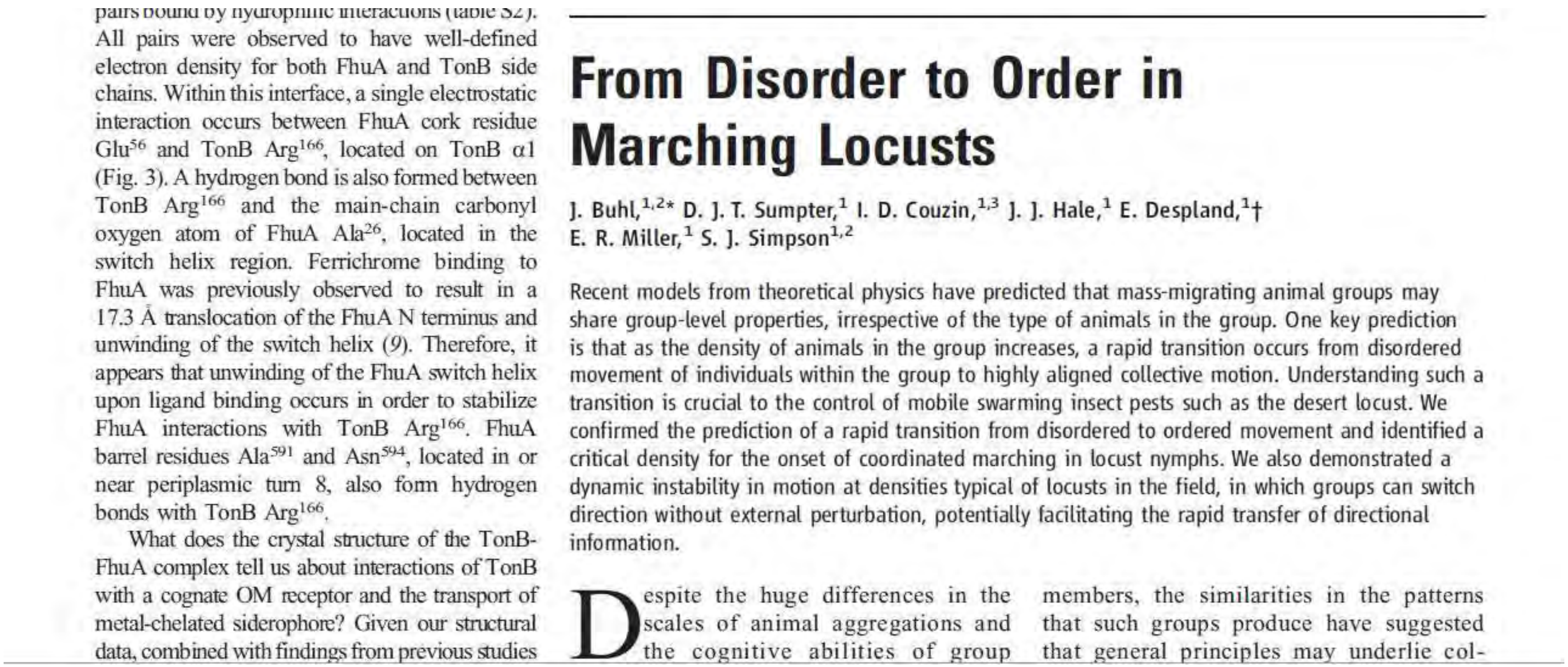
Understanding randomness in locust swarms

Kit Yates
Centre for Mathematical Biology
University of Bath

10/08/20 – Locust Management conference

From Disorder to Order



pairs bound by hydrophilic interactions (table S2). All pairs were observed to have well-defined electron density for both FhuA and TonB side chains. Within this interface, a single electrostatic interaction occurs between FhuA cork residue Glu^{56} and TonB Arg^{166}, located on TonB $\alpha 1$ (Fig. 3). A hydrogen bond is also formed between TonB Arg^{166} and the main-chain carbonyl oxygen atom of FhuA Ala^{26}, located in the switch helix region. Ferrichrome binding to FhuA was previously observed to result in a 17.3 Å translocation of the FhuA N terminus and unwinding of the switch helix (*9*). Therefore, it appears that unwinding of the FhuA switch helix upon ligand binding occurs in order to stabilize FhuA interactions with TonB Arg^{166}. FhuA barrel residues Ala^{591} and Asn^{594}, located in or near periplasmic turn 8, also form hydrogen bonds with TonB Arg^{166}.

What does the crystal structure of the TonB-FhuA complex tell us about interactions of TonB with a cognate OM receptor and the transport of metal-chelated siderophore? Given our structural data, combined with findings from previous studies

From Disorder to Order in Marching Locusts

J. Buhl,[1,2]* D. J. T. Sumpter,[1] I. D. Couzin,[1,3] J. J. Hale,[1] E. Despland,[1]†
E. R. Miller,[1] S. J. Simpson[1,2]

Recent models from theoretical physics have predicted that mass-migrating animal groups may share group-level properties, irrespective of the type of animals in the group. One key prediction is that as the density of animals in the group increases, a rapid transition occurs from disordered movement of individuals within the group to highly aligned collective motion. Understanding such a transition is crucial to the control of mobile swarming insect pests such as the desert locust. We confirmed the prediction of a rapid transition from disordered to ordered movement and identified a critical density for the onset of coordinated marching in locust nymphs. We also demonstrated a dynamic instability in motion at densities typical of locusts in the field, in which groups can switch direction without external perturbation, potentially facilitating the rapid transfer of directional information.

