



**CROWDS IN MOTION:
HERDING, FLOCKING,
SWARMING**

SOMETHING IN THE AIR: THE PHYSICS OF CROWDS

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“I am less interested in how people move than in what moves them.”

— Pina Bausch (1984)

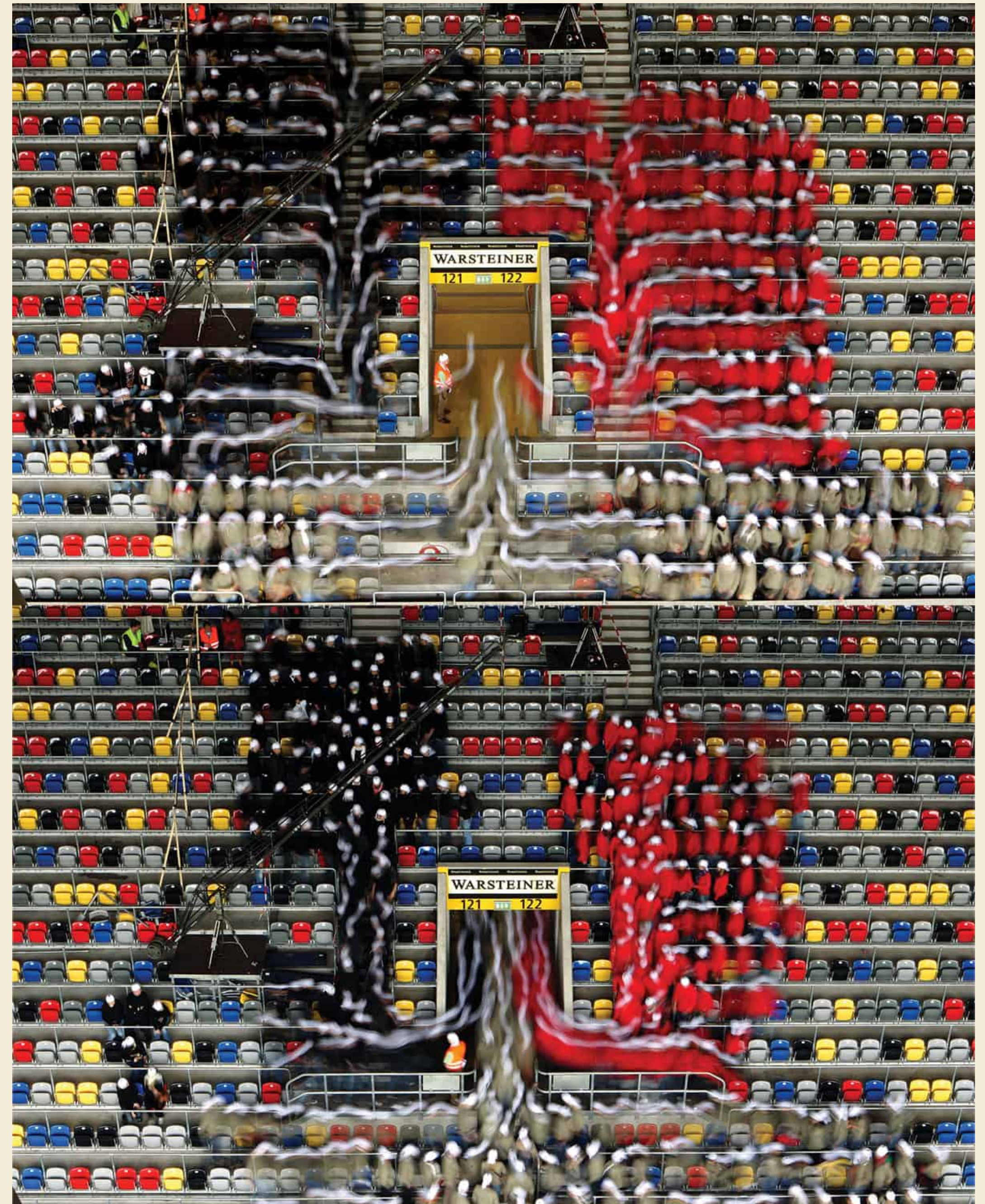
“If you ever get close to a human
And human behaviour
Be ready, be ready to get confused”

— Björk, *Human Behaviour* (1993)

