Francesco Sette

Profile

Francesco Sette's scientific interest and training is on the study of the fundamental properties of condensed matter and on their experimental determination. Aiming to relate material behaviour to the material atomic structure and dynamics, and to its chemical bonding, using synchrotron X-rays, he carried out experimental studies on materials as semiconductors, transition metal oxides and highly correlated systems, as well on states of matter as surfaces, interfaces, molecular systems, and liquids. These studies, measuring local electronic and magnetic properties with X-ray scattering and spectroscopy techniques, investigate the connection among local interatomic structures and macroscopic properties as magnetism, superconductivity, giant magneto-resistance, phase transformations, etc. To implement innovative research, Sette has engaged himself in the development of new and first-of-a-kind synchrotron-based X-ray techniques enabling new investigations. His principal scientific contributions are in the determination of the orbital and spin parts of magnetic moments of a specific atomic species in magnetic materials, and the measurement and identification of structural relaxation effects of hyper-sound propagation in disordered materials and liquids.

Since 2001, becoming Director of Research first and then Director General of the European Synchrotron Radiation Facility (ESRF), his interest and career activities progressively turned towards science programmes development, implementation and management.

F. Sette is considered a pioneer in synchrotron radiation research and technology, an area to which he has devoted the whole of his professional career. With an activity of more than 35 years in the field, he has distinguished himself as a:

- Experimental X-ray scientist (1980-2000), for his scientific contributions in condensed matter physics, and technical developments in synchrotron radiation instrumentation and techniques.

- Science director, manager and executive officer (2001-present), in leading the ESRF during the last decade, and conceiving and implementing its ambitious Upgrade Programme which has totally renewed the facility after approximately 30 years from its initial conception and delivery. In line with the ESRF mission to serve the most demanding synchrotron user community from the ESRF Member Countries and all over the world, his leadership of the ESRF has strongly contributed to further strengthen the ESRF pioneer position and world reference in synchrotron science, and making the ESRF today the role model for every existing and planned synchrotron laboratory.

The inspiring principle of the activity of F. Sette as Director General of the ESRF is to foster scientific excellence, and on such base, to:

- Enable scientific research and technological innovation which is competitive, sustainable, accountable, attractive and transparent;
- Create exciting opportunities to attract, educate, train and motivate the best people in synchrotron science and technology and in science-programme administration;
- Strive for full integration at the ESRF among different genders, cultures, origins, and ages of ESRF staff and users;
- Outreach to the citizens to illustrate the power and value of scientific research, and highlighting its return to society;
- Create as much as possible opportunities for the industrial exploitation of ESRF-generated intellectual property with the purpose to increase industrial competitiveness and job creation in the ESRF partner countries;
- Favour as much as possible cooperation (both at the local level in the Grenoble area and with research organisations in the partner countries and beyond) with the objective to make the ESRF more visible, stronger and widely supported in its world-flagship role for the advancement of synchrotron science, technology and education.

F.Sette is author of more than 300 publications in scientific journals, among which more than 60 on high-impact journals (Physical Review Letters, Nature, Science). He has received several prestigious recognitions and awards for his work, and participated in many international science programme review committees and search and interview panels.

Francesco Sette (FS)
Curriculum Vitae 21 july 2021

Date and place of birth: 8 August 1957 – Roma, Italia
Citizenship: Italy

Civil status: married with four children

Education: Dottore in Fisica (1982) - Summa cum Laude – Università di Roma "Studium Urbis" (today "La Sapienza"), Italy

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Present employment: (2009-2024): Director General, European Synchrotron Radiation Facility, Grenoble, France, http://www.esrf.eu/

Languages: English, French and Italian

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Curriculum Vitae

Summary

I am the Director General of the European Synchrotron Radiation Facility (ESRF) since 1 January 2009.

I hold a doctorate in physics from the University of Rome obtained in 1982.

After my thesis work carried out at the INFN Laboratories in Frascati, I spent eight years in the USA out of which one at Brookhaven National Laboratory in Upton (NY) and seven at the AT&T Bell Laboratories in Murray Hill (NJ) and joined the ESRF in 1991.

Twenty years ago, I co-invented the world's first high energy resolution, high intensity soft X-ray source, which quickly found its way into many synchrotron light facilities throughout the world.

Later, as a group leader at the ESRF, I developed a new generation of inelastic X-ray scattering beam lines, which made possible novel studies on atomic motion and electronic properties of condensed matter using X-rays.

I am fully involved in the operation and upgrade of the ESRF and in the establishment of the long-term strategic mission of this European Facility in the European and Worldwide context of analytical large-scale infrastructures dedicated to research on condensed matter, materials, living matter, and unique cultural heritage artefacts.

I promoted and contributed since 2003 to a global reflection and study for a new generation of diffraction limited high energy photon sources, required for the next steps in fundamental and applied discovery in areas such as clean energy, climate change, health, food and cultural heritage preservation.

I started and presently implementing the ESRF Upgrade Programme (UP), a programme supported by a 500 M€ investment plan started in 2009 and aiming to strengthen and maintain the ESRF leadership in X-ray science. Under my leadership, the UP first phase (2009-2015, 250 M€)) was delivered in time and within budget. This first phase was also the genesis of the UP second and final phase, dubbed the ESRF Extremely Brilliant Source (EBS) programme (2015-2023, 250 M€). I am presently leading the implementation of the EBS programme, which consists of the construction and commissioning of the first of a new kind of very low horizontal emittance and high brightness high energy storage rings, and of an ambitious programme of new instruments exploiting this new X-ray source. The EBS storage ring has been delivered on time and within budget, and is presently in user operation since 25 August 2020 outperforming the most optimistic expectations. The EBS X-ray source id today unique, and its concept is presently being copied worldwide, and is inspiring ongoing and planned upgrade and construction programmes of all synchrotron facilities in the world.

Key Dates:

1) 08-08-1957 – Birth in Rome – Italy
2) 23-06-1982 – Graduation in Physics – University of Rome (Studium Urbis today “La Sapienza”), under Prof. F. Bassani and R. Rosei.
3) 09-1982 to 05-1983 – Scientific Associate to INFN in Laboratori Nazionali di Frascati
4) 06-1983 to 05-1984 – Postdoctoral Fellow at NSLS – Brookhaven National Laboratory
5) 06-1984 to 12-1990 – Member of Technical Staff at AT&T Bell Laboratories – Surface Science Department – Responsible of the AT& Bell Laboratories U4 Beamline at NSLS – Construction of the Dragon Beamline with C.T. Chen: opening of high energy resolution soft X-ray spectroscopy and soft X-ray Circular Magnetic Dichroism, worldwide.
6) 01-1990 to 09-2001 – Senior scientist and Group Head of the Inelastic X-ray Scattering Group at the ESRF – Construction of the ID16 Inelastic X-ray Scattering beamline. Opening high energy resolution phonon spectroscopy with X-ray worldwide.
7) 1990-1992 – Discovery of sum rules for XMCD, with P. Carra and T. Thole.
8) 10-2001 to 12-2008 – Director of Research at the ESRF – Conception, consolidation and launching of the ESRF Upgrade Programme Phase I.

9) 2009 to 2015 – Director General of the ESRF – Successful implementation of the Upgrade Programme Phase I in time and within budget.
10) 2015 to present – Director General of the ESRF – Conception, consolidation, launching and implementation of the ESRF Upgrade Programme Phase II – the ESRF Extremely Brilliant Source Programme, which is due by 2023.

Extended Curriculum Vitae

1) The early days

I was born in Rome – Italy on 8 August 1957. I grew up in Rome, where I followed classical high school studies, which included Greek, Latin, philosophy and human history.

I began my higher education in physics after a starting year in mathematics, profiting of the fact that at the *Studium Urbis* (Founded in 1303 by Pope Boniface VIII) the first two years at the Mathematics (G. Castelnuovo) and Physics (G. Marconi) Institutes are interchangeable. The *Studium Urbis* is nowadays known as University of Rome "La Sapienza".

