



## Department of Physics

### University of Trieste

# Development project of the strategic research activity in Physics of Complex Systems

## Executive Summary

*This document outlines the development plan of the strategic project that the Department of Physics (DP) at University of Trieste has recently approved regarding the Physics of Complex Systems, following the appointment of prof. Alberto Imparato. Professor Imparato, an expert in statistical physics from Aarhus University (Denmark), will oversee the development of this strategic plan.*

*The Department aims at bolstering this research activity by supporting Prof. Imparato's efforts-through hiring two more researchers with expertise in the Physics of Complex Systems with applications in climatology and econo-physics. The Department goal is to establish a center for education and research dedicated in particular to studying extreme climatic events and turbulence in financial markets. Such a center will be unique within the Italian research landscape, and with few comparable counterparts at the international level.*

*To this purpose, the department intends to continue appointing new faculty members of international level by exploiting the "direct call" procedure. This involves soliciting expressions of interest and extensively exploring potential synergies with various institutions within the Trieste Research Area interested in the whole project. One of the main goals of the development plan is to train students that will then be employed in workplaces which require expertise in analytical and statistical analysis of complex models and numerical simulations. By means of the present plan the Department aims thus to address the urgent need to study those phenomena that are characterized by a high degree of unpredictability and complexity using innovative techniques. This is particularly relevant in fields with significant societal impact, such as those related to climatic-environmental and economic-financial crises.*



## Context Analysis

Complex phenomena are characterized by a large number of constituents that interact and correlate typically across various temporal scales, showing behaviors which are highly unpredictable. A typical example is represented by the mutual influences between climatic-environmental or economic-financial crises and social behaviors. The increasing connection between human and non-human agents at different levels requires a thorough description of such complex systems in order to govern them and make their dynamics sustainable.

Despite their great diversity, these complex dynamics present common features that can be studied, understood, and controlled by modern methodologies of statistical and computational physics. The conceptual unity of this framework was recognized by the awarding of the Nobel Prize in Physics in 2021 to Giorgio Parisi.

In particular, researchers working in the field of econo-physics exploit artificial intelligence and information theory to analyze the vast amount of data made available by financial systems. They also employ network theory, non-equilibrium statistical mechanics, and advanced numerical methods to describe and explain fluctuations in financial markets. Additionally, they use the dynamics of populations and social systems to study the influence of collective human behaviors upon the financial realm.

In the field of Climate Physics, researchers combine knowledge of dynamical systems and fluid dynamics, the physics of the atmosphere, and geophysical fluid dynamics to describe climate systems and their changes. Also in this case, non-equilibrium statistical mechanics and rare event methods are used to study and describe emerging phenomena, such as extreme atmospheric events. In climatology, artificial intelligence too plays an increasingly important role in the analysis of the vast amount of available data.

The DP has recently committed to this field, by explicitly including the Physics of Complex Systems among the four specific strategic research avenues outlined in its Department of Excellence project. This project, presented to the Italian Ministry of University and Research (MUR) in 2022, has been funded starting from 2023 and for four years ahead. Within the project, the Physics of Complex Systems is strongly interconnected with parallel initiatives in the fields of High-Performance Computing (HPC) and Big Data, for which relevant expertises already exist within the department.

The University of Trieste has also provided financial resources for the realization of this project, and the DP has recently recruited Professor Alberto Imparato through a “direct call” procedure. Professor Imparato is an internationally renowned



lecturer/researcher with expertise in statistical physics and thermodynamics of stochastic and many-body systems. He has been working for 15 years as a lektor (Associate Professor) at Aarhus University, Denmark. Professor Imparato will take up his position at the DP as soon as the procedures required by current regulations for the “direct call” are completed, and he will personally oversee the implementation and development of this strategic line.

### **Strategic Objectives**

With the strategic project in Complex Systems, the DP intends to create an educational and research environment within which to develop and transmit techniques devoted to understanding and managing such complex phenomena. The DP aims to address this highly relevant challenge by training students who will subsequently work in private companies or higher education institutions by virtue of their expertise in cutting-edge methodologies and technologies, such as the evaluation of confidence levels in forecasts, models, and numerical simulations.

