Fire Ants Build, Morph, and Repair to Survive Floods

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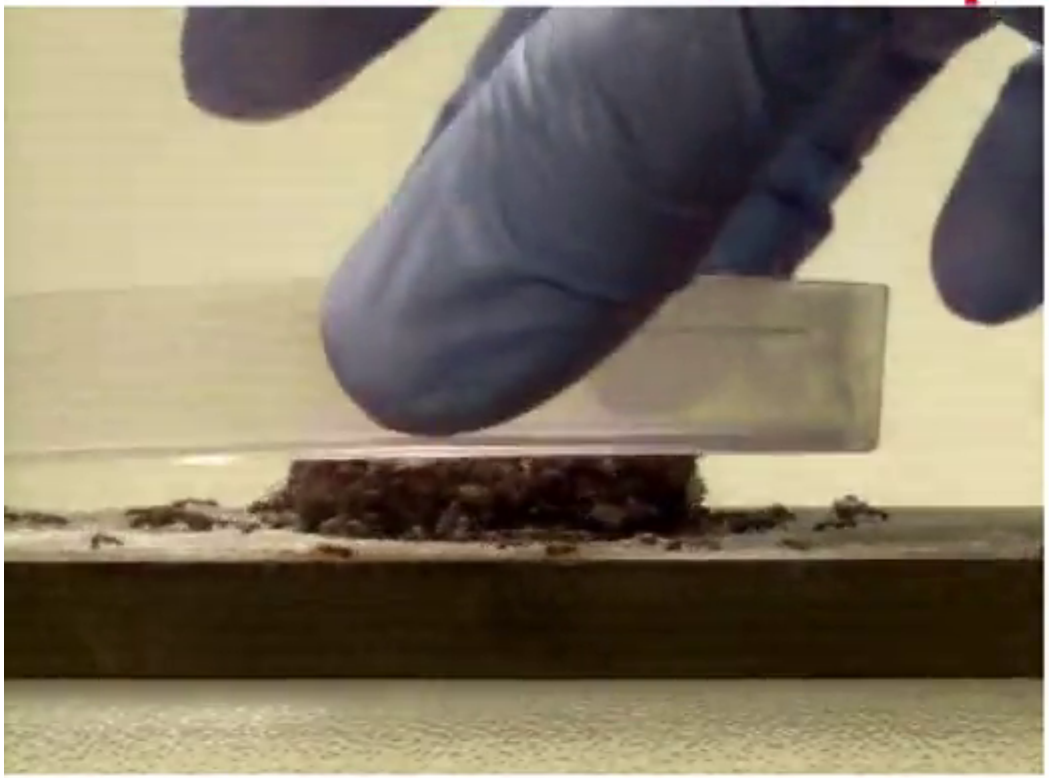
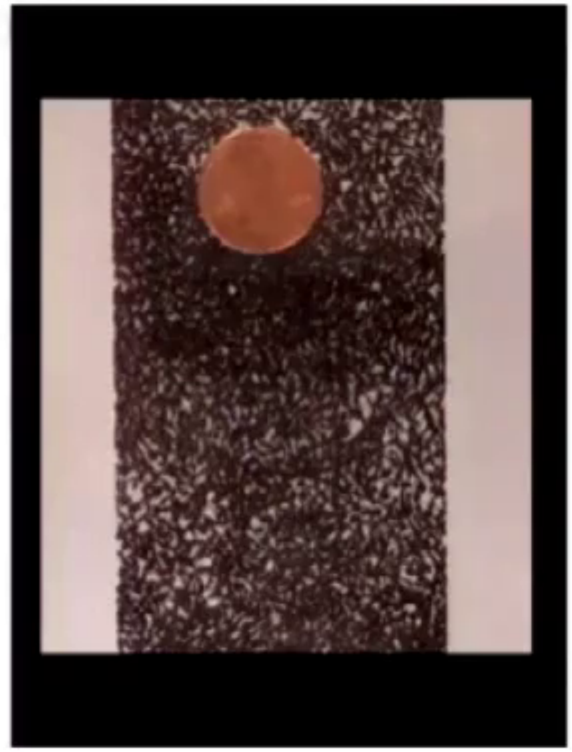
Ants are discrete, yet flow and coalesce like liquids

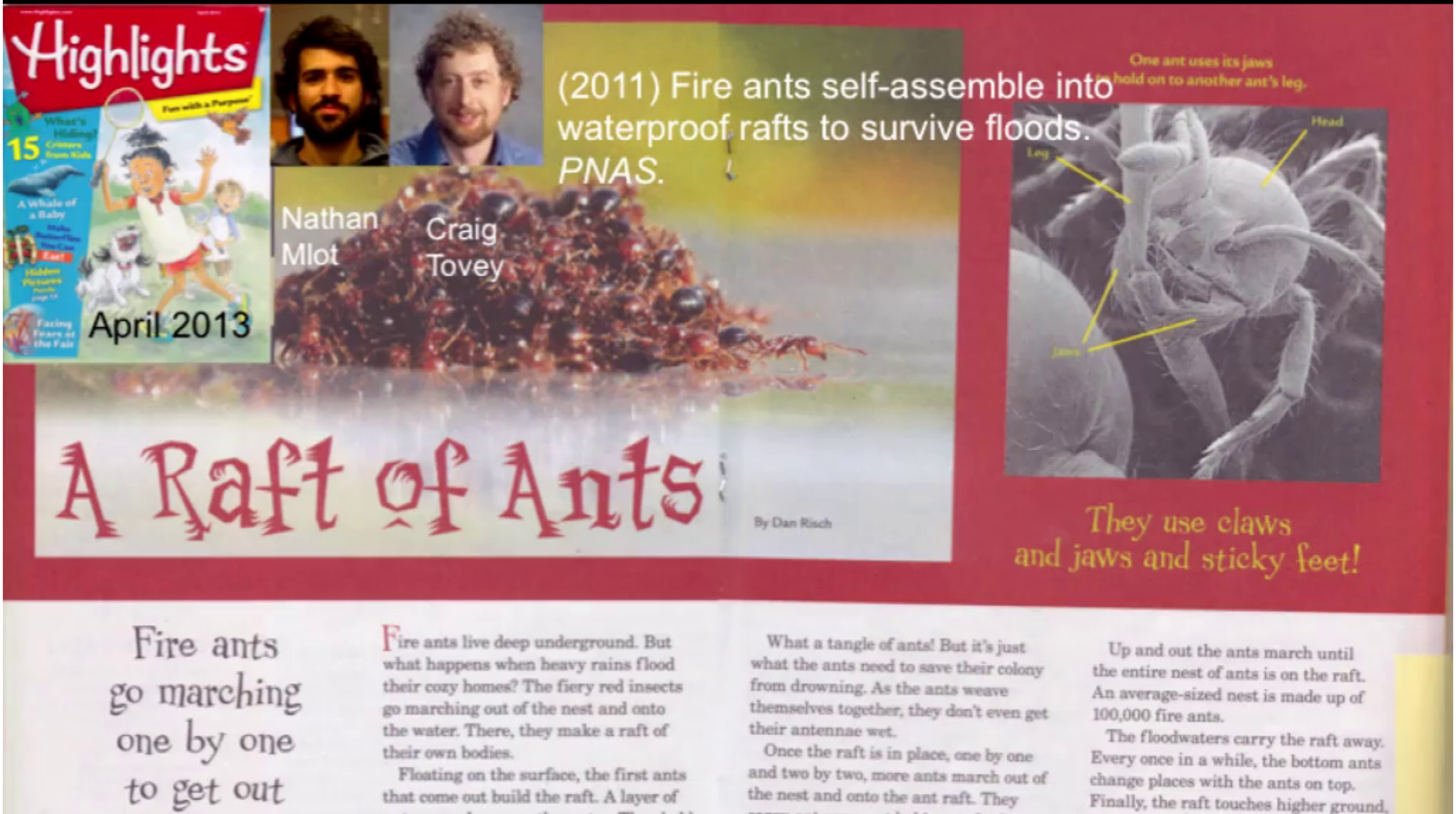
Ants can be both springy and dissipative





Storage of Elastic energy
Elastic modulus $E \sim 10^3$ Pa
e.g., salad greens

Flow through Viscous dissipation
viscosity $\mu = 10^4$ Pa.s
e.g., yogurt



A Raft of Ants

By Dan Risch

They use claws and jaws and sticky feet!

Fire ants go marching one by one to get out

Fire ants live deep underground. But what happens when heavy rains flood their cozy homes? The fiery red insects go marching out of the nest and onto the water. There, they make a raft of their own bodies.

Floating on the surface, the first ants that come out build the raft. A layer of

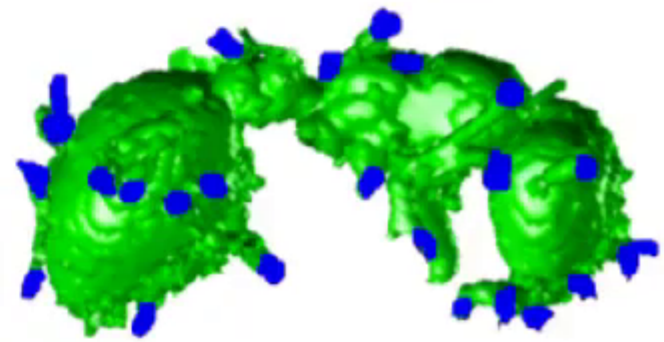
What a tangle of ants! But it's just what the ants need to save their colony from drowning. As the ants weave themselves together, they don't even get their antennae wet.

Once the raft is in place, one by one and two by two, more ants march out of the nest and onto the ant raft. They

Up and out the ants march until the entire nest of ants is on the raft. An average-sized nest is made up of 100,000 fire ants.

