Light, space and time. In the Universe, to see into the distance is to look back in time. Photons travel through space filling it with light and bringing us fragments of a distant past that, according to the most accepted cosmological models, began some 14 billion years ago. How can mankind glimpse the earliest moments of the Cosmos? How can we capture the reflections of its ancient light? The Gran Telescopio CANARIAS (GTC) is the window through which we will observe the most distant objects and study the origin and evolution of the Universe. Thanks to the surface area of its primary mirror, the GTC is currently the largest time machine on the planet.

A telescope is like a cosmic filter. For this reason, the bigger its mirror is the more light it will receive and the farther and clearer it will see. Like a telephoto lens in a camera, a telescope’s power depends on its capacity for collecting light. The GTC’s primary mirror has a surface area equivalent to a single circular mirror 10.4 metres in diameter, giving it a light collecting area more than six square metres larger than other optical telescopes built up to now. This gives the telescope extraordinary vision, equivalent to four million human eyes. It is the only telescope in Europe for which, due to its size, a monolithic mirror was rejected in favour of a segmented mirror made up of 36 hexagonal pieces, each one almost two metres across diagonally.

Its instruments allow it to pick up the faintest celestial objects in the Universe, not only in the visible range, which is the light that the human eye can see, but also in infrared. It is in the infrared spectrum that the GTC will detect the thermal radiation emitted by objects, in the same way as a rattlesnake does in the animal kingdom. OSIRIS and CanariCam are state-of-the-art instruments with cutting-edge features, and they build this double advantage into the GTC. It is a well-known combination: the biggest telescope paired with the best and very latest instruments.

With the GTC the universe of answers will be enlarged and the never before seen will be unveiled. It will be possible to look in more detail at the characteristics of black holes, find out what chemical compounds emerged after the Big Bang, go deeper into dark matter and witness, hidden behind dense molecular clouds, the birth of new stars. The new telescope will also be a tool for discovering planets similar to our own in other star systems. Once fitted with its adaptive optics system, which will allow the correction of image imperfections caused by atmospheric turbulence, the Gran Telescopio CANARIAS will be able to “see” planetary discs like the ones that gave rise to our Solar System, and inside them, potential future planets that could be candidates for housing some form of life.
The ancient people of the Canary Islands revered the mountains. In fact, Roque de los Muchachos was probably a magical and sacred place for the aborigines of La Palma, or “benahoaritas” as they are known. Centuries later, 2,400 metres above sea level beneath the same sky, the Gran Telescopio CANARIAS has been built on the island of La Palma.

The GTC stands at the edge of the Caldera de Taburiente National Park, a place where geography and climate come together to create exceptional conditions for astronomical observation. Geographically speaking, the Observatorio del Roque de los Muchachos (ORM) is close to the Earth’s equator giving the telescope views over the whole of the northern celestial hemisphere and part of the southern. The altitude of the location also guarantees that the GTC can see above the cloud cover, known in popular terms as the “sea of clouds”.

This is a privileged observation point for astrophysics, where 80 per cent of nights are exceptionally clear and the atmosphere is stable and transparent. Above the thermal inversion layer (1,200 -1600m) the prevailing winds are the trade winds and they are dry and constant, which considerably reduces turbulence. Furthermore, the so-called “sea of clouds” acts as a shield against light pollution from urban centres.

The "Sky Law" protects the atmosphere over the island, a pioneering piece of legislation put in place in 1988, which protects the extraordinary astronomical quality of the peaks of La Palma by limiting light, radio wave and atmospheric pollution and air traffic above the ORM. This is another guarantee of observation quality, making this site a true "astronomy reserve". For all of these reasons the Observatory is home to one of the most extensive arrays of telescopes found anywhere in the world, and it is now even better equipped with the addition of the GTC.
The Gran Telescopio CANARIAS is like a jigsaw puzzle with very special pieces. Firstly, its primary mirror is made up of 36 hexagonal segments, each one almost two metres across. The mirror is eight centimetres thick and weighs 470 kilograms. When the segments are put together they form a perfect hyperbola, the shape of a wide-open bowl. This jigsaw, when complete, is equivalent to a circular mirror 10.4m in diameter and weighing nearly 17 tonnes.

