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From the Simple Tube to the **High-Tech Telescope**

Is anybody out there? From time immemorial men have sought ways and means of exploring the universe.

The sun, the moon and the stars have always intrigued mankind. At one time they were thought to be where the gods lived. They were made responsible for fate. The way they were arranged and the way they moved across the heavens determined how time was subdivided into days, months and years. And they guided travelers, especially seafarers, on their journeys.

For thousands of years the only way to observe heavenly bodies was with the naked eye. Then in 1609 Galileo became the first person to use a telescope for astronomical observations. It had been invented a short time before in Holland and consisted of a convex lens and a concave lens in a tube. Although its optical quality was poor – the glass used for the lenses contained cords and color tinges – Galileo was able to distinguish mountains and valleys on the surface of the moon and "handles" on each side of Saturn.

Kepler's Classic

In 1611 Johannes Kepler suggested a telescope comprising two convex lenses, the principle of which is still used today as the "classic refractor" or "Kepler telescope." The first convex lens acts as the objective and produces a realistic image in the focal plane. This image is viewed with the second convex lens which acts as the eyepiece. The image is reversed. In other words it is back to front and upside down, which really does not matter as far as astronomers are concerned.

The First Reflecting Telescopes

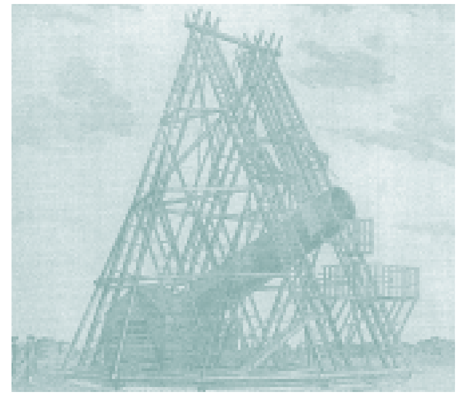
The first workable reflecting telescope was built by Isaac Newton in 1668. A concave main mirror focused the incoming light into a conical bundle, which was reflected to the ocular lens, or eyepiece, by a flat mirror positioned at a 45° angle to the optical axis of the main mirror. In theory there were several more designs for reflecting telescopes in existence. These included the Cassegrain reflector in which a small convex mirror reflects the rays coming from the main mirror back through a hole in its center. However, it was not possible to produce an actual telescope of this type until 1905 because of the hyperbolic contour of the smaller mirror.

Further practical development of Newton's design of the reflecting telescope had to wait until the 18th century when German-born William Frederick Herschel made a considerable contribution. Within a three-year period he built and sold 60 telescopes with an excellent image quality. In 1781 he discovered the planet Uranus and a year later he was appointed "King's Astronomer" at Greenwich Observatory.

To increase the degree of enlargement, bigger and bigger reflecting telescopes were constructed, for the bigger the area of the main mirror, the more light it can collect. But the efficiency of the mirror is dependent not only on its diameter but also on the accuracy of its shape, its surface quality and its reflective coating.

Progress in Mirror Materials

Up to 1835, telescope mirrors were made out of polished metal alloys. Then Justus Liebig invented a process for depositing a dense layer of silver on glass and soon thereafter, glass telescope mirrors with a silvered surface came into



existence. In 1930 the chemically deposited silver was replaced by vapor deposited aluminum. For one thing this gave the mirror a higher reflective power and for another a transparent protective coating of aluminum oxide was formed on the surface which prevented the tarnishing typical of silvered mirrors.

Glass Ceramic Mirror Blanks

Aluminum coating has proved successful up to the present day, but there have been some revolutionary new developments concerning the basic material for the mirror blanks. A drawback with glass or metals is that it expands when heated up and, as a result, "bends" the contour of the mirror. And where wide variations in temperature occur the images produced cannot be used. Attempts were made to develop a material with almost zero thermal expansion. Schott Glas succeeded in doing this with its "Zerodur" glass ceramic, which has been the preferred material for use in telescope and satellite mirror blanks since 1970 ■

Milestones in Material Development

Up to 1835: Polished metal telescope mirrors
1835: Justus Liebig invents a process for depositing a layer of silver on glass
1856: Silver coated glass telescope mirrors
1930 onwards: Aluminum used instead of silver for the reflective coating
1970 onwards: "Zerodur" glass ceramic mirror blanks
1991–93: Schott Glas makes the biggest cast piece of "Zerodur" to date for the Very Large Telescope (VLT) with a diameter of 8.2 meters

Current Telescope Projects

A Step Closer to the Mystery of the Universe

Modern telescopes differ widely in design depending on what they are to be used for. "Zerodur" is very frequently used as the material for mirror blanks.

