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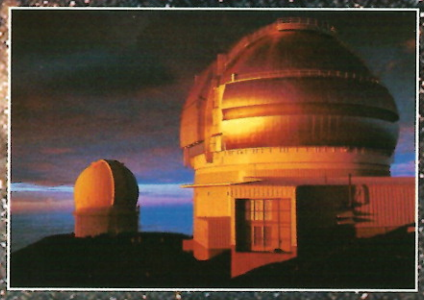
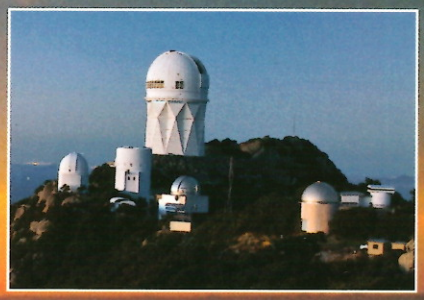


The summit of Mauna Kea, Hawaii

The world's driest desert in Chile



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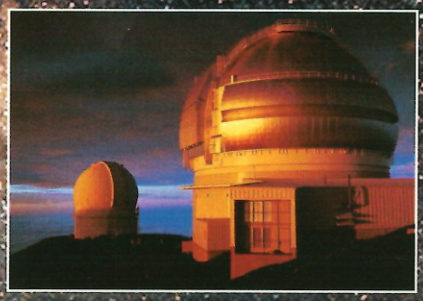

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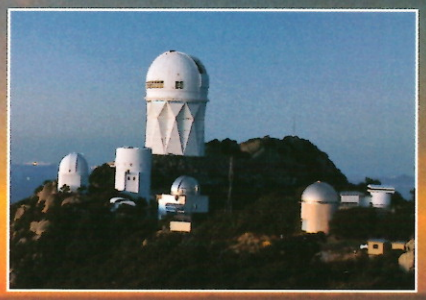

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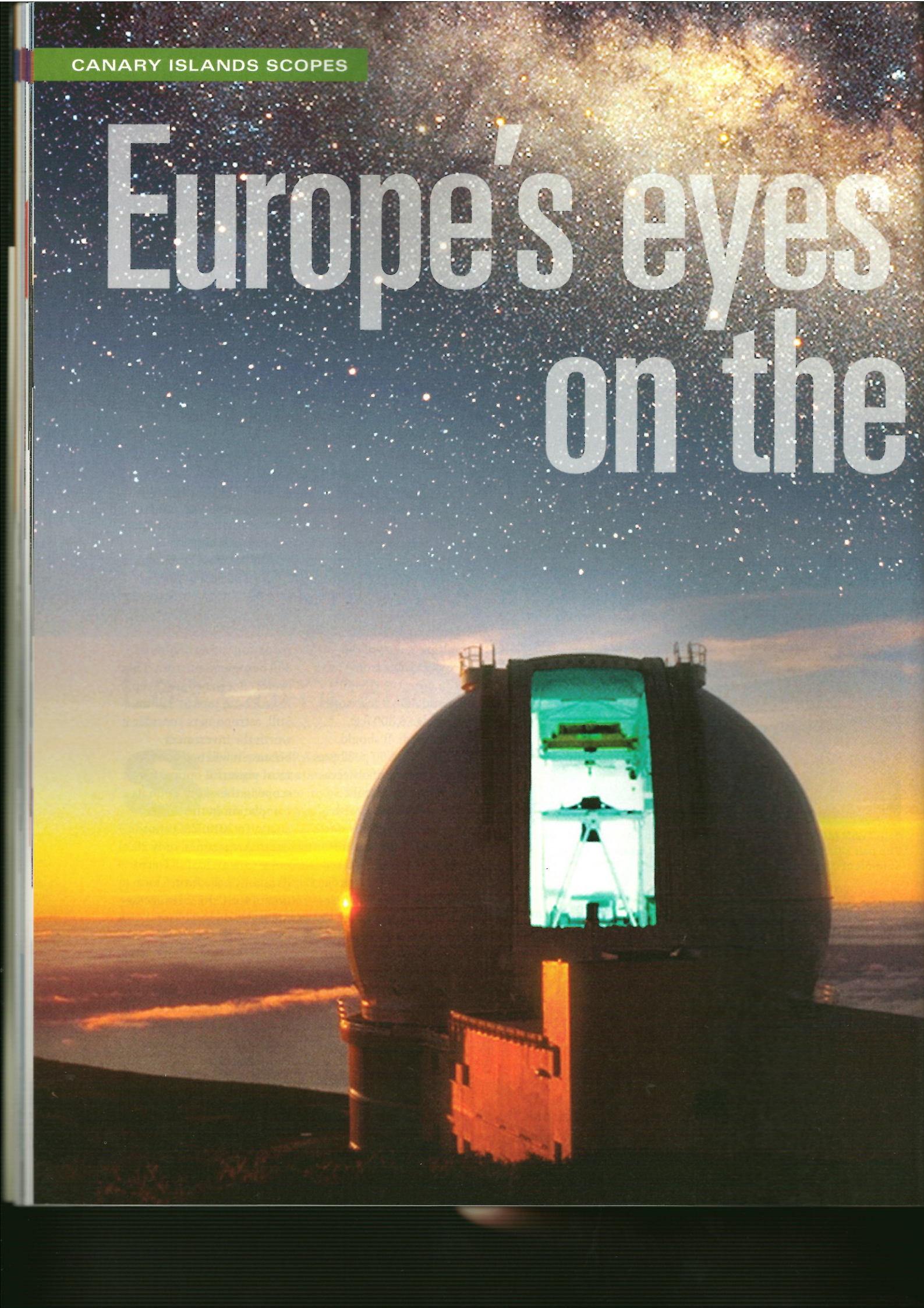
CANARY ISLANDS SCOPES

Europe's eyes on the



THE WILLIAM HERSCHEL TELESCOPE peers out from a sunlit dome on a late afternoon. The Milky Way rides overhead in this composite image.
NIK SZYMANEK AND IAN KING/ING

The world's largest optical telescope joins many other superb astronomical instruments on an island off of Africa's northwestern coast.

