University of Zagreb, Faculty of Science

Faculty of Science - Strategic programme for scientific research from 2018 to 2023

University of Zagreb, Faculty of Science

University of Zagreb, Faculty of Science

The Faculty of Science (PMF) of the University of Zagreb has been one of Croatia's **leading scientific institutions** since its establishment. This prominent position implies great responsibility and sets high standards. Since the STEM (Science, Technology, Engineering and Mathematics) fields of research and education are among the top global trends, Croatia's success in following these trends will largely depend on the capability of PMF in Zagreb to maximally focus research work in the institution on globally relevant topics. This orientation must also influence the educational component of PMF. If we are to accept this premise, then the strategic goals of PMF in science are set naturally. It should be stressed that in most global regions, systematic efforts are in place to raise universities and scientific centres to a higher level. That means that PMF is facing additional efforts to retain its existing position, while improvements will require a highly coordinated policy implemented throughout the faculty as a whole.

Purpose behind the establishment and work of the scientific organisation

PMF was established in 1946 on the tradition of educational and research activities that began in 1876, at the Department of Science of the then Faculty of Philosophy. The purpose behind the establishment of PMF was primarily the higher education of students in the fields of mathematics, physics, chemistry, biology, geology, geography and geophysics. Since its inception, PMF has had a key influence and significance for society as a whole, and for the development of the Republic of Croatia through the education of secondary school teachers, scientific researchers at Croatian universities and institutes, and employees in various companies in the public and private sectors, and entrepreneurs.

An important premise of the strategy is that **university education is essentially founded on scientific research**. Only this form of higher education can respond to the challenges of the rapid changes in our society, which are predominantly the consequence of technological development. Only higher education founded on research can prepare highly educated persons, ready to accept and develop new knowledge and innovations, and be active factors in economic development, and to respond to the challenges of the sustainability of humankind and the environment. Since its inception, PMF has been a cornerstone research institution in the Republic of Croatia.

Scientific research at PMF is performed in several important forms of activities that are interrelated and interconnected. The first is **experimental and theoretical scientific research** on numerous open issues in science, and the results of this research is visible in published scientific papers. PMF scientists are consistently publishing the results of their research in leading global journals, such as *Nature, Science, PNAS, Nature Communications, Science Advances, Royal Society Open Science, Journal of Differential Equations, ACM Transactions of Mathematical Software, Mathematische Annalen, Journal of Mathematical Analysis and Applications, SIAM Journal on Matrix Analysis and Applications, Communications in Partial Differential Equations, International Mathematics Research Notices, Discrete and Continuous Dynamical Systems – Series A, Stochastic Processes and their Applications, Geometry & Topology, Annals of Probability, Probability Theory and Related Fields, Annals of Applied Probability, Journal of the American Mathematical Society, Duke Mathematical Journal, Journal of the European Mathematical Society, Applied and Computational Harmonic Analysis, Physical Review Letters, Physical Review A-E, Nature Physics, Cell, Angewandte Chemie International Edition, Chemistry – A European Journal, Physical Chemistry-Chemical Physics, Inorganic Chemistry, Journal of Organic Chemistry, Analytical Chemistry, The EMBO Journal, PlosONE, Nature Biotechnology, Genome*

University of Zagreb, Faculty of Science

Research, DNA Research, Progress in Retinal and Eye Research, Chemosphere, Freshwater Biology, Hydrobiologia, Nature Climate Change, Atmospheric Chemistry and Physics, Journal of Geophysical Research, Seismological Research Letters, Paleo3, Mineralogical Magazine, Palaios, Lithos, Facies, The Cryosphere, Geomorphology, Palaeogeography, Palaeoclimatology, Palaeoecology (or PALAEO3), Journal of Hydrology, Applied Geography, Journal of Rural Studies and Geoforum. With their quality and originality, some of these publications have achieved significant international response in the international community. PMF scientists are often invited speakers at leading international conferences in the fields of research conducted at PMF.

Today's model of financing research from European sources (e.g. H2020 programme, previously FP7, European structural and investment funds) and Croatian sources (e.g. Croatian Science Foundation (HRZZ), United in Knowledge Fund (UKF), Ministry of Science and Education (MZO)) are aimed at **implementing specific scientific projects within the set schedule**. This form of activity has become exceptionally important, and it is impossible to imagine experimental and theoretical work, and the supervision of doctoral candidates, without project financing of scientific research. Furthermore, project activities are exceptionally important for the development of research infrastructure. In that context, PMF has applied for two projects financed from the EU structural and investment funds: CeNIKS – Centre for the advanced research of complex systems (http://ceniks.phy.hr), and the project CIUK – Centre of excellence in chemistry. Of the many projects currently under implementation at PMF, two projects are European Research Council grants (Scientific centre of excellence for quantum and complex systems, Representation of Lie algebras) that are financed from the EU structural and investment funds. A number of projects are financed from the FP7 programme of the H2020 funds: *Constraining Stellar Mass and Supermassive Black Hole Growth through Cosmic Times: Paving the way for the next generation sky surveys (ERC project), The Janus-face of the localized carrier in cuprates: Generating the pseudogap and high temperature superconductivity (ERC project), Systems medicine approach to chronic inflammatory disease (H2020), Innovative training in methods for future data (Marie Curie ITN), Comparative genomics of non-model invertebrates (Marie Curie ITN), Connectivity among Mediterranean fishery stakeholders and scientists resolves connectivity of fishery population (INTERREG), Marine Ecosystem Restoration in Changing European Seas (H2020), BIOengineered grafts for Cartilage Healing in Patients (H2020), Smart Integration of Genetics with Sciences of the Past in Croatia: Minding and Mending the Gap (H2020)*. PMF scientists often cooperate as partners in scientific projects (where the project lead is another institution). For example, PMF scientist are active in six of the ten Scientific centres of excellence in the field of STEM established in the Republic of Croatia.

The third important form of activity are doctoral studies. Seven doctoral study programmes are offered at PMF: **Biology, Physics, Geology, Chemistry, Mathematics, Doctoral study of geography: space, region, environment, landscape, and the Interdisciplinary doctoral study of Oceanology**. The purpose of doctoral studies is manyfold. First, the doctoral candidate acquires experience in a given scientific discipline which is an important continuation of their undergraduate and graduate studies. Second, the candidate is trained for independent scientific research. Third, the candidate is prepared to accept and apply the newest technology created at the forefront of research, which is why these studies are an important part in the sustainability of Croatian universities and scientific institutions, and for keeping Croatian economic entities (both public and private sector) in line with the newest technologies based on the natural sciences and mathematics. An example are medical physicists, who solely have the expertise for specific segments of working with sophisticated devices in hospitals and health care institutions. Many of the students completing doctoral studies at PMF are today employed at other

institutions, such as the Ruđer Bošković Institute or universities in Split, Osijek and Rijeka.

Therefore, the role of PMF in this form of activity in the Republic of Croatia is exceptionally important, and is deserving of special attention. An important part of the scientific production of PMF comes from the work of doctoral candidates that is visible in scientific and graded papers, such as the dissertation.

The fourth important form of activity related to scientific research is **international cooperation** with scientists, scientific groups and institutions, and scientist **mobility**. International cooperation has an important influence on international research, and on the level of research quality and the selection of topics addressed by scientists. Since its inception, PMF has placed great importance on international cooperation, and this is seen with the Office for International Cooperation, and the position of Vice-dean for international cooperation in the PMF organizational chart. This form of activity is achieved through bilateral projects, the organization of scientific conferences, and through scientist mobility, where scientists spend shorter or longer periods abroad in professional development and training.

The fifth important form of activity related to scientific research involves applied research, or **expert work**. Through scientific work, the research and teaching staff at PMF acquire expertise and credibility in the execution of expert projects that are important for a wide range of aspects affecting Croatian society, particularly those pertaining to sustainable development and environmental and nature conservation. One such example of important expert work is PMF's cooperation with Croatian Waters. For example, projects are currently underway on the Systematic testing of hydromorphological quality elements in rivers in 2016 and 2017 (client: Hrvatske Vode (Croatian Waters); project implemented by Department of Geography, PMF and Elektroprojekt d.d.); Development of methodologies for assessing the hydromorphological condition in standing waters and performing hydromorphological monitoring (client: Hrvatske Vode (Croatian Waters); project implemented by Department of Geography, PMF and Elektroprojekt d.d.); Analysis of biological methods of assessing the ecological condition of phytobenthos, macrophytes and macrozoobenthos in European intercalibration rivers in the Pannonian and Dinaric ecoregions: analysis of the effect of environmental factors and anthropogenic load on biological elements of quality (client: Hrvatske Vode (Croatian Waters); project implemented by Department of Biology, PMF) and Classification system of the ecological potential for artificial and scientifically altered surface water bodies – part I: standing waters in the Pannonian ecoregion and part II: standing waters in the Dinaric ecoregion (client: Hrvatske Vode (Croatian Waters); project implemented by Department of Biology, PMF and Danube Research Institute). As a unit of PMF, the Seismological Survey collects and analyses macroseismic and microseismic data. Earthquake records are examined to notify the public and various services, and in the expert opinions of civil engineers, in home insurance, etc. The Service also drafts seismic studies for the needs of Hrvatska elektroprivrede (Croatian Electric), the Ministry of Defence of the Republic of Croatia, and Croatian Waters, and performs studies in the field of seismology engineering, whose results are applied in designing special interest structures (such as dams, bridges and terminals).

The Botanical Garden is a unit of the Department of Biology, PMF, and is a favourite destination for Zagreb citizens and tourists. Due to the important educational, cultural, historical, and tourism value of the gardens, and their overall significance for the university, the City of Zagreb and the Republic of Croatia, the Botanical Garden was proclaimed a protected monument of park architecture in 1971. The gardens are important in university teaching, in scientific research and expert work in the field of botany, and in the education of the general public of the important of working together to protect and conserve the wealth of Croatia's flora. The Botanical Garden has broad-reaching cooperation with

other such gardens around the world, and this exchange of experiences develops the fundamental activities of botanical gardens in the 21st century, particularly education and the protection of plant biodiversity. PMF scientists participate in projects important for the conservation of Croatia's flora and fauna. For example, in cooperation with the Croatian Environment Agency, they have participated in the work of numerous Red Books and Red Lists that are important for the recognition of species and habitats at the national level, and for determining priority measures for their protection. Finally, PMF regularly works together with economic entities to develop expert studies for the needs of a wide range of clients in the fields of energy, water management, environmental protection, nature conservation, construction and other economic activities.

The sixth form of activity is **cooperation with economic entities**, where applied research and technology transfer play an important role. Modern universities have three important roles. Two have already been mentioned above: scientific research and teaching. The third role is the positive effect on the economy, which can flow through several different channels. One is the movement of human resources that have attained a certain level of expertise (through the completion of undergraduate, graduate or doctoral studies) in the economic sector. The second is cooperation with companies in joint projects through applied research. An example is the cooperation between PMF and Pliva (see detailed description below) and Genos (e.g., H2020 project *Systems medicine approach to chronic inflammatory disease*). PMF scientists have also led many Proof of Concept (PoC) projects that create new ties with the economy. The third is through the creation of spin-off and spin-out companies based on scientific findings, and the transfer of technology. To date, PMF has had an important influence through the first channel, while activities are also in place in the second channel, while the third is a challenge that needs to be achieved.

This seventh form of activity is the **popularization of science**. Popularisation activities have been successfully achieved at PMF for years through the exceptionally popular PMF Open Days (once a year, usually in April) that also receives substantial media attention (TV, radio, etc.), and activities such as Chemistry Magic, Biology Night, Physics Express. The purpose of popularization is to make our scientific activities better known to the general public, as taxpayers who finance the public sector including the university, and to raise awareness amongst primary and secondary school children about science and math to expand the base of smart students wanting to attend PMF.

Many forms of activity are in some way related to scientific research. At the end of this chapter, we also mention the PMF publishing activities. PMF is publisher of six scientific journals: *Acta Botanica Croatica*, *Geofizika*, *Croatica Chemica Acta*, *Glasnik Matematički*, *Hrvatski geografski glasnik* and *Acta Geografica Croatica*. The first four are indexed in the Web of Science, among the total 42 Croatian journals indexed in this internationally recognizable bibliographic database.

Analysis of the scientific potential of the scientific organisation and its position in the scientific and corporate environment

The most important research resource of the Faculty of Science are its human resources. **The faculty employs 275 researchers in scientific-teaching positions, and 157 researchers in associate positions, distributed in seven departments (data as of November 2017)**. The Faculty includes the following departments:

University of Zagreb, Faculty of Science

- Department of Mathematics
- Department of Physics
- Department of Chemistry
- Department of Biology
- Department of Geology
- Department of Geography
- Department of Geophysics.

Each department includes multiple divisions, chairs and centres, including the Croatian Seismology Survey and the Botanical Garden. All units are listed individually in Appendix A.

This strategy largely focuses on strengthening human resources, and with that improving the capacity for project implementation and scientific research at PMF. Currently, there are 118 active projects underway in the Faculty, of which 83 are financed from domestic funding sources, and 35 projects are fully or partly financed from foreign sources. Of these 35 projects, seven are financed from the H2020 programme (one is an ERC project), two from the FP7 programme (one is an ERC project), one project from the European Structural and Investments Funds, one project from the IRI programme, one project from the INTERREG programme, one project from the Erasmus+ programme, two projects from the IAEA programme, two projects from the AUF (Agence universitaire de la Francophonie) programme, and the remainder are bilateral projects. These figures do not include research grants (86 research grants approved in 2017 in the amount of approx. HRK 2.7 million, amount similar to the two prior years). The share of H2020 and FP7 projects is somewhat less than 8% in the total number of projects. The share of projects financed from foreign sources, without cross-border projects is 16/118, or between 13 and 14%. In viewing that figure in light of the 275 researchers employed in scientific and teaching positions, then certain items in the SWOT analysis arise clearly as addressed below.

The Faculty of Science is situated in a highly stimulative environment. Several of the departments of PMF (Mathematics, Physics, Chemistry, Geophysics, Geology and part of Biology) are situated near the Ruđer Bošković Institute, School of Medicine, Institute for Physics, and the Institute for Medical Research and Occupational Medicine. **This large complex of natural, biomedical and biological sciences in northern Zagreb is often referred to as the North Campus**. Several infrastructure projects are underway, and financed from the European Structural and Investment Funds, which will substantially affect the scientific landscape of the North Campus, in which PMF is either a direct factor (project leader) or the PMF scientists participate as partners in these projects.

Below we highlight several of the European Structural and Investment Fund projects that will significantly impact PMF's scientific activities over the next five years. The project **CeNIKS – Centar za napredna istraživanja kompleksnih sustava [Centre for the advanced research of complex systems]** (http://ceniks.phy.hr) was proposed in a competition for Infrastructure support financing from the European Fund for Regional Development. This project, worth EUR 8.2m, is being carried out at the Department of Physics, PMF. A second project was proposed in the same competition: **CIUK – Centar izvrsnosti u kemiji [Centre of excellence in Chemistry].** This project, worth EUR 9.5m, is carried out at the Department of Chemistry, PMF. The purpose of the project is to develop the national scientific research infrastructure that will contribute to the development of innovation capabilities, of both individuals and the collective faculty, contribute to excellence, and the diversity and modernisation of

the national economy. By developing the Department of Chemistry, PMF as the leading national and regional centre, where world-class applied and fundamental research in the field of chemistry is performed, will develop the scientific research personnel with special skills and knowledge in this field. In the long-term, this approach will ensure greater competitiveness and recognisability of activities related to research and developed carried out at the University, both at the national and international scales. Specific objectives of that project should be strengthening the competitiveness of the Croatian economy based on the applicable results of scientific research work, and stimulating new and expanding existing cooperation with economic entities. It is important to note that preparations are underway to apply for structural funds for the Department of Biology, aimed at procuring new scientific equipment and renovating existing spaces to organise new laboratories. Finally, it is expected that the strengthened infrastructural capacities will substantially increase the research and innovation opportunities, thereby also positively affecting teaching activities.

A contract has been signed for a top research project as part of the **Znanstvenog centra izvrsnosti (ZCI) za kvantne i kompleksne sustave te reprezentacije Liejevih algebri [Scientific centre of excellence (SCE) for quantum and complex systems and representations of Lie algebras]** (http://bela.phy.hr/quantixlie/), also financed from the European Structural and Investment Funds, granted in 2016. A grant in the amount of HRK 36,956,624.09 was approved for this project. It is expected to substantially contribute to the development of human resources, and to raise the level of research quality in theoretical physics and mathematics. It is important to note that PMF researchers are participating as partners (or PMF as a partner institution) in the work of five other Scientific Centres of Excellence (SCE) led by other Croatian institutions: SCE for advanced materials and sensors – CEMS (Ruđer Bošković Institute), SCE for biodiversity and the molecular enrichment of plants (University of Zagreb, Faculty of Agriculture), SCE for personalised health care (University of Zagreb, School of Medicine), SCE for fundamental, clinical and translational neuroscience (University of Zagreb, School of Medicine), and the SCE for science on data and cooperative systems (University of Zagreb, Faculty of Electrical Engineering and Computing). Through involvement in these scientific centres of excellence, PMF scientists have the opportunity to strengthen cooperation and take advantage of cooperation with other scientists from around the Republic of Croatia, in order to raise the quality of research nationwide, and to strengthen interdisciplinary and multidisciplinary research.

Projects from the EU Structural and Investments Funds led by neighbouring institutions include the O-ZIP project (Open Scientific Infrastructural Platforms for Innovative Applications in the Economy and Society, http://ozip.irb.hr/), worth EUR 50m and to be implemented at the Ruđer Bošković Institute, and the CALT project (Centar za napredne laserske tehnike – Centre for advanced laser techniques) (http://calt.ifs.hr/), to be implemented at the Institute for Physics. PMF scientists will be able to use the O-ZIP and CALT infrastructure in their research. In addition to these two projects that have been proclaimed as strategically important, funding is soon expected for the Cryogenic Centre product of the Institute for Physics (http://kacif.ifs.hr/).

Procuring capital equipment and project activities have created the scientific infrastructure in the sense of laboratories and their equipment. The organisation of laboratories follows the organisation of PMF by departments, as outlined in detail in Appendix A. A catalogue of PMF's scientific equipment is currently being drawn up, and will give a meticulous overview of PMF's capacities for conducting experimental research and providing commercial services to companies in the corporate sector, and to other legal and natural persons. The current version of the scientific equipment catalogue is found in Appendix C, and will be updated with new items as needed. Each department also contains a library

University of Zagreb, Faculty of Science

housing the literature materials necessary for conducting research, and these capacities are constantly being updated with access provided to relevant global journals in the fields of the natural sciences and mathematics.

PMF scientists enjoy close cooperation with the Ruđer Bošković Institute, Institute for Physics, Croatian Hydrological and Meteorological Service, Institute for Medical Research and Occupational Medicine, Faculty of Textile Technology, Faculty of Chemistry and Technology of the University of Split, Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb, Croatian Geological Survey, Ruđer Bošković Marine Research Centre in Rovinj, Institute for Oceanography and Fisheries in Split, Croatian Conservation Institute, Croatian Institute for Brain Research, Faculty of Veterinary Medicine and Faculty of Science of the University of Split. PMF also works closely with the City Office for Strategic Planning and Development, and the National Centre for External Evaluation of Education. This cooperation unfolds through joint projects, and numerous partnership agreements have been signed, such as the Partnership Agreement as part of the six Scientific Centres of Excellence outlined above, making PMF a partner of all the important actors in the STEM fields in the Republic of Croatia.

PMF scientists also have very strong international cooperation. Part of this international cooperation is achieved through joint international projects. As an example, there are six projects within the Unity for Knowledge fund, where our scientists work together with some of the world's most renowned institutions, such as the Massachusetts Institute of Technology and Imperial College London. Cooperation is also unfolding with numerous other institutions: Caltech, University of Oxford, University of Cambridge, ETH Zurich, University of Chicago, University of Illinois Urbana-Champaign, Chemistry Institute in Ljubljana, University of Ljubljana, University of Graz, University of Vienna, University of Prague, University of Florence, University of Manchester, Weizmann Institute of Science, Tübingen Proteome Center, University of Portland, EMBL Grenoble, Technical University Berlin, Technical University Sydney, University of Stuttgart, University of Trieste, University of Warsaw, University of Heidelberg, University of Jyvaskyla, McGill University, University of Namur, LCC Toulouse, University of Maragheh, Universitat de les Illes Balears, East China Normal University, Kansas State University, Wrocław University of Technology, Universidade de Lisboa, Universität Bielefeld, Sorbonne Universités, University of Hamburg, University of York, University of Padova, Italian National Institute for Environmental Protection and Research (ISPRA), Max Planck Institute for Molecular Genetics Berlin Germany, University Ben-Gurion Beer-Sheva Israel, Centre for Genomic & Experimental Medicine MRC Institute of Genetics & Molecular Medicine, The University of Edinburgh Western General, Broad Institute of Harvard, Eawag, University of Washington, University of Utah, UCLA, University of Florida, Hong Kong University, Purdue University, Universidad Autonoma de Madrid, Universitaet Bonn, Danube Research Institute and Washington University in St Louis.

In addition to international projects, PMF has institutional cooperation in the form of signed cooperation agreements with numerous international institutions. PMF currently has 131 Erasmus agreements with foreign institutions, and 14 cooperation agreements with the institutions: A.P. Vinogradov Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia; University of Trieste, Department of Education and Cultural Processes, Section of Geography and Politics of Territory, Trieste, Italy; University of Bihać, Teacher's College, Bihać, Bosnia and Herzegovina; University of Padua, Department of Geosciences, Padua, Italy; International School for Advanced Studies (SISSA), Trieste, Italy; Basque Centre for Applied Mathematics (BCAM), Bilbao, Spain; University of Environment (UoE), Karaj, Iran; Saints Cyril and Methodius University of Skopje, Faculty of Science, Skopje, North Macedonia; Institute of Nature Conservation of the Polish Academy of Sciences, Kraków,

University of Zagreb, Faculty of Science

Poland; Paul Scherrer Institute, Villigen, Switzerland; Moscow Institute of Physics and Technology, Moskva, Russia; University of Pécs, Pečuh, Hungary; Hungarian Natural History Museum, Budapest, Hungary; School of Science, University of Osaka, Osaka, Japan.

