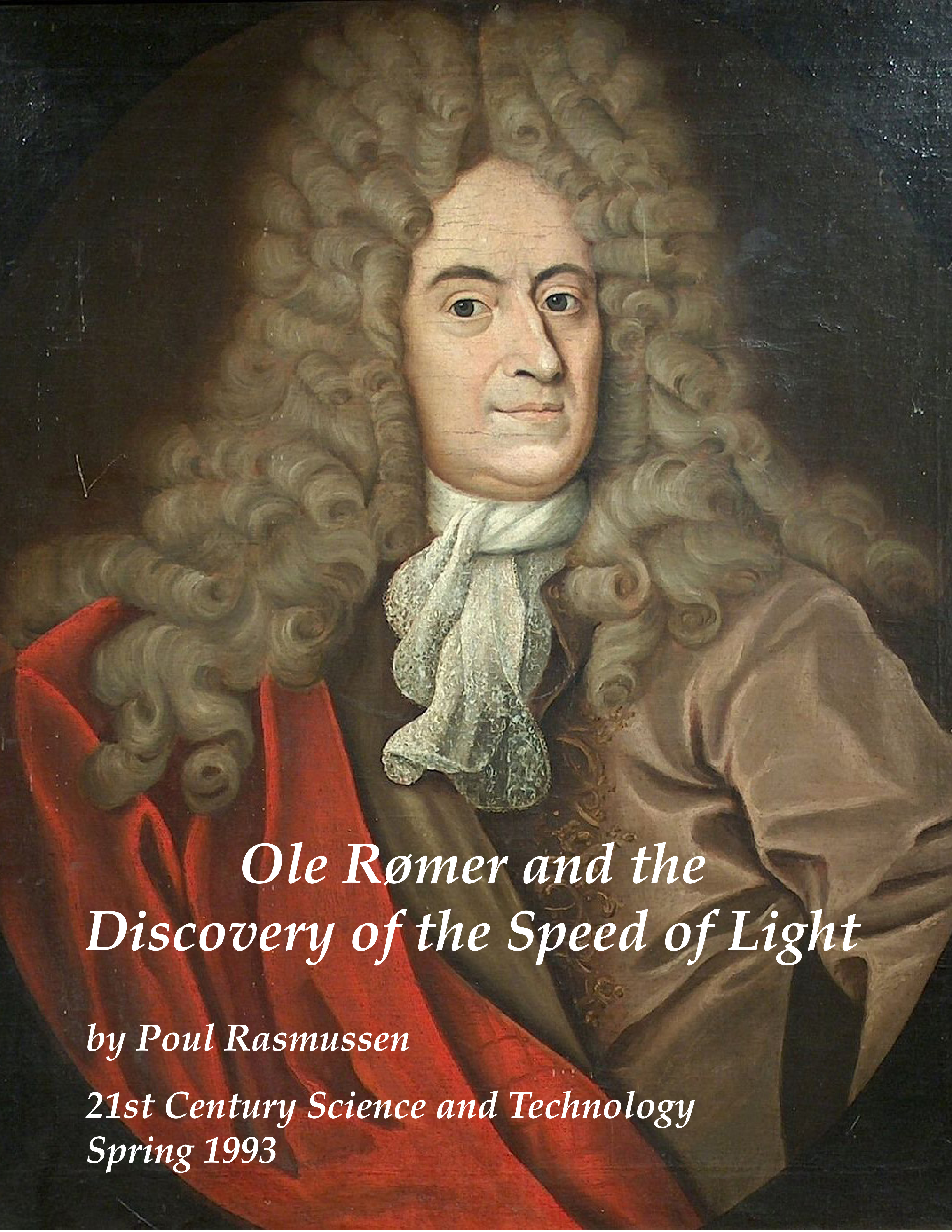

Ole Rømer and the Discovery of the Speed of Light

by Poul Rasmussen

21st Century Science and Technology
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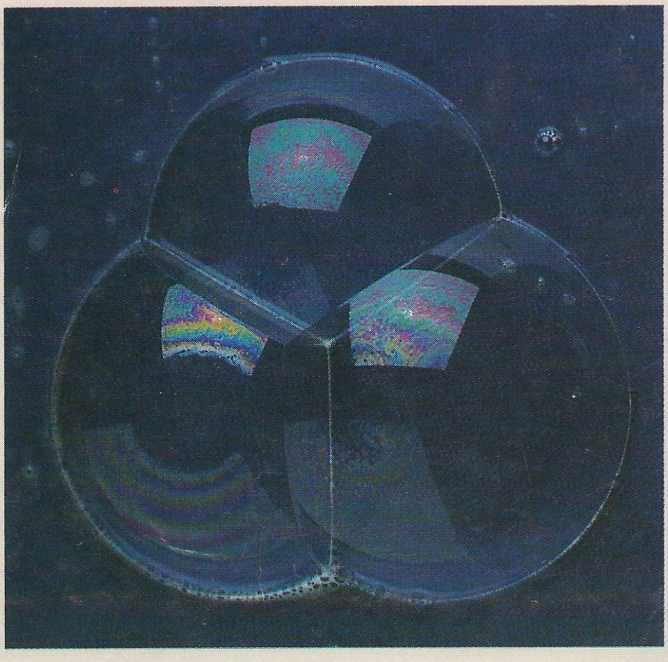
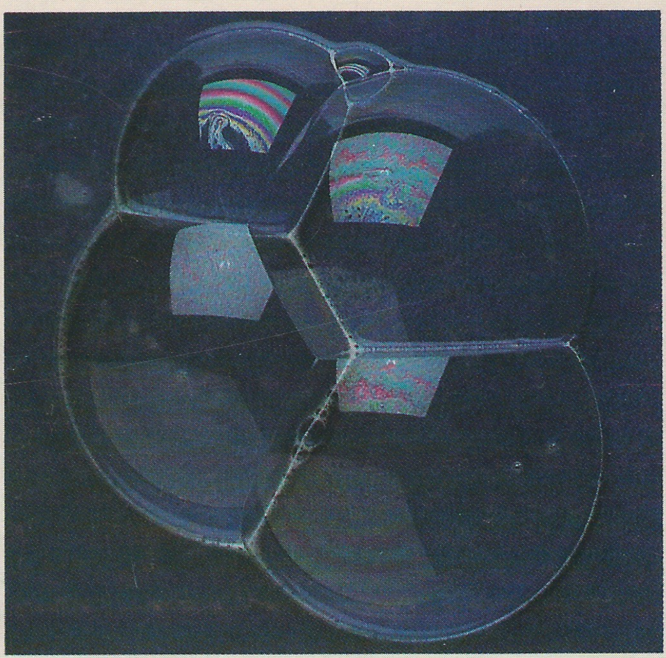




