Wild swarms of midges linger at the edge of an ordering transition

Irene Giardina

Dept. of Physics, University of Rome La Sapienza & CNR-ISC

and

Initiative for the Theoretical Sciences, GC-CUNY

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CNR

Institute for Complex Systems

Dept. of Physics, Rome University La Sapienza

Collective behaviour in animal groups

movie by C. Carere - Starflag

Flocks

Global order

Collective response and coordination

*Pnas 105 (2008), Pnas 107 (2010),Ar**Xiv:1303.7097***

Swarms

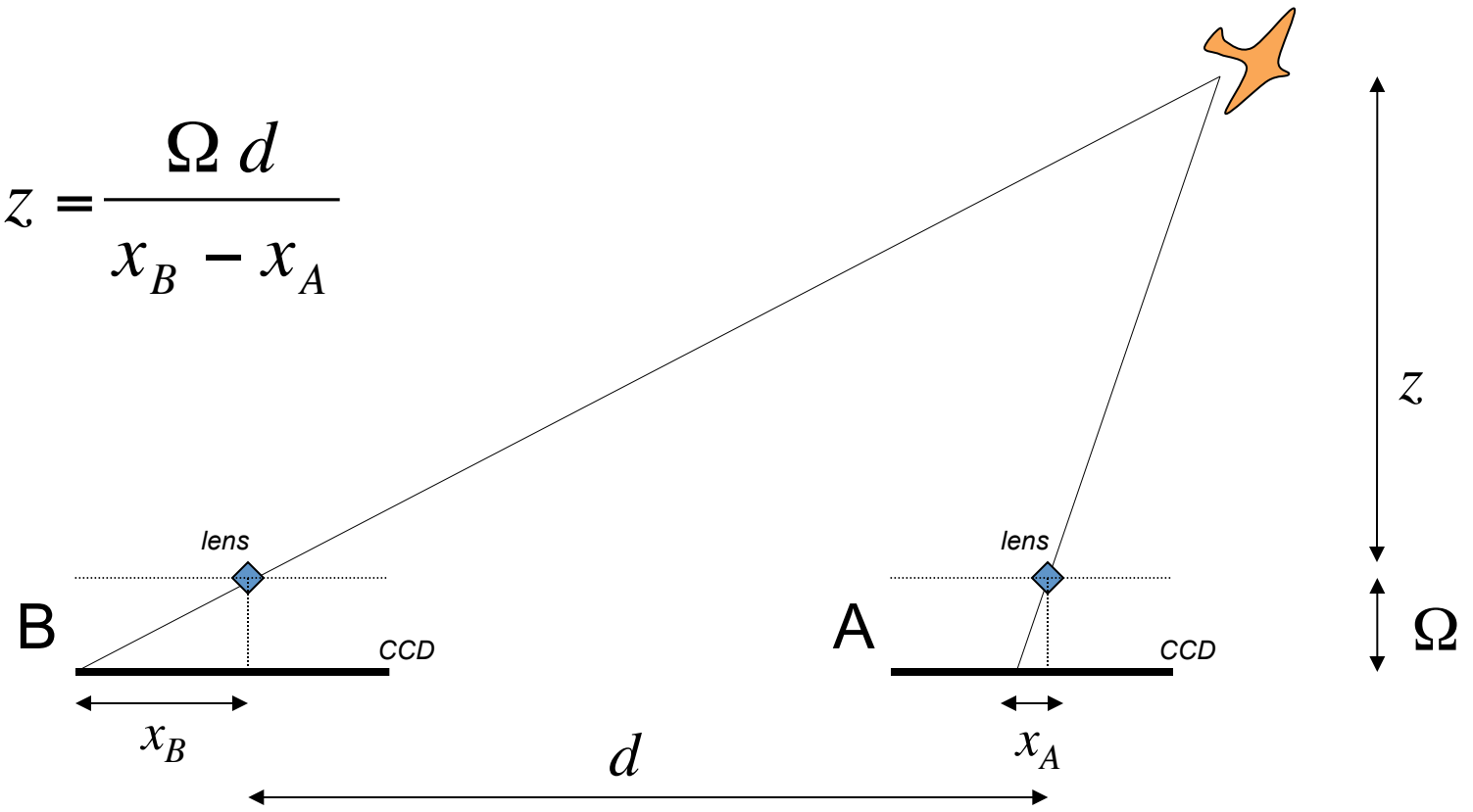
Is there anything `collective' ?

ArXiv:1307.5631

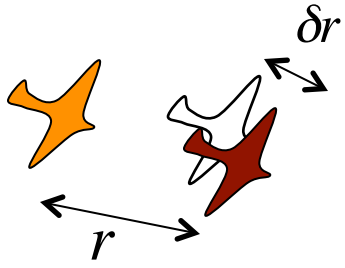
movie by S. Melillo, SWARM

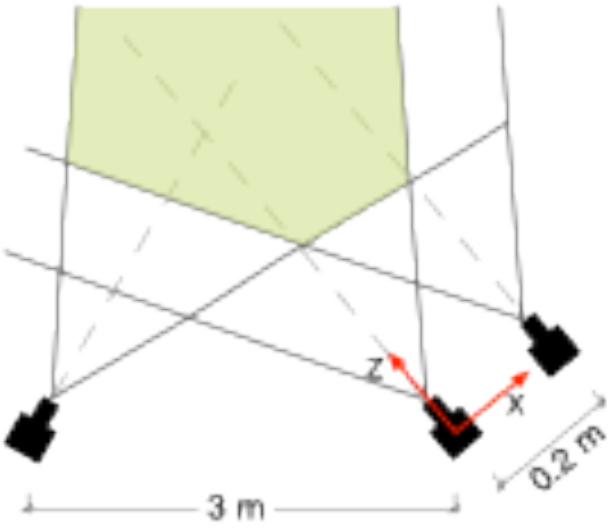
Stereo-Experiments

$$z = \frac{\Omega\, d}{x_B - x_A}$$



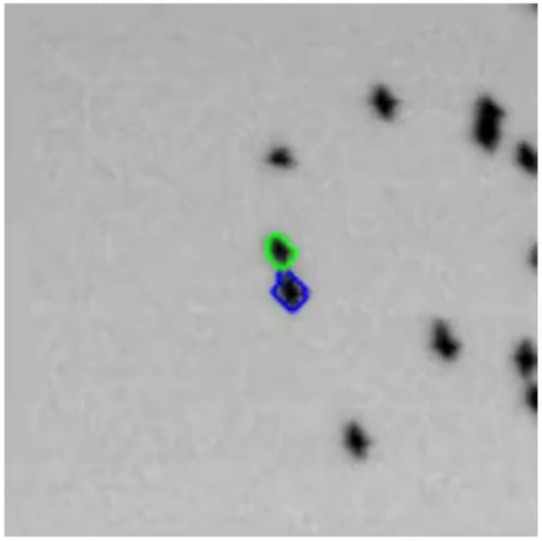
error on relative distances: $\delta r \sim \frac{z^2}{\Omega\, d}\ \delta s$



