

FROM SPINS TO FLOCKS:
AN INTRODUCTION TO DRY ACTIVE MATTER

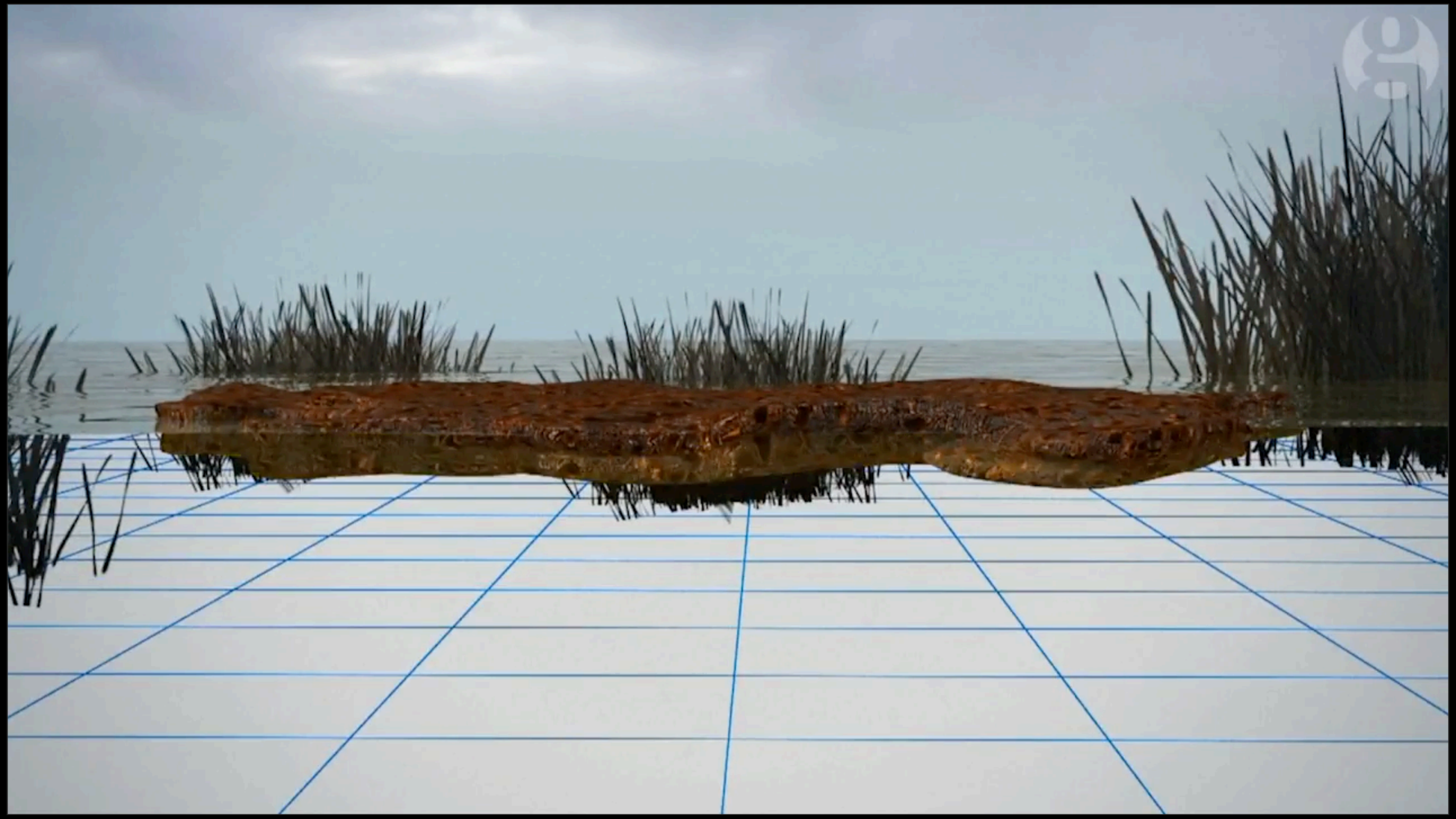
Spins, Games & Networks (SGN) 2026

THE MADDING CROWD:
DENSE HERDS ACROSS SCALES

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video: https://www.youtube.com/watch?v=nwxhESoDRW4

FIRE ANT RAFTS



video: https://www.theguardian.com/environment/video/2017/aug/30/how-fire-ants-houston-forming-rafts-escape-flooding-video

