Research Infrastructures

at the heart of the European Research Area (ERA)

integrated infrastructure initiatives

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» What are they…

Research Infrastructures affect many aspects of our daily and future lives – from our health to our iPods, from our security to our appreciation of the wonders (and dangers) of the universe. The examples in this brochure provide just a tiny window onto their diversity and impacts.

What is a 'research infrastructure'? We have probably all been to one – we have just never recognised it.

The Royal Library of Alexandria – the first known example of an international research infrastructure, and where the scientific method was first developed

The most common type of research infrastructure is a library. These are not just services for lending the latest novels to read. The great libraries are collections which are used by researchers to study 'old' knowledge and develop 'new' knowledge. They are large and centralised; collecting a lot of rare knowledge in one place is more cost effective and efficient and enables connections to be made between apparently unrelated information. They are also built up and maintained over decades or even centuries. Their contribution to the long term development and economic well being of the countries that are fortunate enough to have them is incalculable.

Research infrastructures still include libraries of books and documents, but also large databases – their electronic equivalents – or other types of physical collection such as the European Mouse Mutant Archive (EMMA[1]). This is a 'library' of thousands of strains of mice specially bred for biomedical research. Research Infrastructures include large scientific 'machines'. The European Synchrotron Radiation Facility (ESRF[2]), for example, uses high brightness beams of X-rays to look inside materials down to the atomic level. It can be used for everything from studying protein structures for drug development to 'reading' ancient scrolls that are too fragile to unfold. Similar research is carried out using large neutron sources or lasers. Such machines are expensive and so need to be built and operated as an international collaboration. But some research infrastructures are distributed collections of smaller research capabilities where there is a real benefit in the combination of these resources – such as the hundreds of seismographic stations in NERIES[3] 'Networking Research Infrastructures for European Seismology'.

What Research Infrastructures have in common is that they are large undertakings, whether in physical size or level of organisation, they require a significant level of investment to build or set up and a corresponding level of finance for operation, and they need to have a long term perspective of at least decades to be effective.

The European Synchrotron Radiation Facility

© P.Ginter, ESRF

Map of sesimographic measuring stations in Europe contributing to the NERIES network.

[1] *EMMA – www.emmanet.org*
[2] *ESRF – www.esrf.eu*
[3] *NERIES – www.neries-eu.org*

at the heart of the ERA

…and why do we need them?

Research Infrastructures are at the heart of the European Research Area. They represent an investment of many billions of € and support the research of tens of thousands of researchers, both from academia and industry. In addition they play an important role in training in high technology or advanced methods, which can then be used well outside of their original application.

The variety of modern research infrastructures is enormous. Although many are based on developments originally made in physics laboratories (as were all our techniques for medical imaging), nowadays they have a role and importance across the full breadth of science and technology.

Probably the largest European research infrastructure, and one of the most recent to start operation, is the Large Hadron Collider (LHC) at the CERN[1] Laboratory in Geneva.

© CERN

This massive particle accelerator, a truly international collaboration, is designed to study the behaviour of matter at the very smallest scale in order to better understand the very largest scale – the universe and its origin. Smaller particle accelerators, using technology developed for predecessors of the LHC, are now in common use for cancer treatment.

A different sort of 'database'

Other research infrastructures, such as the Natural History Museum in London[2], have been collecting specimens from around the world for centuries. Genetic sequencing and computing are revolutionising the way in which the collections from different museums can be categorised and 'brought together' to provide a much more complete picture of the origin and diversity of life. Although based on the past, this sort of information is crucial to safeguarding our future. An example is the Millenium Seed Bank[3] which collects, studies and carefully stores thousands of types of seed from around the world, maintaining their genetic diversity for future generations.

Telescopes are among the more well known types of research infrastructure – both on the ground and on satellites out in space. The technology originally developed for collecting faint light from the farthest galaxies now sits in every digital camera. But telescopes also study nearer objects such as the sun. Its activity has a direct and major impact on both our climate and our technology, such as satellites and mobile phones, so understanding and being better able to predict it is critical for our technology dependent society.

The biggest change that has happened to our society in the last 50 years has been brought about by the relentless increase in the power of computers and the capacity of data storage such as hard

© Board of Trustees, Royal Botanic Gardens Kew

disks. Many of the materials and technologies enabling this change arise from work carried out at research infrastructures, and now the largest computers are themselves research infrastructures which carry out 'virtual experiments' modelling everything from climate change to catalysis for carbon capture.

[1] CERN – www.cern.ch
[2] Natural History Museum, London – www.nhm.ac.uk
[3] Millennium Seed Bank – http://www.kew.org/science-conservation/conservation-climate-change/millennium-seed-bank/index.htm

» How safe is toxic waste in a glass cage?

Synchrotrons and free electron lasers produce intense beams of light in the form of X-rays, ultraviolet and infrared. These powerful beams act like 'supermicroscopes' revealing what a material looks like deep down at its molecular level. Their penetrating properties can be used to take virtual slices of materials such as tissue samples or fossils and create three-dimensional images.

Europe produces millions of tons of toxic waste every year. As long standing landfill sites rapidly fill up, finding a safe way to deal with this waste has become a major challenge.

Turning our toxic waste into glass could provide the answer. You may have heard of lead crystal glass, admired for its decorative properties; lead oxide is added to the glass to give it that extra sparkle. Now this idea has been taken one step further. Toxic waste rich in iron and lead is being added during the glass making process to produce glass and glass-ceramic materials that can be freely disposed of, or used in construction and decoration. This method of waste storage is simple and cost-effective. It is an attractive alternative to common incineration, where the residues of combustion are stored in tanks or disposed of in landfill areas and can generate groundwater contamination. Nevertheless, the question arises: how durable are these glasses?

Using synchrotron X-ray beams, a team of scientists from the Aristotle University of Thessaloniki, Greece, and the Berlin synchrotron radiation facility (BESSY) have undertaken experiments to discover just how safe such toxic waste glasses really are[1].

Synchrotrons are able to produce intense beams of X-rays, billions of times brighter than those produced by hospital X-ray machines. These intense beams make it possible to study materials at the scale of atoms. To determine the structure and long term stability of the waste glasses a powerful, non destructive technique called XAFS was used. XAFS provides information on the chemical state and local environment of the iron and lead atoms in the glass.

The X-ray studies have revealed that the glass-making process must be closely monitored to ensure their long term stability. Iron and lead play an important structural role within the glass, so any inconsistencies in the distribution of these toxic elements during production could compromise the glass's stability. It is also vital to have a waste content no greater than 65%.

This study has shown that, having found a way to store our toxic waste in a glass cage, we can also ensure that these glasses remain structurally stable and safe in our environment.

© HZB

BESSY – Berlin synchrotron radiation facility

Glass made from toxic waste

[1] Research carried out during the IA-SFS project (http://www.elettra.trieste.it/i3/)

» Measuring atmospheric aerosols from aircraft

Research aircraft are vital for studying earth and the environment. The instrumentation aboard the aircraft includes in-situ sensors, radar devices and multi-spectral imagers which can be used for studies into weather, climate, pollution and Earth surface observation. The EUFAR project ensures that Europe's aircraft fleet is used to its maximum potential by matching specific scientific projects to the most suitable aircraft.

Air pollution is a serious problem, and not only a recent one. In December 1952 Londoners awoke to thick smog that smothered the city, produced by a combination of the coal that burned to fuel industry and the smoke that billowed from house chimneys to counter the cold weather. Although smog was a part of life for Londoners, on this occasion it lasted 4 days and killed around 4000 people. These problems have not been left behind; more recently a thick smog over Beijing refused to lift in the run-up to the 2008 Olympics.

