine. It is only natural, especially in the light of Tycho's arrogant ways, that there was some feeling of rivalry, especially toward Ursus, who described a similar system.

In Aristotelian theory the planets were attached to spheres and rotated with them. The destruction of these solid orbs made it necessary to find a cause for the motion of the planets, and this cause was provided by the next generations of astronomers and physicists, the sun assuming an importance not accorded to it by either Copernicus or Tycho. Undoubtedly the traditional crystalline spheres would eventually have been discarded without the aid of Tycho's work, but he speeded up the change.

Tycho presented his cosmologic views in his introduction to a pamphlet [5] on weather forecasting by his assistant Flemløs. To explain how the heavens influenced matters on earth and so could be used for prognostication, Tycho described his cosmology, but focused not so much on the system as on the way the heavens affect the earth. He maintained the concept of "free will" while conceding celestial influence. Accepting three elements—earth, water, and air—he theorized that air is the instrument by which the celestial region influences the terrestrial, with the animals and plants therein and, to a lesser extent, men (some more than others). Thus he voiced disagreement with traditional concepts while maintaining the validity of astrology and distinguishing it from astronomy.

Elsewhere Tycho criticized astrologers who drew improper conclusions based on superstition and error rather than astrology itself, which he considered a science for which both accurate knowledge of the course of the stars and experience gained from signs seen in the elementary world were needed. From the lunar eclipse observed during his stay in Leipzig, he predicted the wet weather that followed. Also while in Leipzig, he calculated Caspar Peucer's horoscope, predicting the misfortunes that befell him, as well as his reestablishment. In Rostock, from the lunar eclipse of 28 October 1566, Tycho predicted the death of the aged Sultan Suleiman the Magnificent, but later learned that Suleiman had died before the eclipse. Tycho calculated horoscopes for the three sons of Frederick II; but, although he continued to prepare annual prognostications for his ruler, by 1588, if not earlier, he held them of little importance, preferring to devote himself to the restoration of astronomy.

The German tract on the comet of 1577 stressed the comet's astrological significance, whereas the Latin work did not. In the *Progymnasmata*, the main part of the 1573 nova tract was reprinted, but not the section on the star's signification. These differences can, no doubt, be explained by the differences in the intended audience and a change in Tycho's point of view. Yet as late as 1598, in the autobiography included in the *Mechanica*, he said that both natural and judicial astrology are more reliable than one would think, provided the times are correctly determined and the paths of the celestial bodies and their entrances into the separate divisions of the sky are used in accordance with the observed sky, and their directions of motion and revolution are properly computed. He indicated that he had developed a method for this that he did not care to divulge.

In the *Astrologia*, Flemløs gave 399 short rules for weather prediction from the appearance of the sky, sun, moon, and stars, or animal behavior. However, the daily weather record kept at Hven from 1 October 1582 to 22 April 1597 was not published until the nineteenth century. It recorded the arrivals and departures of Tycho, his visitors, and students or assistants; and, although no instruments were used and precise times were not entered, it provided useful meteorological information for the area—frequency of wind, rain, snow, fog, hail, thunder, halos, and aurorae, and whether the sky was clear, semiclear, or covered. Some estimates were made of the force of winds.

Tycho's main occupation on Hven was the redetermination of the positions of the fixed stars and the observation of the planets, the sun, and the moon for the purpose of improving the ory of their motions. For six years, beginning in 1582, the distance between Venus and the sun was measured with the triangular sextant, which required two observers. Simultaneously the altitudes, and occasionally the azimuths, of Venus and the sun were measured. The distance of Venus from selected bright stars near the zodiac was measured with the same sextant after sunset, altitudes and declinations also being noted. The motions of Venus and the sun between daytime and nighttime observations were considered in calculating the positions of the observed stars. A star's declination was measured directly, but the difference in right ascension between the sun and a star was obtained by trigonometry. Using the right ascension of the sun as given in the tables, the right ascension of the star could be found. The stars were connected with α Arietis by distance measures. By suitable selection of observations, minimizing the effects of parallax and refraction, he determined the right ascension of α Arietis, and with this as reference, he determined the right ascensions of eight standard stars. Later he added three stars near the zodiac.

