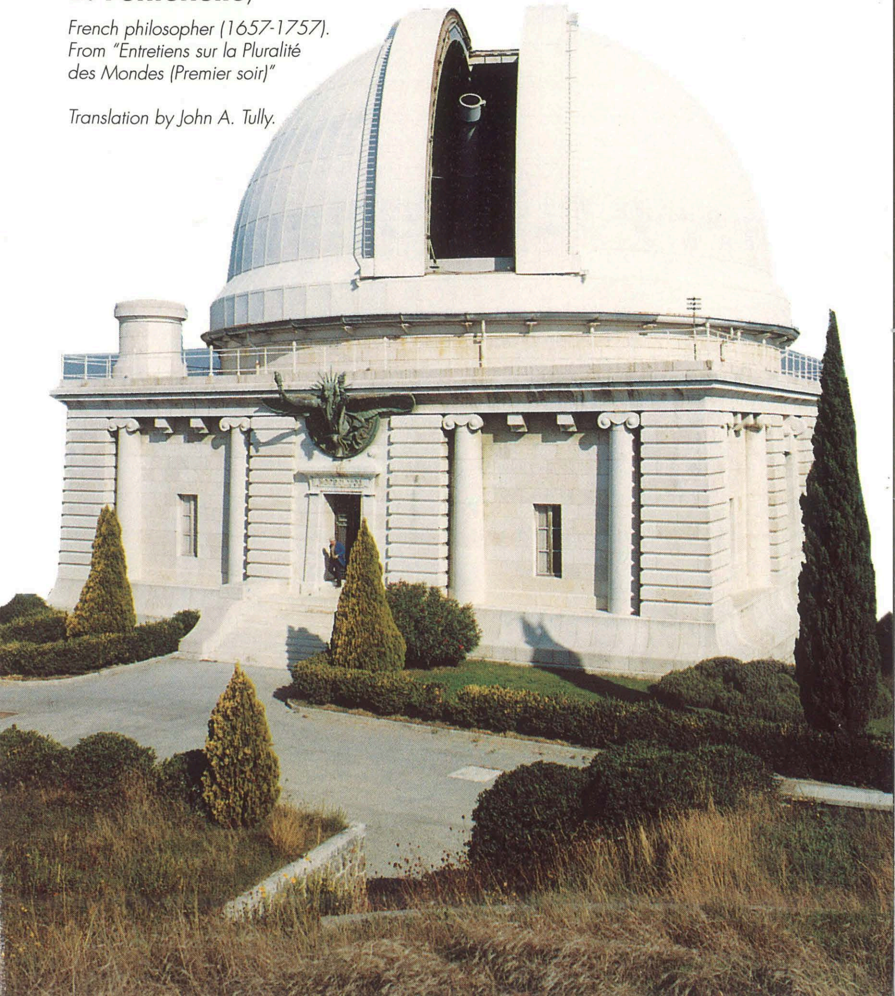
Observatoire de la Côte d'Azur

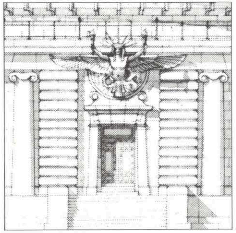
"The whole of philosophy, I told her,
is based on two things,
curiosity and poor eyesight.
For if your eyes were better than they are
you would be able to see whether or not the stars are suns
which illuminate other worlds.
On the other hand, if you were less curious
you would not be bothered to know anyway,
which comes to the same thing.
But one wants to know more than one can see
and that's where the difficulty lies".

***B. Fontenelle**,*

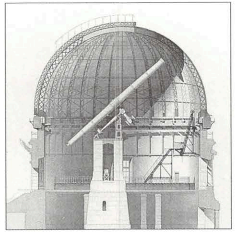
French philosopher (1657-1757).
From "Entretiens sur la Pluralité des Mondes (Premier soir)"

Translation by John A. Tully.

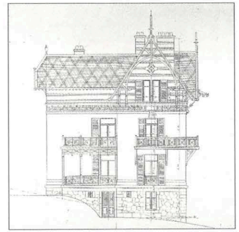




Detail of the main entrance to the large refractor.



Drawing of the large refractor with its supporting pillar and dome.

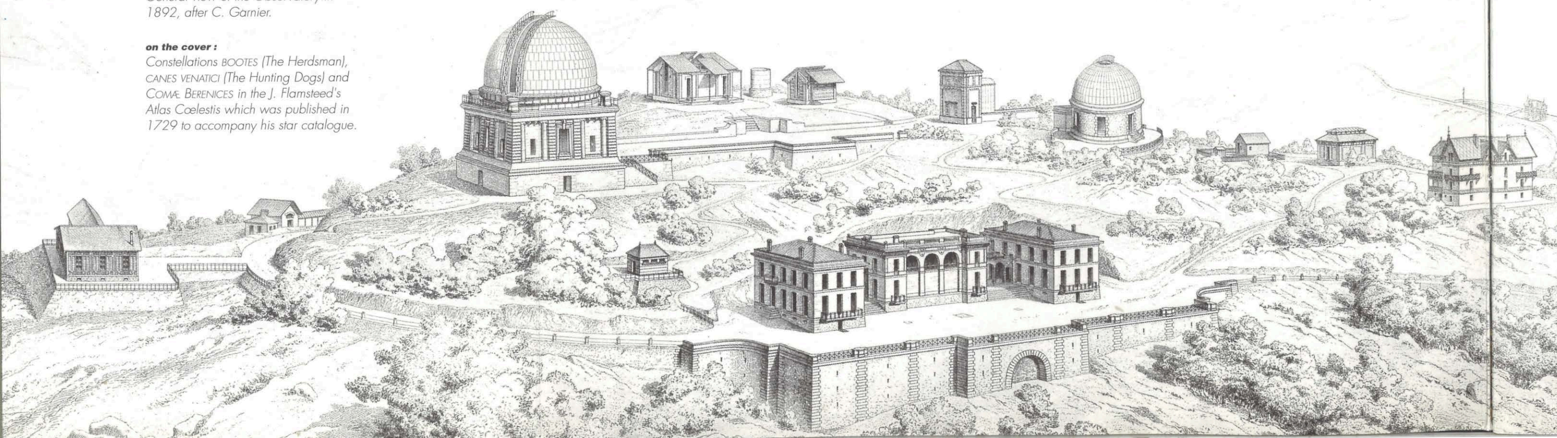


One of the buildings designed by C. Garnier at the close of the last century.

on the flap :
"La Grande Coupole", home of the large refractor at the Observatory of Nice.

below :
General view of the Observatory in 1892, after C. Garnier.

on the cover :
Constellations BOOTES (The Herdsman), CANES VENATICI (The Hunting Dogs) and COMÆ BERENICES in the J. Flamsteed's Atlas Cœlestis which was published in 1729 to accompany his star catalogue.