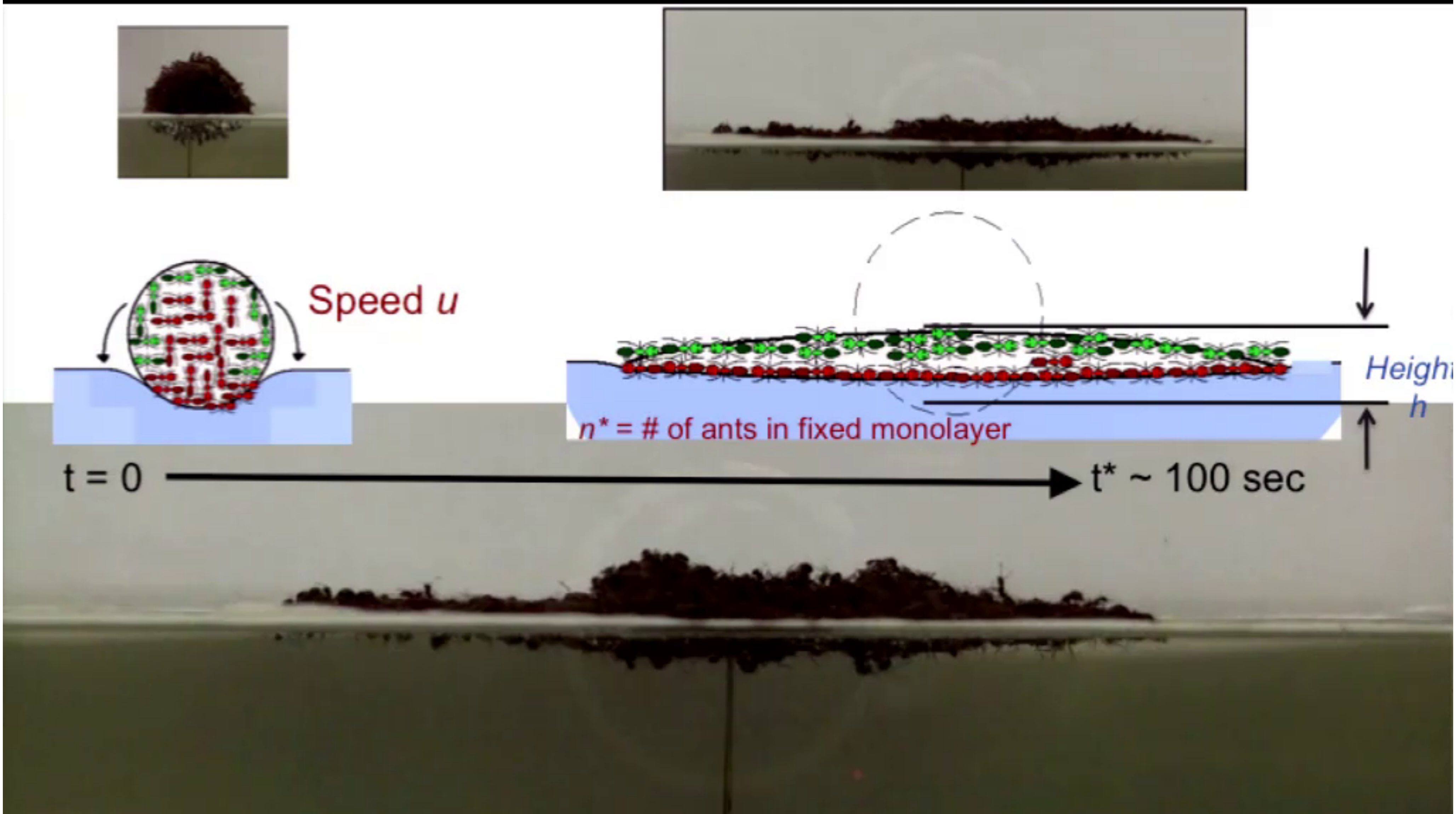
The floodwaters carry the raft away. Every once in a while, the bottom ants change places with the ants on top. Finally, the raft touches higher ground,

Ant Rule 1: Hold on for dear life

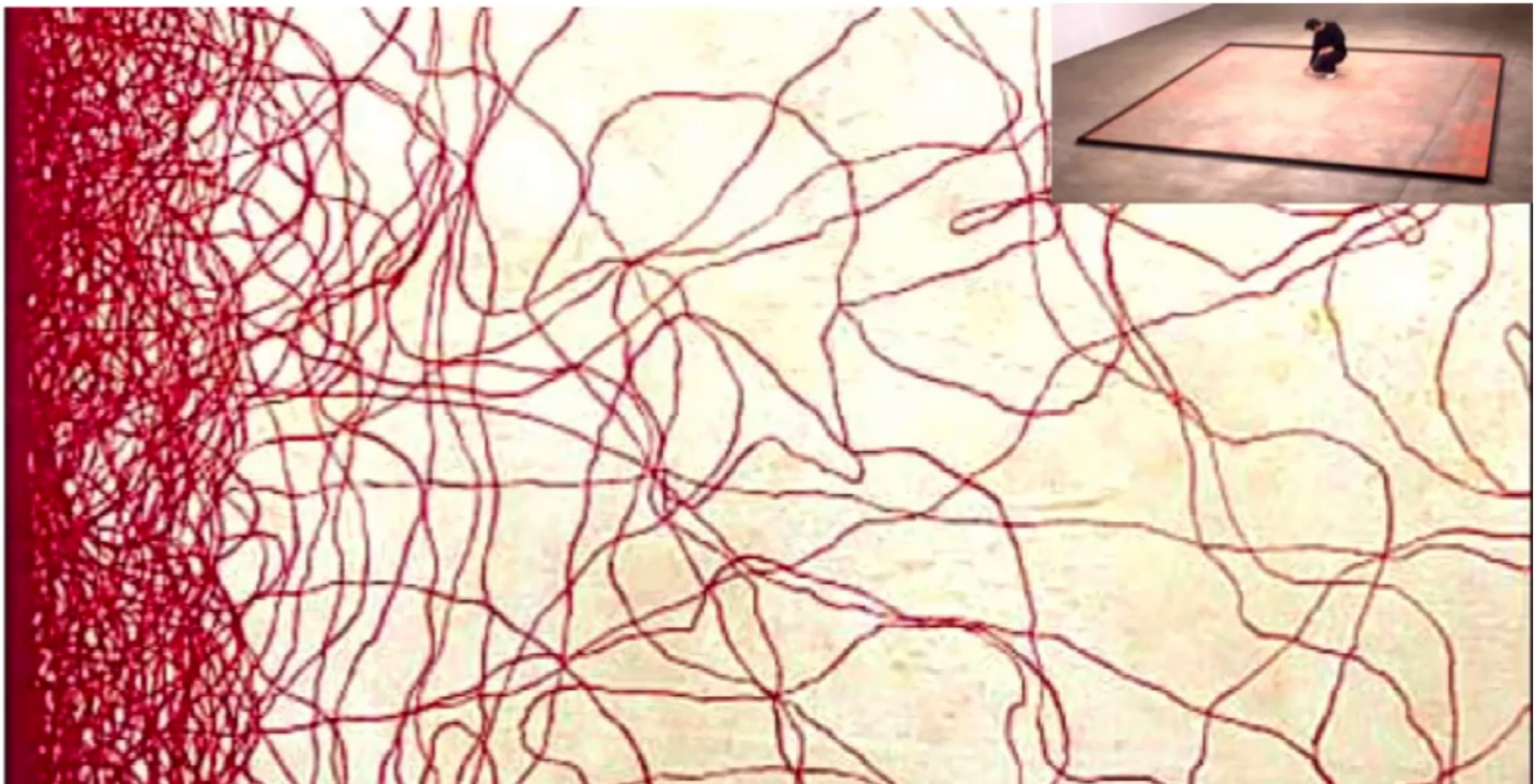


- CT-scans show 14 connections per ant
- Each connection can provide force of 150 X body weight

Foster et al. (2014) *J. Exp. Biol.*



Speed u
n* = # of ants in fixed monolayer
Height
h
t = 0
t* ~ 100 sec



Yukinori Yanagi "Wandering Position" (edge detail) 1998. Ant, crayon, steel video

