Physics in YOUR life

PARTICLES FOR HEALTH

In 1895, Wilhelm Roentgen discovered **X-rays**, an achievement that earned him the first Nobel Prize in Physics in 1901 and marks the beginning of modern medical imaging. Only a few years later it was discovered that the same X-rays can be used to treat cancer. **X-rays are simple and inexpensive to produce, and are still the most commonly used irradiation technology**. Today, they are complemented by charged particle beams, mostly proton beams produced with accelerators, which offer distinct advantages: they can be precisely tuned in direction, size, and energy and, through the so-called Bragg peak, develop their strongest radiobiological effect at exactly the location to be irradiated.

These properties can be used to adjust the treatment in position and volume in three dimensions with millimeter accuracy, making protons an **ideal tool for 'scalpel-like' treatment** of small tumors close to other sensitive organs or tissues. Even greater radiobiological effectiveness is achieved with ion beams, notably carbon ions – a technique often referred to as hadron therapy. Hadron therapy requires higher energies, and bigger and more complex accelerators. So far, only a few dedicated hadron therapy centers have been built, most of them in Europe. **Vigorous R&D is ongoing in order to reduce their size and complexity to a scale that allows for installation in major university hospitals.**

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Physics in YOUR life

MRI for
MEDICAL DIAGNOSTICS

Magnetic Resonance Imaging (MRI) is a non-invasive technique, which produces images of our inner body with an astonishing precision. It can even distinguish sick tissue from healthy tissue. How does it manage to do that?

MRI uses the fact that the nuclei of simple atoms like hydrogen, of which we have plenty in our body, behave like a tiny spinning magnets. When put in an external magnetic field, a hydrogen atom can be oriented parallel or anti-parallel to the field lines. By briefly turning on a radio signal with precisely the right frequency, the atoms can be made to switch from parallel to anti-parallel. When the radio signal is turned off, the atoms return to their original orientation. The interesting thing is that the speed at which they return depends on their environment, and differs for healthy and sick tissue. **This makes it a powerful diagnostic tool to study diseases.**

The funny thing is that MRI was made possible by combining two results from curiosity-driven research: Nuclear Magnetic Resonance (which provides the idea) and superconductivity (which is at the basis of the superconductive magnets used). So MRI is a nice example of how a **fantastic medical instrumentation** emerged from fundamental physics research.

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Physics in YOUR life

Fundamental science in your pocket

THE SMARTPHONE

Your smartphone, which you probably carry in your pocket, is one of the most amazing minilabs in the history of science and technology. We are not always aware of the impact of fundamental research discoveries on our daily lives. But this small complex object, which was first commercialised on a large scale in 2007, **owes its existence to decades of scientific research**, often recognised by the award of the Nobel Prize. For example, the modern development of liquid crystal science and its application to LCD displays has been deeply influenced by the work of P.-G. de Gennes (Nobel in physics, 1991). Another breakthrough for modern cameras was the invention of the imaging semiconductor CCD light sensor, by W. S. Boyle and G. E. Smith (Nobel in physics, 2009). The precise localisation of your smartphone is also possible thanks to the GPS, the global positioning system, that requires accurate time measurement with atomic clocks and the known position of specialised satellites. Without knowldege of many physical principles and of Einstein's relativity theory, the GPS wouln't exist today. Among the technologies that contributed to the modern smartphone let's mention in particular the high-performance semiconducting microprocessors, the high-density memory, the Lithium-ion battery, the data modems and standards for wireless communication, the SIM card intended to securely identify and authenticate subscribers, the touchscreen and the OLED organic light-emitting diode display. **These fantastic achievements, integrated in a single device, were only possible with the collaborative work between research scientists, engineers and industrial developers**.

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Physics in YOUR life

Nanotechnology

FOR CLEAN WATER

More than 840,000 people per year die from a water-related disease and approximately one out of nine people around the world, over **750 million people lack access to safe water**. Water is a finite resource that has many uses and has to serve more and more people. Ensuring that everyone has access to a reliable supply of clean water is crucial to human survival and sustainable progress. **The demand for clean water is rising due to population growth**; at the same time water sources including lakes, rivers and groundwater aquifers are being subjected to increasing contamination and salinisation.