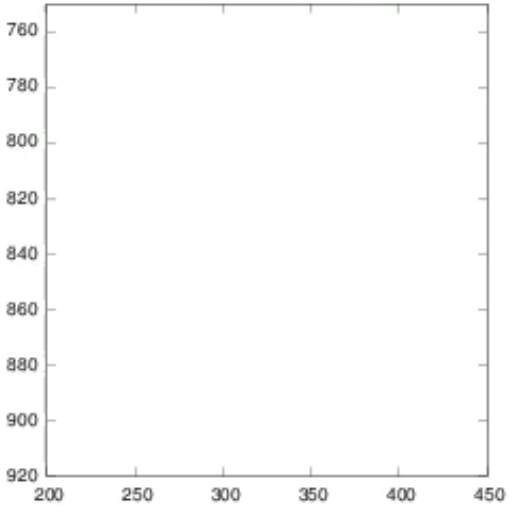

z
x
3 m
0.2 m

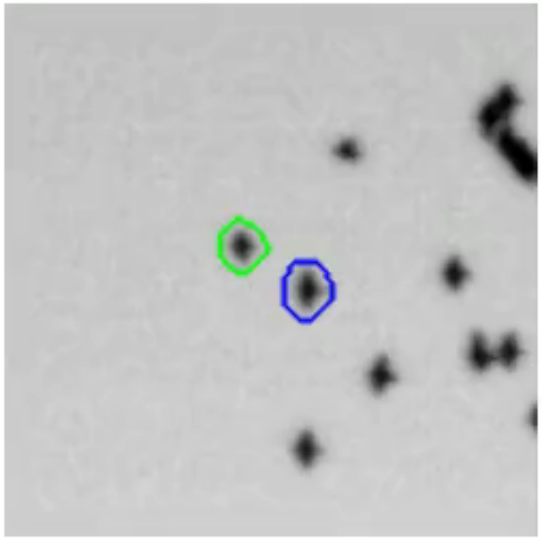
the real enemy: blobs

frame 1

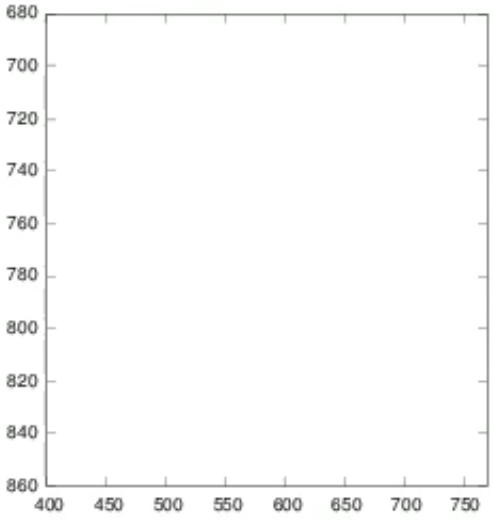


right camera

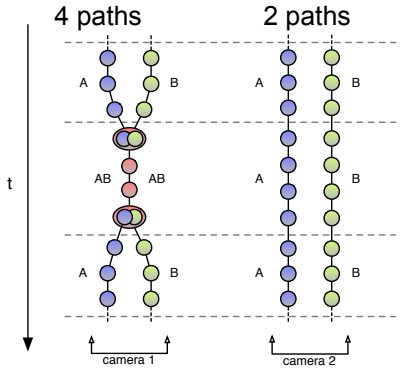




left camera



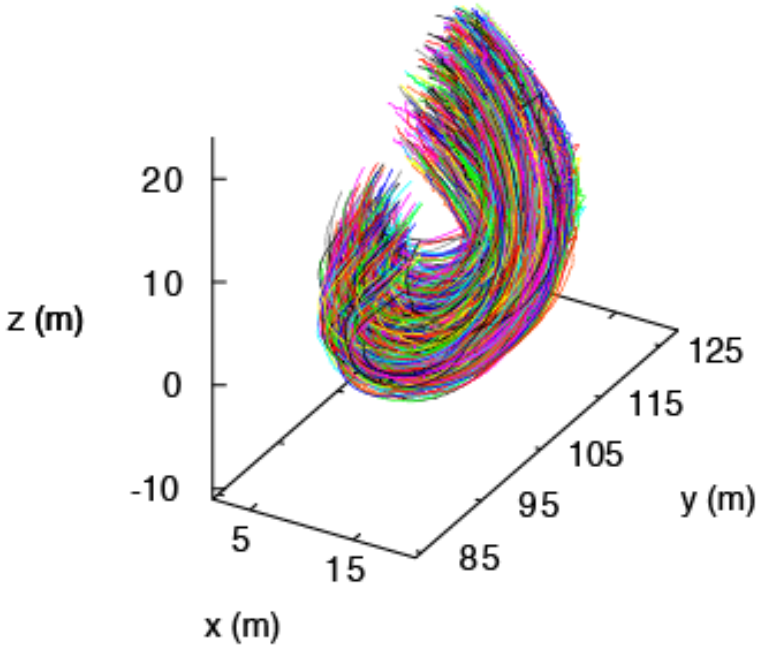
3D tracking: global multi-path recursive algorithm

