Tycho Brahe

family, work and legacy

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Tycho Brahe

Tycho Ottesen Brahe	
	
Born	14 December 1546 Knutstorp Castle, Scania, then Denmark, today Sweden
Died	24 October 1601 (aged 54) Prague
Nationality	Danish
Education	Private
Occupation	Nobleman, Astronomer
Spouse(s)	Kirstine Barbara Jørgensdatter
Children	8
Parents	→ Otte Brahe and Beate Bille

Tycho Brahe, born **Tyge Ottesen Brahe** (14 December 1546 – 24 October 1601), was a Danish nobleman known for his accurate and comprehensive astronomical and planetary observations. Coming from Scania, then part of Denmark, now part of modern-day Sweden, Brahe was well known in his lifetime as an astronomer and alchemist.

Monument of Tycho Brahe and Johannes Kepler in Prague

The Latinized name "Tycho Brahe" is usually pronounced /ˈtaɪkoʊ ˈbrɑː/ or /ˈbrɑːhi/ in English. The original Danish name "Tyge Ottesen Brahe" is pronounced in Modern Standard Danish as [ˈtˢyːə ˈʌd̥əsn̩ ˈb̥ʁɑː].

Tycho Brahe was granted an estate on the island of Hven and the funding to build the → Uraniborg, an early research institute, where he built large astronomical instruments and took many careful measurements. After disagreements with the new king in 1597, he was invited by the Czech king and Holy Roman emperor Rudolph II to Prague, where he became the official imperial astronomer. He built the new observatory at Benátky nad Jizerou. Here, from 1600 until his death in 1601, he was assisted by Johannes Kepler. Kepler would later use Tycho's astronomical information to develop his own theories of astronomy.

As an astronomer, Tycho worked to combine what he saw as the geometrical benefits of the Copernican system with the philosophical benefits of the Ptolemaic system into his own model of the universe, the → Tychonic system. He is generally referred to as "Tycho" rather than by his surname "Brahe", as was common in Scandinavia at the time.[1]

Tycho is credited with the most accurate astronomical observations of his time, and the data was used by his assistant Kepler to derive the laws of planetary motion. No one before Tycho had attempted to make so many redundant observations, and the mathematical tools to take advantage of them had not yet been developed. He did what others before him were unable or unwilling to do – to catalogue the planets and stars with enough accuracy to determine whether the Ptolemaic or Copernican system was more valid in describing the heavens.

Life

Early years

Tycho was born on a farm in Roseau under the name *Tyge Ottesen Brahe (de Knudstrup)*, adopting the Latinized form *Tycho* around age fifteen (sometimes written *Tÿcho*). The incorrect form of his name, *Tycho* ***de*** *Brahe*, appeared only much later. [2]

He was born at his family's ancestral seat of Knutstorp Castle (Danish: *Knudstrup borg*; Swedish: *Knutstorps borg*)[3] in then Danish Scania, now Swedish, to → Otte Brahe and Beate Bille. His twin brother died before being baptized. (Tycho wrote a Latin ode (Wittendorf 1994, p. 68) to his dead twin which was printed as his first publication in 1572.) He also had two sisters, one older (Kirstine Brahe) and one younger (→ Sophia Brahe). Otte Brahe, Tycho's father, was a nobleman and an important figure at the court of the Danish King. His mother, Beate Bille, also came from an important family that had produced leading churchmen and politicians. Both parents are buried under the floor of Kågeröd Church, not far from Knutstorp. An epitaph, originally from Knutstorp, but now on a plaque near the church door, shows the whole family, including Tycho as a boy.

Tycho later wrote that when he was around two, his uncle, Danish nobleman Jørgen Brahe, "*... without the knowledge of my parents took me away with him while I was in my earliest youth.*" Apparently this did not lead to any disputes nor did his parents attempt to get him back. According to one source,[4] Tycho's parents had promised to hand over a boy child to Jørgen and his wife, who were childless, but had not honoured this promise. Jørgen seems to have taken matters into his own hands and took the child away to his own residence, Tost(e)rup Castle. Jørgen Brahe inherited considerable wealth from his parents, which in terms of the social structure of the time made him eminently eligible for the post of County Sheriff, a royal appointment. He was successively County Sheriff to Tranekjær (1542-49), Odensegaard (1549-52), Vordingborg Castle(1552-57) and finally (1555 until his death in 1565) to Queen Dorothea at Nykøbing Castle on Falster[5] . It is hard to say exactly where Tycho was educated in his childhood years, and Tycho himself provides no information on this topic, but the sources quoted below agree that he took a Latin School education from the age of six until he was twelve years old.

On 19 April 1559, Tycho began his studies at the University of Copenhagen. There, following the wishes of his uncle, he studied law but also studied a variety of other subjects and became interested in astronomy. It was, however, the eclipse which occurred on 21 August 1560, particularly the fact that it had been predicted, that so impressed him that he began to make his own studies of astronomy, helped by some of the professors. He purchased an ephemeris and books such as Sacrobosco's *Tractatus de Sphaera*, Apianus's *Cosmographia seu descriptio totius orbis* and Regiomontanus's *De triangulis omnimodis*.

> *I've studied all available charts of the planets and stars and none of them match the others. There are just as many measurements and methods as there are astronomers and all of them disagree. What's needed is a long term project with the aim of mapping the heavens conducted from a single location over a period of several years.* – Tycho Brahe, 1563 (age 17).

Tycho realized that progress in the science of astronomy could be achieved not by occasional haphazard observations, but only by systematic and rigorous observation, night after night, and by using instruments of the highest accuracy obtainable. He was able to improve and enlarge the existing instruments, and construct entirely new ones. Tycho's naked eye measurements of planetary parallax were unprecedented in their precision - accurate to the arcminute, or 1/30 the width of the full moon. His sister Sophia assisted Tycho in many of his measurements. These jealously guarded measurements were "usurped" by Kepler following Tycho's death.[6] Tycho was the last major astronomer to work without the aid of a telescope, soon to be turned skyward by Galileo.

Tycho's nose

While a student, Tycho lost part of his nose in a rapier duel[7] with Manderup Parsbjerg, a fellow Danish nobleman.[8] This occurred in the Christmas season of 1566, after a fair amount of drinking, while Tycho, just turned 20 years old, was studying at the University of Rostock in Germany.[8] Attending a dance at a professor's house, he quarreled with Parsbjerg. A subsequent duel (in the dark) resulted in Tycho losing the bridge of his nose. From this event Tycho became interested in medicine and alchemy.[7] For the rest of his life, he was said to have worn a realistic replacement made of silver and gold[7] , using a paste to keep it attached.[8] Some people, such as Fredric Ihren and Cecil Adams have suggested that the false nose also had copper. Ihren wrote that when Tycho's tomb was opened in 24 June 1901 green marks were found on his skull, suggesting copper.[8] Cecil Adams also mentions a green colouring and that medical experts examined the remains.[9] Some historians have speculated that he wore a number of different prosthetics for different occasions, noting that a copper nose would have been more comfortable and less heavy than a precious metal one.[10]

Death of his uncle

His uncle and foster father, Jørgen Brahe, died in 1565 of pneumonia after rescuing Frederick II of Denmark from drowning. In April 1567, Tycho returned home from his travels and his father wanted him to take up law, but Tycho was allowed to make trips to Rostock, then on to Augsburg (where he built a great quadrant), Basel, and Freiburg. At the end of 1570 he was informed about his father's ill health, so he returned to Knudstrup, where his father died on 9 May 1571. Soon after, his other uncle, Steen Bille, helped him build an observatory and alchemical laboratory at Herrevad Abbey.[7]

Family life

In 1572, in Knudstrup, Tycho fell in love with Kirsten, daughter of Jørgen Hansen, the Lutheran priest in Knudstrup. She was a commoner, and Tycho never formally married her. However, under Danish law, when a nobleman and a common woman lived together openly as husband and wife, and she wore the keys to the household at her belt like any true wife, their alliance became a binding morganatic marriage after three years. The husband retained his noble status and privileges; the wife remained a commoner. Their children were legitimate in the eyes of the law, but they were commoners like their mother and could not inherit their father's name, coat of arms, or landholdings. (Skautrup 1941, pp. 24-5)

Kirsten Jørgensdatter gave birth to their first daughter, Kirstine (named after Tycho's late sister, who died at 13) on 12 October 1573. Together they had eight children, six of whom lived to adulthood. In 1574, they moved to Copenhagen where their daughter Magdalene was born. Kirsten and Tycho lived together for almost thirty years until Tycho's death.

