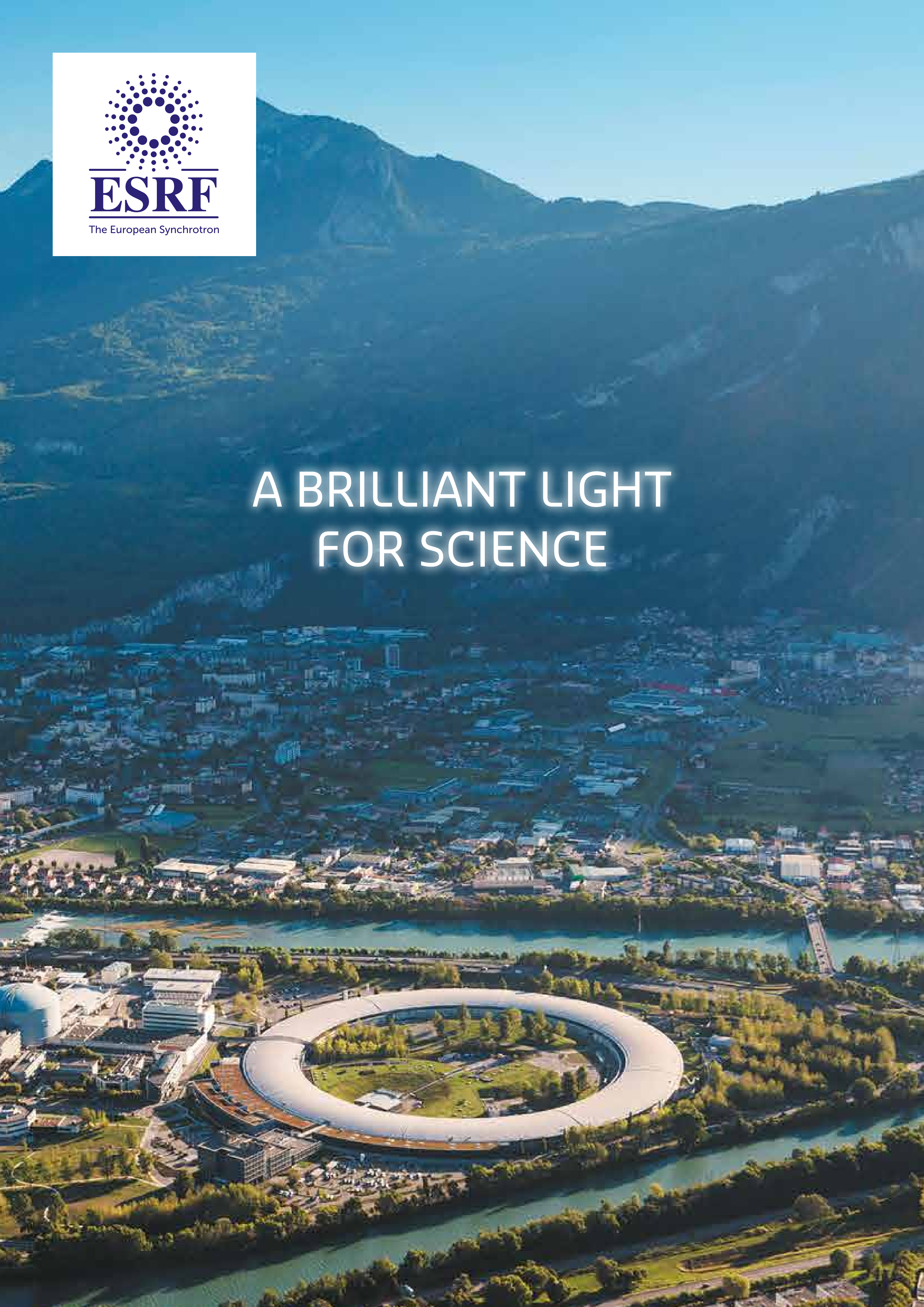
ESRF

The European Synchrotron

A BRILLIANT LIGHT FOR SCIENCE



Located in Grenoble, France, the European Synchrotron Radiation Facility (ESRF) is a shining light on the international research scene. Every year, the ultra-intense X-ray beams produced at the ESRF attract thousands of research scientists from both academic institutions and industry.

THE MOST INTENSE SYNCHROTRON LIGHT SOURCE IN THE WORLD

A unique research facility

Imagine a source that produces X-rays 100 billion times brighter than the X-rays used in hospitals, X-rays that allow us to fathom the structure of matter down to the minutest detail, at the atomic level. Imagine no further! X-rays with these outstanding properties really do exist. They can be found at the ESRF, where they are produced by the high-energy electrons that race around the institute's emblematic "storage ring", an accelerator of impressive proportions.

Working like a giant microscope, the ESRF offers unparalleled opportunities to explore materials and living matter.

A benchmark for science and innovation

Supported by 21 partner countries, the ESRF is the most intense source of synchrotron light. Inaugurated in 1994, the ESRF is an international centre of excellence for fundamental research with a strong commitment to applied and industrial research.

With its 43 highly specialised experimental stations, known as "beamlines", each equipped with state-of-the-art instrumentation, the ESRF offers scientists an extremely powerful research tool that is constantly being upgraded.

Its strength also lies in bringing together in one facility multidisciplinary teams involving some of the world's best scientists, engineers and technicians.

Every year, thousands of scientists come to Grenoble to conduct experiments at the ESRF's beamlines, which operate 24 hours a day, seven days a week.

GETTING TO THE HEART OF MATTER

Unlocking the secrets of matter

What is our planet made of? How much do we know about the processes that sustain life? How can we explain the properties of matter? Will we be able one day to fight cancer more effectively and develop better targeted drugs? To produce renewable materials that are more efficient? To invent new electronic components? To tackle pollution more successfully? None of these questions can be answered without a thorough understanding of the fundamental structure of matter. This is the challenge that drives the research conducted at the ESRF. Thanks to the brilliance and quality of its X-rays, the ESRF provides invaluable insight into the atomic and microscopic structure of matter in all its complexity.

The extreme brilliance of synchrotron X-rays

In visible light and with the help of an optical microscope, it is possible to observe objects the size of a microbe. However, to be able to "see" atoms, which are 10 000 times smaller, we need light with a very short wavelength. In other words, we need X-rays. The extreme brilliance of the X-ray beams produced at the ESRF opens up new fields of application, making it possible, for example, to explore nanoscopic samples and to study chemical and biological reactions on extremely short time scales and in complex environments.