Whereas telescopes at one time were pure observation instruments, through which astronomers used to view the night sky for hours on end, nowadays they are serving increasingly as measuring instruments. Instead of the human eye, CCD chips (Charge-Coupled Device, a semiconductor material component for processing electrical and optical signals) are used as receivers and data collected is stored and processed in computers. Modern astronomy is also no longer restricted to visible light. The entire bandwidth of electromagnetic radiation in the universe can be investigated with different types of telescopes.

VLT

The "Very Large Telescope" (VLT) on the 2660 meter high Cerro Paranal in Chile is currently the largest and most powerful telescope array in the world. It has four main mirrors made of "Zerodur," each with a diameter of 8.2 meters – the largest ever cast in a single piece. The four telescopes are at present still being operated independent of each other, but they are already delivering images from the visible and near infrared spectrum in a sensational resolution. When they are coupled together to make a giant telescope with an effective mirror diameter of 16 meters, it should be possible in theory to watch an astronaut walking on the moon. In practice, however, the VLT is set to explore dim objects in the universe and, for example, collect information for the first time about planet systems of other stars.

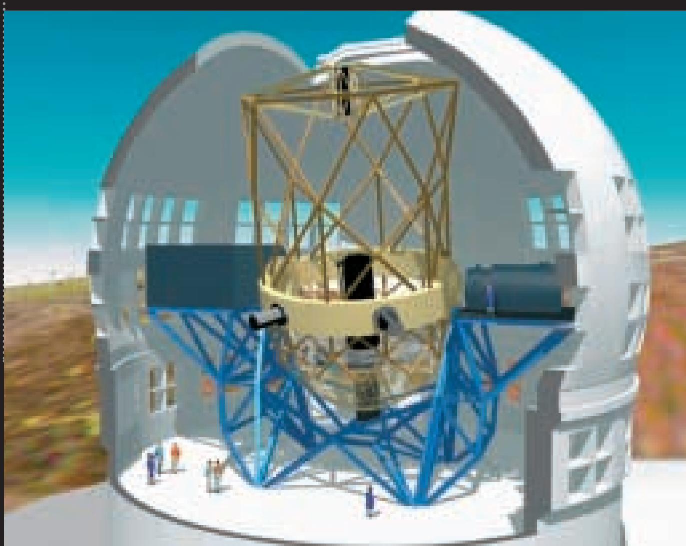
Spectacular and highly detailed VLT photographs of spiral galaxy NGC 1232. The galaxy is 100 million light years away. In its center are older reddish stars, while the arms of the spiral consist of younger blue stars and large quantities of interstellar dust.

The VLT is located on the 2660 meter high Cerro Paranal in the Atacama Desert in Chile.

The fourth 8.2 meter telescope mirror receiving its fine polishing treatment at the French company REOSC.