Specifically, the DP aims to establish a group of researchers sharing a common approach to the study of the two aforementioned subjects (Econo-physics and Climate Physics). Specifically, the common approach is the use of the theory of large deviations and the statistics of rare events. This unifying approach can be applied to the study of both climatic and financial systems, as they are characterized by significant and sudden fluctuations, often on very short time scales. Therefore, a theoretical approach which goes beyond the normal statistical and numerical analysis is required. The creation of such a research group on rare phenomena would make the DP at University of Trieste a center of expertise with a unique national profile and few comparable examples abroad, in particular concerning the recent extreme climatic events and the recurring turbulence in financial markets. The research group will also benefit from the interaction with local stakeholders in both areas, whose input will contribute to inspiring the research topics.

The DP is one of the key actors in the network of cutting-edge scientific and technological institutions known as the "Sistema Trieste", a network which was built with the valuable contribution of many members of the DP too. As such the Department is a fundamental driving force for the development of this strategic line. It is also worth to mention in this context the many synergies with the complementary activities carried out at various research institutions in the region: this makes the "Sistema Trieste" a remarkable example of research network within the Italian and European landscape.





## Positioning Analysis

The key element for modeling a complex physical system is the intrinsic interdisciplinarity needed for the description of its physical, mathematical, and computational components, an approach already adopted at the DP in several research fields. This fact represents an opportunity not to be missed and will have significant practical implications for the increasingly necessary assessment of the sustainability of choices and decisions at political, social, and economic level.

The effective development of a successful response to these challenges goes through the training of specialists with appropriate scientific skills. Some of these specialists are already trained by the DP, that exploits ongoing and potential collaborations with territorial, national, and international partners in teaching, consulting, and research. These partners (or stakeholders) range from public institutions and authorities to research institutes, from small private companies to multinational corporations. The topics of such collaborations span from risk assessment in financial and insurance fields to the prediction of possible scenarios in the climatic and meteorological context. In order to achieve the project goals, the DP will also exploit the existing international collaborations with renowned researchers in both fields.

Currently the DP offers a single master's degree program in Physics, with various curricula. Notably, the curriculum "Fisica dell'Ambiente e Interdisciplinare" already includes courses such as Quantitative Methods for Finance, Climate Dynamics, Physics of the Atmosphere, and Geophysical Fluid Dynamics. These courses are supported by various official agreements, including those with ICTP, OGS, Assicurazioni Generali, and List Spa. Despite the fact that the current educational offer is not as broad as the one envisaged by the present development plan, several master's theses have already been completed in the fields of climate physics and econo-physics. Several doctoral programs are also active, including one on climate change in the Alta Carnia region, funded externally by the Agency for Territorial Cohesion. This project was funded through the collaboration between the DP, the Mountain Community, and the municipalities of that area. It is worth noticing that many master's graduates in Physics from the DP have embarked on successful professional careers in both fields, demonstrating that the DP has nevertheless been able to offer a solid basic education that is well-appreciated by the stakeholders.

As previously mentioned, the appointment of Professor Imparato will contribute to the shaping of the theoretical, educational, and research environment that is expected to boost the transfer of knowledge from academia to stakeholders. Starting from the next academic year, the teaching will be enriched by at least two new courses in the field of statistical mechanics, one on stochastic dynamics and one on the theory of large



deviations and rare events. This will enhance the comprehensive and robust training in this field, emphasized by a change in the curriculum's name that will explicitly include a reference to the "Physics of Complex Systems." The development of the didactical offer will go hand in hand with a rationalization and reorganization of the existing curriculum to improve the acquisition of technical skills in the modeling and numerical simulations of complex systems.