21 partner countries *

13 Member States:
- France: 27.5%
- Germany: 24%
- Italy: 13.2%
- United Kingdom: 10.5%
- Russia: 6%
- Benesync (Belgium, the Netherlands): 5.8%
- Nordsync (Denmark, Finland, Norway, Sweden): 5%
- Spain: 4%
- Switzerland: 4%

8 Associate countries:**
- Israel: 1.5%
- Austria: 1.3%
- Centralsync (Czech Republic, Hungary, Slovakia): 1.05%
- Portugal: 1%
- Poland: 1%
- South Africa: 0.3%

* The legal status of the ESRF is a non-profit private civil company subject to French law

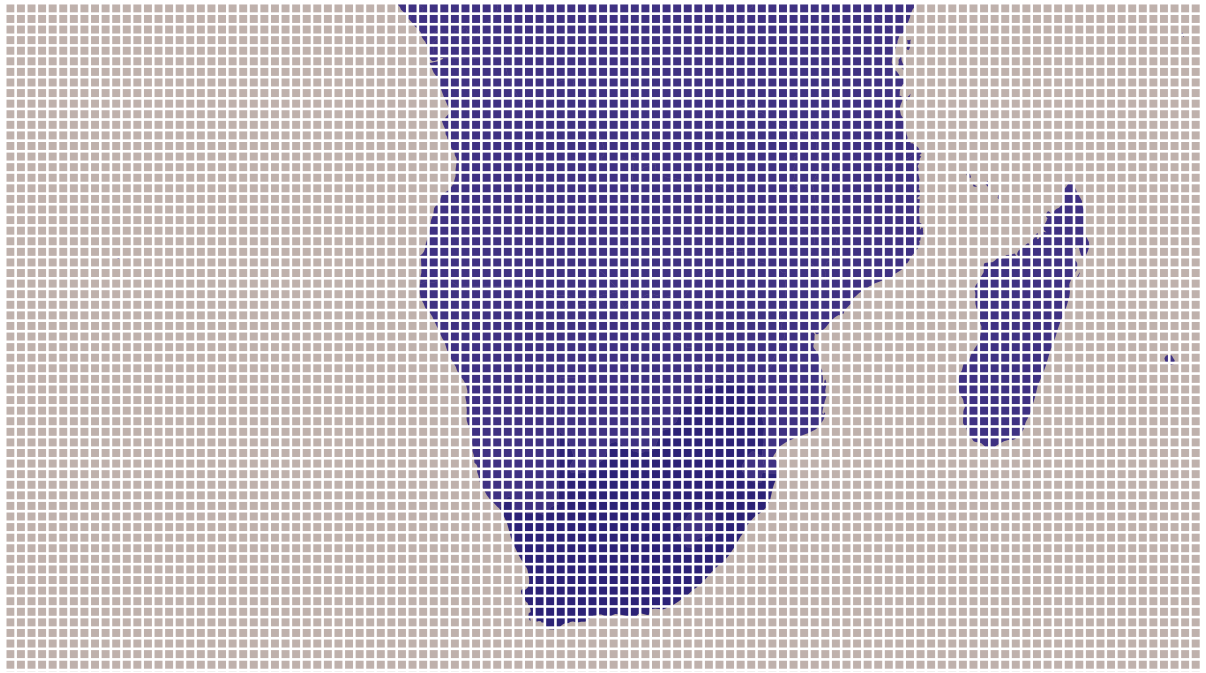
** % of total Members' contributions

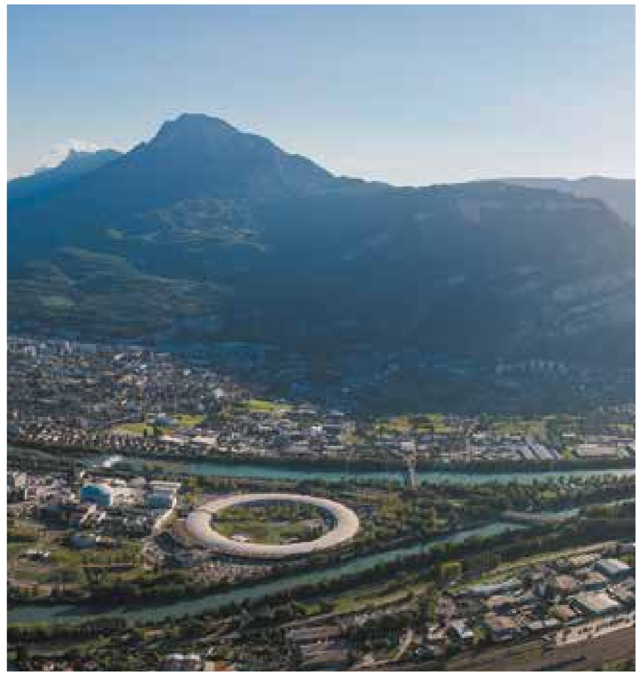
A SHINING EXAMPLE OF INTERNATIONAL COOPERATION

An international vision

In 1988, twelve European countries joined forces to build the biggest synchrotron in the world. This visionary project has made an outstanding contribution to the excellence of European science. Almost thirty years later, the ESRF is a world reference, developing technologies which benefit other synchrotrons. Its user community extends to several thousand scientists from all over the world and continues to grow.

Today the ESRF is a model of international cooperation, with 21 partner countries all driven by the same quest for excellence, the same desire to find solutions to the major technological, economic, societal and environmental challenges facing the modern world.





World-class staff for world-class users

The ESRF is at the forefront of X-ray science with a record number of publications in scientific journals: more than 25 000 reference articles in the last two decades. That's almost 2 000 a year!

In 2009, in keeping with its firm commitment to innovation and to scientific and technical excellence, the ESRF embarked upon an ambitious modernisation programme – the Upgrade Programme. To meet this challenge, the ESRF is able to draw on a world-class workforce offering a unique concentration of skills and know-how. Recruited from 40 different countries and with a wide range of educational backgrounds, the staff of the ESRF brings to the institute an unparalleled wealth of diversity and dynamism.

Training a new generation of scientists

The ESRF is closely involved in the training of young scientists. Many PhD students and postdoctoral fellows get their first taste of life as a researcher at what is one of the most renowned synchrotrons in the world. This steady stream of new scientists is crucial for maintaining the vitality of international research and guaranteeing its future.

The ESRF has also set up a number of educational programmes aimed at younger people to familiarise them with the challenges facing today's scientists, introduce them to science in all its forms, and give them an insight into the diversity of careers in science.