FIRE 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



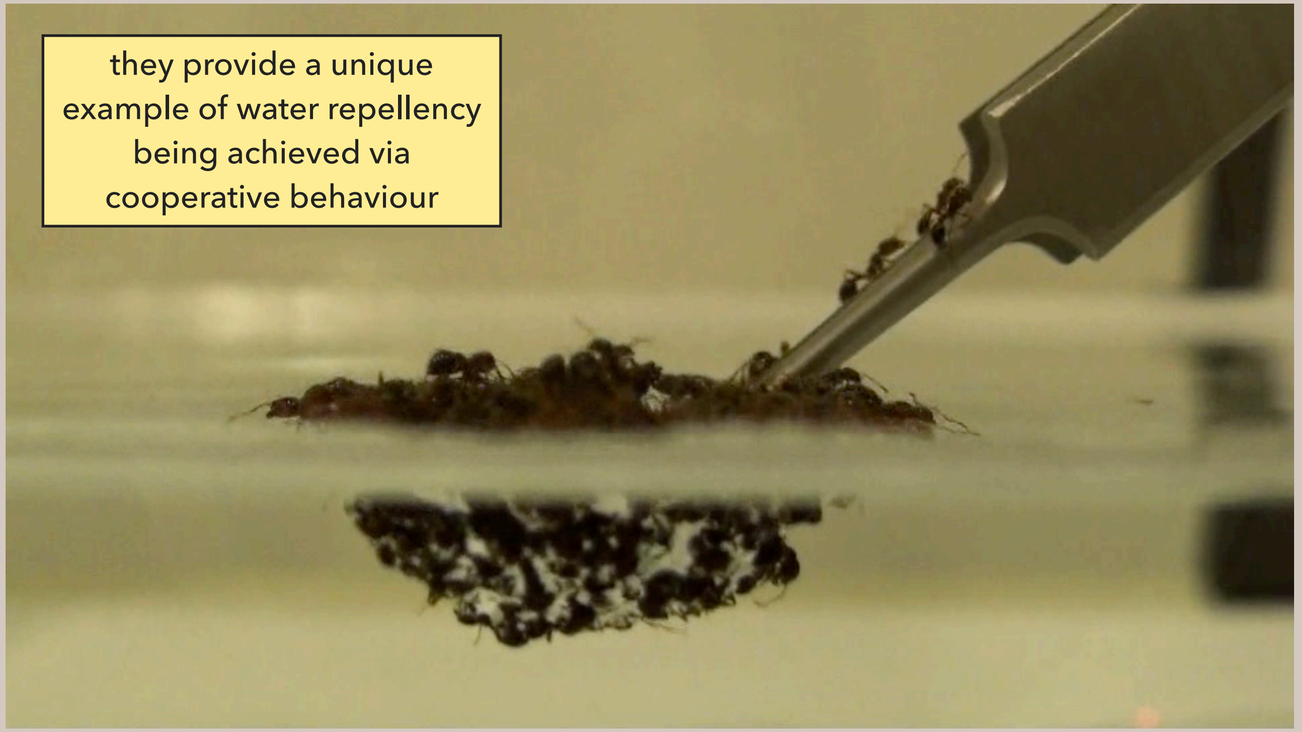


images: Adams et al. *J. Insect Sci.* **11**, 171(2011).

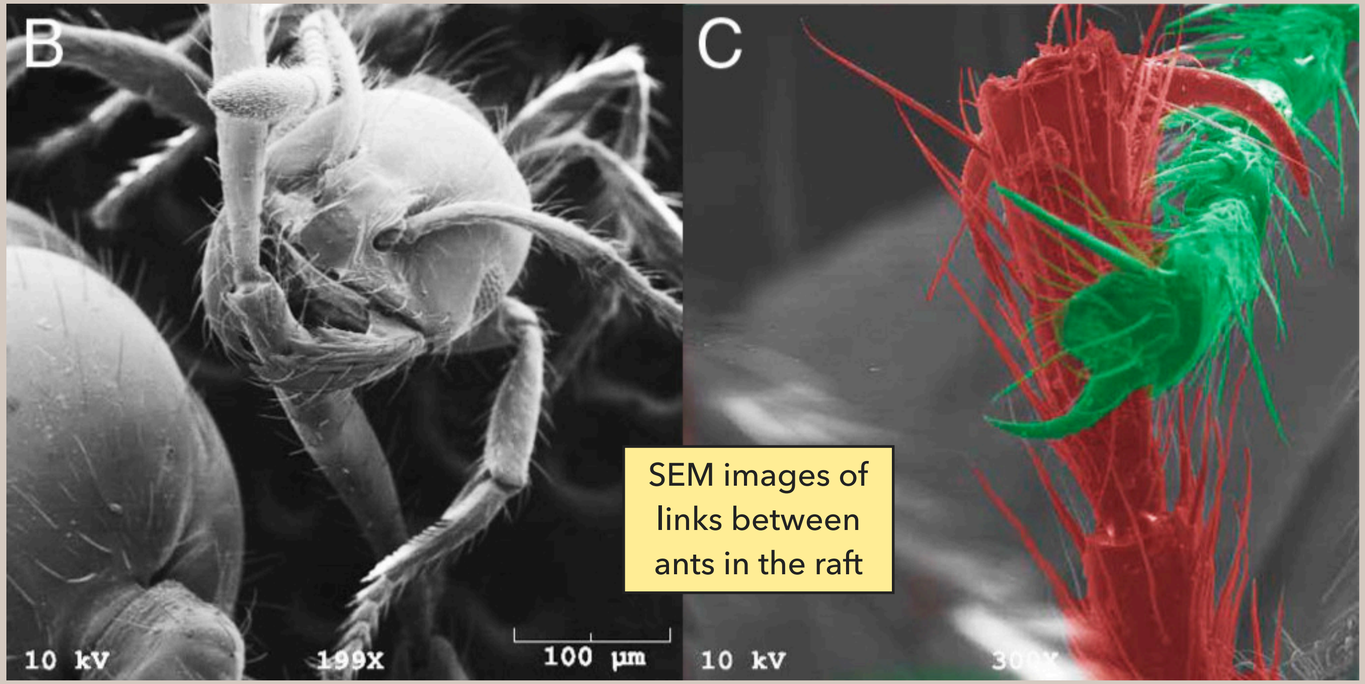
FIRE ANT RAFTS



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



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



SEM images of links between ants in the raft

images: Mlot et al. *PNAS* **108**, 7669-7673 (2011).

source: M Tennenbaum et al (2016), Nature Materials, **15**(1), 54-59.

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

These aggregates store elastic energy on short timescales via leg-to-leg grips, while these bonds break and reform over longer timescales leading to viscous behaviour.

image: TC Schneirla (1944), American Museum Novitates, 1253, 1-26.