Important cooperation is also underway with economic entities in applied research and technology transfer. For example, scientists at the Department of Chemistry, PMF, have intensive cooperation with representatives of pharmaceutical (PLIVA d.o.o, Fidelta d.o.o., Belupo d.d), chemical (Kemika d.d.), petrochemical (INA d.o.o.) and food (Zvijezda d.o.o.) industries. This joint scientific work is primarily dedicated to the development of new methods to synthesize chemical compounds, and methods of qualitative and quantitative analysis of their mixtures in examples that researchers in the economic sector face in their daily work. Research is partly focused on the development of green processes in making chemical compounds; specifically, finding or optimising synthetic paths that use lower amounts of harmful solvents and energy sources. Scientific cooperation with the private sector has resulted in 29 scientific papers in journals indexed in the Current Contents base, five doctoral dissertations and three graduate papers. Cooperation with the private sector is also seen in the implementation of expert projects, where the staff of the Department of Chemistry, PMF apply their scientific expertise and infrastructural capacities to resolve specific problems faced by businesses. In addition to the cooperation with private sector representatives, it is important to stress the cooperation between the staff of the Department of Chemistry with the Croatian Ministry of the Interior. For a minimum of fee used to partially cover the costs of operation of the NMR spectrometer, procured as part of the Interior Ministry call for applications “Strengthening capacities for research, development and innovation”, the scientists at the NMR centre of the Department of Chemistry perform analyses of complex mixtures of opiates seized in the Republic of Croatia.

PMF has had an importance influence on part of the hospital sector through the development of medical physics. There are currently 60 medical physicists employed in the Croatian health care system, performing daily tasks in radiotherapy, nuclear medicine, diagnostic radiology and radiation protection, and also participating in teaching activities at PMF. There is currently a high and urgent demand for the development and application of medical physics in modern diagnostics and therapy procedures (radiotherapy - IMRT, VMAT, SRS, SABRT, diagnostic radiology – fMRI, dwMRI, tensor MRI tractography, msCT, nuclear medicine – SPECT, PET, etc.). The Republic of Croatia has accepted the EU Directive EURATOM 2013/59 and transposed it into the national legislation. This Directive requires the appropriate application of knowledge in medical physics in health care procedures. On the basis of this, the number of medical physicists in Croatia is on the rise (and is expected to exceed 100), and their activities in these areas will only deepen.

The doctoral study programmes are in need of constant updating. One of the challenges faced by the doctoral study programmes is the four-year model of financing doctoral candidates (e.g., CSF), which is in line with global trends, while the recent system of junior researchers enabled a longer period of financing (at least six years) for the candidates to complete their dissertations. It is necessary to focus on a larger number of specialised elective courses with fewer compulsory ones, to allow candidates to spend more time dedicated to their research work and for those courses to better train the candidates within the topics of their dissertations.

It is important to stress that the scientific research at PMF is aligned with the **Smart Specialisation Strategy of the Republic of Croatia for the period 2016–2020 (S3)**, and the **Education Strategy in Science and Technology**, and other **national strategic and sectoral documents**. All larger projects from

the European Structural and Investments Funds passed through an evaluation process to determine their alignment with these documents, and regarding their vertical and horizontal topics.

Specifically, the **SCE QuantiXLie** is aligned with topics in the Smart Specialisation Strategy: the project is compliant with the Partnership Agreement and Operational programme Competitiveness and Cohesion 2014–2020 (OPCC), TO 1 – Strengthening research, technological development and innovation, as it directly contributes to capacity building and to invention and innovation in the fields covered by the SCE. The project is aligned with Investment priority 1a of the OPKK, as it directly contributes to capacity building in the IRI sector for the implementation of high quality research and needs of the economy. Links with the vertical thematic priority areas (TPA) and the sub-thematic priority areas (STPA) are: (i) TPA Energy and a sustainable environment – STPA Energy technology, systems and equipment and STPA Ecologically acceptable technologies, equipment and advanced materials, where research is performed on topological, photonic and condensation systems aimed at developing new generation advanced materials; (ii) TPA Security – STPA Cyber security, where research in the project is focused on the study of elliptical curves, especially constructions of elliptical curves with high torsion groups and a positive range, which are exceptionally important in cryptography of public keys (indicative IRI topic of crypto-communication systems adapted to the EU and NATO standards); (iii) TPA Security – STPA Defence technology and dual-use projects, where the research is focused on new photonic materials that imitate natural systems (like chameleons), and meta-materials (IRI topic of Material engineering (protective clothing and equipment), associated with the indicative topic within the horizontal KET topic Photonics and advanced optics); (iv) TPA Health and quality of life – STPA Pharmaceuticals, biopharmaceuticals, medical equipment and devices, where research is focused on the mechanism of chromosome division in mitosis, which will give better insight into genetic disorders arising from errors in cell division and open new opportunities for their treatment (IRI topic Discovery and development of medicines for humans and animals); (v) TPA Health and quality of life – Health care services and new methods of preventative medicine and diagnostics, where the research is focused on exotic atom cores relevant in medical diagnostics and therapy (IRI topic New diagnostic and therapy tools and applications).

The project CIuK is associated with the vertical thematic priority areas (TPA) of the Smart Specialisation Strategy: (i) TPA Health and quality of life - SPTA Pharmaceuticals, biopharmaceuticals, medical equipment and devices; (ii) TPA Energy and a sustainable environment – STPA Ecologically acceptable technologies, equipment and advanced materials; (iii) TPA Food and the Bioeconomy - STPA: Sustainable food production and processing. Establishment of the Centre of Excellence at the Department of Chemistry will directly contribute to achieving two investments priorities of the Operational programme Competitiveness and Cohesion: strengthening research, technological development and innovations, and investments in education, training, professional development and lifelong learning. The first, which is related to strengthening the public science and research infrastructure, will contribute to improving the infrastructure and technological capacities of the Department of Chemistry, PMF, which are used in successful research studies of national and European interest. These investments will further advance the existing (outdated and uncompetitive) infrastructure currently used in chemistry research, thereby strengthening ties with industry (petroleum, pharmaceutical, construction, and food industries). Increased cooperation with the economy will develop new cooperation, enabling the implementation of chemical research whose results will be applicable in the development of products and services of public and private interest. In addition to the development of infrastructure and human capacities in the area of public scientific

research activities, the CIuK project (Centre of Excellence in Chemistry) will also contribute to increasing employment and strengthening social cohesion in Croatia. This will be achieved through three specific goals: improving quality, relevance and effectiveness of higher education, increasing the rate of higher education attained, and improving working conditions for Croatian researchers.

The project CeNIKS is aligned with the Smart Specialisation Strategy of the Republic of Croatia through its overlap with the following goals: Goal 1. Increase the capacities of the scientific research sector for the performance of high quality research that meets the demands of the economy, and Goal 2. Overcoming the fragmentation of the innovation value change and the large gap between the scientific research and economic sector, Goal 3. Development of smart skills – improving the qualifications of existing and new work force for smart specialisation. The project CeNIKS will improve the scientific infrastructure, while organisational reforms will achieve the prerequisites for achieving scientific excellence of researchers, which will be reflect in a higher number of scientific research projects and publications, and new international cooperation. The project will further improve the qualifications of the work force that will form the foundation for a more innovative and creative public sector that works in synergy with the economy. Project implementation will overcome and reduce the differences between the scientific research and business sector, through cooperation in selected thematic priority areas. Priority areas encompassed within the project are Health and quality of life, Energy and a sustainable environment, Transport and mobility, Security, and Food and biochemistry. The horizontal topics are: (1) key development technologies (KDT), and (2) information and communication technology (ICT). The main objective of the project is the development of new materials and technologies, whereby it overlaps with three different priority areas (and subareas): Health and quality of life (health care services and new methods of preventative medicine and diagnostics), Energy and a sustainable environment (ecologically acceptable technologies, equipment and advanced materials), and the horizonal area (KDT – key development technologies). A part of the project, the Laboratory for optical atomic spectroscopy, is focused on research of the dielectric-barrier discharge (DBD) that can be used to modify surface properties of various materials, which has medical and biomedical applications, particularly in device sterilisation and sterilising wounds, and the treatment of cancer cells. The DBDs of noble gas (helium, argon and other) plasmas will be examined as the carrier of the discharge. The purpose is to determine the key parameters of plasmas and to fully understanding the resulting processes, in order to further adapt and increase the DBD dislocation and ionisation efficiency. This corresponds with the priority area Health and quality of life (health care services and new methods of preventative medicine and diagnostics). Project achievements will ensure the infrastructure for the development and comprehensive characterisation of materials. Two new units will be formed: Laboratory for synthesis and preparation of materials, and the Laboratory for optical spectroscopy and ellipsometry. The first laboratory will be the central place for the installation of top equipment for different synthesis processes, while the second laboratory will be characterised by technology that is currently not found elsewhere in Croatia, though it is standard in laboratories abroad, and it will be used to discover much about material properties. Other parts of the project are focused on various forms of material characterisation (magnetic, transport and electrical properties, structural research and discovery of microscopic mechanisms) and ensuring stable scientific work (unit for cryogenic liquids), as these conditions are currently not in place. This will contribute to the priority areas (and subareas) Energy and a sustainable environment (ecologically acceptable technologies, equipment and advanced materials) and the horizonal area (KDT – key development technologies). The information and communication technologies (ICT) will serve in the integration and interpretation of data obtained in research, and in the organisation of research activities (including the procurement of software).

University of Zagreb, Faculty of Science

Current research topics of project participants were materials that certainly influence environmental sustainability, such as high temperature superconductors, and new forms of nano-electronics such as spintropics, as well as new materials for telecommunications such as topological isolators and more. It is undoubtable that work will continue on these topics and, more importantly, the project will open new areas of research.

Though the associations between the PMF's largest infrastructural projects with the national strategic and sectoral documents are outlined here, the majority of scientific research conducted at PMF listed in this strategy is primarily aligned with those objectives.

With an analysis of the forms of activities that make up the scientific work at PMF, and the description of the scientific potential of the scientific organisation and its position in the scientific and business environment, a SWOT analysis was conducted to define the strength, weaknesses, opportunities, threats associated with achieving the strategic goals.

The SWOT analysis from the Development Strategy of the Faculty of Science, University of Zagreb that was compiled prior to the reaccreditation of the faculty, serves here as a foundation for building the SWOT analysis.

SWOT analysis

Strengths

- Long-standing tradition and reputation of PMF in university education, scientific research and expert work in the fields of the natural sciences and mathematics.
- Scientific excellence and international recognition of individual researchers, competitive research groups and results of their research.
- Intellectual potential of a large, highly competent and motivated staff in scientific, teaching and associate positions, and a favourable ratio of teachers to students.
- Connections at the national and international level, with a substantial number of national and international scientific projects, and the accompanying scientific infrastructure, library fund and periodicals.
- Proximity to other University of Zagreb units and public scientific institutes, which ensures a stimulatory environment for scientific, teaching and expert work.
- Dialogue and acceptance of the needs of different Croatian regions (Osijek, Split, Dubrovnik, etc.) to expand science studies, primarily their development in the scientific fields and teaching activities.
- Establishment of strong connections at the local and regional levels in cooperation with public institutions (e.g. Hrvatske vode, Hrvatska elektroprivreda, national parks, Ruđer Bošković Institute, Institute for Physics, State Hydrological and Meteorological Institute, etc.) in the areas of sustainable development and information science.
- Active inclusion in the daily life of the citizens of the City of Zagreb and Republic of Croatia (Seismological Survey, Botanical Garden, etc.).
- Highly motivated, dedicated and conscientious students at all levels of study.

Weaknesses

- Existing spatial fragmentation and inappropriate spatial housing of parts of the natural sciences seriously hinders the performance of scientific and teaching activities, and adequate

administrative support.

- The division of resources ultimately reduces connections between fields and scientific areas, which largely hinders the implementation of common standards and criteria, and negatively reflects on the indicator effects (quality), on stimulating interdisciplinary study, and on establishing joint research in the sciences.
- Insufficient reliance on international financing sources, and international projects.
- Insufficient number of scientific teaching and junior researcher positions, and post-doctoral positions, which causes staff to be overburdened with teaching and administrative obligations.
- Inadequate evaluation of creating internationally recognizable research groups with large project funding sources, particularly those European Union sources of financing.
- Insufficient number of high quality foreign post-doctoral students (partly due to the fact that post-doctoral salaries from domestic financing sources have been included in the national standard).
- Complex organization causes multiplication of procedures, the quality of project administration is not yet at an appropriate level.
- Inadequate engagement on the public promotion of PMF, from the website to presenting the results of PMF researchers in the Croatian media.
- Lack of cooperation between departments weakens the opportunities for initiating interdisciplinary and multidisciplinary research.
- Non-alignment between departments with regard to study programmes, results in irrational organization of classes.
- Inadequate connections with alumni.
- Inadequate interest of candidates for enrolment into science education study programmes.

Opportunities

- Modernisation of teaching and scientific programmes, and balancing of the existing enrolment quotas with the contemporary achievements and needs of society.
- Alignment with European positions on higher education, and internationalisation and increasing competitiveness of educational programmes at the international level.
- Financing research projects and doctoral candidates through funding of the Croatian Science Foundation.
- Financing research project through funding from the EU funds and joint applications of projects with other Croatian or foreign institutions.
- Improvement of the scientific infrastructure through the application of projects for European structural funds and joint applications of projects with industry (e.g. Met4Pharm).
- Increasing incoming and outgoing mobility of students and faculty at the university, national and international level.
- Establishment of functional connections with other stakeholders in the education system, economy and media.
- Uniting the research capacities in the natural sciences, mathematics and biomedicine in the areas of the North campus of the University of Zagreb.

Threats

- Spatial inequality of the fields of biology, geology and geography within the central Horvatovac location.
- Constant reductions in funding from the state budget and lack of funds from non-budgetary

sources.

- Insufficient number of new scientific-teaching and assistant positions and post-doctoral positions.
- Inadequate level of financial resources extracted for research from the EU funds can place PMF in a weaker position in comparison to the surrounding scientific organisations.
- Inadequate investments from the state budget for maintaining the existing infrastructure.
- Delays to the project to build the North campus of the University of Zagreb.
- Inadequate legislative framework for the development of research work.
- Brain drain of high quality personnel leaving the Republic of Croatia.
- Loss of interest for the study of the natural sciences and the unattractive and poor social status of teaching professions.

Strategic goals

Goal 1	**Increase the presence of PMF on the world scene, particularly in the scientific area of the European Union**
Goal 2	**Retail PMF's leading role in Croatia, and secure a high ranking in the region**
Goal 3	**Increase interdisciplinary and multidisciplinary approaches, and ties with the economy**
Goal 4	**Raise the quality of scientific research personnel**
Goal 5	**Increase the ties between the educational process with the results of research work**
Goal 6	**Built contemporary and advanced scientific infrastructure**

GOAL 1. Increase the presence of PMF on the world scene, particularly in the scientific area of the European Union

Over the past 25 years, the PMF researchers have primarily relied on financing sources from within the Republic of Croatia, and only a small portion attempted to obtain funding at the international level. The assessment of the results of a researcher's scientific work was primarily based on the number of published papers in certain databases (e.g. Current Contents; though certain progress has been made by taking the quartile classifications into consideration). The cause for this was primarily in the advancement policies in place in Croatia, which was largely the consequence of the legislative framework. The advancement policy did not take sufficient consideration of the presence on the international scene, as visible in the projects and quality of the research. Advancements in quality occurred occasionally, usually with the appearance of professors who had a local influence in raising the quality of research work, thereby creating steps forward. Though the trend of "counting papers" has positively influenced the development of science at PMF and in Croatia, its relationship with the development of quality was not always high enough; and sometimes authors relied instead on increasing quantity at the expense of quality.

That is why this goal in particular is demanding, and seeks certain changes in the scientific activities of PMF. In achieving this long-term goal in the forthcoming (somewhat transitional) period, we would primarily rely on the following stimulating measures.

University of Zagreb, Faculty of Science

(1A) Strengthening reliance on international projects (with continued obtaining project funds from domestic financing sources). Efforts should be made to ensure that each department, proportionate to the number of scientific and teaching personnel, achieves the optimal number of international scientific projects in a five-year period (this primarily refers to larger projects with a budget exceeding a certain amount, e.g. HRK 500,000, and not smaller international projects which are also important for raising international cooperation). In order to achieve this goal, it is necessary to:

- design and implement a system to stimulate applications to competitive international projects and a system for rewarding and stimulating scientists who succeed in winning important international projects (the same procedure should also include means to stimulate and reward leaders of large domestic projects, such as those of the Croatian Science Foundation, and professional and development projects, even though the success of PMF applications for CSF projects is strong);
- create strong administrative and financial support for applications and execution of international projects, which includes systematic monitoring and regular reporting on the conditions for international project applications, assistance in developing budgets and compiling financial reports and the financial distribution of indirect costs, to ensure that they are stimulating for the project proposal;
- adequately promote the results of successfully executed projects within PMF and with the public (engage a qualified public relations person).

(1B) Stimulate high quality publications and other elements of scientific work.

- prominent evaluation and rewarding of authors of the highest quality publications (e.g. papers in *Nature* or *Science*) and high quality papers (e.g. high quality journals within the given area, such that 1 – 3 papers from each department are awarded each year), i.e. to develop and implement a Rulebook for rewarding excellence and high quality;
- recording and recognizing all elements of internationally recognized results of our scientists (plenary and invited lectures at important conferences and/or top institutions, international awards, membership in foreign academies, highly cited papers, guest appearances and stays at top institutions, journal editors, etc).

(1C) Stimulate the creation of excellent researcher groups and mentorship.

- give appropriate validation of mentorship work (mentoring doctoral candidates, scientific publications published together with students (undergraduate, graduate, doctoral))
- validate the creation of internationally recognized research groups (leadership of such groups implies project applications, mentorship work and successful scientific work)
- monitoring the influence of former doctoral candidates on the development of science and the economy in the Republic of Croatia

(1D) Stimulate visibility and international cooperation.

- stimulate scientific cooperation with co-authors from relevant global scientific centres
- improve faculty and department scientific news and announcements
- systematically promote scientific discoveries and findings in the media and on social media.

Achieving Goal 1 would mean a stimulating and strengthened atmosphere of ‘positive competition’ at

University of Zagreb, Faculty of Science

PMF.

GOAL 2. Retain PMF's leading position in Croatia and ensure a high ranking in the region.

PMF at the University of Zagreb is the leading scientific and educational institution for the natural sciences and mathematics in Croatia. In the forthcoming period, it is imperative that the faculty retains this position. That is why it must engage in deeper and more comprehensive tracking of its position within the region. By the end of the next five-year period, the goal is to ensure that every department of PMF is within the top ten departments of its kind on the international rankings in the CSE region (Central and Southeastern Europe; for the purposes of this strategy, this can be defined as the region encompassing Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Serbia, Kosovo, North Macedonia, Bulgaria, Romania, Moldavia, Hungary, Czech Republic, Slovakia and Poland). Furthermore, PMF should systematically monitor its scientific project in comparison with several universities in the broader region lying with developed or substantially larger countries. More precisely, in comparison with the universities in Trieste, Ljubljana, Graz, Budapest, Vienna, Athens, Solun and Istanbul. The second strategic goal is to retain and promote the role of the leading scientific and teaching institution in the Republic of Croatia. The long-term goal is to be among the "Top 5 Faculty of Science" in Southeast Europe.

(2A) Stimulate advancement in international rankings. It is necessary to take the appropriate measures to ensure that each of these areas in which PMF operates aims to take steps to raise its position in international rankings (using the Shanghai and Leiden rankings as a reference). One small but important measure within 2A is to ensure the correct and proper entry of the PMF address (affiliation) on research and other publications.

(2B) Systematically recognize and highlight successful departments in accomplishing the measures under 2B and achieving the status and advancement on the appropriate international rankings.

GOAL 3. Increase the interdisciplinary and multidisciplinary approaches and ties with the economy.

To date, PMF has relied on fundamental research, and this will remain a top priority. Today, fundamental research requires not only individual work, but the cooperation of teams of scientists having complementary expertise. One of the expected roles of scientific research at universities is to spur economic development through the development of new technologies. It is important to give greater space to such forms of scientific cooperation at PMF, and to take measures that include:

(3A) Influencing the legislation and university institutions so as to give the appropriate validation to scientific work that has an economic impact.

(3B) Strengthen commercial activities based on scientific research by:

- establishing and implementing assistance channels for PMF scientists in patent applications,
- establishing and implementing channels for the establishment of spin-off (or spin-out) companies at PMF,
- stimulating PMF scientists to launch their own companies based on their acquired knowledge,

University of Zagreb, Faculty of Science

within an acceptable legislative and university framework,

- establishing relationships concerning licensing rights,
- encouraging research aimed at the application of knowledge within development and/or applied projects,
- fostering inclusion in research and development (R&D) projects.

(3C) Strengthening interdepartmental scientific activities by:

- stimulating projects and scientific work that includes multiple departments,
- conducting joint planning to develop deficit areas that have strong interdisciplinary potential, including computer science, educational research in the faculty fields, medical physics,
- organizing a faculty level science colloquy,
- strengthening connections between doctoral study programmes at the faculty.

GOAL 4. Raise the quality of scientific research personnel

Though human resources policies are largely reliant on the state institutions (Ordinance on the election to grades, and Act on Scientific Activities and Higher Education) and the university (Rector's Collegium requirements), PMF should adapt certain elements of its HR policies to ensure alignment with global trends. Furthermore, the PMF scientists may act publicly towards the University, Croatian Parliament, Ministry of Science and Education, and all other relevant institutions, so as to advocate changes to the legislative framework and to adapt this part of the system to meet global trends.

(4A) Stimulate employment and advancement in accordance with the goals of this strategy

- evaluate internationally recognisable and visible scientific success and the leadership of strong projects
- evaluate the creation of recognisable researcher groups
- evaluate the development of individual scientific fields of strategic interest to Croatia or direct value for PMF in retaining its leading position in the area of the natural sciences in Croatia
- plan the development of specific areas: stimulate educational research in PMF areas of activities at all levels and all types of education, and invest in the development of computer sciences
- actively seek successful candidates in the Republic of Croatia and the European Union for applications in competitions, and increase the visibility of competitions.

(4B) Mobility and international presence in HR policies.

- Encourage successful international cooperation (connected with measure 1D)
- Strengthen focus on personnel (post-doctoral fellows, assistant professors, professors) who have international experience in post-doctoral training abroad, as guest scientists/professors; e.g. ensure appropriate replacements in teaching for scientific teaching staff who want to undergo professional development abroad.

GOAL 5. Increase the ties between the educational process and results of research work.