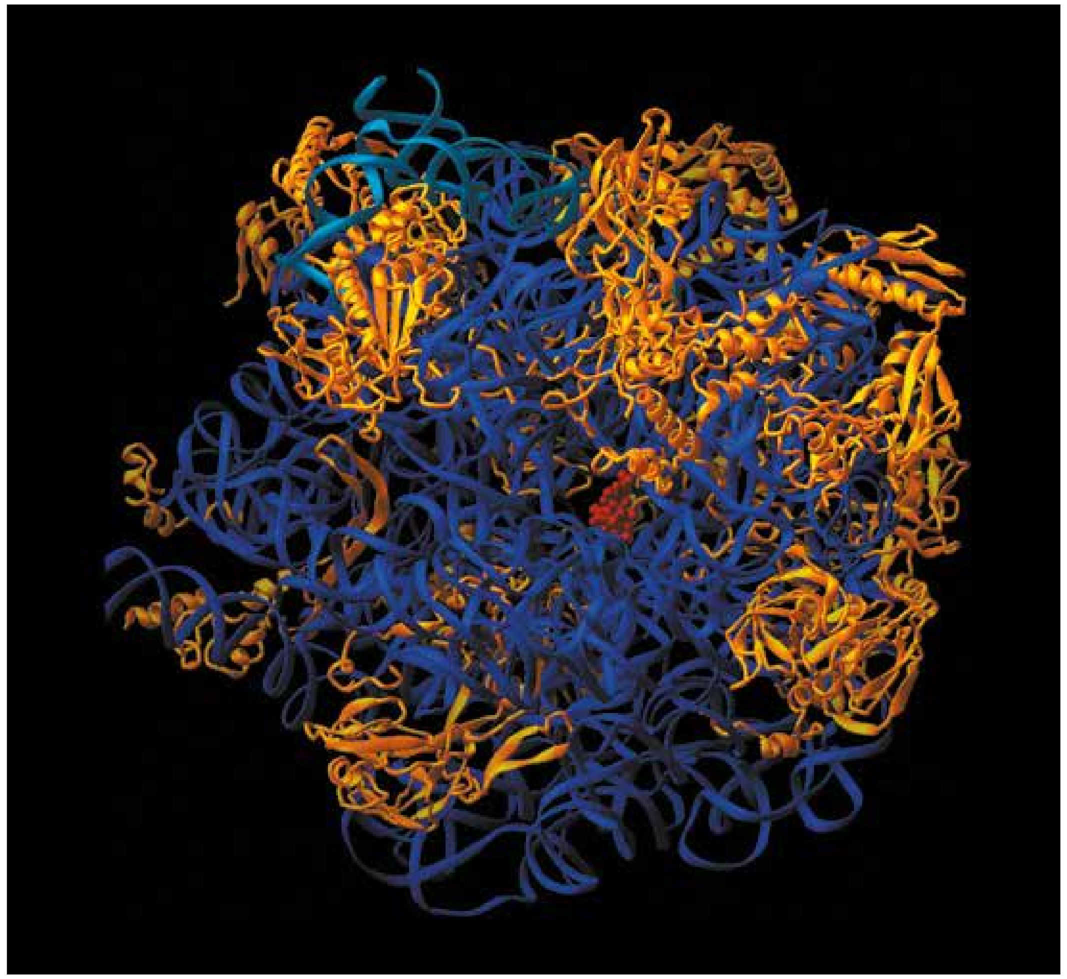
An outstanding setting

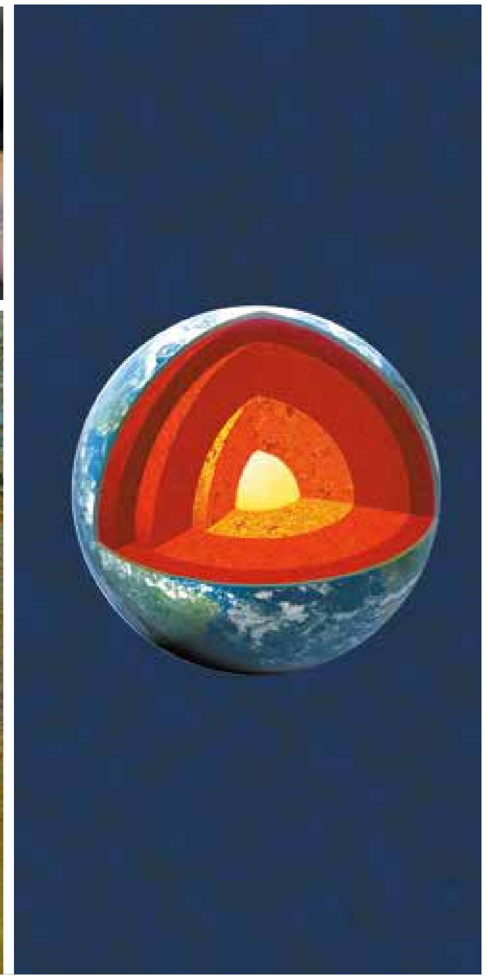
The ESRF is set in an exceptional location offering a quality of life that attracts talented professionals from around the world. Situated in the heart of the French Alps, the cosmopolitan city of Grenoble is a centre of innovation known throughout the world for its research facilities, its universities and its economic vitality.

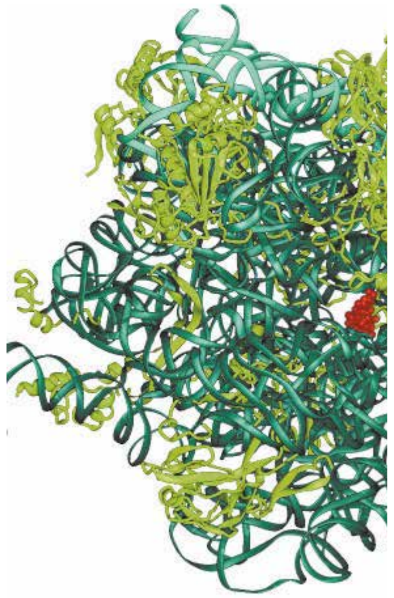
The ESRF enjoys the strategic advantages of being located on the European Photon and Neutron (EPN) Science Campus, a unique science hub which hosts three major international research institutes devoted to the exploration of living matter and materials. The ESRF is also an active partner of the global innovation campus known as GIANT (Grenoble Innovation for Advanced New Technologies), which is the lifeblood of Grenoble's economic and scientific development.

SCIENCE IN ALL ITS FORMS

Observing matter and decoding its secrets. These are the cornerstone of humanity's quest to improve our understanding of the world around us. The intensely bright light produced at the ESRF offers scientists unique opportunities to explore materials and living matter in a multitude of fields, ranging from chemistry and materials physics to archaeology and cultural heritage and from structural biology, health and the life sciences to environmental sciences, information science and nanotechnologies.







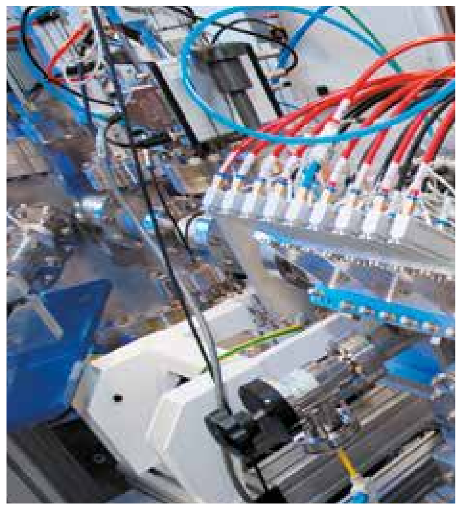
AT THE HEART OF LIFE

A revolution in structural biology

The study of proteins is vital for unravelling the complex mechanisms of living organisms. X-ray crystallography is one of the most commonly used techniques to study individual proteins and understand how atoms are arranged inside them. However, more complex biological systems require a multidisciplinary approach in order to obtain as full a picture as possible. The ESRF offers scientists the chance to use a combination of low- and high-resolution techniques, including diffraction, spectroscopy and microscopy.