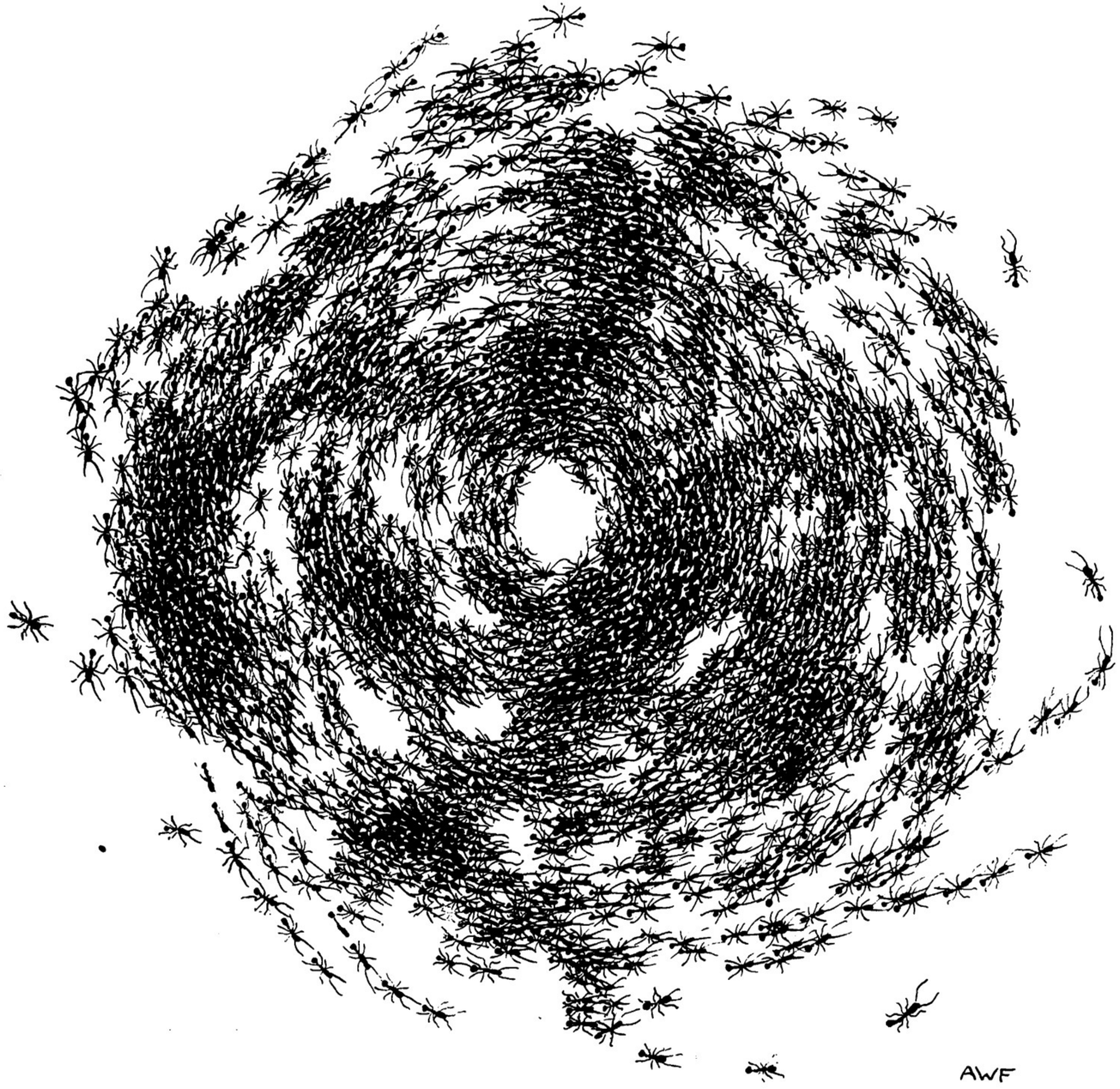


Fig. 1. The circular column of *Eciton praedator*, as drawn from a photograph taken shortly before 12:00 P.M. At that time the ring was approximately 14 cm. in diameter.

ANT MILLS

- These are large vortex formations observed primarily in army ants, such as *Eciton burchellii*.
- These ants are usually blind and forage with the help of pheromones.
- If some ants deviate from the trail and accidentally rejoin it at a earlier position, this can lead to a closed loop.
- Ants in the mill persist until they (usually) die of exhaustion.
- It has been argued (Brady, 2003) that the reason for this is that, unlike almost all other ant species, army ants exhibit obligate collective foraging, and have done so for over 100 million years.
- Local alignment rules lead to coherent group transport but the geometry traps the swarm.

ANT LANES

- Lane segregation is observed in the army ant *Eciton burchelli*. Ants returning to the colony occupy the central part of the column while outbound ones move on either side.
- On narrow paths, unladen outbound ants give way to laden returning ants (as the latter have less maneuverability) while unladen returning ants give way to outbound ants. Furthermore, unladen returning ants do not attempt to overtake the laden ants in front of them.