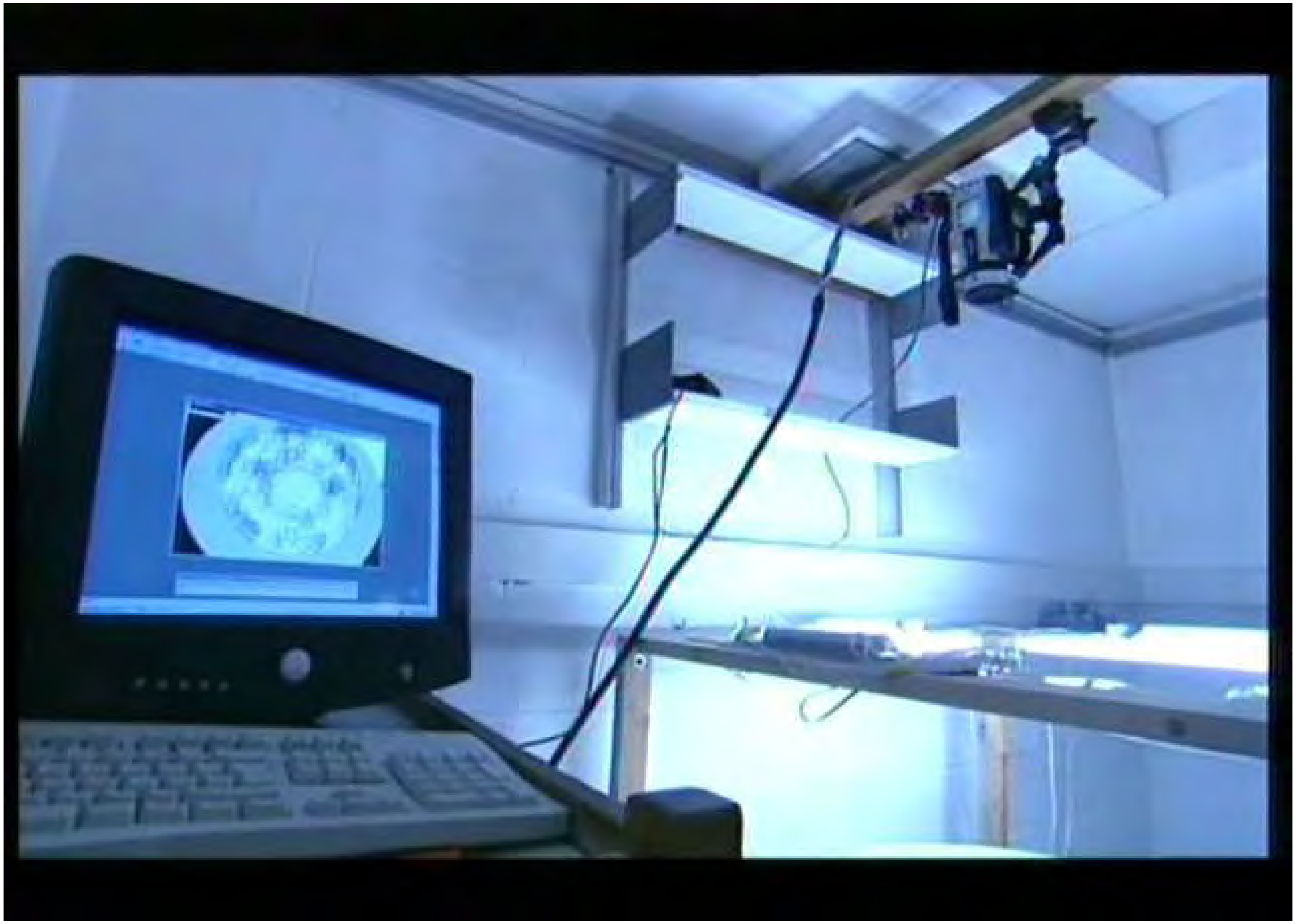
Despite the huge differences in the scales of animal aggregations and the cognitive abilities of group members, the similarities in the patterns that such groups produce have suggested that general principles may underlie col-

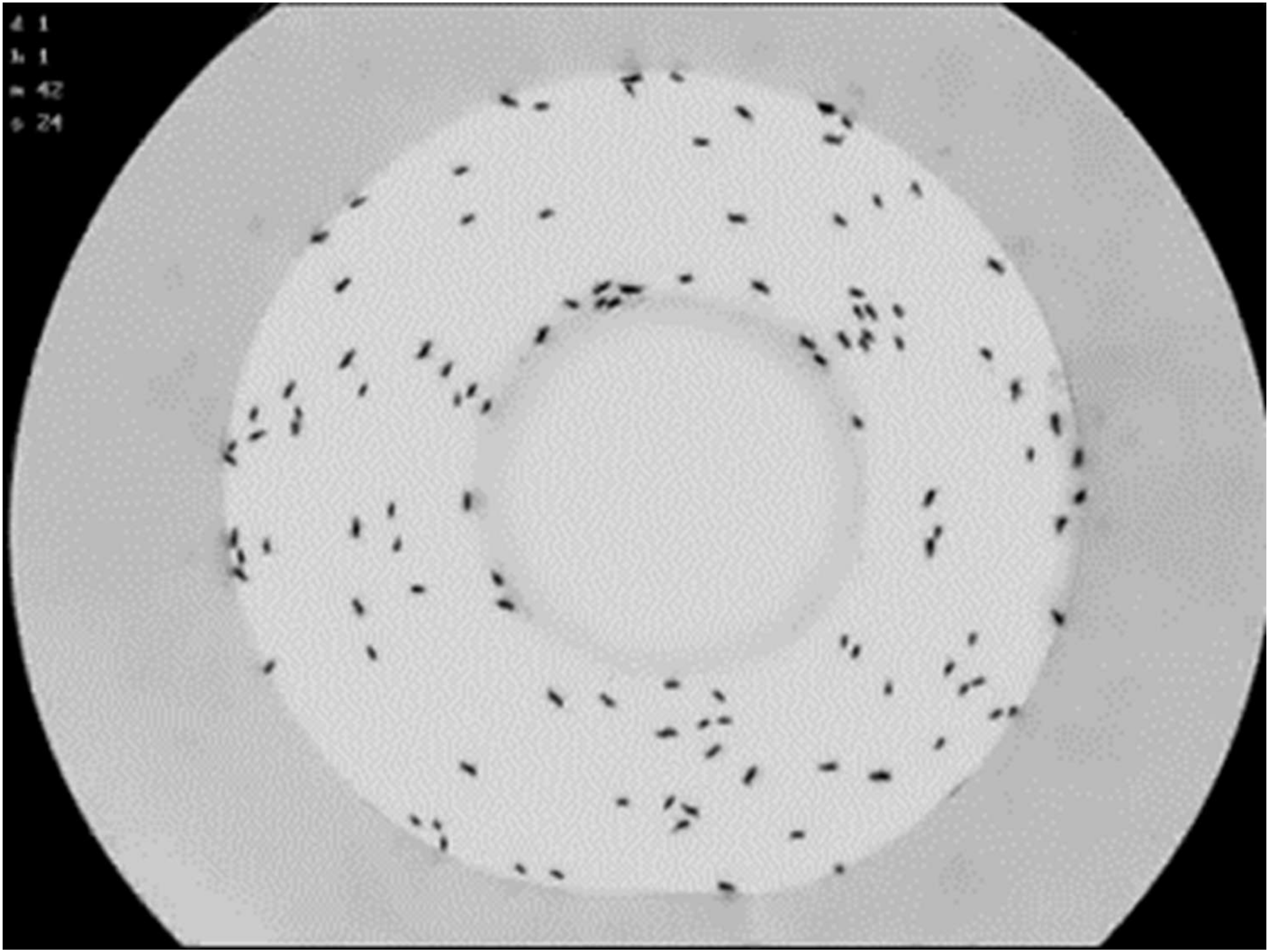
From Disorder to Order in Marching Locusts.