Ribosomes: the builders of proteins

The ribosome is a macromolecular complex situated at the heart of the cell. It consists of RNA and numerous proteins. Its role is to make proteins from the genetic information stored in the genes. After being studied for many years, the structure of the ribosome was finally resolved using synchrotron light. Two of the ESRF's users, Ada Yonath and Venki Ramakrishnan, were awarded the Nobel Prize for chemistry in 2009 for their research on the ribosome. This work opens up important new possibilities, for example for the development of new generations of antibiotics.



CUTTING-EDGE MEDICAL RESEARCH

Making the invisible visible

Thanks to the unique properties of synchrotron light, it is possible not only to improve the conventional X-ray-based techniques used for medical imaging, but also to develop new therapeutic techniques, for example to help fight certain cancers more effectively. The key challenges are: improving tumour targeting, reducing radiation doses, avoiding damage to healthy tissue and increasing the effectiveness of therapies.

Developing new drugs

One of the objectives of the pharmaceutical industry today is to develop better targeted drugs. The research techniques proposed by the ESRF, such as X-ray crystallography, have become vital in helping the industry progress further faster in its understanding of the structure of proteins. One example of this is the malaria parasite known as Plasmodium, which is transmitted to humans by mosquito bites. More than 300 million people are affected by malaria worldwide each year. The parasite uses a particular protein which binds to blood cells in order to enter these cells and then reproduce. Work carried out at the ESRF has allowed scientists to take a crucial step forward in their understanding of the structure of the surface where this binding takes place.

FROM PALAEONTOLOGY TO ART

Back to the origins of humanity

X-ray imaging is being used increasingly for the study of fossils. The ESRF is leader in this field and can offer scientists access to high-quality data and also to non-destructive investigation techniques. Teams at the ESRF have examined famous fossils such as Toumaï and Sediba, revealed insects hidden in opaque amber, and even identified the oldest known primate skeleton.

Preserving our cultural heritage

Why is the yellow in the paintings of great artists such as Vincent Van Gogh and Henri Matisse slowly fading? This question has been answered thanks to experiments using the ERSF's synchrotron radiation which have identified not only the chemical processes taking place in the discoloured paint but also the chemistry behind the preparation of the pigments used by these grand masters. These findings are vital for improving the conservation of these masterpieces and detecting this type of colour degradation at an early stage.

A WINDOW ON THE UNIVERSE

Our planet: so familiar and yet so strange

Earthquakes, volcanic eruptions, plate tectonics: these are all manifestations on the Earth's surface of movements that begin thousands of kilometres beneath our feet. To gain insight into these phenomena, geophysicists use synchrotron techniques to study the composition and structure of the materials that make up the Earth's core. This involves recreating in the laboratory the extreme conditions of temperature and pressure found at the centre of the Earth.

Journey to the centre of the Earth

The temperature at the Earth's core has puzzled scientists for a very long time. The core's temperature is crucial because it not only influences the movements of the Earth's mantle and crust which cause phenomenon such as plate tectonics and volcanic activity, but is also responsible for maintaining the Earth's magnetic field.

Experiments conducted at the ESRF have made it possible to determine the melting point of iron close to the Earth's core. To achieve this experimental *tour de force*, the scientists had to subject tiny samples of iron to pressures of several million atmospheres and temperatures of several thousand degrees Celsius.

EXPLORING THE NANOWORLD

Science at the nanoscale

Invisible to the naked eye, the nanoworld holds a particular fascination for scientists because on this scale matter reveals the most amazing properties. Nanosciences stand at the crossroads between a number of disciplines – physics, chemistry, biology, materials science - and have already sparked a veritable technology revolution. With the promise of many more breakthroughs still to come, synchrotron light is playing a vital part in this revolution as the ideal tool for exploring nanostructures.

For a brighter future

With their longer lifespan and higher energy efficiency, LEDs have gradually replaced conventional light bulbs, revolutionising lighting and screen technology. Scientists and industry are now hoping to develop a new generation of LEDs that would be brighter and cheaper to produce. One of the most promising avenues being explored involves making LEDs from nanowires.
By combining several of the techniques available at the ESRF, nanowires can be studied at high spatial resolutions, making it possible to relate their structural and chemical characteristics to the properties of the light emitted.

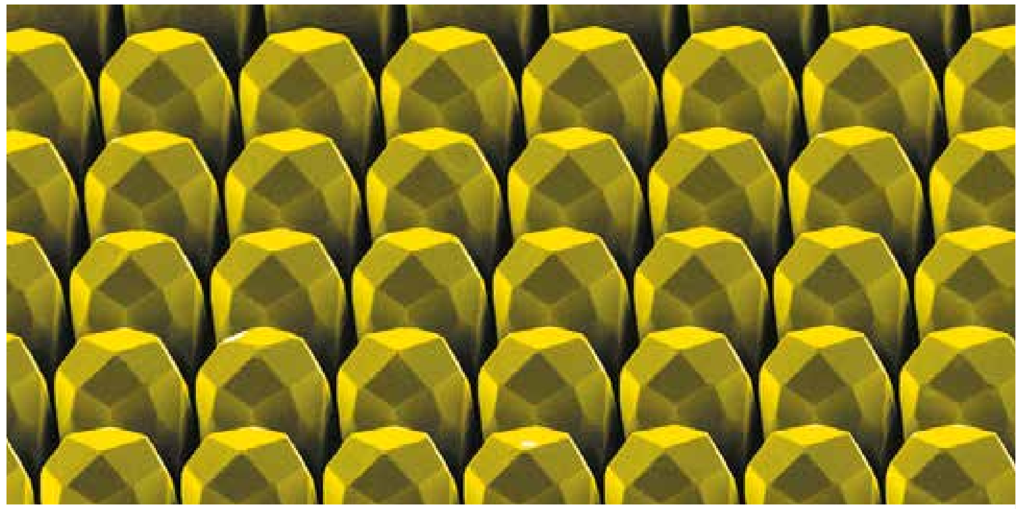
DESIGNING THE MATERIALS OF TOMORROW

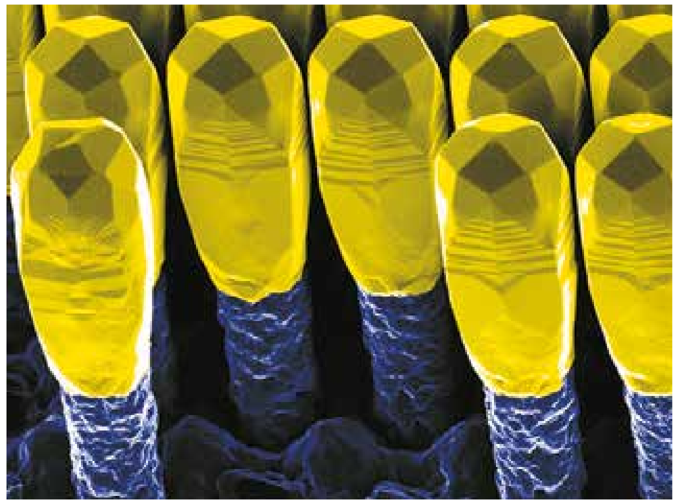
Driving improvements

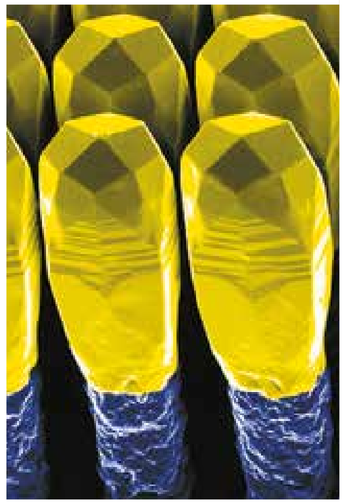
An enormous variety of materials can be studied with X-rays, including metal alloys, semi-conductors, liquid crystals, polymers, colloids, glasses, fibre optics, plastics and catalysts. The synchrotron techniques available at the ESRF are extremely useful not only for studying the behaviour of these materials but also for designing stronger, higher performance materials that are more practical and more environmentally friendly.