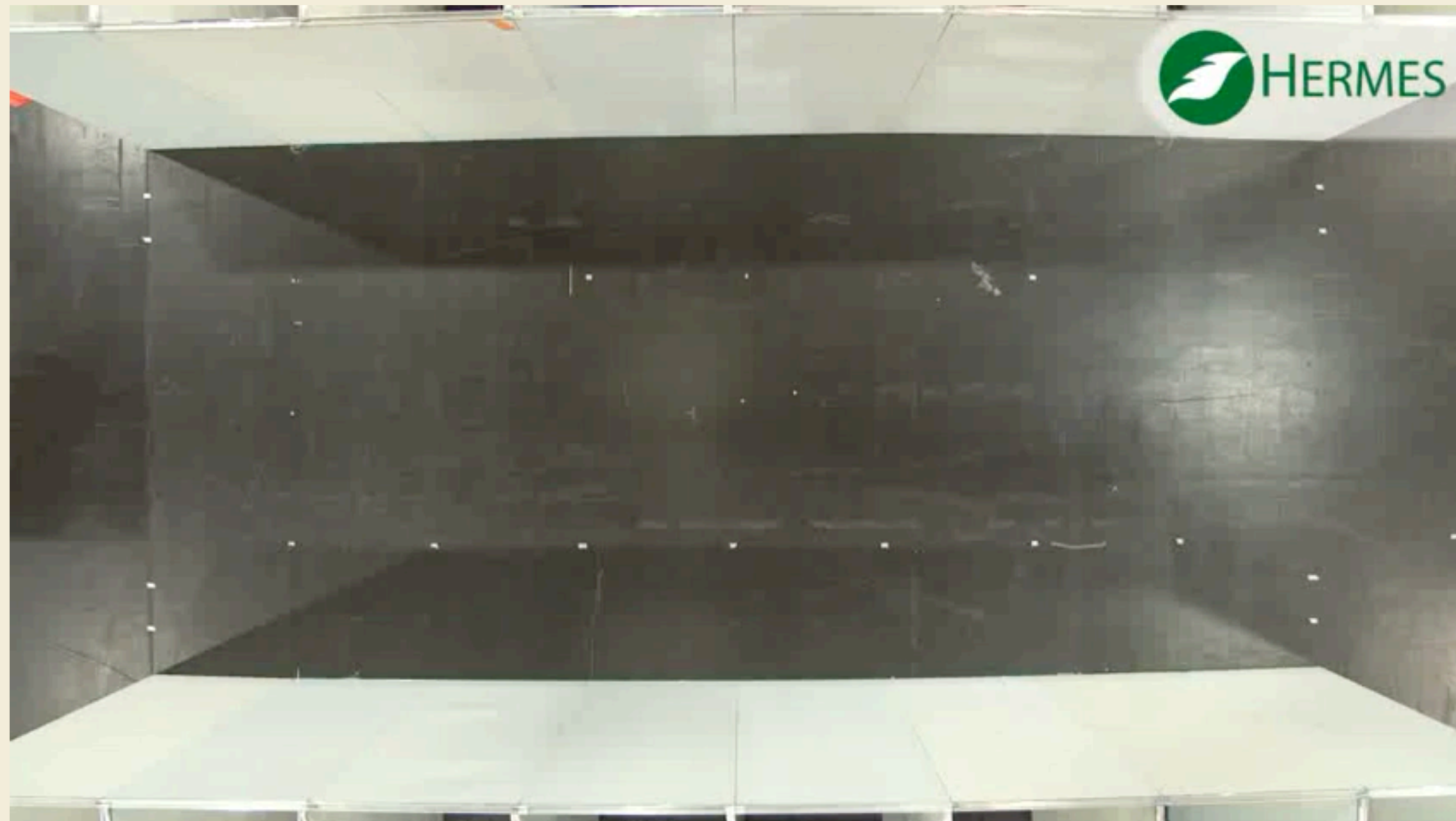




video: https://www.youtube.com/watch?v=e2WfyJXB__8



source: <https://physicsworld.com/a/im-a-football-fan-get-me-out-of-here/>



video: https://www.youtube.com/watch?v=J4J__1OOV2E



Love Parade disaster (Duisberg, Germany, 2010)

CHARACTERISTICS OF CROWD PANIC

- Individuals move faster than normal.
- Physical interactions (pushing) ensue.
- Bottleneck passing becomes uncoordinated.
- Arching and clogging is observed at exits.
- Jams build up.
- Dangerous pressures build up in the jammed crowd, which can bend/break barriers and walls.
- Fallen/injured people are now “obstacles” that slow down escape further.
- Mass behaviour (imitation) occurs.
- Alternative exits are overlooked or not used efficiently.



non-fatal crowd “surge” at an Oasis
concert in Manchester (4x speed)



video: <https://www.youtube.com/watch?v=UstTe4Mw910>

CROWD DISASTERS

- Stampedes can arise as a result of an emergency, or in a collective state of excitement.
- Its prevention is often an engineering/design issue, but has a component of individual/collective strategy.
- Panic has mostly been examined through the lens of social psychology, and very few theories of crowd dynamics have been developed to date.
- This issue remains urgent due to the continuing occurrences of stampedes at mass events.