Philip Ulanowsky

These soap films show shortest paths between three and four points.

WHAT CAN SOAP BUBBLES TEACH YOU?

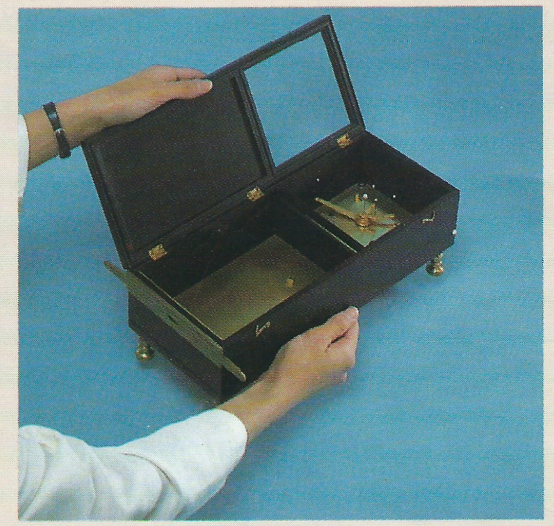
How can students of all ages learn how to think creatively without falling into the pit of "political correctness"? Raynald Rouleau uses soap bubbles and an imaginative dialogue to demonstrate the *method* of learning that characterized Leonardo da Vinci, Johannes Kepler, Gottfried Leibniz, and Plato. The soap bubbles elegantly establish that there is a concept of natural law.

THE DANISH ASTRONOMER WHO PROVED THAT LIGHT DOES NOT PROPAGATE INSTANTANEOUSLY

Ole Rømer discovered the finite velocity of light and determined its value to a remarkable degree of accuracy in the 1670s, thus overturning the Cartesian view that the transmission of light was instantaneous. Poul Rasmussen tells the fascinating story of Rømer, an astronomer and engineer, and his collaboration with the leading scientists of his day, including Huygens and Leibniz.

Eclipsarion reconstruction by Soren Andersen; photograph by Svend Erik Andersen

This Eclipsarion, another of Rømer's ingenious astronomical devices, was built for Louis XIV of France to teach astronomy to his eldest son. The world's first reliable lunar calculator, it used rotating cams and gears to plot the movement of the Sun and Moon over a 200-year period.



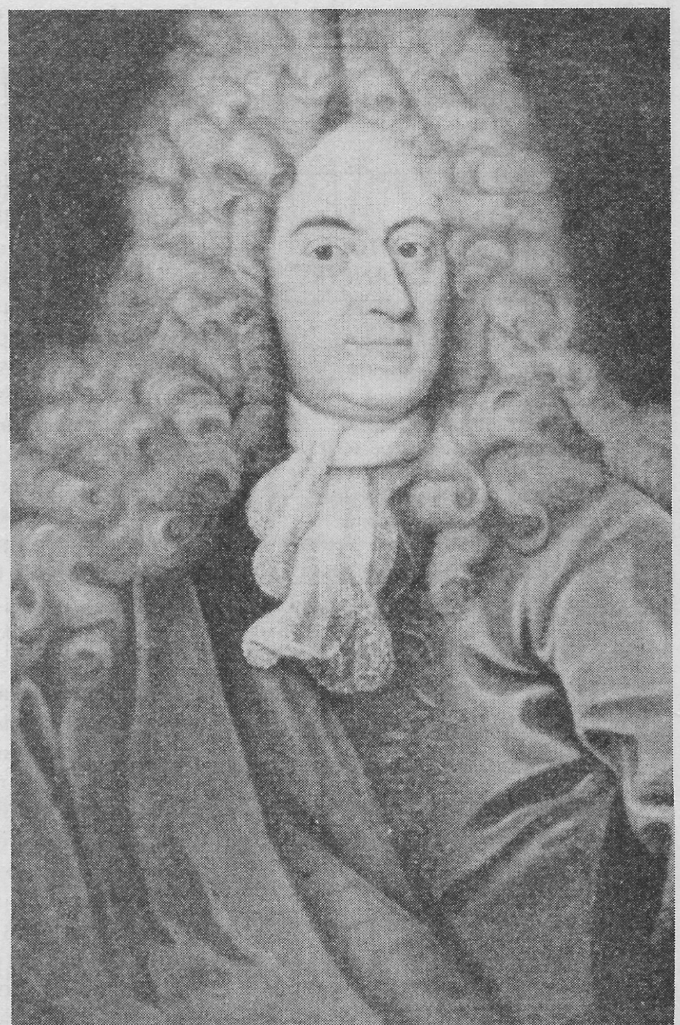
Rømer designed this Jovilabe in order to predict the position of Jupiter's moons in relation to an observer on Earth. By observing when one of the moons entered Jupiter's shadow at different times of year, he was able to calculate the speed of light. Jupiter and its moons are shown as pearls. From a peephole in the cabinet, the moons can be observed as seen from the Earth.

