Collective motion

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Principal collaborators

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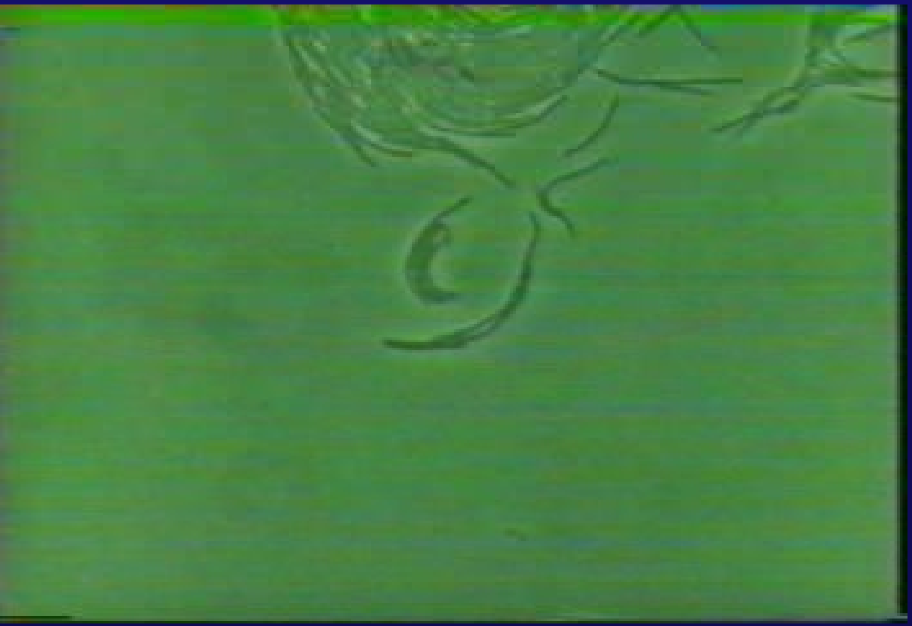
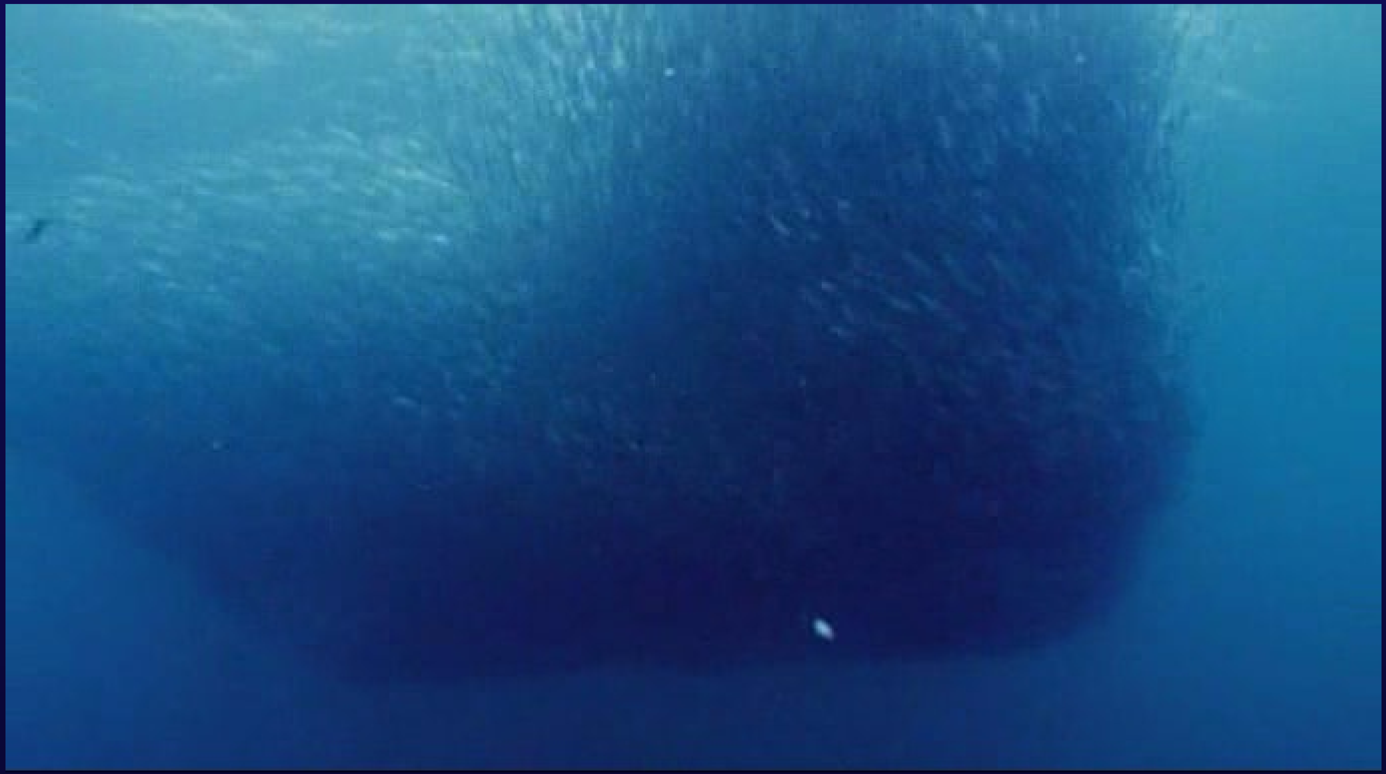
P. Szabó and G. Szöllösi,

Collective motion of



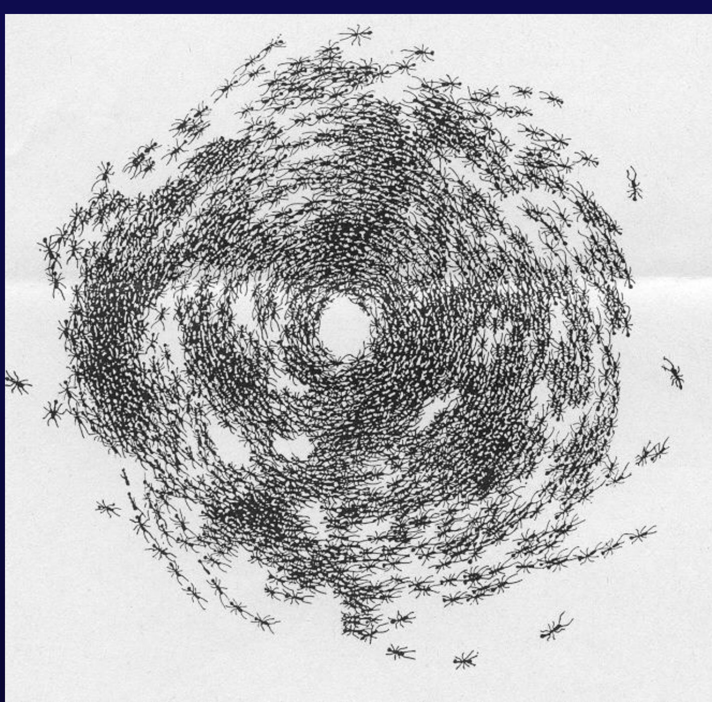


Collective motion

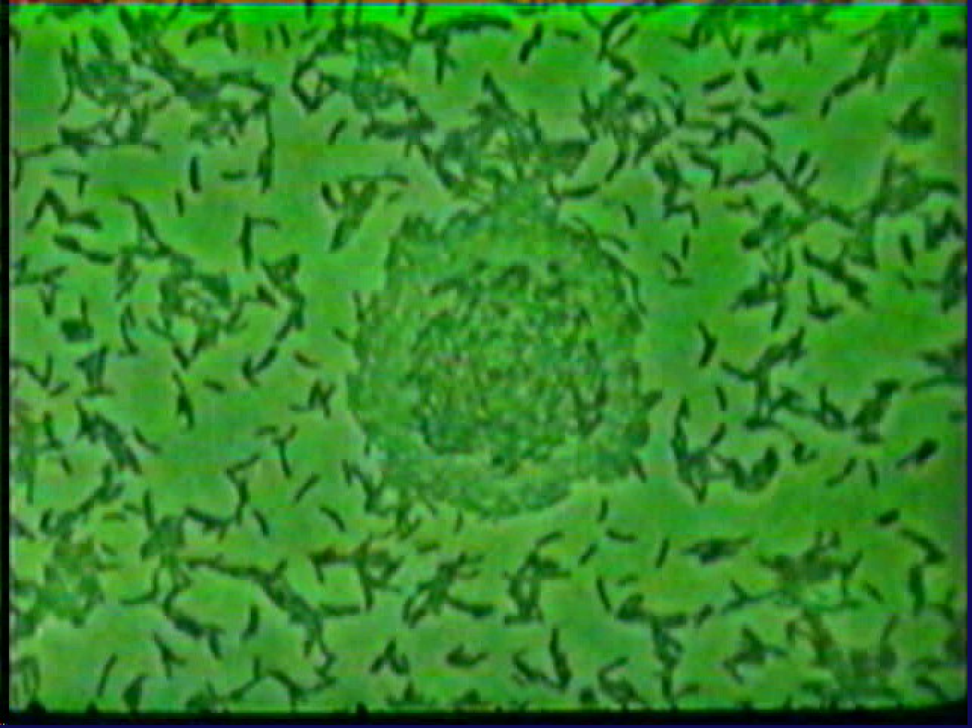
D. Winter

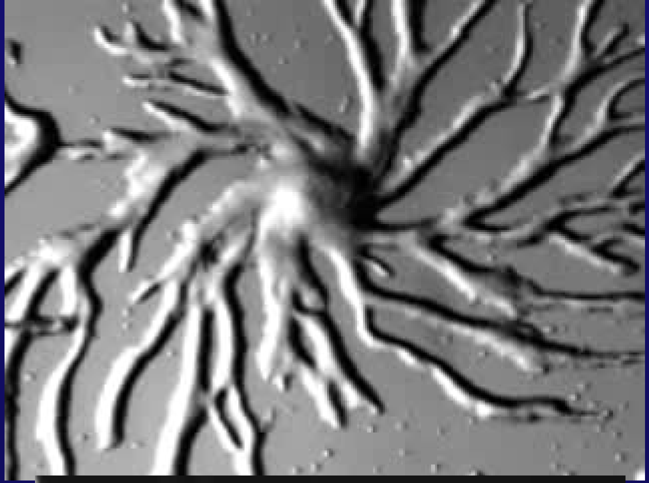
BBC
Massive nature

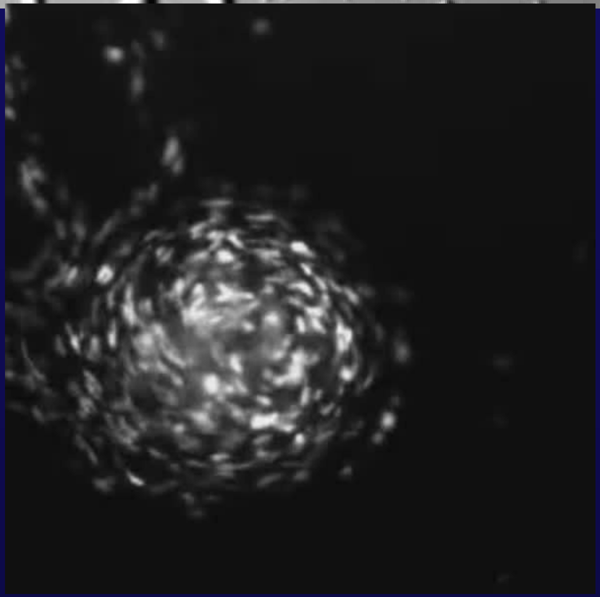
niversal pattern of motion



Locusts (Buhl, Sumpter, Couzin et al, *Science*, 2006)