image: <http://theconversation.com/standing-room-only-32737>



image: <http://crowdmanagementacademy.com/usacrowdmanagement.htm>



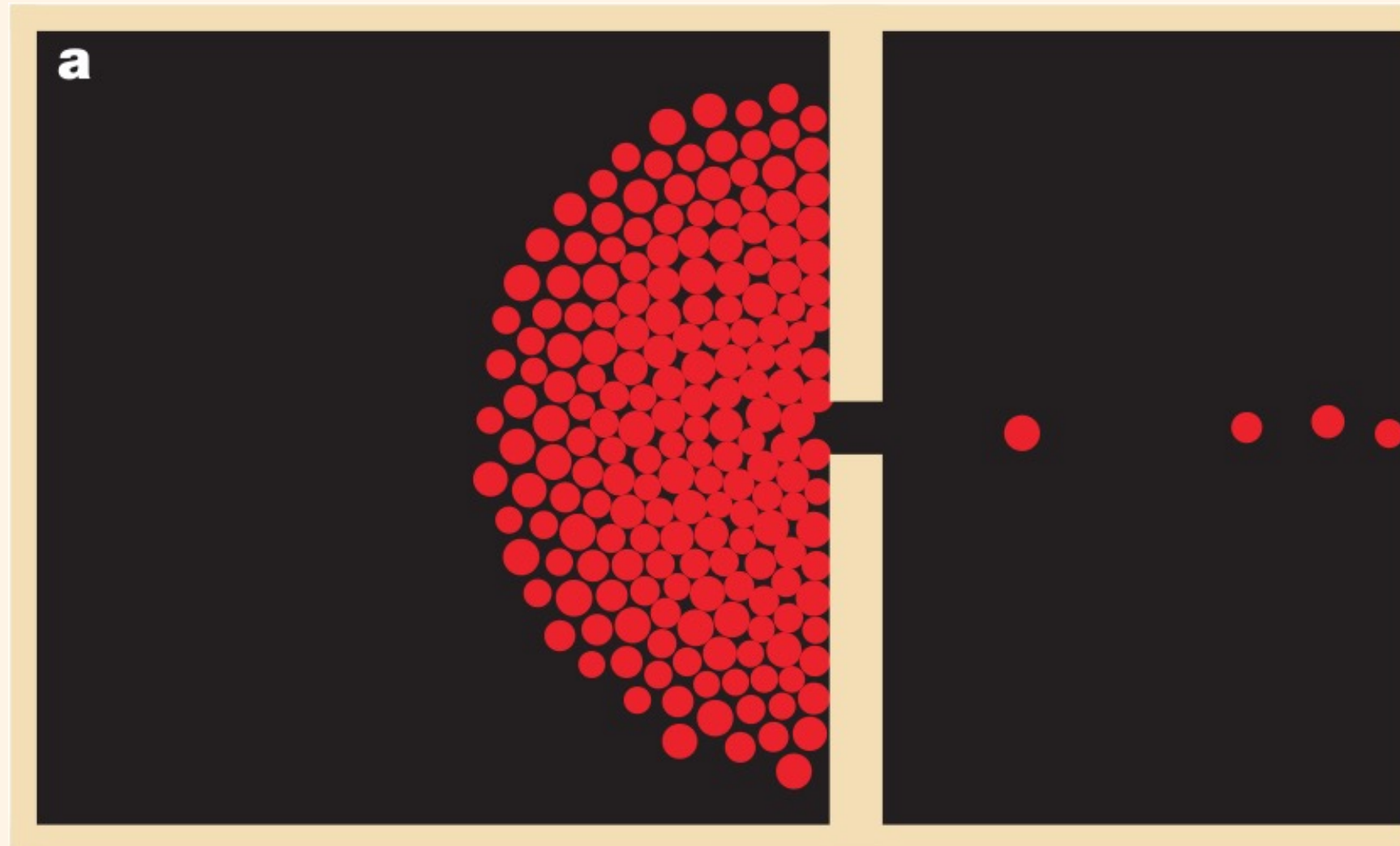
A MODEL FOR CROWD PANIC

- ▶ Helbing et al (2000) introduced a model is based on plausible crowd interactions, drawing from socio-psychological literature, media reports, empirical investigations and engineering handbooks.
- ▶ Propose applications of this model included: testing building designs, i.e. predict outcomes of emergency situations in crowded rooms.

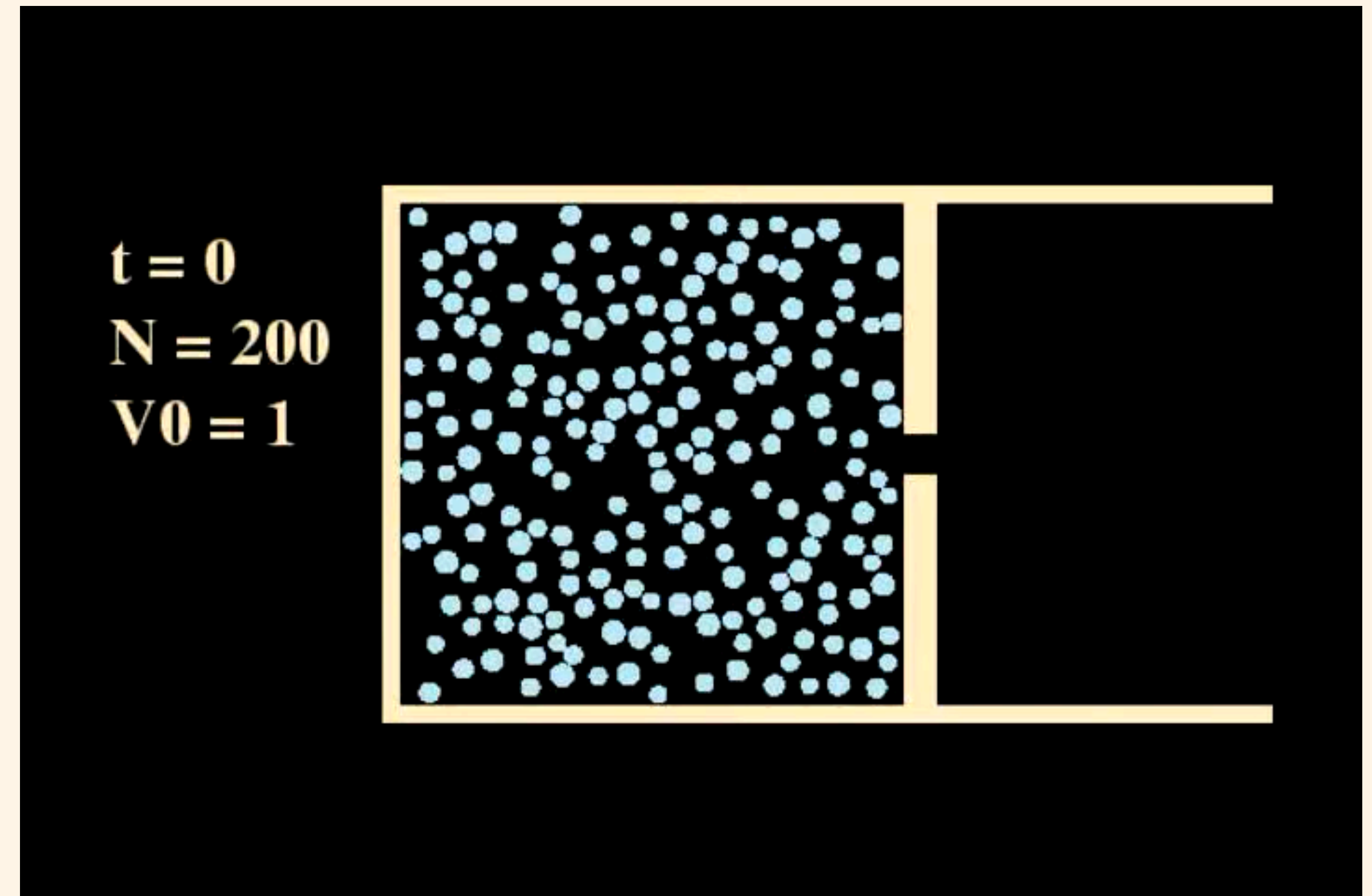
A MODEL FOR CROWD PANIC

- * N agents i of mass m_i intend to move with speed v_i^0 in a direction \mathbf{e}_i^0 .
- * Each agent modifies their velocity \mathbf{v}_i with a characteristic time τ_i based on interactions, leading to a change in position $\mathbf{v}_i(t) = d\mathbf{r}_i/dt$.
- * Each force expression consists of:
 - * A **repulsive interaction term** $A_i \exp \left[(r_{ij} - d_{ij})/B_i \right] \mathbf{n}_{ij}$, where $r_{ij} = r_i + r_j$ is the sum of the pedestrians' radii, $d_{ij} = \|\mathbf{r}_i - \mathbf{r}_j\|$ is the distance between their centres of mass, and $\mathbf{n}_{ij} = (n_{ij}^1, n_{ij}^2) = (\mathbf{r}_i - \mathbf{r}_j)/d_{ij}$ is the normalised vector from j to i (note: i tries to move away from j).
 - * A **body force** that counteracts body compression $k(r_{ij} - d_{ij})\mathbf{n}_{ij}$
 - * A **sliding friction force** that impedes relative tangential motion, $\kappa(r_{ij} - d_{ij})\Delta v_{ji}^t \mathbf{t}_{ij}$, where $\mathbf{t}_{ij} = (-n_{ij}^2, n_{ij}^1)$ and $\Delta v_{ji}^t = (\mathbf{v}_j - \mathbf{v}_i) \cdot \mathbf{t}_{ij}$.
- * And similarly there included forces that describe interactions between the pedestrians and the walls.

