# Telescopes in History

The precise origins of the optical telescope are hidden in the depths of time. In the thirteenth century Roger Bacon claimed to have devised a combination of lenses which enabled him to see distant objects as if they were near. Others who have an unsubstantiated claim to have invented the telescope in the sixteenth century include an Englishman, Leonard DIGGES, and an Italian, Giovanni Batista Porta, whose spyglass was manufactured in Holland for military purposes.

However, a Dutch spectacle-maker from Middleburg, Hans LIPPERHEY, is usually credited with making the first true refracting telescope in 1608. The new instrument was soon being used by the English mathematician Thomas HARRIOT and by Simon MARIUS in Germany to study the night sky. But it was GALILEO GALILEI, then Professor of Mathematics at the University of Padua in Italy, who was the first to construct a telescope for systematic astronomical observations.

The news of the Flemish invention reached Galileo early in 1609. After a few trials, 'sparing neither labor nor expense', he succeeded in arranging two lenses, one convex and one concave, inside a tube, so that they would magnify an object by a factor of three. This rapidly evolved into a more powerful instrument capable of magnifying objects 30 times (see GALILEAN TELESCOPE).

With his improved telescope, Galileo was able to turn his attention to the heavens. His startling discoveries were described in the book, *Sidereus Nuncius* (*The Sidereal Messenger*), which was published in March 1610. In it he wrote:

> (I have seen) stars in myriads, which have never been seen before, and which surpass the old, previously known, stars in number more than ten times. But that which will excite the greatest astonishment by far . . . is this, namely, that I have discovered four planets, neither known nor observed by any one of the astronomers before my time.

This momentous discovery of Jupiter's four major satellites (now dubbed the 'Galilean satellites'; see JUPITER: SATELLITES) demonstrated that bodies other than the Earth might have other objects in orbit around them, and so supported the Copernican view of the solar system.

His telescope also enabled Galileo to produce the first maps of the Moon, revealing its rough terrain along the terminator as it passed through different phases (see MOON MAPS). Venus, too, was shown to have phases. Even the Sun was shown to be blemished as spots appeared and moved across its face (see SUNSPOTS). Evidence from his drawings suggests that Galileo even saw NEPTUNE in 1613, when it was close to Jupiter, but he failed to observe it for long enough to recognize that it was not a 'fixed' star.

Galileo's arrangement of lenses was soon superseded by Johannes KEPLER's system of two convex lenses, though Kepler himself does not seem to have actually built such an instrument. This seems to have been left to an enemy of Galileo, the German Jesuit observer, Christopher SCHEINER (1575–1650), who used his improved version to discover faculae on the Sun.

As the power of refracting telescopes increased, a series of fundamental discoveries were made. For example, by learning to grind lenses with exceptional accuracy and developing an improved eyepiece, Christiaan HUYGENS (1629–95) was able to construct instruments which enabled him to discover Saturn's ring system and its large moon, Titan.

However, refractors had two main disadvantages. The tendency for the object glass (the main lens) to focus different wavelengths of light at different distances caused them to produce rings of false color around stars and planets (CHROMATIC ABERRATION). This effect could be reduced by building telescopes of extremely long focal length, but this, in turn, made them cumbersome and unwieldy.

The largest classical refractor, which was used by Johannes HEVELIUS (1611–87), was 47 m (155 ft) long, and had to be set in place with a hoist. Giovanni Domenico CASSINI (1625–1712) later used a huge refracting telescope at the newly built Paris Observatory—described by Molière as 'an eye-glass to frighten people out of their wits'—to discover the gap in the rings which is named after him. His tubeless instrument comprised a lens which was placed on the balcony of the observatory and pointed more or less in the intended direction, while the observer stood 27 m (89 ft) below in the courtyard, trying to direct the image through a magnifying glass.

In 1671, the same year that G D Cassini moved to the Paris Observatory, Isaac NEWTON presented a revolutionary new telescope to the Royal Society in London. Believing that it would never be possible to make achromatic lenses for refracting telescopes, he designed and built the first practical reflecting telescope. Although its dimensions were modest—the metal mirror was only 1 in (2.5 cm) in diameter, and it was just over 6 in (15 cm) in length—Newton remarked that it would 'discover as much as any three or four foot tube' and he forecast that similar reflectors 6 feet (1.8 m) in length would 'perform as much as any sixty or hundred foot [18–30 m] tube made after the common way'.