<u>Ant Rule 2</u>: wander aimlessly when on top

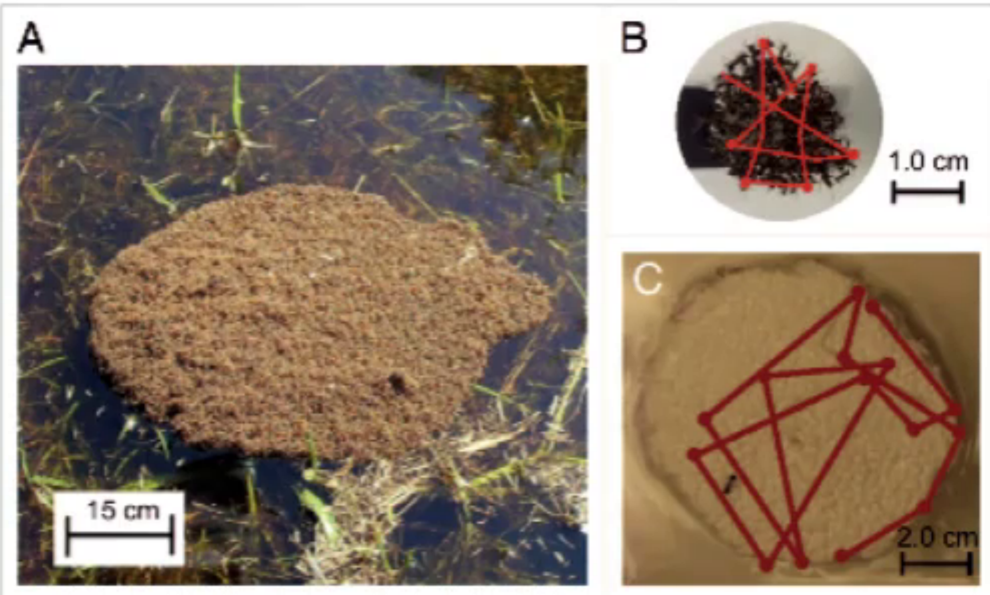
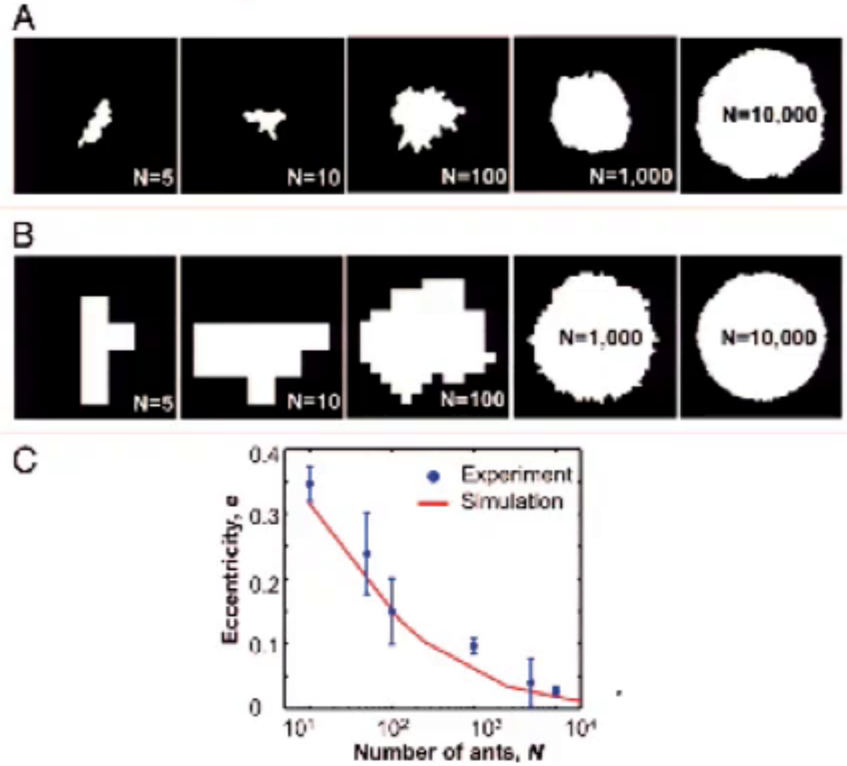


Figure 2. Ant rafts **(A-B)** and a Styrofoam raft **(C)** for measuring ant trajectories. In **(B-C)**, the lines show sample ant trajectories interrupted by the dots indicating turns made by the ant.



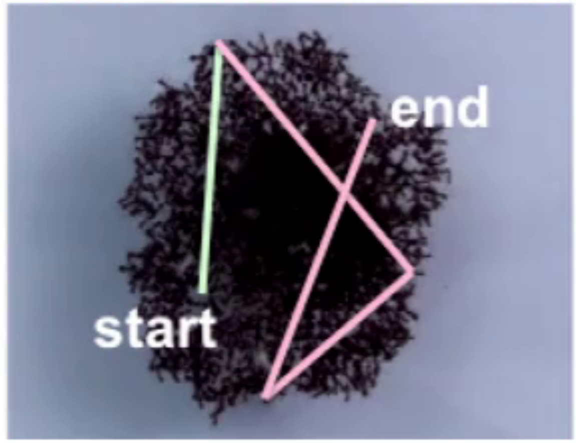
$$u(r) = \begin{cases} v & \text{if } r \le s \\ \frac{vs}{r} & \text{if } r \ge s. \end{cases}$$

v = 0.4 cm/s
s = 4+/- 1.5 cm

- Mlot et al (2012) *Communicative and Integrative Biology*

How far does an ant travel?

Ants make beelines and change direction at raft edge



Ant travel distance:

$$A = \text{E(travel distance)} = \frac{8\pi}{3} + \left(\frac{1}{1-p} - 1\right)\frac{4}{\pi} = 3.1$$

expected distance to edge from random point *x* inside a unit circle

expected # of bounces before sticking

expected edge-to-edge distance

rate of ants sticking to edge per second $= \dfrac{\text{no. of } ants}{\text{travel time}} = \dfrac{n(t)}{Ar/u} = \dfrac{u\sqrt{\gamma \pi n(t)}}{A} = h\dfrac{dn}{dt}$ form a new exterior boundary *h* ants thick


Tanvi Dave

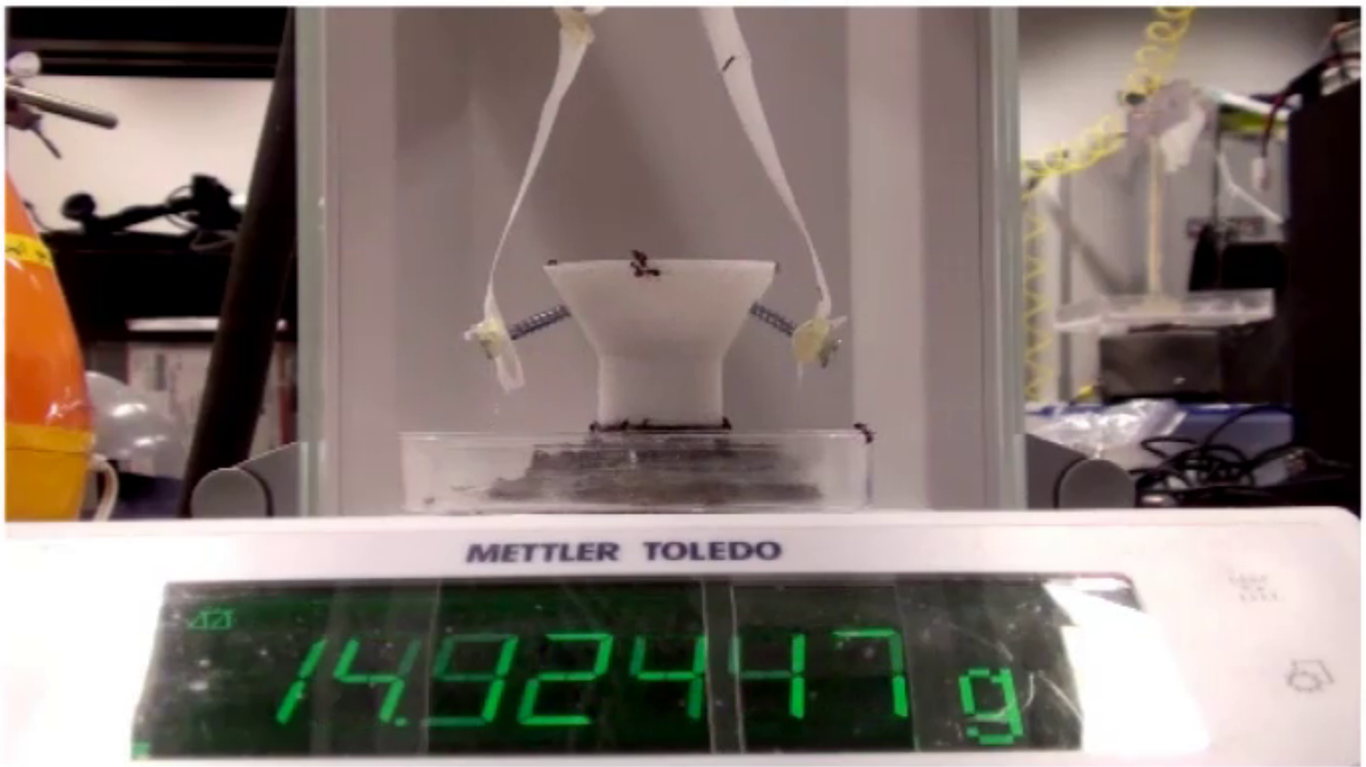
Social loafing
(French Agricultural Engineer, Maximilien Ringelmann, 1913)

- Increase in number of participants leads to decrease of individual contribution to as low as 50%

Why effort decrease

- Coordination loss
- Lack of motivation: Have individualism, effort doesn't matter in big group
- If watched, individuals exert maximum effort


METTLER TOLEDO
12.90011 g


METTLER TOLEDO
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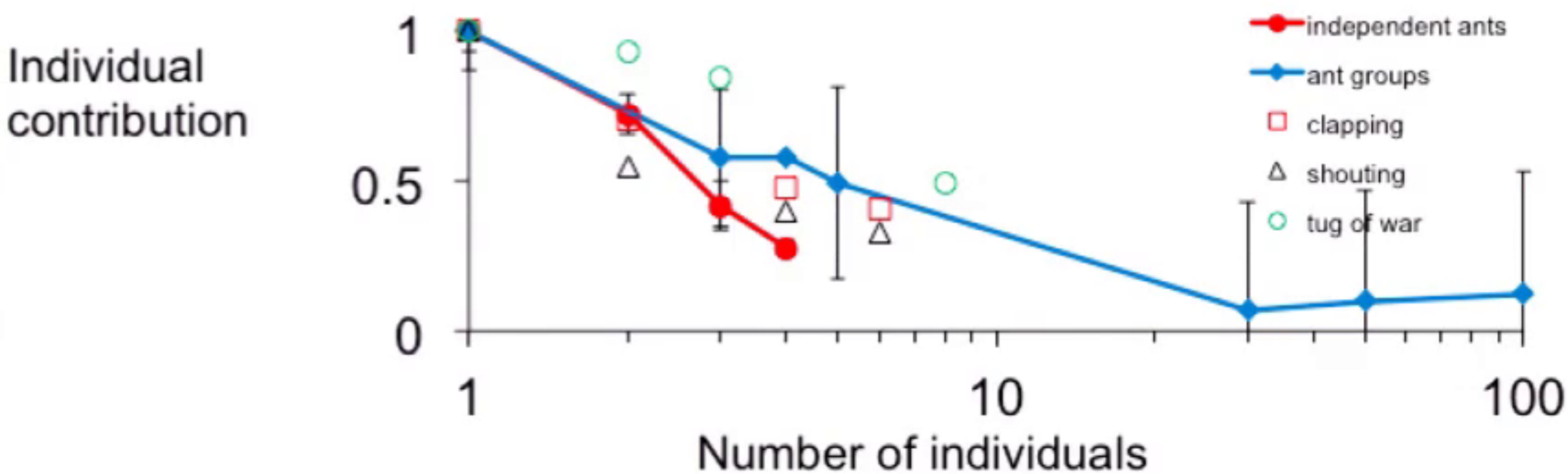
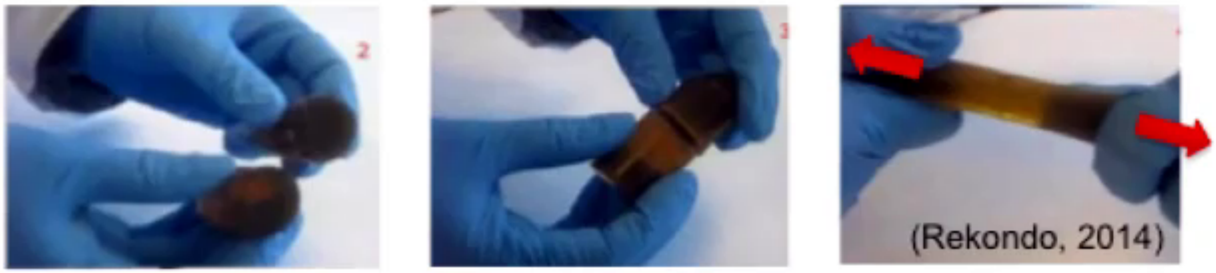


