DYNSYSMATH

DYNamics and non equilibrium states of complex SYStems: MATHematical methods and physical concepts

Coordinatore nazionale: Irene Giardina, ~ 30 strutturati

- **Catania**
  A. Rapisarda, A. Puchino, G.Falci, E. Paladino, A. Ridolfo, F. Pellegrino, G. Angilella, B. Spagnolo
- **Firenze**
  L. Casetti, D. Fanelli, S. Iubinni, A. Mossa, P. Politi, S. Ruffo, R. Livi
- **Milano**
  R. Artuso, F. Borgonovo, F. Ginelli, G. Mantica
- **Parma**
  R. Burioni, D. Cassi, S.M. Wimberger
- **Roma**
  A. Giansanti, A. Campa, A. Cavagna, F. Cecconi, I. Giardina, F. Sylos Labini, M. Viale, A. Vulpiani

Main research themes

Anomalous dynamics and transport

1.a Anomalous transport in Levy Glasses

1.b Quantum transport

1.c Active transport in crowded environments

1.d Neuronal avalanches

1.e Dynamics of complex networks

Long-range models

2.a The unconstrained ensemble

2.b Systems with competing interactions

2.c Self gravitating systems

2.d Long-range coupled spin systems

Emergent collective dynamics in active and living matter

3.a Response in active systems

3.b Critical field theory for inertial swarms

3.c Confined active matter

3.d Non equilibrium thermodynamics and Information processing in stochastic systems

3.e Model building and statistical inference

Active matter

Active particles are able to extract and dissipate energy from their surroundings to produce systematic and coherent motion

- Energy enters and exits the system $\rightarrow$ out of equilibrium

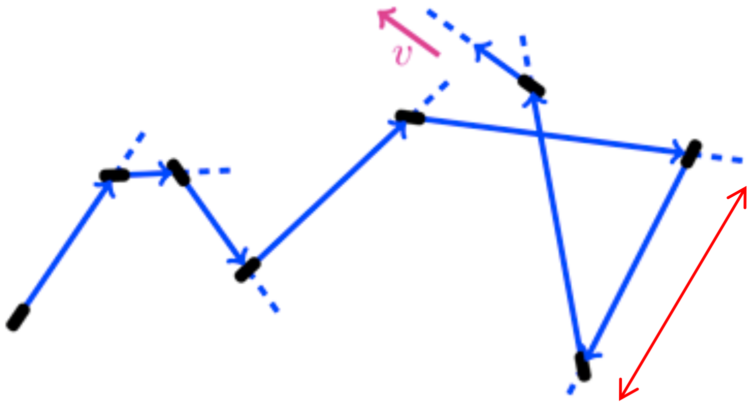
- Energy is spent to perform actions, typically move (self-propel) in a non-thermal way

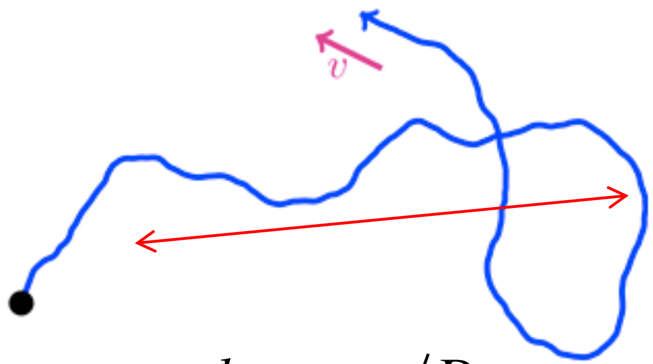
- In active systems, energy is injected and dissipated in the bulk, not from the boundaries, in a way that does not explicitely breaks any simmety

For a gentle intro: S. Ramaswamy, *Annu Rev Cond Mat Phys* **1** 323 (2010).

Simplest model for active particles ?