In 1879 Raphael-Louis Bischoffsheim, a wealthy banker and amateur astronomer, informed the Bureau des Longitudes of his wish to erect a lasting and worthy monument to French Science. By 1881 the summit of Le Mont Gros hill to the east of Nice had been chosen because of its clear sky. Bischoffsheim employed skilled craftsmen to produce optical instruments and the machinery necessary for driving and guiding the refracting telescopes. The observatory was provided with a magnificent library full of scientific works including some complete collections dating back to the XVII century. He asked his friends Charles Garnier and Gustave Eiffel to design the building which was to house La Grande Lunette, the large refractor with a 76 cm objective lens. The enormous dome, whose 24 m diameter exceeds that of the Pantheon, could be rotated easily since it was designed to float in an annular tank of water.

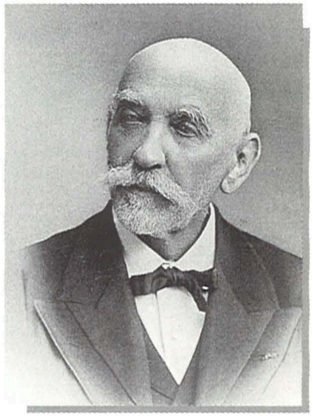
Under the leadership of Henri Perrotin, who directed the observatory until 1904, astronomers on Mont Gros became involved in both positional and physical astronomy. They also made regular meteorological and magnetic recordings. It was during this period that the speed of light was measured and Corsica was linked geodetically to Nice.

In order to strengthen the study of physical astronomy, Bischoffsheim invited the talented young astronomer Henri Chrétien to join the observatory staff. Chrétien was a creative scientist welling over with ideas. During his lifetime he invented some ingenious optical instruments of which the most famous today are the cataphote reflector, the special lenses used in Cinemascope and the combination of mirrors chosen for the Hubble Space Telescope. When Bischoffsheim died the observatory was left, according to his will, to the Sorbonne. It soon became apparent that there was insufficient money to finance the observatory and the First World War marked the beginning of its slow decline.

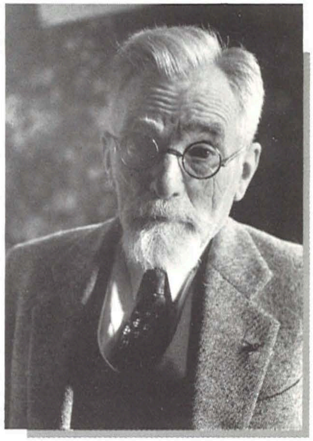
The impetus given to French Science in the early sixties, together with the arrival of Jean-Claude Pecker as director in 1962, signalled the start of a new era. Pecker called upon young astronomers and physicists to collaborate by bringing their observational and theoretical expertise to Le Mont Gros. Instruments were set to work again; Eiffel's dome and the great equatorial refractor it covers were renovated; the library was completely transformed and modernised and so became an asset for the region. The observatory was one of the first laboratories in the South East of France to acquire a digital computer.

In 1974 a new institution known as the CERGA, which means Centre for Geodynamical and Astronomical Study and Research, was created at Grasse by the French government. An observing station specialising in geodynamics and the development of up-to-date equipment for astronomical observations was set up on the Calern Plateau north of Grasse and placed under the directorship of Jean Kovalevsky. Today this centre of research has grown considerably and now hosts new teams of astronomers working with the Schmidt telescope and optical interferometers.

In 1988 the Observatory of Nice, then over 100 years old, became allied to the youthful CERGA to form a single institute : l'Observatoire de la Côte d'Azur.



R.L. Bischoffsheim (1823-1906), founder of Nice Observatory in 1881.



H. Chrétien (1879-1956), astronomer, physicist and inventor.

Measuring distances by laser techniques

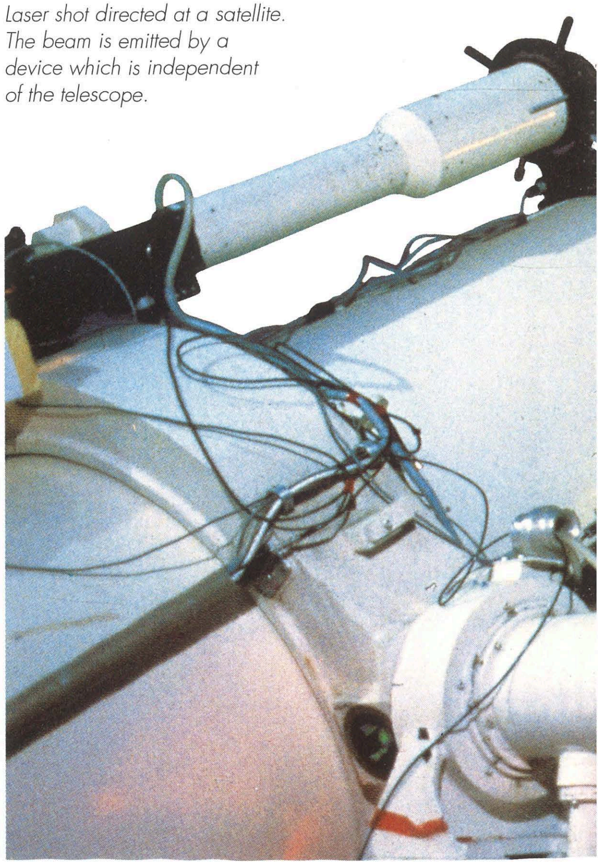
Laser ranged on the Moon by a 1.50 m telescope.

Surveying the Universe was highly esteemed by the ancient Greeks and is still an important activity in modern astronomy. The quest for greater precision is an endless one and each additional decimal place obtained for the Earth's diameter, or distance between Earth and Moon, discloses fine movements and subtle deformations which result from the hidden structure of these well known celestial bodies.

Lasers have revolutionised the technique of measuring distance. One now measures the time interval it takes for a reflected laser pulse to make the round trip to and from a target and from this measurement the distance to the target is calculated. At the Côte d'Azur Observatory laser pulses are aimed at artificial satellites equipped with reflectors and also at the cataphotes which were installed on the Moon by American and Soviet astronauts. The distance between the Earth and Moon is now known to within a few centimetres, and that of artificial satellites with even greater precision.

The light from a laser is ideal for this technique since it can be produced in very short bursts each of which contains a huge number of photons (typically 1,000,000,000,000,000,000 in less than one billion'th of a second). The two lasers on the Calern Plateau operate at about ten shots per second when aimed at satellites or the Moon. The reflected photons are recaptured by telescopes and their arrival time is carefully monitored. Because the lunar reflector is so far away only one photon is recaptured on average out of every 500 laser shots.