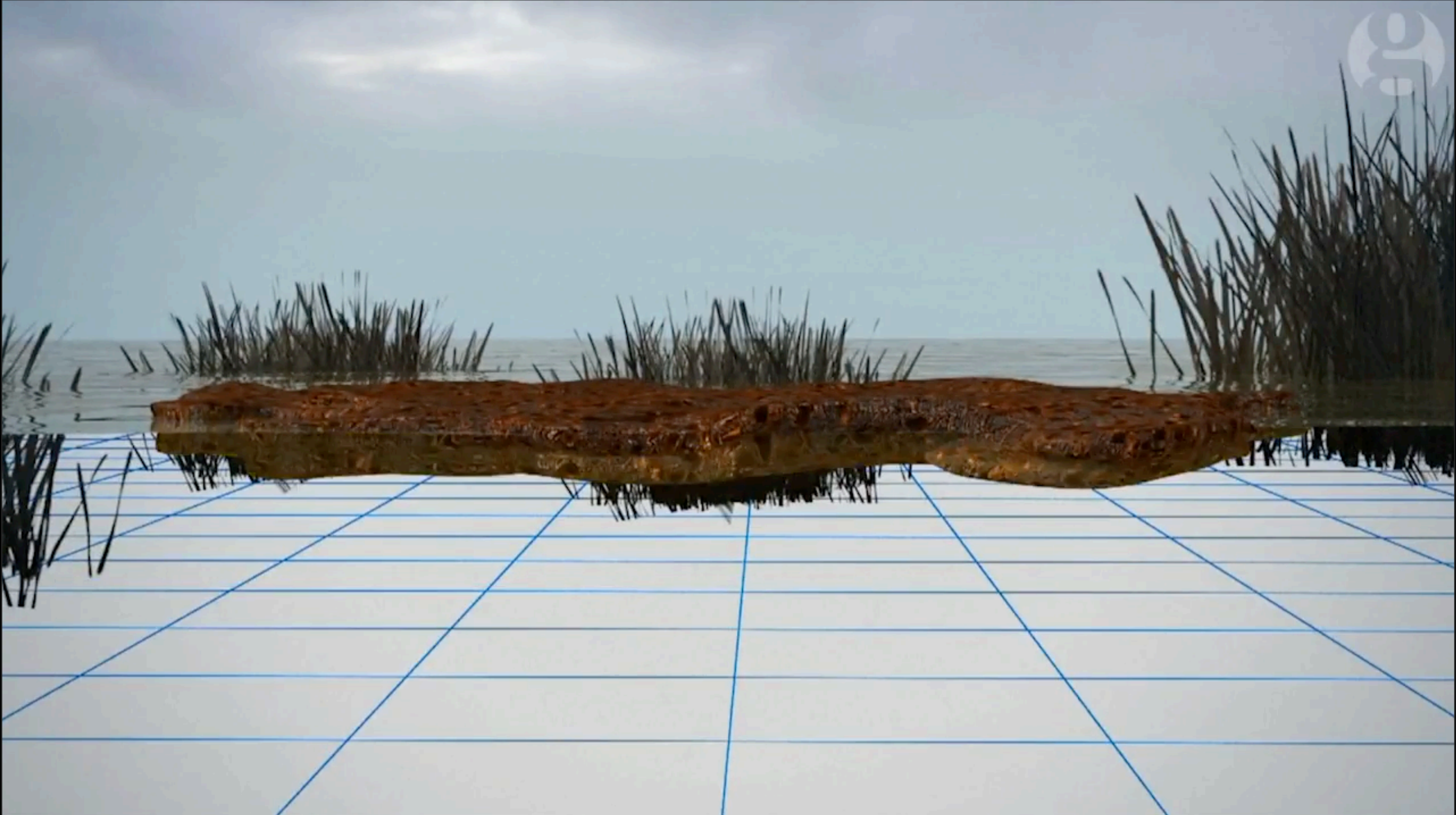
ORDERLY EVACUATION VS CLOGGING



- An orderly evacuation is observed for low desired velocities.
- For large desired velocities, arch-like blocking is observed at the exit.
- Avalanche like bunches of pedestrians leave when the arches break, comparable to intermittent clogging in granular flows.



FIRE ANT RAFTS



FIRE ANT AGGREGATIONS ARE VISCOELASTIC!



Elasticity: After compression, the aggregation approximately returns to its original shape



Viscosity: A lead sphere slowly sinks through the aggregation

ANT RAFTS

the workers form strong links between their tarsi and the tarsi, femur, mandibles or propodeum of other ants



ants trapped below water lift themselves to the surface using bubbles stuck on submerged substrate