In determining the position of another star, a meridian quadrant or armillary was used to measure the declination, and a sextant was used to measure the distance from a known star. For the complete determination, two or three standard stars were used as reference. Included in the *Progymnasmata* (1602), before the section on the nova, are revisions of the solar and lunar theories and a catalog giving the positions of 777 fixed stars. Having indicated familiarity with the work of his predecessors, Tycho, using diagrams, described his observational methods and depicted the instruments used. In his later years he brought the list of stars to 1,000 by the less careful determination of the positions of 223 additional ones. The *Tabulae Rudolphinae*, prepared by Kepler in accordance with his modification of the Copernican system but on the basis of Tycho's observations, did not appear until 1627. Included were logarithm and other tables, the most significant of which were those of the positions of the sun and moon and five planets, and of 1,000 fixed stars calculated for the year 1600.

When he had more instruments, Tycho used several quadrants simultaneously for repeated observations of the sun's meridian altitude, begun 14 December 1576. From March 1582 he mostly used the great mural quadrant. He determined the equinoxes for the years 1584–1588, using the time when the sun was 45° from the equinoxes to determine the position of the apogee and the eccentricity of the orbit instead of using the solstice, the exact moment of which was difficult to find. He believed that the sun moved uniformly in an eccentric circle, but by 1591 he might have noted, from the motion of Mars, another inequality due to that eccentricity. He considered his tables of the sun's motion to be accurate within 10´´ or at most 20´´. His values were 95°30´ for the longitude of the apogee with an annual motion of 45´´ and .03584 for the eccentricity of the orbit, the greatest equation of center being 2°3´15´´.

The difference in the colatitude as determined from his solar observations and his observations of the polestar led Tycho to investigate the effects of refraction, using the armillae at Stjerneborg, and to compose a refraction table. Unfortunately, he assumed the value of 3´ for the sun's horizontal parallax. He also composed a refraction table for the stars. He erred in believing refraction negligible at 45° and over, but made a step forward in determining the refraction for an observation and in correcting the instruments.

Tycho's handling of the lunar theory illustrates not only the accuracy of his observations and his awareness of the need to observe over long periods of time and over the whole course of the moon's orbit, but also his computational prowess and talent for theory construction. His discoveries of new inequalities in both longitude and latitude stem from his efforts at accurate determination of eclipses and his interest in parallax. Making approximately 300 observations of the moon in different parts of its orbit from 1582 to 1595, he noted its position relative to known fixed stars, observing in such a way as to minimize the effects of parallax. In the *Progymnasmata* he recorded twenty–one lunar and nine solar eclipses [6]. At his death all the important lunar perturbations, with the exception of the secular variation of the mean motion, were known.

Tycho made his first discovery regarding the moon's motion in 1587, when preparing his observations of the comet of 1577 for publication. The comet's position obtained from observations of its stellar distances differed by 21´ from the position computed from the lunar distance, suggesting some error in his theoretical position of the moon. Four lunar observations in August 1587 confirmed his suspicion that the inclination of the lunar orbit was 5°15´ instead of the previously accepted 5° of Ptolemy. When Tycho announced this finding in his book on the comet of 1577,[7] he expressly interpreted it as due to a long–term change rather than as a correction of Ptolemy. But in 1595 he discovered that the inclination varied in the short term—that he had, by chance, observed the moon's latitude in quadrature, whereas previous interest in the moon's latitude had been focused on syzygy, where eclipses occur. To account for the semimonthly fluctuations of the inclination, Tycho let the pole of the lunar orbit describe a circle twice a month to bring the pole 5° from the ecliptic when the moon was in syzygy and 5°15´ from it in quadrature, and also to provide a smooth variation in between. Since this device implied an oscillation of the nodes along the ecliptic, Tycho sought and found empirical evidence that such an oscillation did occur, thus making what has been described as "a true deductive discovery." From his determinations of the extreme values for the inclination of the orbit (4°58´30´´ to 5°17´30´´), Tycho deduced a value of 1°46´ for this nodal oscillation.

Tycho's discovery of the third inequality in longitude began with his observation of the lunar eclipse of 1590, in which the moon reached opposition about an hour before the time he had computed. By 1595 he had isolated the cause of his difficulty and had determined the approximate value of the "variation," the discovery of which he announced in his *Mechanica*.[8] During the winter of 1598–1599 another refractory eclipse led him to a fourth inequality—the so–called annual equation with a period of a solar year.