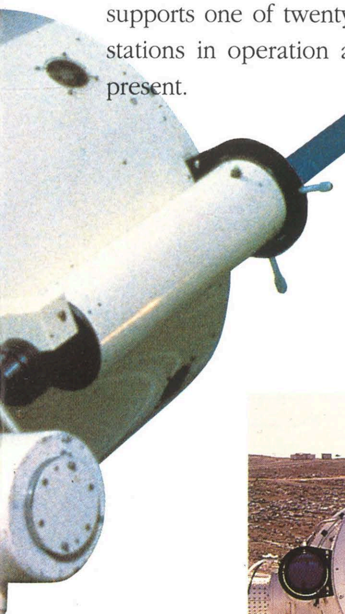
Laser shot directed at a satellite. The beam is emitted by a device which is independent of the telescope.



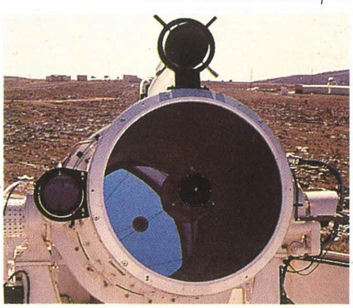
Laser-Satellite and geodynamics

The Earth is only approximately a sphere : not only is it flattened at the poles but its southern and northern hemispheres are not exact copies of each other since it rather resembles a pear. We are able to study the form of the Earth, as well as the movement of continents and the internal constitution of our planet, by carrying out accurate laser measurements of satellite trajectories.

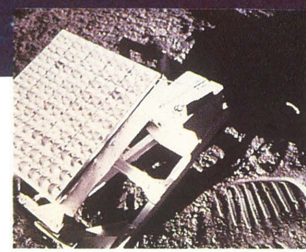
This technique is made possible by having a network of tracking stations conveniently distributed around the world. The Côte d'Azur Observatory supports one of twenty such stations in operation at present.



Front view of the laser-satellite telescope.



Laser-Moon and the theory of gravitation



Laser beam reflector placed on the Moon by astronauts.

The complex motion of the Moon is the result of attractive forces between the Earth, Moon and Sun. Precise measurements of the distance between the Earth and Moon allow gravitational theories to be tested. Measurements carried out for more than 20 years in Texas and on the Calern Plateau have resulted in certain theories being discarded whereas Einstein's General Theory of Relativity has not been challenged.

The Côte d'Azur Observatory acts as the Laser-Moon Co-ordination Centre for the International Earth Rotation Service. This centre co-ordinates the exchange of information and data needed for the technological development and scientific application of Laser-Moon Telemetry.

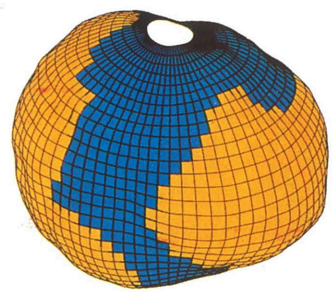
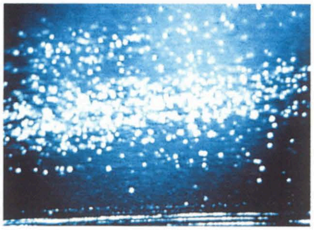


Figure representing the Earth. The undulations are magnified 100,000 times compared to the radius.

The dimensions of stars

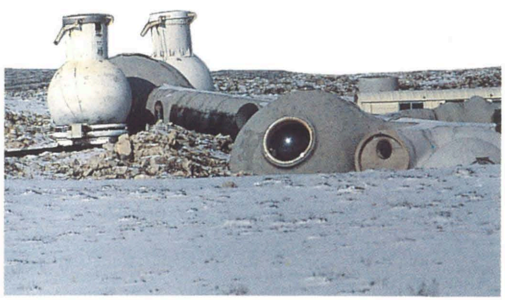


Interference fringes obtained by pointing two telescopes at the star γ Cassiopeiae.

One needs to know the size of a star in order to understand how the stellar machine works. Astronomers only measure angular dimensions with their telescopes, that is to say the area traced out on the sky by a celestial object. From this it is easy to deduce the true size of a star if its distance is known.

Stars are certainly gigantic but are so far away that they look to us no bigger than a pea does at a distance of 1000 km. In theory it should be possible to see the disc of a star with a telescope having a mirror that measures several hundred metres across; but to make such a telescope is a technological challenge which is unlikely to be taken up for many years to come.

One way of dealing with the problem is to use interferometry, which involves aiming two (or more) telescopes at the same star.



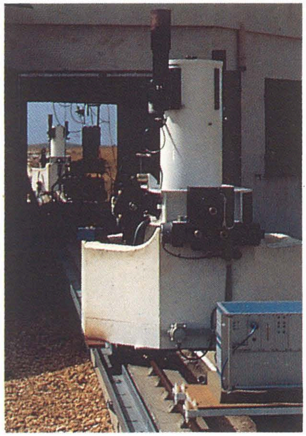
A pair of telescopes mounted in ciment bowls on the Calern Plateau

What matters now is not the diameter of the telescopes but the distance separating them. Thus two fairly small ground based telescopes which are 100 metres apart can detect the same sort of detail as a single 100 metres telescope would if placed outside the Earth's atmosphere. But there is a drawback, for although an interferometer can show up more detail than a single large telescope, the amount of light it collects is less. So an interferometer is not a substitute for a big telescope but rather a complement. Its purpose and performance are quite different and in particular it can only be used to observe the brightest stars.

The Great Nebula in Orion.

By allowing the light from both telescopes to mix one obtains an interference pattern of bright and dark fringes. There is an ideal separation of the telescopes, related to the angular diameter of the star being observed, for which the fringes disappear. The pair of telescopes are mounted on a portion of railway track about 200 metres long and in this way they can be easily moved during an observation until the fringes vanish.

There are some very bold projects underway which aim at putting interferometers into space. These will be situated several hundreds of kilometres apart in order to make out details on the surfaces of stars and also to detect very tightly bound double stars and new planetary systems.

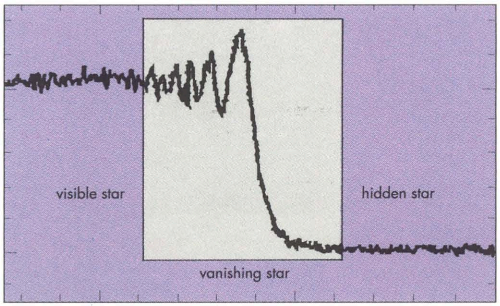


General layout of the small interferometer on the Calern Plateau.