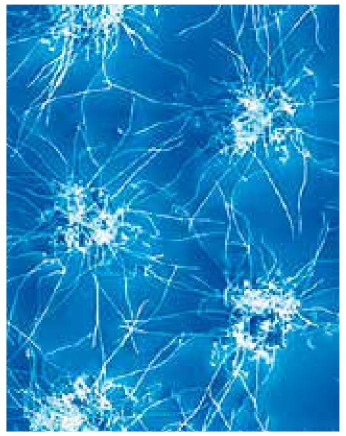
Inspired by nature

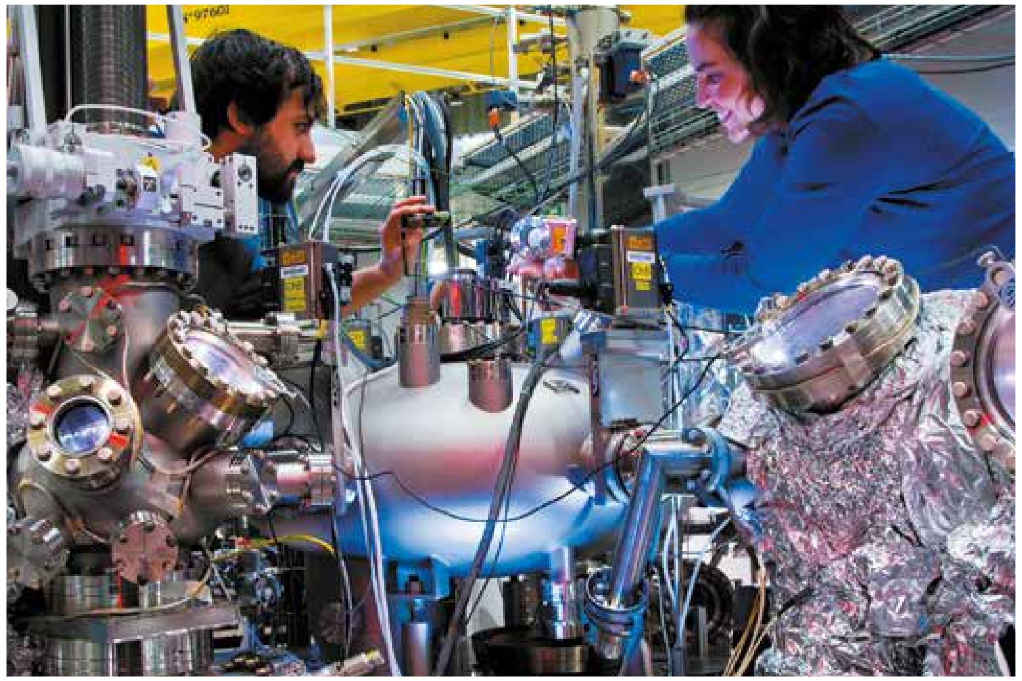
Imagine a polymer that is as strong as steel wire but is also twice as elastic as nylon. No man-made polymer has ever achieved this feat and yet there is a natural polymer which exhibits precisely these properties: the silk thread produced by spiders. Studies conducted at the ESRF to understand how the molecules in spider silk are arranged to give it such extraordinary mechanical properties may one day make it possible to produce fibres of the same quality made of synthetic polymers. Such fibres would, of course, have countless applications in areas ranging from medicine, construction and sport to clothing and the car industry.

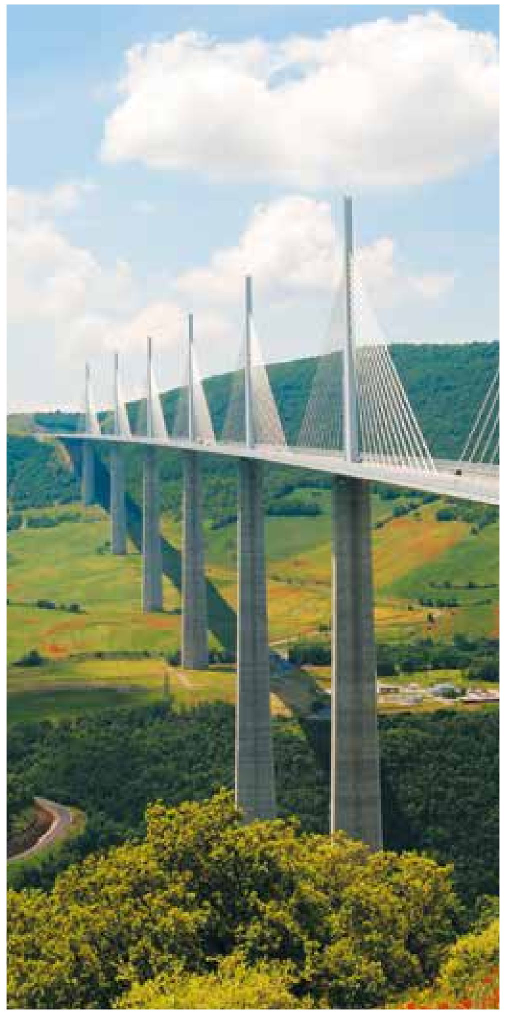


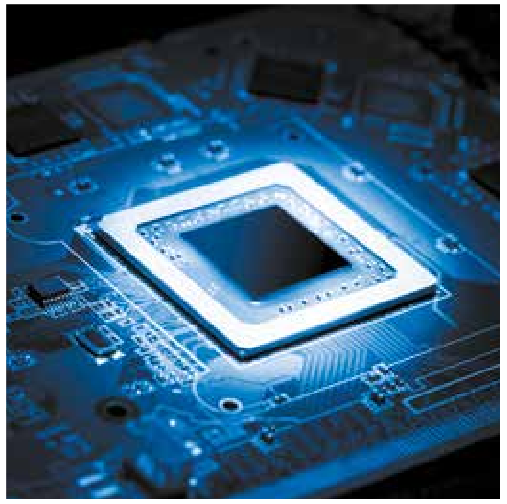












BUILDING A SUSTAINABLE FUTURE

Meeting the challenges of the environment and energy management

Over the last twenty years, a growing share of the research carried out at the ESRF has been devoted to energy and the environment. Finding out more about how lithium-ion batteries work, developing a powerful catalyst for converting biomass into renewable fuel, exploring what happens to nanoparticles in water and soil, reducing the toxicity of certain pollutants, and inventing new materials for storing hydrogen. These are just a few examples of research made possible thanks to the state-of-the-art scientific equipment available at the ESRF.