By Chris Benn, Javier Méndez, and Marc Balcells

northern sky

The Canary Islands

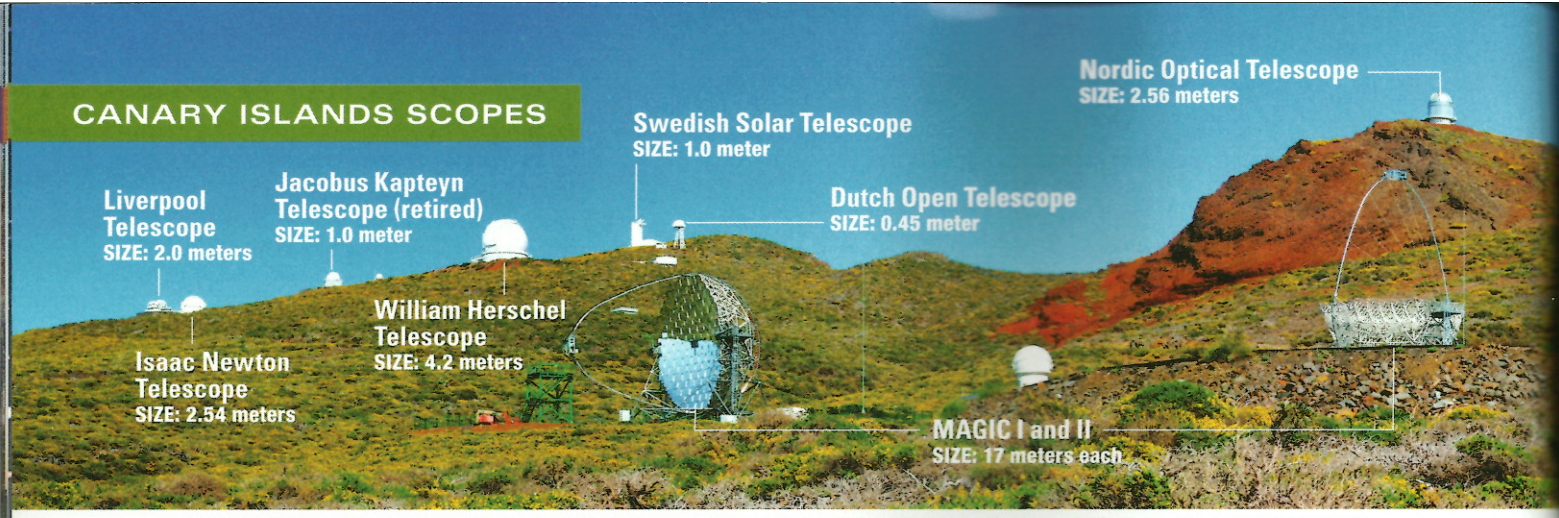
The Canary Islands, off the northwest coast of Africa, have long been a popular tourist destination, enticing visitors with their mild weather and historical attractions. But the northwest-most island in the archipelago, named La Palma, has its own astronomical allures. At the 7,900-foot (2,400 meters) summit of one of its peaks, high above the clouds, sits one of the best observing sites on Earth. Many of Europe's most powerful telescopes take advantage of these skies, including the largest single-aperture optical telescope in the world. As a result, some of the most important space discoveries happened with these instruments.

Chris Benn *is head of astronomy at the Isaac Newton Group of Telescopes (ING).* **Javier Méndez** *is public relations officer at the ING.* **Marc Balcells** *is director of the ING.*

La Isla Bonita

The locals call La Palma *La Isla Bonita* — the beautiful island. It's the greenest of the seven Sun-drenched Canary Islands, thanks to the plentiful supply of water provided by the high, steep slopes. Palm trees, primeval laurel forest, and pines all find their home here, as do plantations of diverse crops from bananas to tobacco.

Like the nearby islands, La Palma sees volcanic activity. The original peak in the northern part of the island collapsed long ago, leaving behind the Caldera de Taburiente — a steep-walled crater 5 miles (8 kilometers) across and 0.93 mile (1.5km)



THE ROQUE DE LOS MUCHACHOS OBSERVATORY stretches out along the rim of the Caldera de Taburiente, some 7,900 feet (2,400 meters) above sea level on La Palma in the Canary Islands. GIOVANNI TESSICINI (TNG)

deep. The caldera and the northern half of the island are no longer volcanically active, but the southern half has seen many eruptions, most recently in 1971.

Going a little further back, during the Spanish conquest of the 15th century, the local inhabitants of the Canary Islands were the *Guanches*. How and when they arrived is still unknown, and their culture disappeared after the Spanish conquest. But they left behind a wealth of enigmatic rock carvings and distinctive place names (Tigalate, Tenagua, Tijarafe), and *Guanche* genes live on in the blond hair of many Canary Islanders.

Over the next 200 years, La Palma's abundant water and its role as a trading post on the way to the New World made it one of the Canaries' wealthier islands, and a target for pirates. The seafront fort kept at bay the likes of Sir Francis Drake, who attacked unsuccessfully in 1585.

One feature La Palma lacks is golden beaches, but this has turned out to be a blessing for astronomers. The hordes of Northern European tourists who flock to the sunny resorts of Tenerife and Gran Canaria to the east have largely shunned the black volcanic sands of La Palma. As a result, there are no brightly lit resorts on the island, and the skies of La Palma are as dark as those of Chile or Hawaii.

