Comets

A Chronological History of Observation, Science, Myth, and Folklore

Donald K. Yeomans

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Contents

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Preface

For millennia, observers have pondered the appearances of comets in the night sky. The concepts developed to explain these mysterious apparitions have a long and intriguing history. For years, the two-volume work by Alexandre Pingré remained the only general history of comets. While still an excellent reference, Pingré's history is now more than two centuries old. In this book, the development of cometary ideas is traced from antiquity until after a fleet of international spacecraft flew past comet Halley in 1986. Because the book's focus is on the cometary theories that were evident in each era, specific observations and individual observers do not receive detailed coverage.

Like the scientists they are concerned with, science historians are influenced by the data to which they have access. To some extent, this book reflects my personal view toward the development of cometary ideas. Because of a vast number of cometary treatises and cometary observations, I had to make decisions as to what ideas and observations were influential to the field. Although current knowledge of cometary phenomena was sometimes used to guide my historical studies, I have not ignored ideas from the past simply because they contributed nothing to the present. My overriding criterion for selecting topics was whether or not they were influential to subsequent inquiries.

The study of comets—tiny remnants from the solar system formation process—allows an examination of the conditions and mixtures from which the major planets formed four and one half billion years ago. Comets probably played a major role in delivering to the early Earth the veneer of carbon-based molecules and volatile gases that allowed life to form. Subsequent collisions of comets with Earth may have wiped out significant numbers of these early lifeforms, allowing only the most adaptable to develop further. The diminutive size of cometary bodies is in no way proportional to their scientific importance.

While researching the history of cometary ideas, I found that the wide diversity of views and the perception of comets as malefic signs or agents of destruction often made for interesting reading. I have included several vignettes that delve into colorful anecdotes and personalities.

The study of comets is historically important, scientifically compelling, and at the same time entertaining; I've tried to convey some of each in the following pages.

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1
The Origin of Cometary Thought

Aristotle presents cometary ideas of ancient Greeks and his own view of comets as terrestrial emanations. The comet and meteorite of 467 B.C. and Caesar's comet of 44 B.C. appear. Seneca outlines cometary ideas of ancient Greeks and Babylonians before expressing his opinion that comets are celestial phenomena like the planets. Pliny the Elder presents a scheme for classifying comets, and Ptolemy's work gives rise to the enduring notion of comets having astrological significance.

ONE TRUISM STANDS OUT in the history of comets—mankind has always been transfixed by their appearances. The Sun and Moon are far brighter, aurorae more impressive, and eclipses more startling. Yet it is comets, with their modest radiance and infrequent visits, that have commanded more concern. In the first century, the Roman sage Lucius Annaeus Seneca (4 B.C.–A.D. 65) explained this phenomenon in his *Natural Questions:*

> No man is so utterly dull and obtuse, with head so bent on Earth, as never to lift himself up and rise with all his soul to the contemplation of the starry heavens, especially when some fresh wonder shows a beacon-light in the sky. As long as the ordinary course of heaven runs on, custom robs it of its real size. Such is our constitution that objects of daily occurrence pass us unnoticed even when most worthy of our admiration. On the other hand, the sight even of trifling things is attractive if their appearance is unusual. So this concourse of stars, which paints with beauty the spacious firmament on high, gathers no concourse of the nation. But when there is any change in the wonted order, then all eyes are turned to the sky. . . . So natural is it to admire what is strange rather than what is great.

> The same thing holds in regard to comets. If one of these infrequent fires of unusual shape have made its appearance, everybody is eager to know what it is. Blind to all the other celestial bodies, each asks about the newcomer; one is not quite sure whether to admire or to fear it. Persons there are who seek to inspire terror by forecasting its grave import. And so people keep asking and wishing to know whether it is a portent or a star.

Right up to the seventeenth century comets were considered to be omens. We still refer to the appearance of a comet as an apparition—a ghost or phantom. The scientific study of comets got off to a late start because the ancients believed them to be divine warnings, usually malefic, of things to come. Scholarly inquiry was limited to such topics as whether comets actually caused the events that followed or served merely as precursors. One did not study ghosts in a scientific fashion.

Aristotle's Meteorologica

Aristotle (384–322 B.C.) was born in Thrace and grew up at the Macedonian court, where his father was the king's physician. In 367 B.C., at the age of 18, he went to the Academy at Athens to study with Plato and remained there until the latter's death 20 years later. Plato referred to him as the intellect of the school. In 343 B.C. Aristotle returned to Macedonia as tutor of Alexander the Great, then a lad of 13. When Alexander died at the age of 33, his conquests had spread Greek culture and learning throughout most of the known world. Thus Aristotle's association with the young prince, which lasted four years, was to have far-reaching effects on history in general and his own life in particular.

Aristotle returned to Athens in 335 B.C. and founded a school of philosophy and rhetoric near the temple dedicated to the god of shepherds, Apollo Lyceus. Hence his school was called the *Lyceum*, and his thought became known as the peripatetic philosophy because of the covered walk, *peripatos*, through which he liked to stroll with his students. He was identified with the Macedonian rulers of Athens and their supporters, and upon Alexander's death in 323 B.C. he fled the city to escape the outbreak of anti-Macedonian sentiment. He died a few months later, in 322 B.C., leaving a body of writings whose importance in the history of Western thought cannot be overestimated. However, he would have been the first to deplore the stagnation of the physical and natural sciences resulting in part from the veneration in which his views were held for centuries.

The compilation of Aristotle's *Meteorologica*, in which his cometary ideas were expressed, was probably completed during his years at the Lyceum. As well as outlining his own views, Aristotle presented and dismissed those of Pythagoras (ca. 560–480 B.C.), Hippocrates of Chios (fl. 440 B.C.), Anaxagoras of Clazomenae (ca. 500–428 B.C.), and Democritus of Abdera (fl. 420 B.C.).

Although Pythagoras was born in Greek Samos and spent 30 years studying with priests and sages in Asia Minor, he established a school in southern Italy when he was about 50 years old. The Pythagorean ideas of beauty required that the heavenly bodies move along simple curves, and they were responsible for establishing the notion that all celestial bodies move in circles, the circle being the perfect curve. Until the work of Johannes Kepler (1571–1630) in the early seventeenth century, belief in the circular motion of heavenly bodies remained largely unquestioned. According to Aristotle, the Pythagoreans believed there was only one comet and that it was a planet. It appeared infrequently and, like Mercury, it rose only a little above the horizon.

As related by Aristotle, Hippocrates of Chios and his pupil Aeschylus believed that a comet's tail was formed when the comet drew up moisture from the Earth below. According to the peculiar optical theories then current, the tail was seen not when sunlight was reflected from the moisture to the eye, but rather when one's sight was reflected to the Sun from the moisture. In the north the comet would assume a visible tail, but in the tropics, where the Sun dries most available moisture, tails could not form. Although the comet had the necessary moisture south of the tropics, it was generally below the horizon and hence invisible. Hippocrates stated that the comet appeared at greater intervals than other stars (planets) because it was slowest to move clear of the Sun. It seems evident from Aristotle's writing that Hippocrates shared the Pythagorean belief in a single comet.

According to Aristotle, Democritus and Anaxagoras declared that each comet was a conjunction of planets approaching one another and so appeared to touch. Although Aristotle easily dismissed this idea, noting that comets were observed in regions of the sky where planets do not travel, he did not subdue it altogether. The notion that comets are caused by planetary conjunctions was popular well into the seventeenth century. Democritus wrote several books on geometry and derived formulae for the areas of cones and pyramids. He is best remembered for his atomist philosophy that all matter is composed of atoms differing in size and weight, with like atoms combining to produce the planets and stars. Anaxagoras, a friend and teacher of Pericles, is chiefly remembered in astronomical history for correctly explaining eclipses and for his cosmology, which posits that the universe was formed from chaotic, diverse seeds pervaded by a world mind that gave them order and set them spinning into a vortex-like motion. This rotary motion of the ether tore away stones from the Earth and kindled them into stars.[1] Charges

The Comet and Meteorite of 467 B.C.

Both Aristotle and Pliny the Elder (A.D. 23–79) mentioned that in a year corresponding to 467 B.C., a meteorite fell at Aegospotami, in Thrace, on the European side of the Dardanelles, and that a comet was seen the same year. In his *Natural History* (Book II, Chapter 59), Pliny noted that the meteorite fell during the daytime: it was brown in color and the size of a wagon load. Pliny also mentioned that Anaxagoras prophesied the event by predicting that, in a certain number of days, a rock would fall from the Sun. In his life of the Spartan general Lysander, the Greek biographer Plutarch wrote of the same prediction and added that before the stone fell, a vast fiery body was seen in the heavens for 75 days continually "but when it afterwards came down to the ground . . . there was no fire to be seen . . . only a stone lying big indeed. . . ."

Anaxagoras considered the sky to be made up of whirling stones. Since Anaxagoras believed that both the Sun and comets were made up of burning stones, the cometary apparition of 467 B.C. may have indicated to him that the furniture of the heavens was slipping and that a large stone could arrive on Earth several days after the comet appeared. It is equally likely that the account of the prophecy is apocryphal.

The early Greeks and Romans had no trouble believing that stones fell from the sky, but Aristotle's cosmology demanded they be first

of impiety were brought against Anaxagoras in Athens for his refusal to admit that the Sun was anything but a mass of stone on fire—not a god.

Aristotle's own views are of the utmost importance in the history of comets. For nearly two millennia his teachings dominated almost every aspect of Western thought. As Galileo witnessed in the early seventeenth century, to doubt the Church-endorsed Aristotelian ideas was heresy. Aristotle's universe was finite, spherical, and geocentric. The first four elements (earth, water, air, and fire) moved naturally along straight, finite—rectilinear—lines confined to the imperfect sublunar world. Later, a fifth element or essence, *quintessence*, became associated with Aristotle's cosmology; it permeated supralunar space where the planets, stars, and Moon moved timelessly in perfect circles. The four concentric spheres were ordered by their nature and density. The first sphere, earth, was the most dense, and the watery sphere lay just above it. These two regions contained the heaviest and coldest elements. Above the watery sphere were located first the airy, then the fiery spheres.

lifted off the Earth's surface by strong winds and then thrown back to the ground. Nevertheless, these thunderstones from the sky were held in awe and in some cases were venerated as thunderbolts or weapons hurled by angry gods. The Roman emperor Elagabalus, when he began his four-year reign in A.D. 218, entered Rome in triumph and brought with him a black stone, probably a meteorite, from Emesa, Syria. It was thought to represent the Sun god, and Elagabalus insisted that it be worshiped publicly.

Silver coin, denarius, struck during the reign of the Roman emperor Elagabalus (A.D. 218–222). The obverse shows the emperor's portrait and the reverse, a four-horse triumphal carriage carrying the stone of Emesa. *(Courtesy of the Natural History Museum, Vienna, Austria.)*

Aristotle made it clear that the fiery sphere was not a region of actual fire, but rather of potential fire. It was a warm, inflammable region, containing fuel-like material so that the slightest agitation, or friction, would set it blazing at its most inflammable point. This combustible material was the fuel of cometlike phenomena. Aristotle described the heavenly bodies and supralunar space in his *De Caelo* (On the Heavens). Comets, however, were treated in his *Meteorologica*, which dealt with the sublunar, or terrestrial world.

Aristotle believed comets would form when the Sun, or planets, warmed the Earth causing the evaporation of dry, warm exhalations (like those in the fiery sphere) from the earth itself. At the same time, the cooler moisture contained in and on the Earth was also evaporated. This cool, moist vapor remained in the lower region of the airy sphere while the warm, windy exhalations rose up through it. At the border of the fourth or fiery sphere, the friction of their motion ignited them and the resultant comet, along with neighboring dry exhalations, was carried about the Earth by the circular motion of the heavens in the fifth sphere. The comet's form and duration depended on the amount and form of the exhalation. If the exhalation, or fuel, happened to take on a diffuse appearance, the resulting comet would be a *fringed star.* Similarly, a *bearded star* resulted from an exhalation stretched in one direction. A comet with little fuel was soon extinguished and if the exhalation was excessively inflammable, it would burn quickly and form a meteor. Meteors, or shooting stars, also formed when the air was condensed by cold, squeezing out the hot, combustible exhalations; in this case, the meteor's motion was rapid, like a slippery fruit stone squeezed between the fingers. A comet most often formed independently, but if the exhalation was ignited by the motion of a fixed star, it could form as a halo. In this case, the halo or fringe only appeared to accompany the star, much as a lunar halo appears to follow the Moon in its motion.

Comets, when frequent, foreshadowed winds and drought because they formed under these conditions. Aristotle considered this to be an observed fact and that supported the fiery nature of a comet's constitution. For an example, he noted in his *Meteorologica* that the meteorite of Aegospotami had to be carried aloft by a wind before it fell back to Earth and "then too a comet happened to have appeared in the west." Like Hippocrates, Aristotle believed that comets are seen more often outside the tropic circles than within, because the Sun and stars moving within the tropic zone not only caused the warm exhalations to be secreted from the earth, but also dissolved them when they were gathering. Since the Milky Way extended far outside the tropic zone, the exhalations tended to gather there undissipated by the motion of the Sun, Moon, and planets. In order to consider the Milky Way as a collecting area for exhalations, Aristotle had to reject the ideas of Anaxagoras and Democritus that the Milky Way was made up of the light from certain stars, visible only in the Earth's shadow.

Aristotle's theories were physical, not metaphysical, in nature. Superstition and astrological predictions were noticeably absent. Although his cosmology of concentric spheres and circular, geocentric, heavenly motions was quickly superseded by Ptolemy's epicyclic motions, Aristotle's views on the nature of comets went mostly unchallenged for the next two thousand years.

Seneca's Natural Questions

Like Aristotle, Lucius Annaeus Seneca was deeply affected by the rulers he served. While Aristotle had the good fortune to serve as tutor to Alexander the Great, Seneca was sentenced to death by two Roman emperors and exiled by another. Born in Cordoba, Spain, about 4 B.C., he was educated in Rome and became one of its leading orators, writers, and teachers. Although a millionaire by today's standards, Seneca's writings and personal habits reflected the *Stoic* philosophy. He was abstemious in food and drink and kept a stoic calm even though his life seemed constantly threatened. Perhaps jealous of Seneca's influence in the Roman Senate, the third emperor, Caligula, condemned him to death. The sentence was not carried out because he was thought to be so sickly that he would soon die anyway.

Messalina, the third wife of the next emperor, Claudius, arranged for her rival Julia Livilla, Caligula's sister, and Seneca to be exiled to Corsica in A.D. 41 on adultery charges that had more to do with the political climate than any moral lapse on Seneca's part. Eight years later Agrippina, who had replaced Messalina as the wife of Claudius, dispatched to Seneca some good news and some bad news. He was to return to Rome to tutor her 12-year-old son—the good news; her son was soon to become the infamous emperor Nero—the bad news. Seneca taught Nero literature and morals, the latter with a notable lack of success. With Seneca's help, Nero ruled competently for a few years, but his mind became more and more unbalanced thereafter. By A.D. 62 Seneca's criticism of Nero's behavior, and worse, his poetry, led to his removal from court.

Seneca's *Natural Questions*, a work devoted primarily to meteorology and astronomy, was written about A.D. 63 during an especially trying period. In an attempt to mollify Nero—who by this time was living a life of total depravity and had arranged for the murders of his stepbrother, his mother, and his wife—Seneca wrote about two contemporary comets:

> . . .the recent one which appeared during the reign of Nero Caesar—which has redeemed comets from their bad character . . .

and,

> . . . the recent one which we saw during this joyous reign of Nero . . .

Viewed with hindsight, his attempt to vindicate the bad reputation of comets to flatter Nero seems outrageous, though admittedly the passages may have been ironic. Nonetheless, in A.D. 65 Seneca was accused of involvement in a conspiracy against Nero and ordered to commit suicide. This time the sentence was carried out.

The earliest ideas about comets come to us primarily from two treatises, the *Meteorologica* of Aristotle and the *Natural Questions* of Seneca. Aristotle presented the teachings of his Greek predecessors from the sixth to the fourth century B.C. Although Seneca included the newer cometary ideas of the Greeks from the fourth to the first century B.C., he was also the source of what we know about the earliest views on comets—those of the Chaldeans or Babylonians. He wrote that Epigenes and Apollonius of Myndus (both fl. fourth century B.C.) had studied among the Babylonians. Unfortunately, they offered conflicting views. The Babylonians, according to Apollonius, classified comets among the wandering stars—the planets—and had determined their orbits. However, Epigenes reported that they had no understanding of comets, considering them to be fires produced by a kind of eddy of violently rotating air.

Both Aristotle and Seneca related their own views on comets only after they had discussed and rejected those of their predecessors, thus taking the remarkably modern stance of mentioning their sources only when they disagreed with them. However, had they not troubled to refute the ideas of their predecessors, we would now be largely ignorant of them. From Seneca we learn the cometary ideas of four Greek scholars: Ephorus of Cyme (fl. 340 B.C.), Epigenes, Apollonius of Myndus, and Posidonius (135–51 B.C.).

Seneca was particularly unkind to the historian Ephorus, calling him a mere chronicler who was often duped and tried to dupe others. For example, he ridiculed Ephorus' observations of a comet that split into two separate pieces, an event that cometary historian Alexandre Guy Pingré (1711–1796) discussed with regard to the comet of 372 B.C. Although Ephorus was the only source to mention the phenomenon, Seneca might have treated him with more respect had he known that several comets have since been observed to split (see Chapter 11).

In Seneca's outline, Epigenes' ideas were but those of Aristotle slightly modified. According to Epigenes, there were two types of comets: one was stationary and the other was in motion among the stars. The stationary type shed light symmetrically and formed when dry and moist exhalations were driven out through narrow apertures in the Earth, forming a whirlwind and setting fire to the surrounding atmosphere. Because of the heavier, moist exhalations, this type of comet was located in the lower regions. The second class of comets, Epigenes suggested, could result from an abundance of dry exhalations that sought the higher regions and were driven by the north wind. Epigenes' cometary fires, like those of Aristotle, remained until the combustible exhalations were consumed.

According to Seneca, Apollonius of Myndus considered comets as heavenly bodies; diaphanous, unequal in size, unlike in color, and waxing and waning like other planets. They were not illusions nor the result of planetary conjunctions. Their orbits, though not visible, intersected the upper part of the universe, and each comet was seen only when it reached the lowest part of its course. Although indicating that comets followed specified orbits, Apollonius maintained there was no reason to believe that the same comet reappeared; they were as numerous as they were varied. Seneca countered Apollonius' ideas by noting that comets cannot be planets because they were not always seen in the zodiac and because stars could often be observed through them. He also pointed out that if its orbit was other than circular, a comet's brightness would increase as it came closer to the Earth. He then observed that some comets attained their maximum brightness on the first day of their appearance, then began to fade. Seneca quoted Apollonius as stating that some comets are "blood-stained and threatening, bringing prognostication of bloodshed to follow in their train." Apart from this observation, however, Apollonius' ideas were quite modern. During the seventeenth century they were cited to support the view that comets were distinctive heavenly bodies traveling in highly eccentric orbits, and as a counter argument to the Aristotelian views that had been dominant until that time.

Seneca mentioned that Posidonius once observed a comet during a solar eclipse and concluded that many comets may be hidden by the Sun's rays.[2] Posidonius, a tutor to Cicero and a friend of Pompey the Great, had considerable influence on contemporary Roman thought. The comets of Posidonius, although transitory, lasted longer than other luminous objects because their motions were higher in the warm region of the ether. Since comets required the combustion of dry exhalations, they appeared during times of drought and, upon their disappearance, heavy rains could be expected. His theories were not particularly original, but helped to spread the Aristotelian views. Much of Seneca's own *Natural Questions* may be attributed to Aristotle, via Posidonius.

Although the Romans had captured the Greek city-states in the second century B.C., the Greeks had captured Roman minds. Typical of Roman scientific writing, Seneca's *Natural Questions* was a popularizing work primarily derived from Greek sources. In general, Seneca's views on meteorology were based on speculation and analogy. However, his views about comets were quite rational, original, and modern. He first asserted that his views differed from those of the Stoic sage Zeno and other Stoic brethren. Comets were not sudden fires but were among nature's permanent creations, and while their orbits generally differed, the two comets seen during his age had circular orbits much like the planets. Seneca suggested that comets moved in closed orbits, traveling in a uniform manner and disappearing only when they passed beyond the planets. To the argument that comets cannot be celestial bodies because their appearance and courses differed so greatly from the planets, he replied in his *Natural Questions* that

> Nature does not turn out her work according to a single pattern; she prides herself upon her power of variation. . . . She does not often display comets; she has assigned them a different place, different periods from the other stars, and

> motions unlike theirs. She wished to enhance the greatness of her work by these strange visitants whose form is too beautiful to be thought accidental.

In an often quoted passage, Seneca addressed posterity and noted some questions that remain unanswered:

> The day will yet come when posterity will be amazed that we remained ignorant of things that will to them seem so plain. . . . Men will some day be able to demonstrate in what regions comets have their paths, why their course is so far removed from the other stars, what is their size and constitution. Let us be satisfied with what we have discovered, and leave a little truth for our descendants to find out.

Going even further, he suggested the scientific method for future cometary studies:

> . . . it is essential that we have a record of all the appearances of comets in former times. For, on account of their infrequency, their orbit cannot as yet be discovered or examined in detail, to see whether they observe periodic laws, and whether some fixed order causes their reappearance at the appointed day.

Beginning with the work of Edmond Halley (1656–1742) in the late seventeenth century, Seneca's advice was heeded and the periodic nature of cometary motion established (see Chapter 6). Most of Seneca's discussions were summed up with a main point or moral. His book on comets pointed to the neglect of learning in contemporary Rome, and as an example he noted that existing cometary ideas were formed with little attention to observational evidence; they were out of touch with reality. While Seneca's views did little, in a quantitative way, to advance understanding of the phenomenon, his rejection of the prevailing Aristotelian theory inspired eventual rethinking of the nature of comets. Unfortunately this rethinking had to wait some 15 centuries.

As a Stoic, Seneca believed in astrology and divination, and while his treatment of comets was rational—even modern—in its approach, he did make one quick bow to superstition by warning that a cometary apparition threatened the whole year with wind and rain. The seeds of superstition had been planted by Aristotle and Seneca and the subject was to flourish under the guidance of Pliny and Ptolemy.

The Natural History *of* Pliny the Elder

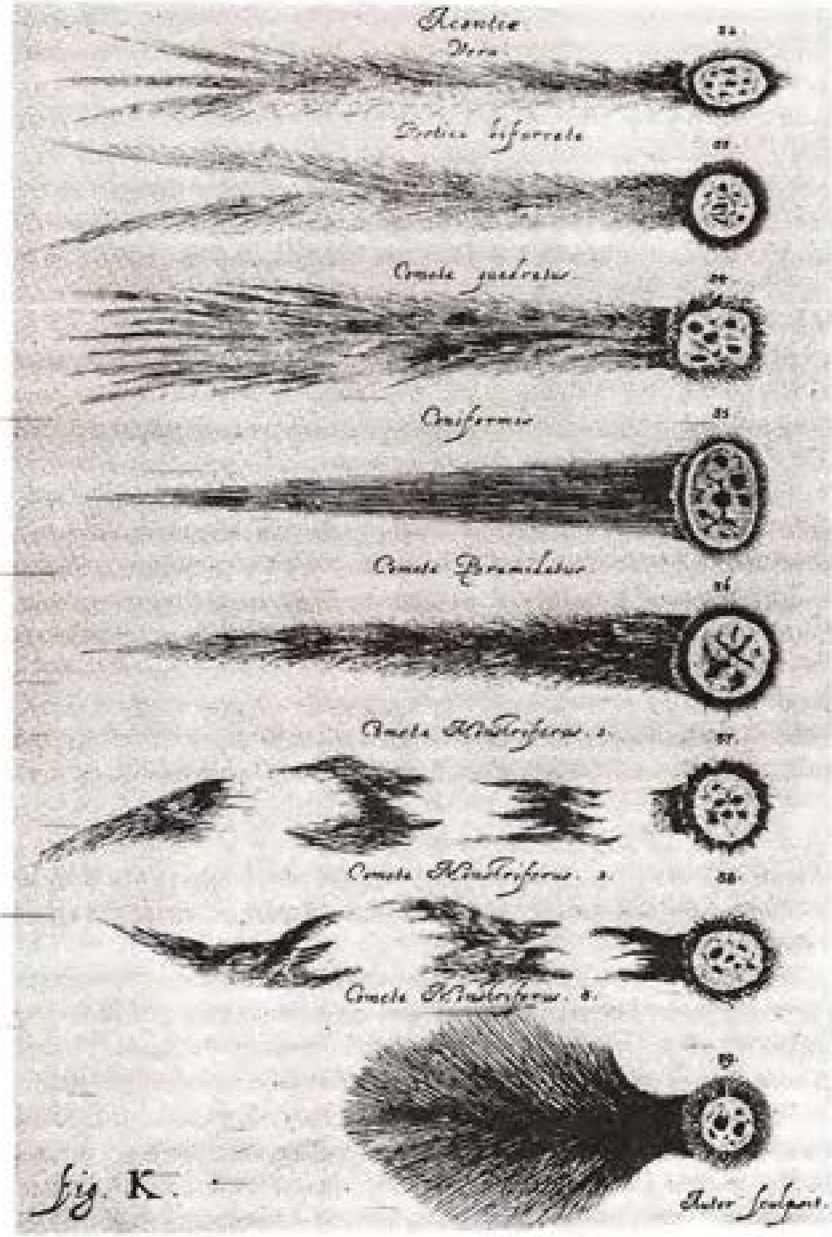
Caius Plinius Secundus, better known as Pliny the Elder, was a lawyer, traveler, administrator, head of the western Roman fleet under the emperor

Vespasian, and one of the most prolific writers of antiquity. He wrote treatises on oratory, grammar, the javelin, and Roman history, but his sole surviving work is *Natural History* in 37 books. His intent was "to give a general description of everything that is known to exist throughout the Earth." He covered 20,000 topics and apologized for omitting others. According to his nephew, the elder Pliny was able to carry out his official duties in addition to his voluminous writings because he had extraordinary zeal, an incredible devotion to study, and needed little sleep. Considering the nature of his writings, perhaps he should have slept longer, written less, and spent more time being critical or, at least, less gullible.

Pliny gathered superstitions, portents, love charms, and magic cures into his work indiscriminately, and his comments on comets are important only because the *Natural History* was so well known and respected during the Middle Ages. Without citing specific sources, he noted that some comets move while others do not, and that they were usually seen toward the north, chiefly in the region of the Milky Way. He did not acknowledge the contemporary views of his fellow Roman, Seneca, and relied almost exclusively on the earlier views of Aristotle. According to Pliny, comets could appear in any direction, but those in the south had no tails. He noted that the shortest and longest periods of a comet's visibility on record were seven and eighty days respectively. He gave more credence to comets as portents than did either Aristotle or Seneca and bolstered his view of comets as terrifying apparitions by noting the disasters that followed a few cometary returns. Pliny went so far as to mention how a particular comet's location, tail direction, and appearance could be used to predict imminent disasters and regions of the world that might be affected. For example, a comet resembling a flute with its tail rays pointing toward the east would indicate a malefic influence on music in the eastern territories.

In addition to Pliny's rules for predicting the nature of disasters following cometary apparitions, another questionable legacy was his system for classifying various types of comets—which would be repeated and often elaborated throughout the Middle Ages and well into the seventeenth century. Seneca had already mentioned a few types of comets, so the classifications did not originate with Pliny. But his writings, by their great popularity, were responsible for the transmission and long survival of the scheme. The 10 types of comets, according to Pliny, were

1. Pogonias: comet with a beard or mane hanging down from the lower part
2. Acontias: vibrating like a javelin with very quick motion
3. Xiphias: short and pointed like a dagger



Even in the late seventeenth century, some of the cometary forms of Pliny the Elder are recognizable in serious scientific works. These eight types of comets were illustrated in Johannes Hevelius' *Cometographia* (Danzig, 1668).

The Comet of 44 B.C.

In his *Natural History* (Book II, Chapter 23), Pliny tells of a temple dedicated by the emperor Augustus (63 B.C.–A.D. 14) to a comet that appeared during athletic games he sponsored in 44 B.C. just after the assassination of Julius Caesar, his father by adoption. Pliny cited Augustus as saying that the comet was seen everywhere as a bright star in the north for seven days, rising an hour before sunset. The common people assumed that it was the soul of Caesar on its way to the region of the immortal gods. The emblem of a star was added to a bust of Caesar that was dedicated in the forum.

Augustus used an emblem of a comet on some of the coins struck during his rule, perhaps to remind his subjects that the reins of power had passed to him from the hands of his now deified father.

This Roman silver coin, denarius, was struck during the reign of the first emperor Augustus (27 B.C.–A.D. 14). The head of Augustus appears on the obverse with the partly obliterated inscription "Caesar Augustus." The reverse shows a stylized comet and the inscription "DIVVS IVLIVS," Divine Julius.

4. Disceus: like a quoit or discus, amber in color
5. Pitheus: figure of a cask, and emitting a smoky light
6. Ceratias: appearance of a horn
7. Lampadias: appearing as a burning torch

8. Hippeus: like a horse's mane in rapid motion
9. Argenteus: silver in color, so bright that it is difficult to look at
10. Hircus: goat comets ringed with a cloud resembling tufts of hair

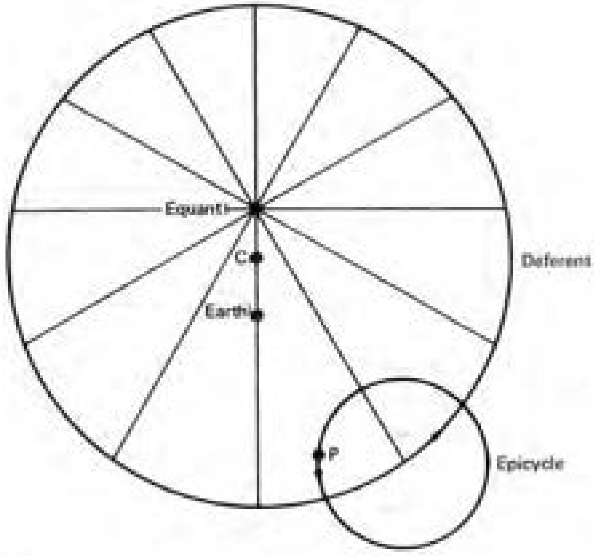
Pliny's work was an extraordinary catalog of truths, half-truths, myths, and outright nonsense. He was more an encyclopedist than a scientist; his knowledge was almost exclusively derived from the writings of others rather than from personal observations. One notable exception occurred when he was in command of a Roman fleet in the Bay of Naples in A.D. 79. When Mount Vesuvius suffered a volcanic eruption on August 23 and 24, overwhelming the towns of Pompeii and Herculaneum, Pliny sailed across the bay to investigate and was killed by the poisonous fumes.

The Tetrabiblos *of Ptolemy and the* Centiloquy

Claudius Ptolemaeus (ca. A.D. 100–175), last of the great astronomers of antiquity, lived and worked in Alexandria, but virtually nothing more is known about him. He is celebrated for his masterwork, the *Almagest*, a comprehensive theory of celestial motions based on the observations of other astronomers as well as his own. His theory rested on a system in which the Sun, Moon, planets, and fixed stars moved daily around a spherical, stationary Earth. In his theory of *epicycles*, Ptolemy assumed that a planet moves upon a circle, an epicycle, the center of which describes a larger circle, a deferent, about a central point. This central point was slightly offset from the immobile Earth. Although the epicycle's center moved nonuniformly upon the *deferent*, the apparent motion of this center appeared to be uniform as seen from the *equant* point.

Ptolemy's system was complex, with enough adjustable variables that planetary motions could be predicted surprisingly well. In the seventeenth century, the accuracy with which one could predict them with the incorrect Ptolemaic system was not much inferior to that available using the correct, heliocentric system of Kepler. Ptolemaic models, using epicycles and equants, can produce planetary positions in longitude differing by only 10 arc minutes from a Keplerian ellipse with the same eccentricity. Though incorrect, the Ptolemaic system was founded on strictly scientific principles and enabled the user to accurately predict the motions of the heavenly bodies. The *Almagest* remained the most influential and widely read work on theoretical astronomy until the seventeenth century.

In a companion volume, the *Tetrabiblos*, Ptolemy explained the astrological influence of the heavenly bodies on earthly matters. Ptolemy believed in, and defended, astrology in his *Tetrabiblos*, in which he treated comets. As



In the Ptolemaic cosmology, a planet, P, moves on a circle or epicyle, the center of which describes a larger circle or deferent about a central point, C. This central point has on one side the Earth and at an equal distance on the other side, an equant point. The center of the epicycle moves nonuniformly around the point C, but as seen from the equant point, the motion of this center appears to be uniform. The eccentricity is defined as the ratio of the distance from C to the Earth with respect to the radius of the deferent circle.

a result, Ptolemy's influence placed comets in the realm of astrology and ushered in more than 16 centuries of cometary superstition.

If Ptolemy had considered comets as heavenly bodies, they would have received scientific treatment in the *Almagest*. However, because they were unusual phenomena, he regarded them as mysterious signs or portents that provoke discord among men and give rise to wars and other evils. Unfortunately, he was even more specific and expanded somewhat on the astrological implications that Pliny had outlined. The part of the sky in which a comet first appeared and the direction the tail pointed indicated the geographic area that was threatened. The shape of the comet suggested the nature of the malefic event and the persons to be affected. Its position relative to the Sun foretold when disaster would strike. Evil was nigh if the comet first appeared near the rising Sun but might be delayed if it was first seen in the west. The length of time during which the comet remained visible was directly proportional to the duration of its ill effects.

Because of his great reputation, many astrological works were incorrectly attributed to Ptolemy in the Middle Ages. One such anonymous tract was the *Karpos*, or *Centiloquy*, which often accompanied the *Tetrabiblos* in medieval Latin manuscripts. It was long accepted as one of Ptolemy's writings and was thus influential. The last of its hundred aphorisms laid down specific rules for predicting comet-related disasters.

- An appearance of a comet at a cardinal point 11 astronomical signs from the Sun implied that the king of a particular kingdom, or one of the princes or chief men, would die.
- An appearance in a succeeding house implied prosperity for the kingdom's treasury, but the governor or ruler would change.
- An appearance in a cadent house (one that had passed the meridian) would be followed by diseases and sudden deaths.
- If the comet's direction moved west to east, a foreign foe would invade the country.
- If the comet was stationary, the foe would be provincial or domestic.

In the centuries that followed, Ptolemy's guidelines, and those in the *Centiloquy*, were used repeatedly to correlate cometary apparitions and terrestrial disasters. During the Middle Ages and in Renaissance times, the bulk of cometary literature was superstitious in nature. Writers seemed unwilling to deviate from Aristotle's ideas on cometary origins or Ptolemy's insistence on the relationship between comets and adversity.

Summary

Among the ancients, Aristotle and Ptolemy were the two dominant scientific authorities and neither one regarded comets as celestial phenomena. Aristotle did not include comets in his work on heavenly bodies *(De Caelo)*, but rather in his treatise on terrestrial phenomena *(Meteorologica)*. Ptolemy's *Almagest* treated the motions of the heavenly bodies but did not mention comets at all; they were left to his companion work on astrology *(Tetrabiblos)*. Under the dominant influence of Aristotle and Ptolemy, the more rational views of Seneca were quickly submerged. Thus the study of comets in the Middle Ages was handicapped by prevalent views that were incorrect, yet very authoritative.

NOTES

1. The notion of an invisible, intangible substance in space, *ether*, which takes a causal part in the motions of planets and transmission of light, was postulated by Aristotle, Anaxagoras, and other ancient philosophers. The idea of a single,

all-pervasive ether received its greatest support in Descartes' cosmology of vortices, a theory that was widely believed prior to the Newtonian era.

2. If Posidonius personally observed a comet during a solar eclipse, it might have been during the total eclipse of either 115 or 103 B.C. or perhaps during the partial eclipse of 94 B.C. Each of these events was observable in the Mediterranean area.

2
Medieval Views

A diffusion of Greek and Roman ideas into western Europe occurs during the Middle Ages. The Christian church embraces the cometary views of Aristotle. Accurate cometary positions begin in the west with Paolo Toscanelli's fifteenth century measurements of several comets. First attempts are made to determine the distance of comets above the Earth's surface. The comet of 1577 is shown to be well above the Moon by Tycho Brahe and his colleagues. Early Chinese astronomers make contributions to the study of comets.

The Period to About 1200: Theology and Superstition

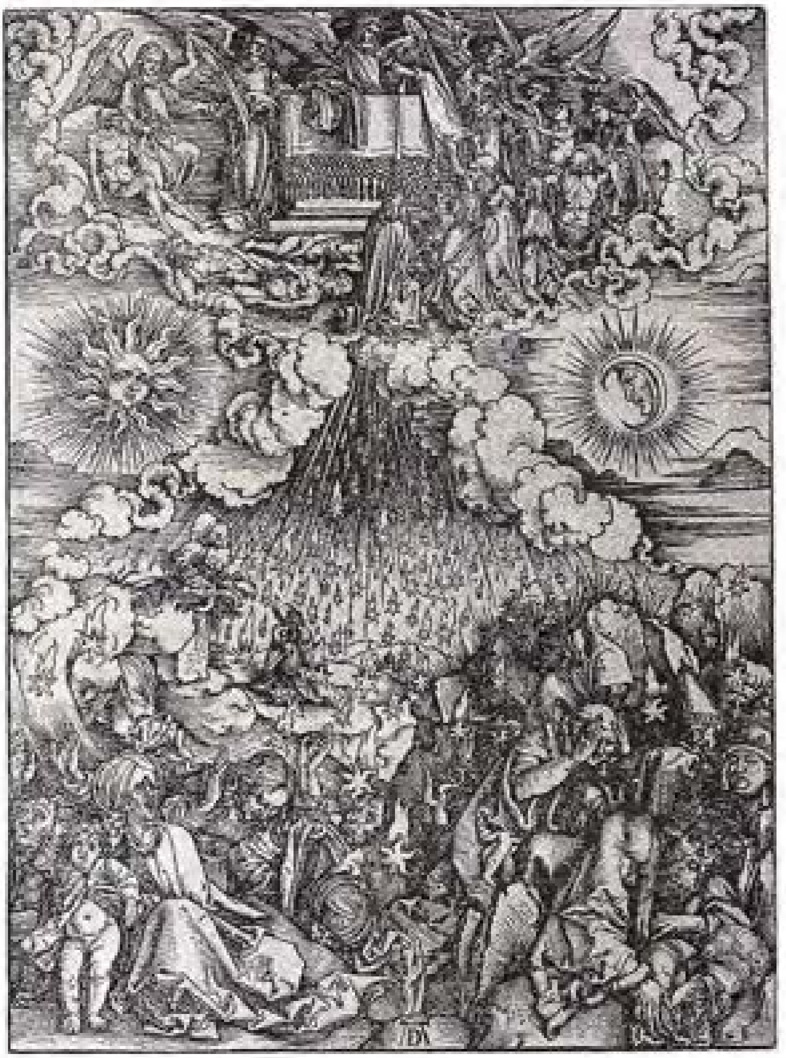
With the disintegration of the Roman empire, general knowledge of the Greek language disappeared and with it went the widespread knowledge of early Greek science. Latin translations of early Greek science were not widely circulated prior to the twelfth century; even so, contemporary views on comets, handed down from church scholars, were clearly derived from Aristotle and Ptolemy. The medieval period was extremely church oriented. It was an age of faith and medieval authorities did not look forward, they looked back. When physics was discussed, it was Aristotelian physics, and whenever computations were required to predict the positions of heavenly bodies, it was Ptolemy's *Almagest* that provided the necessary techniques.

Perhaps the first medieval astronomer was the English Benedictine theologian Bede the Venerable of Yarrow (ca. 673–735). Bede, one of the most enlightened figures of his time, stated that comets portend changes of rule, pestilence, wars, winds, or heat. They never appeared in the western sky; they nearly all were in the north, usually in the Milky Way. Some comets moved with planetlike motions, while others remained stationary. The longest interval a comet remained visible was 80 days, the shortest 7 days. Bede's views were clearly derived from those of Ptolemy and Aristotle.

Around A.D. 1000, a number of previously uncirculated astronomical treatises were translated into Latin from the original Greek. They were generally done by wandering scholars who visited Spanish monasteries and used existing Arabic translations of the early Greek writings. The diffusion of early Greek science into Europe was aided by the crusades of the twelfth century, which created an intercourse between Western Europe and the culturally more advanced Middle East. Aristotle's *Meteorologica* was first translated into Latin in 1156 by Henricus Aristippus of Sicily, while the translation of Ptolemy's *Almagest* did not occur until four years later. By 1200, the works of Ptolemy and Aristotle were in circulation in Latin and hence available to a larger readership in Western Europe. Contemporary churchmen embraced these ideas because of their strict logic, wide knowledge, and scriptural compatibility. The Church had unquestioned authority and the astronomy of Aristotle and Ptolemy was not only approved for teaching, it was virtually sanctified and rendered unassailable.

The theologian Albert Magnus (1193–1280) wrote that a comet was a coarse, terrestrial vapor that gradually rose from the lowest part of the airy region to the upper part where it touched the concave surface of the fiery sphere. The comet then ignited and remained visible until the fuel was exhausted. Albert considered comets as signs, not causes, of malefic events. They cannot cause the death of magnates, since vapor no more rises in a land where a rich man lives than where a pauper resides. Albert and his pupil, Thomas Aquinas (ca. 1225–1274) labored to work out a synthesis of Aristotelian science and Christian theology. The mathematics of Ptolemy was combined with the conceptually simpler and more qualitative astronomy of Aristotle. Aquinas added to the prevalent fear of comets by writing that they were among the 15 signs preceding the Lord's coming to judgment.

Another pupil of Albert Magnus was the English scientist Roger Bacon (1214–1294), who advanced the scientific method by insisting on objective observations and experiments as guides to knowledge. He observed a comet in July 1264, described it in some detail, but drew conclusions that had more to do with contemporary superstition than with the scientific method. Bacon noted that the comet of 1264 appeared in Cancer and moved toward Mars, which—due to the warlike nature of Mars—presaged discord and wars. The comet was described as dreadful and followed by vast disturbances and wars in England, Spain, Italy, and other lands in which many Christians were slaughtered. Martin Luther (1483–1546) went even further, referring to comets as harlot stars and works of the devil. He is quoted as saying "the heathen write that the comet may arise from natural causes, but God creates not one that does not foretoken a sure calamity" (see White, 1910, 1:182).



"The Opening of the Fifth and Sixth Seals." This 1511 woodcut by Albrecht Dürer illustrates John's description of the Apocalypse in Revelation 6:9–17: "And I beheld when he had opened the sixth seal, and lo, there was a great earthquake, and the Sun became black as sack cloth, the full moon became like blood, and the stars of the sky fell to the Earth . . . ." Dürer used the analogy of a meteor shower, and possibly eclipses by the Sun and Moon, to indicate the disorder and terror associated with the apocalypse. (*Courtesy of the New York Metropolitan Museum of Art.*)

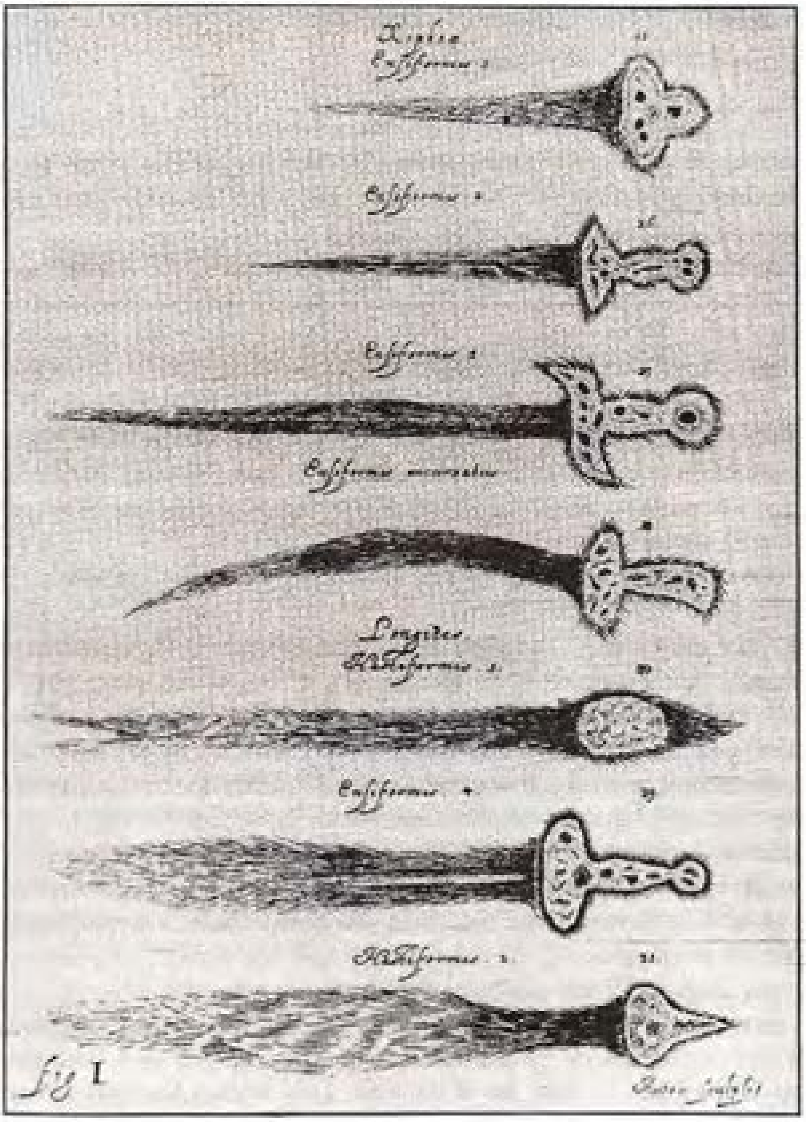
A typical example of medieval cometary thought, written in 1578 by the Lutheran bishop Andreas Celichius, was entitled *Theologische Erinnerung von dem Neuen Cometen. . . .* (The Theological Reminder of the New Comet). In an opinion that represented the majority view of comets during the late medieval period, Celichius wrote that comets are

> . . . the thick smoke of human sins, rising every day, every hour, every moment full of stench and horror, before the face of God, and becoming gradually so thick as to form a comet, with curled and plaited tresses, which at last is kindled by the hot and fiery anger of the Supreme Heavenly Judge.

In a rational reply, the Hungarian scholar, Andreas Dudith (1533–1589), expressed the minority opinion by noting that if comets were caused by the sins of mortals, they would never be absent from the sky. Dudith's common sense views were published in 1579. Another blow to cometary superstition was struck a year later by Blaise de Vigenère. His treatise provided rational counter arguments to many foolish beliefs, including examples of the deaths of many great monarchs with no comet to herald the event.[1] However, the works by Dudith and Vigenère were exceptions, not the rule, and the ripples of rationalism they caused were largely ignored in the wave of contemporary superstition.

During the medieval period to approximately A.D. 1200, there was virtually no original work on comets in the Western world. When comets were ob-

Woodcut showing destructive influence of a fourth century comet from Stanislaus Lubienietski's *Theatrum Cometicum. . . .* (Amsterdam, 1668).



Types of cometary forms, illustrations from Johannes Hevelius' *Cometographia* (Danzig, 1668).

served, care was taken only to note in which constellation they first appeared so that appropriate astrological predictions could be made. Comets were considered terrestrial phenomena, balls of fire thrown at a sinful Earth from the right hand of an avenging God. Cometary superstition reigned supreme and no significant advances were made in understanding the phenomena.

1200–1577: The Rebirth of Scientific Observations

In the period from 1200 to before the comet of 1577, the views on comets were still dominated by superstition and astrological nonsense. However, a few hesitant steps forward were taken and an occasional observer began to make note of comets in a scientific fashion.

The French Dominican Aegidius of Lessines (ca. 1230–1304) observed the comet of 1264 and noted that it was first seen in the evening after sunset; then after a few days it crossed the Sun and appeared in the morning. This observation is noteworthy because, at the time, observations of a particular comet before and after passing the point on its orbit closest to the Sun, its perihelion, were generally attributed to two different comets. Indeed, prior to his comprehensive study of the comet of 1680, Isaac Newton (1642–1727) himself believed that the pre- and postperihelion observations of this object were due to two separate comets.

Peter of Limoges (fl. 1300) was the author of a tract on the comet of 1299 and quite probably an anonymous tract on the comet of 1301 (Halley) as well. The comet of 1299 appeared in late January and remained visible into March. According to Peter of Limoges, it was of moderate size, had a long tail, and was dark blue. As recorded in the anonymous tract, the comet of 1301 appeared September 1 and remained visible for more than a month. The similar ideas from these two tracts suggested that a comet's natural motion was eastward because comets, located in the upper air, slip behind the sky's westward, daily motion. That these two comets were not observed moving directly eastward was due to the influence of Mercury and Mars for the comet of 1299 and Mars alone for 1301. For both comets, celestial longitude and latitude were observed directly using a sighting device, a *torquetum*, for measuring angles. These observations were perhaps the first instance in which astronomical instruments were used in the West. Both treatises concluded with a discussion of the comet's malefic significance, but Peter of Limoges was careful to note the Almighty was not bound by these portents; they were only warnings from a watchful God.

The Florentine physician and astronomer Paolo Toscanelli (1397–1482) made descriptive and positional observations of 6 fifteenth century comets: 1433, 1449–1450, 1456 (Halley), 1457 I, 1457 II, and 1472.[2] These observations were apparently unknown and remained in manuscript form until discovered in 1864 at the National Library in Florence. Giovanni Celoria, director of the Milan Astronomical Observatory, successfully used Toscanelli's observations to compute their orbits. While the surviving details

Paolo Toscanelli

of Toscanelli's life are few, a contemporary biographer described him as modest, religious, a vegetarian, and learned in Greek, Latin, and geometry.

Toscanelli is known primarily for the role he may have played encouraging Christopher Columbus prior to his discovery of the New World in 1492. Interested in navigation and geography, Toscanelli constructed a nautical map of the Atlantic Ocean. Because of extremely poor longitude data, China and Japan were located 100 degrees east of their correct positions. In 1474, Toscanelli is believed to have forwarded the map to the Portuguese canon Ferdinando Martini, who in turn transmitted it to Columbus. In constructing his own navigation charts, Columbus probably used Toscanelli's incorrect map to verify his own, which was even less accurate. Columbus figured he had 2400 miles of ocean between the Canary Islands and Japan. Toscanelli's map suggested 3000 miles. The actual distance was more like 10,000 miles. If the maps of Toscanelli and Columbus had been correct, the voyage might not have been attempted.

During the nearly 40 years that Toscanelli made cometary observations, he was concerned with finding accurate cometary positional data, perhaps to facilitate his use of astrology for his medical profession. After studying Toscanelli's manuscript charts, the science historian Jane Jervis concluded that for the comet of 1433, the positions were determined using crude stellar alignments on his hand-drawn star charts. For the comet of 1449–1450, the positions were determined more accurately with a straight edge on his star charts and for the comet of 1456, his measures were made directly with a torquetum. His series of manuscript pages may be the first time celestial charts were used as an integral part of celestial measurements and not just as pictorial representations of stellar positions.

The Viennese astronomer Georg von Peurbach (1423–1461) was the first to attempt a cometary *parallax determination* using his observations of the 1456 apparition of comet Halley. Parallax determination is a technique for determining the distance of a celestial object by observing it simultaneously from different locations and noting the resulting angular change of the object's apparent position referred to the distant stars. The greater the distance between the observer and the object, the smaller this parallax angle becomes. A parallax determination can also be observed at one location if the measurements are made several hours apart so that the Earth's rotation changes the observer's position between the first and second set of observations. In this latter case, a medieval scientist would attribute the position changes to the rotation of the celestial sphere, rather than the Earth's rotation. The parallax of the Moon can be defined as the largest angle subtended by the Earth's radius, as seen from the distance of the Moon. It is 57 arc minutes, just less than one degree. An object twice the distance of the Moon would have a parallax angle just less than one-half degree.