PMF has a large number of standard programmes that, for the most part, cannot be changed substantially. The positive brand that PMF has in its research work (quality, high level, global relevance)

should be tapped into to develop new forms of education that would be adapted to trends and needs in society (e.g. the study of actuary mathematics, organized in conjunction with British actuaries, the Croatian Actuary Society and the Croatian Ministry of Finance is a good example of this type of cooperation). The following measures are planned.

(5A) Improve the organization of doctoral studies; better connections with the profession; attracting foreign students.

(5B) Strengthen the influence of recent scientific findings on diploma study programmes and the final years of integrated study programmes.

- Constant development of courses and programmes to keep up with the development of the field of research, and offering elective courses that can respond to the need to develop interdisciplinary and multidisciplinary approaches
- Monitor student employability, and its contributions to the development of the Republic of Croatia.

(5C) Develop educational research in faculty fields (at all levels and types of education). An example are the leading centres for educational research in Europe, and compare them with the development of educational research at the CSEs.

(5D) Inclusion of recent scientific findings and new technologies in life-long learning.

- Development of specialist study programmes
- Other forms of connections.

GOAL 6. Build contemporary and advanced scientific infrastructure.

Over the next five years, it is a strategic interest for PMF to use the resources available from European funds and other projects, to develop and strengthen the scientific infrastructure in the fields at PMF. This includes developing the catalogue of scientific equipment, to enable better and wider-reaching use of this equipment, not only by the PMF scientists, but also by other interested parties.

Through the implementation of the CIUK and CENIKS projects, within several years, PMF will substantially modernise and built its scientific infrastructure in the fields of chemistry and physics. In the implementation of those projects, it will be important to invest maximum efforts to apply to future competitions for financing from structural funds and other sources. Maximum efforts are required to ensure that the spatial development of PMF follows the construction of modern and advanced scientific equipment. Specifically, it is necessary to begin construction of the BGG (Biology, Geography, Geology) building.

It is important to note that the numeration of goals is not set by importance, and that goal 1 is not more important than goal 2, and goal 2 is not more important than goal 3, and so on. Furthermore, efforts to meet all goals are planned to begin simultaneously. However, for some research, meeting one goal can substantially facilitate the achievement of another goal. This particularly pertains to goal 6, where one of the weaknesses listed in the study is the existing spatial fragmentation and inadequate spatial accommodation of certain sections of the sciences, which hinders the performance of scientific and teaching activities, and allows for adequate administrative support). It is important to stress that not all departments are in the same position. For example, the Geography Department is dislocated from the Mathematics, Physics, Chemistry and Geophysics Departments, but is all contained within

one building. The Biology Department, on the other hand, is in a much less favourable position, as it is housed in four different locations in four buildings, and furthermore the premises of two divisions within the Biology Department are situated at multiple locations (e.g. Division of Botany is divided among three locations, while the Division of Microbiology is divided among two locations). Accordingly, for the contemporary development of certain research, it is very important to first achieve goal 6 to open space for the achievement of other goals. Achieving this goal would also enable better connections between the Biology and Geography Departments with other departments, thereby facilitating the achievement of goal 3.

Tabular overview of measures/activities with planned results

The table below provides an overview of the measures and activities with the appropriate results for each measure (where applicable), and lists the coordinators and bodies responsible for implementing the activity.

The table also contains the results pertaining to the **organizational development of the institution.** Specifically, there are plans to establish a project office, or organizational unit that would deal with the administration of large projects and aid in their applications, and a centre for advanced computer science, as a measure that will directly contribute to the achievement of goals 1, 2 and 3. Currently, there is no need to restructure the departments and their divisions, instead it is only necessary to improv the functioning of the system with some minor changes to its organization.

The table also lists the **success indicators related to the scientific and professional development of doctoral candidates and post-doctoral fellows**. One of the indicators of fulling measures leading towards goal 1 (and thereby for fulfilling goal 1) is to increase the number of doctoral candidates and post-doctoral fellows at PMF.

Activity/measure – to achieve the strategic goals				
No.	Activity/measure	Activity coordinator; responsible person and body	Implementation deadline (from the date of strategy adoption)	Result of measure / success indicator (target value in a five-year period if applicable)
GOAL 1. Increase the presence of PMF on the world scene, particularly in the scientific area of the European Union				
1.1.	Strengthening reliance on international projects (with continued obtaining project funds from domestic financing sources).	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	ongoing	

University of Zagreb, Faculty of Science

1.1a	design and implement a system to stimulate applications to competitive international projects; adopt internal acts to reward excellence and quality	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	one year	System implemented; internal act adopted
			four years	Increased number of researchers in associate grades (doctoral candidates and post-doctoral fellows) by 5 to 10%
1.1b	Develop and implement a system to stimulate leaders of domestic scientific projects in the form of an internal act to reward excellence and quality	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	one year	System implemented; internal act adopted
			four years	Increased number of researchers in associate grades (doctoral candidates and post-doctoral fellows) by 5 to 10%
1.1c	Develop and implement a system to stimulate the leaders of all other projects associated with scientific research (expert, R&D, etc) not listed under 1.1a and 1.1b	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	One year	System implemented; internal act adopted
1.1d	create strong administrative and financial support for applications and execution of international projects; educate current employees, take special care in the recruitment of new employees, develop and implement an adequately equipped project office	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	Three years	Project office, or establishment of an organisation unit to deal with the administrative support for larger projects and their application (or HR strengthening of the current office for international cooperation)
1.1e	adequate promotion of the results of successfully executed projects within PMF and with the public;	Coordinator: Vice-dean for international cooperation; Faculty Collegium	Two years	Hire a qualified person

	create a position for public relations and hire a qualified person			
1.2.	Stimulate high quality publications and other elements of scientific work	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	ongoing	
1.2a	Strong validation and recognition of authors of top quality papers; adoption of an internal act to reward excellence and quality (see 1.1a)	Coordinator: Vice-dean for science and doctoral studies; dean, department heads, Faculty Collegium, Department councils	One year	System implemented; internal act on rewarding excellence adopted
1.2b	Recording and recognising all elements of the internationally recognised work of our scientists	Department heads	ongoing	Appropriate development and maintenance of department websites
1.3.	Stimulate the creation of excellent researcher groups and mentorship	Coordinator: dean; Faculty Council, Faculty Collegium, Department Councils	ongoing	
	give appropriate validation of mentorship work; hold structures discussions on how to reward mentorship of doctoral candidates, and mentorship of diploma theses that are published in scientific papers; PMF will hold structured discussions on these issues with specific conclusions to be implemented	Coordinator: dean; Faculty Council, Faculty Collegium, Department Councils	One year for structure discussion and making conclusions One year for implementation of conclusions	Structured discussion held Conclusions made Discussion and conclusions implemented
1.3b	validate the creation of internationally recognized research groups; conduct a structure discussion on how to reward the creation and leadership of internationally recognised groups that lead competitive projects	Coordinator: dean; Faculty Council, Faculty Collegium, Department Councils	One year for structure discussion and making conclusions One year for implementation of conclusions	Structured discussion held Conclusions made Discussion and conclusions implemented

1.3c	monitoring the influence of former doctoral candidates on the development of science and the economy in the Republic of Croatia	coordinator: department heads; Faculty Collegium, Department collegia	Three years	Initiate an alumni organisation for each department and organise annual alumni meetings
1.4.	Visibility and international cooperation	coordinator: Vice-dean for international cooperation; Faculty Collegium	ongoing	
1.4a	stimulate scientific cooperation with co-authors from relevant global scientific centres, e.g. organise international cooperation days at PMF (once annually) where scientists cooperating with the most prestigious world centres could be highlighted	coordinator: Vice-dean for international cooperation; Faculty Collegium	Ongoing, once annually	Organise the international cooperation days
1.4b	improve faculty and department scientific news and announcements	Coordinator: Vice-dean for science, department heads, Faculty and department collegia	One year	Existing system for department and faculty news updated and improved
Goal 2: Retain PMF's leading position in Croatia and ensure a high ranking in the region.				
2.1.	Monitor the position of PMF on international rankings with an analysis of progress achieved; determine which measures are required for each field of PMF to achieve a better ranking on international rankings (using the Shanghai and Leiden rankings as a reference); apply those measures	Coordinator: Dean, Faculty Collegium, Faculty Council, department heads, department collegia and councils	ongoing	
2.2.	Systematically recognize and highlight successful departments (fields) in rising in the international rankings. Proposal: Present the position of professions and departments at the Faculty Day (see 2.2a)	Coordinator: Dean, Faculty Collegium, Faculty Council, department heads, department collegia and councils	ongoing	Present the position of each field in comparison to institutions in the surroundings once per year
2.2a	Using the formula of the Shanghai and Leiden	Coordinator: Vice-dean for science,	One year	Success index formula accepted

	rankings, create a success index for each department (scaled by number of people), taking the specificities of each field into account; this measure is necessary as the global rankings do not take only the PMF departments into account, but look much wider (same fields at other faculties), and therefore it is necessary to separate the contribution of the PMF departments to those rankings	department heads, Faculty Collegium, department councils and collegia		
2.2b.	Compare the position of fields in comparison with universities in Trieste, Ljubljana, Graz, Budapest, Vienna, Athens, Solun and Istanbul	Coordinator: Vice-dean for science, department heads, Faculty Collegium, department councils and collegia	Five years	Relative progress over a five year period in at least two of the seven fields in comparison with the stated institutions
	GOAL 3. Increase the interdisciplinary and multidisciplinary approaches and ties with the economy			
3.1.	Influencing the legislative and university institutions so as to give the appropriate validation to scientific work that has an economic impact	Coordinator: Dean, Faculty Collegium, Faculty Council, department heads, department collegia and councils	ongoing	
3.1a.	Organise a systematic discussion with specific conclusions: how to validate the influence of scientists on the economy for the purposes of advancement or employment? How to evaluate the launch of spin-off and spin-out companies? How to properly validate projects with economic entities?	Coordinator: Dean, Faculty Collegium, Faculty Council, department heads, department collegia and councils	Two years	Document drafted with conclusions on how to increase the inclusion of scientific and teaching staff and the results of their research into the economic sector
3.2.	Strengthen commercial activities based on scientific research	Coordinator: Vice-dean for science, department heads, Faculty council, Department councils and collegia	ongoing	
3.2a.	establishing and	Coordinator: Vice-	ongoing	Hold at least two workshops

	implementing assistance channels for PMF scientists in patent applications; organise workshops on the protection of intellectual property	dean for science, department heads, Faculty council, Department councils and collegia		
3.2b.	establishing and implementing channels for the establishment of spin-off (or spin-out) companies at PMF; organise workshops on opening companies	Coordinator: Vice-dean for science, department heads, Faculty council, Department councils and collegia	ongoing	Hold at least two workshops
3.2c.	Within the acceptable legal and university framework, stimulate PMF scientists to launch their own companies based on acquired knowledge; determine requirements concerning licensing rights; e.g. adopt decision of Faculty Collegium that authors of patents (PMF scientists as natural persons) developed as part of projects conducted at PMF should receive a certain percentage of the money (i.e. 30 - 50%); Faculty Collegium to pass decision that will enable authors of patents to launch private companies that will give PMF free licensing rights to the said patents; PMF to hold structured discussion with specific conclusions to be subsequently implemented.	Coordinator: Dean, Faculty Collegium, department heads, Faculty council, Department councils and collegia	One year	Hold structured discussion with specific conclusions to be subsequently implemented (e.g. adopt appropriate decision of the Faculty Collegium)
3.2d.	encouraging research aimed at the application of knowledge within development and/or applied projects	Coordinator: department heads, Department councils and collegia, Faculty Collegium	ongoing	Hold structure discussion with specific conclusions to be subsequently implemented (e.g. adopt appropriate decision of the Faculty Collegium)
3.3.	Strengthening	Coordinator:	ongoing	

	interdepartmental scientific activities	department heads, Vice-dean for science and doctoral studies, Department councils and collegia, Faculty Collegium		
3.3a.	stimulating projects and scientific work that includes multiple departments and components of the University of Zagreb, and joint planning of development of deficit areas that have strong interdisciplinary potential: computational science, education research in the fields of the faculty, constantly monitor the number of projects that include multiple departments	Coordinator: department heads, Vice-dean for science and doctoral studies, Department councils and collegia, Faculty Collegium	ongoing	Five joint interdepartmental projects reported in five years
			Two years	Establish the Centre for Advanced Computational Science
3.3b.	organizing a faculty level science colloquy	Vice-dean for science, department heads	Six months	Discussion of concept of colloquy, colloquy initiated
3.3c.	strengthening connections between doctoral study programmes at the faculty; continuing holding Doctorate Day and symposia for doctoral candidates, increase student information regarding classes from other study programmes	Vice-dean for science, heads of doctoral study programmes	ongoing	Hold Doctorate Day and doctoral candidate symposium once every two years
GOAL 4. Raise the quality of scientific research personnel				
4.1.	Create a systematic policy for employment and advancement	Coordinator: Dean, Faculty Collegium, Faculty council, department heads, department councils and collegia	Two years	

1a.	evaluate internationally recognisable and visible scientific success and the leadership of strong projects; using the measures 4.1a, 4.1b, 4.1c and 4.1d to organise a structured discussion with faculty bodies with specific conclusions	Coordinator: Dean, Faculty Collegium, Faculty council, department heads, department councils and collegia	Two years	Adoption of conclusions of structured discussion, to be subsequently implemented
4.1b.	evaluate the formation of recognisable researcher groups	Coordinator: Dean, Faculty Collegium, Faculty council, department heads, department councils and collegia	Two years	Adoption of conclusions of structured discussion, to be subsequently implemented
4.1c.	evaluate the development of individual scientific fields of strategic interest to Croatia or direct value for PMF in retaining its leading position in the area of the natural sciences in Croatia	Coordinator: Dean, Faculty Collegium, Faculty council, department heads, department councils and collegia	Two years	Adoption of conclusions of structured discussion, to be subsequently implemented
4.1d.	actively seek successful candidates in the Republic of Croatia and the European Union for applications in competitions; make maximum efforts to return scientists back to Croatia	Department heads, department collegia	ongoing	In five years send five requests for a returnee position
4.1f.	plan the development of specific areas; stimulate educational research in PMF areas of activities at all levels and all types of education	Coordinator: Vice-dean for teaching, Faculty Collegium, Faculty council, department heads, department councils and collegia	ongoing	
4.1g	invest in the development of computational sciences; stimulate projects in PMF fields that are closely associated with computational sciences	Coordinator: Vice-dean for science, Faculty Collegium, Faculty council, department heads, department councils and collegia	ongoing	
4.2	Mobility and international presence in HR policies.	Coordinator: department heads, Vice-dean for international cooperation; department councils		

		and collegia; Faculty Collegium		
4.2a.	Encourage successful international cooperation, particularly high quality cooperation (connected with measure 1.4.)	Coordinator: Vice-dean for international cooperation; Faculty Collegium; department councils and collegia;	Ongoing, at least once per year	Organise International cooperation days
4.2b.	Strengthen focus on personnel (post-doctoral fellows, assistant professors, professors) who have international experience in post-doctoral training abroad, as guest scientists/professors; discussion within measures under 4.1	Coordinator: department heads, department councils and collegia	Two years	Conduct structured discussion, adopted conclusions and implement conclusions, see measure 4.1
GOAL 5. Increase the ties between the educational process and results of research work.				
5.1.	Improve the organization of doctoral studies; better connections with the profession; attracting foreign students.	Coordinator: Vice-dean for science and doctoral studies; department councils	ongoing	Organise Doctorate Day once in two years
5.2.	Strengthen the influence of recent scientific findings on diploma study programmes and the final years of integrated study programmes.	Coordinator: vice-dean for teaching, department heads, department councils and collegia	ongoing	
5.2a.	Constant development of courses and programmes to keep up with the development of the field of research, and offering elective courses that can respond to the need to develop interdisciplinary and multidisciplinary approaches	Coordinator: vice-dean for teaching, vice-dean for science, department heads, department councils and collegia	ongoing	

5.2b.	Monitor student employability, and its contributions to the development of the Republic of Croatia	Coordinator: vice-dean for teaching, department heads, department councils and collegia	Ongoing, once per year	Present the Bulletin of the Croatian Employment Bureau at Faculty Collegium and other relevant bodies to determine labour market needs
5.2c.	Attracting foreign students	Coordinator: vice-dean for science, department heads, department councils and collegia	ongoing	
5.3.	Develop educational research in faculty fields (at all levels and types of education). Examples are the leading centres for educational research in Europe, and compare them with the development of educational research at the CSEs	Coordinator: vice-dean for teaching, department heads, department councils and collegia	ongoing	
5.4.	Develop programmes for life-long learning and science; organise seminars and/or summer school courses for primary and secondary school teachers	Coordinator: vice-dean for teaching, department heads, department councils and collegia	ongoing	
5.4a.	Development of specialist study programmes; analyse the market needs for specialised programmes and commence such study programmes as required	Coordinator: vice-dean for teaching, department heads, department councils and collegia	ongoing	
Goal 6: Build contemporary and advanced scientific infrastructure.				
6.1.	Develop the catalogue of scientific equipment	Coordinator: vice-dean for international cooperation, department heads	One year, ongoing	Catalogue published
6.2.	Execution of the CIUK project	Head of the Chemistry Department	Three years	Project completed
6.3.	Execution of the CENIKS project	Head of the Physics	Three years	Project completed

University of Zagreb, Faculty of Science

		Department		
6.4.	Application to competitions for financing from EU structural funds, H2020, FP7, and CSF and other sources of financing	Department heads, science projects	ongoing	
6.5.	Construction of the BGG building	Coordinator: Vice-dean for investments and construction, dean, Faculty Collegium, heads of the BGG departments	Three years	Obtaining the location permit and resolving all land ownership issues; development of the main project

Topics the scientific organisation intends to research and their associations with fulfilling the strategic goals

The PMF scientists have full academic freedom in the selection of research topics. This opinion is aligned with the fact that academic freedom belongs to all members of the academic community, and includes the freedom of scientific and artistic research and creation, teaching, and mutual cooperation and organisation. This strategy lays down the strategic goals and directions of research at PMF. However, it is important to note that if an individual researcher decides to research a topic that is not within this strategy, in accordance with the above academic freedom, they are free to do so. Furthermore, it is important to note that the PMF scientists are required to conduct all research in accordance with the Code of Ethics of the University of Zagreb, in line with all ethical standards and rules. Most of the research to be conducted at PMF over the next five-year period will be in line with this strategy.

Below is an outline of the strategy of the scientific research at PMF, while Annex B provides detailed descriptions of the parts of the strategy that pertain to each PMF department. These list specific directions of scientific research and activities performed at each department. For each activity, the annex lists how it contributes and how it is aligned with the six strategic goals of PMF. PMF will invest maximum efforts over the next five years to take all necessary steps to achieve these goals, which will contribute to raising the quality of scientific research at PMF.

Department of Mathematics

The Department of Mathematics, PMF is the centre of scientific research in mathematics in the Republic of Croatia. The Department employs about one-quarter of all active mathematics researchers in Croatia, and coordinates more than two-thirds of the scientific projects in the field of mathematics. As such, it is required to ensure the development of mathematics in the Republic of Croatia as a whole.

Scientific research at the Department of Mathematics can be divided into three areas: theoretical mathematics, applied mathematics, and computational science.

Many activities could be highlighted in each of these groups. For example, there is a very important and internationally recognised group within theoretical mathematics that study the theory of representation, Lie's algebra, operator theory, number theory, mathematical logics, dynamic systems, differential equations and stochastic processes. The Scientific Centre of Excellence, QuantiXLie, is deserving of special mention as an excellent example of cooperation between theoretical physics and mathematics, in accordance with Goal 3 of this strategy.

Research in the area of applied mathematics includes numerical linear algebra, scientific computation, fluid mechanics, elasticity theory, statistics, biomathematics and biostatistics, financial mathematics, numerical analysis of differential equations and mathematical modelling.

Regarding computational science, in this strategy we stress research nearer to mathematics, particularly the specially developed distributed algorithms in the optimisation of graphs and applied mathematical logic in theoretical computational science. Research associated with mathematical logic has a long tradition at the Department of Mathematics, and the aim is to strengthen research for its application in theoretical computational science (formal verification programmes and formal cooperation systems). Further, research is directed at machine learning and data engineering, where we are planning to establish a centre for advanced computational science in cooperation with the Departments of Physics and Biology. The first step in that direction is a joint application to the ERA Chair competition, which is carefully being prepared.

Enhanced cooperation also exists among these groups, and there is much overlap between these topics. A good example of this is the research in the field of mathematical logic and theoretical computational science, or the research group for applied mathematics that is developing mathematical models that are then used by experts for numerical mathematics to develop numerical algorithms. Indeed, basic mathematical knowledge of differential equations, dynamic systems, general topology, differential geometry and functional analyses are all used in the analysis of these models. Research in biomathematics, biostatistics and financial mathematics are interdisciplinary by nature, and strongly tied to the fundamental research in probabilities and statistics. Furthermore, biomedical mathematics has strong potential for inter-departmental cooperation, both in research and in teaching, as outlined in Goals 3 and 5. Accordingly, cooperation has increased between the Department of Mathematics, Department of Biology and School of Medicine of the University of Zagreb, with the Ruđer Bošković Institute, in order to introduce the new study of biomedical mathematics in English.

In accomplishing the set goals, personnel policies are important and are systematically managed by the department's Council for advancement and recruitment.

Department of Physics

In accordance with the PMF strategic goals, the fundamental premise of the Development Strategy for the Department of Physics, PMF, University of Zagreb is the continuation and further development of established research in the field of physics (thereby contributing to Goals 1 and 2), which are the essential premises of higher education at the department (in accordance with Goal 5, connecting the education process with the results of research work, which should be further strengthened). We are witnesses to the great and rapid changes in science, technology and higher education in society today. The Department of Physics is open to those changes and following them, while relying on its long and vibrant history.

Taking into account the need for scientific activities to systematically cover all important areas of

research in modern physics, several courses of research can be highlighted as the main strategic interests. In theoretical physics, this is above all multi-particle quantum physics, which essentially encompasses research in the theoretical physics of condensed matter, nuclear and atomic physics, and the research of complex systems in biophysics and photonics. Just how important theoretical research is at the Department of Physics is best seen in the launch of the Scientific Centre of Excellent for quantum and complex systems and representative Lie's algebra, called *QuantiXLie*, which brings together physicists from other institutions and mathematicians from PMF and cooperating institutions. The centre's goals are to build cooperation between the various directions of theoretical research in overlapping topics, thereby automatically striving to meet Goal 3 of the PMF strategy (i.e., to increase interdisciplinary and multidisciplinary approaches), specifically Goal 3C to strengthen interdepartmental scientific activity. The second strategic course of research in theoretical physics is the physics of elementary particles, gravitation and cosmology, which bears a long tradition.