Open for business

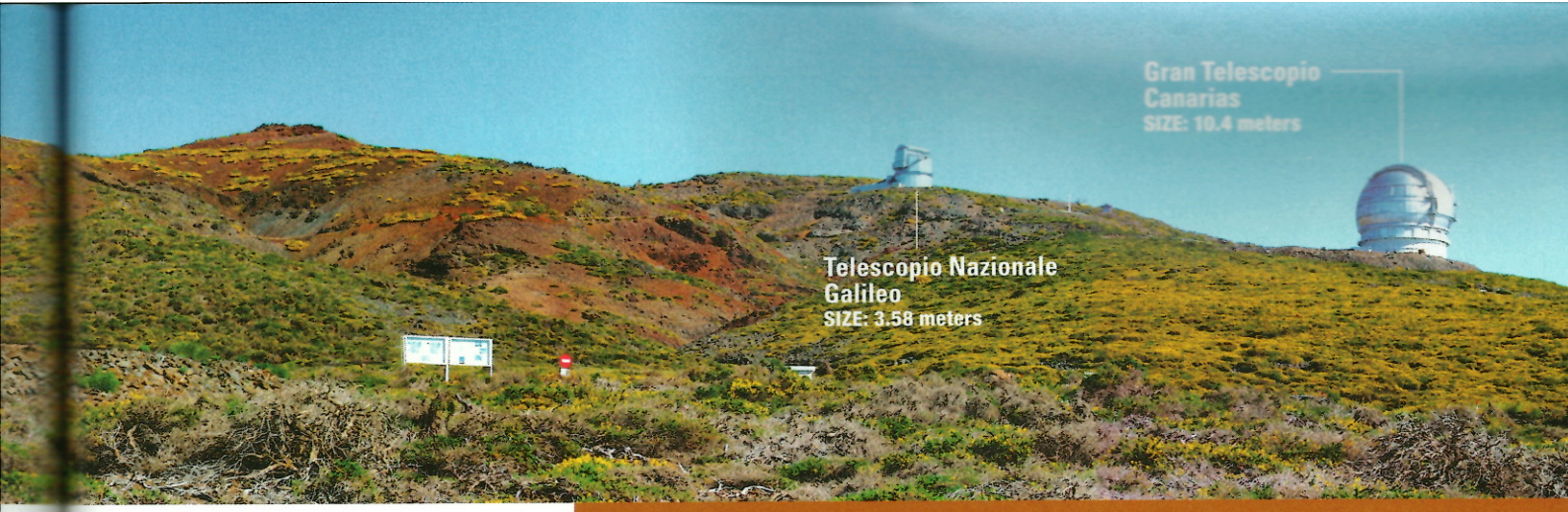
In the late 1960s, British astronomers were hatching plans for a Northern Hemisphere observatory. They were helping build the 3.9-meter Anglo-Australian Telescope in the Southern Hemisphere and wanted a similar telescope in the north. At the time, the United Kingdom's largest telescope was the 2.54-meter Isaac Newton Telescope (INT) at Herstmonceux Castle in Sussex, but the English weather often made observing difficult. The scope deserved and needed a better site, and the astronomers were looking to sunnier climes in the Mediterranean area, various Atlantic islands, and Hawaii.

La Palma emerged as a possible site in 1971 when two astronomers from the Royal Greenwich Observatory stopped at the island and visited the summit, on the rim of the Caldera de Taburiente. The prevailing wind blows from the northwest and passes only over the smooth northern flank of the island before reaching the rim of the caldera, which bodes well for steady airflow and good seeing.

The next year, mules ferried supplies and equipment to La Palma's summit, and site testing began. By 1975, the results were in, and four locations had made the cut: Hawaii, Madeira (far southwest of Portugal), and the Canary Islands of Tenerife and La Palma. Hawaii and La Palma eventually came out on top, with little to distinguish between them astronomically. La Palma, however, is much easier for European astronomers to reach.

At about the same time, thanks to the enthusiastic Spanish astronomer Francisco Sánchez, Spain's government began to understand the importance of creating an international observatory on the Canaries. In 1979, Spain, Denmark, Sweden, and the U.K. signed an agreement: Spain would provide the observatory infrastructure, and in exchange its astronomers would get 20 percent of the observing time on all telescopes located there. The foundations of La Palma's

THE RUGGED CONTOURS of the fog-filled 5-mile-wide (8 kilometers) Caldera de Taburiente National Park stand out in this view. INSTITUTO DE ASTROFÍSICA DE CANARIAS



international observatory were in place; it would be called the Observatorio del Roque de los Muchachos (ORM) after a nearby rocky landmark (literally named "the rock of the boys").

These international agreements, recently extended until 2022, establish a flexible scheme to allow scientific organizations to deploy their telescopes on a site with all the required infrastructure in place: access roads, living quarters, a water supply, electricity, and communications networks. Today, 13 telescopes operate on the ORM under this agreement.

The first scopes

The first telescope on La Palma was a Swedish 24-inch, commissioned in 1982. The next would be the fruit of a British-Dutch collaboration. The two countries agreed in 1981 to join forces to build and operate three reflecting telescopes. The first was the existing 2.54-meter INT, refurbished and relocated from Herstmonceux Castle to La Palma, where it saw first light in 1984. A few months later, the new 1-meter Jacobus Kapteyn Telescope joined it, and soon both scopes were in regular use by astronomers visiting from the Netherlands, Spain, and the U.K. The 4.2-meter William Herschel Telescope (WHT) was the third to come out of this collaboration.

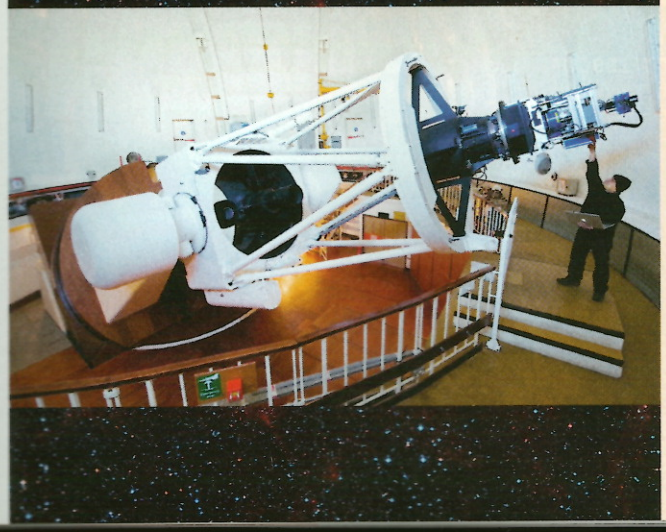
Working conditions for astronomers in those pioneering days weren't as comfortable as they are now. Getting to the observatory from sea level required a one-hour drive up a winding dirt track, often in a thick cloud of orange dust thrown up by any leading vehicles. On the mountaintop, staff and observers initially slept in Spartan huts below the INT building, and meals for the 30 staff members and observers came from the