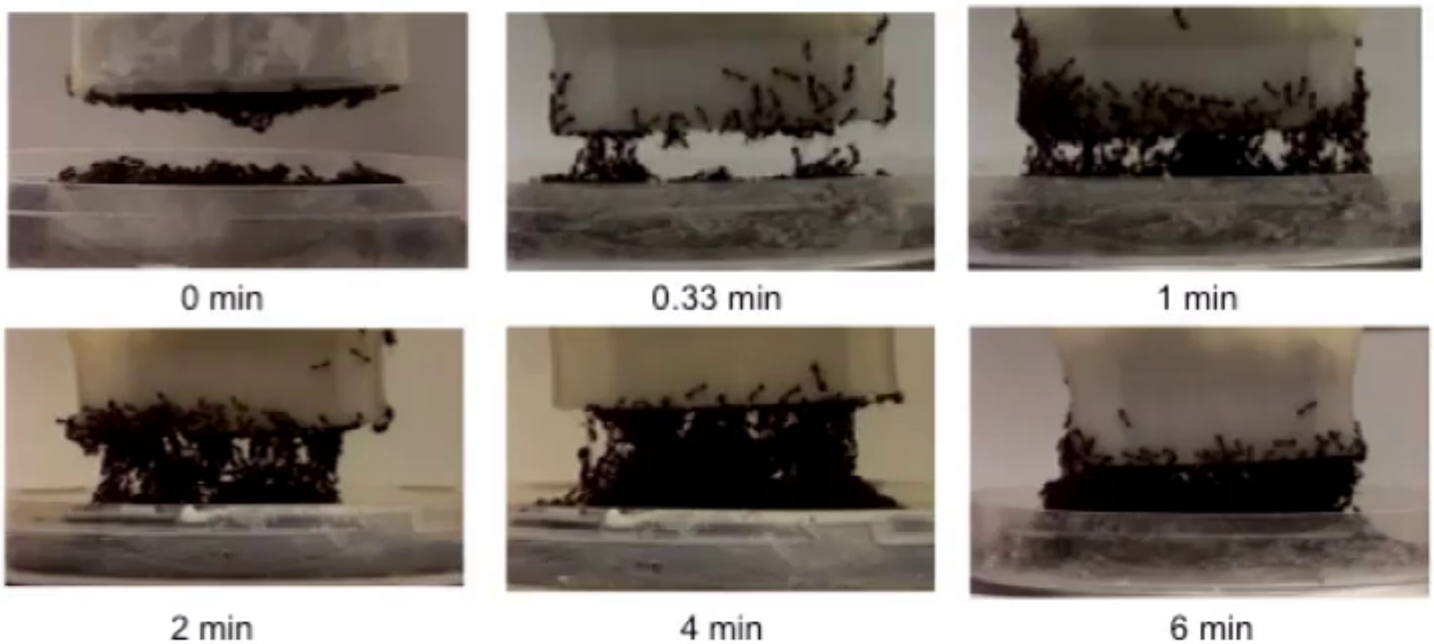
Levine, *Small Groups* 2006

Fire ants overcome Ringelman's effect by self-healing

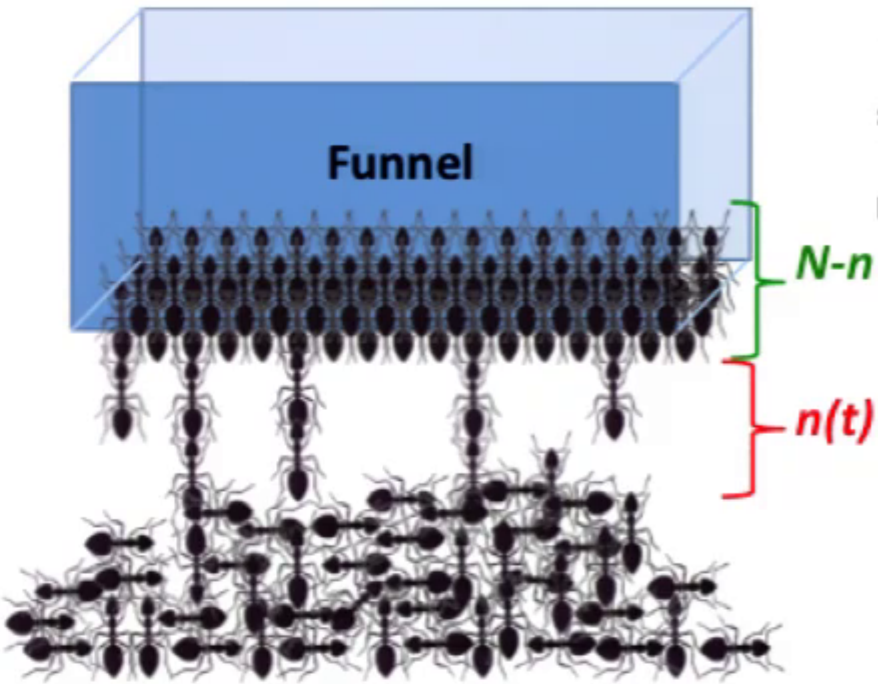


Two fire ant aggregations can anneal together when placed into contact

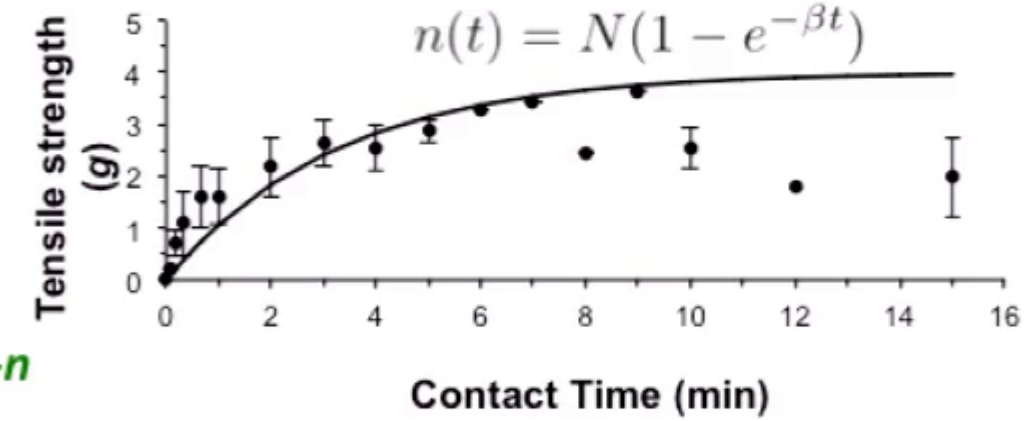
Healing shown by increase of number of connections with time



