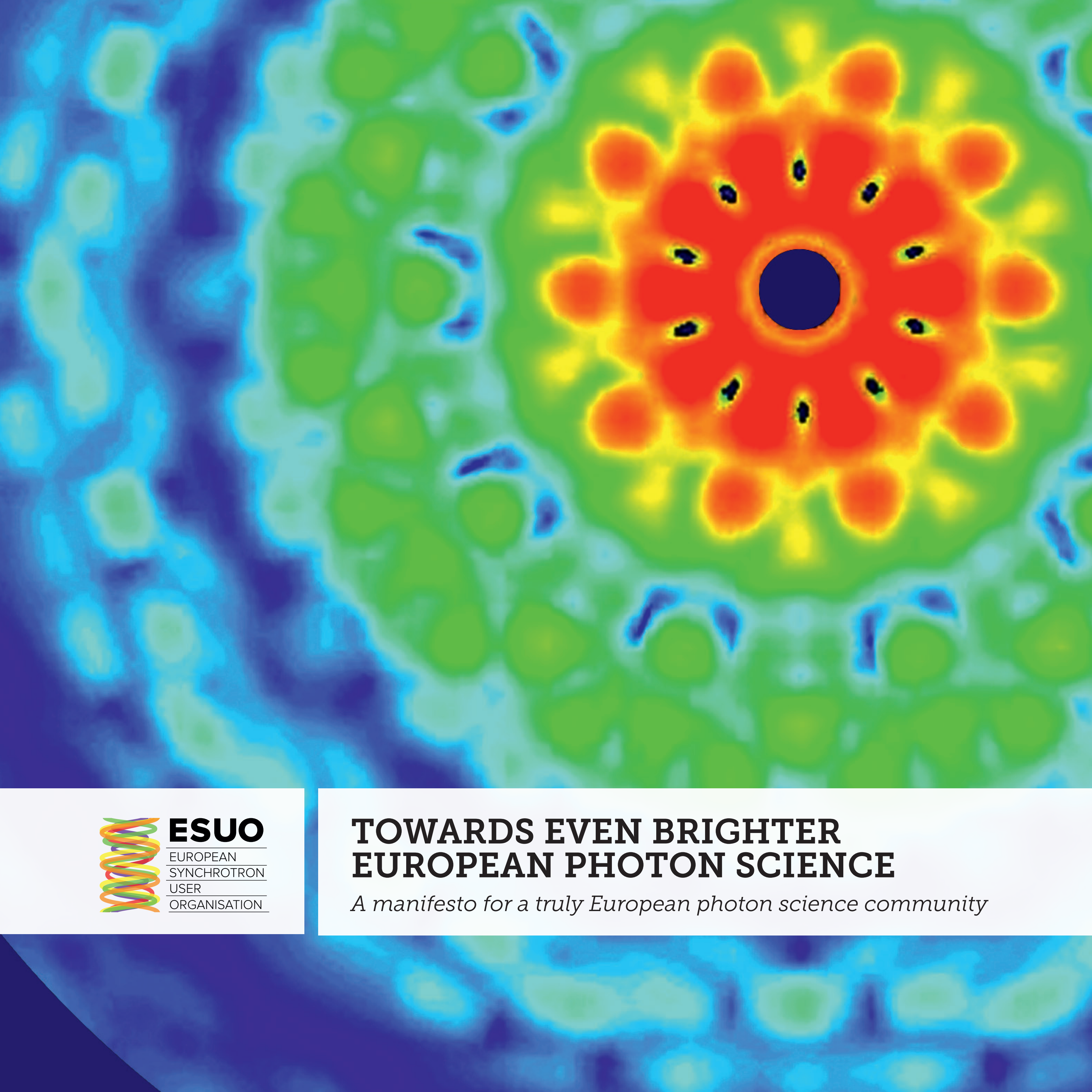


ESUO
EUROPEAN
SYNCHROTRON
USER
ORGANISATION

TOWARDS EVEN BRIGHTER EUROPEAN PHOTON SCIENCE

A manifesto for a truly European photon science community

CONTENTS

FLOODLIGHT OR SPOTLIGHT?

For enlightening science you need them both

Dear Reader,

Crystallography is the shotgun approach at its best. You shoot a large number of photons at a crystal, which is nothing else but a vast number of orderly arranged atoms or molecules. Some photons interact with parts of the crystal, but each of these interactions is too weak to gain much information from it. However, all interactions together reveal fantastic insights into the probe. This is how we learned about the structure of sodium chloride and DNA decades ago. Since then, the structures of many molecules have been revealed, the mechanism of energy transfer in solar cells understood, and the long-time stability of materials analysed – in the floodlight of photon sources called synchrotrons.

But sometimes you need a different approach, for instance when you cannot grow crystals that survive a continuous flood of photons, or when you study extremely fast processes like some catalytic reactions. In these special cases, free-electron lasers are the tools of choice. They provide much more photons in much shorter flashes.

Which tool is superior? The synchrotron's floodlight or the free-electron laser's spotlight? It turns out: none. Both approaches are complementary. They are both shaping our knowledge about matter.

Why am I telling you this? We at ESUO, the European Synchrotron User Organisation, see the complementarity of synchrotrons and free-electron lasers as an analogy for floodlight and spotlight approaches in European science funding.

The floodlight approach of the European Commission in FP6 and FP7 enabled a worldwide unique open access system to European light sources with equal research opportunities for scientists from a broad range of different thematic areas. We are very grateful for the strong and generous EC support granted to the light source facilities and user community during the last decade.

