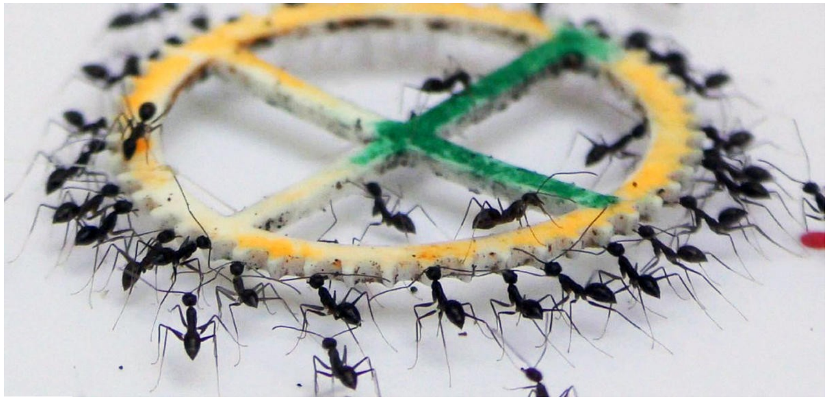
20.12.2018 Košice

Mária Džamová, PF UPJŠ Košice,
Department od Theorethical Physics

The physics of cooperative transport in groups of ants

By *Ofer Feinerman, Itai Pinkoviezky, Aviram Gelblum, Ehud Fonio and Nir S. Gov*



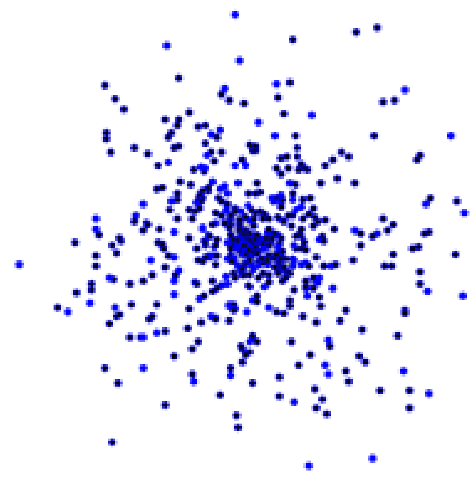
Published in: nature physics

DOI: 10.1038/s41567-018-0107-y

https://www.nature.com/articles/s41567-018-0107-y

Collective behaviour
Biology vs. Physics

many-particle
physical systems



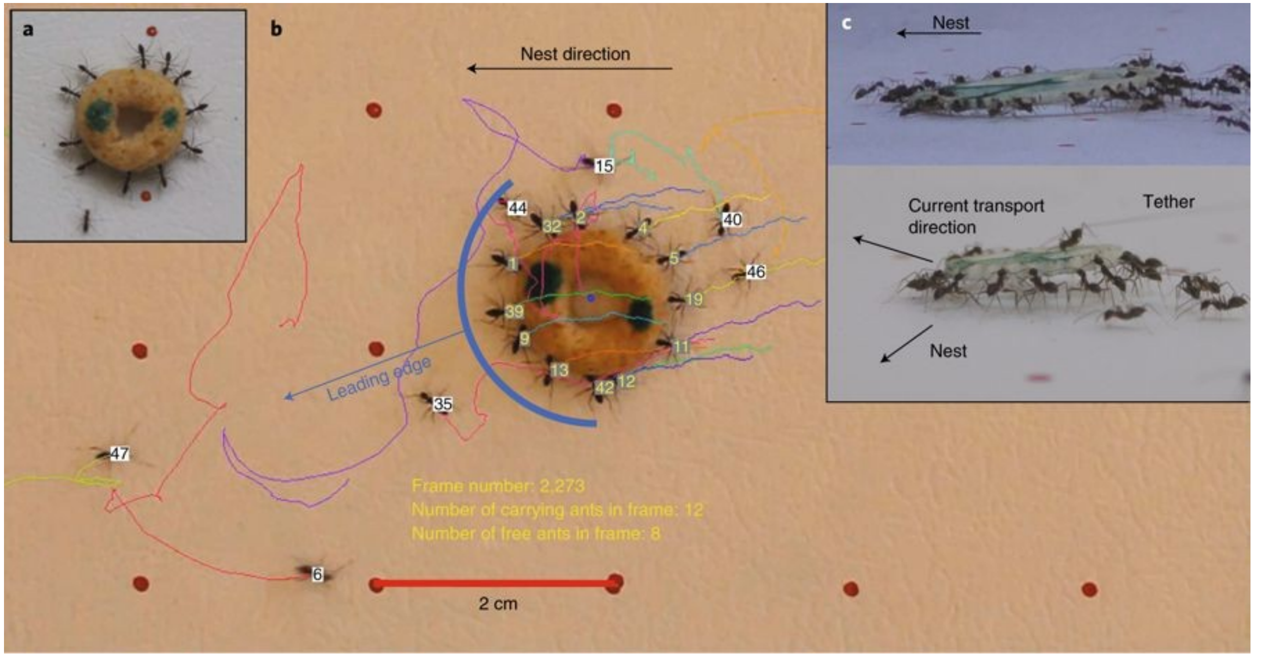
share many
characteristics

Key characterictics:

Interactions between the individuals

Cooperative transport of ants

<u>Experiment / observation:</u>



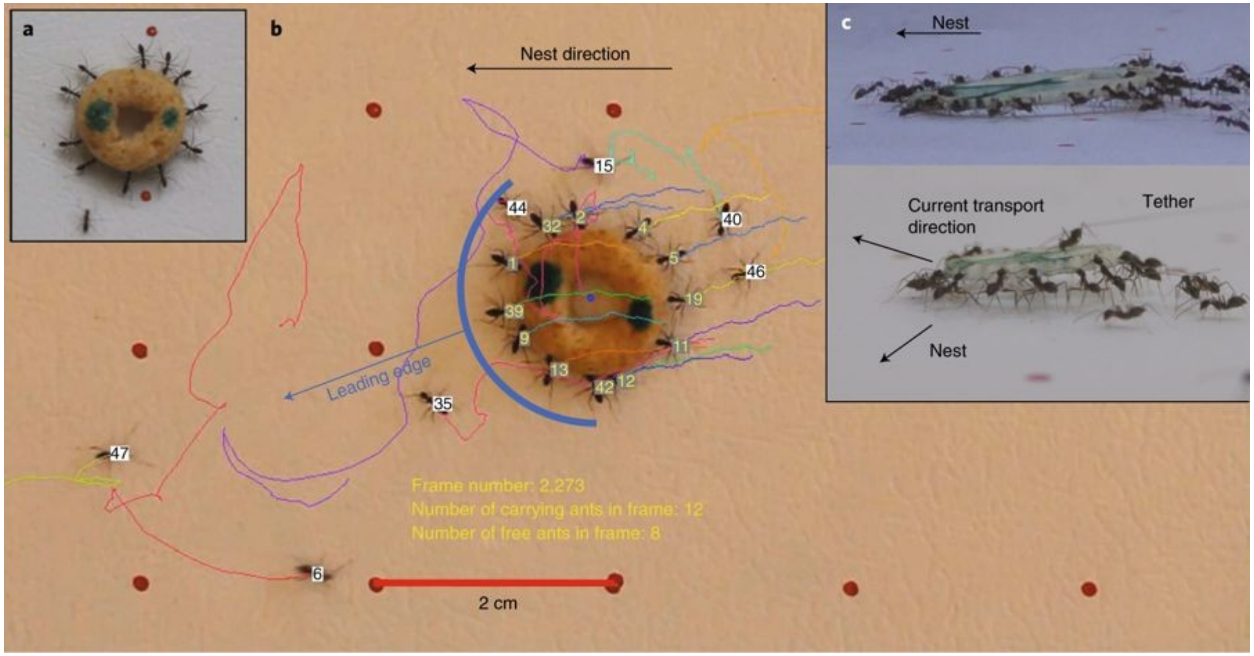
A group of ants carrying a large object

<u>2 conditions:</u>

1. Track whole group of ants and each ant
2. Ants have one collective goal

Cooperative transport of ants

<u>Experiment / observation:</u>

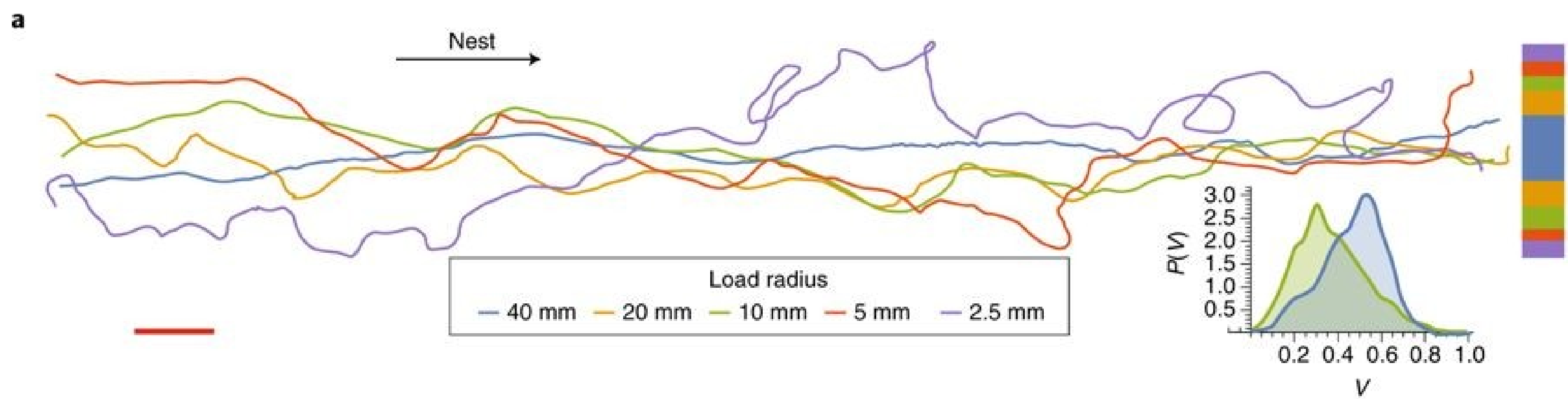


A group of ants carrying a large object

- Mechanical forces, motion,… --> Physics?
- Comparable to a physical system

Ants as a physical particles???