Tycho's theory was put into its finished form by Longomontanus in 1601 and was published in the *Progymnasmata*. In it the first inequality (4°58´27´´) was represented by a double epicycle, while the second appeared in the form of a hypocycle by means of which the center of the deferent was made to pass through the earth twice a month at syzygies and to reach its greatest distance from the earth at quadratures. The third inequality (40´30´´) was accounted for by letting the center of the large epicycle librate on the deferent in the period of half a synodic revolution. Since these mechanisms left no room for the fourth inequality, Longomontanus introduced it—only partially, and to Tycho's expressed displeasure—by dispensing with the anomalistic component of the equation of time.

After the death of Frederick II, 4 April 1588, Tycho gradually lost the favor he had enjoyed at court. His own personality had much to do with this. He was arrogant, haughty with members of the royal family, neglectful of the welfare of the tenants on

Hven, and careless in the maintenance of the public buildings on his fiefs. Although Hven had been conferred on him for life and he had some inherited wealth, the maintenance of his buildings and instruments required additional funds. Young King Christian IV, after gaining majority, did not seem to find that the astronomical work warranted the large expenditures. A quarrel with his former pupil Gellius Sascerides, who was engaged to his daughter Magdalene, put Tycho in an unpleasant light and may have contributed to his desire to leave Denmark. Besides, he may have wanted more opportunity for intellectual intercourse than he had on his island; and he may have hoped for patronage from Emperor Rudolph II, of whose interest in alchemy and astronomy he must have been aware through his correspondence with Hagecius and with Vice–Chancellor Curtius, who had written describing Clavius' method of dividing instruments, which was similar to Vernier's later, more practical one.

After 15 March 1597, the date of the last observation at Hven, Tycho's instruments, printing press, chemical apparatus, and portable possessions were transported to his house in Copenhagen; the mural quadrant and three other large instruments were left behind. Little is known of Tycho's activities in Copenhagen. Early in June he sailed for Rostock with his instruments, press, and other belongings, as well as his family an entourage, including Tengnagel, who had come to Hven in 1595.

On 10 June 1597 the Roskilde prebend was conferred on another. Tycho made an unsuccessful attempt at reconciliation with Christian IV and in October, at the invitation of Heinrich Rantzov, took up residence in the castle at Wandsbeck, near Hamburg. There he continued his efforts to have the king permanently endow Uraniborg. Tycho began observing again 21 October, using only a radius until February 1598, when he got some of his better instruments together. He observed the solar eclipse of 25 February 1598, and later he received records of observations by others and information that it had been observed from beginning to end at Hven. He observed two lunar eclipses and some meridian altitudes but concentrated on the planets. He was assisted by the mathematician Johannes Müller, from Brandenburg, who had visited Hven in 1596 and whom the electress of Brandenburg had asked Tycho to train in chemistry and the preparation of medicines. Among visitors at Wandsbeck was the astronomer David Fabricius.

Tycho now completed the *Mechanica* and dedicated it to Emperor Rudolph II. Excellent woodcuts accompany Tycho's descriptions of his globe and of each of his instruments and its use. Also included are descriptions of Hven and its buildings, the instrument sights and the method of dividing by transversals, and a brief autobiography. From Wandsbeck he distributed a large number of manuscript copies of his star catalog, also dedicated to Rudolph.

Tycho's eldest son brought the emperor the catalog, the *Mechanica*, and a letter expressing the hope that the astronomer could complete his work under the emperor. At the same time Tycho sent bound copies of the catalog to scholars and influential people, including Christian IV, to whom he also addressed a respectful letter. On 24 March 1598 Tycho wrote to Longomontanus, inquiring about Wittich's books and manuscripts, and asked if Longomontanus had seen a recent publication by Ursus that Tycho did not consider deserving of refutation. He requested Longomontanus to join him at Wandsbeck, perhaps to continue work on the lunar theory.