However, the EC philosophy has changed to a spotlight approach in Horizon 2020 – focusing on seven societal challenges.

Photon science has been contributing to these challenges and will continue to contribute. Moreover, we do support the idea of focused objectives. **But we have many reasons to believe that the new spotlight approach will keep many scientifically important projects in the dark** – projects that do not fit one of the seven challenges.

This will affect many of the 25,000 photon scientists ESUO represents and will endanger Europe's pole position in photon science in the long term.

Photon science is unique in its multidisciplinarity. This uniqueness calls for a mixture of floodlights and spotlights. The price tag will not be high, the leverage huge.

This brochure is a contribution to a hopefully fruitful discussion to which we are looking forward to.

Yours sincerely,

Prof. Dr. Dr. h.c. Ullrich Pietsch,
Chair of ESUO

TOWARDS EVEN BRIGHTER EUROPEAN PHOTON SCIENCE

A manifesto for a truly European photon science community

Research at light sources provides insight into all **societal challenges**. This unique feature of photon science stems from its multidisciplinary openness and vast spectrum of methods. Light sources are like Swiss Army knives: They allow scientists to examine the structure of matter and facilitate research projects that shed light into the medical field, into food security, sustainable agriculture and forestry, into climate change and clean energy, into green transport as well as into resource efficiency. The contributions of photon science – for instance in information technology – also affect the innovative, reflective and protective power of societies.

Photon science is truly **multidisciplinary**; at light sources, scientists from many different disciplines meet – be it bioscience, chemistry, physics, or environmental science. Moreover, many projects in photon science are truly **interdisciplinary**, bringing together experts from many fields who examine a common scientific problem. Multidisciplinarity and interdisciplinarity release synergies and foster the exchange of knowledge and experience.

While light sources are vast machines, they serve numerous, but rather small project teams for a short time each. These teams typically comprise only a few scientists. This does not leave much room for overspecialization. Instead each team member has to develop a vast spectrum of problem-solving techniques. As such, light sources are **ideal environments for the education and training of young people**.

1 Advocating open access to European light sources

While there are more than a dozen light sources in Europe, the facilities differ in potential and focus. Together, they provide a spectrum of methods that cannot be offered by each single one. European scientists should be able to select the source best suited for their research. **Thus: We keep strongly advocating quality-based open access to all European sources for all European photon scientists. Fully Europeanizing the access to national light sources will allow specialization of the sources for the merit of the scientific output, independent of whether a country operates an own national light source or not.**

2 Forming a pan-European light source user community

In recent years, European light source users became increasingly more connected – not least thanks to EU-based funding schemes. Scientists from countries across Europe – with national light source and without – met and have formed networks on various scales. These crystallization points of a stable user community strongly need further support.
Thus: We will continue to build a pan-European multidisciplinary light source user community – among others by organizing conferences, providing a central online access point to European light sources at wayforlight.eu, and connecting user subgroups.

3 Minimizing administrative obstacles

Good science knows to make clear why it is to be funded. But the more forms applicants have to fill in, the less time they can spend on pushing back the frontiers of knowledge. For small projects not exactly fitting one of Horizon 2020's seven societal challenges, the bureaucratic obstacles may become just too high. **We encourage everyone to discuss with us how to keep funding these projects possible. The prospective leverages are too high and the multidisciplinary possibilities of light sources are too promising, to miss this opportunity of thinking out of Horizon 2020's box.**

4 Increasing competition to increase competitiveness

The more scientists, the more ideas. Competition pushes the quality of the scientific outcome to an even higher level. The fittest ideas survive and increase Europe's competitiveness with respect to other world regions such as the USA or Asia. **Thus: A central objective of a European light source user community must be to spur on to ever-greater achievements. A pan-European market of scientific ideas will help to be ahead of the rest of the world – not just scientifically.**

5 Training scientists hands-on

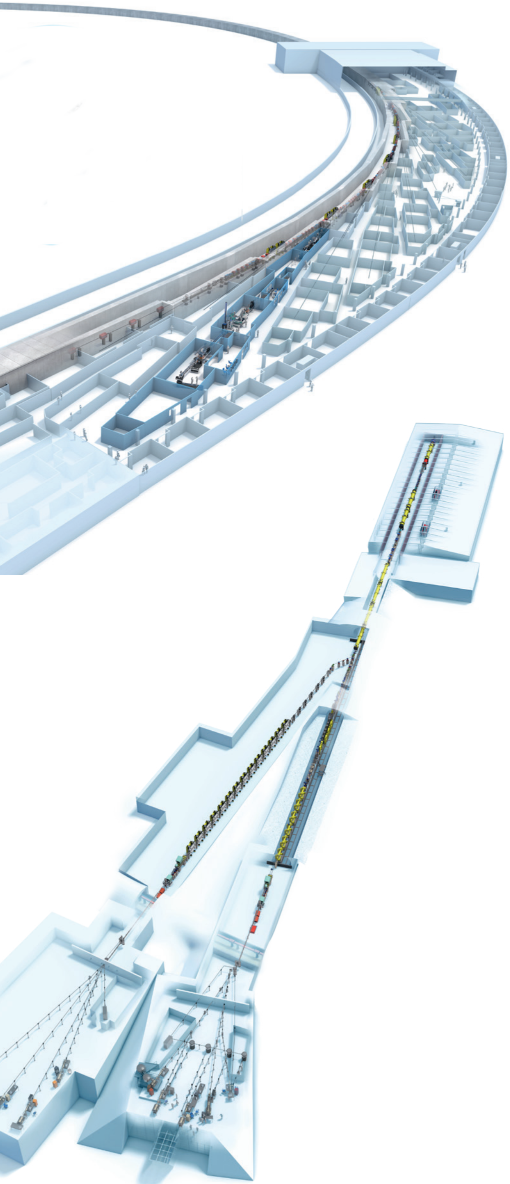
Europe is no uniform space. There are more and less developed regions, light sources are distributed unevenly. This must not result in reduced scientific opportunities for qualified scientists from countries without local national light source. Providing access and on-site experience is for the benefit of everyone. **Thus: We are determined to participate in a European training network that promotes photon science throughout Europe and provides hands-on practicums at European light sources.**