Lunar occultations

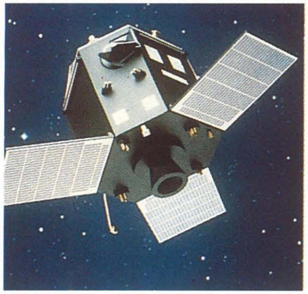
Because of its movement the Moon is continually passing in front of stars and blocking out their light for anything up to two hours.

The time it takes for a star to disappear behind the Moon is extremely brief, being less than a tenth of a second. By rapidly recording the event at around 1000 measurements a second one finds that the starlight actually fluctuates before becoming completely extinguished. The size of the star determines the shape of these fluctuations and astronomers know how to interpret the curve and so find the size as long as the star is bright enough.

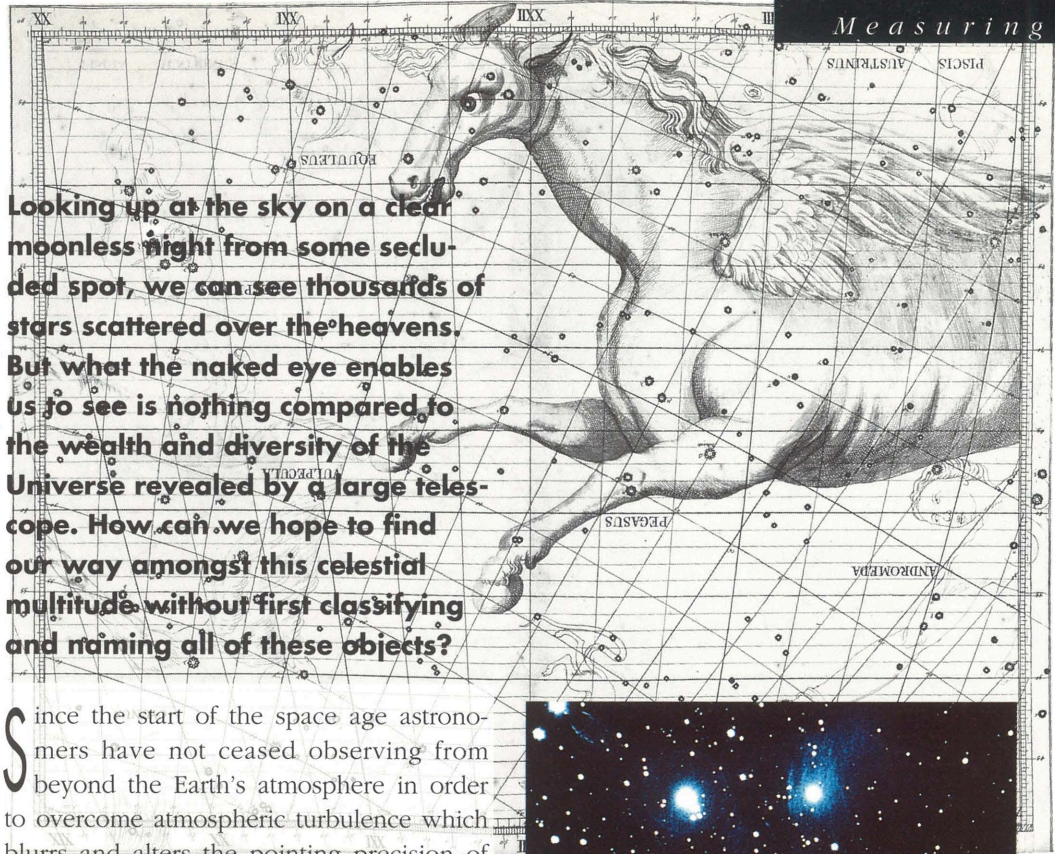


Variation of the light from a star as it vanishes behind the Moon. The grey part lasts only a tenth of a second.

Where are the stars?

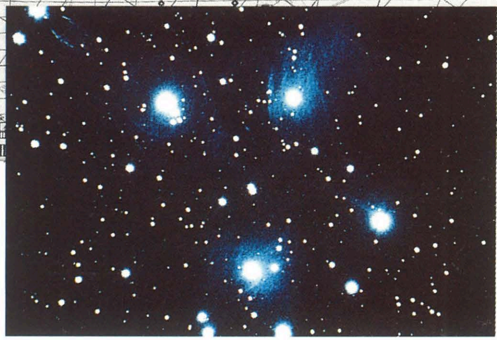


The European satellite Hipparcos, launched in August 1989 by an Ariane rocket.



Looking up at the sky on a clear moonless night from some secluded spot, we can see thousands of stars scattered over the heavens. But what the naked eye enables us to see is nothing compared to the wealth and diversity of the Universe revealed by a large telescope. How can we hope to find our way amongst this celestial multitude without first classifying and naming all of these objects?

Since the start of the space age astronomers have not ceased observing from beyond the Earth's atmosphere in order to overcome atmospheric turbulence which blurrs and alters the pointing precision of telescopes. The satellite HIPPARCOS was launched in August 1989 and is now revolving around the Earth above us at an altitude which varies between 500 and 36,000 kilometres. The telescope it carries is observing continuously in order to monitor the position, distance and brightness of 118,000 stars in our galaxy. The final results of this remarkable space mission will not be available until 1995, by which time computers will have finished analysing the massive amount of data produced by the detectors on board the satellite. Two thousand years after the Greek astronomer Hipparchus constructed his famous list of stars, a new stellar catalogue of unequalled precision will become available for astronomers all over the world to use. HIPPARCOS is a cooperative European mission run by the European Space Agency (ESA). The Côte d'Azur Observatory houses the Co-ordination Centre for one of two groups which are preparing and carrying out all the calculations needed prior to publication.



The well known Pleiades star cluster in the Taurus constellation.

above right

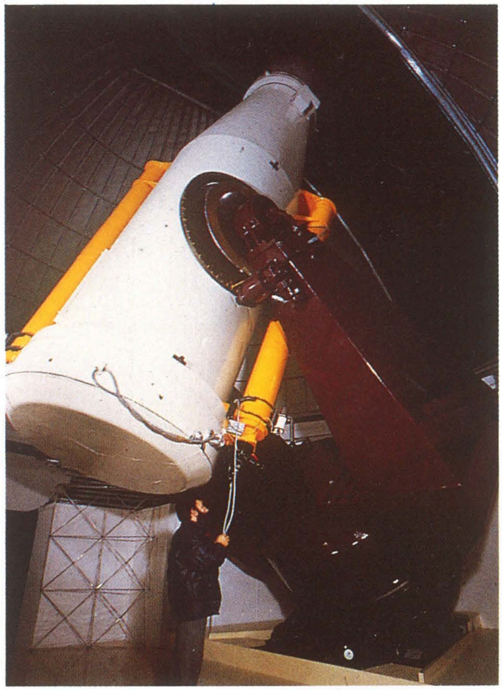
The constellation Pegasus from J. Flamsteed's Atlas Coelestis (1729).