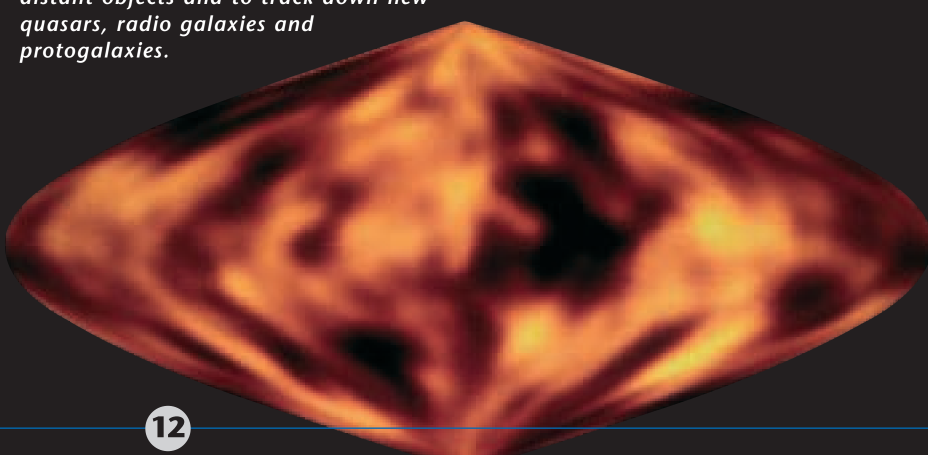
GTC

The Gran Telescopio Canarias (GTC) is currently being built to explore the heavens of the northern hemisphere. Its location on La Palma in the Canary Islands is considered to be one of the best in the world for observations in the visible and near infrared spectrum, for there is very little atmospheric disturbance in that area. The GTC's giant 10.4 meter diameter main mirror was not cast in one piece, but is made up of 36 hexagonal "Zerodur" segments. A sophisticated system of supports, drives and sensors ensures that the individual segments are exactly aligned in relation to each other while astronomic measurements are being carried out. It is planned to start operating with a temporary main mirror consisting of 8 to 10 segments at the end of 2002 with the whole system being ready by 2004.



With a diameter of 10.4 meters and a maximum size of 11.3 meters the GTC is one of the world's largest telescopes.

The primary mirror is composed of 36 "Zerodur" glass ceramic hexagons.

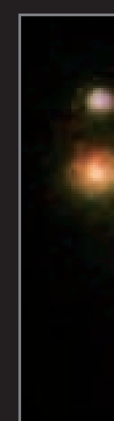


The GTC is set to make it possible to obtain better images than ever of very distant objects and to track down new quasars, radio galaxies and protogalaxies.

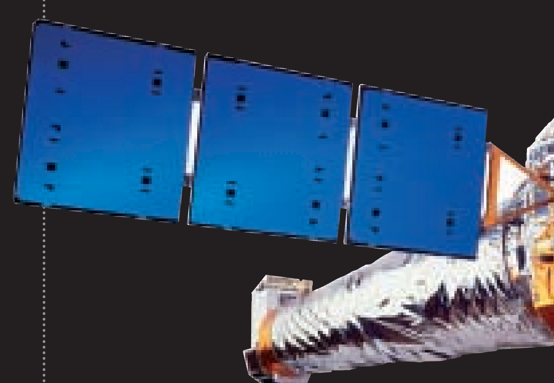
CHANDRA

The Chandra X-ray telescope was transported into space by the space shuttle in 1999. Since then it has circled the Earth in a highly elliptical orbit from which it carries out measurements in the invisible X-ray spectrum. It can be used to investigate the extremely hot gas in a cluster of galaxies for example, which can give indications about the size of black holes.

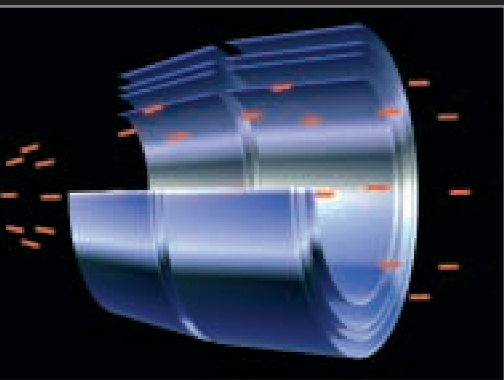
When X-rays strike matter head on, they penetrate deep inside or even pass right through it. For that reason, special cylindrical "Zerodur" mirrors were developed for Chandra which are arranged so that the X-rays are reflected at a grazing incidence and are then reflected onto the detectors.



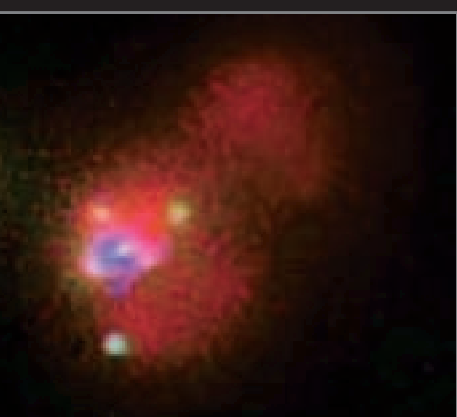
Photograph of the Circinus galaxy taken with Chandra. The red areas correspond to low X-ray energy, green to medium and blue to the highest level. The X-rays are produced in the extremely hot gas of a galaxy cluster and provide information on the size of nearby black holes.