In the mid-fifteenth century, Peurbach taught astronomy at the University of Vienna and wrote an often reprinted theory of the planets and a theory of eclipses. He composed a number of tables of trigonometric sines and chords, constructed sundials, calculated tables of planetary positions, *ephemerides*, and made positional observations of stars and planets. He also wrote a number of lyrical love poems in Latin, all of them addressed to men. Peurbach wrote a brief German treatise when the comet of 1456 was still visible, and followed it with a more formal Latin treatise when it departed. Neither treatise was formally published but a number of manuscript copies exist. His ideas on the physical nature of comets were Aristotelian; comets were hot, dry, terrestrial exhalations rising to the upper regions of air or region of fire where they were ignited under the influence of the stars and planets. Using an unspecified instrument, Peurbach first observed the comet of 1456 on June 10 and followed its motion for most of that month. His parallax determination was not a precise measurement. In fact, he apparently assumed the comet was more than an Earth radius from the Earth's surface and used the comet's slight parallax to verify his assumption. Jane Jervis studied Peurbach's Latin treatise at the Vienna State Library and gave the following outline of Peurbach's reasoning:

- From Ptolemy, the radius of the sublunar sphere is 33 Earth radii.
- One degree on the Earth's surface subtends 16 German miles.
- The Earth's circumference is then $16 \times 360 = 5760$ German miles.
- The Earth's radius is $5760 \div 2\pi = 1000$ German miles (approximately).
- Hence the distance from the sublunar sphere to the Earth's surface is $33{,}000 - 1000 = 30{,}000$ German miles (very approximately).
- If comets are in the upper region, below the sphere of fire, and the sphere of fire is less than say 27,000 German miles measured from the lunar sphere, then the comet must be $30{,}000 - 27{,}000$ or more than 1000 German miles above the Earth's surface.
- The comet's parallax angle was found to be slight and this was taken as proof that the comet was at least 1000 German miles above the Earth's surface.

There is a real question as to whether Peurbach's cometary parallax determination was an attempt to determine the comet's distance or the height of the sphere of fire. Peurbach also used the comet's distance and apparent tail size to compute the linear length of the tail. He computed that the comet's 10-degree tail would make it 80 German miles long. Once again, Peurbach's estimates were crude. At a distance of 1000 German miles, a 10-degree tail would be larger than 175 German miles. Peurbach's treatise also included a brief discussion on the quantity of matter necessary to sustain a fire of this size and a rather lengthy discussion on the comet's portents.

In approximately 1335, the mathematician Levi ben Gerson (1288–1344) suggested that Ptolemy's parallax method for the Moon be applied to determine the distance to a comet. However, it was Peurbach's student Regiomontanus, or Johannes Müller (1436–1476) of Königsberg, who is generally given credit for making known the techniques required for cometary parallax determination. The German city of Königsberg means "King's Mountain." In Latin, Regiomonte translates as "from the royal mountain." Hence, Regiomontanus took his name from his home town. He received his bachelor's degree at age 15 from the University of Vienna and was appointed to the faculty at age 21. Upon Peurbach's death in 1461, Regiomontanus took over his teacher's condensation and explication of Gerard of Cremona's twelfth century translation of Ptolemy's *Almagest*. Although this work was completed sometime before 1463, it was not published until 1496. In 1471, Regiomontanus left for Nürnberg, where the patronage of Bernard

Walther (1430–1504) allowed him to set up an observatory. In 1475, Pope Sixtus IV summoned him to Rome to work on calendar reform, but Regiomontanus died within the year.

Contemporary accounts attribute his death variously to poisoning, the plague, or a comet. If the events surrounding the death of Regiomontanus seemed strange, the events surrounding the fate of his effects were even more peculiar. After his death, Regiomontanus' books, papers, and instruments were acquired by Bernard Walther. Walther used the instruments to continue the observations that he and Regiomontanus had started, but the books and papers were locked up and everyone denied access to them. After Walther's death in 1504, the executors of Regiomontanus' estate apparently started selling his books, all the while denying that they were doing so. Several law suits were initiated over the remains of the estate. Finally, most of the remaining books and papers were acquired by Johannes Schöner, who published a few of them in the 1530s and 1540s. Hence it was an unusually long time before the works were published.

Regiomontanus' major work on comets was first published by Schöner at Nürnberg in 1531 to take advantage of the interest generated by the comet (Halley), which appeared in that year. This work in entitled *Ioannis de Monteregio Germani, viri undecunque doctissimi, de comete magnitudine, longitudineque ac de loco eius vero, problemata XVI*. An English translation of the Latin title would read "Sixteen problems on the magnitude, longitude and true location of comets by the German Regiomontanus, the most learned among men." This work provided several techniques for determining a comet's parallax, as well as determining a comet's position and size. A guide book, it was general in scope with no specific examples of actual cometary measurements. Another work entitled *De cometis*. . . . was first published under Regiomontanus' name by Jakob Ziegler in 1548 as part of Ziegler's history of the universe. It was often reprinted in the sixteenth and seventeenth centuries, including a reprinting in 1668 in the *Cometographia* of Polish astronomer Johannes Hevelius (1611–1687). Although this work was often attributed to Regiomontanus, Jane Jervis made a convincing case for its authorship by someone of Peurbach's school. The *De cometis*. . . . was concerned with the position, size, and distance of the comet of 1472. The qualitative path of the comet through the constellations was described with notes on its apparent speed and tail direction. Based on an estimate of its apparent motion with respect to the star Spica, a parallax of not more than six degrees was determined. The comet was thought to be at least nine Earth radii from the surface of the Earth, putting it in the region of air, but not in the region of fire.

Girolamo Fracastoro (ca. 1478–1553), an instructor of logic and anatomy at Padua, Italy also described the comet of 1472 and observed those

Johannes Müller, or Regiomontanus

seen in 1531 (Halley), 1532, and 1533. In a work that was designed to replace the Ptolemaic epicycles with a system of 76 homocentric spheres, Fracastoro was the first European to report, in print, the antisolar nature of comet tails. His work of 1538 was entitled *Homocentricorum, sive de stellis*. However, the credit for the first European to draw attention to this phenomenon goes to Peter Apian (1495–1552), professor of mathematics at Ingolstadt. Apian's work on the 1531 apparition of comet Halley *Practica auff dz. 1532 Jar . . . .* had a diagram on the title page showing the antisolar nature of comet tails. In this work, as in his later work entitled *Astronomicum Caesareum*, Apian drew diagrams showing the extended radius vector from the Sun to the comet passing through its tail. Perhaps too much has been made of these diagrams since the dust tails, most easily seen with the naked eye, are nearly always strongly curved and rarely appear directly along the extended Sun-comet radius.

When investigating Apian's observations of the comet of 1531, over the interval August 13–23, Edmond Halley (1656–1742) himself mentioned their relative inaccuracy. All eight of Apian's longitudinal observations were discrepant by at least one degree and two were in error by nearly five degrees. While he lacked observational precision, Apian excelled in creating magnificent books. The *Astronomicum Caesareum* is the most spectacular contribution of the bookmaker's art to sixteenth century science. Its pages are large, brilliantly hand colored, and filled with ingeniously contrived mechanisms, up to six layers of paper disks arranged to give planetary positions in addition to calendrical and astrological data. Printed on Apian's private printing press, the book was designed for Charles V and his brother Ferdinand. Flattered by the book, Charles V handsomely rewarded Apian by raising him to the rank of hereditary nobility, crossing his palm with 3000 gold coins, granting him the right to appoint notaries, to award the titles of doctor and poet laureate, and to legitimize children born out of wedlock.

Peter Apian's August 1531 observations of a comet (Halley) in the constellation Leo were used to demonstrate the antisolar nature of cometary tails. Woodcut illustration from Apian's *Practica auff dz. 1532 Jar. . . . (Landshut).* (Courtesy of the Crawford Library, Edinburgh, Scotland.)

Fewer than one hundred copies of this book remain extant, making it more rare than a first edition of Copernicus' *De Revolutionibus*.

Nine years after Apian's beautiful book was published, the first cometary catalog was issued by Antoine Mizauld (1520–1578). Mizauld's book was neither accurate nor beautiful. Entitled *Cometographia crinitarum stellarum* . . . . this work included a catalog of comets and their attendant disasters until 1539. Mizauld was considered gullible and referred to as *Mizzaldus ineptus* by one of his contemporaries. Although Mizauld's own work was somewhat inaccurate, it does contain a reasonably accurate catalog of 46 comets. Alexander Pingré attributed this latter catalog to Paul Eber, Protestant minister and professor of belles-lettres at Wittenberg.

Girolamo Cardano (1501–1576), a teacher at Padua and Rome, acknowledged the importance of parallax measurements for the study of comets but decided upon a supralunar position for a comet seen in 1532, not by parallax measurements, but rather by noting that its apparent speed was less than that of the Moon. Cardano, known chiefly for his mathematical works on probability, was imprisoned by the Inquisition in 1570 for having cast Christ's horoscope and asserting that the events in his life were governed by the stars. He prudently recanted.

Cardano's cometary views were presented in his 1550 work *De Subtilitate* and in his *De Rerum Varietate*, published seven years later. These two works were later republished in his collected works. Cardano thought of comets as globes, or spherical lenses, illuminated by the Sun with the tail formed from sunlight shining through the comet and brought to a focus behind it. He believed the antisolar nature of the tail was common to all comets. When the air became dry, comets appeared, and while they may not have been the cause, they certainly were signs of dryness, corruption, famine, and death. Unlike Fracastoro and Apian, Cardano believed in the supralunar position of at least one comet. Unfortunately, his views were still the minority opinion.

Johannes Vögelin, professor of mathematics at Vienna, attempted a parallax measurement for the comet of 1532. Vögelin's work was outlined in his *Significatio cometae qui anno 1532 apparuit*, first published in 1533 at Vienna and later in a 1574 work by Prague astronomer Thaddeus Hagecius (ca. 1525–1600). Following Regiomontanus' parallax technique, Vögelin took two altitude and azimuth observations 42 minutes apart on October 6 for the comet of 1532. He determined extraordinarily large parallax measurements of 35 degrees, 31 minutes, and 1 second (35° 31′ 1″) and 34 degrees, 58 minutes, and 32 seconds (34° 58′ 32″). On October 6, 1532 the comet was approximately 0.76 *astronomical units*, AU, from the Earth so the correct parallax value for that day should have been approximately 11.5 seconds.[3]

Note that Vögelin, in a custom that is still frequently employed, wrote his result to the nearest arc second when his error was far larger than the result itself. His method appears to be sound and his computations correct, but the observations were not precise enough to give meaningful results. The computed value of the parallax was extremely sensitive to the uncertain values of azimuth measured.

Nicholas Copernicus (1473-1543) observed the comet of 1533 and wrote a brief treatise about it published by M. Curtze in 1878. Copernicus mentioned comets only once in his 1543 masterwork *De revolutionibus orbium coelestium*. Ironically, he assumed comets were terrestrial objects and used their motion in the upper air to demonstrate that these regions take part in the daily celestial rotation:

> It is said. . . . that the highest region of the air follows the celestial motion. This is demonstrated by those stars that suddenly appear—I mean those stars that the Greeks called cometae or poganiae. The highest region is considered their place of generation, and just like other stars they also rise and set. We can

"An awesome, wondrous sign (portending) two earthquakes, seen at Rosanna and Constantinople in the year 1556." Broadside by Herman Gall, printed by Valentin Neuber. (*Courtesy, Department of Prints and Drawings of the Zentralbibliothek, Zurich.*)

say that this part of the air is deprived of the terrestrial motion because of its great distance from the Earth.

Part of book I of Copernicus' *De revolutionibus* was translated into English in 1576 by Thomas Digges (ca. 1546–1595), the sixteenth century leader of the English Copernicans. Digges was nearly alone in being a Copernican with a pre-1577 belief in the celestial nature of comets. This statement is supported by Digges' description of the new star, or *supernova*, seen in 1572. While arguing for its celestial nature, Digges consistently identifies it with the cometary region. However, by 1576, Digges spoke of comets as terrestrial phenomena in his work *A Perfit Description of the Caelestiall Orbes*. This Copernican treatise was appended to his father Leonard's Ptolemaic treatise *A Prognostication Everlasting*. Thomas Digges' switch to treating comets as terrestrial objects in 1576 was particularly untimely because the next year a great comet arrived and subsequent observations would prove that it was definitely a celestial object beyond the Moon.

The Comet of 1577

The great comet of 1577 was an extraordinary apparition. Contemporary descriptions note that it was seen through the clouds like the Moon, and that it rivaled Venus in brightness. It was first recorded on November 1, 1577 in Peru and last recorded January 26, 1578 by Danish astronomer Tycho Brahe (1546–1601). The comet reached perihelion on October 27, 1577 when it was 0.18 AU from the Sun, well inside the orbit of Mercury. The comet's nearly parabolic motion around the Sun was opposite to that of the Earth and planets, or *retrograde* motion, and it approached closest to the Earth, at 0.63 AU, on November 10, 1577. The works published on this comet form a turning point in the history of astronomy because precise observations were used to demonstrate that the Aristotelian views on comets, which had remained dominant for nearly two millennia, were incorrect. The comet of 1577 was shown to be well above the Moon.

First to publish his observations was the German astronomer Michael Mästlin (1550–1631). Educated at Tübingen, as a pupil of Apian, his observations were simplicity itself. Using a thread, he aligned the comet with two neighboring stars, so that they were all on the same great celestial circle. He repeated the process with two different stars. Then using the star catalog in Copernicus' *De revolutionibus*, the stellar positions were noted and the comet's position determined from the intersection of the two great circles connecting the stellar pairs. Some hours later, the observations were repeated and apart from the comet's actual motion on the sky, which he estimated,

Comet of 1577 as seen in a woodcut broadside by Jiri Daschitzsky and published by Peter Codicilus. An artist is seen drawing the comet and is aided by men holding his sketchbook and lantern. The heading reads, "Concerning the fearful and wonderful comet that appeared in the sky on the Tuesday after Martinmass (November 12) of this year 1577." *(Courtesy of the Department of Prints and Drawings of the Zentralbibliothek, Zurich.)*

Mästlin noticed no difference in its apparent position with respect to the neighboring stars. His null parallax determination was based on measurements a few hours apart for three nights in early December 1577.

Using observations from November 12, 1577, until January 8, 1578, Mästlin devised a theory to account for the comet's apparent path. From the observed maximum angle between it and the Sun, the comet was assumed to move on a circular path slightly outside the orbit of Venus—concentric with the orbit but not quite heliocentric. The observed deviations from uniform circular motion were explained by assuming the comet moved on a small epicycle perpendicular to its orbit plane so that it librated back and forth about a mean position. Mästlin believed that the origin of comets was a mystery known only to God, but once created they were celestial phenomena and could be treated as such. A confirmed Copernican by 1572, his heliocentric orbit for the comet of 1577 may have been conjecture. While the true orbit

Michael Mästlin

for this comet was parabolic, he assumed it to be circular. However, his observations covered only 60 degrees of its path, an interval short enough that his theory could roughly explain its observed motion. Mästlin's observations showed the comet to be a celestial object. Nevertheless, he declared it a new and horrible prodigy and devoted a chapter of his book to its portents, concluding that it was a type that betokened peace, but peace purchased by a bloody victory.

The work of astronomer Tycho Brahe is most closely associated with the comet of 1577. A member of Danish nobility, Tycho was sent to Leipzig in 1562 to study law. However, his interest in astronomy was unsuppressed and he left Leipzig in 1565 and began studying at Rostock the following year. He continued at the University of Basel three years later. Tycho's observations of the new star in 1572 did much to spread his fame, and in 1575 King Frederick II of Denmark offered Tycho the island of Hveen in the Danish sound and provided him with enough money to erect a residence and observatory. In fact, two observatories, Uraniborg and Stjerneborg, were erected and the island soon had a windmill, a paper mill, herbaries, flower gardens, and several fishing ponds. Tycho's residence had running water, a library, a chemical laboratory and room for eight assistants. He had at his disposal something like one percent of the annual income of the Danish government, which supported astronomical research to a percentage level never reached since. In return for his princely benefits, Tycho had only to act as a consultant to the Danish royal court on astrological and astronomical matters. He compiled a horoscope at the birth of each royal son and supplied the royal family with annual astrological predictions. Tycho's belief in astrology was genuine, but he took issue with contemporary astrologers whose predictions were unwarranted or too specific.

During the evening of November 13, 1577, Tycho was out by his ponds catching fish for the evening meal when he noticed a comet in the western sky. For the next two and a half months, he observed it whenever the weather was clear. Early in 1578, he wrote a brief manuscript in German setting down his opinions and conclusions on comets in general and the comet of 1577 in particular. This important treatise existed only in the form of two manuscript copies until it was published by Johann Louis Emil Dreyer in 1922 and translated into English in 1979 by J.R. Christianson.

In his German treatise, Tycho quickly dismissed the Aristotelian theory of the cosmos by citing the new star of 1572 as evidence against the immutability of the heavens. He also objected to the Aristotelian notion of comets and concluded, from his own measurements, that the comet's parallax at the horizon could not have been greater than 15 arc minutes. Tycho thought the comet to be at least 230 Earth radii above the Earth's surface and certainly above the Moon's sphere, which he took to be 52 Earth radii. He also recorded his physical observations of the comet, noting that, on November 13, 1577, the head was whitish or Saturnlike in color and 8 arc minutes in diameter. On the same date, the tail had an apparent length of 21 degrees 40 minutes and appeared a reddish dark color similar to a flame seen through smoke. Tycho observed that the tail was directed in an antisolar direction due to the Sun's rays passing through the comet's rarefied and porous head. The head itself was visible because it did not pass all the Sun's light; it was translucent.

Fully one half of Tycho's German treatise was concerned with the astrological implications of the comet. Because it was first seen in the west, the most affected regions would be Western Europe. However, the eastern regions were not exempt from the comet's influence because, as Tycho stated,

> Although this comet appeared in the west and will realize its greatest significance in those lands that lie toward the west, yet it will also spew its venom over those lands that lie eastward in the north, for its tail swept thence.

When Tycho first observed the comet on November 13, it was Saturnlike in color and its apparent position on the sky was not far from Saturn itself. The comet first appeared in the eighth house, which astrology ascribes to death. From its initial position and color, Tycho concluded that the comet augured

Tycho's Noble Nose

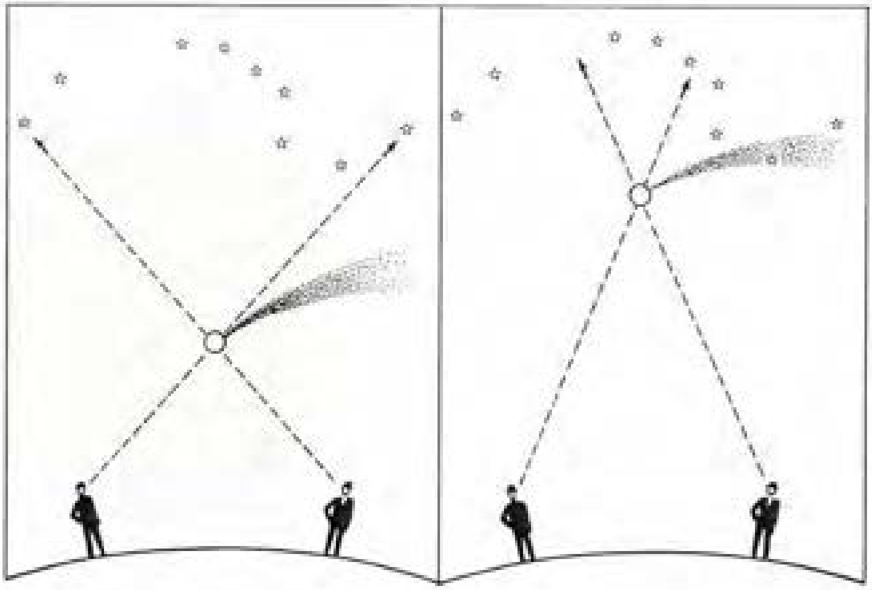
Tycho Brahe

This portrait of Tycho Brahe clearly shows something peculiar about his nose. In fact, a portion of it was artificial. While studying astronomy at Rostock, on the North Sea, the 20-year-old Tycho became engaged in a heated quarrel at a Christmas party with another nobleman named Manderup Parsbjerg. According to a contemporary source, they argued over who was the better mathematician. The two hotheads met on December 29, 1566 at seven o'clock in the evening to settle the dispute. Although the most appropriate choice of weapons would have been paper and pens, they chose swords instead. Tycho came out second best when Parsbjerg's sword sliced off a piece of his nose. Thereafter he wore a metal replacement, said to have been made of gold and silver. Apparently the noble nose had a high copper content as well, since an examination of his skeleton in June 1901 revealed a green stain surrounding the upper end of his skull's nasal opening.

Although Tycho and Parsbjerg became friends after their fateful encounter, Parsbjerg always claimed the duel was a fair one—history does not record whether he boasted of winning the contest by a nose.

an exceptionally great mortality among mankind. Since it was intentionally qualitative and popular in nature, Tycho's German manuscript was probably intended as a report to the Danish royal court. The detailed data and scholarly analysis would be published in a larger, Latin treatise entitled *De mundi*.

Tycho's masterwork on the comet of 1577, published in 1588, is most often given as *De mundi*; the full title of the work is *Tychonis Brahe Dani de mundi: aetherei recentioribus phaenomenis liber secundus qui est de illustri stella caudata ab elapso fere triente Nouembris anni 1577, usq; in finem Ianuarij sequentis conspecta*. Sixteenth century authors seemed to vie for the longest book title, which often served as the book's abstract. Tycho's title would loosely translate to "Two Books Concerning the Quite Recent Phenomena of the Aethereal Region, seen from November 13, 1577, until the following January, by Tycho Brahe, the Dane."



Schematic illustration showing parallax determination. Tycho Brahe and his colleagues observed the comet of 1577 simultaneously from two different locations on the Earth's surface. If the comet was below the Moon and close to the Earth, each observer would see it appearing against an entirely different stellar background. Since each observer noted the comet appearing against nearly the same background stars, the comet must have been quite distant and beyond the Moon.

Tycho's most important conclusions were presented in the first chapter, where he began by deducing new positions for the 12 reference stars used in determining the comet's positions. They were deduced from the measured angular distances, or *offsets*, from neighboring stars whose positions were known. Differing observations, as well as different parallax techniques, were used to determine the comet's supralunar location. On the evening of November 23, its position relative to the star ε Pegasi was determined twice, the second observation was three hours after the first. Assuming the comet was at the same distance as the Moon, its parallax and actual motion on the sky would have had the effect of making the second angular measurement from the star equal to the first. However, the observed difference between the measurements was actually 12 minutes, and Tycho concluded that the comet must have been at least six times more distant than the Moon. Comparing the observations by Hagecius at Prague with his own at Hveen, he found a difference of 1 to 2 minutes whereas it should have been 6 to 7 minutes if the comet were as near as the Moon. Although the observations of Cornelius Gemma (1535–1579), at Louvain, Belgium, were less accurate, a similar comparison with Tycho's own observations also implied a supralunar position.

Tycho examined his physical observations of the comet's tail and concluded that its axis never passed through the Sun but seemed to pass much closer to Venus. He felt the anti-Venus direction of the tail to be an illusion because it would more naturally turn away from the Sun. As did Mästlin before him, Tycho believed that the comet moved in a circular path just outside the orbit of Venus. The observed discrepancies from uniform circular motion were noted and Tycho was the first to suggest that a comet's orbit may not be circular, but *ovoid*. Alternatively, its circular motion might not be uniform. Also included in Tycho's *De mundi* was his Tychonic world system, whereby the Sun revolved around the stationary Earth and the remaining planets revolved about the moving Sun. Stimulated by his conclusions on the comet of 1577, Tycho was unable to accept the original Copernican concept and sought a compromise between the geocentric and Copernican systems. The last portion of this work was devoted to a detailed discussion of the obser-vaions and writings of contemporary astronomers, including the Landgrave

Allegorical woodcut of an eagle with a comet in its beak. A poem by the King's poet, Jean Dorat, identifies the eagle as a minister of God with fire at the head and feet, the former to warn humans, the latter to punish them if they do not mend their ways. From Blaise de Vigenère's *Traicté des comètes, ou Estoilles chevelues apparoissantes extraordinairement au ciel.* (Paris, 1578).

of Hesse Cassel, Hagecius, Cornelius Gemma, and Helisaeus Roeslin (1544–1616).

The astronomer William IV, Landgrave of Hesse Cassel (1532–1592), also believed in the supralunar position of the comet of 1577. His observations, which appeared in Tycho's *De mundi*, included the length and width of the comet's tail and position measurements. He made redundant observations, with his sextant reversed, to account for instrumental errors and noted, but did not correct for, errors due to the refraction of light in the Earth's atmosphere. While he made no parallax determinations himself, the Landgrave believed the comet to be supralunar. Tycho's comparison of the Landgrave's observations with his own showed they were consistent with a location of the comet above the Moon.

The Prague astronomer Thaddaeus Hagecius presented his own work in a tract published in 1578. Hagecius determined a parallax of 5–6 degrees for the comet of 1577, which would have placed it well below the Moon. However, Tycho showed that Hagecius had misinterpreted his own observations, and in a work published in 1580 Hagecius corrected the error and concluded that the comet of 1577 was located above the Moon.

Cornelius Gemma, a doctor and astronomer like his father Gemma Frisius, believed some comets were below the Moon and some above. In his publication of 1578, he gave day-to-day observations of the comet of 1577, noting its position and appearance. From his parallax determination of not more than 40 minutes, he placed the comet above the moon on an orbit near that of Mercury.

Helisaeus Roeslin, a physician and astrologer, also considered the comet of 1577 to be above the Moon in his book *Theoria nova coelestium*. However, Roeslin's inference was based more on conjecture than observations.

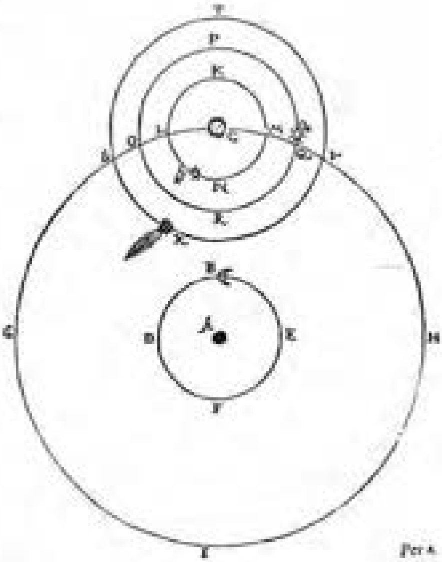
In an unpublished work, the young English astronomer Jeremiah Horrocks (1618–1641) suggested that the comet of 1577 originated in the Sun and issued forth on a rectilinear path. The solar rotation deformed the path into a nearly circular orbit and eventually the comet returned to the Sun. It would be unfair to criticize Horrocks' ideas because he left few notes on the subject and he may not have entertained his ideas seriously.

In the few centuries prior to the comet of 1577, leading astronomers like Peter Apian, Georg von Peurbach, and Johannes Vögelin expressed the prevailing belief that comets were sublunar. The latter two used inaccurate parallax measurements to bolster their viewpoints. While Girolamo Cardano did offer a dissenting opinion, his argument for the comet of 1532 being located above the Moon was not based on parallax measurements but rather on its apparent motion in the sky, which he observed to be slower than that of the Moon.

Smashing the Crystalline Spheres

The placement of the comet of 1577 above the Moon by Tycho Brahe and his colleagues was but one step in the eventual discarding of the Aristotelian cosmology. Yet the strong grip of Aristotle's ideas on Tycho was evident in the world system that he developed for the solar system and the comet of 1577. Tycho was convinced that the Earth occupied the center of the Universe and was not, as Copernicus would have it, whirling about the Sun. In Tycho's world system, the Earth remained stationary at position A while the Sun, C, revolved about it. The orbits of the interior planets Mercury, KLNM, and Venus, PORQ, encircled the moving Sun, as did the orbit for the comet of 1577, TSXV.

In 1577, the planets were thought to revolve in solid crystalline spheres and Tycho carefully placed the comet's sphere so that it did not smash into the neighboring planetary spheres. Tycho balked at representing the sphere of Mars in this system, since it would necessarily encircle that for the comet of 1577 and intersect, or smash, the Moon's crystalline sphere about the stationary Earth. However, by 1584 Tycho accepted as possible the intersection of the planetary and lunar orbits, thus casting aside the notion of solid crystalline spheres for the planetary orbs.



The geocentric world system as represented by Tycho Brahe. From *De Mundi* (Prague, 1603).

Parallax measurements by Michael Mästlin, Tycho Brahe, Thaddaeus Hagecius, and Cornelius Gemma clearly placed the comet of 1577 above the Moon. However, only Mästlin, Brahe, and Horrocks attempted to explain the comet's observed motion. Each considered its orbit to be closed upon itself, but none suggested the motion was periodic. Mästlin and Brahe thought the comet to be a temporary phenomenon that faded from sight as it expired. According to Horrocks, the comet returned to the Sun and disappeared.

Accurate observations of the comet of 1577 enabled Tycho Brahe and his colleagues to finally determine the distance, or parallax, of a comet. The determination of this comet's supralunar position, coming as it did on the heels of the Copernican revolution, helped turn scholars away from the entrenched cometary views of Aristotle and Ptolemy. At the end of the sixteenth century, the intelligentsia generally believed that comets were celestial phenomena. However, their paths and physical nature were still very much in question.

Early Chinese Contributions to the History of Comets

Histories of science have usually been rather chauvinistic toward European contributions to astronomy. The astronomical progress of Eastern cultures, especially the Chinese, has been ignored or dismissed perfunctorily. Fortunately, recent discoveries, translations, and analyses have begun to reveal their extraordinary scientific achievements. Prior to the Arabic astronomers of the eleventh century, the Chinese were the most accurate and prolific observers in the world. Through the tenth century, their astronomical observations of comets, planets, novae, meteors, aurorae, eclipses, and sunspots were virtually the only quantitative measurements being made. The reason for their diligence was astrology. The Chinese astronomer/astrologer was continually called on to guide the ruling sovereign with astrological advice. Unlike the Greek, Roman and medieval European astronomers, who were largely academics, Chinese astronomers were intimately connected to their sovereigns and resided within the walls of the imperial palace. The Viennese historian Franz Kühnert said it well in 1888 (see Needham, 1959):

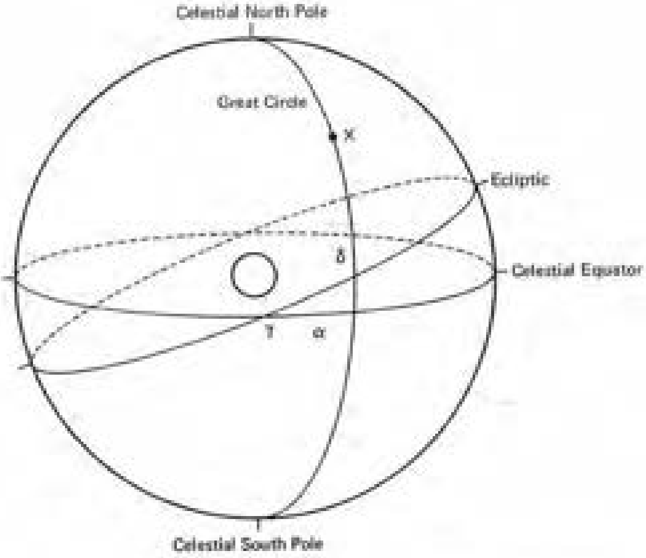
> Probably another reason why many Europeans consider the Chinese such barbarians is on account of the support they give to their astronomers—people regarded by our own cultivated western mortals as completely useless. Yet there they rank with Heads of Departments and Secretaries of State. What frightful barbarism!

There are fundamental differences between early Chinese astronomy and that passed down from the early Greeks. The Hellenistic tradition was more theoretical than observational, emphasizing geometrical formulations for the motions of the celestial bodies. Early Chinese astronomy was empirical, and while this observational approach prevented them from making significant advances in theoretical astronomy, it did allow them to escape the Greek notions of perfect circular motion, immutability of the heavens, and concentric spheres for the planetary regions.

While Hellenistic astronomy was based on a coordinate system defined by the Sun's apparent motion on the sky, an *ecliptic* system, and Arabic astronomy was based on the altitude and azimuth, or *horizon* system, Chinese astronomers employed a coordinate system based on the apparent rotation of the stars about an axis, one end of which was the north celestial pole. It is this equatorial coordinate system that is used by modern astronomers, and the two celestial coordinates (analogous to Earth's longitude and latitude) are right ascension and declination. The right ascension of a celestial object is its Earth-centered angle measured eastward from the vernal equinox, and the declination of the object is its Earth-centered angle measured north or south from the celestial equator, which is simply the extension of the Earth's equator onto the celestial sphere. In this system, the *north polar* distance of an object is defined as an angle equal to 90 degrees minus the value of the object's declination.

The Chinese celestial sphere was divided into *asterisms*, each one consisting of a few neighboring stars, much like smaller versions of our familiar constellations. By the second half of the third century A.D., there were 283 asterisms composed of 1464 stars. Twenty-eight lunar mansions were spread around the celestial sphere in unequal strips of right ascension and the boundary, or wall, of each was established by a reference, or determinative star. The celestial position of an object was denoted as being a certain distance within a particular lunar mansion and occasionally a north polar distance, in Chinese degrees, would also be given. There were 365.25 Chinese degrees in a circle so that one ancient Chinese degree equals 0.9856 western degrees. This ancient Chinese system of expressing celestial coordinates is entirely equivalent to the modern equatorial coordinate system, except the Chinese had no single origin for their right ascension, *lunar mansion*, system. Although they had a perfectly good angular measure in the Chinese degree, it was rarely used to express distances between celestial objects, the size of a comet's tail, a meteor trail, or the zodiacal light. A linear unit such as a *chhih*, a foot, was used. From a seventh century account of the positions of the ecliptic with respect to the 28 lunar mansions, Tao Kiang of Dunsink Observatory determined that 1 *chhih* equals 1.5 western degrees approximately.

In 1973, a book of silk pages was discovered in an ancient Han tomb at Mawangdui, China, dating from about 168 B.C. The silk book has approximately 250 drawings representing such things as clouds, halos, rainbows, lunar occultation, and star groups. Some 29 of the drawings represent types, or forms, of comets; they are the earliest surviving illustrations of comets. Two of the forms are unrecognizable. An example of the original illustrated silk is accompanied here by 27 recognizable types redrawn for clarity. The drawings do not represent specific comets but rather general cometary types, and each is briefly described with the associated portents. Some of the



Schematic illustration showing equatorial coordinate system. The celestial equator is formed by extending the Earth's equator onto the imaginary celestial sphere. The celestial ecliptic is the apparent path of the Sun on the celestial sphere. The point where the Sun appears to cross the celestial equator going north is called the *vernal equinox*, **γ**. It occurs every year about March 21 and marks the beginning of spring in the northern hemisphere. For a celestial object located at point X, its right ascension, **α**, is measured eastward along the celestial equator from the vernal equinox to the great circle passing through the object and the north and south celestial poles. The object's declination, **δ**, is then measured along the object's great circle, north or south from the equator to the object.

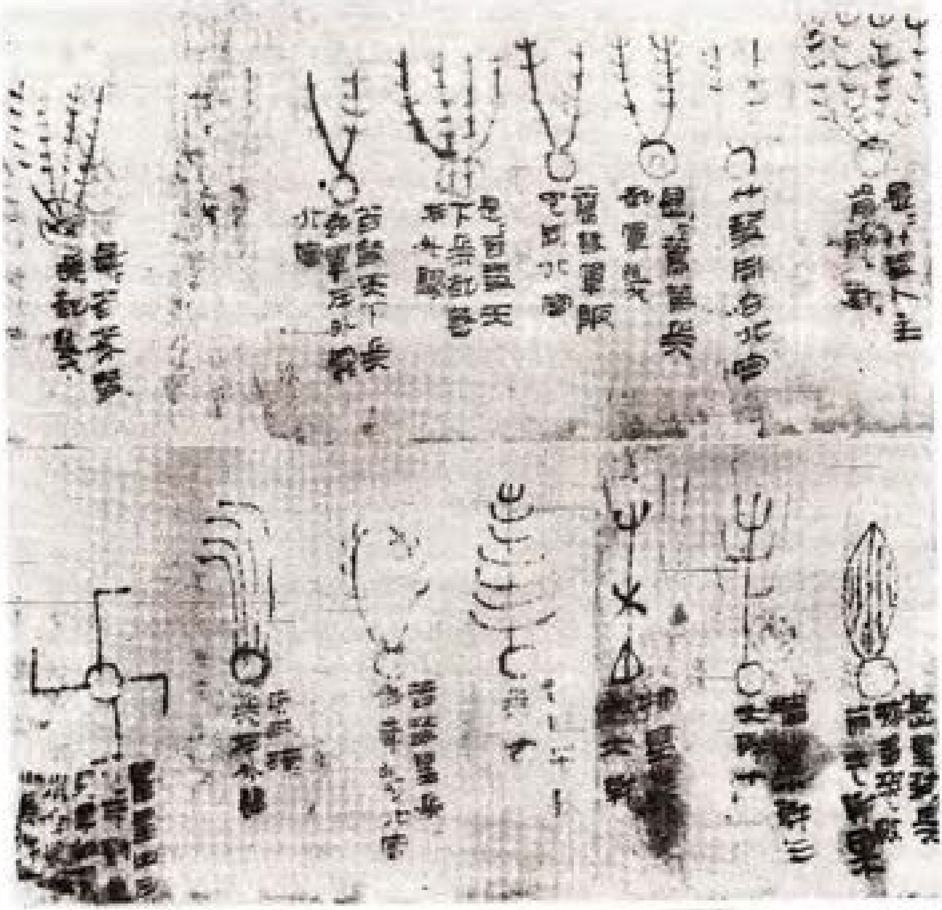
names are used for more than one comet illustration. The comet type and associated portents follow:

1. Chi-Guan:	War comes, general dies
2. Bai-Guan:	Five-day rebellion in the state
3. Tian-shuo:	The small man cries (*shuo* is a ceremonial dance pole)
4. Chan:	State perishes
5. Hui-Xing:	Army that gains the direction will win
6. Bai-Guan:	It appears for 5 days and goes, death in the state
7. Chi-Guan:	Death among generals

8. Pu-Hui:	Disease in the world (*pu* means water weeds)
9. Pu-Hui:	Calamity in the state, many deaths
10. Gan-Hui:	War for years (*gan* means the stem of a cereal)
11. Gan-Hui:	Same portents as for number 10
12. Zhou-Hui:	Bumper harvest but internal war
13. Li-Hui:	Small war, corn plentiful
14. Zhu-Hui:	There will be death of kings
15. Zhu-Hui:	Same as number 14
16. Hao-Hui:	Armies arise, war and famine
17. Hao-Hui:	Revolt in the army, otherwise same as number 16
18. Shan-Hui:	Arms are raised in the world, army abroad will return
19. Shan-Hui:	Same as number 18
20. Shan-Fa-Hui:	War, famine; same as numbers 18 and 19
21. Shen-Xing:	It leads to war, many calamities, fear of defeat and worry about result of conflict (*shen* is the fruit of the mulberry)
22. Qiang-Xing:	Three small battles, seven large battles (a *qiang* is a screen placed next to coffins)
23. Nei-Xing:	War, large battle
24. Gan-Hui:	Means war
25. Shan-Hui-Xing:	Raising of arms, famine during the year
26. Chi-You-Qi:	Army abroad will return
27. Di-Xing:	Appearing in spring means good harvest, in summer means drought, in autumn means flood, in winter means small battles (*di* is a long-tailed pheasant)

From internal evidence, it appears that the contents of the silk book were composed in the fourth century B.C. There is little evidence to suggest intercourse between Greek and Chinese cultures at that time, yet both civilizations considered comets to be malefic signs with similar disastrous consequences.

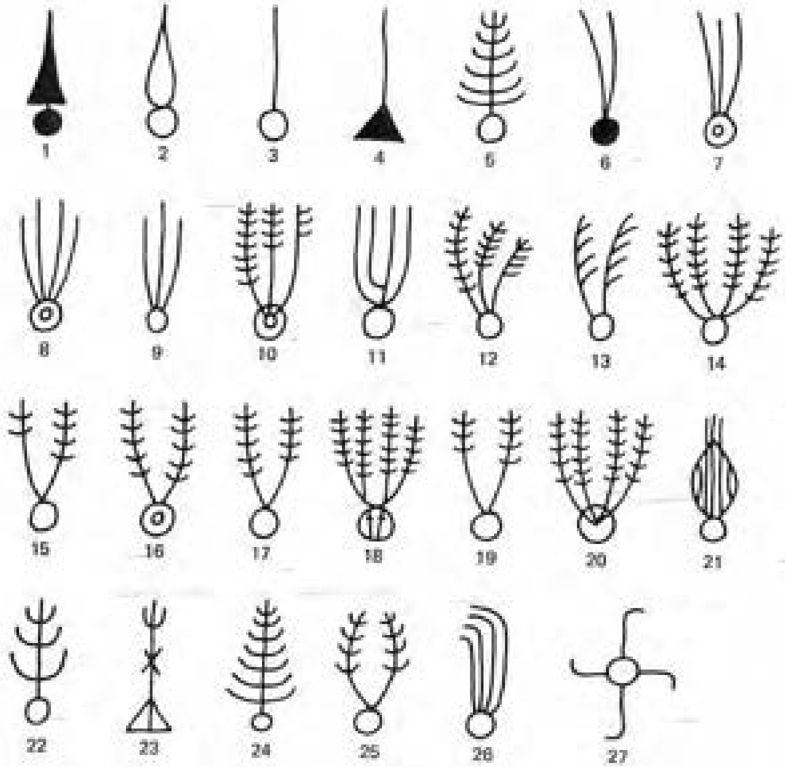
Concerning cometary astronomy, the ancient Chinese astronomers have two "first observations" to their credit. They were the first to note the antisolar nature of comet tails and they may be the first to have noted the unusual *antitail* phenomenon, one that appears to be directed *toward* the Sun.



Some examples of the cometary types displayed in the silk book of the Han tomb (ca. 168 B.C.). The original images have degraded with time. (*Photograph courtesy of F. Richard Stephenson.*)

In about A.D. 635, the Chinese history of the Chin Dynasty (A.D. 265–419) was completed and Li Chung-feng, who was responsible for the astronomical portion of this history, recorded the following paragraphs (see Needham, Beer, and Ho, 1957):

> Among ominous stars the first are the hui-xing, commonly known as broom stars. The body is a sort of star while the tail resembles a broom. Small comets measure several inches in length, but the larger ones may extend across the entire heavens. The appearance of a comet predicts military activities and great



Schematic drawing of cometary types in the Han tomb silk book.

> floods. Brooms govern the sweeping away of old things and the assimilation of the new. A comet can appear in any one of the five colors, depending on the essence of that one of the five elements which has given birth to it.
>
> According to the official astronomers, the body of the comet itself is non-luminous but derives its light from the Sun, so that when it appears in the evening, it points toward the east while in the morning, it points toward the west. If it is south or north of the Sun, its tail always points following the same direction as the light of the Sun—then suddenly it fades. The length of the rays is a measure of the calamity foretold by the comet.

These paragraphs suggest that by approximately A.D. 635, when this history was written, Chinese ideas on the nature of comets had a Hellenistic influence. The notion of five elements giving birth to comets came by some circuitous route, but it originated with Aristotle. The antisolar nature of cometary tails, mentioned in the second paragraph, was the first statement of this phenomenon. This effect was again mentioned in the Chinese descriptions of the A.D. 837 apparition of comet Halley, so it must have been well known by then. Thus Peter Apian's 1532 diagram, showing the antisolar nature of a comet's tail, as well as Fracastoro's 1538 statement to that effect, were preceded by Chinese records some nine centuries earlier.

As additional Chinese dynastic histories were written, a few cometary types, or forms, were added to those mentioned in the Han Tomb silk book. One of these forms was termed a *Chang-keng*, or long path, and may have been the Chinese classification for a comet with two horns or tails, one on either side of the nucleus. The comets seen in A.D. February 467 and November 886 may have exhibited antitails because they were both referred to as *Chang-keng* in the dynastic histories. However, the validity of these sightings remains in question because the Chinese descriptions were vague. A true cometary antitail is seen when an active comet passes through the Earth's orbital plane so that an edge-on view of cometary debris gives the illusion of a sunward spike, or tail (see Chapter 9).

In-depth study of ancient Chinese astronomy has been undertaken only relatively recently. There is much historical research left to be done before the significance of ancient Chinese astronomy is fully realized. The major contribution to date is the work of the science historian, Joseph Needham. To mention only a few of the Chinese contributions is enough to indicate that these astronomers were ahead of their European counterparts up to and including the fourteenth century. Quantitative and detailed Chinese star maps are extant from A.D. 940 through the fourteenth century, a period when Europe had nothing comparable. During the thirteenth century, after a continuous development of complex astronomical instruments, the Chinese invented the equatorial mounting. Even earlier, in 1090, an armillary sphere designed by Su Sung was equipped with a sighting tube and the apparatus was driven with a water-powered clock drive. However, the most important ancient Chinese contributions are dynastic records containing nearly continuous observations of celestial phenomena such as eclipses, novae, sunspots, and comets. The ancient Chinese observations of comets are outlined in the Appendix.

Summary

With the decline of Greek and Roman cultures, scientific empiricism gave way to Aristotelian dogma. The medieval period through 1200 saw the cometary ideas of Aristotle and Ptolemy first translated into Latin, then widely circulated and finally embraced by the European Christian Church.

In the thirteenth century, Albert Magnus (Albert the Great) and Thomas Aquinas brought the science of Aristotle into the theological fold. By so doing, they not only supported these incorrect viewpoints, they granted them sanctuary.

The medieval Church found the Aristotelian views to be safe because there were no serious contradictions with biblical texts. This compatibility is not surprising since many of these texts were written in lands conquered by Alexander the Great and at a time when Aristotle's views were well known and widely believed. With the encouragement of the Church, comets were considered atmospheric phenomena, or signs, sent by an angry God to warn a sinful Earth to repent. Medieval views considered comets analogous to dreadfully close thunder clouds, all the more frightening because they were direct messages from an angry, almighty God. When comets were discussed, it was invariably to question their meaning rather than their nature.

There is a tendency to unfairly condemn the medieval period for the lack of scientific advancement and to dismiss the views during this time as ignorant and superstitious. Science historian Jane Jervis makes the point that medieval scholars asked different questions than their counterparts today; what they saw was affected by what they believed. We still don't know what comets mean, we simply don't ask that question. Modern scientists have learned to ask only questions that can be answered by the scientific method. The early medieval period knew little of empiricism and the scientific method.

The period from 1200 to 1577 saw less than complete devotion to comets as portents, and there were isolated examples of scientific observations in Europe. Beginning with the fifteenth century, the scientific study of comets was reborn and useful observations were made by Paolo Toscanelli, Georg von Peurbach, Regiomontanus, and others. Astronomers began to test the terrestrial nature of comets by attempting to determine their distance from the Earth using parallax measurements.

Although Peurbach had tried a cometary parallax determination as early as 1456, it was not until 121 years later that techniques and instruments were accurate enough to decide whether comets were terrestrial or celestial phenomena. For the comet of 1577, Michael Mästlin, Tycho Brahe, and Cornelius Gemma all made parallax measures and each correctly inferred the comet's position as being beyond the Moon.

The period between the fall of the Roman empire and prior to the comet of 1577 witnessed very little progress in the way of quantitative observations of comets in the West. Fortunately, Chinese astronomers were recording accurate cometary observations for this entire interval.

NOTES

1. In this regard, the French astronomer and historian Alexandre Pingré wrote that the comet preceding the death of Charlemagne, in January 814, may well have been invented by contemporary authors. In the ninth century, great men simply did not die without a great comet in the sky.
2. When comets are first discovered, or recovered, they are given a provisional letter designation indicating the order of discovery within a particular year. Later, when their orbits have been computed, they are given a Roman numeral designation to indicate the order of their *perihelion passage* (the order in which they pass closest to the Sun). For example, comet Halley was the eighth one in 1982 to be discovered or recovered; its provisional designation was 1982h. However, its permanent designation is now 1986 III, since it was the third comet in 1986 that was known to have passed perihelion. To indicate an orbital period less than approximately 200 years, periodic comets are often designated with a P/ prior to their names (i.e., P/Halley).
3. One astronomical unit, AU, is defined as the mean distance between the Earth and Sun. It is approximately 150 million kilometers or 93 million miles.

3

Johannes Kepler, Galileo, and the Comets of 1607 and 1618

Johannes Kepler believes comets are ephemeral. Although his laws explain the motions of the planets around the Sun, Kepler considers comets to move on straight line paths. Galileo and the Roman Jesuits argue over the comets of 1618. Galileo criticizes the Jesuit views and those of Tycho Brahe but does little to advance the understanding of cometary phenomena. The first telescopic observations of comets are made in 1618.

THE CHINESE WERE THE first to observe the comet of 1607 on September 21 as a morning object in the northeast. Toward the end of September, the comet became a northwest evening object attaining a maximum brightness of approximately first or second magnitude.[1] The comet was last seen by Johannes Kepler on October 26, one day before it reached perihelion as it moved into the glare of the Sun. Obvious to the naked eye, its appearance prompted several treatises, the most important of which was Kepler's.

Three comets appeared in 1618, the last of which was the most impressive.[2] Often called *the* comet of 1618, it was first seen in mid-November exiting from the solar glare as a tail projected above the horizon. The tail reached impressive proportions in mid-December and the comet was last seen on January 22, 1619. The appearance of the comet of 1618 also prompted several contemporary treatises and touched off a heated controversy between the Roman Jesuits and Galileo Galilei (1564–1642).

The Ephemeral Comets of Johannes Kepler

In a letter dated July 4, 1603 to his friend David Fabricus, Johannes Kepler stated that when he was a boy of six, his mother led him to a high place to view the comet of 1577. Kepler's future teacher, Michael Mästlin, observed this same comet and determined it to be supralunar. Mästlin used circular orbits within a Copernican system to represent the motion of comets, and it is reasonable to assume that Kepler initially shared his teacher's views. If so, he later abandoned this nearly correct concept for his own erroneous theory. By 1602 Kepler believed that comets were ephemeral, rocket-like bodies having rectilinear motions above or below the Moon. From 1602 on he never deviated from his assumption of rectilinear paths for comets.

Kepler's first work about comets was published in 1604 and entitled *Astronomiae pars optica*. In a short appendix to this work, Kepler noted that comets, like rockets, travel most slowly in the beginning and end of their trajectories. Kepler's logic was Aristotelian but straightforward. Unlike permanent celestial objects, comets were observed to be ephemeral—that is, they moved on straight line trajectories. To admit circular motion, Kepler would have had to concede their divine or permanent nature and comets were simply not observed to be periodic. Within the main text of his book, Kepler outlined an experiment that could be used to create a phenomenon akin to a comet's tail. If a narrow beam of light were directed toward a solid, or water-filled, globe in a darkened room, a taillike image would appear on the opposite wall. He later rejected this conjecture because it was necessary to suppose that some mechanism existed to deflect the light passing through the head toward an observer's eye. In his experiment, the wall played this role.

Kepler first observed the comet of 1607 in the northwest evening sky on September 26 as he stood on a bridge over the Moldau River in Prague. He had just finished watching a fireworks display. He observed the comet for the month that it was visible, and the following year he published a short treatise written in German that was intended for a popular audience. In this work, Kepler set down his ideas on the origin of comets and their tails. According to Kepler, comets were spontaneously created from impurities, or fatty globules, in the ether.[3] This process was likened to an ocean's ability to spontaneously generate whales and sea monsters. Space was as full of comets as fish in the sea but they only became visible when near the Earth. When a comet was created, a special spirit or intelligence formed to guide it. The comet and the attendant spirit were created together, and they dissipated together.