Buhl, J. and Sumpter, DJT and Couzin, ID and Hale, JJ and Despland, E. and Miller, ER and Simpson, SJ

Science 2006; 312:1402-1406.

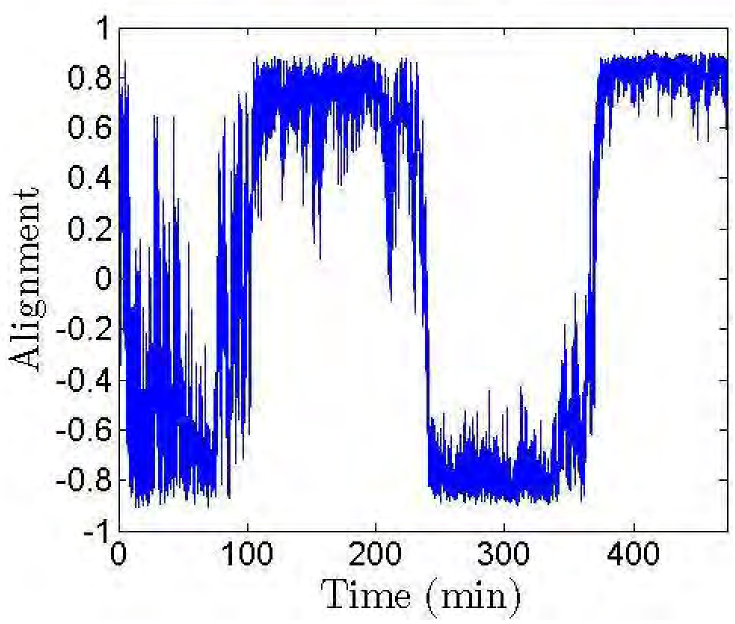
Experimental Setup



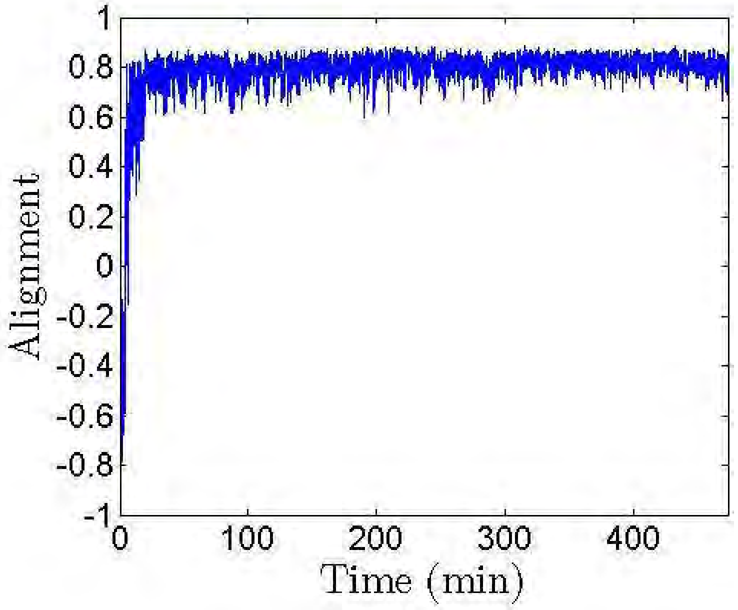

d 1
h 1
m 42
s 24

Experimental Results

- Collective motion
- Switching between two steady states: Clockwise and Anticlockwise
- Noisy/Stochastic process

