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Autobiographical Essay

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Max. F. Perutz: *In Science truth always wins.*

I NEVER thought of myself as an important person and I have made no professional record of my life. There are some autobiographic notes required for my professional promotions and award competition that can be used in this essay. My research results and achievements can be extracted from bibliographic databases and publications (http://bib.irb.hr/lista-radova?autor=021602). I would rather reveal the ideas that guided me in my research, and explain how I managed to provide the experimental and computational facilities required for X-ray crystallography in very complex circumstances. In the era of audio-visual media explosion with fast exchange of information (internet), databases, cloud computing, and nearly with quantum computers at hand, when everything is accessible instantly, it is difficult to turn back sixty years. Today, crystallography contributes to almost all aspects of our lives. It provides the dynamic aspects of the (bio)chemical processes that help decipher the life of a living cell, discover if there is life on the red planet; it helps in the search for efficient drugs to cure diseases, and in the development of new materials for a large range of applications, which drive technology forward to unthinkable levels. It was a great challenge to do research in crystallography sixty years ago when I started, and I consider it even more so today.

Altogether, this is a personal account of the past sixty years of my professional life. I hope you will not mind if I do not mention the names that you would like to see. Too long an essay would not be acceptable for this purpose.

My beginnings

I was born in Čakovec (Croatia) on August 29, 1938. My parents were Zdenka (née John, 1912, Varaždin – 1960, Zagreb) and Ante Prodić (1906, Otočac – 1943). Both my parents were teachers, and in 1942, during the Second World War, they were forced to move from Krapina to Slavonski Brod, where we lived until 1948. During the war time, I became seriously ill (tuberculosis of the knee) and I spent most of my childhood in hospitals far from home. Having graduated elementary school in Slavonski Brod, my mother, my younger sister and I moved to Zagreb where I continued my education. During high school, I also completed my musical education. I graduated from high school in 1957, and entered the University of Zagreb,

Figure 1. My BSc diploma celebration, June 1961, Zagreb with my sister Dubravka.

Faculty of Science and Mathematics, Department of Chemistry-Physical Chemistry, graduating on June 28, 1961 with excellent achievement.

During my education, I had a strong preference for chemistry and physics. Therefore, my choice was physical chemistry, and I was more than satisfied with the courses that gave me substantial knowledge in mathematics, physics, chemistry, and mineralogy. In 1960, academician D. Grdenić offered me the great opportunity to work prior to my diploma as a technician in the X-ray Laboratory of the Department of Structural and Inorganic Chemistry, Ruđer Bošković Institute. X-ray crystallography fascinated me and it remained my lifetime preoccupation. I was privileged that my two mentors were pioneers of X-ray crystallography in Croatia. The research on my BSc diploma thesis, *Crystallographic and X-ray investigations of molybdenyl dibenzoyl methane,* was carried out under the supervision of Prof. D. Grdenić in the X-ray Laboratory of Ruđer Bošković Institute. The aim of the research was to confirm *cis*-configuration of bis-oxo group in the metal complex from two-dimensional X-ray data; intensities were measured by photometer and manually corrected; phases and electron densities were obtained by Patterson and Fourier syntheses, respectively, using Beevers-Lipson strips (provided by D. Grdenić, see *My fifty years of chemistry,* 2000, HDKI/Kem. Ind.), which was the standard procedure in the pre-computer era (Figure 2).