Air pollution can be produced by atmospheric aerosols – tiny particles suspended in the air that have a significant impact on health and climate. To gain a better understanding of their role in air pollution it is vital to measure their properties, distribution and chemical make-up.

Research aircraft Safire-ATR 42

Aerosol particles range in size from the nanometer to the micrometer scale. They can be made of anything from minerals to salt or soot from combustion, even organic particles. This means that the way they interact with water (clouds) and light (sunshine) can be very variable. To gain an accurate picture of aerosols in the atmosphere, we need to take direct measurements from aircraft; which is where the challenge lies. The complex instrumentation required, and the way that aerosol particles are sampled outside the aircraft and then brought to the instrument for analysis, means that it is very difficult to get accurate data.

Scientists and engineers, supported by the European Facility for Airborne Research (EUFAR), were brought together to tackle the problem.

The skills and experience of the team were needed to design and produce the Airborne Aerosol Reference Pods which can be fitted under the wings of many different aircraft in the EUFAR fleet. These pods are designed to give the instruments the exposure they need to the atmosphere undisturbed by the aircraft. One pod contains a suite of instruments for measuring the size distribution of particles, from a few nanometers to 10 micrometers, while another is devoted to measuring the way that aerosol particles interact with light.

The Pods are vitally important for meteorological and climate research. They can be easily adapted to hold different aerosol instruments or instruments used for other atmospheric measurements. For instance, the same pod will be used to enable the measurement of humidity in the atmosphere, from the surface to the stratosphere.

» Storing hydrogen for cleaner cars

Neutron beams can uniquely probe how technologically important materials behave at the atomic scale. Neutrons are scattered by the atoms of a sample in a characteristic way that can reveal structural and chemical changes as they happen. In this way, researchers can evaluate novel materials for particular applications. For example, neutrons can be used to study the movement of hydrogen molecules as they are cycled through hydrogen storage materials.

Concerns about climate change and the use of fossil fuels are leading car companies to consider alternative, more environmentally friendly methods of powering vehicles. A leading candidate is hydrogen which releases energy when it reacts with oxygen to form water, either in a combustion engine or in a fuel cell. However, hydrogen takes up more tank-space than petrol and is also more challenging to handle.

Scientists are therefore looking for materials that can absorb and safely store much larger amounts of hydrogen, take it up quickly and release it efficiently under operating conditions, remain stable at everyday temperatures and work reliably. The first materials studied were metal hydrides, which were effective but relatively heavy. Today, the search is on for lighter materials that work just as well.


Berlin Neutron Scattering Centre (BENSC)

One possibility, being studied by Arndt Remhof and his team at the Swiss federal research institute (Empa), is a lightweight compound – lithium borohydride. This contains four hydrogen atoms for each lithium and boron atom, so that 18 per cent of its weight is hydrogen; it also holds twice as much hydrogen by volume as the liquefied gas. However, the hydrogen is chemically bound to the boron and lithium so is less easy to release at a practical temperature. To prise out the hydrogen, the researchers have been exploring the incorporation of aluminium, which likes to bind with the boron in the compound so destabilising it and releasing the hydrogen.

The reaction is reversible, so the research involved detailed studies of how easily and quickly the various reaction steps happened and whether the reaction could be cycled. *"To absorb and release the hydrogen, we need to be able to shift the reaction back and forth,"* says Professor Remhof. Different approaches to synthesising lithium borohydride were also investigated.

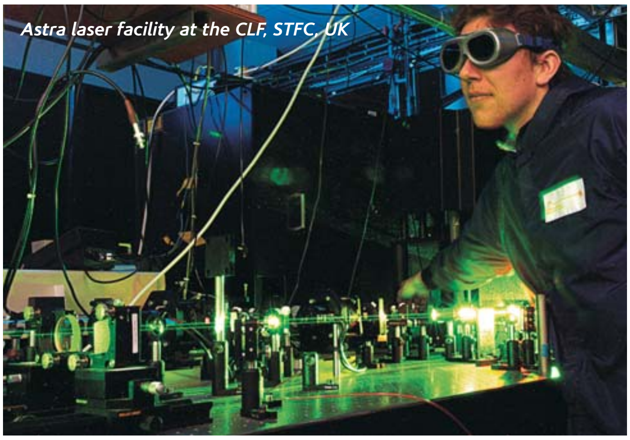
Experiments at the Berlin Neutron Scattering Centre (BENSC) played an important role in uncovering the structural changes as they occurred during the reactions. The results revealed the mechanisms underlying the formation and destabilisation of lithium borohydride and the regulatory influence of the aluminium. They demonstrated that the lithium borohydride/ aluminium combination has potential but that the ideal hydrogen-storage material with all the right characteristics is still some way off.

» Studying photosynthesis for more efficient solar cells

Evolution has led to the exploitation of fundamental mechanisms that remain difficult to observe and therefore to understand or to mimic for devices. New laser-based methods and technologies are key to providing a clearer view. The state-of-the-art laser facilities made available through Laserlab Europe allow for the trialling of very new approaches, limited solely by the creativity and the enthusiasm of researchers. In doing so, Laserlab Europe is helping to create leading edges for Europe in emerging directions.

Solar cells are our own rudimentary equivalent of photosynthesis, but our attempts to match nature's design for converting the Sun's energy into power are, so far, not very impressive!

Undoubtedly the most important chemical reaction on Earth, sustaining life itself, photosynthesis uses the suns energy to drive the conversion of carbon dioxide and water into oxygen and organic compounds such as glucose – 'plant fuel'. Understanding exactly how plants carry this out so efficiently could be the key to producing cheaper and more efficient solar cells. This knowledge may not be too far away.



Astra laser facility at the CLF, STFC, UK

A team of scientists, supported by Laserlab Europe, used the Astra laser at the UK's Central Laser Facility to take ultra-fast laser light measurements of the process. Using an add-on developed by Imperial College, London, this laser can deliver a huge range of colours in each single laser pulse.

Researchers focused on the protein responsible for harvesting light during photosynthesis. Inside this protein, the light energy is guided across the molecule to where it drives the fuel generating chemical reaction. They used a new method, angle-resolved coherent imaging. A single ultra-fast laser flash directed at the protein provides a freeze-frame picture, rich in new detail, of the energy transport and its mechanisms inside the protein before the protein can move. The researchers were able to see new information about the way a wave-like motion of electrons behaves inside the protein.[1]

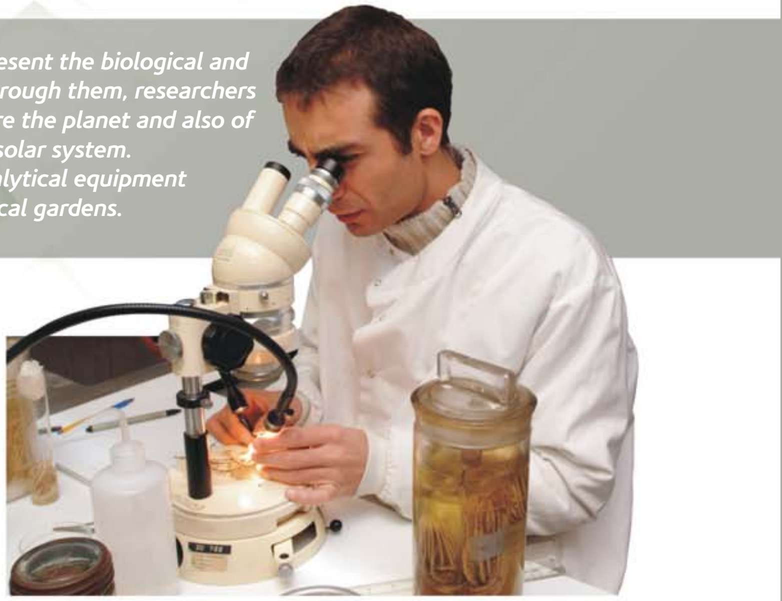
Lead investigator, Dr Ian Mercer from the University College Dublin, Ireland, says *"This is a world first in taking a snapshot that helps us understand something new about photosynthesis, all in a flash that is ten thousand million times faster than a camera flash"*. This also opens the way to look at expensive samples, because only a drop of sample is needed for an image. In contrast, traditional methods require between millions and billions of ultrafast laser flashes accumulated sequentially, typically over hours or days whilst refreshing the sample.