Istituto di Fisica Guglielmo Marconi – Roma

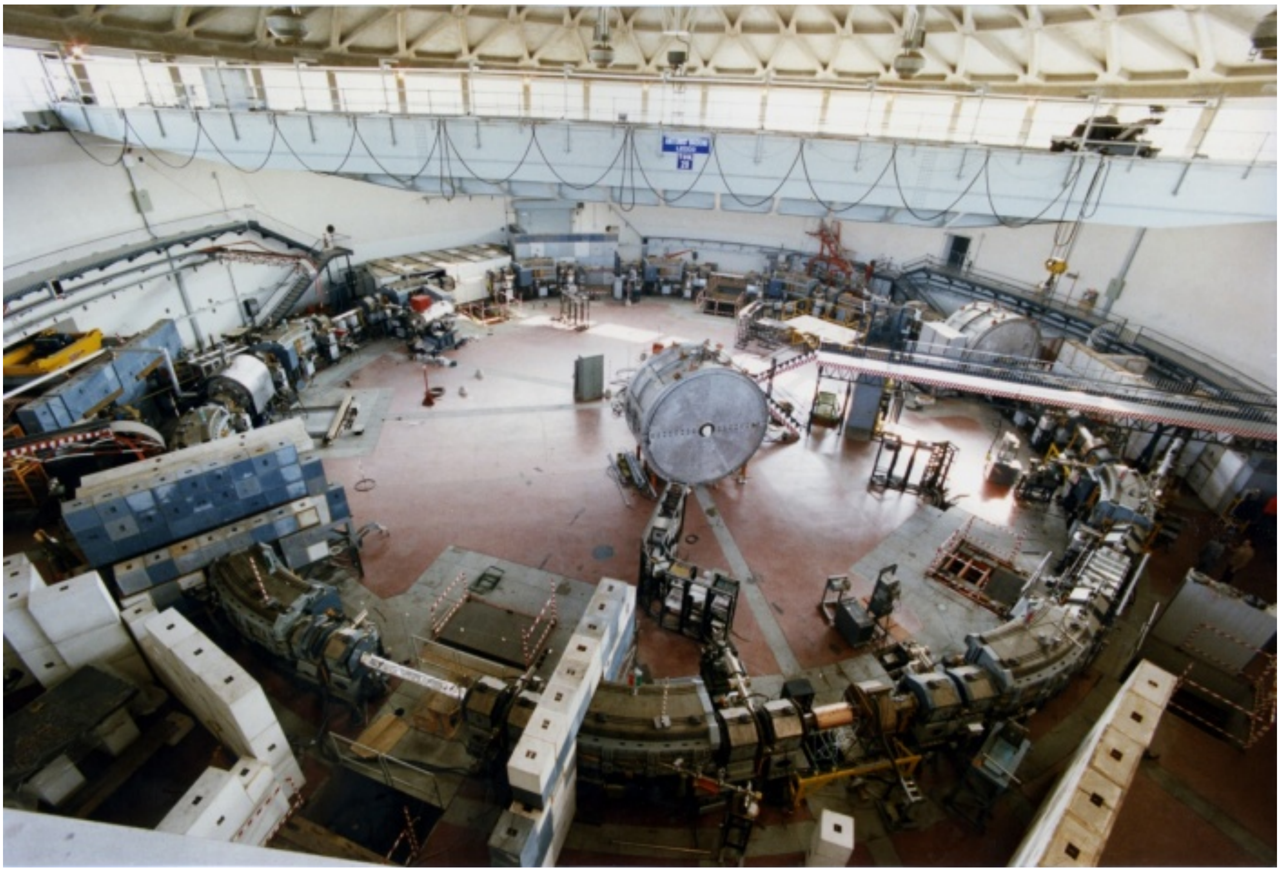
Initially, my interest was in theoretical high energy physics, and I was fascinated by the elegance of the *relativistic quantum electrodynamics* theory and the *Dirac equation*. Finally, however, I decided to dedicate myself to condensed matter experimental physics, joining in 1979 the pioneering programme in synchrotron radiation research that at the time was launched at the Laboratori Nazionali di Frascati of the Italian Institute of Nuclear Physiscs (INFN) by the CNR (Consiglio Nazionale delle Ricerche). It was called PULS (Programma di Utilizzazione della Luce di Sincrotrone), and was the first Italian full-fledged synchrotron user programme using X-rays from the INFN storage ring ADONE.

2) The Frascati times (1979-1983)

My thesis work was carried out under the supervision of Professors Franco Bassani and Renzo Rosei at the PULS, and contributed to the construction and operation of the synchrotron radiation beamlines of this programme.

I largely contributed to the construction and commissioning of the photoemission beamline, and my thesis work was on the study of the electronic properties of metal-semiconductor interfaces and on the adsorption of simple organic molecules on transition metal surfaces using photoemission and electron energy-loss spectroscopies. I published in those early 80's years, a paper reporting the first observation of the formation of a single-atom thick self-standing layer of ordered graphene on a nickel metal Ni(111) surface substrate.

This seminal work ("Structure of graphitic carbon on Ni(111): A surface extended-energy-loss fine-structure study", R. Rosei, M. De Crescenzi, F. Sette, C. Quaresima, A. Savoia, and P. Perfetti, Phys. Rev. B 28, 1161(R) – Published 15 July 1983) was carried out about ten years before the "discovery" of single-atom-thick floating graphene films, which was recognized with the assignment of the Nobel Prize in Physics to the discoverers Andre Geim and Konstantin Novoselov in 2010. A. Geim explicitly cite this work in his Nobel Lecture "Random walk to graphene" published in Reviews of Modern Physics, Volume 83, July-September 2011.



View of the ADONE storage ring and of the PULS beamlines (1982)

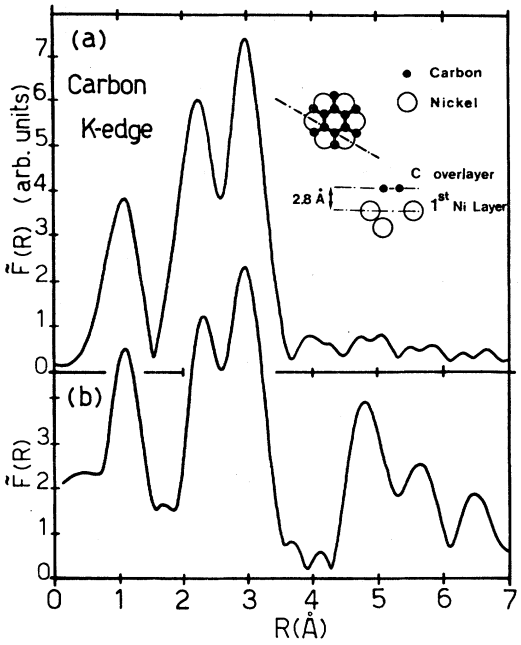


FIG. 3. (a) Fourier transform of an EXAFS model calculation for the system C_{graph}/Ni(111) around the carbon K edge. Phase shifts and amplitudes are taken from Ref. 25. The parameters used were the following: C-C_1 = 1.45 Å, $\sigma_1^2 = 0.003$ Å^2, and $N_1 = 3$; C-C_2 = 2.50 Å, $\sigma_2^2 = 0.009$ Å^2, and $N_2 = 6$; C-Ni = 3.10 Å, and $\sigma_3^2 = 0.009$ Å^2, $N_{Ni} = 3$. The Fourier integration is performed with the same limits used for the experimental $\tilde{F}(R)$ [curve (b)].

3) The USA times (1983 – 1990)

In the 1983-84 period, after completing my thesis work and continuing for a few months to support the beamline activities in Frascati, I was appointed Post-Doctoral fellow at the National Synchrotron Light Source (NSLS) in Brookhaven National Laboratory (BNL) in Upton (NY – USA) under the supervision of Professor J. Stöhr. With the typical freedom of a post-doctoral fellowship in the US, I inspired my work during this time from the work of C. Natoli – an INFN theoretical physicist whom I met extensively during my thesis work in Frascati –, who was interested to understand to which extent features in the near edge X-ray absorption spectra of molecules can be related to the local atomic structure around the X-ray excited atom. In 1983, using the “Grasshopper” beamline at the Stanford Synchrotron Radiation Laboratory (SSRL), I started a systematic experimental study of unbound near edge excitations in core state X-ray absorption spectra of light organic molecules (σ-shape resonances), with the aim to assess whether a relation would exist between the excitation energy of these resonances and the intra-molecular geometry of the considered molecule. I did this in gas molecules for which the internal structure was known, and indeed found an evident correlation, which – once parametrized – was then used to determine on a differential basis the structural modifications induced by processes which do not destroy the molecule but slightly modify its internal geometry.

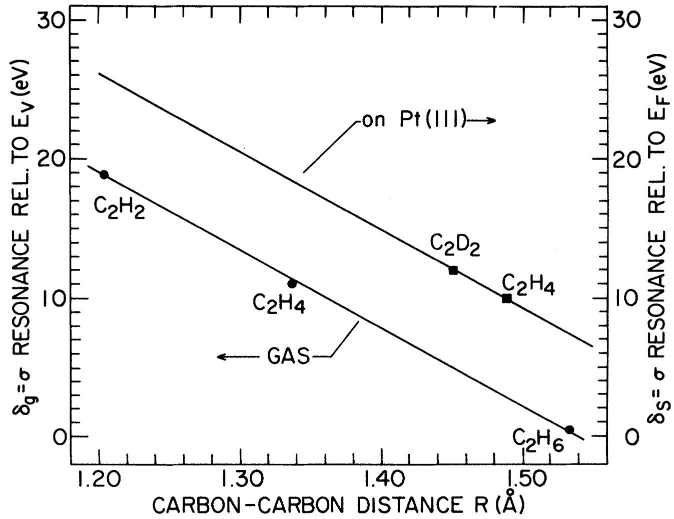


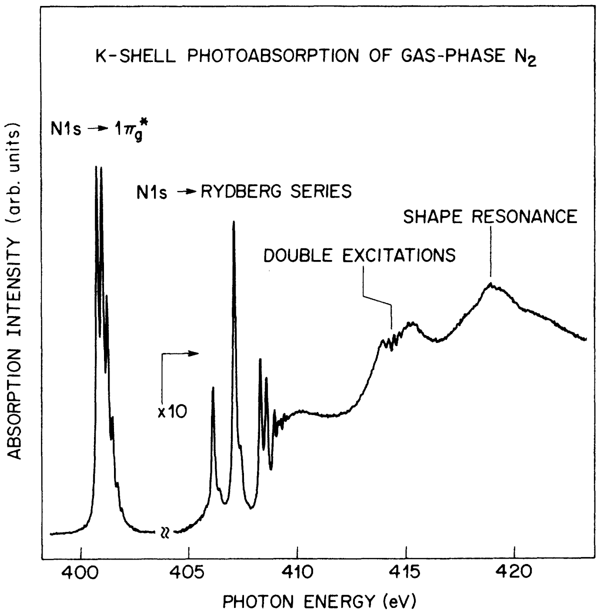
FIG. 1. Plot of the σ shape resonance position relative to the vacuum level E_v for gas-phase molecules (δ_g) (Ref. 5) and relative to the Fermi level E_F for chemisorbed molecules on Pt(111) (δ_s) vs the carbon-carbon bond length R.

This methodology was (and still is) of great importance to understand – for example – intramolecular geometry changes determined by the adsorption of an organic molecule on a catalytic metal surface, as well as to identify precursor states of a chemical reaction. This discovery allowed to establish a new method, dubbed *"bond-distances with a ruler"*, to determine intramolecular geometry variations due to molecular chemisorption on metal surfaces ("Near-Edge X-Ray-Absorption Fine-Structure Studies of Chemisorbed Hydrocarbons: Bond Lengths with a Ruler", J. Stöhr, F. Sette, and Allen L. Johnson, Phys. Rev. Lett. 53, 1684 – Published 22 October 1984). This relation is still amply used nowadays in studies of catalytic reactions to understand chemical bonding and molecular dissociation processes.