Jovilabe reconstruction by Soren Andersen; photo by Svend Erik Andersen

Ole Rømer and the Discovery of The Speed Of Light

How a Danish scientist predicted and then proved, contrary to the established 17th century view, that the propagation of light was not instantaneous.

by Poul Rasmussen



Courtesy of Søren Andersen

Danish astronomer Ole Rømer (1644-1710) discovered the finite velocity of light, determining its value to a remarkable degree of accuracy between 1671 and 1676.

An ingenious experiment by the Danish astronomer and engineer Ole Rømer finally proved in 1676 his prediction that light propagates at a finite velocity. Until then, it had been the view of the science establishment that the propagation of light was instantaneous, as stated by the French philosopher and mathematician René Descartes (1596-1650). Yet, although Descartes was wrong, his ideas died hard. Rømer's experimental evidence was rejected by most of the leading astronomers at the time, who claimed he had erred in his measurements or failed to take into account certain perturbations.

The young Danish scientist received crucial support, however, from Christiaan Huygens (1629-1695), the chief physicist of the day, who was associated with the leading institution of science, the Royal Academy of Sciences in Paris. Rømer's experimental breakthrough soon led to Huygens's formulation of a revolutionary theory of light. In the preface to his 1678 *Treatise on Light,* Christiaan Huygens pays tribute to three "celebrated" gentlemen, the established astronomers Giovanni Cassini and Philippe de la Hire, and the young Ole Rømer. And in Chapter 1, after criticizing the Cartesian doctrine that the transmission of light is instantaneous, Huygens writes:

> But that which I employed only as a hypothesis, has recently received great seemingness as an established truth by the ingenious proof of Mr. Rømer which I am going to relate here, expecting him himself to give all that is needed for its confirmation. It is founded as is the preceding argument upon celestial observations, and proves not only that Light takes time for its passage, but also demonstrates how much time it takes, and that its velocity is even at least six times greater than that which I have just stated.[1]

Rømer's Apprenticeship in Astronomy

Ole Rømer was born in Aarhus, Denmark, in 1644. He entered the University of Copenhagen in 1662, where he became the student of Erasmus Bartholin. Bartholin was an old friend of Christiaan Huygens, but also a hopeless Cartesian. It was Bartholin who discovered the double refraction of light in the Iceland spar (calcite) crystal, a phenomenon that Huygens selected to explain his wave theory of light. Bartholin also collected Descartes's works and had them published. The Bartholin family was infamous for its unabashed nepotism at Copenhagen University. Through three generations, a web of Bartholin brothers, sons, and nephews sat in all the important chairs of the university. Most of them were utterly incompetent and, unfortunately, they kept a number of bright young men away from the university. One of these was the brilliant anatomist, biologist, and founder of the science of geology, Nicolaus Steno (1638-1686), who never got a chair at the University of Copenhagen.

In 1664, King Frederik III of Denmark gave Erasmus Bartholin the commission of preparing the publication of the complete observations of astronomer Tycho Brahe. This was extremely important work because the Brahe observations were the most exact data on the motions of the stars and planets at that time. After a complicated struggle with the legal heirs of Brahe, Johannes Kepler (1571-1630), the German astronomer and collaborator of Brahe, gained possession of Brahe's voluminous notes and observations and made brilliant use of them.

(Kepler did not have to make even one astronomical observation himself; it was all there in Brahe's data.) After the death of Kepler, the Brahe notebooks came to the hands of Kepler's son, Ludwig Kepler, who later sold them to the Danish king.

It was Ole Rømer, who, as a student of Erasmus Bartholin, did most of the compilation and editing of the Tycho Brahe observations. Many years later, in a letter to the philosopher, scientist, and statesman Gottfried Wilhelm Leibniz (1646-1716), Rømer said that it was this work on the observations of Brahe that got him totally fascinated in astronomy.