Although Newton was the first to build a reflecting telescope, the principle of the reflector had originally been suggested by James GREGORY in 1663. However, his design proved extremely difficult to build. Whereas Gregory's instrument relied on a parabolic primary mirror with a central hole and an elliptical secondary mirror, Newton's simply comprised a parabolic primary which reflected light onto a flat, tilted, secondary mirror (see GREGORIAN TELESCOPE).

A variation on the Gregorian design soon arrived with the introduction of the CASSEGRAIN TELESCOPE in 1672. This version used a convex mirror inside the focal length to reflect the light back through a central hole in the main mirror. Today, it is the most common design for large reflecting telescopes. However, it was not until the mid eighteenth century that either the Gregorian or Cassegrain system was fully developed and became widespread. Cassegrain himself was never identified.

Despite these advances, large reflectors remained much more difficult to make than refractors, and half a century elapsed before they were able to compete on equal terms. No important discoveries were made with reflecting telescopes until the time of William HERSCHEL (1738–1822).

Herschel was renowned as the best telescope maker of his time. At his home in Bath, which he turned into a telescope workshop, Herschel experimented with different metal alloys in an attempt to find one with a high reflectivity, good resistance to tarnishing and reasonable ability to hold its shape during daily temperature changes. The best speculum metal alloy for his mirrors was found to be 79% copper and 21% tin. In 1778, he used this mixture for a 6.2 in (16 cm) reflecting telescope with a focal length of 7 ft (2.14 m), which he used for his second and third sky surveys. In 1782, a year after he used this instrument to discover URANUS, he demonstrated its superiority to the skeptical Astronomer Royal, Nevil MASKELYNE, at the Royal Observatory in Greenwich.

Upon receiving patronage from King George III, Herschel began to construct a giant 40 foot long (12 m) instrument with a mirror 48 in (1.2 m) in diameter. Completed in 1789, it remained the largest telescope in the world for more than half a century. On his second night of viewing with this monster, Herschel discovered the sixth moon of Saturn, ENCELADUS. Three weeks later, he discovered a seventh moon, MIMAS. Yet he was generally disappointed with his gigantic creation. It was clumsy to operate, while the mirror tarnished rapidly in the damp climate and distorted under its own weight.

Most of Herschel's discoveries were made with the 18.8 in (48 cm) reflector that he made in 1783. This instrument made a major contribution to the advancement of astronomy when his son, John, installed it at the Cape of Good Hope in 1834–8, and was able to survey the LARGE and SMALL MAGELLANIC CLOUDS, the center of our Galaxy, and the wonders of the southern skies.

The early nineteenth century saw a number of improvements in telescope optics. One of the leading telescope makers was the Director of the Physical and Optical Institute of Munich, Joseph von FRAUNHOFER (1787–1826), the inventor of the equatorial mounting. The most famous of his instruments was the Great Dorpat Refractor which F G W STRUVE set up at the Dorpat Observatory in Estonia in 1824. This 9.5 in (24 cm) refractor was used by Struve to discover more than 2 000 double stars.

Fraunhofer's invention of the diffraction grating and the later introduction of photography (first used in 1840) revolutionized optical astronomy and led to many discoveries. However, not until 1845 was Herschel's 48 inch telescope overtaken in size. Lord ROSSE's 6 ft (183 cm) aperture reflecting telescope contained the largest speculum metal mirror ever made, and had a light grasp more than double that of Herschel's instrument. Built at Parsonstown (now Birr) in Ireland, this instrument enabled Rosse to discover the spiral structure of certain nebulae (now recognized as galaxies), and to resolve others into star clusters.

Although Jean FOUCAULT (1819–68) introduced silver coating for glass mirrors, major astronomical instruments were being equipped with speculum metal mirrors as late as 1862. The last of the line was the Great Melbourne Telescope, whose 48 in (1.2 m) metal mirror required repolishing after a few years' use, and which was generally regarded as a failure.

Whilst reflectors were becoming the most widespread astronomical instruments, there was still considerable interest in pushing refractors to the limit. The culmination of this was the construction of the largest refracting telescopes ever built. The 36 in (0.9 m) instrument was installed at LICK OBSERVATORY in 1888, and was followed by the 40 in (1 m) telescope at YERKES OBSERVATORY in 1897.

The driving force behind the Yerkes project, George Ellery HALE (1868–1938), went on to promote the construction of two gigantic reflecting telescopes. The 100 in (2.5 m) Hooker Telescope on MOUNT WILSON, which was the largest in the world from 1918 until 1948, was the first instrument capable of seeing objects that formed early in the history of the Universe.