In 1984, I joined the "Surface Physics Research" Department at AT&T Bell Laboratories, in Murray Hill (N. J. – USA), as a permanent principal investigator, and I constituted my research group on a programme centred on synchrotron studies in condensed matter physics. I stayed in this institute until end of 1990, and my research activities were mostly carried out using synchrotron radiation at SSRL (Stanford University, Ca) and at the NSLS (Brookhaven National Laboratory, NY). At the NSLS I constructed and operated with my AT&T colleague C. T. Chen a soft X-ray beamline called *Dragon.* During this period, I carried out also many synchrotron experiments as a user at other facilities in USA and Europe.

Beside continuing the activities started in 1983 at SSRL, this time was increasingly devoted to the development of high energy resolution soft X-ray spectroscopy with the development of the *Dragon* monochromator concept. Chen and I constructed this instrument at the NSLS on the AT&T Bell Laboratories port U4 of the NSLS VUV storage ring. First photons were obtained in 1986, marking a historical turn in the soft X-ray spectroscopy discipline. The *Dragon* achieved for the first-time energy resolving power E/ΔE above 10^4 in the energy range 200-1500 eV, which is very important for X-ray spectroscopic studies of light element *K-edges,* transition metal *L-edges*, and rare earth *M-edges*: these are all the relevant edges to access bonding orbitals with minimum intrinsic core-hole lifetime broadening in almost all materials containing these important atoms.

The exceptional energy resolution (10 to 100 times better than ever before) and flux of the new instrument were presented to the world by C. T. Chen, Y. Ma, and F. Sette in a paper entitled "K-shell photoabsorption of the N_2 molecule", which was published in Phys. Rev. A, Vol.40, p. 6737 on 1 December 1989.



K-shell photoabsorption spectrum of the N_2 molecule

The paper abstract reads: "The K-shell photoabsorption spectrum of the N_2 molecule, recorded with unprecedented energy resolution and statistical accuracy, reveals several new Rydberg transitions and double-excitation states. The nearly identical term values, vibrational frequencies, and internuclear separations of the 1s-excited states of N_2 and of the 2x-excited states of NO, allow for a complete peak assignment for the N_2 Rydberg series and strongly support both the core-hole localization picture and equivalent-core model. Subtle differences are related to the final-state charge distribution in the vicinity of the nuclei and to the bonding character of the valence orbitals."

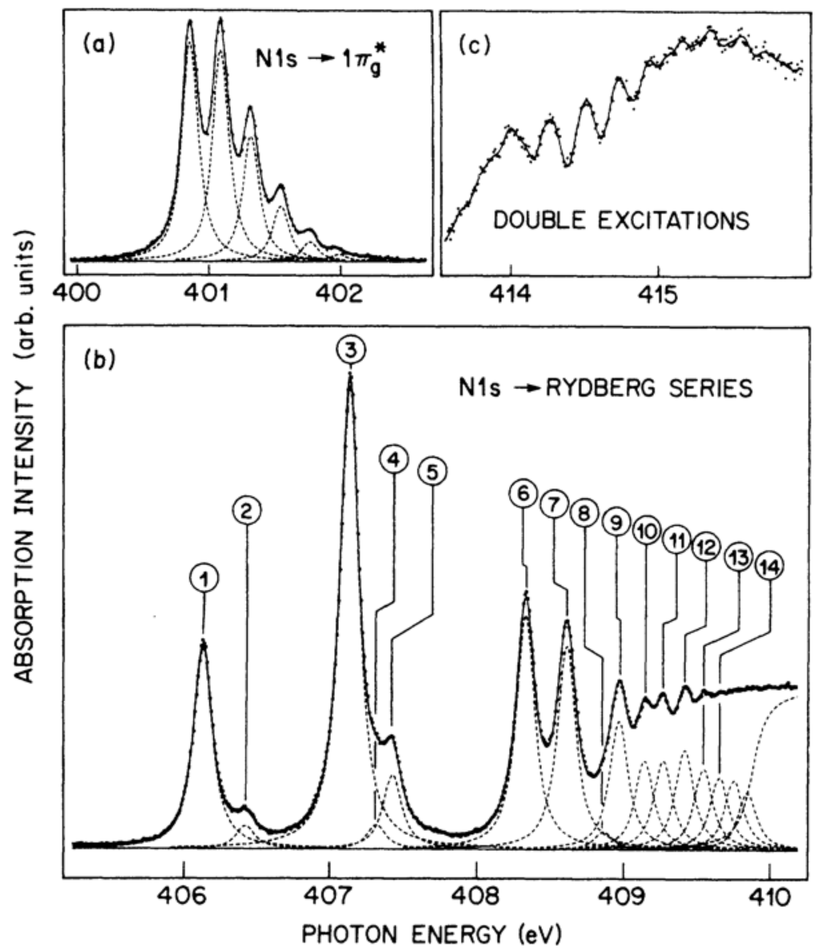
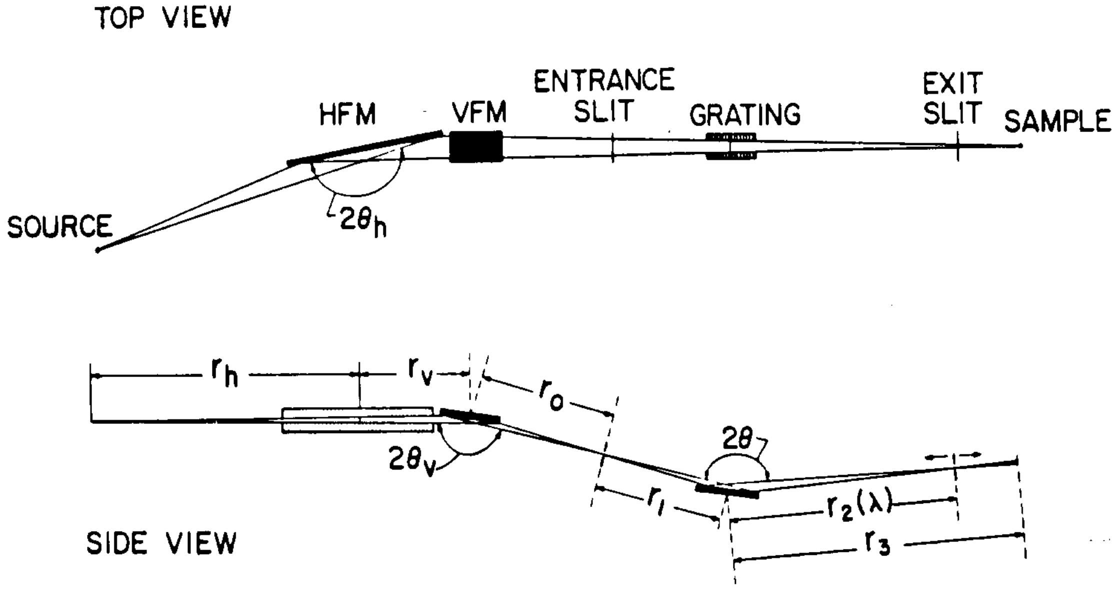


FIG. 2. Photoabsorption spectra of (a) N $1s \rightarrow 1\pi_g^*$, (b) N $1s \rightarrow$ Rydberg series, and (c) double-excitation transitions of gas-phase N_2. Dots represent the experimental data. The solid curves in (a) and (b) are the result of the fitting procedure explained in the text and the dashed curves are the individual Voigt profile determined from the fit. The solid curve in (c) is a smoothing of the data.

This "school-book" experiment opened to the world modern soft X-ray spectroscopy. Nowadays the *Dragon* concept is still the guiding principle of most performing high-throughput and high-resolution soft X-ray spectroscopy beamlines and spectrometers in all synchrotron laboratories worldwide, among which the ESRF (first with the ID12B beamline, followed by ID08, and todays by the ID32 beamline). C. T. Chen and I, in a review article of 1990 entitled "High Resolution Soft X-Ray Spectroscopies with the Dragon Beamline" (Physica Scripta, Vol. 1990, p. 119), wrote: "Novel spectral features and new information regarding core-excitation processes are revealed in the electron photo-absorption and photo-emission experiments performed with a newly constructed synchrotron radiation beamline. This beamline, dubbed *Dragon*, has an unprecedented resolving power and superior transmission in the soft X-ray region. Several experimental results on gas phase, solid and biological systems are presented to exemplify the scientific applications of high-resolution soft X-ray spectroscopies. The possible application of photo-absorption spectroscopy as a tool for chemical analysis is also discussed and a few examples are given."



Geometric layout of the *Dragon* beamline

The *Dragon* concept, representing a gain factor up to 10^2 when compared to previous instruments, opened the way to systematic studies of local bonding of basically any atomic species, enabling analytical studies on nature, symmetry and level of localisation of bonding orbitals for each of the atomic species present in the system. These studies are fundamental in understanding key details of chemical bonding. In fact, many important scientific results were obtained using the *Dragon* by Chen, Sette and collaborators, but also from the users of this beamline. For example, Chen and Sette made a study on the symmetry and bonding orbital occupancy of oxygen atoms in high temperature superconductors, measuring subtle differences among the oxygen orbitals of apical or in-plane oxygen atoms. In the paper “Electronic States in $La_{2-x}Sr_xCu0_{4+\delta}$ Probed by Soft-X-Ray Absorption” the authors, C. T. Chen, F. Sette, Y. Ma, M. S. Hybertsen, E. B. Stechel, W. M. C. Foulkes, M. Schluter, S-W. Cheong, A. S. Cooper, L. W. Rupp, Jr., B. Batlogg, Y. L. Soo, Z. H. Ming, A. Krol, and Y. H. Kao (Phys Rev. Lett., Vol 66, p. 104 of 7 January 1991), report in the abstract: “Oxygen K-edge absorption spectra of carefully characterized $La_{2-x}Sr_xCu0_{4+\delta}$ samples were measured using a bulk-sensitive fluorescence-yield-detection method. They reveal two distinct pre-edge peaks which evolve systematically as a function of Sr concentration. The measured spectra are quantitatively described by calculations based on the Hubbard model, including local Coulomb interactions and core-hole excitonic correlations. The absorption data are consistent with a description of electronic states based on a doped charge-transfer insulator”. These results continue to influence today’s theory of these still elusive materials.

