GRUPPO DI RICERCA Physics of Complex Systems

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1. DATI IDENTIFICATIVI DEL GRUPPO DI RICERCA

Categorie ERC	PE3 – PE10 – LS5
Settore Scientifico Disciplinare	PHYS-02/A PHYS-04/A PHYS-05/B
Parole Chiave (Keywords)	- Non-equilibrium statistical mechanics - Long range interactions - Active matter - Seismic and natural hazard - Neuronal Avalanches - Granular media

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2. COMPOSIZIONE E COORDINAMENTO

Responsabile Scientifico / Coordinatore:

- **Nome e Cognome:** Eugenio Lippiello
- **Qualifica:** Professore Ordinario
- **Email:** eugenio.lippiello@unicampania.it
- ORCID ID 0000-0003-1444-1889

Componenti del Gruppo:

1. Lucilla de Arcangelis (PO), ORCID ID 0000-0001-9247-6783
2. Cataldo Godano (PA), ORCID ID 0000-0003-1420-0137
3. Alessandro Sarracino (PA), ORCID ID 0000-0003-3686-0822
4. Jacopo Alexander Garofalo (PhD student)
5. Fabrizio Rippa (PhD student)
6. Davide Conte (PhD student)

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3. ATTIVITÀ SCIENTIFICA E NETWORK

The research group develops a statistical mechanics framework to investigate interdisciplinary problems spanning condensed matter physics, geophysics, neuroscience, and stochastic thermodynamics. Despite the diversity of microscopic interactions—ranging from magnetic spins to tectonic faults and neuronal networks—these systems display analogous collective

behaviors. Such emergent phenomena, often characterized by scaling laws, power-law distributions, and universality, are hallmarks of complex systems. The group applies theoretical and computational tools of statistical physics—scaling theory, renormalization group ideas, fractal analysis, and stochastic modeling—to uncover the mechanisms underlying collective dynamics far from equilibrium.

Phase Ordering Dynamics
Research focuses on the non-equilibrium evolution of systems quenched from disordered to ordered phases. During phase ordering, domains of competing broken-symmetry states grow in time, while full thermodynamic equilibrium is never reached. The group investigates the impact of long-range interactions and quenched disorder on growth laws, aging properties, two-time correlation functions, and generalized fluctuation–dissipation relations, contributing to the fundamental understanding of non-equilibrium statistical mechanics.

Statistical Seismology
Earthquake occurrence is studied as an emergent collective phenomenon resulting from stress transfer and relaxation in the Earth's crust. The group combines empirical analysis of seismic catalogs with stochastic point-process modeling to characterize spatiotemporal and magnitude distributions of earthquakes. Emphasis is placed on scaling properties, triggering mechanisms, and forecasting performance of statistical and physics-based models. This research contributes to improved seismic hazard assessment and risk management.

Vibrofluidized Granular Media
Granular materials exhibit transitions between solid-like and fluid-like states depending on density, stress, and external forcing. The group studies how mechanical vibrations drive the unjamming transition and collective rearrangements. These processes are relevant to avalanche dynamics, earthquake triggering, and industrial applications in materials processing, food, and pharmaceutical sectors. The research connects granular physics with broader themes in glassy systems and soft matter.

Statistical Models of Neuronal Activity
Spontaneous brain activity displays scale-free neuronal avalanches and complex temporal organization, often interpreted within a criticality framework. The group develops statistical models inspired by non-equilibrium physics to study the interplay between excitation, inhibition, and oscillatory dynamics. This approach aims to identify key interaction mechanisms underlying large-scale brain activity and its response to stimuli.

Stochastic Thermodynamics
Extending thermodynamic concepts to small fluctuating systems, the group investigates molecular motors, active particles, and energy-harvesting devices. Research addresses entropy production, work fluctuations, and efficiency in systems dominated by noise, bridging statistical physics with biological and nano-scale processes.

Overall, the group pursues a unified statistical physics perspective to understand emergent collective behavior across natural and engineered complex systems.

Collaborazioni Nazionali ed Internazionali:

- **Nazionali:** Università di Salerno, Università di Napoli Federico II, Università di Bari, CNR-ISC, INGV, Università Sapienza Roma, Università di Milano, Università di Genova, Università di Padiva
- **Internazionali:** Jaharalal Nehru University, New Delhi, India - Nanyang Technological University, Singapore - Aristotle University, Thessaloniki, Greece - Centro de Física Teórica e Computacional, Universidade de Lisboa, Portugal - LPTMS, CNRS, Université Paris-Saclay, Orsay, France - Centro At'omico Bariloche, Bariloche, Argentina - Institute of Statistical Mathematics, Tokyo, Japan, Sorbonne Université Paris, NIH Bethesda (USA), Universidade Federal do Ceará, Fortaleza (Brasile), PMMH, ESPCI, Paris.

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4. PROGETTI, BREVETTI E PUBBLICAZIONI

Principali Progetti di Ricerca

National Projects

- MUR PRIN 2022 PNRR project P202247YKL, National PI Prof. Eugenio Lippiello
- MUR PRIN 2022 PNRR project P20222B5P9, National PI Prof. Cataldo Godano
- MUR PRIN 2022 (reranking of the final lists) project KWTEB7, Unit's responsible Prof. Alessandro Sarracino, National PI Dr. Andrea Puglisi CNR-ISC
- MIUR PRIN 2017 project 201798CZLJ Unit's responsible Prof. Eugenio Lippiello, National PI, Prof. Angelo Vulpiani, Università Roma "La Sapienza"
- MIUR PRIN 2017 project 201798CZLJ Unit's responsible Prof. Alessandro Sarracino, National PI, Prof. Angelo Vulpiani, Università Roma "La Sapienza"
- MIUR PRIN 2017 project2017WZFTZP, Unit's responsible Prof.ssa Lucilla de Arcangelis, National PI Prof. Rosario Mantegna, Università di Palermo
- PNRR "MNESYS - A MULTISCALE INTEGRATED APPROACH TO THE STUDY OF THE NERVOUS SYSTEM IN HEALT AND DISEASE", Unit Member Prof.ssa Lucilla de Arcangelis, National PI Prof. Sergio Martinoia, Università di Genova