Tycho's elk and dwarf

Tycho was said to own one percent of the entire wealth of Denmark at one point in the 1580s and he often held large social gatherings in his castle. He kept a dwarf named Jepp (whom Tycho believed to be clairvoyant) as a court jester who sat under the table during dinner. Pierre Gassendi wrote[8]

from a translation from Gassendi

that Tycho also had a tame elk, and that his mentor the Landgrave Wilhelm of Hesse-Kassel (Hesse-Cassel) asked whether there was an animal faster than a deer. Tycho replied, writing that there was none, but he could send his tame elk. When Wilhelm replied he would accept one in exchange for a horse, Tycho replied with the sad news that the elk had just died on a visit to entertain a nobleman at Landskrona. Apparently during dinner[11] the elk had drunk a lot of beer, fallen down the stairs, and died.[12] [8]

Death

Tycho died on 24 October 1601 in Prague, eleven days after suddenly becoming very ill during a banquet. Toward the end of his illness he is said to have told Kepler "Ne frustra vixisse videar!", "Let me not seem to have lived in vain."[13] [14] For hundreds of years, the general belief was that he had strained his bladder. It had been said that to leave the banquet before it concluded would be the height of bad manners, and so he remained, and that his bladder, stretched to its limit, developed an infection which later killed him. This theory was supported by Kepler's first-hand account.

Tycho Brahe's grave in Prague, new tomb stone from 1901

Recent investigations have suggested that Tycho did not die from urinary problems but instead from mercury poisoning: extremely toxic levels of it have been found in his hair and hair-roots. Tycho may have poisoned himself by imbibing some medicine containing unintentional mercuric chloride impurities, or may have been poisoned.[15]

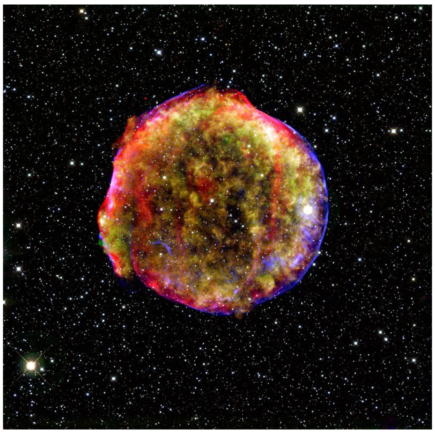
One theory proposed in a 2005 book by Joshua Gilder and Anne-Lee Gilder, suggests that there is circumstantial evidence that Kepler murdered Brahe; they argue that Kepler had the means, motive, and opportunity, and stole Tycho's data on his death.[16] According to the Gilders, they find it "unlikely"[16] Tycho could have poisoned himself since he was an alchemist known to be familiar with the toxicity of different mercury compounds.

Another theory is proposed by Peter Andersen, professor of German Studies at the University of Strasbourg. Andersen discovered the 600-page diary of Count Erik Brahe, a distant Swedish cousin of Tycho. He suggests Erik murdered Tycho, by order of King Christian IV of Denmark, who suspected that Tycho had had an affair with his mother Sophie.[17] In 2009, a group of conservators, chemists and physicians plan to open the vault and perform a forensic analysis on the body.[17]

Tycho Brahe's body is currently interred in a tomb in the Church of Our Lady in front of Týn, in Old Town Square near the Prague Astronomical Clock.

Career: observing the heavens

The 1572 supernova

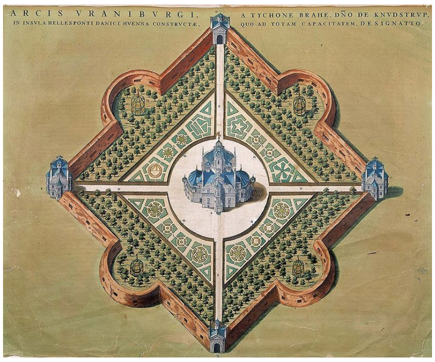


The Calar Alto Observatory imaged Tycho's Supernova Remnant more than four centuries after its discovery

On 11 November 1572, Tycho observed (from Herrevad Abbey) a very bright star, now named → SN 1572, which had unexpectedly appeared in the constellation Cassiopeia. Because it had been maintained since antiquity that the world beyond the Moon's orbit was eternally unchangeable (celestial immutability was a fundamental axiom of the Aristotelian world-view), other observers held that the phenomenon was something in the terrestrial sphere below the Moon. However, in the first instance Tycho observed that the object showed no daily parallax against the background of the fixed stars. This implied it was at least farther away than the Moon and those planets that do show such parallax. Moreover he also found the object did not even change its position relative to the fixed stars over several months as all planets did in their periodic orbital motions, even the outer planets for which no daily parallax was detectable. This suggested it was not even a planet, but a fixed star in the stellar sphere beyond all the planets. In 1573 he published a small book, *De nova stella*[18] thereby coining the term nova for a "new" star (we now classify this star as a supernova and we know that it is 7500 light-years from Earth). This discovery was decisive for his choice of astronomy as a profession. Tycho was strongly critical of those who dismissed the implications of the astronomical appearance, writing in the preface to *De nova stella*: "O crassa ingenia. O caecos coeli spectatores" ("Oh thick wits. Oh blind watchers of the sky").

Tycho's discovery was the inspiration for Edgar Allan Poe's poem, "Al Aaraaf."[19] In 1998, *Sky & Telescope* magazine published an article by Donald W. Olson, Marilynn S. Olson and Russell L. Doescher arguing, in part, that Tycho's supernova was also the same "star that's westward from the pole" in Shakespeare's *Hamlet*.

Tycho's observatories



Watercolor plan of Uraniborg

Tycho published the 1572 observations made from his first observatory at Herrevad Abbey in 1574. He then started lecturing on astronomy, but gave up and left Denmark in spring 1575 to tour abroad. He first visited William IV, Landgrave of Hesse-Kassel's observatory at Kassel, then went on to Frankfurt, Basel and Venice. Upon his return he had decided to relocate to Basel, but King Frederick II, King of Denmark and Norway, fearful of losing such a scientist, offered Tycho the island of Hven in Oresund with funding to set up an observatory. Tycho first built → Uraniborg in 1576 (with a laboratory for his alchemical experiments in its cellar) and then → Stjerneborg in 1581.[7]

When King Frederick II died in 1588 he was buried at Roskilde Cathedral, like other Danish monarchs, and his 11 year old son Christian IV, became the new king. Tycho's influence steadily declined and after several unpleasant disagreements, including neglecting to maintain the chapel where Christian's father was buried,[7] he left Hven in 1597 and moved to Prague in 1599. Sponsored by Rudolf II, the Holy Roman Emperor, he built a new observatory in a castle in Benátky nad Jizerou, 50 km from Prague, and he worked there for one year. The emperor then had him move back to Prague, where he stayed until his death. Besides the emperor himself, he was also financially supported by several nobles, including Oldrich Desiderius Pruskowsky von Pruskow, to whom he dedicated his famous volume, the "Mechanica."

In return for their support, Tycho's duties included preparing astrological charts and predictions for his patrons on events such as births, weather forecasting, and providing astrological interpretations of significant astronomical events such as the comet of 1577 and the supernova of 1572.[20]

Tycho's observational astronomy

Mural quadrant (Tycho Brahe 1598)

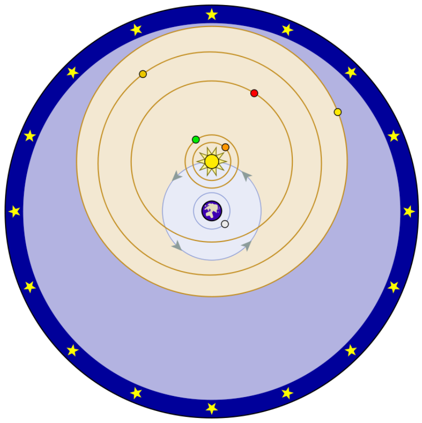
Tycho was the preeminent observational astronomer of the pre-telescopic period, and his observations of stellar and planetary positions achieved unparalleled accuracy for their time. His planetary observations were "consistently accurate to within about 1'," [21] the stellar observations as recorded in his observational logs were even more accurate, varying from 32.3" to 48.8" for different instruments,[22] although an error of as much as 3' was introduced into some of the stellar positions Tycho published in his star catalog due to his application of an erroneous ancient value of parallax and his neglect of refraction.[23] For example, Tycho measured Earth's axial tilt as 23 degrees and 31.5 minutes, which he claimed to be more accurate than Copernicus by 3.5 minutes. After his death, his records of the motion of the planet Mars enabled Kepler to discover the laws of planetary motion, which provided powerful support for the Copernican heliocentric theory of the solar system.

Tycho himself was not a Copernican, but proposed a system in which the Sun orbited the Earth while the other planets orbited the Sun. His system provided a safe position for astronomers who were dissatisfied with older models but were reluctant to accept the Earth's motion. It gained a considerable following after 1616 when Rome decided officially that the heliocentric model was contrary to both philosophy and Scripture, and could be discussed only as a computational convenience that had no connection to fact. His system also offered a major innovation: while both the geocentric model and the heliocentric model as set forth by Copernicus relied on the idea of transparent rotating crystalline spheres to carry the planets in their orbits, Tycho eliminated the spheres entirely.

He was aware that a star observed near the horizon appears with a greater altitude than the real one, due to atmospheric refraction, and he worked out tables for the correction of this source of error.