Matter in the Universe

The material comprising the Universe is assembled into galaxies which are formed from myriads of stars, gas and dust. To inventory and identify all of this material is a long-term task which ought to lead to a better understanding of how the Universe was formed.

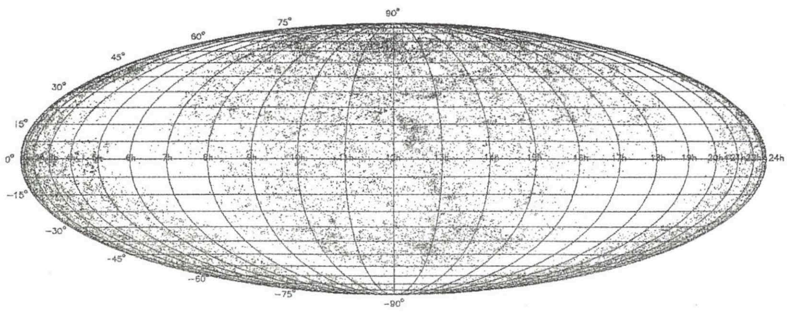
Galaxies are detected on photographs of the sky having a large field of view taken with a Schmidt telescope like the one installed on the Calern Plateau. Each plate contains several hundred thousand images of objects (stars, galaxies, comets, asteroids and artificial satellites) which have to be sorted in order to extract the information one wants. Some astronomers at the Côte d'Azur Observatory have developed software which enables galaxies to be detected entirely automatically from amongst all the images on a plate. Once it has been isolated from the others the object is identified, measured and catalogued.

The counting of galaxies together with other types of observation provides evidence of large scale structures in the Universe whose origin is one of the great enigmas of contemporary cosmology.



The Schmidt telescope at Calern.

Cluster of distant galaxies in Virgo.

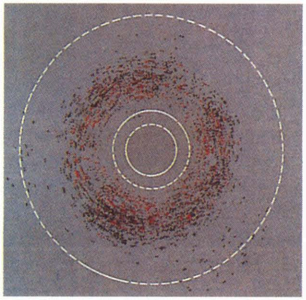


Distribution of galaxies over the celestial sphere.

The techniques of image processing have applications far beyond those of astronomy, for example in the analysis of medical images. A regional collaboration in this field of research has become possible because of the supercomputer installed at Sophia Antipolis in the National Institute of Research in Computer Science and Robotics. (The institute is known by its French acronym INRIA.) The computer is a new generation machine which has 16,384 parallel processors. Access to it, in particular from the Côte d'Azur Observatory, is by an ultra highspeed network called the High Tech Highway (La Route des Hautes Technologies).

Movement in the Universe

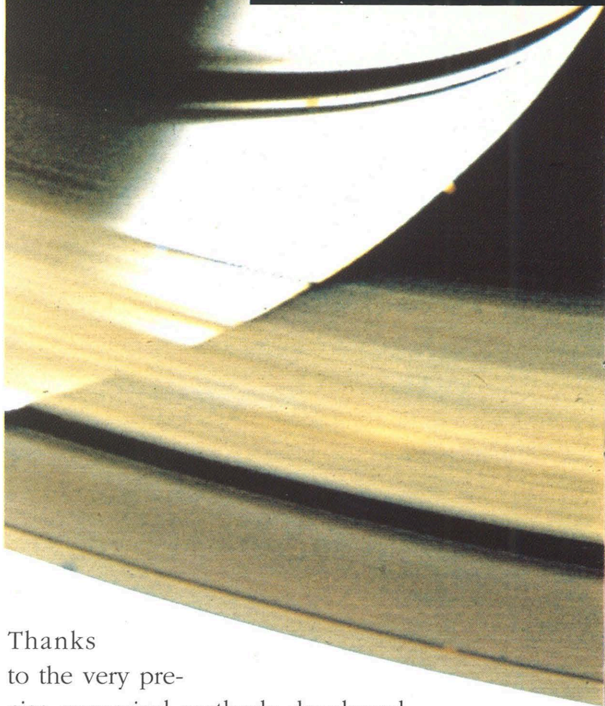
Newtons's celebrated Law of Universal Gravitation allows one to predict easily the movement of two interacting bodies. But this is no longer true for three or more bodies, in which case the movement becomes very complicated and even chaotic as the mathematician Henri Poincaré pointed out towards the end of the last century.



Distribution of asteroids as determined by the infrared astronomical satellite IRAS.

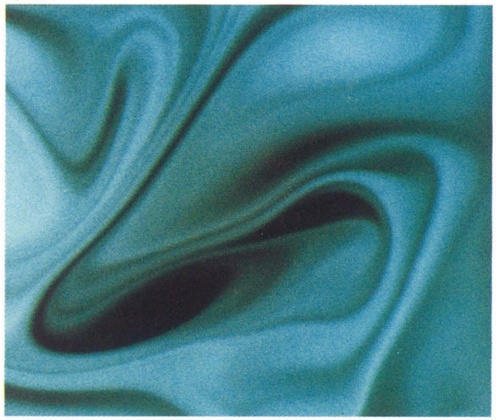
The solar system with its nine major planets and multitude of small bodies of varying sizes comprising dust, grains, rocks, mini-planets and comets, offers a splendid environment for the study of chaotic phenomena which are found moreover in many other disciplines such as chemistry, biology and economy.

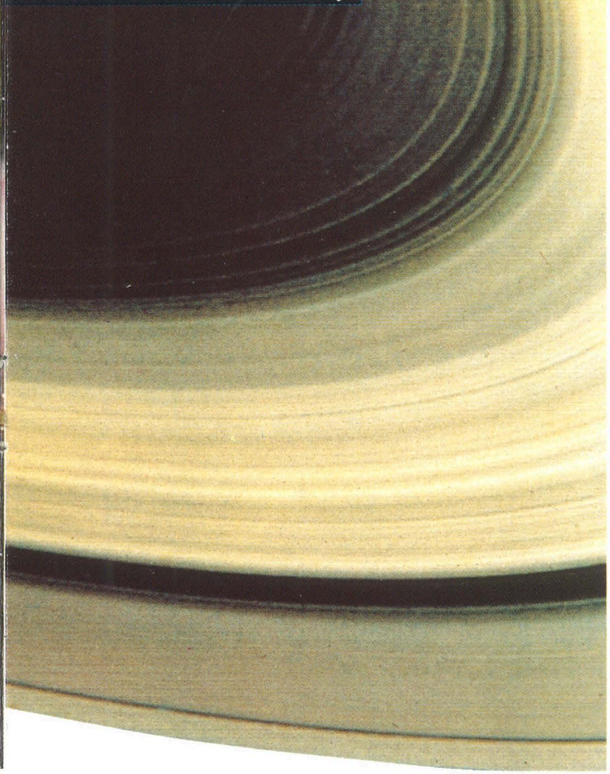
Take the asteroids for example : thousands of them have been counted in the "belt" they occupy between Mars and Jupiter. They hurtle round the Sun in very irregular orbits owing to the combined effects of the Sun and planets. As for planetary rings, why these consist of debris varying from tiny particles of dust to huge chunks of rock weighing several tons which are frequently bashing into each other. All these complex movements are no doubt responsible for the band-like structures which can be seen both in the asteroid belt and in the rings around planets.