Areas of research within the field of experimental physics, that could be strengthened within laboratories at the Department of Physics as strategic priorities, are the physics of complex and functional materials (multiferroics, superconductors, quantum magnets, metal glasses and alloys, etc.). In this field, there are already well equipped and scientifically recognised laboratories for low temperatures and strong magnetic fields, for NMR solid state and high frequency measurements, for microstructure research, for the research of magnetic and electric phenomena, and for the measurement of transport, magnetic and thermodynamic properties. In the near future, the existing research will be strengthened through the CeNIKS project (which has met the criteria for project and activity acceptability verification and the quality assessment, and has moved onto the next phase in the grant awarding procedure), through the proposed project Centre for advanced materials and nanotechnology (to be proposed in the competition for IRI infrastructure projects as part of the European Fund for Regional Development, Operational programme regional competitiveness), and through other projects (including those in the H2020 and CSF programmes). All these projects directly fit in with Goal 6 of the PMF strategy, to systematically build and maintain scientific infrastructure. The CeNIKS project will also invest in the opening of new research capabilities for complex matter: infrared spectroscopy and ellipsometry, and equipment for the synthesis and processing of samples.

Research within experimental physics in other areas (atomic physics, astrophysics, nuclear physics, elementary particle physics, biophysics) would take place within existing and new cooperation (Goal 3) with various institutes in the Republic of Croatia (primarily the Ruđer Bošković Institute and the Institute for Physics) and abroad, with smaller scale measures in the laboratories at the Department of Physics. Further development in the field is planned through the project Centre for advanced materials and nanotechnology, in cooperation with the Departments of Chemistry and Geology, and possibly other PMF departments (in line with Goal 3C). This centre plans to expand the capacities to close the cycle of fundamental research to the development and application of high-tech products. The Centre will also support companies in the high value-added sector in the transfer of technology in knowledge-based economic activities (in line with Goal 3). In cooperation with the clinical hospital centres in Zagreb and the Ruđer Bošković Institute, the Department will continue to advance the current research in the field of medical physics (thereby contributing to Goals 2, 3 and 5).

The importance of all research is retaining and advancing the expert opinions in all relevant fields of modern experimental physics, as this is a requirement for successful student education at the highest level (Goal 5 – increasing the links between the education process with the results of research work).

Furthermore, projects such as QuantiXLie and CeNIKS will increase the visibility of the Department of Physic and PMF on the European and world scientific scene (Goal 1), retain and strengthen the role of PMF in science in the region (Goal 2), and systematically begin to build and restore the scientific infrastructure (Goal 6). The CeNIKS project has also received the support of 11 companies in the private sector, thereby providing strong possibilities for achieving Goal 3 (in the part pertaining to strengthening ties with the economy). In addition to these projects, which are soon to be implemented, many other proposals are planned in international financing competitions (Goal 1A). Young employees are also actively encouraged to propose projects to be financed by domestic (Croatian Science Foundation, University) and international institutions.

The Department of Physics will be particularly active in the establishment of the Centre for advanced computational sciences at PMF, in cooperation with the Departments of Mathematics, Biology and other PMF departments (in line with Goal 3C), since the development and methods of advanced computational science are universal within the natural sciences, and their application is today necessary not only for progress in contemporary theoretical research, but also in experimental research. Within the new centre, joint project applications are expected with the Department of Mathematics and other PMF departments for Horizon 2020 competitions, and in competitions for the European Union structural and investment funds. The first project application as part of establishment of the Centre for advanced computational sciences for the Horizon 2020 ERA Chair competition was strongly supported by the Croatian Ministry of Science and Education, and the National Protection and Rescue Directorate, in addition to nine important IT and high-tech companies, thereby confirming the strong development potential for its inclusion in resolving relevant challenges in society and in cooperation with the economy (Goal 3B).

In achieving the set goals, personnel policies will be very important, and this is managed by the Expanded Collegium of the Department of Physics, thereby contributing to Goal 4.

Department of Chemistry

The development strategy of the Department of Chemistry, Faculty of Science, University of Zagreb, as a recognisable scientific research institution in the field of chemistry, relies on its rich tradition in conducting fundamental and applied scientific research. The Department of Chemistry has always strived to achieve to reach the research and education standards of European and global centres of excellence by promoting adequate HR policies (Goal 4 of the PMF Development Strategy), including students in the work of the department, and strengthening incoming and outgoing student mobility (Goal 5 of this Strategy). In order to further secure high quality education and development of young researchers as the future leaders of scientific research activities, and to contribute to the development of a competitive economy based on the transfer of knowledge and technologies, the Department of Chemistry plans to strengthen these areas and encourage new directions of research.

The scientific research activities planned for development within the Department of Chemistry, PMF encompass several branches of research. One includes biochemistry, bioinformatics, computational science, proteomic and gene research of the transfer of genetic information and protein biosynthesis in all three areas of life, and obtaining a detailed overview in specific biochemically important processes. This area naturally complements research of the interaction of pharmacologically active molecules with biomacromolecules in solution, as in vivo biological research (strategic Goal 3), and structural research of solid-state biomacromolecules. The second important branch of research is

based on the design and synthesis of functional organic and inorganic systems, where special attention is focused on conceiving rapid and ecological and energy efficient ways to prepare them. This certainly includes the characterisation and testing of properties of prepared solid-state compounds and their behaviour in solution, which links areas such as spectroscopy, thermodynamics, x-ray structural analyses, chemical kinetics, supramolecular chemistry, chemometrics, colloidal and intersurface chemistry, electrochemistry and thermal analysis. The development of process analytical methods and the development and application of appropriate analysis methods for real samples, such as environmental samples, is another important branch of research with a long history at the Department of Chemistry. Finally, an important part of the research ongoing in the department is research in the field of computational and theoretical chemistry which is becoming increasingly important, in accordance with global trends. The researchers at the Department of Chemistry have long been preparing and participating in scientific projects (such as UKF, FP7, FIRCA-NIH, bilateral and CSF projects), in cooperation with researchers from throughout Croatia (University of Zagreb, University of Osijek, University of Split, Ruđer Bošković Institute, Institute for Medical Research and Occupational Medicine, Immunology Institute, Naval Institute) and abroad (cooperation achieved with scientists from more than 80 institutions in 20 countries around the world over the past decade). The Department of Chemistry also enjoys cooperation with the researchers at other PMF departments: Biology, Geology and Physics. In accordance with Goals 2 and 4 of the PMF Development Strategy, these forms of cooperation will be further strengthened, particularly in the area of multidisciplinary research.

In order to ensure competitiveness of the researchers at the Department of Chemistry at the international level, ongoing efforts are aimed at strengthening and improving the existing infrastructure, as seen in the successfully executed project Met4Pharm in partnership with PLIVA d.o.o., financed from the European Union Regional Development Fund. Within that project, the Department of Chemistry received a high resolution NMR spectrometer. Projects worthy of mention are the project CIuK, proposed to the Ministry of Science and Education and the preparation of infrastructure projects for the EFRR 2014 – 2020, which is currently in the evaluation stage. Within that project, the department would substantially enhance its infrastructure capacities (Goal 6 of the PMF Development Strategy). The department staff are planning to apply to similar public calls and competitions in the future.

One of the importance strategic goals of the Department of Chemistry is the continuation of the successful existing cooperation with private sector partners, and efforts to further strengthen and expand this cooperation (Goal 3). Over the past decade, scientists at the Department of Chemistry have implemented two scientific and 23 expert projects in cooperation with economic representatives. Furthermore, cooperation with the pharmaceutical, food and petrochemical industries has resulted in the publication of 28 scientific papers, five doctoral dissertations and three diploma theses on topics pertaining to resolving specific problems in the private sector. This form of cooperation should be enhanced after the execution of plans to strengthen structural capacities, and this contributes to the life-long learning of researchers in the economic sector (Goal 5).

Department of Biology

The Department of Biology builds its development strategy, which is aligned with the PMF strategic goals, on a combination of tradition and new research directions that are developing in response to changes in science, the economy and our society. In the teaching sense, the Department of Biology intends to remain a recognisable centre for the education of biological and interdisciplinary university

fields in the Republic of Croatia, with ongoing improvements to the educational process and introducing the appropriate flexibility to respond to current labour market demands (Goal 5). Plans are in place to continue cooperation with other PMF departments, to strengthen international cooperation, and cooperation with the public and private sectors, in accordance with Goals 1 and 3.

The primary strategic interests at the Department of Biology in the forthcoming period encompass several research directions. Researching the biodiversity of Croatia and neighbouring biogeographically connected areas brings together phylogenetic, phylogeographic and ecological research, with increased cooperation with scientists in neighbouring countries and further. The international importance of this research is seen in several Interreg projects, where the scientists of the Department of Biology are either project leaders or partners, while participation in the COST action projects, and a series of applications to internationally competitive projects, also support Goals 1 and 2 of the Strategy. Special attention will be focused on researching the impacts of global climate change and the introduction of alien species on community stability. Ecological research deepens the knowledge in the fields of ecological evolution, ecological genomics, ecotoxicology and archaeobotany.

Strategic research directions include research of the effects of stress conditions on plant and animal models, ecophysiological, ecotoxicological and phytochemical research, and research in the area of plant reproductive biology that can potentially be applied in improving yields in economically important species, the discovery of new biomarkers, drug production and the conservation of Croatia's biodiversity (Goal 3). An important contribution to research is the participation of scientists of the Department of Biology in the Scientific Centre of Excellence for biodiversity and molecular enhancement of plants (CroP-BioDiv), led by the Faculty of Agriculture, University of Zagreb. Research will continue on the forms of cell specialisation and differentiation during reproductive development and embryogenesis, the evolution of plant and animal genomes at the molecular and cytogenic level through the application of contemporary analysis methods of data obtained from new generation sequencing methods, and the development and application of chromosome engineering methods in plant enhancement and the manipulation of biosynthetic paths aimed at producing useful secondary metabolites through the use of plant tissue culture techniques. Accordingly, cooperation will continue with many Croatian (University of Split, Ruđer Bošković Institute and many others) and international research centres (University of Vienna, University of California Davis, Queen Mary University of London, University of Ljubljana, and others). Plans are in place to continue the genetic analysis of bacterial defence mechanisms based on the CRISPR-Cas system, which will further deepen the existing cooperation with the Department of Chemistry and foreign partners.

Biomedical research in a range of areas will be systematically fostered: neurophysiological, endocrinological, epigenetic and metagenomic, as well as research on the influence of bioactive plant compounds and their effects on the cells and tissues of various organisms. The equipment and funds required for this research will be secured through projects of the Scientific Centres of Excellence (SCE for personalised health care and SCE for fundamental clinical and translational neuroscience) in which PMF is a partner institution, together with other faculties, hospitals and economic entities (in accordance with Goal 3). Through the Horizon 2020 projects (Goals 1 and 6), the aim is to establish a new space for secure working conditions with lentiviral vectors for the introduction of CRISPR/Cas9 constructs into various animal cells (cleanroom). Research on flexible molecular tools for precise epigenetic modulation and the modulation of genetic expansion, and their applications in reprogramming diseased into normal states in immune system cells, the research of the molecular biology of tumours, the application of stem cells in regenerative medicine and tissue engineering, and

the development of methods for the analysis of data obtained from next generation sequencing methods are exceptionally relevant.

For many years, the Department of Biology has been recognised as the leading institution for the education of persons working with experimental animals, in the form of the LabAnim expert course. This field of work, which includes both the legislative and ethical dimension of working with animals, will be strengthened at the department, licenced at the international level, and expanded to the regional scale. The scientific part of bioethics discourse, which includes biomedical research, is achieved by the Department of Biology in cooperation with the SCE for integrative bioethics.

Research on the molecular diversity and ecology of various microorganisms, viruses and subviral entities are yet another of the strategic directions of research in the forthcoming period. This includes research of microbial genomics, molecular epidemiology and microbial ecology. In accordance with Goals 2 and 3, cooperation in these areas will continue with other PMF departments, and with many domestic and foreign universities and research centres, such as ETH Zurich, Dutch Institute for Water Treatment B.V. and the Ruđer Bošković Institute.

In accordance with Goal 3B, the continuation of applied research will be encouraged, such as within the National programme for monitoring aquatic ecosystems as the initial strategy in the EU Water Framework Directive. This research is contributing to the development of legislation important for environmental protection and nature conservation (Goal 4A), with the transfer of knowledge to the public sector. Development of the Flora Croatica database will continue, as this is part of the National Conservation Protection Information System of the Republic of Croatia. The Department of Biology plans to maintain, improve and digitise the herbarium and zoology collections, to make their content widely available to the scientific and professional public. For example, the Division of Botany houses two herbarium collections that are registered in the global base *Index Herbariorum*: Herbarium Croaticum (ZA) and the Ivo and Marija Horvat Herbarium (ZAHO), together containing some 260,000 herbarium specimens. One of the important organisation units within the Division of Botany is the Botanical Garden, where activities are taken to ensure the *ex-situ* protection of Croatian flora, with permits and licenses for collection in natural habitats, and breeding for the collection of our rarest, strictly protected indigenous species.

The Department of Biology, PMF is the centre of many areas of natural history research in the Republic of Croatia and beyond, and it intends to retain and strengthen this position (Goal 2). Preparations are in place to apply for domestic and international sources of financing for scientific research (Goal 1). Through its teaching activities, such as the application of research in biology, and adult education, we aim to be recognised as leaders in education (Goals 4 and 5). The Department of Biology plans to give systematic support to applications for domestic and international projects through all available mechanisms (Goal 1), and to invest in the maintenance of existing and procurement of new scientific infrastructure (Goal 6) by applying to structural funds.

Department of Geophysics

The development strategy of the Department of Geophysics is based on the need and inclination for the department, with its long tradition of scientific research, to continue in the future to effectively adapt to the scientific, research, educational, technological and socioeconomic challenges, and to effectively contribute to the fulfilment of the goals defined in the PMF Strategy.

In the area of meteorology, in accordance with Goal 3, research will continue on atmospheric

dynamics, which are important for weather forecasts, early warnings of dangerous weather conditions, air quality and many economic activities (agriculture, energy, tourism, transport and others). Advanced numerical models will be applied and further developed, and special measurements made and their results analysed. The existing equipment will be further updated and expanded. Therefore, documentation is currently being prepared to apply for a Ministry of Science and Education competition for the preparation of infrastructure projects of the European Fund for Regional Development (Goal 6). Cooperation with foreign experts will continue (Goal 1 – visits to top institutions and fostering cooperation with co-authors from those institutions) and scientists of the Croatian Hydrological and Meteorological Service in the area of climate modelling (Goal 3b – encouraging research aimed at the application of knowledge in development and/or applied projects), which has become of strategic importance for the wider community due to recent climate changes and the need for sustainable development. The wealth of experience in climate modelling at the global and regional scales will be complemented by microclimate modelling (Goal 2A – retaining and promoting the role of PMF as the leading institution in the Republic of Croatia).

In the area of hydrosphere research, the development of operative oceanography and the establishment of forecasting systems at sea is of strategic interest for Croatia. The department will cooperate with other national institutions to develop numerical oceanographic models (Goal 2A - retaining and promoting the role of PMF as the leading institution in the Republic of Croatia, Goal 3 – strengthening interdisciplinary and multidisciplinary approaches and fostering applied research). Marine measurements will continue, as important data for operational oceanography, with applications in maritime affairs and geodesics, monitoring climate change and planning sustainable development of coastal areas, which are particularly subject to strong pressures due to their dense population and large commercial activities. Interdisciplinary research in cooperation with chemists and marine biologists is also of strategic importance (Goal 3 – interdisciplinary and multidisciplinary approaches, particularly in strengthening interdepartmental scientific activities). In cooperation with hydrologists and hydrogeochemists, recently launched limnological research will continue (Goal 2 – leading role of PMF in the Republic of Croatia and ensuring a high ranking in the region, and Goal 3 - interdisciplinary and multidisciplinary approaches), with the ultimate goal of establishing a hydrodynamic model of the Plitvice Lakes system, which is of strategic importance for protection of the national park which is also a World Heritage Site (UNESCO). The results of this research will also be incorporated into the development of the newly introduced course Limnology (2016/17 academic year) (Goal 5).

Seismological research in Croatia is conducted solely in the Department of Geophysics, and has been for more than a century. The Seismology Survey, as an organisational unit of the department, performs expert tasks for the state. Accordingly, it is essential that the department nurture all aspects of seismological research. The study of seismology in Croatia and the surrounding regions, the assessment of earthquake threats, research of seismotectonic relationships and structure of the Earth's layers in the Adriatic, Dinaric and Pannonian Basic regions are of strategic importance (Goal 2 – leading role of PMF in Croatia and ensuring high rankings in the region, and Goal 3 – ties with the economy).

Geomagnetic research will continue within the only geomagnetic observatory in Croatia, established in the department in 2012. Due to the quality of the data collected, the observatory has been included in the international network INTERMAGNET. Strategic research includes modelling geomagnetic fields in limited areas and the development of sophisticated techniques to construct calibration curves (Goal

University of Zagreb, Faculty of Science

2 – leading role of PMF in Croatia and ensuring high rankings in the region).

Successful cooperation will continue as strategic research with domestic institutions (University of Zagreb: Faculty of Agriculture, Faculty of Mechanical Engineering and Naval Architecture, Faculty of Electrical Engineering and Computer Science, Faculty of Mining, Geology and Petroleum Engineering, Faculty of Geotechnical Engineering; Croatian Hydrological and Meteorological Service; Faculty of Civil Engineering University of Rijeka; Institute for Oceanography and Fisheries; Croatian Hydrographic Institute) and foreign institutions (University of Virginia and New Mexico Tech, USA; University of Aegean, Greece, Universitat de les Illes Balears, Spain, Zentralanstalt für Meteorologie und Geodynamik, Austria, Helmholtz-Zentrum Potsdam, Germany, Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Germany, International Centre for Theoretical Physics, Italy, and Geological and Geophysical Institute of Hungary). In accordance with Goals 1, 2 and 3, cooperation with other domestic and foreign institute will be encouraged and established, with further stimulation of mobility of department staff (Goal 4B).

In all geophysical disciplines, interdepartmental cooperation will be encouraged (Goal 3). Also, further connections between the education process with the results of research work (Goal 5) and the modernisation of course content with the introduction of new elective courses at the graduate and doctoral level, in line with recent scientific findings, will be stimulated.

Department of Geology

The fundamental premise of the Development strategy of the Department of Geology, Faculty of Science, University of Zagreb is the continuation and further development of geology research, as the essential outcome of higher education at the department. This is in line with Goal 5 listed in the PMF Strategy to connect and strengthen the educational process with the results of research work. The Department of Geology is open to changes in the geosciences and participates in them, relying on its long and important tradition, particularly in the fundamental sciences.

The Department of Geology will also encourage the renewal of scientific infrastructure and actively participate in planning and building a new department facility at the Horvatovac campus, which will contribute to improving scientific research (Goal 6).

In ensuring that the scientific activities systematically cover all the important research areas in the Department of Geology, certain fundamental topics can be highlighted as the main strategic interests.

In the Division of Geology and Palaeontology, the fundamental research is based on the stratigraphic, palaeontological, sedimentological and palaeoecological research of the Dinarides and Pannonian regions, so as to contribute to understanding of their structure, formation and evolution throughout the geological past. Special focus is given to the research of the lithological, sedimentological and palaeontological properties of deposits in the Dinaric (phanerozoic) and Pannonian (particularly the Neogene and Quaternary) areas, clastic sediments of the Dinarides (flysch, molasse), stress events in the geological past (extinctions, impacts, glaciations), palynological findings and their applications in paleogeographic reconstructions of these areas, the specificities of shallow sea carbonate environments during the Jurassic, Cretaceous and Paleogene eras. Fossil records in Phanerozoic rocks are used to study the evolution of life on Earth. In order to explain environmental changes in the geological past, recent sediments and sedimentation in the Adriatic is studied, along with dynamics of coastal changes and the reflections of climate changes and sea levels on the coast and coastal

processes. Some research is also focused on zooarchaeology.

In the Division for Minerals and Petrography, research is focused on crystallo-chemical properties of minerals and their applications in minerology, geology, materials science and environmental research. Particular emphasis will be placed on the minerals of clay, zeolites and oxides. The second area of scientific interest is in the study of the formation and changes in rock in the territory of the Republic of Croatia and surrounding countries, with a look at the depositional and evolutionary models of development of the Pannonian, Dinaric and Adriatic areas, and the Alps and Carpathian Mountains. In association with that, geochemical research of lithostratigraphic units and their geological structures will be conducted. Further, geochemical research of the environment is carried out to differentiate geogenic and anthropogenic impacts on the distribution of metal and other environmentally important compounds, with the aim of characterisation, remediation and management of threatened and sensitive environments. Finally, a part of the research is aimed at geoarchaeology, as the characterisation of archaeological materials using minerology methods.

One of the aims of the Department of Geology is building cooperation among research institutions focusing on similar study areas (such as the Doctoral study of Oceanology), thereby aiming to meet Goal 3 of the PMF Strategy (increasing interdisciplinary and multidisciplinary approaches), especially Goal 3B, strengthening commercial activities based on scientific research, and Goal 4 through the preparation and implementation of HR policies that are aligned with the needs of each division.

Projects such as the current CSF project “Cretaceous geodynamic evidence in the Dinarides and Pannonian Basin”, the project for Plitvice Lakes National Park “Sedimentology, stratigraphy, structural and geological properties of the Plitvice Lakes”, the InterReg project DINOKRAS, and the Croatian-Hungarian bilateral project “Stratigraphy and correlation of Upper Miocene-Pliocene sediments along the Croatia-Hungary border” all further strengthen the leading scientific role of PMF in the region (Goal 2), while cooperation with other constituents of the University of Zagreb, other universities and colleges in the Republic of Croatia, and international scientific institutions ensure that the important role of the Department of Geology, PMF is retained in the international scientific sphere (Goal 1).

Department of Geography

Geographic research in Croatia has a long tradition, and therefore the development strategy of the Department of Geography, PMF is based on cooperation in long-term and contemporary research topics, in accordance with the needs of society and the rapid development of knowledge. Scientific research at the Department of Geography encompasses both physical and social geography research, and covers all important research areas in geography. However, certain directions can be highlighted as strategic interests for development of the Department of Geography. Scientific research is currently carried out by eight fundamental research groups (see below for details).