Engraved portrait of Johannes Kepler. Frontispiece from *Johannes Kepler* by Edmund Reitlinger, Stuttgart, 1868. Engraving based on original oil painting by an unknown artist.

In this same work, Kepler stated that his previously published experiment for creating a cometlike tail phenomenon was premature and offered only as a conjecture. He went on to present his revised ideas on cometary tail formation. The Sun's rays passed through the comet, penetrated its substance, and drew a portion of the head in the antisolar direction. Much like clouds dissipated by the Sun, cometary particles drawn away from the head dissipated in the tail region. The comet lasted only as long as it took the Sun to do this. Although not exactly what Kepler had in mind, this suggestion has been referred to as the first mention that solar radiation has pressure. Kepler believed that comets became visible as sunlight was reflected by the head and tail. Tail curvature was due to the refraction of the sunlight in the somewhat transparent head and tail material. His treatise on the comet of 1607 also presented his ideas on its astrological significance. It contained a few general astrological predictions and the statement that contact with the tail, although extremely unlikely, would render the Earth's atmosphere im-

The Three Laws and World View of Johannes Kepler

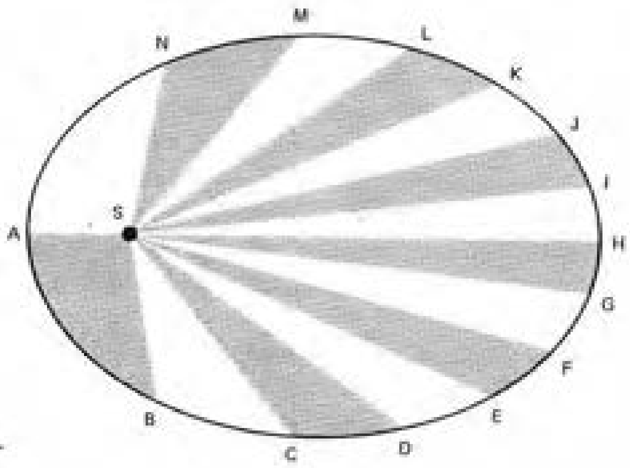
Although Kepler's work on comets added little to the understanding of them, his three laws of planetary motion would prove important in Isaac Newton's subsequent solution to their paths. By simply listing Kepler's three laws, we implicitly couch them in our own modern cosmology—wherein Earth is a smallish planet orbiting one modest Sun amongst billions of others in a dark, infinite void. With the aid of the diagram, Kepler's laws are introduced below in the cosmology he embraced.

While Kepler was one of the very first scientists to support the Sun-centered cosmology of Copernicus, it would be a mistake to assume he disavowed a geocentric viewpoint. Like Copernicus, he thought of the Sun as the center of a finite universe with the stars being lights (not suns) on a very large spherical shell. Kepler assumed that the ratio of the starry sphere's distance to that of the outermost planet Saturn was the same as the ratio of Saturn's distance to the radius of the Sun. He had no evidence for this assumption, but the analogy pleased him. In Kepler's mystical cosmology, special celestial guiding spirits were spontaneously generated and the planets created music as they orbited the Sun. These divine sounds were not physically audible but were heard by the spiritual ear just as the spiritual eye notes the harmony of the sizes of the planetary spheres. Kepler's adoption of the Copernican system in no way invalidated his belief that the Creator's handiwork was done for mankind alone. Far from being humiliated by the Sun's central location, the inhabitants of Earth retain a favored position among the planets, enabling them to view a lovely variety of apparent motions provided by the Earth's five sisters, two of which were closer to the Sun and three farther away. The Creator moved the Earth from the center of the physical system to provide for more interesting journeys around the immobile Sun.

pure and cause widespread mortality. Some took this notion quite seriously when this same comet (Halley) returned three centuries later in 1910.

Although Kepler's German book on the comet of 1607 was first scheduled for publication at Leipzig, he was forced to publish at Halle instead. Lutheran theologians at Leipzig objected to Kepler's creation of special cometary guiding spirits. As was the custom, Kepler intended to publish a

In Kepler's world view, solar magnetic emanations arising from a rotating Sun drive the planets about the Sun, S, in elliptical orbits with the Sun at one focus. This was Kepler's first law. The Sun's motive force on a planet decreases linearly with the planet's distance from the Sun, not as the square of the distance, so that distant planets move most slowly. A particular planet moves slowest in its own orbit when farthest from the Sun, at H, and fastest when closest, at A. Kepler's second law states that this motion can be described by imagining a line drawn from the Sun to the planet sweeping equal areas of the ellipse in equal amounts of time—area ASB = area BSC. Kepler's third law states that the squares of the planetary orbital periods are proportional to the cubes of their orbital semimajor axes (i.e., the semimajor axis in the figure would be one-half the distance AH). Newton would later show that the validity of Kepler's third law depends on a force between the Sun and a planet that varies as the inverse square of the distance between them.



Schematic figure of Kepler's ellipse.

more comprehensive and scientific exposition in Latin shortly after the 1608 German edition. However, the Latin edition was never published separately. There were still theological objections to Kepler's cometary spirits, and noblemen to whom various parts of the book were dedicated kept dying and substitutes had to be found. The printer caused further delays, then maintained that people had lost interest in comets. The problem was finally solved in 1618. Three comets appeared, and Kepler—taking advantage of renewed public interest—published a new essay on comets and worked into it his Latin treatise.

Kepler's 1619 Latin essay, *De cometis libelli tres*, was his cometary magnum opus. Similar to his German tract of 1608, this work was divided into three sections: astronomical, physical, and astrological. In the first section, Kepler adhered to his view that a comet moved along a straight path while the Earth traveled in a circular orbit around the Sun. He outlined 30 propositions on cometary parallax measurements that could be used to determine the difference between a comet's true motion, curved or straight, and its apparent, observed motion. His propositions were applied to the comet of 1607 and the three comets of 1618. After setting down and rejecting rectilinear or circular cometary motion in conjunction with a fixed Earth, he attempted to represent the available cometary observations by assuming the Earth circles the Sun while the comets move along straight paths.

Kepler's inability to satisfy the observations by assuming a fixed Earth strengthened his Copernican views. Since his observations were crude, and the observation interval short, he managed to fit them into a straight line orbit. However, discrepancies between observation and theory reached nearly one degree in celestial longitude and three degrees in latitude. While realizing that his theory did not fit the observations, he believed the agreement could have been improved with more complicated calculations. Referring to the comet of 1607, Kepler noted that additional computations were not warranted because comets do not reappear. As if to underscore the blunder, the comet of 1607 was later identified as comet Halley, the first comet shown to reappear periodically.

Kepler's ideas on the physical nature of comets were essentially the same as those expressed in his German tract 11 years earlier. He surmised that the second and third comets of 1618 were originally part of the same object, but he didn't base this conclusion on observational evidence. According to Kepler, the influence of comets on the terrestrial world was threefold. The first influence was the defiling of the air when a comet's tail touched the Earth. The second was their ominous significance. Employing a classic astrological subterfuge, Kepler backed away from specific predictions based on the comets of 1618, noting that signs or meanings were apparent to those for whom they were intended. The third cometary influence was due to a disruption in the sympathy of nature. According to Kepler, there exists a sympathy of the heavens with that living force that resides within the Earth and regulates its inner works.

> When something unusual arises in the heavens, whether from strong constellations or from new hairy stars, then the whole of nature, and all living forces of

> all natural things feel it and are horror stricken. This sympathy with the heaven particularly belongs to that living force which resides in the Earth and regulates its inner works. If it is alarmed at one place it will, in accordance with its quality, drive up and perspire forth many damp vapors. From there arise long lasting rains and floods, and therewith (because we live by air) universal epidemics, headaches, dizziness, catarrh (as in the year 1582), and even pestilence (as in year 1596).

While Kepler insured his place in the history of science by establishing the elliptical nature of planetary orbits in a heliocentric system, his ideas on comets consisted of a basic Ptolemaic framework interwoven with his own brand of mysticism. If Kepler was a mathematical mystic on the subject of comets, then his equally famous contemporary, Galileo, was a mathematical skeptic.

The Devil's Advocate: Galileo Galilei

As had been the case for bright comets in the previous century, the three comets of 1618 witnessed the publication of numerous tracts, most of which were astrological in nature. One of the most reasonable of these treatises was written anonymously in 1619 by the Jesuit Horatio Grassi, professor of mathematics at the Collegio Romano. In this work, entitled *De tribus cometis annus MDCXVIII*, Grassi dismissed the common fear of comets as groundless and applied Tycho's ideas to the comets seen in 1618. He argued for their celestial nature by citing parallax measurements made in Rome and Antwerp that "scarcely ever exceeded one degree." According to Grassi, comets moved on great circles with constant motion, and their brightness was due to reflected or refracted solar light. As one possible mechanism, he noted Kepler's 1604 experiment with a taillike phenomenon being formed on a wall by sunlight reflected off a crystalline sphere. The comets of 1618 should be placed between the Sun and Moon because their speed was midway between the two.

The newly invented telescope, not yet widely understood, was also mentioned in an erroneous argument for the comet's supralunar position. Grassi believed that a telescope would magnify objects in direct proportion to their distance—the closer the object, the more the telescope would magnify it. Hence, comets should be placed beyond the Moon because the telescope did not perceptibly magnify them as it did the Moon.

Galileo, confined to his bed with severe arthritis and a double hernia, may not have even seen the comets of 1618. Yet, through his friend and student, Mario Guiducci, he replied to Grassi's work in the form of two published lectures. Containing the thinly disguised views of Galileo, Guiducci's work was entitled *Discorso delle comete*. Galileo did not present a coherent

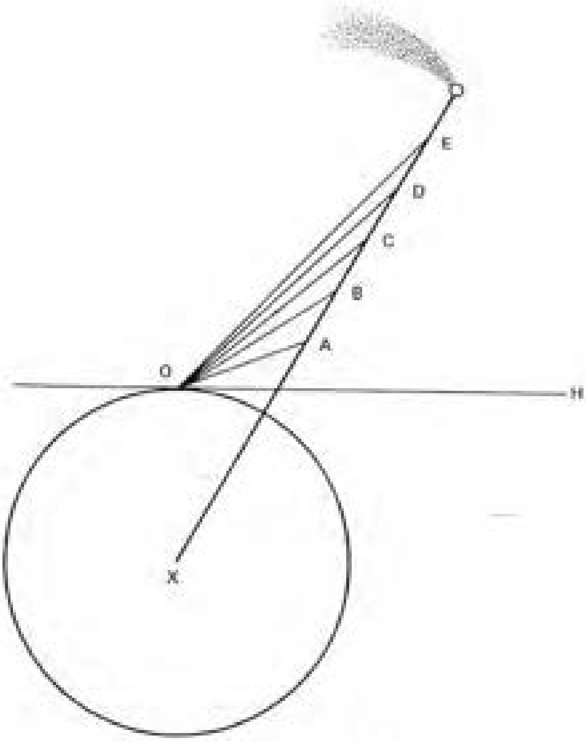
Portrait of Galileo Galilei from his work on sunspots entitled *Istoria e dimostrazioni intorno alle macchie solari. . . .* (Rome, 1613).

cometary theory of his own. Instead, he jabbed away at the minor flaws in Grassi's arguments while occasionally adding a rapier thrust at his major blunders. Galileo relished his role as devil's advocate. In scientific polemics, he was unrivaled. In reading Galileo's reply, one gets the impression he rather enjoyed verbally jousting with Grassi, who was a poor match for the master.

Beginning his role of devil's advocate, Galileo pointed out that comets were not periodic. The only other comet in recent history that could match the splendor of the 1618 comet was in 1577. Assuming that these two comets were the same object traveling in a circular orbit, it would not have traveled even one degree in the observed interval. In fact, the comet of 1618 was observed to move over 90 degrees in its orbit. If the comets of 1577 and 1618 were not the same object, the latter's 90-degree motion in a few months would require that it return in less than a year if its orbit were circular, as Grassi suggested.

Continuing to attack Grassi's ideas, Galileo stated that one must first prove that comets are real objects, rather than reflections, before using the slight parallax observations to infer a supralunar position. For example, rainbows exhibit no parallax because they move as the observer moves. Galileo correctly pointed out that an object's enlargement in a telescope is independent of its distance. Using one contradiction after another, he attacked Grassi's arguments that comets were more distant than the Moon because the telescope showed them to be enlarged less than the Moon. For example, if an annular eclipse is visible with the naked eye and the Sun is farther away than the Moon, the eclipse should appear total when viewed through a telescope!

Galileo also suggested explanations for cometary phenomena. Comets might move vertically upward from the Earth's surface at a uniform rate and in a rectilinear fashion. An observer at O observes the comet slowing down



Galileo's scheme for representing observations of the comet of 1618 without assuming its extraterrestrial nature. The Earth's center is at X, OH is the observer's horizon, and AE is the comet's path.

and decreasing in size as it moves from A to E. H is the eastern horizon, which points to the rising Sun. Galileo felt this explained why comets first appear very large, then grow little or not at all. A comet could shine by sunlight reflecting off a cloud of vapors, and the tail curvature could be due to the refractive effect of the Earth's atmosphere. Galileo also criticized Tycho Brahe directly by pointing out that his explanation for tail curvature was erroneous. Tycho suggested that it was an effect of perspective because one end of the tail was farther from the eye than the other. Galileo pointed out that a straight tail could appear foreshortened but never curved as a consequence of perspective. He also criticized Tycho's suggestion that some comet tails appeared to be directed away from Venus. How could Venus, with its feeble illumination, provide the light source for bright comets? he asked. This, of course, was unfair since Tycho had stated that the Sun was the most likely source of a comet's light. Although Galileo's criticism of Tycho would eventually bring Kepler into the fray, the Roman Jesuits were heard from next.

Offended by Galileo's rebuttal, Grassi and his fellow Jesuits published a direct response to Galileo with a treatise entitled *Libra astronomica*. The Jesuits used the pseudonym Lothario Sarsi for the author. While Galileo did not explicitly state that comets were terrestrial exhalations, Grassi assumed that was what Galileo had in mind. He then outlined the ancient arguments against terrestrial exhalations; for example, they would be impossible to maintain in the midst of the raging north winds. Grassi also argued that if comets were phenomena akin to rainbows, they should—but don't—reflect the Sun's motion. Responding to Galileo's objection to his suggested circular orbit for the comet, Grassi stated that comets could move in ellipses about the Sun. While touching on the truth, Grassi's suggestion was made within a framework that was Tychonic rather than heliocentric. According to Grassi, the Copernican system was "in no way permitted to us Catholics."

The controversy over the comets of 1618 continued with Guiducci himself publishing a long letter to the Reverend Father Tarquinio Galluzzi. Galileo, using his own name this time, responded in 1623 with his *Il saggiatore*, "the assayer." It was written in response to Grassi's *Libra astronomica*, or "astronomical balance." Galileo began by defending himself against Simon Marius, who had claimed prior discovery of four satellites of Jupiter. In fact, Galileo had first seen them; ironically, the names finally adopted for the four so-called Galilean satellites of Jupiter—Io, Europa, Ganymede, Callisto—were suggested by Marius. Galileo returned to the controversy at hand and admonished Sarsi for following Tycho's foolish fabrications in every detail. He referred to a recently published work attacking Tycho by the "distinguished" Scipio Chiaramonti, which he considered a clear rebuttal of Tycho's ideas. Retreating from his previous attack, Galileo pointed out that he never affirmed the location of the comet nor denied that it might be above the Moon; he said only that other authors' theories were not immune from objections. A comet moving rectilinearly away from the Earth was considered because it would explain cometary phenomena more simply and in better agreement with the observations. In his *Il saggiatore* Galileo dismissed Tycho's parallax measurements by stating:

> Tycho himself, among so many disparities, chose those observations which best served his predetermined decision to assign the comet a place between the Sun and Venus, as if these were the most reliable.

Galileo was not one to mince words. In response to Sarsi's assertion that he borrowed the explanation of tail curvature from Kepler, Galileo stated that his ideas required refracted light in the Earth's atmosphere, whereas Kepler's required refraction in the tail itself. He seemed very careful not to step on Kepler's toes after trampling Tycho's.

Although Galileo wrote nothing derogatory about Kepler, he was very critical of Kepler's teacher, Tycho. When Kepler received a copy of Galileo's *Il saggiatore*, he had just finished a defense of Tycho against the peripatetic Italian astronomer Scipio Chiaramonti. The defense against Chiaramonti's *Anti Tycho* was entitled *Tychonis Brahei Dani hyperaspistes* (Shieldbearer of Tycho Brahe, the Dane). It was published at Frankfurt in 1625. Defending Tycho without responding to Galileo's charges would have been unsuitable, so Kepler added an appendix to his work. While avoiding the controversy between Grassi and Galileo, Kepler's appendix answered, point by point, issues related to Tycho or himself. He also straightened out some of Grassi's misconceptions, pointing out that the experiment outlined in his 1604 work *Astronomiae pars optica* was not meant to apply to real comets. It was pure conjecture, an academic exercise to demonstrate how one could simulate a comet's tail by allowing a beam of light to pass through a glass globe. Kepler then expressed his revised views on cometary tail formation:

> The head is like a conglobulate nebula and somewhat transparent; the train or beard is an effluvium from the head, expelled through the rays of the Sun into the opposed zone and in its continued effusion the head is finally exhausted and consumed so that the tail represents the death of the head.

While Galileo suggested that the curvature of cometary tails was due to refraction of light in the Earth's atmosphere, Kepler countered that if this were the case, the curvature would be slight and always upward toward the zenith. In addition, the curvature would exist only when the comet was near the horizon. Kepler stated that his idea of nonuniform motion was not a result of direct cometary observations. Rather, it arose in analogy to observations of rockets and meteors. He went on to explain that after considering the observations of the comets of 1618, he could find no strong reason for establishing that rectilinear motion was slower at each end of the trajectories, so he left the nonuniformity of a comet's motion in doubt.

Returning to his defense of Tycho, Kepler emphasized the extreme care with which Tycho made his observations and implied that Galileo resented Tycho's well-earned authority. Grassi and the Jesuits were also subjected to Kepler's sharp rebuke. To Sarsi's rejection of the Copernican system because "these things are in no way permitted to us Catholics," Kepler responded, "perverse and querulous at best, servile at worst."

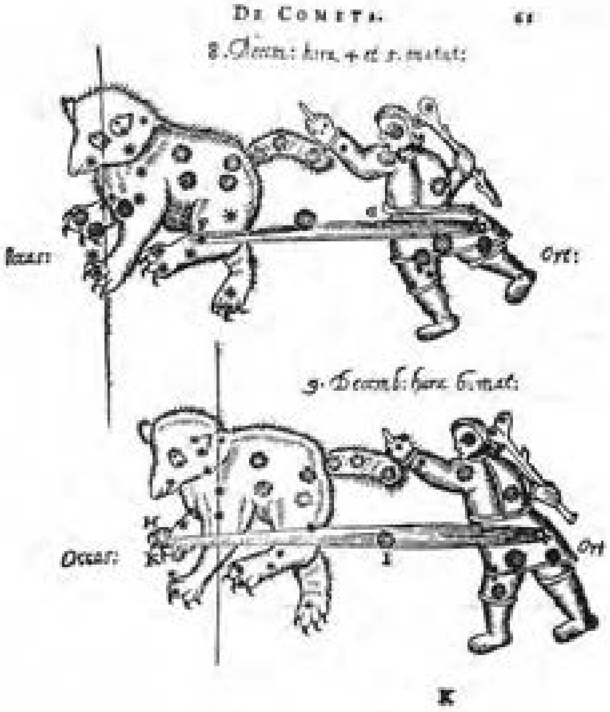
Again using the pseudonym Lothario Sarsi, Grassi answered Galileo's *Il saggiatore* with a weak, heavy-handed response in 1626. Typical of Grassi's clumsy wit was the attempt to suggest that Galileo had been imbibing too freely of wine, pretending that *saggiatore* really meant "winetaster," *assaggiatore*. In the controversy over the comets of 1618, Grassi and his fellow Jesuits were polemical lightweights compared to Galileo. One gets the impression that Galileo could have argued effectively for a flat Earth against Grassi. One also wonders what the outcome might have been had Galileo's battle been, not with Grassi, but Kepler.

Early Seventeenth Century Views on Comets

Although eclipsed by the authoritative views of Galileo and Kepler, contemporary cometary ideas were also expressed by the notable scientists Willebrord Snel (1580–1626), Pierre Gassendi (1592–1655), Seth Ward (1617–1689), and René du Perron Descartes (1596–1650).

Willebrord Snel began his astronomical career under Tycho Brahe's tutelage at Prague. Although best known for his law of refraction, which he formulated about 1621, Snel also published descriptions for the comets of 1585 and 1618 while he was a professor of mathematics at Leiden. He eliminated terrestrial vapors as a possible origin of comets because his own parallax measurements placed the comet of 1618 above the Moon. He believed the Sun constantly threw off exhalations from which sunspots and comets formed. In contrast to cometary material, sunspots were made of a less pure, and hence more opaque, substance. As ejected solar material, comets glowed by their own light. However, Snel did not break with contemporary superstition and professed a belief in comets as portents.

The French scientist Pierre Gassendi left a short essay on comets embedded in his posthumously published, six-volume work *Syntagma philosophicum*. Like Kepler, Gassendi believed that comets moved uniformly along rectilinear paths. Although he was uncertain about their nature, Gassendi was a central figure in the fight against cometary superstition. His common



Comet of 1618 in constellation of Boötes, the herdsman, on December 8, 1618. The long tail is directed toward Ursa Major (the great bear). From Johann Baptist Cysat's *Mathemata astronomica de loco, motu, magnitudine et causis cometae . . .* (Ingolstadt, 1619).

sense arguments formed the beginning of a French movement toward a rational view of comets that would be carried forward by Pierre Petit in 1665 (see Chapter 4).

In his *De cometis*, published in 1653, the Englishman Seth Ward expressed the opinion that comets were eternal and returned periodically on closed orbits, which were circles or ellipses that could either include or exclude the Earth. So great were the extent of these orbits, they could only be seen when nearest the Earth, at perigee. Ward's views were not based on observational evidence but rather on his belief in their eternal nature. The opposite argument was used by Kepler to infer their rectilinear motion.

The possible elliptic nature of cometary orbits was mentioned first by Tycho in connection with the comet of 1577, and was brought up occasionally in the early seventeenth century. In a letter dated February 6, 1610, addressed to Thomas Harriot, the Welsh amateur astronomer Sir William Lower wrote that ellipses "shews a way to the solving of the unknown walkes of comets." Baron Franz Xaver von Zach (1754–1832) discovered a portion of this letter in 1784; the remainder was subsequently found among Harriot's papers in the British Museum. The complete letter was published by Stephen P. Rigaud in 1833.

Of the theories presented in the early seventeenth century, the most original was that of the French scientist-philosopher René Descartes. Before the acceptance of Newtonian cosmology, the Cartesian vortices ruled the day, and—not surprisingly—Descartes' cometary ideas were an integral part of his cosmology. According to Descartes, each star was surrounded by a vortex, supported by the light pressure of the central star and the pressure from particles of neighboring vortices. Caught up in the surrounding ether, planets revolved around the central star like a chip of wood in a whirlpool. Planets and comets were both formed from dead stars, the only distinction being that comets were more dense. In Descartes' imaginative system, both planets and comets were formed when sunspots linked together and completely covered the central star. Once covered, the light pressure supporting the surrounding vortex ceased, the vortex collapsed, and the star—now dead—was caught up in the strongest neighboring vortex. Dead stars of lesser density acquired momentum equal to the surrounding vortex particles and became planets in stable periodic orbits. If the dead star was sufficiently dense, the vortex particles, through continued *agitation*, gave it an escape velocity, allowing it

Comet of 1618 moving northward through the constellations of Libra and Boötes. From John Bainbridge's *An Astronomicall description of the late comet. . . .* (London, 1619).

to move tangentially out of the vortex and become a comet. The comet then wandered from one stellar vortex to another, temporarily taking the velocity and direction of the vortex through which it passed. Its orbit was slightly curved in each vortex. For our own solar system, comets were found at the outer edge—at the distance of Saturn.

While Descartes considered comets more dense than planets, presumably he was comparing the density of the planets with that of the cometary head, or nucleus. The tail and coma phenomena were explained using an optical refraction hypothesis. The nucleus of a comet was seen when solar rays were reflected directly to an observer, while an illusion of a tail was formed when solar rays were refracted in the ether of the vortex before reaching the observer's eye. The number of refracted solar rays was small compared with the number reflected directly to the observer's eye, so the nuclear region appeared brighter than the coma or tail. Descartes' theory, contrived as it was, provided one of the few contemporary explanations of how sunlight could optically pass from the comet's head, form a tail, and then be directed toward an observer's eye. However, among other shortcomings, his theory did not require the tail to point in an antisolar direction. According to Descartes, planets should also exhibit a tail, which was in fact visible in countries where the air was clean and pure. In the pre-Newtonian era, acceptance of Descartes' cosmology was widespread. However, his cometary views were not as well received.

The comets of 1618 prompted influential cometary theories by both Kepler and Galileo and were the first to be observed telescopically. Although Kepler observed the first comet of 1618 on September 6 with the aid of a telescope, it was the last comet seen that year that was extensively studied with the recently invented device. While Galileo was the first to view the heavens with the telescope, there is no record that he ever used it to observe the comet of 1618; that honor goes to the Swiss Jesuit Johann Baptist Cysat (ca. 1586–1657) and the English astronomer John Bainbridge (1582–1643).

After assisting Christoph Scheiner in his observations of sunspots, Cysat became professor of mathematics at Ingolstadt, where he observed the comet of 1618. Cysat measured its position with respect to two neighboring stars and employed a wooden sextant of six-foot radius for most of his measurements from December 1, 1618, through January 22, 1619. He attempted to determine the comet's true motion on the sky by noting its position on consecutive days at the same altitude. The apparent motion was observed over a few hours then compared with the true daily motion. Although his technique was questionable, Cysat believed his observations revealed no sensible parallax. On this basis, he proposed two theories, both of which assumed a fixed Earth. The first theory postulated a Tychonic circular orbit around the Sun located between Venus and Mars. The second theory fit a

Title page of woodcut engraving showing comet in celestial, not terrestrial, space. From John Bainbridge's *An Astronomicall description of the late comet. . . .* (London, 1619).

straight line trajectory to his observations of December 1, 20, and 29. Using a telescope, Cysat also observed the comet's physical appearance. The head and tail dimensions were measured, and it was noted that the head was composed of several condensations after December 8. Cysat likened the comet's appearance to nebulae seen in Cancer, Sagittarius, and the sword of Orion. He believed that it received its light from the Sun and recorded that its tail undulated as if blown by a wind.[4]

John Bainbridge published his observations of the comet of 1618 in a small tract entitled *An Astronomicall Description of the Late Comet*. His observation interval was November 28 to December 26, 1618. Using a telescope in the second week of December, Bainbridge observed the comet with respect to two neighboring stars. By comparing their relative positions near the horizon and the zenith, he determined that its distance from the Earth was more than 10 times the Earth-Moon distance.[5] Its apparent size at this enormous distance precluded a make-up of terrestrial vapors. Although he confessed his ignorance to the Almighty, Bainbridge denied that the comet was formed from the Milky Way or by planetary conjunctions. He ended his tract by arguing against comets as portents. This work was remarkable, not only for the telescopic parallax determination, but for its attack on the Aristotelian system and his clear preference for a heliocentric cosmology. Bainbridge's treatise on the comet of 1618 did not go unrewarded. It was at least partially responsible for his appointment to the first Savilian professorship at Oxford University in 1619.

Summary

The early seventeenth century witnessed the first use of the telescope for cometary observations. This significant step forward in cometary science must be measured against the two steps backward made by the period's two most influential astronomers, Kepler and Galileo. From 1602 on Kepler never deviated from his belief in the straight line motion of comets. However, a few of Kepler's views on the *physical* nature of comets were surprisingly modern: they shine by reflected sunlight and solar rays draw out a portion of the head material in an antisolar direction, so that the tail represents the death of the head.

The controversy over the comets of 1618 began when the Jesuit Horatio Grassi published a reasonable treatise on comets that relied mostly on the ideas of Tycho Brahe. Playing the role of devil's advocate, Galileo and his student, Mario Guiducci, responded with a work that did not really present a coherent cometary theory. Rather, Galileo chose to rebut and ridicule Grassi's arguments and his reliance on Tycho. Galileo, an argumentative, sarcastic, and mocking adversary, was clearly the polemical victor. However, Grassi's position is physically more defensible.

The contemporary views of Willebrord Snel, Pierre Gassendi, Seth Ward, and René Descartes were indicative of the more enlightened viewpoints in the early seventeenth century, and by the end of this period a transition from terrestrial exhalations to celestial objects had been made. However it was still questionable whether comets were eternal or ephemeral, or whether they moved on closed orbits or straight lines. If they moved on closed orbits, no preferred central body was identified. Unfortunately, in the latter half of the seventeenth century, the confusion over the nature and paths of comets was to become worse before getting better.

NOTES

1. The north star, Polaris, is a second-magnitude star. A celestial object whose magnitude is one would be two and one-half times brighter than Polaris while an object two and one-half times fainter would have a magnitude of three. An object whose magnitude is equal to six would be 100 times fainter than a first-magnitude object and just at the limit of naked-eye visibility.

2. See Appendix for observation summaries of the three comets of 1618.
3. The notion of an invisible, intangible substance in space, the ether, which takes a causal part in the motions of planets and transmission of light, had been postulated by the ancient philosophers. The idea of a single, all-pervasive ether received its greatest support in René Descartes' cosmology of vortices, a theory that was widely believed prior to the Newtonian era.
4. The observed wave phenomena in cometary ion tails are believed due to traveling interplanetary magnetic fields that originate with the Sun.
5. At the time of Bainbridge's parallax determination, the comet was actually as far away as 145 times the Earth-Moon distance.

4
The Comet of 1664
Confusion Reigns

Jean Dominique Cassini suggests that the comet of 1664 orbits the star Sirius. Pierre Petit dispels cometary superstition and offers an incorrect prediction for a comet's return. Robert Hooke's comets dissolve in interplanetary ether. Johannes Hevelius introduces the concept of cometary frisbees, and Christiaan Huygens develops a theory of rocketlike comets. Confusion reigns in the contemporary ideas used to explain the comets of 1664 and 1665.

THE COMET OF 1664 was discovered in Spain on November 17, 18 days prior to perihelion. It reached its greatest apparent brightness on December 29, when it passed within 0.17 astronomical units, AU, of the Earth. It was followed telescopically in Spain until March 20, 1665. Christiaan Huygens (1629–1695) first observed it on December 2 from Leiden, and Johannes Hevelius made his first observation 12 days later in Danzig, now Gdansk, Poland. The comet was also observed by Jean-Dominique Cassini (1625–1712) and Giovanni Alfonso Borelli (1608–1679) in Italy, by Adrien Auzout (1622–1691) and Pierre Petit (ca. 1594–1677) in France, Robert Hooke (1635–1702) in England, Samuel Danforth (1626–1674) in North America, several scientists in Spain, and by just about anyone who glanced skyward on a clear night in late December 1664. Due to its proximity to Earth at that time, the comet reached an impressive apparent magnitude of −1, with its tail reaching nearly 40 degrees in length. To the few who could remember the great comet of 1618 and the attendant popular concern, the appearance of this comet was even more impressive. There were many contemporary treatises written about this comet but the majority were astrological or religious in nature.

Only one week after the comet of 1664 was last sighted retreating from the Sun, the less impressive comet of 1665 was discovered at Aix in southern France. It quickly moved into the glare of the Sun and was last seen on April 20, 1665, four days before reaching perihelion. Hevelius observed it from April 6 to 20, and observations were made by Auzout, Petit, Borelli, Hooke, and others. The appearance of the comets of 1664 and 1665 prompted treatises from many important astronomers, and their widely varying conclusions and theories underscored contemporary confusion concerning the nature of comets.

Closed Orbits: The Comet of 1664 as a Permanent Object

As the first of four in the great family of Italian and French astronomers, Jean-Dominique Cassini was an exacting observer of comets. However, he was not a theoretician, and his resistance to new ideas led French science historian Jean-Baptiste Delambre to accuse him of having found his best ideas in the writings of his predecessors, and directing French astronomy backward. Even the Copernican ideas of a century earlier were rejected by the conservative Cassini. Born in Italy, Cassini's early work was carried out in Panzano, Italy, at the private observatory of a rich amateur astronomer, the Marquis Cornelio Malvasia. In 1669 he continued his work in Paris at the newly formed Academy of Sciences.

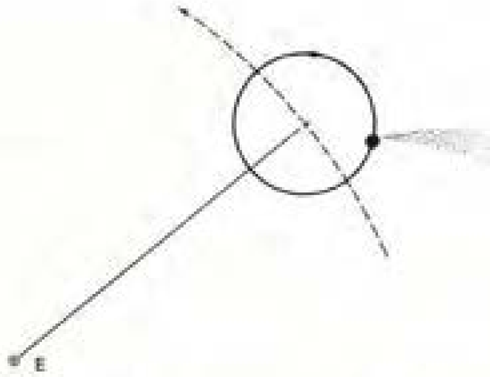
In his account of a comet seen in 1652 and 1653, Cassini began by stating that comets were situated beyond Saturn and formed from terrestrial and planetary emanations. However, after comparing his observations with those of others, he considered comets analogous to the planets, except that their motions were highly eccentric with respect to Earth.

After observing the comet of 1664, Cassini published his ideas on cometary motions in his *Hypothesis motus cometae novissimi*. He correctly noted that the comet of 1664 passed closest to the Earth on December 29, 1664. Using the Earth-Moon and Jupiter-Galilean satellite systems as analogies, Cassini sought this comet's central body. From the position of the comet near *perigee*, he selected the star Sirius. According to Cassini, the center of the comet's circular epicycle was Sirius and the star-comet system itself turned upon a deferent around the Earth. The comet was invisible during most of its orbit due to its very large distance from Earth, approaching Earth only in the lowest part. Although Cassini previously located comets beyond Saturn, there is some evidence that the comet of 1664 passed within Earth's solar orbit. While he theorized a circular orbit about Sirius, his computations for the comet's motion assumed a rectilinear trajectory. To make theory

Jean-Dominique Cassini. (*Courtesy of the Paris Observatory.*)

agree with observations, Cassini employed a computational device and introduced a daily advancement of 6 arc minutes in the comet's perigee and the points, or *nodes*, where its orbit intersected the *ecliptic*. The ecliptic is the plane defined by the Earth's motion around the Sun (or as Cassini would have it—the plane formed by the Sun's motion around the Earth).

Cassini also tried to explain the motion of the great comet of 1680. Pre- and postperihelion observations of this comet were considered observations of two separate comets. Together, these observations could not fit with a great circle, whereas separately they could. For the preperihelion observations before December 18, 1680, Cassini postulated a circular orbit around Earth that intersected the Sun's orbit. He also suggested that cometary orbits were restricted to a certain band on the celestial sphere—a cometary zodiac.



Cassini's theory for the comet of 1664 had the star Sirius as the center of the comet's circular orbit, the epicycle. The star then revolved around the immobile Earth, E, in its orbit, or deferent.

Like Cassini, Adrien Auzout approached astronomy using instruments rather than mathematics. Although he invented neither, the Frenchman Auzout is best remembered for making significant improvements to the final development of the micrometer and telescopic sights.

After observing the comet of 1664 four or five times between December 22 and December 31, 1664, Auzout predicted cometary positions on the sky, an *ephemeris*, for dates from the previous November through February 1665. Finished on January 2, 1665, his *search ephemeris* was the first such prediction to be published. The predicted path of the comet was generated by marking the observations on a celestial globe and then orienting the globe until the observation points fell on its horizon circle. The path along the horizon circle then represented the motion of the comet on the sky, which could be extended forward in time. The position of the nodes and inclination angle that the comet's orbit made with the ecliptic were then easily read directly from the globe. Both Cassini and Auzout used this device to generate a crude search ephemeris, but while Cassini took time to make additional computations based on spherical trigonometry, Auzout rushed his ephemeris into print.

Commenting on Cassini's notion that the comet of 1664 moved in a circular orbit about Sirius, Auzout mentioned that he, too, thought of this idea and noted that the comet of 1651 had about the same speed as Sirius and came to perigee opposite the bright star. Auzout reasoned that if the comets of 1664 and 1651 were one, its reappearance could be expected around 1676. However, as he could find no recollection of a comet that appeared every 12 years and there was no evidence that well-observed comets arrived at perigee in conjunction with a notable star, Auzout could not endorse Cassini's theory. Although Auzout could find no evidence of reappearance, he did not abandon the idea that comets might be permanent celestial bodies subject to return.

Fearing that cometary superstitions were a hindrance to his kingdom, young Louis XIV of France requested a rational book on comets from Pierre Petit. It was a fortunate choice because Petit was an empiricist among the doctrinaire Cartesians. Rising to the royal edict, Petit wrote a work entitled *Dissertation sur la Nature des Comètes*. Much of the book attempted to dispel the common fear of comets. In a geocentric, infinite universe, Petit thought of comets as universal garbage collectors, created to pass into the solar neighborhood and collect waste gases and fumes exhaled by planetary atmospheres. They were permanent celestial bodies that returned at periodic intervals. In the distant reaches of their orbits beyond Saturn, they were invisible, and remained unrecognizable when they had returned in the past.

Turning to the comet of 1664, Petit attempted—but could not detect—a parallax. Using Grassi's invalid argument against Galileo, Petit placed part of its orbit beyond those of the planets because he found that a telescope magnified the planets more than the comet. Noting that celestial bodies have revolutions lasting from 1 day to 30 years, he saw no reason why comets could not have periods of 100 or 1000 years or more. While Petit favored elliptic motion for the comet path, he was not sure whether the ellipse should surround the Sun, the Earth, or neither. For the comet of 1664, he did not place the ellipse around either one.

The following interpretation of Petit's theory for the comet of 1664 was given by James A. Ruffner in 1966. According to Petit, the comet of 1664 should have appeared and disappeared at the same distance from the Earth. He argued that its motion could not be circular since then the observed arc A′P before perigee should have equaled the observed arc PB after perigee. The perigee point P was well determined, and the arc observed with the naked eye before perigee appeared to be longer than the one after perigee. To represent the observations, Petit introduced an ellipse whose major axis was skewed with respect to the line from the Earth to the comet's center of motion. The comet appeared at A and disappeared at B, and its final apparent motion, as seen from the Earth, was nearly stationary near B. Hence, the observed arcs before and after perigee, AP and PB, did not appear to be equal. Petit assumed the comet appeared and disappeared at the same geocentric distance, EA = EB, so that the skewed ellipse satisfied both the observations and his assumptions.

From their physical appearance and similar apparent positions on the sky, Petit claimed that the comets seen in 1664 and 1618 were the same object. He then proceeded back in time at 46-year intervals and identified pos-

An Oversight by the Astrologer John Gadbury

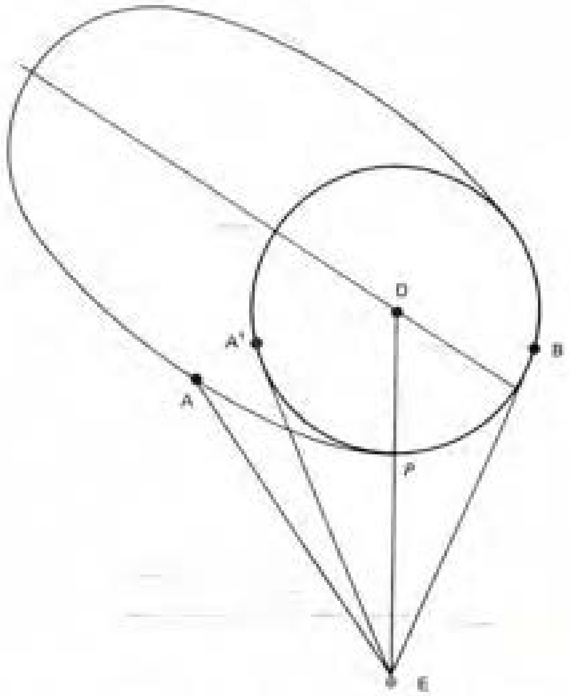
The importance of the comets of 1664 and 1665 was not overlooked by astrologers who attempted to presage their influence by noting the appearance and initial locations of the two visitants. The London astrologer John Gadbury had a particularly fertile imagination. In 1665, he published a booklet entitled *De cometis* in which he outlined the possible unpleasantries that would arise if a comet first appeared in any of the 12 zodiacal constellations. Mr. Gadbury's list follows:

Comet first appears in	*Expected events*
Aries	Diseases affecting the head and eyes, detriment unto rich men, sorrows and troubles to the vulgar
Taurus	Sickness and great earthquakes, death of a great man, detriment to cattle, rotting of fruit
Gemini	Grievous diseases for children, men given to commit fornications, many abortions, prodigious winds
Cancer	Famine, pestilence, wars, abundance of locust or caterpillars and such worms that destroy the fruit
Leo	Vermin, rats, detriment to great ladies, dogs run mad in multitudes, corn destroyed by worms
Virgo	Detriment to merchants, noble women subject to scandals, infamies, and disgrace
Libra	Portends thieves, housebreakers, and highwaymen, extremes of heat and cold, death of some king
Scorpio	Wars and controversies among men, rebellion, scarcity of grain and fruit
Sagittarius	Denotes depression in noblemen
Capricorn	Fornication and adulteries to be rife and common among men, persecution of religious men
Aquarius	Plague sweeps away a multitude, terrible and durable wars, death of an eminent prince or great female
Pisces	Air replete with prodigies, destruction of fish

These rules for predicting events by noting a comet's celestial position would have failed miserably for the comets of 1664 and 1665. The former was seen first in southern Virgo on November 17, 1664, and last on March 20, 1665. As if to continue the cometary portent, the latter was first recorded above Capricorn on March 27, 1665.

Gadbury's rules would have predicted scandals, persecution, and fornication, but London was about to be beset with a different catastrophe. In May 1665, the black plague broke out. Among those who fled the city was Isaac Newton, who would soon help diminish the popular fear of comets. Deaths in May 1665 numbered a few dozen, in June a few hundred, in July over 6000, in August 17,000, and in September over 31,000 persons died. By the end of 1665 nearly 90,000 people had died in London—nearly one-fifth the total population. As a lasting testament to astrological prediction, the comets of 1664 and 1665 first appeared in two of the few zodiacal constellations that did *not* predict some sort of disease or pestilence.

A woodcut by Diebold Schilling, done in 1508–1513, showing the disastrous effects upon the populace after the appearance of a comet (Halley) in 1456. Note the classic symptoms of the black plague, which included splitting headaches, pain to the back and limbs, and fever. (*Courtesy of the Swiss National Museum, Zurich.*)



Pierre Petit's theory for the comet of 1664 suggested elliptic motion for the comet. The comet's ellipse, which enclosed neither the Sun nor the Earth, was skewed with respect to the line ED drawn from the Earth to the comet's center of motion. The total observed path of the comet on the sky was APB.

sible apparitions of the same comet during preceding centuries. He predicted it would be seen approximately every 46 years, the next return would be 1710. Petit gloried in being the first to announce the return of a comet, a prediction based on previous observations and his theory of cometary motions. Just as Columbus fulfilled Seneca's prophesy that in time someone would discover a new world by sea, Petit immodestly felt that he had fulfilled Seneca's prophesy that the way of comets would one day be known. Alas, the world would have to wait another 40 years for a correct prediction: Petit's comet of 1618 and 1664 were entirely different. Writing a century later, Alexandre Pingré put Pierre Petit's work into perspective with an outrageous pun. Keeping in mind that *pierre* is French for stone, Pingré recorded that Petit's system was only "rough chiseled," it failed to decide the nature and position of the cometary orbit and that was the "stumbling stone of Petit," *la pierre d'achoppement de Petit.*

Writing at the same time as Petit, another Frenchman, Claude Comiers (d. 1693), wrote a rational treatise on comets. In addition to a review of existing ideas and a long, balanced discussion of comets as portents, Comiers developed Kepler's theory of tail formation. In what was a rather modern stance, Comiers stated that comets reflect the Sun's light from their atmosphere, their tails form when solar heat rarefies and dissipates the coma material, and the solar rays push this material behind the head in an antisolar direction.

The versatile Italian scientist Giovanni Borelli observed the comet of 1664 from December through the beginning of February 1665. Toward the end of this period, Borelli made parallax measurements and concluded that the comet was beyond the Moon. From his attempts to compute its path, Borelli was forced to conclude that its geocentric distance varied with time. For the sake of computation, he assumed the heliocentric theory to be correct and concluded that the comet probably traveled in an elliptical orbit or another curved path. The Church had forbidden the Copernican system so Borelli referred to it obliquely, giving it a classical name. When his results were published as a letter to Stefano degli Angeli entitled *Del Movimento della Cometa Apparasa il mese di Dicembre 1664*, Borelli further covered his tracks by using the pseudonym Pier Maria Mutoli.

Borelli's attention was also directed to the comet of 1665 and on May 4, 1665, he wrote a letter to Duke Leopold de Medici noting that its motion could not be represented by a straight line. Borelli's observations were best represented with a curved line resembling a parabola. On a trip to Florence Borelli hoped to demonstrate his hypothesis to Leopold by mathematical calculations and a mechanical device. Unfortunately the particulars of the device, if they ever existed, have been lost. A portion of the letter to Leopold was published in 1817 by Baron Franz von Zach.

The comet of 1664, extensively observed and reported in Europe and China, also witnessed the first original astronomical contribution from North America. Samuel Danforth, a puritan clergyman in Roxbury, Massachusetts, published his observations and analysis in *An Astronomical Description of the Late Comet or Blazing Star.* Observing the comet from December 15 to February 14, Danforth noted its varying apparent motion and suggested its circular orbit was offset from the Earth's center. He considered the comet's supralunar position was evident from its slow apparent motion, visibility to all countries, and from his own null parallax determination. Noting that the comet's motion appeared most rapid on December 28, 1664, Danforth stated that it passed closest to the Earth on that day. Attempting to explain its physical appearance, Danforth suggested that "sunbeames" are refracted in the transparent body, congregate together, and become visible as a blazing stream.

The Poetic Use of Comets

After the fact, the two comets of 1664 and 1665 were commonly thought to have presaged the London plague of 1665 and a subsequent fire in late summer 1666. The fire completely destroyed 436 acres of the city within a few days. One year later, the English poet John Milton published *Paradise Lost* and his allusion to a comet becomes all the more meaningful in view of these disasters. Describing the hostile meeting between Satan and Death before the gates of hell, Milton writes:

> On the other side,
> Incensed with indignation, Satan stood
> Unterrified, and like a comet burned,
> That fires the length of Ophiuchus huge
> In the arctic sky, and from his horrid hair
> Shakes pestilence and war

Milton's poetic use of comets is reminiscent of a quote from the Greek poet Homer in the late eighth century B.C. In the nineteenth book of the *Iliad*, speaking of the helmet of Achilles, we read that it shone

> Like the red star, that from his flaming hair
> Shakes down diseases, pestilence and war

Rectilinear Orbits: The Comet of 1664 as a Transitory Object

It was unfortunate that Robert Hooke was a contemporary of Isaac Newton and Edmond Halley. In any other era, he could have stepped out of their shadows and dominated contemporary science. A true Renaissance scientist, Hooke's influence was felt in nearly every branch of the exact sciences.

A woodcut by Diebold Schilling in 1508–1513 illustrates the dreadful effects of the comet of 1472. (*Courtesy of the Swiss National Museum, Zurich.*)

If it were not for continued badgering by the Royal Society of London, Hooke's views on comets might not have been recorded. He observed the comets of 1664 and 1665 and had studied both the observations and other people's theories. He also studied published results on the comet of 1577 and developed a theory that he hoped to test against the observations of a new comet. Hence, Hooke waited until the appearance of the comet of 1677 before he finally published his ideas in 1678 as a Cutler lecture entitled *Cometa or Remarks about Comets*. Hooke first saw the comet of 1677 on May

1 and observed it through May 4 using a six-foot telescope. With characteristic ingenuity, he measured the apparent diameter of the coma by noting its dimensions with respect to the support pole of a neighboring weather cock. Based upon his own and other observations of historic and contemporary comets, Hooke put together a coherent theory to explain their physical appearance and motion.

Hooke suggested that cometary nuclei were solid bodies made up of the same magnetic material residing within the Earth's interior. A nucleus might dissolve by chemical action of the surrounding ether and internal agitation, and the dissolution process would reduce its gravitation. As an analogy, Hooke mentioned an eruption of Mt. Aetna in Sicily, where the internal parts of the Earth were so agitated that matter changed state so as to "confound the gravitating principle." Hooke also used lodestone as an example of a substance that can lose its attracting qualities if it changes state. The contrary effect, repulsion, was also possible. Hence the nucleus dissolved equally on all sides, and the coma and tail material flew away from the center in all directions. Material shot toward the Sun obtained a repulsive virtue and was deflected back in parabolic curves. Single particles continued in their motion until they burned out or dissolved into the ether. In an aside, Hooke noted that the Earth's atmosphere was a result of the ether dissolving parts of its crust.

Since the cometary nucleus does not exhibit a shadow, Hooke concluded that not all of a comet's light was due to the Sun. Some light might be analogous to that produced by the Sun or stars or to the light of such things as decaying filth, rotten wood, or glow worms. He then cautioned the reader against seeking common analogies for a comet's light source since it might differ from other known sources. Any deflection of the tail from the antisolar direction was due to the resistance of the ether. With regard to age, Hooke asked, How could so vast a body be generated? How could it supply a constant stream of ascending parts? How could a newly generated body receive so great a degree of motion? Answering his own questions, he responded that comets were likely as old as the world, retained their original motions, and were still slowly dissolving in the ether. The apparent disappearance of a comet was not due to its consumption but rather to its removal to a great distance from the observer.

Hooke's ideas on cometary motion were intertwined with their physical behavior. By internal agitation and external dissolution, a comet's gravitational principle was disturbed over time. Then the comet no longer circled the central body but tended toward a straight line as it lost its attractive, magnetic virtue. The remaining nucleus would retain some of this attractive virtue so the resultant motion was slightly curved, concave toward the central body. Earth or planetary attractions distorted the comet's path, but as long as it moved faster past any point in the system than a planet would move there, its path would be less sharply curved than the planet's. Although vague as to whether a comet's orbit was once closed, Hooke emphasized the central role of gravitation in its orbital motion:

> I cannot imagine how their various motions can with any satisfaction be imagined . . . without supposing a kind of gravitation throughout the whole Vortice or Coelum of the Sun, by which the Planets are attracted, or have a tendency toward the Sun, as terrestrial bodies have toward the center of the Earth.

In a letter dated January 6, 1680, Hooke wrote to Isaac Newton stating his conviction that gravity decreased in a power proportional to the square of the distance between the two bodies. Thereafter, Hooke was convinced that Newton had stolen the inverse square relation from him. For his part Newton cited Hooke's *Cometa* as proof that Hooke did not know of this relationship in 1678. Newton believed Hooke could not even claim second place because Christopher Wren knew of it in 1677. In fact, Ismael Boulliau suggested it even earlier. In his 1645 work *Astronomia Philolaica*, Ismael Boulliau asserted that if a planetary moving force did exist—which he denied—it should vary inversely as the square of the distance.