Why are the pieces hexagonal though? In nature, hexagons occur when the available space is limited. By eliminating the gaps that occur when circles are grouped together, hexagons can use space more efficiently. The GTC needs to use every inch of its primary mirror if it is to collect the maximum possible amount of light. That is why, like composite eyes in insects, the mirror is divided into hexagonal segments. When light from these 36 individual segments comes together a complete image is formed.

For the GTC, capturing a star is a game of mirrors. The primary mirror’s 36 segments need to work together as a single surface. To keep them in position, sensors at the edges of each segment send information to the control system 20 times a second. Computer-guided actuators induce precise movements in the segments to keep them aligned and maintain the overall shape of the ‘bowl’. This technique is called active optics.

Light travels millions of kilometres from a distant star or galaxy but is only distorted in the last ten or so kilometres as it crosses the earth’s atmosphere. The adaptive optics system, which is soon to be installed at the telescope, is an ambitious technology that compensates for aberrations caused to light as it travels through the atmosphere by using deformable mirrors to apply real-time corrections (around 200 per second). The difference it will make is like seeing an object on the bottom of a swimming pool through swirling water and then seeing it again when the water is calm and clear.

The light’s journey does not end at the primary mirror. The game of mirrors continues at the secondary mirror, which is serrated and adapted to and aligned with the shape of the primary mirror. The secondary mirror can move very quickly on five axes to compensate for bending and thermal expansion in the telescope structure. The GTC also has a third mirror that can interrupt the light’s path, sending it to different foci within the telescope. It is a mirror with a “lift” that can rotate on its axis, slide in and out and “park itself” to divert the photons towards the focal point selected.

It has all been designed to prevent anything getting in the way of the giant’s view. The dome is fitted with a ventilation system to prevent differences in temperature between the interior and exterior causing air turbulence that could distort the image. The telescope can also predict and regulate day-time temperatures inside the dome and forecast the operating temperatures that will be needed at night. All of these systems mean that the GTC will be able to see details equivalent to the headlights of a car in Australia or a bowl of hot beans on the surface of a new moon.

The mirror segments are made of Zerodur™, a special type of vitreoceramic material that has “zero dilation” Like materials used in domestic hobs it expands and contracts very little with changes in temperature, and this helps to avoid image distortion. The mirror’s surface has been polished to a tolerance of 15 nanometres (a nanometre is a millionth of a millimetre), or 3,000 times thinner than a human hair. This means that any bumps in the surface of the primary mirror segments are no higher than 30 nanometres - which would equate to “mountains” just one millimetre high if the mirror was the size of the Iberian Peninsula.

Although all of the segments seem the same, their shapes differ so that, when fitted together, they make the hyperbola. To make it possible to identify the 42 mirrors (36 plus six substitutes) when they are being put together, it was decided to give them Canarian names. The GTC therefore bears the signs of its Canarian heritage on the reverse of each of its segments.

THE CANARIAN NAMES OF THE 42 MIRRORS

ISLANDS: El Hierro, La Palma, La Gomera, Tenerife, Gran Canaria, Fuerteventura and Lanzarote.
PARKS: Timanfaya, Jandía, Tejeda, Teide, Garajonay, Taburiente and Frontera.
NATIVE TREES: Almácigo, Sabina, Marmolán, Sanguino, Drago, Aderno and Mocán.
CANARIAN PLANTS: Cardón, Bejeque, Tabáiba, Verode, Tajinaste, Codeso and Retama.
NATIVE BIRDS: Guincho, Graja, Capirote, Canario, Alpispa, Guirre and Pardela.
TYPICAL DANCES: Folía, Isa, Seguidilla, Tanganillo, Sorondongo, Saltona and Vivo.
The Gran Telescopio CANARIAS is an immense structure over 20 metres high, with parts that weigh several tonnes yet have to perform tiny movements with extreme precision. The structure is made up of three parts: the mount, the tube and the azimuth and elevation rings.