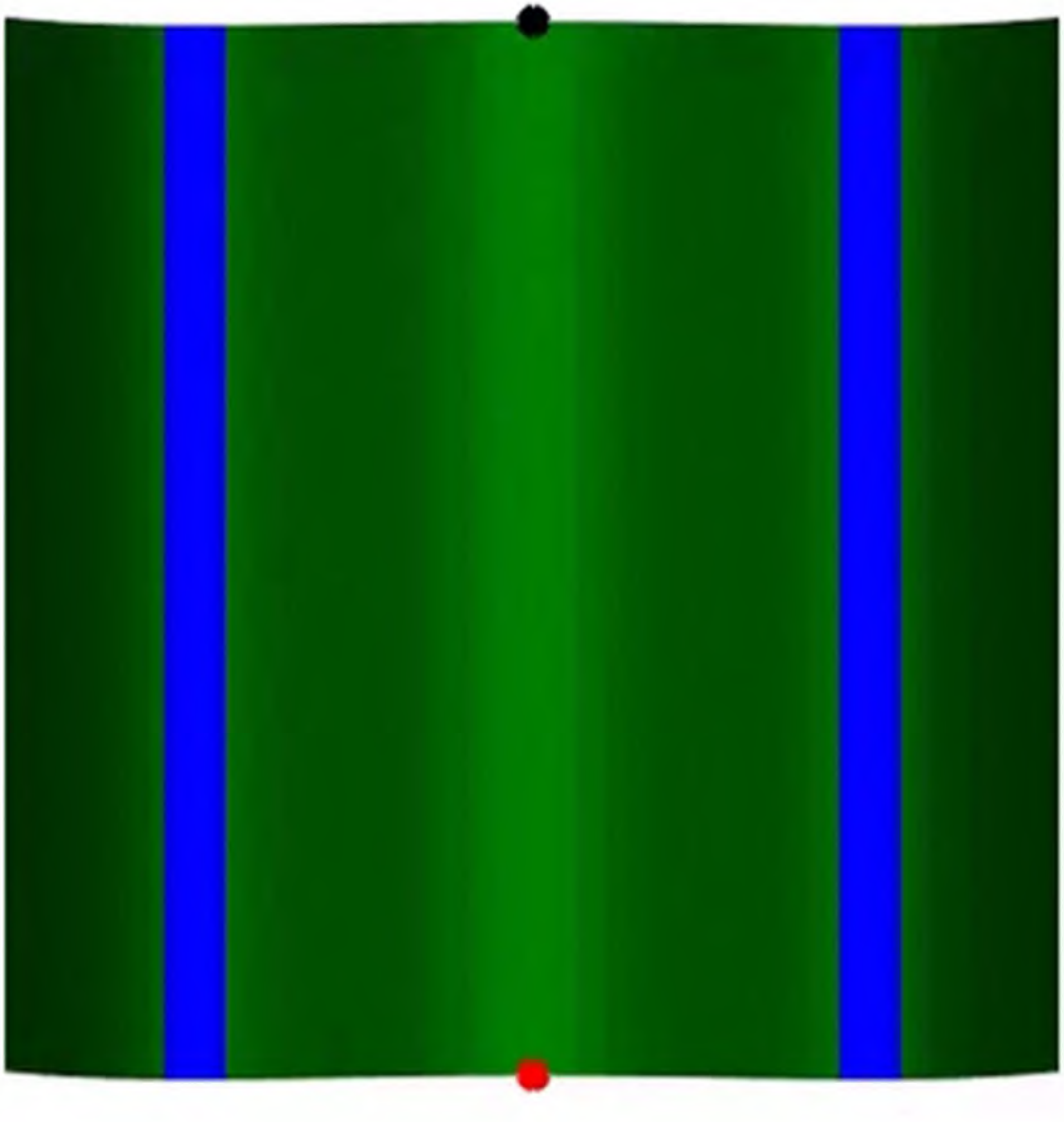


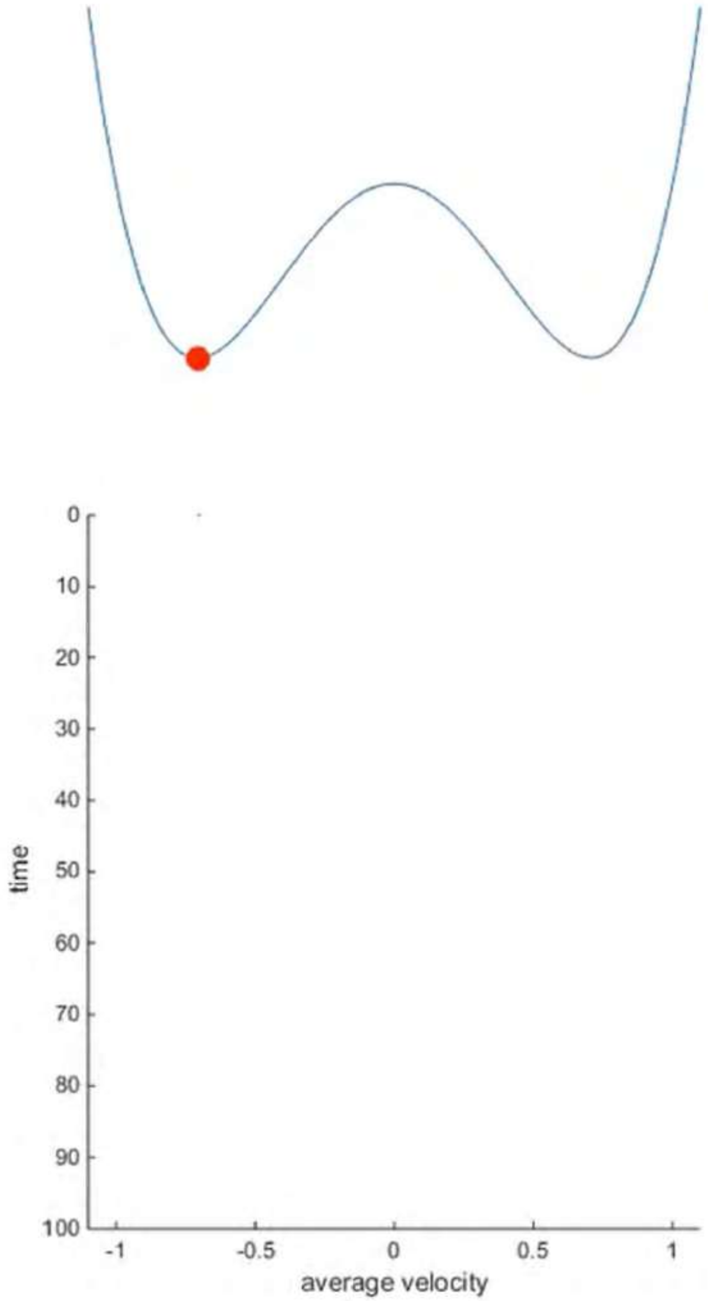
30 Locusts



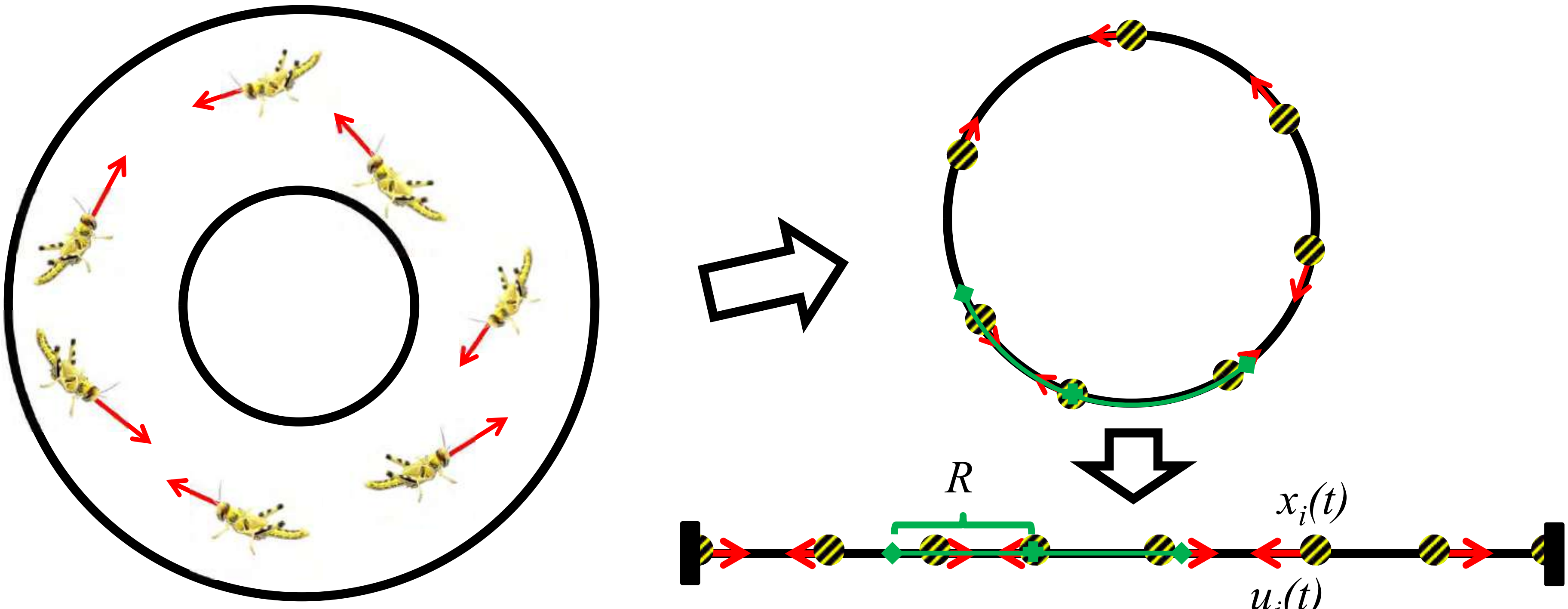
60 Locusts

Stochastic Differential Equation




0
10
20
30
40
50
60
70
80
90
100
time
-1
-0.5
0
0.5
1
average velocity

Towards a model



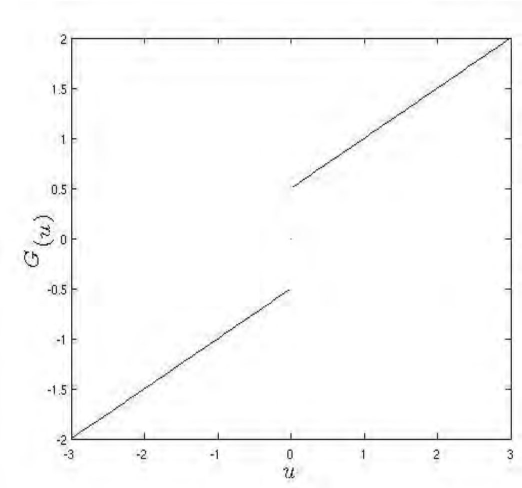
A first attempt

$$\Delta x_i = u_i \Delta t,$$