Concerning the distance to the comet of 1664, Hooke could only conclude that it had no demonstrable parallax. He expressed dismay at the inaccuracy and inconsistency of contemporary position observations. Different observers recorded the comet at different positions at the same time; the more observations he collected, the more inconsistent they became. Hooke could not obtain a meaningful parallax determination and concluded only that the comet's distance was very great. Although he was a firm believer in the Copernican system, contemporary observations were so inaccurate they supported varied hypotheses concerning Earth and cometary motions. In fact, the observed motion of the comet of 1664 could be represented best with an immobile Earth and the comet moving on a circular path. The observations could also be satisfied by assuming the Earth and comet were moving on circular paths, and these were not the only two hypotheses that could represent the observations. He pointed out that elliptical orbits and diverse other hypotheses would also explain the observed phenomena. At the end of his discussion on the comet of 1664, Hooke concluded that the comet's path was a little curved by the Sun.

In the history of science, comets in particular, the number of ideas anticipated by Hooke is surprising. They include universal gravitation, the dynamical effects of planetary perturbations and nongravitational forces (i.e.,

Portrait of Johannes Hevelius from his book *Machinae coelestis pars posterior* (Danzig, 1679).

drag effects of the ether), cometary self-luminescence, and a slowly dissolving cometary nucleus. From the insight and genius of Robert Hooke, we pass to the industry and precision of Johannes Hevelius.

The Polish astronomer Johannes Hevelius' initial astronomical career was crowned by success and good fortune, but later years were submersed in controversy and disaster. Born into a prosperous brewer's family, Hevelius established what was for a time the world's leading astronomical observatory. Like Jean-Dominique Cassini, Christiaan Huygens, and Pierre Petit, Hevelius had Louis XIV as a patron, and for several years he received annual research grants.

To note that the published works of Hevelius were fine examples of seventeenth century printing would be an unfair understatement. Hevelius used fine Dutch paper, drew and engraved his own magnificent plates, and printed his books on his own press. His first work, *Selenographia*, published in 1647, was on lunar topography and a marvel to all who saw it. When shown a copy sent to Italy, the Pope said it would be a book without parallel had it not been written by a Copernican heretic.

The later years of Hevelius' career were marred by controversies. The first was with Adrien Auzout, Pierre Petit, and several other contemporary astronomers over the position of the comet of 1664 in mid-February 1665, the second was with John Flamsteed (1646–1719) and Robert Hooke, who belittled Hevelius' work because he used naked-eye—rather than telescopic—sights. While Hevelius used telescopes for physical observations, he trusted only his naked-eye sights for accurate position measurements. Were it not enough to be at odds with many of his scientific contemporaries, Hevelius' famous Danzig observatory, Stellaburgum, burned to the ground on September 26, 1679. Although he immediately began rebuilding, his new instruments were fewer in number and inferior to those that had been destroyed. Grieved by the loss of his observatory and books and tired from his controversy with Flamsteed and Hooke, Hevelius died on his 76th birthday in 1687. The passing of the last great naked-eye observer in 1687 was accompanied by the printing of Newton's *Principia* the same year, an interesting transition from the old to the new astronomy.

Eager to follow his well-received *Selenographia* with another scientific masterpiece, Hevelius began working on *Cometographia*. By December 1664, when the comet of 1664 arrived, the book was three-quarters complete. Public interest and appetite for cometary treatises were not to be ignored and Hevelius set aside *Cometographia* and rushed into print a forerunner, or synopsis, of the projected work entitled *Prodromus cometicus*. Beginning with a prudent dedication to Colbert, controller general of finance to Louis XIV, this book outlined Hevelius' ideas that later appeared, in more detail, in his *Cometographia*. The *Prodromus cometicus* also detailed his observations of the comet of 1664. From only one day of observations on February 4, 1665, Hevelius found a parallax of 5000 Earth radii. This result was too small by more than a factor of six.

Hevelius stated that all comets respect the Sun as their king and center, as do the planets, making them a kind of spurious planet. He believed that without the Earth's movement, no rational account could be given of any comet's motion. However, in describing the apparent motion of the comet, Hevelius did not eliminate the Earth's annual motion and his scheme depicts the comet's path as a conic section with the Sun at one focus. Although Hevelius had stumbled upon the correct solution to the motion of comets, this result was foreign to his usual careful analysis, especially his firm belief that, as transitory objects, comets should travel on rectilinear paths. Later, in *Cometographia*, he restudied the motion of the comet of 1664, considered the Earth's annual motion, and ascribed quasirectilinear motion to the comet. Nevertheless, the notion that cometary paths were conic sections with the Sun at one focus was published as early as 1665 and was later read by Isaac Newton.

Hevelius' observations of the comet of 1664 were published in *Prodromus cometicus*, and his last observation, on February 18, 1665, placed the comet near the star alpha in the constellation of Aries, alpha Arietis. Auzout, Petit, and every other observer of the comet's motion objected. They noted that when the comet did move past a bright star in Aries three weeks later, it was beta, not alpha, Arietis. On February 18, 1665, the comet of 1664 was actually 6.5 degrees southwest of alpha Arietis and it did, in fact, pass close to beta Arietis on March 11, 1665. To point out the spurious nature of Hevelius' observation, Auzout wrote a letter to Petit, who published it along with his own at the end of his *Dissertation sur la Nature des Comètes*.

The matter should have ended there. However, far from admitting his error, Hevelius conducted a protracted defense of his *Prodromus cometicus* in letters to the secretary of the Royal Society of London, Henry Oldenburg, and in a book entitled *Descriptio cometae . . . 1665 . . . mantissa prodromi cometici*. The first part of this book presented his observations of the comet of 1665 and included a synopsis of his general cometary ideas. The second part was a defense of his *Prodromus cometicus* against Auzout, Petit, and others who had entered the fray. Hevelius finally set aside his defense only when the Royal Society of London refused to endorse his observations. The furor created by this spurious observation had delayed the publication of his cometary magnum opus and his *Cometographia* was not published until 1668.

After nearly 15 years, the *Cometographia* was published as a series of books or chapters. The first chapter presented observational data on the comet of 1652. One of the more interesting observations was the comet's expansion in size as it receded from perihelion. Later, Isaac Newton would have trouble trying to explain a similar phenomenon observed in the comet of 1680. The second and third chapters were devoted to arguments for comets existing beyond the Earth's atmosphere, and Chapters Four and Five presented a parallax determination for the comet of 1652 and a discussion of its true position and distance from the Earth. The work went on to discuss the comets of 1661, 1664, and 1665. It is interesting to note that in his discussion of the comet of 1664, Hevelius did not use his disputed observation of February 18, 1665. The book ended with a catalog of 251 cometary apparitions from the Biblical deluge to 1665.

Embedded in *Cometographia* was Hevelius' theory of comets, an interesting collection of ideas based primarily on those of Kepler. Like Kepler, Hevelius began with the premise that comets were transitory objects, and

Frontispiece from Johannes Hevelius' *Cometographia* (Danzig, 1668). Three allegorical figures showing the Aristotelian idea that comets are sublunar (left), the Keplerian notion that comets move on straight line paths (right) and the idea of Johannes Hevelius (center) that comets originate in the atmospheres of Jupiter and Saturn and move about the Sun on a curved trajectory.

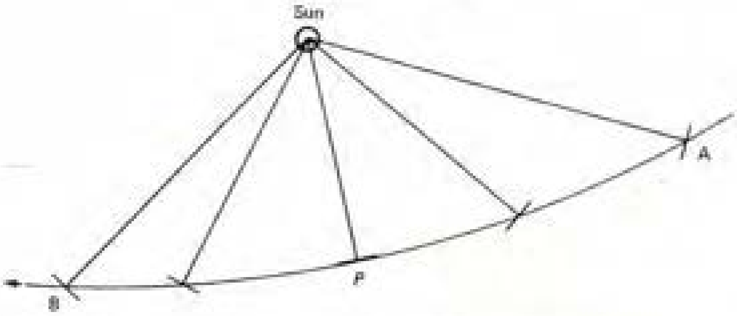
hence their basic motions were rectilinear. Borrowing another idea, Hevelius considered comets to be waste matter, but instead of Kepler's spontaneous creation, Hevelius thought that comets formed in the atmospheres of the giant outer planets. Modifying slightly an idea presented 44 years earlier by Joannes C. Glorioso, Hevelius suggested that all heavenly bodies continually pour forth waste exhalations. The grosser exhalations remained bound to the parent bodies and were responsible for sunspots and clouds; the lighter, more tenuous effluvia arose into the atmosphere. Under the influence of the vertical motion—which was natural to light, tenuous effluvia—and the circular rotation of the planets, the comet effluvia spiraled upward through the atmosphere, where they were flung into space at a uniform velocity on a trajectory tangent to the atmosphere.

Although all heavenly bodies were believed to give forth exhalations, the pale color and large size of Jupiter and Saturn made them the most likely birthplace for Hevelius' comets. He classified comets by which planet produced them. Thus comets forming from Jupiter or Saturn were distinguishable by their respective colors. He noted that the color of the comet of 1531 was a beautiful yellow-gold, while the comet of 1607 was dull. While Hevelius would have attributed these two comets to different classes or birthplaces, they were successive returns of the same comet—Halley.

Once the nascent comets escaped the parent planets, the solar rays began to act upon them to form tails. The tenuous exhalations adhering to the sunward-facing side of a comet's head were rarefied by the Sun's rays and driven back in an antisolar direction. This tail formation idea was similar to Kepler's view, except that Kepler believed the tail represented the disintegration and death of the head, whereas Hevelius believed the comet's head would expand and dissipate at the end of the apparition. Hevelius' telescopic observations of various comets had convinced him that the heads were made up of discrete particles.

Although he hadn't accounted for the Earth's motion in his earlier *Prodromus cometicus*, Hevelius was careful to make this correction in his *Cometographia*. Using his accurate contemporary observations, it became apparent that comets have neither uniform motion nor rectilinear trajectories. He was forced to conclude that comets move on paths that are slightly curved toward the Sun. Due to their natural regard for the Sun and their transitory nature, Hevelius believed that comets traveled on either of the open conic sections, the hyperbola or the parabola. If a comet's path brought it quite close to the Sun, the resulting orbit would be hyperbolic; otherwise the orbit was parabolic. Unlike his earlier suggestion in the *Prodromus cometicus*, the Sun no longer occupied the focus but was now located roughly halfway between the focus and the vertex of the conic. As a device for modifying the natural uniform motion of comets, Hevelius introduced the concept of a disklike comet—an interplanetary frisbee!

As imperfect planetary effluvia, comets agglomerate, not into perfect spheres but into disklike objects. The diskcomet kept its face perpendicular to the solar rays throughout its trajectory AB. Hevelius used the analogy of the Earth's effect on a compass needle to describe the alignment of the diskcomet as it traveled along its orbit. With respect to the Sun, the orientation of the comet changed so that it traveled edge-on at perihelion and nearly face-forward in the extremities of its orbit. Hence, when traveling through



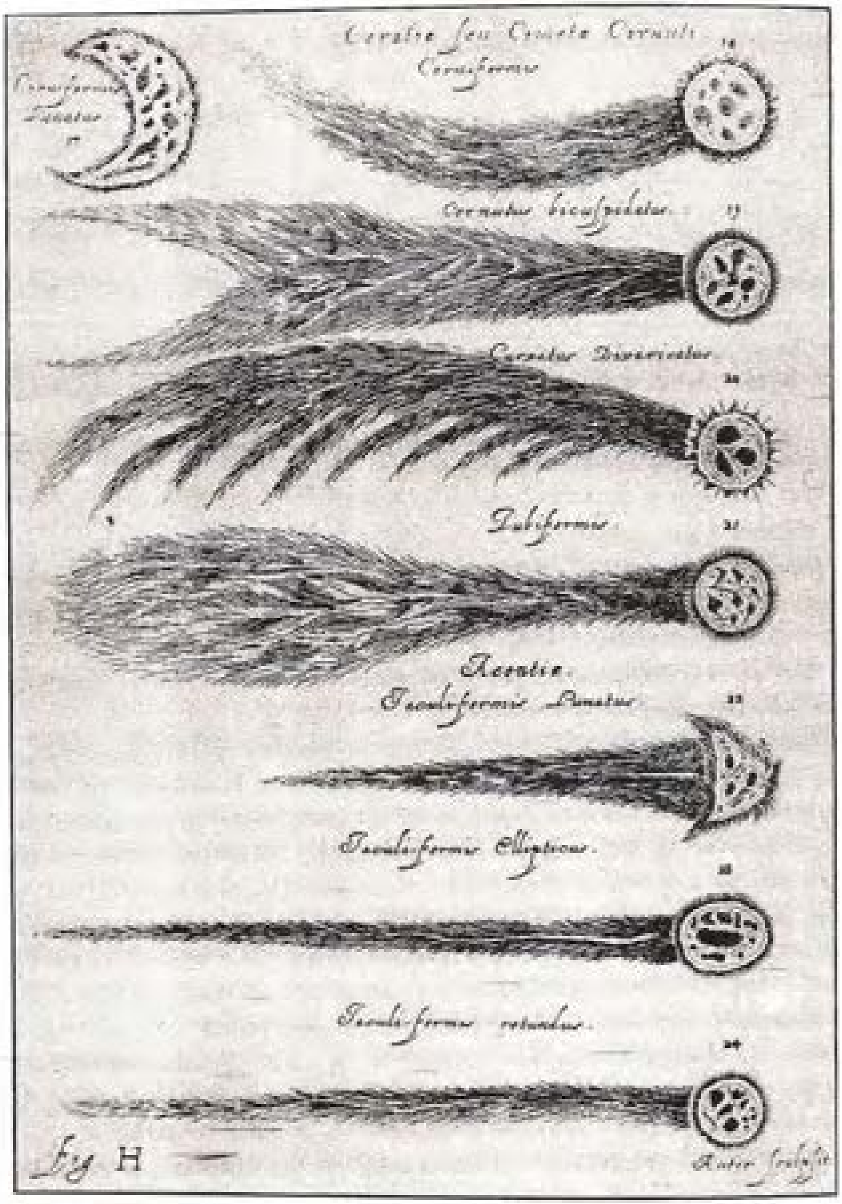
Johannes Hevelius considered comets as disk-shaped objects whose face was always maintained perpendicular to the Sun's rays. At perihelion, P, the disk-shaped comet moved edge-on through the resisting ether and so moved most rapidly there. At either end of the observational arc, AB, the disk-shaped comet was slowed by the resistance of the ether.

the ether, the disk traveled fastest at perihelion in apparent agreement with the observations. The relatively slow motion of the comet far from the Sun was due to the impedance of the ether on the disk-comet as it traveled face forward. Any irregular motion observed near the end of a comet's apparition was due to the uneven disintegration of its head.

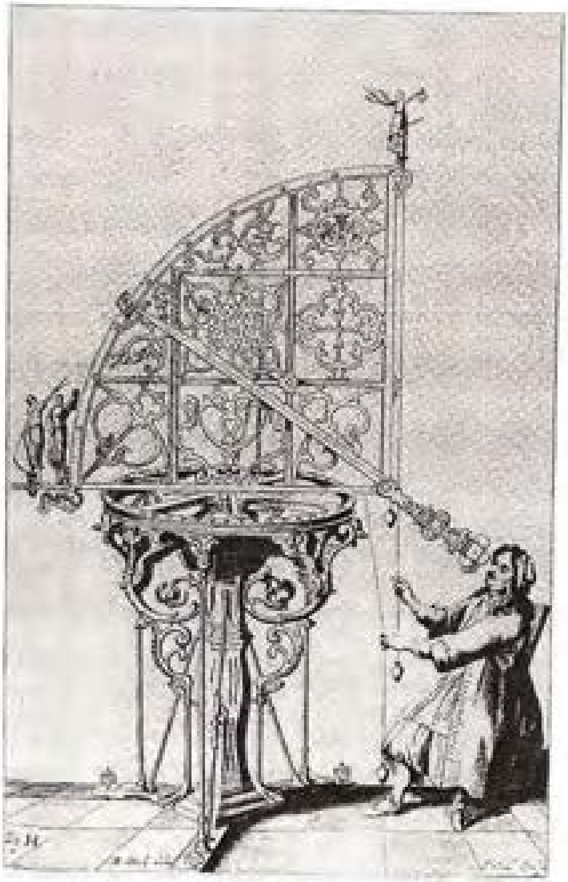
The physical and dynamical cometary theories of Hevelius were intimately connected. By assuming that comets were transitory in nature, Hevelius was forced to assume basic, uniform, rectilinear motion, then an ad hoc physical description of comets to explain the observed deviations from uniform motion. He was fortunate that the comets he considered, from 1472 to 1665, did not show large deviations from rectilinear motion, at least during the intervals of his observations. Had he used his theory to represent the pre- and postperihelion observations of the comet of 1680, he would have failed miserably. Christiaan Huygens did try—and failed.

One of Europe's greatest scientists in the seventeenth century, Christiaan Huygens made important contributions in physics, optics, time measurement, astronomy, and mathematics. If his achievements went relatively unnoticed in the seventeenth and eighteenth centuries, it was largely due to his reluctance to publish ideas he considered incomplete or lacking great significance. He never published his ideas on comets. They have appeared only recently as successive volumes of his *Complete Works* (1888–1950) were published. A native of the Netherlands, Huygens spent most of the period from 1666 to 1681 in Paris under the patronage of Louis XIV. He observed and developed theories for the comets of 1664, 1665, and 1680.

For the comets of 1664 and 1665, Huygens began by assuming their motions were uniform and either rectilinear or curved slightly concave to-



Types of cometary forms showing Hevelius' idea that the heads of comets are disklike and made up of discrete particles. From Johannes Hevelius' *Cometographia* (Danzig, 1668).



Johannes Hevelius observing with his azimuthal quadrant. From his *Machinae coelestis pars prior* (Danzig, 1673).

ward the Sun. While Kepler had introduced nonuniform motion to fit the observations of the comets of 1607 and 1618 with a straight line, Huygens maintained uniform motion, but allowed the path to curve for the comets of 1664 and 1665. To successfully represent the observations of the comet of 1664, Huygens did not have to bend the orbit significantly. However, he had great difficulty using rectilinear motion to explain the observed motion for the comet of 1665, and his final orbit was substantially curved toward the Sun.

The comet of 1680, with its incoming and outgoing paths nearly parallel, was probably the undoing of Huygens' cometary theory and may explain why he never published it. Both Cassini and Huygens reported their views on the comet of 1680 to the Royal Society of London in February 1681 and nei-

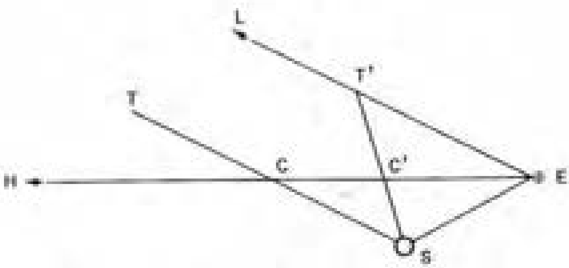
Comet of 1664 in January 1665 moving through the constellation of Cetus the whale. From Stanilaus Lubienietski's *Theatrum cometicum* (Amsterdam, 1668).

ther considered the inbound and outbound legs of the orbit to be due to the same comet. Cassini could not fit a great circle to both the inbound and outbound legs of the comet's orbit and, had he tried, Huygens could not have fit both legs with any path resembling a straight line. Even by ignoring the observations made on the inbound leg, Huygens had to devise a rather contrived theory to explain the comet's behavior. Noting that its outgoing path seemed to originate in the Sun, he suggested that it was shot from the Sun like a rocket. Solar material was ejected from time to time, and when it collected, it ignited to form a rocket-comet. A second ignition was required to form the tail and Huygens noted Robert Boyle's recent work on phosphorus as an apt analogy for a substance capable of this type of double ignition.

According to Huygens, comets differed from planets because they had an intrinsic power that gave them motion relative to the ether that was necessary to explain their deviations from strict rectilinear paths. Unlike the passive planets moved about by the solar vortex, the rocketlike thrusting of cometary nuclei gave them an intrinsic motion. Since the rocket thrust was directed toward the Sun, the deviation of the comet of 1680 from rectilinear motion was slight, since it was already traveling almost directly away from the Sun. However, the comets of 1664 and 1665 were observed traveling more transverse to the Sun-comet direction so that the sunward thrust introduced

Comet of 1665 on April 13, 1665, moving through the constellation of Pegasus, the winged horse. From Stanilaus Lubieniecki's *Theatrum cometicum* (Amsterdam, 1668).

Christiaan Huygens. *(Courtesy of the Paris Observatory).*



Christiaan Huygens devised a clever technique for estimating maximum Earth-comet distances. An observer's lines of sight are directed toward the end of a comet's tail, EL, and toward the comet's head, EH. A line, ST, drawn parallel to EL and through the Sun, S, establishes an upper limit to the comet's distance because at C a comet's tail would have to be infinitely long to be seen by an observer at E. Hence the comet can be no farther from the Earth than the distance EC. For the tail to have a finite length, the comet must be located at some lesser distance, EC', with the end of its tail at position T'. Using the properties of a triangle, the maximum distance of the comet from the Earth, EC, is determined in terms of the Earth-Sun distance, ES, because the angle CES is measured and the angle ECS equals the measured angle LEH.

deviations from rectilinear motion and curved the path slightly concave to the Sun.[1]

In trying to explain cometary tails, Huygens ran into additional difficulties. He rejected the traditional view that they were a result of sunlight refracted in a crystalline cometary sphere. He considered the tail to be a real entity, a kind of smoke whose density was less than that of the head but more than that of the surrounding ether. Hence, tail particles maintained the motion they shared with the head prior to ejection and the pressure of the surrounding ether imparted a slight curvature to the tail. The antisolar nature of comet tails must have been an embarrassment to Huygens because the sunward-facing rocket thrust should have sent the smokey tail particles toward—not away from—the Sun.

Although Huygens chose to ignore this problem, he was aware of the antisolar nature of a comet's tail. Indeed, he used it to crudely determine an upper limit on the distance to the comet of 1680. Assuming that the observer's lines of sight are directed to the end of the comet's tail, EL, and toward its head, EH, a line, ST, drawn parallel to EL and through the Sun, S, establishes an upper limit to the comet's distance at C. That is, a comet at point C must have a tail of infinite length in order to be seen by an observer at E. Hence, by assuming that the comet's tail is finite and antisolar, an upper limit on the Earth-comet distance, EC, can be crudely determined. Applying this technique to the comet of 1680, Huygens correctly placed the comet inside Mercury's orbit when it first emerged from the solar glare in late December 1680.

Summary

In the few decades prior to the 1687 publication of Isaac Newton's *Principia*, knowledge about the nature and motion of comets was in a confused state. Various authorities offered diverse ideas for the nature and motions of comets. However, a few common opinions were evident. For example, the supralunar position of comets was no longer seriously questioned. An increasing number of parallax determinations had convinced nearly every knowledgeable person that comets were not below the Moon. However, Aristotelian cometary ideas were still pervasive, and most contemporary savants still considered the origin of comets to be due to agglomerations or exhalations from heavenly bodies. In many contemporary theories, the all-pervasive ether took an active role in either the appearance or dynamics of comets. Hooke used the ether to dissolve a comet's head and provide the tail curvature. Hevelius suggested the ether as a resisting medium capable of explaining the observed nonuniformity of cometary motions. The ether was a common notion invoked throughout the seventeenth century. It lost some support in the eighteenth century, was resurrected in the nineteenth, and finally was banished in the twentieth century.

Even more important than the Aristotelian concepts of exhalations and the pervasive ether was the notion that transitory objects have rectilinear orbits and permanent bodies travel along circular paths. This principle, so tenaciously held, was a major obstacle to the advancement of cometary thought throughout most of the seventeenth century. The problem with this principle was its status as an axiom, rather than an hypothesis. It was not questioned and often provided a starting point for a particular theory. Hence, in the pre-Newtonian era, two schools of cometary thought were evident. The first believed, a priori, that comets are permanent celestial objects and hence had circular—or at least closed—orbits. To this school belonged Jean-Dominique Cassini, Adrien Auzout, Pierre Petit, Giovanni Borelli, and others. The second school, which included Johannes Hevelius and Christiaan Huygens, considered comets as transitory objects whose basic, intrinsic motions were uniform and rectilinear. Typically, Robert Hooke defied classification by allowing permanence and basic rectilinear motion.

Bound by the pervasive Aristotelian notion that transitory objects have rectilinear paths while permanent bodies have closed orbits, most contemporary scientists first decided whether comets were permanent or transitory, then tried to fit the observations to the appropriate path. Unfortunately, the observations of the comets of 1607, 1618, 1652, 1664, and 1665 could be crudely fit with either a closed orbit or a nearly rectilinear one. What was needed was a comet with a nearly parabolic orbit, with a large number of observations on either side of perihelion so that a definite decision could be made as to its orbital path. Also needed was a person whose genius would allow a break with Aristotelian tradition and permit a theory to be fit to the extensive cometary observations without a priori assumptions. Just such a comet arrived in 1680 and Isaac Newton was there to observe it.

NOTES

1. In 1950, Fred L. Whipple introduced a rocketlike thrusting of the cometary nucleus to successfully explain the slight nongravitational force acting on most active comets—a force that is superimposed on the comet's primary gravitational motion. Huygens incorrectly used the rocket analogy to explain a comet's primary motion.

5

The Comet of 1680

Newton's View from the Shoulders of Giants

Gottfried Kirch makes the first telescopic discovery of a comet in 1680. Georg Dörffel suggests a parabolic path for the comet of 1680. John Flamsteed and Isaac Newton consider whether one or two objects are required to explain the cometary appearances in November and December 1680. Isaac Newton establishes a method for computing the orbital paths of comets traveling on parabolic orbits.

ISAAC NEWTON'S INITIAL INTEREST in comets was not altogether scientific. As a boy, on dark nights he placed candles in paper lanterns and tied them to the tails of kites to terrify the country people, who took them for comets. Later, he made a serious study of the comet of 1680 and, after a false start, developed a theory of cometary dynamics that was as elegant as it was correct. The false start resulted from his view that the comets seen in November and December of 1680 were too different objects.

The first comet to be discovered telescopically, the comet of 1680 was initially seen on the morning of November 14 in the constellation of Leo. Moving quickly toward the Sun, it developed a 20- to 30-degree tail and, for observers in mid-northern latitudes, disappeared into the Sun's glare after the first week in December. After passing perihelion on December 18, the comet was a magnificent spectacle in the late December evenings, when the tail was reported to have reached 70 degrees in length. It remained visible to the naked eye until early February 1681, and with the aid of a telescope, Newton followed it until March 19, 1681. At this time, the English were still using the Julian calendar, so contemporary English observers reported their

Silver medal struck in 1681 commemorating the appearance of the comet of 1680–1681. On the obverse is an illustration of the comet on a stellar background with the inscription *Ao 1680 16 Dec–1681 Jan.* The reverse is a German inscription stating "the star threatens evil things: trust in God who will turn them to good." The capitalized letters in the German legend make a chronogram when arranged into roman numerals (i.e., MDCLVVVVVVI in Arabic numerals is 1681).

observations 10 days earlier than the dates given. To them, there was a morning comet in November and an evening comet in December, a designation that will be retained here. The November comet was a morning object with a relatively modest tail, while the one in December was a bright evening object with an enormous tail. Not only did they appear physically dissimilar, but their apparent motions, when taken together, could not be represented with any figure resembling a circle or a straight line.

Kirch and Dörffel

Gottfried Kirch (1639–1710) and Georg Samuel Dörffel (1643–1688) were contemporary German astronomers who owe much of their renown to the comet of 1680. Both studied under the polymath Erhard Weigel at Jena, Germany.

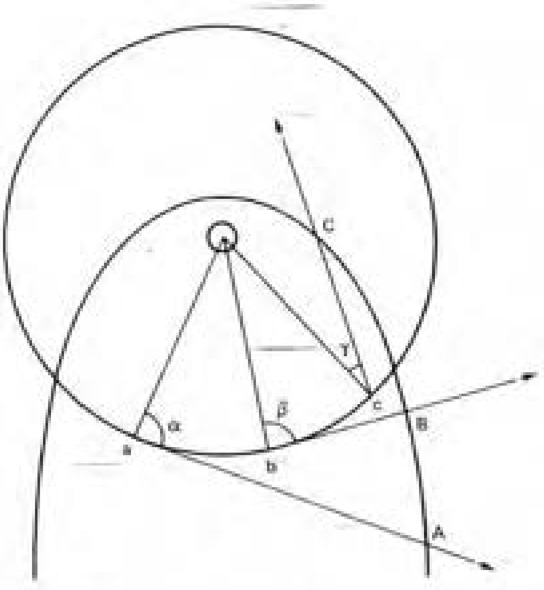
After an apprenticeship with Johannes Hevelius at Danzig, Kirch earned a living computing and publishing calendars and ephemerides. His wife, Maria Margarethe Winkelmann, and two of his children, Christfried and Christine, were also active astronomers. Despite the fact that he had 14 children—or perhaps because of it—Kirch found time to systematically search the heavens with a telescope. On November 14, 1680 at Coburg, after rising early to make observations of the Moon and Mars, he discovered the comet of 1680, the first such discovery to be made with the aid of a telescope. His observations were published in a 1681 Nürnberg tract.

After studying under Weigel in Jena, Dörffel returned to Plauen, where he succeeded his father as minister in the local Lutheran church. He was married three times and had nine children. Apparently Dörffel had no telescope; most of his observations were made with a wooden radius, a device for measuring angles. In 1672, Dörffel began publishing pamphlets of his cometary observations. They were written in a coarse Gothic type and often appeared anonymously or with just the initials M.G.S.D., Master Georg Samuel Dörffel. Distributed only locally, they did not appear to have a significant contemporary impact; however—justified or not—his work has been cited as a forerunner of Newton's theory on comets.

Dörffel's original 1672 tract was entitled *Warhafftiger Bericht von dem Cometen* (True Report of the Comet). An abbreviated work was published the same year. Dörffel noted the position of the comet of 1672 with respect to fixed stars and found no parallax. He then depicted its apparent path as circular and that it moved in the same direction as the planets. Tracts by Dörffel were also published after the appearances of the comets of 1677 and 1682 (Halley), but his fame rests on the 1681 tract that presented his observations and theories on the comet of 1680. Upon receiving news of the comet from Jena and Leipzig, Dörffel observed it on three November nights, before it entered the Sun's glare. In 1680, he rushed into print a short report of these observations entitled *Neuer Comet-Stern . . .* (New Comet-Star).

Dörffel anticipated the comet's reappearance after perihelion, and when it did reemerge from the Sun's glare, he followed it with the naked eye until it faded from view in February 1681. His detailed observations and analysis of the comet's motion were then published in the form of five questions and answers in *Astronomische Betrachtung des Grossen Cometen . . .* (Astronomical Observation of the Great Comet). Dörffel began by establishing the identity of the November and December comet, then described its apparent path through the constellations. To his own question as to how far the comet was from the Earth, he responded that he could not say without more refined parallax measurements. In response to another question, he assured his readers that although he had used the Copernican system to represent the observations, he considered it only a device or useful construction and that the motions of comets could not be used to prove the Copernican system. Besides, he added, this system was contrary to Scripture. The essence of Dörffel's work was given in response to the second question concerning the shape of the comet's orbit.

Dörffel's study of the comet's orbital shape showed the influence of Hevelius' ideas as given in his *Cometographia*. Although he considered comets to be created directly by God, rather than by the planetary emanations that Hevelius suggested, Dörffel did subscribe to Hevelius' disk-comet idea. He believed their observed variable speeds and latitudes ruled out rectilinear paths and he favored the curved trajectories suggested by Hevelius. Dörffel drew a circle to represent the Earth's hypothetical orbit about the Sun. At four-day intervals, he marked off points (a, b, c) corresponding to the Earth's position while the comet was visible. He then drew lines of sight to its direction using angles between it and the Sun, as observed from Earth. (α, β, γ). The comet's actual orbital positions were fixed along the lines of sight by trial and error, choosing them (A, B, C) such that its speed increased regularly toward perihelion, then decreased regularly after perihelion. The true orbit was finally drawn by taking into account its observed latitude at selected dates. Dörffel recognized the resulting curve as a parabola, with the



A schematic drawing showing Georg Dörffel's technique for correctly determining the parabolic motion of the comet of 1680. The points a, b, c correspond to the Earth's position when observations of the comet were made. By using the observed Sun-Earth-comet angles α, β, γ), its actual positions were fixed along the lines of sight by trial and error, choosing the positions A, B, C such that the comet's speed between AB and BC, etc., increased regularly toward perihelion and decreased regularly thereafter.

Sun at the focus, and asked whether this property might not be true of comet orbits in general.

Apart from the suggestion made in Hevelius' *Prodromus cometicus*, which was later withdrawn, Dörffel rightfully claimed priority for the idea of parabolic cometary motion with the Sun at the focus. Although his observations were crude and his orbit represented the comet's true path in shape only, his conclusions were based on his observations, and few preconceived notions entered into his discussion. Considering his observing equipment, Dörffel's efforts were quite extraordinary. However, only by gross exaggeration could his work be considered a forerunner to Isaac Newton's.

Newton and Flamsteed

Though Isaac Newton eventually realized that comets travel in highly eccentric orbits, his initial calculations were based on rectilinear paths. At first, he believed the comets seen in November and December 1680 were two separate objects, each traveling on a nearly rectilinear trajectory.

In contrast to Newton, John Flamsteed did not accept cometary rectilinear motion and predicted that November's comet would reappear after solar conjunction. Due to poor weather, Flamsteed did not observe the comet in November so his prediction was based almost entirely on his belief in comets as permanent bodies traveling on closed orbits. After it reappeared in early December, Flamsteed outlined his theory in letters to Edmond Halley, Isaac Newton, and James Crompton (1648–1694), a fellow of Jesus College, Cambridge. In a letter to Crompton dated February 12, 1681, Flamsteed noted that the comet's diffuse head might be a liquid that reflected the Sun's light less strongly than the solid nucleus. Five days later he pointed out to Halley that the comet's orbit was a curve turning not around the Sun, but before it.

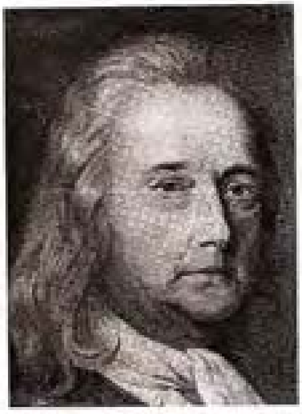
Flamsteed's theory combined solar magnetic attraction and repulsion with the effect of the Cartesian solar vortex. The comet was drawn away from a straight line, AA′, by the combined effects of solar attraction and the rotation of the solar vortex. Upon reaching perihelion, P, the solar magnetic force repelled the comet and, together with the vortex motion, sent it to point B. Flamsteed likened the solar repulsion to that of a lodestone acting on a compass needle, its north pole attracting one end of the needle while repelling the other. His busy schedule prevented him from making any quantitative calculations so Flamsteed made do with some drawings on a large sheet of paper.

Also in his letter to Halley, Flamsteed outlined his ideas on the physical nature of comets. Repeating the Cartesian idea that comets were dead plan-

The Other Side of Isaac Newton

. . . dabbled with astrology and perpetual-motion machines, developed patent medicine recipes, strong interest in biblical chronology and alchemy . . .

If you were asked which famous historical figure had these interests, Sir Isaac Newton would probably not spring immediately to mind. Yet Newton's work included all of them, ranging far beyond the fields of physics and mathematics for which he was most honored.



Isaac Newton in his sixty-fourth year. Portrait by William Gandy, 1706. *(Courtesy of David Eugene Smith collection, Rare Book and Manuscript Library, Columbia University.)*

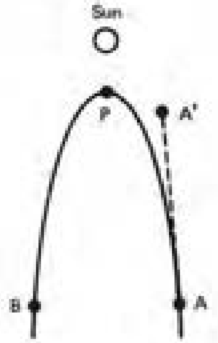
Isaac Newton is given credit for a vast amount of original work, including the nature of colors, the particle theory of light, universal gravitation, the reflecting telescope, and calculus. These efforts are well known and documented, but his interests in other areas are not so well known. In about 1663, Newton briefly investigated judicial astrology and—sometime later—perpetual motion machines. Theology and biblical chronology occupied more of his time than physics and mathematics combined. He studied the Bible to determine and date authorship of several books in the Old Testament and discussed the prophecies given in the New Testament. His recipe for the patent medicine *Lucatello's Balsome*, which he considered effective for measles, smallpox, and the plague, contained turpentine, rosewater, beeswax, olive oil, and sack, flavored with a bit of sandalwood and a pinch of St. John's wort. The idea was to take it warm with broth—then sweat. For colic, burns, bruises and dog bites, one applied it externally.

Newton's active interest in alchemy began in approximately 1669 and extended over many years. When he died, fully one-fourth of his library consisted of alchemical works. Samples of Newton's hair tested for their content of heavy metals from some 30 years after his most active experiments in alchemy showed concentrations many times larger than normal twentieth century hair. One sample showed a mercury concentration 40 times the norm. Between liberal doses of his patent medicine and his zealous pursuit of the alchemical elixir, Newton very nearly poisoned himself. He was fortunate to have lived for 84 years.

ets, formerly from another vortex, Flamsteed thought comets differed little from the obscure large spots on the Moon, which he considered to be aqueous. The coma was due to the humid head vapors, and the tail represented the violent action of the Sun's rays carrying the stream to vast distances. As for tail curvature, he likened the effect to smoke being emitted from a chimney on a moving ship or steam falling on a moving hot iron.

In response to Flamsteed's letter to Halley, which had been passed on to him, Newton began to think seriously about the motion of this comet. In a letter to Flamsteed dated February 28, 1681, Newton wrote that he still felt that the November and December comets were two different objects and offered constructive criticisms for Flamsteed's one-comet theory. Newton objected to Flamsteed's cometary path turning before the Sun and pointed out that the comet runs contrary to the vortex motion there. In addition, the Sun cannot be magnetic because of its extreme heat. A red-hot lodestone loses magnetic properties, and even if the Sun were magnetic, the comet would never be repelled because it would simply turn its pole direction, like a small magnet floating on a walnut shell is attracted by a larger magnet nearby. Using observations on hand, Newton pointed out that if the comets of November and December were one, its motion would have accelerated and decelerated three separate times. Here Newton was misled by confused data. Flamsteed sent Newton observations made in November by the Frenchman

John Flamsteed (1646–1719).



A schematic drawing showing John Flamsteed's first attempt at representing the motion of the comet of 1680. The comet is drawn away from a straight line, AA', by the combined effects of solar magnetic attraction and the rotation of the solar vortex. Upon reaching perihelion, P, the solar magnetic attraction turns to a repulsive force and repels the comet to point B. Note that the comet passes in front of, not around, the Sun.

Father Jean Charles Gallet (1637–1713). However, before passing them on, Flamsteed converted only four of the six observations from the Gregorian to the Julian calendar, which was still used in England. Hence Newton assumed there was a 12-day gap between the fourth and fifth observation times, when there was only a two-day gap.

In a March 7, 1681 response to Newton's letter, Flamsteed straightened out the confusing November observations and defended his cometary ideas against Newton's criticism. He argued that the Sun's magnetic attraction may be unlike that of a lodestone and hence unaffected by the heat. The comet could be repelled at perihelion if it were thrown violently past the Sun without the chance to reverse pole directions. Flamsteed seemed to agree with Newton's suggestion that the comet should have passed behind the Sun, rather than before it, but wondered how the extra distance could have been traveled so quickly. In his letter to Newton, Flamsteed appended a drawing of the comet's orbit showing it passing around the Sun in what appeared to be a parabolic curve.

With the corrected November observations in hand, Newton wrote a letter to Crompton dated April 1681 stating that the comets of November and December were less irreconcilable. His faith in the two-comet theory was shaken, but he still criticized Flamsteed's one-comet theory. He again argued that a hot Sun would lose its magnetic properties, and even if the comet were attracted then repelled by the Sun, it would have been continuously accelerated around the Sun and should have receded faster than it approached. This, of course, was contrary to the observed motion.

In an April 1681 letter to Flamsteed, Newton was still not convinced by Flamsteed's notion of a single comet. He thought it strange that many other comets, such as those of 1665 and 1677, had not been seen passing around the Sun and exiting the solar neighborhood in nearly the same direction from which they entered. Comets that were seen on either side of perihelion—like those of 1472, 1556, 1580, and 1664—had their incoming path in one part of the heavens and the outgoing path in another.

Flamsteed's three arguments for attributing the November and December apparitions to the same comet were all based on its apparent motion as seen from the Earth. The first argument noted its similar rate of motion on either side of perigee. Flamsteed next argued that the November and December comets each reached solar conjunction at the same time, and finally that the apparent northward motion of the November comet moved it toward the place where the December comet emerged from the Sun's glare. The principal significance of Flamsteed's one-comet explanation was not that it was a qualitatively correct scenario for the comet's motion, but rather that his ideas started Newton thinking about a quantitative solution to the problem.

By mid-1681, after corresponding with Flamsteed, Newton's insistence on two comets in November and December was not so absolute. Soon after he last saw the comet on March 19, 1681, Newton began to collect his thoughts, and by mid-1684 he was convinced that comets do travel on closed elliptical orbits. He set out to determine a method whereby these orbits could be computed, describing the problem as one of great difficulty and managing a successful solution just prior to the publication of his *Principia* in 1687. In the last of three books, Newton outlined his method for determining a parabolic cometary orbit using three observations that were nearly evenly spaced in time, then used the comet of 1680 as an example. Although his published technique was a trial-and-error, semigraphical solution, his procedure would allow as complete and exact an analytic solution as the observations would permit.

In 1925, A. N. Kriloff pointed out that it would have been impossible for Newton to achieve the accuracy he did using the technique in the *Principia*. Newton's trial-and-error construction, with compass and ruler, was drawn on a scale of 16.33 inches for the Sun-Earth distance, and his result was accurate to 0.0017 inch! Kriloff suggested that Newton either used a supplementary diagram of much larger scale or guided his construction by calculations he didn't mention. Newton may have first used his newly invented calculus to work the problem rigorously, then laid out the solution in his *Principia* using a simplified, semigraphical form. He also made remarks about how his method could be generalized to elliptic orbits if the comet's period could be established from the interval between returns to perihelion. He had previously shown in Book I that a parabolic path would result from an inverse square force law if the Sun was located at the focus and the object's velocity was at any time the square root of two multiplied by the velocity required to establish a circular orbit through the same point. For example, a comet located at the Earth's distance from the Sun and moving on a parabolic orbit would have an orbital velocity, 42 kilometers per second, equal to the Earth's circular velocity about the Sun, 30 kilometers per second, multiplied by the square root of two, 1.4.

The triumph of Newton's method for the unknown paths of comets was a significant step forward in the history of science. Although a few of his predecessors had correctly suggested qualitative descriptions of cometary orbits, it was Newton who developed a mathematical model for the comet's motion then successfully tried the numbers. Using his orbit determination technique on the comet of 1680, he successfully fit the observations of Flamsteed, Gallet, and others. Where his predecessors used analogies, preconceived ideas, and guesswork, Newton fit his dynamical theory of comets into the framework of his universal gravitational attraction. One of the most influential scientific works ever written, Newton's *Principia* laid a firm mathematical foundation for all subsequent work on the dynamics of the heavenly bodies.

In the same period that Newton developed his cometary orbit determination technique, he established his views on the physical nature of comets. Apparently prompted by Descartes' suggestion that comets were located beyond Saturn, Newton argued that they were actually seen in a region interior to Saturn's orbit. If comets were located beyond it, they would appear most frequently when their angular distances from the Sun were largest and their Earth-comet distances smallest; that is, they would be seen

Engraving from Isaac Newton's *Principia* showing the parabolic path of the comet of 1680. (*Photograph courtesy of Owen Gingerich.*)

most frequently when on the opposite side of the Earth from the Sun, in opposition. However, the observed evidence showed four or five times as many comets in the hemisphere facing the Sun, Newton used this evidence to support his belief that the region where comets were observed was interior to Saturn's orbit. He envisioned a cometary nucleus that was a durable, solid, and compact object whose light was derived from the Sun. To support this latter notion, Newton pointed out that they appeared brightest, not at perigee, but at perihelion.

Concerning the visibility of cometary atmospheres, Newton dismissed the notion of sunlight passing through a diaphanous nucleus. Like Kepler, he argued that there was no matter in space to reflect the sunlight. Because no spectral colors were observable, he also dismissed Descartes' idea that the cometary head was visible because of the lenslike refraction of sunlight in the nucleus. Newton argued that the extreme tenuity of the cometary atmosphere and tail was apparent by analogy with the Earth's atmosphere. Only a few miles thick, it is dense enough to render the stars invisible when illuminated by sunlight, but sunlight illuminating the comet's atmosphere does not appreciably dim the background stars.

The least successful of Newton's works were his views on cometary tails. He acknowledged, and thought possible, Kepler's notion of tail particles carried along by the action of solar rays. This mechanism could operate in free space because the tenuous ether could be expected to yield to the action of the rays, whereas on Earth, this action was not apparent on more dense materials. Although he did not dismiss Kepler's tail formation theory, he offered one of his own. For the comet of 1680, he noted that the postperihelion tail was largest and suggested that it was a very fine vapor, which the head emitted after being heated near perihelion. Analogous to smoke rising in a chimney, cometary tail particles were heated by the Sun's rays, then—in turn—heated the surrounding ether. The subsequent rarefaction and diminished specific gravity of the ether caused it to ascend away from the Sun, carrying along the tail particles. To explain its curvature, Newton used Flamsteed's suggestion that it was due to the motion of the head from which the smoke ascends. The leading convex edge of the tail appeared brightest because the emitted tail particles were more dense there.

Physical observations had shown the atmosphere to shrink, not expand, as the comet approached perihelion. This was troublesome, and Newton suggested that as the comet approached perihelion, the intense heating of the nucleus caused a denser, blacker smoke to be apparent just above the heated surface. The observed shrinking of a cometary atmosphere as it approaches perihelion is currently thought to result from the increasing strength of solar radiation. The excited molecules responsible for light emission in a comet's atmosphere survive only until they are dissociated by solar radiation. As the Sun-comet distance decreases, these molecules encounter more and more intense solar radiation. Very close to the Sun, they dissociate too quickly to travel great distances from the nucleus. Thus, the visible coma can shrink as it approaches the Sun.

Newton's ideas on cometary tails were not well developed. One glaring inconsistency was his use of the ether for his tail theory; he had previously rejected it because there was no evidence of its resistive effect on the planetary and cometary motion. Newton may have grown tired of the topic or he may not have had enough time to better develop his ideas on cometary tails. There is some evidence to indicate that they were a last minute insertion in the *Principia*. After reading a first draft of Book III, Halley wrote to Newton in April 1687:

The Comet of 1680 and Its Fowl Deeds

The appearance of the comet of 1680 marked the zenith of cometary superstition. This credulity would be reversed somewhat after Isaac Newton's work on the comet of 1680; however, before his efforts could stem the tide of superstition, the comet of 1680 would witness a tidal wave of foolishness. Of the approximately 208 known broadsides on all comets, 62 refer to the comet of 1680. At least a dozen different medals were struck, and in Germany alone there were nearly 100 tracts published. Of these, only four were written to quiet superstitious fears. That these four skeptical authors were writing unpopular views is evident; three were anonymous and the other was signed only by the author's initials. Even the significant tracts by Gottfried Kirch and Georg Samuel Dörffel noted that while comets may be natural phenomena, they were nevertheless signs from God.

In Rome, even barnyard fowl responded to the comet's appearance. A letter to the prestigious Academy of Sciences in Paris announced that on the evening of December 2, 1680, a Roman chicken that had never laid an egg began to cluck in a loud and extraordinary fashion. She succeeded in laying an enormous egg with natural markings resembling a comet on a stellar background. A representative of the academy, after apologizing for taking notice of the occurrence, noted that the egg was not marked by a comet as many believed, but rather with several stars. In scientific circles, the comet egg was not taken seriously, but the very fact that the Academy of Sciences felt compelled to

> I do not find that you have touched that notable appearance of Comet tayles, and their opposition to the Sunn; which seems rather to argue an efflux from the Sunn than a gravitation towards him. I doubt not that this may follow from your principles with the like ease as all other phenomena; but a proposition or two concerning these will add much to the beauty and perfection of your Theory of Comets.

In one final speculation in Book III of the *Principia*, Newton suggested that the tail vapors, continually rarefied and dispersed, would spread throughout the heavens and be gradually accreted by the planets, resupplying them with vital fluids spent on "vegetation and putrefaction." Thus, cometary vapors became essential for life on Earth.

comment on it implies that many took it as a portent. Comet eggs were also identified during comet Halley's return two years later and again in 1910. During the 1986 return, the hens of the world seemed devoid of cometary influences.

German broadside by Friedrich Madeweiss showing the path of the comet of 1680 through the constellations. Note the Roman comet egg in the lower right corner. (*Courtesy Adler Planetarium, Chicago.*)

> . . . for all vegetables entirely derive their growths from fluids, and afterwards, in great measure, are turned into dry earth by putrefaction; and a sort of slime is always found to settle at the bottom of putrefied fluids; and hence it is that the bulk of the solid earth is continually increased; and the fluids, if they are not supplied from without, must be in a continual decrease, and quite fail at last. I suspect, moreover, that it is chiefly from the comets that spirit comes, which is indeed the smallest but the most subtle and useful part of our air, and so much required to sustain the life of all things with us.

Newton's 1687 speculation of earthly fluids being replenished by cometary encounters was without observational support, yet nearly three centuries later, John Oró would speculate that cometary encounters may have, in fact, provided the building blocks of life by depositing a layer of organic molecules and water on the early Earth (see Chapter 11).

Summary

From the first telescopic discovery by Gottfried Kirch on November 14, 1680, to Isaac Newton's final telescopic observation on March 19, 1681, the comet of 1680 ushered in a new era of cometary thought. First Georg Dörffel used his own observations to correctly determine that the shape of its orbit was a parabola with the Sun at the focus. Although Dörffel correctly suggested the shape of the comet's orbit, he could not use his theory to accurately define its true orbital path. His work represented the best pre-Newtonian cometary ideas; using his somewhat crude observations and a trial-and-error technique, he achieved a qualitatively correct solution. Although Dörffel's work preceded Newton's by six years, it was unknown to Newton.

John Flamsteed, believing that comets were permanent bodies, supposed that the comets seen in November and December of 1680 were one and the same object moving on a greatly curved trajectory. He suggested that the comet seen in November 1680 would reappear after perihelion. When his prediction was borne out by the December observations, Flamsteed gloried in his successful theory. Apart from the correct connection of the November and December comets, his ideas were largely untenable; however, his unyielding position forced Newton to seriously consider cometary motion.

Using the comet of 1680 as an example, Newton finally developed a technique for determining the parabolic orbit of a comet from three observations. Though his successful solution was the inspired work of just one man in a rather short period of time, Newton built upon the wisdom of his predecessors. In an oft-quoted letter to Robert Hooke dated February 5, 1676, Newton stated "if I have seen further, it is by standing on the shoulders of giants." With respect to Newton's cometary theory, the giants included

Johannes Kepler and his three laws of planetary motion; Johannes Hevelius, who first suggested parabolic motion with the Sun at the focus; Robert Hooke, who touched upon universal gravitational attraction; and John Flamsteed, who not only provided the most accurate contemporary observations of the November and December comet, but also argued for a single object.

Although the physical nature of comets was still largely unknown, Newton had essentially solved the problem of their dynamical behavior. Subsequent research would improve and refine his theory of cometary motion, but all subsequent work would be built on the foundation he laid. After he had successfully tested his theory using the comet of 1680, the technique was available for additional comets and in a prophetic letter to Newton, Halley wrote in April 1687:

> Your method of determining the Orb of a Comet deserves to be practised upon more of them, as far as may ascertain whether any of those that have passed in former times, may have returned again.

Taking up his own suggestion, Edmond Halley would use Newton's method to discover the first periodic comet. Fittingly, it would bear his name thereafter.