Understanding nature's methods of energy transport could give us the knowledge we need to produce our own alternative energy solutions. In addition, continuing advances of this method and laser technology are opening up new avenues for fingerprinting of molecular structure and function which could have applications across many scientific disciplines.

[1] *Ian P. Mercer et al., Phys. Rev. Lett. 102, 57402 (2009)*

» Understanding the Earth's biodiversity

The collections held in Europe's natural history museums represent the biological and geological diversity of the natural world, past and present. Through them, researchers gain knowledge of the animals and plants with which we share the planet and also of the processes that have shaped the world around us and our solar system. SYNTHESYS provides access to 337 million specimens and analytical equipment housed in Europe's major natural history museums and botanical gardens.



Biodiversity describes the variety of life on Earth. It encompasses all living things from micro-organisms to monkeys. As biodiversity comes under threat across the globe the rate of species extinction has rapidly increased. Destruction of habitat, especially in areas such as tropical rainforests, is just one cause of species decline. However, increased access to these remote areas is also leading to the discovery of new species at a record rate.

Every day researchers are discovering and naming new species, all of which play their own unique role in the global ecosystem. Natural history museums, some with collections that go back hundreds of years and come from every corner of the globe, provide the expertise that can identify and give names to these new species. Their huge collections are able to paint a picture of a species' evolution, movement across a continent, and relation to other similar species. Using new techniques, museums are now able to extract and analyse DNA from specimens in collections in order to identify differences in species that are physically very similar.

Zoological specimens stored in the Darwin Centre, Natural History Museum, London. Assembled over hundreds of years, these specimens are still highly relevant to contemporary research

Researchers funded by the European project SYNTHESYS are making breakthroughs in understanding biodiversity – all the way from the depths of the ocean to outer space.

In oceans, and in freshwater, around 5,000 different species of sponge have been identified. A particular type of sponge known as Haplosclerida is of great importance in the investigation of natural marine products and potential drug discovery; many sponges are known to produce chemicals with beneficial pharmaceutical effects. The classification of Haplosclerida is poorly understood. However, researchers carrying out molecular analysis have now been able to clarify certain relationships between sponges. This improved classification has enabled them to carry out targeted exploration of specific species which could produce potentially useful chemicals. This stops the unnecessary harvesting of large numbers of sponges and reduces habitat destruction.

Research focussing on the evolution, ecology and biology of black rock fungi from the Antarctic has improved our knowledge of fungal biodiversity in extreme conditions. Experiments have shown that these fungi have a high resistance to repeated freeze/thaw cycles and to UV-B irradiation, making them perfect for exobiology experiments which are concerned with the effects of outer space on living organisms and the search for extraterrestrial life. As a result of this work, Antarctic black fungi have been selected for experiments outside of the International Space Station.

Inside the Natural History Museum, London, UK

» Accurate weather forecasting

The rise of powerful computers is helping academia and industry alike. High performance computers are vital for fundamental research and computer modelling and are capable of simulating highly complex problems in science and engineering. The science community has an increasing need for computer power. HPC-Europa2 is helping to improve Europe's competitiveness in R&D by facilitating access to supercomputers across Europe.

Accurate forecasting of high impact weather events, like gale force winds or heavy snowfall, is vital for making major decisions and can greatly benefit society, the economy and the environment. For example, a wind turbine has to be shut down if the wind speed is above a certain value; it is critically important to know the probability of this event occurring when deciding how much power an electricity company contracts from a given wind turbine.

An international research and development programme is now working to accelerate improvements in the accuracy of high impact weather forecasts. A major component of this research is the THORPEX Interactive Global Grand Ensemble (TIGGE) which produces 'ensemble-based' predictions of high-impact weather, wherever it occurs, on timescales from days to weeks.

Ensemble-based prediction is a technique designed to estimate the uncertainty that is inherently associated with weather forecasting. This uncertainty comes from our incomplete knowledge of the exact initial conditions (weather measurements are only made at particular places) and unavoidable simplifications of the complexity of nature. The basic principle is to make not only one forecast from our best guess initial conditions, but also a number of additional forecasts using slightly different conditions. The main advantage of this technique, known as Ensemble Prediction, is that it then provides an estimate of the uncertainty associated with the forecast. Ensemble Prediction systems have become an established tool in the weather and climate forecast community, and all major forecast centres around the world have developed such systems for providing probabilistic forecasts.

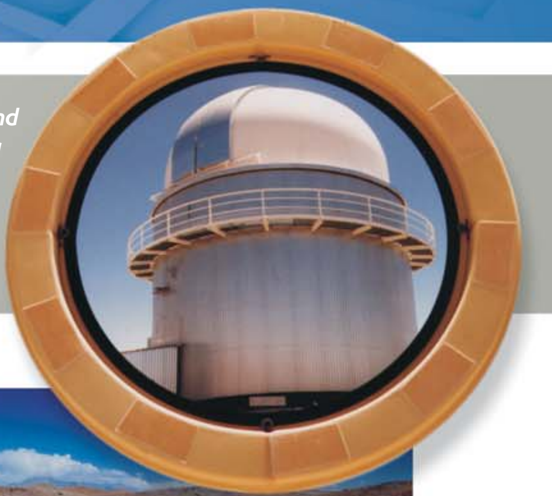
By using high performance computing, TIGGE can now combine ensembles from a large number of sources. By collecting large amounts of data it is then possible to provide a more reliable current forecast by using errors in past forecasts. This research has already proved its worth by improving forecasting temperatures during the cold season both over Northern Extra-Tropics and in Europe. The potential economic benefit is considerable.

HECToR2 High End Computing Terascale Resource

HPC-Europa2
Pan-European Research Infrastructure on High Performance Computing

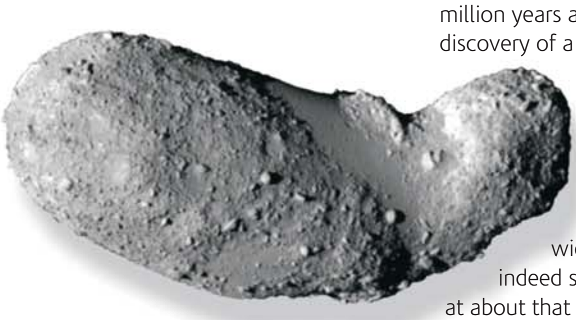
» Beware Asteroids!

Since the invention of the telescope, astronomy has been helping us to understand the universe, from stars to black holes to the big bang that marked the beginning of the universe. The development of infrared and optical telescopes, instruments and observatories is keeping Europe at the forefront of this observational science. OPTICON provides Trans-National Access to European facilities ideal for asteroid studies, as well as supporting many other astronomical research goals.



A meteor impact crater in the Chilean Desert. Inset: Telescope in La Silla, Chile, reflected in a driveway mirror.

Astronomy began for practical reasons. People observed the heavens to develop their calendars, guide them when to plant their crops and to navigate across the oceans. Today atomic clocks and sat-navs have replaced the stars and astronomy has become largely curiosity driven. However, there is a small chance that one day astronomers will save the world.