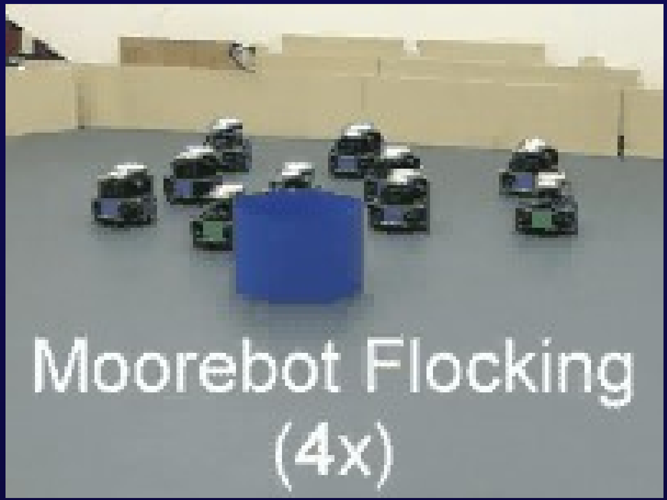






3d

J. Perrin, Microcosmos


Moorebot Flocking
(4x)

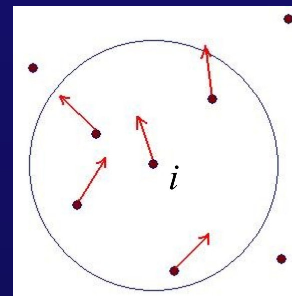
Observation: complex units exhibit simple collective behaviours

(the nature and “rules” of interactions are simpler than the units which produce them)

Our goal: find the basic features/laws of collective motion

Swarms, flocks and herds

- **<u>Model*:</u>** The particles



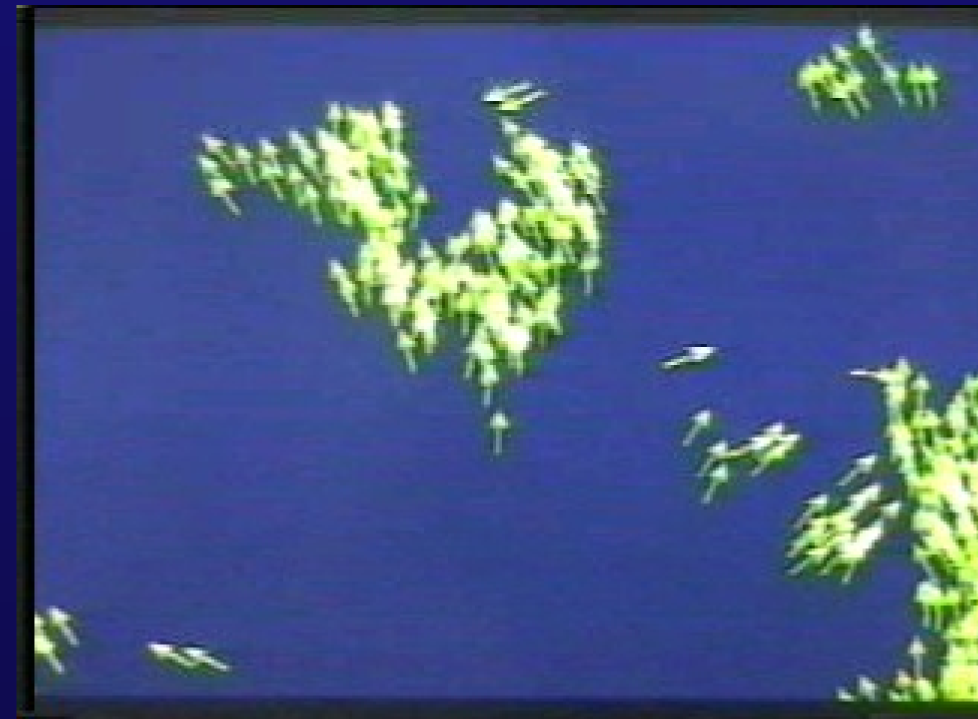
  - maintain a given absolute value of the velocity v_0
  - follow their neighbours
  - motion is perturbed by fluctuations $\vec{\eta}$

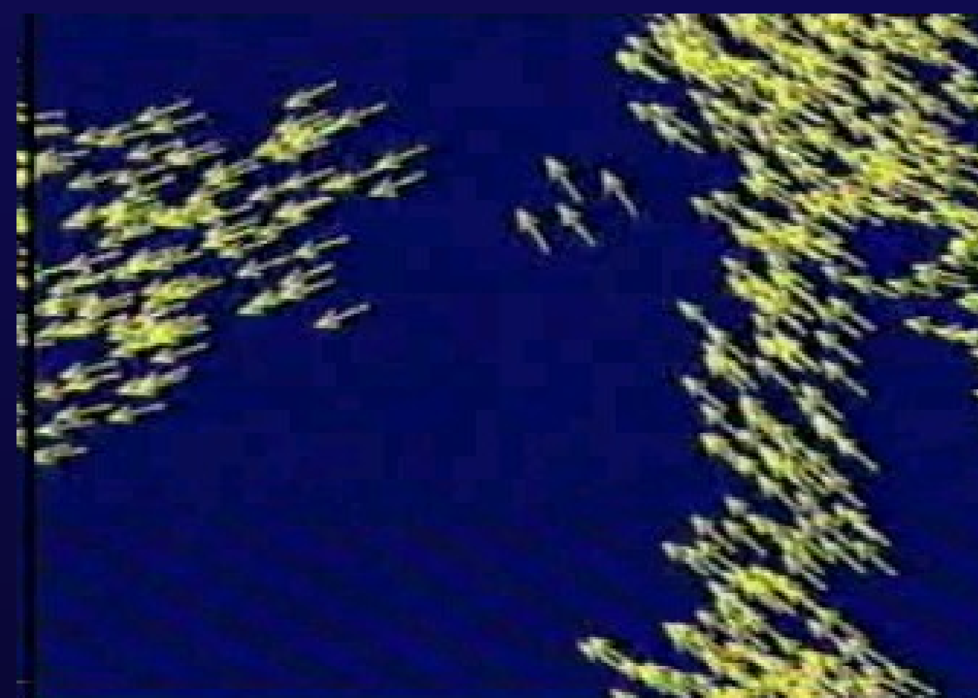
$$e_i(t+1) = E\left[E\left[\left\langle e_j(t)\right\rangle_j\right] + \eta(t)\right]$$

(E converts a direction into a unit vector)

- Follow the neighbours rule is an abstract way to take into account interactions of very different possible origins