6
The Return of Comet Halley

Using Isaac Newton's method, Edmond Halley computes the orbits for 24 comets, finding those of 1531, 1607, and 1682 very similar. Halley predicts his comet's return in late 1758 or early 1759. Astronomers race to recover comet Halley. Clairaut refines Halley's prediction. Palitzsch, a German amateur astronomer, finds Halley's comet Christmas evening 1758—several weeks before the French professional astronomer, Charles Messier.

The Predicted Return of Comet Halley

In 1687, Edmond Halley wrote to Isaac Newton suggesting that Newton's orbit determination technique be tried on comets other than that of 1680. It was not until eight years later, however, that Halley heeded his own suggestion and determined an orbit for another comet. In a letter to Newton dated September 7, 1695, Halley noted that a parabolic curve most closely represented his own and John Flamsteed's observations of the comet of 1683, and that the agreement between these observations and the places predicted by Newton's method was always within one arc minute. Three weeks later in another letter to Newton, Halley mentioned his reexamination of the orbit for the comet of 1680 and indicated that Flamsteed's observations might better be represented by an elliptic orbit, rather than a parabolic one. Halley also requested that Newton procure Flamsteed's observations of the comet of 1682, and in a rather prophetic statement, Halley wrote:

> I must entreat you to procure for me of Mr. Flamsteed what he has observed of the Comett of 1682 particularly in the month of September, for I am more and

more confirmed that we have seen that Comett now three times, since ye Yeare 1531, . . .

By 1695, Halley clearly suspected the periodicity of the comet that was to bear his name. He had tentatively identified, as the same object, the comets of 1531, 1607, and 1682. He was troubled, however, by the two unequal periods between these three apparitions. In another letter in early October 1695, Halley thanked Newton for procuring Flamsteed's observations and requested that he think about the perturbative effects of Saturn and Jupiter on a comet's period. Halley also presented his completed work on the comet of 1680 and again noted that the observations might be made more compatible with the theory if an elliptic orbit was assumed. On October 15, 1695, Halley wrote to Newton stating that he had finished an orbit for the comet of 1664 and suggested that Johannes Hevelius "to help his calculations to agree with the hevens, added 8 or 9 minutes to the places observed, on the 4th, 5th and 8th of December . . . ." After observing that Jean-Dominique Cassini's geocentric theory could not represent the observations to within two degrees, Halley mentioned that his next orbit determination would be for the comet of 1682.

In a letter to Newton dated October 21, 1695, Halley wrote that he had almost finished his computations for the comet of 1682 and reasserted his

German broadside of comet of 1607 (Halley). The German title reads, "About the comet or tailed new star which made itself seen in September of this year 1607." The approximate path of the comet is traced on the constellations from September 16 through October 4 (Julian calendar). (*Courtesy of the Bibliothèque Nationale, Paris.*)

German broadside showing comets of 1680, 1682 (Halley), and 1683. The illustration shows a view of Augsburg, Germany with the comets of 1680, 1682, and 1683 in the sky. Three horsemen of the Apocalypse are in the foreground. The scene is bordered by a clock face, the numerals of which are made of bones, weapons, and instruments of torture. Each of the four corners outside the dial contains an allegorical figure with an appropriate biblical text. (*Courtesy, Adler Planetarium, Chicago.*)

suspicion that those of 1607 and 1682 were one and the same. Since he was becoming rather adept at orbit determination, Halley wrote that he planned to compute orbits for all well-observed comets. By 1696, he was convinced that the comets of 1607 and 1682 were one and according to an entry in the *Journal Book of the Royal Society of London* dated June 3, 1696, Halley demonstrated to the society that these comets' orbits were similar. In another presentation to the society a month later, Halley gave parabolic orbital elements for the comet of 1618. This orbit successfully represented most of the observations and correctly brought the comet inside Mercury's orbit at perihelion.

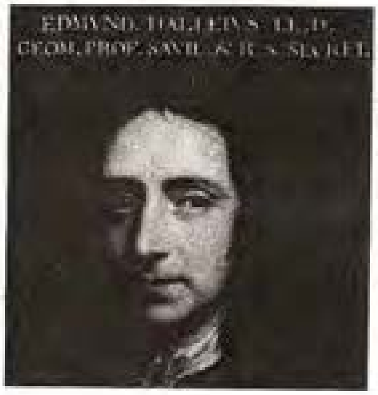
Shortly after reading his results on the comet of 1618 to the Royal Society, Halley left London to take up his duties at Chester as deputy comptroller of the English mint. Between 1698 and 1700, Halley was commissioned as a naval captain and sailed his ship, the *Paramore Pink*, across the Atlantic

Ocean twice, charting the variations, or *declinations*, between magnetic north measured with a compass and true north determined from celestial positions. He hoped that once these local magnetic variations were charted at various longitudes, future sailors could use the charts and their own variation measurements to determine longitude at sea. Unfortunately, magnetic variation measurements do not show systematic changes with longitude, nor

Edmond Halley, Renaissance Man

There are widely divergent opinions as to Edmond Halley's place in history. The nineteenth century mathematician and biographer Augustus DeMorgan noted:

> The period during which he (Halley) held the post of Astronomer Royal, compared with those of his predecessor Flamsteed, and his successor Bradley, is hardly entitled, if we look at its effect upon the progress of science, to be called more than strong twilight night between two bright summer days.



Portrait of Edmond Halley* at about age 30 when he was seeing Newton's *Principia* through press. The inscription above the portrait was added later. (*Reproduced by permission of the president and council of the Royal Society.*)

DeMorgan's unfair judgment of Halley is balanced by the equally unfair assessment by his two surviving daughters, who had the following inscription placed on their father's tombstone at the churchyard of St. Margaret, Lee near London:

> Under this marble, together with his beloved wife, rest Edmund Halley, LL.D. unquestionably the greatest astronomer of his age.

Born on November 8, 1656, Edmond Halley's early interest in science was encouraged by his father, a prosperous London soapmaker and salter. At the age of 20, Halley published his first scientific paper, dropped out of Oxford, sailed south to the island of St. Helena, and over 13 months made the observations that allowed him to compile the first systematic catalog of stars in the southern hemisphere. His *Catalogue of the Southern Stars* was useful for navigation at sea and was partly responsible for Halley being awarded a Master of Arts degree at Oxford without having to take the usual examinations.

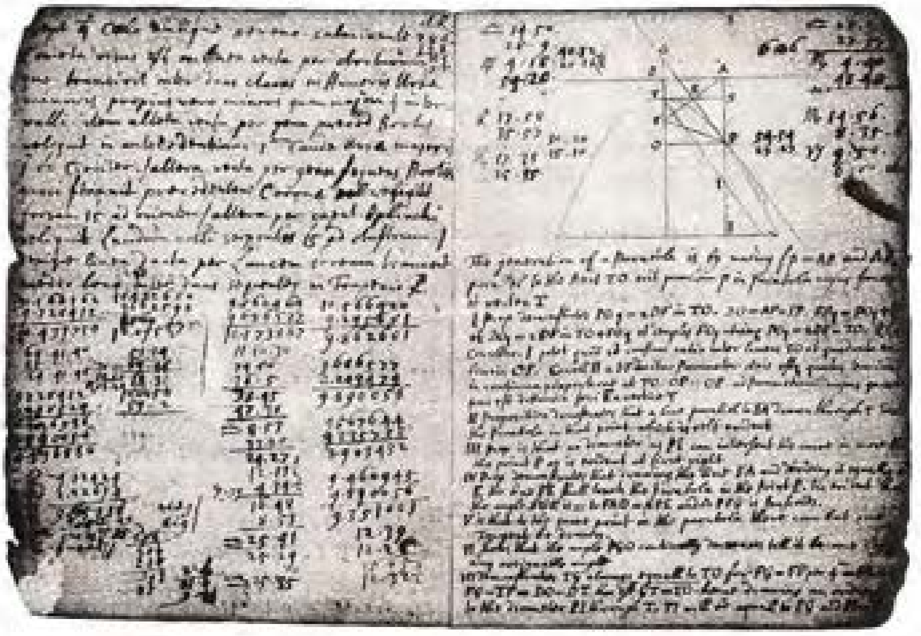
*Although Halley's first name is often given as Edmund, he always wrote it as Edmond.

do they remain constant with time. While Halley's voyages failed to solve the problem of determining longitude at sea, he did publish the first map showing regions of equal magnetic variations. He also charted the positions of coasts and ports encountered during his voyages. In 1701, he made a third voyage to undertake a detailed study of the English Channel, which resulted in the first published tidal chart.

Edmond Halley's genius was diverse. His ideas ranged from the design of an underwater diving bell to the possible infinity of space. During his 85-year lifetime, Halley served as the first corresponding secretary to the Royal Society of London and published the scientific works of its members. Halley himself published significant works in the fields of meteorology, mathematics, and navigation, as well as astronomy. He virtually founded the sciences of geomagnetism and physical oceanography and initiated work in life insurance statistics by publishing the first tables of life expectancies. He was unselfish in recognizing the genius of others, including Isaac Newton. Halley edited Newton's classic work, the *Principia* and, when the Royal Society could not afford to publish it, provided the necessary funds from his own pocket.

In computing the orbit of the comet of 1682 that would later bear his name, Halley used a modified version of Newton's method and the observations of John Flamsteed, wisely ignoring his own less accurate observations. Halley's work was not equal to Newton's profound accomplishments in mathematics, nor did he possess the precise observing techniques of Flamsteed. He was what we might today call an "idea man." His intellect was too lively for him to focus on a single issue for very long, yet he made remarkable contributions. He was the first to recognize that stars have their own motions with respect to each other, and he correctly suggested that some stars appear to vary in intensity because they change their light output over time. He pointed out that observations of the planet Venus during its occasional transits in front of the Sun would allow the distance between the Sun and Earth to be determined; his technique later served as the basis for observing the Venus transits in 1761 and 1769.

Halley's wide range of interests and warm, gregarious manner contrasted sharply with his contemporary colleagues, Isaac Newton and John Flamsteed. One can imagine that Newton was at his best when left alone in his study to focus his prodigious intellect on mathematical constructs. The stern Flamsteed was at his best in the Greenwich observatory making precise and careful position measurements of celestial bodies. No doubt Halley was at his best discussing new scientific ideas with friends at a favorite coffee house.



Two pages from one of Halley's notebooks are shown in this illustration. Edmond Halley recorded his observations of the comet that was to bear his name in the late summer of 1682. On the left-hand page Halley has recorded, in Latin, cometary position measurements for September 4, 1682, measurements that were made with respect to neighboring stars. The right-hand page details, in English, some unrelated notes on the properties of a parabola. *(Courtesy of the Royal Greenwich Observatory.)*

Halley's three voyages are regarded as the first sea journeys undertaken for purely scientific purposes. In 1702 and 1703 Queen Anne sent Halley on diplomatic missions to Europe to advise Emperor Leopold of Austria about the fortifications of seaports on the northern shores of the Adriatic. With Halley's busy schedule, he did not have enough time to bring together and publish his work on cometary orbits. We learn from a letter than Flamsteed wrote on May 30, 1702, to the astronomer Abraham Sharp that Halley had a treatise on comets finished by mid-1702, but this work was not published until 1705.

Halley's famous treatise on comets was first published in Latin as a six-page folio pamphlet. The first edition was printed at Oxford, probably in a very limited quantity as less than a half dozen copies are now extant. Later in the same year, an English translation was published in London and a longer and slightly modified Latin version appeared in the *Philosophical Transactions of the Royal Society.*

MOTUUM COMETARUM IN ORBE PARABOLICO
ELEMENTA ASTRONOMICA.

Comet. Ann.	Nodus Ascend. ° ' "	Inclin. Orbitae ° ' "	Perihelion ° ' "	Distantia Perihelia a Sole	Logarithmus Distantiae Perihelia a Sole	Logarithmus Motus Medii Diurni	Temp. Aequ. Perihel. D. H. '	Perihel. a Nodo ° ' "	
1337	♊ 24 21 0	32 11 0	♉ 7 59 0	40666	9 609236	0 546274	*June* 2 6 25	46 22 0	Retrog.
1472	♑ 11 46 20	5 20 0	♉ 15 33 30	54273	9 734584	0 358252	*Feb.* 28 22 23	123 47 10	Retrog.
1531	♉ 19 25 0	17 56 0	♒ 1 39 0	56700	9 753583	0 328754	*Aug.* 24 21 18	107 46 0	Retrog.
1532	♊ 20 27 0	32 36 0	♋ 21 7 0	50910	9 706803	0 399914	*Oct.* 19 22 12	30 40 0	Direct.
1556	♍ 25 42 0	32 6 30	♑ 8 50 0	46390	9 666424	0 460492	*Apr.* 21 20 3	103 8 0	Direct.
1577	♈ 25 52 0	74 32 45	♌ 9 22 0	18342	9 263447	1 064958	*Oct.* 26 18 45	103 30 0	Retrog.
1580	♈ 18 57 20	64 40 0	♋ 19 5 50	59628	9 775450	0 296903	*Nov.* 28 15 0	90 8 30	Direct.
1585	♉ 7 42 30	6 4 0	♈ 8 51 0	109358	0 038850	9 901813	*Sep.* 27 19 20	28 51 30	Direct.
1590	♍ 15 30 40	29 40 40	♏ 6 54 30	57661	9 760882	0 318805	*Jan.* 29 3 45	51 23 50	Retrog.
1596	♒ 12 12 30	55 12 0	♏ 18 16 0	51293	9 710058	0 395042	*Julii* 31 19 55	83 56 30	Retrog.
1607	♉ 20 21 0	17 2 0	♒ 2 16 0	58680	9 768490	0 307395	*Oct.* 16 3 50	108 5 0	Retrog.
1618	♊ 16 1 0	37 34 0	♈ 2 14 0	37975	9 579498	0 590881	*Oct.* 29 12 23	73 47 0	Direct.
1652	♊ 28 10 0	79 28 0	♈ 28 18 40	84750	9 928140	0 067918	*Nov.* 2 15 40	59 51 20	Direct.
1661	♊ 22 30 30	32 35 50	♋ 25 58 40	44851	9 651772	0 482470	*Jan.* 16 23 41	33 28 10	Direct.
1664	♊ 21 14 0	21 18 30	♌ 10 41 25	1025755	0 011044	9 943562	*Nov.* 24 11 52	49 27 25	Retrog.
1665	♏ 18 2 0	76 5 0	♊ 11 54 30	10649	9 027309	1 419164	*Apr.* 14 5 15	156 7 30	Retrog.
1672	♑ 27 30 30	83 22 10	♉ 16 59 30	69739	9 843476	0 194914	*Feb.* 20 8 37	109 29 0	Direct.
1677	♏ 26 49 10	79 3 15	♌ 17 37 5	28059	9 448072	0 788020	*Apr.* 26 0 37	99 12 5	Retrog.
1680	♑ 2 2 0	60 56 0	♐ 22 39 30	006125	7 787106	3 279469	*Dec.* 8 0 6	9 22 30	Direct.
1682	♉ 21 16 30	17 56 0	♒ 2 52 45	58328	9 765877	0 311313	*Sept.* 4 7 39	108 23 45	Retrog.
1683	♍ 23 23 0	83 11 0	♊ 25 29 30	56020	9 748343	0 337614	*Julii* 3 2 50	87 53 30	Retrog.
1684	♐ 28 15 0	65 48 40	♏ 28 52 0	96015	9 982339	9 986620	*Maii* 29 10 16	29 23 0	Direct.
1686	♓ 20 34 40	31 21 40	♊ 17 0 30	32500	9 511883	0 692304	*Sept.* 6 14 33	86 25 50	Direct.
1698	♐ 27 44 15	11 46 0	♑ 0 51 15	69129	9 839660	0 200638	*Oct.* 8 16 57	3 7 0	Retrog.

Edmond Halley's table of 24 comets with parabolic orbits as represented in the 1752 edition of his *Astronomical Tables*. Note that the comets of 1531, 1607, and 1682 have similar orbital elements. Halley used this similarity to correctly suggest that they were one and the same object.

For such an important work, Halley's "Synopsis of the Astronomy of Comets" was rather brief. Much of the important information is contained in one table giving parabolic orbital elements for 24 comets observed from 1337 through 1698. According to Halley, the table was framed as a result of a "prodigious deal of calculation." It was obvious that the orbits showed no preferred inclination or orientation, and the differences in the perihelion distances made him suspect that many more of them moved unseen in regions more remote from the Sun. Halley also mentioned that none of the 24 comets had hyperbolic orbits. Though he used parabolas in his orbit determination work, Halley believed that the true paths of comets were very eccentric ellipses. After computing a parabolic orbit for a particular comet, he compared its predicted and observed positions at the same time, formed the differences, or *residuals*, between the two angles, then noted whether a slightly different orbital eccentricity might reduce these residuals. In this manner, he showed that the 24 computed orbits could not be hyperbolic, hence each comet must be bound to the Sun.

Although the list of cometary apparitions for which orbital elements are available has grown from Halley's 24 to more than 50 times that, his astute observations are still valid. The most famous conclusion of his treatise of 1705 was that the comets seen in 1531, 1607, and 1682 were the same object. Halley noted that their orbital elements were similar, except for unequal periods between their perihelion passages. The respective periods were over 76 years between 1531 and 1607, but just under 75 years between 1607 and 1682. He suggested that Jupiter's gravitational pulls, or perturbations, on the comet were responsible for the unequal periods, adding that the comet of 1456 was seen passing retrograde between Earth and the Sun:

> tho' no Body made Observations upon it, yet from its Period, and the Manner of its Transit, I cannot think different from those I have just now mention'd. Hence I dare venture to foretell, That it will return again in the Year 1758. And, if it should then return, we shall have no Reason to doubt but the rest must return too.

Using an orbit determination technique developed from Newtonian dynamics, Halley was the first to correctly predict the return of a comet. He was rewarded by having this most famous comet named after him.[1] In his

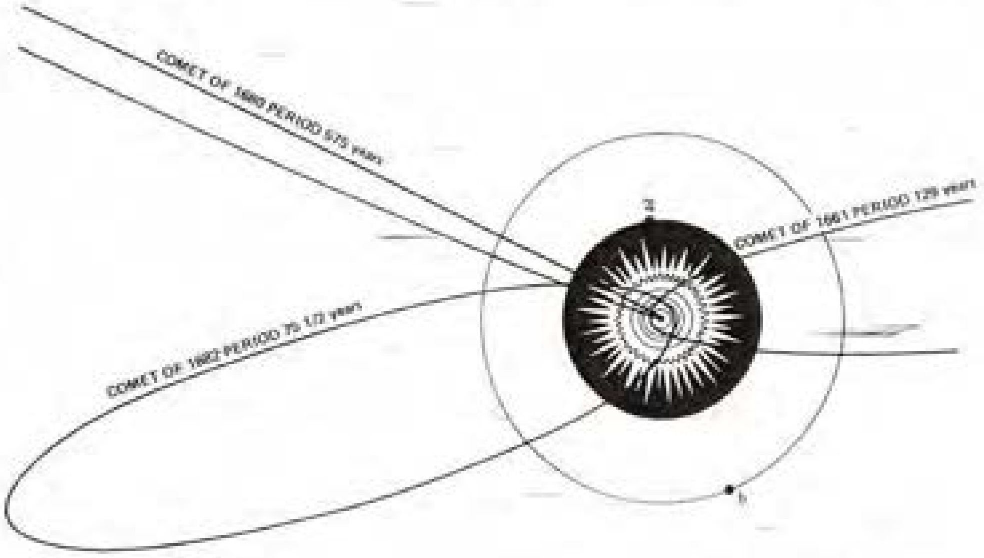


Diagram showing the three periodic comets suggested by Edmond Halley. The comet of 1682 is Halley's comet and its return was predicted by his comparing the similar orbital elements for the comets of 1531, 1607, and 1682. The possible periodicity for the comet of 1661 was noted in Halley's 1705 work on comets and that of the comet of 1680 was first mentioned in the second edition, 1713, of Isaac Newton's *Principia*. The periodic nature of comets 1661 and 1680 was suggested only because of similar time periods between returns; neither one is actually periodic.

1705 treatise, Halley also suggested a possible identity for the comets of 1532 and 1661 but considered Peter Apian's observations of the 1532 comet, which were the only ones available to him, too crude to allow certainty. Inadvertently, Halley also sowed a seed for the post-Newtonian fear of comet-Earth collisions in his 1705 work. Discussing the comet of 1680, he noted—incorrectly—that on November 11 (November 21 in the Gregorian calendar), at 1:06 P.M., this comet passed less than one solar radius above the Earth's orbit.

> This is spoken to Astronomers: But what might be the Consequences of so near an Appulse; or of a Contact; or, lastly, of a Shock of the Coelestial Bodies, (which is by no means impossible to come to pass) I leave to be discuss'd by the Studious of Physical Matters.

Unfortunately cometary collisions were discussed by the not-so-studious as well. Newton's successor in the Lucasian professorship at Cambridge, William Whiston (1667–1752), would later use the comet of 1680 to explain the Biblical flood and predict the end of the world (see Chapter 7).

Although Halley's 1705 treatise predicted the 1758 return of his comet, it was not until his posthumous *Astronomical Tables* that it became generally known that he had revised his prediction to late 1758 or early 1759. Halley's *Tables* contained the necessary information for computing the positions of the Sun, Moon, planets, and comets. Although first published in Latin in 1749, English precepts were added in a 1752 edition. Most of the book, including a revised edition of his "Synopsis of the Astronomy of Comets," was completed in 1717 and printed in 1719. In 1720, Halley succeeded John Flamsteed as Astronomer Royal and set aside the publishing of *Tables* until he could check the lunar tables with his own observations.

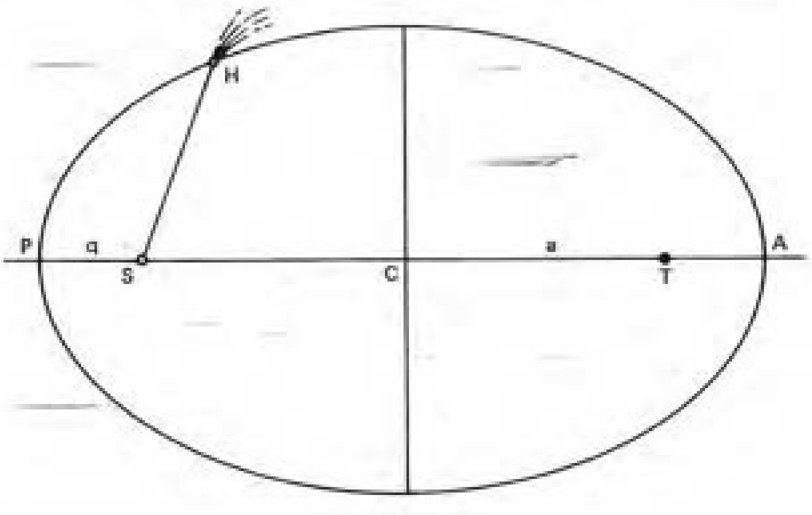
Much of his revised "Synopsis of the Astronomy of Comets" was identical with the 1705 edition, but with important exceptions. Halley worked out an extension to his orbit determination procedure to include elliptic orbits and applied this new technique to the comets of 1607 and 1682. He assumed an average period P of 75.5 years for the comet of 1682 and 76 years for that of 1607, then used Kepler's third law ($a^3 = P^2$) to determine each comet's semimajor axis, a. The eccentricity was then determined from the properties of an ellipse, whereby the known perihelion distance q is related to the semimajor axis a and the eccentricity e by $q = a(1 - e)$.

For the first time, Halley estimated the perturbative effect of Jupiter on the comet's orbit. He correctly gave it as the primary cause of the increase, with time, of the comet's longitude of the ascending node. More importantly, Halley recognized the effect of Jupiter on the comet's orbital period. In preparing *Astronomical Tables* for publication, he became aware of the sizable ef-

Defining the Orbit of a Comet

As the Earth circles the Sun once each year, it does so in a plane called the *ecliptic*. To a rough approximation, other planets in the solar system also move about the Sun in this ecliptic plane. On or about March 21 each year, the Sun appears in the same region of the heavens, and the length of day and night are equal everywhere on Earth. At this time the Sun is said to have reached the *vernal equinox* and Spring begins for the northern hemisphere. The ecliptic plane and the vernal equinox provide convenient references for describing the paths of comets.

Unlike planets, most comets do not confine their paths to the ecliptic plane, nor do they travel in the same direction around the Sun. The Sun's position at one focus of the ellipse is denoted by S, and the point on its orbit where a comet can come closest, perihelion, is P. The comet's distance from the Sun reaches a maximum at aphelion, denoted as A. The direction of the vernal equinox is denoted by the sign of the ram's horns (♈) because this point was once the beginning of the constellation of the ram, Aries. Only three angles are required to completely describe the orientation of the cometary orbit with respect to the ecliptic plane and the vernal equinox. The longitude of the *ascending node*, Ω, is an angular measure of the distance between the vernal equinox and the point (ascending node) where the comet crosses the ecliptic plane going from south to north. The opposite point, where the comet crosses the ecliptic plane going south, is called the *descending node*. At these nodal crossing points the comet is briefly in the plane of the Earth's orbit. If its path passes near enough to Earth's orbit, a meteor shower may result as the Earth runs smack into cometary debris. The two other angles used to orient the comet's orbit are the argu-

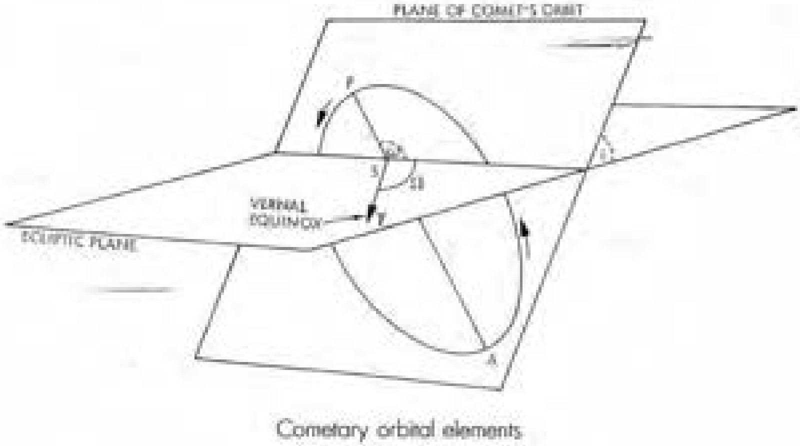


Ellipse relationships

ment of perihelion, ω, the angular separation between the ascending node and perihelion, and the orbital inclination, i. If the inclination is less than 90 degrees, the comet's motion is called *direct*. If the inclination is greater than 90 degrees, the comet's motion is termed *retrograde*, since it would then move in opposition to the eastward motion of the planets about the Sun.

The size and shape of an elliptical orbit are described by the eccentricity and semimajor axis. The eccentricity is given by the ratio of the distance CS to CP. Since the Sun is located at S, the distance CS = 0 for a circular orbit. The eccentricity is also zero in this case. As the eccentricity of an orbit increases, the elliptical path becomes more and more elongated. A parabolic orbit has an eccentricity of one, and a hyperbolic orbit greater than one. Comets moving on either parabolic or hyperbolic orbits are not periodic; they will never return to the Sun. The major axis of an ellipse is the distance AP and, not surprisingly, the semimajor axis a is one-half this distance. This distance is usually expressed in terms of an astronomical unit, AU, the mean distance between the Sun and Earth, approximately 150 million kilometers, or 93 million miles. The perihelion distance in AU, q, between the comet at perihelion and the Sun, distance SP, is given by the expression $q = a(1 - e)$.

The final piece of information that allows a comet's motion to be described is the time, T, that it passes the perihelion point at P. The comet's position in its orbit is often specified using the true anomaly, v, the Sun-centered angle between the comet and the perihelion point, angle HSP. For any comet moving about the Sun, its orbit can be defined uniquely by the six orbital elements, T, e, q, ω, Ω, and i. However, the introduction of a perturbing planet or planets causes slight changes in these orbital elements with time. Thus when the perturbing effects of the planets are taken into account during orbit determination computations, the six orbital elements are strictly valid only for a particular instant of time, or *epoch*.



Cometary orbital elements

fect that Jupiter's perturbations had on Saturn's period; by neglecting these perturbations, Saturn's period could be in error by as much as a month. Halley wondered, How much greater would Jupiter's effect be on a comet traveling in a highly elliptical orbit nearly four times farther from the Sun than Saturn? He noted that in the summer of 1681, the comet of 1682 approached Jupiter close enough that it experienced a perturbative force one-fiftieth of the primary Sun-comet force. This effect would increase the comet's orbit size and period so that[2]

> it is possible that its return will not be untill after the period of 76 years or more, about the end of the year 1758, or the beginning of the next.

Halley discussed Apian's observations of the comet of 1531 and again concluded, as he had in 1705, that—though crude—they were adequate to identify this comet with those of 1607 and 1682. After searching through an unspecified catalog of ancient comets, he concluded that the comets of 1305, 1380, and 1456 appeared at 75- to 76-year intervals.[3] Although the comets of 1305 and 1380 subsequently turned out not to be previous apparitions of his comet, Halley had gathered an impressive amount of data to substantiate his comet's periodic returns in 1531, 1607, and 1682. He expertly presented his case:

> Wherefore if according to what we have already said it should return again about the year 1758, candid posterity will not refuse to acknowledge that this was first discovered by an Englishman.

Hereby acknowledged Dr. Halley!

In his 1749 *Astronomical Tables*, Halley also speculated on the identity of comets seen in 44 B.C., 531, 1106, and 1680. The comet of 44 B.C. was seen shortly after the death of Julius Caesar. However, unlike the comets of 1531, 1607, and 1682, their identity was not determined by comparing their orbital elements. Like previous attempts based only on similar intervals between returns and physical characteristics, the suggested identity of these comets was incorrect.

With regard to Halley's prediction of his comet's return, it is interesting to note that as he gathered more information on the comets of 1531, 1607, and 1682, the wording of his prediction became less definite. Thus, while the statement in the 1705 first Latin edition reads, "I shall venture confidently to predict its return in 1758," the English version in the same year states, "I dare venture to foretell . . . ." In David Gregory's astronomy textbook of 1715 we read, "I think, I may venture to fortel . . . ." In Halley's *Tables* of 1749 and 1752 we read, "if . . . it should return again about the year 1758 . . . ." Halley's decreasing confidence in his own prediction was likely due to his increasing awareness of the problem's complexity and, in particular, the role of planetary perturbations. Halley was aware that an accurate prediction would require perturbation computations that he was unable to make. Though he had done extraordinary, pioneering work in unraveling the mysteries of cometary motions, he had gone as far as he could with the mathematical tools available to him.

The Race for Recovery

After Halley initially predicted his comet's return in late 1758 or early 1759, additional attempts were forthcoming from the Swiss astronomers Jean Philippe Loys de Cheseaux (1718–1751) and Leonhard Euler (1707–1783) as well as from Thomas Stevenson (d. 1764), a plantation owner on the Caribbean island of Barbados. Citing the unequal 76- and 75-year periods between the returns of the comets seen in 1531, 1607, and 1682, Cheseaux thought it probable that there were two comets, each traveling on identical orbits such that when one comet was at perihelion, the other was close to its aphelion. Their orbital periods were constant and identical. Calculating the interval between the perihelion passages in 1531 and 1682 to be 151 years and 10 days, he predicted that the comet last seen in 1607 could be expected to reach perihelion on November 7, 1758, by the Gregorian calendar. This prediction was given in his 1744 work on the comet of that year. Though not discovered by Cheseaux, this comet is often referred to as Cheseaux's because he computed its orbit and ephemeris and described its impressive, multiple tails.

Probably without the knowledge of Cheseaux's work, Stevenson also presented a two-comet theory which found its way into several London newspapers and magazines in October 1758. He suggested a perihelion passage of April 1 for the comet of 1305 and noted that an interval of 302 years and 198 days occurred between this date and the October 16 perihelion that Halley had computed for the comet of 1607. Taking half of this interval and adding it to the 1607 date, Stevenson derived a perihelion passage of January 23, 1759 for the expected return, or February 3, 1759 on the Gregorian calendar. This work is a fine example of how perverse nature can be. Despite using the wrong data—the comet of 1305 was not Halley's—and an incorrect theory, Stevenson arrived at a nearly correct result; the actual perihelion passage time for the 1759 return was March 13 using the Gregorian calendar.

In 1746, the mathematician Leonhard Euler published his prediction for the return of comet Halley. Euler, whose prolific scientific output included some 560 books and articles, worked or corresponded with the science academies at Berlin and St. Petersburg for most of his career. Having been asked by his colleague Joseph-Nicolas Delisle (1688–1768) to determine paths for the comets of 1742 and 1744, Euler was familiar with the technique for computing cometary orbits. Like Halley, Euler was disturbed with the different time intervals between the comet's returns in 1531, 1607, and 1682. Rather than attribute the difference to planetary perturbations, Euler assumed that the comet's period decreased from 76 to 75 years because of the drag effects of the interplanetary ether. Hence Euler concluded that the next return would be in 1757.

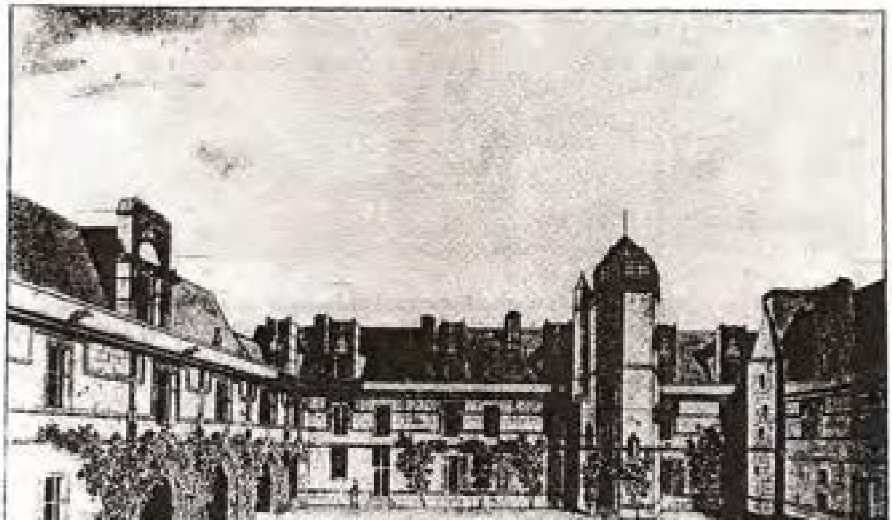
Without a date for the expected comet's return to perihelion, accurate predictions for its specific celestial locations at various times, an ephemeris, could not be determined. However, a number of more general ephemerides were computed in an attempt to assist the expected recovery. In 1754, Thomas Barker (1722–1809), a grandson of William Whiston, constructed 12 different ephemeris tables, each one based on the supposition that the comet would reach perihelion during a different month. From these tables, he constructed an additional table indicating, for each month, where in the sky the comet was likely to be first visible.

In 1755, the Dutch astronomer Dirk Klinkenberg (1709–1799) produced a set of ephemerides similar to Barker's. Under several different suppositions for the comet's perihelion passage times from June 14, 1757 to May 15, 1758, he plotted the comet's resultant positions as seen from Earth. In February 1757, the English instrument maker and science popularizer Benjamin Martin (1705–1782) published a broadside showing the comet's orbit overlying that of the Earth. Its path was represented from its ascending node, 115 days before perihelion, to its descending node, 30 days past perihelion. In 1757, T. J. Jamard, a French cleric and colleague of comet cataloger Alexandre Pingré, charted the positions of the comets of 1531, 1607, and 1682 on a celestial chart and presented it to King Louis XV and the Royal Academy of Sciences in Paris. In an accompanying memoir, Jamard made 14 assumptions as to the time of year the comet would reach perihelion, then described viewing conditions, probable brightness, and tail lengths that might be expected for each time.

In 1757, the French astronomer Joseph-Jérôme Lefrançais de Lalande suggested that the comet would be most easily seen during the month of November, when it and the Sun would be on opposite sides of the Earth. Assuming that the comet would first be sighted 0.4 times farther from Earth than the distance between the Sun and Earth, or 0.4 AU, he gave the most likely positions for first sighting it on various November dates.

After spending 22 years as an astronomer in St. Petersburg, where he helped establish an observatory, Joseph-Nicolas Delisle returned to Paris in 1746. He was made astronomer to the Navy and put in charge of its new observatory at the Hotel de Cluny, near the Sorbonne. Delisle hoped to facilitate the comet's recovery by charting regions of the sky where it might first be visible. He noted that the comet in 1531 was first seen 18 days prior to perihelion, in 1607 it was sighted 33 days prior to perihelion, and in 1682 the interval between perihelion and discovery was 24 days. Hence, he expected the comet might be first sighted some 35 days prior to perihelion. Using this assumption, Delisle then calculated, at 10-day intervals, where the comet would be expected to appear on the sky and plotted these positions on a celestial map. The resultant plots were two ovals, the smaller one for sighting the comet 35 days prior to perihelion and the larger one for recovering the comet some 25 days prior to perihelion. It was along arcs connecting identical days on these two ovals that Delisle instructed his assistant Charles Messier (1730–1817) to look for the comet.

Using a 4.5-foot focal length, Newtonian reflector telescope, Messier began searching for the expected comet in mid-1757. The comet's path was fairly well known from the orbits computed from the 1607 and 1682 observa-



Hotel de Cluny as it looked in the eighteenth century showing Messier's observatory atop the tower. (*Courtesy of Owen Gingerich.*)

Star chart drawn by Joseph-Nicolas Delisle to aid Charles Messier's search for comet Halley. The ovals drawn on the chart represented the expected positions of the comet for various dates, assuming that the comet would be discovered 25 days prior to perihelion, large oval, and 35 days prior to perihelion, small oval. (*Courtesy Crawford Library, Royal Observatory, Edinburgh.*)

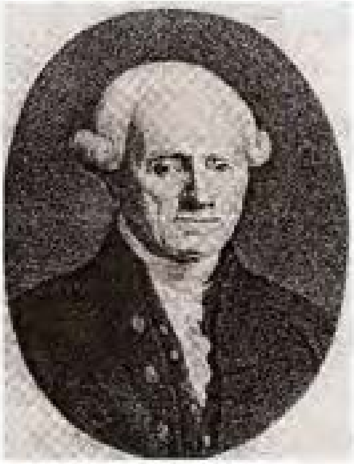
tions, but its actual position along this path at any given time was still very uncertain. What was needed was an improvement in the comet's predicted time of perihelion passage. Enter Alexis-Claude Clairaut (1713–1765).

A child prodigy, the French mathematician Clairaut read his first published scientific paper at the age of 12. In the late 1740s, Euler, Clairaut, and the French mathematician Jean LeRond D'Alembert published ap-

Alexis-Claude Clairaut

proximate solutions to the three-body problem whereby the motion of one body about another is determined taking into consideration the perturbative effects of a third body. They applied their techniques to the theory of the Moon's motion. These efforts are considered the first approximate solutions of the three-body problem in celestial mechanics. In this case, the three-body problem requires the solution of the Moon's motion about the Earth, taking into consideration the perturbations of the Sun. According to Lalande, it was he who first suggested that Clairaut apply his theory of three bodies to the motion of comet Halley. When Clairaut began his computations in June 1757, he used a modified version of the analytic technique developed for his lunar theory to refine the predictions for comet Halley's return. Since the return was imminent, Clairaut was racing against time. His refined prediction would have to precede the comet's recovery. To assist him in the lengthy computations, Clairaut enlisted the aid of his

Charles Messier, the Ferret of Comets



Charles Messier

Charles Messier had such single-minded devotion to the discovery of comets that King Louis XV of France gave him the nickname *birdnester*, or ferret of comets. Born in Badonviller, Lorraine, France on June 26, 1730, Messier was the tenth of 12 children. When 21 years of age, Messier arrived in Paris and was hired by Joseph-Nicolas Delisle as a clerk assistant at the Marine Observatory at the Hotel de Cluny. Messier's neat handwriting and drafting skill were his only job qualifications; his consummate skill in making astronomical observations would require on-the-job-training. Even by contemporary standards, the telescopes he employed were crude and inefficient. None had a light-gathering power greater than a refracting telescope of 3.5 inches aperture.

Although possessed with keen eyesight and extraordinary zeal for observing, Messier had little mathematical ability and left the computation of cometary orbits to colleagues such as Pierre-François André Méchain (1744–1804), a rival comet hunter and calculator in the Department of the Navy, and Jean-Baptiste-Gaspard De Saron, an eminent lawyer and president of the Paris parliament. During the day, Messier would often make meteorological and sunspot observations, and during moonlit nights he would observe the occultation of stars by the Moon. However, the time when the Moon was down and the skies were dark was reserved for comet searches. Messier is credited with 13 comet discoveries; his first, comet 1759 II, and his last, comet 1798 I.

young colleague Lalande, who in turn enlisted the aid of Madame Nicole-Reine Étable de la Brière Lepaute, wife of the clock maker to King Louis XV, Jean André Lepaute.

Initially the plan was to compute the comet's motion around the Sun over the 1607 to 1759 interval taking into account Jupiter's perturbative effects. Not only does Jupiter influence the comet's motion by its direct gravi-

On September 12, 1758, Messier noted a little cometlike cloud or nebula in the constellation of Taurus. So not to confuse this type of nebula with comets just beginning to appear, Messier began to systematically note their celestial positions. Once cataloged, Messier would no longer confuse these objects with the comets he so eagerly sought. What appeared to Messier as cometlike patches of light were actually galaxies, star clusters and nebulae of glowing gases. Descriptions and positions of some 45 *Messier objects* were published in 1774; an additional 58 objects were added in publications in 1780 and 1781. Although Messier did not originally find many of the objects in his catalogs, he was the first to clearly describe them, note their positions in the sky, and publish them collectively.

Today, his cometary discoveries are less well known than the so-called *Messier objects*, though he considered them only annoying distractions in his continuing search for comets. Messier was ambitious and sought recognition of his observing skills through membership in and correspondence with various scientific societies. Though he was made a member of the Royal Society of London in 1764 and of the academies at Berlin and St. Petersburg, he was denied membership in the Academy of Sciences in Paris until 1770 because the French were reluctant to add a mere observer to their ranks. In 1806, he was awarded the Cross of the Legion of Honor from the emperor Napoleon.

One contemporary anecdote, though perhaps apocryphal, demonstrates Messier's single-minded and zealous pursuit of cometary discoveries. From J.-F. La Harpe, a correspondent in St. Petersburg, we learn that Messier's attendance at his wife's deathbed cost him his thirteenth comet discovery—French amateur astronomer and apothecary of Limoges, Jacques Leibax Montaigne, found it first. When a visitor offered condolences for his recent loss, Messier—thinking only of the comet—answered, "I had discovered twelve; alas, to be robbed of the thirteenth by that Montaigne!" His eyes filled with tears. Then, realizing that the visitor was commenting on his wife's death, Messier added "Ah! the poor woman."

tational attraction, it also indirectly affects the comet's motion by slightly altering the Sun's position. Both these direct and indirect perturbative effects of Jupiter were taken into account. Lalande was charged with providing Clairaut with tables of elongations (Jupiter-Sun-comet angles) and distances between Jupiter and the comet for hundreds of points around the comet's orbital path. The effects were so large that Clairaut decided to compute the effects of Saturn as well, so Lalande and Lepaute calculated the tables for Saturn as they had for Jupiter. According to Lalande, the three of them made calculations from morning to night—sometimes even at dinner—for over six months. He also claimed the arduous work left him with an unspecified malady that changed his temperament for the rest of his life. Lalande, who can always be counted upon to supply juicy bits of astronomical biography, relayed that Madame Lepaute's work was not properly acknowledged by Clairaut because of the demands by an envious but unnamed female friend. Madame Lepaute was first given proper credit for her work in the 1759 edition of *Tables Astronomiques de M. Halley* edited by Lalande.

Computing only the perturbative effect on the comet's orbital period, Clairaut established that the interval between the 1682 and 1759 perihelion passage would be 618 days longer than the corresponding interval between 1607 and 1682; 518 days due to Jupiter's influence and the remaining 100 days due to Saturn's. To test his method, he computed the perturbative effects of Jupiter and Saturn over the 1531 to 1607 interval and found that the computed, or predicted, time of perihelion passage in 1682 differed from the actual time by 27 days.[4] Clairaut felt that his prediction for the comet's upcoming return to perihelion in mid-April 1759 would also be accurate to within a month. Although not explicitly stated, his computations indicated April 15, 1759, as the predicted perihelion passage time—nearly 33 days too late. This is only a modest error considering the uncertainty in the planetary masses, the perturbations from neglected or undiscovered planets, and the approximations that had to be made in the method itself. Clairaut emphasized that his calculations could not take into account unknown forces acting in the distant regions of the solar system—forces due to other comets or possibly an undiscovered planet.

Clairaut's first paper on the predicted return of comet Halley was read to the Academy of Sciences in Paris on November 14, 1758. After an exhausting computational effort, Clairaut, Lalande, and Lepaute must have been very anxious before the paper's presentation. If the comet was recovered prior to their announced result, their work might have been perceived as a mere footnote in astronomical history rather than the classic work it turned out to be. They could not afford to wait until the paper was published to announce their result. Clairaut had to appear in person before the academy to win the race between himself and the comet. His strategy succeeded. The comet was recovered less than six weeks after his verbal announcement. The published version of his prediction did not appear until January 1759—well after the first sighting.

In 1760, after the comet was recovered, Clairaut corrected some errors in the earlier work, made more comprehensive perturbation calculations for

Saturn, and suggested a perihelion passage of April 4, 1759. His essay two years later moved this date back further, to March 31, 1759, which Clairaut considered to be within 19 days of the observed perihelion passage. A comparison by Peter Broughton in 1985 between Clairaut's work and the 1971 work by Tao Kiang identified six days of this remaining error as due to the planets Uranus and Neptune, which hadn't yet been discovered; another six days due to the neglected effects of Mercury, Venus, Earth, and Mars; and four days from errors in the masses of Jupiter and Saturn that Clairaut adopted.

Clairaut shared with Leonhard Euler's son, Johann-Albrecht Euler, the award offered in 1759 by the St. Petersburg Imperial Academy of Sciences for the best essay on comet Halley's motion. Both works were published in 1762. In his essay on highly eccentric orbits in the three-body problem, Euler observed that the comet's mass must be very small relative to the Earth since no effects on Earth's motion were apparent during the comet's close approach in late April 1759, when it actually came within 0.15 AU of the Earth. In his own prize essay, Clairaut refined his computations for Jupiter's perturbations on the comet's motion for a period in 1681 and, in response to the contest's guidelines, added a discussion of a resisting medium to his 1762 essay. He considered the effect of ether drag and decided that it was negligible.

Recovery at Last

During the mid-eighteenth century, the dominance of French astronomy was clear. In the post-Newtonian era, French astronomers abandoned the ideas of René Descartes and embraced Newtonian mechanics. The preeminent astronomical discipline was celestial mechanics, and the most visible problem was the approaching return of comet Halley. By the end of 1758, Delisle's search had been carried out by Messier for over a year and Clairaut had refined Halley's prediction for the comet's perihelion passage. It seemed likely that when comet Halley was recovered, the Frenchman Messier would find it first.

As part of his search for comet Halley, Messier discovered another comet on August 15, 1758, which he followed until November 2. An earlier, independent discovery of the comet of 1758 was made on May 26, 1758 by De la Nux, observing on what is now Reunion Island in the Indian Ocean. De la Nux was an advisor to the superior counsel for the island and a correspondent to the French academy. Clairaut was given a fright by this comet, but soon realized that this was not the one he had been laboring over for several months.

For the months of November and December 1758, the skies over Paris were frequently cloudy and Messier managed to continue his search with only a few hurried observations. Finally, on the cloudless evening of January 21, 1759, he noticed a hazy patch in the constellation Pisces that physically resembled the comet he had observed a few months earlier. Due to some neighboring, hazy nebulae he was uncertain as to his discovery but the comet's motion soon gave it away. Messier's observations were made using a 4.5-foot Newtonian reflecting telescope, and it is clear that he had extended his search beyond the confines of the search ovals drawn on Delisle's chart. Messier later speculated that if Delisle had made less restrictive assumptions on the number of days before perihelion that the comet would first be discovered, he might have found it much earlier. Whereas Delisle had assumed the comet would not be sighted more than 35 days prior to perihelion, Messier's recovery was actually some 51 days before. There is no evidence to indicate that Messier's search took advantage of Clairaut's mid-April prediction for the comet's perihelion passage. Delisle's search chart did not assume when the comet would reach perihelion, only the time interval between perihelion and its first appearance. After his recovery of comet Halley on January 21, Messier continued to observe it on January 22, 23, 25, 27, 28, 31 and February 1, 3, 4, 13, and 14, until it was lost in the evening twilight.

With what must have been great excitement, Messier immediately announced his discovery to Delisle, who urged him to carefully follow the comet but not to reveal its presence to anyone else. As Delisle's assistant, Messier had to suppress his historic observations, and Delisle refused to announce his assistant's recovery for more than two months. The motive for this suppression is not clear. Perhaps Delisle considered the discovery his own personal property, to be revealed only at the proper moment in history, or perhaps he wished to be absolutely sure that the comet Messier had discovered was the returning comet Halley. In any case, Delisle's announcement of the comet's return was made only after the comet was observed by Messier on April 1, 1759 as it exited from solar conjunction in the morning sky. On the same day, word was received in Paris that the triumphal recovery by Messier on January 21 had been preceded by nearly a month—by a German amateur!

Johann Georg Palitzsch (1723–1788) was a farmer and amateur astronomer living in Prohlis, a small town near Dresden in Saxony. At 6 P.M. on Christmas evening, 1758, Palitzsch directed his eight-foot telescope toward the heavens. He was well aware that comet Halley was expected, but there is no clear evidence that he was using some sort of search ephemeris. Upon directing his telescope toward the constellations of Cetus and Pisces, he noted a nebulous star near the variable star Mira Ceti between the stars ε and δ Piscium. His observations on the next two nights indicated the object's

Johann Georg Palitzsch

movement and he recognized it as a comet. Palitzsch's observations were communicated to Christian Gotthold Hoffman, who in turn published them in the second 1759 issue of Dresden's newspaper. Hoffman, who was chief commissioner of the excise in Dresden, observed the comet himself on December 27, 1758, but neither Hoffman nor Palitzsch identified it with comet Halley.