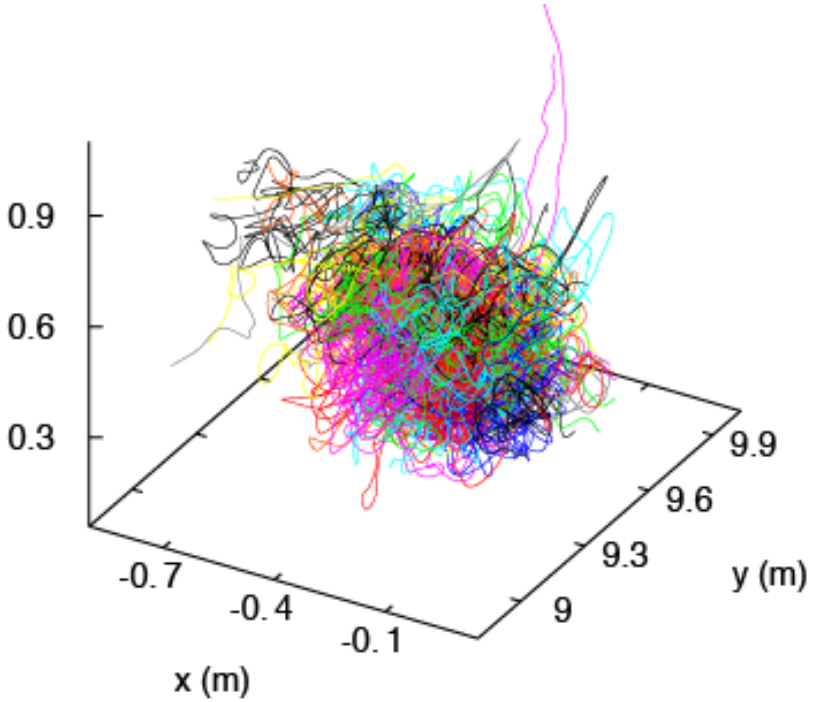


score matrix

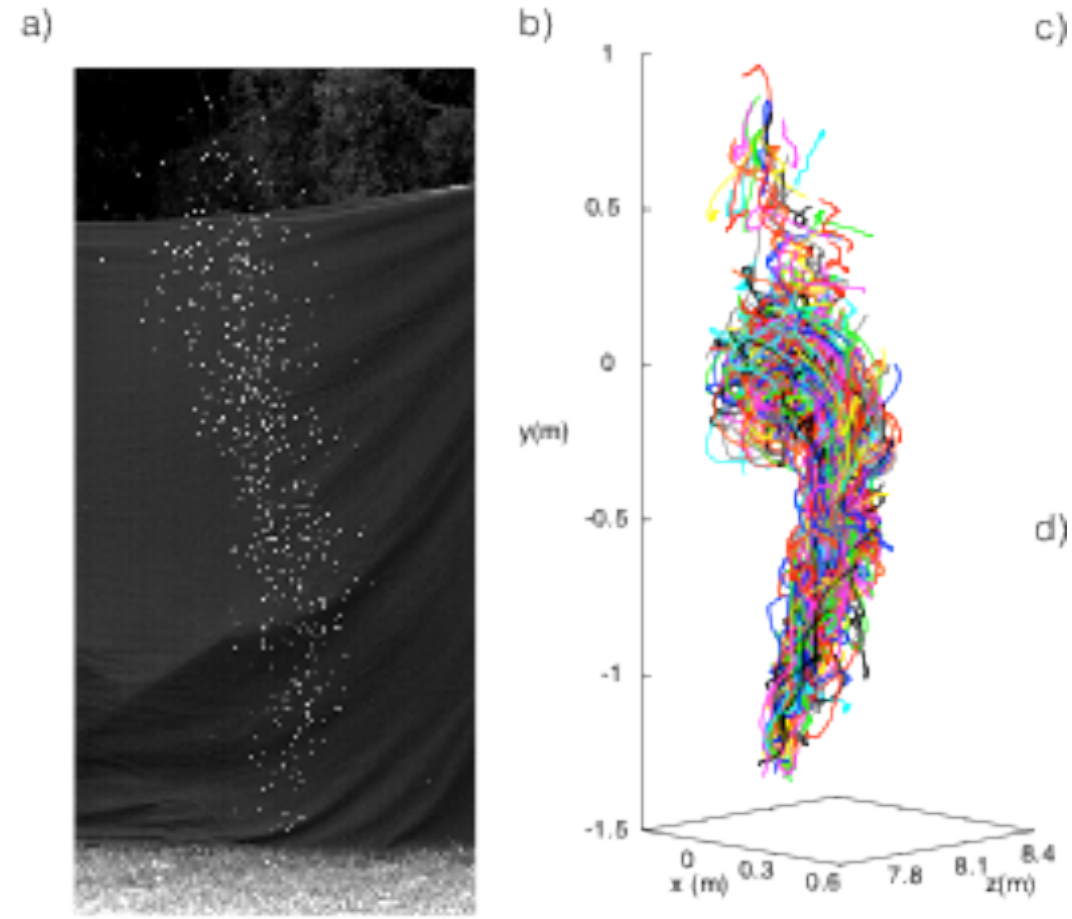
	A	B
AA	10	4
AB	7	7
BA	7	7
BB	4	10

2 real birds

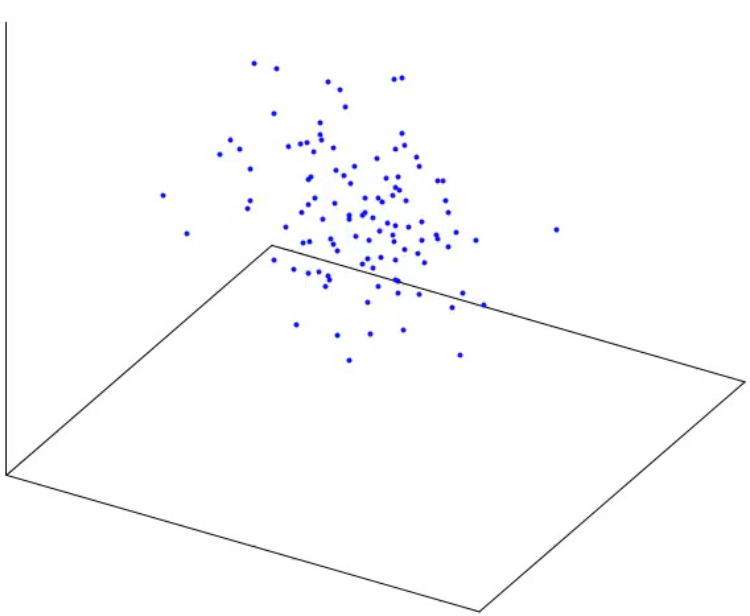


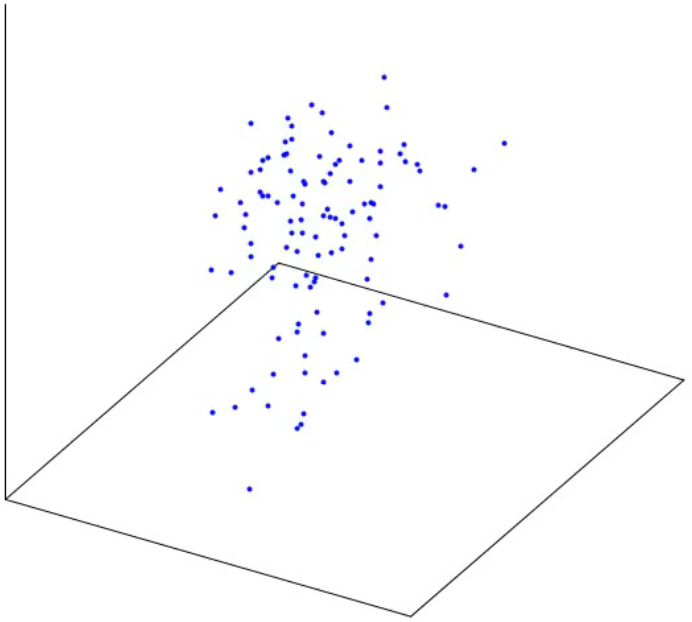