13 The number of telescopes on the Observatorio del Roque de los Muchachos

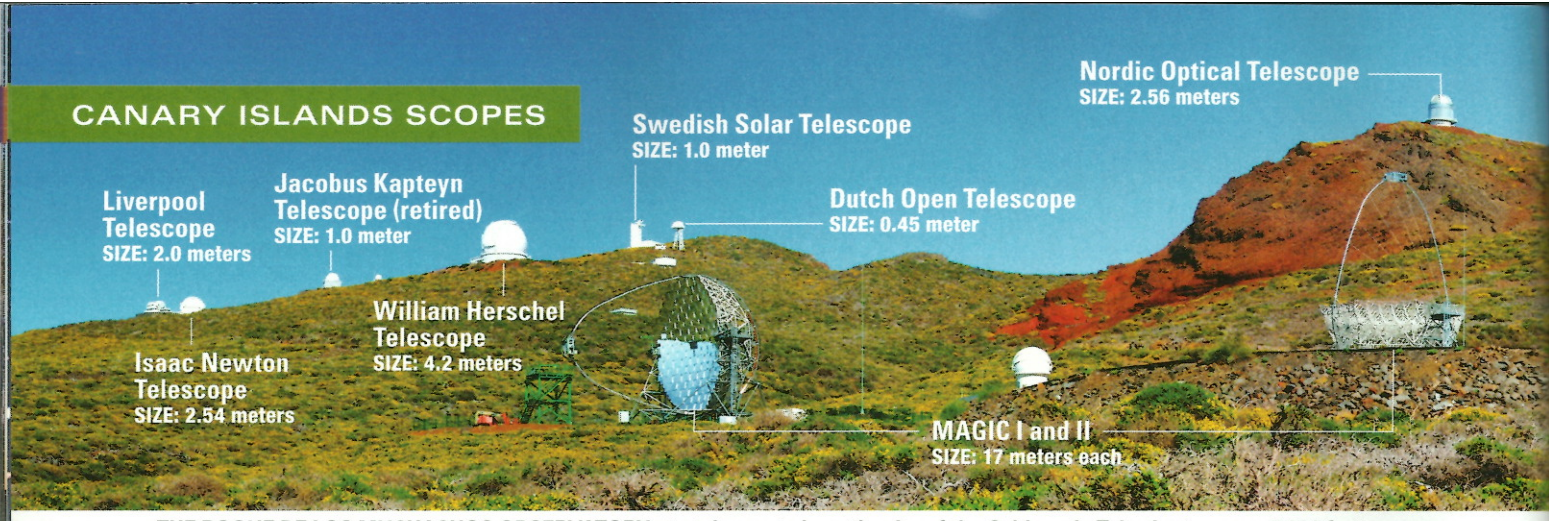
Isaac Newton Telescope

WEBSITE: www.ing.iac.es
TOURS: 10 A.M. to 1 P.M. every day in the summer, and 10 A.M. to 1 P.M. Tuesdays, Thursdays, and Saturdays the rest of the year (reservations required)
TELESCOPE:
- 2.54-meter optical Isaac Newton Telescope

THE CRESCENT NEBULA (NGC 6888), as seen in this Isaac Newton Telescope photo, formed when a Wolf-Rayet star's winds slammed into previously ejected gas. DANIEL LÓPEZ (IAC)



THE ISAAC NEWTON TELESCOPE was the first large instrument on La Palma, although its 2.5-meter mirror now ranks it fifth in size on the island. MAX ALEXANDER



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THE RUGGED CONTOURS of the fog-filled 5-mile-wide (8 kilometers) Caldera de Taburiente National Park stand out in this view. INSTITUTO DE ASTROFÍSICA DE CANARIAS

CANARY ISLANDS SCOPES

ROBERT WAGNER (MAX-PLANCK-INSTITUT FÜR PHYSIK, MÜNCHEN)

THE GRAN TELESCOPIO CANARIAS rises above one of the two MAGIC telescopes on La Palma. MAGIC observes Cerenkov light emitted when cosmic gamma rays strike Earth's atmosphere.

LA PALMA sits at the western edge of the Canary Islands, which in turn sit off the northwestern coast of Africa. *ASTRONOMY:* ROEN KELLY AND RICK JOHNSON

tiny INT kitchen. By 1985, hotel-style living quarters became available.

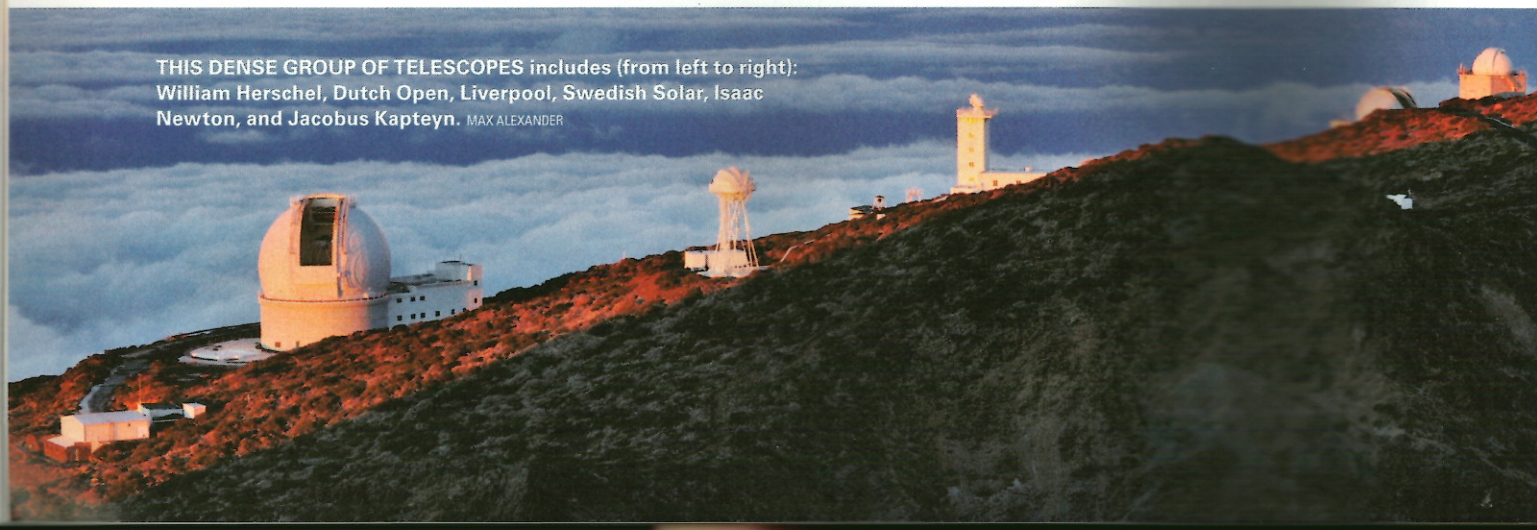
The 4.2-meter WHT was the third-largest scope in the world at the time of first light in June 1987, and it was designed to gather photons from the faintest and most distant objects known. The mirror's size comes from Owens-Illinois' pre-existing 4-meter mirror mold, whose diameter increased slightly each time a mirror was chipped out. WHT's was the third they made — hence the 4.2. The mold produced a near-perfect paraboloid mirror, however, deviating from the required shape by less than 1/3,000 millimeter.