Empirical findings



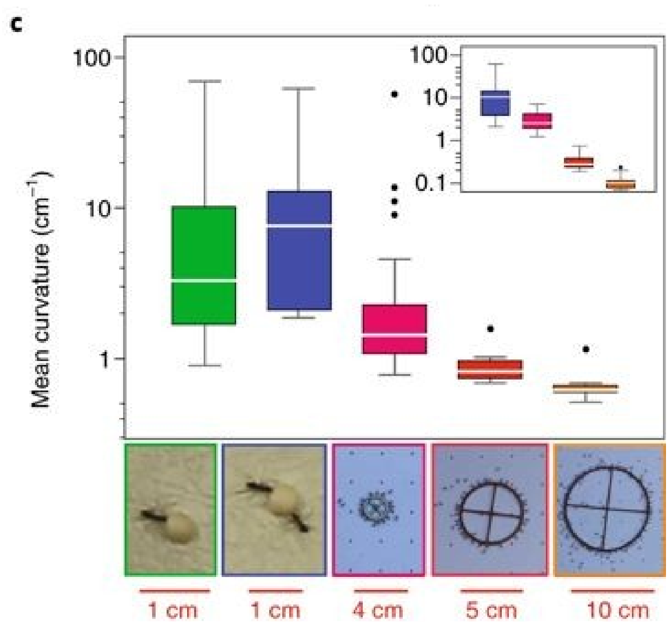


Fig. c: Mean curvature of trajectories
of object of different sizes

Fig. a: Trajectories for various load size

Two possible explanations

Two models

1. Uncoupled-carriers model

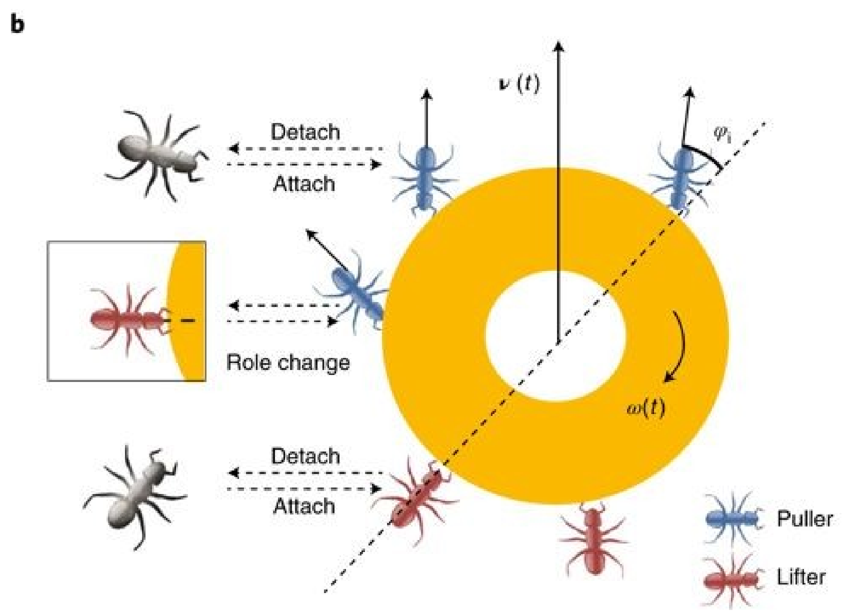
- Smart and independent ants
- Rule: ***Pull the load independently of others***
- Motion of the load:
- Possible explanation for the association:

Larger groups ➡ **Smoother trajectories**