Attanasi et al, arXiv:1305.1495 (2013)

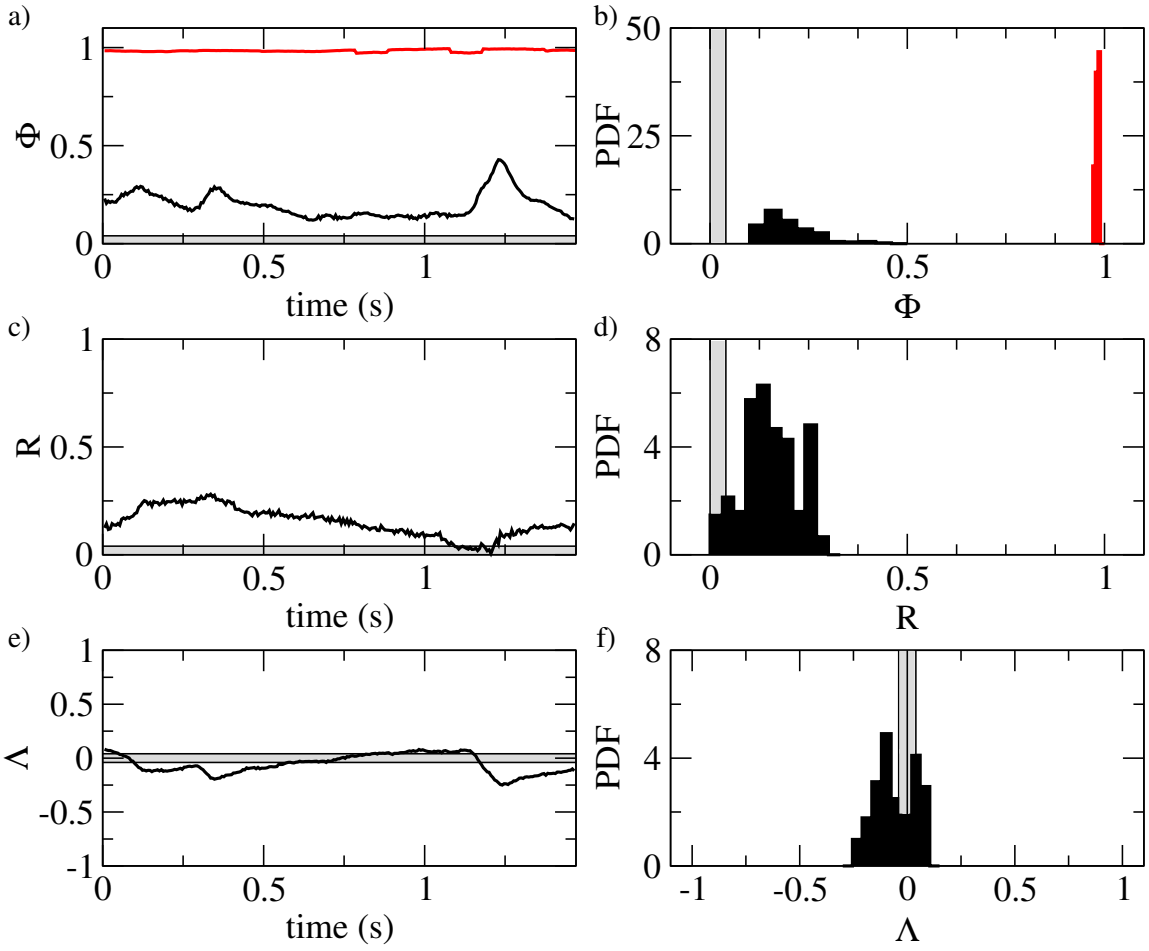

a)
b)
c)
d)
1
0.5
0
-0.5
-1
-1.5
y(m)
0
0.3
0.6
7.8
8.1
8.4
x (m)
z(m)

natural vs. non-interacting swarm





can you tell who is who?



no global order

what is important for the group?