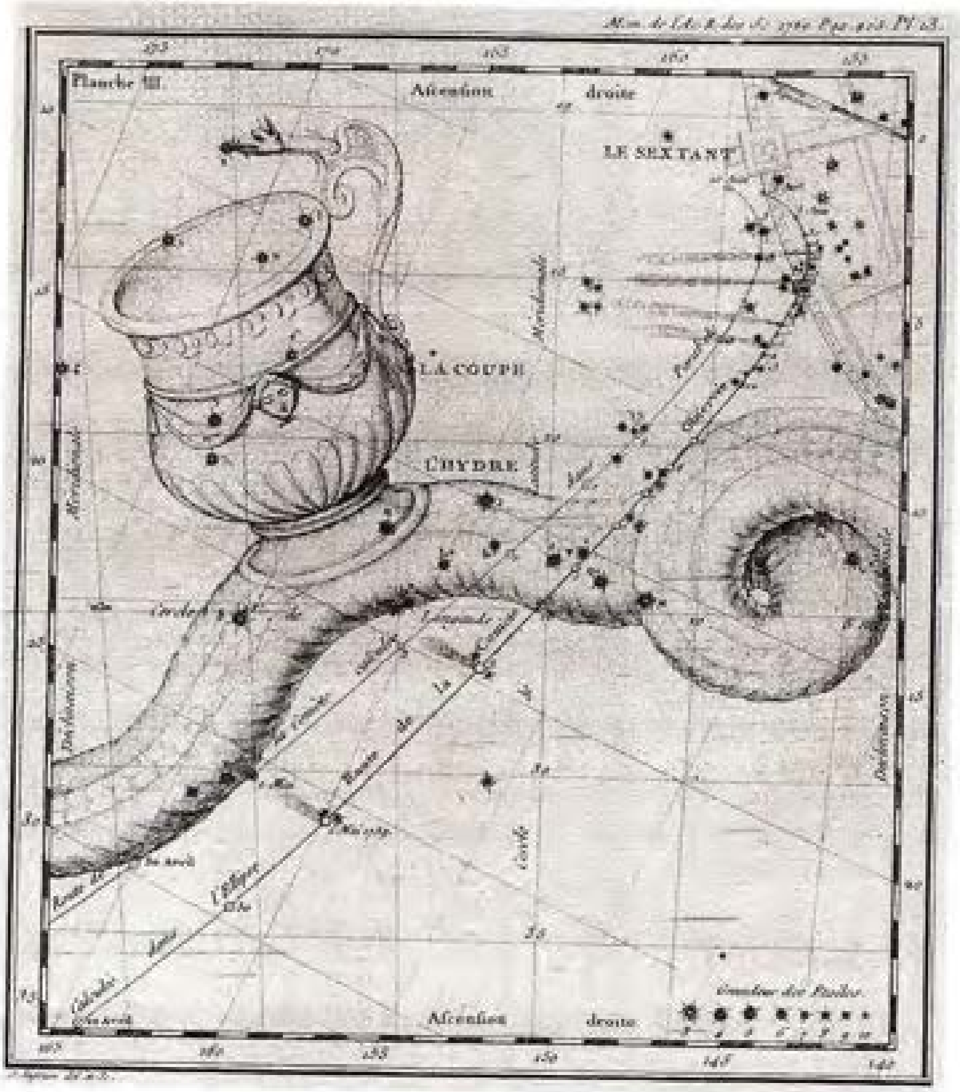
The discovery of comet Halley was announced in an anonymous, 15-page tract published in Leipzig dated January 24, 1759. Soon after the author learned of Palitzsch's observations, he realized that the comet was the one Halley had predicted. Using a geometrical construction, which probably relied on the 1682 orbit with an adjusted perihelion passage, the author computed the circumstances of the comet's future path from January 28 through May 13, 1759. This ephemeris gave not only the comet's longitude and latitude for various dates, but also when its position, brightness, and tail length would make for advantageous viewing. The author checked his computations by observing the comet on January 18 and 19 with a three-foot telescope to make sure his predictions were in accord with his observations. The ephemeris was in error by only about 0.3 to 0.8 degrees in longitude through mid-April and grew to approximately 1.5 to 2.0 degrees thereafter. The date of the comet's closest approach to Earth was correctly predicted to be April 26, and the predicted time of perihelion passage, March 14, was only one day too late.

Overall, this pamphlet served as a complete and accurate observing guide for the comet's apparition. This remarkable work is so rare that outside Germany, only the copies at the Crawford Library in Edinburgh, Scotland and at the Stanford Library in California have been located. The title of the tract begins *Anzeige dass der im Jahre 1682 erschienene und von Halley nach der Newtonianischen Theorie* . . . (announcement of the reappearance of Halley's comet, which appeared in the year 1682 and according to Newtonian theory . . .). The author was probably Gottfried Heinsius, professor of mathematics at the University of Leipzig. His identity is evident from the obvious astronomical knowledge required to write the tract and from a letter he wrote to Leonhard Euler dated April 21, 1759, reporting that he observed the comet with a three-foot telescope on January 18, 19, 22, and 27 and that he authored a tract on it.

Word of this tract reached Paris on April 1, 1759. In a letter dated February 20, probably from Christian Mayer, professor of mathematics at Heidelberg, Delisle and Messier learned of the German observations. They must have been shocked to hear that several prior German observations and an ephemeris had been published in late January 1759. On this same day, Messier had already told several astronomers at the Paris academy that he had observed the comet from January 21 through February 14, when it entered solar conjunction, and on that very morning, April 1, 1759, he had recovered the comet as it emerged.[5]

There was a good deal of confusion at the Paris academy in early April 1759 when the German observations became known and Messier's observations of January and February were finally made public. Some members of the academy refused to believe that Messier's observations were genuine and suggested they be omitted from any orbit computations. Messier's observations were soon admitted to be genuine, however, and he traced the comet's motion on a large celestial map. He was then allowed to accompany Delisle to Versailles on April 5th to announce the comet's appearance to King Louis XV and to present the king with the celestial map showing its motion through the heavens. Having had the rug pulled out from under him, Delisle formally published Messier's recovery in the first volume of *Mercure de France* in July 1759. Seven years later, Messier's observations were published in the *Mémoires de l'Académie Royale des Sciences.*

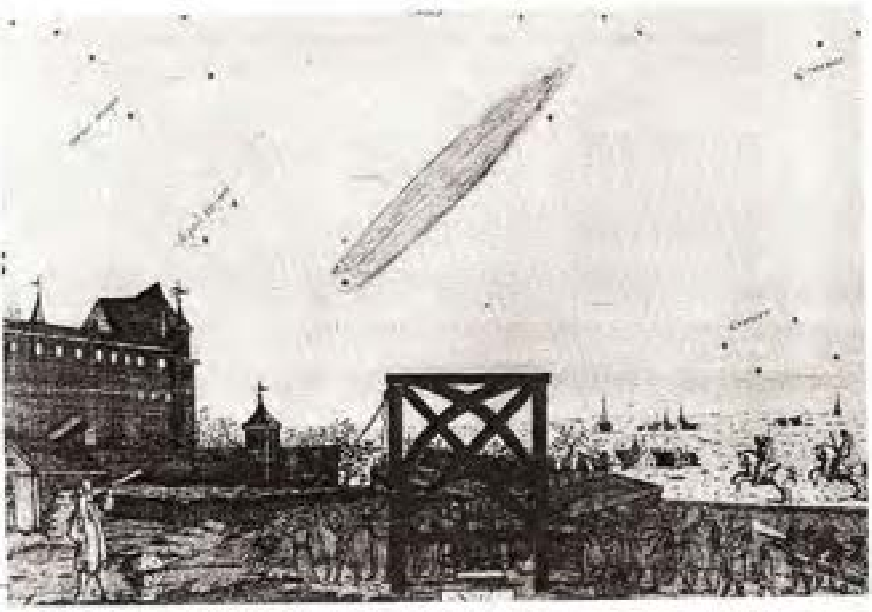
The collective pride of the Paris academy must have been deeply wounded, since the recovery of comet Halley was made by a German amateur more than three months before they knew anything about it. This embarrassment may have still been evident at comet Halley's next return in 1835. In



Star chart showing track of comet Halley from April 29, 1759, until June 15, 1759. This chart was similar to the one presented by Joseph-Nicolas Delisle and Charles Messier to King Louis XV on April 5, 1759. (*Courtesy Crawford Library, Royal Observatory, Edinburgh.*)

what appears to be an attempt to shift the blame to the Leipzig astronomer, who did in fact publish his observations, the French celestial mechanician, Philippe G. de Pontécoulant, stated in 1835 that

> An astronomer of Leipzig (Palitzsch) observed it soon after , but as a lover of his mistress, and a miser of his treasures, jealous of his discovery, which he



German broadside illustration of comet Halley in 1682. Nürnberg, 1682. The engraving shows comet Halley just before dawn in late August. It is being observed by a number of people, some using telescopes, at the private observatory of Georg Christoph Eimmert, located on the western part of the city wall of Nürnberg, Germany. (*Courtesy Adler Planetarium, Chicago.*)

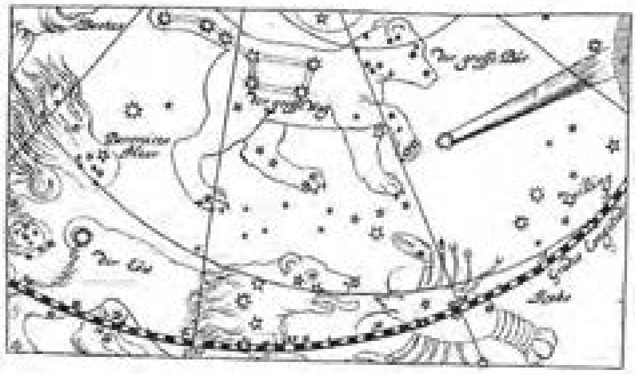
would participate with no one, the German astronomer abstained from divulging the secret . . .

Summary

Using a modified version of ~~Isaac~~ Newton's method, Edmond Halley computed parabolic orbits for 24 well-observed comets and concluded from their similar orbital characteristics that those seen in 1531, 1607, and the one he and Newton observed in 1682 were one and the same. He boldly predicted that this comet would return again in 1758. Although he had verbally announced his results to the Royal Society of London in 1696, it was not until 1705 that Halley first published his prediction. In 1717 Halley made a revised prediction for the comet's return in late 1758 or early 1759, but it was not published until 1749, seven years after his death.

Alexis-Claude Clairaut's classic refinement of Halley's prediction was completed only six weeks prior to the comet's actual discovery. His prediction was in error by less than 33 days.

Wahre Abbildung und Stand des Cometen / wie solcher über Franckfurt am Mayn den 15. 17. und 21. Augusti in der Nacht von 9. biß Morgens halb vier Uhr / Nord-Osten zu / dieses 1682. Jahrs / und im Zeichen deß Krebs / unter den fordern Pfoden deß grossen Beers / nach Astronomischen Observation, erschienen.



Schau die Wunder-Fackel-Kertze!
Sünden-sichres Menschen-Hertze /
Ach bedencke / ach erkenne
Wie sie an dem Himmel brenne /
Und umb deiner Boßheit wegen
Dir zur Straffe / eil entgegen:

Setzet doch mit Buß zusammen
Löschet diese Zoren-Flammen /
Daß ô Teutsche Landes Erde /
Gottes Grimm gemiltert werde /
Der uns dräuet mit Cometen
Buß und Betens ist vonnöthen.

Franckfurt am Mayn / zufinden bey Johann Georg Walthern / den Laden auff dem Pfarreysen / habend.

German broadside of comet Halley in 1682. The Julian calendar was in use in Frankfurt at this time. The German text, translated by Ruth Freitag, follows:

True picture and position of the comet as it appeared to astronomical observation over Frankfurt am Main on the 15th, 17th, and 21st of August, in this year of 1682, from nine o'clock at night until 3:30 in the morning, to the northeast, in the sign of Cancer, under the forefeet of the Great Bear.

Look at the wonderful torch-candle!
O human heart, so prone to sin!
Take heed and recognize
How it burns in the sky
And because of your wickedness
Hastens to bring you to punishment;
Assemble then with penitence,
Extinguish these flames of wrath,
That on the soil of the German land
God's fury will be abated
Who threatens us with the comet
And requires our repentance and prayer.

(Courtesy of Martin Luther University, Universitäts- und Landesbibliothek, Halle-Wittenberg, Germany.)

In mid-1757 Joseph-Nicolas Delisle and his assistant, Charles Messier, began searching for the comet from their observatory in the tower of the Hotel de Cluny in Paris. Delisle mapped out an area on a celestial chart where he felt the comet would first be recovered and instructed Messier to begin the search. Finally, on January 21, 1759, Messier found the comet, but Delisle insisted on keeping his assistant's precious discovery a secret. The announcement of Messier's discovery of comet Halley was delayed 10 weeks, until the comet passed perihelion and emerged from the Sun's glare. Unknown to Delisle and Messier, Halley's comet had already been discovered by a German amateur astronomer on Christmas evening 1758 in the constellation of Pisces.

The bold prediction and successful recovery of comet Halley in 1758 and 1759 was the most visible confirmation of Newtonian dynamics in the eighteenth century. At least this one comet was periodic, and—by inference—many others were likely to be periodic as well. Moreover, Clairaut's technique for accurately predicting future returns of periodic comets was used as a model for 150 years, including the 1835 and 1910 returns of comet Halley. Especially in France, celestial mechanics was the preeminent astronomical discipline during the eighteenth century and the successful prediction of comet Halley's return prompted many enthusiastic studies of cometary orbits. Efforts to discover additional periodic comets continued throughout the eighteenth century but with only two successes, several failures, and at least one outright fraud.

NOTES

1. The term *Halley's comet* appeared as early as 1765, when Nicolas-Louis de Lacaille (1713–1762) used it in *Mémoires de mathématique et de physique, tirés des registres de l'Académie Royale des Sciences, de l'année 1759, 1765*, p. 522–524.
2. In a memoir published in 1765, Joseph-Jérôme Lefrançais de Lalande (1732–1807) pointed out that in 1683, the comet was again near Jupiter and experienced a perturbative acceleration nearly opposite to that suffered in the summer of 1681. Hence, Lalande implied that Halley's delaying the perihelion time into early 1759 may have been fortuitous.
3. In David Gregory's 1715 textbook, *The Elements of Astronomy, Physical and Geometrical*, Halley commented that on looking over some histories of comets, he found one seen about Easter 1305 that may have been a previous apparition of the comet seen in 1456, 1531, 1607, and 1682. Sometime before 1717, when he had finished "Synopsis of the Astronomy of Comets" for inclusion in *Astronomical Tables*, Halley added the comet of 1380 as a possible return of the same comet.

4. Clairaut actually gave 37 days as the difference between the actual and predicted times of perihelion passage in 1682, but it is clear from his work that he meant 27 days.
5. For mid-European observers, the comet's apparition was broken into three phases. The first phase, from December 25, 1758, through February 14, 1759, ended when the comet disappeared into the evening twilight. Rounding perihelion on March 13, 1759, the comet again became visible in early April before it sank below the local horizon. Its third period of visibility was from early May to when it was last seen on June 22. The comet passed within 0.12 AU of the Earth on April 26, 1759, and became a rather impressive naked-eye object.

Epilogue

If there is a central theme that runs throughout the history of comets, it must be the public concern they have commanded—concern completely disproportionate to their infrequent visits, subtle radiance, and modest sizes. Before the seventeenth century, comets were considered portents—warning shots fired at a sinful Earth from the right hand of an avenging God. In the post-Newtonian era, when their paths were understood to intersect that of the Earth, they were considered actual agents of destruction. At one time or another, they have been blamed for presaging war and pestilence and held responsible for the deaths of great men and the birth of good wine, for periods of drought and Noah's flood, for severely cold weather and the London fire of 1666. They have been described as the carriers of both life-seeds to the early Earth and horrific missiles that will one day snuff out life as we know it.

The range of phenomena attributed to comets is extraordinary—some of it true, much of it nonsense. But all of it adds to their considerable mystique and perhaps explains the universal interest shown in these, the solar systems' smallest bodies. They are currently thought to be the building blocks of the major planets and sources for some of the Earth's water, volatiles, and organic molecules. Cometary impacts on Earth have deposited some of the biogenic material from which primitive life may have ultimately formed. Subsequent impacts, however, could have easily erased many of Earth's life forms, leaving only the most adaptable to develop further.

During their infrequent encounters with Earth, comets have directly influenced the evolution of life itself. Within the solar system, the diminutive size of comets is in no way proportional to their importance. Next to the Sun itself, theirs is the most important realm.

Appendix

Naked-Eye Comets Reported Through A.D. 1700

This appendix provides a compilation of the naked-eye comets until A.D. 1700. The date of the comet's first appearance is given followed by the country or countries from which useful records exist. If the comet was observed well enough so that an orbit has been determined, additional information appears in parentheses: the perihelion passage time, P; the minimum Earth-comet distance, d, in astronomical units; and the date on which this close approach occurred. One astronomical unit, AU, is approximately 93 million miles or 150 million kilometers. In many cases, brief notes are provided on the comet's motion and physical behavior with question marks (?) denoting possible uncertainties in the text descriptions.

At the end of each entry, the relevant sources are provided. Often, these sources can provide additional information on a particular apparition. Commonly used sources, such as Ho Peng Yoke and Alexandre Guy Pingré, have been abbreviated. For example Ho (5) refers to the fifth comet mentioned in Ho Peng Yoke's 1962 catalog and P500 refers to page 500 in Pingré's work of 1783–84. Primary sources are listed after each cometary apparition; other sources are mentioned only if they provide additional information. The following catalog of cometary apparitions is meant to provide a guide to where comprehensive observations were made and what records are extant. For the early apparitions of comet Halley, we have relied on the comprehensive observation summaries given by Stephenson and Yau (1985).

Chinese observers had different names for different cometary forms. One of these is the *po*, or bushy star comet, signifying a symmetric, diffuse image without a tail. However, the term *bushy star comet* was sometimes used to describe a comet with a tail as well. A *hui* comet, or *broom star*, is one with a tail. We have adopted the bushy star and broom star designation. When noting the angular length of a comet's tail, the Chinese usually used a linear unit of measure termed a *chi*, or foot. We have assumed that 1 chi is approximately 1.5 degrees, as determined by Tao Kiang in 1972, and this seems to be a good approximation when the tail lengths are fairly modest. However when the object is listed in the Chinese sources as tens of chi, the 1.5 degrees per chi conversion factor is no longer accurate, and longer tail lengths are often recorded by assuming that 1 chi is approximately 1 degree. The estimates given for the longer tail lengths must be considered very approximate.

Dates prior to October 1582 are referred to the Julian calendar. Although the perihelion passage times and Earth close approach times are Greenwich mean times, the Chinese dates of observation have been left in terms of the reported local times.

In general, Chinese records denote the particular asterism or lunar mansion where a particular comet was sighted on a given date. An *asterism* defines a group of stars that neighbor one another and each of the 28 lunar mansions defines a range of right ascension on the celestial sphere. Ho's identifications of the asterisms and lunar mansions with the more familiar constellations have been used throughout this catalog. Uncertainty in a comet's position is sometimes introduced because the original record mentions a lunar mansion to specify a comet's longitude only, whereas Ho generally identifies a specific constellation for each lunar mansion, thus specifying both the comet's longitude and latitude.

Physical and orbital information for cometary apparitions after 1700 are provided in the works by Kronk (1984) and Marsden (1989).

11th century B.C. (perhaps about 1059 B.C.); China. When King Wu-Wang waged a punitive war against King Chou, a broom star comet appeared with the handle of the broom star pointing east. Ho (2), Pankenier (1983).

1002 B.C. A comet was seen in Leo (uncertain event), P251.

974 B.C. Spring; China. A bushy star comet appeared in the north polar region. Ho (3). Pankenier (1983) notes that Ho's date should read 963 B.C. and that a systematic four-year error in the reporting of events at that time assigns this event to 959 B.C.

633 B.C.; China. A broom star comet appeared in Auriga with its tail pointing toward Chhu State. Ho (4).

613 B.C. Autumn; China. A broom star comet entered the constellation of the Great Bear. This is probably the first comet for which a verifiable record exists. Ho (5).

532 B.C. Spring; China. A new star was seen in Aquarius. Ho (6).

525 B.C. Winter; China. A bushy star comet appeared in the winter near Antares. Ho (7).

516 B.C.; China. A broom star comet appeared. Ho (8).

500 B.C.; China. A broom star comet was seen. Ho (9).

482 B.C. Winter; China. A bushy star comet appeared in the east. Ho (10).

481 B.C. Winter; China. A bushy star comet was seen. Ho (11).

480 B.C.; Greece. At the time of the Greek battle of Salamis, Pliny noted that a comet, shaped like a horn (*ceratias* type), was seen. Barrett (1).

470 B.C.; China. A broom star comet was seen. Ho (12).

467 B.C.; China, Greece. A broom star comet was seen. This event is often, but incorrectly, attributed to comet Halley. This is the comet that Plutarch noted appearing prior to the falling of the meteorite at Aegospotami, Greece. Ho (13), Barrett (2), P255.

433 B.C.; China. A broom star comet was observed. Ho (14), P258.

426 B.C. Winter; Greece. A comet appeared in the north around the time of the winter solstice. Barrett (4).

373–372 B.C. Winter; Greece. A comet was seen in the west at the time of the great earthquake and tidal wave at Achaea, Greece. From the Greek descriptions of the comet's motion, Pingré infers that its perihelion was located in Virgo or Libra and that its perihelion distance was quite small. Pingré considers this comet to be the one the Greek Ephorus reported to have split into two pieces. The accounts given by Aristotle and Seneca suggest the comet was seen in the winter of 373–372 B.C. while the account of Diodorus Siculus, an historian of the second half of the first century B.C., suggests the comet was seen in the following year. Barrett (5), P259.

361 B.C.; China. A broom star comet appeared in the west. Ho (15), P263.

345–344 B.C.; Italy. Comet seen in the west. Uncertain event. Barrett (6), P264.

341–340 B.C.; Greece. A comet appeared for only a few days in the equatorial zone near Leo. Barrett (7), P264.

305 B.C.; China. A broom star comet appeared. Ho (16).

303–302 B.C.; China, Greece. A broom star comet was seen. A Greek marble stele records a comet during the rule of Leostratus. This so-called Parian Marble records a series of events starting from Cecrops, legendary King of Athens, until 264–263 B.C. Ho (17), Barrett (8).

296 B.C.; China. A broom star comet was seen. Ho (18).

240 B.C. (P = May 25.1, d = 0.45 on June 4); China. Comet Halley was described as a broom star and it first appeared in the east, then at the north. During the month May 24 to June 23, it was seen in the west. Ho (19), P265.

238 B.C.; China. A broom star comet appeared in the west, then in the north moving southward toward Sagittarius. It lasted 80 days. Ho (20) notes that this account may refer to two comets.

234 B.C. January–February; China, Babylonia. A broom star comet was seen in the east. Ho (21). Fragmented Babylonian records note a comet seen in the east during the last part of the night sometime within the interval January 23 to February 20. Hunger (1989).

214 B.C.; China. A bright star or comet appeared in the west. Possibly a nova. Ho (22).

210 B.C. June–July; Babylonia. During the interval June 24 to July 22, a comet was seen with its tail directed toward the east. Hunger (1989).

204 B.C. August–September; China, Rome. A bushy star comet was observed near Arcturus for over 10 days before disappearing from sight. Ho (23), Barrett (10).

172 B.C.; China. A tailed star comet was observed in the east. Ho (24).

164 B.C. (P = November 12.6, d = 0.11 on September 29) Babylonia. According to Stephenson et al. (1985), analysis of Babylonian tablets in the British Museum suggests that Comet Halley was seen in the east before the lunar month beginning October 21 and in the west while in Sagittarius during the period October 21 to November 19. During this latter period, the comet passed 2.5 degrees west and 7.5 degrees north of the planet Jupiter. Its motion as computed by Yeomans and Kiang (1981) is consistent with these observations. No Chinese records of this apparition have been found.

163 B.C. September 5; Babylonia. During the first part of the night, a comet became visible above α Coronae with its tail pointing toward the south. Hunger (1989).

162 B.C. February 6; China. A thien-chhan comet, or celestial magnolia tree, appeared in the southwest. Ho (25).

157 B.C. October; China, Babylonia. A bushy star comet appeared in the west near Scorpius. Its tail pointed northeast, measured more than 15 degrees, and reached the Milky Way. It went out of sight after 16 days. Ho (26). Babylonian diaries suggest that a comet was noted from October 19 until November 15. Hunger (1989).

155 B.C. Winter; China. A broom star comet appeared from the southwest. Ho (27).

155 B.C. September; China. A broom star comet was seen at the northeast. Ho (28).

154 B.C. February; China. A tailed star comet was seen in the west. Ho (29).

148 B.C. May; China. Comet seen in the northwest. Ho (30).

147 B.C. May 13; China. A white broom star comet, with a 15-degree tail, appeared at night in the northwest in Orion. It moved away at dawn and became smaller and went out of sight after 15 days. Ho (31).

147 B.C. August 6 (P = June 28, d = 0.15 on August 4); China. A white tangle star comet appeared in the southwest below Scorpius. On August 8 it was located north of Scorpius and its tail reached about 90 degrees (?). It left on August 16. Ho (32). Seneca records a comet after the death of Demetrius, king of Syria, and a little before the Greek Achaean war in 146 B.C. It was described as large like the Sun, reddish like fire and bright enough to dissipate the darkness. Barrett (19).

147 B.C. October; China. There was a comet in the northwest. Ho (33).

138 B.C. April; China. A bushy star comet appeared in Hydra, and traveled north through the north polar region until reaching the Milky Way. Ho (34).

138 B.C. May; China, Babylonia. A bushy star comet appeared in Hercules and traveled as far as Vega. Ho (35). Babylonian diaries record a comet that had previously set in Libra reappeared in the west on May 28. Hunger (1989).

138 B.C. August; China. There was a bushy star comet in the northwest. Ho (36).

137 B.C. October; China, Greece. There was a comet seen in the northeast by the Chinese. Seneca notes that, at the beginning of the reign of the Greek Attalus III, a comet spread out into *unlimited* size. Ho (37), Barrett (20).

135 B.C. July; China. A bushy star comet was seen in the north. Ho (38).

135 B.C. September; China. A tailed star comet appeared in the east stretching across the heavens. It lasted 30 days before leaving. Ho (39).

134 B.C. September; China. A tailed star comet stretched across the heavens. Quite possibly this apparition is a confused transcription of the September 135 B.C. comet. Roman sources note that when the Greek Mithridates VI was born a comet shone for 70 days and the whole sky seemed to be ablaze. Ho (41), Barrett (21).

120 B.C. Spring; China, Babylonia. A bushy star comet was seen in the east. Ho (42). Babylonian diaries record a comet seen on May 18 in Aries; it became stationary to the east sometime later than May 20. The same comet was seen on June 16 with its tail directed toward the south and on July 13 during the beginning of the night. Hunger (1989).

119 B.C. May; China. A tailed star comet was again seen in the northwest. Ho (43), P271.

110 B.C. June; China. A bushy star comet was first seen in Gemini. After more than 10 days, it was seen in Ursa Major. Ho (44).

110 B.C. November 23; Babylonia. A comet was seen in the east with its tail directed toward the west. Hunger (1989).

108–107 B.C.; China. A bushy star comet was seen near the region of Canis Minor and Gemini. Ho (45).

102 B.C. (Approximately); China. A bushy star comet was seen among the stars of Boötes. Ho (46).

87 B.C. (P = August 6.5, d = 0.44 on July 27) China, Italy. Comet Halley. A medieval Chinese encyclopedia states that a bushy star comet appeared in the east during the month from August 10 to September 8. Kiang (1972) notes that Halley would have been seen in the west during that time and suggests that the month may have been incorrectly transcribed in the secondary Chinese source. The comet would have been seen in the east in the previous month. Since the motion of Comet Halley in 87 B.C. is quite well established from orbit extrapolations, it seems likely that it was indeed the one referred to in the Chinese medieval source. Stephenson et al. (1985) note that according to Babylonian records, a comet was visible "day beyond day" during the lunar month July 14 to August 11, and a reasonable interpretation of those records suggests that the comet was last seen on August 24. The motion of the comet as given by Yeomans and Kiang (1981) indicates that its solar elongation on August 24 was only 31 degrees and decreasing with time. The Babylonian account also records the first quantitative measurement of comet Halley's tail noting that it was observed to be 4 cubits long, or approximately 10 degrees. Ho (47), Barrett (27).

84 B.C. March; China. A bushy star comet was seen in the northwest. Ho (48).

83 B.C. (approximate year); China. A tangle star comet was seen in the west, east of Hercules. It passed near Altair and entered Pegasus. Ho (49).

69 B.C. February; China. A bushy star comet was seen in the west about 30 degrees from Venus. Ho (52).

69 B.C. July 23; China. A white guest star measuring 3 degrees and pointing southeast appeared and remained above Spica in Virgo. Possibly, this was a nova. Ho (53).

69 B.C. August 20; China. A guest star was seen at the northeast of Corona Borealis moving in a southerly direction. On August 27 it entered the region near southern Hercules with its white tail pointing southeast. Ho (54).

61 B.C. August; China. A bushy star comet was seen in the east. Ho (55).

49 B.C. April; China, Korea. A guest star stayed about 15 degrees northeast of Cassiopeia. It measured over 15 degrees and pointed toward the west. It left Cassiopeia and went to the northern enclosure. Ho (56), Barrett (32).

47 B.C. June–July; China. A bluish-white guest star, with rays less than 1 degree in length, appeared in southeastern Perseus. Ho (58).

44 B.C. May–June; China, Korea, Italy. A broom star comet was seen at the northwest. It was reddish-yellow and measured about 12 degrees. After a few days, it was located near Orion, measured over 15 degrees, and pointed toward the northeast. During the games that Octavian was holding in honor of the assassinated Julius Caesar, several Roman authors reported a comet was seen in the north for 3 to 7 days. Ho (59), Barrett (34).

32 B.C. February; China. A bushy star comet appeared in Pegasus. It (later?) measured about 90 to 105 degrees in length and about 1.5 degrees in width and was bluish-white in color. Ho (60).

12 B.C. August 26 (P = October 10.8, d = 0.16 on September 10) China, Italy. This apparition of comet Halley was extensively observed in China. It was first seen on August 26 as a bushy star comet near Canis Minor and last seen in Scorpius some 56 days later. This was the comet reported by the Romans as marking the death of the Roman General Agrippa. Ho (61), Barrett (40).

10 B.C.; China. A bushy star comet was seen in Boötes near Arcturus. Ho (62).

5 B.C. March; China. A broom star comet appeared near Capricornus for over 70 days. Ho (63).

4 B.C. February 23 (?); China, Korea. A bushy star comet was seen near Altair. Ho (64).

A.D. 13, December; China. A broom star comet was observed. Ho (65).

22 November–December; China. A bushy star comet appeared in Hydra. It moved toward the southeast and went out of sight after 5 days. Ho (66).

39 March 13; China. A broom star comet appeared near the Pleiades with a tail measuring over 45 degrees. It moved northwest into Pegasus and lasted 49 days. Ho (68).

46–47 between December 17 and January 15; Korea. A bushy star comet was seen in the south. It went out of sight after 20 days. Ho (69).

54 June 9; China, Korea. A broom star comet in Gemini developed a white vapor tail, 7 degrees long, pointing southeast. It moved toward the northeast and went out of sight after 31 days. Various Roman sources refer to a comet seen at the time of the emperor Claudius' death. Ho (70), Barrett (43), P284.

55 December 12; China. A guest star with rays measuring about 3 degrees moved in a southwest direction. After 113 days, it went out of sight in the northeast of Cancer. Ho (71).

59 July; Korea. A bushy star comet was seen in Perseus. Ho (72).

60 August 9; China, Italy. A broom star comet, with a tail of about 3 degrees, was seen in the north of Perseus. It moved slightly to the north and arrived at a point south of Virgo. After 135 days, it went out of sight. (Possibly the comet went over the north polar region and then south toward Virgo.) It is not impossible that this sighting and the comet recorded in Korea in July of the previous year are the same object. Seneca and various Roman sources mention a comet, during the reign of Nero, that was seen for several months moving from north to south. Ho (73), Barrett (44).

61 September 27; China. A guest star was seen northwest of Boötes pointing toward Corona Borealis. It went out of sight after 70 days. Ho (74).

64 May 3; China, Italy. A guest star with a white, 3-degree tail was seen to the south of η Virginis. It was seen for 75 days. A comet mentioned by the Romans Tacitus, Suetonius, and Pliny may well be this object. Ho (75), Barrett (45), P286.

65 July 29; China. A tailed star was seen extending 37 degrees in Hydra. It moved near Leo and into Perseus and its vapor reached ι and κ Ursae Majoris. It went out of sight after 56 days. Ho (76).

66 January 31 (P = January 26.0, d = 0.25 on March 20) China. Comet Halley was first sighted in the east on January 31, again on February 20, and finally about April 10 when it was 1.54 and 0.77 AU from the Sun and Earth respectively. Hence the comet was visible to the naked eye for some 74 days after perihelion. Ho (78).

71 March 6; China. A guest star was seen near the Pleiades. After 60 days it gradually went out of sight near Regulus. Ho (80).

75 July 14; China. A broom star comet appeared in Hydra, with a tail measuring about 4 degrees. It turned to the south of Coma Berenices and entered the region of Virgo and Leo. Ho (81).

76 October 7; China. A broom star comet, with a 3-degree tail, appeared in the region of Hercules-Ophiuchus-Aquila. It approached the western region of Capricornus and went out of sight after 40 days. Ho (82), Barrett (47).

77 January 23; China. A broom star comet with a tail of 12 degrees was seen in the western region of Aries. It moved slowly north to the region of Draco-Ursa Minor-Camelopardus and went out of sight after 106 days. Ho (83).

79 April; Korea, Italy. A broom star comet was first seen in the east and then in the north, disappearing after 20 days. This may be the comet that prompted the Roman emperor Vespasian to joke—"this hairy star is an omen for the king of the Persians"—since Persian kings wore their hair long and Vespasian was balding. Ho (84), Barrett (79), P290.

84 May 25; China. A guest star measuring 4 degrees appeared in the eastern, morning sky in Aries. It passed Cassiopeia into the north polar region where it remained for 40 days before going out of sight. Ho (85).

85 June 1; Korea. A guest star entered the north polar region. Ho (86).

101 January 12; China. A grayish vapor measuring 45 degrees rose from the north of Eridanus pointing at Canis Major. It was there for 10 days. Ho (87).

104 May 30; China. A white vapor, like loose cotton, developed in the north polar region. On June 10 it moved westward to the Pleiades and went out of sight on June 24. Ho (89).

110 January; China. A broom star comet was seen at the south of Eridanus pointing northeast. It was of grayish color and measured about 10 degrees. Ho (91).

110 July 27; China. A grayish guest star, as large as a pear, had 3-degree rays pointing southwest toward ι and κ Ursae Majoris. Ho (92).

117 January 9; China. A guest star was seen in the west. On January 20 it was in Aquarius. It went as far as the middle of Aries. Ho (93).

125–126 December–January; China. A guest star, possibly a nova, was seen in the region of Hercules-Serpens-Ophiuchus-Aquila. Ho (94).

126 March 23; China. A guest star entered the region of Goma Berenices-Virgo-Leo. Ho (95).

128 September–October; Korea. A tailed star stretched across the heavens. Ho (96).

132 January 29; China. A guest star was seen in Capricornus with rays more than 3 degrees pointing southwest. It was grayish in color and went out of sight in northern Aquarius. Ho (97, 98).

133 February 8; China. A guest star was seen southwest of Eridanus. It had a white vapor measuring about 3 degrees wide and about 75 degrees long. Ho (99).

141 March 27; (P = March 22.4, d = 0.17 on April 22) China. Comet Halley. On March 27 a broom star was seen in the east with a tail about 9 degrees long and pale blue in color; this was certainly the singly ionized carbon monoxide (CO^+) ion tail. The comet was observed until late April. Ho (100), Barrett (50).

149 October 19; China, Korea. A yellowish-white broom star comet with 7-degree rays pointing southeast appeared within the region of Hercules-Serpens-Ophiuchus-Aquila. It went out of sight on October 22. Ho (101).

153 November; Korea. A broom star comet was first seen in the east, then in the northeast. Ho (102).

154 January 31; Korea. A guest star trespassed against the Moon. Ho (103).

158 March–April; Korea. A bushy star comet was seen in Ursa Major. Ho (104).

161 June 14; China. A guest star appeared in Pegasus. When it came near Antares, it turned into a broom star comet developing a ray measuring about 7 degrees. Ho (105).

178 September; China. A broom star comet appeared north of Virgo with a tail several degrees long. It moved eastward, developed a red tail 70 to 90 degrees long and after 80 days went out of sight in Eridanus. Ho (106).

180 Winter; China. A broom star comet appeared near Sirius-Canis Major-Puppis moving eastward. It went out of sight after reaching Hydra. Ho (107).

182 August–September; China, Korea. A broom star comet was seen below Ursa Major moving eastward. It reached eastern Leo and went out of sight after 20 days. Ho (108).

186 November; Korea. A bushy star comet appeared in the northwest for 20 days. Ho (110).

188 March–April; China. A broom star appeared at the boundary of Andromeda and Pisces. After retrograding and entering the region of Draco-Ursa Minor-Camelopardus, it appeared three times and went out of sight after more than 60 days. Ho (111).

188 July 28; China. A guest star, as large as a 3-pint vessel, appeared at Corona Borealis. It moved southwest at first then southeast into Scorpius and went out of sight. Ho (112).

191 October; China, Korea. A white, banner comet with a tail measuring over 100 degrees appeared in southern Virgo. Ho (113).

193 November–December; China. A bushy star comet appeared near Spica and moved toward the northeast. After entering the region of Hercules-Aquila-Serpens, it went out of sight. Ho (114).

200 November 6; China. A bushy star comet was seen near the Pleiades. Ho (115).

204–205 December–January: China, Korea, Rome. A bushy star comet appeared in the region of Gemini and Cancer. It entered the region near Leo. Ho (116, 117).

206 February; China. A bushy star comet was seen with its head in Ursa Major but its tail penetrating the pole star. Ho (118).

207 November 10; China. A bushy star comet appeared in the region of Crater. Ho (119).

213 January–February; China. A bushy star comet appeared in Gemini. Ho (120).

217 November–December; China, Korea. A bushy star comet was seen in the northeast. Ho (121).

218 May–June; (P = May 17.7, d = 0.42 on May 30) China, Rome. Halley's comet was seen for approximately 40 days from early May to mid-June. For the first 20 days it was described as a bushy comet seen in the east. It moved from Gemini into Ursa Major and then into Ophiuchus. A comet caused panic in Rome during the revolt against the emperor Macrinus. Ho (122), Barrett (53).

222 November 4; China. A guest star appeared in Virgo. Ho (123).

225 December 9; China. A bushy star comet appeared in Leo Minor. Ho (124).

232 December 3; China. A bushy star comet appeared near Crater. Ho (125).

236 November 30; China. A bushy star comet appeared near Polaris measuring about 4 degrees. On December 15 it became a broom star comet in Hercules. Ho (126).

238 August 21; China. A broom star comet measuring 4 degrees appeared in Hydra. It retrograded, moved westward, and went out of sight after 41 days. Ho (127).

238 September 30; China. A guest star was observed retrograding in the north of Pegasus. On October 11 it trespassed against Hercules and went out of sight on October 16. Ho (128).

240 November 10; (P = November 10, d = 1.0 on November 30) China. A broom star comet measuring 30 degrees appeared in Scorpius, swept through Sagittarius, and trespassed against Venus. On December 19, it trespassed against Aquarius. Ho (129).

245 September 18; China. A white, broom star comet measuring 3 degrees appeared in Hydra moving southeast. After 23 days it disappeared. Ho (130).

247 January 16; China. A broom star comet measuring 1 degree appeared for 156 days near Corvus. Ho (131).

248 April–May; China. A bluish-white broom star with rays measuring 9 degrees pointing southwest was seen near the Pleiades. Ho (132).

248 August–September; China. A broom star comet appeared for 42 days near Crater measuring 3 degrees and moving toward Corvus. Ho (133).

251 December 21; China. A bushy star comet appeared for 90 days moving westward from Pegasus. Ho (134).

252 March 24; China. A white broom star comet measuring 75 to 90 degrees appeared in the west in Aries. Its rays pointed south and penetrated Orion. After 20 days it went out of sight. Ho (135).

253–254 December–January; China. A broom star comet measuring 75 degrees appeared in western Virgo pointing southwest. After 190 days it went out of sight. Ho (136).

254 December; China. A white vapor was seen coming from Sagittarius. Its width extended several tens of degrees and its length traversed across the heavens. Ho (137).

255 February; China. A broom star comet appeared extending approximately northwest from Capricornus to Corvus. Ho (138).

257–258 December–January; China. A white broom star comet was seen in Virgo. Ho (139).

259 November 23; China. A guest star was seen within the region of Coma Berenices-Virgo-Leo. After turning to the east, it moved southward and passed Corvus. It disappeared after 7 days. Ho (140).

260 July–August; Korea. A bushy star comet appeared in the east for 25 days. Ho (141).

262 December 2; China. A white broom star comet measuring less than a degree appeared in Virgo and changed its course toward the north. After 45 days it went out of sight. Ho (142).

265 June; China. A white broom star comet measuring more than 15 degrees was observed at Cassiopeia pointing toward the southeast. It went out of sight after 12 days. Ho (143).

268 February 18; China. A bluish-white broom star comet appeared in Corvus. It moved toward the northwest and then turned east. Ho (144).

269 October–November; China, Korea. A bushy star comet appeared in the region of Draco-Ursa Minor-Camelopardus. Ho (145).

275 January–February; China. A bushy star comet appeared within Corvus. Ho (146).

276 June 23; China. A bushy star comet was seen in Libra. During August the comet appeared near Arcturus, and during September it appeared in the region of Coma Berenices-Virgo-Leo, stretching as far as Crater and Ursa Major. Ho (147).

277 February–March; China. A bushy star comet appeared in the west. It appeared in Aries during the period April 20 to May 29, then near π Leonis (May 20–June 17). It appeared at the east (June 18–July 17) and then within the region of Draco-Ursa Minor-Camelopardus (August 16–September 14). Ho (148).

278 May–June; China. A bannerlike comet appeared in Gemini. Ho (149).

279 April; China. A bushy star comet appeared in northern Hydra. Within the period April 28 to May 27 it appeared near π Leonis, and during the period July 26–August 24 within the region of Draco-Ursa Minor-Camelopardus. Ho (150).

281 September; China. A bushy star comet appeared in western Hydra. Ho (151).

281 December; China. There was a bushy star comet in Leo. Ho (152).

283 April 22; China. A bushy star comet was seen in the southwest. Ho (153).

287 October–November; China. A bushy star comet measuring hundreds of degrees (?) appeared for 10 days in Sagittarius. Ho (154).

290 May; China. A guest star was seen in the region of Draco-Ursa Minor-Camelopardus. Ho (155).

295 May; (P = April 20.4, d = 0.32 on May 12) China. Comet Halley, observed during the month of May, began as a bushy star comet in northern Pisces and later became a broom star in the west. Apparently, the Chinese recognized that the comet seen in early May on the eastern horizon was the same object seen later that month on the western horizon. Ho (156).

299 October–November; Korea. A guest star trespassed against the Moon. Ho (157).

300 April–May; China. An ominous star was seen in the south, possibly a meteor or nova. Ho (158).

300–301 December–January; China, Korea. A broom star comet was seen west of Capricornus pointing approximately north. Ho (159).

301 May–June; China. A broom star comet appeared near Aquarius. Ho (160).

302 May–June; China, Korea. A broom star comet appeared in the day. Ho (161).

303 April; China. A broom star comet appeared in the east pointing toward Ursa Major. Ho (162).

305 September; China. A bushy star comet appeared in Taurus near the Pleiades. Ho (164).

305 November 21; China. A bushy star comet appeared in Ursa Major. Ho (165).

315 September–October; Korea. A bushy star comet was seen in the northeast. Ho (166).

329 August–September; China. A bushy star comet appeared in the northwest trespassing against Ursa Major. It went out of sight after 23 days. Ho (167).

336 February 16; China, Korea, Rome. A broom star comet in Andromeda appeared in the western evening sky. The death of the Roman emperor Constantine in May 337 was presaged by a hairy star of unusual size. Ho (168), Barrett (54), P301.

340 March 25; China. A bushy star comet was seen in the region of Coma Berenices-Virgo-Leo. Ho (169).

343 December 8; China. A white broom star comet measuring 10 degrees appeared in Virgo. Ho (170).

349 December 2; China. A white broom star comet measuring 15 degrees appeared in Virgo with its ray pointing toward the west. On January 29, 350, a broom star comet was again seen in Virgo. One Chinese source mentions a broom star comet seen on March 30, 350. Ho (171).

358 June 26; China. A broom star comet was seen extending from northern Perseus to northern Aries. Ho (172).

363 August–September; China. A bushy star comet was seen in Virgo. A contemporary Roman historian records a comet presaging the death of the Roman emperor Jovian who died in February 364. Ho (173), Barrett (55).

374 March 4; (P = February 16.3, d = 0.09 on April 2) China. Comet Halley appeared as a bushy star comet near western Aquarius. It traveled westward, becoming a broom star comet in Libra on April 2. The Chinese observational records are remarkably brief considering that the comet made a close Earth approach near opposition in early April. A bushy star comet was recorded as being seen on November 19 in the region of Hercules-Aquila-Serpens, but it could not have been comet Halley. Ho (175).

383 October–November; Korea. A bushy star comet appeared in the northwest. Ho (176).

389; Rome. Roman sources describe a strange and unusual star that was seen near Venus for 26 days. Pingré notes problems with the original reports and suggests the comet appeared near Jupiter, not Venus, in August. Barrett (57), P303.

390 August 7; (P = September 5, d = 0.10 on August 18) China, Korea, Rome. A bushy star comet appeared in Gemini. On September 8 it entered the region of northern Ursa Major. It was white in color and measured over 100 degrees. On September 17 it entered the north polar region and went out of sight. A Roman source reported a sign that appeared in the sky hanging like a column and blazing for 30 days. Ho (178), Barrett (58).

395 March; Korea. A bushy star comet appeared in the northwest for 20 days. Ho (180).

395 October; China. A tangle star comet, resembling loose cotton, moved toward the southeast and reached Aquarius. Ho (181).

396 July–August; China. A broom star comet was seen near the Pleiades. At first, a large yellow star appeared in Taurus for more than 50 days. In the period mid-December 396 to mid-January 397, the yellow star reappeared. The yellow star was possibly a supernova. Ho (182).

400 March 19; (P = February 25, d = 0.08 AU on March 31) China, Korea, Rome. A bushy star comet measuring 45 degrees appeared in the region between Andromeda and Pisces. Its upper portion reached Cassiopeia. It entered Ursa Major and between April 10 and May 9 it entered Leo. Roman historians noted a very large comet stretching from the sky to the ground. Ho (183), Barrett (61), P306.

400 September; Korea. A bushy star comet was seen in the east. Ho (184).

401 January 2; China. A bushy star comet was seen between the regions of Corona Borealis and Cygnus. Ho (185).

402 November–December; China. A white guest star, which resembled loose cotton, was seen at the west of the region Coma Berenices-Virgo-Leo. During the period January 9 to February 7, 403 the comet moved east into this region. Ho (186).

414 July 20; China. A bushy star comet appeared south of the Pleiades. Ho (187).

415 June 24; China, Korea. A broom star comet left the region of Hercules-Aquila-Ophiuchus-Serpens for the second time and swept a region in southern Hercules. It was then seen near the border between Libra and Ophiuchus. Ho (188).

416 October–November; China. A long broom star comet appeared in Ursa Major. On November 22 it entered the region of Coma Berenices-Virgo-Leo. It was seen for more than 80 days. Ho (189).

416–417 December–January; China. A broom star comet appeared from Cygnus and entered the region of Coma Berenices-Virgo-Leo. It then moved to Ursa Major and trespassed against Draco. After more than 80 days it reached the Milky Way and went out of sight. Ho (190).

418 June 24; China, Rome. A bushy star comet appeared within Ursa Major. On September 15 it appeared as a broom star comet with its handle arising from Leo and its rays extending to more than 100 degrees sweeping across northern Ursa Major. This account may refer to two different comets, one seen in June and the other in September. However, the Roman sources quoted by Pingré note that a cometlike phenomenon was seen during a solar eclipse on July 19, 418, and a comet was seen from mid-summer to the end of autumn. Ho (191), P309.

419 February 17; China, Korea. A bushy star comet appeared at the western wall of the region Coma Berenices-Virgo-Leo. Ho (192).

420 May; China. A tailed star comet extended across the heavens. Ho (193).

421 January–February; China. A guest star was seen in Crater. Ho (194).

422 March 26; China, Rome. A bushy star comet appeared in Aquarius. It moved toward the Milky Way and Cygnus and swept Altair. Roman sources note a comet, with a very long white ray, lasting 6 nights in March. Ho (195), P311.

422 December 18; China. A bushy star comet was seen in Pegasus. Ho (196).

423 February 13; China. A white bushy star comet measuring more than 30 degrees appeared in the eastern region of Pegasus and went out of sight after 20 days. A different Chinese source notes the comet in eastern Pisces in February with a 30-degree tail extending southeast to the Milky Way. Ho (197).

423 December 13; China. A bushy star comet appeared in northern Libra. Its tail measured 60 degrees, pointing northwest toward Boötes and facing Arcturus. It moved eastward and its length increased 9 to 10 degrees daily. After more than 10 days it went out of sight. During the interval from mid-December 423 to mid-January 424, a broom star comet was also recorded in Cetus. Ho (198).

435 June–July; China. A comet appeared in Leo. Hasegawa (298).

436 June 21; China. A bushy star comet was seen in Scorpius. Ho (199).

442 November 10; (P = December 15, d = 0.58 AU on December 7) China. A bushy star comet appeared in Ursa Major and entered Auriga. It passed through Taurus and reached Eridanus. More than 100 days later it disappeared in the west. Ho (201).

449 June–July; China. A broom star comet appeared north of the Pleiades. Ho (202).

449 November; China. A broom star comet entered the region of Coma Berenices-Virgo-Leo. Ho (203).

451 June 10; (P = June 28.2, d = 0.49 on June 30) China, Rome. Comet Halley was first seen June 10 near the Pleiades as a broom star. On July 13 it was recorded in southern Hercules. When the comet was last seen on August 15, it was 48 days past perihelion. This is the comet reported during the defeat of Attila the Hun at Chalons, France. Ho (204), P312.

453 February–March; China, Rome. A bushy star comet was seen in the west. This may be the comet reported just prior to the death of Attila in 453. Ho (205), P313.

454; Korea. A bushy star comet measuring 30 degrees was seen in the northwest. Ho (206).

460 November; China. A tailed star comet, over 15 degrees in length, appeared in Cetus. Ho (207).

461 April 20; China. A tailed star comet appeared in Cygnus. It was red in color and as long as a piece of cloth. Ho (208).

464–465 December–January; China. During the period from mid-December to mid-January a tailed star comet was seen near Vega. It was pure white in color. Ho (209).

467 February 6; China, Europe. A white vapor, called a long path, was seen stretching across the heavens from the southwest to the southeast. This type of comet may have two tails but the report does not rule out an auroral display. European sources report a large prodigy in this year. Ho (210), P314.

483 November–December; China. A guest star, the size of a peck measure and looking like a bushy star comet, appeared in Orion. Ho (211).

498 December; China. A broom star comet was seen in Leo. It passed through southern Cancer and reached the Milky Way. Ho (212).

501 February 13; China. A tailed star comet was seen stretching across the heavens. A comet recorded on April 14 may also refer to this object. Ho (213, 214).

507 August 15; China. A bushy star comet was seen in the northeast. Ho (215).

520 October 7; China. A broom star comet, as bright as a flame, was seen in the east. Ho (216).

530 August 29; (P = September 27.1, d = 0.28 on September 3) China, Rome. Comet Halley. On August 29 a broom star was seen in the northeast morning sky west(?) of Ursa Major. Its pure white tail was reported to be 9 degrees long. On September 4 it was seen as a northwest evening object with a 1-degree tail pointing to the southeast. It gradually turned to Libra and on September 23 it was barely visible. On September 27 it could not be seen (in the evening twilight?). Ho (217), P315.

533 March 1; China. A tailed star comet appeared. Ho (218).

535; China. A bushy star comet appeared in the region of Coma Berenices-Virgo-Leo. It passed Ursa Major and Pegasus before going out of sight. Ho (219).

537 February; China. A guest star was seen in the region of Draco-Ursa Minor-Camelopardus. Ho (220).

539 November 17; (P = November 6, d = 0.70 on November 27) China, Europe. A broom star comet appeared in Sagittarius measuring over 1 degree and pointing southeast. Its length gradually increased to over 15 degrees and it went out of sight on December 1 after reaching western Aries. Ho (221), P319.

541 February–March; China, France. A guest star appeared in the region of Draco-Ursa Minor-Camelopardus. Ho (222), P321.

560 October 9; China. A broom star comet was seen with its 6-degree rays pointing southwest. Ho (223).

561 September 26; China. A guest star appeared in Crater, possibly a nova. Ho (224).

565 April 21; China. A broom star comet was seen. Ho (225).

565 July 22; (P = July 15, d = 0.54 AU on September 13) China. A broom star comet appeared in Ursa Major. It entered southern Pegasus and its length gradually increased to over 15 degrees pointing northeast. After more than 100 days its length diminished to 4 degrees and it went out of sight ~~in~~ northern Aquarius. Ho (226).