- **<u>Result:</u> *ordering is due to <u>motion</u>***

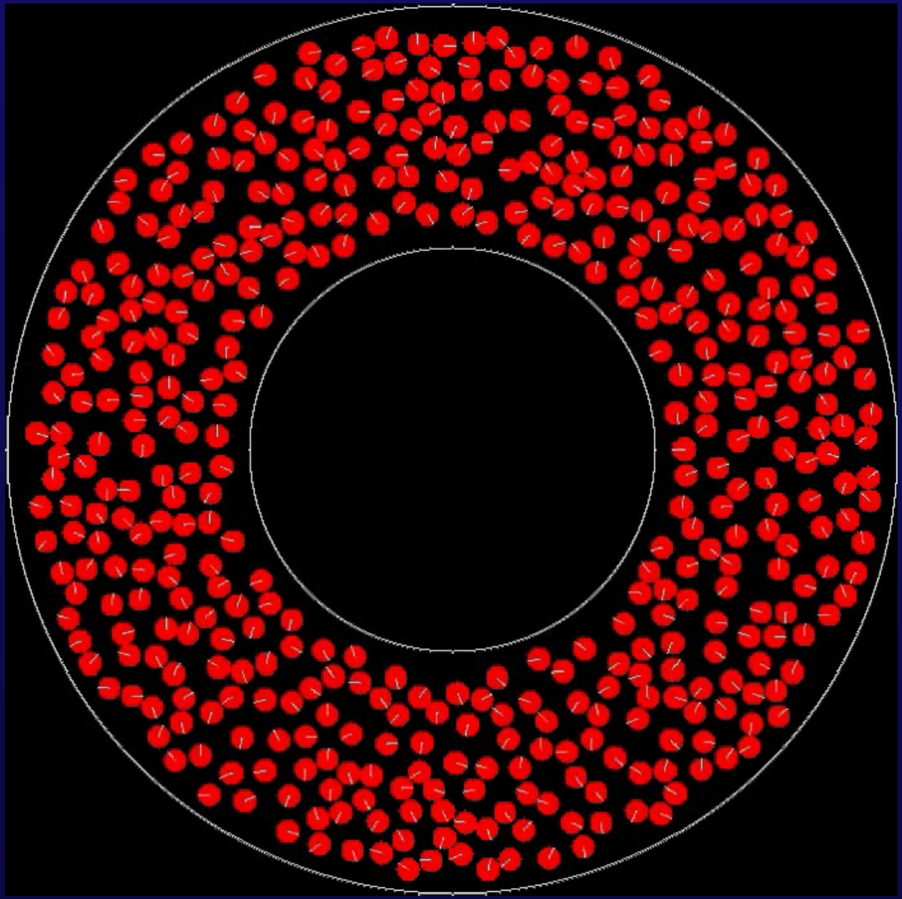




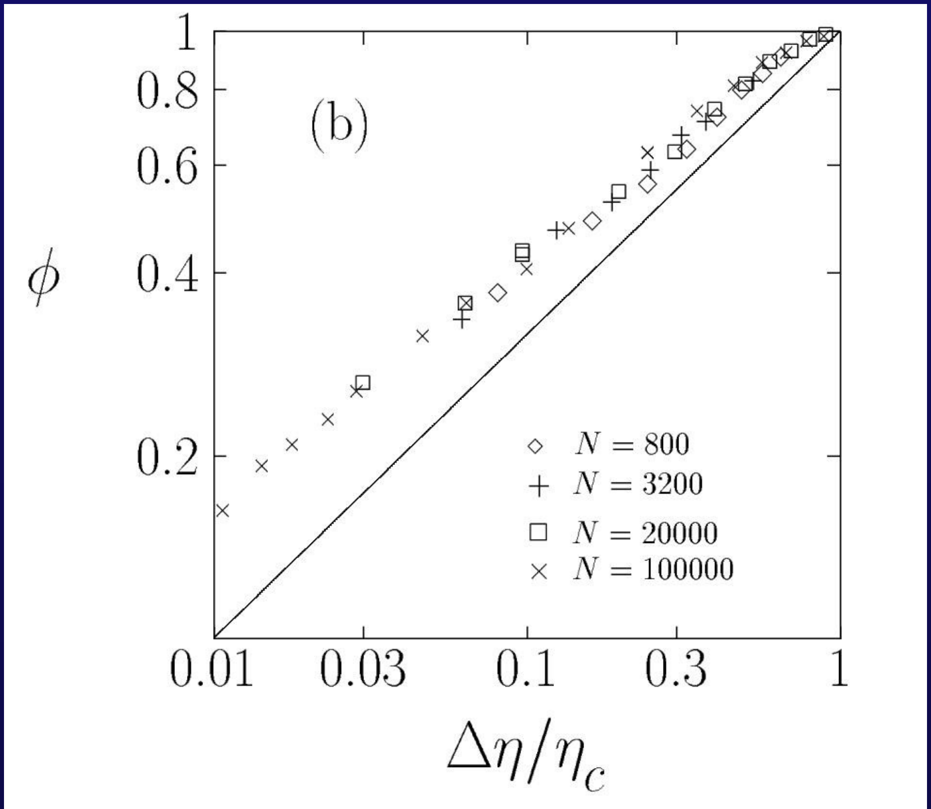
* T.V, A. Czirok, E. Ben-Jacob and I. Cohen, PRL, 1995

Lessons:

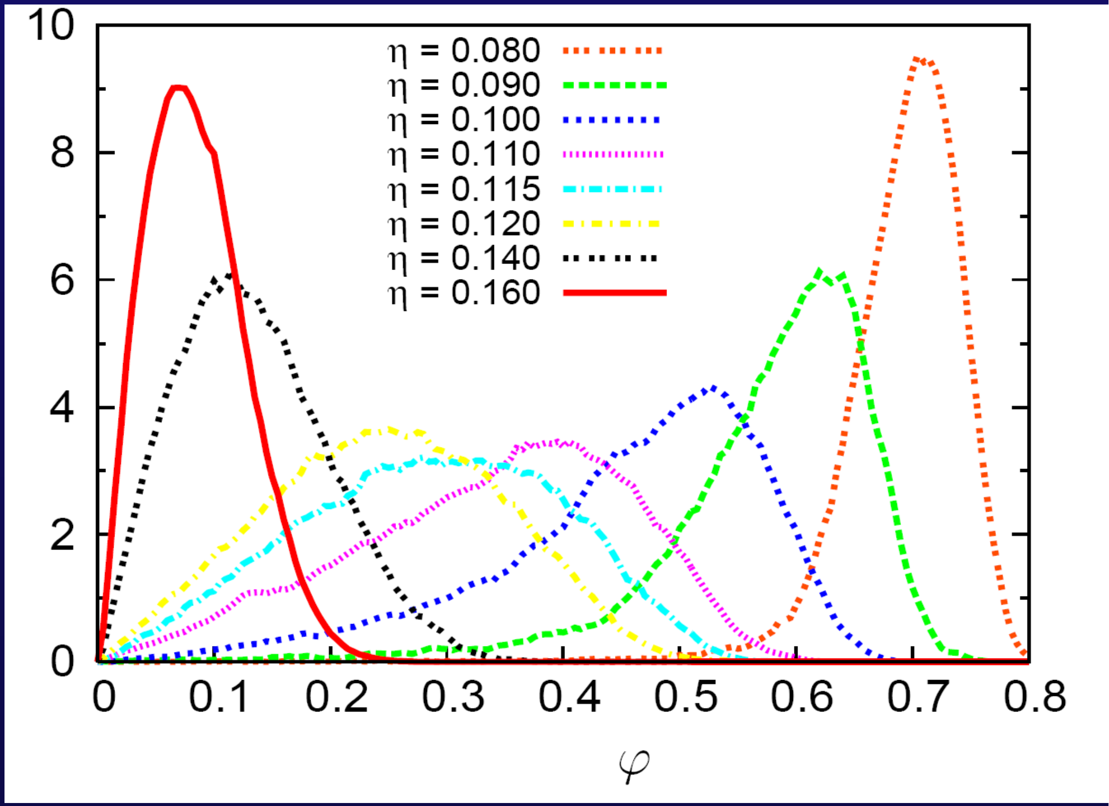
1. Some patterns of motion are universal
2. Simple models can reproduce this behavior
3. A simple noise term can account for numerous complex deterministic factors
4. In many cases ordering is due to motion!



Continuous transition in the scalar noise model for small velocity



Order parameter versus noise

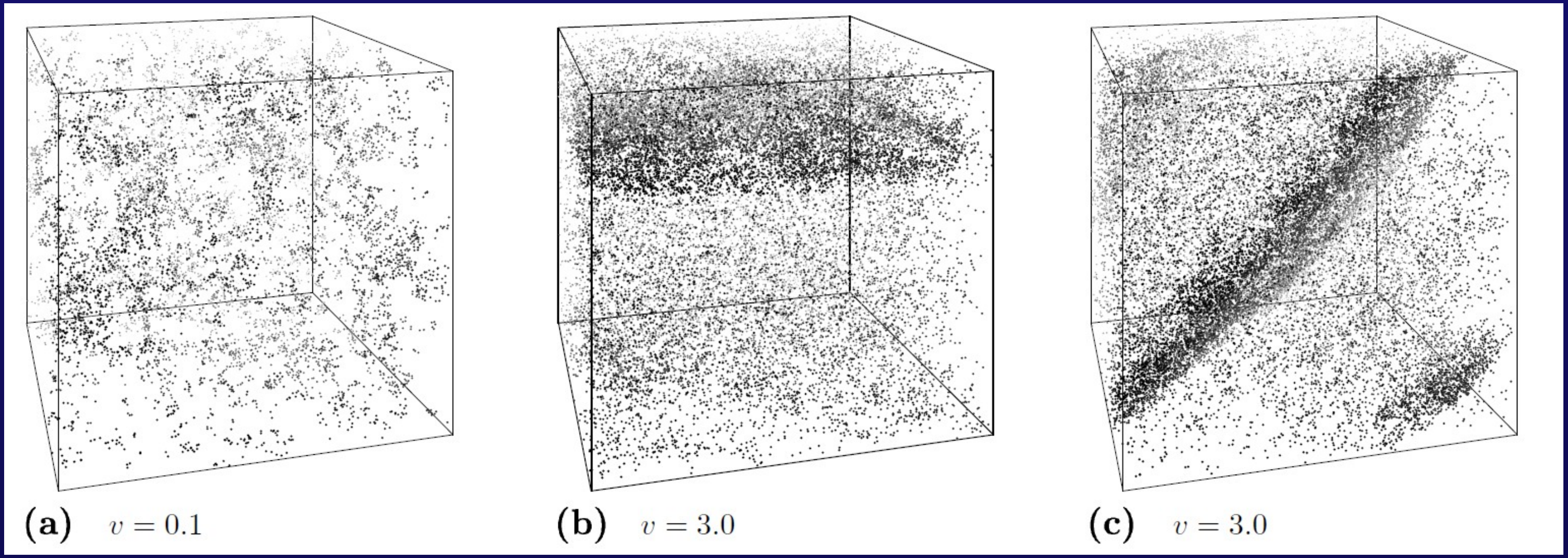


Probability distribution function
of the order parameter for various noise levels

J. Phys. A 1997
A. Czirok, H. E. Stanley and T.V.

Physica A, 2007 Jan.
M. Nagy, I. Daruka and T.V.

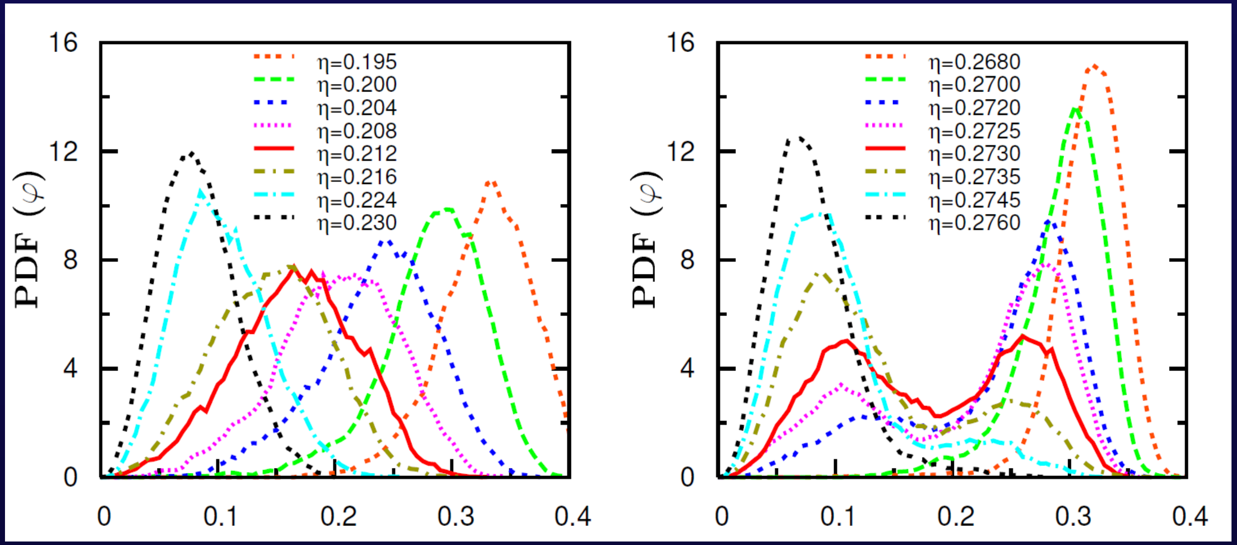
And in three dimensions? … very similar!



v=0.1

“single humped”

i.e, second order transition



v=0.5

“double humped”

i.e, first order transition

Probability distribution of the order parameter

Visualizations of various 3d versions

Scalar noise
(1995 PRL Vicsek et al model)
Low velocity (v=0.1)

Scalar noise model
High velocity (v=3.0)
(motivated by 2004 PRL Gregoire, Chate)

Visualizations of various 3d versions Reynolds-type models

More “realistic” model
(***with repulsion + attraction***
Reynolds, Couzin and others)
Periodic boundary conditions