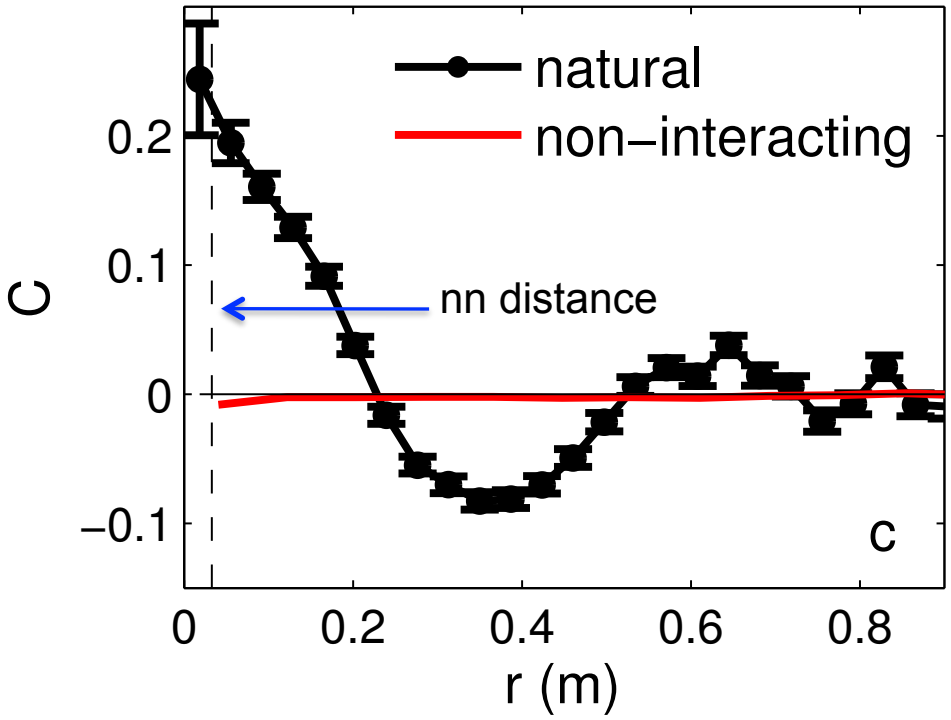
1. we synchronize our behaviour (order)
2. we synchronize our *changes* of behaviour (?)

move the focus from the mean behaviour to the fluctuations wrt the mean

correlation function

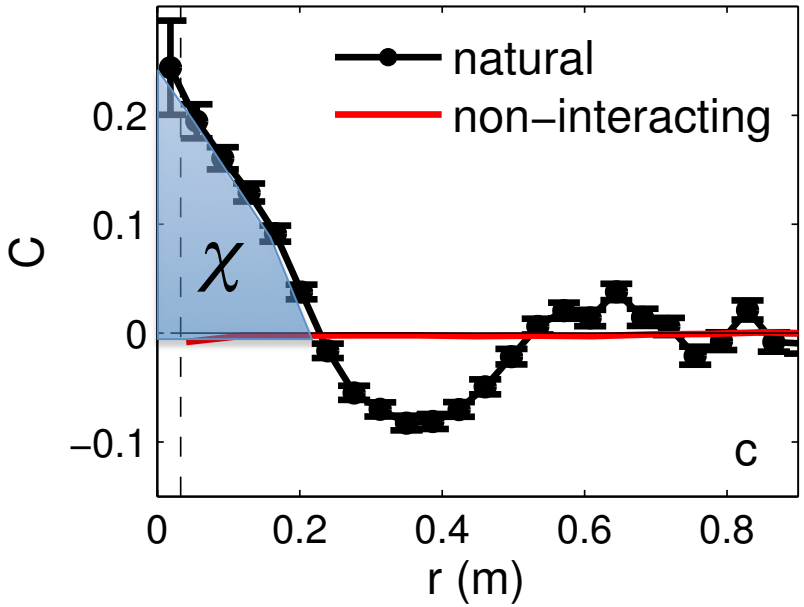
$$C(r) = \langle \vec{u}(0) \cdot \vec{u}(r) \rangle \qquad \vec{u}_i = \vec{v}_i - \vec{V}$$

velocity fluctuation



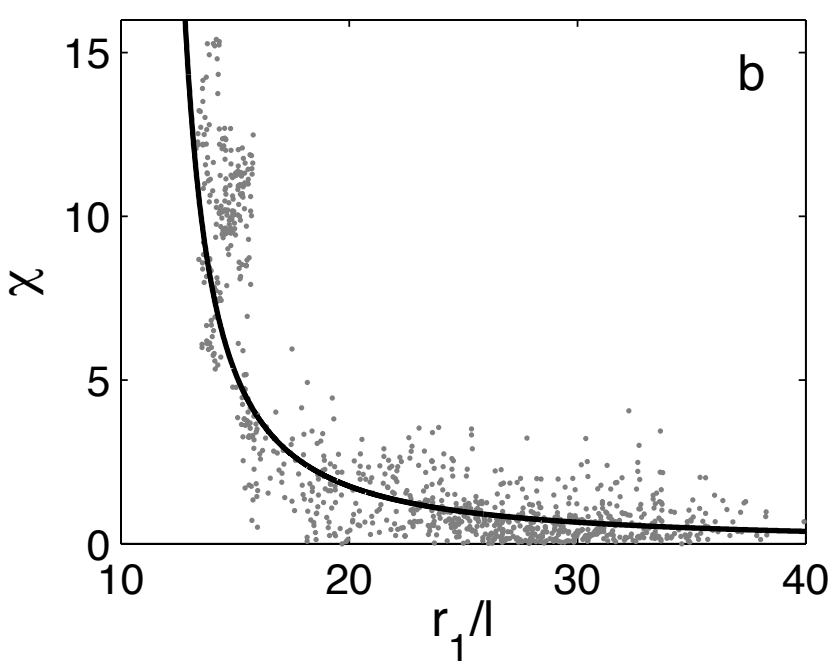
despite the lack of order, behavioural correlations extend much further than each individual's nearest neighbours