6 Assisting the industry in innovating

Light sources do not only offer beam time to publicly funded science, they also address industrial research. Yet, many industrial sectors in many European countries are not fully aware of these methodological possibilities. This has prevented and still prevents opportunities for innovation. **Thus: We will include the European industry in our efforts and show – through focused outreach activities – how to best benefit from modern light sources. There is no doubt that the involvement of the European industry will lead to exciting innovations and increase Europe's competitiveness.**

LOOKING BETTER AND BETTER INTO MATTER

Modern light sources provide the means of understanding the material world



A new era of science started when Wilhelm Conrad Röntgen discovered X-rays in 1895. For the first time in history, it was possible to look into matter and not just onto it. Not surprisingly, X-ray tubes have swiftly found their way into science and hospitals. But these tubes are not adequate for today's scientific applications, which hunger for more and more intense light. This is where synchrotron sources and free-electron lasers come in.

Making electrons shine

To generate light for photon science, you need electrons, a particle accelerator, and special arrangements of magnets. First, you accelerate the electrons in bunches to high energies. Next, you direct the particles through the magnets, which force them onto a tight slalom course. In this process, each individual electron emits radiation that adds up to an impressive intensity.

Looking into the material world

To obtain insights into the material world, scientists use the intense light from modern light sources in many different ways. The methods employed include imaging (taking pictures), diffraction (studying the superimposed deflection of light) and spectroscopy (measuring the energy of photons and other particles).

Understanding and controlling matter

The molecular world is a complex one. The better we understand this world, the more controllable it gets. The opportunities such control offers are countless – among them tailor-made materials, pharmaceutics with less side effects, new computer power and clean energy sources.

< Today's photon science uses two kinds of light sources: circular synchrotrons (top) and linear free-electron lasers (bottom). The light of the latter is much more focused and brighter.

Solving the societal challenges multidisciplinarily

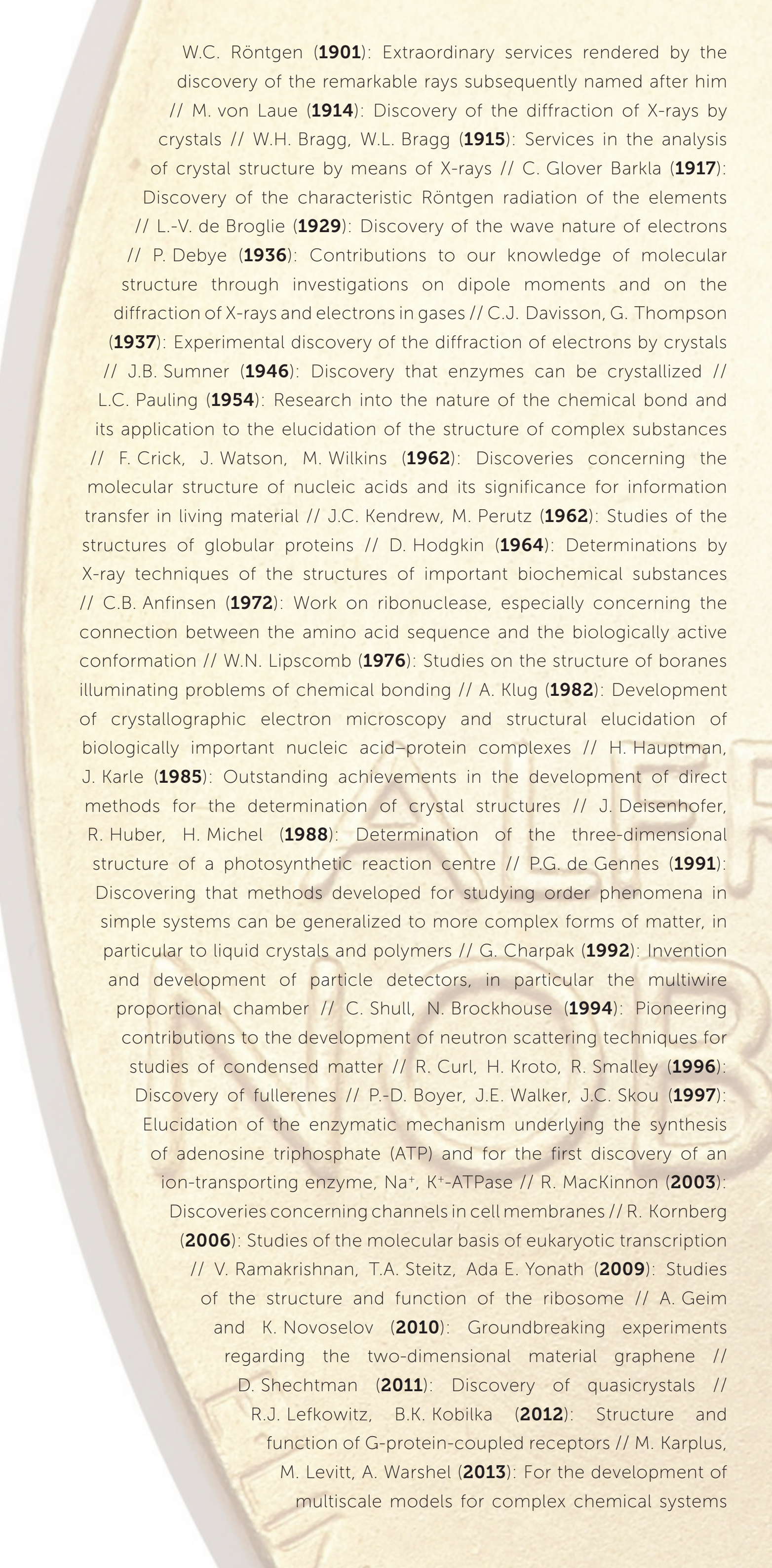
Photon science enables us to **tackle many current societal challenges** – be it health and wellbeing, new paths for secure, clean and efficient energy, environmental issues, resource efficiency, and raw materials.