$$\Delta u_i = \{G(\bar{u}_i^{loc}) - u_i(t)\}\Delta t + \Delta Q \eta(\bar{u}_i^{loc}),$$

where $\bar{u}_i^{loc} = \frac{1}{n_i(t)} \sum_{j \in \mathcal{J}_i^R} u_j(t)$

and $G(z) = \frac{1}{1+\beta}\{z + \beta \text{sign}(z)\}.$

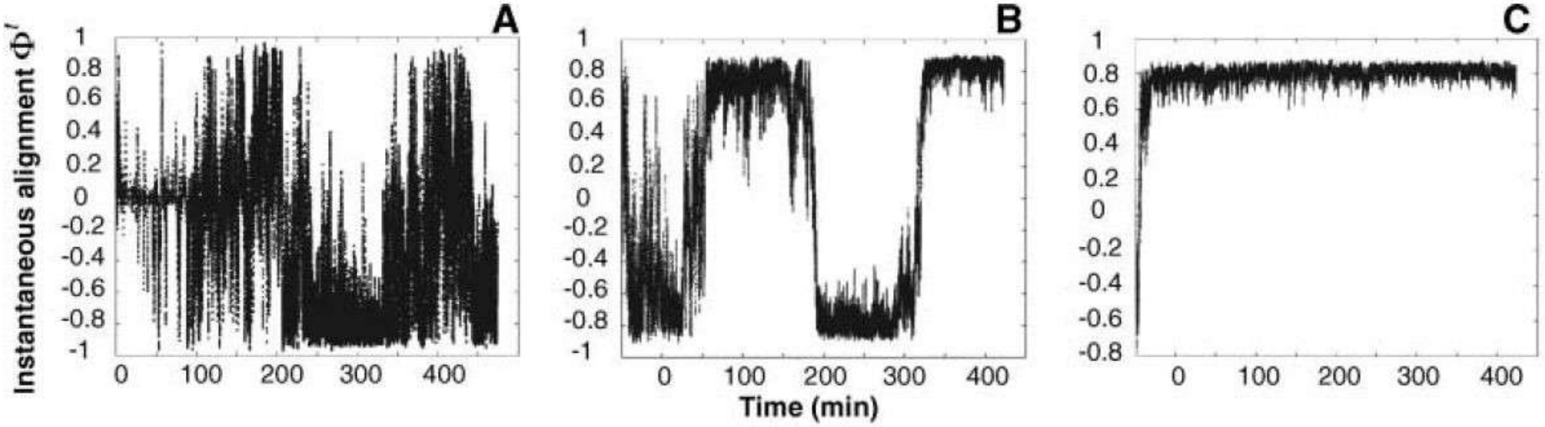


Collective Motion of Self-Propelled Particles: Kinetic Phase Transition in One Dimension.