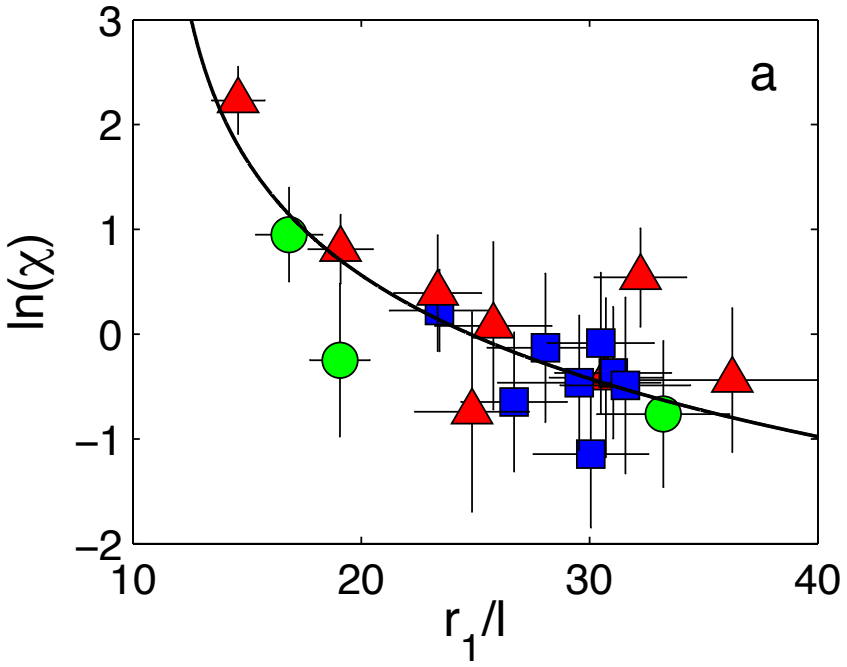
Integrated correlation - susceptibility



χ is the total amount of correlation in the system and it is connected to the collective response

Susceptibility increases with density





nearest neighbour distance in units of body length

the closer midges are, the more they interact, the larger the correlation: metric interaction

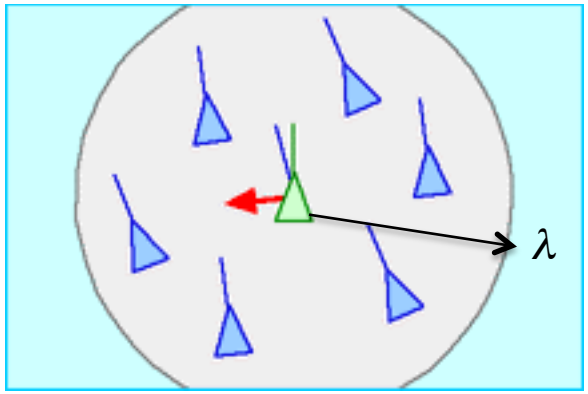
- swarms display no collective order
- yet, velocity correlations are very strong
- the amount of correlation grows with decreasing n.n. distance
- an effective alignment force **must** be present

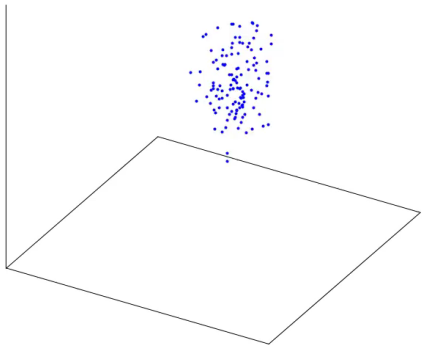
Alignment models

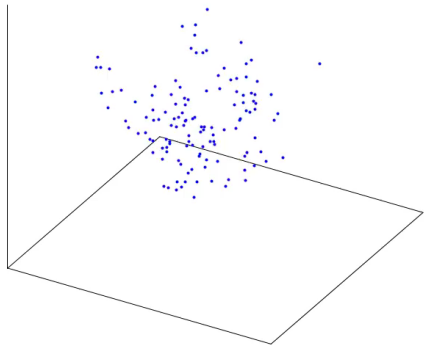
$$\vec{v}_i(t+1) = \vec{v}_i(t) + \sum_{j \in \lambda_i} \vec{v}_j(t) + \vec{\xi}_i$$

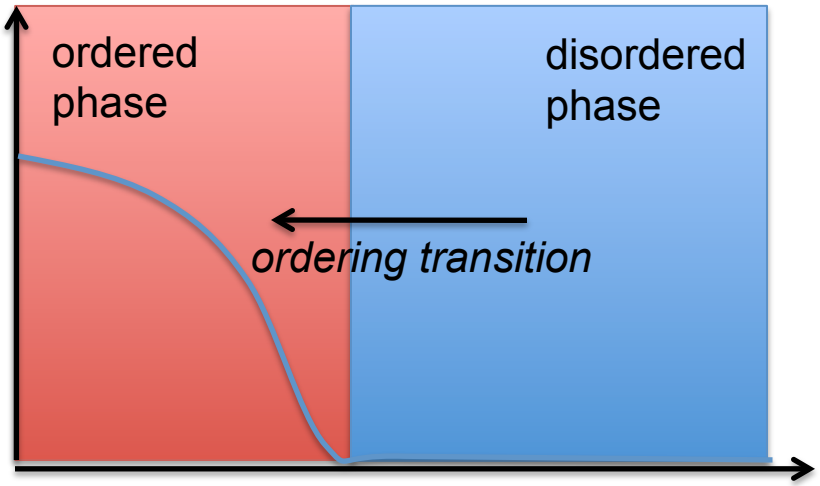
Vicsek model

+
harmonic potential
(marker)