Studying photosynthesis for a greener future

Photosynthesis is a process involving the oxidation of water molecules and the release of oxygen. In nature, only one protein complex, known as photosystem II, is capable of producing this vital chemical reaction with the maximum efficiency. Photosystem II is found in plants, algae and cyanobacteria and has been studied down to the finest detail by X-ray crystallography. To take things a step further, however, another technique, known as time-resolved X-ray absorption spectroscopy, was needed, allowing scientists working at the ESRF to observe the sophisticated water oxidation cycle “on line” from beginning to end. An understanding of this mechanism should make it possible to use solar energy to produce hydrogen, which would pave the way for a new generation of rechargeable batteries.

INDUSTRY

A “super-microscope” for industry

Synchrotron light is used increasingly to meet very specific industrial needs relating to the life cycle of materials. This can involve anything from new product R&D, developing and optimising manufacturing processes, quality control and monitoring how products age to metrology and end-of-life recycling and recovery. 30% of the research work carried out at the ESRF involves industrial partners. Some of the many fields of application are: pharmaceuticals and biotechnology, chemistry and catalysis, cosmetics, food products, automotive engineering and construction, nanotechnologies and semi-conductors, energy, the environment, metallurgy and advanced materials.

The electronics of tomorrow

The possibility of examining electronic components on the microscopic and nanoscopic scale is of crucial importance for an industry that is forced to keep pace with a rapid rate of innovation. The ESRF, along with a number of other research partners, is involved in a European programme for technology development and dissemination aimed directly at businesses, in particular small and medium-sized enterprises (SME). The projects being developed at the ESRF focus on the advanced characterisation of micro- and nano-electronic devices.

HOW DOES THE ESRF WORK?

Synchrotron light is produced when high-energy electrons circulating in a storage ring are deflected by magnetic fields. The first synchrotron radiation beam was observed in 1947. Since then, spectacular progress has been made not only in accelerator physics, electronics, and computing, but also in magnet and vacuum technologies. As a result, it is now possible to produce extremely intense X-ray beams for which there is a huge and growing demand.

The linear accelerator (or "linac")

Electrons emitted by an electron gun are packed into "bunches" at the start of the linac and then gradually accelerated using electromagnetic waves until they are travelling very close to the speed of light.

The booster synchrotron

The electrons then enter the booster synchrotron, a ring with a circumference of 300 metres. The electrons travel round this ring several thousand times, gaining a little more energy with every lap. Once they reach their final energy of 6 billion electron-volts, a process which takes barely 50 milliseconds, they are sent into the storage ring.

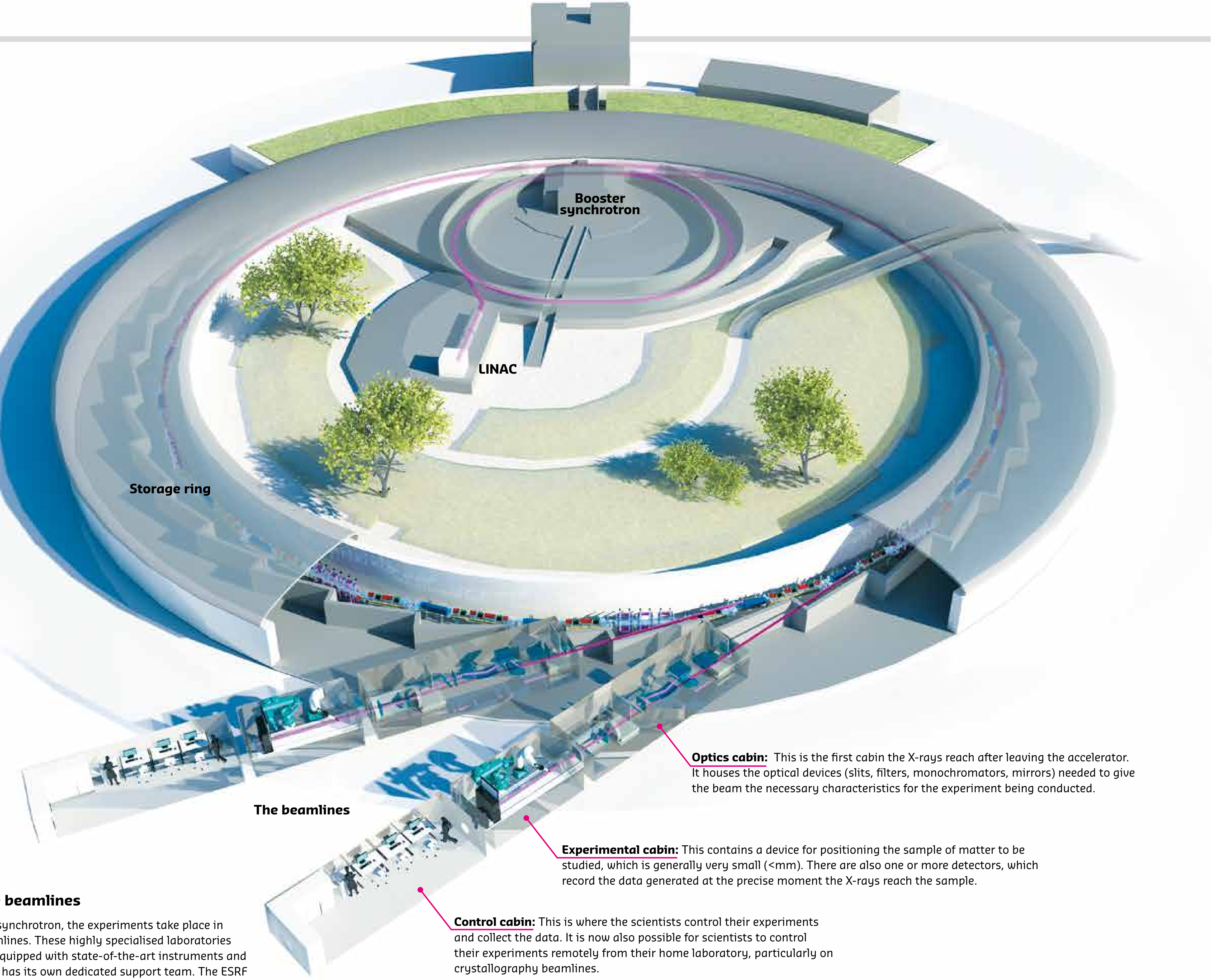
The storage ring

The storage ring has a circumference of 844 metres. The electrons travel for hours around the storage ring at the speed of light inside a tube under ultra-high vacuum conditions (around 10^{-9} mbar). As they travel round, they pass through different types of magnets, such as bending magnets, undulators and focusing magnets. Each time they pass through certain magnets, the electrons lose energy in the form of electromagnetic radiation, known as "synchrotron radiation".