Inter-departmental Projects

- Valere "E-Passion", Unit's Responsible Prof. Eugenio Lippiello, PI Prof. Massimo Vitelli, Dipartimento di Ingegneria

MOST RELEVANT RECENT PUBBLICATIONS

E. Lippiello, G. Petrillo, C. Godano, L. Dal Zilio. "Toward recognizing the waveform of foreshocks". Geophysical Research Letters 52 (15), e2025GL115466 (2025).

J.A. Garofalo, E. Lippiello, F. Rippa. "Competition between long-range and short-range interactions in the voter model for opinion dynamics". The European Physical Journal B 98 (3), 1-11 (2025).

E. Lippiello, L. de Arcangelis, C. Godano. "Positive Answer on the Existence of Correlations between Positive Earthquake Magnitude Differences". Physical Review Letters 133 (24), 244101 (2024).

E. Lippiello, G. Petrillo. "b-More-Incomplete and b-More-Positive: Insights on a Robust Estimator of Magnitude Distribution". Journal of Geophysical Research: Solid Earth 129 (2), e2023JB027849 (2024).

A. Tramelli, V. Convertito, C. Godano. "b value enlightens different rheological behaviour in Campi Flegrei caldera". Communications Earth & Environment 5 (1), 275 (2024).

V. Convertito, A. Tramelli, C. Godano. "Evaluation of the b Maps on the Faults of the Major (M > 7) South California Earthquakes". Earth and Space Science 11 (6), e2023EA002933 (2024).

G. Petrillo, A. Rosso, E. Lippiello. "Testing of the seismic gap hypothesis in a model with realistic earthquake statistics". Journal of Geophysical Research: Solid Earth 127 (6), e2021JB023542 (2023).

F. Corberi, M. Kumar, E. Lippiello, P. Politi. "Domain statistics in the relaxation of the one-dimensional Ising model with strong long-range interactions". Chaos, Solitons & Fractals 173, 113681 (2023).

F. Corberi, A. Iannone, M. Kumar, E. Lippiello, P. Politi. "Coexistence of coarsening and mean field relaxation in the long-range Ising chain". SciPost Physics 10 (5), 109 (2021).

G. Petrillo, E. Lippiello, F.P. Landes, A. Rosso. "The influence of the brittle-ductile transition zone on aftershock and foreshock occurrence". Nature Communications 11 (1), 3010 (2020).

E. Lippiello, G. Petrillo, C. Godano, A. Tramelli, E. Papadimitriou, et al. "Forecasting of the first hour aftershocks by means of the perceived magnitude". Nature Communications 10 (1), 2953 (2019).

A. Plati, A. Puglisi, A. Sarracino. “Thermodynamic uncertainty relations in the presence of non-linear friction and memory”. Journal of Physics A: Mathematical and Theoretical 57 (15), 155001 (2024)

P. Rizkallah, A. Sarracino, O. Bénichou, P. Illien. “Absolute negative mobility of an active tracer in a crowded environment”. Physical Review Letters 130 (21), 218201 (2023)

I. Apicella, S. Scarpetta, L. De Arcangelis, A. Sarracino, A. De Candia. “Power spectrum and critical exponents in the 2D stochastic Wilson–Cowan model”. Scientific reports 12 (1), 21870 (2022)

P. Rizkallah, A. Sarracino, O. Bénichou, P. Illien. “Microscopic theory for the diffusion of an active particle in a crowded environment”. Physical Review Letters 128 (3), 038001 (2022)

A. de Candia, A. Sarracino, I. Apicella, L. de Arcangelis. “Critical behaviour of the stochastic Wilson-Cowan model”. PLoS computational biology 17 (8), e1008884 (2021)

F. Lombardi, O. Shriki, H.J. Herrmann, L. de Arcangelis, “Long-range Temporal Correlations in the Broadband Resting state Activity of the Human Brain revealed by Neuronal Avalanches”, Neurocomputing 461, 657–666 (2021). doi.org/10.1016/j.neucom.2020.05.126

M. K. Nandi, A. Sarracino, H. J. Herrmann, L. de Arcangelis “Scaling of avalanche shape and activity power spectrum in neuronal networks”, Physical Review E 106, 024304 (2022).

F. Lombardi, H. J. Herrmann, L. Parrino, D. Plenz, S. Scarpetta, A. E. Vaudano, L. de Arcangelis, O. Shriki, “Beyond pulsed inhibition: Alpha oscillations modulate attenuation and amplification of neural activity in the awake resting-state”, Cell Reports 42, 113162 (2023).

Cesar I. N. Sampaio Filho; Lucilla de Arcangelis; Hans J. Herrmann; Dietmar Plenz; Patrick Kells; Tiago Lins Ribeiro; José S. Andrade Jr, “Ising-like model replicating time-averaged spiking behaviour of in vitro neuronal networks”, Scientific Reports 14, 7002 (2024).

Roberto Zaccariello, Hans J. Herrmann, Alessandro Sarracino, Stefano Zapperi, Lucilla de Arcangelis, “Inhibitory neurons and the asymmetric shape of neuronal avalanches”, Phys. Rev. E 111, 024133 (2025).