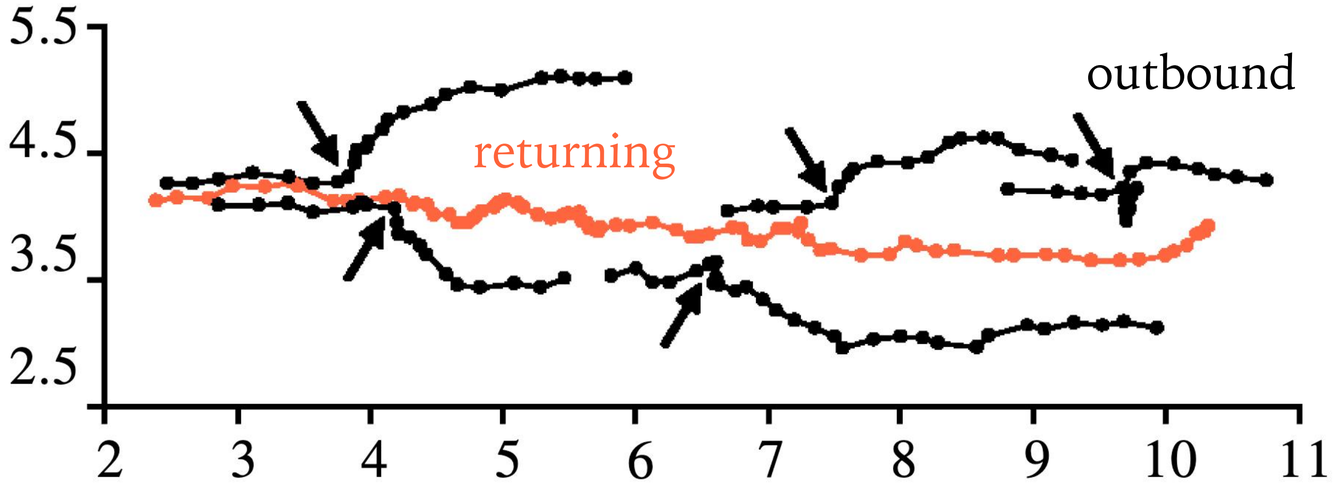
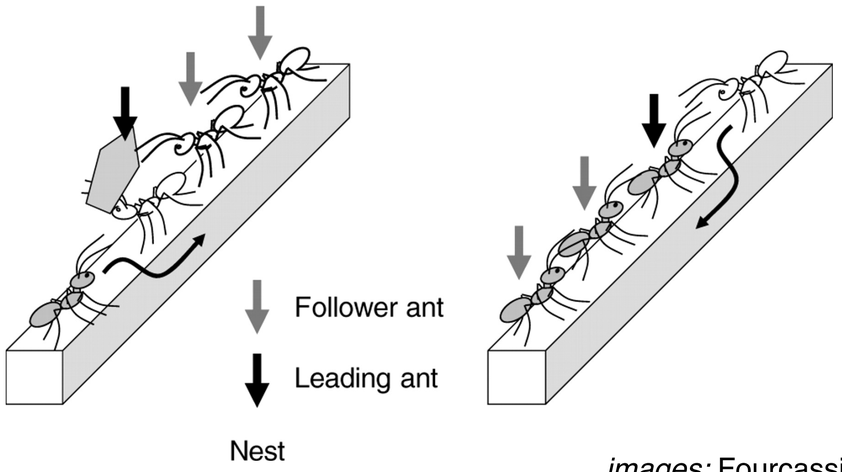
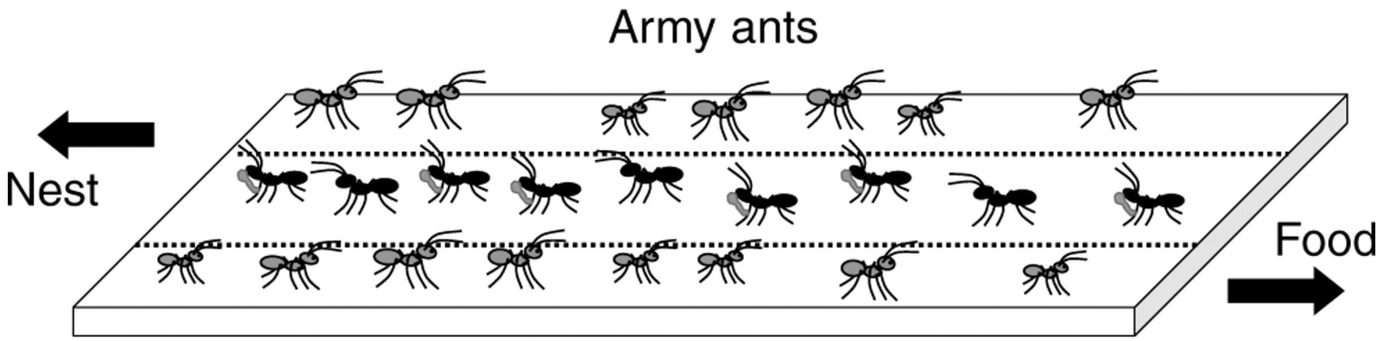


image: Couzin & Franks, Proc. Roy. Soc. B, **270**(1511), 139 (2003).





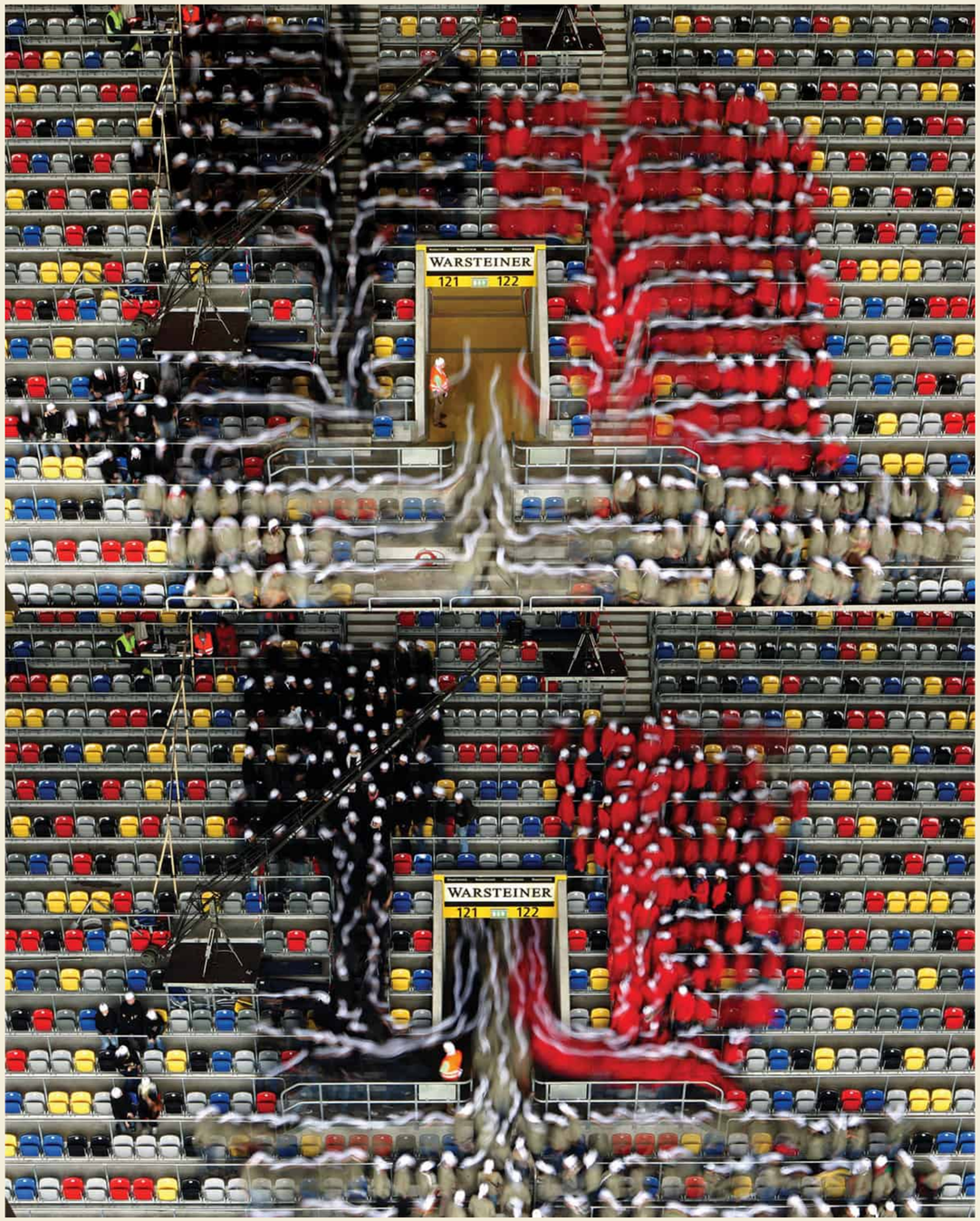
images: Fourcassié, Dussutour & Deneubourg, J. Exp. Biol. **213**(14), 2357-2363 (2010).



video: https://www.youtube.com/watch?v=e2WfvJXB__8



video: https://www.youtube.com/watch?v=J4J__lOOV2E



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



Photo: Eric Wiffers

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.

