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Decreto Rettore Università di Roma "La Sapienza" n. 3472/2021 del 16/12/2021

IRENE ROSANA GIARDINA

Curriculum Vitae

Rome, 26/12/2021

Part I – GENERAL INFORMATION

Full Name	Irene Rosana Giardina
Spoken Languages	Italian, English, French

Part II – EDUCATION

Type	Year	Institution	Notes
PhD in Physics	1998	University of Rome La Sapienza	Advisor: G. Parisi
MSc in Physics	1994	University of Pavia	Laurea degree in Physics 110/110 *cum laude*
Pre-graduate studies	1989-1994	Collegio Ghislieri	Fellow

Part III – APPOINTEMENTS

IIIA – Academic Appointments

Start	End	Institution	Position
2013	present	University of Rome La Sapienza (Dept. of Physics)	Associate Professor in Theoretical Physics (FIS 02/A2)
2013	2014	Initiative for the Theoretical Sciences, The Graduate Center, CUNY, New York	Visiting Professor (CUNY Fellowship, 1 year)
2009	2013	Institute for Complex Systems - CNR, UOS Sapienza, Rome	Researcher
2003	2009	Centre for Statistical Mechanics and Complexity, INFM-CNR, Rome	Researcher (TD and Tenure Track researcher)
2002	2003	University of Rome La Sapienza (Dept. of Physics)	Assistant Professor with Fellowship of the Italian Research Ministry MIUR,

			program “Rientro dei Cervelli”
1999	2001	Laboratoire de Physique Théorique, Centre Energie Atomique CEA-SACLAY, France	Post-doc
1998	1999	Theoretical Condensed Matter Physics Group, at the Department of Theoretical Physics, Oxford University	Post-doc

IIIB – Invited Visiting Periods

2011	The Graduate Center, City University of New York (5 weeks)
2009	Department of Physics, Princeton University & Rockfeller University, New York (3 weeks)
1999	Santa Fe Institute (3 weeks)
1998	Nordita Institute (3 weeks)

IIIC –Commissions of trust

Period	Role
2021	Member of the International Advisory Committee of IUPAP StatPhys28
2021 - present	Member of Strategic Committee, Center for Mathematics and Theoretical Physics, Rome
2019-2022	Appointed Member of the External Academic Advisory Council, Princeton Physics Department
2018	Member of the International Advisory Committee of IUPAP StatPhys27

IIID – Affiliations

Period	Role
2016 -present	Research Associate, National Institute of Nuclear Physics (INFN) – Rome1 node
2013 - present	Research Associate, Institute for Complex Systems, National Research Council (CNR)

Part IV – TEACHING AND TUTORING

IVA – University teaching

Year	Institution	Lecture/Course
2017-present	University of Rome La Sapienza (Dept. of Physics)	“Statistical Physics”, laurea triennale in fisica (6 CFU)
2016-present	University of Rome La Sapienza (Dept. of Physics)	“Theoretical Biophysics”, laurea magistrale in fisica (Master degree, 6 CFU)
2016-2017	University of Rome La Sapienza	“General Physics”, module II (6 CFU)

	(Dept. of Earth Sciences)	
2014-2016	University of Rome La Sapienza (Dept. of Earth Sciences)	"General Physics", modules I and II
2010-2011	University of Rome La Sapienza (Dept. of Physics)	"Physical and Mathematical Models for Economy", laurea magistrale in fisica (Master degree, 60 hours)
2004-2008	University of Rome La Sapienza (Dept. of Physics)	Yearly PhD course in "Disordered Systems and Anomalous Diffusion"

IVB – Invited courses

Year	Institution	Lecture/Course
2017	Summer school in Theoretical Biophysics, Cargese	Collective behavior in biological groups
2014	Beg Rohu Summer school in 'Non equilibrium statistical mechanics and active matter',	Collective behavior in animal groups
2006	Les Houches Summer School "Complex Systems"	Metastable States in Glassy systems
2006	Les Houches Meeting	Econophysics
2001	Ecole Nationale Superieure de Telecommunication, Paris	Phynance Statistique
1999	Mini-school in stochastic finance Nordita	Minority Games

IVC– Advising

Type	Description
Bsc Advisor	A. De Concilio Moschen (ongoing) S. Raponi (2021) M. Bussoni (2019); V. Salvati (2016); F. Iannelli (2011) - MSc in Physics at Humboldt Un. Berlin; R. Tavarone (2009) - PhD in Physics at Technische Un. Berlin, postdoc at IIT, Senior Machine Learning Scientist at Snips, London; R. Marino (2009) – PhD at KTH Stockholm, now Postdoc in Rome La Sapienza.
MSc Advisor	E. Loffredo (2021)– now PhD student at Ecole Normale Superieure Paris G. Spera (2020) – now PhD student at University of Paris D. Venturelli (2019)– now PhD student at Sissa, Trieste; F. Ferretti (2018) - PhD at Sapienza, Phys. Dept.; D. Piovani (2012) - PhD at Imperial College London, Head of research -Data Science at Nam.r, Paris; E. Silvestri (2010)- PhD Roma 3; A. Cimarelli (2010) - SISSA master in scientific communication – journalist; B. Capone (2006) – PhD at Cambridge University - now RTDB at Dept. of Phys. Roma 3; G. Mosetti (2003) - PhD in Physics at Fribourg Un., postdoc at ISI Turin
PhD Advisor	M. Veca (ongoing) F. Ferretti (discussion on Feb 2022) – postdoc at MIT from 2022; E. Silvestri (2014) - currently software developer at PTV-Sistema; A. Procaccini (2008, co-tutoring) – former postdoc Polito & HuGen Torino,

	now at PTV-Sistema.
Member in PhD Committee	T. Arnoulx de Pirey (Université de Paris - Physics, 2021); D. Martin (Université de Paris - Physics, 2021); M. Durve (ICTP – Physics, 2020); A. Altieri (Sapienza University & Paris-Saclay – Physics, 2018); S. Toulet, (Université de Toulouse III – Biology, 2015); S. Motsch (Université de Toulouse III - Applied Mathematics, 2009); K. Anand (King's College London - Applied Mathematics, 2009); F. Raynaud (Université Paris Diderot-Paris 7 - Physics, 2009).
Postdoctoral mentoring	A. Jelic - currently at ICTP, Trieste; E. Shen - Technical Lead Engineer, Zebra Technologies, Canada; S. Dey – now Assistant Professor at SRM AP University, India; S. Melillo – now CNR researcher at ISC, Rome; M. Viale - now CNR researcher at ISC, Rome; L. Parisi – now CNR researcher at ISC, Rome; G. Gosti, now postdoc at Dept. of Physics Rome. S.M. Duarte - researcher at Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro; F.Ginelli – now Associate Professor at University of Insubria; A. Attanasi - Product Manager at PTV-Sistema; L. Del Castello - private entrepreneur; C. Creato - programmer at PTV Sistema.
Student mentoring	M. Colucci (excellence cursus, Dept. Physics, Sapienza, 2019); G. Piccioli (excellence cursus, Dept. Physics, Sapienza, 2018); F. Ferretti (SSAS research work, Sapienza, 2017); F. Ghoulmie' (DEA stage, CEA-Saclay, 2001).