The telescope mount is a metallic spider capable of bearing a weight of around 400 tonnes. The secondary mirror assembly alone weighs over ten tonnes and it supports a mass of more than two tonnes. Despite these colossal statistics, maximum distortion in the mount is less than 300 microns. The grand scale of the GTC does not mean that it is insensitive: some of the components of this “telescopic body” can sense changes in temperature and activate the relevant systems to compensate for them.

How can 400 tonnes move every night to search for the stars? Like a tame elephant, the world’s largest telescope can move with very little input thanks to hydrostatic lubrication. The GTC is fitted with bearings that effectively float the whole of the superstructure on a thin film of pressurised oil. The job of these bearings is to make it easy for the telescope’s moving parts to rotate and to lessen vibration. The 2,700 litres of oil needed to make this possible are constantly pumped through a circuit, cooled and returned to the bearings. Thanks to this “pool of oil”, the whole of the telescope structure can be moved with just a push of the hand.

The dome protecting the GTC is shaped like a spherical helmet. It is designed to prevent turbulence both inside and outside the telescope. It is 34 metres in diameter and, when all of its parts are taken together, 45 metres tall - somewhat higher than the cathedral in Seville. When our very own “astronomical cathedral” opens its doors to the Universe, the position of the stars will be measured 20 times a second so that the movements the telescope needs to make can be calculated. When it locates a celestial object, the GTC moves along two perpendicular axes: the azimuth (horizontal) and elevation (vertical). It works in a similar way to the canon on a tank, which rotates on its base and moves up and down to locate its target.

The telescope is fitted with a complex real-time control system to manage all of its mechanisms and optics. This system consists of a network of over 50 computers and servers connected by several kilometres of fibre optics.
Large telescopes of 8 to 10 metres are always referred to as a generation. The GTC is the largest, with its 10.4 metre diameter mirror and the biggest light collecting surface of them all: 81.9 square metres.

Next in line, at 10 metres, are the two north American Keck telescopes in Hawaii. At 8 metres we have the four European Very Large Telescopes (VLT) in Chile, the two Anglo-American Gemini in Chile and Hawaii, the Japanese Subaru, also on the Hawaiian island of Mauna Kea, and the two 8.4 metre mirrors of the Large Binocular Telescope (LBT) in Arizona. Moving up in scale, next come the Hobby Eberly Telescope (HET), in Texas, and the Southern African Large Telescope (SALT), in South Africa. Although they have large mirrors, 9 and 11 metres in diameter respectively, their useful receptive surface area is smaller than the GTC’s and their range of movements is more limited.

However, it is not only the diameter of the primary mirror that makes these large telescopes different. In terms of astronomy, the extra 6.2 square metres that the Gran Telescopio CANARIAS has over the Keck is not the deciding factor. Being the latest in the generation of large telescopes, the GTC has tried to improve on the design of its predecessors, learning from their experience. It is the technological breach opened up between it and its predecessors that really makes the difference.

Compared to the first large telescopes, for example, there is a technological leap of something like 15 years. The GTC’s mirrors are more highly polished, its mechanical structure is much sturdier and it has one of the best motors and codifiers yet built. With its large light collecting surface, image quality is paramount, and the telescope brings together two technologies to optimise it to the full: active optics and adaptive optics. Rigidity in the event of external disturbances, one of the most important requirements for image stability, is now several times greater than in other telescopes like the GTC.

With the most up to date and innovative technology built-in, the GTC is the best telescope the world has ever seen. Its secret lies not only in its size, but also in its three outstanding qualities: excellent image quality, high technical reliability and maximum observational efficiency. The GTC will mostly operate in queued observation mode, in which a computer monitors the atmospheric conditions, climate, remaining observing time and available instruments. This allows scientists to continually select the best instruments and observation modes for the prevailing conditions, so that the telescope is used to its full potential and the scientists make the best use of their time.
A telescope without instruments would make no sense: it would be like an eye without a retina. Although the light collecting capacity of a telescope is fundamental to its capacity for observing distant celestial bodies, it is the scientific instruments that bring it to life, allowing it to analyse and study the photons it picks up.