Despite it being the norm for most large telescopes nowadays, the WHT's alt-azimuth mount was something of a novelty back then. The construction is cheaper for this kind of mount than for an equatorial design, and the alt-azimuth also allows for two Nasmyth foci, where detectors can collect the light. These are ideal for experimental cameras that the astronomer can adjust while observing, and those not robust enough to swing about on the back end of the telescope. The design has provided an opportunity to test many innovative observing techniques at the WHT, such as a prototype of an ambitious adaptive-optics camera for the planned 40-meter European Extremely Large Telescope (see page 53).

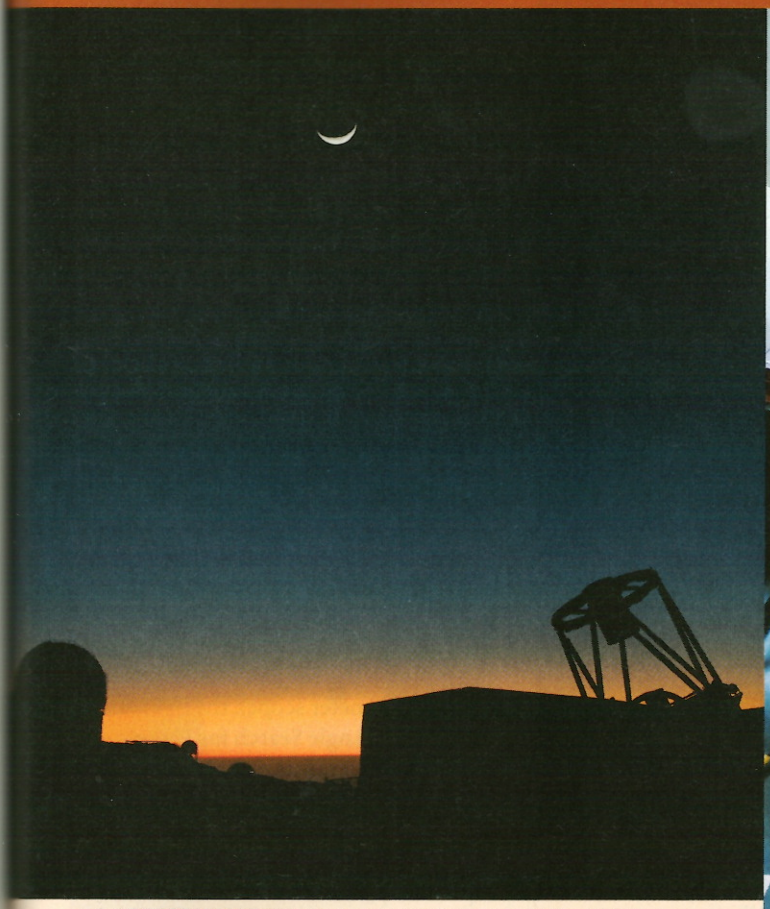
The WHT's multiple focal stations give astronomers greater control over how they use their time at night. It takes only a few minutes to switch between the various focal stations, so astronomers can respond rapidly to, say, a change of weather that requires switching to a backup observing program, or an "override" request for an image of a newly discovered supernova.

For 25 years, the WHT has been one of the most scientifically productive 4-meter telescopes in the world. To maintain its competitive edge, plans are now afoot to build a powerful new camera for it. The WHT Enhanced Area Velocity Explorer (WEAVE) will be a multi-object spectrograph, able to observe up to 1,000 stars and galaxies in a single exposure. After WEAVE sees first light in 2016, the WHT will spend much of its time carrying out surveys of millions of stars and galaxies.

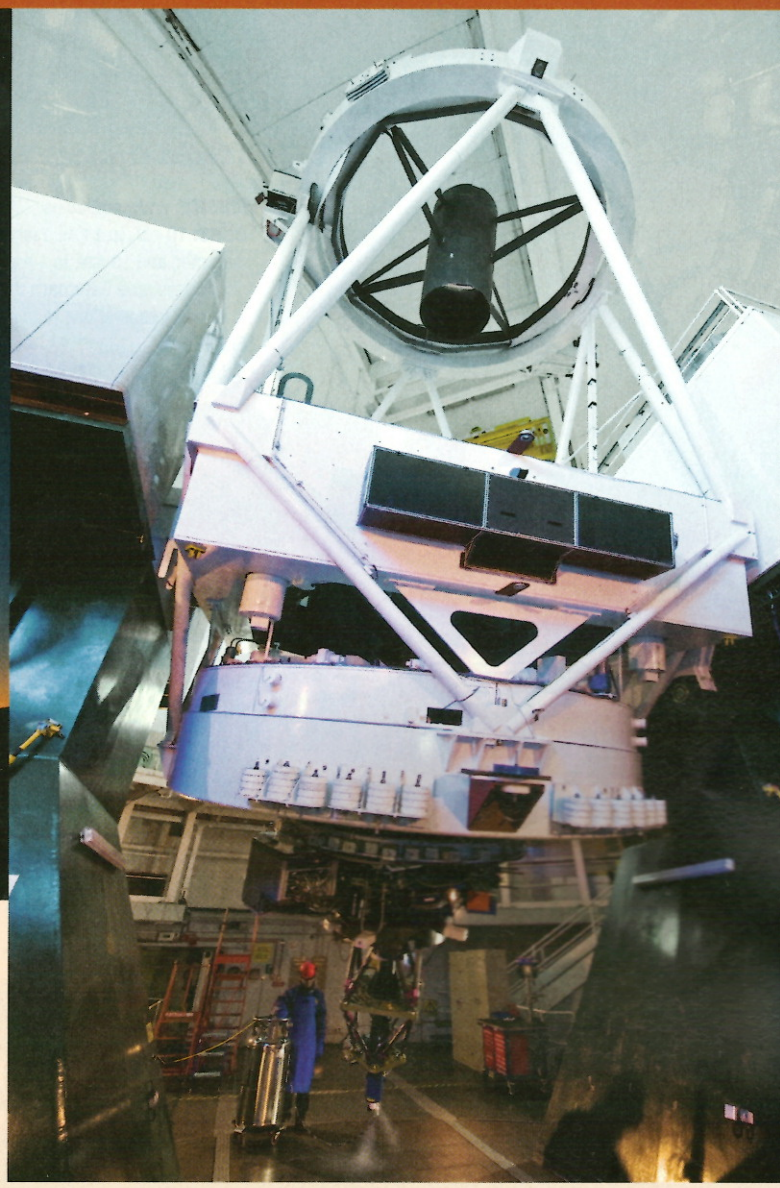
One of the most important of these surveys will complement results from the European Space Agency's upcoming Global Astrometric Interferometer for Astrophysics (GAIA) satellite. GAIA will map the three-dimensional positions of a billion stars in our galaxy, and WEAVE will measure the velocities of a large sample of them. Knowing the current positions and motions of the stars,