Rantzov asked the elector of Cologne to use influence with the emperor and to try to interest Barwitz, the Austrian privy councillor, in Tycho's cause. Tycho himself wrote to Hagecius, hoping he would influence the emperor and the vice–chancellor. He also investigated the possibilities for settling in the Netherlands. Shortly after the middle of September 1598, having been assured that he would be welcome in Prague, Tycho left Wandsbeck with his sons, his students, and a few instruments. Longomontanus reached Wandsbeck after Tycho's departure but accompanied Tycho's ladies as far as Magdeburg. He returned to Denmark, however, and did not rejoin Tycho until January 1600. An epidemic of pestilence and dysentery in Prague caused Tycho to remain in Dresden. The first week in December, he moved to Wittenberg.

On Tycho's arrival in Prague in June 1599, he was escorted to the home of the late Vice–Chancellor Curtius and was soon granted an audience by the emperor, who arranged for him to receive financial support. Tycho had only a few instruments with him, but tried to display them in the same splendid setting they had had at Uraniborg. He never again got his instruments properly set up, nor did he make any important observations. He observed the end of a partial solar eclipse 22 July. He did not want to remain in the city of Prague and soon took up residence in the castle of Benatky, one of those offered him by the emperor. On a hill above the Iser about twenty–two miles northeast of Prague, Benatky had unobstructed views of the skies. It was small, but he altered it to fit his needs, building a laboratory and an observatory and planning to set up the instruments in separate rooms. He had difficulty, however, in obtaining the necessary funds. His family arrived, and he sent his eldest son for the four large instruments left at Hven. These, as well as the instruments and books that Tycho had brought with him as far as magdeburg, were delayed in transit, the latter not arriving in Prague until November 1600.

Tycho's assistants in Bohomia included Longomontanus (January 1600–4 August 1601), David Fabricius (June 1601), Johannes Müller (March 1600–Spring 1601), and Melchior Joestelius, a mathematician from Wittenberg, who returned there before June 1600 but who was probably responsible for completing the solution of triangles by the prosthaphaeretic method that Tycho said he and Joestelius had done together. The assistant most important for the future of astronomy, Johannes Kepler, a firm believer in the heliocentric system, arrived at Benatky 3 February 1600. Longomontanus was working on Mars, but that planet was eventually turned over to Kepler. The relations between Tycho and Kepler were frequently strained.

In the summer of 1600 Tycho moved to Prague and set up his instruments in the Belvedere, a villa belonging to the emperor and close to the castle. Kepler, who had returned to Graz to settle his affairs and call for his family, arrived in Prague in October. Until April 1601 he was mostly engaged, at Tycho's behest, in a refutation of Ursus, although the latter had died in

August 1600. Because of Tycho's death, the refutation remained unpublished until the nineteenth century. The emperor bought Curtius' house, and Tycho took possession of it in February 1601. The Kepler family moved there, too, although Kepler returned to Graz on business from April to August 1601. Kepler worked on the ories of Mercury, Venus, and Mars, and tried to persuade Tycho of the impossibility of describing the motion of the sun (or of the earth) as uniform in an eccentric circle.

Tycho died after an illness of eleven days, probably caused by prostate difficulties. He was buried with pomp on 4 November in the Tyn Church in the city's main square, his tomb marked by an upright slab bearing a life–size raised image of him with an inscription. On his deathbed, Tycho begged Kepler to complete the *Rudolphine Tables* as quickly as possible and expressed the wish that their theory be demonstrated in accordance with the Tychonic system.

Kepler did not obtain Tycho's instruments. They were stored beneath the Curtius house, and their subsequent fate is uncertain. The great globe was placed in the Round Tower in Copenhagen in the middle of the seventeenth century, having first been in Silesia, at Rosenborg Castle in Denmark, and at the University of Denmark. Some instruments must have been carried off during the Thirty Years' War, for they were discovered in a castle in Sweden in the twentieth century. Kepler had difficulties with Tengnagel and Tycho's other heirs over the records and publications. Giving him due credit, Kepler used the records of Tycho's observations, especially of Mars, to derive the laws of planetary motion, announcing the first two in his *Astronomia nova* (1609) and the third in the *Harmonices mundi libri V* (1619). He published Tycho's *progymnasmata* (1602), already partly printed at Uraniborg, and the *Tabulae Rudolphinae* (1627), in conformity with a heliocentric system.