- $$\vec{v} \propto \vec{F}_{tot} = \sum \vec{F}_i$$

2. Coupled-carriers model

- Ants are coupled to each other
- Rule: *Ants in the leading edge - pull and those at the trailing edge - lift (to reduce friction).*



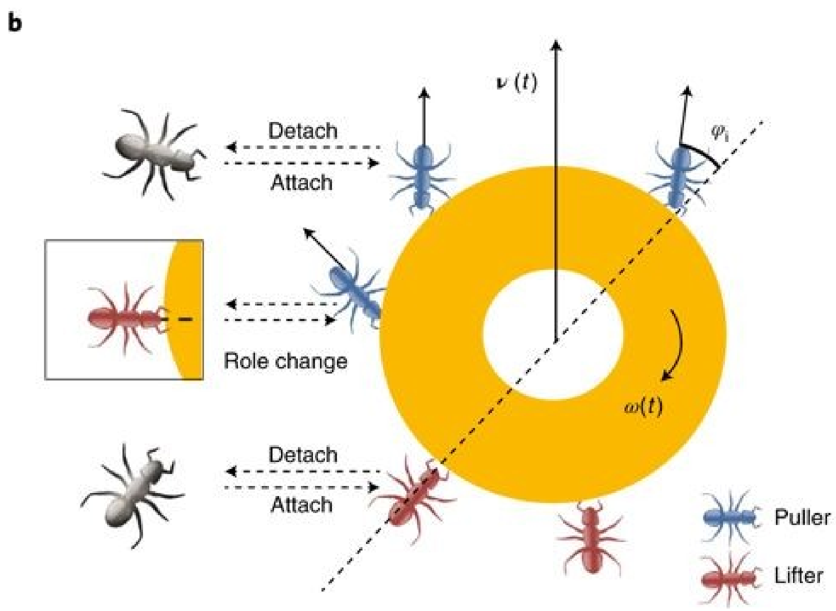
Transition rates:

$$r_{l \to p} = K_c e^{\frac{\hat{p}_i F_{tot}}{F_{ind}}}$$

$$r_{p \to l} = K_c e^{\frac{-\hat{p}_i F_{tot}}{F_{ind}}}$$

K_c – decision making rate
$\hat{p}_i$ – unit vector along body axis of ant
F_{ind} – coupling parameter