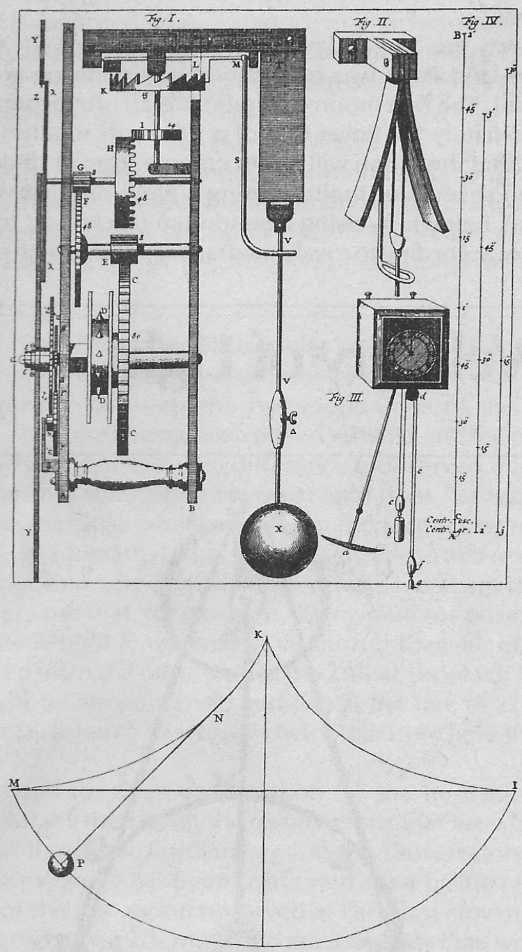
A Cold Winter in Hven

In 1666, the French Academy of Sciences was established in Paris. Construction of the Academy's observatory began the next year and was completed in 1672. Copies of the Tycho Brahe observations and of Kepler's Rudolphine Tables derived from them came into the possession of the Academy. In order to make full use of them, it was necessary to establish the exact longitudinal difference between the new Academy observatory in Paris and Tycho Brahe's observatory, Uraniborg, on the island of Hven, near Copenhagen.

The problem of accurate determination of longitude was also directly linked to the military and economic problem of navigation and creation of correct nautical maps. Until that time, the longitudinal values could be established only by the number of days of travel. Rømer was convinced that the Dutch and Portuguese had deliberately created incorrect maps by noting false information about travel time.

Christiaan Huygens's invention of the pendulum clock in 1656, employing the isochronic property of the cycloid curve, made it possible to have time measurements precise enough for making comparable astronomical observations from different locations on the planet (Figure 1).

In 1671, the Parisian Academy of Sciences sent astronomer Jean Picard (1620-1672) to Copenhagen in order to determine the exact longitudinal position of Brahe's observatory, Uraniborg. King Christian V asked Erasmus Bartholin to help Picard with the practical arrangements, but Bartholin had no intention of making astronomical observations on cold windy nights on the island of Hven. He therefore ordered his young assistant, Ole Rømer, to help Picard. The sensitive Frenchman was not accustomed to the icy winds of Scandinavia, and after a few months had to leave the



(a)

(b)

Figure 1
THE HUYGENS PENDULUM CLOCK AND THE CYCLOID

The accuracy of the pendulum clock, invented by Christiaan Huygens of Holland in 1657, was a crucial piece of instrumentation in Rømer's determination of the velocity of light. The Huygens clock is more mathematically elegant than the later "grandfather clock," which uses a regulator to control the amplitude of the pendulum's swing.

In Huygens's device (a), the supporting rope of the pendulum wound against a cycloid curve (upper right detail), causing the suspended bob to trace out the curve's involute. Since the cycloid curve is self-similar under involution, the bob traces another cycloid (b). The cycloid curve, as Huygens had earlier discovered, is isochronic—that is, the period of the swing is the same regardless of its amplitude.

Source: *Christiaan Huygens' The Pendulum Clock or Geometrical Demonstrations Concerning the Motion of Pendula as Applied to Clocks*, translated with notes by Richard J. Blackwell (Ames, Iowa: The Iowa State University Press, 1986) island, sick with scurvy and pneumonia. But Picard stayed on in Copenhagen, and from there instructed Rømer on how to conduct the observations.

To the Academy in Paris

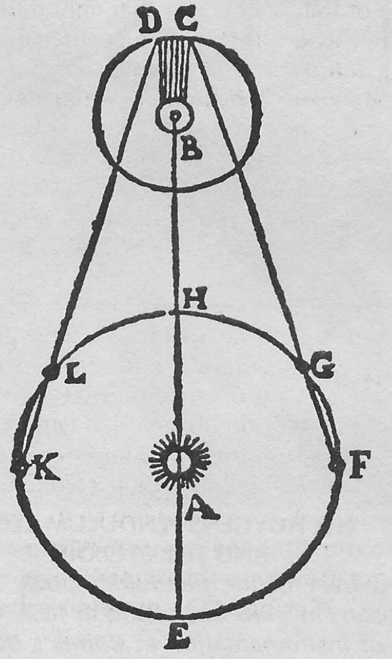
The collaboration between Picard and Rømer was very fruitful and in 1672 Picard returned to Paris with the observations needed to establish the correct longitudinal position of the old Tycho Brahe observatory on Hven. Ole Rømer followed Picard to Paris and during the summer of 1672 Rømer was admitted to the Academy of Sciences. Christiaan Huygens, the most noted physicist in Europe at the time, was already there, and in his first letter home, Rømer speaks with great admiration of him. Another young scientist also arrived in Paris that summer. His name was Gottfried Wilhelm Leibniz. He became a close friend of Rømer and of other members of the Academy, but he never became a member himself. The reason for this was, as one Danish source put it, that Leibniz really was there as a political agent.[2]

The way the longitudinal difference between the island of Hven and Paris was established was quite simple and beautiful. The first moon of Jupiter has an orbital period of approximately 1.7 times that of a full Earth rotation. That means that the moon will either emerge from or disappear into the shadow of Jupiter during a night of observations (see box below). By using a pendulum clock fixed to local time (set according to a wall quadrant calibrated to the Sun),

Rømer's Proof of the Finite Velocity of Light

This report to France's Royal Academy of Sciences describes Ole Rømer's proof that light travels at a finite velocity. Written by an unknown author, the report was published in the Journal des Sçavans, *Vol. XX, December 1676. The English translation is by Laurence Hecht, who has added the footnotes.*

The illustration is from the 1676 report. The Sun is at A *and Jupiter at* B. C *and* D *are the positions of the first moon of Jupiter as it enters and exits from the planet's shadow.* FGHK *and* L *are the Earth at various positions of its orbit.* F *is known as* first quadrature; K *as* second *or* last quadrature.