Thus Tycho's accurate observations of the positions of the sun, moon, stars, and planets provided the basis for refinements of the Copernican doctrine. Had the observations been as accurate as Tycho considered them, or less accurate than they actually were, the history of astronomy would have been different. But they provided the suitable degree of accuracy at the critical time. A discrepancy of 8´ of arc between theory and observation led Kepler to his reformation of astronomy.

NOTES

1.*Opera omina*, II, 342–343; V, 81, Dreyer (1890), p. 30, erred in describing the Hainzels.

2.*Dialogue Concerning the Two Chief World Systems*, Stillman Drake, trans. (Los Angeles, 1962), pp. 358 ff.

3. Pingré *Cométographie*, I (1783), 511, says the comet was seen in Peru as early as 1 November.

4.*Opera omnia*, IV [2].

5.*En Elementisch oc Jordisch***ASTROLOGIA** , 1591.

6.*Opera omnia*, II, 98

7.*Ibid*., IV, 42.

8.*Ibid*., V, 111.

9. A broadside, item 3026 in Zinner, *Geschichte und Bioliographie* (Leipzig, 1941), is not included.

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There is no complete bibliography of the vast literature dealing with Tycho Brahe's life or work. Neither is there a printed list of his writings. Also lacking is a bibliography of works with references to him. Nevertheless, the following bibliography is selective.

The impact of Tycho's work must be studied in the writings, both printed and MS, of his contemporaries and immediate followers. Works by and about Kepler, including the recent ones, are of particular importance, but the writings of less important seventeenth–century men also give evidence of the influence of Tycho in Europe and the East. In honor of the 300th anniversary of Tycho's death (1901) and the 400th anniversary of his birth (1946) much was written, both scholarly and popular.

I. Original Works. Tycho's writings were collected as *Tychonis Brahe Dani Opera omnia*, J. L.E. Dreyer, ed., 15 vols. (Copenhagen, 1913–1929), which includes charts, diagrams, facsimiles, maps, portraits, and tables, and is copiously annotated.[9]

His books on the nova of 1572 are *De nova et nullius aevi memoria prius visa stella*… (Copenhagen, 1573; facs. ed., 1901), trans. into Danish by Otto Gelsted as *Tyge Brahe: Den ny Stjerne (1572)*… (Lemvig, 1923), and partially trans. into English by

John H. Walden in Harlow Shapley and Helen E. Howarth, eds., *A Source Book in Astronomy* (New York–London, 1929), pp. 13–19; and *Astronomiae instauratae progymnasmata…* (Prague, 1602; Frankfurt, 1610). A number of seventeenth–century tracts summarized or translated excerpts from the *Progymnasmata*, the most important work on the 1572 nova.

Tycho's book on the comet of 1577 is *De mundi aethereirecentioribus phaenomenis…* (Uraniborg, 1588; Prague, 1603; Frankfurt, 1610). Part of ch. 8 is trans. in Marie Boas and A. Rupert Hall, "Tycho Brahe's System of the World," in *Occasional Notes of the Royal Astronomical Society*, **3** , no. 21 (1959), 252–263 (trans. on pp. 257–263).

His letters have been brought together by Dreyer in the *Opera omnia* and in *Tychonis Brahe Dani Epistolarum astronomicarum…* (Uraniborg, 1596; Nuremberg, 1601; Frankfurt, 1610); *Tychonis Brahei et ad eum doctorum virorum epistolae…*, F.R. Friis, ed., **2** vols. (Copenhagen, 1876–1909); and Wilhelm Norlind, *Ur Tycho Brahes brevväxling, från Latinet* (Lund, 1926), 23 letters trans. into Swedish, with notes, and "Några Anteckningar till Tycho Brahes brevväxling," in *Nordisk astronomisk tidsskrift* (1956), no. 2, 51–55.

Tycho's book on his instruments is *Astronomiae instauratae mechanica* (Wandsbeck, 1598; Nuremberg, 1602), also in facsimile of 1598 ed., B. Hasselberg, ed. (Stockholm, 1901); the 1598 ed. was printed in Rantzov's castle near Hamburg on Tycho's press by Philip de Ohr. For trans., see Hans Raeder, Elis Strömgren, and Bengt Strömgren, eds. and trans., *Tycho Brahe's Description of His Instruments and Scientific Work…* (Copenhagen, 1946).