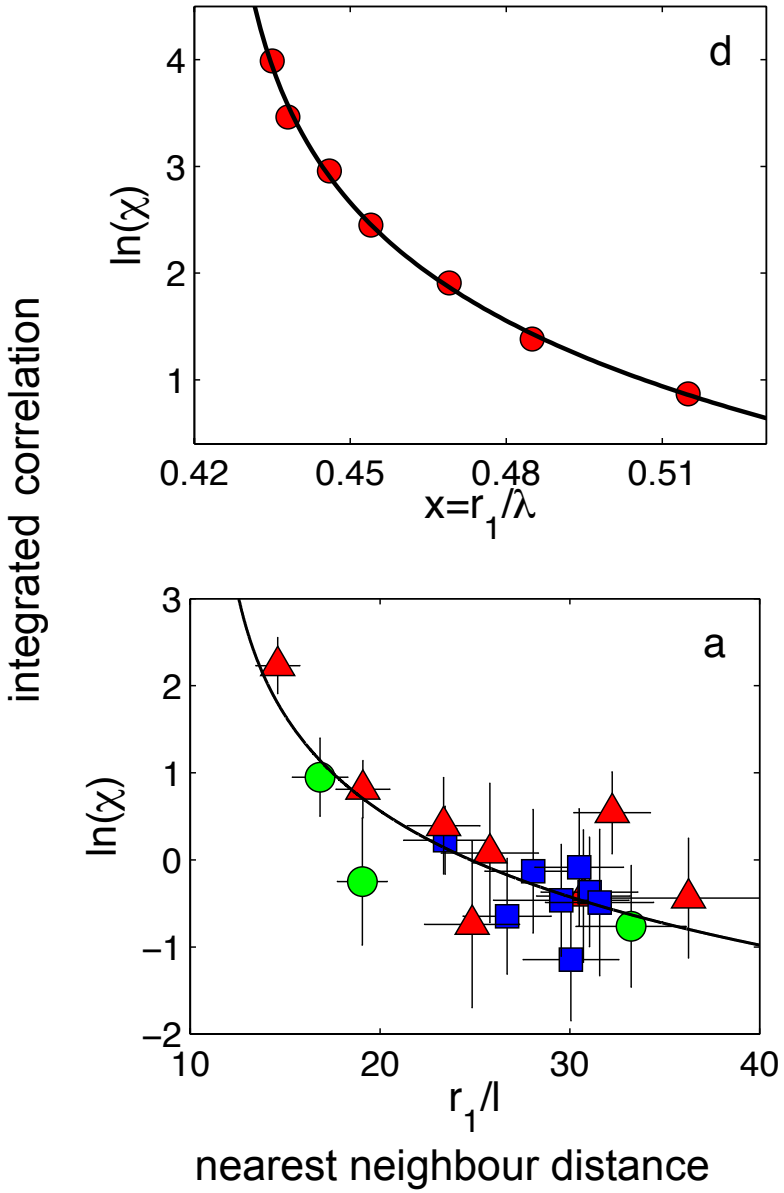








Order is not the only consequence of alignment

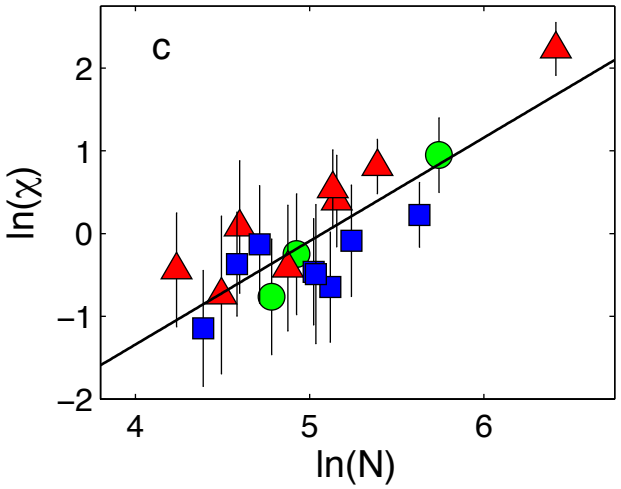


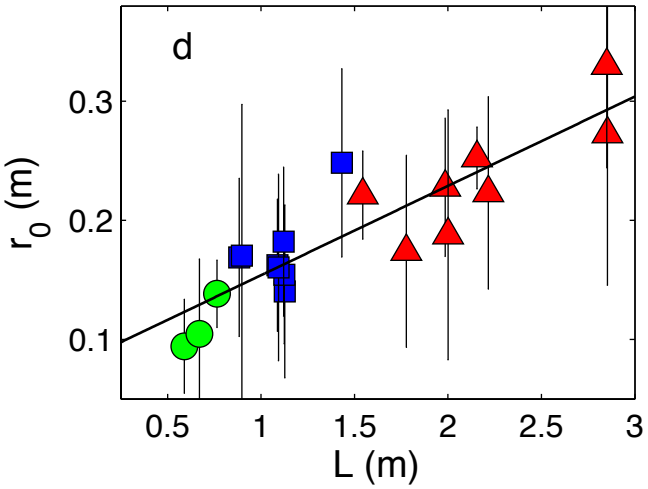
disordered phase

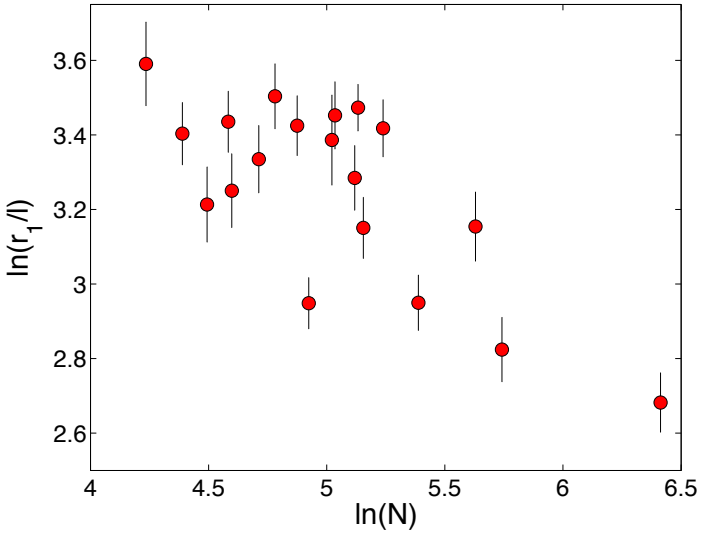
the degree of correlation increases as we approach the transition from above

swarms are disordered
but there is an
underlying ordering transition

How far are natural swarms from the critical ordering transition ?