From the beginning, X-rays were used for **medical science** and as a common diagnostic technique. Photon science has made accessible the **structure of simple and complex crystals**, which has laid the foundation for many technical, medical and pharmaceutical applications. Photon science also helped us study **catalytic processes**, understand the mechanism of energy transfer in **solar cells**, unravel the structure of **superconductors,** and detect **trace elements**.

Without photon science, we would still theorize about the workings of genetics, but since the days of James Watson and Francis Crick we have known the exact shape of the molecules containing our **genetic code**. In recent decades, photon science helped us to decipher the structure of more and more molecules. Ever better light sources allow ever higher temporal and spatial resolution. The scientists' dream of **molecular movies** is in reach.

Photon science sheds light on the small pieces of bigger and more complex systems. You don't use synchrotron light to directly study a whole brain, a photovoltaic cell, or an airplane engine. However, to gain control over the clockwork, you need to better understand the workings of the gear wheels.

Photon science earned 28 Nobel Prizes >



W.C. Röntgen (**1901**): Extraordinary services rendered by the discovery of the remarkable rays subsequently named after him // M. von Laue (**1914**): Discovery of the diffraction of X-rays by crystals // W.H. Bragg, W.L. Bragg (**1915**): Services in the analysis of crystal structure by means of X-rays // C. Glover Barkla (**1917**): Discovery of the characteristic Röntgen radiation of the elements // L.-V. de Broglie (**1929**): Discovery of the wave nature of electrons // P. Debye (**1936**): Contributions to our knowledge of molecular structure through investigations on dipole moments and on the diffraction of X-rays and electrons in gases // C.J. Davisson, G. Thompson (**1937**): Experimental discovery of the diffraction of electrons by crystals // J.B. Sumner (**1946**): Discovery that enzymes can be crystallized // L.C. Pauling (**1954**): Research into the nature of the chemical bond and its application to the elucidation of the structure of complex substances // F. Crick, J. Watson, M. Wilkins (**1962**): Discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material // J.C. Kendrew, M. Perutz (**1962**): Studies of the structures of globular proteins // D. Hodgkin (**1964**): Determinations by X-ray techniques of the structures of important biochemical substances // C.B. Anfinsen (**1972**): Work on ribonuclease, especially concerning the connection between the amino acid sequence and the biologically active conformation // W.N. Lipscomb (**1976**): Studies on the structure of boranes illuminating problems of chemical bonding // A. Klug (**1982**): Development of crystallographic electron microscopy and structural elucidation of biologically important nucleic acid–protein complexes // H. Hauptman, J. Karle (**1985**): Outstanding achievements in the development of direct methods for the determination of crystal structures // J. Deisenhofer, R. Huber, H. Michel (**1988**): Determination of the three-dimensional structure of a photosynthetic reaction centre // P.G. de Gennes (**1991**): Discovering that methods developed for studying order phenomena in simple systems can be generalized to more complex forms of matter, in particular to liquid crystals and polymers // G. Charpak (**1992**): Invention and development of particle detectors, in particular the multiwire proportional chamber // C. Shull, N. Brockhouse (**1994**): Pioneering contributions to the development of neutron scattering techniques for studies of condensed matter // R. Curl, H. Kroto, R. Smalley (**1996**): Discovery of fullerenes // P.-D. Boyer, J.E. Walker, J.C. Skou (**1997**): Elucidation of the enzymatic mechanism underlying the synthesis of adenosine triphosphate (ATP) and for the first discovery of an ion-transporting enzyme, Na^+, K^+-ATPase // R. MacKinnon (**2003**): Discoveries concerning channels in cell membranes // R. Kornberg (**2006**): Studies of the molecular basis of eukaryotic transcription // V. Ramakrishnan, T.A. Steitz, Ada E. Yonath (**2009**): Studies of the structure and function of the ribosome // A. Geim and K. Novoselov (**2010**): Groundbreaking experiments regarding the two-dimensional material graphene // D. Shechtman (**2011**): Discovery of quasicrystals // R.J. Lefkowitz, B.K. Kobilka (**2012**): Structure and function of G-protein-coupled receptors // M. Karplus, M. Levitt, A. Warshel (**2013**): For the development of multiscale models for complex chemical systems