Novel nanomaterials are playing a crucial role in water sanitation and management. Indeed, the newest water sanitation technologies act at the nanometer scale: desalination and water purification through reverse osmosis are making rapid progress in polymeric science. Combining different graphene-based devices allows to design functionalized systems able to filter water at the molecular level, reducing the overall energy cost. Such systems will be very useful for water cleaning in developing countries where water and energy shortages are closely related. Biocompatible functionalised nanoparticles can nowadays be designed with extremely high precision to selectively adsorb pollutants in solution. Carbon-based electrodes allow to convert waste of the water sanitation process into energy.

These are only a few of the countless examples of the role that nanoscience and physics are playing in the water purification sector, clearly a multidisciplinary challenge. Indeed, in addition to further technological developments the free **access to clean water will be of strategic importance in maintaining political stability and peace worldwide.**

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Physics in YOUR life

LED THERE BE LIGHT

The new millennium began with the wide-spread introduction of the smallest, most robust, fast and economic light source that technology has ever produced, **the Light Emitting Diode** (LED). Once again, the actors in the scene are semiconductors, materials that previously revolutionized electronics. And it is thanks to them that scientists managed to produce light at very low energy consumption, compared to conventional light sources. After candles, incandescent light bulbs and fluorescent lighting, LEDs are the fourth illumination technology.

How does a LED works? LEDs are extremely tiny light bulbs, easy to fit into an electrical circuit. They don't produce light by heating a filament; this is why they don't get hot. Instead, light is produced just by the motion of electrons in a semiconductor material, like in standard transistors. According to quantum theory, electrons that fall into a lower energy level, release energy in the form of light particles, called photons.

LEDs have many advantages over other light sources: lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching. That's why in the last decade we moved into a LED-centric world, with LEDs used in many applications such as car headlights, advertising displays, TV screens, general home and industrial lighting, traffic signals, camera flashes, and lighted wallpaper.

What can we expect from the future? Probably a wireless lighting revolution. But this has yet to come!

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Physics in YOUR life

Innovative Materials for
SUSTAINABLE ENERGY

Energy is a major challenge of the 21st century. **The world's growing demand for new energy sources will require many more renewable energy systems based on innovation and novel materials.** Such innovative materials have the capacity to transform the way we capture, transport, store or conserve energy. Today the sustainable energy economy depends critically on a wide array of metals including indium, lithium, gallium and tellurium, as well as rare earth elements and precious metals such as platinum and silver. These elements are used in high-technology applications ranging from permanent magnets for wind turbines and electric vehicle motors, metal alloys for batteries, to energy-efficient lighting, fuel cells, and photovoltaic solar cells. In our everyday lives, these materials are also used for consumer electronics in digital cameras, mobile phones, LCD/ LED TVs, and many other devices. **The potential shortfall of such critical materials is a growing concern**. Physicists, chemists and engineers are therefore developing new materials with better properties and new fabrication techniques to create more abundant and cost-effective substitutes. Numerical simulations are used in parallel to experiments in a continuous research process, based on public or private partnerships and international collaborations. **You might be surprised to know that in your smartphone almost all stable elements of the periodic table are present!**