Even more results have been obtained until nowadays thanks to many subsequent developments, especially on the *Dragon* beamlines using undulator devices of modern third-generation synchrotron sources.

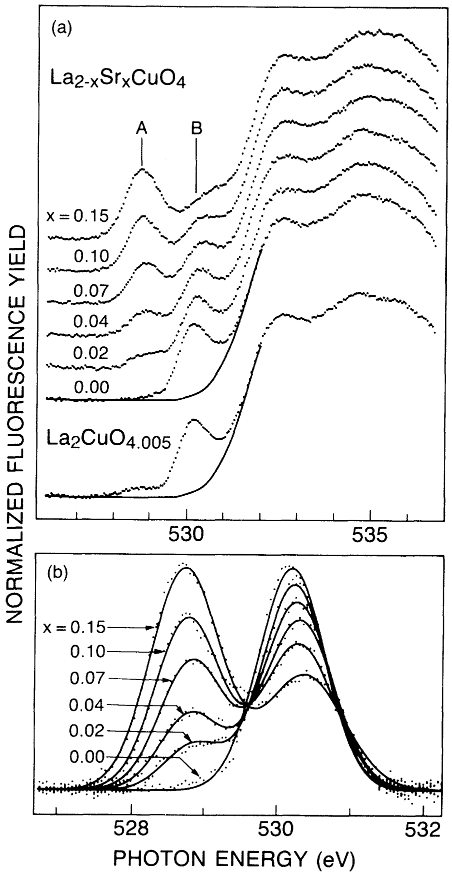


FIG. 1. (a) Normalized fluorescence yield at the O K edge of $La_{2-x}Sr_xCuO_{4+\delta}$. The solid curves are the common background described in the text. (b) The difference between the data of $La_{2-x}Sr_xCuO_4$ and the common background. The solid lines are the fitted curves using two Gaussian line shapes.

On *Dragon* science, one should underline another spectacular development of the *Dragon* optics carried out by C.T. Chen and I in the late 80's, which consisted in the ability to select in a straight forward and efficient manner monochromatic soft X-ray photons with full control of the photon beam polarisation (linear, circular-right or circular-left). In fact, thanks to this new optics and experimental protocol, for the first time circularly polarised photon beams were produced in the soft X-rays, following the one year earlier achievement in the hard X-ray region.

We measured L-edges XMCD spectra in magnetically oriented Nickel, demonstrating that X-ray Magnetic Circular Dichroism (XMCD) on magnetically oriented materials, after its discovery in the hard X-rays by G. Schütz and colleagues (1987), is much more efficiently observed in the soft X-ray region. These results are published in a pioneering paper entitled "Exchange, spin-orbit, and correlation effects in the soft-X-ray magnetic-circular-dichroism spectrum of Nickel" (Phys Rev. B Rapid Comm., Vol. 43, p. 6785 of 15 March 1991). The authors, C. T. Chen, N. V. Smith, and F. Sette, write in the paper-abstract: "A tight-binding analysis of soft-X-ray-absorption and magnetic-circular-dichroism (MCD) spectra on Ni at the 2p 3d thresholds yields values for the valence spin-orbit parameter and exchange splitting which are respectively larger and smaller than the ground-state band-structure values by a factor of about 2. The discrepancies are attributed to core-hole correlation effects. A feature that appears 4 eV above the main white lines, but only in the MCD spectrum, is also attributed to correlation effects."

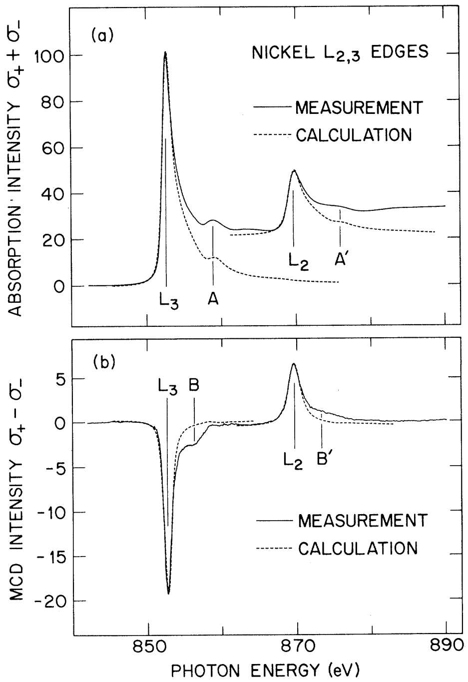
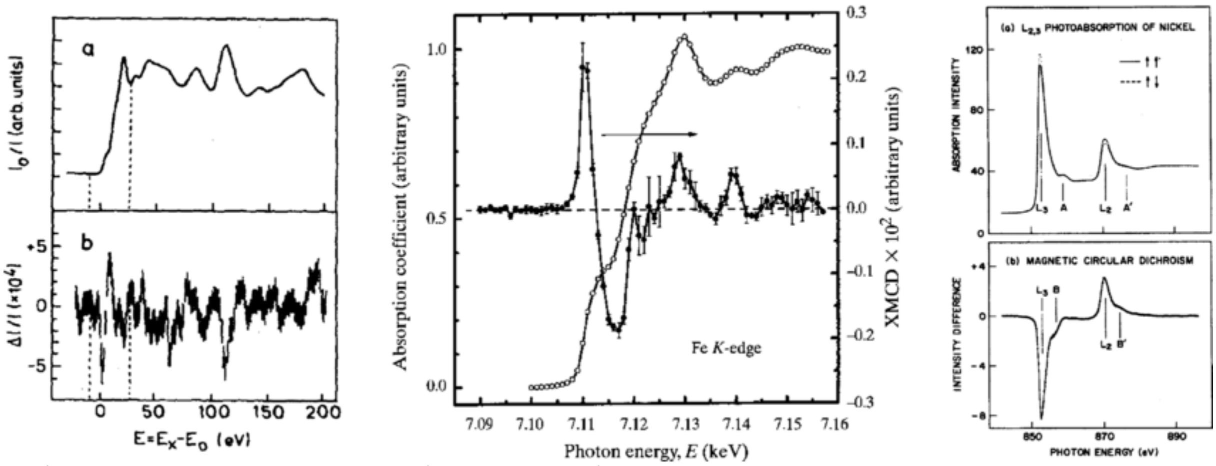


FIG. 1. Comparison between experimental soft-x-ray spectra (full curves) and an optimal tight-binding simulation (dashed curves) of the L_3 and L_2 white lines in Ni: (a) the total absorption $(\sigma_+ + \sigma_-)$; (b) the magnetic-circular-dichroism $(\sigma_+ - \sigma_-)$. The raw experimental MCD spectrum shown here has been magnified by a factor of 1.85 to account for incomplete photon polarization and sample magnetization.

The quality of the soft X-ray MCD spectra of transition metals is exceptional, and the level of detail much higher than what can be measured in hard X-ray spectra at the K-edges of these materials. In iron, for example, the Fe K-edge XMCD signal is ~ 0.1% of total absorption, while at Fe L-edges is ~ 10%!
This much higher efficiency (x100), enabled Chen and Sette to develop a new branch of investigation – known today as soft-XMCD spectroscopy – which allows studying in detail the atomic origin of magnetism in ubiquitous transition metal oxides. Every synchrotron source, today, as at least one of such a Soft-X-ray XMCD spectroscopy station.

I demonstrated by a simple one-electron calculation that integrated XMCD spectra, scaled to the corresponding integrated absorption spectra, allow to estimate the ground state expectation value of the *angular momentum* of the excited atom. This finding stimulated further theoretical work by P. Carra and T. Thole, who generalised this simple result to the many-electron case and obtained a set of relations (*sum-rules*), which provided the theoretical comprehension of these magnetic effects in X-ray spectroscopy, and established a general procedure to quantitatively determine the orbital and spin parts of the magnetic moment of a given atom in a magnetic material from the XMCD of its absorption spectra.



Left) First Fe K-edge XANES and EXAFS (different scales) XMCD spectra. Reprinted with permission from [22]. Copyright (1987), American Physical Society. (Middle) More recent Fe XMCD from the APS. (Right) First soft X-ray MCD spectrum, reported for Ni metal. Reprinted with permission from [23]. Copyright (1990), American Physical Society. From "X-ray magnetic circular dichroism—a high energy probe of magnetic properties", Tobias Funk, Aniruddha Deb, Simon J. George, Hongxin Wang, Stephen P. Cramer, Elsevier, Coordination Chemistry Reviews 249 (2005) 3–30

This work was published in a paper entitled "X-ray circular dichroism as a probe of orbital magnetization", B. T. Thole, P. Carra, F. Sette, and G. van der Laan, Phys. Rev. Lett. 68, 1943 – Published 23 March 1992. In the paper abstract, the authors wrote: "A new magneto-optical sum rule is derived for circular magnetic dichroism in the X-ray region (CMXD). The integral of the CMXD signal over a given edge allows one to determine the ground-state expectation value of the orbital angular momentum. Applications are discussed to transition-metal and rare-earth magnetic systems."

This *sum-rule*s work, was published after I moved to the ESRF in 1991, and is up to today the most cited paper out of the more than 32 000 that were published so far from work carried out at the ESRF, including those which were linked to the Chemistry Nobel prizes of 2009 and 2012.

Altogether, the possibility to efficiently and precisely measure soft X-ray MCD and theoretically interpret quantitatively the XMCD spectral data has allowed to measure the magnetic moments atom by atom, and retrieve *quantitative* information on the orbital and/or spin nature of each atomic species magnetism. In turn, this has allowed to understand origin and behaviour of the macroscopic magnetic properties of the investigated system and discover *single-atom* isolated magnets. XMCD has indeed enabled a very important experimental activity that, thanks to synchrotron radiation soft X-ray spectroscopy, investigates the local magnetic properties of atoms down to a single-atom magnetic structure. The importance of this discovery is testified by the many hundreds of scientific publications based on the soft X-ray MCD technique that Chen and I developed.