Persistent random walkers



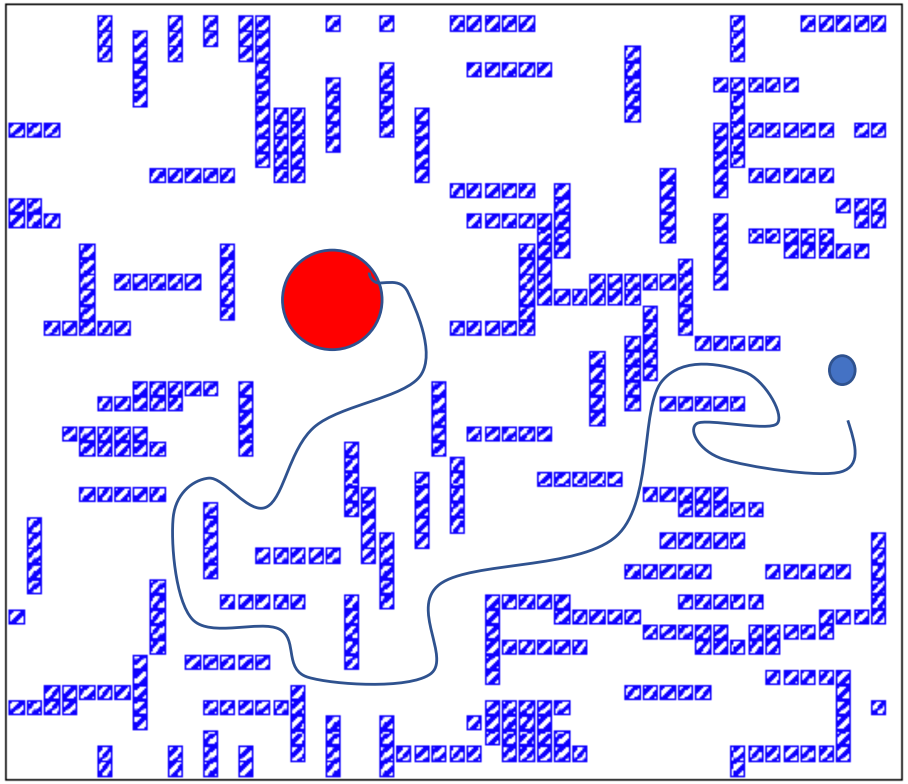


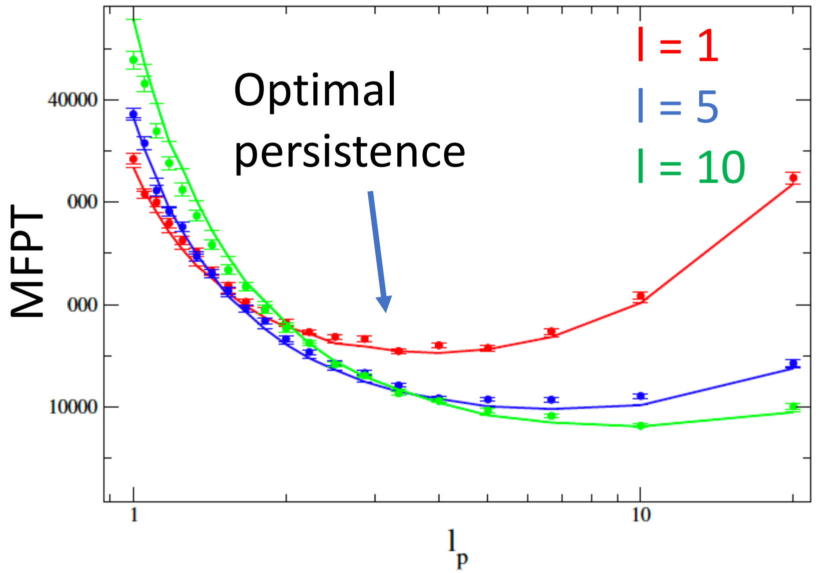
$$l_{pers} \sim v_0/D$$

At length scales >> l_{pers} undistinguishable from a standard random walk

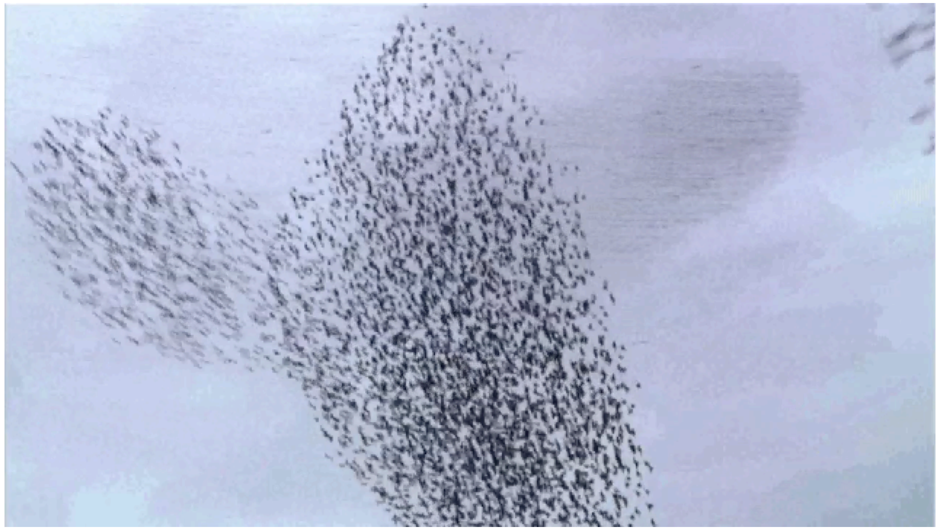
Nonequilibrium effects emerge (MIPS, rectification of thermal fluctuations, etc.) emerge when interacting on scales << l_{pers}