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Physics in YOUR life

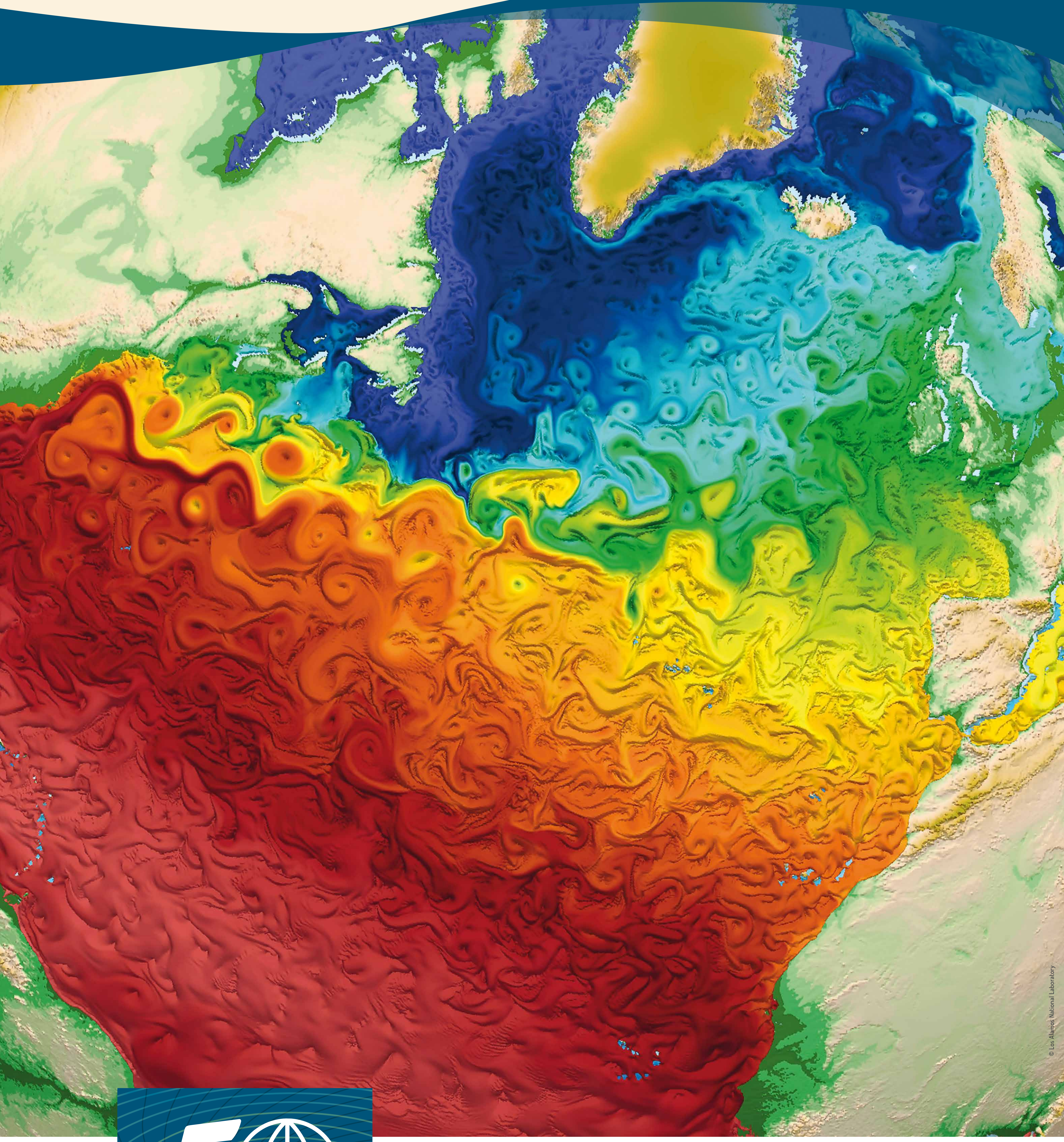
Modelling for

CLIMATE CHANGE

We are all concerned about climate change and its effects on the future of our planet's ecosystems and we all enjoy accurate weather forecast for the planning of our outdoor activities.

In order to better understand the influence of the large number of different parameters on our biosphere and to make projections, scientists have developed climate models based on well-established physical principles. They use quantitative methods to simulate the interactions of the main drivers of climate, such as the atmosphere, the oceans, the land surfaces and the ice caps. All climate models take account of the incoming energy from the sun as electromagnetic radiation, as well as the outgoing energy as long wave (far infrared) radiation. Any imbalance results in a change of temperature at the Earth's surface. Climate modelling is rather complex and requires very powerful computing resources to combine all available data collected today or in the past from Earth-based and satellite observations.

The complexity of developing reliable climate models that take into account all of the major parameters, including the role of human activities contributing to the great increase of CO2 in the atmosphere has led to intense debate. Nonetheless, it is well accepted today that the "Atmosphere-Ocean General Circulation Models" provide credible quantitative estimates of future climate change. **It is nevertheless the responsibility of each citizen to contribute to the safeguard of our planet with his/her personal engagement and not to leave it only to the scientists!**



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Physics in YOUR life

Lasers for COMMUNICATION

Whenever you send an E-mail, or surf on the Internet, you will probably be using optical fibers to transport your digital information. Nowadays optical fibers carry much of the internet, telephone systems and cable television signals. The reason is that optical fibers have important advantages over copper cables: they have a higher capacity, lower losses over distance and are less susceptible to interference. Such fibers are made of glass about the size of a human hair, surrounded by a so-called cladding that prevents the light from leaving the fiber. Strands of such fibers are bundled together to form cables that are easily bent. The light pulses are well channeled by the curved optical fibers. Digital data are transmitted through such fibers by pulses of infrared light generated by Light-Emitting Diodes (LEDs) or small lasers.