To perform the huge number of multiplications needed to produce much of his astronomical data, Tycho relied heavily on the then-new technique of *prosthaphaeresis*, an algorithm for approximating products based on trigonometric identities that predated logarithms.

Tycho's Geo-heliocentric Astronomy



In this depiction of the Tychonic system, the objects on blue orbits (the moon and the sun) revolve around the earth. The objects on orange orbits (Mercury, Venus, Mars, Jupiter, and Saturn) revolve around the sun. Around all is sphere of fixed stars.

Kepler tried, but was unable, to persuade Tycho to adopt the heliocentric model of the solar system. Tycho believed in geocentrism because he held the Earth was just too sluggish to be continually in motion and also believed that if the Earth orbited the Sun annually there should be an observable stellar parallax over any period of six months, during which the angular orientation of a given star would change. This parallax does exist, but is so small it was not detected until the 1830s, when Friedrich Bessel discovered a stellar parallax of 0.314 arcseconds of the star 61 Cygni in 1838.[24] Tycho advocated an alternative to the Ptolemaic geocentric system, a geo-heliocentric system now known as the → Tychonic system. In such a system, first proposed by Heraclides in the 4th century BC, the Sun annually circles a central Earth (regarded as essentially different from the planets), while the five planets orbit the Sun. [25] In Tycho's model the Earth does not rotate daily, as Heraclides claimed, but is static.

Another crucial difference between Tycho's 1587 geo-heliocentric model and those of other geo-heliocentric astronomers, such as Paul Wittich, Reimarus Ursus, Roslin and Origanus, was that the orbits of Mars and the Sun intersected. [26] This was because Tycho had come to believe the distance of Mars from the Earth at opposition (that is, when Mars is on the opposite side of the sky from the Sun) was less than that of the Sun from the Earth. Tycho believed this because he came to believe Mars had a greater daily parallax than the Sun. But in 1584 in a letter to a fellow astronomer, Brucaeus, he had claimed that Mars had been further than the Sun at the opposition of 1582, because he had observed that Mars had little or no daily parallax. He said he had therefore rejected Copernicus's model because it predicted Mars would be at only two-thirds the distance of the Sun.[27] But he apparently later changed his mind to the opinion that Mars at opposition was indeed nearer the Earth than the Sun was, but apparently without any valid observational evidence in any discernible Martian parallax.[28] Such intersecting Martian and solar orbits meant that there could be no solid rotating celestial spheres, because they could not possibly interpenetrate. Arguably this conclusion was independently supported by the conclusion that the comet of 1577 was superlunary, because it showed less daily parallax than the Moon and thus must pass through any celestial spheres in its transit.

Tychonic astronomy after Tycho

Galileo's 1610 telescopic discovery that Venus shows a full set of phases refuted the pure geocentric Ptolemaic model. After that it seems 17th century astronomy then mostly converted to geo-heliocentric planetary models that could explain these phases just as well as the heliocentric model could, but without the latter's disadvantage of the failure to detect any annual stellar parallax that Tycho and others regarded as refuting it.[29] The three main geo-heliocentric models were the Tychonic, the Capellan with just Mercury and Venus orbiting the Sun such as favoured by Francis Bacon, for example, and the extended

Capellan model of Riccioli with Mars also orbiting the sun whilst Saturn and Jupiter orbit the fixed Earth. But the Tychonic model was probably the most popular, albeit probably in what was known as 'the semi-Tychonic' version with a daily rotating Earth. This model was advocated by Tycho's ex-assistant and disciple Longomontanus in his 1622 *Astronomia Danica* that was the intended completion of Tycho's planetary model with his observational data, and which was regarded as the canonical statement of the complete Tychonic planetary system.

A conversion of astronomers to geo-rotational geo-heliocentric models with a daily rotating Earth such as that of Longomontanus may have been precipitated by Francesco Sizzi's 1613 discovery of annually periodic seasonal variations of sunspot trajectories across the sun's disc. They appear to oscillate above and below its apparent equator over the course of the four seasons. This seasonal variation is explained much better by the hypothesis of a daily rotating Earth together with that of the sun's axis being tilted throughout its supposed annual orbit than by that of a daily orbiting sun, if not even refuting the latter hypothesis because it predicts a daily vertical oscillation of a sunspot's position, contrary to observation. This discovery and its import for heliocentrism, but not for geo-heliocentrism, is discussed in the Third Day of Galileo's 1632 *Dialogo*. [30] However, prior to that discovery, in the late 16th century the geo-heliocentric models of Ursus and Roslin had featured a daily rotating Earth, unlike Tycho's geo-static model, as indeed had that of Heraclides in antiquity, for whatever reason.

The fact that Longomontanus's book was republished in two later editions in 1640 and 1663 no doubt reflected the popularity of Tychonic astronomy in the 17th century. Its adherents included John Donne and the atomist and astronomer Pierre Gassendi.

Johannes Kepler published the *Rudolphine Tables* containing a star catalog and planetary tables using Tycho's measurements. Hven island appears west uppermost on the base.

The ardent anti-heliocentric French astronomer Jean-Baptiste Morin devised a Tychonic planetary model with elliptical orbits published in 1650 in a Tychonic simplified version of the → Rudolphine Tables.[31] The tenacious longevity of the Tychonic model into the late 17th century and even the early 18th century was attested by Ignace Pardies who declared in 1691 that it was still the commonly accepted system and by Francesco Blanchinus who said it was still such in 1728.[32]

Indeed in possible support of this latter claim, it is especially notable that even the 1726 third edition of Newton's *Principia* was studiously no more than Tychonic geo-heliocentric in its declared six established astronomical phenomena in the preliminary 'Phenomena' section of Book 3, from which it sought to demonstrate its theory of universal mutual gravitational attraction. For example, Phenomenon 3 stated "The orbits of the five primary planets – Mercury, Venus, Mars, Jupiter and Saturn – encircle the sun.", thus notably excluding the Earth from primary planethood in agreement with Tycho's model.[33] But in fact even Newton's empirical reasoning for going beyond the extent of the partial degree of heliocentrism of the Capellan model to the Tychonic with Mars, Jupiter and Saturn also orbiting the Sun was strikingly invalid:

> "Because Mars also shows a full face when near conjunction with the sun, and appears gibbous in the quadratures, it is certain that Mars goes around the sun. The same is

> proved also with respect to Jupiter and Saturn from their phases being always full;..."[34]

But of course these phenomena of these three outer planets are equally well explained by the Ptolemaic geocentric model.

It seems it was James Bradley's 1729 publication of his discovery of stellar aberration, three years after the *Principia*'s third edition and two after Newton's death, that finally put paid to all forms of geocentrism. For this annual oscillation of stars was only satisfactorily explicable by the conjunction of the heliocentric hypothesis that the Earth annually orbited the Sun with that of the finite speed of light. The discovery of this novel phenomenon thus completed the heliocentric revolution with the complete conversion from all geo-heliocentrism to pure heliocentrism thereafter as now empirically established fact.

Legacy

Although Tycho's planetary model became discredited, his astronomical observations are considered an essential contribution to the Scientific Revolution. A traditional view of Tycho, originating in the 1654 biography *Tychonis Brahe, equitis Dani, astronomorum coryphaei, vita* by Pierre Gassendi and furthered by the 1890 biography by Johann Dreyer, which for a long time was considered the most essential work on Tycho, is that Tycho was primarily an empiricist, who set new standards for precise and objective measurements.[35] According to historian of science Helge Kragh, the origin of this view is Gassendi's opposition to Aristotelianism and Cartesianism and it fails to account for the diversity of Tycho's activities.[35]

Tycho considered astrology a subject of great importance,[36] and he was in his own time also famous for his contributions to medicine and his herbal medicines were in use as late as the 1900s.[37] Although the research community Tycho created in Uraniborg did not survive him, while it existed it fulfilled the roles of being both a research center and an important center of education, functioning as a graduate school for Danish as well as foreign students of both astronomy and medicine.[37] Tycho manoeuvred confidently within the political world and his success as a scientist relied on his political skills to ensure funding for his work.

The crater Tycho on the Moon is named after him, as is the crater Tycho Brahe on Mars.