The Itokawa asteroid observed by Japan Aerospace Exploration Agency (JAXA) Asteroid Explorer "HAYABUSA". © JAXA

That stones fall from the sky has been known for centuries, but the possible consequences became appreciated only recently. The discovery of the rare element iridium in a thin geological layer supported the idea that the dinosaurs were wiped out by an asteroid impact 65 million years ago. The discovery of a huge crater off the coast of Mexico was the 'smoking gun' which confirmed that a 6km wide asteroid had indeed struck the Earth at about that time.

How common are such disasters? What could be done if another asteroid impact threatened? Using large format electronic detectors, more powerful versions of the CCD 'chips' in today's cameras and telephones, telescopes across the world scan the sky every night in search of asteroids that might one day threaten the Earth. Thousands are detected each year, but only a handful could be dangerous. These become prime targets for further study.

Using telescopes of all sizes, from University run 0.5 metre telescopes to the giant 8 metre Very Large Telescopes of the European Southern Observatory, astronomers observe faint asteroids as they move across the sky. How large are they? What are they made of? Are they ice or rock – solid flying mountains or loose aggregates of boulders? In which direction do they spin and how quickly? All of this will be vital to know if we ever plan to try and deflect an asteroid away from our planet.

So astronomers measure spectra, from the visible to the infrared, to reveal the presence of specific types of ice or minerals. Comparing these spectra with meteorites in our collections provides other clues. Careful measurements of an asteroid's brightness can reveal how quickly it rotates, which tells us about its internal strength and rigidity. Large brightness variations imply a cigar like object; smooth light curves suggest a sphere. Dark objects may be much bigger than first thought, bright shiny ones much smaller. We cannot tell when this knowledge will be needed, but when it is, we had better be ready.

Comet Hale-Bopp over the JKT Telescope in La Palma.

» Catching supernovae in the act

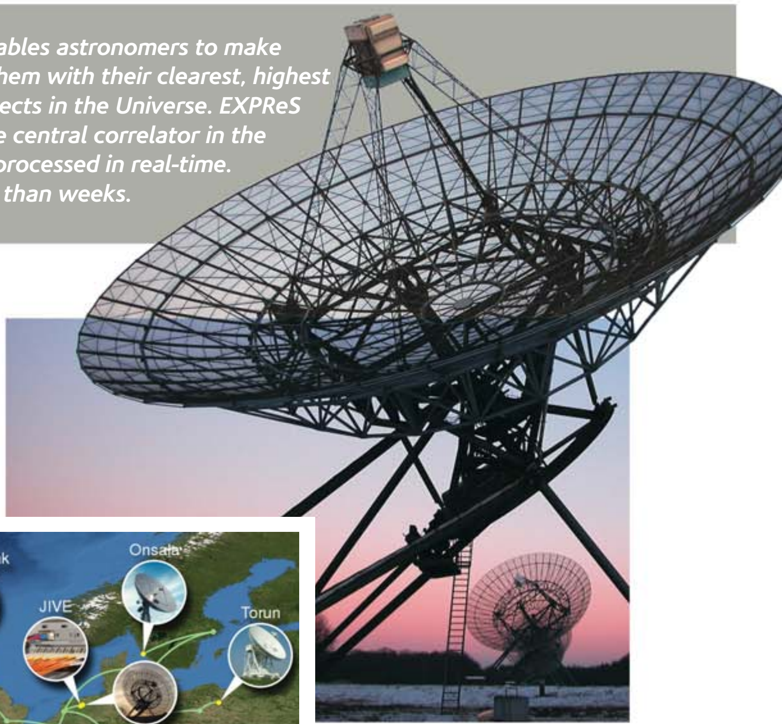
The technique of Very Long Baseline Interferometry (VLBI) enables astronomers to make simultaneous observations from many telescopes, providing them with their clearest, highest resolution view of some of the most distant and energetic objects in the Universe. EXPReS has connected Europe's most powerful radio telescopes to the central correlator in the Netherlands so that data can be streamed electronically and processed in real-time. Astronomers receive their processed data within hours rather than weeks.

There is more in the night sky than we can see with our eyes, even with the best optical telescopes. However, radio astronomy is able to reveal hidden objects by detecting the radio waves they emit. These radio waves travel uninterrupted across the universe and can penetrate the dusty environments where stars and planets are often born. Radio waves also provide us with unique information about explosive energetic processes like Supernovae.

At the end of its life, the central region of a massive star collapses at a tremendous rate, resulting in a rapid increase in temperature and density. This explosion results in a supernova, a brilliant exploding star that briefly outshines billions of other stars in its neighbourhood. Interaction of gas from the explosion with interstellar material produces large scale shocks which accelerate tiny particles to super speeds; these particles can be traced by radio instruments.

With the technique of Very Long Baseline Interferometry (VLBI), a number of radio telescopes located hundreds of kilometers apart observe the same region of sky at the same time to simulate a single telescope as large as Europe. The data is combined by a central supercomputer or 'correlator', producing the highest precision images that can accurately measure a supernova's expansion. The traditional VLBI method records data onto hard disks and ships them to the correlator over a period of weeks, but because supernovae are unpredictable and fleeting, astronomers are often denied the ability to quickly identify suspected events.

The Express Production Real-time e-VLBI Service (EXPReS) project has connected some of the world's most sensitive radio telescopes to high-capacity, high-speed communication networks, streaming and correlating data in real time. Astronomical images are made in a matter of hours rather than weeks. When activity is detected, astronomers can quickly organise follow-on observations, enabling them to study supernovae in greater detail than was ever possible before.



Westerbork Synthesis Radio Telescope

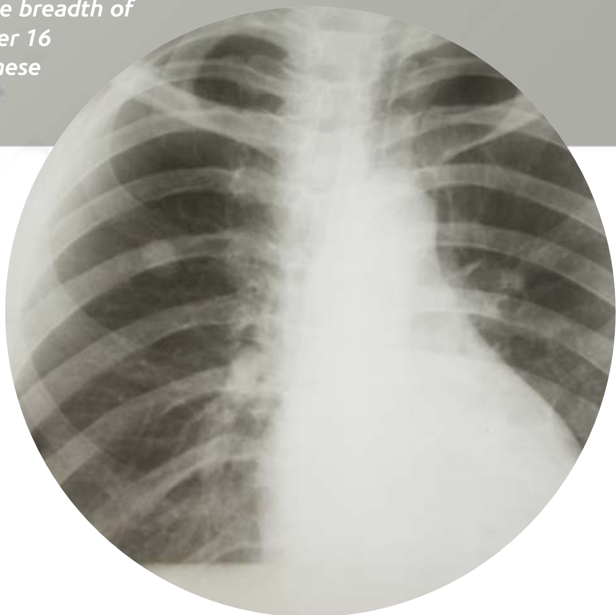
Telescopes across Europe that participated in observations of a supernova

Supernovae play a very important role in astronomical research. The rate at which supernovae occur provides crucial information about the birth and life of stars in that galaxy. There are large campaigns to identify supernovae with optical telescopes, but galaxies with the most active star-forming regions, that potentially produce the largest number of massive stars, are often the most hidden from optical telescopes because of dust. Radio observations are essential to understanding the star formation history in these systems.

Research Infrastructures

» Fighting cancer cell-by-cell

The beams of light produced by synchrotrons and free electron lasers can be used for a range of applications. They can study the shape of molecules, analyse chemicals to determine their make-up and watch cells as they react to drugs. Their application covers the breadth of science from physics to cultural heritage. ELISA brings together 16 laboratories from 8 countries, helping to promote access to these facilities across Europe.

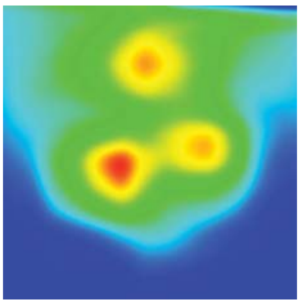


Cancer is one of the largest causes of mortality in Europe, second only to heart disease. Quick and reliable diagnosis, low side-effect therapies and widespread prevention are the three keystones in the war against cancer. Using synchrotron light, scientists have been able to identify and mark cancer cells with unprecedented accuracy, opening up new pathways for diagnosis and therapy.