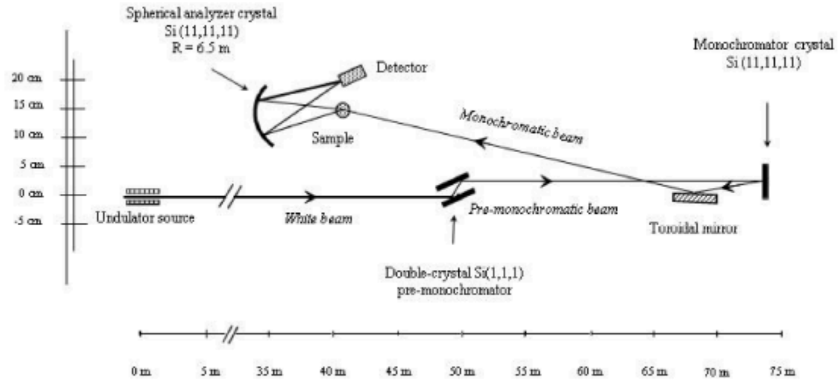
4) The ESRF times (1990 – 2001)

I decided to come back to Europe following the decision in 1988 to construct the European Synchrotron Radiation Facility in Grenoble, France, and thanks to contacts that Professor Massimo Altarelli, at the time Director of Research at the ESRF, established with me. I joined the ESRF at the end of 1990, time at which the construction of the new facility had just started.

I was recruited by the ESRF with the task to construct a very high energy resolution X-ray beamline to perform spectroscopy of collective excitations (in particular phonons) using Inelastic X-ray Scattering (IXS) as an alternative to Inelastic Neutron Scattering (INS). The interest of this development was linked to the fact that IXS would allow to access scattering kinematic conditions very difficult (often impossible) for INS, and/or study materials available in much smaller quantities with respect to what is needed in a prototypical INS experiment (rare samples, and samples at extreme pressure and temperature conditions, for example). Ultra-high energy resolution IXS started with few pioneering experiments carried out at HASYLAB (DESY – Hamburg) by E. Burkel, J. Peisl, and B. Dorner (Europhys. Lett.3, (1987) 957-61). These authors demonstrated the possibility to measure phonons in Beryllium with an energy resolution of ~25-40 meV. The challenge was however huge, as interesting experiments which would be competitive with INS required to bring the X-ray energy resolution from 25 meV to ~ 1 meV! The hope – in the early 90's – was that with the expected much higher source performances of the ESRF, this challenge could be met at least at the level of ~ 10 meV.

ESRF state of construction in late 1990

I perceived the potential of the ESRF revolutionary approach to synchrotron science, which would have delivered an X-ray source with a gain factor of 10^3-10^4 in brilliance when compared to all other available sources worldwide. Therefore, I accepted the challenge to construct an ultra-high energy resolution IXS beamline, which required conceiving and developing new perfect crystal optics technology to drastically improve energy resolution of previous pioneering IXS experiments, and complex and stable instrumentation to properly handle these perfect crystals. In fact, the construction of such an IXS beamline required reaching routinely and with high mechanical stability resolving power in the 10^8 range to study at ~ 20 keV X-ray incident energy phonon excitations of few meV. I created a small group made of scientists, engineers, technicians and students, and established important collaborations with leading academic groups in the field (University of L' Aquila – Italy, Maximilian University – Munich, HASYLab – DESY, Hamburg), which also constituted the core of the future IXS user community at the ESRF.

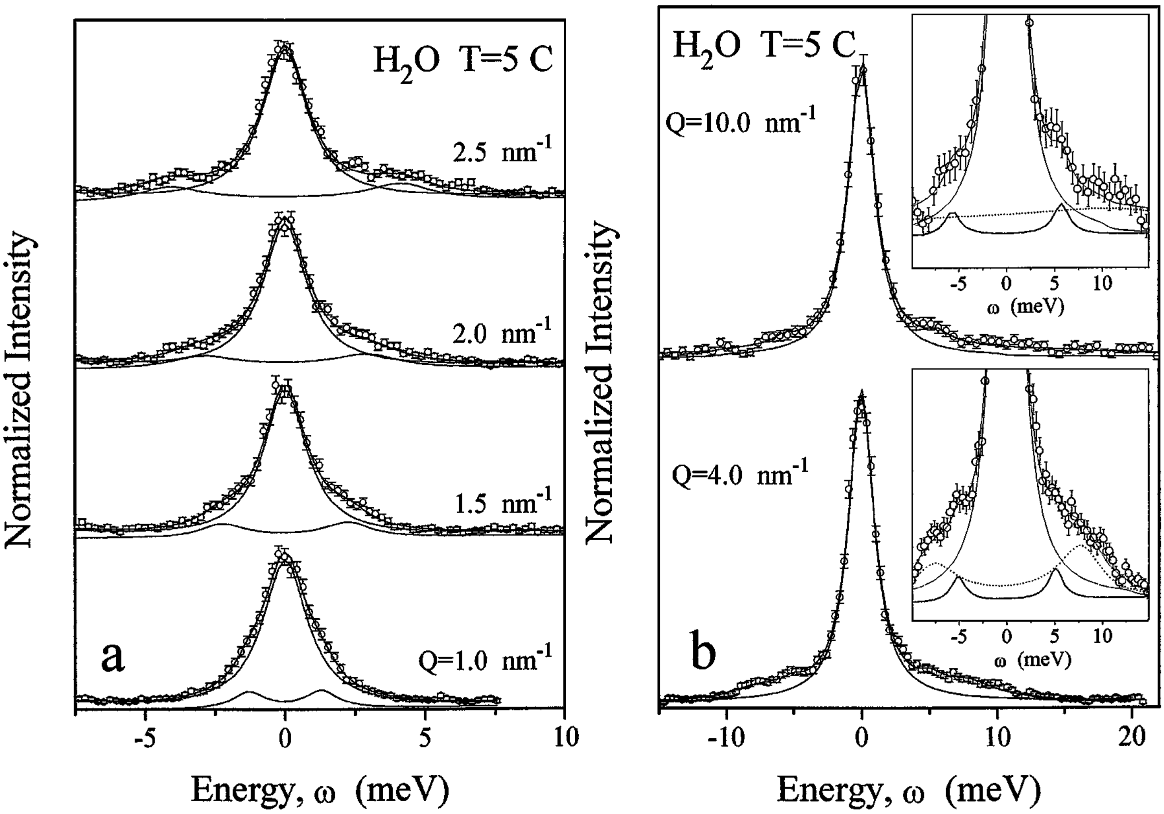


Layout of the IXS beamline ID-16 at the European Synchrotron Radiation Facility.

With them, I conceived and realised a new IXS instrument with unprecedented performance, and conceptually different (horizontal instead of vertical scattering geometry) with respect to the HASYLAB pioneer set-up. This new instrument outnumbered by more than one order of magnitude the initially sought most optimistic expectations. It enabled, in fact, to push the energy resolution to 0.8 meV using 26 keV X-rays, thanks to a novel design based on perfect crystal optics, milli-Kelvin temperature stability and control of the whole set-up at room temperature, state-of-the-art X-ray mirror focusing, new detector technology, and extreme overall mechanical and temperature stability.

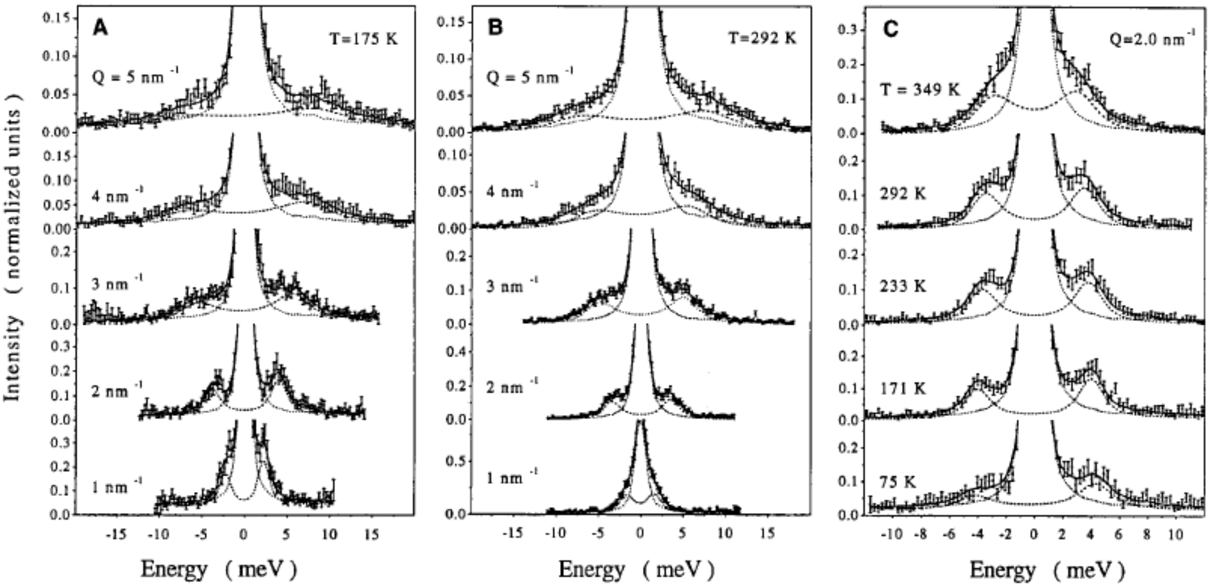
This new ESRF IXS beamline set a new standard in IXS spectroscopy, opened a new field of investigation and created a vibrant users' community which could study phonon-like excitations at conditions not reachable by INS experiment at existing neutron sources. This is for example the case in liquids and disordered systems phonon like excitations at small momentum transfers, and for samples only available in small quantities and/or in small volumes as is the case for rare samples and samples at extreme thermodynamic conditions, respectively. The ESRF instrument, which is still fully operational and continuously improved, has inspired almost identical instruments that were constructed in USA (APS – Argonne National Laboratory) and Japan (SPRING-8 – Osaka), as well as similar programmes under development at the new XFEL sources.