The instruments all have unique characteristics and they determine the telescope’s specialisms. Together, the world’s biggest telescope and these unique instruments constitute a powerful tool for astronomical observation. The first instrument in operation was **OSIRIS**, closely followed by **CanariCam**. At a later date, **EMIR** and **FRIDA** will join them. New ultramodern instruments will continue to be developed for the GTC, keeping it in the vanguard of technology.

**OSIRIS** made its first astronomical observations last March and is, for now, the only instrument installed on the telescope. Its vision is sharp and fast, almost ten times quicker than other similar instruments thanks to its filters, which can be adjusted at will. It works in the visible range, in other words the light that a human eye can detect. Its main asset is its spectroscope, which it uses to study celestial objects by analysing their spectrum. To do this it uses an innovative system of tunable filters which, together, are equivalent to 19,000 conventional filters. OSIRIS’ power lies in this type of filter, which will make it possible to do science with the GTC that is not possible with other telescopes. OSIRIS can study artefacts of the evolution of galaxies and the Universe itself, and is the result of a partnership between the Instituto de Astrofísica de Canarias (IAC) and the Instituto de Astronomía of the Universidad Nacional Autónoma de México (IA-UNAM).

Among the latest generation of instruments is also **CanariCam**, a camera at the forefront of infrared astronomy, which will make a single night of observation with the GTC as productive as 40 nights with a 4 metre telescope. CanariCam, which is planned for installation in spring 2010, will be the first thermal infrared instrument to perform both polarimetry and coronography, making it capable of work that would need at least three different instruments at other telescopes. Using polarimetry, for example, it will examine polarised radiation emitted by the coldest objects in the Universe, like stars in formation or extrasolar planets around distant stars. It will analyse the form, structure and composition of a large range of objects and will be particularly useful for detecting brown dwarfs and studying the centre of our galaxy in detail. Coronography is a technique in which a mask is used to create artificial “eclipses,” blocking out the light from a star. It is used to identify planets around very bright stars. CanariCam was designed and built by the University of Florida (United States).

The second generation of instruments will feature two infrared devices. **EMIR**, whose development was led by the IAC, is a multi-object spectrograph with the widest range ever designed for Astronomy. This instrument, which will cover the near infrared range, is a key tool for the study of star formation in the Universe and will also allow spectra from several different sources to be obtained simultaneously.

The other actor on the stage will be **FRIDA**. A project led by the Instituto de Astronomía of the Universidad Autónoma de México, FRIDA will be the first instrument to work with light corrected by the GTC’s adaptive optics system. After the telescope has eliminated in real time the turbulence caused to light by its journey across the atmosphere, FRIDA will commence work using its Integral Field Unit. This is when the "spectroscope in three dimensions" will come into play.
The Instituto de Astrofísica de Canarias (IAC) first put forward the idea of building a large telescope in 1987, when the William Herschel Telescope entered service with a 4.2 metre diameter mirror. The IAC had three reasons for wanting to embark on such a huge project: First, to provide Spain’s astronomy community with its own cutting edge telescope; second, to keep the Canarian observatories in the front row worldwide; and third to expand advanced technology capability in Spanish industry.

In the early days, support for the proposals was unforthcoming. There was little confidence in Spain’s ability to take forward such a big project alone and international participation was thought essential. Could Spain lead the construction of a large telescope? The cutting edge nature of the project and its economic potential, as a means for increasing capacity in industry and providing opportunities for technology transfer, were ultimately convincing and the support needed was secured.

At the instigation of the IAC, the GRANTECAN public company was set up in 1984 to provide efficient management of the development and construction of the GTC. In the course of a decade more than a thousand people, from one hundred companies, have worked on the design, construction and commissioning of the telescope. In all that time the cost of the GTC to the Spanish citizen has been under 25 cents a year. The total cost of the project is around 104 million euros, over ten percent less than the original budget after adjusting for inflation. The original budget was not excessive either; on the contrary, it was argued at the time that it was too low and that the telescope could therefore not be built.