2. Coupled-carriers model



Transition rates:

$$r_{l\rightarrow p}=K_c e^{\frac{\hat{p}_i F_{tot}}{F_{ind}}}$$

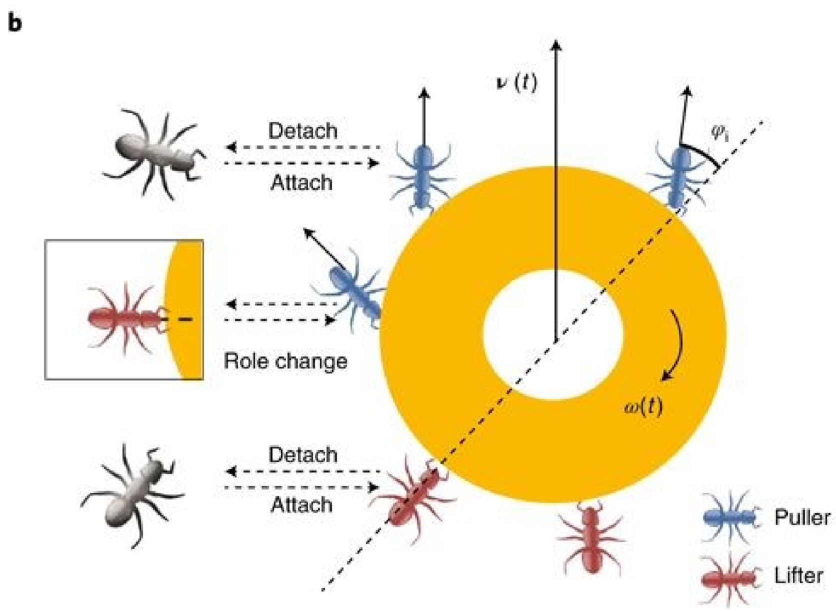
$$r_{p\rightarrow l}=K_c e^{\frac{-\hat{p}_i F_{tot}}{F_{ind}}}$$

Consequences:

$F_{tot} \gg F_{ind}$ ➡ Ant align pulling force with the total force. ➡ **Coordinated**

$F_{tot} \ll F_{ind}$ ➡ Ant randomly pull or lift.. ➡ **Uncoordinated**

2. Coupled-carriers model



Transition rates:

$$r_{l\rightarrow p}=K_c e^{\frac{\hat{p}_i F_{tot}}{F_{ind}}}$$

$$r_{p\rightarrow l}=K_c e^{\frac{-\hat{p}_i F_{tot}}{F_{ind}}}$$

Consequences:

$F_{tot} \gg F_{ind}$ → **Coordinated** → Smooth trajectories, higher speed

$F_{tot} \ll F_{ind}$ → **Uncoordinated** → Irregular trajectories, lower speed

Transition between two motion modes

Model comparison

Uncoupled-carriers

$$\vec{v} \propto \vec{F}_{tot} = \sum \vec{F}_i$$

Should be independent of group size!!!