THIS DENSE GROUP OF TELESCOPES includes (from left to right): William Herschel, Dutch Open, Liverpool, Swedish Solar, Isaac Newton, and Jacobus Kapteyn. MAX ALEXANDER



▲ **A CRESCENT MOON hangs above the dome of the William Herschel Telescope (left) and the open-truss structure of the robotic 2-meter Liverpool Telescope.** MAX ALEXANDER



▶ **THE 4.2-METER WILLIAM HERSCHEL TELESCOPE was the third largest in the world when it saw first light in 1987 (it currently ranks number 21). Ten years later, it detected the first optical afterglow from a gamma-ray burst.** MAX ALEXANDER

SPIRAL GALAXY NGC 7217 shows tightly wound arms and a ring of star formation in this William Herschel Telescope image. MISCHA SCHIRMER (ING) AND GILLES BERGOND (IAA, GRANADA)

STARBURST GALAXY M82 generates plumes of glowing hydrogen, which appear red in this William Herschel Telescope image. PABLO RODRÍGUEZ-GIL (IAC) AND PABLO BONET (IAC)

William Herschel Telescope

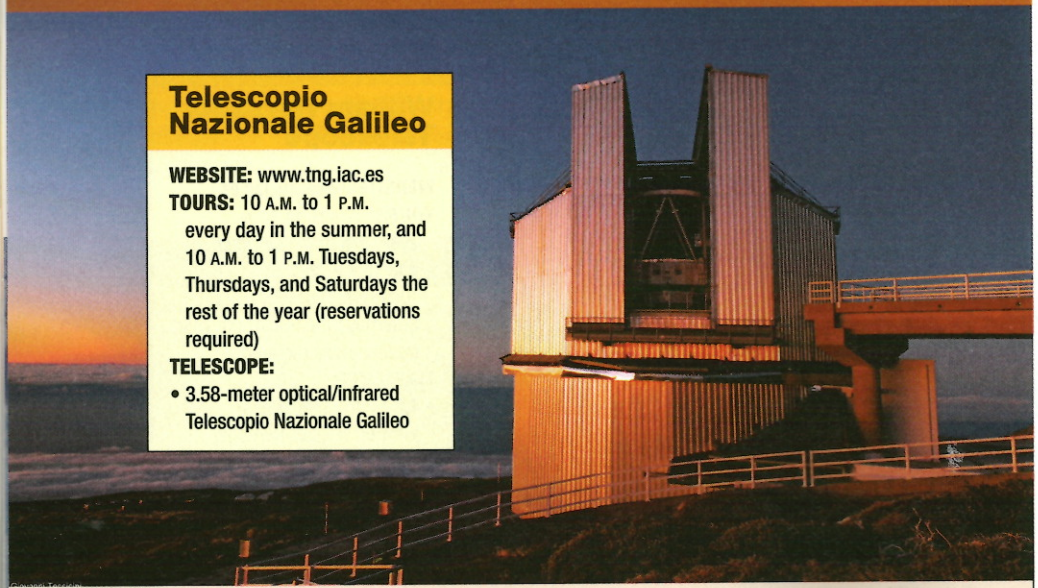
WEBSITE: www.ing.iac.es
TOURS: 10 A.M. to 1 P.M. every day in the summer, and 10 A.M. to 1 P.M. Tuesdays, Thursdays, and Saturdays the rest of the year (reservations required)
TELESCOPE:
- 4.2-meter optical/near-infrared William Herschel Telescope

Nordic Optical Telescope

WEBSITE: www.not.iac.es
TOURS: 10 A.M. to 1 P.M. every day in the summer, and 10 A.M. to 1 P.M. Tuesdays, Thursdays, and Saturdays the rest of the year (reservations required)
TELESCOPE:
- 2.56-meter optical Nordic Optical Telescope

THE 2.56-METER NORDIC OPTICAL TELESCOPE is a collaboration among Denmark, Finland, Iceland, Norway, and Sweden. It sits near the Caldera de Taburiente's summit at a spot known for steady atmospheric conditions. IAC'S PHOTO ARCHIVE

The TNG is named for Italian scientist Galileo Galilei, the first to turn a telescope to the heavens.



Telescopio Nazionale Galileo

WEBSITE: www.tng.iac.es
TOURS: 10 A.M. to 1 P.M. every day in the summer, and 10 A.M. to 1 P.M. Tuesdays, Thursdays, and Saturdays the rest of the year (reservations required)
TELESCOPE:
- 3.58-meter optical/infrared Telescopio Nazionale Galileo

ITALY'S 3.58-METER TELESCOPIO NAZIONALE GALILEO, modeled on Chile's New Technology Telescope, is La Palma's third-largest optical scope. GIOVANNI TESSICINI (TNG)

astronomers can then effectively reverse time and learn the events that led to the Milky Way's current conditions.

The growing family

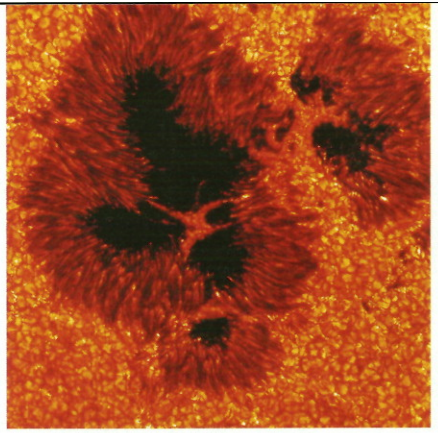
Over the past 30 years, many countries have brought their telescopes to the ORM. Denmark, Finland, Iceland, Norway, and Sweden have operated their 2.56-meter Nordic Optical Telescope (NOT) since its first light in 1988 upon a windswept perch close to the summit, a location renowned for its excellent seeing. A little lower down, the Italians have their 3.58-meter Telescopio Nazionale Galileo (TNG), which saw first light in 1998; it's modeled closely on the European Southern Observatory's New Technology Telescope in La Silla, Chile (see page 44).