Monday, December 7, 1676
PROOF CONCERNING THE MOTION
of light discovered by M. Romer
of the Royal Academy of Sciences

For a long time Philosophers have been at pains to determine by some experiment if the action of light is conveyed in an instant to any distance whatsoever, or if it requires some time. Mr. Romer of the Royal Academy of Sciences came upon a method based on observations of the first moon of Jupiter, by which he demonstrates that over a distance of about 3,000 leagues[1], such as is quite close to the size of the Earth's diameter, light does not need even 1 second of time.

Let *A* be the Sun, *B* Jupiter, *C* the position of the first moon as it enters the shadow of Jupiter, and *D* where it comes out, and let *EFGHKL* be the Earth at various distances from Jupiter.

Now suppose that the Earth, being at *L* approaching the second quadrature[2] of Jupiter, had seen the first moon at the time of its emergence or exit from the shadow at *D;* and that after about 42½ hours, that is after one revolution of this moon, the Earth, being found at *K,* sees the moon return to *D:* It is clear that if the light needs time to traverse the interval *LK,* the moon will be seen to return to *D* later than it would have if the Earth had remained at *L,* such that the revolution of this moon, as observed by its exits from the shadow, will be retarded by just so much time as the light will have needed to pass from *L* to *K,* and contrariwise, at the other quadrature *FG,* where the Earth in approaching it heads into the light, the revolution, as observed by its entrances into the shadow, would appear to be just so much sped up as those of the exits from the shadow had appeared prolonged. And because in the approximately 42½ hours that the moon needs to make each revolution, the distance between the Earth and Jupiter, at either quadrature, changes by more or less 210 Earth diameters, it follows that if for the length of each Earth diameter, 1 second of time is needed, the light the observer notes the time that the moon either disappears or reemerges from the shadow of Jupiter. One then has an hour/minute/second for the event at the island of Hven. On the same night, the observations are conducted in Paris with a similar clock and the hour/minute/second of the event is recorded. The difference in time between the two observations will give the longitudinal difference between Hven and Paris, according to the equation: 24 hours of time equals 360 degrees of longitude.

The Light 'Hesitates'

In Paris, Rømer continued to work on observing the first moon of Jupiter under the leadership of the Franco-Italian astronomer Giovanni Cassini (1625-1712). Rømer also used the observations of the first moon of Jupiter in 1676 to determine the actual speed of light.

Unfortunately, Cassini remained faithful to Descartes, and for the rest of his life fought tooth and nail against Rømer's discovery. During a discussion at the Academy about the Jupiter system in August-September 1676, Cassini admitted that there were irregularities in the apparent orbital periods of the first two moons, but he insisted that this was caused by physical irregularities in the orbits of the moons, and nothing else. Curiously enough, he was partly right, because the interaction of all four moons actually does make all the orbits irregular, a phenomenon known today as the Wargentin Perturbations. However, Cassini was saying this to counter Rømer's argument that the reason for the irregularities in the observations came from the *time* it took the light to traverse the different distances between the Earth and Jupiter at different times of the year.

In September 1676, after a series of observations during the month of August, Rømer announced to the Academy that on the basis of almost eight years of observations conducted by Jean Picard and later by him, he could now predict, that when Jupiter would again be observable in the night sky in November, the first moon of Jupiter would appear almost 10 minutes *later* than calculated from the set of observations in August. The reason for this, Rømer said, was that the Earth had moved farther away from Jupiter, and therefore the distance from the Sun to this moon of Jupiter and back to the Earth had increased. "The light hesitates," Rømer said.

On November 9, 1676, at 5:35:45 in the afternoon, Ole Rømer observed the first moon emerge from behind the shadow of Jupiter 10 minutes later than calculated in August. Interpolating the distance that the Earth had moved in its orbit away from Jupiter during that time interval gives almost the correct 300,000 kilometers per second for the speed of light. In his original presentation, as reported to the *Journal des Sçavans* (see box), Rømer actually gave two different values for the speed of light. When referring to the observation of November 9, Rømer said that the light was delayed by 10 minutes. But he also referred to his observations in general, and here he said that light travels the full diameter of the Earth's orbit (twice the distance from the Sun to the Earth) in 22 minutes. This yields a considerably different value for the speed of light. Ole Rømer was fully aware of the discrepancy and attributed it to the irregularities of the moon's orbit around Jupiter (the aforementioned Wargentin Perturbations). Nonetheless, Rømer said, this does not change the fact that the light "hesitates."

Rømer presented his work at a meeting of the Academy on Saturday, November 21, 1676. A report of this meeting was published in the *Journal des Sçavans* on December 7, 1676. These one and one-half pages were all that was ever published on Rømer's discovery. Further elaborations by him exist only in his private letters to Huygens.

The reaction to Ole Rømer's discovery of the speed of light was no less of an uproar than that concerning cold fusion today. The European scientific community was immediately polarized. The vast majority of scientists simply closed their minds and refused to accept the possibility of a finite velocity of propagation for light. It was very difficult for the fine professors in all the universities to accept a

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would need 3½ m. for each of the intervals, *GF* and *KL*, the which would cause a difference of about half of a quarter-hour between the two revolutions of the first moon—the one having been observed at *FG* and the other at *KL*, whereas no sensible difference is observed.