In the study of physical geography, there are two fundamental research groups that examine changes in the environment (climatic, hydrological, geomorphological, changes in land use and land cover - LULC). Social geography research includes six fundamental research groups that are involved in the planning and evaluation of demographic and economic resources in the area, and research of cultural landscapes, processes and changes in urban and rural areas as parts of the local, regional and national spatial identities.

Physical and social geography research today is carried out within CSF projects and University of Zagreb

grants. In the forthcoming period, plans are in place to encourage applications to scientific projects, in accordance with Goal 1 of the PMF Strategy. Establishment of a more effective system to seek out available funds has been proposed (assistant department head for science and international cooperation and department coordinator for EU projects and finding new personnel solutions, in accordance with Goal 4), such as the European Social Fund, European Regional Development Fund, Unity through Knowledge Fund, JPI Europe, competitions of the Ministry of Culture, Croatia Academy of Sciences and Arts, etc. Furthermore, applications will be encouraged of young scientists, particularly doctoral candidates, to Croatian Science Foundation competitions within the programmes "Establishment of research projects", "Partnerships in research", "Career development projects for young researchers" and other projects than enable the employment of youth.

The Department of Geography has a strategy to stimulate scientific excellence by encouraging the publication of high quality scientific publications. Recognising and encouraging excellence has been ongoing at the Department of Geography since 2015, and will certainly continue, in line with Goal 1B of the PMF strategy. Stimulating excellence also contributes to the formation of excellent research groups and mentorship work (Goal 1C) and connections between the educational process and the results of research work (Goal 5).

In the forthcoming period, the Department of Geography has the strategic goal of researching educational resources, curriculum geography and life-long learning, which is directly aligned with Goals 5C and 5D of the PMF strategy.

The department research groups have strong cooperation with associates from other PMF departments (such as the Departments of Biology and Physics), and other institutions in the Republic of Croatia (University of Zadar, Ruđer Bošković Institute, Croatian Waters, etc.) and abroad. In the forthcoming period, research will continue within existing cooperation (research groups, associates), while new cooperation is planned with other PMF departments, partners in Croatia and abroad, in line with Goal 3 of the PMF Strategy to increase interdisciplinary and multidisciplinary approaches and to enhance ties with the economy.

The Department of Geography has already implemented numerous measures to modernise the doctoral study programme to achieve better ties between the educational process with research results that stimulate interdisciplinary studies. The primary focus of the study programme is on research, with a wide range of courses to meet the specificities of individual research topics. The study programme was approved by virtue of a Decision of the Senate, University of Zagreb in 2014 and to date has attracted a larger number of candidates from related fields (Goal 5A). New approaches to study were introduced, such as annual internal conferences for doctoral candidates, which are constantly being upgraded, which is also in line with Goal 5 of the PMF Strategy.

Modernisation of the Laboratory for Physical Geography and GIS Laboratory is planned (Goal 6), and their importance is high for continued scientific research and student education.

The aim of all the listed measures is to retain the role as the leading institution in the region, in accordance with Goal 2 of the PMF Strategy.

University of Zagreb, Faculty of Science

Appendix A – PMF organizational structure

For a better overview of the strategy, this Appendix lists all the units (divisions, chairs, centres) operating within each department, in which the PMF scientists are distributed. This overview displays the scientific potential of PMF. The Appendix was prepared based on the Ordinance on the organisation of work posts, as the primary source.

The **Department of Mathematics** is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of mathematics. The composition of the Department of Mathematics is:

- Division of Algebra and Foundations of Mathematics
- Division of Geometry
- Division of Mathematical Analysis
- Division of Numerical Mathematics and Scientific Computing
- Division of Applied Mathematics
- Division of Probability Theory and Mathematical Statistics
- Division of Topology
- Division of Computer Science
- Chair of Didactics in Mathematics and Informatics.

The Department of Physics is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of physics. The composition of the Department of Physics is:

- Division of Experimental Physics
- Theoretical Physics Division of Condensed Matter
- Theoretical Physics Division of Elementary Particles and Fields
- Division of Theoretical Physics.

The **Department of Chemistry** is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of chemistry. The composition of the Department of Chemistry is:

- Division of Organic Chemistry
- Division of Physical Chemistry
- Division of General and Inorganic Chemistry
- Division of Analytical Chemistry
- Division of Biochemistry.

The **Department of Biology** is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of biology. The composition of the Department of Biology is:

- Division of Botany
- Division of Zoology
- Division of Animal Physiology
- Division of Molecular Biology
- Division of Microbiology

University of Zagreb, Faculty of Science

- Botanical Garden.

The **Department of Geology** is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of geology. The composition of the Department of Geology is:

- Division of Geology and Palaeontology
- Division of Mineralogy and Petrography.

The **Department of Geography** is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of geography. The composition of the Department of Geography is:

- Division of Physical Geography
- Division of Social Geography
- Division of Regional Geography and Methodologies
- Cartography and Technical Centre.

The **Department of Geophysics** is the branch of the faculty organised for the execution of activities in higher education, science and expert work in the field of geophysics. The composition of the Department of Geophysics is:

- Andrija Mohorovičić Geophysical Institute
- Croatian Seismological Survey.

Appendix B – Detailed overview of the scientific topics planned for research, with special goals for each topic

Department of Mathematics

Division of Algebra and Foundations of Mathematics

Division activities are focused on the topics described below.

- Recently, there was important progress in the Langlands program, namely, proof of the existence of the endoscopic transfer of local and global discrete series representations from the split classical groups to GL(n), mainly due to Arthur. The research in our group is coordinated with that development. For example, we calculate Jacquet modules of the discrete series representations, which will enable the full understanding of the parabolically induced representations from the discrete series (generalized principal series). In the theory of automorphic forms, we develop explicit constructions based on the work of Arthur and Moeglin. In that way, we explicitly construct new series not only of the discrete series representations, but also of the isolated unitary representations.
- The main research topics in the number theory group are the elliptic curves, modular forms, Diophantine equations, Diophantine approximations, and the application of the number theory in cryptography. We study the structure of the groups attached to the elliptic curves over rational numbers and over algebraic number fields. We examine the relations between arithmetic properties of the Fourier coefficients of the modular forms and arithmetic geometry. We research Diophantine m-tuples and their various generalizations, especially in the ring of integers of the fields of small degree. In the area of Diophantine approximations, we examine the problem of separation of the roots of polynomials and connections with the classifications of transcendental numbers. We also research into applications of the elliptic curves and Diophantine approximations in cryptography.
- In this division there is a group which studies vertex-algebra theory and related infinite-dimensional Lie algebras. We study C_2 finite vertex-algebras which are closely related with mathematical physics and quantum group theory. Special emphasis is on the construction of new vertex-algebras, their representations and intertwining operators. The vertex operator theory is also used in constructions of the new combinatorial basis of representations of affine Kac-Moody Lie algebras, and in proving combinatorial identities. We also examine embeddings of finite dimensional Lie algebras and related conformal embeddings of affine vertex algebras.

Division of Geometry

The main areas of scientific research in this division in the future period can be categorised into three thematic areas, that continue on the research from the previous five-year period.

- Differential geometry of curves and surfaces in special ambient spaces. The purpose of the research is to study the differential geometry properties of curves and surfaces including Riemann manifolds as the Lorentz-Minkowski space, and Lorentz spatial forms and, in general, affine manifolds; spaces with degenerated metrics, such as isotropic spaces and three-dimensional manifold families, i.e. Thurston spaces. A deeper understanding of these geometries can be attained by studying their submanifolds with certain properties, such as special classes of surfaces of known curvature.

University of Zagreb, Faculty of Science

- Finite geometries and design theory. In this area, we study the issue of the existence and classification of block designs and t-designs, symmetrical configurations, differential groups and designs over finite fields. For the purpose of reduction of combinatorial complexity of a problem, additional conditions are often set, in the form of the action of appropriate groups of automorphisms. Also, we will examine the different regular substructures in final projective and polar spaces. The research intensively uses algebraic and other theoretical methods, as well as computational techniques and methods. The development of algorithms and programs for the construction and classification of final structures is an important part of this research.
- Geometric properties and special models of quasigroups. We examine the geometric properties of particularly interesting subclasses of idempotent medial (IM) quasigroups, particularly pentagonal quasigroups. One of the fundamental objectives is to determine the spectrum of all orders of the ultimate pentagonal quasigroups, and to extract similar results for other subclasses and establish associations with graphs, directional graphs and designs.

Division of Mathematical Analysis

The division activities are described below.

- Various forms of orthogonality in Hilbert C*-modules. The main objective of this topic is to continue studying the various forms of orthogonality on Hilbert C*-modules, particularly the Birkhoff-James orthogonality, strong Birkhoff-James orthogonalities and orthogonalities with respect to the internal project. Studying these topics includes a characterisation of various class elements of the Hilbert C*-modules in orthogonality terms, characterisation of overlap between modules that preserves a certain form of orthogonality, consideration of relations between various orthogonalities and similar problems.
- The base framework between Hilbert spaces and Hilbert C*-modules. The primary goal consists of two parts: continuing research on the fundamental theories of base frames of Hilbert C*-modules. In particularly, we are planning to develop interrelations between the base frame and strict/external base frame of Hilbert C*-modules, and expand the results on perturbations of base frames in the context of Hilbert C*-modules, on the ultimate expansions of Bessel series to base frames and, in particular, to the Parseval bases, on the Riesz bases, etc.
- Dirac cohomology of Harish-Chandrin modules and the application of Dirac cohomologies is a relatively new invariant of the Harish-Chandrin modules that contains much interesting information. In the coming period, the research will be focused on the following problems: studying representations obtained using Dirac inductions, special representations of discrete series, application of Dirac cohomologies to representation restriction problems; attempts to strengthen the Dirac inequalities with applications on the study of unitary representations, and calculating Dirac cohomologies of the highest weight unitary modules.
- Inequality for positive linear functionals. The aim of this research is to examine inequalities that apply to positive linear functionalities, such as the Chebyshev and Grüss inequalities with two linear functions, etc. Quasilinearity, monotony and limited functional associated differences that appear in inequalities will be examined. Research will continue on the properties of the h-convex function.

Division of Numerical Mathematics and Scientific Computing

The research interests in the division and plans for the future period are tied to the development of a theoretical basis of scientific computing, and the development and validity of mathematical software

developed on those theoretical concepts. Research directions are based on recent activities and results obtained within research projects. Due to interdisciplinarity, the applicability of results of planned research are expected to lay the foundation for new interdepartmental cooperation, with the aim of achieving strategic Goal 3C. Our plans are also aligned with the plans to establish the Centre for Advanced Computational Science (joint interdepartmental project within Goal 3C). For certain research directions, we are planning to develop new courses in the doctoral study programme, to train doctoral candidates in accordance with strategic Goal 5.

- Matrix spectral decomposition. We plan to continue our successful research in the development of numerical methods for classic and generalised spectral and SVD decomposition. It has been shown that the class of robust Jacobian type methods for SVD decompositions and various matrix reductions on canonical forms can be effectively applied to multiprocessor computers, and this development will continue in the forthcoming period. In addition to development of numerical algorithms, we work on the theory of perturbation and on the convergence proofs. The goal is to continue successful integration of our software into the LAPACK software package.
- Control theory. A part of the division members works on control theory, based on the development of theoretical and numerical aspects, and the application of control theory to concrete engineering problems. This research group is focused on important topics: reduction models for large management systems, managing network dynamic systems, optimal management of systems described with regular and partial differential equations, and management costs for partial differential equations. Over the next five years, cooperation will be strengthened with researchers from the US and Germany to develop new theoretical methods and results, analyse the accompanying numerical issues, develop the appropriate computer software, and confirm the application of the newly developed methods on systems emerging from practical problems. This will bridge the space between theoretical considerations and industrial application.
- Reduction of the dimensions of dynamic systems and data-driven methods. We plan to strengthen the development of methods for identification and approximation of dynamical systems to low-dimension models. We expect progress and further development of the achieved results, particularly modern techniques of reduction of dimensions of data-driven models (POD, DEIM, Vector Fitting, Dynamic Mode Decomposition, Koopman linearisation) and the application of the IRKA methods on high-processor computers.
- Operator equations. We plan to continue the development of algebraic methods of approximation of operator equations (Lyapunov and Riccati equations) by a low rank operator approximation, based on the Krylov type, as well as a modern approach based on random sampling in the operator image.
- Spectral analysis of mechanical systems. We plan to continue our initial research and development of numerical methods for solving linear and nonlinear eigenvalue problems in different applications. The Arnoldi and Schur-Krylov type methods, and modern methods based on numerical calculation of Cauchy integrals are of particular interest. In that context, we will deal in the development of ultimate elements method based on operator numerical analysis. An interesting area of application is in elasticity theory and optics (photonic crystals).
- Spline approximations. We investigate approximations with a special type of spline function, such as Chebyshev splines, cycloid splines, tension splines, and q-splines. In addition to the development of new numerical algorithms for efficient computing of these splines, the theory of their approximation properties is developed, and based on these, algorithms for specific applications. In the next five years, we plan to continue the theoretical and practical work on these issues, to improve the appropriate algorithms, and for their application in issues of advection and diffusion in geophysics and image processing.
- Numerical methods for singularly perturbed problem for ODE. Over the past decade, technological progress in data collection and demands for building more complex mathematical

models has dramatically increased the need for effective numerical solutions of high order problems. These problems require a completely different approach from that applied to classical numerical linear algebra problems: data are now typically represented with sparsely filled matrices or tensors, or on the other hand, permit the approximation of matrices or low-range tensors. Division members have been included in research problems to address the issues of high order schemes from various aspects. Since the focus of research in numerical mathematics is increasingly shifting towards high order schemes, an important strategic move is planned to increase activities towards the development of numerical methods for tensor calculations. This research direction is particularly aligned with plans to develop the Centre for Advanced Computational Science.

- Development of mathematical (numerical) software. All planned research directions include the development of numerical algorithms and the accompanying software applications. Since the development of robust software tools for industrial application is an important interdisciplinary branch of research, which plays an important role in the modern development of technology, systematic research will focus on the development of industry quality software. That development can have a commercial effect and is planned as a contribution towards strategic Goal 3B and the development of the Centre for Advanced Computational Science.

Division of Applied Mathematics

The scientific activities of this division are focused on the development of mathematical models used in the natural, technical and biomedical sciences. Division activities are associated with mathematical modelling and mathematical analysis of tasks described using regular and partial differential equations that most often originate from continuum mechanics. This includes setup, analysis of properties (existence, uniqueness/non-uniqueness, correctness of the task, etc.) and numerical analysis of models. Research directions at the division are:

- Development of techniques for partial differential equations (PDE): homogenisation theory and application in optimal design and inverse tasks for PDE, Friedrich's system as a frame for studying different types of PDEs, analytical objects and tools for studying fundamental issues in PDE theory, weak topologies on function spaces and distributions, applications in PDEs, and properties of pseudo-differential operators and other techniques of microlocal analysis, and application on rapid averaging, rapid management, compactness of compensation, semi-classic analysis, etc.
- Fluid mechanics. Research in this field includes mathematical modelling, analysis and numerical simulation of fluid flows in narrow domains (pipes, fissures) or in porous environments. Fluids can be Newtonian or micropolar, single- or multi-phase, and physical processes can be convective, diffusive, dispersive, conductive, isothermal or non-isothermal. Theoretical analysis is based on a priori assessments for initial equations and on various concepts of convergence and compactness. We apply asymptomatic analysis and homogenisation.
- Elasticity theory. This research relates to extractions and justifications of lower-dimensional models in three-dimensional elasticity. Models for high elastic, plastic, and biodegradable materials are of interest. These models are the basic part in the creation of complex models composed of multiple structures, with possible different dimensions (stick or scale system).
- Fluid and structure interactions. Due to their application in medicine, the analysis of the interaction of Newtonian fluids and elastic bodies modelled as thin (lower-dimension model) or thick (full three-dimensional model) bodies are of particular interest. Important questions

include: existence, uniqueness, stability, solution regularity, design, implementation and analysis of numerical schemes, analysis of parabolic and hyperbolic systems.

Division of Computer Science

- *Online* combinatorial optimisation algorithms. The aim is to develop new deterministic or randomised algorithms for a known online problem, primarily a problem with the k server. These new algorithms must be better than the existing ones with regard to competitiveness or computing complexity. For new algorithms, mathematical analysis of their competitiveness and computing complexity is performed. Experimental evaluation of those parameters on the computer will also be conducted.
- Distributed heuristics for NP-hard problems. The goal is to develop new distributed heuristics for problems such as vehicle direction (VRP), Hamilton cycle, etc. Thanks to cooperation of many simultaneous processes, these heuristics should be capable of resolving very large problems in an acceptable time frame. For new heuristics, experimental evaluation will be performed on the computer network. Their accuracy (deviations from optimum), calculation time and acceleration will be measured.
- Robust combinatorial optimisation algorithms. The aim is to develop robust algorithms for selected optimisation problems in graphs and networks. Robust algorithms give acceptable solutions when there is an uncertainty in the input values, expressed through a series of possible “scenarios”. For each observed robust variation of the selection optimisation problems, it is necessary to determine the class of computational complexity that this variation belongs to. For each algorithm, mathematic analysis of its computational complexity will be performed. Algorithms will also be evaluated on the computer.
- Automatic translation. The aim is to prepare mono- and bilingual resources necessary for automatic translation. The prepared resources of graphic algorithms will be analysed and evaluated using relational databases. Development of a system of universal marking of words in the dictionary for the purpose of the proper marking of the appearance of words in the text; analysis of parabolic-hyperbolic types of systems.
- Top computational competencies. The aim is systematically monitoring new trends and steps forwards in disciplines relevant for teaching computer science at the Department of Mathematics. Disciplines of special interest are: programming languages, structure of data and algorithms, databases, computer networks, software engineering, parallel and distributed computing, formal languages and automation.

Division of Probability Theory and Mathematical Statistics

Most scientific phenomena and daily life display an inherent non-specificity. Division scientists use stochastic and dynamic models to describe such behaviour. They rely on stochastic methods to gain insight, predict or make conclusions about this behaviour. Research projects are aimed at improving the understanding of the role of chance in each of the five following problem groups:

- Analysis and theory of potential Markov processes. We examine several issues relating to the theory of potential and analysis of trajectory properties of Lévy processes, processes that behave similar to Lévy processes, and Feller processes.
- Stochastic methods in modelling heavy-tail phenomena. We plan to study tail behaviour of stationary processes, limit theorems for extremes and the sums of chance observations, and the application of the obtained results to analyse time series, in non-life insurance and other areas.
- Stochastic methods in harmonic analysis. We plan to obtain a complete theory of general

"tangled" multi-linear singular integral operators, and to use martingal methods in the characterisation of low permeable filters in wave theory.

- Stochastic methods in biomedicine and social science issues. We plan to cooperate on the development of mathematical models of the growth of biological lenses (with S. Bassnett, WU in St. Louis), on the analysis of modified branching processes in telomer shortening (with I. Rubelj, IRB), to research the local asymptotic properties of approximate MLE diffusion parameters of drift, and to apply them to the adaptation of the von Bertalanffy model on tumour spheroid data (with Ž. Bajzer, Mayo Clinic), and to improve cooperation established on previous research in the areas of behavioural economics and innovation processes (with J. Cvitanić, CALTECH, D. Prelecom, MIT, and S. Radas, EI).
- Ergodic properties of expanded dynamic systems. The aim is to fully describe the invariant likelihood of measures of expanded differential equations on discrete and uninterrupted space, such as the Frenkel-Kontor model, reaction-diffusion equations, and the Navier-Stokes equation, and to statistically describe their dynamics.

Division of Topology

The scientific interests in the division include fundamental research in certain areas of topology and dynamic systems. Planned research is focused in the following areas:

Study certain classes of low dimensional discrete chaotic dynamical systems. Particular interest is in obtaining a better understanding of the dynamics of hyperbolic and partially hyperbolic maps on surfaces, the dynamics of families of homeomorphisms on surfaces (with homoclinic tangencies) and the topological properties of strange attractors in chaotic dynamical systems. With these goals, we explore conjugacy invariants, methods of symbolic dynamics and kneading theory, topological entropy, rotational theory.

Discrete dynamical systems generated by diffeomorphisms in R^n and C^n and their bifurcations. We investigate analytic germs of diffeomorphisms with asymptotic expansions in scales of powers and (iterated) logarithms (in particular, the Dulac maps). The objective is to contribute to the theory of formal and analytic classification of diffeomorphisms and families of such mappings, to reading the intrinsic properties of generating functions, such as multiplicity, formal and analytic class, from the epsilon-neighbourhoods of orbits of associated discrete dynamical systems (fractal properties of their orbits), and study applications to continuous dynamic systems within the 16th Hilbert's problem and cyclicity.

Fractal zeta functions of fractal sets and complex dimensions as a generalization of box dimensions and the notion of Minkowski content, and their application to dynamical systems. The research interest originates from the Riemann hypothesis and Weyl-Berry's conjecture. The objective is to explore various types of singularities of zeta functions of fractal sets and to associate them with other geometric properties of these sets, to examine the types of complex dimensions that occur in orbits and trajectories of dynamical systems, to understand the properties of dynamical system generators from zeta functions and complex dimensions of the orbit, and to investigate complex dimensions of orbits that undergo bifurcations.

Topology and computability. Investigation of the theory of computable metric and topological spaces and, in general, computable analysis and topology. The objective is to find conditions under which a set is computable or contains computable points, determine properties of computability structures on metric spaces, and to study the relationships between computability, topology, geometry and analysis.

Chair for Didactics in Mathematics and Computer Science

The interests of the Chair for Didactics in Mathematics and Computer Science are fundamental research in the areas of mathematics and computer science teaching at all levels. Interests also include researching the understanding and application of fundamental mathematical concepts in the context of mathematics and other course subjects, particularly in the natural sciences.

- Research of mathematical and computer science education. The aim is to recognise, characterise and understand the appearance and processes that appear or can appear in learning and teaching mathematics and computer science at all levels of education process, by applying existing theoretical frameworks or developing new ones. The focus will be on educational studies (planned and implemented curricula) and studies of conceptual images (including preconceptions and misconceptions) and though processes that pupils and students in teacher training develop while learning mathematics and programming and in solving problem tasks.
- Research implies fundamental mathematical concepts in the context of the natural sciences. Education research today has recognised many fundamental mathematical concepts and skills that pupils find difficult to comprehend. Meanwhile, their understanding and application is important for mathematics and physics, and other science subjects. To better connect mathematics with other subjects and to develop appropriate teaching content and methods that enable more sensible teaching, the aim is to research these concepts and the comprehension difficulties associated with them within mathematics and other natural science subjects, especially physics.