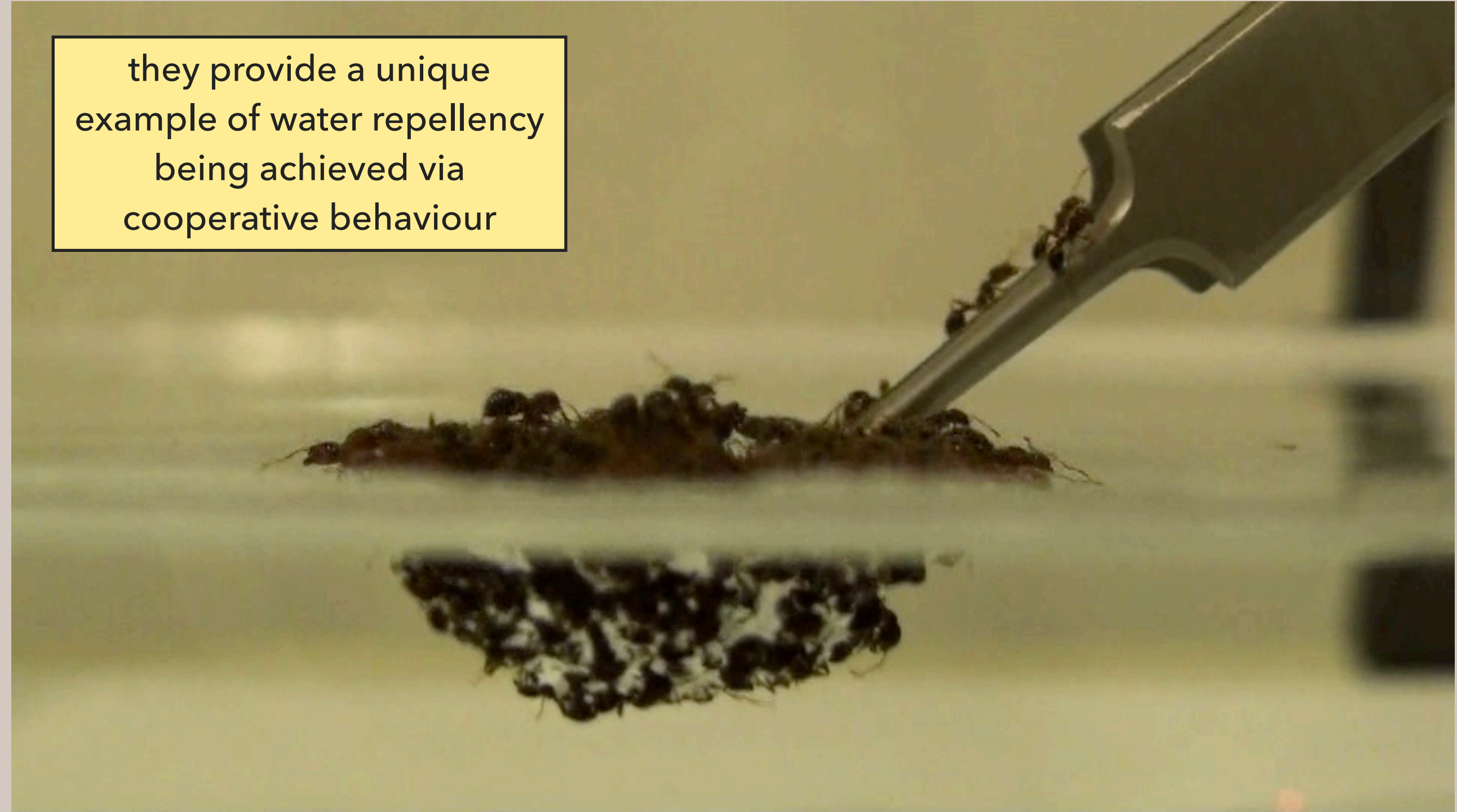
R. Strecker