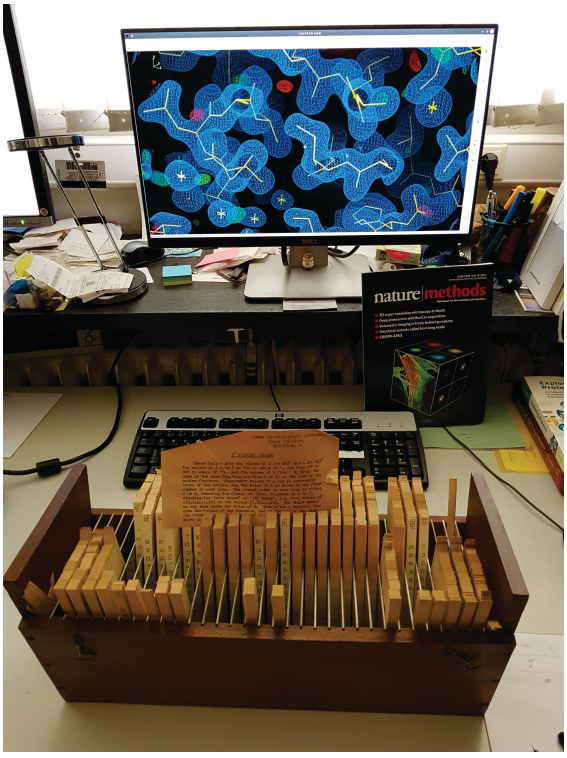

Figure 2. Beevers-Lipson strips in a wooden box provided by D. Grdenić in 1950. It is the very same box I used 60 years ago for the Fourier summation. One can immediately see the difference between the old fashion method and modern technology.

'Science is not a quiet life'
(Max F. Perutz, 1997)

I continued to work in the X-ray Laboratory of the Ruđer Bošković Institute where I completed my MSc and PhD studies under the supervision of academician Stjepan Šćavničar. My MSc thesis was entitled *Crystal structures of double nitrates of Th(IV) and two-valent metals,* which I defended at the Faculty of Science and Mathematics on December 12, 1963. My collaboration with Prof. Jože Slivnik and his world-renowned group for complicated syntheses of fluorine compounds (including noble-gas fluorides) of the Jozef Stefan Institute, Ljubljana, introduced me to the structural investigation of novel fluorine compounds. The research resulted with my PhD thesis *Structural investigation of some fluorozirconates and fluorotitanates of hydrazinum (II),* which I defended at the Faculty of Science and Mathematics on July 3, 1968.

In 1968, I was promoted to Research Associate, in 1976 to Senior Research Associate, and in 1981 to Senior Scientist. Finally, in 1998, I was re-elected permanently to Senior Scientist position until my official retirement in 2004. Since then, I have continued my research to the present day. In 2005, I was elected to the rank of Ruđer Bošković Institute Scientist Emerita.

In 1968, my private life took a new turn; I married Dragutin Kojić (journalist), and our daughter Kristina was born. My professional life moved forward requiring even more work and responsibility. I was asked to be the head of the X-ray Laboratory in my early career (1965–1966, 1972). However, the basic equipment we had was completely out of date. There was no X-ray diffractometer for the single-crystal diffraction method and we lacked computer facilities. In order to be able to collect diffraction data, I intensified my contacts with well-equipped laboratories and collaborated with colleagues from Ljubljana, particularly with Prof. Ljubo Golič (Prof. J. C. Speakman's postdoc), from whom I also learned greatly about the implementation of large crystallographic software packages, such as the X-ray system, which I installed in Zagreb in 1970. Already at that time, crystallography was well established in Ljubljana; I have it found inspiring to maintain contacts with his successor, Prof. A. Meden, (Bilateral project 2006–2007) and Dr. D. Turk, Institut Jožef Stefan (Bilateral project 2000–2002).

I also developed a close collaboration with the crystallographic group at the University of Trieste, firstly with Prof. G. Allegra, and later with Prof. L. Randaccio and the members of his team. On a few occasions I also had access to data collection facilities at the Department of

Structural and Inorganic Chemistry, Faculty of Science and Mathematics in Zagreb.

I was the head of the X-ray Laboratory (1989–1997) of the Department of Material Science and Electronics. Dr. S. Popović was responsible for leading the research in the field of powder diffraction until 1987, when he was promoted to the professor position and taught experimental physics at the Faculty of Science and Mathematics. Finally, after many struggles, in 1989, financial support from the official authorities was obtained, and the single-crystal Nonius-CAD 4 instrument and Philips powder diffractometer were purchased. In 1997, in the Department of Physical Chemistry, I was given the opportunity to establish an interdisciplinary oriented *Laboratory for chemical and biological crystallography* involving physicists, chemists, one mathematician, and one mineralogist.

Since then, the single crystal method was separated organisationally from the powder diffraction method, and two independent research groups were founded. The coworkers of the X-Laboratory, Dr. D. Balzar, Dr. B. Gržeta, and Prof. S. Popović (working part-time) joined the Science and Technology of Materials Department under the leadership of Dr. S. Musić.