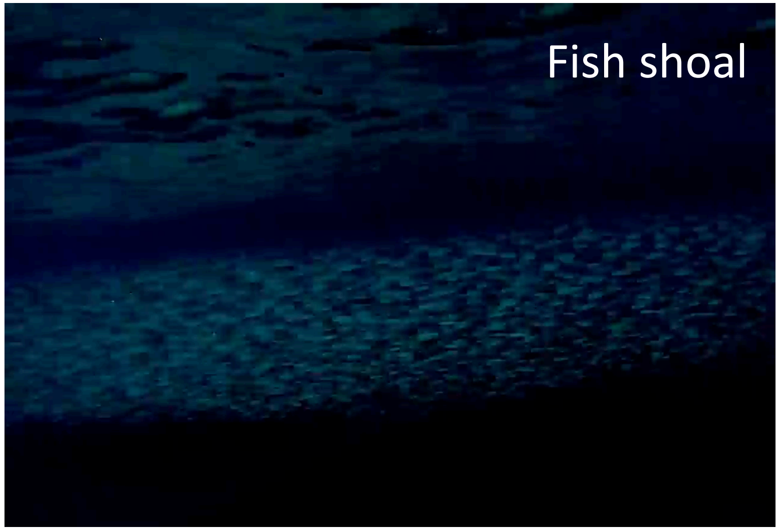
Optimal transport properties in a crowded environment

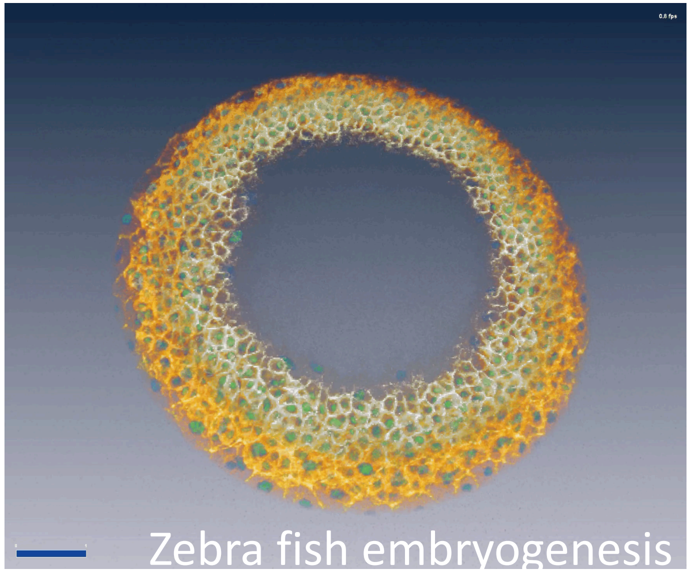




Collective motion in living system

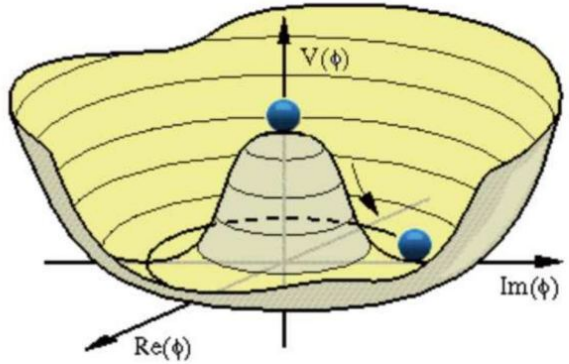






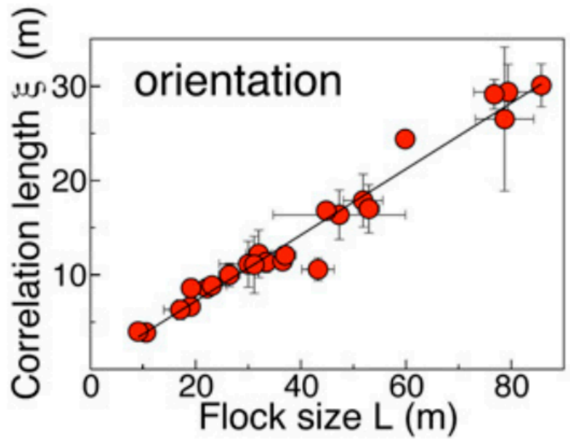
Collective motion follows spontaneous symmetry breaking of a continuous symmetry