It does not follow however that light does not require any time; because, after having examined the matter more closely, he found that what was not sensible in two revolutions, became very considerable when several are taken together, and that, for example, 40. revolutions observed from the side of *F*, were sensibly shorter than 40. others observed from the other side of the Zodiac on which Jupiter might be encountered; and this at the rate of 22. for the whole distance *HE* which is twice that from here to the Sun.[3]

The need for this new equation for the hesitation of light is established by all the observations that have been made at the Royal Academy and at the Observatory for eight years, and it has been confirmed anew by the emergence of the first moon observed at Paris last November 9 at 5:35:45 in the afternoon, 10 minutes later than would have been expected by calculating it from those observed in the month of August when the Earth was much closer to Jupiter; as Mr. Romer had predicted to the Academy since the beginning of September.

But to remove all room for doubt that this inequality is caused by the hesitation of light, he demonstrates that it cannot come from any eccentricity, or other cause such as is ordinarily brought forth to explain the irregularities of the Moon and other planets; although he has nonetheless perceived that the first moon of Jupiter is eccentric and that therefore its revolutions are advanced or retarded to the degree that Jupiter comes closer to or moves farther from the Sun, and even that the revolutions of the primary moving body are unequal; without these three last causes of inequality, however, preventing the first from being manifested.

Notes

1. "Lieues," 1 lieue = 4 kilometers.
2. When the Earth is 90 degrees before the position of maximum elongation, or *E*. The planet moves counterclockwise around the Sun.
3. ". . . & ce à raison de 22. pour tout l'intervalle *HE*. . ." The number "22." appears to refer to minutes.

French astronomer Jean Picard (1620-1682) was dispatched to Copenhagen in 1671 on a mission to determine the longitude of the island of Hven, where Tycho Brahe's painstaking astronomical observations had been made.

world in which light transmission was not instantaneous—and in which Descartes was utterly wrong. Cassini, De la Hire, and Bartholin all died as unreformed Cartesians.

Huygens's Response

Christiaan Huygens was in Holland at the time and did not hear about Rømer's discovery until the summer of 1677, when he saw it published in the British magazine *Philosophical Transactions*. He immediately wrote Rømer for more information. Unfortunately, the letters between the two have never been published in full, but from the fragments that have been translated from Latin, it is clear that Rømer and Huygens were on exactly the same wavelength, so to speak. Rømer gave all the information that Huygens asked for, but he also wrote that there were many things that should be discussed in person. In December 1677, Rømer writes to Huygens:

> First of all, I am expecting something from you on the explanation of refraction. I hope that the entire secret of the propagation [of light] can now be disclosed. How great it would be, if this Miracle of Nature could be explained in a simple mechanical way! Afterwards, upon a secure foundation, we would be able to investigate the entire organization of the world edifice, which I believe can be completely understood (as much as the human mind can penetrate), when we have gotten an insight into the essence of light and the nature of weight. I wish no more than to be with you, and personally, which is much easier than through letters, get to know your thoughts in such a way that I can use them as the parameter when I put my own observations and thoughts into order and also when I plan out new experiments that can perfect Philosophy.[3]

Unfortunately Rømer and Huygens never met again, although Huygens later intervened a couple of times on his behalf. Huygens must have known about the severe attacks on Rømer from prominent personages, including Cassini and De la Hire in Paris. In the fall of 1677, Huygens wrote to Jean Baptiste Colbert, famed minister of finance of the French king Louis XIV, praising Rømer's work to the heavens. Finally in 1678, very much thanks to written depositions from Huygens, an official report from the Academy to Jean Baptiste Colbert on the continued debate between Rømer and Cassini praised Rømer's "beautiful discovery." Thus the official attitude of the Academy was settled in favor of Rømer.

Huygens's epoch-making *Treatise on Light*, the first complete exposition of the wave theory of light that had originated with Leonardo da Vinci, was communicated to the French Academy in 1678 and published in French in 1690. It owed its origin to Rømer's crucial discovery.

In Britain, the founder of the Greenwich Observatory, John Flamsteed, immediately supported Rømer. So did Edmund Halley, and also Isaac Newton, though Newton later opposed Huygens's wave theory, failing to see that Huygens's light waves were transverse and thus not the same as the longitudinal waves by which sound is propagated.

Thanks to the interventions of Huygens and Colbert, Rømer received support from the court of Louis XIV. Rømer became a teacher of the Dauphin (the king's eldest son), and also worked on some of the engineering projects at Versailles, serving as one of the key engineers in the design of the huge water and fountain works.

The Planetary and Eclipse Machines

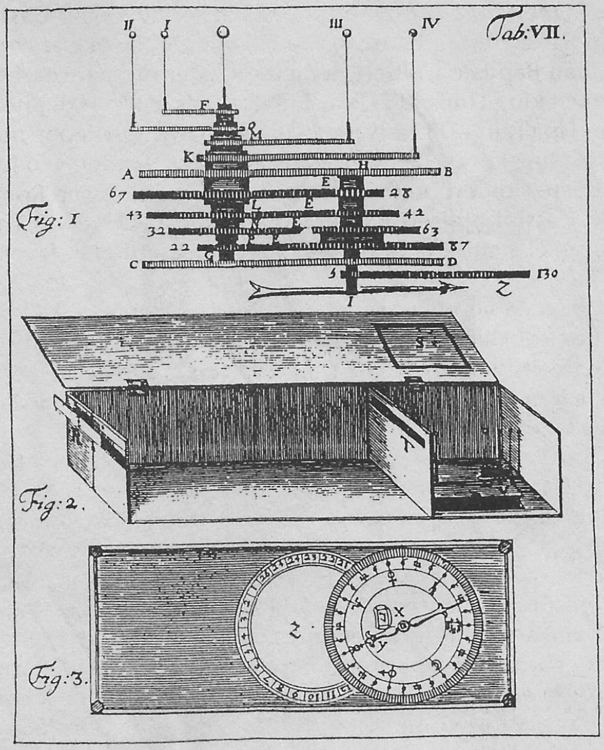
On a special commission from Louis XIV, Rømer constructed two very elaborate mechanical models of the solar system. One was a so-called Planetary Machine, showing all six of the then-known planetary orbits around the Sun. The other, the Eclipse Machine or Lunarium, described the orbit of the Moon in relation to the Earth and Sun. This machine was so precise that it could be used to predict solar and lunar eclipses. (A photo of the Lunarium appears on the back cover of this issue.)