The 200 in (5 m) Hale Telescope on Mount PALOMAR, completed in 1948, was used for photographic studies which opened the way to further discoveries. Its giant primary mirror was a ribbed casting of Pyrex glass, while its parabolic surface was coated with a thin film of highly reflective aluminum. In 1976, an even larger 236 in (6 m) telescope was completed on Mount Semirodriki in the Caucasus region of the Soviet Union.

For a while, their great weight and the difficulties in casting such monolithic mirrors seemed to present an insurmountable barrier to the development of still larger telescopes. The primary mirror of the Hale Telescope weighs 13 tonnes, and was once considered the practical limit for telescope size.

While the giant reflectors were being used to study ever smaller fields of view, Bernhard SCHMIDT (1879–1935) was inventing a telescope which could take wide angle photographs. The first Schmidt camera, built in 1930, used a thin glass corrector plate to overcome spherical aberration. It soon spread around the world's major observatories and was incorporated in various hybrid designs such as the SCHMIDT–CASSEGRAIN.

The next major advance was the replacement of mechanical control systems by computers. In contrast to the Hale Telescope, which used huge motor-driven worm wheels controlled by a quartz crystal clock, the ANGLO-AUSTRALIAN Telescope, completed in 1975, set a new standard in computer control and pointing accuracy.

Computer control was also the key to the introduction of the multiple mirrors and segmented mirrors that broke the telescope size barrier. Leading the way was the

MULTIPLE MIRROR TELESCOPE (MMT), which was built on Mount Hopkins in Arizona in 1977. By using six 72 in (1.8 m) mirrors in a circular array on an alt-azimuth mounting, the telescope's effective light-collecting area was equivalent to a single 172 in (4.5 m) instrument. One of these mirrors was used in the discovery of the first gravitationally lensed quasar.

The revolutionary MMT system was eventually replaced by a modern lightweight mirror with a honeycomb construction in 1998. Mirrors of this type consist of glass ribs between a thin, but rigid, concave mirror and a flat back plate.

In recent years, adaptive and active optics have been introduced in an attempt to compensate for image degradation caused by the atmosphere. Meniscus mirrors, that are too thin to support their own weight, and segmented mirrors can now be adjusted by computer-controlled servomechanical actuators so that they maintain their optimal shape and position at all times. Small adaptive mirrors may also be inserted in the light path of the telescope to correct atmospheric distortions. The EUROPEAN SOUTHERN OBSERVATORY's 138 in (3.5 m) New Technology Telescope was one of the pioneers in the development of such active and adaptive optics.

The largest mirrors in the world today, installed in the twin Keck telescopes on Mauna Kea, Hawaii, are made from 36 hexagonal 72 in (1.8 m) mirrors which fit together like bathroom tiles (see UNIVERSITY OF HAWAII INSTITUTE FOR ASTRONOMY). These segments effectively create a single mirror, 400 in (10 m) in diameter, with four times the collecting power of the Hale Telescope.

Another new technique that will eventually operate on the Keck telescopes is optical interferometry. Light from nearby, but separate, telescopes is combined so that the resulting image is equal to that received from a single giant telescope.

The European Southern Observatory started construction of the world's largest optical interferometer in 1996. The Very Large Telescope (VLT) in northern Chile will eventually combine the light from four 315 in (8 m) telescopes, producing a performance equivalent to that of a 630 in (16 m) instrument.

Meanwhile, advances in technology have also enabled scientists from the University of Arizona, Ohio State University and German and Italian astronomical research institutions to cast the largest single-piece mirror ever made. The LARGE BINOCULAR TELESCOPE at Mount Graham Observatory in Arizona will eventually be equipped with two 331 in (8.4 m) primary mirrors which have a thickness of only 1.1 in (28 mm) in the center and 35 in (894 mm) at the edge. These will provide an image comparable to that of a single 75 ft (23 m) telescope when construction is complete in 2002.

Such advances have, at least partially, nullified the advantages of placing telescopes in space. However, despite its relatively small 95 in (2.4 m) mirror, the HUBBLE SPACE TELESCOPE (launched in 1990) continues to return some of the highest resolution optical images of faint galaxies located billions of light years away. An 8 m class replacement with a folding mirror, known as the Next Generation Space Telescope, is in the pipeline for a 2008 launch(see SPACE INSTRUMENTATION: NEXT GENERATION SPACE TELESCOPE). Multiple space telescopes using optical interferometry, which will be capable of imaging Earth-size planets around nearby stars, are envisaged for the following decade.

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