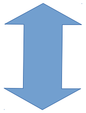
Coupled-carriers

$$\vec{v} \propto \overline{F_{tot}}$$

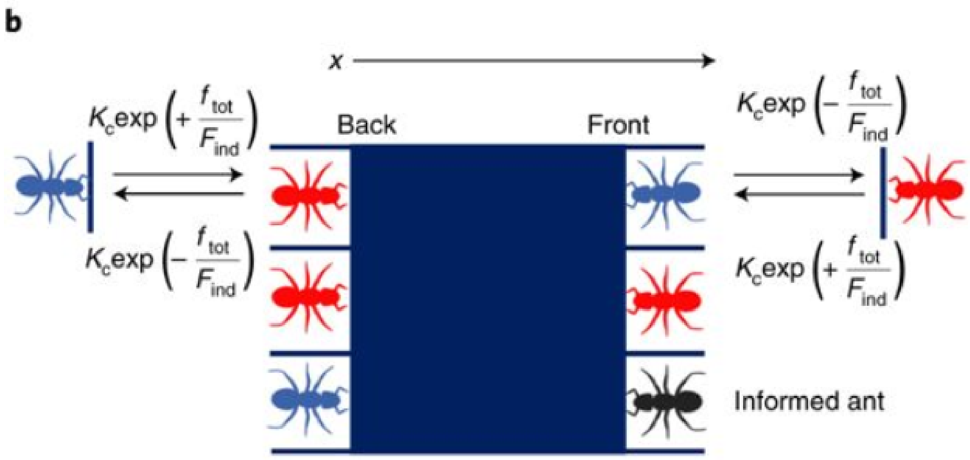
Experimental results support the prediction od the coupled-carriers model

Statistical mechanics model

Coordinated – uncoordinated motion



Order – disorder transitions



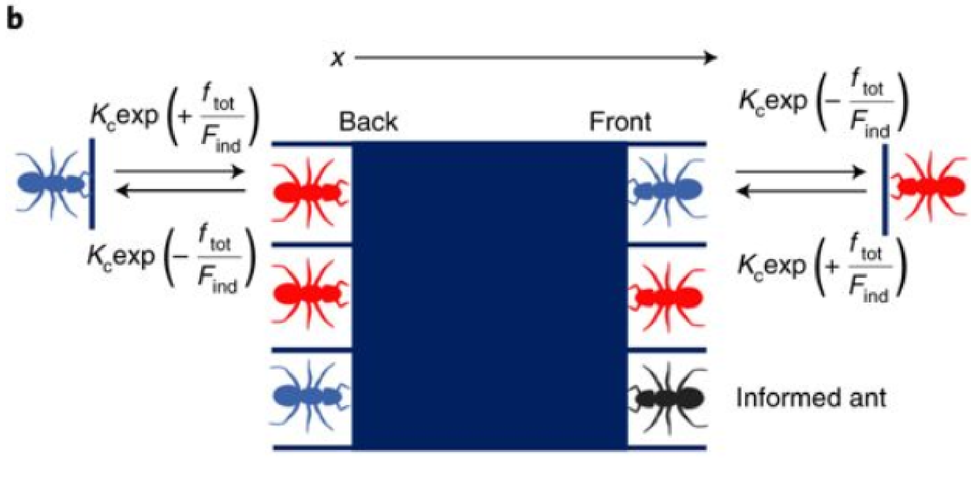
Due to translation invariance, this maps to a fully connected **Ising model**

$$H = \frac{-f_0}{F_{ind}} \sum_{i \neq j} p_i p_j \sigma_i \sigma_j$$

SM model:

- N ants, N/2 on each edge
- Simplification: load moves along one dimension

Statistical mechanics model

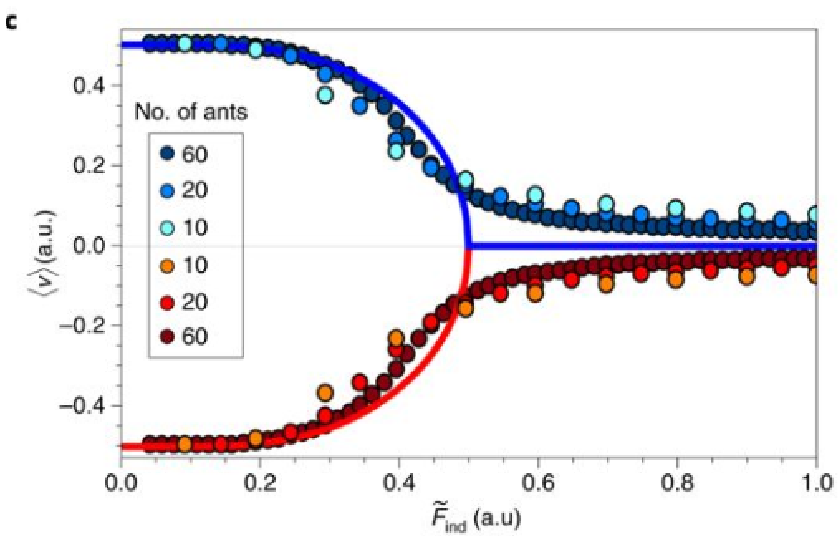


$$H=\frac{-f_0}{F_{ind}}\sum_{i\neq j} p_i p_j \sigma_i \sigma_j$$

f_0 – pulling force

$p_i=+1,-1$ – right / left side of tho load

$\sigma_i=0,1$ – lifter / puller



Exact mean-field solution to H: $(T=1)$

$$\frac{F_{tot}}{N}=\frac{f_0}{2}\tanh\left(\frac{F_{tot}}{F_{ind}}\right)$$

Second-order phase transition

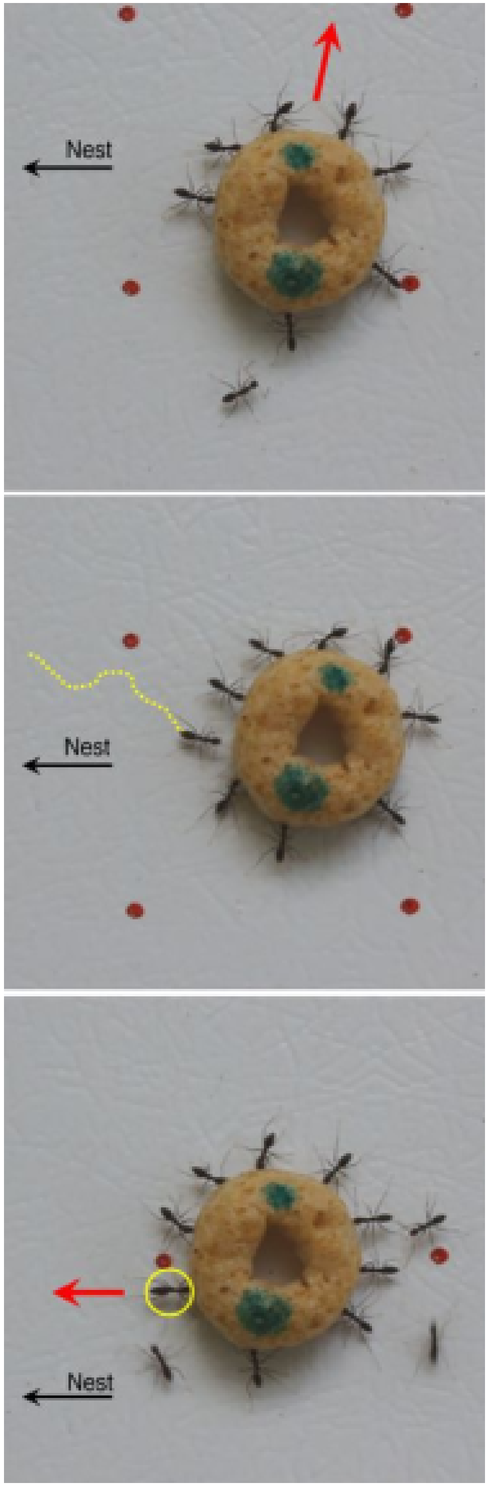
Ant leadership

Second-order phase transition **=** Divergence in susceptibility at critical point