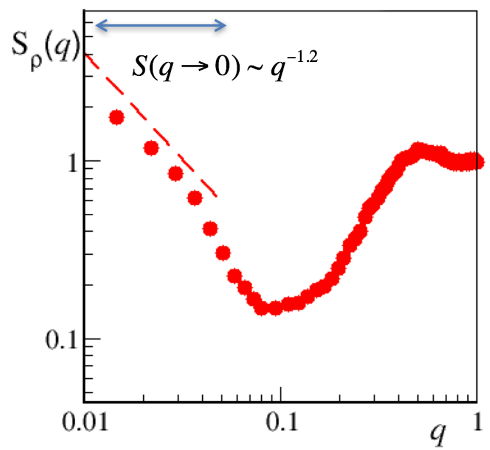
Slow massless modes (Nambu-Goldstone)



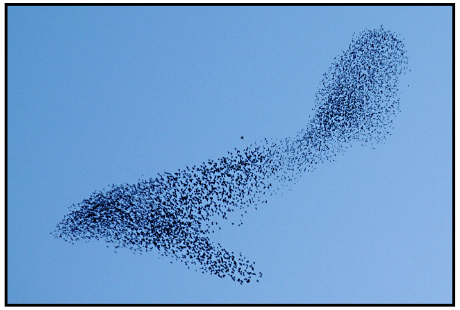
1. **The system is neutral towards small fluctuations in the velocity orientation**
   velocity fluctuations correlations are long ranged
2. **Particles actually move one w.r.t. each other according to velocity fluctuations also density fluctuations become long ranged**

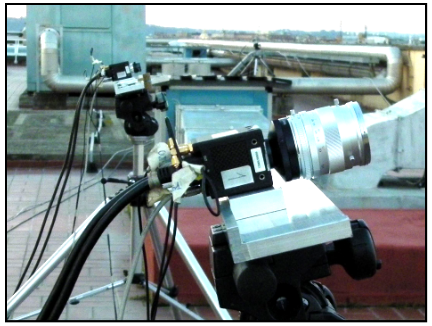
Verified by experimental measures in starling flocks and epithelial cells:

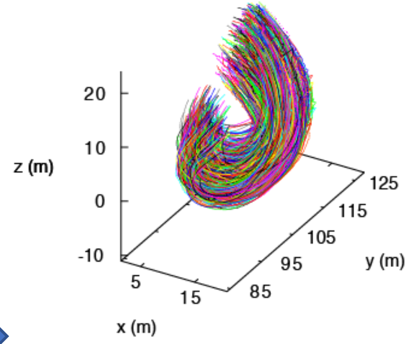


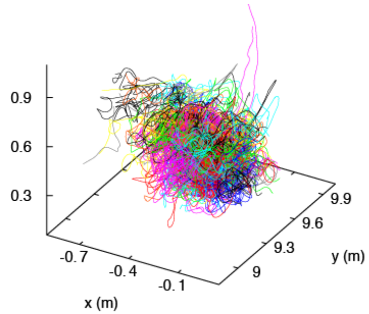


Collective behaviour in living groups: flocks, swarms and cells









- Statistical analysis of collective motion: structure, correlations, info-propagation
- Statistical inference: from data to models

- How do coordination arises in living interacting groups?
- What features regulate robustness/adaptation/response?
- Can we define behavioral classes?

Irene Giardina (Dept.), Andrea Cavagna, Stefania Melillo (ISC)   www.cobbs.it

A. Cavagna – ERC advanced Grant

Renormalization group approach to the collective behaviour of strongly correlated biological systems

Dynamical Renormalization Group Approach to the Collective Behavior of Swarms

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We study the critical behavior of a model with nondissipative couplings aimed at describing the collective behavior of natural swarms, using the dynamical renormalization group under a fixed-network approximation. At one loop, we find a crossover between an unstable fixed point, characterized by a dynamical critical exponent $z = d/2$, and a stable fixed point with $z = 2$, a result we confirm through numerical simulations. The crossover is regulated by a length scale given by the ratio between the transport coefficient and the effective friction, so that in finite-size biological systems with low dissipation, dynamics is ruled by the unstable fixed point. In three dimensions this mechanism gives $z = 3/2$, a value significantly closer to the experimental window, $1.0 \leq z \leq 1.3$, than the value $z \approx 2$ numerically found in fully dissipative models, either at or off equilibrium. This result indicates that nondissipative dynamical couplings are necessary to develop a theory of natural swarms fully consistent with experiments.