THE EUROPEAN LIGHT SOURCE LANDSCAPE

18 light source centres, tens of thousands of users, and one user organization

18 light source centres

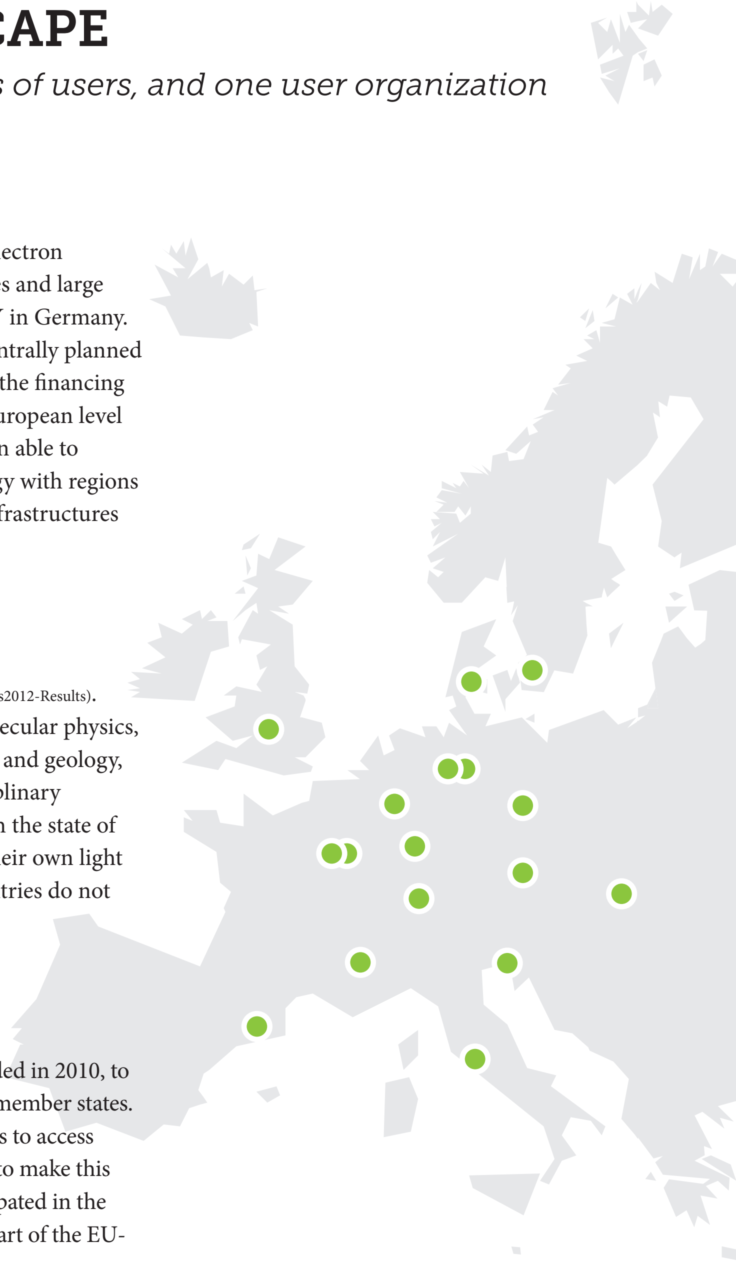
Europe hosts 18 centres with facilities for synchrotron and free-electron laser research – among them, small ones with just a few beamlines and large infrastructures like ESRF in France, Diamond in the UK or DESY in Germany. ◆ The landscape of European photon science centres is neither centrally planned nor organized. With the exception of ESRF and European XFEL, the financing is to a large extent national, although infrastructure funds on a European level have helped to improve national centres. ◆ So far, Europe has been able to compete in terms of scientific progress, innovation and technology with regions of comparable critical mass like USA or Japan, whose research infrastructures are more centrally and efficiently organized.