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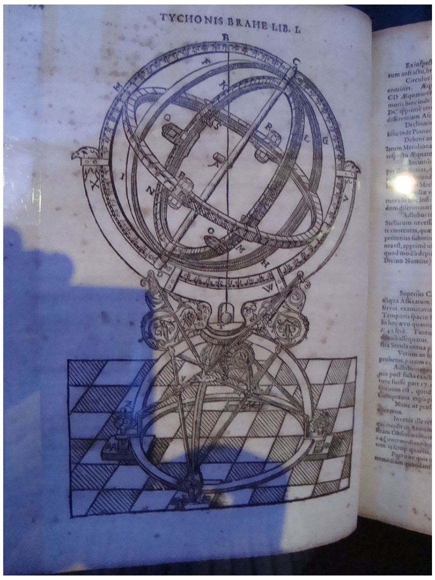

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- Wilson & Taton *Planetary astronomy from the Renaissance to the rise of astrophysics* 1989 CUP (articles by Thoren, Jarell and Schofield on the nature and history of the Tychonic astronomical model)

External links

- Brahe, Tycho [41] MacTutor History of Mathematics
- Tycho Brahe [42] pages by Adam Mosley at Starry Messenger: An Electronic History of Astronomy, University of Cambridge
- Astronomiae instauratae mechanica, 1602 edition [43] - Full digital facsimile, Lehigh University.
- Astronomiae instauratae mechanica, 1602 edition [44] - Full digital facsimile, Smithsonian Institution.
- Astronomiae instauratae mechanica, 1598 edition [45] - Full digital facsimile, the Danish Royal Library. Includes Danish and English translations.
- Electronic facsimile editions of the rare book collection at the Vienna Institute of Astronomy [46]
- Brahe Bio [47] at Skyscript
- The Galileo Project [48] article on Tycho Brahe
- The Observations of Tycho Brahe [49]
- Tycho's 1004-Star Catalog: The First Critical Edition [50], edited and analyzed astronomically and statistically by Dennis Rawlins.

External links

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This interesting fact was apparently first pointed out in the 20th century by the philosopher of science Imre Lakatos in his *Newton's effect on scientific standards* posthumously published in his 1978 *Philosophical Papers Volume 1*. In addition to the many logical reasons that have been adduced by such as Duhem, Popper, Feyerabend, Lakatos and others, such as Leibniz and Roger Cotes, to show that Newton did not validly deduce his law of gravity from Kepler's three laws of planetary orbits, this fact also further scuppers the inductivist-positivist claim that he did, since Kepler's laws were heliocentric. Of course in the General Scholium added to its 1713 second edition Newton did endorse heliocentrism in stating "The six primary planets revolve about the sun in circles concentric with the sun..." (p940 Cohen & Whitman *Principia*) But the *Principia* never gave any proof that the Earth orbited the sun, not even an invalid one such as were his Phenomenon 3 proofs that Mars, Jupiter and Saturn did.
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Family

Brahe

Brahe may also refer to the German name of the Brda river in Poland.

The original arms of Brahe family

Brahe (originally *Bragde*) is the name of a Scanian noble family that was influential in both Danish and Swedish history but has its family roots in Swedish origin. The first member of the family is speculated to have been Verner Braghde from Halland.[1] Better documented is Peder Braghe to Gyllebo who appears in late 14th century records. He fathered two sons, Axel and Thorkild. What later became the Danish branch descended from Axel and what later became the Swedish, descended from Thorkild's daughter.[1]

Per Brahe was in 1561 granted dignity as a count by Eric XIV of Sweden and in 1620 was the family introduced on the Swedish *Riddarhuset* (House of Knights) as the first counts. The family died out in 1930, after which the foremost comital family became Lewenhaupt.

Notable members

The Danish family

- → Otte Brahe (1517-1571): nobleman, governor and member of the Rigsraad
- → Tycho Brahe (1546-1601): nobleman, astronomer, astrologer and alchemist
- → Sophia Brahe (1556-1643): horticulturalist, healer, historian and astronomer

The Swedish family

- Per Brahe the Elder (1520-1590): statesman
  - Erik Brahe (1552-1614)
  - Gustaf Brahe (1558-1615), *riksrad* of Sweden -loyal to king Sigismund- and later, Polish general.
  - Magnus Brahe (1564-1633)
    - Ebba Brahe (1596-1674): lady-in-waiting and mistress of future king Gustavus Adolphus, wife of Jakob De la Gardie
  - Abraham Brahe (1577-1650)
    - Per Brahe the Younger (1602-1680): soldier and statesman, Governor General of Finland, Drost of the Realm
    - Nils Brahe (1604-1632): general in the Swedish army
      - Nils Brahe (1633-1699)
- Erik Brahe (1722-1756): politician of the court party, failed with a coup d'état to reestablish the absolute monarchy and was executed.
- Magnus Fredrik Brahe (1756-1826),

- Magnus Brahe (1790-1844): Marchal of the Realm and the right hand man of Charles XIV John

External links

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Source: http://en.wikipedia.org/w/index.php?oldid=257192354
Contributors: Baronnet, Firsfron, Gustavo Szwedowski de Korwin, Jgeortsis, Shenme, Terot, 4 anonymous edits

Otte Brahe

Otte Brahe [Ottə̩ 'b̥ʁɑːʊ] (c. 1517 – 9 May 1571), was a Danish (Scanian) nobleman who is best known for his son, → Tycho Brahe.

Life

Family life

Brahe married Beate Bille in 1544. Both the Brahes and the Billes were among the most powerful noble families in Denmark during their lives. Both families owned farms, forests, and land as well as very nice homes in several Danish cities including Copenhagen. Both families controlled many. Together they built a brick castle at Knudstrup that was completed in 1550. Their first child was a daughter, Lizbeth. This was followed by twin boys on 14 December 1546. However, one of the twins died before being baptized and named. The other was named Tyge (after Brahe's father). It is for their son Tyge that Brahe is best known as he became a famous astronomer and took on the name → Tycho Brahe as a teenager. Strangely, their son Tyge was kidnapped by Brahe's older brother, Jørgen, in 1548. Tycho later wrote: "without the knowledge of my parents [Jørgen took] me away with him while I was in my earliest youth. He supported me generously during his lifetime." While Jørgen took Tyge without their permission, it does not appear that Brahe and his wife did much to get him returned. Together, they had twelve children, eight of which survived childhood including daughter → Sophia Brahe. Brahe was not enthusiastic about any of his five sons learning Latin, the language of education at the time, considering it a waste of time. Instead, he arranged for them to become military leaders, perhaps by working on court manners, horsemanship, and sword fighting.

Political life

The Brahe family was powerful. At one point, in a bid to expand his estate at Knudstrup, he burned the crops of seven farmers and chased them into the forest. Brahe was a close ally of the Danish king. Later in Brahe's life he became governor of Helsingborg castle (probably due to the influence of Peder Oxe). From 1563 he was a member of the Rigsraad oligarchy (about 20 members) that ruled Denmark.

Death

Brahe fell very ill in Denmark in late 1570, Brahe later died in May 1571 leaving Bille a widow. Included in his estate were 500 farms, 60 cottages, 14 mills, Knutstrup Castle, manor houses in the country, and houses in Copenhagen. His estate was not fully settled until 1574.

Book collector

In 2007 the young Mexican scholar Juan Pablo Ortiz-Hernández edited an unknown Spanish book of songs belonged to Otte Brahe. The publication of the mentioned collection of poems is being prepared by Ortiz and the hispanist Kenneth Brown in association with the Hispanic Society of America and it represents a significant contribution to the discipline of medieval Spanish literature.

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Contributors: BOTijo, Charles Matthews, FeanorStar7, Leolaursen, Saddhiyama, Someguy1221, Studerby, 20 anonymous edits

Sophia Brahe

Sophie Brahe, or Sophia, (24 August 1556 – 1643) was a Danish horticulturalist and student of astronomy, chemistry, and medicine, best known for assisting her brother → Tycho Brahe with his astronomical observations.

She was born in Knudstrup to → Otte Brahe rigsråd, or advisor to the King of Denmark; and to Beate Bille Brahe, leader to the household for Queen Sophie. Famous astronomer → Tycho Brahe was her oldest brother. She was the youngest of ten children. She started assisting her brother with his astronomical observations in 1573, and helped him with the work that became the basis for modern planetary orbit predictions, frequently visiting his observatory → Uranienborg, on the island of Hveen. Tycho wrote that he had trained her in horticulture and chemistry, but he told her not to study astronomy. He expressed with pride that she learned astronomy on her own, studying books in German, and having Latin books translated with her own money so that she could also study them (Tjørnum). Brother and sister were united not only by science, but by the fact that their family did not approve of science as being an appropriate activity for noble people. Tycho referred with admiration to her 'animus invictus', her determined mind (Det Kongelige Bibliotek).

She married Otto Thott in 1576, when she was 19 or 20 and he was 33, and had one child with him before he died in 1588. Her son was Tage Thott, born in 1580. Upon her husband's death she managed his property in Ericksholm, running the estate to keep it profitable until her son came of age. During this time, she also became a horticulturalist, in addition to her studies in chemistry and medicine. The gardens she created in Ericksholm were supposed to be exceptional. Sophie was particularly interested in studying chemistry and medicine according to Paracelsus, where small doses of poison might serve as strong medicines. She also helped her brother with producing horoscopes, continuing with that until 1597 (Det Kongelige Biblioteck).

On 21 July 1587, King Frederick II of Denmark signed a document transferring to Sophia Brahe title of Årup farm in what is now Sweden (Svensson, et.al).