Healing rate similar to raft growth rate



β = 1 of 3 free ants connect per minute



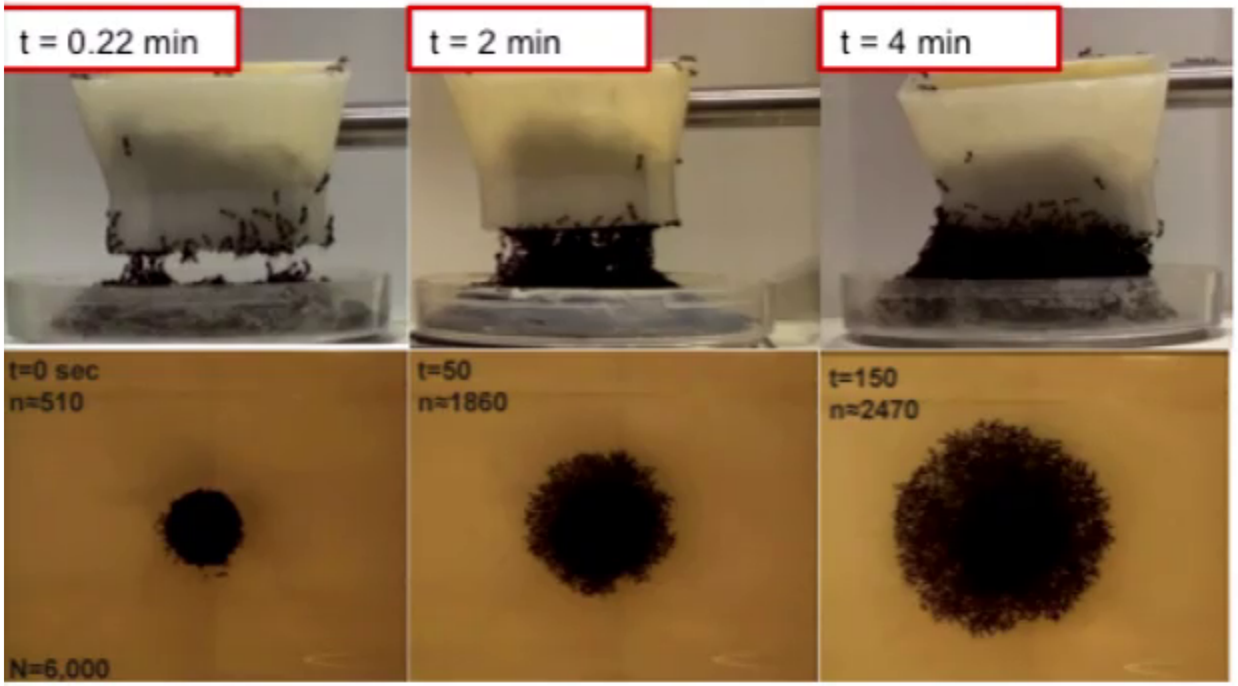
Self-healing rate model

$$dn/dt = \beta(N - n)$$

rate of ants connecting per second

Number of free ants

Growth and repair are the same phenomenon



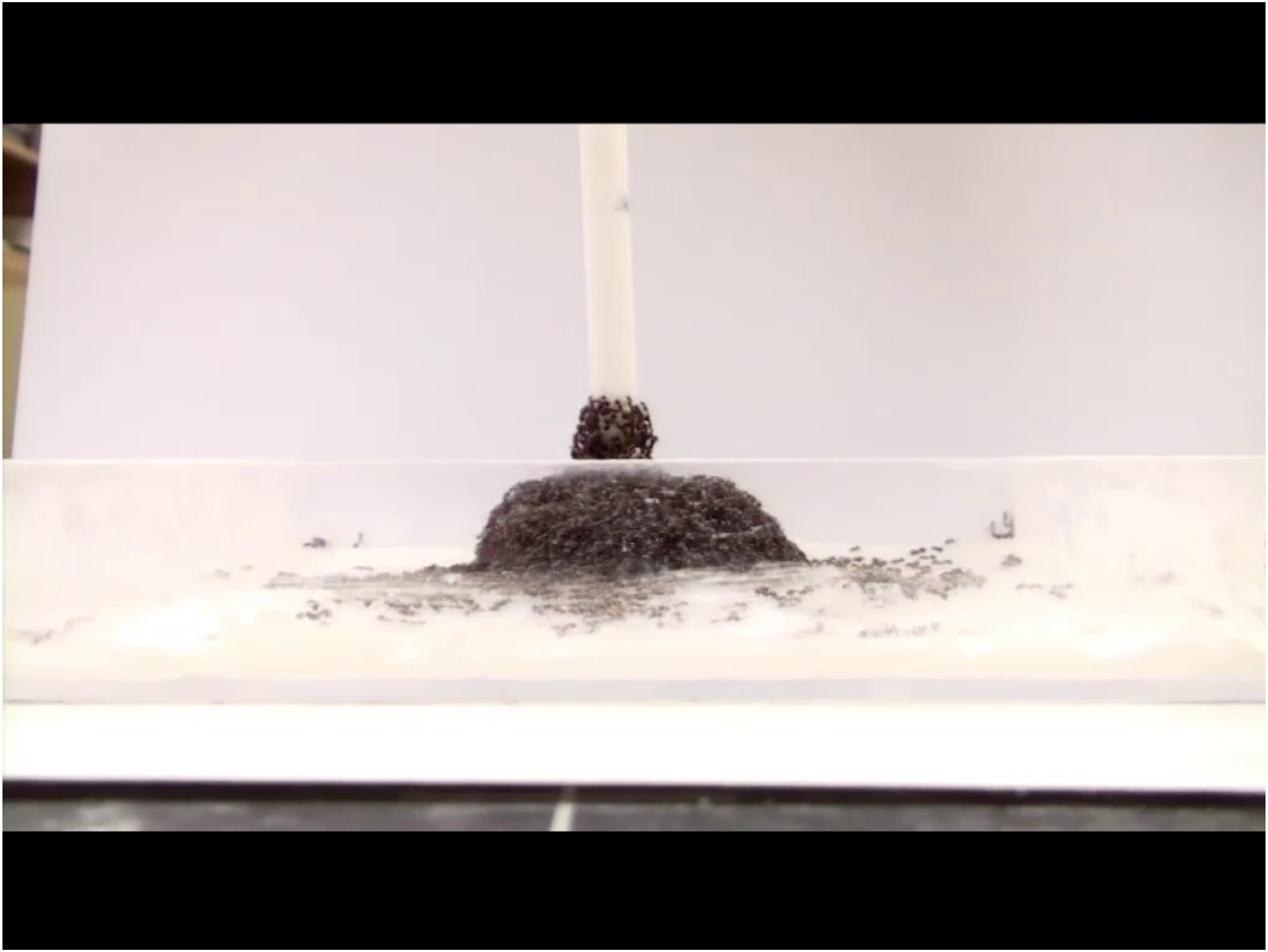
- Growth and repair are the same process: random motion of ants, and accretion at the "edge" of the structure

- rate is dependent on number of free ants

- as a result, growth/healing resemble negative exponentials

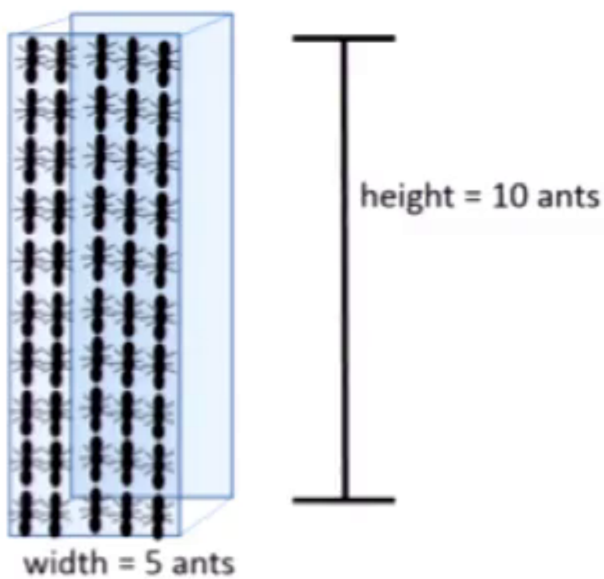
- are there other structures that grow slower?

Where do ants spend their vacation?
In trumpet-shaped towers



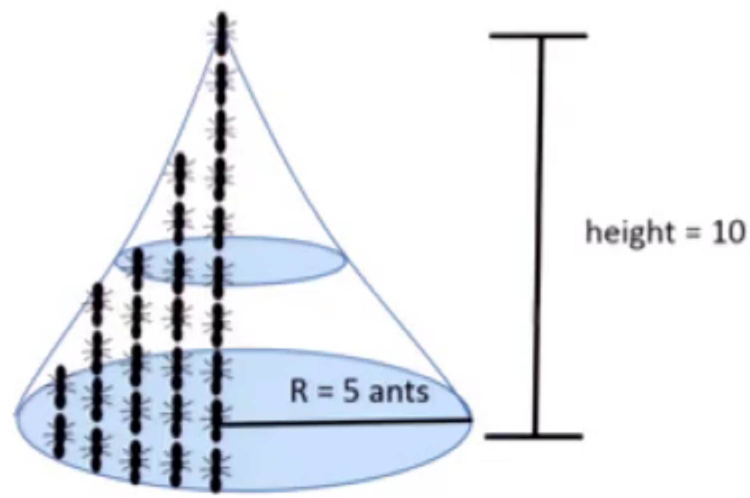
What's the best shape for a tower?

For rectangular shape: ants on the bottom carry more load



Each ant in the bottom layer of this tower carries 9 ants

For exponential shape: load is evenly distributed



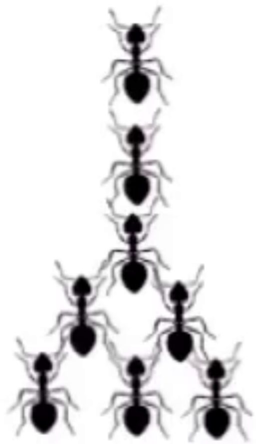
For the same 10 ants height and number of ants, we will show that each ant is holding 3.8 ants

Exponential profiles corresponds to columns of constant stress (Timoshenko 1930)

Trumpet-shaped towers characterized by ant strength α

For α = 2 ants

Layer i



$i = 1$

$i = 2$

$i = 3$

$i = 4$

$i = 5$

Width grows exponentially

Vertical Force Balance

Let X_i be the number of ants in layer i

$$\alpha X_{n+1} = \sum_{i=1}^{n} X_i$$

\# of ants layer $n+1$ can support = # of ants in layers 1 to n

The Shape Law

$$X_n = \begin{cases} \beta & \text{for } 1 \le n \le \alpha \\ \beta(1 + 1/\alpha)^{n-\alpha} & \text{for } n > \alpha \end{cases}$$

Who: Minyons de Terrassa (Casteller group)

Where: Barcelona, Spain

When: 22 November 1998.

Goal: To become First 10 story tower with 3 person layers.