Other additions include the British Liverpool Telescope (a robotic 2-meter instrument); the Belgian Mercator Telescope (a 1.2-meter scope); the British Super Wide Angle Search for Planets, or SuperWASP (two sets of eight camera arrays); and the German Major Atmospheric Gamma-ray Imaging Cerenkov array, or MAGIC (two 17-meter gamma-ray telescopes) — not to mention the record-breaking Spanish 10.4-meter, the Gran Telescopio Canarias!

During the day, the twin 17-meter eyes of the MAGIC telescopes gaze sightlessly at the northern horizon. Tourists driving past often slow to a halt to take photos and puzzle over the huge white buildings reflected in each telescope. In fact, there are no white buildings — just 17-meter distortions of the nearby detector boxes at the focus of each dish.

At night, the dishes search for brief flashes of Cerenkov light that signal the impact of gamma rays with Earth's atmosphere. MAGIC can deduce where in the sky the light waves came from, and it studies some of the universe's most energetic and mysterious phenomena, such as supernova remnants and distant quasars.

But deep-sky objects aren't all that the clear, calm skies above La Palma offer astronomers: Conditions are also perfect for studying the Sun. The 1-meter Swedish Solar Telescope (SST) often zooms in on sunspots large enough to dwarf our planet. Thanks to the use of adaptive optics, which cancel out some of the blurring introduced by Earth's atmosphere, the SST delivers



FILAMENTARY SUNSPOTS and solar granulation come to light in this view taken through the Swedish Solar Telescope. MATS LÖFDAHL/ROYAL SWEDISH ACADEMY OF SCIENCES

THE SWEDISH SOLAR TELESCOPE, whose 1-meter primary lens (inside the structure at top) makes it the world's second-largest solar scope, takes exquisitely sharp images of our nearest star. TIM VAN WERKHOVEN

sharper solar images than any other telescope in the world.

All together, the various optical telescopes provide astronomers with an impressive toolkit. Need to monitor the brightness of a star? Just use the Liverpool Telescope. Multi-object infrared spectroscopy? Then you'd want the WHT. The telescopes are nominally national facilities, but in practice most European astronomers can compete for time on the majority of the instruments.

The different national organizations employ a staff of about 170 representing various countries to run the telescopes. They work partly at the observatory and partly in offices in or around the island's main town, Santa Cruz de La Palma. The ORM is a truly international collaboration on all levels.

The neighboring observatory

OBSERVATORIO DEL TEIDE sits on the flanks of 12,000-foot (3,700 meters) Mount Teide on Tenerife, southeast of La Palma in the Canary Islands. IAC'S PHOTO ARCHIVE

Some 87 miles (140 kilometers) southeast of the Observatorio del Roque de los Muchachos lies the 12,000-foot (3,700 meters) peak of Mount Teide on the nearby island of Tenerife. Here, the sky is not as dark as it is above La Palma, thanks to Tenerife's large population and booming tourism industry. But the seeing and transparency are still excellent, and Observatorio del Teide boasts several solar telescopes and some small nighttime telescopes.

The 89-mile (144km) line of sight across the Atlantic Ocean between La Palma and Tenerife islands creates an interesting opportunity for testing various technologies. The most exotic experiment yet took place in 2007 when a team from the University of Vienna transmitted quantum-entangled photons from La Palma to Tenerife, setting a world distance record. These experiments pave the way for secure transmission of encryption keys over distances and other futuristic technology.

King of the mountain

In the mid-1990s, La Palma still lacked an 8- to 10-meter telescope, so the Instituto de Astrofisica de Canarias (IAC) in Tenerife, which operates the ORM, launched a project to build one. The Spanish and Canarian governments initially provided funding, with Mexico and the University of Florida later joining in. It took a while, but first light occurred in July 2007, and science observations at the Gran Telescopio Canarias (GTC) formally began in July 2009 with an inauguration by Spain's King Juan Carlos I.

The GTC's primary mirror measures 10.4 meters, making it the largest single-aperture optical telescope in the world — and it can actually observe infrared light, as well. The mirror, modeled on the successful telescopes at Hawaii's Keck Observatory (see page 18), is made up of 36 hexagonal segments. Each segment is made of a ceramic material famed for its ability to avoid expanding and contracting with changing temperature.

Unlike the WHT, with its paraboloid primary mirror, the GTC's mirror is hyperboloid in shape, allowing for a Ritchey-Chretien telescope design that offers a wider field of view. The secondary mirror is made of beryllium, a lightweight, high-rigidity metal capable of withstanding the rigors of observing in the infrared. Like most modern telescopes, the GTC has an alt-azimuth mount. Its two Nasmyth platforms host its Optical System for Imaging and low Resolution Integrated Spectroscopy (OSIRIS) visual camera, as well as its CanariCam mid-infrared camera.

The Gran Telescopio Canarias saw first light in July 2007, and science observations began 2 years later.

THE MILKY WAY arches above the Gran Telescopio Canarias, whose 10.4-meter mirror makes it the world's largest single-aperture optical telescope. DANIEL LÓPEZ AND THE IAC'S PHOTO ARCHIVE

Gran Telescopio Canarias

WEBSITE: www.gtc.iac.es
TOURS: 10 A.M. to 1 P.M. every day in the summer, and 10 A.M. to 1 P.M. Tuesdays, Thursdays, and Saturdays the rest of the year (reservations required)
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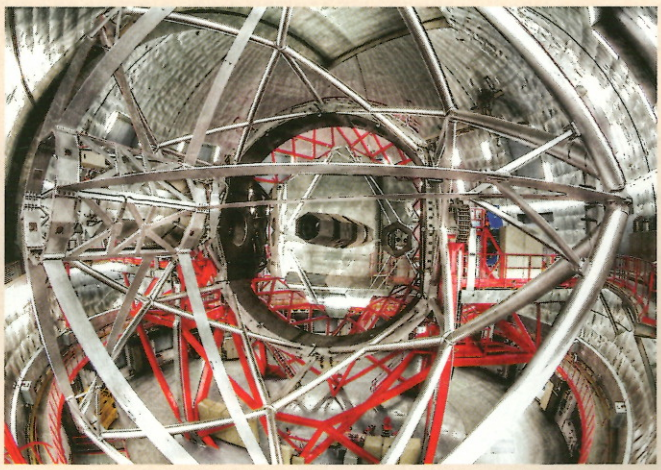