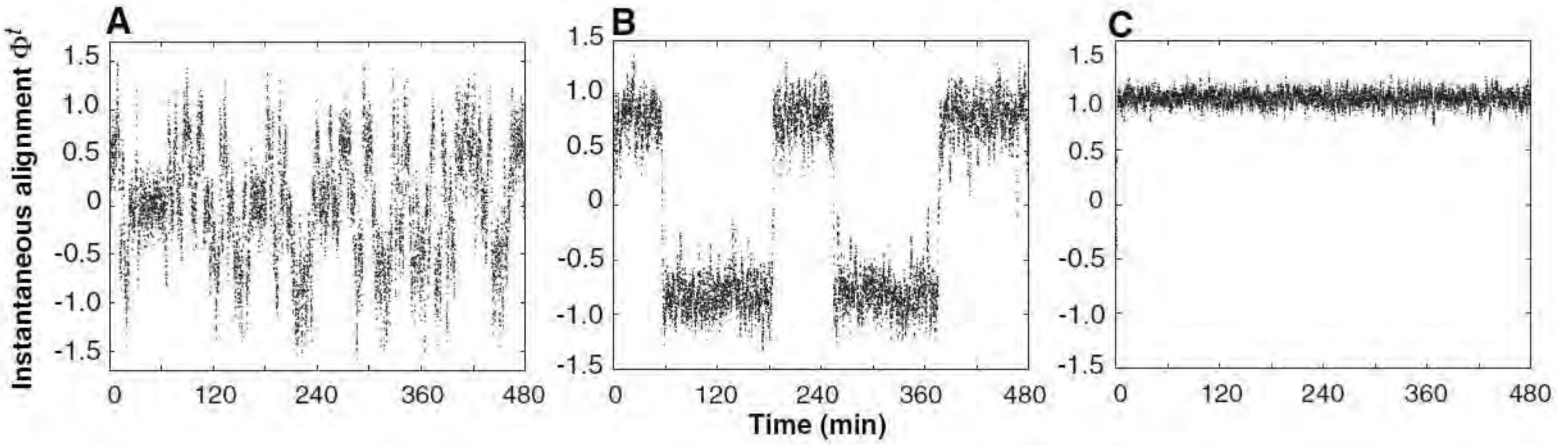
Czirok et al. PRL 1999; 82(1):209-212.

Model data comparison

Experimental data



N=5 N=30 N=60



Model Output $\eta(\bar{u}_i^{loc}) \equiv 1$

Inherent Noise

Inherent noise can facilitate coherence in collective swarm motion

Christian A. Yates[a,1], Radek Erban[a,b], Carlos Escudero[c], Iain D. Couzin[d], Jerome Buhl[e], Ioannis G. Kevrekidis[f], Philip K. Maini[a,g], and David J. T. Sumpter[h]

[a]Centre for Mathematical Biology and [b]Oxford Centre for Collaborative Applied Mathematics, Mathematical Institute, University of Oxford, 24-29 St. Giles', Oxford OX1 3LB, United Kingdom; [c]Instituto de Matemáticas y Fisica Fundamental, Consejo Superior de Investigaciones Cientificas, Serrano 123, 28006 Madrid, Spain; [d]Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544; [e]School of Biological Sciences and Centre for Mathematical Biology, Heydon-Laurence Building, A08, University of Sydney, Sydney, NSW 2006, Australia; [f]Department of Chemical Engineering, Program in Applied and Computational Mathematics and Mathematics, Princeton University, Engineering Quadrangle, Olden Street, Princeton, NJ 08544; [g]Department of Biochemistry, Oxford Centre for Integrative Systems Biology, University of Oxford, South Parks Road, Oxford OX1 3QU, United Kingdom; and [h]Mathematics Department, Uppsala University, Box 480, 751 06 Uppsala, Sweden

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Among the most striking aspects of the movement of many animal groups are their sudden coherent changes in direction. Recent observations of locusts and starlings have shown that this directional switching is an intrinsic property of their motion. Similar direction switches are seen in self-propelled particle and other models of group motion. Comprehending the factors that deter-

of the rules that govern the interaction of fish (6, 7) and birds (8, 9). However, establishing these rules is technically difficult because it requires automated tracking of individuals over long periods of time and quantification of often complicated interactions.

Coherent animal groups often make sudden changes in direction (1, 10–12). In some cases a switch in direction is a response

Inherent noise can facilitate coherence in collective swarm motion.

Yates, C.A. and Erban, R. and Escudero, C. and Couzin, I.D. and Buhl, J. and Kevrekidis, I.G. and Maini, P.K. and Sumpter, D.J.T.

PNAS 2009; 106(14):5464.

Model Revision

Recall the velocity update equation,

$$\Delta u_i = \{G(\bar{u}_i^{loc}) - u_i(t)\}\Delta t + \Delta Q \eta(\bar{u}_i^{loc}),$$

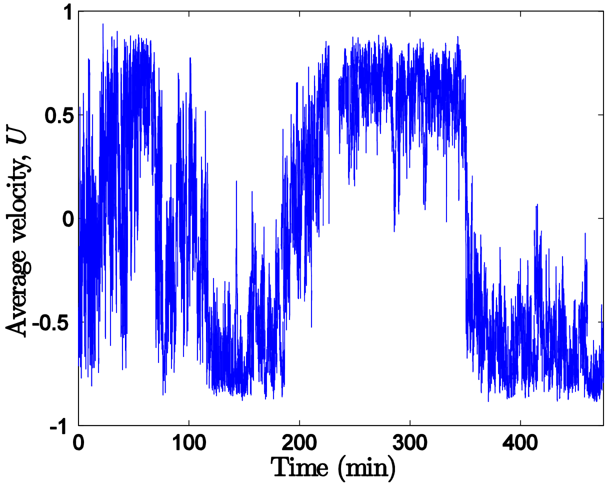
Previously $\eta(\bar{u}_i^{loc}) \equiv 1$.