25,000 users and counting

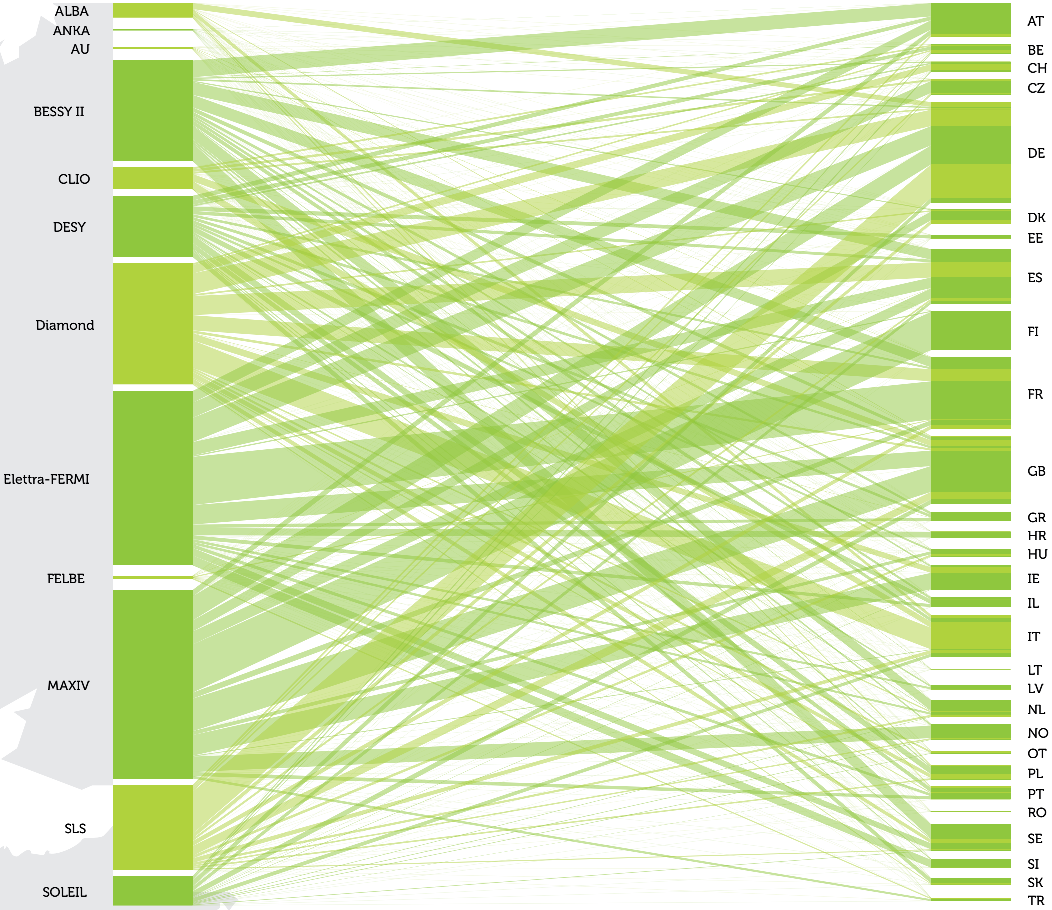
The European light sources serve about 25,000 users (pan-data.eu/Users2012-Results). ◆ These users sport very different scientific backgrounds – in molecular physics, materials science, organic and inorganic chemistry, biochemistry and geology, among others. This makes photons science a uniquely multidisciplinary endeavour. ◆ The light source users come from countries in which the state of photon science varies dramatically. While some countries have their own light sources and vivid national user organizations, more than 10 countries do not even offer funding on a national level.

1 European user organization

ESUO – the European Synchrotron User Organisation – was founded in 2010, to represent all European photon science users. Today, ESUO has 25 member states. ◆ One of ESUO's main objectives is to enable all European scientists to access appropriate light sources solely on the basis of scientific merit and to make this access as simple as possible. ◆ As a counselling body, ESUO participated in the development of standardizations of beam lines and proposals (as part of the EU-funded CALIPSO project) available at wayforlight.eu.



The diagram shows the national interweaving of research at European light sources. The left side displays selected light sources and their respective beamline hours used for transnational access. These hours are correlated to the group leaders' home institution countries (right side).



The data are provided by the EU-funded CALIPSO project (calipso.wayforlight.eu) which among others offered Transnational User Access to about 1,500 European users in a time span of 18 months. The project is coordinated by Elettra in Italy and groups 20 research organisations in Europe.

GUIDING CONSERVATION IN THE ARTS

A European team has used light sources across the continent to study the ageing process of medieval paintings. Their insights help conservators to choose the best approach for restoration.

> ***"For our studies we needed access to very different analytical techniques. These we could only find at different light sources. In total, we utilized six different laboratories. This unique European offer has proved very useful for Europe's heritage of medieval artworks; it should be preserved, too."***
>
> Nati Salvadó,
> project leader

For artistic effect, medieval altarpieces often exhibit golden and silvery areas created by means of very thin metal foils. To attach these foils to the background, adhesive substances like egg yolk, drying oil or animal glue were used. Additionally, varnishes were applied for protection from the atmosphere.

The ravages of time have taken their toll on numerous of these precious masterpieces. In many cases, the silvers blackened, partially reversing the intended effect. To restore these medieval artworks, you need to understand the alteration processes.

This is the objective of Nati Salvadó from *Universitat Politècnica de Catalunya* and her team. Their study involves the analysis of micrometric layers formed by a large variety of compounds – some of them present in extremely low amounts. Thanks to their high resolution and small footprint, analytical techniques with synchrotron radiation prove to be most adequate for these studies.

The team was able to show that the studied alterations are mostly due to atmospheric corrosion occurring through the damaged varnish or cracks in the painting, and not due to reactions with the adhesive substances. This knowledge is of extremely high value for conservator and restorers who want to make the paintings shine again in their original beauty.

The medieval altarpiece "Santa Llúcia", MNAC: The arrow indicates where one of the studied samples was taken from.

NEW CLASS OF MATERIALS DISCOVERED

You don't discover a new class of materials every day. A Polish team of physicists had this rare privilege – with help of theoretical models and radiation from the Swedish light source MAX Laboratory.