More “realistic” model

In a cylinder

More “realistic” model

Birds’ view

Visualizations of various 3d versions
Flocking with turning
Stereo view

Collective turning is introduced through coupling of the acceleration of the particles

Weak coupling (close to ’95 PRL scalar noise model)

Regular view Stereo view Yet another stereo view

“Critical” coupling (new model)

Regular view Stereo view

A further lession:

Apparently during evolution the “parameters” of birds are “tuned” to values keeping a flock close to a “critical state” (to a state with large fluctuations) such as the aerial displays of starlings

Such a state seems to be optimal for the propagation of information which is useful from the points of

- exploration
- collective decision making

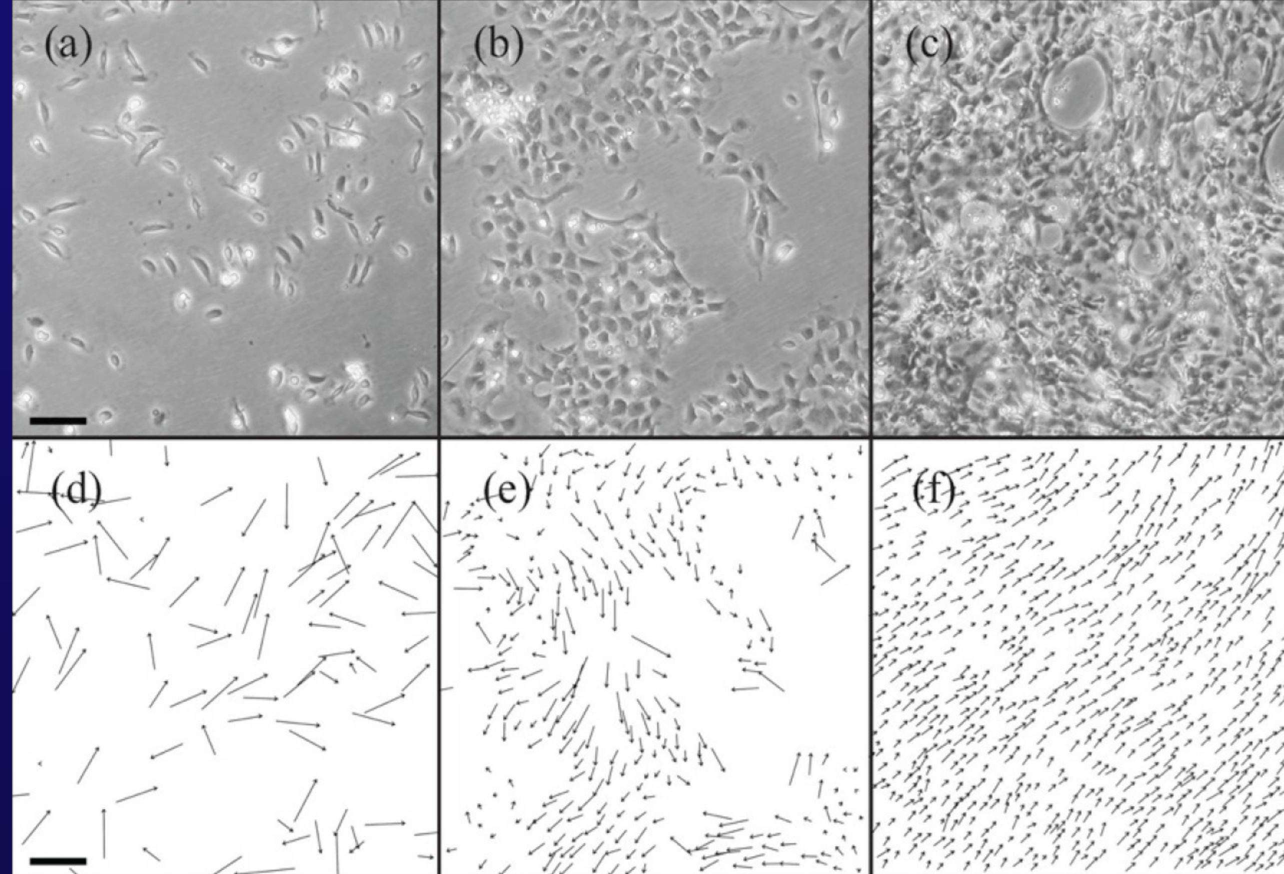
Collective motion of keratocites

Relevance:

- Wound healing
- Tissue engineering
- Embriogenesis

We obtain skin cells from scales of gold fish kept in the lab

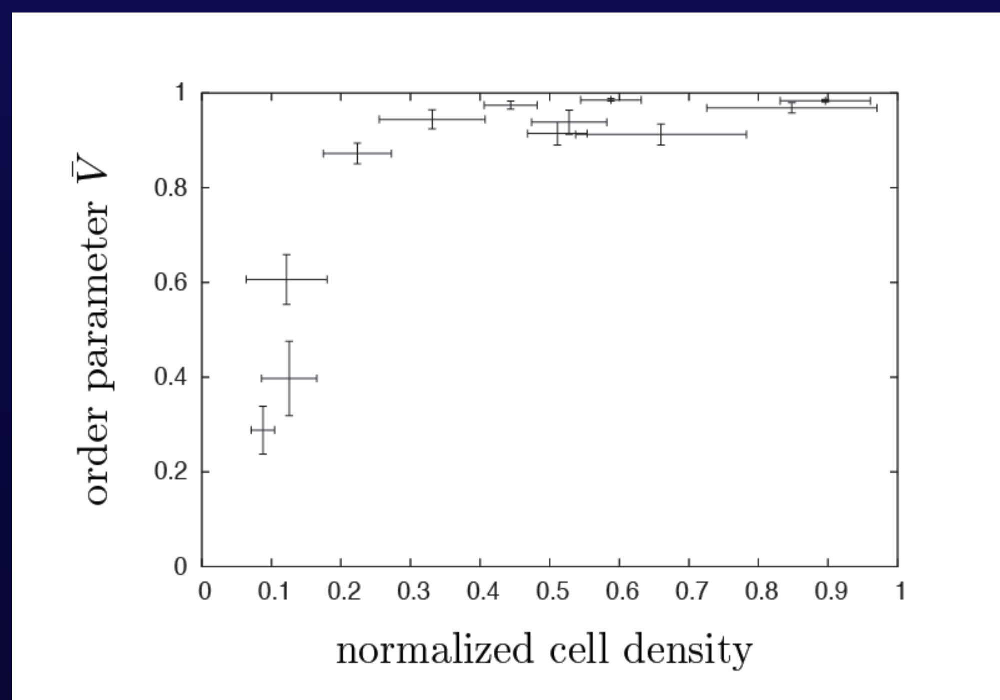
Experiment, i.e., we can control density



Velocities from tracking

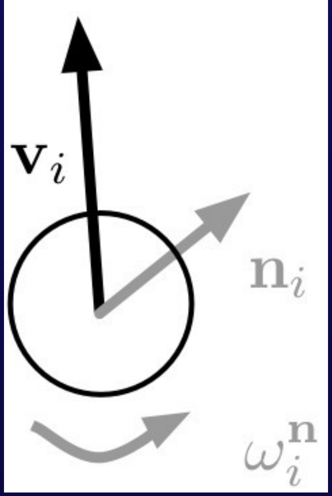
Order parameter

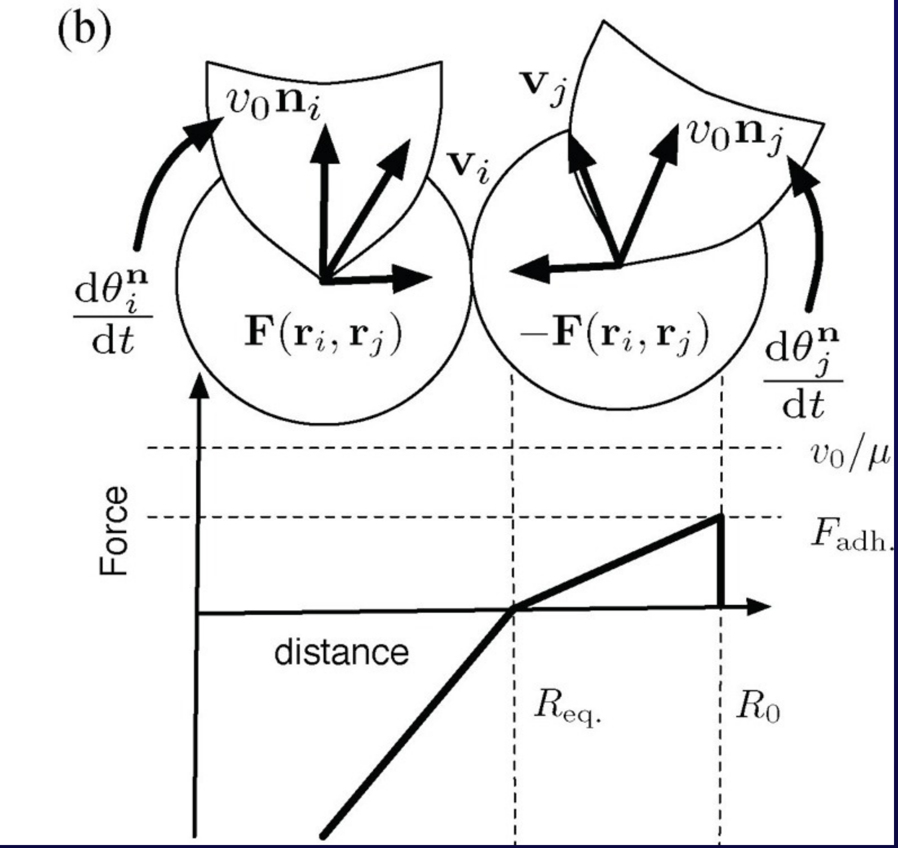
$$\bar{V} = \left\langle \frac{1}{N} \left| \sum_{i=1}^{N} \frac{\mathbf{v}_i(t_k)}{|\mathbf{v}_i(t_k)|} \right| \right\rangle_{t_k}$$