568 July 20; China. A bushy star comet appeared in southern Gemini moving northward. After one month it reached Cancer and went out of sight. Ho (227).

568 July 28; (P = August 27, d = 0.09 AU on September 25) China. A guest star was seen in Libra. On September 3 a white guest star, resembling loose cotton, was seen near Antares. On September 27 it trespassed Delphinus and entered Pegasus. On October 16 it entered the region between Andromeda and Pisces and became smaller. On November 5 it was in western Aries. It is not clear whether this entire account refers to one comet, or to a nova seen on July 28 and a separate comet seen from September 3 to November 5. Ho (228).

574 April 4; (P = March 25, d = 0.89 AU on April 5) China. A bluish-white guest star, as large as a peach, appeared in Auriga. It gradually moved eastward while its length increased to 3 degrees. It traveled eastward through Ursa Major during the month of May and went out of sight after 93 days. Ho (229).

574 May 31; China. A bushy star comet was seen near the region of Draco-Ursa Minor-Camelopardus. It was the size of a fist and reddish-white in color. It pointed toward Leo and gradually moved southeast, while its length increased to 22 degrees. On June 9 it reached southern Ursa Major and went out of sight. Ho (230).

575 April 27; China. A bushy star comet appeared near Arcturus. Ho (231).

579 November; Korea. A tailed star comet stretched across the heavens and went out of sight after 20 days. Ho (232).

582 January 15–20; China, France. A broom star comet was seen in the southwest. Ho (233), P324.

583 February 20; China. A tangle star comet was seen. Ho (234).

588 November 22; China. A bushy star comet appeared in western Capricornus. Ho (235).

595 January 9; China, Korea, Europe. A broom star comet appeared in northern Aquarius. It reached northeastern Pisces. Korean records put the comet in Virgo. Ho (236), P324.

607 February 28; China. A tailed star comet that extended across the heavens was seen in eastern Pegasus and went out of sight after 20 days. Ho (237).

607 April 4; China. A tailed star comet was seen in the west extending across the heavens. It traveled through Pisces, Aries, and Virgo (?). The Chinese account states that this comet was again seen on October 21 in the south. It was seen in Virgo, Hercules, and nearly circled the sky before going out of sight in late January 608. This was certainly a separate comet altogether. Ho (237).

607 March–April; (P = March 15.5, d = 0.09 on April 19) China. Comet Halley. Three or four separate apparitions of cometlike objects result in a confusing set of observations in 607. Stephenson and Yau (1985) suggest that Halley was first recorded on April 18 in Gemini and Ursa Major. It passed Perseus, Auriga, and Gemini. It may also have been seen on March 30 in eastern Pegasus and followed for 20 days before being lost in the eastern morning twilight. Ho (237).

607 June 25; China. A bushy star comet was seen near the region of Ursa Major and Coma Berenices. Ho (238).

608 October 22; China. A broom star comet appeared in Auriga, swept Ursa Major, and went out of sight after reaching Scorpius. Ho (239).

615 July; China. A bushy star comet appeared southeast of Ursa Major. It measured one-half degree, looked black, and pointed and scintillated as it moved toward the northwest for several days until it reached Ursa Major. Ho (240).

617 July; China. A bushy star comet appeared in Leo. It was reddish-yellow, measured less than a half degree and went out of sight after a few days. Ho (241).

617 October; China. A broom star comet was seen in Pegasus. Ho (242).

626 March 26; China. A bushy star comet was seen near the Pleiades. On March 31, the comet was in Perseus. Ho (243).

634 September 20; China, Japan. A bushy star comet was seen in Aquarius for 11 days before going out of sight. The Japanese recorded a tailed star comet seen in the south during the month of September and (another?) broom star comet seen in the east during the month of February 635. Ho (244).

639 February; China, Japan, Korea. The Koreans recorded a bushy star comet seen in the northwest during the month of February. The Japanese recorded a tailed star comet seen on March 5, and the Chinese reported a bushy star comet appeared near the Pleiades on April 30. Ho (245).

641 August 1; China. A bushy star comet was seen in the region of Coma Berenices. It disappeared on August 26. Ho (246).

642 August 9; Japan. A guest star was seen. Ho (247).

647 September; Korea. A broom star comet appeared in the south and many stars drifted north. Ho (248).

662 Spring; Korea. A guest star was seen in the south. Ho (249).

663 September 29. A broom star comet measuring over 3 degrees appeared in Boötes. On October 1, it went out of sight. Ho (250).

666 February 15; China. A comet appeared in the region of Coma Berenices-Virgo-Leo. Hasegawa (390).

667 May 24; China. A broom star comet appeared at the northeast in the region of Auriga and Taurus. It was not visible on June 12. Ho (251).

668 May–June; China, Korea. A broom star comet appeared in northern Auriga. It went out of sight on June 7. Ho (252).

672 October; Korea. A broom star comet was seen on seven occasions in the north. Ho (253).

675 November 4; China. A broom star measuring 7 degrees in length appeared in southern Virgo. Ho (254), Hasegawa (395).

676 September 4; China, Japan, Korea, Europe. A broom star comet appeared in Gemini pointing toward the northeast. It measured over 4 degrees, increasing in size to 45 degrees. It entered Ursa Major, and after 58 days it went out of sight. Ho (255), P331.

681 October 17; China, Japan. A broom star comet, measuring 7 degrees, appeared in the west within the region of Hercules-Aquila-Serpens-Ophiuchus. As it moved eastward it became smaller, reached the region north of Altair, and went out of sight on November 2. Ho (256).

683 April 20; China, Korea. A broom star comet appeared in northern Auriga. After 25 days it went out of sight. Ho (257).

684 September 6; (P = October 2.8, d = 0.26 on September 7) China, Japan. Comet Halley. On September 6 or 7 a broom star was seen in the west with a tail more than 15 degrees long. It was observed for approximately 33 days. Ho (258).

684–685 December–January; Japan. A bushy star comet appeared at the zenith. It moved along with the stars of the Pleiades, and after approximately one month it went out of sight. Ho (258). An Italian source gives the interval of appearance as 684 December 25 through 685 January 6. Newton, R.R. (p. 679).

693 July 20; Korea. A broom star comet appeared in the east. Five days later, it appeared in the west. Ho (p. 214).

699 March; Korea. A white vapor spanned the heavens and a bushy star comet was seen in the east. Ho (259).

701 March–April; Korea. A broom star comet entered the Moon. Ho (260).

707 November 16; China. A broom star comet appeared in the west for 43 days before going out of sight. Ho (261).

708 July 28; China. A bushy star comet appeared in northern Aries. Ho (262).

709 September 16; China. A bushy star comet appeared in the region of Draco-Ursa Minor-Camelopardus. Ho (263).

712 July–August; China. A broom star comet moved from Leo to the region of Coma Berenices-Virgo-Leo. After reaching Arcturus, it went out of sight. Ho (264).

718 December 8; Japan. A broom star comet was observed. Ho (265).

725 February 11; Japan. A bushy star comet was seen. Ho (267).

729 January. Two comets were reported lasting 14 days, one in the east before sunrise and the other in the west after sunset. A single comet near the sun and with high declination would explain the reported sightings. P335, Chambers (250).

730 June 30; China. A broom star comet appeared in Auriga. On July 19 the bushy star comet was seen in Taurus. Ho (268).

738 April 1; China. A bushy star comet appeared in the region of Draco-Ursa Minor-Camelopardus. It passed the *box* of Ursa Major and after more than 10 days it was unobservable due to dark clouds. Ho (269).

744 Winter; Korea, Syria. An ominous star, as large as a five-peck measure, appeared in the central heavens. It went out of sight after 10 days. A great comet was seen in Syria. Ho (270), P336.

745 January 8; Japan. A bushy star comet was seen. Ho (271).

759 April; Korea. A broom star comet appeared. It went out of sight in the autumn. Ho (272).

760 May 17; (P = May 20.7, d = 0.41 on June 3) China. Comet Halley was first seen in the eastern sky before dawn with a white tail some 6 degrees long. First seen in northern Aries, it moved rapidly northeast. It passed through Taurus, Orion, Gemini, Cancer, and Leo. It was observed for approximately 50 days and was extinguished at a position 7 degrees west of β Virginis in western Virgo. Ho (273).

760 May 20; China. An ominous star measuring several tens of degrees was seen in the south (or possibly the west). During the month June 18 to July 16 it was extinguished. Ho (274).

761 May–June; Korea. A broom star comet was observed. Ho (275).

762. A comet like a beam was seen in the east. P337.

764 April–May; Korea. A bushy star comet appeared in the southeast. Ho (276).

767 January 21; China. A broom star comet appeared in Delphinus with its rays gradually invading northern Ophiuchus. It measured more than 1.5 degrees, and after 20 days it went out of sight. Ho (277).

768 Spring; Korea. A broom star comet was seen in the northeast. Ho (278).

770 May 26; (P = June 5, d = 0.30 on July 10) China, Japan, Korea. A white, broom star comet with a tail extending some 75 degrees was seen in the north. On June 19 it moved eastward approaching northern Auriga. On July 9 it was in northern Canes Venatici, and on July 25 the comet went out of sight. Ho (279).

773 January 15; China, Japan. A tailed star comet appeared east of Orion's belt. Ho (280).

776 January 11; China. A comet appeared in Delphinus and trespassed near α Herculis. It measured several degrees in length, and after 20 days it disappeared. Hasegawa (437).

813 August 4; Constantinople. A comet was seen that resembled two moons joined together. They separated, and having taken different forms, at length appeared like a man without a head. Despite this peculiar description, Pingré considers it to be a comet. This is a questionable appearance at best. P337.

814 April 17; China. A broom star comet appeared in the east. Ho (281).

815 April–May; China, Korea. A tailed star comet was seen in the region of Coma Berenices-Virgo-Leo. The Korean records note a comet appearing on September 7 in the region of Corvus and Crater with a 9-degree tail pointing west. Ho (282).

817 February 17; China, Europe. A broom star comet appeared in Taurus measuring more than 3 degrees and pointing southwest. After 3 days it came near Orion and went out of sight. Ho (283), P339, Newton, R.R. (p. 675).

821 February 27; China. A bushy star comet appeared in Crater. On March 7 the comet was above the planet Mercury near western Virgo. However, on March 7, Mercury was in Pisces, not Virgo. Ho (284).

821 July; China. A broom star comet appeared in northern Taurus measuring 15 degrees. It disappeared after 10 days. Ho (285), Hasegawa (447).

823 February 19; Japan. A bushy star comet appeared in the southwest for 3 days. Ho (286).

828 September 3; China. A broom star comet measuring 3 degrees appeared in Boötes. Ho (287).

834 October 9; China. A broom star comet appeared near Coma Berenices. Its tail measured over 15 degrees and pointed west. It moved northwest and went out of sight after 9 days. On October 31 a broom star comet again appeared in the east. Its rays measured 4 degrees and were very intense. Ho (289).

836 July–August; Korea. A bushy star comet was seen in the east. Ho (290).

837 March 22; (P = February 28.3, d = 0.04 on April 11) China, Japan, Europe. It is fortunate that this apparition, during which comet

Halley made its closest recorded approach to the Earth, is covered by the most detailed set of observations preserved in the Far Eastern records. On the night of March 22 a broom star appeared in the east with an 11-degree tail pointing west; it was then on the border between Pegasus and Aquarius. On the night of April 6 the comet was in Aquarius with a 15-degree tail pointing slightly south. On April 8 the comet was in western Aquarius with its tail increasing in both length and width. On April 9 the tail was split into two branches. On the evening of April 11 the comet was in Virgo and the 75-degree tail was undivided and pointing north. The next night the tail was pointing east, while the comet moved northwest. On April 13 the comet was in western Hydra and its tail reached its maximum length of over 90 degrees and pointed east. Thus, in a few weeks the Chinese reported the tail pointing in all four directions. On the night of April 28 the comet's tail was 4 degrees and pointing east. The comet went out of sight near Leo. Pingré records European observations through May 7. Ho (291), P340.

838 November 10; China, Japan, Korea. A broom star comet was seen measuring 30 degrees. On November 11 it was 37 degrees in length; on November 12 it was 45 degrees. On November 13 the comet was above Antares, with its 52-degree tail pointing toward Corvus. On the night of November 21 the comet appeared from the east, stretching across the heavens from east to west. One Chinese account has this comet going out of sight on December 28. Ho (292).

839 February 7; China, Japan, Europe. The comet appeared at the west, some 14 degrees from central Pegasus. Another Chinese source states the comet was in Aquarius on February 7. On March 12 it was seen at the north of Perseus. It went out of sight on April 13. Ho (292), P345.

840 March 20; China. A broom star comet appeared in eastern Pegasus and lasted 20 days. Ho (293).

840 December 3; China. A broom star comet appeared in the east. Ho (294).

841 July–August; China. A broom star comet appeared in northern Aquarius. Ho (295).

841 December 22; China, Japan, Europe. A broom star comet appeared in Piscis Austrinus. It was later found in Pegasus, then entered the region of Draco-Ursa Minor-Camelopardus. It went out of sight on February 9, 842. Ho (296), P346.

852 March–April; China, Japan. A broom star comet appeared in Orion. The Japanese note the comet was seen in the west with a tail larger than 50 degrees. Ho (297).

855 February 23; Japan, France. A tailed star comet was seen. Ho (298), P347.

857 September 22; China. A broom star comet measuring 4 degrees appeared west of Antares. Ho (299).

864 June 21; China, Japan, Europe. A broom star comet was seen in the northeast morning dawn. It was yellowish-white, measured 4 degrees, and was found in western Aries. The Japanese recorded a broom star comet on April 23, and French sources recorded a comet during the first 20 days of May. There is insufficient evidence to determine whether two separate comets appeared. Ho (300), P347, Newton, R.R. (p. 675).

868 January; Korea. A guest star trespassed against Venus. Ho (302).

868 January 21; Japan, Europe. A broom star comet was observed. The month is somewhat uncertain. In Europe a comet was recorded on January 29 in Ursa Minor. It advanced toward Triangulum and lasted 17 days. Ho (301), Hasegawa (471), P348.

868 February; China. A broom star comet appeared in Aries. This comet is possibly a later sighting of the comet seen in the previous month. Ho (303).

869 September–October; China, Europe. A broom star comet was seen in Perseus pointing northeast. Ho (304), P348.

875 March–April; Korea. A bushy star comet appeared in the east for 20 days. Ho (305).

875 June 5; Japan, France. A red broom star comet, with pointed rays, appeared in the northeast. On June 9 it measured over 15 degrees in northern Auriga. On June 24 a bushy star comet was seen. The death of the emperor Louis II was announced by a burning star that showed itself on June 7 in the north. Ho (306), P348.

877 February 11; Japan. A guest star appeared in Pegasus. Ho (307).

877 March; China, Europe. The Europeans record a comet in Libra seen in the west in March and lasting for 15 days. The Chinese record a comet in the period from June through July. P349.

882 January 18; France. A comet with a prodigiously long tail was seen. This is a questionable apparition. P350.

885; China. A broom star comet was seen near Castor, in Gemini. Ho (309).

886 June 13; China. A bushy star comet appeared in eastern Scorpius and passed Ursa Major and Boötes. Ho (310).

886 November 16; China. A comet known as the *long-path* type was seen coming from the west. It was white in color, 21 degrees in length, and bent at an angle. Eventually, it fell like a meteor. Ho (311). Possibly, this comet exhibited a tail directed toward the Sun as well as away from it.

890 May 23; Europe. A tailed comet was reported. Chambers (288).

891 May 12; China, Japan, Europe. A broom star comet appeared in Ursa Major. It moved eastward, swept Arcturus and entered the region of Hercules-Aquila-Serpens-Ophiuchus. It became over 100 degrees long and went out of sight on July 5. On May 11 the Japanese reported a guest star east of Antares. Ho (313), P350.

892 June; China, Europe. A white, cometlike banner was seen. It was 3 degrees long, shaped like hair and after several days it stretched from the midheaven to the horizon. European records put the comet in the tail of Scorpius, but note that it lasted 80 days and was followed by drought in April and May. If this is correct the European sighting would imply the comet was seen at the beginning of the year. Ho (312), P351.

892 December 28; China. A comet of the type called *celestial magnolia tree* was seen in the southwest. On December 31 it turned into a cloud and faded away. Hasegawa (486) places this comet in Sagittarius. Ho (314).

893 May 6; China. After many days of overcast sky, a broom star comet appeared in Ursa Major with a tail over 100 degrees. It moved eastward, swept Arcturus, and entered the region of Hercules-Aquila-Serpens-Ophiuchus. After more than 37 days, it became concealed by clouds. This entry has a peculiar similarity to the comet of 891. Ho (315).

894 February–March; China, Japan. A bushy star comet appeared in eastern Gemini. Ho (316).

894 August; China. An ominous, or evil, star appeared. Ho (317).

896 November–December; China. Three guest stars, one large and two small, appeared in northern Aquarius. Moving eastward together, they sometimes approached one another, then separated, giving the illusion that they were fighting among themselves. After 3 days the two smaller ones disappeared while the larger one faded away in northern Aquarius. Ho (318).

900 February; China. A guest star was seen in southern Hercules. It was as large as a peach and its rays concealed from view a small group of stars west of α Herculis. Ho (319).

900 August; Japan. A comet was seen. Hasegawa (493).

902 February–March; China. A guest star the size of a peach appeared in Cassiopeia. On March 2 a meteor arose from Ursa Major and reached the guest star, which was then remaining stationary. On March 4 the guest star was in northern Cassiopeia. In the following year it was still visible. (If this is a comet, this last statement is likely an error.) Ho (320).

904 July 15; China. A comet appeared in the east. It was many degrees in length and pointed to the southwest. Hasegawa (495).

904 November–December; Europe. A comet seen in the east lasted for 40 days. P352.

905 May 18; (P = April 26, d = 0.21 on May 25) China, Japan, Europe. A star resembling Venus appeared in the northwest evening sky. It emitted rays of 45 to 60 degrees and was blood-red in color. On May 19 its color resembled that of white silk. On May 22 the comet appeared in northern Gemini, but penetrated Ursa Major. Starting from Leo on June 12 it reached the western wall of the region of Hercules-Aquila-Serpens-Ophiuchus. Its brightness was very intense and it stretched across the heavens. On June 13 the sky was overcast; when it cleared on June 18, the comet had disappeared. Ho (321), P352.

907 April 7; Japan. A broom star comet was seen. Two days later it trespassed against Venus, then in Aries, and measured about 45 degrees. It went out of sight on April 15. Ho (322).

908 March; Korea. A bushy star comet was seen in the east. Ho (323).

911 June; China. A guest star trespassed against a group of stars in southern Hercules. Ho (324).

912 May 15; (P = July 18.7, d = 0.49 on July 16) China, Japan. Comet Halley. The Chinese observations of mid-May are discordant and were probably copied incorrectly, but contemporary Japanese observations during the second half of July are reasonably consistent with Halley's motion. The Japanese reported that a broom star comet was seen on the night of July 19 in the northwest. On July 21 and 22 it was the same. On July 24, Chinese records note that it was seen in the southeast although its appearance in the northwest seems more likely. On July 25 it was seen in the northwest direction, and on July 28 it was seen in the west direction. Ho (325).

918 November 7; Japan. A broom star comet appeared in the southwest and lasted three days. Ho (326).

923; China. A broom star comet was seen. Ho (327).

928 December 13; China. A bushy star comet appeared in the southwest measuring over 15 degrees. It was pointing southeast and was found in western Capricornus. Ho (328).

930 June–August; Japan. A guest star was seen in Aquarius. Ho (329), Hasegawa (508).

934 December 19; China. A broom star comet appeared in Aquarius and swept northern Capricornus. Ho (331).

936 September 21; China. A broom star comet appeared in Aquarius and swept northern Capricornus. It was small in magnitude and measured over 1 degree. This account has a peculiar similarity to that of the 934 December comet. Ho (332).

938 January 31; China. A bushy star comet was seen in the north. Ho (333).

939 February 24; Japan. A long star was seen in the sky. Hasegawa (512).

939 July(?); Italy. A comet of surprising grandeur was seen for eight nights. It threw out rays of extraordinary length. P354.

941 April; Japan. A star appeared in the west. It was bright and looked like a white rainbow. It had a small head but a large tail and it lasted two months before going out of sight. Ho (334).

941 August–September; China, Europe. A bushy star comet, several degrees long, was seen in the region of Hercules-Aquila-Serpens-Ophiuchus. It disappeared after 70 days. The Chinese accounts give various dates for the view period of this comet. Ho (335), P354.

942 October 18; France. A comet appeared for three weeks in the west and advanced gradually eastward to the meridian. P355.

943 November 5; China. A broom star comet near Spica appeared in the east, with its 15-degree tail pointing west. Ho (336).

947 February 20; Japan. A strange *lance star* appeared in the west. Ho (337).

947 September 12; China. A broom star comet appeared in the east, near the horizon. Its tail swept southern Leo Minor and on September 27, it went out of sight after having reached southern Leo. Ho (338).

948 March 2; Japan. A broom star comet was seen in the southwest. Ho (339), Hasegawa (521).

956 March 13; China. A bushy star comet appeared in southeastern Orion with its rays pointing southeast. Ho (340).

957 March 6; Japan. A white comet was seen 20 to 30 degrees in length. Hasegawa (523).

961 March 16; Japan. A broom star comet appeared in the southwest with its light resembling a wildfire. Ho (341), Hasegawa (526).

962 January 28; (P = December 28, 961, d = 0.35 on February 24) China. A guest star appeared in western Pegasus. It had a tail and emitted some faint rays. On February 19 it moved southwest and entered Libra. It went out of sight on April 2 when it reached a region near α Hydrae. Ho (342).

965 March 12; Japan. A guest star, possibly a meteor, was seen from southwest to northeast. Ho (343), Hasegawa (529).

967 January 8; Japan. A broom star comet was seen in the south. Ho (344), Hasegawa (530).

972 February 1; Japan. A broom star comet measuring over 6 degrees penetrated the Moon. Ho (345).

975 August 3; China, Japan, Europe. A broom star comet appeared in northwest Hydra measuring 60 degrees. In the morning, it was seen in the east pointing southwest. Moving westward, it passed through 11—of 28—lunar mansions before going out of sight after 83 days. Ho (346), P357.

977 March 16; Japan. At 8 P.M., two comets were seen, in the northeast and the southeast. Ho (347), Hasegawa (535, 536).

983 April 3; China. A guest star appeared in Virgo moving northward. Ho (348).

989 August 12; China. A guest star appeared west of Castor. It became dimmer and developed some rays and a tail that pointed southwest. Another Chinese account places this comet in the previous month. Ho (349).

989 August 12; (P = September 5.7, d = 0.39 on August 20) China, Japan, Korea. Comet Halley. On August 12 and 13, a bluish-white broom star appeared in northern Gemini. In the morning it was seen at the northeast for 10 days. Later, in the evening, it was seen at the northwest. It passed near Arcturus, and after 30 days reached a region east of Spica and disappeared. Ho (350).

990 February 2; China. A guest star appeared in Corvus. It retrograded and reached western Hydra. After traveling 40 degrees within 70 days, it went out of sight. Ho (351).

990 August–September (?); Europe. A star with a long tail appeared in the north. After some days, it was in the west with its tail pointing east. P359.

995 August 10; France. A comet was seen for 80 days. P359, Newton, R.R. (p. 676).

998 February 23; China, Japan. A broom star comet appeared in Pegasus with rays measuring over 1 degree. On March 8, it disappeared. Ho (352).

1000 December 14; France. A comet appeared for nine days. A meteor fell at about the same time and reports of the two events are confused. Some sources report the year as 999, rather than 1000. P360.

1003 February; Europe. A comet was seen in the west near sunset and then near sunrise in the east. P362, Newton (p. 674).

1003 December 21; China, Europe. A broom star comet trespassed against Cancer. On December 24, it trespassed against Cancer and Gemini. It was the size of a cup, bluish-white in color, and over 6 degrees long. After passing northern Gemini and Auriga, it entered eastern Orion and went out of sight. It lasted 30 days. Ho (354), P362.

1005 October 4; China, Europe. A guest star with rays like a bushy star comet appeared in Draco. Gradually it passed Cassiopeia and went out of sight after 11 days. Ho (355), P362.

1006; Korea. A broom star comet was observed. This record may refer to the nova observed in Lupus during the month of April 1006. Ho (357).

1009 May; Europe. A comet resembling a large beam was seen for four months in the southern parts of the sky. P365.

1011 February 8; China. A guest star appeared in Sagittarius. Ho (358).

1014 February 12; (P = April 6, d = 0.04 on February 25) China, Korea, Japan. A broom star comet appeared in the western evening sky. On February 27 it entered Auriga, and on March 7 it entered Perseus. Ho (359).

1017; Europe. A comet, like a large beam, was seen for four months. P366.

1018 August 3; (P = August 27, d = 0.38 on August 9) China, Japan, Korea, Europe. A broom star comet, measuring more than 30 degrees, appeared in the northwest. On August 13 the rays had become more intense. The Korean records mention the comet in the handle of Ursa Major on August 3 with the 60-degree tail pointing southwest. Ho (360), P366.

1019 February 6; Korea, Europe. A broom star comet appeared in Ophiuchus pointing west. Ho (361), P367.

1019 July 30(?); China. A broom star comet measuring about 4 degrees appeared in the handle of Ursa Major. Moving westward, it passed Leo and reached Hydra. It reached a length of 45 degrees and after 37 days, it went out of sight. There is some uncertainty in dating this record, and it may refer to the comet seen in August 1018. Ho (362).

1020 January 26; Korea. A broom star comet appeared in Ophiuchus. Ho (363).

1021 May 25; China, Korea. A guest star as large as a plum appeared in Leo. It moved rapidly past Regulus into western Virgo, concealing the star β Virginis. After 75 days it entered the horizon and went out of sight. Ho (364).

1023 France; Europe. A comet appeared in Leo. P368.

1032 July 15; China. A guest star appeared at the northeast above the horizon with rays shooting out like a comet. It went out of sight on July 27. Ho (366).

1033 March 5; China, Japan, Europe. A yellowish-white broom star comet with rays measuring about 3 degrees was seen in the northeast. In France, the comet was seen on March 9 in the morning sky. It lasted for three days. Ho (365, 367), Hasegawa (572), P369.

1034 September 20; China, Japan, Korea. A bushy star comet measuring 10 degrees long and one-half degree wide appeared in western Hydra. After 12 days, it went out of sight. Ho (368).

1035 January 15; China. A star with vaporous rays appeared in southeastern Pisces. Ho (369).

1037 March 19; Korea. Five comets, each measuring 7 to 9 degrees, were seen. Ho (370).

1041 September; Korea. A broom star comet about 45 degrees long appeared in the east and went out of sight after more than 20 days. Ho (371).

1041 November; Korea. A broom star comet about 45 degrees long appeared in the east and went out of sight after more than 10 days. Ho (372).

1049 March 10; China. A broom star comet appeared in Aquarius. In the morning, it was observed in the east pointing southwest. It reached western Aries before going out of sight after 114 days. Ho (373).

1053 February 25; Korea. A broom star comet, over 15 degrees long, appeared in Centaurus and then entered Crater. Ho (374).

1056 August–September; China, Japan. A broom star comet appeared in the region of Draco-Ursa Minor-Camelopardus and reached Hydra. It was white in color and measured more than 15 degrees. It went out of sight on September 25. Ho (376, 377), Hasegawa (585).

1056 December; Korea. A comet was seen in Corvus. Hasegawa (586).

1060 December 22; Japan. A broom star comet about 7 degrees long appeared in the south and disappeared after 5 days. Ho (378).

1063 June 8; Korea. A comet appeared near Arcturus. Hasegawa (590).

1063 August 22; Korea. A comet several degrees long was seen in Libra. Hasegawa (591).

1063 December (?); Korea. A comet appeared in the region of Hercules-Aquila-Serpens-Ophiuchus, then moved toward eastern Scorpius. The month of the comet's appearance is uncertain. Hasegawa (592).

1065 September 11; China, Korea. A guest star trespassed against Hydra. Ho (379).

1066 April 3; (P = March 20.9, d = 0.11 on April 24) China, Japan, Korea, Europe. Comet Halley. A broom star comet appeared in Pegasus. In the morning it was seen in the east with a length of about 10 degrees. It pointed southwest and reached Aquarius. It moved eastward and disappeared when near the Sun. On the evening of April 24 it was seen in the southwest. On April 25 it was in Auriga with its white vapor branched and stretched across the sky penetrating Gemini, Coma Berenices, and Leo, and reached Virgo and Libra. On April 26 the tail was 22 degrees long. The comet passed eastward from Pegasus all the way to Hydra and went out of sight after 67 days. Comprehensive Chinese observations allow the comet to be placed as a morning object in the east from April 3 through 22 and—after solar conjunction—as a western evening object from April 24 through June 6. The comet was last observed 77 days from perihelion, suggesting an unusually bright postperihelion apparition. According to an eleventh century manuscript in the archives of the cathedral in Viterbo, Italy the comet was observed in the eastern morning sky by a cleric for 15 days beginning on April 5. Reappearing in the western evening sky on April 24, "it looked like an eclipsed Moon, its tail rose like smoke halfway to the zenith, and it kept shining to about the beginning of June." Stein (1910), Ho (380).

1069 July 12; China. A guest star appeared at the longitudes of western Sagittarius. On July 23 it trespassed against Sagittarius and then went out of sight. Ho (381).

1070 December 25; China. A guest star appeared in Cetus. Ho (382).

1072 October 14; Korea. A firelike star appeared and trespassed Pegasus. Hasegawa (601).

1073 September 10; Korea. A guest star appeared in eastern Pegasus. Ho (383), Hasegawa (602).

1074 August 19; Korea. A guest star as large as a melon appeared in eastern Pegasus. Ho (384).

1075 November 17; China, Korea, Japan. A bluish-white star, looking like Saturn, appeared in the southeast at the longitudes of Corvus. On November 18 it grew a ray in the northwest measuring 4 degrees. On November 19 the ray measured 7 degrees, and the next night it measured 10 degrees pointing obliquely toward κ Corvi. On November 29 it entered the horizon and went out of sight. Ho (385).

1080 January 6; China, Korea. A broom star comet trespassed against Scorpius. A Korean record states that on February 5 a white vapor ran from the Pleiades to Crater and Corvus. Ho (386), Hasegawa (607).

1080 August 10; (P = September 10, d = 0.06 on August 5) China, Japan. A broom star comet appeared at the northwest in Coma Berenices.

Its white vapor measured 15 degrees and pointed obliquely to the southeast at the longitudes of Corvus. On August 13, it moved northwest and was found within the longitudes of Crater. On August 15 it measured 4 degrees and penetrated Coma Berenices obliquely. On August 20 it trespassed Leo and on August 24 it entered the horizon and went out of sight. On August 27, it reappeared in the morning at the longitudes of western Hydra and finally disappeared after a total of 36 days. Ho (387).

1090 March 31; Japan. Two strange stars were seen, one in the southeast and one in the southwest. Ho (388). Hasegawa (610) notes a Japanese record giving three comets.

1092 January 8; (P = February 22, d = 0.25 on January 7) China. A guest star appeared from the longitudes of eastern Orion, trespassing against and then concealing the stars at its sides. On January 9 it trespassed against the stars of eastern Eridanus, and on January 30 it entered northern Pisces. It went out of sight on May 7. Ho (389).

1097 October 2; (P = September 22, d = 0.52 on October 15) China, Korea, Japan. A broom star appeared in the west. On October 6 the comet appeared at the longitudes of Libra looking like Saturn. It was white in color and bright, with its tail measuring 4 degrees. On October 9 the rays measured 7 degrees. On October 16 it trespassed southern Hercules and the next night it moved slightly eastward and trespassed near α Ophiuchi. It went out of sight on October 25. Ho (390).

1106 February 9; China, Japan, Korea, Europe. On February 10 a broom star comet the size of the mouth of a cup appeared in the west. Its rays scattered in all directions as if broken into fragments. The comet was more than 60 degrees long, 4.5 degrees wide, and pointed obliquely toward the northeast. From northern Pisces, it traveled through Aries into Taurus before disappearing into twilight. The Japanese and Korean records note the comet was first seen in the southwest on February 9 and lasted over a month. According to Pingré, the comet was seen during the day and very close to the Sun as early as February 4 or 5. This comet is perhaps the progenitor of the Kreutz sungrazing family of comets. Curiously, a medieval European annalist stated that a meteor detached itself from the comet on February 16 and fell to Earth. Ho (391), P384, Newton, R.R. (p. 673), Marsden (1967, 1989).

1106 December 14; Korea. A broom star comet was observed. Ho (392).

1109 December; Europe. A comet with a tail pointing south was seen near the Milky Way. P389.

1110 May 29; (P = May 18, d = 0.49 on June 12) China, Japan, Korea. A broom star comet with rays measuring 9 degrees appeared in northern Pisces. It moved northward and entered the region of Draco-Ursa

Minor-Camelopardus. It then entered the horizon and went out of sight in the northwest. On June 9th the comet was seen in southern Cassiopeia. The next night it was in northern Cassiopeia, and on June 14 it had moved into Draco. A German annalist noted the comet from June 9 to June 30. Ho (393), Newton, R.R. (p. 678).

1113 August 15; Korea. A bushy star comet was seen in Pegasus. Ho (394).

1114 late May; Europe. A comet with a long tail was seen for several nights. P391.

1118 April 23; Japan. A comet was seen for only one night. Hasegawa (626).

1123 August 11; Korea. A bushy star comet was seen near the stars ε and δ in Ursa Major. Ho (395).

1126 July 19; China, Japan, Europe. A broom star comet measuring about 4.5 degrees was seen in the region of Draco-Ursa Minor-Camelopardus. Ho (396), P391.

1127 January 8; China. A white vapor arose at night in the region of Coma Berenices-Virgo-Leo and a broom star comet also appeared. Another Chinese source notes a comet stretching across the whole sky during the period between December 16, 1126, and January 14, 1127. Ho (397).

1130 December 30; Korea. A vapor measuring about 9 degrees and resembling a broom star comet appeared in northern Auriga. Ho (398).

1131 September–October; China. A broom star comet was seen. Ho (399).

1132 January 5; China. A broom star comet was seen. Ho (400).

1132 October 5; (P = August 30, d = 0.04 on October 7) China, Japan, Korea, Europe. The Japanese discovered the white broom star comet pointing west at the longitude of λ Orionis. On October 7 the Chinese noted a white broom star comet seen in northern Aries with intense rays, measuring over 45 degrees, and pointing northwest. On October 8 it moved south, reaching eastern Pisces, but its rays had become fainter and only 15 degrees in length. On the next night it moved further south and its rays measured only 3 to 4 degrees. According to the Japanese, it went out of sight on October 12 but the Chinese record its last appearance on October 27. Ho (401), P392.

1138 June–July; China. A guest star was guarding western Aries. Ho (402).

1138 September 3; China, Japan. A broom star comet was observed in the east. It went out of sight on September 29. On August 27 the Japanese reported a white broom star comet in the northwest measuring 8 to 9 degrees. It remained a few days before going out of sight. Ho (403).

1139 March 23; China. A guest star guarded eastern Virgo. Ho (404).

1145 April 15; (P = April 18.6, d = 0.27 on May 12) China, Japan, Korea, Europe. Like the previous return of Comet Halley, the observed period during this apparition is extraordinary. According to Pingré, Europeans first sighted the comet on April 15. In China it was apparently seen from April 26 until July 6, 78 days past perihelion. When first sighted by the Chinese on April 26, the comet was described as a broom star in the eastern, or morning, sky. On May 3 the comet, now described as a bushy star comet, was seen near northern Pisces. On May 9 the rays, which were some 20 degrees in length, pointed west. After entering solar conjunction, the comet emerged from the solar glare on May 16 in the west-northwest evening sky; its rays pointed east and were about 5 degrees in length, being partly covered with clouds. On May 17, after the skies had cleared, the broom star was seen with a 20-degree tail. On June 4 the broom star was close to the Moon and its rays were not seen. On June 8 its rays were 3 degrees in length, and on June 14 it was in western Hydra. On July 6 the broom star had dispersed. Ho (406), P393.

1146 December 29; China, Japan. A broom star comet appeared in the southwest in southern Pegasus. It measured about 15 degrees and gradually faded after more than 10 days. Ho (407).

1147 February 8; (P = January 28, d = 0.32 on December 29, 1146) China, Japan. A broom star comet over 15 degrees long was seen in the east. On February 13 it appeared in western Aquarius, with its rays measuring 15 degrees and approaching Delphinius. On February 14 it moved gradually northward, and on February 25 it faded away. Possibly, the comet seen in late December 1146 was this same object seen prior to its late January 1147 solar conjunction. Ho (408).

1155 May 5; Europe. A comet was seen. P394.

1156 July 23; China, Japan, Korea. A broom star comet appeared in the east. On July 25 it was seen in Gemini and was about 15 degrees in length. On July 30 it moved in a northeast direction, and on August 4 it trespassed against northern Canes Venatici. According to the Korean records, the comet was seen until August 25. Ho (409).

1161 July 22; China. A broom star comet appeared at the northeast of δ Ursae Majoris. Ho (410).

1163 August 10; Korea. A guest star trespassed against the Moon, which was then in Pisces. Ho (411).

1165 August; Europe. Two comets appeared before sunrise, one in the north and the other in the south. P394.

1166 April 23; China, Japan. A broom star comet appeared between the stars β Virginis and σ Leonis. It penetrated β Virginis, was white in color, and about 4 degrees long. After 20 days it went out of sight. Ho (412).

1175 August 10; China. A bushy star comet appeared in the northwest above Corona Borealis, in the northwestern region of Hercules. It was as small as Mars, but its rays radiated copiously in all directions. On August 15, it went out of sight. Ho (413).

1178 January 14; Japan. A broom star comet appeared at the southeast. On January 18 its rays became more intense. The Japanese also observed the comet on January 27th. Ho (414).

1181 August 6; China, Japan, Europe. A guest star appeared in southern Andromeda and trespassed against Cassiopeia. It went out of sight after lasting 185 days. Another Chinese source notes the guest star appearing on August 11 in Cassiopeia and lasting 156 days. Ho (415), P395.

1185 February 2; Japan. A banner comet measuring over 15 degrees was seen at the southeast. It was located in the eastern region of Hydra. Ho (416), Hasegawa (656).

1189 March 16; Japan. A reddish-white, broom star comet appeared in the east. It was over 15 degrees long and located in Coma Berenices. Ho (417).

1189 April 17; Japan. A white vapor appeared in the sky and pierced Ursa Major. Hasegawa (659).

1192 November 24; Japan. There were invocations for a comet. Hasegawa (660).

1198 November; England. A comet appeared for 15 days. P396.

1202 March; Japan. A broom star comet appeared. Ho (418).

1210 February–March; China. A guest star with rays spread out like a red dragon was seen in the region of Draco-Ursa Minor-Camelopardus. Ho (420).

1210 October 19; Japan. A broom star comet appeared in the west near the region of Hercules-Aquila-Serpens-Ophiuchus. It pointed east, measured over 15 degrees, and was seen throughout the night. On November 28 it was seen again. Ho (421).

1211 May–June; Korea, Europe. Pingré reports a comet seen for 18 days in Poland during the month of May. The Koreans recorded a white vapor appearing on June 18 and traveling through western Hydra, Crater, Corvus, the region of Coma Berenices-Virgo-Leo, and Ursa Major before disappearing. Hasegawa (668), P397.

1217 Autumn; Europe. A star was seen after sunset. It turned toward the south pointing a little westward. P398.

1220 January 25; Japan. A red broom star comet appeared in the northwest near the region of western Cassiopeia. Ho (422).

1220 February 6; Korea. A broom star comet appeared in Cepheus. Its tail measured about 4 degrees and pointed northwest. Ho (423).

1220 March 21; Korea. A bushy star comet appeared in Leo. Ho (423).

1221 January; Korea. A bushy star comet appeared near ε and δ Ursae Majoris. Ho (424).

1221 March 30; China. A comet was seen. Hasegawa (675).

1222 September 3; (P = September 28.8, d = 0.31 on September 6) China, Japan, Korea. Comet Halley. Korean observers first discovered the comet prior to solar conjunction on September 3 in southern Ursa Major. The observations describe it as a broom star, with a tail more than 5 degrees long pointing west. After the comet reached conjunction on September 5, Japanese observers described it as a broom star seen in the northwest. On September 8 it appeared in the northwest, its center as large as a half moon and white in color. However, the tail rays were red and more than 25 degrees long. Although the Korean observers record the comet as being visible during the day on September 9, this seems unlikely since it was 0.33 AU from the Earth at the time. However, Joseph N. Marcus and D.A.J. Seargent have suggested that this enhanced brightness might have been a result of forward scattering of sunlight from cometary dust particles since the Sun-comet-Earth angle was 136 degrees at the time of the reported daylight observation. On September 10 the broom star comet appeared in eastern Virgo with its tail pointing toward Arcturus. On September 25 it was in Libra, 4 days later it was seen in the southwest, and on October 8 was extinguished. Ho (425), Marcus and Seargent (1986).

1223 July; Europe. Early in July, a comet appeared in the western evening twilight. P400.

1224 July 11; China. A guest star guarded and trespassed against Scorpius. This record may refer to a nova rather than a comet. Ho (427).

1225 March 29; Japan. A comet was seen on March 29 and 31 and April 2. Hasegawa (680).

1230 December 4; (P = December 28, d = 0.13 on December 15) China, Japan. A guest star appeared in the west. The next night the comet was in the constellation Cygnus. On December 8 a star appeared from below Cygnus. It was as large as Saturn, but not as bright. On December 13 the comet entered the region of Hercules-Aquila-Serpens-Ophiuchus and departed December 26. On December 31 it passed a region west of Antares moving southeasterly. One Chinese source suggests the comet went out of sight as late as March 30, 1231. Not all accounts given for this comet are consistent. Ho (428).

1232 October 17; China, Japan. A white broom star comet appeared in the east. Its tail was more than 15 degrees long and bent like an elephant's tusk. It came from a region southwest of Spica and moved southward until October 27, when its tail measured 30 degrees. On October 31 it was not seen because of bright moonlight. Between 3:00 and 5:00 A.M. on November 11 it was seen in the southeast with a tail over 60 degrees. It lasted until December 14. Ho (429).

1239 May 27; Japan. An ominous star was seen in the northwest. Ho (431), Hasegawa (685).

1240 January 27; (P = January 21, d = 0.36 on February 2) China, Japan, Europe. A reddish-white broom star comet appeared in the southwest, measuring 4 degrees and pointing southeast. Two nights later it again appeared and was of the same size as Saturn, with its rays extending up to 6 degrees. On January 31 it was seen in Pegasus, and on February 1 it was seen at the side of Jupiter, the same size as Venus, with its rays measuring 7 degrees and pointing northeast. On February 2 it was facing Jupiter and was visible all night. On February 5 it was in eastern Pegasus, and on February 13 it was in southern Andromeda. On February 21 its rays were still faintly visible, and two nights later it was in Cassiopeia. On March 31 it went out of sight. Ho (432), P403.

1240 August 17; China. A guest star appeared in Scorpius. Ho (433).

1242 March 28; Japan. A comet was seen in the northwest. Hasegawa (688).

1245 February 24; (P = April 1, d = 0.11 on February 22) Japan. A guest star appeared in the southeast. On February 25 it appeared in the region of Ophiuchus and Aquila, and the next night it was seen in western Capricorn. On February 28 it resembled loose cotton. On March 30 a broom star comet was seen in eastern Pegasus. It measured 3 degrees and went out of sight on April 4. Ho (435).

1264 July 21; (P = July 20, d = 0.18 on July 29) China, Japan, Korea, Europe. A comet appeared in the northwest. On July 26 the broom star comet was in northern Hydra, with a tail reaching 100 degrees and illuminating the heavens. On July 31 it was in Cancer, on August 2 it was in Gemini, and on August 17 it was at a longitude corresponding to the eastern region of Orion. Toward the third week in September its rays slightly decreased, and on October 10 it finally went out of sight. The Japanese records note that its tail was only about 4 degrees on July 28, but its rays extended across the heavens on July 31. Pingré notes that it was seen in France as early as July 14 or 17. Aegidius of Lessines observations are summarized by Thorndike (1950). Ho (436), P406.

1265 Autumn; Europe. A comet appeared at the beginning of autumn and lasted until the end of that season. It was visible from midnight. A sixteenth century European annalist noted a star of unusual brilliance that poured out smoke like a furnace. P411, Newton, R.R. (p. 674).

1266 January 17; Japan. A broom star comet appeared in the east. It lasted until sometime within the interval February 7 to March 8. Hasegawa (699) has the comet first observed on January 18 in the southwest. Ho (437).

1266 August; Europe. Before morning twilight a comet was seen near the constellation Taurus. P413.

1268 August 27; Japan. A broom star comet was seen. Hasegawa (701) gives August 13 as the first date of observation and notes it was seen in the north. Ho (438).

1269 August; Scotland. A very fine comet was observed in the east during August and September. P415.

1273 February 5; Japan, Korea. A broom star comet was seen by the Japanese on February 5 and by the Koreans on February 17. Ho (439).

1273 April 9; China. A bluish-white guest star, with the appearance of loose cotton, appeared in Auriga. It moved from a region near ε and δ Ursae Majoris to a region in Boötes south of Arcturus. It lasted 21 days. The Japanese recorded a guest star on April 12 seen in the northwest. Ho (439), Hasegawa (705).

1273 October 17; Japan. A comet was seen in the west between 7:00 and 9:00 P.M. Ho (439).

1277 March 8; China, Japan, Korea. A broom star comet appeared in the northeast measuring over 4 degrees. Korean sources mention a banner comet seen on April 1. Ho (440).

1293 November 7; (P = October 28, d = 0.17 on November 22) China, Japan, Korea. A broom star comet measuring over 1 degree in length entered the region of Draco-Ursa Minor-Camelopardus. On November 25 it reached the region between η and γ Virginis; later, on December 23, it reached the box of Ursa Major. Ho (441).

1297 March 12; Japan, Korea. The Koreans noted a broom star comet appearing in Gemini. It lasted six days, but on March 25 it reappeared in Gemini. The Japanese noted that a comet measuring 9 degrees was seen in the west between 7:00 and 9:00 P.M. on March 13. Ho (442).

1297 September 14; China, Japan. An ominous star seen by the Japanese in the east between 7:00 and 9:00 P.M. appeared in southern Andromeda. Four days later, it was seen again in approximately the same location. Ho (443).

1299 January 6; (P = March 31, d = 0.75 on February 2) China, Japan, Korea. A comet approximately 2 degrees long appeared in the southern morning sky. On January 24 it was seen in the constellation Columba. Peter of Limoges noted that the comet had a long tail and was dark blue in color. On February 24 it was in the 14th degree of Taurus with a latitude of 5 degrees south. It remained visible until March 5. Ho (444), Thorndike (1950).

1299 October 23; Japan. A comet measuring 30 degrees in length appeared in the southeast between 3:00 and 5:00 A.M. Ho (445).

1301 September 1; (P = October 25.6, d = 0.18 on September 23) China, Japan, Korea, Europe. Comet Halley. Pingré notes that Europeans first discovered the comet on September 1. If so, this would imply that the comet was already unusually bright. Korean observers first sighted the broom star on September 14. Chinese observers first noted the white broom star comet, some 7 degrees long, on September 16 in Gemini. Later it passed into Ursa Major, Canes Venatici, and Corona Borealis and measured 15 degrees in length. Then it shortened to slightly more than 1 degree as it went to the south of δ and ε Ophiuchi. It went out of sight on October 31. Thorndike (1950) notes that the French cleric Peter of Limoges, Petrus Lacepiera, made observations of the comet's position with respect to the stars during the interval September 30 to October 6, when the comet moved southeast from Scorpius into Sagittarius. On September 15, between 3:00 and 5:00 A.M., Japanese observers noted a broom star comet in the east measuring more than 4 degrees; on September 23, between 7:00 and 9:00 P.M., they noted that it reappeared, this time in the northwest with its tail longer than 15 degrees. Ho (446), P420, Jervis (1985).

1301 November–December; Europe. Before Christmas, a comet was seen in the west after sunset. It set before midnight and lasted 15 days. On December 1 it was in Aquarius or Pisces. P423.

1303 July 27; Japan. A white comet measuring over 1 degree in length was seen in the northeast. Hasegawa (722).

1304 February 3; China, Japan, Korea. A white broom star comet was seen in Pegasus. Until April 18 it measured abut 1 degree in length and pointed southeast, then its length gradually increased. It pointed northwest, swept northern Lacerta, and went out of sight after 74 days. Korean observers placed the comet near the border of Andromeda and Pisces on February 7. Ho (447), Hasegawa (723).

1304 December 24; (P = January 19, 1305, d = 0.14 on December 22) Japan, Korea. A broom star comet appeared in northern Aquarius, and on December 30 it had entered southern Pegasus. Japanese observers noted that on December 26 it was seen in the west with a white tail, more than 1 degree, pointing eastward. Ho (448), Hasegawa (724).

1305 April; Europe. From April 15 through April 21, a large comet with a long tail was seen. P424.

1305 June 19; Japan. At 4:00 A.M., a comet was seen in the northeast. It was not seen after July 1. Hasegawa (726).

1307 March 20; Japan. There were invocations for an evil star. The star disappeared on the third day of the praying. Hasegawa (727).

1307 August 24; Korea. A broom star comet appeared in eastern Scorpius. Ho (449).

1313 April 13; China, Japan, Korea. A broom star comet appeared in Gemini. It remained visible for two weeks. Ho (450), P425.

1315 October 29; China, Japan, Europe. A guest star appeared in the region of Coma Berenices-Virgo-Leo. On November 28 it turned into a broom star comet and trespassed against the region of Draco-Ursa Minor-Camelopardus. It passed Corvus and reached eastern Pegasus after traversing 15 lunar mansions. It went out of sight on March 11, 1316. Ho (451), P426. According to Thorndike (1950), the French physician and astrologer, Geoffrey of Meaux, observed this comet from mid-December through February 12 and because of its height above the horizon and brightness, it was visible day and night without setting.

1330 April 7; Japan. A comet was seen in the northwest on April 7 and 12. Hasegawa (736).

1337 May 4; China, Korea. A bushy star comet appeared in Cassiopeia. It went out of sight on July 31 in Corona Borealis. Ho (454), Hasegawa (738).

1337 June 26; (P = June 14, d = 0.39 on July 21) China, Japan, Korea, Europe. A broom star comet appeared in the northeast and was located near the Pleiades moving toward the region of northern Perseus. It was a large white comet with a linear dimension of over 1 degree. On June 27 it traveled southwest and increased its speed daily until June 30, when its tail was about 4 degrees. On July 6 it swept Cassiopeia, on July 14 it swept Ursa

Minor, and on the next night it passed Polaris. On July 27 it trespassed Corona Borealis, and on July 29 it swept γ Herculis. On August 4 it swept Serpens Cauda, and on August 7 its rays were barely seen under the brightness of the Moon. On August 19 its rays became much weaker, but still could be seen northwest of Antares. It went out of sight on August 28 after passing a total of 15 lunar mansions. Ho (455, 452), Hasegawa (739), P429.

1338 April 15; Japan, Europe. Japanese invocations for a guest star were held. The comet was moving eastward in Gemini and set about midnight. On April 17 it was some 24 degrees within Gemini, with a latitude of 17 to 18 degrees. It lasted for about 2 weeks. Hasegawa (741), P433.

1340 March 24; (P = May 13, d= 0.35 on March 29) China, Japan, Korea. A white broom star comet, resembling loose cotton, appeared in northwestern Scorpius. It was about one-half degree long pointing southwest. It gradually moved northwest, and on March 25 was no longer visible, disappearing in Leo after having appeared for a total of 32 days. Ho (456, 453), Hasegawa (742), P434.

