As such it was the second retrograde satellite found after Phoebe, a satellite of Saturn.

In an effort to follow the motion of comet 1P/Halley and predict its upcoming perihelion passage in 1910, Cowell and Crommelin applied Cowell's method to the motion of comet Halley and predicted its perihelion passage time as 1910 April 17.1. This date turned out to be 3 days early, and in hindsight, this is what should have been expected since later work showed that the icy comet's rocket-like outgasing effects lengthen its orbital period by an average of 4 days per period. In an earlier work published in 1907, Cowell and Crommelin made the first attempt to integrate the motion of comet Halley backward into the ancient era. Using a variation of elements method, rather than the direct numerical integration technique used later, they accurately carried the comet's motion back in time to 1301 by taking into account perturbations in the comet's period from the effects of Venus, Earth, Jupiter, Saturn, Uranus, and Neptune. Using successively more approximate perturbation techniques, they then carried the comet's motion back to 239 BCE. At this stage, their integration was in error by nearly 1.5 years in the comet's perihelion passage time, and they adopted a time of 15 May 240 BCE, not from their computations but from a consideration of the ancient Chinese observations themselves.

Toward the end of his career, Cowell became disappointed that he was not appointed the Plumian Professor of Astronomy at Cambridge when the position became open in 1912 and was again disappointed the following year when he failed to be appointed to a Cambridge Professorship of Astronomy and Geometry. It was ▶ **Arthur Eddington** who was elected to succeed Sir ▶ **George Darwin** in the Plumian chair of astronomy and experimental philosophy in 1913.

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Cowling, Thomas George

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Born **Walthamstow**, **London**, **England**, **17 June 1906**
Died **Leeds**, **England**, **16 June 1990**

English mathematician and theoretical astrophysicist Thomas Cowling gave his name to a model of stellar structure in which all of the energy is released very close to the center and to a theorem relevant to the generation and structure of the magnetic fields of the Earth and Sun. However, the part of his work that has the strongest resonance down to the present is the classification of vibrational modes in the Sun or other stars into *p* (where pressure is the restoring force) and *g* (where gravity is the restoring force) modes, separated by a fundamental radial oscillation, all of which have now been seen and which provide vital information on the deep interiors of the Sun and other stars.

Cowling was the second of four sons of Edith and George Cowling, an engineer with the post office, who brought home a large horseshoe magnet that may well have contributed to his son's lifelong interest in magnetism. The family members were all lifelong active Baptists.

Cowling married Dorris Marjorie Moffatt in 1935 and was survived by her and their three children.

Cowling graduated from a county-supported grammar school in 1923 and won a scholarship to Brasenose College, Oxford, where he earned a first-class degree in mathematics in 1927 and a teaching diploma in 1928. This delayed his start in research toward the Ph.D. (1930) by 1 year, so that he had the opportunity to become the first Oxford student of ► **Edward Milne**. Milne made him work on the structure of stellar atmospheres. Among the results was the conclusion that work by ► **Sydney Chapman** purporting to show that the magnetic field of the Sun could not extend out very far was simply wrong. The Sun must have open field lines extending very far out (far beyond the orbit of the Earth). It is a tribute to Chapman that he reacted to this by offering Cowling his first job as a demonstrator in the mathematics department at Imperial College, London.

Cowling spent his entire career in university mathematics departments: Swansea, 1933–1937; Dundee, 1937–1938; Manchester, 1938–1945; Bangor, 1945–1948; and Leeds, 1948–1970, the first three in lectureships and the last two as professor. He guided very few research students or fellows; only Eric Priest (a solar physicist) and Leon Mestel (a mathematically inclined astrophysicist particularly interested in magnetic fields) remained in astronomy.

A number of Cowling's calculations were of considerable importance at the time. These included a demonstration that magnetic field lines must be frozen into an ionized gas (1932). A more developed version of it was later published by ► **Hannes Alfvén**, whose relationship with Cowling was one of mutually respectful criticism.