His tables are in *Historia coelestis…*, Lucius Barrettus (pseud. of Albert Curtz), ed. (Augsburg, 1666). Kepler's *Tabulae Rudolphinae…* (Ulm, 1627) are based on Tycho's observations and the Copernican–Keplerian system of the universe.

The MS material has been thoroughly used by Dreyer in his biography and in the *Opera omnia*, and MSS for which he gives bibliographical details will not be described here. For his biography Norlind has examined MS sources; see also his "On Some Manuscripts Concerning Tycho Brahe," in *The Observatory*, **78** , no. 903 (1958), 73–75. It is impossible to list here MSS in which Tycho is discussed, e.g., Gregoriana (Rome) 530, ff. 208–211, a letter dated 26 January 1601 from Magini in Mantua to Clavius in Rome, which speaks of Tycho's book on the star of 1572; or Ambrosiana (Milan) D 246 inf. 83r, the fragment of a letter from Padua in 1592 that speaks of Tycho and Galileo, who had just begun his lectures there. Nor need the location and description of the presentation copies of the *Mechanica* and the MS copies of the catalog of stars be listed.

Letter no. 102 (*Opera omnia*, XIV, 68) is at The Historical Society of Pennsylvania, Philadelphia, as are an undated autograph and an autograph dated 10 August 1594. Presumably the letter from Tycho to T. Saville (1 December 1590) cited in the British Museum's Sloane Collection catalog of 1782 is the same as the museum's Harleian 6995, 40 used by Dreyer (*Opera omnia*, VII, 283–285). The same catalog of the Sloane Collection lists an MS of the *Demundi aetherei…*, Two letters in the hand of a sixteenth century scribe are in the possession of the author: Tycho to Caspar Peucer, 13 September 1588, 23 leaves (*Opera omnia*, VII, 127–141), and Caspar Peucer to Tycho, 10 May 1589, 9 leaves (*Opera omnia*, VII, 184–191).

An interesting summary (from Padua) of Tycho's work, *Epitome de restitutione motuum solis ac lunae, et de nova*stella anni 1572, is preserved in Venice (Marciana lat. Cl. VIII, Cod. XXXVII, 3493). In Milan (Ambrosiana D 246 inf. 84r–87v) there are part of the *Mechanica* and epigrams to Scaliger.

II. Secondary Literature. The best single treatment of Tycho's life and work is J. L.E. Dreyer, *Tycho Brahe, a Picture of Scientific Life and Work in the Sixteenth Century* (Edinburgh, 1890; repr. New York, 1963). This is based on and cites the sources available in 1890, and forms the basis for this article. Except for Tycho's major publications, works cited by Dreyer are not in this bibliography, although they include much material to which the reader may want to refer, such as Gassendi's biography of Tycho (1654) and Tycho's *Opera omnia*, (1648), which presents the *Progymnasmata* and *De mundi aetherei* rather than the complete works. More recent biographies are John Allyne Gade, *The Life and Times of Tycho Brahe* (Princeton, 1947), with a bibliography that, while not selective, includes some useful items that appeared after Dreyer's work; and Wilhelm Norlind, *Tycho Brahe. Mannen och verket. Efter Gassendi overs. med kommentar* (Lund, 1951); *Tycho Brahe* (Stockholm, 1963); and *Tycho Brahe. En biografi. Med nya bidrag belysande hans liv och verk* (Lund, in press), with a summary in German.