For mechanical reasons, Rømer could not make the orbits in the Planetary Machine elliptical, but he tried to imitate this by not placing the Sun directly in the center of the circles. In addition, the planetary orbits were not simple concentric circles with a common center but each had its own center and its own relationship to the Sun.

Only five copies of these two machines were made. One set each was made for Louis XIV of France, the King of Denmark, the Emperor of China, the Emperor of Siam (Thailand), and the Shah of Persia. In China, Rømer's machines came as if they were gifts from heaven. The Chinese, with their lunar calendar, celebrate important religious ceremonies at lunar eclipses. Therefore, the primary job of the imperial scientists was to predict these eclipses. Many a poor scientist had lost his head because of his failure to predict accurately. With Rømer's Lunarium, a few turns of the handle could predict the day of the next eclipse.

Rømer's Planetary Machine had a very complex gear system, and in order to make it work with a minimum amount of friction, Rømer made the teeth of the gears in the shape of epicycloids. He was the first ever to do so.

In 1681, Rømer was called back to Copenhagen by King



Rømer's copperplate print of his design for the Jovilabe, a device that allowed him to measure the movement of Jupiter's moons and thus calculate the speed of light. The instrument, which shows Jupiter and its four moons as pearls, was used to predict when a moon enters Jupiter's shadow. From a peephole in the cabinet, the moons can be observed as seen from the revolving Earth. The angle between Jupiter and the Earth is adjustable, as are the calendar dials (on the underside of the cabinet).

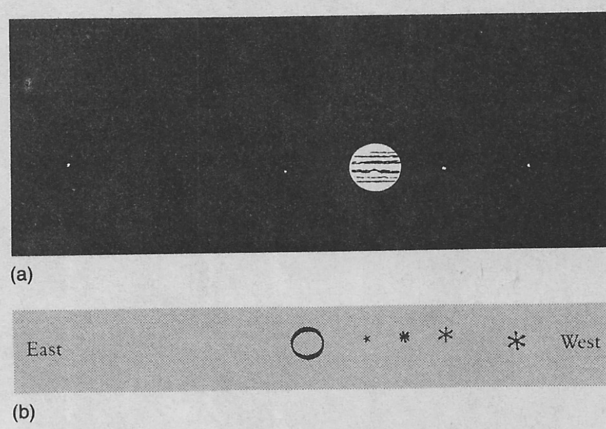


Figure 2
THE GALILEAN MOONS OF JUPITER

Jupiter and its four largest moons as they appear through a small telescope (a). Galileo first saw the moons on January 7, 1610, and by noting their changing position on several succeeding nights, he concluded (to his astonishment) that there were four stars "wandering around Jupiter like Venus and Mercury around the Sun." He published a series of his drawings of the moons that same year in The Sidereal Messenger *with a call to other astronomers to determine the periods of these satellites. One of these drawings is shown in (b).*

The four moons, known as the Galileans, are one of the greatest delights for the beginning astronomer. On different nights, one may see all four lined up on one side of the planet, three on one side and one on the other, or two and two. The inner moon, Io, with a period of about 42½ hours, was the subject of Rømer's careful observations. He developed his discovery of light's "hesitation" as an explanation for why the revolution of Jupiter's moons appeared to be irregular.

Sources: Margaret K. Wetterer, *The Moons of Jupiter* (New York: Simon and Schuster, 1971), p. 77; Galileo Galilei, *The Sidereal Messenger*, translated by Albert Van Helden (Chicago: University of Chicago Press, 1989), p. 68.

Christian V. Unfortunately, this meant an almost total halt to Rømer's astronomical research. He simply did not have the time (although in 1685 he was appointed head of the Royal Observatory in the Round Tower). He became the city engineer of Copenhagen and later also police chief and mayor. He was on almost every commission set up by the King to build up Copenhagen. Thanks to Rømer, Copenhagen became the second city in the world after Paris to have street lighting. He modernized the sewer system, the water system, the streets, the fire department, and the police department among other things.

Only during a brief period, 1689-1690, did Rømer have a chance to continue his work on astronomy. Much of his time was spent on improving the various astronomical instruments. In his apartment in the center of Copenhagen, Rømer set up a small observatory, where his new instrument, the *Machina Domestica* (House Instrument), protruded through the window (Figure 3). It was in working with this telescope that Rømer gradually developed the idea of his last important invention, the transit instrument.

Leibniz stayed in close contact with Rømer during this period. There are reasons to believe, according to Axel V. Nielsen, that Leibniz came to Copenhagen in 1682 to meet with Rømer.[4] When Leibniz became involved in setting up the Berlin Observatory, he asked Rømer for advice. In a letter dated December 15, 1700, Rømer described for Leibniz his own plans to build a new observatory, this time outside of Copenhagen. He also described a new instrument that he was planning to build. Four years later, on December 9, 1704, Rømer wrote Leibniz again, this time giving the details of his new instrument, which had finally been built. He called it *Rota Meridiana,* the meridian circle (Figure 4). His was the first such device in which the vertical measuring scale of the instrument was in the form of a full circle instead of the usual partial arc. In this way the instrument was no longer sensitive to changes in temperature. *Rota Meridiana* is the model for all modern transit instruments.