Cowling demonstrated in 1934 that an axisymmetric field cannot be maintained by dynamo action. This result bears the name of "Cowling antidynamo theorem" and prevents axisymmetric approaches from describing the magnetic field of the Earth and Sun.

Another Cowling demonstration showed that the lowered temperatures of sunspots must be maintained by magnetic fields connected with the solar interior (1935). In the Cowling model for stellar structure, energy generation is confined to the extreme center. A core with convective energy transport and an envelope with radiative energy transport are now known to describe the conditions of hydrogen-burning stars of more than about 1.5 solar masses, which are powered by the CNO cycle.

Cowling considered the possible runaway pulsational instability of stars with centrally concentrated energy generation (1935). He showed that convection would take over before the instability got out of hand except in very massive stars. Such stars are now known to display such instabilities as luminous blue variable or Hubble-Sandage variable stars, and he went on to classify less-violent pulsations that actually do occur in stars like the Sun (1941).

Cowling's close scientific association with ► **Ludwig Biermann**, and perhaps other central European colleagues, led to his being considered unreliable during World War II. He remained in his department, although he realized afterward that some of the problems Chapman asked him to work on (gas diffusion theory for instance) had been relevant to the atomic bomb project and others to the development of radar. Back problems from 1957 onward and a mild heart attack in 1960 gradually curtailed Cowling's activities. Although he had been a strong proponent of a national center of theoretical astrophysics, by the time such centers were established in Cambridge and Sussex in the late 1960s, he was not able to relocate.

Recognition of Cowling's work came in the form of a Gold Medal of the Royal Astronomical Society, the Bruce Medal of the Astronomical Society of the Pacific, election to the Royal Society (London), and award of its Hughes Medal of which he never learned, dying just 2 days after the announcement. He served as president of the Royal Astronomical Society (1965–1967), of the commission on the International Astronomical Union on Stellar Constitution (1955–58), and the IAU commission on plasmas and magnetohydrodynamics in Astrophysics (1964–67). Cowling was both unusually tall and unusually (even for his generation) given to formal dress, so that an unsuspecting younger astronomer might well find himself being introduced in effect to Cowling's middle waistcoat button.

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Crabtree, William

Jean-Pierre Luminet
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Born **Broughton near Salford**, **Greater Manchester**, **England**, **June 1610**
Died **Broughton near Salford**, **Greater Manchester**, **England**, **July 1644**

William Crabtree was among the first to observe a transit of Venus.

The son of a prosperous yeoman farmer, Crabtree studied at Manchester Grammar School. He received no university education, making a career as a clothier or a merchant in Manchester from 1630 or so. He was also employed as a land surveyor and a cartographer.

Self-educated in astronomy, Crabtree made precise observations by which he could establish the latitude of Manchester. By such observations, he was convinced of the accuracy of the *Rudolphine Tables* published by ► **Johannes Kepler** in 1627, so Crabtree converted the tables to decimal form and accepted Kepler's theory of elliptical planetary orbits.

Crabtree's correspondence with ► **Jeremiah Horrocks** and ► **William Gascoigne** about clocks, telescopes, and micrometers shows his recognition of the importance of instruments in refining observational accuracy. As one of the earliest Englishmen to study sunspots, Crabtree closely collaborated with Horrocks on the observation of the transit of Venus across the Sun. According to Keplerian calculations, this rare event would take place on 4 December 1639. Crabtree and Horrocks set up their instrument in Hoole, near Liverpool, and observed the transit at the right time. Projecting the image of the Sun from their telescope on to a graduated sheet of paper, they could deduce the value of the Sun-Earth distance as 14,700 times the radius of the Earth. This value for the astronomical unit was much more accurate than any calculated hitherto. Ford Madox Brown painted the astronomer-merchant observing the Venus transit in one of the 12 historical murals commissioned to decorate the Great Hall of Manchester's new Town Hall in about 1880. Crabtree, who was a wealthy and healthy 29-year-old merchant in 1639, is depicted as a wild-eyed, skeletal septuagenarian observing with a brass telescope of late eighteenth-century design, and he is accompanied by an appropriately pre-Raphaelite wife!

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