International networking and interdisciplinary approach are essential in science

My career and life were significantly influenced by postdoctoral studies abroad. In 1972, I spent six months at the Department of Chemistry, University of Uppsala in the group of Prof. I. Olafsson, who was one of the world's leading experts on hydrogen bonding. In addition to X-ray crystallography, they used spectroscopic techniques and theoretical methods. To study hydrogen bonding by X-ray diffraction, one needs to carry out experiments as accurately as possible. Therefore, I decided to take advantage of being in such an excellent place. There I also had the chance to experience the good tradition continued from the time of Prof. Gunnar Hägg, former head of the department. Under the supervision of Prof. R. Liminga (one of the directors of the International Science Programme) and friendly support in computing by Dr. Å. Kvick (who later developed his career at ESRF, Grenoble), my stay in Uppsala was extremely useful and successful. During that period, I mastered many experimental details in data collection, but I also learned more about crystal packing forces. Hydrogen bonding has remained one of my favourite research topics. Hydrogen bonds play a significant role in molecular architecture; these interactions join the molecules in water and ice, in all living cells, and many sophisticated materials influencing their properties. After completing my PhD thesis, I had established my main goals: to select a new field of research, and to find out how to modernise the equipment. In order to open up possibilities to find financial support for expensive equipment, I wanted to put chemical crystallography in the focus of my research. It was very important to demonstrate the close relation between molecular and crystal structure and physical-chemical properties, molecular structure and chemical reactivity. In the early 1970's, drug design started to be a very promising field. At the beginning, it was based on structure/function correlation. Therefore, I decided to determine the crystal and molecular structures of organic and biologically (glycosides, nucleosides, natural compounds), as well as pharmaceutically relevant molecules. Quite a number of compounds were synthesised at the Ruđer Bošković Institute by Prof. V. Škarić, Prof. K. Mlinarić-Majerski, Dr. Š. Horvat, and academician M. Žinić and their collaborators. However, the solution to the 'phase problem' in a more general approach did not exist in Croatia, although A. Bezjak, together with D. Grdenić, published in 1960, the first structure of organic molecule (mellitic acid, *Nature* **185**, 756). Ten years later, the universal software package MULTAN (M. M. Woolfson, P. Main, G. Germain) for solving organic structures, was available in the crystallographic community, and I installed it and made it available to users. To master the 'direct methods' for a phase determination of structure factors, in 1976, I went to the Medical Foundation of Buffalo, USA, to join the group of H. Hauptman. The scientific and human relations I experienced there were excellent. D. Harker, one the first founders of direct methods, who was already retired at that time, used to come to the Institute to share his knowledge and history with us. I learned a lot about the organisation of the research on the large scale from Dr. W. L. Duax. He was the first editor of *The IUCr Newsletters* and served it for 25 years. Dr. W. L. Duax was supportive to many crystallographers in Croatia and other parts of former Yugoslavia, whom he met during his Fulbright visit.

Figure 3. In 1987, Dr. W. L. Duax as the Fulbright fellow visited our crystallographic community. The photo was recorded in Božidar Jakac Art Museum located in the building of the former Kostanjevica Monastery.

Figure 4. Dr. W. L. Duax during his visit to Zagreb presented the lecture at PLIVA (1987). From left to right: B. Glunčić, W.L. Duax, B. Kojić-Prodić, K. Kovačević, B. Šušković, and B. Gašpert.

Dr. D. A. Langs helped me overcome difficult moments with his Irish humour and good ideas on the theoretical aspects of direct methods. Dr. G. De Titta and Dr. R. H. Blessing with their broad crystallographic knowledge, and Prof. Vivian Cody with her excellent sense for reality, were always open for discussion. In 1985, H. Hauptman and J. Karle shared the Nobel Prize for the solution to the phase problem. Although I was lucky to be at the right place to pick up the required knowledge, it was clear to me that theoretical work would not bring me support for purchasing equipment. Thus, I turned to the practical aspect of the application of direct methods in crystallography.

In that period, I attended various workshops and schools to find out how to select and apply the more suitable method for the particular crystallographic problem. For the improvement of my knowledge of different fields of mathematics (inequalities, algebraic methods, theory of probability, and others) used in crystallography, I am deeply grateful to the finest lecturers: Prof. G. M. Sheldrick, the University of Göttingen, Prof. M. M. Woolfson and Prof. P. Main, both from the University of York, Prof. C. Giacovazzo from the University of Bari, and my colleagues Prof. A. L. Spek from the University of Utrecht, Prof. P. T. Beurskens from the University of Nijmegen, and last but not least, Prof. of applied mathematics E. Coffou, University of Zagreb.