↕

Implement a small external field **=** including an uncoupled ant

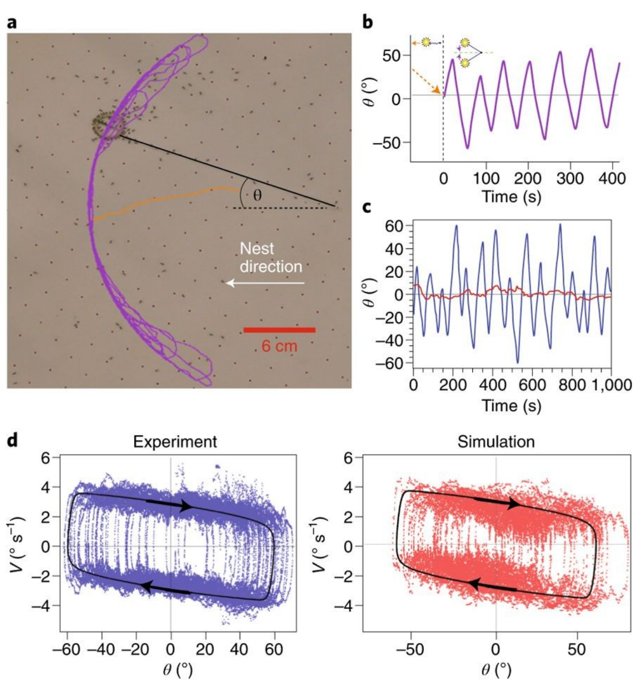
- Carriers are mediated by informed **leader ants**
- Informed ants attached to the load, they are well oriented.
- Rule: ***Ignore the rest and pull towards the nest.***
- After ~10 sec switch to being regular carrier.

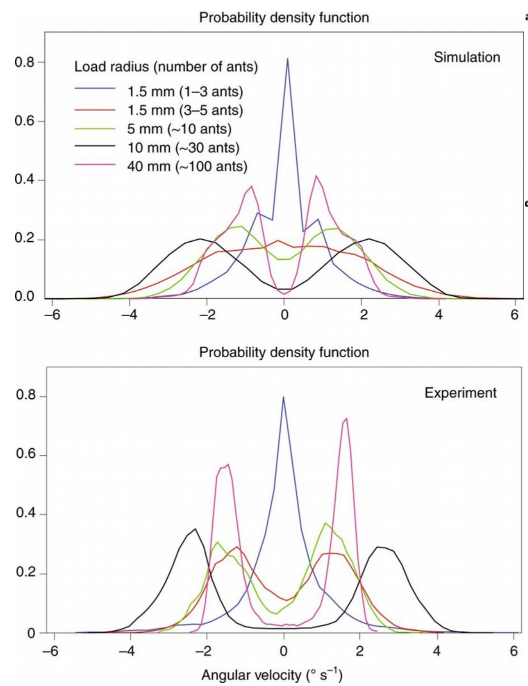


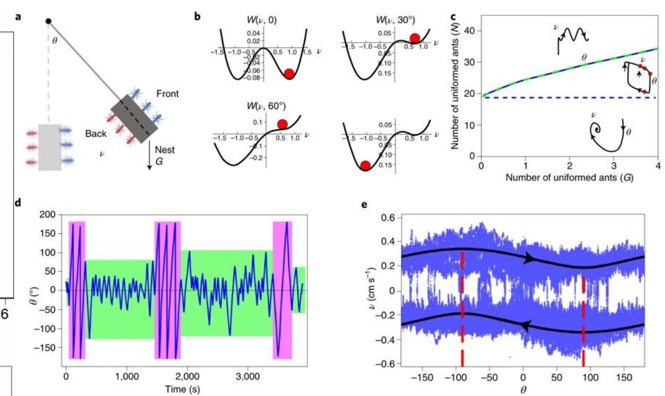
Motivation to continue reading

Models in constrained conditions:

- Oscillatory motion under constrained conditions
- Phase transition under constrained conditions







Thank you for your attention!