1345 July 31; (P = August 23, d = 0.05 on July 31) Japan, Korea, Europe. A broom star comet appeared in the region of Draco-Ursa Minor-Camelopardus. On August 3 it appeared near Castor in Gemini. On August 2 the Japanese noted that a white broom star comet, about 6 degrees long, was seen in the northeast. European records note that the comet first appeared in Ursa Major and went out of sight after reaching Leo, where the Sun was located. Ho (457), P435.

1347 August; Europe. A comet was seen in Taurus and in the head of Medusa. It was seen in Italy for 15 days and elsewhere for 2 months. P435.

1348 September 7; Japan. A comet appeared in the evening. Hasegawa (745).

1349 January–February; Japan. A guest star was seen in the interval between January 19 and February 17. Ho (458).

1351 November 24; (P = November 19, d = 0.05 on November 29) China, Europe. A bushy star comet was seen in northern Pisces. On November 26 it was seen in western Aries and the next night in northern Aries. On November 29 it appeared near the Pleiades and the next night was near Aldebaran in Taurus, but barely visible. Ho (459), P437.

1356 May 3; Korea. A guest star trespassed against the Moon, then in Gemini. This may have been a nova. Ho (460).

1356 September 21; China. A bluish-white broom star comet, about 1 degree long pointing southwest, was seen in the east. It appeared in western Hydra. It went out of sight on November 4 and had been seen moving northwesterly for over 40 days. Ho (461).

1360 March 18; China, Europe. A broom star comet appeared in the east. Ho (462), P438.

1362 March 5; (P = February 25, d = 0.44 on March 25) China, Japan. A bluish-white broom star comet measuring over 1 degree in length was seen in southern Pegasus. On March 17 it trespassed against the stars in northern Pegasus, its rays measuring over 30 degrees. On March 28 it wasn't seen, but it left a bent, white vaporous structure stretching across the heavens toward the west and sweeping Arcturus. On April 1 it passed the Sun and the rays were not visible. The comet was near the Pleiades and as large as a wine glass with a dull and faint color. On April 7 it went out of sight. Ho (463).

1362 April 25; China. A tailed star comet several tens of degrees long appeared in northern Aquarius. It disappeared after more than 40 days. Ho (464).

1362 June 29; China, Japan, Korea. A white broom star comet over 1 degree long appeared in the region of Ursa Minor and Draco. It moved in a southeast direction and pointed southwest. On July 6 its rays swept ι Draconis. The Koreans observed it on July 29 in northern Cassiopeia with a tail more than 1 degree in length. On August 2 it went out of sight. Ho (465).

1363 March 16; China. A broom star comet appeared in the east. Ho (466).

1364 March 30; Korea. A broom star comet was seen south of the region of Coma Berenices-Virgo-Leo, one was seen by the side of Arcturus, one was seen in Ursa Major, and one was seen in northern Libra with a red color and measuring more than one degree. A literal interpretation of the Korean record would suggest four different comets. Ho (467).

1366 October 25; (P = October 18, d = 0.03 on October 26) China, Japan, Korea. Periodic comet Tempel-Tuttle. A bushy star comet, the color of loose cotton and the size of a peck measure, appeared near the star δ Ursae Majoris. It moved southeast, passed and trespassed against Draco. On October 26, the comet was in southern Pegasus and the next night it was in western Aquarius. During its southeastern journey it trespassed Draco and Lyra, and went out of sight in western Aquarius. Ho (468), Hasegawa (758).

1367 February 20; Korea. A comet was seen on the horizon. Hasegawa (759).

1368 February 7; China. A broom star comet appeared in northern Taurus. Ho (469).

1368 April 8; (P = May 5, d = 0.14 on April 2) China, Japan, Korea. A broom star comet measuring over 12 degrees and pointing northeast was seen in Perseus. On April 26 it went out of sight northeast of Capella. Ho (470), Hasegawa (760, 761).

1370 January 31; Korea. A broom star comet appeared in the northeast. Ho (471).

1371 January 15; Europe. A very great comet was seen in the north with its tail directed toward the south. P442.

1373 April–May; China. From April 23 to May 22 a broom star comet entered the region of Draco-Ursa Minor-Camelopardus three times. Ho (472).

1374 March 11; Japan, Korea. A broom star comet measuring over 15 degrees was observed in the east. It lasted 45 days before going out of sight. Ho (473), Hasegawa (765).

1375 November; China. A comet appeared in Sagittarius. Hasegawa (766).

1376 June 22; (P = July 31, d = 0.18 on June 27) China, Japan, Korea. A white comet stopped in Cetus. It passed into eastern Pisces and Perseus, entered the region of Draco-Ursa Minor-Camelopardus, swept Ursa Major, and pointed toward Draco. It then entered Hydra and on August 8 went out of sight. The Japanese records note that a broom star comet appeared in the northeast on July 10. On July 25 it was seen at the northwest measuring over 15 degrees, and in the morning it appeared again at the northeast. Ho (474).

1378 September 26; (P = November 10.7, d = 0.12 on October 3) China, Japan, Korea, Europe. Comet Halley. The Chinese discovered the comet, measuring over 15 degrees, on September 26 near Capella. A week later, Korean observers noted that its position was less than 10 degrees from the north celestial pole. It swept Ursa Minor, then η Draconis on October 4. It was last seen on October 11 in Scorpius; it was cloudy after October 11 until November 9. Japanese observers were still offering prayers against the comet on November 15, so it may have been followed until then. However, Chinese observers recorded it only through October 11. Ho (475), P442.

1379 April; Japan. A broom star comet appeared in the east. Ho (476), Hasegawa (769).

1379 September 23; Japan. A comet appeared. Hasegawa (770).

1381 November 7; Japan, Korea. A broom star comet appeared in Libra. It measured over 15 degrees and went out of sight after 15 days. Ho (477).

1382 March 11; Korea, Europe. A bushy star comet was seen at the north. Ho (478), P443.

1382 September 19; Korea, Europe. A broom star comet measuring over

15 degrees in length appeared at the eastern wall of the region of Coma Berenices-Virgo-Leo. Though perhaps not trustworthy, a European account notes a comet appearing in the month of December. Ho (480), P443.

1384 September–October; China. A comet swept the constellation Crater at night. Hasegawa (775).

1385 October 23; (P = October 24, d = 0.74 on November 9) China, Japan. A star appeared in the region of Coma Berenices-Virgo-Leo. On October 30 it entered Crater measuring over 15 degrees. On November 4 it trespassed against Hydra. Ho (481), Hasegawa (776).

1388 March 29; China. A star appeared in eastern Pegasus. Ho (482).

1389 June–July; China. A white comet more than 15 degrees in length was seen in ecliptic longitudes similar to that of western Capricornus. Hasegawa (779).

1391 May 23; China, Korea. Two broom star comets were seen. One entered the region of Draco-Ursa Minor-Camelopardus while the other trespassed against northern Camelopardus and swept Cepheus. Korean records note a broom star appearing on May 11 for more than 10 days and a guest star appearing on May 22 in the region of Draco-Ursa Minor-Camelopardus. Ho (483).

1392 March 18; Korea. A broom star comet stretched across the heavens. Ho (484).

1397 December 25; Japan. A guest star was seen in the northwest. Ho (485), Hasegawa (785).

1399 October 7; Japan, France. A guest star was seen in the southern sky. Pingré notes that in November a star of extraordinary brilliance was seen with its tail turned toward the west. It lasted only a week. Ho (486), Hasegawa (787), P445.

1402 February 20; (P = March 21, d = 0.71 on February 19) Japan, Korea, Europe. A broom star comet measuring about 9 degrees appeared northeast of Pisces with its rays pointing east. On February 22 it appeared in the east with its rays radiating in all directions. On March 8 the rays continued to be of the same magnitude, and on March 19 it went out of sight. Pingré notes that this comet was first seen about February 8 in Europe; afterwards, during the fourth week in March, it became so bright as to appear in the daytime for eight days. Europeans followed the comet until the middle of April. Ho (487), P446, Hind (1877).

1402 June; Europe. From June to September an immense comet was seen in the west. It perhaps reached its greatest brilliancy at the end of August and was noted to be visible during the daytime. P449.

1403 December 18; Korea. A broom star comet appeared in the northeast. Ho (488).

1404 March 1; Korea. A bushy star comet was seen in the east. Ho (489).

1407 December 15; China. A broom star comet was seen. Ho (491).

1408 July 14; Japan. A guest star was seen. Ho (492).

1410 December 23; Korea. A guest star appeared. Hasegawa (799), P452.

1413 August 18; Korea. A comet appeared. Hasegawa (800).

1414 April 8; Japan. An evil star was seen. Ho (493).

1415 September; China. A broom star comet was seen in Sagittarius. Ho (494).

1416 July 29; Japan. An ominous star was seen. Ho (495).

1417 March 18; Korea. A comet was seen at the east. Hasegawa (804).

1419 June 12; Japan. An object like a tailed star comet was seen at the northeast after 11:00 P.M. Ho (496).

1421 January 9; Japan. A broom star comet measuring 7 degrees appeared at the northwest between 7:00 and 9:00 P.M. Ho (497).

1421 December 27; Japan. A guest star was seen. Ho (498).

1430 November 14; China. A tangle star comet appeared in southern Pisces moving southeasterly. It passed through Cetus and into Fornax and went out of sight after eight days. Ho (501).

1431 January 4; China. A bright, yellowish-white star appeared in eastern Eridanus. It disappeared after 15 days but appeared again on April 29. This sighting might have been a nova. Ho (502).

1431 May 15; China. A bushy star comet measuring over 7 degrees appeared in Gemini. Ho (503).

1432 February 3; China. A broom star comet appeared in the east measuring over 15 degrees. Its tail swept southern Cygnus and its course was toward the southeast. It went out of sight, but on October 26 reappeared in the west. It then went out of sight after 17 days. Hasegawa (1980) considers the comet reappeared on February 29 rather than October 26. One Chinese source has the comet reappearing on March 29 and lasting 17 days. Possibly there were 2 comets in 1432. Ho (504).

1433 September 15; (P = November 8, d = 1.23 on October 9) China, Japan, Korea, Europe. A broom star comet measuring over 15 degrees appeared in Boötes. On October 2 it entered Corona Borealis. On October 12 it swept the star κ Ophiuchi. On November 2 it was in the western heavens and was very small; two days later it went out of sight. The Italian Paolo

Toscanelli first observed the comet on October 4 as it moved southward into Corona Borealis. He followed it until October 31. Ho (505), P453, Jervis (1985).

1434 April 14; Japan. A broom star comet was seen in the east. Ho (506).

1434 September 11; Japan. A broom star comet was seen in the east. Ho (507).

1437 March 11; Korea. A guest star, possibly a nova, appeared in Scorpius and went out of sight after 14 days. Ho (508).

1438 March 16; Japan. A guest star was seen. Ho (509).

1439 March 25; (P = May 9, d = 0.31 on March 30) China, Japan, Korea, Europe. A broom star comet as large as a pellet appeared in eastern Hydra. On April 2 it was more than 75 degrees, moved toward the west, and swept western Leo. It extended northward and trespassed Cancer. Korean records put the comet in Gemini on April 12. Ho (510), P454.

1439 July 12; China. A broom star comet measuring over 15 degrees appeared near the star Aldebaran in Taurus. It pointed southwest and went out of sight after a total of 55 days. Ho (511).

1443 May 3; Japan. An evil star was observed. Ho (512).

1444 August 6; China, Japan, Korea, Europe. A broom star comet appeared at the eastern wall of the region of Coma Berenices-Virgo-Leo. It measured over 15 degrees, and its length increased daily. On August 15, it entered a region near the star Spica, in Virgo, and went out of sight. Ho (513), P454.

1449 December 20; (P = December 9, d = 0.50 on January 26, 1450) China, Korea. A broom star comet appeared at the region of Hercules-Aquila-Serpens-Ophiuchus. It measured over 3 degrees, passed the longitudes of eastern Scorpius, and went out of sight on January 12. Korean records note it was visible through the end of January 1450. Observing from Florence, Paolo Toscanelli followed the comet from December 26, 1449 through February 13, 1450 using a ruler to determine its position with respect to neighboring stars. Ho (514), Jervis (1985).

1452 March 21; China. A bushy star comet appeared in Taurus. Ho (515).

1453 January 4; China. A star appeared in Cancer moving slowly towards the west. Ho (516).

1456 May 27; (P = June 9.6, d = 0.45 on June 19) China, Japan, Korea, Europe. Comet Halley. The Chinese first observed the broom star comet in northern Aries on May 27 with a 3-degree tail pointing southwest. By June 7 the tail length had increased to over 15 degrees, and on June 22 the comet was seen in northern Hydra with a tail more than 13 degrees long sweeping northern Leo. On June 28 it appeared in eastern Hydra, measuring over 10 degrees and moving southwest. On July 6, it measured over one degree and entered the region of Coma Berenices-Virgo-Leo. The Italian Toscanelli observed the comet from June 8 to July 8. When the comet was near solar conjunction on June 17, he made note of it both in the morning and evening sky. Peurbach, in Vienna, tried to measure the comet's parallax—the first attempt of its kind. Ho (517), P459, Hellman, Jervis (1985).

1457 January 14; China, Japan. A broom star comet again appeared in Taurus measuring one-half degree. It moved toward the southeast, gradually increased in length, and went out of sight on January 23. Paolo Toscanelli recorded its position from January 23 to 27, 1457. Ho (518), Jervis (1985).

1457 June 15; (P = August 8, d = 0.27 on July 2) China, Japan, Korea, Europe. A broom star comet with a half-degree tail pointing southwest was seen in southern Pegasus and appeared to be vibrating. On June 22 it measured over 15 degrees and concealed a region near Pegasus. It moved from the southwest to the northeast in Pegasus, then into Andromeda, Perseus, and Gemini. Korean observers recorded the comet through July 16, while the Japanese noted the comet was a morning object on July 30, with a tail 7 degrees long, and was still visible on August 19. Paolo Toscanelli, in Florence, noted the comet's positions from July 6 through August 29, 1457. Ho (519), P464, Jervis (1985).

1457 October 26; China, Korea. A broom star comet with a half-degree tail pointing north appeared near Spica in Virgo. Ho (520).

1458 December 24; (P = November 7, d = 0.21 on December 23) China, Korea. A white star, pointing west, was seen in Hydra. On December 27 its body became smaller and appeared like loose cotton in northern Leo. On December 31 it developed a ray measuring one-half degree, and it went out of sight on January 12, 1459, in Gemini. Korean observers followed the comet through January 13, 1459, and record what may be another comet beginning again on February 1. On February 13 it was in northwestern Aries, and observations continued on several days until April 8 when its light was recorded as faint. Ho (521).

1459 October–November; China. A broom star comet appeared. Ho Peng Yoke and Ang Tian-Se (30).

1461 July 30; China. A star as white as powder appeared in northern Ophiuchus. On August 2 it turned into white vapor and went out of sight. Ho (522).

1461 August 5; China. A broom star comet appeared in the east and pointed southwest. It entered the longitude of Gemini, and on September 2 it went out of sight. Ho (523).

1462 June 29; (P = August 4, d = 0.29 on July 2) China. A darkish white star appeared in Cassiopeia and trespassed against Ursa Major. On July 16, while still in Ursa Major, it gradually became smaller. Ho (524).

1465 March; China. A broom star comet measuring over 45 degrees was seen in the northwest. It first appeared in the interval between February 25 and March 26 and was seen for 3 months. Ho (525).

1468 September 18; (P = October 7, d = 0.67 on October 2) China, Japan, Korea, Europe. A star appeared in Hydra moving northeast. After 5 days, its rays exceeded 45 degrees and pointed southwest. Henceforth, it appeared in the eastern morning sky and at dusk in Pegasus. It trespassed against northern Canes Venatici and Ursa Major, then turned and entered the region of Hercules-Aquila-Serpens-Ophiuchus. After leaving this region, it gradually diminished in size, trespassed against Scutum, and went out of sight on December 8. One Chinese source noted a bushy star comet in Ursa Major during the interval between July 19 and August 17. Ho (526), P467.

1469 March–April; Japan. A guest star was seen (possibly a nova). Ho (527).

1469 September 3; Japan, Korea. A broom star comet was seen in the east. Korean observers followed the comet until October 10. Ho (528).

1471 March–April; China. A bushy star comet appeared in Virgo. Ho Peng Yoke and Ang Tian-Se (36).

1471 May 20; Japan. A guest star was seen. Ho (529).

1471 Autumn; Poland. A very great comet was seen before sunrise. It lasted a month in Virgo and Libra. This reference may well belong to the comet first seen on December 25, 1471. P469.

1471 December 25; (P = March 1, 1472, d = 0.07 on January 23, 1472) China, Korea, Japan, Europe. The Chinese noted a broom star comet appearing in Virgo pointing west on January 16. It moved northward trespassing against a region near Arcturus and sweeping eastern Coma Berenices. It reached Leo with its tail pointing west. On January 24 its rays grew and stretched across the heavens from east to west. It moved northward for over 28 degrees, trespassing against many stars in Ursa Major and even appearing at midday. On January 27 it moved south and trespassed against stars in western Aries and eastern Pisces, where it was observed on February 17. Gradually it diminished, but took a long time to disappear altogether. Korean observers noted the comet in Virgo, with faint rays, as early as January 7, then reported its tail as being some 30 degrees in length in the third week of January, decreasing to 15 degrees in the last week and steadily thereafter, with the last Korean report of the comet, only faintly visible, on February 21. Pingré notes European observations from December 25, 1471. Paolo Toscanelli, then 75 years old, recorded its position from January 8 through 28, 1472. On January 8, it was in Libra, and on January 22 it was moving very quickly only 15 degrees from the north pole. On the evening of January 23 it was moving more than one degree per hour, and on January 26 it was seen in Aries. Its extreme angular motion on the sky January 22 and 23 was due to its close Earth approach. Ho (530), P471, Jervis (1985).

1476 February; Japan. A guest star was seen between January 27 and February 24. Ho (531).

1476 December; Europe. A small pale blue comet was seen from the last of December 1476 until January 5, 1477. P477.

1480 March 17; Japan. A broom star was seen in the southeast. Ho (532).

1482 June–July; Japan. A large star, perhaps a guest star, was seen at the east. Ho (533).

1489 November 6; China. A broom star comet was seen. Within the month from November 23 to December 21 a guest star was seen in the region of Hercules-Aquila-Serpens-Ophiuchus. Ho Peng Yoke and Ang Tian-Se (38).

1490 December 31; (P = January 8, 1491, d = 0.52 on January 13, 1491) China, Japan, Korea. A broom star comet appeared in Cygnus with its tail pointing northeast. It trespassed against western Pegasus and on January 10, 1491, it was in the middle region of Pegasus. On January 22 it trespassed Cetus. Korean observers followed it until February 14, 1491. Ho (534, 535). Hasegawa (1979, 1980) considers there were three naked-eye comets seen in January through February 1491 and provides orbits for two of them. However, his orbit for comet 1491 I satisfies all the observations reported here fairly well.

1495 January 7; China. A slow-moving star appeared in Ophiuchus, approaching Sagittarius. On March 20 it entered southwestern Pegasus. Ho (536).

1499 August 16; (P = September 9, d = 0.06 on August 17) China, Korea. A star appeared in southeastern Hercules, passed into Draco, Ursa Minor, and Ursa Major, and went out of sight on September 6. Ho (537).

1500 May 8; (P = April 30, d = 0.83 on June 2) China, Japan, Korea. A broom star comet appeared near the border between Capricornus and Aquarius. It moved into Pegasus and increased its length to over 5 degrees. It then became smaller, approached Draco, and trespassed against Ursa Major. On July 10 it went out of sight. Pingré notes European records of a comet in Sagittarius and Capricornus during the month of April. Ho (538), P479.

1502 November 28; China. A star appeared in western Hydra, moved eastward into Crater, then back to western Hydra. It disappeared on December 8. Ho (539).

1506 July 31; China, Japan. A star like a pellet, with a darkish-white color and faint rays, appeared near northeastern Orion. Its length gradually increased to 3 degrees like a broom, then reached Ursa Major in the northwest. On August 11, the comet showed a bright ray extending 4 degrees to the southeast. After 3 days, it measured 7 degrees and swept southern Ursa Major. Finally it entered the region of Coma Berenices-Virgo-Leo. The Japanese reported a white comet that appeared in the northwest between 7:00 and 9:00 P.M. on August 7. It was seen in Ursa Major with a 15-degree tail. Ho (540).

1520 January–February; China. During the interval January 20 to February 18, a broom star comet was observed. Ho (541).

1521 February 7; China. A star like a fire appeared in the southeast. It turned white, measured 9 to 10 degrees and stretched from east to west. It then bent like a hook and disappeared after some time. This was possibly an auroral display. Ho (542).

1523 July–August; China. During the interval of July 13 to August 10, a bushy star comet appeared in the region of Hercules-Aquila-Serpens-Ophiuchus. Ho (543).

1529 February 9; China. A tailed star stretched across the heavens. Ho (544).

1529 August; China, Korea. A tailed star again appeared during the interval of August 4 to September 2. Korean sources noted a white broom star comet appearing in the west on September 1. It measured 6 to 7 degrees and on September 18 it shifted to the east. Ho (545).

1531 February 5; Japan. A broom star comet was seen. After a month and a half, it went out of sight. Ho (546).

1531 August 5; (P = August 26.2, d = 0.44 on August 14) China, Japan, Korea, Europe. Comet Halley. A broom star comet appeared in Gemini measuring over 1 degree. Its rays increased in length, and when it reached Crater it measured over 10 degrees and swept central Gemini at the northeast. It swept across Coma Berenices and, to the southeast, brushed a region near Spica in Virgo. It gradually diminished in size and went out of sight after 34 days. Japanese sources note the comet appeared in the northeast between 5:00 and 7:00 A.M. on August 9. It measured 7 degrees and was bluish-white. Later it was seen in the northwest. Korean sources note the comet on August 10 as being white in color and 15 degrees in length. Halley (1752) notes the comet was observed from August 13 to 23 by Peter Apian at Ingolstadt. Pingré suggests the first European sightings were in late July or early August. Ho (547), P487, Hellman (1971).

1532 March 9; China. A darkish-white star with pointed rays appeared at the southeast. After 19 days it went out of sight. Ho (548).

1532 June 21; Japan. A broom star comet was seen at the northeast. After a few weeks it went out of sight. Ho (549).

1532 September 2; (P = October 18, d = 0.67 on September 21) China, Japan, Korea, Europe. A broom star comet measuring about 1 degree appeared in southern Gemini. (Chinese sources have it moving northeast into Cygnus but that seems unlikely.) It then gradually increased to over 15 degrees and swept a region near the star Spica in Virgo. It appeared until December 21. Korean sources first record the comet on September 14 near the border between Cancer and Hydra. On October 2 it shifted to an object on the eastern horizon and appeared white in color with a 15-degree tail. It appeared until December 30, when its light became faint. Japanese sources record the comet in the east on September 15. It was observed by Peter Apian, Girolamo Fracastoro, and Johannes Vögelin. From their observations, its motion can be tracked from southern Gemini southeastward into Leo, Virgo, and Libra. Ho (550), P491, Jervis (1980), Hellman (1971).

1533 June 27; (P = June 15, d = 0.42 on August 2) China, Japan, Korea, Europe. On July 1 a broom star comet measuring over 7 degrees appeared in Auriga with its tail sweeping into western Perseus. Its length gradually increased to over 15 degrees, then it trespassed against western Cassiopeia. On September 16 it went out of sight. A Korean account places the white comet in northern Auriga on June 27 with a tail measuring 10 to 12 degrees. It entered Perseus, went west through Cassiopeia, and reached Cygnus. On August 26 its size gradually diminished. The Japanese recorded the broom star comet in the north on July 15. European observers included Copernicus, Peter Apian, Gemma Frisius, and Girolamo Fracastoro. Ho (551), P496, Jervis (1985), Hellman (1971).

1534 June 12; China. A star appeared in southwestern Cassiopeia. It moved eastward and went out of sight after 24 days. Ho (552).

1536 March 24; China. A star appeared in Draco. It moved eastward and entered the Milky Way. On April 27 it went out of sight. Ho (553).

1537 March 8; Japan. A broom star appeared at the northwest. Ho (554).

1538 January 9; (P = December 30, 1537, d = 0.94 on December 17, 1537) Japan, Korea, Europe. The Japanese recorded a broom star comet on January 9. Korean sources note a broom star comet appeared in the west on January 21. It was white and measured about 45 degrees. On January 29 it developed a faint vapor. On January 17 Peter Apian saw the comet, with a 30-degree tail, some 5 degrees into Pisces with a latitude of 17 degrees north. Five days later, Gemma Frisius put it 9 degrees in Pisces with a latitude of 11 degrees north. Ho (555), P498.

1539 April 30; (P = May 12, d = 0.2 on May 31) China, Korea, Japan, Europe. A broom star comet was seen in Leo. Its rays pointed southeast and measured about 4 degrees. After 10 days it went out of sight. Korean records note a broom star comet in Leo on April 20. Its tail was white and 7 to 9 degrees long. During the interval of May 18 to June 15 it passed into Hydra. In Europe it was observed by Gemma Frisius and Peter Apian. Ho (556), P500.

1545 December 26; China. A star appeared in Draco. It entered western Sagittarius and turned to a northeast course. In the following month it went out of sight. Ho (557).

1549 March 7; Korea. A broom star comet was seen in the northeast. From March 29 to April 26 it shifted to the east. Ho (558).

1554 June 23; China, Korea. A broom star comet appeared beside δ Ursae Majoris. It then moved near the horizon and disappeared after 27 days. The Korean records note that a broom star comet with a white tail measuring about 2 degrees appeared in Ursa Major on June 26 and went out of sight on July 11. Ho (559).

1555 October–November; China. A comet appeared in the Pleiades. It moved north to Ursa Major. Hasegawa (913).

1556 February 27; (P = April 22, d = 0.08 on March 13) China, Japan, Korea, Europe. A broom star comet was seen in Corvus. Moving northeast into Virgo, it entered the region of Draco-Ursa Minor-Camelopardus. Its white tail measured about 7 degrees. On April 20 it reached eastern Pegasus, but both its size and brightness had gradually diminished. On May 10 it went out of sight. In Europe it was first noted on February 27 and followed by Paul Fabricius, Joachim Heller, Erasmus Flock, and others. Heller's observations on February 27 put it a few degrees southwest of Spica moving northeast. In mid-March, it moved rapidly northeast through Boötes and Draco. By April 1 it had passed through Cassiopeia into Andromeda. Ho (560), P502, Hellman (1971), Crommelin (1917).

1556 August; China. A comet appeared. It was some degrees in length and disappeared at the end of the month. Hasegawa (915).

1557 October 10; (P = September 22, d = 0.30 on October 25) China, Korea, Europe. A broom star comet appeared in Serpens pointing northeast. It disappeared on November 13. Korean records put the comet in Sagittarius when it faded from view. Ho (561). Pingré also mentions a comet in Sagittarius during October. P507.

1558 August 8; (P = September 14, d = 0.14 on August 11) Japan, Korea. Korean records note that a broom star comet with a white tail measuring 6 to 7 degrees appeared in the region of Coma Berenices-Virgo-Leo. From August 14 to September 11 it diminished in size and shifted its position to the region of Hercules-Aquila-Serpens-Ophiuchus. Japanese records note that a broom star comet was seen on August 9. European records place the comet under Coma Berenices on August 6, and on the 15th under the tail of the great bear, Ursa Major. On August 20 it was located 28.5 degrees from the end of the tail of Ursa Major and 30.5 degrees from Arcturus. P508, Ho (562), Hellman (1971).

1567 January 10; Korea. A tailed star comet one-half degree broad and 7 to 8 degrees long appeared in the south. It was wide at the top but narrow at the base. Ho (563).

1569 November 9; China. A broom star comet, pointing northeast, appeared in the region of Hercules-Aquila-Serpens-Ophiuchus. It went out of sight on November 28. Ho (564). European observations put the comet in Ophiuchus, Sagittarius, and Capricornus during November. P509.

1573 July; China, Europe. A comet was seen in Pisces. P511, Hasegawa (928).

1576 July–August; China. During the interval July 26 to August 23 a broom star comet was seen. Ho (566). Hasegawa (929) notes a Korean record citing the comet on September 2.

1577 July–August; Korea. During the interval July 15 to August 13, a broom star comet was seen. Ho (567).

1577 October 19; (P = November 8, d = 0.12 on November 3) Berlin, Germany. Leonard Thurneysser observed the comet in Capricorn on October 19 and followed it for 10 days. On October 29 it was in Sagittarius with its tail pointing toward Aquila. Landgraf (1977).

1577 November 8; (P = October 27, d = 0.63 on November 10) China, Japan, Korea, Europe. The Japanese noted the broom star comet in the southwest evening sky on November 8. It had a nucleus as bright as the Moon and a white tail over 60 degrees long. The Chinese first note the comet in the southwest on November 14. It appeared darkish-white and measured several tens of degrees. The vapor formed a white rainbow stretching from eastern Scorpius across Sagittarius to western Aquarius. It went out of sight after one month. European observers followed it until January 26, 1578. Tycho Brahe's long series of observations from November 13 through

January 26 indicate the comet moved northeastward from Aquila into western Pegasus. On November 13 Brahe estimated its coma diameter and tail length to be 7 arc minutes and 22 degrees respectively. Ho (568), P511, Hellman (1971).

1578 February 22; China, Korea. Chinese records note a large star like the Sun came out from the west, encircled by a number of stars at the west. This may be an account of a fireball. Korean records note a tailed star comet stretching across the heavens like a white chain. It went out of sight after a few days. Ho (569).

1578 November–December; China. A comet was seen in the east with a white tail stretching across the sky some 75 to 90 degrees in length. Hasegawa (932).

1580 October 1; (P = November 28, d = 0.23 on October 12) China, Japan, Korea, Europe. A broom star comet appeared at the southeast. It increased in length every night and stretched across the Milky Way. After more than 70 days, it went out of sight. The Japanese recorded the comet first on October 9. Mästlin discovered the comet on October 2, and eight days later both Tycho Brahe and Hagacius first observed it. Tycho made detailed observations through December 12. Its motion was generally westward from beneath the box of Pegasus through Aquila and Ophiuchus. It was last seen on January 14. Ho (570), P521.

1581 September; China. A comet was seen in the west and its light shone the Earth. After more than 30 days it went out of sight. Hasegawa (935).

1582 May 12; (P = May 6, d = 0.83 on May 9) China, Japan. Tycho Brahe discovered the comet on May 12, less than 11 degrees from the bright star Capella, and observed it until the 17th. On May 20 the Chinese noted a broom star comet appearing in the northwest like a chain with its tail pointing toward Auriga. After more than 20 days it went out of sight. On May 13 the Japanese noted a broom star comet in the northwest evening sky measuring over 100 degrees like a white cloud or rainbow. Ho (571), P544.

1582 September–October; China. A comet was seen stretching across the heavens. It was blue in color and pointed to the northwest. After about 49 days it disappeared. Hasegawa (938).

Transition from Julian Calendar to Gregorian Calendar

1584 July 11; China. A star appeared northwest of Antares. Ho (572).

1585 October 13; (P = October 8, d = 0.14 on October 18) China, Japan, Korea, Europe. A broom star comet about 1 degree long appeared in southern Aquarius. Every evening it was found moving eastward and diminishing in size. It was last seen on November 27. Tycho Brahe was prevented by bad weather from seeing it before October 28, but the Landgrave of Hesse's astronomer, Christoph Rothmann, recorded its motion from October 18 through November 18 as it moved northeast from eastern Aquarius through Pisces. Ho (573), P550.

1587 August 30; Japan. An object like a guest star was seen throughout the day. Perhaps it was a nova. Ho (574).

1587 October; Korea. During the interval October 2 to 30 a broom star comet was seen at the west. Its tail was bent and measured 45 to 60 degrees. Its rays illuminated the ground and after three months, it went out of sight. Ho (575).

1590 March 5; (P = February 8, d = 0.25 on March 3) China, Europe. A comet was seen in the southeast. After more than 10 days it disappeared. On March 5 it was discovered in Pisces by Tycho Brahe and described as having a tail 7 degrees long. Brahe followed its eastward motion until October 16. Hasegawa (944), P554.

1591 April 13; China. A star appeared in the northwest. It looked like a broom star comet and measured over 1 degree. It passed eastward through Pegasus and then measured about 3 degrees. On April 23 it entered western Aries. Ho (576).

1592 December 2; China. From December 2 to 4 a guest star moved westward in Cassiopeia. It remained visible until March 1593. Ho (577).

1593 July 30; (P = July 19, d = 0.45 on August 27) China, Japan, Korea. A broom star comet appeared in Gemini. On August 19 it retrograded and trespassed against Cassiopeia before entering the region of Draco-Ursa Minor-Camelopardus. On August 3 the Japanese noted a comet at midnight in the northwest measuring 15 degrees; they record it last seen on August 16 but the Koreans record it last on September 19. One of Tycho Brahe's assistants observed it from August 4 through September 3. Its motion was generally northwest from Gemini, winding up in the Milky Way between Cygnus and Cepheus on September 3. Ho (578), P557.

1596 July 19; (P = July 25, d = 0.56 on July 15) China, Japan, Korea, Europe. The Koreans recorded a broom star comet the same size, or brightness, as Capella appearing in Gemini. The Chinese recorded a broom star comet on August 5 appearing in the northwest. It was also moving toward the northwest and measured over 1 degree when it entered Crater. It went out of sight on August 22. These two accounts are difficult to reconcile since Crater is southeast—not northwest—of Gemini. European observations clearly suggest the comet was first seen in Auriga in mid-July. It then moved eastward through Gemini and Leo. Tycho Brahe first observed the comet on July 24 and followed it until August 3. Ho (579), P560.

1600 September 2; Korea. A broom star comet was seen in Ursa Major. By September 27 its rays had diminished when it shifted inside the region of Coma Berenices-Virgo-Leo. Ho (580).

1601 December 20; Korea. A comet with a long tail was seen in the northeast. Hasegawa (951).

1602 August 26; Korea. A comet with a tail about 11 degrees long was seen for a long time moving southeast from southwestern Ursa Major into Coma Berenices. Hasegawa (952).

1607 September 21; (P = October 27.5, d = 0.24 on September 29) China, Japan, Korea, Europe. Comet Halley. When first discovered by the Chinese on September 21 it was reported in Gemini, moving slowly toward the northwest with its tail pointing toward the southwest. (It was actually moving southeast on September 21.) On October 12, it was moving eastward in Scorpius and was last seen on October 26 as it moved into solar conjunction. Johannes Kepler, at Prague, made observations from September 26 to October 26, while Longomontanus, at Malmo, Sweden and Copenhagen, Denmark observed from October 1 to 26. William Lower and Thomas Harriot observed the comet from September 22 to October 6 and from September 21 to October 22 respectively. Harriot's observations were the most accurate position measurements recorded during this apparition. Ho-Peng-Yoke and Ang Tian-Se (75), P3, Halley (1752), Bessel (1804), Yeomans (1977), Roche (1985).

1607 November–December; China, Korea. Korean records report a comet in southwestern Ursa Major, while Chinese records note a comet was seen in the west with its red tail pointing east. Hasegawa (956).

1609: A large star appeared in the southwest casting its pointed rays in all directions. Ho-Peng-Yoke and Ang Tian-Se (76).

1615 August–September; China. A comet, shaped like a broom, was seen in the morning. Hasegawa (959).

1618 August 25; (P = August 17.6, d = 0.52 on August 20) Europe, China, Korea. The comet was discovered in Hungary on August 25 and two days later by Kepler near Linz, Austria, where it rose in the morning sky with its tail pointing west. The Koreans noted the comet on August 28 below Ursa Major with a bluish-white tail more than 15 degrees long. On September 1, Kepler observed the comet 10 degrees within Leo with a north latitude of 23.5 degrees. Five days later, the comet scarcely had a tail when viewed with the naked eye. As seen through Kepler's telescope, it was rather large and resembled a cloud. (This was probably the first use of a telescope for observing a comet.) Kepler last observed it on September 25 in Cancer. P4, Hasegawa (960).

1618 November 16; (P = November 8.9, d = 0.36 on December 6) Europe, China, Korea. This comet's tail was first seen rising above the morning horizon by several observers. Its head, although below the horizon, was in Libra. For northern hemisphere observers it was best seen only in December and late November, when it had moved away from the Sun's glare. On November 18, Jesuit observers in Rome noted the tail to be 40 degrees in length. The Swiss Jesuit Johann Baptist Cysat followed the comet from December 1, 1618, through January 22, 1619, and the English astronomer John Bainbridge followed it from November 28 through December 26, 1618. As pointed out in Chapter 3, both Cysat and Bainbridge used telescopes for some of their observations. On November 26 Chinese observers noted the broom star comet in Libra measuring over 15 degrees and pointing southeast. The tail gradually pointed to the northwest and swept the stars of Ursa Major. On November 30, Korean observers noted a comet in the east with a tail several degrees long. P6, Ho-Peng-Yoke and Ang Tian-Se (77).

1618 November 10; (P = October 27.9, d = 0.17 on November 19) Europe, China, Korea. This comet was seen between November 10 and December 9, 1618 moving westward from a region near Libra into western Hydra. On the morning of November 20, Kepler noted its tail and observed its head near the head of the Centaur. P5, Landgraf (1985).

1619 February–March; China. Between February 14 and March 15, a broom star comet appeared in the southeast measuring 100 degrees. It cast its rays downward and its tail was bent and sharp-pointed. In one moment it was seen in the northeast and at another it was seen in the west. Ho-Peng-Yoke and Ang Tian-Se (78).

1621 January 22; Korea. A comet was seen. Hasegawa (966).

1621 February 8; Korea. A comet appeared. This comet is likely to be identical with the previous entry. Hasegawa (967).

1623 November 24; Japan. A comet was seen in the west. Hasegawa (969).

1624 July–August; China, Japan. The Chinese recorded that a large star entered the Moon, while the Japanese noted a comet appeared in the south. Hasegawa (970).

1625 January 26; Europe. A comet was observed in Eridanus and Cetus by Wilhelm Schickard observing near Tübingen, Germany. It was seen from January 26, 1625, until February 12. Olbers (1824).

1627 Summer; Korea. A comet appeared with the Moon. Hasegawa (972).

1628 August 13; Japan. A comet was seen in the southeast. Hasegawa (973).

1629 November 13; Korea. A comet appeared. Hasegawa (974).

1630 January–February; Japan. A comet was seen in the northwest. Hasegawa (975).

1633 November; China. During the period November 2 to 30, a broom star comet appeared. Ho-Peng-Yoke and Ang Tian-Se (79).

1638 June–July; Korea. A reddish comet appeared and lasted for one month. Hasegawa (977).

1639 October 26; (P = November 29.4, d = 0.08 on October 26) Korea, China. Korean observers reported a guest star that appeared in eastern Orion, and the next day it moved to southern Orion and covered an unknown star. The Chinese reported a comet seen in Orion sometime during the period between July 30 and October 25. On October 27 Placidus de Titis noted a comet with a small tail in Canis Major. Hasegawa (978), Ho-Peng-Yoke and Ang Tian-Se (80), Olbers (1831).

1640 December 21; A broom star comet appeared. Possibly it appeared on October 22, but the December date seems more likely in light of John Evelyn's notation in his diary that a comet was seen about the time of the Earl of Strafford's trial in 1640. Strafford was impeached on November 11, 1640. Ho-Peng-Yoke and Ang Tian-Se (81), Chambers (506).

1647 September 29. A comet some 12 degrees long was seen soon after sunset in Coma Berenices. It moved eastward through Boötes into Corona Borealis and lasted one week. P9.

1652 December 17; (P = November 13.2, d = 0.13 on December 20) China, Europe, Africa. The Chinese reported the comet on December 22 as an extraordinary star with a pale vapor. It moved toward the northwest and entered Taurus. European observers noted the comet first on December 18 and followed it until the first few days of January 1653. Hevelius, at Danzig, followed the comet from December 20 until January 8 and described it as being a pale and livid color and as large as the Moon. At the Cape of Good Hope, the comet was reported first on December 17 in the east-southeast evening sky. Its position was southward from the head of Orion with the tail pointing northward. On December 24, its head was 1 degree from the Pleiades, and the tail, pointing east-southeast, was described as reaching its greatest brightness. Ho-Peng-Yoke and Ang Tian-Se (82), P9, McIntyre (1949), Hind (1879), Knobel (1897).

1653 August 21; Korea. A comet appeared and became small near Castor and Pollux in Gemini. It then moved northwest to eastern Camelopardus. Its blue-white tail, one-half degree in length, pointed to the southwest. It disappeared on September 15. Hasegawa (982).

1656 April 1. Peter Mundy, an Englishman sailing off the coast of India, recorded a comet that he observed in the morning sky. Its tail pointed upwards. After the weather cleared on April 6, he again noted it with a tail 6 to 7 degrees in length spreading upward to the southeast. It was located about 12 degrees southwest of Venus. Maunder (1934).

1656 September 2; Korea. A comet was seen in Gemini resembling the great star in Auriga, Capella. Its blue-white tail was less than one-half degree in length. It disappeared on September 17. Hasegawa (983).

1661 February 3; (P = January 27.4, d = 0.61 on January 29) Europe. Hevelius observed the comet from February 3, when it was in eastern Aquila, throughout the remainder of the month and into March. He made physical observations through his telescope noting multiple structures in its head. It moved slowly westward through Aquila and was last observed on March 28 in western Aquila. This comet was mistakenly thought by many, including Edmond Halley, to be a return of the comet of 1532. P10, Halley (1705).

1661 December 16; Korea. A guest star was seen in western Aquarius moving northeast. Another Korean record noted the star disappeared on January 1, 1662. Hasegawa (985).

1664 November 17; (P = December 5.0, d = 0.17 on December 29) China, Korea, Japan, Europe. The great comet of 1664 was seen from November 17, 1664, through March 20, 1665, rising in the morning hours in November and December, then switching to an evening object for the first few months of 1665. The Chinese first noted the broom star comet on November 18 in Corvus. On November 26 its grayish tail was about a degree in length and pointing toward the southwest. On December 16 it was in Crater with its tail over 5 degrees and pointing to the northwest. The next night it was in western Hydra with its tail pointing north. On December 29 it was in Gemini, and on January 1, 1665 it moved northwest and reached western Taurus. Two nights later, with its tail pointing northeast, it reached northern Aries. On January 8 it reached northwestern Aries with its blue tail pointing east. On January 20, it was in northern Pisces with a tail that measured approximately 3 degrees. In Europe, the comet was extensively observed by Christiaan Huygens in Leiden, Johannes Hevelius at Danzig, Adrien Auzout and Pierre Petit in France, and several others. With the aid of a telescope, the comet was followed until March 20 when its increasing distance from the Sun and Earth, as well as its approaching solar conjunction, made additional observations impossible. P10, Ho-Peng-Yoke and Ang Tian-Se (83), Petit (1665), Maunder (1934).

1665 March 27; (P = April 24.7, d = 0.57 on April 4) China, Korea, Japan, Europe. The comet of 1665 was observed extensively throughout

Europe from March 27 through April 20, when it came too close to the Sun for further observations. Hevelius observed it from April 6 through 20. Chinese observers first noted the comet on March 28 in northwestern Aquarius. On April 13 it was in eastern Pegasus with its tail measuring more than 7 degrees. On April 17 it entered northern Pisces. P22, Ho-Peng-Yoke and Ang Tian-Se (84).

1666 February; Korea. A comet was seen in the winter by Korean observers and an observer in Ceylon, now Sri Lanka, made note of a comet in February. P23, Hasegawa (988).

1668 March 3; (P = February 28.1, d = 0.80 on March 5) China, Korea, Japan, India, Africa, Europe. The comet was first seen at the Cape of Good Hope on March 3 and two days later in Brazil and in Lisbon, Portugal. It was most easily visible to observers in southern latitudes. On March 10 J.D. Cassini, in Bologna, Italy noted it extending from Cetus to the middle of Eridanus, some 30 degrees in length. In Goa, India positions of its head were mapped from March 9 through March 21, and at the Cape of Good Hope from March 3 through 23. Chinese observers noted the comet from March 7 through March 30, when it went out of sight. On March 7 it was described as a stretch of white light in the southwest, measuring over 9 degrees and pointing toward the southeast. On March 18 it extended over 40 degrees in Eridanus. This comet is probably a member of the Kreutz group of sungrazing comets. P22, Ho-Peng-Yoke and Ang Tian-Se (85), Henderson (1843), Marsden (1967, 1989).

1672 March 2; (P = March 1.9, d = 1.02 on March 15) Europe. The comet was discovered by Hevelius in Pegasus on March 2 and followed by him until April 22, when it was in northern Orion. Cassini followed it from March 26 to April 7. P23, Berberich (1888).

1673 March 10; China. A strange star appeared in western Aries. It was white, like a peach in size, and with a short tail pointing to the east. It was also seen the next night. Ho-Peng-Yoke and Ang Tian-Se (86), Hasegawa (991).

1676 February 14; China, Europe. A comet was seen by a French Jesuit on February 14 in Eridanus. It was last seen on March 9. On February 18, the Chinese reported an extraordinary white star in northern Eridanus. P23, Ho-Peng-Yoke and Ang Tian-Se (87).

1677 April 27; (P = May 6.5, d = 0.54 on April 17) Europe. The comet was discovered by Hevelius at Danzig on April 27 and followed by him until May 8, when it entered into morning twilight. On May 3 John Flamsteed reported a tail length of 6 degrees. P24.

1678 September 11; (P = August 27.1, d = 0.26 on August 28) Europe. Philippe de La Hire first detected this comet in Aquarius. It was seen for the last time on October 7 in Pisces. P24.

1680 November 14; (P = December 18.5, d = 0.42 on November 30) Europe, China, Japan, Korea, North America. This first telescopic discovery of a comet was made by the German astronomer Gottfried Kirch on the morning of November 14. It remained a morning object until the first few days of December, when it entered into solar conjunction. On December 18 it was seen at noon in the Philippines, less than 2 degrees from the Sun. John Flamsteed, at Greenwich, first detected its tail in the evening sky on December 20, with the head being observable two days later as it exited the solar glare. Extensive observations were made by many European observers. In the British colony of Maryland in North America, Arthur Storer noted its tail was 15 to 20 degrees in length on November 29. The Chinese reported the comet first on November 23 in Crater. It had a white tail more than 1 degree long pointing toward the west. On December 21, the Chinese observed it coming out of solar conjunction with a darkish-white color and a tail over 60 degrees long pointing toward the northeast. The last observations were made by Isaac Newton on March 19, 1681. Its motion from discovery to last observation was generally eastward, passing nearly around the entire sky from western Leo into Auriga. P25, Ho-Peng-Yoke and Ang Tian-Se (88), Newton (1687), Broughton (1988), Selga (1930).

1682 August 15; (P = September 15.3, d = 0.42 on August 31) Europe, China, Africa. Comet Halley. The comet was first seen in England on August 15; by the Jesuits of Orleans, France on the night of August 23; by Arthur Storer in the British colony of Maryland from August 24 through September 22; by Cassini, Abbé Picard, and Philippe de La Hire in Paris, August 25 through September 21; by Samuel Dörffel in Plauen, Germany August 25 through September 20; by Hevelius in Danzig, Poland August 26 through September 13; and by John Flamsteed at Greenwich, England August 30 through September 19. Halley himself observed the comet that was to bear his name from September 5 to 19. When discovered, the comet was above Gemini. It then moved in a southeast direction going out of sight in eastern Virgo. The Chinese noted its tail as more than 3 degrees on August 26, growing to 9 degrees three days later. Although Flamsteed's astrometric positions are the most accurate, having a mean error of approximately 13 arc minutes, the observations by Storer were surprisingly good, achieving an accuracy of 38 and 13 arc minutes in longitude and latitude. Though his observing equipment was crude, his accuracy exceeded that of Hevelius and Halley himself. At the Cape of Good Hope, the comet was discovered on September 8 and followed until September 24, when it was last observed.

P28, Halley (1752), Ho-Peng-Yoke and Ang Tian-Se (89), Broughton (1988), McIntyre (1949).

1683 July 23; (P = July 13.6, d = 0.32 on September 4) Europe, China. John Flamsteed first observed the comet on July 23 and followed it until September 5. Hevelius observed it from July 30 to September 4. The Chinese discovered the comet on August 2 in Auriga moving slowly toward the southwest. P28, Ho-Peng-Yoke and Ang Tian-Se (90).

1684 July 1; (P = June 8.8, d = 0.17 on June 27) China, Europe. At Rome, Francesco Bianchini observed this comet from July 1, in Virgo, through July 17 when it was in Boötes. On July 1 the Chinese noted the comet as a bright white star in Corvus. P28, Ho-Peng-Yoke and Ang Tian-Se (91).

1686 August 12; (P = September 16, d = 0.32 on August 16) China, Korea, Africa, South America. First seen at the Cape of Good Hope, the comet's position was put at the left shoulder of the Hare, Lepus, with its 35-degree tail stretching into Gemini. Two days later, in Brazil, the comet was noted just below the belt of Orion as bright as a first-magnitude star with a tail 18 degrees in length. On August 16 and 17, Jesuits in Siam (Thailand) reported the tail length as 15 degrees. The comet was observed until September 22. Chinese observers reported that on September 3 it moved 10 degrees and when it reached southern Cancer showed traces of a tail. Korean observations put the comet in northwestern Hydra on September 14. P28, Ho-Peng-Yoke and Ang Tian-Se (92), Hasegawa (999), McIntyre (1949).

1688 November 2; China. Chinese observers noted that an extraordinary white star appeared in southern Andromeda for three days. Ho-Peng-Yoke and Ang Tian-Se (93).

1689 November 24; (P = November 30.7, d = 0.74 on December 14) Africa, India. At the Cape of Good Hope a tailed star was seen in the southeast morning sky on November 24 and 25. It was again seen in the morning sky on December 9 with a tail more than 4 degrees long. On December 8 the comet's tail in the arms of Centaurus was noted by Father Richaud in Pondicherry, India. The comet moved in a southern direction with its tail reaching a length of 60 degrees before going out of sight in the first few days of January 1690. This comet may be a member of the Kreutz sungrazing comet group. P29, McIntyre (1949), Marsden (1967).

1690 September–October; China. Chinese observers noted a new yellow star in Sagittarius that lasted two nights. This is probably a nova rather than a comet. Hasegawa (1002) gives a date of October 23 while Ho-Peng-Yoke and Ang Tian-Se (94) prefer a date of September 29.

1695 October 28; South America. While in Brazil, the French Jesuit P.

Jacob discovered this comet's tail on October 28 an hour before sunrise. Two days later the tail was described as reaching Virgo with the comet's head in Libra. The tail reached a length of 30 to 40 degrees and the comet was last reported on November 19, just before full moon. If this comet is a member of the Kreutz sungrazing comet group, its perihelion passage time would be October 23.1. P33, Marsden (1967).

1698 September 2; (P = October 17.5, d = 0.21 on September 7) Europe. Philippe de La Hire and Jean-Dominique Cassini observed this comet first between β and κ Cassiopeia on September 2 and followed it as it first moved west then rapidly south. In mid-September, the Moon's brightness interfered with observations. When last observed on September 28 it was in Scorpius. P36, Hind (1876).

1699 February 17; (P = January 13.9, d = 0.18 on February 18) China, Europe. This comet was first observed in the northern heavens by the Jesuit missionary De Fontenay in Peking, China. He followed its southeastern motion until February 26 when it was in northern Orion. The comet was also followed by Cassini and Maraldi I at Paris from February 20 until March 2. P36, Hind (1879).

1699 October 26; (P = October 10.9, d = 0.07 on October 27) Germany. Gottfried Kirch observed a faint, but still naked-eye nebulosity in Argo moving in a generally southward direction. He was unable to locate the object the next morning. This single observation has been identified as a return of the short period comet Tempel-Tuttle. P36, Schubart (1965), Yeomans (1981).

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Chapter 10

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