As I implemented direct methods in crystallography, we were successful in structure determination of organic molecules, macrocycles, pharmaceuticals-H2-antagonist cimetidine and analogues, pirenzepine-antimuscarinic agent, β-blocker – diltiazem, and other biologically active molecules. These achievements brought me the National Science Award in 1971. Our experience and results led us to the long-lasting collaboration with the pharmaceutical industry PLIVA Research Institute (1972–2001). To determine the molecular crystal structure of an organic

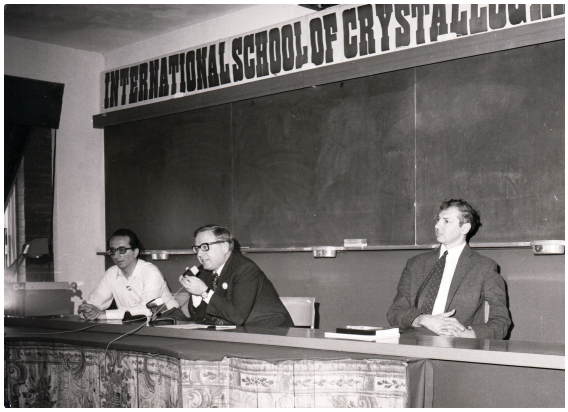

Figure 5. Erice, March 1974 at the International School of Crystallography dedicated to the direct methods in crystallography: Scientific Director of the School Prof. M. M. Woolfson, President of the Italian Crystallographic Association Prof. S. Vaciago, and Organisation Director Prof. L. Riva Di Sanseverino (from right to left).

Figure 6. Erice, March 1974 at the International School of Crystallography (from left to right): H. Hauptman - Nobel Laureate 1985, G. Germain, G. D. Adretti, G. Allegra, P. I. Rentzeperis, L. Nassimbeni, (?), G. Gilli, G. Chiari, and B. Kojić-Prodić.

molecule, it is important to pay attention to stereo–chemistry, conformational analysis, and particularly for pharmaceuticals, to the absolute configuration. To answer these questions, we included spectroscopic methods in our research. In that aspect of research, I have found important my collaboration with academician Vitomir Šunjić and Prof. G. Snatzke, the University of Bochum (Bilateral cooperation 1986–1991), who was one of the leading experts in CD-spectroscopy. Do coincidences in life happen? When I was an undergraduate student in 1960, Prof. K. Balenović asked me to present a student seminar based on C. Djerassi's book *Optical Rotatory Dispersion* (McGraw Hill & Co, 1960). Such high demands were typical of him. At that time, there was no Amazon.com online to obtain a recently printed

book within 24 hours. I found it in the Library of the US Embassy in Zagreb! By the way, I borrowed many textbooks and biochemistry books in that very library. Still, I remember when I bought my first student book in 1958, *Textbook of Organic Chemistry,* by C. R. Noller, which cost me a fortune at that time.

From the early 1980's, we were using the efficient software packages, SHELX for structure solution and refinement (G. M. Sheldrick) and PLATON for analysis of molecular geometry and intra- and intermolecular interactions (A. L. Spek). I cannot resist revealing my admiration for these two professionals, how they developed and improved their software. At international meetings, they both attended the lectures dealing with theory & computing, and among many presentations they recognised 'the right stuff ' and in a couple of months, they had implemented the novelties into their packages. There were many challenges in crystallography in the 1980's, but there was no basic equipment in my lab. In such circumstances, I saw no solution and I accepted a year's grant to joint my colleagues at the Chemistry Department of the Utrecht University. I worked jointly with Prof. A. L. Spek on his project related to chemical crystallography, which required solving and interpreting a huge number of structures for chemists in The Netherlands. This was an interesting part of my scientific experience, which helped me meet many scientists working in different fields from various labs throughout the country. The most significant impact on my approach to science and its organisation I owe to the late Prof. Jan Kroon, from whom I gained profound insight into hydrogen bonding. He taught me to combine X-ray structure analysis with molecular modelling in studies of biologically relevant molecules. The collected knowledge and experience gave me a good start for our joint scientific project in 1991, financed by the European Union. Jan was very good in direct methods, symmetry, theory of chemical bond, and many other matters; one could say that he was an all-around crystallographer. I am very grateful to him and his wife Dr. Loes M. J. Batenburg, a talented crystallographer, for their friendship and the many happy moments we shared together.