When operating and maintenance expenses are taken into account alongside the construction costs, each night of observation at the GTC costs around 80,000 euros. This explains why selection processes must be strict, so that time at the telescope is only allocated to the best observation proposals.

Ninety per cent of the finance has come from the Spanish Government and the Autonomous Community of the Canaries (70/30), together with significant investment by the European Regional Development Fund (FEDER). The Canaries has also provided natural resources in the form of its skies, which are of an exceptional quality for astronomical observation. The Governments of Spain and the Canary Islands each have a fifty per cent stake in GRANTECAN, although this does not guarantee any observing time for astrophysicists from the Canaries. The remaining ten per cent of the funding has come in equal parts from the United States and Mexico. In return they will have access to five per cent of observing time, with ninety per cent going to astrophysics research groups in Spain.

The Gran Telescopio CANARIAS was conceived, led and built by Spain. Over seventy per cent of this monumental feat of engineering was delivered by Spanish companies, which have become more competitive and gained an international presence as a result. The building of a complex instrument like the GTC shows how a scientific initiative can mobilise industry, helping it to expand into fields of ultramodern technology. The telescope’s essential components were built in Spain and, locally, industries in La Palma were very involved in in the construction and commissioning phases. This project, with its made in Spain label, has been an engine driving industrial development and led to increased demand for technology in our country.
Convincing partners in other countries was a tough job. Spain’s inexperience and the low budget for the project were seen as insurmountable obstacles and damaged confidence. For this reason, initially only Spain was prepared to invest. Finally, in 2001, a group of institutions in Mexico and the United States joined the Gran Telescopio CANARIAS project as partners. The agreements reached meant that each country would contribute 5% of the telescope’s budget in return for 5% of observing time. The project increased joint working between the institutions and led to an exchange of researchers, PhD students and staff. The GTC became a flagship international project with Spain at the helm.

**Mexico**

Mexico became a partner when agreements were signed with the Institute of Astronomy of the National Autonomous University of Mexico (IA-UNAM), the Institute of Astrophysics, Optics and Electronics (INAOE) and the National Council for Science and Technology of Mexico (CONACYT). These Mexican institutions contribute 5% of the telescope’s budget and they have been very involved in building important components for the GTC. The partnership deal with Mexico also includes an exchange of observing time at the GTC for time at the Gran Telescopio Milimetico, the largest radio telescope in the world in its frequency range. Its 50 metre diameter antenna possesses excellent sensitivity and permits astronomers to observe, from Mexico, regions of the Universe obscured by interstellar dust.

**University of Florida**

The University of Florida Research Foundation also has a participation agreement with the Gran Telescopio CANARIAS. The NorthAmerican institution agreed to contribute 5% of the telescope’s budget and to undertake other tasks and investments prior to its use. In addition to an exchange of post-doctoral researchers and technicians, the agreement has led to joint work on instrumentation projects. The Department of Astronomy at the University of Florida built the CanariCam instrument, a thermal infrared camera, for the GTC infrared.
Now that the retirement of the Hubble space telescope has been announced and astronomers have started designing a new generation of ground-based 40 metre and larger super telescopes, the Gran Telescopio CANARIAS’ position as a powerful platform for Astronomy in the twenty first century is assured.

Just as four-metre telescopes paved the way for large telescopes of eight metres and beyond, the GTC is an ideal tool for developing ideas about the E-ELT.

With the GTC, Spain has joined the ranks of countries that can pursue “big science” projects. The telescope secures the place of the Observatorio del Roque de los Muchachos in the “first division”, and gives the Spanish astrophysics community a world class machine for cutting-edge science. It also confirms Astrophysics as the branch of Spanish science that has made the largest contribution on the world stage.

The experience gained through building, fine-tuning and operating the GTC is of huge value for the design of future telescopes, in particular the European Extremely Large Telescope (E-ELT). The Canaries is the only place in Europe where the E-ELT can be built, and it would be 16 times more powerful than the GTC. In the race between Europe and the United States to install telescopes with a diameter upwards of 40 metres, there are only two main candidates: the Canary Islands and Chile.