Part V – AWARDS AND HONORS

Year	Title
2021	Delbruck Prize in Biological Physics, American Physical Society https://www.aps.org/programs/honors/prizes/delbruck.cfm
2018	National Habilitation for Full Professor (ASN 2016) in sectors SC 02/A2, SSD FIS/02 (Theoretical Physics) and SC 02/B2, SSD FIS/03 (Theoretical Condensed Matter)
2018	Prize for excellent teaching, Faculty of Mathematical and Physical Sciences, Sapienza
2017	Invited participant to the 27th Solvay Conference for Physics `The Physics of Living Matter: Space, Time and Information in Biology'
2017- present	Nominated member of AcademiaNet
2016-2018	ERC grantee Proof of Concept – European Research council (2016)
2013-2014	National Habilitation for Full Professor (ASN 2012) in sectors SC 02/A2, SSD FIS/02 (Theoretical Physics) and SC 02/B2, SSD FIS/03 (Theoretical Condensed Matter)
2012-present	Member of the Young Academy of Europe
2010-2015	ERC grantee Starting Grant (consolidator level) - European Research Council (2010)
2002-2003	MIUR "Rientro dei Cervelli" grant
1989	Alfiere del lavoro della Repubblica Italiana

Part VI – FUNDING INFORMATION

VIA – Grants as PI / coordinator

Year	Role and Title	Program	Grant value
2021-2023	National Coordinator of the PRIN project: *Response, control and learning: building new manipulation strategies in living and engineered active matter*	PRIN 2020, MUR	687.510 euro
2021 -2024	National Coordinator of DYNSYSMATH: *Dynamics and non equilibrium states of complex systems*	National Specific Initiative, National Institute of Nuclear Physics	Funds for travels (~ 50.000-70.000 Euro/year for the whole network) + 1 postdoc
2017-2021	Principal Investigator of project *Collective phenomena and off-equilibrium behavior in biological networks*	Bando Sapienza Progetti di Ricerca Medi	35.750 euro
2016-2018	Principal Investigator - project "PROCEEDS"	ERC-Proof of Concept	150.000 euro
2010-2015	Principal Investigator of project "SWARM" – *Empirical analysis and theoretical modelling of self-organized collective behavior in three-dimensions: from insect swarms and bird flocks to new schemes of distributed coordination*	ERC-Starting Grant (consolidator level*) – Panel PE2	1.124.000 euro
2010-2012	Scientist in Charge of project "PASSAROLA" for Silvio Manuel Duarte	Marie-Curie Fellowship (IEF)	166.239 euro
2010-2013	Principal Investigator - project "ARTSWARM"	IIT-Seed	605.000 euro

* In 2010 the ERC had 1 single call with two sub-classes defined by seniority, starting and consolidator. In the following years the two levels were separated into distinct calls.

VIB- Grants as participant/member

Year	Role and Title	Program	Grant value
2017-ongoing	Member and Deputy Coordinator of ADINMAT	MAECI BANDO 2017- Italy-Israel joint lab	200.000 euro
2014-2018	Network Member/ Member of the Managing Committee - project "Flowing Matter"	COST Action - EU Framework, cooperation grant	189.000 euro (for the whole network)

2013-2016	Participant to PRIN project *Statistical Mechanics of Complex and Disordered systems*	PRIN 2010, MUR	
2005-2007	Co-Investigator of the Rome node for project "STARFLAG"	STREP-EU-FP6	320.000 euro (for Rome node)
2004-2007	Participant to project EVERGROW	ECC integrated Project	
2002-2006	Participant to DYGLAGEMEM	ECC MTR Network	
2002-2006	Participant to STIPCO	ECC MTR Network	
2002-2004	Participant to PRIN project *Disorder and Complexity in Statistical Mechanics*	PRIN 2002, MIUR	

Part VII – KEY INVITED LECTURES

Invited seminars and invited talks at Conferences and Workshops

Year	Event
2022	Nobel Symposium `Predictability in Science in the age of AI', Stellenbosch Institute for Advanced Study (STIAS), South Africa (accepted, October 2022)
2022	Conference 'Engineering Life - Active Matter Across Scales', Dresden (accepted, June 2022)
2022	Winter School 'Active Matter in Biology', Institut Curie Paris (accepted, February 2022)
2021	ICTS -TIFR program "Celebrating the Science of G. Parisi", Bengaluru
2021	Invited seminar, NSCS webinar series, Weizmann Institute
2021	Brazilian Meeting of Statistical Physics, ENFE 2021
2021	Conference on Complex Systems CCS 2021, Lyon
2021	Seminar Series "Interactions, feedback and crises", College de France, Paris
2021	APS March Meeting, Delbruck Invited Session (prize winner seminar)
2020	Invited seminar, Simons Webinars Series - Cracking the glass problem
2020	Invited seminar, Canes Seminar Series, King's College, webinar
2019	Higgs Invited Colloquium – Higgs Center for Theoretical Physics, Edinburgh
2019	Conference "Micromotility", SISSA and Istituto Veneto, Venezia
2019	Invited Colloquium, Physics Department, Stockholm University, Stockholm
2019	Invited Colloquium, Physics Department, Fribourg University
2018	Keynote lecture, Conference ANTS 2018, CNR, Rome
2018	23rd Rencontres Claude Itzykson: Statistical Physics of Disordered and Complex Systems, CEA-Saclay

2018	APS March Meeting, Invited Session for the Delbruck prize to B. Bialek - Los Angeles
2017	27th Solvay Conference for Physics `The Physics of Living Matter: Space, Time and Information in Biology' (invited participant), Brussels
2017	Conference Fismat 2017, Trieste
2017	Workshop "Active Living Matter", Aspen
2017	Conference "Advances in Mathematics and Theoretical Physics", Rome
2017	SISSA Physics Colloquium, invited lecture, Trieste
2017	MECO42 – 42nd Conference of the Middle-European Cooperation in Statistical Physics, Lyon
2016	Workshop `Microswimmers' – From Single Particle Motion to Collective Behaviour, Bonn
2016	STATPHYS2016, Invited talk, Biological Physics Section, Lyon
2016	Workshop `Statistical physics methods in biology and computer science' ENS, Paris
2016	Workshop `Collective Motion', Uppsala University
2016	Workshop 'Dynamics and information processing: from cells to tissues', Les Houches
2015	ICMS Complexity Science Winter School, TU Eindhoven
2015	Workshop 'Active Liquids', Leiden Lorentz Center, Leiden
2015	113th Statistical Mechanics Conference, Rutgers University, Rutgers
2015	Workshop 'Flowing matter across the scales', Rome
2014	APS March Meeting, Invited talk, Focus Session 'Physics of Behavior', Denver
2014	Conference 'Active Processes in living and non-living matter', Kavli Institute for Theoretical Physics at the University of California, Santa Barbara
2012	Workshop `Statistical Physics and Information Processing in Biology', Institut H. Poincare, Paris
2011	Conference "Collective Dynamics and Pattern Formation in Active Matter Systems", Max Planck Institute, Dresden
2011	Extended Workshop "Theoretical physics and the phenomena of life: Optimization and emergent behaviour", Graduate Center, CUNY, New York
2010	Workshop Statistical Physics and Biology of Collective Motion, Max Planck Institute, Dresden
2010	Workshop on Biophysics, CUNY, New York
2009	Princeton Physics Colloquium, invited lecture: "Collective animal behaviour: theoretical speculations and empirical groundings", Princeton University
2009	APS March Meeting 2009, Invited session: 'Active Soft Matter: From Granular Rods to Flocks to Living Cells'
2009	Workshop 'Self-organization and dynamics of active matter', Institut Henri Poincare, Paris
2008	22nd General Conference of the Condensed Matter Division of the European Physical Society, Rome
2008	4th European Conference on Behavioural Biology ECBB, Dijon
2007	Conference "Complexity, Metastability and Nonextensivity", Erice
2007	Workshop "Modelling and control of physical networks", Pisa