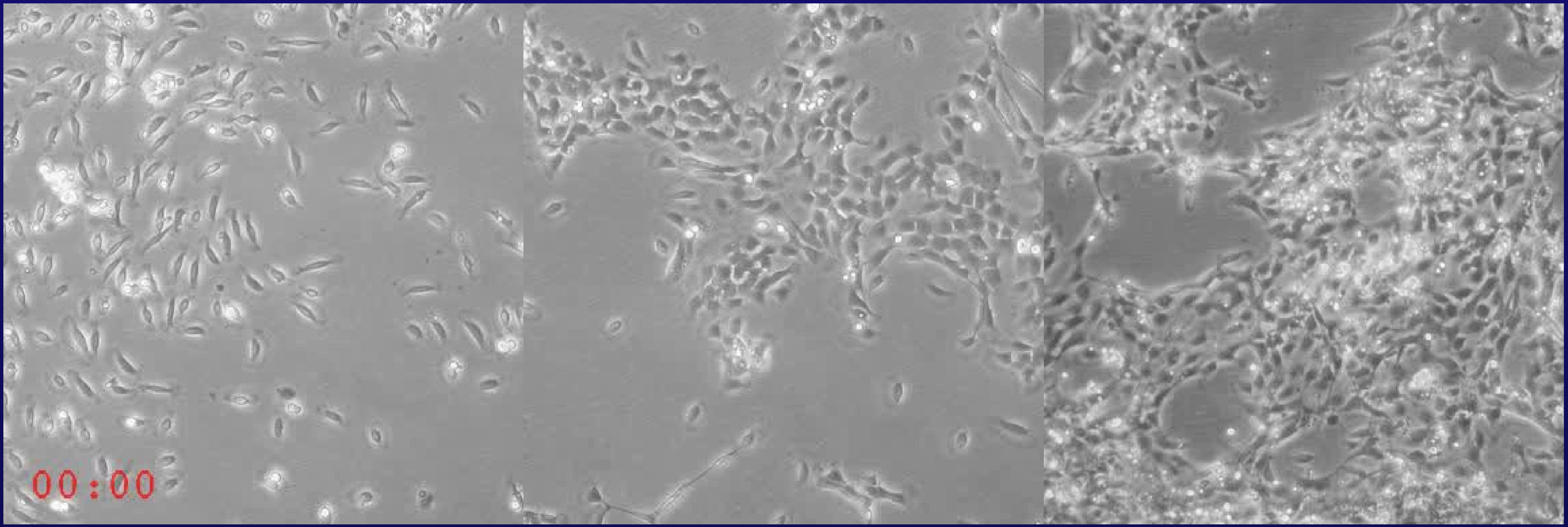
Modelling the group motion of keratocites

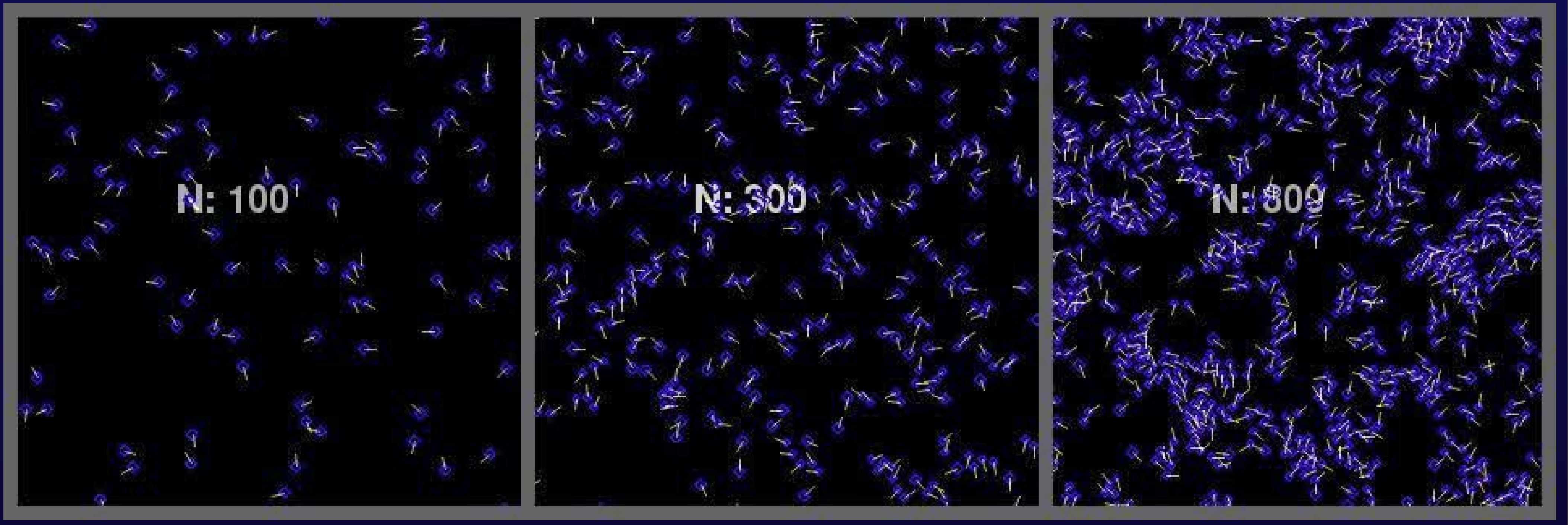
Qualitatively new feature:
the velocities of the neighbours are not part of the equations





The preferred direction of motion of a cell is approaching the actual direction with a rate τ .
Actual direction is given by: preferred direction plus “pushing” by other cells

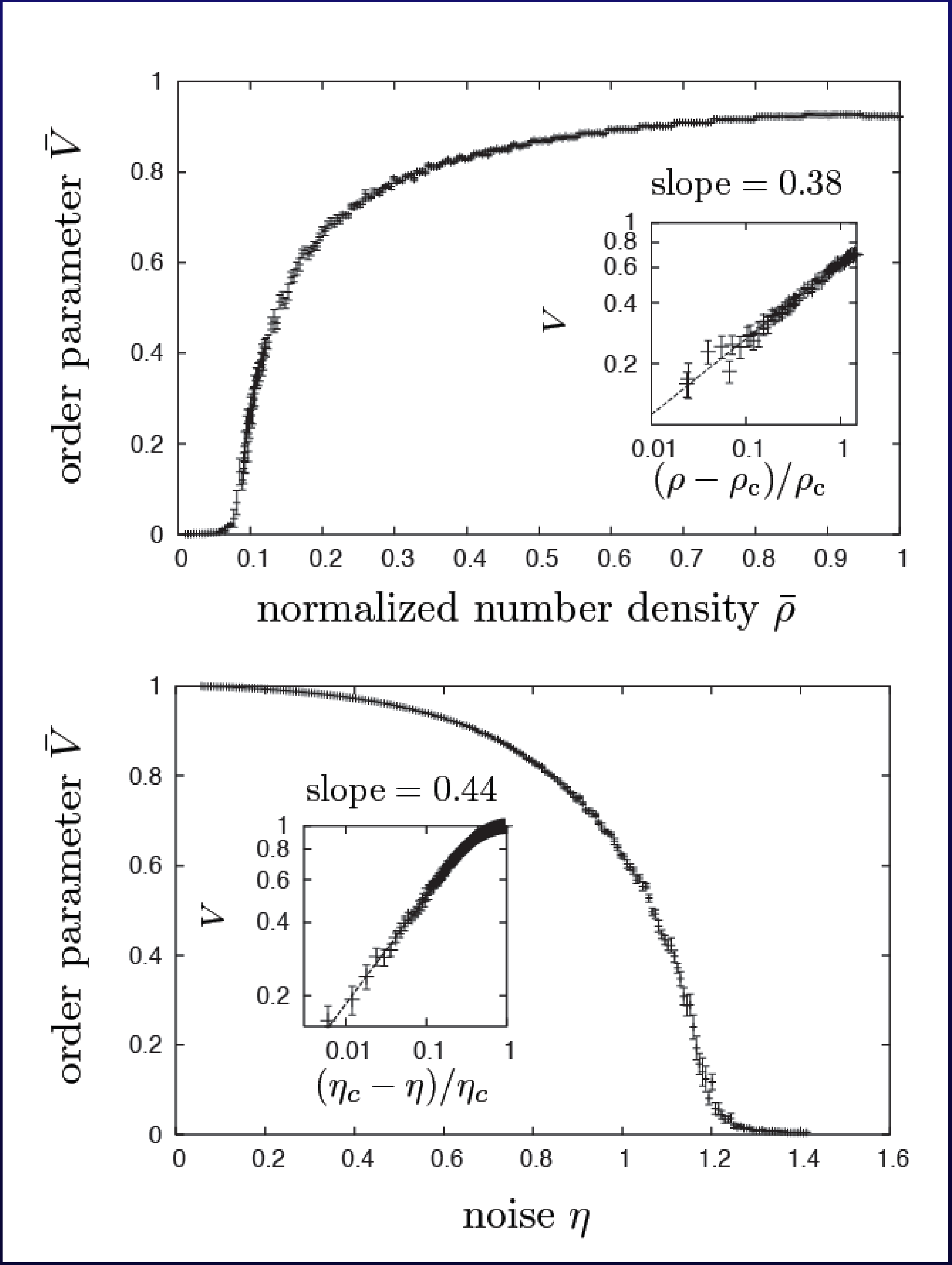

00:00


N: 100
N: 300
N: 809

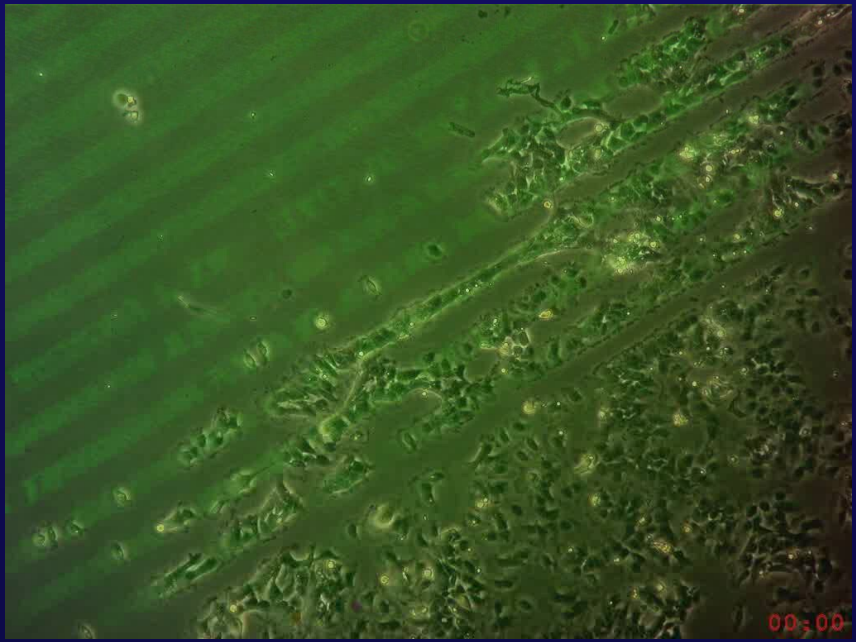
Disorder-order phase transition as a function of

density (ρ)