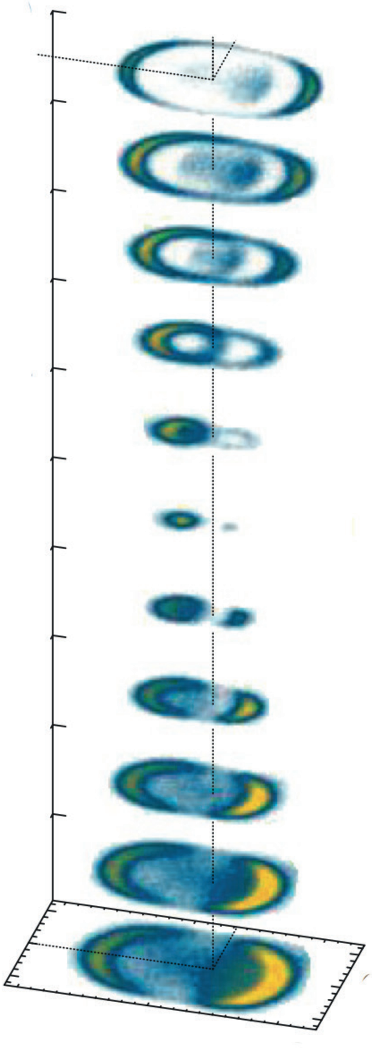
"I am sure that our discovery would not have been possible without European support. Poland has not got a national light source – yet. The collaboration with MAX IV Laboratory has been so fruitful, it has even made feasible the plans for our own source SOLARIS."

Bogdan Kowalski,
project leader

Topological insulators conduct electrical currents on their surfaces only – a neat feat for which the combined efforts of no less than quantum theory, time-reversal symmetry and relativistic effects are necessary. Not just due to this theoretical extravagance, the discovery of topological insulators has been hailed one of the most important recent developments in condensed-matter physics.

In 2011, theoretical calculations suggested the existence of topological *crystalline* insulators, a new class of topological materials in which crystalline symmetry plays the role of time-reversal symmetry. Shortly thereafter, a team of Polish physicists around project leader Bogdan Kowalski discovered the first topological crystalline insulator of its kind – by using synchrotron radiation at Max-lab in Sweden and cooperating with Swedish colleagues.

Unlike time-reversal symmetry, crystalline symmetry can be broken by stretching or squeezing the respective system. This enables you to deliberately open or close conducting channels using mechanical pressure. This feature could be employed in components used in areas such as energy, electronics, and the computer industry.



Compare measurements like this with theoretical predictions to know if you have found something new.

STUDYING AIR POLLUTION IN LONDON

European scientists looked into the chemical composition of aerosols from London. To cover the full range of elements, a Swiss and a German light source had to be used.

> ***"Our analysis has profited vitally from the access to two synchrotron facilities. At our home light source SLS, we could perform high resolution studies in the range of the lighter elements. But we needed access to DESY to shed light on the heavier pollutants."***
>
> Suzanne Visser,
> PhD student

Air pollution in London has been a problem for many decades. In particular, particulate matter was found responsible for adverse health effects, such as pulmonary or cardiovascular diseases.

To better characterize the conditions leading to critical pollution situations in London, a one-year field project dubbed *ClearfLo* was carried out in 2011 and 2012. A dozen universities from the UK and several institutes from other countries were involved, among them the Paul Scherrer Institute in Switzerland.

The Swiss project, led by Markus Furger, analysed the elemental content of air samples using synchrotron radiation at the Swiss Light Source for the lighter elements (sodium to zinc) and at DESY in Germany for the heavier elements (titanium to lead).

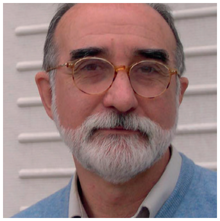
The combined results allowed the team to identify anthropogenic and natural sources.

Barium and antimony, for example, show a double maximum in the course of a day that coincides with the traffic rush hours. Both elements are known to originate from brake wear in vehicles. Sodium and magnesium, however, do not show such a variation as they originate mainly from sea salt.

One of two sample collection stations in London. The analysis was carried out in Switzerland and Germany.

INVESTIGATING A SPREADING DISEASE

Spanish researchers used a special kind of low-temperature X-ray microscope at BESSY in Berlin to take three-dimensional pictures of vaccinia-infected cells.



"Since we needed the unique setup that only BESSY could offer, we relied on transnational access for carrying out our experiments. This has turned out to be an extremely fruitful intra-European endeavour."

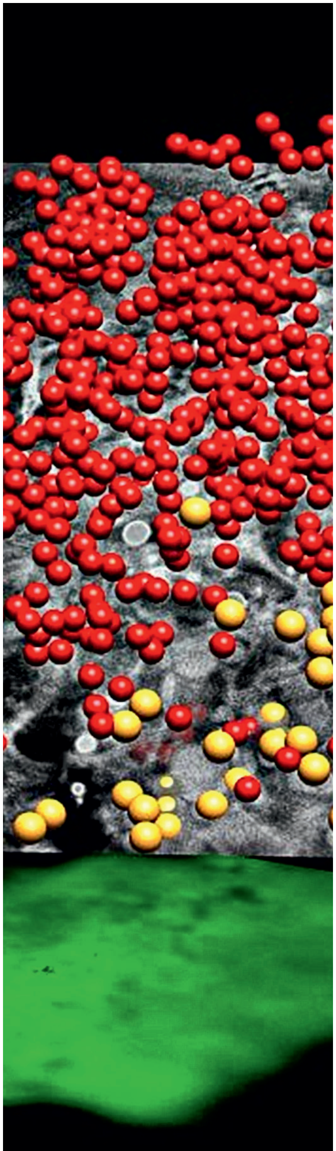
José L. Carrascosa,
project leader

For plagues like vaccinia to spread around the world, their viral agents have to spread within infected cells first. After the viruses have trespassed the cellular membranes, they make the cell build copies of themselves and occupy more and more parts of their involuntary host.