2007	Workshop “Bio inspired design of networks", Cambridge
2006	Les Houches Meeting "Statistical Physics of Glasses, Spin Glasses, Information Processing and Combinatorial Optimization", Les Houches
2005	94th Statistical Mechanics Meeting, Rutgers University, Rutgers
2005	LAWNP'05, 9th Latin American Workshop on Nonlinear Phenomena, San Carlos de Bariloche
2005	National Conference of the Italian Physical Society, SIF 2005
2004	Conference “Fundamental aspects of complexity”, ICTP, Trieste
2004	SPHINX Workshop on Econophysics, Oxford
2002	XXI national conference of Theoretical Physics and Condensed Matter, Fai della Paganella
2001	NATO Advanced Research Workshop ``Application of Physics to Economic Modelling '', Prague
1999	ICTP workshop “Unifying Concepts in Glass Physics”, ICTP, Trieste
1999	CECAM workshop "The Instantaneous Normal Mode Approach to Dynamics in Liquids", ENS Lyon
1999	CECAM workshop “Phase space and energy landscapes in disordered systems, ENS Lyon

Part VIII – SERVICE

VIIIA – Editorial and Reviewing activity

Period	Role
2018-present	Editor in chief – Journal of Statistical Physics
2019-present	Reviewing Editor - eLife
2020-present	Advisory Editorial Board, Papers in Physics
2011-2017	Mathematics Consulting Editor for Animal Behaviour
1999-present	Referee for the following journals: Nature Physics, Nature Communications, Proceedings of the National Academy of Sciences USA; Physical Review (Letters, B and E); Journal of Physics A; Europhysics Letters; Physica A; Physica D; European Physical Journal B; Journal of Statistical Physics; Quantitative Finance; Journal of Economic Behavior and Organization; Proceedings of the Royal Society B; Neural Computing and Applications; Ethology; Ecology Letters; Animal Behaviour; Plos One; Plos Computational Biology; Robotics and Autonomous Systems; Swarm Intelligence
2021	Project reviewer for Alliance Sorbonne University
2020	Project reviewer for the European Research Council
2016-2017	Project Reviewer for the Einstein Foundation
2015-2017	Project Reviewer for the Human Frontier Science Program
2012-2016	Project Reviewer for the National Science Foundation
2012	Reviewer VQR-ANVUR (National Research Evaluation 2004-2010), panel 02

VIIIB – Academic service

Period Role

2021-present	Director's Delegate for Teaching President of the Physics Teaching Planning Committee Member of the Didactic area coordination Committee
2019-present	Coordinator of the Master program in Biosystems (M.Sc. in Physics)
2019-present	Member of the Scientific Board - PhD in Physics
2019-present	Member of the Committee for ERC projects
2018-19	Member of the Committee Direct Calls
2018-present	President of the Committee General Seminars
2014-2021	Member of Committee for the verification of master's degree requirements

VIIIC– Conference organization and networking

Start	End	Institutition	Position
2021	2022	SIFS	Member of the SIFS `Program Committee' to prepare the candidature of Florence as host for the STATPHYS29 Conference in 2025
2021	2022	SIFS 2022 – Convegno Nazionale della Società Italiana di Fisica Statistica	Member of the Scientific Committee
2019	2023	CNRS	Member of the International Research Network "Predictability, Adaptation and Navigation - PAN"
2019	2019	XXIV Convegno Nazionale di Fisica Statistica e dei Sistemi Complessi	Member of the Scientific Committee
2018	2018	Conference Disordered Serendipity, Rome	Member of the Organizing Committee
2018	2018	ICTP workshop on Collective Behaviour, Trieste	Member of the Organizing Committee and Director for the Physics section
2015	2018	CNRS	Member of the European Scientific coordination network "Evolution, Regulation and Signalling" (ERS)
2014	2018	COST ACTION (EU Framework, cooperation grant)	Network member and Italian Member of the Managing Committee
2011	2011	Graduate Center, CUNY, New York	Organization (together with W. Bialek, A. Cavagna and P. Nelson) of the Extended Workshop "Theoretical physics and the phenomena of life: Optimization and emergent behaviour"

VIIID– Dissemination and Science Popularization

- I. Giardina, APS-DBIO Living Histories talks (2021)
- I. Giardina, *La meccanica della Vita – Dialogo del Farnese,* French Embassy, Rome (2019)
- *The lord of the Fireflies,* conversation of I.Giardina and artist R. Meier, Istituto Svizzero, Roma (2019)

- I. Giardina, *La Scienza a scuola,* Zanichelli, dissemination events for high-school students (2016 & 2017);
- A. Linke, I. Giardina, contribution to the interview for the exhibition and book *The Appearance of That Which Cannot Be Seen* (2016);
- I. Giardina, *Physique Statistique et vols d'etourneaux*, dissemination talk, Theatre Reine Blanche, Paris
- I. Giardina, *Comportamenti collettivi nei gruppi animali*, dissemination talk for the Series "Nelle segrete stanze, sguardi nel mondo della ricerca, Rome (2015).
- I. giardina, *La fisica e il volo degli uccelli*, caffe'-scienza, formascienza (2012).
- A. Linke, I. Giardina et al., *Flocking- Cohesion of the aggregation,* art video, from an interdisciplinary collaboration between the Starflag project (CNR-INFM) and HfG – Staatliche Hochschule für Gestaltung Karlsruhe (University of Art and Design Karlsruhe). Venice Biennale (2008); 'Notation' exhibition, ZKM Karlsruhe (2008); Romaeuropafestival (2009);
- A. Cavagna & I. Giardina, *The seventh starling*. Significance 5, 62-66 (2008).
- A. Cavagna & I. Giardina, *Comportamenti collettivi negli animali e nella specie umana*, Enciclopedia Treccani 'Nuovo Millennio' (2008)
- Interdisciplinary Conference "Bridge the Gap", Fondazione Prada and other locations, Milan (2005)

Part IX – RESEARCH ACTIVITY

- Overview and Research Highlights

My background is in theoretical and statistical physics. After my PhD on Spin Glasses, I have worked for several years on disordered and glassy systems, applying analytical and numerical techniques to models in condensed matter physics. My main results in this field concern the topological characterization of complex landscapes and its connection to non-equilibrium dynamics. Along the years, I have exported and applied techniques developed in statistical physics to complex behaviour in other contexts, from stochastic growth processes to multi-agent models and biological problems.
About fifteen years ago, my interest focused on the collective behaviour of living systems. I founded with Andrea Cavagna the COBBS Lab (Collective Behaviour in Biological Systems, - www.cobbs.it). Our lab was the first to collect 3D large-scale experimental data in the field and to do theory starting directly from the data. Our approach, based on the statistical physics of interacting systems, has opened an entirely new field of research bringing the biophysics revolution – well-established on microscopic systems – to the behavioural scale. Since then, my group is devoted to developing new experimental, analytical and numerical tools to investigate collective phenomena in living aggregations.
In 2021 I have been awarded, together with A.Cavagna, the Delbruck Prize for Biological Physics, the highest prize in biological physics of the American Physical Society, `*for the incisive combination of observation, analysis, and theory to elucidate the beautiful statistical physics problems underlying collective behavior in natural flocks and swarms.'*

Given the diversified nature of my interests, during my career I contributed to several fields in statistical physics, biophysics, and multi-agent theories. Below a brief description of my achievements, organized by subject. More emphasis is given to my current research activity (last point below). Cited papers refer to the full publication list.