### **Working Plan**

In order to develop the strategic project in the Physics of Complex Systems and achieve the specific goals concerning the teaching and research activities in the fields of econo-physics and climate physics, it is necessary to complement the recently appointed faculty member with two new members with specific expertise in the two fields.

To this end, through its webpage and other social media, the DP will solicit expressions of interest from teachers/researchers currently employed at universities, research institutes, or scientific organizations abroad, who meet the conditions for recruitment through a "direct call", tentatively at the level of Associate Professor. A description of the skills that will be required for the two positions is detailed below:

1) Complex Systems specialist with specific expertise in econo-physics

The ideal candidate is a physicist with expertise in one or more of the following topics:

Econo-physics, out-of-equilibrium statistical mechanics, network dynamics, dynamics and evolution of social networks, adaptative behaviour in social and financial systems, quantitative economics and finance, statistical inference and learning.

2) Complex Systems specialist with specific expertise in Climate Physics

The ideal candidate is a physicist with expertise in one or more of the following topics:

Dynamical systems, climate dynamics, global and regional climate variability and change, extreme events, fluid dynamics, out-of-equilibrium statistical mechanics, machine learning.

The recruitment of the two new faculty members will be accompanied by a strengthening of the didactical offer in the corresponding fields. As mentioned above, starting by the academic year 2024/25, for the students enrolling in the physics of complex systems such an offer will be enhanced with the insertion of at least two new courses in the field of statistical mechanics. The entire offer will be reorganized too, in order to enhance the overall educational experience.



The addition of the two new faculty positions will lead to a further expansion of the educational offer for the fields specified above. This expansion will also be emphasized in the new title of the curriculum, which will be renamed "Physics of Complex Systems: Climate and Finance." In case the new didactical offer outlined in this document proves successful, by gaining interest and attention from prospective students, the long-term goal is to transform the curriculum into a distinct master's program in the Physics of Complex Systems, separate from the current master's program in Physics.

### **Scientific Committee**

The Department of Physics intends to avail itself of an international panel of experts in the field of Complex Systems in order to receive suggestions and guidance on implementing the proposed strategic plan. The following experts have already confirmed their availability to take on this role. This Scientific Committee will play a crucial role in shaping and defining the department's initiatives in the area of Complex Systems at large with particular focus upon econo- physics and climatology, providing advice and ensuring alignment with international standards and best practices in the field.

- Freddy Bouchet  
Laboratoire de Météorologie Dynamique, Ecole Normale Supérieure and CNRS  
<http://perso.ens-lyon.fr/freddy.bouchet/>
- Silvio Franz  
Laboratoire de Physique Théorique et Modèles Statistiques, Université Paris-Saclay and CNRS  
<https://www.lptms.universite-paris-saclay.fr/membres/franz/>
- Filippo Giorgi  
the Abdus Salam International Centre for Theoretical Physics (ICTP)  
<https://www.ictp.it/member/filippo-giorgi#biography>
- Roberto Livi  
University of Firenze, Istituto dei Sistemi Complessi ISC-CNR  
<https://www.unifi.it/p-doc2-2013-200010-L-3f2a3b2d392e2b-0.html>
- Rosario Nunzio Mantegna  
University of Palermo  
<https://www.unipa.it/persone/docenti/m/rosario.mantegna/?pagina=curriculum>
- Matteo Marsili  
the Abdus Salam International Centre for Theoretical Physics (ICTP)  
<https://www.ictp.it/member/matteo-marsili#biography>



- Iacopo Mastromatteo  
Capital Fund Management, CFM-Paris  
<https://www.econophysix.com/team/iacopo-mastromatteo>
- Antonello Provenzale  
Istituto di geoscienze e georisorse – CNR  
<https://www.igg.cnr.it/organizzazione/personale-igg/antonello-provenzale>
- Angelo Vulpiani  
University of Rome La Sapienza  
<https://corsidilaurea.uniroma1.it/user/11681>
- Riccardo Zecchina  
Bocconi University – Milano  
<https://cs.unibocconi.eu/people/riccardo-zecchina>