Soleil Synchrotron, France
© C. Kermarrec/SOLEIL

X-ray imaging (radiography) is the most common method of producing medical images, due to the high penetration depth of X-rays in tissues. However, contrast agents are needed to reveal the tissue structure and function of an organ using X-rays. Colloidal gold was demonstrated to be a non-toxic, chemically inactive marker that could be implanted directly into cells of interest. Malignant brain cells were encouraged to engulf the gold nanoparticles by phagocytosis, which literally means 'cell eating', and were then implanted into laboratory rat's brains and allowed to develop into tumours. A team of scientists from the University of Saskatchewan in Canada showed that using synchrotron X-ray imaging it was then possible to look at both the structure of the cancer cells and trace their movement in the brain of a live rat[1]. The ability to do this with such high resolution shows promise for the accurate assessment of a tumour's response to therapy in humans.

Synchrotron light can also be used to study single cells, which have important implications in biomedicine, but special probes like vibrational microscopy are needed. Scientists working at the Laser Centre VU in Amsterdam have succeeded in isolating whole cancer cell nuclei. By passing a beam of infrared light through the nuclei and analysing the different wavelengths of light absorbed, they have obtained a single infrared spectrum which gives vital information about the molecular structure of the cell. A chemical image of an isolated nucleus obtained using a synchrotron microscope is even able to identify the DNA around the nucleotides. These results help to build up a picture of the precise spectrum of the cell nucleus and key identifying markers.



An optical image of an isolated nucleus (left) and a chemical of the same area (right), obtained with a synchrotron microscope: in the second one it is possible to identify the DNA around the nucleotides

[1] Research carried out during the IA-SFS project (http://www.elettra.trieste.it/i3/)

» Moving cancer radiotherapy from labs to operating theatres

Lasers can be found in every section of our society, from electronics to entertainment, from medicine to industry. They are also a valuable and versatile tool for scientific research, able to track the movement of drug molecules in living cells or, with the use of high power lasers, able to recreate the conditions inside stars. Laser research has a vast array of applications. Laserlab Europe brings together many laser laboratories to keep Europe at the cutting-edge of laser technology.

Millions of patients every year undergo radiotherapy to destroy cancer cells. Some radiotherapies use high-energy electron beams, either directly or after their conversion into gamma-rays. The high-energy electrons are produced by specially designed accelerators driven by powerful radiofrequency generators. Usually the tumour is located deep inside the body and, before reaching it, the beam releases a considerable amount of energy into healthy tissues which are consequently damaged. Researchers are now developing compact laser technology to minimise this damage.

Laser laboratory at Max Born Institute, Berlin, Germany

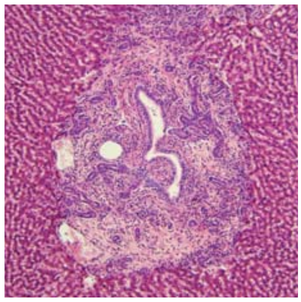
Laserlab Europe

In order to reduce damage to healthy tissue, a novel technique known as Intra-Operatory Radiotherapy (IORT) is increasingly used. IORT involves irradiating the patient with electrons in the operating theatre right after the tumour has been surgically removed, destroying tumour cells that the surgery has missed. Damage to healthy tissues is then drastically reduced. Because electrons don't have to penetrate deeply, they can be fewer in number and have a lower energy, which means smaller accelerators than for ordinary radiotherapy. However, IORT still needs a machine more than two meters high and over half a tonne in weight, requiring a large area to be radiation protected.

A recent Laserlab Europe experiment may have produced a breakthrough in this field. A French-Italian team has shown that most of the problems presently affecting the IORT technique can be overcome by using laser light rather than radiofrequency to produce electrons for radiotherapy. The cumbersome IORT machine could then be replaced with a tabletop laser able to accelerate a beam of electrons suitable for cancer radiotherapy.

At the SLIC laboratory in Saclay, France, researchers fired ultra-short laser pulses onto a suitable target, creating a frequency much higher than radiofrequency. In this way electrons suitable for IORT therapy of tumours are generated in a few millimeters instead of one meter or more. By then passing these electrons through a slice of tantalum the researchers were able to create gamma-ray photons that could also be used in radiotherapy[1].

Because the laser beam can travel for several tens of meters without any significant loss, the laser itself can be located outside the operating theatre and serve several theatres. The only equipment needed in the theatre is the *mini-accelerator* box that can be easily handled and applied to the surgical wound.



A jumbled mass of cancer forces its way in healthy liver tissue in this microscopic view. 100X

A European collaboration including CEA (France), CNR (Italy), laser and medical industries is presently considering the concrete possibility of exploiting such a scientific breakthrough. This exciting scenario has been promoted by the Laserlab Europe consortium.

[1] *Phys. Rev. Lett. 101 105002 (2008)*

» Towards a better cancer treatment

Both X-rays and neutrons penetrate objects, and so can be used to 'see' inside them. The two types of beams are reflected from the arrays of atoms in a material to give characteristic scattering patterns that reveal how the atoms are arranged. Both techniques have their advantages and complement each other well when used together. For example neutron scattering is particularly good at penetrating deeply and displaying more clearly those lighter atoms such as hydrogen.

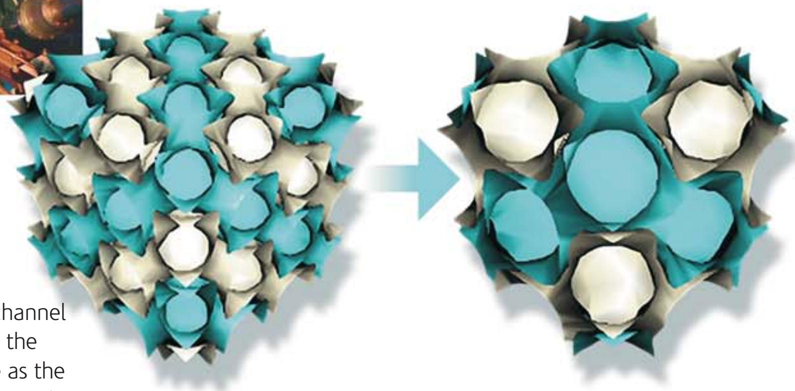
Diseases such as cancer ideally require a drug to be delivered to, and released at, a target location in the body – a tumour for example – so that the surrounding healthy tissue is not affected. One type of delivery 'vehicle' being investigated is made of molecules similar to those making up living cell membranes, and so is highly biocompatible. These biomaterials are generally non-toxic and environmentally friendly and so also have other important applications, for example in foods or in domestic and personal care products.

Cell membranes consist of double layers – 'bilayers' – of long-chain molecules called lipids, lined up in orderly arrays. These bilayers may curve round and form an enclosed surface – a 'vesicle' like a simple cell – which can then encapsulate a guest drug molecule. But they can also assemble into more complex shapes. For example, in solution the lipid monoolein will assemble into a cube shape made up of intertwined channels. Therapeutic agents could potentially be captured in the channels, and so many pharmaceutical companies are interested in exploring such structures as drug-delivery systems.