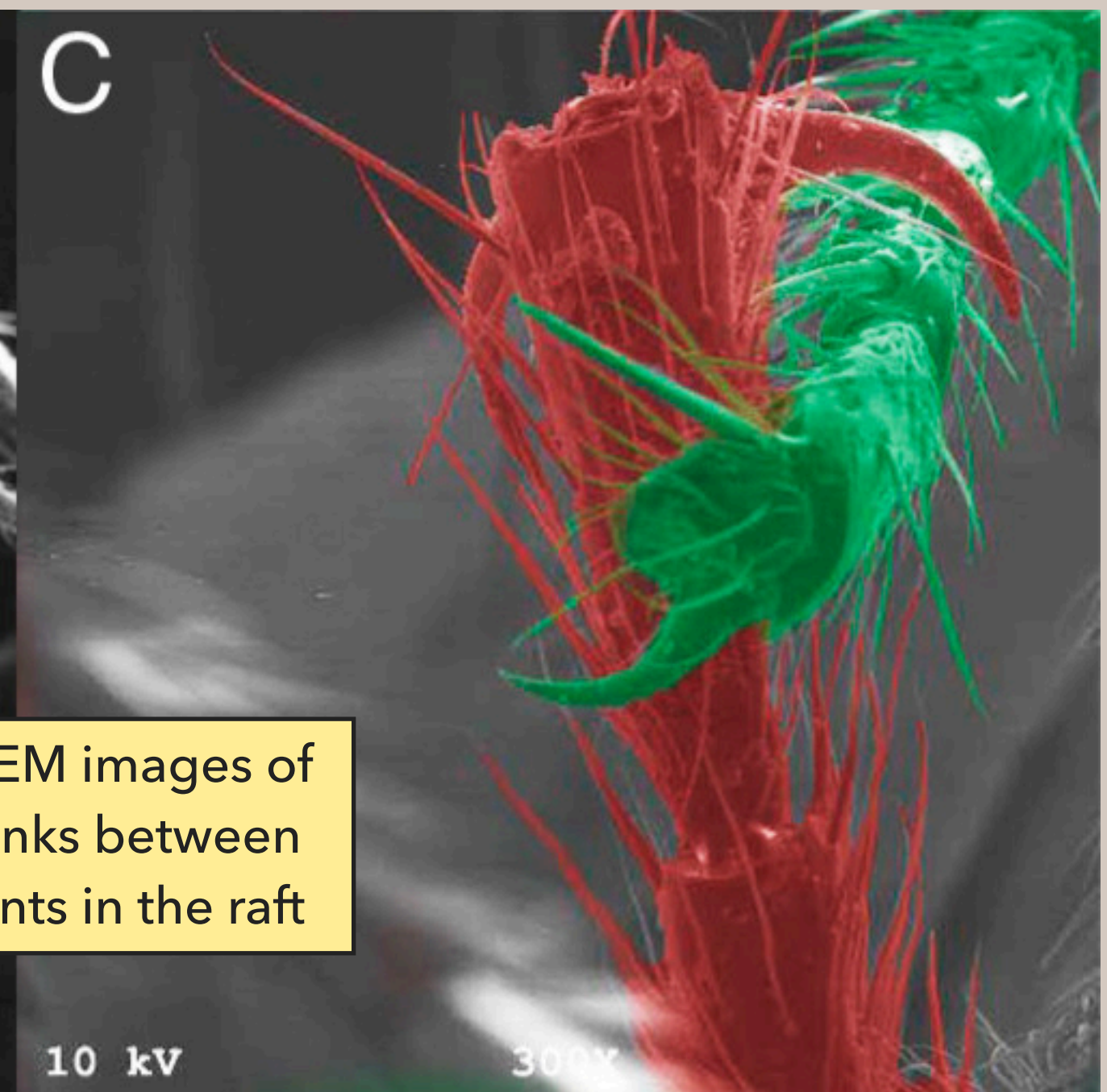
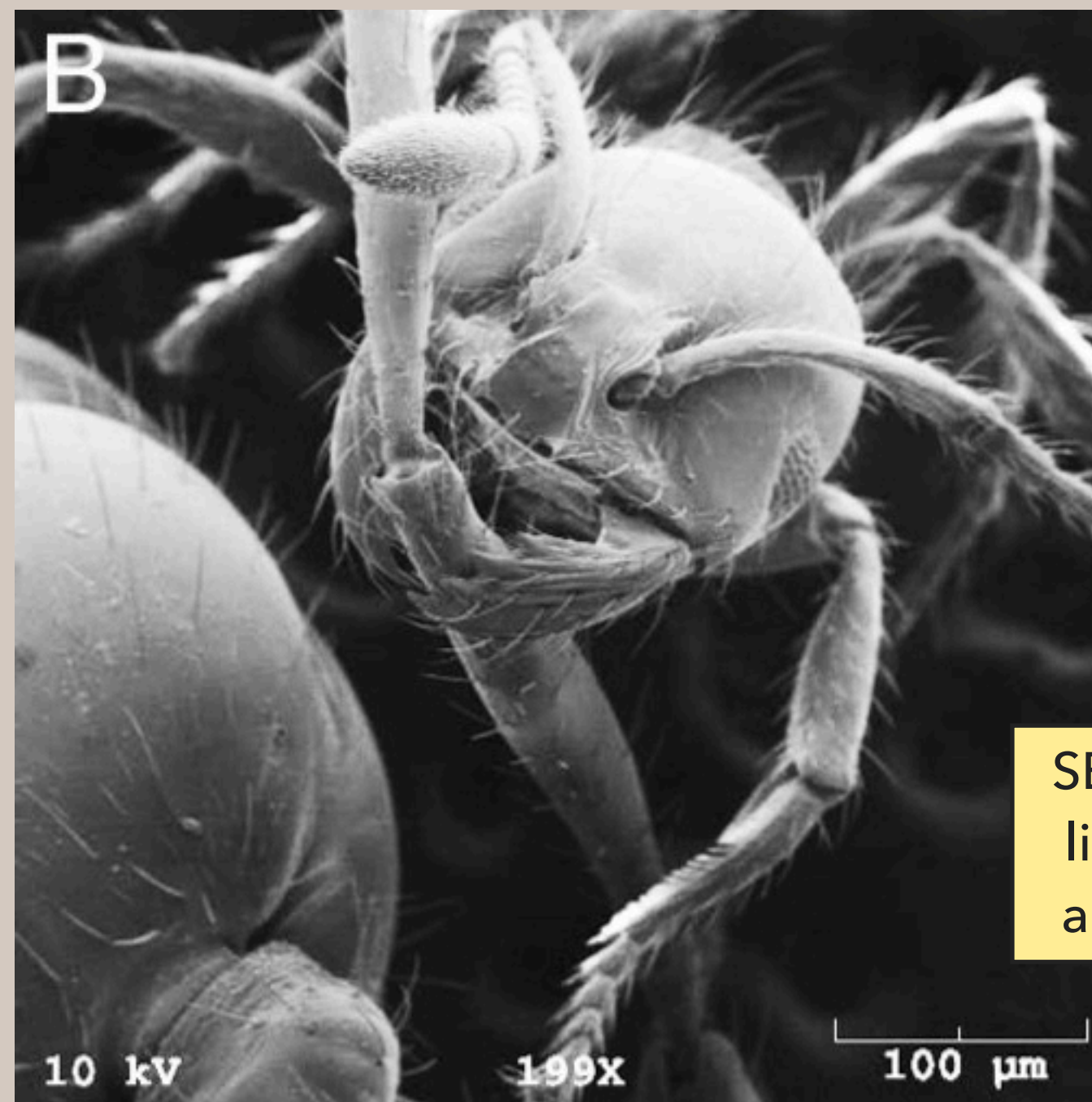
R. Strecker