Recent problems

1. Precise numerical assessment of hydrodynamic theories

PHYSICAL REVIEW LETTERS **123,** 218001 (2019)

Editors' Suggestion

Quantitative Assessment of the Toner and Tu Theory of Polar Flocks

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[5]*Beijing Computational Science Research Center, Beijing 100094, China*
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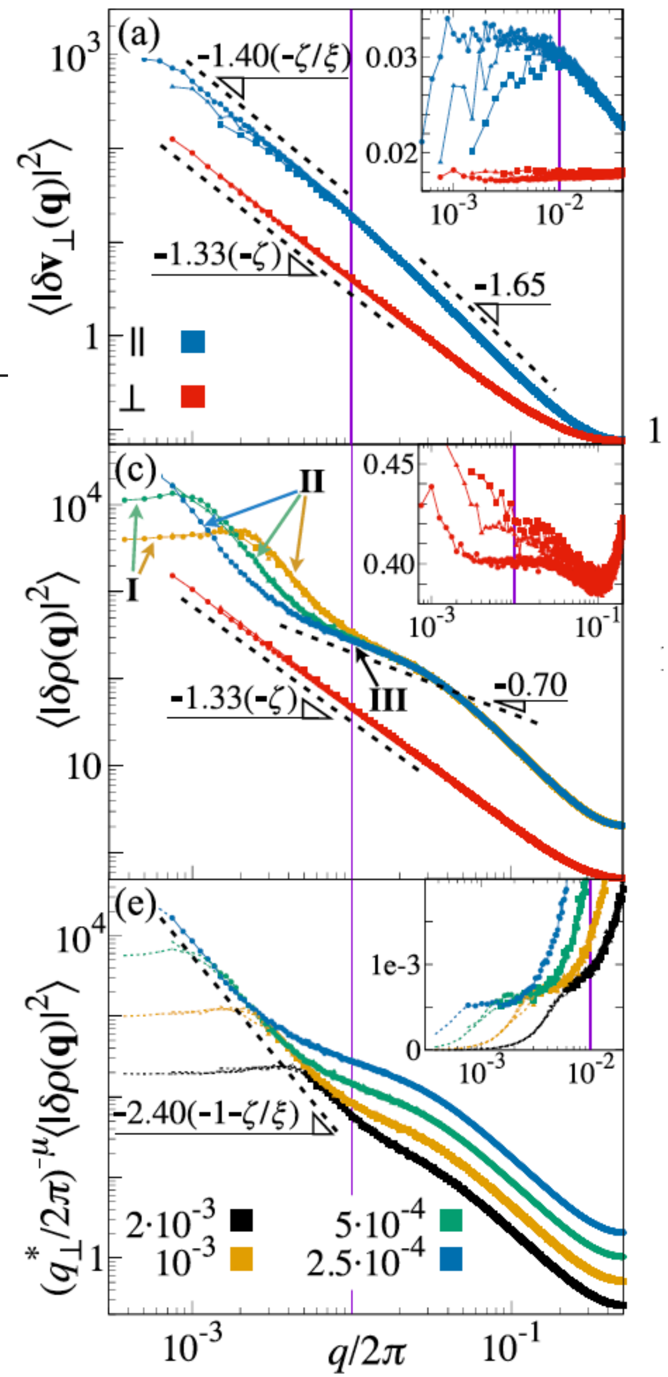