I used extensively this instrument to study collective excitations in liquids and disordered systems (glasses), and gave seminal contributions to the understanding of longitudinal hyper-sound excitations in liquids at terahertz frequencies. For example, I showed that the phenomenon of the *fast sound* in water is due to a structural relaxation between two very different dynamical (viscous at low frequencies and elastic at high frequencies) sound propagation regimes. In the paper "Transition from Normal to Fast Sound in Liquid Water", of F. Sette, G. Ruocco, M. Krisch, C. Masciovecchio, R. Verbeni, and U. Bergmann, (Phys. Rev. Lett. 77, 83 – Published 1 July 1996), the authors wrote in the paper-abstract: "Inelastic x-ray scattering data from water at 5°C show a variation of the velocity of sound from 2000 to 3200 m/s in the momentum transfer range 1–4nm^{-1}. The transition occurs when, at ≈4meV, the energy of the sound excitations equals that of a second weakly dispersing mode. This mode is reminiscent of a phonon branch in ice *Ih* crystals, which is shown here to be of optical transverse character. The present work accounts for most of the highly debated difference between hydrodynamic (≈1500m/s) and high-frequency (≈3200m/s) velocities of sound in water." These were the first measurements of hyper-sound in a liquid up to the first maximum of the liquid structure factor.



The IXS spectra of water at T - 5 ±C (o) shown together with the total fits and the individual components, as explained in the text, at the indicated Q values. The data are normalized to their maximum intensity corresponding to (a) 1.4, 1.2, 1.1, 1.0 counts/s and total counts of 450, 360, 60, 350 at Q - 1.0, 1.5, 2.0, 2.5 nm^{-1}, respectively; (b) 2.8 and 2.4 counts/s (total counts 1100 and 500) at Q=4 and10 nm^{-1}, respectively. The insets of (b) emphasize the weakly dispersing features at ~4-5 meV together with the total fit and the individual components. The Q resolution was 0.2 and 0.4 nm^{-1} for the data in (a) and (b), respectively.

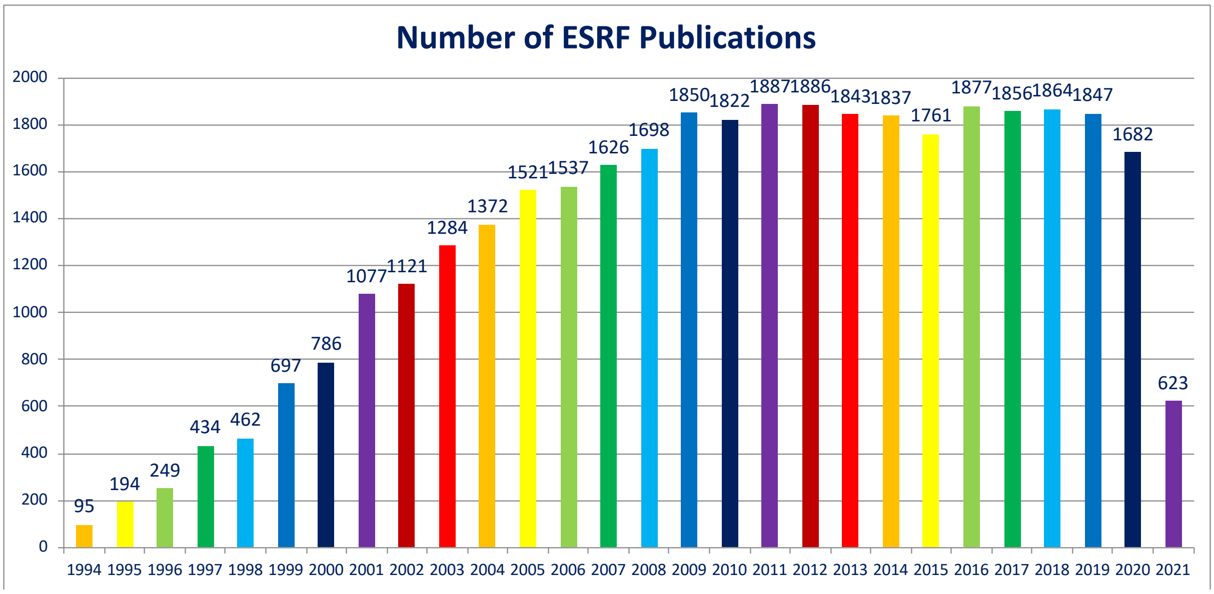
Similarly, I reviewed our work on the high frequency dynamics in glasses in a paper entitled "Dynamics of Glasses and Glass-Forming Liquids Studied by Inelastic X-ray Scattering" (Science, 05 June 1998, Vol. 280, Issue 5369, pp. 1550-1555 by F. Sette, M.H. Krisch, C. Masciovecchio, G. Ruocco and G. Monaco). Here the paper-abstract reads: "The development of inelastic X-ray scattering with millielectron volt energy resolution at the European Synchrotron Radiation Facility in Grenoble, France, provides a method for studying high-frequency collective dynamics in disordered systems. This has led to the observation of propagating acoustic phonon-like excitations in glasses and glass-forming liquids down to wavelengths comparable to the interparticle distance. Using the inelastic X-ray scattering results on glycerol as a representative example, it is shown that the microscopic dynamic properties are related to the excess of vibrational states in glasses and to the consequences at the microscopic level of the liquid-glass transition. Moreover, they allow derivation of the infinite frequency sound velocity, a quantity related to the structural relaxation times and to the change of ergodicity at the liquid-glass transition."



(A) IXS spectra of glassy glycerol at 175 K at the indicated Q values. The data (o), shown with the error bars, are superimposed to the fit (solid line) as explained in the text. The dashed and dotted lines represent the quasi-elastic and inelastic contributions, respectively, to the total fits. The data are normalized to the central peak intensity. The typical counting time was 100 s/point. (B) as in (A) for liquid glycerol at 290 K. (C) IXS spectra of glycerol at Q 5 2 nm21 at the indicated temperatures. Symbols and lines are as in (A).

5) The ESRF times (2001 – 2008)

I was appointed to serve as Director of Research at the European Synchrotron Radiation Facility in 2001. I received from the ESRF Council a first five-year mandate (2001-2006), which was renewed by a further three-year period (2007-2009). During this time, I was responsible for the areas of condensed matter physics, chemistry, material science, and X-ray optics at the ESRF. Starting this new assignment centred on science management responsibilities, I increasingly dedicated time and energy in developing programmes in tandem with the other Director of Research for life sciences to the benefit of the ESRF user community and synchrotron science in general. With the other Director of Research, I was responsible for the development, coordination and implementation of synchrotron science programmes in fundamental and applied research in condensed matter physics and chemistry, material science and engineering, environmental and cultural heritage research, soft matter science, structural biology and medical applications. My activity during this period contributed to make the ESRF a world leading facility in providing to its users' community state-of-the-art opportunities in the field of synchrotron science. This was the time following the end of the ESRF Construction period (1998), and the priority was to consolidate the ESRF operation and user programme. The success of the ESRF Experiment Division activities and of the operation of the whole facility is amply testified by the fact that the scientific productivity from the work carried out at the ESRF during the period in which I was Director of Research, reported in refereed publications, grew linearly going from ~1100 publications in 2001 to more than 1800 in 2009 at an essentially constant number of instruments.

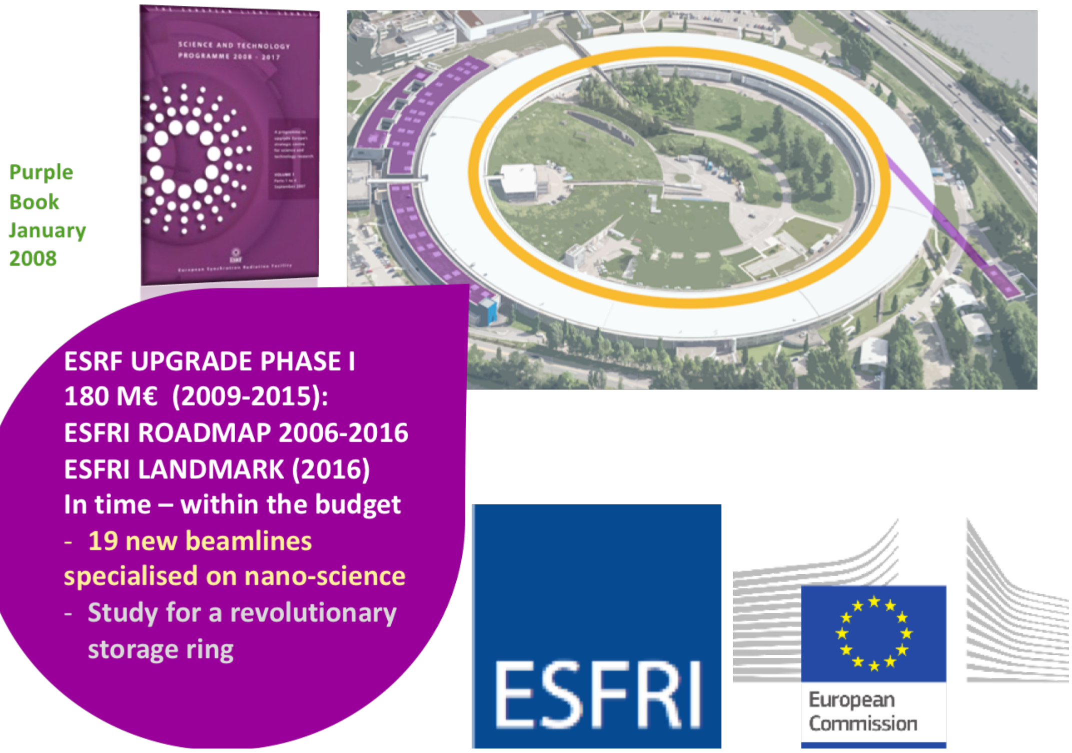


Number of publications on peer-reviewed journals reporting scientific results from experiments carried out at the ESRF. Nowadays, ESRF users publish more than 1800 papers every year. This number was around 1000 in 2001 and increased to 1800 in 2009, i.e. during the period in which F. Sette was Director of Research at the ESRF.