So this is another example of the use of the laser, in addition to its everyday-life use for bar-code scanners, laser surgery, laser welding and cutting, laser printing, just to name a few. **Lasers are omnipresent in modern life**. After the laser emerged from basic research in the 1950s, people used to twit that the laser was “a solution looking for a problem”... the opposite became true!

Physics in YOUR life

GPS for
LOCALIZATION AND NAVIGATION

Whenever you are lost, a Global Positioning System (GPS) can tell you precisely where you are. And the GPS-navigation in your car takes you to your destination with an astonishing precision. How does GPS manage to do that? Here is the answer. **Your GPS device knows its position by precisely measuring the distance to a few satellites orbiting around the Earth**. This distance is determined from the time it takes for a radio signal to travel between the satellites and you or your car. This time measurement must be done with great precision, because radio waves travel with the speed of light. An error as small as 1 microsecond translates into an error of 300 meters. Present-day atomic clocks achieve much higher accuracies. The problem is solved, one would think.

But an unexpected complication shows up. We need Einstein's theory of relativity. The reason is that the clocks in the satellites, moving fast and at great distance from the Earth, are slightly faster than ground-based clocks. This would result in errors of about 11 km after only a single day if no corrections were made! So the clocks in the satellites are adjusted before launch, precisely by the amount dictated by theory.

If Einstein didn't predict modern GPS, his theory of relativity made it possible!

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Physics in YOUR life

Radio waves for
TRACKING AND IDENTIFICATION

RFID, Radio-frequency identification, uses radio waves for the identification and tracking of tags attached to objects, from automobiles to family pets. The nice thing about using radio waves is that the tag does not have to be in the line of sight of the reader: **it can already be read if passed near a reader, even if it is covered.** Since the tag can be miniature-size, it can be built into almost anything, including credit cards.

In most such systems, the card itself doesn't need a battery or other power source. The electrical current required is *induced* by the radio waves from the transmitter. This *induced current* provides enough energy to complete the simple computation performed on the RFID chip and lets the chip communicate with the transmitter. Depending on the type of tag and the radio frequency used, such **RFID systems can work over distances of 10 cm to over 10 meters**. This makes them ideally suited for applications like paying for your train or bus, or for paying toll on the highway. Or even collecting data from RFID badges worn by patients in the hospital. Obviously, these possibilities call for security measures to safeguard privacy and avoid misuse. **But RFID provides a nice example of cutting-edge technology emerged out of basic research and making our life just a bit simpler.**

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Physics in YOUR life

Spectroscopy for
ENVIRONMENTAL MONITORING

Environmental monitoring is the big stethoscope we have on Earth, **designed to characterise and monitor the quality of its breath**. As the Native American Chief Seattle said, “we don’t inherit the earth from our ancestors, we borrow it from our children”. It is in this perspective that the United Nations started the United Nations Climate Change Conferences (as COP21 in Paris) to assess progress in dealing with climate change. Light has been used by scientists as an analogue of the stethoscope. **With light spectroscopy one can monitor and analyse trends of water or air quality in real time**. Imagine using light like your voice in a cave. Once you scream the echo produced brings information about the nature of the cave you are in. In a similar way, when shining a light beam into air or water, the light signal reflected as “echo” yields information about its chemical composition and pollution. This is how spectroscopy for environmental monitoring works.

The faster and more widely this information is spread and applied, the better our society can use it in environmental impact assessments. In a not so distant future, citizens will be equipped with spectroscopic smartphone add-ons and applications, and will themselves collect real-time data. **This form of citizen science will help to improve the quality of life at all levels**, from individual houses to large cities and finally for the benefit of mankind itself.