FIRE ANT RAFTS

they provide a unique example of water repellency being achieved via cooperative behaviour



the ants' cuticles are mildly hydrophobic, allowing them to trap a plastron of air around their bodies which prevents them from drowning



SEM images of links between ants in the raft

Does ant behaviour remind you of anything?!



MOSHING

- A chaotic but loosely organised form of collective dancing at concerts, and is of many different types.
- Originated in the California hardcore punk scene in the late 70s. Later adopted by fans of heavy metal, hip hop and other genres.
- The name comes from a misheard lyric “mash it - mash down Babylon!” at a concert by the band Bad Brains, whose vocalist had a Jamaican accent.
- It continues to be divisive, with both proponents and detractors.

SOME TYPES OF MOSHING

“Mosh pit”



video: <https://www.youtube.com/watch?v=5jKU7gdxncE>

Highly disordered activity

“Circle pit”



video: <https://www.youtube.com/watch?v=jAhATK2fKMg>

Highly ordered vortex-like behaviour

MODELLING BEHAVIOUR IN MOSH PITS

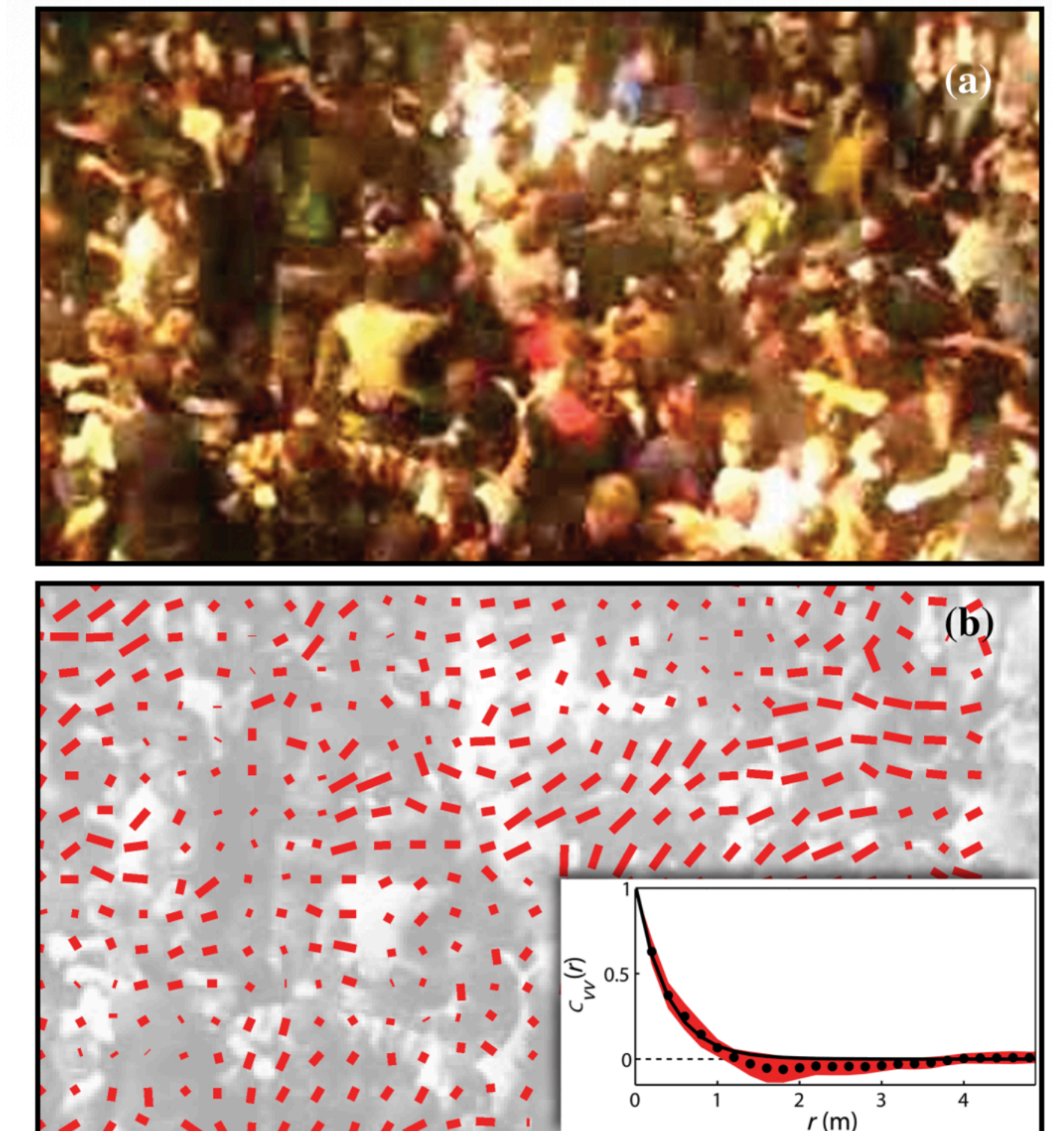
- Silberberg et al (2013) modelled the behaviour of moshers as two types of soft-bodied particles labeled active and passive MASHers.
- The active MASHers experience the following forces:

$$\mathbf{F}_i^{\text{repulsion}} = \begin{cases} \epsilon \left(1 - \frac{r_{ij}}{2r_0}\right)^{3/2} \hat{r}_{ij} & \text{if } r_{ij} < 2r_0, \\ 0 & \text{otherwise,} \end{cases}$$