At those times, I was not only interested in optimising the ESRF User programme, but I was also very much concerned by the need to develop a new strategic long-term vision for the ESRF. At those times, the great success of the ESRF was also at the basis for the construction of many other third generation synchrotron sources in Europe and worldwide: construction of highly performing sources was ongoing or starting in all ESRF Member Countries except Belgium and The Netherlands, and all these programmes were dwelling and greatly benefitting from the ESRF know-how. In this rapidly changing context, I saw the need to conceive a new major step in synchrotron science in order to create new opportunities in X-ray science and maintain the pioneering role of ESRF in the long term, and thus enable the ESRF to continue to represent an added value for all its users and its Member Countries' communities.

In 2003, the at-the-time ESRF Director General, Prof. W. G. Stirling, supported my proposal to dedicate a part of the User Meeting to start discussing possible visons on the future of the ESRF, and allowed me to make a presentation on my views about the future X-ray science and technology, and a programme for the ESRF in the upcoming 10-20 years: the ESRF Upgrade Programme was born. This presentation was a great success, and steered consensus and support of the whole users' community. I then continued to propel and structure the plans of the ESRF Upgrade Programme (UP) with its two phases, recognising the need to conceive a new generation of beamlines, but also possibly a new source with much increased brilliance thanks to a sharp decrease of the electron beam horizontal emittance. Thanks to these preliminary activities, which were immediately welcomed and supported by the whole ESRF Management and Council, the ESRF UP was presented as a full-fledged programme in 2007 to the synchrotron user community to seek engagement and support to go on. At that time, by presenting the UP, the ESRF was the first synchrotron centre looking forward to open *again* a new page in synchrotron science for the benefit of the world's user community. This programme has become today the undebated world reference for what existing and new green field synchrotron sources should do. The first phase (Phase-I) of the ESRF Upgrade Programme was included on the ESFRI roadmap since its inception in 2006 as an ESFRI (European Strategic Forum on Research Infrastructure)

Project. Its implementation was launched by the ESRF Council in 2009 with an investment envelope of 180 M€, and a total of ~ 250 M€ including the dedicated workforce. The ESRF Council, simultaneously to launching the UP-Phase I, decided in 2007 to offer to me the possibility to serve as ESRF Director General from 2009, and to give me the responsibility of the UP implementation. I accepted the offer, and the UP-Phase I programme was successfully delivered in time by end of 2015 and within budget, and became an ESFRI Landmark in 2016.



The ESRF Upgrade Phase I was part of the first edition of the ESFRI Roadmap published in 2006, and was funded at the level of 180 M€ by the ESRF Council starting from 2009. It was delivered in time in 2015 and within budget. It is described in the ESRF Purple Book, which can be downloaded from the ESRF web site.

6) The ESRF times (2009 – present)

I was appointed ESRF Director General initially for the period 2009-2013, with three successive prolongations of three (2014-2016), four (2017-2020) and four (2021-2024) years respectively.

During this period, I have been promoting, strengthening and opening the use of the ESRF to a world community that counts today more than 10 000 scientists from academia, research labs and industry. As ESRF Director General, I am responsible of the definition and implementation of the ESRF science and technology programme. The implementation of the ESRF programme (Operation and UP) requires my direct and continuous involvement in overseeing, managing and coordinating activities as:

i) The relations with the Council and the Delegates of the individual ESRF Partner Countries to ensure a balanced return on investment, and address all matters that may arise on specific situations;
ii) The definition of the medium and long-term scientific programme, and the associated financial planning;
iii) The monitoring of the peer-review process, which is based on scientific-excellence, and

which assigns access to beam time on the ESRF instruments and related facility services to the ESRF users;

iv) The promotion of synchrotron radiation uses by industry;

v) The implementation of the machine preventive maintenance and beamlines continuous refurbishment plans;

vi) The educational and outreach programmes for the promotion and visibility of ESRF activities with the scientific community, the funding agencies, the next generation of scientists and facility technical and administrative staff, and the general public;

vii) The use of the financial resources assigned to the ESRF by the Member and Partner Countries via the ESRF Council on a yearly basis according to the overall programme, and the monitoring of programmes implementation according to the established planning.

viii) The promotion of ESRF values, based on diversity, scientific and technological excellence, and transparency.

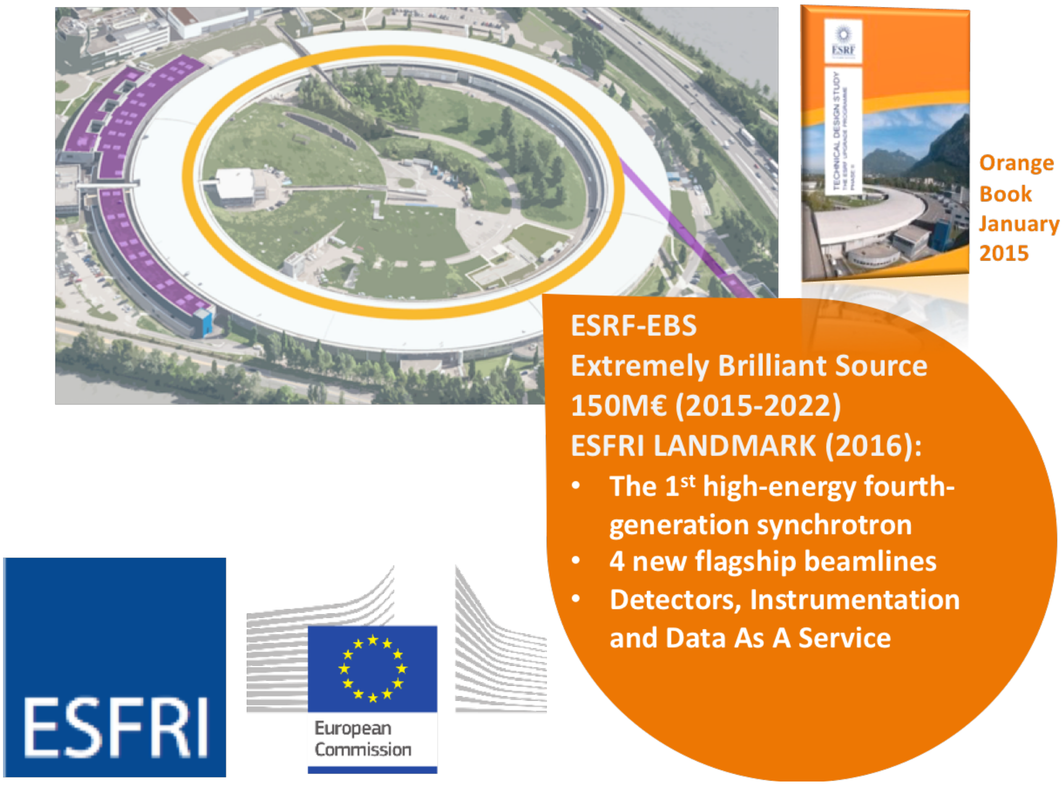
Highlights of this period are:

a) The timely and within budget implementation of the ESRF UP-Phase I during the period 2009-2015.

b) During the period 2009-2012, I continued to follow my objective to identify a solution for a new storage ring source with much increased performances thanks to a drastic reduction (.01 to 0.001) of the stored electron beam size and divergence in the horizontal direction. Many studies were carried out in the period 2000-2009 by the ESRF Beam Dynamics Group, which were based on Prof. D. Einfeld's seminal work on the MBA (Multiple-Bend-Achromatic) lattice: unfortunately, they did not provide a viable solution for the upgrade of a high energy (6 GeV) storage ring as the ESRF, but showed viable options for the construction *ex-novo* of a low energy (~3 GeV) ring. In fact, these studies constituted the basis for the launching of the MAX-IV programme in Lund, and the SIRIUS programme in Campinas. A revolutionary turn took place in 2012 thanks to an original idea of Pantaleo Raimondi, who was recruited in 2012 as ESRF Accelerator and Source Division Director by the ESRF Council for his proven expertise in storage ring lattice dynamics. He proposed an original Hybrid MBA lattice concept, which solved all difficulties encountered with the basic MBA. This excellent solution, after careful benchmarking, gave rise to the EBS (Extremely Brilliant Source) storage ring lattice design, which has been optimised to the ESRF storage ring tunnel and existing insertion device source points. I led the process to shape up the EBS programme from its initial theoretical studies to its benchmarking and key components engineering design. This allowed to put together a full EBS programme in less than two years, and to present it in its different technical, logistic and financial aspects to the ESRF governing bodies in 2014. The EBS programme was finally fully endorsed by the ESRF Council, which gave green light to its implementation in June 2014. The EBS programme includes also an ambitious experimental programme, and is presented in the ESRF Orange Book, which was published at the beginning of 2015.
In the concluding remarks of the Orange Book Foreword, my fellow Directors and I note: "The ESRF Upgrade Programme, thanks to the strong collaboration existing among the ESRF Member and Scientific Associate Countries, will pave the way for future synchrotron science, and contribute at a global level to an exciting time for fundamental discoveries and innovative applications. The new opportunities in X-ray science, complementing and extending other advanced analysis tools for material and living matter, will contribute with key discoveries to

the sustainable well-being of our society: new smart materials will optimise the use of existing natural resources and provide better production and management of clean energy, new understanding of biological processes at the mesoscopic and cellular levels will introduce new drugs and create new diagnostic and therapeutic programmes, and studies of exotic natural thermodynamic states will help us to better understand our planet, its resources and evolution. These far-sighted plans will attract a new generation of scientists who, with the use of a new generation of X-ray probes, will be able to explore and understand more effectively than today many of the mysteries of the world surrounding us."

The EBS programme is presently in an advanced stage of implementation, fully in line with the time-schedule set in 2015 and within the provisional budget envelope as agreed in 2014. In particular, the delivery to users of the major element of the EBS programme, the new EBS storage ring, is in user operation since 25 August. Its delivery took place in time and within budget and its performances are better than the most optimistic expectations.