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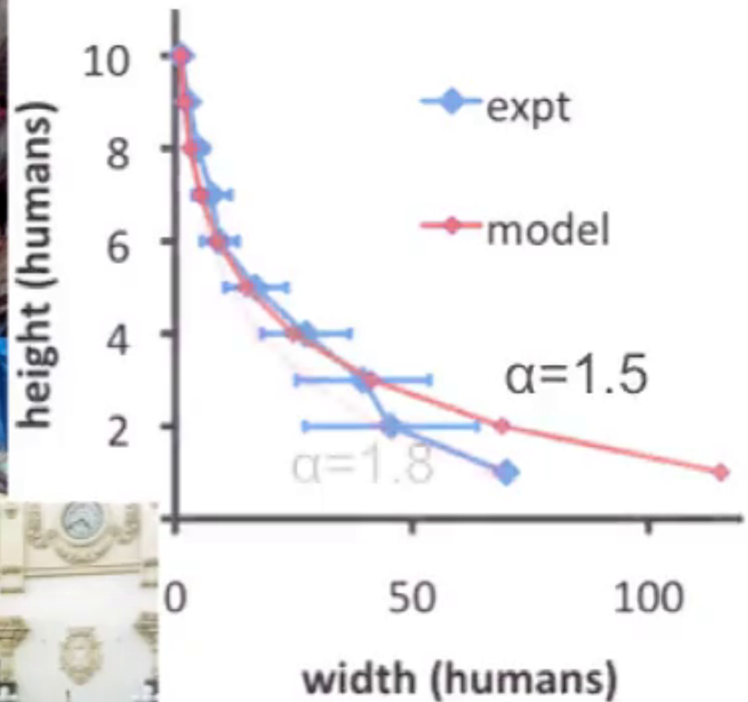
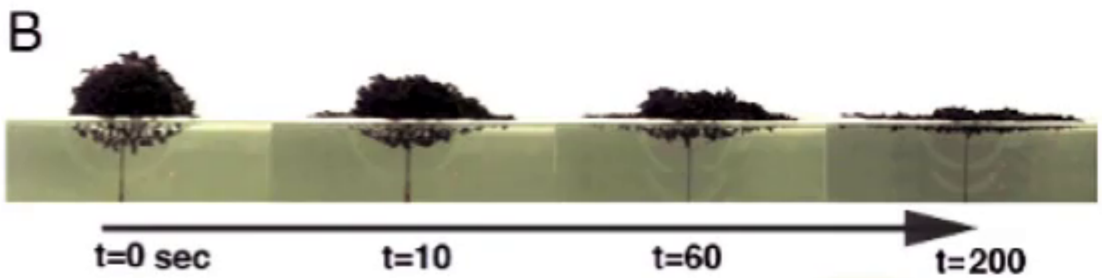
Human towers also follow the Shape Law

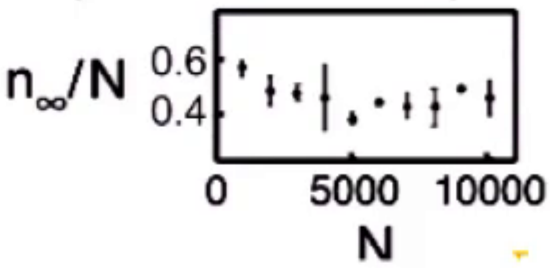


- data averaged from 26 towers gathered using Google Image

Ant Rule 3: First, be a brick. Then flow like water

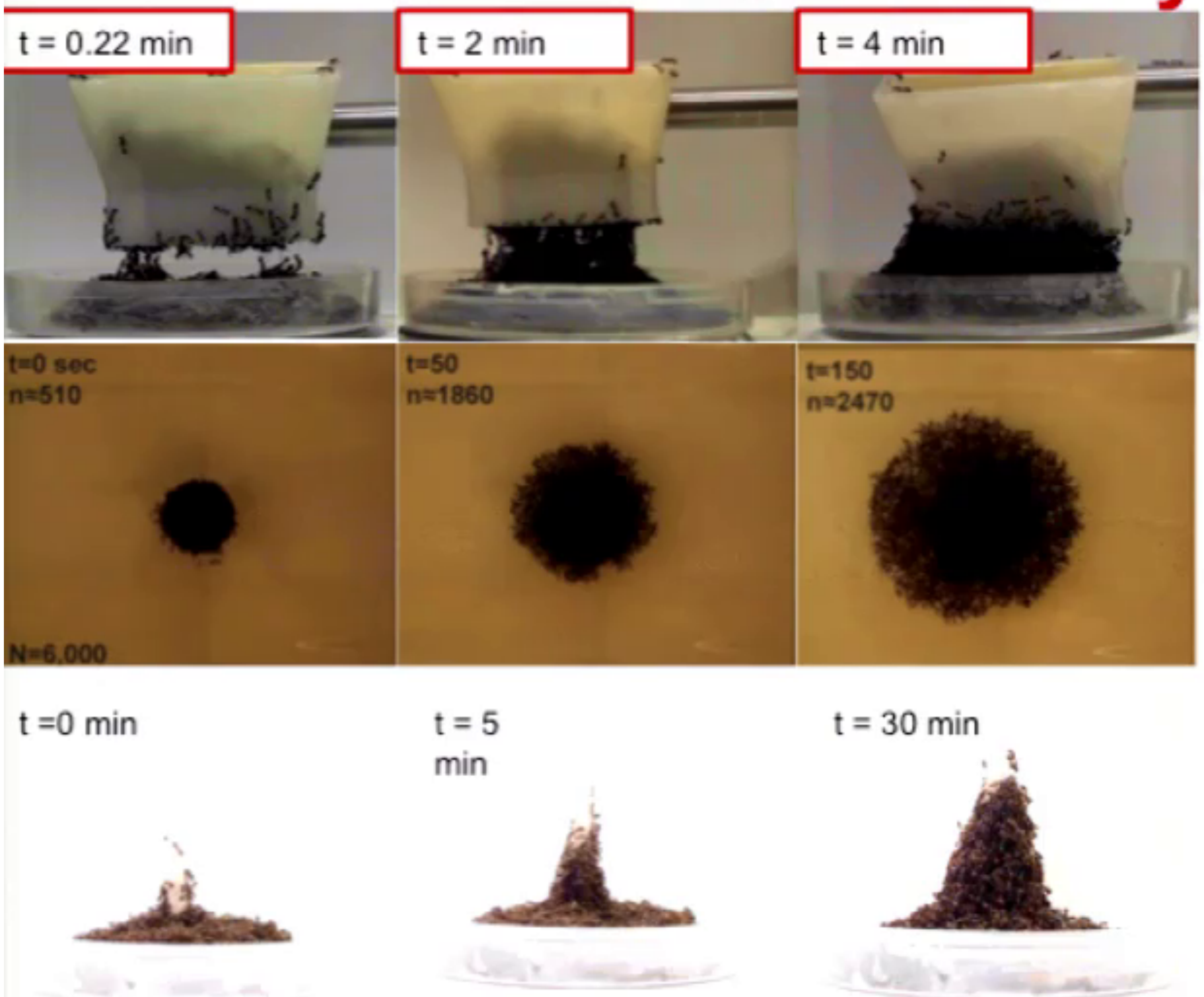
- ant rafts at equilibrium when each ant support 1.5 body weights





- towers avalanche until a shape is constructed where each ant carries 2 ant weights