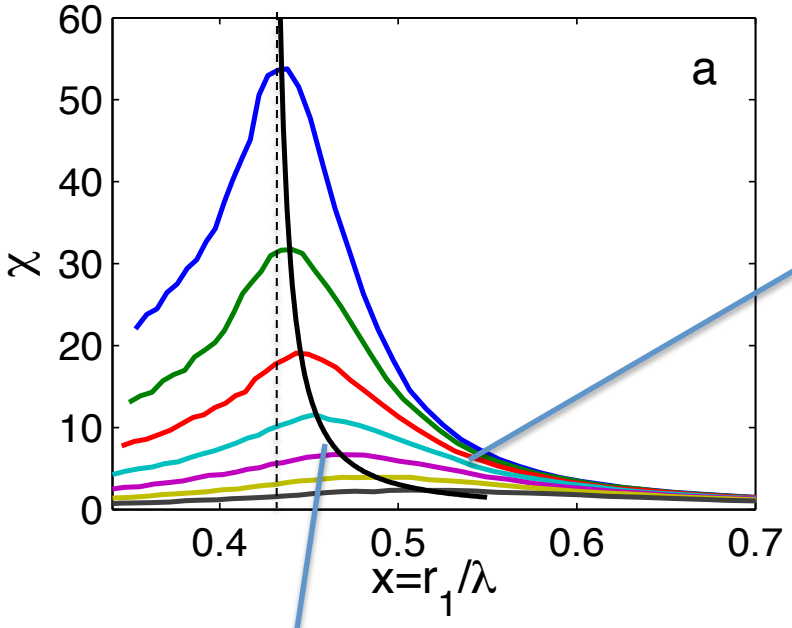


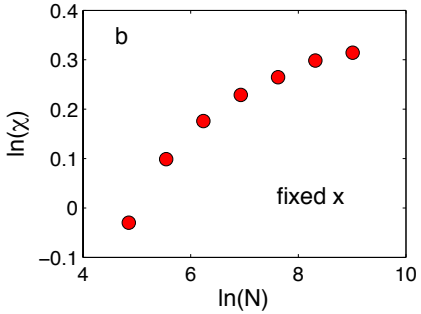


swarms are in the critical region

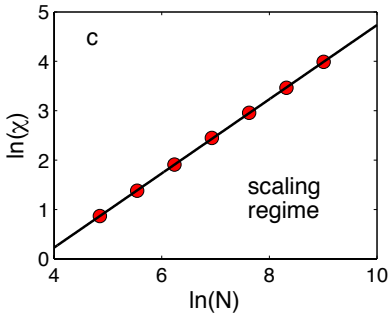
size and density are NOT independent

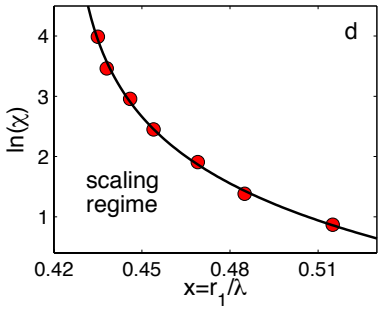
Revisiting finite size scaling





it is the pair *x,N* that tells me how `critical' is the system





to get scaling behavior *x,N* must be close to the critical line

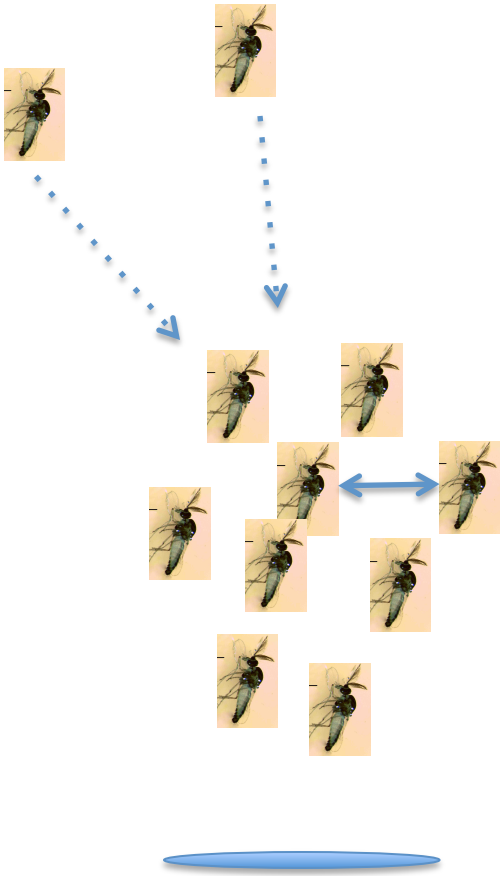
$$x \approx x_c + \frac{1}{N^{1/3\nu}}$$

as found in data

swarms are effectively critical

density and size are tuned as to achieve nearly maximal susceptibility at that size ⟶ collective response on the group scale

What is the mechanism fixing density vs. size ?

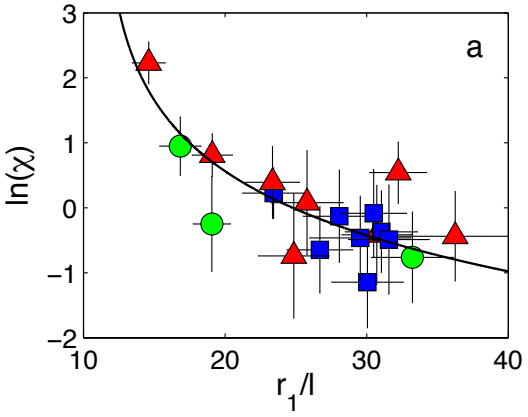


1) something fixes the density and the size increases up to the size sustainable with the correlations present at that density

2) given a number of insects attracted to the marker the density increases up to the value that grants sufficient correlation to make the swarm stable

size and density self-adjust to make the swarm stable

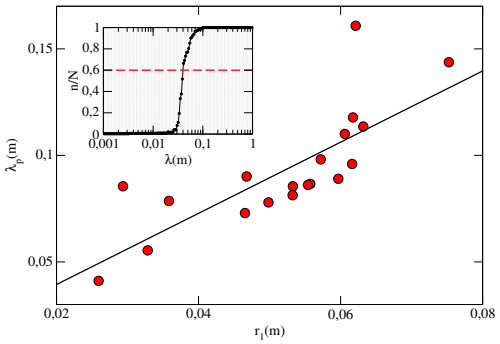
Estimate of the interaction range



let's use the Vicsek scaling relation

$$\chi \sim \frac{1}{(x - x_c)^{\gamma}} \qquad x = \frac{r_1}{\lambda}$$

$$\frac{r_1^c}{l} \in [9.0 : 13.5]$$



percolation argument

$$\frac{r_1^c}{\lambda} = 0.6$$

we estimate an interaction range $\lambda \sim 15 - 22l \sim 2 - 5cm$

consistent with male-male auditory response (1-1.5 cm)

- collective behaviour and collective order are **not** the same

- swarms are disordered but exhibit significant quasi-critical correlation

- we believe that correlation, rather than order, is the true signature of collective behaviour, as large correlations enable the group to respond collectively to stimuli/perturbations

- however, it is crucial to pin down experimentally the relationship between correlation and response

towards a fluctuation-dissipation theorem for biological systems?

COBBS group

Massimiliano Viale
Stefania Melillo
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Andrea Cavagna

Irene Giardina

Dasyhelea flavirons

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