THE HUGE 10.4-METER MIRROR of the Gran Telescopio Canarias consists of 36 hexagonal segments and was modeled after the twin Keck telescopes on Mauna Kea, Hawaii. PABLO BONET AND THE IAC'S PHOTO ARCHIVE

TWIN LOBES OF GAS rush from a hot star embedded in emission nebula Sharpless 2-106, as seen in this shot from the Gran Telescopio Canarias. GRAN TELESCOPIO CANARIAS AND IAC

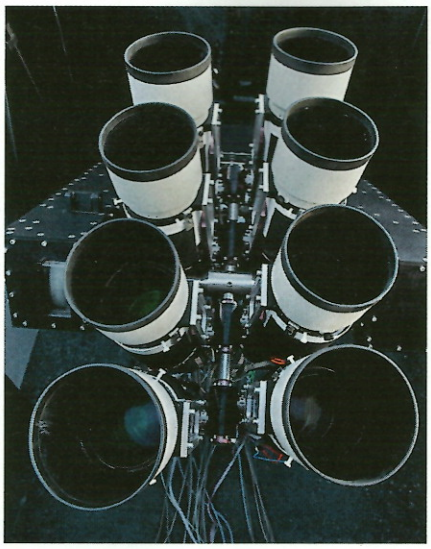
OSIRIS was the first scientific instrument on the scope, and the IAC designed and built it. The camera features tunable filters, devices that transmit a small range of wavelengths. By taking repeated exposures while slowly varying the transmitted wavelength, astronomers can obtain spectra of large regions such as galaxies or nebulae in one go.

The University of Florida produced the CanariCam, which allows astronomers to obtain images and spectra of a specific range of infrared light (wavelengths of 7.5 to 25 microns). Such data is crucial for understanding star formation because the process often takes place within dense molecular clouds that absorb optical wavelengths but allow infrared waves through.

The construction of the GTC proved to be a powerful catalyst for Spanish industry, which handled about 70 percent of the physical labor in building the telescope, dome, and instruments. The telescope's completion is another landmark in the rapid development of Spanish astronomy, which in 30 years has grown from almost nothing to become one of the premier European forces in the field.

The scientific fruits

With such a powerful plethora of telescopes at the ORM, it's no surprise that



THIS EIGHT-CAMERA ARRAY — known as the Super Wide Angle Search for Planets (SuperWASP) — monitors millions of stars in the search for worlds outside our solar system. By the start of 2012, SuperWASP already had nabbed 65 planets. MAX ALEXANDER

many of them should play a powerful role in the advance of astronomy. For instance, the discovery that the expansion of the universe is accelerating — one of the greatest remaining unsolved puzzles in physics — owes a lot to La Palma's telescopes. The two teams of astronomers who won the 2011 Nobel Prize in physics for this discovery made use of the INT, WHT, and NOT to measure the increasingly far-off distances to extragalactic supernovae. This provided the evidence for the existence of a mysterious "dark energy" that somehow accounts for 72 percent of the stuff in the universe, but whose nature remains unknown.

Another of La Palma's contributions to science has to do with one of the biggest enigmas of the 1990s: the nature of gamma-ray bursts (GRBs) — puzzling flashes of light first detected by American satellites checking for evidence of clandestine nuclear tests. Nobody had seen an optical counterpart to a GRB, but such a sight would be crucial to find out how far away they are. Several telescopes at the ORM were part of coordinated campaigns to detect these bursts optically. On February 28, 1997, the WHT struck gold, catching the optical afterglow of a GRB before it faded. Since then, astronomers have detected many more in visible light, and they now suspect that the phenomena are associated with unusually violent star deaths in distant galaxies. Because of their intense brightness, GRBs are visible from incredible distances; Italy's TNG spotted one in 2009 with a record-breaking redshift of 8.1 — about 13.1 billion light-years away.

But not all of La Palma's science successes are extragalactic and energetic. The ORM's SuperWASP is one of the most prolific planet-hunters in the world, watching for regular dips in stars' brightnesses, which happen whenever planets pass in front of them. Many of the ORM's telescopes were useful when it came time to study these transits in more detail, and in 2009, the WHT obtained the first ground-based direct detection of an extrasolar planet in the near-infrared visual spectrum.

The WHT, until 2007 the most powerful telescope on the mountain, has scored many other firsts, obtaining the deepest ground-based image of the sky, the first spectrum of a near-Earth object that subsequently hit our planet, the first optical images of the surface of a star other than the Sun, the first detection of a brown dwarf, and the first strong evidence of black holes in our galaxy. And with the GTC now up and running, who knows what kinds of amazing discoveries the ORM's scopes will make?

The island of La Palma has seen pirate attacks, Spanish conquistadors, scientific breakthroughs, and pioneering astronomers. It's clear that a place with so much history will continue to make more of it for years to come.

Students, visitors welcome

Unlike the national telescopes of yesteryear, most of today's cutting-edge light buckets (such as the ones in Hawaii and Chile [see pages 18 and 44]) lie far away from their users. In addition, time on them is so precious that local staff, or computer programs, do much of the observing, juggling different projects during the night so as to match them to the prevailing conditions. These two factors make it more difficult for young astronomers to get hands-on training at a research telescope.

By contrast, the telescopes on La Palma are relatively accessible, and students are frequent observers. They also get work as support astronomers at both the 2.54-meter Isaac Newton Telescope (INT) and the 2.56-meter Nordic Optical Telescope. The former recruits four students each autumn, who live on La Palma for the next year; they typically spend 40 percent of their time supporting visiting observers at the INT and working on other observatory duties, and the rest of the time pursuing their own research. Outside of work, they get to learn a new language, immerse themselves in the local culture, and explore La Palma's natural wonders. Over the past 10 years, some 40 students from seven different countries have taken part in this popular program.

STUDENTS GET HANDS-ON TRAINING at the Roque de los Muchachos Observatory. Here, two of them help operate the 2.5-meter Isaac Newton Telescope in support of visiting astronomers. ING

Interested tourists are also welcome at the observatory. La Palma receives daily flights from Madrid, Spain, and the larger Canary Islands, and less frequently from other European countries. For details on taking a tour of the facility, visit www.iac.es.