Thanks to the very precise numerical methods developed during the past twenty years, especially at the Côte d'Azur Observatory, the origin of the bands has been partly explained, although many puzzling features still remain.

Numerical simulation of turbulent flow displayed on a computer screen.

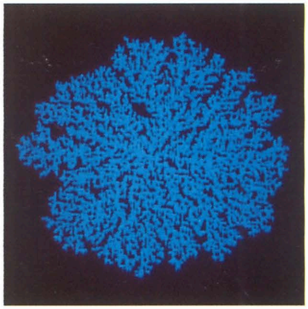




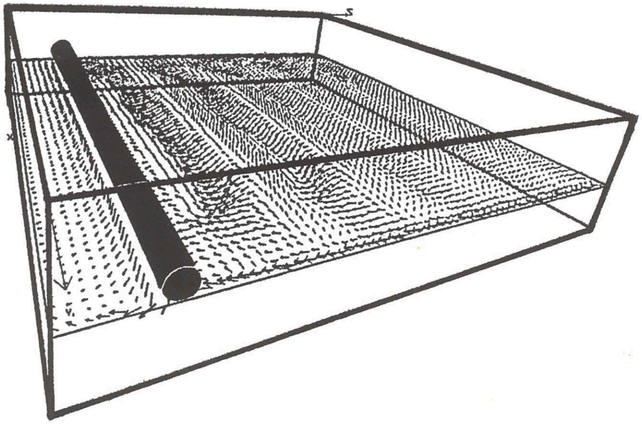
Saturn's rings as seen by the space probe Voyager.

Gravitational force also controls the movement of fluids such as the flow of water in a river, or that of gas in stars and the atmospheres of planets. Often the flow appears to be turbulent and full of eddies.

All sorts of mathematical tools are used to try and understand and predict the behaviour of turbulent motion. Pioneering research at the Côte d'Azur Observatory has been involved in the numerical simulation of such movements. In one method the fluid is approximated by millions of tiny fluid cells and their movement is followed with the help of supercomputers which can be accessed from the observatory via cable and satellite links. An alternative approach, which is ideally suited for use on parallel computers and has been developed in collaboration with many laboratories abroad, consists of representing the fluid by a network of fictitious molecules (up to a billion of them) which are constrained to move along the network mesh while obeying certain rules derived from classical mechanics. Because of the scientific and technological interests, applications of this method extend well beyond its use in astronomy.

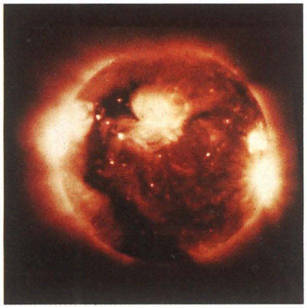


Numerical simulation of fractal growth.



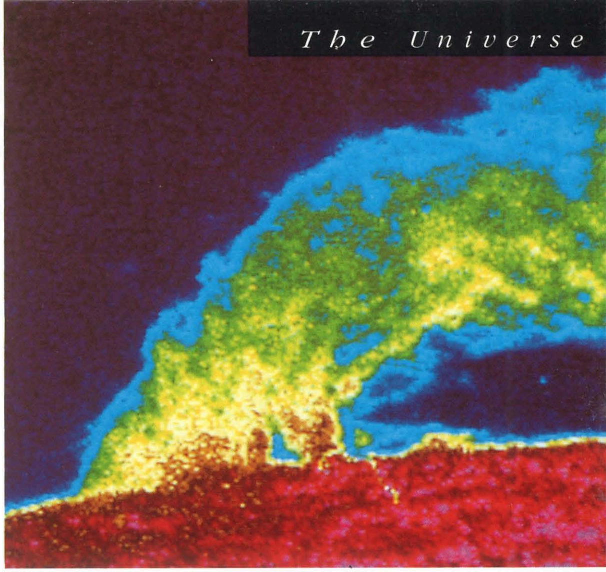
Numerical simulation of a fluid flowing around an obstacle

What is going on inside the sun?



The Sun as it appears at X-ray wavelengths.

At the centre of the Sun a 15 million degree nuclear furnace provides energy in the form of photons which propagate at the speed of light. In the less dense outer layers energy is transported towards the surface by the upsurging of huge gas bubbles : this is convection. Photons from the Sun's core are absorbed and re-emitted many times so that their journey outwards lasts millions of years. Only those which are emitted by a thin layer at the surface called the photosphere can reach us directly.



The Sun vibrates just as a musical instrument does and the frequencies of all those waves travelling beneath its surface, some as far as the centre, depends on the composition and structure of the solar material. Each wave which reaches the surface brings evidence about the depth of the convection zone, the speed with which internal layers are rotating, the temperature of the interior, etc. These vibrations cause the Sun's surface to rise and fall by between 10 cm and several metres which,