We will verify

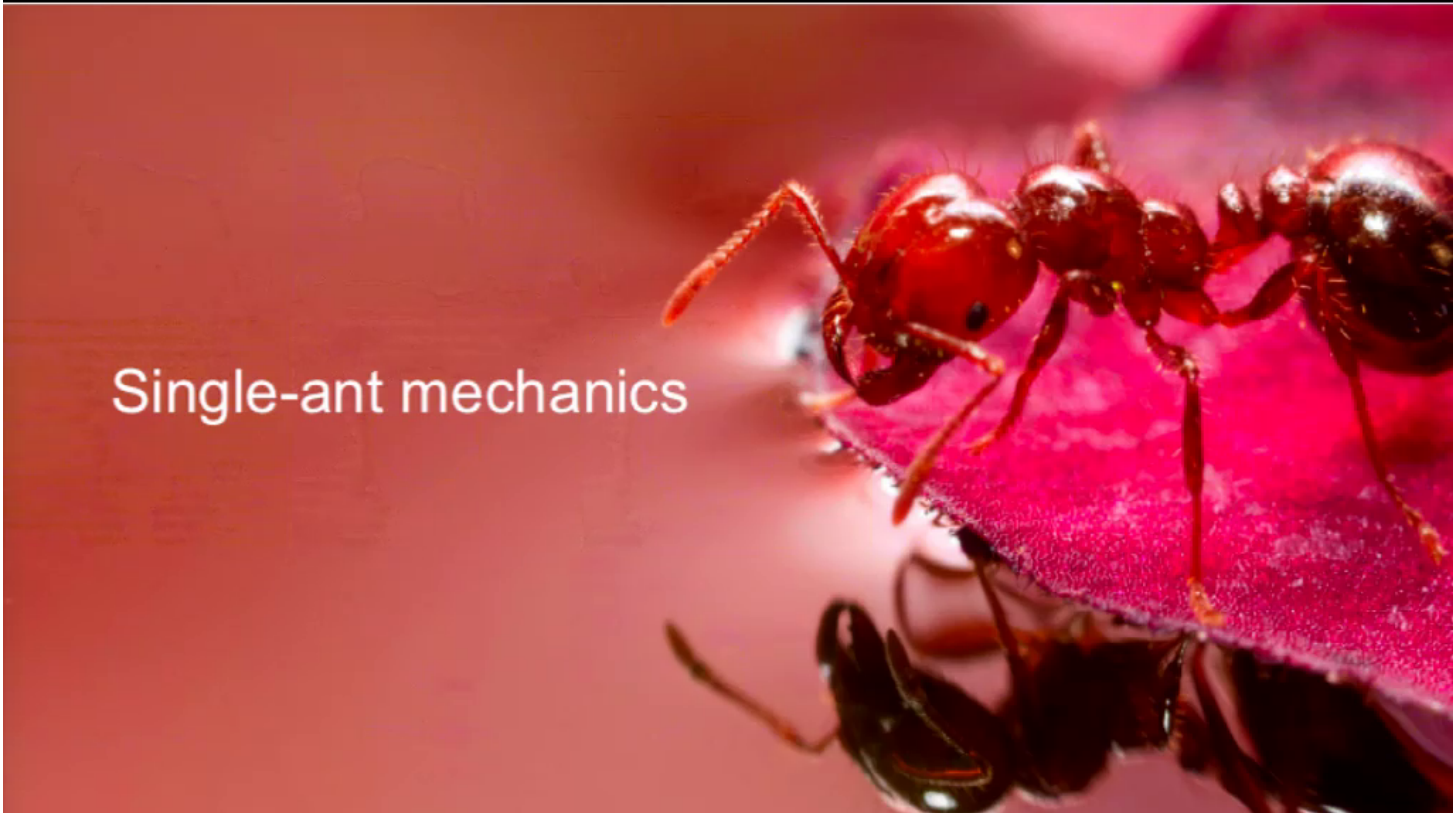


Three ant rules sufficient to predict motion of raft, tower

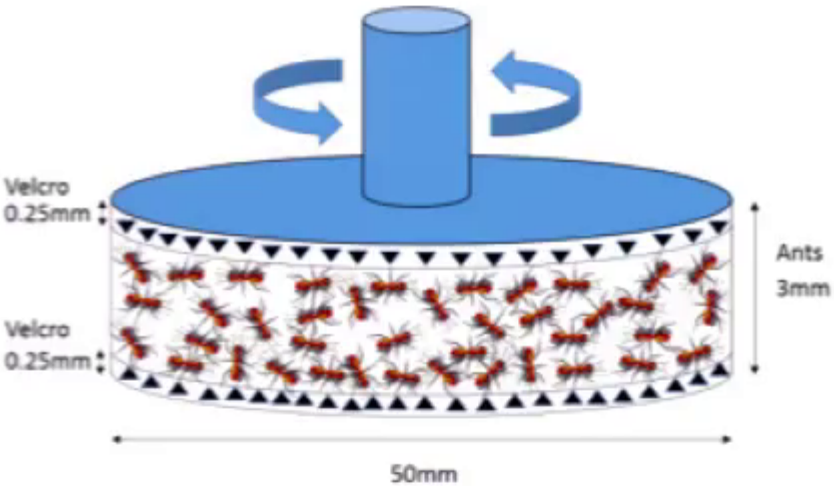
Ant Rule 1: Hold on for dear life.

Ant Rule 2: When on top, wander aimlessly.

Ant Rule 3: Be a brick. Then flow like water.


Single-ant mechanics

Ant force measurement in a "blender"



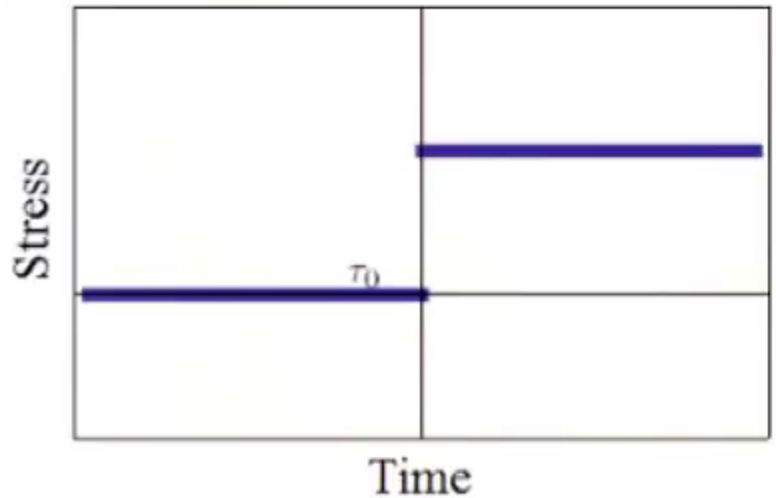
Static plates

Slow

Fast

- Rheometer fitted with velcro plates, glass containment cylinder
- Ants are always moving

Do ants budge when pushed?



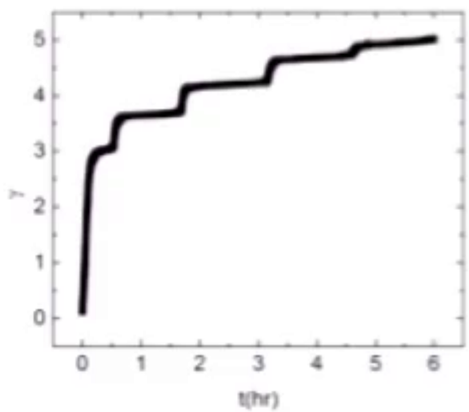
- "Creep" Test
  - Apply a constant stress
  - Measure Strain

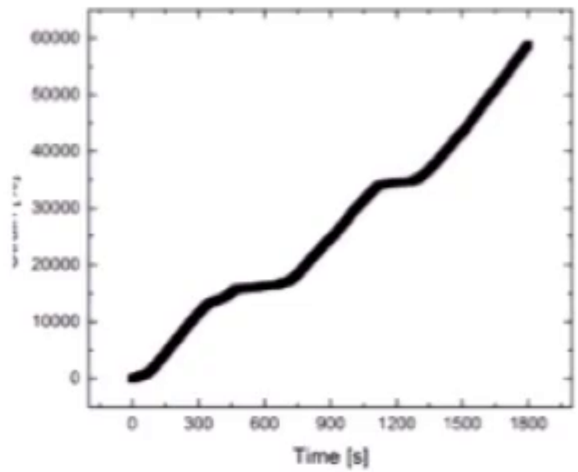
Push on them

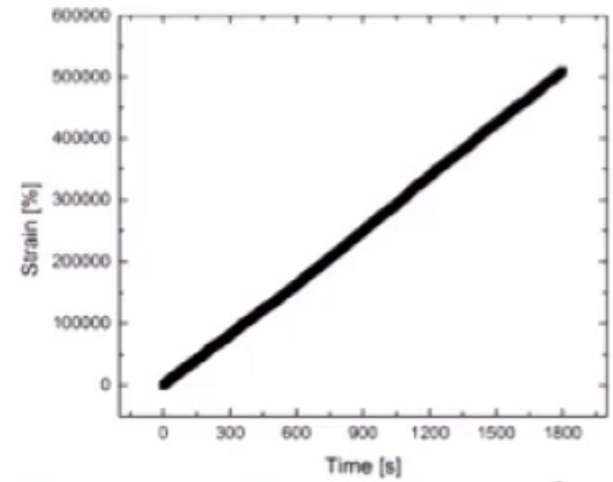
Do they budge?

Ants resist pressures less than 20 Pa (2 ant weights), and then flow at higher pressures

% deformation of ants







Applied Stress = 5 Pa | 40Pa | 100Pa

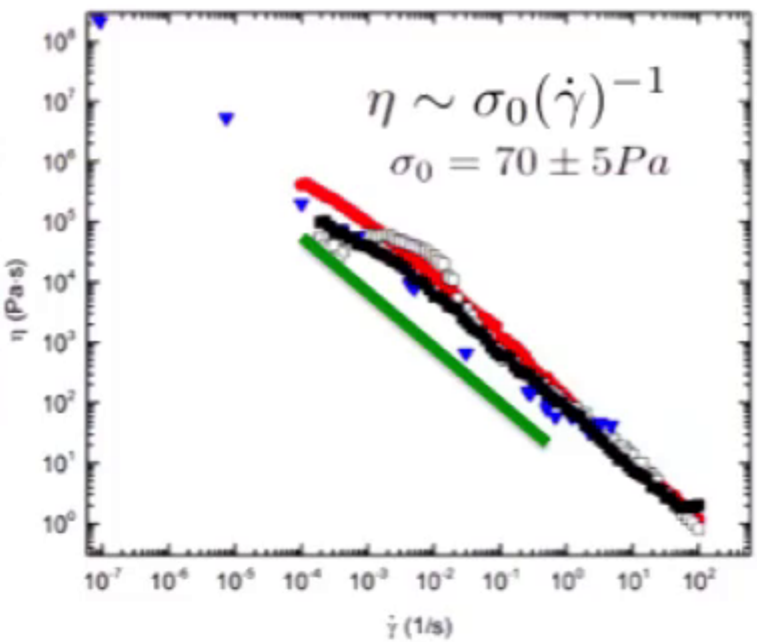
Ants resist low stresses

Ants periodically resist intermediate stresses

Flow at high stress

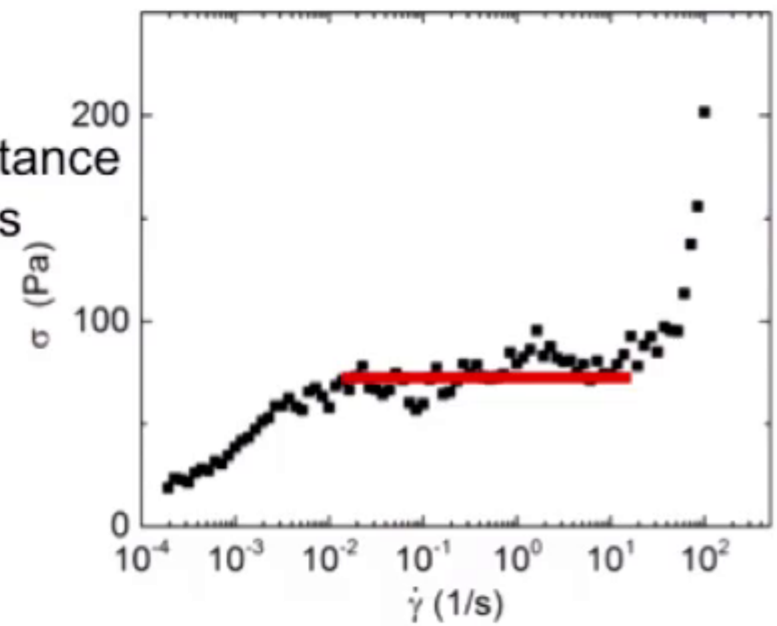
Elastic regime | Rafts | Stick-slip, Avalanches | Towers | Steady Flow