Department of Physics

Division of Experimental Physics

- Experimental research in condensed matter physics includes the preparation and investigation of structural, macroscopic and microscopic properties of a broad spectrum of modern materials. These include organic and inorganic materials, low dimensional conductors, oxide heterostructures, topological insulators, as well as materials that exhibit collective phenomena such as superconductivity and quantum magnetism, heavy ferroics, magnetic nanoparticles, single molecule magnets, complexes of magnetic ions, molecule-based magnets, multiferroics, high entropy and amorphic alloys and compounds, complex magnetic structures, ionic conductors, ferromagnetic graphite, soft matter, metal cluster complexes and other materials of importance for basic or applied physics. Research in search of new phase materials and studying the critical phenomena at the boundaries of those phases is particularly interesting. Such a wide field of study requires various techniques to determine the microscopic structure (X-ray scattering, electronic microscopy), local features (nuclear magnetic and quadrupole resonance) and macroscopic properties (magnetic and electrical characteristics, magnetotransport, thermoelectric and thermodynamic properties, high-frequency transport) in a wide span of external conditions (including extreme conditions such as very high and low temperatures and intense magnetic fields). Macroscopic properties are deduced from measurements of static magnetisation, magnetic moment, AC susceptibility, resistance and magneto-resistance, Hall and Nernst effects, thermopower, microwave conductivity, nonlinear radio-frequent conductivity and magnetic properties in the electrical field.
- Experimental research in atomic and molecular physics are focused on the study of atomic and

molecular processes in the high-pressure discharge in metal vapours in the high-frequency discharges in noble gases, using conventional and laser spectroscopic methods.

- Experimental nuclear physics research includes investigations of nuclear structure and properties of nuclei and hadrons, nuclear reactions of astrophysical and technological importance, and nuclear and particle processes of interest to the fundamental questions of quantum mechanics and the standard model. Studies are carried out in laboratories in Croatia and in specialized European and world accelerator centres. An important component is the application of nuclear methods in the study of materials, environment and medicine. Studies in experimental physics of elementary particles at high energies are focused on the research of Quark-Gluon Plasma (QGP) at RHIC and LHC colliders and spin structure of nucleons at RHIC.
- Research in the field of Astrophysics is focused on the following topics: (a) the structure, development and interaction of stars, (b) the origin and development of galaxies, and (c) the properties of interstellar matter.
- Physics education research includes investigations pupil and student comprehension of fundamental physics concepts, investigations in the field of educational neuroscience and development and testing of the new teaching strategies and materials.
- Neurobiophysical research uses neurodynamic methods for functional brain imaging, magnetoencephalography (MEG) and electroencephalography (EEG), to explore sensory and cognitive processes, multi-sensory integration, and cortical plasticity in basic and translational studies.
- The Division for Experimental Physics dedicates substantial attention to the development of top instrumentation that enables the execution of the most demanding experiments, and also enables the development of technology at the highest level. Recent examples of such accomplishments are the development of ultrasensitive multichannel picoampermeters, development of cryogenic radiofrequency amplifiers, development of experimental setups for measurement under uniaxial pressure, or the development of detectors for fundamental and applied research. This instrumentation finds a path towards patent protection and customers in developed Western countries.
- In cooperation with Zagreb clinical hospital centres and the Ruđer Bošković Institute, the division will continue to advance research in the field of medical physics. In the context of the increasing need for medical physics in the Republic of Croatia, the division is the natural nucleus for the formation of strategies of scientific research in medical physics, and the development of such strategies is planned, in cooperation with other scientific and clinical centres.

Theoretical Physics Division of Particles and Fields

- **Gravitation and black holes.** General research on parity violating effects in gravity by studying holography, anomalies, entropy, black holes. The focus is in particular on the natural candidates for parity violating gravity interactions – the Chern-Simons terms, both pure gravitational and mixed gauge-gravitational ones - using extra-dimension models such as those inspired by the string theory. The expected outcome is a significant increase in understanding the consequences of parity violating gravitational interactions, not only in relation with possible CP violations, but also for other effects, e.g. for corrections to black hole entropy. Also, research on general properties of classical scalar and electromagnetic field in a curved spacetime: question of symmetry inheritance and the interaction between the fields and black holes.
- **Phenomenology of elementary particles and fields.** The goal of this research is to study the

fundamental strong force, as described by the theory of quantum chromodynamics (QCD) and physical processes happening at hadron accelerators, including electroweak production of as-yet-unseen particles at the large hadron collider (LHC). Thereby, we investigate models of new physics in which such new particles are introduced in attempts to explain neutrino masses and abundance of dark matter in the universe. To achieve these objectives, we study specific hadronic processes, both in the high-energy regime where strong force is weak enough for perturbative approach, as well as in regimes where non-perturbative features of QCD, such as confinement and chiral symmetry breaking come to the fore. Our focus is on processes measured by the range of experimental collaborations which facilitates close contact with reality and immediate testing of our results and ideas.

Theoretical Physics Division of Condensed Matter

- **History of Physics.** The main subject of research will be Croatian natural sciences communities, especially the community of physicists, in the period 1875-1950. The goal is to elucidate the scope, the structure and the dynamics of the community, in particular the influence of the development of natural sciences and mathematics studies on the Croatian society.
- **Graphene and related materials.** This research is dedicated to graphene modelling, single and multi-layered systems, undoped, intercalated and doped systems, in particular doped with alkali and alkaline earth metals, mechanical deformed systems, graphene nanoribbons, carbon nanotubes and graphene-based compounds. The research will include band structure and excitation spectrum calculations, transport and optical properties calculations (including ballistic conductivity, and plasmon excitations), Raman spectra and magnetic properties calculations, a study of pseudomagnetic fields effects created by mechanical deformation, a study of spatially inhomogeneous systems leading to charge/spin confinement. One part of this research is also related to studies of nanoelectromechanical systems (NEMS) where magnetic and pseudomagnetic fields affect the magnetic coupling and nanomechanics controlled via spin.
- **High temperature superconductors and related materials.** It is a part of longstanding efforts to understand the physical mechanisms that govern in these materials. Our study will include the modelling of collective, transport and electromechanical properties, calculations of the dynamical conductivity and the dependence of the relaxation functions on frequency and temperature, temperature dependence of various transport coefficients, calculations of the imaginary part of the memory function, review how the electron-phonon scattering affects the electronic spectrum, the conductivity and Raman scattering. Our efforts will be dedicated to understand: i) the mechanism of doping and the emergence of free charge, (ii) the nature of the metallic response, (iii) the pseudogap appearance in the spectroscopic data (iv) and the nature of the magnetic response function. This is also related to the research of transition metal oxides, e.g. nickelates and iridates, aiming to design a technologically desirable materials, and to better understand the superconductivity phenomenon in different groups of high temperature superconductors.
- **Organic compounds deposited on surfaces and on small metal clusters**. This research includes the band structure calculations and how it affects spectroscopic data (optical absorption, EELS, photoemission, etc.) for organic molecules (benzene, terilen, fullerene, etc.) deposited on the surfaces of noble metals (eg. Au^{111}), or on metal clusters such as Au^{147}. The strong Coulomb interaction requires a solution of the Bethe-Salpeter equation that takes into account exciton creation and excited electron-hole interaction.

- **Layered transition metal dichalcogenides.** In low-dimensional materials, including layered transition metal dichalcogenides, electron-electron and electron-phonon interactions give rise to various low temperature phases and phase transitions (e.g. charge/spin density waves, superconductivity, metal-insulator transition, Peierls instability, structural superstructure, different magnetic phases, etc.) making them interesting to theoretical and experimental studies, but also for a possible technological application. This research will include ground state calculations, crystal structure optimization, band structure and excitation spectra calculations (phonon, magnon), and calculations of optical, transport and magnetic properties.
- **Theoretical research of new, mostly low-dimensional materials.** The aim of this research is to understand the basic properties and new phenomena important for technological application, and to model them, allowing for a synthesis of future class materials having an impact on technological development.

Division of Theoretical Physics

- **Nuclear structure.** The aims of the research currently carried out in the field of theoretical nuclear physics at PMF are the development and application of new theoretical approaches, based on the theory of energy density functions that enable precise modelling of the structure of quantum systems on the femtometre scale, including predictions of the properties of exotic femtosystems far from the valleys of nuclear stability that are still not accessible in experiments. Linking nuclear physics with the theory of energy density function allows for the development and application of a universal microscopic approach to describing and modelling exotic quantum systems on the femtometre scale, and in establishing links between quantum chromodynamics and the wealth of phenomenology in nuclear physics. Models of nuclear structure based on energy density functions includes additional correlations arising from the re-establishment of broken symmetries and from fluctuation deformations of the atomic core. The general coordinate model and collective Hamiltonian model based on a relativistic density function is applied in the description of quantum phase transitions in atomic cores, phenomena associated with the evolution of scale structures in exotic nuclei, superheavy nucleus structures, and the properties of exotic exciting models in nuclei outside stability valleys. An important research topic is the microscopic modelling of the process of spontaneous and induced nuclear fission, particularly the distribution of fission products. A key element for the precise modelling of the structure of exotic femtosystems are detailed numerical simulations on distributed and parallel computer systems. Therefore, the described research includes an important component in the development of effective numerical algorithms and distributed computer codes adapted for modelling exotic femtosystems. In order for theoretical predictions to be quantitatively comparable with the results of recent research, it is necessary to include reliable error assessments of theoretic models, which implies the use of advanced methods in information geometries and Bayesian analysis.
- **Nuclear astrophysics.** Nuclear astrophysics combines nuclear physics, elementary particle physics and astrophysics to research the processes occurring in the stars. A particularly important question is when, and under what conditions, are elements heavier than iron formed, as this is key to understanding the creation and composition of the Earth, the chemical evolution of the galaxies, and fundamental properties and interactions in atomic nuclei. A fundamental part of this research is the application of a self-supporting theoretical approach, based on relativistic energy density functions, descriptions of the properties of atomic nuclei that are important in the application of astrophysical models that describe the evolution of the

stars. A particularly important direction of research is examining the properties of cores, their excitation, processes and decay under conditions of the finite temperatures characteristic for different stages in star evolution. At the centre of the research are reactions important for the nucleosynthesis of heavy elements – the rapid acceptance of neutrons, reactions induced by neutrinos and the acceptance of electrons. To describe this in detail, it is necessary to first understand the finite phases in the evolution of heavy stars – the explosion of supernovas and formation of neutron stars. Research on the beta-decay of neutron-rich nuclei and the subsequent emission of neutrons is particularly important. This decay determines not only the dynamics of extreme astrophysical events, such as supernova explosions or neutron star collisions, but also the determination of the likelihood of delayed neutron emissions is important in nuclear reactors and can be key in resolving specific problems, such as reactor antineutrino anomalies. Research of important astrophysical processes and decay often encompasses the entire periodic system, nuclei from stability values to binding limits, which implies numerical simulations on a large number of atomic nuclei. That is why advanced computing is an important part of the research in nuclear astrophysics, in order to improve the numerical algorithms and mass parallelisation calculations. A significant research topic is the precise determination of properties of nuclear materials that are relevant in nuclear physics and in many astrophysical applications. Researching energy symmetries in infinite nuclear matter and the comparison of theoretical predictions of series of collective excitations in the atomic nuclei and new and high precision experimental data can form ties between finite femtosystems and infinite nuclear materials.

- **Optics and photonics.** The research aims currently researched theoretically in the fields of optics and photonics at PMF are the design and development of new photonic structures for light propagation (electromagnetic waves) with intriguing properties, such as the emulation of artificial magnetic fields, researching optical non-linearities in new materials such as graphene, and understanding new non-linear occurrences in these materials, as well as the development of structures that support plasmon excitation with a higher density of electromagnetic energy on spatial scales less than the vacuum wavelength. These aims are at the forefront of the global research in this field. The scientists of the Department of Physics aim to continue and strengthen cooperation with the world's most prestigious institutions and scientists in the field, thorough joint scientific papers and projects. Scientific research that strives to meet these goals unites the theories of classic electrodynamics and the physics of condensed matter and laser physics. Electromagnetic waves are studied in the presence of different materials, dielectrics and conductors, and their properties are used to design new phenomena and seek new effects with interesting properties, often with potential applications in sensors, optical devices, etc. This direction of research follows the development of new materials and applies the response functions of those materials (conductivity, dielectric response) to design new artificial photonic structures.
- **Ultracold atomic gases.** The goals of theoretical research currently conducted in the field of ultracold atomic gases as PMF include designing new methods for creating quasiparticle excitations with fractional statistics (anyons), theoretical understanding of multiparticle systems (fundamental states, observations that can give a clear list of those states, i.e. to date we have examined the distribution of quasi-impulses and correlation pairs). These goals are closely aligned with the research programme ongoing for several years, and which deals with the design of methods to create artificial or synthetic magnetic fields for atoms, understanding of multiparticle dynamics in the presence of synthetic magnetic fields, and understanding topological phases that appear in multiparticle systems

with (synthetic) magnetic fields. These goals are at the forefront of research on this topic in the world. Scientific research that strives to meet these goals unites multiparticle quantum physics, the interrelationships of light and atoms, laser physics and fundamental quantum physics. In all direction, a strong emphasis is placed on analogies with optical systems, where our group also has a great deal of expertise.

- **Cell biophysics.** The goals of the research of theoretical biophysics at PMF are revealing and understanding the physical principles that lead to self-organisation within the live cell, as the foundation of functioning of all living organisms. Key elements include the creation of the spindle apparatus in meiosis, the positioning and transport of organelles within the cell, and cell movement. In all these processes, the fundamental drivers are the molecular motors that interact with microtubules or actins. In studying these processes, theoretical models are designed, using known properties of molecular motors and microtubules obtained in in vitro experiments, and fundamental knowledge from classic mechanics, and statistical and non-linear physics. Once developed, models are tested analytically and numerically, and the obtained predictions are then experimentally tested. This research is performed in close cooperation with experimental groups at the Ruđer Bošković Institute and other global institutions.
- **Bioinformatics.** Tandem repetitions account for the majority of the genome of all eukaryotes, and mostly occur in the area of centromeres and pericentromeric heterochromatin. In the genome of humans and higher primates, these repetitions are organised into symmetrical higher-order structures. Recent DNA research has shown that tandem repeats play an important role in the structural organisation of the chromosome, in cellular metabolism, speciation and gene expansion regulation, and increasingly raises the question of their formation and activity. The scientific activity of the bioinformatics group is focused on developing algorithms and computer applications for the identification, classification and analysis of all types of repetitions in the genomes of various eukaryotes, particularly in the genome of humans, higher primates and Neanderthals. Analysis of tandem repetitions includes modelling the development of repetitive higher order structures, particularly in the area of sudden accelerations (phase transition). These hypothetical models facilitate our understanding of the evolution of entire gene sequences, genome organisation and the role of non-coding parts of the genome in the gene regulation network. Findings on the formation and means of activity of higher order structure may contribute to the direct application of these results in clinical research by revealing the causes of various diseases resulting from mutations within tandem samples.

Department of Chemistry

Division of Analytical Chemistry

Various studies are planned to be performed at the Division of Analytical Chemistry for the purpose of developing sensitive and selective analytical methods. Analytical atomic spectrometry (AAS, ICP-AES, ICP-MS) will be applied for development of new methods for quantitative metal content determination, with the optimisation of existing analytical procedures in sample preparation and improving spectral control of matrix effects. Special focus will be placed on methods of spectrometric quantification of elemental and isotopic composition of biomaterials and nanomaterials. Developed analytical methodology will strength multidisciplinary researches and it will be implemented through existing and planned joint- projects with economic sector (Goals 2 and 3 of the Strategy).

University of Zagreb, Faculty of Science

Structural analysis of inorganic, organic and biological compounds will be performed by using MS, NMR, UV-Vis, IR and Raman spectroscopies. Structure, interactions and binding modes of bioactive molecules will be investigated by spectroscopic, computational and other physico-chemical methods. Special attention will be devoted to design of novel bioactive compounds and drugs. Hydrogen bonds and their impact on stability, structure and reactivity of studied systems will be studied as well. Process analytical approaches to monitoring chemical and physical processes will be developed and implemented.

IR and Raman spectroscopy will be used for analysis of various synthetic and real samples. Within the vibrational spectroscopic methods, surface-enhanced Raman scattering (SERS) techniques will be developed, which will be applied for structural analysis as well as for study of intermolecular interactions and binding modes of small organic molecules with biomacromolecules. Development of SERS sensors for detection and quantification of various chemical species will include preparation and characterization of nanostructured metallic surfaces and spectra analysis by chemometric methods.

The HPLC and/or UHPLC chromatographic methods will be applied for analysis of real samples (food, dyes, pharmaceuticals, etc.). Modern analytical procedures based on hyphenated methods such as LC-SPE-NMR and LC-MS for purity profiling of bioactive compounds, drugs and natural products will be developed. In that respect already established collaboration with industry will be extended (Goal 3 of the Strategy). Complex mixtures and aggregation processes in petroleum samples and derivatives will be evaluated.

It is worth highlighting the successful collaboration of scientists of the Division of Analytical Chemistry with several research groups from abroad, which in line with Goals 2 and 4 of the Strategy should be increased.

Division of Biochemistry

Protein biosynthesis accuracy. The goals of research in this field are to obtain a better understanding of the molecular basis and biology importance of cell membranes that ensure the precision of protein biosynthesis (translation). Incorrectly synthesized proteins affect cell survival and functionality, are associated with aging and the development of neurodegenerative diseases. Using kinetic, biochemical, biophysical, genetic, proteomic and computational and genetic approaches, we investigate the co-dependence of the structure and function of aminoacyl-tRNA synthetases (AARS), the key proteins that control the accuracy of protein biosynthesis, and analyse the importance of the corrective reactions these enzymes have developed to keep a high level of translation fidelity. Erroneously synthesized model proteins will enable an understanding of the influence of inaccurate protein biosynthesis on disturbances to the structure and function of proteins. Understanding these processes provides a platform for the synthesis of target inhibitors with pharmacological applications, additional components for multi-component antibiotics, and the treatment of diseases caused in erroneous protein synthesis. The research is highly competitive and performed in conjunction with prominent research groups around the world who have complementary expertise (structural biology, laboratory evolution, bioinformatics). The research of protein biosynthesis accuracy also includes proteomic research, to analyse the understanding of the importance or permissiveness of translation accuracy at the global scale. A long-term goal of proteomic research based on mass spectrometry (LC-MS/MS) is to further expand and procure the necessary instrumentation in the division, as contemporary biochemical research is more and more dependent and nearly unthinkable without that aspect.

Designing new protein properties. The aims are to research protein engineering methods to create

proteins with new and improved properties that have a superior biotechnological and biomedical applications. Furthermore, redesigning proteins has wide application in biochemical, biophysics and cell biology research, as it enables the creation of specific properties that can be used to analyse the structure and function of proteins, and to monitor their localisation in the cell. Research is directed towards the installation of synthetic amino acids into proteins in order to effectively expand the standard amino acid alphabet. Interesting candidates for expanding the alphabet are the fluoridated amino acids, as fluoridated therapeutic peptides may facilitate passage through the membrane, thereby increasing pharmacological effect. On the other hand, attractive biotechnology lines of research may encompass the redesign of existing protein biosynthesis systems, with the purpose of preventing the installation of amino acids not involved in protein-building, but which accumulate in the cell. This problem is present in the production of therapeutic proteins in bacterial cells, and it is an important problem in the pharmaceutical industry. The research is international, multidisciplinary and lies at the crossroads of biochemistry, synthetic biology, and biotechnology.

Aminoacyl-tRNA synthetase as an antibiotic target. The research aims in the area of antibiotic action mechanisms are to explain the ties between the structure and function of aminoacyl-tRNA synthetases (AARS) and their role as a target in the production of natural antibiotics and as a target in the development of synthetic drugs. Particularly emphasis has been placed on research relating to antibiotic resistance, as this is one of the most important health problems we face today. Mupirocin is an antibiotic that inhibits protein biosynthesis through the inhibition of isoleucil-tRNA synthetase (IleRS). Mupirocin resistance is a common problem in hospital strains of the pathogenic bacterial species, *Staphylococcus aureus*. Resistance, both in hospital strains and in nature, develops through the evolution of IleRS with less sensitivity to mupirocin, or by the acceptance into the cell of an additional IleRS that is not sensitive to mupirocin. Using kinetic, biochemical, biophysical, genetic, computational and genetic research, in cooperation with groups that work on biochemical evolution and structural biology, the aim is to answer the key question of how antibiotic resistance functions, and the role of translation fidelity in that process.

New additional functions of aminoacyl-tRNA synthesis. Aminoacyl-tRNA synthetase often has additional functions in the cell, participating in a range of cellular processes that are not directly associated with protein biosynthesis. Research of additional functions will be directed towards poorly studied plant aminoacyl-tRNA synthetase, to examine its role in the cellular responses of plants to abiotic stress. This research is based on biochemistry, molecular biology and genetic methods. Furthermore, protein interactors and the biological role of macromolecular complexes involving plant aminoacyl-tRNA synthetase and their influence on plant growth and development will be examined. The subject of the research will also be amino acid:[protein carrier]-ligase, the bacterial homologues of aminoacyl-tRNA synthetase, which have evolved new and unexpected substrate specificity towards an aminoacylated protein carrier instead of tRNA. Their biological role is not known, they do not participate in protein biosynthesis, instead are most likely involved in the biosynthesis of secondary metabolites or antibiotics.

Protein interactions with other biomolecules. Specific interactions between molecules are very important for all biological processes. In order to understand complex interactomic systems in the cell, protein interactions with other proteins, with nucleic acids, and with small ligands are studied. Different techniques and methods will be used to analyse these macromolecular interactions, with an emphasis on quantitative methods of determining the strength of complexes (thermophoresis,

fluorescence spectrometry, isothermal titration calorimetry). This research has potential applications in biotechnology and biomedicine, since many drugs act as inhibitors and modulators of biomacromolecules and their complexes.

Computer methods in biochemical research. Contemporary trends in (bio)chemical research implies the use of computer methods in daily work. Computer methods serve in the study of the structure, motion and energy at the atomic level of biological macromolecules, such as proteins, nucleic acids and their mutual complexes, and their complexes with small compounds. In the lack of experimentally resolved structures, computer methods are used to predict protein structures on the basis of their amino acid order. Predicting protein structure has been significantly advanced in recent years, with regard to the methodological development and exponential growth of the number of experimentally resolved structures that are used as structural patterns in modelling. That is why computer methods serve as a complement to experimental research, and can substantially contribute to achieving the set goals: studying the structure and function of erroneously synthesized model proteins and proteins with built in synthetic amino acids, then modelled aminoacyl-tRNA synthetase (AARS), with the aim of discovering more about mupirocin resistance and examining their new, additional functions. With research on AARS, computer methods are used to model and study the structure, function and mapping of interaction networks, and in the study of catalytic mechanisms and other enzymes that participate in important metabolic pathways in the cell. This is based on molecular modelling methods of varying complexity, such as molecular mechanics and molecular dynamics models, quantum mechanics methods and their mutual combinations and EVB methods.