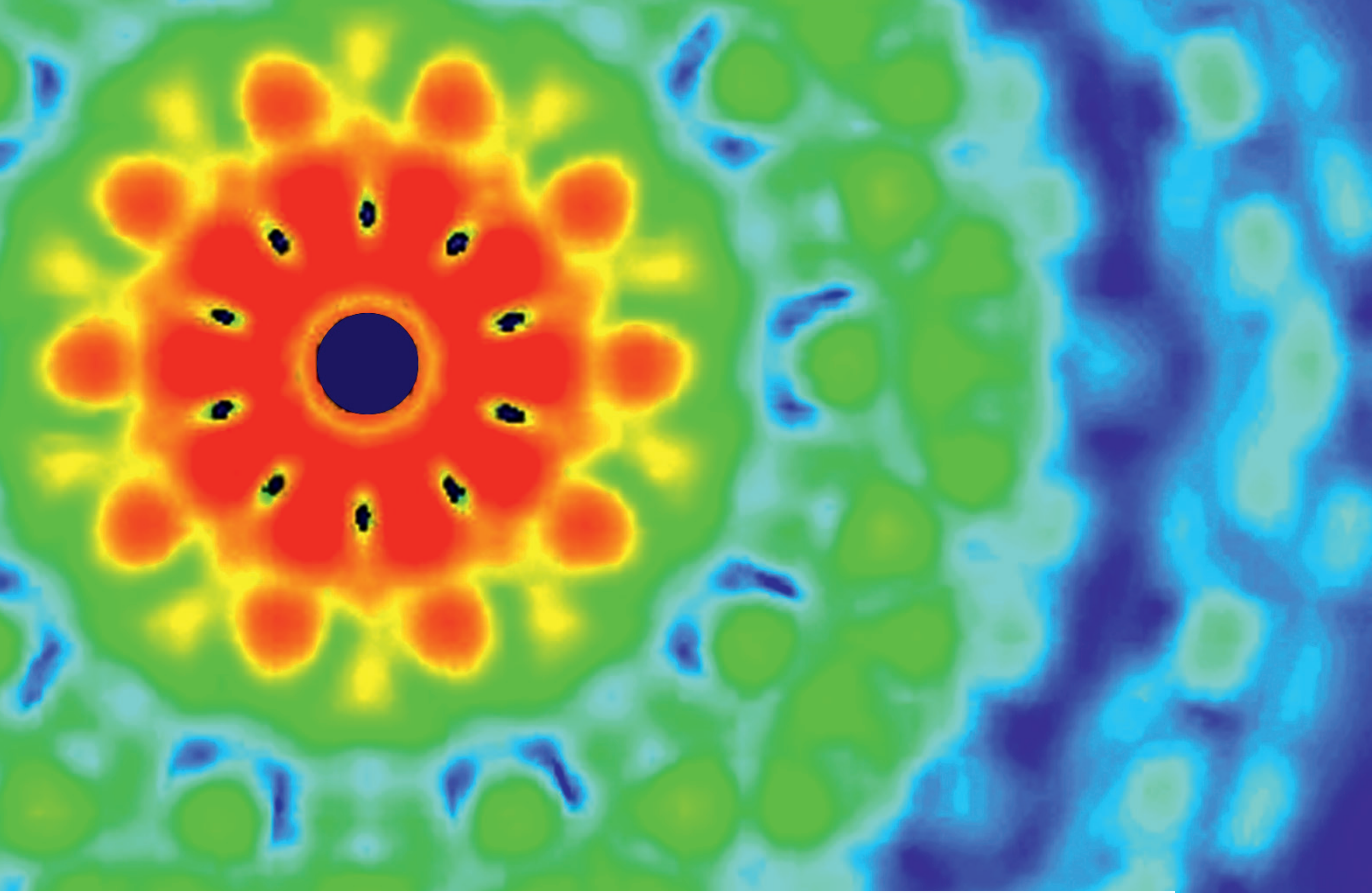
But which parts of the cell are infected first? Which the most? And how about the distribution of still immature and already mature viral particles? Answers to these questions are crucial to better understand the inner workings of plagues – and also of less intimidating diseases. With every piece of knowledge we can glean, our possibilities to counteract increase.

To observe the intracellular spreading of vaccinia viruses, researchers from Madrid and Barcelona used the cryogenic X-ray microscope at BESSY II in Berlin. This approach allowed them to overcome the limitations of conventional electron microscopy.

To obtain steady, unblurred pictures, José L. Carrascosa and his team froze the cells several hours after infection, before using X-rays generated by BESSY II for the photo shooting.



Vaccinia-infected cell: Yellow spheres mark the location of immature virus particles, red spheres represent mature ones.



Cover image
X-ray diffraction image of randomly oriented nano particles. Diffraction images like this are counted among the intermediate results photon scientist have to interpret when they examine samples by X-rays. These images are related to the original objects by mathematical rules called Fourier transformation. The tenfold symmetry of the image (the ten leaves of the flower) allows to deduce that the particles spot a fivefold symmetry.

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Proof reading: Ilka Flegel, Jena **Image credits**: B. Pedrini, PSI, and C. Gutt, Universität Siegen (cover/back); DESY and illustrato, Franziska Lorenz & Jochen Stuhrmann, Hamburg (page 6); Dirk Rathje (page 9); the corresponding projects (pages 10-13)