The ESRF Upgrade Phase II, known as the ESRF EBS (Extremely Brilliant Source) programme aims to the construction of a new revolutionary storage ring, which will provide a new X-ray source with an enhancement of brilliance and coherence of a factor of 100 as compared to what is available today. It represents a major technological breakthrough and will mark the opening of a new page in synchrotron science. It was entirely developed at the ESRF and the ESRF Council decided its construction in the period 2015-2022. Today the ESRF is constructing the ESBS, and about 18 projects worldwide are moving in the same direction. EBS is already considered a Landmark in the ESFRI Roadmap update of 2016 and 2018. The project is advancing according to schedule and within budget. The ESRF Orange Book, can be downloaded from the ESRF web site.

Moreover, the ESRF-EBS and its lattice design are today's basis for all envisioned upgrade programmes of existing third generation sources and future new green field synchrotron centres.

The ESRF-EBS is noted as a Landmark Programme in the ESFRI Roadmap updates published in 2016 and in 2018.

c) Following the successful delivery of the UP-Phase I, I realised that the new experimental hall is an ideal place for a state-of-the-art Cryo-EM installation for structural biology to be used in conjunction with the ESRF macromolecular crystallography beamlines and the EPN Science Campus structural biology facilities and platforms jointly operated with the EMBL, IBS and ILL partners. Following a visit of the Diamond Light Source in June 2015, where a similar plan was under implementation by the Cambridge structural biology groups, I invited the campus partners in September 2015 to propose this idea which was immediately supported. It was then agreed to empower the ESRF Director of Research J. Susini to define a strategy for the timely construction and future operation as a ESRF public beamline of such Cryo-EM platform in one of the new ESRF experimental halls. With ESRF providing the resources for the purchase of the instrument and its yearly maintenance, an operation model has been agreed with staff provided by the four campus partner institutes. The model for the construction and operation of this new platform was supported by ESRF SAC and Council by end of 2015, and its construction launched. The new Cryo-EM platform is now operational since November 2017, i.e. one month after the 2017 Nobel Prize in Chemistry was granted to the pioneers of Cryo-EM for structural biology. This platform, after almost four years of user operation, is a great success in terms of performance, efficiency of operation, scientific results, and in offering unique research opportunities to many users group which do not have access to such state-of-the-art facilities in their lab and in their countries.

d) Definition, launching in 2016, and implementation of the ESRF Data Policy, which is based on the Open Data and *FAIR* data concepts. This has allowed in 2020 to publish a position paper on the ESRF Data Management Strategy, and to draw a long-term Data Strategy Implementation Plan starting from 2022, fully imbedded in the operation of the facility following the completion of the EBS programme in 2023.

e) Management of an important crisis in 2010 due to the wish of two Member Countries to denounce the ESRF Convention in order to reduce their participation to the ESRF programme. I was able to propose to the Council a pathway to avoid such denunciation, which could have been catastrophic for the ESRF and for the implementation of its UP. This pathway represented an immediate reduction of 6% of the ESRF resources, and required a major consequent rescaling of the ESRF operation objectives and of the UP-Phase I deliverables. It preserved, however, all of the main features of the UP science-programme, and therefore the attractiveness of the ESRF in the long term. The process was managed avoiding losing ESRF expertise and staff.

f) Successful management of the negotiations between the National Research Centre – Kurchatov Institute and the ESRF Council leading to the decision of the Russian Federation to join the ESRF Programme as a new Member Country with a share of 6% of the ESRF. This allowed to re-establish the full ESRF operation budget to the levels of 2010, and to establish the budget envelope required to launch the ESRF-EBS programme.

g) Identification and implementation with Council's support of a share redistribution model following the accession of Russia to the ESRF.

h) Successful management of the negotiations between new Partner Countries and the ESRF Council leading to the decision of: i) South Africa and India to join the ESRF, ii) Austria and Israel to increase their participation to the ESRF programme, and iii) Czech Republic, Hungary and Poland to renew their participation to the ESRF Programme.

i) Successful management of the negotiations between the CEA and the ESRF Council leading to the construction of the IBS building on the ESRF-ILL EPN Science Campus site, which also led to a further increase of 3 M€ on the exceptional 15 M€ contribution of France to the ESRF-ILL site infrastructure in the frame of the CPER programme 2007-2013.

j) Successful management of the negotiations between France and the ESRF Council leading to France granting an 8.7 M€ exceptional contribution to the ESRF for the implementation of the EBS project in the frame of the CPER programme 2014-2020.

k) Successful implementation of a contract with the European Investment Bank (EIB) for the cash-flow management of the EBS programme spending profile. This methodology, proposed by the ESRF Management, supported by the ESRF Council and accepted by the EIB, has become since 2014 a very attractive tool for matching spending and income profiles of large research infrastructure projects.

l) Under Council's mandate, drive a negotiation process with the ESRF Unions for the development of a new salary evolution model at the ESRF, which aims to sustainably manage the ESRF salary mass drift (ongoing).

m) Management and implementation of the reorganisation of the ESRF divisions dedicated to providing support to the operation of the storage ring and of the beamlines, and of the ESRF R&D activities for the development of new instrumentation and data infrastructure. This reorganisation allowed the creation of two new support divisions with about 40% of the whole ESRF staff, which are adapted to face the challenges imposed by the UP and the facility operation needs. This major reorganisation was successfully carried out in the 2009-2011, and has greatly contributed to an efficient mobilisation of internal resources to the implementation of a new project management structure.

7) Other professional activities

During my 35-yearlong scientific and science management career, I have worked in the most advanced synchrotron centres in Europe, USA and Japan. This opportunity has allowed me to develop a deep understanding and knowledge of techniques and applications of synchrotron radiation science in very different research domains, to establish contacts and trust with the best scientific groups internationally, and to acquire a broad vision and managerial capacity. This experience has been pivotal for my present activities, providing me with the capacity to analyse complex situations in science strategy and policy, and to manage difficulties and opportunities in order to bring to successful completion the scientific and technical projects under my responsibility, always with an approach to provide the best return to scientific research and to the citizen's investment in science.

I have been called to be part of (and often to chair) many important international committees to contribute with my skills to the advancement of complex scientific programmes, as for example:

i) Scientific and technical committees of internationally renowned centres (DESY (Hamburg), SLAC (Stanford), BNL (New York), APS (Chicago), Diamond (Oxford), SPRing-8 (Osaka), ELETTRA (Trieste), etc.);

ii) Committees for the development of new programmes as X-ray FELs (Hamburg, Stanford and Osaka) and the new neutron spallation sources as the ESS (Lund);

iii) Search and interview committees for high responsibility positions in science management and strategy (Director General of DESY, Director General of the European XFEL, Direttore of LNF-INFN (Italy), Scientific Director of IIT (Italy), Directors General and of Research of many European synchrotron laboratories, etc.;

iv) Strategic committees for the management and assignment of public research funds (CNGR (Italy), Helmholtz Association Programme Oriented Funding (Germany), Science Policy Committee (Stanford University, USA), International Science Policy Committee (National Research Centre – Kurchatov Institute, Russian Federation) etc.);

v) Numerous activities in the context of preparation, implementation and post-analysis of framework programmes FP6, FP7, H2020 and future HE-FP9 of the European Commission;

vi) Member of the EIROForum DG assembly and Chair of EIROForum in the period 2014-2015, and 2021-2022;

vii) Strong implication in the Grenoble ecosystem education – research – innovation – industry – citizen-life, in particular via the participation to the GIANT Partnership Council (Grenoble Innovation And New Technology, http://www.giant-grenoble.org/fr/), and to Excellence Project IDEX, called **"**Université Grenoble Alpes : Université de l'innovation", which is supported by the French programme "Investissements de l' Avenir", and aims to create a strong synergy among all actors in the Grenoble area that can contribute to excellence in education programmes centred on research and innovation;

viii) Member of the Council of the **"**Université Grenoble Alpes : Université de l'innovation"

8) Honours and awards

1) 1988 R&D 100 Award: a) Winner CS Dragon; b) Organisation: AT&T Bell Laboratories; c) Co-developers: CT Chen and F. Sette
https://www.rd100conference.com/awards/winners-finalists/year/1988/

2) ESRF Young Scientist Award 1995: At the 6th ESRF Users' Meeting held on 20 and 21 November 1995, and attended by some 300 participants, the first "Young Scientist Award" was made. This award, accompanied by a cash prize of 5 000 FF, was given to me (ESRF Inelastic X-ray Scattering Group) for "the ground-breaking measurements, by inelastic scattering, of the collective excitations of water in previously inaccessible regions of the energy-momentum plane. These demonstrated the new scientific horizons opened up by his uncommon achievements in the construction of the very high-resolution set-up on ID16 - performed in less than four years - and included the design, implementation and validation of many novel and daring technical concepts".

3) Vittorio Mazzacurati Prize, awarded by the Italian Physical Society in 2003

4) Doctor Honoris Causa of National Research Centre Kurchatov Institute (NRC-KI) in Moscow, awarded by the Director of the NRC-KI Professor Mikhail Kovalchuk, “for his contribution to the development of synchrotron radiation experimental techniques and for his active role in strengthening the cooperation between Russian and European research infrastructures”.

5) Roentgen Medal 2018: to be awarded in Remscheid in April 2019
   The Roentgen Medal is a German science award, which has been awarded since 1951 by the city of Remscheid.
   This honours persons who have "in the broadest sense have contributed to the advancement and diffusion of X-ray techniques in science and applications". The Medal Committee of the Society of Friends and Supporters of the German X-ray Museum in Remscheid-Lennep e.V. proposes suitable candidates to the Lord Mayor of the city of Remscheid, who decides the winner and introduces the ceremony.

6) Friedel – Volterra Prize 2018: to be awarded in Nantes in July 2019
   To honour the memory of Vito Volterra and Jacques Friedel, the Italian Physical Society (SIF) together with the Société Française de Physique (SFP), awards a prize for a physicist involved in some Italian-French collaboration, in recognition of distinguished work in Physics research carried out within the past 10 years.