Institut Laue-Langevin (ILL) – Reactor pool

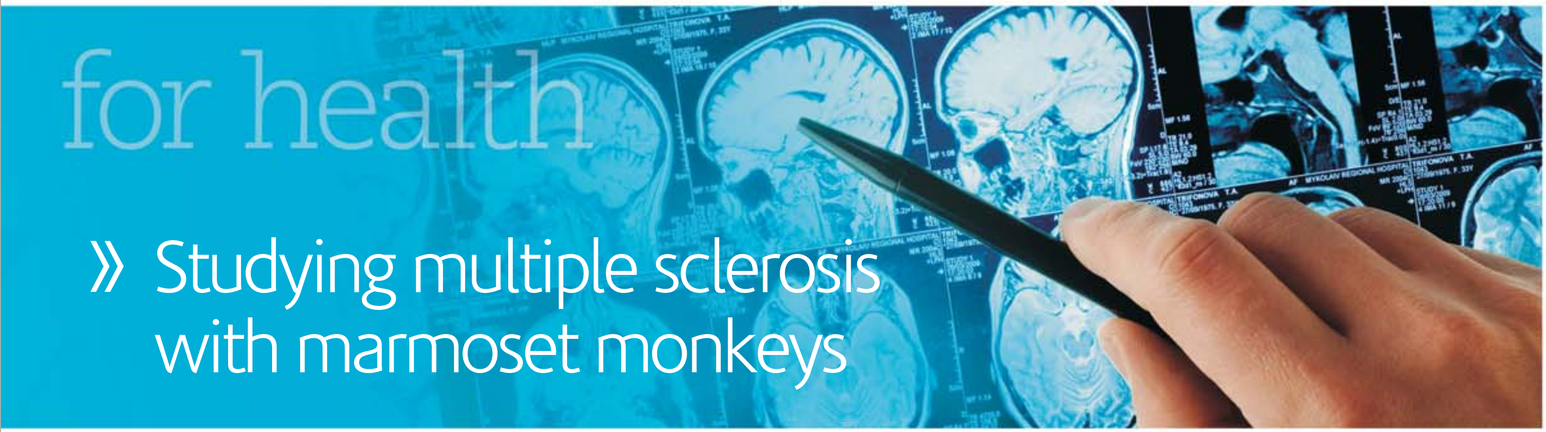
One important aspect is to control the uptake and release of the drug from the channels. An ideal approach would be to adjust the size of the channel openings by exploiting the change in temperature as the lipid 'cube' is injected into the body. A team of Bulgarian, French and German researchers has recently been exploring this strategy. They discovered that the channels in the lipid cube can be made to expand at room temperature by introducing a guest molecule, octyl glucoside, which causes the lipid channels to swell with water. However, not much was known about how the temperature and concentration of the guest molecules affected the stability of the system or the reversibility of the swelling.

Small angle neutron scattering, in combination with small angle X-ray scattering, was able to throw light on these aspects, revealing details of the changes in structure. The results confirmed that, at room temperature, a certain optimum concentration of octyl glucoside can be encapsulated in a swollen cubic network that is stable. However, on heating above body temperature, the structure shrinks and squeezes out the guest molecules. The studies also showed that the process completely reverses on cooling. The team is now planning to develop the system so that it can take up real drug molecules, and release them at a specified body temperature.



The cubic structure of the lipid, monoolein, swells when it takes in the guest molecule, octyl glucoside

nmi3



» Studying multiple sclerosis with marmoset monkeys

Understanding the biology of primates helps us to understand our own biology and has important implications for human medicine. Primate research provides an insight into socio-biological evolution and behaviour and provides models for research into genomics and biotechnology for health. EUPRIM-Net links eight European primate centres in order to combine their wide range of biological and biomedical R&D activities, their extensive knowledge and infrastructure resources as well as their experience in primate housing and breeding.

Multiple sclerosis (MS) is the most common neurological disorder affecting young adults. Around 1 in every 1000 individuals suffers from the condition, which can have a variety of symptoms from muscle spasms to problems with vision and balance. As yet there is no cure for MS, so finding effective treatments to ease the symptoms for sufferers is vitally important.

Breeding facility for rhesus monkeys at the German Primate Centre

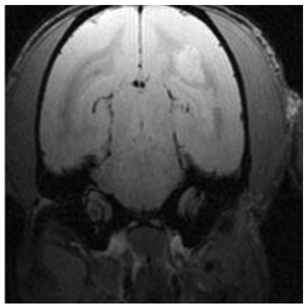
Multiple sclerosis affects the central nervous system and is believed to be an autoimmune disease; this means that the body mounts an immune response against its own cells. In the case of MS the immune system attacks the myelin sheath, a protective, insulating layer that surrounds nerve fibres and helps to speed up nerve impulses. The damage or loss of myelin, known as demyelination, causes the nerve impulses to become slow and distorted. This is the root cause of the symptoms for people suffering from the condition.

Scientists from the Biomedical Primate Research Centre, Rijswijk, The Netherlands proposed that using primates to study MS could help advance research into effective treatments. Most approved medications have been developed as a result of testing on rodents, but cells in the body targeted by these medications are now believed to have less of a role in MS than previously thought. The obvious physical differences between inbred laboratory mice and the outbred human population, and our differing immune systems, could be the reason why treatments that are effective in rodents do not show the same promising effects in humans.

The efficacy of the drugs currently available is relatively poor.

The marmoset monkey was identified as an ideal candidate for MS studies. The condition takes on the same relapsing/remitting progressive course in the marmoset as it does in humans. Marmosets are born as chimeric twins, which means that although twins may have genetic differences their immune systems are identical. This is especially useful in evaluating therapies as one twin can receive a test drug while the other receives a placebo. Once the drug has been administered it is possible to monitor any beneficial effects using MRI scans, exactly the same process that a patient undergoing treatment would go through. As the marmoset brain closely displays a human-like ratio of white to grey brain matter the MRI scan is an invaluable tool in evaluating the effects of treatment.

This research, carried out in The Netherlands and supported by EUPRIM-Net, is an excellent example of why primate research is invaluable in providing models of the human system and the diseases affecting it.



A characteristic MS-like brain white matter lesion visualised with Magnetic Resonance Imaging (MRI)

» From ancient fossils to old masterpieces

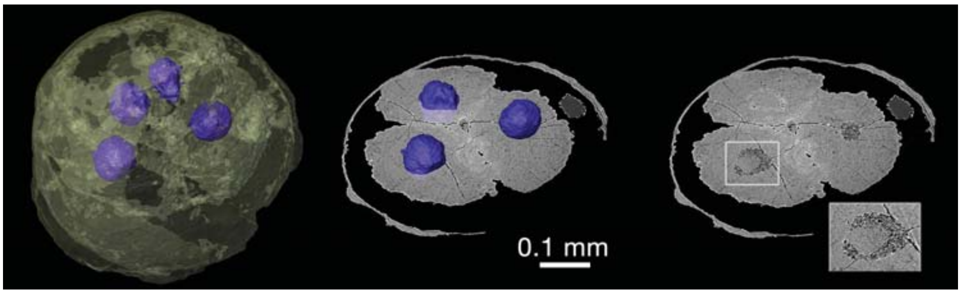
Synchrotron light has unique characteristics that can reveal otherwise inaccessible details of materials, allow their manipulation and provide information in multiple fields of study including electronics, materials engineering, environmental sciences, medicine, and micro and nanotechnologies. Using the same methods, scientists are also able to discover the inner structure of fossil embryos and analyse the composition of 15th century paints.

Retaule de la Mare de Dieu dels Consellers by artist Lluis Dalmau

Animals first appeared in the fossil record less than 600 million years ago. Sediments from the following 100 million years were unusually good for fossil preservation. Even the most delicate of structures, such as the minute embryos of marine invertebrates, have been preserved in exquisite detail. This detail, hidden for millennia, can now be revealed using synchrotron light.

At the TOMCAT beamline at the Swiss Light Source, scientists from the University of Bristol and the Swedish Museum of Natural History are using synchrotron X-rays to look into the finest features of these early embryos[1].