In the mid 1980's, we were successful in determination of crystal and molecular structures of organic and biologically active compounds and drugs. In 1985, I managed to gain access to the Cambridge Structural Data Base, and made it available to all crystallographic groups of former Yugoslavia. This was a major organisational and financial task, which came to reality by the strong support of Data Base founder, Olga Kennard, OBE FRS, and her successor F. Allen, FRSC CChem. In the 33 years of its use in our country, it has been an indispensable tool not only for crystallographers, but also for chemists and materials scientists. In 1988, I joined the group of Prof. Ada Yonath,

Figure 7. Prof. Jan Kroon (passed away on May 3, 2001) was the Head of the Department of Crystal and Structural Chemistry, University of Utrecht. He was an excellent scientist and great personality, and I owe him greatly.

Synchrotron Station DESY, Hamburg, to learn about the use of synchrotron radiation, crystallisation of macromolecules, and cryo-techniques required for data collection, which she had developed among the first in the field. The knowledge I had gained there was extremely useful when we started protein *crystallography. In 2009, Ada Yonath shared the Nobel Prize with T. Steitz and V. Ramakrishnan for* the discovery of the 3D structure of ribozyme.

Finally, we installed a new four-circled Nonius-CAD4 instrument in 1989. The joint project related to the plant growth hormone, auxin, with Dr. W. L. Duax, Dr. V. Magnus, and myself, was financed by the National Science Foundation (1988–1992).

The last decade of the past century, the wartime in Croatia, was the most difficult due to human, financial, and organisational reasons. Altogether, it was a great challenge! As we had in-house equipment, we were able to plan our research in accord with our ideas, in spite of the

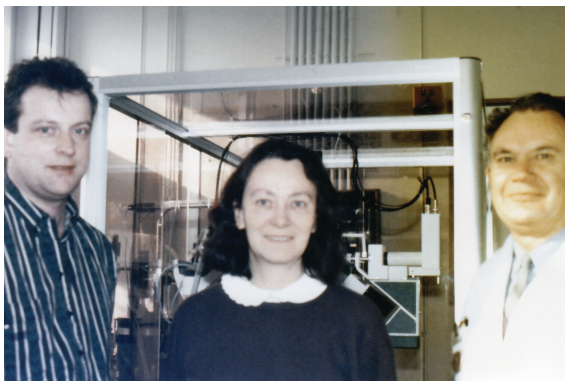

Figure 8. Our first single crystal X-ray diffractometer was installed in 1989: (from left to right) person responsible for installation of Nonius diffractometer, B. Kojić-Prodić, and our technician T. Žic - a highly motivated coworker.

Figure 9. In the late spring of 1990, we celebrated the installation of our first diffractometer (from left to right): Academician S. Šćavničar, B. Kojić-Prodić, Z. Šeparović, Rector of the University of Zagreb, V. Škarić, Director of Ruđer Bošković Institute.

war. At the beginning of the war in Croatia, in 1991, the European Community, Brussels, granted Prof. J. Kroon, V. Magnus and myself, the project entitled *Conformation and Molecular Dynamics of Biologically Active Plant Glycosides*; I was the principal investigator and project coordinator. Due to the war, our signed contract reached Zagreb in a diplomatic bag. In order to realise our project, we needed adequate hardware and software to perform 3D-modelling, including molecular dynamics, and luckily, a graphical station was planned within the financial part of our project. However, in reality, things are rarely simple. At that time, the working combination for crystallography included a *Silicon Graphics* station and *Biosym* software. Although we had reserved money for purchasing hardware, we needed permission to buy it. There was a dogma about Hewlett-Packard being the only good hardware, and no one understood that, for biological modelling, we required hardware of dedicated performances and professional software. I managed to overcome that obstacle with a reference letter from PLIVA. However, the licence fee of US$80,000 for Biosym was a nightmare. Effective negotiation and logical arguments secured us the software. After leaving the administration and financial world behind us, our visual contact with the 3D world of molecules fascinated us all.