Live ants "play dead" when forced to flow



Rate of deformation

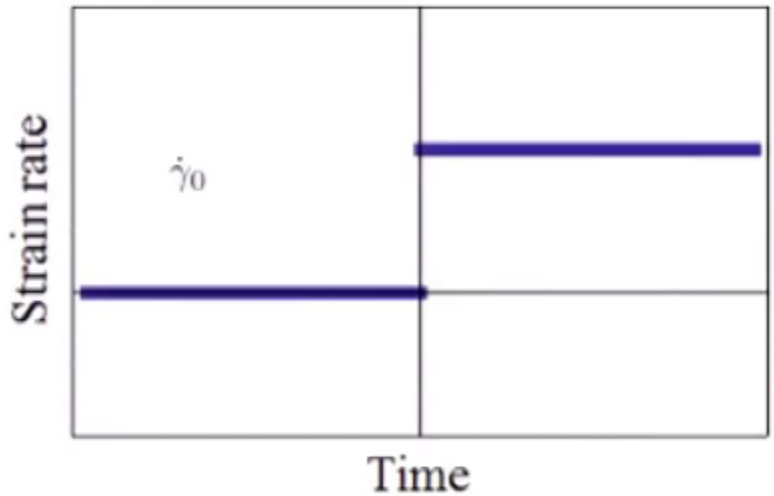
Resistance of ants



Rate of deformation

- Both live and dead release grip at constant stress of 70 Pa (pressure of 7 ant weights)

How much do they resist if forced to flow?



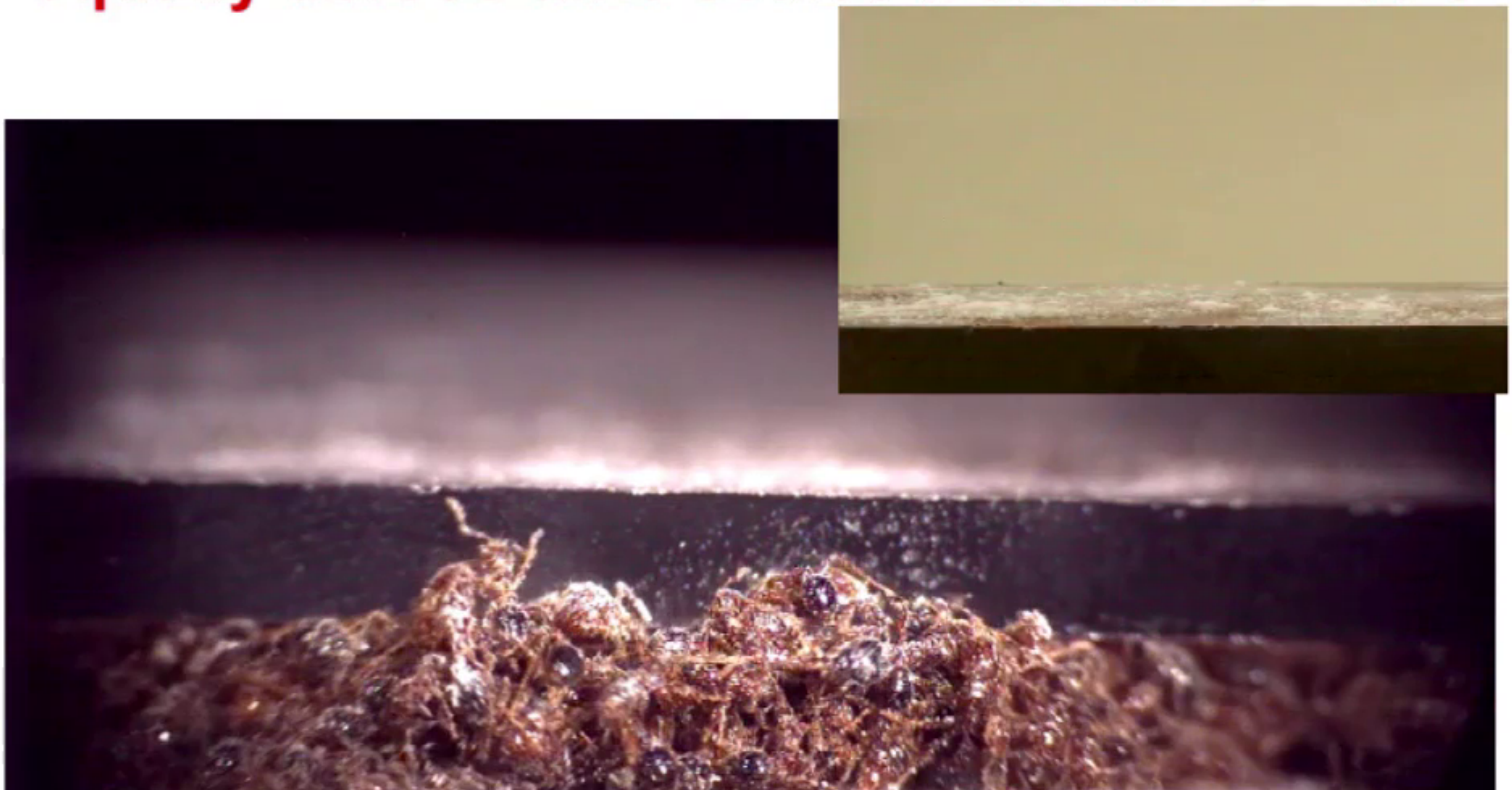
- CSR test (controlled strain rate test)
  – Apply a constant strain rate
  – Measure Stress

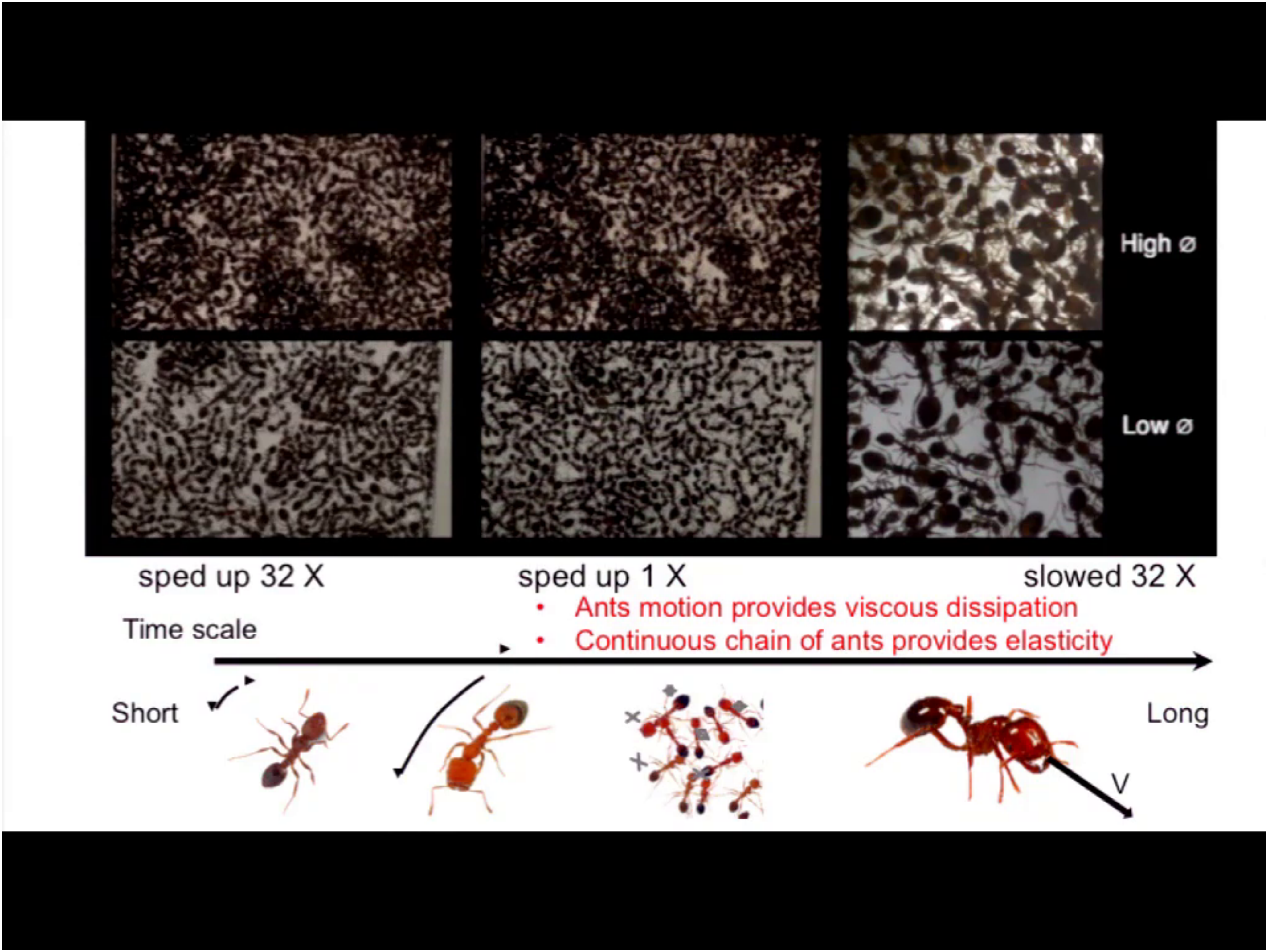
Make the ants flow

Measure their resistance

$$\tau = \dot{\gamma}\eta$$

G' = G'': Ants store and dissipate energy equally across time scales from 0.01 s - 10 s




High ø
Low ø
sped up 32 X
sped up 1 X
slowed 32 X
Ants motion provides viscous dissipation
Continuous chain of ants provides elasticity
Time scale
Short
Long
V

Ants are smart materials that respond according to context

Tension	Shear	Compression
150 body weights	7	2