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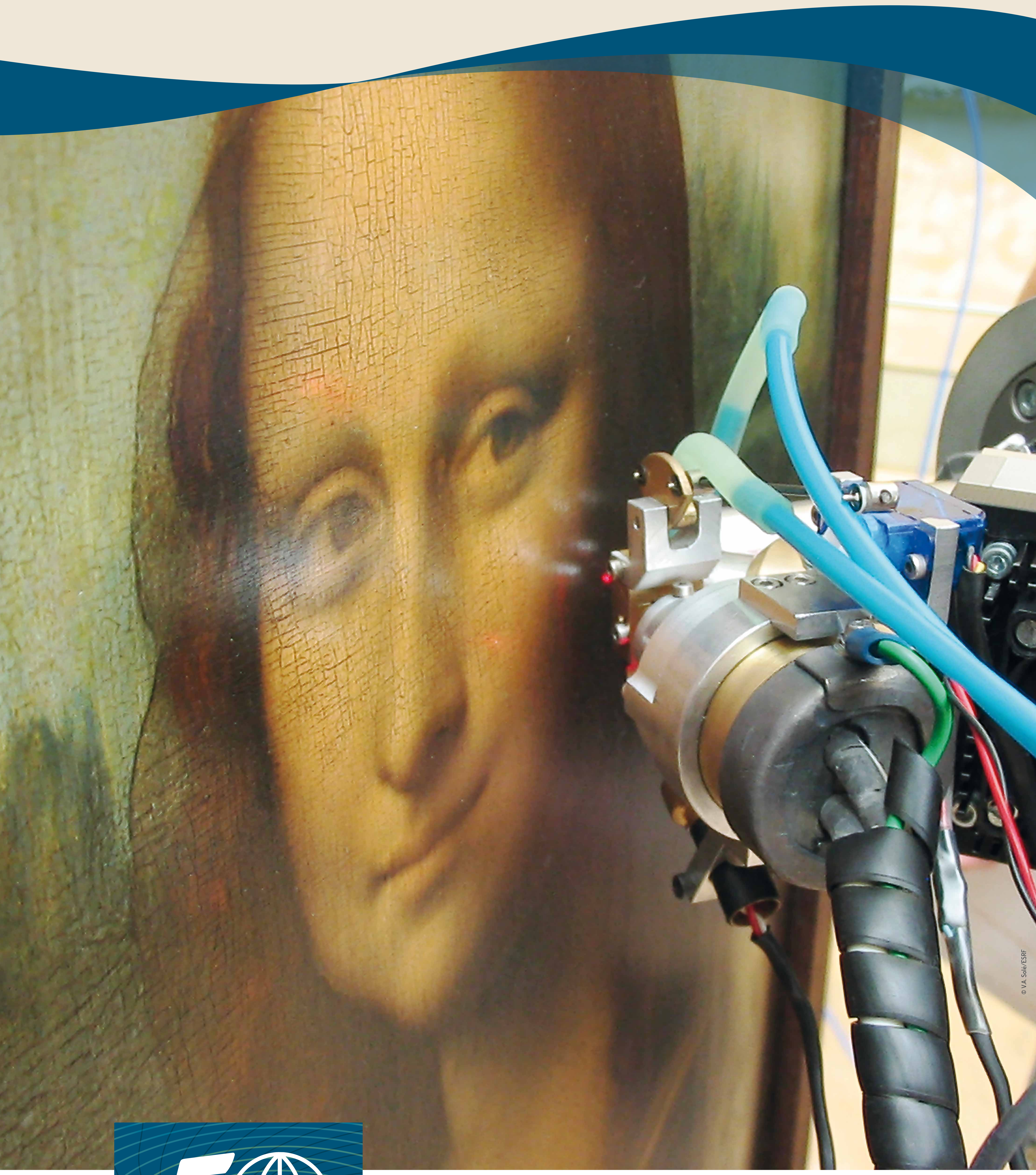
Physics in YOUR life

Physics for
CULTURAL HERITAGE

Physical methods, often based on techniques and instruments from nuclear and particle physics, have become **essential tools for the analysis, understanding, and preservation of our cultural heritage.** Probably the best-known example is the radiocarbon dating method, which allows precise age determination of archeological objects as old as 50 000 years, by measuring the content of radioactive carbon-14 isotopes. Ion beams from particle accelerators can be used to analyse the chemical composition of antique alloys and glasses whereas neutron beams from reactors can help identify trace elements in ceramics, providing information about their origin. The combination of different methods allows the precise, non-destructive determination of the age and provenance of archeological objects and artworks. **Very important today, such techniques provide a way to distinguish genuine art from forgery!** Sterilisation of valuable objects through irradiation with gamma rays eliminates bioactivity such as bacteria or fungi, and contributes to their long-term preservation. Many of these methods cannot be applied to objects that are too large or too sensitive to be transported to reactors or accelerator laboratories. This limitation is increasingly overcome with a new generation of powerful yet small-size, portable particle accelerators, which can be brought into museums and archeological sites. Another nice example of particle physics application is the recent discovery of a void in the Great Pyramid on the Giza Plateau in Egypt, using portable detectors of the omnipresent cosmic ray muons.



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