We now make $\eta(\bar{u}_i^{loc}) = \frac{3}{2}\left\{1 - \left(\frac{\bar{u}_i^{loc}}{|\bar{u}_i^{loc}|_{\max}}\right)^2\right\}$,

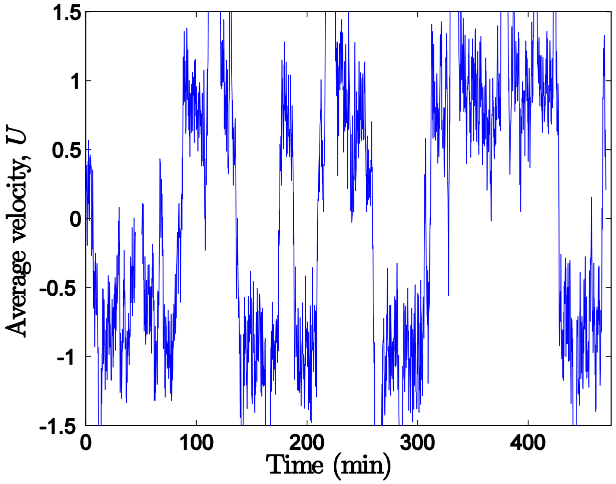
where $|\bar{u}_i^{loc}|_{\max}$ is the maximum of the

absolute value of the mean velocity.

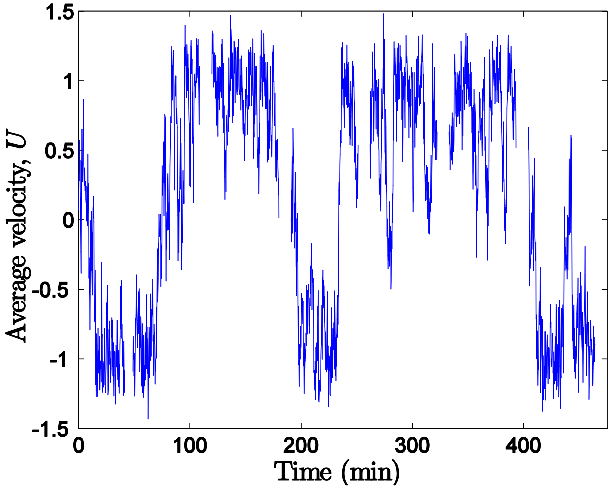
Revised model causes locusts to stay together for longer