- Glassy and disordered systems.

During my PhD with Giorgio Parisi in Rome I started working on spin-glasses. These systems are typical examples of condensed matter disordered systems where quenched disorder is present in the form of heterogeneous interactions between the spins. As a consequence, they exhibit non-trivial behaviour, with multiple thermodynamic phases and off-equilibrium dynamics. The energy landscape of spin-glass models is a complex one, rich in minima and saddles of every sort. Due to frustration, the system can find many different ways to organize in stable equilibria, it can remain trapped in sub-optimal metastable states, or can

never equilibrate due to marginal modes. A crucial issue is to understand how the features of the (free) energy landscape determine the behaviour of the system. During my PhD I started addressing this problem for several mean-field models, which could be treated analytically (see [71-73]). Later on, I further developed this line of research by focusing on different categories of finite-dimensional models, from spin-glasses to structural glasses. My works had impact in the field under several respects. I developed several theoretical techniques (from constrained equilibrium methods, to Replica theory, field theory and supersymmetry) to address the problem of metastability. While in Oxford, A. Cavagna, J. P. Garrahan, and I were the first to study the role of the Becchi-Rouet-Stora-Tyutin (BRST) supersymmetry and of the related Ward identities in spin-glasses [69,70]; back in Rome, our BRST line of research led to an important collaboration with M. Mezard and G. Parisi [51,52,53,56]. We discovered the link between symmetry properties of the complexity and stability features of the free energy stationary points, explaining how to correctly characterize the topology of spin glasses. In a next long-lasting collaboration with A. Cavagna and T.Grigera, we showed that the topology of the landscape has a fundamental role in glassy systems: for example we found that in some systems a dynamical slowing down in temperature is tuned by an underlying topological transition in the energy landscape between saddles and minima [57,58,60,64]. This result had strong impact in the study of the glass transition, where a dynamical crossover occurs (the viscosity increasing of 15 orders of magnitude in a few degrees) without an apparent bona fide transition. Our works triggered a new interest towards the role of saddle points (unstable modes) in the landscape, which were not considered before.
I also worked on spin glasses form a complementary perspective. Many analytical results on these systems had been obtained in the mean field limit, and an open problem was (and still is) how to derive them in finite dimensions. C. De Dominicis, with whom I collaborated during my period at IpTh in Saclay, had developed a field theory around the mean field solution, whose order parameter – a tensor – described all possible fluctuations in a multi-state structure. Together, we derived expressions for observable quantities that could be measured in the data [48].
My main contributions on glasses and spin glasses are summarized in the book I wrote together with C. de Dominicis (Random Fields and Spin Glasses, Cambridge University Press, 2006), and a series of lectures given at a Les Houches summer school on complex systems.

- Stochastic growth and critical dynamics

While in Saclay, I had a very productive collaboration with J.P. Bouchaud, with whom I worked on several subjects (see also next point). I started exploring the role of disorder beyond the context of glassy systems, but always focusing on the consequences of a complex landscape. In particular, I was interested in the problem of diffusion and growth in a random force field, where the long-time dynamics is affected by the statistical properties of the random force. The problem can be seen as a model for population evolution under environmental constraints, and theoretically bridges two fields, the one of random diffusion and the one of stochastic growth equations (KPZ like). Using a dynamical field theory approach, we showed that a new Renormalization Group fixed point appears, corresponding to a novel behavior of proliferation assisted transport, i.e. growth helps jumping barriers and changing the dynamic critical exponent [62,79]. Back in Rome, my interest in disorder and diffusion remained quite vivid and indeed from 2004 to 2008 I held a PhD course on `Disordered systems and anomalous diffusion', at the Department of Physics, Rome La Sapienza

- Agent-based models and cooperative games

Glassy systems are deeply rooted in condensed matter but are also paradigms of complex behaviour. Spin-glass models, for example, are used to describe neural networks and optimization problems. The very concept of landscape has been very broadly used in biology (fitness replacing free energy). Clearly, techniques and concepts developed in this field may be precious when dealing with generic systems of many interacting units, in presence of heterogeneities and/or complex dynamics.
When I was in Oxford, I started working on the Minority Game (MG; Challet & Zhang 1997), a simple model of interacting adaptive agents, which initiated the agent-based approach in econophysics. With my collaborators, we applied statistical physics techniques to this model [65,67], leading the way to several analytical and numerical works afterwards (see, e.g., Challet et al, Minority Games, Oxford University Press, 2005). The MG overturns the paradigm of the 'representative rational agent' adopted by Game Theory and traditional microeconomics. Rather, it assumes heterogeneous agents, which behave adaptively. The

heterogeneous nature of its constituents, analogous to disorder in spin-glass models, leads to non-trivial collective equilibria and population dynamics.
Providing a good description of opinion aggregation in a system of competing agents, the MG has been regarded as a minimal model for a market and it has been intensively studied. Yet, it does not incorporate any mechanism of price formation and, as such, it remains inevitably simplistic. During my postdoc in Saclay, I have worked precisely in this direction in collaboration with J.P. Bouchaud: we developed agent-based models of financial markets, which retained the philosophy of the MG but were more realistic [59,63,76,77,78]. These models allowed a clear understanding of a few important collective phenomena characterizing the behaviour of markets, such as herding and bubble formation [59], and volatility clustering [63]. Back in Rome, I collaborated with A. De Martino with whom we explored some generalizations of MG-like models [47,50,55]. On this subject I have tutored 1 DEA stage while in Paris, 1 B.Sc. and 1 M.Sc. Thesis in Rome, I held 1 course in Paris, a series of lectures at a Les Houches Workshop, and the M.Sc. course of Mathematical and Physical models for Economy (Physics Department, Rome).

- Physics of Living Systems – Collective Behavior in Biological System

Collective behavior is widespread in biological systems, ranging from the microscopic scale of cell colonies and bacterial populations to the macroscopic scale of animal aggregations like insect swarms and bird flocks. In many such cases, the collective behaviour is self-organized, i.e. there is no leader or external stimulus guiding the group towards the common pattern, rather coordination occurs spontaneously as a consequence of the local interactions between individuals. This mechanism, which produces global patterns from local rules, is known as self-organization (Camazine S et al, 2001) and very much resembles ordering in equilibrium condensed matter systems. This mechanistic analogy with physical systems suggests that statistical physics might provide an inspiring reference conceptual framework to study collective behaviour in living groups. Indeed, many efforts have been devoted by physicists to address these systems, and a whole new branch of research, called Living Active Matter, has enormously grown in the last years. Flocks and swarms are considered as the archetype of active matter: systems of interacting `self-propelled' individuals. Still, when I entered the field, all models and theories had been applied and tested only on aggregations living at the microscale (cell tissues, amoebes, bacteria, filaments). No data on groups living at the macroscale were available. Starting from these premises and stimulated by our experience in the Starflag project (a cooperative EU network devoted to flocking), Andrea Cavagna and I founded the COBBS (Collective Behaviour in Biological Systems) lab. Our aim was to set up experiments, provide data, and build up theory from the data. More broadly, our entire research activity in the last 15 years can be summarized in a few very general questions: **Can we build a statistical physics of interacting biological systems?** If so, how such a theory would differ from the statistical physics we are used to? These questions are by far non-trivial, in particular for animal groups where i) mutual interactions are not only of mechanical or chemical origin but are often mediated by cognitive processes; ii) groups are large but finite, making finite size effects important. What we have shown with our work is that natural flocks and swarms indeed comply to the general statistical laws required for a statistical physics approach to be pursued: even more, they very nicely obey both static and dynamic scaling laws. Along the years we have then developed a theoretical approach consistent with the data, revealing a whole set of non-trivial features in terms of nature of the interactions, mechanisms of information propagation and critical properties. Gradually, we are including in our analysis different species (starlings, robins, midges, mosquitoes, stem cells) in the hope of finding general properties/mechanisms and possibly define `classes' of large-scale behavior, in the statistical physics sense. Our major findings are summarized in a recent Physics Report and in a few other Reviews [12, 29, 40].
Combining experimental and theoretical work, COBBS established itself as one the leading groups in the field, as shown by the large impact of our publications and the number of competitive grants awarded (1 ERC-consolidator (2010-2015), 1 ERC-PoC (2015-2018), 1 Marie Curie (2010-2012) to me, 1 ERC -Adv (2018-2023) to A. Cavagna, + several grants to other group members). The group has hosted along the years a large number of young researchers, postdoc and students, working under the coordination of myself and A. Cavagna and currently includes (besides ourselves) 3 researchers, 3 postdocs and 5 PhD students.