The **bending magnets** are essential because they force the electrons to change direction. They are also a source of synchrotron light, which is emitted tangentially to the curved path of the electron beam and is directed towards the beamlines.

The **undulators** are magnetic structures made up of a series of small magnets with alternating polarity. The beams of X-rays they produce are a million times more intense than those generated by the bending magnets and have brightness and coherence properties that are close to lasers.

The **focusing magnets**, also known as magnetic lenses, are used to focus the electron beam so that the beam is as narrow as possible.



Optics cabin: This is the first cabin the X-rays reach after leaving the accelerator. It houses the optical devices (slits, filters, monochromators, mirrors) needed to give the beam the necessary characteristics for the experiment being conducted.

Experimental cabin: This contains a device for positioning the sample of matter to be studied, which is generally very small (<mm). There are also one or more detectors, which record the data generated at the precise moment the X-rays reach the sample.

Control cabin: This is where the scientists control their experiments and collect the data. It is now also possible for scientists to control their experiments remotely from their home laboratory, particularly on crystallography beamlines.

The beamlines

In a synchrotron, the experiments take place in beamlines. These highly specialised laboratories are equipped with state-of-the-art instruments and each has its own dedicated support team. The ESRF has 43 such beamlines. The different areas of a beamline are described hereafter:

PREPARING THE FUTURE

Since it was first opened, the ESRF, the world's first "third-generation" synchrotron light source, has broken one record after another (source brilliance, X-ray beam stability and coherence). After twenty years of success and scientific excellence, the ESRF has embarked upon an ambitious and innovative modernisation programme, known as the Upgrade Programme. Following completion of Phase 1 of this programme, the ESRF is now taking up a brand new challenge with the launch of the ground-breaking project ESRF – EBS.

Designing a new generation of synchrotrons

With ESRF - EBS (which stands for Extremely Brilliant Source), the ESRF is consolidating its pioneering role and preparing for the future by developing a new generation of synchrotrons capable of producing a source of synchrotron light that is more intense, more coherent and more reliable than ever before. This unique project, which will mobilise the efforts of all 21 partner countries of the ESRF, represents an investment of € 150 million over the period 2015-2022.

A technological challenge

ESRF - EBS poses many technological challenges, the main one being the delivery of the first of a new kind of storage ring based synchrotron source with a normalised horizontal emittance of at least a factor 10 better than any existing or currently planned projects, and at least a factor 100 more brilliant than the ESRF source today.

An important instrumentation programme and an ambitious "big data" strategy will guarantee that the qualities of the new X-ray source are exploited to the full. This challenging and unique project will pave the way to provide new tools for the investigation of condensed matter and life science, which will better worldwide scientific cooperation and the quest to finding durable answers to the great technological, economic, societal and environmental challenges facing our society.

Phase I
180 million € during the period 2009 to 2015

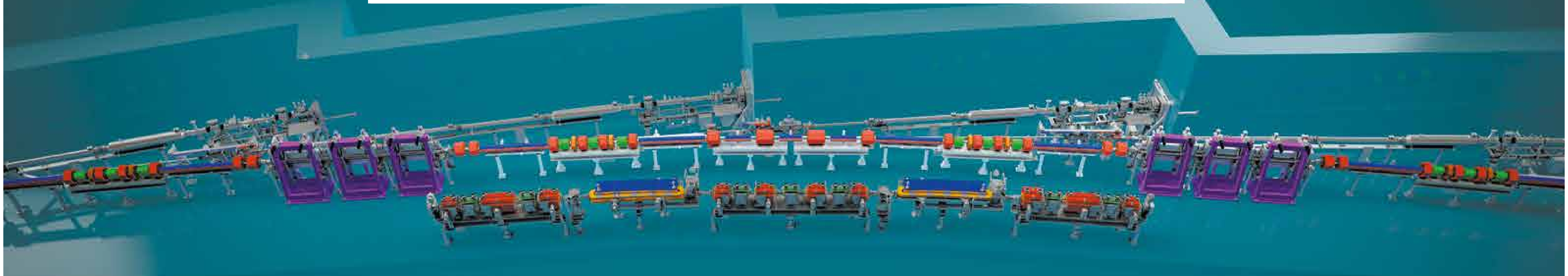
- The constuction of 19 new generation experimental stations to explore the nanoworld
- The creation of a new ultra-stable experimental hall of 8000 m²
- The improvement and refurbishment of most of the cutting-edge scientific equipment

ESRF – Extremely Brilliant Source
150 million € during the period 2015 to 2022

- The construction of a new storage ring, inside the existing structure
- The construction of new state-of-the-art beamlines
- An ambitious instrumentation programme (optics, high-performance detectors)
- An intensified big data strategy

A new design for the storage ring

The key feature underpinning the ground-breaking ESRF – EBS project is the new storage ring design developed by the teams at the ESRF. The main parts of the storage ring, in particular the bending and focusing magnets, will be replaced by more sophisticated components. Sequencing will be improved, with the aim of achieving an ultra-low emittance X-ray source which has less divergence and is smaller in size. The diagram below shows the current layout (at the bottom) and the new design (above).