Division of Physical Chemistry

Scientific work in the Division of Physical Chemistry is an inseparable part of the teaching process and includes the research in the fields of theoretical and computational chemistry, thermodynamics, chemical kinetics, electrochemistry, colloid and interface chemistry, macromolecular chemistry, chemometrics and education.

In theoretical chemistry, quantum-chemical methods are used to calculate potential energy surfaces and dipole moment surfaces, which enables highly accurate determination of spectroscopic properties of molecules and reaction mechanisms. Interactions of biological macromolecules, as well as their structural and dynamical properties, are studied using force field based computational methods with purpose of understanding biochemical processes at the molecular level. Quantitative structure-activity relationship models are generated for investigating biological activity of different classes of compounds.

Thermodynamic investigations involve equilibria of ion association and complex forming reactions in solutions and on the surface. Structures of complexes and relevant thermodynamic parameters are determined by means of experimental and computational chemistry methods. Parallel kinetic investigations provide an insight into the reaction mechanisms. The continuation and extension of already ongoing successful collaborations with pharmaceutical industry related to physico-chemical characterization and synthesis of pharmaceutically active compounds is planned (Goal 3 of the Strategy).

Investigations in the field of colloid and interface chemistry deal with the development of theoretical models and experimental techniques for the characterization of interfaces. Aggregation, adsorption and electrical interfacial layer at the solid/liquid interface will be studied. These investigations will be performed in collaboration with several research groups from Croatia and abroad (Goals 2 and 4 of the Strategy).

In the physical chemistry of macromolecules, properties of polyelectrolytes and proteins in solution are studied, as well as their adsorption on solid substrates. Formation and properties of polyelectrolyte complexes and multilayers are also investigated. Special emphasis in these investigations will be given on the study of their antibacterial properties and on the specific aspects of ionic condensation on polyions. For that purpose, the already fruitful collaboration with researchers from the Faculty of Health Sciences and the Faculty of Chemistry and Chemical Engineering, University of Ljubljana will be strengthened.
Chemometric methods are developed and applied to interpretation of complex experimental data and their reduction to significant parameters. Use is made of modern computer methods, chemometrics, spectrometry, (micro)calorimetry, potentiometry, conductometry, optical reflectometry, electrokinetics and acoustophoresis. Scientific work in the field of chemistry education is dedicated to developing a quantitative approach to chemical problems, based on clearly defined notions and their interrelations.

Division of General and Inorganic Chemistry

The strategy of the Division of General and Inorganic Chemistry is based on the results and experience achieved and attained during the last decade of research through domestic and international research projects (Goals 2 and 4 of the Strategy). Plans are in place to continue research in the field of new organic and coordination compounds, solid state chemistry, supramolecular chemistry and protein chemistry (*H. pylori* proteins and insulin derivatives) and other biologically active compounds. The research will encompass design, preparation and detailed structural spectroscopic and thermal characterisation of the prepared compounds. Research on proteins will include cloning, purification, crystallisation, and structural characterisation. A variety of experimental methods shall be employed in order to study inter- and intramolecular interactions and their influence on molecular structure and properties. The main objectives of the above research are:

- Fundamental research in the field of development of new, environmentally friendly, methods of preparation of organic, bioorganic and organometallic compounds;
- Potential application of novel methods of synthesis and materials with designer properties (e.g. optical, thermal or magnetic) in industry;
- New insight into the influence of study inter- and intramolecular interactions on the structure of solids;
- Structural characterisation of proteins for the purpose of obtaining new insight into the relationship between protein structure and function;
- Transfer of the obtained knowledge and experience into education an all levels from undergraduate to postgraduate study;
- Intensifying international collaboration though participation in European and bilateral research projects.

In addition to the scientific research outlined above, expert work concerning the chemical synthesis and physical and chemical characterisation of pharmaceutically active solids is also performed in collaboration with partners from industry. In accordance with Goal 3 of the Strategy, this form of cooperation will be further deepened in the forthcoming period.

University of Zagreb, Faculty of Science

Division of Organic Chemistry

Since the start of scientific activities in the division, research has been focused in two directions: organic synthesis and physical organic chemistry. These two areas are still dominant today, though with new areas of focus in accordance with the contemporary development of the chemical sciences.

Synthetic organic chemistry is oriented towards design of new bioactive compounds containing heterocyclic aromatic and nonaromatic substructures as well as investigation of their interactions with enzymes, primarily cholinesterases. Research of pyridone derivatives is directed towards synthesis of compounds with antitumor effects, and synthesis of pyridone mannosides with application in antiadhesion therapy. Medicinal chemistry studies include design of new molecular conjugates of modified immunomodulating peptides, comprising molecular modelling approach. Prominent research includes the use of molecular modelling methods.

Research in physical organic chemistry is focused towards the development of new conceptual frameworks for explaining mechanisms of thermal organic reactions in condensed phases. Reaction mechanisms in solution are investigated with a computational chemistry approach, and methodology of solid-state reactions investigations is based on study of aromatic C-nitroso compounds dimerization reactions. Since these systems show photo/thermochromic effects, corresponding molecular aggregates could in principle possess externally controlled dynamical properties allowing their use in field of molecular electronics. These molecules are also investigated as potential building blocks for self-assembling mono- and multilayers, as well as three-dimensional supramolecular systems.

Future activities in field of organic synthesis will be directed towards design and synthesis of new aromatic and supramolecular systems, their experimental and theoretical study, as well as possible applications (biosensors, molecular electronics, "smart" drugs, new materials, etc.). The second part of synthetic research will comprise design and synthesis of bioactive molecules, especially heterocyclic systems, glycoconjugates and peptides with possible antiproliferative, antibacterial, antitumor, immunomodulating, antioxidative and different inhibitory effects, using conventional as well as new, faster and ecologically more acceptable methods.

Investigation of thermal and photochemical organic reactions mechanisms in condensed phases will be conducted simultaneously with theoretical and experimental approach. Computational results will help to better understand the intermolecular interactions in different solvents and polycrystalline systems. The study of solvation effects will be continued using newly developed computational approach. Experimental studies will be focused towards detailed investigations of kinetics and thermodynamics of organic reactions in solid phase, with emphasis to reactions in cryogenic conditions. New equipment will facilitate opening of new research directions based on mono- and multilayers formed on ordered surfaces.

Department of Biology

Division of Botany

Scientific research groups within the Division of Botany study algae and higher level plants. The plant physiology group plans to conduct research on the biochemical and molecular responses of plants and lichens to stress conditions to determine stress tolerance mechanisms. Other research involves measurable indicators with potential application in assessing the effects of different environmental pollutants, and research on the biological effects of plant bioactive compounds. The scientific interests

of the phytochemistry group includes analyses of bioactive compounds in plants, foods and beverages of plant origin, metabolism and mechanisms of biological effects of plant bioactive compounds, and finding natural compounds and plant extracts with optimal biological effects on human health. The systematic botany and flora group conducts research in the field of flora biodiversity, phylogeny and phylogeography, palynology and biogeography. The geobotany and archaeobotany group conducts research on the flora and vegetation of different habitat types that are important both as fundamental knowledge on biodiversity and the ecology of the examined habitats, and in developing management plans for protected areas and inland waters, and also archaeobotanical analysis of carpological and anthracotic remains collected on submerged and terrestrial archaeological localities for the purpose of reconstructing historical environments and settlements, and obtaining insight into the various aspects of plant use. The plant ecology and biogeography group researches the dynamics of vegetation cover and biological diversity, with regard to changes in abiotic factors and land use, with special emphasis on the analysis of the effects of invasive species and indicator plant species to assess changes in environmental conditions. The algae group examines the biodiversity of phytoplankton and phytobenthos and their relationships with biological, physical and chemical indicators on site, for the purpose of gaining a better understanding of the community responses to changes in freshwater and marine ecosystems. The Division of Botany houses two herbarium collections that are registered in the global database *Index Herbariorum* – Herbarium Croaticum (ZA) and Herbarium Ivo and Marije Horvat (ZAHO), together with about 260,000 herbarium specimens. The Division plans to strengthen cooperation within the division and with other divisions of the Department, and with other PMF departments. Cooperation with other scientific institutions, the public and private sector, and international institutions will continue and be deepened. In the forthcoming period, research will be focused in the following areas:

- Research on the effects of stress conditions on plants and ecophysiological, exotoxicological and phytochemical research that can potentially be applied in improving yields of commercially important species, discovery of new biomarkers, production of medicines and conserving the biodiversity of the Croatian flora;
- Discovery of natural compounds and plant extracts with optimal biological effect in preserving and improving human health;
- Studying the diversity of Croatia's flora and the flora of neighbouring biogeographical areas, using phylogenetic, biogeographic, archaeobotanical and palynological methods, developing new generation molecular markers and their use in the protection and enhancement of plants and in archaeobotany;
- Development of an online platform for modelling the distribution of taxa and generating dichotomous keys (parallel and sequenced, single- and multi-input) for taxon revelation, and maintaining and developing the Flora Croatica database as part of the National Conservation Information System of the Republic of Croatia;
- Studying plant diversity and its habitat conditions in space and time, and the application of the obtained knowledge in nature conservation, management of protected areas and inland waters, and the reconstruction of historical environments and relationships between humans and plants;
- Continuous maintenance, improvement and digitalisation of herbarium collections to preserve plant diversity and increase the accessibility of collection content to the scientific community and expert public;
- Researching the ecology of seed germination of strictly protected Croatian plant species;

University of Zagreb, Faculty of Science

- Research of the ecophysiological properties of plant species that enable their greater success in specific environmental conditions, with special emphasis on foreign invasive plant species;
- Application of new methods in determining the biodiversity of marine and freshwater microalgae, experimental analysis of mixotrophy, research on the influence of climate change on Croatian lakes and the Adriatic Sea, and the development of the Croatian-Chinese Environmental Protection Research Centre.

Division of Animal Physiology

The research at the Division in the forthcoming period is planned in two directions.

The first includes research on animal and cellular models with the aim of applying the obtained results in the human population (translation research):

- Within the project SCE for fundamental, clinical and translational neuroscience, in which members of the division cooperate as associated, new experimental models will be developed to study the development and disturbances to the work of the central nervous system, such as hypoxic-ischemic lesions and Alzheimer's disease.
- Research in the field of immunology, oncology and physiology will be based on the application of new forms of delivery of bioactive components (polyphenols) via nanoparticles or nanocrystals in an animal model of peritoneal angiogenesis, and their effectiveness will be examined on animal models of diabetes, osteoporosis, inflammatory skin and intestinal diseases, and their association with the modulation activities of the intestinal microflora.
- In the field of endocrinology and reproduction, research will examine the effects of different procedures of *in vitro* manipulation of reproductive cells on oxidative stress and genome stability.
- In the field of metabolism physiology and toxicology, research will be conducted on the bioavailability of bioactive substances in the body, toxicological *in vivo* and *in vitro* research of the security of bioactive compounds and residues present in food, and the effects of intracellular lipid metabolism on the oxidative stress of the cell and organs.

The second research direction includes research in the field of ecophysiology, behaviour and molecular ecology of wild species of vertebrates:

- In cooperation with the Zagreb Zoo and the University of Indiana, research is conducted on the ecological, physiological, ontogenetic, genetic and epigenetic determinants of behavioural and cognitive traits of vertebrates, using a lizard model;
- Research on animal behaviour traits that enable survival in the environment, using a model of the Dinaric vole, a rodent endemic to the Western Balkans;
- In the area of molecular ecology, research will be conducted on the genetic diversity and structuring and processes important for the adaptive evolution of different vertebrate populations, such as the tern, roe deer, red deer, dolphin, wild boar and otter, using neutral and adaptive genetic markers.

Division of Microbiology

In the Division of Microbiology, scientific research is conducted on fungi, bacteria, viruses and subviral pathogens. Confirming their biodiversity is one of the fundamental strategic goals in order to ensure their identification, characterisation using classical microbiological and contemporary molecular methods to determine their biological traits. The research is conducted on samples from various

ecological niches, including different natural and artificial aquatic and terrestrial environments (fresh water, runoff, soil, sludge, forests, orchards, vineyards), and on samples from a variety of domesticated animals, humans and plants.

Achieving progress in research based on studying the genome of microbes and their molecular epidemiology is the foundation for the development of microbial ecology, another strategic goal of the division. Researching the interaction of microbes, their hosts and the environment is another aspect that contributes to achieving the strategic goal of developing microbial ecology, and connecting the Division of Microbiology with professions that primarily study the microbe as a causative agent of disease. For that reason, the study of pathogenic bacteria in the environment is conducted in cooperation with the Departments of Geology and Chemistry at PMF, with the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb; School of Medicine, University of Split; Faculty of Technology and Metallurgy, University of Belgrade; Université Grenoble Alpes; Split Clinical Hospital Centre; Public Health Institute of Split-Dalmatia County; Croatian Public Health Institute, and Zagreb Wastewaters. Pathogenic bacteria on plants are studied in cooperation with many foreign university and research centres (INRA, John Innes Center Norwich), and with the Croatian Centre for Agriculture, the Village and Food – Plant Protection Institute (HCPHS-ZZB). The latter cooperation applies contemporary research methods, and the application of results of measures taken in plant protection in the Republic of Croatia, within the professional activities carried out by HCPHS-ZZB.

Research on fungi and oomycetes primarily concerns the study of the biodiversity of different plant pathogens and the molecular dual interactions between mushrooms – plants, and trilateral interactions virus – mushroom – plant, in cooperation with Croatian and foreign university and research centres: ETH Zurich; University of Osijek; Faculty of Forestry, University of Zagreb; Faculty of Forestry, University of Skopje; and the Croatian Forestry Institute.

Plant viruses are traditionally researched in the Division, for the purpose of conserving this legacy in functional laboratories, experimental jars and in the virus collection, which is yet another long-term objective of the Division. Expanding the virological research interests will also extent to subviral pathogens (satellite RNA viruses and viroids) and on environmental viruses, fungi and animal hosts, as important drivers and models of molecular evolution, biodiversity regulators, biogeochemical cycles, mechanisms of disease development and health protection, and the development of nanotechnological tools, particularly in biomedicine (e.g. altered adenovirus vectors used in gene therapy). Projects are carried out in cooperation with the Faculty of Agriculture, University of Zagreb, Ruđer Bošković Institute, and virology research groups in the region (National Biology Institute in Ljubljana; Faculty of Biotechnology, University of Podgorica) and beyond (Université de Liège, France; Università di Bari, Italy; Penn State, USA), and the research results are transferred to activities with professional organisations, above all the Croatian Microbiological Society.

This has positioned the Division for Microbiology as the main microbiological research centre in Croatia and the region, and the intention is to further develop and improve the activities and status. Through our teaching activities, various means of application of results, and through adult learning, we want to be recognised as leaders in education in the practical application of contemporary microbiological methods and concepts.

Division of Molecular Biology

The Division of Molecular Biology includes a number of scientific research groups covering a range of research topics.

University of Zagreb, Faculty of Science

- The research interests of the stress biology group are examining the impacts of abiotic stress (saline, osmotic, and heat stress and stressed caused by heavy metals and nanoparticulate metals) on plants, and understanding the plant response to stress at the cellular level, and at the chromosome, gene and protein levels.
- The oldest group in the division examines the organisation and evolution of the plant genome at the cytogenic and molecular level. The aim of this group in future research is to apply chromosome markers in phylogenetic research and in the organisation and evolutions of tandem DNA sequences and to determine their role in speciation.
- The group that addresses the mechanisms of plant development studies the sexual and asexual reproduction of plants using the models *Arabidopsis thaliana* and *Vitis vinifera*. Future research is directed at revealing the mechanisms and regulation of reproductive capacities of egg cells and somatic cells using RNA sequencing methods, reverse genetics, and methods to prove protein interactions. The group plans to apply the potential of somatic embryogenesis to obtain new desired traits for agriculture, without the use of genetic engineering techniques.
- The biomedical group conducts research in the field of tumour biology, regenerative medicine and tissue engineering, intercellular communication and the effects of the microorganisms on cellular mechanisms. The research includes analysis of transcription regulation in animal cell, communication networks of tumour cells and the microenvironment, regulation system of plasminogenic activation that regulates tissue remodelling, identification of the mechanisms of inductive selective death of tumour stem cells, and the effects of viruses on the cell cycle. In regenerative medicine and tissue engineering, research is focused on the differentiation of stem cells in three-dimensional systems, the creation of bone and cartilage tissue, and development of bioreactor systems, carriers, differentiation parameters and the analysis of differentiated tissues. The projects of this group are aimed at developing new methods and discovering the processes that can be transferred to clinical practice.
- The research group for bioinformatics and computational biology takes a quantitative approach to biological processes at the systematic level. The bioinformatics group is the most cited research group at the Department of Biology, and among the most cited at all of PMF, and based on the number of published articles in the leading expert journals, it is one of the most successful groups at the University of Zagreb. Some research topics within the group are: metagenomics, as the interaction between microbial communities and their environment (including humans) at the genome level; genomic multi-cellular organisms – processes of development and cellular differentiation and the genetic conditions for the emergence of multicellular organisms; development genomics of mammals – as the transcription processes of coding and non-coding RNA that are necessary for the successful development of the fertilised egg cell; epigenomic malignant cell transformation – mutation markers and their association with epigenetic factors for the purpose of diagnosis and classification of tumour diseases and epigenomic virus infections – mechanisms of insertion of the HIV-1 virus in the human genome, with an emphasis on the epigenome and chromatin structure.
- The epigenetic group examines the regulation of protein glycosylation under normal physiological conditions and in complex human diseases. The purpose is to explain how the variability of protein glycosylation achieved through epigenetic regulation participates in the underlying state and different course of disease in the human population. For that purpose, modern methods of bisulphite sequencing and chromatin immunoprecipitation are applied. The goal is also to discover the functional importance of GWAS hits in IgG glycosylation, using the newest methods in genetic and epigenetic engineering, such as TALEN/CRISPR technology.

University of Zagreb, Faculty of Science

- The molecular bacterial genetics group studies the mechanisms of resilience of the bacterium *Escherichia coli* from attacks by foreign DNA (bacteriophages and plasmids) using the CRISPR-Cas system. This research is aimed at explaining how this system is regulated, specifically the Cas3 protein which is a key defensive protein. The research encompasses all levels of genetic regulation: from transcription, post-transcription, protein stability, changes in protein conformation to its proteolytic degradation. The group also aims to explain the ties between the CRISPR-Cas system and homologous recombination and DNA repair.

Division of Zoology

The Division of Zoology deals with the study of the diversity, distribution, ecology, taxonomy, ecotoxicology, reproductive biology, phylogeny and phylogeography, ecological evolution and genomics, evolution and biogeographic properties of all parts of the fauna of the Republic of Croatia, and the processes that have given rise to such properties of fauna. These activities of the division, which include elements of expert and scientific work, are carried out through the independent activities of division staff, in cooperation with related institutions in Croatia and abroad. The fundamental research directions in the forthcoming period are:

- DNA barcoding of the biodiversity of Croatian fauna. Phylogenetic and phylogeographic research, biological and ecological aspects of the current distribution, taxonomy and phylogeny of arthropods (insects, crustaceans) and fish, flatworms, freshwater cnidarians and their endosymbionts, and research of the evolutionary aspects of symbiosis.
- Ecological research, including the development of tools and solutions for restoring degraded marine habitats, and the recovery of their biological diversity and ecosystem function. Special attention is focused on researching the impacts of global climate change and the introduction of alien species on freshwater communities and native species. Ecological research deepens the study in the fields of ecological evolution and ecological genomics. The influence of anthropologically caused ecological change (pollution, biological introductions and fisheries activities) on the rapid evolution of natural populations. Sinecological research of aquatic communities and the properties of a range of aquatic biotopes is also continuing.
- Applied research as part of the National Monitoring Programme for aquatic ecosystems, as an initial strategy in the context of the EU Water Framework Directive. Research on the effects of different pressures and determining bioindication. This research is the basis for drafting legislation and monitoring systems. In this research, the collected data are processed and interpreted and published as scientific papers.
- Ecotoxicological research aimed at studying the effects of pollution on organisms in the environment, and the development of specific biological methods for the faster and more accurate determination of negative anthropogenic effects. Laboratory research is continuing to determine the effects of individual pollutants on the course of cell differentiation and cell (ultra)structure in certain aquatic organisms.
- Expert projects (monitoring programs) in which new young scientists (assistants) will be employed.

Department of Geophysics

- **Meteorology and climatology.** Using fundamental geophysics approaches (measurements and observations, numerical simulations and theoretical development), we continue to study atmospheric processes and phenomena at the small, medium and large scales. We also study the creation, transmission, distribution and deposition of pollutants in the air, the vertical

structure of the urban and suburban border layers, dissipation of turbulent eddies, turbulence kinetics and potential energy budgets over complex terrains, and the three main classes of non-standard radio wave refraction in the atmosphere. We examined the air currents over complex coasts and mountains, including phenomena such as the winds (bora, jugo and maestral), deep convection and the development of fog. Due to the current interactions of the system atmospheric – sea, a part of the research on local and regional weather and climate is performed in conjunction with oceanographers, using advanced statistical methods and climate modelling of varying degrees of complexity. Certain numerical models (simulators) will also be modified, with the aim of improving the parameterisation of turbulence. Research will continue on climate variability and climate change in Europe. Special attention will be focused on the effects of atmospheric large-scale modes and the contribution of slower components of the climate system (sea, soil, ice) through the possible extended action of those modes. Physical mechanisms that enable such connections will be explored using numerical simulations using global and regional climate models, and statistical analysis of the measured data. In cooperation with the State Hydrological and Meteorological Institute, we will begin research on urban heat islands in conditions of current and future climates using microclimate model MUKLIMO 3 using meteorological fields and vertical profiles, and spatial information on the relief properties and land uses as extracted from GIS bases. The research will contribute to the understanding of atmospheric small-scale processes, and its results will serve to modernise course content.