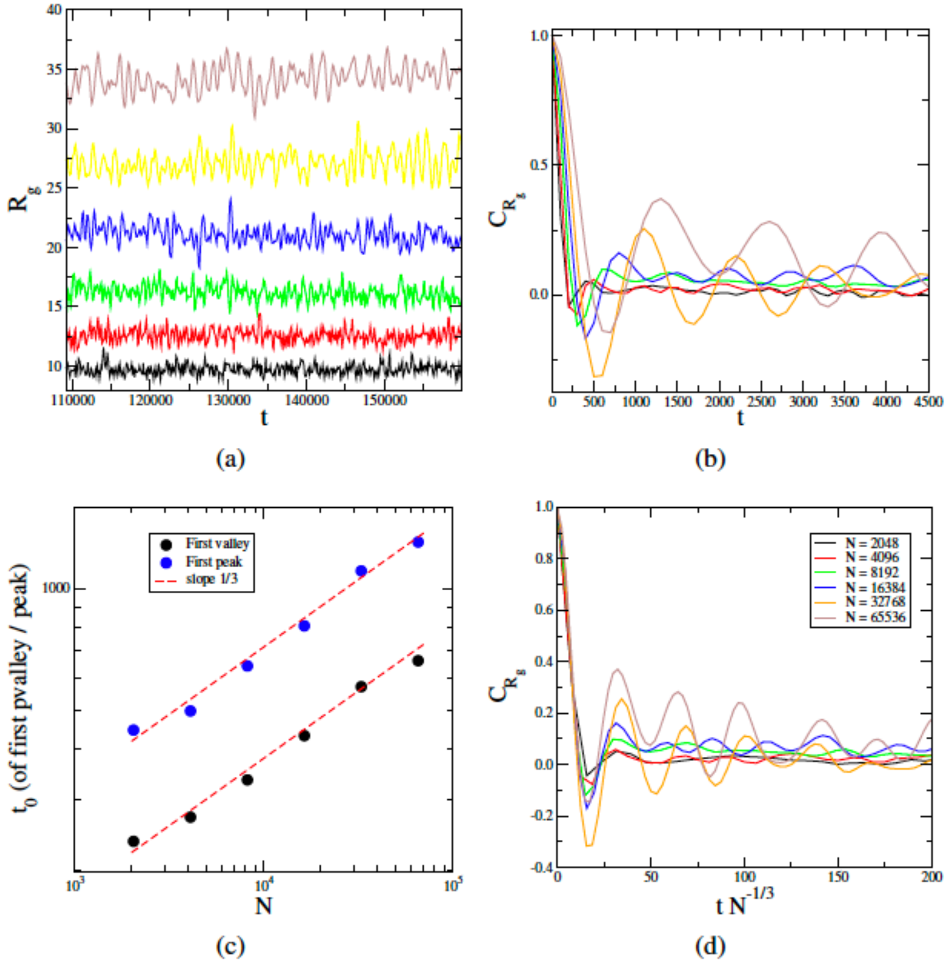
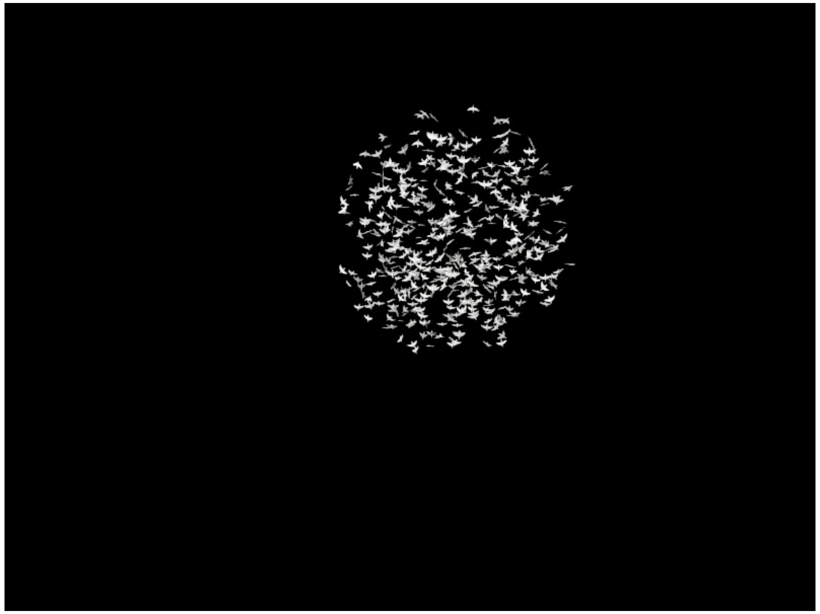
	$d=2$		$d=3$		$d\geq 4$
	TT95	Numerics	TT95	Numerics	Mean-field
χ	-0.20	$-0.31(2)$	-0.60	$\simeq -0.62$	$1-d/2$
ξ	0.60	0.95(2)	0.80	$\simeq 1$	1
$\zeta \equiv d-1 +2\chi+\xi$	1.20	1.33(2)	1.60	1.77(3)	2
z	1.20	1.33(2)	1.60	$\simeq 1.77$	2
GNFs	1.60	1.67(2)	1.53	1.59(3)	$1+2/d$