Unfortunately, Rømer did not get much time for using his new instrument, although his students did. However, during the month of October 1706, he did perform a series of detailed observations. The records of three of these ob-

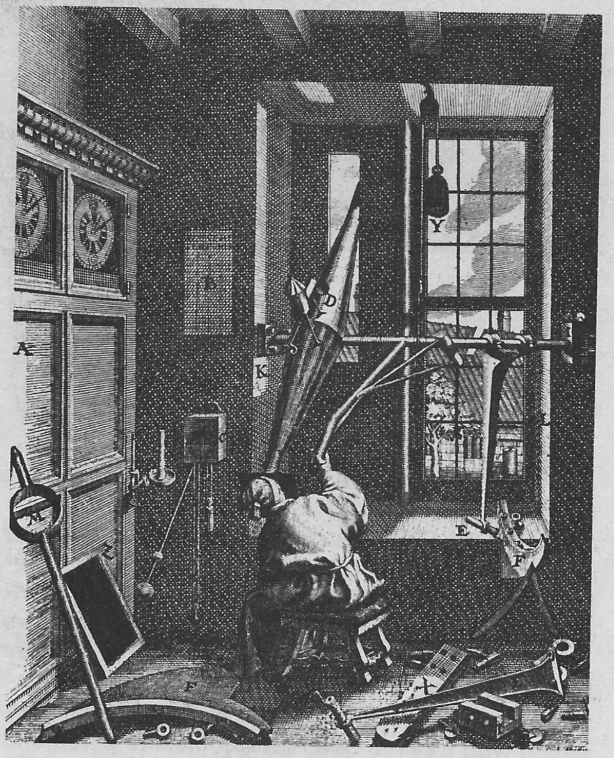


Figure 3
RØMER'S HOUSE INSTRUMENT
During a brief period from 1689-1690, Rømer was able to take time from his administrative activities in the city of Copenhagen to return to astronomy. His instrument, the Machina Domestica, *which he set up in his house in the city, is portrayed here, with various appurtenances; C is a Huygens pendulum clock.*

servations are known as the *Triduum,* and together with another set of Rømer's notes known as the *Adversaria,* they are the only writings of Rømer that survived the great Copenhagen fire of 1728.

The *Triduum* is a set of raw, undigested data, which Rømer never got a chance to work through. However, from the letters to Leibniz and from some comments in the *Adversaria,* it is known that Rømer was looking for the parallactic motion of the fixed stars. Almost 50 years after the death of Rømer, the observations in the *Triduum* became the basis of another important discovery. In 1756, the German astronomer and mathematician Tobias Mayer compared Rømer's detailed observations from 1706 with a set of new observations by the French astronomer Nicolas Lacaille. In this way, Mayer was able to show that some of the stars were no longer in the same position as they had been in 1706. The proper motion of the "fixed" stars had been discovered.

Only a few scattered portions of Ole Rømer's letters to Huygens and Leibniz have been translated from Latin. A translation from Latin into Danish of most of the correspondence of Ole Rømer, including correspondence with Huygens and Leibniz, is now in progress.

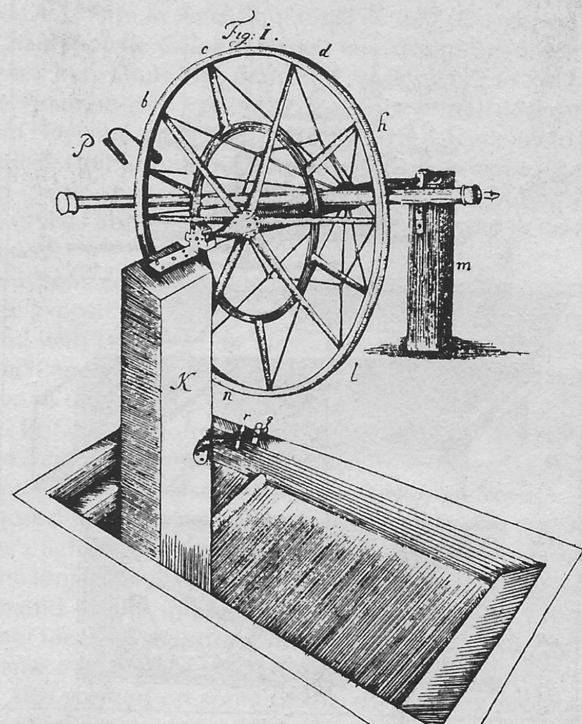


Figure 4
RØMER'S TRANSIT
In 1700, Rømer conceived the idea of a new instrument he called Rota Meridiana *(meridian circle), which became the model for all modern transit instruments. By making the vertical measuring scale in the form of a full circle, instead of the usual partial arc, the instrument was no longer sensitive to changes in temperature. The first* Rota Meridiana, *completed in 1704, is shown here.*

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Notes

1. Christiaan Huygens, *Treatise on Light* (New York: Dover Publications, 1962).
2. Axel V. Nielsen, *Ole Rømer, En skildring af Hans Liv og Gerning* (Aarhus: Glydendal, 1944), p. 45.
3. Andreas Nissen, *Ole Rømer, Et Mindeskrift* (København: Fr. Bagges Kgl. Hofbogtrykkeri, 1944), p. 27.
4. Nielsen, p. 65.