The 3D image obtained with X-rays can be virtually 'dissected' in a computer at a scale of one-thousandth of a millimeter – without harm to the unique and delicate fossils. The most ancient of these fossils are about 570 million years old. They show the earliest stages of individual development, the sequential cleavage of an egg into an embryo consisting of an increasing number of cells. The patterns of cell and nucleus division throw light on the origin of animals from a group of micro-organisms known as single-celled protists.



An embryo-like fossil from the time of the earliest animals, 570 million years ago. Cell nuclei (blue) are preserved with internal structures.

In rocks about 540 million years old, embryos include fully developed young animals ready to hatch. They have a complex anatomy that would be impossible to untangle without the help of X-ray tomographic microscopy. The fossils and the technique open up wholly new possibilities for understanding the earliest evolution of animals.

Unlocking the past is a speciality of synchrotrons, which have also allowed us to investigate the methods and materials used by Gothic artists over 400 years ago. Samples of Gothic paintings from artists such as Martorell, Huguet and Dalmau have been studied with beams of high energy infrared light across a range of wavelengths. The absorbed light creates a spectrum akin to a fingerprint that is characteristic of the chemicals contained in the sample. By matching the spectra with those of reference materials it is possible to determine the origins of binding media, resins, and drying oils.

Besides extending our knowledge of the way that ancient materials are prepared, the results provide an opportunity to develop improved conservation methods appropriate to each painting. The art can then be appreciated for many years to come.

The Swiss Light Source (SLS) at the Paul Scherrer Institut

[1]Research carried out during the IA-SFS project (http://www.elettra.trieste.it/i3/)

for imaging

» To HD TV

High-performance computing is a powerful tool for use across the fields of science and technology. Supercomputers are often used to help solve problems in areas such as weather forecasting, climate research and molecular modelling. Many experiments can now be replaced with computer simulations of real systems. Being able to share huge amounts of data via networks and the internet has also led to a collaborative approach to problem solving. HPC-Europa2 is helping to provide hundreds of researchers with access to first-class supercomputers and giving them technical support and training.

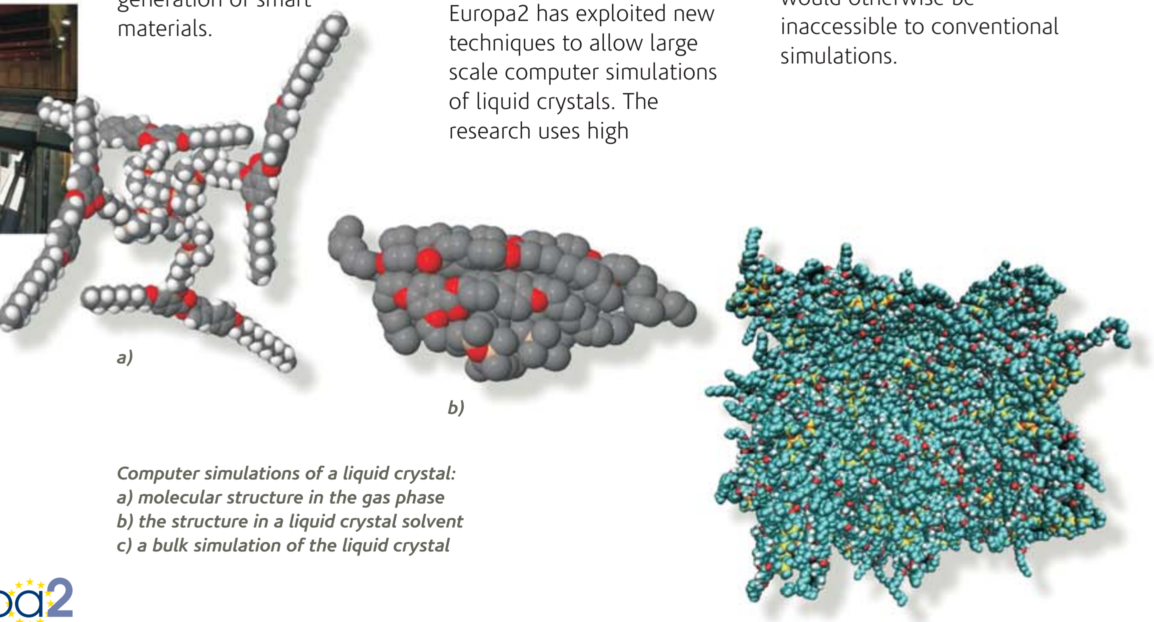
Modern computer screens, mobile phones, and LCD televisions all have liquid crystal displays. In fact, liquid crystal devices are all around us. This technology has its origins in nature, where liquid crystals are abundant. They exist in a state between a liquid and a solid, but share properties of both. For example, they may flow like a liquid but have molecules that are arranged more like a solid. This combination is the key to their potential use in materials biology.

Liquid crystals provide the possibility for the production of a new generation of materials which would be able to spontaneously assemble their molecules into a desired structure, a process known as 'self-assembly'. Constructing materials at the molecular level would no longer be a complex process, if only the right molecules could be found. It would be like applying special cement to bricks, throwing them all together in a pile and having a house appear! Scientists are learning from biology, taking examples of self assembly in nature and using them to produce a new generation of smart materials.

Computer simulation provides an important route to helping understand the link between molecule interactions and self-assembly. In particular, simulations can show how changes in the structure of molecules can lead to changes in the way they order themselves in complex materials. Ultimately, these calculations can provide a way of designing new materials by coding the correct information about how materials should self-assemble.

Work supported by HPC-Europa2 has exploited new techniques to allow large scale computer simulations of liquid crystals. The research uses high performance parallel computers; a network of computers that are all studying a different aspect of the process. The combination of many processors working efficiently provides a way of studying self-assembly processes that take place on long time scales and over long length scales which would otherwise be inaccessible to conventional simulations.

BSC MareNostrum supercomputer housed in the Torre Girona chapel



a)

b)

c)

Computer simulations of a liquid crystal:
a) molecular structure in the gas phase
b) the structure in a liquid crystal solvent
c) a bulk simulation of the liquid crystal

HPC-Europa2
Pan-European Research Infrastructure on High Performance Computing

» Are you as healthy as you feel?

The Survey of Health, Ageing and Retirement in Europe (SHARE) collects information about health, social well-being and the economic situation of more than 40.000 people all over Europe, taking into account the countries' different cultural backgrounds and public policy approaches. The survey's aim is to allow for a better understanding of the ageing process and to provide necessary information for reforms to Europe's social security and health care systems.

Ageing Europeans are increasingly healthy and active. More than 65% of respondents to a survey of those between 50 and 100 years of age say they are in good health. Self-rated general health shows large cross-country variations; the healthiest respondents live in Scandinavian countries and the least healthy live in Southern Europe. But that is only half of the truth.

Using objective health measures, such as grip strength and frequency of illnesses, the SHARE survey (Survey of Health, Ageing and Retirement in Europe) helps reveal interesting contradictions due to country specific reporting styles. For example, Germans rate their health a lot worse than it actually is. Objectively more than one third of Germans over 50 are in excellent health, but only one fifth actually say so. On the other hand, Danes and Swedes feel a lot healthier than they are. Almost half of them are very healthy according to their own rating, but only one third are according to SHARE health measures. By objective criteria the Swiss are the healthiest Europeans and, maybe not surprisingly, they are also those who spend most on their health.

As the number of healthy retirees grows rapidly relative to a declining workforce, pension systems are under pressure and it will be especially important to use the labour force at hand more efficiently in the future. SHARE data shows that in many European countries this is not yet the case. Nowadays older people today have a growing number of healthy life years, but nevertheless many leave employment early even if they do not have any functional limitations. The number of healthy persons between 50 and 64 who work ranges from 50% in Scandinavia to only 20% in Southern Europe and Poland. These differences between countries and welfare regimes are due to different institutional incentives and the varying job quality across European countries. From an individual point of view, leaving the labour market early can be a real problem in later life. Particularly in some Southern and Central European countries, people who retired early are more likely to be in financial hardship in the long run, especially if they need long term care later.