Recent problems

2. Surface tension in finite flocks





$$T_2 \propto \frac{R^{3/2}}{\sqrt{\sigma}}$$

Eq. droplets

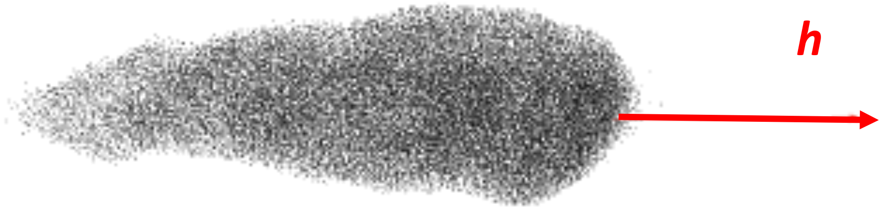
$$T \propto \frac{\langle R_g \rangle^{\upsilon/3}}{\sqrt{\beta}}$$

Flocks

$$2/3 < \upsilon/3 < 1,$$

Recent problems

3. Response to external fields (linear regime, finite perturbations, etc.)



Infrared SF divergence is suppressed

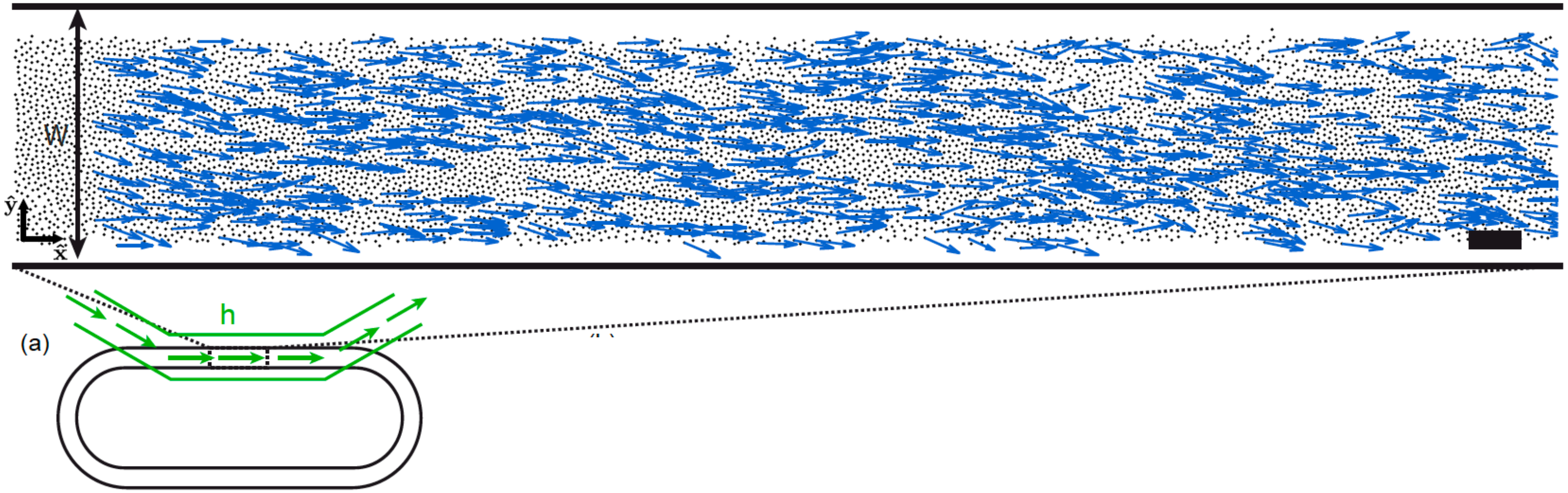
$$S_\rho(q) \sim \frac{1}{\langle \bar{b} \rangle q^z + h}$$