Data time series

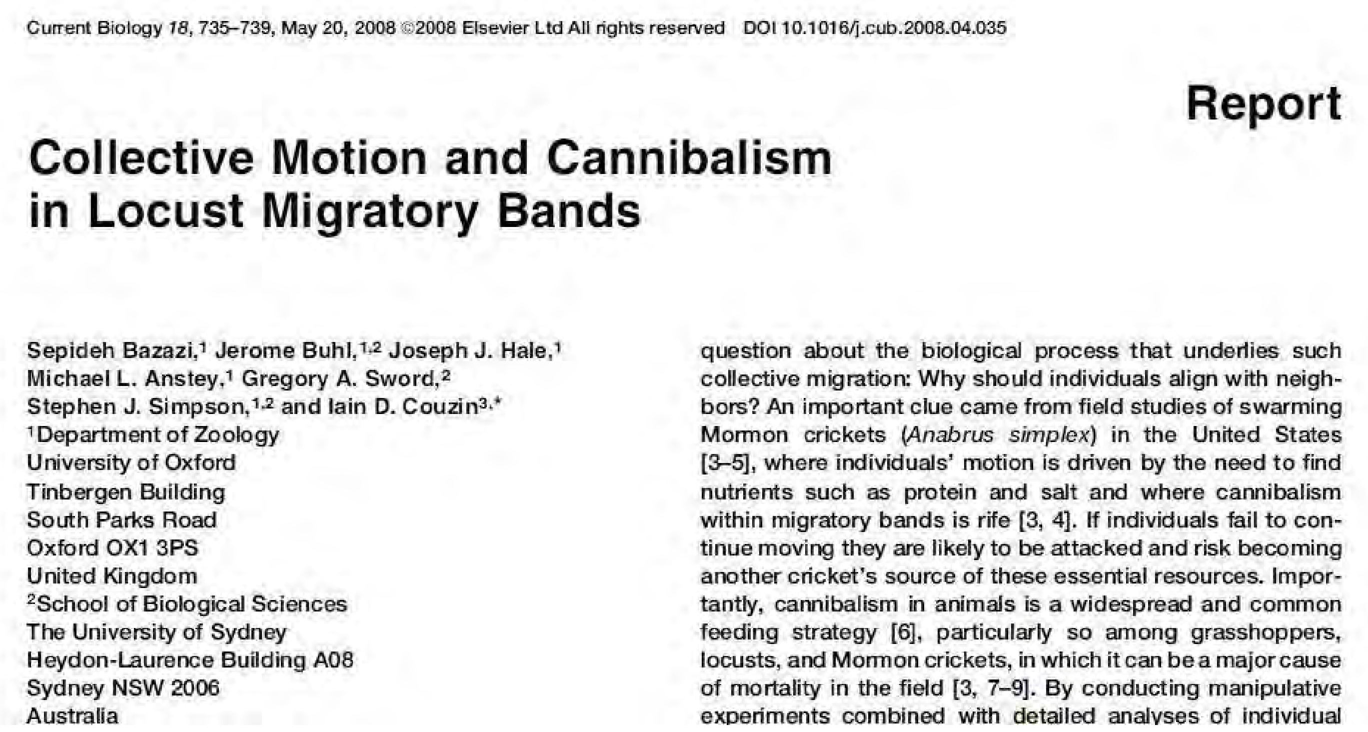


Old model time series



New model time series

Cannibalism



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Report

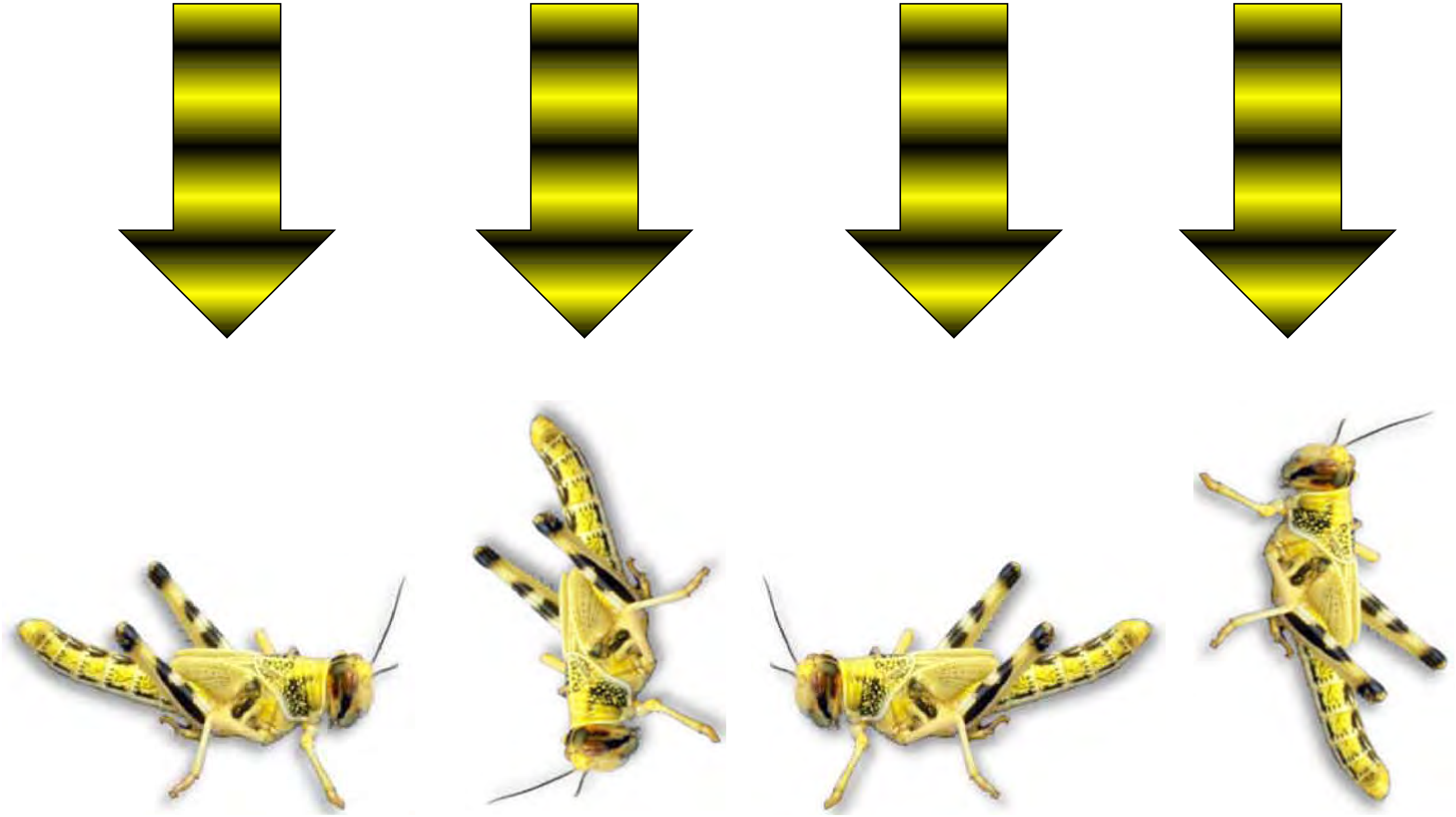
Collective Motion and Cannibalism in Locust Migratory Bands

Sepideh Bazazi,[1] Jerome Buhl,[1,2] Joseph J. Hale,[1]
Michael L. Anstey,[1] Gregory A. Sword,[2]
Stephen J. Simpson,[1,2] and Iain D. Couzin[3,*]
[1]Department of Zoology
University of Oxford
Tinbergen Building
South Parks Road
Oxford OX1 3PS
United Kingdom
[2]School of Biological Sciences
The University of Sydney
Heydon-Laurence Building A08
Sydney NSW 2006
Australia

question about the biological process that underlies such collective migration: Why should individuals align with neighbors? An important clue came from field studies of swarming Mormon crickets (*Anabrus simplex*) in the United States [3–5], where individuals' motion is driven by the need to find nutrients such as protein and salt and where cannibalism within migratory bands is rife [3, 4]. If individuals fail to continue moving they are likely to be attacked and risk becoming another cricket's source of these essential resources. Importantly, cannibalism in animals is a widespread and common feeding strategy [6], particularly so among grasshoppers, locusts, and Mormon crickets, in which it can be a major cause of mortality in the field [3, 7–9]. By conducting manipulative experiments combined with detailed analyses of individual

Collective motion and cannibalism in locust migratory bands.
Bazazi S, Buhl J, Hale JJ, Anstey ML, Sword GA, Simpson SJ, Couzin ID
Curr. Biol. 2008; 18(10):735-9.

Potential impacts of cannibalism



Summary

- Locust behaviour can be effectively represented with a self-propelled particle model.
- Increased individual randomness when unaligned help the swarm stay together.
- Cannibalism – dangerous to fall out of line as sides are vulnerable.

Acknowledgements

- Collaborators: Radek Erban (Oxford), David Sumpter (Uppsala), Carlos Escudero (Madrid), Iain Couzin (Princeton), Jerome Buhl (Sydney), Yannis Keverekidis (Princeton) and Philip Maini (Oxford), Alan McKane (Machester), Louise Dyson (Warwick).