In 2017 the 27th Solvay Conference for Physics was dedicated to `The Physics of Living Matter' and gathered the most prominent groups working on biophysics to discuss the major problems and advancement in the field. I was invited to participate (the only representative of an Italian Institution), a sign of the relevance of our research line worldwide.

In 2021 I have been awarded, together with A.Cavagna, the Delbruck Prize for Biological Physics, *`for the incisive combination of observation, analysis, and theory to elucidate the beautiful statistical physics problems underlying collective behavior in natural flocks and swarms.'*

Below a short summary of our main findings:

Experiments and 3D tracking
As I mentioned above, my group has an important experimental activity. Our experiments are 3D stereo-tracking experiments and consist of collecting synchronized triplets of images at a fast rate [18, 40, 43]. In order to transform these raw images into actual 3D spatio-temporal trajectories, one needs to match different images of the same individual across different cameras and to follow it in time, which is not easy if individuals belongs to a large, crowded group. The breakthrough which allowed us to gather all of our data was a new tracking method - that we developed ourselves - which combines computer vision and optimization theory, together with ideas from statistical physics and renormalization, into one single algorithm [21]. Thanks to these advancements we are able to track for several seconds individual trajectories in groups of thousands individuals in the field. Data analysis then allowed us to quantitatively characterize the statistical properties of flocks and swarms in terms of order and structure [31, 38, 41, 42, 44, 26].

Flocks: Topological Interactions, Large scale correlations and quick information propagation
It took us more than 3 years to produce the first generation of 3D data (2005-2007). By analyzing the proximity structure of birds within a flock we detected a strong anisotropy in the nearest neighbours spatial distribution given a bird. We used such anisotropy as a proxy of the inter-individual interaction and determined its range. By analyzing flocks with different densities, we found that such range was a constant number when measured in units of neighbours, rather than in units of meters. We concluded that interaction in flocks is not based on metric distance as in physical systems (and as assumed by all models up to then), but on a density-invariant topological distance [45], which is more robust against ‘evaporation’ of the group under the violent density fluctuations typical of biological systems under predation (as we theoretically showed in [32, 33]). This work had a strong impact and now has more than a thousands citations.
The interaction range that we found in flocks was approximately of 7 neighbours, which is quite short. Given the startling coordination of flocks, it was clear that something had to make up for such short-ranged interaction at the level of the correlation. In 2010 we thus measured the equal-time spatial correlations of velocity fluctuations and found them to be long-ranged, namely with a correlation length, ξ, that scales with the system’s size. From a field-theory standpoint this result was not surprising: flocks have a spontaneously-broken continuous symmetry (rotation), hence we should expect some massless Goldstone mode, namely an infinite correlation length. Definitely less trivial was the fact that i) equal time correlation functions obeyed static scaling laws but with exponents different from the ones predicted by existing models; ii) also the supposedly massive mode, namely the modulus of the velocity (i.e. the speed), was long-range correlated. To explain this behaviour we recently proposed a mechanism based on marginal speed control [3,9], where individual speeds are regulated by a locally flat confining potential. The resulting interacting theory produces long-range speed correlations while keeping fluctuations finite, as observed in natural flocks [3].
All these findings indicate that a good theory to describe these systems should include short range topological interactions based on mutual alignment and speed adjustment, as also confirmed by statistical inference methods (see point below).
All our analysis up to 2010 had been static, whereas collective behaviour is primarily a dynamical phenomenon and cross-group information transfer is a major biological issue. Between 2010 and 2013 we run a new data-taking campaign to measure information transfer across turning flocks. Data clearly indicated the existence of linear phase waves (the phase φ_i being the angle between the group direction of motion and that of individual i), [25] that could not be reproduced by previous theories of collective motion. By comparing data to active matter models, we realized in 2014 that there was a key missing ingredient in the latter, namely the coupling between the order parameter and the generator of the rotations of the order parameter, i.e. the spin. We therefore developed a new theory including such ingredient [20,23,25]. This coupling gives rise to a non-dissipative second-order inertial term in the equation of motion, which produces linear spin waves. Our new theory made a quantitative prediction about how the speed of propagation of the

wave depends on the polarization of the system. Experimental data show that this prediction is very accurately verified [25].

Swarms of insects: near-criticality and dynamic scaling

After working for several years on flocks, in 2011 we started collecting data on natural swarms of midges in the field. The idea was to explore the opposite extreme of the order-disorder spectrum and check whether something interesting might be going on in the disordered (swarm) phase as well. Most past studies argued that it couldn't, as swarming was supposed to be just an epiphenomenon of the confined random walk of each insect around an environmental marker (light, water, etc). We thought differently, and proceeded to build an entirely new experimental setup to investigate this issue. The data immediately showed that, despite the low value of the order parameter, velocity correlation was very large [24]. Besides, data from different groups of different sizes and densities exhibited a near-critical finite-size scaling behaviour, suggesting that criticality might in fact play a role in the collective behaviour of swarms [26]: these groups are not polar (which would be biologically unfunctional as they should remain localized for reproduction) but linger at the edge of an ordering transition where correlations (hence response) are maximal.

Having established in a robust experimental way the existence of unusually strong correlation in swarms, we turned our attention to dynamical scaling. From a statistical physics viewpoint, this was the natural next step along the path of building a comprehensive theory of collective behaviour. The dynamic correlation function of velocities, $C(k,t)$, is in principle a complicated function not only of space (or momentum, k) and time, but also of all possible biological parameters, like density, noise, species, etc. To our great surprise, we found that by adapting to natural swarms the classic prescription of Halperin and Hohenberg (Rev. Mod. Phys 49, 435 (1977)) for dynamic scaling, we could collapse all space-time correlation functions of many different real swarms (of 4 different species) onto one single master curve [13]. The analysis also allowed us to estimate from the data the dynamic critical exponent of natural swarms, which turns out to $z \sim 1.3$, a value not explained by any current theory.

Towards a field theory of interacting biological systems

Experimental findings of static scaling in flocks and dynamic scaling in swarms show that – despite the complexity of the individuals and of their mutual interactions – only a few features are in fact important to determine the large scale behaviour. This is indeed the essence of scaling laws: most of microscopic details are irrelevant, correlations only depend on the correlation length and the characteristic time.