During the times she visited at Uranienborg, she met Erik Lange, a nobleman who studied alchemy. In 1590, there are records that Sophie took 13 visits to Uranienborg, and they became engaged in that year. Unfortunately, Lange used up most of his fortune with alchemy experiments, so their marriage was delayed some years, while he avoided his debtors and traveled to Germany to try and find patrons for his work. Tycho Brahe wrote the poem Urania Titani during their separation, as a letter from his sister Sophia to her fiance in 1594. In 1599, she visited Lange in Hamburg, but they do not marry until 1602, in Eckenförde. They lived in this town for a while in extreme poverty. There is a long letter to Sophie's sister Margrethe Brahe, in which Sophie describes having to wear stockings with holes in them for her wedding. Lange's wedding clothes had to be returned to the pawn shope after the wedding, because they could not afford to keep them. This letter is said to express anger with her family for not accepting her science studies, and for depriving her of money owed to her. The letter is described as personal, emotional, and also showing humor. By 1608, Erik Lange was living in Prague, and he died there in 1613 (Det Kongelige Bibliotek).

Sophie Brahe personally financed the restoration of the local church, Ivetofta kyrka. She planned to be buried there, and the lid for her unused sarcophagus remains in the church's armory (Svensson, et. al). However, by 1616 she had moved back permanently to Denmark and settled in Helsingør. She spent her last years writing up the genealogy of Danish noble families, publishing the first major version in 1626 (there were later additions). Her work is still considered a major source for early history of Danish nobility(Det Kongelige Bibliotek). She died in Helsingør in the year 1643, and was buried in Kristianstad, in Trefaldighets kyrka, with the Thott family (Tjørnum).

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External links

- Works by or about Sophia Brahe [1] in libraries (WorldCat catalog)

External links

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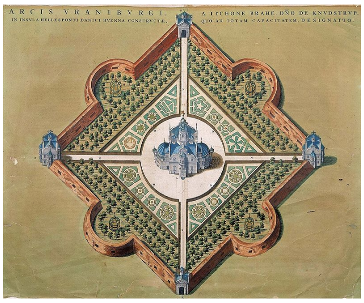
Observatories

Uraniborg

Uranienborg (Swedish: *Uraniborg*) was an astronomical/astrological observatory operated by → Tycho Brahe; built circa 1576-1580 on Hven (also spelled Ven or Hveen), an island in the Øresund between Zealand and Scania, at that time belonging to Denmark.



Tycho Brahe's Uraniborg from his 1598 mechanica book

History

The building was dedicated to Urania, the Muse of Astronomy and named Uranienborg, "The Castle of Urania." It was the first custom-built observatory, and the last to be built without a telescope as its primary instrument. The cornerstone was laid on August 8, 1576. Tycho abandoned Uranienborg in 1597, and it was destroyed in 1601. The grounds are currently being restored.

Tycho Brahe's Uraniborg main building from the 1663 Blaeu's Atlas Major

The main building of Uraniborg was square, about 15 meters on a side, and built mostly of red brick. Two semi-circular towers, one each on the north and south sides of the main building, giving the building a somewhat rectangular shape overall. The main floor consisted of four rooms, one of which was occupied by Tycho and his family, the other three for visiting astronomers. The northern tower housed the kitchens, and the southern a library. The second floor was divided into three rooms, two of equal size and one larger. The larger room was reserved for visiting royalty. On this level the towers housed the primary astronomical instruments, accessed from outside the building or from doors on this floor. Outrider towers, supported on pillars, housed additional instruments slightly further from the building, giving them a wider angle of view. On the third floor was a "loft", subdivided into eight smaller rooms for students. Only the roofs of the towers reached this level, although a single additional tower extended above the loft in the middle of the building, similar to a widow's walk, accessed via a spiral staircase from the 3rd floor. Uraniborg also featured a large basement; it housed an alchemical laboratory in one end, and storage for food, salt and fuel at the other.[1]

A large wall, 75 meters on a side and 5.5 meters high was planned to surround Uraniborg, but never built, instead a high earth mound was constructed and lasted until today being the only remain of the observatory still in place. Uraniborg was located in the very middle, with an extensive set of intricate gardens between the mound walls and the building. In addition to being decorative, the gardens also supplied herbs for the Tycho's medicinal chemistry experiments. The gardens are currently being re-created, using seeds found on-site or identified in Tycho's writings.

Uraniborg was an extremely expensive project. It is estimated that it cost about 1% of the entire state budget during construction,[2] .

Shortly after construction it became clear that the tower-mounted instruments were too easily moved by wind, and Tycho set about constructing a more suitable observation site.[2] The result was → Stjerneborg ("castle of the stars"), a smaller site built entirely at ground level and dedicated purely to observations (there was no "house"). The basic layout was similar to Uraniborg, with a wall of similar shape surrounding the site, although the enclosed area was much smaller. The instruments were all placed underground, covered by opening shutters or a rotating dome in buildings built over the instrument pits.

Upon losing financial support from the new king, Christian IV of Denmark, Tycho abandoned Hven in 1597 and both Uraniborg and Stjerneborg were destroyed shortly after Tycho's death. Stjerneborg was the subject of archaeological excavations during the 1950s, resulting in the restoration of the observatory.[3] Stjerneborg now houses a multimedia show.

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[2] "TYCHO BRAHE'S castle URANIBORG and his observatory STJÄRNEBORG" (http://www.hven.net/EUBORG.html)

[3] Google Map of Uraniborg (http://maps.google.com/maps?f=q&hl=en&q=Ven,+Sweden&sll=37.0625,-95.677068&sspn=40.732051,96.152344&ie=UTF8&cd=1&geocode=0,55.906098,12.695870&ll=55.907811,12.696403&spn=0.001765,0.005869&t=h&z=18&om=1)

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Source: http://en.wikipedia.org/w/index.php?oldid=274164545

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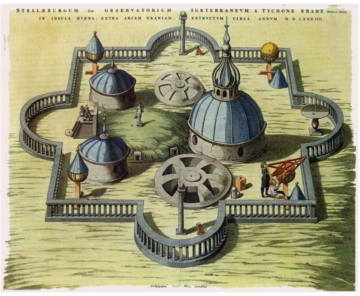
Stjerneborg

Stjerneborg ("Star Castle" in English) was → Tycho Brahe's underground observatory next to his palace-observatory → Uraniborg, located on the island of Hven in Oresund.



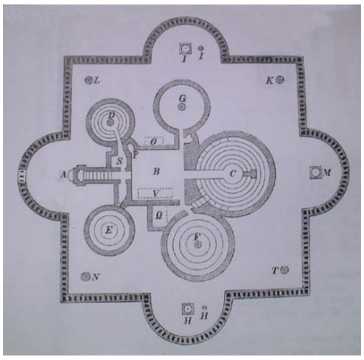
drawing of an above ground view of Stjerneborg

Tycho Brahe built it circa 1581, when he found Uraniborg neither stable nor large enough for his precision instruments. He named it Stellaburgi in Latin. Both the Danish and Latin names mean "castle of the stars".

The underground portions of the observatory were excavated in the 1950s and are today fitted with a roof approximating a multimedia show open to the public.

Click on the schematic for more details on the function of the various chambers.

Stjerneborg as it exists today



schematic of Stjerneborg showing underground chambers

Source: http://en.wikipedia.org/w/index.php?oldid=268913038

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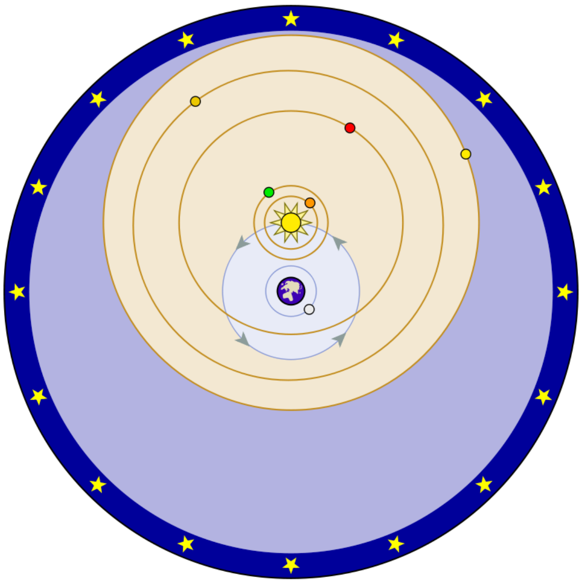
Achievements

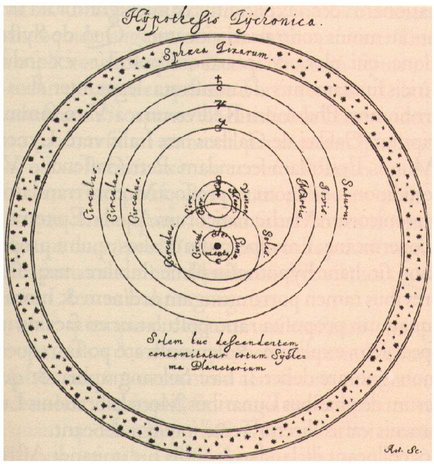
Tychonic system

The **Tychonic system** (or *Tychonian system*) was a model of the solar system published by → Tycho Brahe in the late 16th century which combined what he saw as the mathematical benefits of the Copernican system with the philosophical and "physical" benefits of the Ptolemaic system. The model may have been inspired by Paul Wittich, a Silesian mathematician and astronomer.[1] A similar geoheliocentric model was also earlier proposed by Nilakantha Somayaji, a Keralese mathematician and astronomer.[2][3]



In this depiction of the Tychonic system, the objects on blue orbits (the moon and the sun) rotate around the earth. The objects on orange orbits (Mercury, Venus, Mars, Jupiter, and Saturn) rotate around the sun. Around all is a sphere of fixed stars.