Post-graduate physicist, V. Puntarec, a young fellow of enormous capacity and skill, operationalised the X-ray diffractometer, hardware and software, and we all appreciated his contribution. Sanja Tomić, theoretical physicist, joined our group and started work on her PhD thesis *Conformational analysis of glycosidic conjugates of indol-3-acetic acid and tryptophol by X-ray diffraction and computational chemistry* (1994). She built up a very successful career in molecular modelling of auxins, and later she continued with her independent research projects at the Ruđer Bošković Institute. We performed very intensive research on the plant growth hormone and its conjugates in collaboration with Dr. V. Magnus. Biljana Nigović carried out research on her MSc (1989) and PhD (1992) theses on the synthesis, structural characterisation, and biological activity of auxin conjugates. Snježana Antolić, married Steiner, completed her MSc (1995) and PhD (1999) theses in the auxin field, and after her postdoc at Yale, she moved permanently to Switzerland. In 2001, B. Bertoša joined the group and started his PhD on the modelling of auxin binding protein under Sanja's mentorship. We characterised more than fifty auxin derivatives and systematised them according to their biological activity using bio-assays and computational chemistry methods. At that time, our approach and results in the field of auxin physiology were exceptional, and Dr. V. Magnus and our group obtained recognition from the United States Department of Agriculture, USDA (1993). The significant advancement of that research was due to the support of the National Science Foundation through the four-year project with W. L. Duax. V. Magnus and I obtained an invitation for a contribution in *Encyclopaedia of Agrochemicals,* published by Wiley in 2002.

Within my collaboration with PLIVA, Zrinka Banić Tomišić, my PhD student, carried out research on her thesis related to conformational analysis of constitutional parts of peptidoglycan from a bacterial spore cell-wall (1996), synthesised by Dr. Dina Keglević. X-ray structure analysis, ^{1}H NMR + ^{1}H NOE spectroscopy and molecular dynamics were used. NMR-stereochemical studies on glycosides were done in collaboration with Dr. Jurka Kidrič from the National Institute of Chemistry, Ljubljana.

We had already entered the field of biological crystallography successfully, and in order to move forward in the field, protein crystallography was our goal. My strong interest was directed toward enzymes and their catalytic mechanisms. During the 1990's, academician V. Šunjić used lipases in the enantioselective synthesis. In catalytic reactions, commercial lipases of known 3D structures were used, although their catalytic mechanisms were unknown. Thus, we found the joint scientific interest to apply molecular modelling in these reactions. Dr. Sanja Tomić took on the responsibility for that part of the research. To move our research forward, I initiated bilateral collaboration with Prof. W. Saenger, Freie Universität, Berlin (1996–1998), which enabled us the financially significant project with the Volkswagen Foundation (1997–2000). Dr. Marija Luić (mineralogist), a trained crystallographer (PhD student of Prof. C. Giacovazzo), bravely plunged into protein crystallography in Prof. Saenger's group (1997–2001). After graduation (2001), Ivana Leščić, married Ašler, joined our group, and her MSc and PhD theses were related to

purification and biochemical and bioinformatic characterisation of bacterial lipase from *S. rimosus.* In order to use mass spectrometry in protein characterisation, I initiated a bilateral project with Prof. G. Allmaier, Technical University of Vienna (2002–2005), which Ivana successfully continued. We were then able to turn to protein purifications and molecular genetics in order to provide very pure proteins for crystallisation, and structural and functional characterisation. Our experimental facilities in that period were more than modest; however, due to our collaboration with colleagues from the Laboratory for Cellular Biochemistry, we jointly used our finances to work during difficult times. Some of our molecular genetics experiments were carried out with the assistance of Dr. J. Pigac and Dr. D. Vujaklija. To overcome many experimental and organisational problems, and to find a straight solution to some complex scientific questions, I was inclined to exploit the scientific networking built throughout joint research, workshops, postgraduate and postdoctoral studies for my collaborators and myself. In this respect, I would like to mention my contacts with Prof. K.-E. Jaeger, Director of the Molecular Enzyme Technology Institute, Jülich, Prof. F. Spener, University of Münster, and Prof. G. Klebe, University of Marburg, who opened new views in my research. One of my BSc students, F. Kovačić (2005), gained an excellent chance to master molecular biology, and establish himself as a competent scientist under the mentorship of Prof. Jaeger.