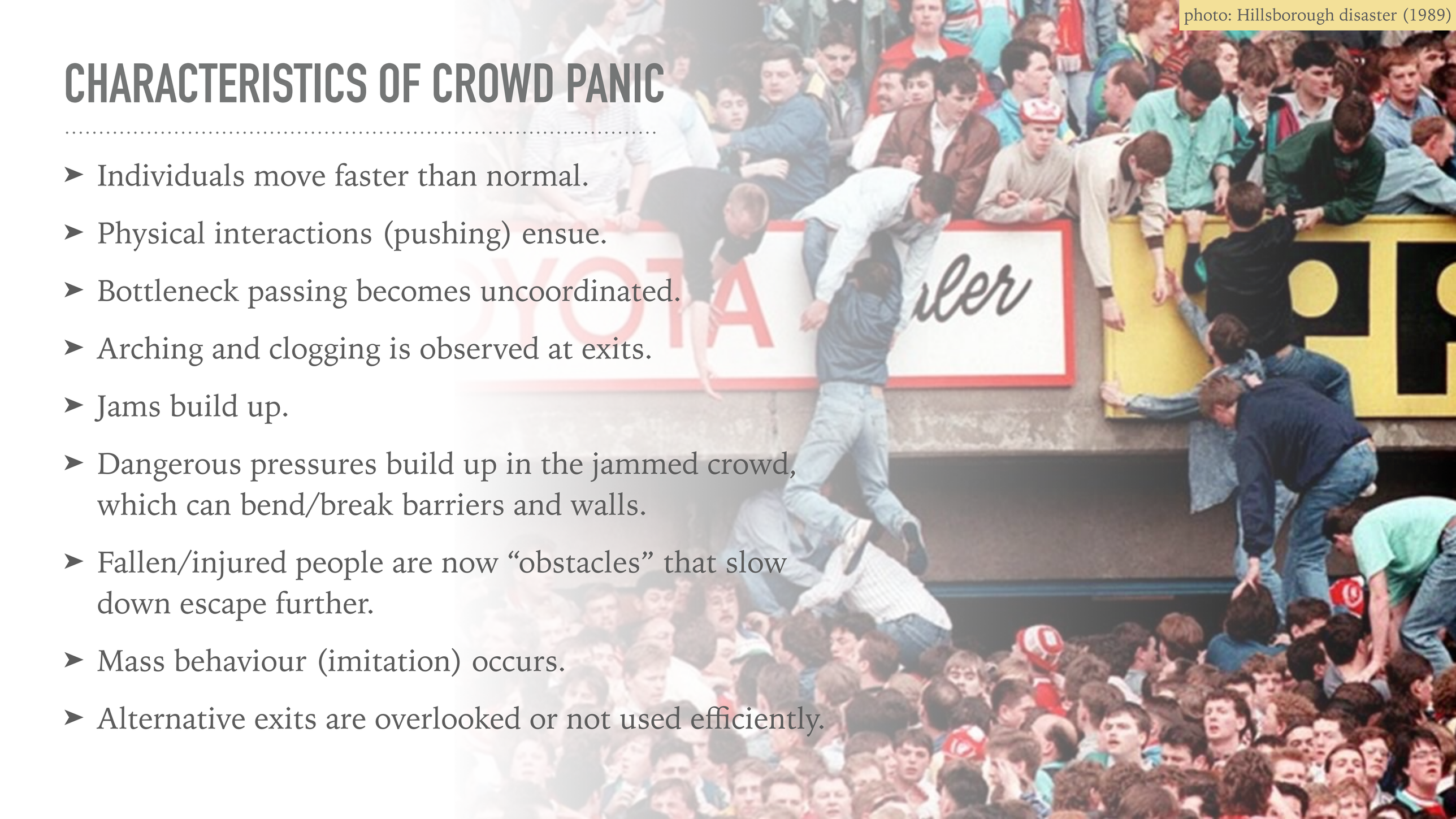


photo: Hillsborough disaster (1989)

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.

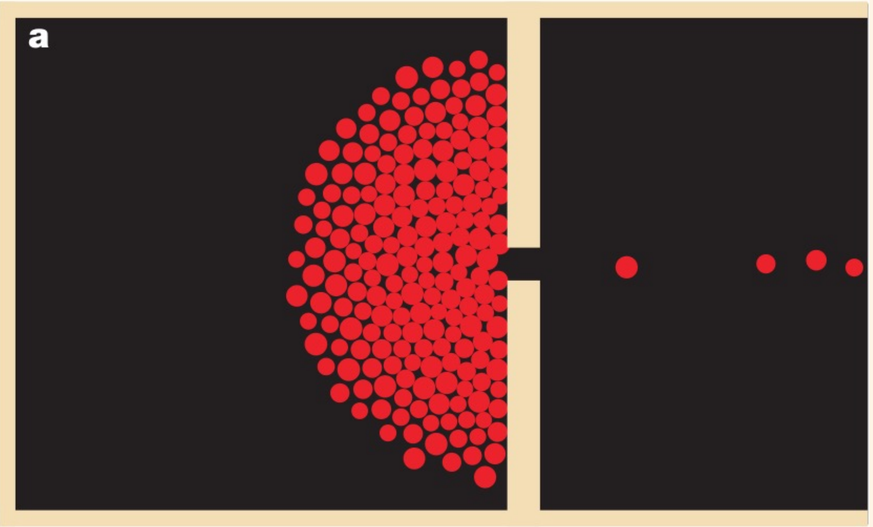
A MODEL FOR CROWD PANIC

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. This comprised:

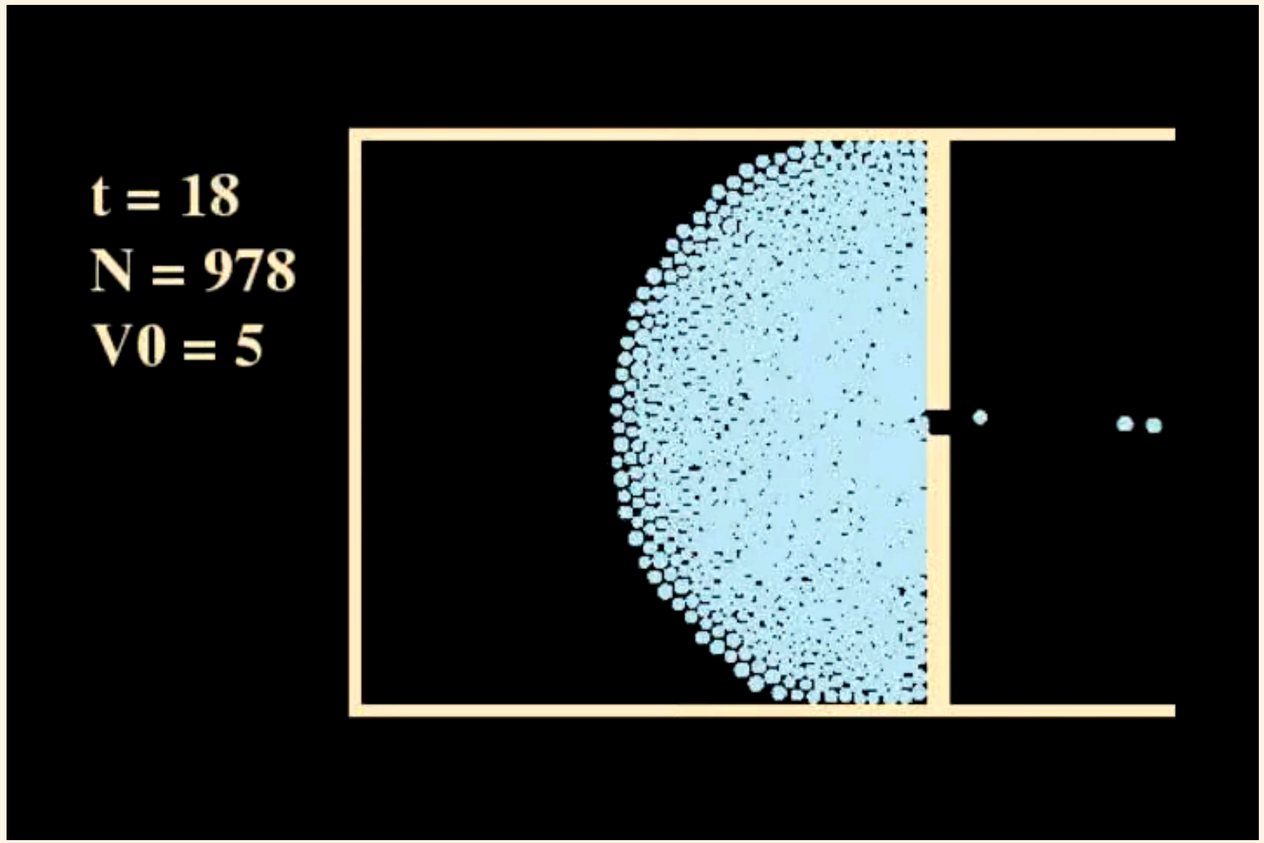
- N agents i of mass m_i intend to move with speed v_i^0 in a direction $\mathbf{e}_i^0$.
- Each agent modifies their velocity $\mathbf{v}_i$ with a characteristic time τ_i based on interactions, leading to a change in position $\mathbf{v}_i(t) = d\mathbf{r}_i/dt$.
- Each force expression consists of:
  - 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**.

video and image: D. Helbing et al, Nature **407**, 487–490 (2000).

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.



- Certain types of room shapes facilitate orderly evacuation while others make things worse.

Human mills?!



video: https://www.youtube.com/watch?v=NQ--mzFkuVA



Photo by Evgeniy Smersh on Unsplash

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

image: JL Silverberg et al (2013), Phys. Rev. Lett., **110**(22), 228701.

MODELLING BEHAVIOUR IN MOSH PITS

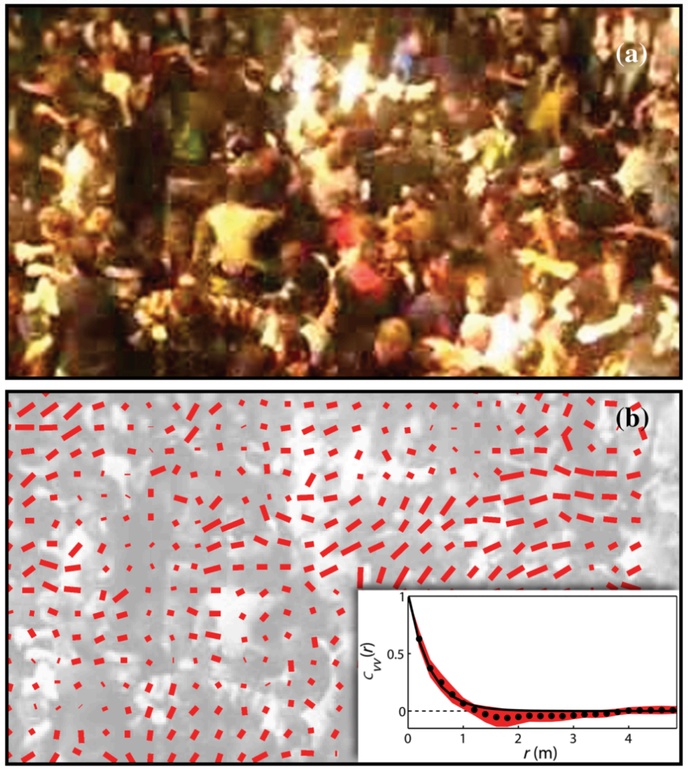
- Silberberg et al (2013) modelled the behaviour of moshers as two types of soft-bodied particles labeled active and passive MASHers.
- The active MASHers experience the following forces:

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

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

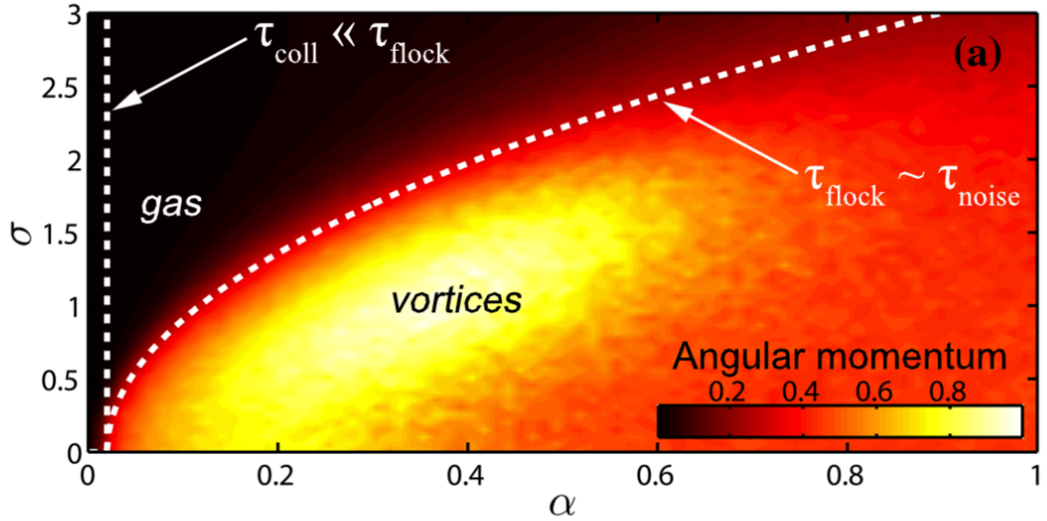
$$\mathbf{F}_i^{\text{flocking}} = \frac{\alpha \sum_{j=0}^{N_i} \mathbf{v}_j}{\left| \sum_{j=1}^{N} \mathbf{v}_j \right|}, \qquad \mathbf{F}_i^{\text{noise}} = \eta_i \text{ with 0 mean and } \sigma \text{ std.}$$

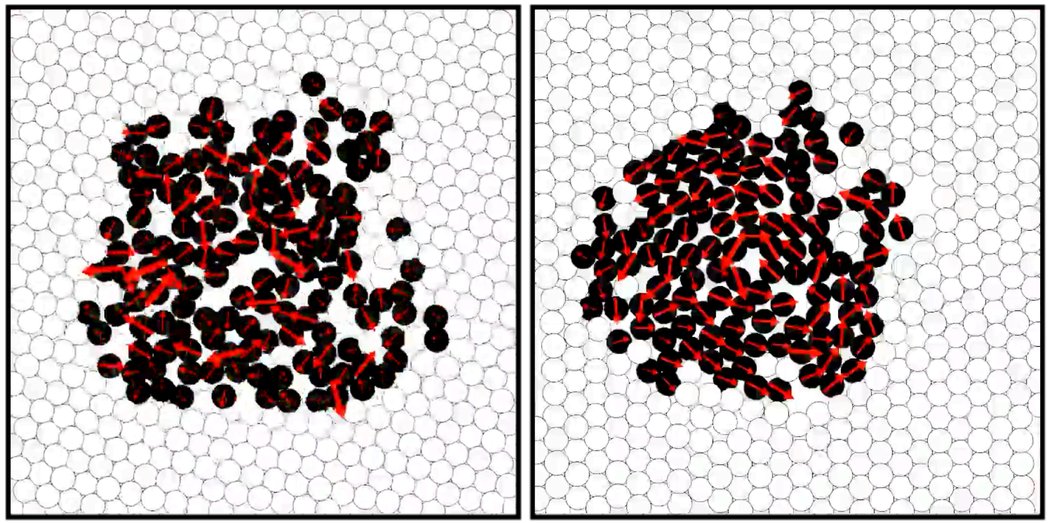
while the passive MASHers are only subject to repulsion.



images/videos: JL Silverberg et al (2013), Phys. Rev. Lett., **110**(22), 228701.

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 $\rho = 0.94$, 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: $\tau_{flock} = v_0/\alpha$, $\tau_{noise} = v_0^2/2\mu\sigma^2$ and $\tau_{coll} = 1/(2r_0 v_0 \rho)$.

MODELLING BEHAVIOUR IN MOSH PITS

- High-energy human can collectives spontaneously recover the exact same rotational symmetry-breaking seen in army ant mills. Unlike in the case of ants, here we purely have local steric repulsion and self-propulsion, and no chemical trails.
- As there is no net crowd polarity or bottlenecks, the collisions relax into a steady gas-like state, in contrast to the case of crowd panic, where a directed drive in a tightly confined environment leads to jamming (although both involve dense, high-energy human interactions).