It is essentially a geocentric model with the Earth at the center of the universe. The Sun and Moon revolve around the Earth, and the other five planets revolve *around the Sun*. It can be shown through a geometric argument that the motions of the planets and the Sun relative to the Earth in the Tychonic system are equivalent to the motions in the Copernican system.



Tychonic system

Tycho argued, quite correctly, that if the Earth is moving, then we should be able to detect a change in our position relative to stars (the technical term is parallax). But he wasn't able to detect that change in relative position, so he concluded that the Earth isn't moving. In reality, our position relative to stars does change. But stars are so far away that the change in angles is so small that it can't be observed by the naked eye, and that's why Tycho wasn't able to detect it. It wasn't until hundreds of years later that people built telescopes that were accurate enough to detect stellar parallax. Astronomers of Tycho's time didn't realize how far away stars were.

A further consideration for Tycho and his followers was biblical scripture. Some poetic passages seem to assume that the Sun moves or the Earth is stable.

Tycho's system was foreshadowed, in part, by that of Martianus Capella, who described a system in which Mercury and Venus are placed on epicycles around the Sun, which circles the Earth. Copernicus, who cited Capella's theory, even mentioned the possibility of an extension in which the other three of the six known planets would also circle the Sun. [4]

The Tychonic system became a major competitor with the Copernican system as an alternative to the Ptolemaic. After Galileo's observation of the phases of Venus in 1610, most cosmological controversy then settled on variations of the Tychonic and Copernican systems. In a number of ways, the Tychonic system proved philosophically more intuitive than the Copernican system, as it reinforced commonsense notions of how the Sun and the planets are mobile while the Earth is not. Additionally, a Copernican system would suggest the ability to observe stellar parallax, which could not be observed until the 19th century. On the other hand, because of the intersecting deferents of Mars and the Sun (see diagram), it went against the Ptolemaic and Aristotelian notion that the planets were placed within nested spheres. Tycho and his followers revived the ancient Stoic philosophy instead, since it used fluid heavens which could accommodate intersecting circles.

After Tycho's death, Johannes Kepler used the observations of Tycho himself to demonstrate that the orbits of the planets are ellipses and not circles, creating the modified Copernican system that ultimately displaced both the Tychonic and Ptolemaic systems. However, the Tychonic system was very influential in the late 16th and 17th centuries. After the Galileo affair, which transpired early in the 17th century, Copernicanism was officially forbidden to astronomers in the Roman Catholic Church; the Tychonic system was a religiously acceptable alternative that matched available observations. Jesuit astronomers in China used it extensively, as did a number of European scholars.

The discovery of stellar aberration in the early 18th century by James Bradley established that the Earth did in fact move around the Sun, after which Tycho's system fell out of use among scientists. In the modern era, the few who still subscribe to geocentrism use a Tychonic system with elliptical orbits. See *modern geocentrism*.

External links

[1] Owen Gingerich, *The Book Nobody Read: Chasing the Revolutions of Nicolaus Copernicus*, Penguin, ISBN-10: 0143034766

[2] Ramasubramanian, K. (1994), "Modification of the earlier Indian planetary theory by the Kerala astronomers (c. 1500 AD) and the implied heliocentric picture of planetary motion", *Current Science* **66**: 784-90

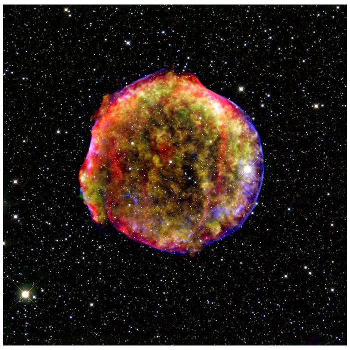
[3] Joseph, George G. (2000), *The Crest of the Peacock: Non-European Roots of Mathematics*, p. 408, Princeton University Press, ISBN 978-0-691-00659-8

[4] (http://webexhibits.org/calendars/year-text-Copernicus.html)

Source: http://en.wikipedia.org/w/index.php?oldid=269725460

Contributors: Andycjp, Hibernian, Jagged 85, Logicus, PhilKnight, Sdrtirs, Shaheenjim, Wwoods, Yvwv, 3 anonymous edits

SN 1572

Supernova SN 1572	
 X-ray image of the SN 1572 remnant as seen by Calar Alto Observatory	
Observation data (Epoch ?)	
Supernova type	Type Ia[1]
Remnant type	Nebula
Host galaxy	Milky Way
Constellation	Cassiopeia
Right ascension	0^{h} 25.3^{m}
Declination	+64° 09′
Galactic coordinates	G.120.1+1.4
Discovery date	November 1572
Peak magnitude (V)	-4
Distance	7500 light-years (2.3 kpc)
Physical characteristics	
Progenitor	Unknown
Progenitor type	Unknown
Colour (B-V)	Unknown

SN 1572 (*Tycho's Supernova*, *Tycho's Nova*), "B Cassiopeiae" (B Cas), or ***3C 10*** was a supernova of Type Ia[1] in the constellation Cassiopeia, one of about eight supernovae visible to the naked eye in historical records. It burst forth in early November 1572 and was independently discovered by many individuals. [2]

Historic description

The appearance of the Milky Way supernova of 1572 was perhaps one of the two or three most important events in the history of astronomy. The "new star" helped to revise ancient models of the heavens and to inaugurate a tremendous revolution in astronomy that began with the realized need to produce better astrometric star catalogues (and thus the need for more precise astronomical observing instruments). The supernova of 1572 is often called "Tycho's supernova", because of the extensive work that → Tycho Brahe (1573, 1602, 1610) did in both observing the new star and in analyzing his own observations and those of many other observers. But Tycho was not even close to being the first to observe the 1572 supernova, although he was apparently the most accurate observer of the object (though not by much over some of his European colleagues like Wolfgang Schuler, Thomas Digges, John Dee and Francesco Maurolico).

In England, Queen Elizabeth called to her the mathematician and astrologer Thomas Allen, "to have his advice about the new Star that appeared in the Cassiopeia to which he gave his Judgement very learnedly," the antiquary John Aubrey recorded in his memoranda a century later.[3]

The more reliable contemporary reports state that the new star itself burst forth sometime between 1572 November 2 and 6, when it rivalled Venus in brightness. This corresponds to an absolute magnitude of -15.8, nearly twenty times as bright as a full moon. The supernova remained visible to the naked eye into 1574, gradually fading until it disappeared from view.

Supernova remnant

Radiological detection

The search for a supernova remnant was negative until 1952, when Hanbury Brown and Hazard reported a radio detection at 158.5 MHz.[4] This was confirmed at wavelength 1.9 m by Baldwin and Edge (1957),[5] and the remnant was also identified tentatively in the second Cambridge radio-source catalogue as object "2C 34" and identified more firmly as "3C 10" in the third Cambridge list (Edge et al. 1959). There is no dispute that 3C 10 is the remnant of the supernova observed in 1572-1573. Following a review article by Minkowski (1964),[6] the designation 3C 10 appears to be that most commonly used in the literature when referring to the radio remnant of B Cas (though some authors use the tabulated Galactic designation G120.7+2.1 of Green 1984, and many authors commonly refer to it as "Tycho's supernova remnant"—somewhat of a misnomer, as Tycho saw the pointlike supernova, not the expansive radio remnant). Because the radio remnant was reported before the optical supernova-remnant wisps were discovered, the designation 3C 10 is used by some to signify the remnant at all wavelengths.

SN 1572 is associated with the radio source G.120·1+1·4. It has an apparent diameter of 7.4 arc minutes, and is located approximately 7500 light-years (2.3 kpc) from our Solar system.

Optical detection

The supernova remnant of B Cas was discovered in the 1960s by scientists with a Palomar Mountain telescope as a very faint nebula. It was later photographed by a telescope on the international ROSAT spacecraft. The supernova has been confirmed as Type Ia,[1] in which a white dwarf star has accreted matter from a companion until it reaches the Chandrasekhar limit and explodes. This type of supernova does not typically create the spectacular nebula more typical of Type II supernovas, such as SN 1054 which created the Crab Nebula. A shell of gas is still expanding from its center at about 9,000 km/s.