A statistical physics approach based on (relatively) simple models is therefore possible and experimentally grounded. Experiments on both flocks and swarms showed that the critical exponents (static and dynamic) in these systems are different from those predicted by existing models. Analysis of correlation functions (in swarms) and of the dispersion law (in flocks) also indicate that inertial dynamical terms play a crucial role and cannot be discarded. Starting from these observations we started working on a field theory approach to study large scale critical properties. Such a theory should appropriately incorporate both behavioural inertia and activity. The first ingredient implies including in a non-trivial way both reversible and dissipative dynamical terms. The second one corresponds to assume convective terms and covariant derivatives, and the breaking of Galilean invariance, as the system is out of equilibrium. Overall, the resulting field theory has three coupled fields (density, velocity, and spin – i.e. the rotational symmetry generator), and a plethora of interacting and mode coupling terms. To achieve progress, we proceeded in steps.

We first considered the theory at equilibrium (i.e. pointers rather than flockers) to explore the role of mode-coupling terms. An RG computation [7, 8] revealed the presence of a crossover in the critical dynamics, giving rise to exponents closer to the experimental ones at large but finite sizes (i.e. in the regime relevant for natural groups). We then included the presence of activity, and addressed the full theory within the incompressibility limit. The computation has been arduous [1,2,5] – due to the large number of diagrams – but results rewarding: the RG flow indeed predicts a novel out-of-equilibrium fixed point where both inertia and activity are relevant, and the theoretical dynamic critical exponent is consistent with the experimental value [1].

Future work in this direction involves considering additional generalizations: exploring the theory in the ordered phase; including density fluctuations – at least to some degree; considering topological interactions, for which terms breaking the reciprocity of interactions could generate additional off-equilibrium features [14,19]. Finally, terms regulating speed adjustment are likely to play a role in the deeply ordered phase, where they can generate large scale speed correlations [3].

Maximum entropy and statistical inference

Modeling based on experimental data is a difficult job. Broadly speaking it proceeds by steps: we start with reasonable hypothesis, build models with them, check their predictions and look for further tests and improvements. Using a more systematic approach, one can use statistical inference methods where assumptions are at least kept under control. The maximum entropy method tries to do exactly this: given a set of experimental observations, it builds the least structured probability distribution compatible with the given data. In other words, maximum entropy keeps to the bare minimum the number of assumptions (and therefore of parameters). Several years ago we started a productive collaboration with W. Bialek (Princeton), T. Mora & A. Walczak (ENS), who had applied similar methods in the past on different biological networks. We started by considering experimental data about the equal time velocity correlations in bird flocks and the results were quite neat: one succeeds in fitting the data and in predicting new experimental quantities, by means of a maximum entropy model, which has a surprisingly low number of parameters [22, 27, 34]. The inference procedure beautifully derives the short-range topological nature of the interaction from directional quantities, confirming the results obtained in our first paper using structural properties. More recently, we have theoretically developed novel schemes of dynamical maximum entropy inference [28]; applications to experimental dynamical trajectories revealed how flocks are quasi-equilibrium systems, in the sense that directional information travels much faster than network rearrangements [15]. More recently, we generalized dynamical inference to second order dynamical processes, a problem – quite surprisingly – never systematically addressed before [6]. Our results pinpoint the relevance of memory and non-Markovian features in inference procedures whenever experimental data consists in partial observations of the full set of degrees of freedom, a rather general feature of most experimental protocols. We also explored the link between continuous dynamical models and their discretized counterparts, and used a Renormalization Group approach to classify discrete auto-regressive stochastic equations in classes of large scale behavior [4].

Classifying out-of-equilibrium and response behavior in polar living matter

A distinctive feature of active matter systems is that they are intrinsically out of equilibrium due to the self-propulsion of the individuals. Energy is injected into the system at the individual level (i.e. the active force regulating motility) making non-equilibrium different from what observed in driven or disordered systems. Much work has been devoted in recent years to characterize this behaviour. Most analyses have focused on non-polar MIPS (Motility Induced Phase Separation) systems, where motility produces aggregated patterns but there is no orientational order. What we are doing, on the contrary, is to look at systems with alignment where motility helps establishing long range directional order. With a few PhD students we are using techniques from stochastic thermodynamics to study analytically and numerically the Entropy Production Rate (EPR), and violations of dynamical fluctuation dissipation relations between response and correlation functions. The aim of this study is twofold. At the theoretical level we wish to show that EPR behaves differently in MIPS and in polar systems, identifying different classes of non-equilibrium. At a more practical level we wish to understand what ingredients regulate collective response, in order to appropriately interpret and describe perturbation experiments in midge swarms.

Diversification and future projects

In the light of investigating collective phenomena on a variety of different living systems, we recently started several collaborations and are setting up a novel set of experimental campaigns. In the last two years we set up experiments on stem cell colonies in collaboration with M. Riminucci and her group in Sapienza. Preliminary data and analysis show self-confinement and emergence of global order in the cell colonies, a behaviour that we would like to confirm and explain theoretically. We also set up experiments on mosquito swarms in a large-scale facility in Perugia, in collaboration with the group of R. Spaccapelo. More importantly, we are developing and setting up a new experimental apparatus that will allow us to track natural groups on timescales much longer than in the past. The objective is to eventually compute space-time correlation functions on large time lags, and perform perturbation experiments. This effort will allow us to test our theoretical predictions, further investigate issues related to large scale dynamical classes, and develop an understanding of response behaviour.

Building a National Active Matter network

Active Matter represents today one of the most growing branches of condensed matter and statistical physics. As compared to the general global wide trend, however, synergistic activity in this field has been scarce so far in Italy, both in terms of funding and networking. For this reason, a few years ago, together with a few colleagues, we decided to set up a network of groups working on living and artificial active matter. We discussed a common roadmap to address general problems and open questions to be investigated across scales and systems, from cells and micro-swimmers to animals and artificial units. The resulting effort is a project focusing on response, control and learning in living and engineered active matter, that has been recently funded as a PRIN project, and which I coordinate.

Part X – SUMMARY OF SCIENTIFIC ACHIEVEMENTS

In the following I include the citation reports and scientific indicators from the three main Databases used in my field of research, Scholar, Scopus and ISI-WOS.