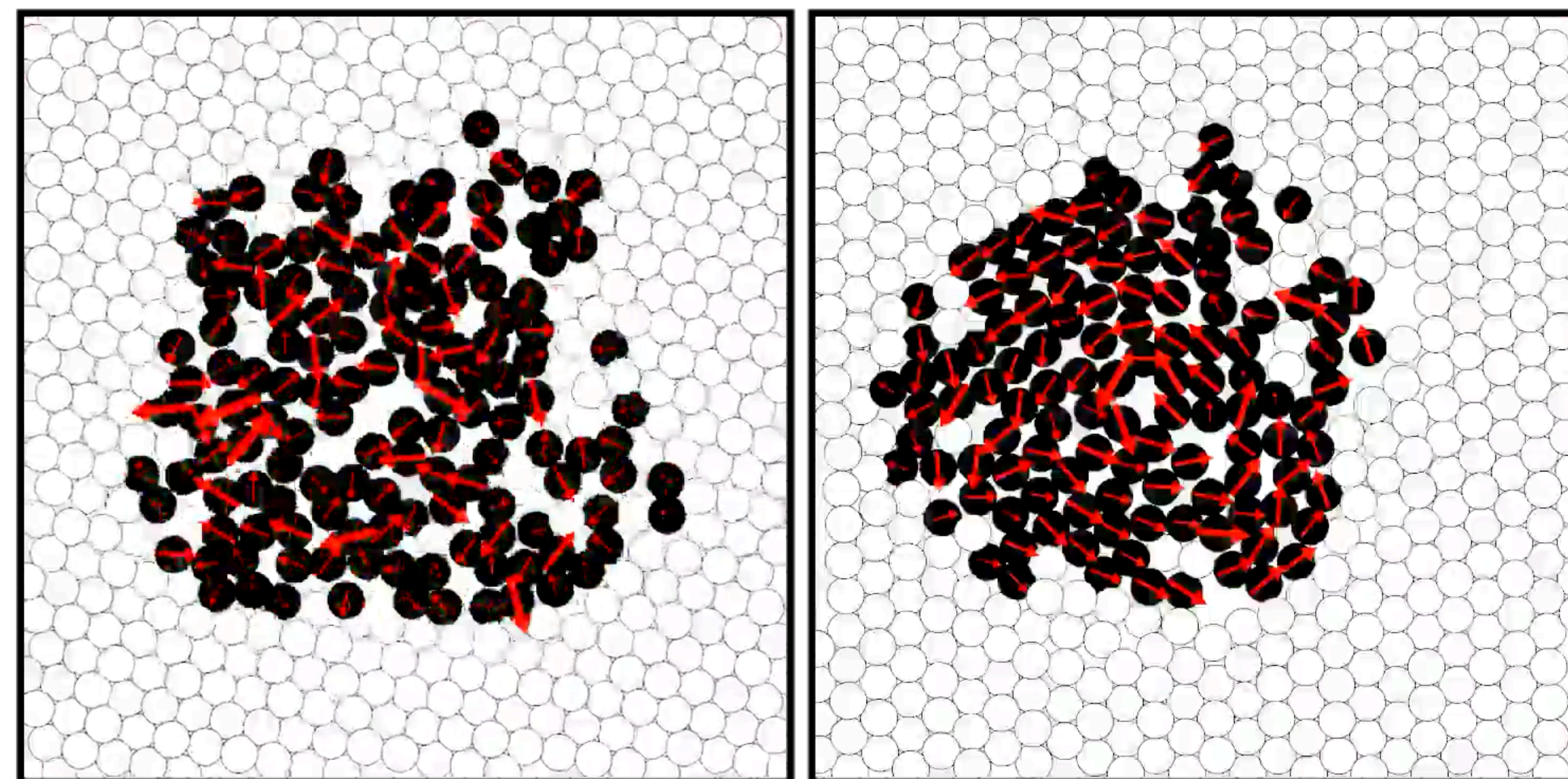
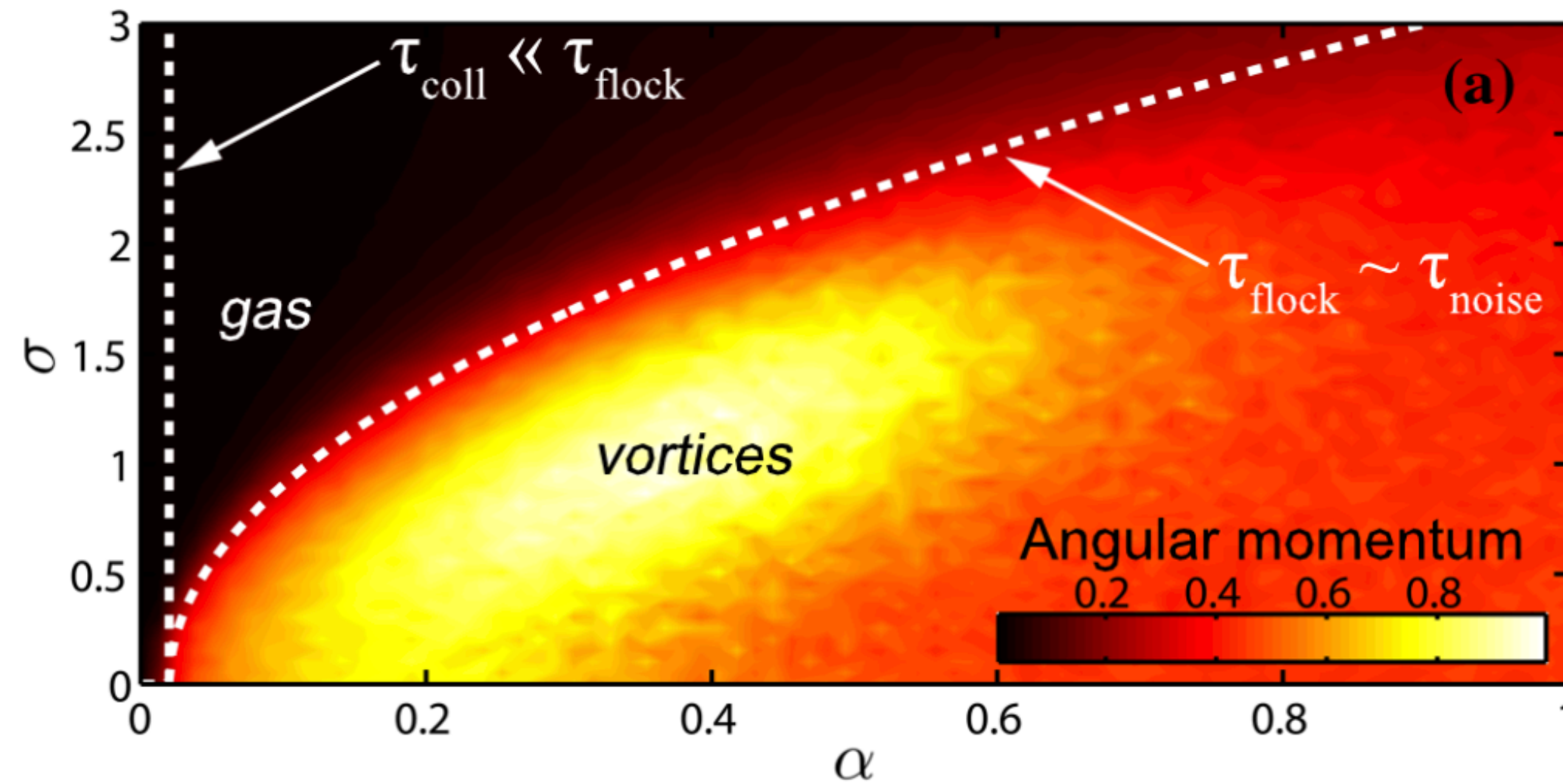
$$\mathbf{F}_i^{\text{propulsion}} = \mu(v_0 - v_i)\hat{v}_i$$

$$\mathbf{F}_i^{\text{flocking}} = \frac{\alpha \sum_{j=0}^{N_i} \mathbf{v}_j}{\left| \sum_{j=1}^N \mathbf{v}_j \right|}, \quad \mathbf{F}_i^{\text{noise}} = \eta_i \text{ with } 0 \text{ mean and } \sigma \text{ std.}$$

while the passive MASHers are only subject to repulsion.



MODELLING BEHAVIOUR IN MOSH PITS



gas

vortex

- Examining the angular momentum of the active MASHers over the (α, σ) space for a fixed packing fraction $\sigma = 0.94$, we find that there is a regime where an ordered vortex-like state exists, whereas for low flocking strength the crowd behaves more like a disordered gas.

- The model has three time scales that can be found from dimensional analysis:

$$\tau_{\text{flock}} = v_0/\alpha, \quad \tau_{\text{noise}} = v_0^2/2\mu\sigma^2 \text{ and}$$

$$\tau_{\text{col}} = 1/(2r_0v_0\rho).$$

FURTHER READING

Articles/Reviews

- * C. Castellano et al, *Statistical physics of social dynamics*, *Rev. Mod. Phys.* **81** 591 (2009).
- * D. Helbing, I. Farkas & T. Vicsek, *Simulating dynamical features of escape panic*, *Nature* **407**, 487–490 (2000).
- * Silverberg, J. L., Bierbaum, M., Sethna, J. P., & Cohen, I., *Collective motion of humans in mosh and circle pits at heavy metal concerts*, *Phys. Rev. Lett.*, **110**(22), 228701 (2013).
- * Mlot, N. J., Tovey, C. A., & Hu, D. L. (2011). *Fire ants self-assemble into waterproof rafts to survive floods*, *Proc. Natl. Acad. Sci. USA*, **108**(19), 7669-7673.





THANK YOU!