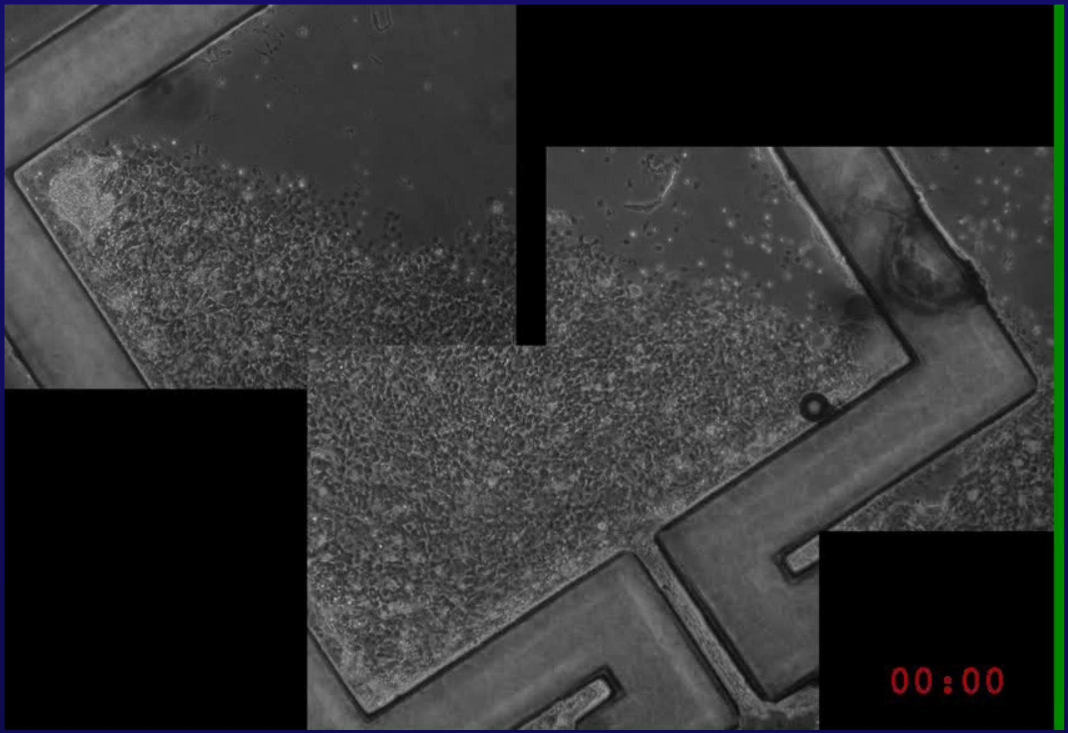
perturbations (η)



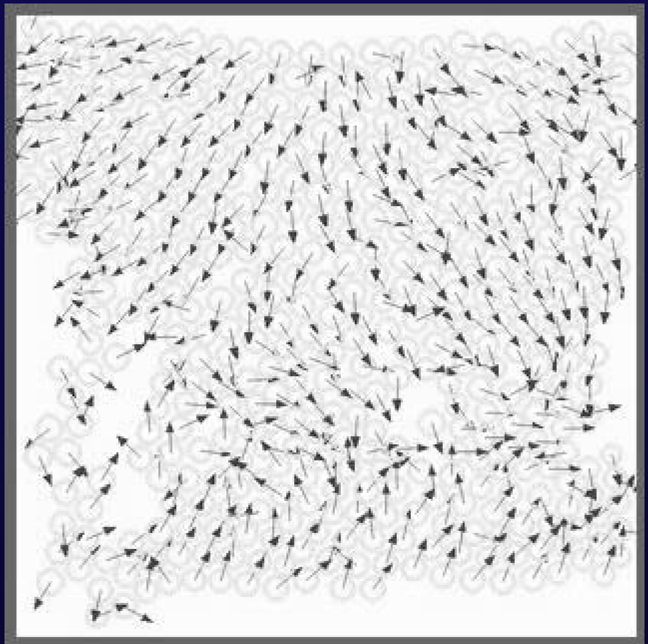
Group motion in confined geometry



Along adhesive strips



In a rectangular pool



Group motion of humans
(theory)

- **Model:**
  - Newton's equations of motion
  - Forces are of *social, psychological* or *physical* origin (herding, avoidance, friction, etc)
- **Statement**:
  - Realistic models useful for interpretation of practical situations and applications can be constructed

EQUATION OF MOTION for the velocity of pedestrian *i*

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t) e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} \vec{f}_{ij} + \vec{f}_{iW} \quad ,$$

$$\vec{f}_{ij} = \left[A_i \exp\left[\left(r_{ij} - d_{ij} \right) / B_i \right] + k g \left(r_{ij} - d_{ij} \right) \right] \vec{n}_{ij} + \kappa g \left(r_{ij} - d_{ij} \right) \Delta v_{ji}^t \vec{t}_{ij} \quad ,$$

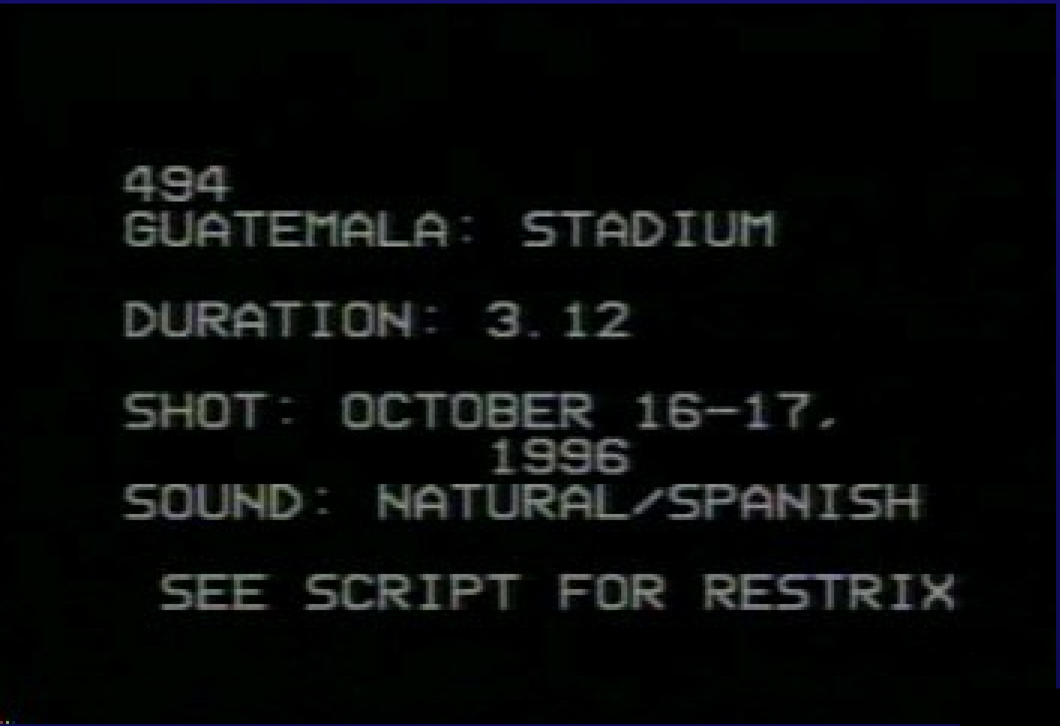
"psychological / social", *elastic* repulsion and sliding *friction* force terms, and *g(x)* is zero, if $d_{ij} > r_{ij}$, otherwise it is equal to *x.*

MASS BEHAVIOUR: "herding"

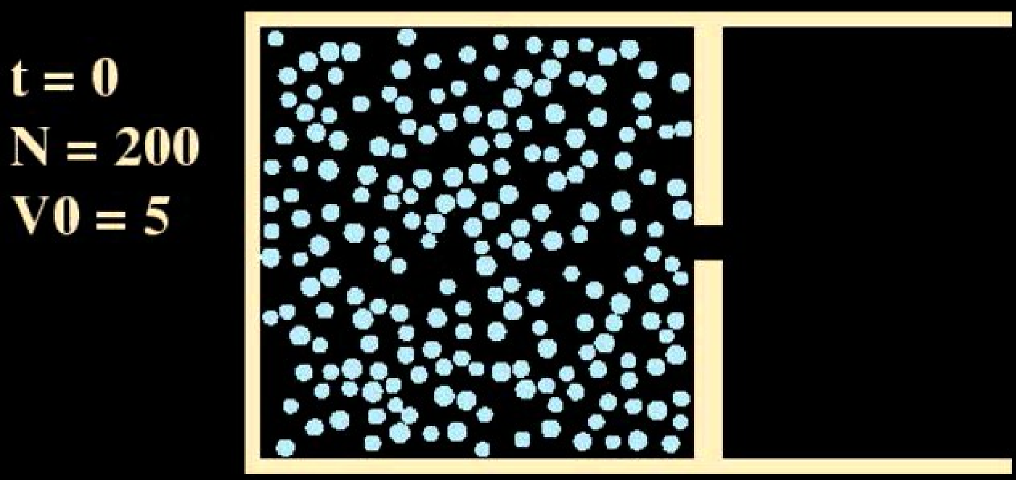
$$\vec{e}_i^{\,0}(t+1) = N\left[\left(1 - p_i\right) \vec{e}_i(t) + p_i \left\langle \vec{e}_j(t) \right\rangle_j \right] ,$$

where $N(z) = z / \|z\|$ denotes normalization of z .

Panic



- Escaping from a closed area through a door
- At the exit physical forces are dominant !