Diverging longitudinal susceptibility

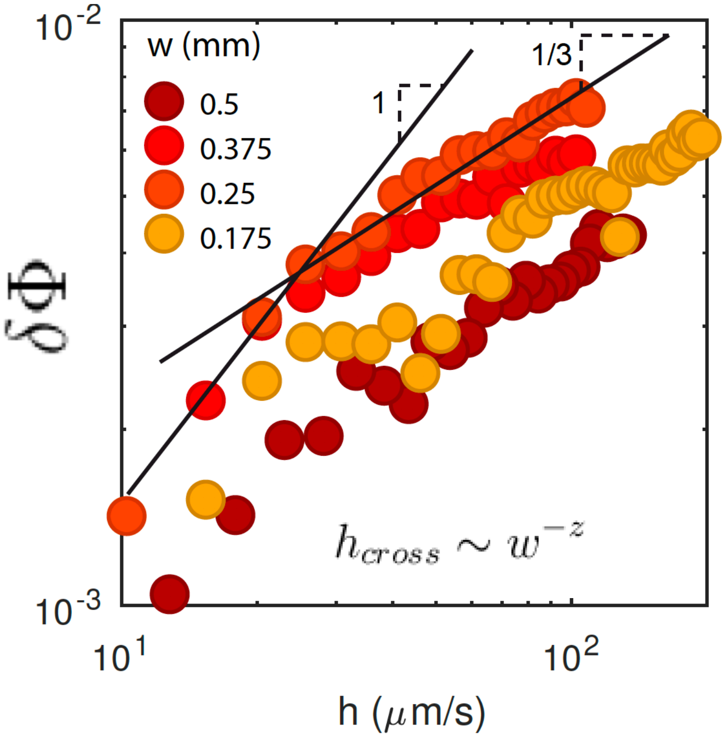
$$\chi_{//} = \frac{\delta\Phi(h)}{h} \sim h^{-\nu} \qquad h \gg L^{-z}$$

$\nu \approx 0.6$

Experiments: Longitudinal response and susceptibility



Colloidal Quincke rollers subjected to a flow field (in green) of speed *h*

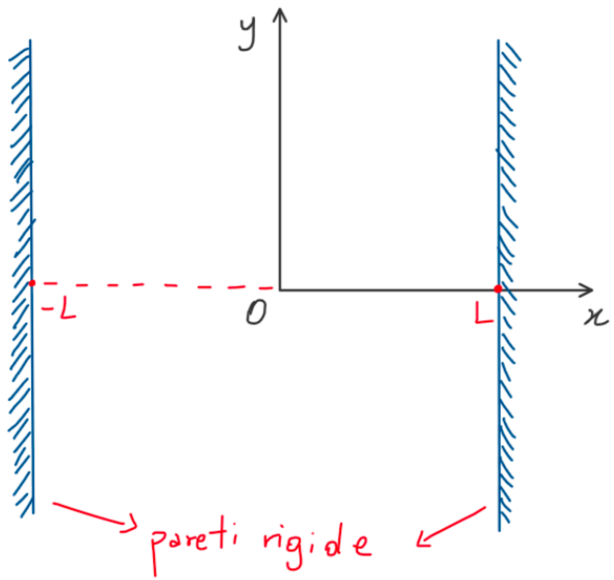


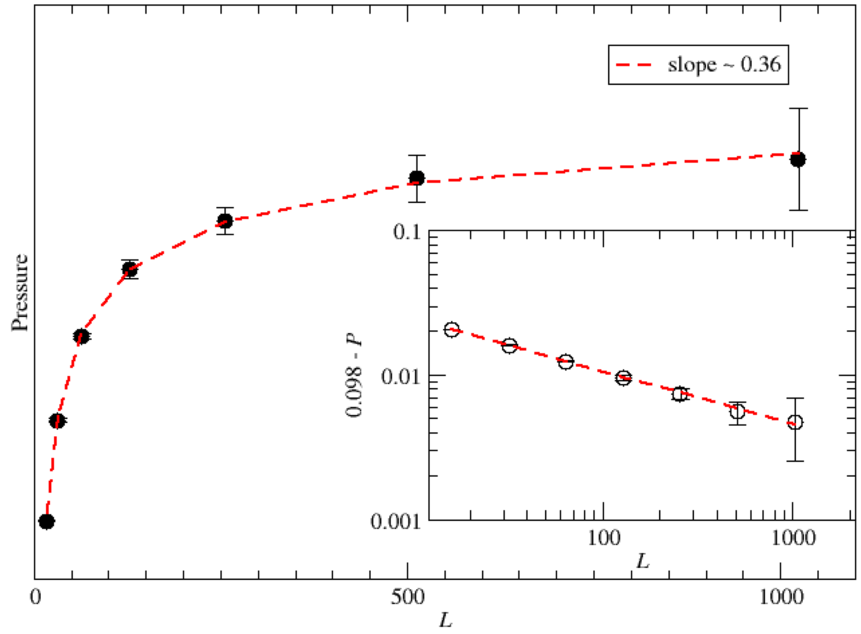
Theoretical predictions are expected to hold as long as the external field affects a finite fraction of particles.

A. Morin, D. Bartolo, PRX 8, 021037 (2018).

Recent problems

4. Confined systems, Casimir forces in Flocking





$$P \propto L^{\alpha-1}$$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