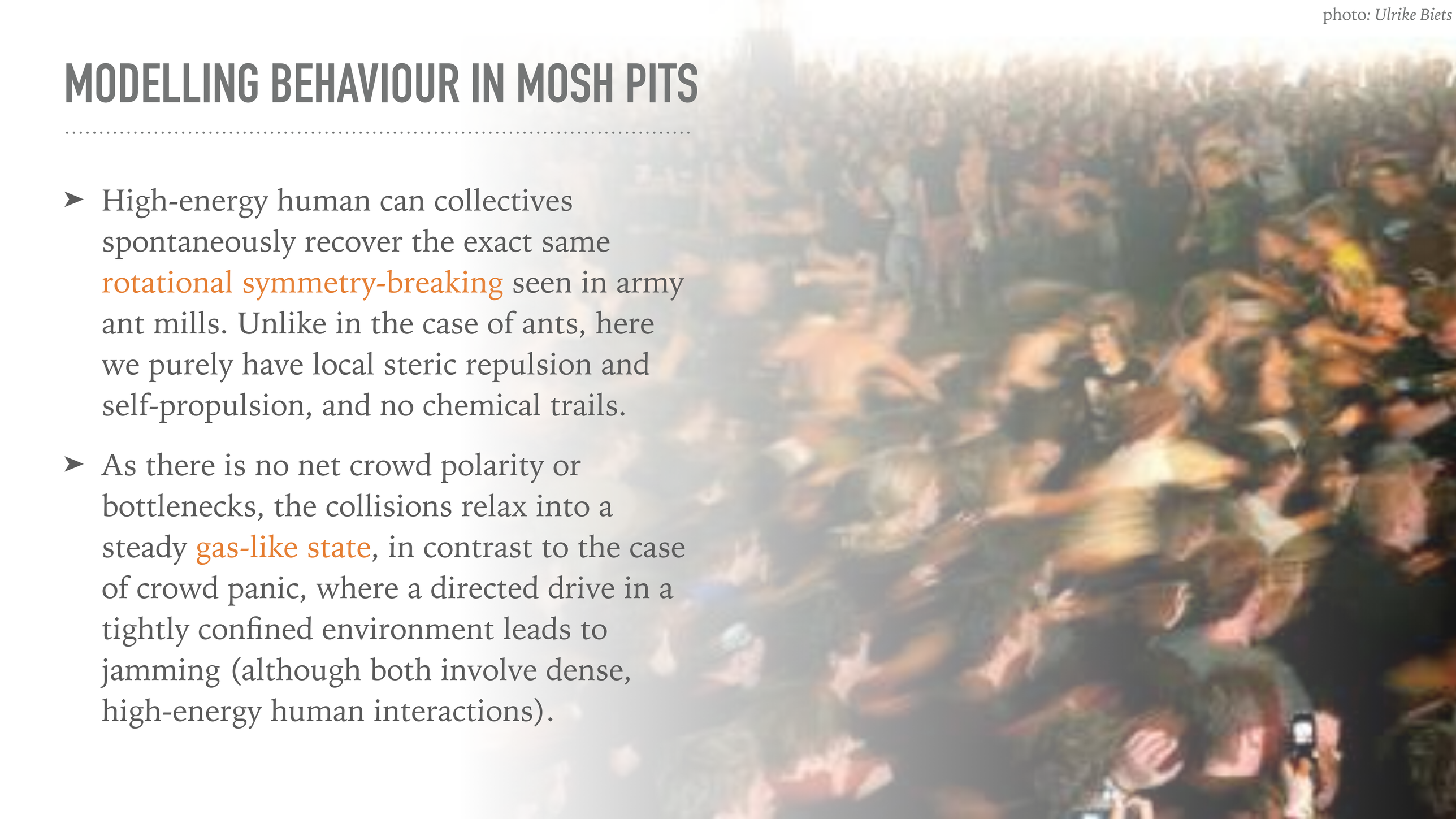


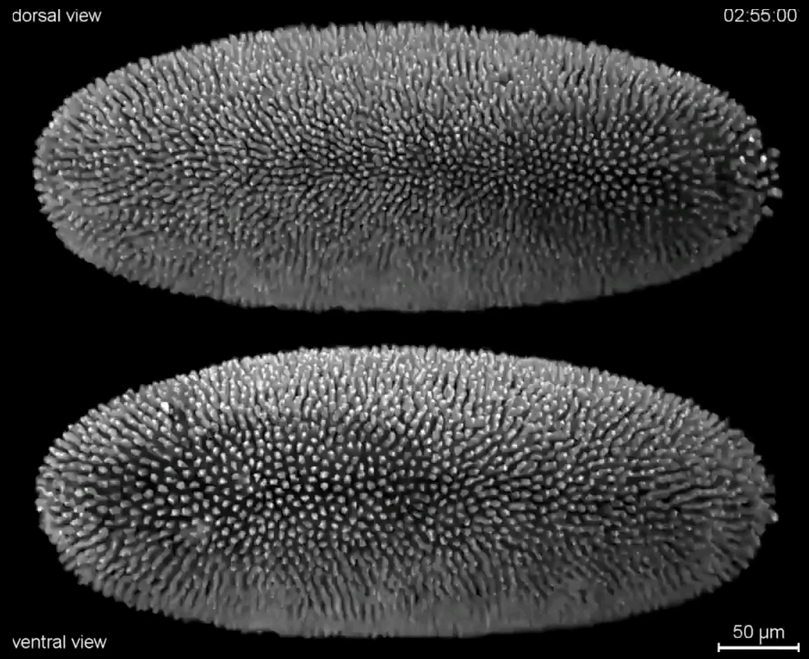
photo: *Ulrike Biets*



video: BBC Earth https://www.youtube.com/watch?v=UVko9jyAkQg



video: BBC Earth https://www.youtube.com/watch?v=okacULqnDDQ



video: https://www.youtube.com/watch?v=nFIYvaygF1M



video: https://www.youtube.com/watch?v=tpE2tAPcPq0



image: Mlot et al. *PNAS* **108**, 7669-7673 (2011).

FURTHER READING

Articles

- N. J. Mlot, C. A. Tovey & D. L. Hu, *Fire ants self-assemble into waterproof rafts to survive floods*, Proc. Natl. Acad. Sci. USA, **108**(19), 7669-7673 (2011).
- M Tennenbaum et al, *Mechanics of fire ant aggregations*, Nature Materials, **15**(1), 54-59 (2016).
- D. Helbing, I. Farkas & T. Vicsek, *Simulating dynamical features of escape panic*, Nature **407**, 487–490 (2000).
- J. L. Silverberg, M. Bierbaum, J. P. Sethna, & I. Cohen, *Collective motion of humans in mosh and circle pits at heavy metal concerts*, Phys. Rev. Lett., **110**(22), 228701 (2013).

Reviews

- C. Castellano et al, *Statistical physics of social dynamics*, Rev. Mod. Phys. **81** 591 (2009).



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

— Björk, *Human Behaviour* (1993)

THANK YOU!