Two bright fellows from our laboratory, both my PhD students, A. Višnjevac and Z. Štefanić, developed their careers in entirely different directions. Dr. A. Višnjevac (PhD in 2001) was attracted by bioinorganic chemistry, and went on for a postdoctoral study under Prof. Olivia Reinaud, Paris Descartes University; he has remained devoted to the idea of designing synthetic enzyme catalyst. It is quite a task! In addition, he exhibits great organisational and social skills. Dr. A. Višnjevac has exploited his talents successfully over the last five years in organising a few scientific meetings and workshops. So far, his greatest hit has been the organisation of the 29th European Crystallographic Meeting in Rovinj, 2015 (about 1100 attendees). Z. Štefanić, theoretical physicist, earned his PhD in 2004, and his strong background in physics and mathematics has been greatly beneficial to his career and the group as well. He is an expert in crystallographic computing and graphics, and protein structure determination, but is also very persistent in repairing the frequent failures of our diffractometer. It seems his favourite preoccupation is programming for computer graphics. Devoted friendship between A. Višnjevac and Z. Štefanić keeps a good spirit of the group. During my research career, I was leader of scientific projects financed by Croatian authorities: 1990–1997, 1997–2002, 2002–2006. Within the frame of these projects, the results obtained by my coworkers and myself were qualified, according to criteria of excellence, among the top in Chemistry of Croatia. In total, I was leader of four domestic scientific projects, fourteen international, and participated as collaborator on four international projects.

Since my official retirement (December 31, 2004), Dr. Marija Luić has been the head of the Laboratory for Chemical and Biological Crystallography, and principal investigator in the research related to the structure and catalytic mechanism of purine nucleoside phosphorylase. She has intensified protein crystallography in the group and supports very active research in the laboratory.

In 2004, K. Molčanov joined our group, and he was my last PhD student. In my scientific career, I was focused on hydrogen bonding, whereas molecular dynamics was extensively employed in our research. In the last fifteen years, I had been interested in proton and charge transfer and noncovalent interactions, such as π-interactions of nonaromatics. Thus, Krešo Molčanov's thesis included structural and dynamic aspects of hydrogen bonding in substituted quinones (2008). At that time, Krešo was a beginner and I was retired, and none of us had money for expensive chemicals. One day, he entered my office with a kilogram of quinone, and in a second my wish and Krešo's practical nature helped us to decide to start with quinones. From the beginning, I had in mind the biological function of semiquinones, and we wanted to expand our knowledge of radicals. The research included rather simple preparation procedures, which turned to radicals and their anions. Krešo was very imaginative and many new compounds were prepared and tailored by crystal engineering. These compounds exhibit a large variety of properties leading the research in a few directions: metal complexes with quinoid ligands, compounds of semiconducting properties, and radical anions of magnetic properties. In 2015 Dr. Molčanov's scientific project was granted by Croatian authorities and he is the mentor to Ph D student V. Milašinović.

Crystal structure analysis revealed pronounced stacking arrangement of quinoid rings and other types of interactions being responsible for particular physical property. The most striking forces in these crystals can be assigned to stacking interactions between nonaromatic rings. These interesting interactions and unknown charge-transfer mechanism motivated Krešo and me to think about a charge density analysis. In 2014, the first contact with Prof. C. Lecomte in Nancy was realised, and Dr. K. Molčanov started practising the method with Dr. Ch. Jelsch, Prof. Lecomte's successor. Since then, many compounds comprising quinoid system were objects of charge density studies performed by K. Molčanov and Ch. Jelsch, and new bonding effects, such as a multicentring bond, were discovered. In order to gain close insight into the nature of

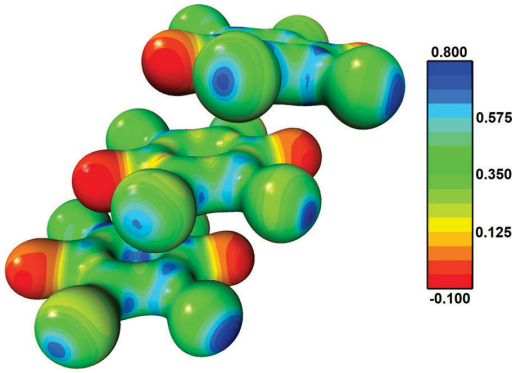

Figure 10. Electrostatic potential derived from X-ray charge density in a trimer of tetrachloroquinone anion plotted onto an electron density isosurface of 0.5 e Å^{-3} (K. Molčanov *et al. Chem. Eur. J.* **2018**, *24*, 8292). The significantly short distance (2.84 Å) within the trimer with its total charge –2 suggested the presence of a multicentre bond, which was confirmed by charge density study and DFT calculations.