XA – Scholar indicators (Dec 2021)

	All	Since 2016
Total Citations	8412	4273
Hirsch (H) index	43	30
i10-index*	65	46

*number of publications that have at least 10 citation

citations of most cited paper	1836	Ballerini et al., PNAS 105 (4), 1232-1237 (2008)
Renowned papers (> 500 citations)	2	
Famous papers (250-499)	2	
well-known papers (100-249)	16	15 papers + 1 book

XB – Citation report for the **<u>entire scientific production</u>** (1996-2021)

Scopus Database

Papers [international]	80
Books [scientific]	1
Total Citations	5289
Average Citations per Product	65.3
Hirsch (H) index	35
Normalized H index	1.4

ISI-Wos Database

Papers [international]	80
Books [scientific]	1
Total Citations *	4858
Average Citations per Product*	60.73
Hirsch (H) index*	33
Normalized H index*	1.32

** the ISI citation report does not include the book*

Total Impact factor *(Clarivate JCR)*	363.30
Impact factor per publication	5.19

XC – Citation report for the scientific production of the **last 15 years**
(counted as specified in the call)

Scopus Database

Papers [international]	46
Books [scientific]	1
Total Citations	4041
Average Citations per Product	86
Hirsch (H) index	27

ISI-Wos Database

Papers [international]	44
Books [scientific]	1
Total Citations *	3698
Average Citations per Product*	84.05
Hirsch (H) index*	25

* *the ISI citation report does not include the book*

Total Impact factor *(Clarivate JCR)*	281.80
Impact factor per publication	6.71

Part XI– SELECTED PUBLICATIONS

List of the publications selected for the evaluation
(Citations from Scholar, IF related to publication year)

1. Building general Langevin models from discrete datasets
   F Ferretti, V Chardès, T Mora, AM Walczak, I Giardina
   Phys. Rev. X **10**, 031018 (2020). IF: 15.762. Cit: 13

2. Dynamical renormalization group approach to the collective behaviour of swarms
   A Cavagna, L Di Carlo, I Giardina, L Grandinetti, TS Grigera, G Pisegna
   Phys. Rev. Lett. **123**, 268001 (2019). IF: 8.385. Cit: 19

3. The physics of flocking: Correlation as a compass from experiments to theory.
   Cavagna, A., Giardina, I., & Grigera, T. S.
   Physics Reports **728**, 1-62 (2018) - IF: 28.295 - Cit: 65

4. Dynamic scaling in natural swarms
   A.Cavagna, D. Conti, C. Creato, L. Del Castello, I. Giardina, TS. Grigera, S.Melillo, L. Parisi, M. Viale
   Nature Physics **13**, 914-919 (2017) - IF: 22.727 - Cit: 53
   Cover article -
   The Marvelous Physics of Swarming Midges, New York Times

Press/media release:
http://www.ansa.it/canale_scienza_tecnica/notizie/fisica_matematica/2017/10/05/il-valzer-dei-moscerini-esiste-la-fisica-ne-svela-la-coreografia-_65cf8718-e7d3-49d4-b01a-106cf8e8eaa7.html

5. Nonsymmetric interactions trigger collective swings in globally ordered systems
A.Cavagna, I. Giardina, A. Jelic, S. Melillo, L. Parisi, E. Silvestri, M. Viale
Phys. Rev. Lett. **118**, 138003 (2017) - IF: 8.839 - Cit: 10

6. Local equilibrium in bird flocks
T. Mora, A. Walczak, L. Del Castello, F. Ginelli, S. Melillo, L. Parisi, M. Viale, A. Cavagna, I. Giardina
Nature Physics **12**, (12), 1153-1157 (2016) - IF: 22.806 – Cit: 63

7. Silent Flocks: constraints in signal propagation across biological groups
A. Cavagna, I. Giardina, TS. Grigera, A. Jelic, D. Levine, S. Ramaswamy, M. Viale
Phys. Rev. Lett. **114**, 218101 (2015) - IF: 7.645 – Cit: 45
Press/media release:
https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.114.218101 (Synopsis in Physics)

8. Flocking and turning: a new model for self-organized collective motion
A.Cavagna, L. Del Castello, I. Giardina, T. Grigera, A. Jelic, S. Melillo, T. Mora, L. Parisi, E. Silvestri, M. Viale, AM. Walczak
J. Stat. Phys. **158**, 601-627 (2014) - IF: 1,537 – Cit: 99

9. Finite-size scaling as a way to probe near-criticality in natural swarms
A. Attanasi, A. Cavagna, L. Del Castello, I. Giardina, S. Melillo, L. Parisi, O. Pohl, B. Rossaro, E. Shen E. Silvestri, M. Viale
Phys. Rev. Lett **113**, 238102 (2014) - IF: 7.512 – Cit: 135
Press/media release:
https://physics.aps.org/articles/v7/120 (Viewpoint in Physics)

10. Information transfer and behavioural inertia in starling flocks
A. Attanasi, A. Cavagna, L. Del Castello, I. Giardina, TS. Grigera, A. Jelić, S. Melillo, L. Parisi, O. Pohl, E. Shen, M. Viale
Nature Physics, **10** (9), 691-696 (2014) - IF: 20,147 – Cit: 282
Cover article

11. Social interactions dominate speed control in poising natural flocks near criticality
W. Bialek, A. Cavagna, I. Giardina, T. Mora, O. Pohl, E. Silvestri, M. Viale, AM. Walczak
Proc. Natl. Acad. Sci. US **111** (20), 7212-7217 (2014) - IF: 9,674 – Cit: 177

12. Bird flocks as condensed matter
A. Cavagna, I. Giardina
Ann. Rev. Cond. Matt. Phys. **5**, 183-207 (2014) - IF: 14.786 – Cit: 137

13. Statistical mechanics for natural flocks of birds
W. Bialek, A. Cavagna, I. Giardina, T. Mora, E. Silvestri, M. Viale, A. M. Walczak
Proc. Natl. Acad. Sci. US **109**, 4786-4791 (2012) - IF: 9.737 – Cit: 587

Press/media release:
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https://arstechnica.com/science/2012/03/animal-magnetism-using-magnetic-models-to-understand-flocks-of-birds/
https://www.wired.com/2012/03/starling-flock-dynamics/

14. Scale-free correlations in starling flocks
A. Cavagna, A. Cimarelli, I. Giardina, G. Parisi, R. Santagati, F. Stefanini, M. Viale
Proc. Natl. Acad. Sci. USA **107**, 11865-11870 (2010) - IF: 9.771 – Cit: 842
Press/media release:
https://www.allaboutbirds.org/how-do-starling-flocks-create-those-mesmerizing-murmurations/
http://www.peterbeerli.com/classes/images/4/4e/AmSci2011Hayes.pdf
https://physicsworld.com/a/birds-flock-with-scale-invariance/
https://www.wired.com/2010/06/starling-physics/

15. Interaction Ruling Animal Collective Behaviour Depends on Topological rather than Metric Distance: Evidence from a Field Study
M. Ballerini, N. Cabibbo, R. Candelier, A. Cavagna, E. Cisbani, I. Giardina, V. Lecomte, A. Orlandi , G. Parisi, A. Procaccini, M. Viale & V. Zdravkovic V
Proc. Natl. Acad. Sci. USA **105**, 1232-1237 (2008). IF: 9.380. Cit: 1832
Press/media release:
https://physicstoday.scitation.org/doi/full/10.1063/1.2800090
https://www.telegraph.co.uk/news/science/science-news/3323488/Study-of-starling-formations-points-way-for-swarming-robots.html
https://www.sciencenews.org/article/birds-network-too

16. Random Fields and Spin Glasses
C. De Dominicis and I. Giardina
Cambridge University Press, Cambridge (2006). Cit:198

Part XII– FULL PUBLICATION LIST

- **Books and Book Chapters:**

Collective behavior in animal groups
I. Giardina
in “The Physics of Living Matter: Space, Time and Information: Proceedings of the 27th Solvay Conference on Physics”, D. Gross, A. Sevrin and B. Shraiman eds.
World Scientific Publishing, Singapore (2020)

Comportamenti Collettivi
A. Cavagna & I. Giardina
in Enciclopedia Treccani XXI secolo (2010)

Metastable states in glassy systems
I. Giardina
in "Les Houches - Session LXXXV: Complex Systems", J.-P Bouchaud, M. Mezard and J. Dalibard eds.,Elsevier, Amsterdam (2007).