Discovery of the companion star

In October 2004, a letter in *Nature* reported the discovery of a G2 star, similar in type to our own Sun.[7] It is thought to be the companion star that contributed mass to the white dwarf that ultimately resulted in the supernova. A subsequent study, published in March 2005, revealed further details about this star: labeled Tycho G, it was likely a main sequence star or subgiant prior to the explosion, but had some of its mass stripped away and its outer layers shock-heated from the effects of the supernova. Tycho G's current velocity is perhaps the strongest evidence that it was the companion star to the white dwarf, as it is traveling at a rate of 136 km/s, which is more than forty times faster than the mean velocity of other stars in its stellar neighbourhood.

Observation of light echo

In September 2008, the Subaru telescope obtained the optical spectrum of Tycho Brahe's supernova near maximum brightness from a scattered-light echo.[8] It has been confirmed that SN 1572 belongs to the majority class of normal SNe Ia.

See also

- List of supernova remnants

External links

- solstation.com: Tycho's Star [9]
- The Search for the Companion Star of Tycho Brahe's 1572 Supernova [10]
- cnn.com: Important days in history of universe [11]

External links

[1] Krause, Oliver; *et al.* (2008). "Tycho Brahe's 1572 supernova as a standard type Ia as revealed by its light-echo spectrum". *Nature* **456** (7222): 617–619. doi: 10.1038/nature07608 (http://dx.doi.org/10.1038/nature07608).

[2] [http://www.sciencedaily.com/releases/2008/12/081203133809.htm *Blast From The Past: Astronomers Resurrect 16th-Century Supernova*] ScienceDaily (Dec. 4, 2008)

[3] Oliver Lawson Dick, ed. *Aubrey's Brief Lives. Edited from the Original Manuscripts*, 1949, *s.v.* "Thomas Allen" p. 5.

[4] Hanbury-Brown, R.; Hazard, C. (1952). "Radio-Frequency Radiation from Tycho Brahe's Supernova (A.D. 1572)". *Nature* **170** (4322): 364–365. doi: 10.1038/170364a0 (http://dx.doi.org/10.1038/170364a0).

[5] Baldwin, J. E.; Edge, D. O. (1957). "Radio emission from the remnants of the supernovae of 1572 and 1604". *The Observatory* **77**: 139–143. Bibcode: 1957Obs....77..139B (http://adsabs.harvard.edu/abs/1957Obs....77..139B).

[6] Minkowski, R. (1964). "Supernovae and Supernova Remnants". *Annual Review of Astronomy and Astrophysics* **2**: 247–266. doi: 10.1146/annurev.aa.02.090164.001335 (http://dx.doi.org/10.1146/annurev.aa.02.090164.001335).

[7] Ruiz-Lapuente, Pilar; *et al.* (2004). "The binary progenitor of Tycho Brahe's 1572 supernova". *Nature* **431** (7012): 1069–1072. doi: 10.1038/nature03006 (http://dx.doi.org/10.1038/nature03006).

[8] "Tycho Brahe's 1572 supernova as a standard type Ia explosion revealed from its light echo spectrum" (http://arxiv.org/abs/0810.5106v1). arXiv.org. October 28, 2008. http://arxiv.org/abs/0810.5106v1.
[9] http://www.solstation.com/x-objects/tycho-s.htm
[10] http://www.ing.iac.es/PR/newsletter/news9/science7.html
[11] http://www.cnn.com/2008/LIVING/wayoflife/01/01/important.days/index.html

Source: http://en.wikipedia.org/w/index.php?oldid=273301815

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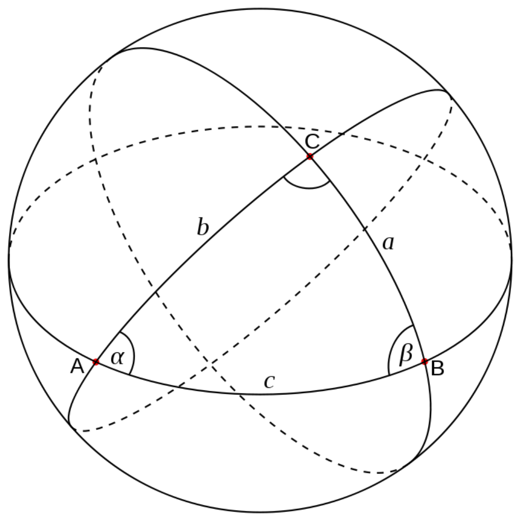
Prosthaphaeresis

Prosthaphaeresis was an algorithm used in the late 16th century and early 17th century for approximate multiplication and division using formulas from trigonometry. For the 25 years preceding the invention of the logarithm in 1614, it was the only known generally-applicable way of approximating products quickly. Its name comes from the Greek *prosthesis* and *aphaeresis*, meaning *addition* and *subtraction*, two steps in the process.[1] [2]

History and motivation



A spherical triangle

In sixteenth century Europe, celestial navigation of ships on long voyages relied heavily on ephemerides to determine their position and course. These voluminous charts prepared by astronomers detailed the position of stars and planets at various points in time. The models used to compute these were based on spherical trigonometry, which relates the angles and arc lengths of spherical triangles (see diagram, right) using formulas such as:

- $\cos a = \cos b \cos c + \sin b \sin c \cos \alpha$
- $\sin b \sin \alpha = \sin a \sin \beta$

When one quantity in such a formula is unknown but the others are known, the unknown quantity can be computed using a series of multiplications, divisions, and trigonometric table lookups. Astronomers had to make thousands of such calculations, and because the best method of multiplication available was long multiplication, most of this time was spent taxingly multiplying out products.

Mathematicians, particularly those who were also astronomers, were looking for an easier way, and trigonometry was one of the most advanced and familiar fields to these people. Prosthaphaeresis appeared in the 1580s, but its originator is not known for certain; its contributors included the mathematicians Paul Wittich, Ibn Yunis, Joost Bürgi, Johannes Werner, Christopher Clavius, and François Viète. Wittich, Yunis, and Clavius were all astronomers and have all been credited by various sources with discovering the method. Its most well-known proponent was → Tycho Brahe, who used it extensively for astronomical calculations such as those described above. It was also used by John Napier, who is credited with inventing the logarithms that would supplant it. (Additional information: Nicholas Copernicus mentions prosthaphaeresis several times in his work De Revolutionibus Orbium Coelestium, published in 1543.)

The identities

The trigonometric identities exploited by prosthaphaeresis relate products of trigonometric functions to sums. They include the following:

- $\sin a \sin b = \frac{1}{2}[\cos(a - b) - \cos(a + b)]$
- $\cos a \cos b = \frac{1}{2}[\cos(a - b) + \cos(a + b)]$
- $\sin a \cos b = \frac{1}{2}[\sin(a + b) + \sin(a - b)]$
- $\cos a \sin b = \frac{1}{2}[\sin(a + b) - \sin(a - b)]$

The first two of these are believed to have been derived by Bürgi, who related them to Brahe; the others follow easily from these two. If both sides are multiplied by 2, these formulas are also called the *Werner formulas*.

The algorithm

Using the second formula above, the technique for multiplication works as follows:

1. **Scale down**: By shifting the decimal point to the left or right, scale both numbers to a value between -1 and 1.
2. **Inverse cosine**: Using an inverse cosine table, find two angles whose cosines are our two values.
3. **Sum and difference**: Find the sum and difference of the two angles.
4. **Average the cosines**: Find the cosines of the sum and difference angles using a cosine table and average them.
5. **Scale up**: Shift the decimal place in the answer to the right (or left) as many places as you shifted the decimal place to the left (or right) in the first step, for each input.

For example, say we want to multiply 105 and 720. Following the steps:

1. **Scale down**: Shift the decimal 3 to the left in each. We get: 0.105, 0.720
2. **Inverse cosine**: cos(84°) is about 0.105, cos(44°) is about 0.720
3. **Sum and difference**: 84 + 44 = 128, 84 - 44 = 40
4. **Average the cosines**: ½[cos(128°) + cos(40°)] is about ½[-0.616 + 0.766], or 0.075
5. **Scale up**: We shifted 105 and 720 each 3 to the left, so shift our answer 6 to the right. The result is 75,000. This is very close to the actual product, 75,600.

If we want the product of the cosines of the two initial values, which is useful in some of the astronomical calculations mentioned above, this is surprisingly even easier: only steps 3 and 4 above are necessary.

A table of secants can be used for division. To divide 3746 by 82.05, we scale the numbers to 0.3746 and 8.205. The first is approximated as the cosine of 68 degrees, and the second as the secant of 83 degrees. Exploiting the definition of the secant as the reciprocal of the cosine, we proceed as in multiplication above: Average the cosine of the sum of the angles, 151, with the cosine of their difference, 15.

½[cos(151°) + cos(-15°)] is about ½[-0.875 + 0.966], or 0.046

Scaling up to locate the decimal point gives the approximate answer, 46.

Algorithms using the other formulas are similar, but each using different tables (sine, inverse sine, cosine, and inverse cosine) in different places. The first two are the easiest because they each only require two tables. Using the second formula, however, has the unique advantage that if only a cosine table is available, it can be used to estimate inverse cosines by searching for the angle with the nearest cosine value.