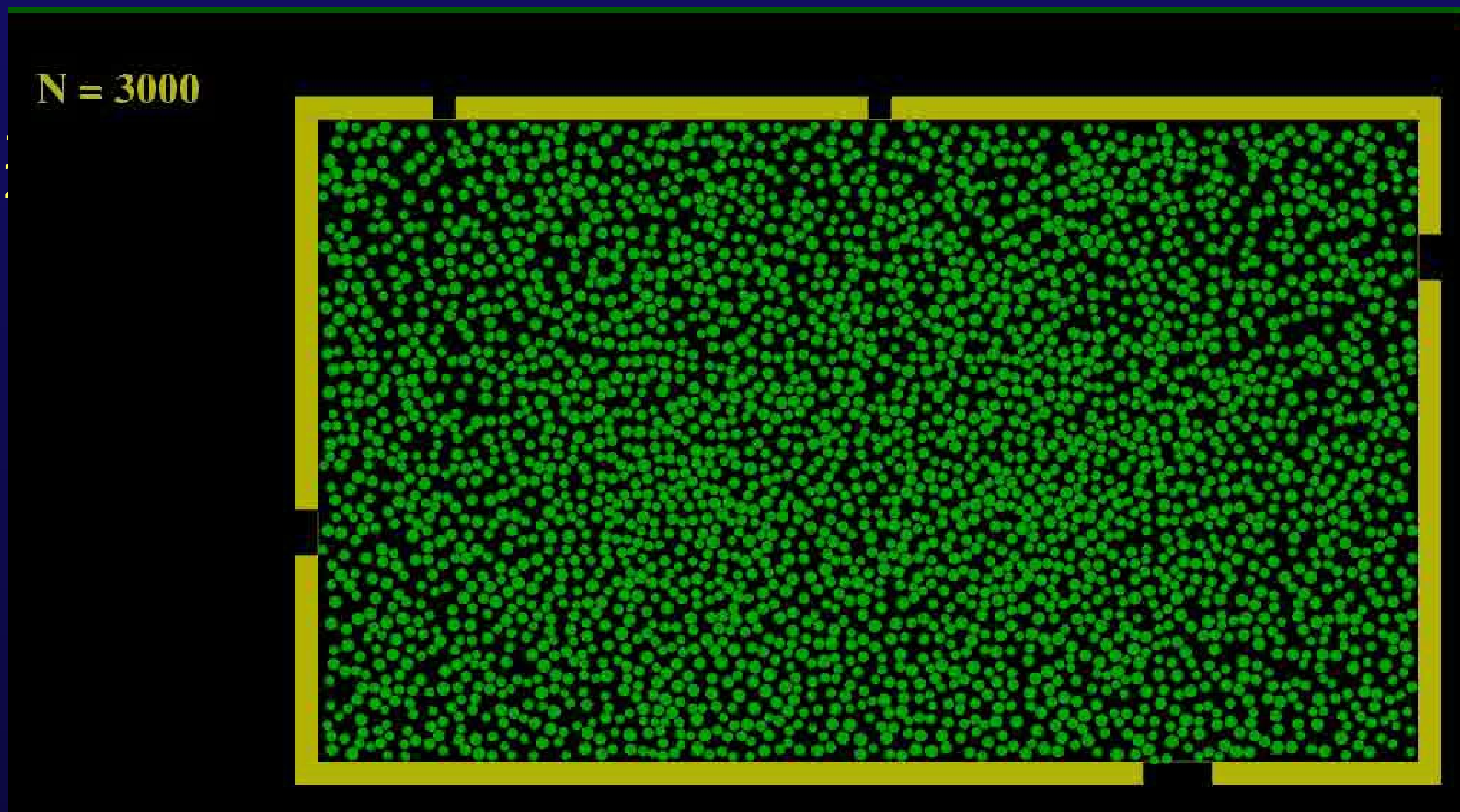
Nature, 407 (2000) 487

The “impatience
or anxiety factor”

N=3000

N after 50 sec

“patient” 9.
“impatient” 2



Comparing bird and human soaring strategies

Zs. Ákos, M. Nagy and T. Vicsek

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http://angel.elte.hu/~vicsek

http://angel.elte.hu/thermalling

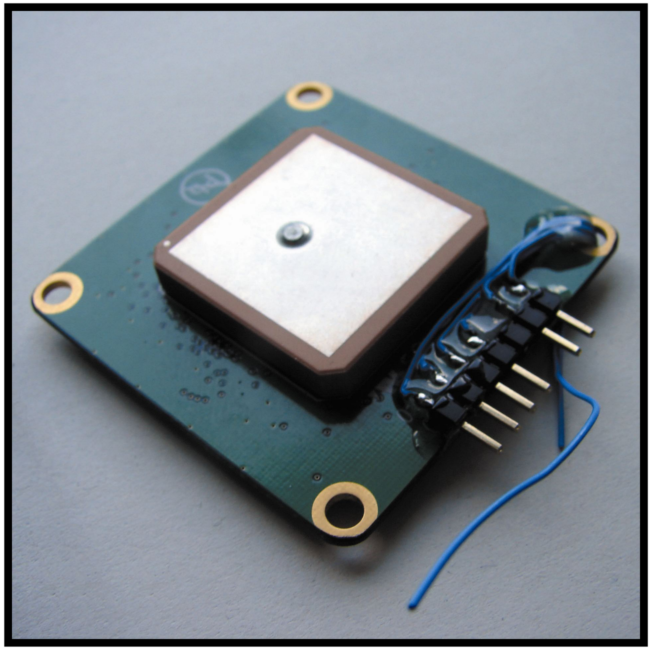
Zs. Á, M. N., T. V.: *PNAS*, 2008

The art of soaring

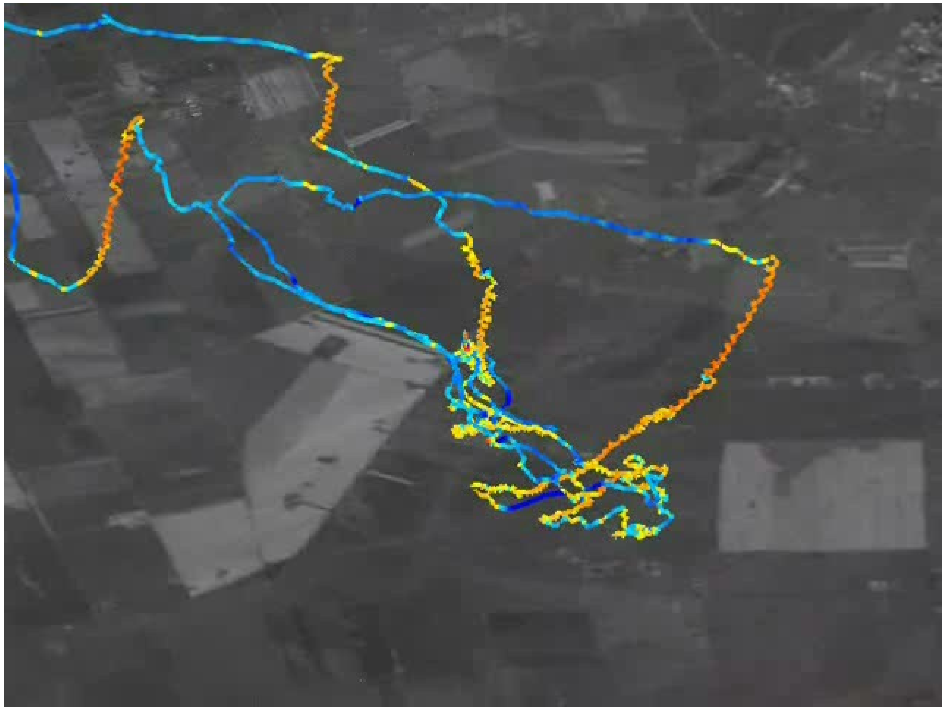
Birds of pray, large migrating birds, human gliders all do it

Collecting data

Lightweight GPS
Resolution:
1m, 1sec

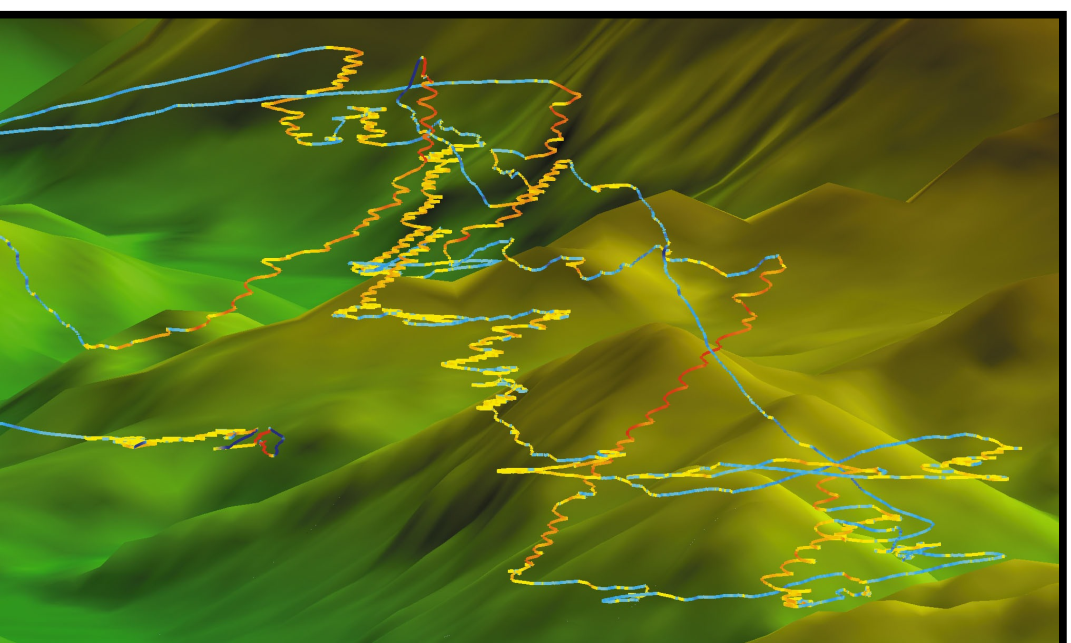


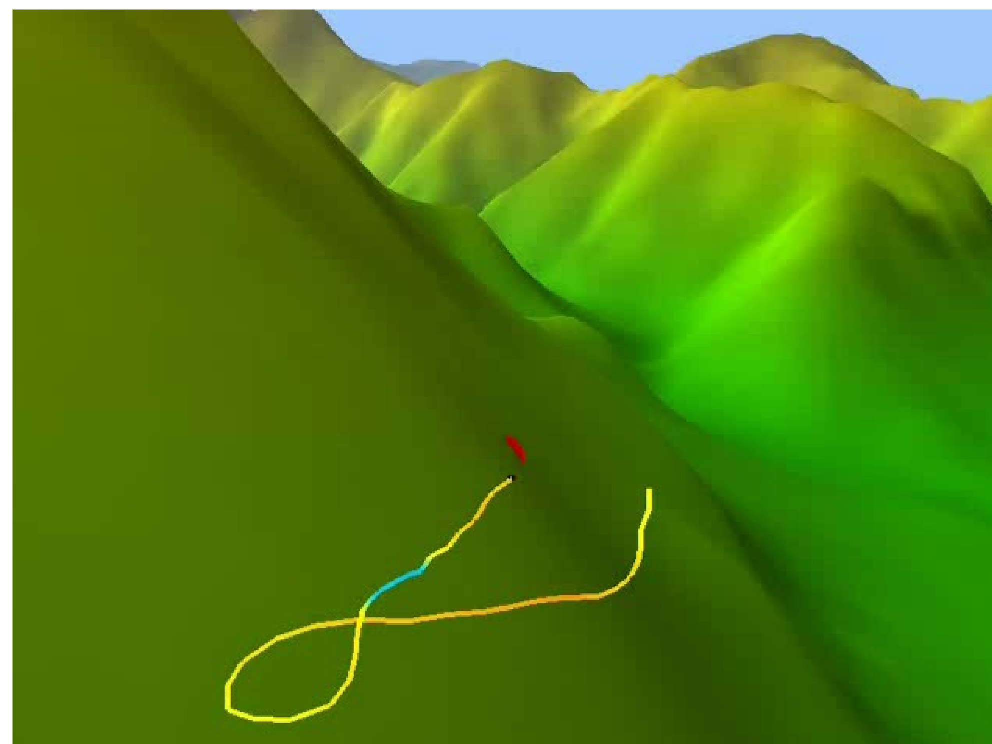
Tracks:



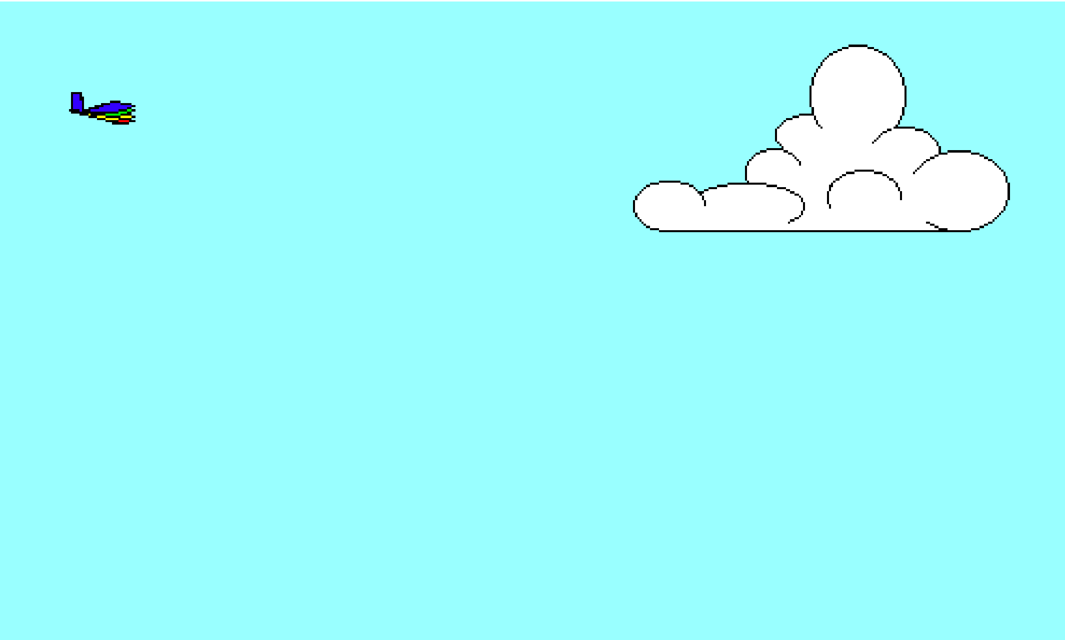
Falcon

paraglider



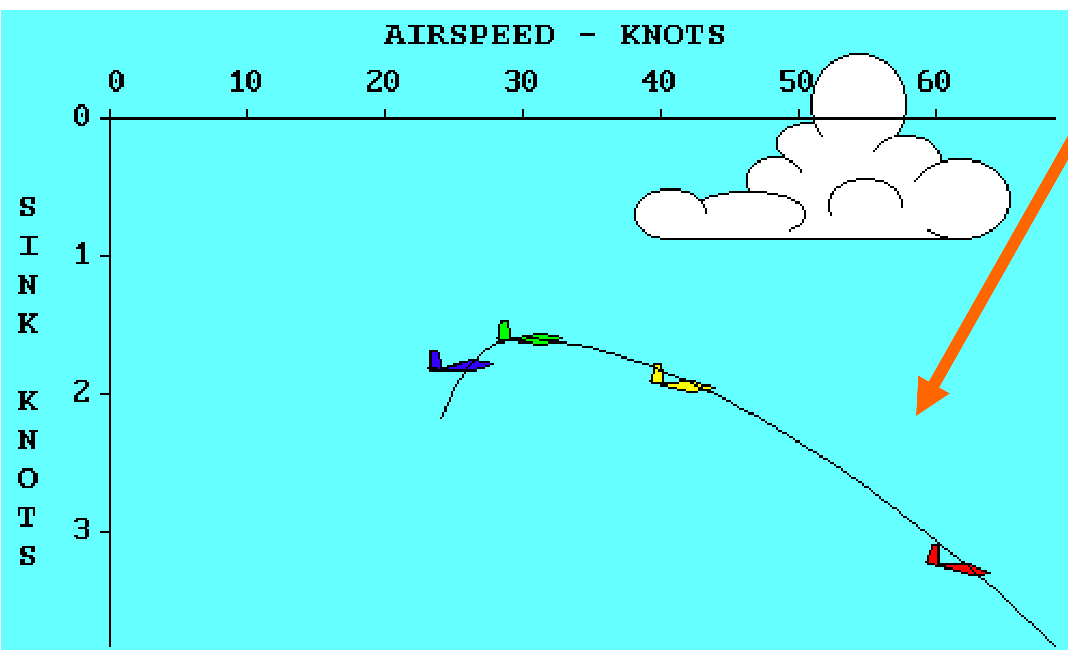


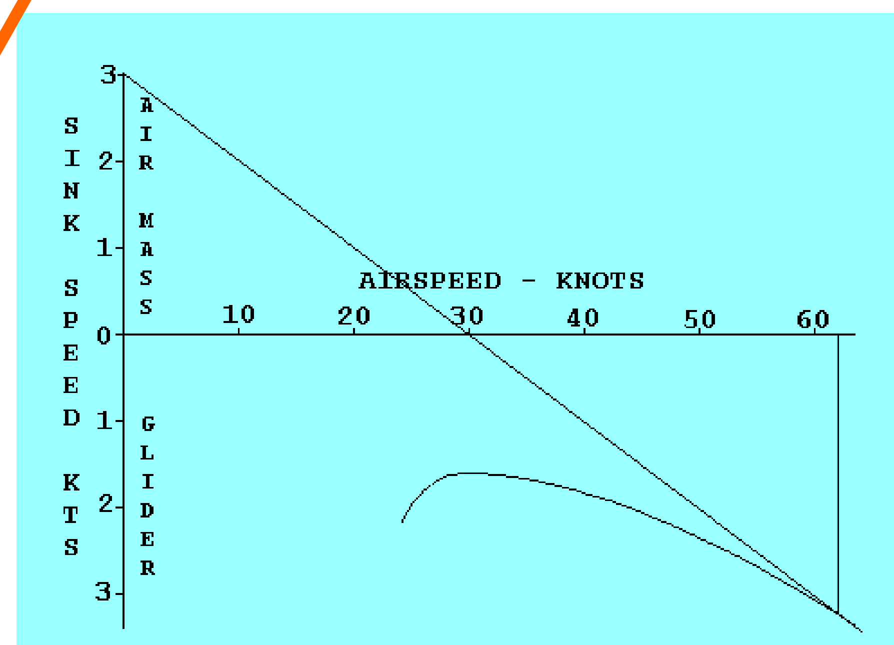
The MacCready theory (principle)



$$\frac{p(v_{xy}) - v_{climb}}{v_{xy}} = \frac{dp(v_{xy})}{dv_{xy}} .$$

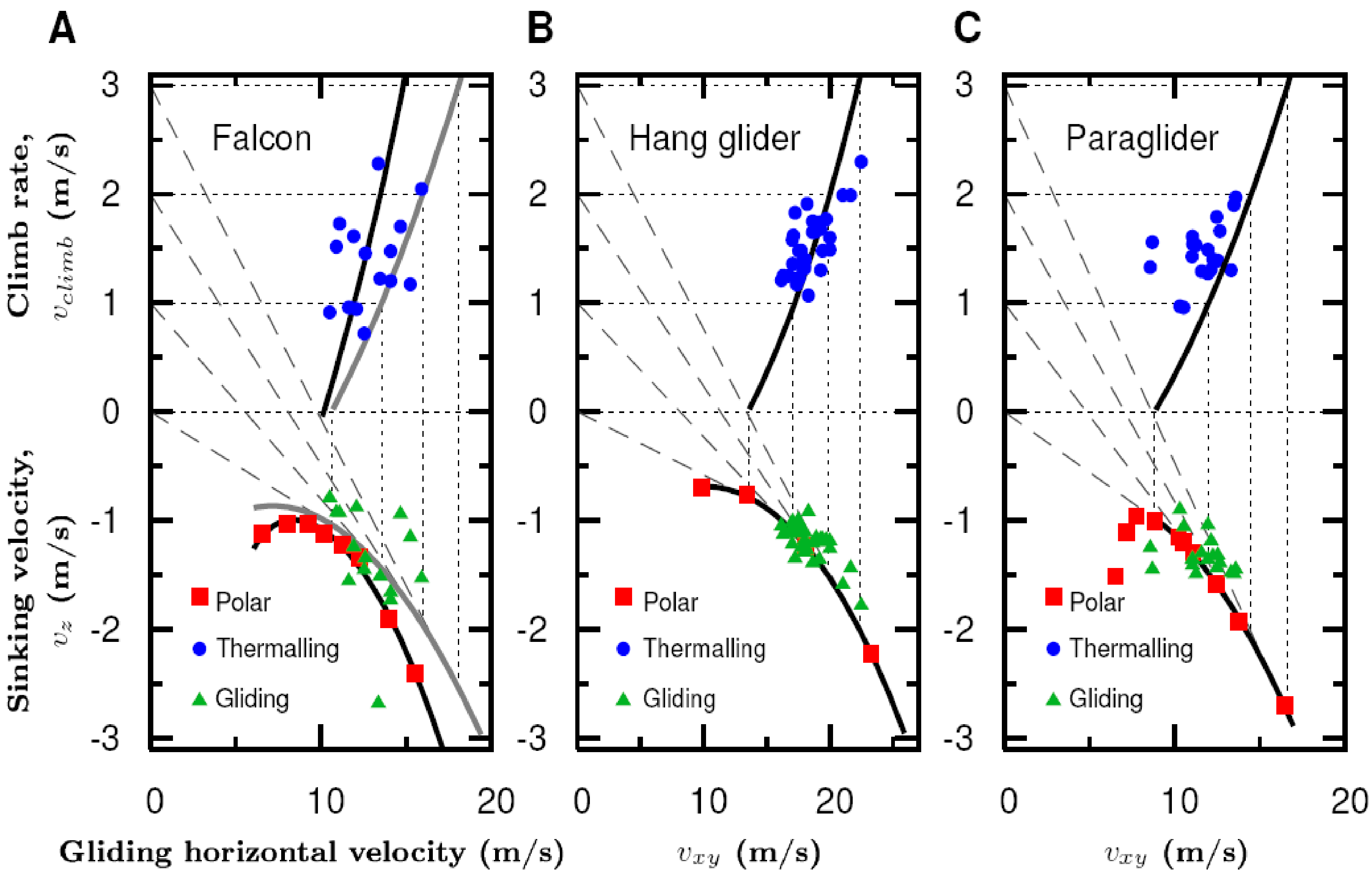
$p(v_{xy})$ – polar curve





Comparison with the predictions of the theory

Upper black lines: optimal strategy for the given polar curves
Blue dots: measured horizontal gliding velocities for the given climb rates

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