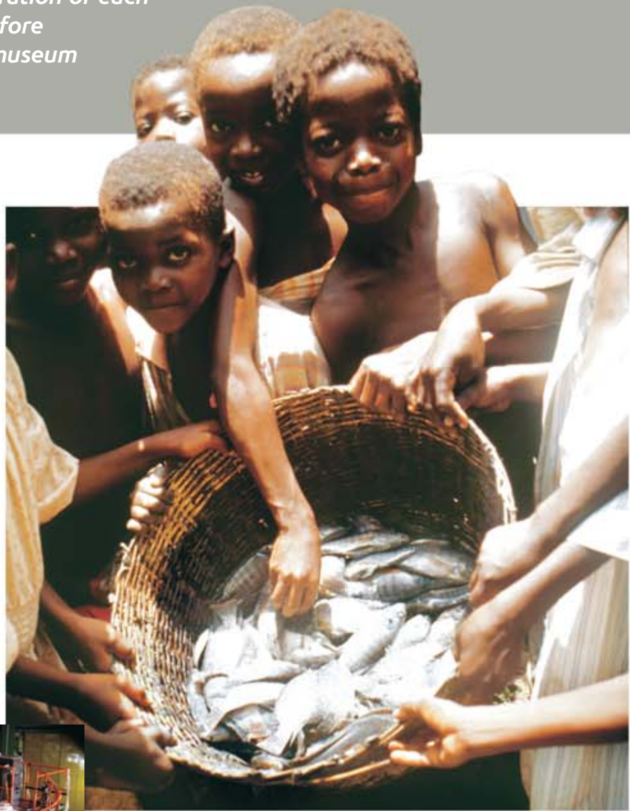
How to promote healthy, happy and active ageing is a major concern for all ageing societies. SHARE will help Europeans to tackle this demographic challenge.

SHARE
Survey of Health, Ageing and Retirement in Europe
50+ in Europe

for people

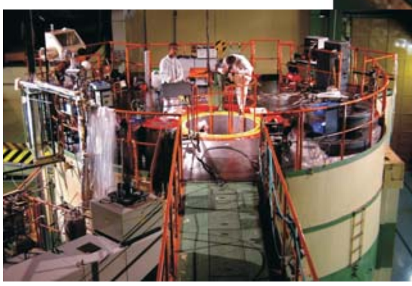
» Neutrons probe malnutrition in children

Neutron Activation Analysis is a powerful tool used to determine the concentration of elements in a sample. Chosen samples are bombarded with neutrons, this causes the elements within to emit patterns of radioactivity. By studying the radioactive emissions it is possible to reveal the concentration of each individual element. This process is non destructive and therefore increasingly used to analyse samples of value, for instance museum artefacts and works of art.



Malnutrition is one of the main causes of death amongst children in developing countries. A key factor is the uptake of trace elements from food, water and the environment. Some elements are toxic while others are essential to good health. Analysing hair samples provides a simple way of assessing their concentration. The trace elements are detected by using a source of neutrons to 'activate' them (induce nuclear reactions) so that they emit characteristic patterns of radioactivity. Instrumental Neutron Activation Analysis (INAA) can measure the concentrations of as many as 40 elements simultaneously.

Professor Nicholas Spyrou from the University of Surrey, UK, has been using INAA to evaluate health issues for more than 30 years. Recently, he and his team carried out studies in Tanzania to assess the effects of diet and environment on the health of children in different localities. A quarter of children in Tanzania suffer from malnutrition, mainly as a result of a poor diet lacking in protein or essential minerals.



Reactor hall at the Nuclear Research Institute Rez, Czech Republic

Measurements were made of 20 elements that are essential to good health or are toxic. The researchers studied hair samples from children on the island of Zanzibar, both in the city and in a fishing village, from Dar es Salaam on the mainland coast and from the inland region of Mount Kilimanjaro. The samples were analysed at the LVR-15 nuclear reactor of the Nuclear Research Institute Rez in the Czech Republic and the results compared with known elemental concentrations found in healthy children around the world.

Children in Zanzibar town had normal levels of trace minerals, but higher levels of cobalt and arsenic which might be associated with the local drinking water and food. Children in the village had low levels of zinc, copper and potassium, but higher levels of manganese, bromine and strontium, probably related to the mainly fish diet. Higher concentrations of iron and cobalt, but lower levels of the essential element zinc, were found in the Dar es Salaam group. Of more concern was that the children from Kilimanjaro had much higher levels of aluminium, which might come from the local volcanic soil in which vegetables are grown. Aluminium is toxic and non-essential, so this result requires further study. The hair samples also revealed elevated levels of vanadium, chromium and cobalt, which could be the result of pollution from local industries.

nmi3

Research Infrastructures for food

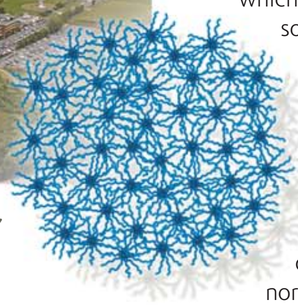
» Secrets of the perfect yoghurt

Beams of subatomic particles called neutrons are able to penetrate objects; they interact with the object's atoms in a characteristic way that reveals how they are arranged and how they behave. Neutrons have unique qualities that make them highly suitable for studying novel materials for advanced technology, as well as structures and processes significant to healthcare, food and consumer products, the environment and energy-generation. To produce neutrons requires large-scale facilities where researchers can go to carry out their experiments.

Milk is a key part of the human diet, providing an extremely versatile source of protein and calcium. For example, acidifying milk or allowing it to ferment causes most of the protein, called casein, to clump into 'curds' – the basis of cheese and yoghurt. Optimising the quality of these dairy products requires an understanding at the microscopic level of how the casein is distributed in milk and how this changes during processing.

Surprisingly, the details of the microscopic structure are still controversial. Electron microscopy had shown that the casein proteins, together with the mineral calcium phosphate, assemble into minute particles called micelles. However, it was not clear how the protein and calcium salt were arranged within them. One suggestion was that the micelles consisted of smaller clusters, containing a calcium phosphate core surrounded by a casein shell that effectively keeps the mineral in suspension. Other models suggested a more fluid assembly.

ISIS neutron source, STFC Rutherford Appleton Laboratory, UK



A casein micelle, showing its nano-cluster substructure

To clarify the structure, an international team of researchers has been using the ISIS neutron scattering facility at the STFC Rutherford Appleton Laboratory in the UK. Neutrons are ideal for looking at assemblies of large molecules, such as micelles, since neutron scattering at small angles gives information about the micelle size and shape. These experiments involved a particularly neat trick, which is to substitute some of the hydrogen atoms in the samples with deuterium atoms. This heavier version of hydrogen scatters differently from normal hydrogen, and so can be used to 'highlight' selected structural features, such as the casein component.

To understand the substructure better, the researchers added various substances that would break up the micelles in different ways. These included urea and a detergent (sodium dodecyl sulphate), which both disrupt the weak attractions holding the protein structures together, and sodium citrate – a food flavouring used to control acidity – which solubilises the calcium. These are processes that happen naturally in yoghurt production. The experiments showed that the micelles do fragment into the proposed clusters, eventually breaking down completely into separate protein molecules.

"The value of casein to the dairy industry is huge, and this is the first time that fragments of disrupted casein micelles have been characterised in such detail," says team member Kees de Kruif of NIZO Food Research in the Netherlands.

nmi3

integrated infrastructure initiatives

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http://i3.neutron-eu.net/

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