- **Oceanography.** Future oceanographic research will focus primarily on data collection, not only at the permanent mareographic state at Bakar (established in 1929), but also as a part of special experiments that will use pressure mareographs, undulators and other equipment. All collected data will be analysed with the appropriate statistical methods, both standard and newly developed methods. Focus will be placed on examining a broad spectrum of processes in the sea, from long-term changes in sea levels, to storm surges and coastal seiches, to river outflows into the sea. Special attention will be focused on applying diverse models to reproduce observations. For example, semi-empirical models will be used in considering sea level trends, two-dimensional barotropic models in the analysis of sea responses to atmospheric activity, and three-dimensional barocline models in the reproduction of sea properties, and sea movements in areas around river mouths.

- **Seismology.** The Department of Geophysics of PMF is the only institution in Croatia to conduct seismological research, and therefore the research plan is essential diverse, though focused on research of the seismicity of Croatia. The Seismology Survey, in accordance with the available funding, will continue to increase the density of the basic seismograph network in Croatia, and will continue recording earthquakes, archiving digital seismographs, cataloguing earthquakes and sharing data with partners abroad. The scientific work will be focused on exhaustive research of specific areas (such as Mt. Velebit), with the aim of identifying seismogenic faults, their properties and role in the seismo-tectonic structure. Work will continue to examine anisotropic rates, attenuation properties and the structure of the core and upper mantle under Croatia, using contemporary inversion methods of seismological observations (receptor functions, tomographs using microseismic unrest and spatial waves, etc.). In the field of seismological engineering and earthquake engineering, work will continue to measure the dynamic properties of important structures so as to identify those that are threatened due to the appearance of building – ground resonance, and all tasks associated with revising the assessments of the earthquake hazard in Croatia.

University of Zagreb, Faculty of Science

- **Geomagnetism.** Research of geomagnetic fields in Croatia will continue with data collection at the only Croatian geomagnetic observative, which started operations in Lonjsko Polje in July 2012. The data from the observatory will serve in the theoretical analysis of the distribution of all magnetic elements, developing geomagnetic maps, modelling field anomalies in the Croatian area and their interpretation. Scientific work in geomagnetism will be strengthened with the modelling of geomagnetic fields in a limited area using spheric harmonic analysis on the spherical cap. With that, special attention is given to the development of sophisticated techniques for the construction of calibration curves, i.e. baselines, in the case of large degradation data primarily arising from temperature instabilities and errors in absolute observations. This most often occurs in observatories, like the Croatian one, which do not have stable temperature conditions secured for high quality measurements. Efforts will be invested in continuous upgrading of the measurement quality and standards at the observatory, to ensure that measurements are aligned with the requirements of INTERMAGNETA.

Department of Geology

Scientific research groups within the Department of Geology research rocks from a range of aspects: petrology, sedimentary, palaeontology, mineralogy, geochemistry, palaeoenvironmental and recent environments, ecological and palaeoecology, and geoarchaeology.

The primary planned topics of research by division are outlined below.

Division of Geology and Palaeontology

- Contribute to the understanding of geological evolution of the areas of the Dinarides and the Pannonian basin

The Inner Dinarides and their border areas towards the Outer Dinarides contain many surface sedimentary rocks that contain information about the history of orogenesis and palaeogeographic development of the broader region. The biostratigraphic and sedimentology properties of mostly deep-sea sediments will be studied to determine the palaeographic and geodynamic links within the Dinarides mountain range, and also with neighbouring segments of the Alpine orogenetic belt (Croatia, BiH, Slovenia, Austria, Serbia, Montenegro). Dating transgressive sediments will contribute to a better understanding of the development of the synorogenic basin in that area. Studying the provenance of clastic materials will reveal their composition and potential petrogenesis and thermal history of original relief, which is highly beneficial in reconstructing the history of geodynamic active areas.

Research will be conducted on Miocene deposits and the biota of Paratethys and surrounding lands, with emphasis on connections between stress events and organismal behaviour. Special attention will be paid on the middle Miocene environments and transgressive and regressive cycles. Among the shallow sea environments, bioconstructions will be performed of red algae and bryozoa and the edge shelf environments. Among the biota of deep-sea environments, the pelagic and benthic molluscs (with chemosymbionts) will be studied, along with less known benthic organisms (e.g. crustaceans, deep sea urchins, sponges).

- Research of stress events in the geological past, e.g. impacts, extinctions and glaciation

Traces of glaciation in the Dinarides is the focus of study, and this will be directed at determining the extent of the Pleistocene ice cover, directions of its expansion and the carrying of detritus materials, and understanding its dynamics, i.e. the expansion and contraction, aimed at establishing a regional

stratigraphic framework of the Pleistocene (divided into regional levels). Determination of the age of Pleistocene deposits and their palaeontological content will be carried out in cooperation with relevant scientists around the world, and in Croatia with the Department for Palaeontology and Quaternary Geology of the Croatian Academy of Sciences and Arts and with the Ruđer Bošković Institute.

The aim is to research geological traces of asteroid impacts, to reveal the properties and composition of impactogenic materials and particles, to understand the origin of impact detritus and its chronostratigraphic age. This interdisciplinary research is conducted in cooperation with researches at the Department of Chemistry, PMF, the Ruđer Bošković Institute and the Department for Palaeontology and Quaternary Geology of the Croatian Academy of Sciences and Arts.

This research will also examine the causes and course of extinction recorded in the rocks in the Dinaric region (e.g. at the Guadalupian-Lopingian boundary and the Permian-Triassic boundary).

- Specificities of shallow-sea environments with carbonate sedimentation during the Mesozoic and Cenozoic, with regard to their geographic distribution in the Republic of Croatia

In the Outer Dinarides areas, which includes the area of the Croatian coastal belt south of Karlovac, research will examine the Mesozoic succession of primarily shallow-sea deposits. This research will focus on sedimentology (structural and textural properties of limestones) and stratigraphic (on the basis of the biostratigraphic range of microfossils and determination of the absolute age using strontium isotopes). The established environmental conditions discovered in sequential frameworks of varying degrees (from the cycle of increasing shallowness to higher order sequences), will be compared to enable a regional reconstruction of the Outer Dinarides area. A comparison with the successions of Mesozoic siliciclastic and carbonate deposits of the Inner Dinarides and Austro-Alpine areas will allow for a possible palaeogeography of the area in the Inner and Outer Dinarides (where the research will partly encompass research of the Mesozoic surface outcrops within the Pannonian basin and the Inner Dinarides). With such set boundaries, specific research will focus on the ichnology of terrestrial reptiles, in order to create a determination of organism size, and perform possible palaeogeographic reconstructions based on the regional stratigraphic and environmental data obtained from this research.

- Research of river mouths, coastlines and coastal processes, and marine sediments to determine changes in the deposition environment during the Pleistocene and Holocene, and anthropogenic influence on sediments

Research will be conducted along the eastern Adriatic coast and coastal area, with special emphasis on river mouths, estuaries and deltas of the eastern Adriatic rivers. Sediment cores will be extracted from these areas to conduct sedimentology analyses, micropalaeontology analyses and geochemical analyses to describe the order of deposit layers in the karst river mouths during the Pleistocene and Holocene. The geomorphological evolution of those areas will be reconstructed to expand the knowledge about sea levels in the past, climate changes and human activities that occurred after the period of the last glacial maximum. Special attention will be dedicated to the phenomenon of submerged karst and indicators of changing sea levels (saline wetlands, tidal undercuts, bioconstruction indicators and archaeological indicators).

In addition to sediment cores, sedimentology and palaeontology research will continue on surface

sediments on the seabed in the coastal area and open sea, for the purpose of evolution and mapping the seabed, and defining and describing marine habitats. Furthermore, the results of geochemical research of surface sediments will be used to characterise the state of marine environments, particularly those under strong anthropogenic influences.

Detailed research of coastal morphology and research and monitoring of coastal processes, particular in the area of beaches, coastal cliffs and river mouths, will contribute to the understanding of how these environments function (source-to-sink concept), thereby creating the foundation for sustainable management of coastal areas.

The results of this research will significantly facilitate the drafting of expert studies to monitor and assess coastal and transitional aquatic environments, in accordance with the European Union Directives.

Division of Mineralogy and Petrography

- Crystal chemistry properties of minerals with applications in minerology, geology, materials science and environmental research, with particular emphasis on clay and zeolites.

With the fundamental research of crystal chemistry properties of minerals for the purpose of determining known and new mineral species and their genesis in various geological environments, research will also focus on the interdisciplinary research associated with the role of minerals in interaction with living organisms and the influence of minerals on the distribution of certain elements and compounds in the environment. This is particularly important in the prevention of pollution, and in environmental protection and remediation. A part of the research will be directed at the application of minerals in contemporary technological processes, and will strengthen the ties towards other disciplines included in the preparation and characterisation of new materials, both at the faculty and the university, and in other research institutions in Croatia and abroad. Particular attention will be focused on the minerals clay, zeolites and oxides.

- Genesis and changes to rocks in the Republic of Croatia and neighbouring countries, with a look at the evolutionary models of development of the Pannonian, Dinaric and Adriatic areas, and the geochemistry research of lithostratigraphic units and geological structures and mineral deposit sites.

Fundamental scientific research encompassing magmatic and metamorphic rock and their roles and importance in the reconstruction of geological events in the orogenic areas of the Carpathians, Dinarides and Alps, and in the crystalline substrate of the Pannonian basin will be focused on determining the detailed temporal and petrogenetic conditions within the pre-Variscan, Variscan and Alpine orogeneses, and on the establishment of cause and effect relationships between the examined processes. Considering that the importance and spatial and temporal scope of the oldest and youngest orogeneses within the Republic of Croatia have not yet been fully explained, nor are the details known of certain episodes of the Variscan orogenesis, specific research is planned to precisely determine the petrological, mineralogical, structural geological, geochemical and isotopic properties of magmatic and metamorphic rocks, and the associated processes occurring in various geotectonic environments and geodynamic entities. The focus of the research will be shifted from studies at the level of individual magmatic-metamorphic complexes, towards a detailed three-dimensional structural, textural and microtectonic analysis of rock systems, determining the isotope composition of individual phases, inclusion studies and an analysis of complex properties and the internal structure of accessory

minerals, such as zirconium, apatite, monazite and xenotime, which appear in both types of rock. Territorially, this research will predominantly be conducted in the Republic of Croatia. Meanwhile, thanks to broad scientific cooperation, research in specific areas in Central and Eastern Europe will be expanded, as this is of exceptional importance for monitoring the rock systems that extend outside the national borders, and for the interpretation f the development of larger geodynamic entities.

The research on sediments and sedimentary rock will be focused on the Neogene and Quaternary deposits of the Pannonian basin, and the Quaternary deposits of the Adriatic area. In the Pannonian region, special attention will be given to address two research goals. The first is to define the geochemical character and deposition time of pyroclastic deposits and the accompanying sediments and sedimentary rock. To date, these deposits have been poorly studied, and they are the basis for defining the duration of terrestrial, freshwater, lake and marine phases in the development of the basin over time, in which the transition from syn-rift to post-rift stage occurred in its evolution. The second goal is to define the deposition model for the period of the Lower Miocene and Pliocene in the Pannonian region of Croatia, which on the one hand would contribute to a better definition of the general evolution model for the entire Pannonian area, while on the other it would be an important factor in hydrocarbon research. In conjunction with scientists from the Croatian Geological Survey, INA, University of Budapest and University of Pecs, research has already begun in the oil and gas rich area of the Drava Depression, and plans are in place to expand this research to parts of the Pannonian area. In the Adriatic area, research will continue to examine the origin and age of Pleistocene sediments that are important as the main source of beach material on the islands and mainland coast.

- Geoarchaeology – characterisation of archaeological materials using mineralogical methods.

This research will result in a characterisation of the archaeological materials and materials used in the construction of historical structures, based on the use of mineralogical methods. Over the past 15 years, the Division for Mineralogy and Petrography has been actively involved in archaeological research, particularly in the phase characterisation of ceramics, metals and stone archaeological artefacts and pigments, and involve in the study of stone wearing processes in order to improve methods for its protection. Important cooperation in this area has been achieved with the Croatian Conservation Institute. In recent years, the work of the Division has also been recognised by local museum institutions, and so the aim is also to expand the existing research, and apply the obtained results to determine the provenance of rock used to build structures found at archaeological sites and in the construction of historical buildings.

- Geochemical research of the environment with the aim of differentiating geogenic and anthropogenic factors that influence the distribution of metals and other important environmental compounds, with the aim of characterisation, remediation and managing threatened and sensitive environments.

Environmental research will be carried out with the aim of differentiating geogenic and anthropogenic factors influencing the distribution of potentially toxic compounds and other important environmental compounds, for the characterisation, remediation and management of threatened and sensitive environments, and to develop risk models. Special attention will be given to the influence of individual segments of human activities on the environment (agriculture, industry, catastrophic events such as forest fires), with the monitoring of the distribution of key elements and chemical compounds that can affect the natural balance or affect living organisms. A part of the research will focus on the influence of handling various types of waste on the environment, from the perspective of the geological

substrate and distribution of potentially toxic compounds, and this will further pertain to the strategy for the adequate handling and recycling of waste. The research will place an emphasis on the ties between humans and the environment, through the development of medical geology, which is a continuation of the research on kidney stones.

Department of Geography

- **Geomorphology and palaeoenvironment.** Research of karst from the aspect of geomorphology and palaeoenvironment, i.e. the questions of the formation, evolution and recent dynamics of the karst relief, has traditionally been studied by a research group at the Department of Geography, PMF. The most recent research topics are associated with the influence of geological structures on the development of karst relief forms, clima-geomorphological research (e.g. measurements of the intensity of karst denudation) of the development of morphometric methods, and geomorphological mapping in the GIS environment. The karst relief is often under the influence of other morphogenetic processes, such as glacial processes that were important in the past. Therefore, one of the research aims is the analysis of glacial karst on the surface and in speleological structures. This period is directly associated with the different distribution of land and sea in the Adriatic region, which has a very important role in the reconstruction of palaeoenvironment properties during the late Pleistocene and Holocene. Therefore, we use different markers (geomorphological, biological, archaeological, and others) to reconstruct palaeoclimate properties and to define and explain the sea level oscillations. Changes to the environment and climate are also studied based on analyses of speleothems and tufa. This research is based on field work, and isotope methods are extremely important; these are conducted in conjunction with the Ruđer Bošković Institute. An important goal in this research group is the further development and equipping of the laboratory for physical geography and geomorphology.
- **Climatology, hydrogeography and geoecology research.** Research is directed at planning the functional spatial organisation and sustainable development. The strategy is directed at fundamental and applied research, personnel development, knowledge transfer, technological development, procurement of computer, GIS and research equipment, and strengthening cooperation with domestic and foreign partners. Research of this group encompasses analyses of the influence of abiotic factors on ecosystems, where geomorphological, pedological, hydrochemical, anthropogenic and biological indicators are applied in the research and monitoring of the state of the environment. The research also includes the analysis of natural hazards, microclimate research, study of geological diversity and geoheritage, ecosystems of settlements and anthropogenic geomorphology, and the geographic aspects of conservation and ecosystem services. Within the hydrogeographic research, inventories and evaluations are conducted of the hydromorphological state of flowing and standing waters, of riparian and catchment areas, and runoff regimes within the EU Water Framework Directive. One of the goals is to develop the hydrological atlas of the Republic of Croatia, and to study the ecologically acceptable flow rates, and water resource management and water supply as part of sustainable regional development. Climatology research is focused on regional climate analyses, research of city climates, analysis of climatic changes and the variability of climatic elements in the instrumental period, and the influence of climate on geographic evaluation in space. An important part of this research is regionalisation based on physical geography components of the landscape.
- **Urbanisation, social structure of the city and regional development.** Regional development

of Croatia is based on an urban system, and therefore, special attention in the research is given to the network of towns and cities, the functional classification and role of cities in the administrative and territorial organisation of the country. Furthermore, the research will examine the differentiating characteristics, development potential and limitations of urban surroundings. It will also shape recommendations and development measures to validate potential suburban areas in the future development of city regions. Furthermore, the research examines the city space itself, and its spatial structure (functional, morphological, social and cultural traits), including: quality of life, problem areas in the city, sustainable city development with an emphasis on sustainable (alternative) transport, spatial mobility, social space and cultural differentiation, segregation and the daily environment. Methodological instrumentation of the research ranges from the exact (GIS, field work) to qualitative methods (interviews, focus groups). Spatial imagination and mental maps are emphasized as the product of spatial daily practices, and therefore are an important part in researching the city space. The obtained results are important in improving spatial planning and regional development, validating spatial resources, functional integration and approaches to solving the problem of uneven regional development in Croatia. There is a potential for a broad spectrum of applicability of the research results in the commercial and public sectors, and the results will contribute to improving the quality of public policies.

- **Sustainable development and planning of rural and peri-urban areas in Croatia.** About half of Croatia's total population lives in rural and peri-urban settlements, which cover an area of nearly 90% of the total national territory. Excluding such areas that directly surround large city regions, the Croatian rural environment is characterised by primarily unfavourable development traits, negative demographic situation and processes (depopulation, aging), and weaker infrastructural and economic development in comparison with urban areas. Meanwhile, the rural and peri-urban areas are of strategic interest as they are the most important areas for food production and locations of key natural resources. They are also important for other important functions, such as residential areas, various commercial activities, nature conservation, locations of large infrastructure and energy facilities, recreation. Primarily negative development trends on the one hand, and alignment of all these functions on the other, often raises dilemmas and conflicts concerning their planning and sustainable development. This gives rise to the key directions of research: models and measures of development of various forms of rural areas, variations of scenarios of possible directions of future development, influence of new stakeholders on demogeographic and socioeconomic processes in rural areas, comparative analyses of trends in rural Croatian areas and other European, particularly transitional, countries.
- **Demographic aspects of development in Croatia.** The contemporary demographic development of Croatia is marked by unfavourable processes and structural properties, which has contributed to a reduction of the overall "human capital" as the main driver of socioeconomic development. The consequence of these processes is seen in the unevenness of regional development, the sustaining and deepening of the gap between the village and the city, and between the centre and periphery, and in the uneven development of the network of settlements, etc. In the (re)evaluation of the Croatian national territory, demographic potential plays a great role at all levels, as the total qualitative and quantitative, real and potential social and biological properties of the population. Accordingly, the research is focused on: recent changes in the spatial orientation; dynamic and structural properties of the population at all spatial levels; demographic development of marginal and problem areas;

trends of population development in city region settlements; and the influence of demographic processes on planning education functions. The aims of the research are the identification, evaluation and projection of the demographic potential of Croatia and its regions, determining the guidelines for shaping the population policies and strategies of uniform regional development of Croatia, and proposed interventions in the school network and organisation of enrolment districts for primary and secondary schools that would ensure sustainability and rational organisation of the educational role.

- **Cultural landscape and spatial identity.** Changes to the environment in the Republic of Croatia will be studied, particularly changes to land cover and changes in land use. The aim of the research is to develop deductive models that include physical changes to the environment (landscape) and sociogeographic and physical geography factors that affect the observed changes. The possibility of including human behaviour and the decision-making process will also be included in examining changes in land cover and land use. A special aspect is the link between social changes (such as depopulation and its consequences in space), the manner and intensity of validation of spatial use of lands, and the resulting changes in the environment. These mechanisms largely affect the increase in the occurrence of environmental hazards, such as fires. The cultural landscape contains a combination of past and present, and of material and immaterial values, and as such is part of the heritage. These values are used to build the spatial identity (local, regional, national). The research will also include the perspective aspects of spatial identity, particularly at the regional level. Historical maps as a source will be used to research the border identity, as ambivalent regional identity in the past, specifically in the period from the early new age to today. Surveys and interviews and an analysis of media content will be used in research on the perspective scope and formative elements of today's traditional Croatian region.
- **Tourism and spatial development of Croatia.** Tourism is one of the most important branches of the Croatian economy, with a tendency of even greater qualitative and quantitative growth, and a more pronounced spatial expansion from the leading coastal tourism destinations towards inland areas. An interdisciplinary approach to tourism research, the thematic interaction of space and tourism is very important, as all tourist attractions are strongly territorialised. Therefore, a key goal of the research within this topic is to examine the interrelationship of space and tourism. This implies: a) the identification and evaluation of natural and anthropogenic spatial resources in the attraction basis of Croatian tourism, b) analysis of the spatial properties of tourism trends, and c) determining the spatial implications of tourism in the transformation of tourism areas in Croatia – tourism localities, tourism towns, tourism regions, i.e. Croatian tourism destinations at all hierarchical levels. The importance of such defined research is seen in the possibilities for the optimal design of tourism products offered in Croatian destinations, and focusing the spatial development of Croatia in the context of tourism, in line with the postulates of the desired sustainable development. Rational planning and management of space and its resources is exceptionally important in the turbulent transition period of Croatian tourism, due to pronounced globalisation in the European Union, when interest in spatial use is increasing in the many of the highly tourism developed parts of Croatia, due to the increasing numbers of potentially interested visitors.
- **Didactic processes in teaching geography and organising education.** In this area, four main topics will be address. 1. Didactics in geographic education. The aim is to study the effectiveness of learning and teaching strategies, the applicability of teaching resources in achieving the learning outcomes, and the form and criteria of evaluating accomplishments.

The research results should be included into the geography curriculum at all educational levels. 2. Subject curriculum in geography for primary and secondary education. The aim is to align geographic education in primary and secondary schools with the Croatian Qualifications Framework and the development of the scientific field of geography. Determine groups of learning outcomes on the basis of analysis of the current situation in the system, the labour market demands, and in accordance with the goals of the Strategy of Education, Science and Technology. Contribute to the application of the Croatian Qualifications Framework in the teaching and education system. 3. Initial education, training and professional development of teachers and geography professors in schools. The aim is to contribute to developing a professional standard, qualifications standard and improvement of the competencies for organised learning and teaching that is pupil-centred. 4. Educational resource and human resources in teaching geography. The aim is to continue researching the effects of demographic development on changes to the exploitation index and load coefficient of human resources in teaching geography at the level of enrolment districts and by region. Apply GIS-based analyses to design models that are applicable in redefining school networks, the initial education of teachers and geography teachers, human resources management, and in regional development.

University of Zagreb, Faculty of Science

Appendix C – PMF Catalogue of equipment

The bilingual (Croatian/English) catalogue of scientific equipment and computer programs at PMF is available at the following link:

http://www.pmf.unizg.hr/_download/repository/PMF__Katalog_znanstvene_opreme_i_racunalnih_programa.pdf,

which can be accessed by clicking on Documents in the left menu on the home page of the PMF website, then Other Documents.

Literature

1. PMF Self-analysis, 2014
2. Ordinance on the organisation of work posts at PMF.