The island of Hven is discussed in the anonymous "Stjerneborg", in *Nordisk astronomisk tidsskrift*, n.s. **20** , no. 3 (1939), 79–99; Francis Beckett and Charles Christensen, *Uraniborg og Stjaerneborg* (Copenhagen–London, 1921), text in Danish, summary and explanation of plates in English, title also given in English: *Tycho Brahe's Uraniborg and Stjerneborg on the Island of Hveen*; C. L.V. Charlier, *Utgräfningarna af Tycho Brahes observatorier påön Hven sommaren 1901*, which is *Acta universitatis Lundensis. Lunds universitets årsskrift*, **37** , afdeln. 2, no. 8 (Lund, 1901); John Christianson, "The Celestial Palace of Tycho Brahe", in *Scientific American*, **204** , no. 2 (1961), 118–128; Charles D. Humberd, "Tycho Brahe's Island", in *popular Astronomy*, **45** (1937), 118–125, which reproduces the Cologne map of 1586 and translates the Latin explanations inserted on the map and its back; William Lengert, *Tycho Brahe–tryck* (Malmö, 1940); N.A. Møller Nicolaisen, "Et Tycho Brahe–minde paa Hven,", in *Nordisk astronomisk tidsskrift*, n.s. **11** , no. 3 (1930), 122–128; "Tycho Brahes mølledaemning paa Hven", *ibid*., no.4, 173–175; "Tycho Brahes papirmoølle", *ibid*., n.s. **14** , no. 3 (1933), 85–95; and *Tycho Brahes papirmølle paa Hven. Udgravningen 1933–34 og forsøg til rekonstruktion…* (Copenhagen, 1946); Harald Mortensen, "Johnnes Mejers kort over øen Hven", in Skäne årsbok (1925), pp. 9–16; and "Et Tycho Brahe–minde paa Hven", in *Nordisk astronomisk tidsskrift*, n.s. **11** , no. 4 (1930), 172–173; and Lauritz Nielsen, *Tycho Brahes bogtrykeri. En bibliografisk–boghistorisk undersøgelse* (Copenhagen, 1946).

Works treating other subjects are Joseph Ashbrook, “Tycho Brahe’s Nose”, in the column “Astronomical Scrapbook”, in *Sky and Telescope*, **29** , no. 6 (1965), 353, 358; F. Burckhardt, *Zur Erinnerung an Tycho Brahe 1546–1601*…. (Basel, 1901); John Christianson, “Tycho Brahe at the University of Copenhagen, 1559–1562”, in *Isis*, **58** (1967), 198–203; and “Tycho Brahe’s Cosmology From the ‘Astrologia’ of 1591”, *ibid*., **59** (1968), 312–318; J. L.E. Dreyer, “Note on Tycho Brahe’s Opinion About the Solar Parallax,” in *Monthly Notices of the Royal Astronomical Society*, **71** , no. **1** (1910), 74–76; “The Place of Tycho Brahe in the History of Astronomy”, in *Scientia*, **25** , no. 83–3 (Mar. 1919), 177–185; and “On Tycho Brahe’s Manual of Trigonometry,” in *The Observatory*, no. 498 (Mar. 1916), 127–131; Antonio Favaro, “Ticone Brahe e la corte di Toscana,” in *Archivio storico italiano*, 5th series, **3** (1889); Edvard Gotfredsen, “Tycho Brahes sidste sygdom og død” (“Tycho Brahe’s Last Disease and Death”), in *Københavens Universitets medicinsk-historiske museum; Arsbereining 1955–1956*; Poul Hauberg, “Tycho Brahes opskrifter paa Laegemidler,” in *Dansk tidsskrift for farmaci*, **1** , no. 7, 205–212; C. Doris Hellman, “Was Tycho Brahe as Influential as He Thought?,”, in *British Journal for the History of Science*, **1** , pt. **4** , no. **4** (Dec. 1963), 295–324; Flora Kleinschnitzová, “Ex Bibliotheca Tychoniana Collegii Soc. Jesu Pragae ad S. Clementem,” in *Nordisk tidskrift för bok–och biblioteksväsen*, **20** (1933), 73–97; Wilhelm Krebs, “Facsimile einer eigenhändigen Zeichnung Tycho’s de Brahe von dem grossen Kometen 1577,” in *Das Weltall. Illustrierte Zeitschrift för Astronomie und verwandte Gebiete***12** (1911), 52–53; Martha List, *Des handschriftliche Nachlass der Astronomen Johannes Kepler und Tycho Brahe* (Munich, 1961); Knud Lundmark, “Tycho Brahe och astrofysiken,” in *Nordisk astronomisk tidsskrift*, n.s. **11** , no.3 (1930), 89–112; and “Om Tycho Brahes liv och gärning,” in *Cassiopeia* (1945), 14–47; N. A. Møller Nicolaisen, “Nicholai Raimarus Ursus contra Tycho Brahe,” *ibid*. (1942), 81–91; Harald Mortensen, “Portraeter af Tycho Brahe,” *ibid*. 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