these bonding effects, collaborations with theoretical chemists had intensified. At the beginning, we collaborated with Dr. D. Babić, and later with Dr. J. Stare from the National Institute of Chemistry. With time, a new dilemma on the interpretation of molecular interactions required us to intensify collaboration on wider level. The versatile properties of the quinoid system are related to the dynamics of its electronic structure, which are in the femto- to atto-second time scale. Time-resolved spectroscopies using X-ray lasers gave us a chance to move further this research. The most recent experimental set up, a very complex one, provides insight into the dynamics of ultrafast processes. I believe that Dr. K. Molčanov will direct his research to the most promising new area. I cannot stop thinking that the human mind has no limits.

Teaching activities

My teaching was related to MSc and PhD studies at the Faculty of Science and Mathematics and the Faculty of Pharmacy and Biochemistry, the University of Zagreb. I designed and taught the course entitled Instrumentational Analytical Methods in History of Arts at the Academy of Fine Arts, University of Zagreb, Department of Conservation and Restauration. I was mentor to twelve PhD students, eight MSc, and ten BSc students.

Application of X-ray diffraction for chemical identification of archaeological samples, biominerals, and samples of various origins

In addition to my scientific research, I paid quite a lot of attention to the use of my knowledge in practical aspects of X-ray crystallography. In order to support medical

Figure 11. The most significant Istrian frescos painted by V. of Kastav, 1474; Analysis of pigments published by B. Kojić-Prodić et al. *J. Appl. Cryst*. 9(1976) 485. Human nature has been preserved over time – a reach merchant with a treasury box wants to corrupt death to postpone his departure.

diagnostics, I standardised the analysis of biominerals of various kinds. I used X-ray powder diffraction, chemical spot tests, IR spectroscopy, and some optical microscopy methods for identification of a wide variety of archaeological specimens. We were asked rather often to resolve different chemical problems related to technology, corrosion, purity of raw-materials and quality-tests of final products. This was time-demanding work based on analysis of several hundred samples.

Social activities related to science

- President of Collegium Emeritorum, October 2011–2015
- Co-Editor Acta Crystallographica, 2004–2014
- Head of the National Affiliated Centre of the Cambridge Crystallographic Data Centre, responsible for implementation and dissemination of crystallographic data bases in Croatia, Slovenia, and Macedonia, 1985–2007
- Member of the International Commission for Chemical Crystallography of the International Union of Crystallography, 1989–1998
- Referee for Ministry of Science and Technology, Croatia
- Referee for international scientific journals
- Member of the Evaluation Committee for National Science Awards, 2004–2009.
- Referee for Human Frontier Science Program
- Member of Croatian Crystallographic Association and the Croatian Association of Crystallographers
- Member of the Croatian Association of Biochemistry and Molecular Biology
- Member of Organizing Committees of National Crystallographic Meetings and International Meetings and Workshops
- Vice-president of the Election Board - Chemistry, Ruđer Bošković Institute, 1980–1983

- Vice-president of the Scientific Board of Ruđer Bošković Institute, 1981–1983
- President of the Scientific Board of Ruđer Bošković Institute, 1985–1987
- Vice-president of the Scientific Board of the University of Zagreb, 1986–1988

In addition to this list, I would like to mention my engagements in the modernisation of the institute's library (1980–1990), and in the working groups to define priority lists for financing equipment in the country and our institute (1980–1995). I must admit that priority lists were my nightmare that I shared with my colleagues.

Awards

2018 DAAD acknowledgment on the 20th anniversary of the Croatian Branch of DAAD
2011 Ruđer Bošković Institute Award
2010 National Science Award for Life Achievement (Croatia)
2005 Title of Scientist-Emerita
2003 Member of European Academy of Sciences (Brussels)
2000 DAAD Visiting Scientist Award
1997 Croatian Academy of Sciences and Arts Award
1995 DAAD Visiting Scientist Award
1971 National Science Award (Croatia)

Zageb, July 2018