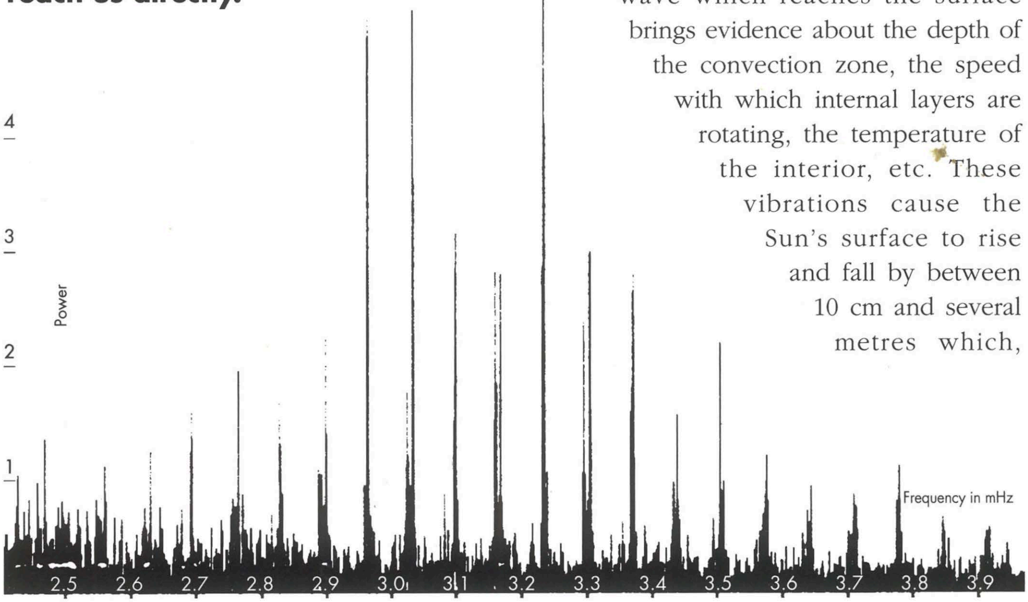
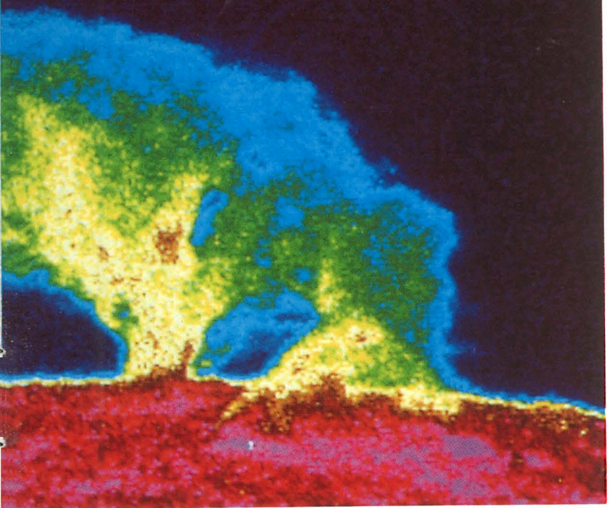


Diagram of the Sun's 5 minute vibrations as measured at the South Pole.

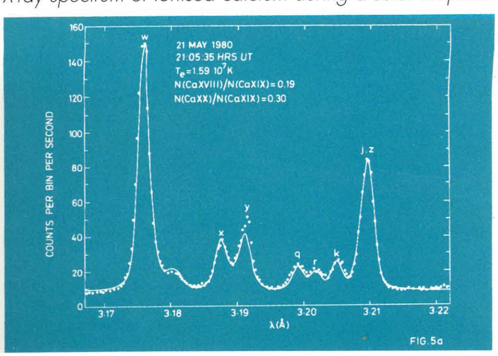


An archway of hot gas above the surface of the Sun.

compared to the 700,000 km radius, is very small indeed. The vibrations have closely spaced frequencies and in order to separate them one needs to observe the Sun continuously for several days on end.

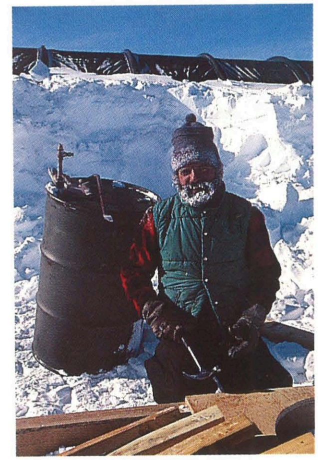
A team from the Astrophysical Laboratory at Nice University, in collaboration with astronomers of the Côte d'Azur Observatory, succeeded in making the first ever continuous observation of the Sun by installing their equipment at the South Pole. Members of the team are now engaged in setting up an international observation network in order to keep track of the Sun from readily accessible locations scattered around the World. Within a few years a satellite belonging to the European Space Agency will take over the task of continuously monitoring the Sun's vibrations.

X-ray spectrum of ionised calcium during a solar eruption.



Material which cannot be seen by the naked eye extends far beyond the solar disc and forms what is known as the solar corona. This tenuous mantle of hot gas emits an abundance of X rays which can be captured and detected only in outer space. It is from here that observations have shown just how complex and rich this outer region is. Material is seen to be trapped in great loops of magnetic field; enormous dark regions called coronal holes exist through which streams of electrically charged particles pour out into the interplanetary medium. A few days after emerging from the Sun these streams give rise to the Aurorae Borealis as well as perturbing radio communications. There are also enormous eruptions which eject solar material out to distances of up to 500,000 kilometres.

Atomic physicists at the Côte d'Azur Observatory are participating in the analysis of X-ray radiation from these eruptive zones in order to determine the temperature, which is of the order of tens of millions of degrees, as well as the density, chemical composition and speed of the gas.



At the South Pole you have to do everything yourself ... with a smile.

L'Observatoire de la Côte d'Azur (OCA) is a government institute which comes under the Ministry for Higher Education. It is divided into three scientific departments which are supported by the CNRS (National Centre for Scientific Research). The Observatory is spread over three sites in the Maritime Alps. These cover 1000 acres on the Calern Plateau near Grasse and 90 acres on Le Mont Gros in Nice.

