Pablo Villegas

Critical Collective Phenomena

Renormalization, multiscale organization, and critical dynamics in heterogeneous systems

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Research Profile

Statistical physicist developing a unified multiscale framework for heterogeneous systems, based on renormalization, spectral methods, and geometric approaches to complex networks.

My research focuses on establishing predictive principles for collective behavior, with particular emphasis on the Laplacian Renormalization Group and its applications to brain dynamics, ecology, and data-driven complex systems.

Scientific Metrics

Publications	25+ peer-reviewed articles
Citations	1,000+ citations
h-index	16

Appointments

2023–Present	**Research Scientist**, Enrico Fermi Research Center, Rome, Italy
2022–2023	**Postdoctoral Research Associate**, Enrico Fermi Research Center, Rome, Italy
2020–2022	**Postdoctoral Research Associate**, IMT School for Advanced Studies, Lucca, Italy
2019–2020	**Postdoctoral Research Associate**, ISC-CNR, Rome, Italy
2018–2019	**Postdoctoral Orientation Fellowship**, University of Granada, Spain
2015–2018	**PhD Fellowship**, Statistical Physics Group, University of Granada, Spain

Selected Contributions

2023	**Nature Physics**: Established the *Laplacian Renormalization Group* framework for heterogeneous networks. Cover article with accompanying *News & Views*.
2025	**Physical Review Letters**: Introduced a renormalization perspective on networks with multiple structural scales.
2018	**PNAS**: Developed a Landau–Ginzburg framework for cortical dynamics, showing that scale-free avalanches emerge at the edge of synchronization.
2024	**Physical Review E**: Revealed scale-free organization in tropical rainforests using statistical-physics methods. Editor's Suggestion; featured in *Physics*.
2025	**Physical Review E**: Demonstrated the emergence of strange attractors in complex networks (single-author).

Selected Publications

P. Villegas, T. Gili, G. Caldarelli, and A. Gabrielli
Laplacian Renormalization Group for heterogeneous networks
***Nature Physics 19**, 445–450 (2023). Cover article; accompanied by a News & Views.*

A. Poggialini, P. Villegas, M. A. Muñoz, and A. Gabrielli
Networks with many structural scales: a Renormalization Group perspective
***Physical Review Letters 134**, 057401 (2025).*

S. di Santo*, P. Villegas*, R. Burioni, and M. A. Muñoz
Landau–Ginzburg theory of cortex dynamics: scale-free avalanches emerge at the edge of synchronization
***PNAS 115**(7), E1356–E1365 (2018). *Joint first authors.*

P. Villegas, T. Gili, G. Caldarelli, and A. Gabrielli
Evidence of scale-free clusters of vegetation in tropical rainforests
***Physical Review E 109**, L042402 (2024). Editor's Suggestion; featured in Physics.*

P. Villegas
Strange attractors in complex networks
***Physical Review E 111**, L042301 (2025). Single-author paper.*

Ongoing Manuscripts

Under revision	I Fernandez-Iriondo, A Jimenez-Marin, J Cortes, P Villegas, *Structural coarse-graining enables noise-robust functional connectivity and reveals hidden inter-subject variability.*
Under revision	G. Iannelli, P. Villegas, T. Gili, and A. Gabrielli, *Topological Symmetry Breaking in Antagonistic Dynamics.*
Under revision	S. Meloni, A. Gabrielli, and P. Villegas, *Higher-order contagion processes in 3.99 dimensions.*
Under revision	G. Iannelli and P. Villegas, *Chladni states in Ising Spin Lattices.*

Selected Talks

2025	Complex Networks and Their Applications – StatPhys29 Satellite Workshop, Venice, Italy. Talk.
2025	StatPhys29 – The 29th International Conference on Statistical Physics, Florence, Italy. Talk.
2024	Complex networks: from socio-economic systems to biology and the brain, Lipari, Italy. Talk.
2024	NetSciX 2024 – International School and Conference on Network Science, Venice, Italy. Talk.
2023	Granada Seminar: Machine Learning and Physics, Granada, Spain. Talk.
2022	Conference on Complex Systems, Mallorca, Spain. Talk.

Supervision

PhD supervision	Giulio Iannelli (2022–2025), Gabriele Poidomani (2022–Present), Lorenzo Grimaldi (2023–Present), Lorenzo Lucarini (2024–Present), Ottavia Falconi (2024–Present).
Master's theses	Lorenzo Lucarini and Ottavia Falconi (2023–2024).

Grants, Awards, and Projects

2020	**Seal of Excellence**, MSCA-IF High Quality Project: *Statistical Mechanics of Tropical Rainforests* (87.0/100), ISC-CNR, Rome.
2017	**Mobility Grant**, University of Strathclyde, funded by MINECO.
2015–2018	**Doctoral Grant** (FPI Programme), University of Granada, funded by MINECO.
Projects	Participation in funded projects including *Structure and function of cortex neural networks* (P20_00173), *Advances in statistical physics of living systems* (PID2020-113681GB-I00), and *Collective response in ecosystems* (ERANET-LAC 2016).

Teaching and Service

Teaching	Teaching support at the University of Granada in computational physics, statistical physics, physics of complex systems, and complementary training in physics and chemistry (2016–2019).
Reviewing	Referee for *Physical Review Letters*, *Physical Review X*, *Science Advances*, *Nature Communications*, *Physical Review E*, *PLoS One*, *Physica D: Nonlinear Phenomena*, *Neurocomputing*, *Scientific Reports*, *Journal of Physics: Complexity*, and *Cambridge Elements*.

Education

2014–2018	**PhD in Physics**, Univ. of Granada, Spain. *Magna cum laude*. Dissertation: *Phases and phase transitions in living matter*. Advisor: Miguel Á. Muñoz.
2014–2015	**MSc in Teaching Compulsory and Pre-University Secondary Education, Vocational Training and Language Teaching**, Univ. of Granada. Grade: 9.1/10.
2013–2014	**MSc FisyMat: Biomathematics**, Univ. of Granada. Grade: 9.7/10. Thesis: *Synchronization: Study and applications of the Kuramoto model.*
2008–2013	**BSc+MSc in Physics (Licenciado en Física)**, Univ. of Granada. Grade: 7.5/10.

Visits, Languages, and Technical Skills

Visits	University of Erlangen–Nürnberg (2019), University of La Plata (2019), University of Parma (2018), University of Strathclyde (2017).
Languages	Spanish (native), Italian (near-native), English (fluent working proficiency).
Technical skills	Python, C, Fortran, R, LaTeX, OpenMP, GNU/Linux, Matlab, Mathematica, Maxima.