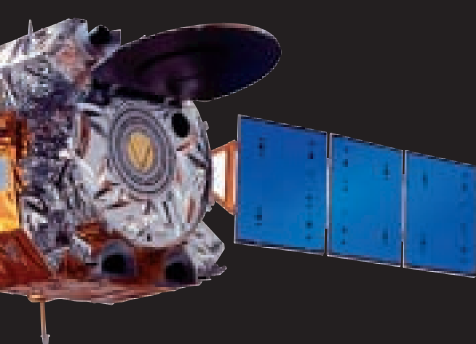


The Chandra observatory circles the Earth in an elliptical orbit at a distance between 10,000 and 140,000 kilometers and is thus well away from radiation belts that could interfere with its operations.



At the heart of the Chandra telescope: a high resolution mirror module with special cylindrical "Zerodur" mirrors.

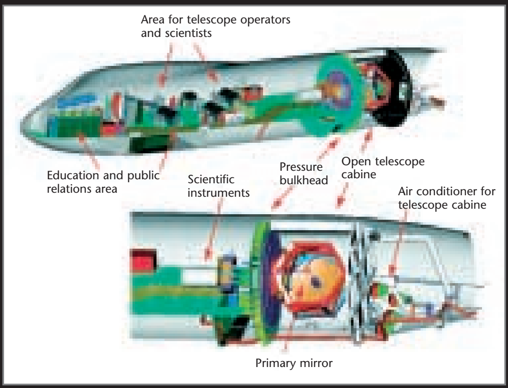




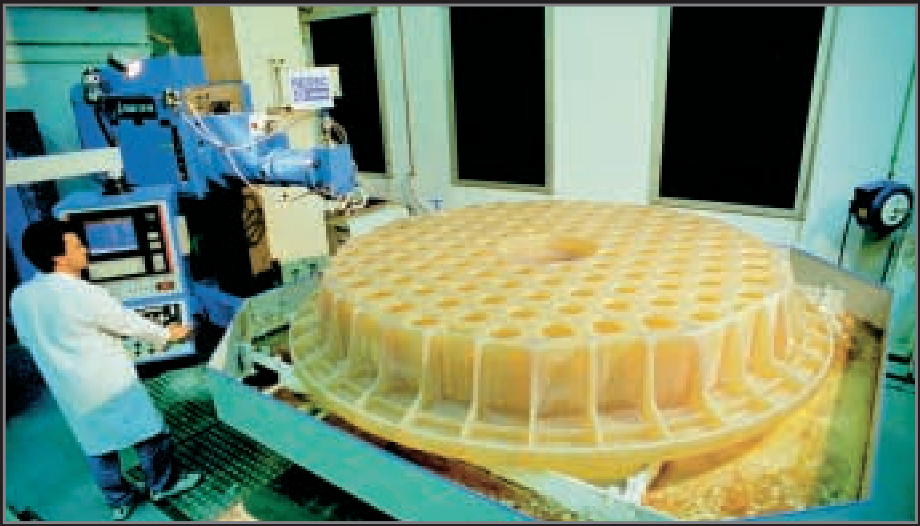
SOFIA

SOFIA stands for "Stratospheric Observatory for Infrared Astronomy" and it is basically a jumbo jet (Boeing 747) with a telescope on board. As the majority of the infrared radiation being investigated does not penetrate the Earth's atmosphere, SOFIA's scientific observation flights are expected to take place from 2004 at a height of about 13 km. The conditions found there are rough, i.e. low pressure, turbulent winds and a temperature of about –60 °C. The "Zerodur" mirror substrate can withstand all this very well, even though its reverse side consists only of a thin honeycomb structure. By producing it in this way it was possible to reduce its weight from an original figure of 4 tonnes to 850 kg ■

SOFIA airborne telescope: the optical instrument is installed in the Boeing 747's fuselage.



A view of the interior of SOFIA.



A honeycomb structure has been milled out of the reverse side of the "Zerodur" mirror blank, reducing its weight from four tonnes to 850 kilograms.

Electromagnetic Radiation

Only a fraction of the radiation coming from space can pass through the Earth's atmosphere, namely visible light and the adjoining infrared and UV radiation. This means that the thinner the atmosphere, the more ultimately reaches the surface of the Earth. That is why the large terrestrial telescopes are located on high mountain peaks. On the other hand if information is required from the shorter wave radiation range (e.g. X-ray light) or the longer wave (e.g. far infrared or microwaves), then it is necessary to go outside the Earth's atmosphere completely to carry out the measurements from an aircraft, a captive balloon or satellites.