Random Fields and Spin Glasses

C. De Dominicis and I. Giardina
Cambridge University Press, Cambridge (2006)

La Formulazione delle Storie della Meccanica Quantistica
I. Giardina
Bibliopolis, Napoli (1998)

- **Peer reviewed research papers:**

[1.] Natural Swarms in 3.99 Dimensions
A Cavagna, L Di Carlo, I Giardina, TS Grigera, S Melillo, L Parisi, G Pisegna, M Scandolo
arXiv preprint arXiv:2107.04432. Submitted to Nature Physics (2021)

[2.] Dynamical renormalization group for mode-coupling field theories with solenoidal constraint
A Cavagna, L Di Carlo, I Giardina, TS Grigera, G Pisegna, M Scandolo
J. Stat. Phys. **184**, 26 (2021)

[3.] Marginal speed confinement resolves the conflict between correlation and control in natural flocks of birds
A Cavagna, A Culla, X Feng, I Giardina, TS Grigera, W Kion-Crosby, S. Melillo, G. Pisegna, L. Postiglione, P. Villegas
arXiv preprint arXiv:2101.09748. Under review at Nature Commun. (2021)

[4.] A Renormalization Group Approach to Connect Discrete-and Continuous-Time Descriptions of Gaussian Processes
F Ferretti, V Chardès, T Mora, AM Walczak, I Giardina
arXiv preprint arXiv:2101.06482. Submitted to Phys. Rev. E (2021)

[5.] Equilibrium to off-equilibrium crossover in homogeneous active matter
A Cavagna, L Di Carlo, I Giardina, TS Grigera, G Pisegna
Phys. Rev. Res. **3,** 013210 (2021)

[6.] *Building general Langevin models from discrete datasets*
F Ferretti, V Chardès, T Mora, AM Walczak, I Giardina
Phys. Rev. X **10**, 031018 (2020)

[7.] *Dynamical renormalization group approach to the collective behaviour of swarms*
A Cavagna, L Di Carlo, I Giardina, L Grandinetti, TS Grigera, G Pisegna
Phys. Rev. Lett. **123**, 268001 (2019)

[8.] *Renormalization group crossover in the critical dynamics of field theories with mode coupling terms*
A Cavagna, L Di Carlo, I Giardina, L Grandinetti, TS Grigera, G Pisegna
Phys. Rev. E **100**, 062130 (2019)

[9.] *Low-temperature marginal ferromagnetism explains anomalous scale-free correlations in natural flocks*
A. Cavagna, A. Culla, L. Di Carlo, I. Giardina & T.S. Grigera,
Comptes Rendus Physique **20**, 319 (2019).

[10.] *Physical constraints in biological collective behavior*
A. Cavagna, I. Giardina, T. Mora, A. M.Walczak
Current Opinion in Systems Biology **9,** 49 (2018)

[11.] *Propagating speed waves in flocks: a mathematical model.*
Cavagna A., Conti, D., Giardina, I., & Grigera, T. S.
Phys. Rev. E. **98**, 052404 (2018)

[12.] *The physics of flocking: Correlation as a compass from experiments to theory.*
Cavagna, A., Giardina, I., & Grigera, T. S.
Physics Reports **728**, 1 (2018)

[13.] *Dynamic scaling in natural swarms*
A.Cavagna, D. Conti, C. Creato, L. Del Castello, I. Giardina, TS. Grigera, S.Melillo, L. Parisi, M. Viale
Nature Physics **13**, 214 (2017)

[14.] *Nonsymmetric interactions trigger collective swings in globally ordered systems*
A.Cavagna, I. Giardina, A. Jelic, S. Melillo, L. Parisi, E. Silvestri, M. Viale
Phys. Rev. Lett. **118,** 138003 (2017)

[15.] *Local equilibrium in bird flocks*
T. Mora, A. Walczak, L. Del Castello, F. Ginelli, S. Melillo, L. Parisi, M. Viale, A. Cavagna, I. Giardina
Nature Physics, 12, (12), 1153-1157 (2016)

[16.] *Entropic effects in a nonequilibrium system: Flocks of birds*
M Castellana, W Bialek, A Cavagna, I Giardina
Phys. Rev. E **93** (5), 052416 (2016)

[17.] *Spatio-temporal correlations in models of collective motion ruled by different dynamical laws*
A.Cavagna, D. Conti, I. Giardina, TS. Grigera, S. Melillo, M. Viale
Physical Biology, 13 (6), 065001 (2016)

[18.] *Error control in the set-up of stereo camera systems for 3d animal tracking*
A Cavagna, C Creato, L Del Castello, I Giardina, S Melillo, L Parisi, ...
Eur. Phys. J. Special Topics **224** (17-18), 3211-3232 (2015)

[19.] *Emergence of collective changes in travel direction of starling flocks from individual birds fluctuations*
A.Attanasi, A. Cavagna, L. Del Castello, I. Giardina, A. Jelic, S. Melillo, L. Parisi, O. Pohl, E. Shen, M. Viale
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[20.] *Flocking and turning: a new model for self-organized collective motion*
A.Cavagna, L. Del Castello, I. Giardina, T. Grigera, A. Jelic, S. Melillo, T. Mora, L. Parisi, E. Silvestri, M. Viale, AM. Walczak
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[21.] *GReTA – A novel global and recursive tracking algorithm in three dimensions*
A.Attanasi, A. Cavagna, L. Del Castello, I. Giardina, A. Jelic, S. Melillo, L. Parisi, F. Pellacini, E. Shen, E. Silvestri, M. Viale
Pattern Analysis and Machine Intelligence, IEEE Transactions on, issue **99**, (2015)

[22.] *Short-range interaction vs long-range correlation in bird flocks*
Cavagna, L. Del Castello, S. Dey, I. Giardina, S. Melillo, L. Parisi, M. Viale
Phys. Rev. E **92**, 012705 (2015)

[23.] *Silent Flocks*

A.Cavagna, I. Giardina, TS. Grigera, A. Jelic, D. Levine, S. Ramaswamy, M. Viale
Phys. Rev. Lett. **114**, 218101 (2015)

[24.] *Finite-size scaling as a way to probe near-criticality in natural swarms*
A. Attanasi, A. Cavagna, L. Del Castello, I. Giardina, S. Melillo, L. Parisi, O. Pohl, B. Rossaro, E. Shen, E. Silvestri, M. Viale
Phys. Rev. Lett **113**, 238102 (2014)

[25.] *Information transfer and behavioural inertia in starling flocks*
A. Attanasi, A. Cavagna, L. Del Castello, I. Giardina, TS. Grigera, A. Jelić, S. Melillo, L. Parisi, O. Pohl, E. Shen, M. Viale
Nature Physics, **10** (9), 691-696 (2014)

[26.] *Collective behaviour without collective order in wild swarms of midges*
A. Attanasi, A. Cavagna, L. Del Castello, I. Giardina, S. Melillo, L. Parisi, O. Pohl, B. Rossaro, E. Shen, E. Silvestri, M. Viale
Plos Comput. Biol., **10** e1003697 (2014)

[27.] *Social interactions dominate speed control in poising natural flocks near criticality*
W Bialek, A Cavagna, I Giardina, T Mora, O Pohl, E Silvestri, M Viale, A.M. Walczak
Proc. Natl. Acad. Sci. US **111**, 7212-7217 (2014)

[28.] *Dynamical maximum entropy approach to flocking*
A.Cavagna, I. Giardina, F. Ginelli, T. Mora, D. Piovani, R. Tavarone, AM Walczak
Phys. Rev. E, **89**, 042707 (2014)

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