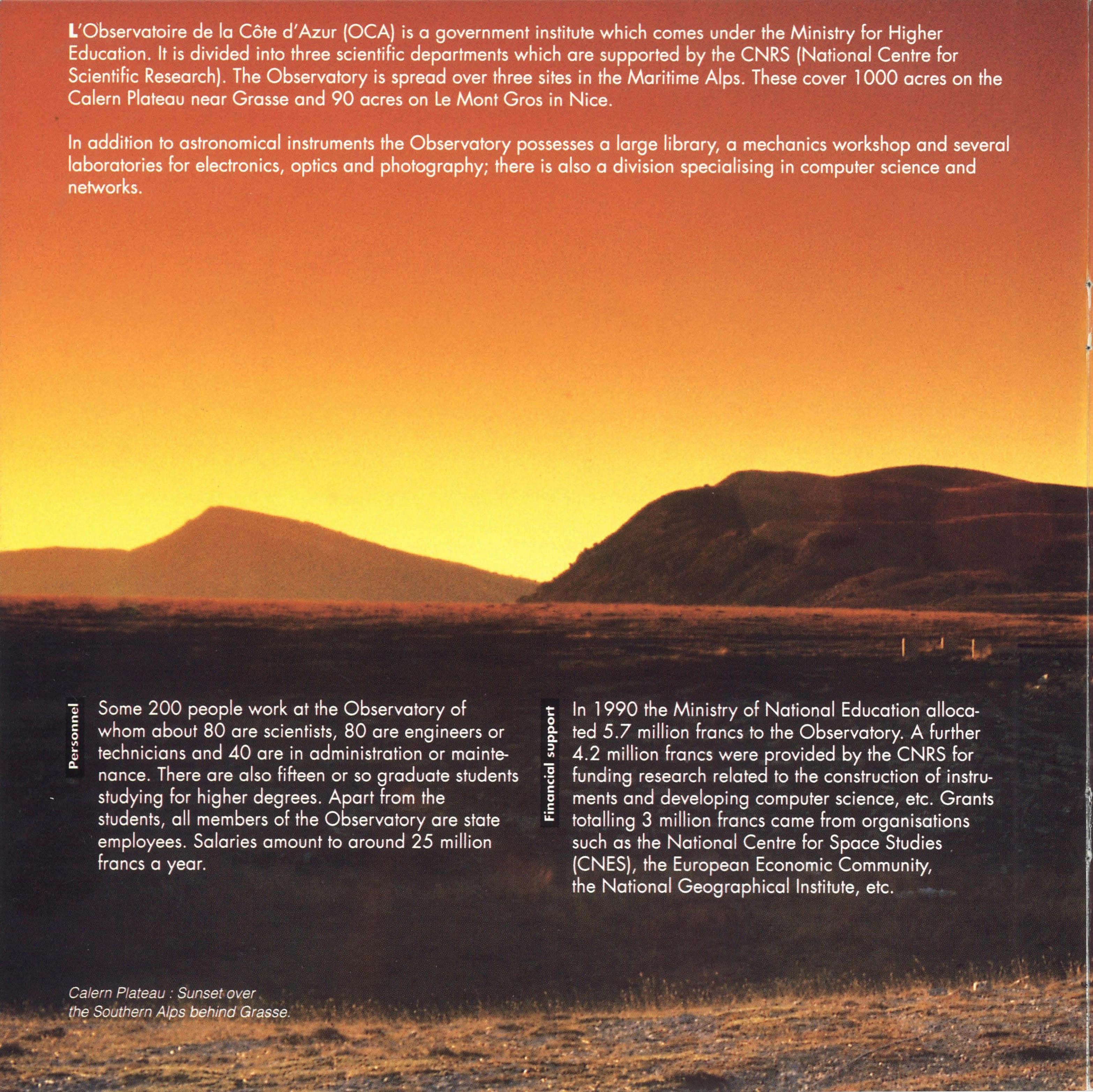
In addition to astronomical instruments the Observatory possesses a large library, a mechanics workshop and several laboratories for electronics, optics and photography; there is also a division specialising in computer science and networks.

Personnel

Some 200 people work at the Observatory of whom about 80 are scientists, 80 are engineers or technicians and 40 are in administration or maintenance. There are also fifteen or so graduate students studying for higher degrees. Apart from the students, all members of the Observatory are state employees. Salaries amount to around 25 million francs a year.

Financial support

In 1990 the Ministry of National Education allocated 5.7 million francs to the Observatory. A further 4.2 million francs were provided by the CNRS for funding research related to the construction of instruments and developing computer science, etc. Grants totalling 3 million francs came from organisations such as the National Centre for Space Studies (CNES), the European Economic Community, the National Geographical Institute, etc.



Calern Plateau : Sunset over the Southern Alps behind Grasse.

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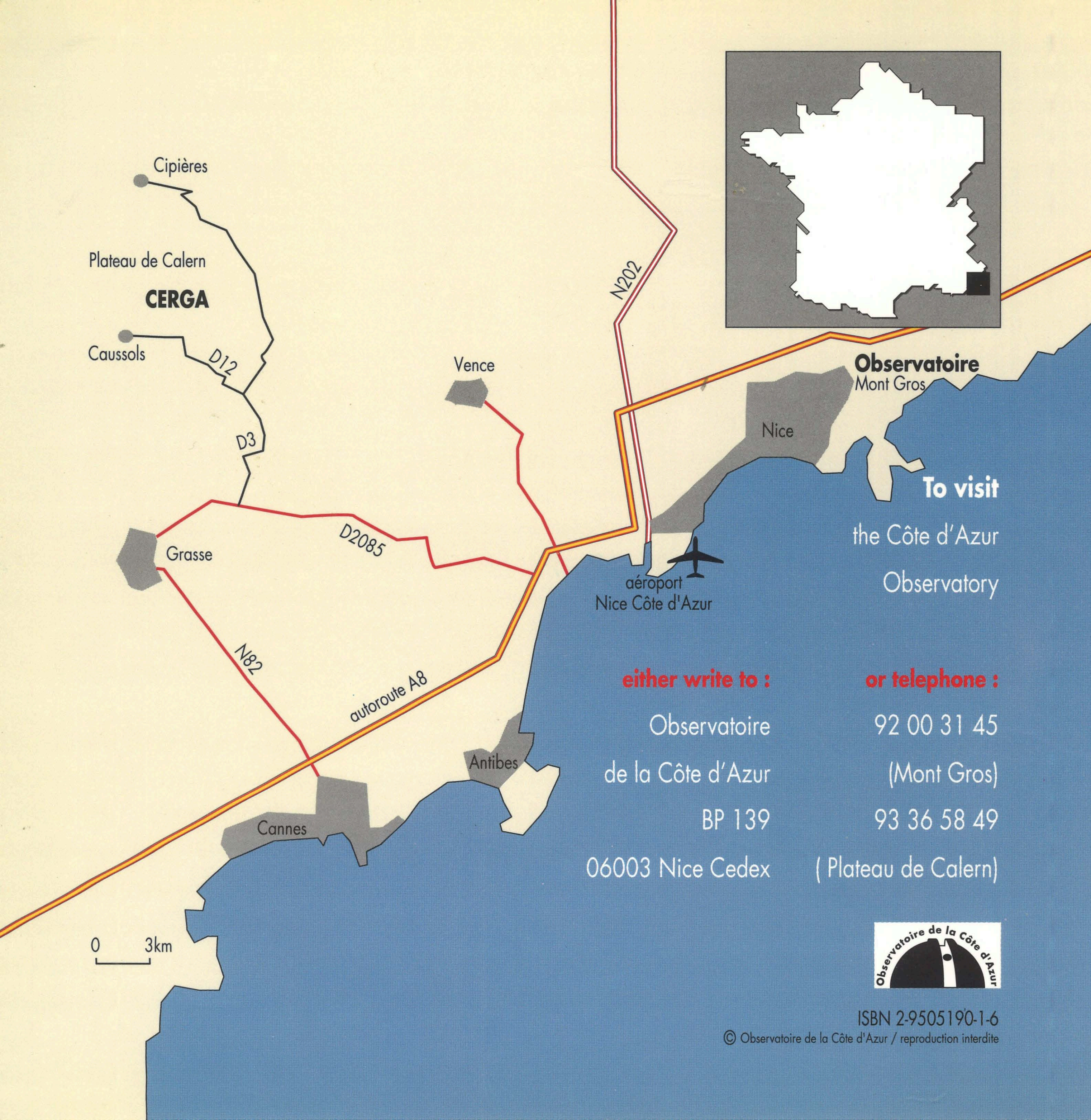

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