Notice how similar the above algorithm is to the process for multiplying using logarithms, which follows the steps: scale down, take logarithms, add, take inverse logarithm, scale up. It's no surprise that the originators of logarithms had used prosthaphaeresis. Indeed the two are closely related mathematically. In modern terms, prosthaphaeresis can be viewed as relying on the logarithm of complex numbers, in particular on the identity e^(ix)=cos x + i sin x.

Decreasing the error

If all the operations are performed with high precision, the product can be as accurate as desired. Although sums, differences, and averages are easy to compute with high precision, even by hand, trigonometric functions and especially inverse trigonometric functions are not. For this reason, the accuracy of the method depends to a large extent on the accuracy and detail of the trigonometric tables used.

For example, a sine table with an entry for each degree can be off by as much as 0.0087 if we just choose the closest number; each time we double the size of the table we halve this error. Tables were painstakingly constructed for prosthaphaeresis with values for every second, or 3600th of a degree.

Inverse sine and cosine functions are particularly troublesome, because they become steep near -1 and 1. One solution is to include more table values in this area. Another is to scale the inputs to numbers between -0.9 and 0.9. For example, 950 would become 0.095 instead of 0.950.

Another effective approach to enhancing the accuracy is linear interpolation, which chooses a value between two adjacent table values. For example, if we know the sine of 45° is about 0.707 and the sine of 46° is about 0.719, we can estimate the sine of 45.7° as:

0.707 × (1 - 0.7) + 0.719 × 0.7 = 0.7154.

The actual sine is 0.7157. A table of cosines with only 180 entries combined with linear interpolation is as accurate as a table with about 45000 entries without it. Even a quick estimate of the interpolated value is often much closer than the nearest table value. See lookup table for more details.

Reverse identities

The product formulas can also be manipulated to obtain formulas that express addition in terms of multiplication. Although less useful for computing products, these are still useful for deriving trigonometric results:

- $\sin a + \sin b = 2\sin[\tfrac{1}{2}(a + b)]\cos[\tfrac{1}{2}(a - b)]$
- $\sin a - \sin b = 2\cos[\tfrac{1}{2}(a + b)]\sin[\tfrac{1}{2}(a - b)]$
- $\cos a + \cos b = 2\cos[\tfrac{1}{2}(a + b)]\cos[\tfrac{1}{2}(a - b)]$
- $\cos a - \cos b = -2\sin[\tfrac{1}{2}(a + b)]\sin[\tfrac{1}{2}(a - b)]$

External links

- PlanetMath: Prosthaphaeresis formulas [3]
- Daniel E. Otero Henry Briggs [4]. Introduction: the need for speed in calculation.
- Mathworld: Prosthaphaeresis formulas [5]
- Adam Mosley. Tycho Brahe and Mathematical Techniques [6]. University of Cambridge.
- IEEE Computer Society. History of computing: John Napier and the invention of logarithms [7].
- Math Words: Prosthaphaeresis [8]
- Beatrice Lumpkin. *African and African-American Contributions to Mathematics* [9]. Discusses Ibn Yunis's contribution to prosthaphaeresis.
- Prosthaphaeresis [10] and beat phenomenon in the theory of vibrations, by Nicholas J. Rose

External links

[1] Pierce, R. C., Jr. (January 1977). "A Brief History of Logarithms". *The Two-Year College Mathematics Journal* (Mathematical Association of America) **8** (1): 22–26. doi: 10.2307/3026878 (http://dx.doi.org/10.2307/3026878).
[2] Prosthaphaeresis (http://www.nmt.edu/~borchers/prost.pdf), by Brian Borchers
[3] http://planetmath.org/encyclopedia/ProsthaphaeresisFormulas.html
[4] http://cerebro.xu.edu/math/math147/02f/briggs/briggsintro.html
[5] http://mathworld.wolfram.com/ProsthaphaeresisFormulas.html
[6] http://www.hps.cam.ac.uk/starry/tychomaths.html
[7] http://pages.cpsc.ucalgary.ca/~williams/History_web_site/time%201500_1800/John%20Napier%20and%20invention%20of%20logs.htm
[8] http://www.pballew.net/arithm18.html#Prostha
[9] http://www.pps.k12.or.us/depts-c/mc-me/be-af-ma.pdf
[10] http://www4.ncsu.edu/~njrose/pdfFiles/Prostha.pdf

Source: http://en.wikipedia.org/w/index.php?oldid=272476833

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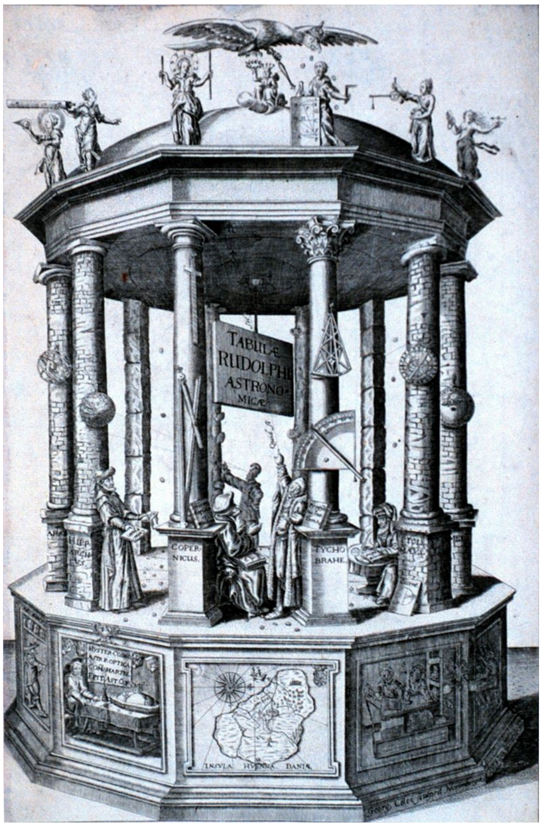
Rudolphine Tables

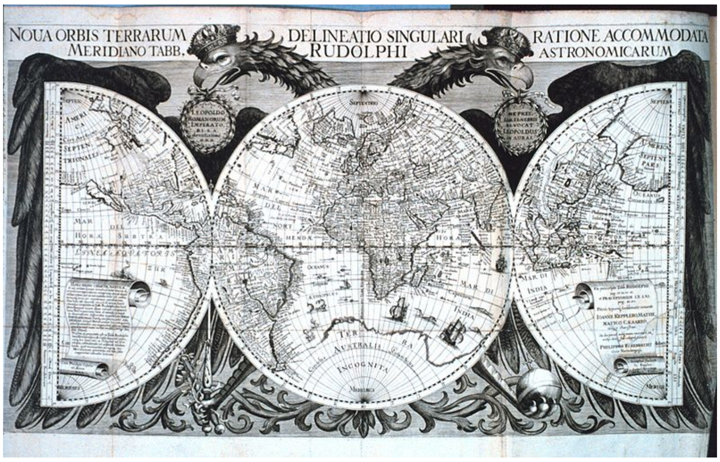
The **Rudolphine Tables** (Latin: *Tabulae Rudolphinae*) consist of a star catalog and planetary tables published by Johannes Kepler in 1627. Named after Emperor Rudolf II, they contain positions for the 1,006 stars measured by → Tycho Brahe, and 400 and more stars from Ptolemy and Johann Bayer, with directions and tables for locating the planets of the solar system.



The iconic frontispiece to the *Rudolphine Tables* celebrates the great astronomers of the past: Hipparchus, Ptolemy, Copernicus, and most prominently, → Tycho Brahe.

The new tables supersede the older Prussian Tables (Erasmus Reinhold, 1551) and Alphonsine tables (13th century). The purpose of the Rudolphine Tables is essentially to provide an accurate tool for erecting horoscopes, including many function tables of logarithms and antilogarithms, and instructive examples for computing planetary positions.

The tables based observations by Tycho Brahe are accurate mostly up to one arc minute,[1] and were the first to include corrective factors for atmospheric refraction.[2]



The map of the world from the *Rudolphine Tables*

Publication

When publishing the Rudolphine Tables, Kepler was hard-pressed to fight off Tycho's numerous relatives. These relatives throughout the entire publication process were constantly trying to win control of the observations for the profit of them, with the case that Tycho's work should benefit his own family, and not one of Tycho's own competitors. Kepler considered this very unfair, because he and Tycho had been collaborating to work together on the data for many years before Tycho's death, and was responsible for much of the calculations and organization of the data. Nevertheless, Kepler did win control of the tables and published them himself while the Brahe family got none of it.

See also

- Star cartography

External links

- Universitätsbibliothek Kiel – Digiport: Tabulæ Rudolphinæ [3] - Bartsch version from 1627, with appendices on Schiller's Christian constellations and Bartsch'es own constellation innovations.

External links

[1] Uranometria 2000.0, vol 1, page XVII, Tirion, Lovi and Rappaport, 1987, ISBN 0-993396-15-8
[2] The New Encyclopædia Britannica, 1988, Volume 10, pg. 232
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Version 1.2, November 2002

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