New design of a cell of the storage ring

NEW SCIENTIFIC CHALLENGES ON THE HORIZON

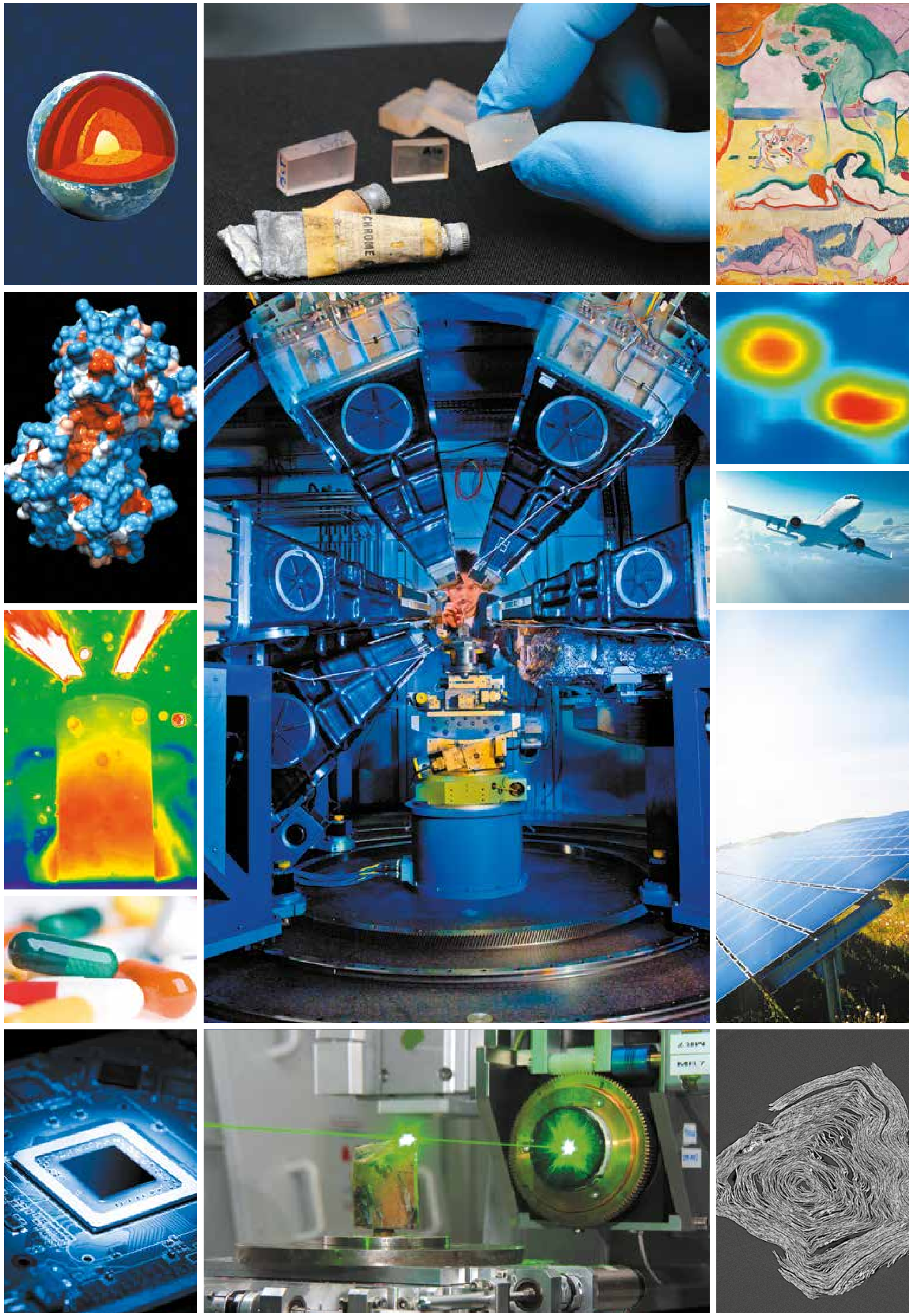
The exceptional properties of the new X-ray source will pave the way for increasingly advanced research projects requiring better spatial and time resolution and ever more sophisticated experimental conditions.

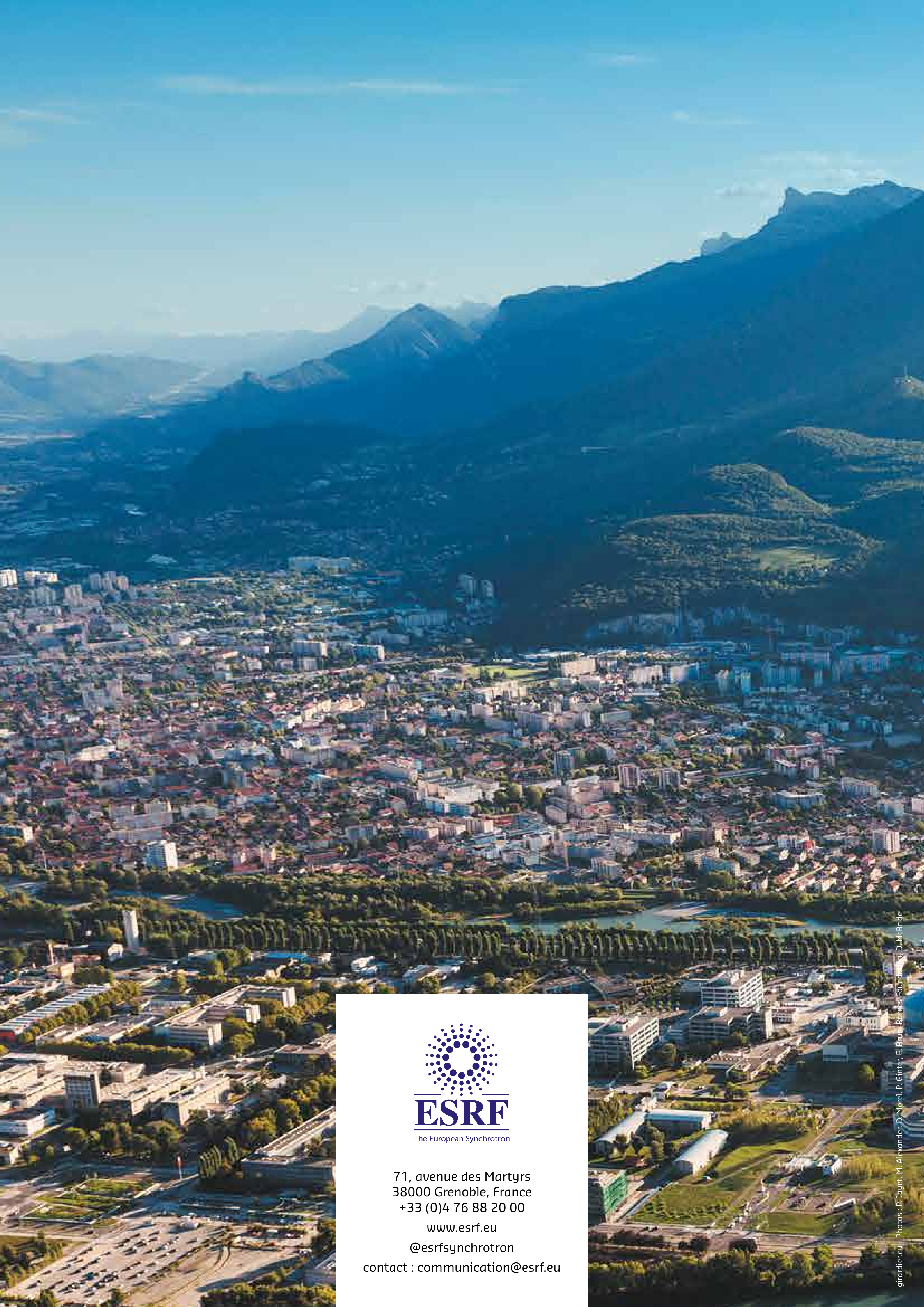
As we pursue our exploration of the nanoworld, the possibility of examining nano-objects individually is set to revolutionise a variety of fields where miniaturisation has become a key issue, ranging from information technologies and communication to health, energy and the environment.

We will be able to apply the analysis of chemical and biological reactions on ultra-fast time scales (down to a nanosecond or even a picosecond) to increasingly complex systems. Using X-ray cinematography, we will be able to meet new challenges in nano-electronics, catalysis and cellular biology.

The experimental environment is also evolving, making it possible to reproduce extreme conditions at a beamline (extreme in terms of temperature, pressure, atmosphere and a variety of other constraints), allowing scientists to characterise *in situ* and *in operando* the most novel materials and processes.

In structural biology, the study of proteins will benefit enormously from techniques made possible thanks to the enhanced brilliance of the ESRF's X-ray beams, such as "serial crystallography", which can be applied to minute crystals at ambient temperature. However, the most spectacular progress will perhaps be in X-ray microscopy, which will enable scientists to establish the missing links between the different scales (molecular, cellular, tissue) and finally understand the "big picture" about how life works.





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